Designing the muon system for a 10 TeV muon collider

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International MUON Collider Collaboration

MuCol

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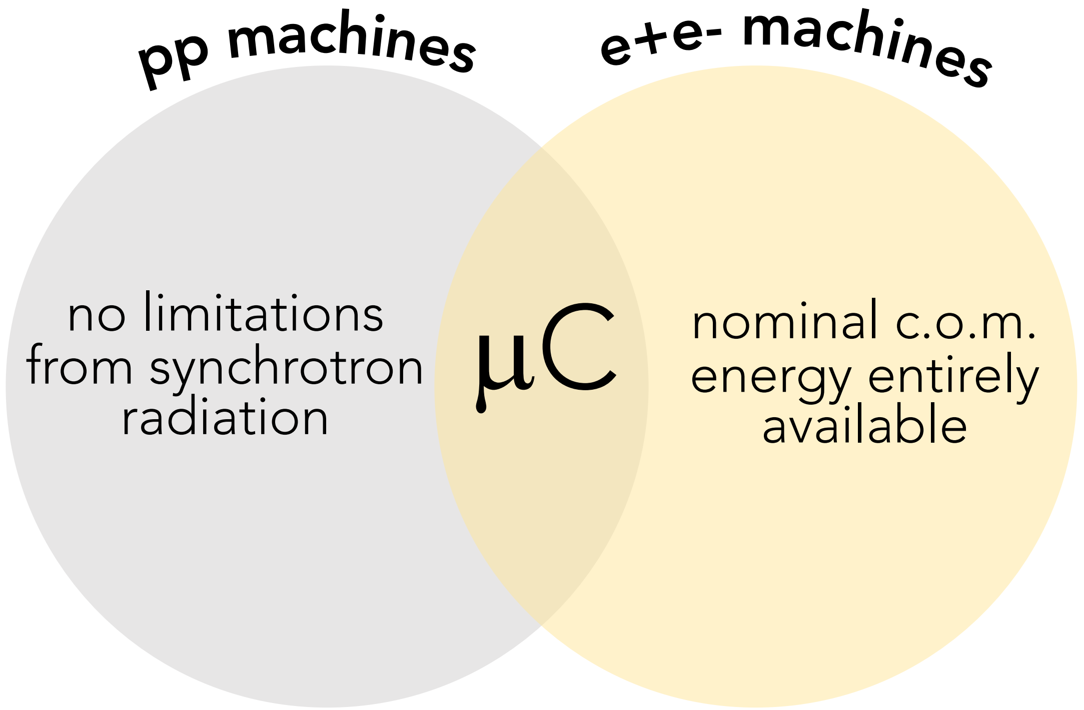
Summary

1. General introduction
2. Detector design
3. Alternative proposal for the muon system*
4. Conclusions and perspectives

References*

- C. Aimè et al., *Fast timing detectors for the muon system of a muon collider experiment: requirements from the simulation and prototype performance*, JINST 19 (2024) 03, C03052
- M. Brunoldi, *PICOSEC: optimization of a fast timing detector for applications at a muon collider experiment*, MSc. Thesis, Università degli Studi di Pavia (2023)
- M. Brunoldi, *Simulation and R&D studies for the muon spectrometer at a 10 TeV Muon Collider,* poster @16th Pisa Meeting on Advanced Detectors (2024)

Why a muon collider



Physics potential

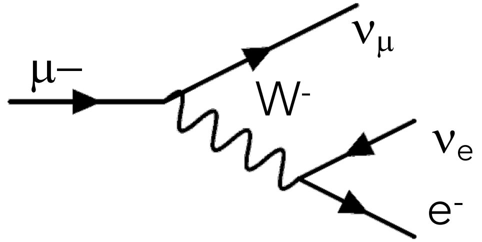
- D. Zuliani, *Higgs Physics at Multi-TeV Muon Collider*, 18th July, 17:36 @Higgs Physics
- Y. Ma, *Higgs-muon interactions at a multi-TeV muon collider*, 20th July, 09:21 @Higgs Physics
- M. Loeschner, *Z' boson mass reach and discrimination at muon colliders*, 20th July, 12:10 @Beyond the SM

	3 TeV	10 TeV	14 TeV
luminosity	$1.8\ 10^{34}$ cm^{-2} s^{-1}	$2\ 10^{35}$ cm^{-2} s^{-1}	$4\ 10^{35}$ cm^{-2} s^{-1}
# bunches	$2.2\ 10^{12}$	$1.8\ 10^{12}$	$1.8\ 10^{12}$

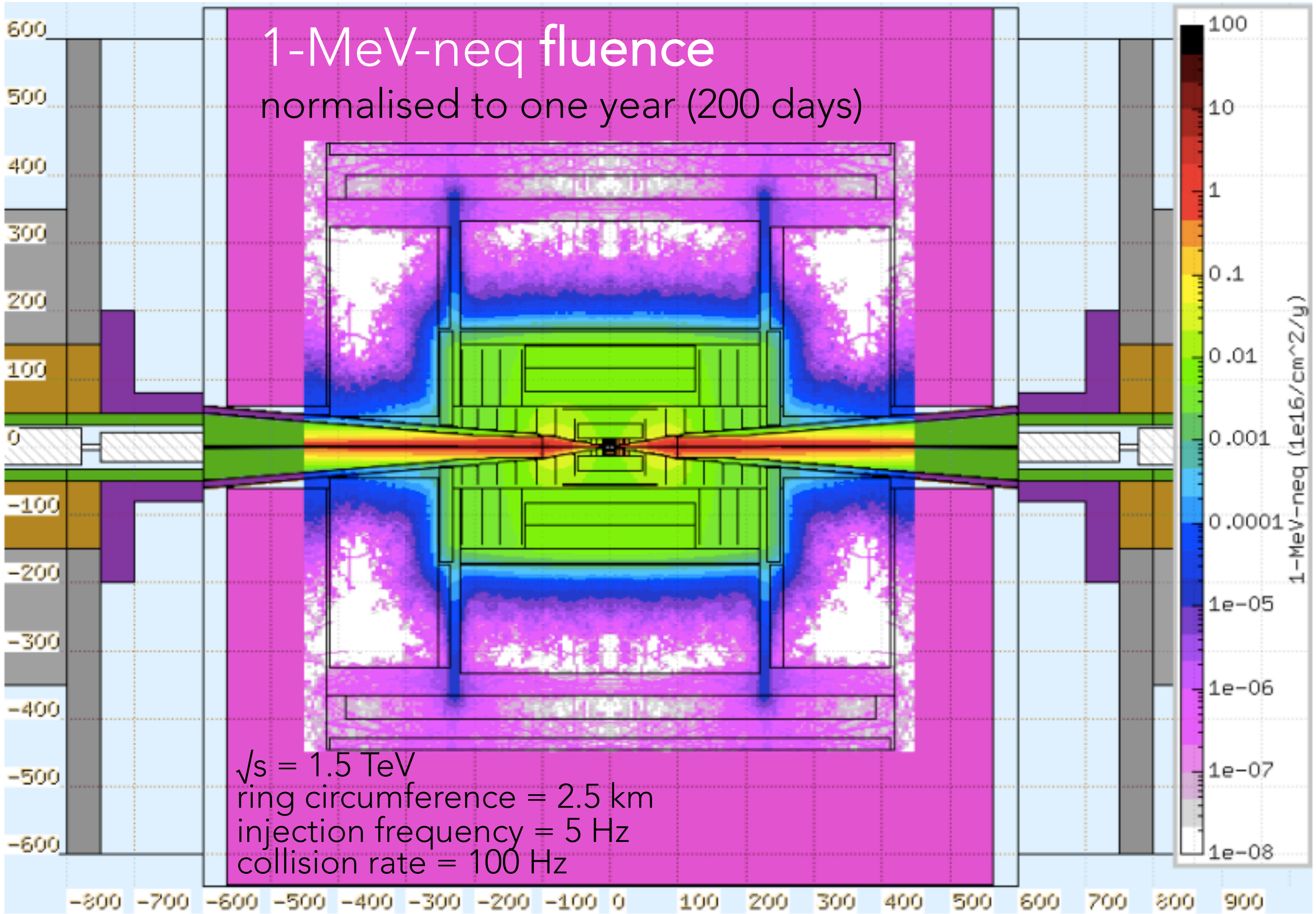
C. Accettura et al., *Towards a muon collider*, Eur. Phys. J. C 84 (2024)36

Challenge: beam-induced background (BIB)

Muon decay originates electrons and positrons



subsystem	fluence
tracker	10^{14}-10^{15} $cm^{-2}y^{-1}$
ECAL	10^{13}-10^{14} $cm^{-2}y^{-1}$
HCAL	10^{11}-10^{12} $cm^{-2}y^{-1}$
muon	10^{10} $cm^{-2}y^{-1}$



Starting point: concept for the 3 TeV detector

hadronic calorimeter

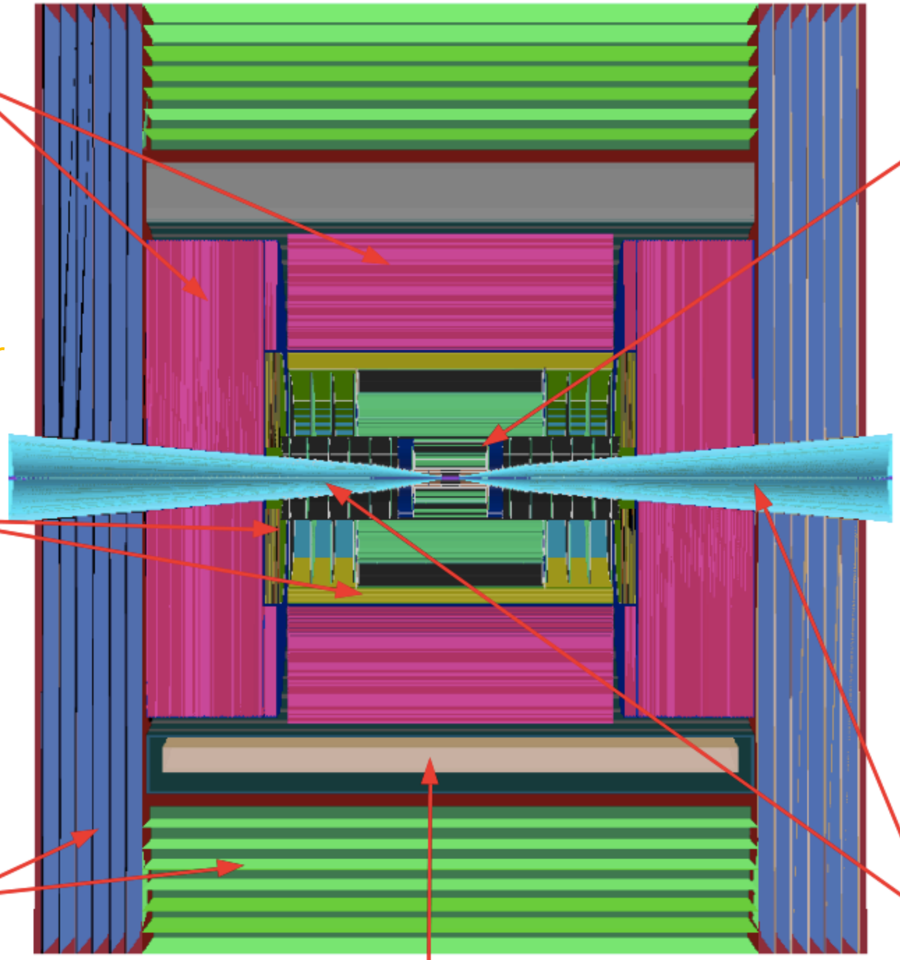
- 60 layers of 19-mm steel absorber + plastic scintillating tiles
- 30x30 mm^2 cell size
- 7.5 λ_I

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 (3.57 T)

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 cone + borated polyethylene cladding

Toward a 10 TeV muon collider

➡ D. Lucchesi, *Muon Collider progress*, 19th July, 11:03 @Accelerator

hadronic calorimeter

➡ L. Longo, *MPGD-based Hadronic calorimeter for a future experiment at Muon Collider*, 20th July, 15:21 @this section

electromagnetic calorimeter

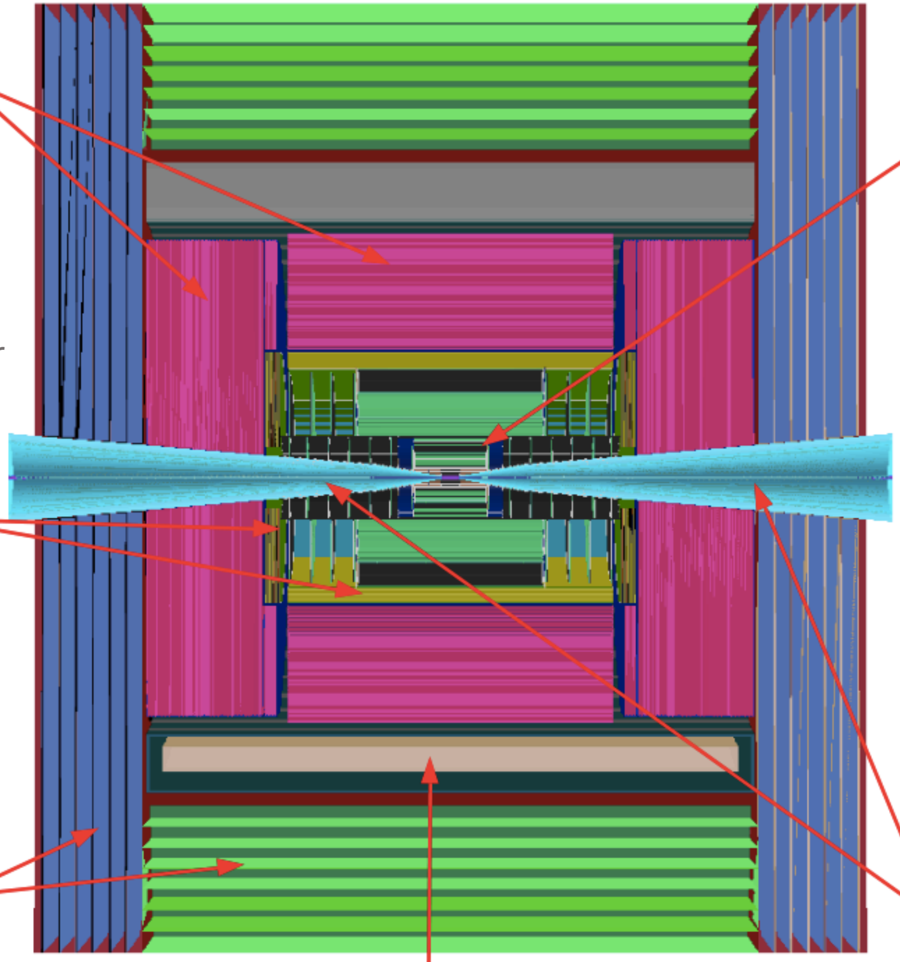
✧ 40 layers of 1.9-mm W

⬅ R.Gargiulo, *Crilin: a semi-homogeneous crystal calorimeter for the Muon Collider*, yesterday @this section

muon detectors

✧ 7-barrel, 6-endcap RPC layers interleaved in the magnet's iron yoke

✧ 30x30 mm^2 cell size



superconducting solenoid (~5 T)

tracking system

➡ M. Casarsa, *Detector performance for low and high momentum particles in 10TeV muon collisions*, 20th July, 17:53 @this section

- 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

➡ D. Calzolari, *Machine-detector interface design for a 10-TeV muon collider*, 19th July, 10:45 @Accelerator

Muon system for a 10 TeV muon collider

hadronic calorimeter

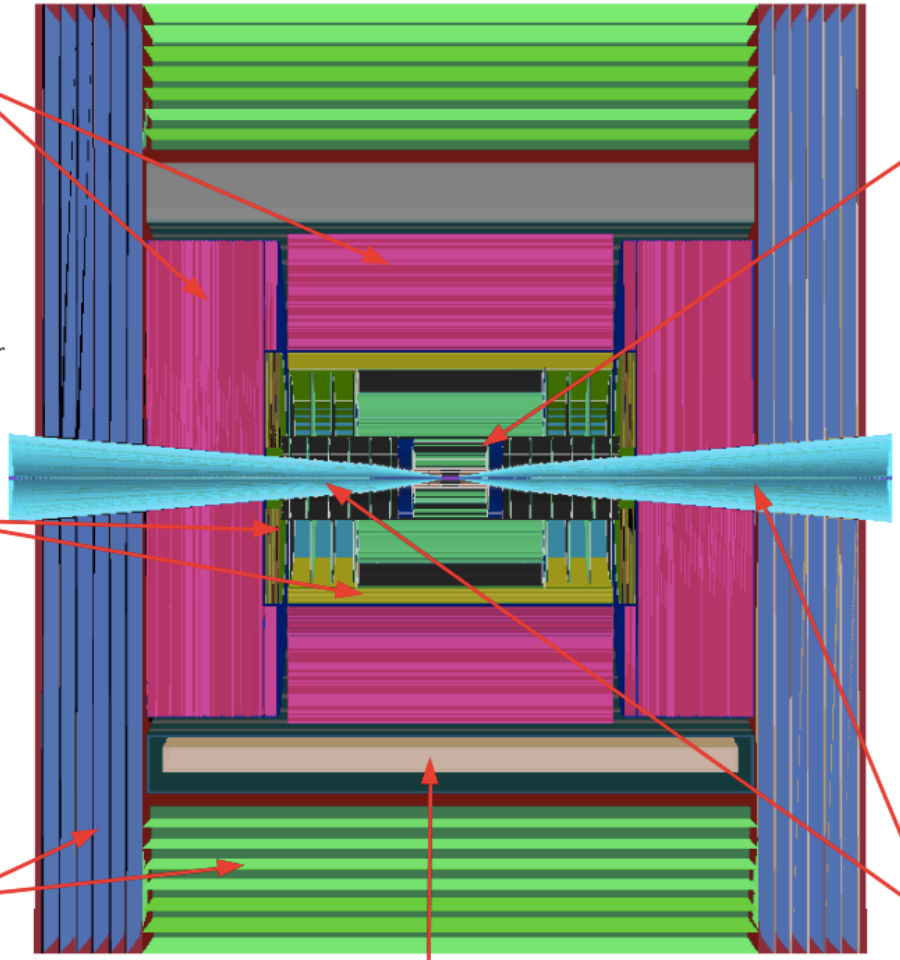
- 60 layers of 19-mm steel absorber + plastic scintillating tiles
- 30x30 mm^2 cell size
- 7.5 λ_I

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 MPGD layers
- 100x100 μm^2 cell size



superconducting solenoid (~5 T)

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- Vertex Detector:
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shielding nozzles

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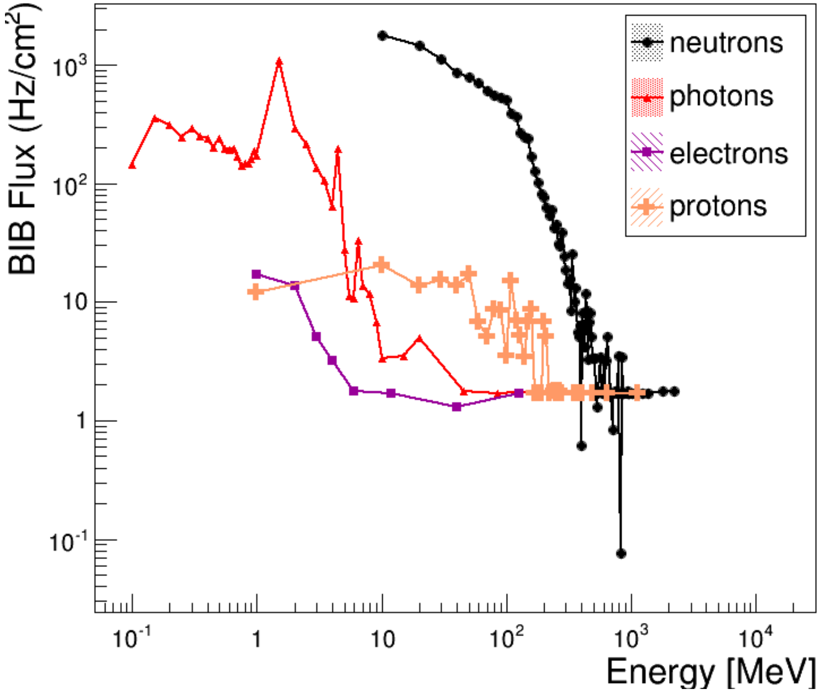
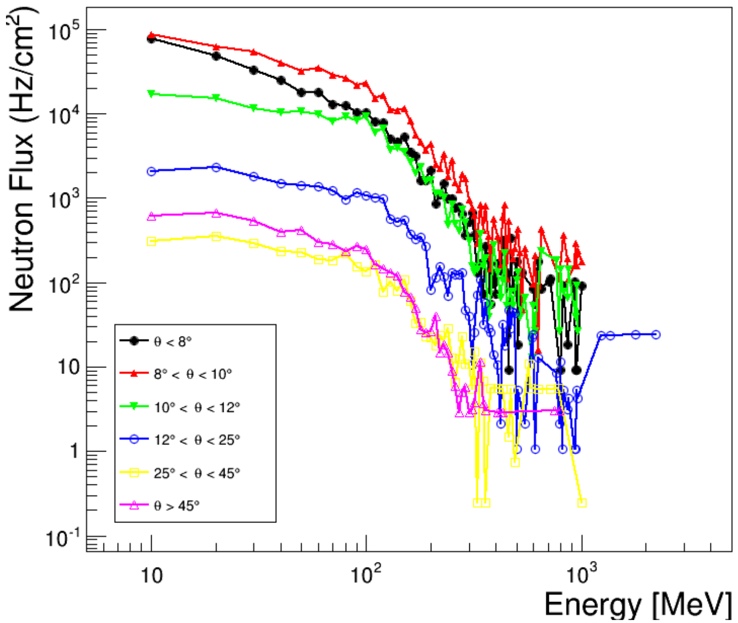
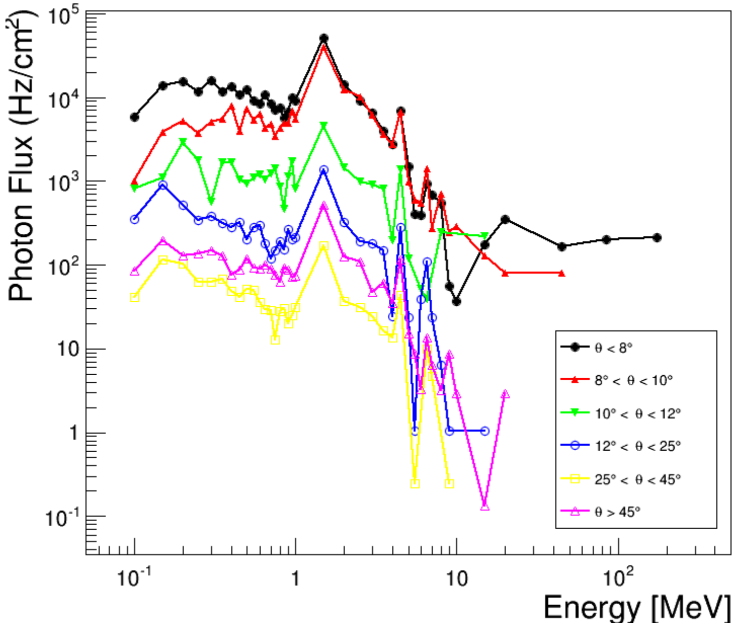
Characterization of the BIB in the muon system

BIB mainly composed of neutrons and photons



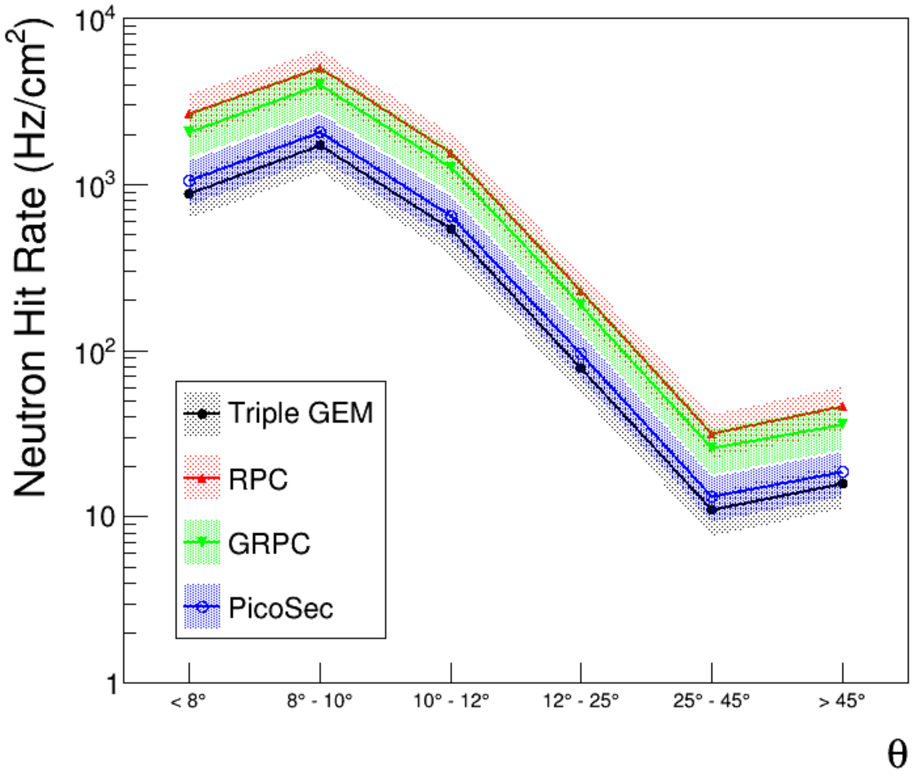


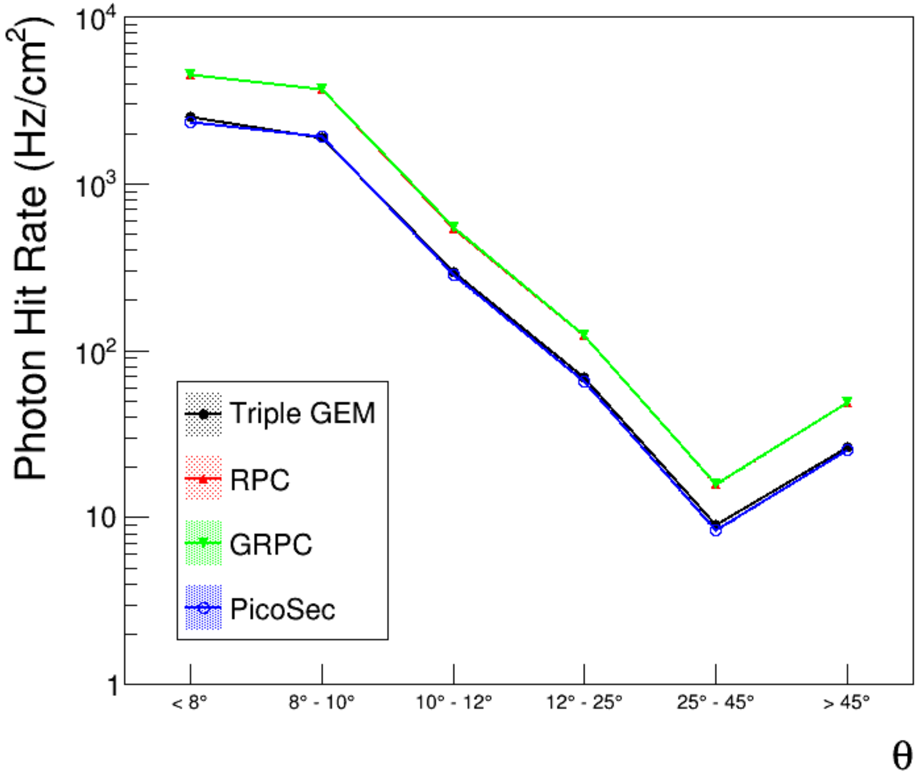


Energy ranges at $\sqrt{s} = 1.5$ TeV

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

Why MPGD





	RPC (HPL or glass)	MPGD
time resolution	1 ns	5-10 ns
spatial resolution	~1 mm	~100 µm
rate capability	~1 kHz/cm^2	~100 kHz/cm^2

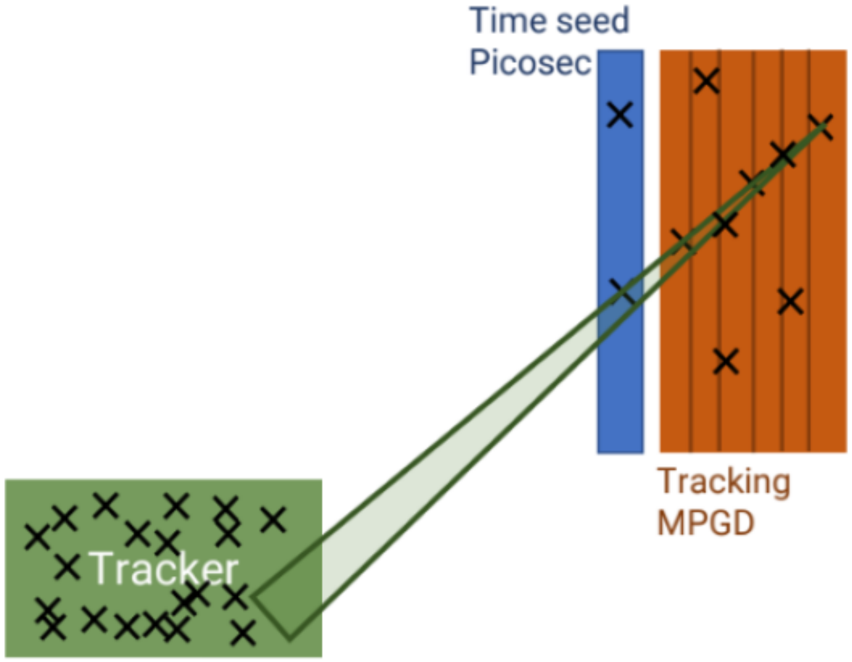
muon detectors

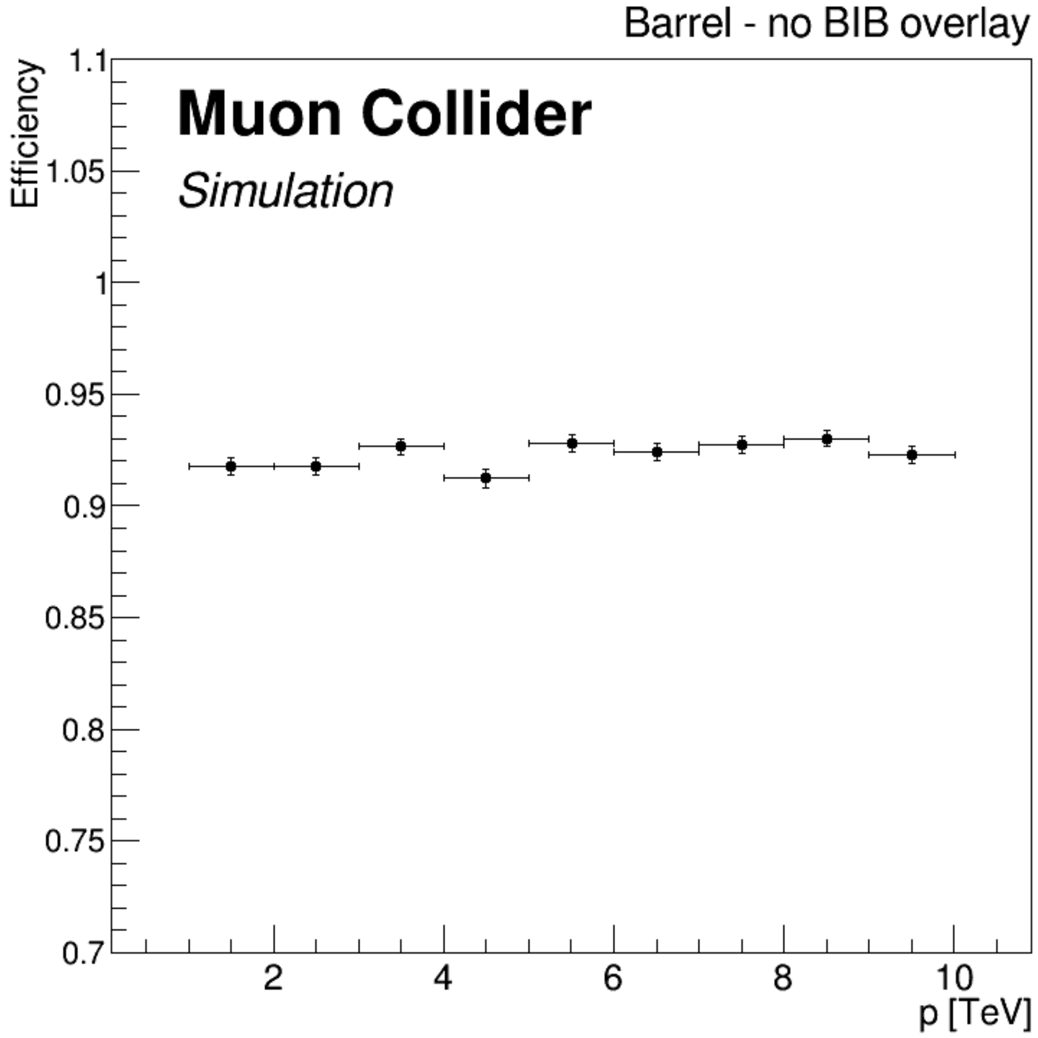
- 7 GEM layers in the barrel
- 6 GEM + Picosec layers in the endcap

Muon reconstruction

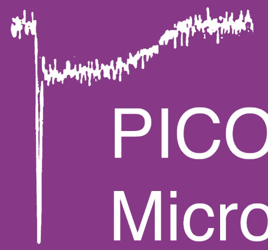
Standalone algorithm

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 3-5 layers
c. reconstructed hits in all tracker subsystems can be filtered

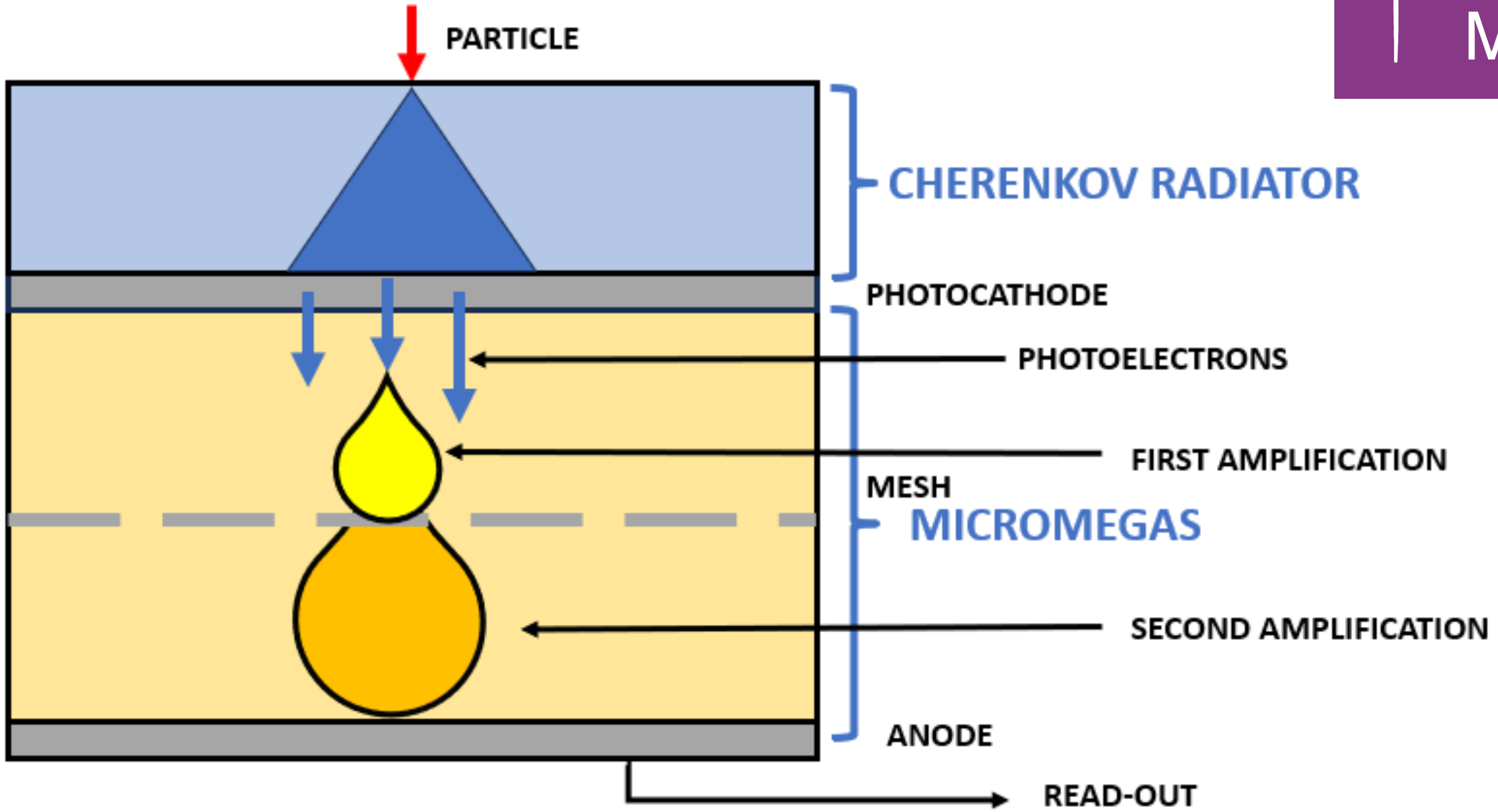




Picosec for fast timing



Gas Mixture:
$Ne/C_2H_6/CF4$
80/10/10



1. Look at **Cherenkov light**, not the ionisation

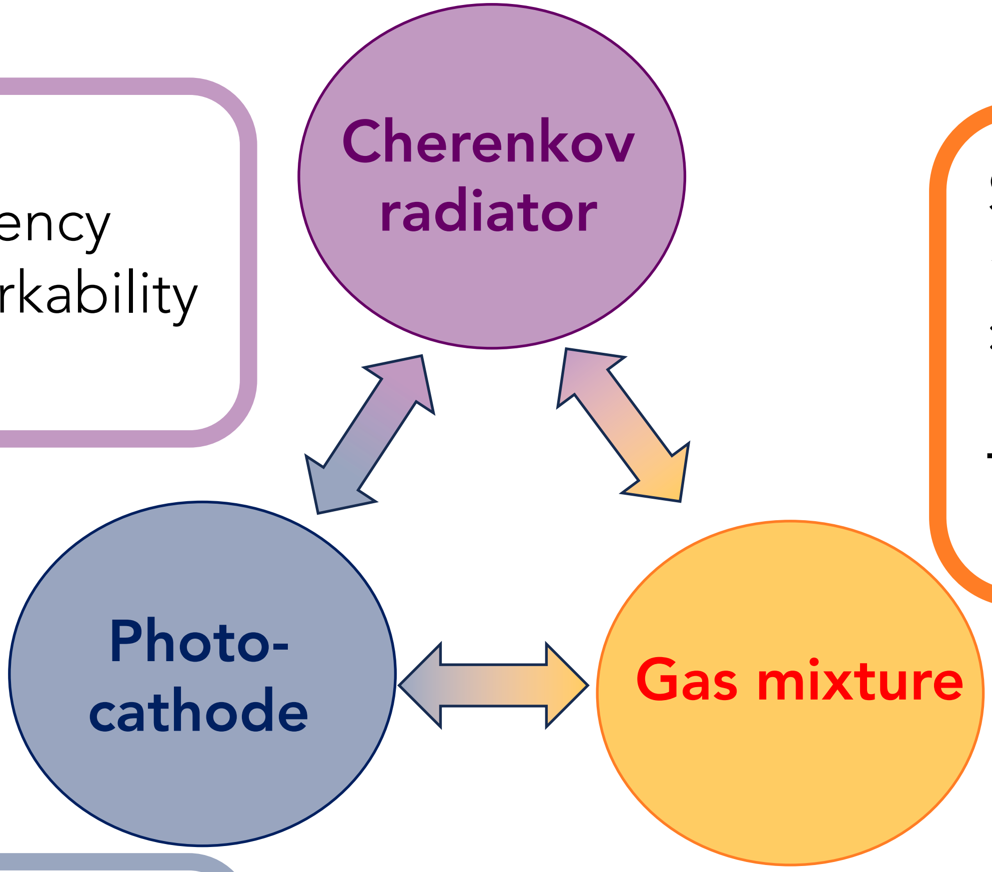
   Photo-electrons created promptly with the MIP passage

2. Remove the drift gap and start the avalanche as soon as possible

R&D on Picosec

Standard: MgF_2
- ✓ High UV transparency
- × Fragility, cost, workability

Test: Quartz



Standard: Ne / C_2H_6 / CF_4
- ✓ High gain and drift velocity
- × Cost, Global Warming Potential

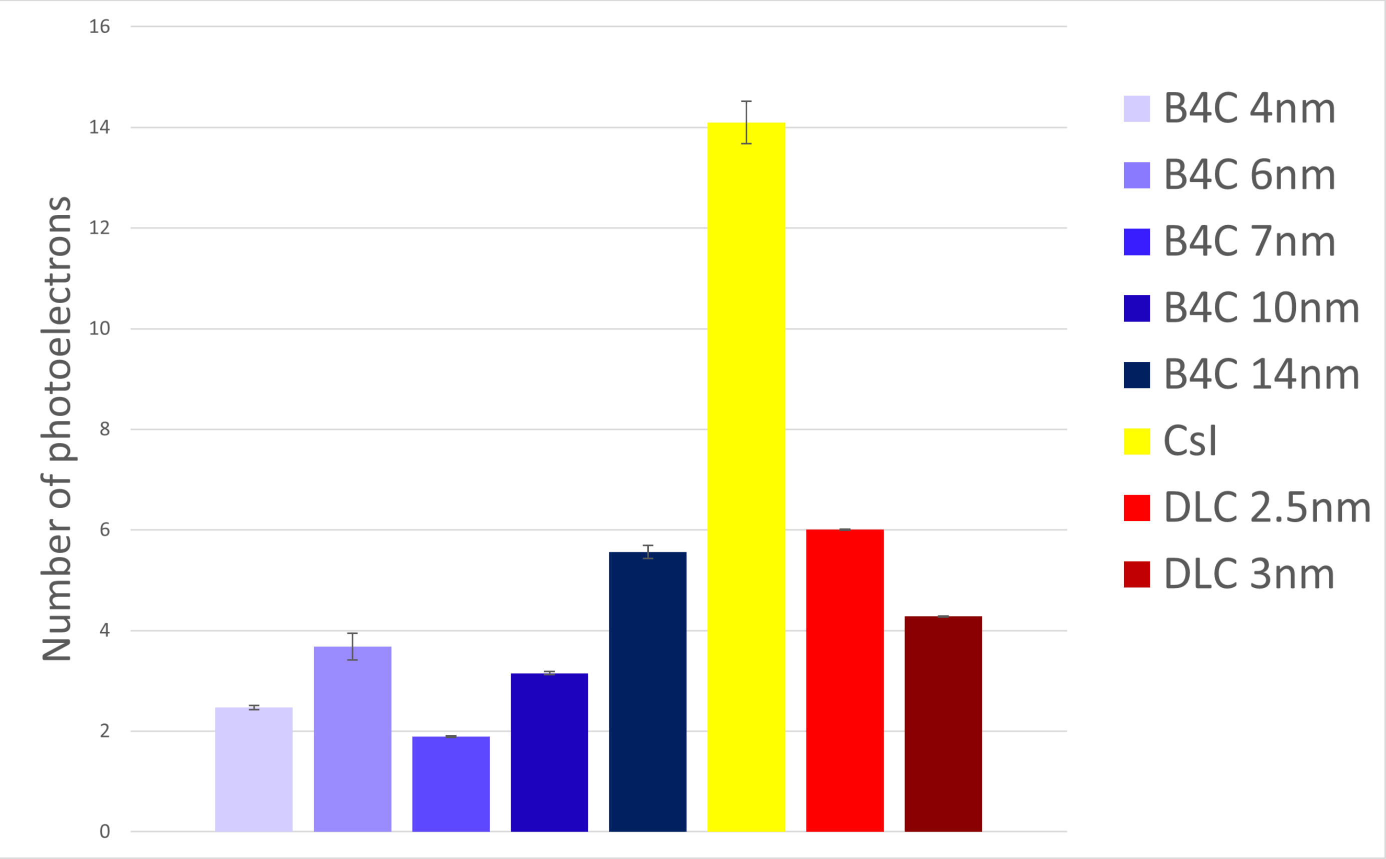
Test: Ne/iC_4H_{10}

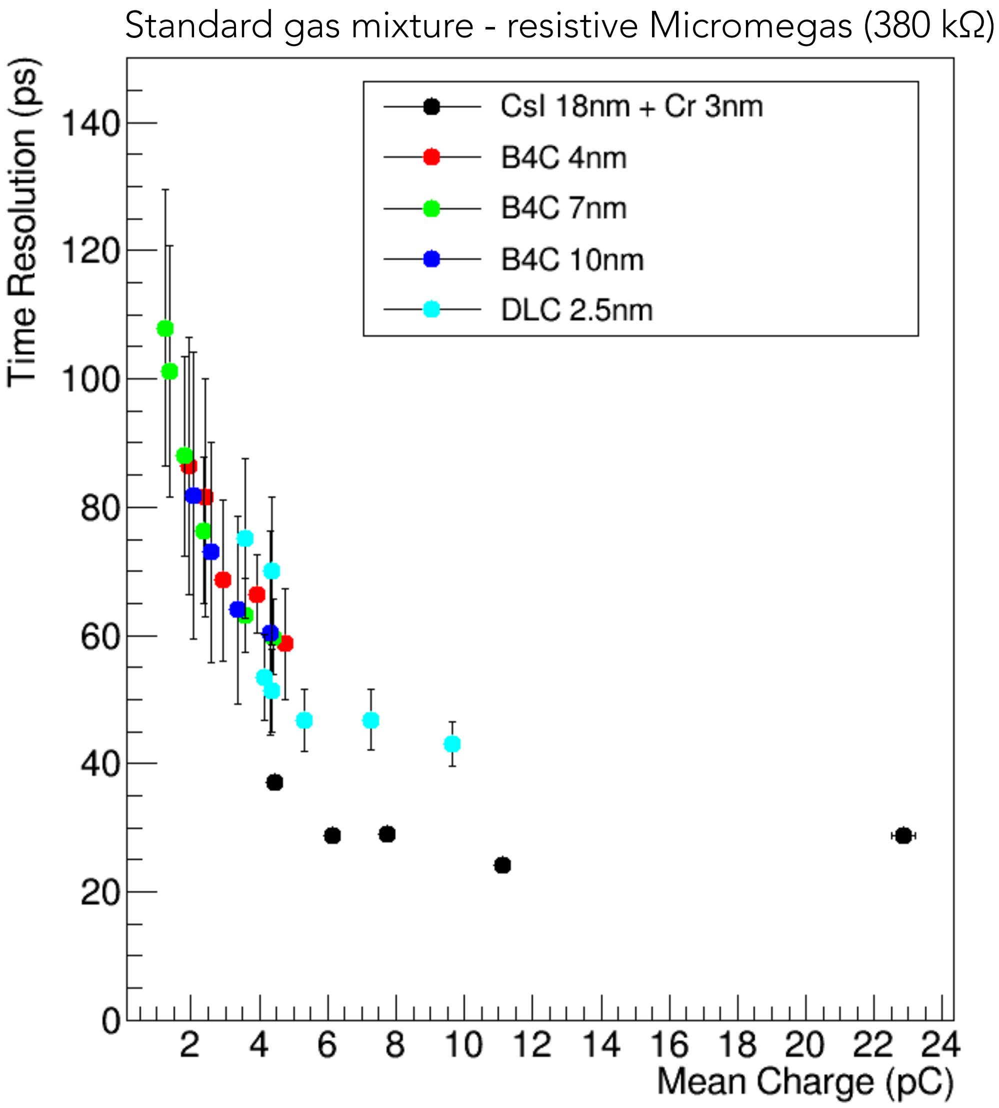
MIXTURE	GWP 100y
Ne/C_2H_6/CF_4 80/10/10	740
Ne/ iC_4H_{10} 90/10	0.34
Ne/ iC_4H_{10} 94/6	0.2

Standard: CsI (+ Cr)
- ✓ High conversion efficiency
- × Hygroscopicity, durability

Test: B_4C, DLC

Photocathode

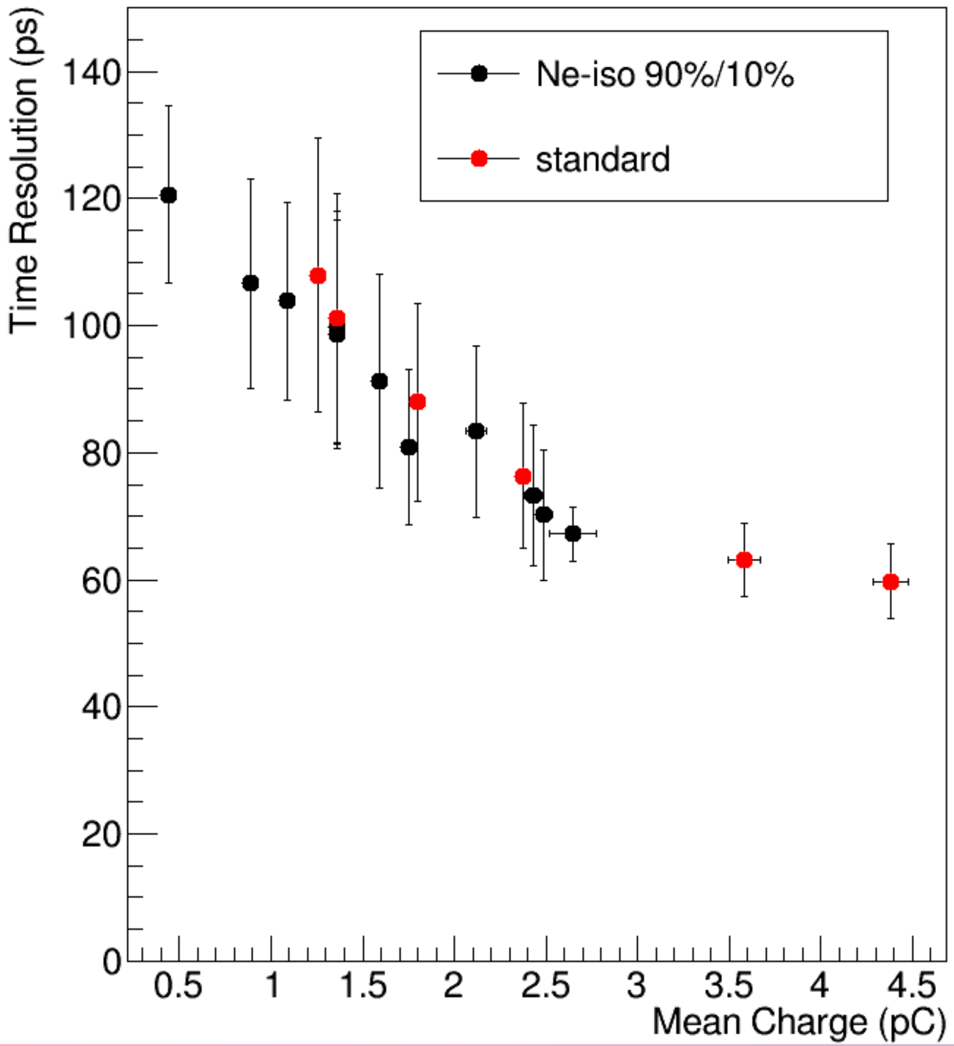




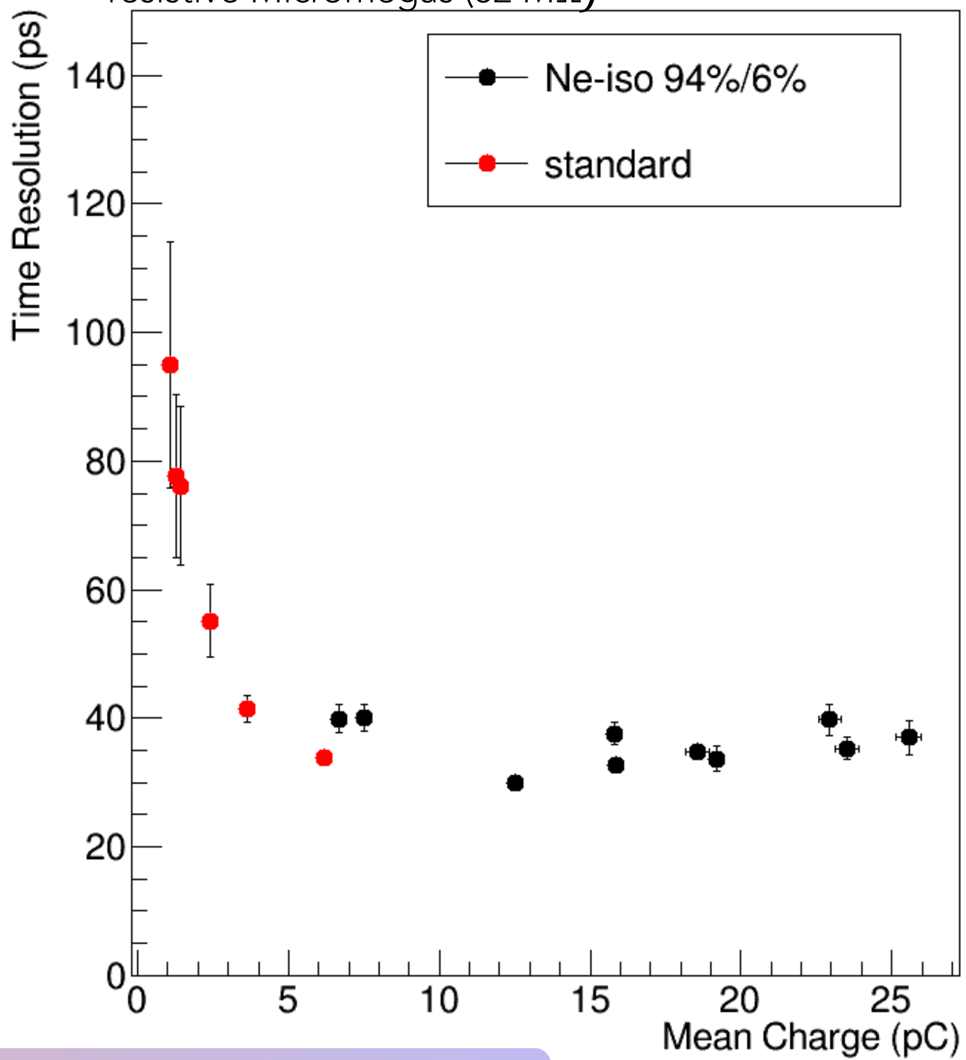
DLC good candidate for robust photocathode

Gas mixture

Photocathode: B4C 7 nm thick – resistive Micromegas (380 kΩ)

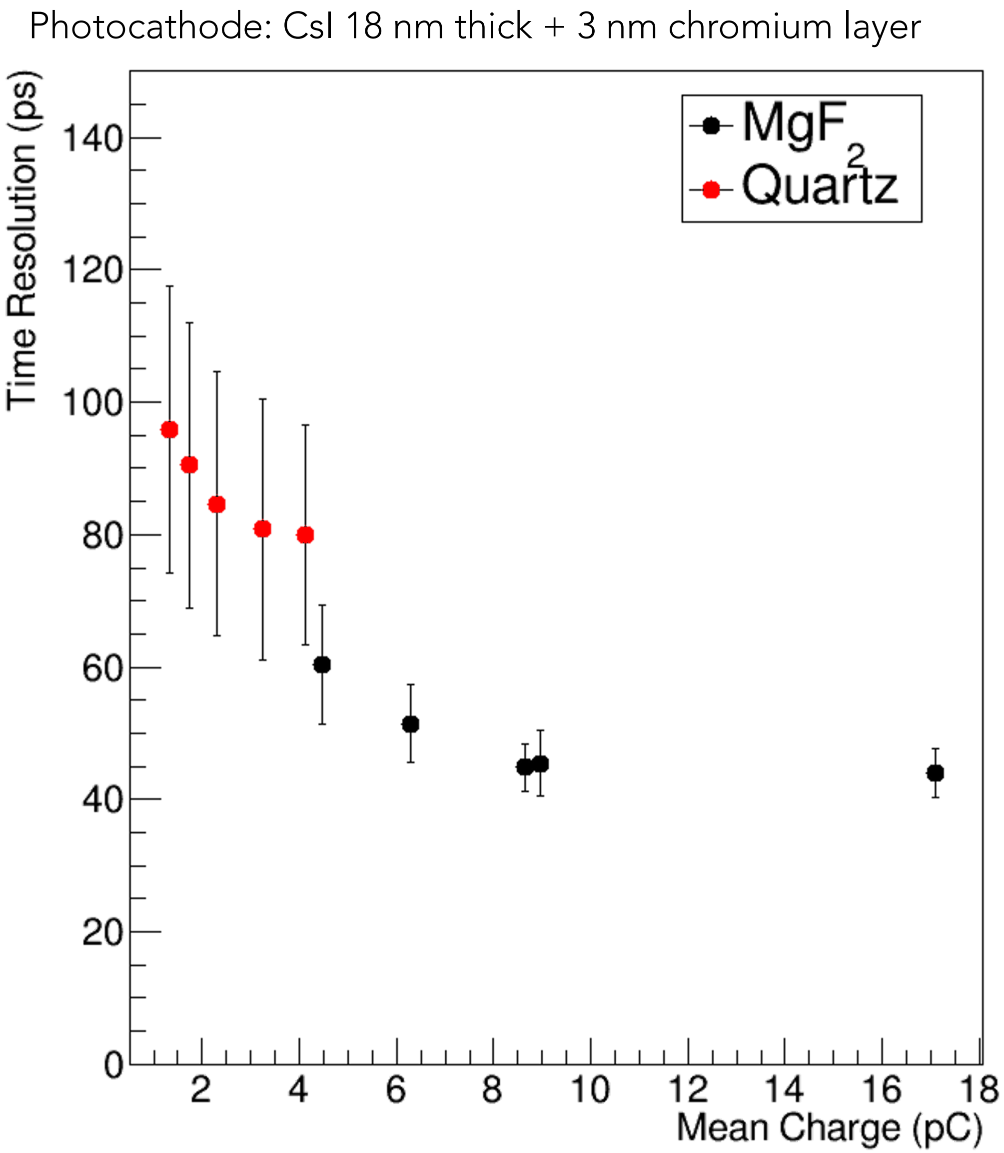


Photocathode: CsI 18 nm thick + 3 nm chromium layer – resistive Micromegas (82 MΩ)



Mixture of 94% Ne and 6% isobutane could be a viable alternative

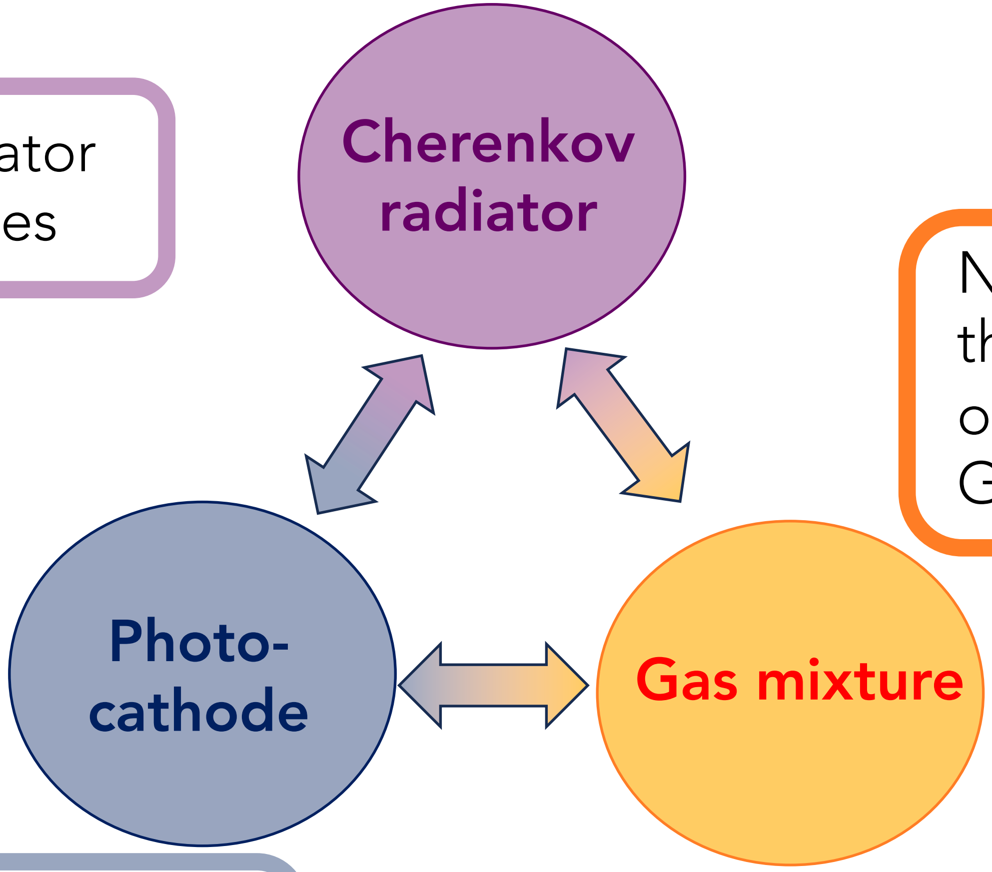
Radiator



The standard MgF_2 remains preferable

R&D summary

MgF_2 is the best radiator among the tested ones



Ne/iC_4H_{10} 94/6 comparable to the standard but wider operating range , reduced GWP

CsI grants higher performance but DLC 2.5nm could be a good alternative

Conclusions

- Muon collider represents a promising and challenging machine for the future of high energy physics
- Different options for the muon system are under study in particular to address the performance required by a Muon Collider and reduce the impact on the environment
- The combination of MPGDs could be an interesting option
  - GEM technology is suitable for tracking with a good spatial resolution
  - Picosec is capable of achieving excellent performance in terms of time resolution that could help to mitigate BIB effect in the muon forward region

Thanks for your attention