



FCC Week 2018

Amsterdam, April 9-13, 2018



FCC-ee Beam Vacuum Concept: the Beam Pipe of FCC-ee

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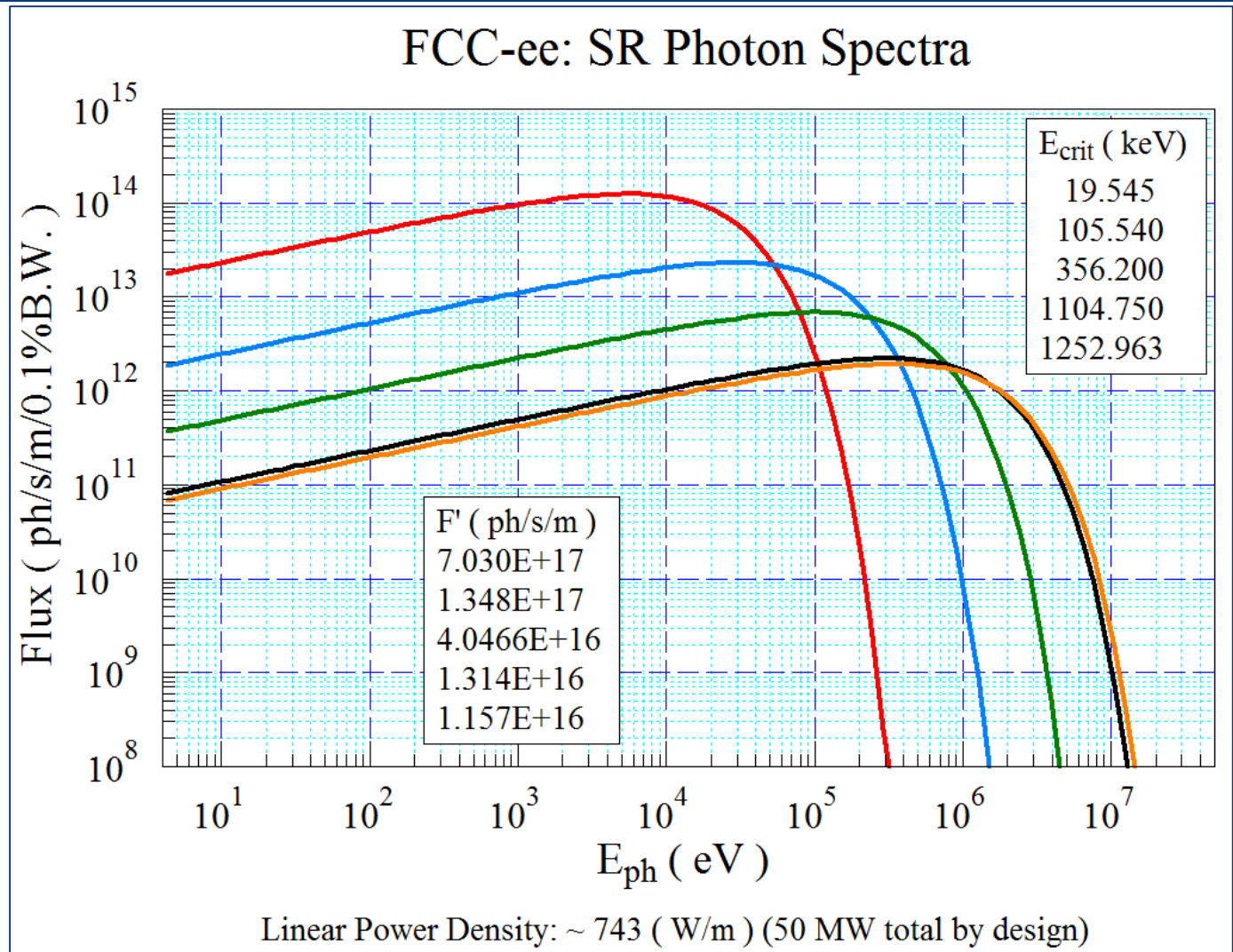
Machine parameters

- Machine parameters from official web page <http://tlep.web.cern.ch/content/machine-parameters>
- Very small vertical emittance for all energies
- High current (B-factory level) for Z-pole
- Luminosity lifetime τ_{lum} dominates beam current decay, but vacuum lifetime must be at least several times longer than τ_{lum} : good vacuum is a must

parameter	Z	W	H (ZH)	tbar
beam energy [GeV]	45.6	80	120	182.5
arc cell optics	60/60	90/90	90/90	90/90
momentum compaction [10^{-5}]	1.48	0.73	0.73	0.73
horizontal emittance [nm]	0.27	0.28	0.63	1.45
vertical emittance [pm]	1.0	1.0	1.3	2.7
horizontal beta* [m]	0.15	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	2
length of interaction area [mm]	0.42	0.5	0.9	1.99
tunes, half-ring (x, y, s)	(0.569, 0.61, 0.0125)	(0.577, 0.61, 0.0115)	(0.565, 0.60, 0.0180)	(0.553, 0.59, 0.0350)
longitudinal damping time [ms]	414	77	23	6.6
SR energy loss / turn [GeV]	0.036	0.34	1.72	9.21
total RF voltage [GV]	0.10	0.44	2.0	10.93
RF acceptance [%]	1.9	1.9	2.3	4.9
energy acceptance [%]	1.3	1.3	1.5	2.5
energy spread (SR / BS) [%]	0.038 / 0.132	0.066 / 0.153	0.099 / 0.151	0.15 / 0.20
bunch length (SR / BS) [mm]	3.5 / 12.1	3.3 / 7.65	3.15 / 4.9	2.5 / 3.3
Piwinski angle (SR / BS)	8.2 / 28.5	6.6 / 15.3	3.4 / 5.3	1.39 / 1.60
bunch intensity [10^{11}]	1.7	1.5	1.5	2.8
no. of bunches / beam	16640	2000	393	39
beam current [mA]	1390	147	29	5.4
luminosity [$10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	230	32	8	1.5
beam-beam parameter (x / y)	0.004 / 0.133	0.0065 / 0.118	0.016 / 0.108	0.094 / 0.150
luminosity lifetime [min]	70	50	42	44
time between injections [sec]	122	44	31	32
allowable asymmetry [%]	± 5	± 3	± 3	± 3
required lifetime by BS [min]	29	16	11	10
actual lifetime by BS ("weak") [min]	> 200	20	20	25

SR spectra and outgassing loads

- **Z-Pole: very high photon flux (→ large outgassing load);**
- **Z-pole: compliance with scheduled operation (integrated luminosity first 2 years), requires quick commissioning to $I_{\text{NOM}}=1.390$ A;**
- **T-pole (182.5): extremely large and penetrating radiation, critical energy 1.25 MeV;**
- **T-pole (and also W and H): need design which minimizes activation of tunnel and machine components;**
- **W, H-pole: intermediate between Z and T; still $E_{\text{crit}} >$ Compton edge (~100 keV)**



SR spectra and outgassing loads

- Gas Load for W-, H-, T-poles will have a significant contribution proportional to SR power, due to Compton photons (as per LEP operation, ref. “The pressure and gas composition evolution during the operation of the LEP accelerator at 100 GeV”, M. J. Jimenez et al., Vacuum 60 (2001) p183-189);

F (FCC-ee)>100 keV (%)	
Z	0.0639
W	9.220
H	28.852
T(175)	47.810
T(182.5)	49.717

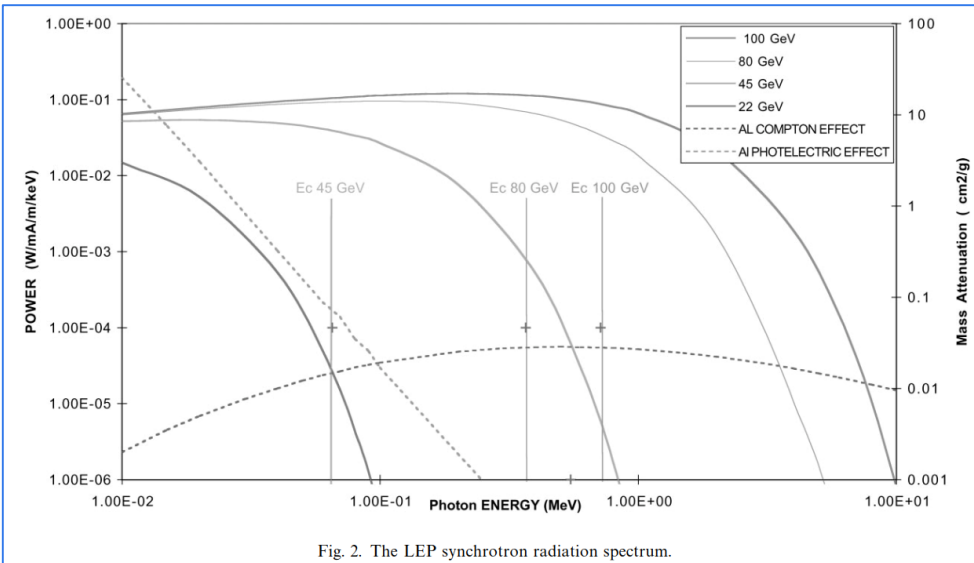


Fig. 2. The LEP synchrotron radiation spectrum.

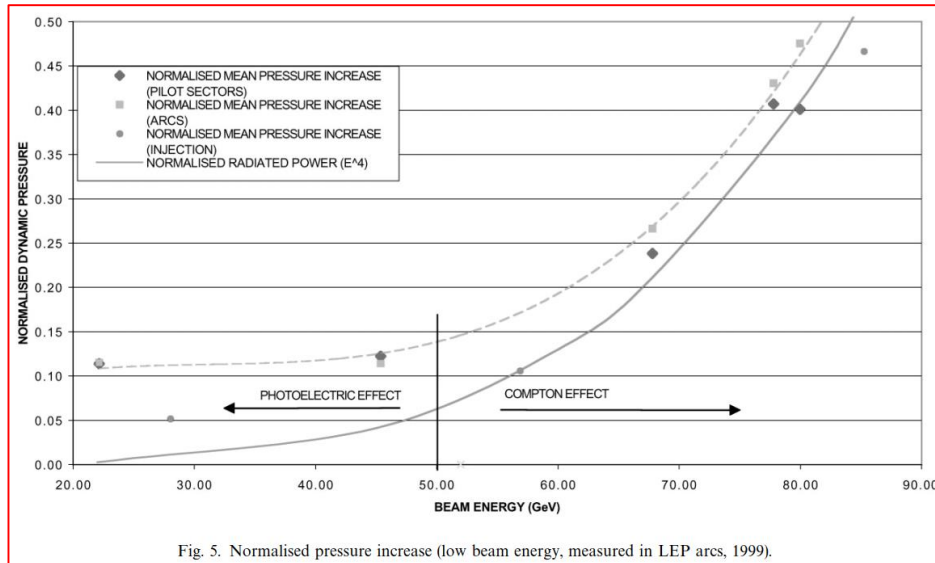
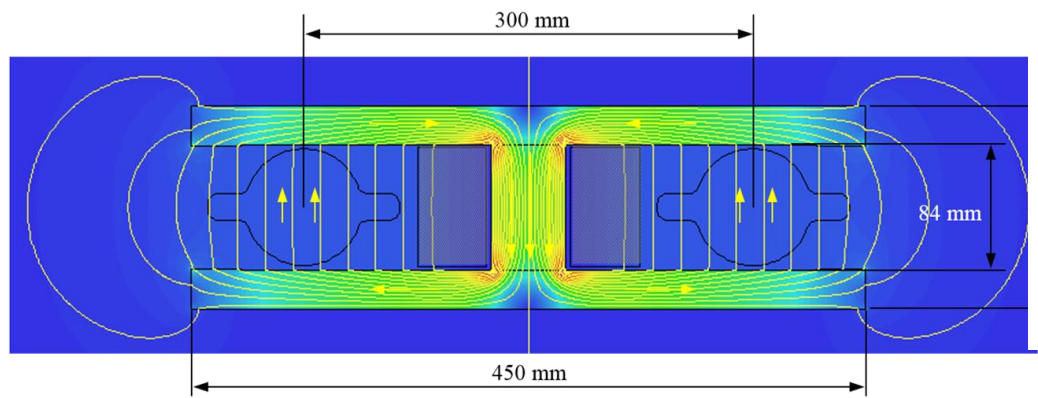


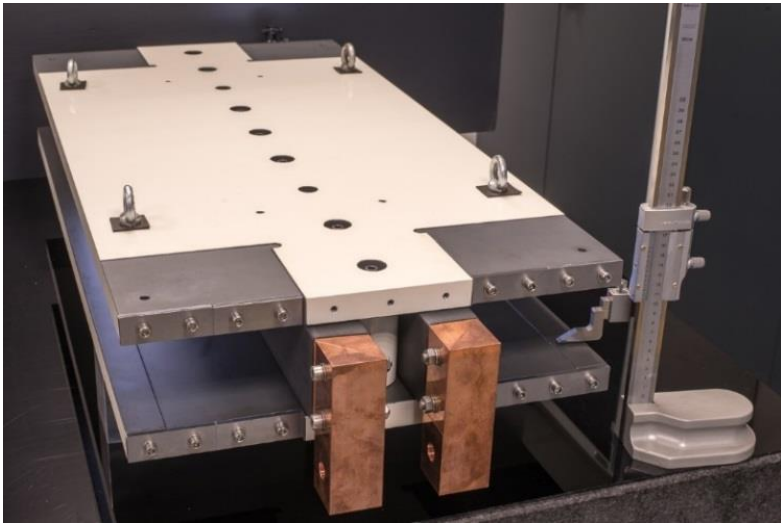
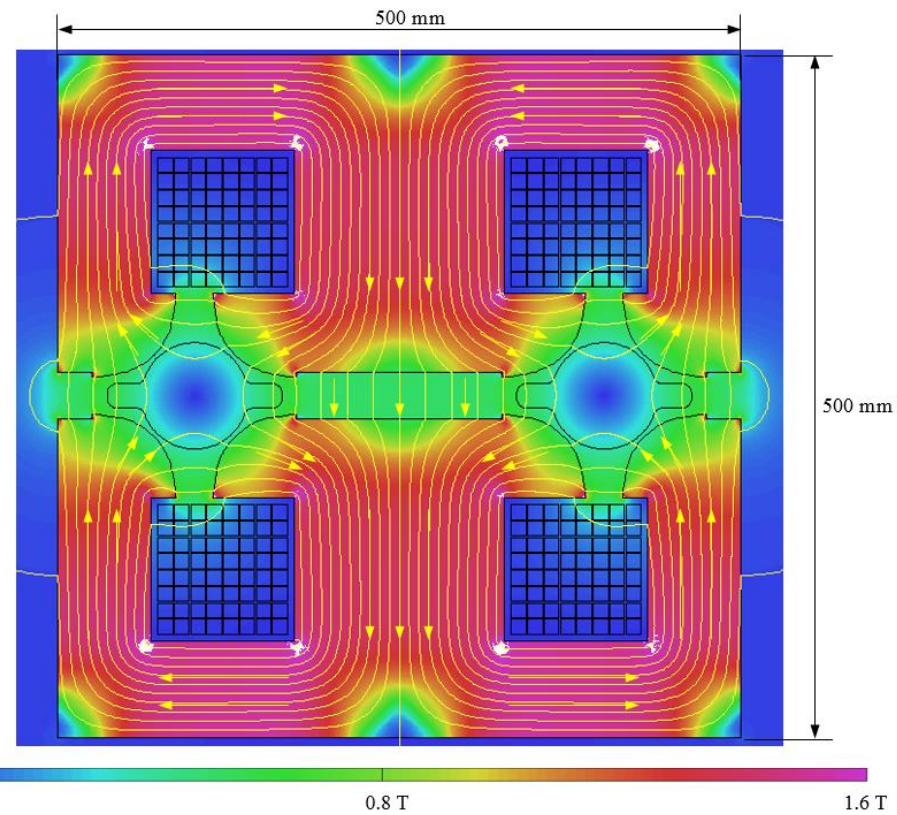
Fig. 5. Normalised pressure increase (low beam energy, measured in LEP arcs, 1999).

- If copper alloy is chosen as the material for the vacuum chamber, then a smaller fraction goes into Compton, and shielding improves;
- In addition, copper has a lower photon-stimulated desorption yield;

Integration with magnets

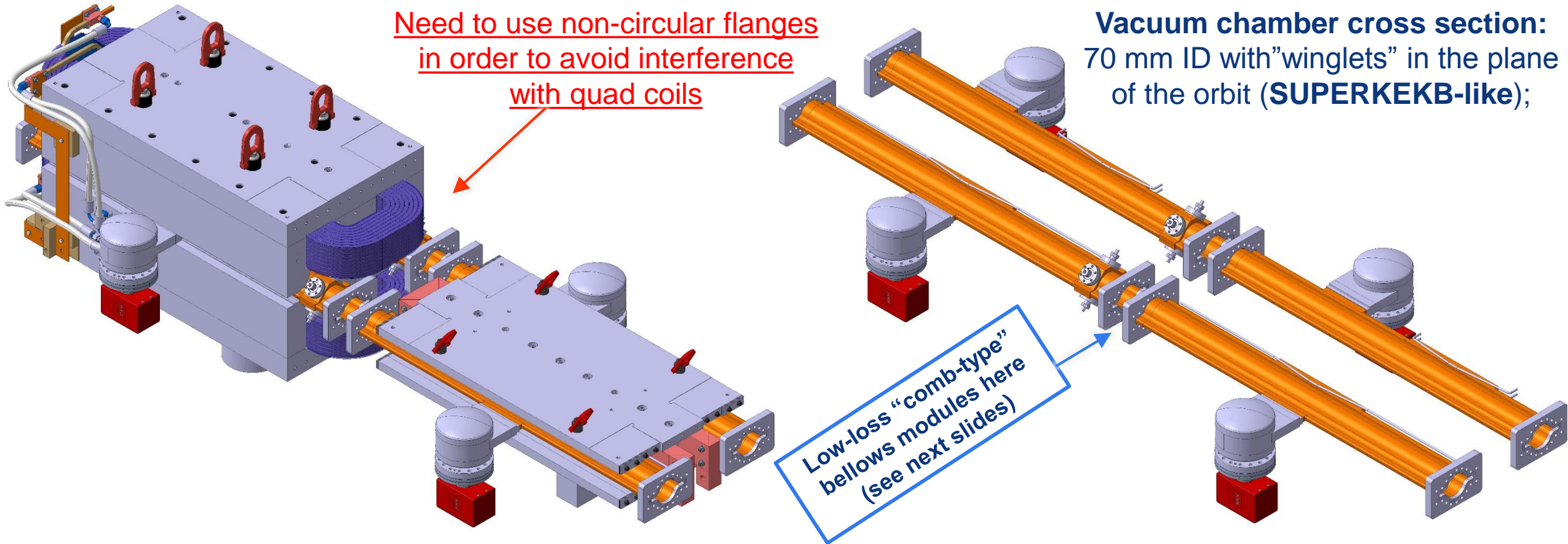


Combined-yoke
dipoles and
quadrupoles –
← Magnetic models →
and 1m-long
prototypes



Courtesy of **A. Milanese, CERN**
(see his contribution at *Proc. FCC Week 2017*, Berlin)

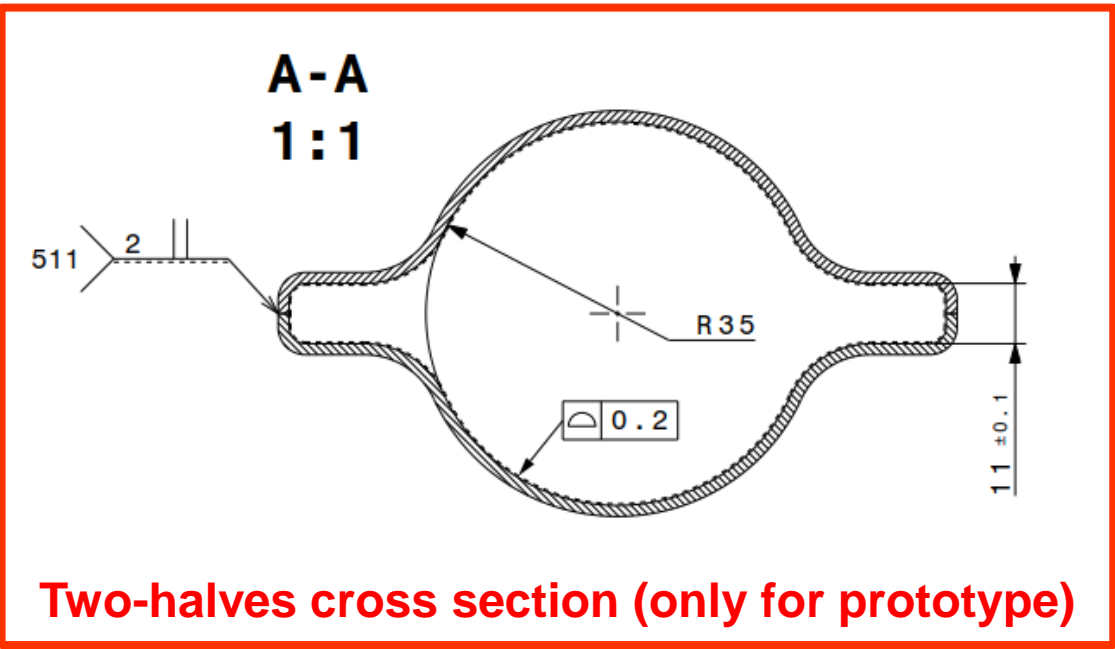
Vacuum chamber geometry



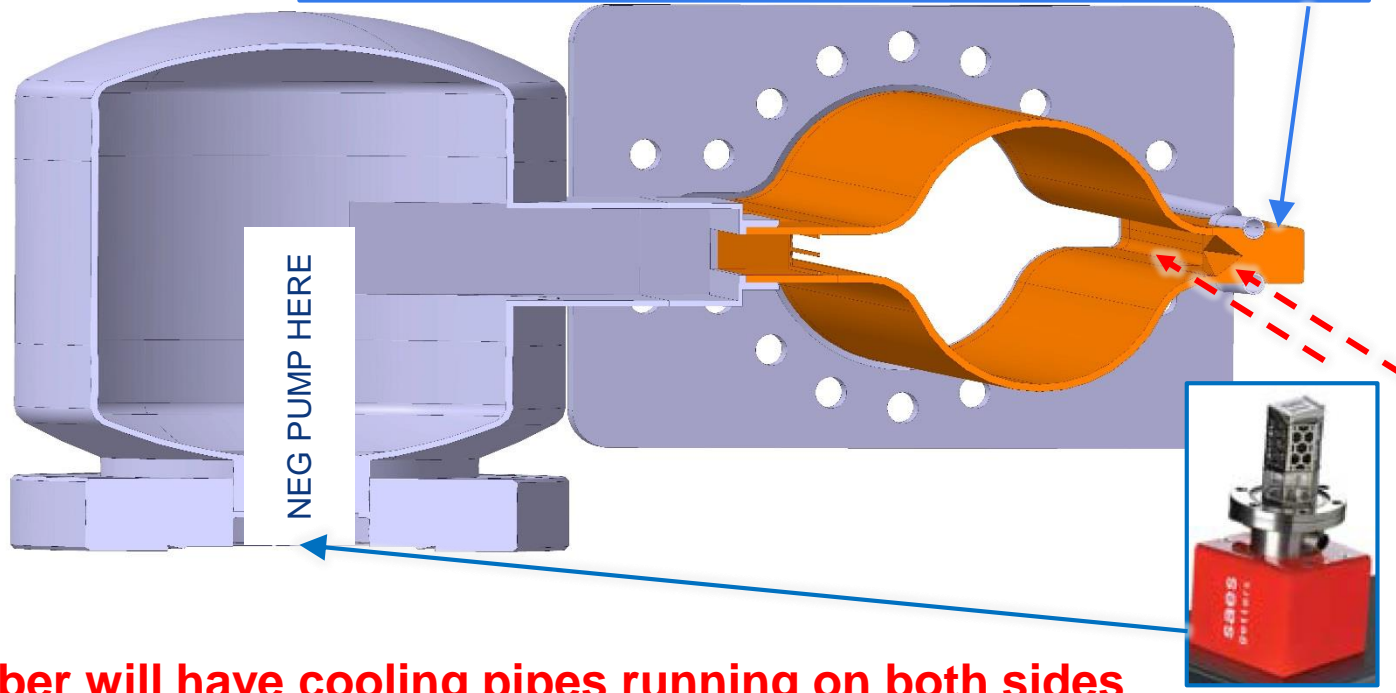
- CAD model of the 1m-long common-yoke dipole and quadrupole prototypes with arc vacuum chambers (courtesy of **M. Gil Costa, CERN/CIEMAT**);
- The chambers feature **lumped SR absorbers** with **NEG-pumps** placed next to them;

Vacuum chamber geometry

Material: OFC copper

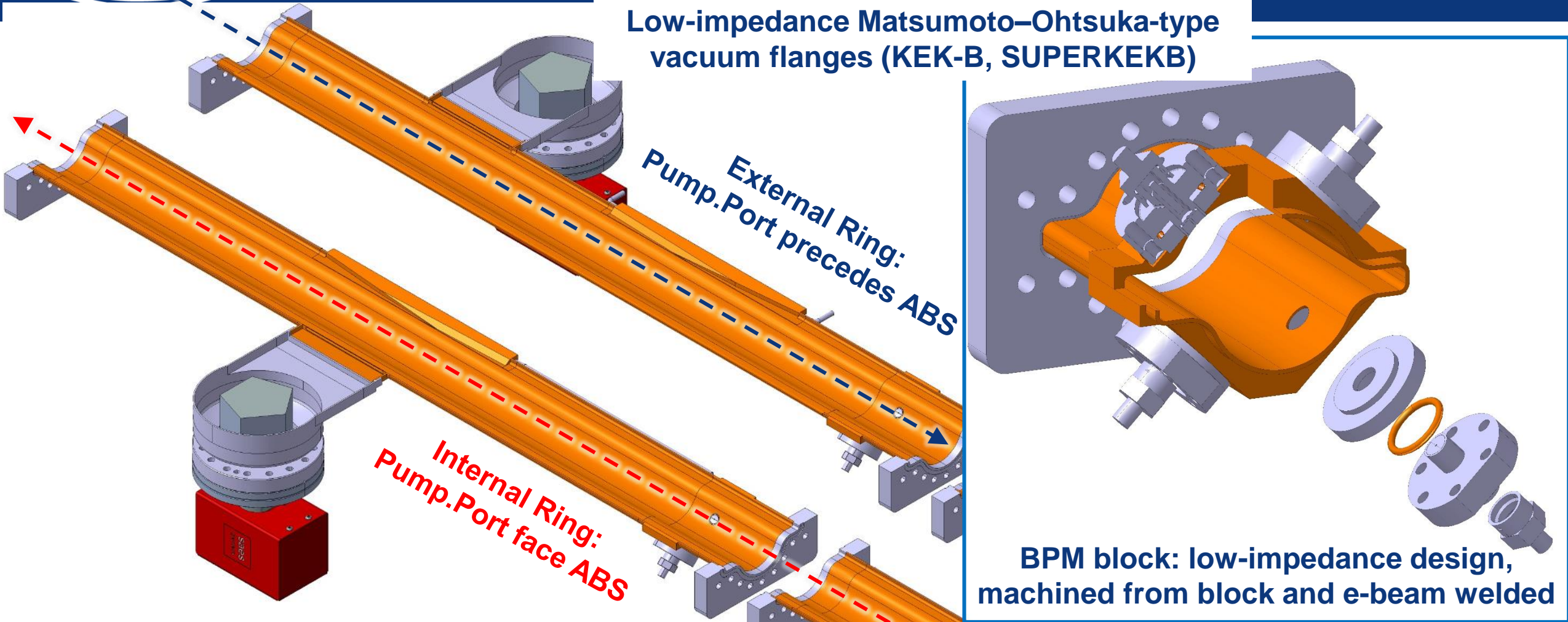


Lumped absorbers (1 every ~ 6 m, covering the entire horizontal SR photon fan)



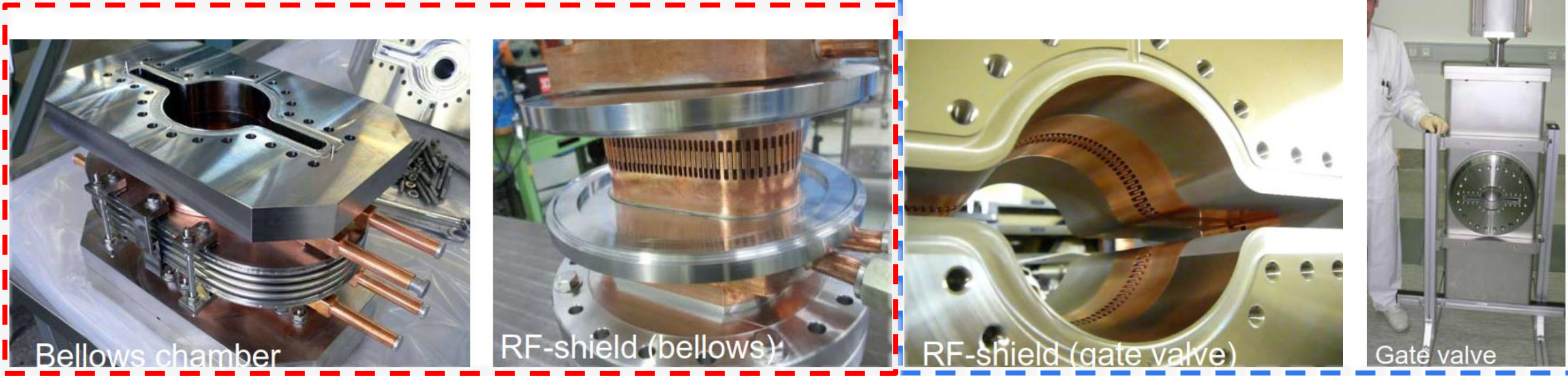
- **Left: Cross-section of the prototype (real chamber will have cooling pipes running on both sides of wigglets);**
- **Right: Cross-section at pumping dome/absorber location; The connection to the beam chamber is via a slotted grid; The SR absorber is placed in front of the pumping dome (for external beam only); The conductance of the pumping dome and tapered transition is ~ 110 l/s (CO, 20 C);**

Vacuum chamber geometry



This vacuum chamber geometry, with lumped absorbers, is also useful in order to minimize the amount of scattered high-energy radiation (see A. Infantino et al., “Radiation environment assessment in the FCCh and FCCee machines”, this conference)

RF contact fingers



Low-loss, water-cooled, “comb-type” contact fingers (KEK concept, to be adapted to our dimensions)

- Ref. - Y. Suetsugu et al., “*Design and construction of the SuperKEKB vacuum system*” – J. Vac. Sci. Technol. A 30 (2012) 031602
 - K. Shibata, KEK, *Proc. ELOUD’12*, June 2012

Vacuum pumping system

- The common-yoke design for the magnets does not allow us to use a chamber-antechamber design like LEP; the proposed pumping concept is based on a design philosophy combining a reduction of the SR-induced outgassing load thanks to the lumped absorbers, the use of high-speed/high-capacity pumps placed next to the absorbers, and the use of thin-film coatings or surface texturing which would reduce the amount of gas generated by SR photons and avoid the contribution to outgassing of e-cloud multipacting;

The proposed, baseline design is the following:

- NEG-coating
- High-capacity lumped NEG pumps (NEXTorr, SAES Getters)

One open issue with NEG-coating is its contribution to the longitudinal resistive-wall instability¹;

- It is being addressed experimentally now at CERN², and will be also tested with SR at the Photon Factory soon³

- 1 E. Belli et al., “*Impedance model and single-beam collective effects*”, this conference
- 2 T. Finkley Sinkovits et al., “*Minimum effective thickness for activation and low total electron yield of TiZrV non-evaporable getter coatings*”, this conf.
- 3 Y. Tanimoto et al., Photon Factory, KEK (*to be published*)

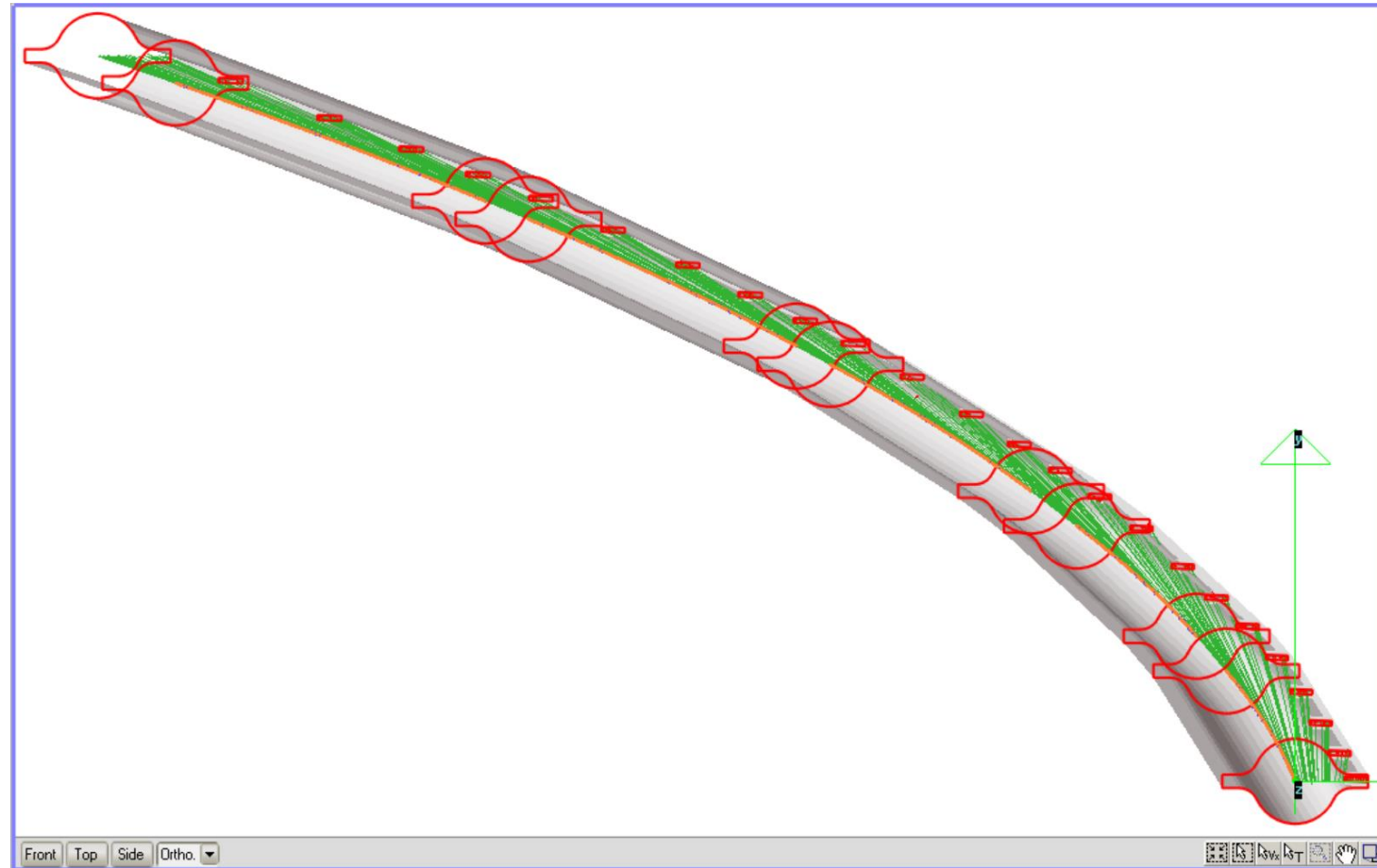
E-cloud mitigation

- As already mentioned, the baseline option is the use of NEG-coatings; it is known to have a low SEY
- An experimental research program is underway at CERN in order to determine what minimum thickness of the NEG-coating would be tolerable without affecting the longitudinal resistive-wall instability threshold, providing a sufficiently low secondary electron yield (SEY), and providing also a low photon-stimulated desorption (PSD) yield after repeated saturation/activation cycles.
- So far (see refs. 1 and 2 previous slide) 30, 90, and 200 nm-thick coatings have been tested via XPS analysis (oxygen dissolution profiles vs depth), and 4 thermal cycles (activation at 250 C);
- The results are encouraging
- Plan-B options are:
 - amorphous carbon
 - titanium nitride
 - laser-ablated surface texturing¹⁻⁴
 - clearing electrodes

1 O. Malyshev et al., “A Facility for Studying ESD from NEG Coated Surfaces at Cryogenic Temperatures”, this conf.
2 O. Malyshev et al., “NEG Coatings and laser surface engineering (LASE) electron cloud mitigation techniques”, this conf.
3 T. Sian et al., “New LASE surfaces obtained with various lasers and their parameters for e-cloud mitigation”, this conf.
4 R. Valizadeh et al., “Recent development in Laser ablation surface engineering for reduction of secondary electron yield”, this conf.

Expected performance, pressure profiles in the arcs

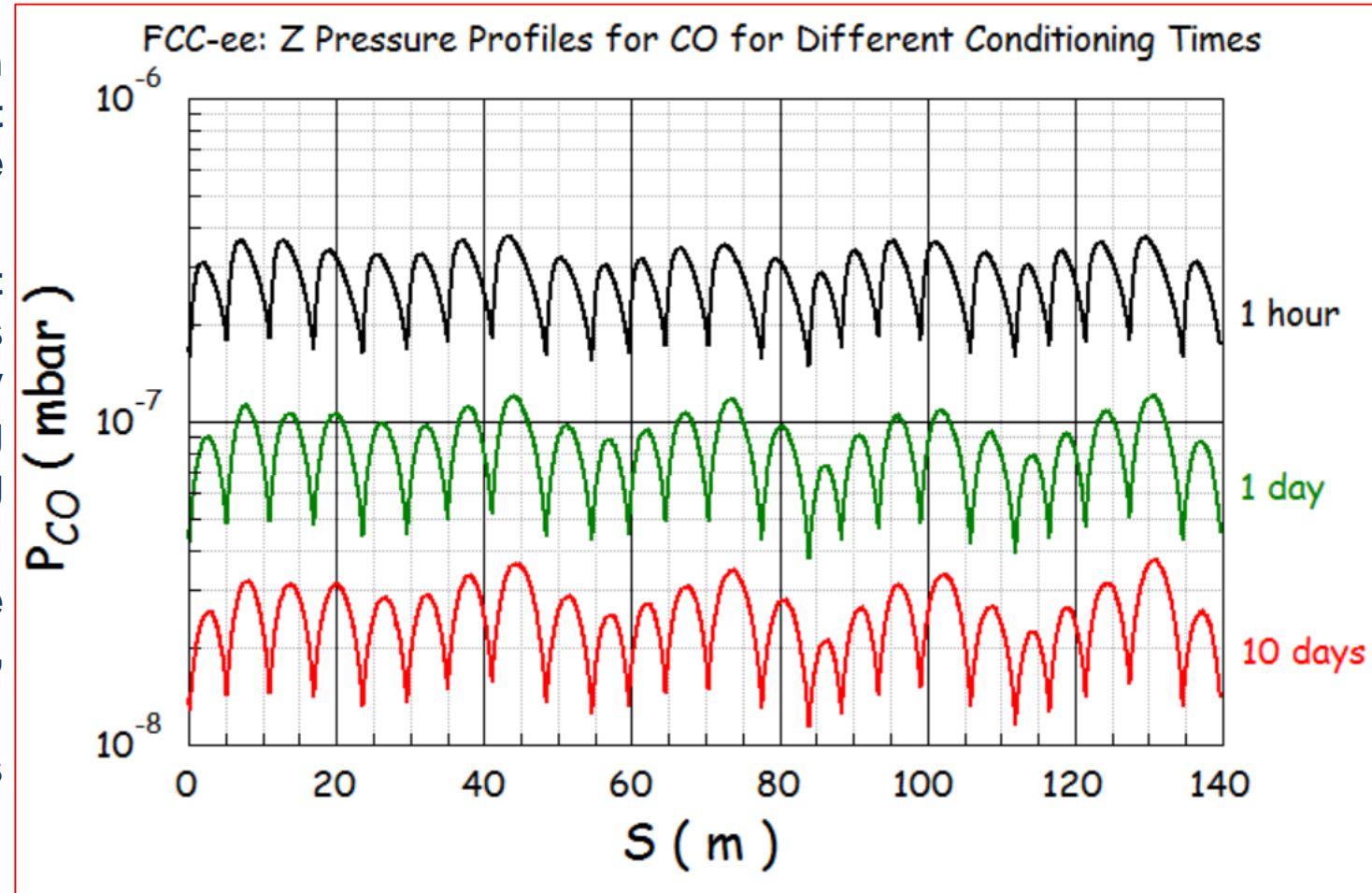
- One ~140 m-long section of the arc lattice (latest optics) has been modelled (5 dipoles of 3 different lengths and 3 quadrupoles)
- Lumped SR absorbers have been placed so that they cover 100% of the primary SR photon fan (i.e. ray-tracing with zero reflectivity, see figure)
- In total, 24 absorbers placed at ~ 5.8 m average distance between each other
- Periodic boundary conditions (not strictly true, but close enough for vacuum purposes)
- 1 NEG pump upstream of each absorber (like for the external beam, worst case)



3D SYNRAD+ model for ray-tracing;
Boundaries of dipole-to-quad areas and SR absorbers are
highlighted in red

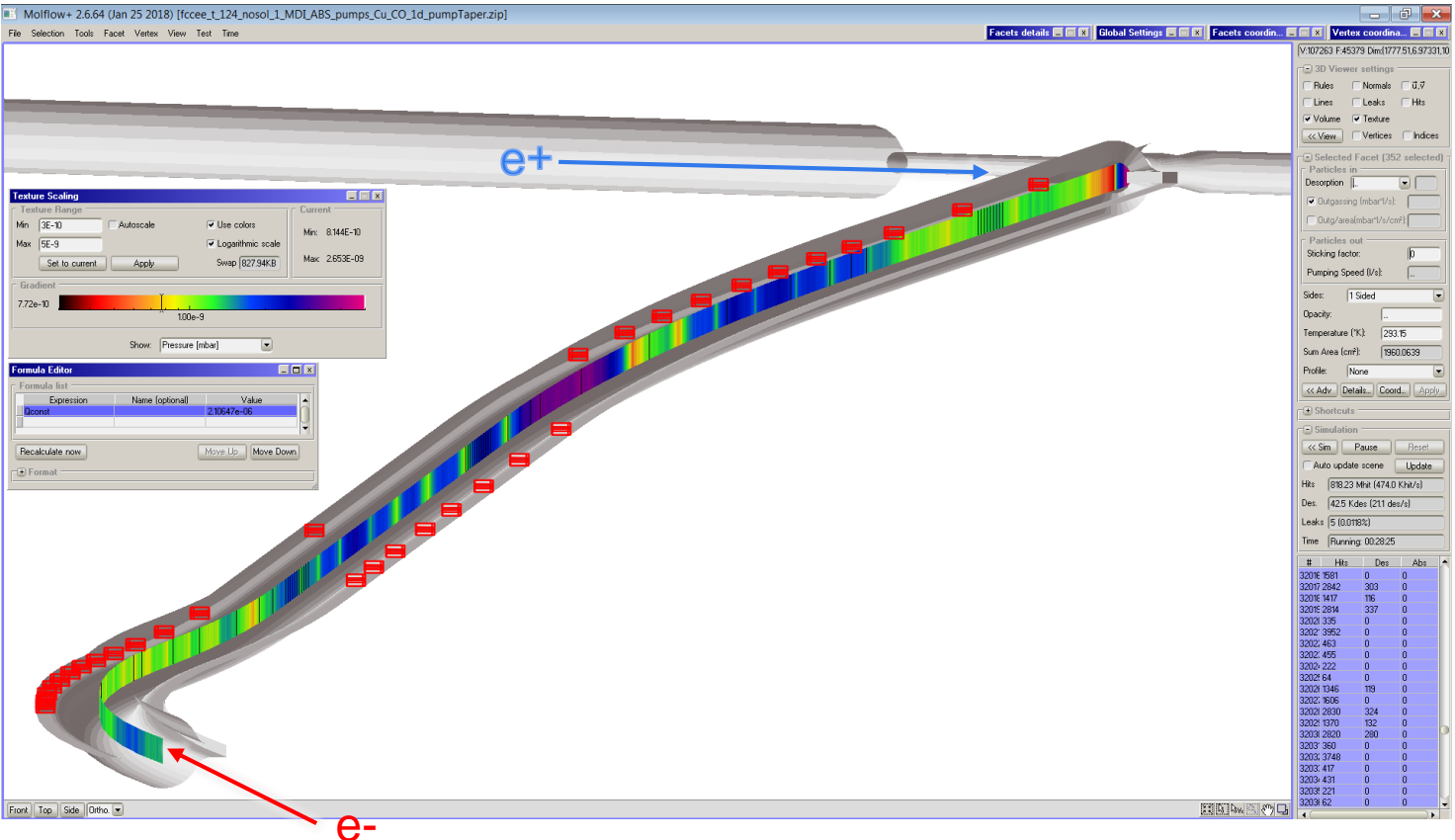
Expected performance, pressure profiles in the arcs

- The SYNRAD+ MC ray-tracing code has been run with energy- and angle-dependent reflectivity curves, in order to get a surface mapping of the SR photon distribution
- The photon map has been used as an input to the MC code Molflow+, which calculates the corresponding pressure and density profiles; Molflow+ requires a “conditioning time” and the definition of the pumping speeds as an input
- The pressure curves on the right assume 100% CO gas (real case probably ~80% H₂, ~20% CO and CO₂, and traces of CH₄)
- It is assumed here that one NEG pumps is installed upstream of each absorber



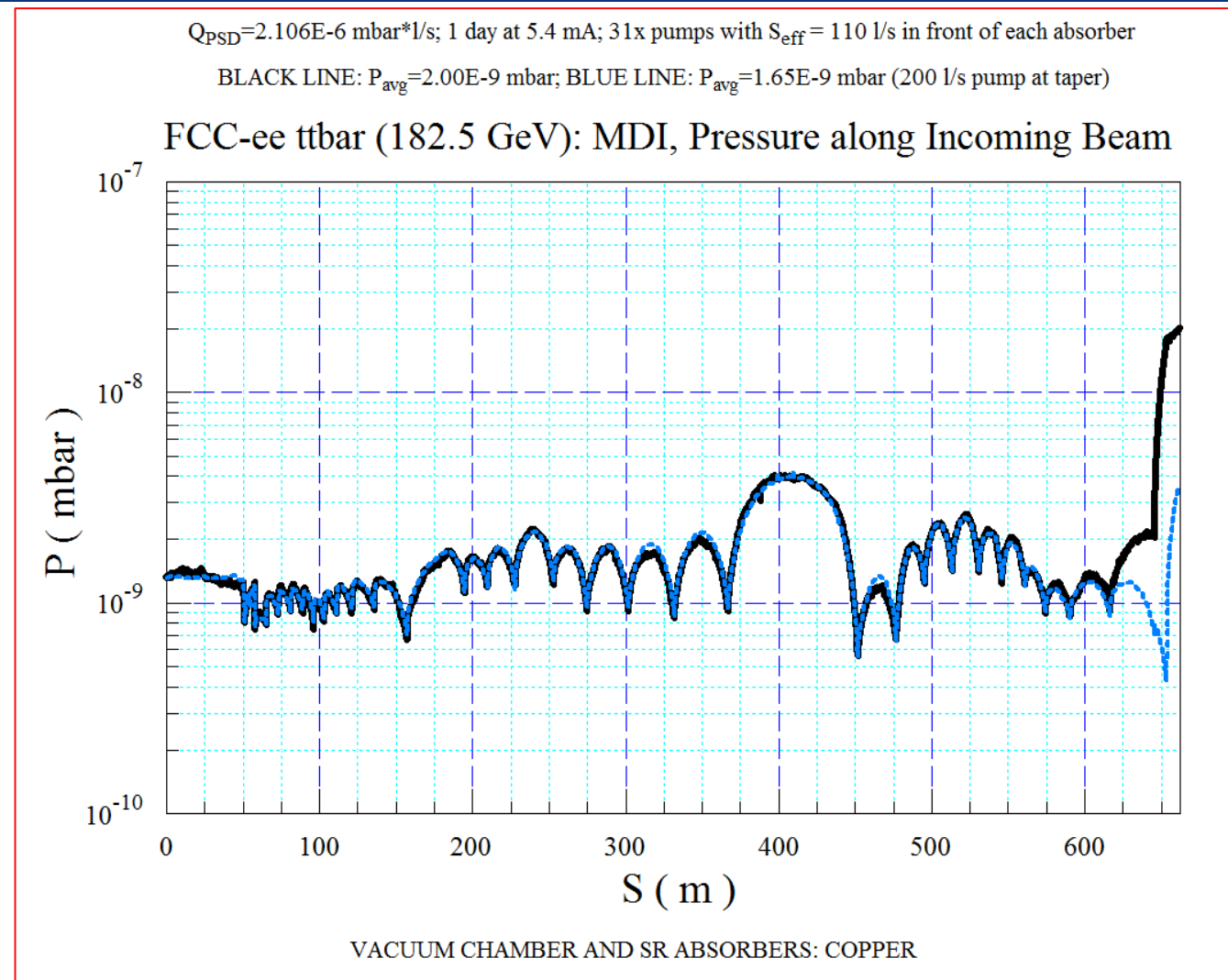
Machine Detector Interface areas

- Modelling work has also been carried out for the MDI areas of FCC-ee, see relevant MDI meeting, study group, and workshop pages on indico
- A 3D model of the vacuum chamber geometry ~ 660 m upstream of the IP has been created; it implements the SUPERKEKB-type cross-section with lumped absorbers and NEG pumps already described for the arc chambers
- SYNRAD+ and Molflow+ have been run, coupled for the high-current Z-pole machine
- The figure on the right shows the model with the colour-coded pressure along the beam path and the absorbers in red



Machine Detector Interface areas

- The figure on the right shows the pressure profile for the T-pole at 182.5 GeV, after a vacuum conditioning of 1 day at full current (5.4 mA)
- The blue curve assumes a higher pumping speed at the taper placed immediately before the QC2L2 final-focus quadrupole: it helps decrease the pressure bump near the IP
- See also:
 - A. Kolano, “Mitigation of synchrotron radiation from IR”, this conf.
 - F. Collamati et al., “Beam-gas background characterization in the FCC-ee IR”, this conf.
 - M. Boscolo, “MDI status and overview”, this conf.



Summary and conclusions

- Following the developments on the design of the arc magnets and optics, a vacuum chamber cross-section has been chosen
- It is derived from that successfully implemented in the two rings of SUPERKEKB, with reduced dimensions (70 mm ID circular tube with two small “winglets” in the plane of the orbit)
- Careful ray-tracing and vacuum considerations have convinced us that a lumped absorber design would improve the vacuum performance and shorten the commissioning time
- “Thin” NEG-coating is the baseline choice for e-cloud mitigation and in order to shorten the vacuum conditioning due to SR photon irradiation
- Plan-B e-cloud mitigation options are being considered too: TiN, amorphous carbon, LASE texturing, and clearing electrodes
- Implementation of the same concept in the MDI areas has also been studied: it would generate a low-background at the IP

Work to do for the CDR:

- Cost estimate for vacuum chambers, pumping system, NEG-coating (or other technology)
- Full arc model to pass on to FLUKA team for R2E and tunnel activation studies