International
MUON Collider
Collaboration

MDI requirements for detector solenoid

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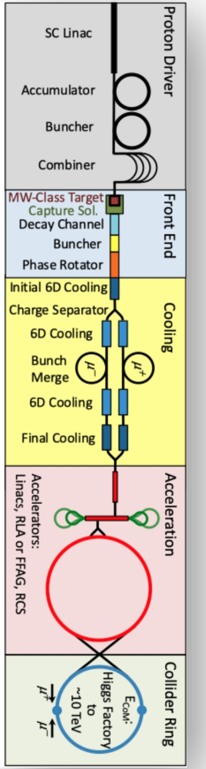
Outline



- **MDI geometry:**
  - Lattices under study
- **Effects of the solenoid for the muon decay**
  - Small effect at all energy
- **Effects of the solenoid for the incoherent pair production**
  - The higher, the better
- **What tools we have now**
- **Conclusions**

Workflow in the IMCC

Machine-Detector Interface: MDI

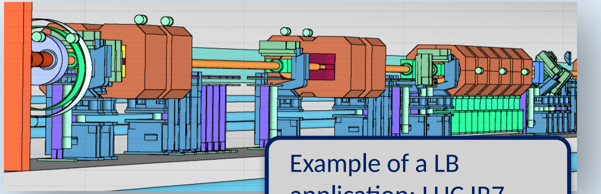
1. Lattice design

The magnet optics is computed via dedicated codes (e.g. MAD-X).

The output is a twiss file, containing the machine elements in a sequence

2. FLUKA geometry model

Via LineBuilder (LB), complex geometries are assembled in a FLUKA input file



Example of a LB application: LHC IR7

3. BIB simulation

With the built geometry, a FLUKA simulation is run.

The position and momentum of the decay muons are sampled from the matched phase-space

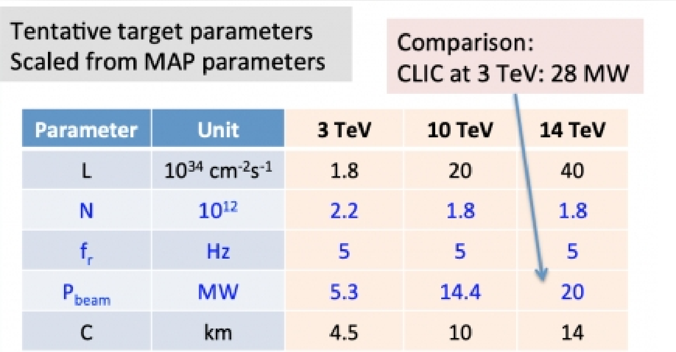
BIB data to detector experts

Iteration with lattice design experts to mitigate the BIB

CERN STI/BMI is currently responsible for the geometry built at √s = 3 and 10 TeV

Interaction region: MDI

- MDI is a **difficult challenge** for the muon collider. First studies were done by the MAP collaboration (energies up to 6 TeV). So far, IMCC focused on studies for energies up to 10 TeV.
- Objectives of the new studies:
  - Devise a conceptual IP design achieving **background** levels **compatible** with **detector operation**, both in terms of physics performance and acceptable cumulative radiation damage.
  - The focus energies are 3 TeV and 10 TeV.

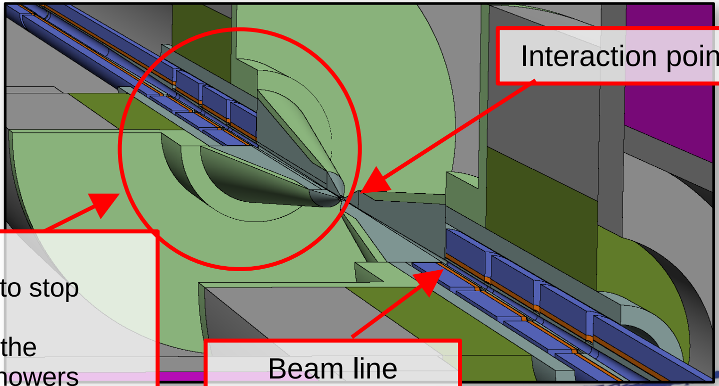


Tentative target parameters
Scaled from MAP parameters

Comparison:
CLIC at 3 TeV: 28 MW

Parameter	Unit	3 TeV	10 TeV	14 TeV
L	10^{34} cm^{-2}s^{-1}	1.8	20	40
N	10^{12}	2.2	1.8	1.8
f_r	Hz	5	5	5
P_{beam}	MW	5.3	14.4	20
C	km	4.5	10	14

Geometry of the MDI



Interaction point

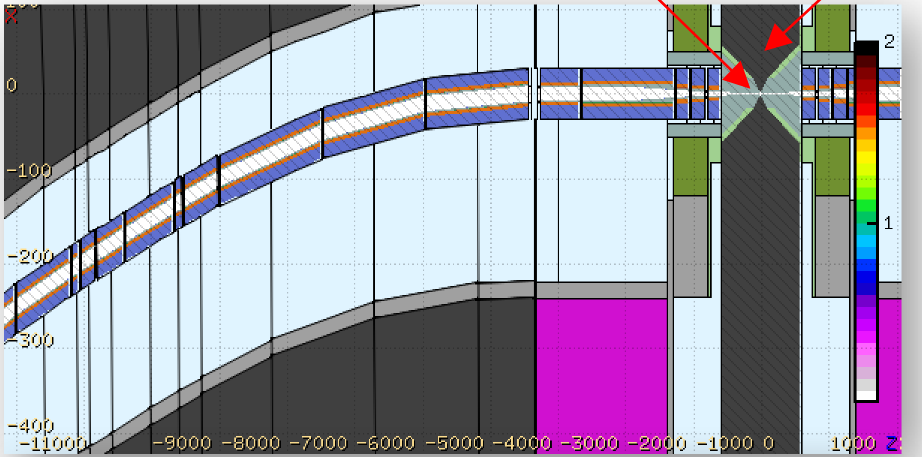
Nozzle:
- Outer boron layer to stop neutrons
- Tungsten core for the electromagnetic showers

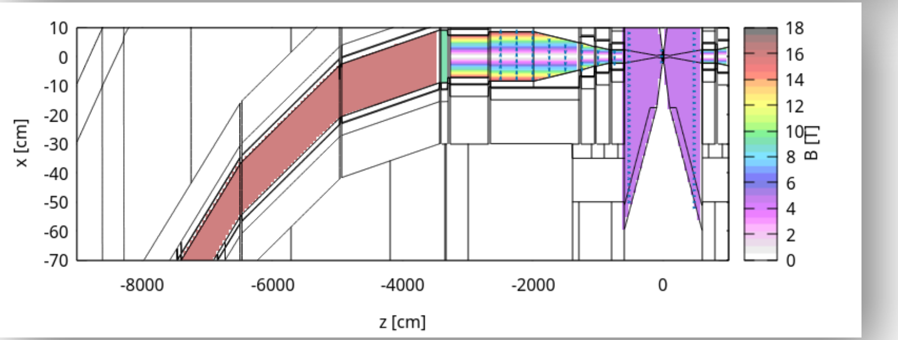
Beam line

MDI: lattice v.0.4

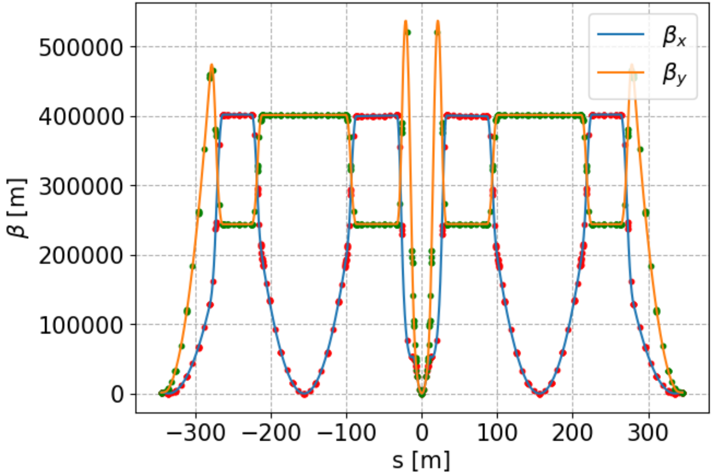
Nozzle (shielding)

Detectors (not modeled)

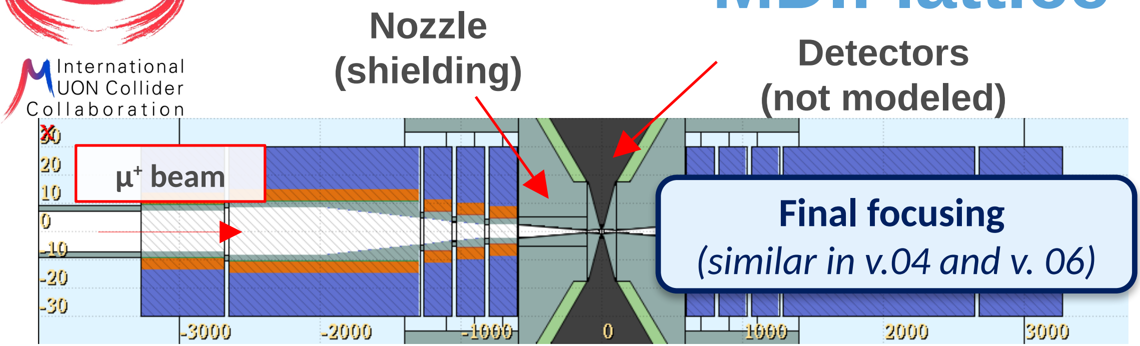




- The v.0.4 is the first having both the final focusing region and the chromaticity correction.



MDI: lattice v.0.6

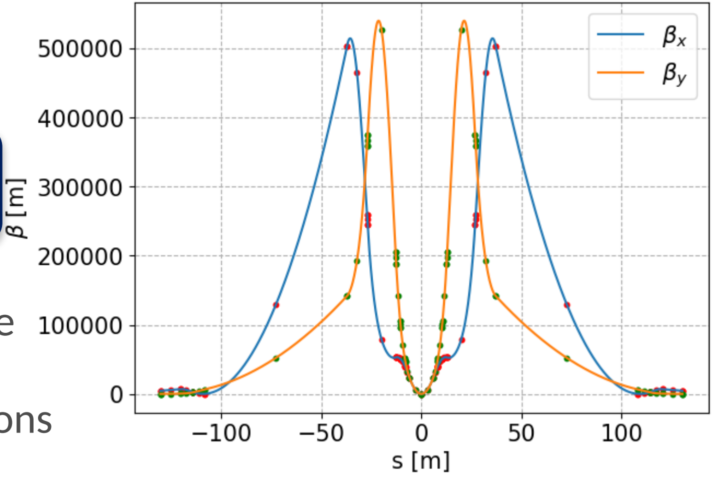

Nozzle (shielding)

Detectors (not modeled)

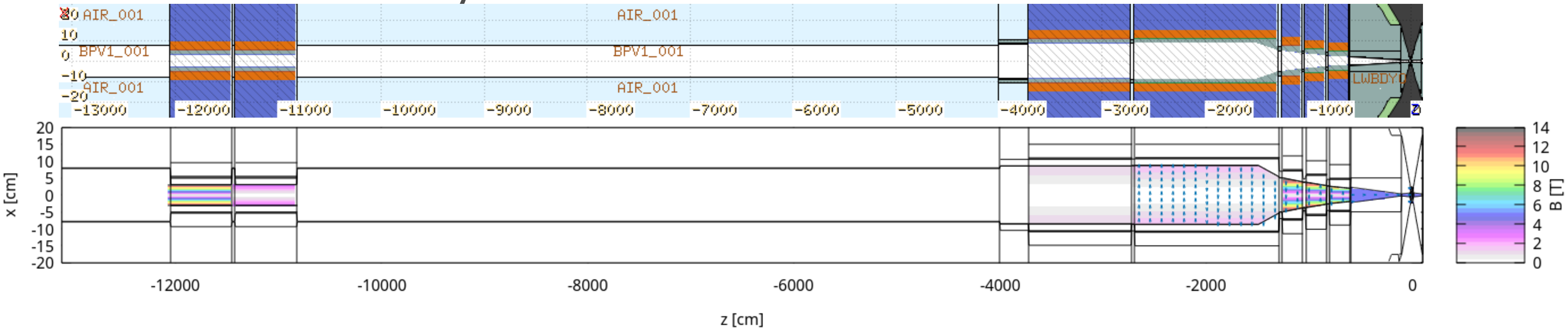
μ⁺ beam

Final focusing

(similar in v.04 and v. 06)

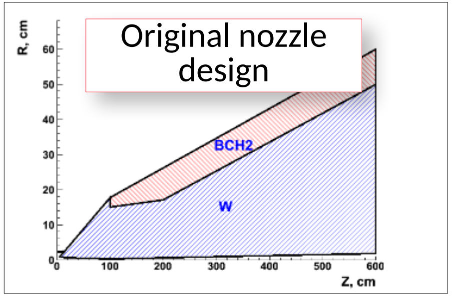


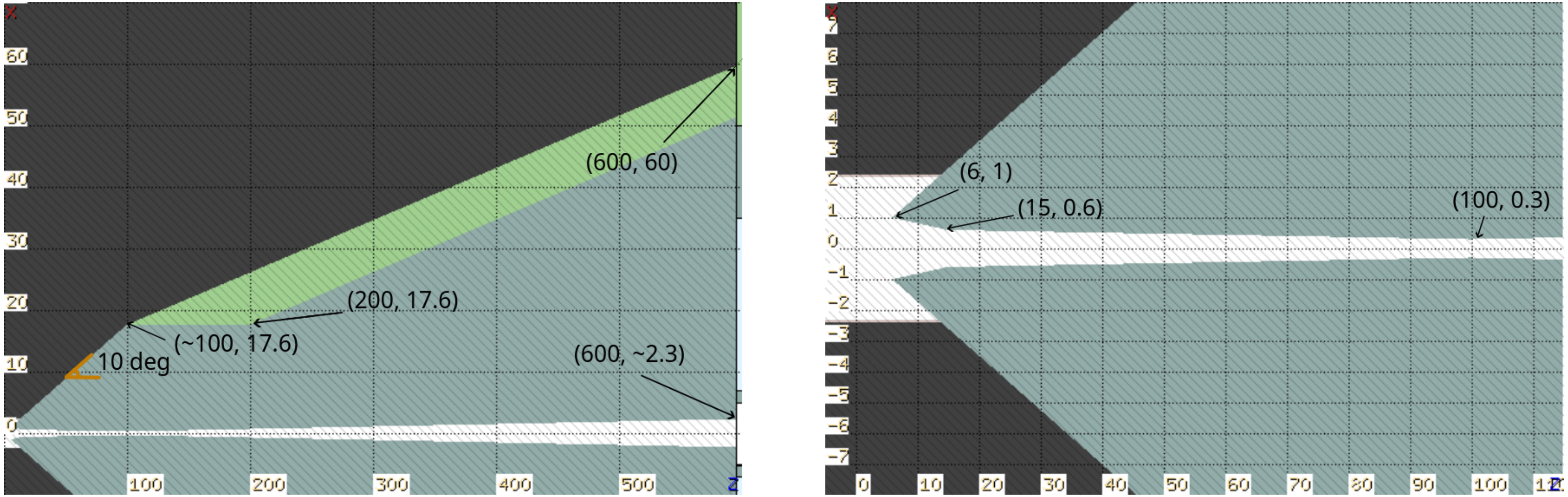
- Differently from previous versions, v06 does not have dipole components after the final focus
- As a consequence, higher BIB is expected coming from regions far away from the IP
- Results for BIB are **not yet used for detector studies**



MDI: nozzle details

- Our implementation of the nozzle follows the original design from MAP collaboration
- These details are shared in the **parameters document**


Original nozzle design

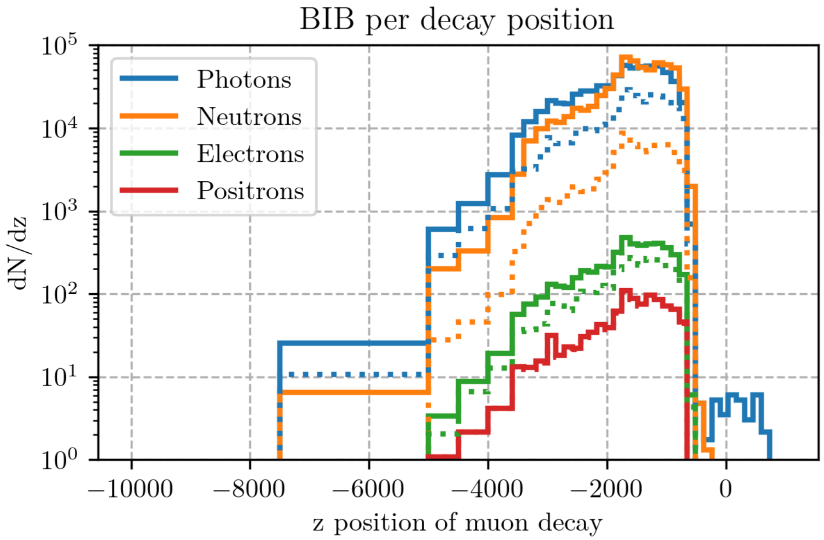


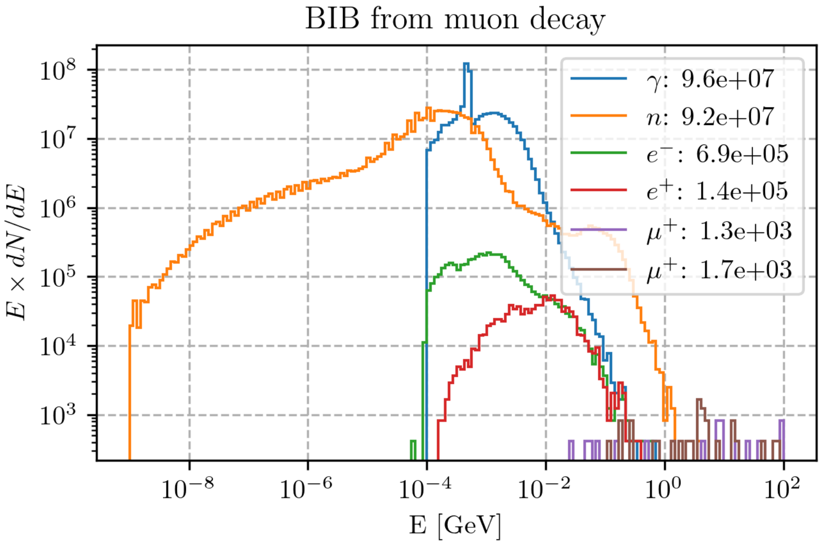
(a) Nozzle shape

(b) Tip details

μ decay @ √s = 10 TeV: particle origin and spectra

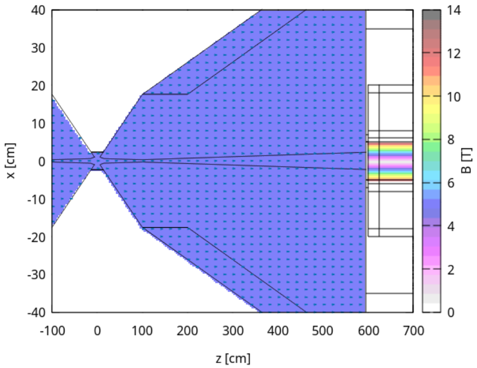
- The dipolar component in the line pushes secondary electrons and positrons on the magnet aperture. Therefore the BIB contribution from muon decays far away from IP is negligible.
- The particle spectra show a major contribution from photons, neutrons an electron/positrons

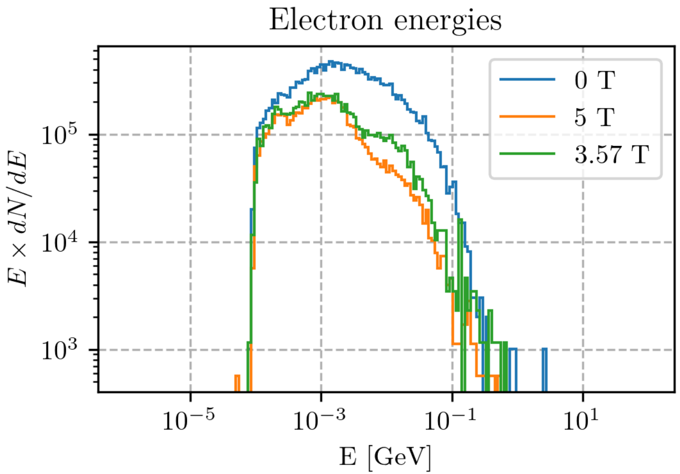


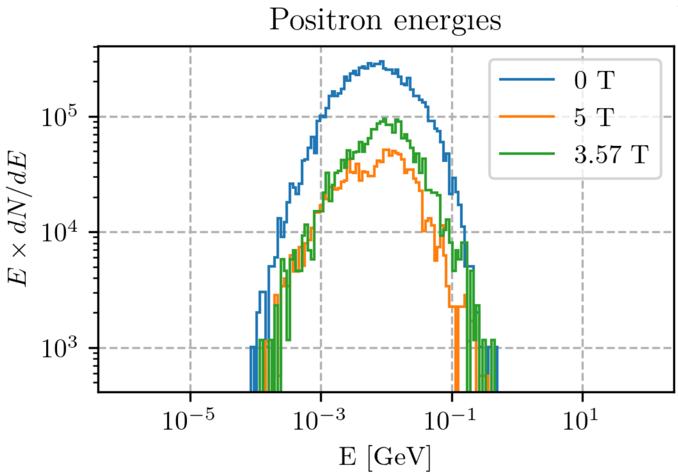


Effect of the solenoid field for muon decay

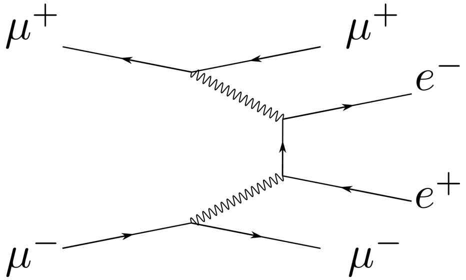
- We consider an hard edge uniform magnetic field in the nozzle area [-L*, L*]
- As seen in previous meeting, different magnetic field intensity (3.57 and 5) do not significantly change the background

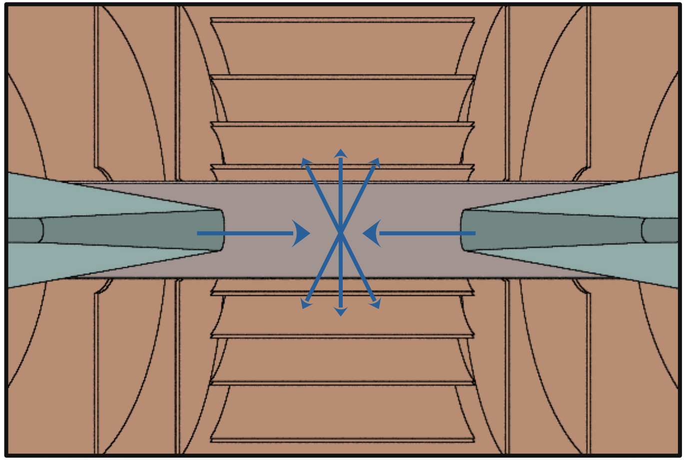



Electron energies

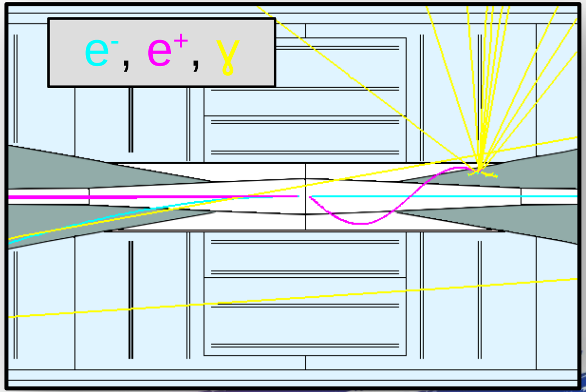

Positron energies

Incoherent pair production



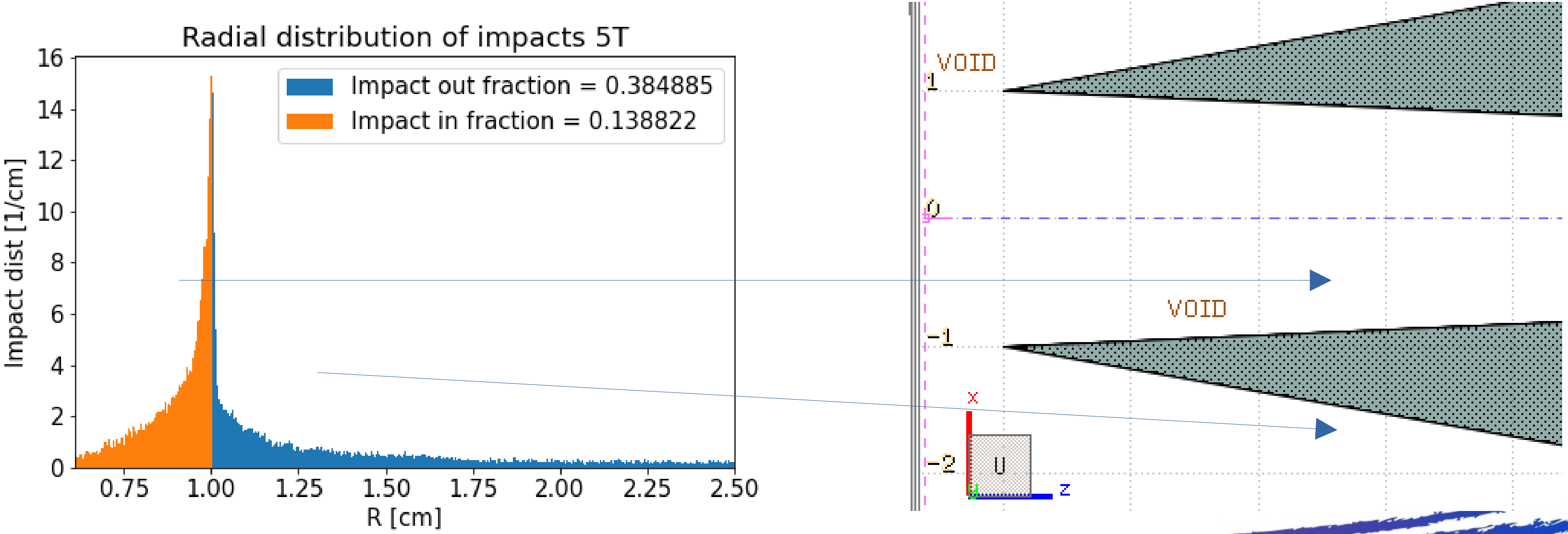


- At very high beam energies, beam-beam effects are not negligible. The most important phenomenon is due to the **incoherent beam-beam pair production $\mu^+\mu^- \to \mu^+\mu^- e^+ e^-$**.
  - The incoherent pair production e^+/e^- are provided by D. Schulte and are obtained by a **Guinea-Pig simulation**
- The **total number** of crossing is much **lower** than the muon **decay** case.
- The produced electrons are **energetic** and they **impact** directly on the **detectors**, since are generated in the IP, hence they might be dangerous despite the low total number.



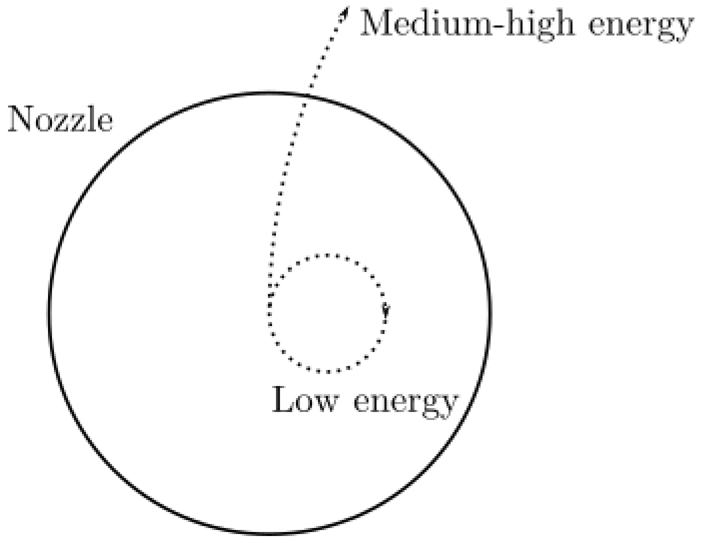
Effect of the solenoid field for incoherent pair production

- The $e^{+/-}$ generated in the interaction point have non zero divergence. Part of these particles are impacting on the inner and outer side of the nozzle
- The BIB mitigation objective focus on trapping the pairs though the solenoidal field



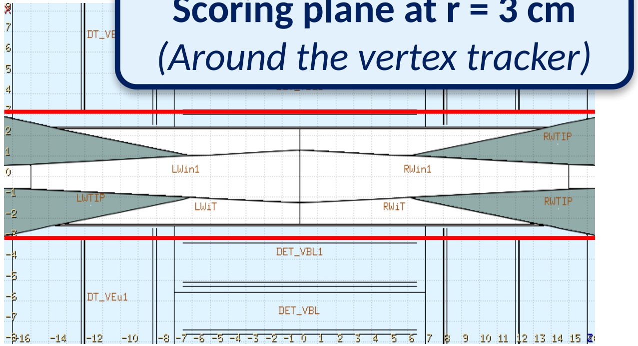
Effect of the solenoid field for incoherent pair production

- With a solenoid magnetic field, the particle trajectory in the transverse plane is modified.
- The effect is prevalent with low energy particles, which are trapped inside a spiral trajectory, and they will not impact on the nozzle walls.

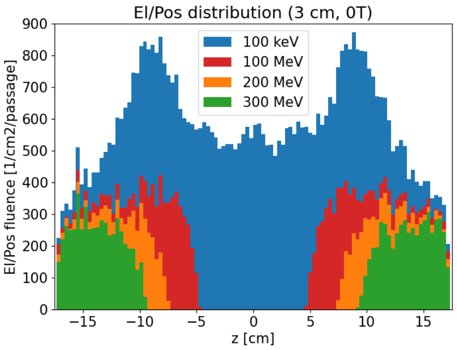


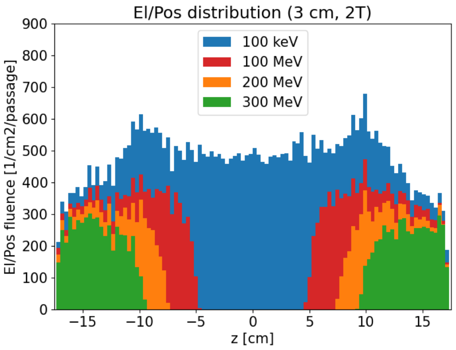
Effect of the solenoid field for incoherent pair production

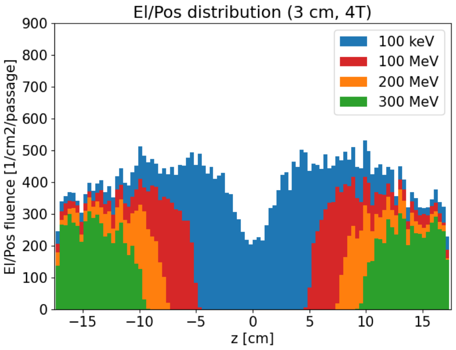
- Having a solenoid field reduces significantly the pair production impact on trackers.
- Ideally one would like to have the magnetic field as high as possible

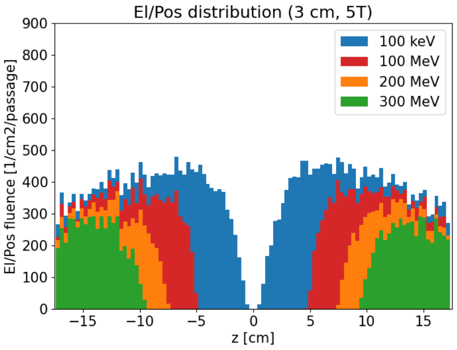


Scoring plane at r = 3 cm
(Around the vertex tracker)







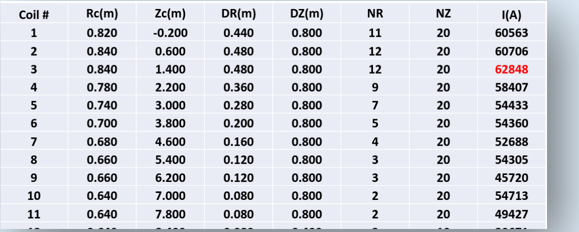


What tools we have

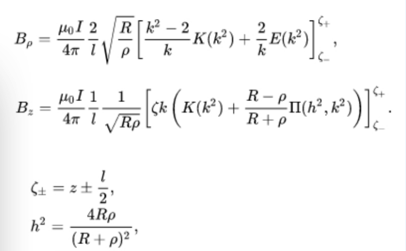
- Ideally, magnet and detector experts have to come up with a solenoid design. Requirements on the MDI are more flexible.
- To exchange information on the magnetic field, we could implement the magnetic field map in FLUKA to observe the consequences.

Example: magnetic field for target studies

Coil configuration



Coil #	Rc(m)	Zc(m)	DR(m)	DZ(m)	NR	NZ	I(A)
1	0.820	-0.200	0.440	0.800	11	20	60563
2	0.840	0.600	0.480	0.800	12	20	60706
3	0.840	1.400	0.480	0.800	12	20	62848
4	0.780	2.200	0.360	0.800	9	20	58407
5	0.740	3.000	0.280	0.800	7	20	54433
6	0.700	3.800	0.200	0.800	5	20	54360
7	0.680	4.600	0.160	0.800	4	20	52688
8	0.660	5.400	0.120	0.800	3	20	54305
9	0.660	6.200	0.120	0.800	3	20	45720
10	0.640	7.000	0.080	0.800	2	20	54713
11	0.640	7.800	0.080	0.800	2	20	49427



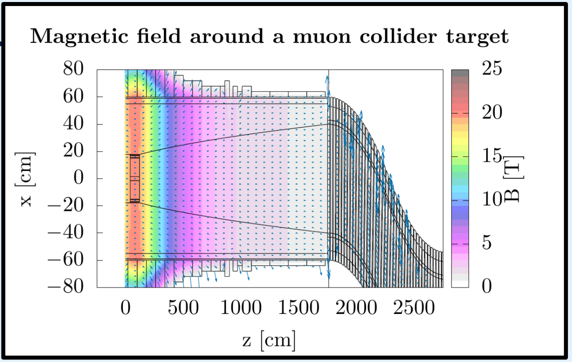
$$B_\rho = \frac{\mu_0 I}{4\pi}\frac{2}{l}\sqrt{\frac{R}{\rho}}\left[\frac{k^2-2}{k}K(k^2)+\frac{2}{k}E(k^2)\right]_{\zeta_-}^{\zeta_+},$$

$$B_z = \frac{\mu_0 I}{4\pi}\frac{1}{l}\frac{1}{\sqrt{R\rho}}\left[\zeta k\left(K(k^2)+\frac{R-\rho}{R+\rho}\Pi(h^2,k^2)\right)\right]_{\zeta_-}^{\zeta_+}.$$

$$\zeta_\pm = z \pm \frac{l}{2},$$

$$h^2 = \frac{4R\rho}{(R+\rho)^2},$$

... in house code



Conclusions

- A solenoid component is important for the MDI
- The effect of the magnetic field (given that a sufficient intensity is reached) does not strongly affect the BIB coming from the muon decay
- The **incoherent pair production can be strongly limited via a solenoidal magnetic field**. A magnetic field around 5 T contains the low energy electrons inside of the nozzle
- **MDI** requirements are potentially **less stringent** than the detectors and engineering ones. Nevertheless, we need to have a solenoidal field with sufficient strength to get rid of the low energy electrons
- Once a tentative solenoid has been designed, I can plug it in in FLUKA to observe the real field effect on the beam (e.g. study the effects of a non zero radial component of the magnetic field)

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Thank you
for your attention!