Vacuum Considerations for FCC-ee

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Agenda:

1. Introduction
2. FCC-ee parameter list
3. SR spectra, photon flux and power densities
4. Vacuum specifications
5. Vacuum chamber geometries: different options and SR ray-tracing
6. Pumping system options: pressure profiles
7. Considerations about background in the interaction region
8. Other vacuum components
9. Booster and pre-accelerator chain; Tunnel integration
10. Conclusions and future work

1. Introduction

- The FCC-ee is a very challenging machine, since it aims at accommodating 4 different energies, the Z-, W-, H- and T-pole, running at 45.6, 80, 120, and 175/182.5 GeV, respectively, with rather stringent time schedule driven by integrated luminosity at each energy;
- It has become immediately evident that, vacuum-wise, **the Z-pole is the most challenging one**, with its B-factory-like currents of almost 1.4 A, compared to the 10 mA or so that LEP stored at the time at the same energy;
- FCC-ee is conceived as a **very low-emittance, high-luminosity machine**, and therefore **all impedance issues and related beam instabilities must be avoided**: this requirement calls for a very careful design of its vacuum system, with very low-loss components, such as flanges, synchrotron radiation (SR) absorbers, tapers, resistive wall (NEG-coating);
- We have tried our best to take advantage of the lessons learned in the last 2 decades on B-factories (SLAC, KEK, Cornell) and the legacy studies on LEP, trying to combine different features, design, and material choices into a reasonable solution applicable to **a twin ~100 km ring (plus ~100 km booster!)**;
- <u>This talk discusses the status report which has led to the CDR, and the proposed needed R&D and prototyping, should further funding be made available.</u>

2. FCC-ee parameter list (as per CDR)

- The list of machine parameters for the Z- and T-pole machines is shown here below (https://tlep.web.cern.ch/content/machine-parameters); Highlighted in red are those which may affect vacuum:

parameter	Z	ttbar
beam energy [GeV]	45.6	182.5
arc cell optics	60/60	90/90
momentum compaction [10^{-5}]	1.48	0.73
horizontal emittance [nm]	0.27	1.45
vertical emittance [pm]	1.0	2.7
horizontal beta* [m]	0.15	1
vertical beta* [mm]	0.8	2
length of interaction area [mm]	0.42	1.99
tunes, half-ring (x, y, s)	(0.569, 0.61, 0.0125)	(0.553, 0.59, 0.0350)
longitudinal damping time [ms]	414	6.6
SR energy loss / turn [GeV]	0.036	9.21
total RF voltage [GV]	0.10	10.93
RF acceptance [%]	1.9	4.9
energy acceptance [%]	1.3	2.5
energy spread (SR / BS) [%]	0.038 / 0.132	0.15 / 0.20
bunch length (SR / BS) [mm]	3.5 / 12.1	2.5 / 3.3
Piwinski angle (SR / BS)	8.2 / 28.5	1.39 / 1.60
bunch intensity [10^{11}]	1.7	2.8
no. of bunches / beam	16640	39
beam current [mA]	1390	5.4
luminosity [10^{34} $cm^{-2}s^{-1}$]	**230**	**1.5**
beam-beam parameter (x / y)	0.004 / 0.133	0.094 / 0.150
luminosity lifetime [min]	70	44
time between injections [sec]	122	32
allowable asymmetry [%]	±5	±3
required lifetime by BS [min]	29	10
actual lifetime by BS ("weak") [min]	> 200	25

Table 2.2: Comparison of synchrotron radiation between FCC-ee, LEP2 [159], and PEP-II [159] at their highest energies.

		FCC-ee	LEP2	PEP-II (high energy ring)
Highest beam energy	[GeV]	182.5	104.6	9.0
Bending radius	[km]	10.760	2.584	0.167
Synchrotron radiation loss per turn	[GeV]	9.05	4.07	0.0034
Critical energy in the arc dipole	[MeV]	1.06	0.83	0.0082
Beam current / species	[mA]	5.5	3	1960
Radiation power per beam	[MW]	50	12.2	6.8
Total radiation power per arc length	[kW/m]	1.2	1.1	5.5

Actually, e_{crit}(182.5 GeV, 10,760 m) = **1.253 MeV**

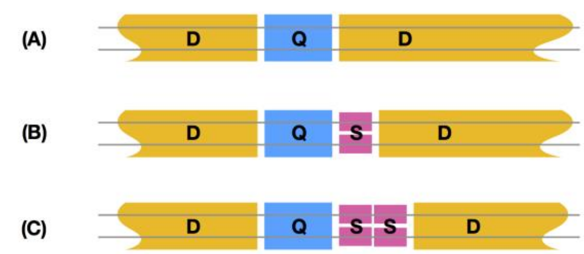


Figure 2.4: Three magnet arrangements around a quadrupole. D: twin-aperture dipole, Q: twin-aperture quadrupole. S: single-aperture sextupole. (A) no sextupole, (B) single aperture, singlet sextupole only for 60°/60°, (C) single aperture, doublet sextupole for either 60°/60° or 90°/90°. In case (C) for 60°/60°, only the part of the doublet next to the quadrupole is powered. As a result, three dipole lengths are needed to maintain a constant distance between quadrupoles.

3. SR spectra, photon flux and power densities

- **FCC-ee will be a very powerful and intense source of highly-collimated synchrotron radiation** (SR);
- Its critical energy, photon flux and power are given by the well-known formulae:

$$E_c = \frac{2218 \cdot E^3(GeV)}{\rho(m)}$$

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

(k_F and k_P account for photons with energy e>4 eV)

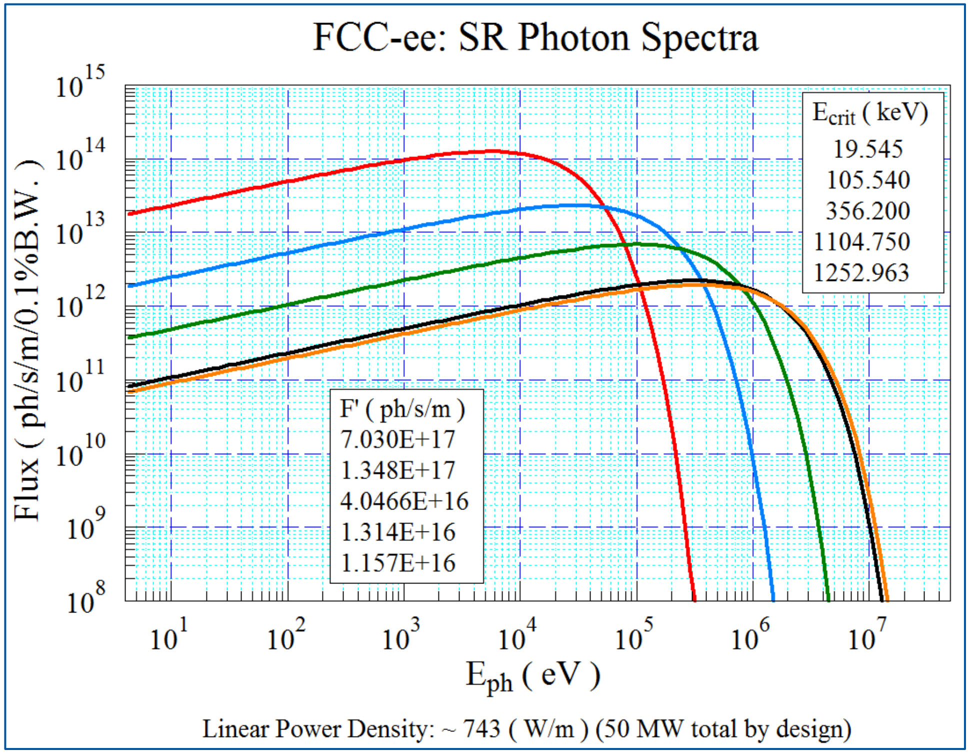
$$P(W) = 88.46 \cdot \frac{E^4(GeV) \cdot I(mA)}{\rho(m)} \cdot k_P$$

→ limited by design at 50 MW/beam

E (GeV)	E_c (keV)	I (mA)	F (ph/s)	P (MW)
45.6	19.57	1390	$4.85 \cdot 10^{22}$	~ 50
80	105.69	147	$9.30 \cdot 10^{21}$	~ 50
120	356.63	29	$2.79 \cdot 10^{21}$	~ 50
182.5	1254.5	5.4	$7.88 \cdot 10^{20}$	~ 50

← γ=357,143; 1/γ=2.8 μrad
Vertical footprint at 30 m ~ 0.6 mm!
→Very high power density!

SR flux (left) and power (right) spectra:

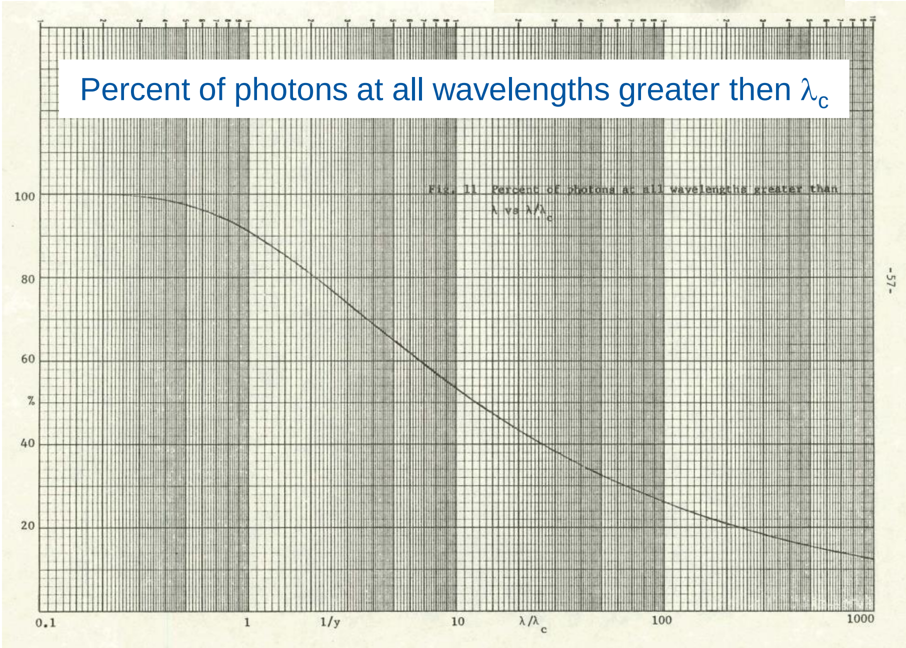


I (mA)
1390
147
29
5.4

SPECTRA AND
OPTICS OF SYNCHROTRON RADIATION

G.K. Green

April 15, 1976



- For photon energies above 100~200 keV creation of Compton photons becomes dominant: for the ttbar machine 50% of the photon have energy above 100 keV!

- Supra-linear increase of the photon flux inside of the vacuum chamber → increased photon-induced outgassing (see bonus slides)

4. Vacuum Specifications

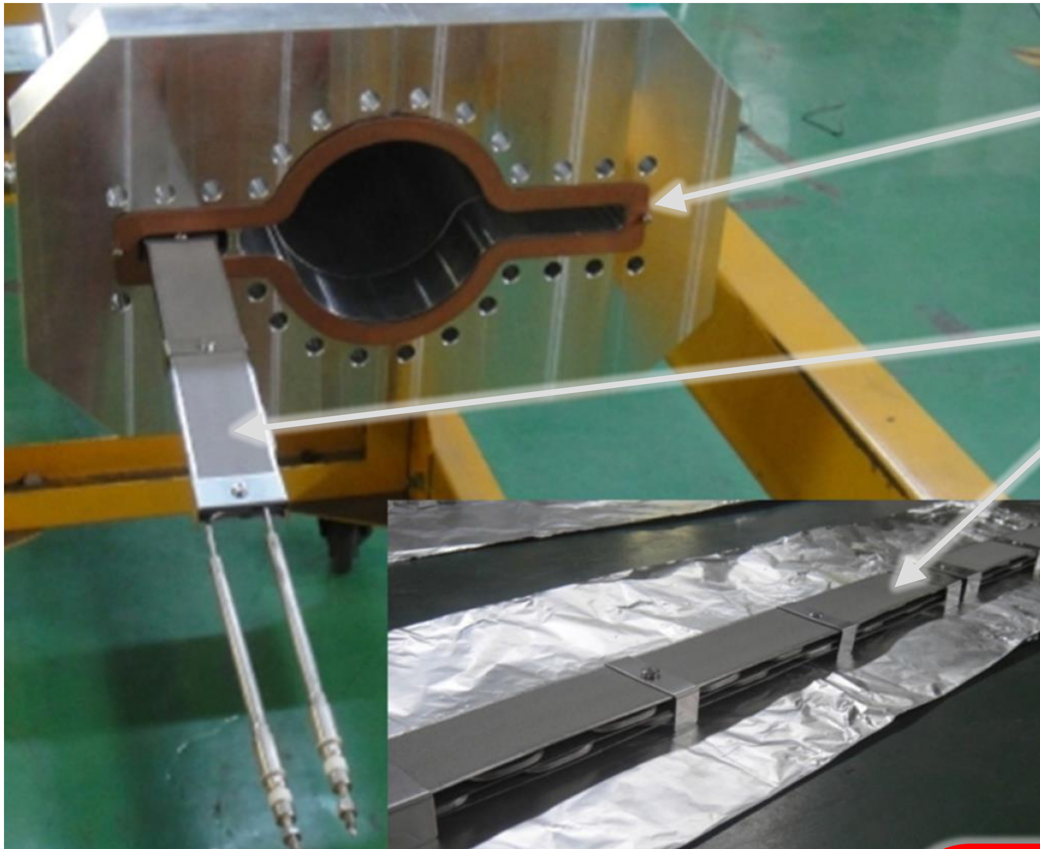
- Sufficiently long beam-gas scattering lifetimes, longer than the luminosity ones:

	Z (30k bunches)	Z (90k bunches)	W	H	T
Luminosity lifetime [min]	94	185	90	67	57/44

- **Short vacuum conditioning time**: we want to reach quickly the nominal luminosity with low pressure background, low beam losses, reduced activation of machine components and tunnel, etc…
- **E-cloud- and ion-trapping-free e+ and e- rings**: we want to avoid beam instabilities and beam blow-up due to excessive e-cloud, beam-ionization (then low pressure requirement), fast-ion instabilities, etc…
- **Optimized vacuum system**, with easy to manufacture vacuum chambers (2x100 km + full energy injection booster… industrial-scale mass production needed);
- **Efficient and cost-effective pumping system**: again, it's a twin-ring 100 km machine, we can't install ~1 pump/m as has been done for some B-factories;
- **Use existing and proven technologies** as much as possible;

5. Vacuum chamber geometries: different options and SR ray-tracing

- Having hosted the only lepton accelerator running up to ~100 GeV beam energies, it has become natural at CERN to look for the applicability of the LEP vacuum chamber geometry and pumping system concepts;
- LEP was a large, single chamber twin beam, with pretzeled orbits and relatively low currents. The only real problems due to the SR-induced heating came from areas immediately downstream of the polarization wigglers (many leaks!); Its beam chamber cross-section was elliptical 131x70 mm^2 (HxV);
- The FCC-ee is a very low emittance machine, and detailed studies have proven that an elliptical chamber would excite quadrupolar moments which would destabilize the stored bunches, and should therefore be avoided; **A cross-section as close as possible to that of a circle should be preferred**;
- We have therefore abandoned the first proposal (see FCC Week 2016 and earlier), which called for a vertically squeezed elliptical chamber incorporating "V"-shaped SR absorbers;
- We have chosen a SuperKEKB-type of chamber, which has a round part with two small "winglets" in the plane of the orbit; At SuperKEKB such a chamber hosts on one side a distributed pumping based on multiple, stacked NEG strips, installed behind a slotted wall (next slide);



Special bakeable low-loss copper seal (Matsumoto-Ohtsuka-type)

3x NEG strips, with integrated heater for NEG activation

This cross section can be extruded out of aluminium (like for the 4 GeV low-energy e^+ ring), or made welding different pieces out of copper (like for the 7 GeV high-energy e^- ring);

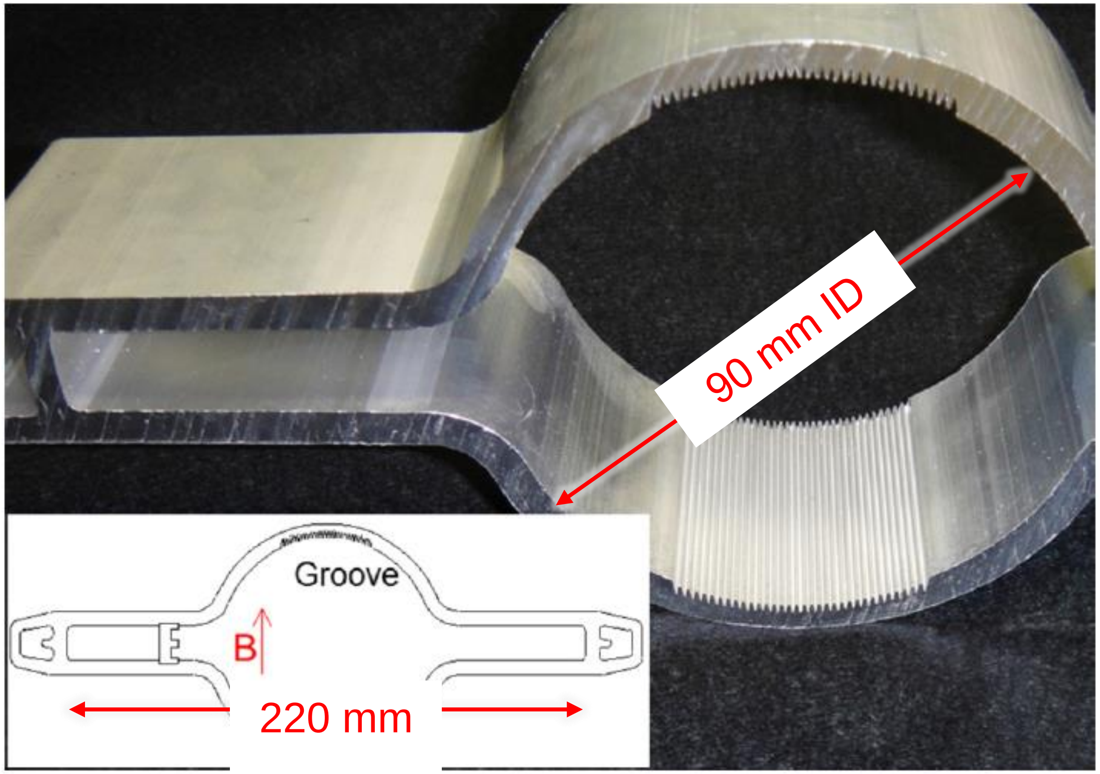
- For FCC-ee running at the ttbar-pole, the SR critical energy is around 1.25 MeV, making an aluminium chamber not the best choice in terms of radiation leakage (see bonus slides and F. Cerutti's presentation, FCC Week conferences);
- A copper chamber would be preferable;

JVSTA
Journal of Vacuum Science and Technology A

Design and construction of the SuperKEKB vacuum system

Yusuke Suetsugu, Ken-ichi Kanazawa, Kyo Shibata, Takuya Ishibashi, Hiromi Hisamatsu et al.

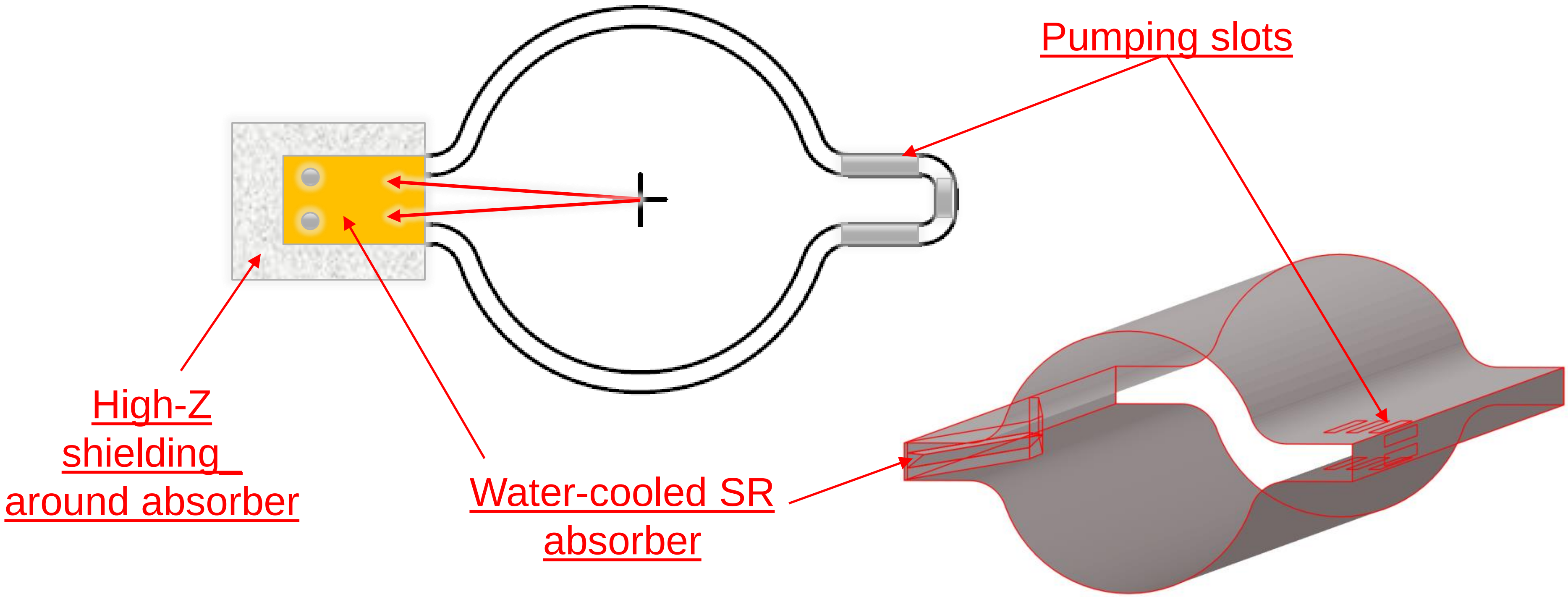
Citation: J. Vac. Sci. Technol. A **30**, 031602 (2012); doi: 10.1116/1.3696683



- The e+ ring, especially at the Z-pole with many short bunches and 4 ns spacing, is **expected to suffer from e-cloud**;
- **E-cloud mitigation MUST be part of the design**;
- One possibility is to use ←**grooved surfaces**, like done at SuperKEKB;
- Another possibility is to use **thin-film coatings** having a below-threshold secondary-electron yield (SEY);
- **SuperKEKB** has opted for TiN instead of NEG-coating, after having tested both on a test section of KEK-B (see "Continuing study on the photoelectron and secondary electron yield of TiN coating and NEG (Ti–Zr–V) coating under intense photon irradiation at the KEKB positron ring", NIM A 556 (2006) 399–409);
- Based on the very positive experience on LHC's warm sections, and on SR-light sources, we firstly proposed to use NEG-coating. Recent experimental results (@CERN and Y. Tanimoto, Photon Factory KEK) have shown that a **thin (150 nm) NEG-coating** would not loose its vacuum properties after 10 saturation-activation cycles. See Y. Tanimoto's contribution FCC Week 2019.

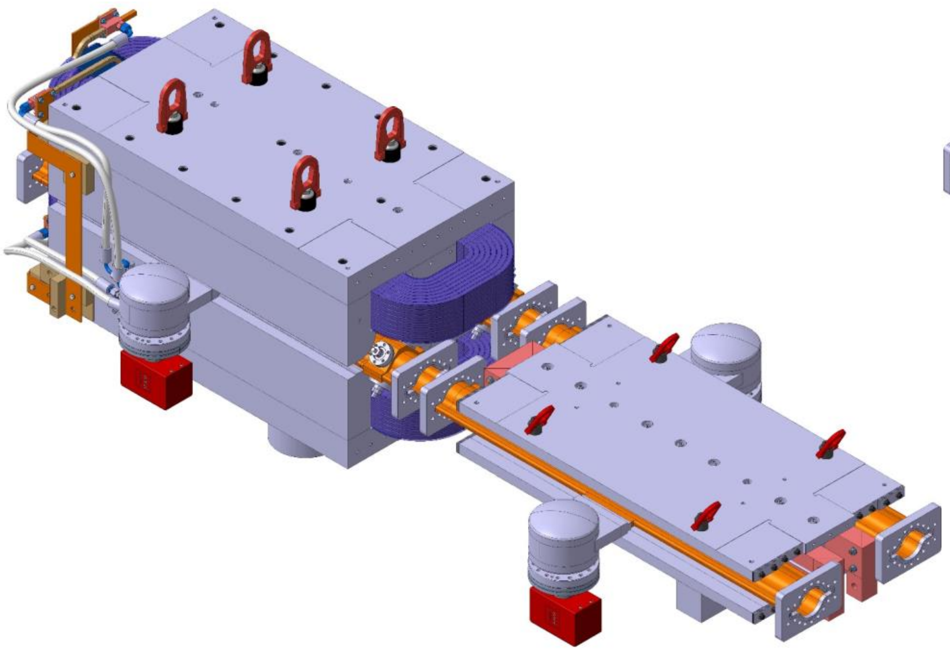
Lumped SR absorbers, 300 mm long (~ 6 m spacing on average, in the arcs)

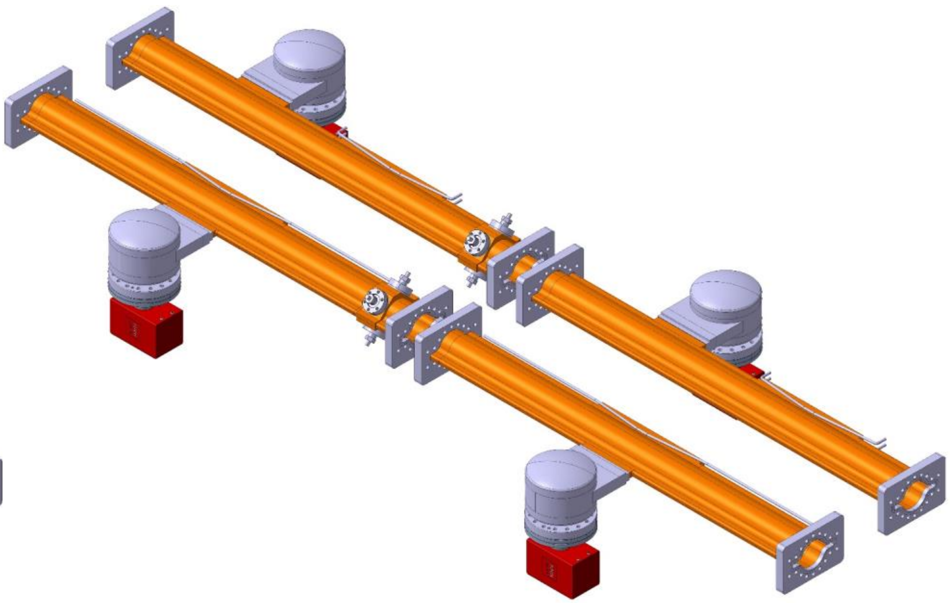
Vacuum chamber cross section:
70 mm ID with”winglets” in the plane of the orbit (SUPERKEKB-like);



- Localization of Compton-scattered background at lumped SR absorbers (as per FLUKA simulations, F. Cerruti et al.);
- Localization of outgassing load and efficient pumping (as per extensive MC simulations);

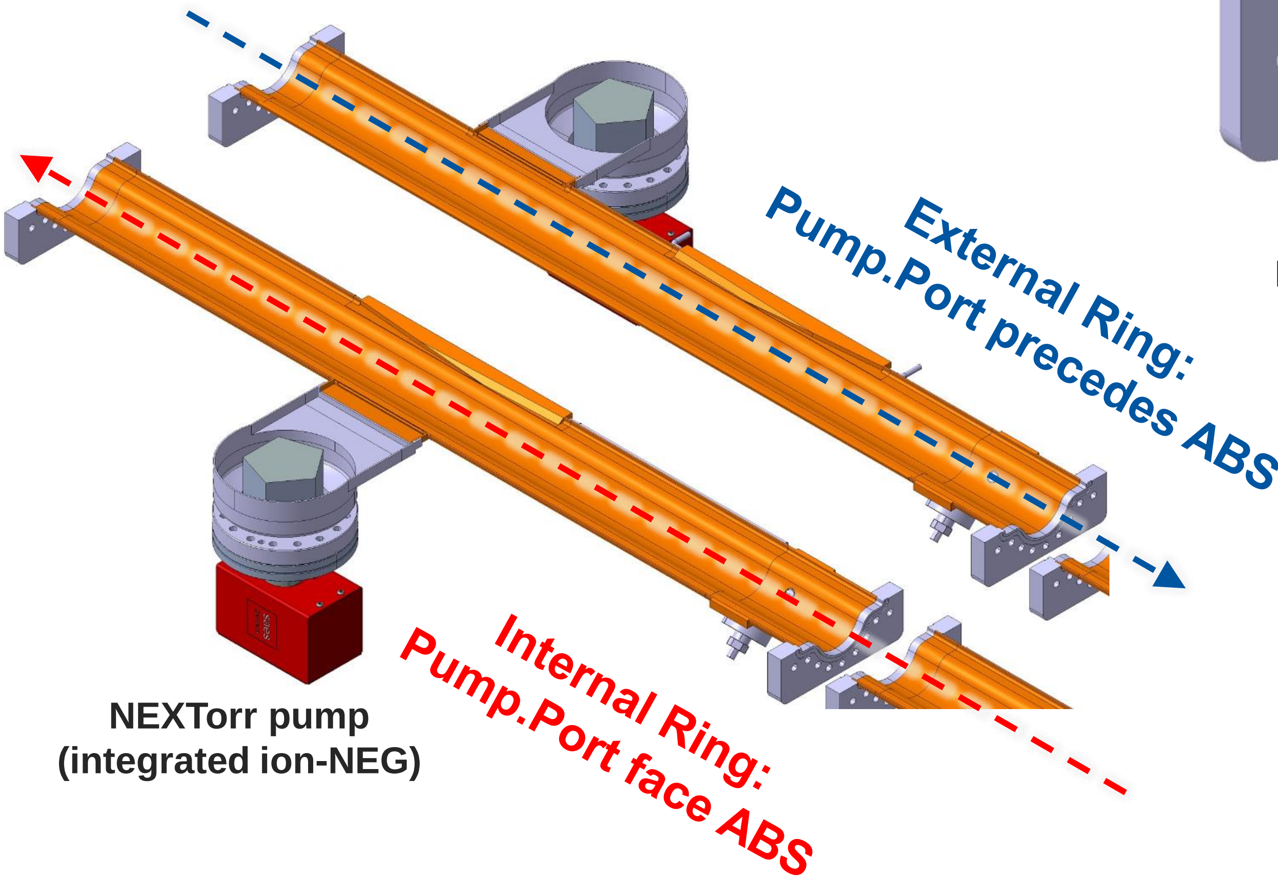
(CAD models M Gil Costa, CERN)



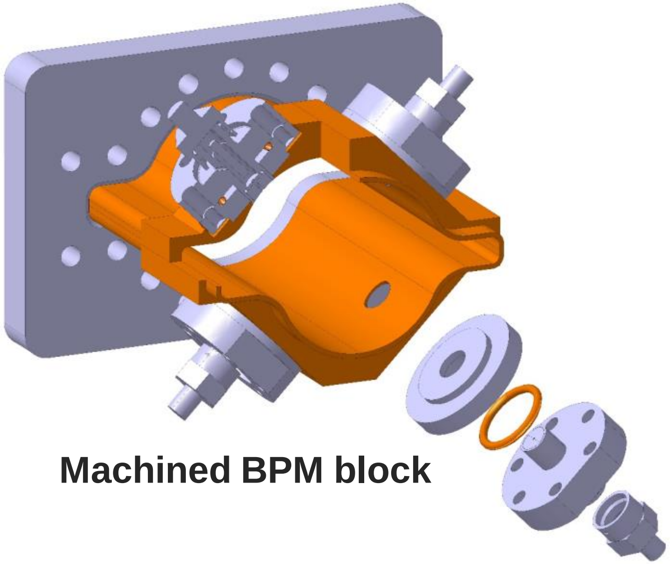


- CAD models of the common-yoke dipole and quadrupole magnets (1m-long prototypes, A. Milanese, CERN), and SUPERKEKB-type vacuum chambers with integrated SR absorbers and pumping domes; NEXTorr pumps (SAES Getters, Milan, Italy) are installed at each pumping dome;

(CAD models M Gil Costa, CERN)

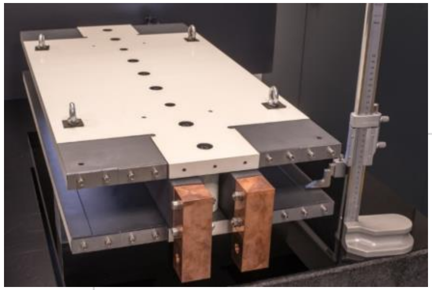


NEXTorr pump
(integrated ion-NEG)

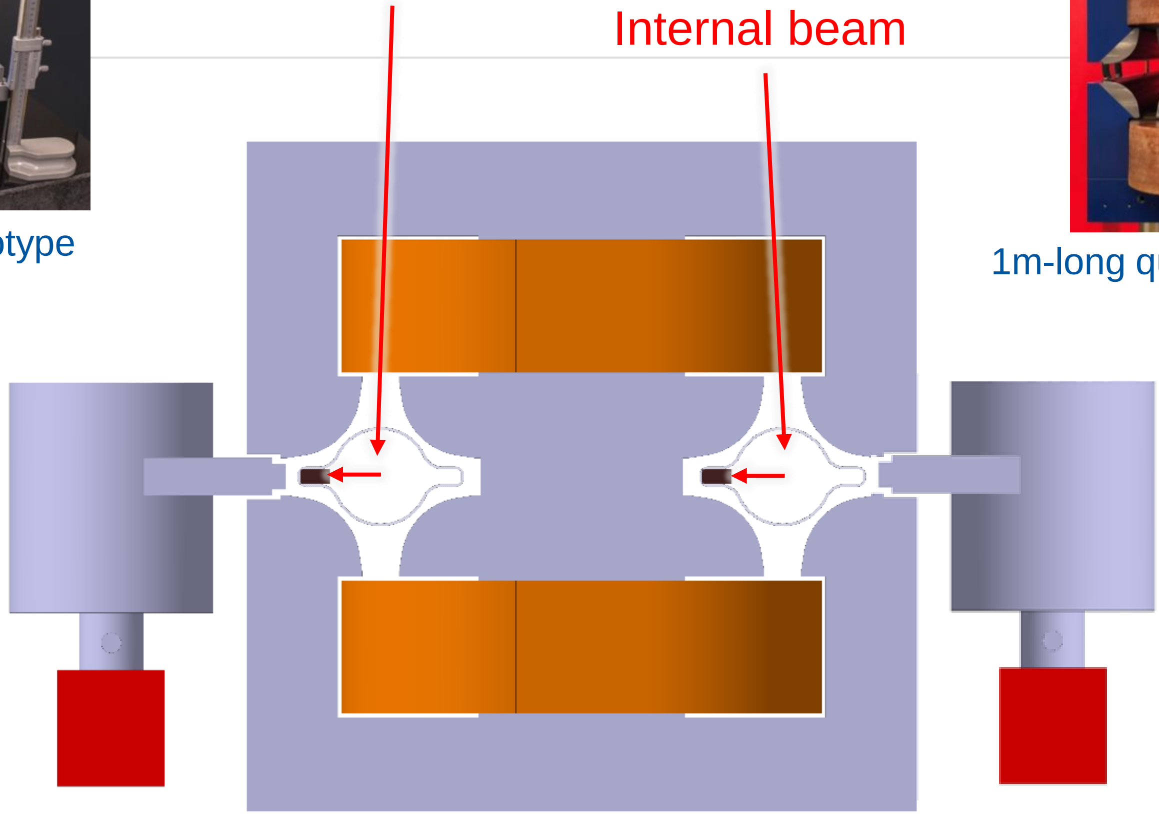


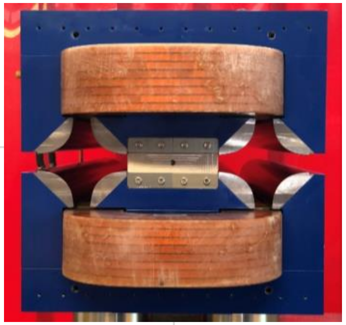
Machined BPM block

1m-long mock-ups with pumping domes
(3D printing technol., C. Duclos, CERN)



1m-long dipole prototype

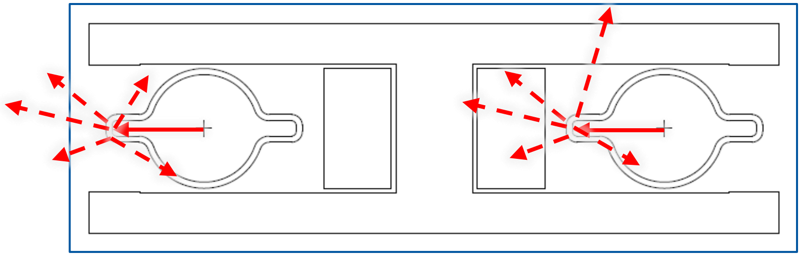




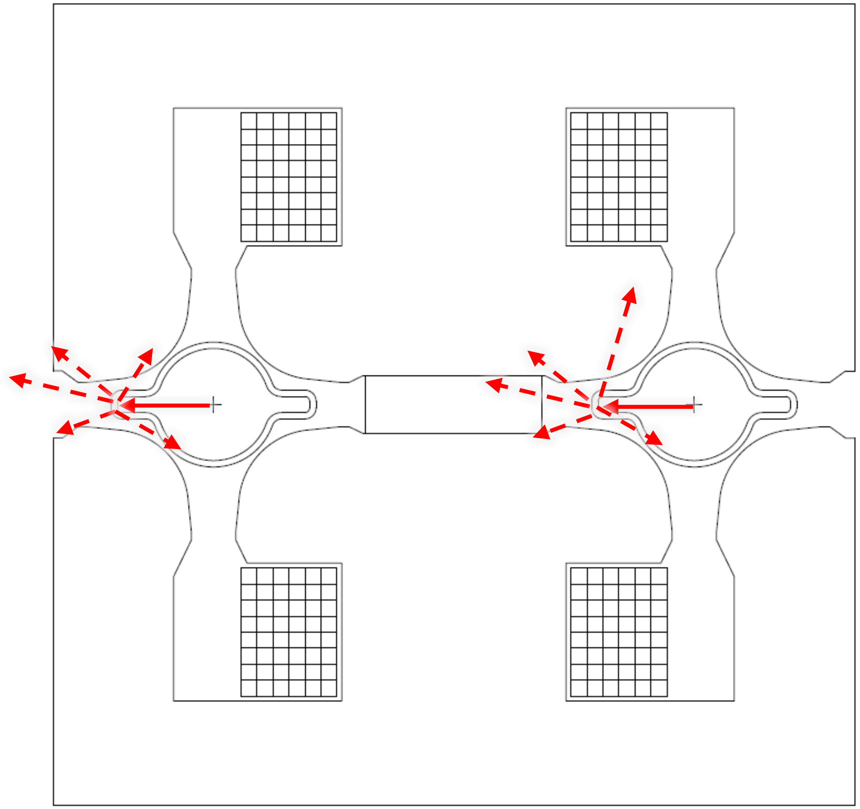
1m-long quadrupole prototype

FCC-ee: Integration view of the vacuum chambers with absorbers, pumping plenums with NEXTorr pump, within one common-yoke quadrupole

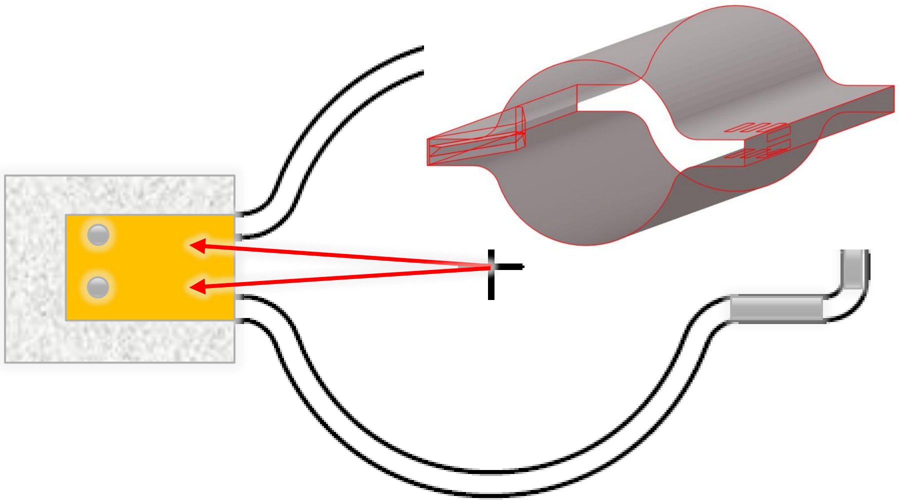
(courtesy of Fani Valchkova-Georgieva, CERN-EN-ACE)



- FCC-ee main arc **dipole** and quadrupole cross-section (see A. Milanese's talk," FCC-ee Warm magnets design", FCC Week 2017);
- A SuperKEKB-type cross-section has been drawn to scale: it has a 70 mm ID circular part with two 25x10 mm^2 (HxV) "winglets" on the plane of the orbit (int. dimensions);
- The intense SR fans (⟵) generated by the stored beams are intercepted inside the winglet on the external side of the ring;
- At SuperKEKB the whole length of the winglet is irradiated by SR, and therefore it needs a cooling channel along it (see previous slide);
- **It becomes evident that the internal beam's SR fan irradiates the corresponding dipole coil, while the external one irradiates the tunnel components**;



- For the **quadrupole** design, though, the coils are in a lower-irradiation area/configuration;
- **These considerations apply mainly to the W-, H-, and T-pole machines, as the Z has a critical energy of only ~20 keV**, well below the Compton edge;

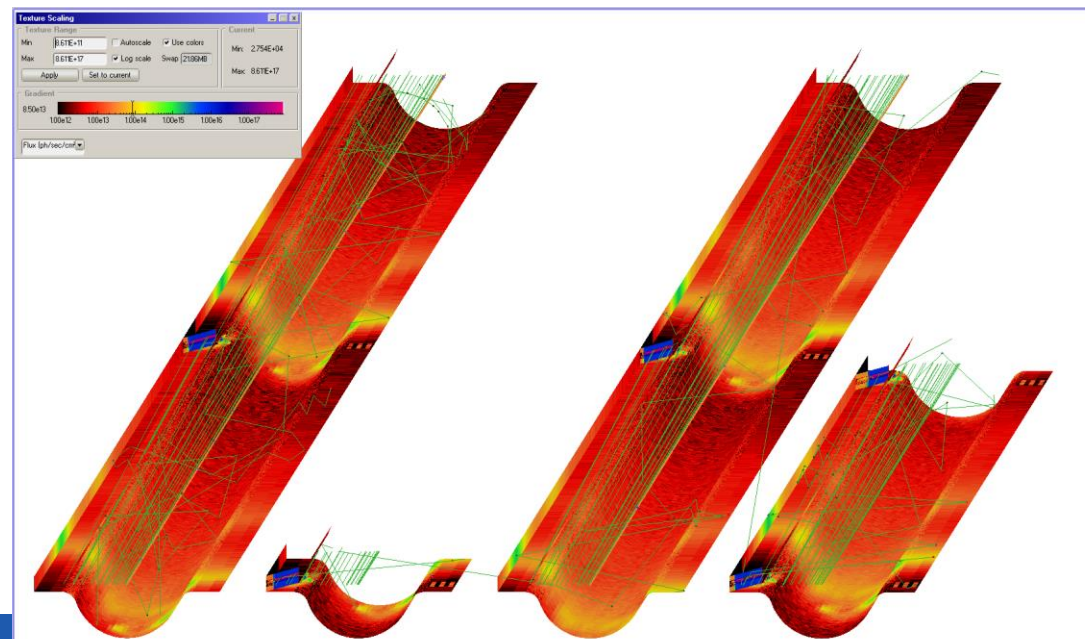


- For the selected radius of curvature of the orbit in the dipoles (10.76 km), and the 70 mm ID of the chamber, the distance between the source point of the SR and the first collision with the absorbers or the 70 mm ID wall is of the order of ~**<u>36 m</u>**;
- This distance, combined with the natural vertical divergence of the SR fan, makes such that **<u>only a fraction of 1% of the photons miss the 10 mm-high absorber and land on the chambers's wall</u>** (see next slides);
- In order to limit the amount of Compton radiation leakage, and the possible **<u>radiation damage and components' activation</u>**, we propose to install at appropriate locations a number of <u>lumped SR absorbers</u>, in such a way that they cover the whole horizontal angle of the SR fan;
- **High-Z shielding could be added on the external part of the absorber**;
- For geometric impedance reasons, the absorber should have a <u>tapered shape</u>, and do not protrude into the circular part of the vacuum chamber;
- On the opposite winglet, <u>pumping slots</u> could be machined, to allow molecules generated on the absorber (and elsewhere as well) to reach lumped pumps installed on a <u>pumping dome</u> (see previous slides);

- The absorbers have a <u>V-shaped surface</u> where the primary SR photons impinge at a <u>small angle</u> thus reducing the SR power density (which for the T-pole is relevant);

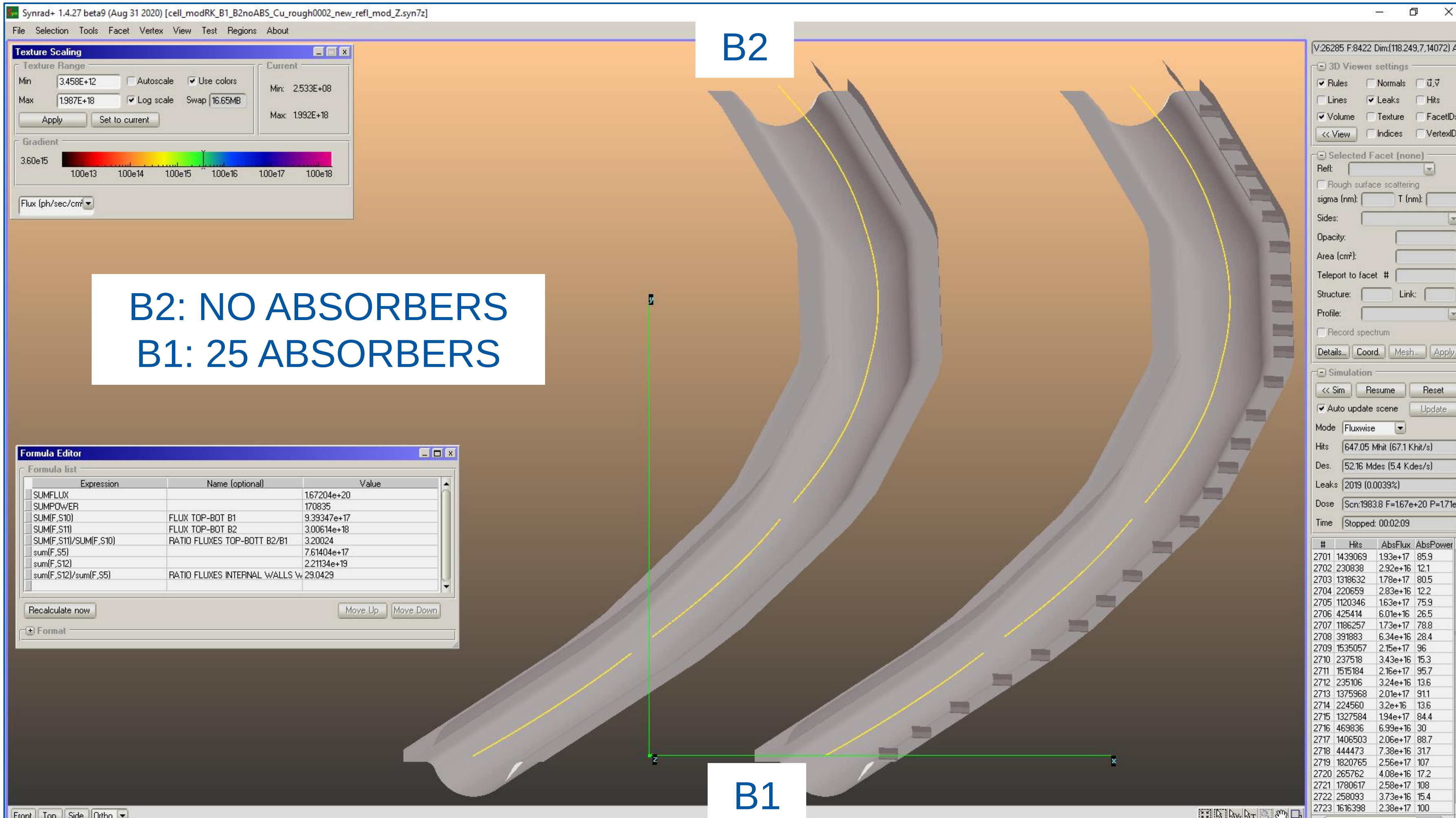
OLD 50m HALF-CELL LATTICE

- ← SR photon flux density for the no-photon scattering case (zero reflectivity);
- Less than **0.8%** of the primary photons miss the 5 absorbers and land on the vacuum chamber;
- *Note: this model shows an older version of the lattice, with 2x 10m-long dipoles (it doesn't affect the results/conclusions);*

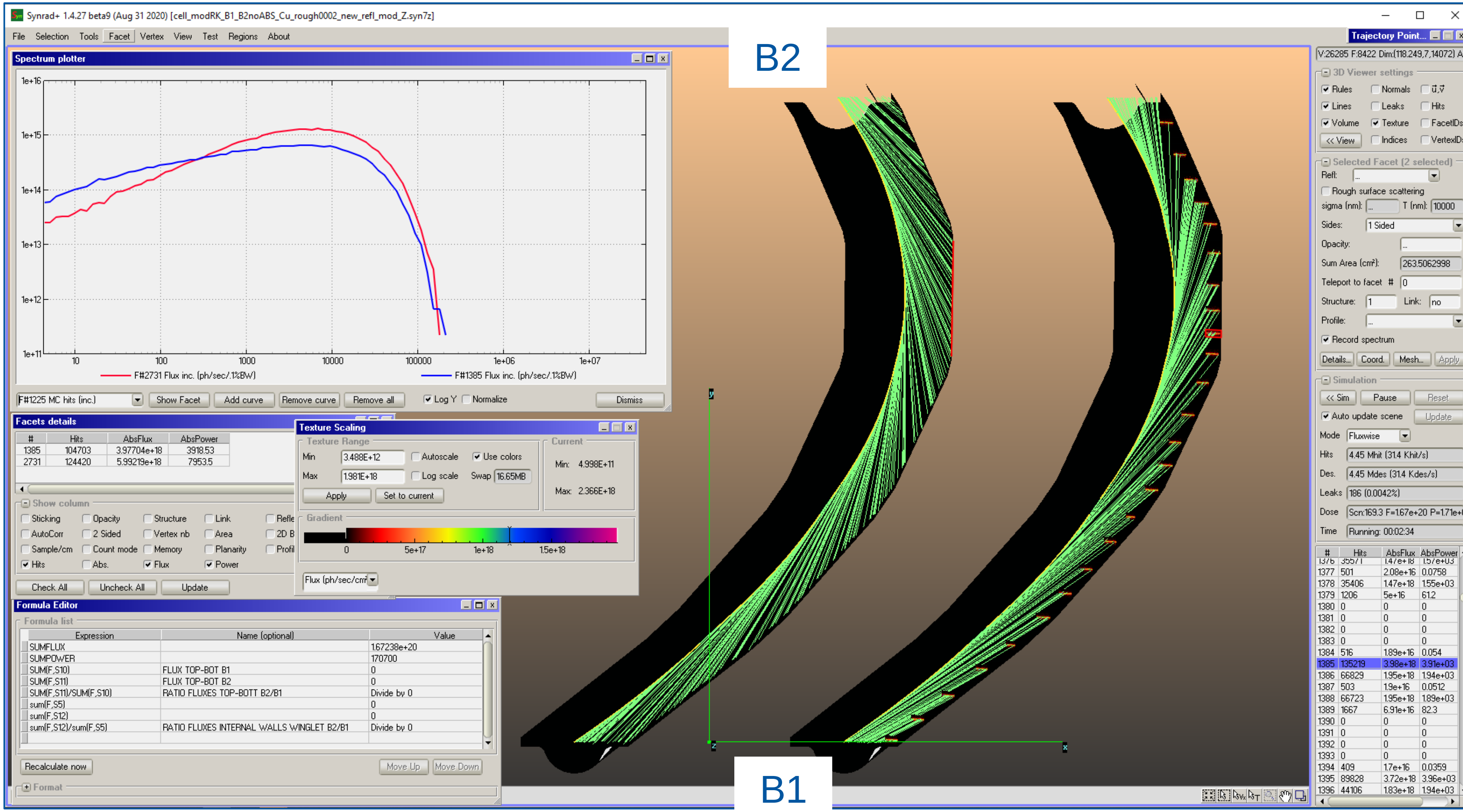


- SR photon flux density for the realistic photon scattering case (angle&material dependent) →
- About **4.6%** of the primary photons are scattered and land on the vacuum chamber;
- **These scattered photons can generate photoelectrons which "seed" the e-cloud effect;**
- Total Power: 17.6 kW/25m →

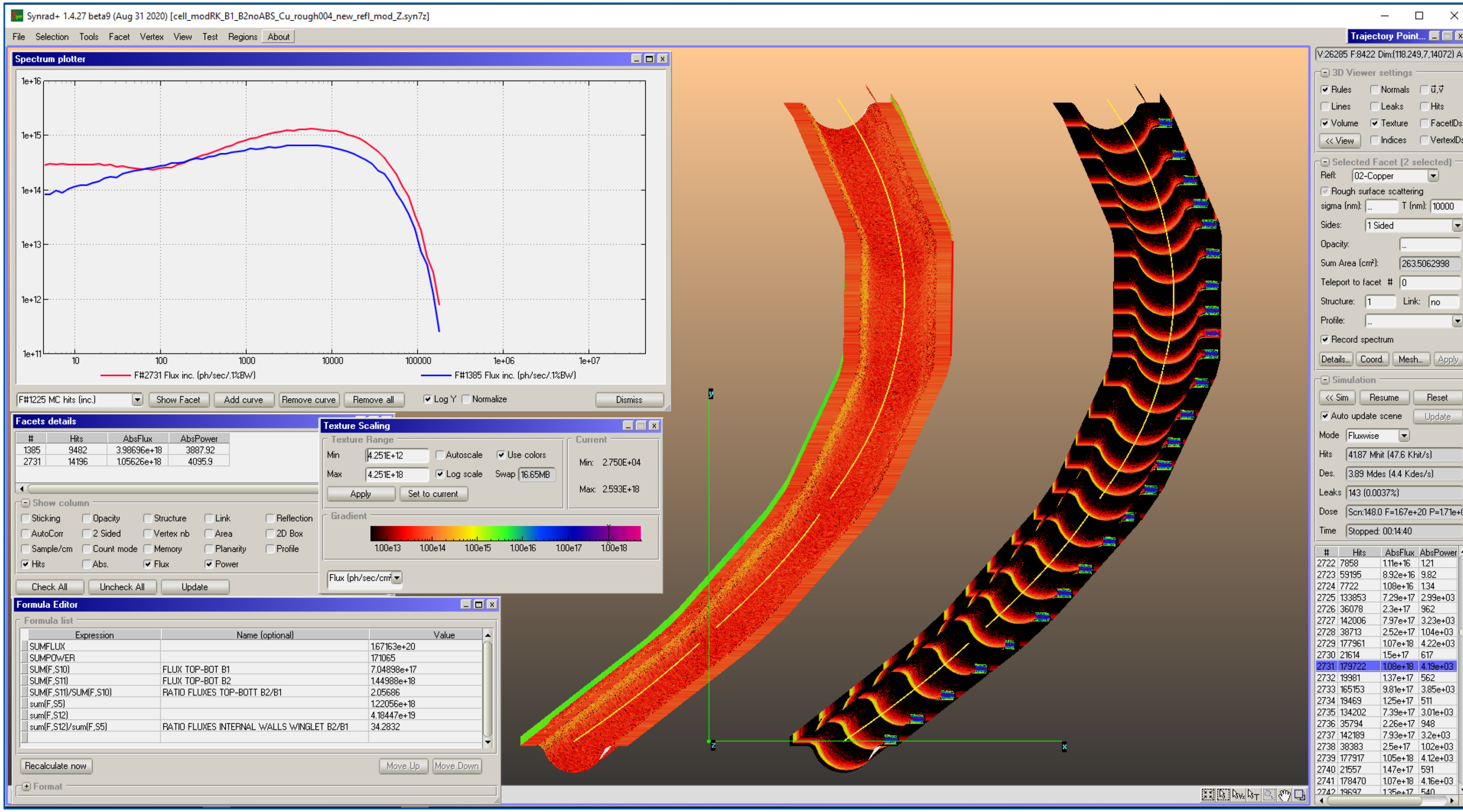
- A ~ 140 m arc section, 5 dipoles + 5 quads, has been modelled with SYNRAD+ and then used as input for FLUKA studies **(NEW LATTICE)**
- Beam 1 and Beam 2, for the Z-pole, generating a total of 171 kW of SR
- B2 has 25 absorbers along the external perimeter, while B1 doesn't



- A ~ 140 m arc section, 5 dipoles + 5 quads, has been modelled with SYNRAD+ and then used as input for FLUKA studies
- **No photon scattering**



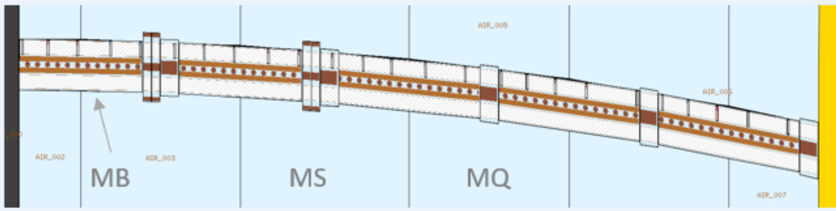
- A ~ 140 m arc section, 5 dipoles + 5 quads, has been modelled with SYNRAD+ and then used as input for FLUKA studies
- **<u>With photon scattering</u>**: ~ uniform bath of photons for B2 (no absorbers); localized photon reflections off the absorbers for B1



- Collaboration with **FLUKA team** towards assessing the advantage of having localized SR absorbers rather than a continuous SR strip along the chamber
- A ~ 140 m arc section, 5 dipoles + 5 quads, has been modelled with SYNRAD+ and then used as input for FLUKA studies (**courtesy B. Humann, CERN-EN-STI-BMI**)
- Work underway…

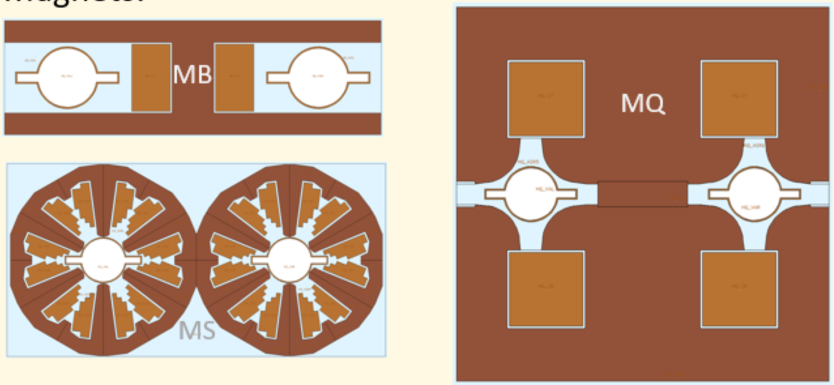
SR Studies in the FCCee arc in FLUKA

Periodic Cell:



- 140.824m embedded in the current FCCee tunnel design
- 5 dipoles (MB): 2x21.4m, 3x24.6m; 56.6mT at 182.5GeV
- 3 quadrupoles (MQ): 2.9m; 10T/m maximum gradient
- 4 sextupoles (MS): 1.4m
- 30cm beam separation
- 25 absorbers in dipoles and quadrupoles (designed & placed by R. Kersevan)

Magnets:

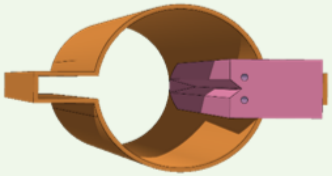


- So far working only with analytical magnetic fields
- Prototypes for MB and MB already produced
- MS still in design phase

Goal of simulation:

- Deposited energy and power on magnets, tunnel environment and absorbers at 182.5GeV
- Investigating integrated dose (damage to insulator material on the coils) and fluence
- For a complete study both beams have to be studied

Absorber:

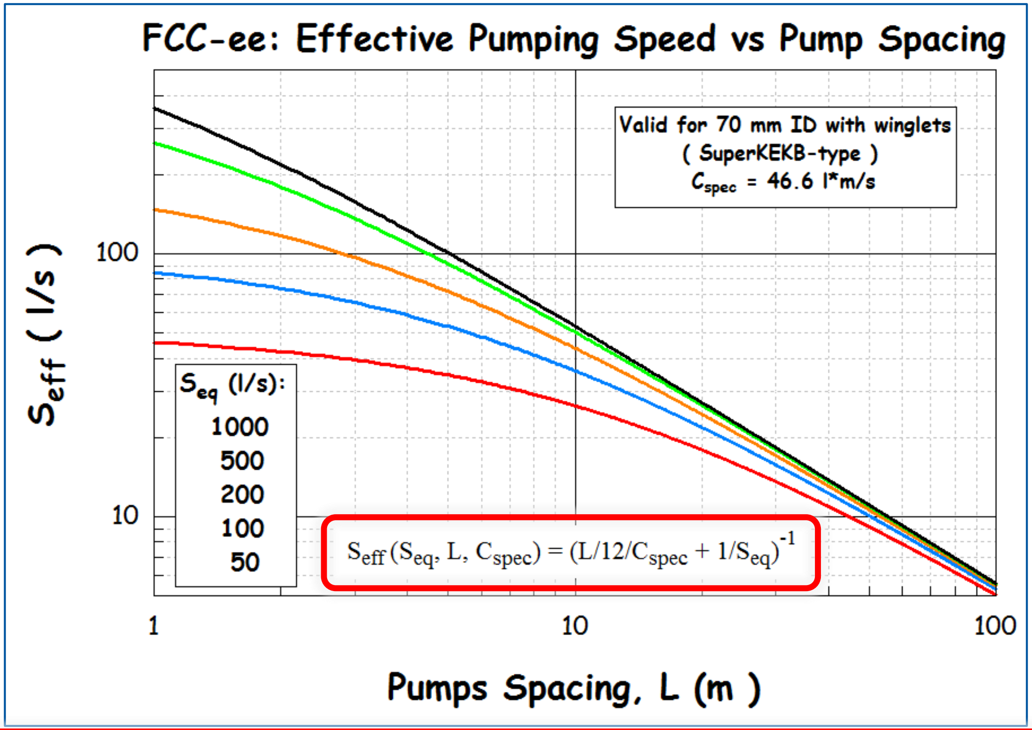


- On the outer wall of the vacuum chamber
- Angled surfaces for better distribution of power due to smaller impacting angle
- Copper – Chromium – Zirconium alloy
- 30cm length
- 5-6m between the absorbers
- Water cooled

6. Pumping system options: pressure profiles

- SuperKEKB, like LEP before it, implements a distributed pumping system based on stacked strips of St707 NEG (see ref. cited above);
- Unfortunately our magnet cross-section is not compatible with a 220 mm horizontal width (internal, plus chamber wall thickness, and eventually installation tolerances): that's why we have smaller "winglets", with an horizontal dimension of only 25 mm each;
- In these 25 mm one would not be able to install the regular 30 mm-wide St707 strips. SAES has produced recently an integrated, high-capacity ("ZAO" alloy) distributed pump, giving approximately 800 l/s/m pumping speed for H_2;
- We have therefore explored the effect on the pressure profiles generated by different pumping configurations, taking into account the presence of the quad/dipole yokes, and coils, which would limit space for the installation of a pumping plenum;
- Out of the 4-5 lumped absorbers every 25 m (see previous slides), **we have calculated the pressure profile for CO when 1, 2, or 3 lumped pumps are installed in the straight part of the lattice (short dipole-dipole interconnect, and quadrupole drift area);**
- **We have also calculated the pressure when a distributed pumps is installed along the 2 dipoles;**

- The specific conductance of our 70 mm ID chamber with 25mm-wide winglets has been calculated to be **<u>46.6 (l·m/s)</u>**, for CO at 20 °C;
- For a long, constant cross-section chamber (conductance C_{spec}) with equally-spaced pumps (distance L) of the same nominal pumping speed S_{eq} the effective pumping speed S_{eff} is given by a simple formula shown in the figure:



Ref.: LEP's 131x70 mm² (HxV) elliptical chamber: C_{spec}=100 (l·m/s)

LEP vacuum chamber section

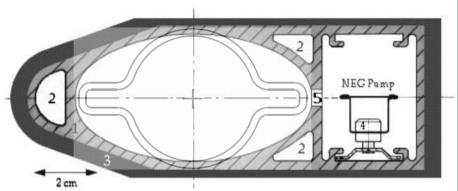
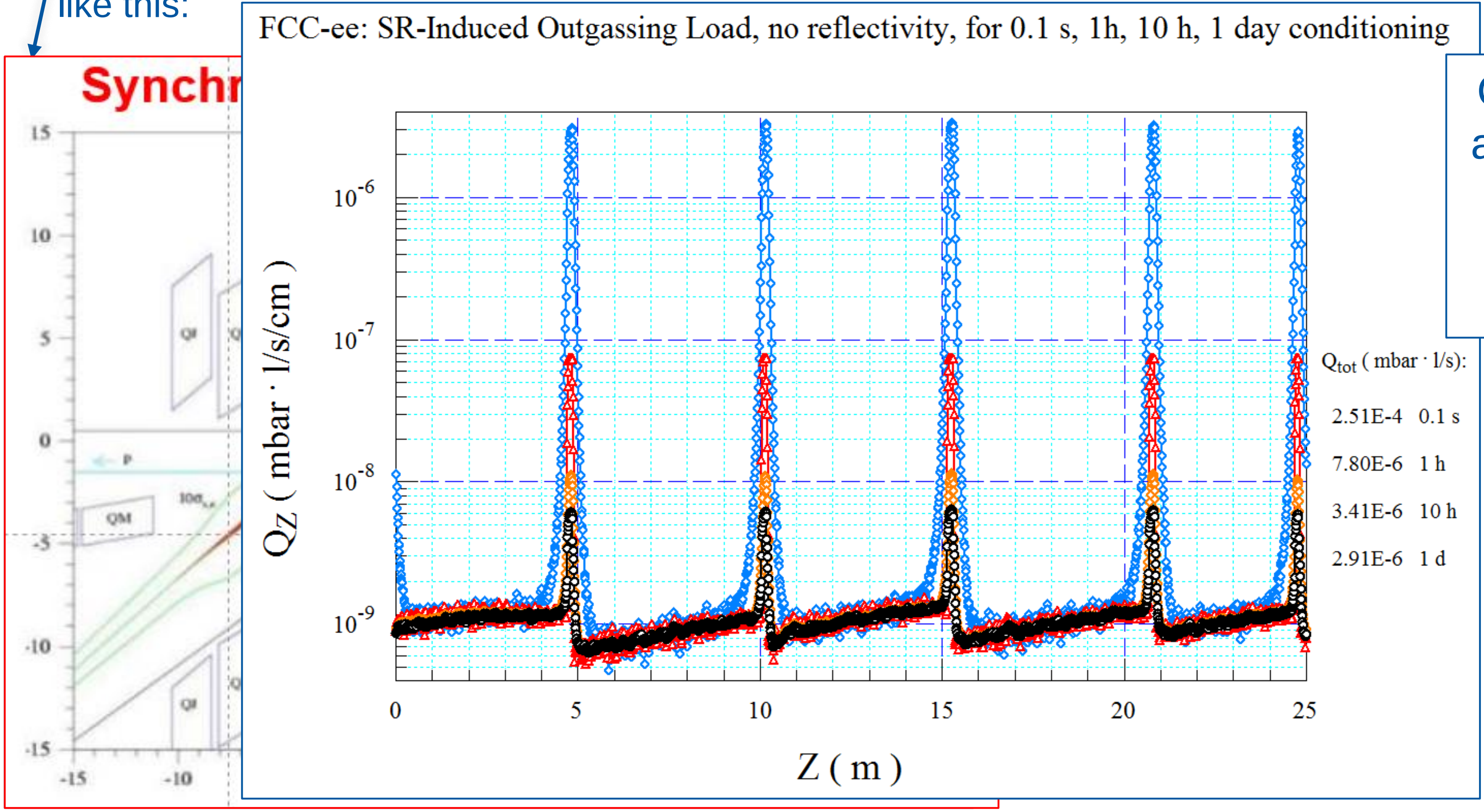


Fig. 2 : Vacuum chamber section made of (1) extruded aluminium profile with the elliptic beam channel, three cooling water ducts (2) and surrounded by 3 to 8 mm thick lead shield (3). The NEG pump (4) is housed in a separate pump channel connected to the beam channel by a row of longitudinal slots (5).

- What this means is that the relatively small C_{spec} translates into the need for many lumped pumps installed at a short distance L from each other, which <u>increases the complexity, reliability, and cost of the vacuum chamber</u> (more machining of the extruded parts, more pumping plenums, more flanges, more probable leaks, etc…)

- In order to obtain the pressure profiles (via Test-Particle Monte Carlo code Molflow+), we need to **compute the SR-induced outgassing load**;
- Sometimes a simple 2D geometric ray-tracing with a CAD system is made, essentially using a projection of the vacuum chambers in the plane of the orbit, and **assuming no photon scattering**;
- Under this hypothesis, the gas load vs beam orbit coordinate z(m) for the Z-pole machine would be like this:

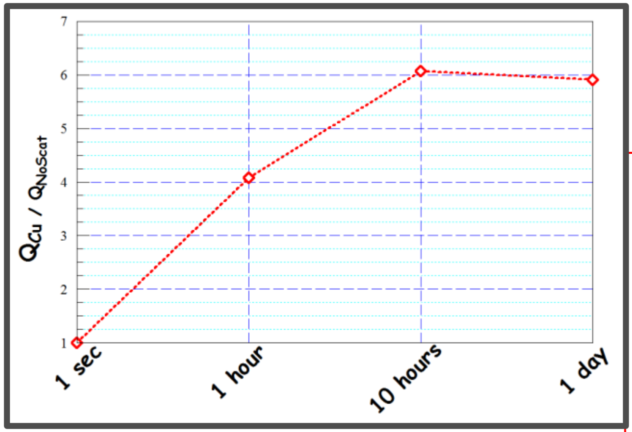


Computed at constant nominal current: 1390 mA

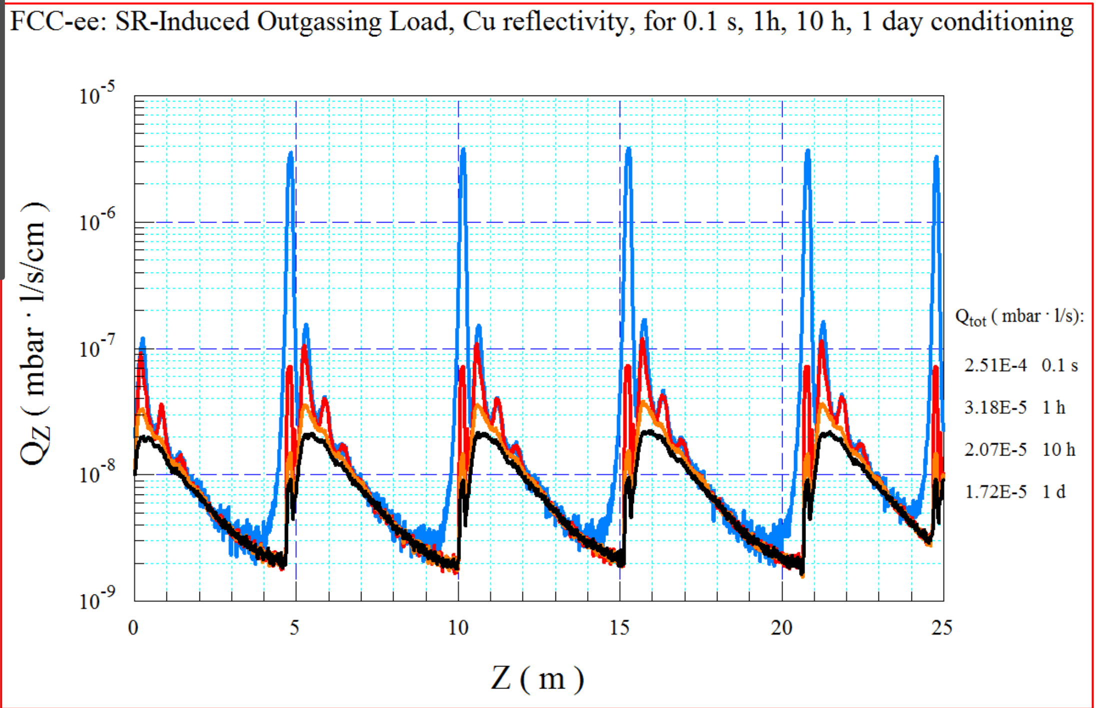
… i.e. five outgassing "spikes" corresponding to the 5 lumped absorbers;

- The integrated gas loads are shown in the table; the first one is proportional to the instantaneous absorbed photon flux distribution;

- In reality, the copper absorbers and the copper vacuum chamber will scatter most of the SR photons;
- **A realistic scattering model, with full dependence on the photon energy, angle of incidence, material, and surface roughness has been implemented recently** (see M. Ady, PhD thesis, EPFL-CERN, 2016, "Monte Carlo simulations of ultra high vacuum and synchrotron radiation for particle accelerators", http://cds.cern.ch/record/2157666?ln=fr)

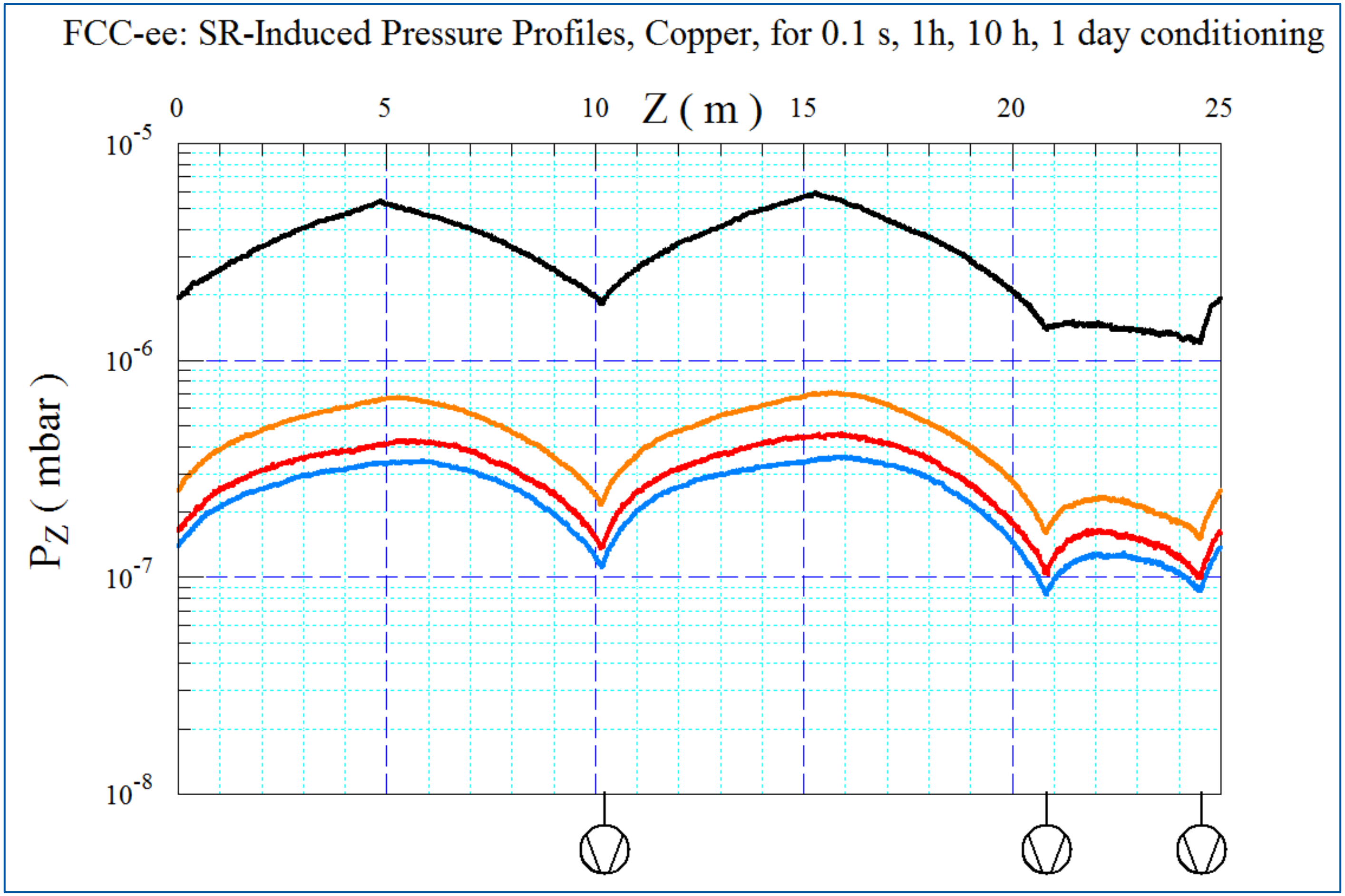


Computed at constant nominal current: 1390 mA



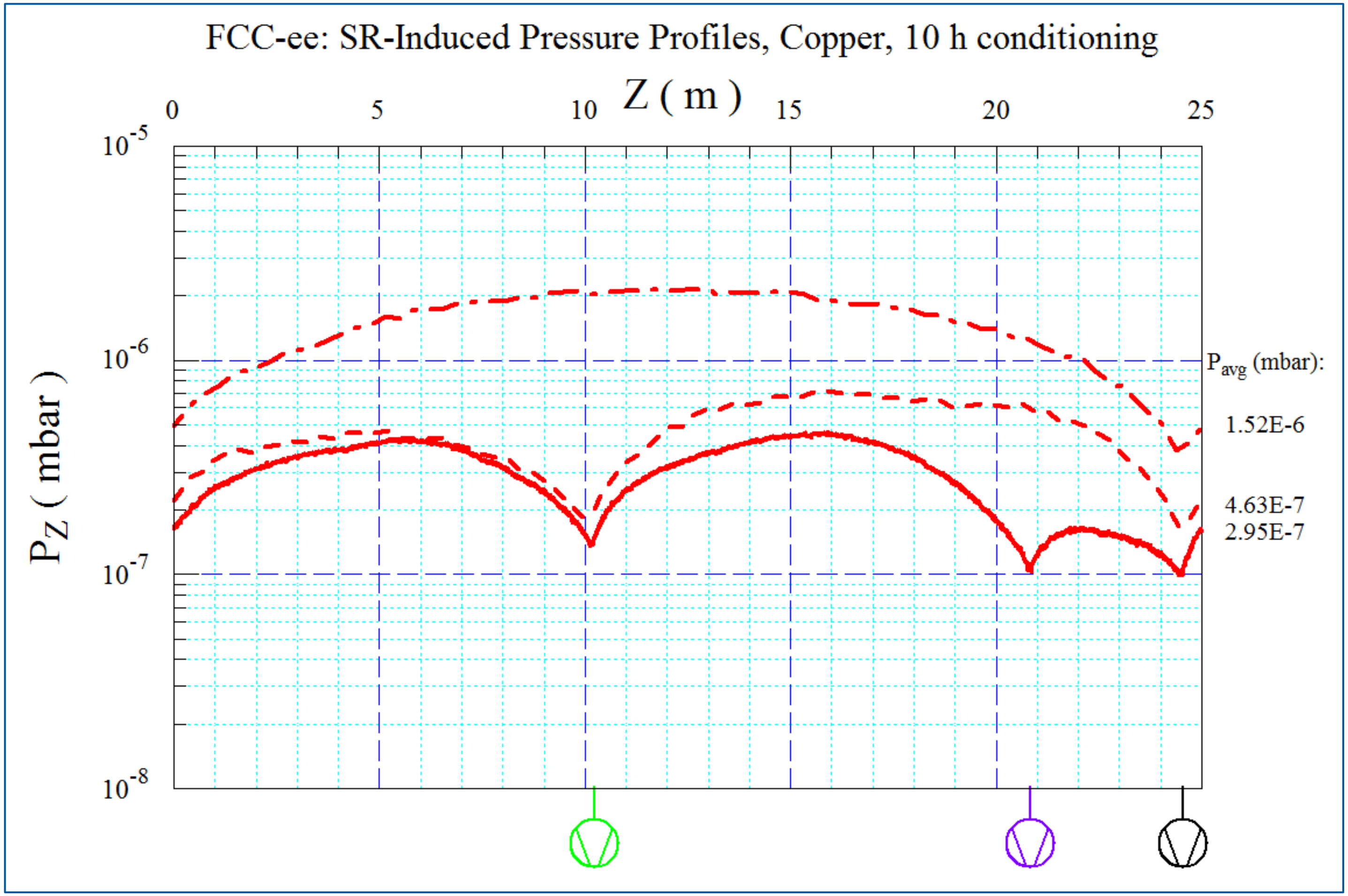
- This results in a dramatic increase of the SR-induced outgassing load profiles, and also of the integrated gas load, because the outgassing yield η(mol/ph) depends on the integrated photon dose, locally: **approximately 6 times bigger for long conditioning times**;

- Pressure profiles corresponding to the **realistic case of Cu reflectivity**, for the Z-pole are (valid for CO at 20 °C):



- They refer to the case when 3 pumps per 25 m arc length are installed, with <u>133 l/s effective pumping speed each</u> (effect of conductance of pumping slots);

- What if we vary the number of pumps per cell? **(3 pumps/25 m arc length → 10k pumps/ring!)**



- Reducing from 3 to 2 and then to 1 pump per 25 m arc length we increase the average pressure by a factor of 1.6 and 5.2, respectively (note: this is valid for the 13.9 A·hr integrated dose), **a consequence of the conductance limitation**;

- It can be seen that even after 1 full day at nominal current (33.4 A·hr), the average pressure is of the order of $2 \cdot 10^{-7}$ mbar, which is very high (we aim at *low 10^{-8} range* or better)
- For CO one typically finds that the product of the beam-gas scattering lifetime τ and the pressure ***P*** follow the relationship

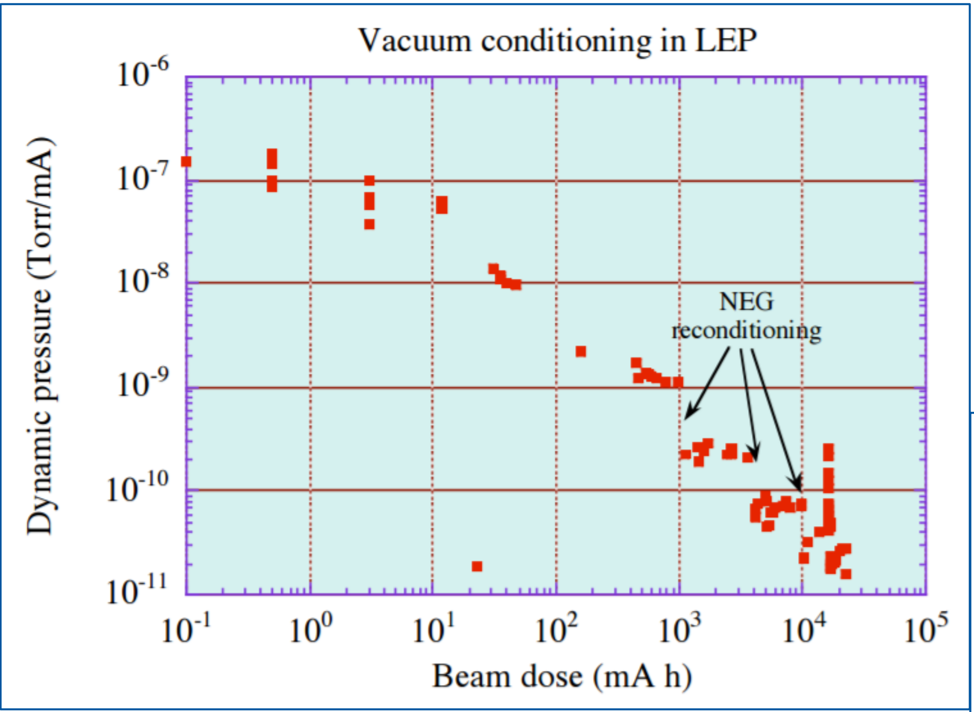
$$\tau P = 4.52 \cdot 10^{-8} (mbar \cdot hour)$$

(see http://cas.web.cern.ch/cas/zakopane-2006/PDFs/Grobner.pdf)

- This means that if we want to have this lifetime contribution much longer (say 10x) than the luminosity lifetime (~100÷200 minutes for the Z-pole, depending on the number of bunches), we would need the pressure to be $\sim 1 \div 2 \cdot 10^{-9}$ mbar or better, and only when the pressure would be at least in the low-10^{-8} mbar range could we get a gas-scattering lifetime similar to the luminosity lifetime, 1.6 ~ 3.2 hours;

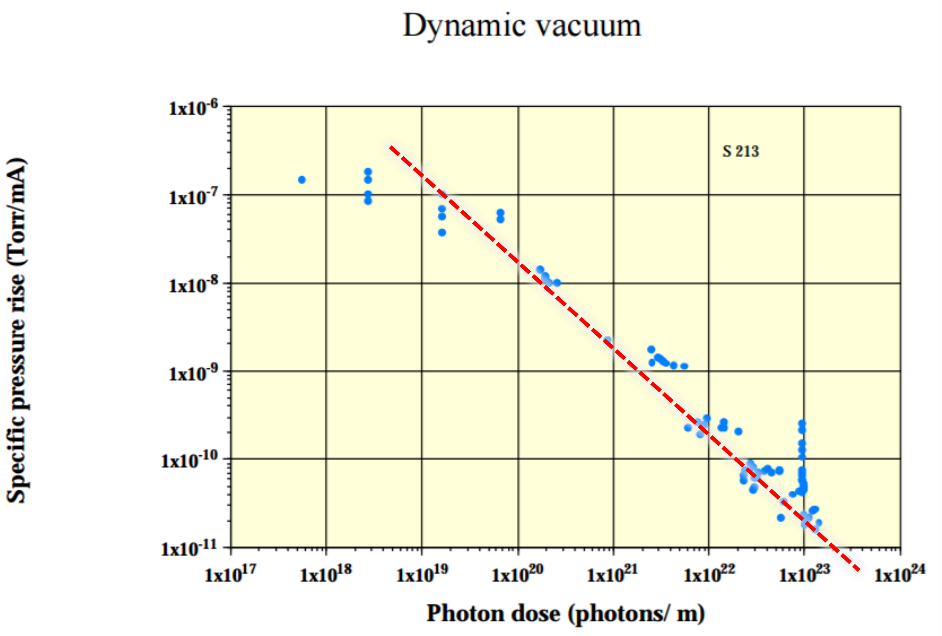
- **It becomes therefore evident that for the Z-pole the vacuum conditioning time could be long, unless we are able to implement some sort of distributed pumping;**
- Ideally, a very much reduced photodesorption yield η(mol/ph) would be the best solution, for instance via massive **NEG-coating of the chambers**. We have recently experimentally validated the “thin NEG” solution (CERN and Y. Tanimoto, KEK).

- A reminder: how did LEP condition? (ref. O. Grobner, op. cit)



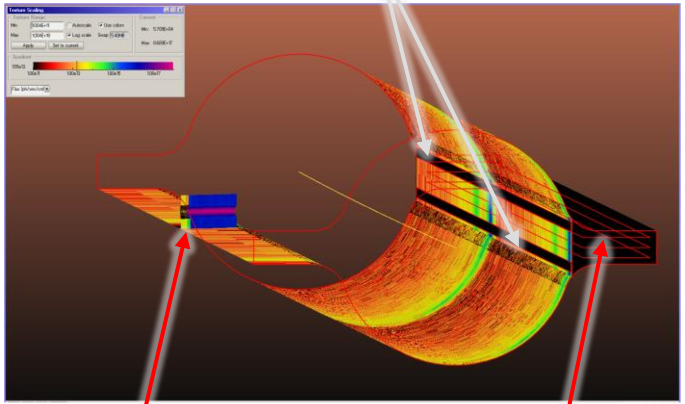
FCC-ee Z-pole at 1390 mA generates an average linear flux of $4.86\cdot10^{17}$ (ph/s/m);
It would then need 114.3 hours in order to accumulate $2\cdot10^{23}$ (ph/m); →

The corresponding pressure would be $1.85\cdot10^{-8}$ mbar, or about 1~2 hours beam-gas scattering lifetime;



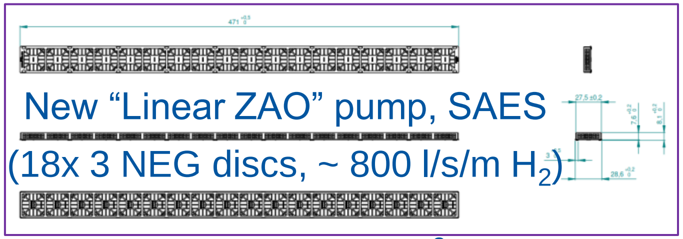
Discontinuities correspond to NEG activation/reconditioning
Data at 45 GeV during initial running of LEP

- **What is the effect of a distributed pumping?**
- We have added a 3-strip distributed NEG pump in the winglet of dipole 1 and 2, opposite to the absorbers (with only 100 l/s/m for the NEG strips ( ), a rather conservative value);
- Re-run the ray-tracing SYNRAD+ code (assuming all photons going through the 2 longitudinal pumping slots are adsorbed), then Molflow+ to get the pressure:

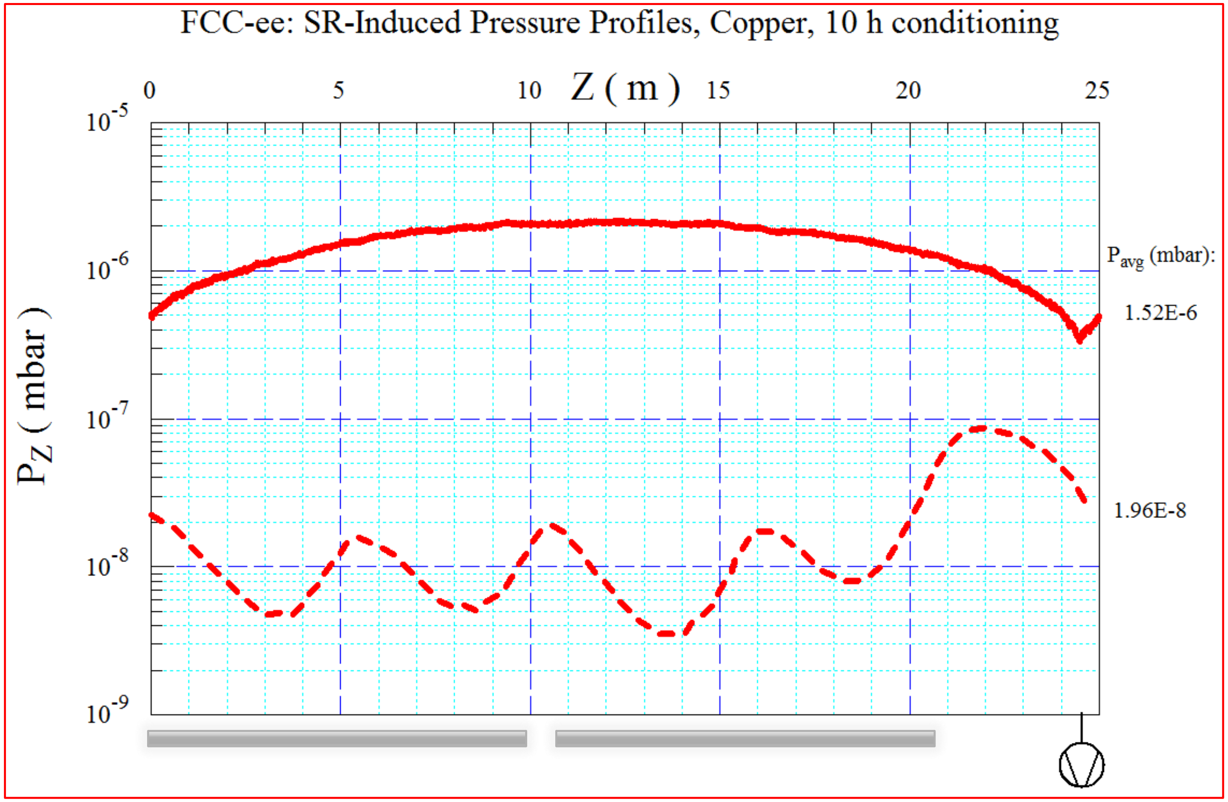


SR absorber (~ in the middle of 10m-long dipole)

3x 20mm wide NEG strips



~ 500 x 25 x 8 mm^3

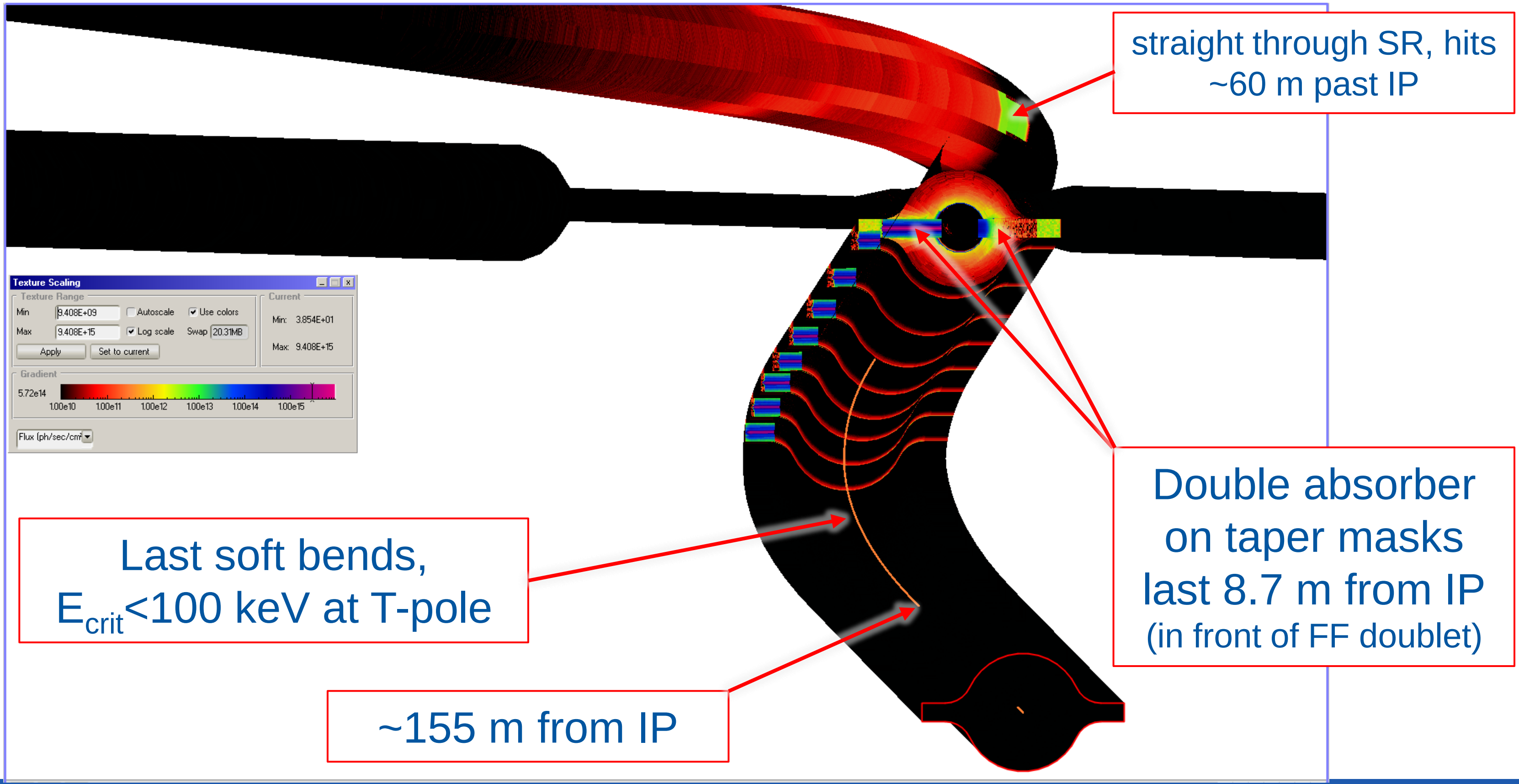


- *The average pressure is **~ 1/77** of the one without distributed pumps: very effective!*

7. Considerations about background in the interaction region

(see also M. Boscolo and M. Sullivan, presentations on MDI at FCC Week 2019, reflecting the CDR choice)

- **The use of lumped absorbers placed at strategic locations to intercept all of the primary SR fan can be applied to the interaction region too;**
- Modelling results show that it would be possible to prevent most of the SR photons from reaching, either directly or via multiple Compton-scattering chain, the Be chamber, thus protecting the detector electronics and lowering the detector background;



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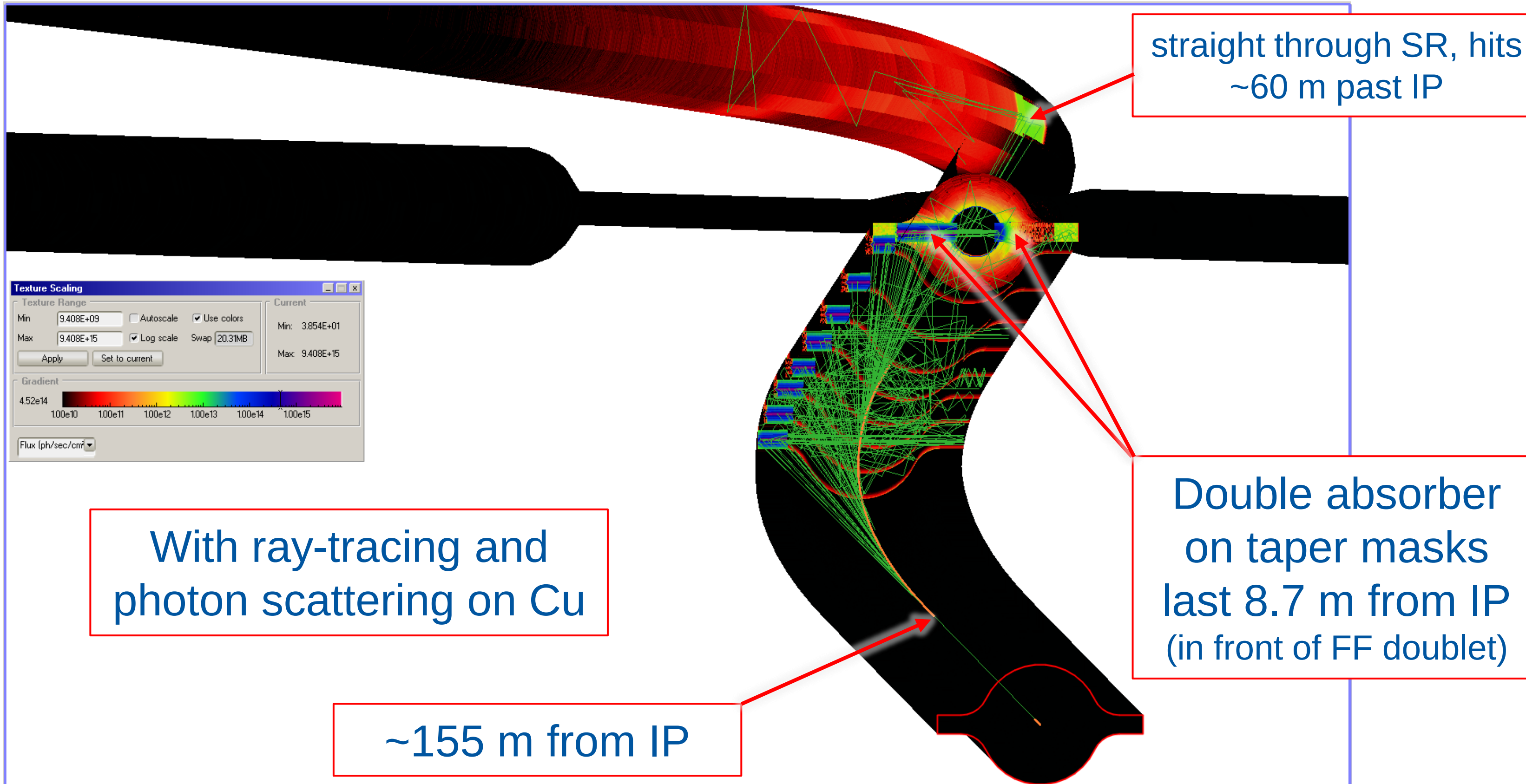
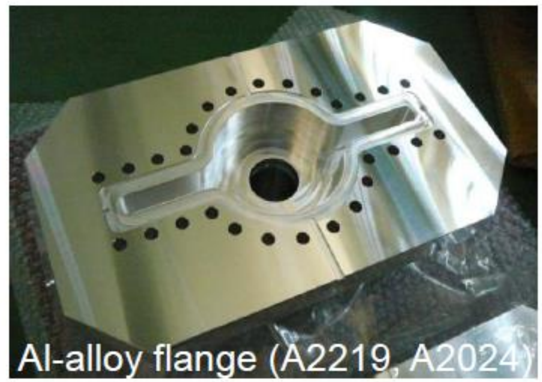
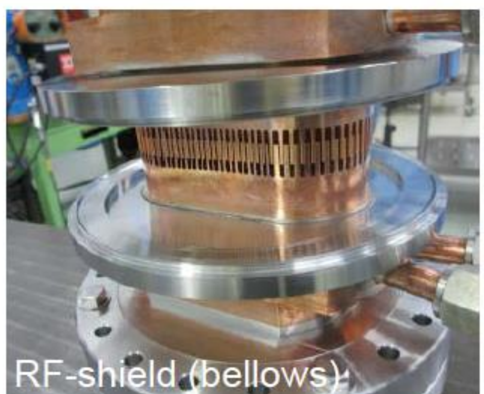


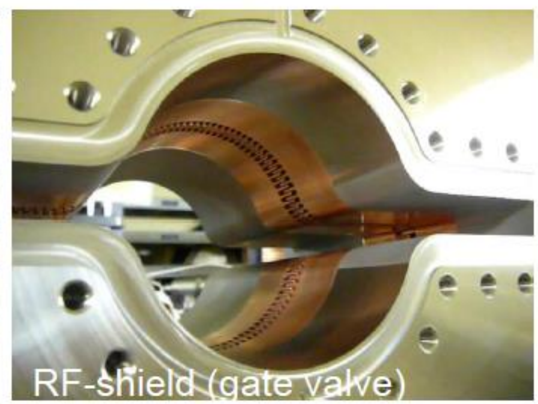
8. Other vacuum components

- SuperKEKB has done an excellent job at prototyping and leading to industrial production of a number of critical items for vacuum, namely low-loss bakeable metal seals, "**comb-type**" **RF contact fingers and gate valves with non-round openings**;
- **We believe that it would be worth adapting these concepts to FCC-ee;**

Courtesy: Y. Suetsugu, KEK



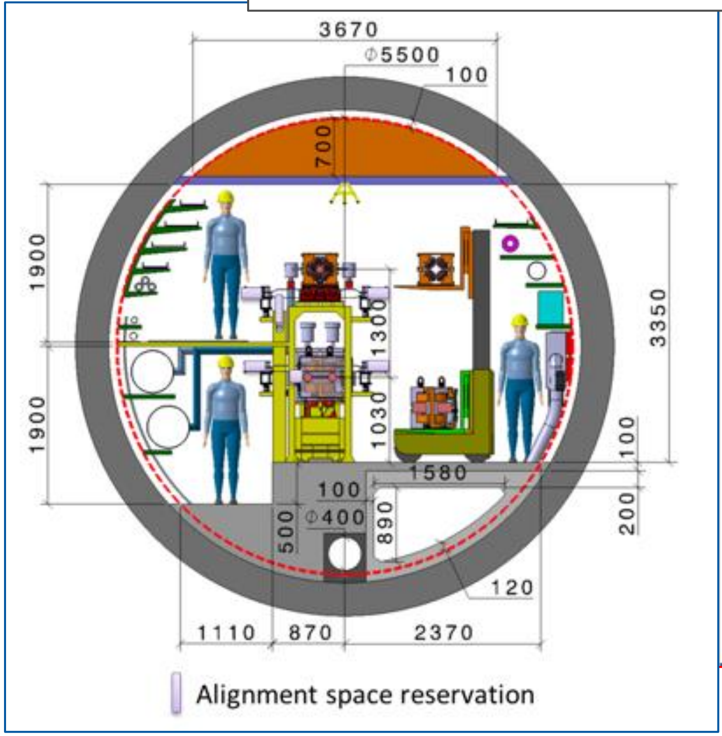


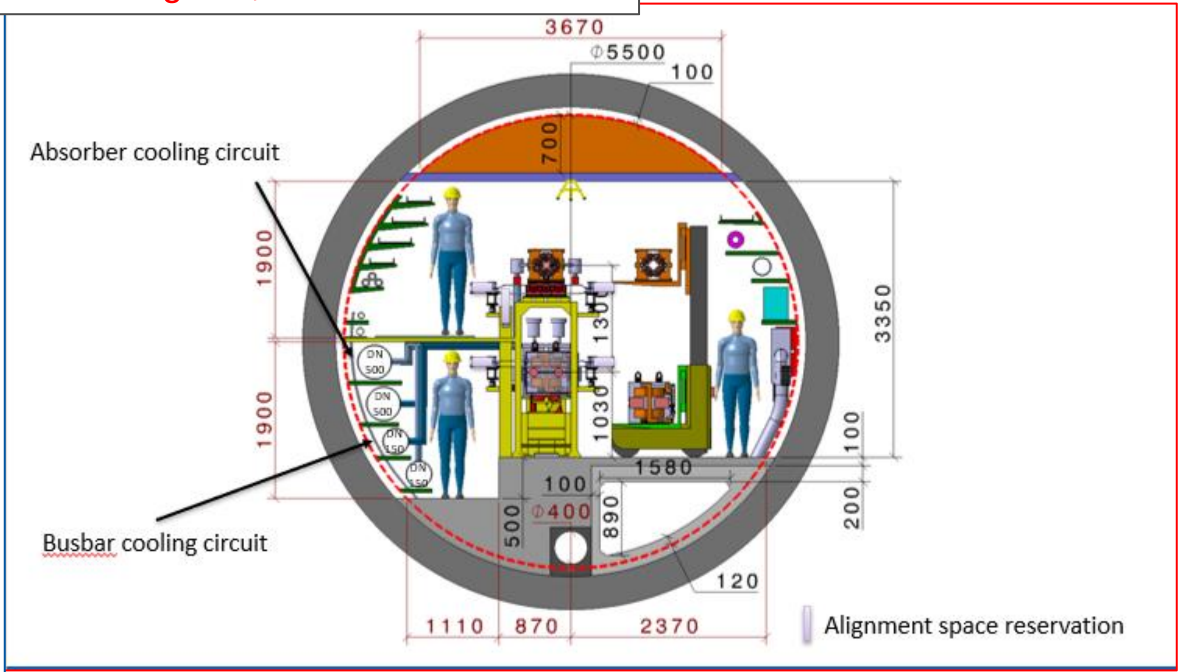


9. Booster and pre-accelerator chain; Tunnel integration

- Booster: preliminary calculations: more challenging than foreseen, due to rather large duty-factor and need to accelerate both e- and e+ beams to full energy (unlike LEP)
- An ad hoc working group has been set up, to look at tunnel integration issues, and try to simulate the amount of work necessary in order to install a typical arc sector
- Worked together with Alignment group
- Left: Oct 2019; Right: Feb 2020

Courtesy: Fani Valchkova-Georgieva, CERN-EN-ACE





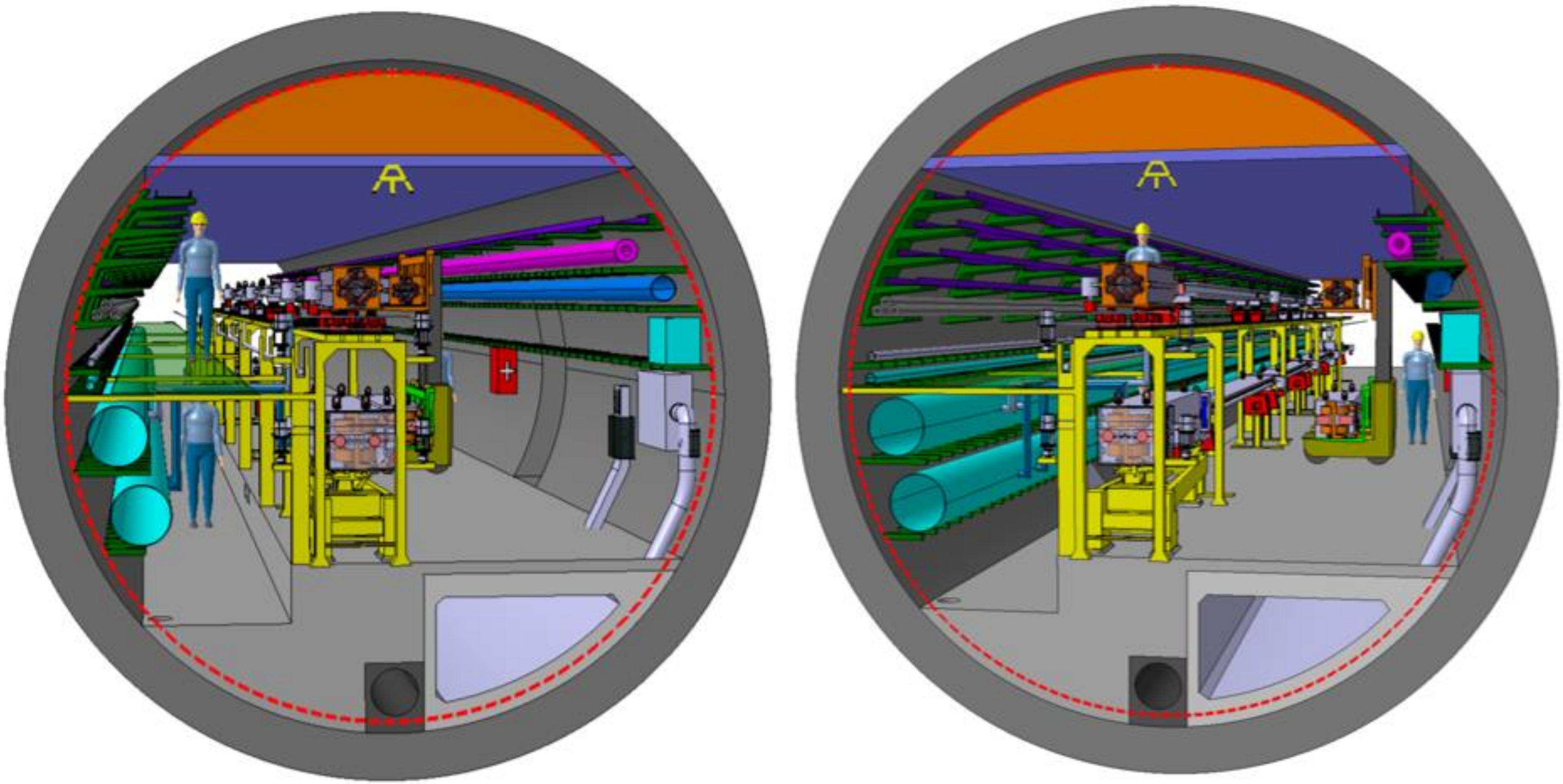
9. Booster and pre-accelerator chain; Tunnel integration

- Integration of booster ON TOP of FCC-ee machine; Looking at ways to install ~ 8m-long magnets (dipole families) and similar length vacuum chambers;

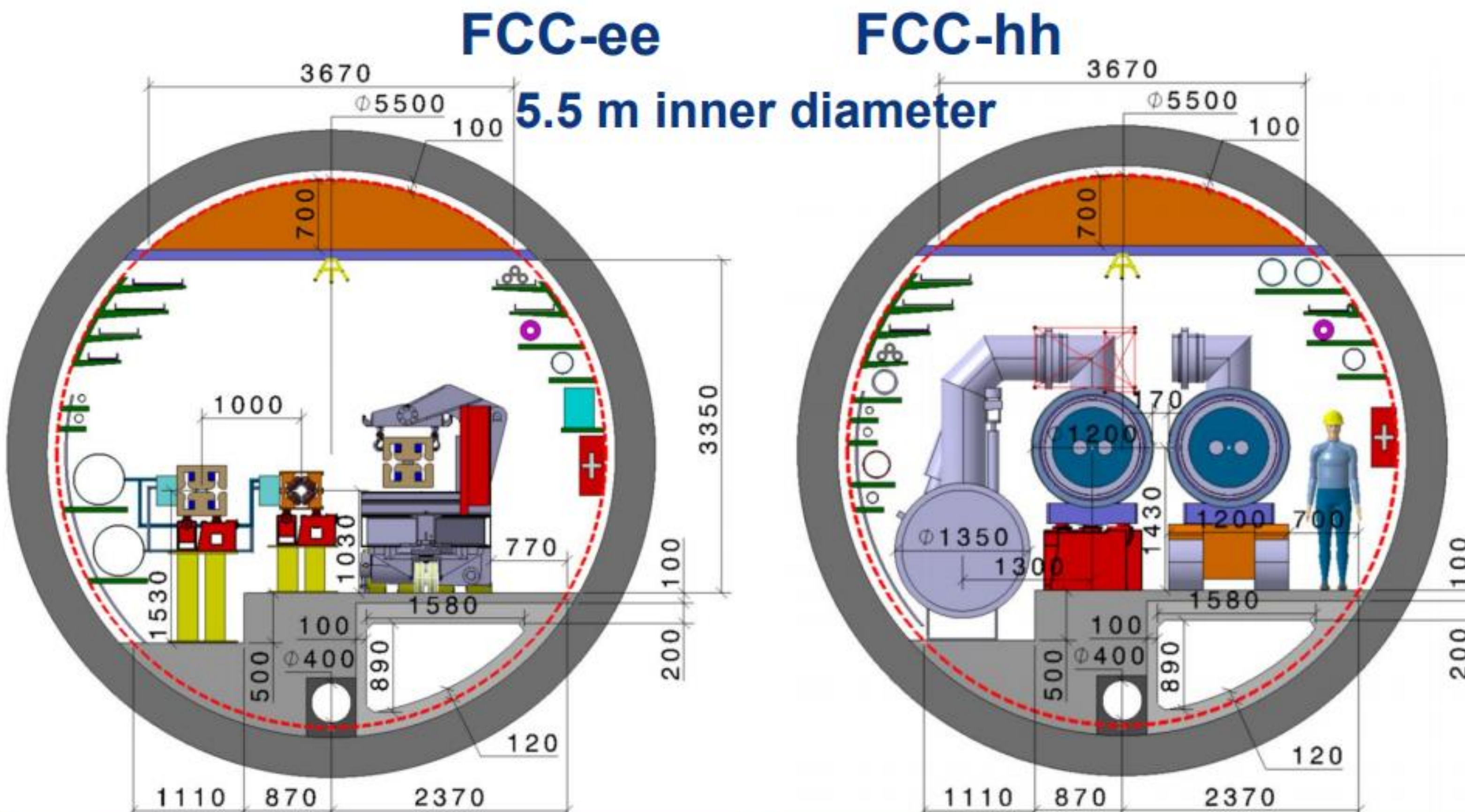
- Challenging sequence of installation and alignment, before and after bakeout;

Isometric view

Courtesy: Fani ValchKova-Georgieva, CERN-EN-ACE



Tunnel integration in arcs



Future Circular Collider Study
Michael Benedikt
FCCW 2019, 24 June 2019, Brussels

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10. Future work towards the TDR (if R&D funds will be available)

- **Design and integration** of vacuum chambers and components (e.g. low-loss, low/impedance RF contact fingers) within the common-yoke arc dipoles and quadrupoles; Chamber supports and their alignment and **integration in the tunnel**;
- Development of **copper-based, low-loss UHV flanges**;
- Test at light sources (e.g. KARA/KIT and/or Dafne/Frascati) of FCC-ee vacuum chambers and components, with special emphasis for the **high-power lumped SR absorbers** (extremely high SR power densities at the ttbar resonance energy);
- Identification of **EC mitigation surface treatments** for the e+ ring (e.g. laser-ablation, NEG-coating, amorphous carbon), with particular attention to industrialization of the process and related cost issues;
- Analysis of further issues related to vacuum for the **Machine Detector Interface areas**;
- Detailed analysis and ray-tracing for special areas, such as **polarization wigglers** for the FCC-ee storage ring and **emittance reduction wigglers for the FCC-ee booster**; How should the **booster vacuum chamber be shielded** (high-Z material)?
- Test of integrated "**Linear ZAO**"-type distributed NEG pumps (SAES Getters, Milan, Italy); Passive or active NEG activation? Promising solution, ~ 800 l/s/m for H_2.

THANKS FOR YOUR ATTENTION ☺

BONUS SLIDES

LEP vacuum chamber section

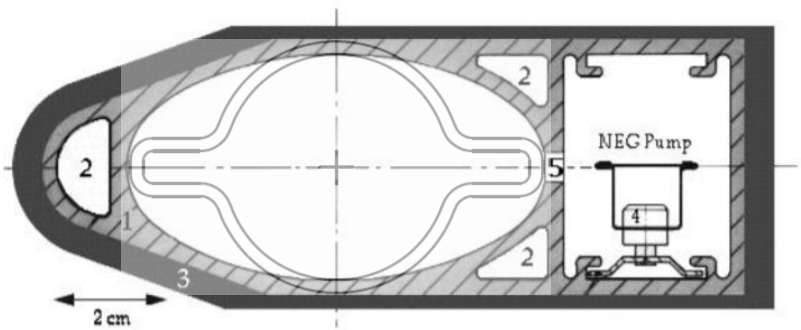


Fig. 2 : Vacuum chamber section made of (1) extruded aluminium profile with the elliptic beam channel, three cooling water ducts (2) and surrounded by 3 to 8 mm thick lead shield (3). The NEG pump (4) is housed in a separate pump channel connected to the beam channel by a row of longitudinal slots (5).

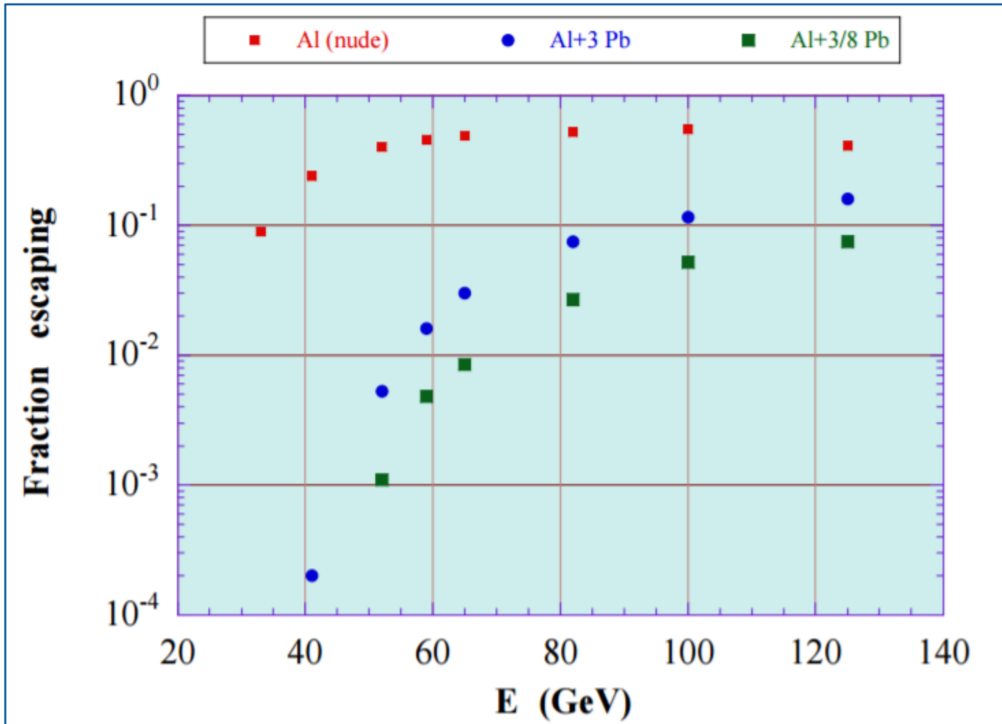
Experience from the LEP Vacuum System

O. Gröbner

CERN, LHC-VAC

Workshop on an e^+e^- Ring at VLHC

ITT, 9-11 March 2001



Fraction of s.r. escaping from LEP aluminium vacuum chamber as a function of the energy.

Cases studied:
Nude chamber
3 mm uniform lead coating
3 mm on top and bottom between dipole magnet gap and
8 mm on lateral parts

BONUS SLIDES

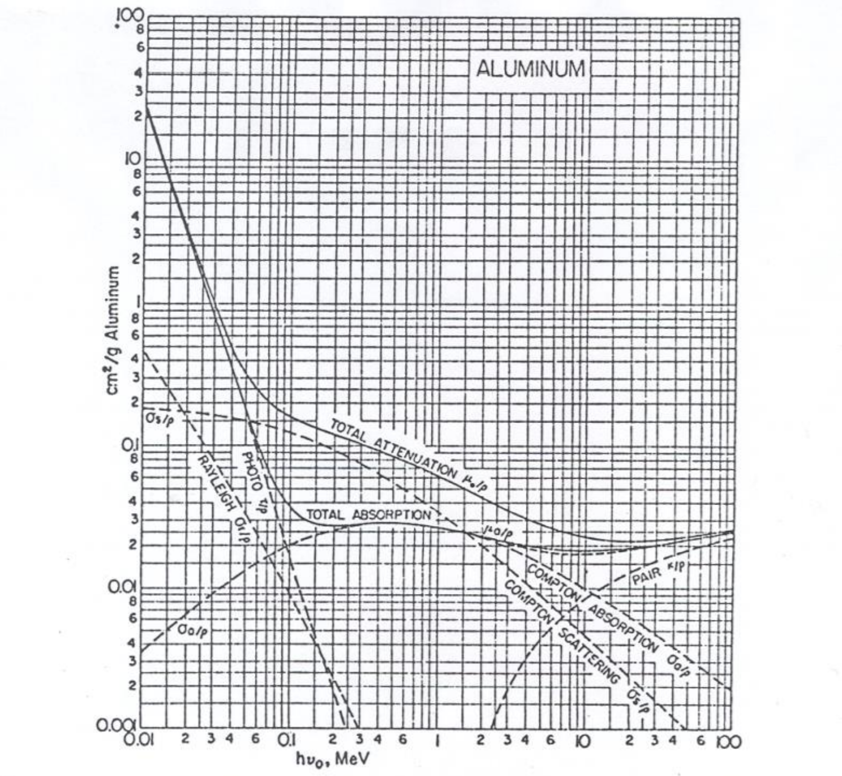
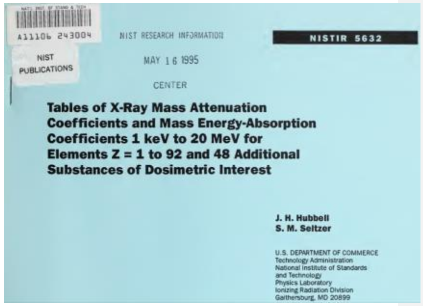


Fig. 8e-8. Mass attenuation coefficients for photons in aluminum ($Z = 13$). The dashed branch on the μ_a/ρ curve shows the effect of excluding annihilation photons [Eq. (8e-47)]. The corresponding linear coefficients for aluminum may be obtained by multiplying all curves by $\rho = 2.70$ g/cm³ Al. [*From Evans* (E1).]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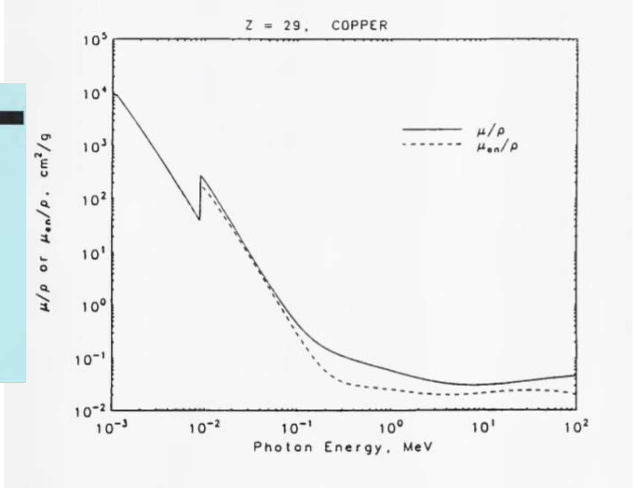
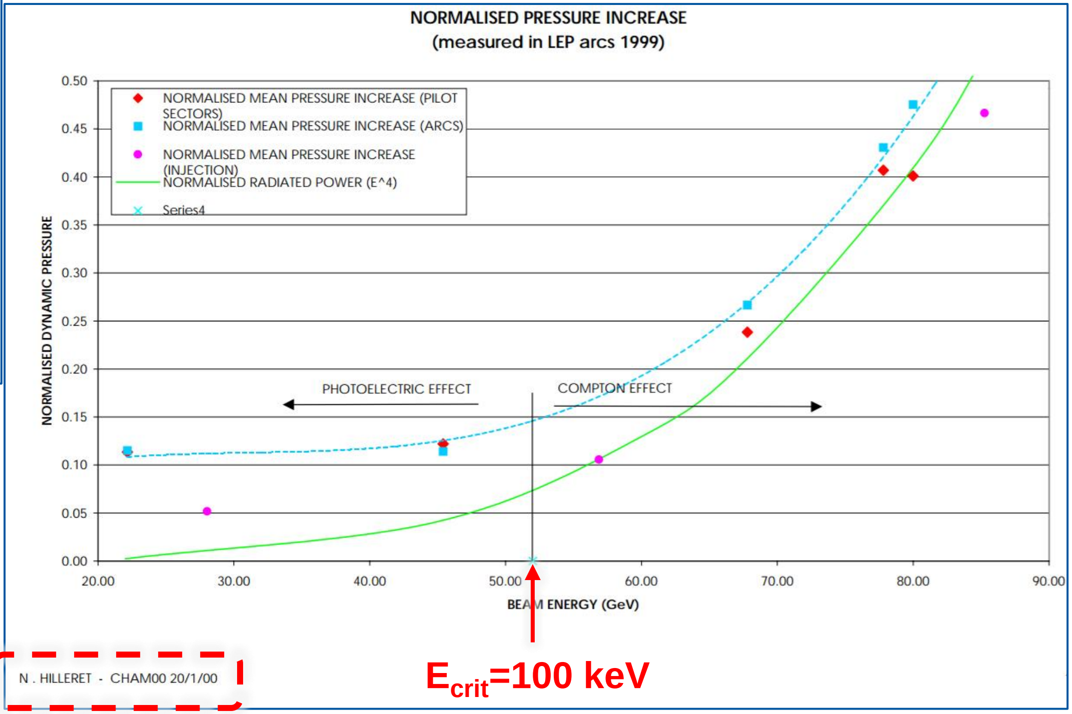
NIST PUBLICATIONS

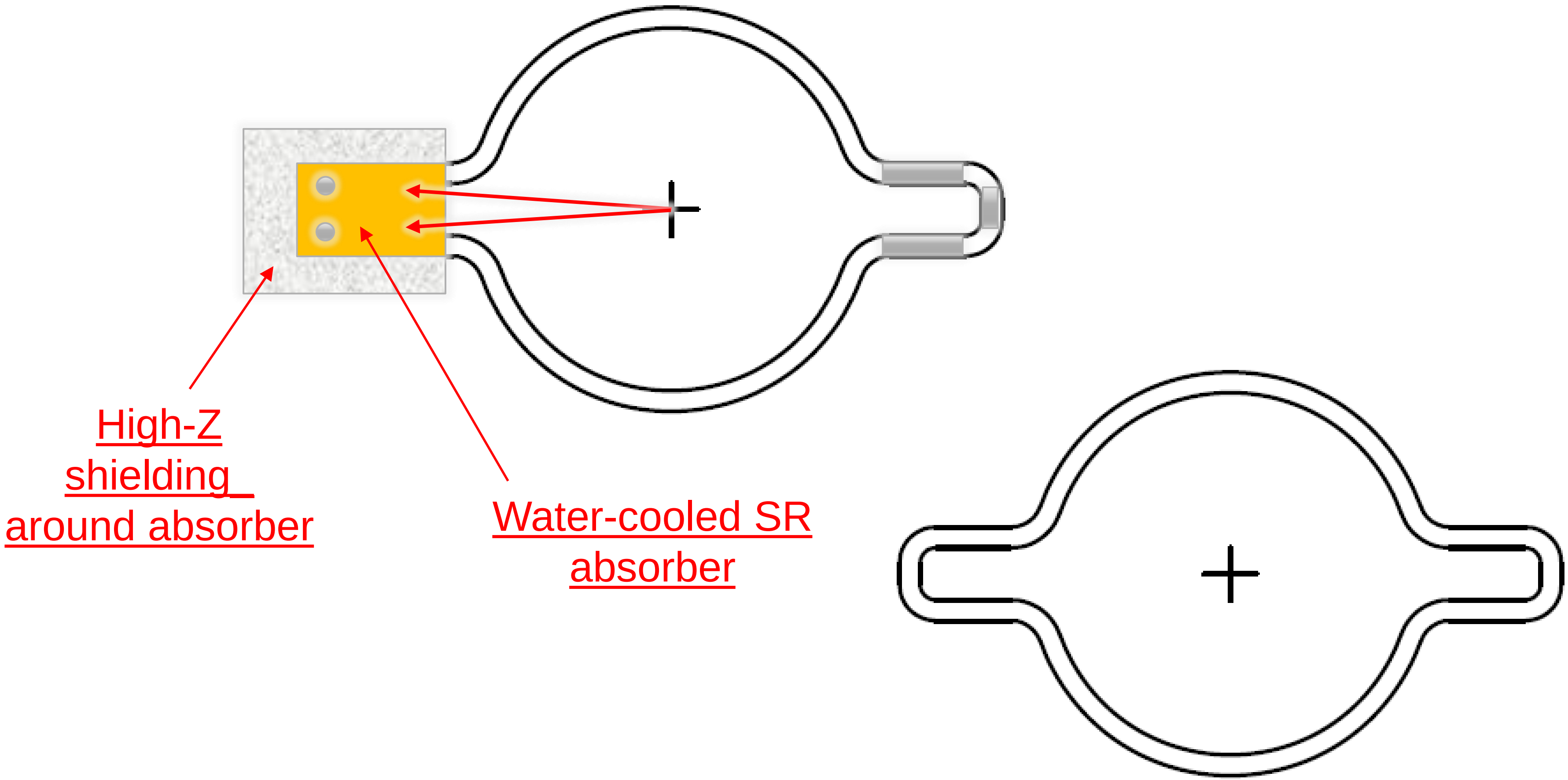
Tables of X-Ray Mass Attenuation Coefficients and Mass Energy-Absorption Coefficients 1 keV to 20 MeV for Elements Z = 1 to 92 and 48 Additional Substances of Dosimetric Interest

J. H. Hubbell
S. M. Seltzer

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards and Technology
Physics Laboratory
Ionizing Radiation Division
Gaithersburg, MD 20899



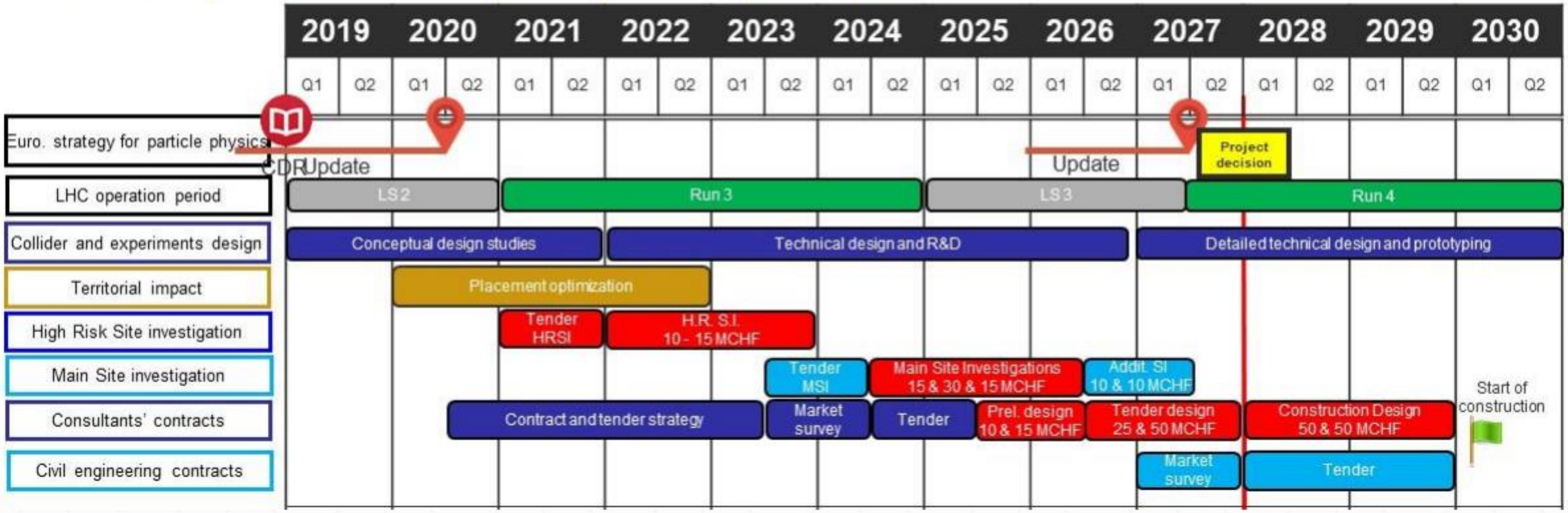




High-Z shielding around absorber
Water-cooled SR absorber

Feasibility study tunnel – updated planning

Timeplan CE project preparation 2019 – 2030



- **Schedule of major processes leading to start of construction begin 2030.**
- **For proof of principle feasibility: High risk site investigations 10 - 15 MCHF in the period 2022/23.**
- **Additional CE investments will be required in MTP period to allow start of construction in 2030: MSI 45 MCHF, PD 10 MCHF: Total of 55MCHF.**

M. Benedikt, CERN