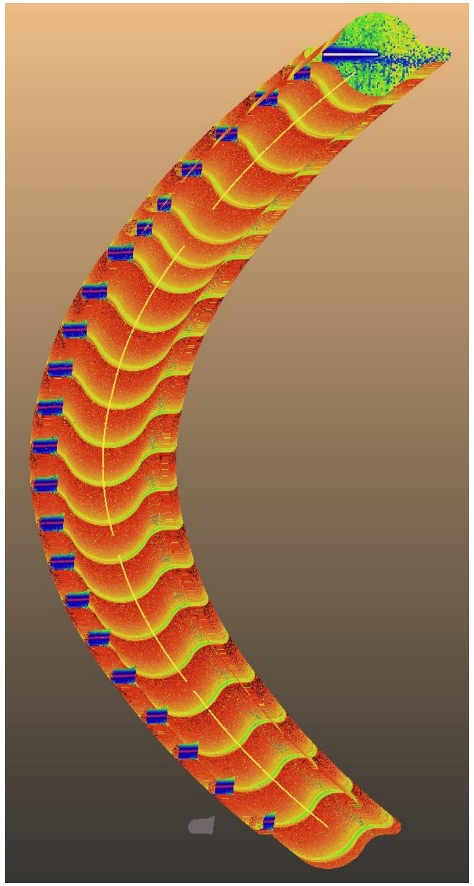
FCC

SYNCHROTRON RADIATION MANAGEMENT, PRESSURE PROFILES

Marton ADY, CERN

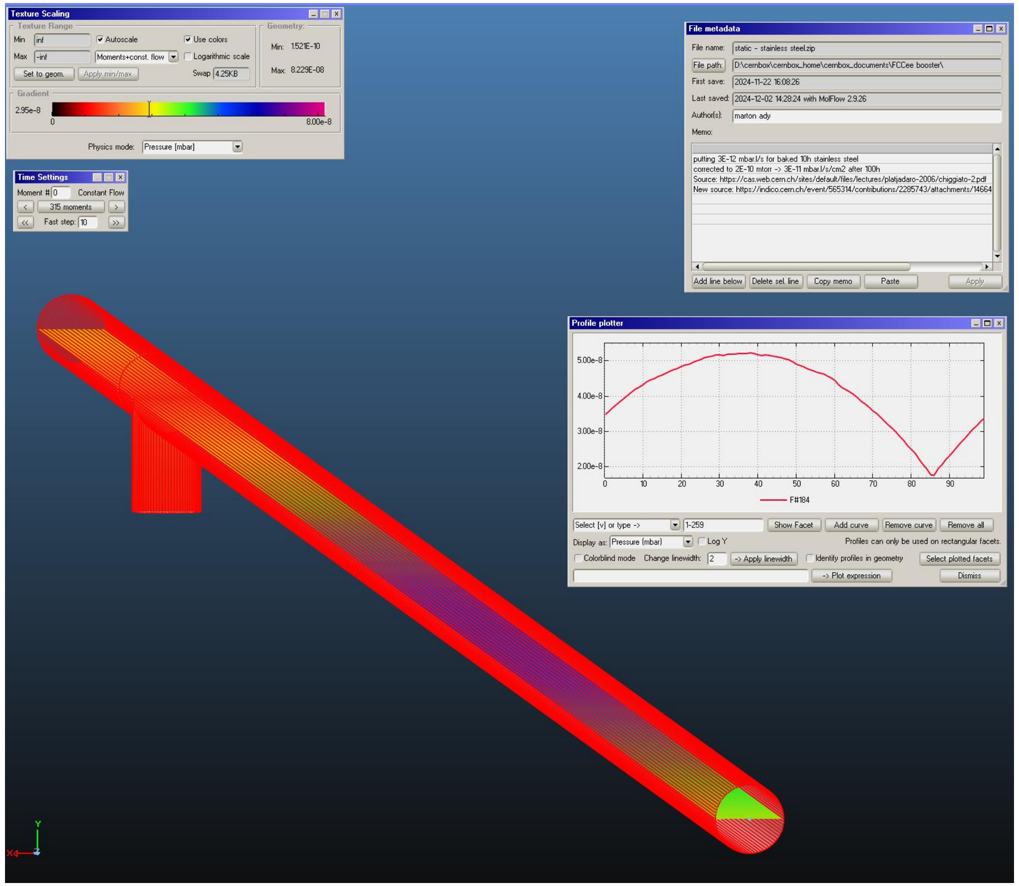
FCC Week, Vienna, 21-05-2025

Collider ring



Absorber placement study

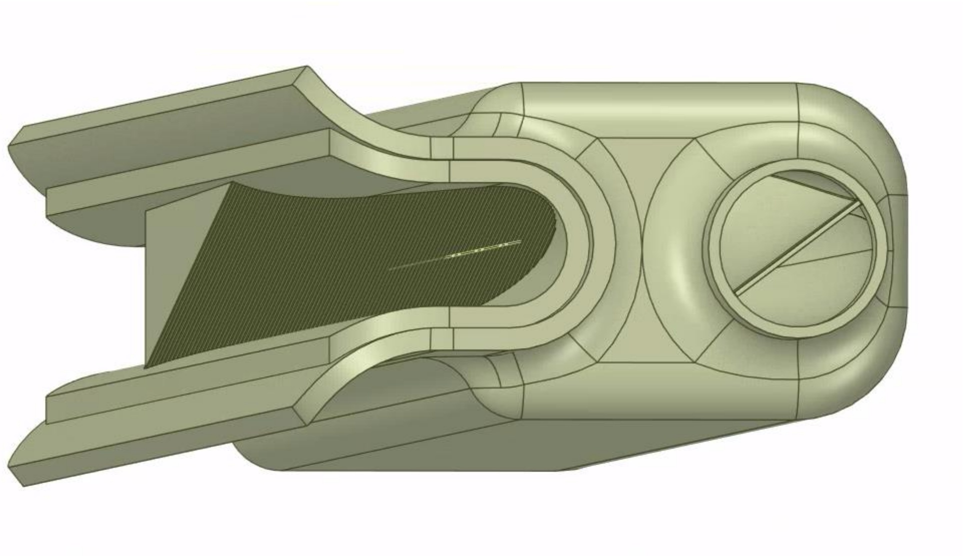
Booster ring



Dynamic and static pressures

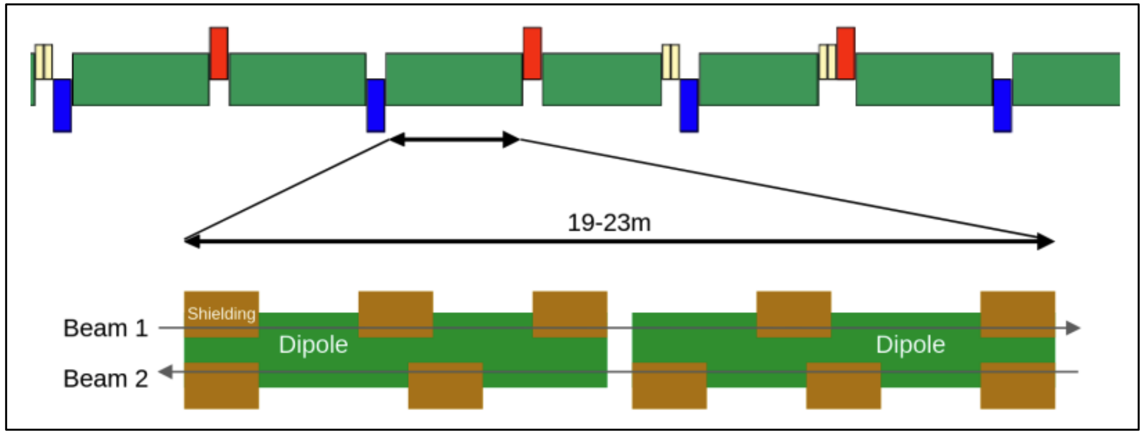
The task

~50MW/beam synchrotron radiation



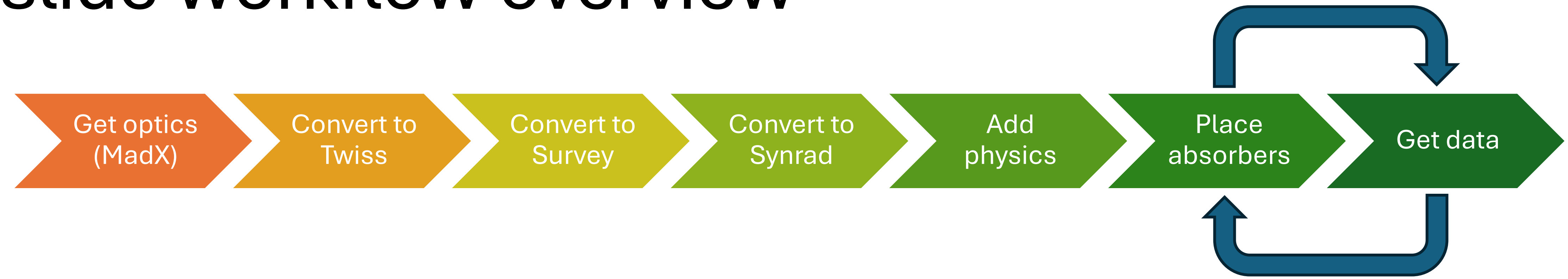
place discrete absorbers, 4 per magnet?

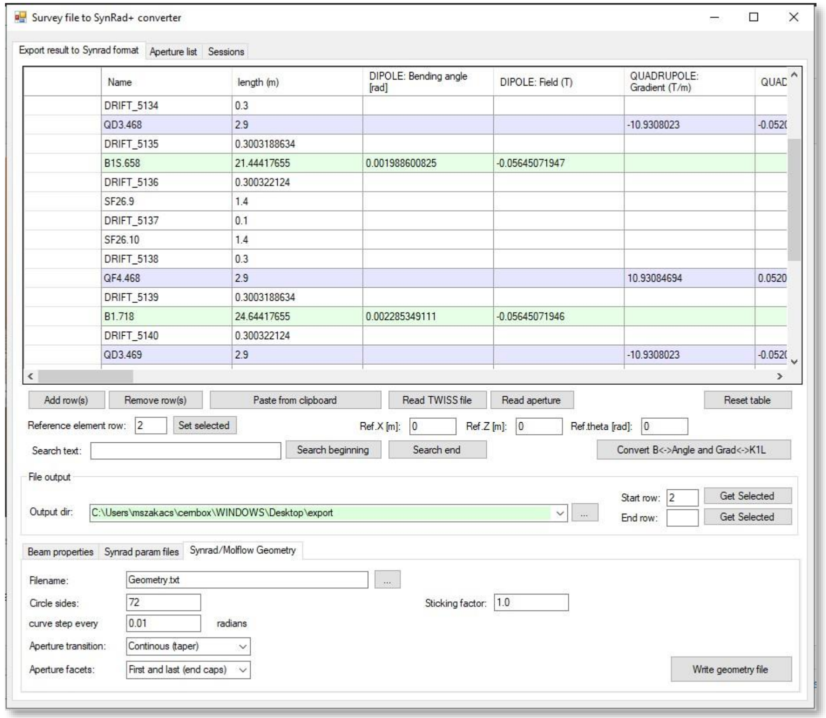
FCC consists of 130m “supercells” with 5 magnets



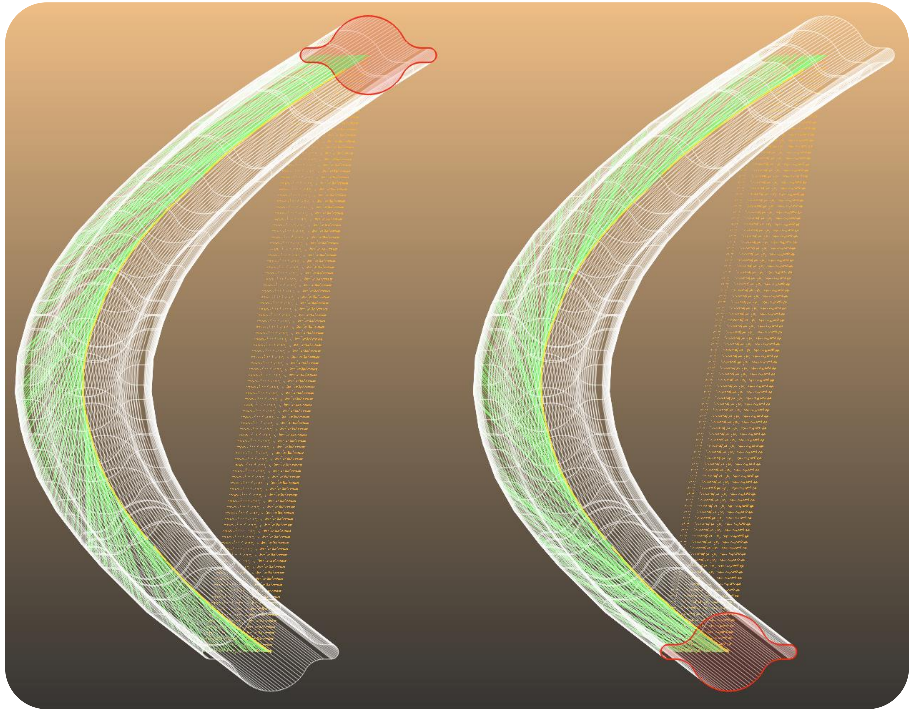
“Find absorber placement as periodic solution”

1-slide workflow overview

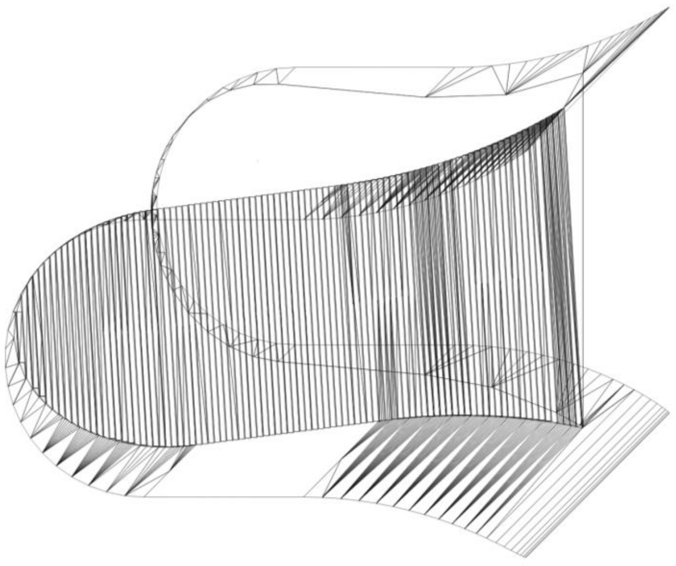




Opticsbuilder



Synrad geometry

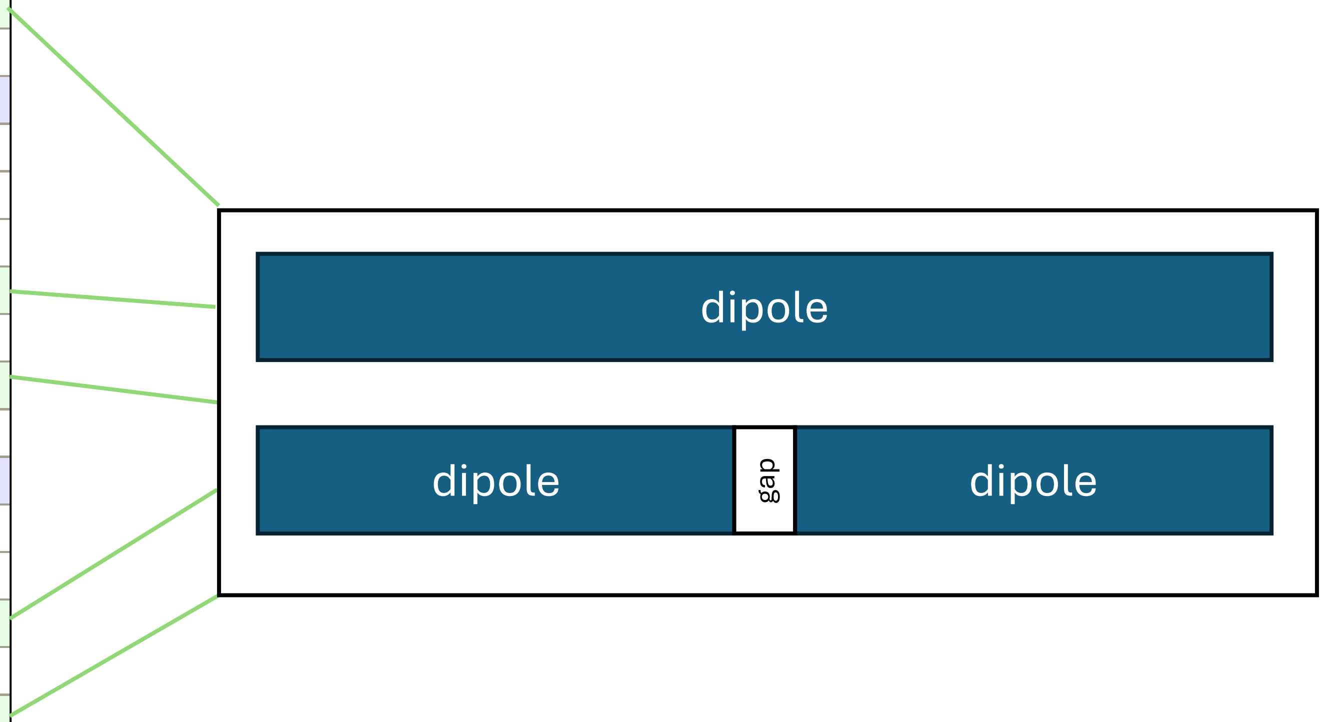


Absorbers

First step: manually edit magnets in OpticsBuilder

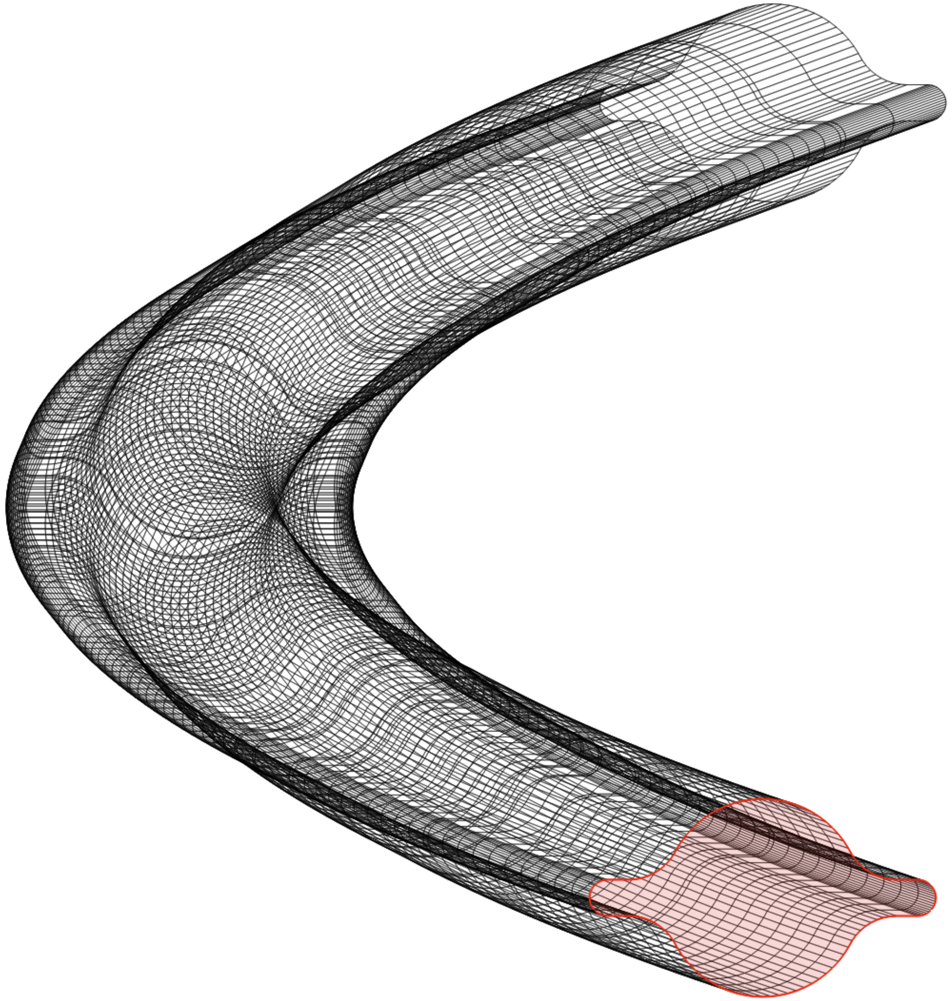
130.2m 5-cell pattern in OpticsBuilder:

Name	length (m)	DIPOLE: Bending angle [rad]	DIPOLE: Field (T)
B1S.156	19.70537223	0.001966470217	-0.01517874778
DRIFT_811	0.3		
QD1.11	2.9		
DRIFT_812	0.2		
SD22.1	1.3		
DRIFT_813	0.2		
B1L.40	21.15537223	0.00211117095	-0.01517874777
DRIFT_814	3.4		
B1.198	22.65537223	0.002260861364	-0.01517874777
DRIFT_815	0.3		
QF2.11	2.9		
E.ARC	0		
DRIFT_816	0.2		
B1.199	22.65537223	0.002260861364	-0.01517874777
DRIFT_817	6.35		
B1S.157	19.70537223	0.001966470217	-0.01517874778
DRIFT_818	0.3		
QD1.12	2.9		
DRIFT_819	3.15		

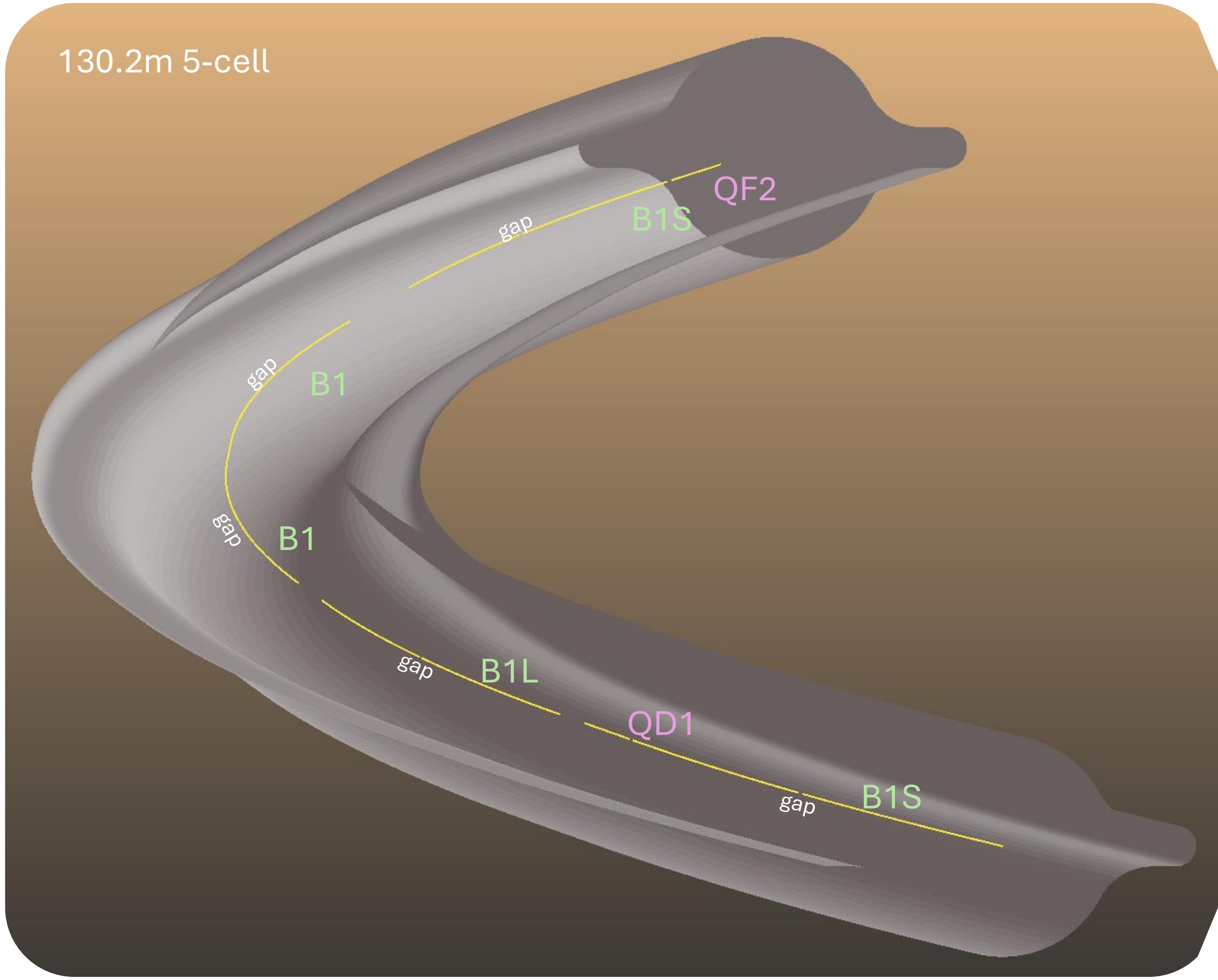


Lattice functions kept the same

Generate SynRad geometry and optics

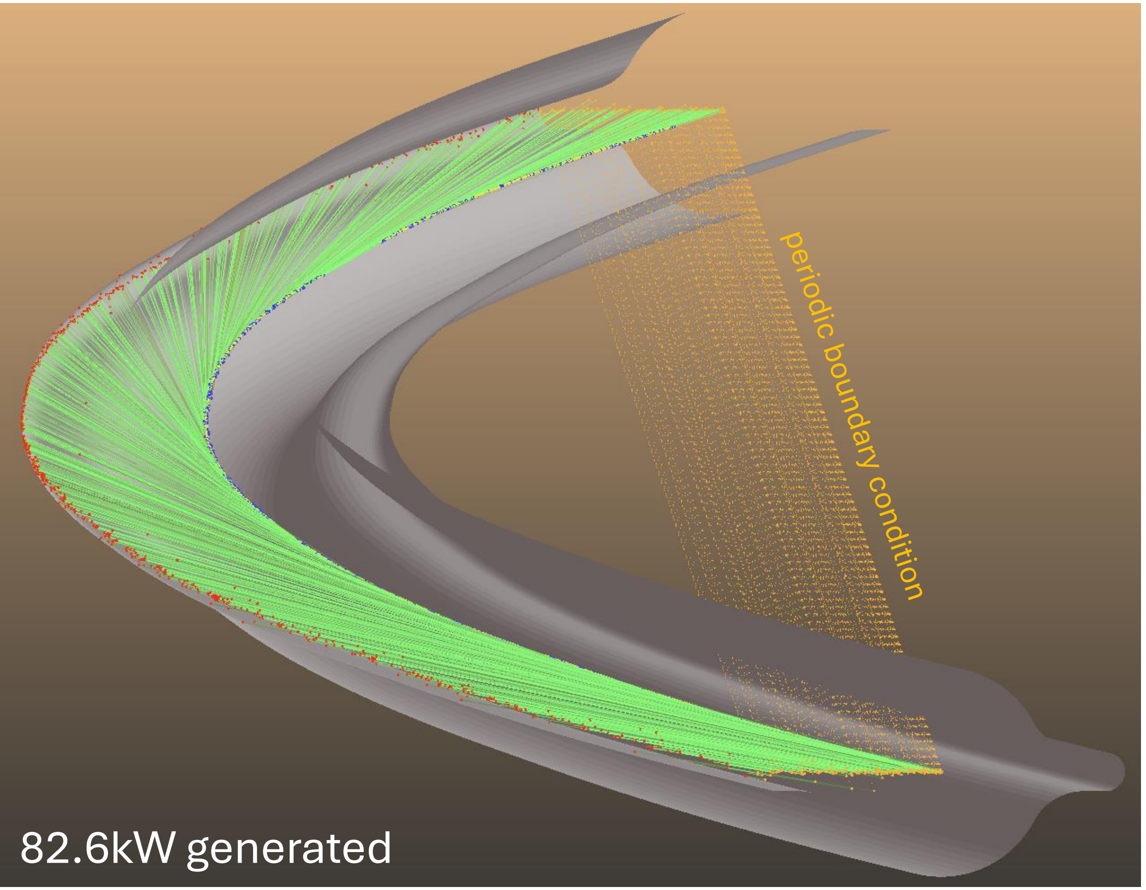


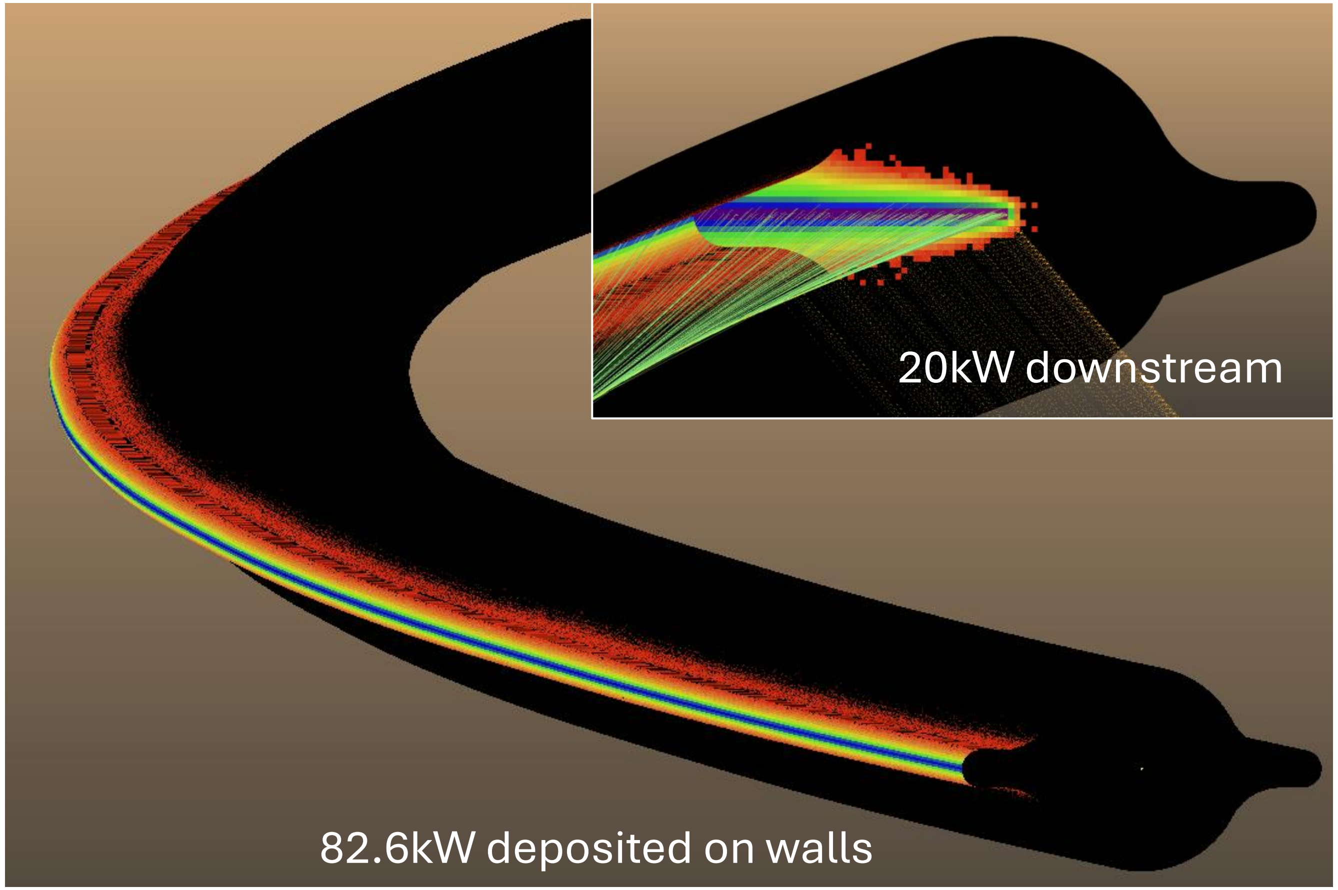
Geometry: 17100 polygons

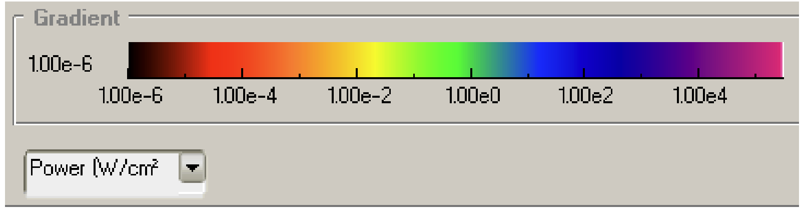


adding optics

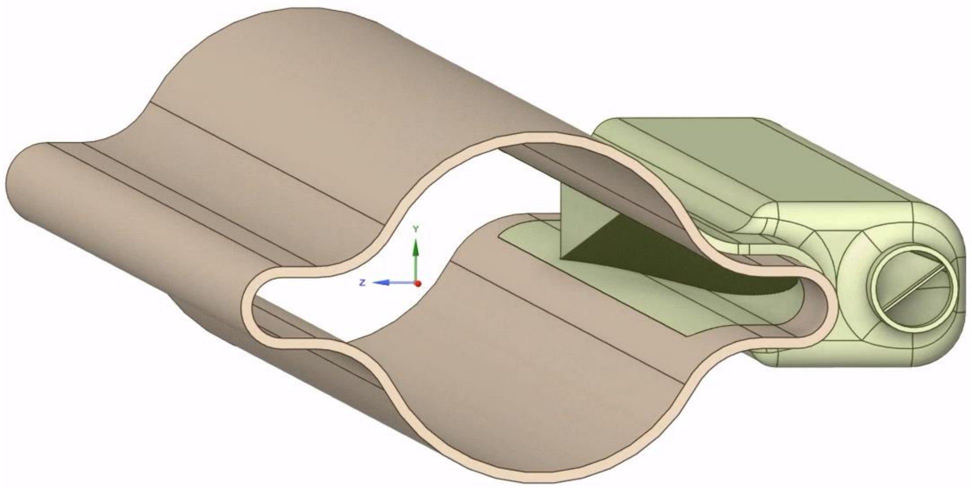
Simulation: verifying photon generation (no absorbers)



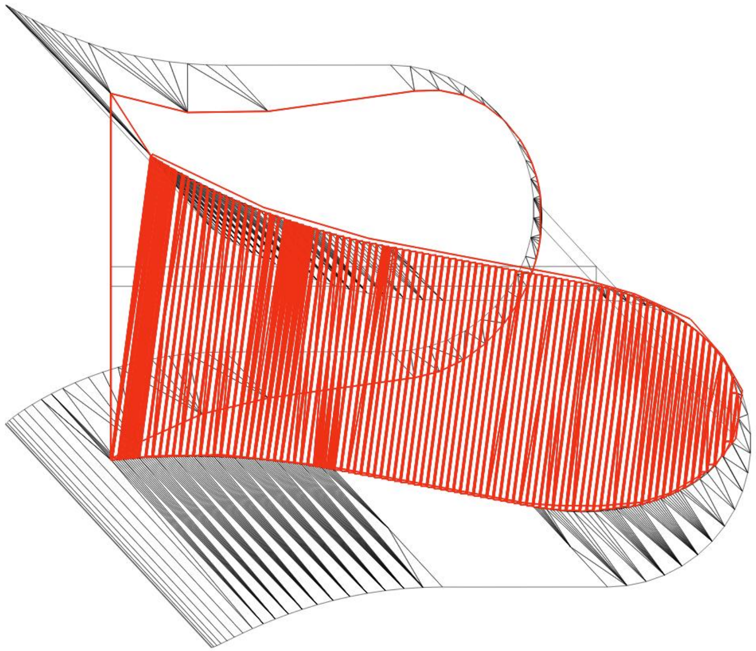




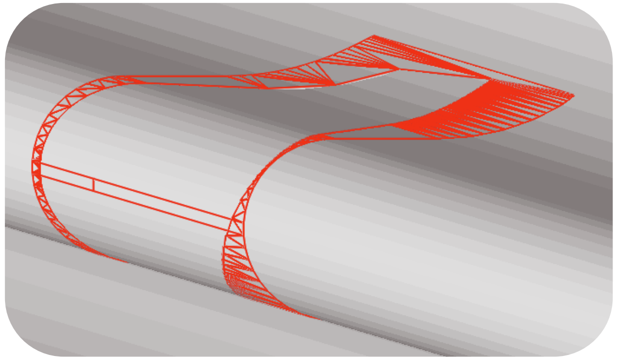
Adding the sawtooth* absorbers



Model (Fabrice Santangelo, TE-VSC)



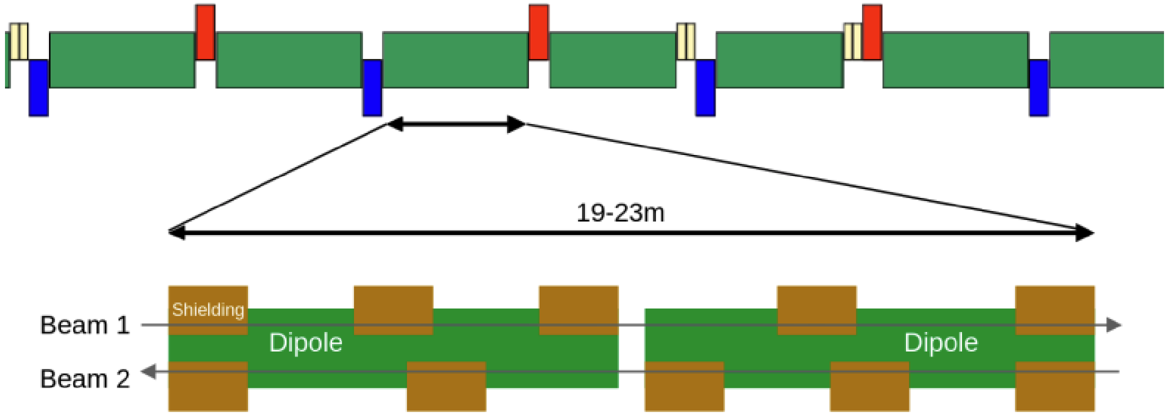
1134 polygons
sawtooth modeled as-is

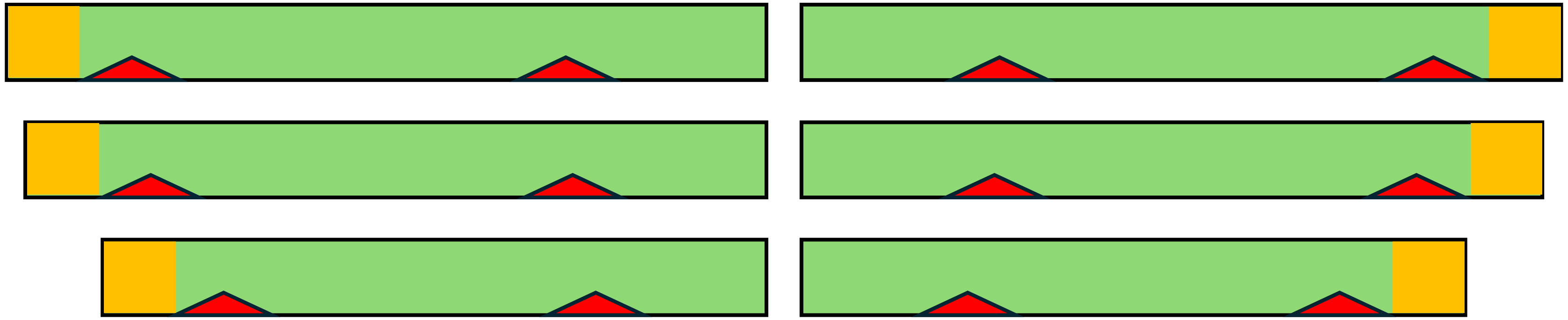


transparent facets help align

* Sawtooth details: see talks of Marco Morrone and Stefania Grozavu in this session

Add absorbers: first attempt – equal spacing





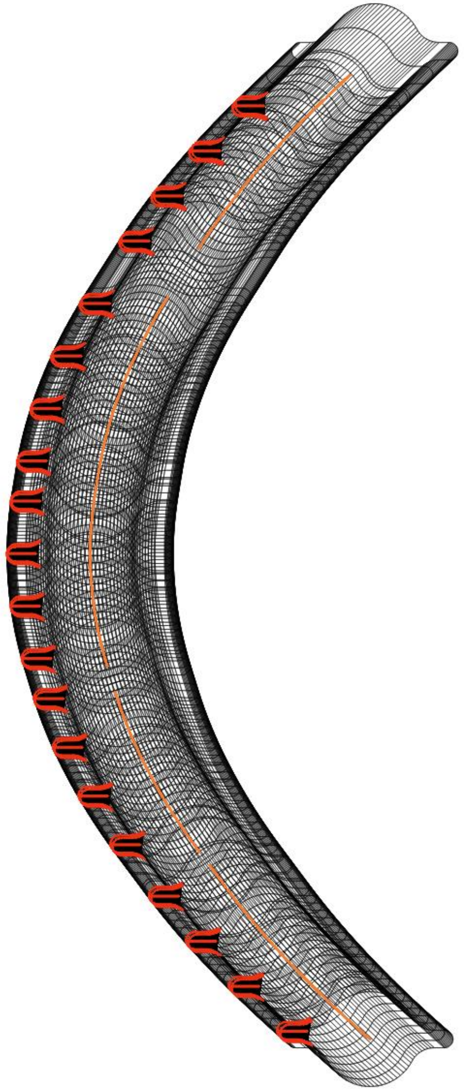
B1 (22.655m)

B1L (21.155m)

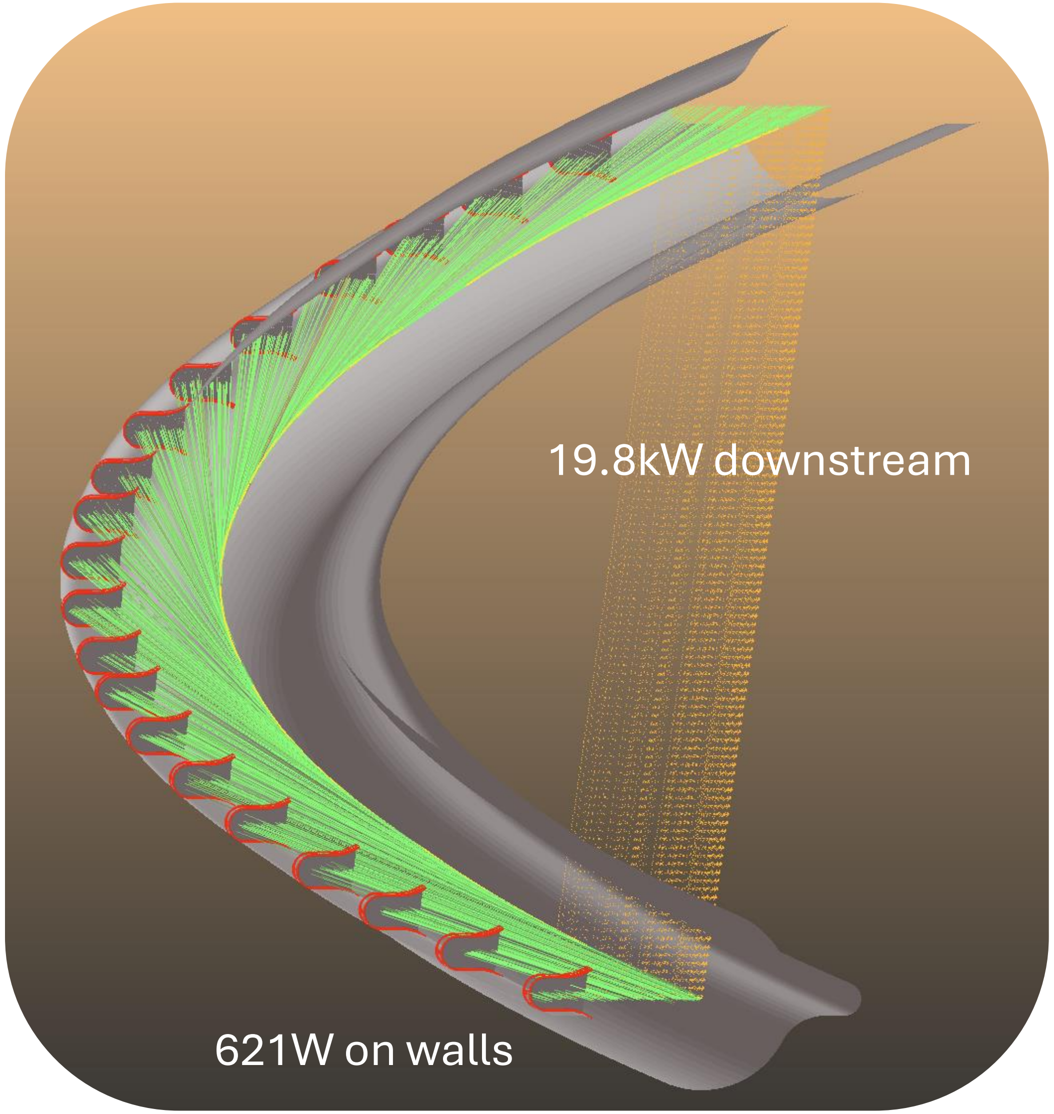
B1S (19.7m)

55cm / 75cm reserved for shielding

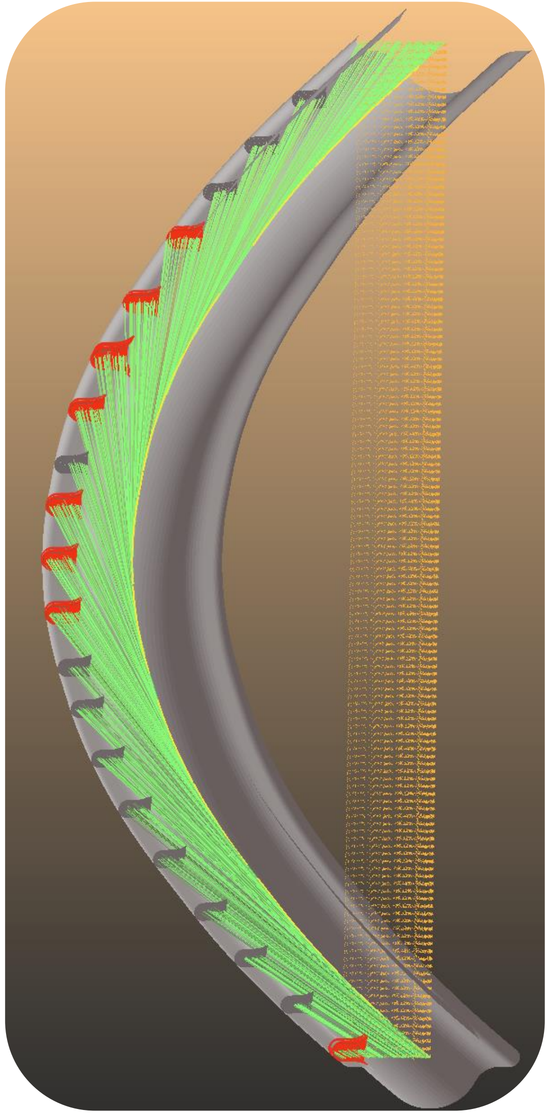
Simulation: equal spacing



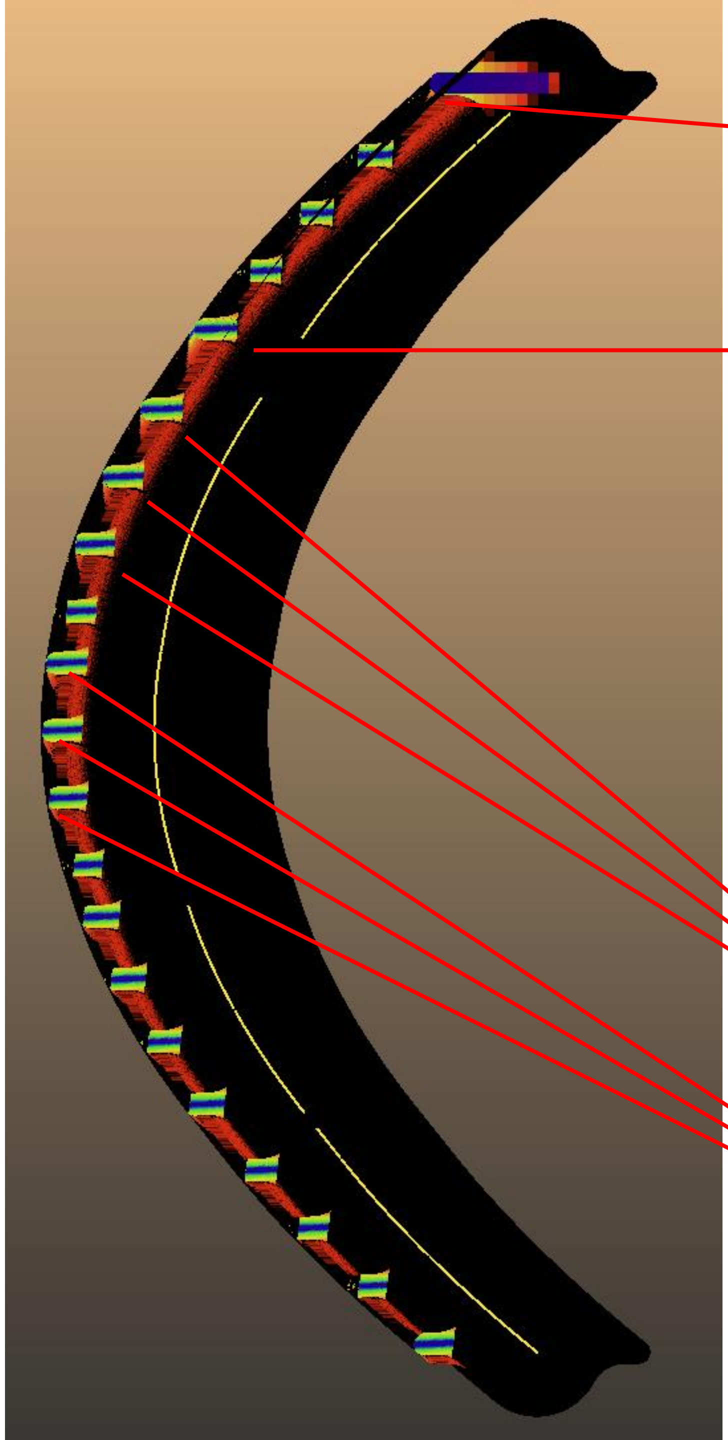
5 dipoles * 4 absorbers = 20 total

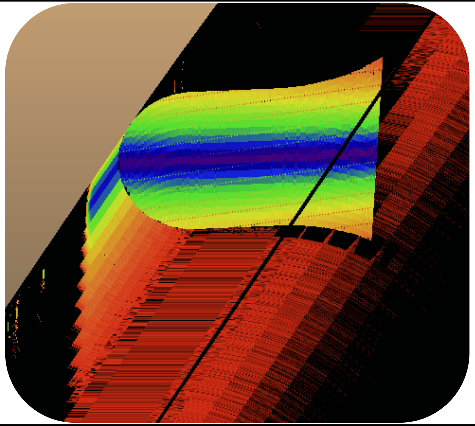


82kW on absorbers (4.1kW avg, 4.8kW max)



8 abs > 4.5kW



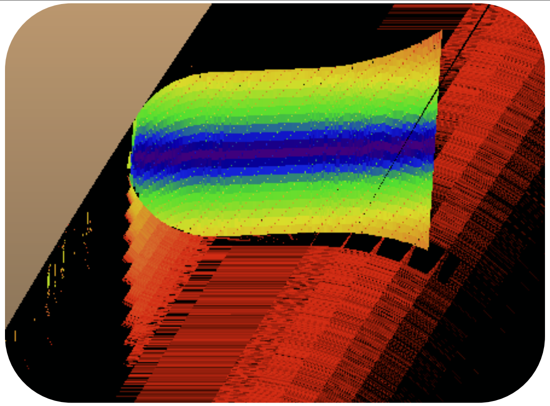


B1.199_second_half	11.177686115	0.001130430682	-0.01538244039
DRIFT_817	6.35		
B1S.157_first_half	9.702686115	0.0009832351085	-0.0154134057

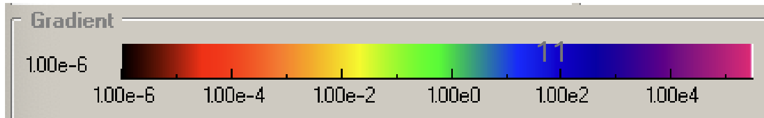
B1S.157_second_half	9.702686115	0.0009832351085	-0.0154134057
DRIFT_818	0.3		
QD1.12	2.9		
DRIFT_819	3.15		

6.35m

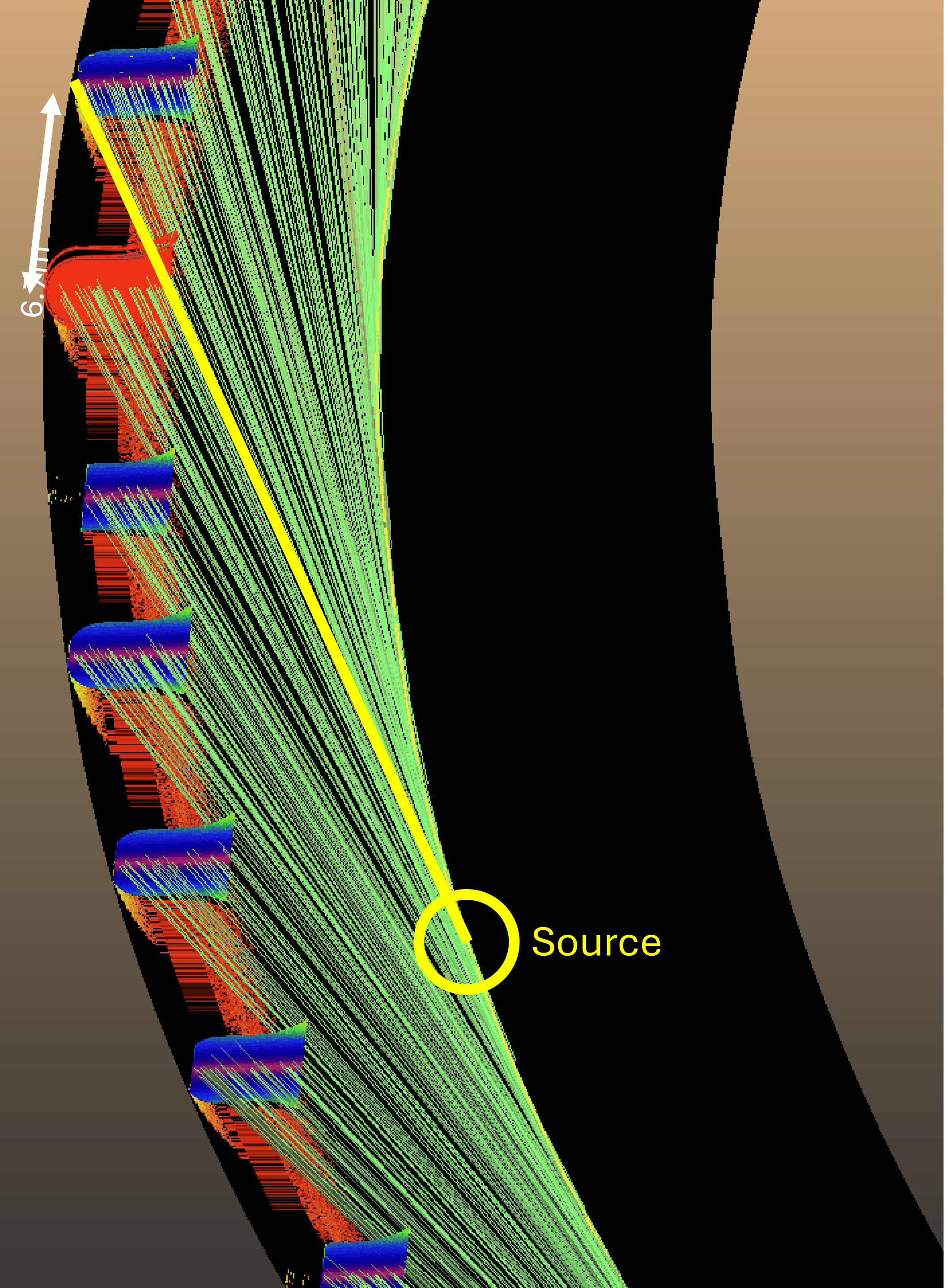
Expected problems (>6m drift)

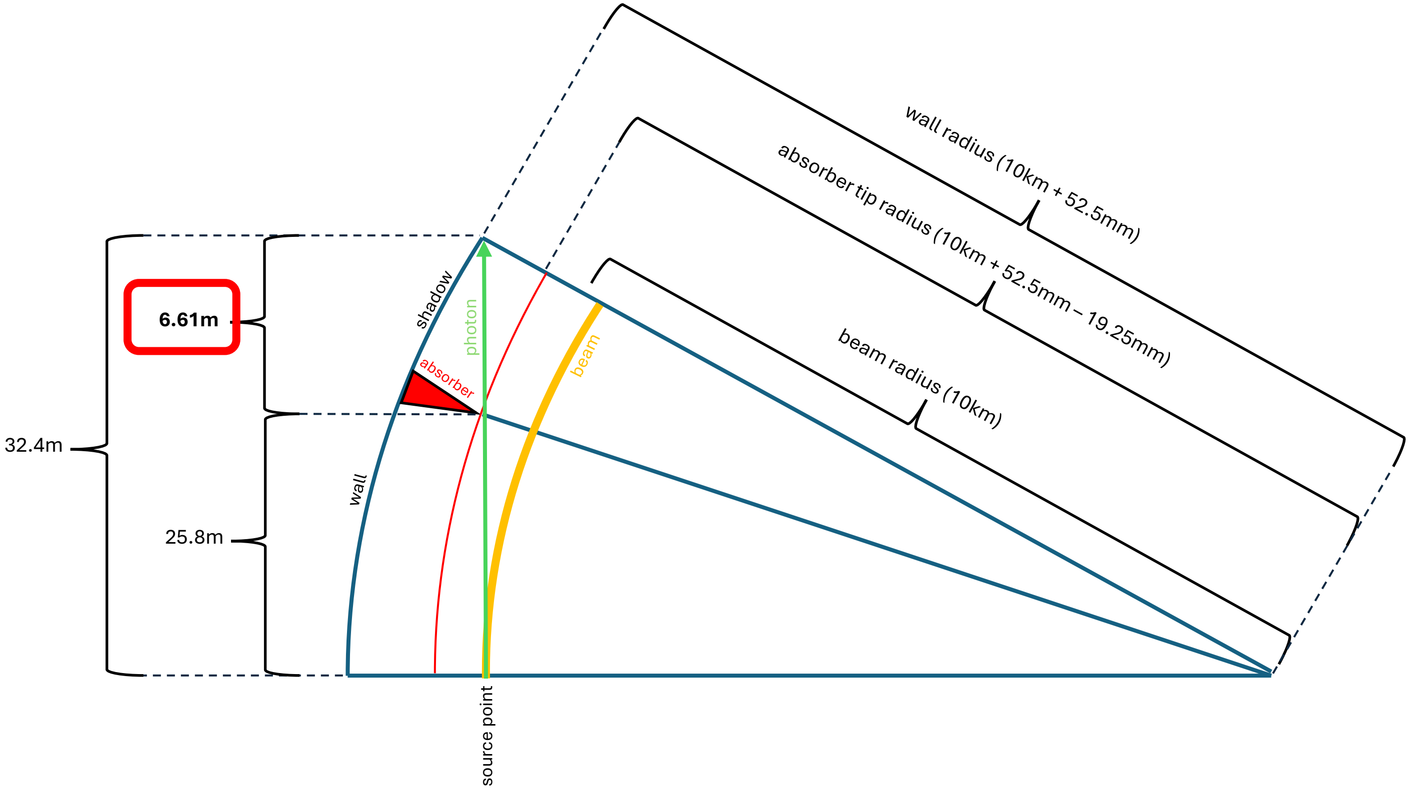


B1 magnets: too sparse spacing



Solving the drift problem: increase absorber protrusion



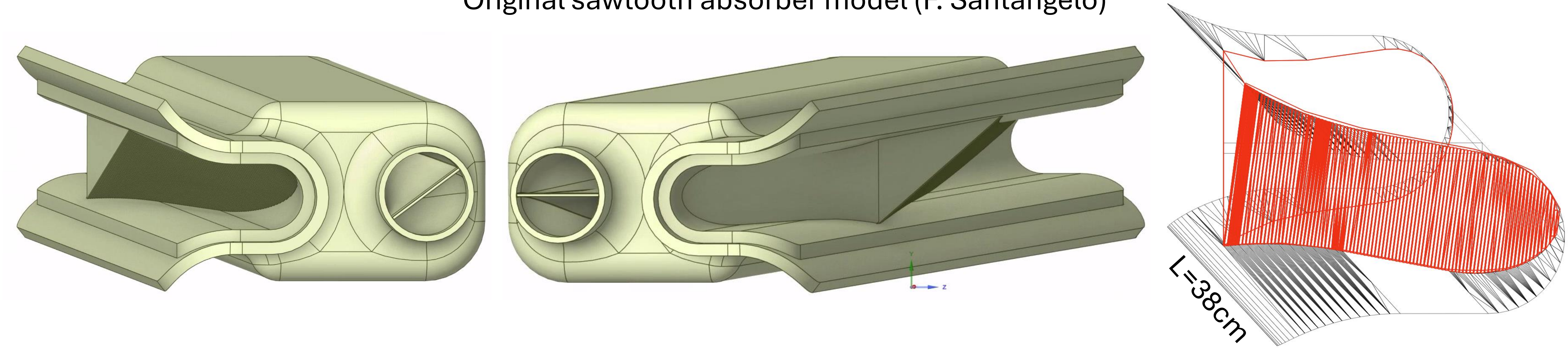


Conclusion: One absorber shades max. 6.6m of the wall

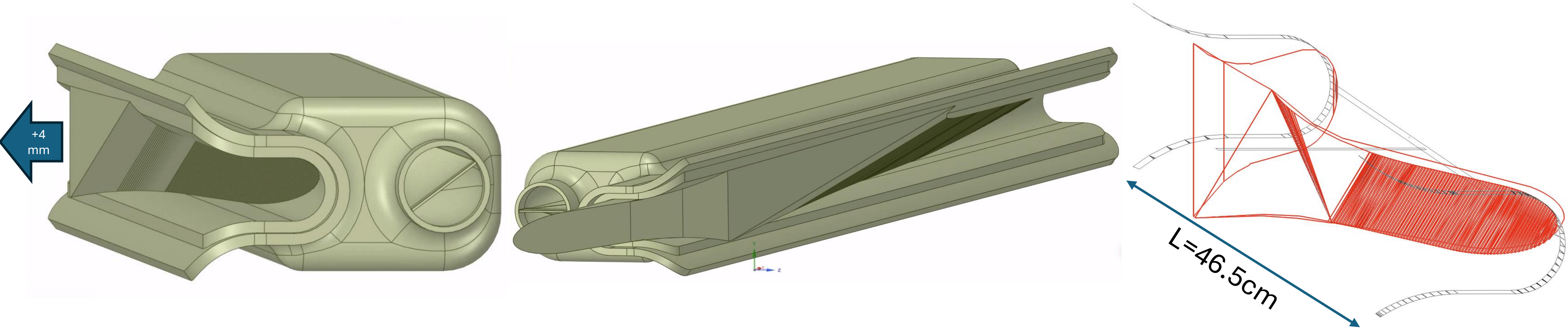
shadowed length: 6.61m -> 7.85m = +19%

absorber protrusion: 19mm -> 23mm = +21%

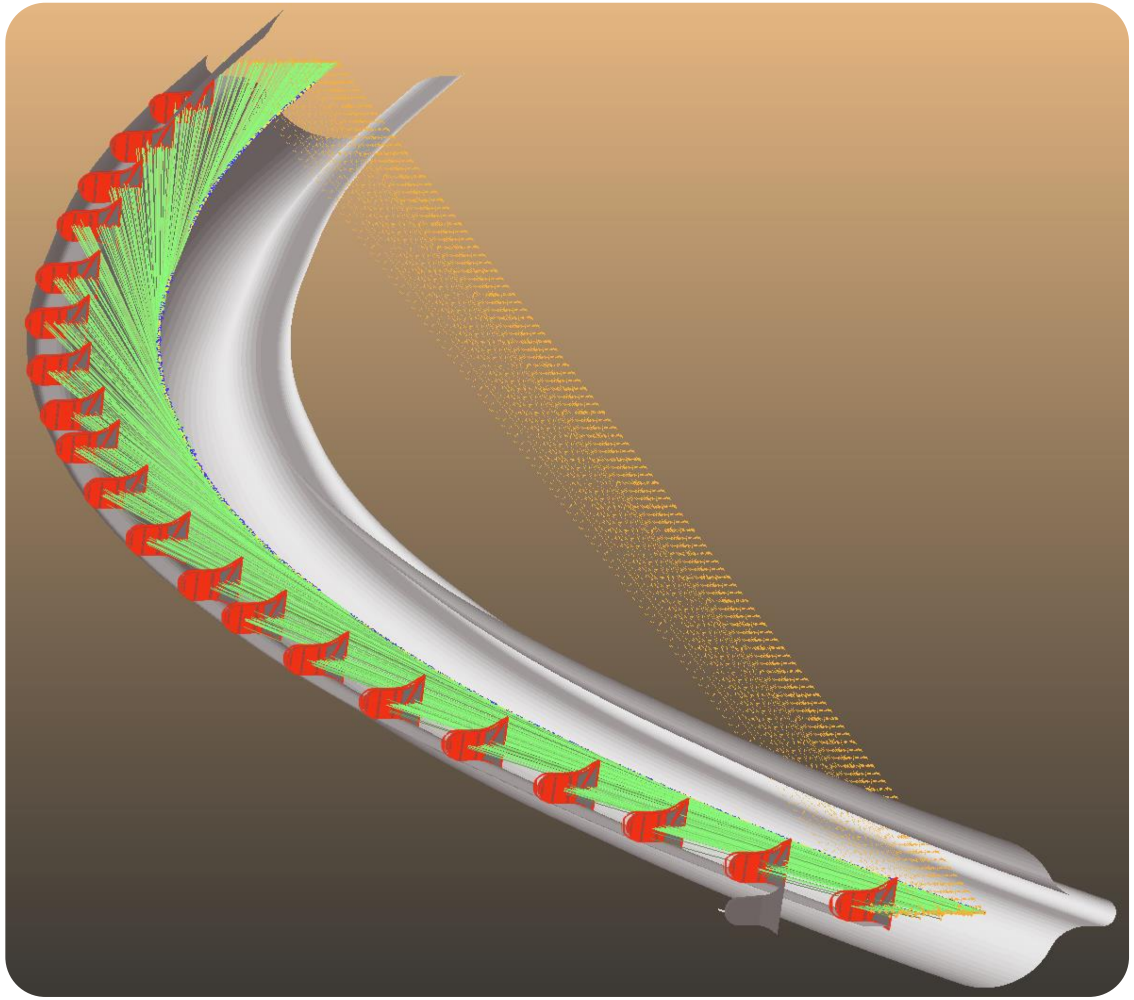
Original sawtooth absorber model (F. Santangelo)

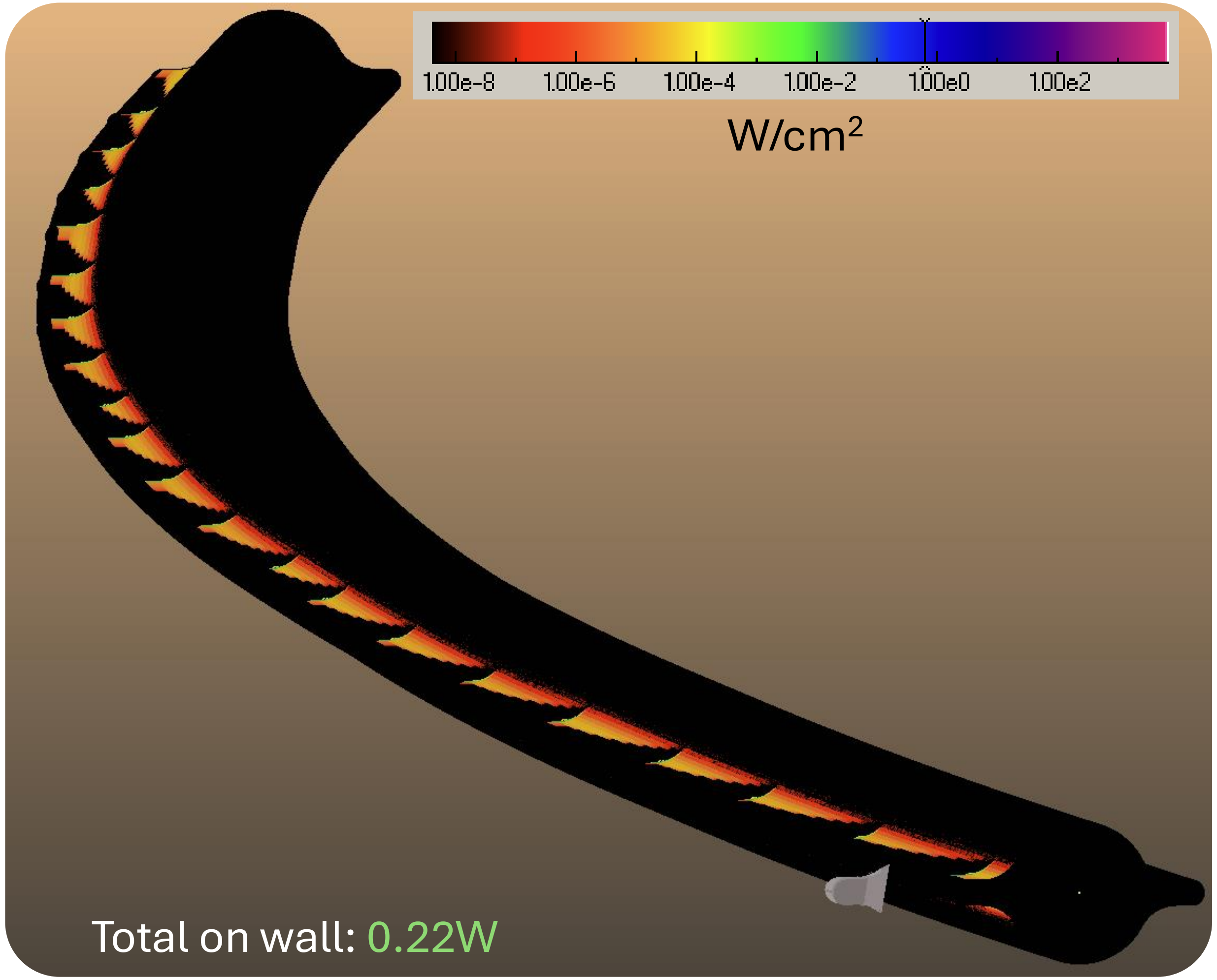


Modification (preliminary, partial sawtooth)

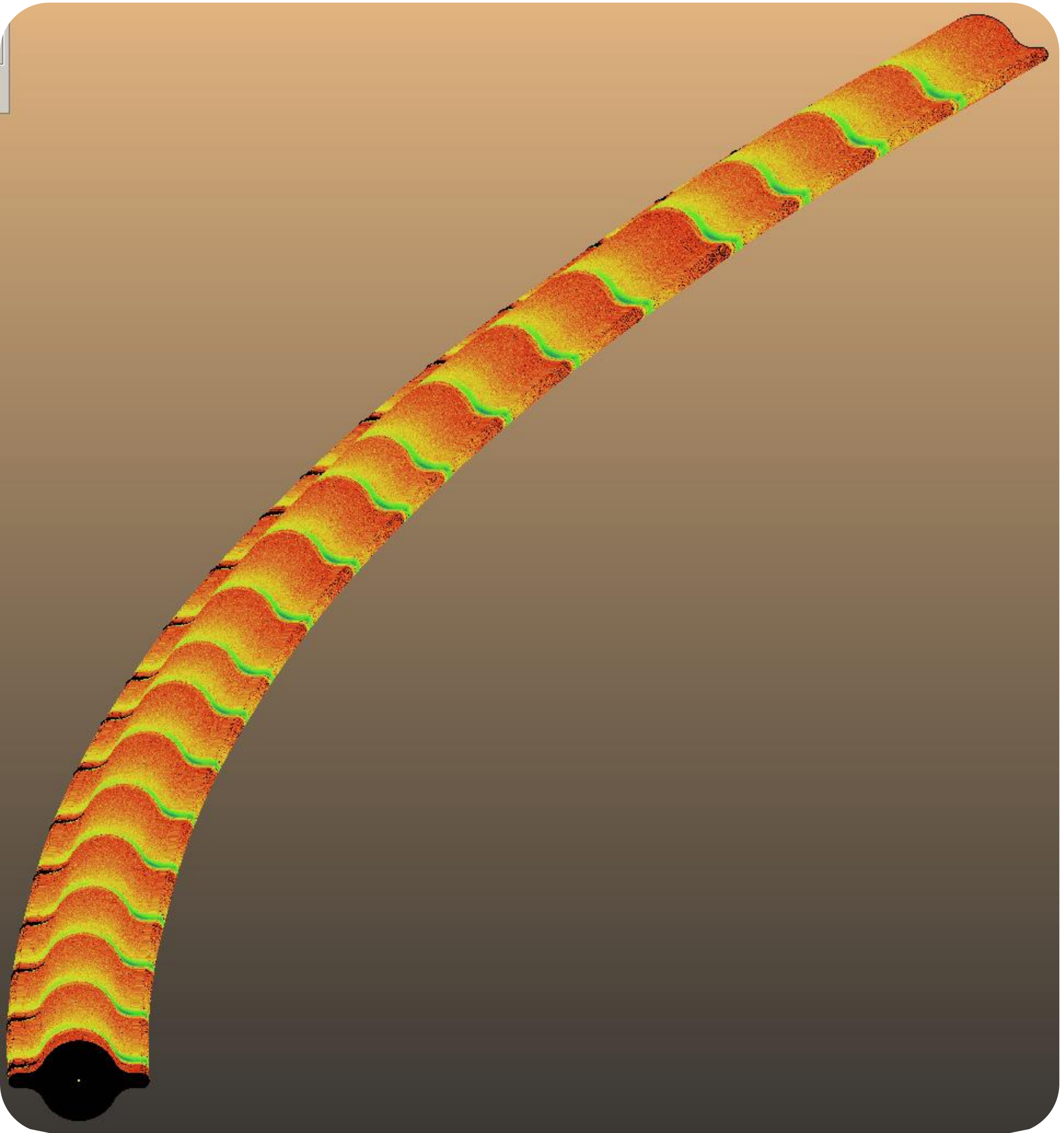


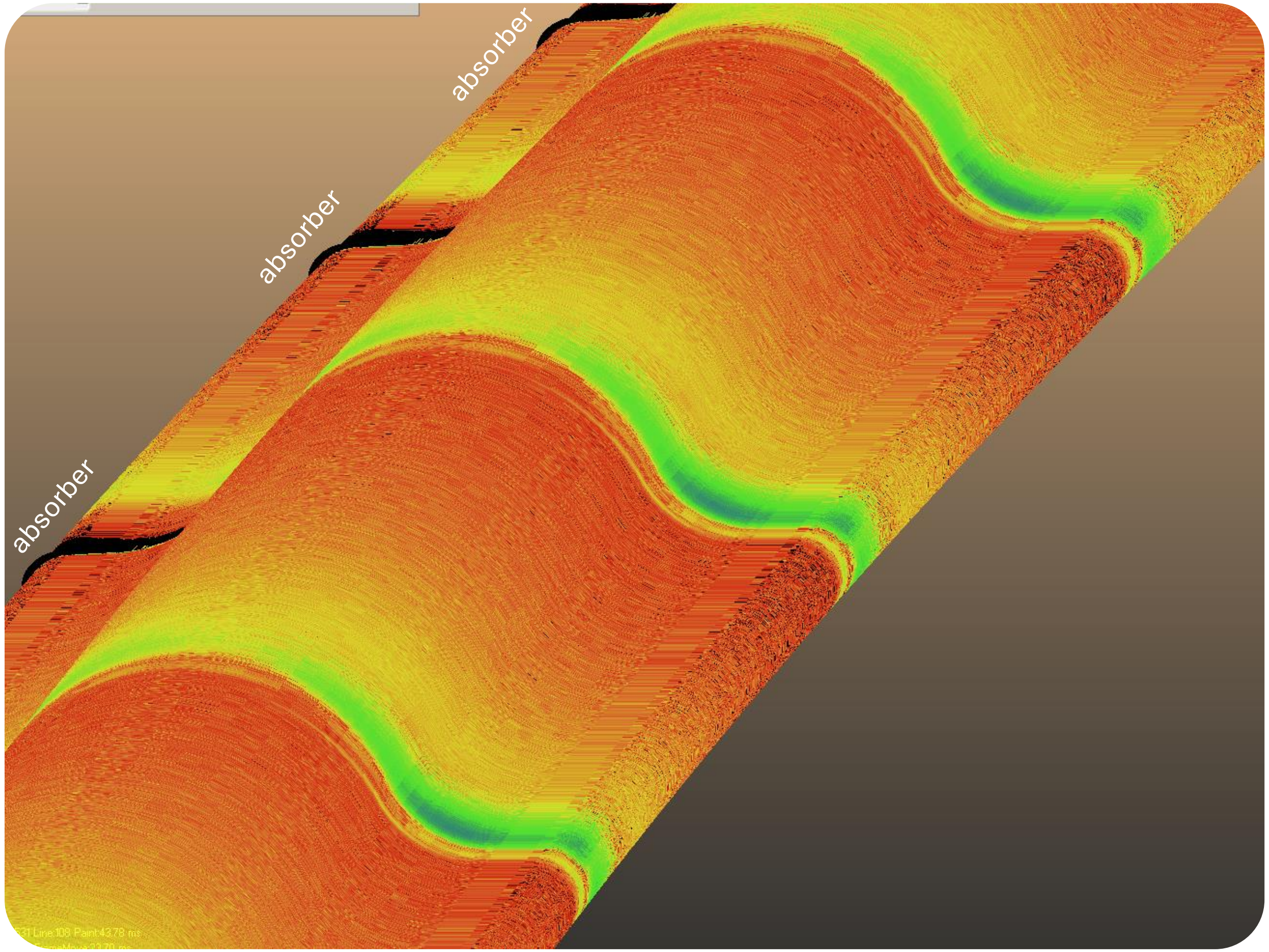
Larger absorbers:
Negligible direct hits on outer walls



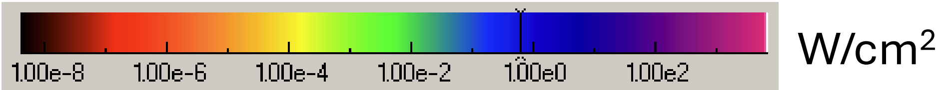


Secondaries: 380W (2.9W/m) on walls

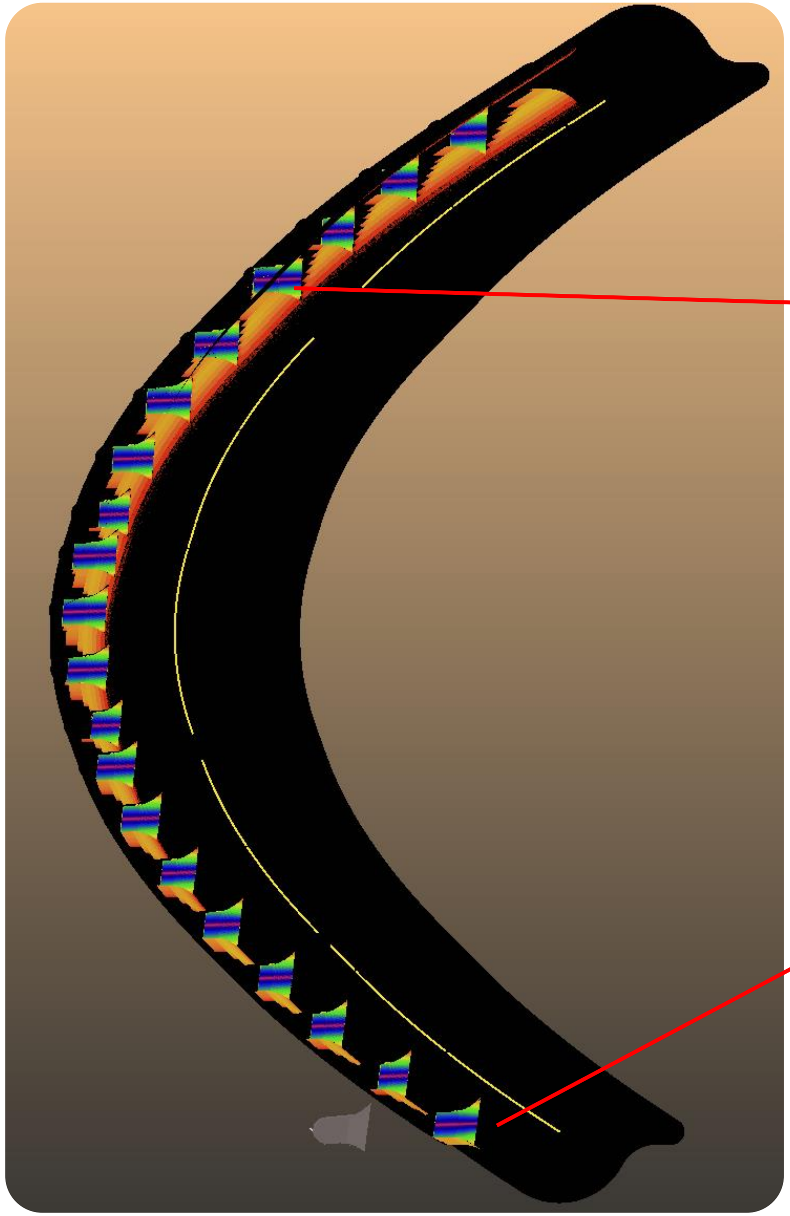


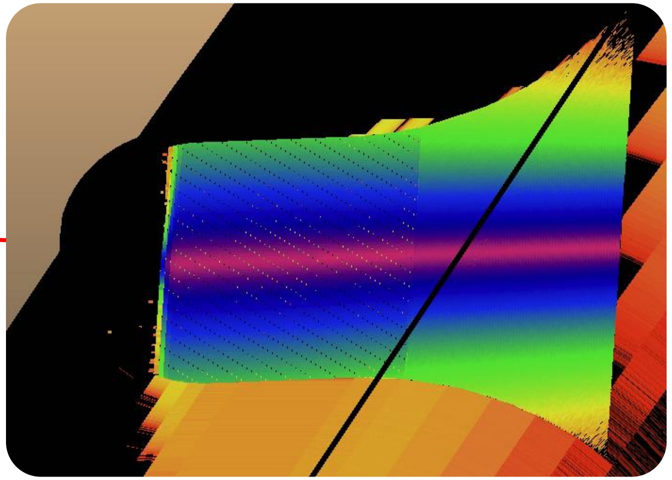


Largest load opposite absorbers

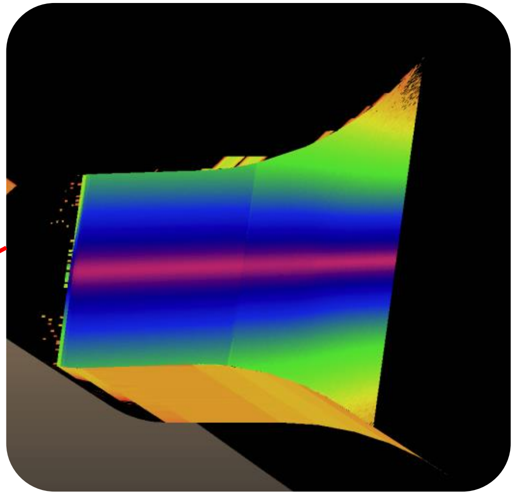


Load on absorbers: largest after drifts

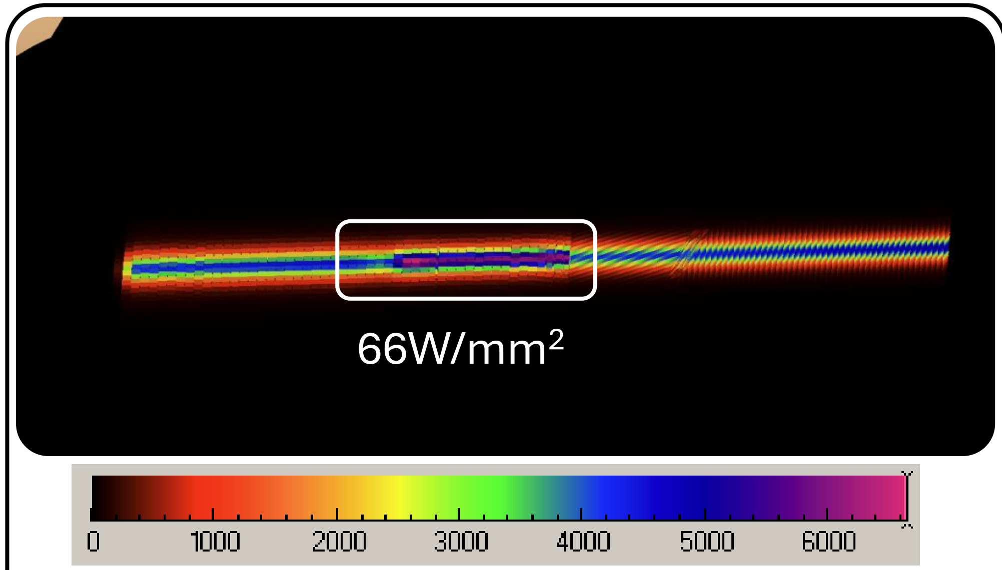




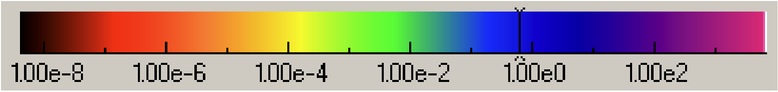
5200W



4580W



W/cm² (linear scale)



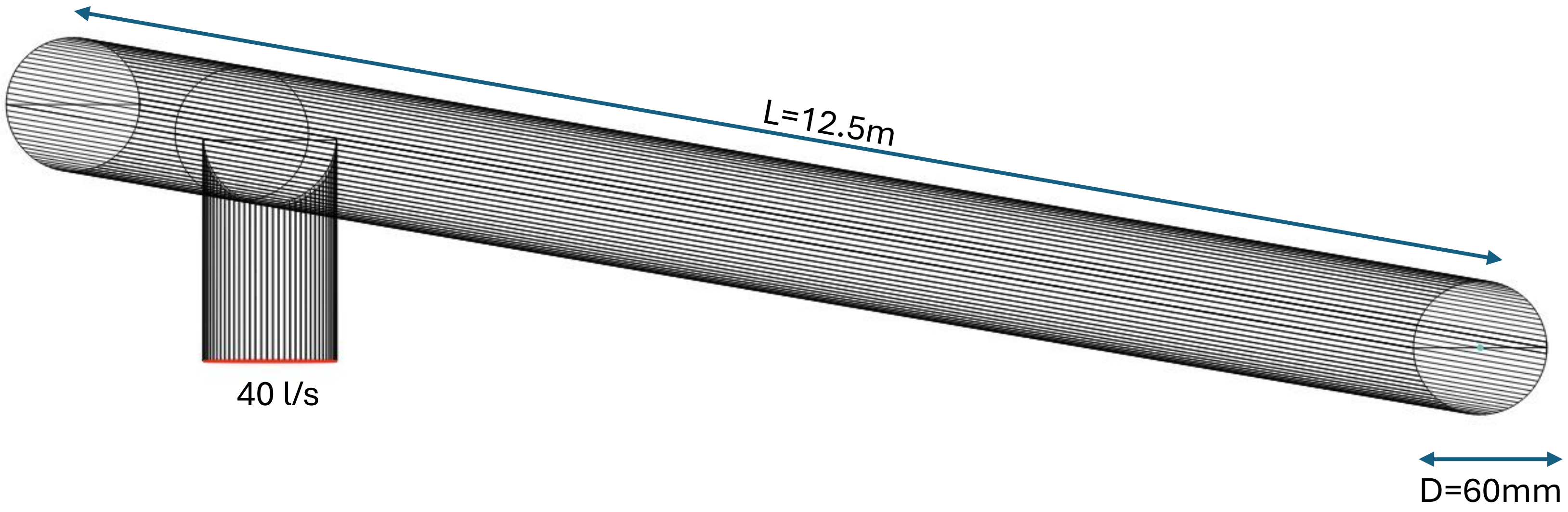
W/cm²

Conclusion (collider SR management)

- Increasing the absorber protrusion shows complete shadowing
- Should be repeated with real sawtooth (0.9mm sides)
- Total power (5.3kW) – check with cooling simulations
- Power density: decrease angle and make longer?
- 46.5cm too long for 3D printer
- Impedance validation required
- If above passed, 4 absorbers/magnet feasible

Second part: booster ring pressure profiles

- Can we build the booster ring without bakeout and without NEG coating?
- A representative 12.5 m-long "half-cell" model with a 60 mm inner diameter was analyzed, featuring a single 40 l/s ion pump placed between the dipole and quadrupole magnets (lumped pumps in absence of NEG)



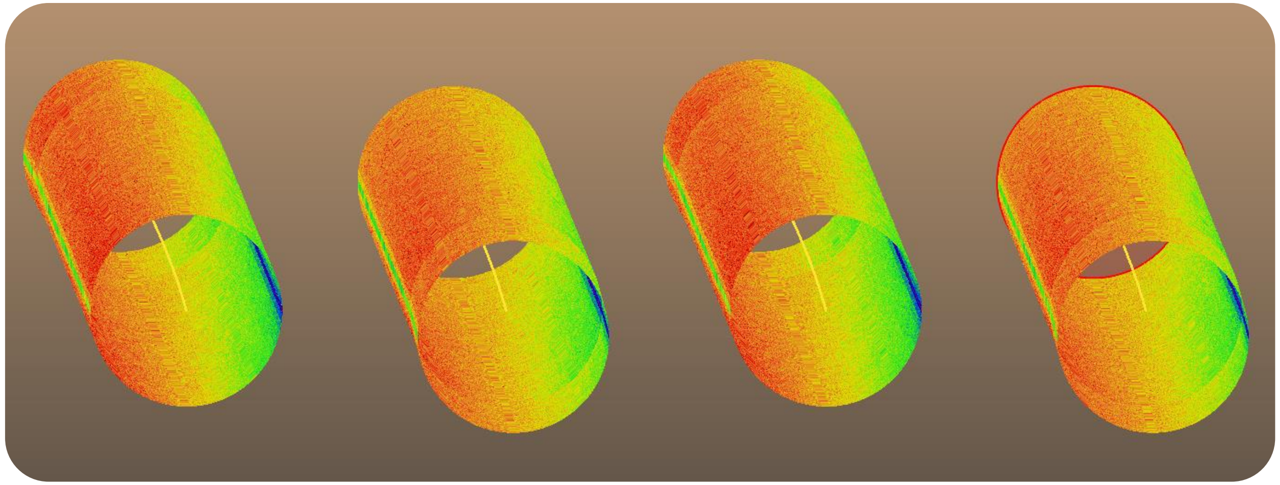
Calculation steps

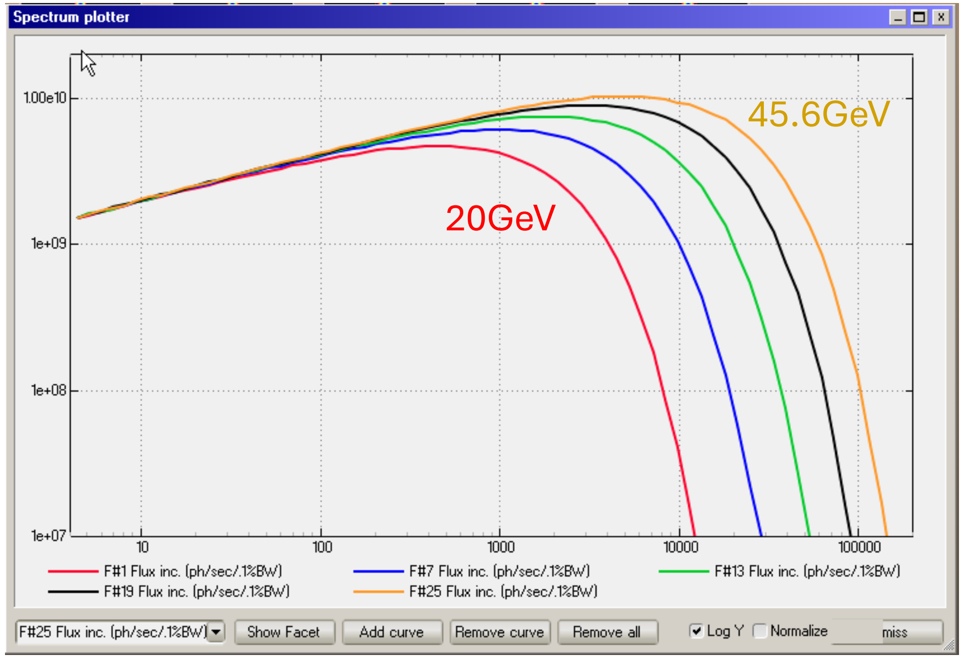
Dynamic vacuum:	Calculate SR spectrum	Scale with booster cycle	Vacuum simulation
Static vacuum:	Get material outgassing	Vacuum simulation	

Dynamic vacuum

Step1: Estimate synchrotron radiation

Dipoles





Magnet parameters:

- B=6.5mT at 20GeV
- I=14.83mA*
- L=4*11m

Part of SR above 4eV ("SR_factor"):

- 20 GeV: 83%
- 45.6GeV: 92%
- took the average

Practical formula: Flux = 8.08E17 * E[GeV] * I[mA] * SR_factor * Ring_fraction = 2.36E17 photons/s (at mid-energy, full current)

SynRad result: 2.24E17 photons/s

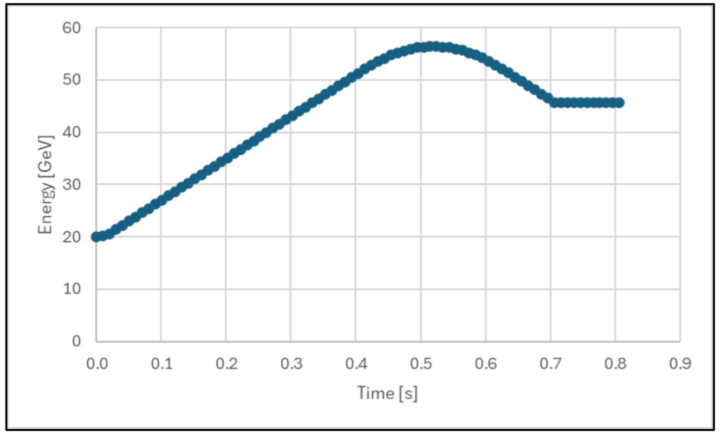
→ 44m modeled / 64486m magnetic circumference
SR flux: 5.3E15 photons/sec/m

*thank you Antoine Chance and Anton Lechner for the confirmation!

Dynamic vacuum

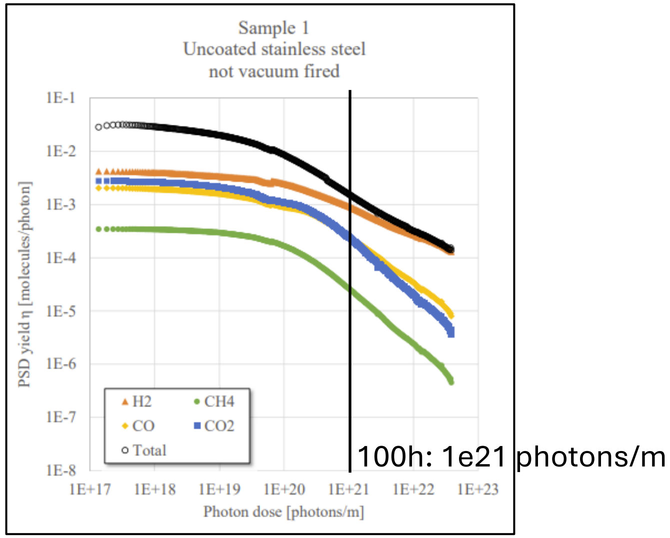
Step2: construct dynamic outgassing for vacuum simulation

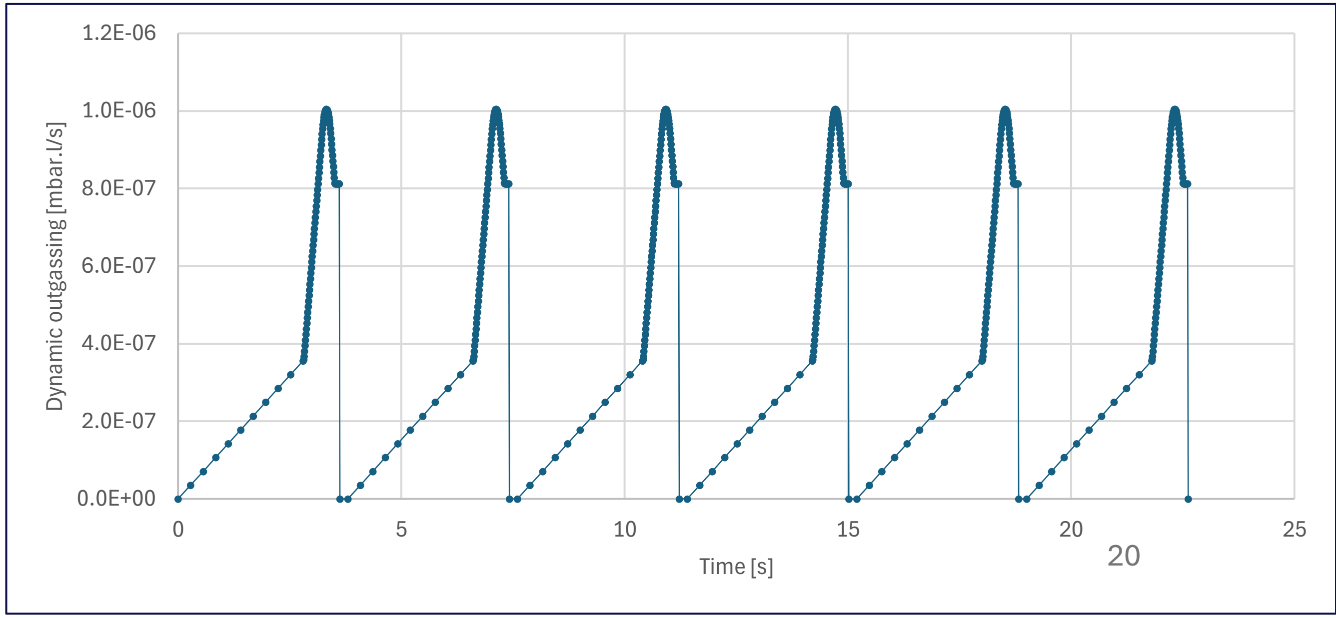
- Representative booster cycle (Z mode):
  - 2.8s accumulation: 0 to 14.83mA linear current increase
  - 0.8s ramp-up cycle with energy overshoot
  - 0.2s magnet ramp-down



digitized data: Antoine Chance (CEA)

- Flux = 8.08E17 * E[GeV] * I[mA]
- Outgassing: PSD_yield * Flux
  - Choose η=3E-4 mol./photon for CO



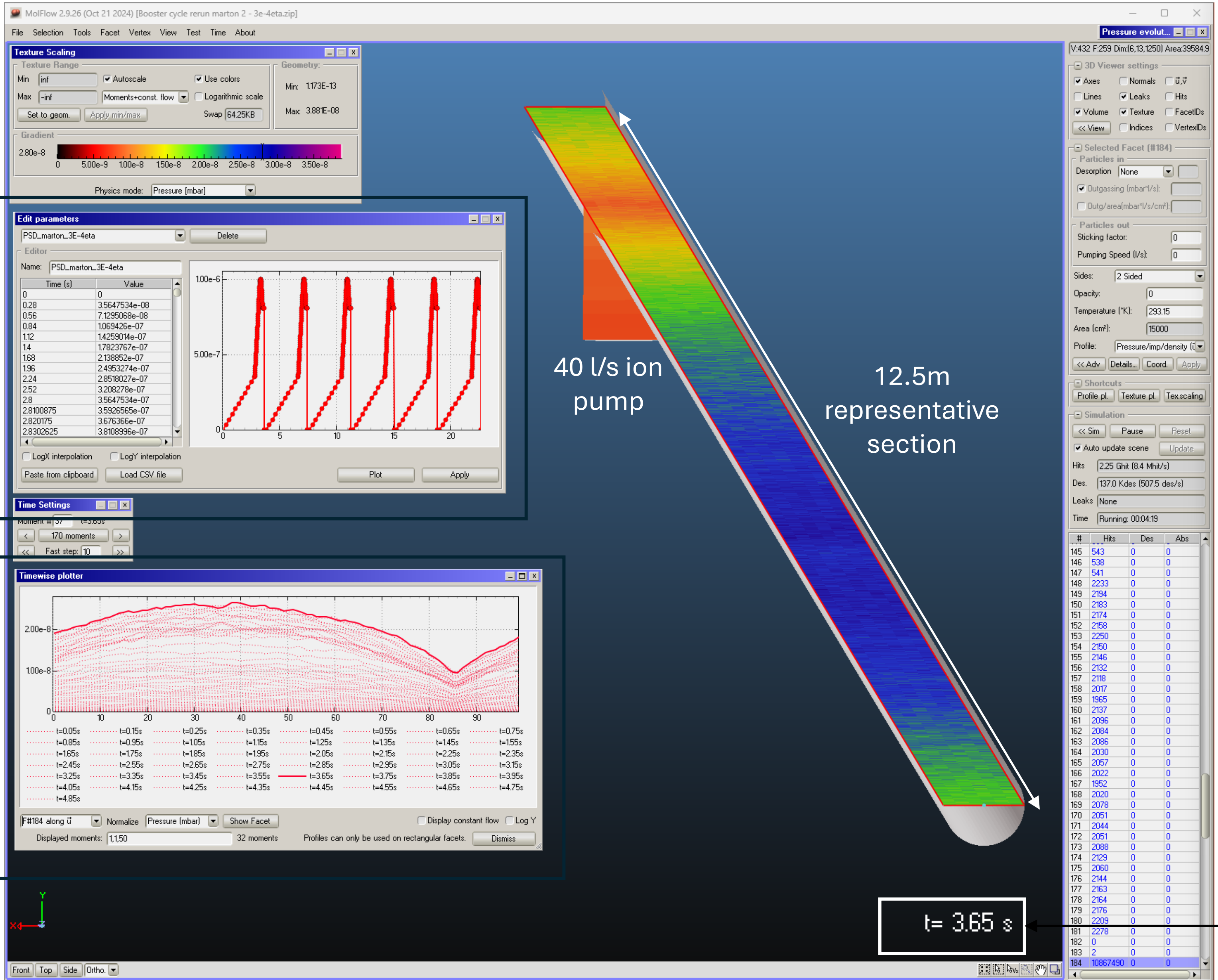


Dynamic vacuum

Step3: vacuum simulation

Time-dependent outgassing

Pressure profiles at different moments



Mass: 28 (CO)

Temp: 300K

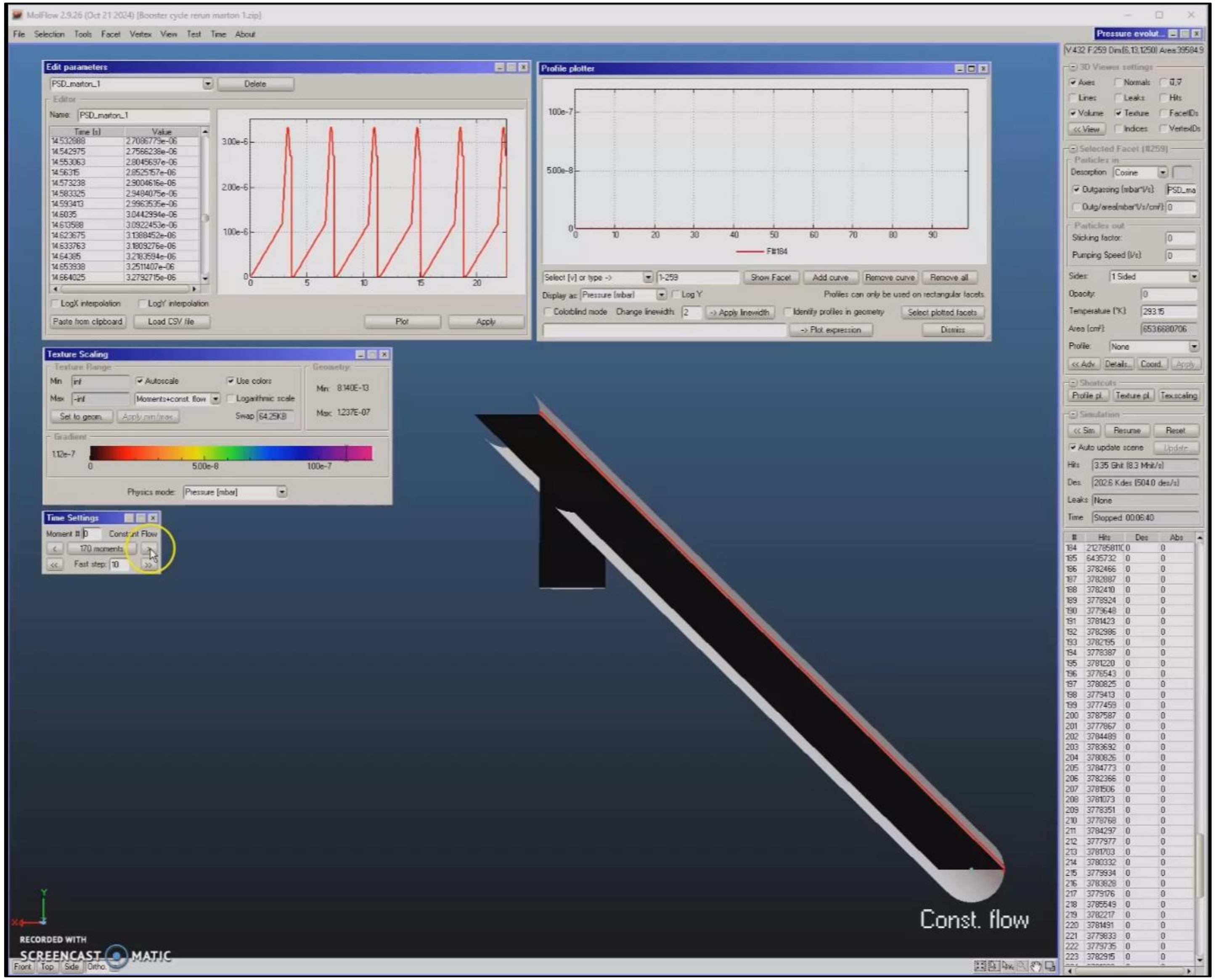
Typically, the gas species are (ordered per fraction): H_2, CO, CO_2, CH_4 (baked system), plus H_2O (if unbaked), which can initially be the predominant gas specie

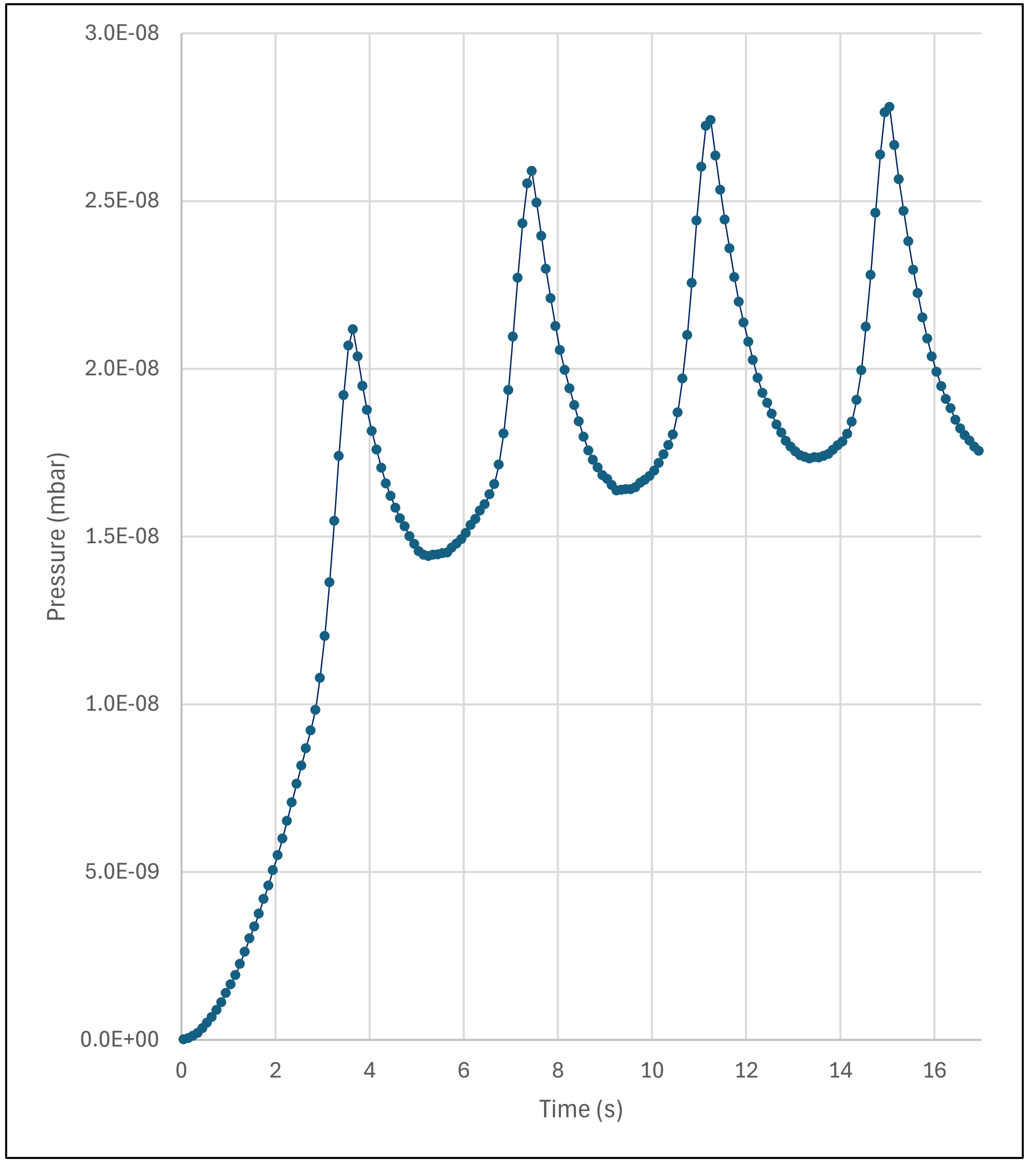
➢ We have considered CO because it has an atomic number much higher than that of hydrogen, and therefore its effect in terms of beam bremsstrahlung (BS) is ~15x bigger then for H2... (Zeff*(Zeff+1) dependence for BS, Zeff =weighted effective atomic number for C and O)

Snapshot displayed on model

Dynamic vacuum

Step4: pressure results

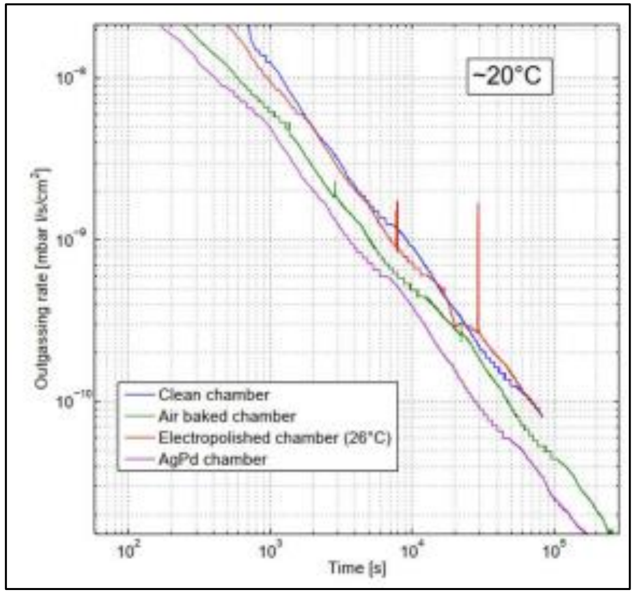


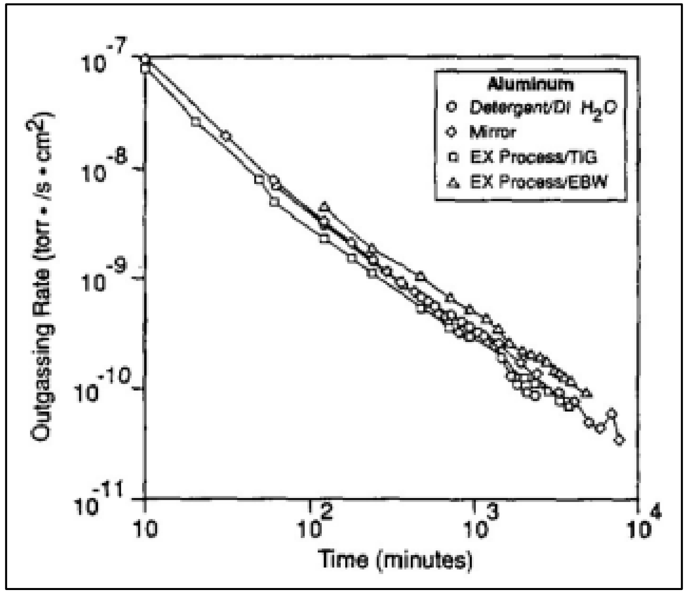


Static vacuum

Step1: material outgassing rate

Unbaked materials: dominated by water vapor





4. Outgassing of water vapour from unbaked metal alloys

After thorough surface cleaning, water vapour dominates the outgassing process of metals in vacuum. For metal alloys, the outgassing rate is inversely proportional to the pumping time (t) and the empirical relationship of Eq. 13 is in general applied at CERN for design of vacuum systems.

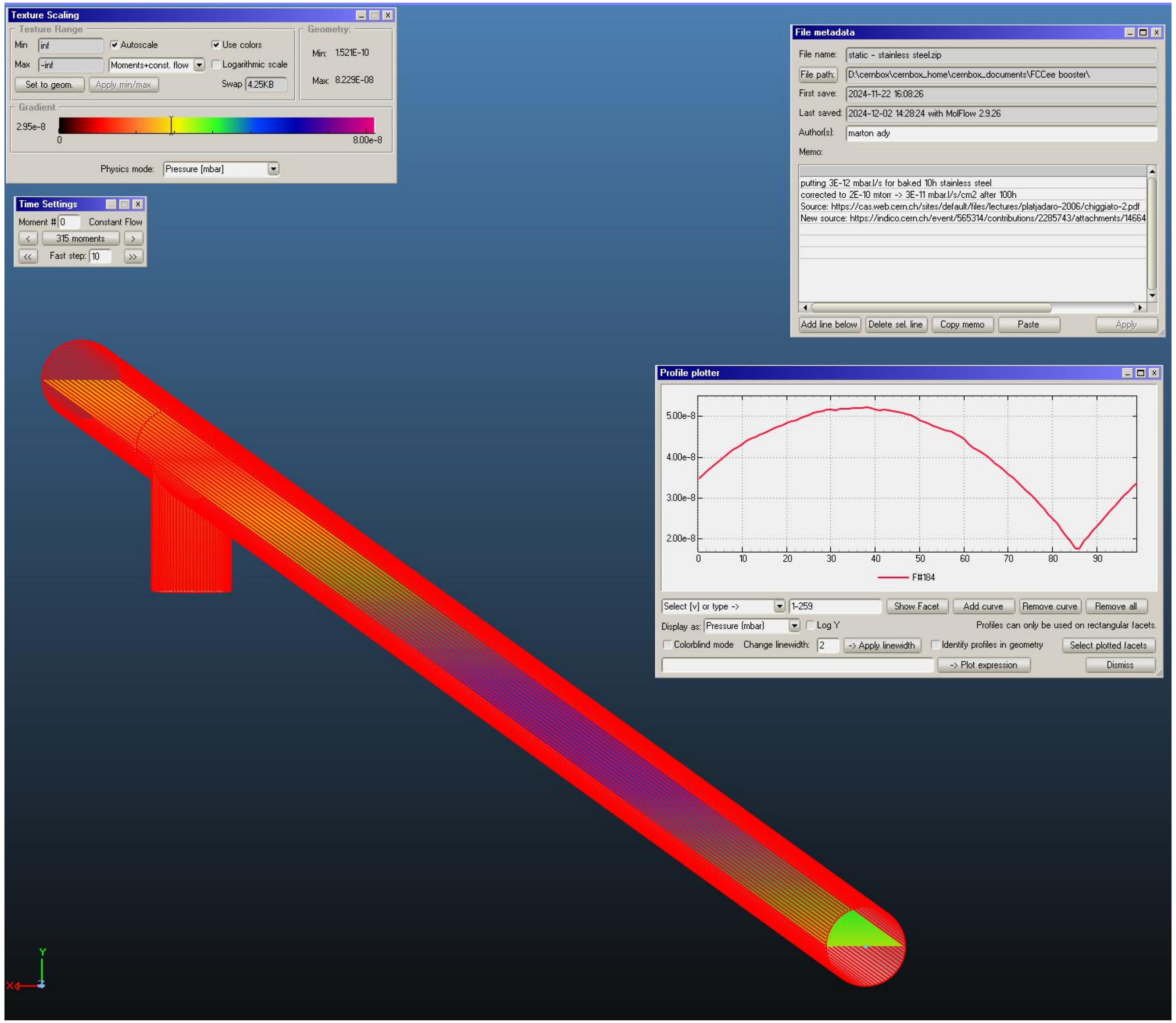
$$q_{H_2O} \approx \frac{3 \times 10^{-9}}{t[h]} \left[\frac{mbar\ l}{s\ cm^2}\right] \qquad (13)$$

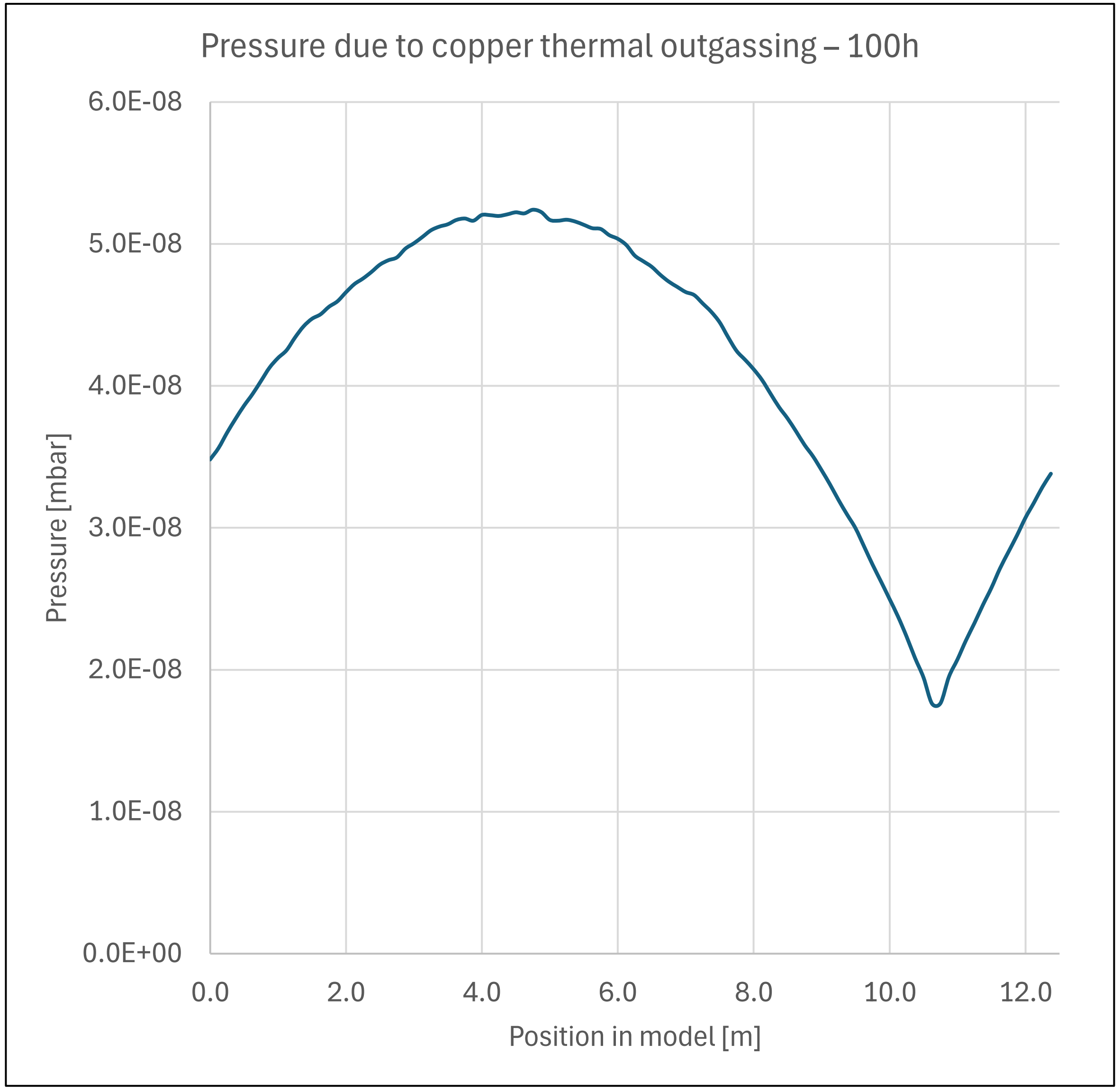
After 100 hours:
3E-11 mbar.l/s/cm^2

Outgassing properties of vacuum materials for particle accelerators Paolo Chiggiato
Proceedings of the 2017 CERN–Accelerator–School course
https://cds.cern.ch/record/2723690/files/2006.07124.pdf?version=1

Static vacuum

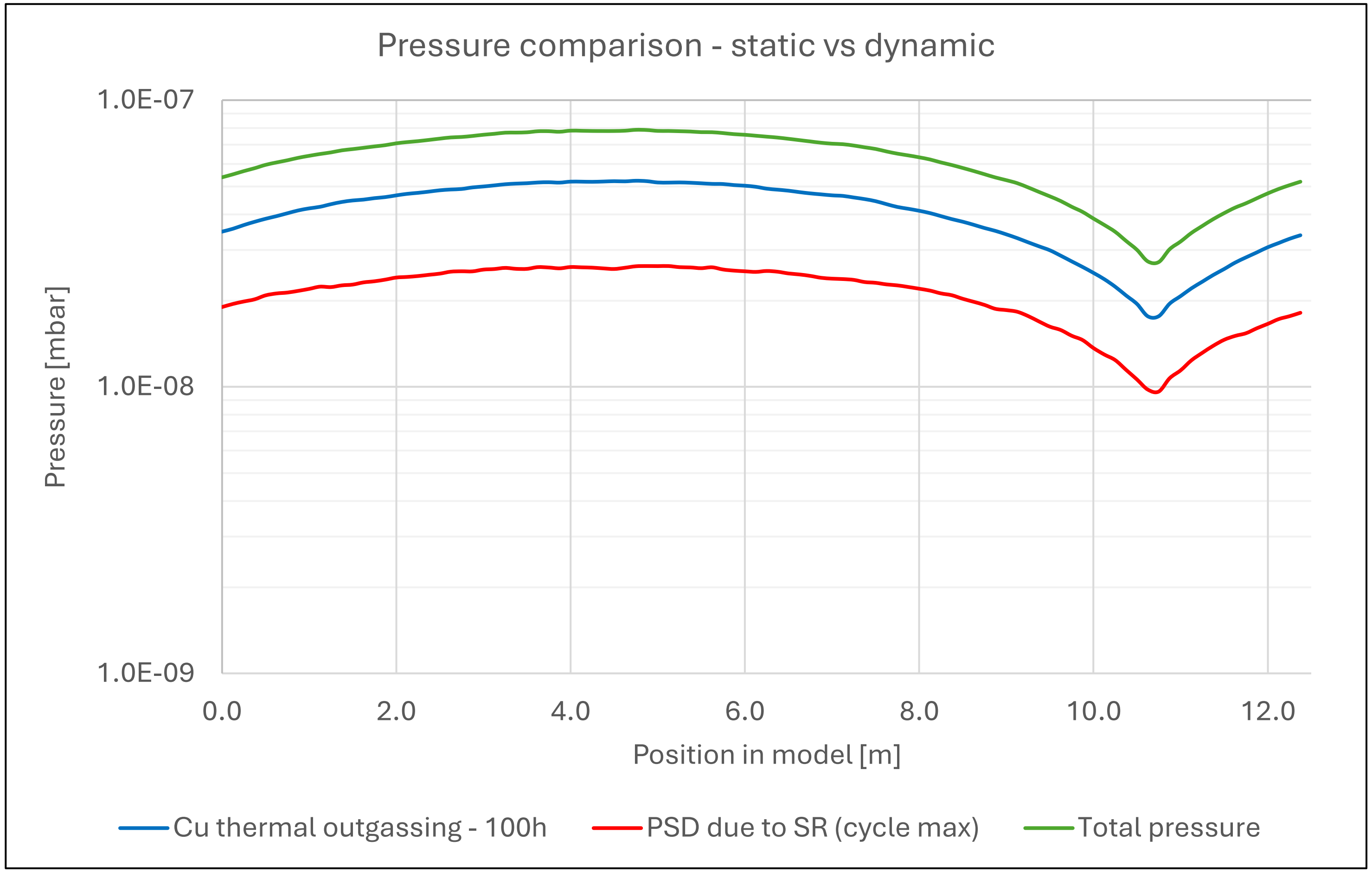
Step2: static simulation





Static / dynamic pressure comparison

After 100h conditioning:



$Q_{thermal} \sim t^{-1}$

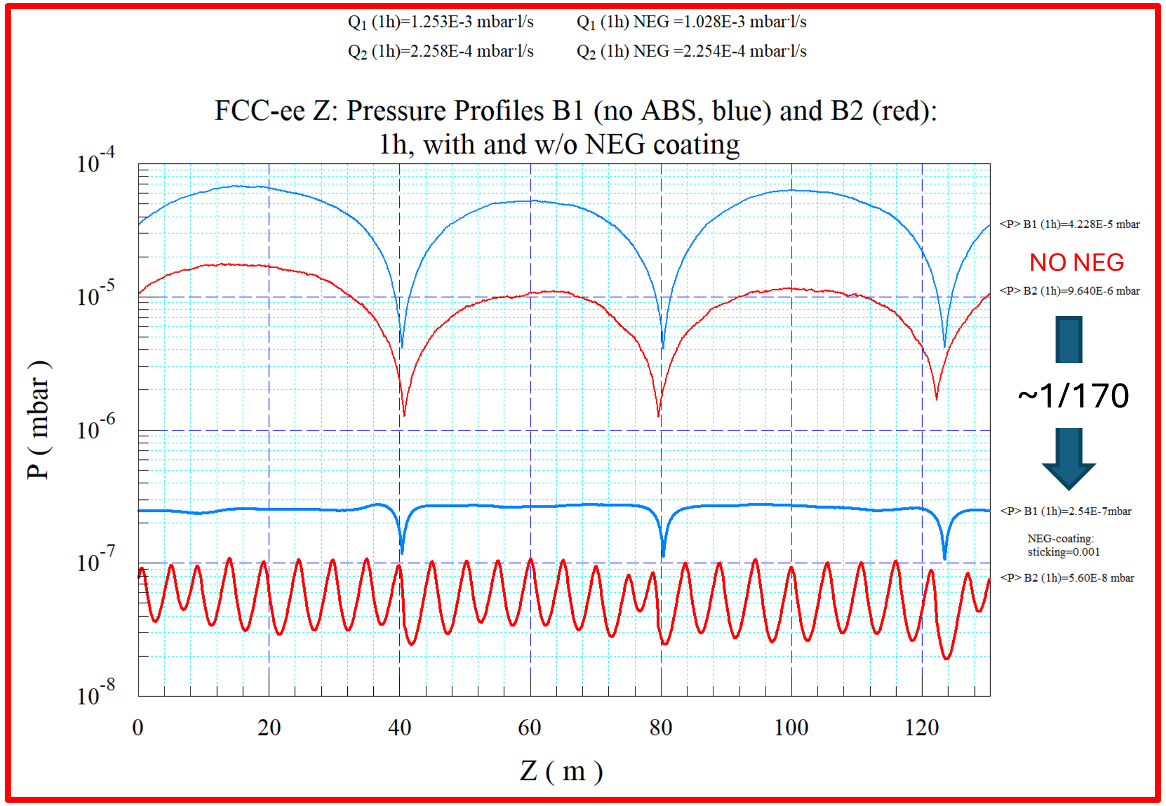
$Q_{PSD} \sim t^{-0.6}$

Outgassing properties of vacuum materials for particle accelerators, Paolo Chiggiato
Proceedings of the 2017 CERN–Accelerator–School course
https://cds.cern.ch/record/2723690/files/2006.07124.pdf?version=1

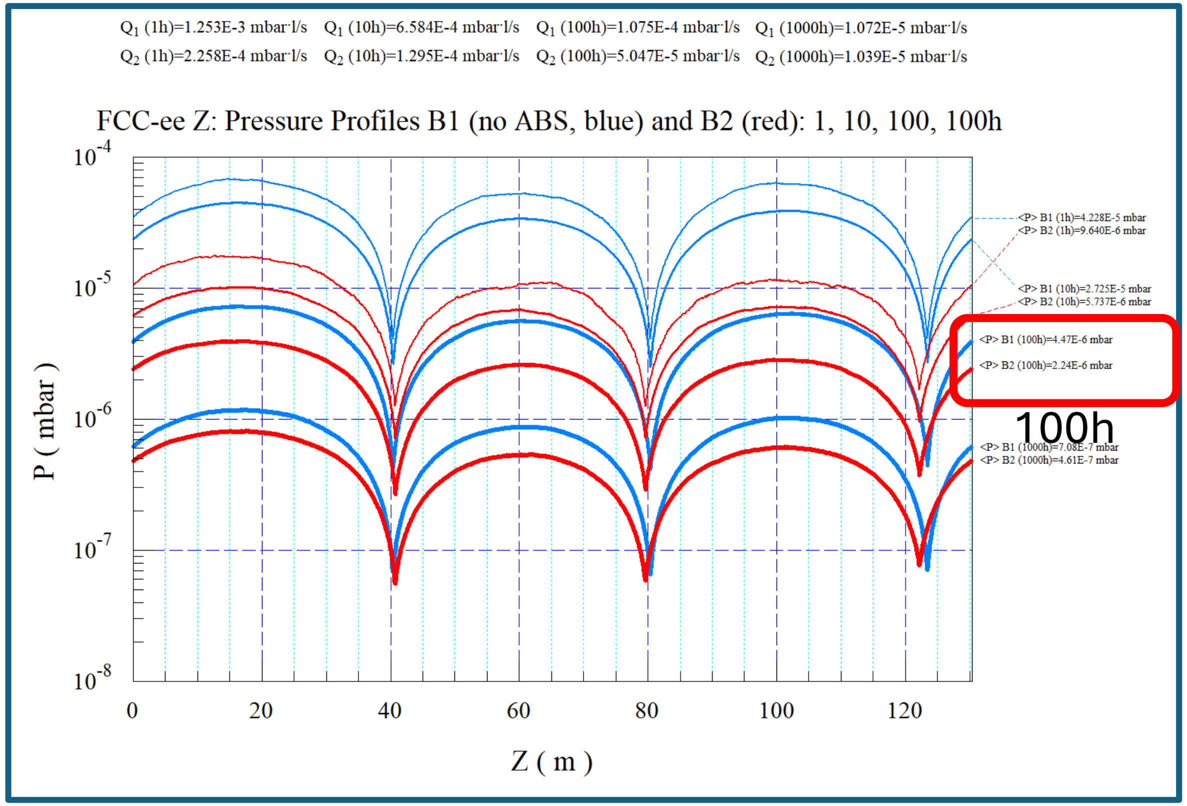
Monte Carlo simulations of ultra high vacuum and synchrotron radiation for particle accelerators
Marton Ady, CERN/EPFL, 2016
https://cds.cern.ch/record/2157666

The case for NEG coating

Cedric Garion / Roberto Kersevan, FCC Week 2024:



- effect of NEG coating (1h case)



- The PSD pressure profiles have been calculated for 4 different beam doses, corresponding to times of 1 h, 10 h, 100 h, 1000 h at nominal current (1270 mA); Simulated gas: CO
- case with 3x 100 (l/s) lumped pumps/beam, and <u>no NEG-coating</u>

Conclusion (booster vacuum)

- The average pressure after around 100h (0.8Ah) of conditioning is around 3E-8mbar
- This is exactly the max. pressure by the latest beam-gas calculations*
- It would be preferable to have an in-situ bakeout system installed, and consequently NEG-coating of the vacuum chambers, as this would reduce the number of external pumps and their cabling by a factor of about 5
- Additionally, the NEG-coated solution would guarantee very fast reconditioning of any vacuum sector needing venting during operation.

*F. Zimmermann. Update on booster vacuum system, operation mode and polarisation time estimate in the DR Presented at the 183rd FCC-ee Optics Design Meeting & 54th FCCIS WP2.2 Meeting (2024)