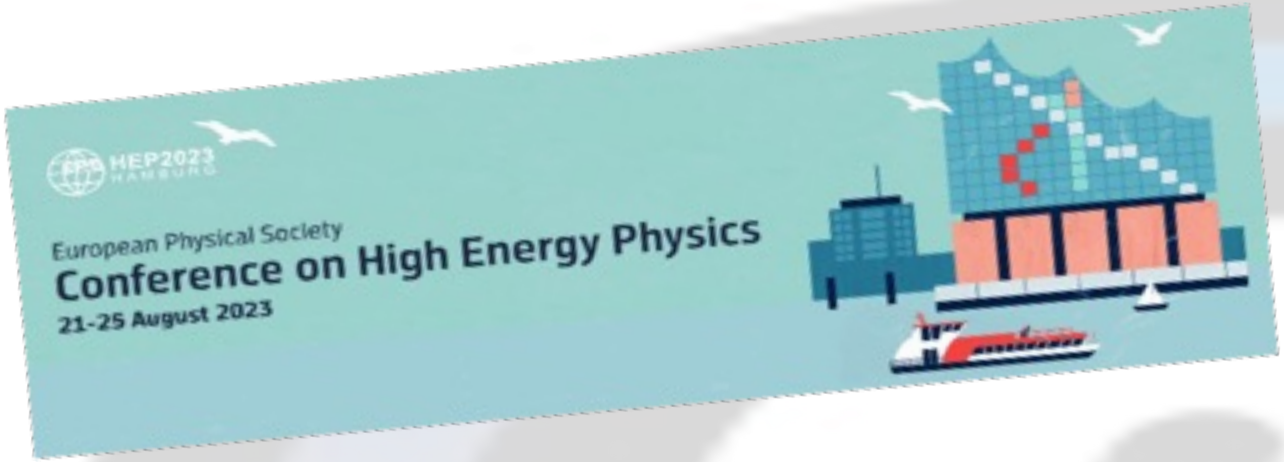


This project has received funding from the European Union's Research and Innovation programme under GA No 101094300.

MuCol

International MUON Collider Collaboration

aMUSE

Machine-Detector interface for multi-TeV Muon Collider

Nazar Bartosik, Daniele Calzolari, Luca Castelli, Anton Lechner and
Donatella Lucchesi
For International Muon Collider Collaboration

Università degli Studi di Padova

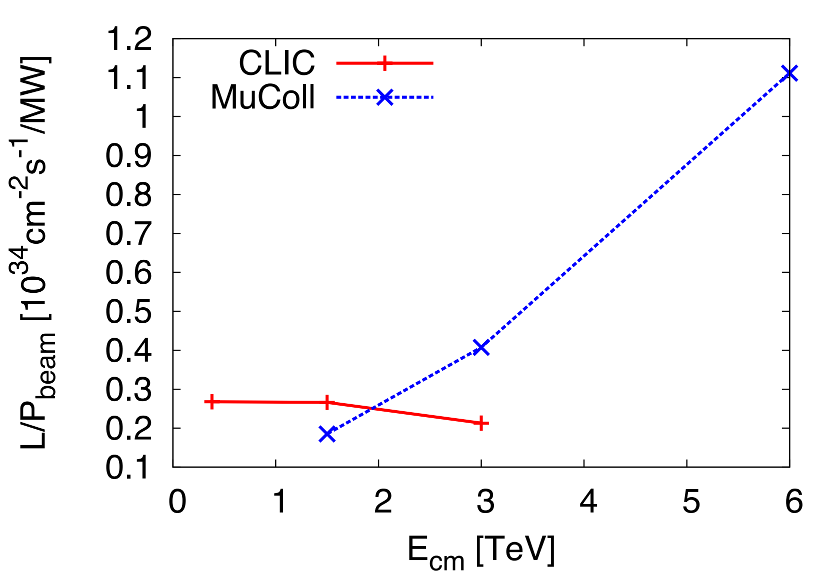
CERN

INFN Istituto Nazionale di Fisica Nucleare

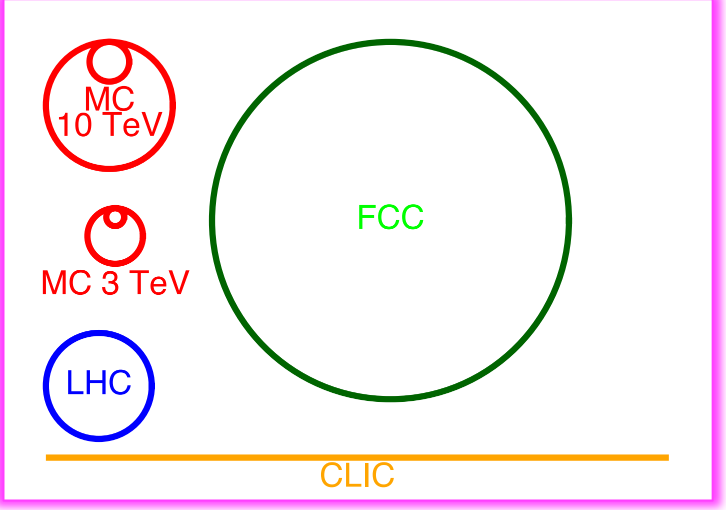
Muon Collider: the next generation machine

High center of mass energy & high luminosity & power efficient: luminosity increase per beam power

Parameter	Symbol	Unit	Target value		
Centre-of-mass energy	E_{cm}	TeV	3	10	14
Luminosity	$\mathfrak{L}$	$1 \times 10^{34}\,cm^{-2}\,s^{-1}$	2	20	40
Collider circumference	C_{coll}	km	4.5	10	14
Muons/bunch	$N_\pm$	1×10^{12}	2.2	1.8	1.8
Repetition rate	f_r	Hz	5	5	5
Total beam power	$P_- + P_+$	MW	5.3	14	20
Longitudinal emittance	ε_l	MeV m	7.5	7.5	7.5
Transverse emittance	$\varepsilon_\perp$	µm	25	25	25
IP bunch length	σ_z	mm	5	1.5	1.1
IP beta-function	$\beta^*_\perp$	mm	5	1.5	1.1
IP beam size	$\sigma_\perp$	µm	3	0.9	0.6



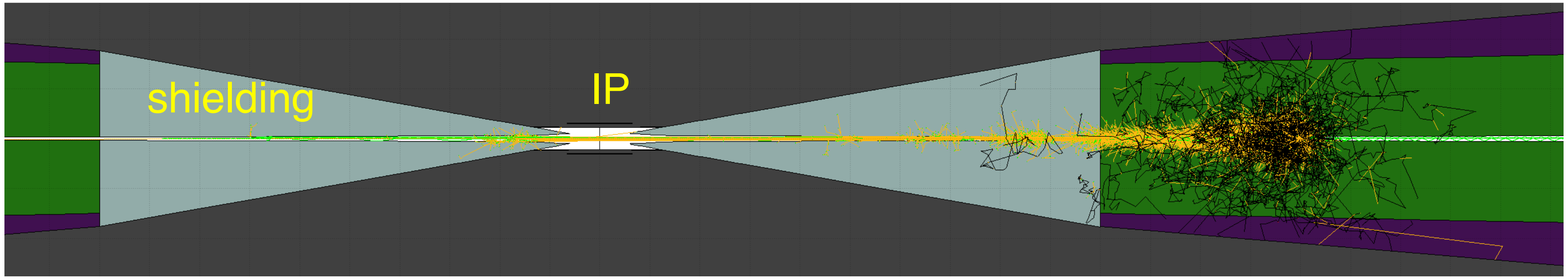
Compact: cost effective & sustainable



- M. Casarsa Higgs physics prospects at Muon Collider with a detailed detector simulation
- L. Sestini R&D towards the detector for the Muon Collider
- C. Aimè New physics and hidden sectors at Muon Collider
- F. Meloni Detecting disappearing tracks and other exotica at a Muon Collider
- K. Skoufaris Status of the International Muon Collider Complex Study at 10 TeV

Beam background sources in the detector region

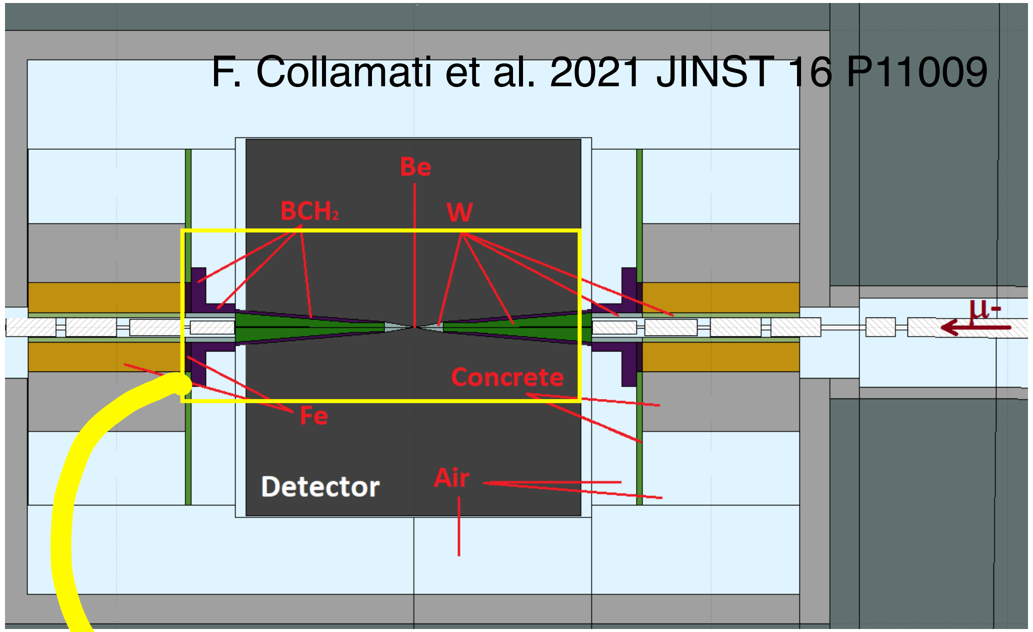
- ✗ Muon decay along the ring, $\mu^- \rightarrow e^-\bar{\nu}_e\nu_\mu$: dominant process at all center-of-mass energies
  - ❋ electromagnetic showers ⟹ electrons and photons
  - ❋ photons from synchrotron radiation from the energetic electrons in collider magnetic field
  - ❋ Photonuclear interaction with materials, mainly shielding, ⟹ hadronic component
  - ❋ Bethe-Heitler muon, $\gamma + A \rightarrow A' + \mu^+\mu^-$
- ✗ Incoherent e^-e^+ production $\mu^+\mu^- \rightarrow \mu^+\mu^-e^+e^-$: could be important at $\sqrt{s}\sim 10$ TeV
  - ❋ small transverse momentum e^-e^+ ⟹ trapped by detector magnetic field
- ✗ Beam halo: level of acceptable losses to be defined, not an issue now

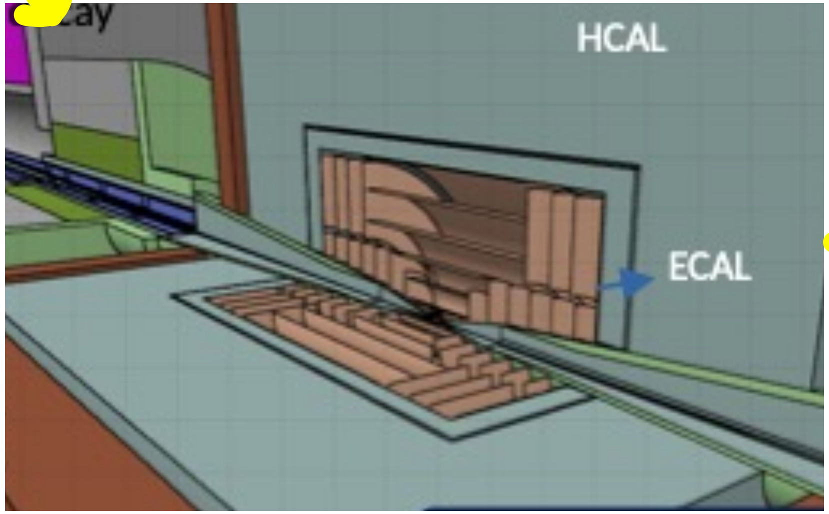


Single muon decay tracks

F. Collamati et al. 2021 JINST 16 P11009

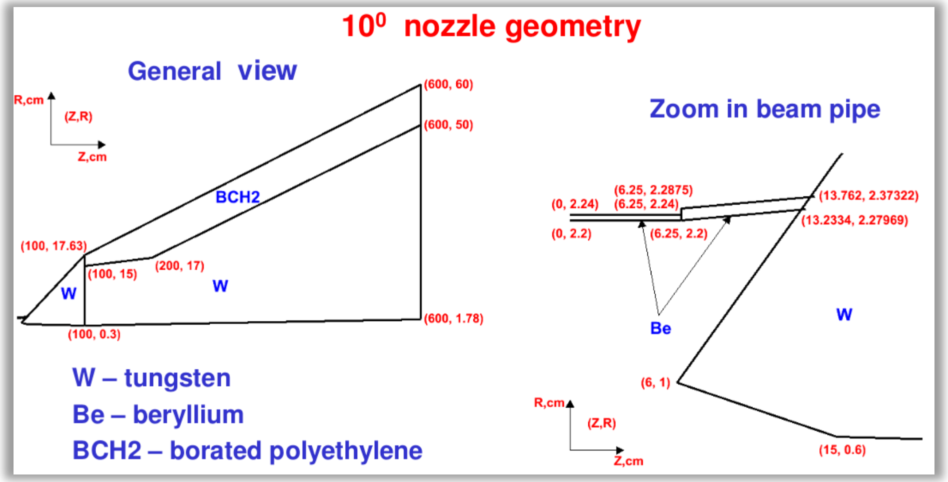
Shielding structure, the nozzles



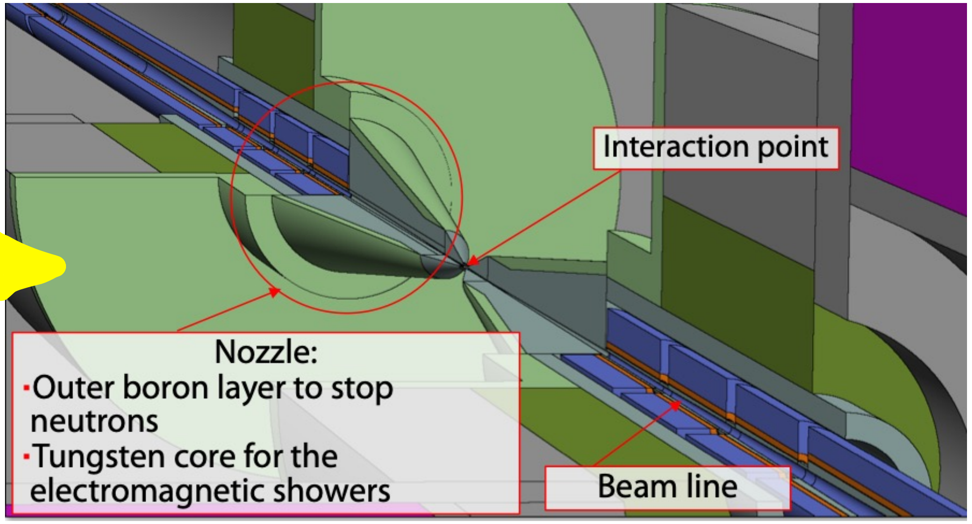


Designed by MAP (Muon Accelerator Program)

N.V. Mokhov et al. *Muon collider interaction region and machine-detector interface design* Fermilab-Conf-11-094-APC-TD



Optimized for $\sqrt{s} = 1.5$ TeV



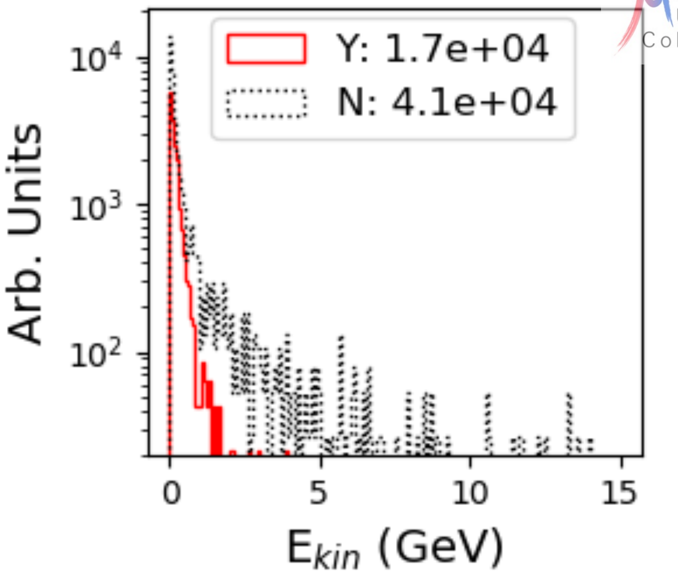
D. Calzolari [IMCC Ann. meeting Orsay 2023]

The effect of the nozzles

F. Collamati et al. 2021 JINST 16 P11009

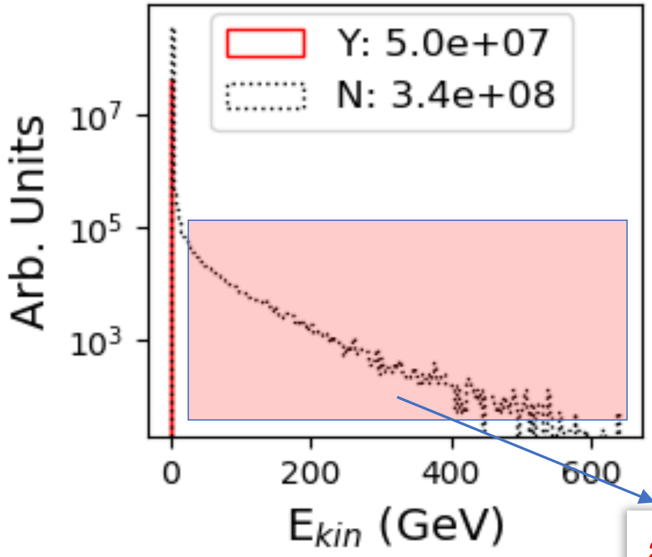
- Muon beam 0.75 TeV, IR designed by MAP
- Beam-induced Background generated with FLUKA
- Compare what arrives on the detector with and without the nozzle

charged hadrons

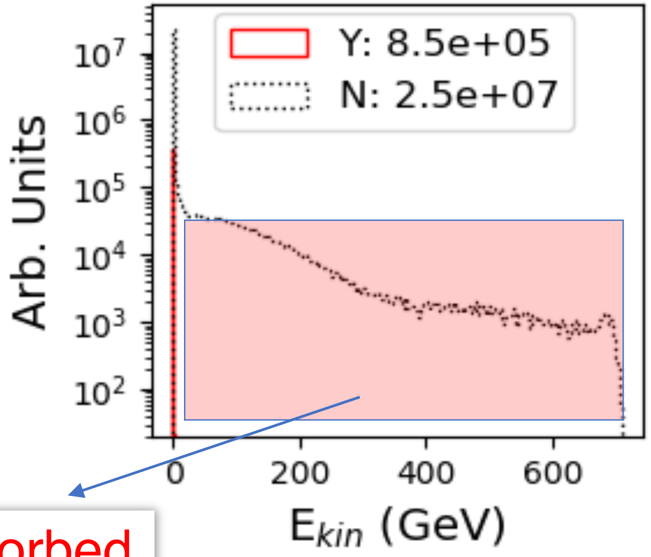


Charged hadrons absorbed

Photons

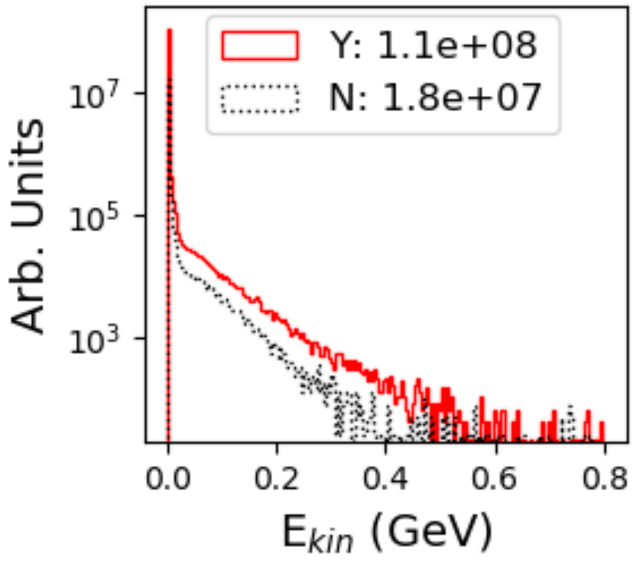


electrons/positrons



absorbed

neutrons



Neutrons increased

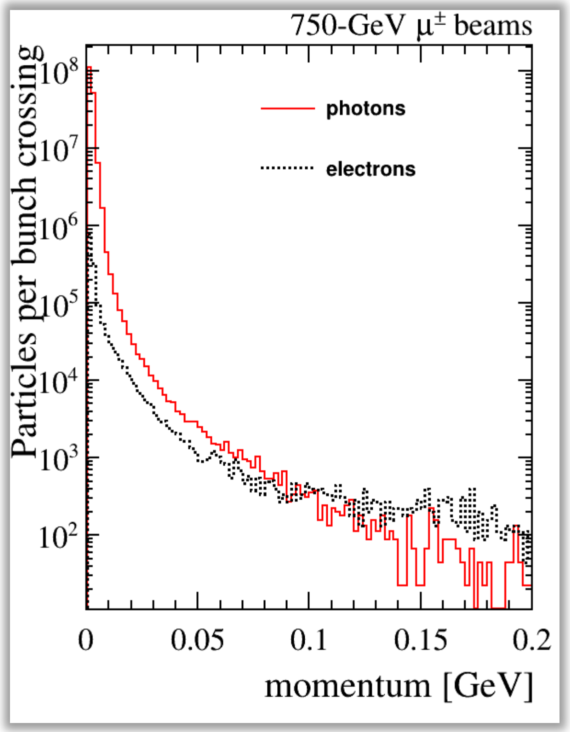
Without the nozzle the detector is flooded by high energy particles

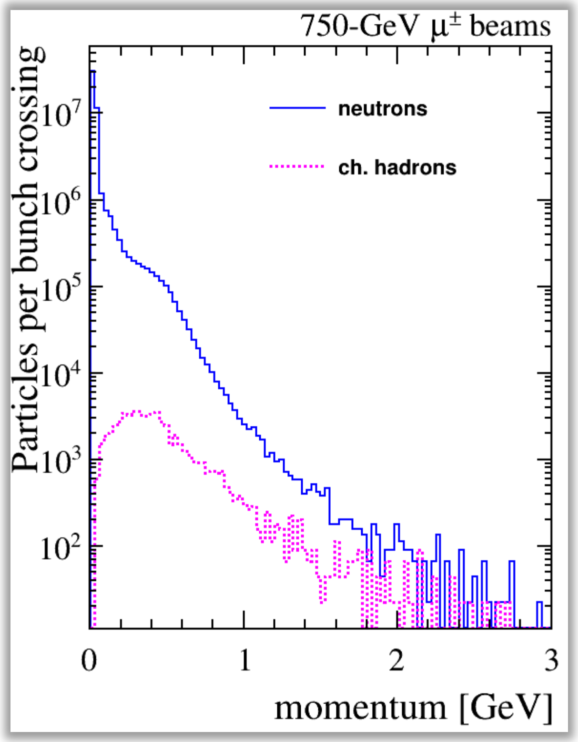
Survived beam-Induced background properties

Particles arriving on the detector with the nozzle:

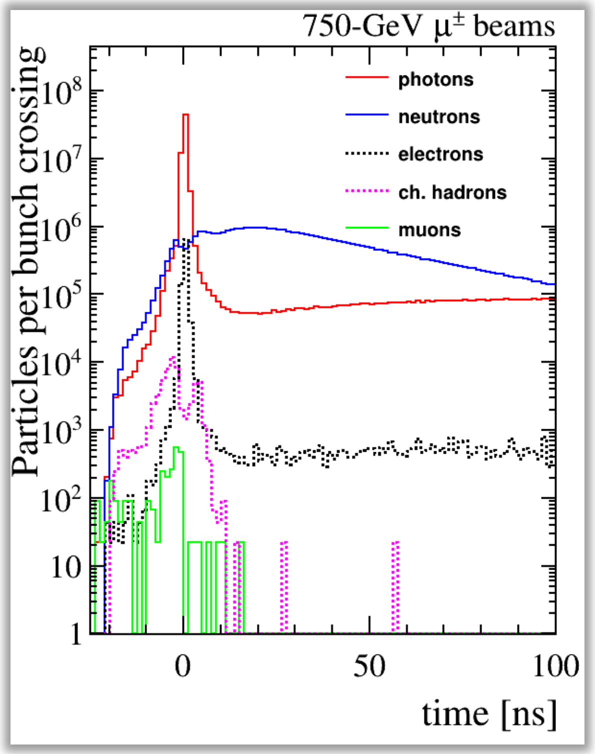
- Muon beam 0.75 TeV, IR designed by MAP
- Beam-induced Background generated with MARS15

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





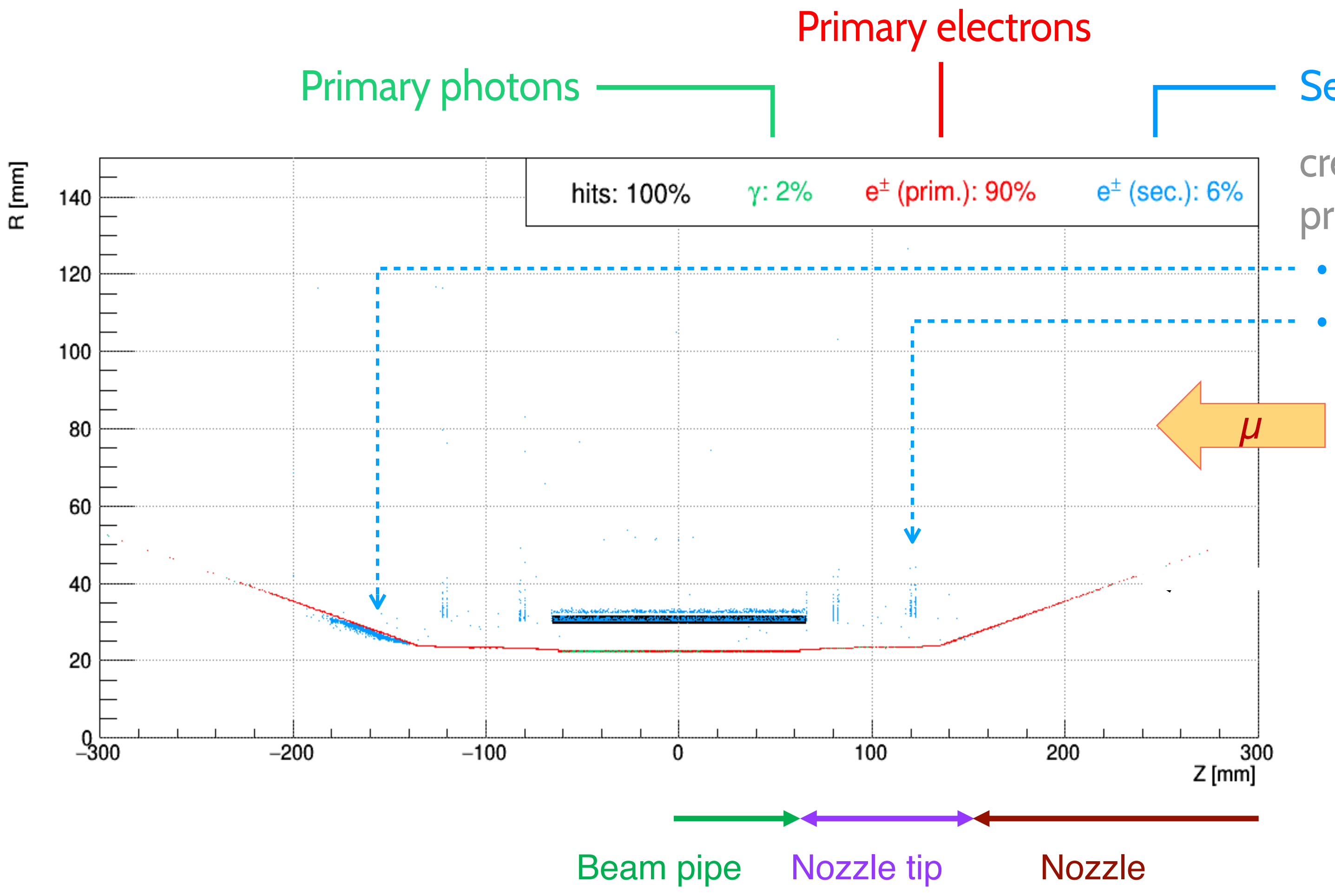
Low momentum particles



Detector read-out window [-1ns,15ns]
Partially out of time vs beam crossing t_0

Despite the nozzles, huge number of particles arrives on the detector

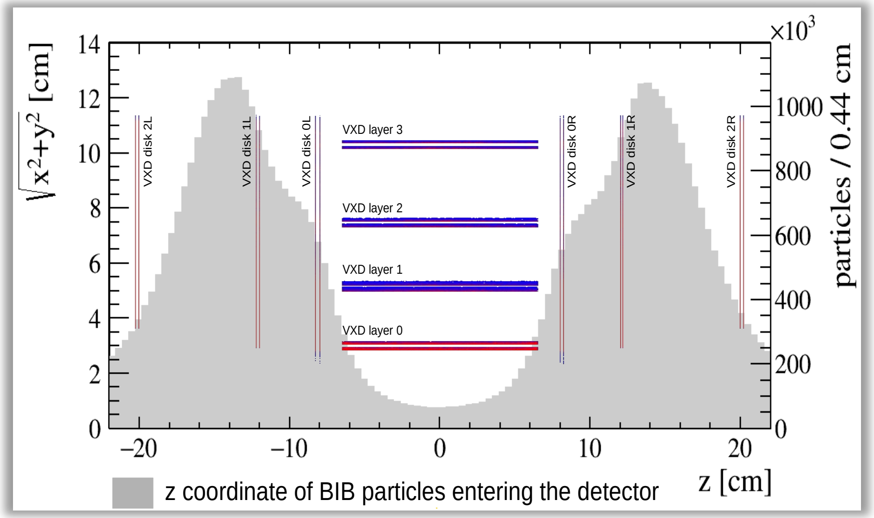
Origin of particles creating hits in the detector: tracker layer 0



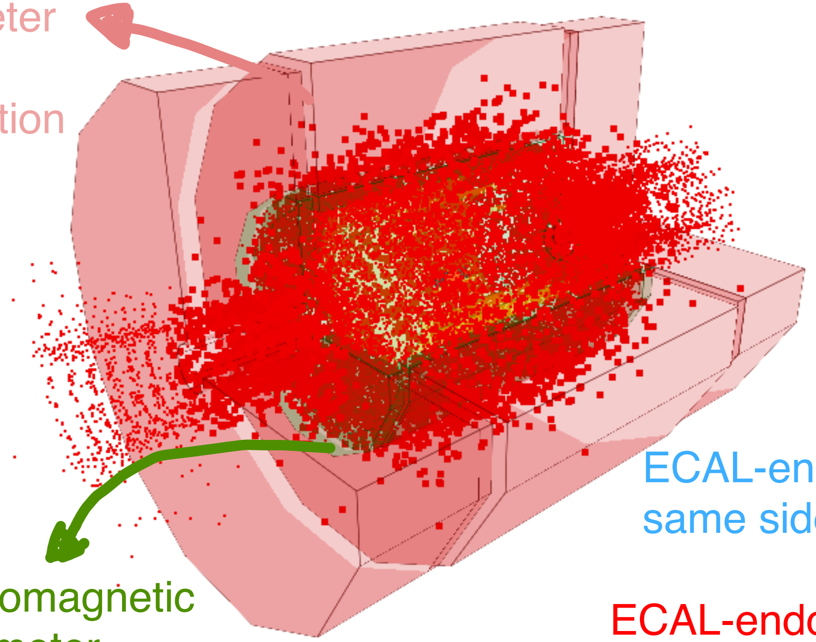
Secondary electrons created by interaction of primary photons with:

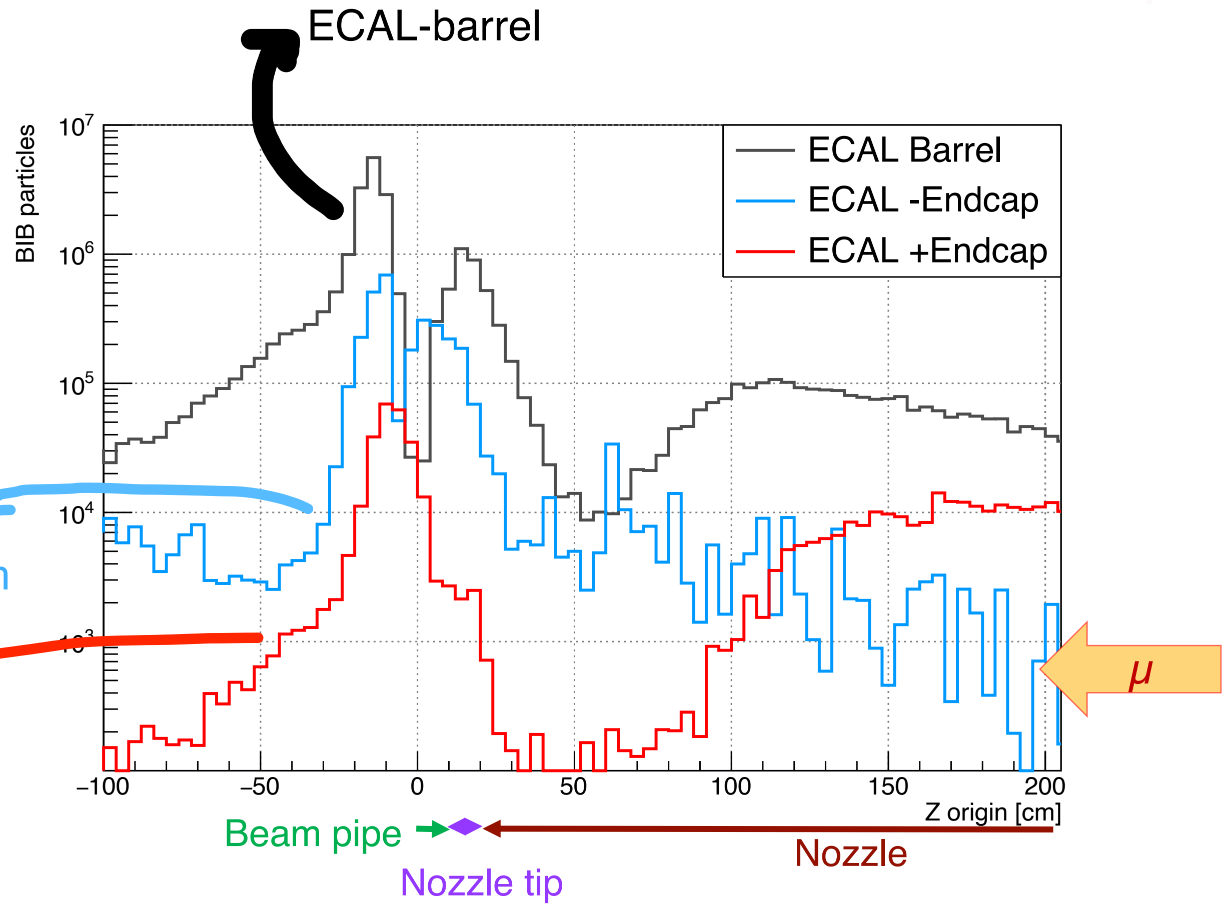
- MDI material
- detector material

Vertex layout



Origin of particles creating hits in the detector: calorimeter

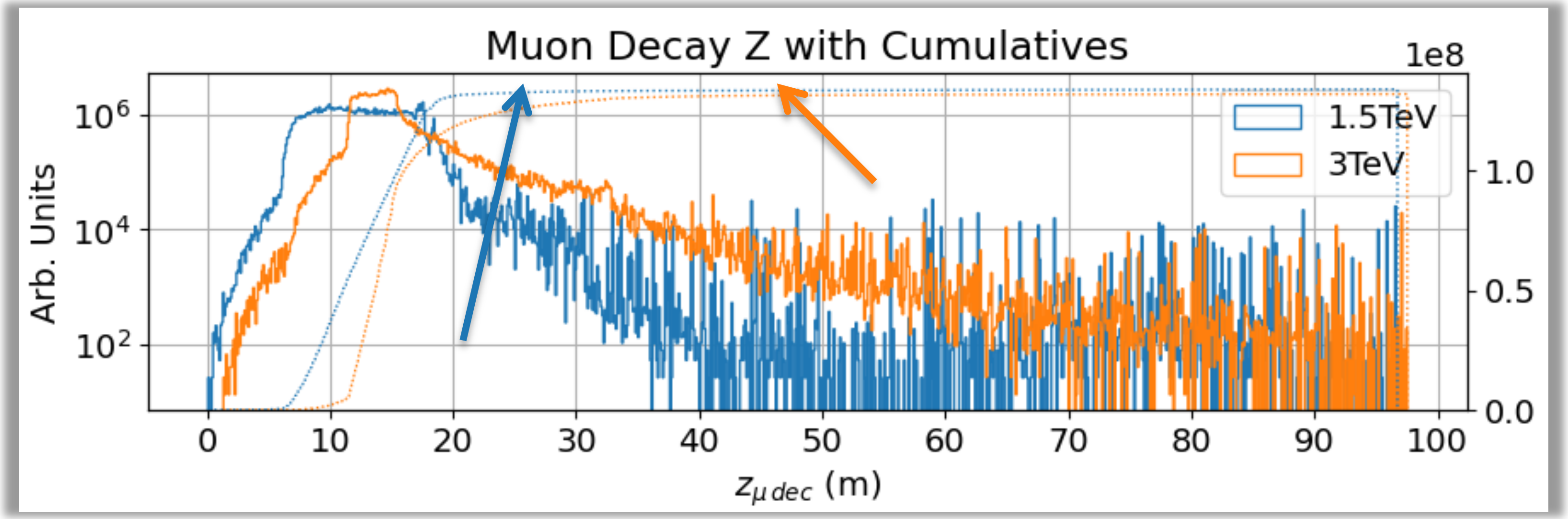




z position of the original particle background that generated a given hit in ECAL
Background dominated by photons, detailed study of the origin needed to mitigate effects on ECAL inner layers

Beam-induced background study at $\sqrt{s} = 3$ TeV

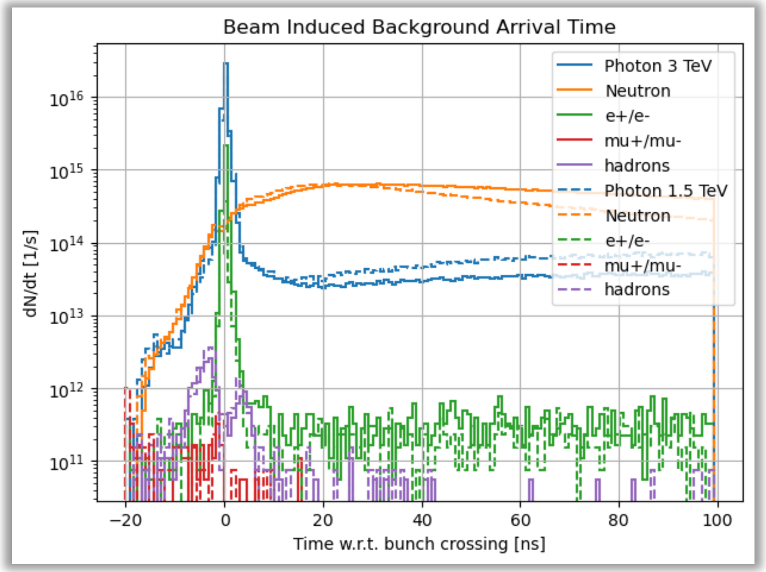
- Interaction region at $\sqrt{s} = 1.5$ and $\sqrt{s} = 3.0$ TeV designed by MAP
  [Y. Alexahin, et al. Journal of Instrumentation (2018) 11002]
- Nozzles designed for $\sqrt{s} = 1.5$ TeV, not optimized for $\sqrt{s} = 3.0$ TeV
- L*=6 m and detector magnetic field 3.57 Tesla
- Beam-induced background generated with Fluka

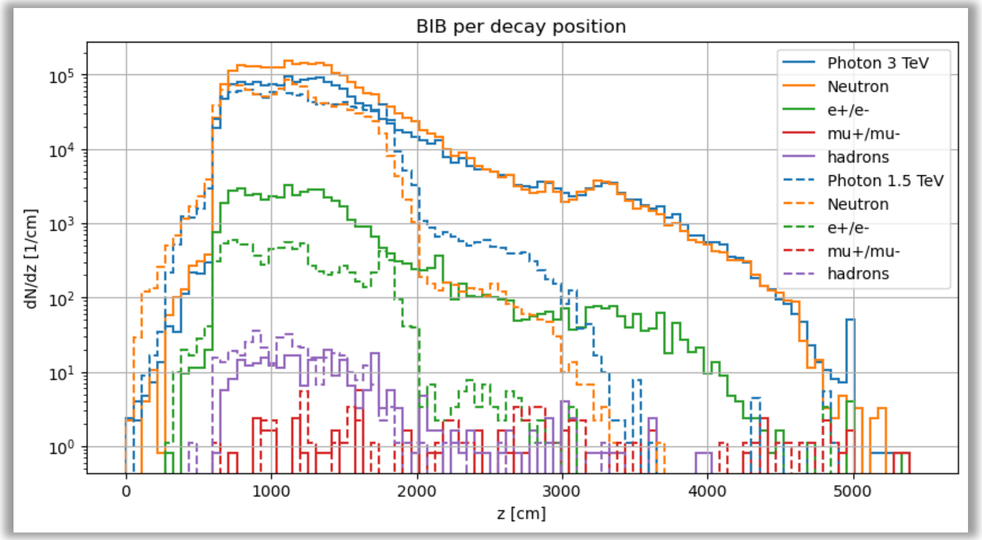


Distance from IP of primary muons decay to consider to include all possible decay on detector surface:

- $\sqrt{s} = 1.5$ TeV $z_\mu \leq 25$ m
- $\sqrt{s} = 3.0$ TeV $z_\mu \leq 45 - 50$ m

Beam-induced background comparison $\sqrt{s} = 1.5\ vs.\ \sqrt{s} = 3$ TeV



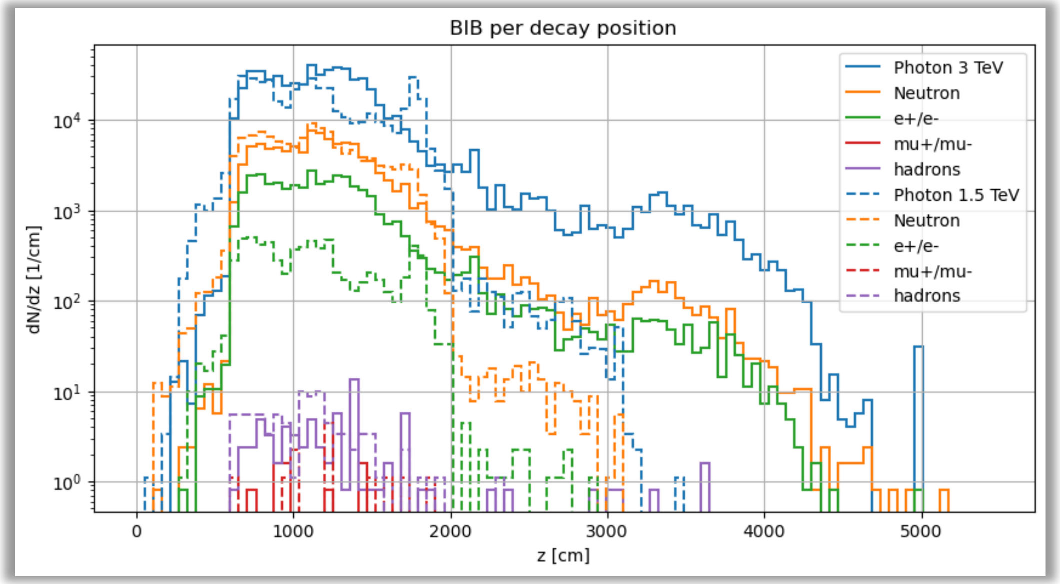


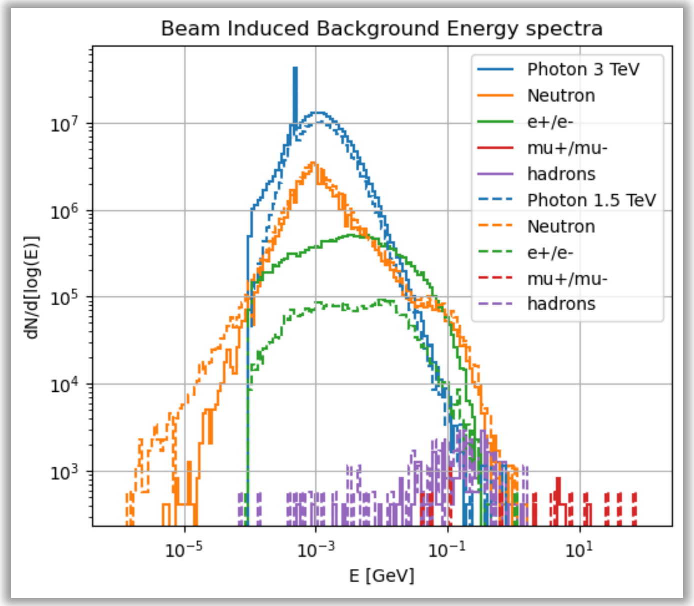
No time requirements

Z position of the muon generating a given particle arriving to the detector area

Time window [-1,15] ns

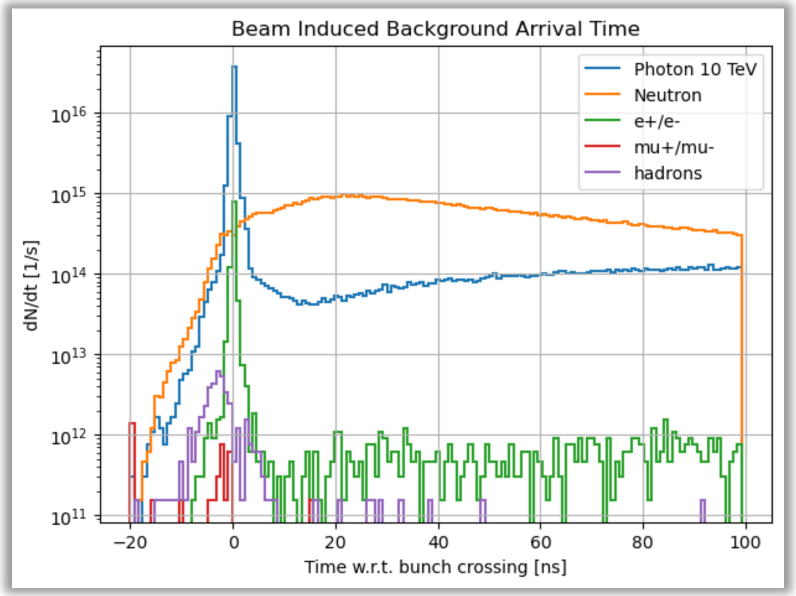
Optimized IR lattice & nozzles at $\sqrt{s} = 1.5$ TeV to minimize e^-e^+ in the inner part of the detector



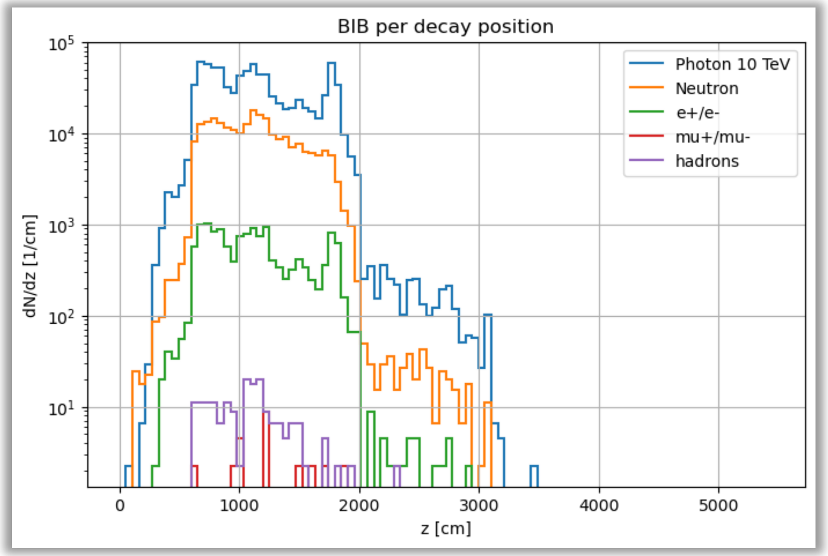


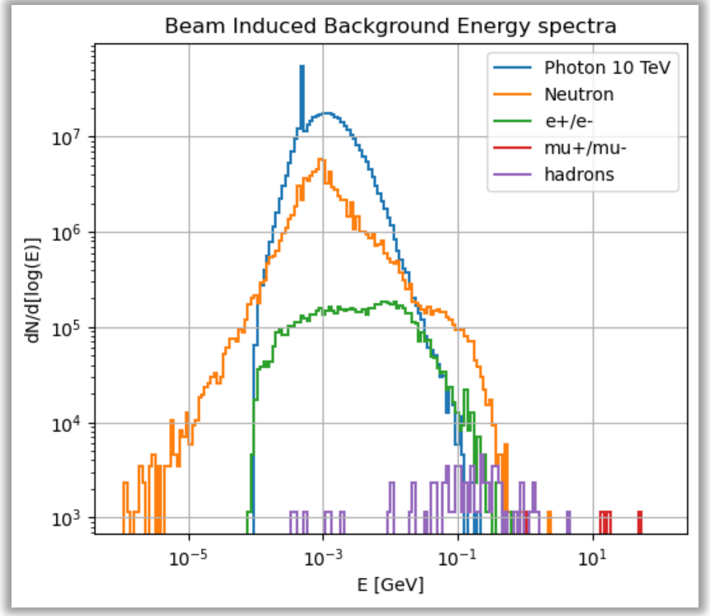
First look at beam-induced background at $\sqrt{s} = 10$ TeV

- Interaction region designed by IMCC (K. Skoufaris & C. Carli, CERN)
- Nozzles designed for 1.5 TeV
- L*=6 m and detector magnetic field 5 Tesla
- Beam-induced background generated with Fluka



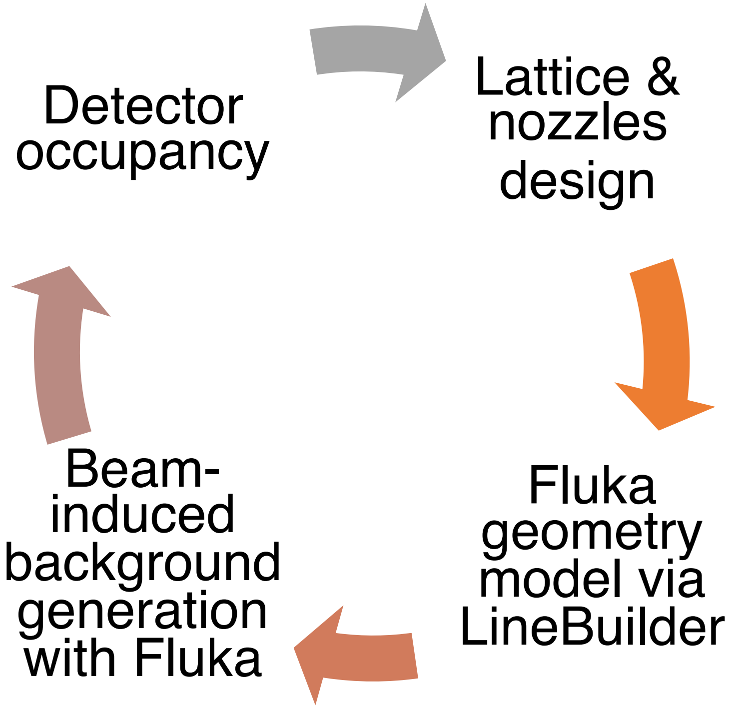
Time window [-1,15] ns

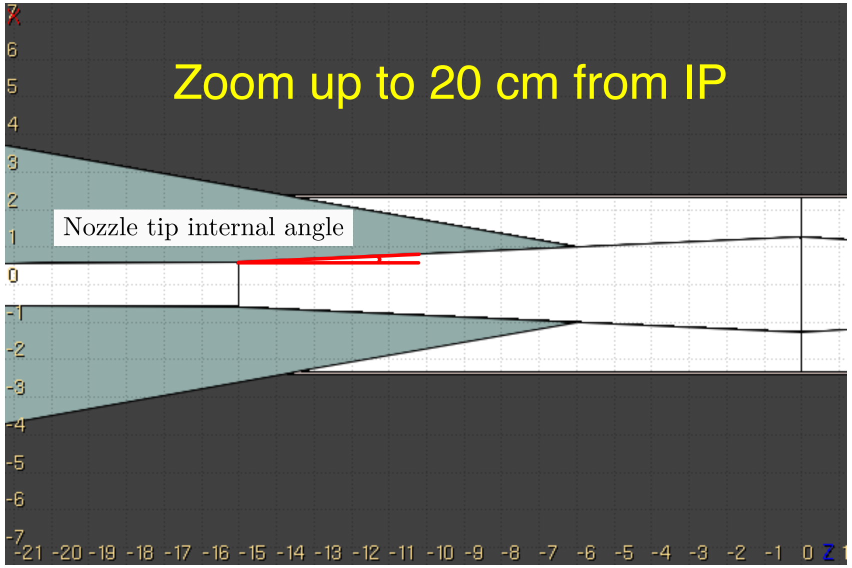


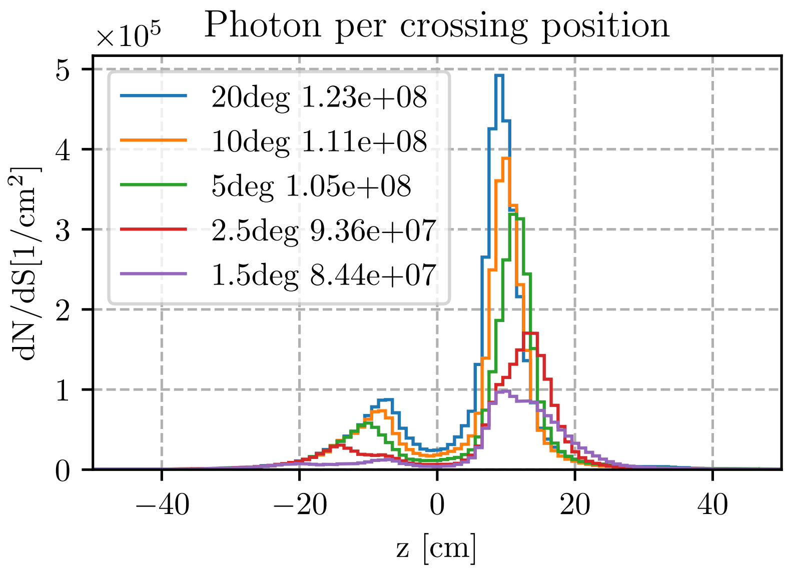


Distance from IP of primary muons decay like $\sqrt{s} = 3$ TeV, need to extend it

Beam-induced background fluxes & characteristics determined by IR & nozzles ⇒ iterative optimization process







D. Calzolari et al.
IPAC2023 proceedings

Default value 2.5 deg

Summary

- Software tools ready and validated to:
  - generate beam-induced background starting from different IR configurations & nozzles
  - Propagate particles in the detector and evaluate effects on occupancy
- Optimization of baseline nozzles proposal in progress

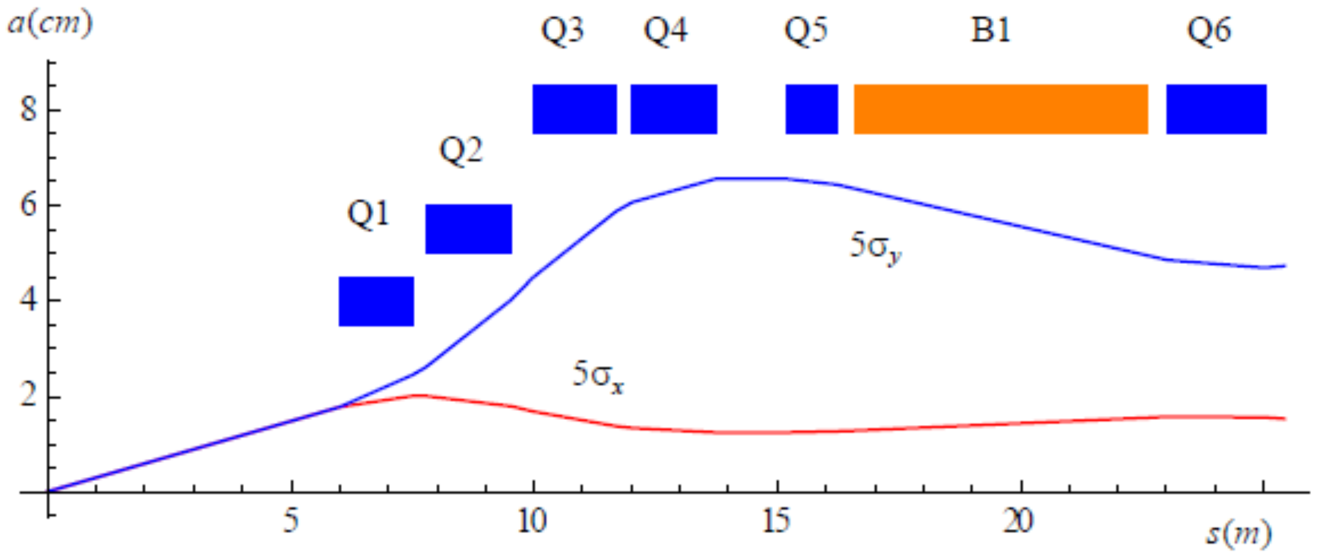
Near future activities

- Study different IR configurations
- Investigate a different nozzle concept: shape, new/different materials
- Study engineering of nozzles (several tons of tungsten)

Additional Slides

Optimization of Interaction Region at $\sqrt{s} = 1.5$ TeV

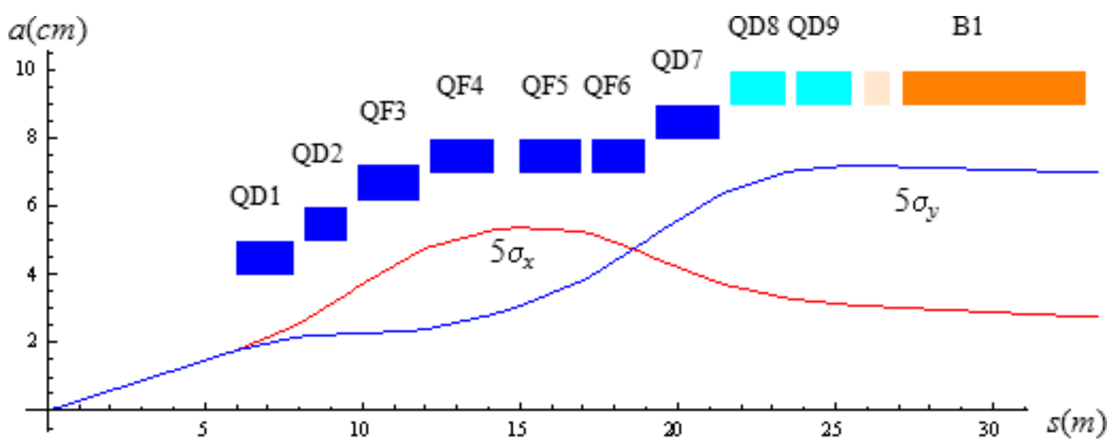
Y.I. Alexahin et al. *Muon Collider Interaction Region Design* FERMILAB-11-370-APC
N.V. Mokhov et al. *Muon collider interaction region and machine-detector interface design* Fermilab-Conf-11-094-APC-TD



Q1, Q2 : focusing quadrupoles
Q3, Q4, Q5: defocusing quadrupoles

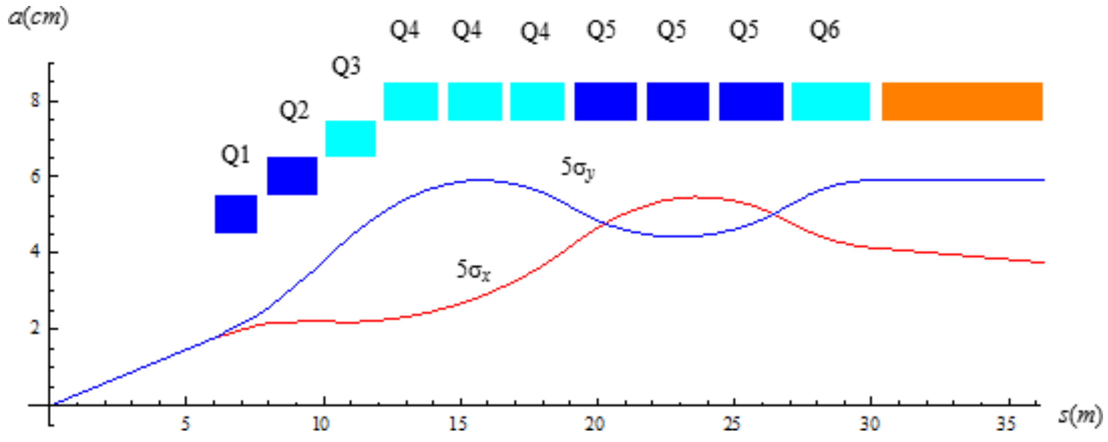
Quadrupoles in Nb_3Sn characteristics in the papers.
Dedicated dipoles to minimize the number of decay electrons in the coils and in the inner part of the detector.

Interaction Regions at $\sqrt{s} = 3$ TeV [Y. Alexahin, et al. Journal of Instrumentation (2018) 11002]



Triplet FF quadrupole apertures and 5σ beam envelopes for $\sqrt{s} = 3$ TeV and β∗ = 5 mm. Defocusing magnets with 2 T dipole component are shown in cyan.

Chosen for the first $\sqrt{s} = 3$ TeV study



Quadruplet FF quadrupole apertures and 5σ beam envelopes for $\sqrt{s} = 3$ TeV and β∗ = 5 mm. Defocusing magnets with 2 T dipole component are shown in cyan.