International MUON Collider Collaboration

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Radiation load on final focusing magnets with schemes version 0.7 and 0.8

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On behalf of the IMCC

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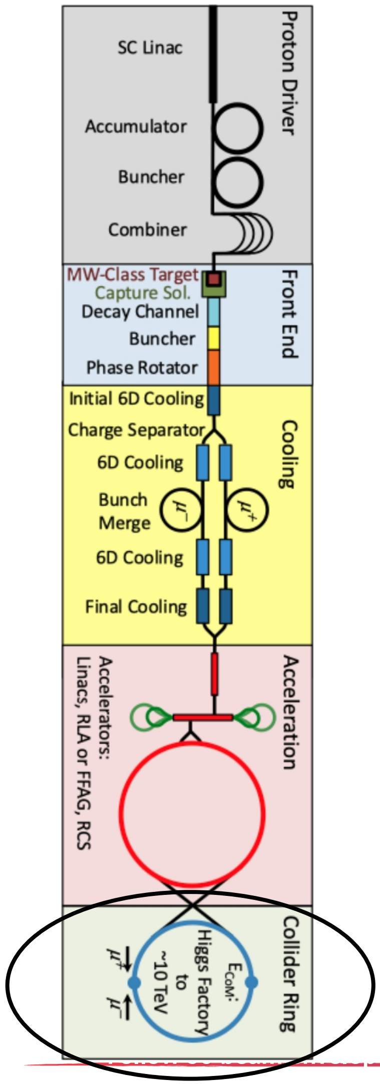
Outline



- **Current existing lattices**
- **Lattice options evolution:**
  - v 0.4: chromatic correction without drift
  - v 0.6: long drift before final focusing quadrupoles
  - v 0.7: chicane with a residual angle
  - v 0.8: no residual angle, lower dipole strength
- **Radial build of the magnets**
- **Current radiation load**
- **Conclusions**

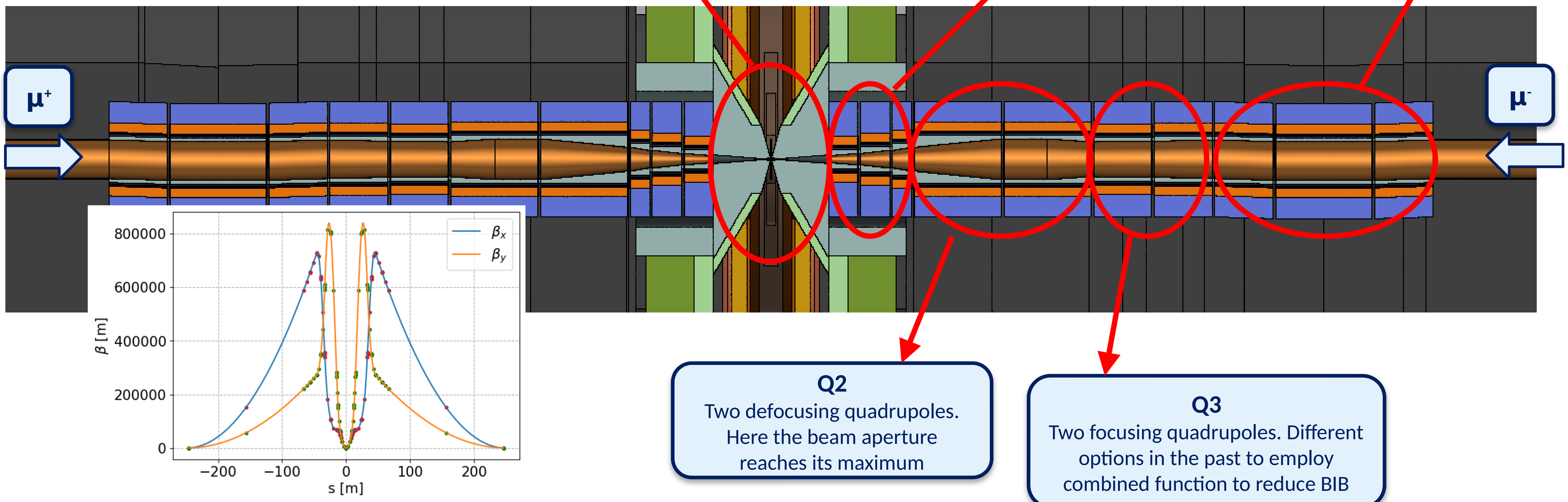
Final focus optics

Overview of the lattice version 0.8. The novel approach does not leave a residual angle and does not require combined function magnets

Interaction point (IP) & nozzle
Reduce the amount of decay-induced background by several order of magnitude

Q1
Three focusing quadrupoles to control the beam size in the IP

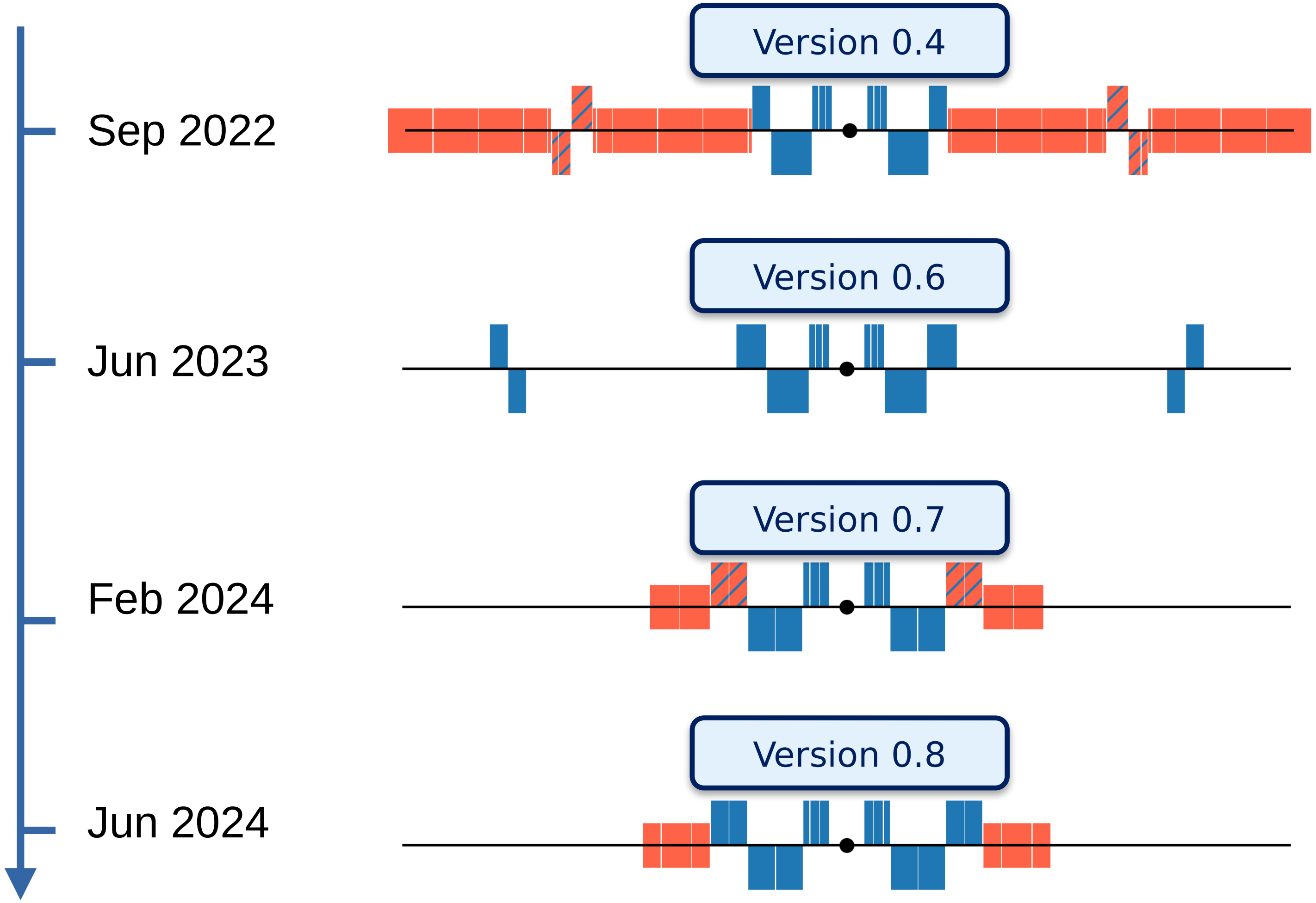
Chicane
Three dipoles that remove the electrons coming from the line



Q2
Two defocusing quadrupoles. Here the beam aperture reaches its maximum

Q3
Two focusing quadrupoles. Different options in the past to employ combined function to reduce BIB

Evolution of the optics



Dipolar components suppress BIB outside of the final focus. The BIB sample distributed (and considered baseline)

All the muon decays in ~200 meters from the IP give a non negligible contribution to the BIB

A chicane is added to partially clean the line from the secondary electrons before they reach the nozzle

The chicane concludes with 0 angle, and the magnet aperture is increased in the dipoles

Radial build of the magnets

- The radial build of the magnets for the version 0.8 is listed in table
- Still conflicting requirements in terms of field strengths and magnet apertures

Radial build	Thickness (mm)
beam screen	0.01
shield	2.53
shield support +thermal insulation	1.1
cold bore	0.3
insulation (kapton)	0.05
clearance + liquid helium	0.01
Sum	4

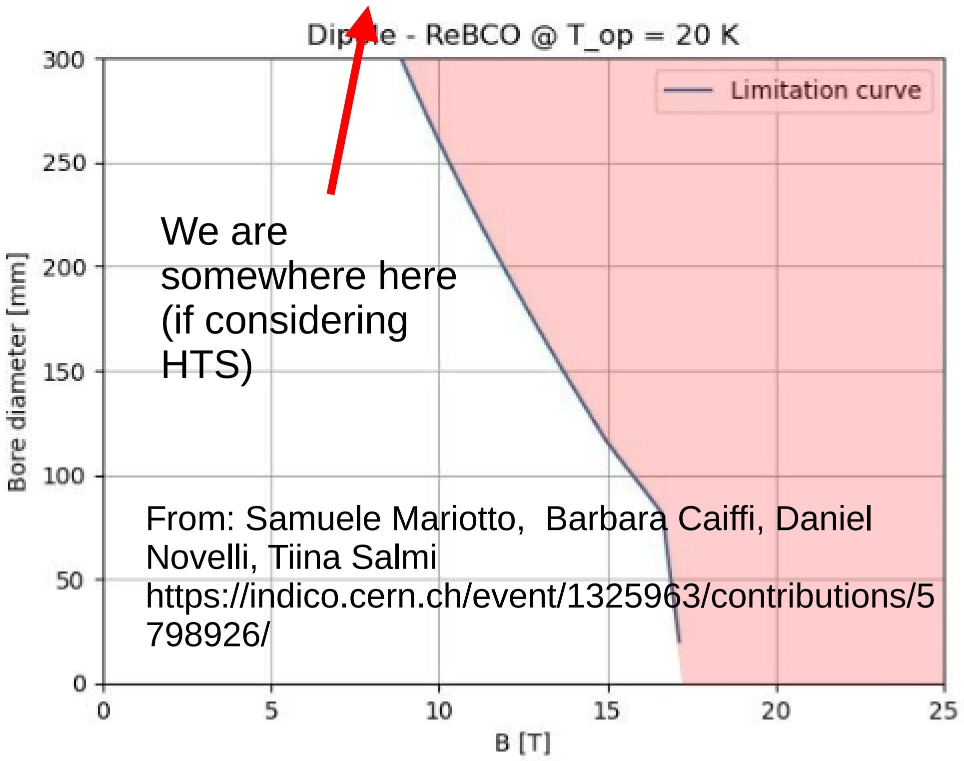
Increased to 4.53 for the dipoles

		Dynamic beam aperture [cm]		
Name	L	Upstream	Downstream	Magnet aperture radius [cm]
IB2	6	8.71	9.00	16
IB1	10	9.02	9.49	16
IB3	6	9.51	9.79	16
IQF2	6	9.81	9.20	14
IQF2_1	6	9.12	8.84	13.3
IQD1	9	8.98	10.33	14.5
IQD1_1	9	10.28	6.12	14.5
IQF1B	2	5.91	4.62	10.2
IQF1A	3	4.45	2.97	8.6
IQF1	3	2.84	1.78	7

Dipole requirements

		Dynamic beam aperture [cm]			
Name	**L**	**Upstream**	**Downstream**	**Magnet aperture radius [cm]**	**B field [T]**
IB2	6	8.71	9.00	16	8.1
IB1	10	9.02	9.49	16	-9.7
IB3	6	9.51	9.79	16	8.1

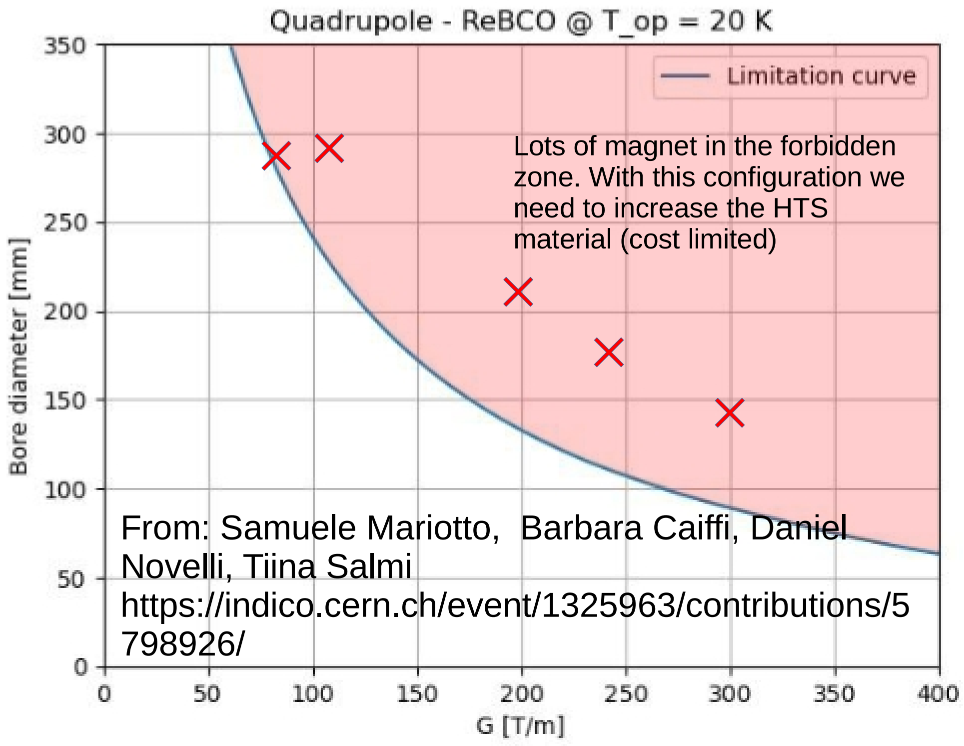
- A quite large aperture requirement is needed to restrict the TID below 10 MGy/y
- The field has to be large enough to significantly induce dispersion on the decay electrons



- HTS is mainly limited by cost production

Quadrupole requirements

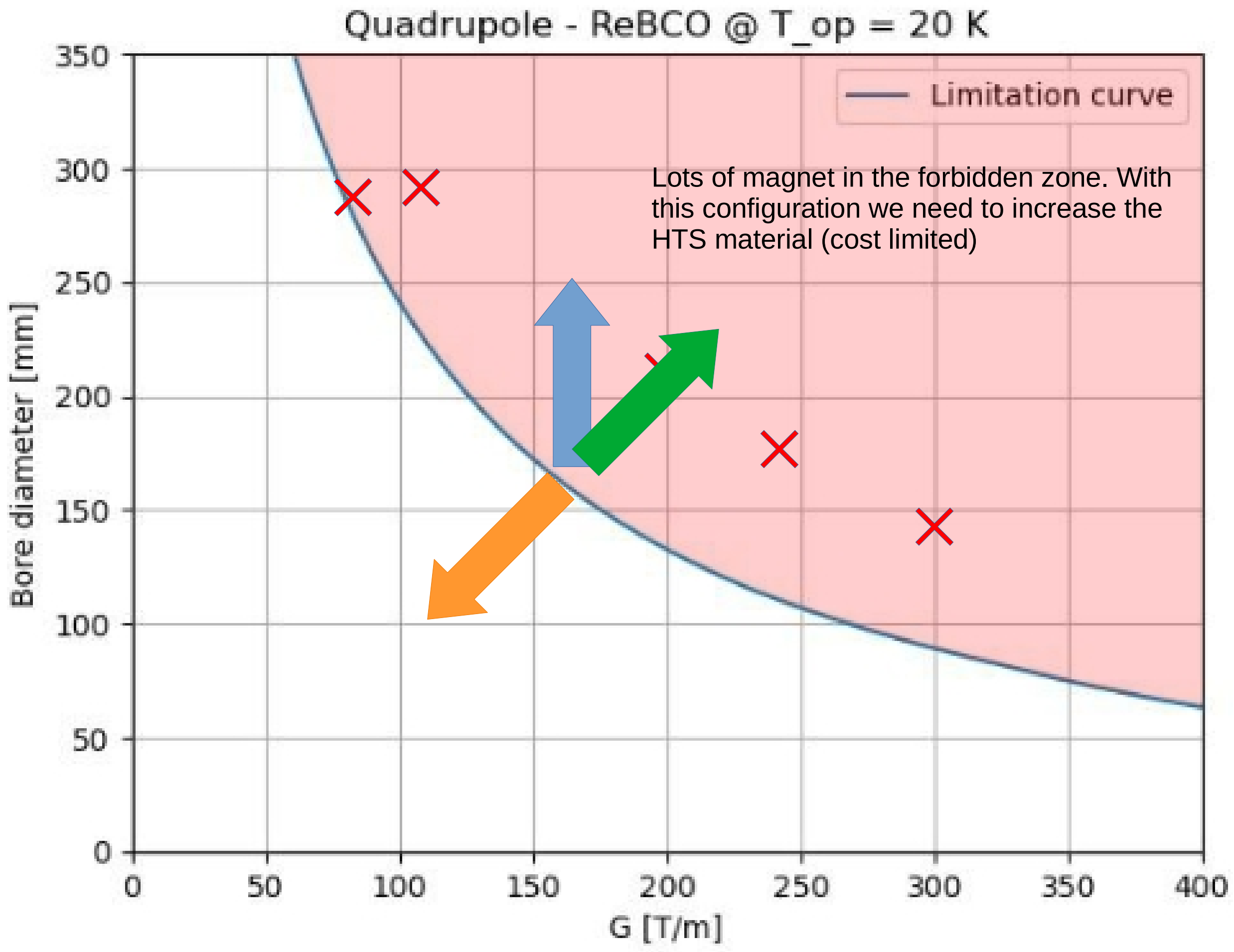
		Dynamic beam aperture [cm]			
Name	**L**	**Upstream**	**Downstream**	**Magnet aperture radius [cm]**	**dB_y/dx [T]**
IQF2	6	9.81	9.20	14	85.2
IQF2_1	6	9.12	8.84	13.3	85.2
IQD1	9	8.98	10.33	14.5	-115.4
IQD1_1	9	10.28	6.12	14.5	-115.4
IQF1B	2	5.91	4.62	10.2	205.1
IQF1A	3	4.45	2.97	8.6	241.8
IQF1	3	2.84	1.78	7	300.2



- In the current scheme, the magnets do not satisfy the requirements
- We can still use the current scheme, but with higher costs, or we need to reduce the field intensity (more complicated focusing scheme)

- HTS is mainly limited by cost production and protection. Working @20K the margin curve is also a limiting factor.

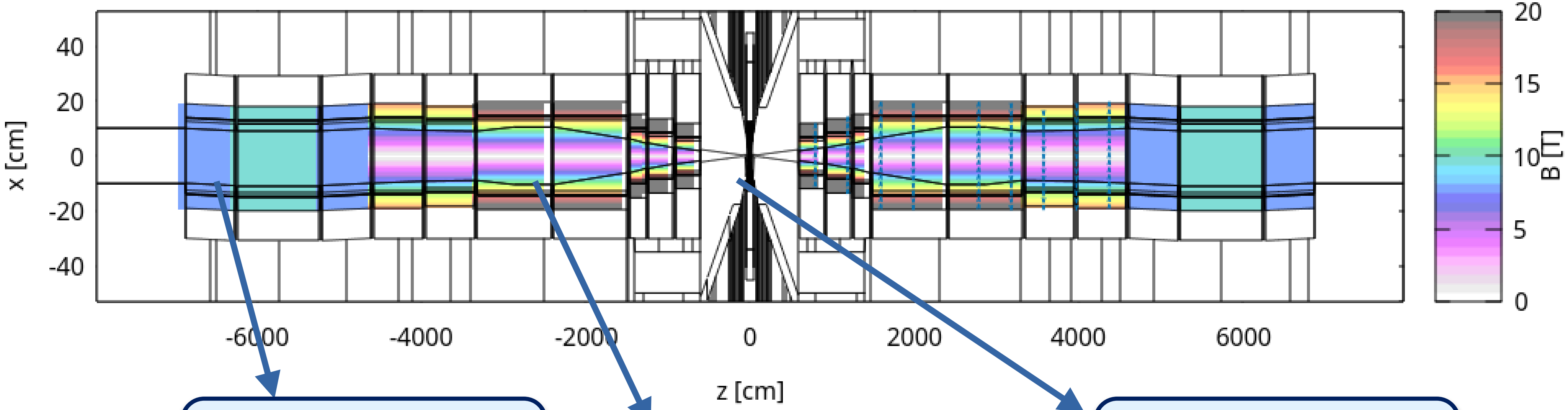
Conflicting requirements for magnets



From: Samuele Mariotto, Barbara Caiffi, Daniel Novelli, Tiina Salmi
https://indico.cern.ch/event/1325963/contributions/5798926/

- Radiation load requirement: larger aperture allows for more shielding
- Magnets requirements: small aperture and field intensities. Depending on the technology there are different limitation.
- Beam dynamics requirement: larger apertures and field strengths allows for easier control on the beam shape in the final focus

FLUKA magnetic field

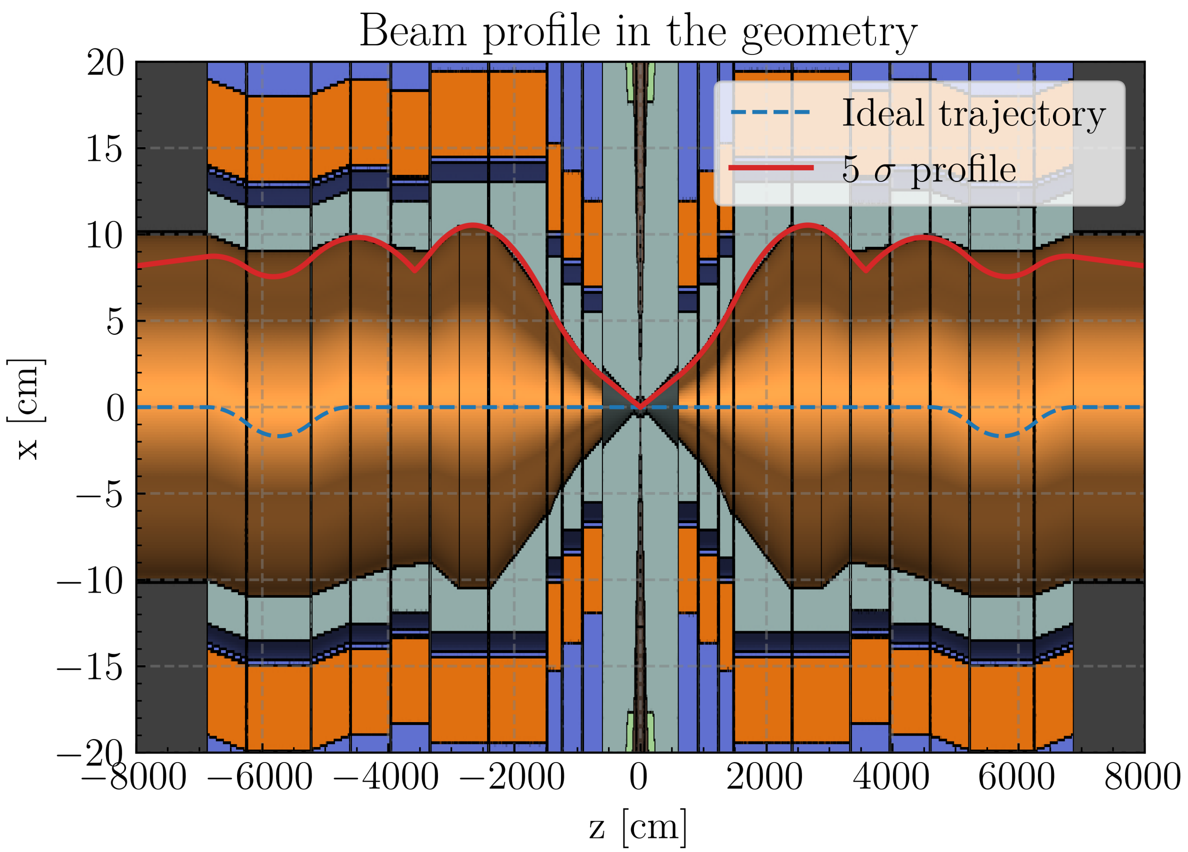


Dipole
Dipolar field assumed uniform in the magnets. No fringe fields.

Quadrupoles
Assumed analytic formulation up to the magnet yoke

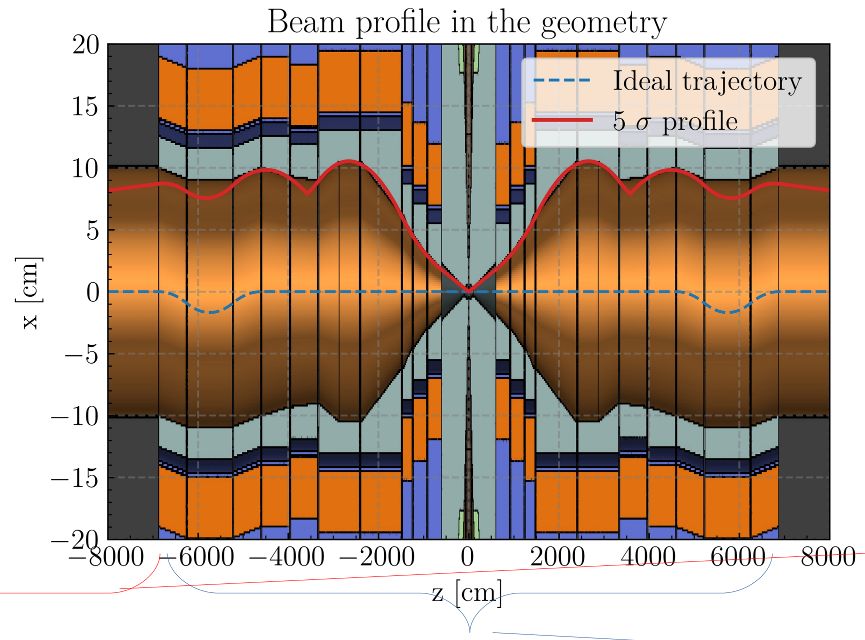
Solenoid
Not plotted here, it mitigates the background

Particle trajectories



Simuation parameters

Bunch intensity	Frequency	Time in a year [s]	GeV/g → J/g	GeV/ g → J/kg	Len collider [m]	Primaries per second [p/s]	Primaries per year [p/y]	Total power factor [mW/cm3]	Total ionizing dose factor [MGy/y]	DPA factor [DPA/y]
1.80E+12	5.00E+00	1.20E+07	1.60E-10	1.6E-07	1.00E+04	9.0E+12	1.1E+20	1.4E+06	1.7E+07	1.1E+20



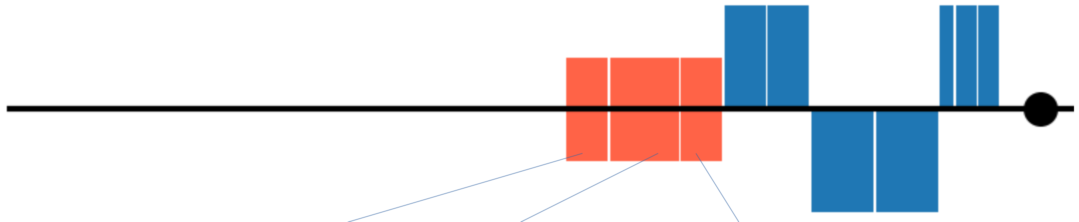
Simulations performed for this study. The background coming from the straight section is decoupled from the one coming from the final focus.
Electron/photon threshold: 1.25 MeV (~1 mm in copper)

Name	Decays per cycle	Length of the trajectory [m]	Decay per unit length	Total number of decays	Dose factor
vp08_out_FF	5.0E+02	1.8E+02	5.8E+04	1.0E+07	3.1E+05
vp08_in_FF	5.0E+02	1.4E+02	5.8E+04	7.9E+06	2.4E+05

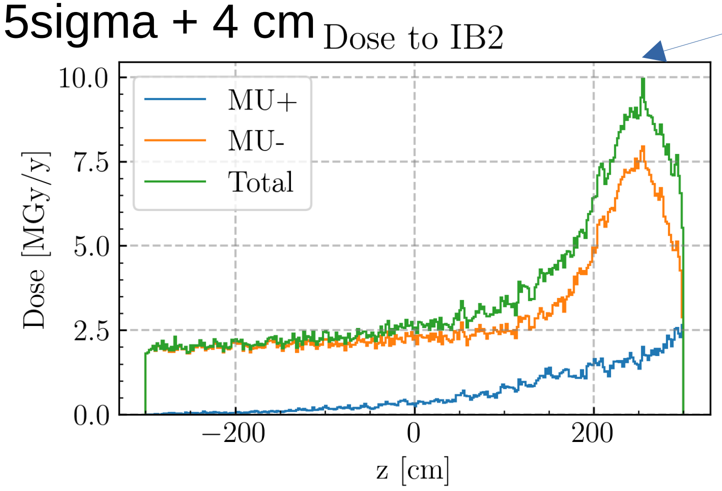
Radiation load: dipoles (4 cm)

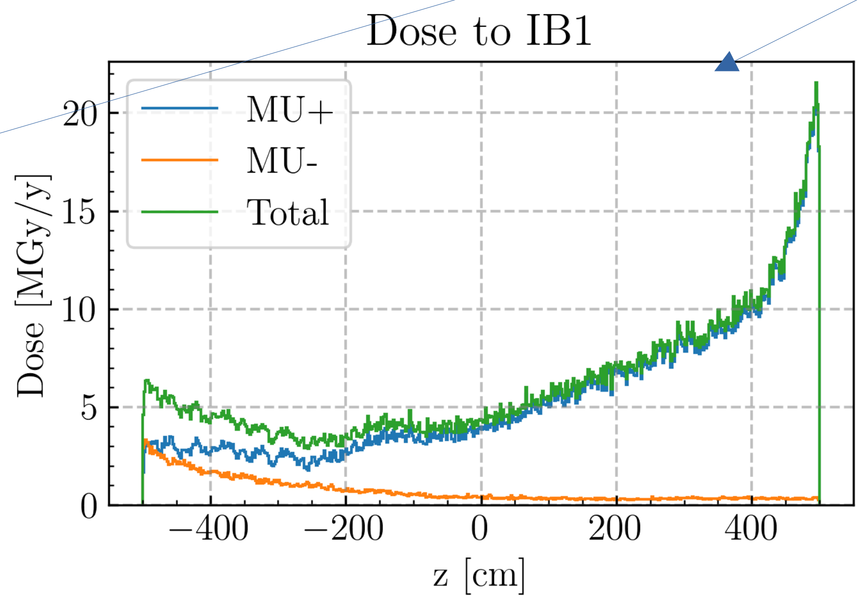
- The limiting factor for the shielding requirements is always the TID cumulated during the lifetime of the collider

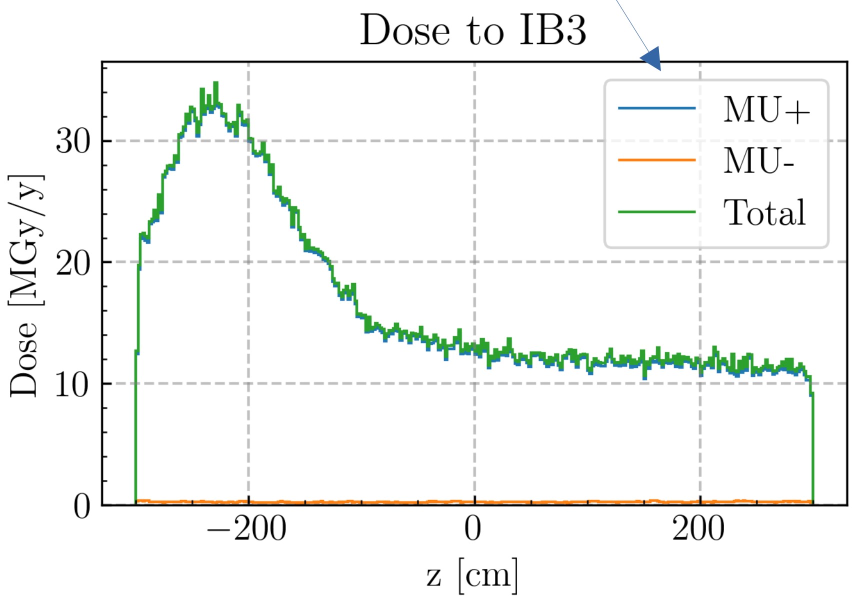
- Approximately 50 MGy can be tolerated.



IB2 can potentially survive with 5sigma + 4 cm

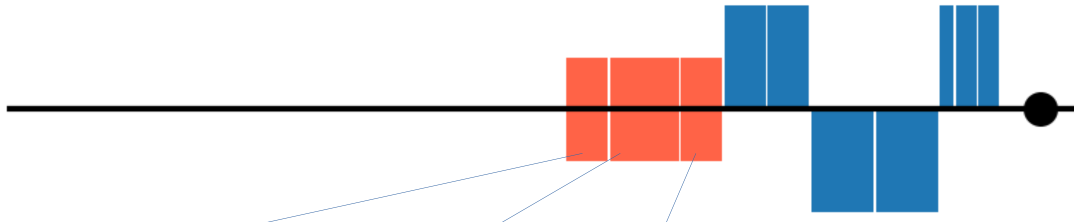




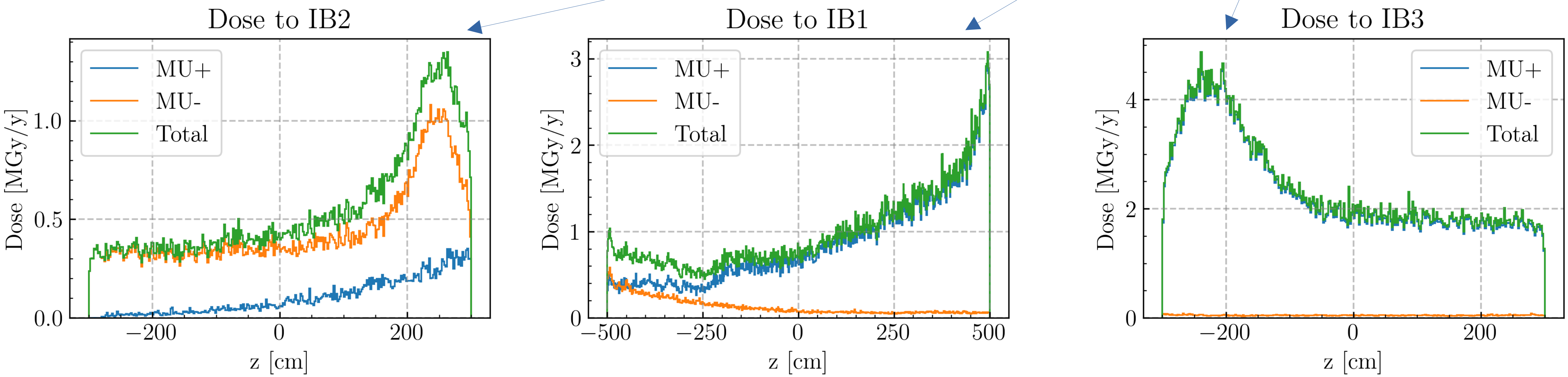


Radiation load: dipoles (6 cm)

- Two additional cm of tungsten reduce the TID of a factor 10 (typically it follows an exponential behaviour).

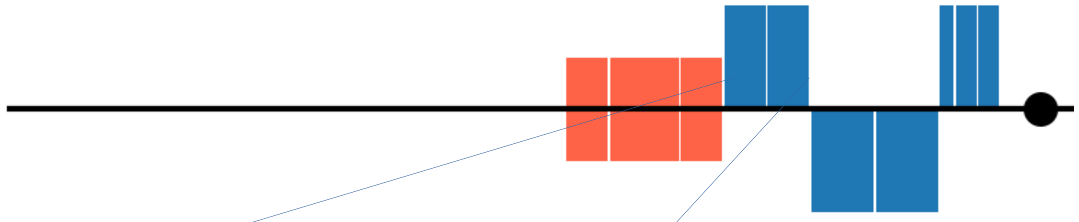


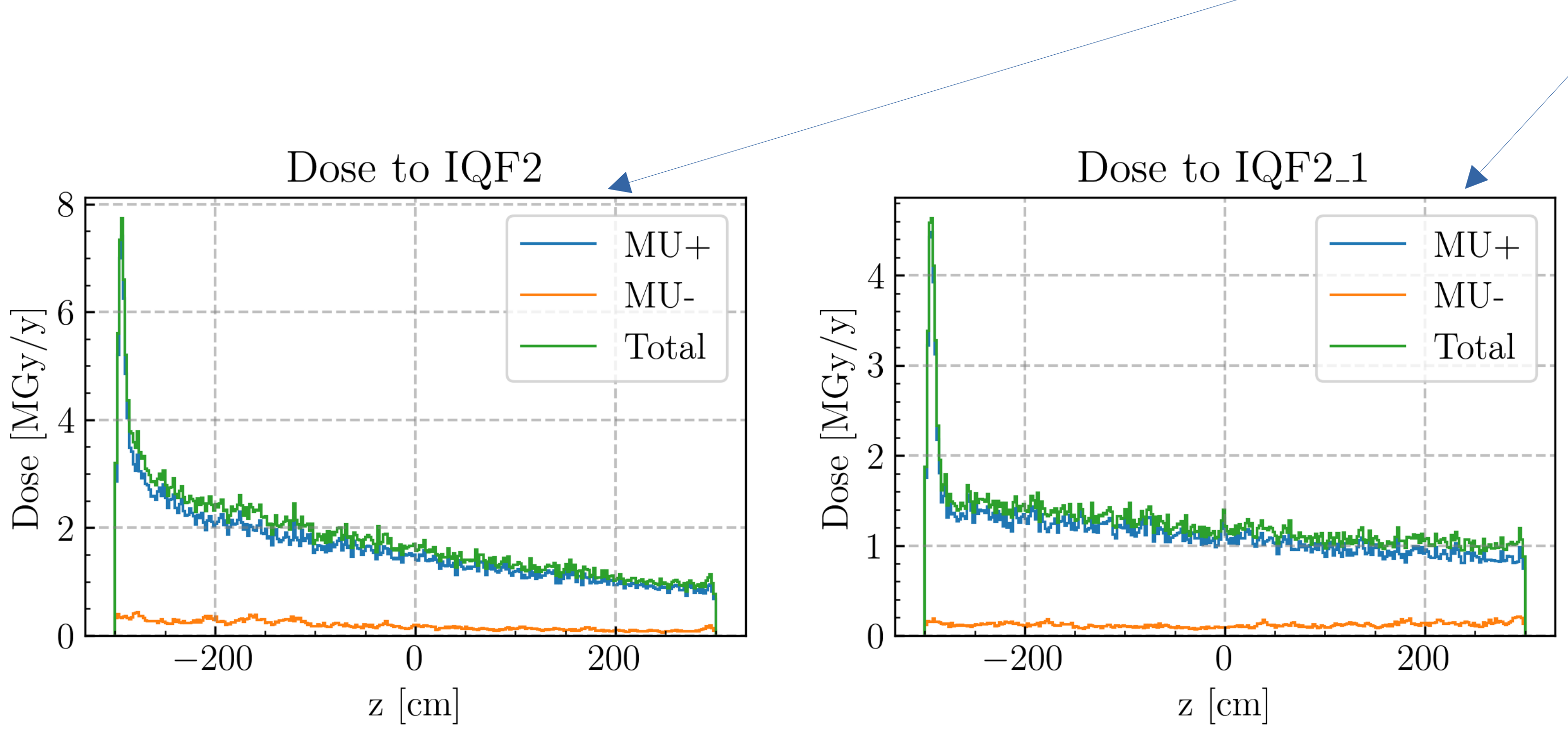
- The dipoles can be operated safely up to 10 years



Quadrupole radiation load: Q3

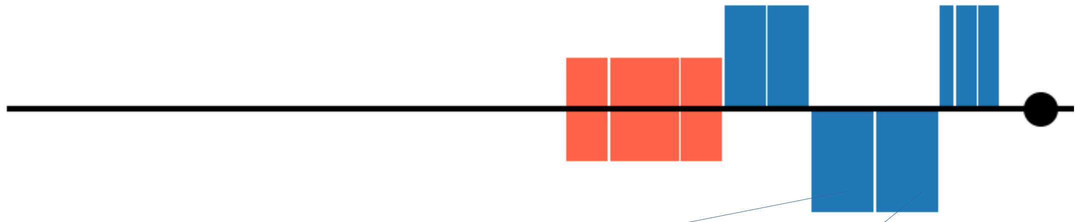
- Already with 5σ + 4 cm magnet aperture, all the quadrupoles suffer from less than 10 Mgy/y of TID

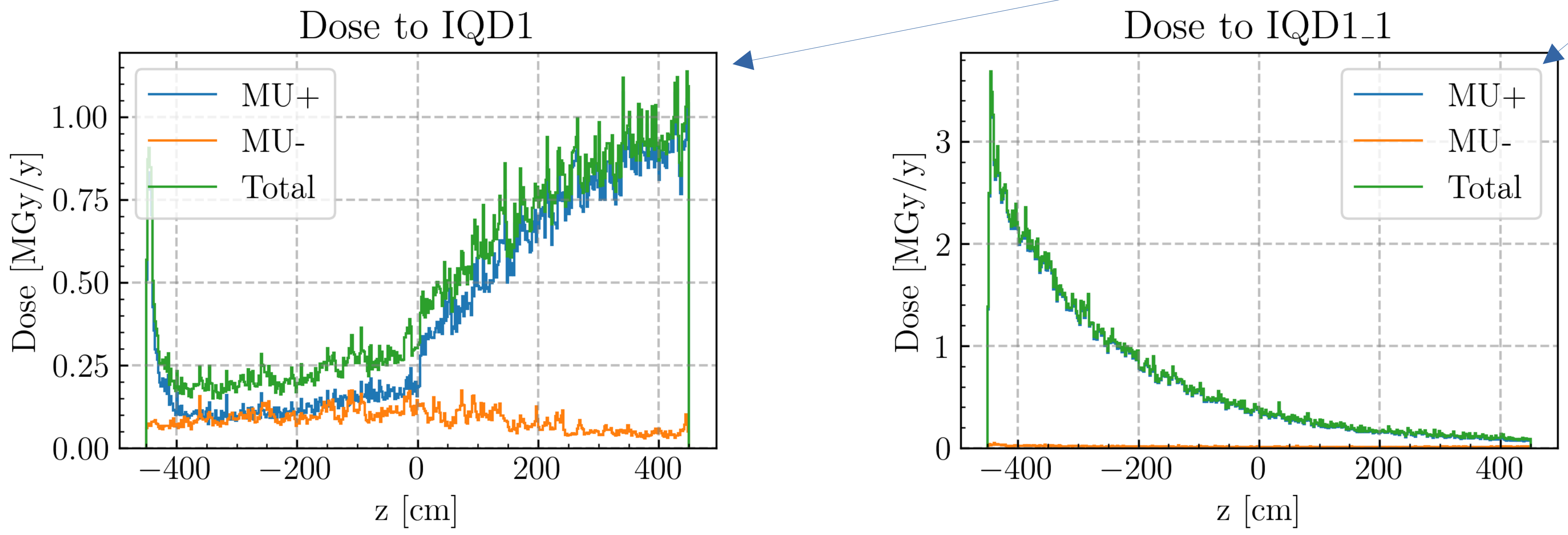




Quadrupole radiation load: Q2

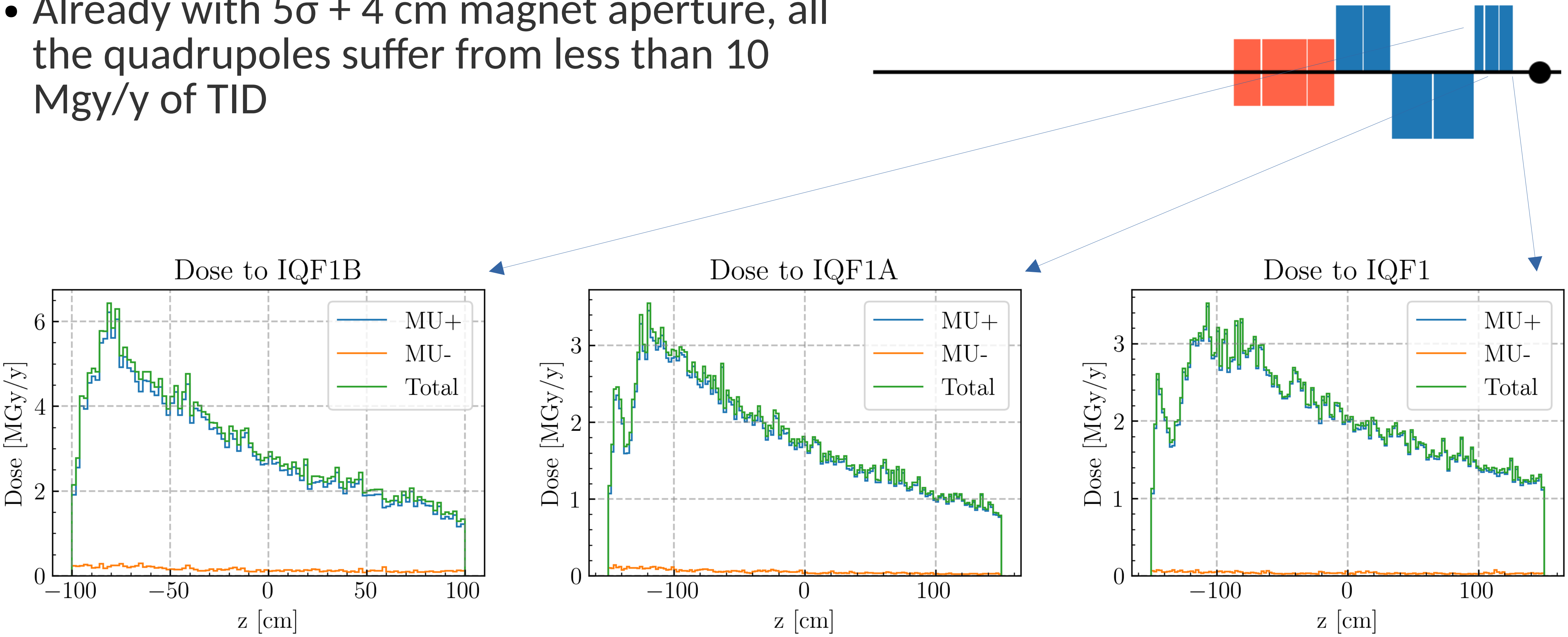
- Already with 5σ + 4 cm magnet aperture, all the quadrupoles suffer from less than 10 Mgy/y of TID





Quadrupole radiation load: Q1

- Already with 5σ + 4 cm magnet aperture, all the quadrupoles suffer from less than 10 Mgy/y of TID



Conclusions

- A novel lattice configuration has been tested for the long term survivability.
- A chicane would require ~(6 cm + 5σ) magnet aperture for the dipoles and ~(4 cm + 5σ) for quadrupoles
- Neither of the two options are affordable with the current magnet concepts. Three possible solutions:

  1) Reduce the integrated radiation load (less muons, less time)

  2) Reduce the insulation thickness to increase the space for the tungsten layer

  3) Increase the material budget for the HTS components.

*Less luminosity *Higher costs

Thank you

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Comment on simulation parameters

- The mesh is around 1 mm in radial dimension.
- In the CSDA the corresponding energy is around 1.2 MeV. This energy is set as threshold for photons and electrons