The Future Circular Collider: vacuum challenges

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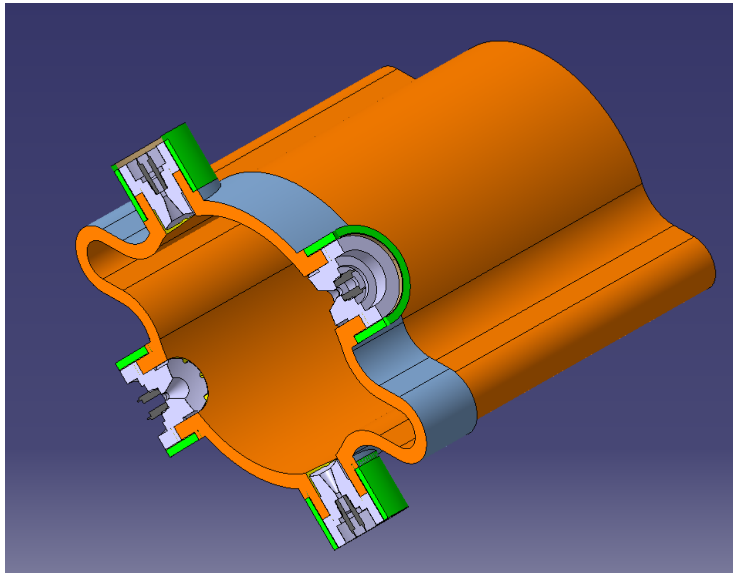
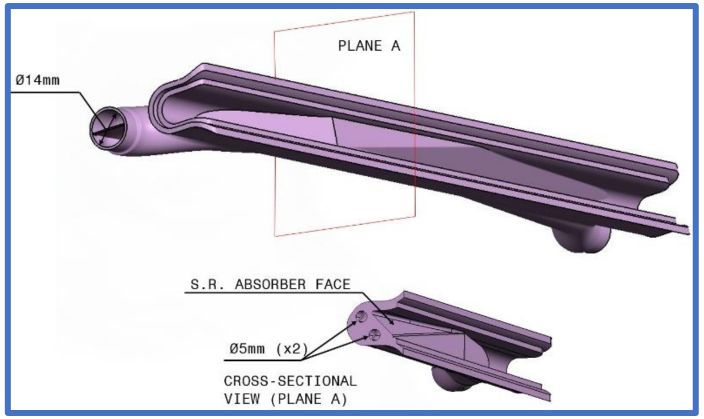
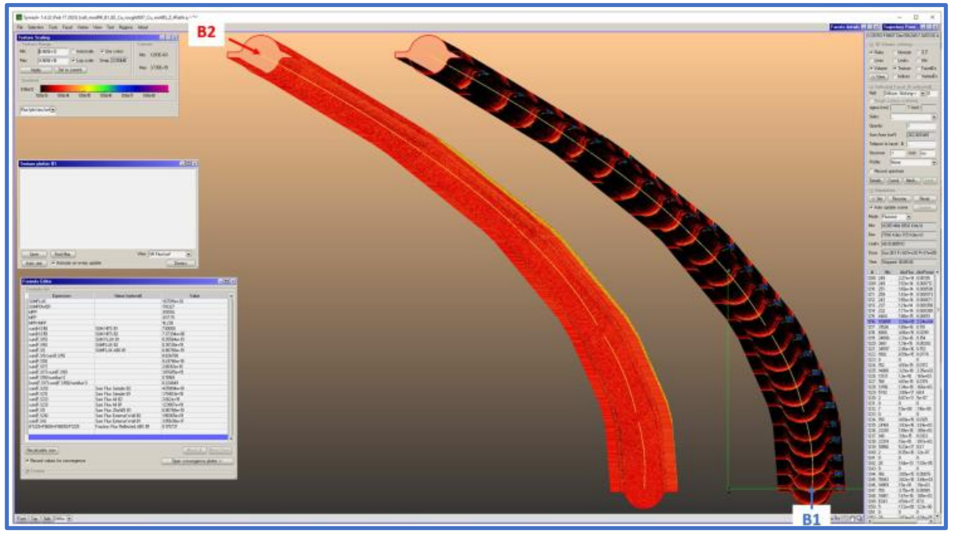
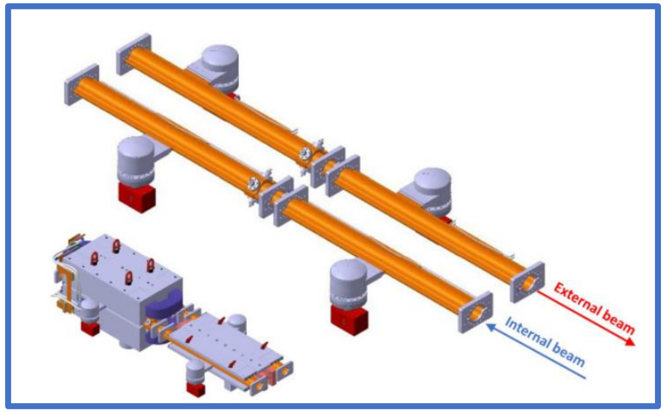








Future Circular Collider: Timeline (slide M. Benedikt, FCC Week 2023, London)

Design study started in 2013, kick-off meeting at Univ. Geneva, funded by Horizon2020 EuroCirCol program

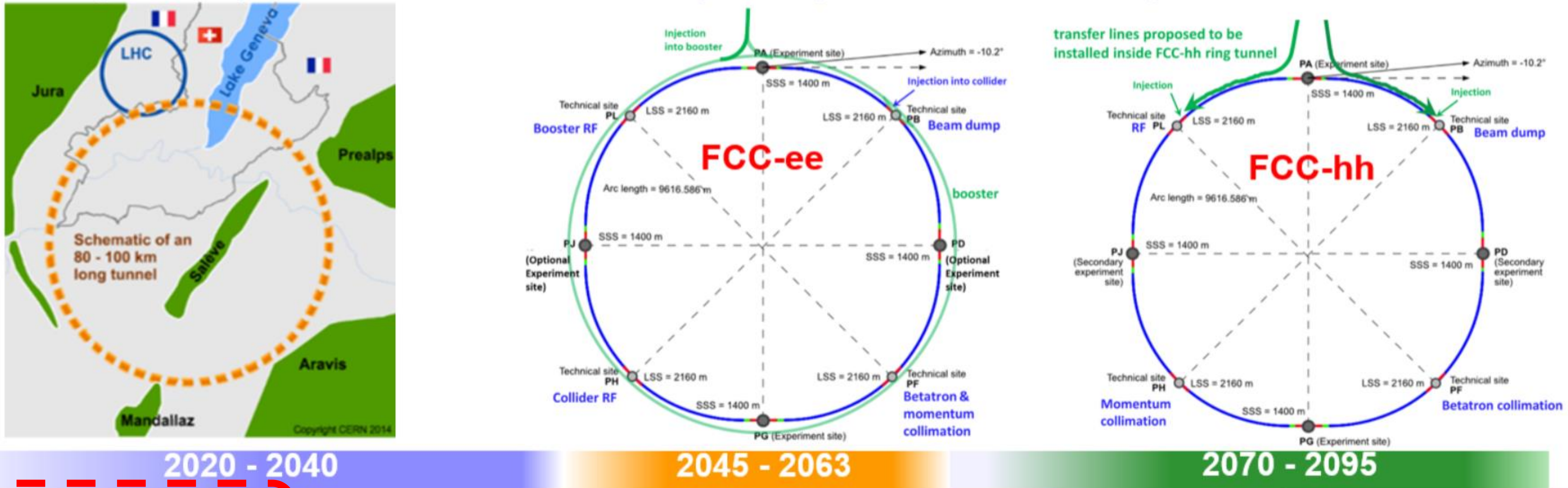
It includes also linear collider concept (CLIC), not discussed here

FUTURE CIRCULAR COLLIDER

FCC integrated program

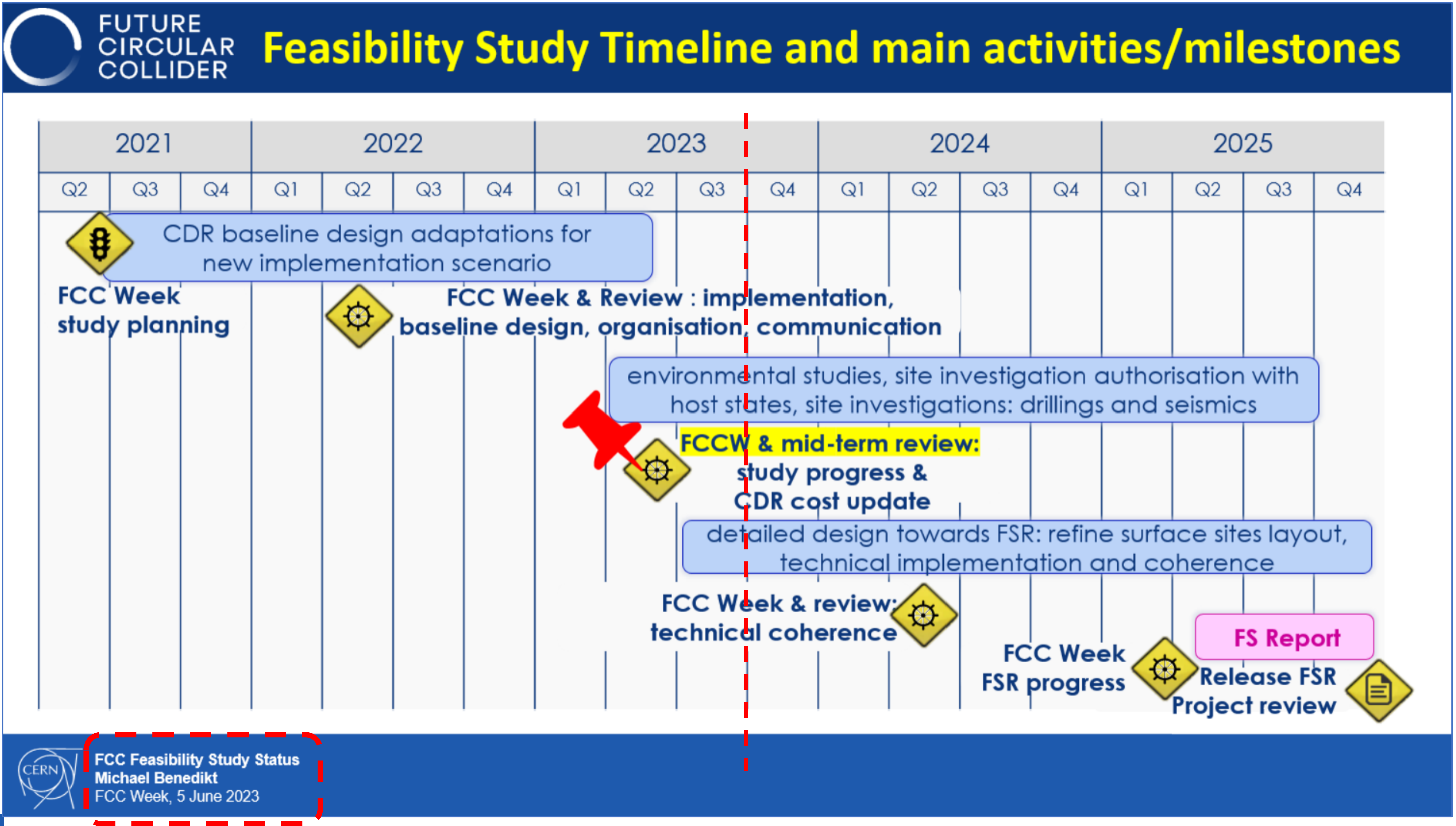
comprehensive long-term program maximizing physics opportunities

- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, pp & AA collisions; e-h option**
- highly synergetic and complementary programme boosting the physics reach of both colliders (e.g. model-independent measurements of the Higgs couplings at FCC-hh thanks to input from FCC-ee; and FCC-hh as “energy upgrade” of FCC-ee)
- common civil engineering and technical infrastructures, building on and reusing CERN’s existing infrastructure
- FCC integrated project allows the start of a new, major facility at CERN within a few years of the end of HL-LHC



FCC Feasibility Study Status
Michael Benedikt
FCC Week, 5 June 2023

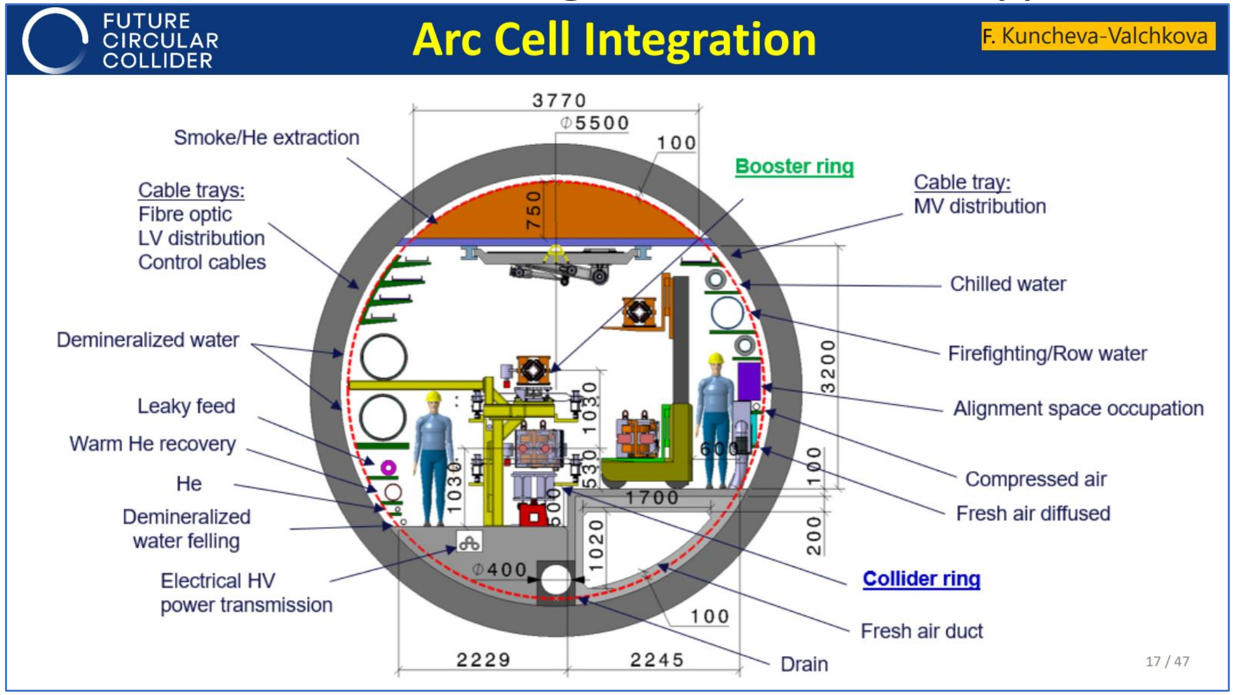
Feasibility Study Timeline and main activities/milestones

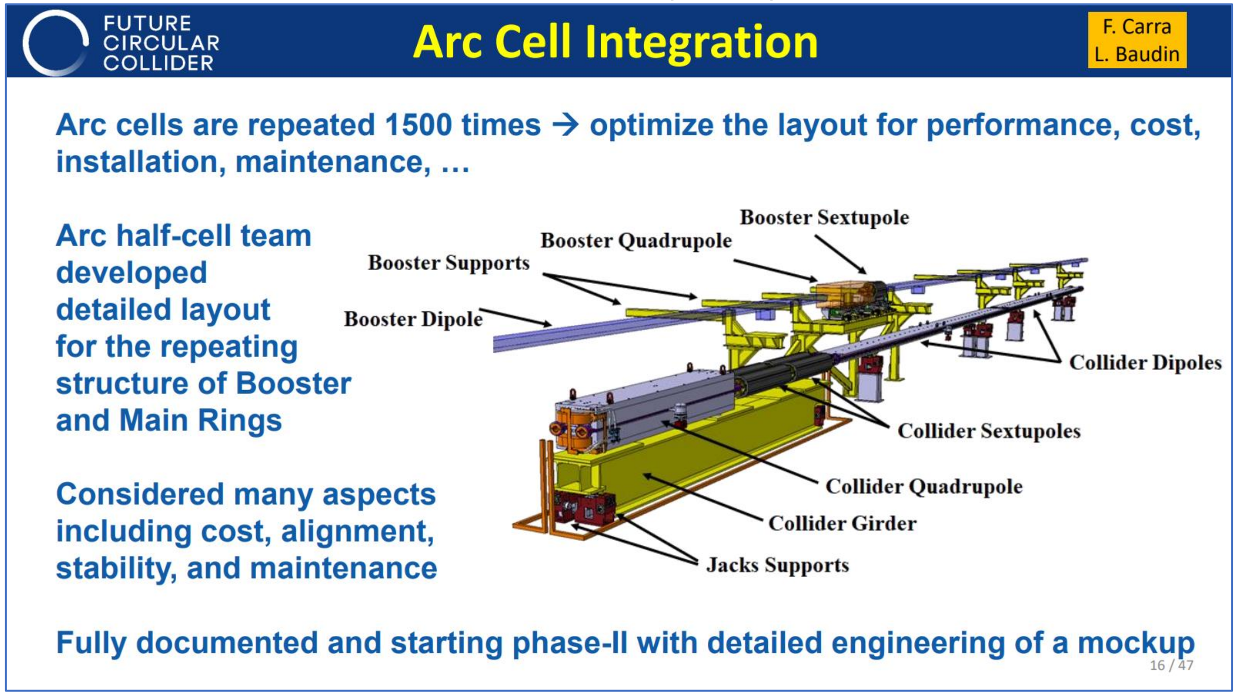


- FCC-ee is a very large machine ⬇
- It is highly modular, i.e. most of the length of the machine is a repetition of a "basic cell"
- There is a large margin of cost-optimization and industrialization of most components: vacuum chambers, bellows, beam-position monitor blocks, flanges, RF-contact fingers, etc…
- The prototyping phase has already started, exploring new technologies (e.g. additive manufacturing, see examples below)

Parameter	unit	2018 CDR [1]	2023 Optimised
Total circumference	km	97.75	90.657
Total arc length	km	83.75	76.93
Arc bending radius	km	13.33	12.24
Arc lengths (and number)	km	8.869 (8), 3.2 (4)	9.617 (8)
Number of surface sites	—	12	8
Number of straights	—	8	8
Length (and number) of straights	km	1.4 (6), 2.8 (2)	1.4 (4), 2.031 (4)
superperiodicity	—	2	4

- The tunnel along the arcs has a typical cross-section as shown below (left)

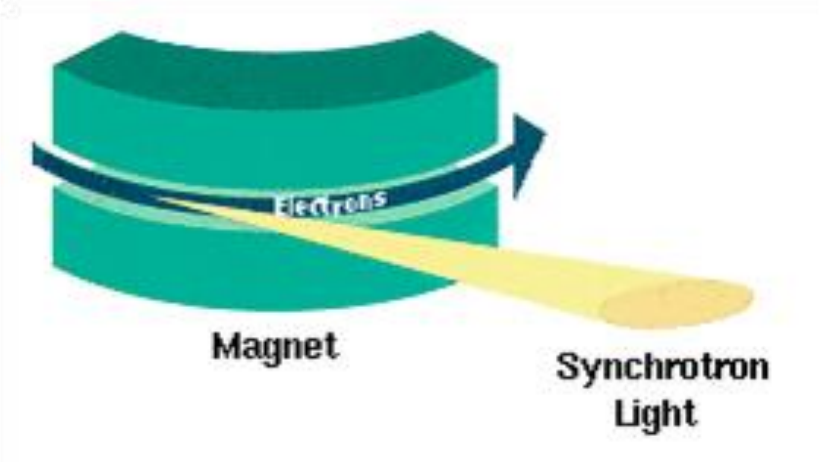




- There are TWO counter-rotating beams (e- and e+) guided by dipole, quadrupole, and sextupole magnets (above, right)
- Above the two rings of the collider, there is a THIRD ring, the full-energy injection BOOSTER, which injects both e- and e+ (in opposite directions) whenever necessary
- There are, therefore, about 3x 91 km ring vacuum system, plus additional (many) km of TRANSFER LINES (TLs) from booster to collider rings, and also other TLs from other accelerators in the chain

- The vacuum chamber geometry is strongly linked to the design of the magnets
- We need to pump out all air molecules present inside the vacuum chamber after installation, and then also all of the molecules which are generated via several physical effects, such as PHOTODESORPTION, ELECTRON CLOUD, RESISTIVE WALL HEATING, BEAM LOSSES, and more…
- We need to remove as many RESIDUAL GAS molecules as possible, to avoid their collision with the stored e- and e+ beams
- The typical average pressure compatible with the correct functioning of the collider is "few" 10^{-9} mbar (10^{-10} mbar in the INTERACTION REGION, where collisions occur)
- 10^{-9} mbar means that out of 1 TRILLION molecules only 1 is left: ***rarefied gas dynamics***
- In order to get below this pressure value, we adopt state-of-the-art technologies, several of them invented at CERN in the past, and new ones under development now
- Challenge: applying these technologies to "regular"accelerators (i.e. having circumferences of ~500-1000 m) is rather easy albeit costly; now we need to reduce costs without compromising on quality. Plenty of opportunities for industrial optimisation.

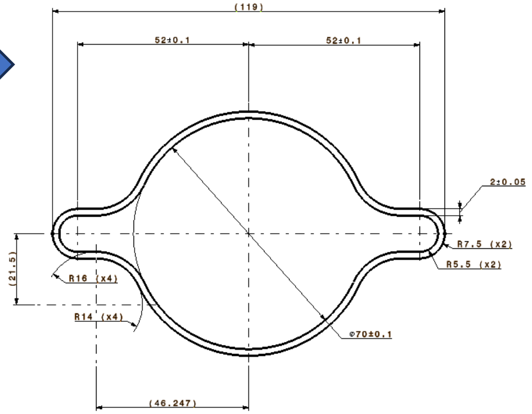
- One of the main sources of RESIDUAL GAS is the **synchrotron radiation (SR)-induced outgassing**
- SR is the emission of **intense electromagnetic radiation when an energetic charged particle moves in a strong magnetic field**: it is a “searchlight” beam of photons with energy between microwaves and gamma rays (very energetic and penetrating)



- Upon striking the vacuum chamber wall, SR “pulls out” some molecules, which must be removed as fast as possible, to avoid interference with the beam
- The FCC-ee machines are all designed to generate a maximum of **50 MW of SR power per beam** (i.e. 100 MW of unavoidable “waste heat”)
- **All vacuum components hit by SR need therefore to be carefully designed and cooled**

Prototyping of vacuum components

- The vacuum chamber cross section in the arcs is

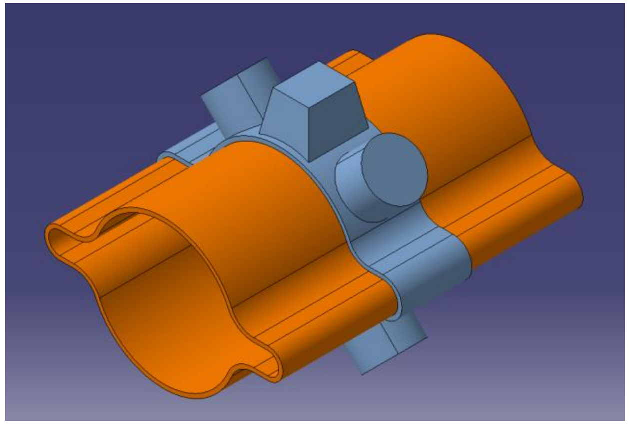


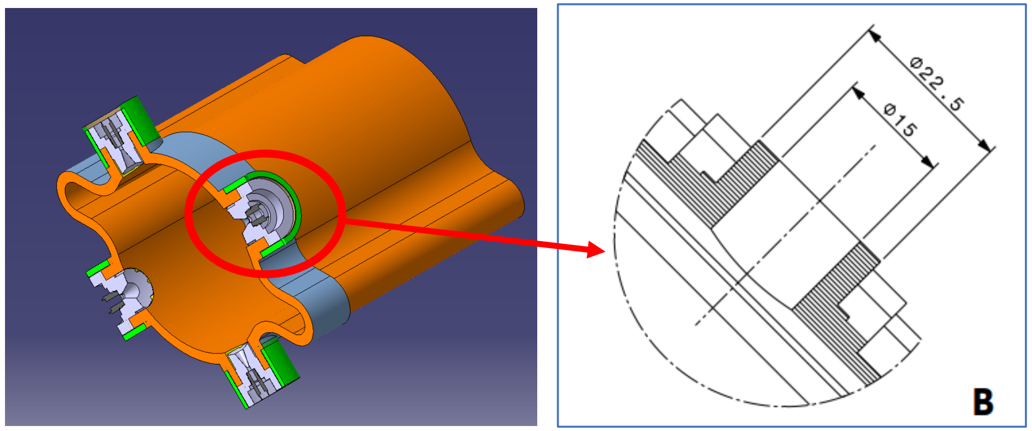
- It is made out of **extruded copper alloy**; it will be NEG-coated and every 5.5~6 m there will be a **SR PHOTON ABSORBER** (**SRA**) which will intercept the SR generated along the preceding dipole magnets.
- The design of the SRAs is **very demanding**, because each of them will receive a highly collimated SR fan, with **very high surface power density**
- In addition, the SRAs must satisfy some **geometrical criteria** which make their design challenging: we are prototyping some innovative design implementing **ADDITIVE MANUFACTURING** (3D printing) and **STIR-WELDING** technology, with **SHAPE-MEMORY ALLOY** rings for joining the different vacuum chamber segments and bulk **COLD-SPRAY DEPOSITION** for selected components
- **Upon selection of the most suitable technology, we will look for INDUSTRIAL PARTNERS capable to deliver large quantities of these components in a TIMELY FASHION, following STRICT QUALITY CONTROL procedures**

Prototyping of vacuum components: Selection of examples

Chamber: 2mm layer sprayed all around

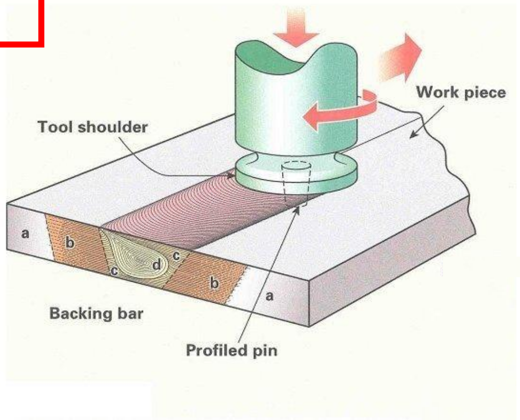
Chamber prototype with x4 bosses for direct BPM buttons machining and SMA rings

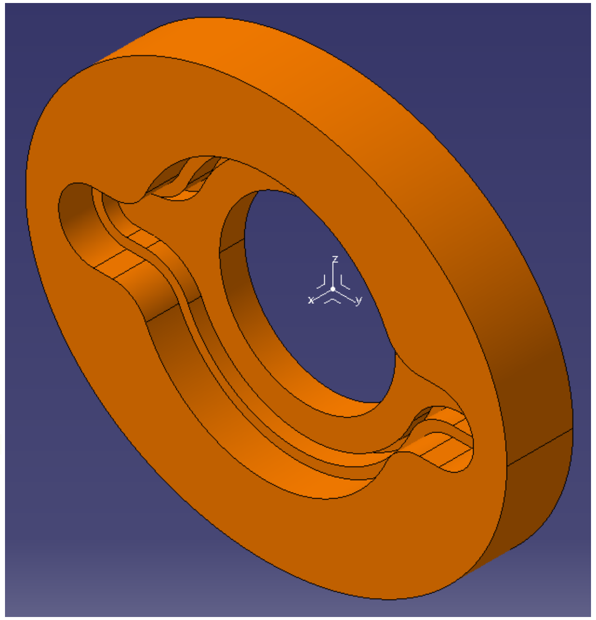




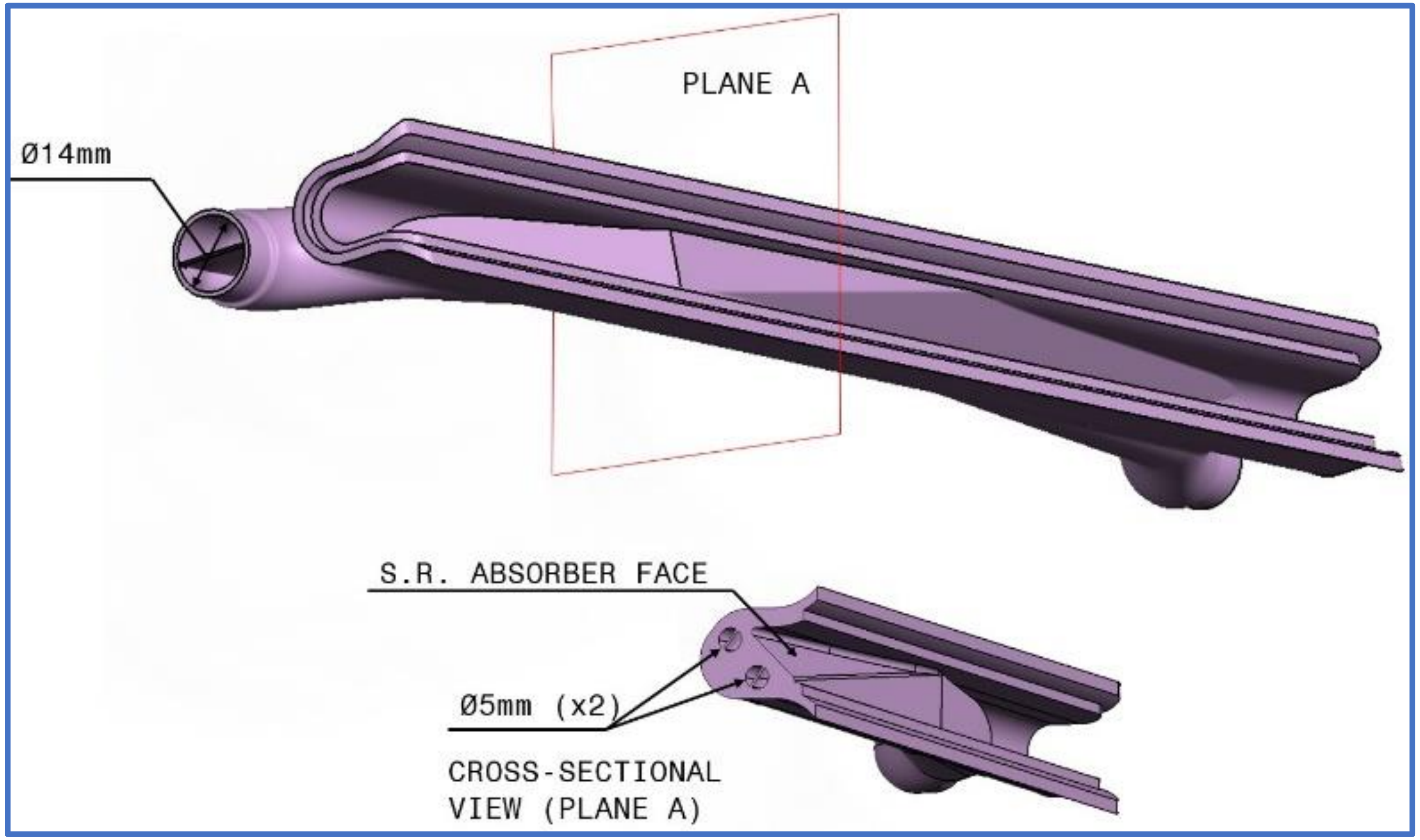
FRICTION STIR WELDING →

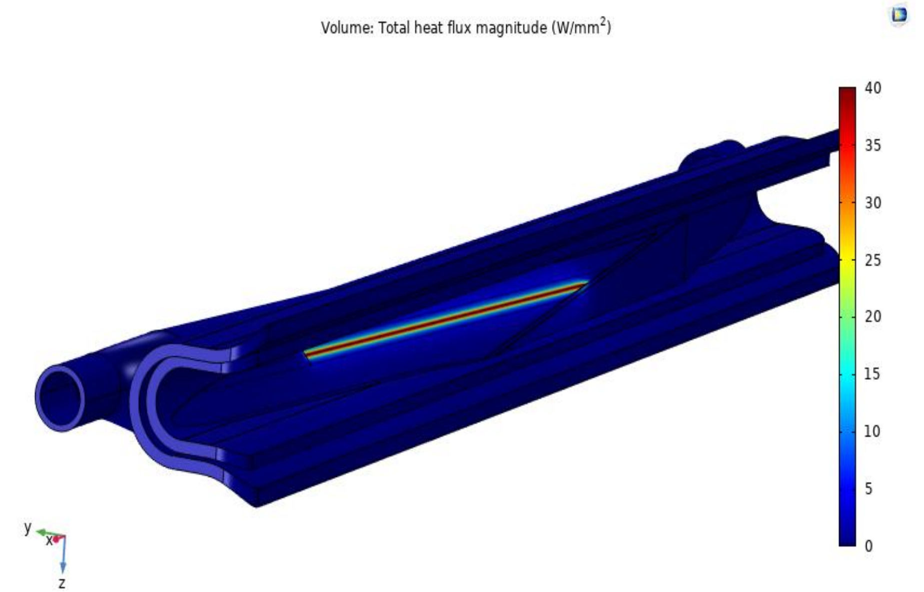
- **Flange is redesigned as per Phase 1 results**

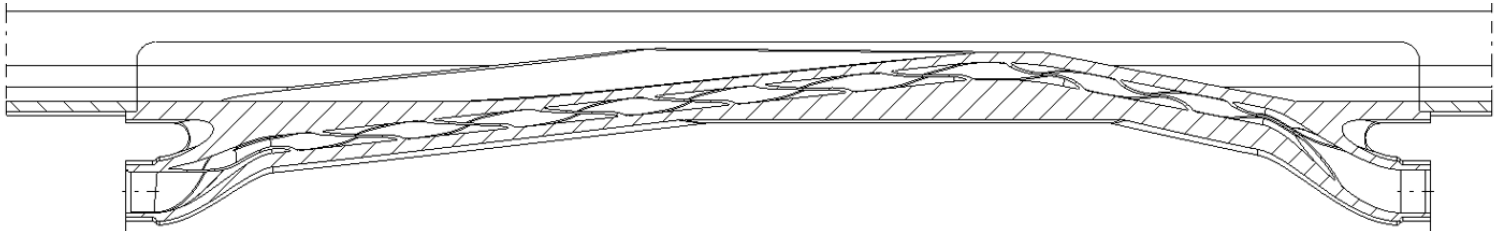




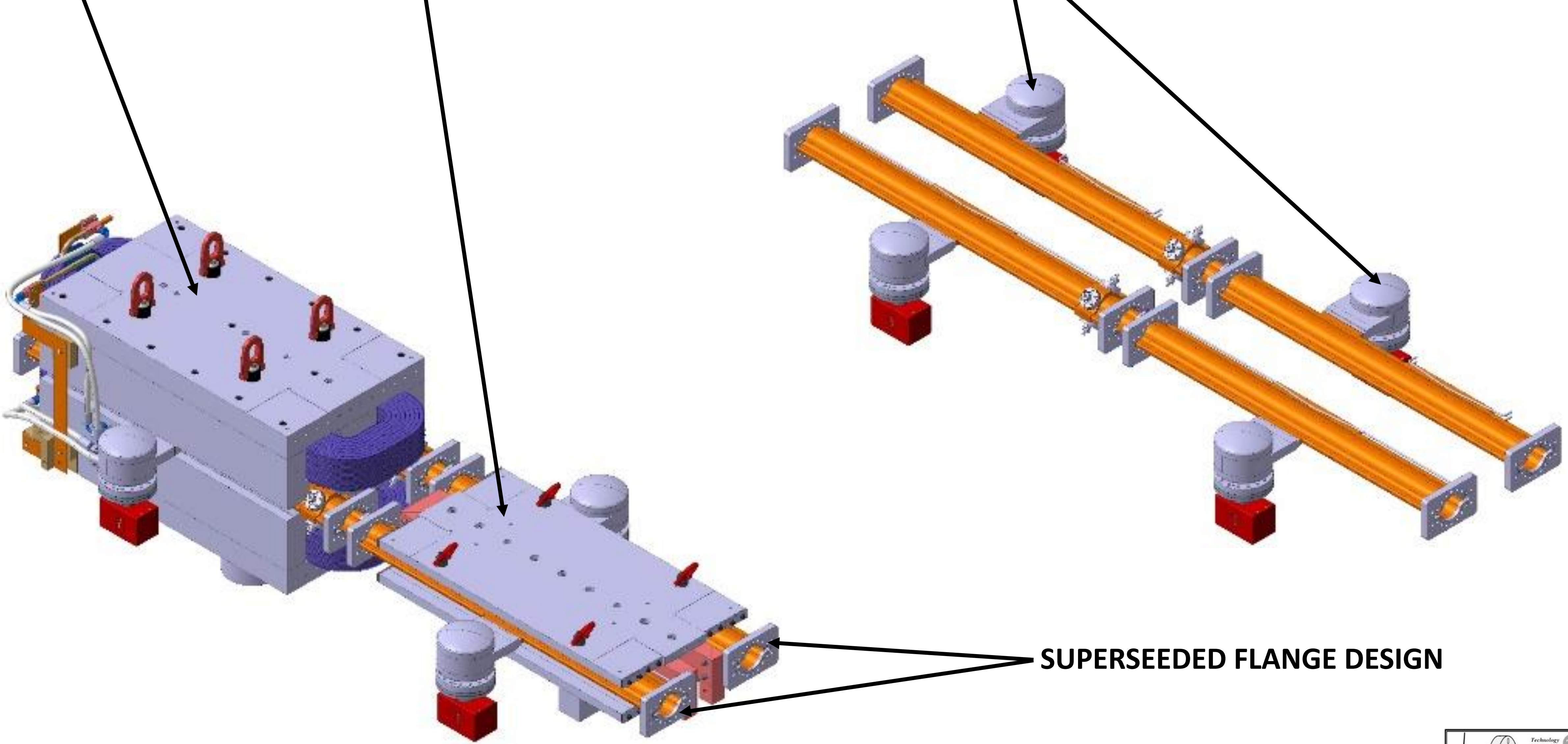
Another example: 3D-PRINTED SR ABSORBER, with INTEGRATED COOLING CIRCUIT AND SWIRL TAPE TO IMPROVE HEAT EXCHANGE





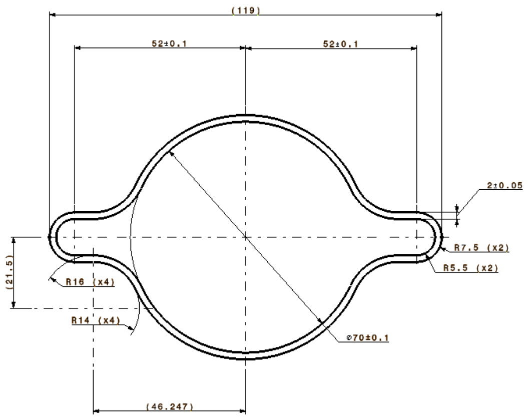


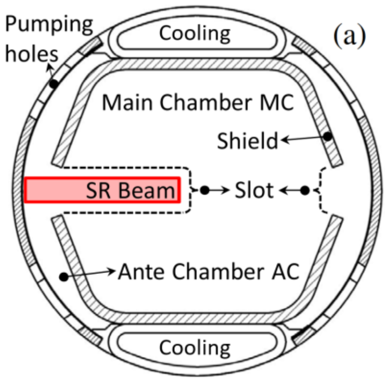
View of the VACUUM CHAMBERS with PUMPING DOMES (right) and inside QUADRUPOLE and DIPOLE MAGNET (left)



Second phase: FCC-hh

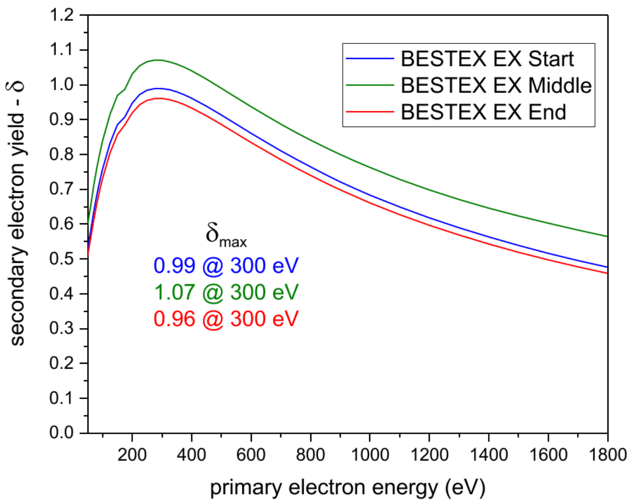
- The vacuum chamber cross section (not to scale)





- Operating at cryogenic temperature. We are investigating different surface treatments, coatings, etc.

- Example: Coating with Ti + a-C to reduce secondary electron yield, to prevent e-cloud formation



FCC-hh beam screen prototype testing

Karlsruher Institut für Technologie

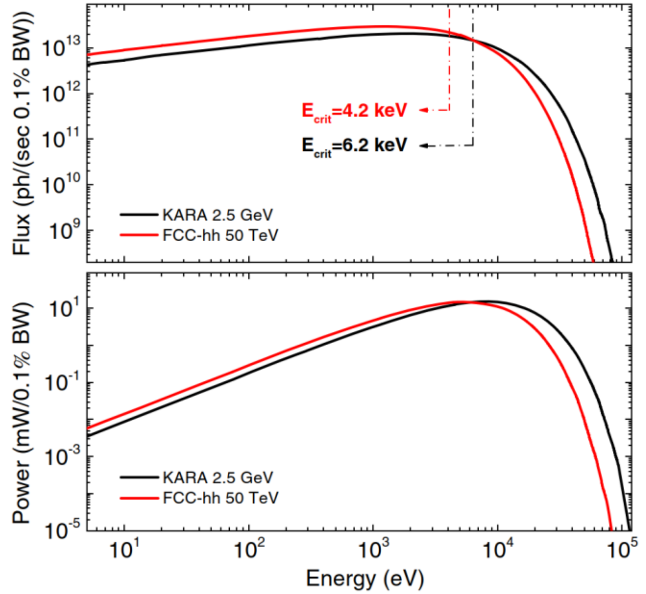
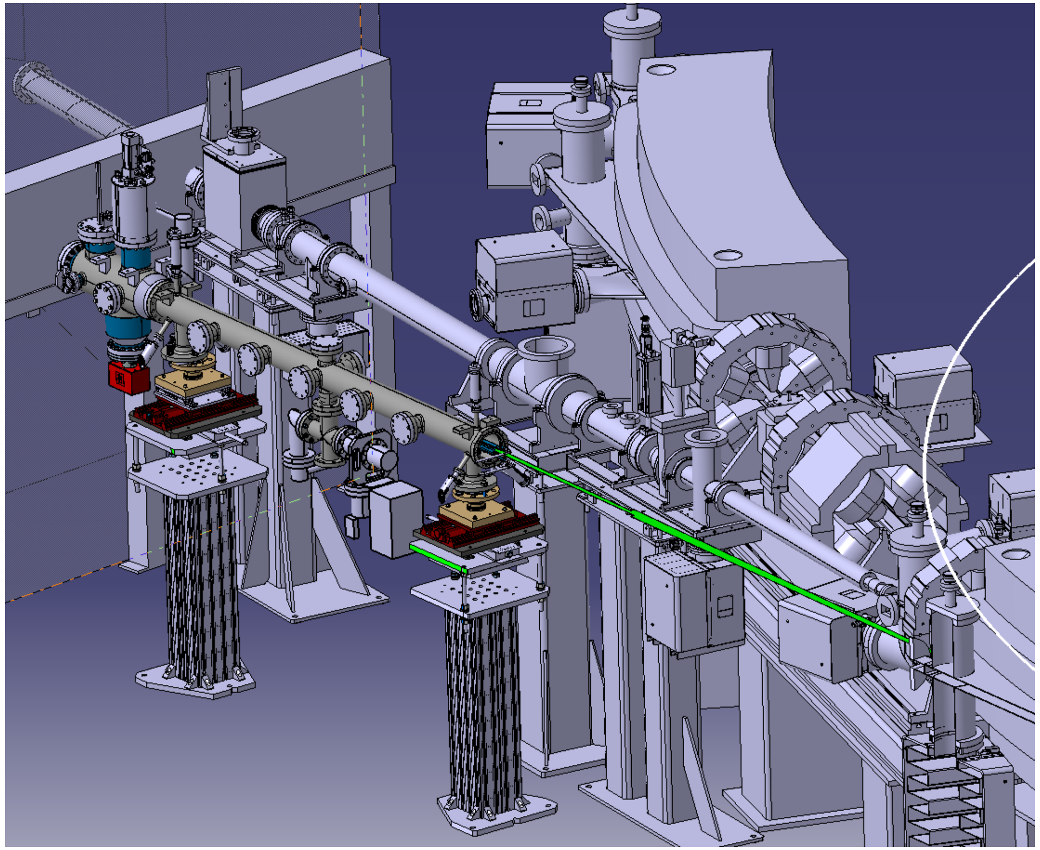
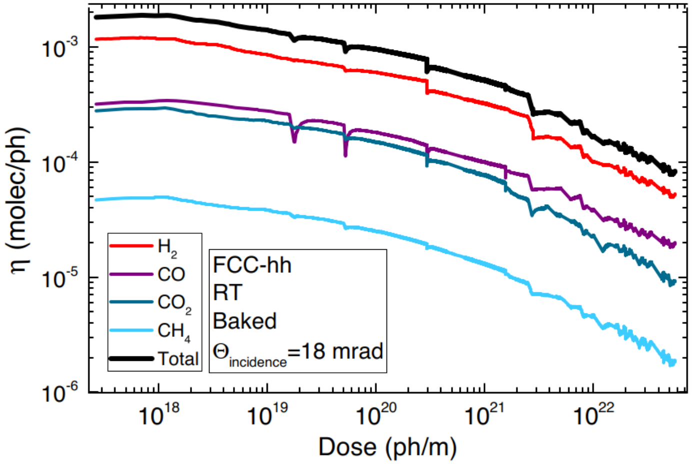


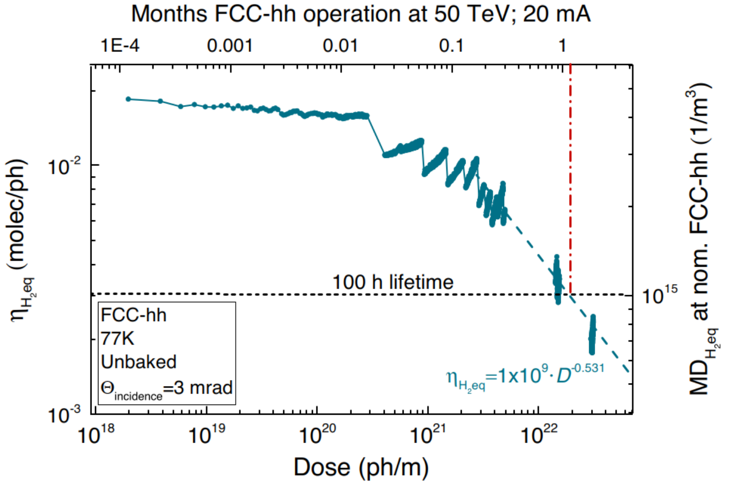
TABLE I. Comparison of the BESTEX (for the configuration of this specific work) and the FCC-hh relevant baseline parameters.

	BESTEX	FCC-hh
Critical energy [keV]	6.2	4.3
SR flux [ph/s/m]	4.84×10^{16}	1.7×10^{17}
SR power [W/m][a]	32	32[b]
Glancing angle [mrad]	18	1.35

[a]Power received at the BS.
[b]Average value. Power ranges between 21 and 42 W/m.







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L. A. Gonzalez, et al. *Commissioning of a beam screen test bench experiment with a future circular hadron collider type synchrotron radiation beam.* DOI: 10.1103/PhysRevAccelBeams.22.083201

L. A. Gonzalez, et al. *Photostimulated desorption performance of the future circular hadron collider beam screen.* DOI: 10.1103/PhysRevAccelBeams.24.113201

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- Support from the FCC study group management and technology department is also acknowledged

Backup slides

- BESTEX schematic