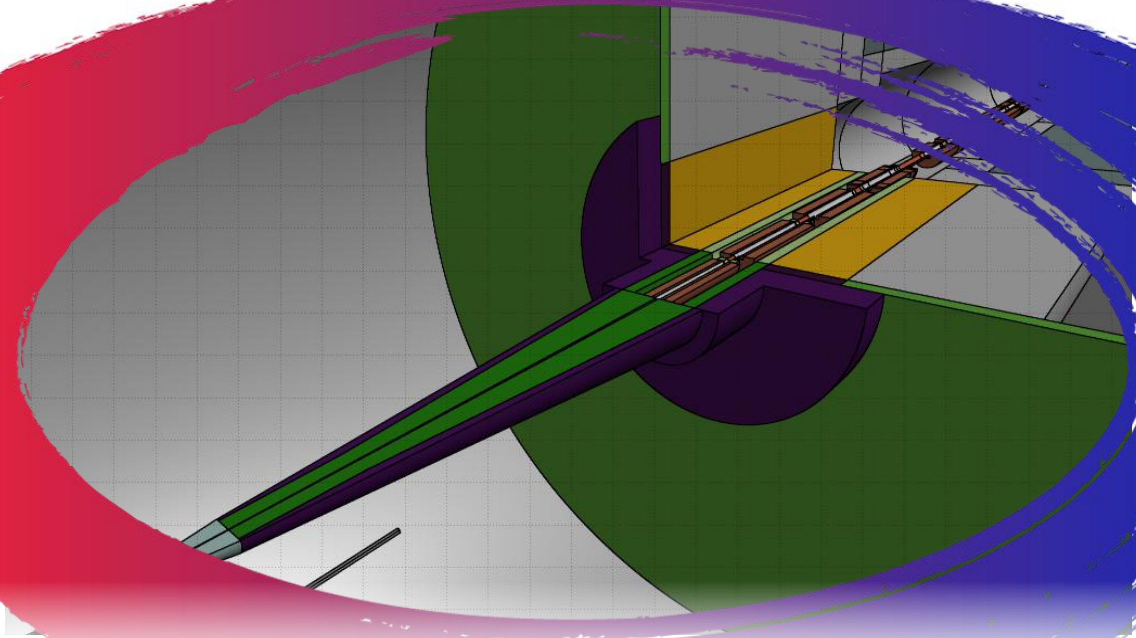
International
MUON Collider
Collaboration

Beam Induced Background at 3 TeV

Jan 28, 2022

CERN



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BIB simulations with FLUKA

- Full simulation of muon trajectory, decay and transport of decay products including hadron production by leptons and photons, and muon pair production by photons
- Machine layout directly from optics files through the LineBuilder interface
- Provide list of particles and their properties at the interface betw machine and detector hall, to be transported in the detector
- Provide radiation maps in the detector

In this presentation:

- **BIB @ 1.5 TeV vs 3 TeV CM energies**
- **3 TeV with solenoidal field B = 0, 3.57, 10 T:**
- **3 TeV nozzles cladding BCH2 vs Tungsten**
- **Dose maps @ 1.5 and 3 TeV**

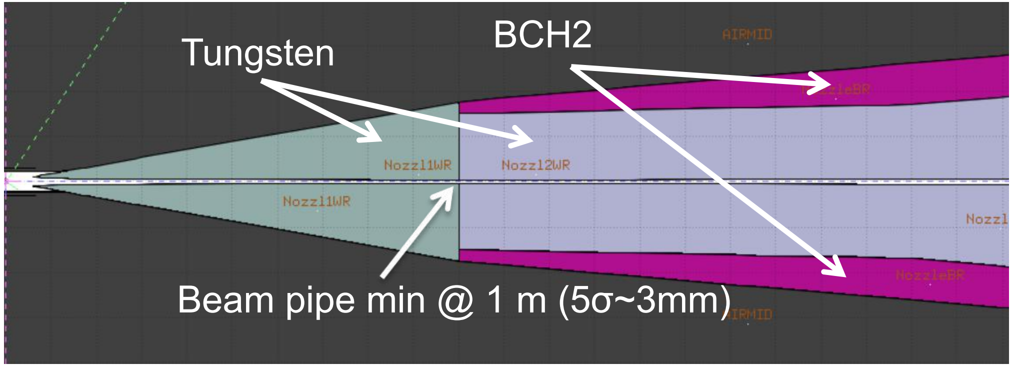
Goal: **to investigate how BIB varies with CM energy, solenoidal magnetic field of detector and nozzles cladding**

1.5 vs 3 TeV

Injected at 200m from IP
Beam $\sigma_{x,y}$, $\sigma'_{x,y}$ from optics

Injected at opposite IP
"Ideal beam" $\sigma_{x,y}=\sigma'_{x,y}=0$

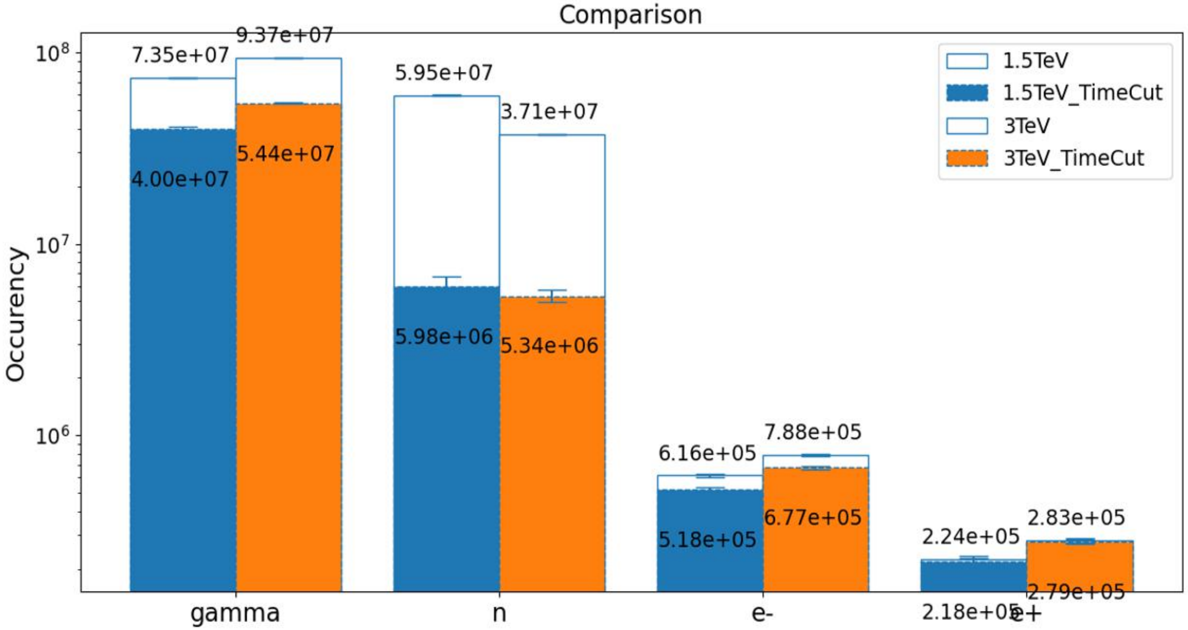
Only one muon beam (mu- counterclockwise) 2e12 particles
Solenoidal (detector) magnetic field in the IR 3.57 T
BCH2 nozzles cladding, no liners/masks
Muon decays within 100 m from IP
Shielding and nozzles optimized for 1.5 TeV

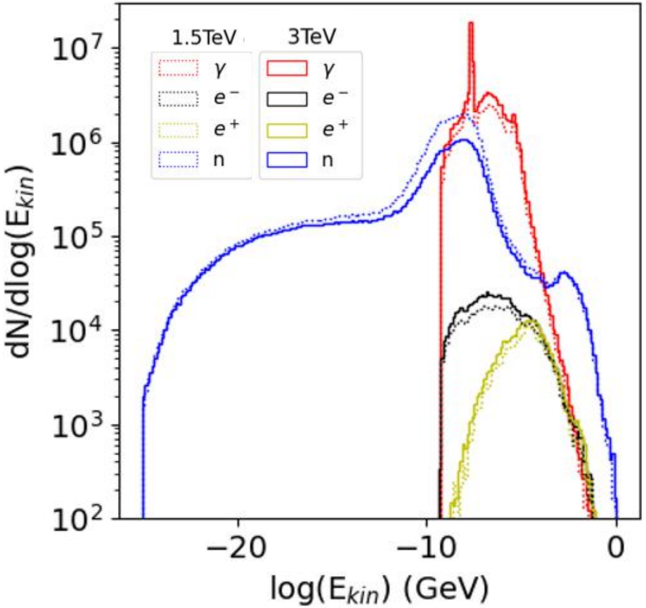


Note: time cut = [-1, 15] ns selects BIB relevant in detector

1.5 vs 3 TeV: number & energy distribution

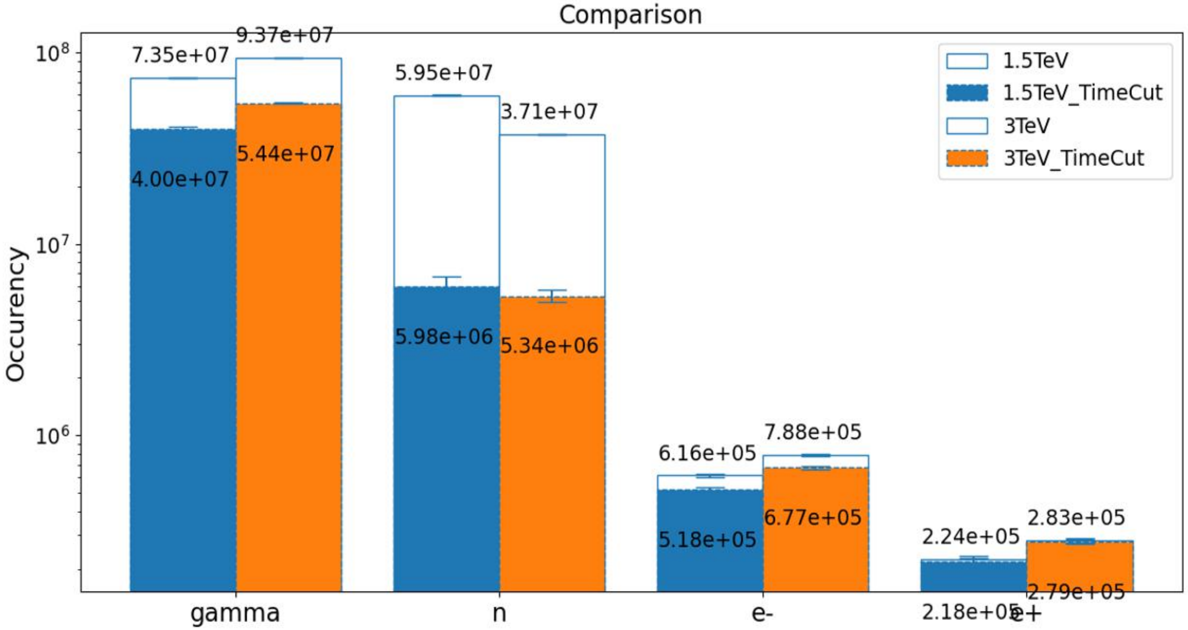
- Comparison most relevant BIB particles
- Energy cutoffs 100 keV for γ, e+, e- and 1e-14 GeV for n
- BIB slightly higher at 3 TeV except for neutrons, total number very similar



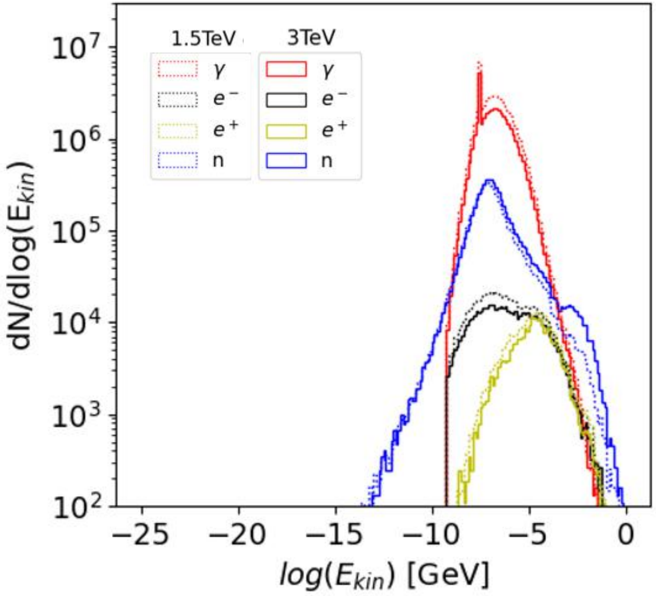


1.5 vs 3 TeV: number & energy distribution

- Comparison most relevant BIB particles
- Energy cutoffs 100 keV for γ, e+, e- and 1e-14 GeV for n
- BIB slightly higher at 3 TeV except for neutrons, total number very similar
- Time cut [-1 ns,15 ns]: at both energies slow neutrons removed, photon reduction, small reduction for e-, no impact on e+

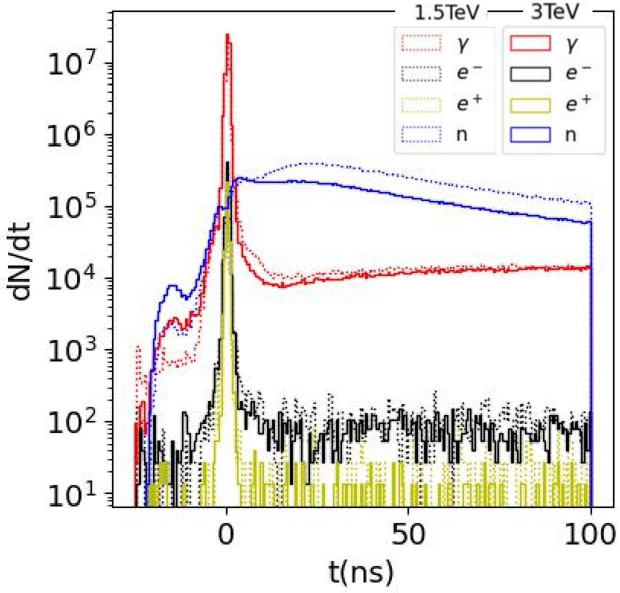


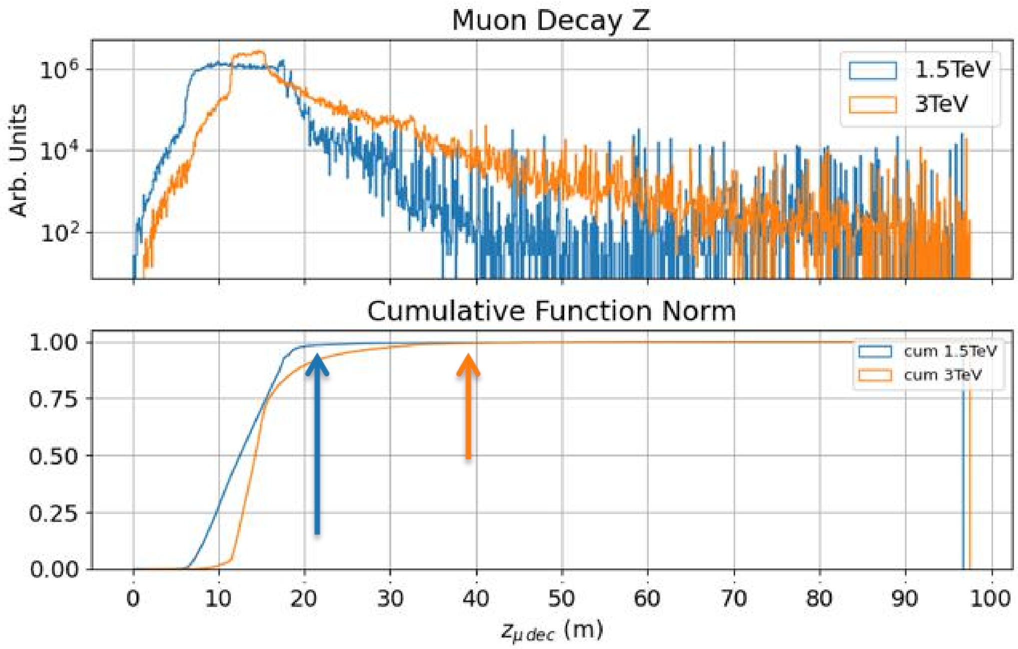
Time cut [-1 ns, 15 ns]



1.5 vs 3 TeV: time & z muon decay

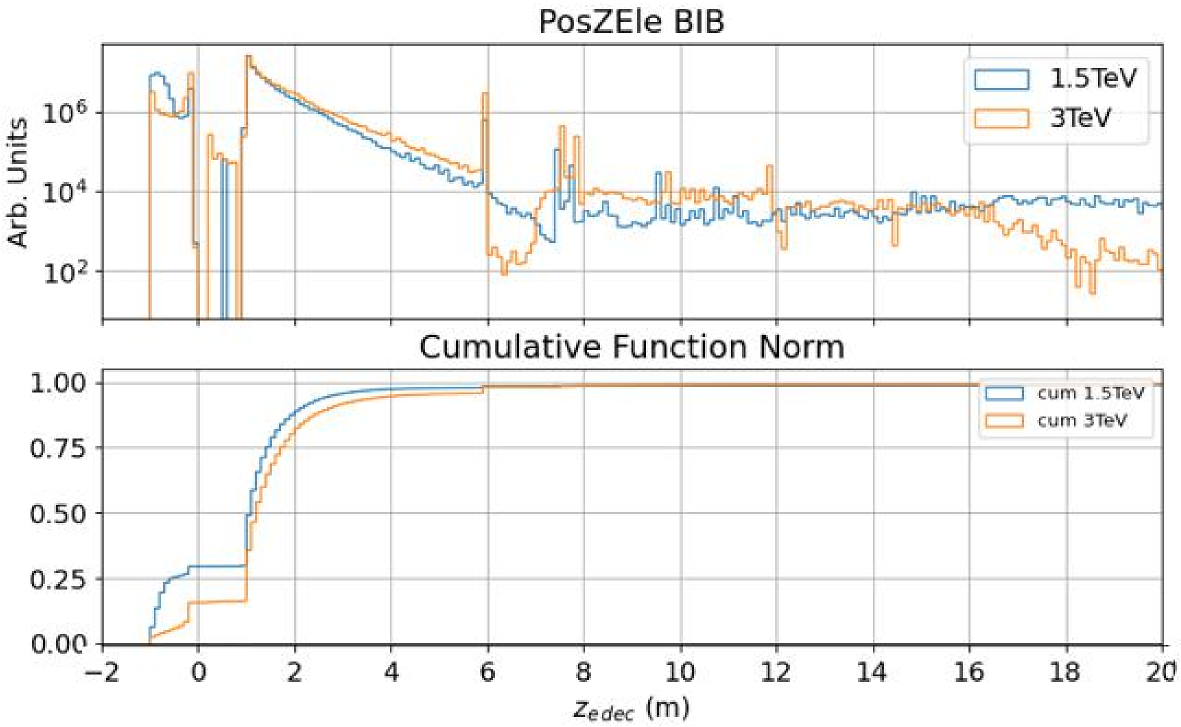
- Very similar time structure
- Primary muons decay logitudinal coordinate contributing to BIB for γ, e+, e-, n: @1.5 TeV z_μ < ~25 m @3 TeV z_μ < ~40 m





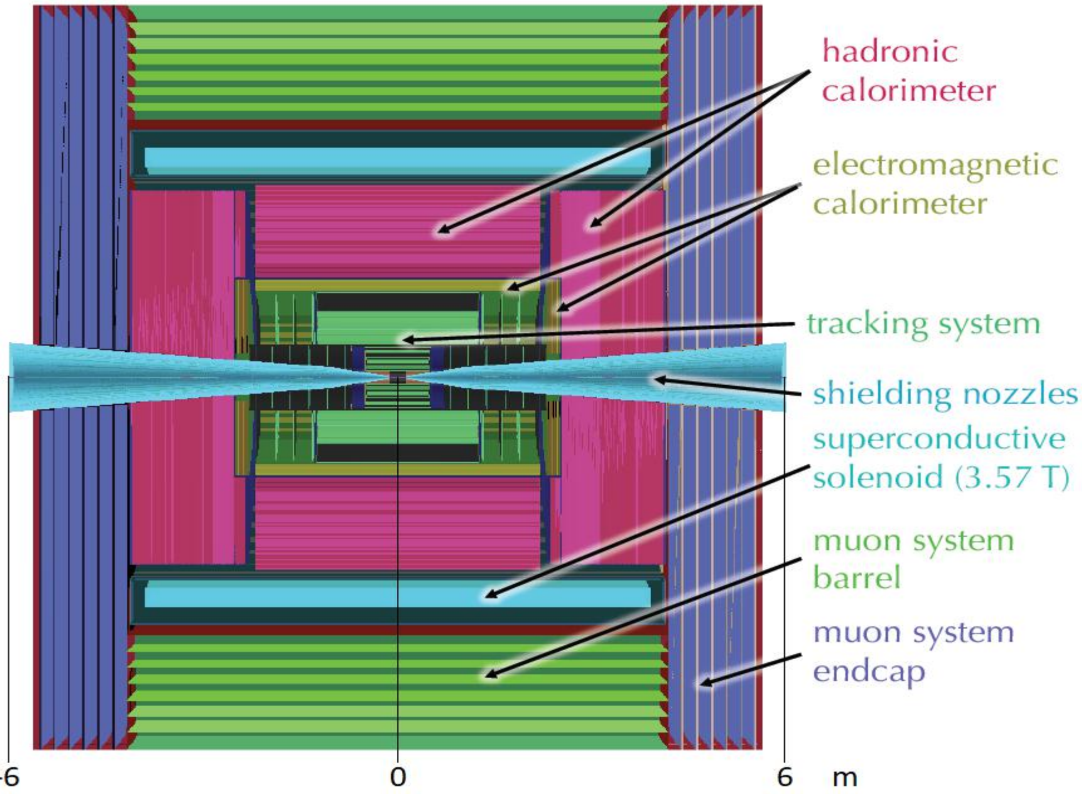
1.5 vs 3 TeV: z of parent e- first interaction

- First interaction of electrons from muons decay generating BIB:
  80% interactions within 2 m from IP



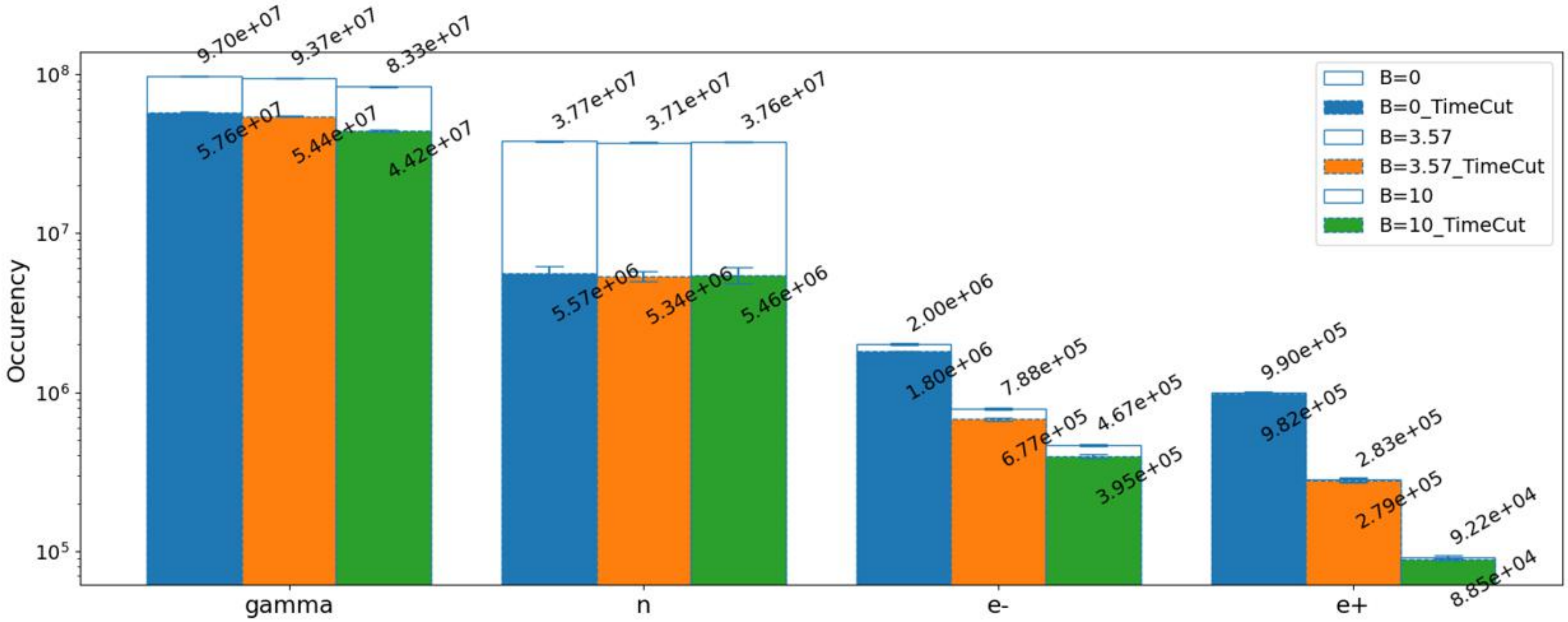
3 TeV B=0, 3.57, 10 T

Value from detector design @ 1.5 TeV

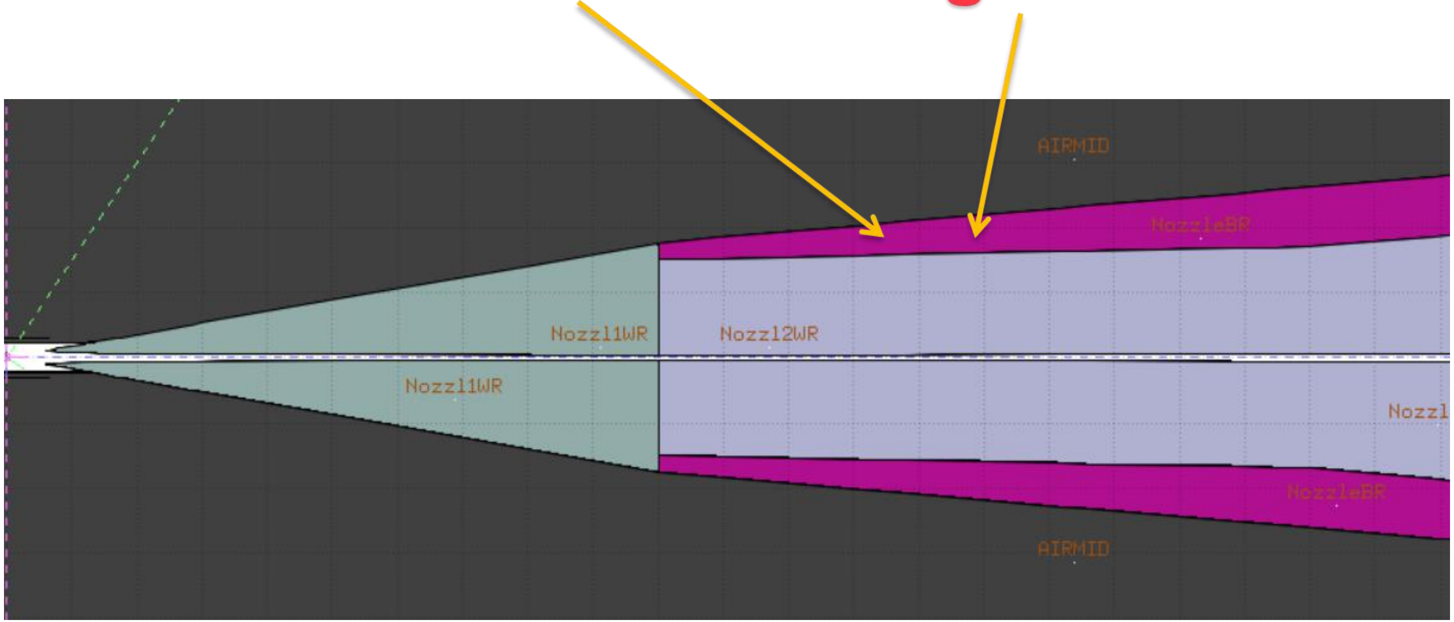


3 TeV: B impact on number

- Main impact of different B values on e+, e- both on the total and particles after time cut: e+, e- trapped in the Be pipe at IP (R_{pipe}=2.2 cm)
- Helical trajectory of charged particles in soldenoidal magnatic field with $r(m) = \frac{p_\perp(GeV/c)}{0.3\,B(T)}$
  ex: $p_\perp$=23.5 MeV/c B=3.57 => 2.2 cm



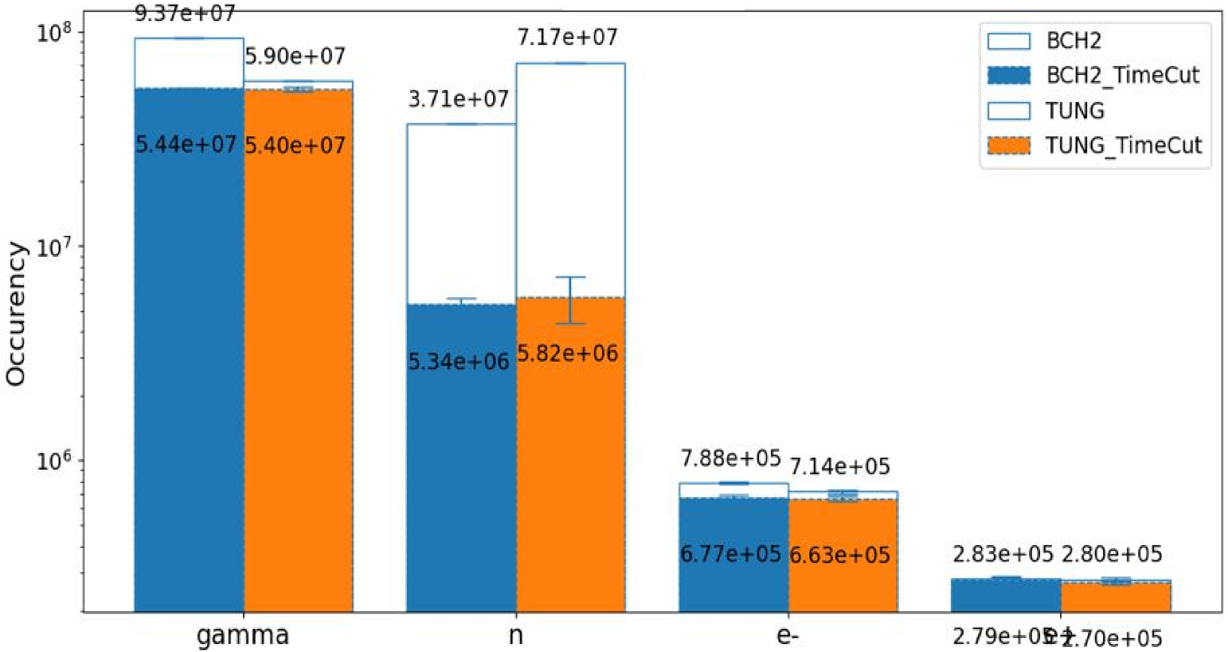
3 TeV BCH2 vs Tungsten

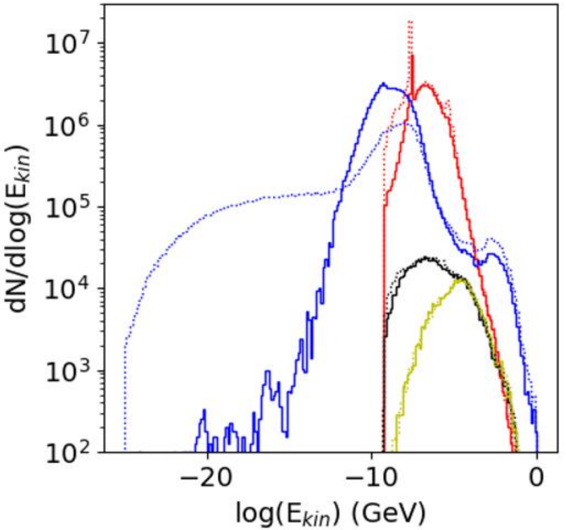


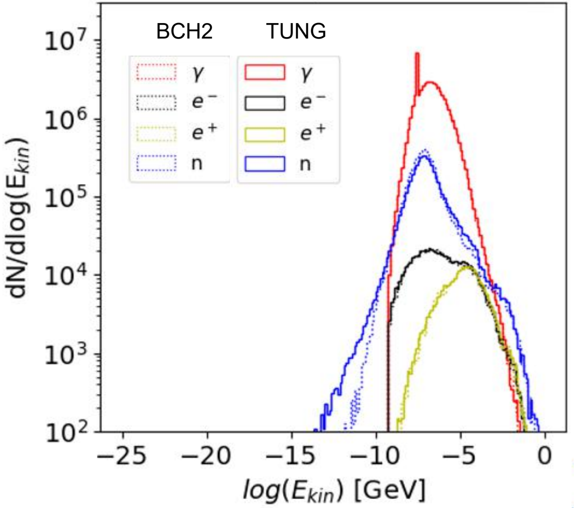
3TeV: BCH2 vs tungsten

- Impact of BCH2 cladding or full tungsten nozzles on BIB can be appreciated on the total number but not on relevant selection for detector determined by the time cut

Note: out of time particles are relevant for radiation damage, removing BCH2 doubles neutrons but reduces photons

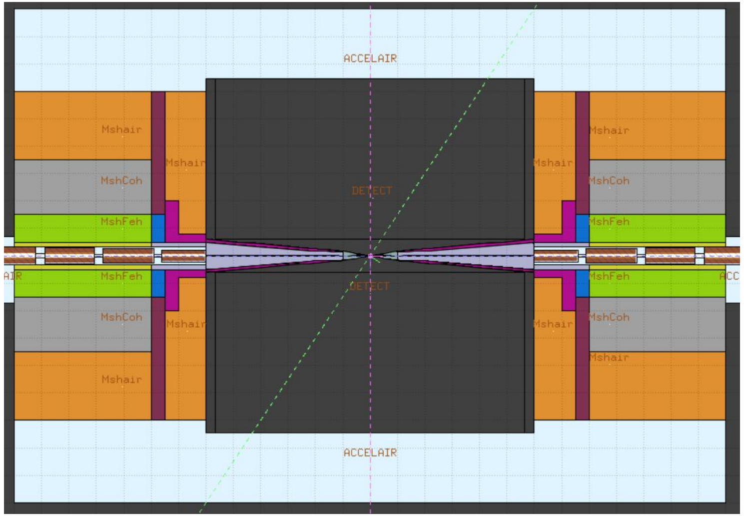


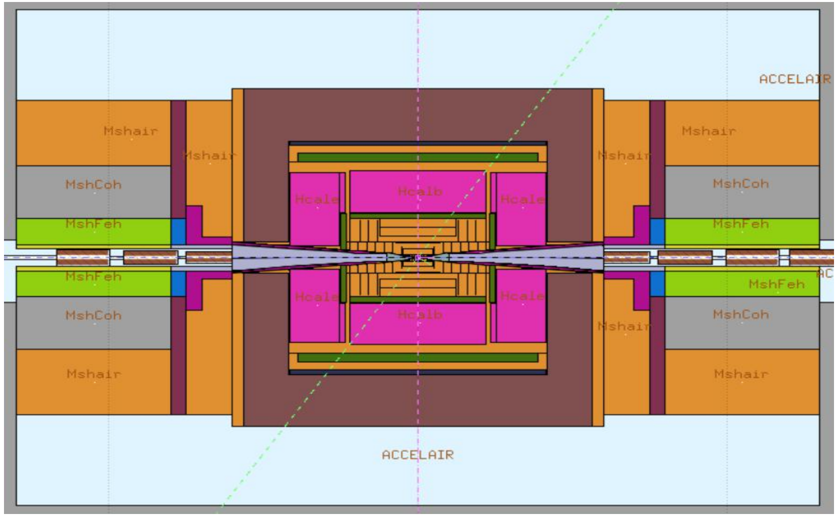




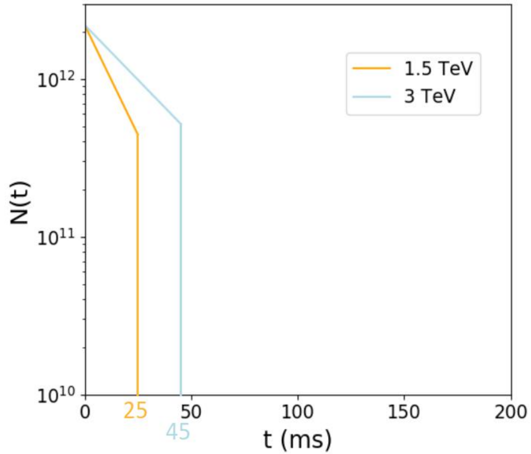
Dose maps

To produce the doses the black body to dump BIB
is substituted by the actual detector in FLUKA





Normalizations & B field



The values considered here for 3 TeV are taken from European Strategy for Particle Physics Accelerator R&D Roadmap p.152 and the ones for 1.5 TeV have been extrapolated.

1.5 TeV CM energy: 2.5 km ring, 8.33 μs per turn and γτ=15.6 ms.
Injection at 5 Hz (every 200 ms), beam dump at 3000 turns (after 25 ms), 15 kHz collision rate. Average muon beam intensity per fill:

$$\overline{N} = \left(\int_0^{25\,ms} 2.2e12\, e^{-t/15.6\,ms}\, dt\right)/25\text{ ms} = 1.1\ 10^{12}$$

3 TeV CM energy: 4.5 km ring, 15 μs per turn and γτ=31.23 ms.
injection at 5 Hz (every 200 ms), beam dump at 3000 turns (after 45 ms), 15 kHz collision rate.
average muon beam intensity per fill:

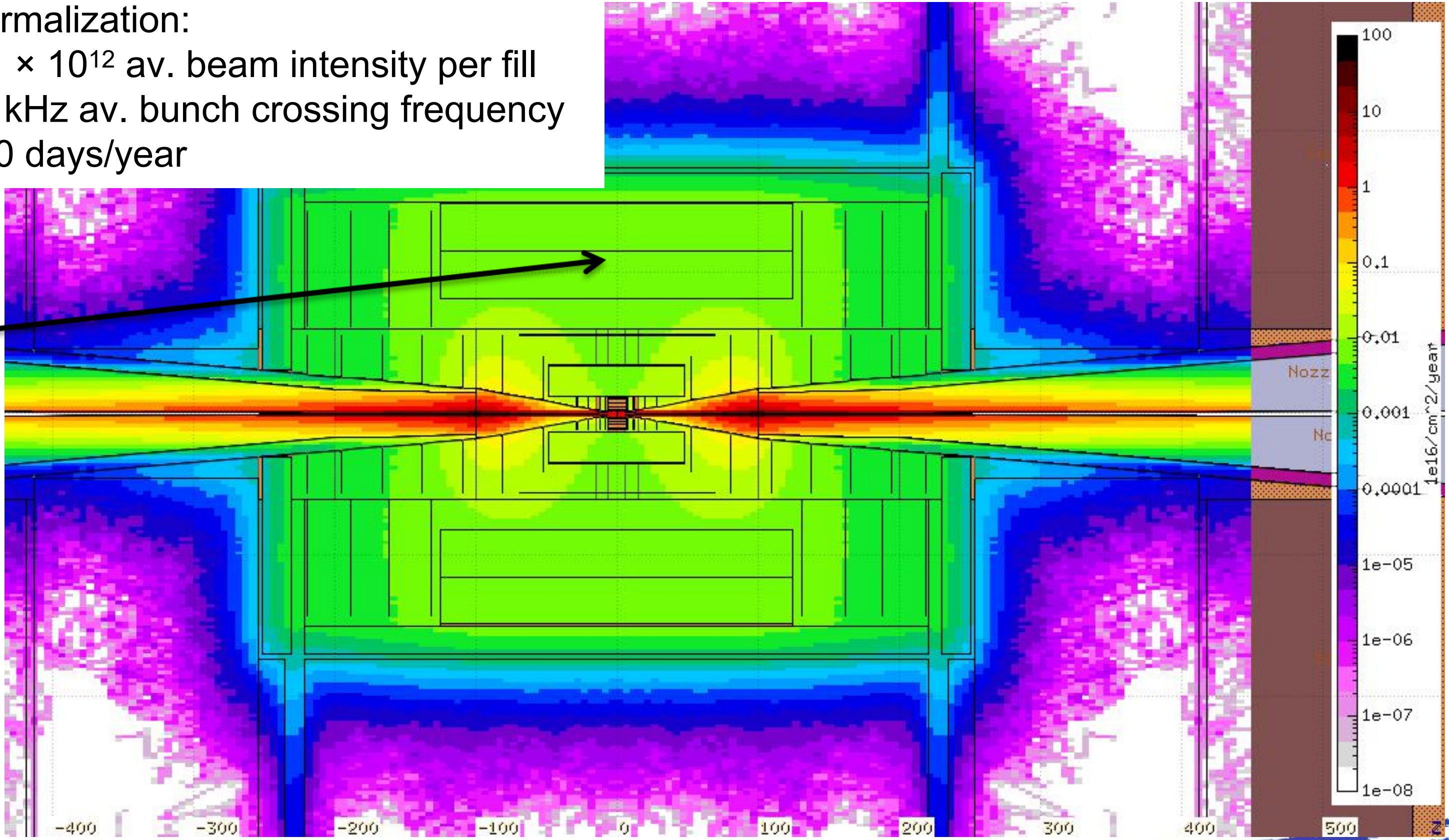
$$\overline{N} = \left(\int_0^{45\,ms} 2.2e12\, e^{-t/31.235\,ms}\, dt\right)/45\text{ ms} = 1.16\ 10^{12}$$

In the following simulations:
B=3.57 T @1.5 TeV
B=3.82 T @3 TeV (linear interpolation if B=5 T @10 TeV, it is an hypothesis)

1.5 TeV: 1MeV neutron equivalent

Color scale: 10^{16} / cm^2 / year
Normalization:
1.1 × 10^{12} av. beam intensity per fill
15 kHz av. bunch crossing frequency
200 days/year

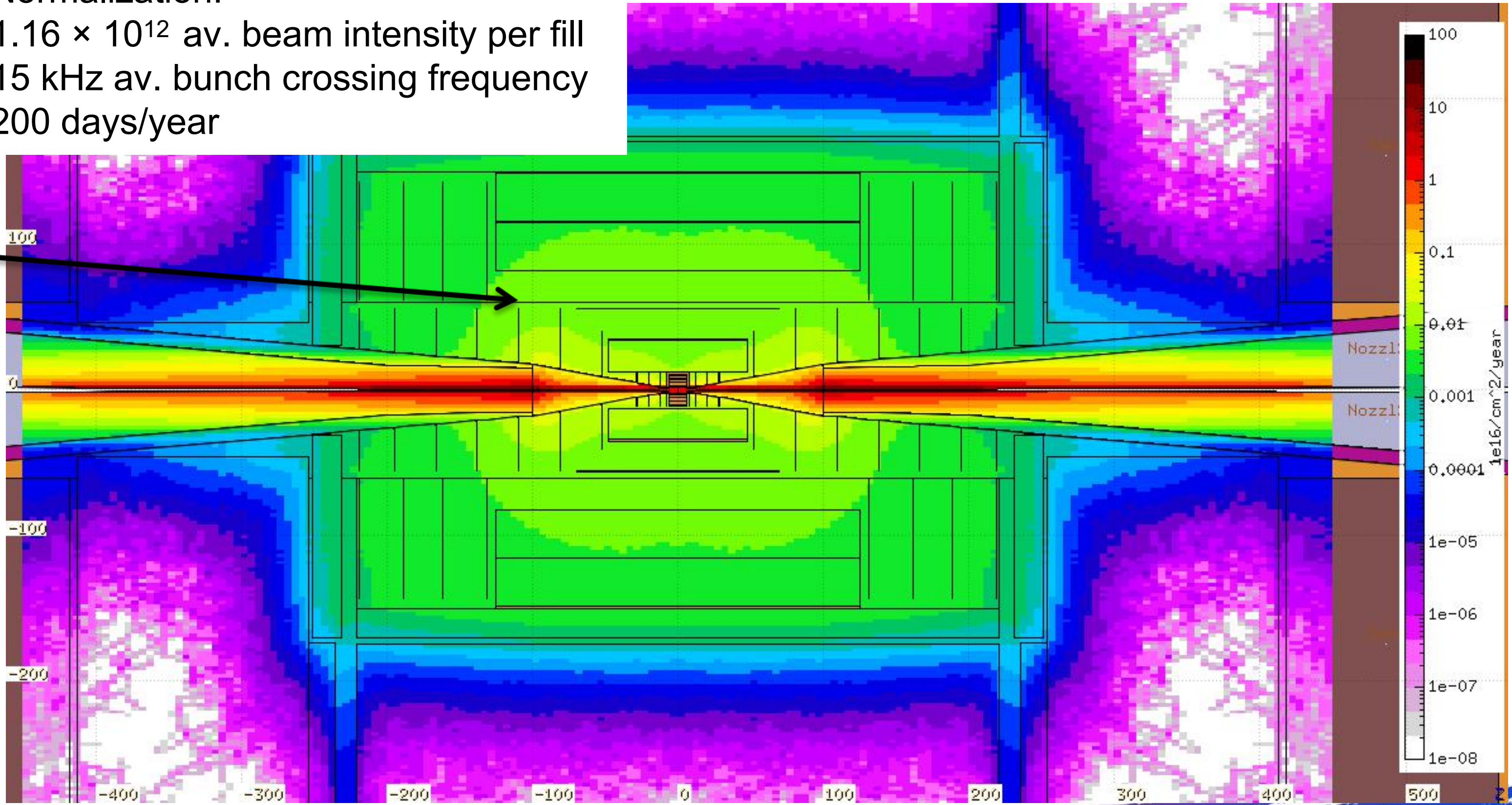
~1e14 cm^-2/year



3 TeV: 1MeV neutron equivalent

Color scale: 10^{16} / cm^2 / year
Normalization:
1.16×10^{12} av. beam intensity per fill
15 kHz av. bunch crossing frequency
200 days/year

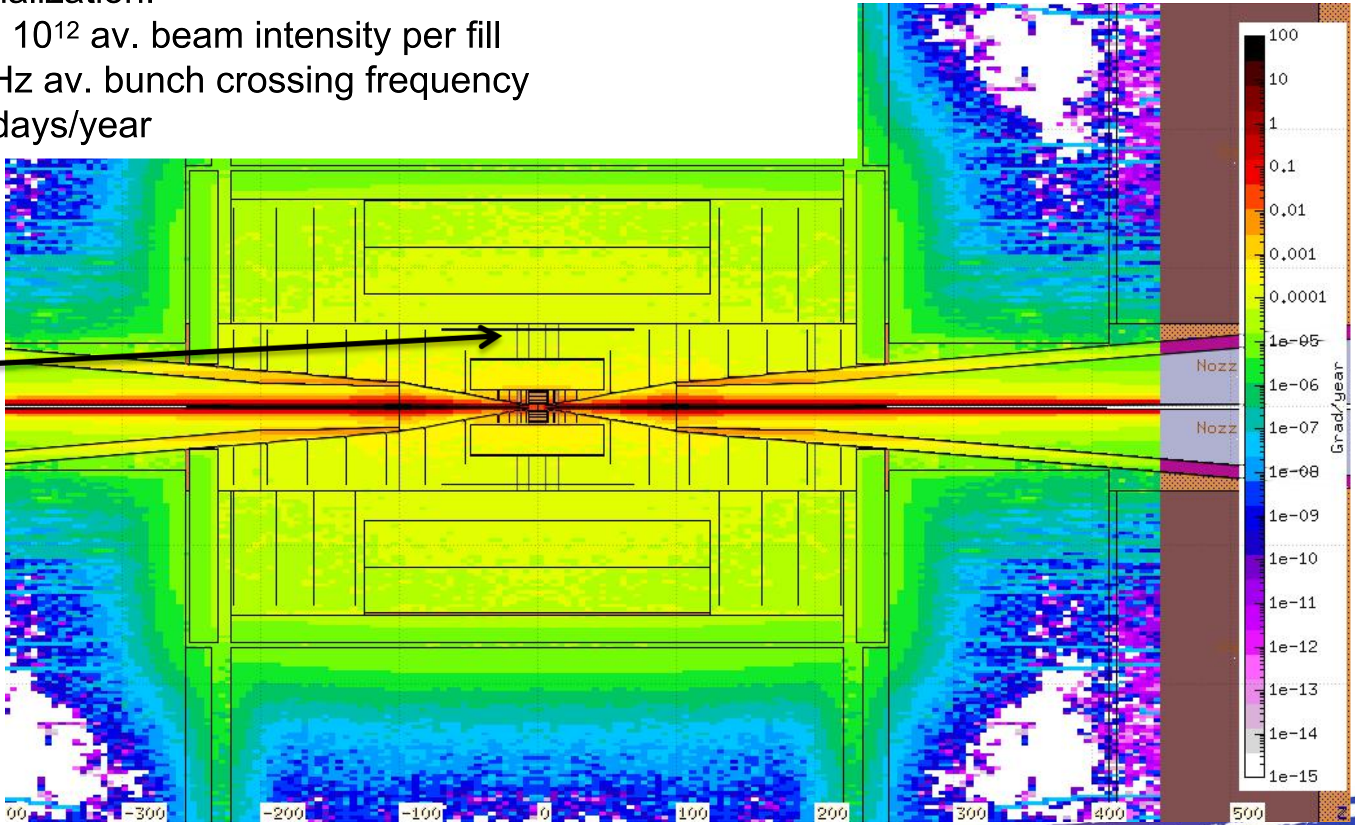
~1e14 cm^-2/year



1.5 TeV: Total Ionizing Dose

Color scale: Grad/year (GeV/g=1.6e-7Gy, 1Gy=100rad)
Normalization:
1.1 × 10^{12} av. beam intensity per fill
15 kHz av. bunch crossing frequency
200 days/year

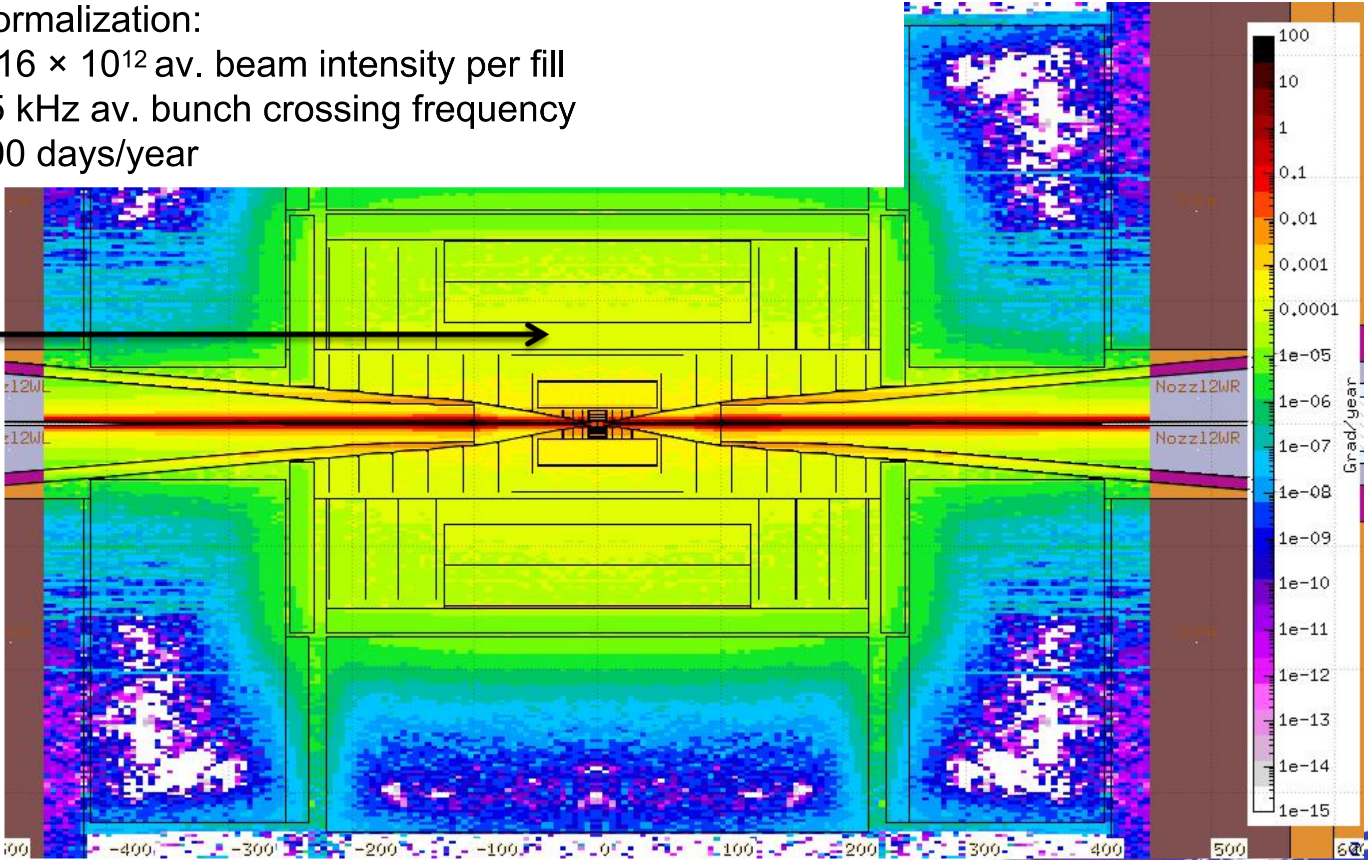
~1e-3/1e-4 Grad/year



3 TeV: Total Ionizing Dose

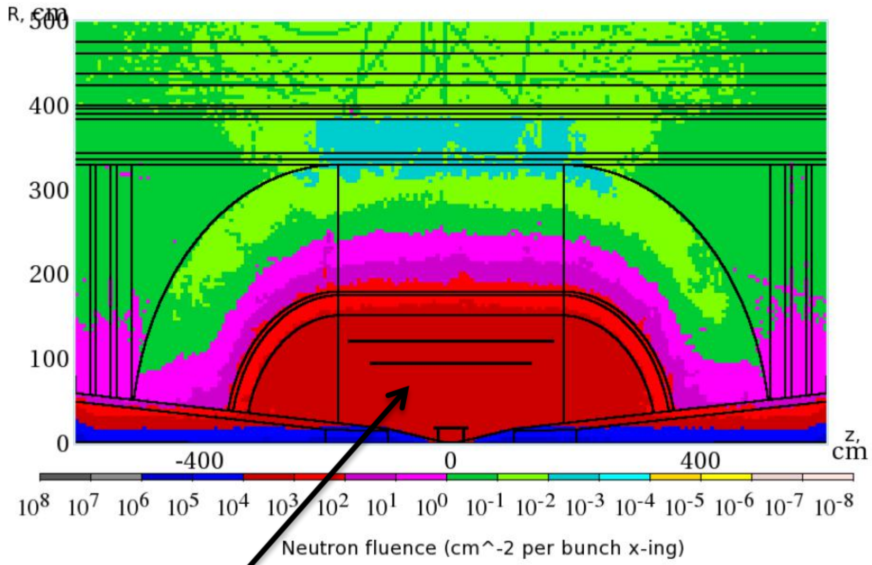
Color scale: Grad/year (GeV/g=1.6e-7Gy, 1Gy=100rad)
Normalization:
1.16×10^{12} av. beam intensity per fill
15 kHz av. bunch crossing frequency
200 days/year

~1e-3/1e-4 Grad/year

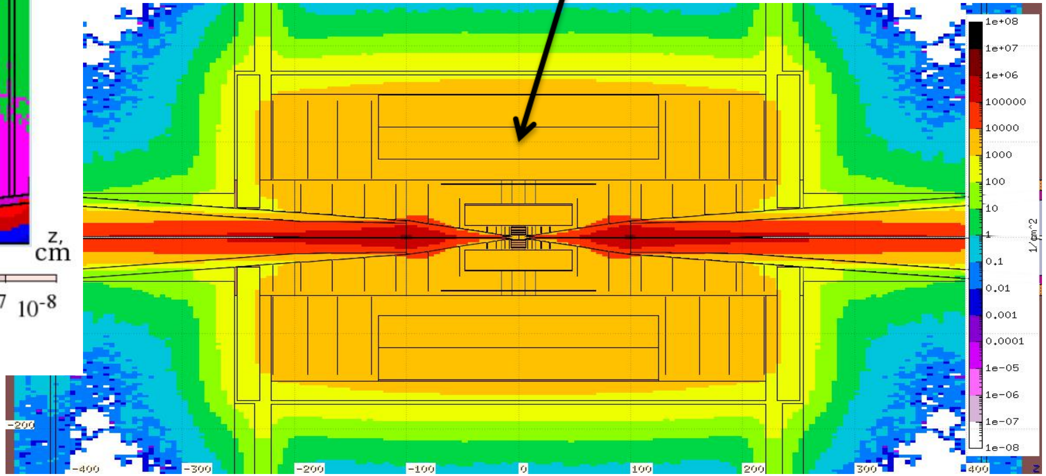


Neutron flux @ 1.5 TeV

Check with MAP numbers from N. Mokhov Phys Proc 37 (2012)
Normalization: per bunch cross, 2e12 muons/bunch
Different detector shape



~1e3/1e4



~1e3/1e4

Conclusion & plans

Summary:

- **Comparison 1.5 TeV vs 3 TeV:** BIB slightly higher at 3 TeV except for neutrons, total number very similar. Time cut [-1 ns,15 ns] acts the same way at both energies. For most relevant particle families, @1.5 TeV it's enough to consider muon decays within 25 m from IP but @3 TeV 40 meters are necessary.
- **3 TeV with solenoidal field B = 0, 3.57, 10 T:** Main impact of different B values is on BIB e-, e+ both on the total and on particles after time cut.
- **3 TeV nozzles cladding BCH2 vs Tungsten:** No BCH2 cladding (full tungsten) doubles neutrons but reduces photons. The effect vanishes when time cuts are applied.
- **Dose maps @ 1.5 and 3 TeV:** With normalizations described in slide 13, doses are similar for the two energies. 1MeV neutron equivalent is around ~1e14/15 cm^-2/year on the tracking system and ~1e14 cm^-2/year on ECAL. TID is ~1e-3 Grad/year on the tracking system and ~1e-4 Grad/year on ECAL.

Next steps:

- **$\sigma_{x,y}$, $\sigma'_{x,y}$ from optics for the beam @3 TeV**
- **Insertion of liners and masks**
- **Change dimensions of nozzles**
- **Detailed studies on dose maps**

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Thank you for your attention

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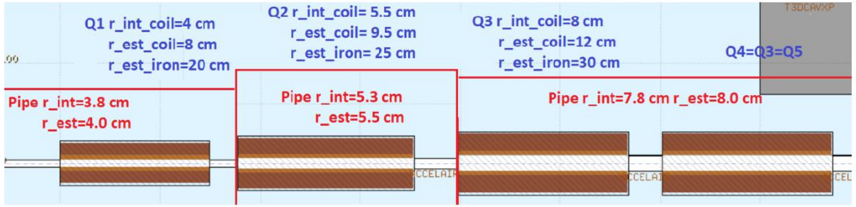
International MUON Collider Collaboration

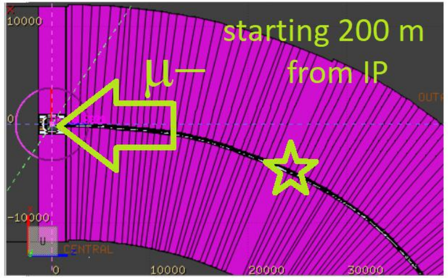
1.5 TeV

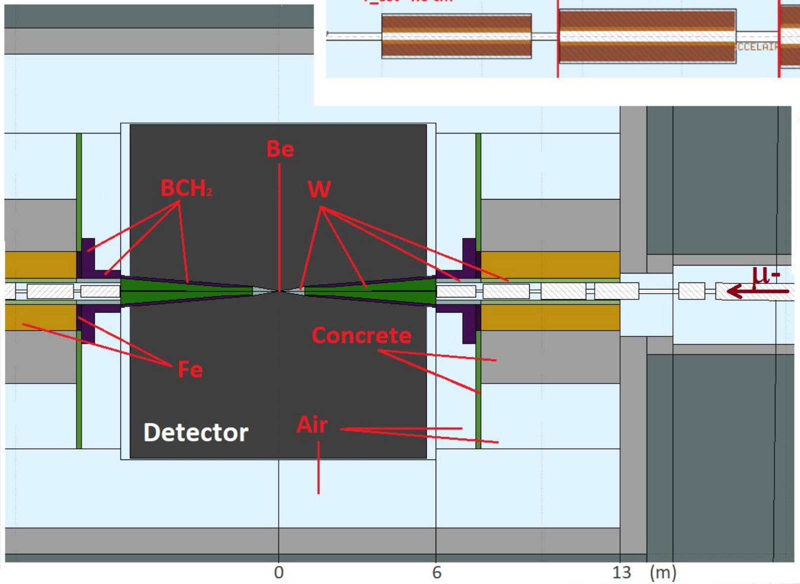
- Machine design and optics files provided by MAP
- Details on the FLUKA simulation and comparison with MARS in Advanced assessment of beam-induced background at a muon collider F. Collamati et al 2021 JINST 16 P11009

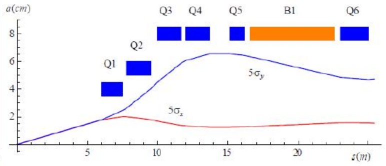
IR Quadrupoles



IR

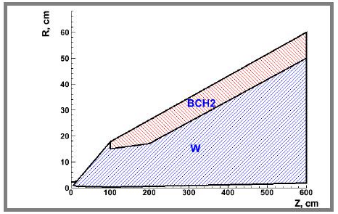






Parameter	Value	
Beam momentum	750	GeV/c
Beam momentum spread	0	GeV/c
Bunch intensity	2×10^{12}	
$\epsilon^n_{x,y}$ normalised RMS emittance	$25\ \pi\ 10^{-6}$	m rad
$\epsilon^g_{x,y}$ geometric RMS emittance	$3.5\ \pi\ 10^{-9}$	m rad
$\sigma_{x,y}$ RMS beam size	5.96	μm
$\sigma_{x',y'}$ RMS beam divergence	596	μrad

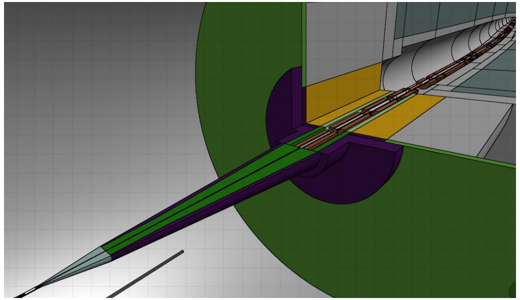
Nozzle

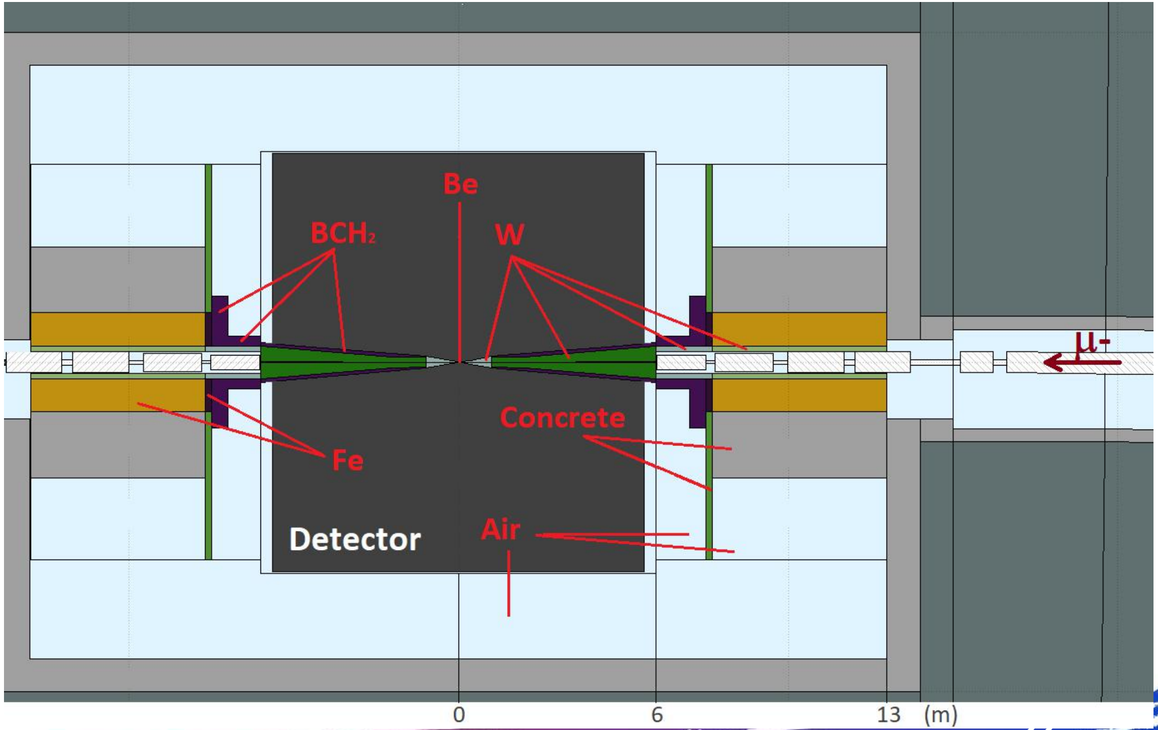


1.5 TeV

N.V. Mokhov and S.I. Striganov, Physics Procedia 37 (2012),2015.

- Starting point and crosscheck vs. MAP reference

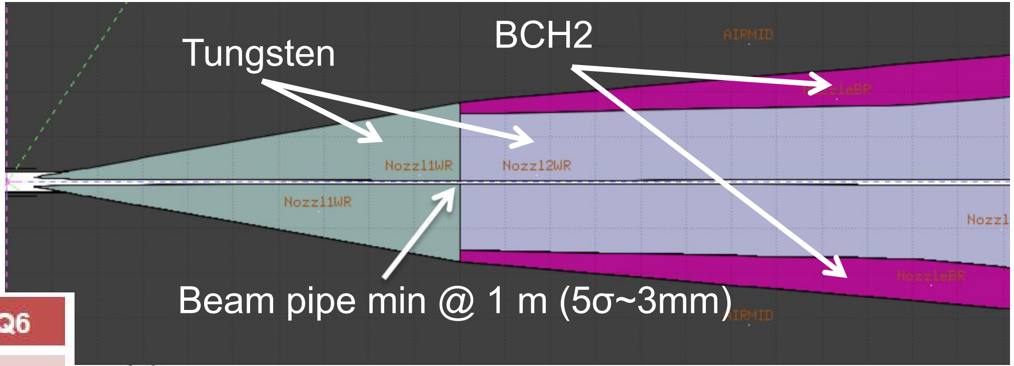




For BIB: detector replaced by perfectly absorbing material (BlackBody)

3 TeV

- Simulation baseline: “ideal” muon beam ($\sigma_{x,y}=\sigma'_{x,y}=0$), solenoidal (detector) magnetic field 3.57 T in IR, no liners/masks
- Machine design and optics files provided by MAP
- Same IR layout and nozzles design for 1.5 TeV



	Q1	Q2	Q3	Q4	Q5	Q6
aperture (mm)	90	110	130	150	150	150
G (T/m)	267	218	-154	-133	129	-128
B (T)	0	0	2	2	2	2
length (m)	1.6	1.85	1.8	1.96	2.3	2.85

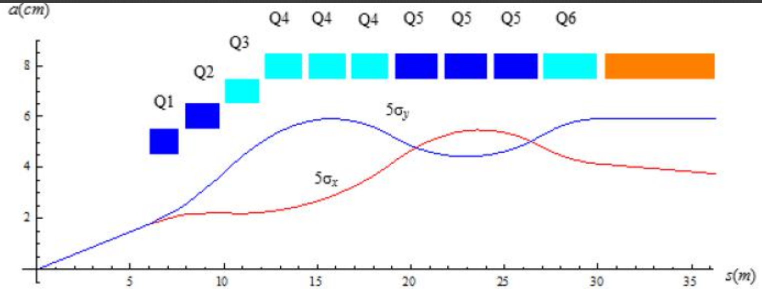
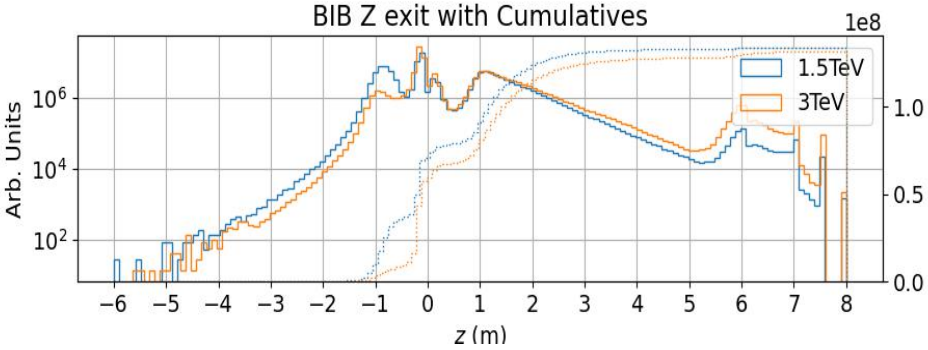
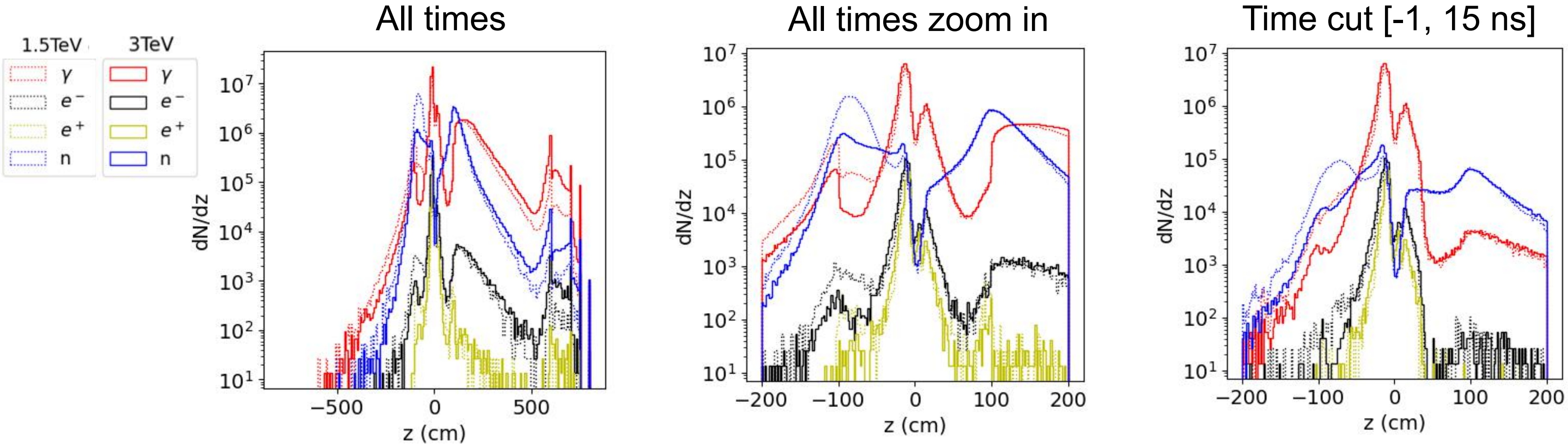


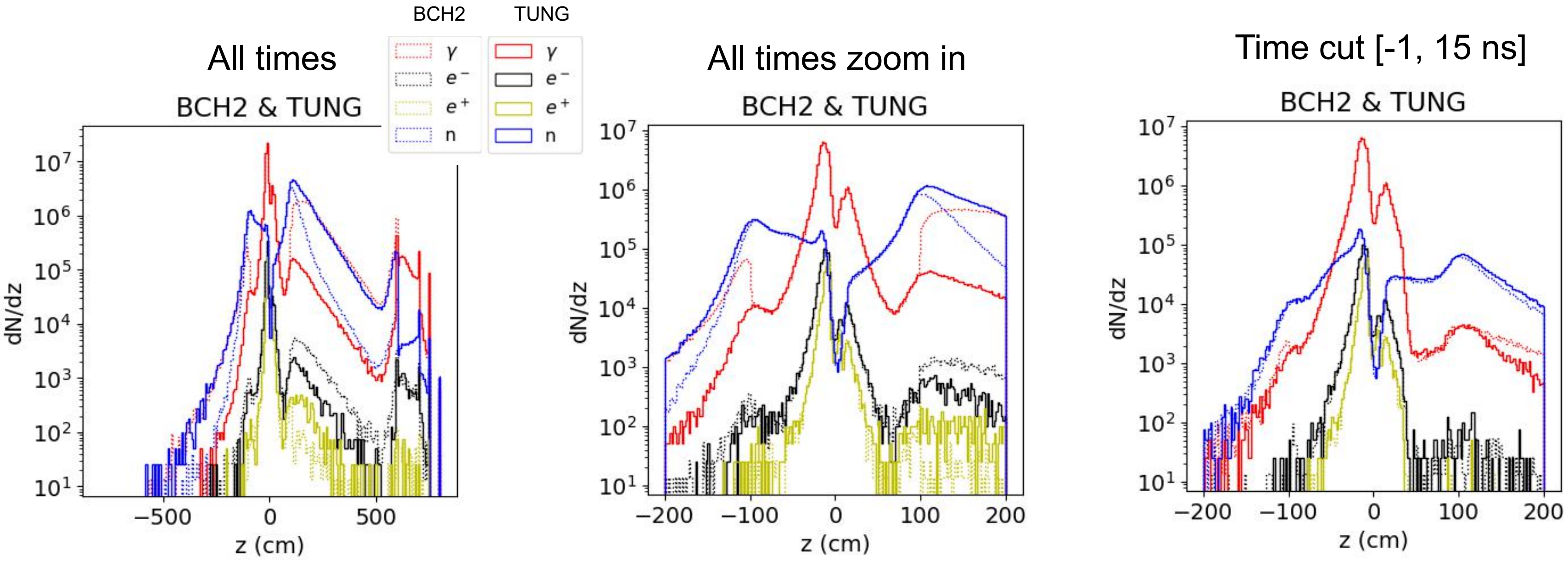
Figure 3: Quadruplet FF quadrupole apertures and 5σ beam envelopes for $E_{\text{c.o.m.}}$= 3 TeV and β^* = 5mm. Defocusing magnets with 2 T dipole component are shown in cyan. Beam parameters are given in the summary table of Section 5.

1.5 vs 3 TeV: z of BIB exit from machine





3 TeV: z of BIB exit from machine



3 TeV: B impact on energy distributions

Energy distributions after time cut [-1 ms, 15 ns]

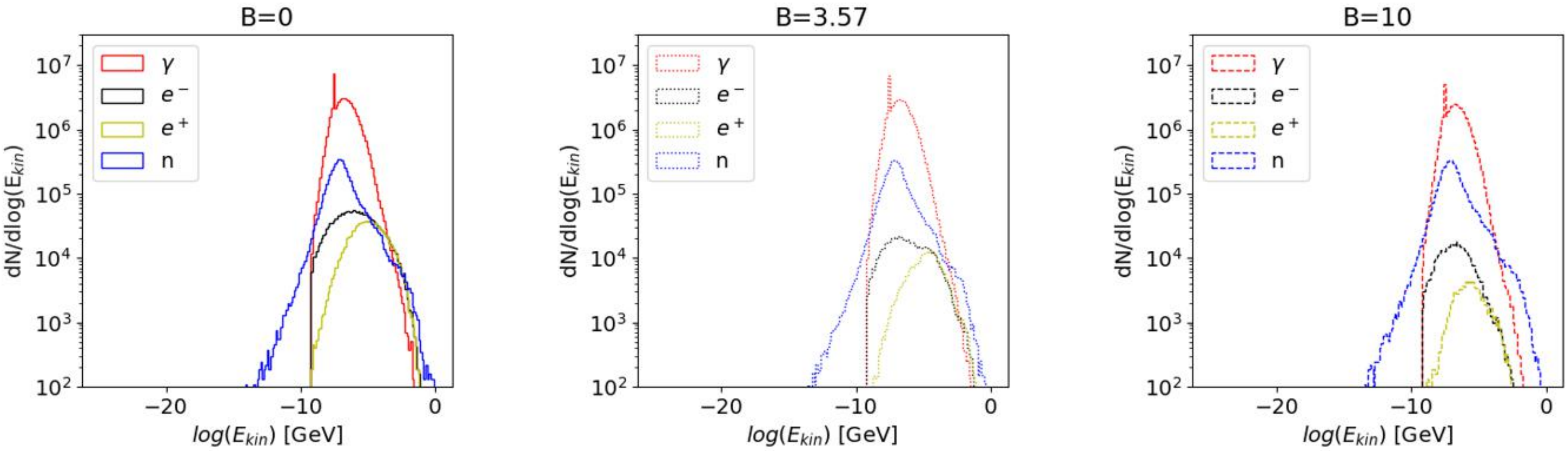


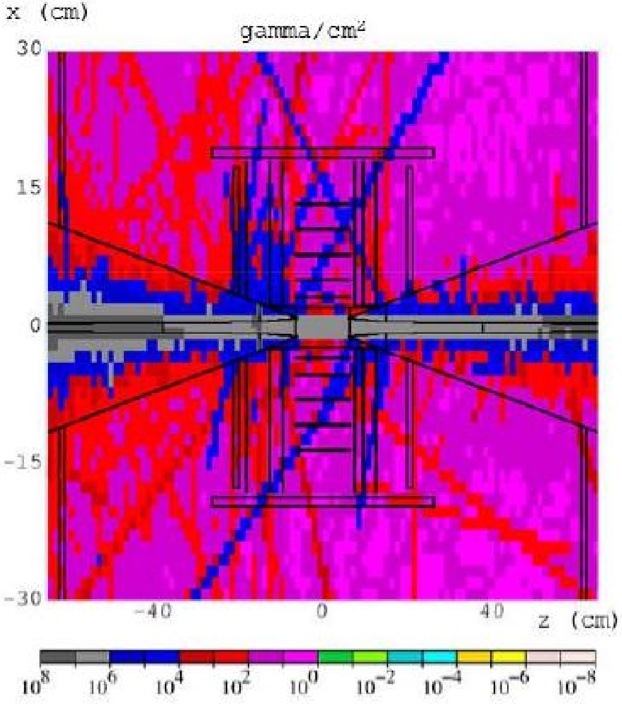
Table 5.1: Tentative parameters for a muon collider at different energies, based on the MAP design with modifications. These values are only to give a first, rough indication. The study will develop coherent parameter sets of its own. For comparison, the CLIC parameters at 3 TeV are also given. Due to beamstrahlung only 1/3 of the CLIC luminosity is delivered above 99% of the nominal centre-of-mass energy ($\mathcal{L}_{1,1\infty}$). The CLIC emittances are at the end of the linac and the beam size is given for both the horizontal and vertical planes.

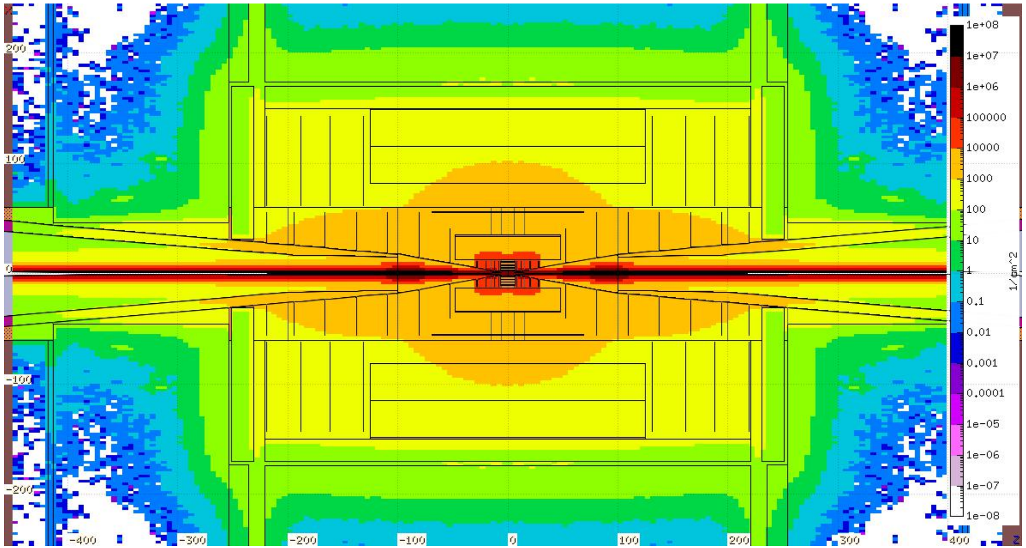
Parameter	Symbol	Unit	Target value			CLIC
Centre-of-mass energy	E_{cm}	TeV	3	10	14	3
Luminosity	$\mathcal{L}$	$10^{34}\text{cm}^{-2}\text{s}^{-1}$	1.8	20	40	5.9
Luminosity above $0.99 \times \sqrt{s}$	$\mathcal{L}_{0.01}$	$10^{34}\text{cm}^{-2}\text{s}^{-1}$	1.8	20	40	2
Collider circumference	C_{coll}	km	4.5	10	14	—
Muons/bunch	N	10^{12}	2.2	1.8	1.8	0.0037
Repetition rate	f_r	Hz	5	5	5	50
Beam power	P_{coll}	MW	5.3	14.4	20	28
Longitudinal emittance	ϵ_L	MeVm	7.5	7.5	7.5	0.2
Transverse emittance	ϵ	μm	25	25	25	660/20
Number of bunches	n_b		1	1	1	312
Number of IPs	n_{IP}		2	2	2	1
IP relative energy spread	δ_E	%	0.1	0.1	0.1	0.35
IP bunch length	σ_z	mm	5	1.5	1.07	0.044
IP beta-function	β	mm	5	1.5	1.07	
IP beam size	σ	μm	3	0.9	0.63	0.04/0.001

$$L = \frac{\overline{N}^2 r\,\gamma}{4\pi\beta\varepsilon^n} = \frac{\overline{N}^2 r}{4\pi\sigma^2} = \frac{(1.16\;10^{12})^2 15\;10^3}{4\pi(3\;10^{-4}\;)^2} = 1.8\;10^{34}\;cm^{-2}s^{-1}$$

Photon flux @ 1.5 TeV

Check with MAP numbers
per bunch cross 2e12 muons/bunch





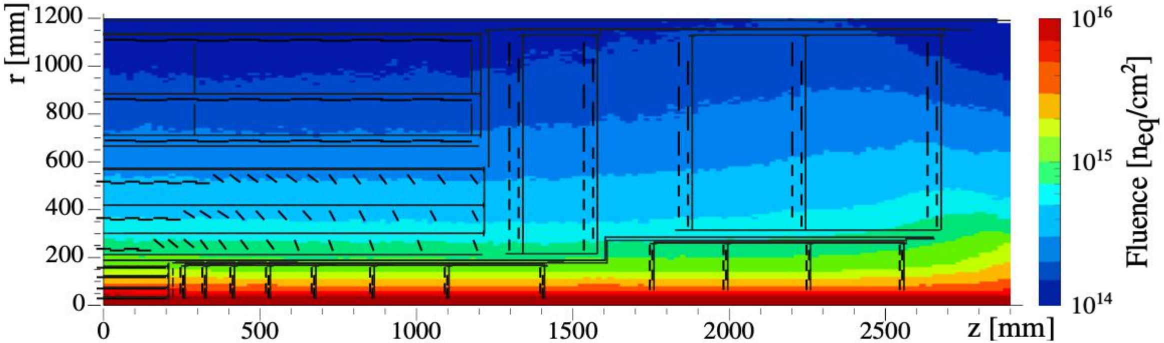


Figure 2.2: Integrated particle fluence in 1 MeV neutron equivalent per cm^2, for the Phase-2 tracker. The estimates shown correspond to a total integrated luminosity of 3000 fb^{-1} of pp collisions at $\sqrt{s} = 14$ TeV, and have been obtained with the CMS FLUKA geometry version 3.7.2.0.

Table 2.1: Maximum expected fluence for selected detector regions or components (detailed in Section 2.3) of the tracker. Values are for 3000 fb^{-1} of pp collisions at $\sqrt{s} = 14$ TeV assuming a total cross section, σ_{pp}, of 80 mb. The positions in r and z at which the quoted maximum fluence levels for the respective region or component type are reached are also given.

Region or component	Max. fluence [n_{eq}/cm^2]	r [mm]	z [mm]
IT barrel layer 1	2.3×10^{16}	28	0
IT barrel layer 2	5.0×10^{15}	69	0
IT barrel layer 4	1.5×10^{15}	156	89
IT forward, ring 1	1.0×10^{16}	51	252
IT service cylinder	1.3×10^{15}	170	260
OT PS modules	9.6×10^{14}	218	129
OT 2S modules	3.0×10^{14}	676	2 644

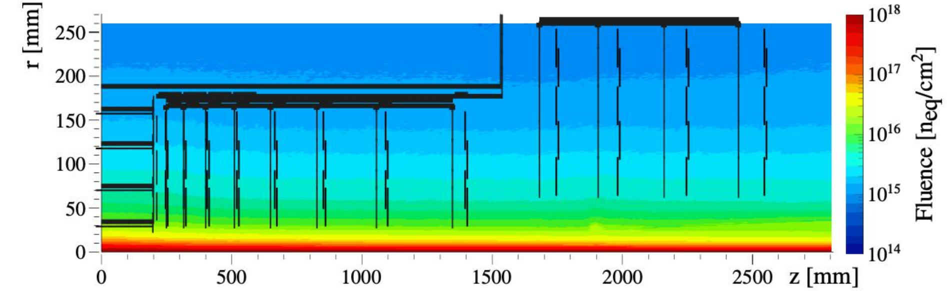


Figure 8.2: Integrated particle fluence in 1 MeV neutron equivalent in silicon per cm^2, for the region of the CMS Inner Tracker. The estimates shown correspond to a total integrated luminosity of 3000 fb^{-1} of pp collisions at $\sqrt{s} = 14$ TeV, and have been obtained with the CMS FLUKA geometry version 3.7.2.0.

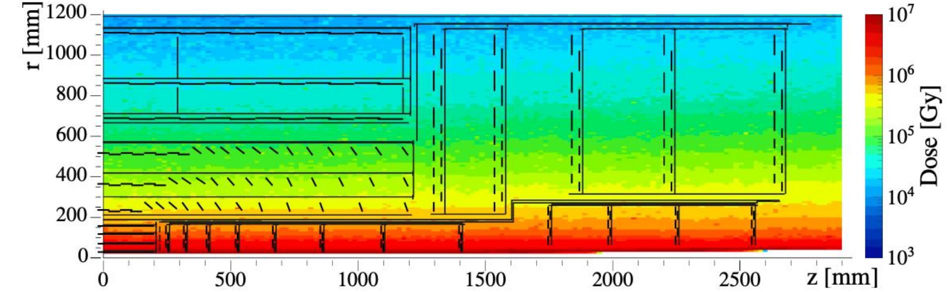


Figure 8.3: Total ionizing dose in Gy, for the Phase-2 tracker. The estimates shown correspond to a total integrated luminosity of 3000 fb^{-1} of pp collisions at $\sqrt{s} = 14$ TeV, and have been obtained with the CMS FLUKA geometry version 3.7.2.0.

max=1.2 Grad/3000 fb-1