Enhancing the search for Lepton Flavor Violating decays through the GEM upgrade of the Forward Muon Detector at the CMS Experiment

Felice Nenna (INFN Bari & University of Padua)

PhD in Technologies for Fundamental Research in Physics and Astrophysics

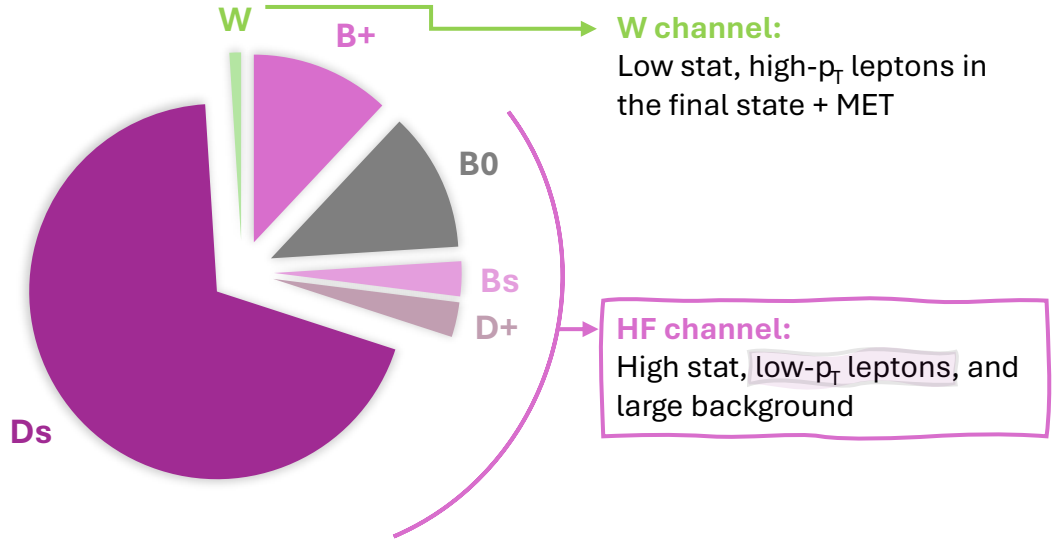
Supervisors: Piet Verwilligen, Federica Maria Simone

Motivations

- **Why $\tau \to 3\mu$?** It's a golden channel for charged **LFV** tests:
  1. **Fully reconstructed** final state
  2. **Clean** experimental signature
  3. **Abundant τ production** at the LHC from various sources

SM (BSM) predicts BR($\tau \to 3\mu$) ~ 10^{-55} (10^{-8}–10^{-10})

CMS BR($\tau \to 3\mu$) < 2.9×10^{-8} @ 90% CL (Full Run2)



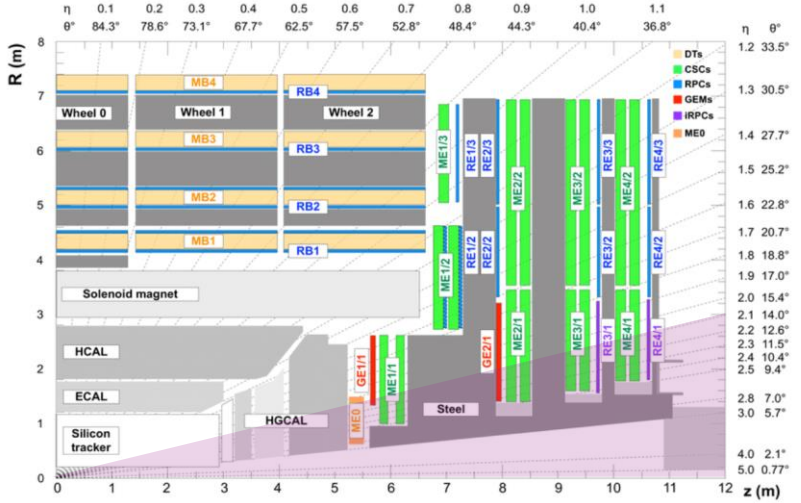
- **GEM upgrade of the forward muon detector**

In 2029: HL LHC → luminosity increase by 5 – 7.5 → **CMS Phase 2 Upgrade**

Three new GEM stations in the forward region of the endcaps:

- complement muon stations to reduce L1 trigger rate
  - **Improve** online p_T measurement
- extend muon trigger coverage $2.4 < \eta < 2.8$
  - **Increase** low-p_T leptons acceptance

Major improvements in the HF $\tau \to 3\mu$ channel foreseen

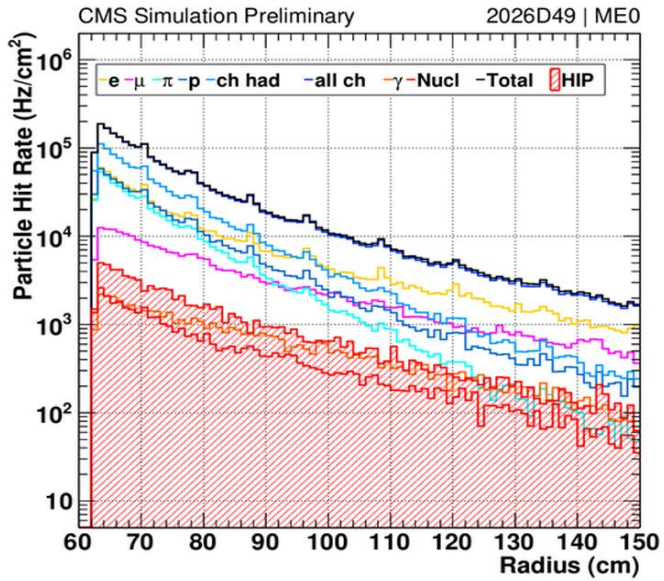


Muon system extension in η: the ME0 station

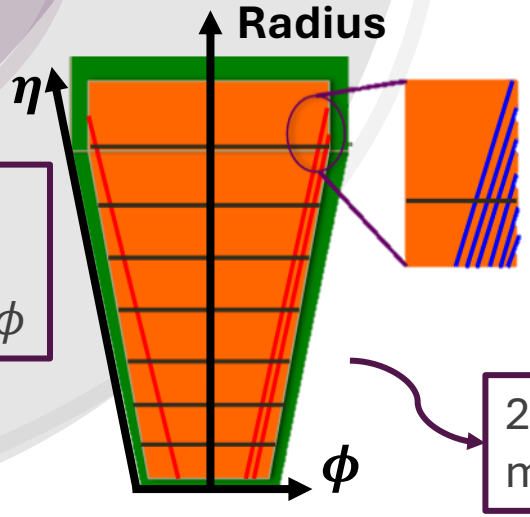
The ME0 will be the closest detector of the muon system to the interaction point → highest rates (max $\sim 150\ \mathrm{kHz/cm^2}$)

The main requirements in order to properly operate ME0 to trigger on muons are:

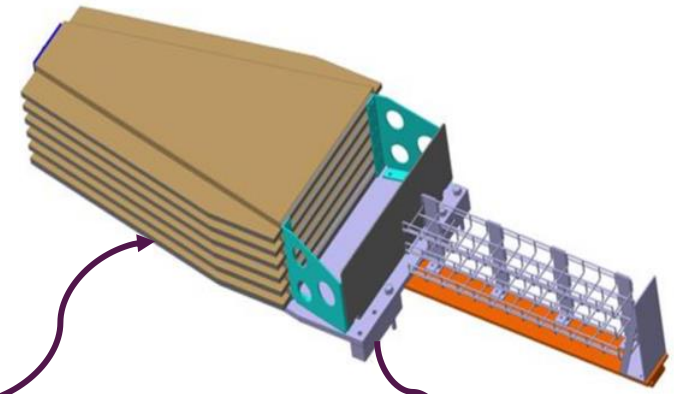
- **Rate capability** → $\sim 150\ \mathrm{kHz/cm^2}$
  Test beam campaign at the GIF++ in 2023 → **~95% efficiency @ $\sim 150\ \mathrm{kHz/cm^2}$**
  work of my Master's thesis
- **Time resolution** → ~ 10 ns per chamber
  Analysis ongoing



CMS Collaboration, "**Rate capability of large-area triple-GEM detectors and new foil design for the innermost station, ME0, of the CMS endcap muon system**"

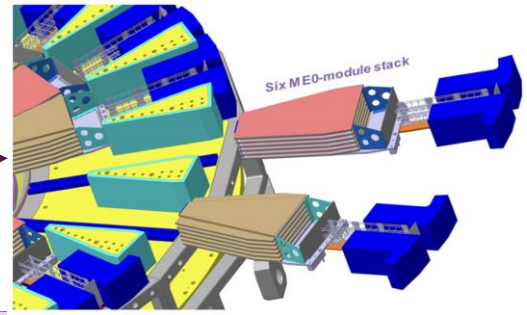


Triple-GEM
8 η partitions
384 strips along ϕ



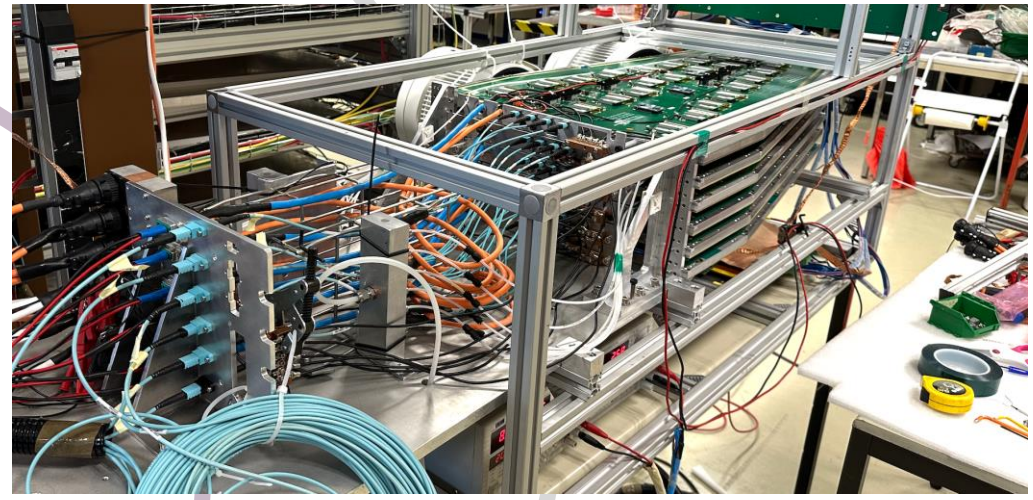
20 degrees stack made of 6 layers

18 stacks per endcap



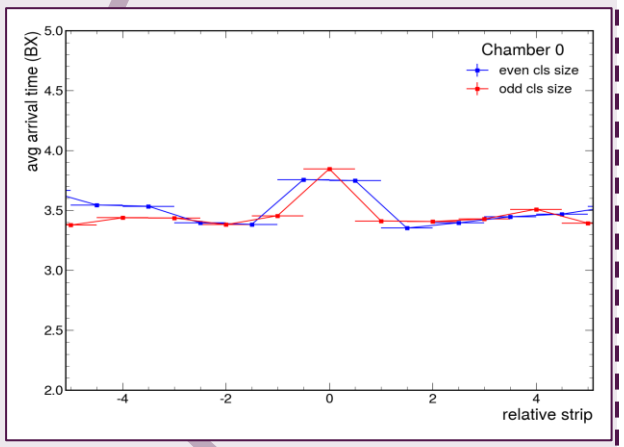
Time resolution with cosmic rays

At April 2024, first measurements of time resolution with the first complete 6-layer ME0 stack with cosmics muons

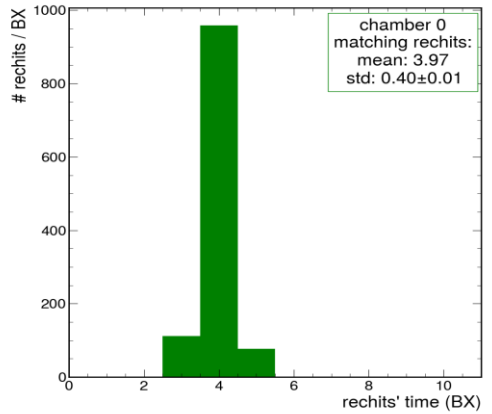


Evidence that the time resolution of the digital hits is affected by the different nature of induced signals, i.e. *regular* vs *cross-talk*

→ Cross-talk signals arrive, on average, before the regular signal spoiling the arrival time distribution



In the clustering process, the time of the cluster is taken as the one of the last firing strips



$\sigma_t = 10.0 \pm 0.3\ ns$

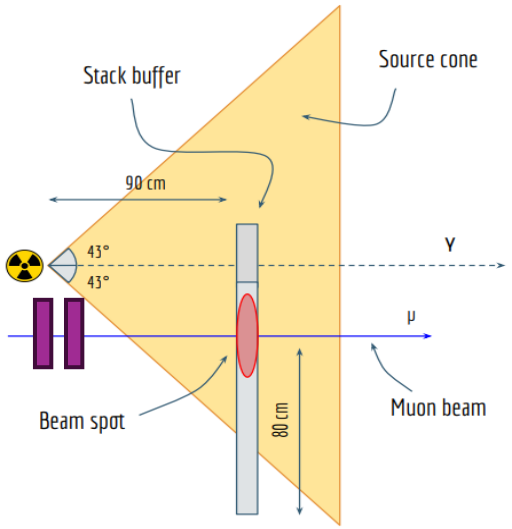
Time resolution under γ irradiation at GIF++

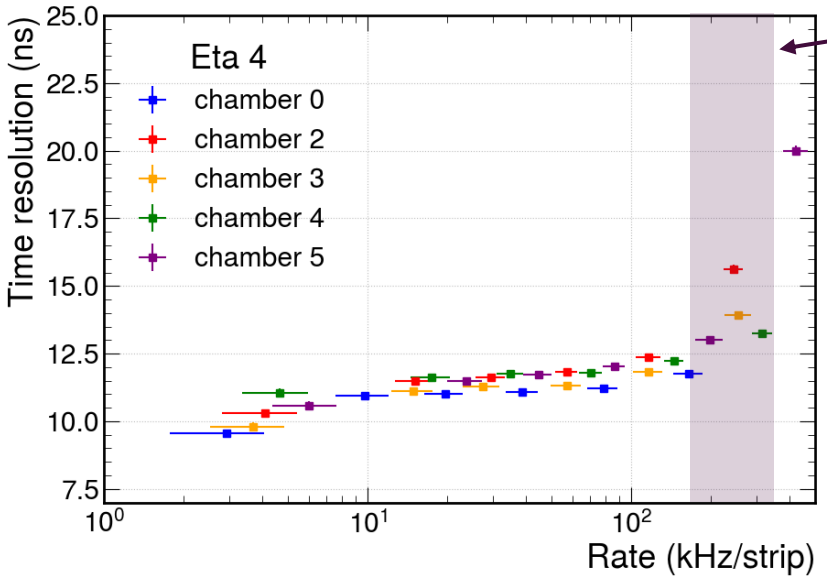
The Gamma Irradiation Facility (GIF++) provides:

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

ME0 stack used **standalone** for reconstruction

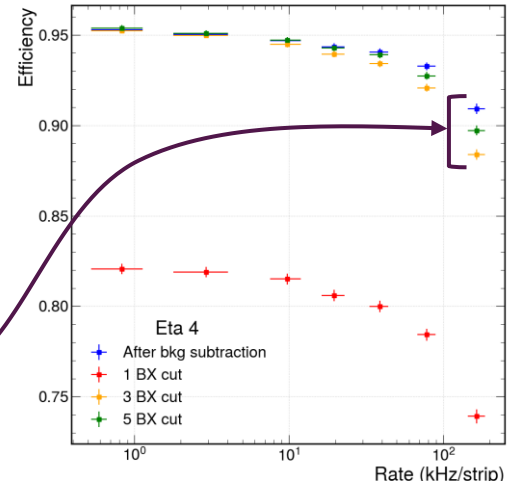
2 GIF++ scintillators out of the irradiation field are used as trigger.





Time resolution of the chambers increases up to **15 ns @ 250 kHz/strip**

Cutting on the hits that arrive within a 3 BXs range around the central one: **Efficiency drop ~ 0.1 to 3%**



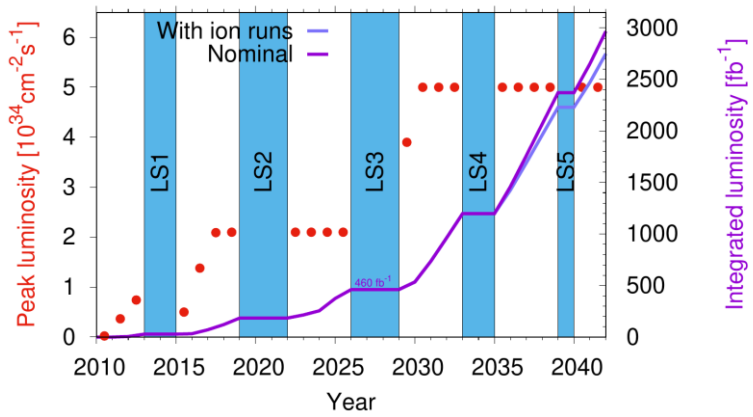
$\tau \to 3\mu$ projection for ESPPU

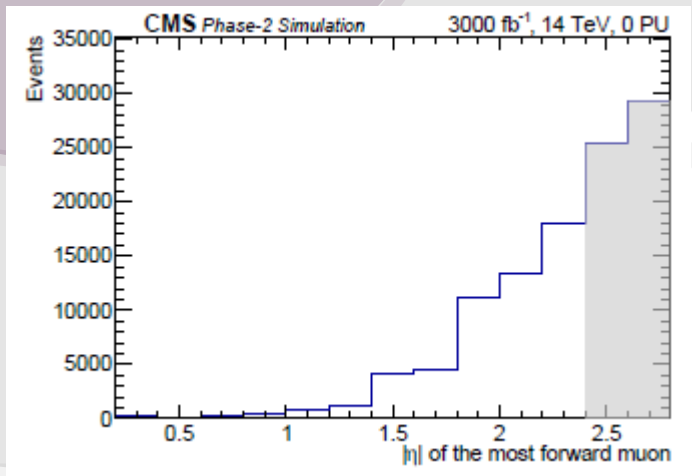
ATLAS, CMS, Belle II and LHCb have agreed to prepare a joint submission to the **European Strategy for Particle Physics Update** (ESPPU) from major flavour physics experiments

Renew the Phase-2 projection for the $\tau \to 3\mu$ channel

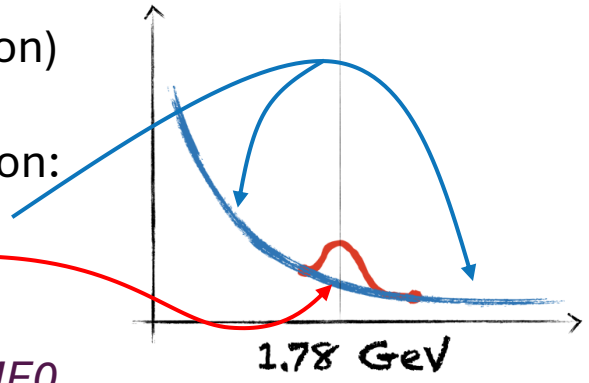
Already performed in 2017 with a simplified analysis (CMS AN-17-176)

Guide lines: extrapolate from Run1/Run2 data to 2000-3000 fb^{-1}





$\tau \to 3\mu$ will benefit as well from the extended muon system acceptance $2.4 < |\eta| < 2.8$ (with ME0 installation)



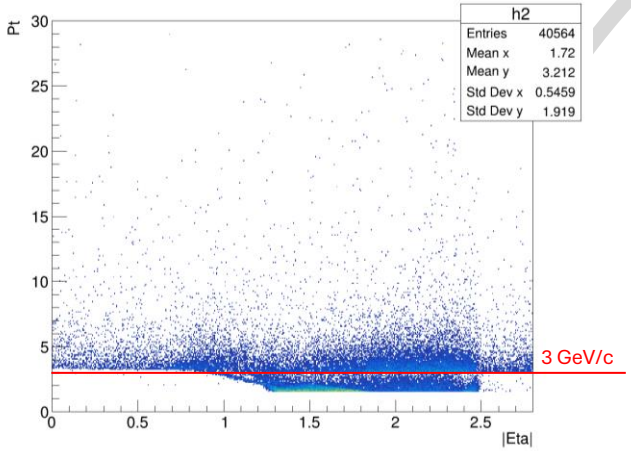
PLAN: reproduce the Run 2 analysis (cut-based + BDT) on:

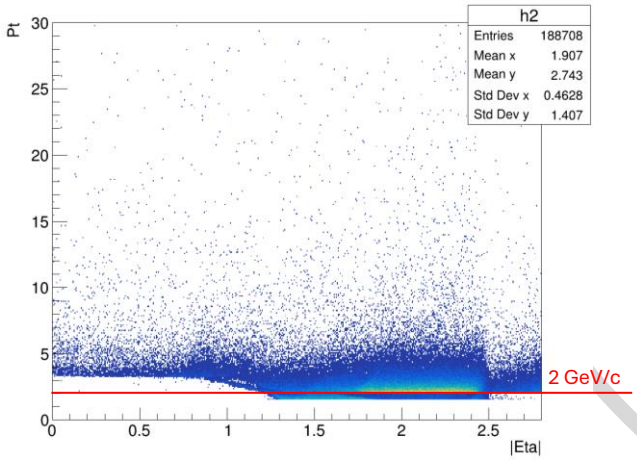
- Phase-2 Minimum Bias samples for the background
- Phase-2 signal samples

+

- Additional event categories: *muons in ME0*
- Include the *W production channel*

First studies on private signal samples

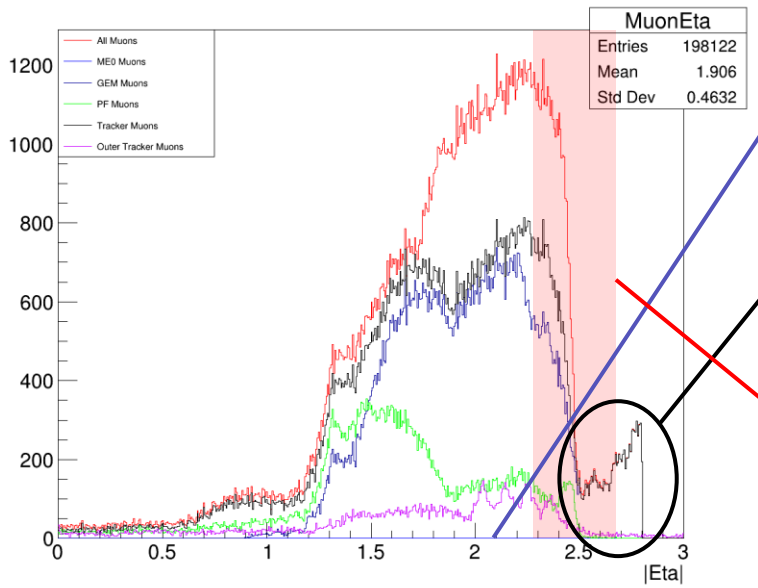




First look at Phase-2 simulations of $D_s \rightarrow \tau(\rightarrow 3\mu)\nu_\tau$ with PU=200 at 14TeV:

- Tau3Mu n-tuplizer with loose cuts (i.e. 3 muons with a valid primary vertex)
- First distributions showed a sharp cut at p_T<3.0 GeV/c → due to the cut on the *slimming* muons at the MiniAOD step
- New sample with looser cut at p_T<2 .0 GeV/c

MuonEta

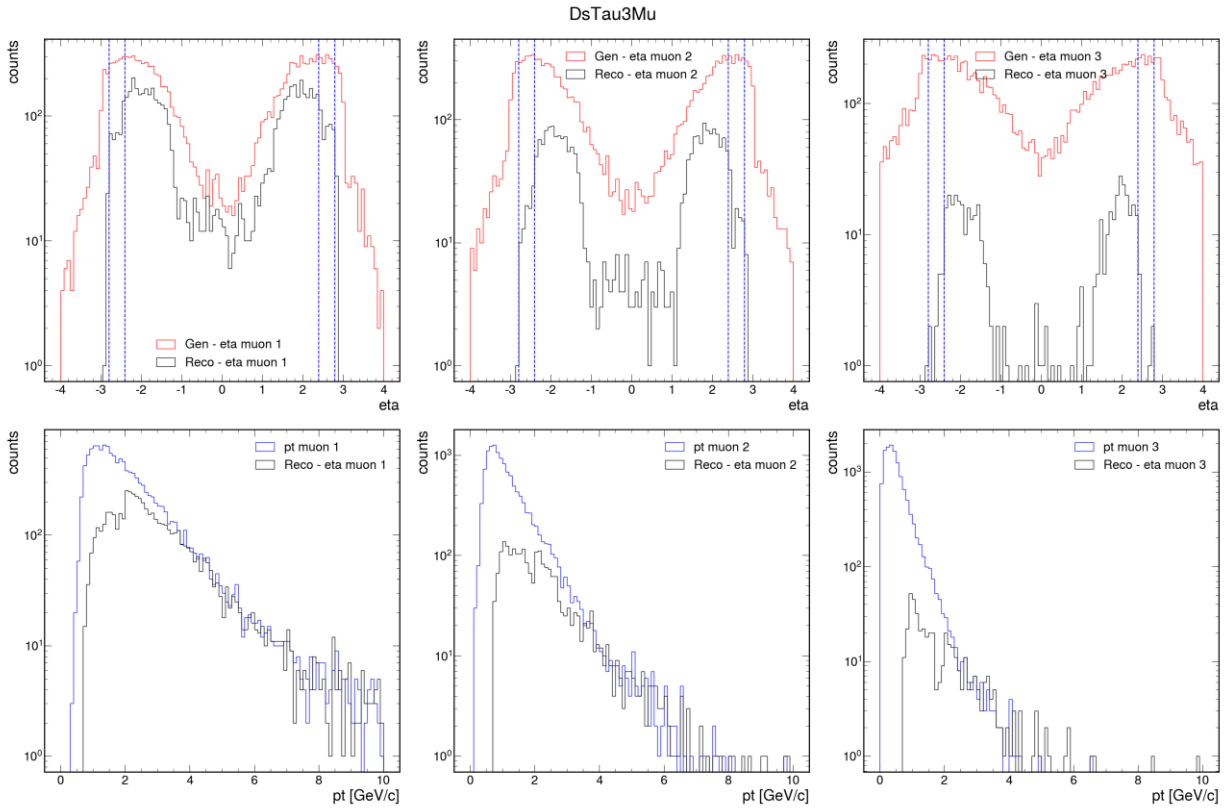


No *isME0muons* → *isME0Muon* category has been deleted ME0 = {GEM muons in station 0}

ME0 muons are only Tracker muons (Glb muons need more than one muon station)

Sharp drop in efficiency for |eta|>2.4

Gen VS Reco muons



Instead of the Tau3Mu ntuplizers, a simpler one is used that takes in all the reco muons.
Reco muons are associated to the generated muons only geometrically by dR:

- Drop at pt > 2.4 :
  - At digi level: 97% efficiency per layer
    99% efficiency for the segment

Maybe due to ME0 reconstruction inefficiency?

Next steps

- Develop a refined algorithm to reconstruct the tracks with the ME0 stack (***base-road method***)
- **Segment efficiency** and **time resolution** under high background rate
- Minimum bias sample production to obtain a first estimation for the **Phase-2 projections** by the end of January *(plot approval has been set to Jan 27th)*


Thank you
for your attention!
And Merry Christmas!