FCC-ee positron source target design, fabrication & updates on P3 integration

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Date: 21th May 2025

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1. FCC-ee positron source target in the injector complex

1. FCC-ee positron source target in the injector complex

FCC-ee Injector complex

Going from 6 GeV to 2.86 GeV

- improves reliability
- eliminates the need for a common linac
- more efficient and sustainable solution aligned with performance and operational goals.

This talk is focused on the positron source target:

- Thermo-mechanical studies update
- Prototype R&D status
- P3 experiment update

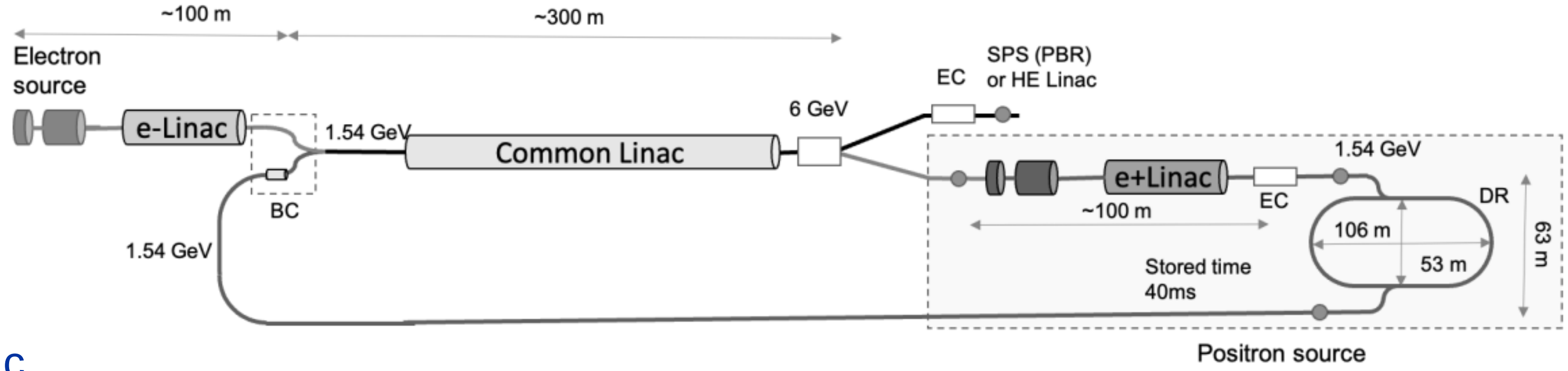


Fig. 6 GeV previous layout of the FCC-ee injector complex. BC: bunch Compressor. EC: Energy Compressor. [Craievich et al 2022]

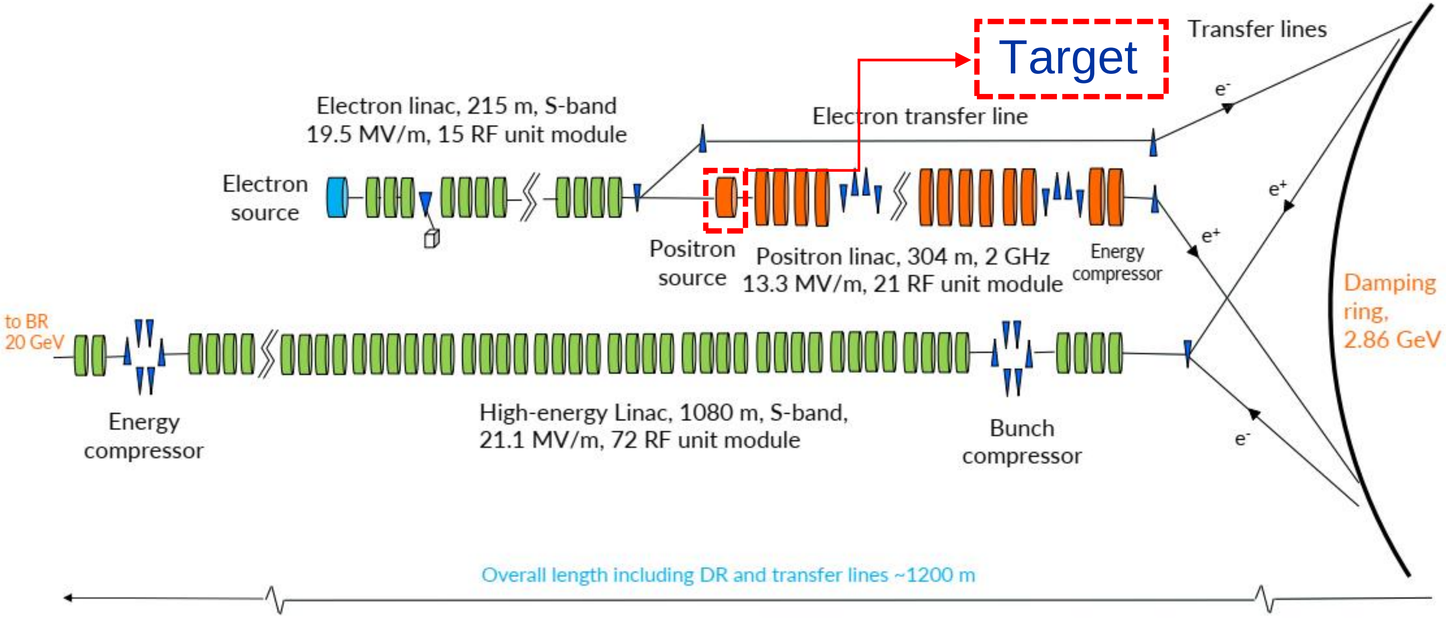


Fig. 2.86 GeV layout of the FCC-ee injector complex [FCC-Feasibility Study vol 2 2025]

2. Thermo-mechanical studies update

2. Thermo-mechanical studies update (1/4)

Positron source design:

- Fixed tungsten (W) target
- Integrated shielding
- Embedded Tantalum (Ta) cooling pipes
- Symmetry around x axis (1/2 model)
- General dimensions: D70x128.5mm

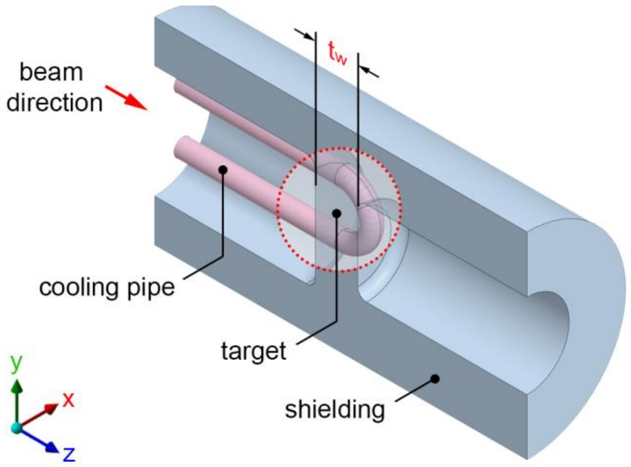


Fig. FCC-ee positron source target half section model

Model setup:

Parameter	6 GeV	2.86 GeV
Beam size RMS (mm)	1.0	1.0
Bunch intensity x e10 (nC)	1.3 (2.08)	2.37 (3.8)
Bunches per pulse (-)	2	4
Frequency (Hz)	200	100
Target thickness t_w (mm)	17.5	15
Beam power (kW)	4.99	4.3
Beam power on target (kW)	1.46	1.26

Table. Beam and geometry parameters for the simulations

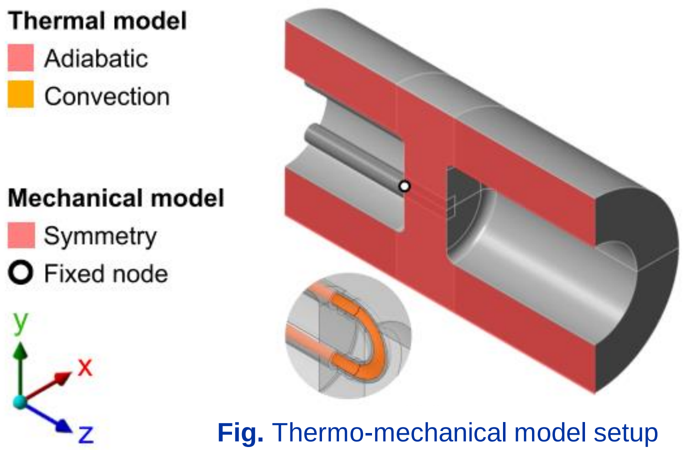


Fig. Thermo-mechanical model setup

2 Thermo-mechanical studies update (2/4)

Power density deposition:

- Main input for the thermomechanical simulations
- 6 GeV → 2.86 GeV = 4.3% reduction in maximum deposited power density (W/m^3)

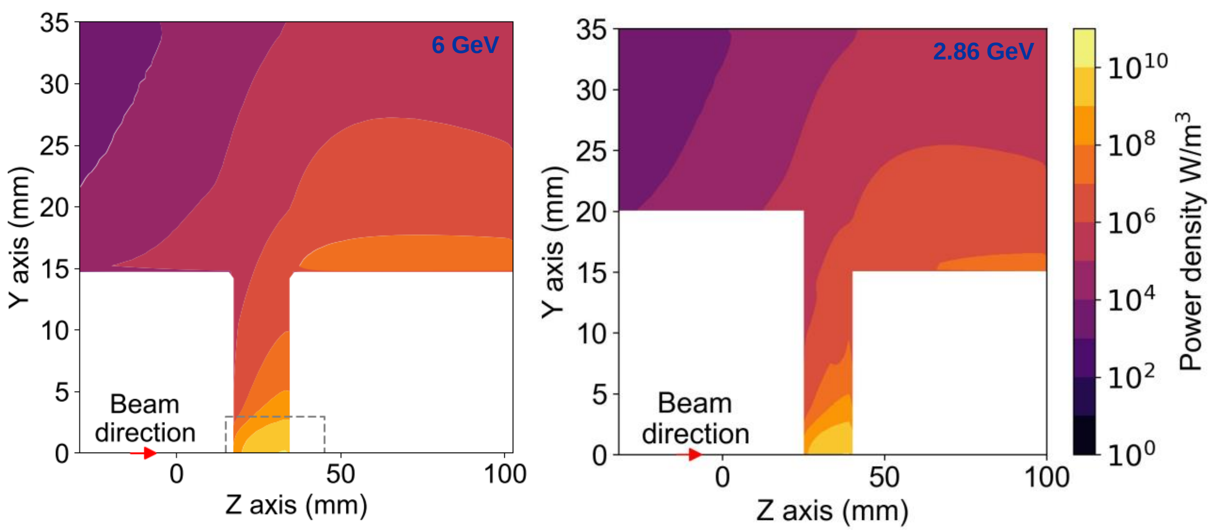


Fig. Power density deposition map obtained from FLUKA used as input for the thermo-mechanical simulations for the (left) 6 GeV vs (right) 2.86 GeV W target. **[B. Humann and M. Daugaard @CERN SY-STI]**

Steady-state results:

- By reducing the e- beam energy, a thinner target is used. As a result, it gets less power deposited with 9.2% lower thermo-mechanical stresses.

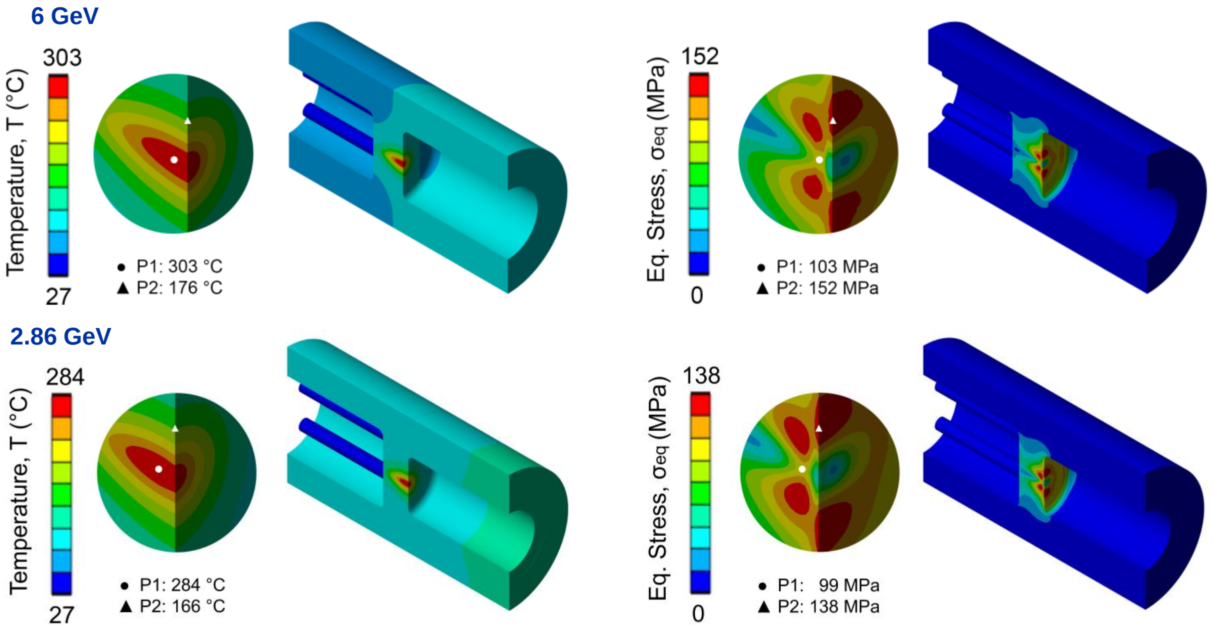


Fig. Temperature (left) and equivalent stress (right) distributions for the (top) 6 GeV vs (bottom) 2.86 GeV W target

2 Thermo-mechanical studies update (3/4)

Steady state results:

Deformation mechanism maps [Ashby et al. 1972]

Tmax < DBTT [350-400] °C

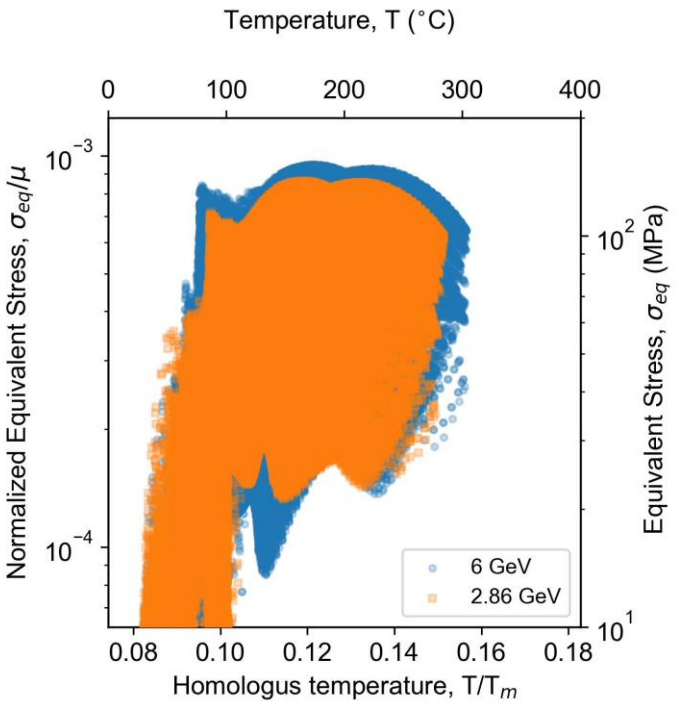


Fig. Deformation mechanism maps for polycrystalline tungsten: 6 vs 2.86 GeV. Legend: A: Elastic regime, B: Theoretical shear stress, C: Dislocation glide, D: Dislocation creep, E: Diffusional flow (Nabarro creep) and F: Diffusional flow (Coble creep).

Transient results:

E_{beam} [GeV]	ΔT [°C]	Δ σ_{eq} [MPa]	Δ ε_{eq} [με]	Nf x1E9 [cycles]	Δ ε_{lim} [με]
6	22	510	787	2.7	719
2.86	45	222	475	1.35	741

Table. Thermo-mechanical comparison between 6 vs 2.86 GeV e- beam

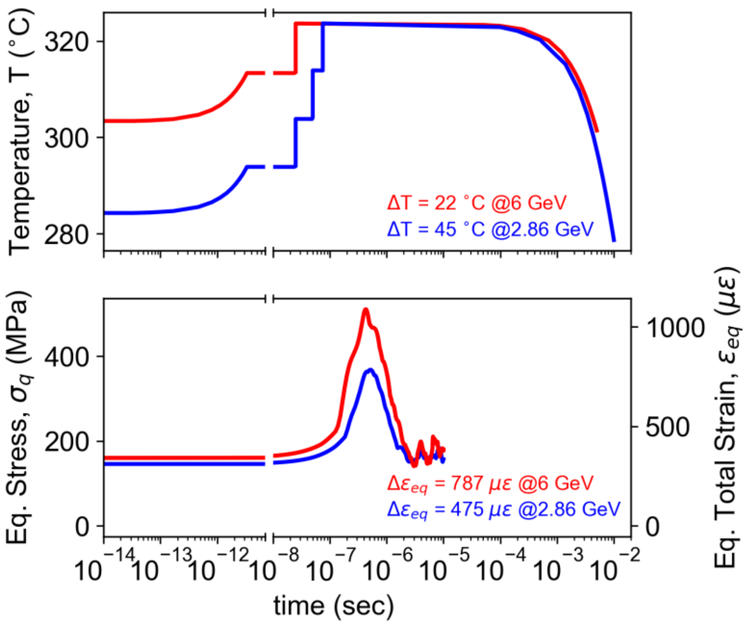


Fig. Transient-state for a single e− beam pulse after reaching steady-state: comparison between the 6 (red) and 2.86GeV (blue) W targets.

Thermal fatigue:

Required lifetime = 155.4 [days/year]

Universal slope method [Manson 1964]

$$\Delta\varepsilon_t = D^{0.6}N_f^{-0.6} + 3.5\frac{\sigma_u}{E}N_f^{-0.12}$$

D: ductility **σ_u: ultimate tensile strength [MPa]**

E: Young's Modulus [MPa] **Nf: number of cycles to failure**

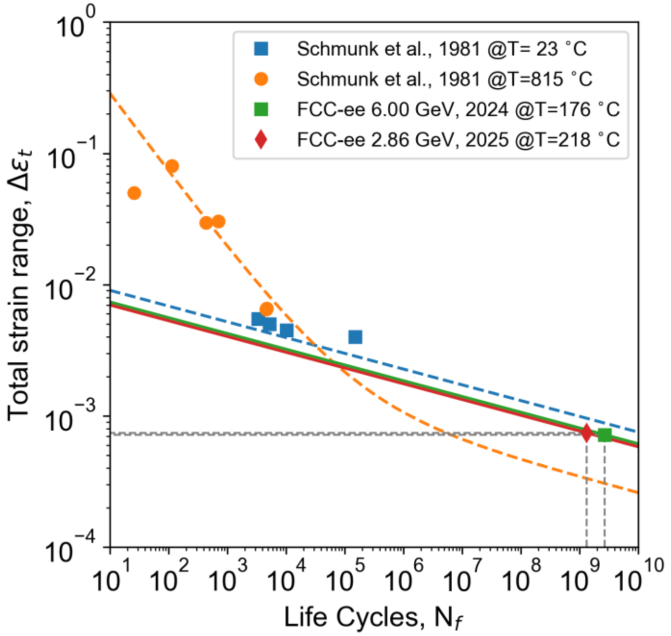


Fig. Universal slope method for tungsten [Schmunk et al., 1981]

2 Thermo-mechanical studies update (4/4)

Summary:

Going from 6 GeV (200 Hz x 2 bunches) to 2.86 GeV (100 Hz x 4 bunches):

- Better **thermo-mechanical performance** for the W target
- **Steady state** temperature and thermal stresses are reduced by 6.3 and 9.2 %, respectively.
- **Dynamic effects** are reduced by a factor of 2.3 (1.7) in terms of equivalent stress (strains).
- The **thermal fatigue** assessment shows that the required lifetime of 155.4 days/year is feasible.

Next steps:

- Validation of the manufacturing route by producing a **prototype**
- **Radiation damage** needs to be re-evaluated. Previous estimation was O(1 DPA/year)

3. Target prototyping

2. Target prototyping: HIP capsule (1/3)

Motivation:

To manufacture a prototype of the **positron source target** with an embedded **cooling system** using Hot Isostatic Pressing (HIP) to join both parts by diffusion bonding.

Constraints:

Target thickness: available space to place the cooling pipes

- W: 15 mm
- Ta: 18 mm
- Diameter: 37 mm (for P3)

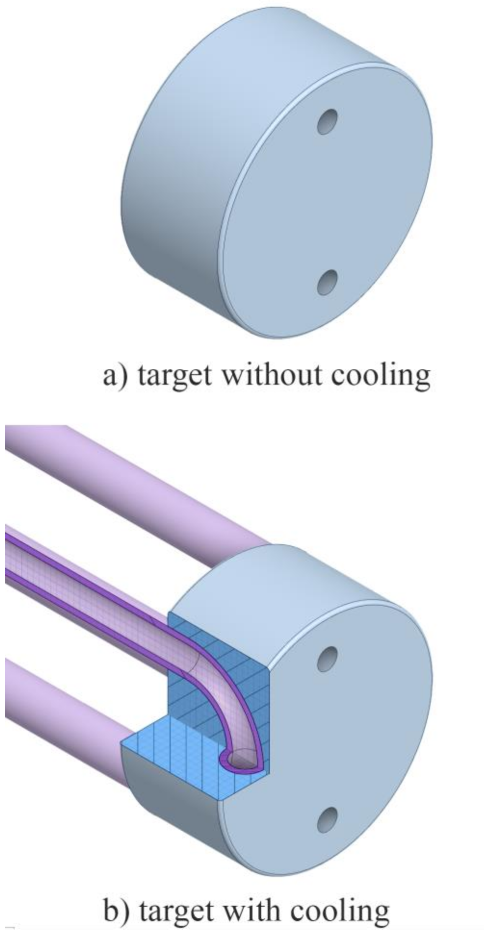


Fig. P3-target prototypes

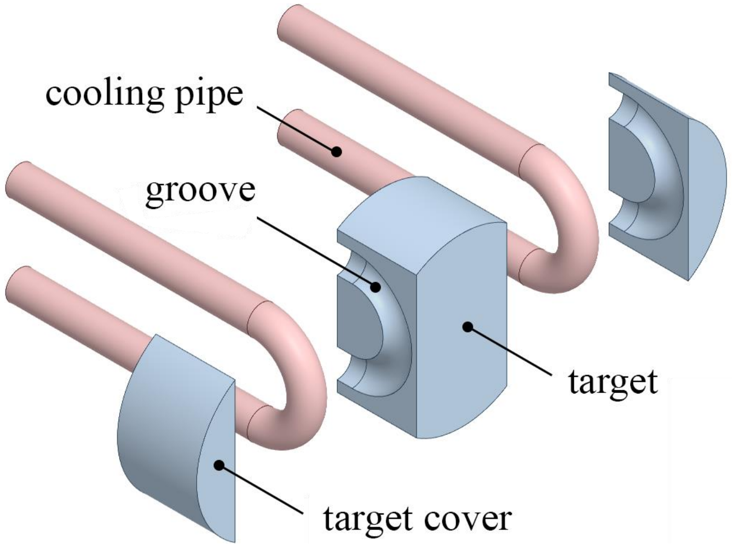


Fig. P3-target with cooling components

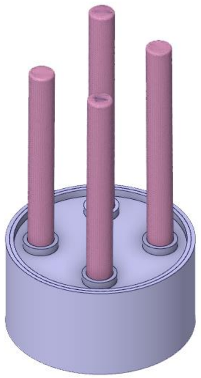


Fig. P3-target with cooling HIP capsule

2. Target prototyping: HIP capsule (2/3)

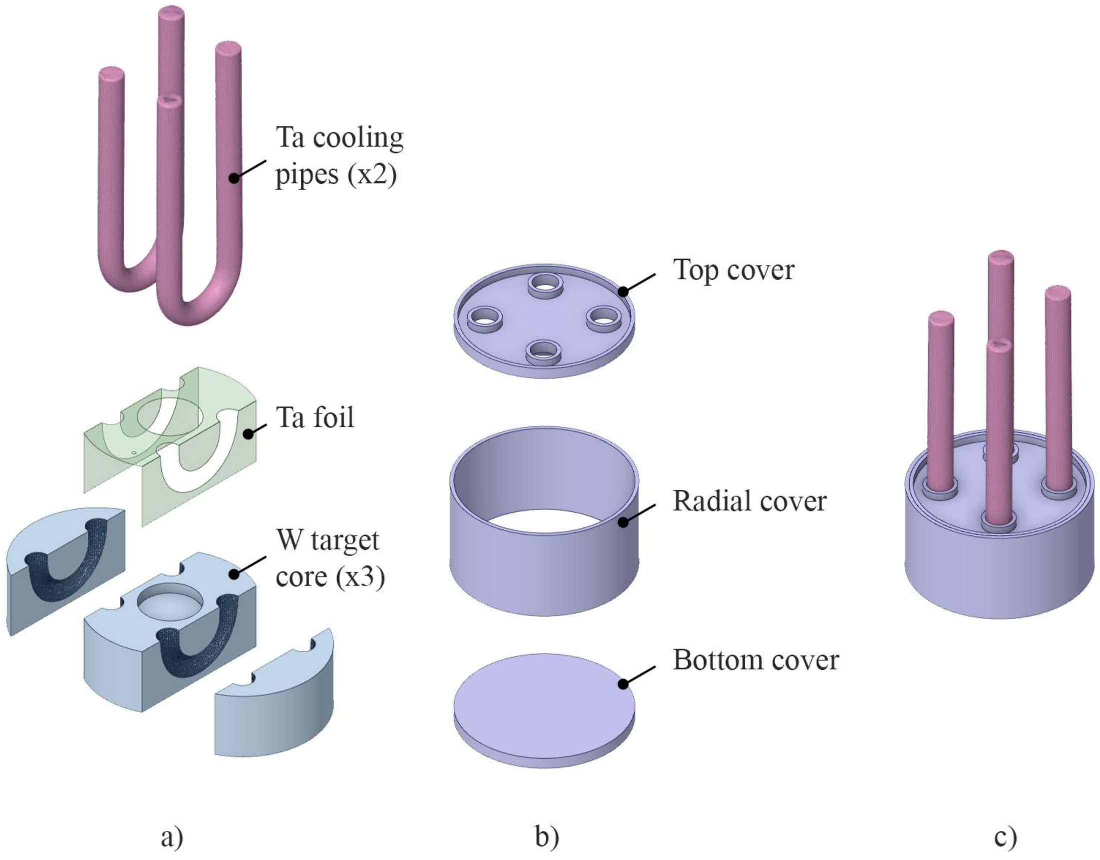


Fig. P3-target with embedded cooling pipes prototype: a) exploded view of the target components only, b) exploded view of the HIP capsule components only and c) HIP capsule final assembly.

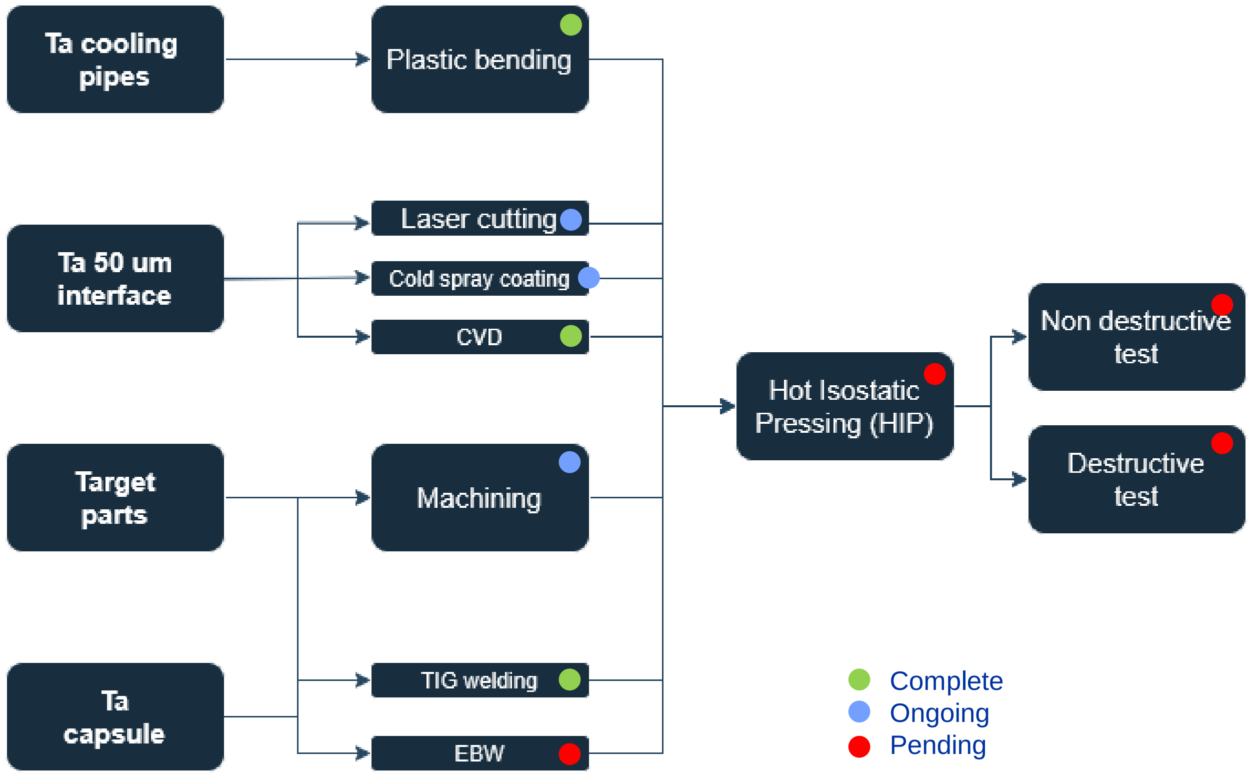


Fig. P3-target with embedded cooling pipes prototype: process diagram

2. Target prototyping: HIP capsule (3/3)

Special thanks for all the technical support to:
[A] T. Coiffet and MME team
[B] K. Guergar and R. Seindebinden (SY-STI-TCD)
[C] W. Vollenberg (TE-VSC)

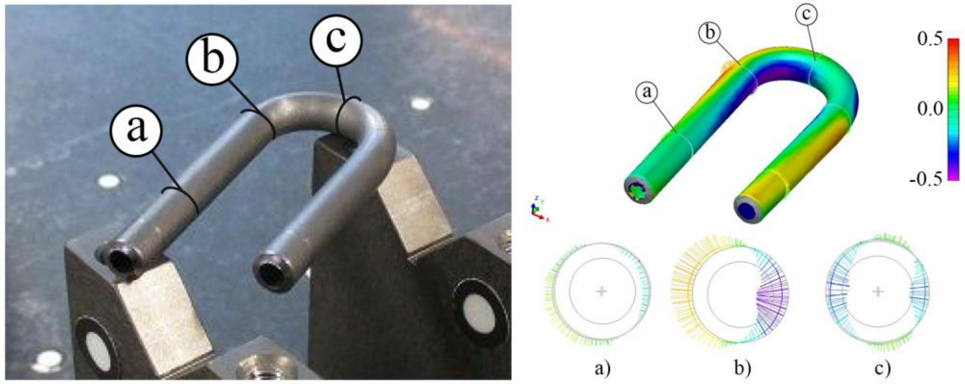


Fig. Ta cooling pipes prototype: (left) 180° elbow and (right) scanned geometry [A]

Fig. Welding test (left) mock-up of tantalum and (right) stainless steel used for training [A]

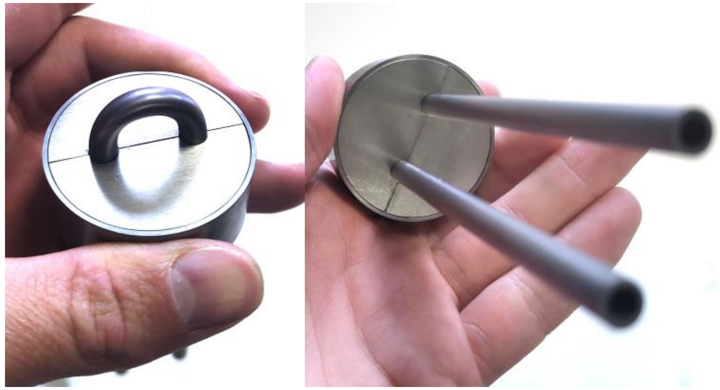


Fig. Target prototype (simplified version)

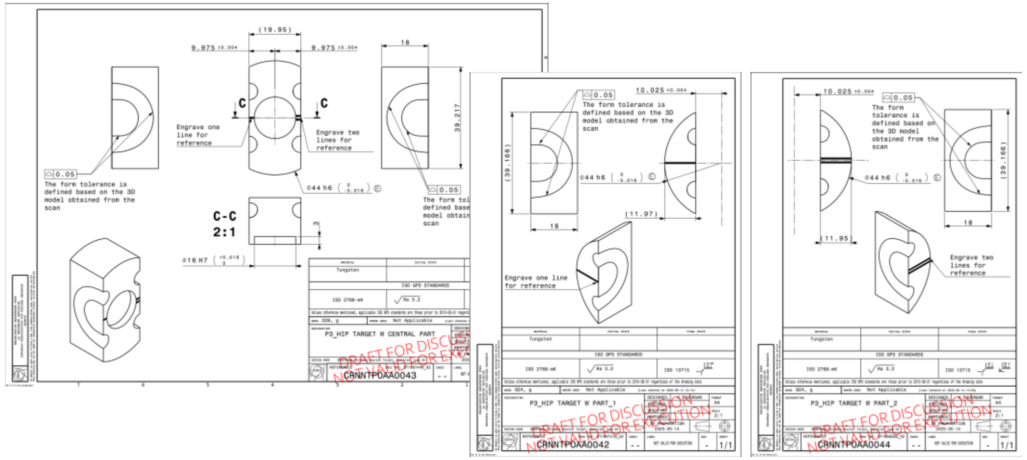


Fig. W target parts: 2D drawings [B]

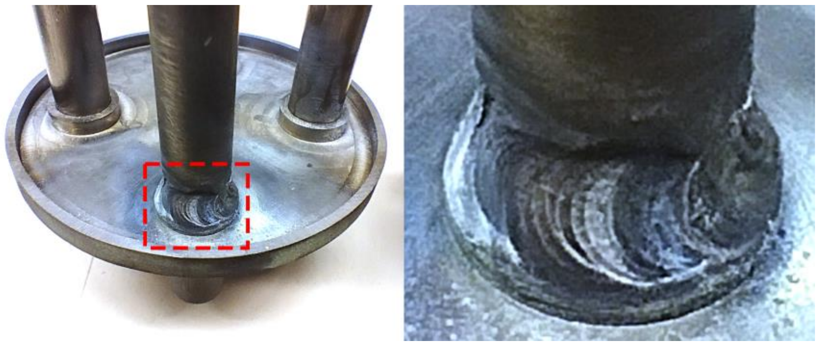


Fig. Welding test for the Ta-Ta joint on the HIPing capsule (left) mock-up and (right) zoom of the resulting joint [A]

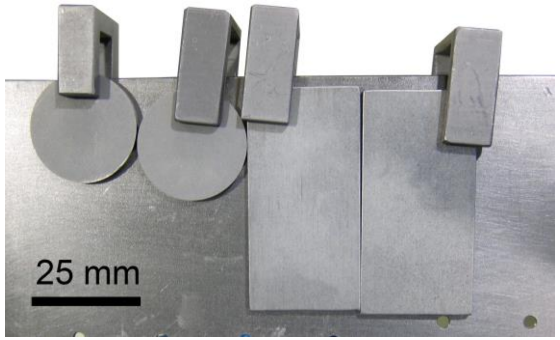


Fig. Ta CVD coating in W substrates [C]

4. PSI Positron Production (P3) Experiment update

4. P3 Experiment update (1/4)

In a nutshell: e+ source demonstrator for FCC-ee under installation in SwissFEL

Goal: to produce positrons in 2026 using the 3-6 GeV SwissFEL e- beam as drive beam

Status: experiment under assembly, installation in the SwissFEL tunnel in August 2025

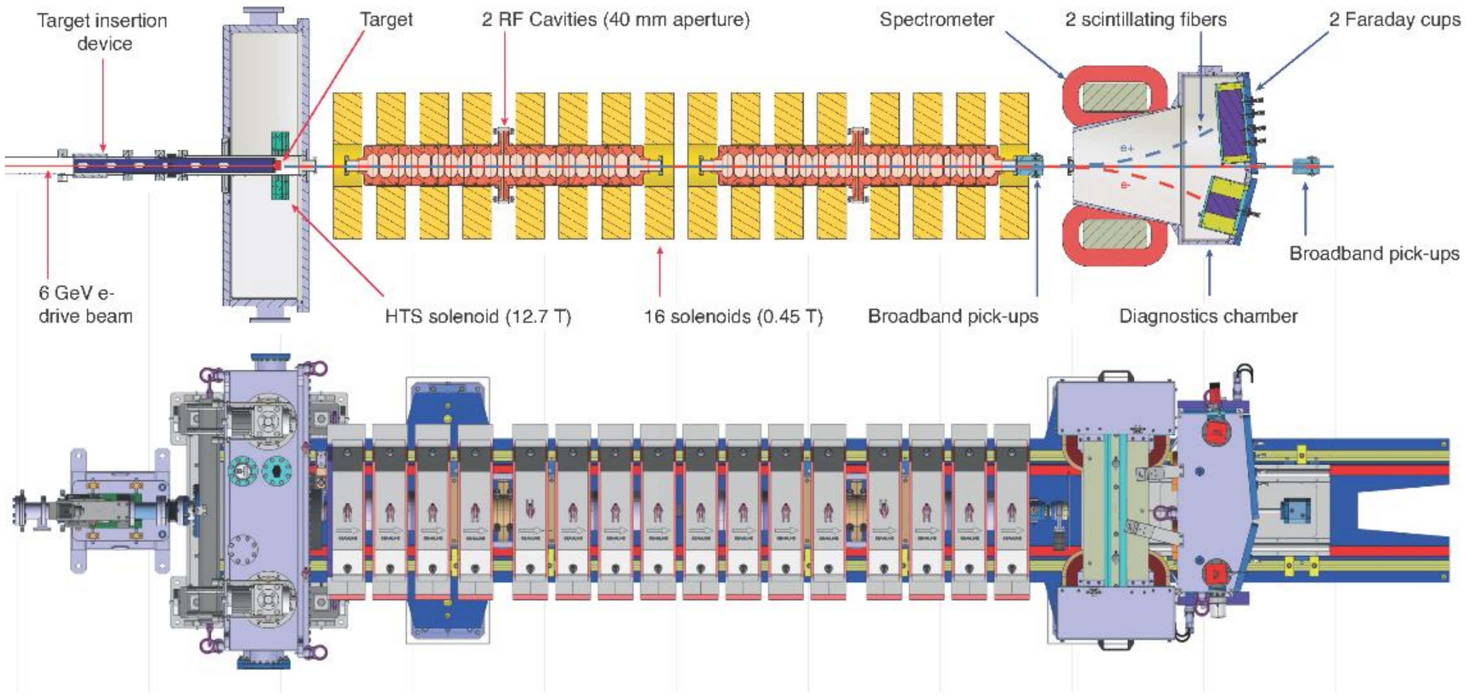


Fig. P3-Experiment: (top) cross section with the main components and (bottom) Layout top view [N. Vallis 2024]

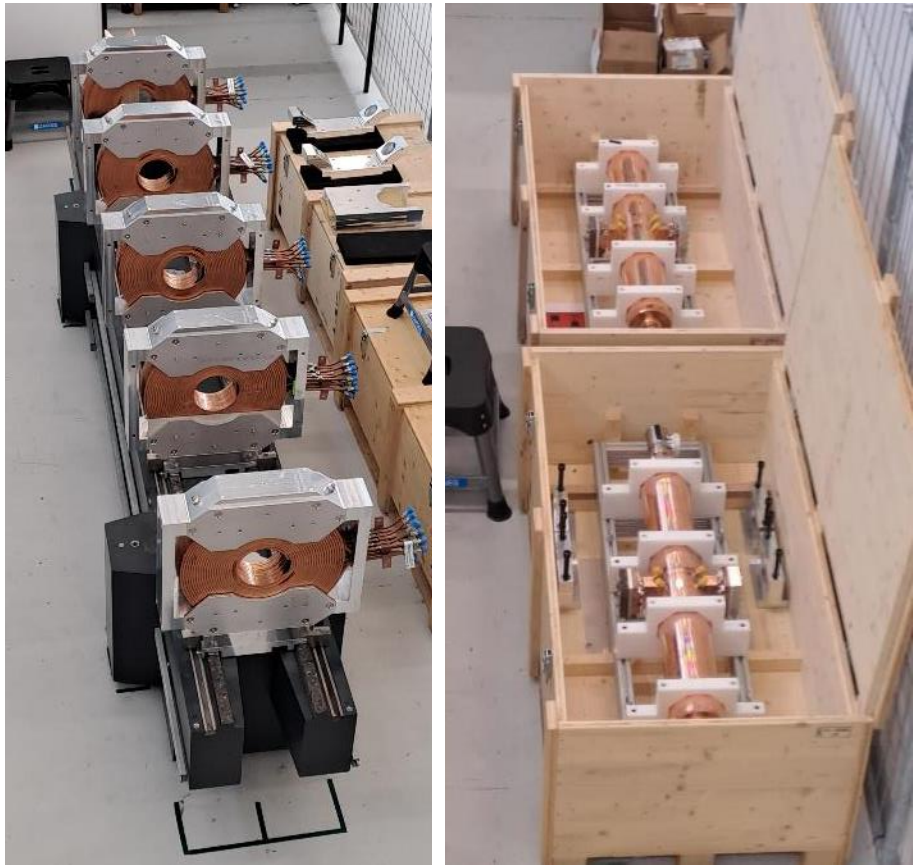


Fig. NC solenoids and S-band cavities ready for installation

4. P3 Experiment update (2/4)

PSI

HTS solenoid

- All 5 coils ready and successfully tested in liquid nitrogen
- Installation of the coil package in the cryostat under way, should be finished by end of May
- Cool-down and power test at 15K in June
- Installation of the cryostat in the bunker in summer shutdown

Fig. Coil pack installation

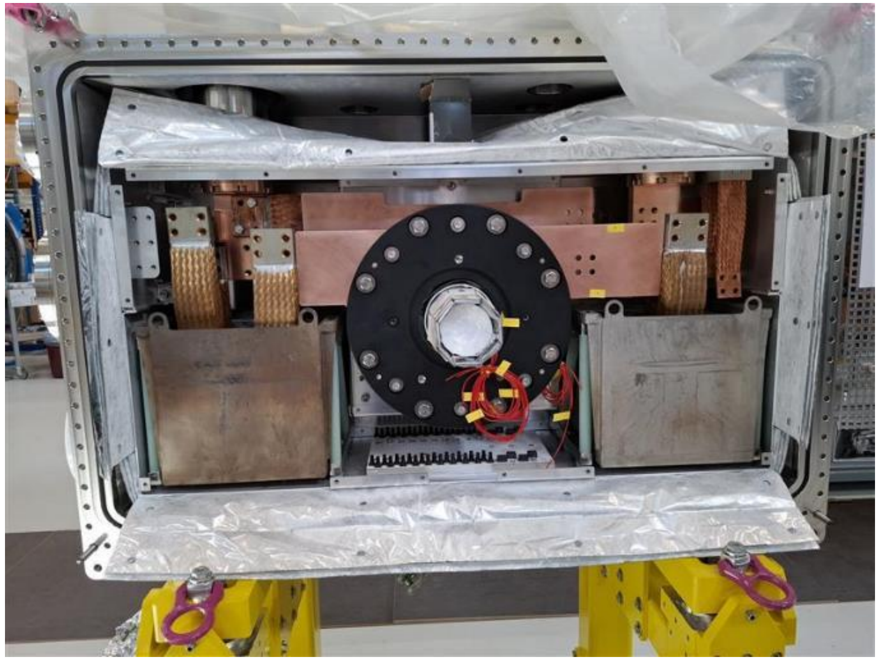


Fig. Coil pack and thermal buffers installed inside cryostat

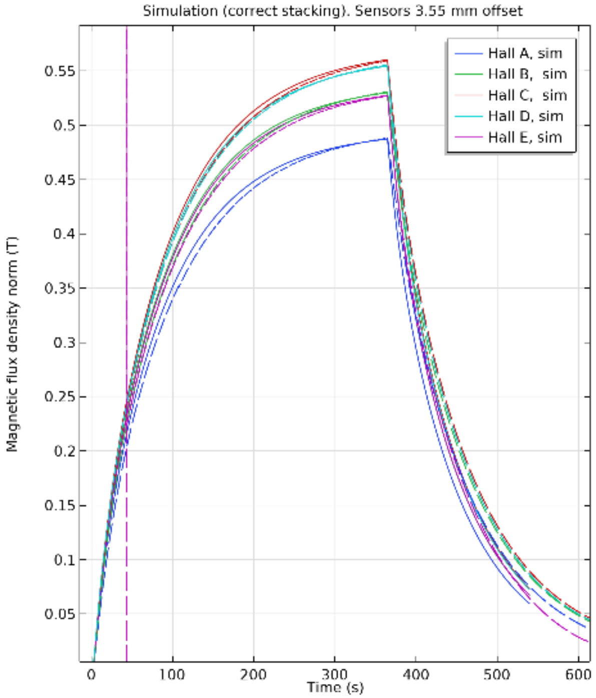


Fig. Hall sensors measured vs scaled simulated maxima

4. P3 Experiment update (3/4)

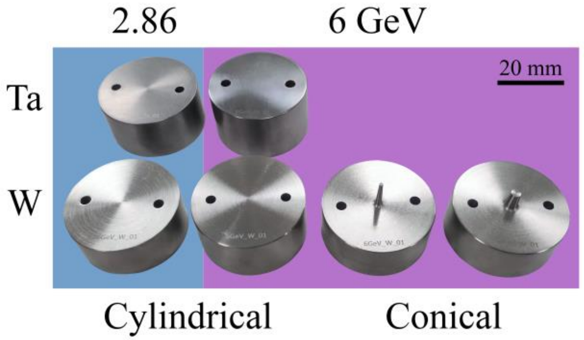


Fig. P3 available fixed targets. Models without cooling.

P3-Target Insertion Device (P3-TID)

Mechanical subsystem in charge to host the **fixed target** inside of the HTS solenoid

Parameters to explore for e+ yield production:

- Geometry (cylindrical vs conical)
- Material (Ta and W)
- Beam energy (2.86-6 GeV)
- Axial position (+/- 50 mm)

Current status:

- Ready to be tested at CERN before the planned installation at PSI (Summer 2025)

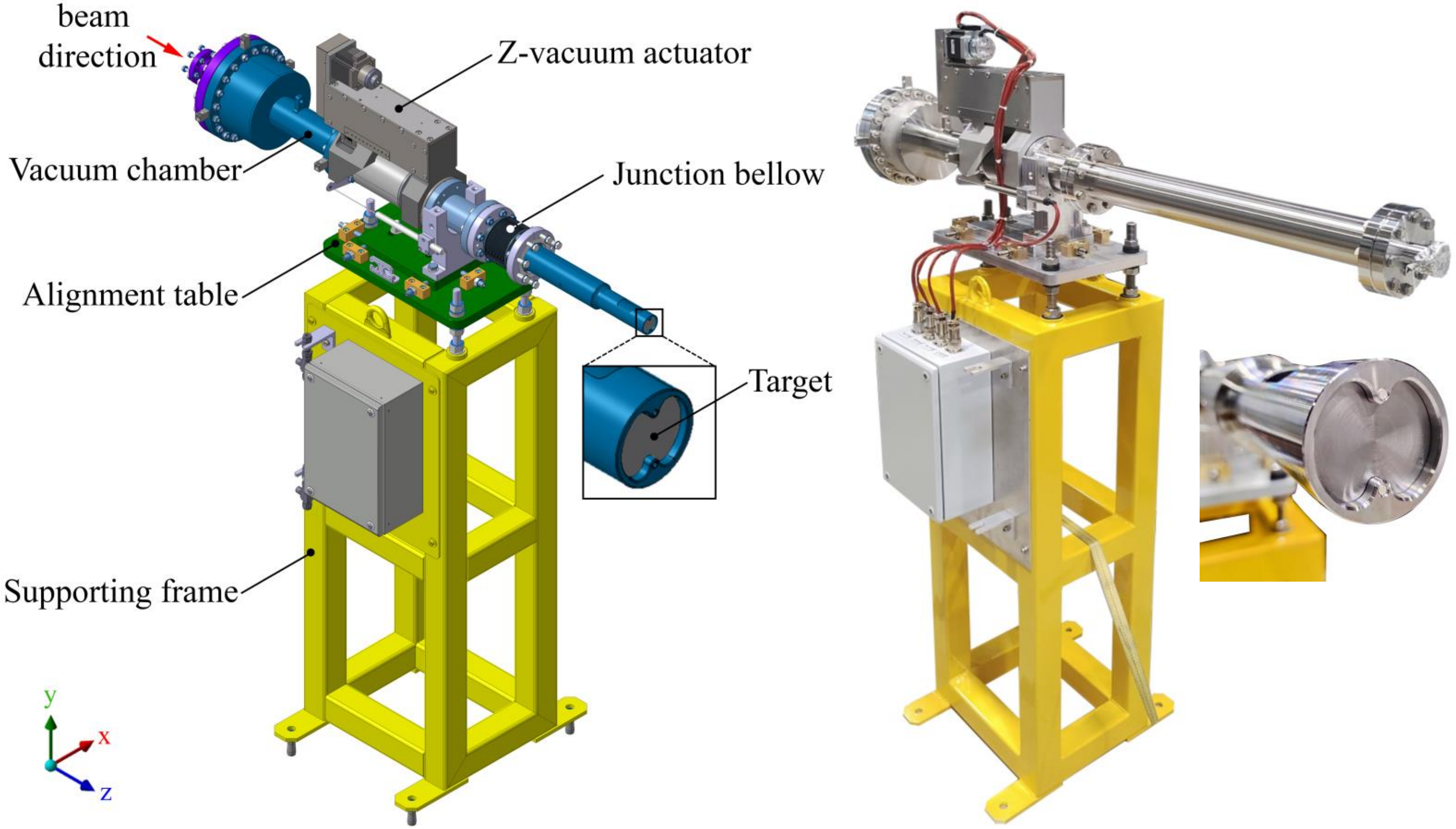
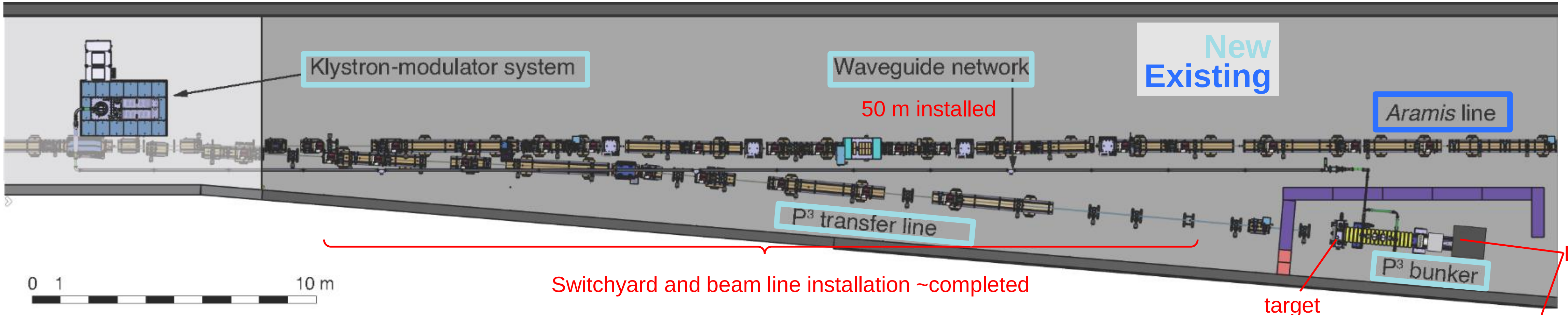


Fig. P3-TID subsystem (left) CAD design and (right) mounted assembly.

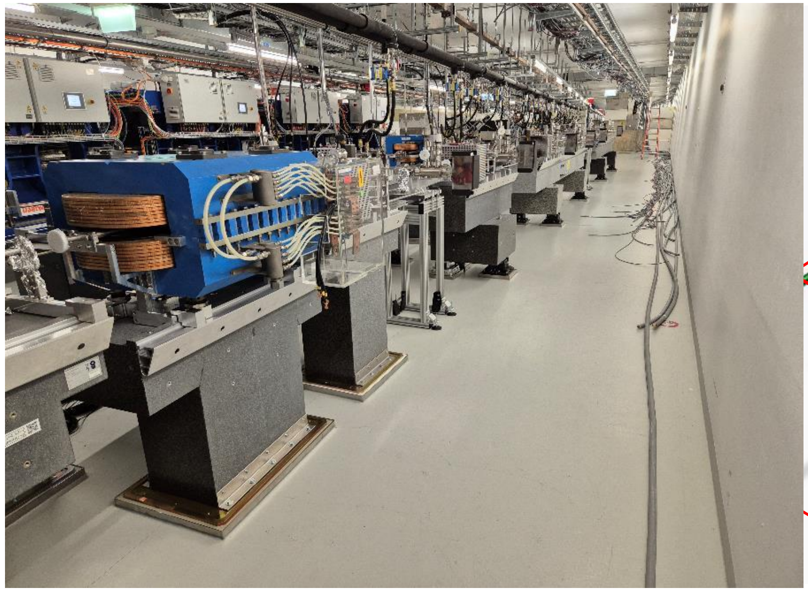
4. P3 Experiment update (4/4)

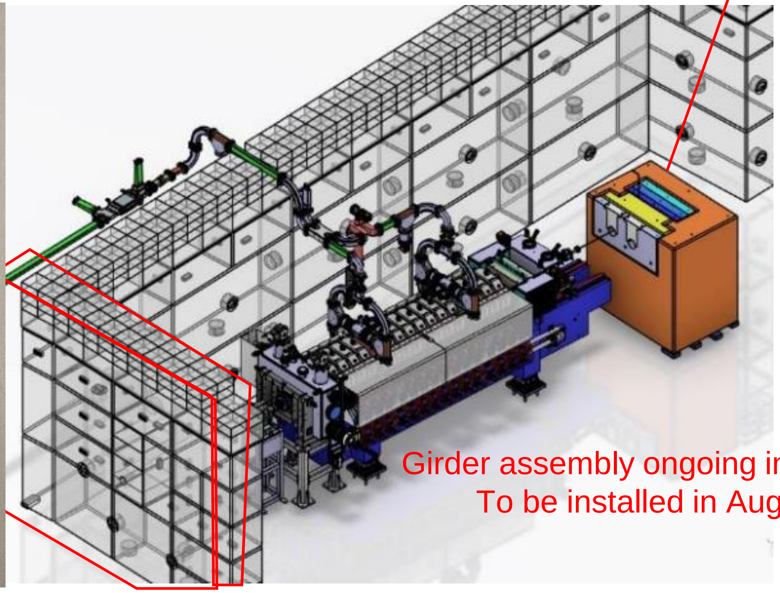


Status installation in SwissFEL

- Beam line ready
- August shutdown
  - Installation of the experiment
  - Bunker assembly completed
- Modulator commissioning end of 2025
- **e+ beam in 2026**

Figures credits: *M. Schär, D. Hauenstein and M. Zykova*





5. Conclusions

5. Conclusions

- By moving from 6 GeV to **2.86 GeV**, the FCC-ee positron source target (W) **improved its thermo-mechanical performance**. The obtained reduction in terms of temperature and stresses are beneficial from the operational point of view. However, further work is needed to estimate the impact of **radiation damage** on the material properties and this information must be included in the numerical model.

- The manufacturing of the **target with embedded cooling pipes** prototypes are ongoing. Extensive R&D efforts are made to validate the processing route.

- The status of the **P3 experiment** was reviewed. All subsystems are ready, and its installation is foreseen at PSI during the August shutdown. The exploitation in 2026 will play a key role for FCC-ee to validate experimentally new design concepts and technologies.

6. Questions?

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