FCC

FLUKA studies for the FCC-ee MDI

Alessandro Frasca, Kevin André, Manuela Boscolo, Helmut Burkhardt, Daniele Calzolari, Andrea Ciarma, Barbara Humann, Anton Lechner, Giuseppe Lerner

FCC week 2024, 12 June 2024

alessandro.frasca@cern.ch

Introduction

In the FCC-ee interaction regions machine equipment exposed to several radiation sources

→ FLUKA studies to estimate the relevant quantities (power deposition, radiation levels) and contribute to equipment design

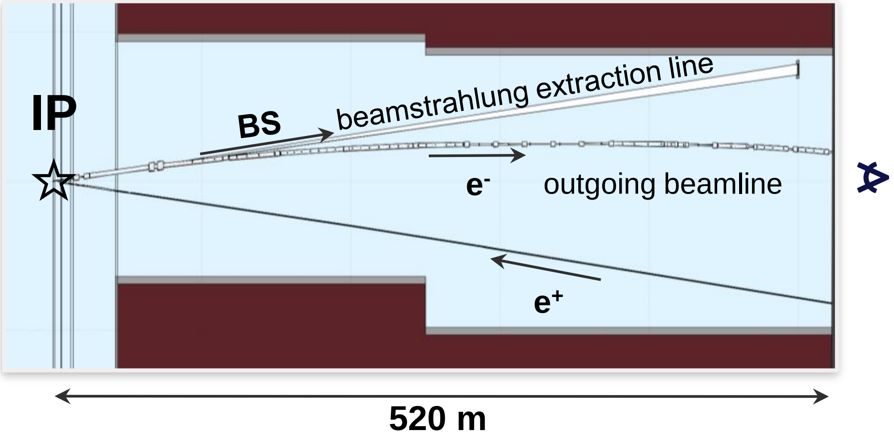
Outline

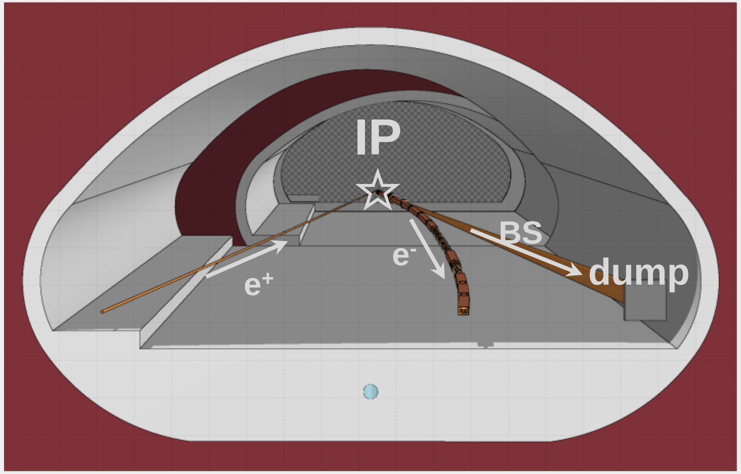
- FLUKA model of FCC-ee experimental insertion
  - geometry
  - sources
- overview of tunnel radiation levels (beamstrahlung+synchrotron radiation+radiative Bhabha)
- impact of radiative Bhabha on FFQs
  - total power absorbed (to be evacuated by cryogenic system)
  - peak energy deposition in SC coils (quench risk and cumulative damage to insulator)

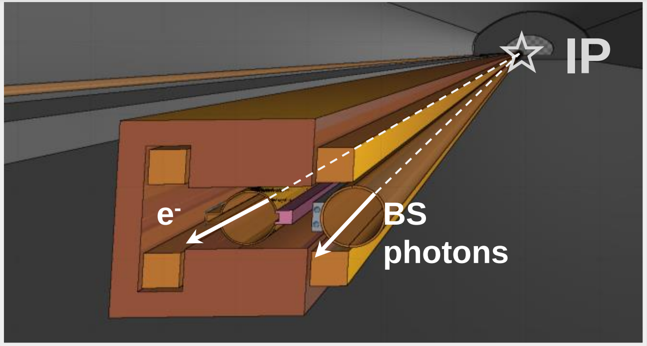
Previous talks

- FCC week 2023, London (Jun 5 – 9, 2023)
- FCC-ee MDI & IR mockup workshop, Frascati (Nov 16 – 17, 2023)
- 7th FCC Physics workshop, Annecy (Jan 29 – Feb 2, 2024)
- FCC-ee MDI meeting #52, CERN (Mar 11, 2024)
- 6th FCC-ee Radiation and Shielding Meeting, CERN (Apr 24, 2024)

FLUKA geometry of the FCC-ee IR (right of IP)







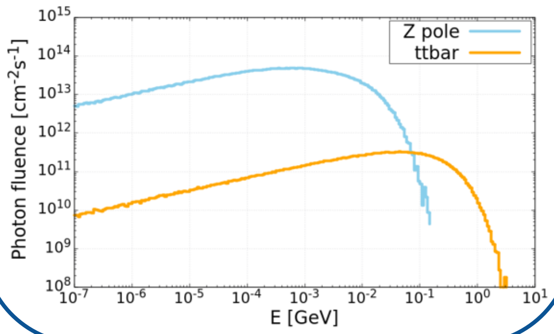
Optics lattice v22

- **concrete tunnel** surrounded by soil
- **copper beam pipe** (35mm radius)
- **CuCrZr SR absorbers** (no additional shielding)
- **dipoles and quadrupoles** (including magnetic fields)
- conical **copper extraction line**
- **beamstrahlung dump** and shielding`

Sources

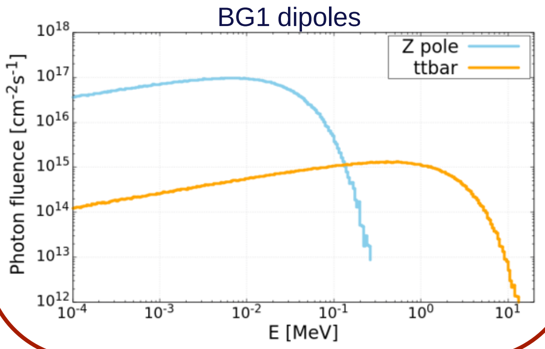
Beamstrahlung photons

- photons emitted in the EM field of the counter-rotating bunch at the IP
- intense photon flux (nominally **370kW** @Z-pole, **77kW** @ttbar)
  - dedicated dump (see talk by M. Calviani)
- sampled from distributions generated with GUINEA-PIG++ by A. Ciarma



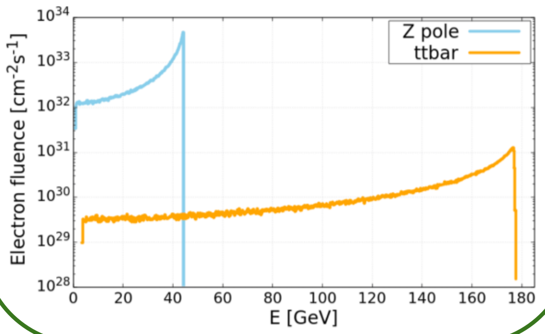
Synchrotron radiation

- photons emitted by beam particles when bent by the magnets
- SR from the beam incoming to the IP neglected (1kW in 500m)
- SR from the outgoing beam much more intense (**164kW** in 500m)
- generated run-time by FLUKA when transporting beam particles along the magnets



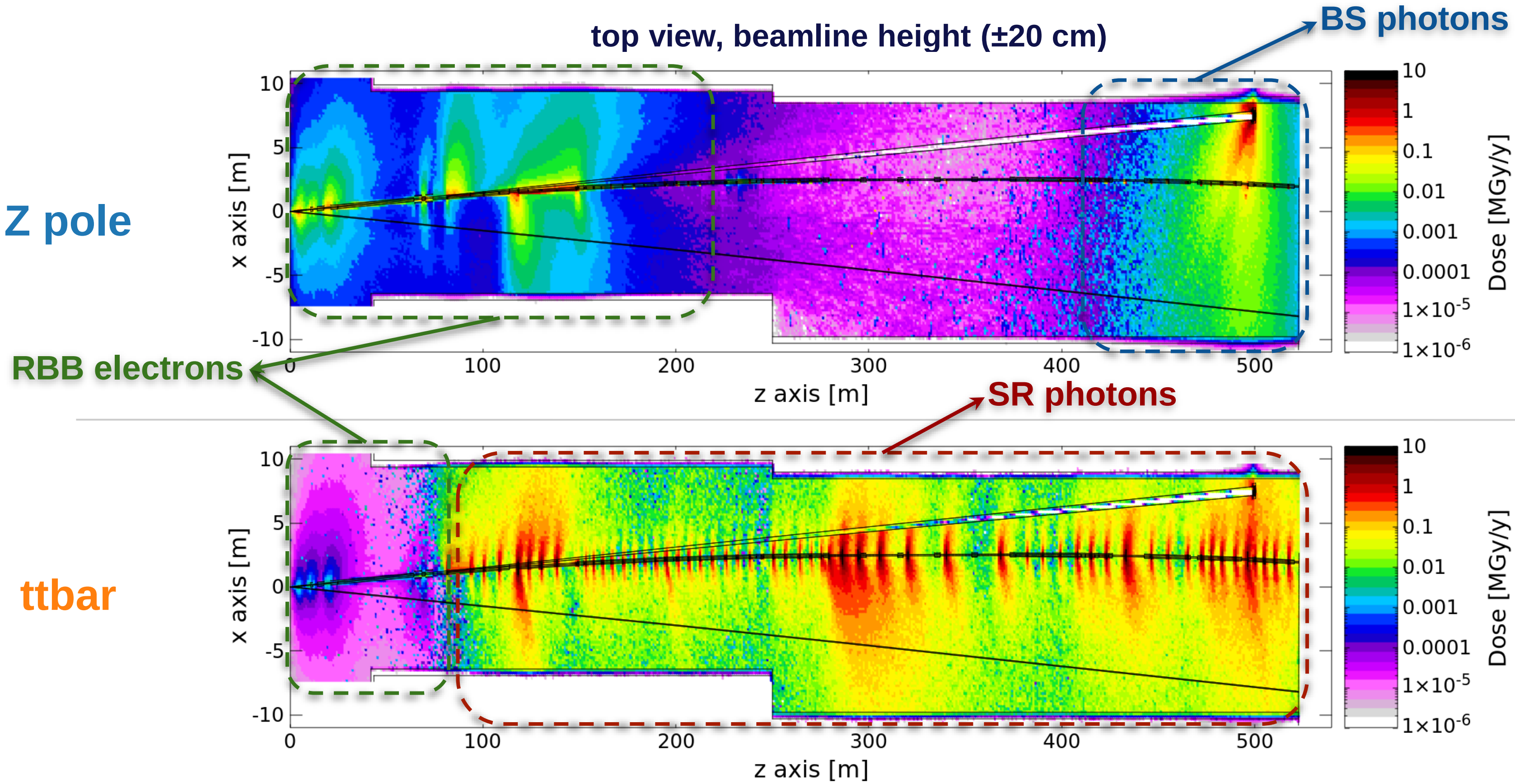
Radiative Bhabha electrons

- electrons scattered in radiative Bhabha at the IP and radiating one or more photons (up to 100% of their energy)
- off-momentum electrons outgoing from the IP with significant angle
  - lost downstream
- sampled from distributions generated with BBREM and GUINEA-PIG++ by A. Ciarma



Overview of tunnel radiation levels

Annual TID in the tunnel from BS, SR, and RBB



Impact of radiative Bhabha on FFQs

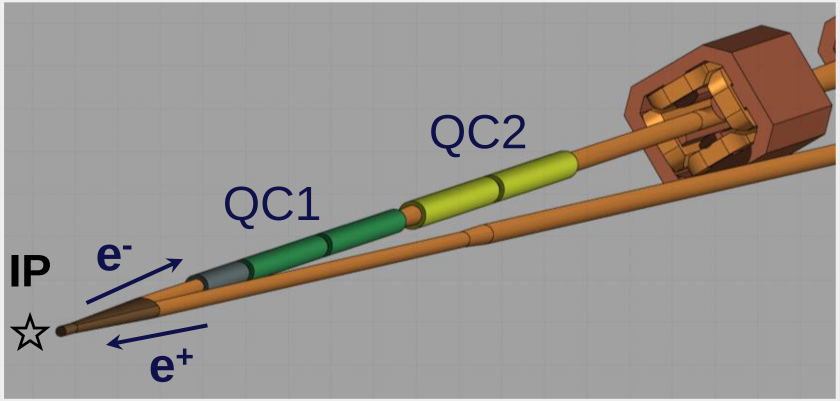
FLUKA model of final focus

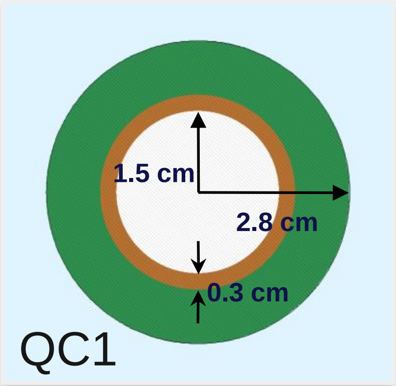
Geometry:

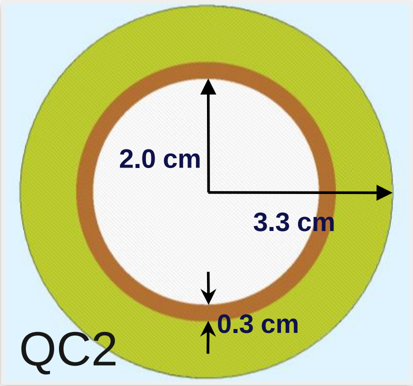
- dummy model of central chamber
- dummy model of FFQs on the outgoing beamline (1-cm thick in equivalent material)

FFQ equivalent material:

- density = 3.367gcm^{-3}
- volume fractions
  - **Al** 0.6540582
  - **NbTi** 0.0619107
  - **Cu** 0.1176303
  - **Paraffin** 0.0977433
  - **Kapton** 0.0686575







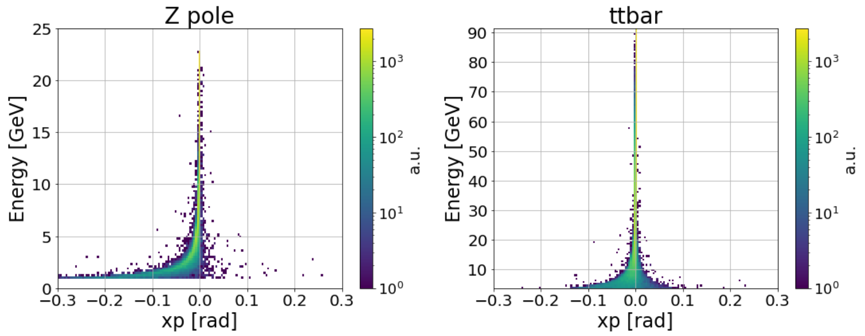
Radiative Bhabha distributions

BBBrem : radiative Bhabha event generator (CM of scattering particles)

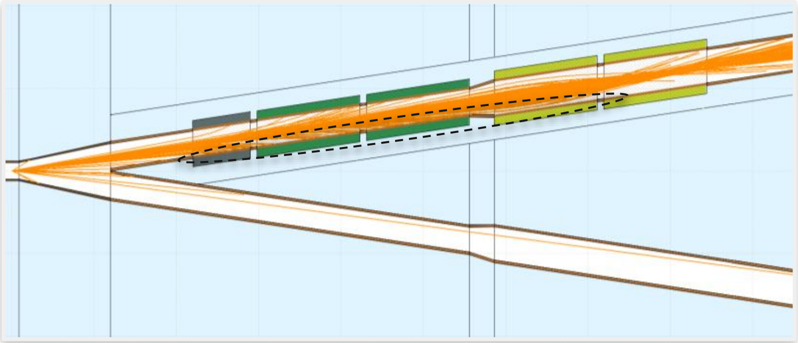
- cut in maximum distance between interacting particles → minimum momentum transfer
  - **1 σ_y cut**: minimum distance to account for the realistic electric field screening caused by bunch particles (experience at LEP from measurements of beam lifetime, see paper by H. Burkhardt)
- cut in minimum energy carried by the emitted photon → maximum energy of scattered electron
  - **50%** energy cut (electrons up to 22.8 GeV and 91.25 GeV) to study impact on FFQs (see MDI talk for a full analysis of Bhabha loss distribution)

GUINEA-PIG++: particle in cell software for beam-beam effects to apply the boost to generated e-:

- asymmetric beam-beam effects (see talk by D. Shatilov) → asymmetric losses on FFQs



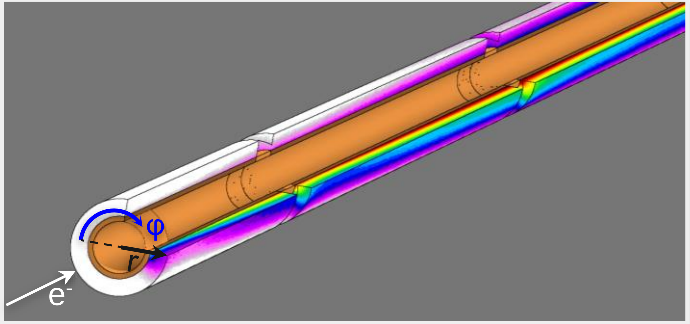
⇒



Power deposition in FFQ superconducting coils

simulated distributions **1 σ_y cut, 50% energy cut**

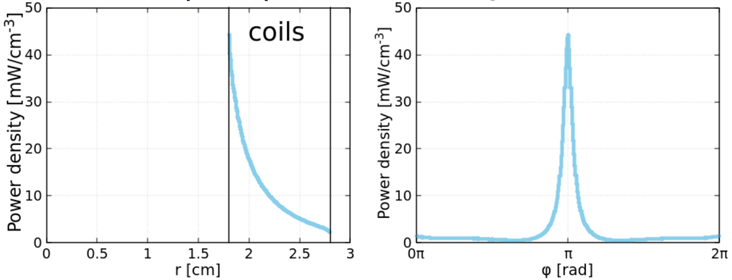
- **Z pole σ*ε=**18.2 mb, L=1.82E+36 $s^{-1}cm^{-2}$
- **ttbar σ*ε=**19.2 mb, L=1.33E+34 $s^{-1}cm^{-2}$



TOTAL POWER DEPOSITED

	Z pole	ttbar
QC1R1	0.30 W	3.4 mW
QC1R2	1.54 W	20.4 mW
QC1R3	2.00 W	29.7 mW
QC2R1	0.20 W	1.9 mW
QC2R2	0.04 W	1.8 mW

Z pole, peak values in QC1R2



High gradients in energy deposition distribution
→ high local peak power density and maximum Total Ionizing Dose (TID)

Power deposition in FFQ superconducting coils

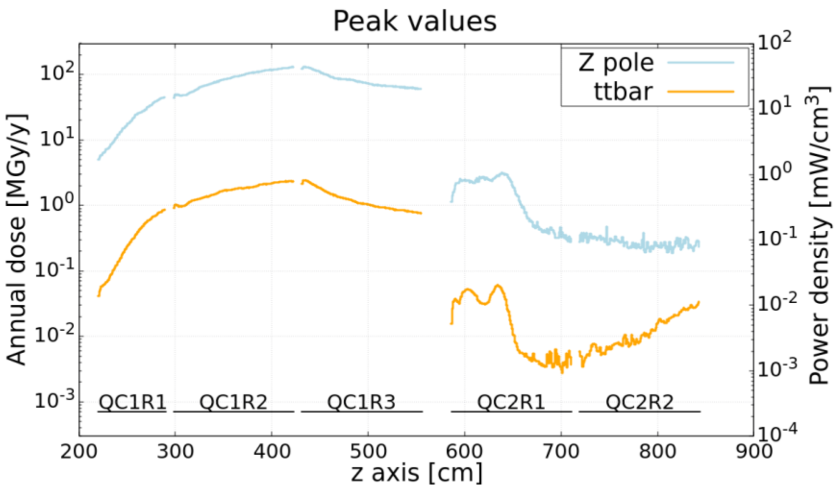
simulated distributions **1 σ_y cut, 50% energy cut**

- **Z pole $\sigma^*\varepsilon$=**18.2 mb, L=1.82E+36 $s^{-1}cm^{-2}$
- **ttbar $\sigma^*\varepsilon$=**19.2 mb, L=1.33E+34 $s^{-1}cm^{-2}$

TOTAL POWER DEPOSITED

	Z pole	ttbar
QC1R1	0.30 W	3.4 mW
QC1R2	1.54 W	20.4 mW
QC1R3	2.00 W	29.7 mW
QC2R1	0.20 W	1.9 mW
QC2R2	0.04 W	1.8 mW

Annual dose computed assuming 10^7 s of operation per year at the reference instantaneous luminosity

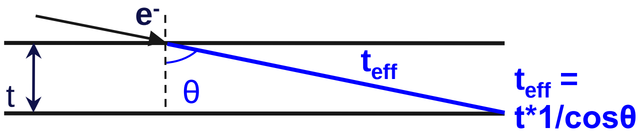


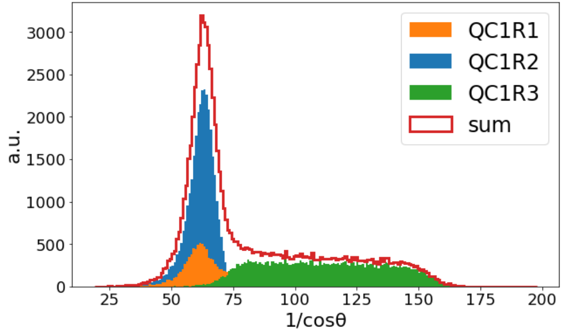
Shielding needed in an area already with tight space constraints!

Electron impact angle analysis

Radiative Bhabha electrons impacting at small angles:

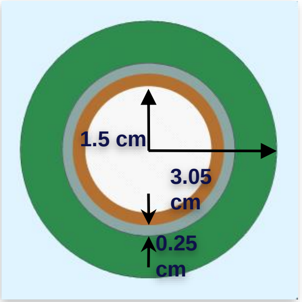
- higher effective shielding thickness $\mathbf{t_{eff} = t*1/cos\theta}$
- $1/\cos\theta >> 10$
- radiation showers see **>>10x shielding thickness**
- few mm of W (X_0= 0.35 cm) shielding can be effective
- limiting factor: Molière radius (~size of energy deposition cone)→0.93 cm for tungsten

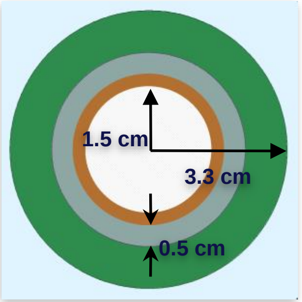




Distribution of 1/cosθ for electrons impacting in QC1 at Z pole

Conceptual shielding studied: **0.25 cm**, **0.5 cm** and **1 cm** thick layer of tungsten around QC1
→ impact on magnet design (greater aperture needed)

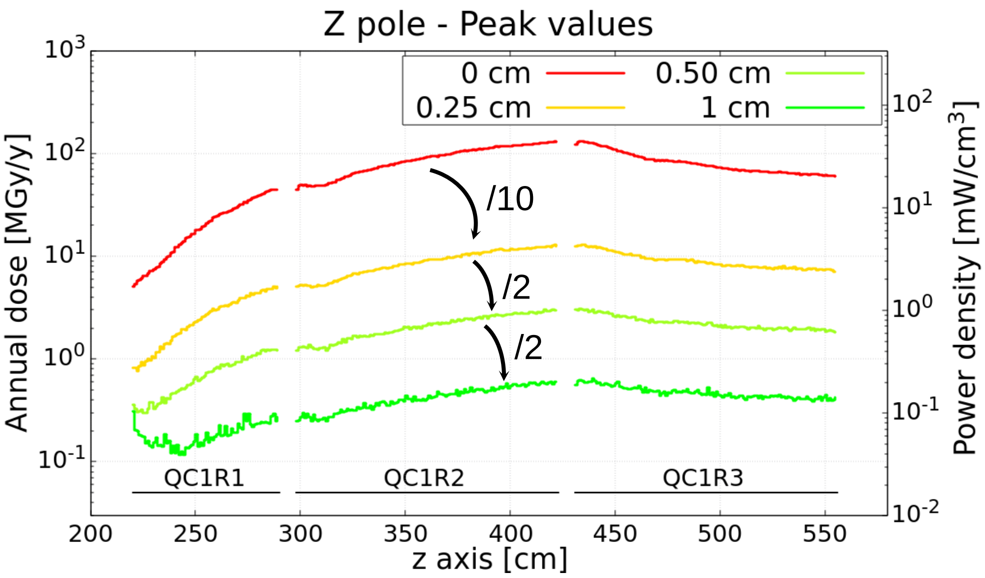




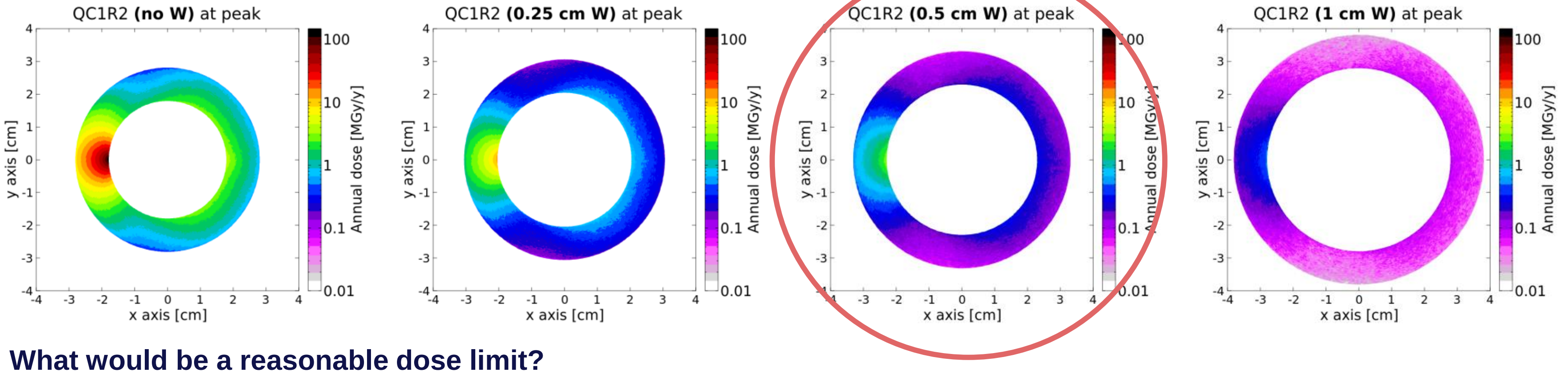
Shielding effectiveness

TOTAL POWER DEPOSITED

	0 cm	0.25 cm	0.5 cm	1 cm
W1	–	0.44 W	0.57 W	0.67 W
QC1R1	0.30 W	0.07 W	0.03 W	0.01 W
W2	–	2.19 W	2.85 W	3.34 W
QC1R2	1.54 W	0.34 W	0.14 W	0.05 W
W3	–	2.75 W	3.59 W	4.22 W
QC1R3	2.00W	0.44 W	0.19 W	0.07 W



Considerations on tungsten shielding



What would be a reasonable dose limit?

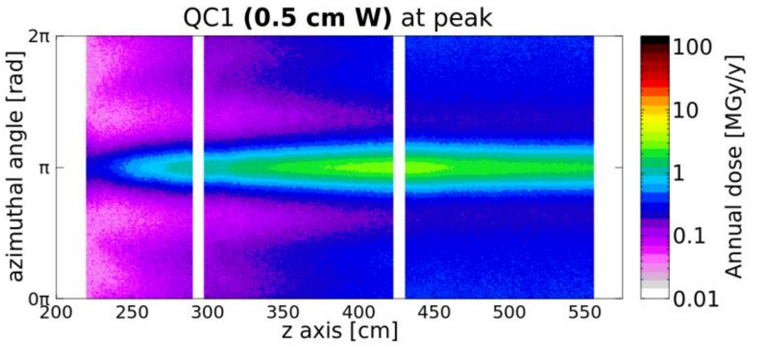
- at LHC inner triplet quadrupoles limited to **30 MGy** (crossing inversion at ATLAS to overcome the design target of 300 fb^{-1})

→ preliminary indication is that 5 mm shielding is necessary mainly because of TID

5 mm of tungsten ensures

- peak dose: 3 MGy/y
- peak power density deposition: 1 mW/cm3

- asymmetric design can be considered



iterations with magnet design experts shall follow on this evidence (results already anticipated to John Seeman)

Summary and prospects

Beamstrahlung dump

- input is being provided for thermomechanical and radiation protection studies (see previous talks and talk by M. Calviani)

Synchrotron radiation

- studies will follow to further reduce the tunnel radiation levels with additional shielding

FFQs power and dose study

- computed contribution from radiative Bhabha electrons (main contribution)
- 0.5cm-thick tungsten shielding would ensure safe values of peak power deposition and TID
- missing additional contributions (not yet studied): incoherent pair production, Z→qq, beam gas scattering, and possibly others to be quantified

Next topic to be approached

- radiation load to the detector, starting from establishing what are the key radiation sources

Thank you for your attention!

Backup

Power deposition in tungsten shielding