

Development and Exploitation of MPGD detectors for the upgrade of the CMS experiment

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XL cycle | National PhD in *Technologies for Fundamental Research in Physics and Astrophysics*

Curriculum: DETECTORS

Admission to the II year

University of Padova, INFN Bari, University of Bari

Supervisors: Dr. Piet Verwilligen (INFN Bari)

Dr. Federica Simone (University & INFN Bari)

Research topics and objectives

❖ Analysis of spatial and timing performance of ME0 stack:

- **Validate performance** of the detector in high intensity background environment using data from the **GIF++ test beam** campaign of July 2024

This analysis has been completed

First results presented in a [poster](#) at VCI and in the corresponding published [proceeding](#)

Final results presented in a [poster](#) at IWorld and in the upcoming proceeding

- Evaluate performance of ME0 detectors using **cosmic ray data** to support module validation | **Ongoing**
- **Final validation** of the mass-produced ME0 detectors and electronics | **Planned**

❖ Analysis of the trigger performance of the GE1/1 chambers installed in the CMS experiment using pp collision data collected in 2024 and 2025 runs

This analysis is ongoing and scheduled to be completed by the end of the second year

❖ Studies of muon reconstruction in ME0 system using HL-LHC simulations

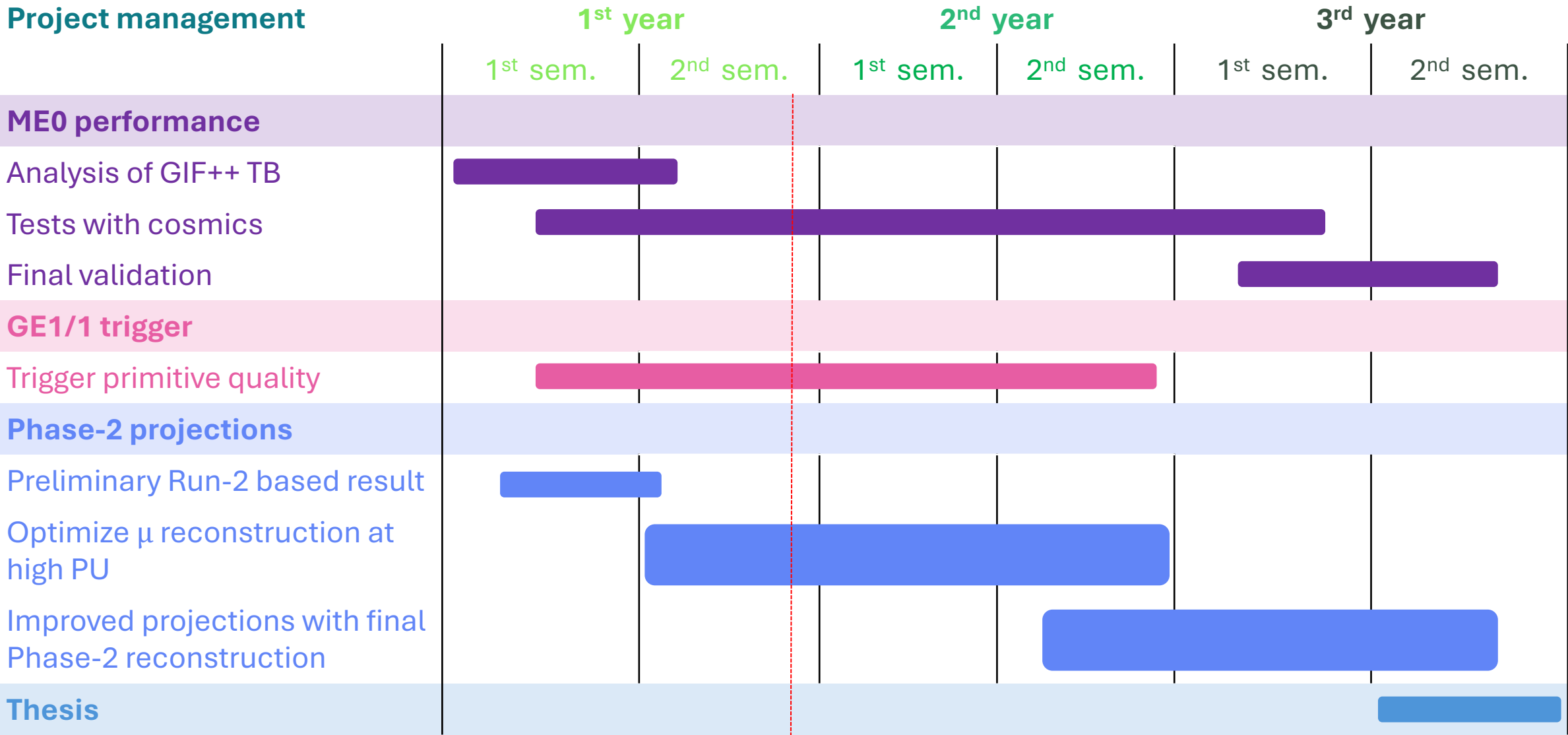
- Enhance **muon reconstruction** and identification to the ME0 coverage in the high Pile-Up scenario
- Evaluate the **impact** of the ME0 station in the **HL-LHC flagship analyses**
 - Projections for HL-LHC of the CMS sensitivity to Lepton Flavor Violating decays
 - Improved projections with final Phase-2 reconstruction algorithm

This analysis is ongoing and scheduled to be completed by the end of the third year

Preliminary results based on Run 2 paper presented in 2 talks at [IFAE](#) (+ corresponding accepted [proceeding](#)) and [NuFact](#)

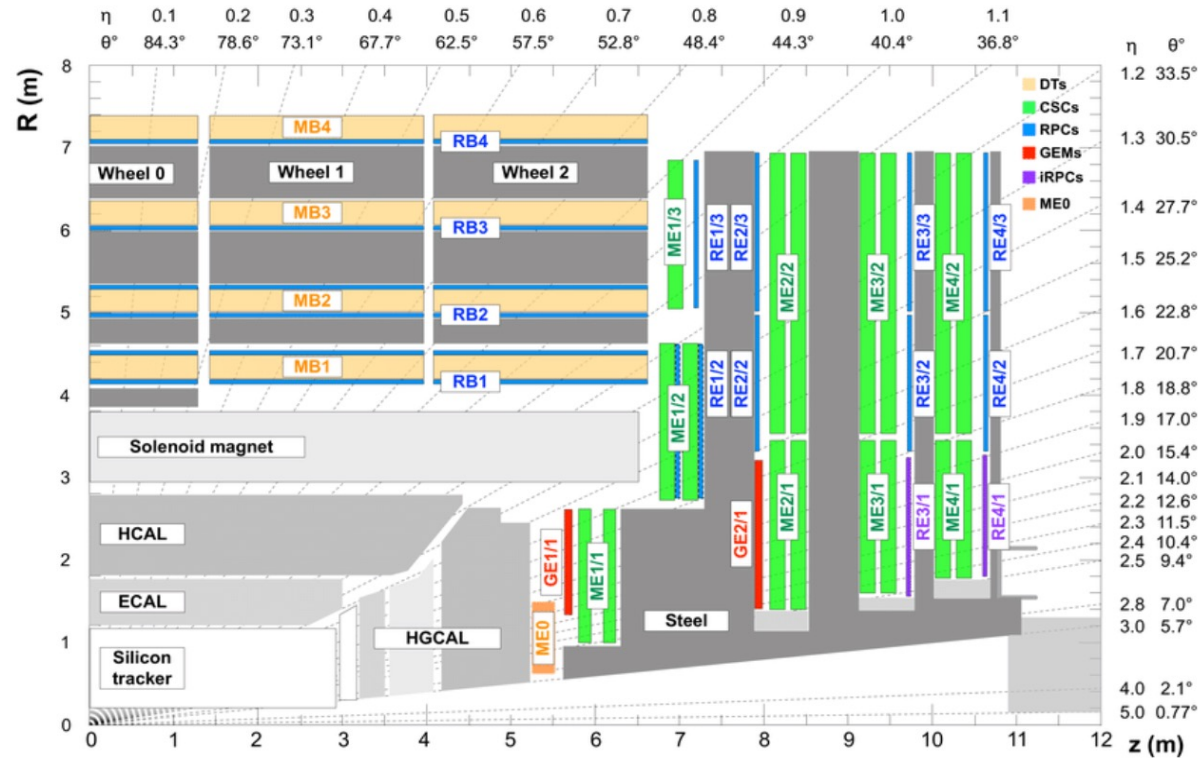
Full PhD schedule

Project management

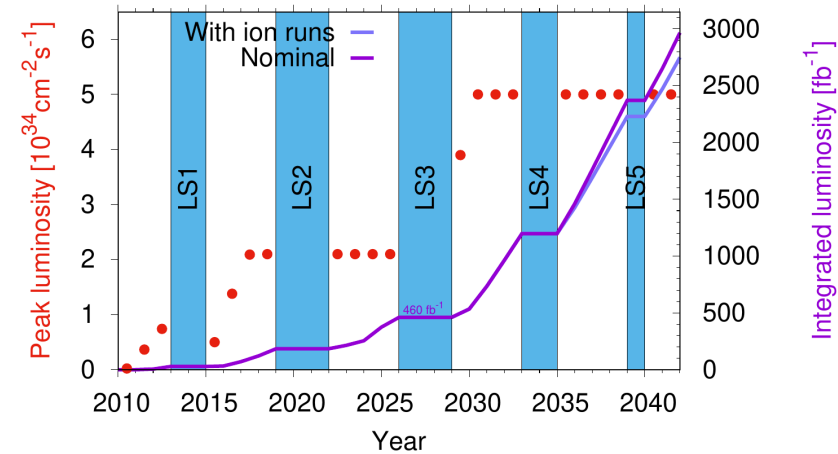


I AM HERE

Motivations



In 2029, the High Luminosity LHC project will start delivering a luminosity up to 5 – 7.5 times the nominal LHC luminosity ($10^{34} \text{ cm}^{-2} \text{ s}^{-1}$), causing an increase in the rate of particles traversing the detectors.



Three new GEM stations installed/foreseen (**GE1/1**, **GE2/1** and **ME0**):

- Complement the existing muon stations to **decrease** the trigger rate
- **ME0** station will **extend** the muon trigger coverage up to $|\eta| < 2.8$
 - Challenging environment due to unprecedently **high pile-up** (PU) track multiplicity
- **Increase** CMS **sensitivity** to rare decays with low p_T /high η final state muons

First year activity: ME0 detector performances



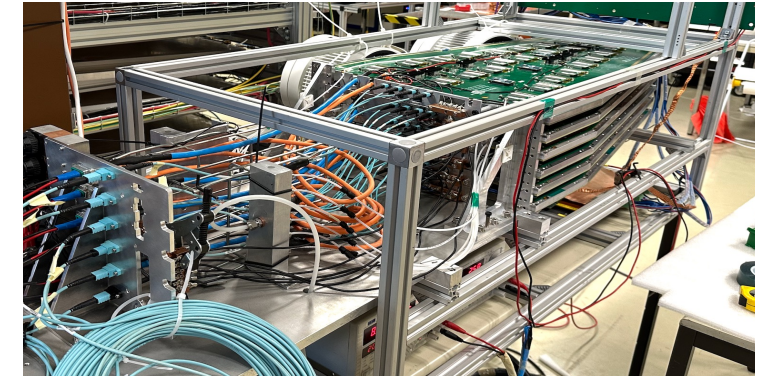
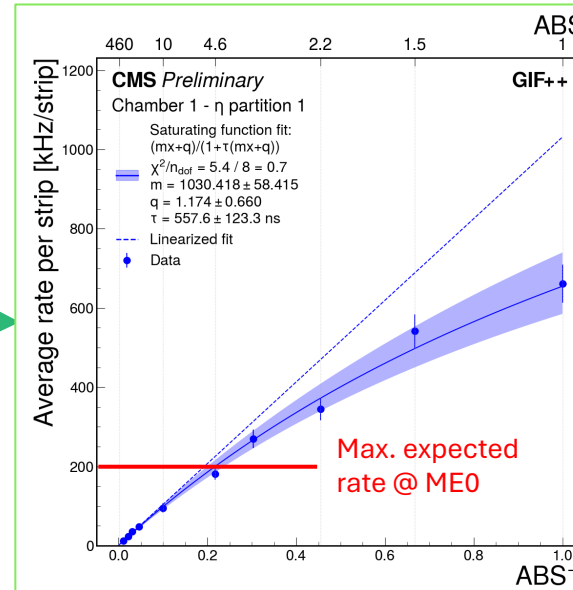
Before production started: check performances in a high-rate radiation environment

→ 2022-2024: test beam campaign at GIF++

The Gamma Irradiation Facility (GIF++) provides:

- ❑ A high energy **muon beam** (~ 80 GeV)
- ❑ A radioactive source: $14 \text{ TBq } ^{137}\text{Cs}$

Able to operate the chambers up to 200 kHz/strip

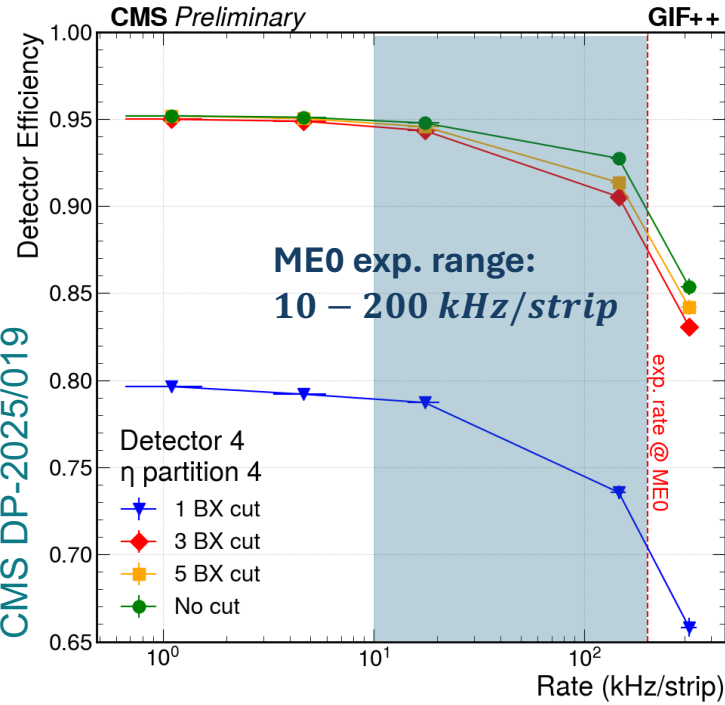


ACHIEVED GOAL

Study efficiency and time resolution of the ME0 detectors under the expected radiation rate in HL-LHC

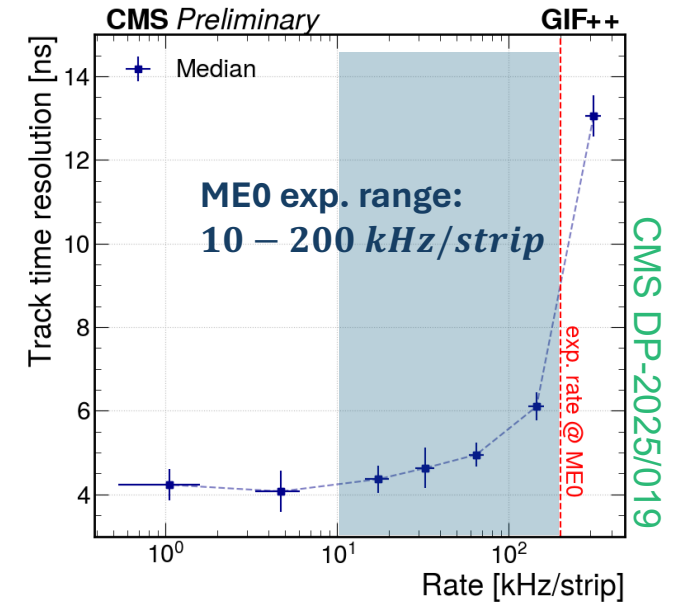
I developed a complete analysis framework in python for the evaluation of efficiency and timing of the ME0 stack

First year activity: ME0 detector performances



- ✓ The contribution of the background to the efficiency has been subtracted with a statistical procedure
- ✓ The efficiency drop is $\sim 3\%$, which corresponds to $\sim 150 - 200 \text{ ns}$ in terms of dead time of the single layer
- ✓ The dead time is **compatible** with the expected front-end dead time due to different cluster sizes of muons and bkg hits
- ✓ At the expected ME0 rate $\sim 150 \text{ kHz/cm}^2$ the chambers have an efficiency for muons of $\sim 90\%$

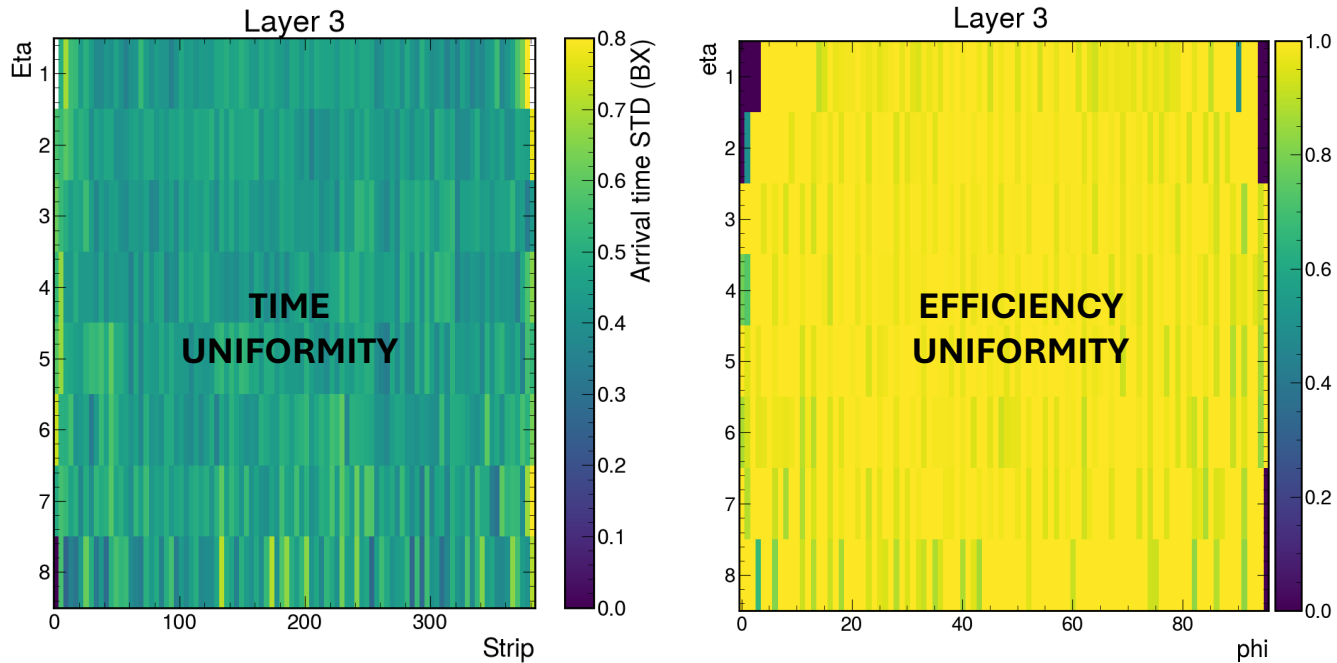
- ✓ Time resolution of the single chambers improved from $\sim 18 \text{ ns}$ to $\sim 10 \text{ ns}$, and the time resolution of the stack is $\sim 4 \text{ ns}$ increasing up to $\sim 8 \text{ ns}$ under irradiation
- ✓ Combining spatial efficiency and time resolution, the results show that a **3 BX** $[-1,0,+1]$ cut preserves a high efficiency, while ensuring a reduced background contamination.



Ongoing activity: ME0 detector performances

Contribution to the analysis of data from cosmic stand for ME0 stacks:

- Updated algorithm for tracking with the ME0 stack
- Developed code for the analysis of the timing performances
- Handling of the central analysis code used at CERN laboratory

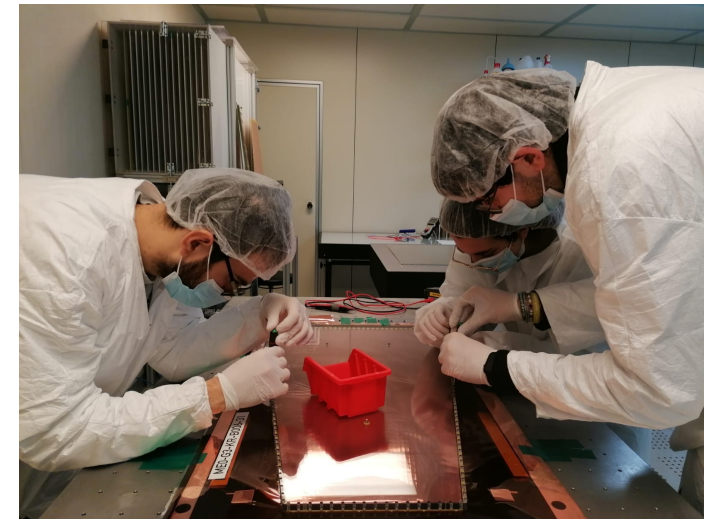


- ❖ Excellent time resolution (~ 10 ns)
- ❖ High efficiency ($> 95\%$)

Uniform response over all η partitions!



QC8 cosmic stand at lab 904



INFN Bari one of the main ME0 production sites

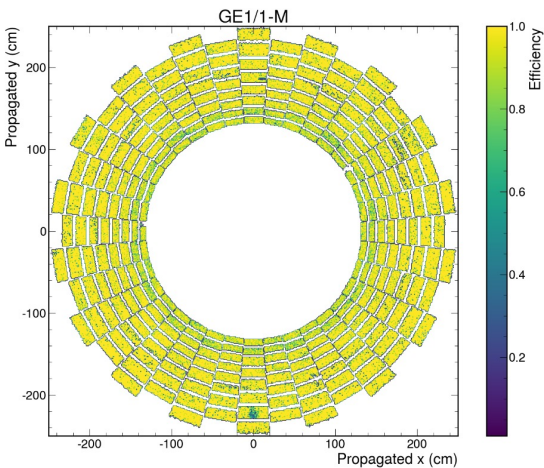
Ongoing activity: GE1/1 Trigger

Integration of GEM data with the CSC measurements allows substantial improvement in standalone muon momentum resolution, enlarging the lever arm

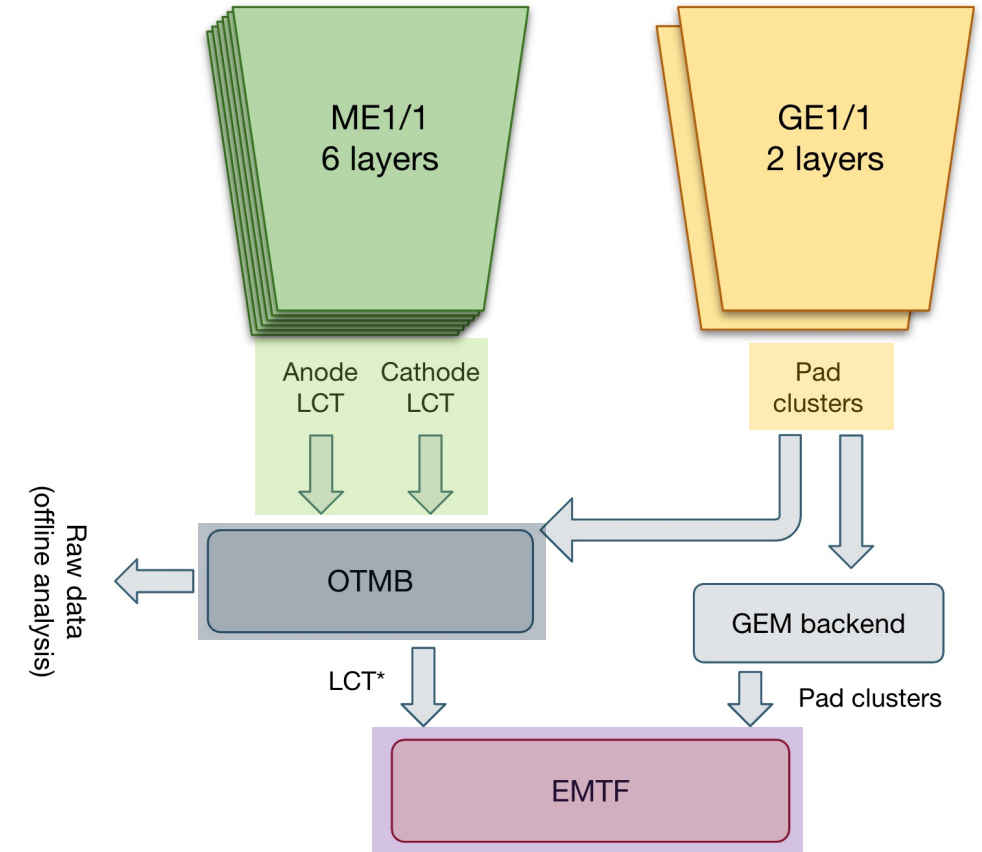
FINAL GOAL | evaluate the quality of the information GEM system provides to the muon trigger

Basic elements:

- **LCT: local charged track**
 - CSC trigger primitive built with anode and wire clusters in 4 or more layer
- **GEM pad cluster:**
 - GEM trigger primitive built by clustering neighbouring GEM hits in the same eta partition

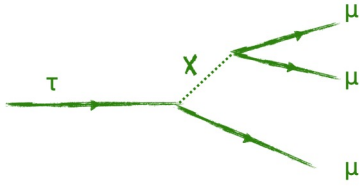


- ❖ The **redundancy** from the two GEM layers operating in an OR configuration ensures **high overall efficiency**
- ❖ **Time resolution optimization** (~17–12 ns) is progressing well, supporting better matching with CSC ME1/1



* possibly improved by GE1/1 hits

Ongoing activity: GEM Upgrade Physics cases



$\tau \rightarrow 3\mu$ is the golden channel for Lepton Flavor Violation at LHC

The main sources ($\sim 99\%$) of τ 's are heavy mesons (D_s and B) and decay into 3 muons with:

- Very low momenta (peak@ $\sim 1 - 1.5$ GeV)
- Significantly boosted in the forward region

→ Only $\sim 1.3\%$ of the muons survive the CMS acceptance ($p > 2.5\text{GeV}$ and $|\eta| < 2.4$)

Upper limit
stat. limited!

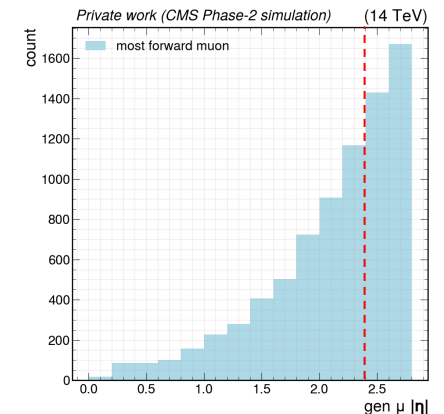
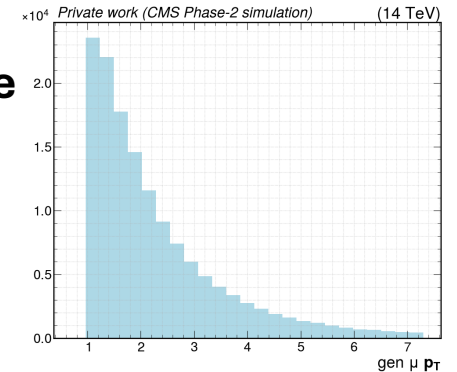
ME0 extends the CMS muon coverage up to $|\eta| < 2.8$ → **doubles** the signal fiducial **acceptance**
GEM-CSC tandem **improves purity** of reconstructed low momentum muons

First projections of this limit were published in the Technical Design Report (2017):

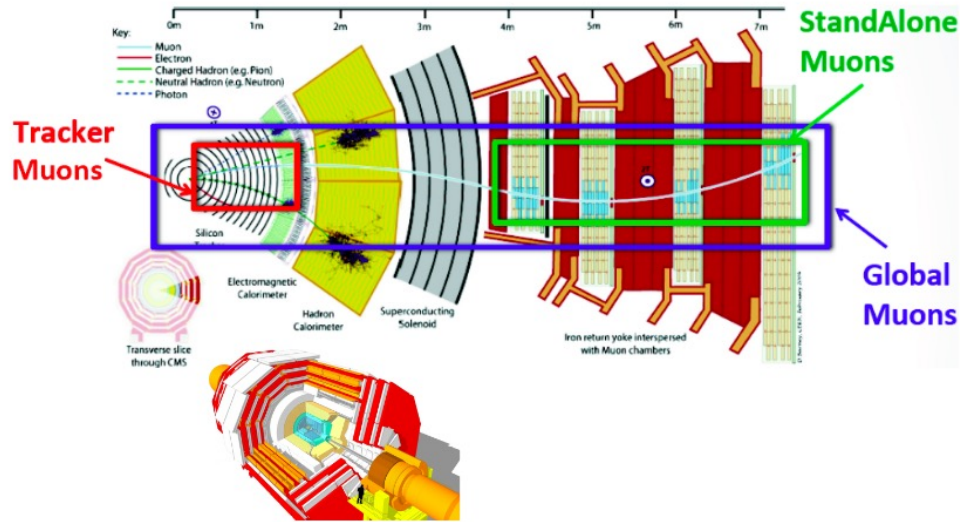
- ☐ No GEM-CSC tandem developed
- ☐ General reconstruction scheme not suitable for the very forward region

FINAL GOAL | perform a renewed projection of the upper limit for $\tau \rightarrow 3\mu$ in Phase-2 scenario

Contributed to the latest **Run2-based projection** produced for the Update of the European Strategy for Particle Physics (ESPPU) and published in CMS public note ([CMS-NOTE-2025-004](#))



Ongoing activity: GEM Upgrade Physics cases



In the ME0 pseudorapidity coverage, muons can be reconstructed only as Tracker muons, but the **unprecedented** Pile-Up expected in HL-LHC implies:

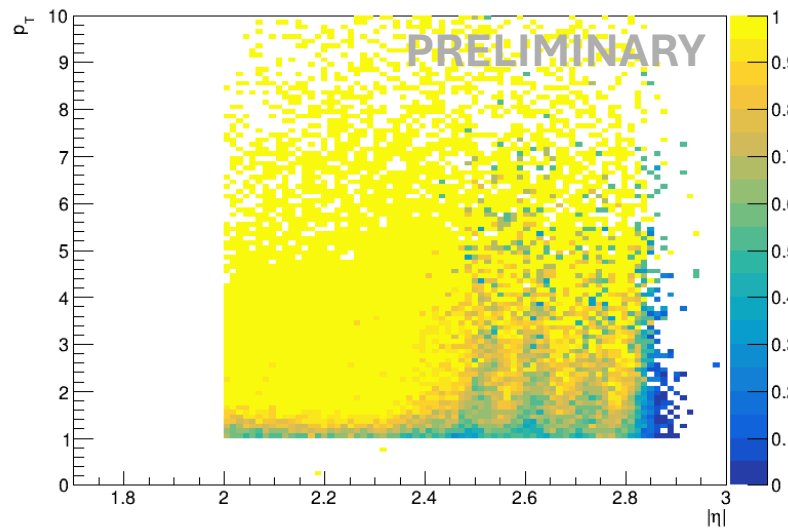
- ❖ High probability of fake muons
- ❖ High p_T thresholds to control trigger rate
- ❖ Very limited acceptance for interesting Physics channels



My study focuses on:

- Developing a reliable algorithm to extend high-quality muon reconstruction to ME0 coverage
- Finding new reasonable p_T thresholds for very forward muons
- Performing complete HL-LHC projection of $\tau \rightarrow 3\mu$ channel remarking the advantages of Phase-2 upgrades

Ongoing effort to optimize **matching** between tracks in the inner tracker and segments reconstructed by ME0 to increase efficiency



Training activities

courses

1. Big Data Analysis in Python (2.5 CFU)
✓ Exam passed in May 2025
2. Novel Detectors for Future Colliders (2 CFU)
3. Neural Networks (4 CFU)
4. Fundamental of FPGA-based digital design (2.5 CFU)

schools

Attended:

1. DRD1 Gaseous Detector School (CERN) | 27 Nov.- 6 Dec. 2024
2. National PhD TFPa Retreat (LNGS-L'Aquila) | 17 - 21 Feb. 2025
3. Flavor Physics at LHC School (CERN) | 26 – 30 May 2025

Scheduled:

1. CMS Data Analysis School (DESY) | 13 – 17 Oct. 2025
supported from Erasmus+ short mobility PhD KA131

Conferences and Workshops

- ❖ **Talk** at Incontri di Fisica delle Alte Energie (IFAE 2025) | 9-11 Apr. 2025
Lepton Flavor Violation in Heavy Flavor decays at the CMS experiment
✓ Proceeding submitted and accepted
- ❖ **Poster** at The Platform for Advanced Scientific Computing (PASC) Conference | 16-18 Jun. 2025
Interactive Visualization of High-Energy Physics Events via Nvidia Omniverse
- ❖ **Poster** at the 26th International Workshop on Radiation Imaging Detectors (iWoRID) | 6-10 Jul. 2025
Performance of triple-GEM detectors for the ME0 system of the CMS Phase-2 Upgrade
□ Proceeding submission by September 30th
- ❖ **Talk** at the 26th International Workshop on Neutrinos from Accelerators (NuFact) | 1-6 Sep. 2025
Search for LFV and LFUV in Heavy Hadron Decays at CMS

Thank you
for your attention!