Synchrotron radiation studies for the FCC-ee arc with FLUKA

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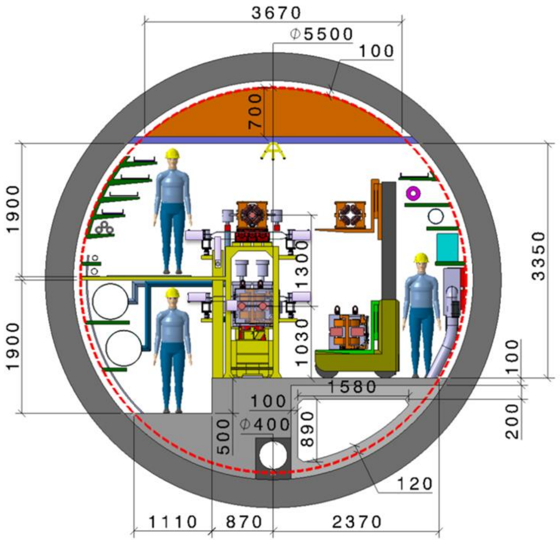
Acknowledgments to J. Bauche, M. Benedikt, R. Garcia-Alia, G. Lerner, R. Kersevan & F. Valchkova-Georgieva

Agenda

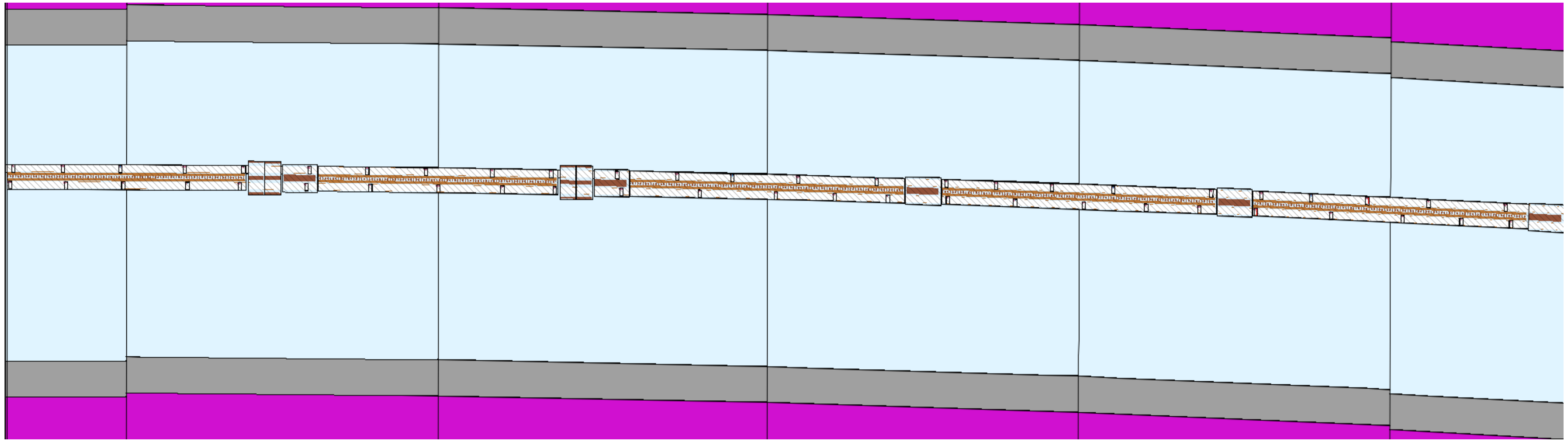
1. Simulation setup
2. Synchrotron radiation
3. Power and dose comparison
4. R2E levels
5. Conclusion

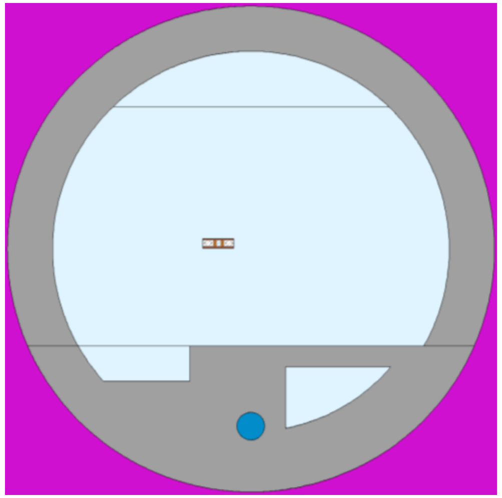
Simulation Setup

- 182.5GeV (ttbar): most challenging case for energy deposition studies
- Representative arc cell → periodic re-insertion of the particles
  - 140m
  - 5 dipoles, 5 quadrupoles, 4 sextupoles
- SR source: photons emitted in dipoles → indirect approach
  - Soon: e-, e+ in all magnets → direct approach



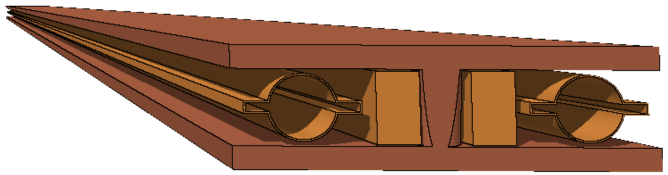
Tunnel layout by F. Valchkova-Georgieva (IOWG, 16.10.2019)



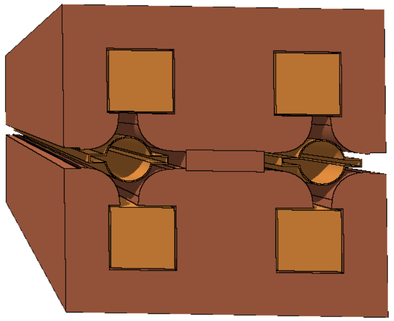


Magnets

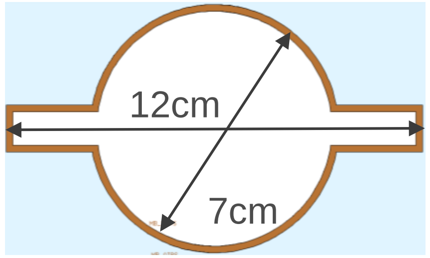
General: 30cm beam separation



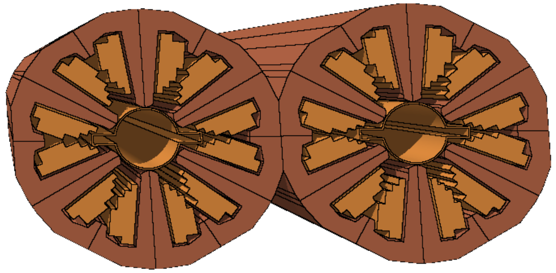
Dipoles (MB):
- Long: 24.64m (l_{mag})
  (Simulations were performed before 24m long model was abandoned)
- Short: 21.44m (l_{mag})
- 56.6mT at 182.5GeV



Quadrupole (MQ):
- 2.9m (l_{mag})
- 3.2m (l_{mech})
- Maximum gradient: 10.0T/m



Vacuum chamber (VC):
- Copper
- 2mm
- Winglets



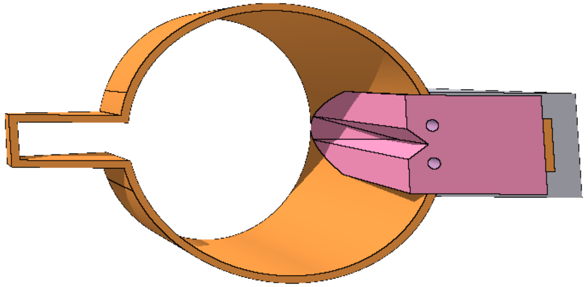
Sextupole (MS):
- 1.4m (l_{mag})
- No prototypes and technical drawings so far (ending of coils,…)

Magnets designed from scratch in Fluka. Technical drawings received from J. Bauche

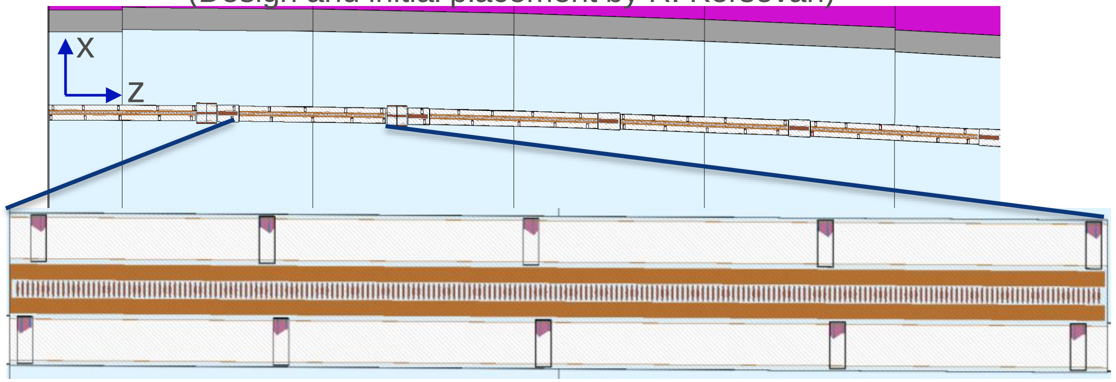
Model comparison: absorber vs continuous shielding

Absorbers (ABS):

- CuCrZr alloy
- Length: 30cm
- 5-6m distance
- Angled surfaces for even power distribution
- Water cooled
- 25 ABS in each beam (MBs, MQs)

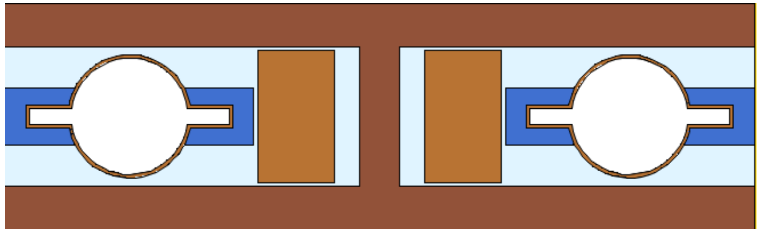


(Design and initial placement by R. Kersevan)



Continuous shielding:

- Equivalent to LEP layout
- Continuous shielding around VC in MBs
  - Due to space restrictions from yoke and coils respectively, no shielding in MQs and MSs.
- Intermet180 (Tungsten alloy)
- Shielding thickness:
  - Top/bottom: 1cm
  - Sides: 1.3cm



Synchrotron Radiation (SR)

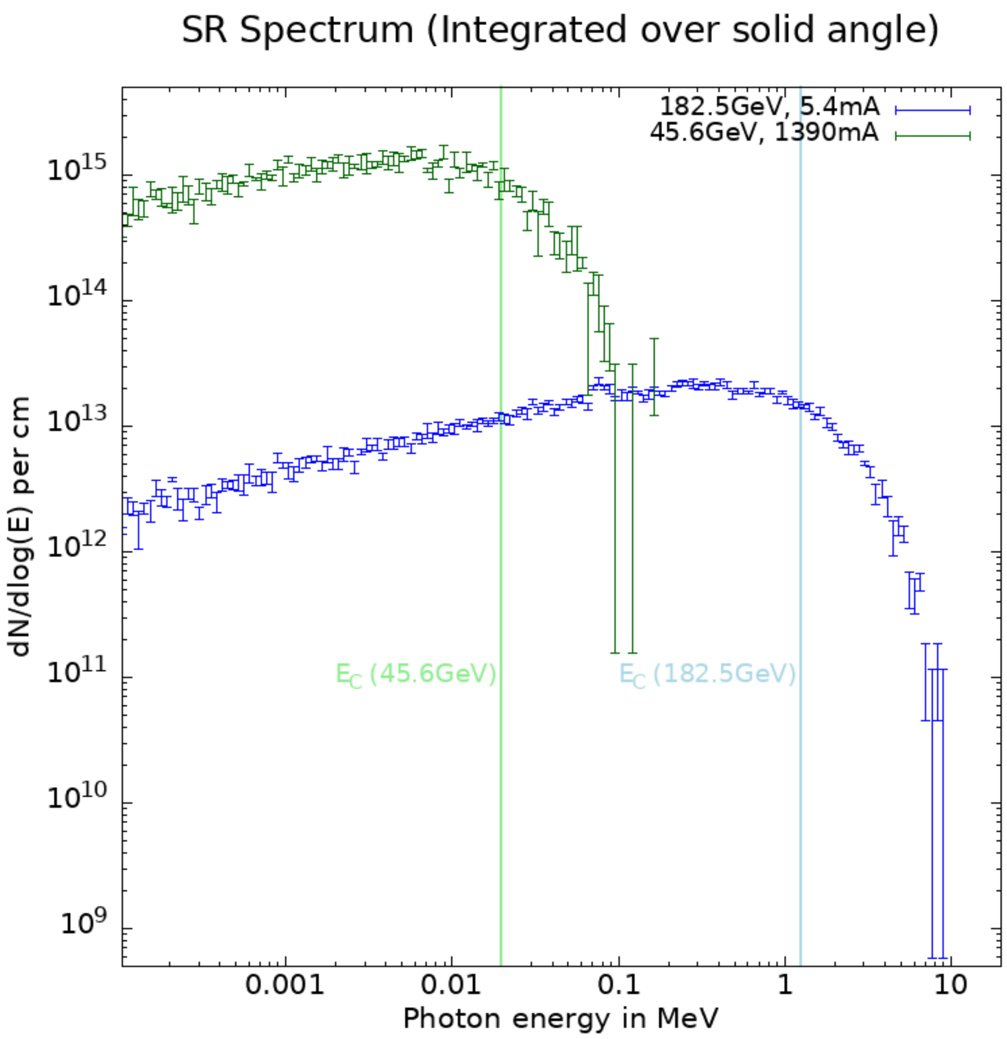
- **Electromagnetic radiation** emitted tangentially with an angular spread by charged particles moving along a curved trajectory
- The **lighter** the particle and the higher the **energy**, the stronger the effect:

$$\Delta E \propto \frac{E^4}{m^4}$$

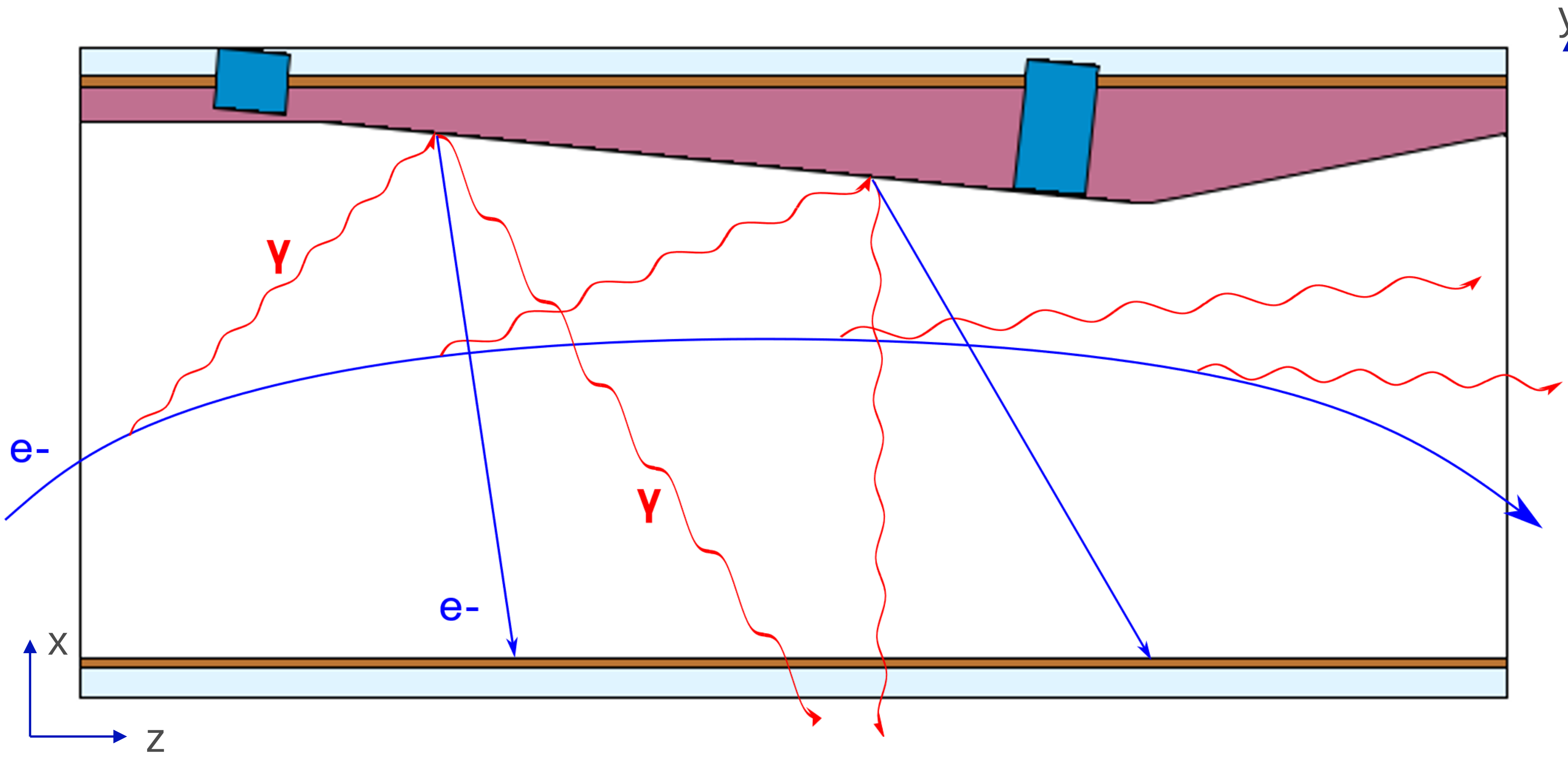
- SR related numbers in FCC-ee ($\rho = 10.76\text{km}$):

Energy loss (ΔE)	9.2GeV/turn
Critical energy * (E_C)	1.25MeV
Power whole ring	50MW
Power 140m	168kW

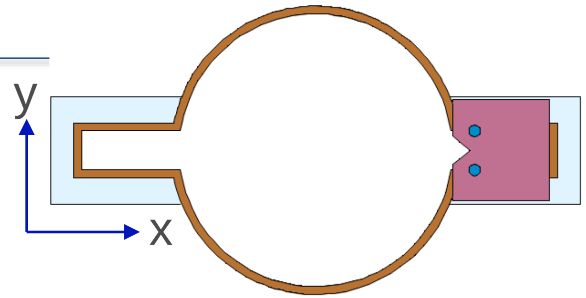
*** Critical energy (E_C):** half of energy is carried by particles below, the other half above



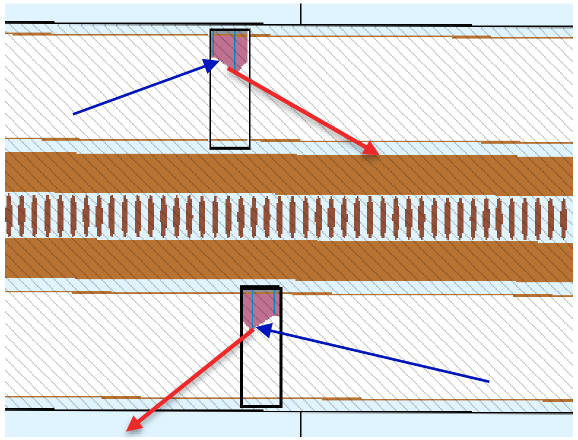
Absorber working & reflection



Compton scattering: photon collides with electron and is scattered into a different direction, dominant in the MeV range



External beam: reflected particle → magnet yoke

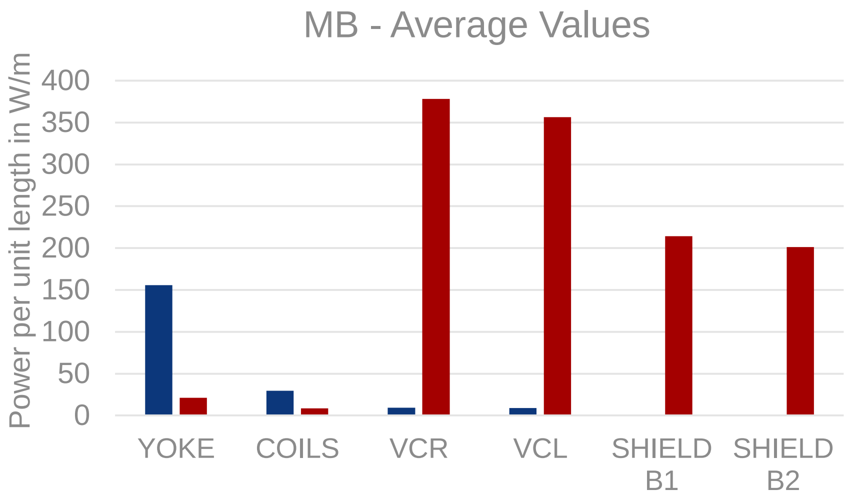


Internal beam: reflected particle → tunnel

Power distribution on the tunnel & magnets

	ABS		Continuous	
MB *	23.4kW	14%	3.5kW	2%
MQ	2.9kW	1.7%	17.4kW	10.4%
MS	0.1kW	<0.1%	7.1kW	4.2%
ABS, Shield/VC	**131kW**	78%	**135kW**	81%
Tunnel	9.5kW	6%	3.5kW	2.1%
Total	**167kW**		**167kW**	

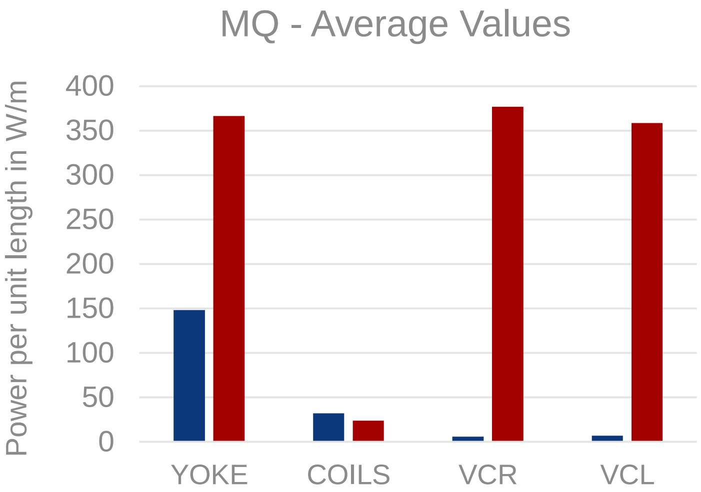
* Without VC and shielding

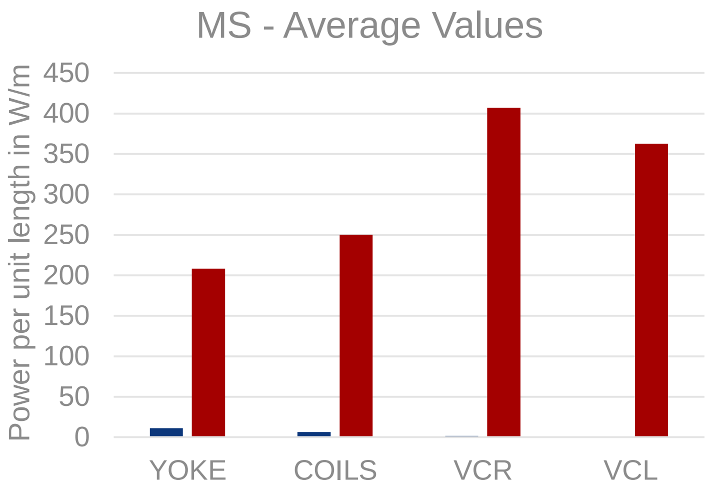


Component	Material
Yoke	Iron
Coils	Copper
VCR/VCL	Copper
ABS	CuCrZr
Shielding	INERM180

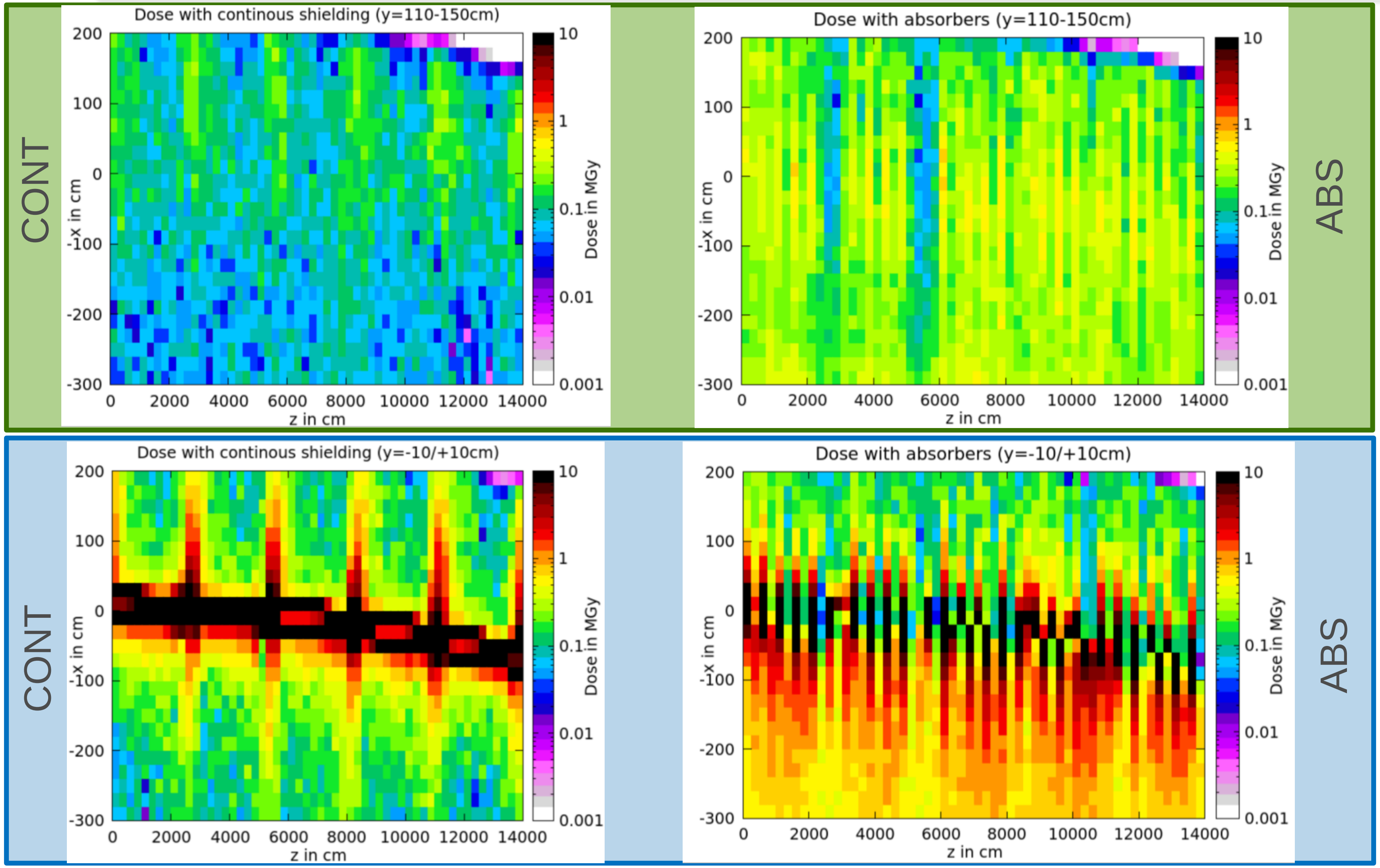
Normalisation:
I=5.4mA
E=182.5GeV
Runtime: 10^7s

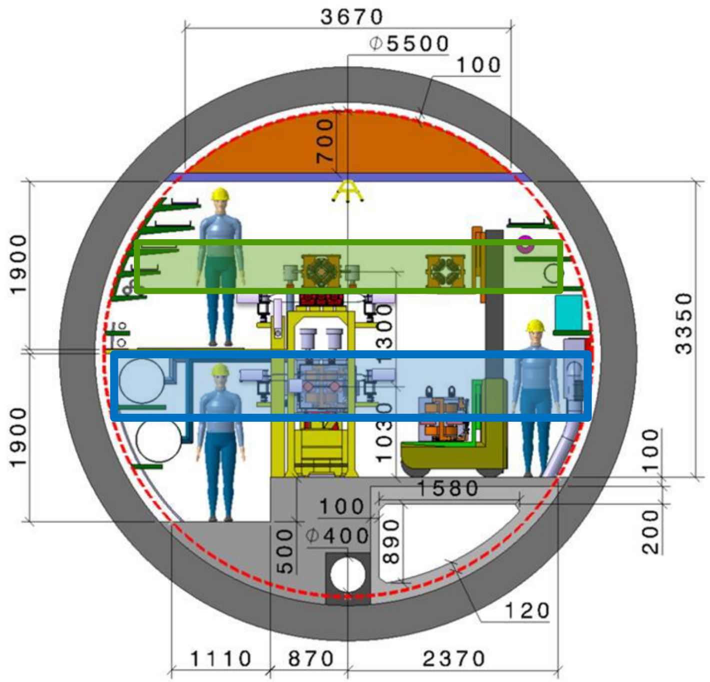
ABS
Continuous





Dose in the tunnel environment

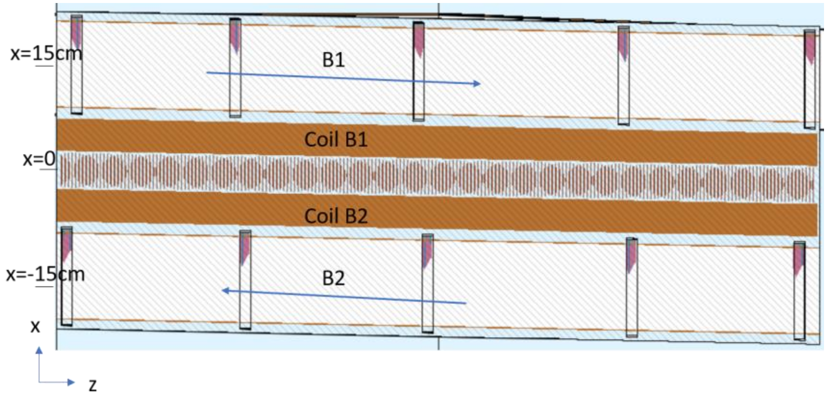




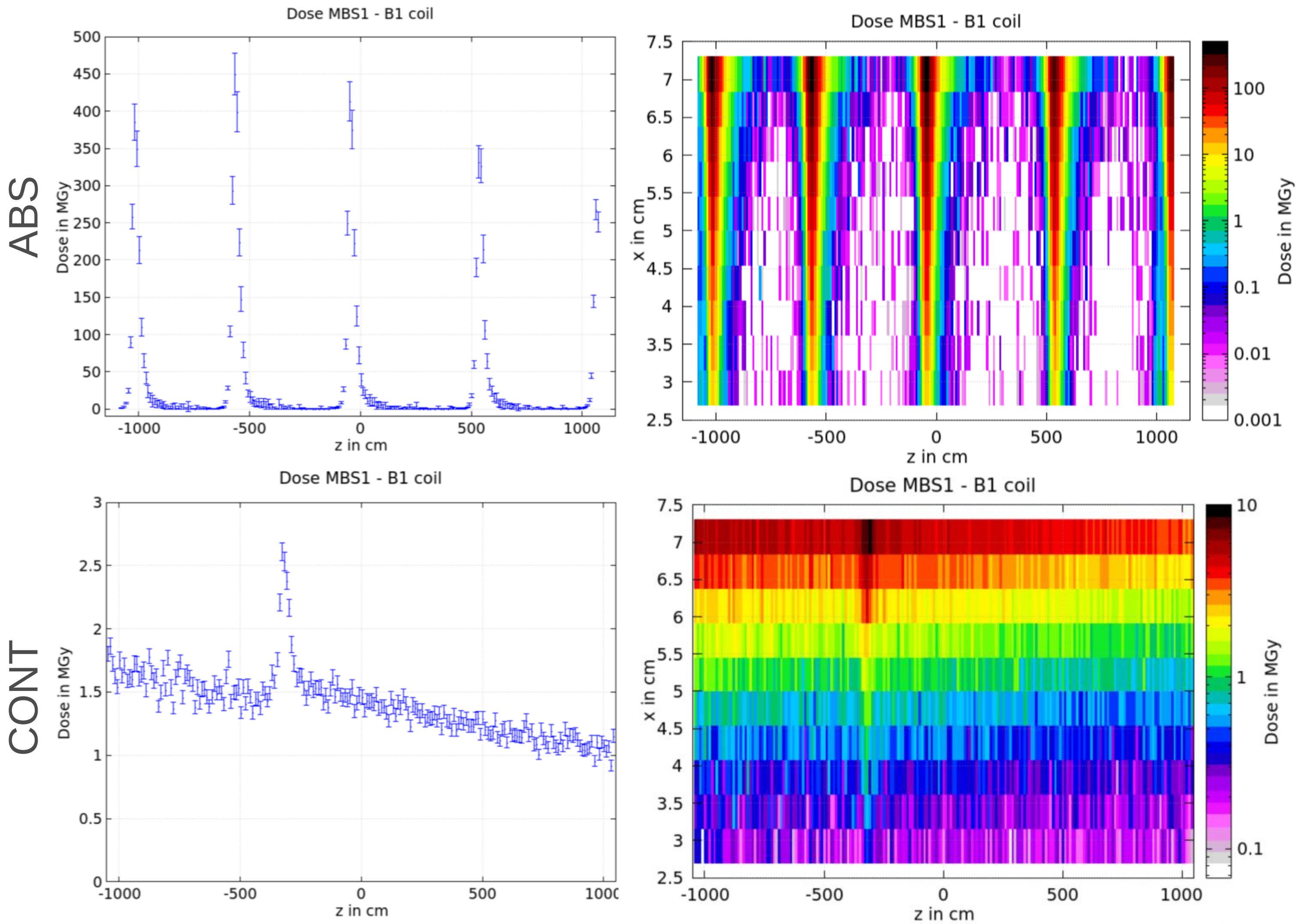
	Continuous	ABS
Top, Center	120kGy	500kGy
Middle, ext.	200kGy/ 1.2MGy peak	600kGy
Middle, int.	200kGy	1.2MGy

Dose and energy density on the coils (MB)

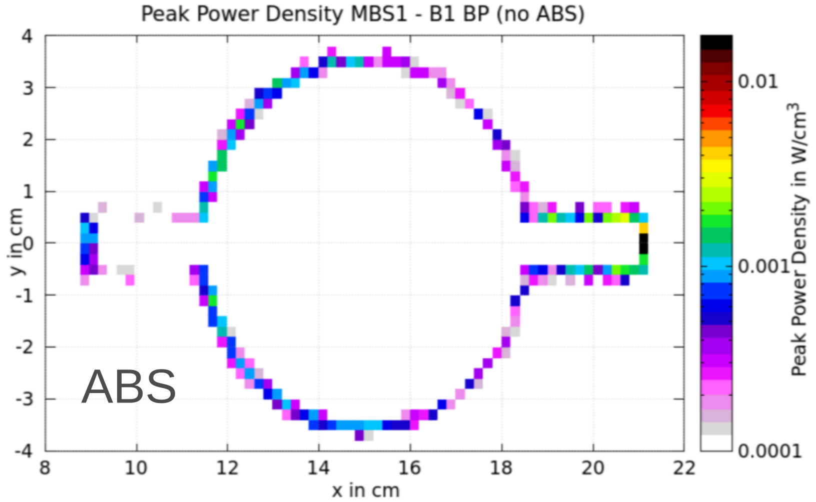
Top-View MB:



- **ABS:**
  - Up to 500MGy at location of ABS;
  - Strongly localized around y=0
  - Other locations: <1MGy
- **CONT:** peak caused by missing lack of shielding in MQs
- Dose in coils of **MQs** negligible due to protection of yoke



Energy density on the BP

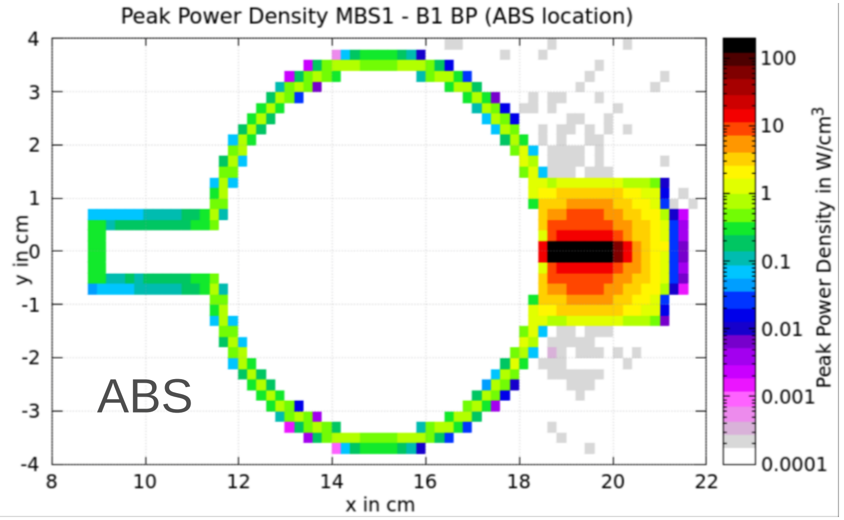


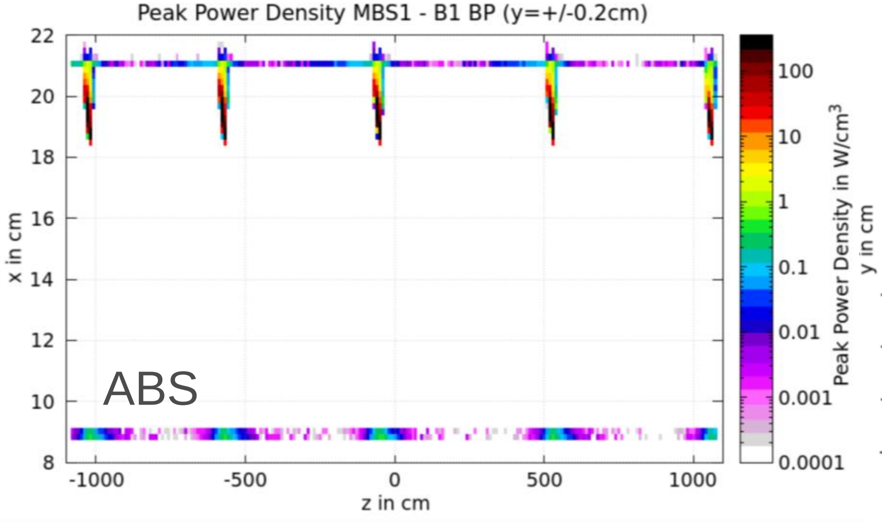
- Similar situation as for coils

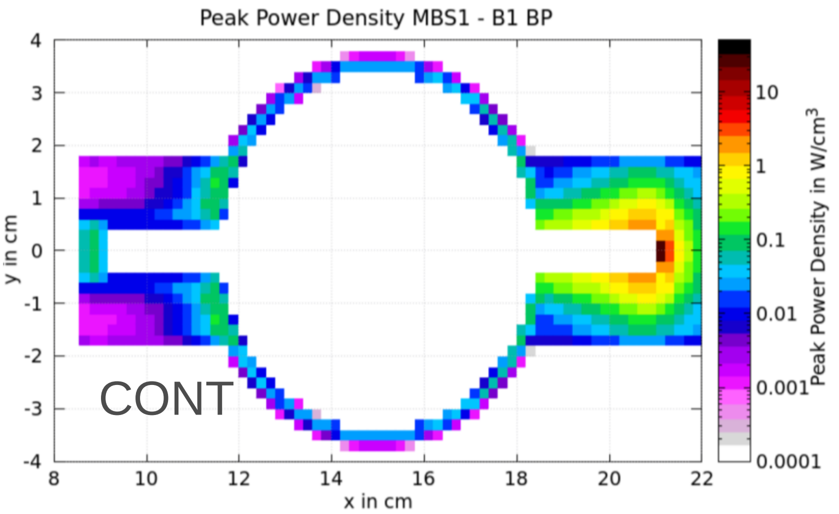
ΔT:
- ABS: 100K/s on absorber
- CONT:10K/s on vacuum chamber

→ Cooling feasible?

- **ABS**: deal with strong peaks (up to 400W/cm^3) at absorbers, otherwise low power
- **CONT**: constant power (up to 40W/cm^3 peaks) on the vacuum chamber over whole magnet, but lower power



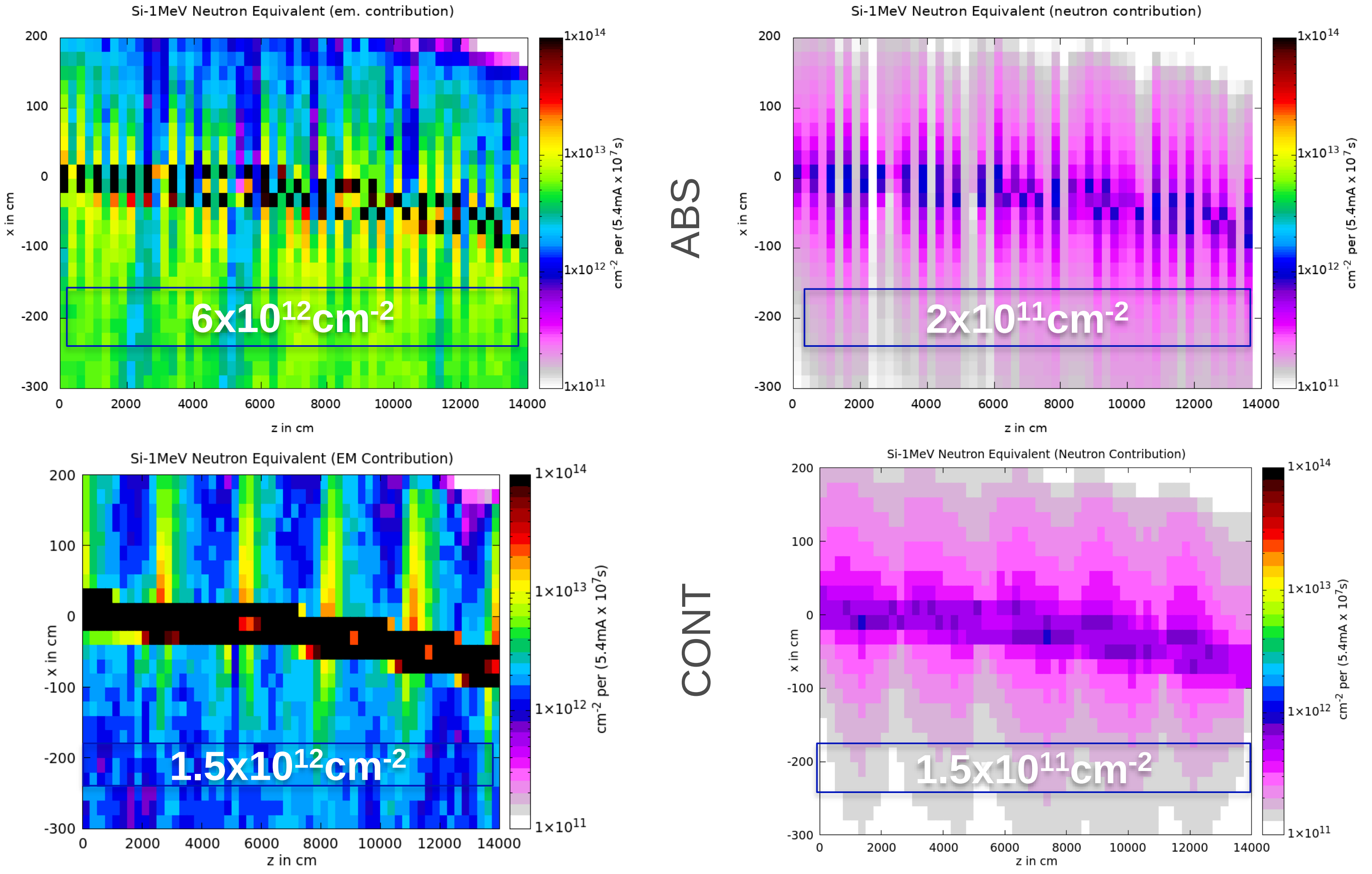




R2E: Si-1MeV neutron equivalent fluence

- Low abundance of neutrons, since they are only produced by photons >~10MeV
- High abundance of electromagnetic particles leads to higher contribution

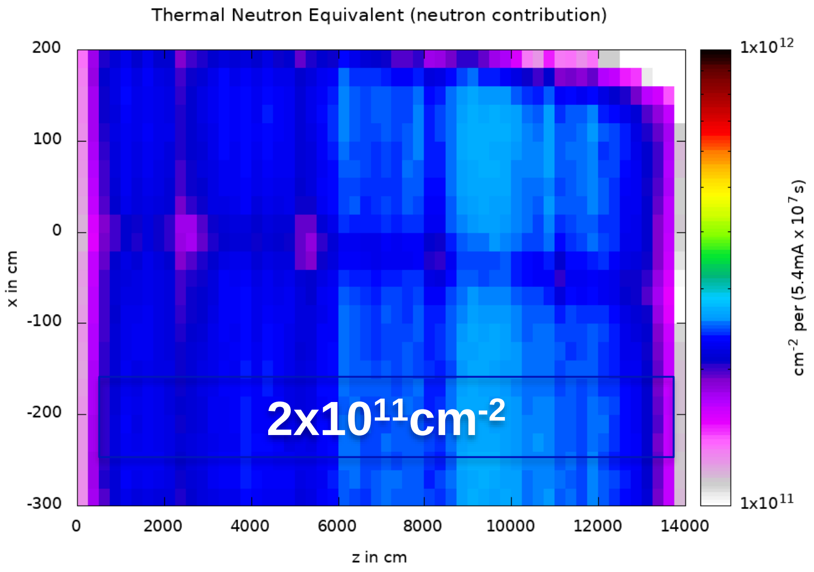
- CONT: em. contribution better shielded, no significant difference in the neutron contribution



Results normalized to 10^7s (one year at the current design) and 5.4mA

R2E: high energy hadron equivalent fluence & thermal neutron equivalent fluence

Thermal neutron eq fluence:

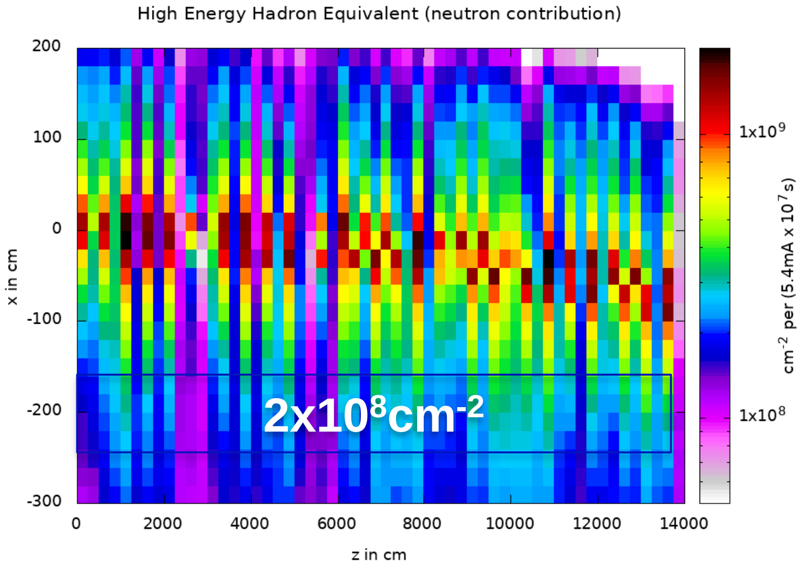


- Neutrons create secondary neutrons and thermalize
- Thermal neutron equivalent looks identical for both cases

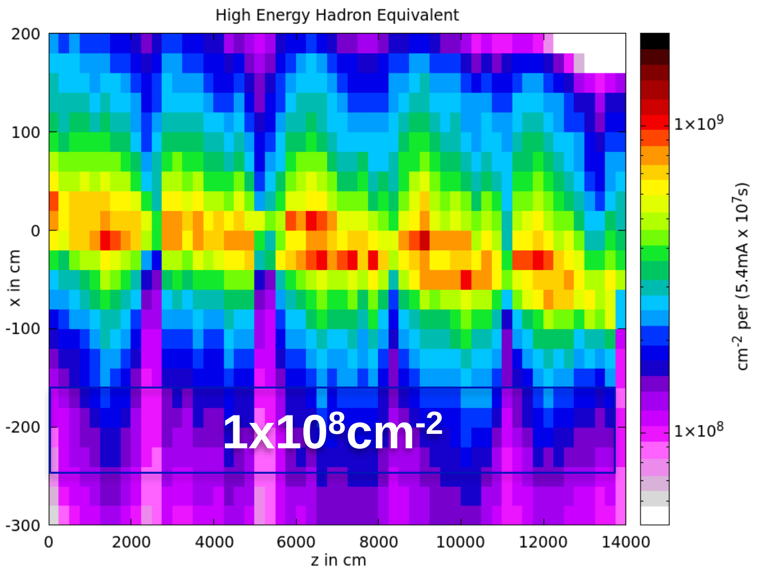
HEH-eq fluence:

- HEH-eq fluence is lower due to low energy of neutrons → low weight
- Similar results for both designs for HEH-eq

ABS



CONT



Results normalized to 10^{7}s (one year at the current design) and 5.4mA

Summary and outlook

Summary:

- Lower dose values in the tunnel for “continuous” scheme
  - Problem of space restrictions in MQs and MS
  - High peaks in places of MQs due to missing shielding
- Booster location on top: barely any fluctuations along z
- **Cont**: higher values for dose and peak power on coils and BP over the whole magnet → cooling?
- **ABS**: strong peaks for dose and peak power, but otherwise low values → dose levels feasible?
- No strong differences for R2E related values

Outlook:

- Superconducting MQs and MSs for improved power consumption
- Booster impact on the collider determined by its time at top energy
- Collimation system → beam-collimator interaction
- Other FCC-ee FLUKA related projects:
  - Dump system
  - Positron target

Any questions?

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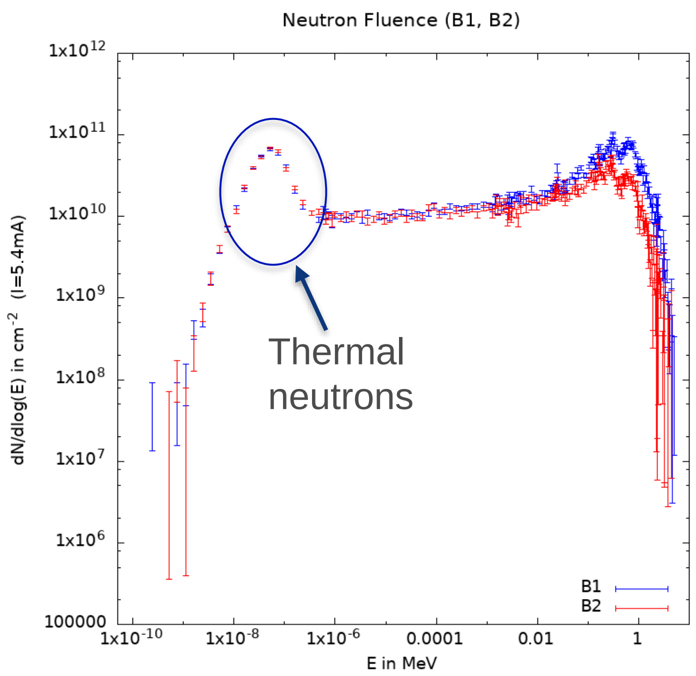
Fluence in the tunnel – ABS layout



Neutron fluence:
- Similar results for beam 1 and beam 2
- Magnets are "transparent" for neutrons
- Peak at 0.025eV from thermal neutrons

Electromagnetic particles fluence:
- Higher fluence obtained for B1 due to scoring at the outside of the tunnel
- Magnets stop particles from B2