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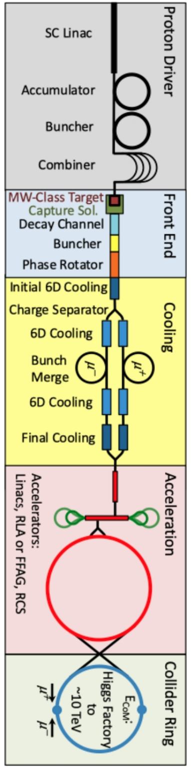
10 TeV Muon Collider: MDI update: pair production and nozzle tip studies

D. Calzolari (CERN – SY/STI/BMI) on behalf of the IMCC

April 2024

Outline



- **Machine-Detector Interface (MDI):**
  - Geometry of the interaction region
  - Current version of the nozzle
- **Luminosity:**
  - Beam-beam effects and luminous region
- **New incoherent pair production sample**
- **Electron fluences in the first tracker layers:**
  - Incoherent pair production
  - Muon decay background

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.
- **Main objectives:**
  - Study the beam-induced background (BIB) and identify mitigation strategies for the **3 TeV** and **10(+) TeV** collider options.
  - Develop a credible **interaction region (IR) design** that yields background levels compatible with detector operation (1. enabling physics performance reach, 2. reducing radiation damage to acceptable levels)

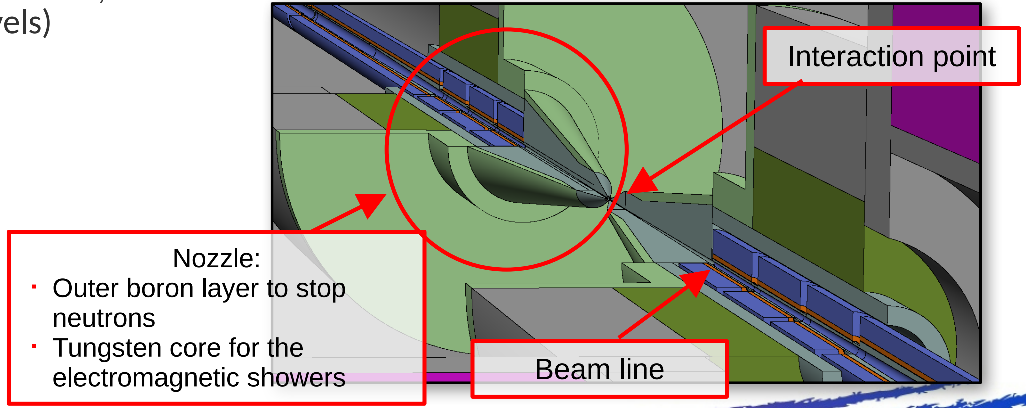
Tentative target parameters
Scaled from MAP parameters

Comparison:
CLIC at 3 TeV: 28 MW

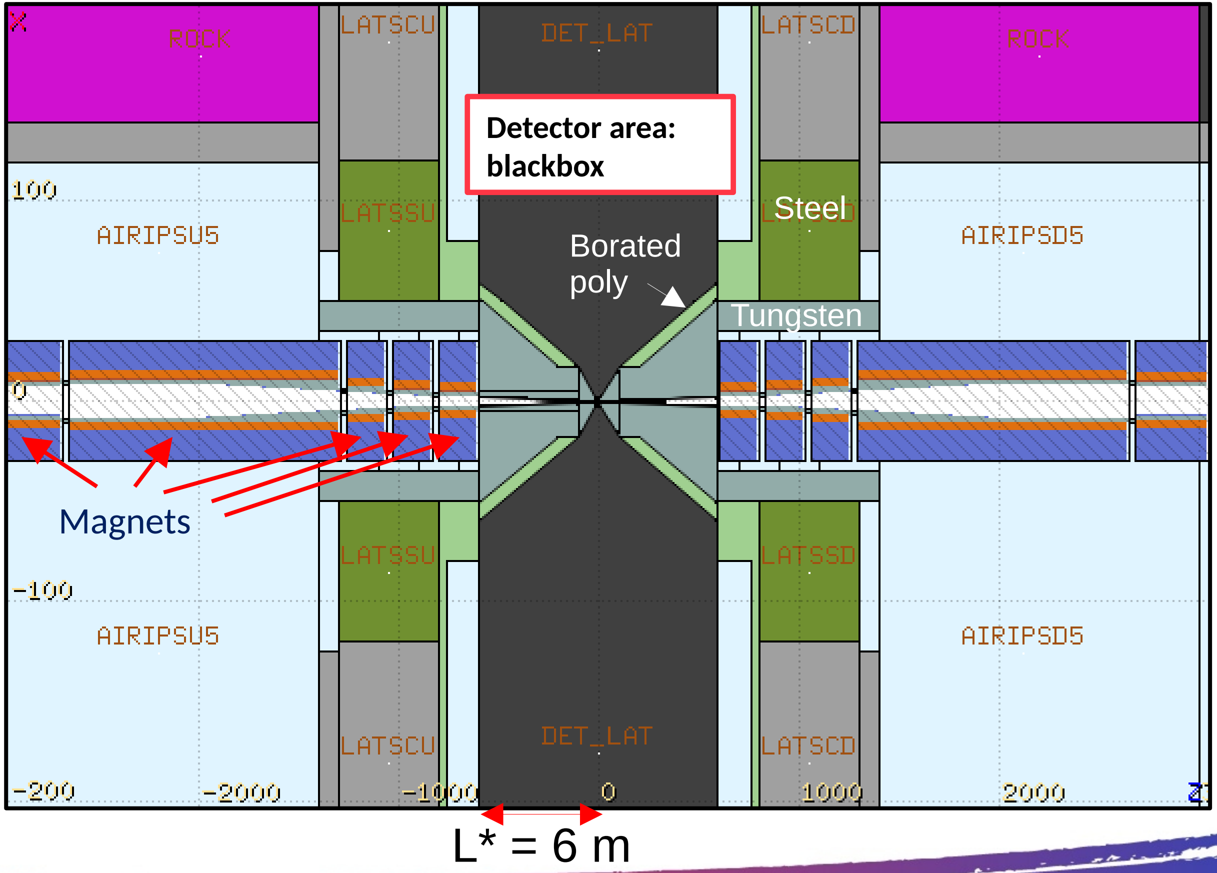
Parameter	Unit	3 TeV	10 TeV	14 TeV
L	10^{34} cm^{-2}s^{-1}	1.8	20	40
N	10^{12}	2.2	1.8	1.8
f_r	Hz	5	5	5
P_{beam}	MW	5.3	14.4	20
C	km	4.5	10	14

- **MDI Working Group**:
  - Formed last year in course of the Muon Collider Community meetings
  - Shall bring together expertise from different areas (lattice design, particle-matter interactions, detectors, magnets etc.)
  - Meetings every last Friday of a month (Indico event category)

Geometry of the MDI



MDI: geometry of a 10 TeV collider



Luminosity: some consideration

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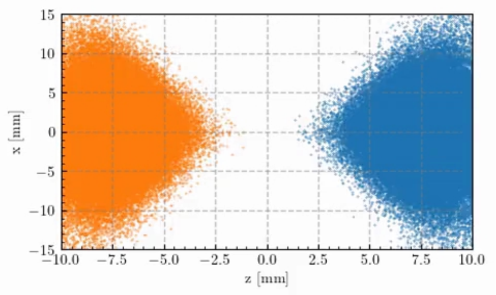
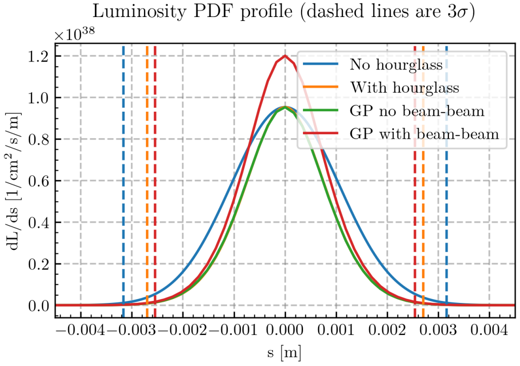
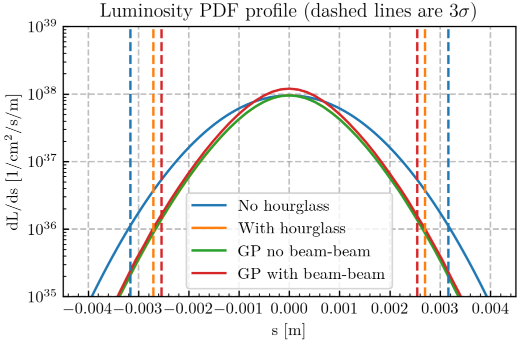
- As shown during the annual meeting (see this presentation), the luminosity is enhanced due to the pinch effect.
- S. P. Griso raised another point: what is the extension of the luminous region? In other words, where are collision happening?
- I calculated the luminous region with and without beam effects. In all cases, the interactions will occur in the very close proximity of the IP.

Tiny luminous region: σ << 1 cm

Important hourglass effect: β depends on s

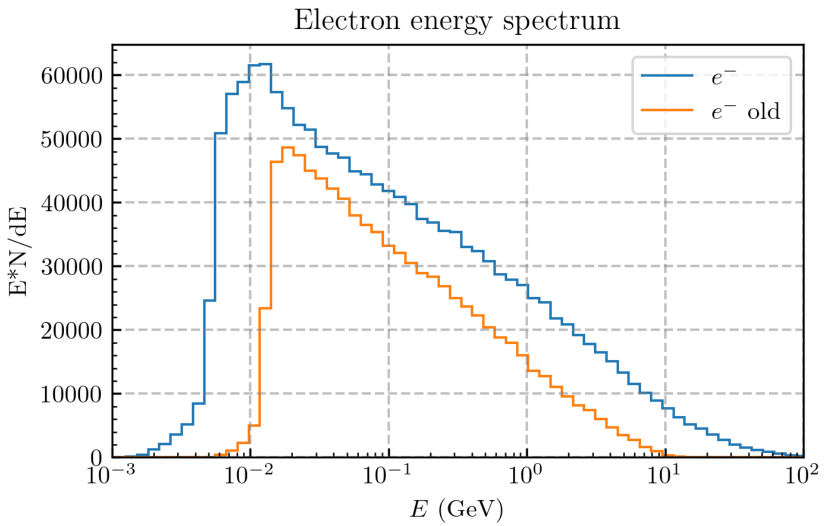






Incoherent pair production: new sample

- With Guinea-Pig, I produced a new incoherent pair production background sample.
- The new software version allows to fully simulate the interaction between muons, while in the past the interactions were simulating with a mass scaling of the electrons.
- With higher virtuality, pairs can have more kinetic energy



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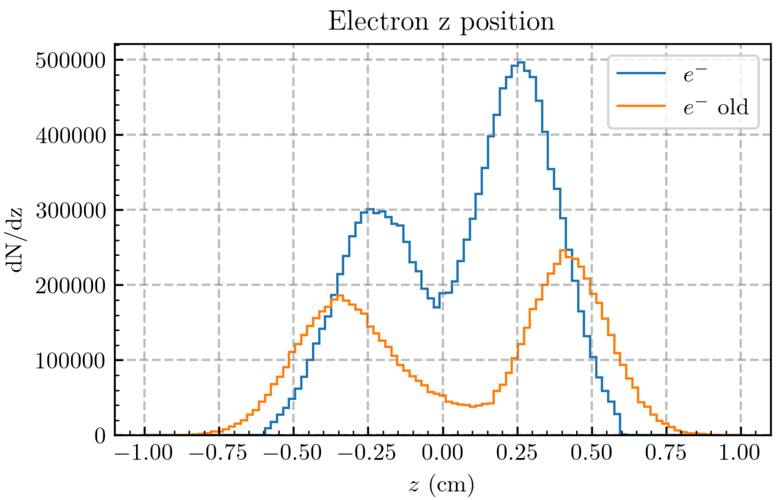
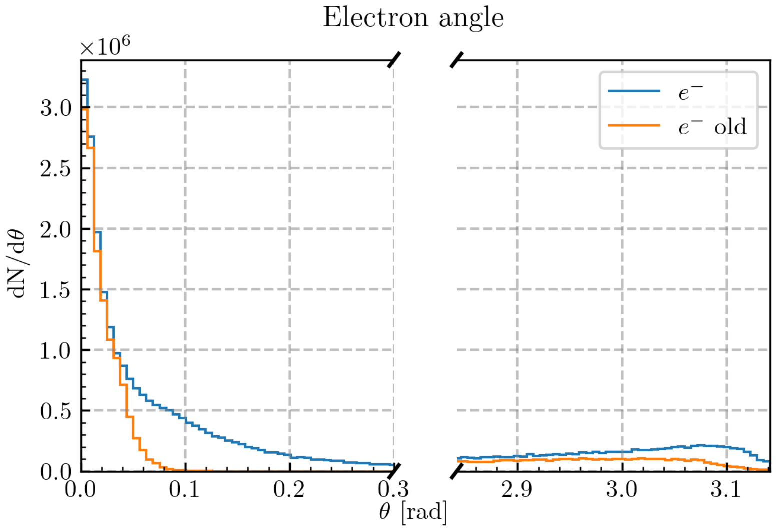
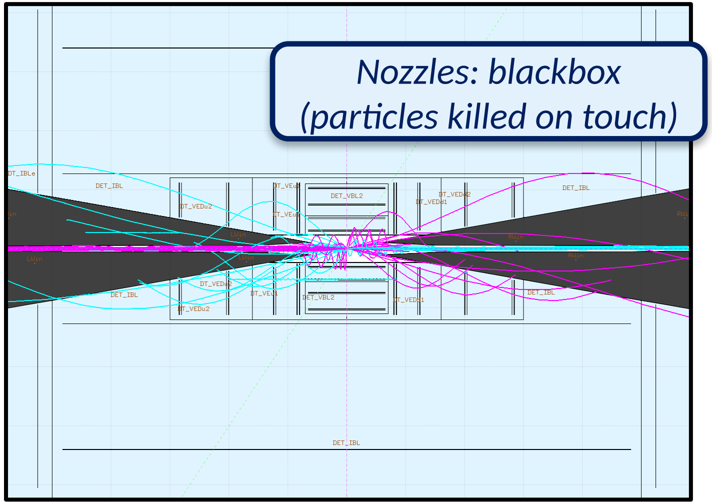
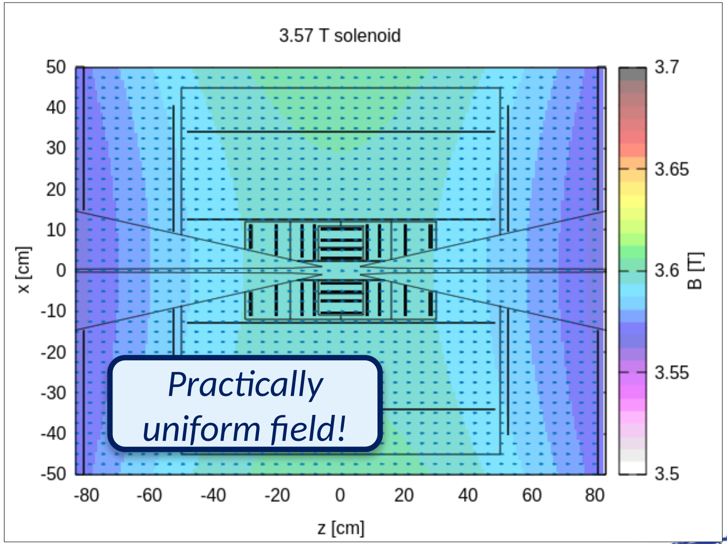




Incoherent pair production: fluences in trackers

- A large fraction of electron (positrons) are not intercepted by the nozzle, and will travel in the trackers without shielding.
- To calculate these fluences, I modeled the nozzle as a blackbox to observe only the "direct" fluences

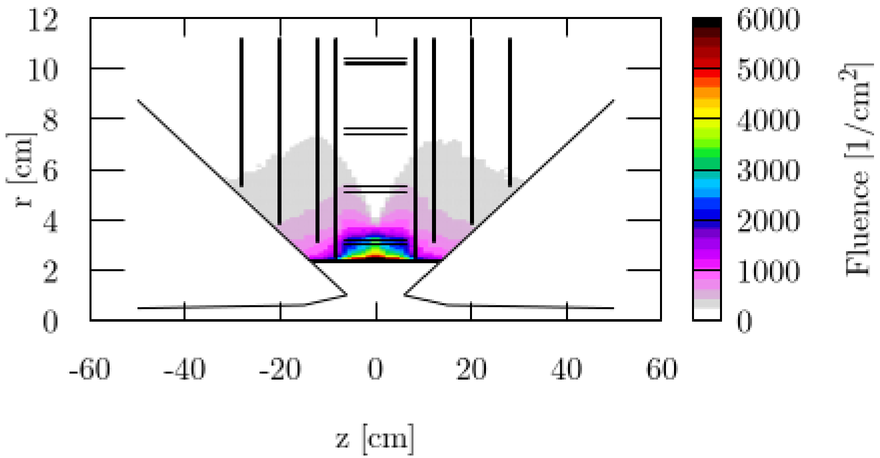




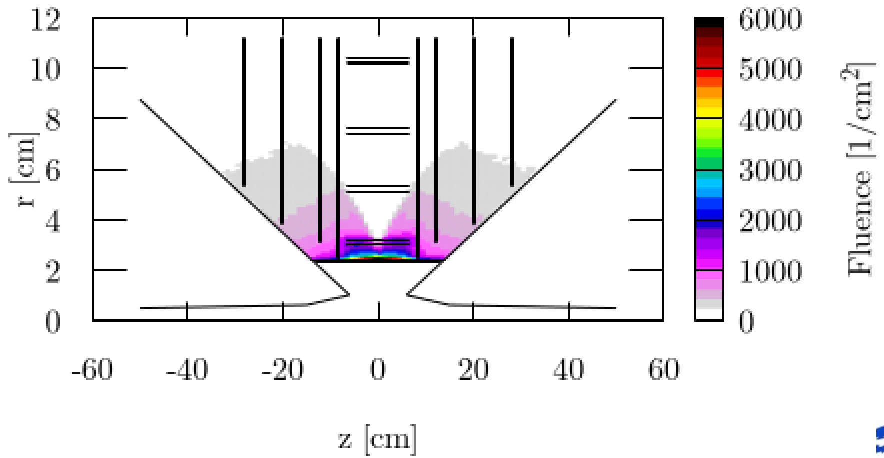
Incoherent pair production: fluences in trackers

- A large fraction of electron (positrons) are not intercepted by the nozzle, and will travel in the trackers without shielding.
- To calculate these fluences, I modeled the nozzle as a blackbox to observe only the "direct" fluences.
- With an higher field, the first double layer has a lower $e^{+/-}$ fluence and the second layer is spared

Electron/positron fluences with 3.57 T solenoid

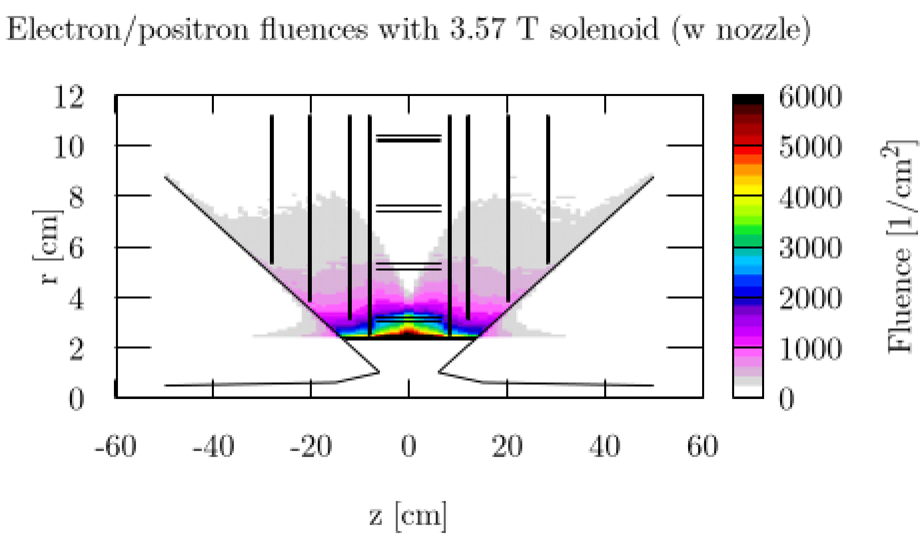


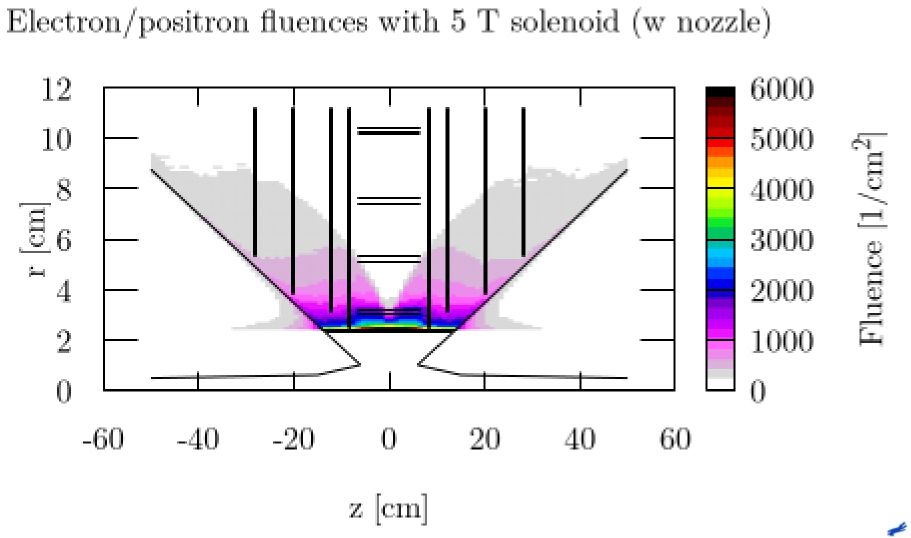
Electron/positron fluences with 5 T solenoid



Incoherent pair production: fluences in trackers

- When including the contribution of the interactions with the nozzles, there is an additional fluence of secondary particles.
- The contribution from these secondary particles is not a dominant factor in the overall background





Incoherent pair production: comparison fields

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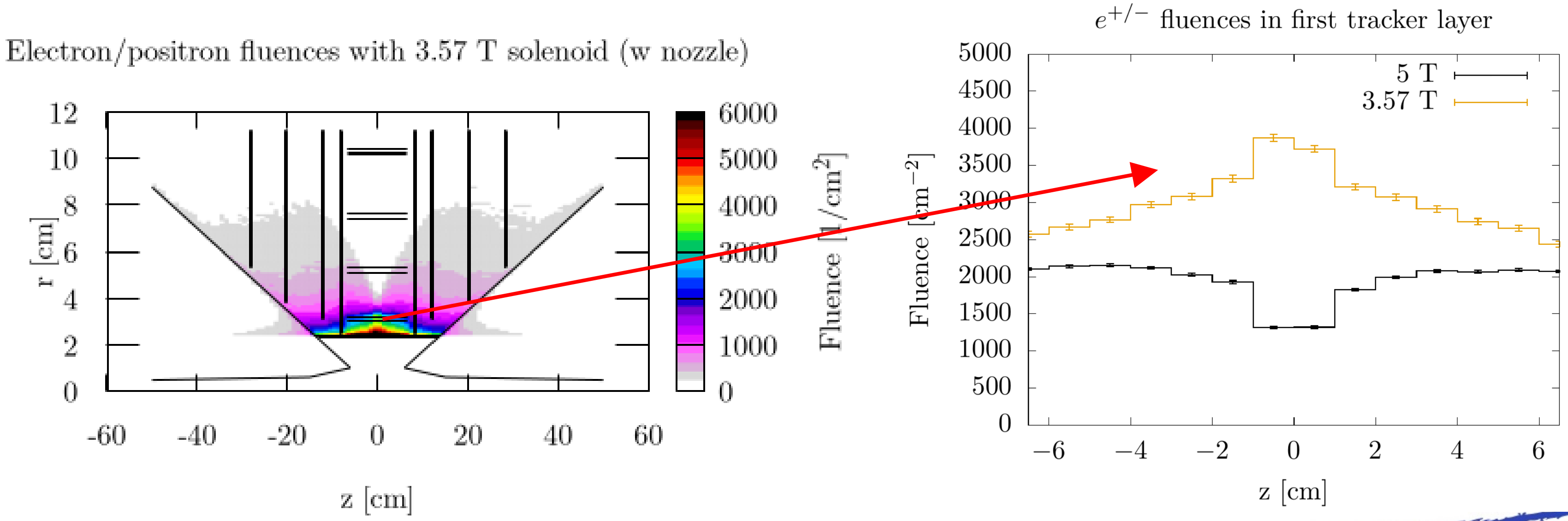
- The contribution from these secondary particles is not a dominant factor in the overall background



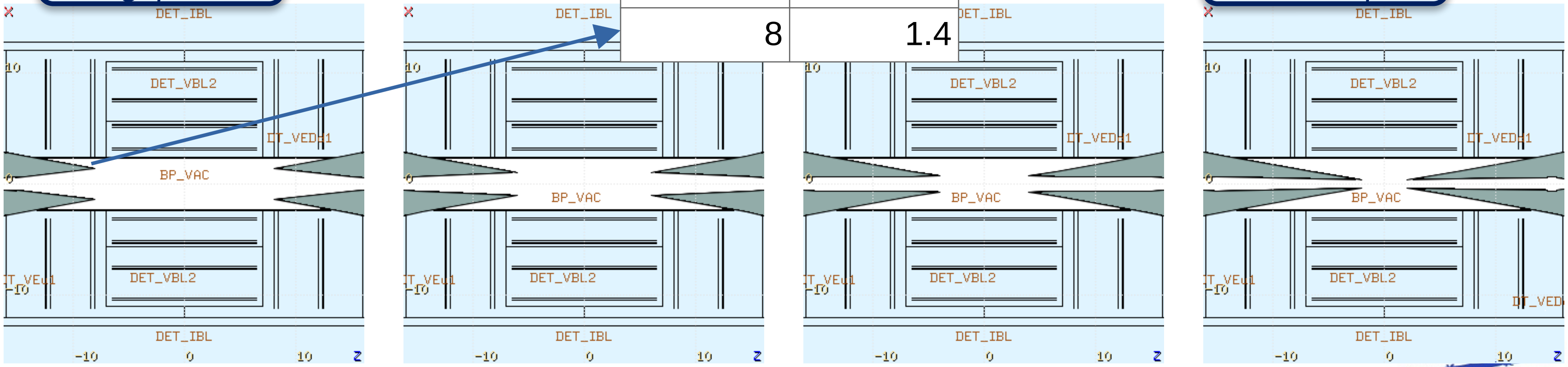
Decay background: nozzle tip influence

- To continue study the effect of the BIB on the first tracker layer, I simulated the fluence in case of different nozzle tip shapes

z [cm]	r [cm]
6	1
4	0.7
2	0.35
8	1.4

From large gap…

… to very close nozzle tips



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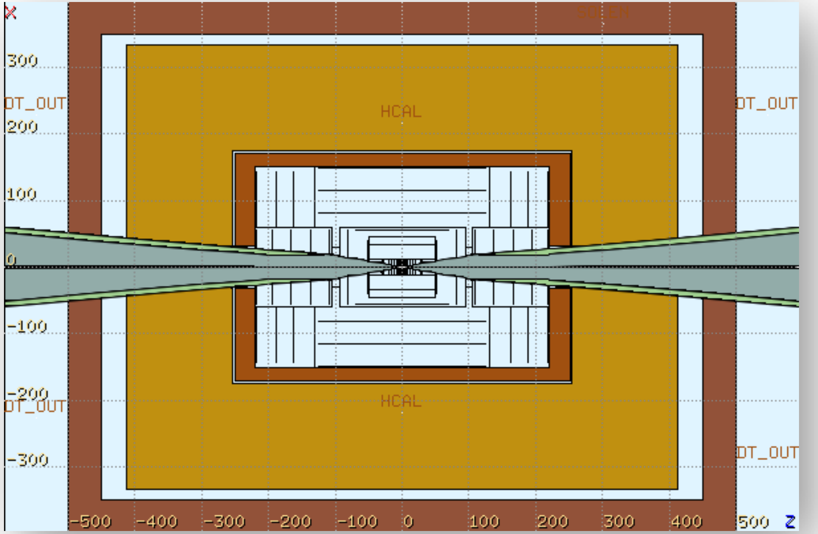
Decay background: nozzle tip influence

- To continue study the effect of the BIB on the first tracker layer, I simulated the fluence in case of different nozzle tip shapes.
- The geometry of the nozzle area is shown in figure. The only relevant parts are the nozzles and the trackers.
- No timecuts are applied (but can be done for future simulations)

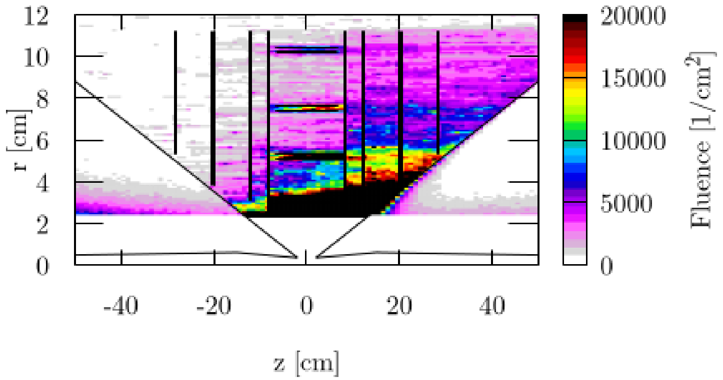


Number of original decays simulated	Total number of secondaries produced	Secondaries produced per decay	Expected number of decays	Expected number of secondaries to nozzle area
9.22E+04	2.85E+07	308.77	1.18E+07	3.64E+09

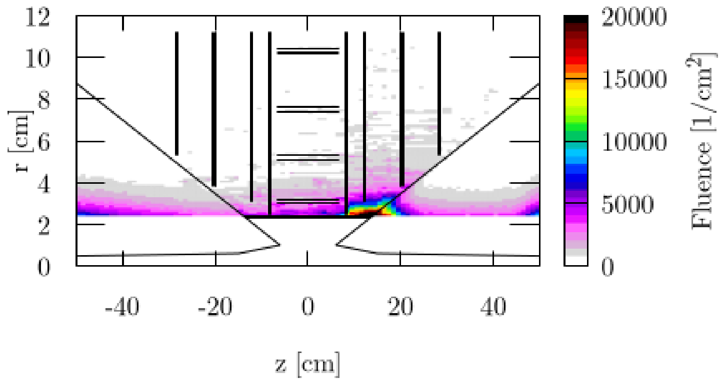
Decay background: nozzle tip influence

- Three possible configuration are shown
- For the 2 cm, the tip position cause a necking in the inner cone aperture. The results show that this should be avoided

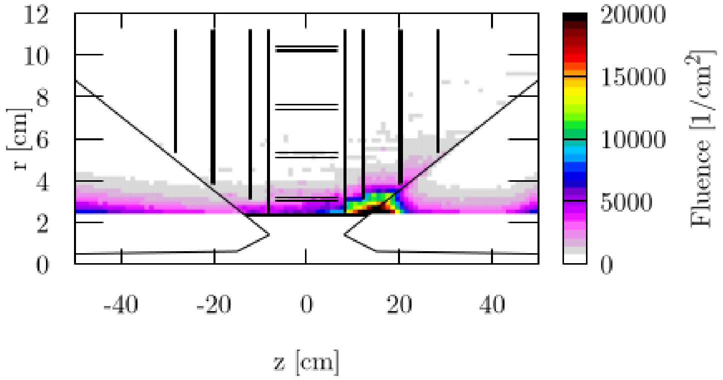
Fluence with nozzle tip at 2 cm



Fluence with nozzle tip at 6 cm



Fluence with nozzle tip at 8 cm



Decay background: nozzle tip influence

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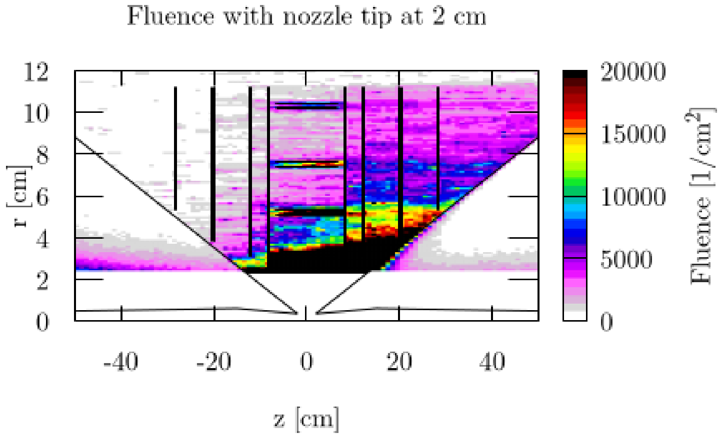
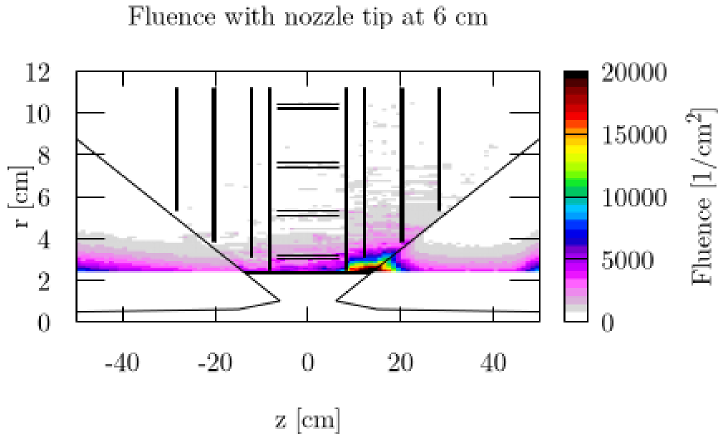
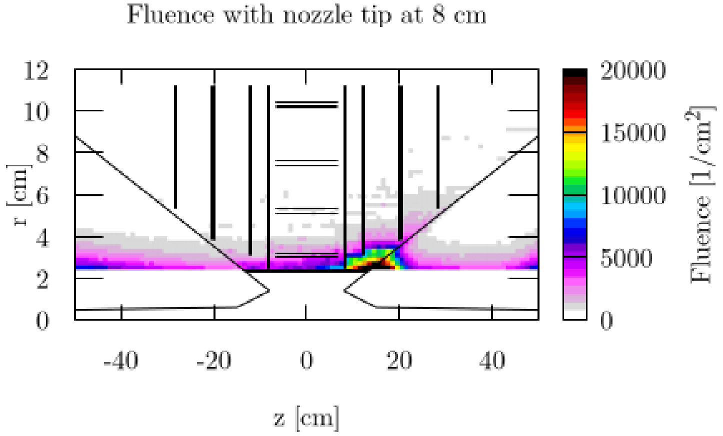
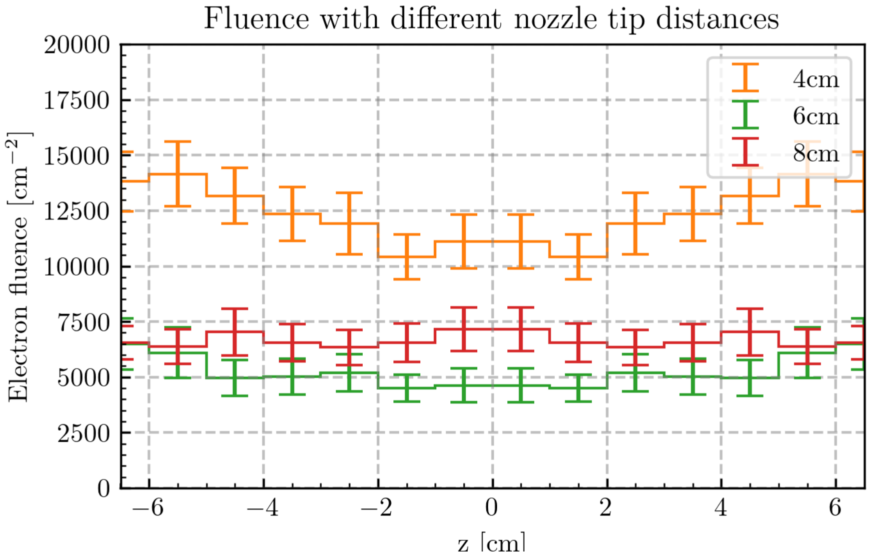


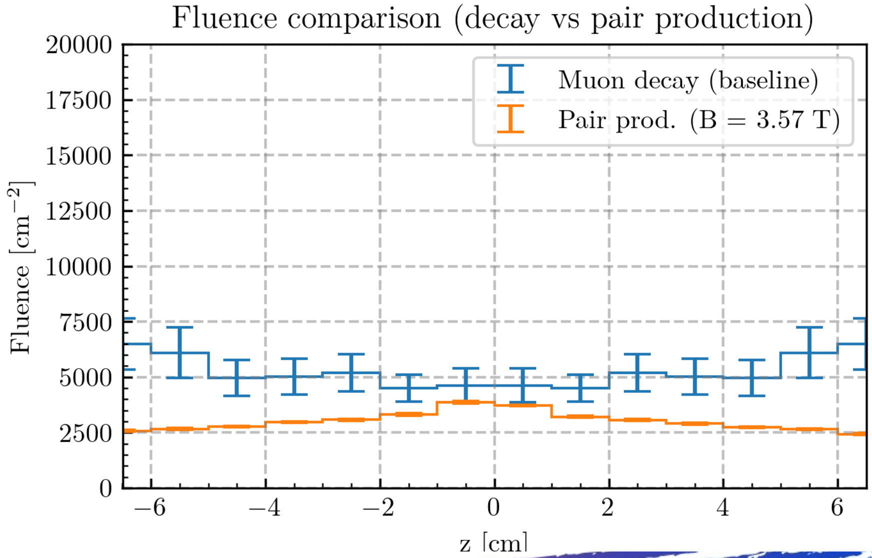




Decay background: nozzle tip influence

- The comparison between different nozzle tip position is shown. This time includes contribution from both beams.
- The results show better performances with larger gaps. This is advantageous also from the mechanical engineering perspective (larger relative tolerances)





Conclusions

- Guinea-pig software was used for the calculation of the luminous zone and the generation of the incoherent pairs.
- The **luminous zone** has very **small longitudinal size**. The real shape can be used for detector performance simulations to sample the "real" vertex position.
- **Incoherent pairs** with the new Guinea-pig version have **harder spectra and more abundant particle multiplicity**.
- **Solenoidal field intensity has an influence in the $e^{+/-}$ fluences**. Using a realistic magnetic field map is not strictly required for simulation within the tracker region.
- The **nozzle tip** has a strong influence on the electron fluences in the first tracker layers. A distance of **4 cm or more is required** to avoid EM showers reaching the detectors from the nozzle tip.

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Thank you
for your attention!

Workflow in the IMCC

Machine-Detector Interface: MDI

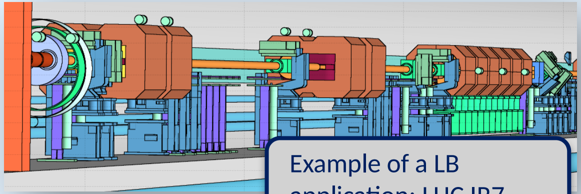
1. Lattice design

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

Iteration with lattice design experts to mitigate the BIB

BIB data to detector experts

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