FCC Week 2018

Amsterdam, April 9-13, 2018

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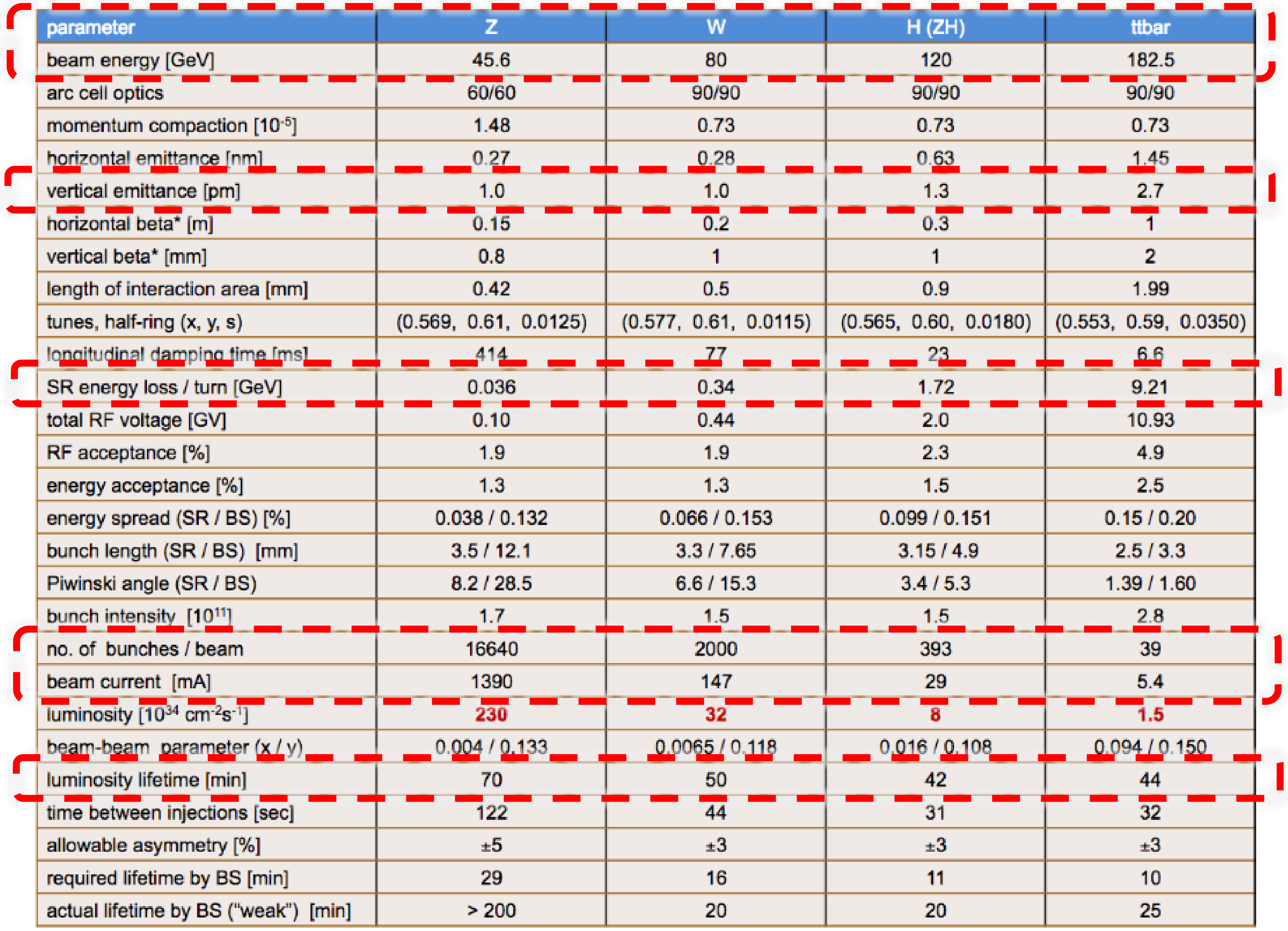
Machine parameters

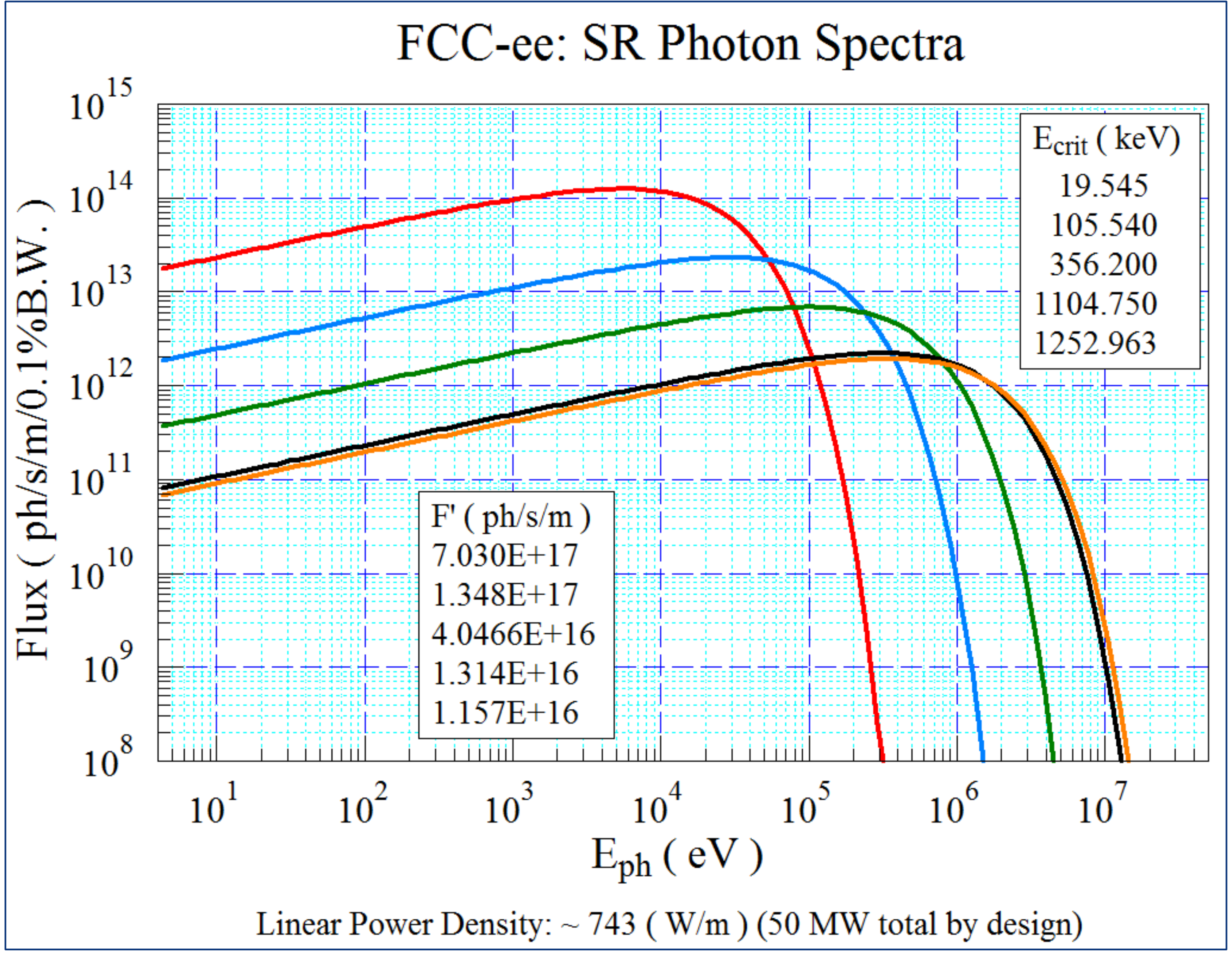
- **Machine parameters from official web page** http://tlep.web.cern.ch/content/machine-parameters
- **Very small vertical emittance for all energies**
- **High current (B-factory level) for Z-pole**
- **Luminosity lifetime τ_{lum} dominates beam current decay, but vacuum lifetime must be at least several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



parameter	Z	W	H (ZH)	ttbar
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} $cm^{-2}s^{-1}$]	**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_{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_{crit} > Compton edge (~100 keV)**


FCC-ee: SR Photon Spectra

Linear Power Density: ~ 743 (W/m) (50 MW total by design)

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

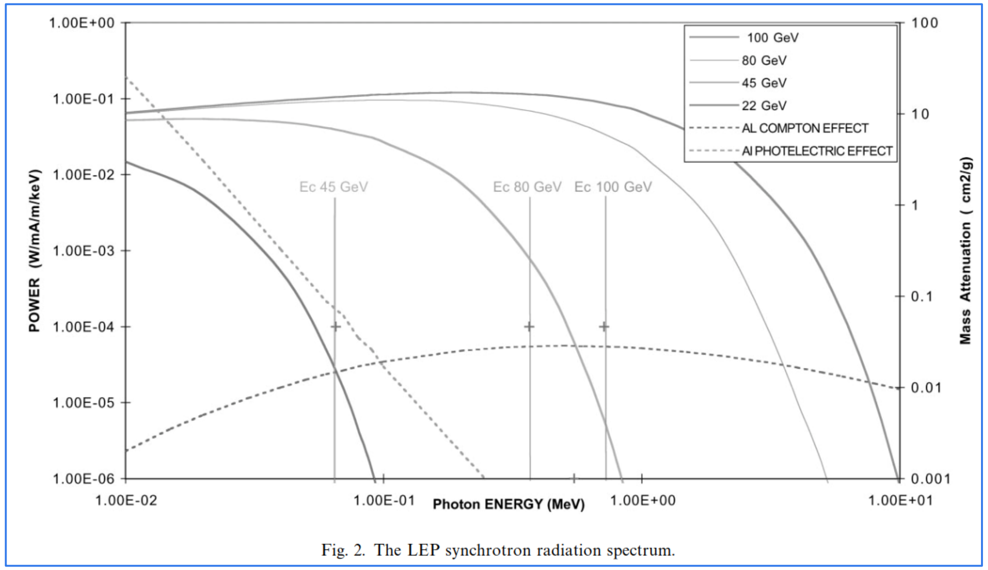


Fig. 2. The LEP synchrotron radiation spectrum.

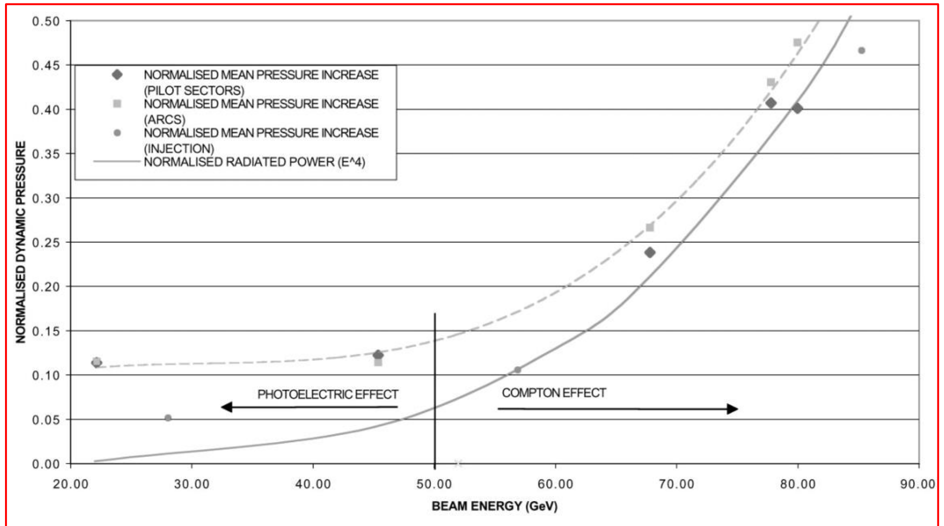


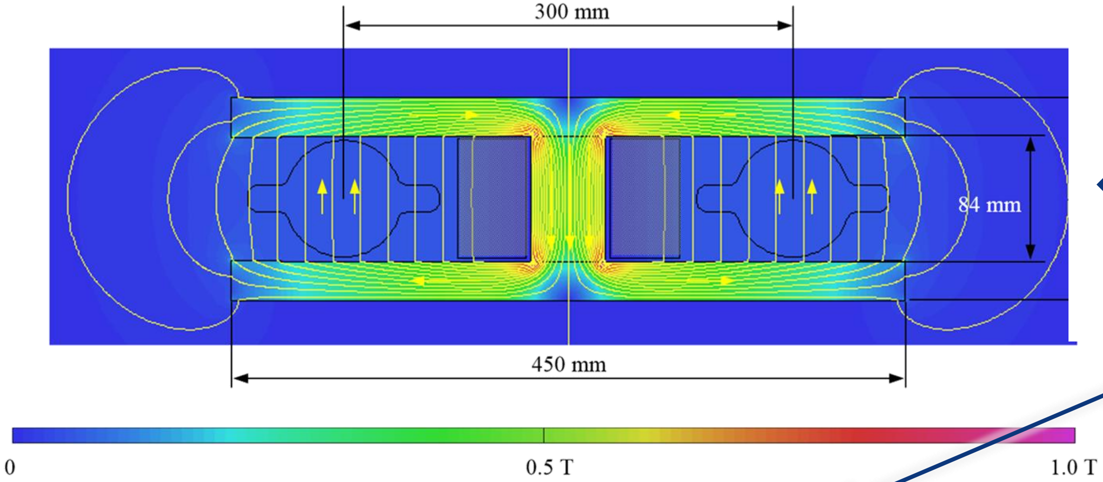
Fig. 5. Normalised pressure increase (low beam energy, measured in LEP arcs, 1999).

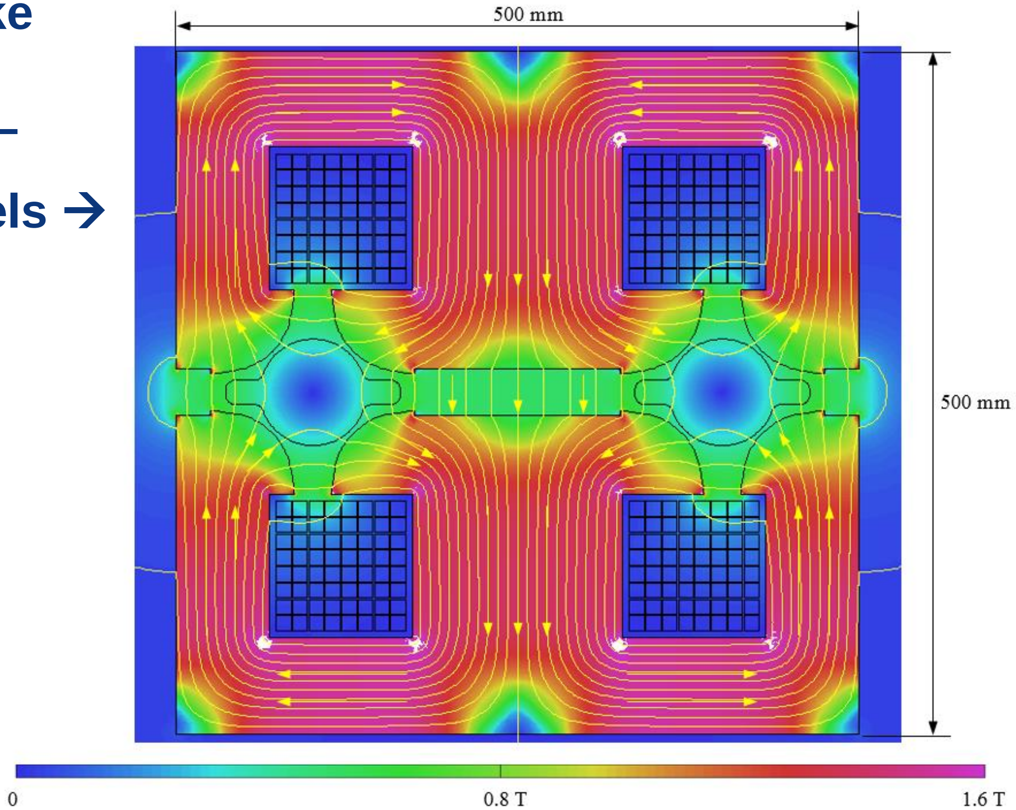
- If copper alloy is chosen as the material for the vacuum chamber, then a smaller fraction goes into Compton, and shielding improves;
- In addition, copper has a lower photon-stimulated desorption yield;

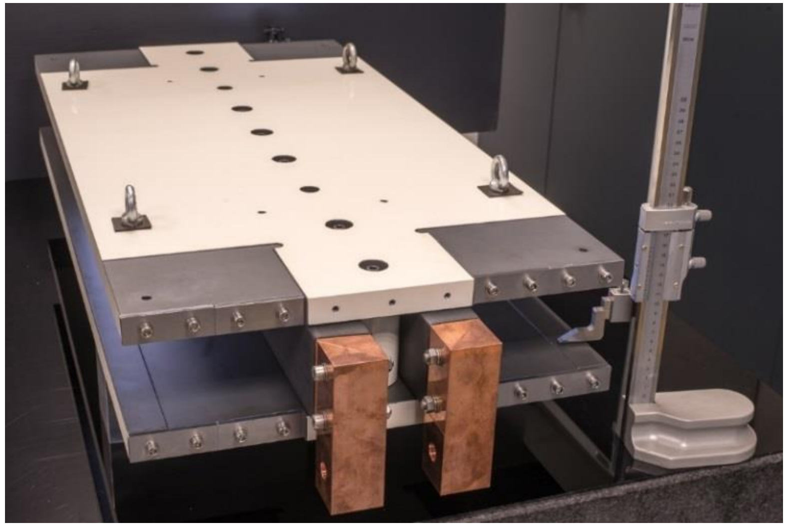
Integration with magnets

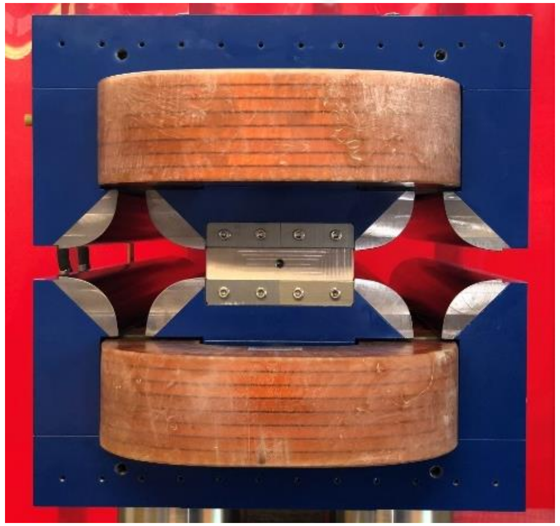
Combined-yoke dipoles and quadrupoles –

← Magnetic models → and 1m-long prototypes



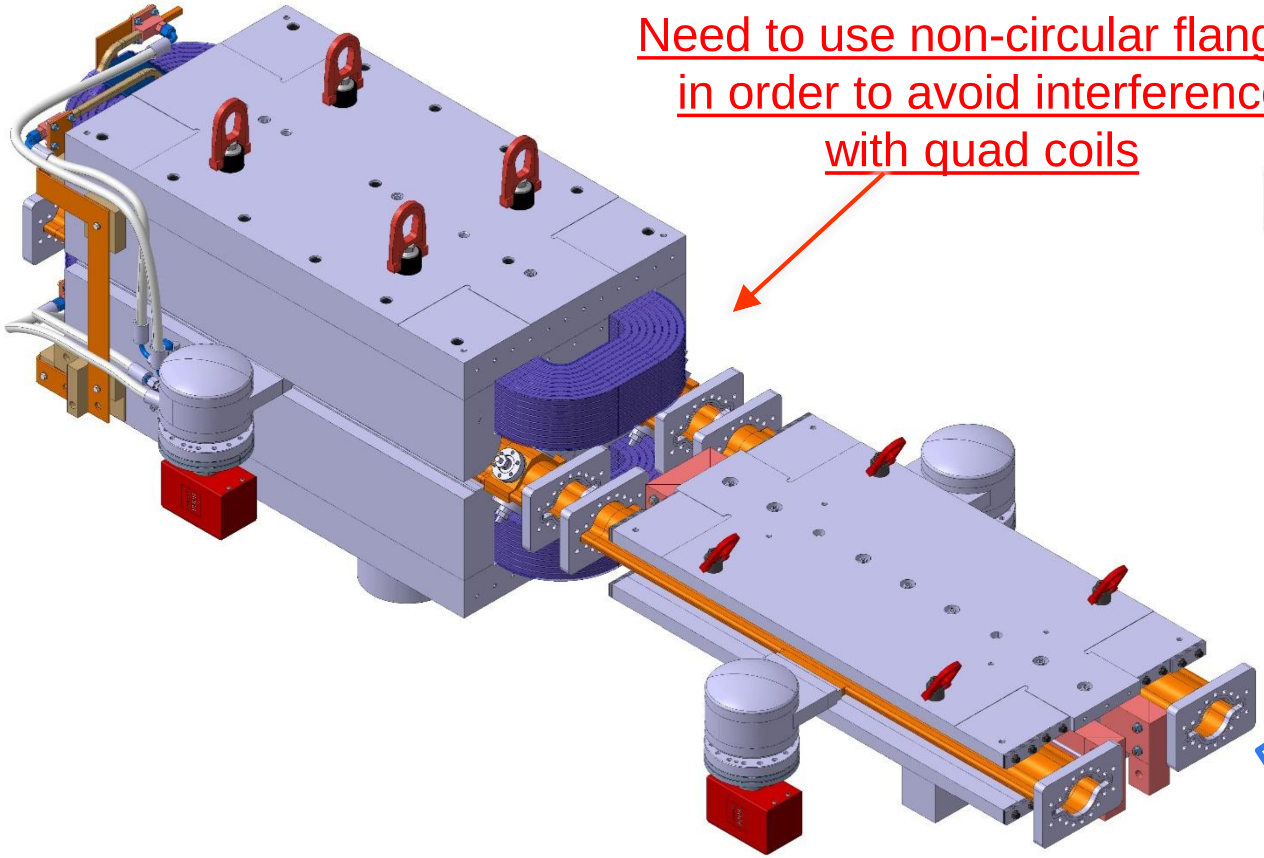




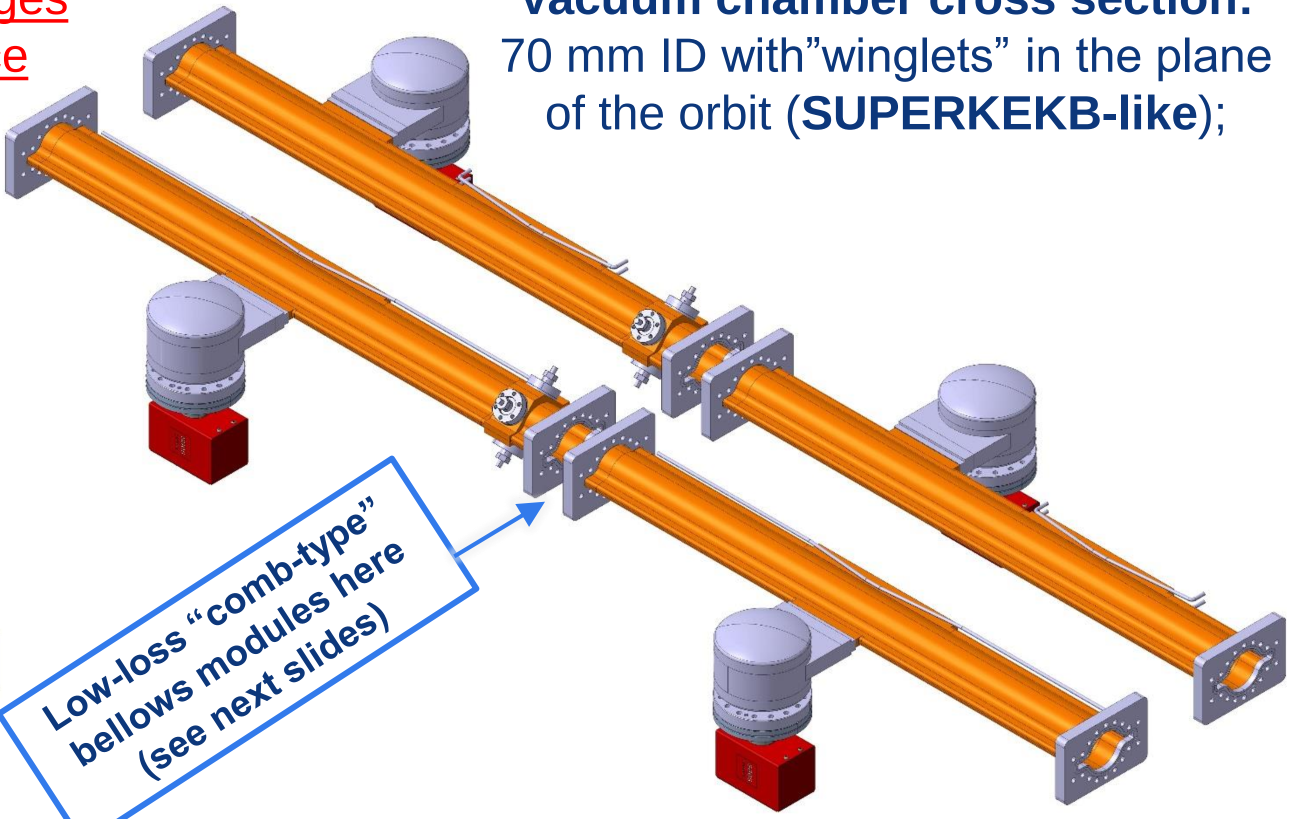


Courtesy of **A. Milanese, CERN**
(see his contribution at *Proc. FCC Week 2017*, Berlin)

Vacuum chamber geometry



Need to use non-circular flanges in order to avoid interference with quad coils



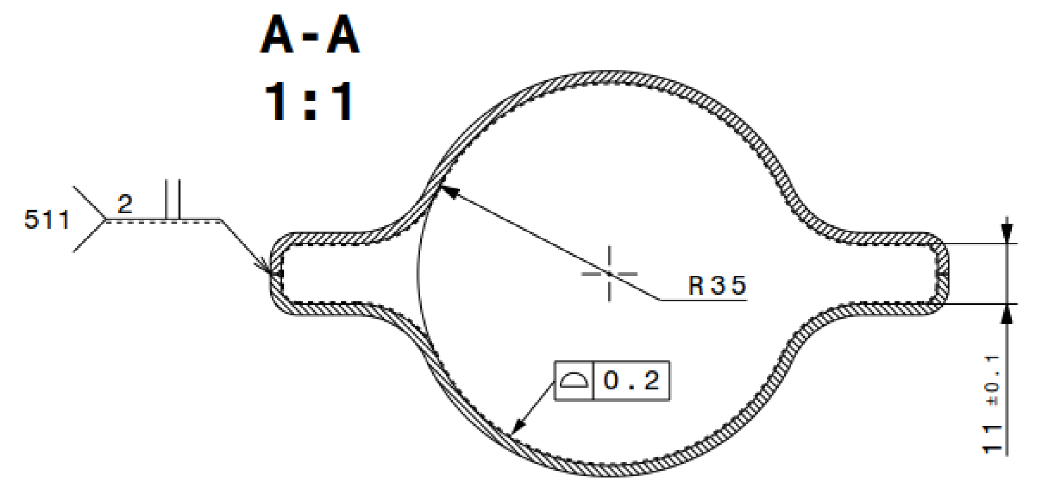
Vacuum chamber cross section:
70 mm ID with"winglets" in the plane of the orbit (**SUPERKEKB-like**);

Low-loss "comb-type" bellows modules here (see next slides)

- CAD model of the1m-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;

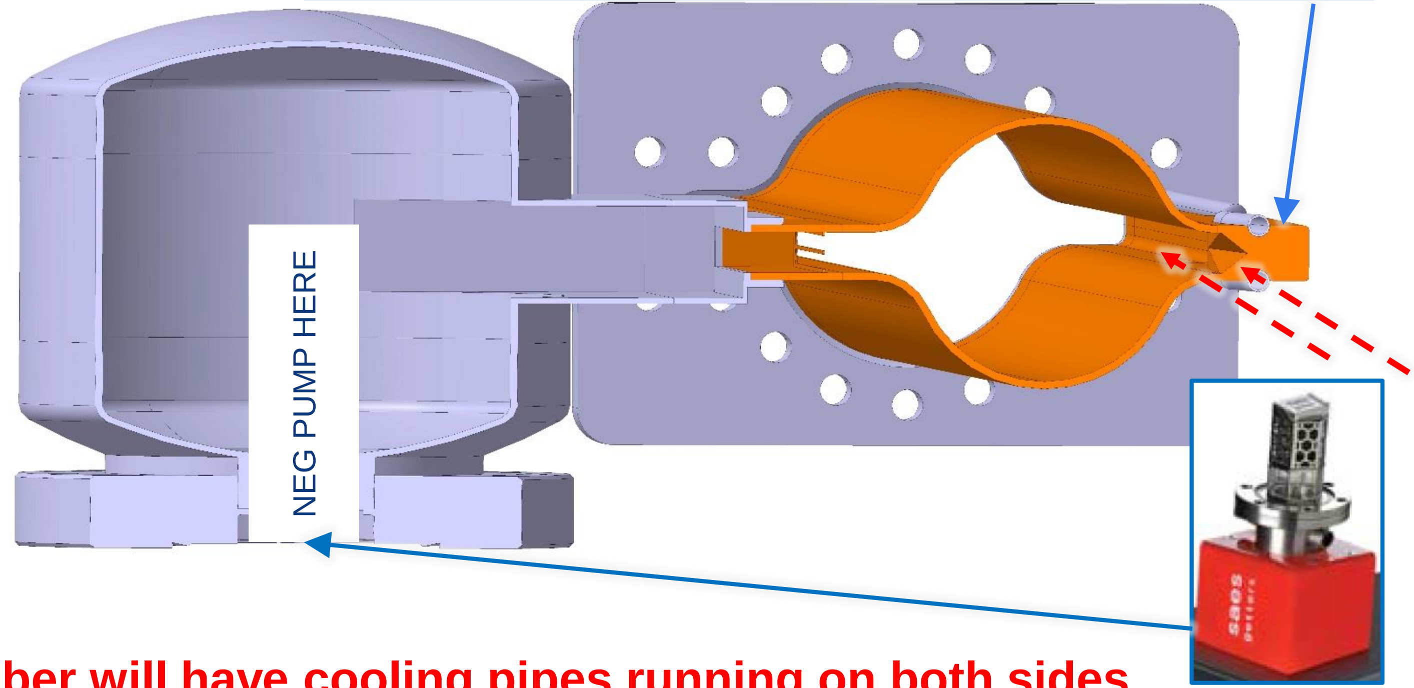
Vacuum chamber geometry

Material: OFC copper; Specific Cond.: 48.2 l·m/s (CO, 20 ºC)



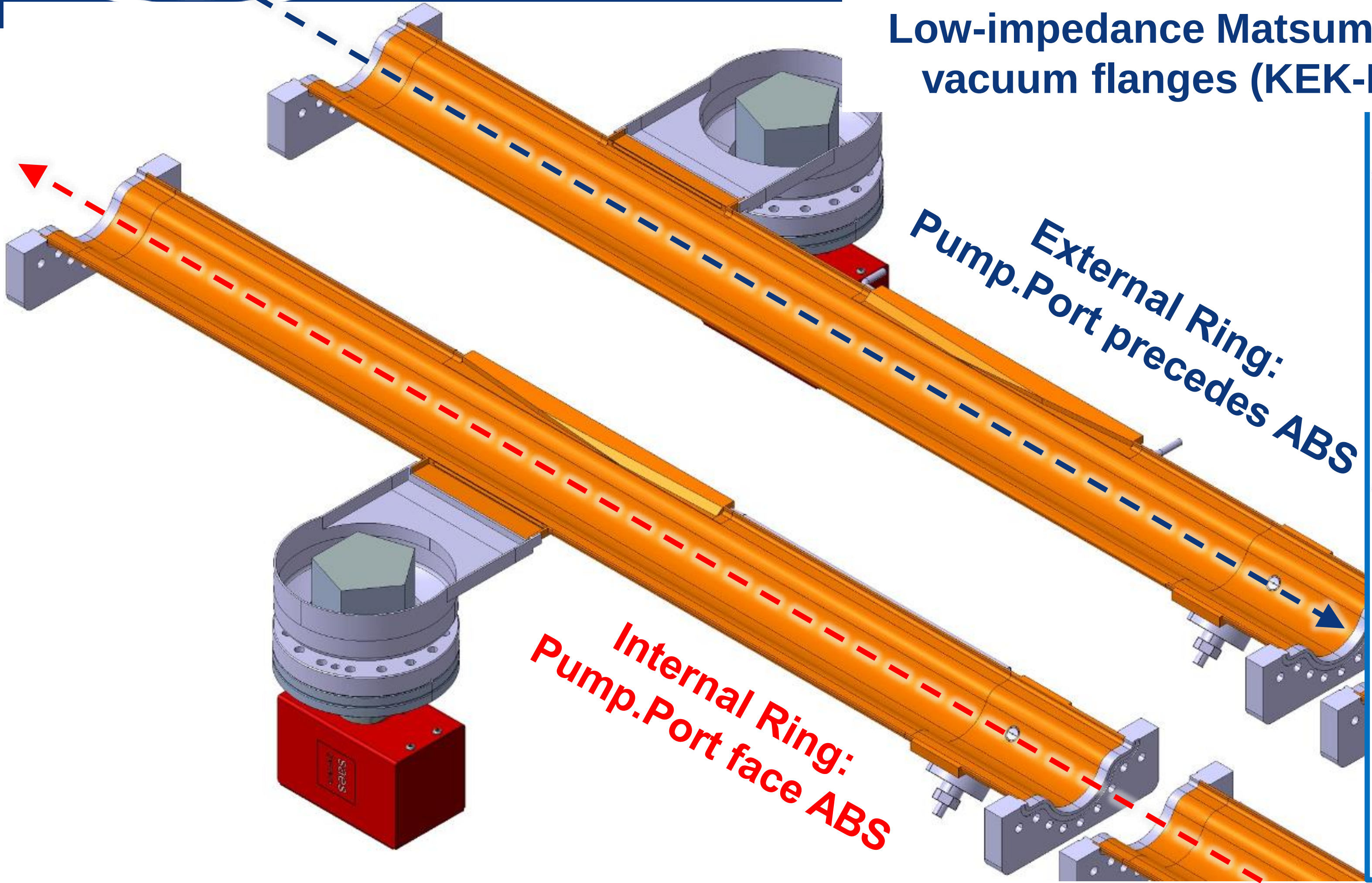
Two-halves cross section (only for prototype)

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

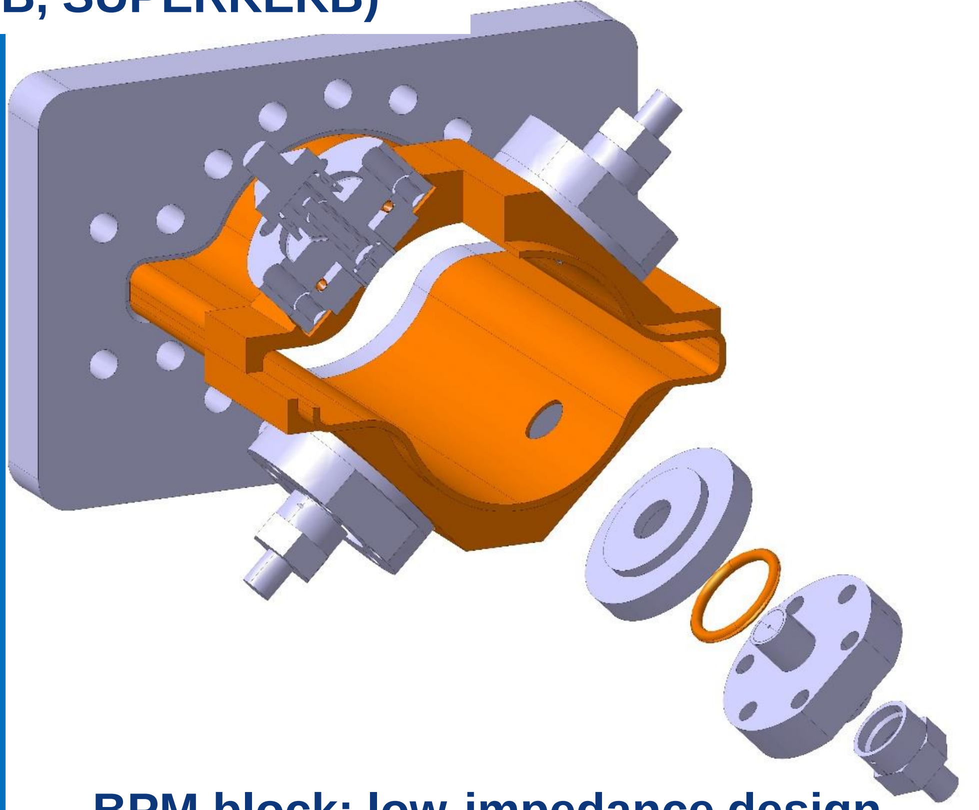


- **Left: Cross-section of the prototype (real chamber will have cooling pipes running on both sides of winglets;**
- **Right: Cross-section at pumping dome/absorber location; The connection to the beam chamber is via a slotted grid; The SR absorber is placed in front of the pumping dome (for external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

Vacuum chamber geometry



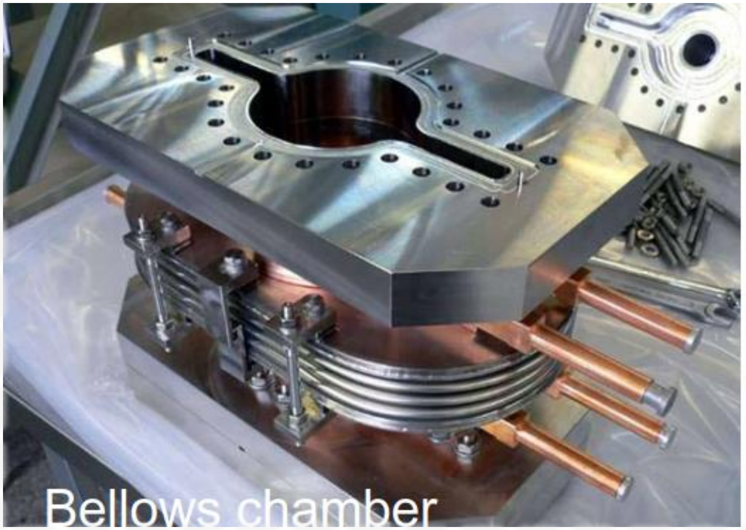
Low-impedance Matsumoto–Ohtsuka-type vacuum flanges (KEK-B, SUPERKEKB)

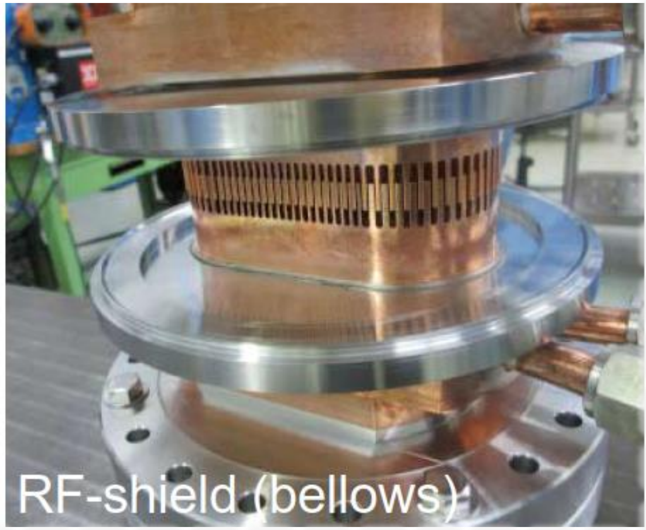


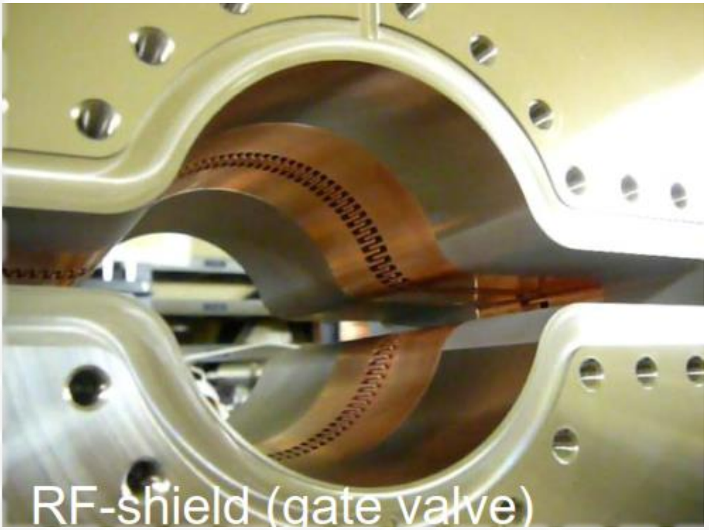
BPM block: low-impedance design, machined from block and e-beam welded

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 FCChh 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. ECLOUD’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 (to reduce photon-stimulated desorption and photo-electron production)
  - High-capacity lumped NEG pumps (NEXTorr, SAES Getters)

One open issue with NEG-coating is its contribution to the longitudinal resistive-wall instability[1];

- It is being addressed experimentally now at CERN[2], and will be also tested with SR at the Photon Factory soon[3]

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[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 texturing[1-4]
  - clearing electrodes

[1] O. Malyshev et al., "*A Facility for Studying ESD from NEG Coated Surfaces at Cryogenic Temperatures*", this conf.

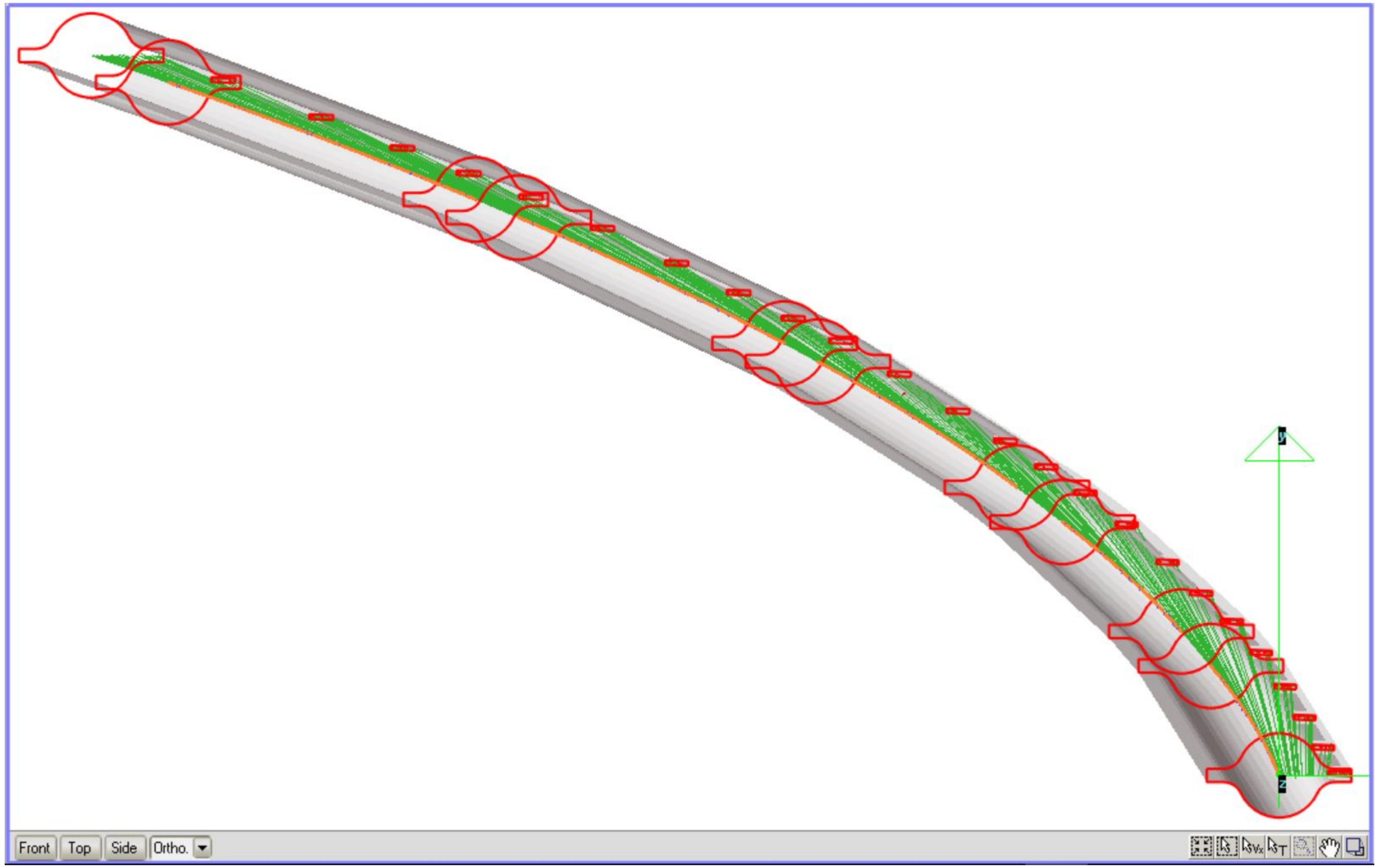
[2] O. Malyshev et al., "*NEG Coatings and laser surface engineering (LASE) electron cloud mitigation techniques*", this conf.

[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

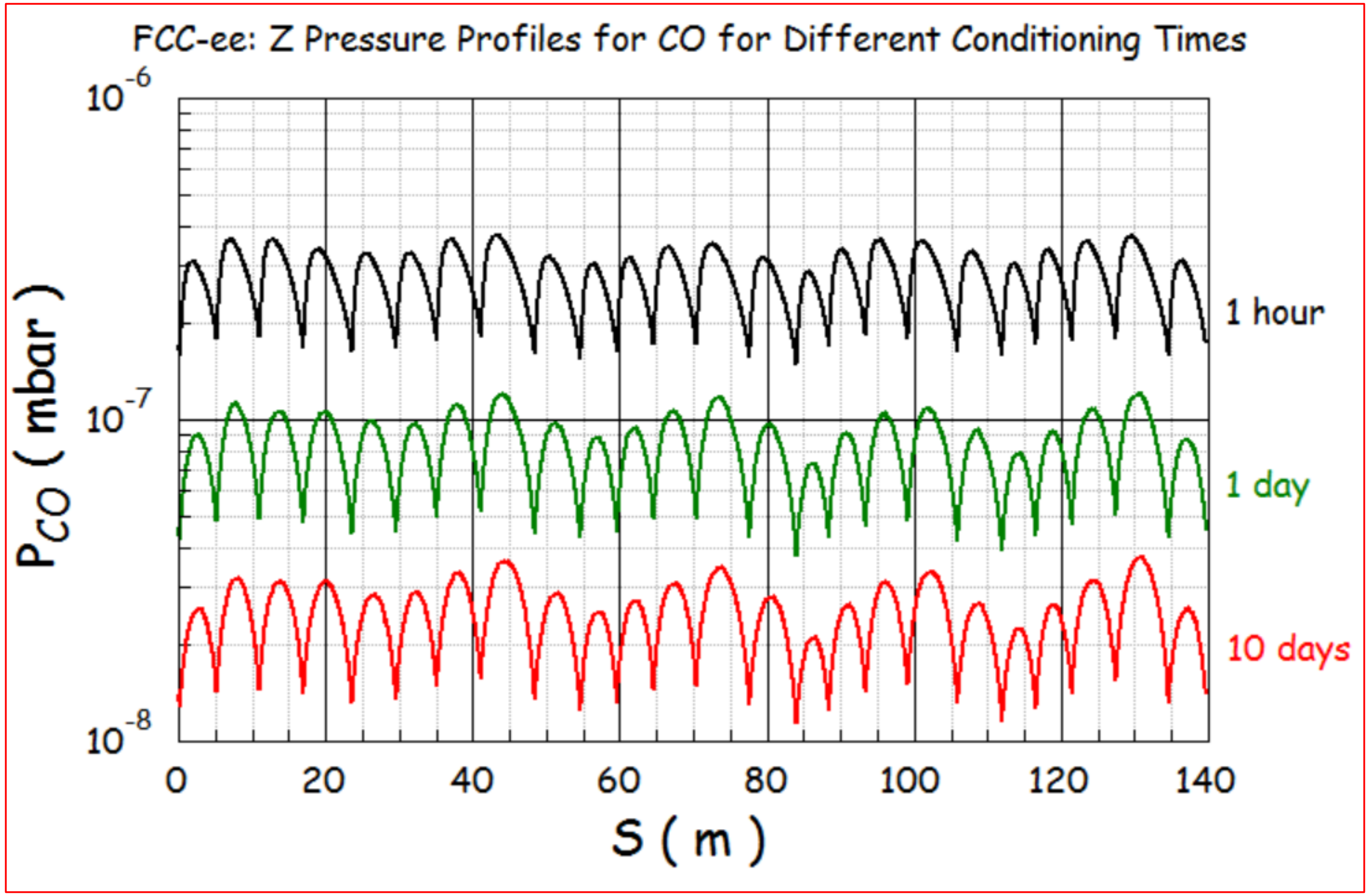
- One ~140 m-long section of the arc lattice (latest optics) has been modelled (5 dipoles of 3 different lengths and 5 quadrupoles)
- Lumped SR absorbers have been placed so that they cover 100% of the primary SR photon fan (i.e. ray-tracing with zero reflectivity, see figure)
- In total, 24 absorbers 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

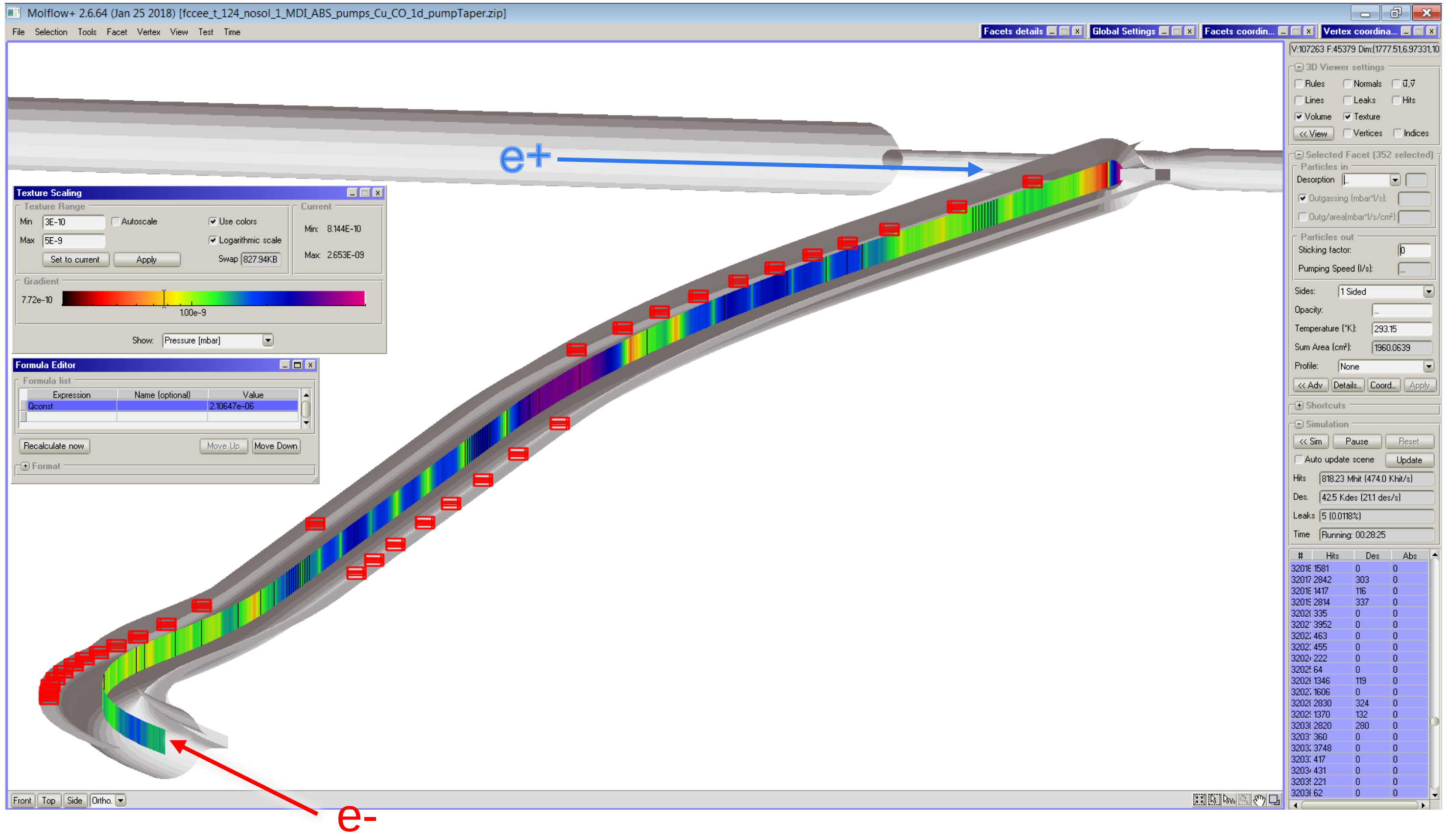
Expected performance, pressure profiles in the arcs

- **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% H_2, ~20% CO and CO_2, and traces of CH_4)**
- **It is assumed here that one NEG pumps is installed upstream of each absorber**
- **Without absorbers (photons hitting all along the external wall), gas load ~4x higher and conditioning time ~ 2.5x longer (not shown here)**



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**



Molflow+ 2.6.64 (Jan 25 2018) [fccee_t_124_nosol_1_MDI_ABS_pumps_Cu_CO_1d_pumpTaper.zip]

Texture Scaling

Texture Range
Min 3E-10
Max 5E-9
☐ Autoscale
☑ Use colors
☑ Logarithmic scale
Swap 827.94KB

Current
Min: 8.144E-10
Max: 2.653E-09

Gradient
7.72e-10
1.00e-9

Show: Pressure [mbar]

Formula Editor

Formula list

Expression	Name (optional)	Value
Qconst		2.10647e-06

V:107263 F:45379 Dim:(1777.51,6.97331,10

3D Viewer settings
☐ Rules ☐ Normals ☐ $\vec{u},\vec{v}$
☐ Lines ☐ Leaks ☐ Hits
☑ Volume ☑ Texture
☐ Vertices ☐ Indices

Selected Facet (352 selected)
Particles in
Desorption: ...
☑ Outgassing (mbar*l/s):
☐ Outg/area(mbar*l/s/cm²):
Particles out
Sticking factor: 0
Pumping Speed (l/s): ...
Sides: 1 Sided
Opacity: ...
Temperature (°K): 293.15
Sum Area (cm²): 1960.0639
Profile: None

Simulation
☐ Auto update scene
Hits 818.23 Mhit (474.0 Khit/s)
Des. 42.5 Kdes (21.1 des/s)
Leaks 5 (0.0118%)
Time Running: 00:28:25

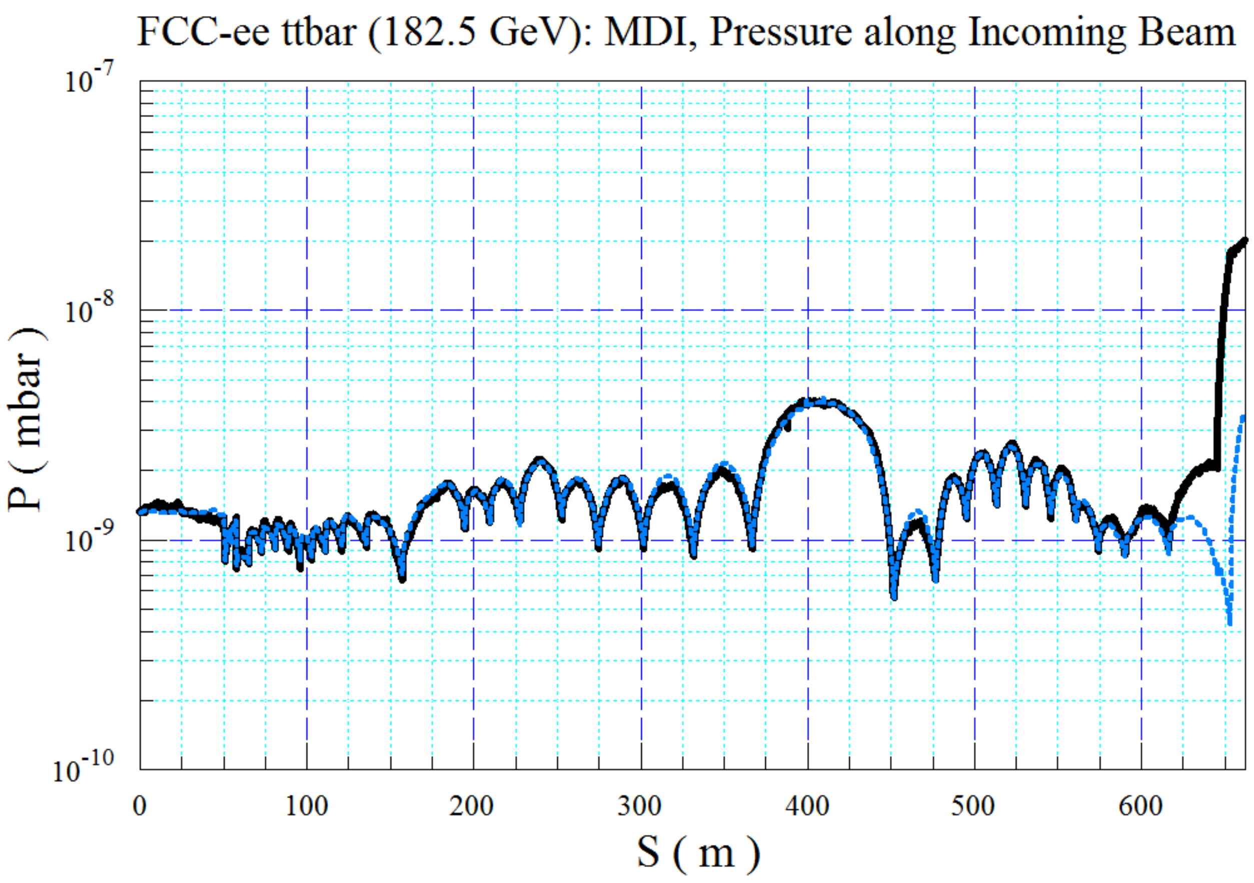
#	Hits	Des	Abs
3201	1581	0	0
32017	2842	303	0
3201	1417	116	0
3201	2814	337	0
3202	335	0	0
3202	3952	0	0
3202	463	0	0
3202	455	0	0
3202	222	0	0
3202	64	0	0
3202	1346	119	0
3202	1606	0	0
3202	2830	324	0
3202	1370	132	0
3203	2820	280	0
3203	360	0	0
3203	3748	0	0
3203	417	0	0
3203	431	0	0
3203	221	0	0
3203	62	0	0

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.**

Q_{PSD}=2.106E-6 mbar*l/s; 1 day at 5.4 mA; 31x pumps with S_{eff} = 110 l/s in front of each absorber

BLACK LINE: P_{avg}=2.00E-9 mbar; BLUE LINE: P_{avg}=1.65E-9 mbar (200 l/s pump at taper)



VACUUM CHAMBER AND SR ABSORBERS: COPPER

Summary and conclusions

1. **Following the developments on the design of the arc magnets and optics, a vacuum chamber cross-section has been chosen**
2. **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)**
3. **Careful ray-tracing and vacuum considerations have convinced us that a lumped absorber design would improve the vacuum performance and shorten the commissioning time**
4. **“Thin” NEG-coating is the baseline choice for e-cloud mitigation and in order to shorten the vacuum conditioning due to SR photon irradiation**
5. **Plan-B e-cloud mitigation options are being considered too: TiN, amorphous carbon, LASE texturing, and clearing electrodes**
6. **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:

- **Interact with lattice people in order to determine the length of the real chambers (dipoles in lattice have lenghts > 20 m, *irrealistic* for fabrication and transport)**
- **Full arc model to pass on to FLUKA team for R2E and tunnel activation studies**

Many thanks to M. Ady, CERN, for support with lattice file conversion and integration into SYNRAD+ code