Interplay between Accelerator and Detector design

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Muon Collider Physics and Detector workshop
Dec 14, 2022, 12:00 AM → Dec 16, 2022, 5:00 PM America/Chicago
1West
Fermilab

Università degli Studi di Padova

INFN
Istituto Nazionale di Fisica Nucleare

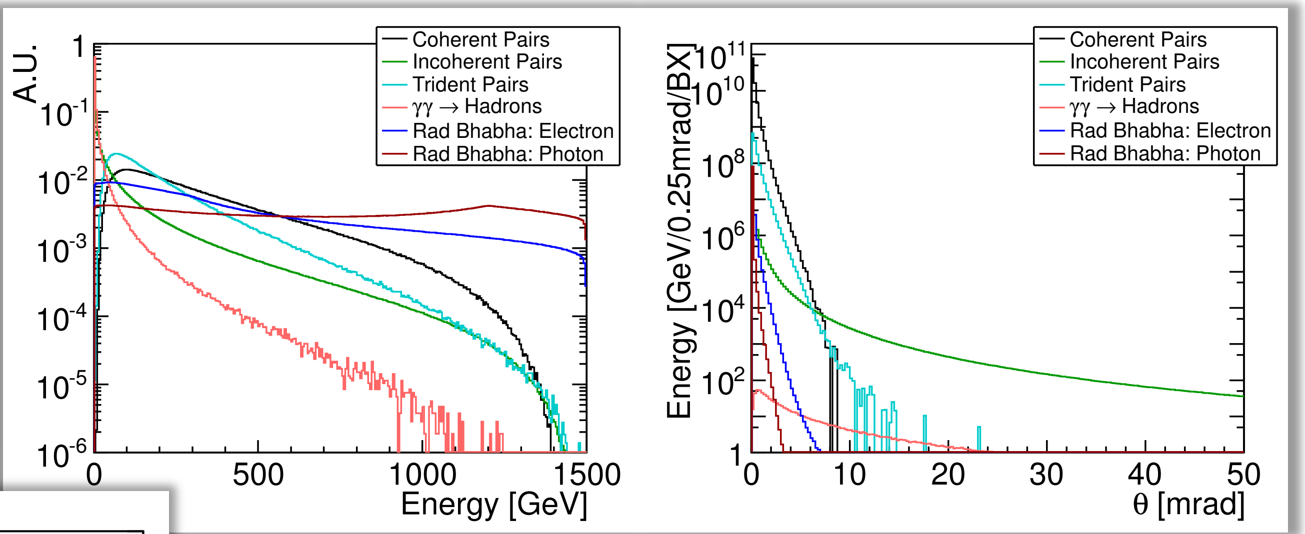
Why Interaction Region definition and Detector design are coupled: e^+e^- collisions at 3 TeV, CLIC

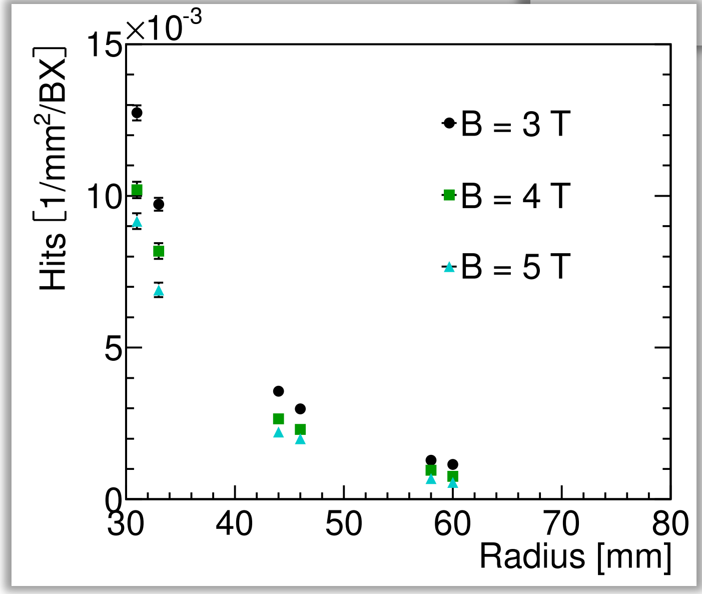
Interaction Point size X/Y/Z ~45 nm/~1 nm/ 44 μm

LCD-note-2011-021

Background	Total	Particles per BX $\theta > 10$ mrad	$\theta > 7.3°$ and $p_T > 20$ MeV
Coherent pairs	$6 \cdot 10^8$	≈ 0	0
Trident pairs	$7 \cdot 10^6$	≈ 0	0
Incoherent pairs	$3 \cdot 10^5$	$8 \cdot 10^4$	60
Radiative Bhabha $e^\pm/\gamma$	$1 \cdot 10^5$	3/0	0/0
$\gamma\gamma \to$ hadrons	102	96 (47 charged)	54 (25 charged)

Beam-induced background





Having that background generated, CLIC designed the 3 TeV detector, as example the occupancy on the vertex barrel detector as function of the magnetic field

Why Interaction Region definition and Detector design are coupled: $\mu^+\mu^-$ collision, Muon Collider

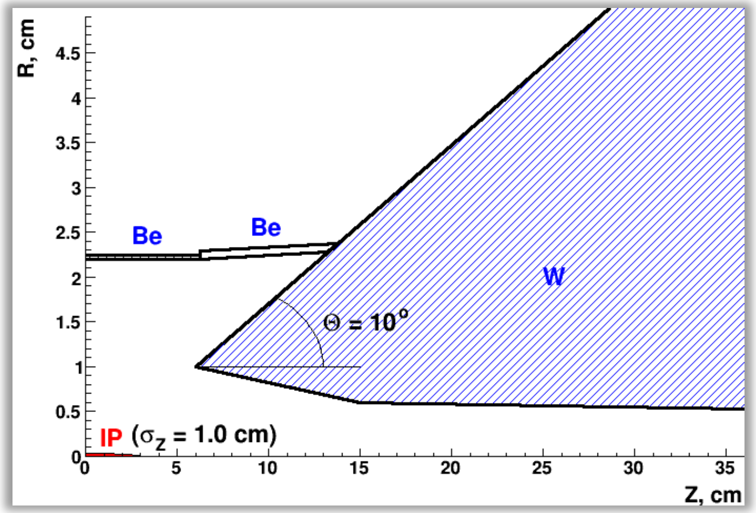
The muon collider presents a unusual (so far) situation.

The high luminosity requires high number of muons per bunch ($N_\mu \sim 2 \cdot 10^{12}$)

The only case studied in detail

Muons decay particles: $4{\times}10^5$decays per meter of lattice, E_{beam}= 0.750 TeV with $2{\times}10^{12}\,\mu$/bunch mainly: electrons/positrons, photons, neutrons, charged hadrons and muons

So far, the best way to mitigate the particle fluxes effects on detector is to use the nozzles, two shielding cones made of tungsten and borated polyethylene entering in the detector .



Designed by MAP.

Di Benedetto et al., *A study of muon collider background rejection criteria in silicon vertex and tracker detectors.* Journal of Instrumentation13(2018)

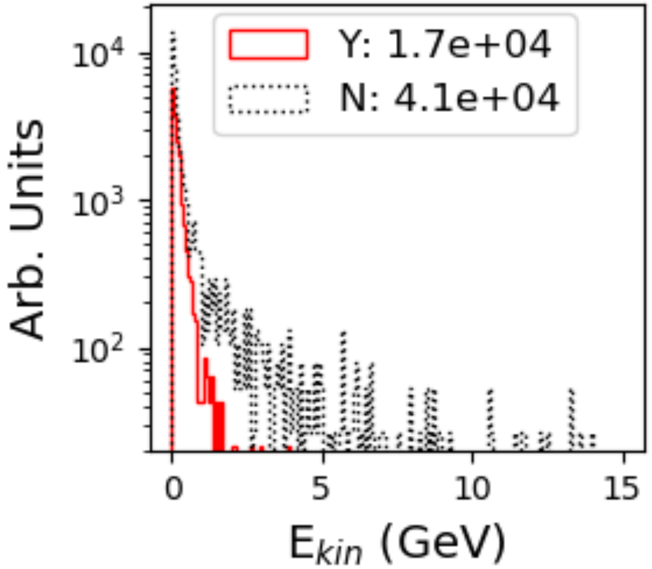
The effect of the nozzle

F. Collamati et al. 2021 JINST 16 P11009

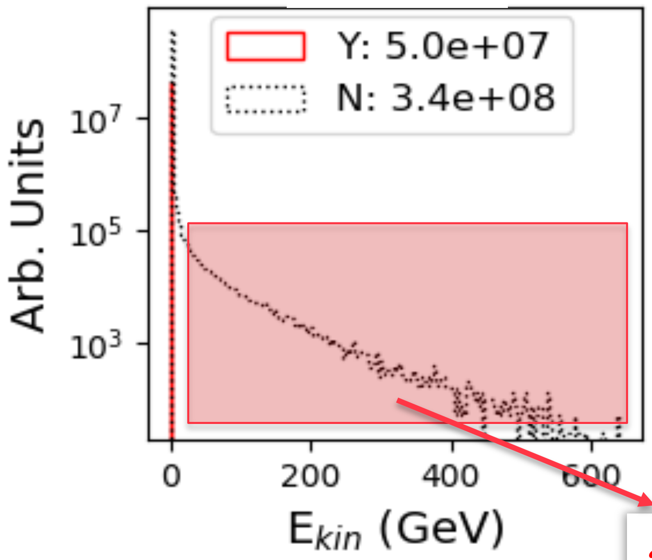
- Muon beam 0.75 TeV, IR designed by MAP
- Beam-induced Background generated with FLUKA
- Compare what arrives on the detector with and without the nozzle

Charged hadrons absorbed

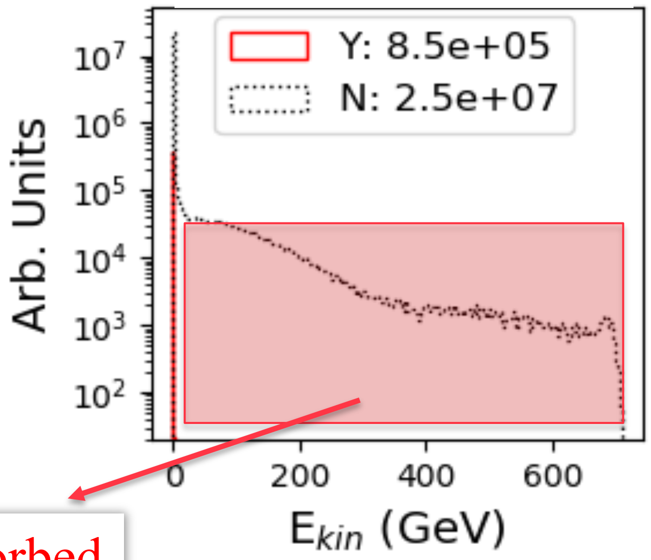
charged hadrons



Photons



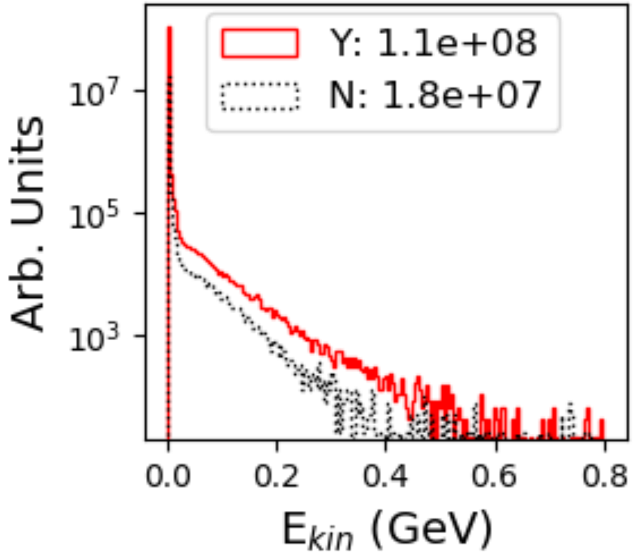
electrons/positrons



absorbed

Neutrons increased

neutrons



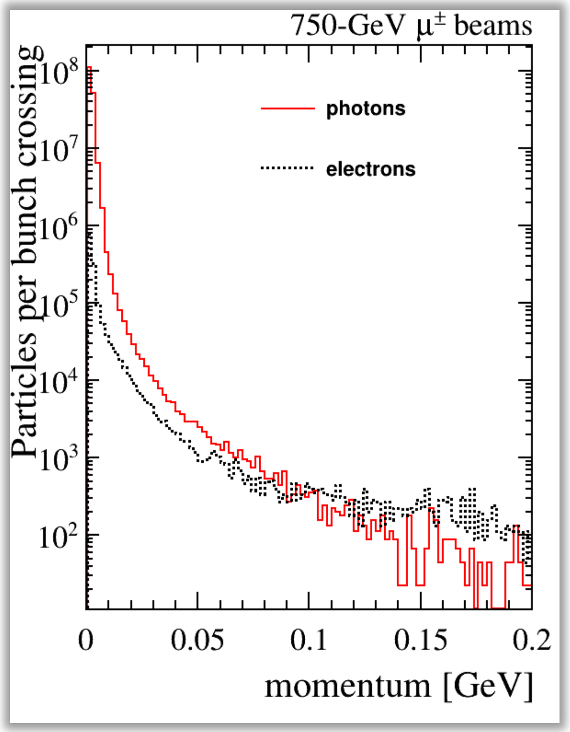
Without the nozzle the detector is flooded by high energy particles

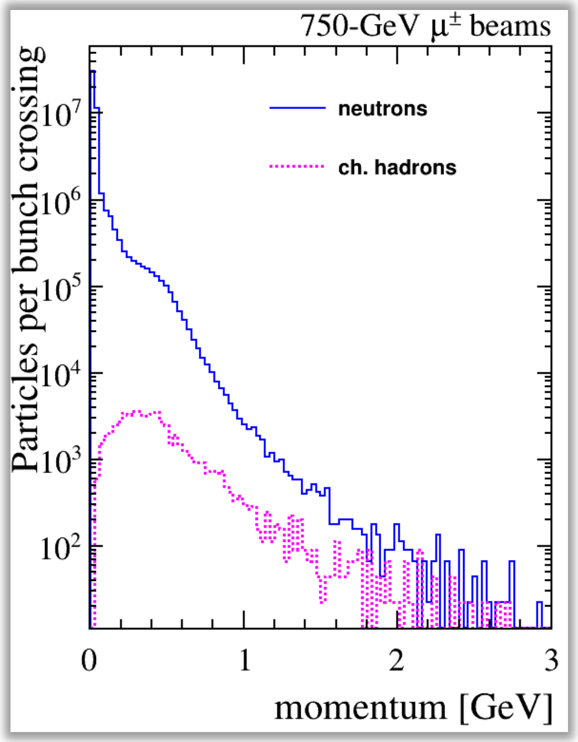
The survived Beam-Induced Background Properties

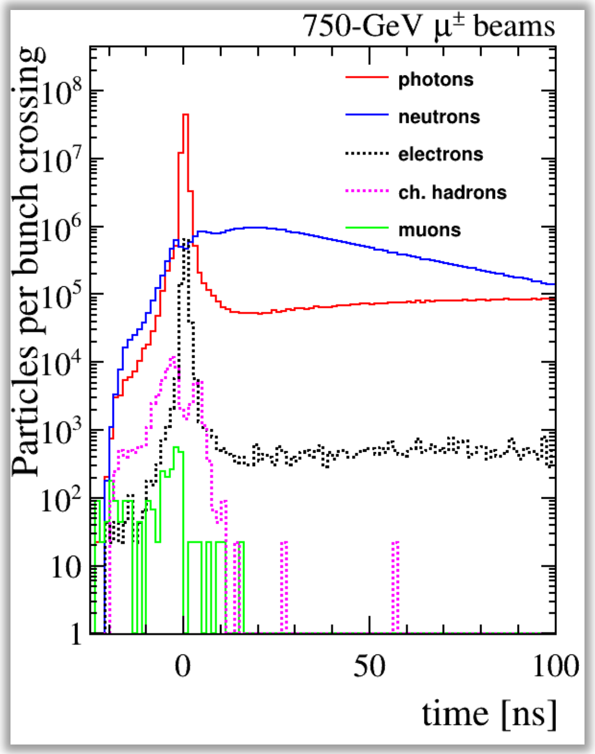
Particles arriving on the detector with the nozzle:

- Muon beam 0.75 TeV, IR designed by MAP
- Beam-induced Background generated with MARS15

N. Bartosik *et al* 2020 *JINST* **15** P05001







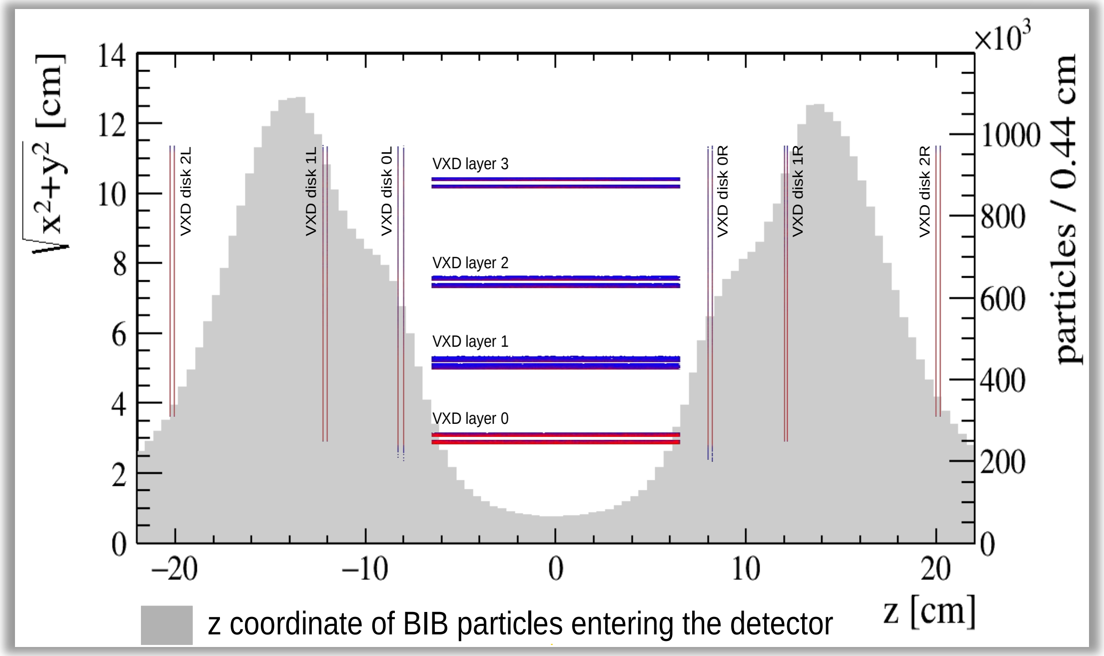
- Low momentum particles
- Partially out of time with respect to beam crossing t_0

Nevertheless, huge number of particles arrives on the detector

Impact of the Beam-Induced Background on tracker design

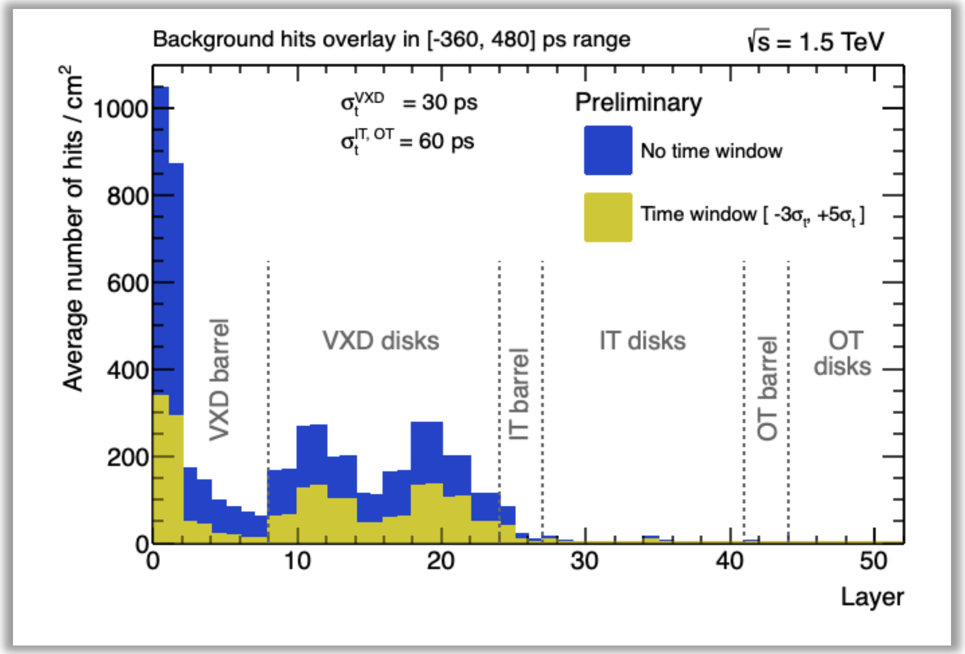
Locate tracker layers avoiding beam hot spots, or design IR that do not generate hot spots.

Preliminary



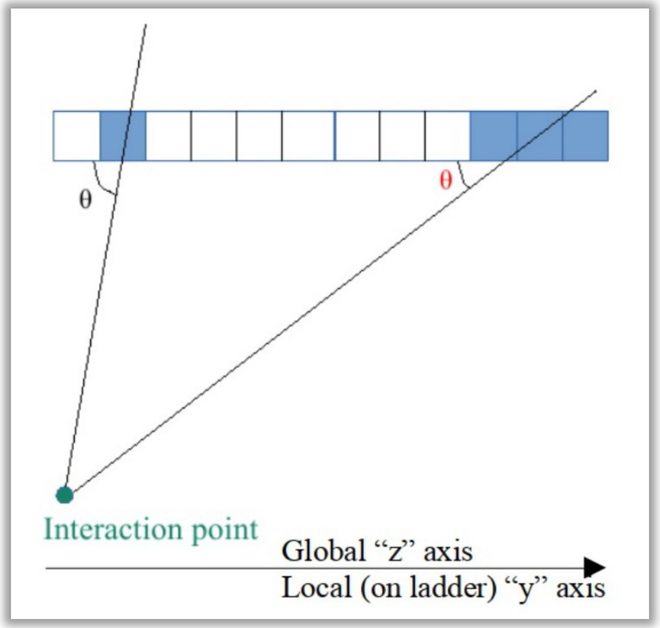
Require sensor with good time resolution to reduce hits from out-of-time background. Effectiveness at high energies to be studied.

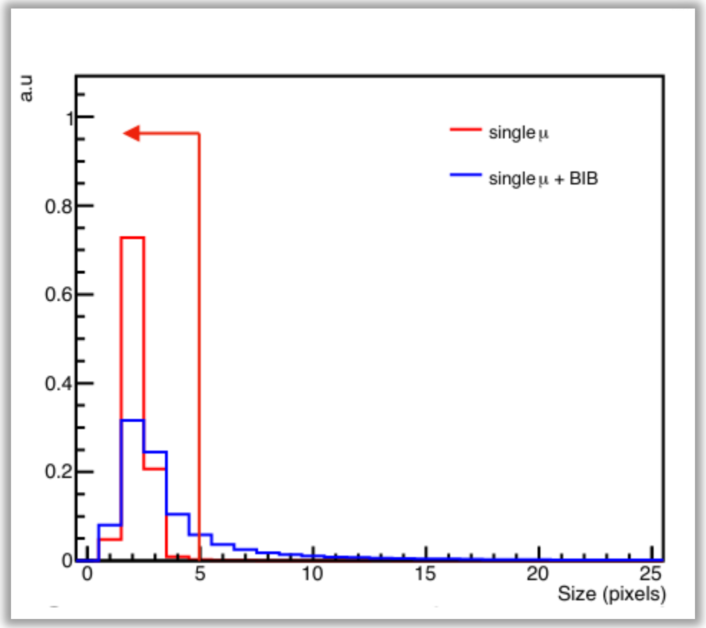
Preliminary



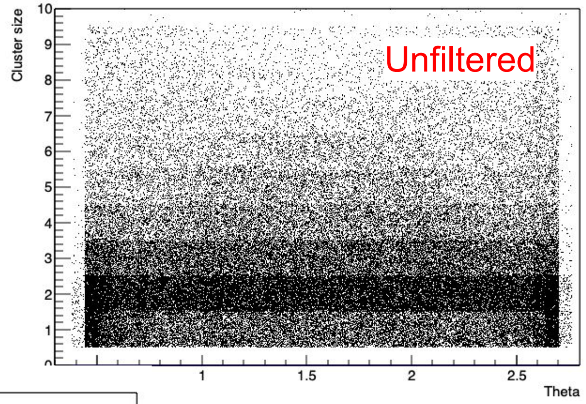
Impact of the Beam-Induced Background on track reconstruction

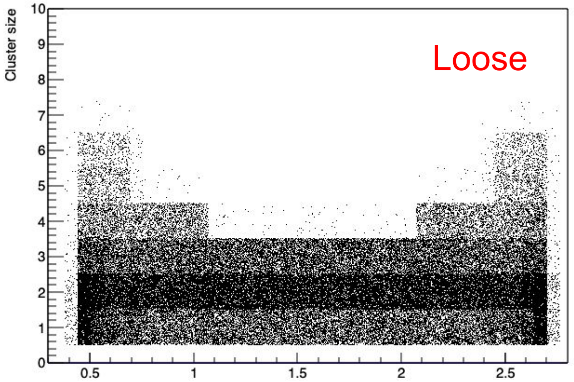
Realistic digitization reduce BIB hits





N. Bruhwiler
S. Pagan Griso

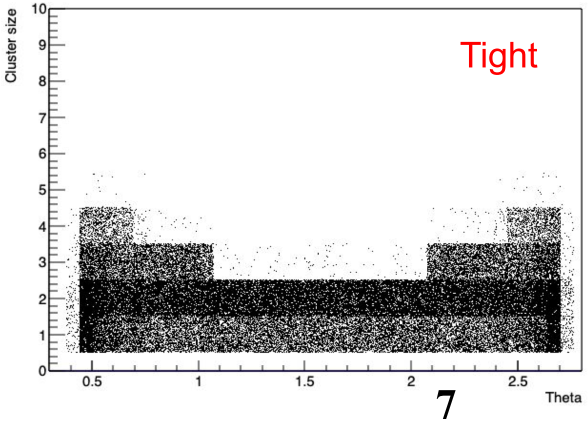




81% kept

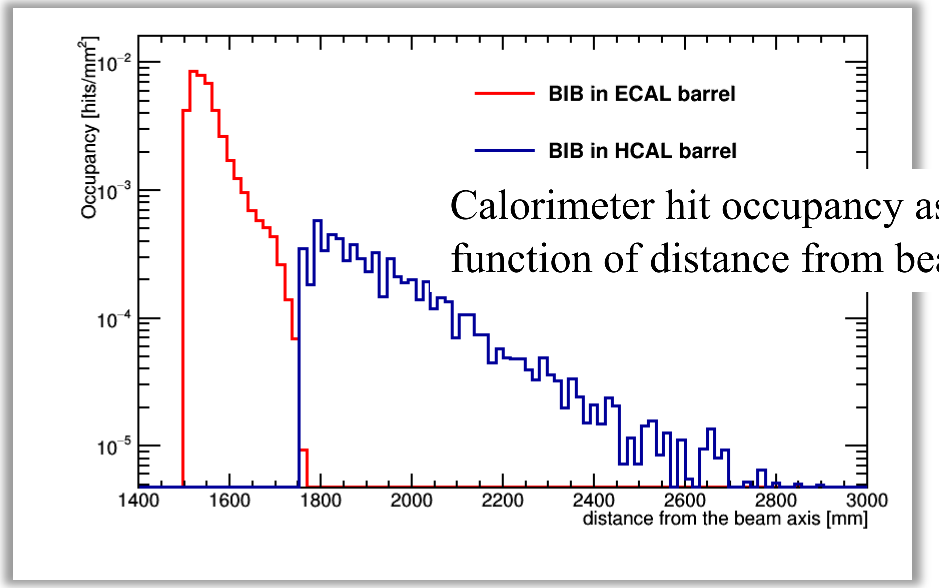
K. Krikza *Detector and Reconstruction Performance* for Snowmass 2022

65% kept

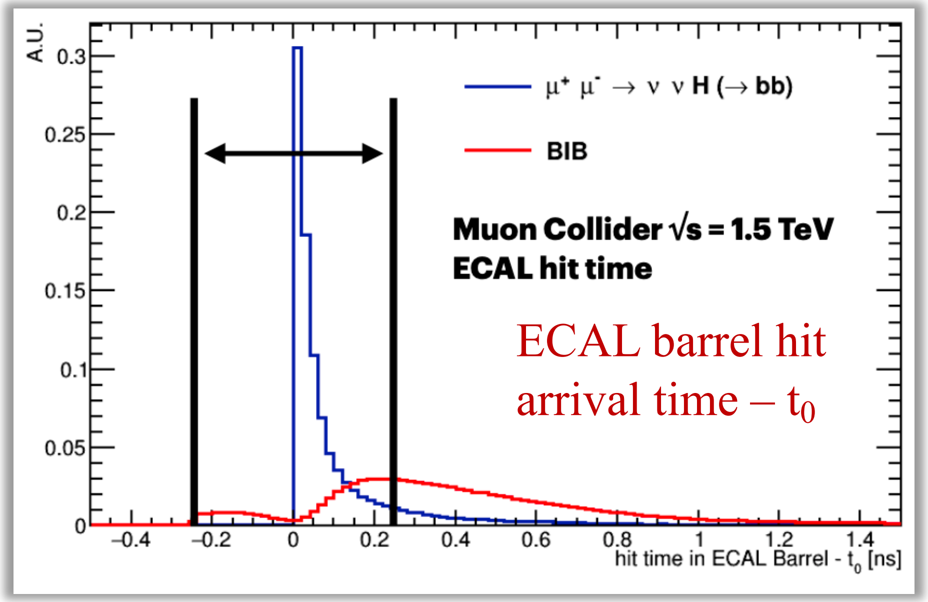


Efficiency: 100% for track reconstruction

Impact of the Beam-Induced Background on Calorimeter

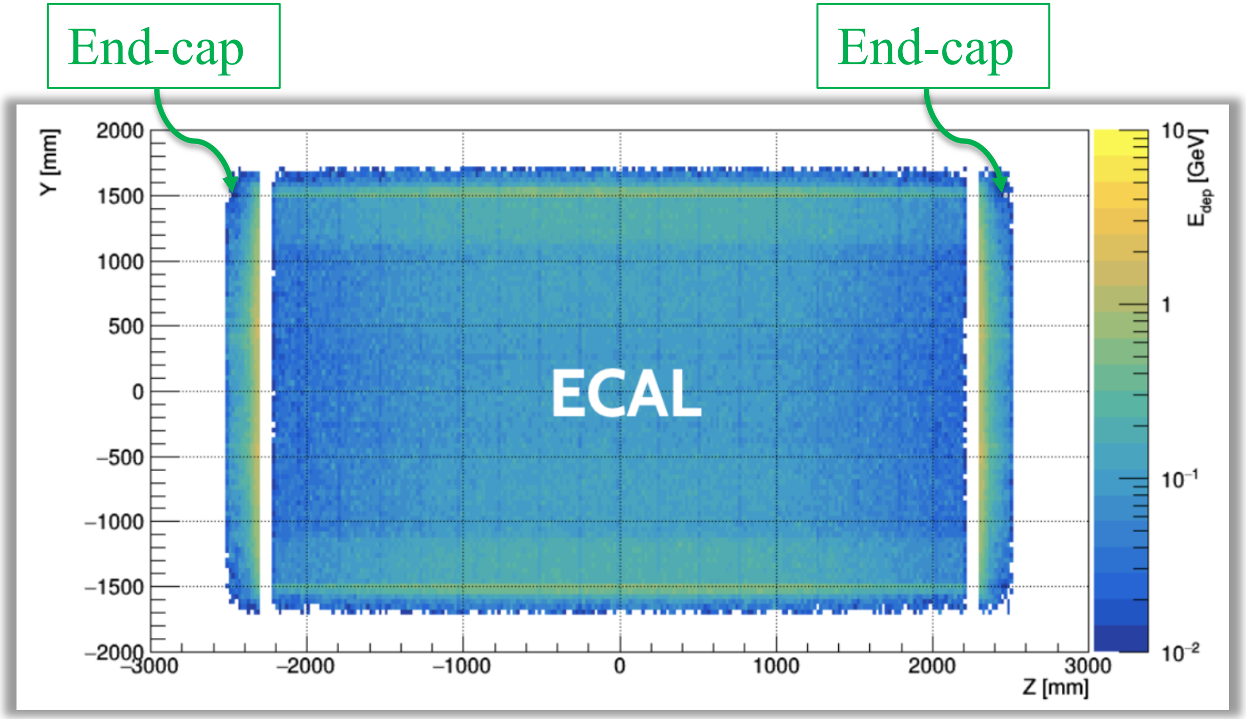


Calorimeter hit occupancy as function of distance from the beam axis



ECAL barrel hit arrival time – t_0

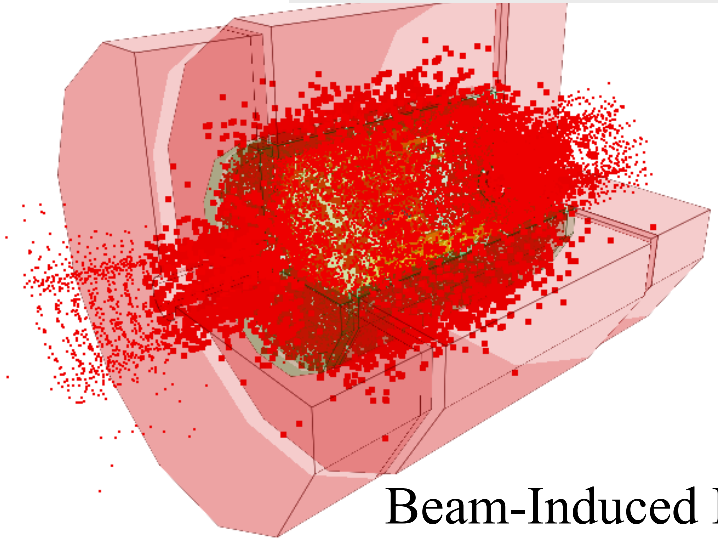
Lorenzo Sestini & Massimo Casarsa



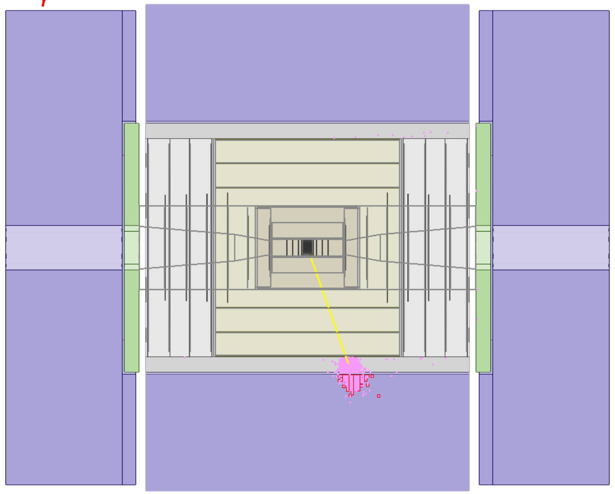
Energy distribution in the calorimeter endcap region

Impact of the Beam-Induced Background on Calorimeter Reconstruction

Lorenzo Sestini & Massimo Casarsa



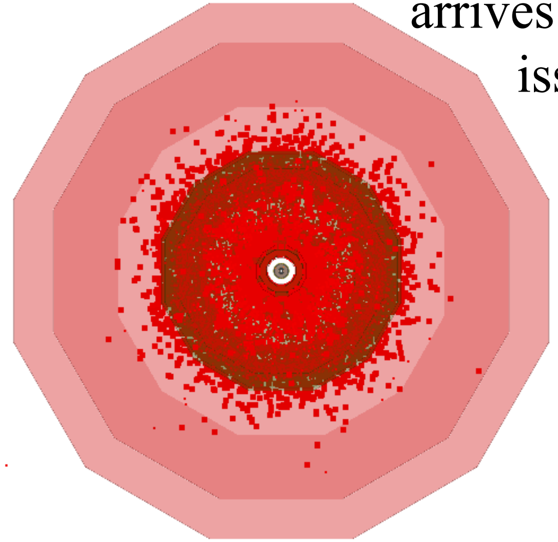
Create an issue in the object reconstruction

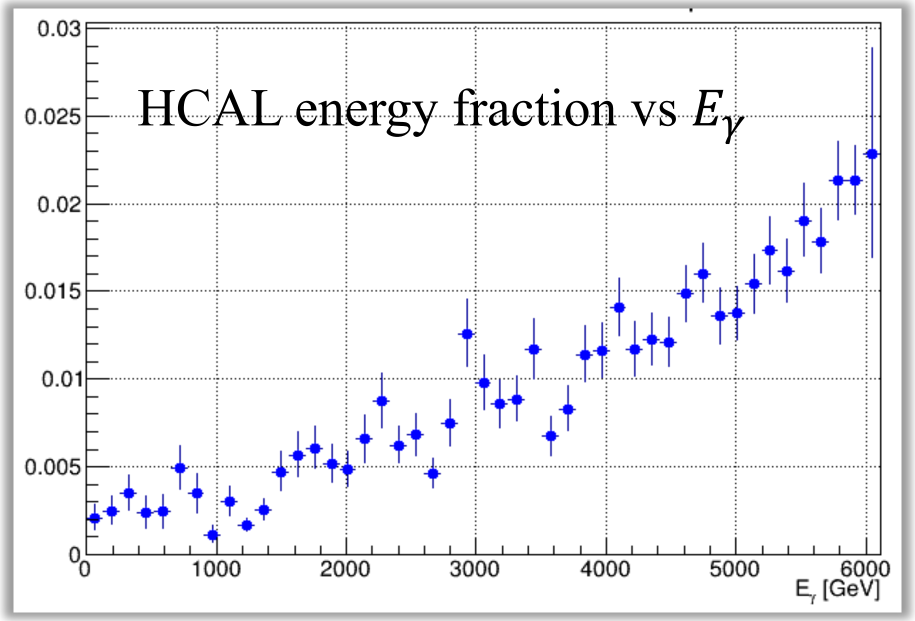


Photon gun

No Beam-Induced Background

Beam-Induced Background arrives to HCAL but not an issue





Is that all we can do?

Would it be possible to design a different Interaction Region that reduced the Beam-Induced Background?

Is there room for nozzle optimization?

First look at different center-of-mass energies keeping the same nozzle

Number of each particle type arriving to the detector

Monte Carlo simulator	MARS15	MARS15	FLUKA	FLUKA	FLUKA
Beam energy [GeV]	62.5	750	750	1500	5000
μ decay length [m]	$3.9 \cdot 10^5$	$46.7 \cdot 10^5$	$46.7 \cdot 10^5$	$93.5 \cdot 10^5$	$311.7 \cdot 10^5$
μ decay/m/bunch	$51.3 \cdot 10^5$	$4.3 \cdot 10^5$	$4.3 \cdot 10^5$	$2.1 \cdot 10^5$	$0.64 \cdot 10^5$
Photons ($E_\gamma > 0.1$ MeV)	$170 \cdot 10^6$	$86 \cdot 10^6$	$51 \cdot 10^6$	$70 \cdot 10^6$	$107 \cdot 10^6$
Neutrons ($E_n > 1$ MeV)	$65 \cdot 10^6$	$76 \cdot 10^6$	$110 \cdot 10^6$	$91 \cdot 10^6$	$101 \cdot 10^6$
Electrons & positrons ($E_{e^\pm} > 0.1$ MeV)	$1.3 \cdot 10^6$	$0.75 \cdot 10^6$	$0.86 \cdot 10^6$	$1.1 \cdot 10^6$	$0.92 \cdot 10^6$
Charged hadroms ($E_{h^\pm} > 0.1$ MeV)	$0.011 \cdot 10^6$	$0.032 \cdot 10^6$	$0.017 \cdot 10^6$	$0.020 \cdot 10^6$	$0.044 \cdot 10^6$
Muons ($E_{\mu^\pm} > 0.1$ MeV)	$0.0012 \cdot 10^6$	$0.0015 \cdot 10^6$	$0.0031 \cdot 10^6$	$0.0033 \cdot 10^6$	$0.0048 \cdot 10^6$

Nozzle optimized

Same nozzle optimized for 750

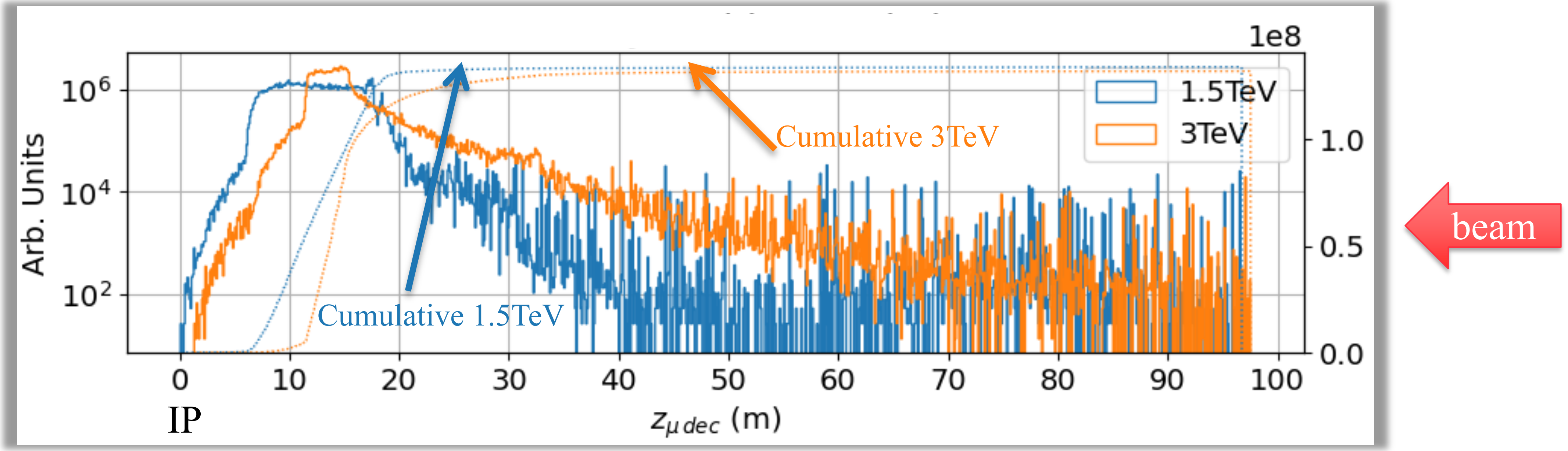
The nozzle dominates the particle flux arriving to the detector

Preliminary Considerations of the Interaction Region effect on Beam-induced Background

Comparison of 1.5 TeV and 3 TeV CoM energy: effect of the beam energy

- IR at 1.5 TeV and 3 TeV designed by MAP, L*=6 m, solenoid magnetic field 3.57 T
- Beam-induced Background generated with FLUKA
- Compare what arrives on the detector with same nozzle

Z position of muon decay producing particles arriving to the detector



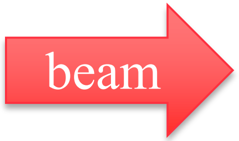
- The region where the muon decays contribute to the Beam-Induced background slightly larger at lower energy
- Primary muons decay to include Beam-Induced background : @1.5TeV z_μ <25m @3TeV z_μ <40m

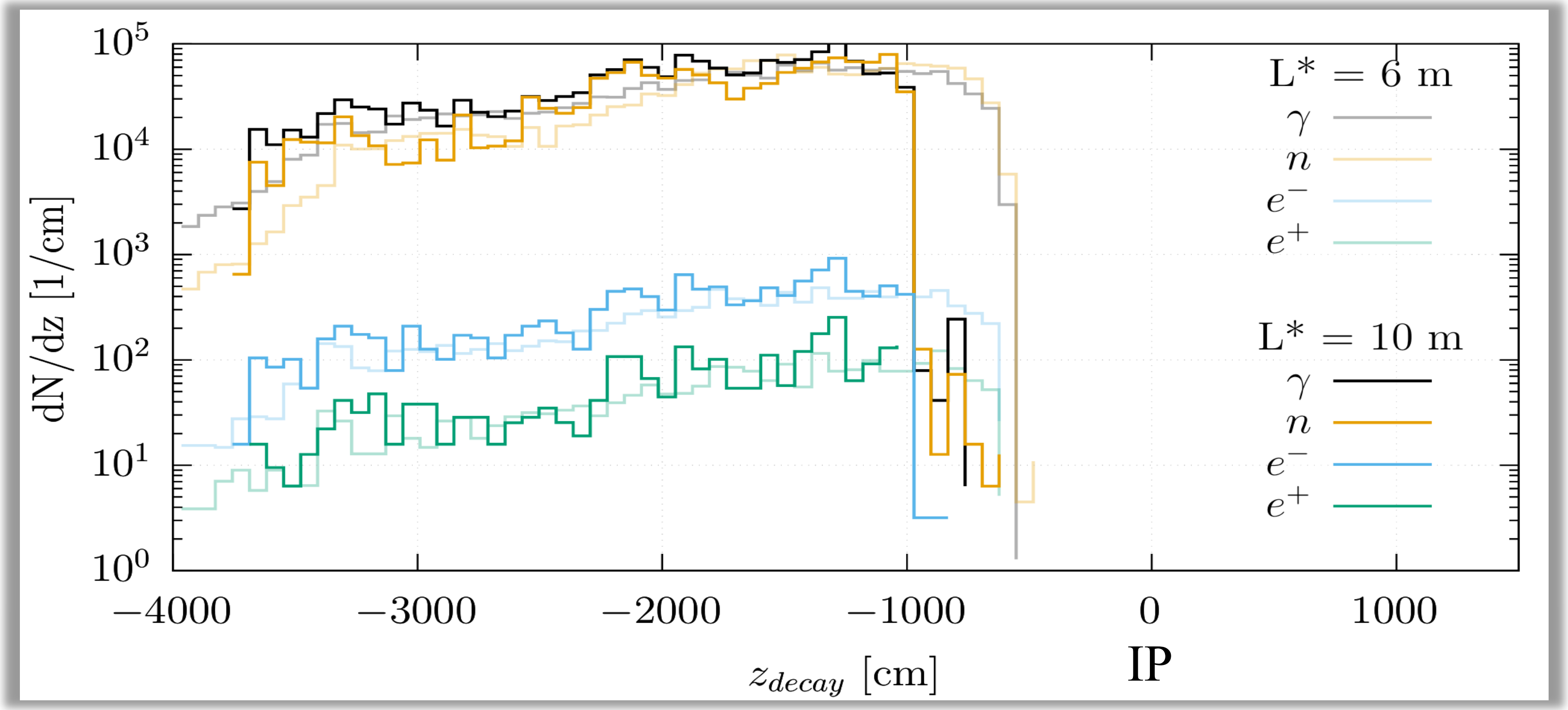
Comparison different L* at 10 TeV on Beam-Induced Background

- IR at 10 TeV designed by CERN L* = 6 m and 10 m, solenoid magnetic field 5 T
- Beam-induced Background generated with FLUKA
- Compare what arrives on the detector with same nozzle (1.5 TeV)

Daniele Calzolari (CERN)
MDI Study meeting 9-12-2022
https://indico.cern.ch/event/1227265/

Z position of muon decay producing particles arriving to the detector





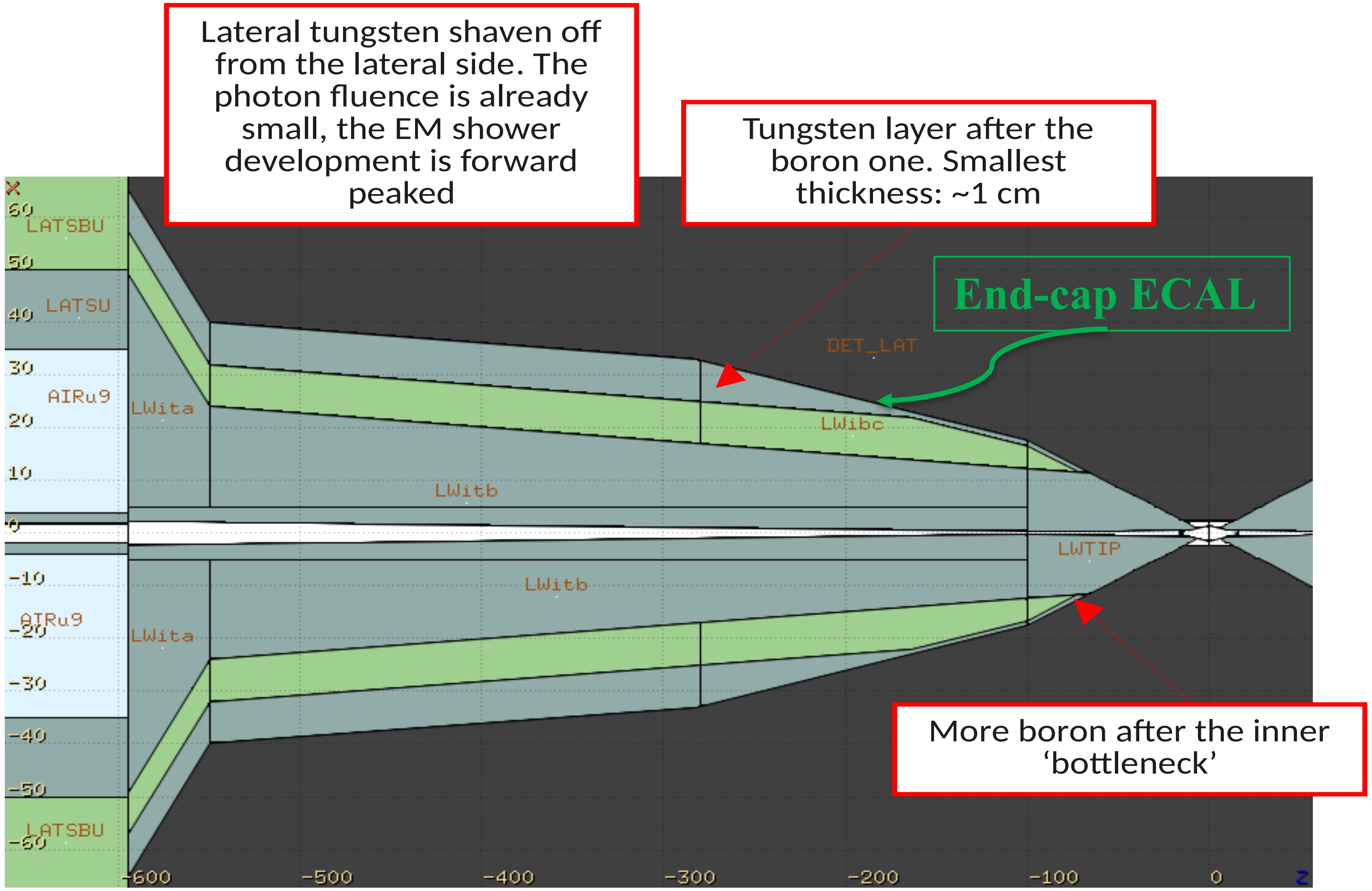
Longer L* seems beneficial to reduce Beam-Induced Background on the detector

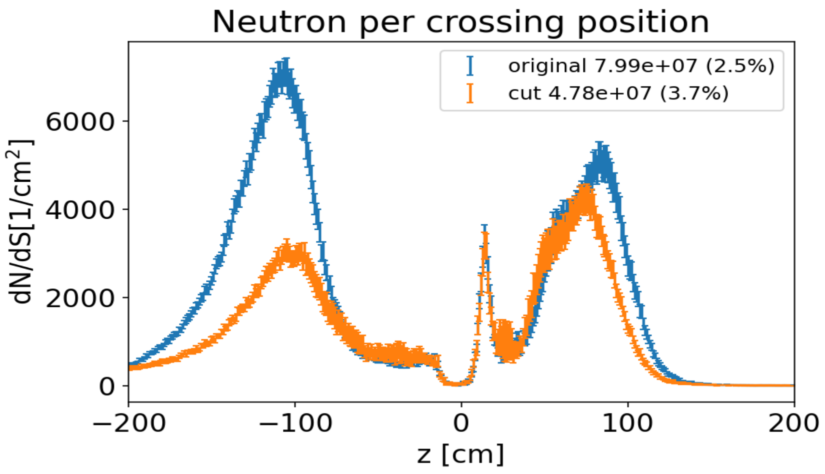
Preliminary Nozzle Optimization

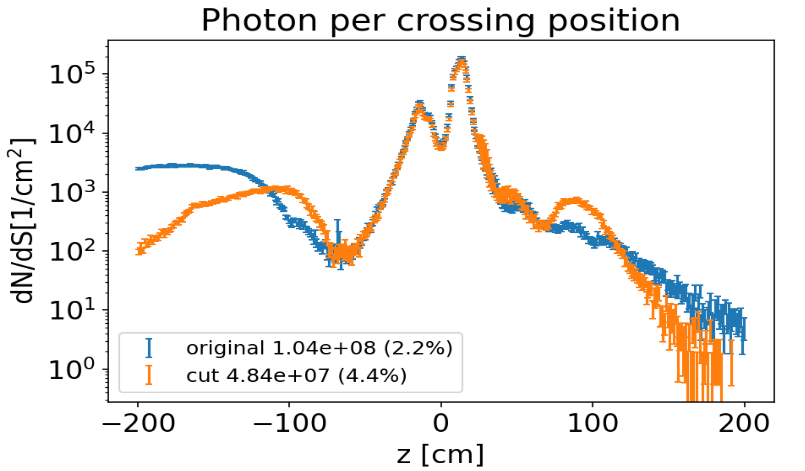
Current nozzle optimization: nozzle shape

Daniele Calzolari (CERN) IMCC Annual Meeting
https://indico.cern.ch/event/1175126/timetable/#20221012

- Considering the particle fluences in the **nozzle**, a tentative nozzle geometry reshaping has been conducted.







Current nozzle optimization: nozzle shape

Daniele Calzolari (CERN) IMCC Annual Meeting
https://indico.cern.ch/event/1175126/timetable/#20221012

- Considering the particle fluences in the **nozzle**, a tentative nozzle geometry reshaping has been conducted.

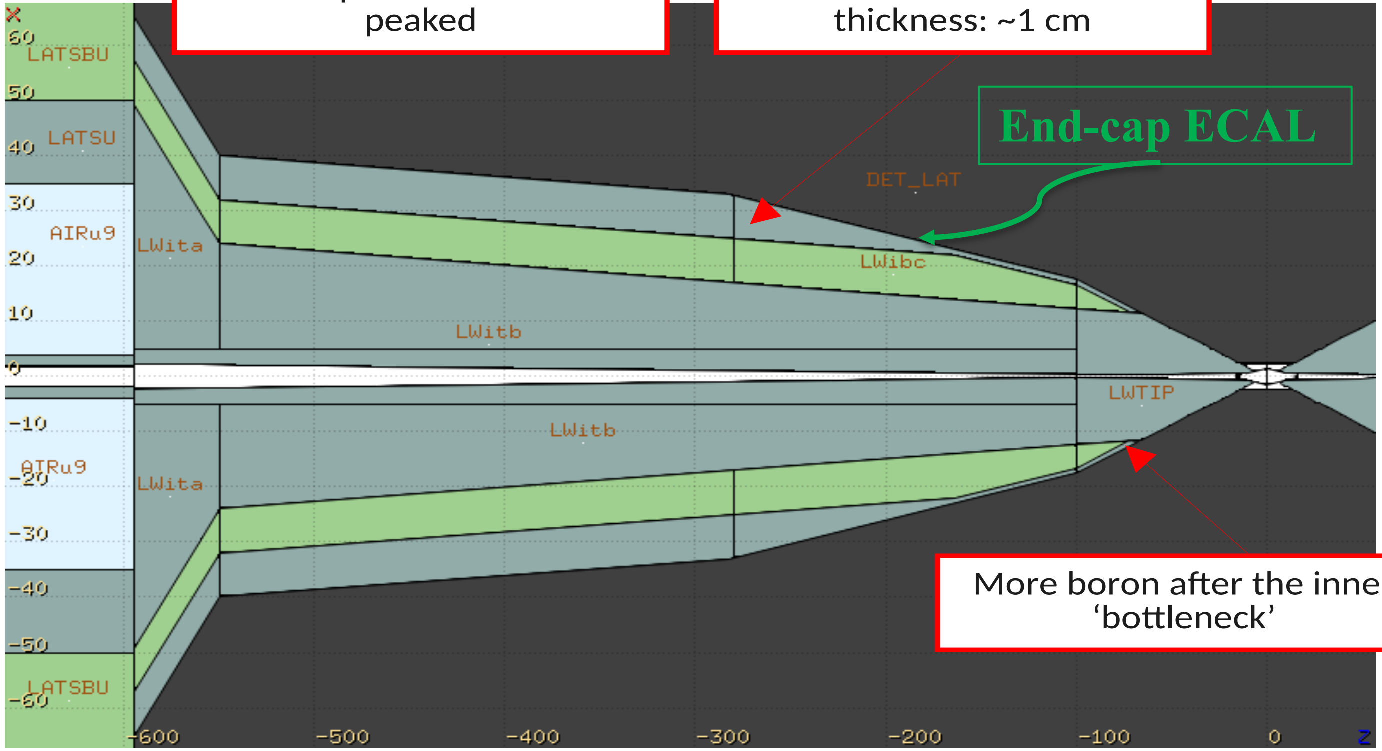
Effect on detector occupancy to be studied

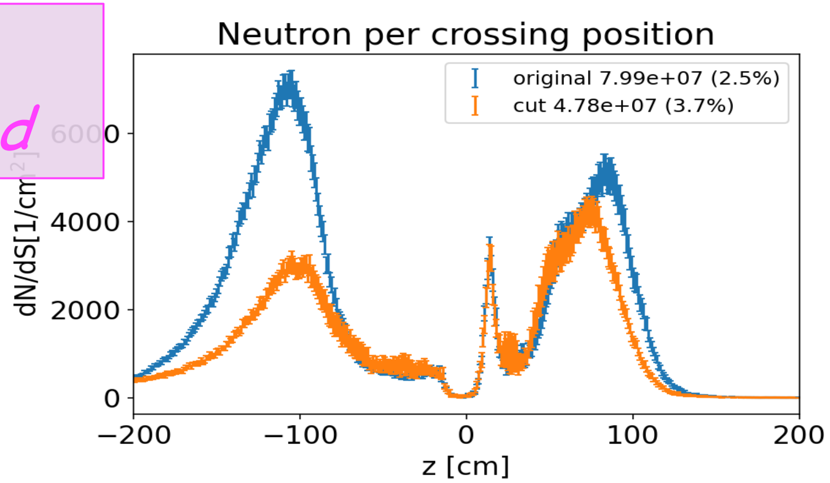
Lateral tungsten shaven off from the lateral side. The photon fluence is already small, the EM shower development is forward peaked

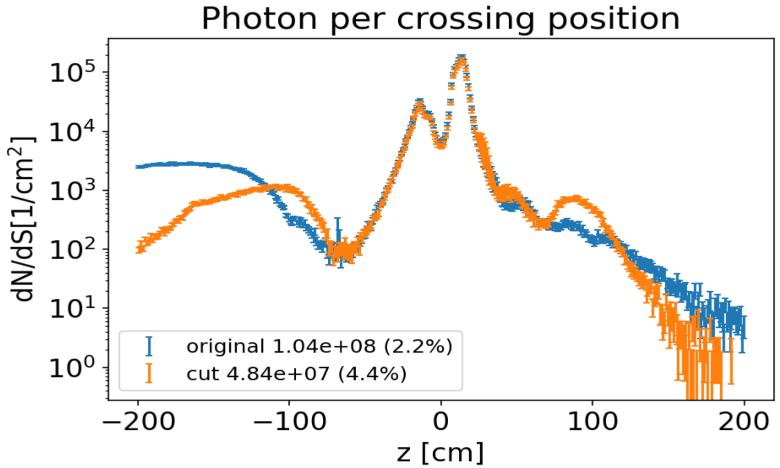
Tungsten layer after the boron one. Smallest thickness: ~1 cm

End-cap ECAL

More boron after the inner ‘bottleneck’







Current nozzle optimization: angle tip

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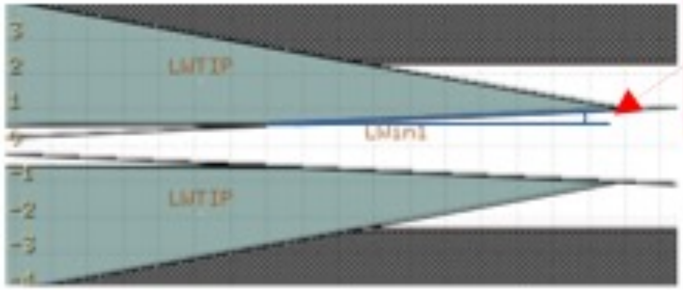
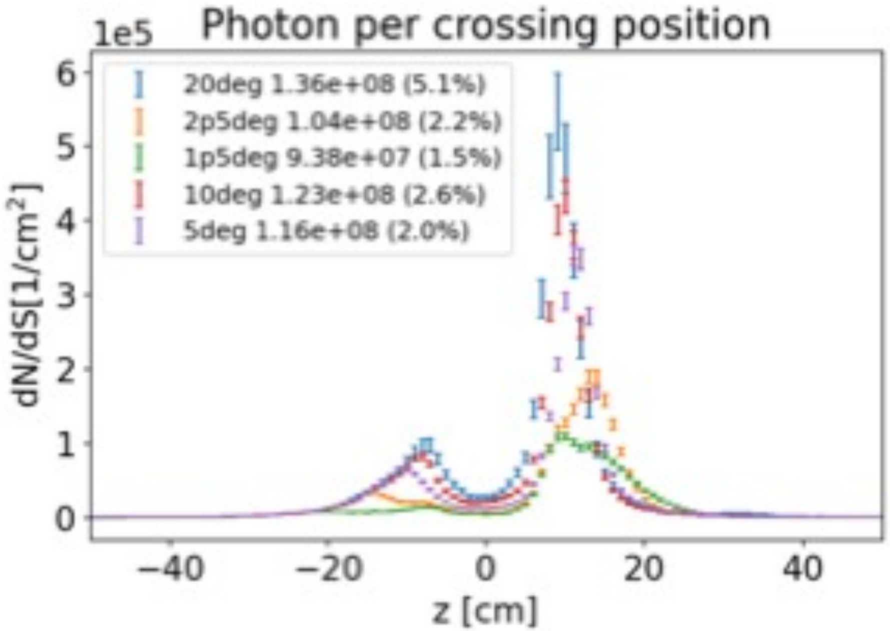
https://indico.cern.ch/event/1175126/timetable/#20221012

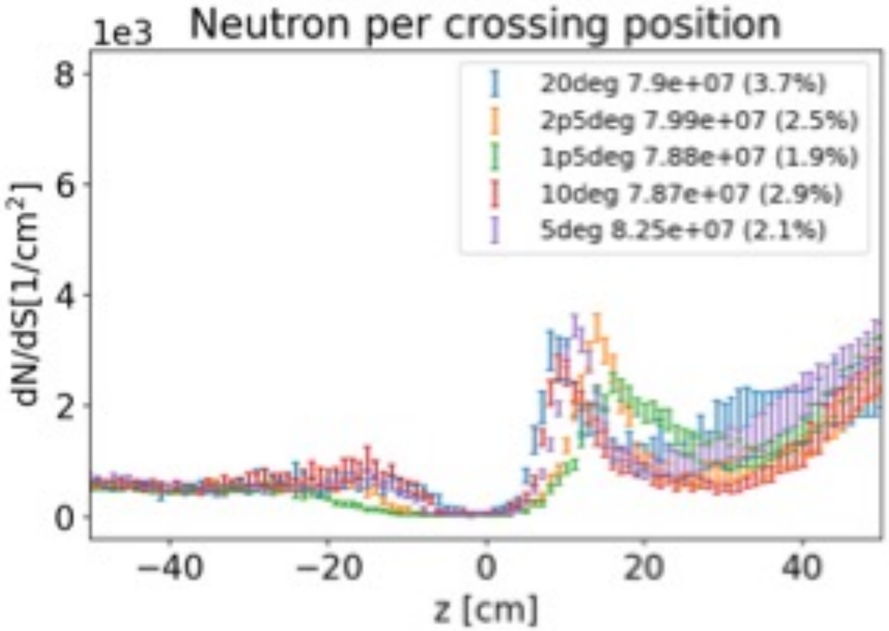
- Considering the aperture of the **nozzle**, various **angles** have been tested. The scope of the optimization of these parameters, is not to reduce the overall number of particles going into the detectors, but to **reduce** their **peaks**.
- The results shows a clear advantage to **reduce the tip angle** down to very small values.



Starting from 2.5 deg, we modify this angle.

Effect on detector occupancy to be studied

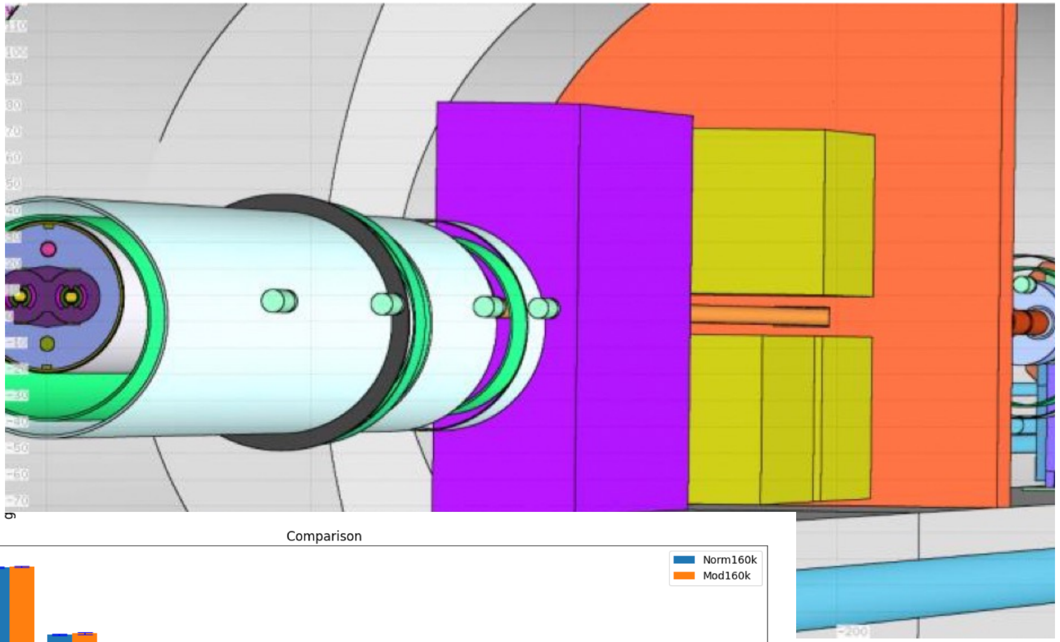


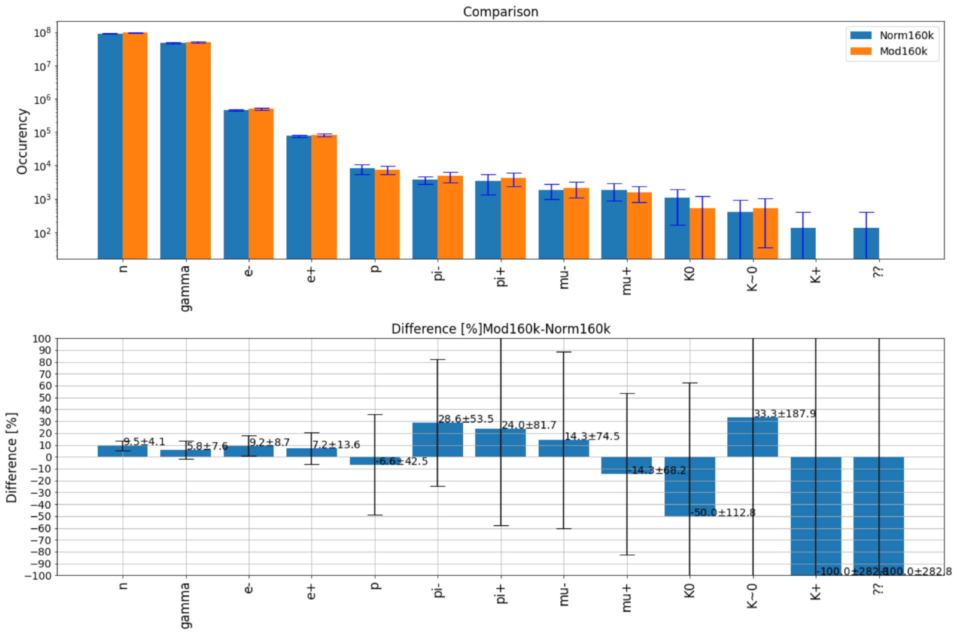


The Tool to Generate and Study Beam-Induced Background

ternational
ON Collider
aboration

The Software

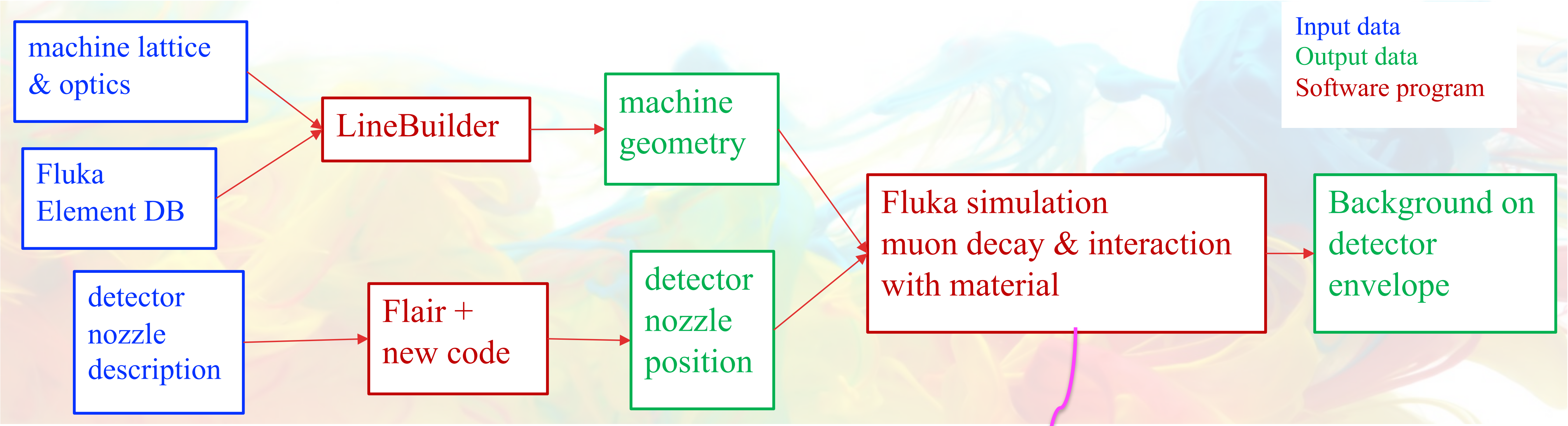




Francesco Collamati (INFN) IMCC Annual Meeting
https://indico.cern.ch/event/1175126/timetable/#20221012

- FLUKA + LineBuilder used to reconstruct the machine geometry in the simulation
  - Direct connection between optics files and Monte Carlo
    - Easy to test the effect of possible variations in the machine configuration, beam energy, MDI optimization..
- (semi) Automized analysis program to quickly evaluate the effect of any modification

Software workflow



It would be great to have also a MARS15 Beam-Induced Background generation…

Summary

- Effects of the Beam-Induced Background on the detector for some (few) center-of mass energies have been and are being studied.

- Preliminary studies show that the nozzle is the key element to determine the flux of particles on the detector and their characteristics, momentum and energy.

- Detector design and optimization is a complex process, it involves IR design, absorbers, nozzle, detector and magnetic field.

- The interaction region design plays a crucial role in the detector design for muons collisions studies and therefore in physics performance

All the studies and the activities presented are being performed in the Physics and Detector Performance Group which includes Europe, US and Cina.