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FCC-ee vacuum System

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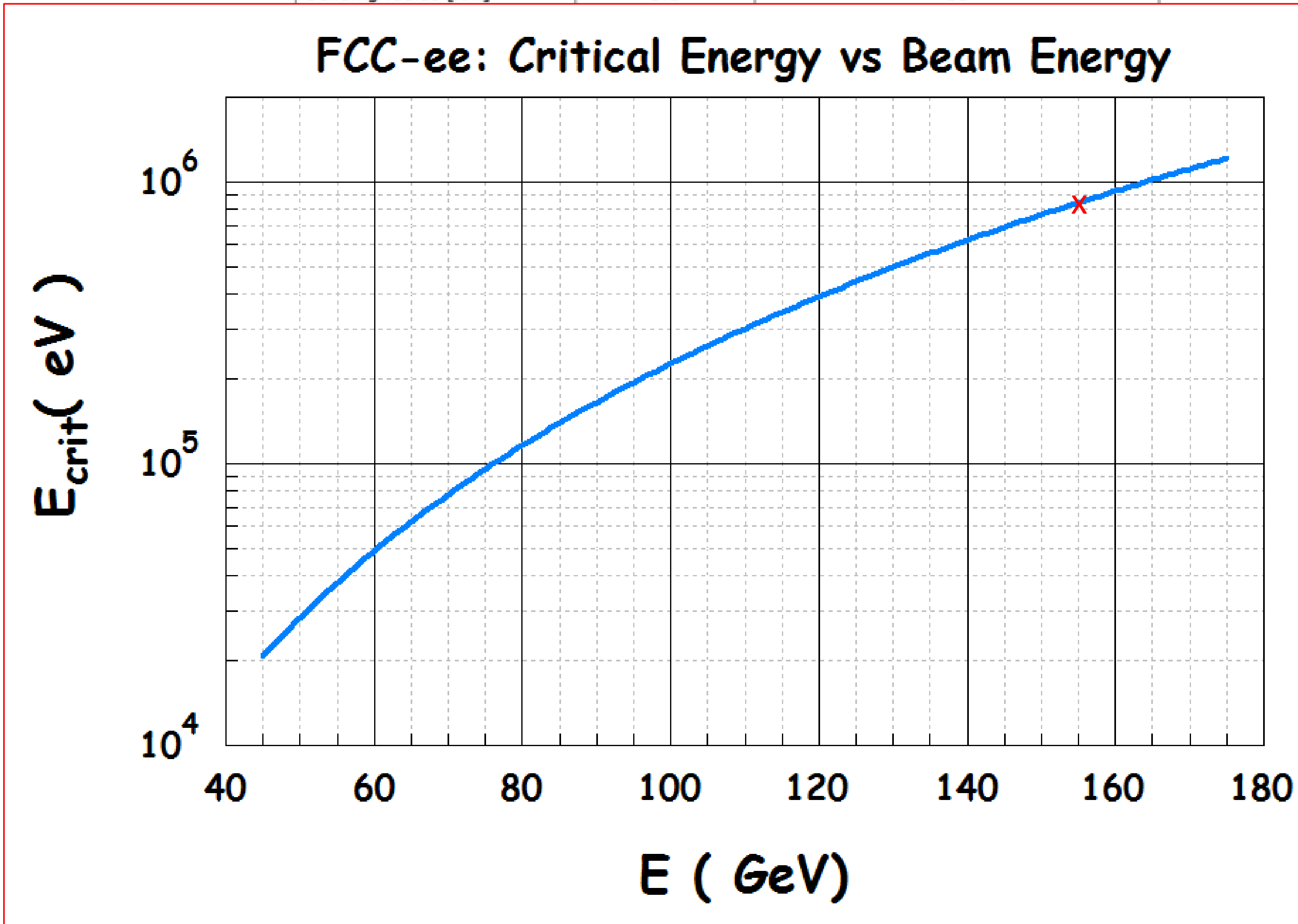
X: LEP-104 GeV

	LEP1	LEP2	Z	W	H	tt
Circumference [km]	26.7		100			
Bending radius [km]	3.1		11			
Vertical	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Luminosity lifetime [min][2]	1250	310	213	52	21	15
Beamstrahlung critical	No		No	No	Yes	Yes



[1] Does not take into account the contribution of damping and emittance wigglers.
[2] The luminosity lifetime corresponds to 4 IPs.

- At the TLEP workshops no. 4 and 6 the different versions of the FCC-ee accelerator have already been discussed in terms of SR spectra, flux, power and their linear and surfacic densities (see bonus slides)
- Vacuum-wise the most challenging is the Z-pole machine at 45.5 GeV, due to its extremely large beam current, 1450 mA

Outgassing:

- Under the assumption of a large bending radius and no lumped absorber (à-la LEP) the specific outgassing rate **Q(mbar · l/s/m)** is related to the linear photon flux **F(ph/s/m)** by the formula:

$$Q = \eta \cdot F \cdot k$$

- where η is the photon-induced desorption (PID) rate **(mol/ph)** and **k** is a conversion factor **(mbar·l/mol)**, k=4.05E-20 (@ 20 °C).
- The linear photon flux is: **F = 8.08E+17 · E(GeV) · I(mA) / (2πρ)** , with ρ = 9791.21 m; for **FCC-ee Z**, **F** = 5.3E+22/ (2πρ) = 5.3E+22/ 6.16E+4 = **8.6E+17 (ph/s/m)**
- This leads to **Q** = η · 8.6E+17 · 4.05E-20 = **η · 3.48E-2 (mbar*l/s/m)**
- η varies over several orders of magnitude **(~1E-2 → ~1E-7)**: it depends on the material, cleaning procedures, surface finish, any eventual coatings, bake-out temperature, and most of all it depends on the **integrated photon dose (ph/m)** at a given location (determined by the geometry of the vacuum chamber and any photon absorbers, **accounting for photon scattering**)
- For a given/needed average pressure along the ring, dictated by machine-physics issues, such as beam-gas scattering lifetime, beam-loss and related energy deposition, e-cloud (for the e^+ beam), etc… **it is therefore important to get as quickly as possible a low η**

- This reduction can be obtained by collecting the photon flux on **short discrete absorbers** (like done on most modern light sources), and installing near the absorbers as much pumping speed as possible (compatibly with conductance limitations)
- To improve things even further, **NEG-coating** would be beneficial, as it possesses an **intrinsically low PID yield** (>2 orders of magnitude lower than un-coated surface)
- **NEG-coating would also be beneficial in reducing the e-cloud in the e^+ ring**
- Other possibility is given by **TiN-coating**, as employed on a large scale at KEK-B and SuperKEKB as well, although TiN does not give a PID yield reduction, and therefore needs to have some sort of effective pumping installed along with it. **Same for a-Carbon** and the **Laser-Engineered Surface Structures (LESS).**

Pumping:

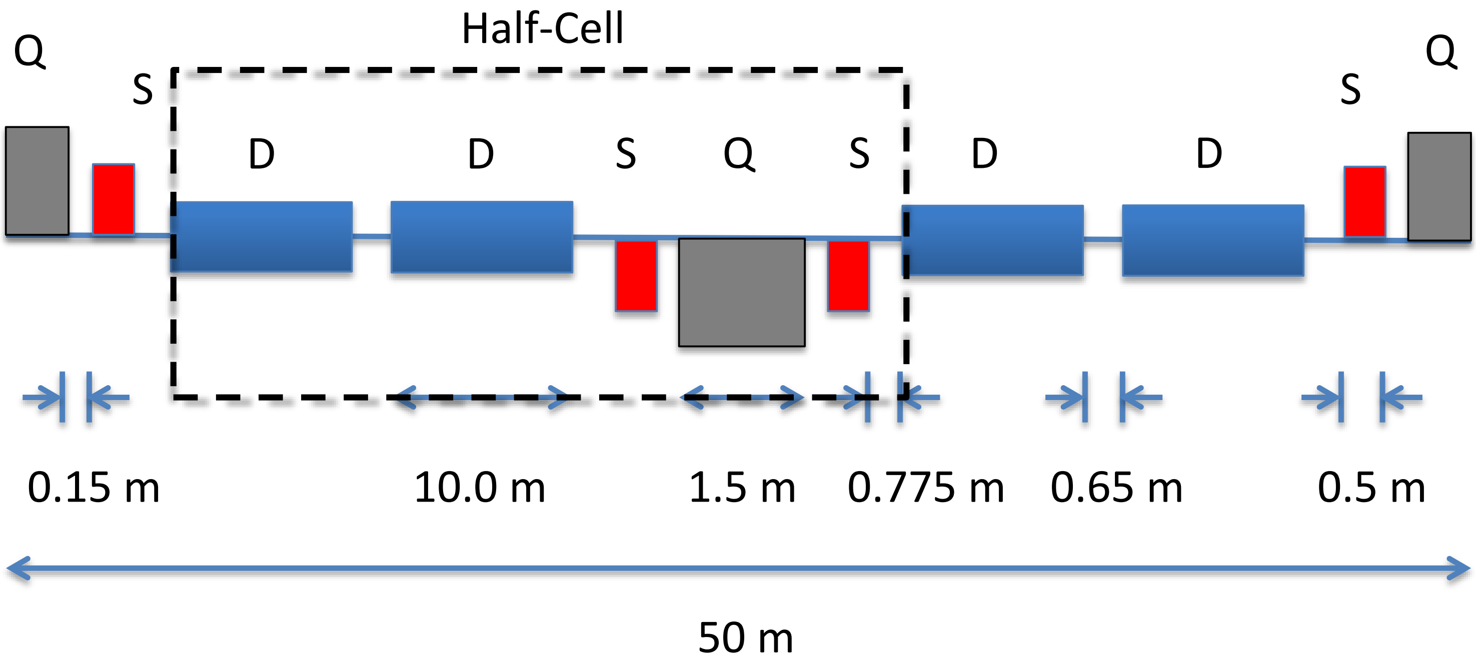
- **Lumped pumping** (number of pumps depending on the conductance of the vacuum chamber) can be prohibitively expensive for a 100 km-long machine
- **Distributed pumping** can be implemented only via NEG-strips (like LEP did), as the magnetic field of the dipoles is too weak for implementing distributed ion-pumps (like the US B-Factory did for the high-energy ring, or CESR at Cornell)
- Distributed pumping can also be obtained by applying **NEG-coating** (like in the LHC's LSSs)
- The advantage of distributed pumping vs lumped pumping is that the former does not depend on the conductance of the chamber, while the latter does
- In-situ bake-out is highly recommended, and probably necessary in order to obtain rapidly a low-Z residual gas composition. **It is mandatory in case of NEG-coating.**

Conceptual proposal:

- Based on the considerations outlined above, a conceptual design has been proposed which implements **localized SR absorbers** (to speed-up the conditioning time and minimize photon scattering)
- Another important feature of the localized absorbers is that they allow concentrating the **Compton-scattered flux** (especially for the very-high energy machines), which could constitute a potential source of activation in the tunnel and damage to the magnet coils and any sensitive electronic equipment, in addition to the formation of ozone and related corrosion (see L. Lari's presentation at 6^{th} TLEP Workshop, and F. Cerutti at FCC Kick-Off, Univ. Geneva)
- The proposed cross-section of the vacuum chamber is **elliptical, 90x30 mm^2 (HxV)**
- The material of choice is **copper, 2 mm-thick** (C. Garion, TE-VSC, has checked its mechanical fitness under bake-out conditions: OK)
- Aluminium could also be a choice, but it is much more transparent to penetrating gamma rays, possibly requiring additional distributed shielding (like LEP). Aluminium has also a higher PID as compared to copper, in case of non-NEG-coated chamber
- The interconnecting space between dipoles and between dipoles and quadrupoles has been used to install **SR photon absorbers** (**with heavy shielding**), bellows, BPMs, pumping ports, flanges, connections for water cooling of the chambers/absorbers, and the necessary anchoring fixed points, **as schematized below**:

FODO Cell – V16

(B.Harer, CERN)



D = Dipole, L = 10 m

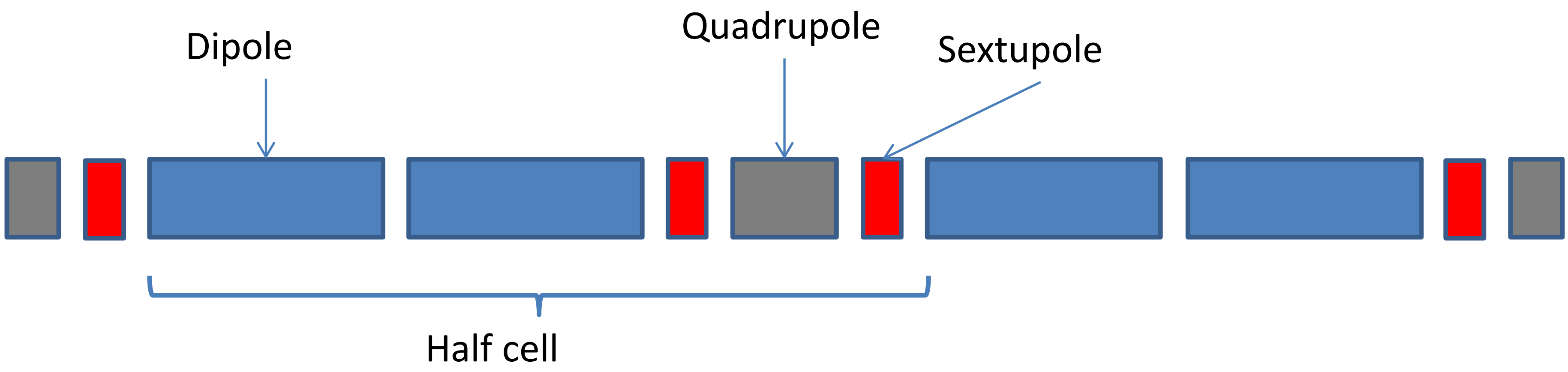
Q = Quadrupole, L = 1.5 m

S = Sextupole, L =0.5 m

→ Total number of dipoles: 2x 6152 ←

Courtesy: B. Harer

TLEP cell layout



Assumptions:

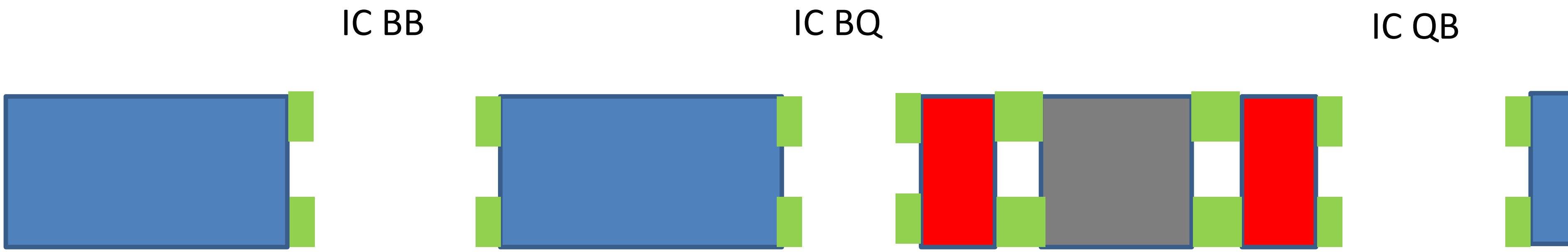
1 Absorber, 30~35 cm long, downstream of the dipole

Dipole length: ~ 10 m

Quad length: ~ 1.5 m

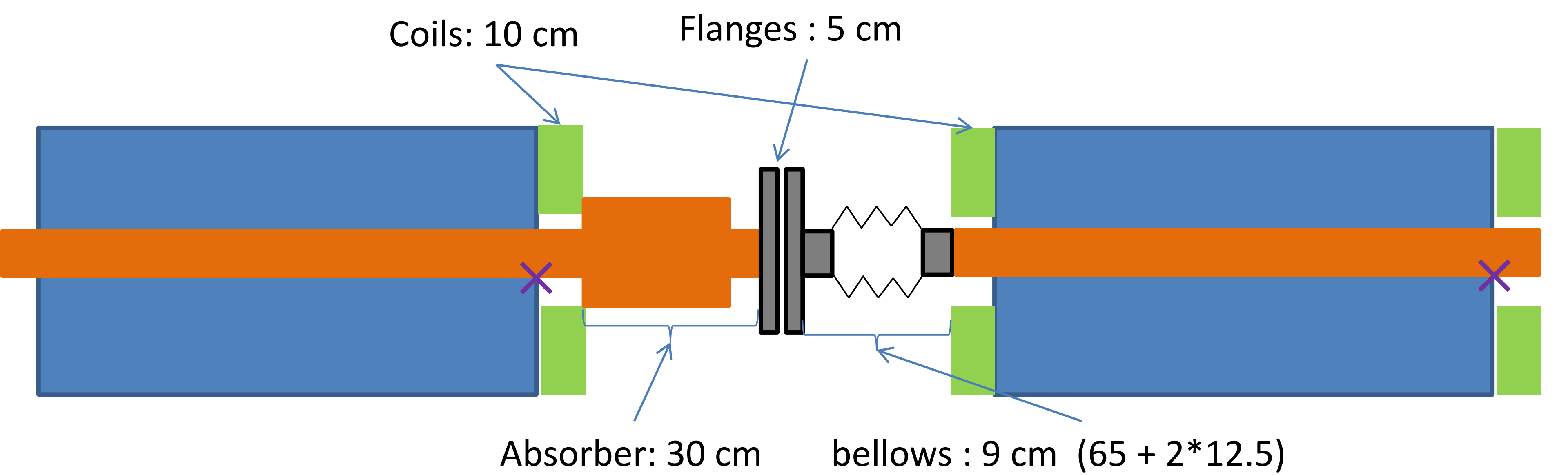
Courtesy: C. Garion

Interconnection types and naming convention



Assumptions:
Quadrupoles and sextupoles with the same chamber and on **same girde**r (two halfs?)

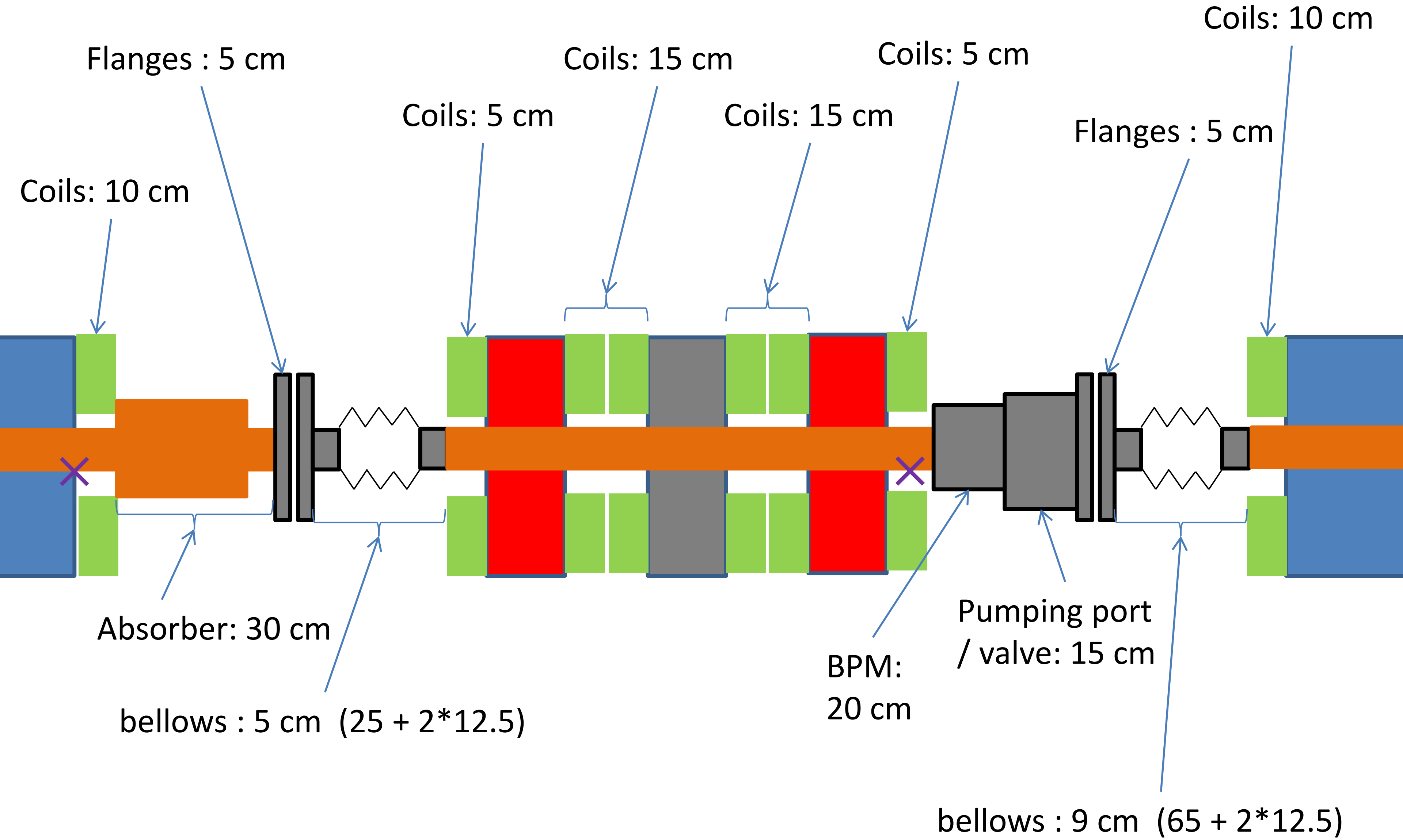
Interconnection BB



→ IC BB: ~ 65 cm

Courtesy: C. Garion

Interconnections BQ and QB (conceptual, dimensions subject to change)

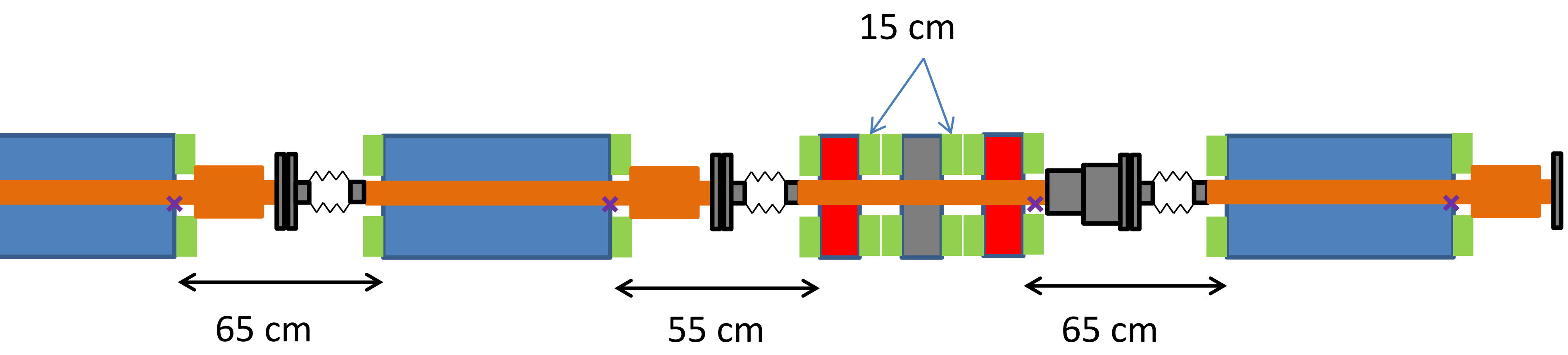


→ IC BQ: ~ 55 cm

→ IC BQ: ~ 65 cm

Courtesy: C. Garion

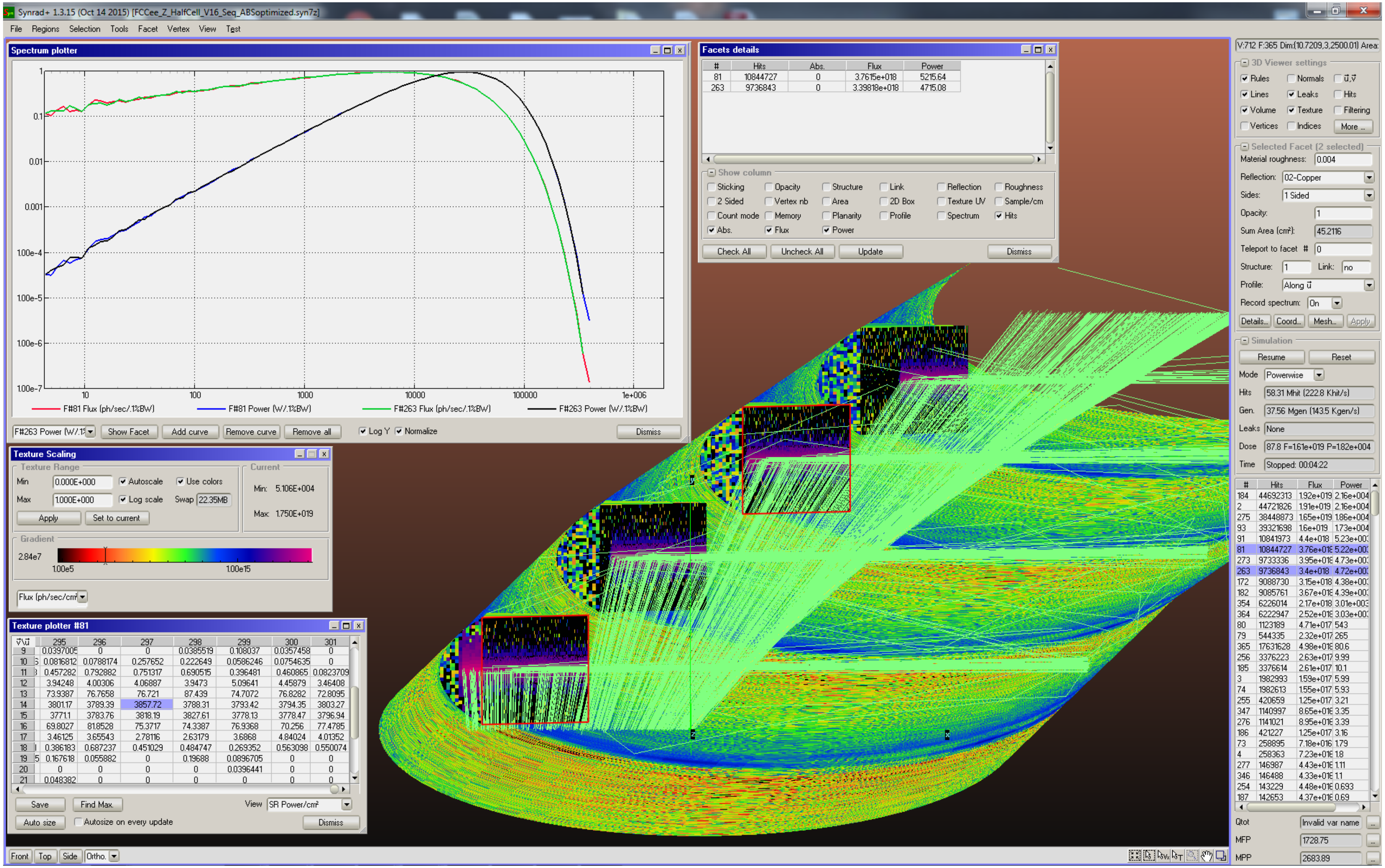
Half cell (conceptual, dimensions subject to change)



L_interconnection: 185 cm (coils extremities included)

Courtesy: C. Garion

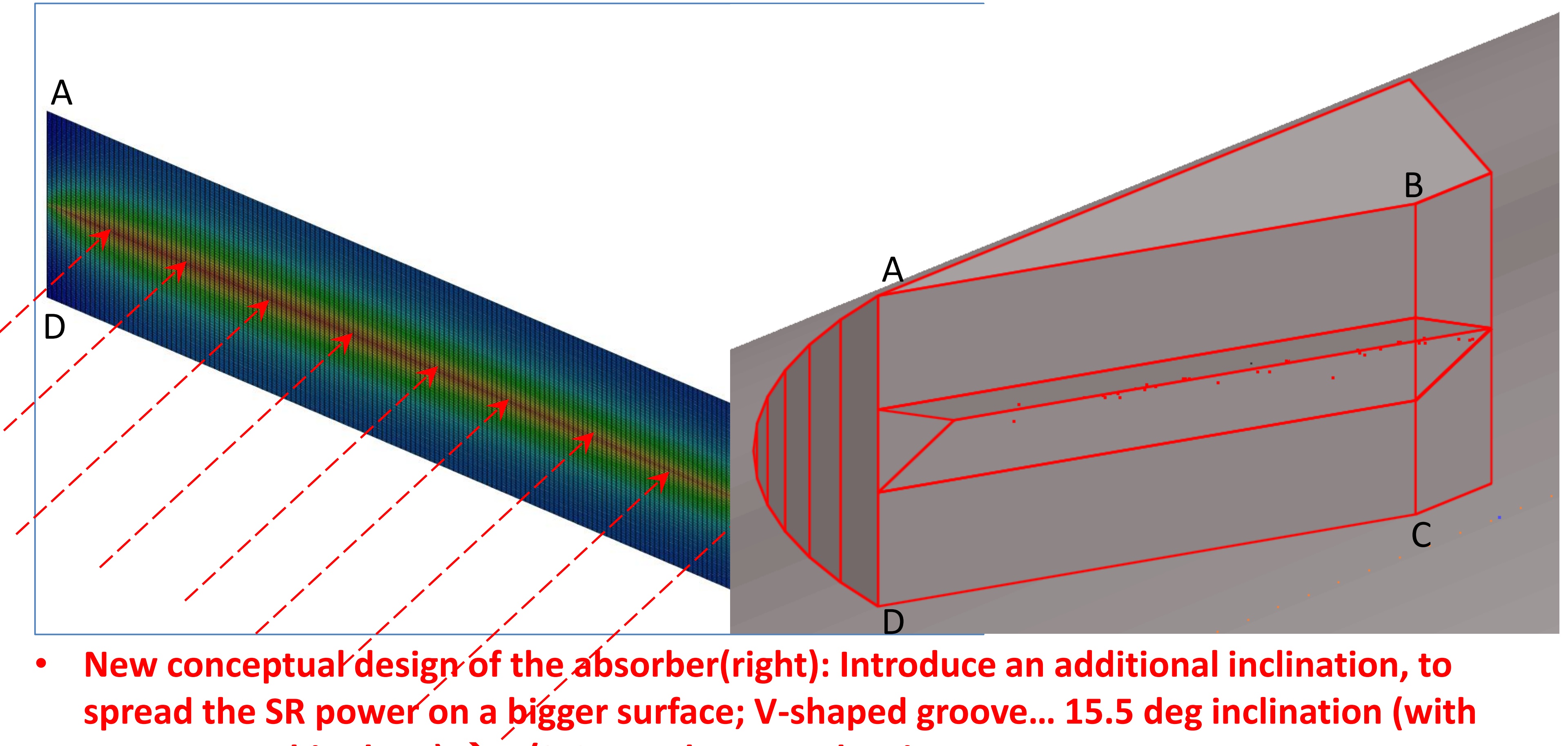
Photon ray-tracing: 175 Gev tt vs 45.5 GeV Z



- 30 cm-long wedge-shaped absorbers (Cu or GlidCop); One placed inside each 10m-long dipole, plus 1 in the 0.65m-long dipole-dipole IC and 1 in the IC BQ (or IC QB)
- Distance between tip of absorber and beam axis is 24 mm
- **The photon flux of the Z-machine is >50 times higher than that of tt!**

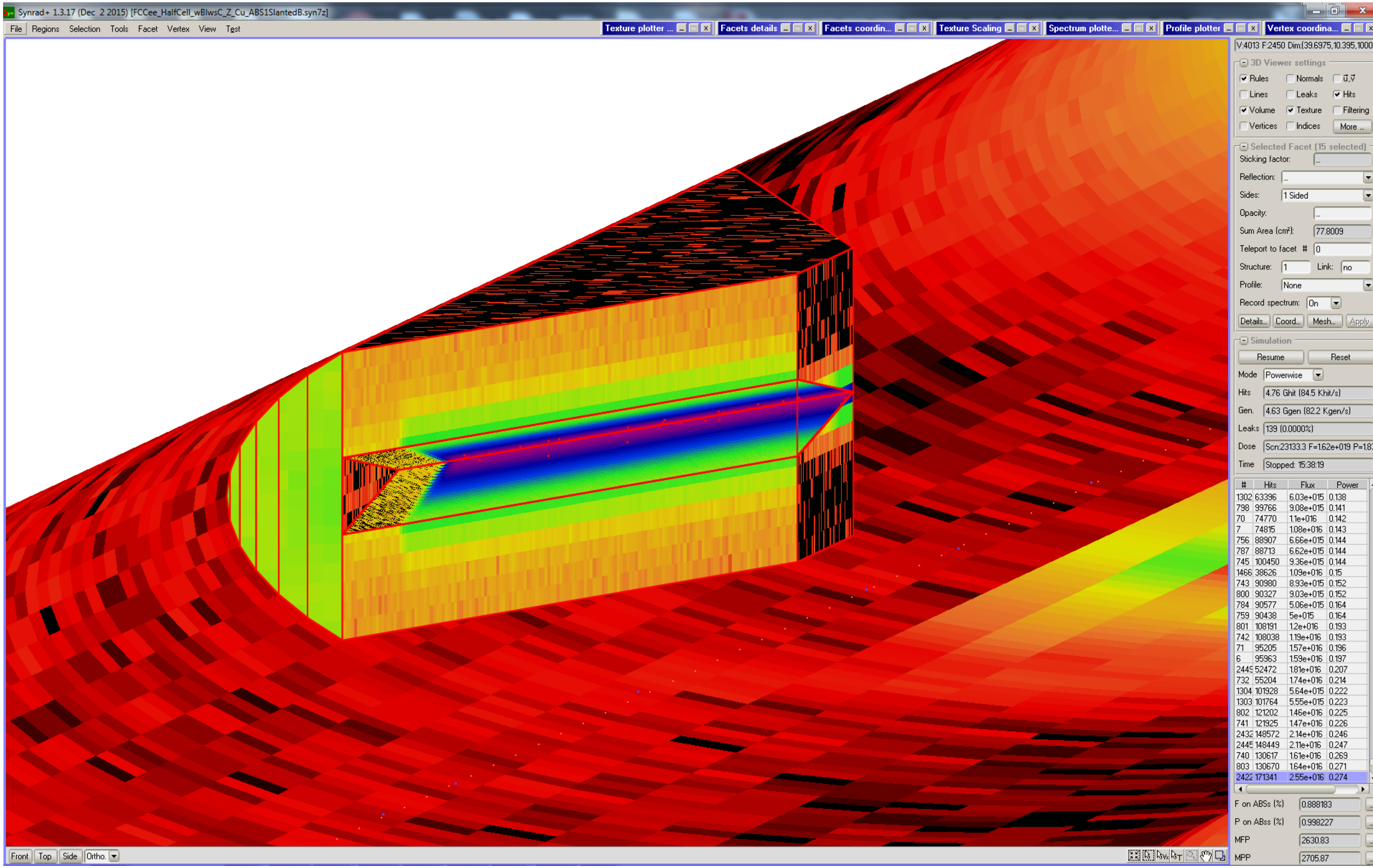
Photon ray-tracing: 175 Gev tt vs 45.5 GeV Z

- Flat absorber inclined only around a vertical axis is not sufficient: the power density (W/mm²) is locally too high, would probably need GlidCop instead of OFH copper



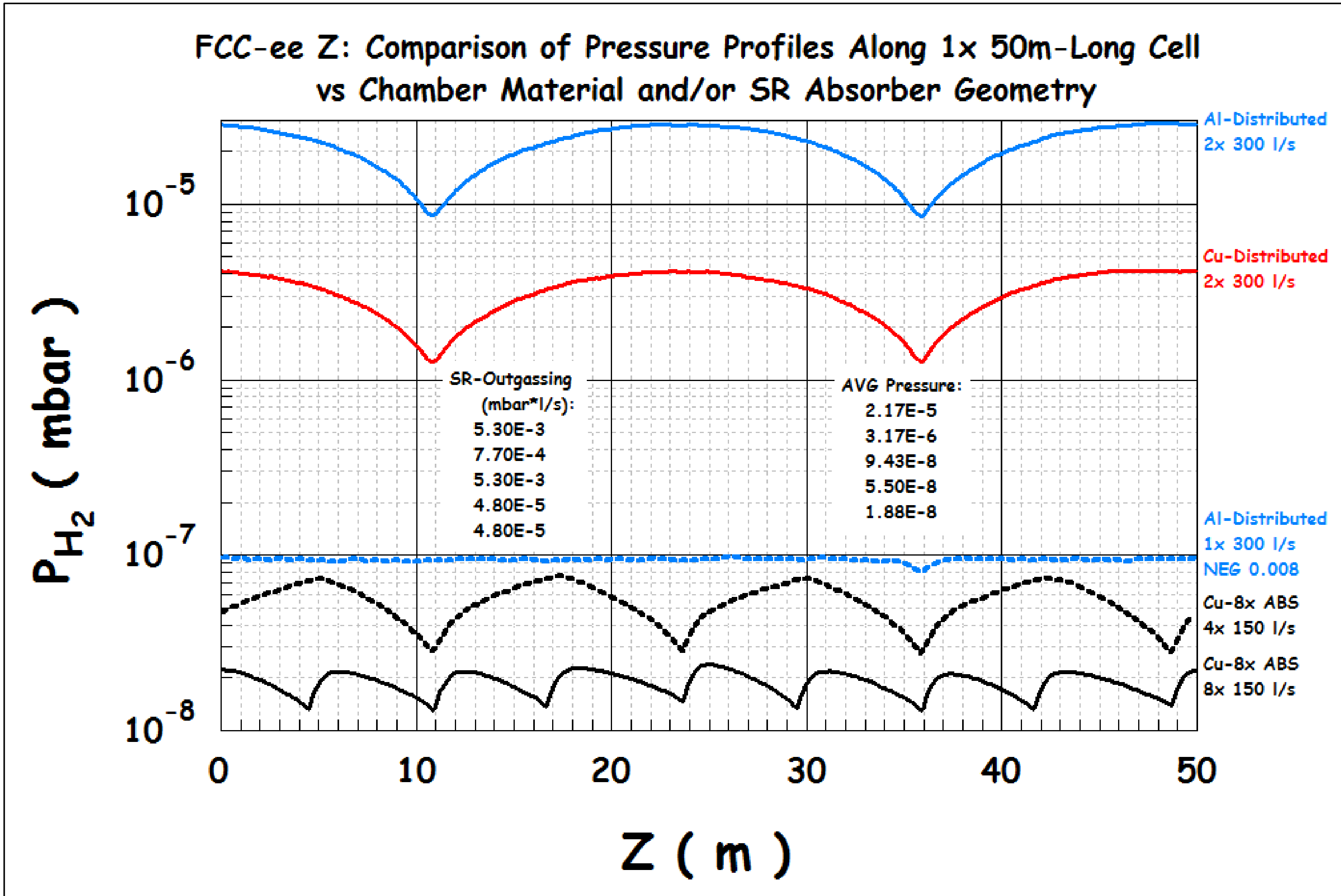
- **New conceptual design of the absorber(right): Introduce an additional inclination, to spread the SR power on a bigger surface; V-shaped groove… 15.5 deg inclination (with respect to orbit plane) → 1/3.6 x peak power density**
- **Groove dimensions: 4 mm high, ~ 150 mm-long**

Photon ray-tracing: 45.5 GeV Z



- 35 cm-long wedge-shaped absorbers (Cu or GlidCop) with V-groove to reduce power density;
- Analysis of temperature distribution in case of **vertical misalignment** under way;

Pressure Profiles for Different Pumping/Material/Coating Choice



Conclusions and to-do list:

- A preliminary cost-analysis NEG-coating vs lumped pumping has been carried out, based on the cost of LEP and the experience gained on the extensive NEG-coating of the LHC's LSSs
- Based on this, it is argued that **NEG-coating is an economically attractive option** w.r.t. the lumped pumping one (no explicit cost estimate mentioned here)
- A closer look at the sectorisation of the vacuum system should be given, especially in terms of total electric power needed in the tunnel during bake-outs
- R&D on bake-out heating systems capable of sustaining the high-radiation background near the shielded absorbers needs to be carried out (removable jackets?)
- Prototyping of the welding (brazing?) joint between Cu chamber and absorbers needs to be done
- The **extremely high vertical collimation** of the SR power generated by the W and tt machines is difficult to simulate experimentally: **$1/\gamma$ of the order of 3 μrad**, i.e. **+/- 40 μm SR fan projected at 26.5 m**! (tt case), slightly diluted by the beam size and lattice functions
- The calculated SR power density (W/mm^2) is a bit higher than that of the crotch absorbers of existing light sources (ref. ESRF 3-Tesla wiggler absorber: peak power density **~ 210 W/cm^2**; material GlidCop): need careful optimization of the geometry of the absorbers and their cooling (high water flows with concomitant corrosion issues and neutron production) (collab. FLUKA team)
- Effect of the periodic arrangement of the protruding SR absorbers (and their shape) on the **geometric impedance budget** is being carried out (collab. Univ. Rome)
- Integration of conceptual design with cross-section of magnets
- **Booster:** waiting for details about the magnets' size and lattice
- **By Rome's FCC Workshop, the FLUKA and geometric impedance analysis and results will be integrated in this presentation**

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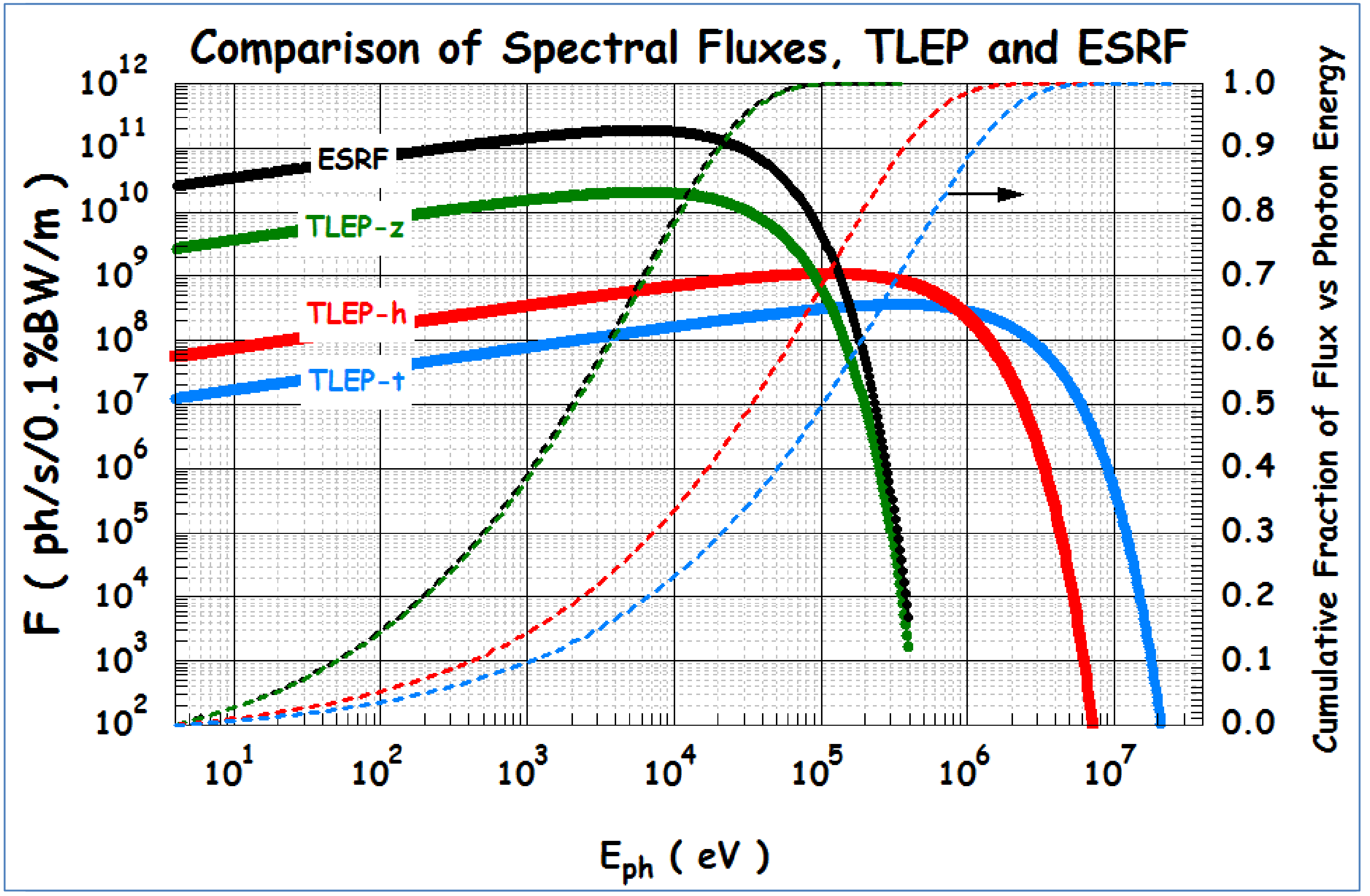
BONUS SLIDES

Update on TLEP Vacuum Design

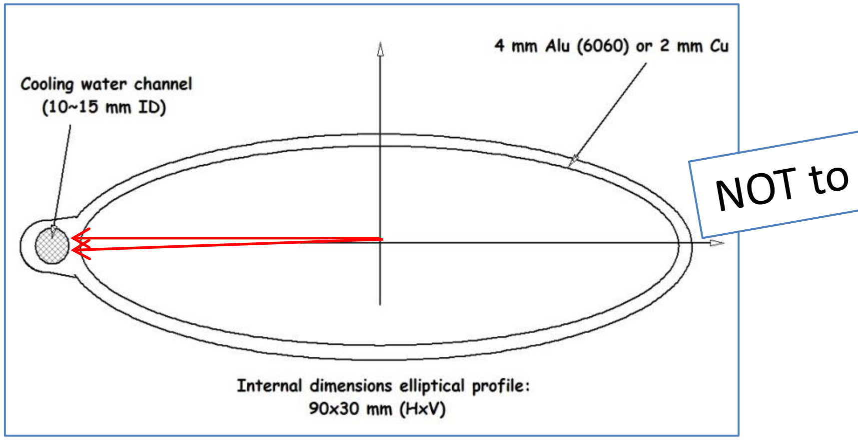
- **SR Spectra, Linear Power Densities**

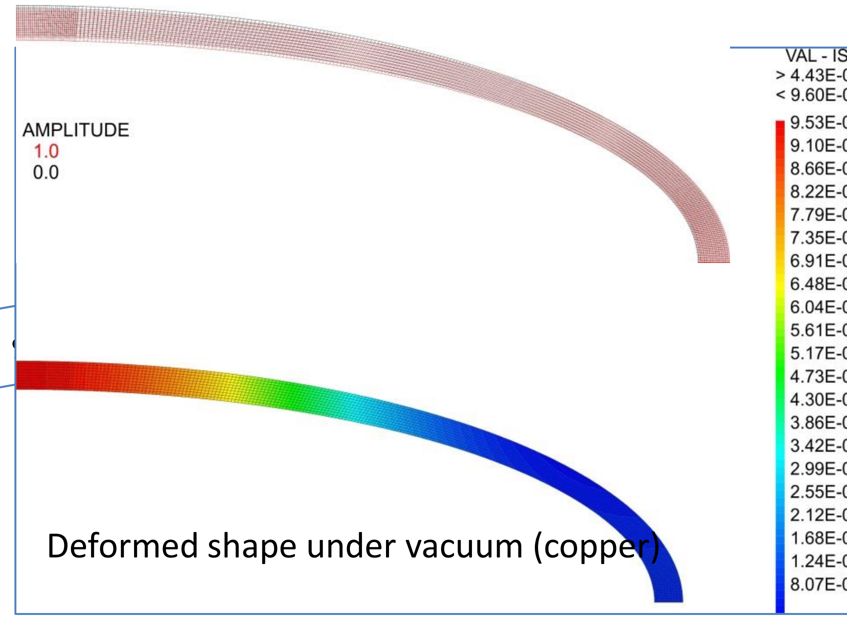
- The SR spectrum of TLEP-t and –h, are compared to the spectrum for LEP-2 and that of the 6 GeV ESRF light source



Update on TLEP Vacuum Design

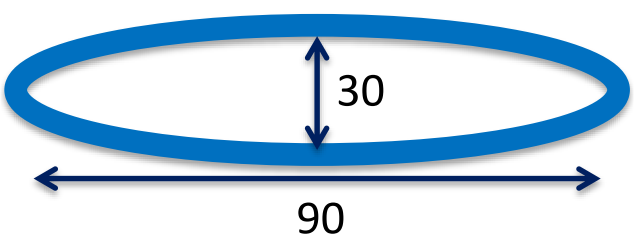
- **Conductances, Pressure Profiles**
- 90x30 mm2 elliptical cross-section

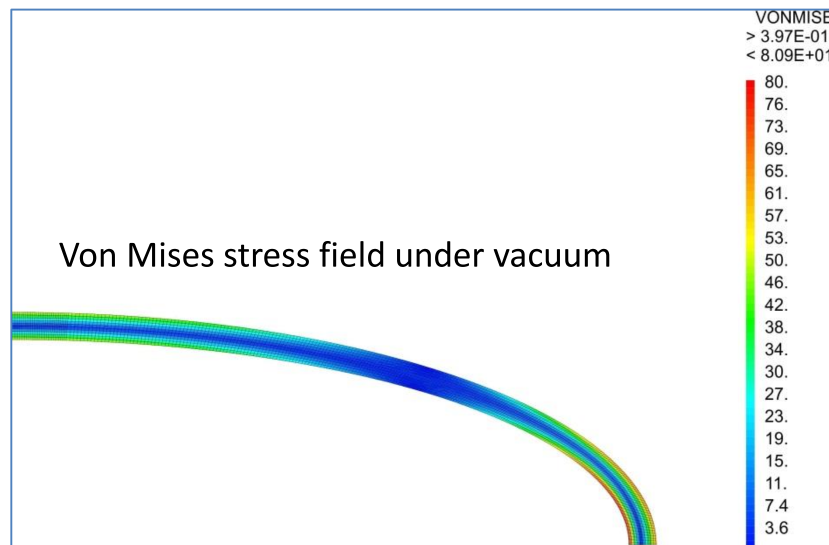




→ A minimum thickness of 2 and 4 mm is considered for copper and aluminium, respectively.

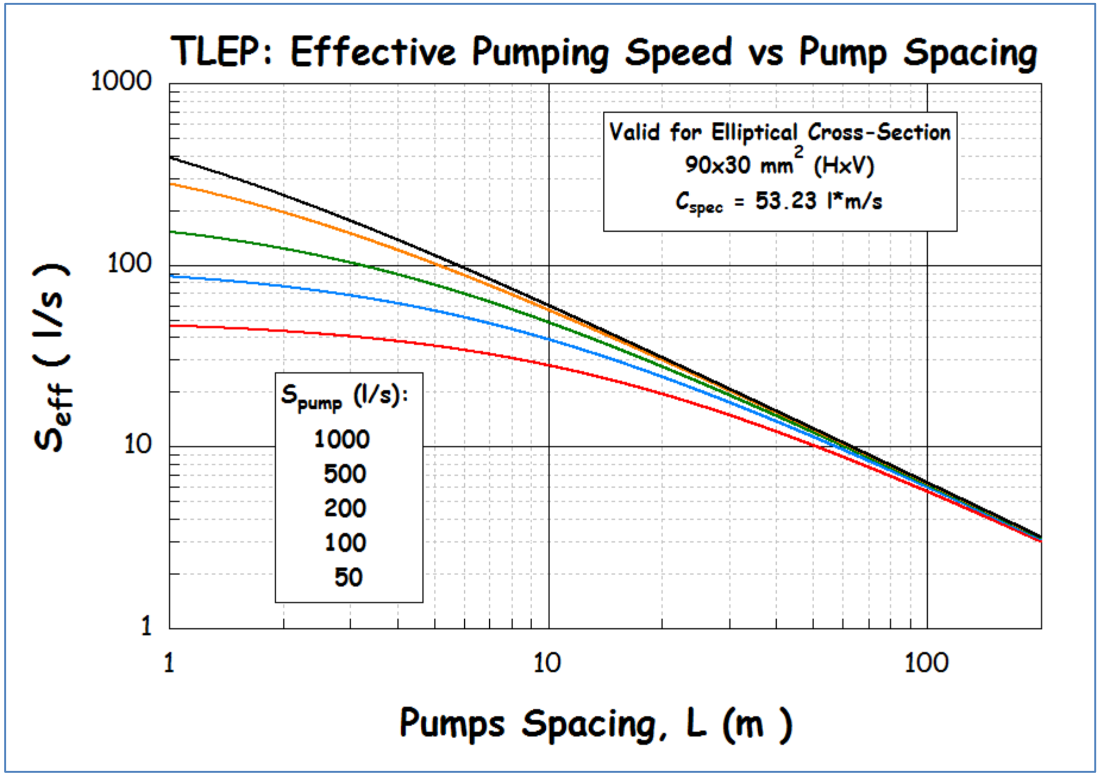
Cross section





Update on TLEP Vacuum Design

- **Conductances, Pressure Profiles**
- The specific conductance of a 90x30 mm² elliptical cross-section is 53.23 l*m/s
- In a uniform cross-section tube with uniform outgassing, a regular pump spacing of L meters will decrease the installed pumping speed S_{inst} via the well known equation
- $S_{eff} = (1/S_{inst}+L/12/C_{spec})^{-1}$



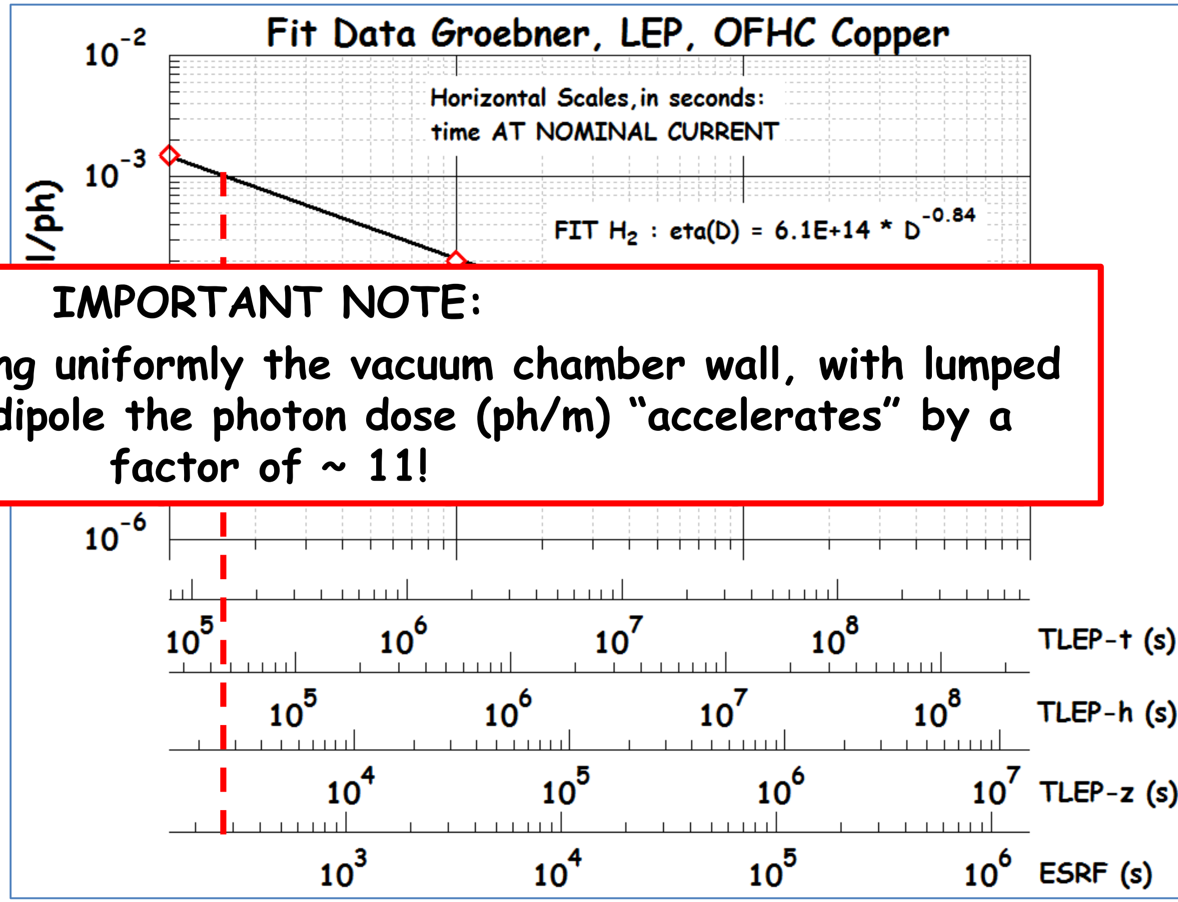
<u>It doesn't pay to install large pumps,as the conductance will "kill" the pumping speed!</u>

<u>1000 l/s pumps spaced ~ 11m apart will give only a ~53 l/s effective speed</u>

Update on TLEP Vacuum Design

- **Vacuum Conditioning Time**
- The photodesorption yield data measured for copper (previous figure) are fitted and used to find the "conditioning time at full nominal current " for the 3 versions of TLEP and, for reference, for the ESRF

	LEP2	TLEP-t	TLEP-h	TLEP-z	ESRF
Energy (GeV)	104	175	120	45.5	6
Current (mA)	4	5.4	24	1,180	200
Radius (m)	3096	**9569.5**	**9569.5**	**9569.5**	23.4
E_{crit} (eV)	805,862	1,242E+6	4.005E+5	21,833	20,504
Total Flux (ph/s)	3.36E+20	7.64E+20	2.33E+21	4.34E+22	9.70E+20
Total Powe (MW)					
Spec. Flux (ph/s/m)					
Spec. Powe (W/m)					
Specific Outgassin (mbar·l/s/m) **(mol/ph)**					

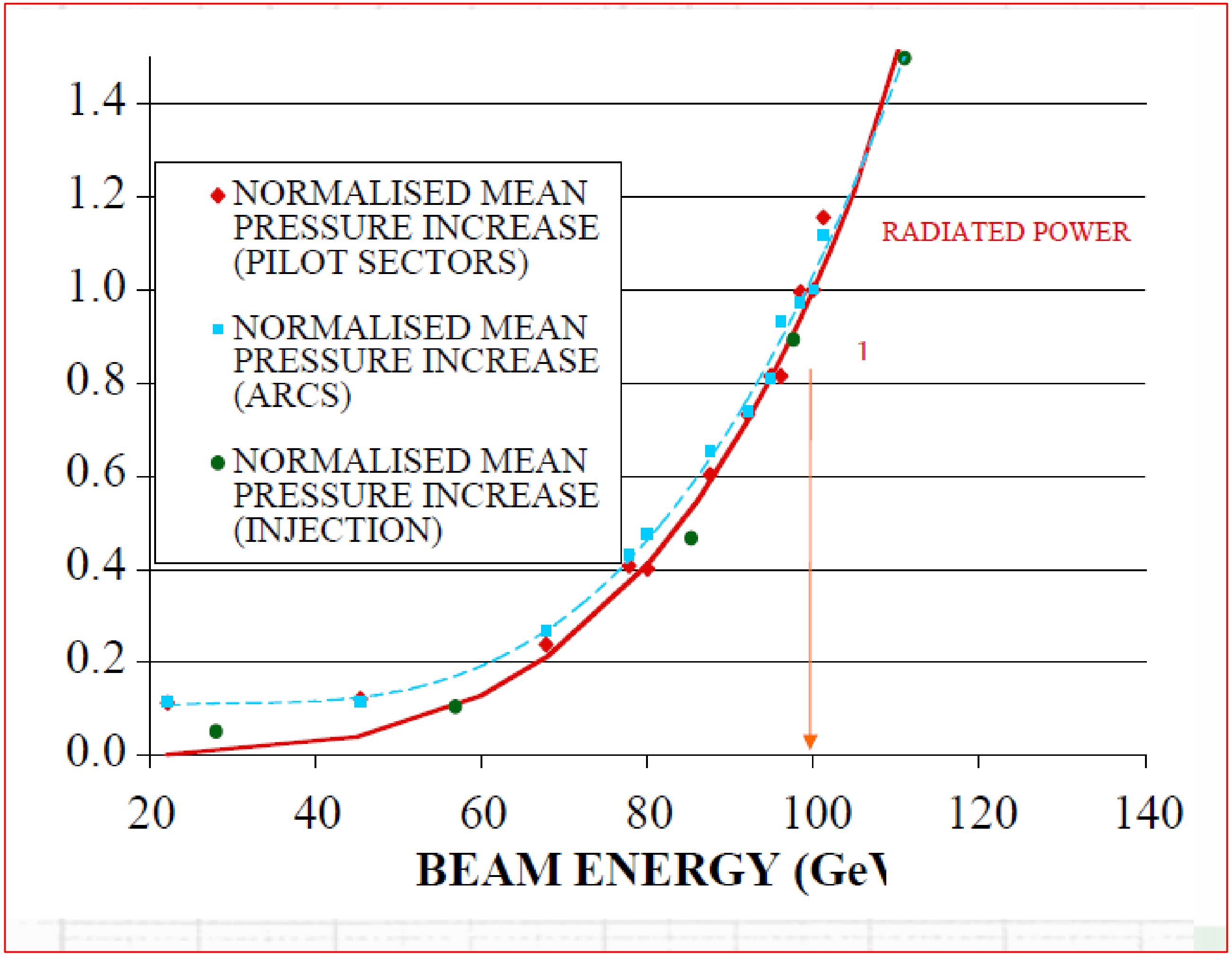


IMPORTANT NOTE:

This is valid for SR hitting uniformly the vacuum chamber wall, with lumped absorbers after each dipole the photon dose (ph/m) "accelerates" by a factor of ~ 11!

- **Example: in order to get to eta=1.0E-3 mol/ph, one would have to fill the ring at nominal current for 130k sec for TLEP-t, 46k sec for TLEP-h, 1600 sec for TLEP-z, vs 300 sec for the ESRF dipole**

Update on TLEP Vacuum Design



- Behaviour of the pressure in LEP and LEP-2 vs beam energy and SR power (N. Hilleret, CAS Vacuum 2006)

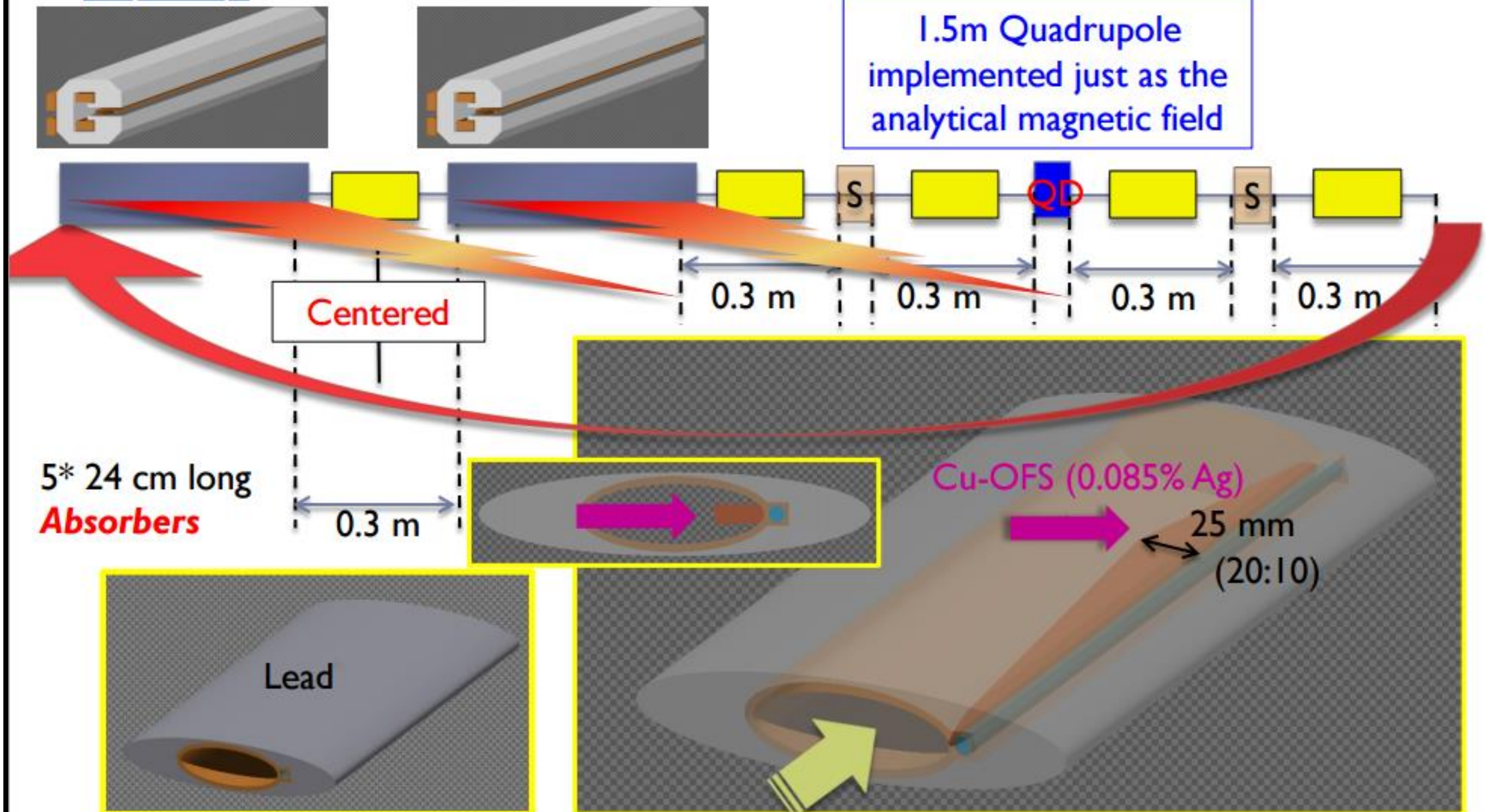
FLUKA status and plan

Sixth TLEP workshop
CERN, 16 -18 October 2013

F. Cerutti#, A. Ferrari#, L. Lari*, A. Mereghetti#
#EN Dept. & *BE Dept.

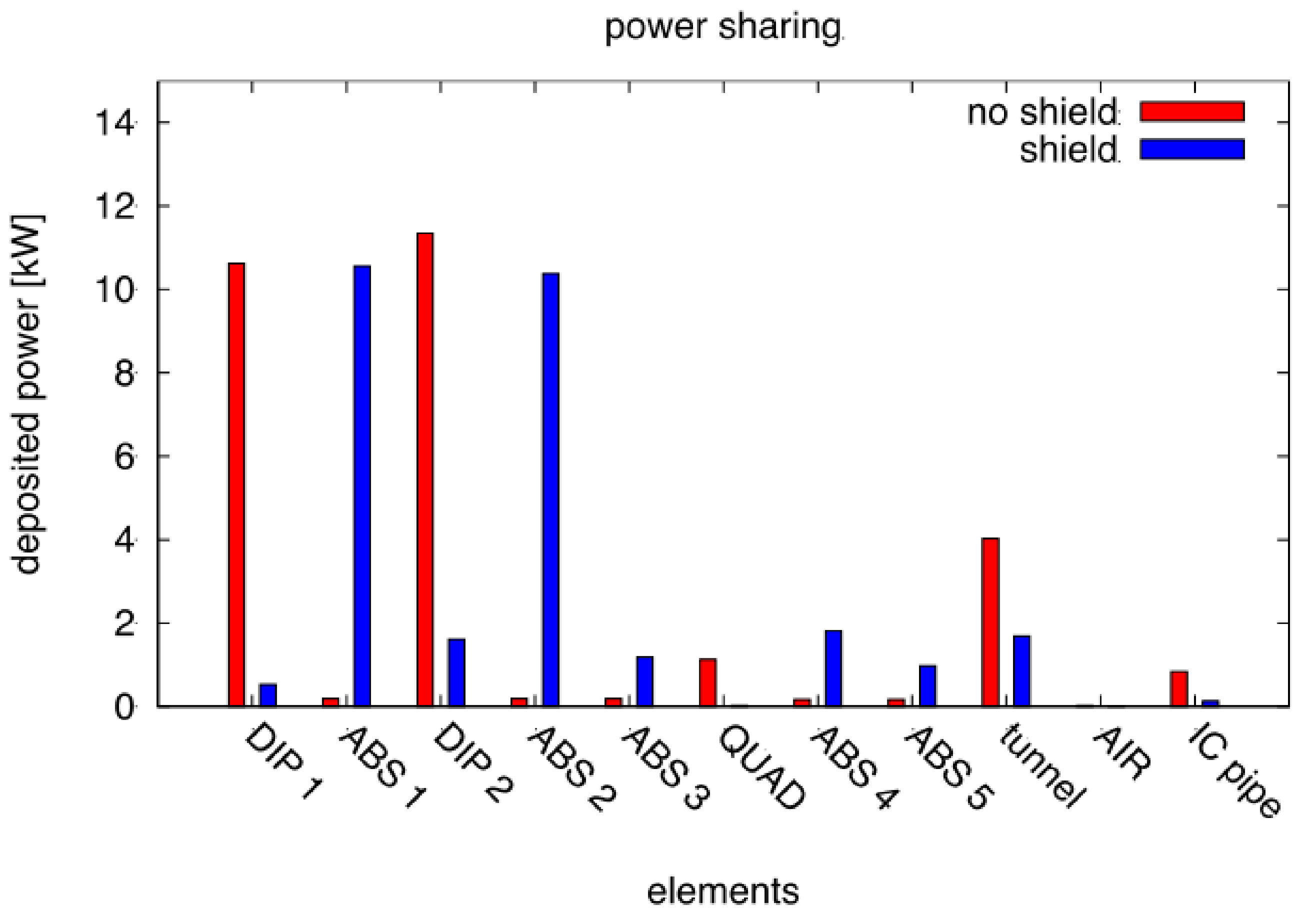
FLUKA model: summarizing

1.5m Quadrupole implemented just as the analytical magnetic field

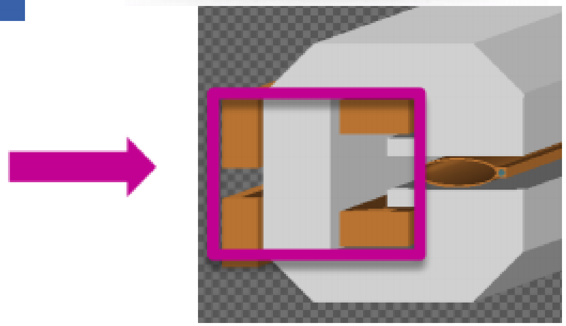


Total power

All results take into account a Beam current = 10 [mA]



Dose in the coils



Averaged along the Dipole length