Synchrotron radiation (SR) studies for the FCC-ee arc with FLUKA

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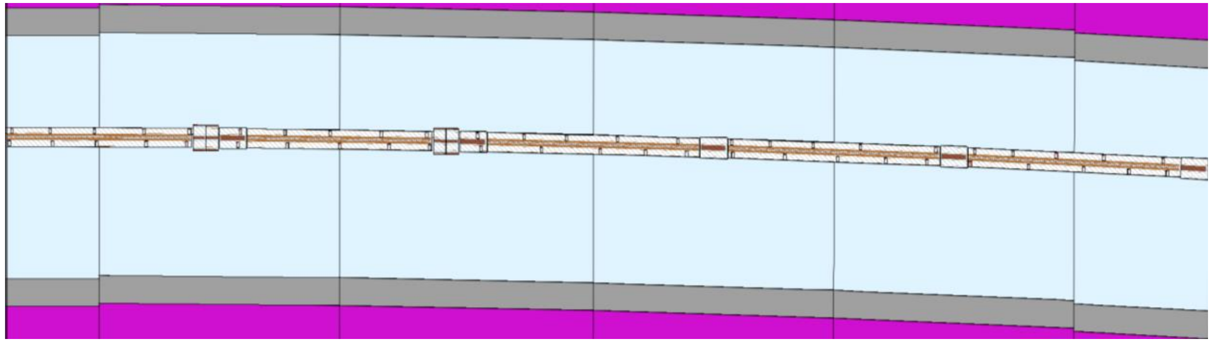
Acknowledgments to J. Bauche, M. Benedikt, R. Garcia-Alia, G. Lerner, R. Losito, R. Kersevan & F. Valchkova

Agenda

1. Simulation setup - reminder
2. Synchrotron radiation: spectrum
3. Dose levels in the tunnel
4. Si-1MeV neutron equivalent fluence
5. Conclusion & Outlook

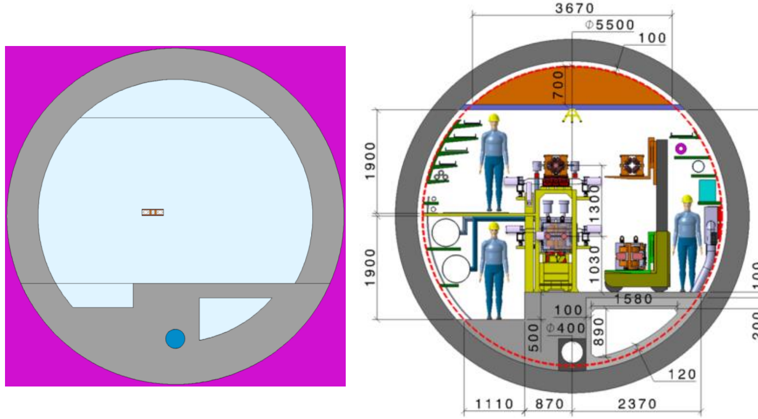
Simulation Setup

- 182.5GeV (ttbar): most challenging case for energy deposition studies
- Representative arc cell (140m) → periodic re-insertion of the particles
  - 5 dipoles, 5 quadrupoles, 4 sextupoles



- SR source (**NEW!**): e-, e+ in all magnets → direct approach
- **Different layouts performed:**
  - **Absorbers: Tungsten** (Inermet180) vs. **copper** (CuCrZr)

	Tungsten	Copper
+	Better absorption properties (higher Z and density)	Easier to manufacture, better behavior in vacuum
-	Brittle, harder to manufacture, cost	Less good energy absorption properties



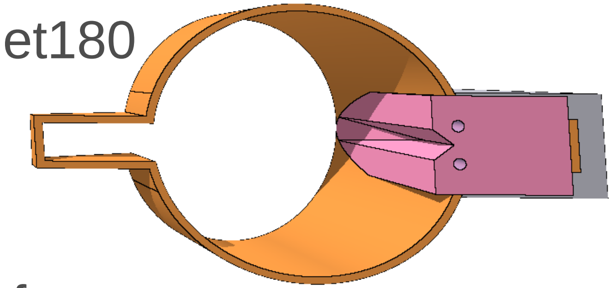
Tunnel layout by F. Valchkova-Georgieva (IOWG, 16.10.2019)

  - **Continuous shielding** (comparable to LEP design): tungsten, 1cm around winglet

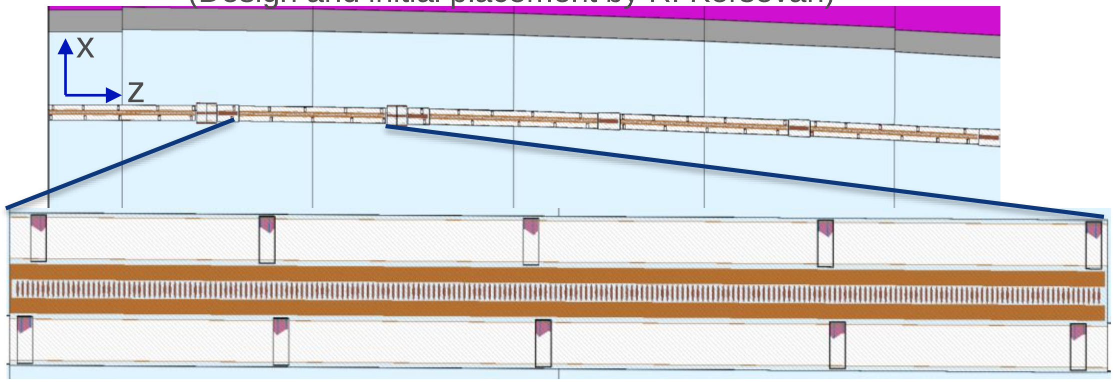
Model comparison: absorber vs continuous shielding

Absorbers (ABS):

- CuCrZr or Inermet180
- Length: 30cm
- 5-6m distance
- Angled surfaces for even power distribution
- Water cooled
- 25 ABS in each beam (MBs, MQs)

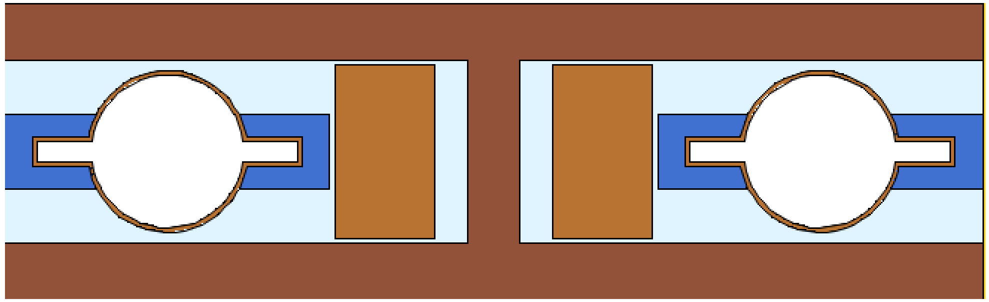


(Design and initial placement by R. Kersevan)



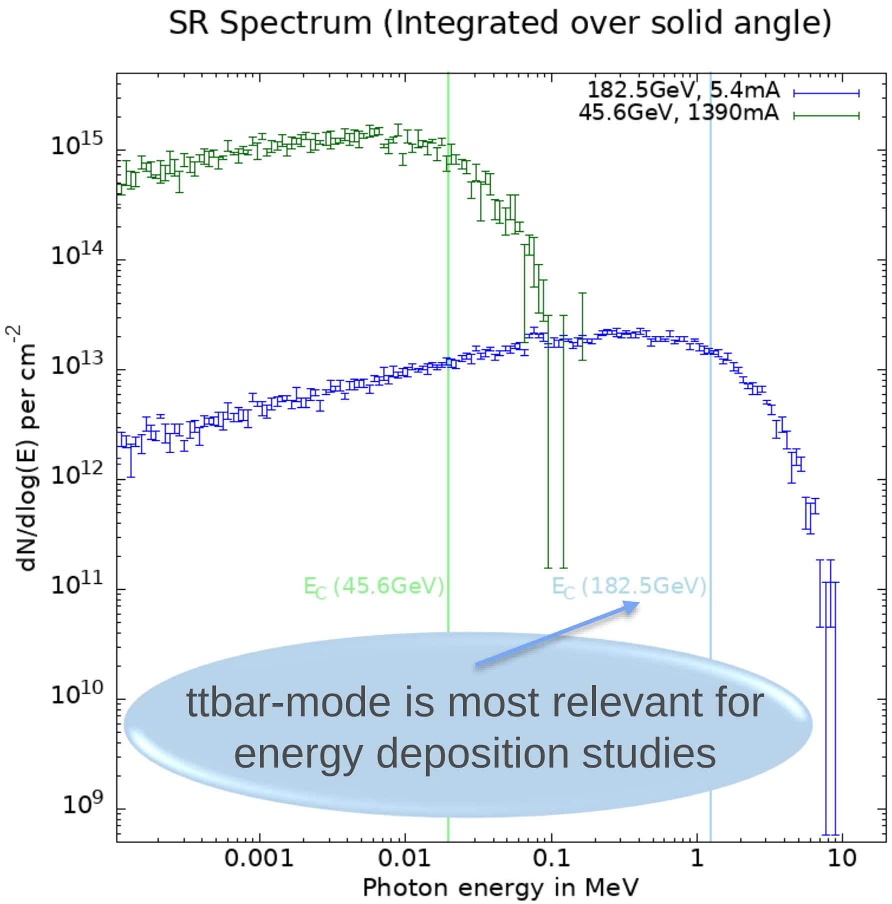
Continuous shielding:

- Equivalent to LEP layout
- Continuous shielding around VC in MBs
  - Space restrictions due to yoke and coils → no shielding in MQs and MSs.
- Intermet180
- Shielding thickness:
  - Top/bottom: 1cm
  - Sides: 1.3cm



Source term – Synchrotron Radiation

SR Spectrum of primary electrons:



- **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:

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

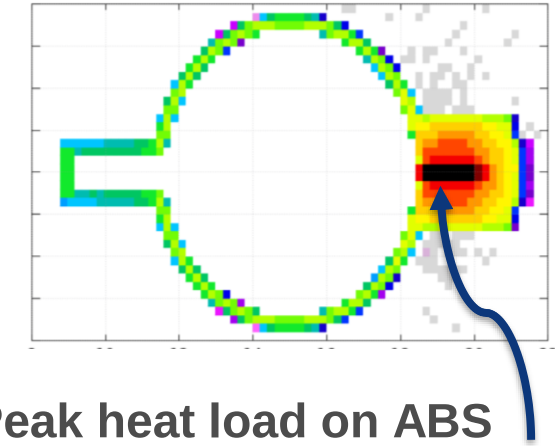
- SR related numbers in FCC-ee ($\rho = 10.76\text{km}$):

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

Power deposition comparison: Tungsten vs Copper vs Continuous

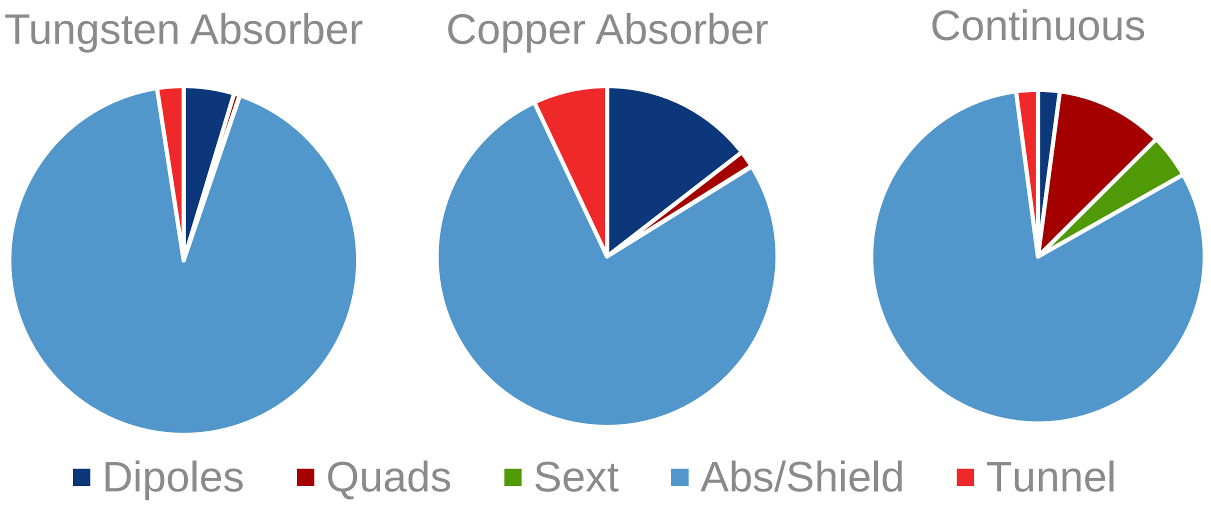
Power	Tungsten		Copper		Continuous	
Dipoles*	7.8kW	4.7%	23.4kW	14%	3.5kW	2%
Quads	0.9kW	0.5%	2.6kW	1.6%	17.4kW	10.4%
Sexts	0.05kW	0.03%	0.09kW	0.06%	7.1kW	4.3%
ABS, Shield/VC	**155kW**	**92.3%**	**131kW**	**78%**	**135kW**	**81%**
Tunnel	4.1kW	2.4%	9.5kW	7%	3.5kW	2.1%
Total	168kW		168kW		167kW	

* Without VC and shielding



Peak heat load on ABS
(hottest spot on the absorber)
In the (unrealistic) adiabatic assumption**:**

- Tungsten: 280K/s
- Copper: 100K/s
- Continuous: 10K/s



Normalisation:
Current: 5.4mA
Energy: 182.5GeV
Runtime: 10^7s

Power distribution on the absorbers and MBs

Power comparison different ABS:

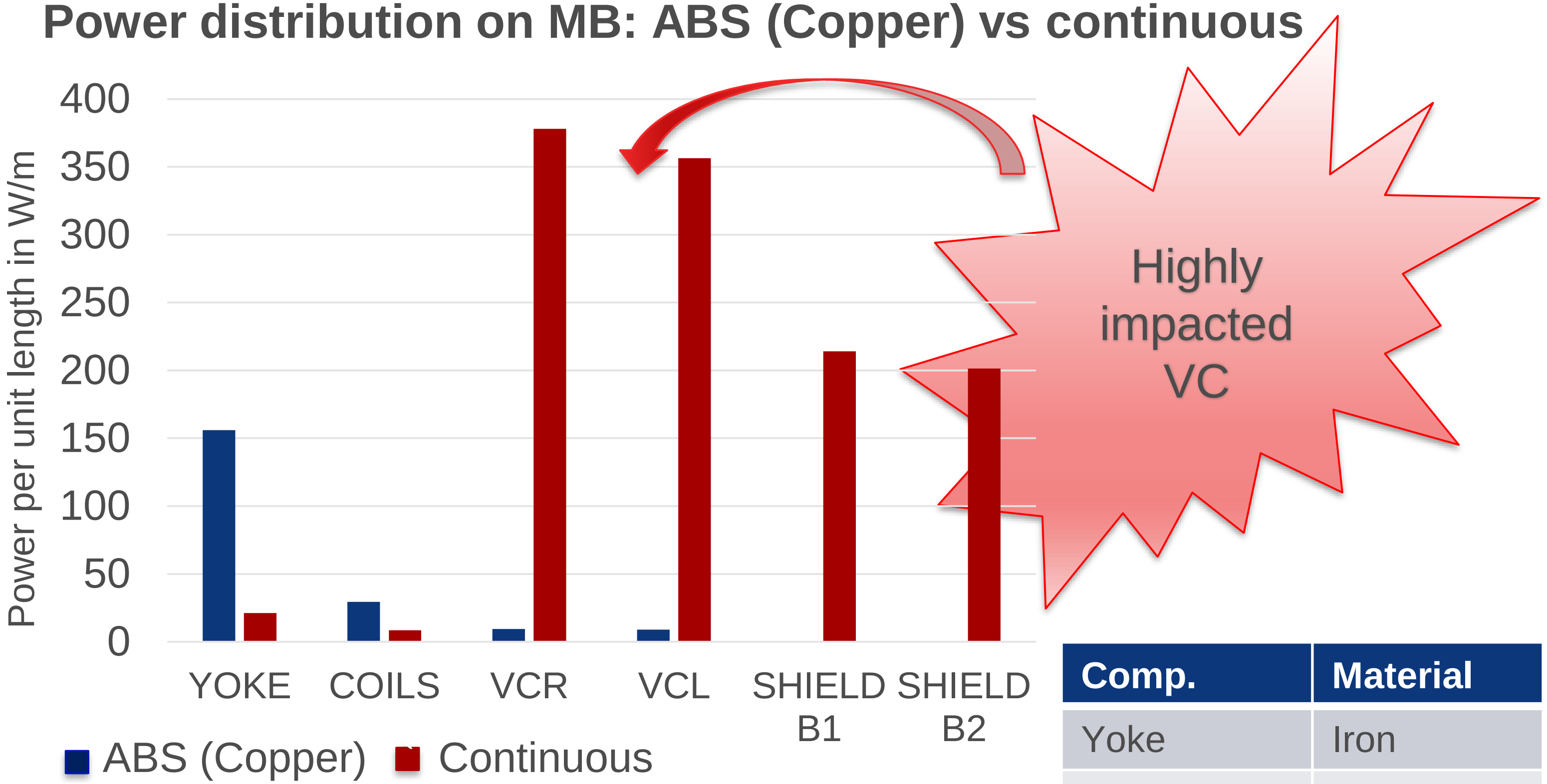
Power on ABS	Tungsten	Copper
Absorber	97%	94%
Cooling	0.4%	1%
BP	2.6%	4%

Percentage calculated from one representative absorber

Power on MB	Tungsten (1.7kW)	Copper (5.3kW)
Yoke	64%	72%
Coil	24%	21%
BP	12%	7%

Percentage calculated from one representative MB

Power distribution on MB: ABS (Copper) vs continuous



Absorber (CuCrZr, 30cm): ~2.6kW (W/m not meaningful)

Comp.	Material
Yoke	Iron
Coils	Copper
VCR/VCL*	Copper
Shield	Inerm180

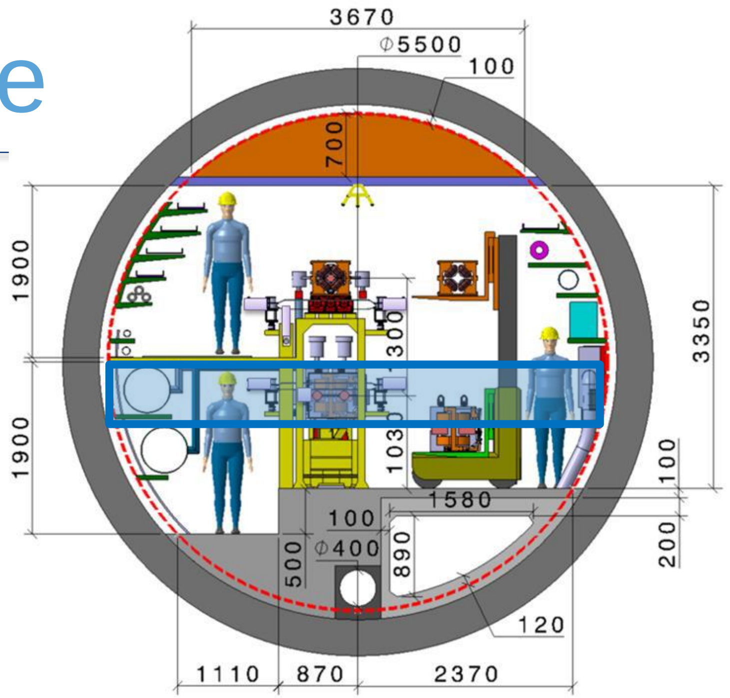
* VC…Vacuum Chamber (right/left)

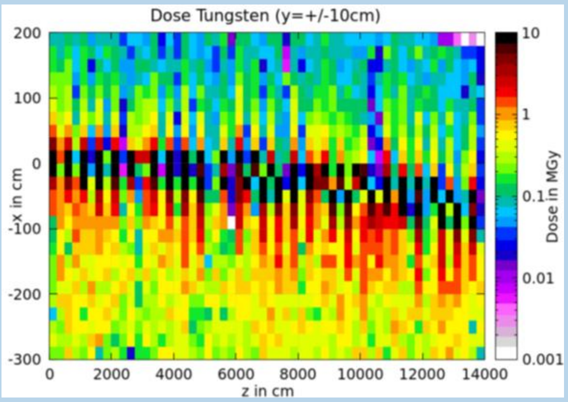
Dose in the tunnel environment – y centre

- Higher dose internally due to backscattering of particles on ABS

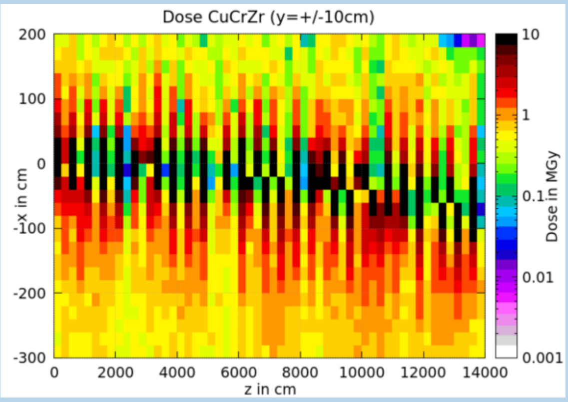
- One order of magnitude higher dose than for tungsten (especially externally)
- Higher dose internally

- Peaks due to missing shielding in MQs
- Externally higher dose values
- On average lowest dose

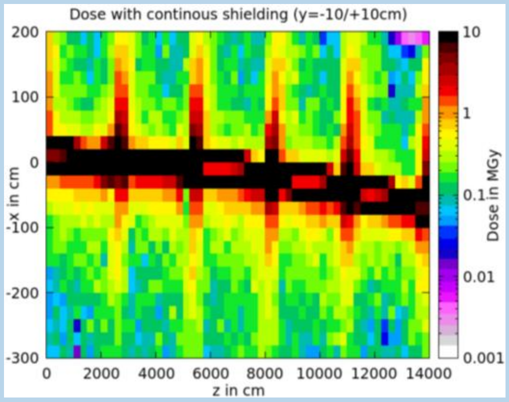




TUNGSTEN



COPPER



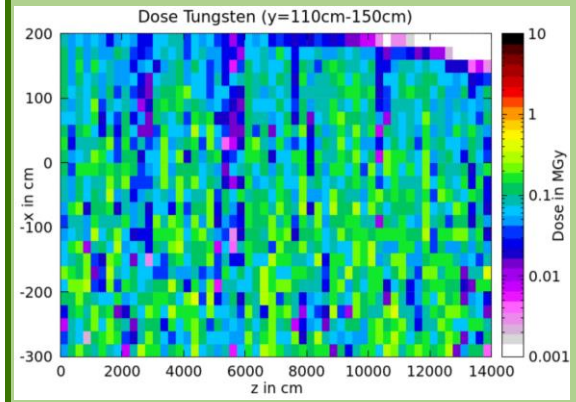
CONTINUOUS

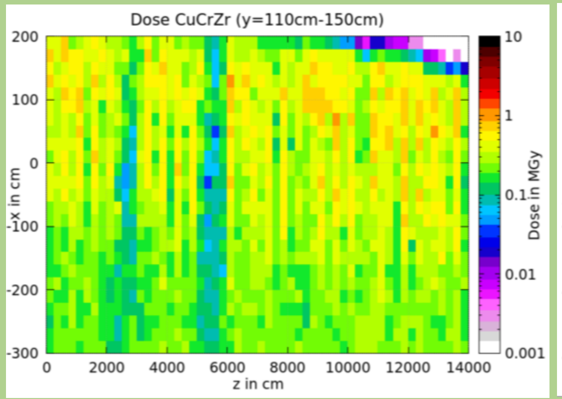
	Tungsten	Copper	Cont.
Middle, ext.	100kGy	600kGy	200kGy/ 1.2MGy
Middle, int.	500kGy	1MGy	200kGy

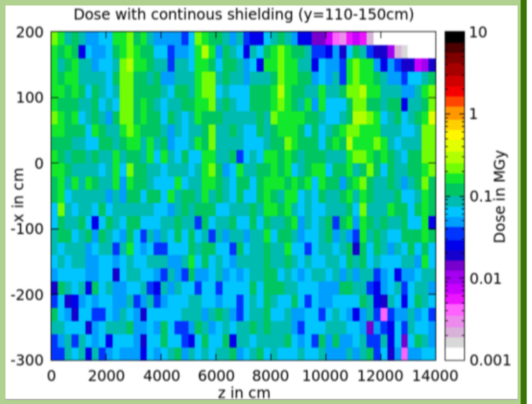
HL-LHC arcs reference value: 1.4Gy (!)
(https://edms.cern.ch/ui/file/2302154/1.0/HL LHC_Specification_Document_v1.0.pdf)

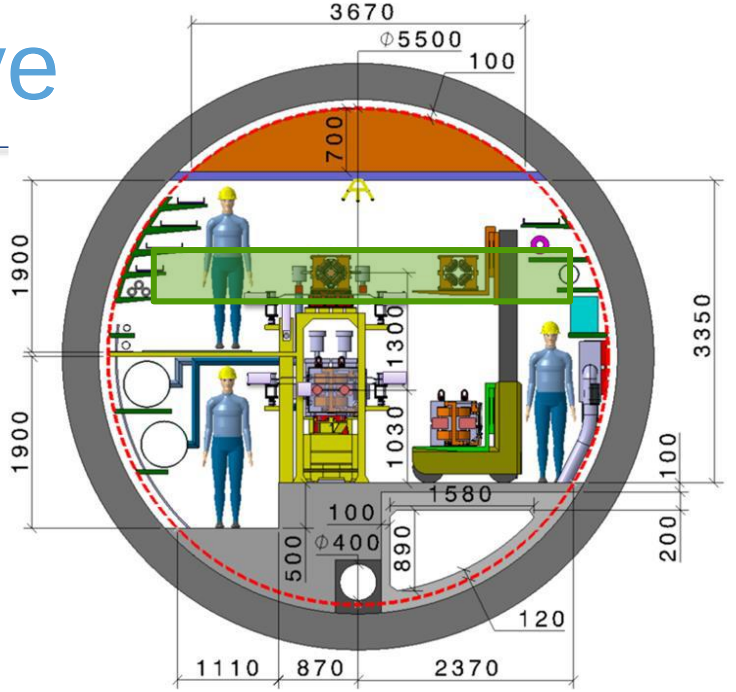
Dose in the tunnel environment – y above

TUNGSTEN	COPPER	CONTINUOUS









- Lowest obtained dose levels
- Homogeneously distributed

- Less effective ABS lead to higher dose
- Lower dose level at z~5500cm due to absorber placed in MQ

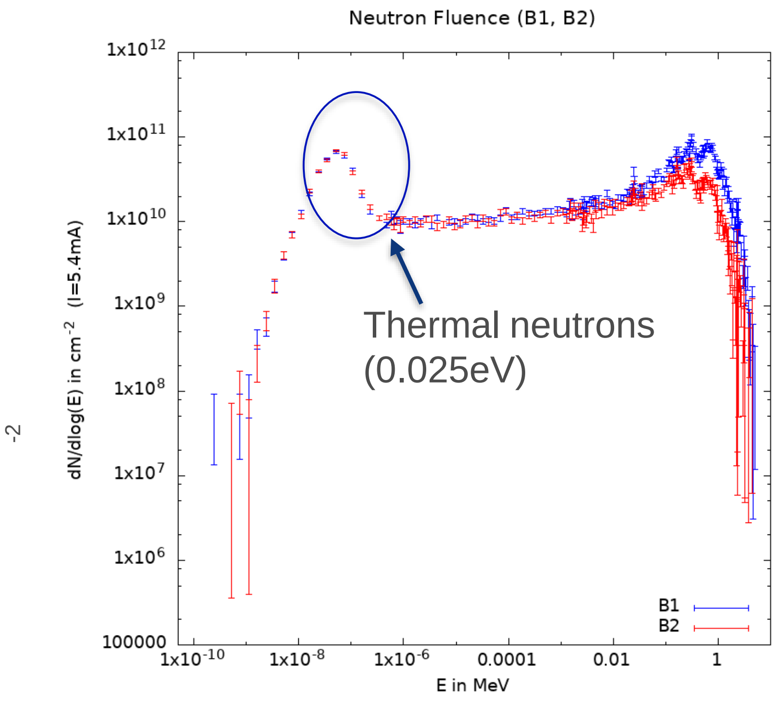
- Areas of higher dose due to MQs without shielding

	Tungsten	Copper	Cont.
Top, Cent.	100kGy	300kGy	120kGy

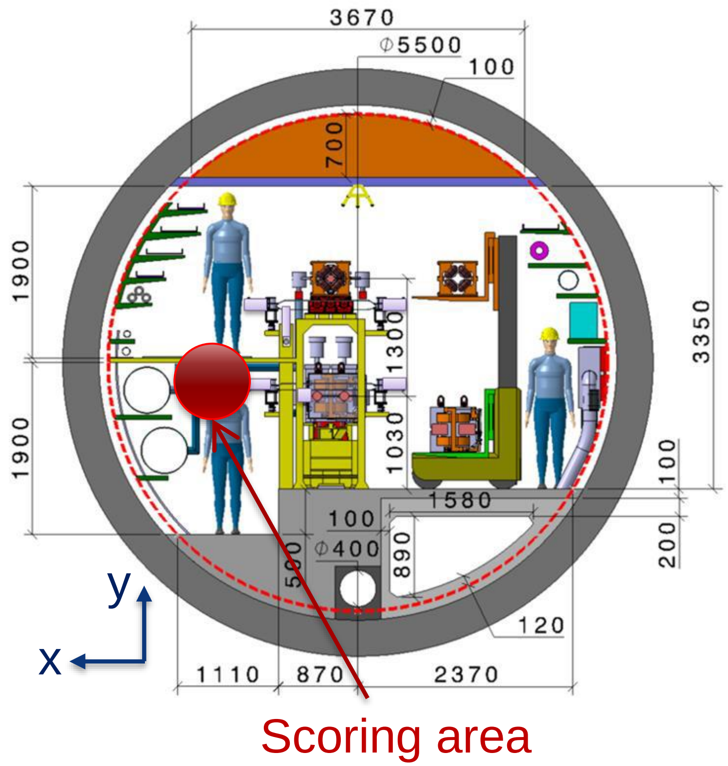
HL-LHC arcs reference value: 1.4Gy
(https://edms.cern.ch/ui/file/2302154/1.0/HLLHC_Specification_Document_v1.0.pdf)

Booster on top of collider
Shielding options for R2E are under study

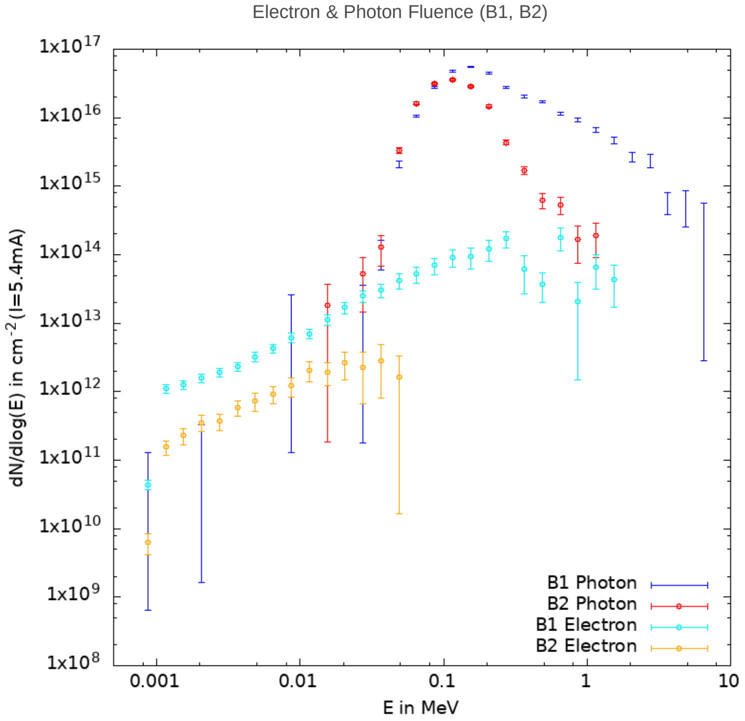
Fluence in the tunnel – ABS (Copper) layout



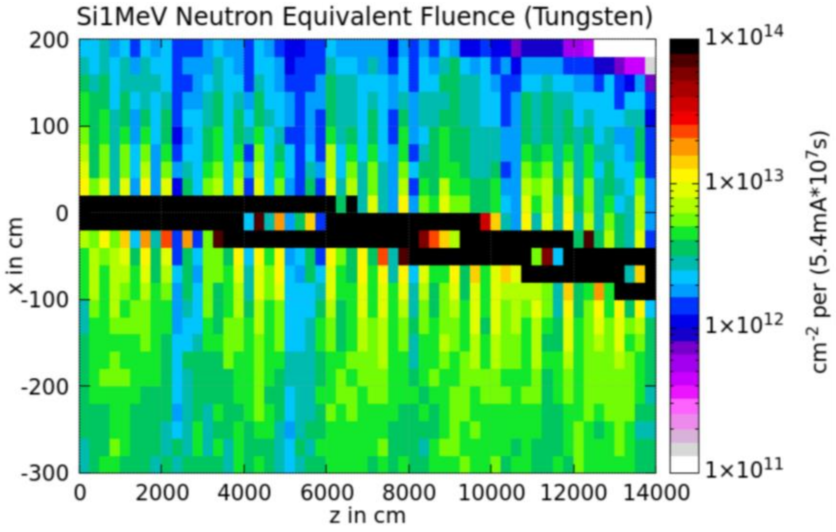
Neutron fluence:
- Similar results for B1 and B2
- Magnets are "transparent" for neutrons



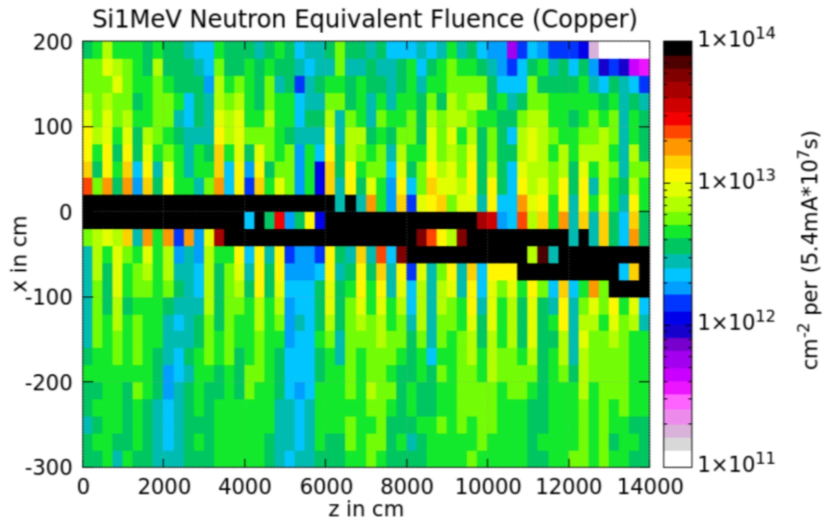
Electromagnetic particles fluence:
- B1: higher fluence obtained due to scoring at the outside of the tunnel
- B2: particles absorbed in magnets



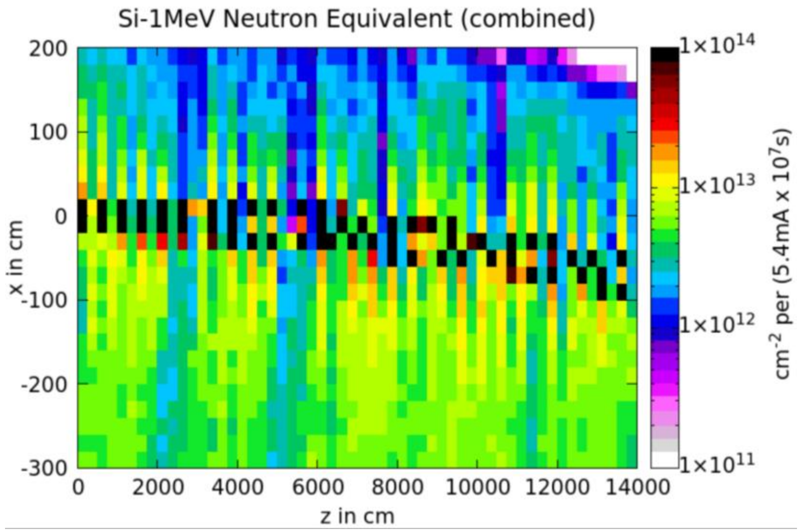
R2E: Si-1MeV neutron equivalent fluence



ABS Tungsten



ABS Copper



Continuous

- Similar levels for all case, different contribution levels on the level of neutrons and em particles
  - Tungsten: high Z leads to lower production threshold for neutrons
  - Copper: higher production threshold for neutrons, but stronger impact from em particles

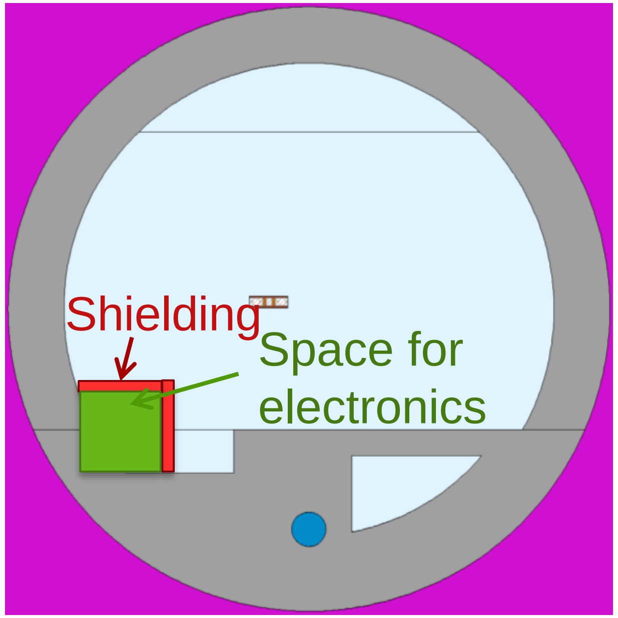
  → Total levels are similar
- HL-LHC arcs reference: $1.6x10^{10}cm^{-2}$

Summary

- **Heat load**:
  - Tungsten absorbers have best absorption properties, but cost and manufacturing properties are disadvantageous;
  - VC highly impacted in case of continuous shielding
- **Peak heat load on the absorbers**:
  - 2.5x higher for tungsten absorber → cooling feasible, outgassing?
- **Radiation to electronics:**
  - Highest **dose** levels for the copper absorbers in the tunnel environment
  - Lower **dose** levels on top of accelerator are favorable for booster placement
  - **Si-1MeV eq. fluence** similar for all three cases but different levels of contributions from neutrons and em. particles
  - Si-1MeV neutron equiv. fluence ~2 orders of magnitude higher than in HL-LHC, but bigger differences are obtained in dose levels (kGy instead of Gy → 5 orders of magnitude!)

Outlook

- Radiation studies for possible **shielding** in the tunnel for **R2E**
  - Test different materials (lead, concrete) & thicknesses (1cm, 3cm, 10cm)
- Investigate lower beam energies to assess if they comply with radiation safe environment in the tunnel (<1Gy/year)
- **Gas bremsstrahlung** simulation
  - Lowest energy (Z pole → higher current)
  - Constant beam-gas profile → find critical residual gas density



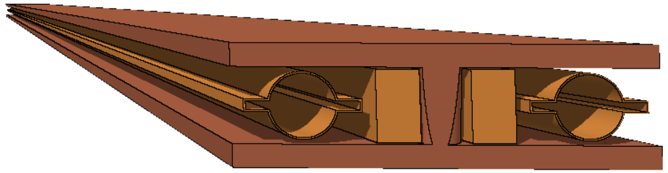
- Other Fluka/FCCee related ongoing activities: Heat load studies for the **positron target**

Any questions?

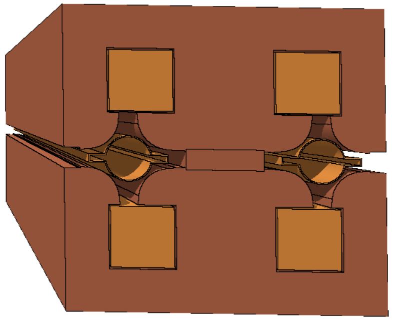
Backup slides

Magnets

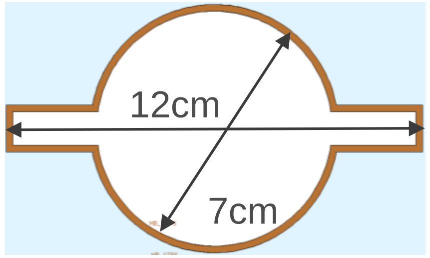
General: 30cm beam separation



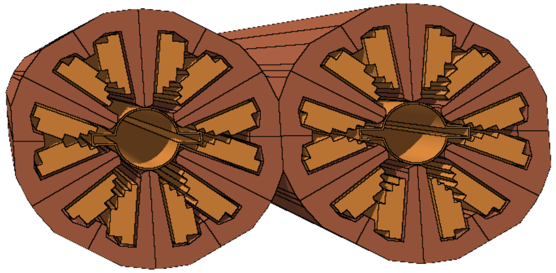
Dipoles (MB):
- Long: 24.64m (l_{mag})
  (Simulations were performed before 24m long model was abandoned)
- Short: 21.44m (l_{mag})
- 56.6mT at 182.5GeV



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



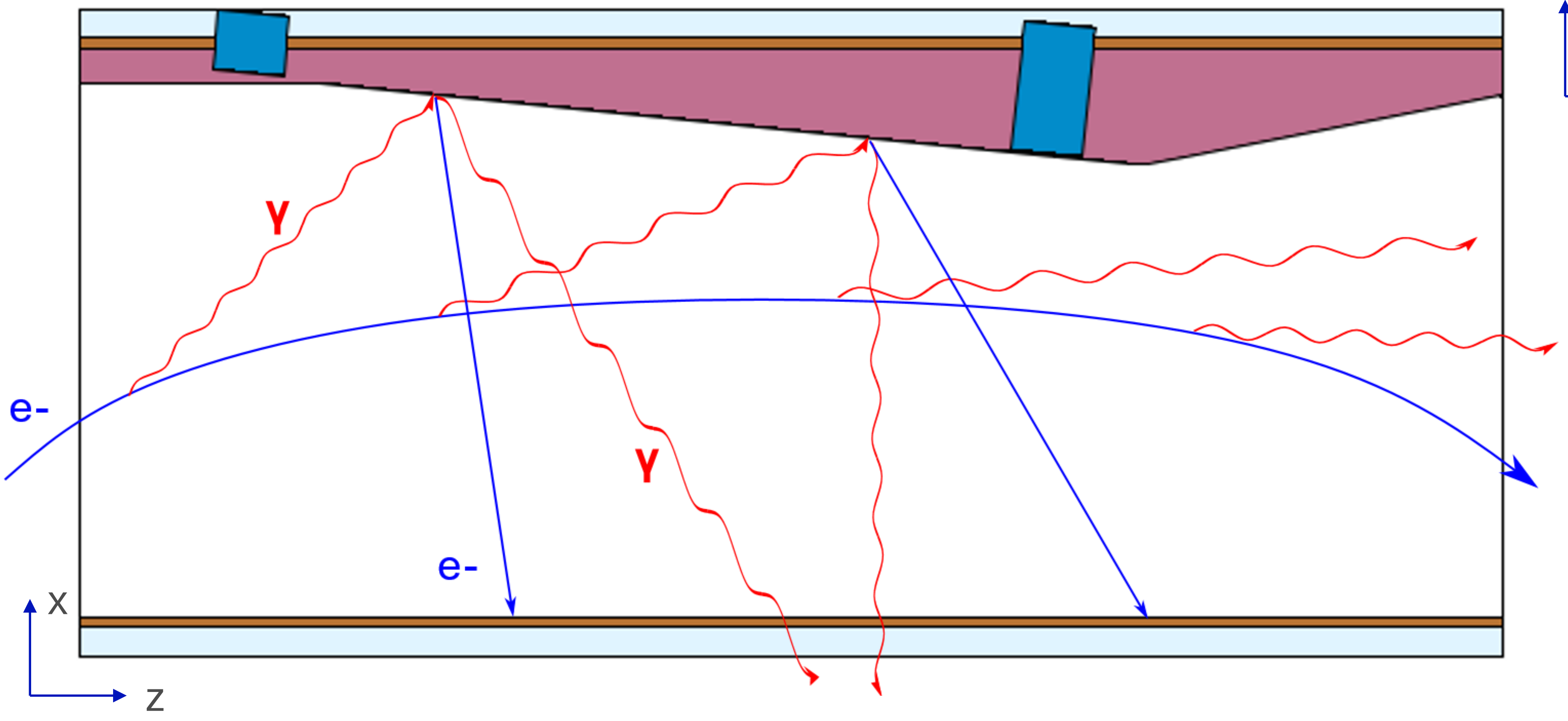
Vacuum chamber (VC):
- Copper
- 2mm
- Winglets



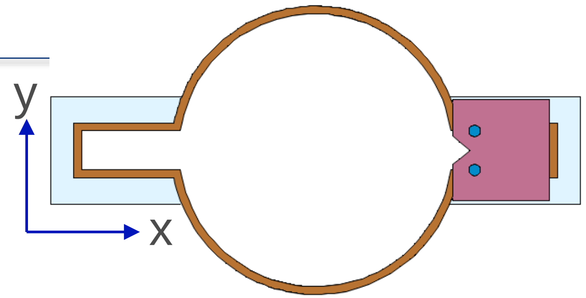
Sextupole (MS):
- 1.4m (l_{mag})
- No prototypes and technical drawings so far (ending of coils,…)

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

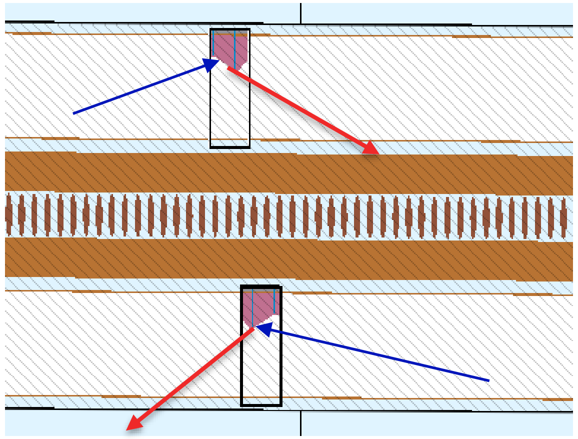
Absorber working & reflection



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