Detector design @10 TeV including MDI

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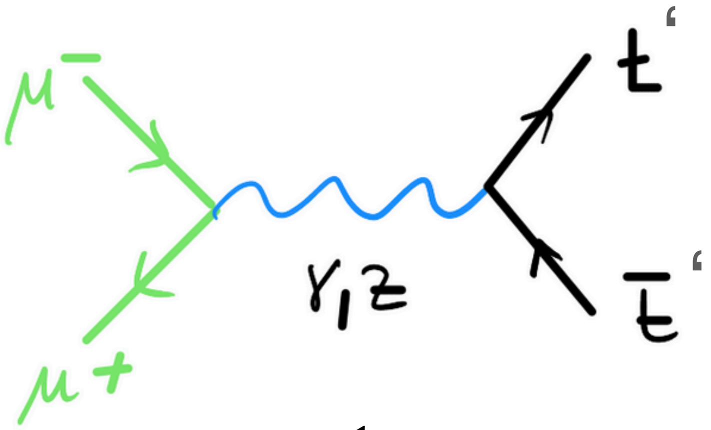
for Physics and Detector - Italia

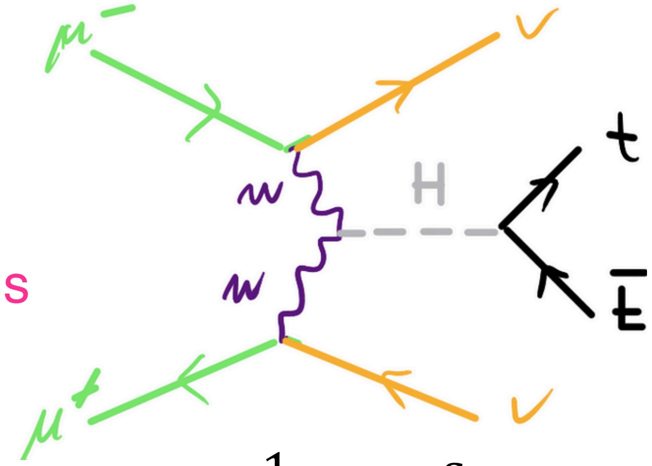
Physic processes: two colliders in one

F. Maltoni
"Physics Overview" Annual Meeting IMCC

Multi-TeV muon collider opens a completely new regime :



Different physics can be probed in the two channels



$$\sigma \sim \frac{1}{s}$$

Energetic final states
(heavy particle or very boosted)

$$\sigma \sim \frac{1}{M^2} log^n \frac{s}{M}$$

Standard Model coupling measurements
Discovery light and weakly interacting particles

Muon Colliders, 1901.06150
The muon Smasher's guide, *Rept.Prog.Phys.* 85 (2022) 8, 084201 2103.14043
Muon Collider Forum Report, 2209.01318
Towards a Muon Collider, *Eur.Phys.J.C* 83 (2023) 9, 864, 2303.08533

First detector concept at $\sqrt{S} = 3$ TeV based on CLIC's detector concept CLICdp-Note-2017-001

- Removed forward luminosity detectors
- Inserted nozzles
- Adapted tracker detector
- Magnetic field modified to cope with available beam-induced background

hadronic calorimeter

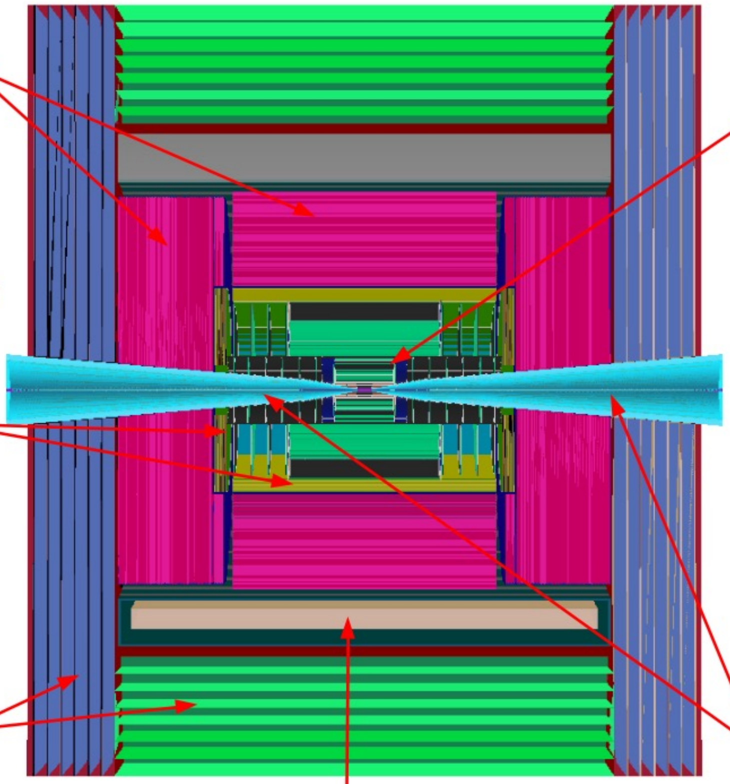
- 60 layers of 19-mm steel absorber + plastic scintillating tiles;
- 30x30 mm^2 cell size;
- 7.5 λ_I.

electromagnetic calorimeter

- 40 layers of 1.9-mm W absorber + silicon pad sensors;
- 5x5 mm^2 cell granularity;
- 22 X_0 + 1 λ_I.

muon detectors

- 7-barrel, 6-endcap RPC layers interleaved in the magnet's iron yoke;
- 30x30 mm^2 cell size.



superconducting solenoid (3.57T)

tracking system

- Vertex Detector:
  - double-sensor layers (4 barrel cylinders and 4+4 endcap disks);
  - 25x25 μm^2 pixel Si sensors.
- Inner Tracker:
  - 3 barrel layers and 7+7 endcap disks;
  - 50 µm x 1 mm macro-pixel Si sensors.
- Outer Tracker:
  - 3 barrel layers and 4+4 endcap disks;
  - 50 µm x 10 mm micro-strip Si sensors.

shielding nozzles

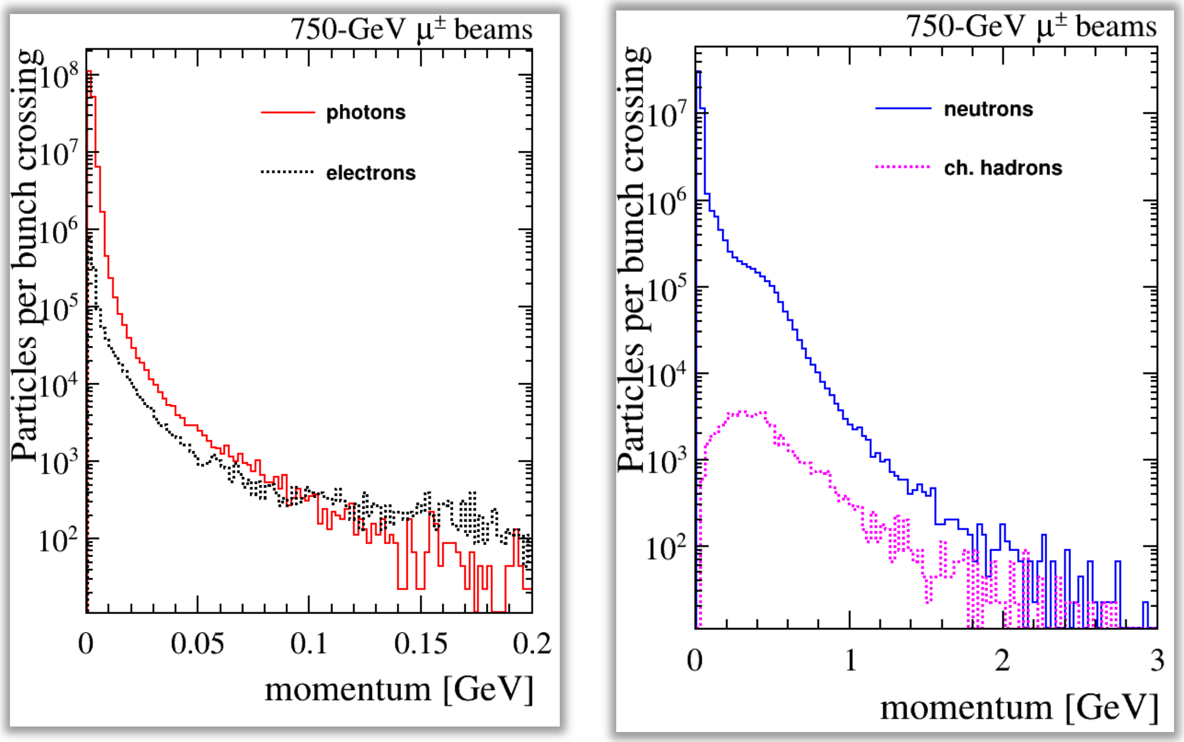
- Tungsten cones + borated polyethylene cladding.

ILCSoft is the simulation and reconstruction framework, forked from CLIC's software.
Transition to key4hep in progress, timeline depending on person power.
Tutorial made in July 2023.

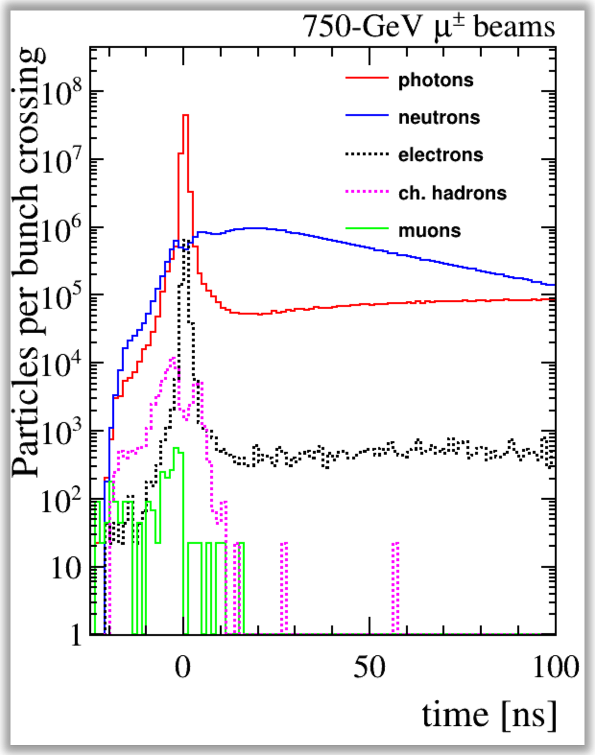
Survived beam-Induced background (BIB) properties

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

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



Low momentum particles

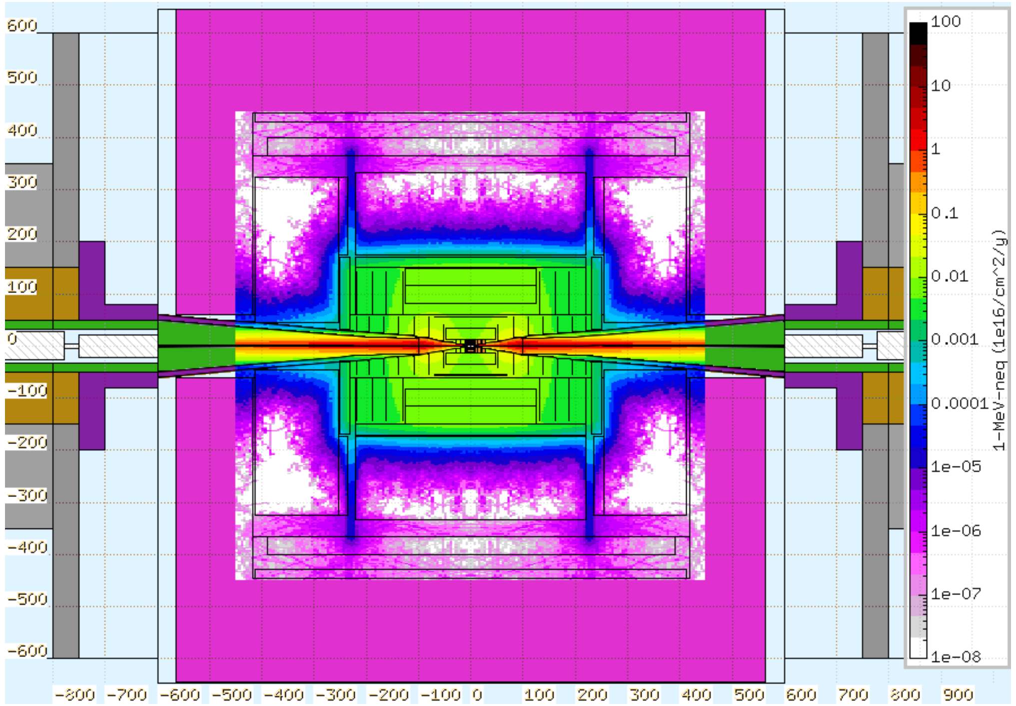


Partially out of time vs beam crossing

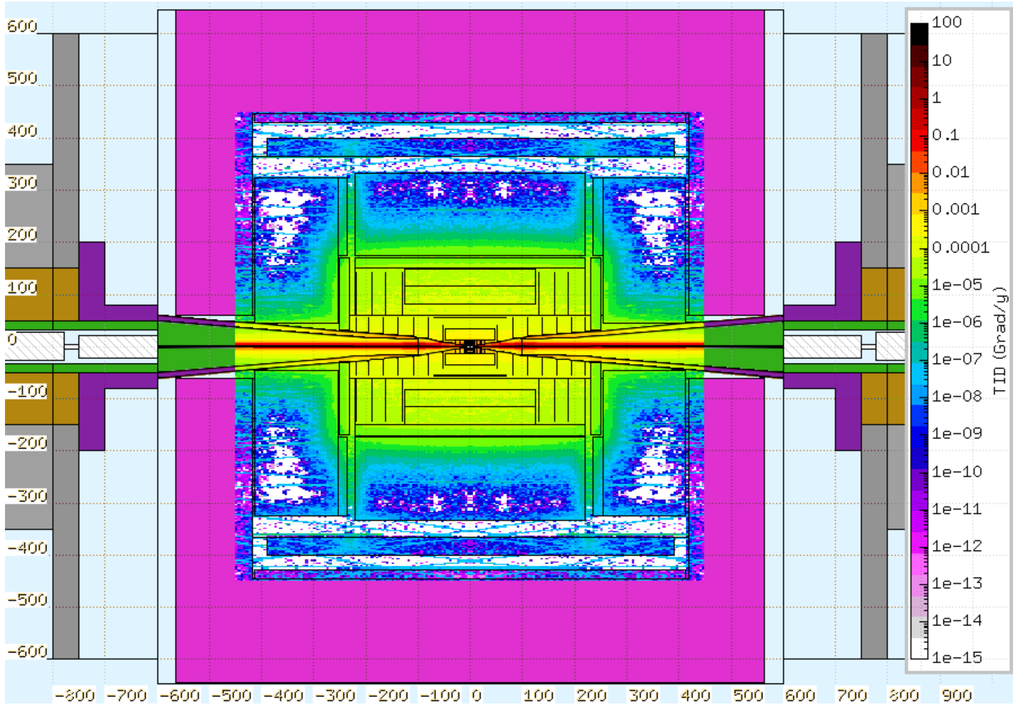
Beam-induced background generated with FLUKA by using the interaction region layout.
Particles propagated into the detector with GEANT.

Radiation environment

1-MeV neutron equivalent fluence per year



Total ionizing dose per year



Assumptions:

- Collision energy 1.5 TeV
- Collider circumference 2.5 km
- Beam injection frequency 5Hz
- Days of operation/year 200

Radiation hardness requirements like HL-LHC (expected)

	Maximum Dose (Mrad)		Maximum Fluence (1 MeV-neq/cm^2)	
	R= 22 mm	R= 1500 mm	R= 22 mm	R= 1500 mm
Muon Collider	10	0.1	10^{15}	10^{14}
HL-LHC	100	0.1	10^{15}	10^{13}

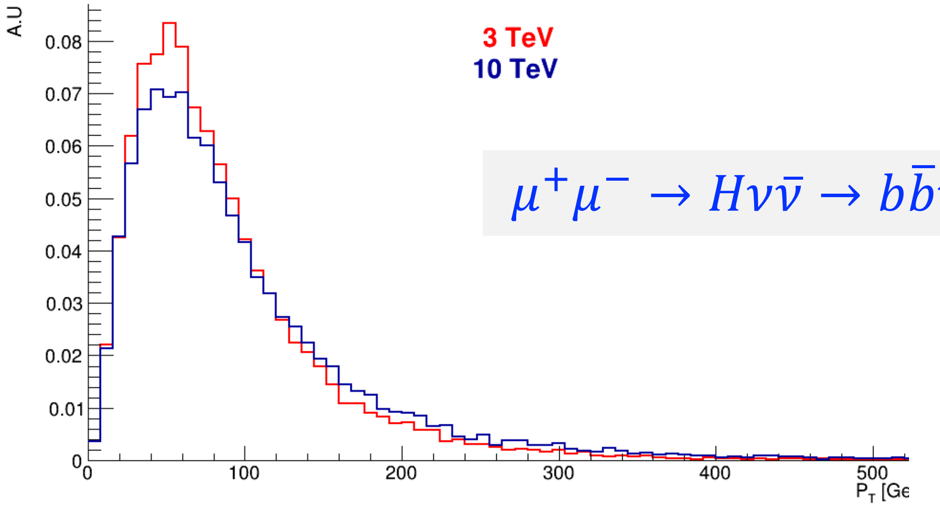
K. Black, Muon Collider Forum Report

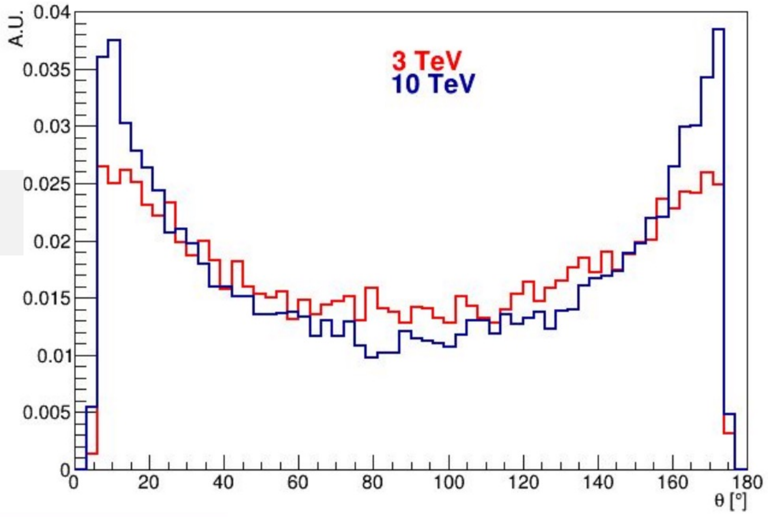
Detector for $\sqrt{s} = 10$ TeV: definition of requirements

Physics requirements: three classes of processes

Low momentum, forward-boosted phenomena, ex. Higgs boson.

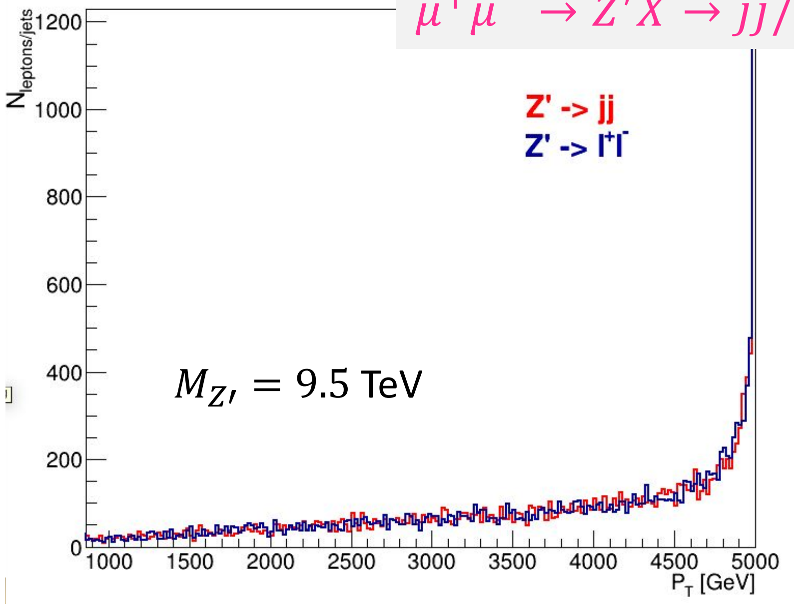
$\mu^+\mu^- \rightarrow H\nu\bar{\nu} \rightarrow b\bar{b}\nu\bar{\nu}$

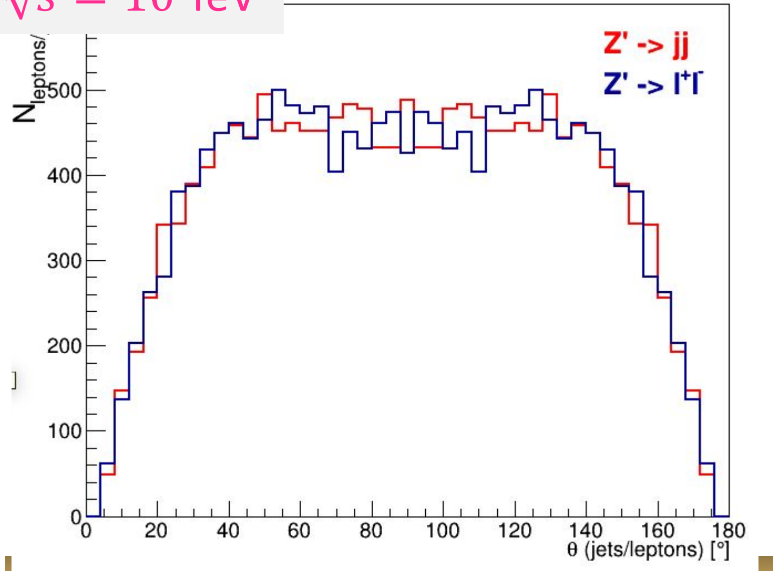




High momentum central phenomena, ex. Z'

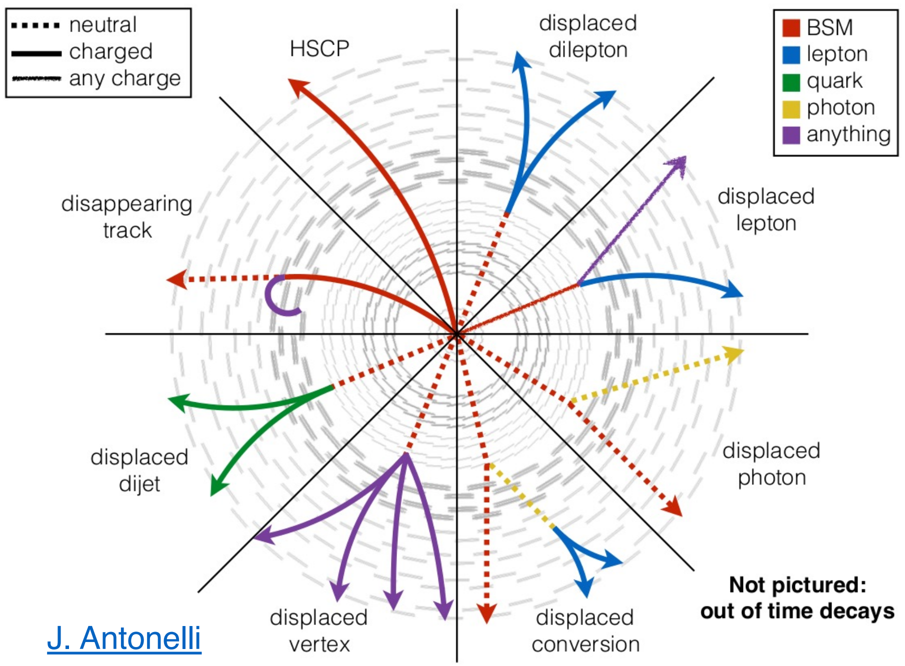
$\mu^+\mu^- \rightarrow Z'X \rightarrow jj/\ell\ell X \; \sqrt{s} = 10$ TeV





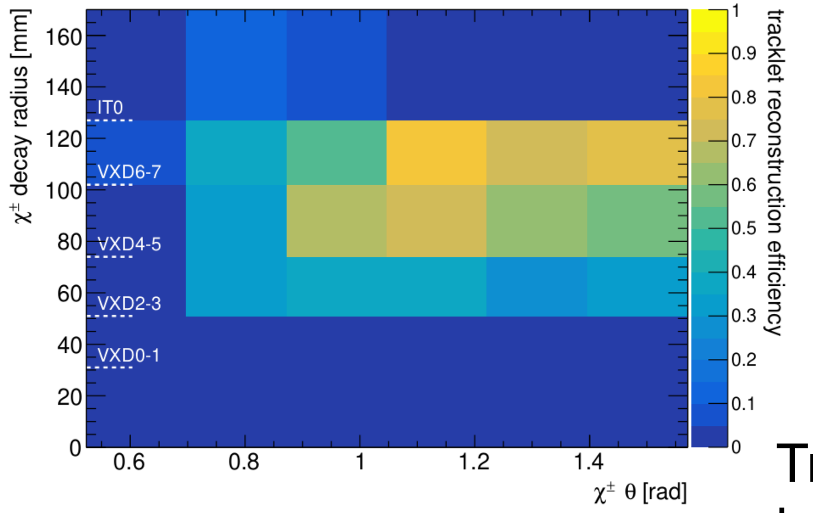
Physics requirements: three classes of processes cont’d

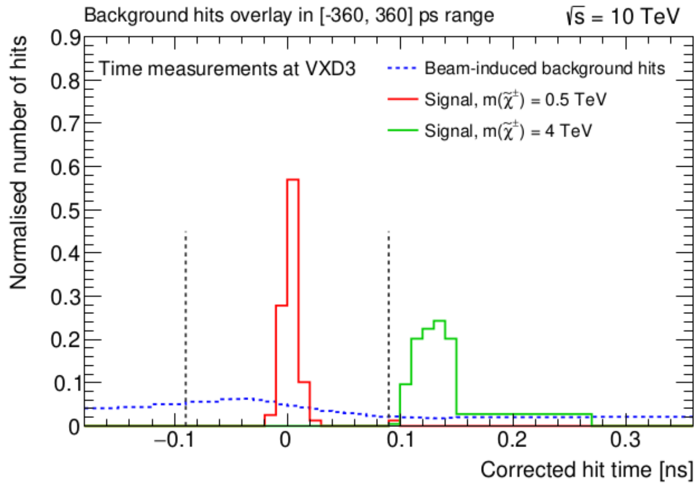
Less conventional signatures from BSM processes, ex. Disappearing Track



J. Antonelli

R. Capdevilla et al.,. JHEP 06, 133 (2021)



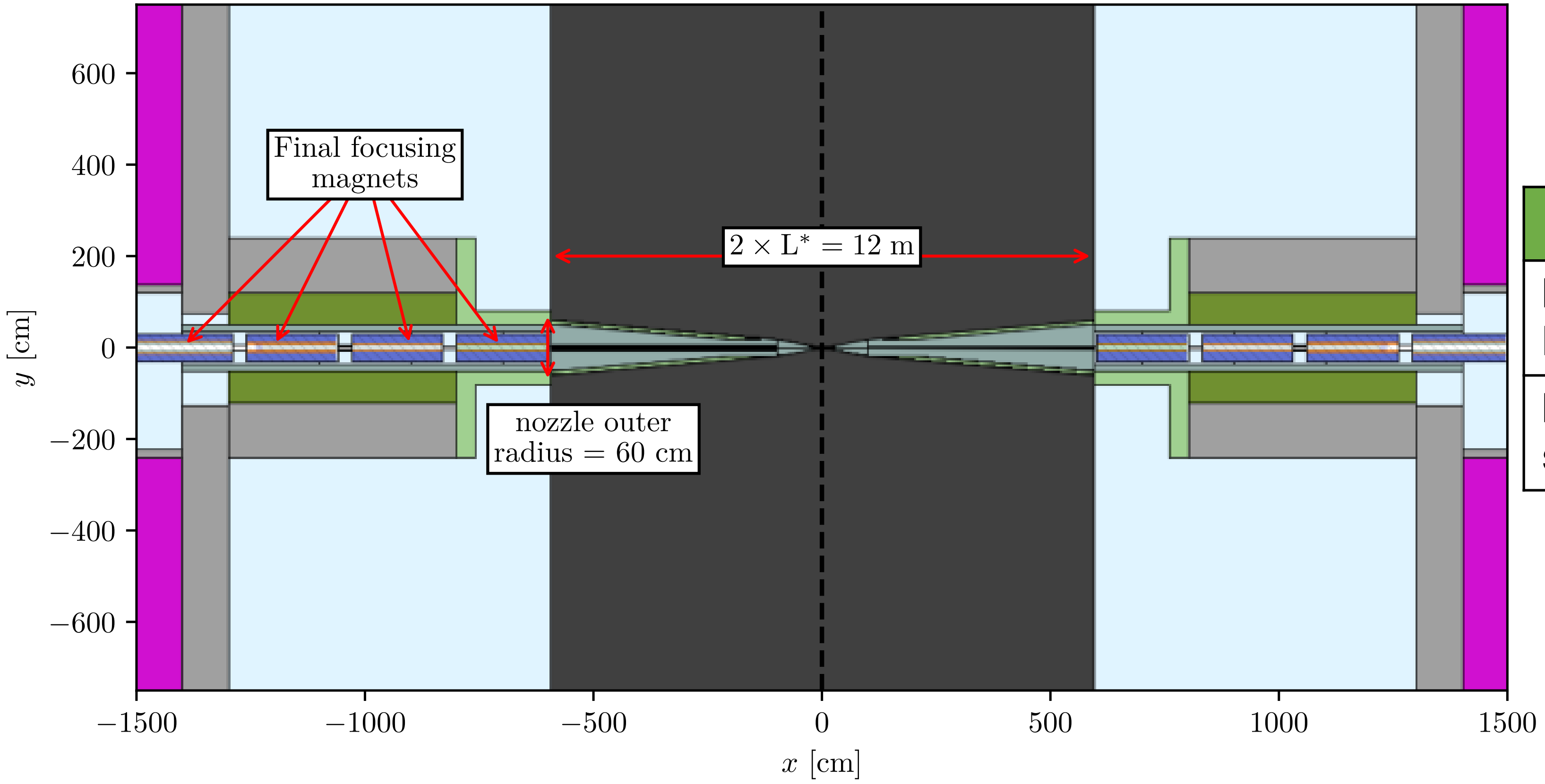


Tracker design important to avoid limitation of performance

Collider interaction region requirements

Longitudinal size of the detector determined by position of final focusing magnets.
At $\sqrt{s} = 10$ TeV it would be very difficult from the the lattice point of view to have more than ± 6 m

C. Carli, A. Lechner, **D. Calzolari**, K. Skoufaris



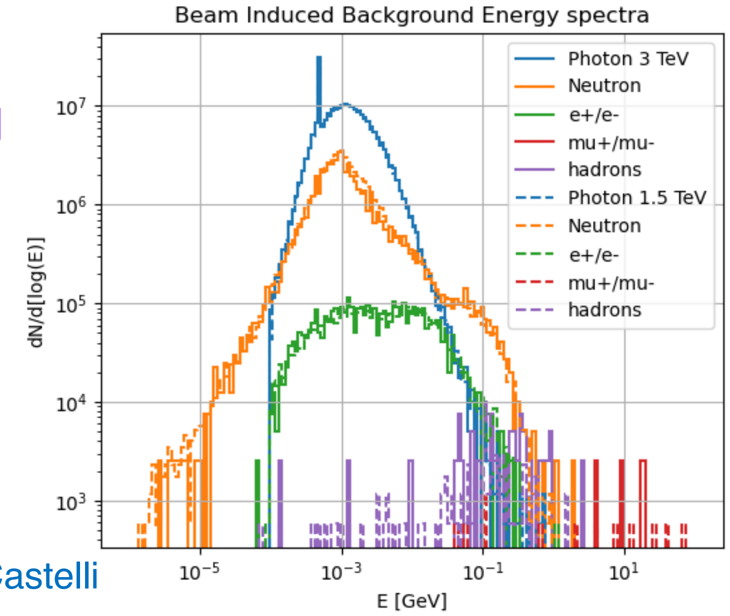
	LHC	MC
bunch length σ_z	7.7 cm	1.5 mm
bunch size $\sigma_\perp$	16.7 μm	0.9 μm

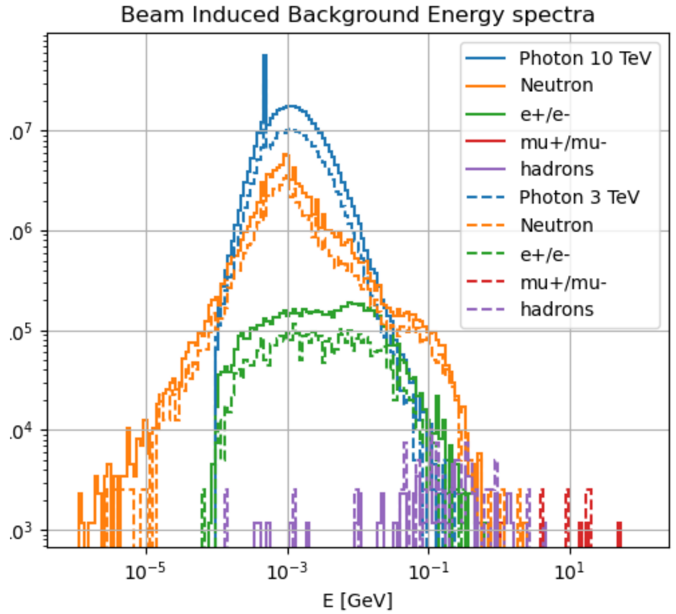
International MUON Collider Collaboration

Beam background sources in the detector region

1) Muon decay along the ring, $\mu^- \to e^- \bar{\nu}_e \nu_\mu$: dominant process at all center-of-mass energies
   - ❈ photons from synchrotron radiation of energetic electrons
   - ❈ electromagnetic showers from electrons and photons
   - ❈ hadronic component from photonuclear interaction with materials
   - ❈ Bethe-Heitler muon, $\gamma + A \to A' + \mu^+\mu^-$
2) Incoherent e^-e^+ production, $\mu^+\mu^- \to \mu^+\mu^- e^+ e^-$: important at high $\sqrt{s}$
   - ❈ small transverse momentum $e^-e^+ \implies$ trapped by detector magnetic field
3) Beam halo: level of acceptable losses to be defined, not an issue now

1) Muon decay along the ring fluxes arriving on detector dominated by shape, material, dimensions of nozzles

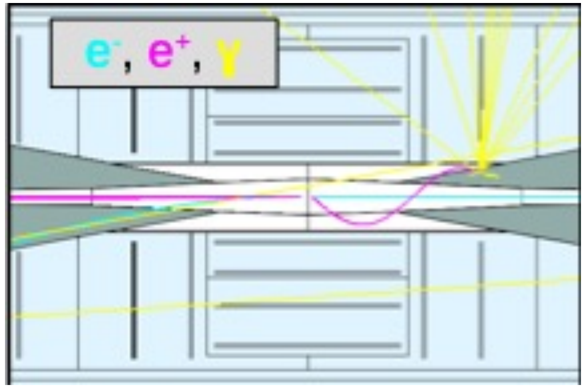




D. Calzolari, L. Castelli

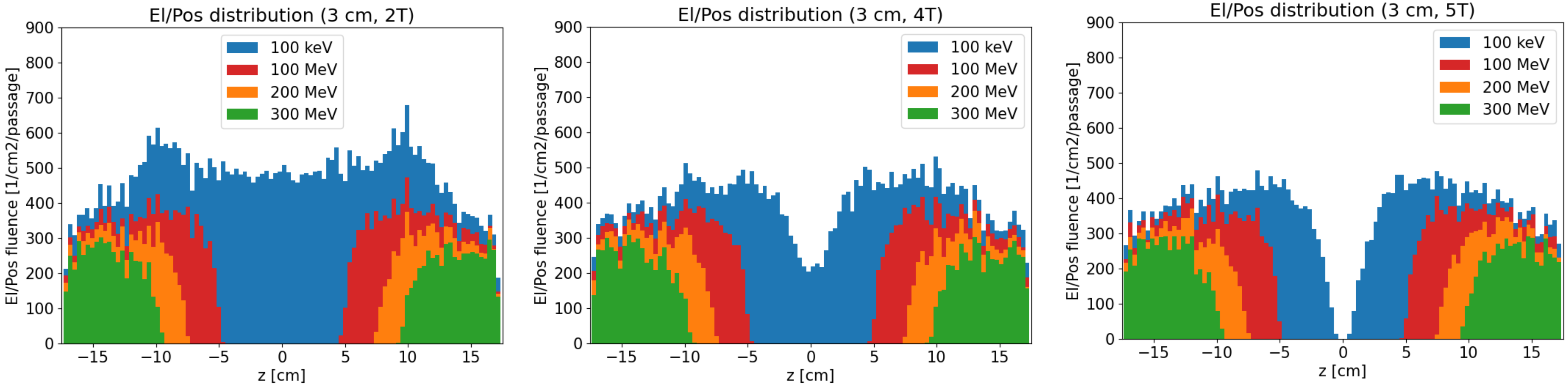
2) Incoherent e^-e^+ production $\mu^+\mu^- \to \mu^+\mu^- e^+ e^-$

- Study in progress by using *Guinea-Pig* program
- Incoherent e^+e^-
  - produced in time with bunch crossing at interaction point
  - very energetic



- Study focuses on reduce the component arriving on the detector by trapping it through solenoidal field

D. Calzolari, Magnet for 10 TeV Detector



Magnetic field needed to reduce beam-induced background

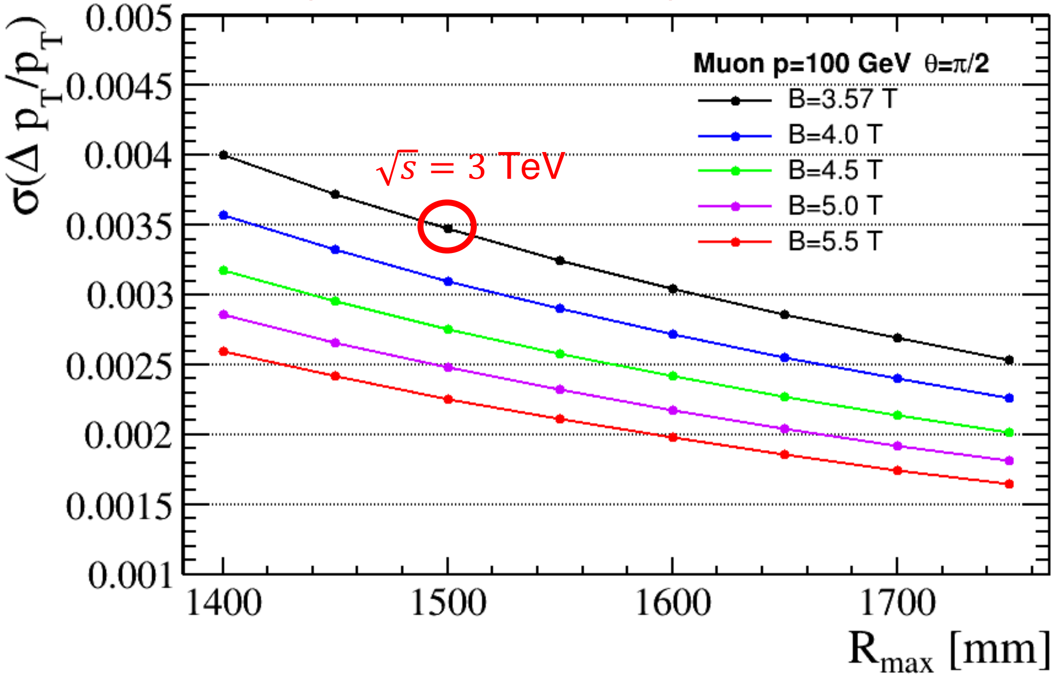
Which magnetic field for the detector?

Analytic formula to relate magnetic field and track momentum resolution

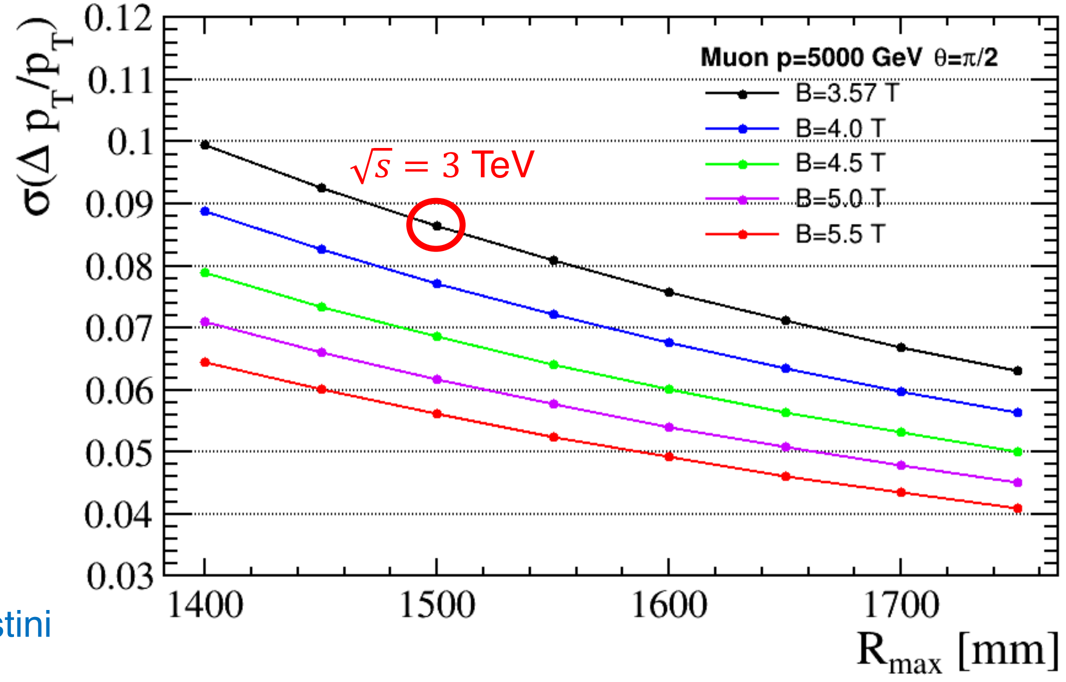
$$\frac{\sigma_{p_T}}{p_T} \cong \frac{12\sigma_{r\varphi} p_T}{0.3BL^2}\sqrt{\frac{5}{N+5}}$$

Z. Drasal and W. Riegler, NIM A 910 (2018) 127

p_μ = 100 GeV at θ_μ = 90°



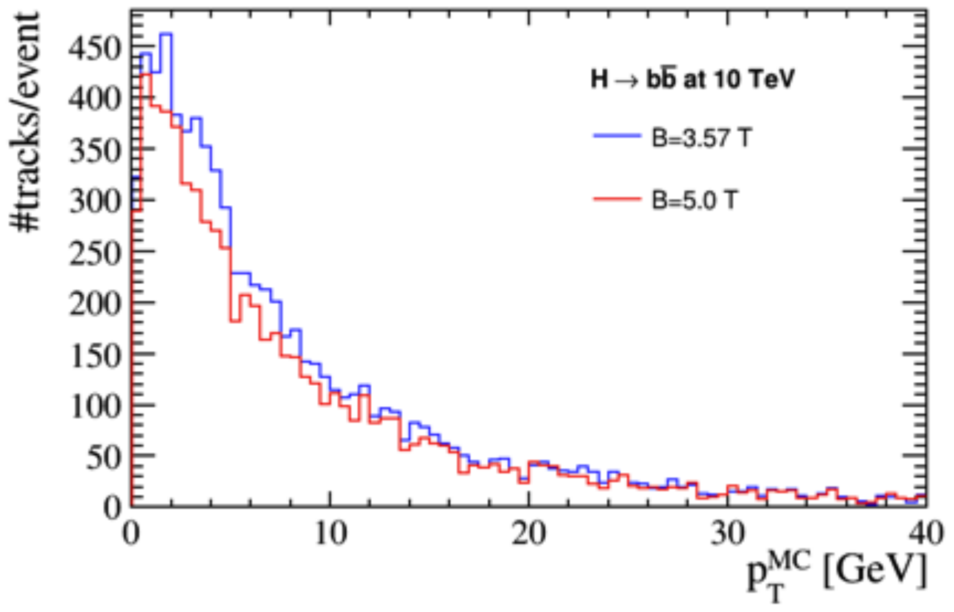
p_μ = 5000 GeV at θ_μ = 90°



L. Sestini

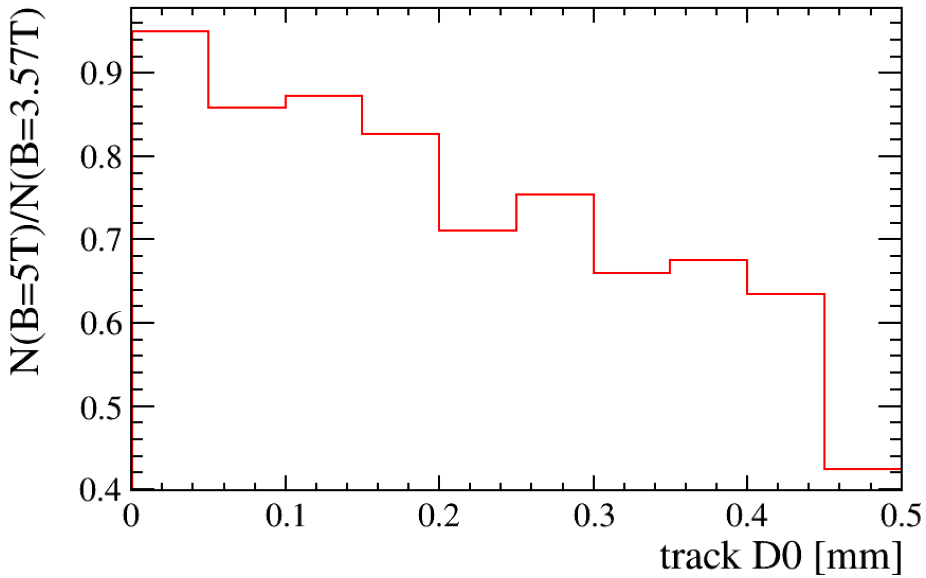
Tracking and magnetic field

generator-level p_T of reconstructed tracks



L. Sestini

N_{tracks}(B=5 T)/N_{tracks}(B=3.57 T) vs track impact parameter



Study of track efficiency with B= 5 T vs. B = 3.57 T
by using $H \rightarrow b\bar{b}$ generated at $\sqrt{s} = 10$ TeV:

- inefficiency ~ 15%
- mainly due to displaced tracks

A magnetic field of about 4 T or 5 T is needed
Magnet should not be a problem, but…

Detector magnet meeting

Detector magnet for 10 TeV MuC

https://indico.cern.ch/event/1324236

5 October 2023
CERN
Europe/Zurich timezone

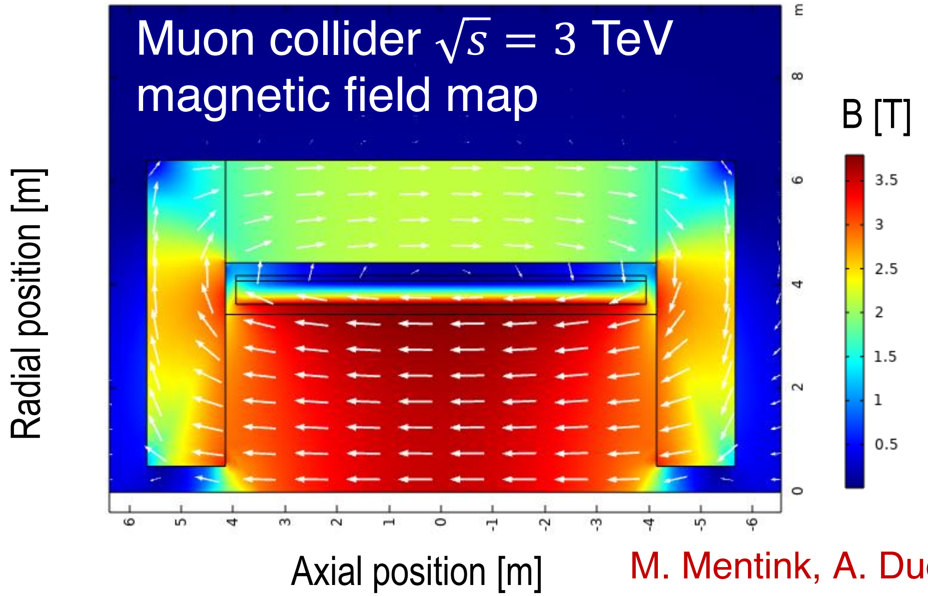
Enter your search term

- Overview
- Timetable
- Contribution List
- Registration
- Participant List
- Videoconference

Contacts
donatella.lucchesi@cern...

The design of a possible detector for a 10 TeV center of mass energy muon collider requires the definition of possible detector magnet configurations and technologies . The presence of the beam-induced background shielding structure complicates the magnet design. This meeting brings together detector, machine-detector interface and magnet experts to start the discussion on possible configurations of the complete interaction region.

MuCol · iFAST · Funded by the European Union



M. Mentink, A. Dudarev, B. Cure

CERN organization for Detector Magnets

B. Cure

Steering committee set up at CERN in March 2023

Decision taken by AT and RC CERN Directors and Department Heads EN, EP & TE, on a cooperation between the Accelerator and the Research sector on experiments magnets.

Co-leaders: Said Atieh (EN/MME), Benoit Curé (EP/CMX)

Cooperation at CERN between the Accelerator and the Research sectors on experiments magnets.

It concerns in particular the issue of non-availability of Alu-stab SC.

Working Group (initiated following the SDMW)

Members from: - **CERN** EN, EP, TE departments.
- **KEK.**

The WG is now working on establishing a program on coextrusion pro... with institutional and industrial part...

Message conveyed by magnet experts attending the meeting

We need to action it, NOW ?

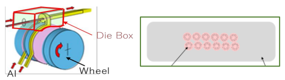
A. Yamamoto

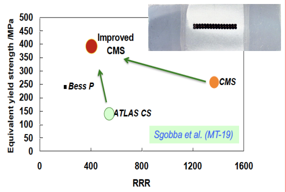
Urgent Action Required:

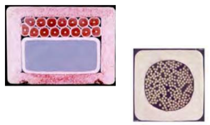
- **Al-stabilized superconductor technology** needs to be resumed,
  - **"Co-extrusion technology"** of Al-stabilizer to be resumed, and
  - "Hybrid-structure technology" by using electron beam welding (EBW)
  - **Laboratory's leading effort very important** to advance the technology
- CERN is now working for establishing a program on coextrusion process for Al-stab SC with institutional and industrial partners.

Remarks:

- It will be **needed** to investigate **backup solutions** such as:
  - soldering technology of NbTi/Cu conductor with Cu-coated Al-stabilizer, and/or CICC. ,,,
- It will be encouraged to investigate Al-stabilized HTS for specofoc applications



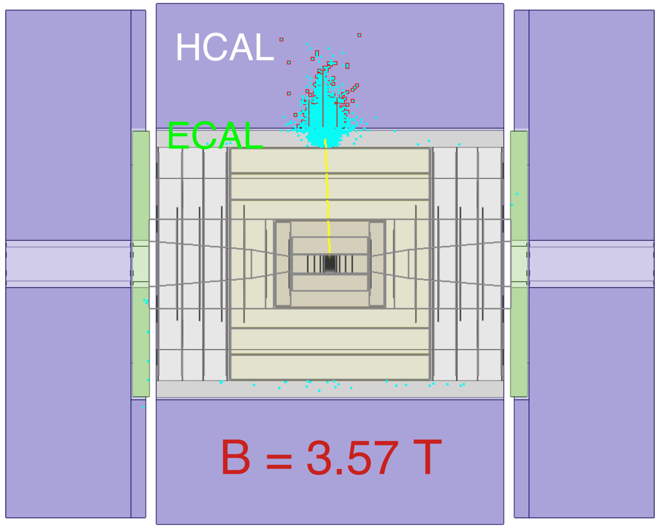




Photon and jet reconstruction

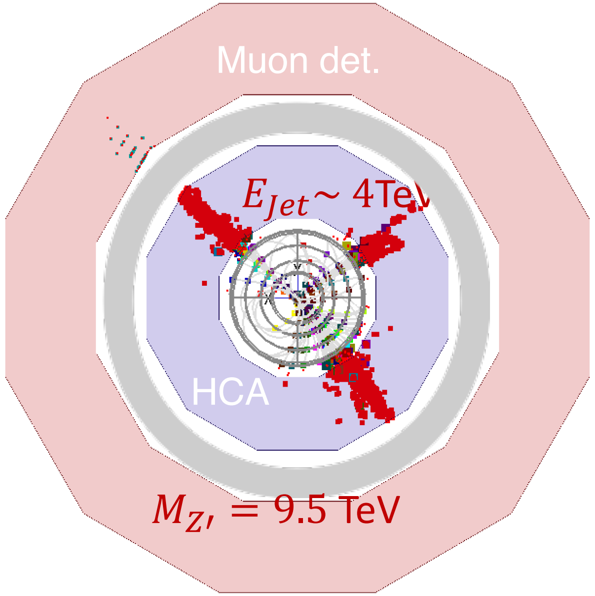
central 5 TeV photon

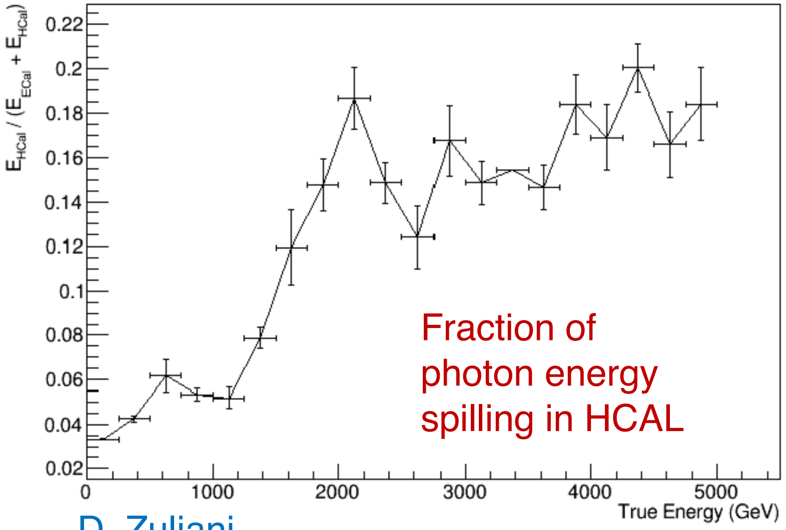
M. Casarsa



Desired ECAL :
- Deep: ~25X_0
- High granularity
- Longitudinal segmentation
- Timing ~100 ps
- CRILIN @10 TeV under study

$\mu^+\mu^- \rightarrow Z'X \rightarrow jjX$ $\sqrt{s} = 10$ TeV



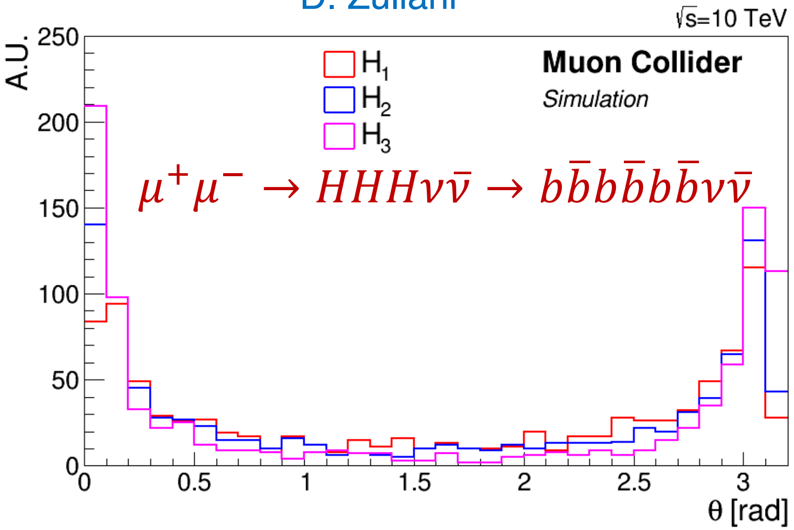


D. Zuliani

E_γ[GeV]

Desired HCAL :
- Deep: ~8.5λ_i
- Good forward coverage
- Sufficient granularity to be used in particle flow

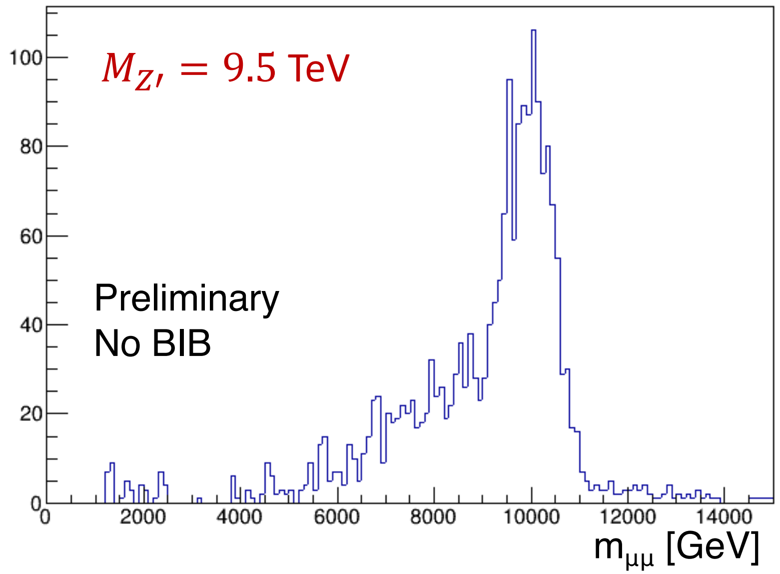
D. Zuliani



Muon reconstruction

- Need to cover a momentum range from few GeV up to TeV
- New approach needed:
  - usual methods for low momentum;
  - combine information from muons detector, tracker and calorimeter information, jet-like structure.

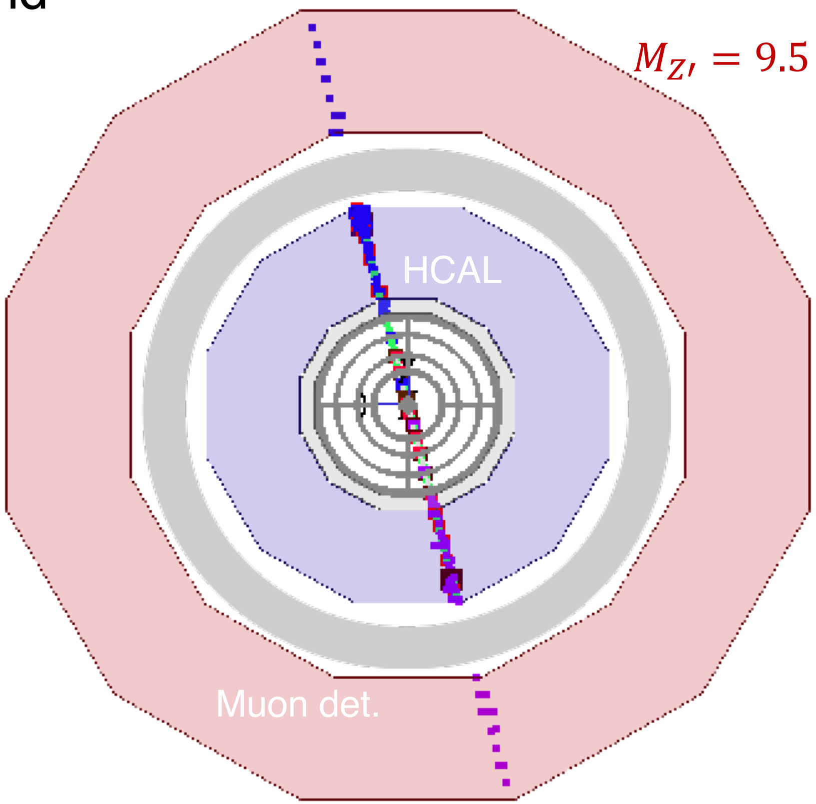
$\mu^+\mu^- \to Z'X \to \mu\mu X$ $\sqrt{s} = 10$ TeV



B = 5 T

$\mu^+\mu^- \to Z'X \to \mu\mu X$ $\sqrt{s} = 10$ TeV

$M_{Z'} = 9.5$ TeV



Outlook

International MUON Collider Collaboration

- On several occasions it has ben demonstrated that a detector at 3 TeV CoM energy is competitive with CLIC $\Longrightarrow$ DONE

- Beam-induced background at $\sqrt{s} = 10$ TeV ready to be processed in the detector with the nozzles of $\sqrt{s} = 1.5$ TeV. Incoherent pair production inclusion in progress.

- The requirements for a detector at 10 TeV CoM energy have been setup:
  - Magnetic field around 4-5 T
  - Study:
    - ECAL inside magnet HCAL outside
    - Both inside