FCC

Arc vacuum system and synchrotron radiation

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Relevant machine and vacuum parameters

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Regular Article

FCC-ee: The Lepton Collider

Future Circular Collider Conceptual Design Report Volume 2

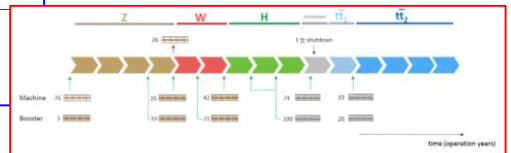

Fig. 4. FCC-ee operation time line. The bottom part indicates the number of cryomodules to be installed in the collider and booster, respectively, during the various winter shutdown periods; also see [22].

Table 1. Machine parameters of the FCC-ee for different beam energies.

	Z	WW	ZH	tt	
Circumference (km)	97.756				
Bending radius (km)	10.760				
Free length to IP l^* (m)	2.2				
Solenoid field at IP (T)	2.0				
Full crossing angle at IP θ (mrad)	30				
SR power/beam (MW)	50				
Beam energy (GeV)	45.6	80	120	175	182.5
Beam current (mA)	1390	147	29	6.4	5.4
Bunches/beam	16 640	2000	328	59	48

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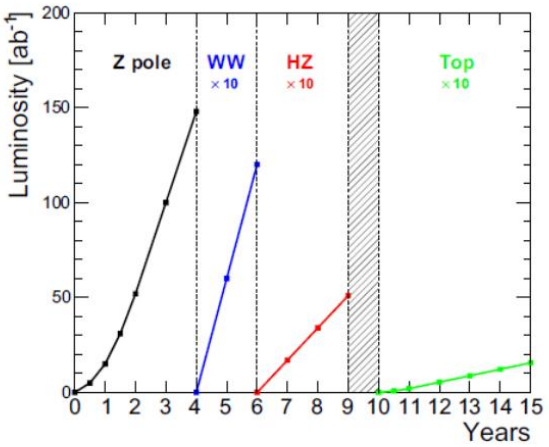


Fig. 1.2. Operation model for the FCC-ee, as a result of the five-year conceptual design study, showing the integrated luminosity at the Z pole (black), the WW threshold (blue), the Higgs factory (red), and the top-pair threshold (green) as a function of time. The hatched area indicates the shutdown time needed to prepare the collider for the highest energy runs.

Big variation of nominal current vs beam energy, since all machine versions are <u>limited to 50 MW of synchrotron radiation per beam</u>

$$P\,(W) = 88.46 \cdot E^4(GeV) \cdot I(mA) / \rho(m)$$

$$F\,(ph/s) = 8.08 \cdot 10^{17} \cdot E(GeV) \cdot I(mA)$$

We aim at an average pressure giving a beam-gas scattering lifetime large enough not to be detrimental to the integrated luminosity, say in the <u>low 10-9 mbar range</u>, or better, with a gas composition of 80~90% hydrogen, and no molecular masses above 44 (CO_2).

Typically, 80~90% H_2, 10~20% $CO+CO_2$, traces of CH_4

Vacuum chamber cross section

The choice of the vacuum chamber cross section is dictated by many different effects and requirements:

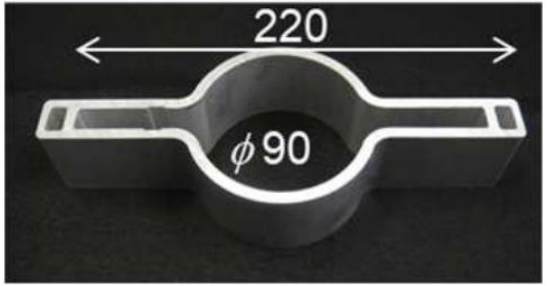
- **Minimize time to condition (to speed-up integrated luminosity at Z, most difficult case, vacuum wise)**
- **Minimize beam-gas scattering effects, i.e. minimize pressures and improve pumping efficiency**
- **Deal with large flux of Compton-scattered secondaries (at WZ, H, ttbar)**
- **Keep fabrication complexity to a minimum (2x 98 km rings!);**
- **Satisfy impedance requirements (geometric and resistive-wall as well)**

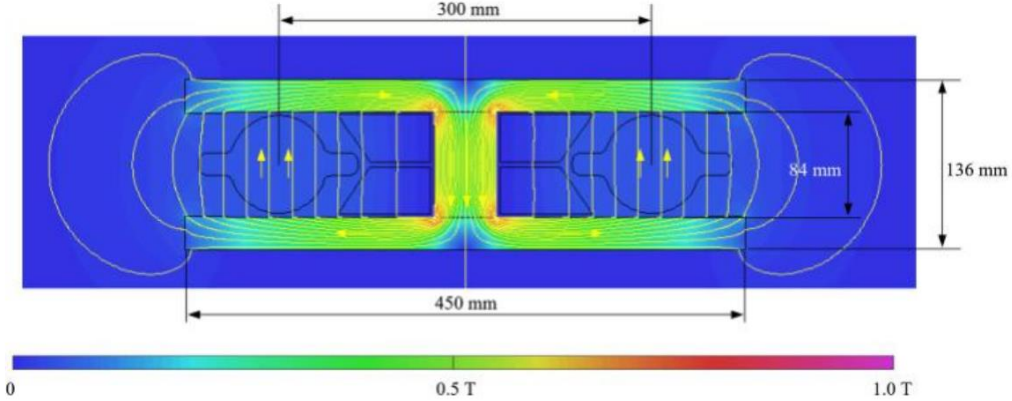
Vacuum chamber cross section

For this reasons we have proposed, in the CDR, to adopt a modification of the SuperKEKB vacuum chamber cross section (*), i.e. a circular chamber with two small symmetric "winglets" in the plane of the orbit

The diameter of the circular part is 70 mm (ID), vs 90 for SuperKEKB; vertical gap in our dipoles is 84 mm, same as the inscribed circle in the quadrupoles

The winglets we can accommodate taking into account the 300 mm horizontal beam-beam separation and the structure of the common-yoke dipoles and quadrupoles (**) are smaller than those of SuperKEKB. In our case the horizontal width is only 120 mm



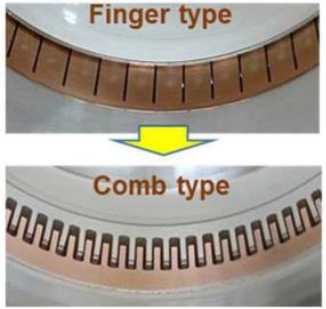


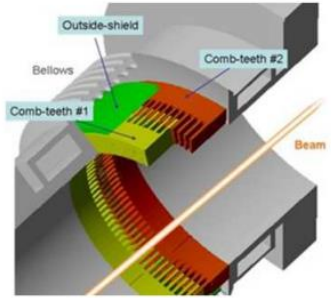
(*) Y. Suetsugu, this conference

(**) J. Bauche, this conference

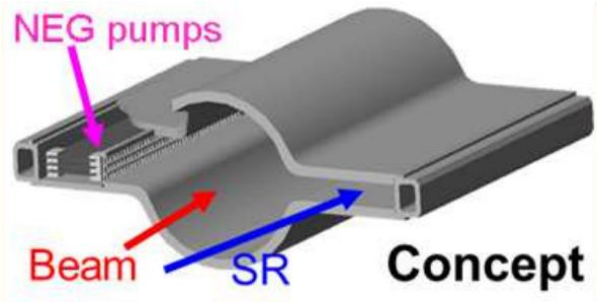
Vacuum chamber cross section

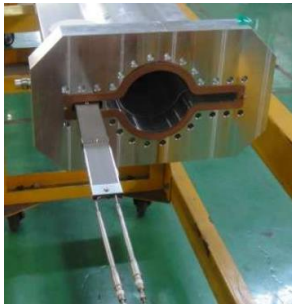
If we adopt the SuperKEKB vacuum chamber cross-section then it comes natural to try and adapt also the SuperKEKB concept for the MO-type flanges, bellows, and gate valves (*). This will probably help reduce the geometric impedance budget:





Unfortunately we can not adopt the distributed NEG pumping solution, since our winglets are not wide enough, only ~ 25 mm

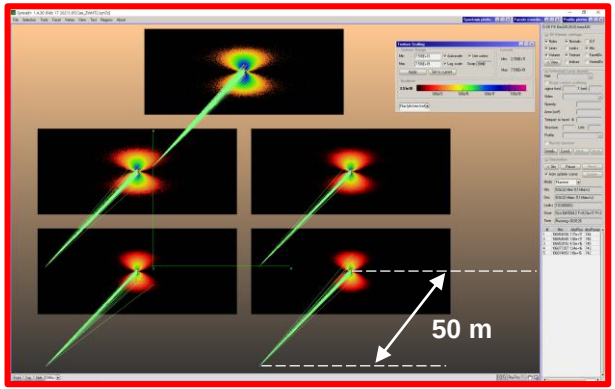




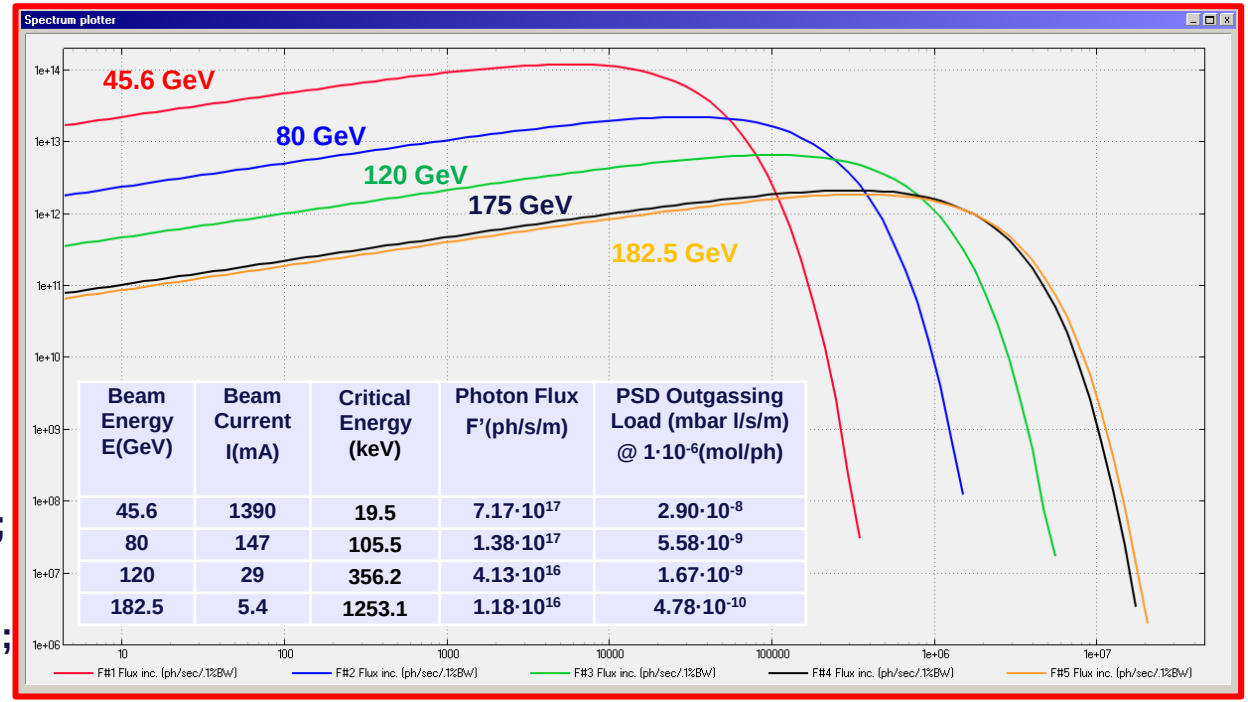
(*) Y. Suetsugu, this conference
(**) J. Bauche, this conference

Synchrotron radiation spectrum, flux, power

SR Spectra computed with SYNRAD+



- Radiation projected onto five 14x6 cm^2 screens;
- 1 cm-long dipole arc trajectories;
- Flux distribution shown here,
- Logarithmic scale for textures, 6 orders of magnitude displayed;



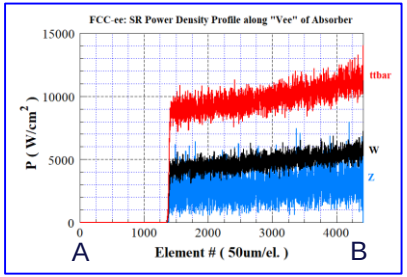
Beam Energy E(GeV)	Beam Current I(mA)	Critical Energy (keV)	Photon Flux F'(ph/s/m)	PSD Outgassing Load (mbar l/s/m) @ $1\cdot10^{-6}$(mol/ph)
45.6	1390	19.5	$7.17\cdot10^{17}$	$2.90\cdot10^{-8}$
80	147	105.5	$1.38\cdot10^{17}$	$5.58\cdot10^{-9}$
120	29	356.2	$4.13\cdot10^{16}$	$1.67\cdot10^{-9}$
182.5	5.4	1253.1	$1.18\cdot10^{16}$	$4.78\cdot10^{-10}$

Units: Vertical: photons/s/(0.1% bandwidth)/m; Range [10^6 - $2\cdot10^{14}$]
Horizontal eV; Range [4 - $5\cdot10^6$]

SR absorbers: yes or no?

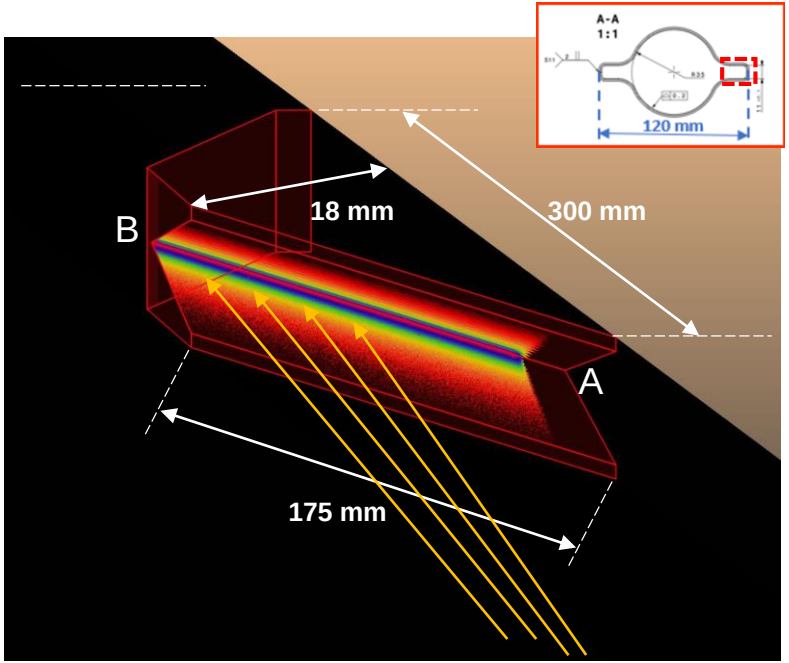
- **The high beam energy generates an extremely narrow fan of SR, swiping a strip along the external wall of the vacuum chambers**
- **If the SR is let impinge onto the vertical wall at the end of the winglet on the external side (60 mm from the beam axis), then the average photon travels ~38 m before hitting the wall**
- **If SR absorbers like in the figure are used, 1 every ~5.6 m, then the average distance is ~34.6 m**

Beam Energy E(GeV)	Natural SR Vertical Angle, 1/γ (μrad)	Vertical Fan Height at 35 m, (mm)	Beam Current I(mA)	Linear Photon Power Density (*) P'(W/m)	Peak Surface Photon Power Density (*) P''(W/mm²)	Peak Surface Photon Power Density (**) P''(W/mm²)
45.6	11.2	0.40	1390	~ 620	~ 1.4	~ 32
80	6.4	0.22	147	"	~ 2.2	~ 56
120	4.3	0.15	29	"	~ 3.0	~ 85
182.5	2.8	0.10	5.4	"	~ 4.0	~115



*On external wall

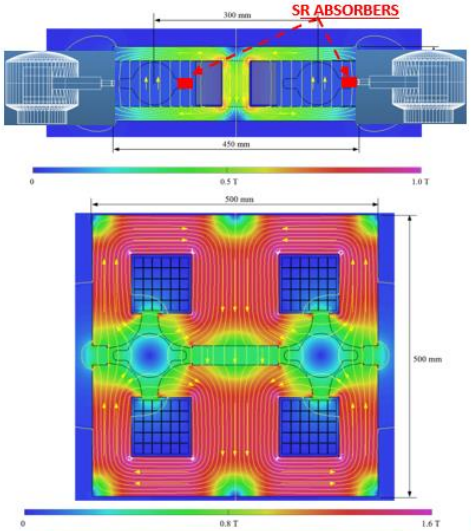
**On absorber



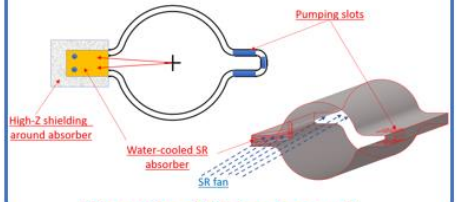
Pumping solutions

- **The 120 mm horizontal width of the chamber with winglets does not let us install a linear NEG pump like SuperKEKB has done**
- **This leaves us with only two choices: use many lumped pumps, or use <u>NEG-coating</u>**
- **The specific conductance of the 70 mm ID chamber with winglets is ~47 l·m/s (ref. LEP ~ 100 l · m/s): This means that the system is conductance limited, and we would need to install un unreasonable number of pumps in order to obtain a sufficient effective pumping speed**
- **We plan to use NEG-coating (as thin as 150 nm, to minimize the resistive-wall impedance contribution) in order to profit from its low photon-stimulated molecular desorption (PSD) and also a rather low photoelectron yield (PEY) and secondary electron yield (SEY) as well**
- **Low PEY and SEY are mandatory for the e+ ring, in order to avoid/minimize the electron cloud effect (ECE)**
- **Even a small residual sticking coefficient *s* for the NEG-coating gives a large distributed pumping speed, 11.8·*s* (l/s/cm^2, CO gas), with the coated wall surface of ~ 3120 (cm^2/m) or 36700·*s* (l/s/m)**

Pumping solutions

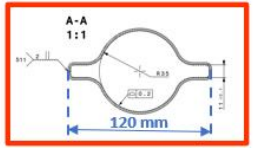


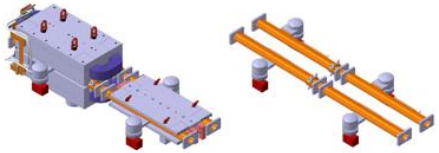
Material: OFC copper;
Specific Cond.: ~47 l·m/s (CO, 20 ºC)



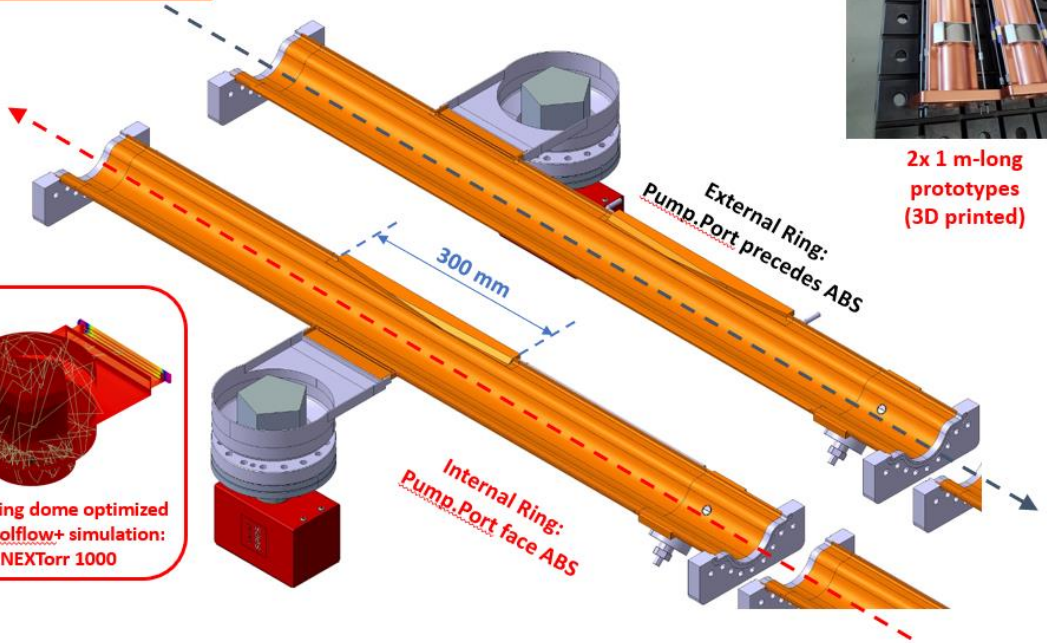
Schematics of SR absorbers and pumping slots (internal beam)

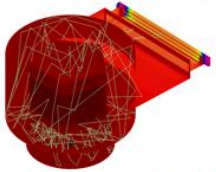
FCC-ee CAD Models





2x 1 m-long prototypes (3D printed)

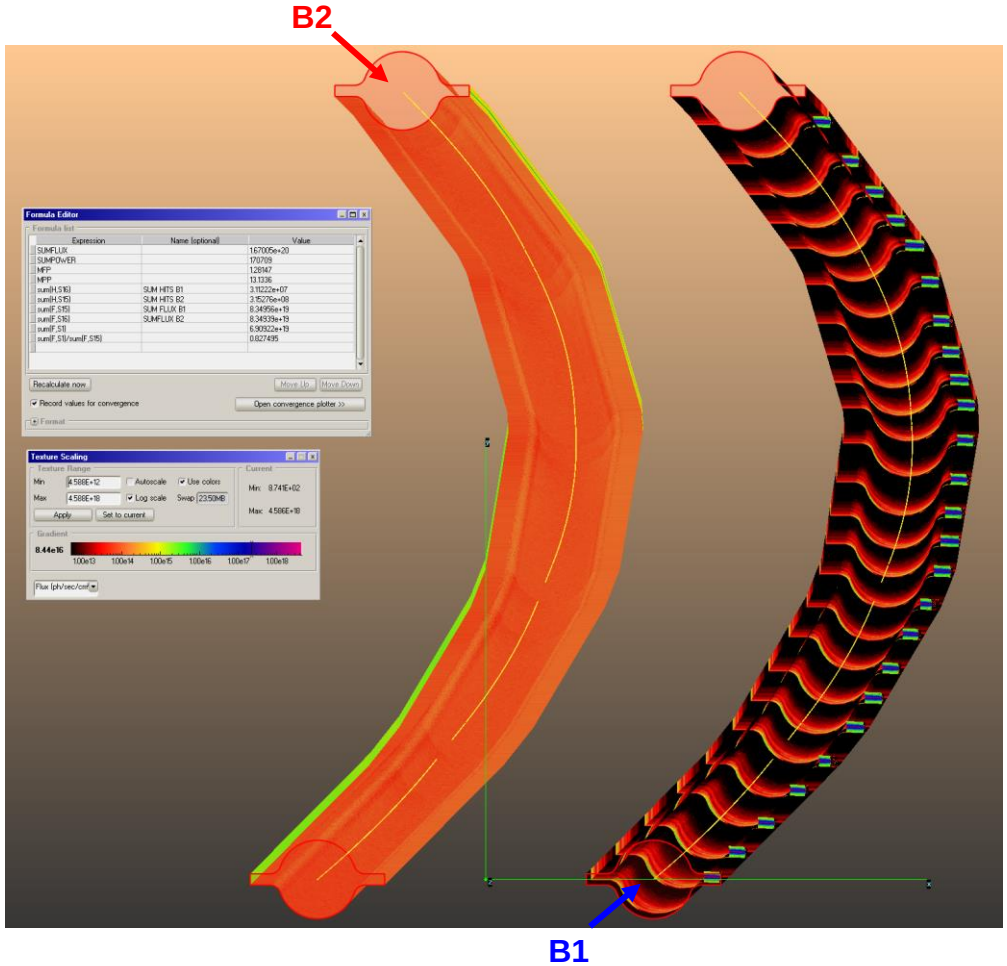




Pumping dome optimized via Molflow+ simulation: NEXTorr 1000

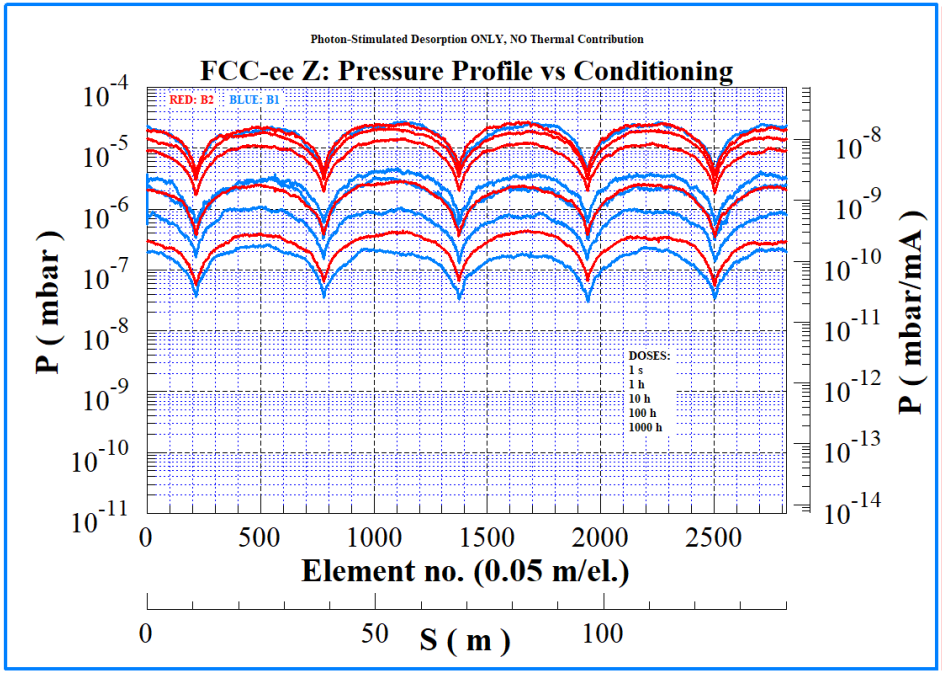
Pressure profiles

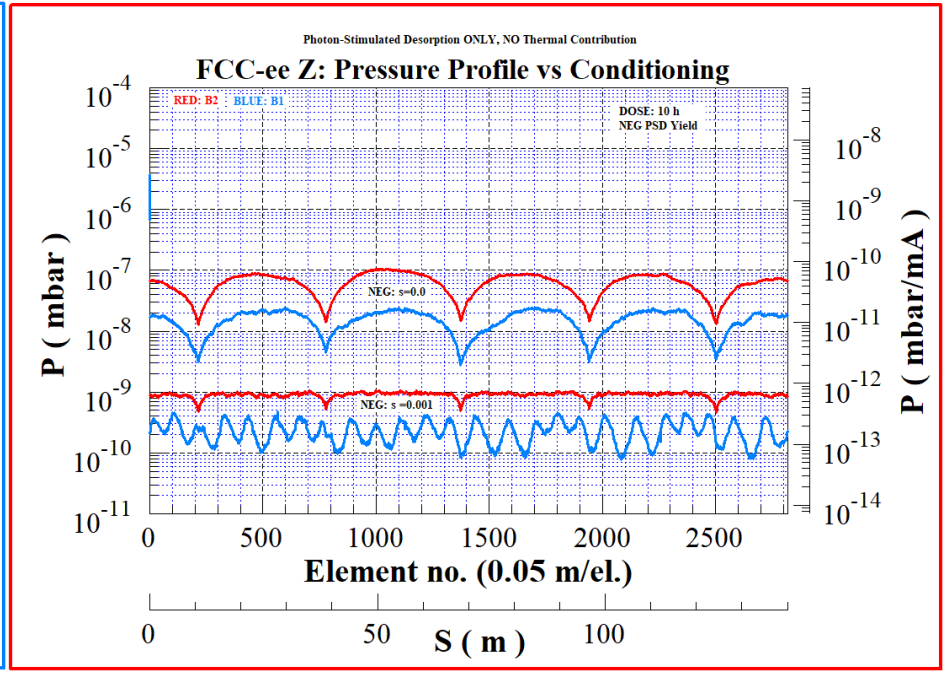
- **We have used Molflow+ to calculate the PSD pressure rise at different beam doses, using the photon irradiation maps calculated by SYNRAD+**
- **A sample 140.7 m-long section of an arc has been considered, with the two beams side by side**
- **The orbits along 5 dipoles interleaved with 5 quadrupoles are simulated, importing the lattice files from MADX into SYNRAD+**
- **The 3D model for B1 has 25 absorbers placed at ~ 5.6 m average spacing (avoiding quadrupoles and sextupoles which have tight coils), while B2 has no absorbers, and the SR fan is let impinge onto the bottom of the external winglet (see also B. Humann, this conf.)**



Pressure profiles

- **We have calculated the PSD pressure profiles for 5 different beam doses, corresponding to times of 1 s, 1 h, 10 h, 100 h, 1000 h. Simulated gas: CO**
- **On the left the case with 5x 100 (l/s) lumped pumps/beam, and no NEG-coating**
- **On the right, the case with NEG-coating, saturated (i.e s=0) and with some residual sticking (s=0.001)**





Future work: prototyping, experiments, …

- **Design prototype vacuum chambers with and without SR absorber (~ 2 m-long) and test them at light source (KARA/KIT?)**
- **Test behavior of thin NEG-coating at light source**
- **Define deposition technique for dipolar ~ 12 m-long vacuum chambers (horizontal sputtering with mole?, other techniques?)**
- **In-situ measurement of photoelectron yield at light source**
- **Test other thin-films with potential application to FCC-ee: amorphous carbon (a-C), hydrophobic silicon films (to reduce pump down time without bakeout); test surface texturing techniques (e.g. LASE)**
- **Determine material and fabrication technology of SR absorbers and bonding technique to the vacuum chamber (surface power density above 100 W/mm^2 at the ttbar energy)**
- **Design, fabricate, and test bellows with RF fingers, under elongation and misalignment conditions similar to those expected for FCC-ee**
- **Continue collaboration with FLUKA team (see B. Humann, this conference), magnet group, tunnel integration working group, and machine optics group (plus MDI)**

The next 4~5 years are going to be fun… ☺

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Thank you for your attention!

Questions?