FUTURE CIRCULAR COLLIDER

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

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https://indico.cern.ch/event/1116677/

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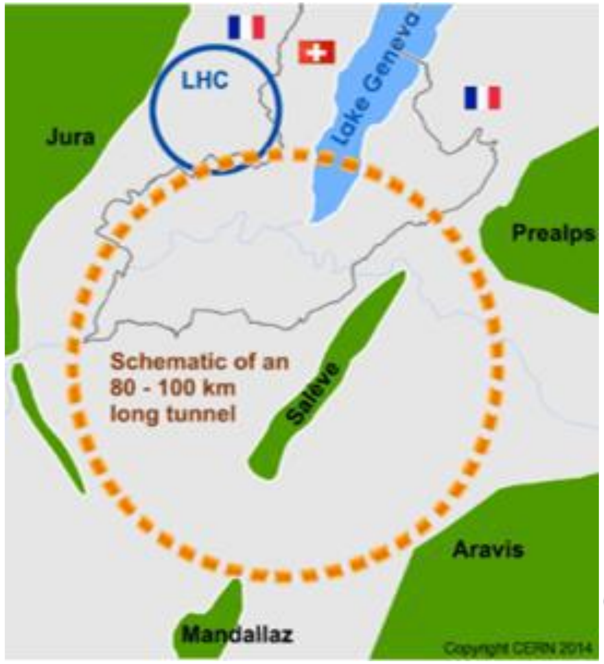
Agenda

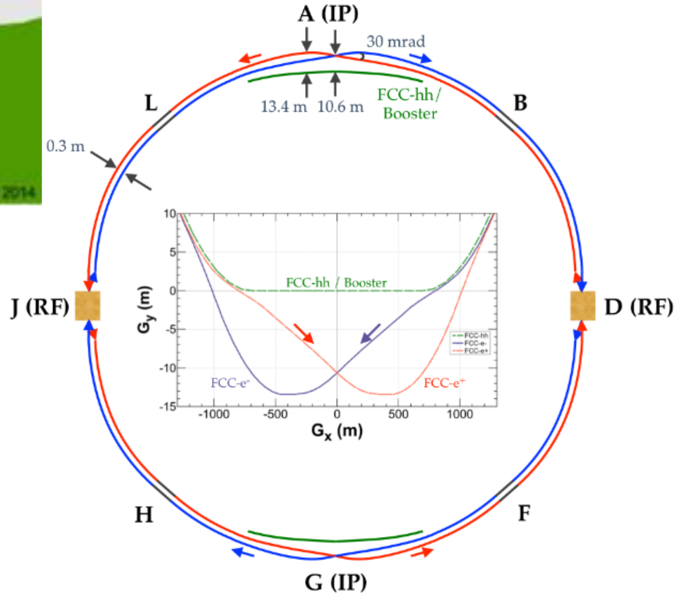
1. FCC-ee & Synchrotron Radiation
2. Simulation Setup
3. Dose Levels in the Tunnel
4. R2E Protection Scheme
5. Conclusion & Outlook

Introduction: FCC-ee

- Future circular collider lepton machine
- Inspired by LEP machine
- First stage of the FCC program (FCC-hh is supposed to follow)
- Circumference: ~91km
- 4 operation modes:

  45.6GeV-**182.5GeV**





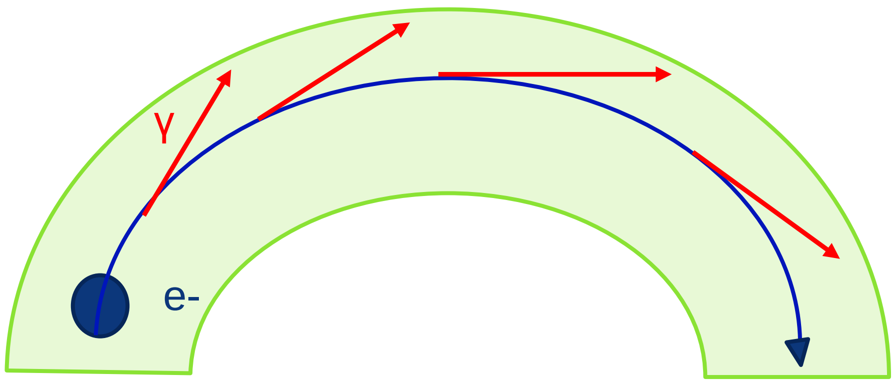
Introduction: Synchrotron Radiation (SR) (i)

- **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:

$$\Delta E = \frac{e^2}{3\varepsilon_0(\boldsymbol{m_0}c^2)^{\boldsymbol{4}}}\frac{\boldsymbol{E^4}}{\rho}$$

e …Electric charge
ε_0 …Vacuum permittivity
m_0 …Mass at rest
E …Momentum
ρ …Bending radius

→ SR is a major source of radiation in lepton machines



Introduction: Synchrotron Radiation (SR) (ii)

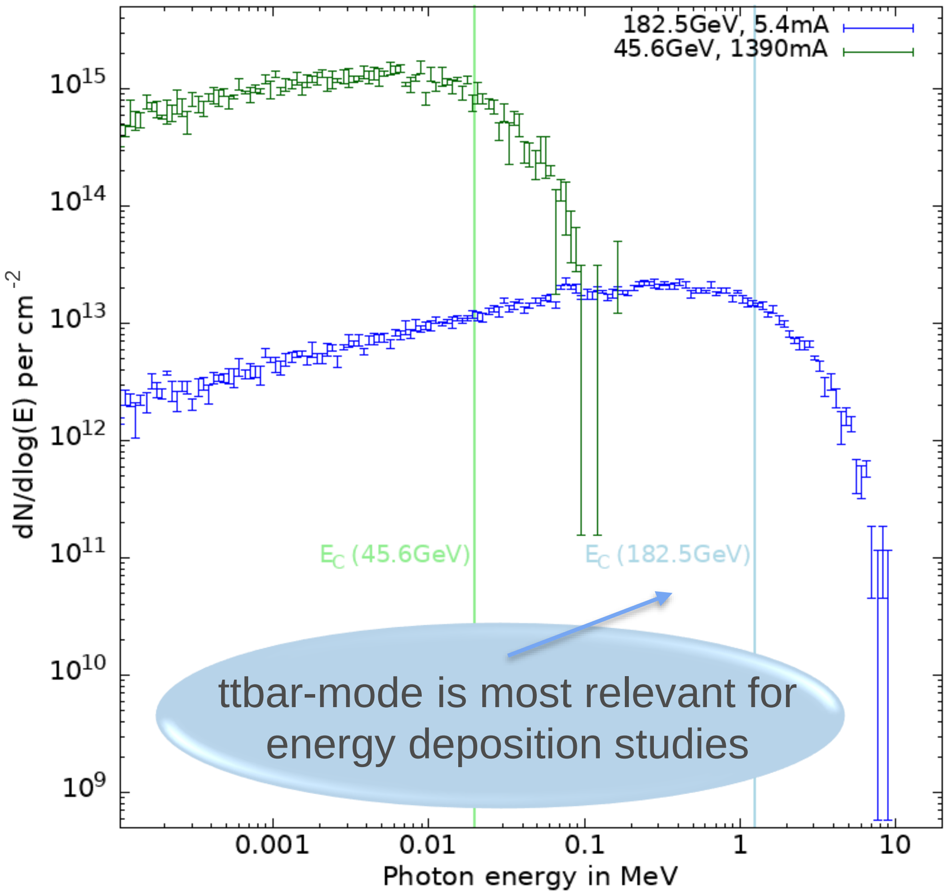
- **Critical energy (E_C):** divides the spectrum into two equal parts of deposited power

$$E_C[\text{MeV}] = 2.21 \cdot 10^{-6} \frac{E^3[\text{GeV}]}{\rho[\text{km}]}$$

- **Power** on the arcs is constant:
  - $P = \Delta E[\text{GeV}] \cdot I[\text{mA}] = 50\text{MW}$ (whole ring)
  - Same power for all operation modes
- SR related numbers in FCC-ee ($\rho = 10.76\text{km}$):

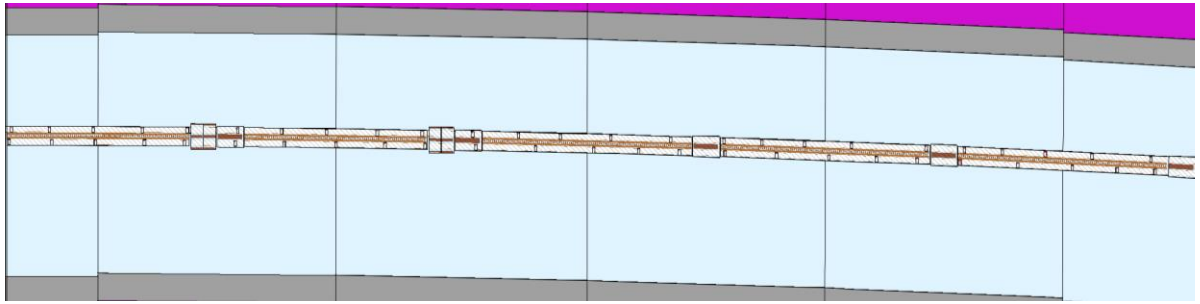
Energy loss (ΔE)	9.2GeV/turn
Critical energy (E_C)	1.25MeV
Power whole ring	50MW
Power 140m	168kW

SR Spectrum of primary electrons:

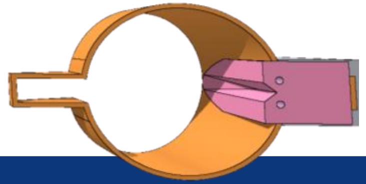


General simulation layout

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

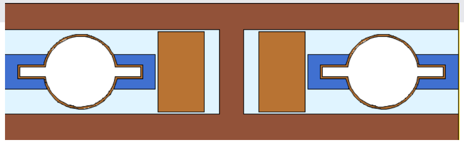


- SR source: e-, e+ in all magnets
  → direct approach
- 5.4mA, 10^7s (one year)
- **Different layouts performed:**
  - **Absorbers: Tungsten** (Inermet180) vs. **copper** (CuCrZr)



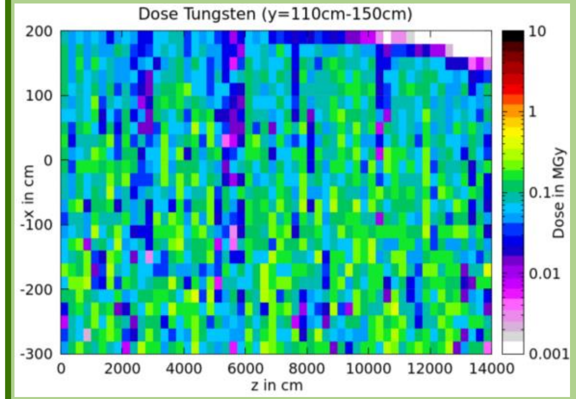
	Tungsten	Copper
+	Better absorption properties (higher Z and ρ)	Easier to manufacture, better behavior in vacuum
-	Brittle, harder to manufacture, cost	Less good energy absorption properties

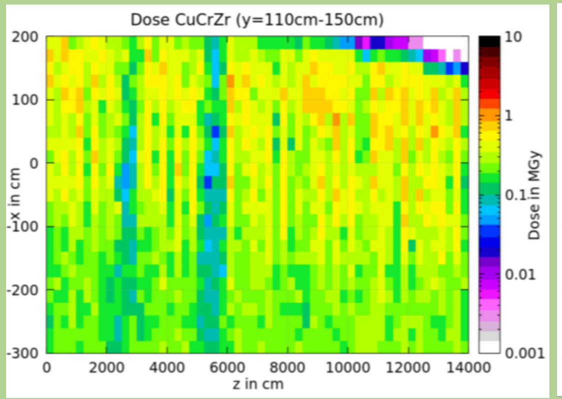
  - **Continuous shielding** (comparable to LEP design): tungsten, 1cm around winglet

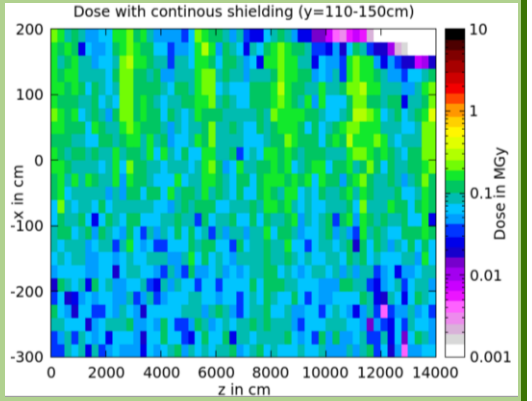


Dose in the tunnel environment – y above

TUNGSTEN	COPPER	CONTINUOUS



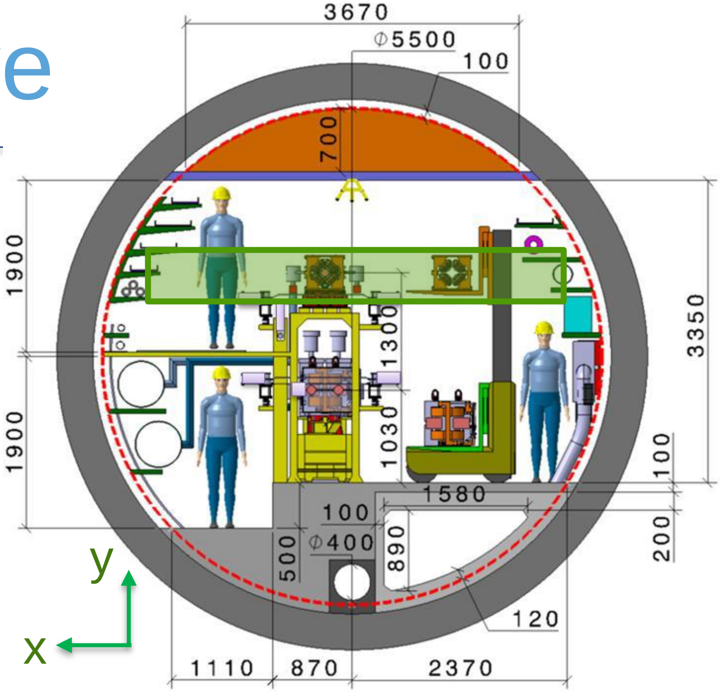




- Lowest obtained dose levels
- Homogeneously distributed

- 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



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

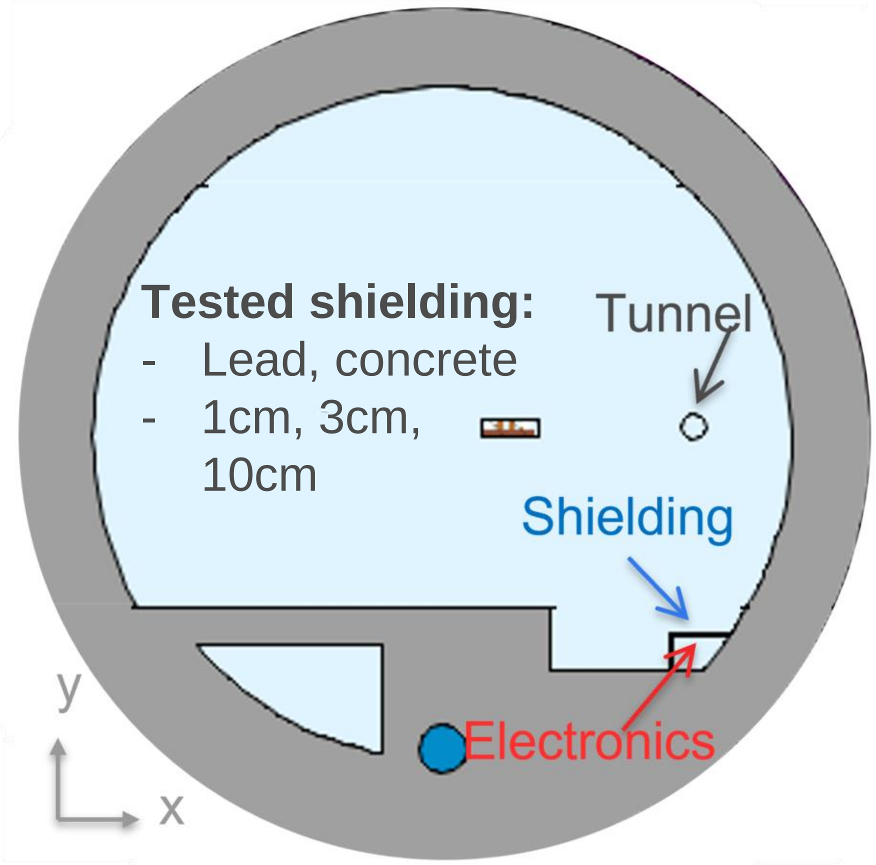
	Tungsten	Copper	Cont.
Top, Cent.	100kGy	300kGy	120kGy

HL-LHC arcs reference value: 1.4Gy

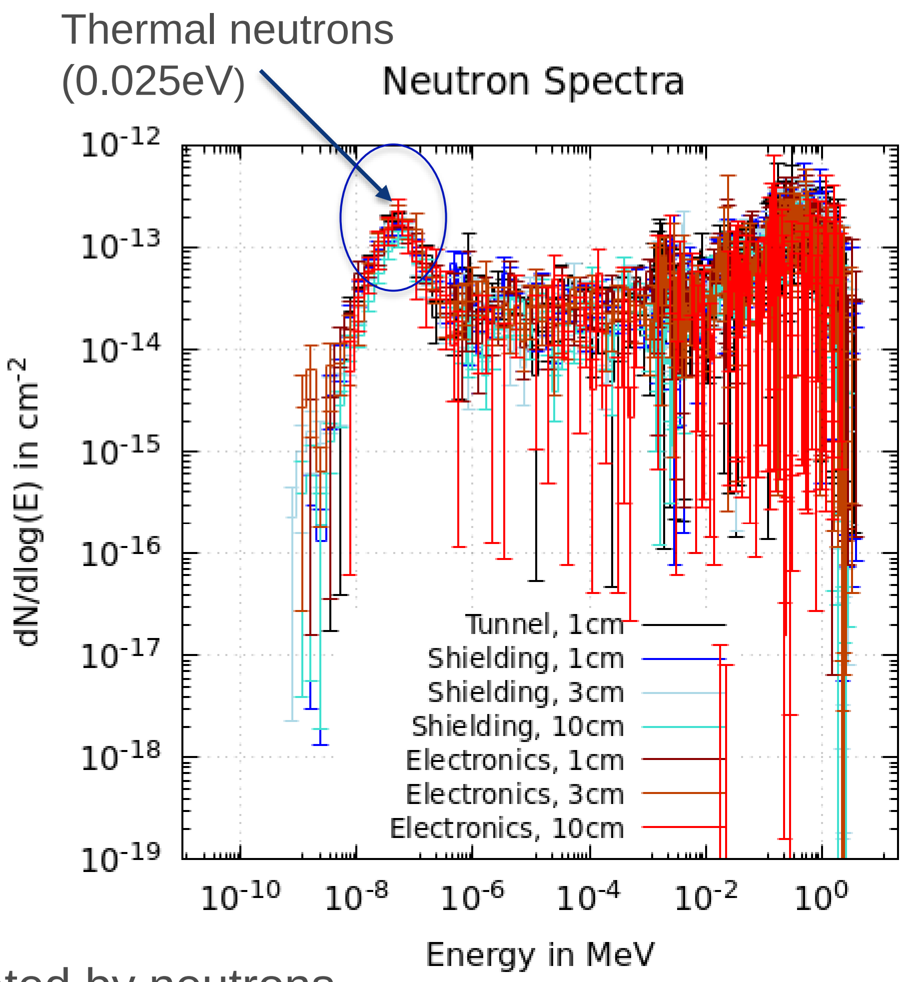
(https://edms.cern.ch/ui/file/2302154/1.0/HLLHC_Specification_Document_v1.0.pdf)

Shielding for R2E needed

Fluence in the tunnel – Neutrons



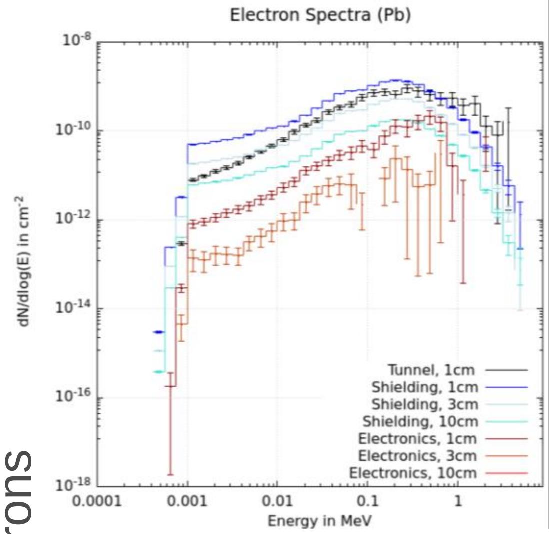
- Magnets and shielding are "transparent" for neutrons
- Order of magnitude similar for the results for the different materials and shielding thickness
- Spectra for thermal neutrons nearly identical
- Higher energy range bigger differences, but no reliable statistics

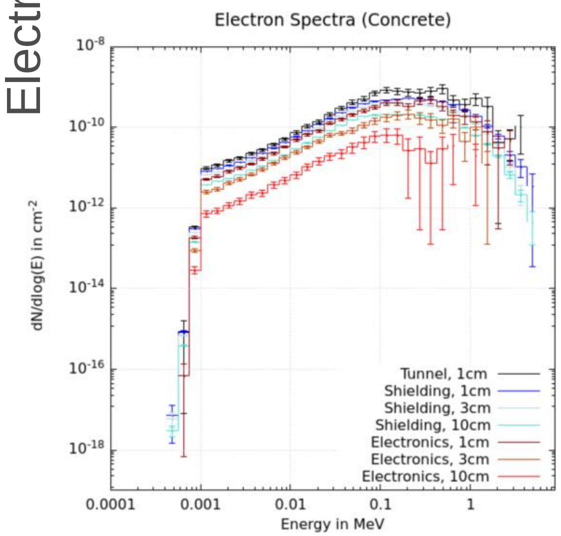


→ Shielding not efficient for quantities dominated by neutrons

Fluence in the tunnel – Photons & Electrons

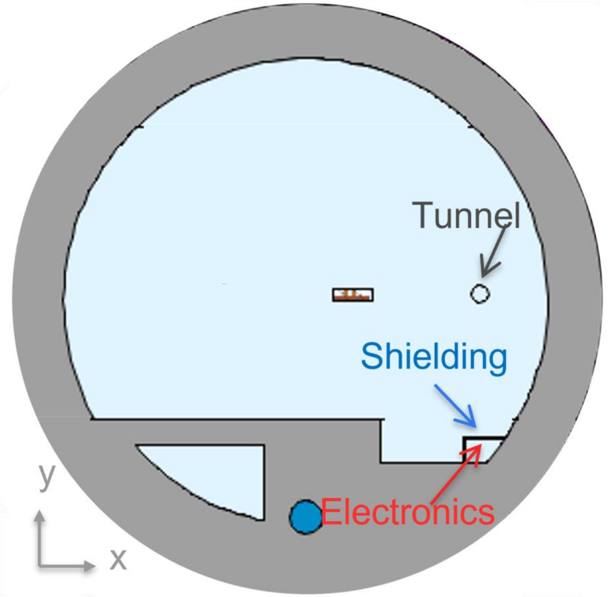
Electrons

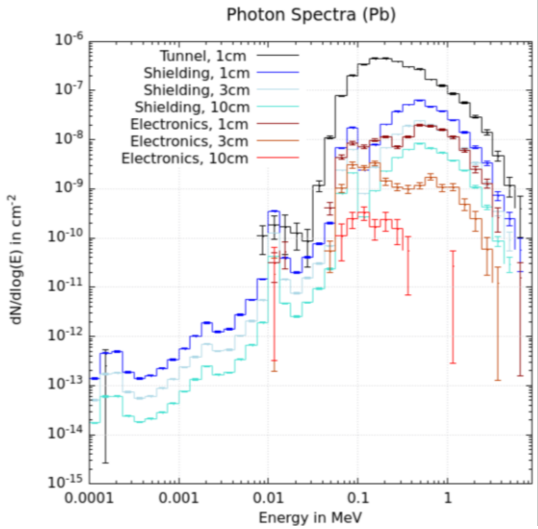


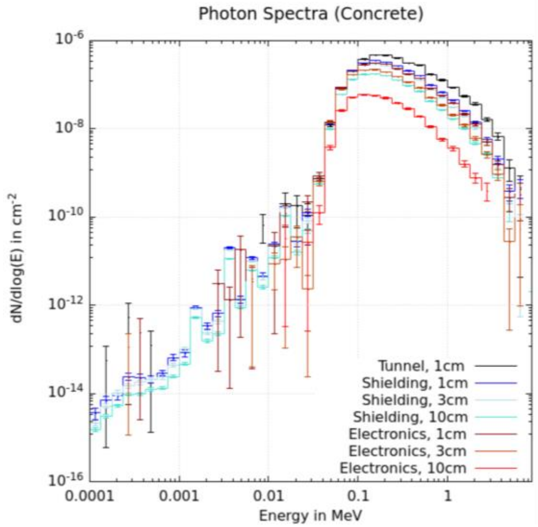


- Electromagnetic particles attenuated by shielding
- Less attenuation in the spectra for concrete shielding

→ This type of shielding efficient for quantities that depend on the electromagnetic particles







Photons

R2E Levels in the electronics area

LEAD	Dose	Si-1MeV	HeH	The. Neu
1cm	100kGy	3E11	5E7-5E8	2.3E11
3cm	50kGy	1E11		2E11
10cm	<1kGy *	5E10		1.5E11

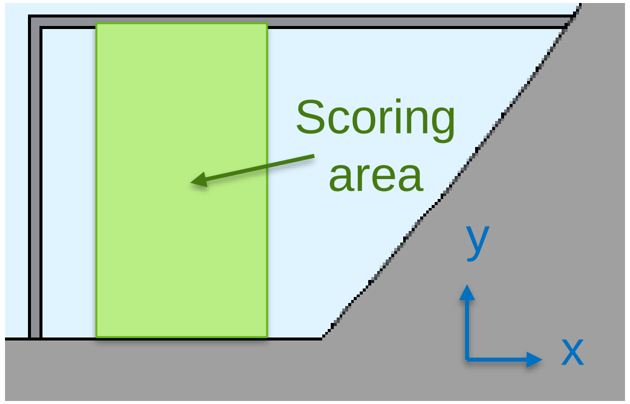
* Not detectable with current simulation layout (biasing needed)

CONC.	Dose	Si-1MeV	HeH	The. Neu
10cm	30kGy	5E10	6E7	3E11

Dose … Integrated dose
Si-1MeV … Si-1MeV neutron equivalent fluence
HeH … High energy hadron equivalent fluence
The. Neu … Thermal neutron equivalent fluence

- Lead more efficient than concrete
  - 3cm lead equivalent to 10cm of concrete
- Dose: Dominated by em. particles that shielded well by lead
- Si-1MeV neutron equivalent fluence: strong dependence on em. particles → shielding works well
- High energy hadron equivalent fluence and thermal neutron fluence: Similar for lead and concrete due to transparency of the material for neutrons

	min	max
x	120cm	131cm
y	-175cm	-198cm
z	6700cm	8200cm



Summary & Outlook

- High integrated dose levels (~300kGy) and neutron equivalent fluences in the FCC-ee arcs call for shielding in the tunnel to protect the electronics
- Shielding options studied:
  - Lead, concrete
  - 1cm, 3cm, 10cm
  - 3cm of lead ≈ 10cm of concrete

- Current shielding layout does not provide sufficient protection from neutrons
  - possible solution: add a 3cm layer of borated polyethylene outside of the lead to stop neutrons to move further inside
    - Hydrogenated material slows neutrons down
    - Boron captures neutrons ones they are slowed down
    - Photons produced in the organic layer are stopped in the lead layer

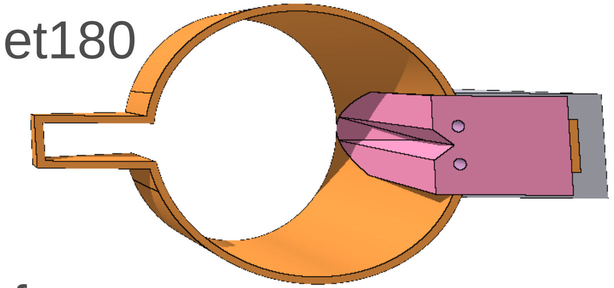
Any questions?

Backup slides

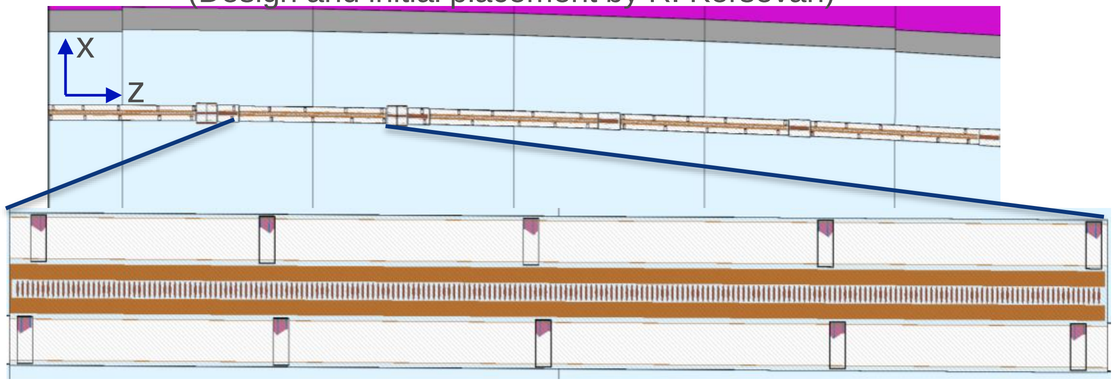
Model comparison: absorber vs continuous shielding

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)

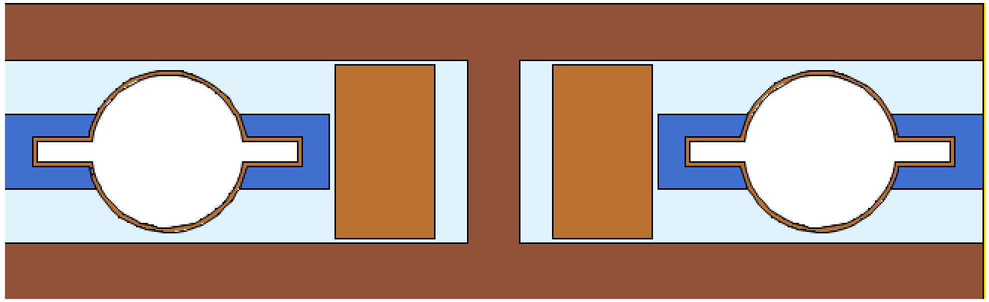


(Design and initial placement by R. Kersevan)



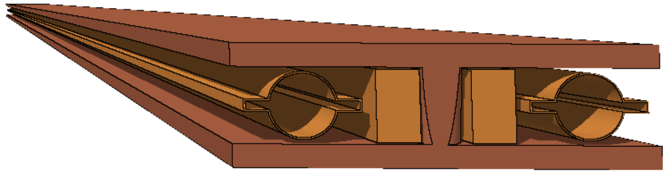
Continuous shielding:

- 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

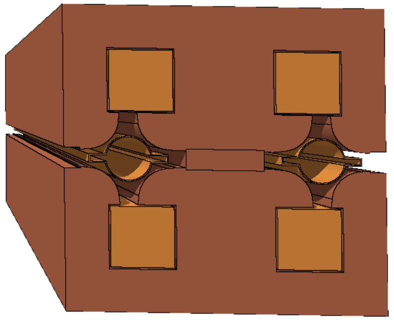


Magnets

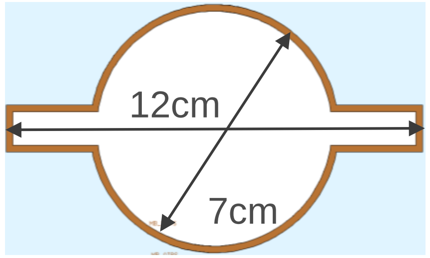
General: 30cm beam separation



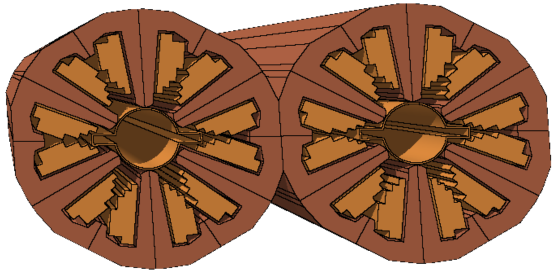
Dipoles (MB):
- Long: 24.64m (l_{mag})
  (Simulations were performed before 24m long model was abandoned)
- Short: 21.44m (l_{mag})
- 56.6mT at 182.5GeV



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



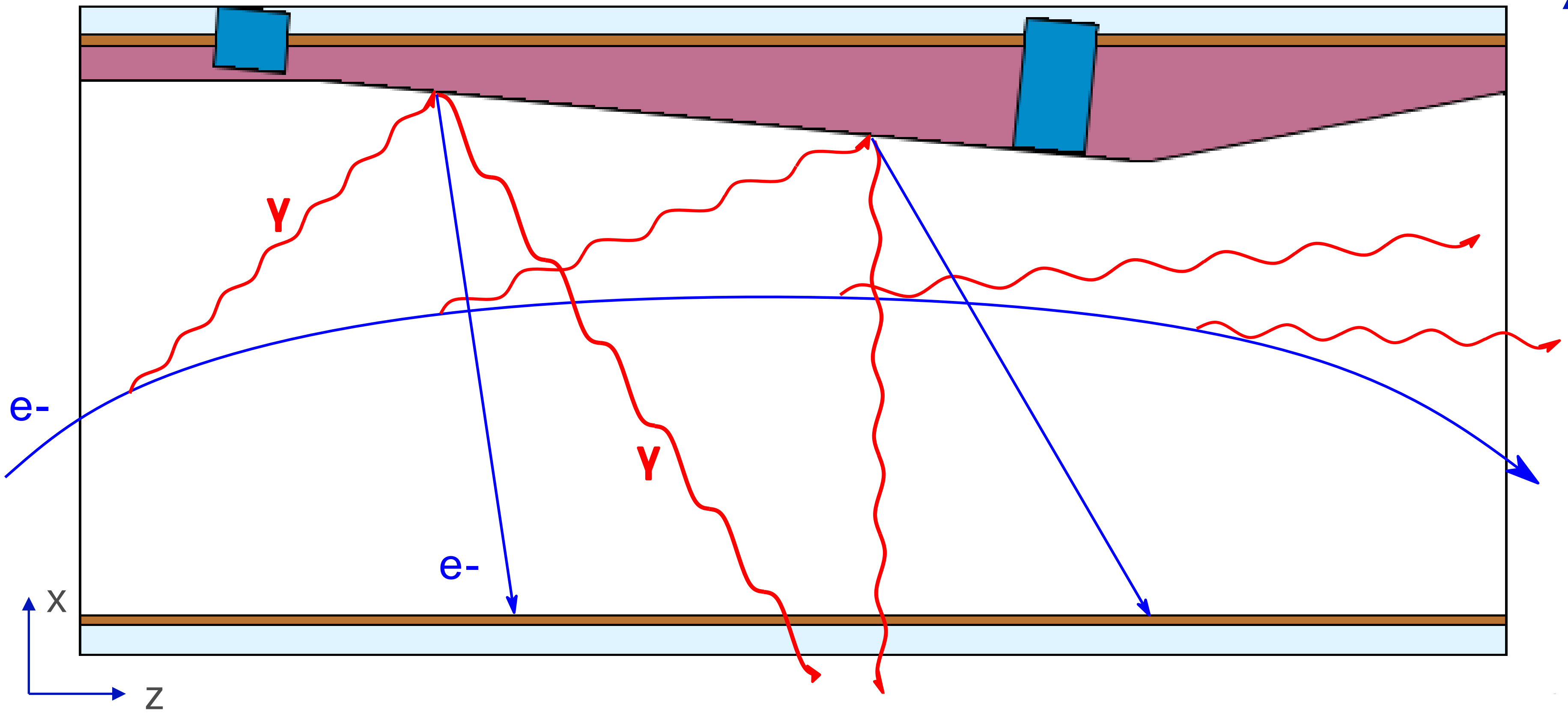
Vacuum chamber (VC):
- Copper
- 2mm
- Winglets

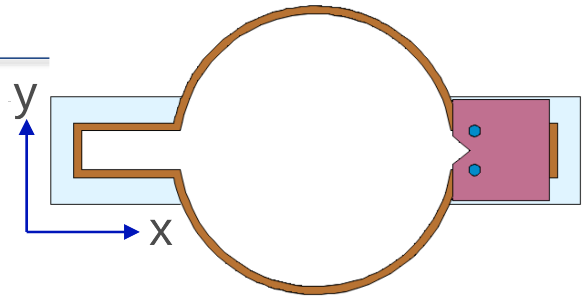


Sextupole (MS):
- 1.4m (l_{mag})
- No prototypes and technical drawings so far (ending of coils,…)

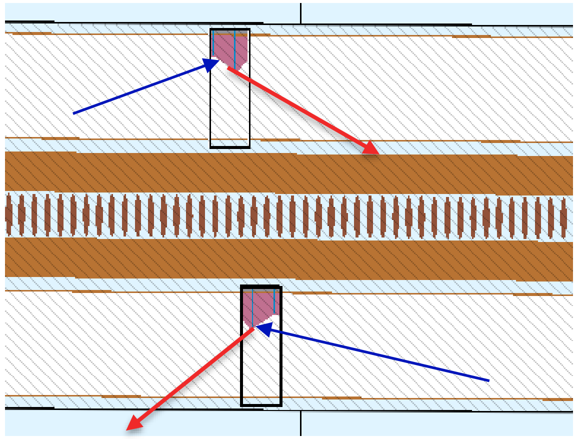
Magnets designed from scratch in Fluka. Technical drawings received from J. Bauche

Absorber working & reflection





External beam: reflected particle → magnet yoke



Internal beam: reflected particle → tunnel

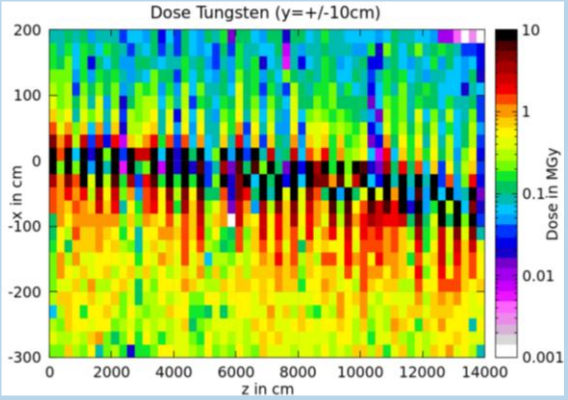
Compton scattering: photon collides with electron and is scattered into a different direction, dominant in the MeV range

Dose in the tunnel environment – y centre

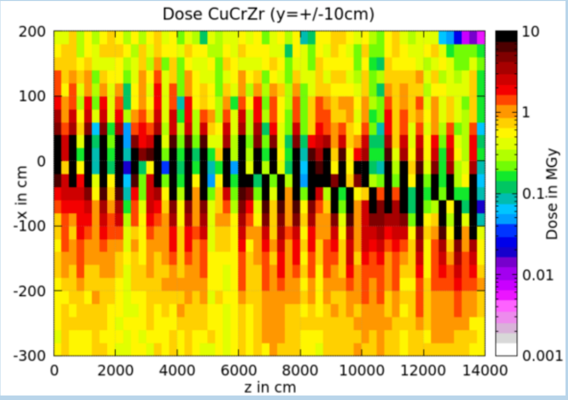
- Higher dose internally due to backscattering of particles on ABS

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

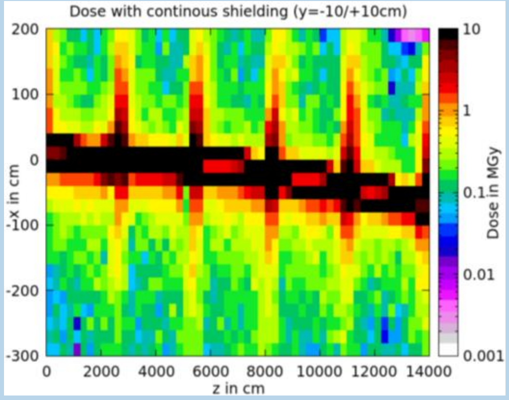
- Peaks due to missing shielding in MQs
- Externally higher dose values
- On average lowest dose



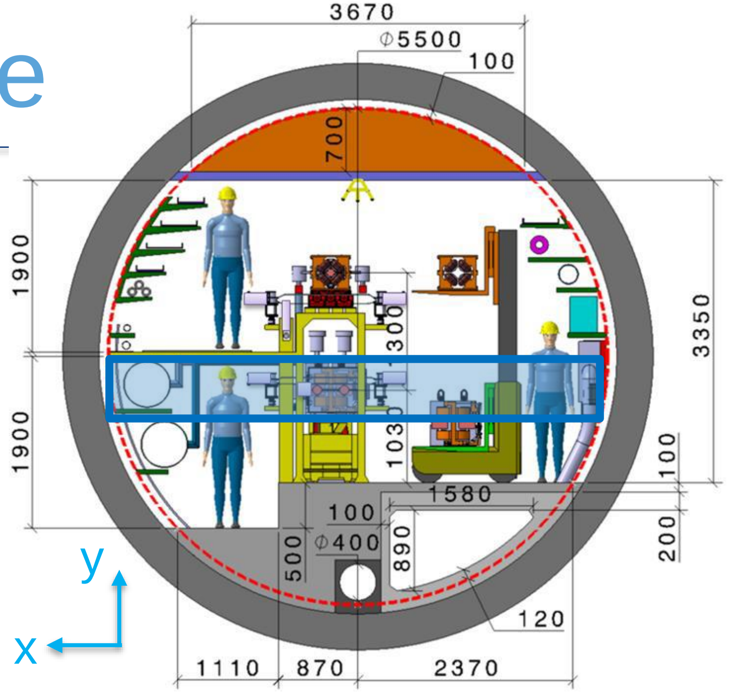
TUNGSTEN



COPPER



CONTINUOUS



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

	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/HLLHC_Specification_Document_v1.0.pdf)