UNIVERSITÀ DI PAVIA

INFN Istituto Nazionale di Fisica Nucleare

International MUON Collider Collaboration

Riunione di collaborazione
RD_MUCOL Italia
Pavia 19-21 dic 2022

Muon R&D

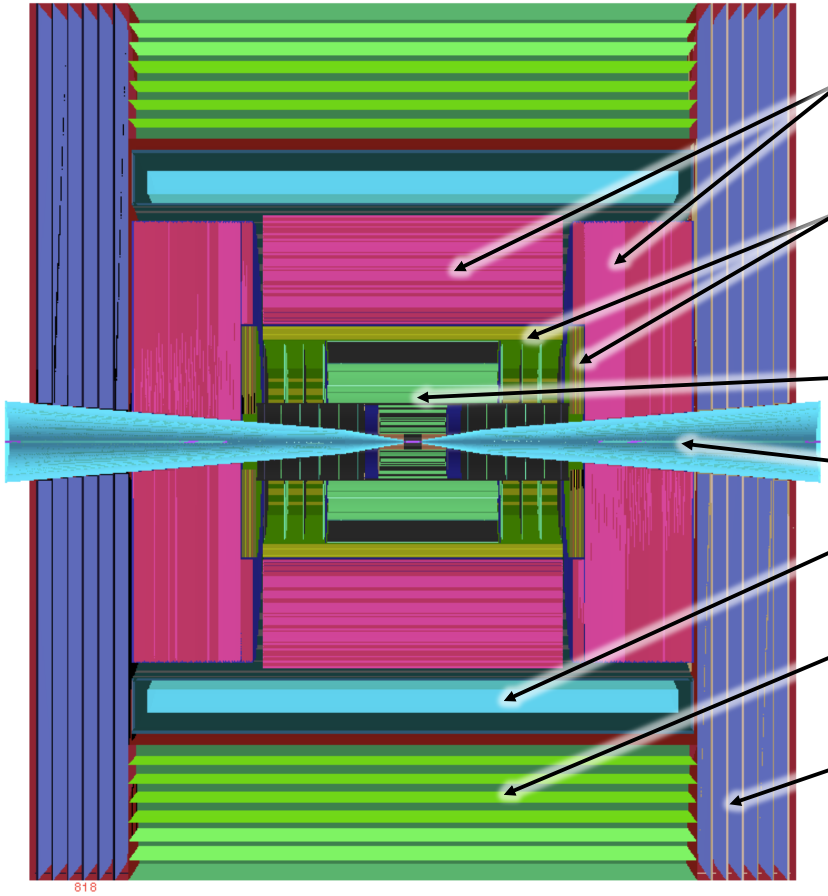
Pavia group

Summary

1. Muon system
    1. Current simulation
    2. Beam-induced Background (BIB)
2. Muon reconstruction
    1. Preliminary results without BIB
    2. Dealing with BIB
3. R&D on detectors
    1. Comparison of technologies
    2. Picosec
    3. Test beam results

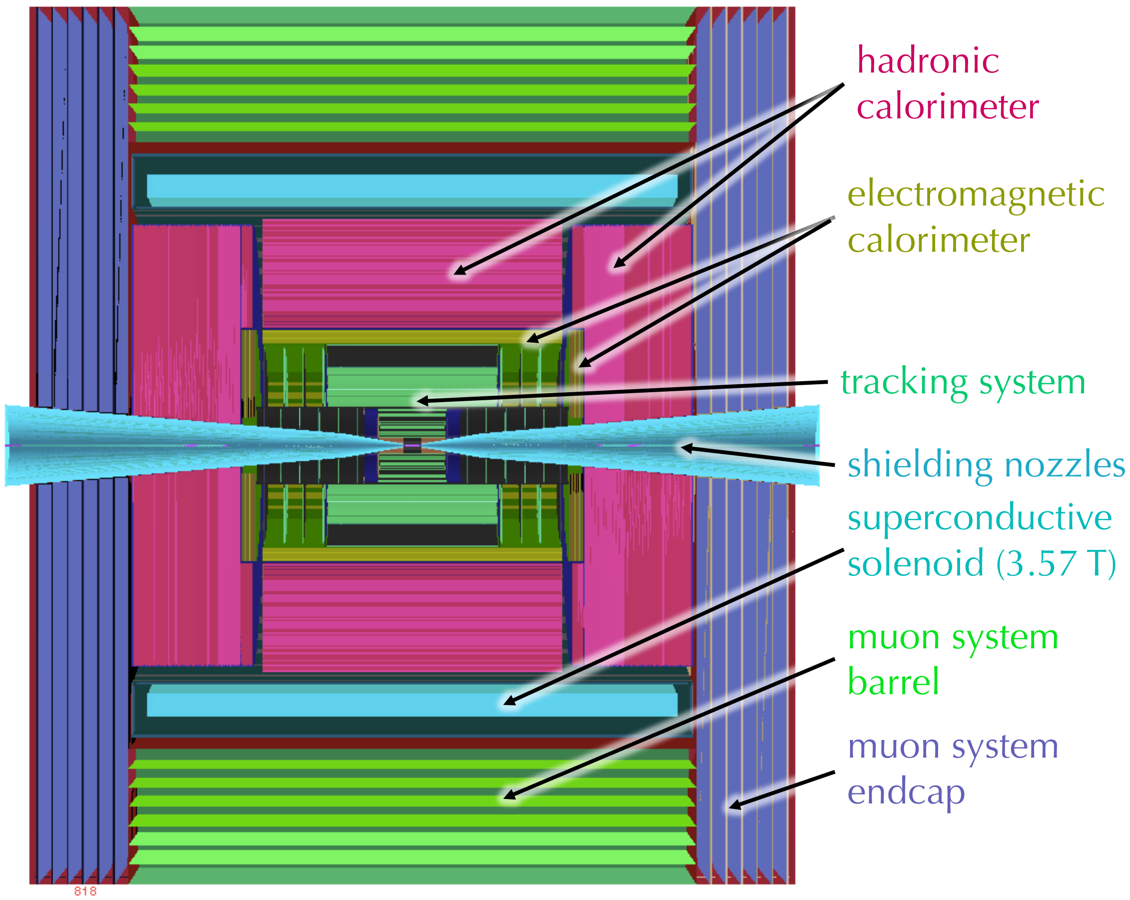
Muon Collider detector

arXiv:2203.07964v1 *Simulated Detector Performance at the Muon Collider*



Subsystem	Region	R dimensions [cm]	|Z| dimensions [cm]	Material
Vertex Detector	Barrel	3.0 – 10.4	65.0	Si
	Endcap	2.5 – 11.2	8.0 – 28.2	Si
Inner Tracker	Barrel	12.7 – 55.4	48.2 – 69.2	Si
	Endcap	40.5 – 55.5	52.4 – 219.0	Si
Outer Tracker	Barrel	81.9 – 148.6	124.9	Si
	Endcap	61.8 – 143.0	131.0 – 219.0	Si
ECAL	Barrel	150.0 – 170.2	221.0	W + Si
	Endcap	31.0 – 170.0	230.7 – 250.9	W + Si
HCAL	Barrel	174.0 – 333.0	221.0	Fe + PS
	Endcap	307.0 – 324.6	235.4 – 412.9	Fe + PS
Solenoid	Barrel	348.3 – 429.0	412.9	Al
Muon Detector	Barrel	446.1 – 645.0	417.9	Fe + RPC
	Endcap	57.5 – 645.0	417.9 – 563.8	Fe + RPC

Muon system



Geometry based on CLIC detector
arXiv:1202.5940 *Physics and Detectors at CLIC: CLIC CDR*

Current design

Iron yoke plates instrumented with:

- 7 layers of detectors in the barrel
- 6 layers in both endcaps

Detector technology: Glass Resistive Plate Chamber (GRPC)

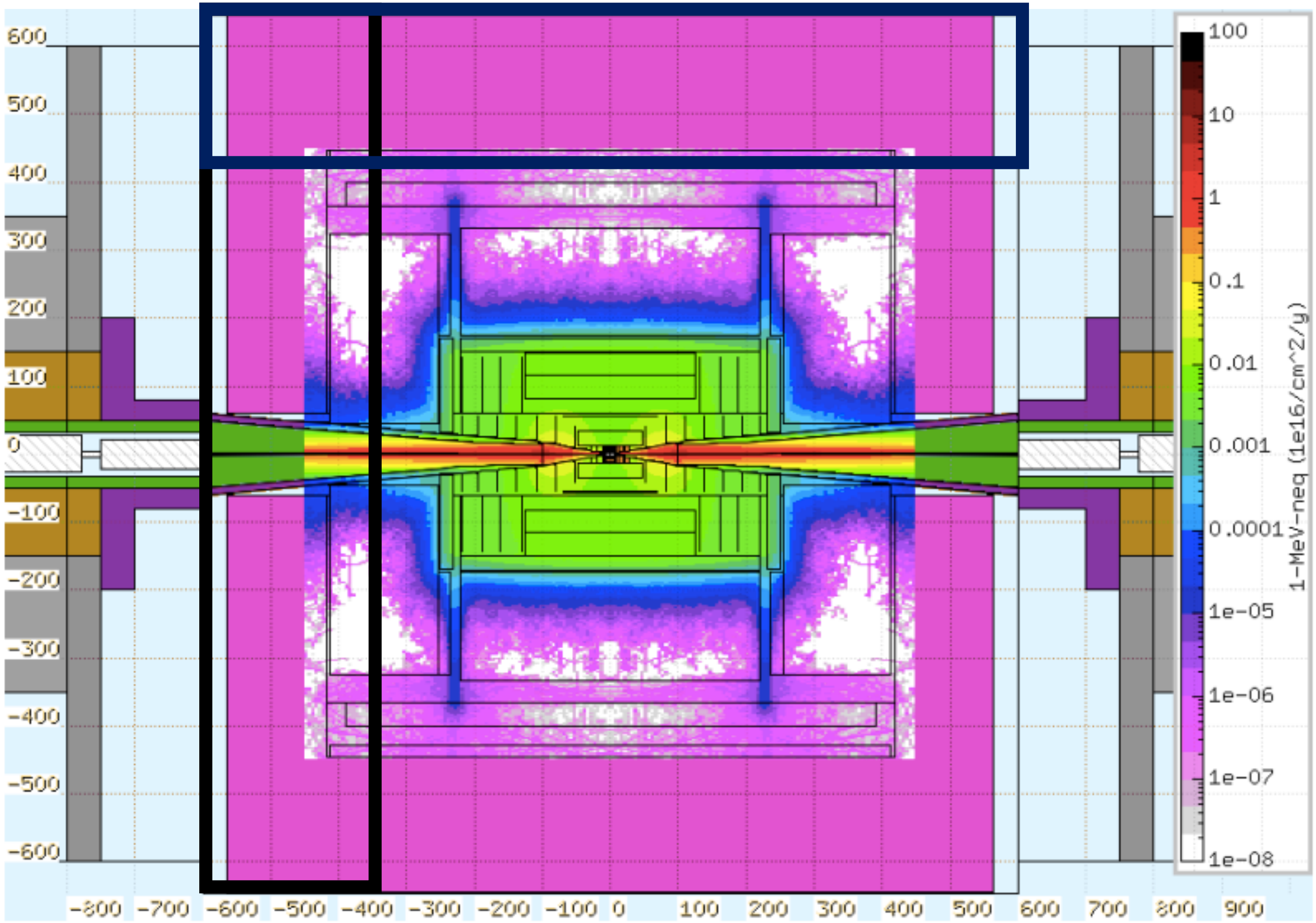
Detector cells: 30x30 mm^2

Magnetic field:

- 1.34 T in barrel
- 0.01 T in endcaps

Beam-induced background

arXiv:2203.07224v1 *Promising Technologies and R&D Directions for the Future Muon Collider Detectors*



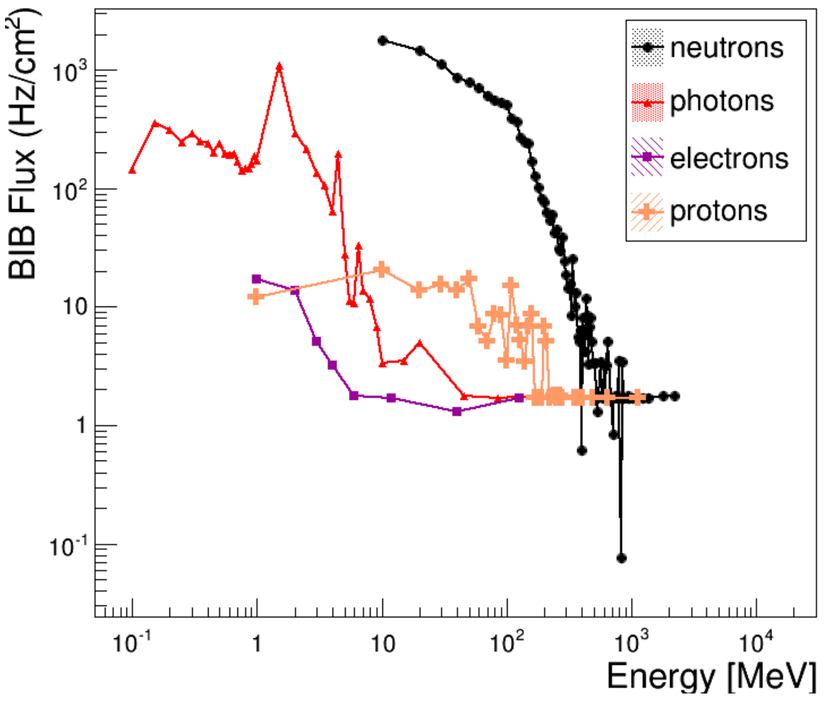
1-MeV-neq **fluence**
$\sqrt{s}$ =1.5 TeV
ring circumference = 2.5 km
injection frequency = 5 Hz
normalised to one year

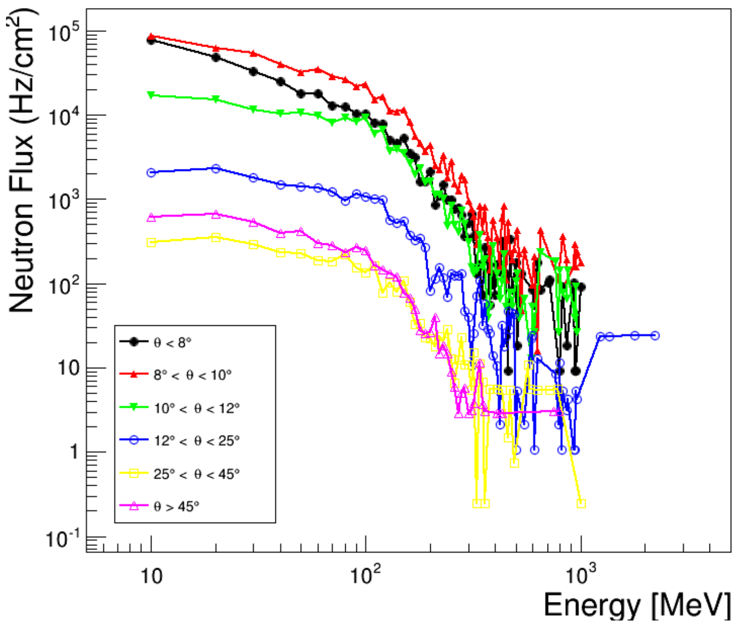
ANNUAL MEETING @CERN
Francesco Collamati *Machine-induced background studies for 1.5 TeV and 3 TeV*

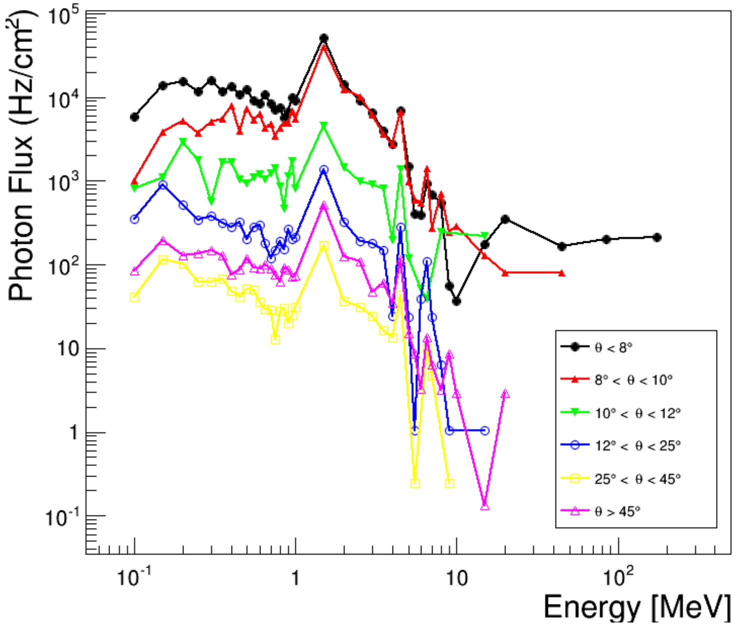
BIB occupancy in the muon system is very low

Beam-induced background in the muon system

BIB mainly composed of neutrons and photons





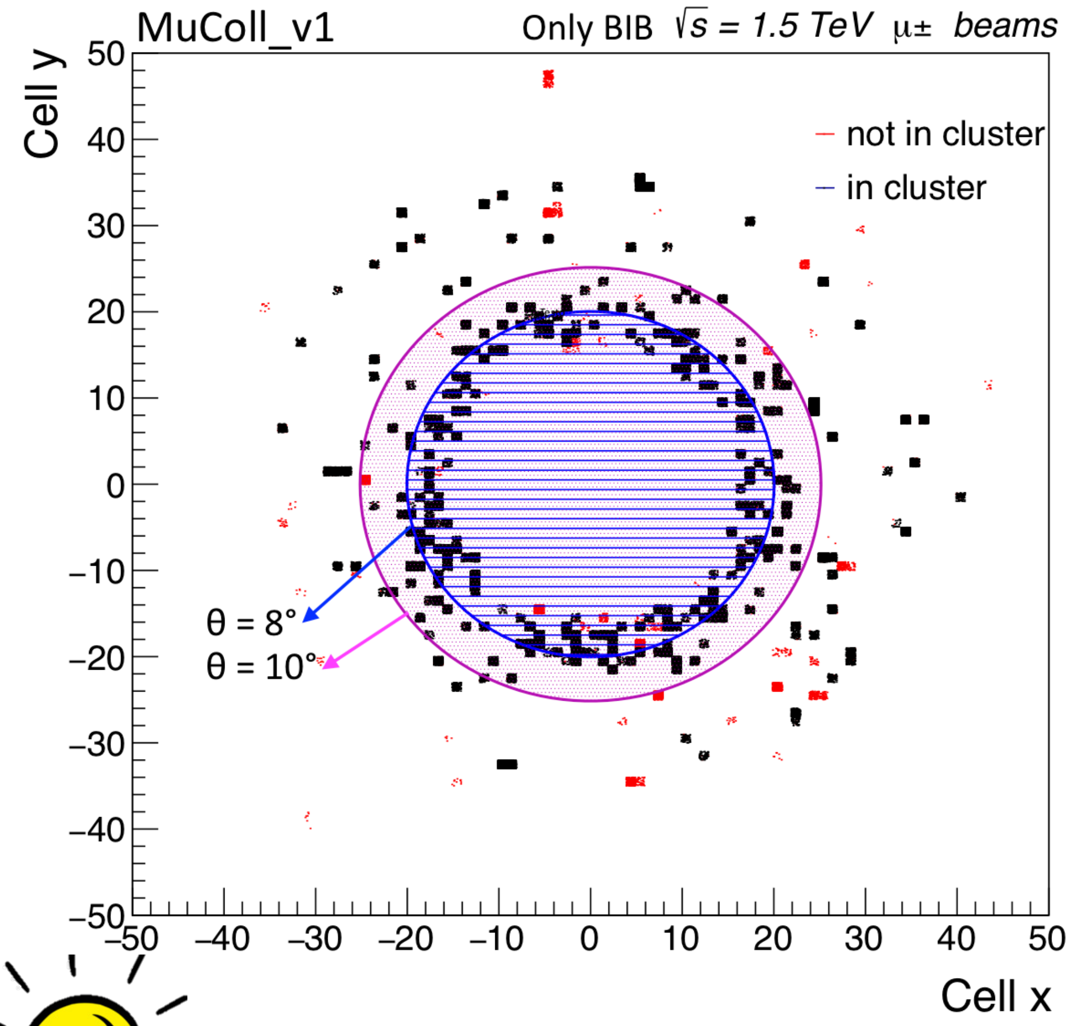


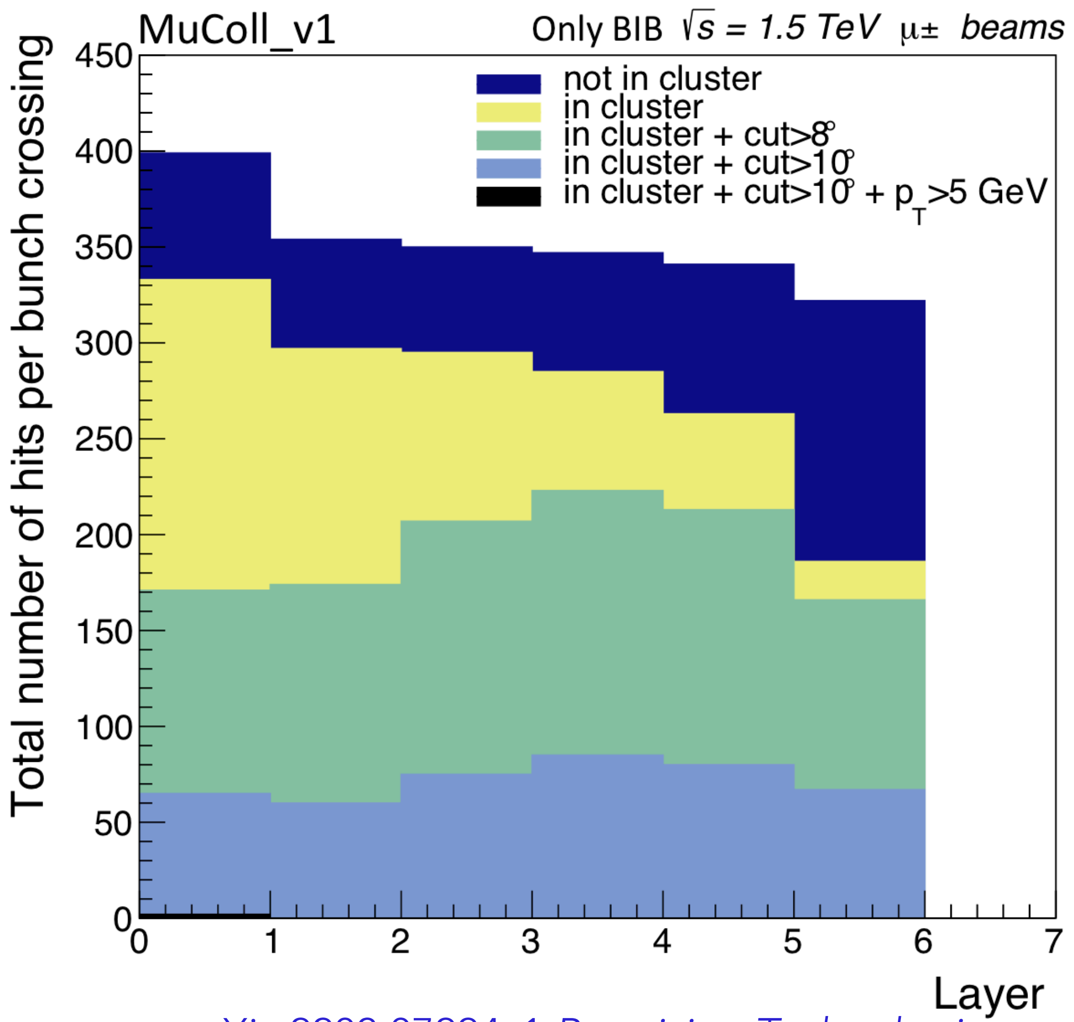
Energy ranges at $\sqrt{s} = 1.5$ TeV

- neutrons: from 10 MeV to 2.5 GeV
- photons: from 100 keV to 200 MeV

BIB hits concentrated around the beam axis in the endcaps

Geometrical cut + other cuts to reject almost all BIB hits in the muon system





Standalone muon objects to seed the global muon track reconstruction

arXiv:2203.07224v1 *Promising Technologies and R&D Directions for the Future Muon Collider Detectors*

Muon reconstruction

Karol Krizka *Tracks reconstruction algorithms performance*

Algorithms for tracks

1. From electron positron colliders: **Conformal Tracking** (CT)
   - with BIB: too long
     - strategies:
       a. Region of Interest (ROI)
       b. double-layer filter
2. From hadron colliders: **Combinatorial Kalman Filter** (CKF) implemented using A Common Tracking Software (ACTS)

Muon reconstruction

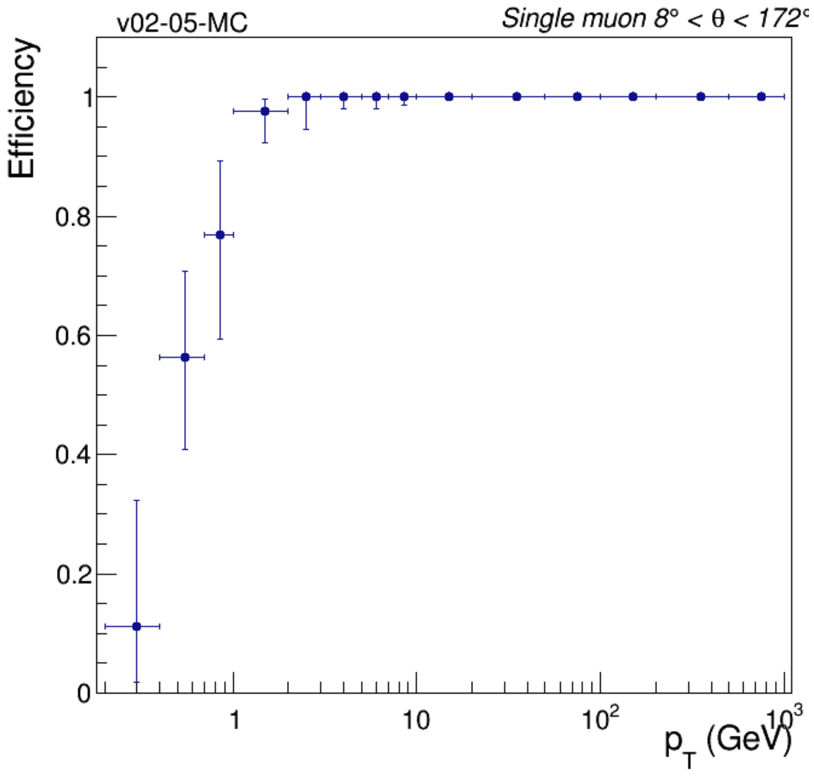
Muons are reconstructed with the **Pandora Particle Flow** algorithm by matching tracks in the inner detector with clusters of hits in the muon system.

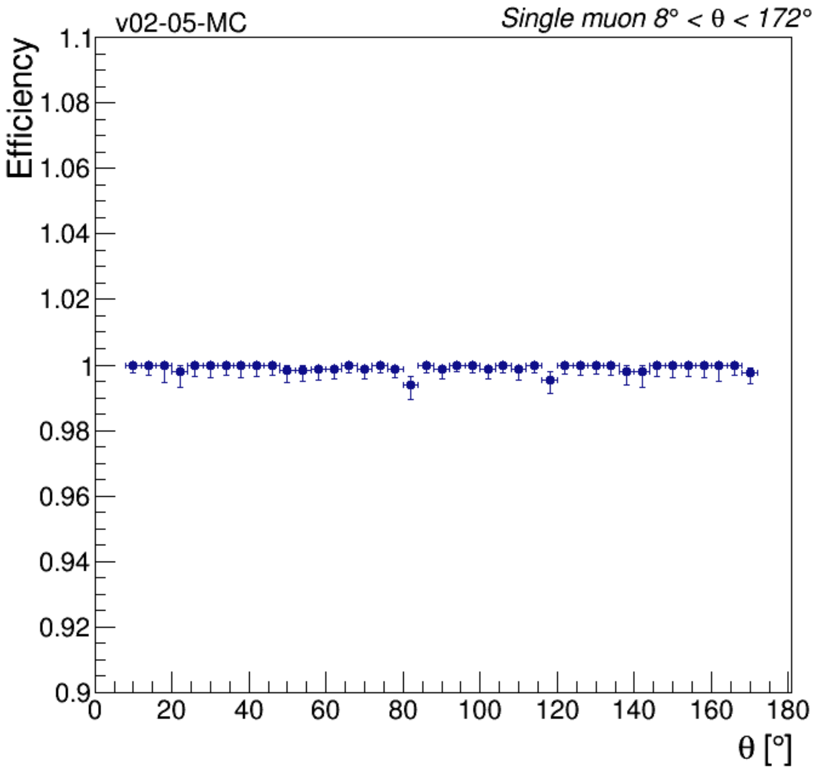
Cluster = combination of hits (one hit per layer) inside a cone extending to the neighbouring layers

First results without BIB

CT + Pandora

Single muon efficiency

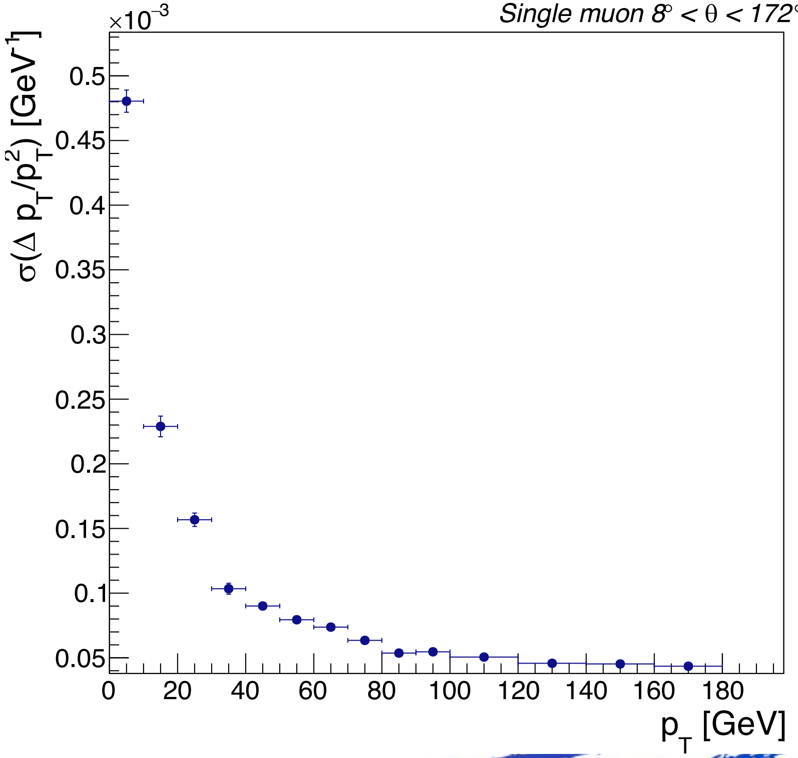




Single muon efficiency ~100% for muons with p_T >10 GeV

Transverse momentum resolution

$\Delta p_T = p_T$ of the generated muon $- p_T$ of the Pandora reconstructed track

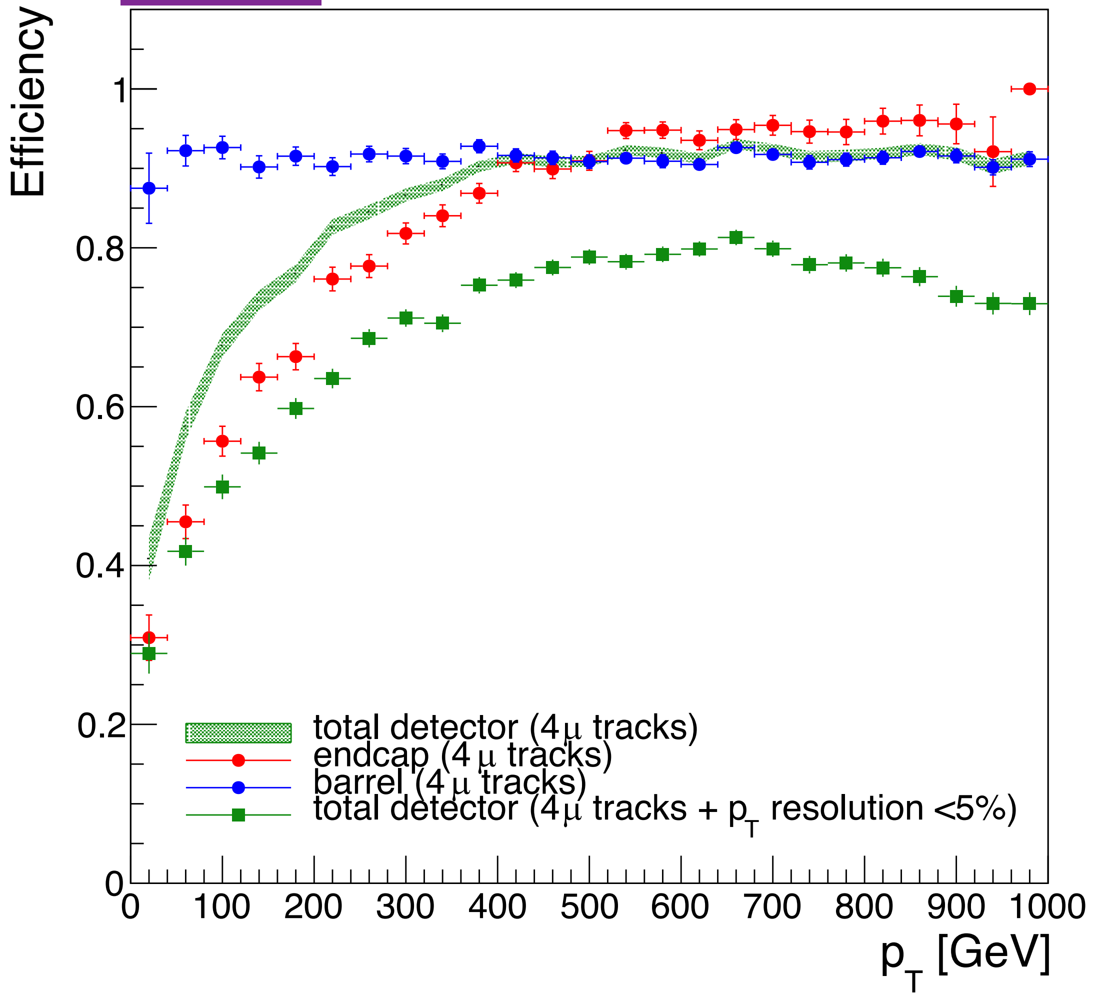


First results without BIB

CT + Pandora

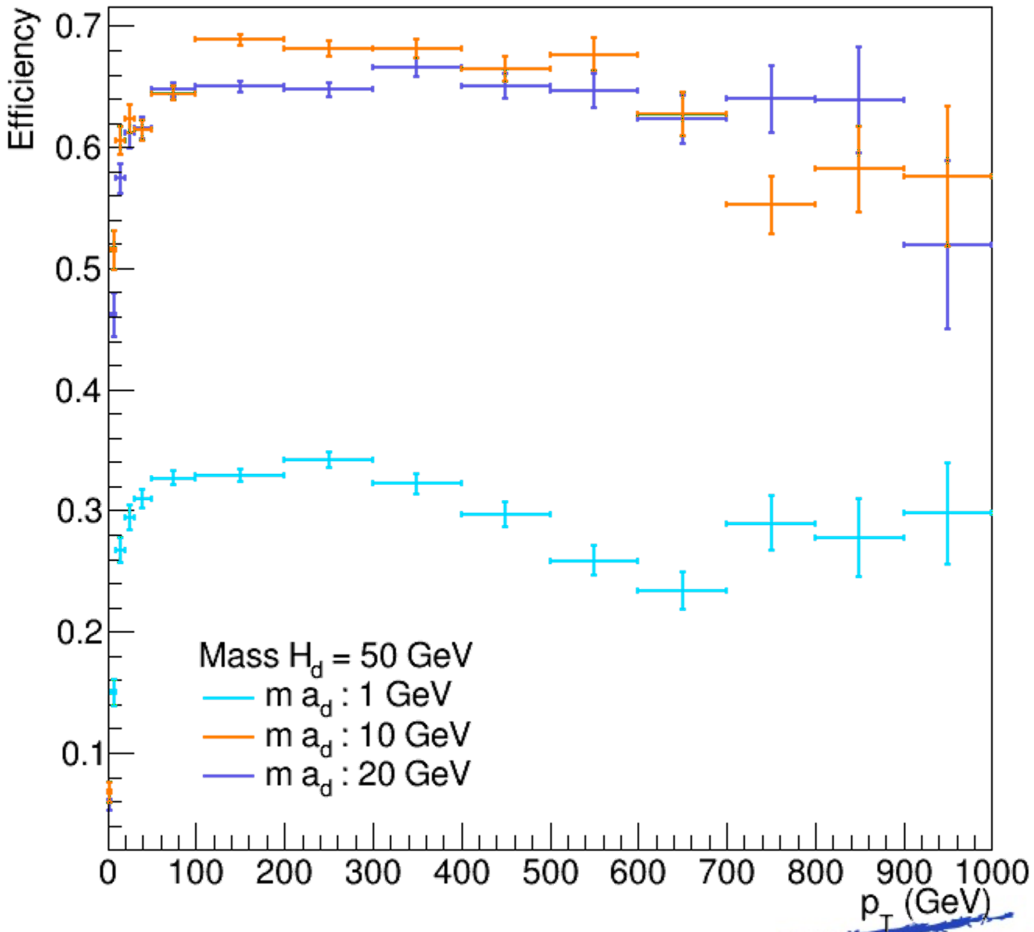
Physics channels efficiency

4 muons



8 muons

DOI: 10.22323/1.398.0644



Dealing with BIB

Muon reconstruction is quite straightforward without BIB.

But with BIB new strategies have to be adopted

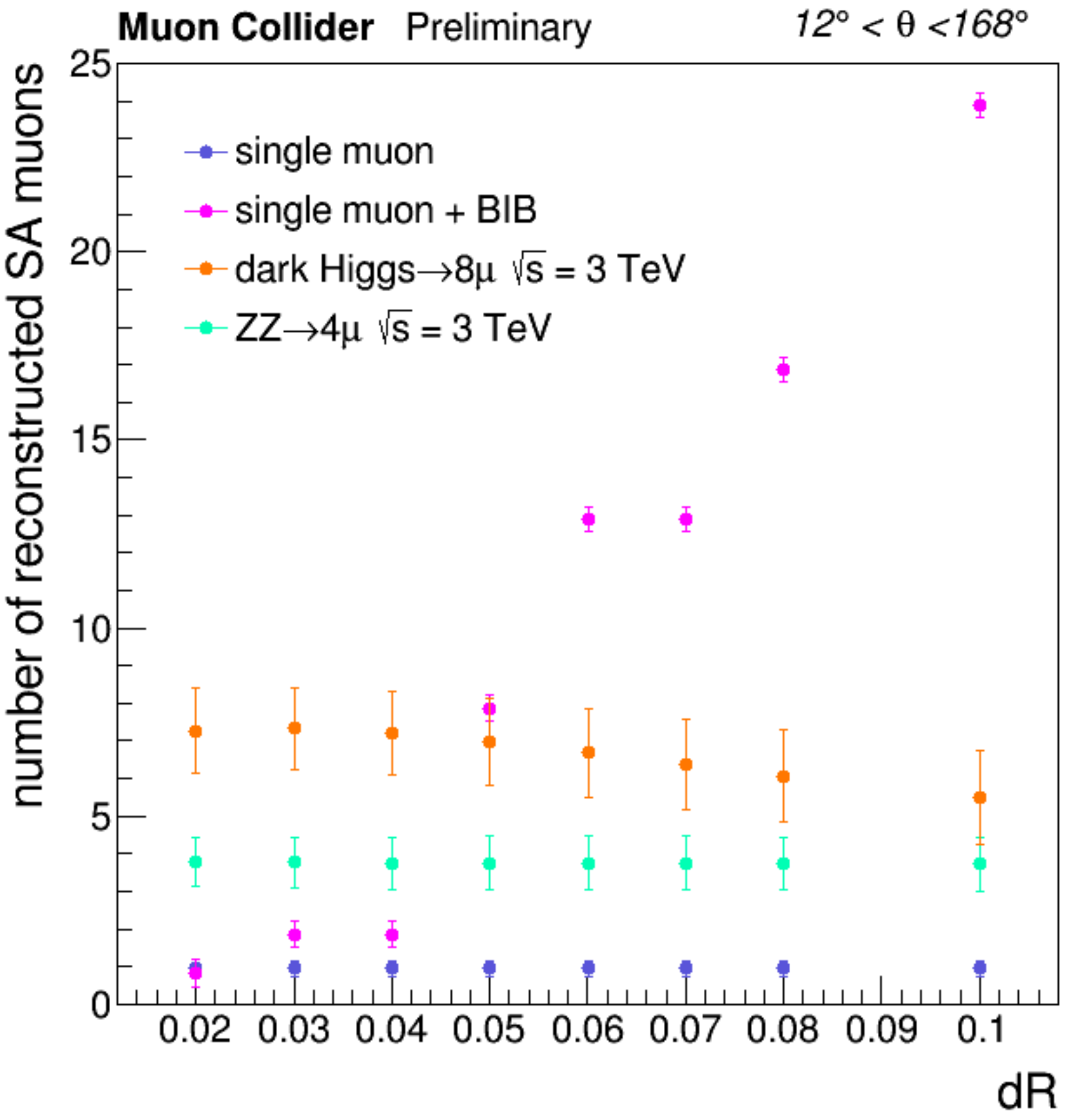
Standalone muon reconstruction
exploiting the low BIB occupancy in the muon system to identify a ROI for CT

ACTS
overcome CT limits

CT (ROI)

1. Standalone muon reconstruction

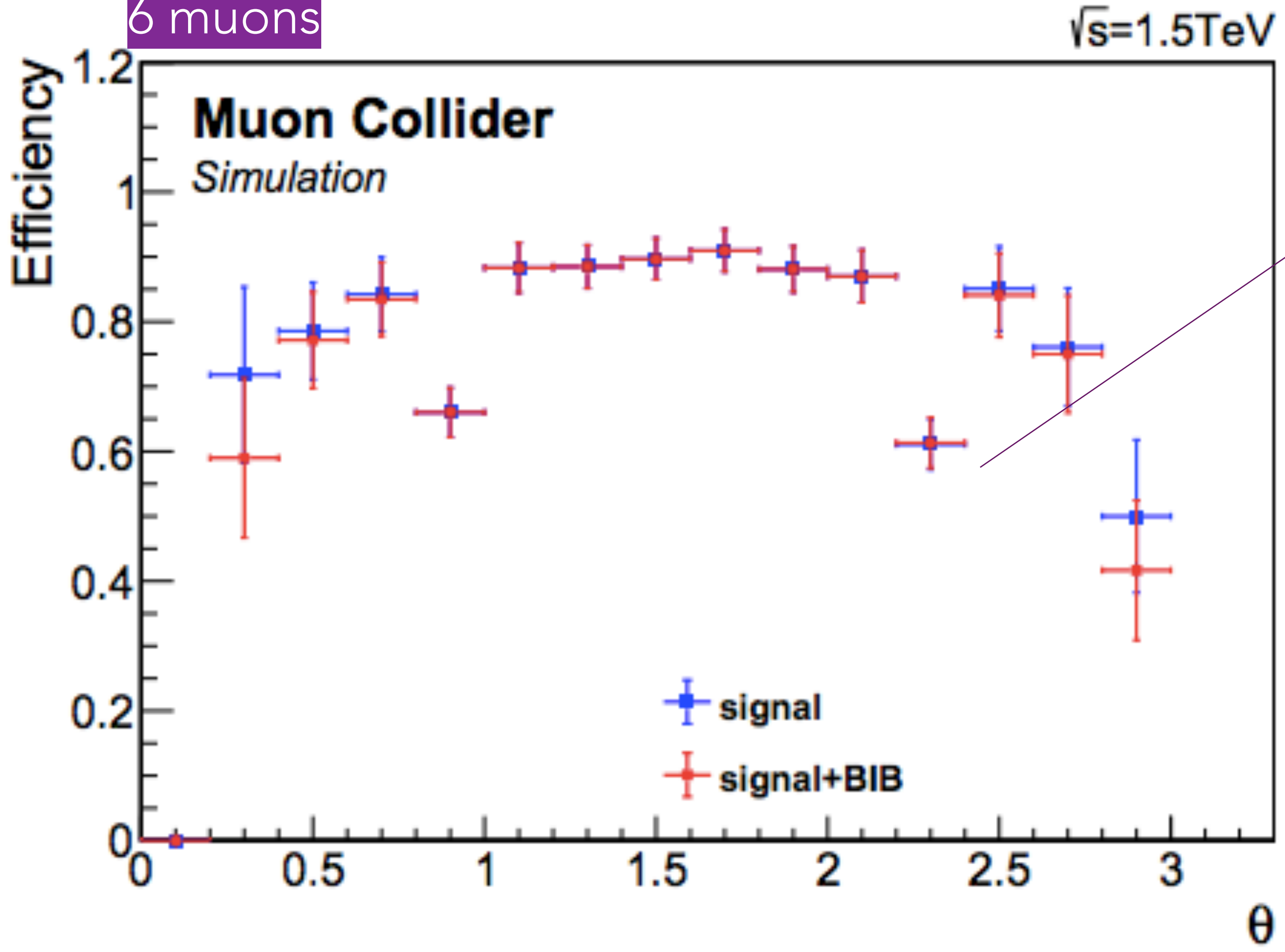
a. muon hits clustered inside a cone with angular aperture ΔR (selected value = 0.02)
b. standalone muon track created if there are hits at least in 5 layers
c. reconstructed hits in all tracker subsystems filtered (ROI)
d. Conformal tracking algorithm applied



Limits

arXiv:2203.07964v1 *Simulated Detector Performance at the Muon Collider*

6 muons



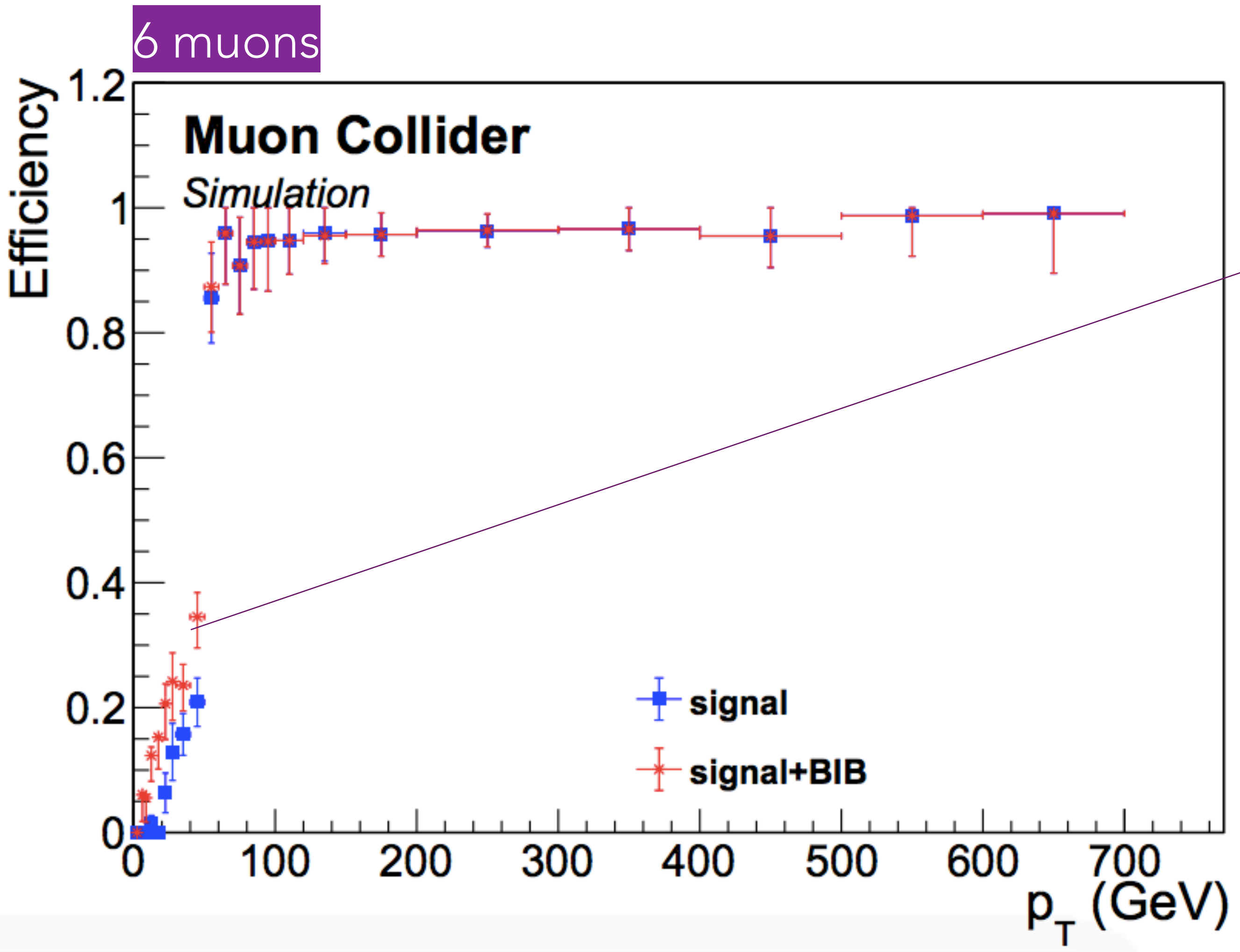
$\theta < 15°$ and $\theta > 165°$ CT limit

$\theta \sim 32°$ and $\theta \sim 132°$

a specific approach for track with hits both in endcap and barrel is required

Limits

arXiv:2203.07964v1 *Simulated Detector Performance at the Muon Collider*



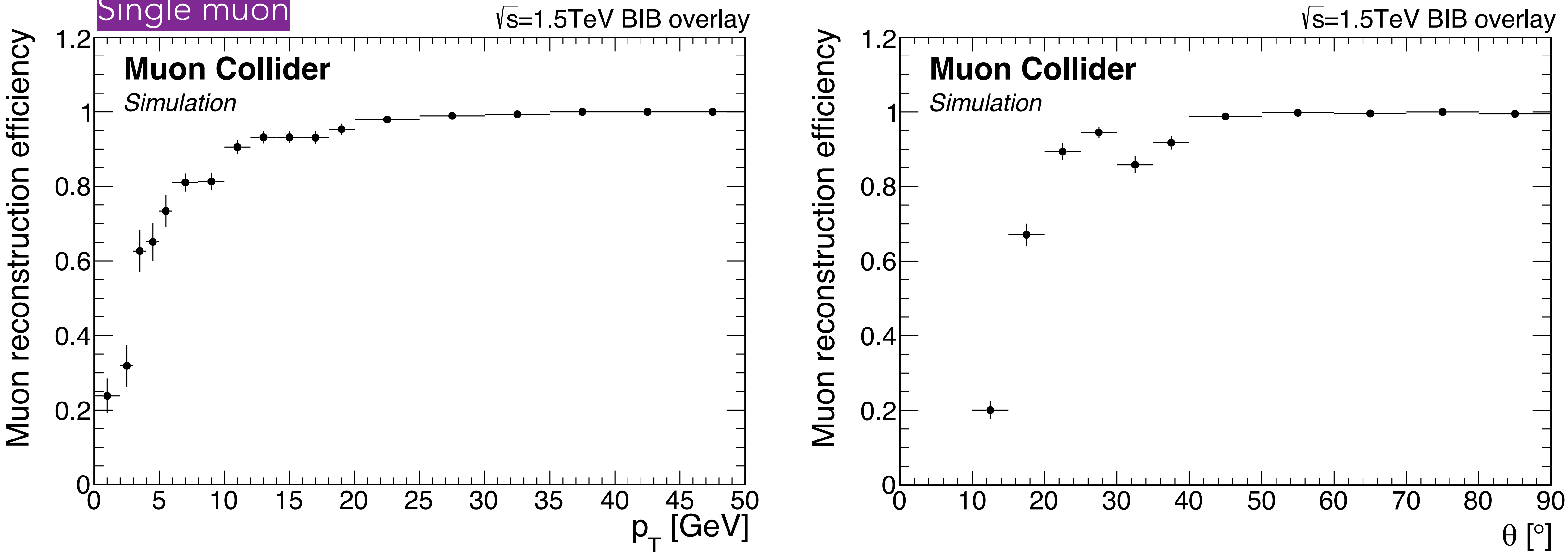
Low p_T

- inefficiencies in reconstruction in the region between barrel and endcap
- parameter tuning for high curvature tracks

2. ACTS

ACTS + Pandora

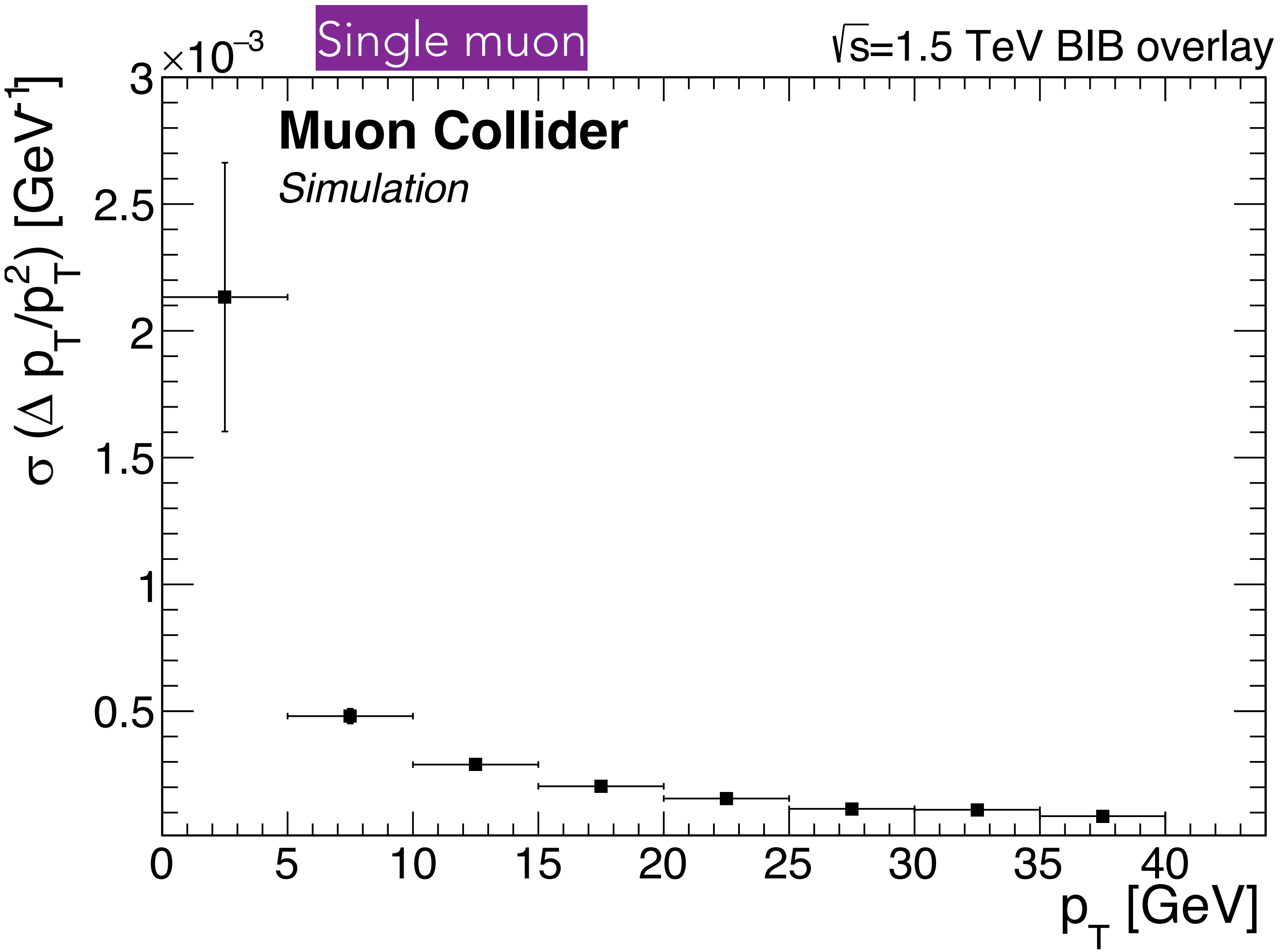
Single muon



Efficiency >99% for p_T >10 GeV and >98% for $8° < \theta < 172°$

2. ACTS

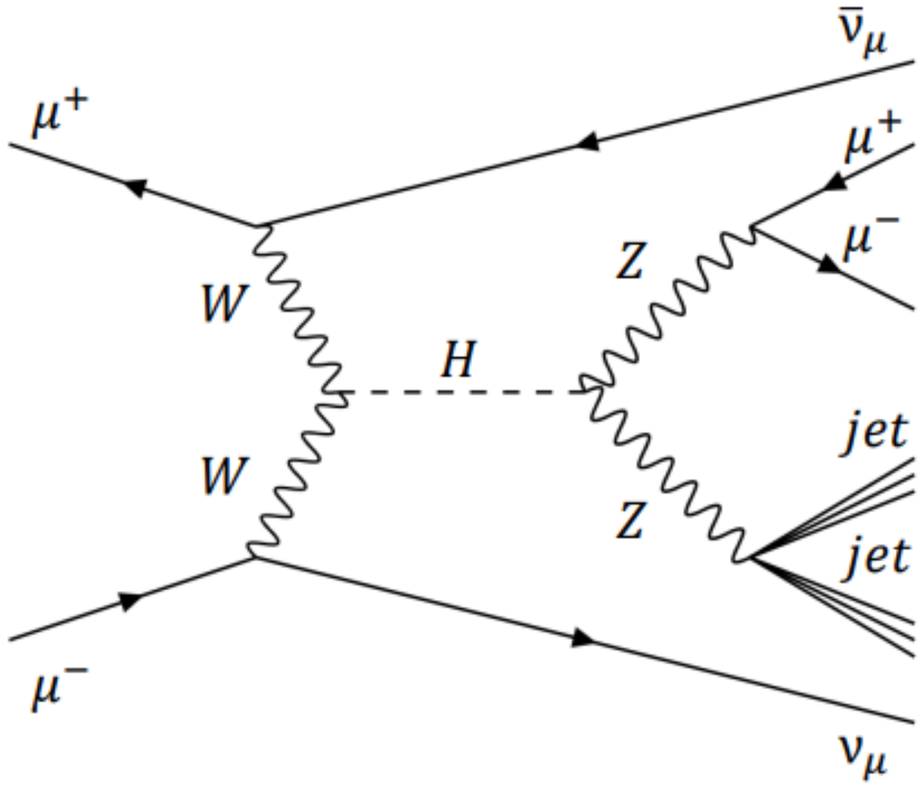
ACTS + Pandora



Resolution less then 10^{-4} GeV^{-1} for $p_T > 30$ GeV

Limits?

Physics channel



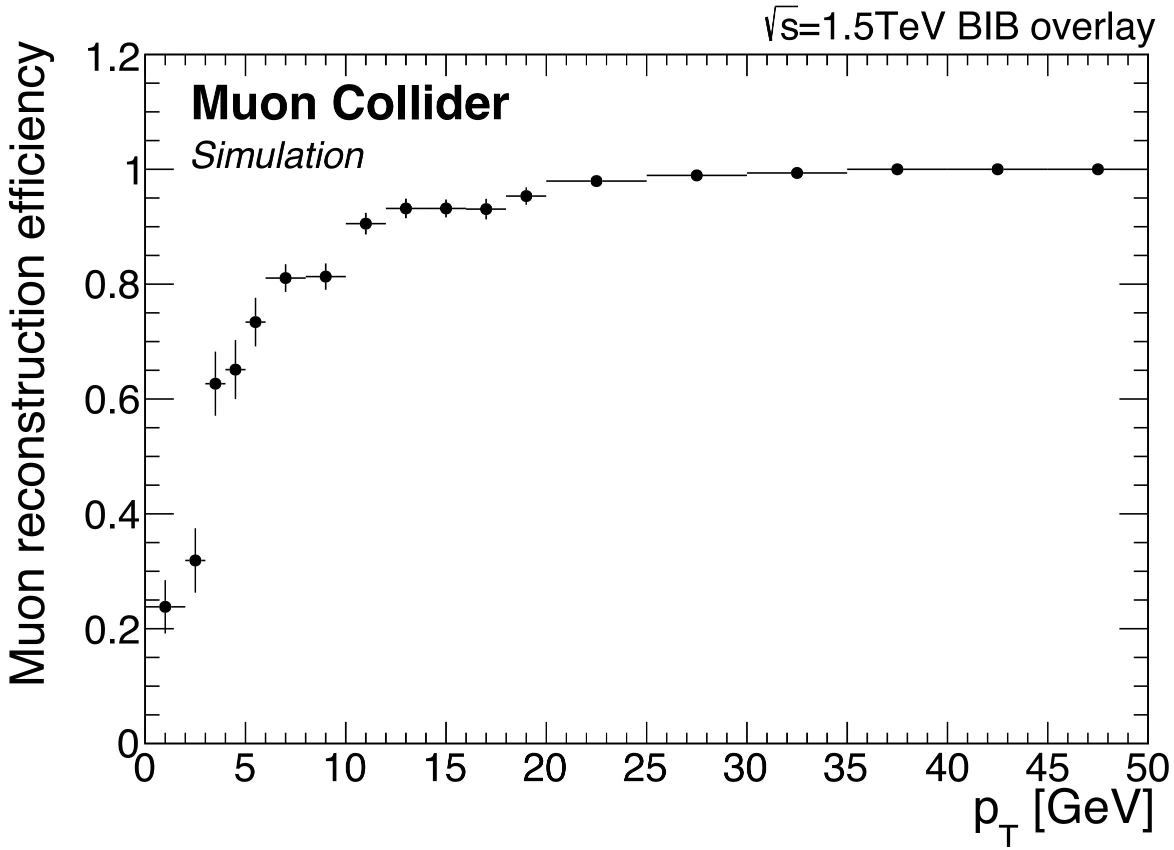
https://indico.cern.ch/event/1197844/
Study of H->ZZ at 3 TeV CoM energy*

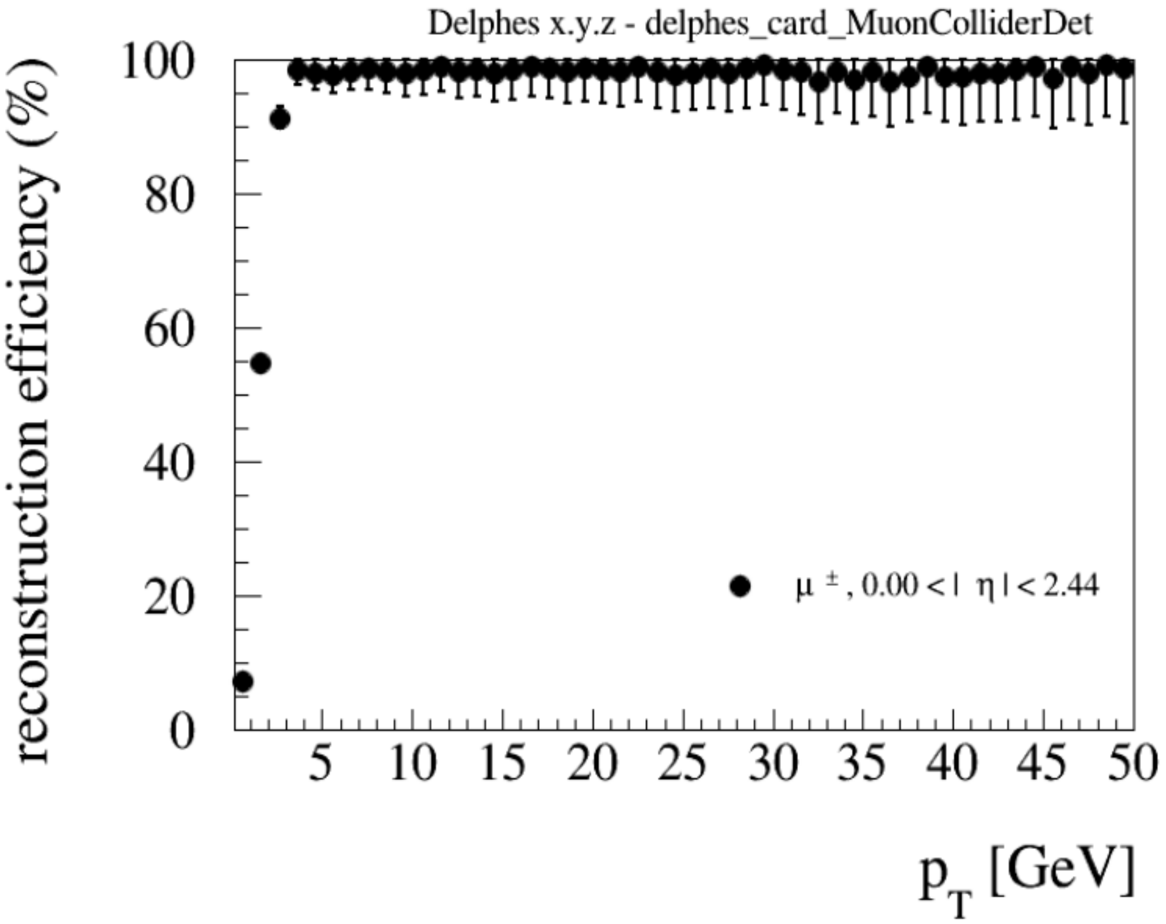
Single muon ~ 80%

to be investigated
(ACTS+Pandora, TrackState?)

Requirement	Signal events (4000)	ε_s^{abs}	ε_s^{rel}	Background events (9996)	ε_b^{abs} Efficiency of the all event	ε_b^{rel}
$\mu^+\mu^-$ detected	1804	0.451	0.451	2824	0.283	0.283
$p_t(\mu)$ > 10 GeV	1584	0.396	0.878	2685	0.269	0.951

Towards fast simulation





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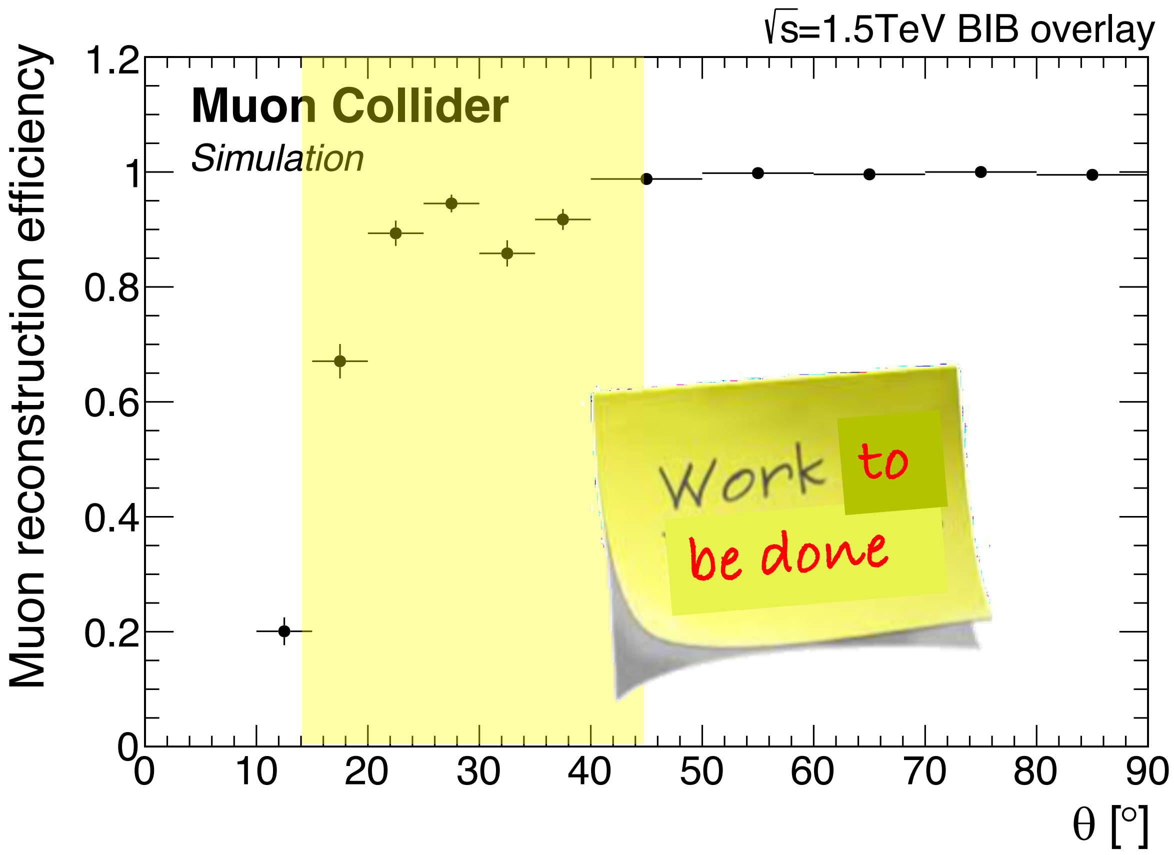
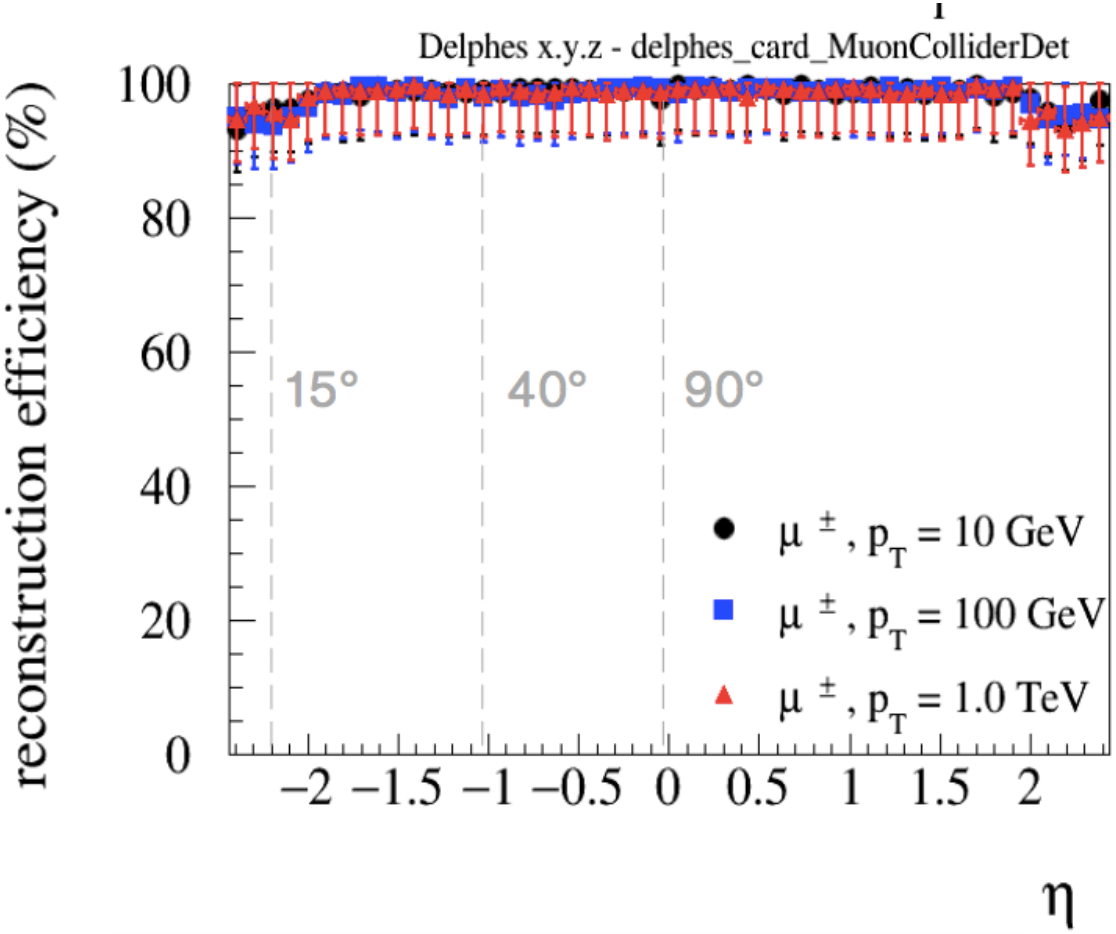




Conclusions about reconstruction

What we learned so far

BIB occupancy in the muon system is very low

Muon reconstruction is straightforward without BIB

ACTS + Pandora is perfectly efficient in case of single muons with BIB

Out-in approach seems more efficient for multimuon channels

To do list

Systematic comparison between ACTS and CT + Pandora
- Technical checks: e.g. trackState not defined?

Finalize algorithm also for Delphes card

Technologies for the muon system

Classical gaseous detector

- Double gap Glass RPC
- Double gap HPL RPC

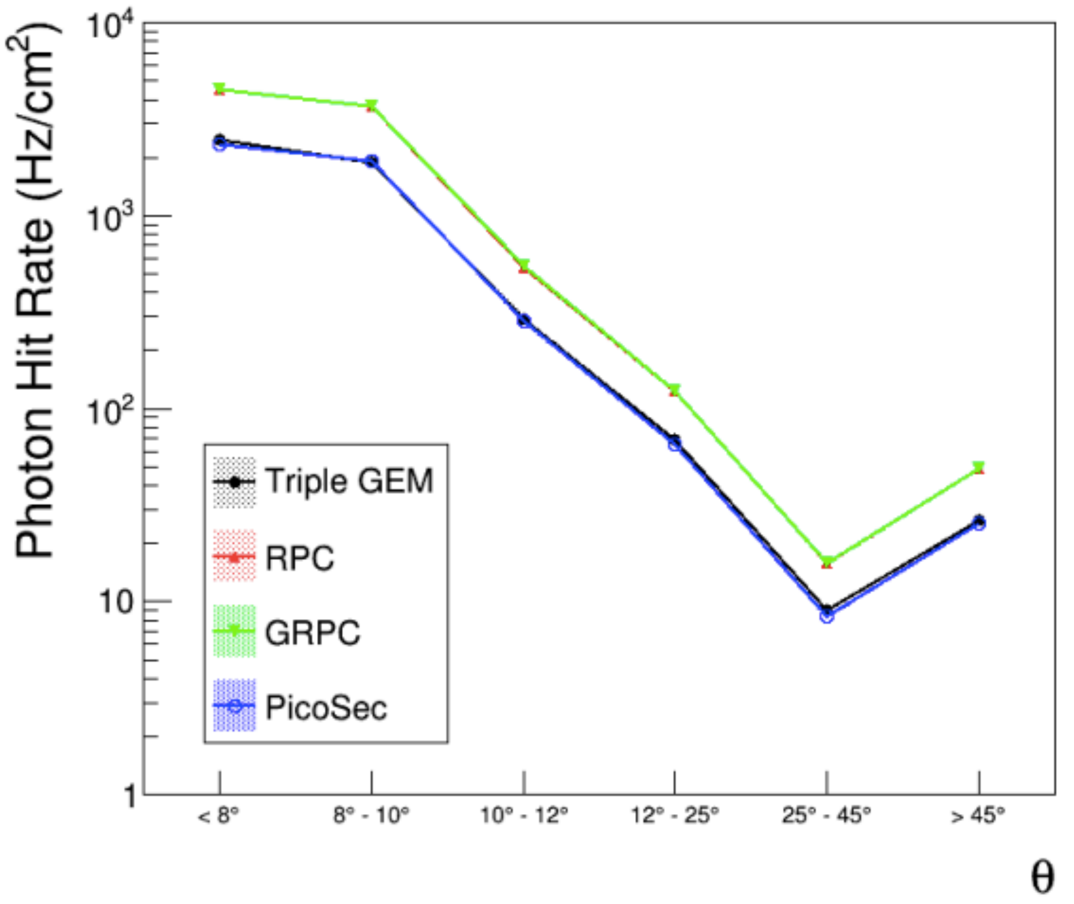
Classical Micro Pattern Gaseous Detectors (MPGD)

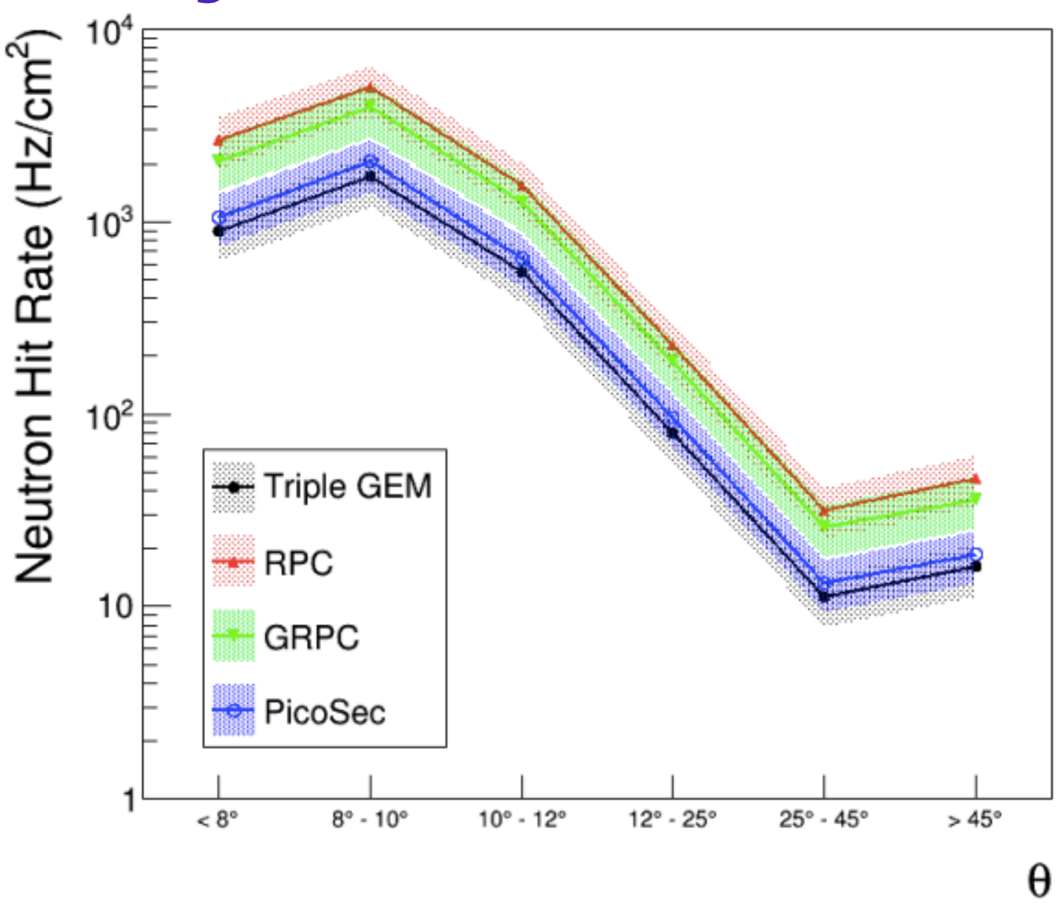
- Triple GEM

New generation MPGD

- PicoSec

Technologies for the muon system





- Picosec has lower expected hit rate than RPC
- Expected Hit Rate for RPC already at the limits for current technology

Technologies for the muon system

Detector	σ_t	σ_x	Rate capability
RPC (HPL o Glass)	1 ns	~mm	~ 1 kHz/cm^2
Standard MPGD (GEM, Micromegas)	5-10 ns	~100 μm	> 100 kHz/cm^2

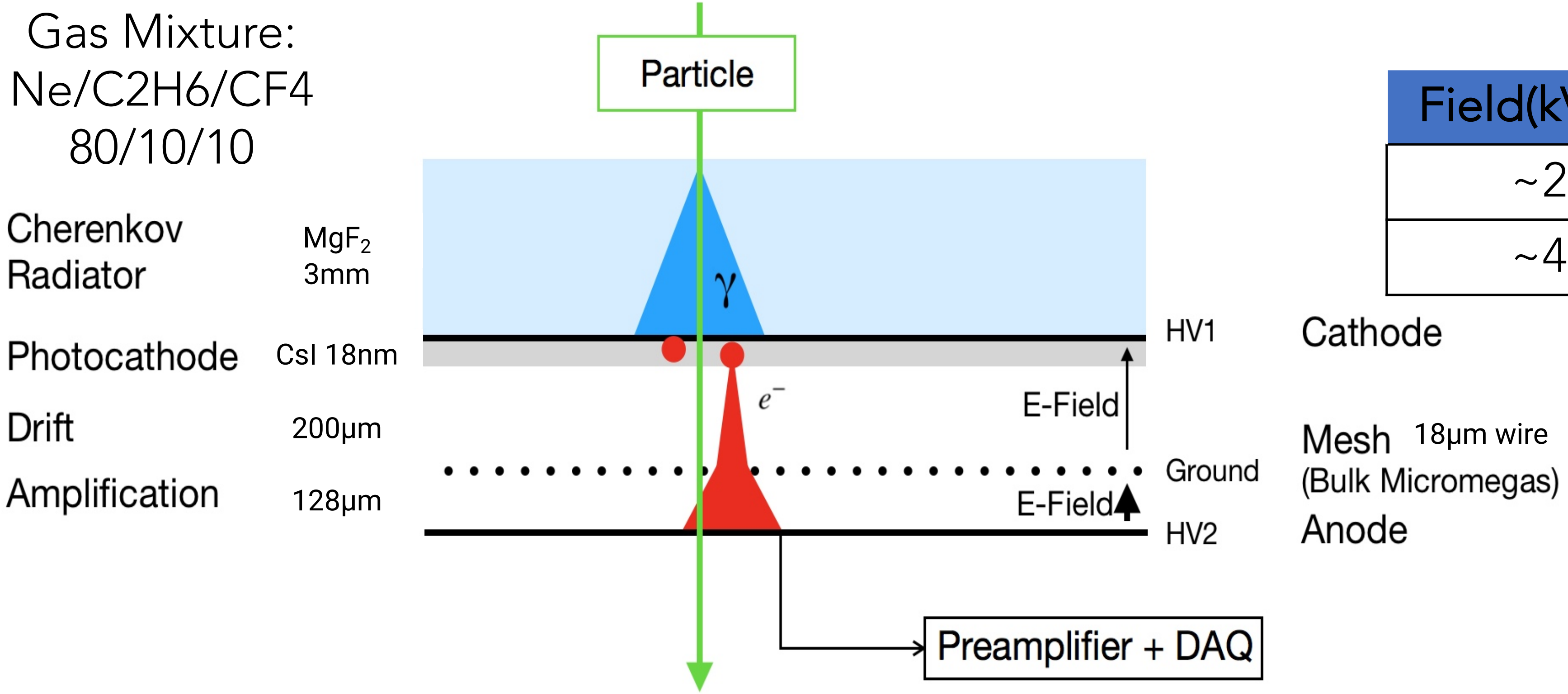
R&D Goal: develop a detector able to reach good performance on all the three items

⟶ a dedicated timing layer, to be combined with muon tracking layers

Picosec

https://indico.cern.ch/event/1224307/
Davide Fiorina *Picosec test beam -Preliminary results*

Gas Mixture:
Ne/C2H6/CF4
80/10/10



Field(kV/cm)	Gain
~20	~10^2
~40	~10^3

1. Look at **Cherenkov light**, not the ionisation
   Photo-electrons created promptly with the MIP passage
2. Remove the drift gap and start the avalanche as soon as possible

Measured time resolution ~ 25 ps

Plans for the single channel

New radiators

- MgF2 is the most UV trasparent material but:
  - High cost, fragile
  - Non perfectly stable during material deposition (imperfection on half of the samples)
- Investigate:
  - CaF_2 BaF_2, sapphire
  - Quartz → the most promising for large areas, low cost and robustness (lower transparency)

New photocathodes

CsI has the best performance in terms of time resolution, resistive photocathodes are more promising for the long term and robustness

- B4C and DLC
- (Graphene and nanodiamonds trials by RD51)

New Gases

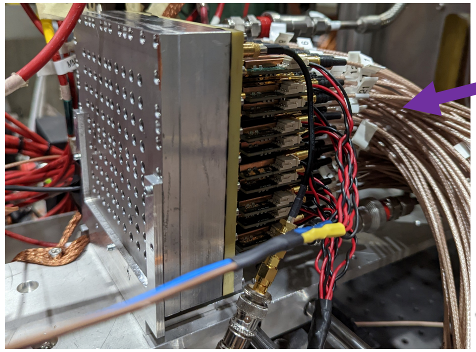
Baseline Ne/C2H6/CF4 80/10/10 – Flammable, High GWP, High cost!

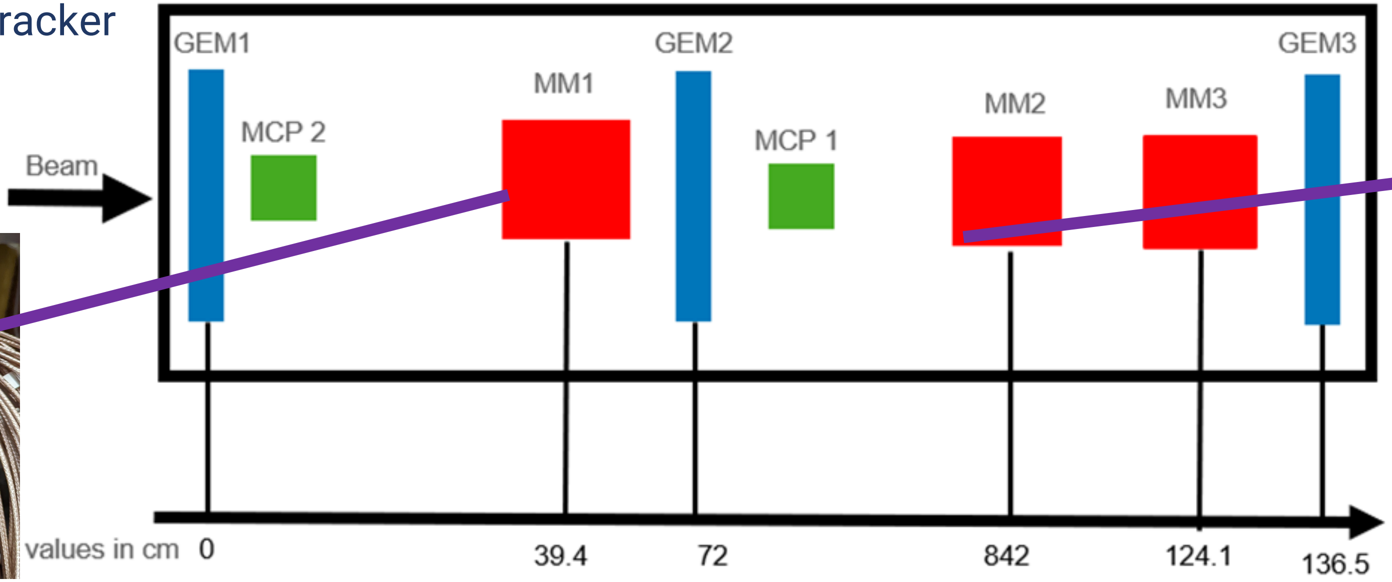
- Removal of CF4
- Substitution of C2H6 (ethane) with iC4H10 (isobutane) or even better CO2
- Look for a Neon substitute (very difficult…)

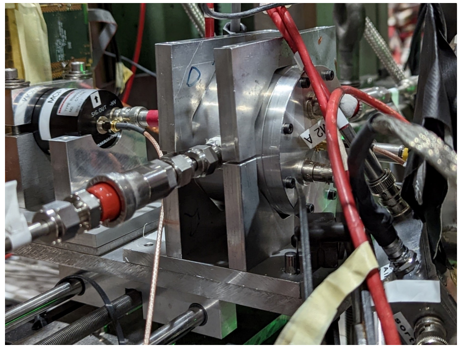
Test beam 19Oct-1Nov 2022

MCP for time reference $\sigma_t \approx 5$ps

RD51 GEM-based tracker





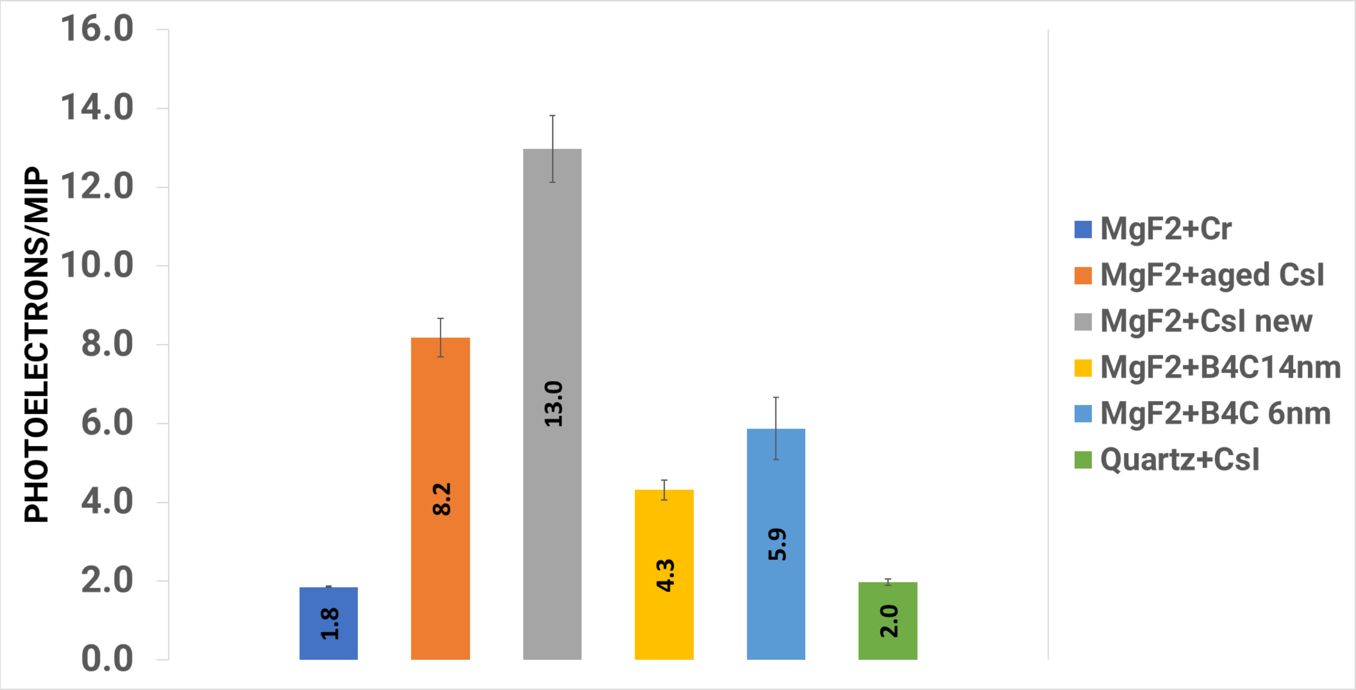


RD51 single-channel detector
used as performance reference

GOALS

1. Measure different **radiator+photocathode combination yield** (photoelectrons/MIP) and compare with RD51 detector
2. Measure **time resolutions** with different radiator+photocathode combination

Test beam: combination yield (radiator)



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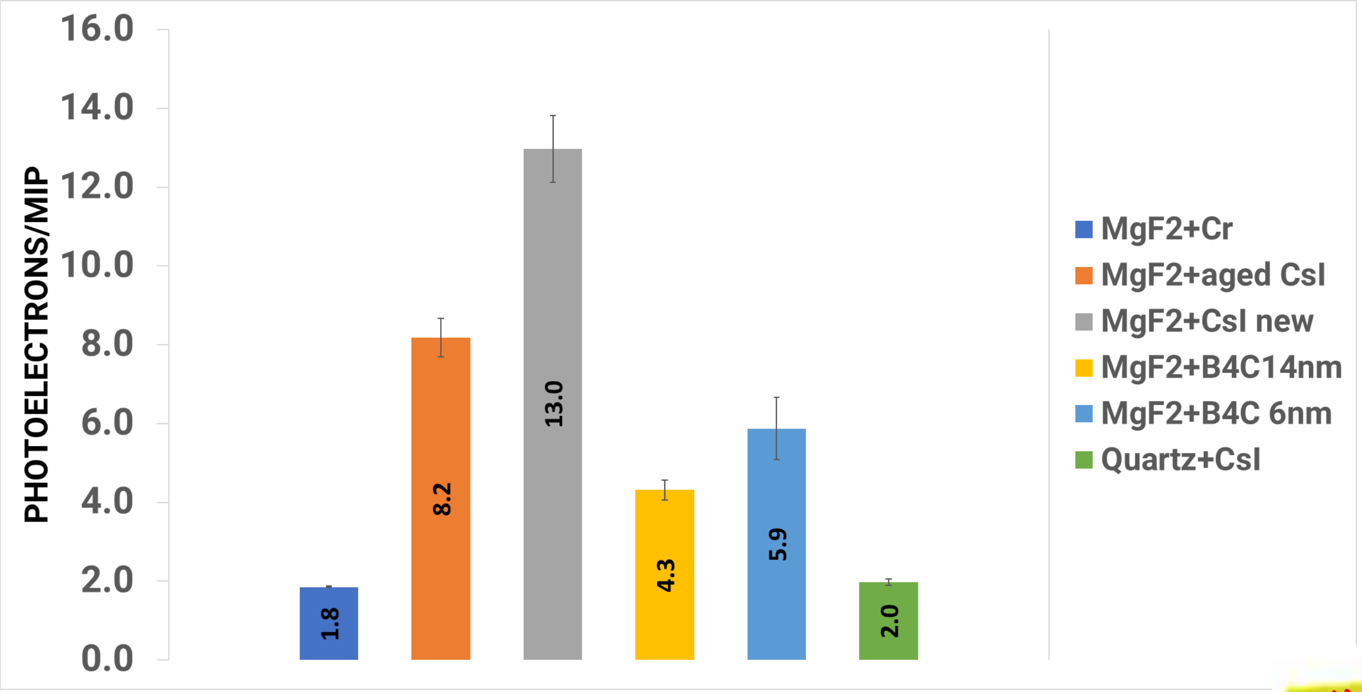
Test beam: combination yield (radiator)

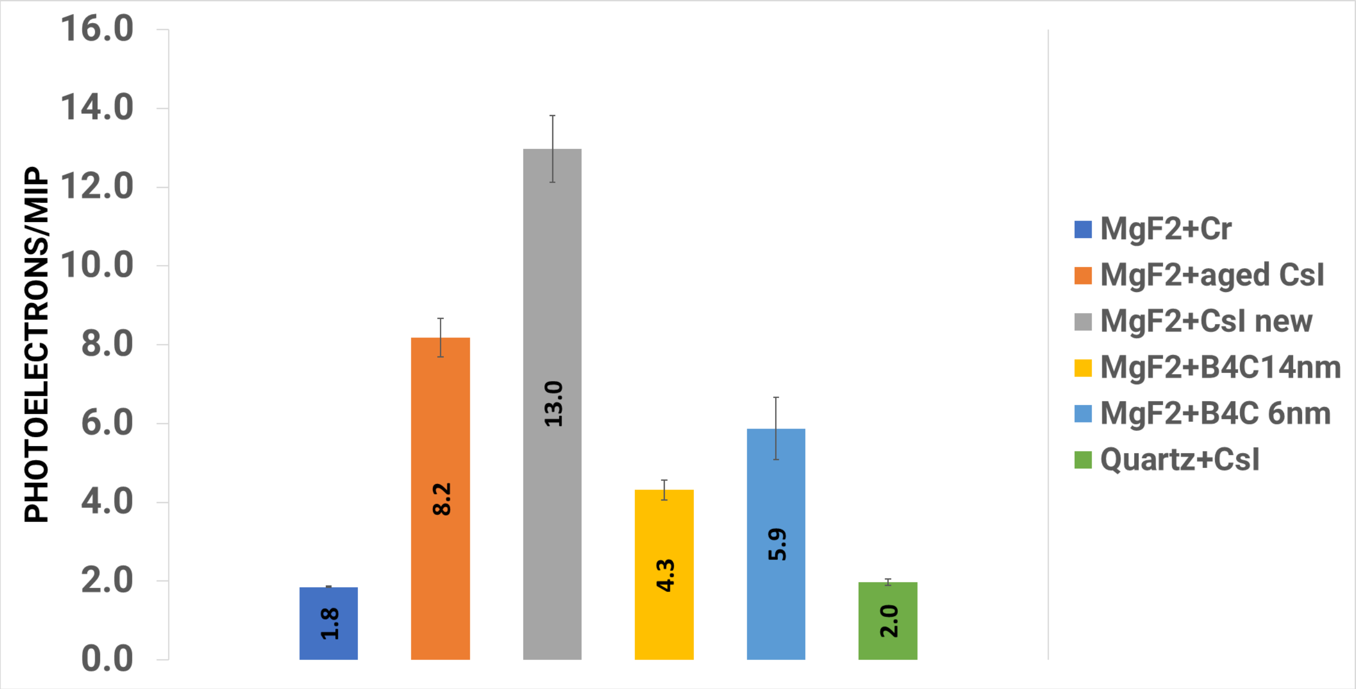


MgF2 (3mm) vs Quartz (2.6mm)

Quartz less transparent and thinner (≈15% less photoelectrons expected but here is too much).

Still promising

Test beam: combination yield (photocathode)



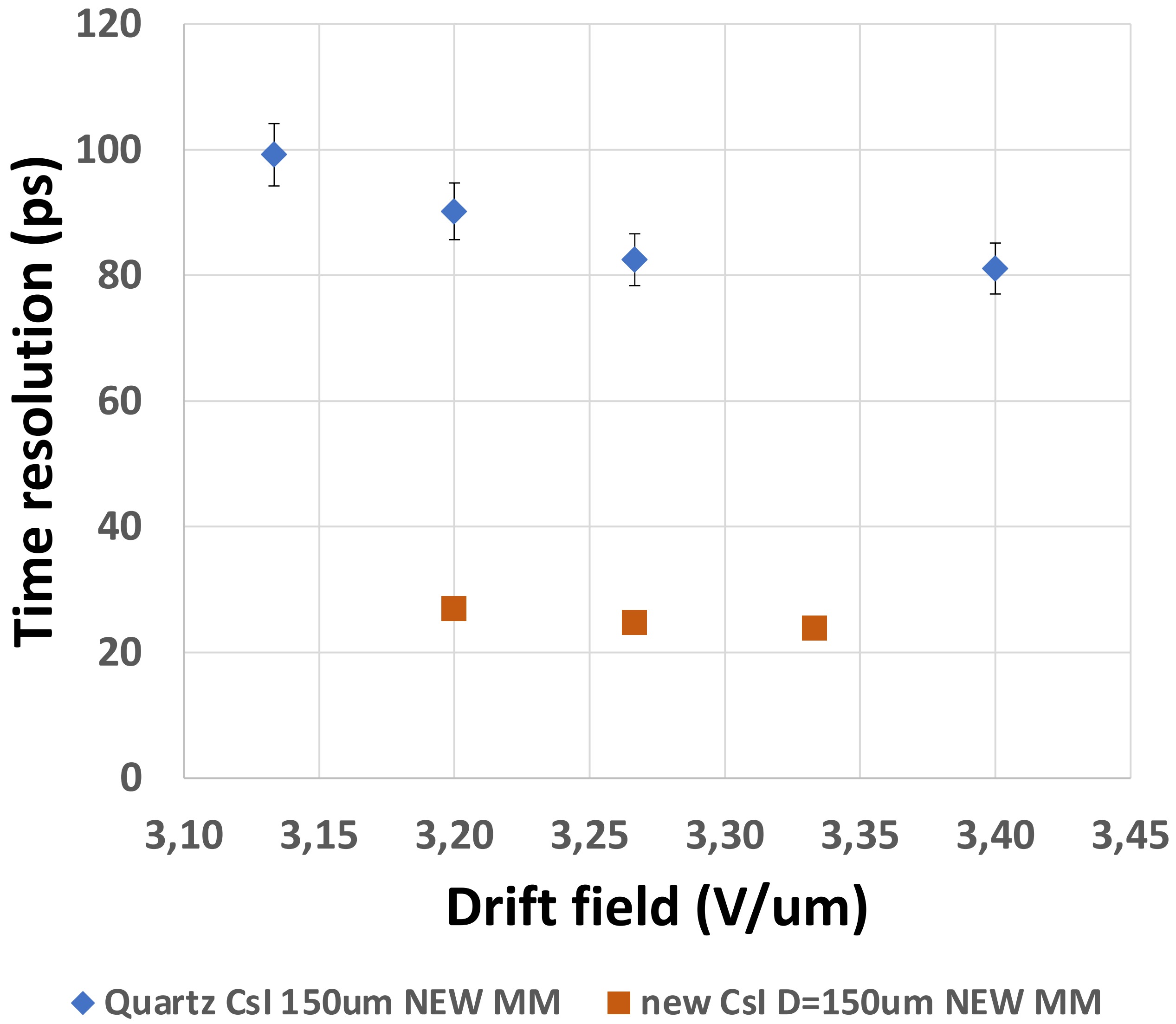
New photocathodes

CsI has the best performance in terms of time resolution, resistive photocathodes are more promising for the long term and robustness but hygroscopic

- B4C and DLC
- (Graphene and nanodiamonds trials by RD51)

DLC not available, B4C similar behaviour !neutrons

Test beam: time resolution



The more the photoelectrons, the lower the time resolution

- CsI measurement as before 24ps@ 3.3kV/cm
- Quartz can provide <100 ps

Conclusions about Picosec R&D

What we learned so far

Expected time resolution with CsI achieved

Different configurations (photocathode+radiator) achieved <100 ps

To do list

Test new photocathodes (DLC) and radiators

Test with pions

10x10 cm^2 procurement on going