Technology Development and Manufacturing Opportunities for the FCC-ee Vacuum System

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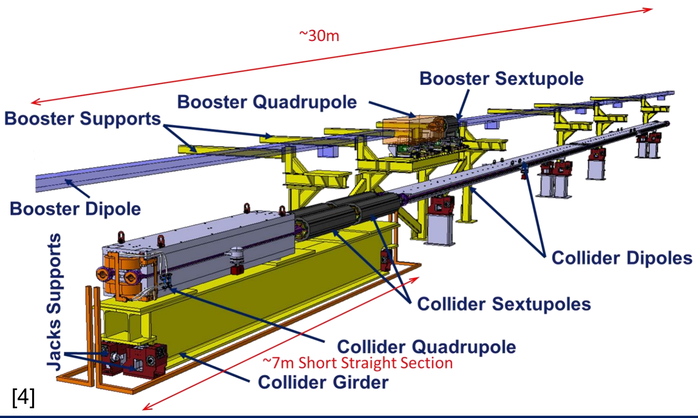
Abstract

The FCC-ee or Future Circular Collider for electrons and positrons is a key study in CERN's long-term programme, aiming to advance precision physics through unprecedented energies and luminosities. Achieving these goals requires an ultra-high vacuum system maintaining pressures lower than 10^{-9} bar along a 91km ring. Two vacuum chambers (VCs) form a roughly 180km long system, that must combine performance, reliability, cost efficiency, beam stability and long service life under intense synchrotron radiation with minimal maintenance. Design, material selection, and manufacturing are therefore critical. The vacuum chamber must offer mechanical robustness, low particle desorption, and compatibility with coatings such as the non-evaporable getter (NEG) coating inside and thermally sprayed coatings outside. Cu-OFS (copper oxygen-free silver) has been chosen for the chamber. Synchrotron Radiation Absorbers (SRAs), exposed to high photon and thermal loads, are being developed using laser powder bed fusion (L-PBF) of CuCrZr, enabling optimised cooling channels and intercepting surfaces. Cold-Spray Additive Manufacturing followed by CNC-machining is envisioned to produce leak-tight sockets for the Beam-Positioning Monitors (BPM) directly on the chamber profile. The bake-out system (BOS) is vital to activate the NEG by heating to around 230°C. It demands a radiation-hard, reliable, and efficient multilayer metallic-ceramic coating applied via thermal spraying. The beampipe, assembled from segments whose length is defined by magnet layout, uses copper-alloy flanges joined to the VC by friction-stir welding. Numerous laser-welded and brazed connections attach cooling lines and auxiliary components to the VC. **This poster summarises the main challenges and R&D activities focused on material optimisation, coating technologies, and manufacturing, combining conventional and additive methods to enable reliable, scalable solutions for the FCC-ee vacuum system. The main difficulty is the industrialisation/automation of the production.**



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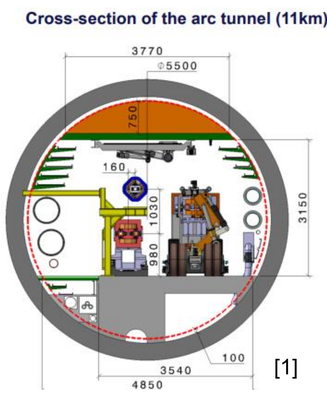

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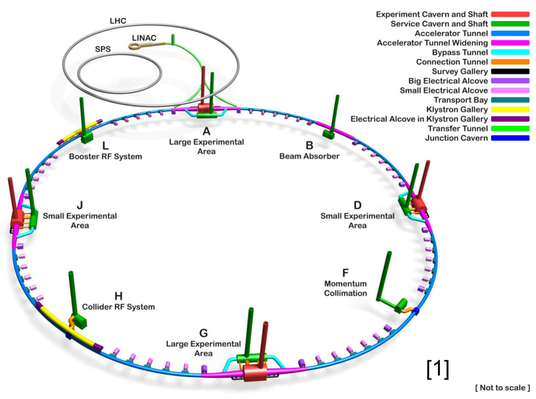

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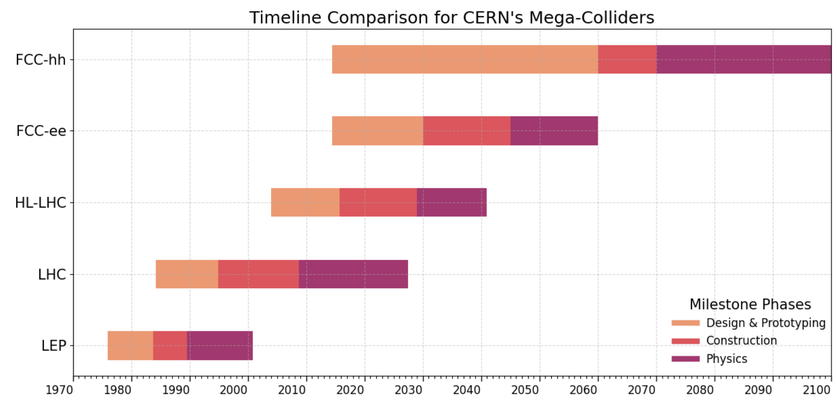
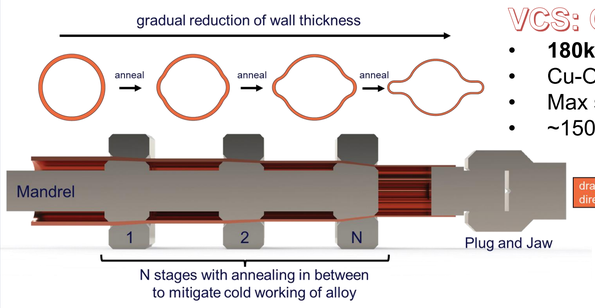


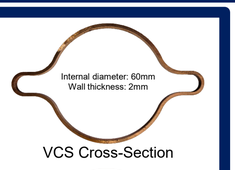
Cold Drawing/Extrusion

Vacuum chamber (VC) for **storage ring (VCS)** and **booster (VCB)**



VCS: Cold Drawing

- **180km** extruded length
- Cu-OFS
- Max segment length: 12m
- ~15000 pieces



VCS Cross-Section

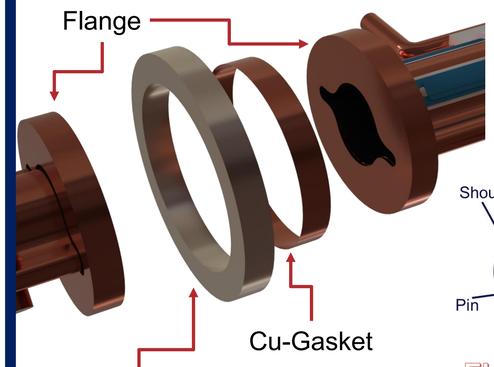
VCB Cross-Section

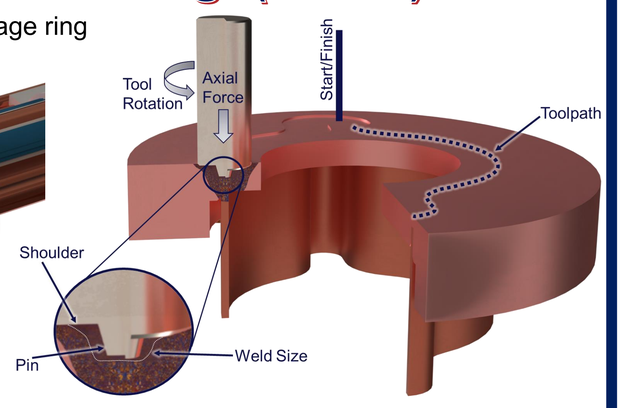
VCB: Tube Extrusion

- **91km** extruded length
- Cu-OFE or Cu-OFS
- Max segment length: 12m
- ~7500 pieces

Friction Stir Welding (FSW)

Joining of **VCS** and flanges for storage ring

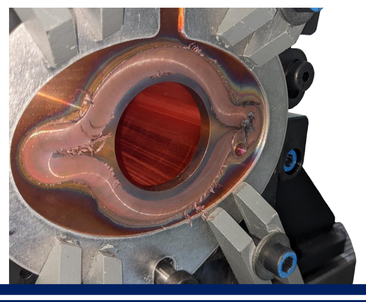




Flanges and FSW in numbers:

- ~30.000 flanges for storage ring
- ~10.5km of combined welding line
- Flange alloy: CuCrZr or CuNi2SiCr

Press-fit assembly → Welding → Machining

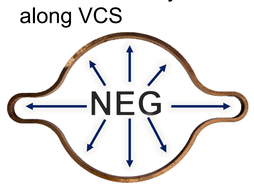


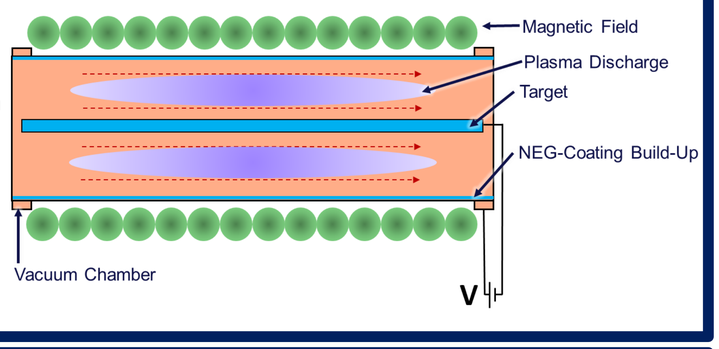
Physical Vapor Deposition

Magnetron Sputtering – Non-Evaporable Getter Coating (NEG)

NEG Key Facts:

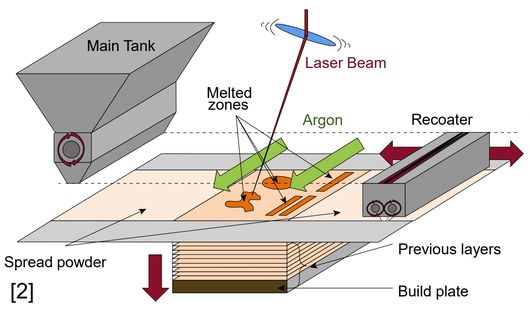
- Ternary Ti-Zr-V alloy
- PVD-Coating
- Thickness: 150 nm – 200nm
- Coated on every chamber along VCS





Laser-Powder Bed Fusion

Synchrotron Radiation Absorber (SRA)



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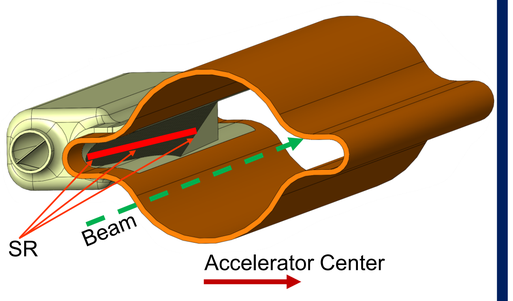
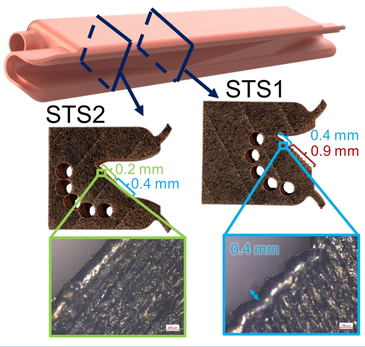


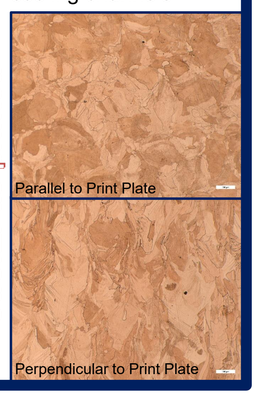
SRA Key Facts:

- Intercepts synchrotron radiation (photons) and converts their energy to heat
- **~28000 pieces** along the storage ring
- Alloys: CuCrZr or CuCP
- Complex geometry for intercepting surface (sawtooth pattern) and for internal cooling channels

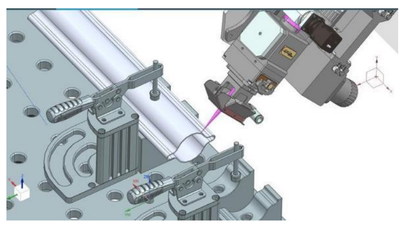


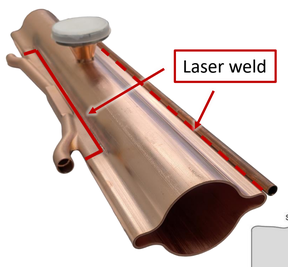
STS…Saw Tooth Sample

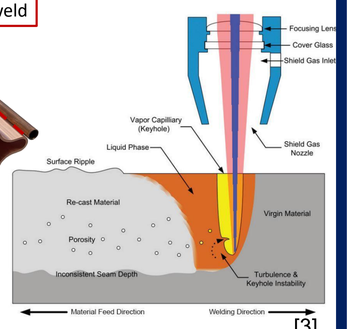
Possible cooling channel designs



Laser Welding







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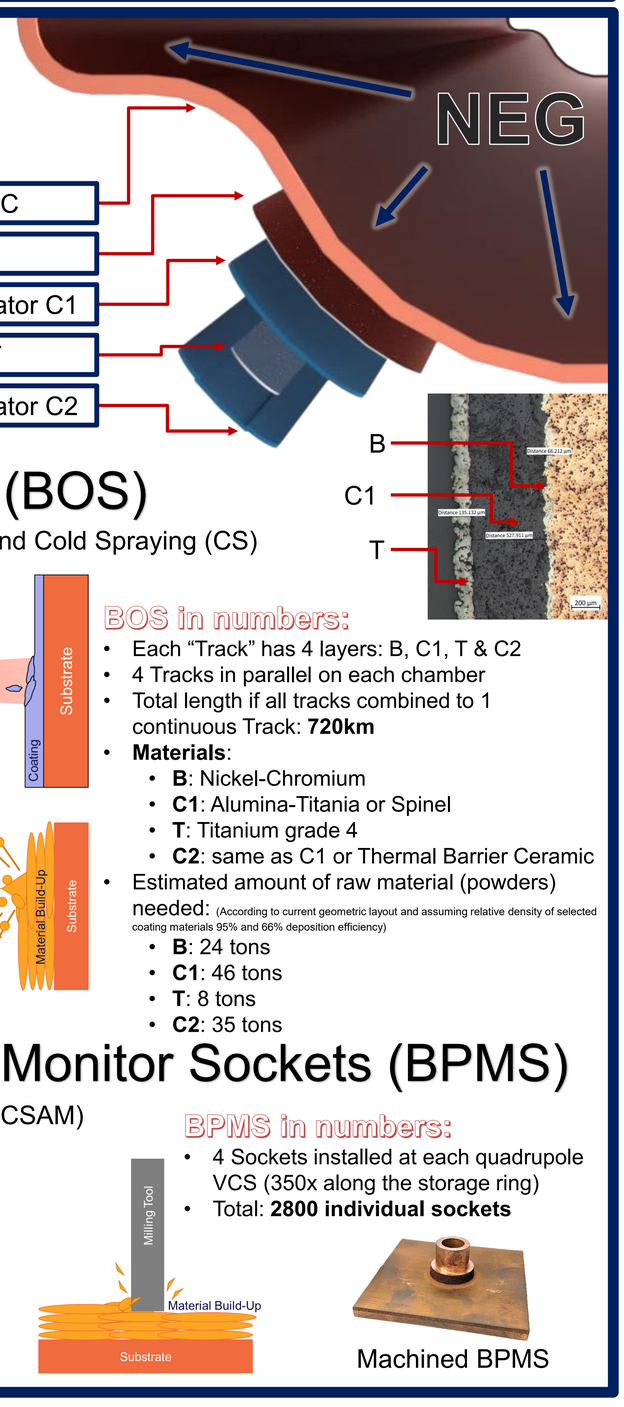
Key Facts:

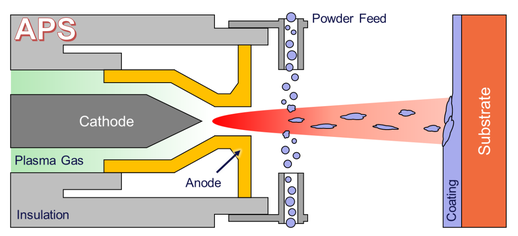
- Spotwelding of cooling tubes to VCS and VCB
- More than **450km** of cooling tubes needed
- Welding of SRA to VCS
- Buttwelding of prototype chambers and alternative technology for flanges

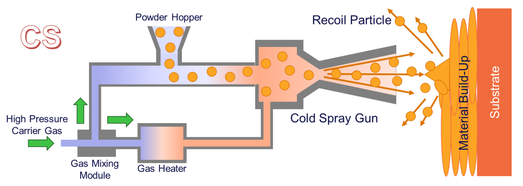
Thermal Spraying



Bake-Out System (BOS)

Atmospheric Plasma Spray (APS) and Cold Spraying (CS)



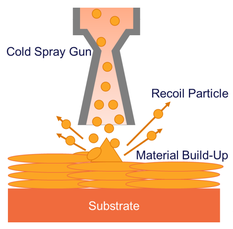


BOS in numbers:

- Each "Track" has 4 layers: B, C1, T & C2
- 4 Tracks in parallel on each chamber
- Total length if all tracks combined to 1 continuous Track: **720km**
- **Materials**:
  - **B**: Nickel-Chromium
  - **C1**: Alumina-Titania or Spinel
  - **T**: Titanium grade 4
  - **C2**: same as C1 or Thermal Barrier Ceramic
- Estimated amount of raw material (powders) needed: (According to current geometric layout and assuming relative density of selected coating materials 95% and 66% deposition efficiency)
  - **B**: 24 tons
  - **C1**: 46 tons
  - **T**: 8 tons
  - **C2**: 35 tons

Beam Positioning Monitor Sockets (BPMS)

Cold Spray Additive Manufacturing (CSAM)



Sprayed BPMS

BPMS in numbers:

- 4 Sockets installed at each quadrupole VCS (350x along the storage ring)
- Total: **2800 individual sockets**

Machined BPMS

[1] M. Benedikt *et al.*, 'Future Circular Collider Feasibility Study Report Volume 2: Accelerators, Technical Infrastructure and Safety', CERN Document Server, 2025. doi: 10.17181/CERN.EBAY.7W4X.
[2] M. Brandt, *Laser Additive Manufacturing: Materials, Design, Technologies, and Applications*. in Woodhead Publishing Series in Electronic and Optical Materials. Kent: Elsevier Science, 2016.
[3] The Fabricator "The Evolution of Laser Welding Technology" in "The Fabricator", online: https://www.thefabricator.com/thefabricator/article/laserwelding/the-evolution-of-laser-welding-technology, 31.08.2022
[4] J.-P. Burnet, 'Accelerator Technologies and Technical Infrastructure', presented at the presented at FCC-Week 2025, Vienna, May 19, 2025. [Online]. Available: https://indico.cern.ch/event/1408515/contributions/6506645/

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