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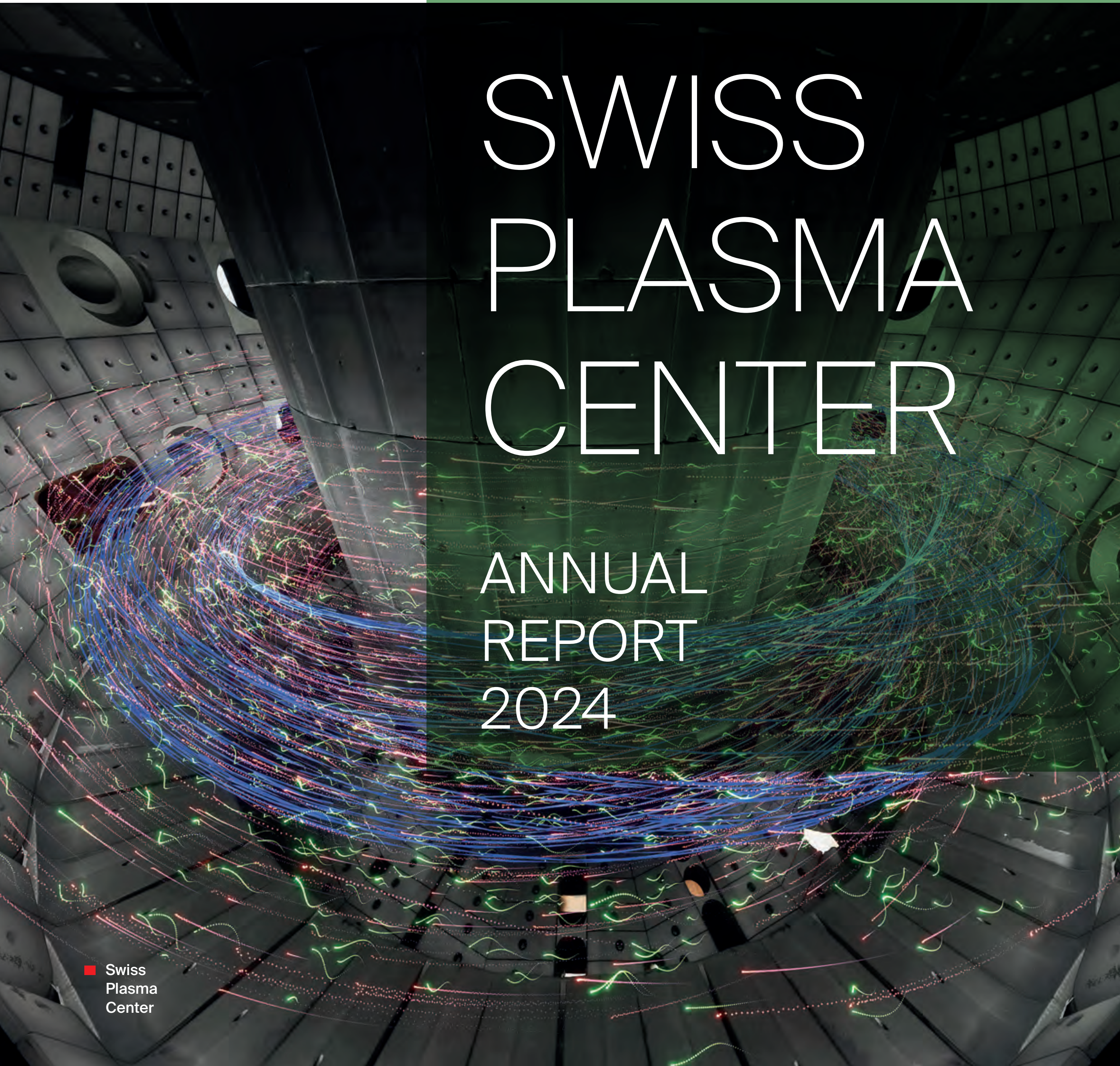


SWISS PLASMA CENTER

ANNUAL REPORT 2024

Swiss
Plasma
Center

Table of contents

A word from the Directors

The year 2024 was a transition period for our Center. We have consolidated our role in the world fusion scene, as part of the revamped fusion program that recognizes the importance of basic research and education in conjunction with public private partnerships. In our central role in the EUROfusion Consortium, we have prepared our comeback to full membership of it, as Switzerland will rejoin the European research area, hopefully in 2025.

We now have a key role in supporting the European program's transition to the ITER operational phase and the subsequent DEMO developments through continued R&D, education and training initiatives, and collaborations with industry partners.

Such central role was underlined by the responsibility that I have taken myself, initially still being SPC Director: after serving for five years as Chair of the EUROfusion General Assembly, I was elected to become its Programme Manager (or CEO).

After a few months of overlap, Prof. Paolo Ricci, became the new Director of the Center, in July 2024. One could not imagine a better person to further strengthen the Center in all its endeavors, in research, education and technology transfer, and lead it towards the ITER and DEMO era.

It is important to underline how our respective visions, although naturally declined according to our experience, background and personalities, are aligned at the service of the Center and EPFL, and see the Center as fully integrated in the European roadmap to fusion energy, as well as an engine for innovation in plasma related R&D areas, and a unique hub for education and training for fusion, plasma physics and technology.

> *“Nowhere else could I find the combination of professionalism, human warmth, commitment and loyalty to the common cause that I have experienced with all the teams and collaborators of the SPC.”*

From a personal point of view, the gratitude I have for all of my colleagues at SPC for the many years in which I had the honor to lead the Center can hardly be expressed. Nowhere else could I find the combination of professionalism, human warmth, commitment and loyalty to the common cause that I have experienced with all the teams and collaborators of the SPC.

The Swiss Plasma Center was, and will always be, home and family for me. I leave it only as Director, as I wish I will be able to participate in its activities for a long time in the future. And I believe I leave it in excellent shape.

Ambrogio Fasoli

PROF. AMBROGIO FASOLI
Vice-president of academic affairs
SPC Director until June 2024

As I take over the responsibility of the directorship of the Swiss Plasma Center, I would like to express my heartfelt thanks to Prof. Ambrogio Fasoli for his extraordinary leadership and generous mentorship. The way he has guided the Swiss Plasma Center over the past decade, shaping it into a world-leading institution, will always remain an inspiring example for me. Stepping into this role is both a great honour and a profound responsibility, one that I approach with humility and determination.

I also want to warmly thank all my colleagues at the Swiss Plasma Center for the incredible support I have felt during these first months. Experiencing the daily commitment, goodwill, and sense of community within the SPC has made me truly understand what Ambrogio meant when he said that he had never found such human warmth and dedication anywhere else. Being able to rely on such an outstanding team is inspiring as we look ahead to the challenges and opportunities before us.

> ***“Being able to rely on such an outstanding team is inspiring as we look ahead to the challenges and opportunities before us.”***

I receive the Swiss Plasma Center in excellent shape. The final parliamentary approval of the initiative launched in 2022 to further modernize our infrastructure, named Swiss Fusion Hub, finally came in 2024, with a budget allocation of 12.5MCHF. This constitutes a great collective success, in these times of public budgetary restrictions. The Swiss Fusion Hub is now a crucial part of the 2025-2028 Swiss Roadmap for Research Infrastructures.

This initiative involves a range of upgrades to the TCV tokamak, including enhanced diagnostics and real-time control systems, a redesigned divertor structure, and additional microwave heating. Additionally, the superconductors' test facility will be upgraded with the new high-field EDIPO2 coil. These improvements are set to significantly extend the reach and impact of our research for many years to come.

Despite Switzerland’s (hopefully temporary) exclusion from Euratom and the European Research Area, the cooperation agreement between EPFL and Fusion for Energy—generously supported by SERI—enabled us to continue contributing to ITER across several key domains. These include mm-Wave Physics and Technology, the Plasma Control System Simulator Platform, Boundary Modelling for ITER, as well as multiple tokamak physics studies carried out on the TCV Tokamak in support of ITER’s objectives.

Together with Prof. Fasoli, I would like to emphasize that our achievements and our growing prominence in fusion and plasma science R&D are the direct result of the dedication, expertise, professionalism and teamwork of all SPC members—for which we extend our heartfelt thanks. We would also like to express our gratitude to all our stakeholders for their continued support, especially the ETH Board, SERI, the EPFL Faculty of Basic Sciences and Institute of Physics, the Swiss National Science Foundation, the ITER International Organization, EUROfusion, and Fusion for Energy.

PROF. PAOLO RICCI
SPC Director since July 2024

RESEARCH HIGHLIGHTS

TCV Core

The year 2024 was very successful for TCV, including a record-breaking 4661 plasma shots—the highest number ever recorded in a single year. The machine operated almost continuously throughout the year, pausing only briefly in August and November to be equipped with two distinct configurations of divertor baffles: first the SILO set (short-inner, long-outer), followed by the LILO configuration (long-inner, long-outer), after an initial phase without baffles. As in previous years, the experimental campaign was shared between the domestic programme and the EUROfusion Work Programme on Tokamak Exploitation (WPTE), encompassing a broad and diverse set of scientific investigations. Operation was facilitated by the recent installation of a full neutron and gamma-ray shield, removing all limitations related to radiation safety. In parallel, preparations were made for further hardware upgrades, including the addition of two new gyrotrons and a highly customized set of divertor baffles in the near future. Highlights are presented below by Dr **STEFANO CODA**, who supervises TCV operations and science.

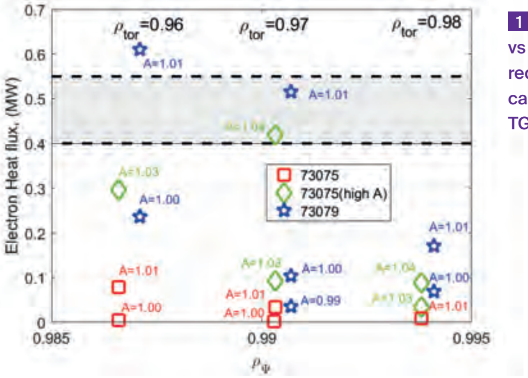
> ***“One of the objectives of the 2024 campaign was to produce plasmas relevant for the ITER baseline scenario.”***

TCV CORE PHYSICS

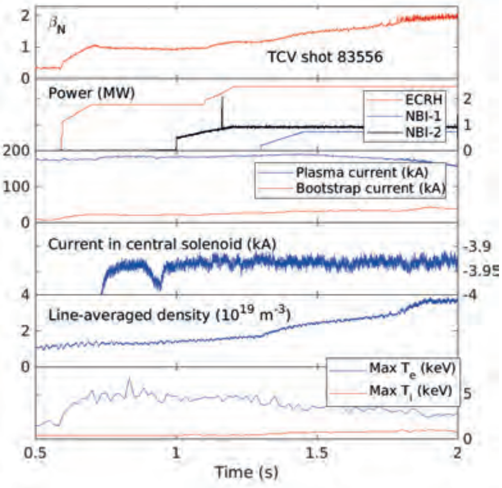
The tokamak “core” is the confined part of the plasma, featuring closed and nested flux surfaces. A great variety of physics phenomena occur in the core and are the object of specialized though inter-related studies, utilizing the large diagnostic set of TCV as well as its ever-expanding control toolbox. Naturally, core and edge are also inextricably tied and indeed the long-term goals of tokamak research must involve efficient core-edge integration.

One of the objectives of the 2024 campaign was to produce plasmas relevant for the ITER Baseline (IBL) scenario. The challenge is to obtain good confinement, measured by the “enhancement factor” (H_{98}), targeting values above unity, while avoiding instabilities that degrade it by tearing apart the nested magnetic flux surfaces, e.g. the so-called “Neoclassical Tearing Modes” (NTMs). Simultaneously, it is desirable to achieve a high enough plasma pressure, measured by the “normalized beta” factor (β_N). With the use of both Neutral Beam Injection (NBI) and Electron Cyclotron Resonance Heating (ECRH), a confinement enhancement factor H_{98}~1.2 and a normalized beta β_N~1.6 were achieved before triggering NTMs.

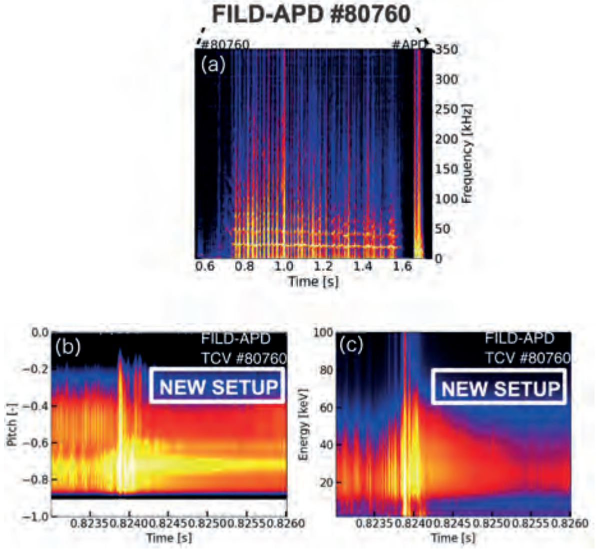
Low to High confinement (L-mode, H-mode) transition shows as the formation of strong gradients, forming a “pedestal” in the pressure profile near the edge. Pedestal investigations explored deuterium fueling and nitrogen seeding. NBI-driven L-H transition thresholds were analyzed over a range of densities, currents, and ion species. Results generally aligned with known scaling laws. The first nonlinear gyrokinetic simulations of the pedestal determined that, at high gas puffing, the electron heat



1 Heat flux calculated by gyrokinetic simulations of ETG modes in the H-mode pedestal, vs the experimental value represented by the grey band. In the low-gas-puffing case (shot 73075, red squares) the predictions significantly underestimate the heat flux, while in the high-puffing case (73079, blue stars) the predictions reach experimentally relevant values, suggesting ETG-driven transport could be the limiting factor in this scenario.



2 Relevant time traces for an advanced tokamak discharge, reaching β_N~2 and featuring ion heating from two neutral beams in addition to ECRH.



3 **(a)** Spectrum from fast FILD measurements showing losses associated with ELMs (vertical stripes) and low-frequency MHD. **(b-c)** Example of fast ion losses around an ELM occurring at t=0.824 s, resolved on a sub-ms time scale in energy and pitch.

flux can be primarily driven by ETG modes, which could then be responsible for limiting pedestal formation (**Figure 1**).

The formation of runaway electron (RE) beams during start-up and following disruptions poses a major threat to reactor integrity. To suppress them, central ECRH was used to lower initial RE seed populations by up to a factor of 1000. This effect is attributed to improved RE transport and a reduction in loop voltage. For safely terminating post-disruption RE beams, the Benign Termination method has shown strong potential. It relies on creating a low-density, recombined companion plasma within a specific range of neutral gas pressure — a concept with direct relevance for ITER.

> ***"A benign termination method has shown strong potential for terminating post-disruption runaway electron beams."***

Exploration of advanced high-confinement regimes obtained by plasma shaping remained central on TCV. In high-density H-mode discharges, a gradual increase in upper triangularity from 0.0 to 0.6 triggered a transition from Type-I ELMs (large repetitive bursts of plasma near the edge, which are potentially harmful to the operation of the tokamak) to a Quasi-Continuous Exhaust (QCE) regime, which is much more favourable. Moreover, the power deposition is spread out over a much wider area.

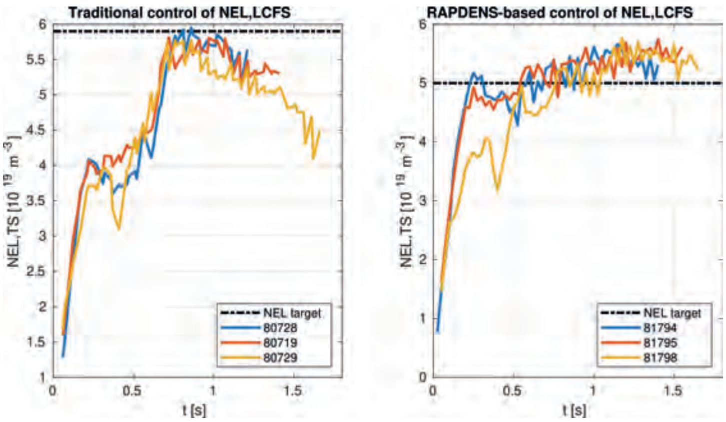
Negative triangularity (NT) scenarios continued to show strong potential as an inherently ELM-free, high-confinement regime. Stable, high-performance plasmas (β_N~1.8, H_{98}~1) were sustained with NBI heating, exhibiting elevated central T_e and T_i compared to positive triangularity (PT) L- and H-modes.

Various heating and current drive strategies were devised to support advanced scenarios characterized by high bootstrap current and high beta, with the goal of achieving steady-state operation. Non-inductive internal transport barrier (ITB) configurations temporarily attained central T_e=11 keV and β_N~1.85, although the Ti lagged over an order of magnitude behind. By increasing the ion heating power, these scenarios progressed into fully non-inductive, semi-stationary regimes that exhibited features of both ITB and edge transport barriers (ETB), reaching comparable β_N values with T_i/T_e>0.3 (**Figure 2**).

A burning plasma will contain a population of fast ions (FIs) having energies well above thermal. These FIs can destabilize a number of modes such as Toroidal Alfvén Eigenmodes (TAEs) and energetic geodesic acoustic modes (EGAMs). In TCV, these FIs are produced by NBI. Research has progressed significantly thanks to enhanced NBI and diagnostic capabilities. TAEs, destabilized by counter-injected NBI, were then suppressed using on-axis ECRH. Investigations into FI losses benefited from improved Fast Ion Loss Detector (FILD) instrumentation and modeling. These studies uncovered distinct FI transport characteristics within and between ELMs, with inter-ELM losses attributed to TAEs and NTMs, respectively. For the first time, velocity-space-resolved measurements with microsecond resolution captured the bursty, filamentary dynamics of FI losses around the ELM onset, revealing clear shifts in pitch and energy (**Figure 3**).

> *"Negative triangularity was confirmed as a high confinement regime inherently free from deleterious edge instabilities."*

In pursuit of fully integrated plasma control, TCV's adaptable digital distributed control system underwent substantial hardware and software modernization. Many real-time control algorithms were successfully deployed, while both diagnostic and actuator capabilities continued to grow. A new supervisory framework, SAMONE, was expanded further to coordinate multiple simultaneous control goals, successfully demonstrating control of plasma beta in high-performance NT scenarios, along with advanced management of density, shape, NTMs, and divertor detachment. Progress in machine learning and AI further supported these efforts, enabling real-time event detection, plasma trajectory optimization, latent variable-based state estimation, and live monitoring of neutron emission rates.



4 Comparison of NEL (line-averaged electron density) in different divertor geometries: short- (blue), medium- (orange) and long- (yellow) legged divertor with D_2 fueling and N_2 impurity seeding. Traditional density control on the left, showing the incapability of the control scheme to keep the density constant to the target as impurity seeding is performed. RAPDENS-based control on the right, where the density can be maintained close to its target value during the discharge.

CONTROLLING THE DENSITY

During a plasma discharge in a tokamak, the plasma electron density profile evolves in a timescale of tens of miliseconds as microwaves, energetic and thermal neutral particles interact with the plasma to provide external heating and fueling. The plasma density profile affects many important aspects of the plasma, such as its stability and confinement properties.

Different diagnostics are available on TCV to measure the density profile. A far -infrared laser (FIR) provides high-frequency (10 kHz) measurements of the line-integrated density along different laser chords. In addition to the FIR, the Thomson Scattering (TS) diagnostic produces accurate local density measurements along a vertical laser chord at a frequency of 20-60 Hz.

As part of **FRANCESCO PASTORE**'s PhD thesis, the real-time capable code RAPDENS, RApid Plasma DENsity Simulator, has been programmed, tested, and deployed in the TCV plasma control system to reconstruct the plasma density profile, incorporating the real-time information from FIR and Thomson scattering diagnostics with a lightweight model of the plasma particle balance.

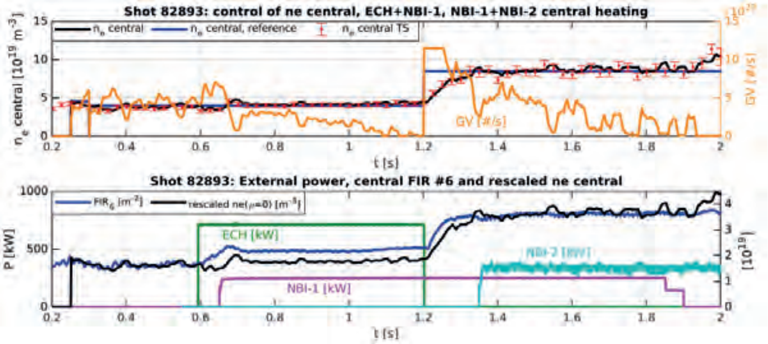
Density control schemes have been developed with RAPDENS to support detachment studies, (**Figure 4**) keeping the line-averaged electron density (NEL) controlled. Local control of the density has also been demonstrated using external heating actuators (**Figure 5**) such as Electron cyclotron heating (ECH) and/or Neutral beam (NB) injection, in low- and high-confinement plasmas.

The employment of such control techniques can be used to localize and suppress MHD modes that degrade the plasma confinement and for optimization of the plasma scenario for high-performance operation.

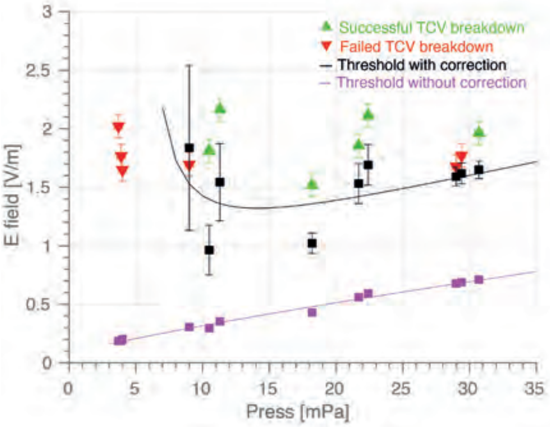
HOW TO START UP A TOKAMAK?

As tokamaks move towards energy-producing reactors, a solid physics understanding of all aspects of the tokamak discharge is necessary. Validated theoretical simulations of the plasma behavior at every stage are required to reduce uncertainty and mitigate potential risks in their operation. The start-up phase has received relatively little attention with few examples of validated theoretical models. Recent experiments at TCV, led by **PEDRO MOLINA**, have scanned various experimental parameters looking for patterns in the ‘first-light’ (breakdown) threshold (**Figures 6 and 7**).

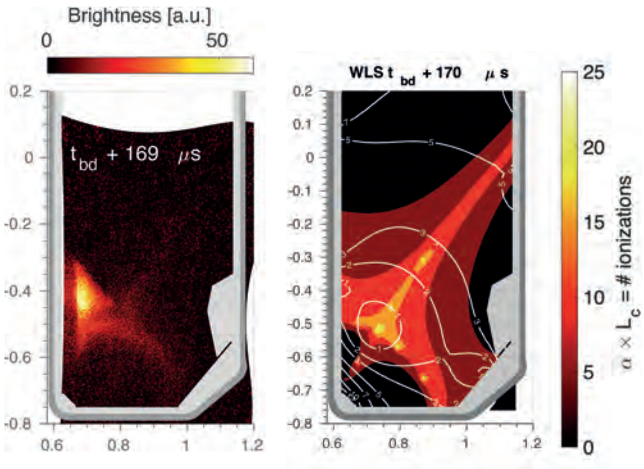
It has been found that while the currently accepted 0D Townsend theory can recover the experimental trends, a factor of x10 ionizing collisions per connection length is required prior to reliably reproducing the experimental breakdown threshold in TCV. This is an important result that has been confirmed via two separate electro-magnetic reconstruction methods including error analysis. This work sets a solid foundation for the optimization of breakdown scenarios in TCV in single-axis as well as double-axis (doublet) plasmas which are the focus of current breakdown experiments.



5 Control of central electron density with D2 gas valve (GV) fueling in an L-mode discharge, heated with ECH X2, NBI-1 and NBI-2. The control task is fulfilled during the different heating regimes, and the reconstructed central electron density (in black, first subplot) is coherent with the offline TS data points. A step in the density reference target (in blue, first subplot) is placed at 1.2 s, and the controller provides additional gas flux to reach the new level of the target density.



6 Scan of breakdown conditions varying applied E-field and neutral pressure. In green upward-facing and red downward-facing triangles are conditions that did and did not lead to a breakdown, respectively. Magenta and black squares and lines show the minimum electric field required for breakdown according to 0D Townsend theory using the standard formula (magenta) and featuring a correction (black) of 10 ionizing collisions per unit length.



7 Visible radiation maps produced by a fast camera **(a)** compared with where Townsend modeling predicts ionization should occur **(b)**. The breakdown process begins near the inner wall of TCV in contrast to where the Townsend theory model predicts it should take place: at the middle of the vessel where the poloidal magnetic field null was programmed. This is an important result for future devices which should consider in their control strategies that the breakdown may not commence at the poloidal magnetic field null.

TCV Boundary

Successful operation of a fusion reactor depends crucially upon the boundary plasma. Adequate confinement of the extremely hot, 100 million °C plasma core must be ensured whilst removing the helium produced by the fusion reactions and avoiding damage to the plasma facing wall structures. By leveraging TCV's unique magnetic shaping capabilities, operational flexibility and excellent diagnostic accessibility, the TCV team, and in particular its Boundary Group led by Prof. **CHRISTIAN THEILER**, works on advancing the fundamental understanding of the complex, turbulent boundary plasma and developing solutions for a reactor. Here are some notable achievements from 2024.

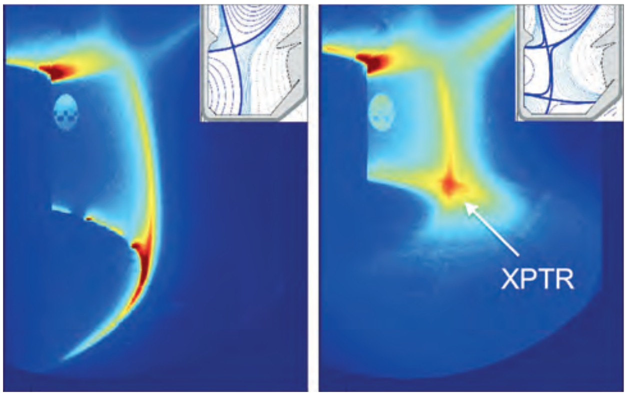
Ideally, one would like to have a cold plasma near the machine walls and reduced plasma-wall contact, thus essentially "detaching" the plasma from any material surfaces, while keeping good fusion core performance. Despite substantial progress in our understanding of the boundary plasma, quantitative predictions for future reactors are still accompanied by large uncertainties. It is unclear whether currently foreseen "conventional" boundary solutions will be adequate for a reactor. New ideas, such as alternative magnetic geometries of the boundary plasma, are therefore being explored.

To assess the level of plasma-wall interaction and extrapolate our results to a future reactor via validated modeling, TCV's divertor baffles remained central in 2024. The 'baffles' are used to separate the region where the divertor legs impact the wall from the region of the main plasma. Extensive datasets, including different baffle lengths and detailed measurements e.g. of ion temperature, parallel flows, and profiles of electron density and temperature, were used to challenge predictions from the SOLPS-ITER code, which is widely used in the community. Improved core-edge coupling and kinetic corrections in the plasma boundary Scrape-Off Layer (SOL) yielded significant improvements over previous simulations, which predicted overly dense and cold plasma conditions near the wall. Synergetic benefits of impurity seeding and baffling were also demonstrated, identifying the key physics behind enhanced divertor impurity retention. The interplay of turbulence and kinetic neutrals in detachment was studied using the fluid code GBS.

> ***"It is unclear whether currently foreseen 'conventional' boundary solutions will be adequate for a reactor. New ideas, such as alternative magnetic geometries of the boundary plasma, are therefore being explored."***

Alternative divertor configuration (ADC) studies confirmed strong exhaust benefits from an extended divertor leg but showed no significant influence of enhanced poloidal flux expansion on divertor cooling, in both experiments and SOLPS-ITER simulations. In Ohmic L-mode, a new regime with an X-Point Target Radiator (XPTR) was discovered, **Figure 1**. The XPTR shares similarities with the "conventional" X-Point Radiator (XPR) developed at AUG, JET, TCV and elsewhere, but localizes the radiation zone around the secondary X-point, remote from the core plasma, thus featuring detachment without significant edge cooling and closeness to disruptive limits. The XPTR features a strongly reduced detachment density.

Plasma operational regimes with enhanced confinement and their mutual interaction with the boundary plasma were a central topic in 2024 as well. The assessment of power exhaust in negative triangularity (NT) ADCs focused on the Snowflake geometry. Interestingly, this scenario proved to be particularly

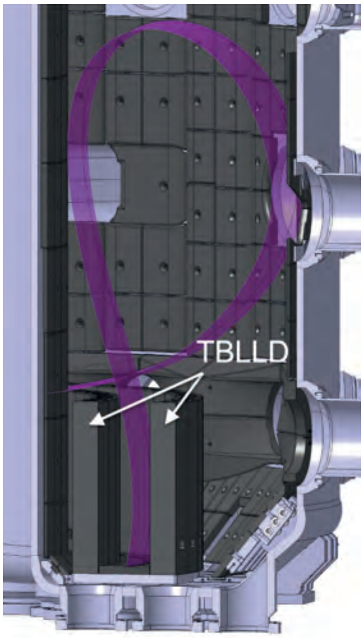


1 Light emission from excited deuterium atmos (D-alpha) in a conventional divertor (left) and in an X-Point Target divertor. The X-Point Target Radiator (XPTR) is clearly visible.

stable, allowing for a stationary, NBI heated high-performance NT scenario with higher central ion and electron temperatures than in comparable, positive triangularity L- and H-modes. Initial impurity seeding experiments showed very favourable detachment characteristics, featuring an XPR and only modest degradation in stored energy. Dedicated SOL width studies in NT furthermore identified the upper (non-X-point) triangularity as the key parameter determining the SOL width: increasing it from 0 to 0.6 results in a 2.5-fold increase in SOL power and density fall-off.

Boundary-related diagnostics and associated analysis routines were further developed in 2024, including more reliable thermal helium beam measurements, extended spectroscopic divertor flow inference, and the development of a unifying perspective on sparse view tomographic reconstructions for plasma imaging.

Last but not least, TCV's next large upgrade to test the novel concept of a Tightly-Baffled, Long-Legged Divertor (TBLLD) was started, **Figure 2**, combining key divertor benefits with minimal added engineering complexity.



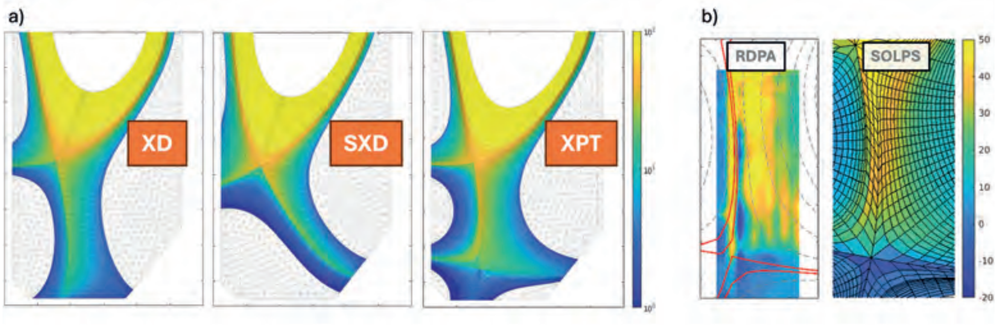
2 Initial design of the upcoming Tightly-Baffled, Long-Legged Divertor (TBLLD) in TCV.

EXPERIMENTAL AND NUMERICAL VALIDATION OF ALTERNATIVE DIVERTOR CONFIGURATIONS

Compared to current devices, future fusion reactors will face even more extreme heat and particle loads on plasma facing components. For this reason, alternative divertor configurations (ADCs) are studied as a promising route to enhance plasma exhaust capabilities. ADCs leverage advanced magnetic geometries – such as increased divertor leg length, larger total and poloidal flux expansion, or secondary X-points –, and are expected to facilitate detachment onset and widen the margin for safe operational conditions.

However, such predictions, and their extrapolation to future reactors, must be confirmed by experiments and understood through comprehensive modeling.

In the framework of his PhD thesis, **MASSIMO CARPITA** investigates the physics of ADCs, with experimental campaigns on TCV in different plasma scenarios. The experimental analysis is supported by interpretative edge plasma modeling with SOLPS-ITER, one of the most widely employed boundary simulators in the community. Upgrading the simulation workflow that is used to include particle drifts, a key aspect of divertor physics, Massimo managed to reduce the simulation time from months to days. The speed-up enabled a broad set of ADC simulations, including geometries with secondary X-points in the divertor, simulated for the first time with SOLPS-ITER on TCV, **Figure 3**. The code-experiment comparisons highlight the importance of drifts in retrieving experimental results, and shed new light on the complex physics of ADCs.



3 Examples showing recent progress in SOLPS-ITER modelling of alternative divertor configurations:
a) plasma temperature [eV] in different types of configurations;
b) code-experiment comparison of the potential [V] structure at the secondary X-point of an X-point target configuration.

TCV Diagnostics

The year 2024 was a period of intense operational activity with extensive exploitation of our diagnostic suite. This year also marked a significant transition in leadership within the diagnostics research line, as Dr. UMAR SHEIKH assumed responsibility following the retirement of Dr. Basil Duval. Under this new leadership, the team has established three primary objectives: enhancing accessibility and usability, expanding diagnostic applications across research areas, and positioning TCV as a testbed for novel diagnostic technologies such as those required for reactors. These strategic priorities are designed to strengthen educational initiatives, maximize the scientific output from TCV and contribute meaningfully towards the development of fusion energy for grid-scale deployment.

Two major diagnostic developments during 2024 were the Ion Cyclotron Emission (ICE) diagnostic and a modular, mobile hard X-ray (HXR) detection system called BGO.

ION CYCLOTRON EMISSION (ICE) DIAGNOSTIC

Ion Cyclotron Emission (ICE) refers to the spontaneous radiation of electromagnetic waves occurring at the ion cyclotron frequency and its harmonics. This phenomenon is driven by energetic ions, including fusion-born alpha particles or fast ions, which interact with the plasma via the Magnetoacoustic Cyclotron Instability. When these fast ions possess sufficiently large perpendicular velocity relative to the magnetic field, they enter resonance with background plasma waves, resulting in amplified emissions in the ion cyclotron frequency range.

ICE is a passive, non-invasive diagnostic, enabling monitoring of energetic ion populations without plasma perturbation – particularly crucial for studying alpha-particle confinement. Additionally, ICE provides insights into fast-ion transport mechanisms and plasma stability, making it an essential tool for investigating wave-particle interactions. It is currently being developed for use on ITER.

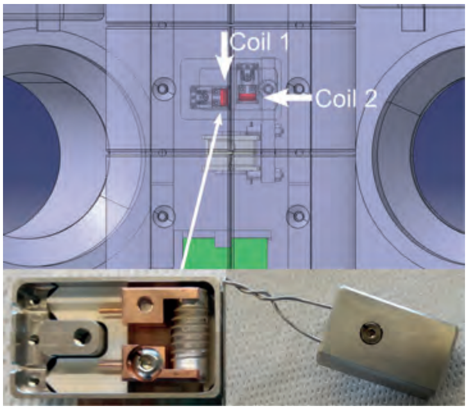
On TCV, the ICE system was installed and commissioned during the 2024 campaign. It comprises two orthogonally positioned magnetic coils measuring toroidal and vertical magnetic fluctuations, see **Figure 1**. The system incorporates a 1 GS/s (1 billion samples per second) data acquisition system with continuous measurement over entire TCV discharges. This high temporal resolution has permitted the clear detection of ICE signals at the second harmonic (~20 MHz), facilitating investigations into various plasma wave phenomena and potential Whistler wave activity around 200 MHz during runaway electron experiments, see **Figure 2**. These capabilities significantly enhance TCV's ability to study fast-ion-driven instabilities and their impact on plasma confinement, directly contributing to the development of improved control strategies for fusion plasmas.

> ***"These strategic priorities are designed to strengthen educational initiatives, maximize the scientific output from TCV and contribute meaningfully towards the development of fusion energy for grid-scale deployment."***

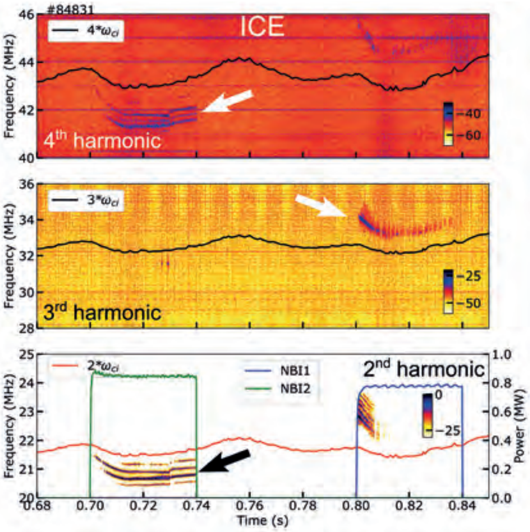
BISMUTH GERMANIUM OXIDE (BGO) HARD X-RAY (HXR) DIAGNOSTIC

Runaway electrons (REs) are relativistic electrons that can be generated during a tokamak disruption. They can cause severe damage to plasma facing components and are thus an area of intense research. HXR photons, see **Figure 3**, that are emitted when these REs interact with electric fields from charged particles, can contain important information regarding the energies, pitch angles and spatial distribution of REs. Thus, through the study of HXRs we yield valuable insights into RE dynamics and transport.

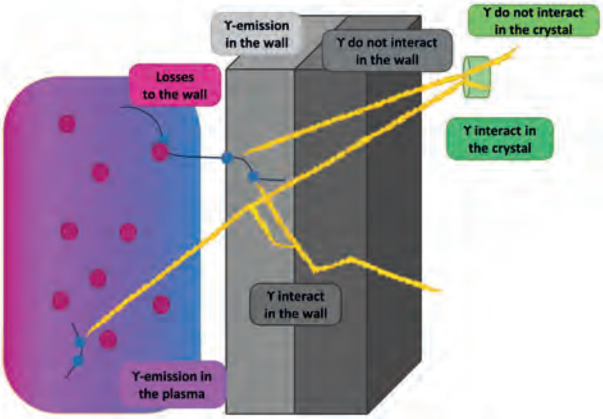
To exploit this diagnostic opportunity, a modular HXR detection system was developed for TCV in 2024. The system employs three independent detectors, each consisting of a Bismuth Germanium Oxide (BGO) scintillator crystal coupled to a photomultiplier tube (PMT) assembly, see **Figure 4**. The BGO crystals efficiently convert incident X-ray energy into visible light photons, which are subsequently detected and amplified by the PMTs. Electronic circuits then transform the resulting current signals into measurable voltage outputs.



1 Ion Cyclotorn Emission (ICE) diagnostics in the TCV vacuum vessel, showing the positions of the two orthogonal magnetic coils.



2 ICE diagnostics results, here showing multiple harmonic frequencies.



3 Different mechanisms of hard-X-ray photon emission and detection. The colored left part is the TCV plasma where photons can be emitted. Another possible emission is from electrons lost from the plasma and hitting the wall. Multiple interactions can occur in the wall. Finally, the photons are detected outside the TCV vacuum vessel.

> *"These capabilities significantly enhance TCV's ability to study fast-ion-driven instabilities and their impact on plasma confinement, directly contributing to the development of improved control strategies for fusion plasmas."*

4 Two of the Bismuth Germanium Oxide (BGO) hard X-ray detectors in the TCV hall.

Each detector underwent comprehensive calibration to validate their response across a range of operating conditions and characterize their energy response. Measurements were made with detectors positioned at different locations around the tokamak during a range of experimental scenarios. Initial results have demonstrated the anisotropic nature of RE Bremsstrahlung emission and its dependence on plasma impurity content and species. These measurements provide critical experimental data for validating models of RE interaction with materials, and transport - key issues for ITER and future reactors.

FUTURE PERSPECTIVES

Looking ahead, TCV is preparing for a major upgrade involving the installation of a tightly baffled long-leg divertor, which will obstruct lines of sight for numerous existing diagnostics. Consequently, innovative solutions are required to maintain and enhance diagnostic capabilities in this constrained environment. Development efforts are already underway, with prototype diagnostics being tested for compatibility. The coming year will focus on continued development of these prototype systems and finalization of diagnostic integration plans, ensuring TCV maintains its cutting-edge capabilities for plasma physics research.

TCV Heating

Plasmas in the TCV tokamak, in addition to the Ohmic heating caused by the electric current flowing in it, can be heated by two high power auxiliary heating systems, namely Neutral Beam Injection (NBI) and Electron Cyclotron Resonance Heating (ECRH). Dr **JEAN-PHILIPPE HOGGE**, Senior Scientist (MER), is the leader of the TCV Heating research line. The main achievements of the year 2024 are exposed below.

NEUTRAL BEAM INJECTION (NBI) SYSTEM

Both heating beams (the low-energy 28 keV/1.3 MW NBI-1 and the high-energy 52 keV/1.1 MW NBI-2) were actively used in TCV domestic and international (EUROfusion) experimental campaigns in 2024. NBI-1 was used in over 1300 TCV shots, delivering over 700 MJ of energy into the tokamak plasma. NBI-2 injected 160 MJ in 500 pulses, which is approximately double the deposited energy achieved in the previous three years since the second beam was installed at the TCV. In parallel with day-to-day operation, significant work was done to improve the heating beams.

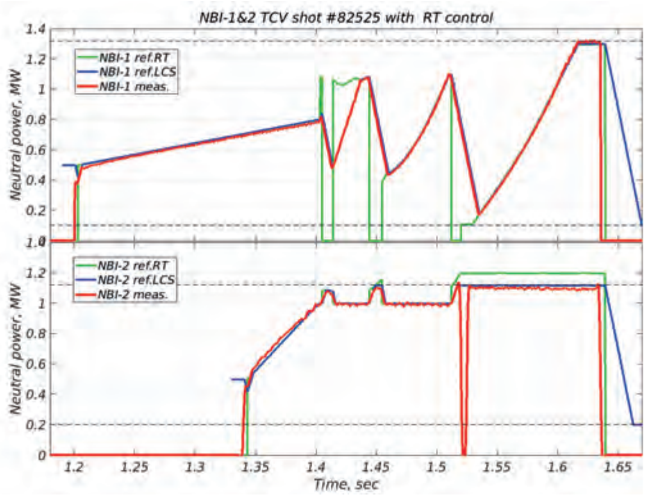
> *“Control of NBIs power, integrated with the TCV's real-time control system is essential for access to desired plasma parameters as plasma stored energy, plasma beta and instabilities.”*

The neutral beams were integrated into the TCV real-time (RT) control system (CS), enabling control of plasma characteristics through real-time variation of the neutral beam power, based on RT measurement of plasma parameters (**Figure 1**). The selection of reference power signal between the waveform pre-programmed by the TCV physics operator which stored in shared memory, and the reference from the TCV distributed RT system, are controlled by a logical signal from TCV RT CS. Control of NBIs power, integrated with the TCV's real-time control system is essential for access to desired plasma parameters as plasma stored energy, plasma beta and instabilities.

Integration of thermocouples into the beam ducts was modified by implementing a thermal paste for more effective thermal contact with the duct walls. This modernization (together with bronze's better thermal conductivity) significantly improved the temperature measurements of the beam ducts, which previously showed significant discrepancies compared to the preliminary theoretical estimations.

Development of an alternative ion optics for the first heating beam, designed for intermediate particle energies up to ~38 keV, has commenced (**Figure 2**). The first results of a beamlet geometry numerical optimization are optimistic for beam losses before entering into the tokamak.

The design of a new Ion Optical System (IOS), optimized for the beam energy of 35-40 keV, has been started. This energy range could help to fill the gap between NBI-1 and NBI-2 and corresponds to medium plasma densities in TCV (4-5 × 10^{19} m^{-3}), thereby increasing the TCV experimental flexibility.



1 Example of TCV shot with simultaneous real-time control of power for two beams (NBI-1 on top, NBI-2 on bottom); red – measured NBI neutral power, green – reference from TCV real-time system, blue – reference in used by NBI local control system accounting for limits for min/max power and dP/dt range.

ELECTRON CYCLOTRON RESONANCE HEATING (ECRH) SYSTEM

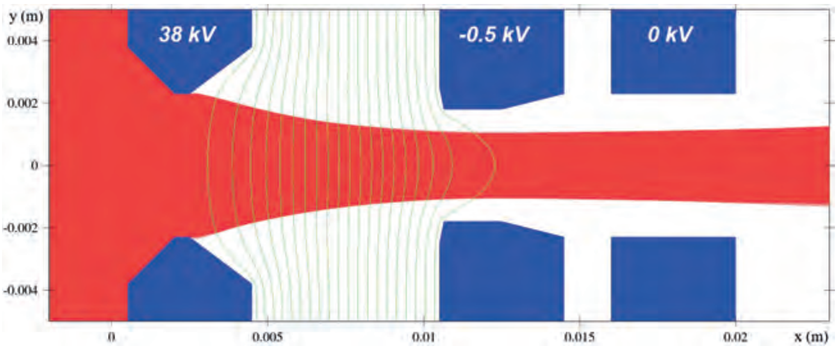
In 2024, the TCV ECRH system, composed of G10 (126/84 GHz, 900 kW, 2s, Thales), G11 (126/84 GHz, 900 kW, 2s, Thales), G1 (82.7 GHz, 700 kW, 2s) and G7 (118 GHz, 500 kW, 2s, lateral port) has been fully available during the experimental campaigns.

> ***“In 2024, the TCV ECRH system, composed of four gyrotrons, has been fully available during the experimental campaigns.”***

In parallel to the ECH system operation, important modifications of the gyrotron platform were undertaken to prepare the installation of a third bi-frequency gyrotron (G12, 126/84 GHz, 900 kW, 2s, Thales). A new tower (similar to those of G10 and G11) was installed on the north-west of the platform (**Figure 3**), at the location of the decommissioned G9, and the transmission lines were adapted.

A level 0, the high voltage zone was deeply modified with the installation of new electric cages allowing the technical staff to safely work during the ECH system operation. More than just a simple duplication, even though the functionalities remain unchanged, the control system has been completely redesigned to take advantage of the latest hardware technological developments in the field.

On the TCV operation side, besides the continued exploration of central ECH to disperse the runaway electrons (RE) and mitigate their potentially harmful effects, the stabilization of Alfvén eigenmodes by ECRH/ECCD and the progress in steady state non inductive advanced scenarios can be listed in the ECH related achievements.



2 IBSimu modeling of new TCV NBI beamlet for 38 keV Deuterium beam.

3 Tower of the future G12 bi-frequency gyrotron during its assembly phase.

Theory and Numerical Simulation

Fusion plasmas are extraordinarily complex systems, with multiscale and multiphysics processes ranging from the motion of individual particles to collective phenomena spanning the entire machine. Fusion plasma theory is based on advanced mathematical models and powerful computer simulations that reveal how plasmas behave, providing essential insights that cannot be deduced directly from experiments. Theory guides experiments, interprets their results, and helps design the next generation of reactors like ITER and DEMO.

From new plasma shapes to turbulence and transport, from wall interactions to runaway electrons, the SPC theory group, led by Prof. **PAOLO RICCI**, continues to broaden our understanding of fusion plasmas. The 2024 results of the group are remarkable for their depth and diversity – only a small selection can be presented here. Each advance strengthens the scientific foundation needed to make fusion a reliable source of clean energy for the future.

Our work relies on some of the world's fastest supercomputers, operated for instance by CSCS and CINECA. It also benefits from the EPFL EUROfusion Advanced Computing Hub, which improves and optimizes the codes we and our EUROfusion partners use. Among the activities of the Advanced Comuting Hub, we mention FusReal, an immersive tool that uses game-engine technology to render fusion plasmas and devices (**see cover page**). FusReal is now a valuable tool both for research and for outreach activities.

INSTABILITIES AND FAST PARTICLES

Plasmas are held in place by strong magnetic fields, but they can develop instabilities (collective motion that can grow and, if uncontrolled, possibly disrupt the plasma discharge). Such instabilities interact with fast particles, including the energetic ions produced by fusion reactions themselves. Controlling them is crucial for ITER and DEMO.

In 2024, we advanced VENUS-KMHD, a new simulation tool able to capture effects that previous codes could not, such as wide particle orbits and resonance conditions challenging to model. We also upgraded the VENUS-LEVIS code to run on GPU processors, enabling detailed studies of how heavy impurities move in the presence of magnetic instabilities. Finally, the JOREK simulation code for plasma instabilities was advanced with faster data handling and new synthetic diagnostics, validated against experimental signals.

TURBULENCE AND HEAT TRANSPORT

Turbulence in plasmas yields swirls and eddies that move heat and particles around, reducing their confinement. SPC researchers continue to push the frontier of turbulence modeling.

> ***"We simulated from first-principles how turbulence can self-organize into regions of improved confinement called internal transport barriers (ITBs)."***

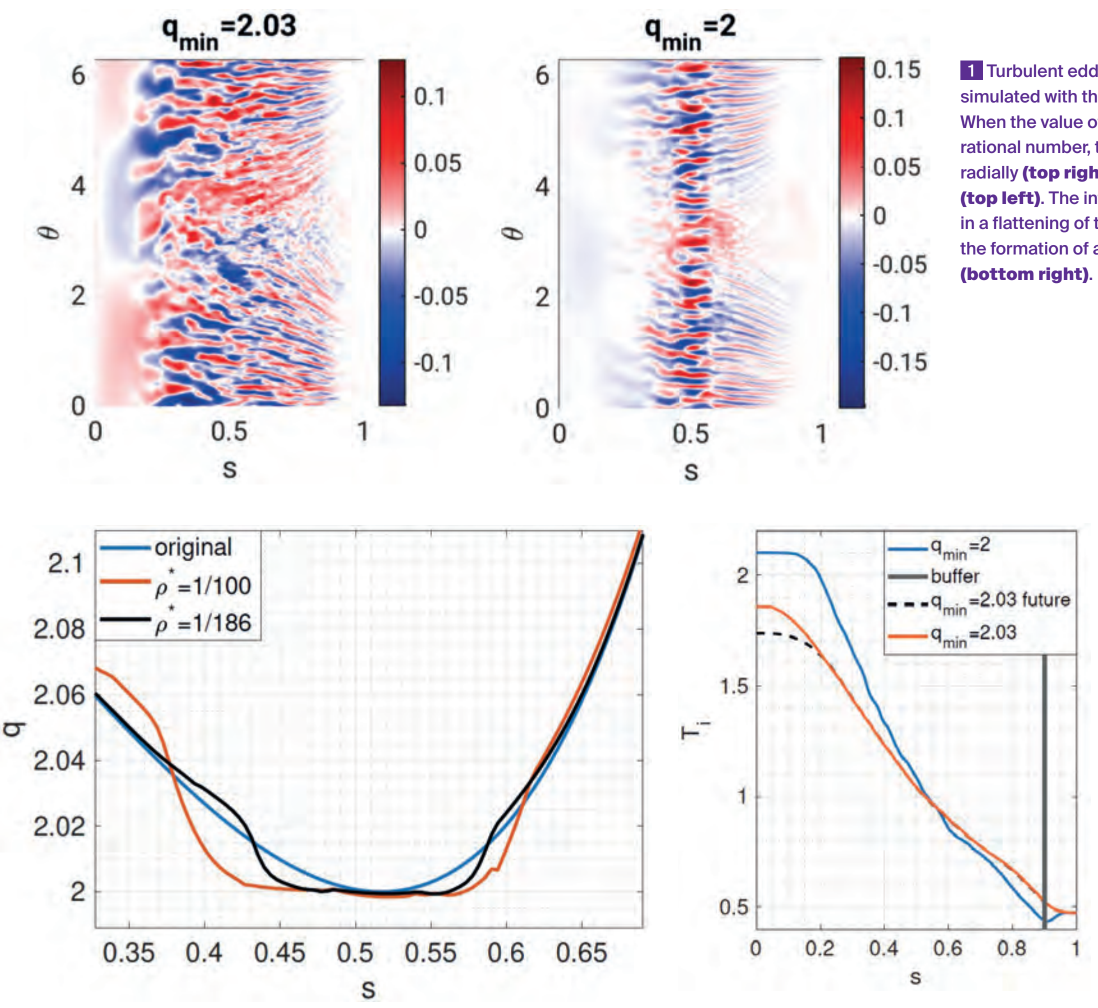
With the ORB5 code, **Figure 1**, we simulated how turbulence can self-organize into internal transport barriers (ITBs) – regions where heat is better confined and energy stays in the plasma for longer. These results show how turbulent structures interact with magnetic field lines and reveal new mechanisms for improved plasma performance.

By running carefully designed numerical scans, it was discovered new behaviors of turbulent eddies, how they can "squeeze" themselves to reduce transport, and how they redistribute electric currents. These results open a fresh line of research on a phenomenon that has puzzled plasma physicists for decades.

In parallel, the available energy approach was extended to provide quick estimates of turbulent transport without the need for massive simulations, helping speed up the design of future reactors.

SHAPING PLASMAS: NEGATIVE TRIANGULARITY

The shape of the plasma cross-section strongly influences its performance. In most devices the plasma is shaped like a rounded triangle pointing outward (positive triangularity). A promising alternative is negative triangularity, where the triangle points inward. This unusual shape has shown surprisingly good confinement in experiments.



1 Turbulent eddies in a reversed shear tokamak simulated with the global gyrokinetic code ORB5. When the value of the safety factor q is a low-order rational number, the turbulent eddies are squeezed radially **(top right)** as compared to other cases **(top left)**. The interaction with turbulence results in a flattening of the q profile **(bottom left)** and the formation of an internal transport barrier **(bottom right)**.

> *"The SPC led a large European project devoted to the topic of plasma shaping."*

The Swiss Plasma Center led TSVV-2, a large European project devoted to this topic. The team concluded that a negative triangularity power plant could be attractive, but it would look quite different from today's designs: it would require less external heating, allow higher radiation levels, and favor more compact shapes. It was studied how this shaping changes the need for external heating power. Using simplified models, we showed that negative triangularity can reach high performance even with low heating input, provided the magnetic field and fusion gain Q (a measure of how much more power the plasma produces than it consumes) are sufficient. This opens new possibilities for burning plasma experiments.

PLASMA-WALL INTERACTIONS

Where the plasma touches the reactor walls, very thin boundary regions called sheaths form. These sheaths act as cushions that control the flow of particles and heat flow towards the vessel materials, and therefore play a key role in the duration of reactor components.

In 2024, we generalized the classic Bohm-Chodura condition, which describes the plasma state at the sheath entrance, to include turbulent fluctuations and kinetic effects, making it more realistic for fusion devices. A new simulation tool for sheaths was also developed, initially in one dimension but with a roadmap toward more complete models. These advances bring us closer to accurate predictions of the plasma interaction with reactor walls.

RUNAWAY ELECTRONS

> *"SPC researchers played a central role in analyzing recent experiments at JET on runaway electrons."*

During sudden plasma disruptions, beams of highly energetic runaway electrons can form and damage the reactor walls. SPC researchers played a central role in analyzing recent experiments at JET. They identified patterns in the light emitted by runaway electrons and linked them to magnetic islands (localized structures in the magnetic field).

TURBULENCE IN STELLARATORS AND THEIR BOUNDARY

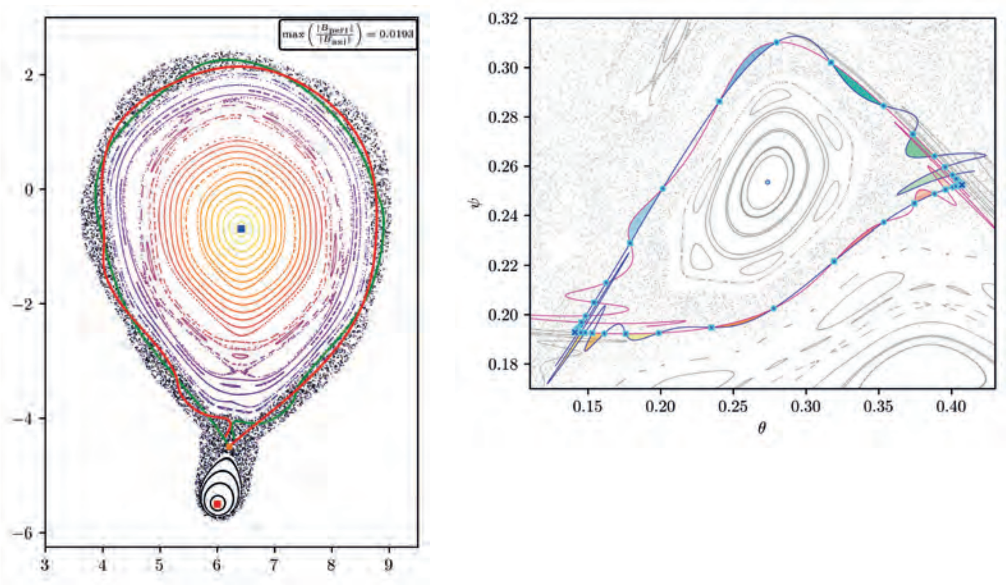
Stellarators are fusion devices similar to tokamaks but with magnetic fields shaped in a more complex, twisted way to confine the plasma. In 2024, we performed global turbulence simulations for the W7-AS stellarator, showing how turbulence develops in different magnetic configurations and affects the heat load on divertor plates.

A new algorithm was also created to map the hidden structures in magnetic fields, the stable and unstable “manifolds” that guide or block heat transport. Applied to both stellarators and tokamaks, **Figure 2**, it offers a fast way to optimize magnetic configurations.

PLASMA FLOWS AND SURPRISES IN EXB SHEAR

Plasma flows can be beneficial because they often suppress turbulence. One key type is ExB flow shear, caused by the presence of electric and magnetic fields. ExB flow shear has long been thought to reduce turbulence.

In 2024, however, SPC researchers discovered a surprising exception. In some cases, ExB flow shear can actually enhance turbulence driven by temperature gradients. This unexpected result could be especially important for spherical tokamaks and challenges long-held assumptions about plasma flows.



2 Maps of magnetic field lines in tokamak **(left)** and stellarator **(right)** configurations, showing regions of nested flux surfaces, magnetic islands and chaotic regions.

UNDERSTANDING INFERNAL MODES IN ADVANCED TOKAMAK REGIMES

Advanced tokamak regimes, featuring extended regions of low magnetic shear, are promising candidates for future fusion reactors (record-breaking DT pulses at JET have been obtained in this regime) but are also more prone to specific MHD instabilities, the so-called infernal modes.

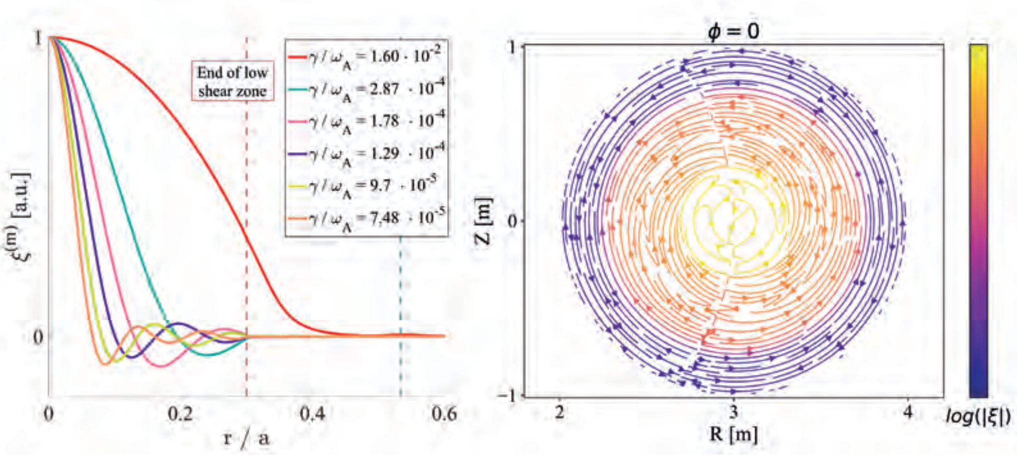
In her PhD thesis, **MARGOT COSTE-SARGUET** investigates the physics underlying these instabilities, including resistive diffusion, compressibility, toroidal effects and plasma shaping. Developing a new modular resistive MHD solver as well as analytic dispersion relations and stability criteria, she explores the critical regions and parameters which influence the linear stability of advanced tokamak regimes.

This work reveals that infernal modes can grow collectively as a discrete spectrum (see **Figure 3**), leading to a cascade of different perturbations for single mode numbers (m, n). Such spectra can in particular arise due to the combination of resistivity and negative triangularity configurations in advanced tokamak regimes. Understanding these fast-growing modes is essential for designing stable scenarios in future reactors and for clarifying the physics behind global reconnection events such as sawteeth.

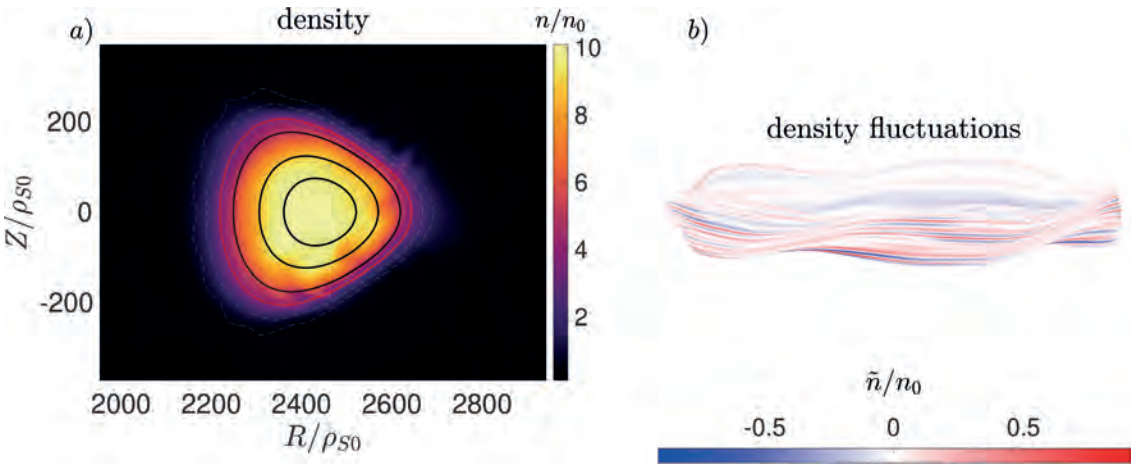
TURBULENCE AT THE BOUNDARY OF STELLARATORS

Predicting turbulent transport in the boundary of stellarators is essential for future fusion power plants but remains challenging due to fully three-dimensional geometry and the resulting richness of turbulent dynamics. In previous years, the GBS code used to simulate highly collisional plasmas typical of the boundary region has been extended to 3D fields, successfully validated on TJK, a small-scale machine in Stuttgart, and used to study toy-model analytical fields, showing turbulent properties substantially different from those in typical tokamak studies.

In 2024, **ZENO TECCHIOLI**, PhD student at the SPC, scaled up in size and relevance by performing the first global turbulent simulations of the W7-AS stellarator, the predecessor of W7-X, the world's largest stellarator. The simulations, **Figure 4**, reveal the coexistence of coherent modes within the confined plasma region and broadband turbulence extending to the open-field-line region, reproducing key experimental trends. In particular, we find that the inclination of fluctuating structures in radial–poloidal planes arises from the local magnetic shear, clarifying an effect previously identified but not explained. These results demonstrate predictive capability for boundary turbulence in stellarators and provide physics insight directly relevant to W7-X and future reactors.



3 Spectrum of m=n=1 infernal modes, for constant q = 1.0001 in the core and q_a = 10. **Left:** radial plasma displacements ξ versus minor radius, and corresponding linear growth rates γ/ω_A. **Right:** stream plot of the displacement for the 3rd mode in the spectrum.



4 W7-AS turbulence simulation obtained with the GBS code. In **a)**, snapshot of the total plasma density on a given cross-section at fixed toroidal angle. The red surface is the last-closed flux surface. In **b)**, amplitude of the density fluctuations on the last-closed flux surface. Both quantities are normalised to a reference value.

Basic Plasma Physics and Applications

The Basic Plasma Physics and Applications (LTP2A) group, led by Prof. **IVO FURNO**, carries out research using two mid-sized experimental plasma devices: the TORoidal Plasma Experiment (TORPEX) and the Resonant Antenna Ion Device (RAID). Activities in the framework of the Advanced WAKefield Experiment (AWAKE) collaboration are also conducted in the LTP2A group. The group also investigates applications of low-temperature plasmas in biology and life sciences within the bio-plasmas laboratory. Combining advanced experimental methods with theoretical and numerical modeling, the research aims to advance the understanding of fundamental plasma processes and their technological applications. The main research areas are summarized below.

RAID, TORPEX AND AWAKE: UPGRADES AND DIAGNOSTICS DEVELOPMENT

The activities on RAID and TORPEX were continued along the research lines started in previous years. Building on diagnostic developments achieved on these devices, the group has contributed to research within the AWAKE collaboration. These activities are briefly summarized below.

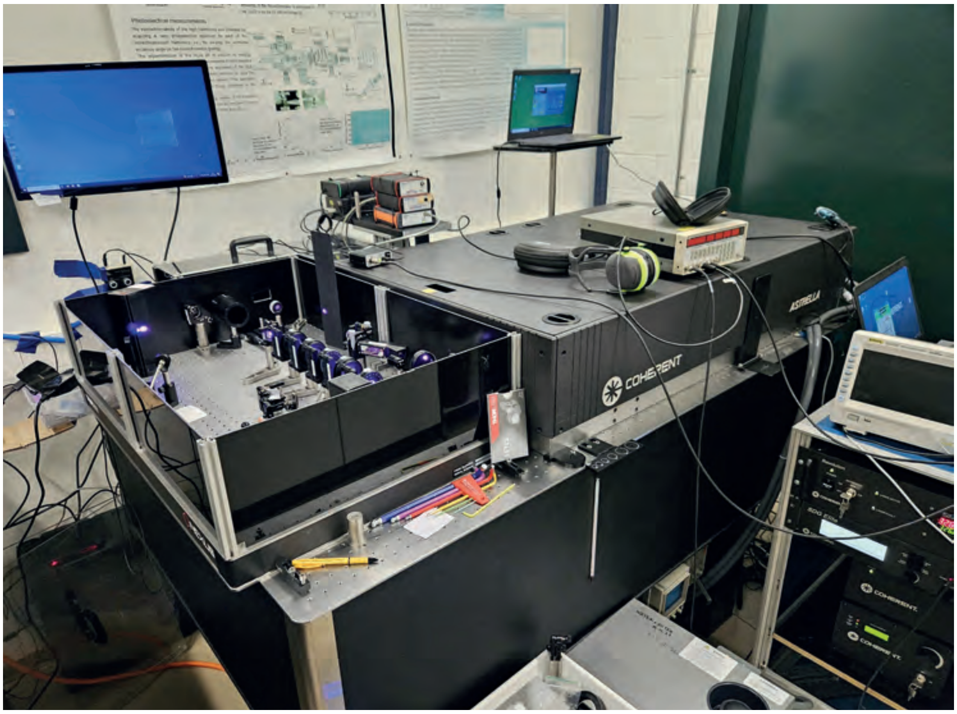
In fusion, as well in basic plasma physics research, collisional radiative models (CRMs), are used to interpret emission of electromagnetic waves from the plasma. In previous years, a CRM, dubbed CoRa-He, was developed at SPC to be used in plasma conditions relevant to RAID and tokamak divertors. In the period covered by this report, Cora-He was verified against established models and validated with experimental data obtained on RAID. The influence upon the code predictions of different number of included levels, recombination processes, and singlet-triplet mixing have been evaluated. Here, a comprehensive set of plasma parameters, electron density ne and temperature T_e, from Thomson Scattering (TS) and spectroscopic data from Optical Emission Spectroscopy (OES) was obtained. The effects of different parameters for wall recombination and for opacity (radiation trapping) have been evaluated and lead to deeper understanding of those processes in RAID plasmas.

In 2024 we made significant progress on a EUROfusion Enabling Research (EnR) project whose objective is to develop and experimentally test in the RAID device the feasibility of a femtosecond two-photon absorption laser induced fluorescence (TALIF).

In collaboration with the Lausanne Center for Ultrafast Science (LACUS) of the EPFL, we focused on developing the optical system to generate and transport the delicate fs ultraviolet (UV) laser pulses. Key activities included constructing a fourth-harmonic generator to attain the required wavelength of 205nm with high pulse energy (see **Figure 1**) and building the diagnostics necessary to experimentally determine the energies as well as the pulse spectral properties. Initial measurements of energies of ~80 μJ and spectral widths of ~0.5nm are close to the design target values withexcellent stability over time. In parallel, we designed and constructed the beam path necessary for routing the laser over ~15 m and injecting it into RAID. With the system almost ready, we plan to carry out experiments in 2025 for an assessment on the feasibility of fs-TALIF by the end of 2025 or early 2026.

In collaboration with the AWAKE consortium, whose aim is to develop a proton-driven plasma wakefield accelerator, and leveraging the technical advances implemented on the Thomson Scattering (TS) diagnostic at RAID in 2023, the TS system previously installed at CERN was significantly upgraded, see **Figure 2**. This enabled axial density scans in both plasma sources presently investigated at AWAKE, the Helicon Plasma Source (HPS) and the Discharge Plasma Source (DPS), in view of assessing their axial uniformity.

In the HPS, the performance of two different sets of radio frequency (RF) antennas was assessed in terms of achievable density and homogeneity. In the central part of the HPS the homogeneity was found to be better than the current uncertainty of the measurement. Moreover, a comparison of different diagnostics, involving TS, a CO2 -laser interferometer, and a movable Langmuir Probe system, revealed the parasitic effect of the view ports at the HPS on the plasma distribution, therefore highlighting the necessity of a local diagnostic that does not require the use of view ports.



1 Femtosecond ultraviolet laser system based on the fourth harmonic generation (FHG) of a 820 nm pulse (computed pulse width 160 fs).

> *“Our Thomson scattering measurements confirm densities achievable at the AWAKE target value of 7 x 10^{20} m^{-3}.”*

After demonstration of the TS capabilities, the system was adapted to the requirements of the DPS to perform axial density scans over a 3-meters DPS prototype. The local TS measurement results exhibit excellent agreement with line-integrated measurements from a He:Ne laser interferometer and confirm densities achievable at the AWAKE target value of 7 x 10^{20} m^{-3}. Due to the better accessibility of the plasma in the DPS, which facilitates easier implementation of the TS setup, relative uncertainties in the TS measurements could be reduced by a factor of 2 in comparison to the HPS

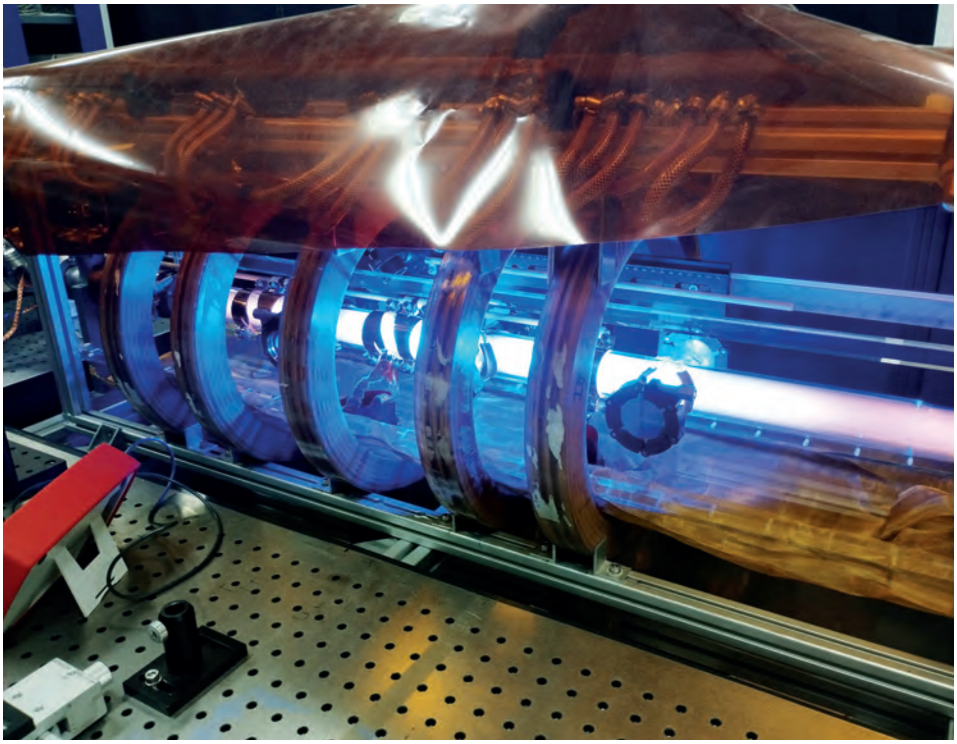
> *“In 2024 we focused on the investigation of fast ion transport in TORPEX.”*

On TORPEX, we characterized the plasma dynamics in the X-point magnetic configuration (for several magnetic shears), which is of upmost importance to understand the physics in the vicinity of X-points in magnetically confined fusion devices. In 2024, we focused on the investigation of fast ion transport, which has been an important subject of study in TORPEX due to its relevance for fusion plasmas, where α-particles or fast ions from plasma heating mechanisms need to be confined. A beam of 6Li+ ions is injected into a hydrogen plasma featuring an X-point magnetic geometry. The ions then propagate in the plasma and are detected with a gridded energy analyzer. The detector is installed on a motorised system to reconstruct the beam profile in the poloidal plane while the source is installed on a toroidally movable system, to finally obtain 3D measurements. This year, suprathermal ions were injected near the position where instabilities are generated. First analysis indicates a non-diffusive transport of the suprathermal ion beam, being super- or sub-diffusive depending on the energy of the injected ions. In parallel, we continued the exploitation of the birdcage resonant antenna. Experiments have been performed in both hydrogen and argon plasmas. Systematic helicon plasma characterization has been done for a set of machine parameters (magnetic field and birdcage power). The helicon wave has been characterized in 3D, with the first measurements of a toroidal wavelength. Next step will involve the injection of fast ions in helicon plasmas in TORPEX.

LOW TEMPERATURE PLASMAS FOR BIOLOGICAL APPLICATIONS

Research on low-temperature plasmas for biological use focuses on plasma and plasma-activated water for pathogen sterilization and on understanding plasma–organism interactions. Several new projects launched in 2024 are summarized below.

Within the framework of the EPFL Solutions for Sustainability (S4S) Initiative, the project “New Plasma-Based Sterilization Methods” has continued, aiming to reduce the energy consumption and environmental impact of current sterilization practices used at EPFL and more broadly in life sciences laboratories and medical settings worldwide. This project aligns with the strategic mission of the S4S initiative to develop sustainable solutions that decrease energy dependence and carbon footprint by leveraging EPFL’s strong R&D capabilities.



2 A side view of the helicon plasma cell at CERN where Thomson Scattering measurements are performed.

> *“Our project is aiming to reduce the energy consumption and environmental impact of sterilization practices broadly used in medical laboratories worldwide.”*

According to the initial milestones, the most promising plasma sources, Surface Dielectric Barrier Discharge (SDBD) and Volume Dielectric Barrier Discharge (VDBD), shown in **Figure 3**, were identified and systematically tested on representative microorganisms. Microorganism sterilization was first tested in ultrapure water, achieving complete bacterial inactivation (>6-log reduction) with an energy consumption of 0.05–0.15 kWh/l.

Subsequently, microorganisms were treated in organic liquid waste (culture media), such as Luria-Bertani (LB) broth. In this configuration, it was observed that plasma-generated reactive oxygen and nitrogen species (RONS)—the primary inactivating agents—are strongly influenced by the composition of the treated medium itself. Dilution of the culture media was found necessary to achieve full decontamination, with an associated energy consumption of 0.5 kWh/l, corresponding to a 50% reduction compared to autoclave sterilization.

Effective decontamination was demonstrated on bacteria (Micrococcus luteus, Gram-positive; Escherichia coli, Gram-negative), yeast (Saccharomyces cerevisiae), and fungi under standard sterilization conditions. The protocols were further optimized by including post-treatment incubation and dilution of liquid media up to 50%, which proved necessary for complete inactivation. This modification, however, effectively doubles the liquid volumes to be processed, thereby posing a practical limitation for large-scale applications. In parallel, collaboration with Campus Biotech enabled virus decontamination tests, although timelines were extended due to production and analysis constraints. To address the limitations of plasma discharges, we started investigating alternative solutions which will couple plasmas to wet heat sterilization.

While the antimicrobial effectiveness of plasma and plasma-activated water (PAW) is well established, progress in the field is still hindered by the absence of a comprehensive understanding of the mechanisms underlying their biological effects. A key objective of the bio-plasmas laboratory is to address this knowledge gap and overcome the main barrier to advancement in this emerging area. To this end, interactions between plasma or PAW and bacteria are investigated using a wide range of state-of-the-art diagnostics available at the Swiss Plasma Center. These tools enable a holistic characterization of the plasma–bacteria system through detailed electrical, laser-based, and liquid-phase measurements.

Among the diagnostics employed, a novel impedance flow cytometry technique was utilized in 2024 to study the effects of plasma treatment on bacterial cells and membranes. This method, developed in collaboration with the Swiss company Amphasys, allows the dielectric spectra of plasma-inactivated E. coli to be recorded and compared with those of viable cells. By analyzing impedance signals across multiple frequencies, the impact of plasma exposure on different subcellular layers of E. coli can be resolved. This approach provides new insight into bacterial inactivation mechanisms, enabling the optimization of plasma discharges for targeted biomedical applications.

3 The VDBD bubbling device for liquid waste sterilization.

Applied Superconductivity

The Applied Superconductivity group, unlike the rest of SPC, is located at premises of Paul Scherrer Institute (PSI) in Villigen, 35 km west of Zurich. Under the leadership of KAMIL SEDLAK, the group develops superconductors for fusion magnets, and tests conductor prototypes for various tokamaks (ITER, EU DEMO, DTT, SPARC, BEST, CFETR, STEP).

In 2024, significant effort was devoted to the conceptual design of EDIPO 2 test facility, which should be commissioned by 2028. The procurement tender for 1.6 ton of high-current Nb_3Sn strands, out of which EDIPO main magnets shall be built, was launched. In parallel, the project leader of EDIPO 2, Xabier Sarasola, launched a tender on the R&D on EDIPO 2 magnet development. Part of the contract is preparation of the magnet engineering design that should generate magnetic fields of up to 15 T in the sample region (to be compared to 10.9 T in SULTAN). Prototype conductors, i.e. copper dummy and a medium-length Nb_3Sn cable, are being manufactured in WST company, China. In 2025, they should be tested in SULTAN facility (**text box next page**).

> ***"EDIPO 2 should generate magnetic fields of up to 15 Tesla in the sample region (to be compared to 10.9 Tesla in SULTAN)."***

EUROfusion DEMO remained the main source of our R&D projects. However, an interesting shift towards stellarator research is clearly observed. Even within EUROfusion itself, a very agile research group formed within the Prospective Research and Development (PRD) work package. It is investigating the stellarator concept of HELIAS 5-B (**text box below**). In addition, we were approached by the fusion startups Proxima Fusion and Gauss Fusion, both promoting stellarators for fusion power plants. For Proxima Fusion, we tested bending limits of stacks of high-temperature superconductor (HTS) tapes, and we started the discussion on the full-size conductor tests in SULTAN test facility. For Gauss Fusion, we are heat-treating Nb_3Sn short samples, which Gauss Fusion needs for the development of demountable joints. Such joints would allow an easy maintenance of the innermost components of the reactor. Also Gauss Fusion is planning to test the full-size conductor prototypes in SULTAN.

A NEW TOOL FOR THE DESIGN OF STELLARATOR COILS

A candidate of fusion reactor using magnetic confinement is the stellarator, which has an inherently steady-state nature. Among the various stellarator types, the optimized stellarator represents a promising topology. One challenge is the complex coil shapes required to create the necessary magnetic field to confine the plasma.

DANIEL BIEK works on developing a parametric tool for the design of stellarator coils consisting of magneto-static, mechanical, and thermal-hydraulic analyses. The code is based on the output of the stellarator coil optimization: the central current lines. The first case study is done for HELIAS 5-B, which is based on low-temperature superconductor (LTS) magnets with a peak field in the magnet winding pack of 12 T (see **Figure 1**). Additionally, the figure illustrates the field lines in the plasma region. Furthermore, the tool is applied for the new CIEMAT configuration QI4X (B_{peak}≈13 T). For this configuration, HTS and LTS coils are considered and compared.

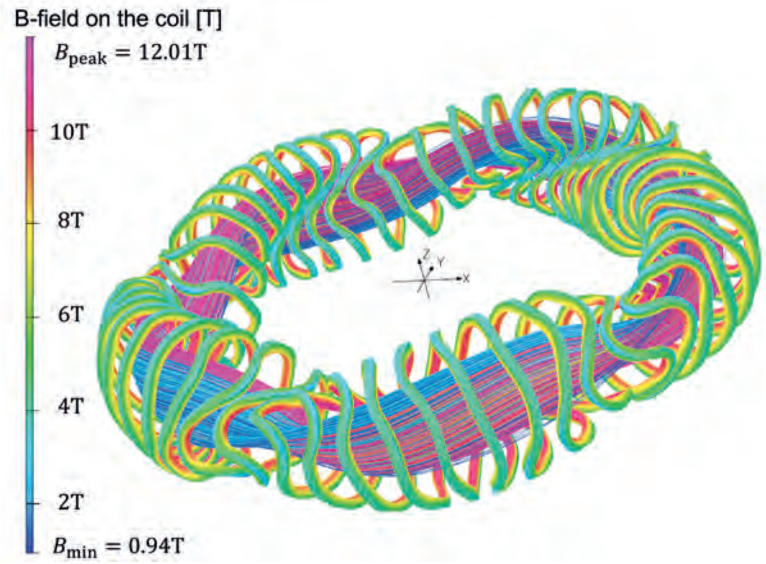
Given the existence of various stellarator configurations, the development of a parametric tool for magnetic design will significantly accelerate the overall stellarator design process and its evaluation.

PROTOTYPES FOR THE NEW EDIPO 2 MAGNET

To de-risk EDIPO 2's magnet design before its final production, **JACK GREENWOOD** has designed several technology prototypes over the last year, and he will test them in the SULTAN facility over the next 18 months.

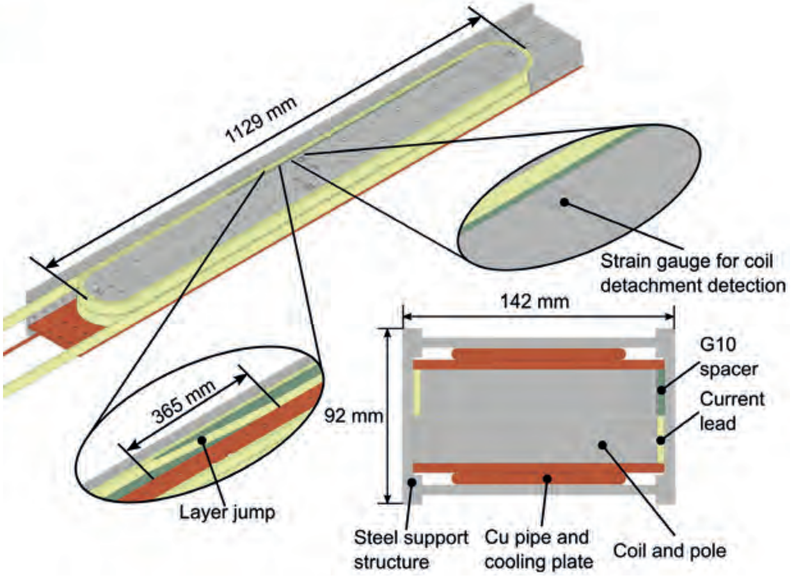
Firstly, a straight sample has been designed, that will allow us to test lengths of the 2-stage Nb_3Sn Rutherford cable used to wind EDIPO 2's coils. DC tests in fields up to 10.9 T aim to verify that the Nb_3Sn's critical superconducting properties do not degrade because of the cabling process, or the repeated cable charging and discharging that is expected over EDIPO 2's lifetime. We will also subject the sample to AC fields, so that we learn about the cable's AC loss behaviour, which is an important input for tuning the systems to protect the EDIPO 2 magnet during quenches.

Secondly, a subsize racetrack coil (**Figure 2**) has been designed, which includes many of the critical technologies that are found in EDIPO 2's full-sized racetrack coils. For example, EDIPO 2's coils will have detachable poles that will be replaced after the Nb_3Sn's 650 °C heat treatment. The coils will also feature continuous transitions between coil layers. In these transitions, aka "layer jumps", the cable will be subjected to hard-way bending. The SULTAN test aims to verify and validate the designs and manufacturing processes for these aspects.



1 Magnetic flux density of Helias-5B and the rotational transformation of the field lines within the stellarator.

"An interesting shift towards stellarator research is clearly observed."



2 The EDIPO 2 subsize coil design.

International Activities - ITER

Research activities at SPC are conducted in the frame of international collaborations with ITER via Fusion for Energy (F4E). Dr TIMOTHY GOODMAN leads the area in the field of plasma heating systems, in particular high-power microwaves.

EUROPEAN GYROTRON FOR ITER AND DTT

Two ITER-like, 170GHz, 1MW gyrotrons from THALES are tested at our test facility at SPC, FALCON. The first one is a prototype owned by Fusion For Energy (F4E) and the other one is to be delivered to the Diverter Test Tokamak (DTT) following its factory acceptance test.

The final delivery to DTT will include a new 2-mirror Matching Optics Unit (MOU) to replace the "standard" 5-mirror RF conditioning unit (RFCU) at FALCON. Prior to removal of the RFCU, some modifications were made that were required for evaluation of effectiveness of shielding in the ITER design.

> ***"The transmission line and matching optics unit were aligned to such a precision as to achieve more than 95% of the power into the desired mode."***

Following the removal of the RFCU, the transmission line and MOU were realigned. The transmission line (TL) was aligned with millimeter precision over the ~9m length of the TL. The mirrors of the MOU were aligned with sub-millimeter precision to inject the output beam of the gyrotron into the transmission line with greater than 95% of the power in the desired HE11 mode; the power was then measured at very short (ms) pulse-length.

Before the start of long pulse (minutes) operation, tests of the modulation capabilities of the high voltage power supplies were witnessed by both F4E and DTT verifying that the facility, previously repaired, was still fit for purpose for later modulation testing with the DTT gyrotron.

At high energy (long pulse, high power), the MOU was tested with several different mm-wave absorbing structures inside: a) no absorber, b) absorber support structure only, c) two different sets of absorbing plates attached to the support structure and d) absorbing ceramics plasma-sprayed directly on the cooled end-flanges of the MOU (no support).

From a) it was shown that internal bellows of the MOU would overheat without some absorbing material in the MOU. From b) & c) it was determined which ceramic thickness was best to absorb the power, but also that clamping absorbers to a support structure did not provide sufficient thermal contact to effectively evacuate the heat. Test d) proved that the optimal ceramic absorber on the cooled end-flanges resulted in a stable internal bellows temperature and no hot spots of overheating of either the absorber, or the MOU parts.

The power density of stray radiation within the MOU was measured, using bolometers borrowed from W7X in Greifswald, to be 0.73MW/m^2/MW transmitted power and was shown to be roughly uniform (with ~14%) within the MOU near the end flange.

The DTT gyrotron was tested further to measure the range of operation with respect to the beam radius and the magnetic field at the angle at the cathode. Additional tests were carried out to better understand the frequency shift of the gyrotron and the power losses in the gyrotron cavity and internal launcher as these did not conform to expectations from simulations.

F4E PROTOTYPE GYROTRON

In October 2024, it was determined that the cavity cooling of the DTT gyrotron limited the power output of the gyrotron to 0.75MW. As the power specification for this gyrotron is 1MW, it was decided to ship the gyrotron back to THALES for repair. The gyrotron was replaced by a similar F4E gyrotron provided to the FALCON facility for testing the components of the four Upper Launchers (ULs) that F4E will deliver to ITER. SPC optimized the operation of this gyrotron and provided data that confirmed that when switching between gyrotrons of the same design, the tight tolerances specified by THALES for the superconducting magnet of the gyrotron are sufficient to ensure proper operation. This is an extremely important feature for fusion power plants that will need to be able to replace components rapidly as they age, or break, without having to realign and re-optimize complex sub systems. Furthermore, it provides confidence that the DTT gyrotron will perform well in the foreseen magnet.

1 First IR camera (lime green) view of the DWU (object with all the blue cooling lines and gold-plated EU-US adapters on each end).

> *“All transmission line loss rates measured at FALCON are compliant with ITER specifications.”*

All loads tested show very low reflected power and no measurable effect on the operational behavior of the gyrotron. All derived TL loss rates measured at FALCON are compliant with ITER specifications.

UPPER AND EQUATORIAL LAUNCHER EX-VESSEL WAVEGUIDES

The Electron Cyclotron (EC) ITER Upper Launchers (UL), including the ex-vessel waveguides that are part of those launchers, is being constructed by the Technical Integrator (TI) who will be responsible to provide the final analysis, documentation, production, and delivery of the launchers. SPC reviews updates of the final design along with Fusion For Energy (F4E).

During 2024, negotiations were finalized between the TI and F4E to perform stray radiation tests of a full-scale model of the beam enclosure of the UL, including uncooled mirrors. These tests should allow F4E to present reliable and convincing arguments for the viability of the UL to safely fulfil its role for the 20-year lifetime within the ITER machine. Design work began in 2024 and testing will take place in 2025.

Meanwhile, testing of components of the EU sections of TL that are delivered as part of the UL continued at the FALCON facility. One crucial component is the diamond window unit (DWU) that allows RF radiation to pass, but confines Tritium and acts as a vacuum barrier between the ITER tokamak vacuum and that of the US ITER transmission line. Diamond has extremely low power absorption when the thickness is optimally chosen for the gyrotron frequency. Its superb high thermal conductivity makes it an ideal choice as a window. The mechanical design of such a DWU is very challenging as ITER requires 100% inspection of all welds for Safety Important Class components acting as confinement barriers. F4E supplied a DWU of one potential design to FALCON. SPC modified one US ITER MB mirror, in agreement with US ITER, to incorporate an arc detector looking down each leg of the MB.

The DWU designed by F4E and manufactured by Gutmar has been successfully tested. No arcing was observed during testing. The peak power was 1MW ±10% at short pulse length (≤0.2s). The longest pulse length used was 180s at 750kW. Infrared measurements (see **Figure 1**) from various viewing angles showed no hot-spots and good uniformity of the cooling.

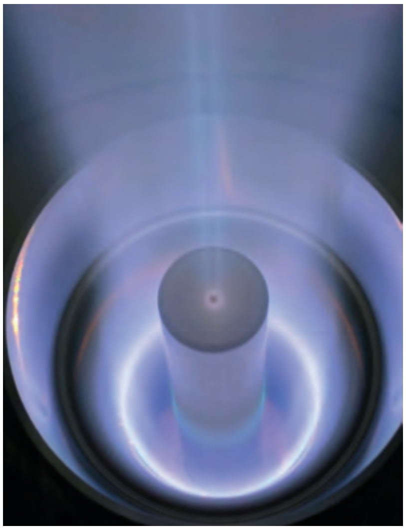
The diamond window cooling does not reach steady state in these short pulses, but the peak electric field is the highest possible. The cooling time constants for all parts of the DWU were determined and provided in the report delivered to F4E. There is no evidence of any leak across the DWU.

T-REX

The TRapped Electrons eXperiment – T-REX, funded by SNSF, after its first operation achieved back in September 2023, successfully underwent commissioning and concluded numerous test campaigns. Tests were aimed at determining the general experiment behavior, specifically to evaluate the current distribution among the main components for a wide range of voltages, magnetic fields, pressures and gases. Our in-house code FENNECS has shown very good agreement with the experimental results. Our work attracted the attention of Eurofusion which decided to classify T-REX as indispensable facility for nuclear fusion technology development.

> *“Eurofusion decided to classify T-REX as indispensable facility for nuclear fusion technology development.”*

T-REX is being continuously improved, and new diagnostics have been implemented. The design of the experiment allows it to be easily upgraded, shut down, and restarted. This is an exceptional feature for the formation of the new generation of scientists who can work on different types of diagnostics and quickly implement and test their new ideas. **Figure 2** shows the light emitted from the residual gas in the T-REX chamber as the electrons pass through it. Analysis of the visible light provides one of the many diagnostic opportunities.

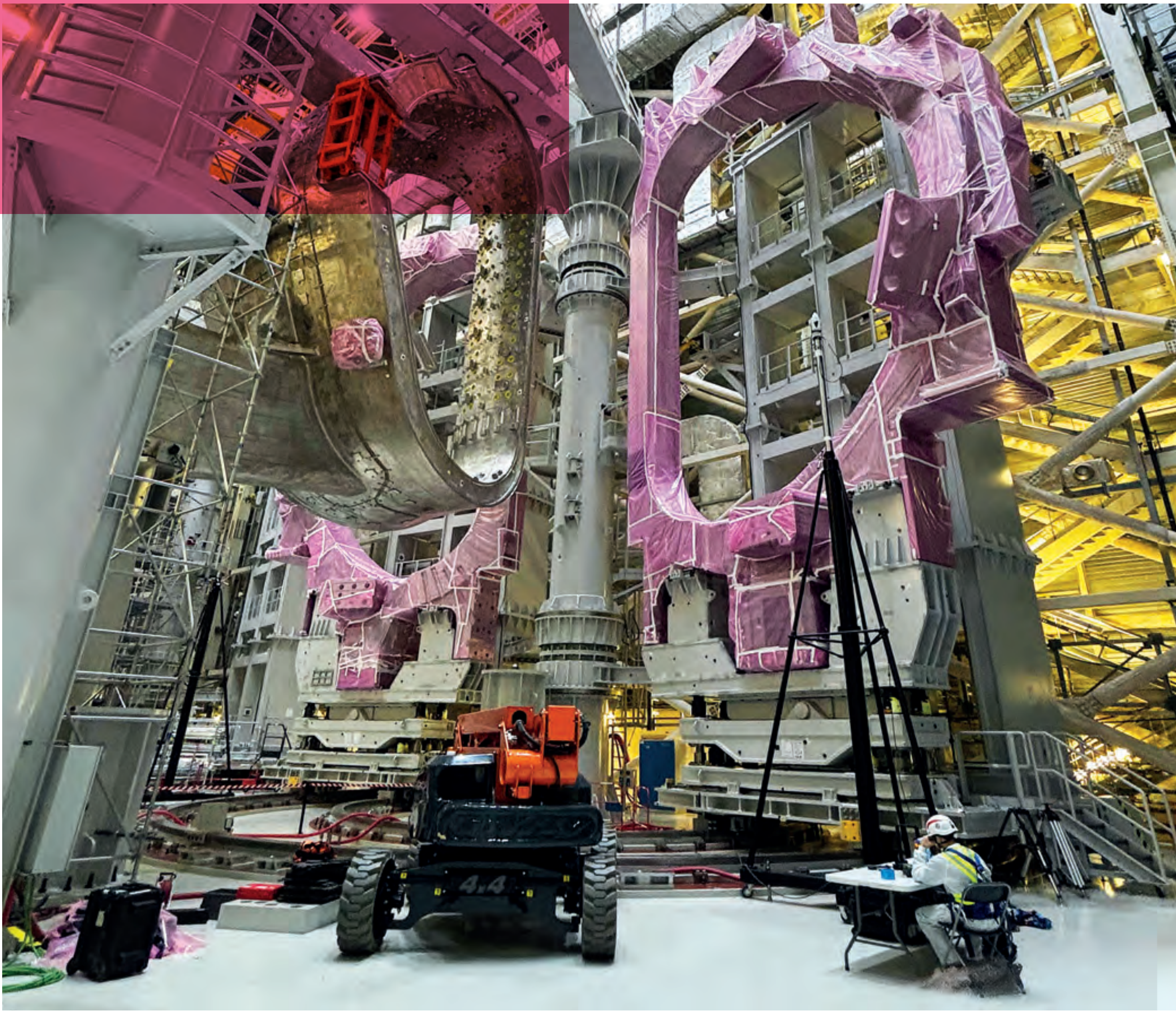


2 Visible light emitted near the electrodes of T-REX.

ITER, EUROPE AND SWITZERLAND

After a historical year for fusion milestones in 2023, with record fusion energy produced at JET and record fusion yield in laser-driven fusion at National Ignition Facility at Livermore in the US, 2024 has been a year in which public and political interest for fusion has reached its highest intensity ever.

"2024 has been a year in which public and political interest for fusion has reached its highest intensity ever."



Several political instances of the highest level, including heads of state, in several nations, among which Germany, France, Italy, China and in the EU, and encompassing international agencies like IAEA, have officially referred to fusion as an important element of their energy and industrial policy for decarbonization. International meetings have gathered many stakeholders to re-iterate the political support to fusion, and to start a coordination that goes beyond the traditional EU or ITER channels.

In this context, Italy – as G7 president – hosted the inaugural ministerial meeting of the World Fusion Energy Group, an initiative by the International Atomic Energy Agency (IAEA). The European Commission, Fusion for Energy (F4E), the ITER Organization and EUROfusion attended the event in Rome with representatives from international governments as well as private companies, industry, research and other stakeholders. The IAEA established the group with the aim of forming a cohesive and inclusive platform to accelerate the research, development, demonstration and deployment of fusion energy through international cooperation.

> *“The level of private investments has exceeded 8 billion euros worldwide.”*

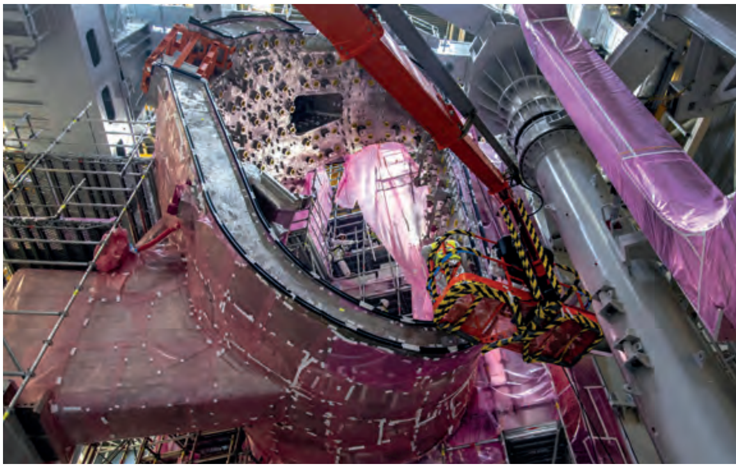
The level of private investments has exceeded 8 billion euros worldwide, and the geographical distribution of the investors and the initiatives has become larger and larger, including a very significant growth of start-ups in different parts of Europe.

The ITER project advanced at a very good pace in 2024, with significant progress both in the repairs of the thermal shields, the completion of the first European vacuum vessel sector, and of the last one from Korea. The completion of all toroidal field coils from both Europe and Japan also represented a crucial milestone. In addition, the ITER management engaged with several private companies, launching a new policy of knowledge sharing with all fusion stakeholders.

The new ITER baseline, taking advantage of the project delays to install several systems before the first plasma, and based on Tungsten as first wall, reactor-relevant material, was endorsed by the ITER Council. The resulting realistic and dependable plan will allow for quicker advancement toward exciting experiments, specifically those involving the complete fusion fuel mix and optimal plasma performance, ultimately reaching the burning plasma stage.

In Europe, Fusion for Energy and EUROfusion have taken a significant step to strengthen their partnership with a renewed Memorandum of Understanding. F4E and the European fusion laboratories, participating in the EUROfusion consortium, already engage in a wide range of activities in fusion R&D and engineering. Present collaborations include the operation of the joint international fusion experiment JT-60SA in Japan and the design of Test Blanket Modules, to name a few. The Memorandum of Understanding sets a broad scope for future activities drawing upon knowledge transfer and the possibility of mutual in-kind contributions.

In alignment with the EUROfusion vision for an increased level of integration between public research institutions and industries, the European Commission has launched a Coordination and Support Action (CSA) to prepare for potential future Public-Private Partnerships (PPPs) on Fusion Energy. The idea is to establish an industry-led European association, representing the European fusion industry and relevant fusion-related technology centers and research organizations, which could possibly evolve into a long-term European Technology and Innovation Platform. In addition, the CSA should lay down a Strategic Research and Innovation Agenda on Fusion Energy, with provisions for managing intellectual property and technology transfer.



In 2024, Switzerland could still not be associated to the research Framework Programme FP9, hence formally cannot participate to Euratom and ITER. Nevertheless, the role of SPC and EPFL in the activities of the EUROfusion Consortium was still central, thanks to EPFL’s participation as an associate partner to the Max Planck Institute of Plasma Physics (Germany). SPC teams could also participate to ITPA, ITER Associates and Fellow schemes via the IEA Technology Cooperation Program on tokamaks.

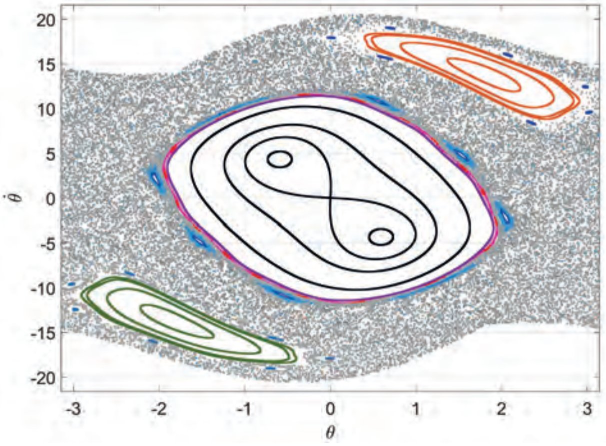
Moreover, EPFL and the SPC can collaborate and directly exchange with ITER in several key R&D areas thanks to the cooperation agreement that was signed between EPFL and F4E and generously supported by the Swiss State Secretariat for Research, Education and Innovation (SERI).

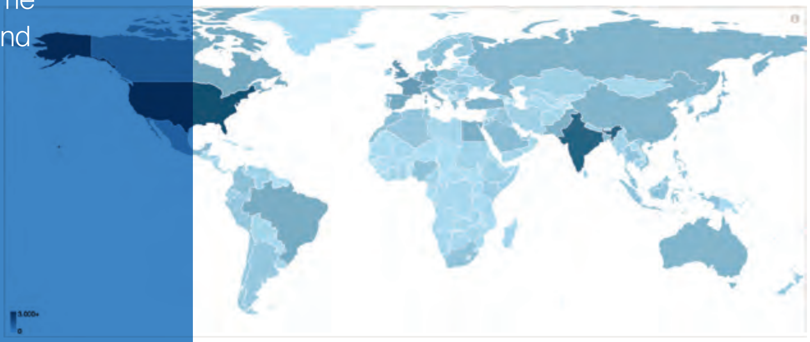
We are grateful to the Max Planck Institute of Plasma Physics, SERI, and F4E, as these mechanisms allow us to operate effectively in full synergy within Europe, and with the ITER partners, in view of a seamless, and hopefully imminent transition to being fully re-associated to the European research area and EURATOM, a vital requisite for the longer term.

TEACHING

The education of future generations of plasma physicists is one of the core missions of SPC. Being tightly embedded into the academic fabric of EPFL is a clear asset for attracting young talents to the field.

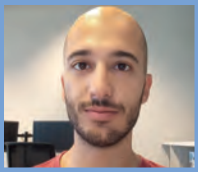
In 2024 we trained record numbers of PhD and Master students. We are proud to see SPC having become a vibrant community of highly motivated, bright and young researchers.





Geographical distribution of the registered participants to the MOOC course on plasma physics given by SPC in 2024.

The top-class quality of education provided at SPC is demonstrated, among other things, by a substantial number of awards and grants that have been obtained by PhD students and Post-Doctoral researchers throughout the past years. 2024 was no exception:



FILIPPO BAGNATO got the 2nd Prize CAEN in Experimental Physics, awarded at the ICFDT7 - 7th International Conference on Frontier in Diagnostic Technologies, for his thesis carried out at SPC.

BAPTISTE FREI received the 2024 PhD Research Award of the European Physical Society, for his work entitled "A Gyrokinetic Moment Model of the Plasma Boundary in Fusion Devices" for its outstanding treatment bridging the gap between fluid and kinetic descriptions.

CASSANDRE CONTRÉ and **MARTIM ZURITA**, two PhD students at SPC, won the Dean's Prize of the Faculty of Basic Sciences in recognition of their contribution to teaching activities.

SOPHIE GORNO was awarded a Distinction of the EPFL Doctoral School for her PhD carried out at the SPC "Experimental study and interpretative modelling of the Power Exhaust in Configurations with Multiple X-Points in TCV".

DANIEL BIEK, PhD student at SPC, received an Excellence Award, Poster Competition at the 4th Int. School on Numerical Modelling for Applied Superconductivity.

At the end of 2024 the SPC had 56 PhD students enrolled in the Doctoral School of EPFL and 33 Post-Doctoral researchers. In 2024, **Antonio Coelho**, **Claudia Colandrea**, **Sophie Gorno**, **Antoine Hoffmann**, **Lorenzo Ibba**, **Stefano Marchioni**, **Moahan Murugappan** and **Curdin Wüthrich** obtained their PhD in physics for their work carried out at SPC.

The SPC is providing a complete curriculum of plasma physics courses at all levels: Bachelor, Master and Doctoral School, at the EPFL and within the European-wide education initiative FUSENET.

The SPC is giving two Massive Open Online Courses (MOOC) on Plasma Physics Introduction and Applications. These courses also include lectures on plasma medicine, superconductivity for fusion and laser-plasma interaction, together with experts from Sorbonne University in Paris and Ecole Polytechnique in Palaiseau. The SPC MOOC on plasma physics is highly successful, with a record number of almost 20,000 subscribed learners in 2024 from around the globe.

In addition to plasma physics courses, SPC staff is teaching several classes in general physics, advanced physics, computational physics and mathematical methods for physics. In 2024 we reached a record total number of students of 2340 (excluding the MOOC) and a record of almost 140’000 student-hours.

18	Number of courses given by SPC staff at Bachelor, Master and Doctoral levels
2,340	Number of students in these courses
130	Average number of students in the classes of these courses
1,036	Number of hours taught by SPC staff in these classes
137,998	Number of student-hours taught by SPC staff
19,995	Number of subscribed learners in the MOOCs on Plasma Physics of SPC
56	Number of PhD students at SPC at the end of 2024
33	Number of Post-Docs at SPC at the end of 2024
64	Number of Master students supervised at SPC for semester and thesis projects
30	Number of Visiting PhD students, Master exchange students and Internships

GARANCE DURR-LEGOUPIL-NICOUD, PhD student at SPC made the Best Overall Presentation at the FuseNet PhD Event 2024.

DAVIDE MANCINI, post-doctoral fellow at SPC, has been awarded a EUROfusion Research Grant (ERG) for his project “Three-dimensional turbulent simulation of plasma detachment in negative triangularity configurations”.

SIMON VAN MULDERS, post-doctoral fellow at SPC, has been awarded an ERG grant for his project “Towards real-time capable integrated core-edge plasma modelling including impurities, from TCV and AUG to ITER and DEMO”.

RALF MACKENBACH obtained the Rubicon Grant from the Dutch Research Council.

GUANGYU SUN got the Chinese Government Award for Outstanding Students Abroad.

YOERI POELS, PhD student at SPC, was awarded a EUROfusion Engineering Grant (EEG) for his project “Integration of machine learning and database tools for enhanced control room operation”.

OUTREACH

The Swiss Plasma Center recognizes the importance of outreach activities and conducts a broad variety of initiatives. This year was marked by a project realized for the Day of Women and by the participation of the Center to the ‘Scientastic Festival’. Beside these two major events, efforts were focused on more traditional activities such as the visits of the Center which once again broke records, contributions to a wide range of media, conferences given on-site or outside, as well as the publication of printed or electronic documents for the general public.

7 + 7 WOMEN IN SCIENCE

To mark the international Day of Women and Girls in Science, 7 brilliant female scientists of the SPC have been interviewed on the reasons which led them to pursue a career in science. In addition they were asked to give the name of a women in science who inspired them. The output of the interviews have been published on Instagram, one per day during the full week preceding the Day of Women. A global news item has taken up all these interviews and has been published on the SPC news channel.

SCIENTASTIC FESTIVAL

The theme of the 2024 edition of the Scientastic Festival, organised by EPFL, was “The Scientific Approach”. The SPC was invited to participate in this main outreach activity. Helios, the plasma demonstrator, was moved to the building located at the crossroads of the various festival venues. Enhanced with a few posters and a screen showing a presentation, the stand attracted large crowds throughout the weekend. Similarly, the tour of the tokamak was a great success. Tours of the machine took place at a steady pace, much to the satisfaction of the approximately 2’000 visitors who entered the hall.

TECDAYS, YOUTH FORUM SWITZERLAND AND OTHER EVENTS

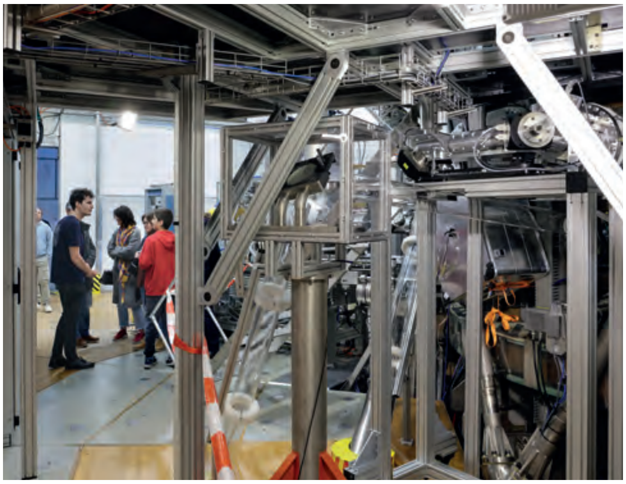
As in previous years, our fusion research activities have been presented at several events, notably at TecDays, organised by the Swiss Academy for Research and Technology (SATW), for high-school students. These interactive presentations, in French, German or Italian, depending on the language region of Switzerland are an excellent opportunity to explain the basics of nuclear fusion and give an insight to the tokamak technology and research to high school students further away from EPFL. In 2024, the young organisers of the Youth Forum Switzerland invited us to participate in a pannel discussion on the Future of Energy. The event took place at the International School of Zug and Luzern and gathered about 400 students from local and international schools across the world.

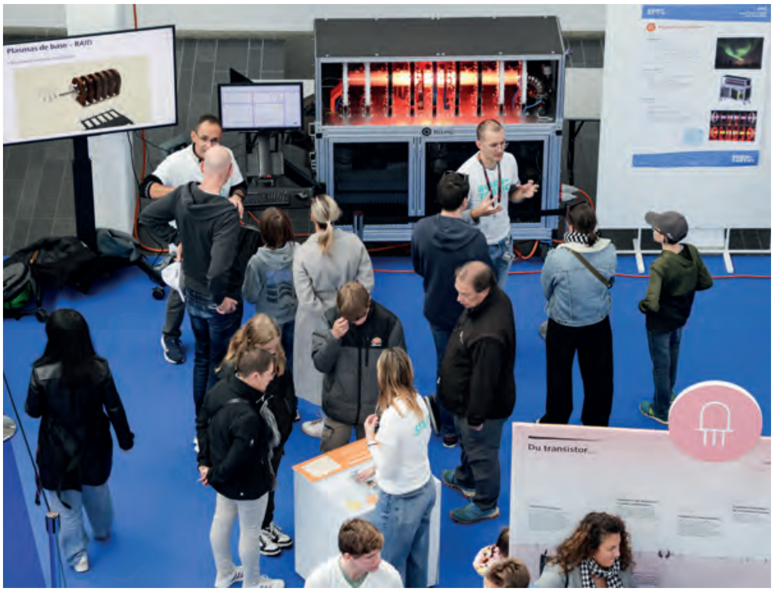
MUDAC

In the frame of the preparation of an exhibition on the Sun that was going to take place the following year at the Cantonal Museum of Design and Contemporary Applied Arts, an artist, Rocio Berenguer, came to the SPC to shoot a film in the tokamak zone. In front of the camera, she moved and danced between the scientific equipment, giving these spaces an unusual atmosphere, see photo.

VISITS

Visits to the Swiss Plasma Center remained a key component of the outreach activities in 2024. Approximately 180 groups, representing more than 4,400 visitors, discovered the tokamak and other facilities during the year. The majority of participants were young people aged between 15 and 22. Nearly half of the visitors (48%) came from Switzerland, while 30% were from the United Kingdom often combining their visit to the SPC with a tour of CERN. Additional visitors came from Italy (4%), Greece (3%), Norway (3%), Luxembourg, Belgium, as well as from more distant countries including Tunisia, China, Saudi Arabia, Turkey, and the United States.





SERVICES AND ADMINISTRATION

The administration and technical and engineering services are the Swiss Plasma Center's strong backbone. All collaborators are providing essential daily support in a broad range of competencies allowing the lab fame to shine domestically and internationally.

Dr Yves Martin

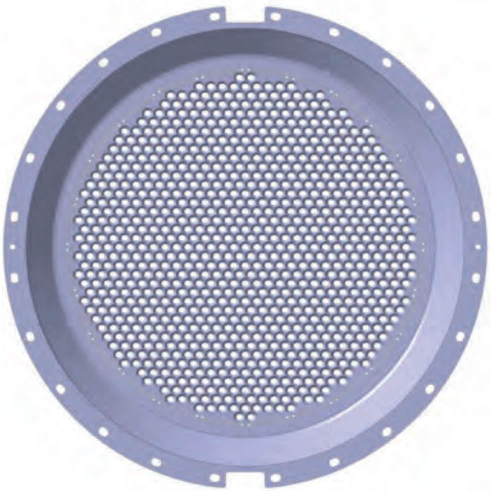
CAO COMM' &
HEAD OF SERVICES

Dr Patrick Blanchard

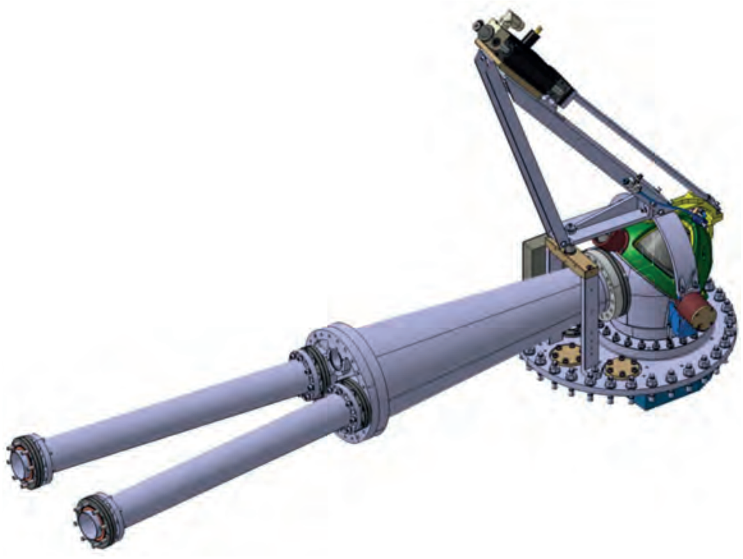
HEAD OF SERVICES
since June 2024

Dr Christian Schlatter

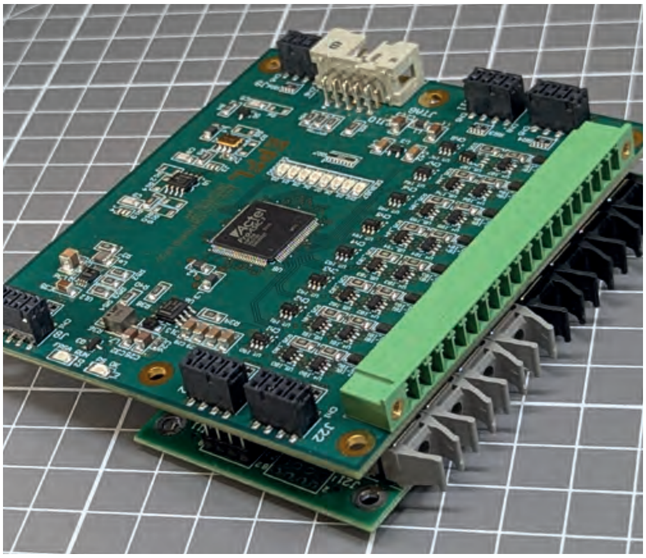
CFO



TCV DNBI: new potato-shape grid design, manufacture and tests.



X3 microwave launchers: new dual-beam launcher for TCV.



PanFib Upgrade: Advanced Digital IOs.

Matthieu Toussaint

MECHANICS CONSTRUCTION OFFICE AND WORKSHOP

Frédéric Dolizy

VACUUM TECHNICS

Damien Fasel

ELECTRICAL HIGH POWER INSTALLATIONS

Pascal Lutz

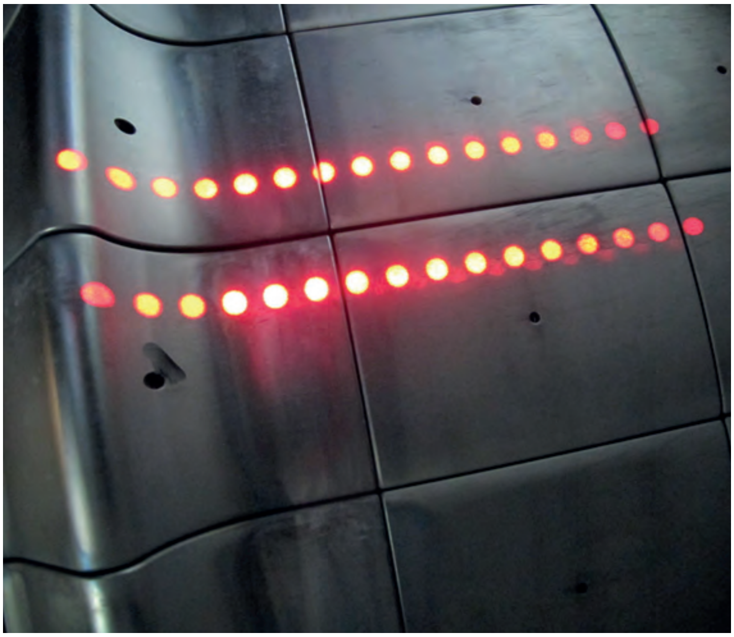
ELECTRONICS

Joan Decker

IT

SPC technical services are an essential part of the SPC organization and its success. More than 45 highly skilled technicians, engineers and PhDs, organized into five specific fields of expertise, provide daily technical competences and resources to the scientific teams. Together, we develop new concepts, explore new solutions and manufacture new systems, mainly for our different experiments, but also for international experiments like ITER, DEMO and JT60SA.

Such level of support and expertise dedicated to our experiments and directly available allows us to develop the unique solutions that high-level research is requesting, thus driving innovation and excellence in our center. It also provides the indispensable help to maintain and repair our complex experiments with a sense of priority and flexibility that allows our lab to be recognized worldwide as ever highly innovative, productive and flexible.



TCV Tangential DSS: in-vessel calibration.

Amongst the 2024 activities, the selection below highlights the capabilities of our services:

- **Gyrotron G12**
  Cryo-pump substation design and manufacture and design of a new power supply for the anode and the filament
- **TCV DNBI**
  New potato-shape grid design, manufacture and tests
- **TCV new gas injection**
  New gas controller system manufacture and installation
- **X3 microwave launchers**
  Design of a new dual-beam launcher
- **TCV FILD diagnostic**
  New rotating head for increased energy and velocity pitch coverage
- **DNBI arc discharge**
  Design and test of new power supply system 480A/450V at 50kV potential
- **RAID TALIF**
  Design, manufacture and installation of a new laser transmission line
- **JT60SA PCI diagnostic**
  Design of a laser transmission system
- **Real-time fieldbus**
  Development of a new SoC FPGA

2024 was also time to warmly thank Yves Martin who stepped down as head of services after 16 years and who was replaced by Patrick Blanchard since June.

PEOPLE, FACTS AND FIGURES

> *“I defend a science that serves as a vector for peace showing that impermeable borders are nothing more than an unnatural political artifact.”*
>
> **AMBROGIO FASOLI**

Participants to the 2024 Joint Varenna-Lausanne international workshop on Theory of Fusion Plasmas.

A key figure in fusion research in Switzerland and Europe, physicist and professor at EPFL, **AMBROGIO FASOLI**, was inducted into three of the most prestigious scientific circles: the Academia Europaea for Europe, the Accademia dei Lincei for Italy, and the Society of Arts and Sciences of Zurich (SATW) for Switzerland.

Prof. **CHRISTIAN THEILER** was promoted to Associate Professor of Plasma Physics at the School of Basic Sciences (SB) on 12 March 2024.

The Joint Varenna-Lausanne international workshop on the Theory of Fusion Plasmas, for which Prof. **JONATHAN GRAVES** is the Scientific Director, took place from Sept. 2 to 6, bringing together 86 participants, with 24 invited talks and 51 posters. and a record number of oral presentations and posters to be published.

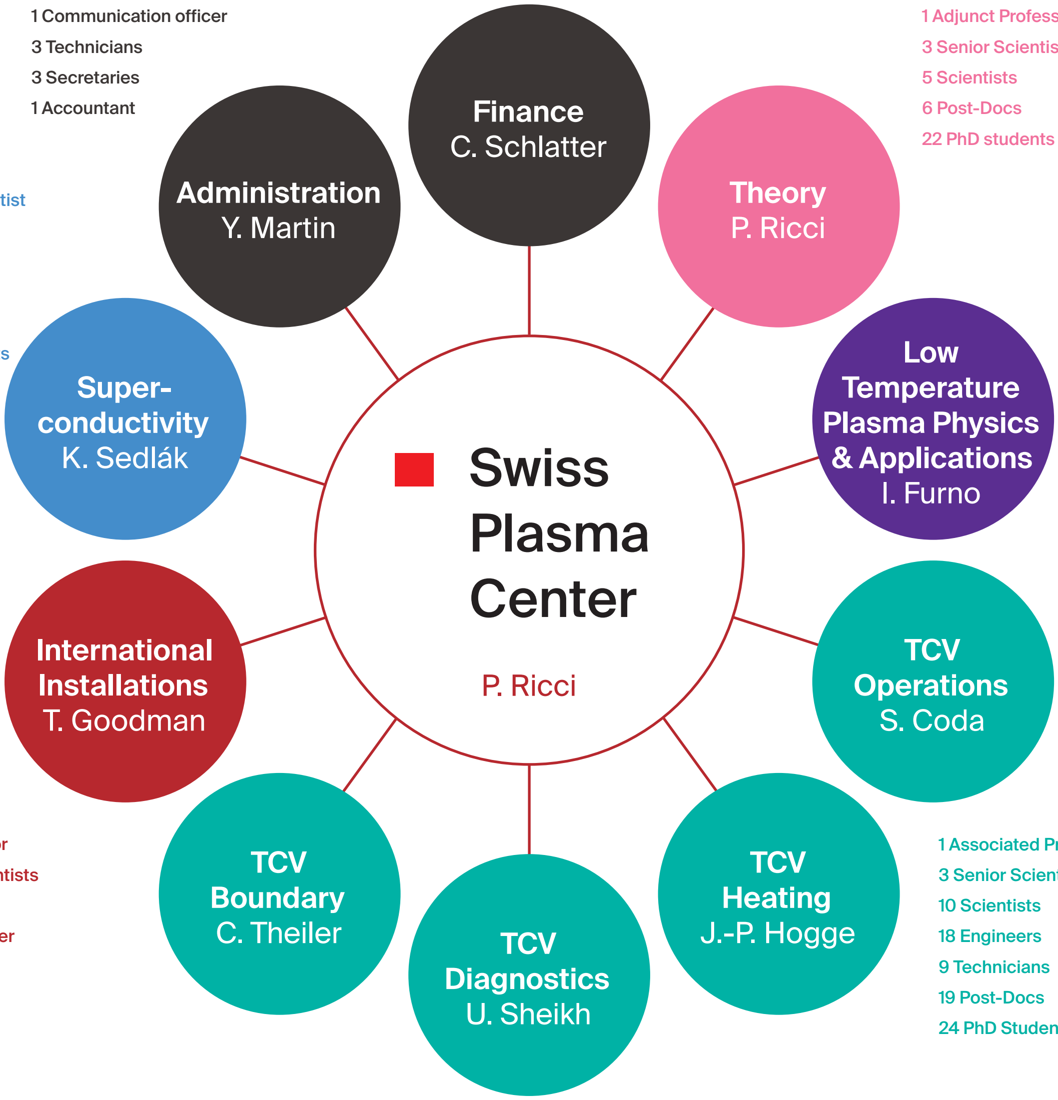
HUMAN RESOURCES

206	Total headcount
178	Full-time Equivalents
51	PhD students (FTE)
34	Post-Docs (FTE)
19	Collaborators joined SPC in 2024
21	Collaborators left SPC in 2024
33	Nationalities represented in SPC staff

STRUCTURE

2 Scientists
1 Engineer
1 Communication officer
3 Technicians
3 Secretaries
1 Accountant

1 Full Professor
1 Adjunct Professor
3 Senior Scientists
5 Scientists
6 Post-Docs
22 PhD students



1 Senior Scientist
4 Scientists
2 Engineers
6 Technicians
3 Post-Docs
2 PhD students
1 Secretary

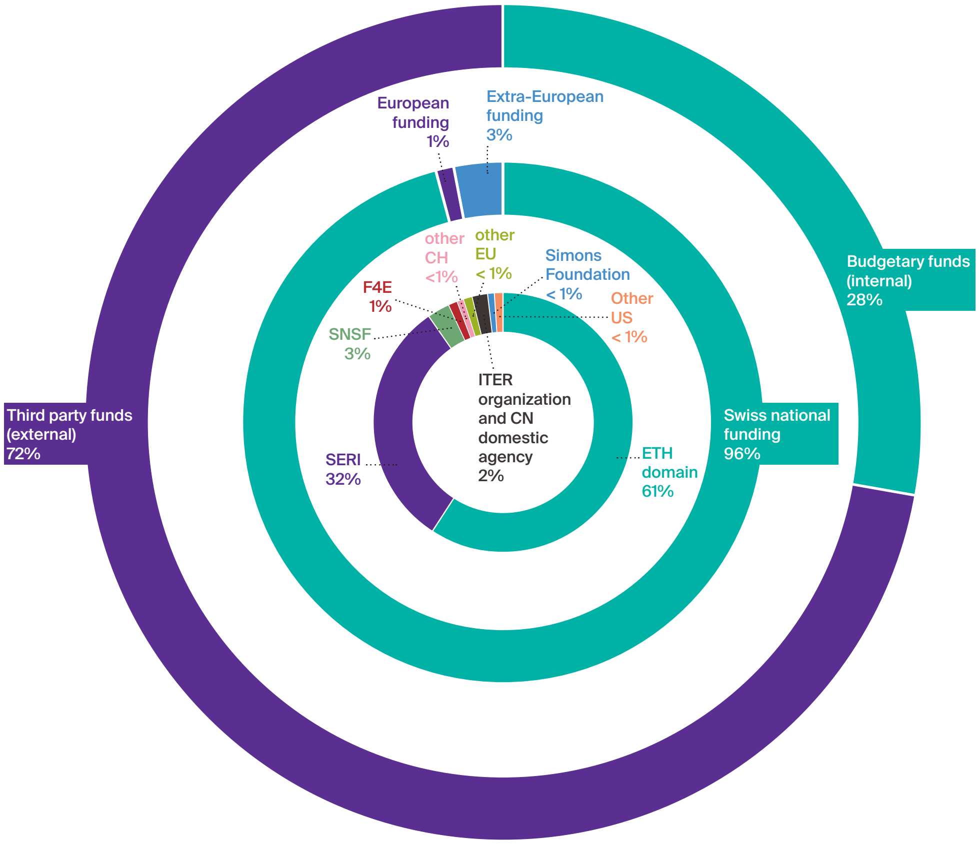
1 Adjunct Professor
4 Scientists
2 Engineers
2 Technicians
4 Post-Docs
5 PhD students

1 Full Professor
2 Senior Scientists
3 Scientists
1 Liaison Officer
8 Engineers

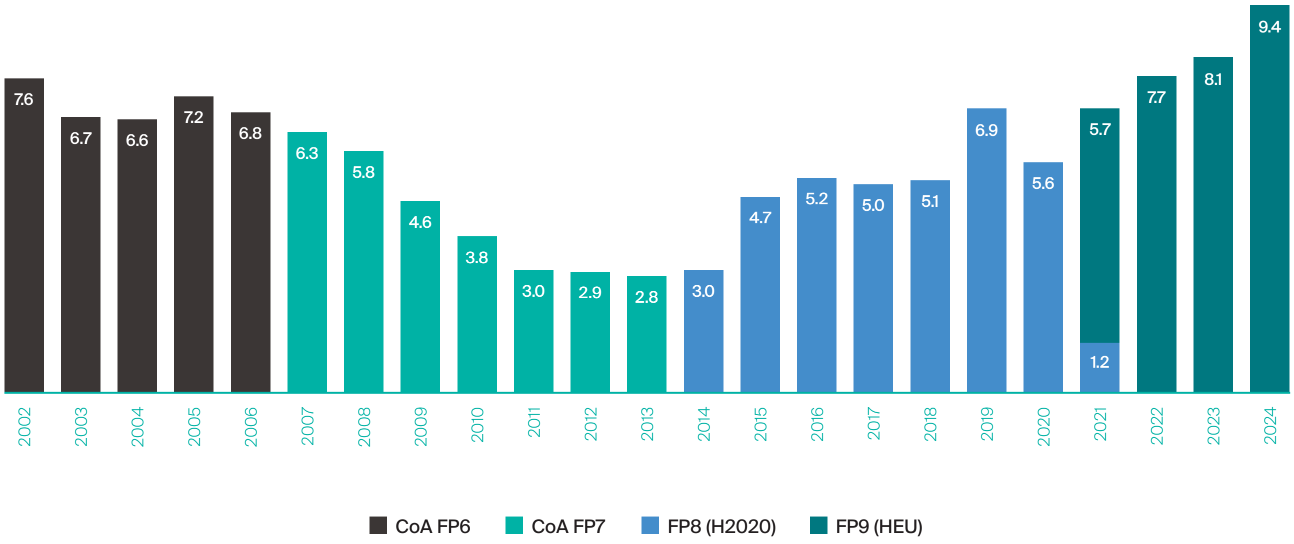
1 Associated Professor
3 Senior Scientists
10 Scientists
18 Engineers
9 Technicians
19 Post-Docs
24 PhD Students

FUNDING 2024

including indirect costs



EURATOM FUSION CONTRIBUTION TO EPFL [MCHF]



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