International MUON Collider Collaboration

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Machine-detector interface and beam-induced background studies for a 10 TeV muon collider

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On behalf of the IMCC

Funded by the European Union

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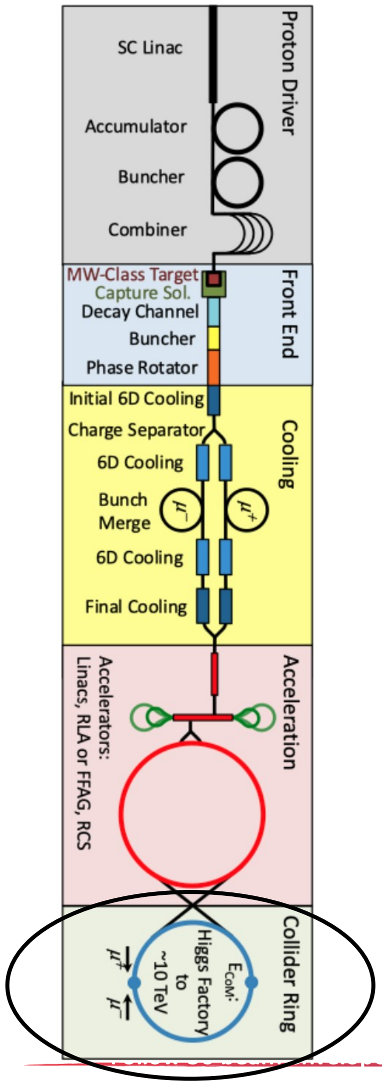
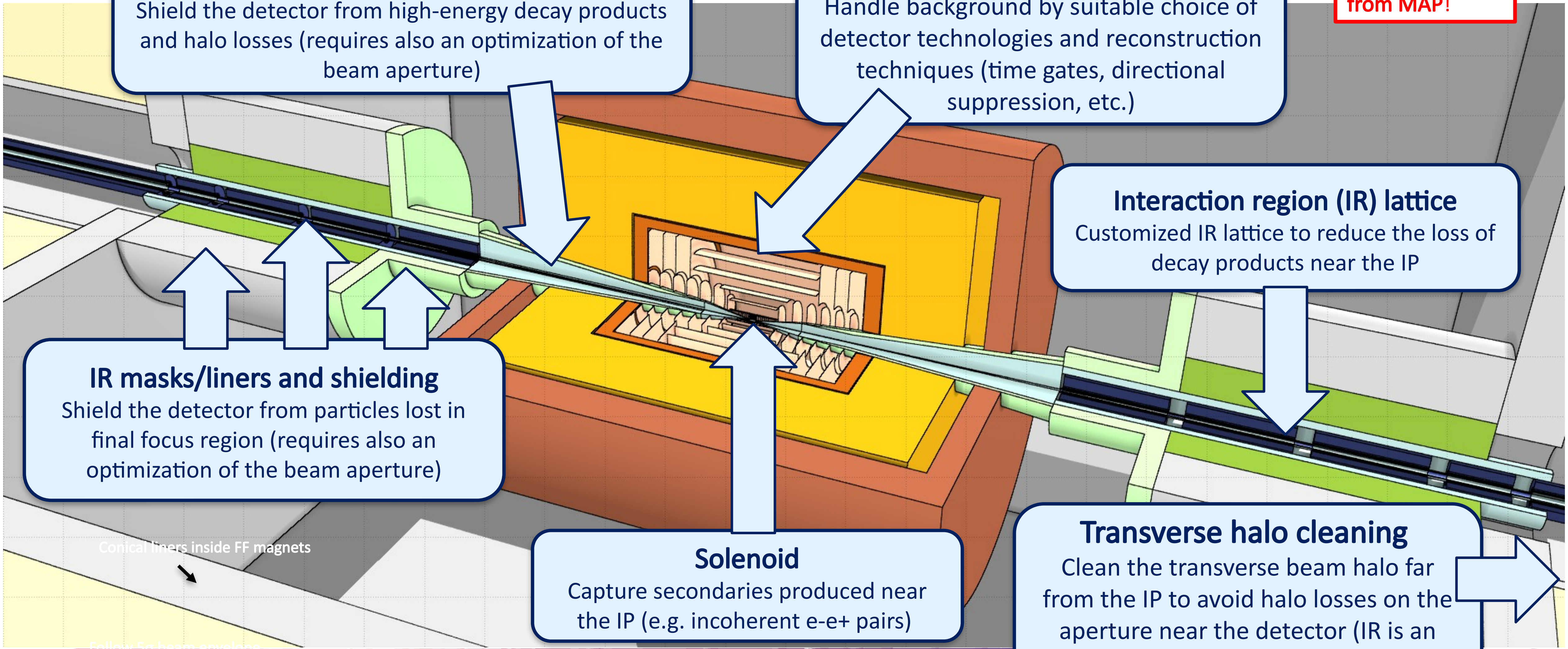
Outline



- **MDI overview**
- **Beam induced background sources**
- **Current existing lattices**
- **Simulation approach for decay-induced background**
- **Comment on the last lattices:**
  - v 0.7: chicane with a residual angle
  - v 0.8: no residual angle, lower dipole strength
- **A tentative nozzle proposal** (based on studies with lattice version v 0.7)
- **Incoherent pair production background in the trackers**

Machine-detector interface

Many concepts from MAP!



Conical absorber inside detector (nozzle)
Shield the detector from high-energy decay products and halo losses (requires also an optimization of the beam aperture)

Detector
Handle background by suitable choice of detector technologies and reconstruction techniques (time gates, directional suppression, etc.)

Interaction region (IR) lattice
Customized IR lattice to reduce the loss of decay products near the IP

IR masks/liners and shielding
Shield the detector from particles lost in final focus region (requires also an optimization of the beam aperture)

Solenoid
Capture secondaries produced near the IP (e.g. incoherent e-e+ pairs)

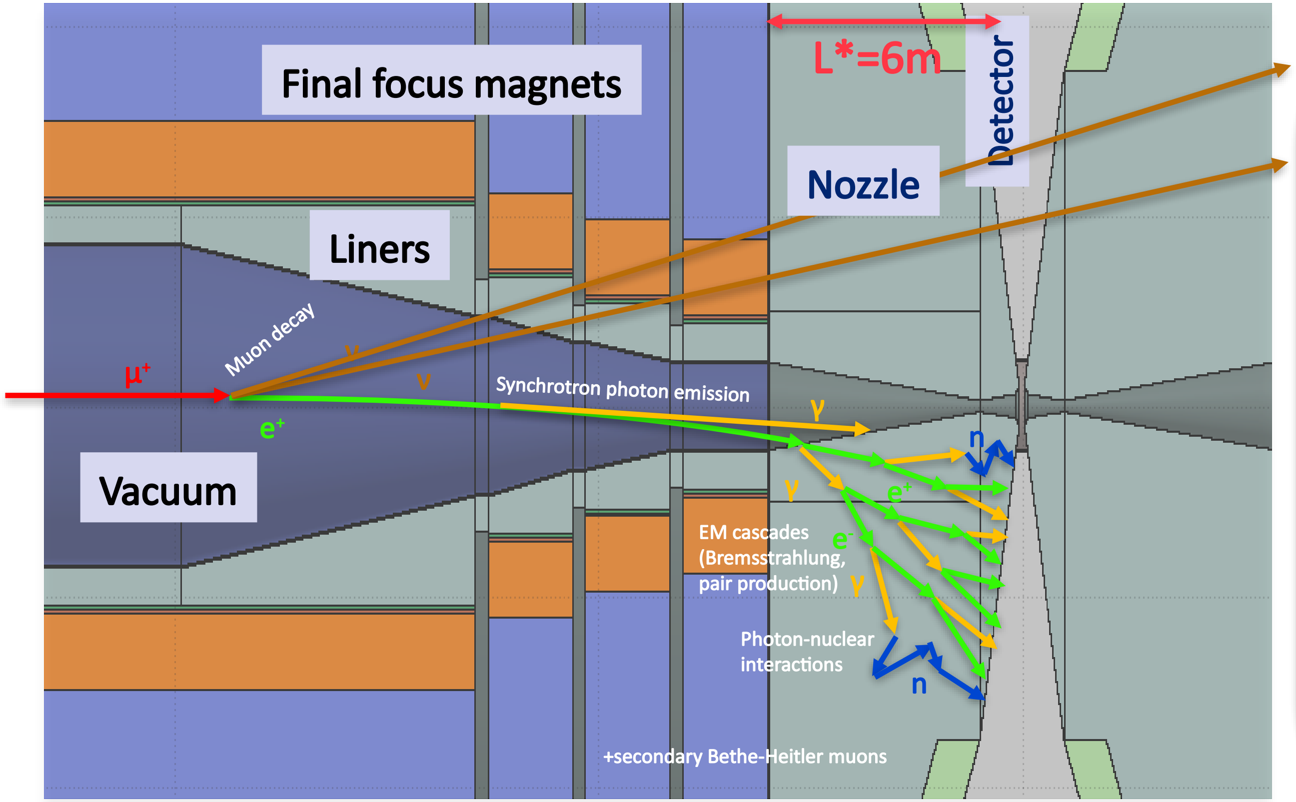
Transverse halo cleaning
Clean the transverse beam halo far from the IP to avoid halo losses on the aperture near the detector (IR is an aperture bottleneck)

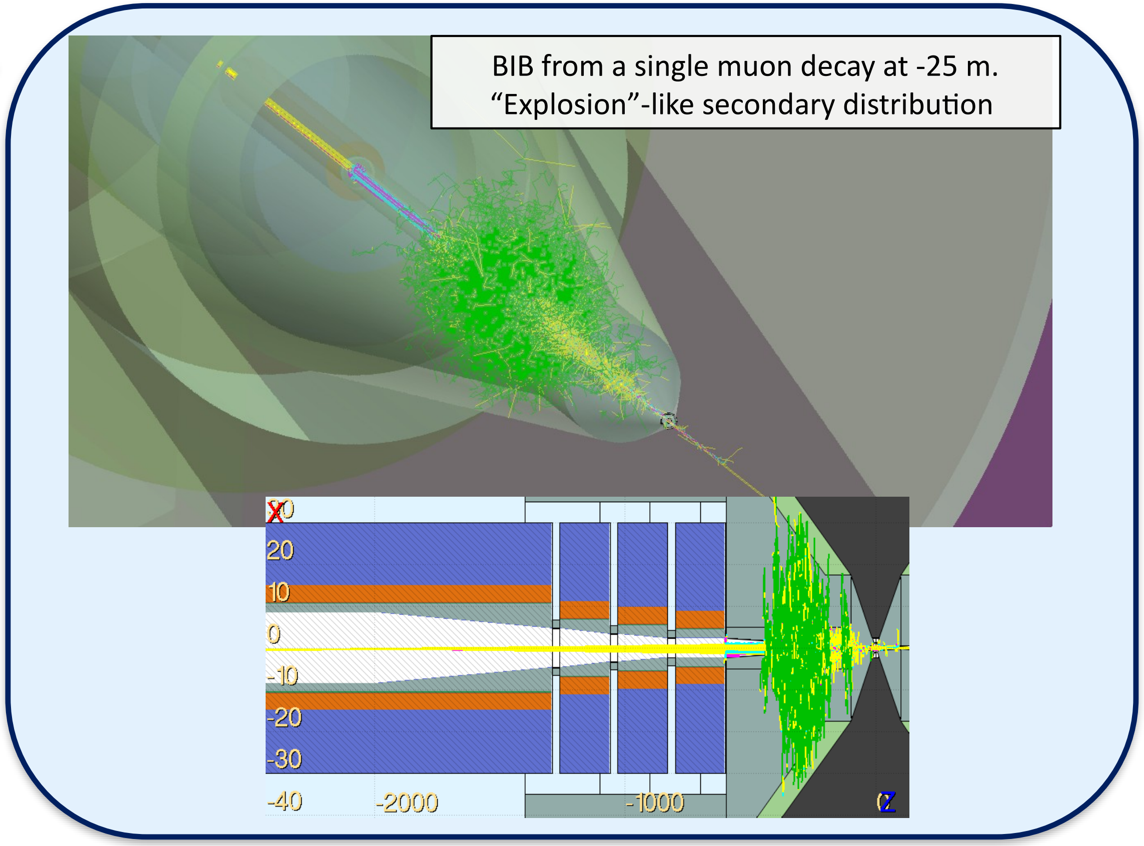
Beam-induced background

	Description	Relevance as background
Muon decay	**Decay of stored muons around the collider ring**	**Dominating source**
Synchrotron radiation by stored muons	Synchrotron radiation emission by the beams in magnets near the IP (including IR quads → large transverse beam tails)	**Small**
Muon beam losses on the aperture	Halo losses on the machine aperture, can have multiple sources, e.g.: • Beam instabilities • Machine imperfections (e.g. magnet misalignment) • Elastic (Bhabha) μμ scattering • Beam-gas scattering (Coulomb scattering or Bremsstrahlung emission) • Beamstrahlung (deflection of muon in field of opposite bunch)	**Can be significant** (although some of the listed source terms are expected to yield a small contribution like elastic μμ scattering, beam-gas, Beamstrahlung)
Coherent e^-e^+ pair production	Pair creation by real* or virtual photons of the field of the counter-rotating bunch	**Expected to be small** (but should nevertheless be quantified)
Incoherent e^-e^+ pair production	Pair creation through the collision of two real* or virtual photons emitted by muons of counter-rotating bunches	**Significant**

Decay-induced background

	Description	Relevance as background
Muon decay	Decay of stored muons around the collider ring	Dominating source

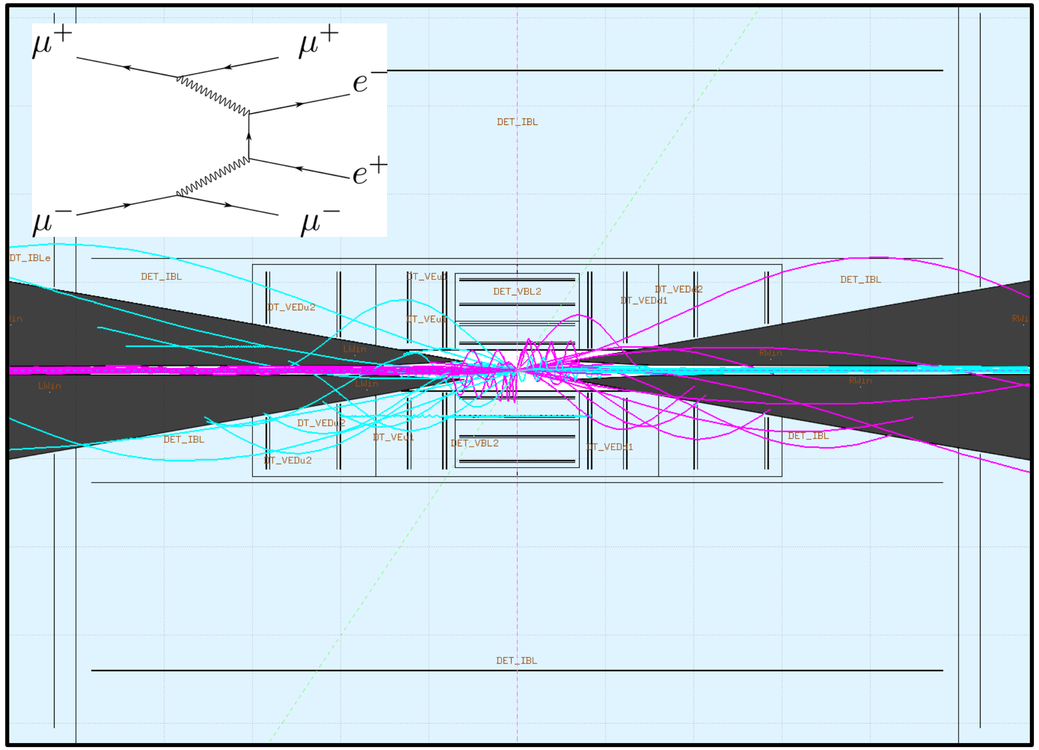




Incoherent pair production

	Description	Relevance as background
Incoherent e^-e^+ pair production	Pair creation through the collision of two real* or virtual photons emitted by muons of counter-rotating bunches	Significant

- High energy → non negligible beam-beam effects. The most important phenomenon is due to the **incoherent beam-beam pair production μ+μ- →μ+μ-e+e-**.
  - The incoherent pair production e^+/e^- are provided by D. Schulte and are obtained by a **Guinea-Pig simulation**
- Low total particle multiplicity.
- ...**but** the produced **electrons are energetic** and they **impact** directly on the **detectors**, since are generated in the IP



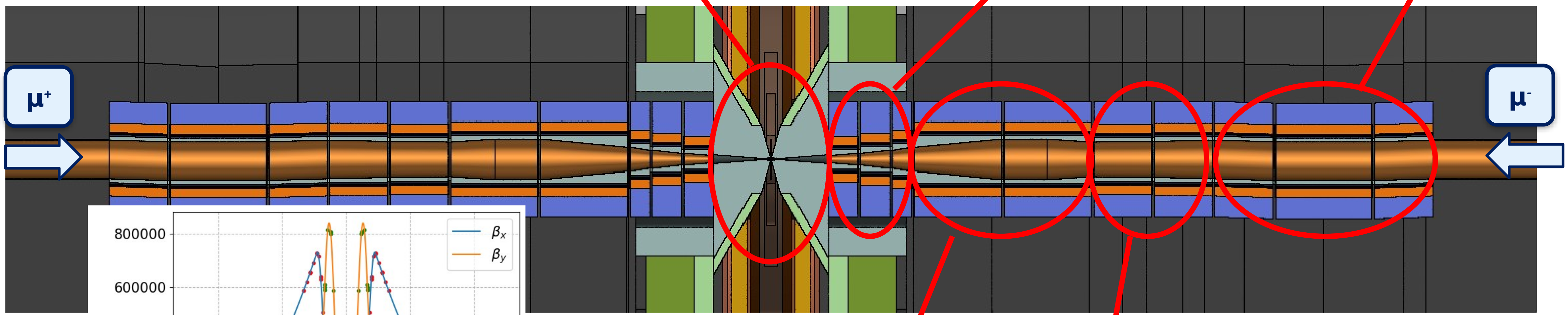
Final focus optics

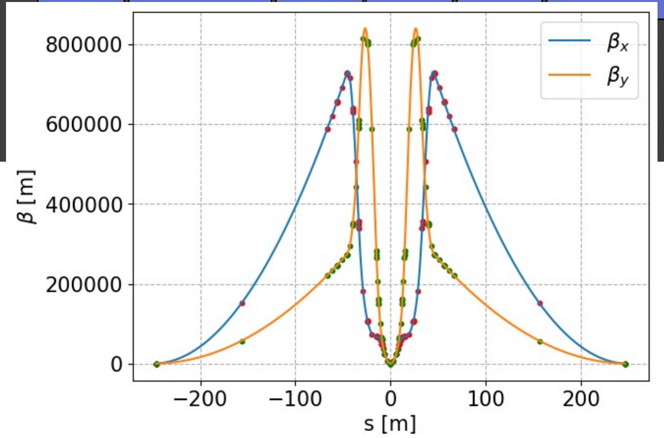
Overview of the lattice version 0.8. The novel approach does not leave a residual angle and does not require combined function magnets

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

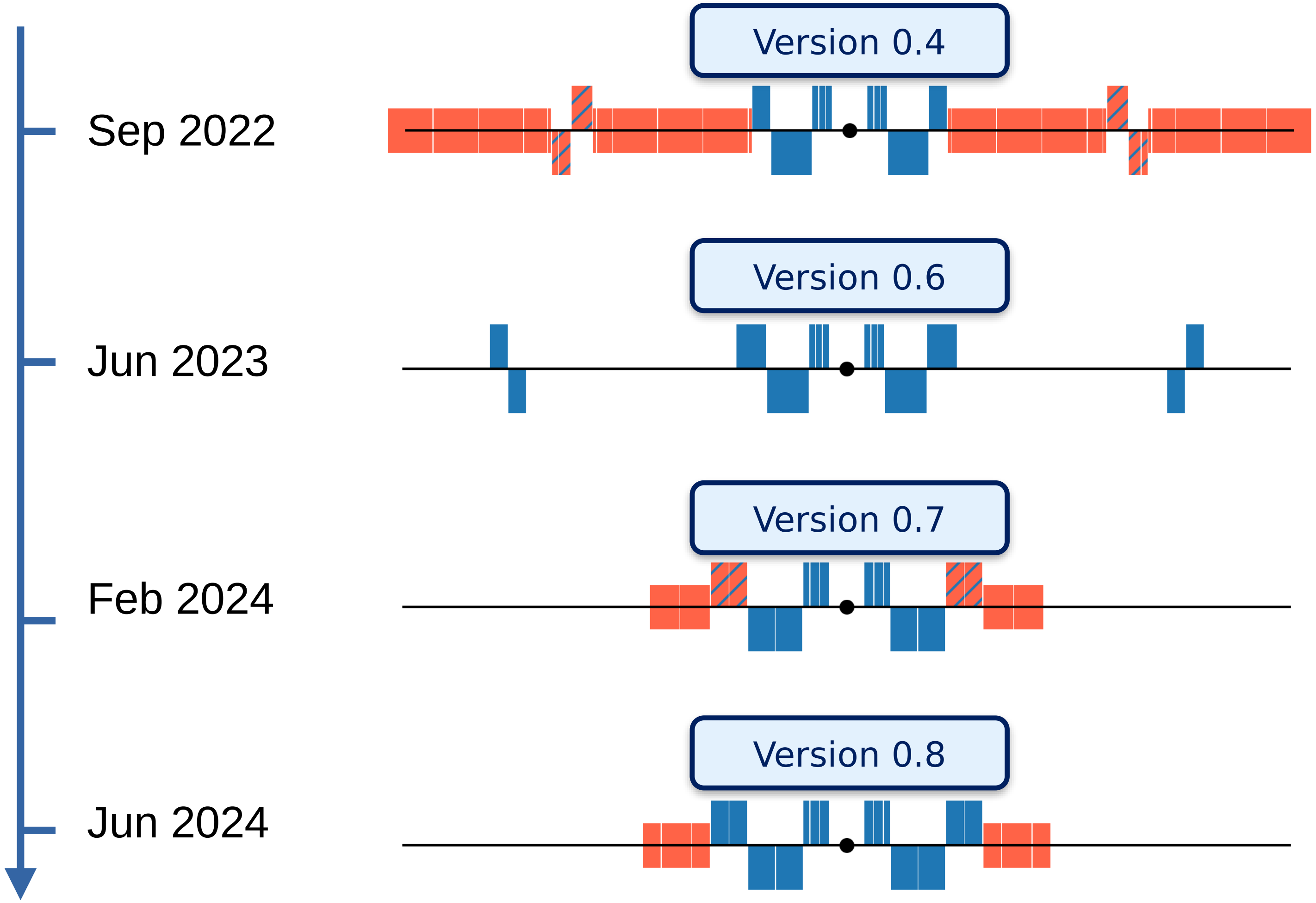




Q2
Two defocusing quadrupoles. Here the beam aperture reaches its maximum

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)

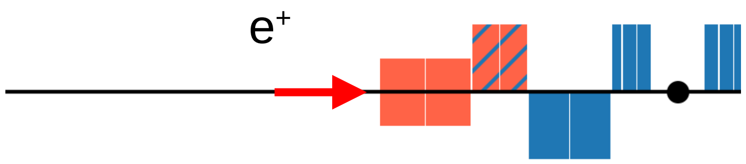
All the muon decays in ~200 meters from the IP give a non negligible contribution to the BIB

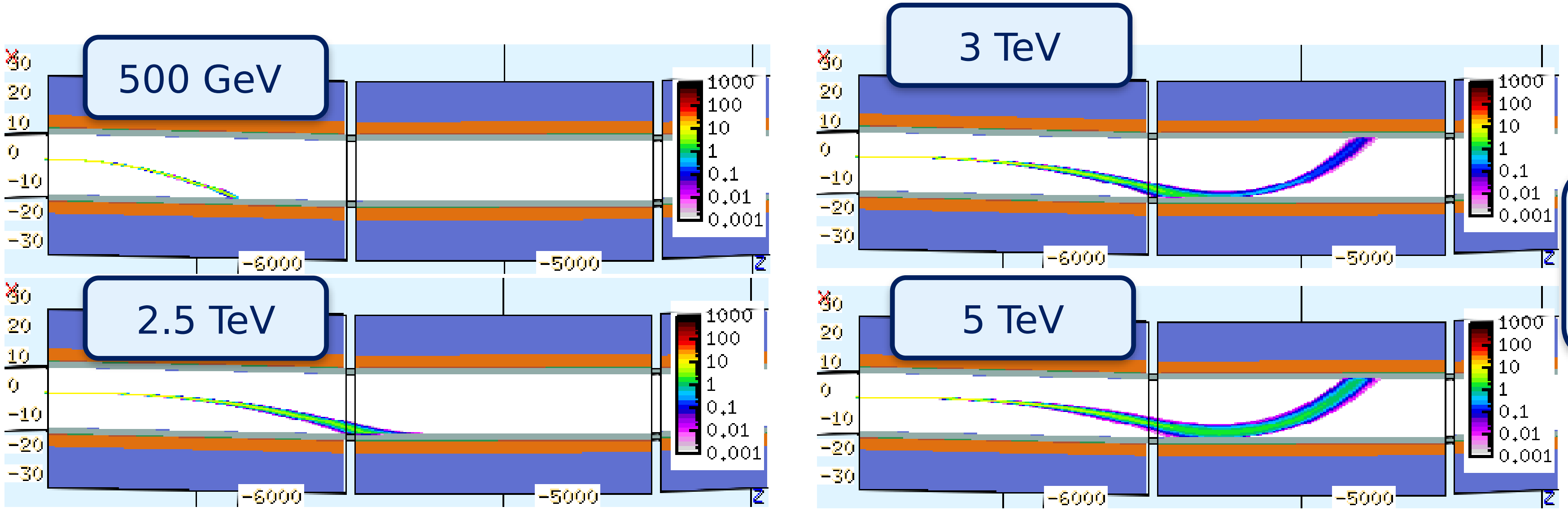
A chicane is added to partially clean the line from the secondary electrons before they reach the nozzle

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

Chicane effect (v 0.7 and 0.8)

- Considering a pencil beam positrons along the ideal trajectory, the path in the first two magnets is reported.
- Two hotspots are generated in the first and second magnets





Synchrotron radiation is a dominant effect!

Simulation strategy

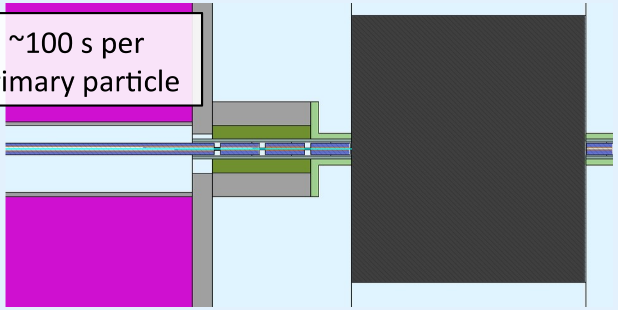
- Simulating all the processes from the muon decay to the background entering in the detector area is **expensive**.
- Another more useful strategy is to adopt a 2 step simulation: all the particles are simulated in the line, and reloaded for the nozzle and detector simulations

1 μ decay

1. From muon decay to nozzle area

Machine dependent

~100 s per primary particle

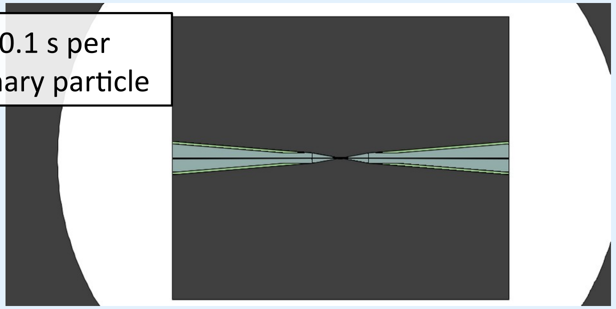


~300 secondaries to nozzle

2. Nozzle area to detectors

Nozzle dependend

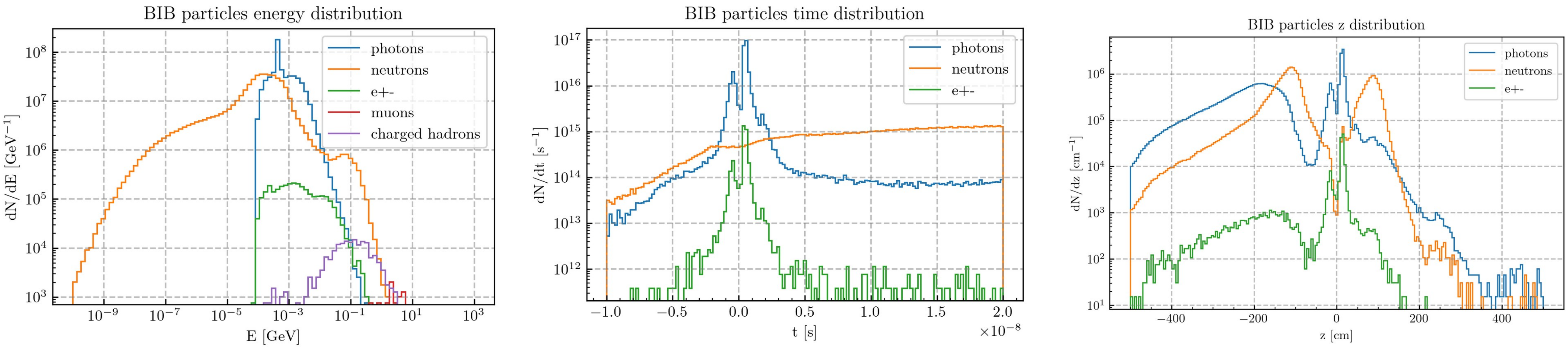
~0.1 s per primary particle



~20 BIB particles to det

BIB with lattice version 0.8

- The results are perfectly in line with the past studies
- The shapes of the energy, time and spatial distribution are partially affected by the lattice, but the nozzle has a dominant effect



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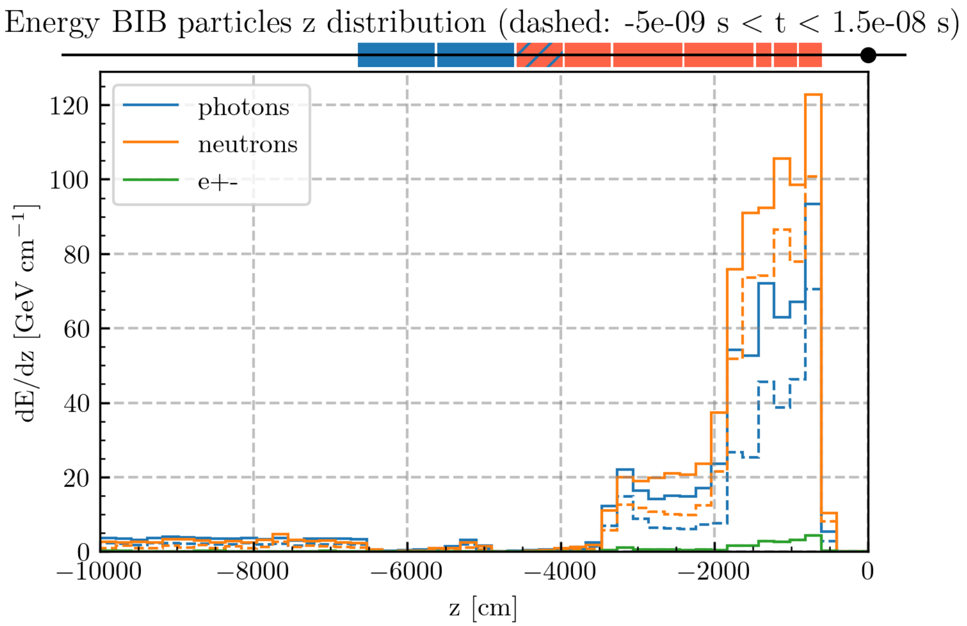
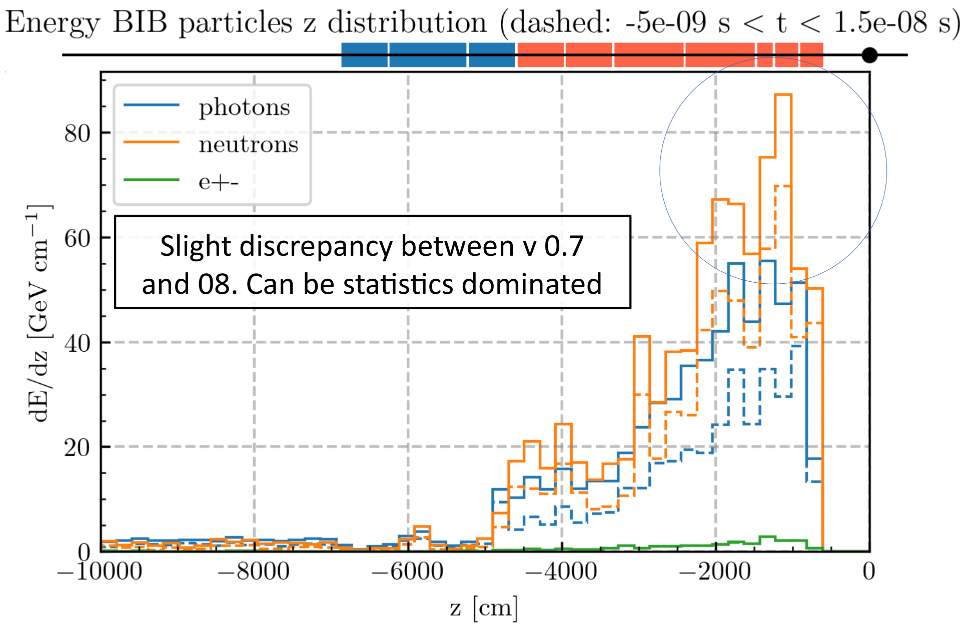


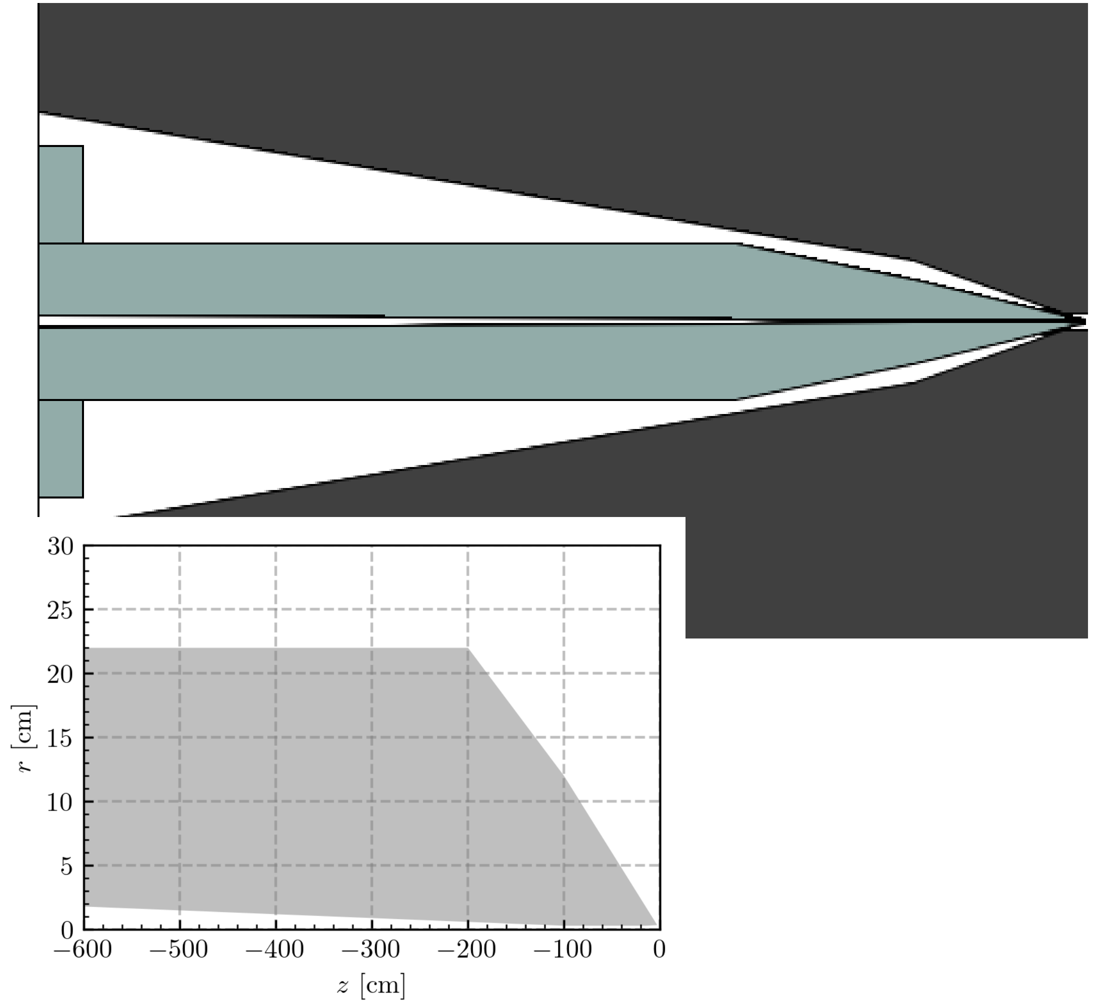


Comparison lattices

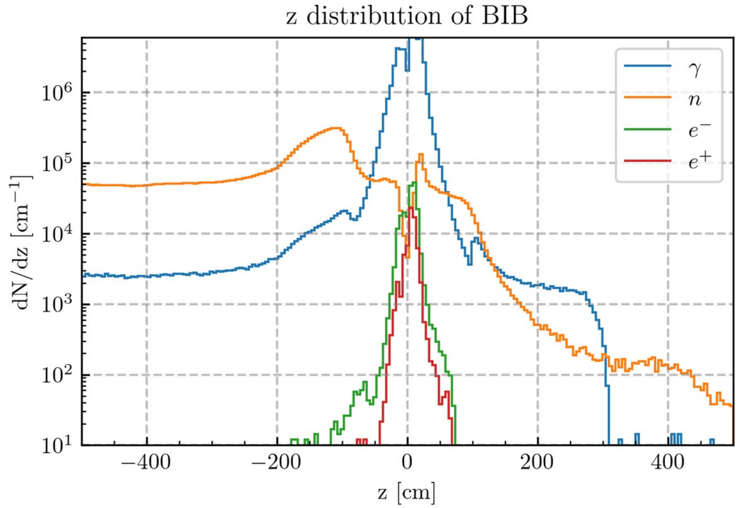
- All different lattices offer consistent performances at 10 TeV. More advanced metrics than the total particle multiplicity should be used

Collider energy	1.5 TeV	3 TeV	10 TeV (v 0.4)	10 TeV (v 0.7)	10 TeV (v 0.8)
Photons	7.1E+7	9.6E+7	9.6E+7	1.6E+8	1.6E+8
Neutron	4.7E+7	5.8E+7	9.2E+7	1.5E+8	1.4E+8
e^+/e^-	7.1E+5	9.3E+5	8.3E+5	9.2E+5	8.9E+5
Ch. hadrons	1.7E+4	2.0E+4	3.0E+4	4.9E+4	5.2E+4
Muons	3.1E+3	3.3E+3	2.9E+3	5.0E+3	3.3E+3

Nozzle optimization tentatives (v 0.4)

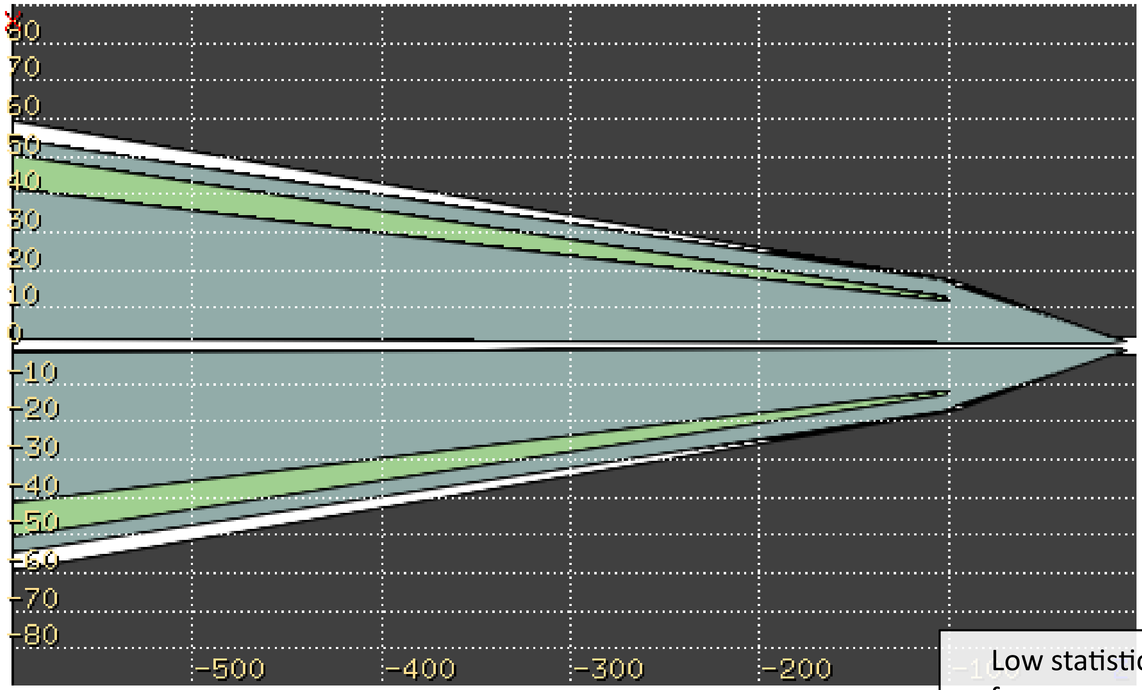


- Simple “thin” nozzle. Easier to manufacture and to insert in detectors.
- Neutron absorber not yet included
- BIB still unsatisfactory (background increases of a factor 3)



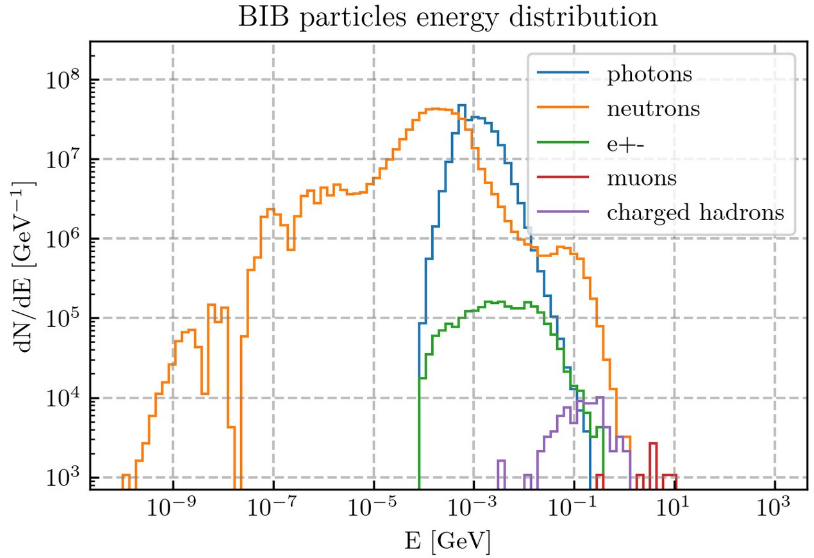
Possible nozzle: MAP like (v 0.7)

- MAP-like nozzle. Internal angles and profile kept (following 5 sigma of the beam profile)
- Reduced external size (possibly reduce it even more far away from IP)
- Additional layer of borated poly to reduce high multiplicity, low energy gammas



Low statistics: unreliable counts for muons and charged hadrons

	photons	neutrons	e+-	muons	charged hadrons
new	8.0E+07	1.5E+08	7.2E+05	3.9E+03	2.4E+04
original	1.6E+08	1.5E+08	9.2E+05	5.0E+03	4.9E+04

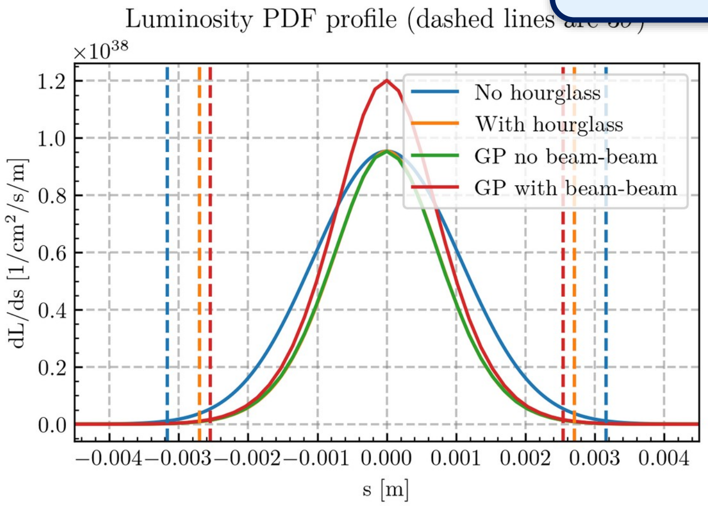


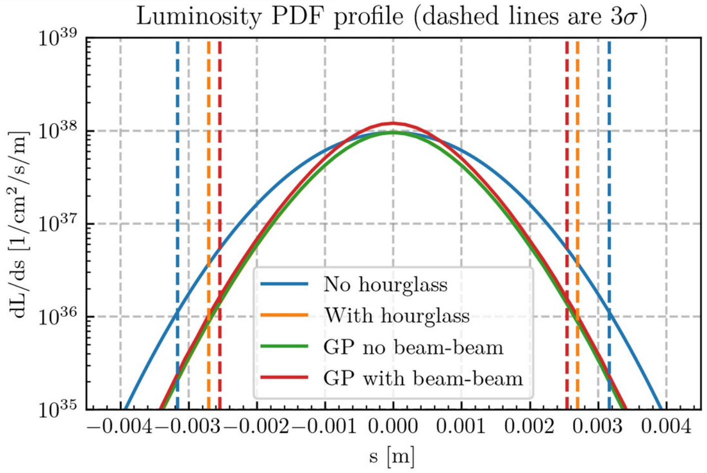
Beam profile in the IP

- As shown during the annual meeting (see this presentation), the luminosity is enhanced due to the pinch effect.
- Question during annual meeting 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.

Important hourglass effect: β depends on s

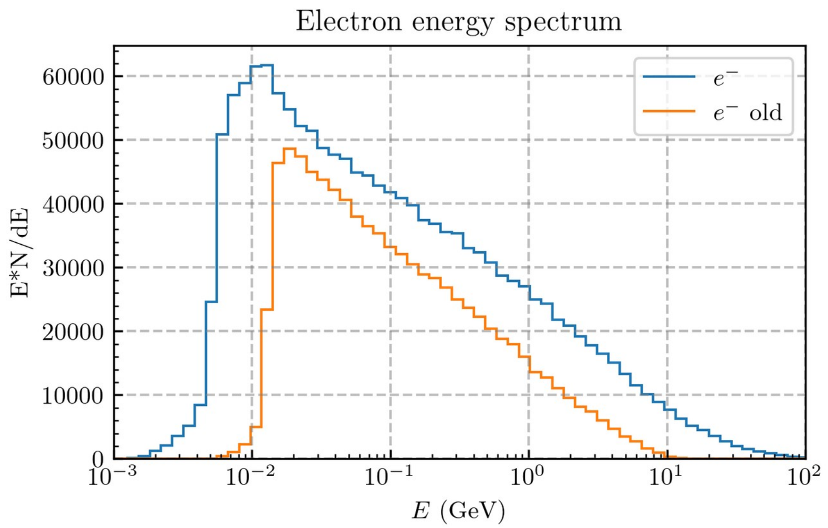
Tiny luminous region: σ << 1 cm

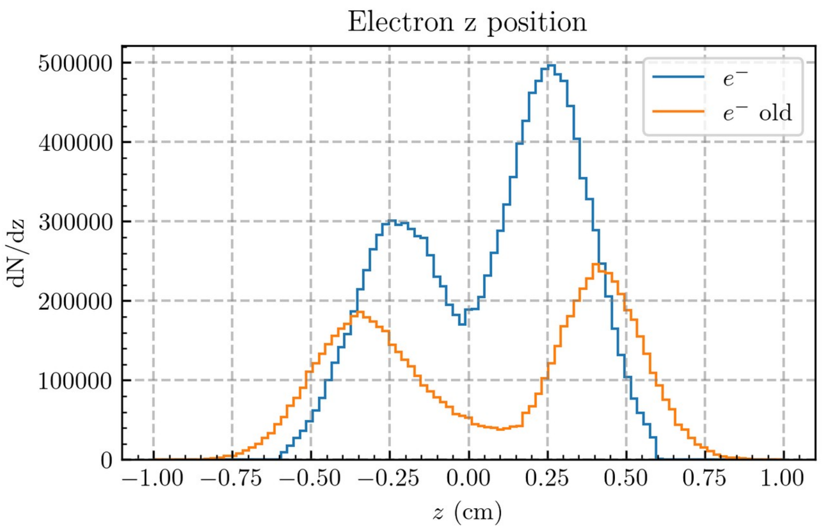


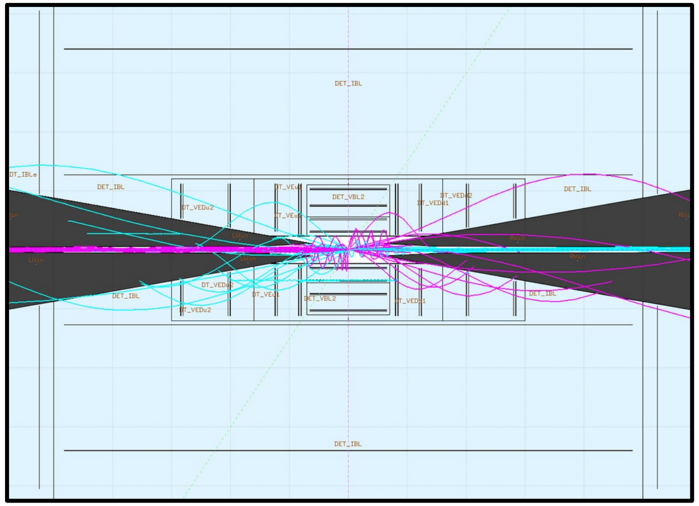


Incoherent pair production background: sample

- 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

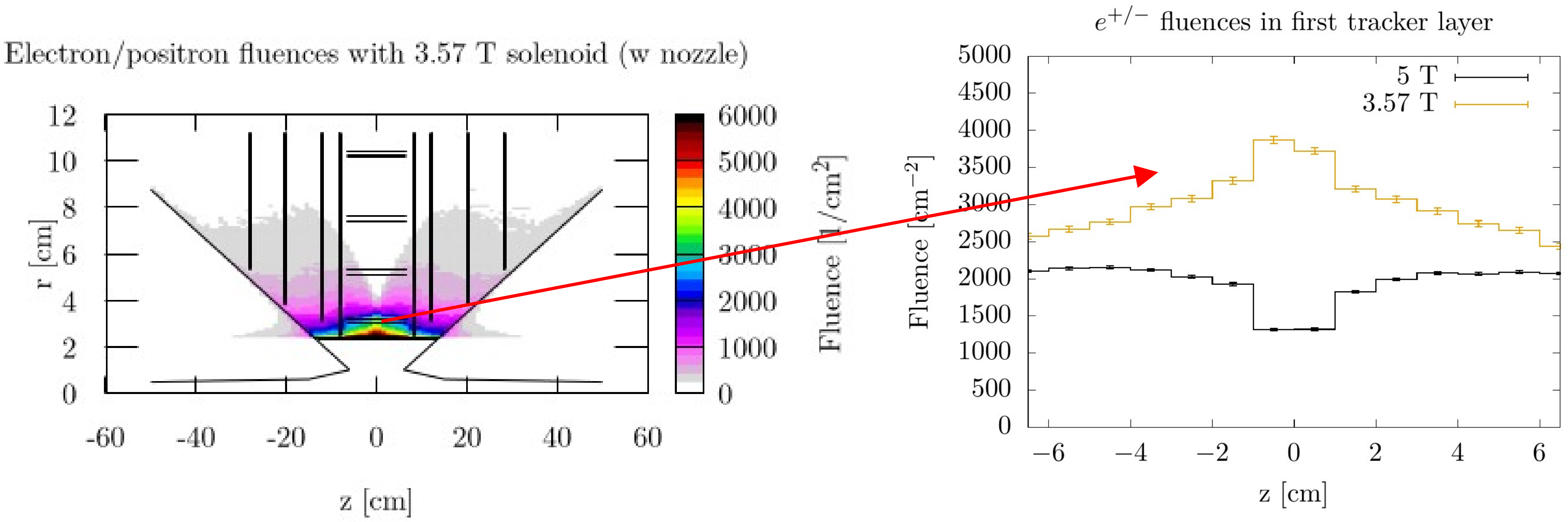






Incoherent pair production background: background

- 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, **but plays a major role in the innermost tracker layers.**



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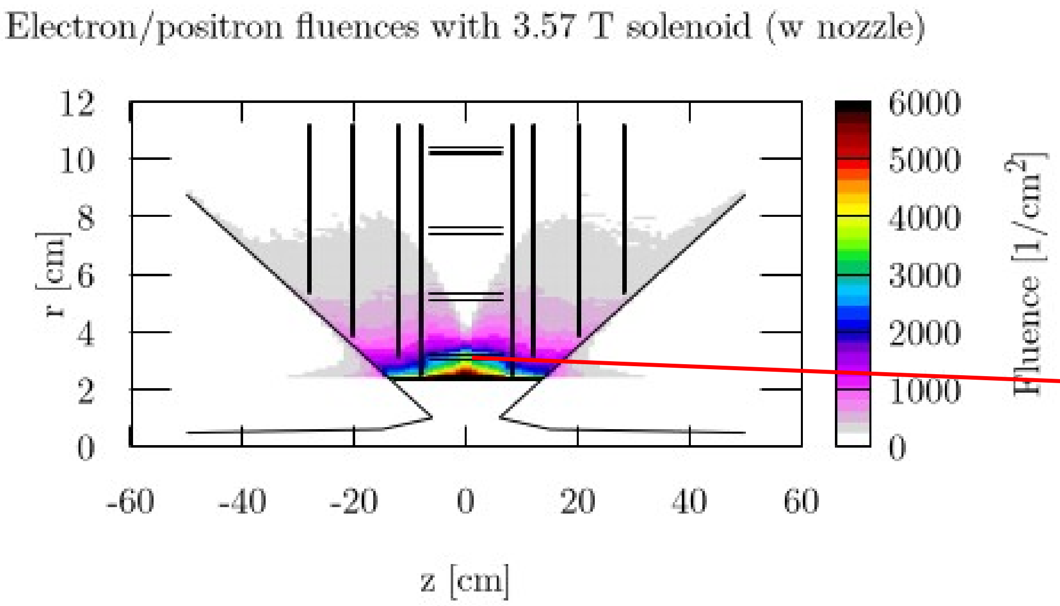

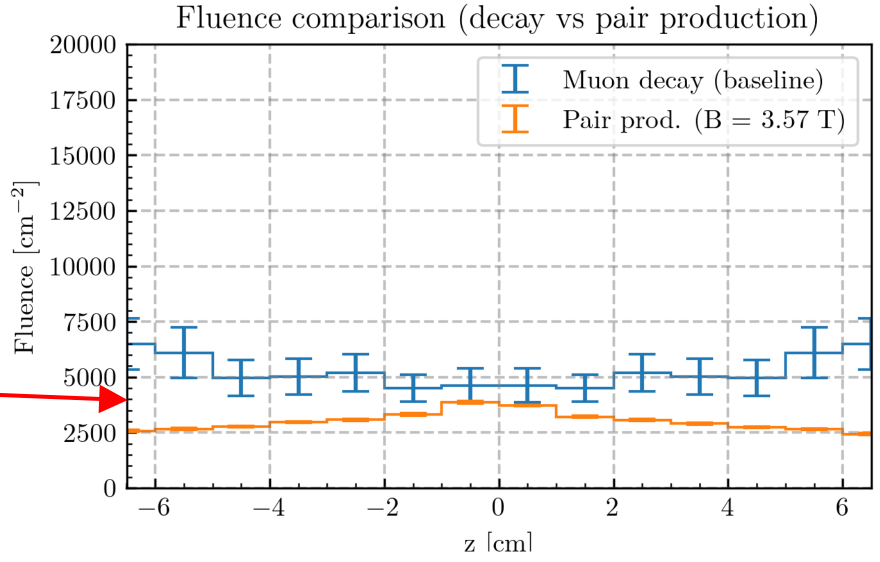

Conclusions

- Beam induced background assessed in various lattice configurations:
  1) **Version 0.4**: validated and used by colleagues in detector reconstruction studies
  2) ...**to version 0.8**: latest lattice version
- Across different lattices the **background** got **worse** after the introduction of a **straight section**.
- Different nozzle options explored: a **“thin” nozzle** would increase the BIB of a factor 3.
- A **MAP like nozzle** with better neutron absorber placement can mitigate all low energy gammas produced in the neutron absorption.
- **Pair production** background has been assessed. Despite the low counts, those electrons might impede with the **innermost tracker layers**.

Thank you

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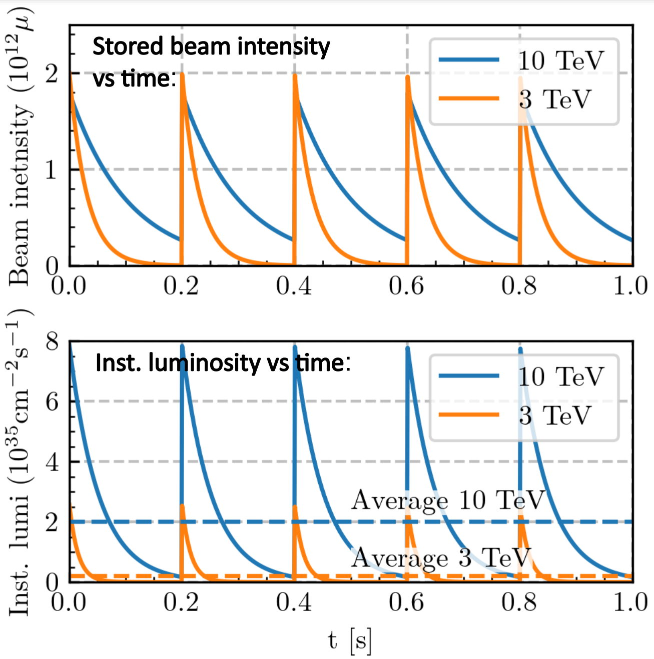
Recap collider parameters

	=3 TeV	=10 TeV
Beam parameters		
Muon energy	1.5 TeV	5 TeV
Bunches/beam	1	
Bunch intensity (at injection)	2.2×10^{12}	1.8×10^{12}
Norm. transverse emittance	25 µm	
Repetition rate (inj. rate)	5 Hz	
Collider ring specs		
Circumference	4.5 km	10 km
Revolution time	15.0 µs	33.4 µs
Luminosity		
Target integrated luminosity	1 ab^{-1}	10 ab^{-1}
Average instantaneous luminosity (5/10 yrs of op.)	2×10^{34} $cm^{-2}s^{-1}$ / 1×10^{34} $cm^{-2}s^{-1}$	2×10^{35} $cm^{-2}s^{-1}$ / 1×10^{35} $cm^{-2}s^{-1}$

$\tau = 2.2\times10^{-6}$ s

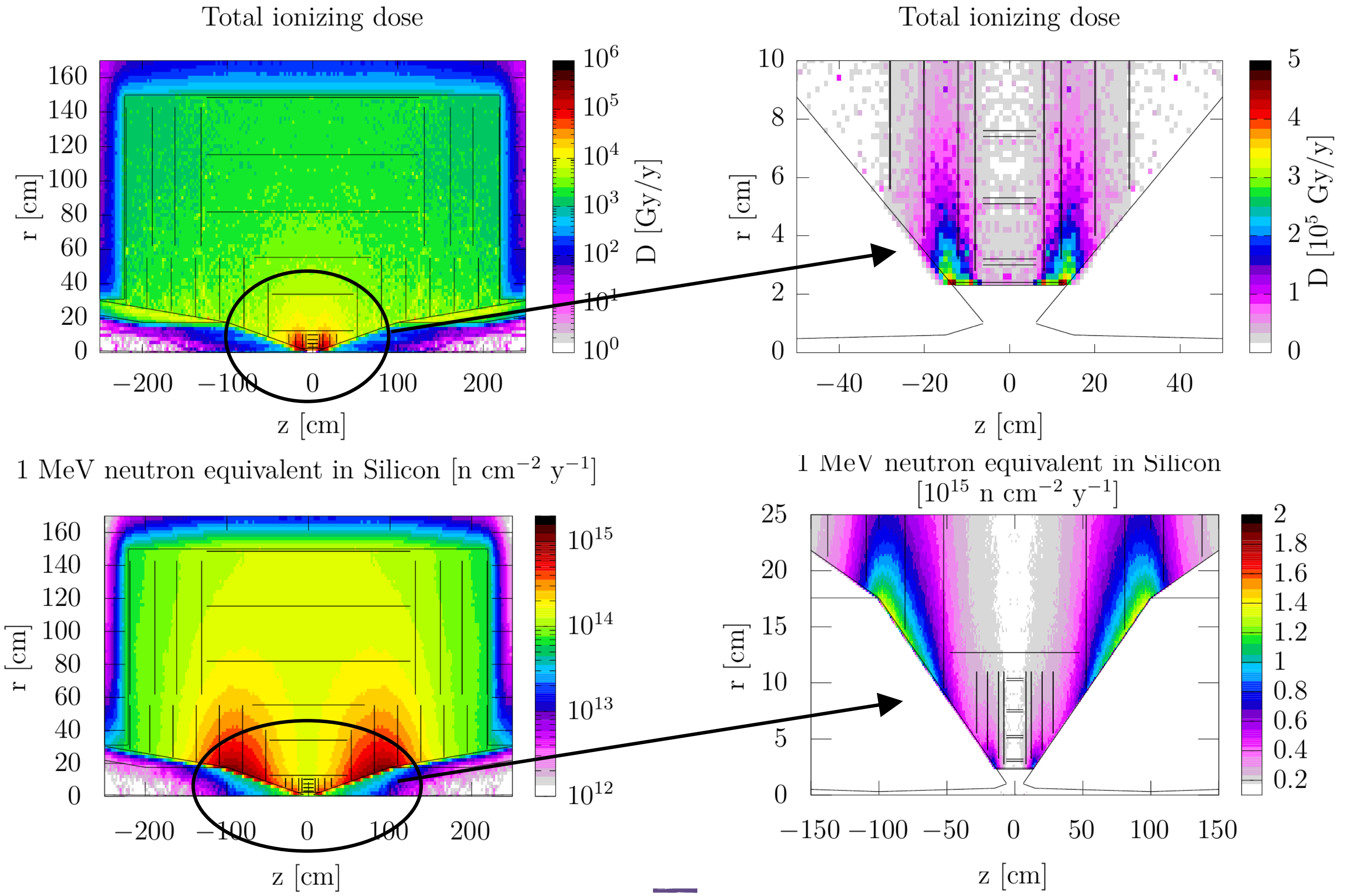
Muon decay	=3 TeV	=10 TeV
Mean muon lifetime in lab system ($\gamma\tau$)	0.031 s	0.104 s
Luminosity lifetime	1039 turns	1558 turns



See also parameter doc: https://cernbox.cern.ch/s/NraNbczzBSXctQ9

Radiation damage (v 0.4)

*Radiation damage estimates for 10 TeV (**MAP nozzle, CLIC-like detector**)*
Includes only contribution of decay-induced background!



Per year of operation (140d)	Ionizing dose	Si 1 MeV neutron-equiv. fluence
Vertex detector	200 kGy	3×10^{14} n/cm^2
Inner tracker	10 kGy	1×10^{15} n/cm^2
ECAL	2 kGy	1×10^{14} n/cm^2