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

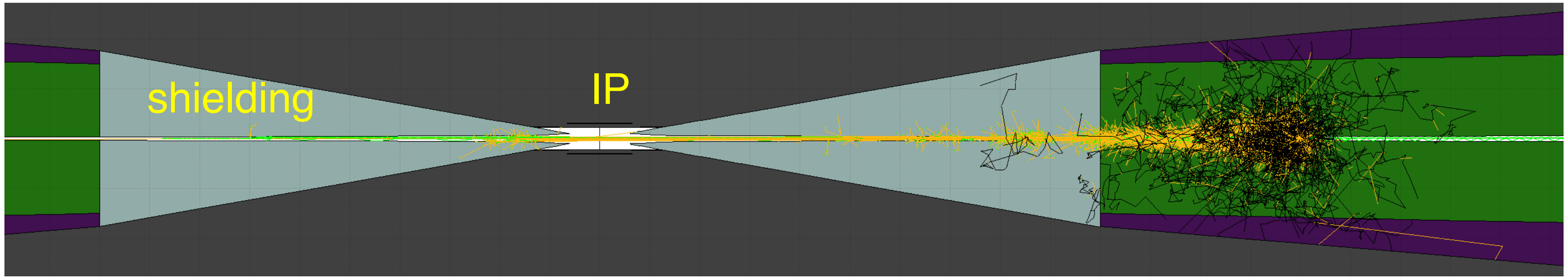
Machine-detector interface: status and future developments

Riunione di referaggio, 4 settembre 2023

Donatella Lucchesi

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 $\Longrightarrow$ electrons and photons
  - ❊ photons from synchrotron radiation from the energetic electrons in collider magnetic field
  - ❊ Photonuclear interaction with materials, mainly shielding, $\Longrightarrow$ 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^+ $\Longrightarrow$ trapped by detector magnetic field
- ✗ Beam halo: level of acceptable losses to be defined, not an issue now

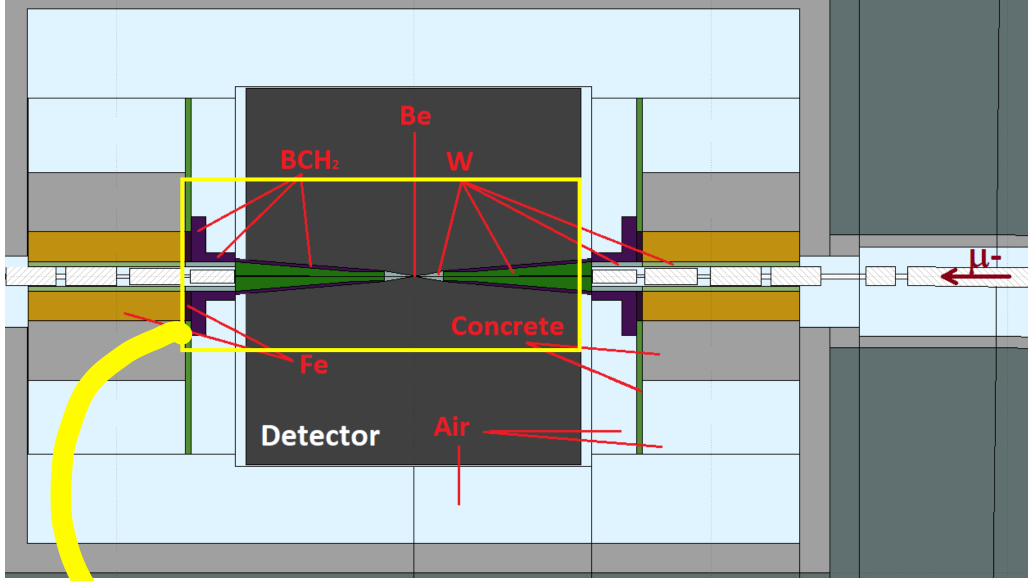


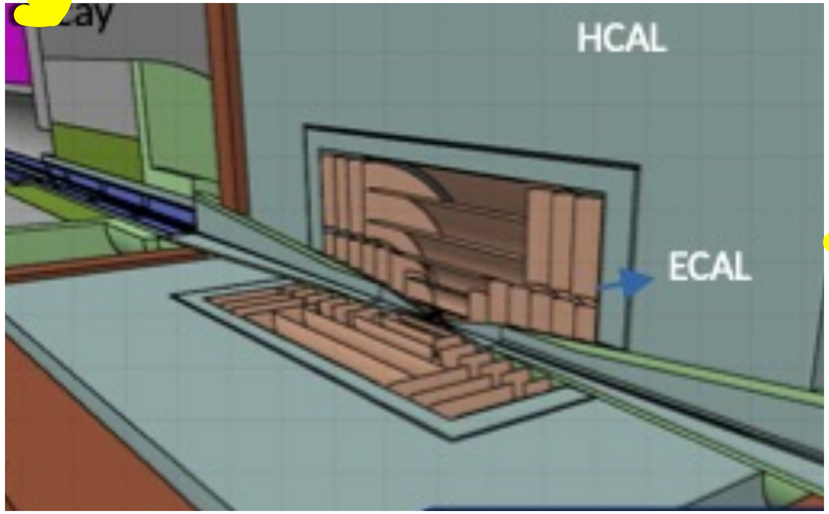
Single muon decay tracks

F. Collamati et al. 2021 JINST 16 P11009

Shielding structure, the nozzles

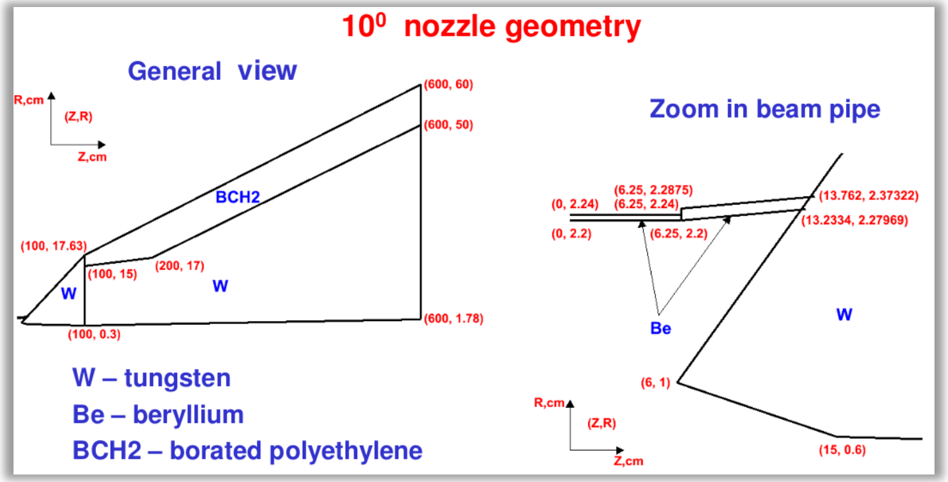
F. Collamati et al. 2021 JINST 16 P11009



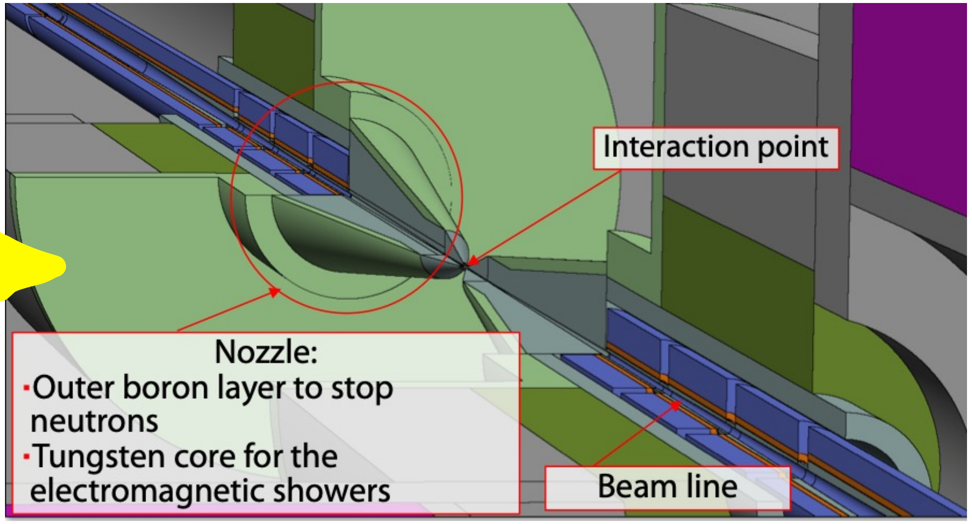


Designed by MAP (Muon Accelerator Program)

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



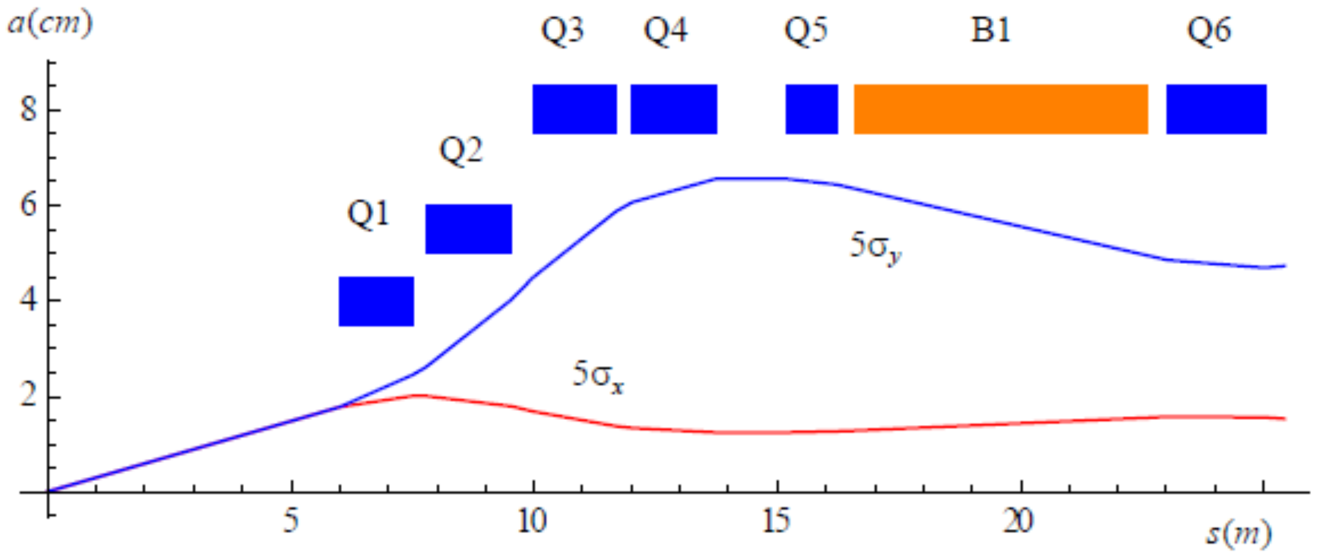
Optimized for $\sqrt{s} = 1.5$ TeV



D. Calzolari
[IMCC Ann. meeting Orsay 2023]

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
Space between Q4 - Q5 is for beam diagnostics/correctors.
B1: dipole

Quadrupoles in Nb_3Sn → detailed characteristics in the papers.

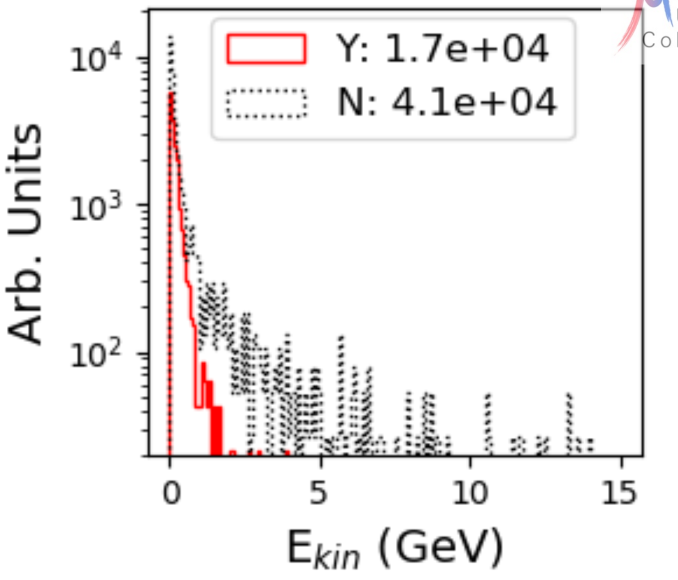
Dedicated dipoles to minimize the number of decay electrons in the coils and in the inner part of the detector.

The effect of the nozzles

F. Collamati et al. 2021 JINST 16 P11009

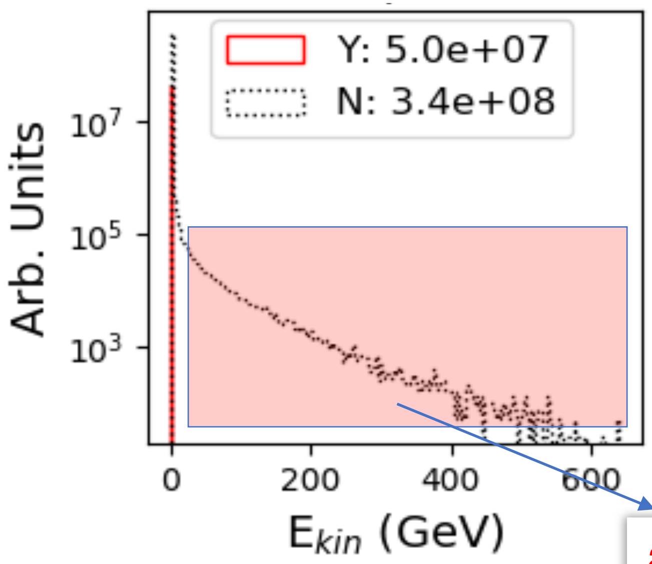
- Muon beam 0.75 TeV, IR designed by MAP
- Beam-induced Background generated with FLUKA
- Compare what arrives on the detector with and without the nozzle

charged hadrons

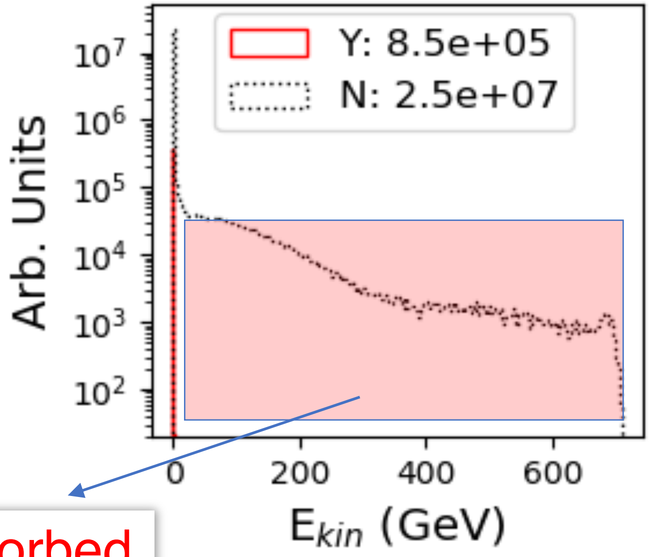


Charged hadrons absorbed

Photons

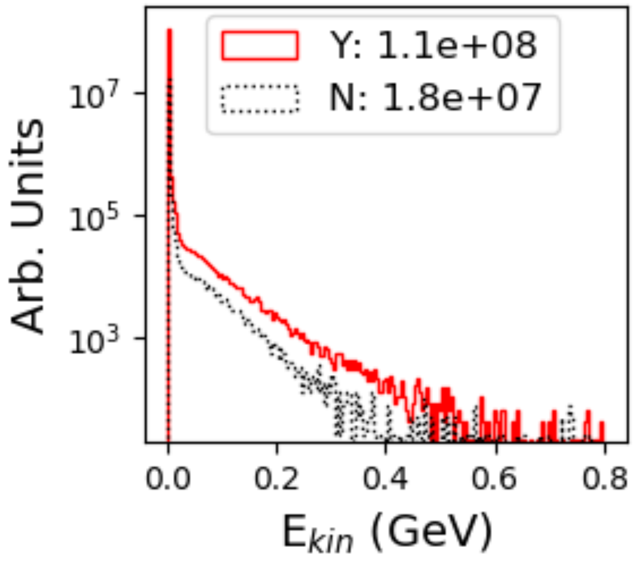


electrons/positrons



absorbed

neutrons



Neutrons increased

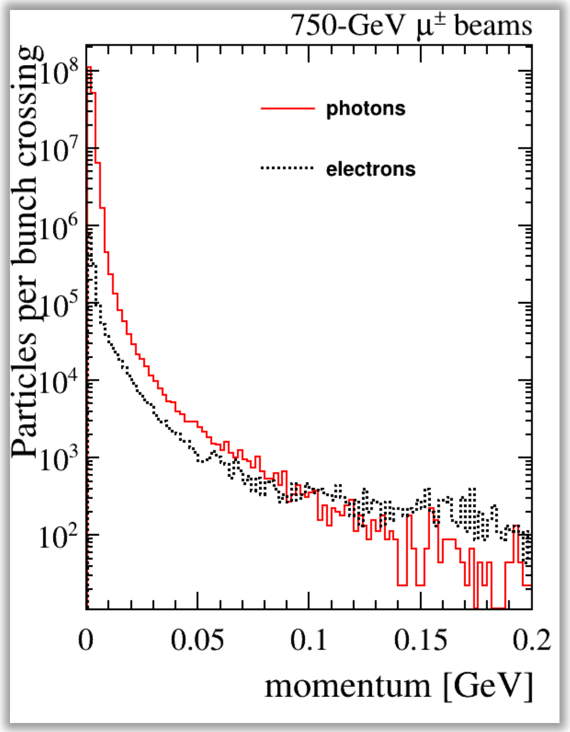
Without the nozzle the detector is flooded by high energy particles

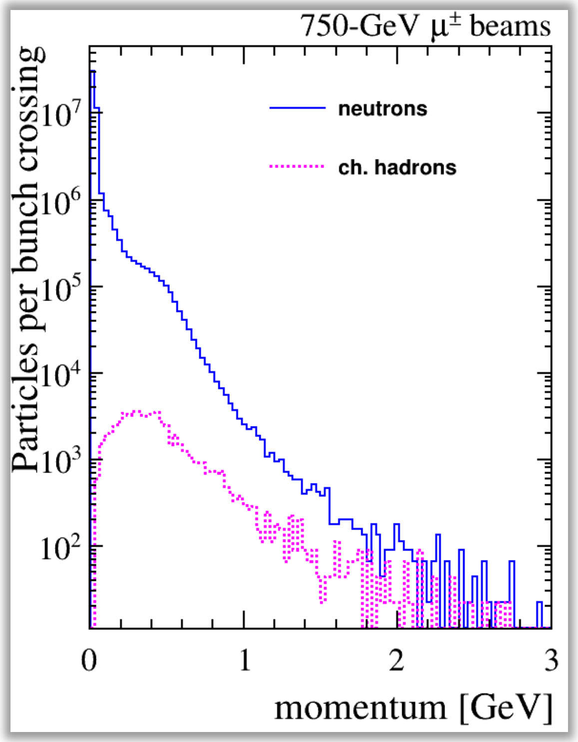
Survived beam-Induced background properties

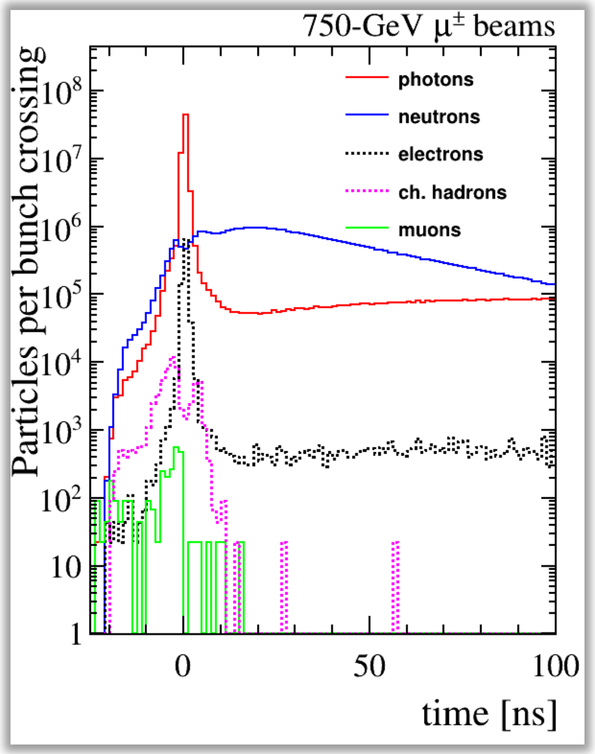
Particles arriving on the detector with the nozzle:

- 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

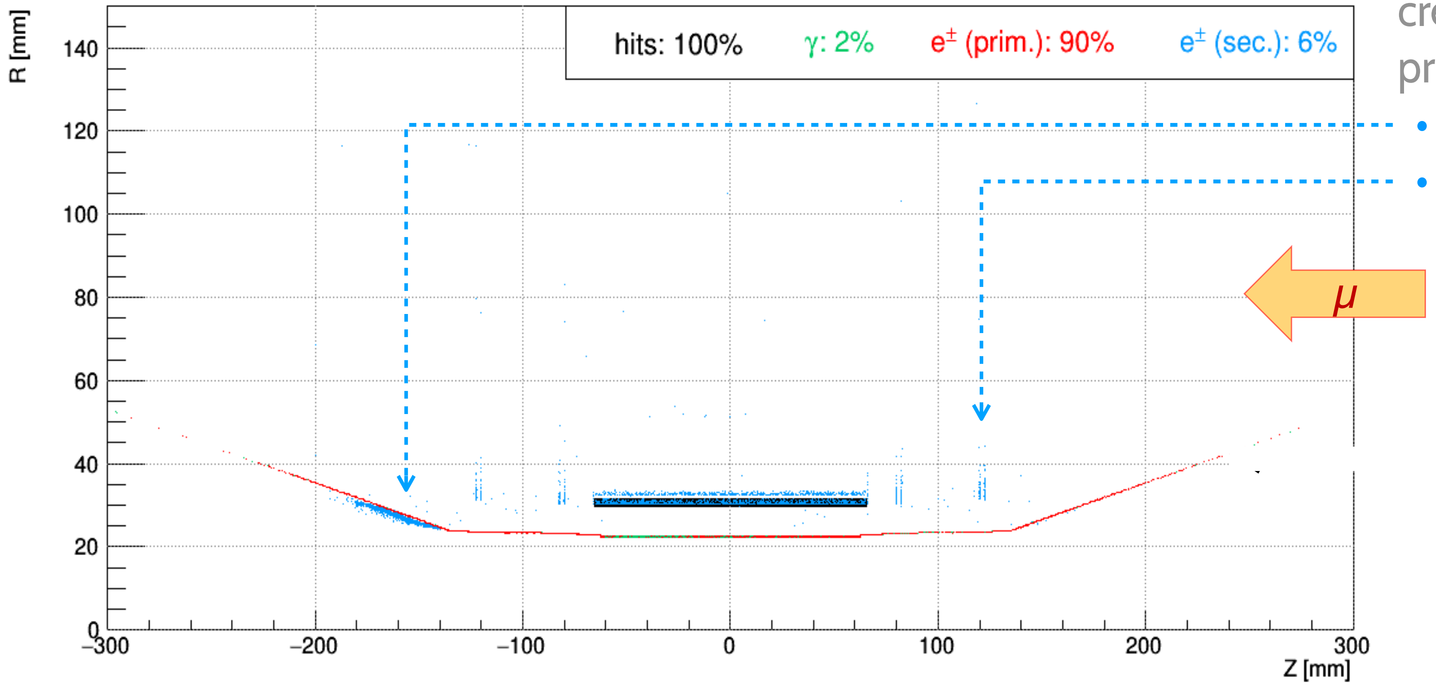
Primary photons

Primary electrons

Secondary electrons

created by interaction of primary photons with:

- MDI material
- detector material



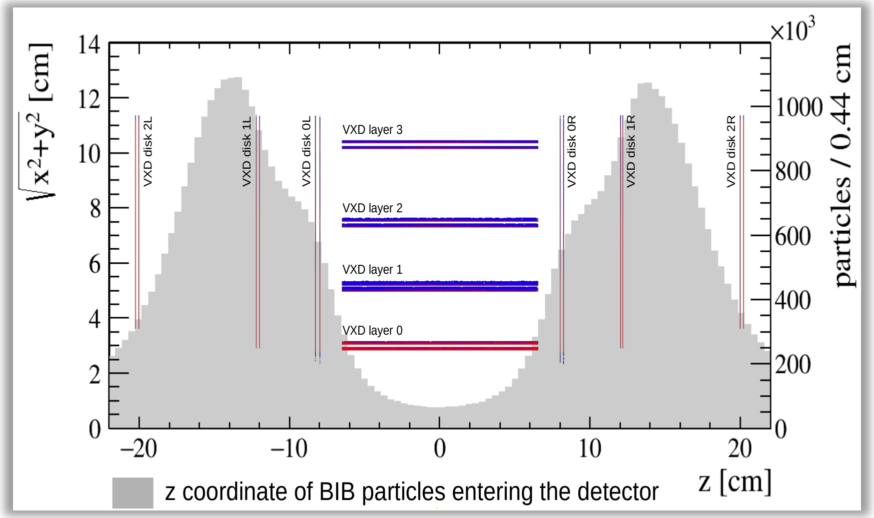
Beam pipe

Nozzle tip

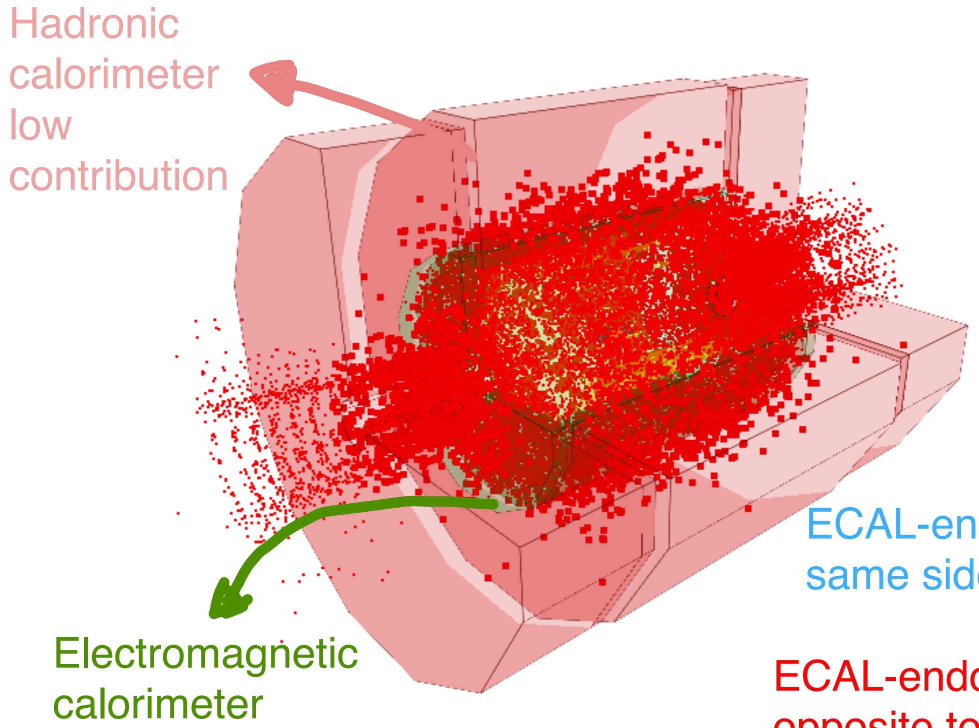
Nozzle

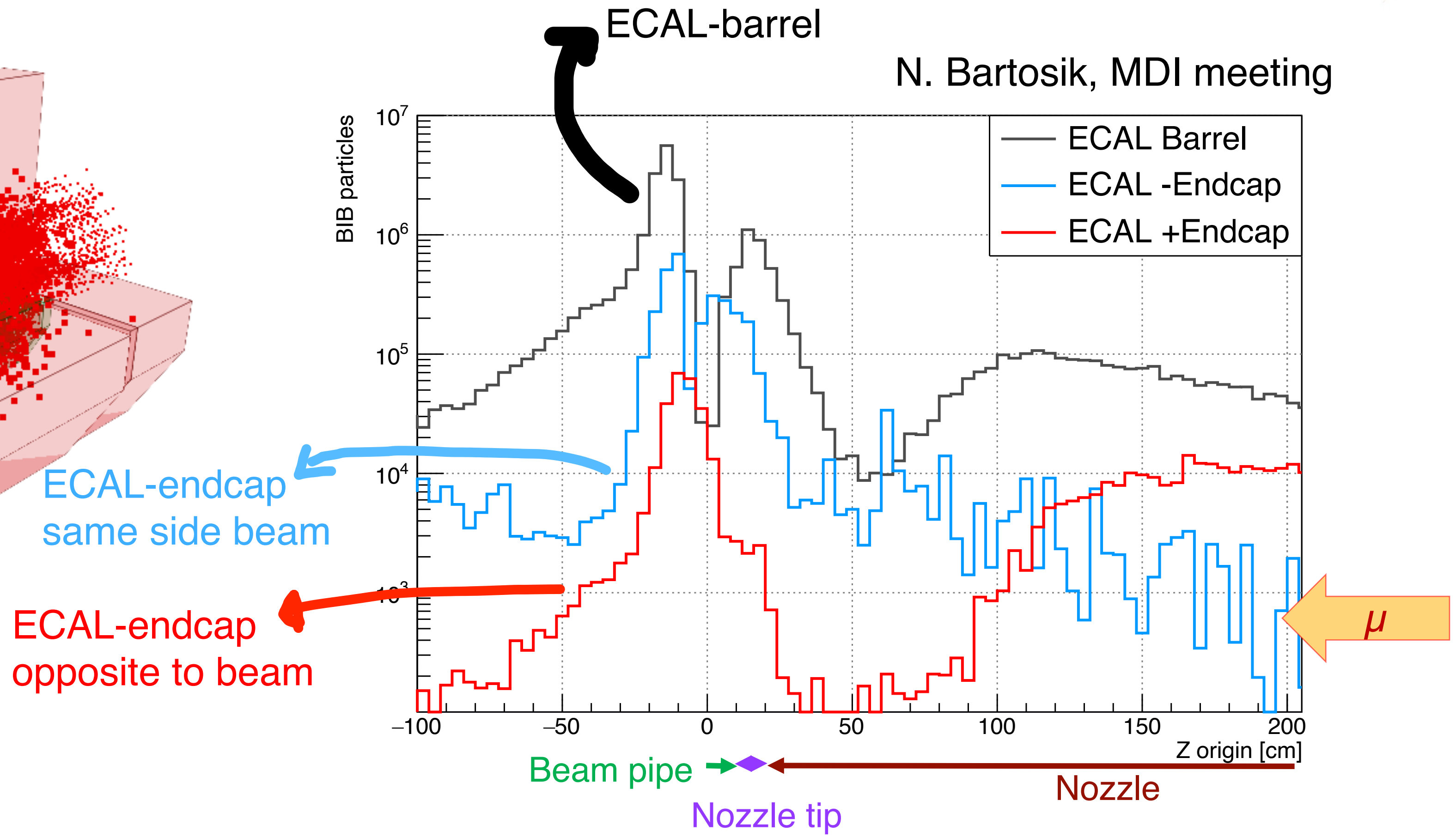
N. Bartosik, MDI meeting

Vertex layout



Origin of particles creating hits in the detector: calorimeter

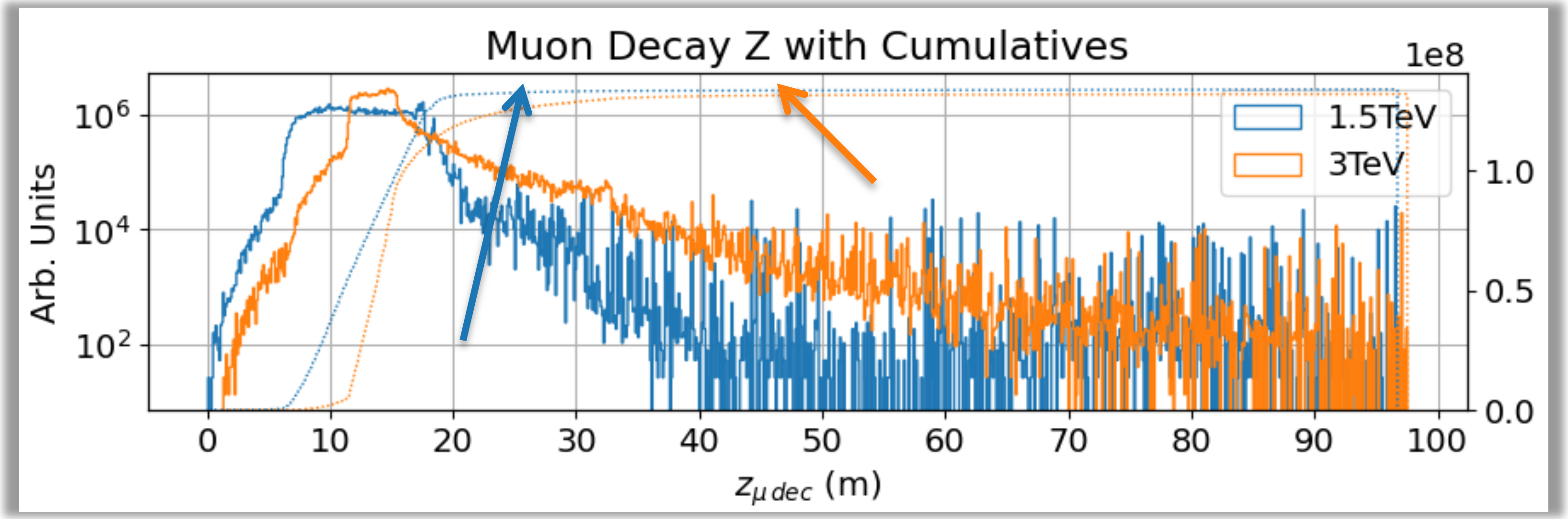




z position of the original particle background that generated a given hit in ECAL
Background dominated by photons, detailed study of the origin needed to mitigate effects on ECAL inner layers

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

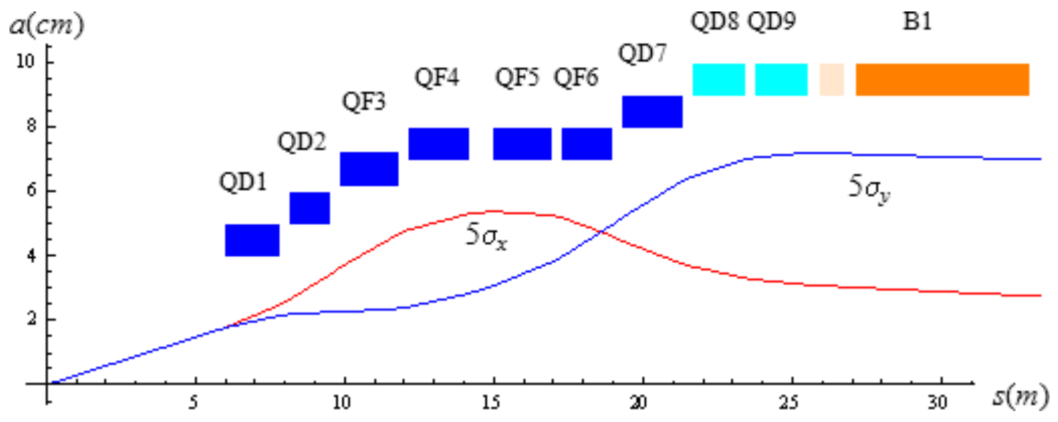
- Interaction region at $\sqrt{s} = 1.5$ and $\sqrt{s} = 3.0$ TeV designed by MAP
  [Y. Alexahin, et al. Journal of Instrumentation (2018) 11002]
- Nozzles designed for $\sqrt{s} = 1.5$ TeV, not optimized for $\sqrt{s} = 3.0$ TeV
- L*=6 m and detector magnetic field 3.57 Tesla
- Beam-induced background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

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

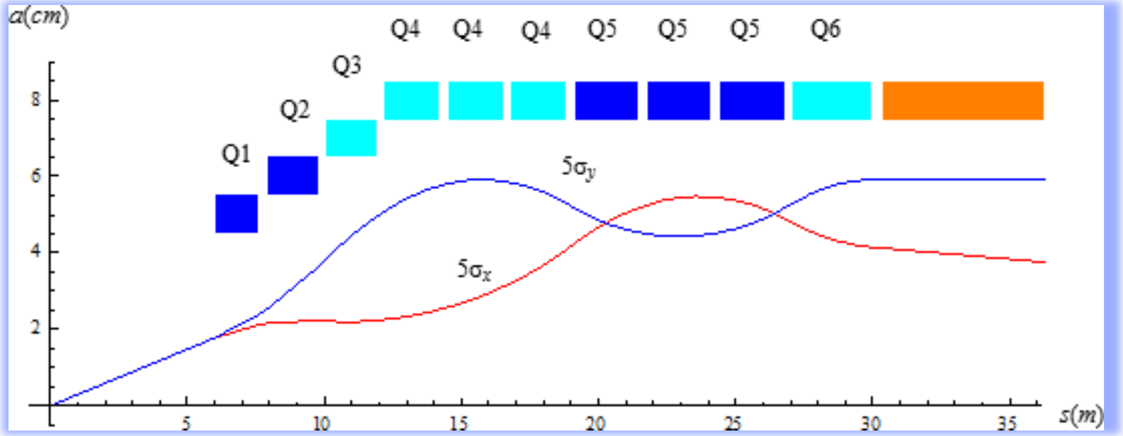


Triplet FF quadrupole apertures and 5σ beam envelopes for $\sqrt{s} = 3$ TeV and β∗ = 5 mm.

Defocusing magnets with 2 T dipole component in cyan.

The order of focusing and defocusing quadrupoles chosen to minimize horizontal beta-function at the B1 dipole used for dispersion generation.

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



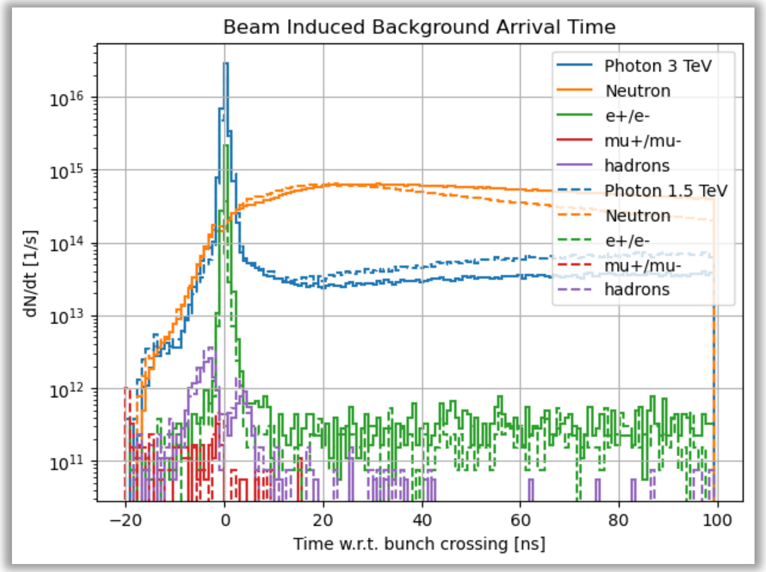
Quadruplet FF quadrupole apertures and 5σ beam envelopes for $\sqrt{s} = 3$ TeV and β∗ = 5 mm.

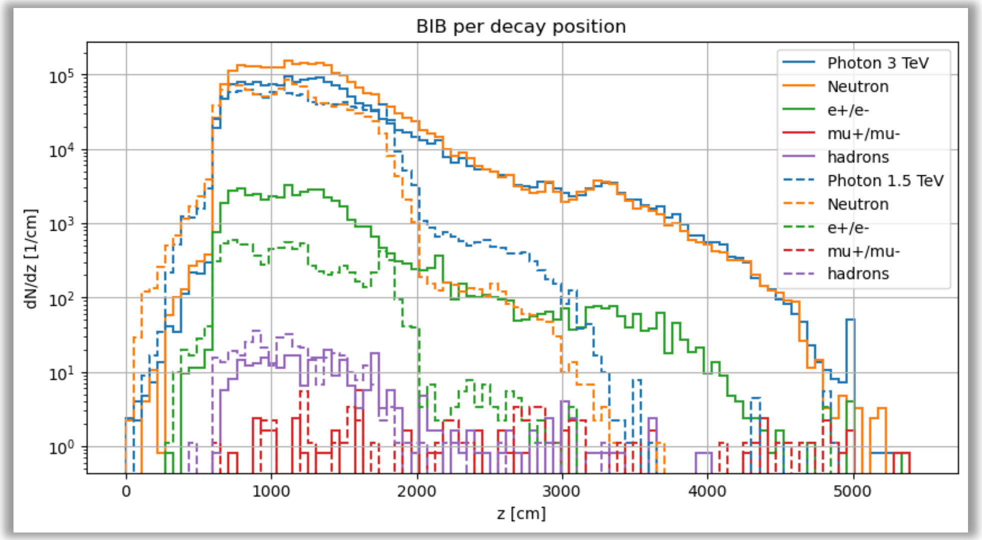
Defocusing magnets with 2 T dipole component in cyan.

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

L. Castelli

No time requirements

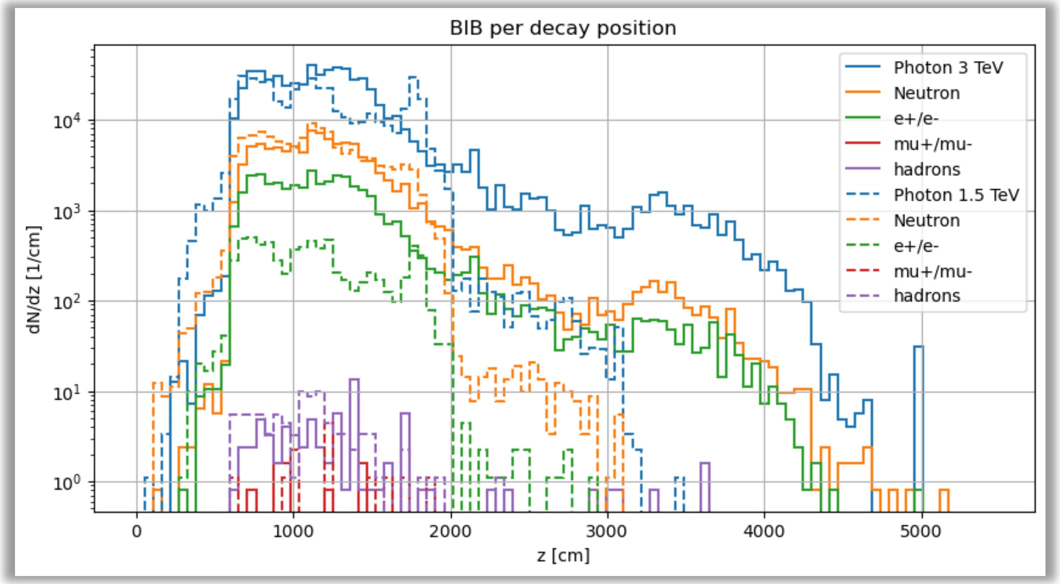


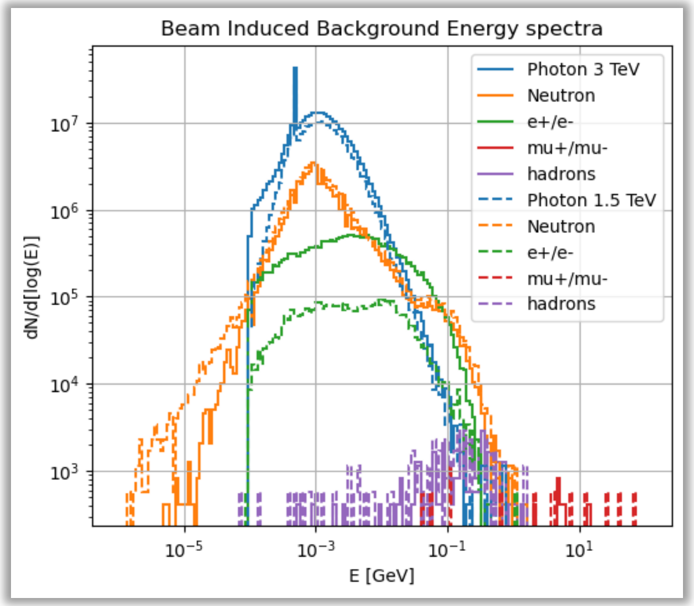


Z position of the muon generating a given particle arriving to the detector area

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



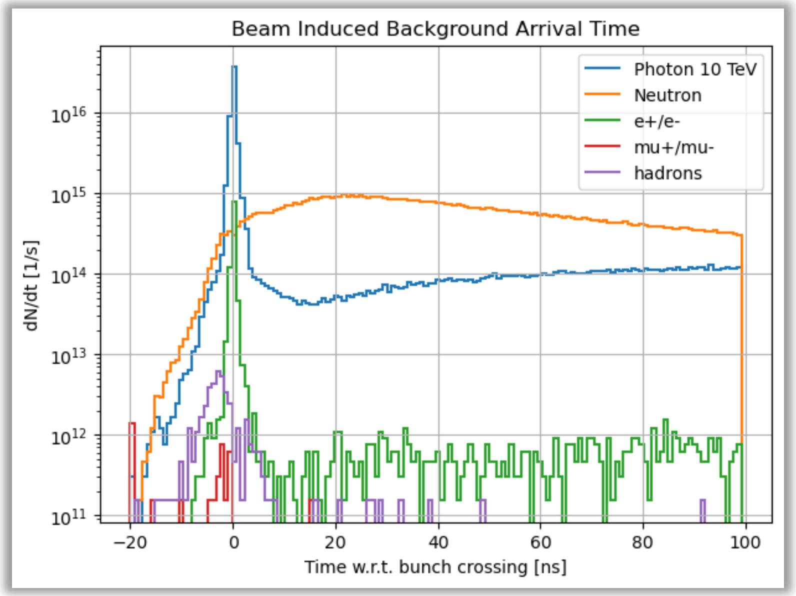


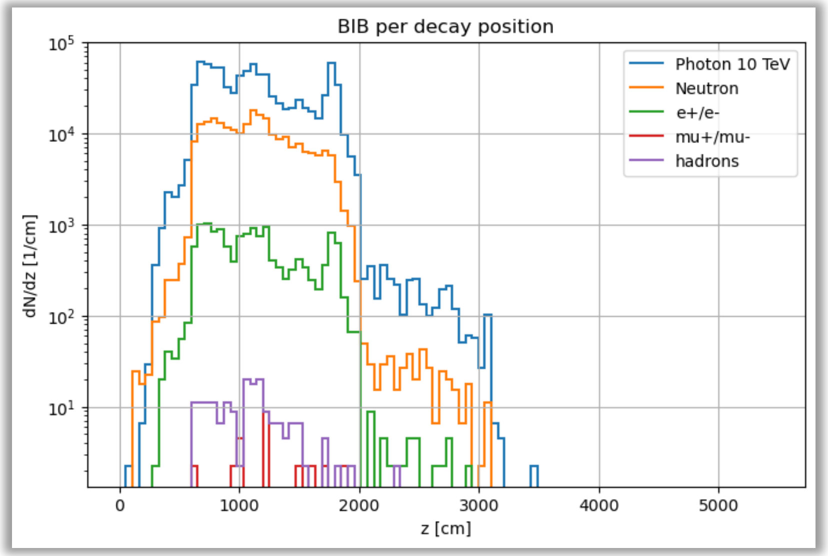
First look at beam-induced background at $\sqrt{s} = 10$ TeV

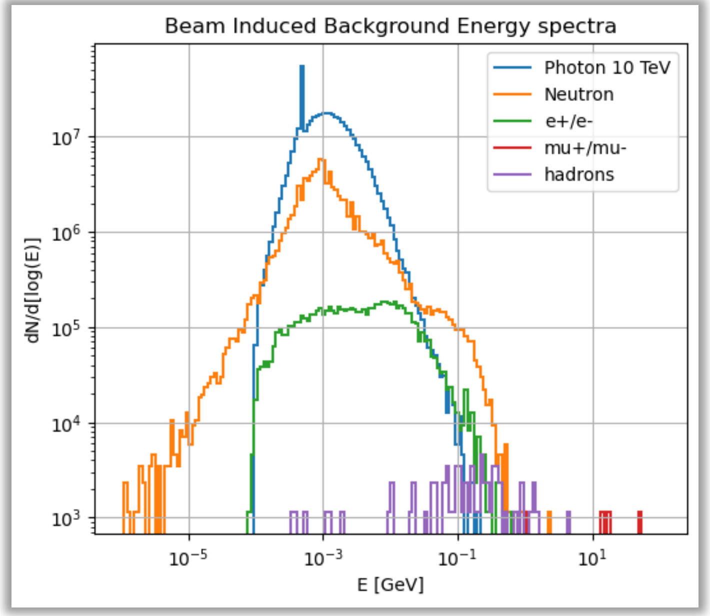
- Interaction region designed by IMCC (K. Skoufaris & C. Carli, CERN)
- Nozzles designed for 1.5 TeV
- L*=6 m and detector magnetic field 5 Tesla
- Beam-induced background generated with Fluka

Time window [-1,15] ns

L. Castelli

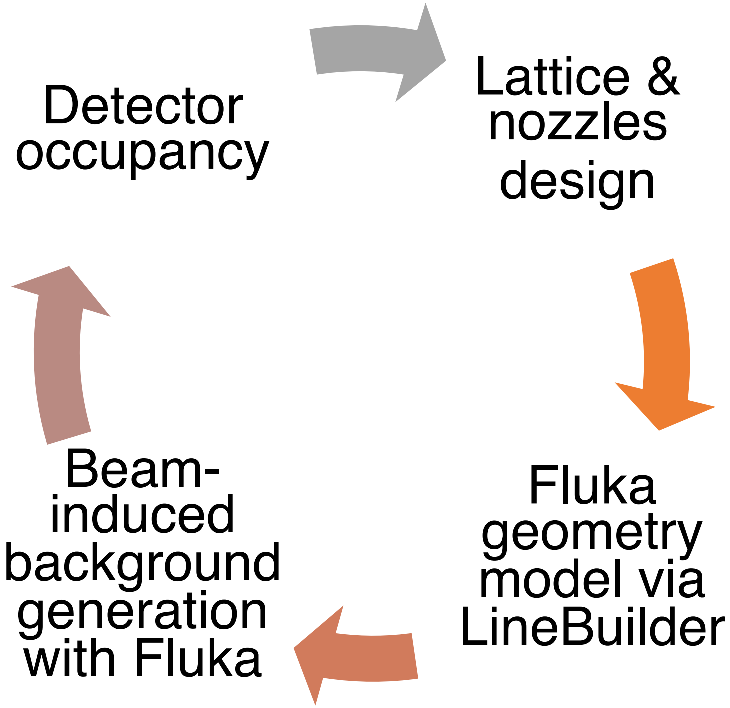


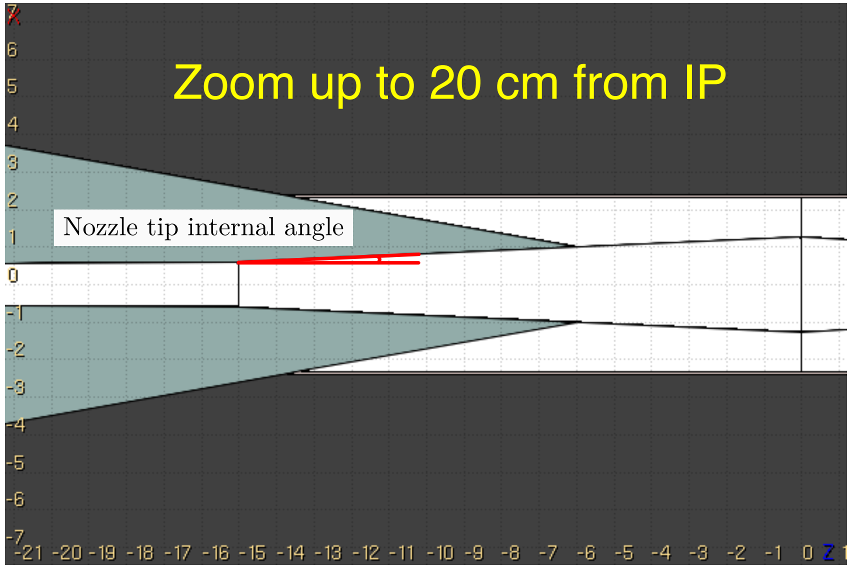


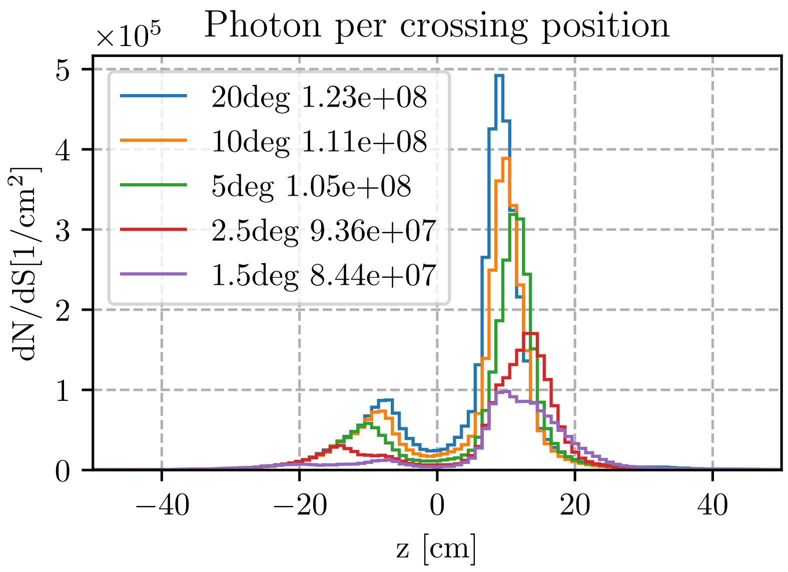


Distance from IP of primary muons decay like $\sqrt{s} = 3$ TeV, need to extend it

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







D. Calzolari et al.
IPAC2023 proceedings

Default value 2.5 deg

Near future activities

- Optimization of baseline nozzles for 3 TeV starting from the MAP IR designs
  - By evaluating the detector occupancy (PhD INFN-Accelerators)

- Definition of a “baseline” 10 TeV IR, design “baseline” nozzles to produce and study beam-induced background
  - Needed to produce a detector concept at 10 TeV (accelerator & MDI group)

- Investigate a different nozzle concept: shape, new/different materials
  - It will be done for 10 TeV, if successful we will re-think the 3 TeV (PhD – Padova CERN funds)

- Started a collaboration with CERN engineers to engineering nozzles, several, ~40, tons of tungsten to be placed in the detector and close to FF