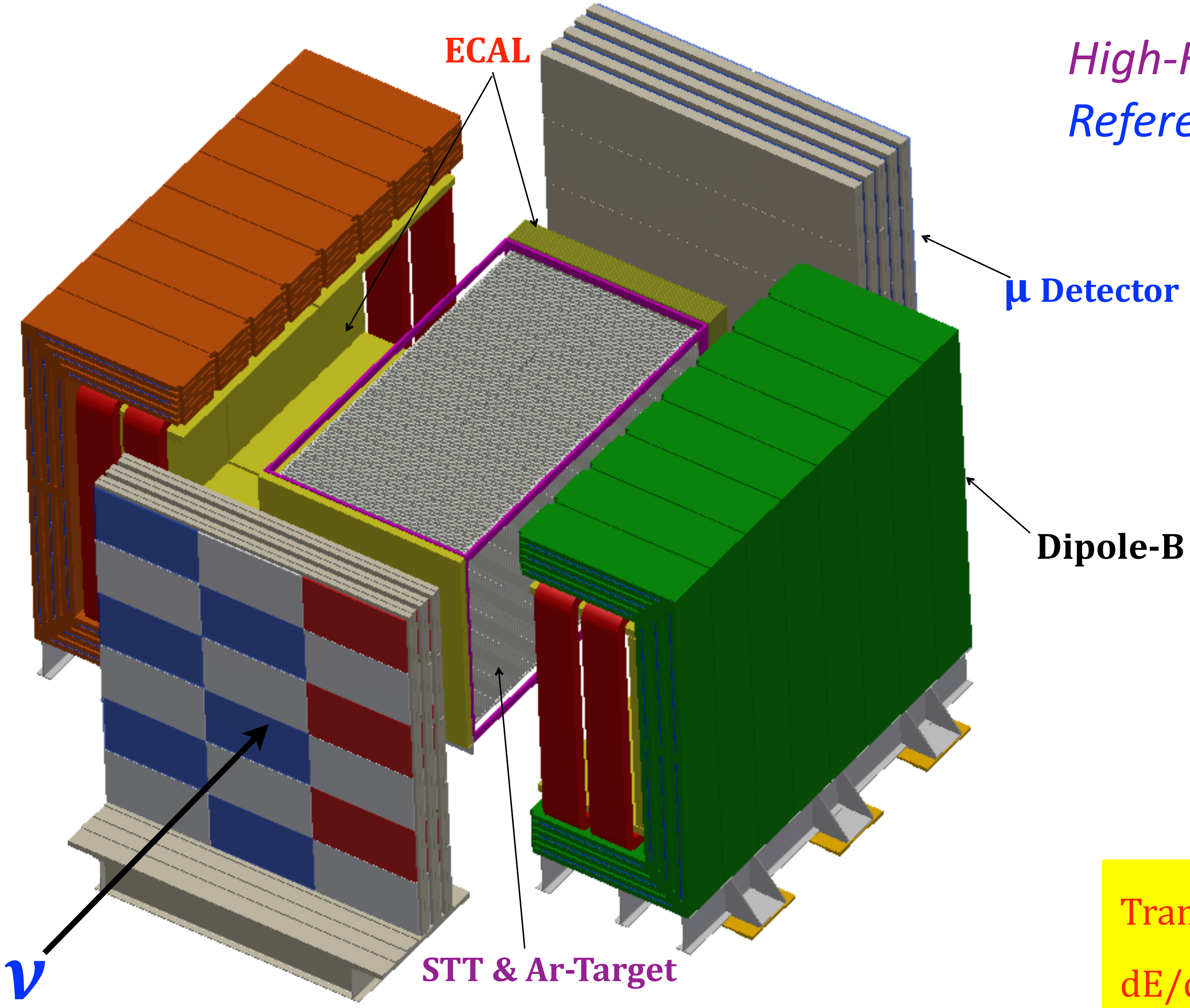
Electron/Positron Measurement in FGT

Xinchun Tian, Sanjib R. Mishra, Roberto Petti

….. *very much a work in progress*

High-Resolution Fine Grain Tracker:
Reference ND of DUNE



- ~3.5m x 3.5m x 6.5m STT ($\rho \simeq 0.1$ gm/cm^3)
- 4π-ECAL in a Dipole-B-Field (0.4T)
- 4π-μ-Detector (RPC) in Dipole and Downstream
- Pressurized Ar-target (≃x5 FD-Stat) ⇛ *LAr-FD*

Transition Radiation ↠ $e^{+/-}$ ID ⇒ γ

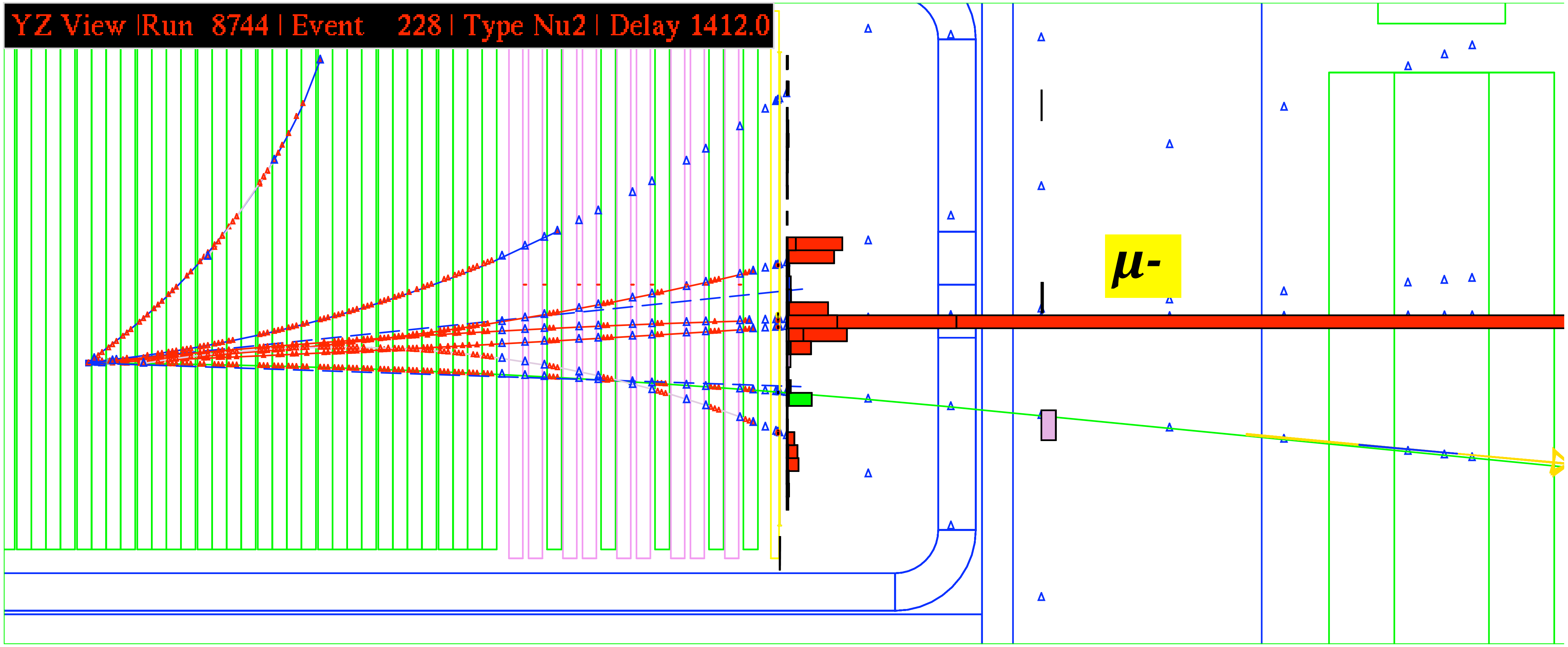
dE/dx ↠ Proton, $\pi^{+/-}$, $K^{+/-}$

Magnet/Muon Detector ↠ $\mu^{+/-}$ $e^{+/-}$

(⇒ ***Absolute Flux measurement***)

$1X_0 \sim 600$ cm / $1\lambda \sim 1200$ cm

A ν_μ CC candidate in NOMAD



Observation ⇛

(1) Hadrons are tracks, enabling the momentum vector measurement

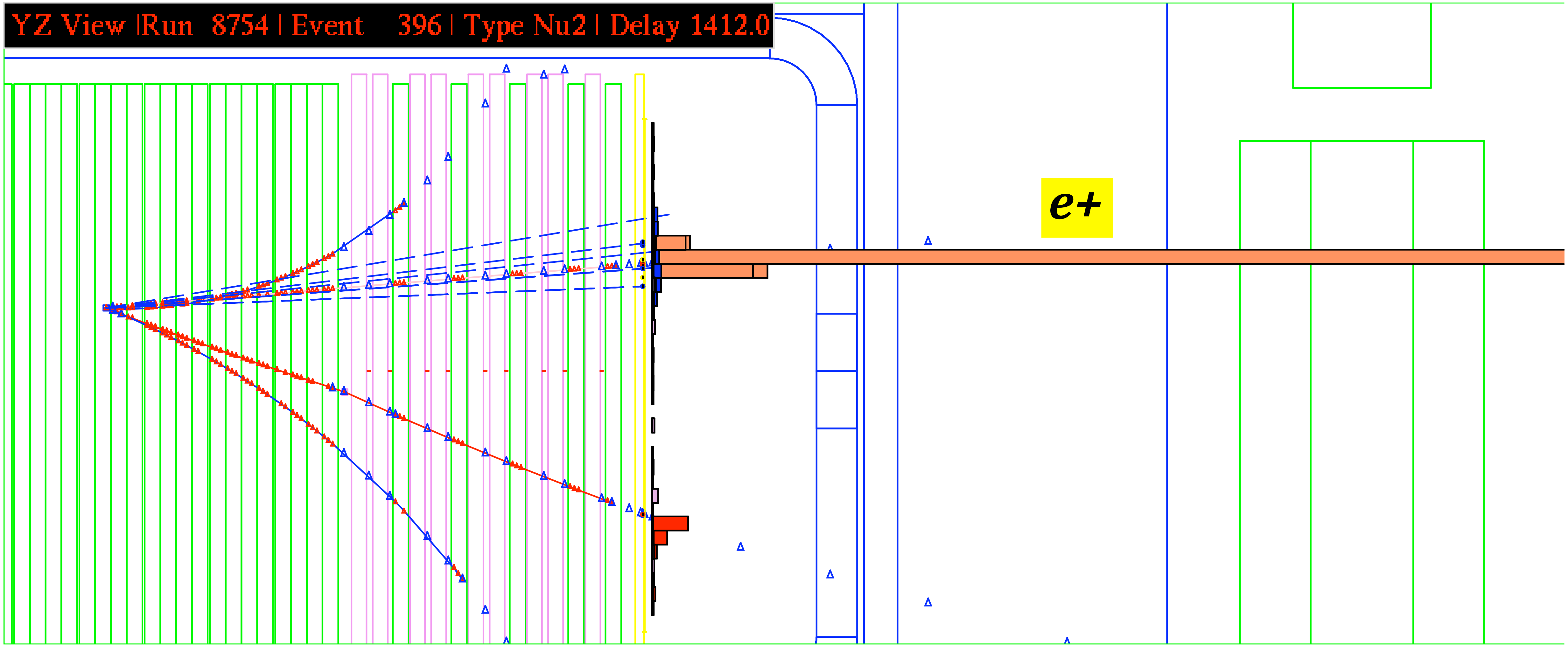
(2) μ is kinematically separated from Hardon-vector ⇒ Miss-PT Measurement

(3) FGT offers ~x5 higher tracking-points for hadronic tracks

A $\bar{\nu}_e$ CC candidate in NOMAD

⇛ *Most difficult to measure among the 4 ν-species*

In FGT, >x5 higher track-points



Conclusion ⇛

(1) $e \Leftarrow \nu_e \leftrightarrow \mu \Leftarrow \nu_\mu$ *are Tracks: Curvature & Direction with very high precision*

(2) Universality equivalence: μ-$\nu_\mu \leftrightarrow e$-$\nu_e$

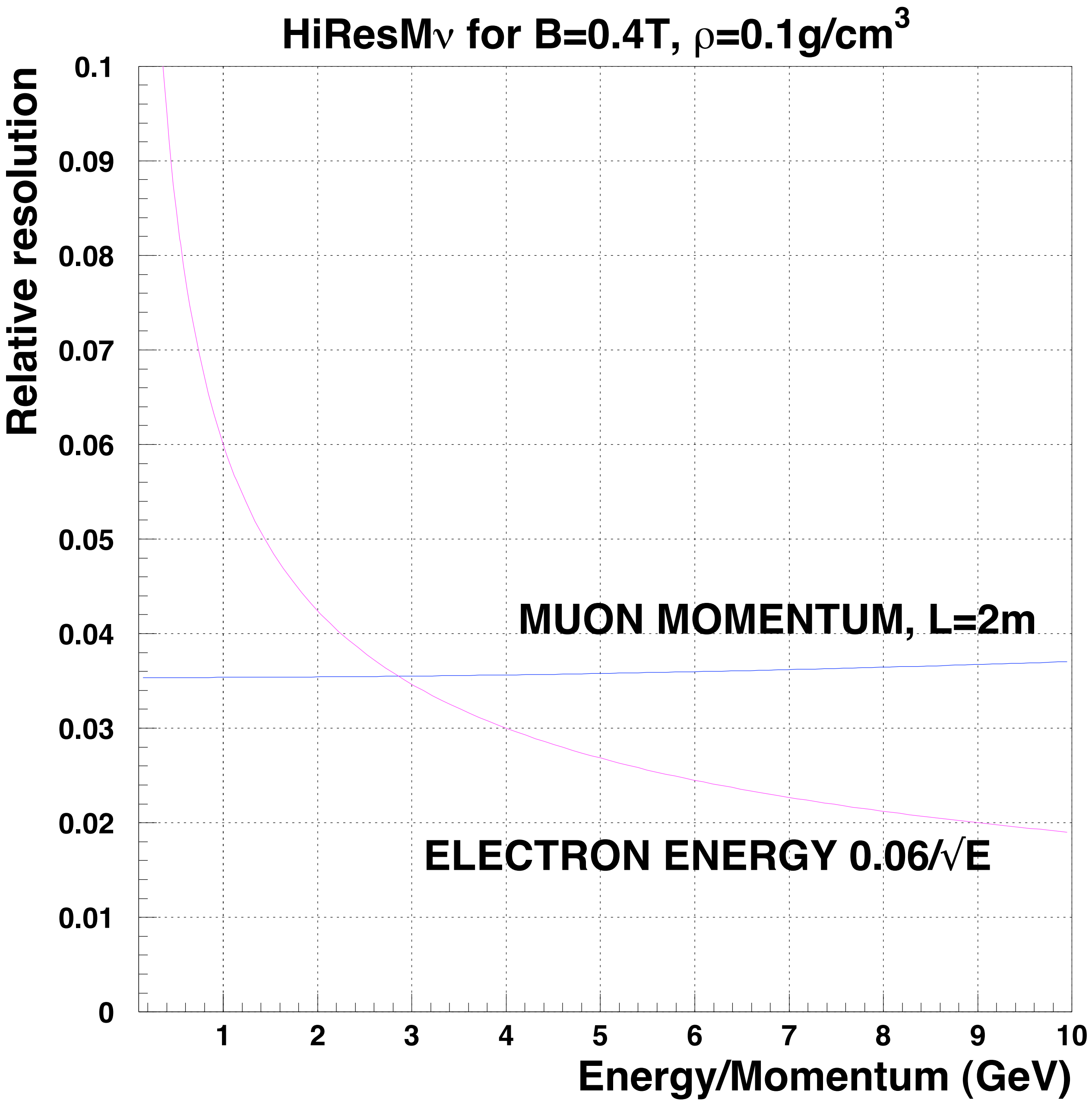
Resolutions in FGT

- ρ ≃ 0.1gm/cm^3
- Space point position ≃ 200μ
- Time resolution ≃ 1ns

- CC-Events (≥*2Trk*)Vertex: δ ≃ *O*(100μ)

- Energy in Downstream-ECAL ≃ 6%/√E
- μ-Angle resolution (~3 GeV) ≃ *O*(2 mrad)

- μ-/+ Energy resolution (~3 GeV) ~ 3.5%
- e-/+ Energy resolution (~3 GeV) ~ 3.5%



Electron/Positron Measurement in FGT

✳ $\nu_e \leftrightarrow e^-$; *anti-*$\nu_e \leftrightarrow e^+$;

✳ e- Momentum Vector Measurement:

Track-reconstruction in STT:
Curvature ⇒ |**p**| & "-" or "+"
Direction-cosines ⇒ STT Track-fit extrapolated to the vertex including dE/dx

Energy ⇒ Cluster & Brem-Strip in the ECAL: *A more precise measure of* $|\mathbf{p_e}|$

✳ e-ID Measurement:

*1*st: Transition Radiation (*TR*) measurement in the STT

*2*nd: Energy-profile, *Transverse and Longitudinal energy-deposition pattern*, in the ECAL (match the STT-Track with the ECAL-Track)

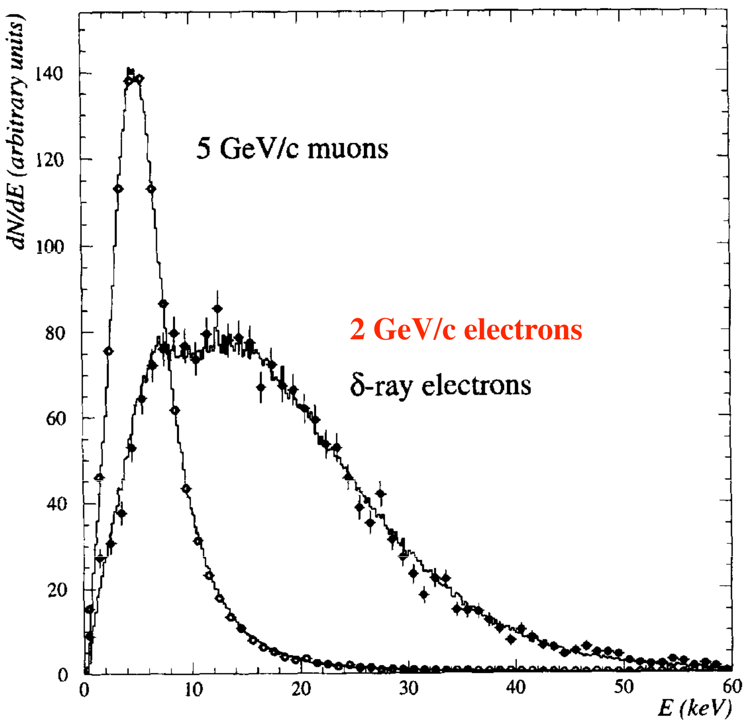
Note: *ECAL has a 4π-coverage ⟹ Wide-angle e-/e+ acceptance*

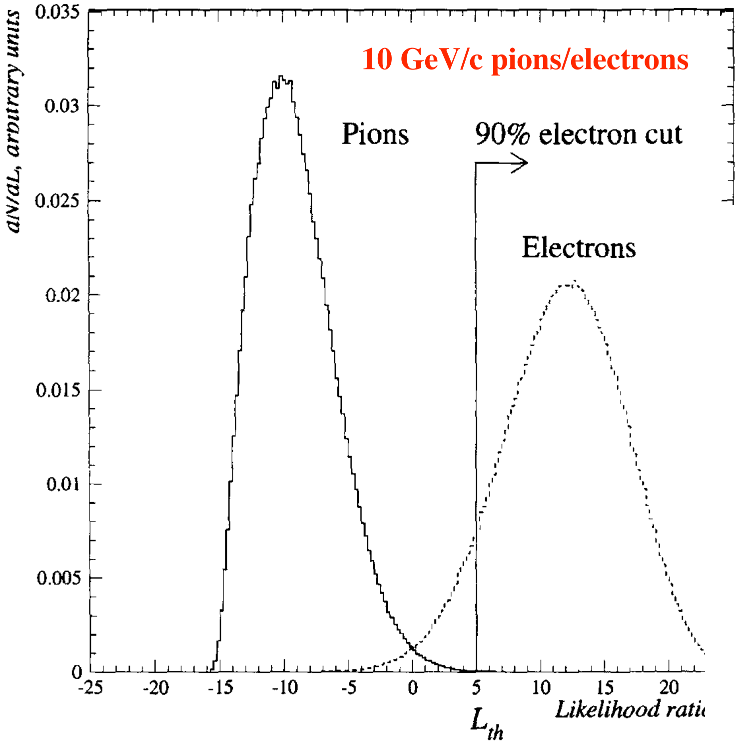
⟹ π/μ *reduced by* ~10^{-4} *while Electron-Eff > 90%*

*3*rd: Pattern of energy loss (*Helical track-fit*) in STT

Electron ID: TR - The most potent discriminant

Analog readout: pulse height





NOMAD TRD reaches a 0.1% pion contamination for isolated tracks of momenta 1-50 GeV/c with 90% electron efficiency

Ro

South Carolina C

✺Atlas-TRT's Geant4 simulation conducted for the FGT config. verifies the e/μ-π separation ➢

(*See P.Nevski LBNE-DocDB#432-V1*)

Electron TR-Eff as a function of Pe for 10^{-3} rejection of π/μ

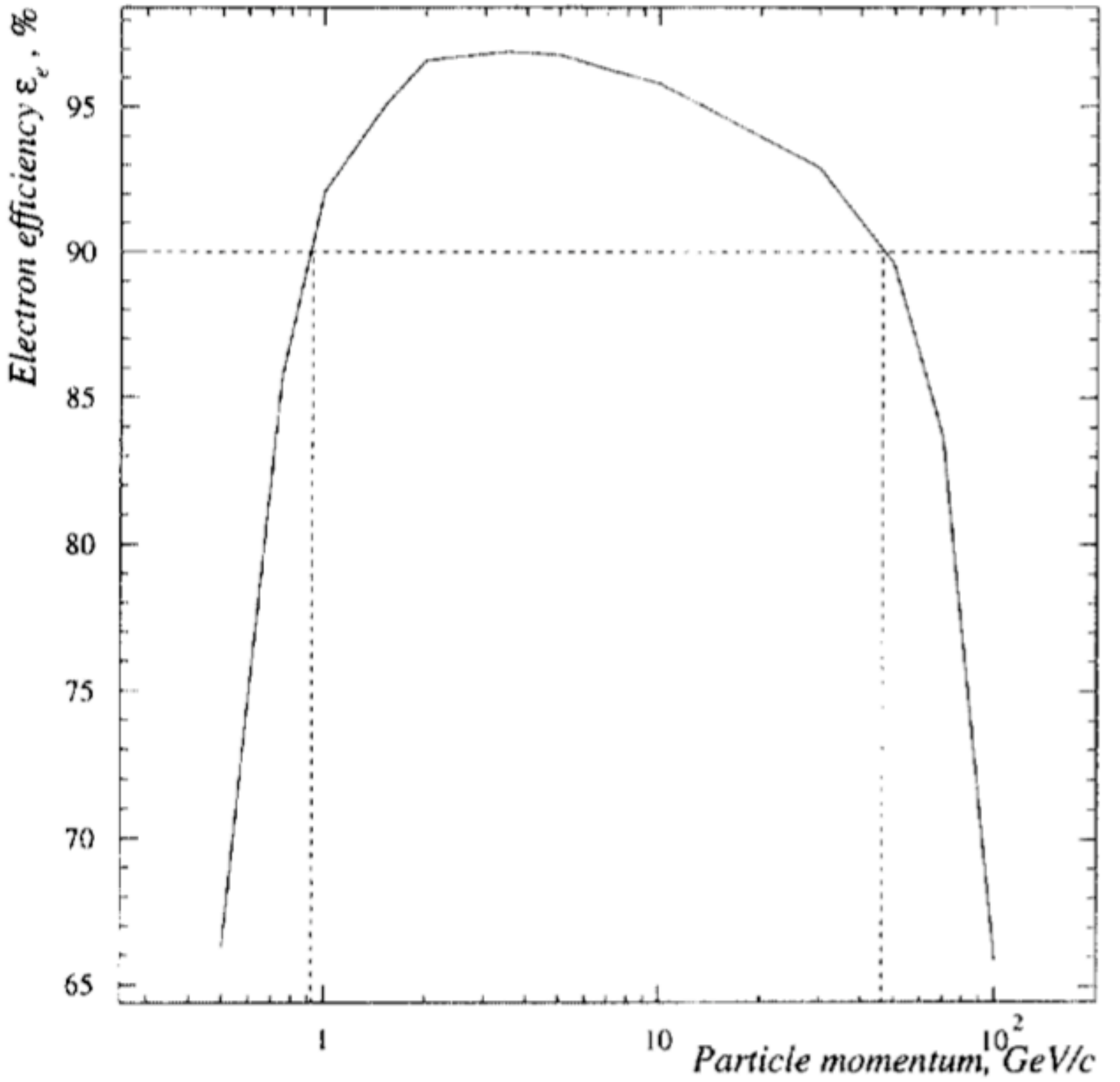


Fig. 8. Monte Carlo predicted electron efficiency ε_e correspond
ing to $\varepsilon_\pi = 10^{-3}$ as a function of the momentum of the particl
for 9 associated hits.

Electron ID: ECAL - Energy, Longitudinal and Transverse Profiles as discriminants

Measure ➻ *e*, **γ**, *&* *n*/K^0**s**

✴ Scintillator-Pb calorimeter: Motivated by the T2K-ECAL design
Alternating planes of X/Y planes
2.5cm Sci-slats read on both ends (SiPM)

✴ Downstream (Forward) ECAL:

60 Layers with *1.75mm* Pb-sheets: 20X_0
Single electron ⇒ ~6%/√ E

✴ Barrel ECAL:

18 Layers with *3.5mm* Pb-sheets: 10X_0

✴ Upstream ECAL:

18 Layers with *3.5mm* Pb-sheets: 10X_0

Will be updated: *More details (plots/#s) later*

Electron Efficiency in FGT (Prelim.)

Efficiencies/Purity from Fast-MC. (TR cut: *40-planes of ST*)
Cross-checked against NOMAD Data -vs- MC

- ✴ P > *0.5* GeV: Efficiency ~ *~58%*; *Purity >90%*
- ✴ Efficiency & *Purity* largely energy independent
- ✴ Fast-MC of NOMAD yeilds : Efficiency ~ *~38%*; *Purity ~82%*
  NOMAD Geant-MC (Data-driven): Efficiency ~ *~40%*; *Purity ~79%*

Electron Energy Resolution in FGT (Prelim.)

- ✴ **δ**|P| ~ *10% (@FWHM)*
- ✴ **δ**|E| (ECAL) ~ 3.6% *(consistent with 6%/ √E)*
- ✴ NOMAD Geant-MC (Data-driven): **δ**|P| ~ *13% (@FWHM)*
  δ|E| (ECAL) ~ 2.0% *(~ 3%/ √E)*

A final separation of $\nu_e \Rightarrow e$ *from the non-prompt* $\pi^0 / \pi^{+-} \Rightarrow$ *e/e-like*

- ✴ Use the Lepton-Hadron kinematic isolation to reduce the impurity (…*later*)

Test-Beam Calibration of STT (TR) and ECAL (Shape)

- ✴ Measurement of the STT prototype in a Test-Beam
  - ⇒ Check/obtain calibration
  - ⇒ dE/dx, TR: e *vs* μ *vs* π *vs* …. in momentum bins

  ⟹ Essential before full-scale fabrication

- ✴ Measurement of the STT and ECAL prototypes in a Test-Beam
  - ⇒ Obtain energy (ADC ⟹ GeV) calibration
  - ⇒ Measure the energy-dependent non-Gaussian tails
  - ⇒ Particle ID: e *vs* μ *vs* π *shower-shape* discriminant in momentum bins

  ⟹ Essential before full-scale fabrication

in situ Constraint on the *Electron-efficiency*

✴ Measure the TR and ECAL Efficiencies using source of pure e^+e^-

(1) Select $\gamma \twoheadrightarrow e^+e^-$ conversions using track reconstruction

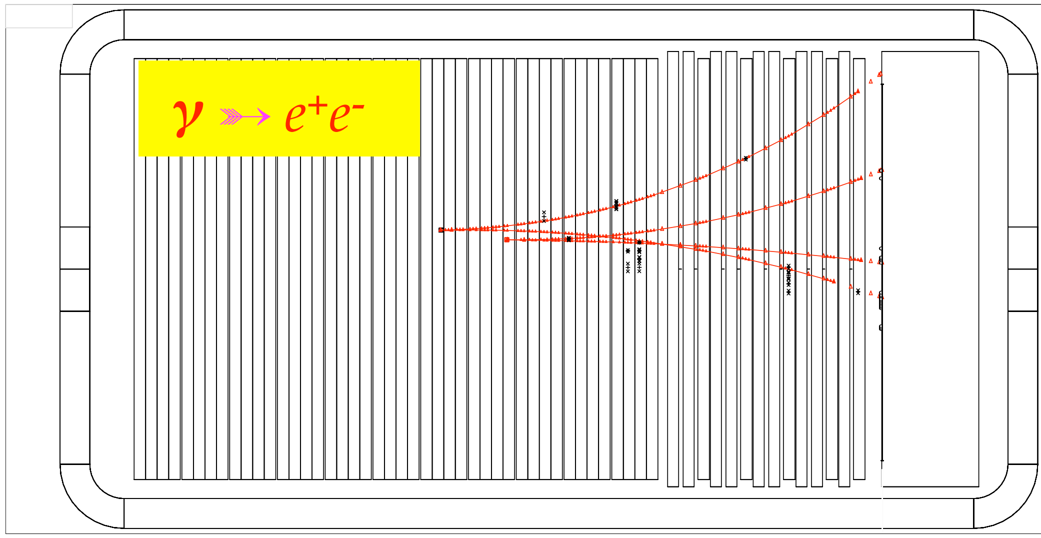
& kinematics

⇒ A V^0 separated from the vertex (>1cm)

⇒ The opening angle in X-Z plane is <5 mrad

⇒ Mee < 30 MeV (consistent with a Photon)

⟹ ~ *5. 10*^{7} reconstructed Photons with Purity > 99%



Sanity-Check: Apply the analysis to, and learn from, the NOMAD data (*see fig.*)

Estimates of the parametrized calculation, Purity & Eff, agree within 15%.

(2) On the $e^{-/+}$ tracks, impose the TR-cuts (Data & MC)

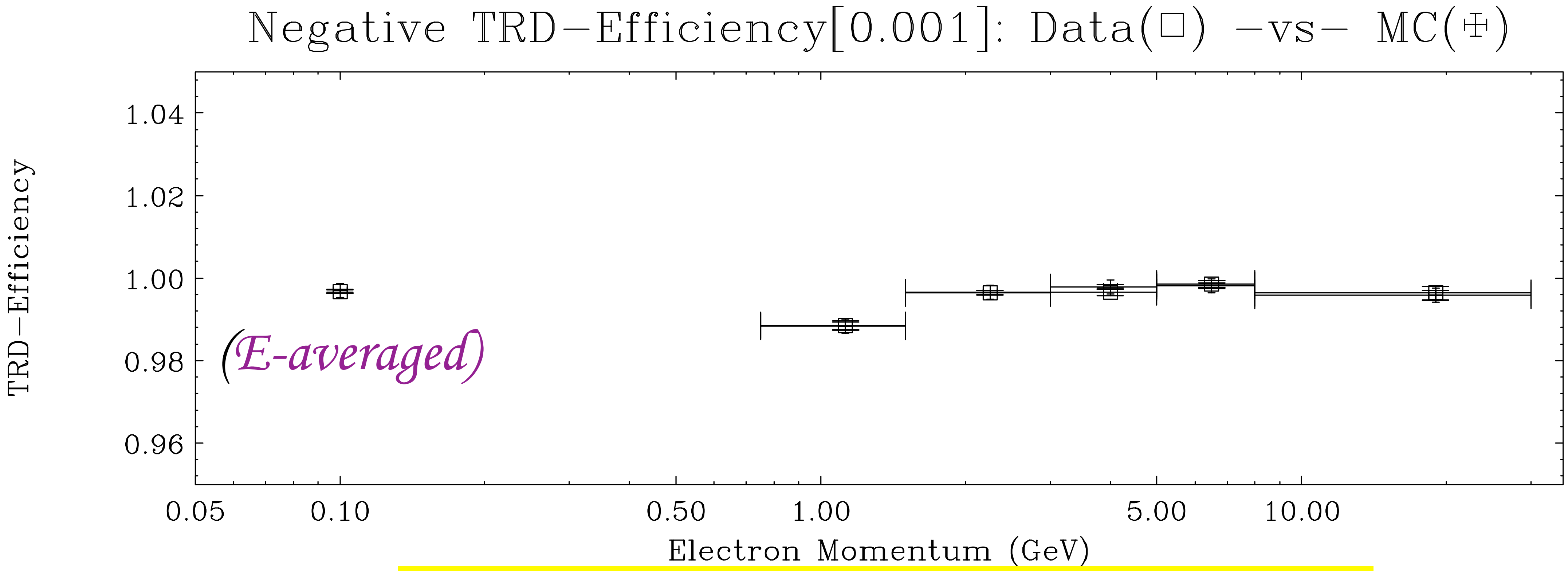
⇒ *Evaluate the TR efficiency in Data and MC*

(3) On the $e^{-/+}$ tracks, impose the ECAL Shower-Shape cuts (Data & MC)

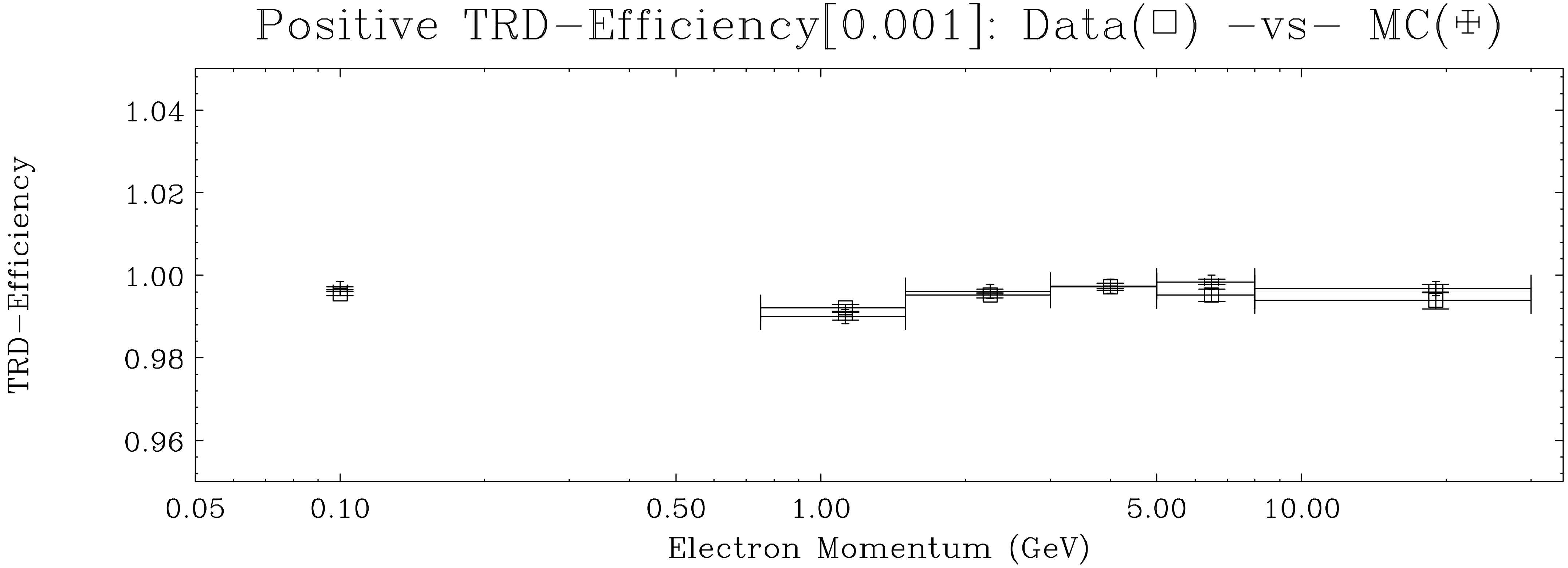
⇒ *Evaluate the ECAL-Id efficiency in Data and MC*

e-/e+ TR-Efficiency in Data *.vs.* MC Using $\gamma \rightarrow e^+e^-$ sample

(γ's come from $\pi^0 \rightarrow \gamma\ \gamma$)



Conclusion ⇛ *Data-Eff - e⁻ = MC-Eff - e⁻ at << 1%*



NOvA experience: EM-Shower-ID

✴ NOvA is a tracking calorimeter

- ⇒ Cell: 4cm(X) * 15.6m(Y) * 6.6cm(Z) [ND: 4.2m(Y)]
- ⇒ Longitudinal Sampling: 0.17X_0 along the beam-direction (6.6cm)
- ⇒ Transverse Sampling: ~4cm alternating X/Y planes
- ⇒ Timing: 500 ns window in 10 μs spill

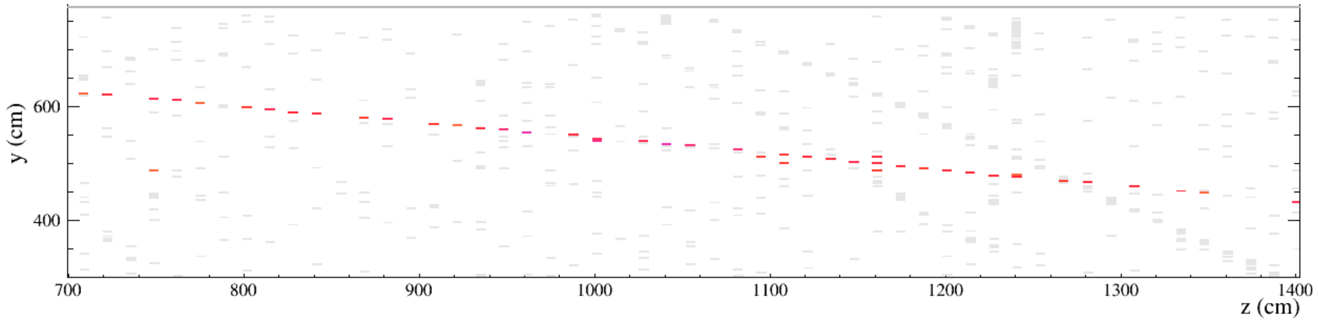
versus

✴ FGT-ECAL

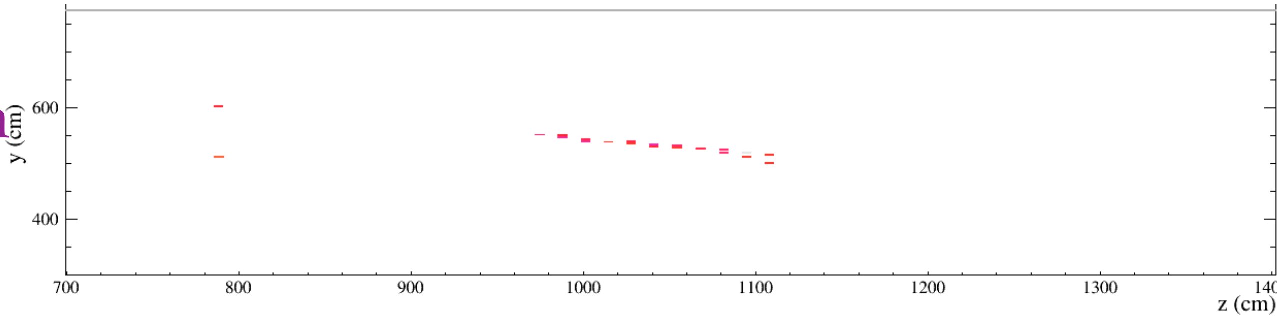
- ⇒ Cell: 2.5cm(X) * 4m(Y) * 20cm(Z)
- ⇒ Longitudinal Sampling: 0.3X_0 along the beam-direction (0.55X_0 for Barrel)
- ⇒ Transverse Sampling: ~2.5cm alternating X/Y planes
- ⇒ Timing: ~1 ns Ecal-Cluster time-resolution in 10 μs spill

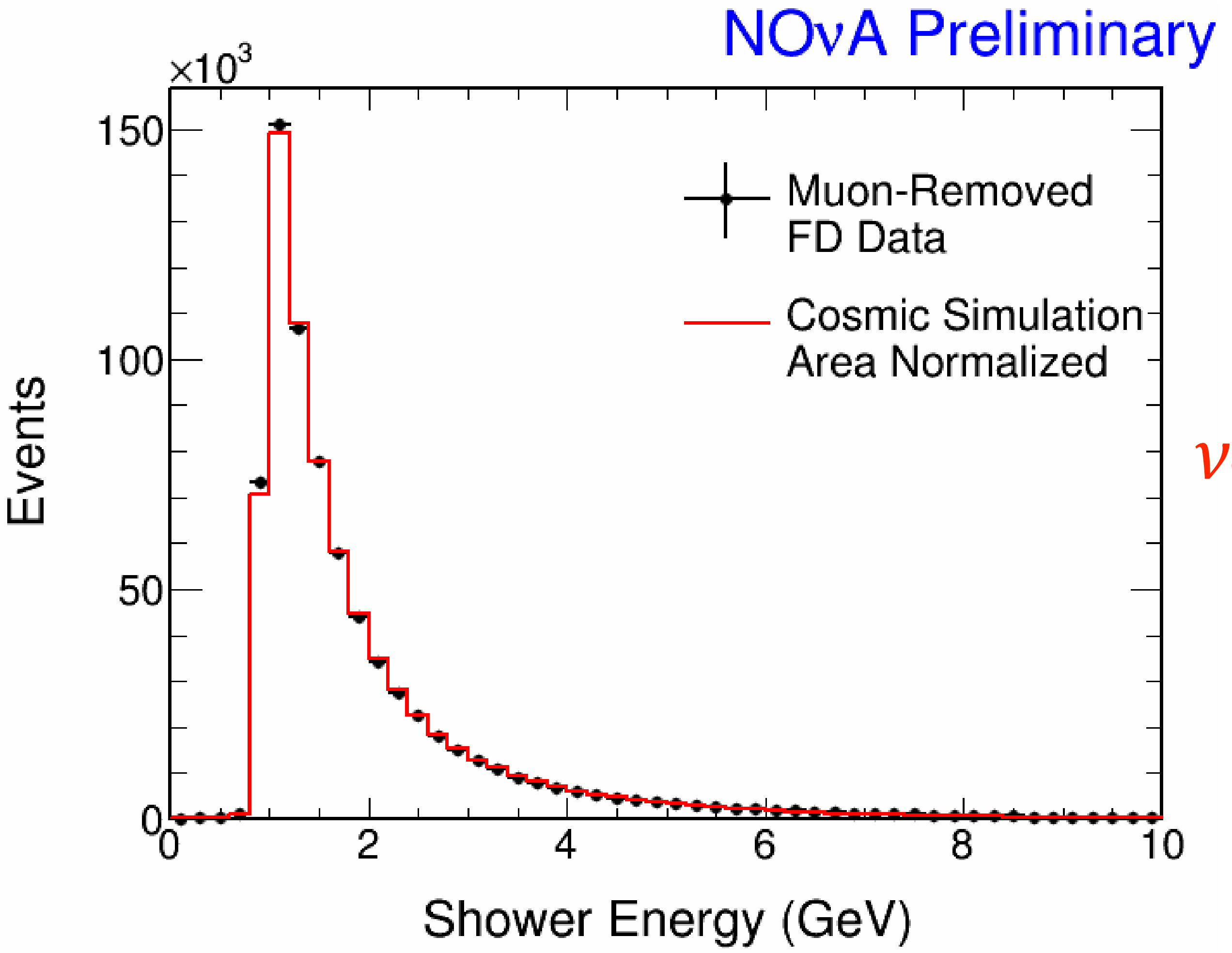
in situ Constraint on the Em-Shower reconstruction in NOvA

- ✴ Use the μ-Removed Cosmic-Brem in FD

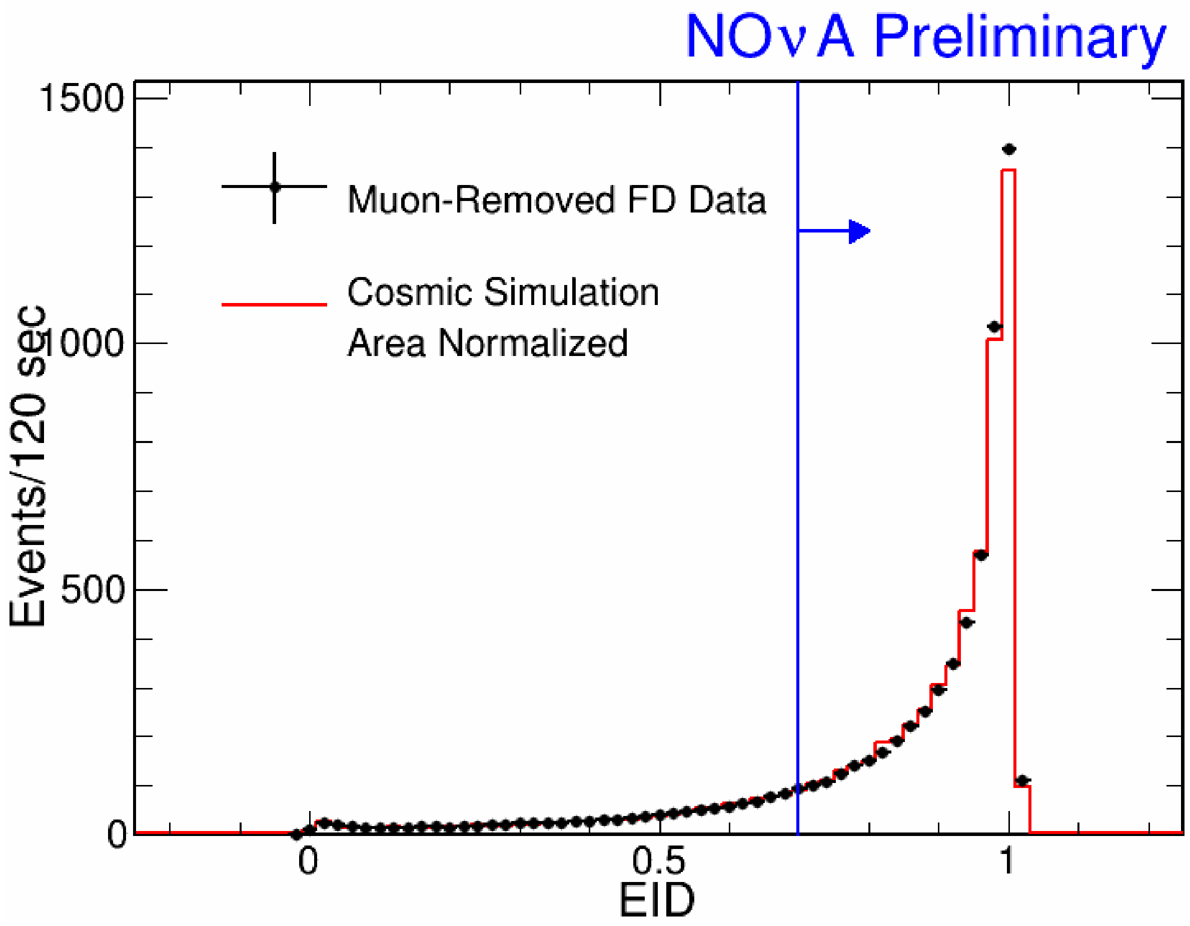


μ-Rm $\Rrightarrow$





ν_e El-ID $\Rrightarrow$



in situ Constraint on the *Electron/ECal Energy Scale*

✴ Measure π^0 produced in the ν-interactions

Expect ~ $\mathcal{O}$(10M) reconstructed π^0 using γ-conversion and γ-clusters

Use π^0 mass, constrain the ECAL energy scale *(…see Figs.)*

✴ Measure K^0 produced in the ν-interactions

Expect ~ $\mathcal{O}$(200k) reconstructed $K^0 \twoheadrightarrow \pi^0\,\pi^0$ using γ-conversion and γ-clusters

Use sharp K^0 mass, constrain the ECAL energy scale

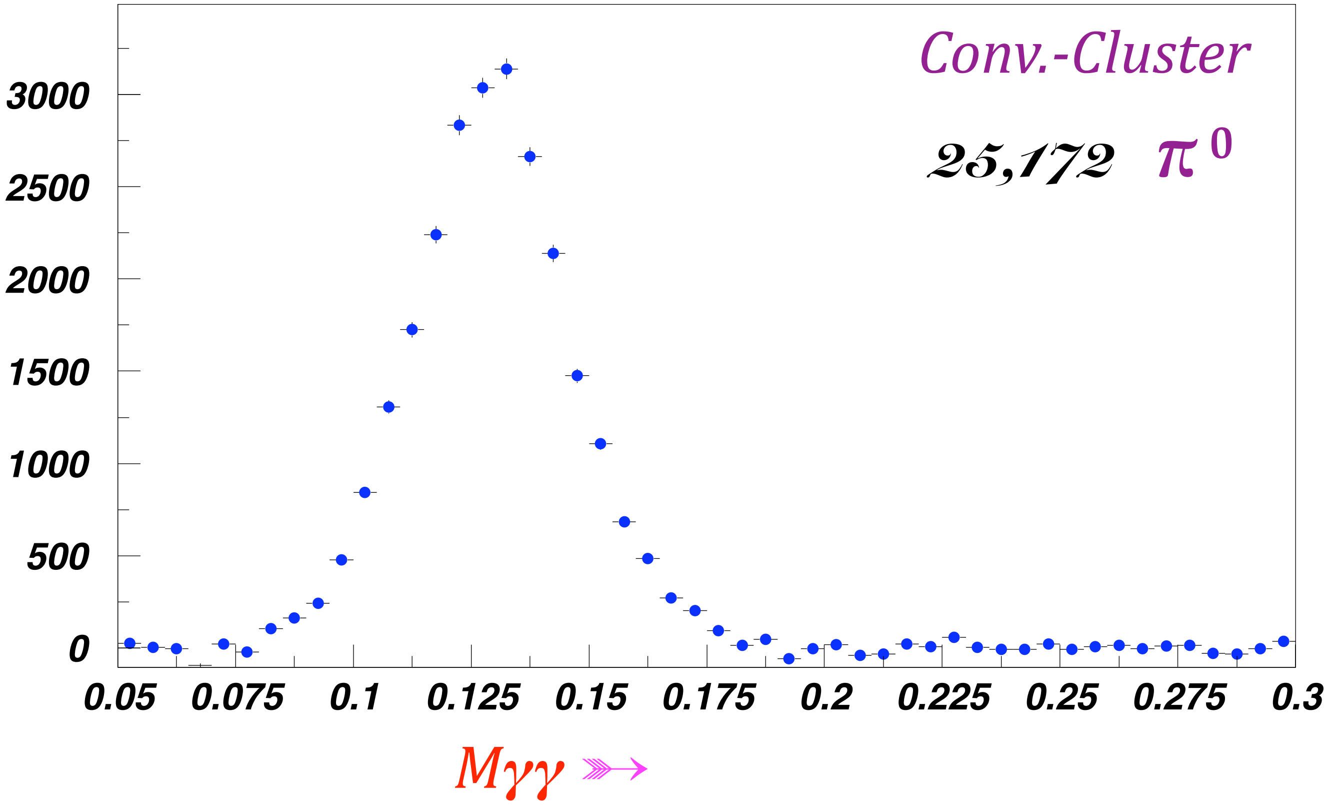
✴ Measure $\eta \twoheadrightarrow \gamma\,\gamma$ produced in the ν-interactions *(…see Fig.)*

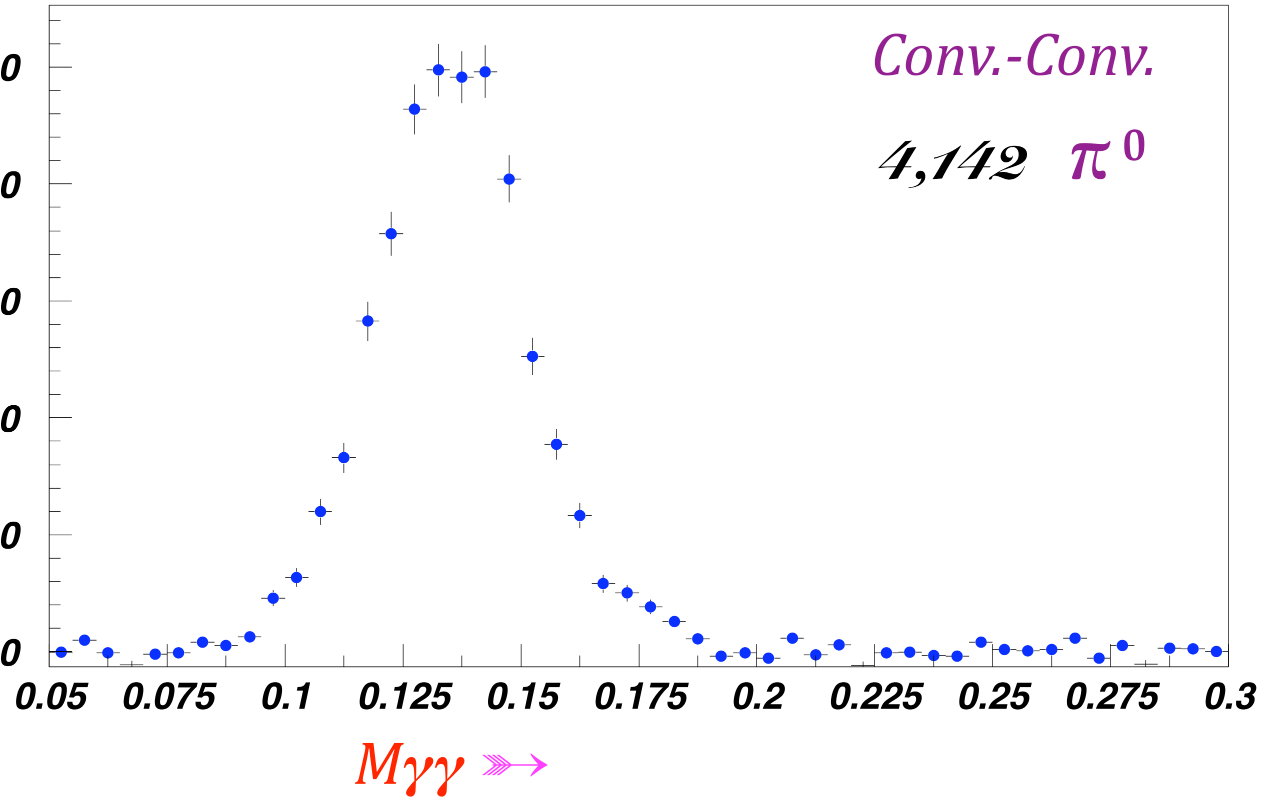
Expect ~ $\mathcal{O}$(0.4M) reconstructed η using γ-conversion and γ-clusters

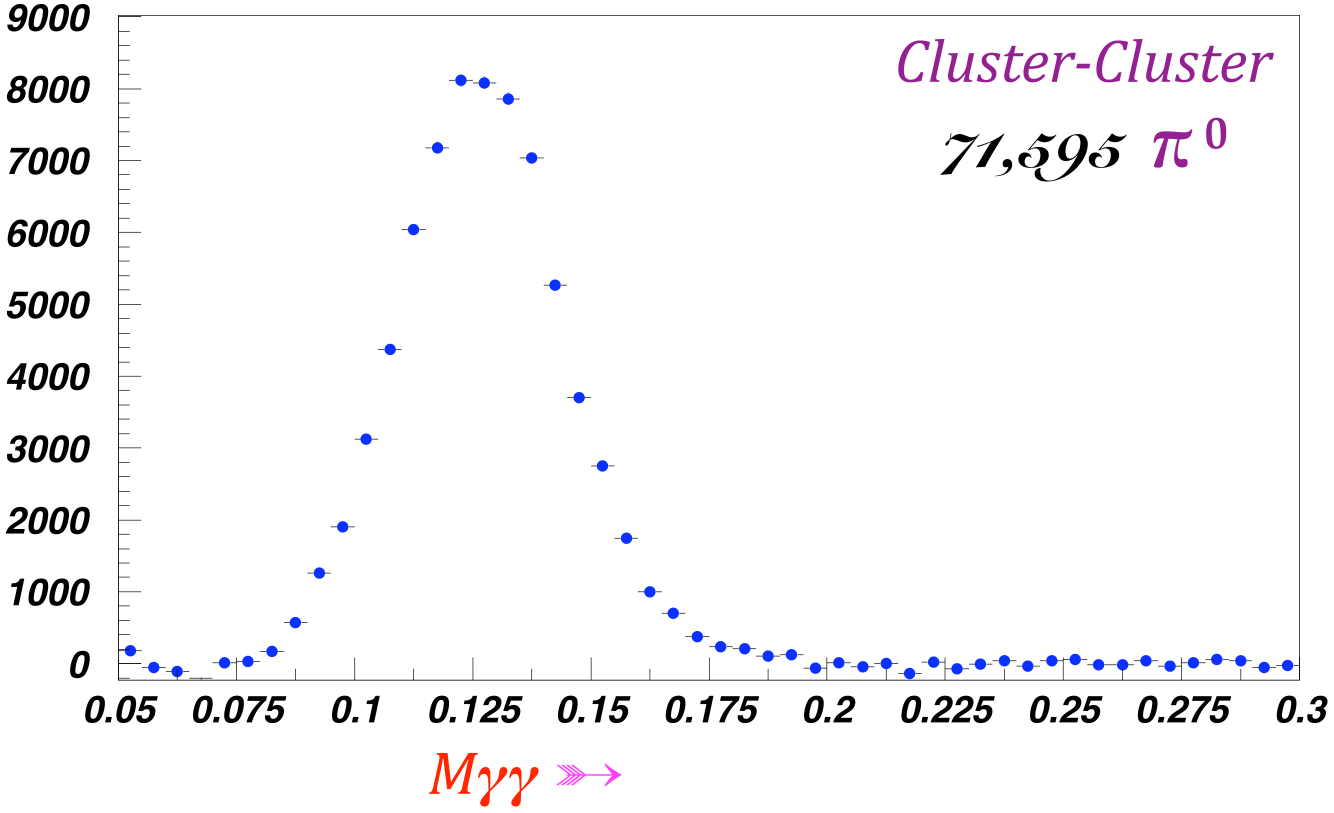
Use sharp η mass, constrain the ECAL energy scale

π^0 Reconstruction using NOMAD Data (ν_μ-CC Sample)

(background: fit data excluding 80< $M_{\gamma\gamma}$ <170 MeV)

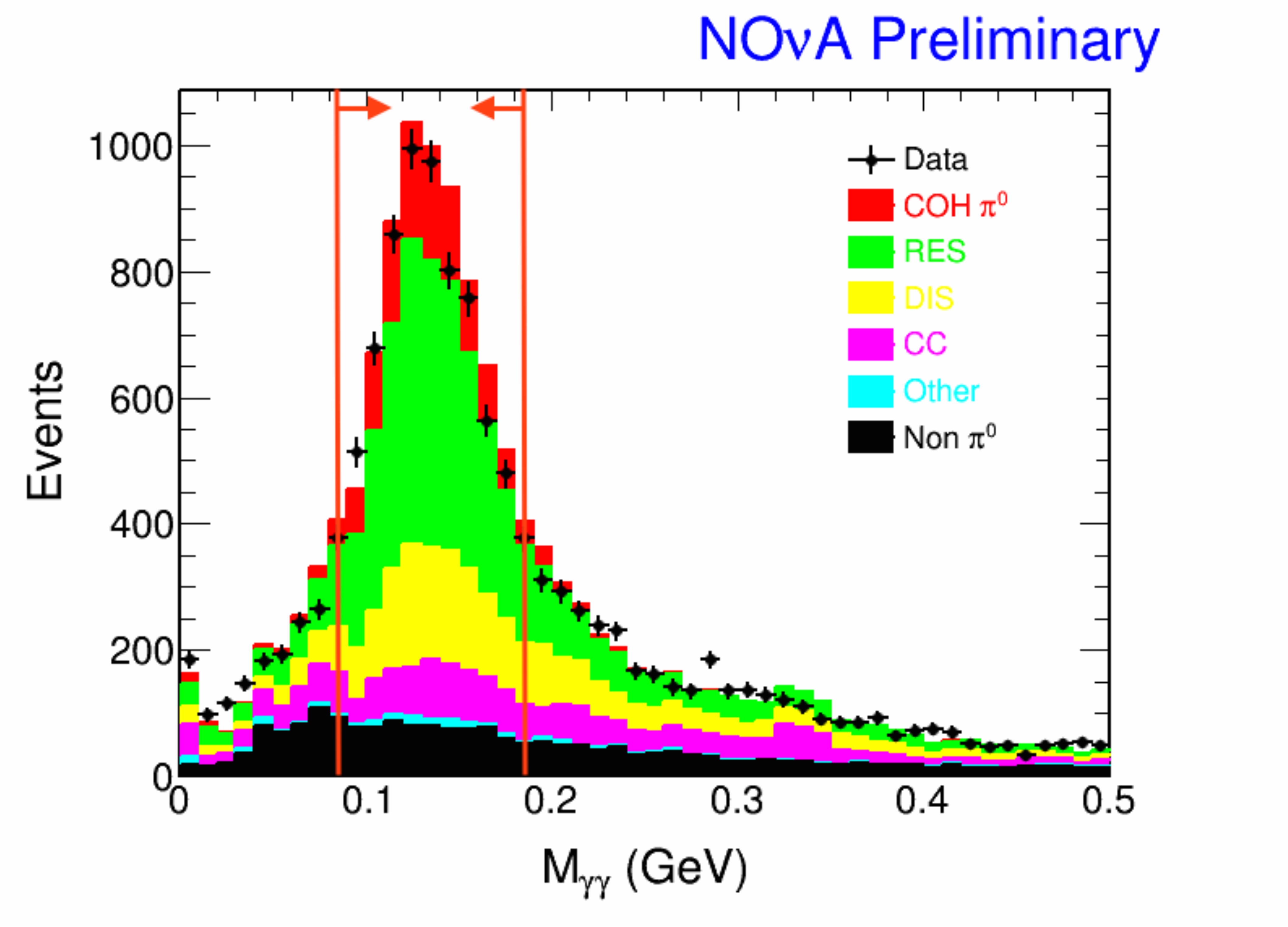






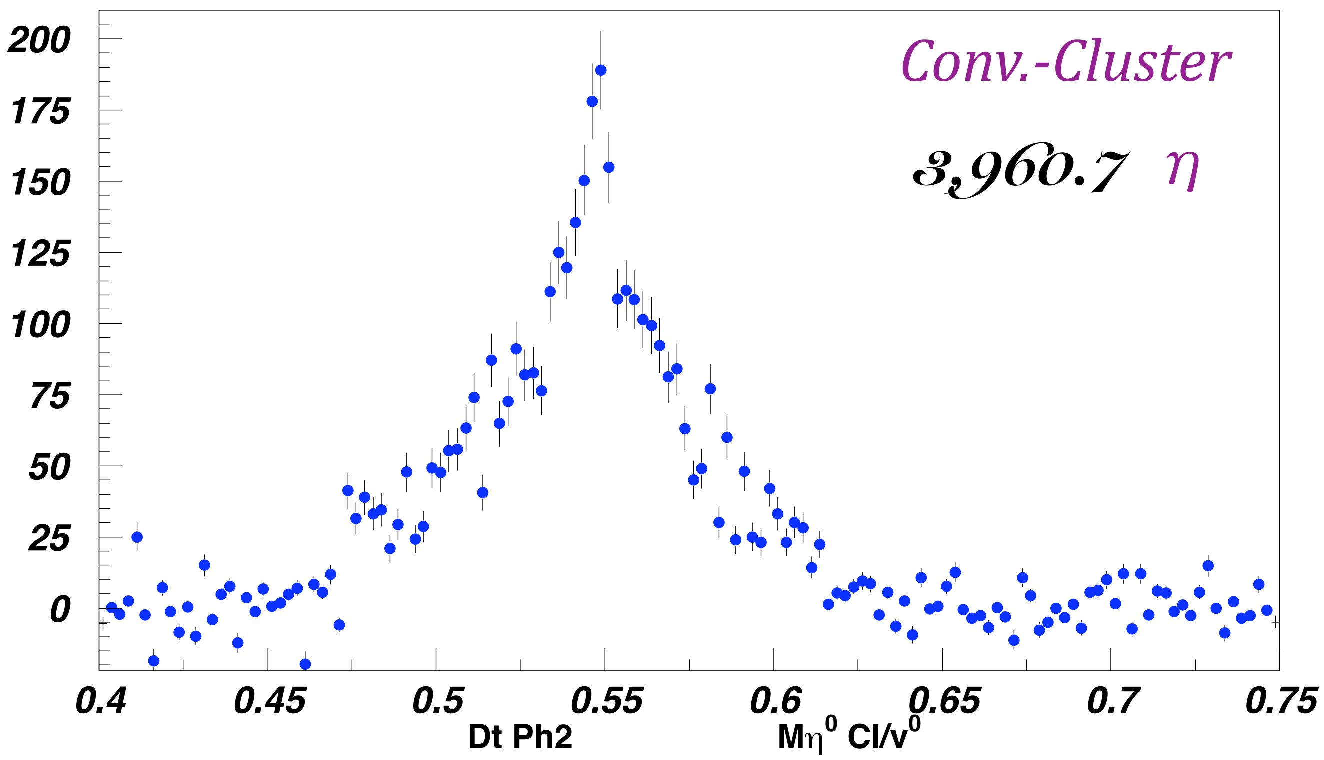
π^0 Reconstruction in NOvA (NC⇔no-μ Sample)

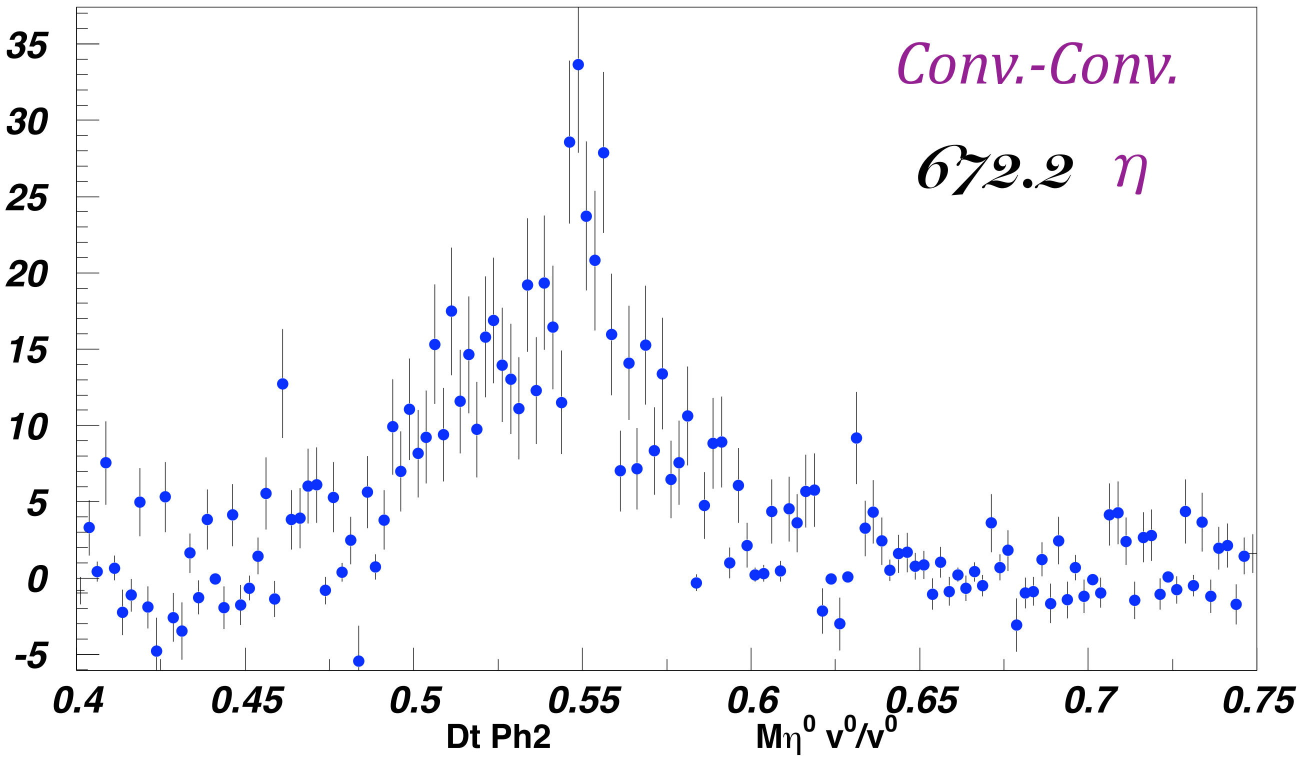
Constraint on the EM-energy Scale

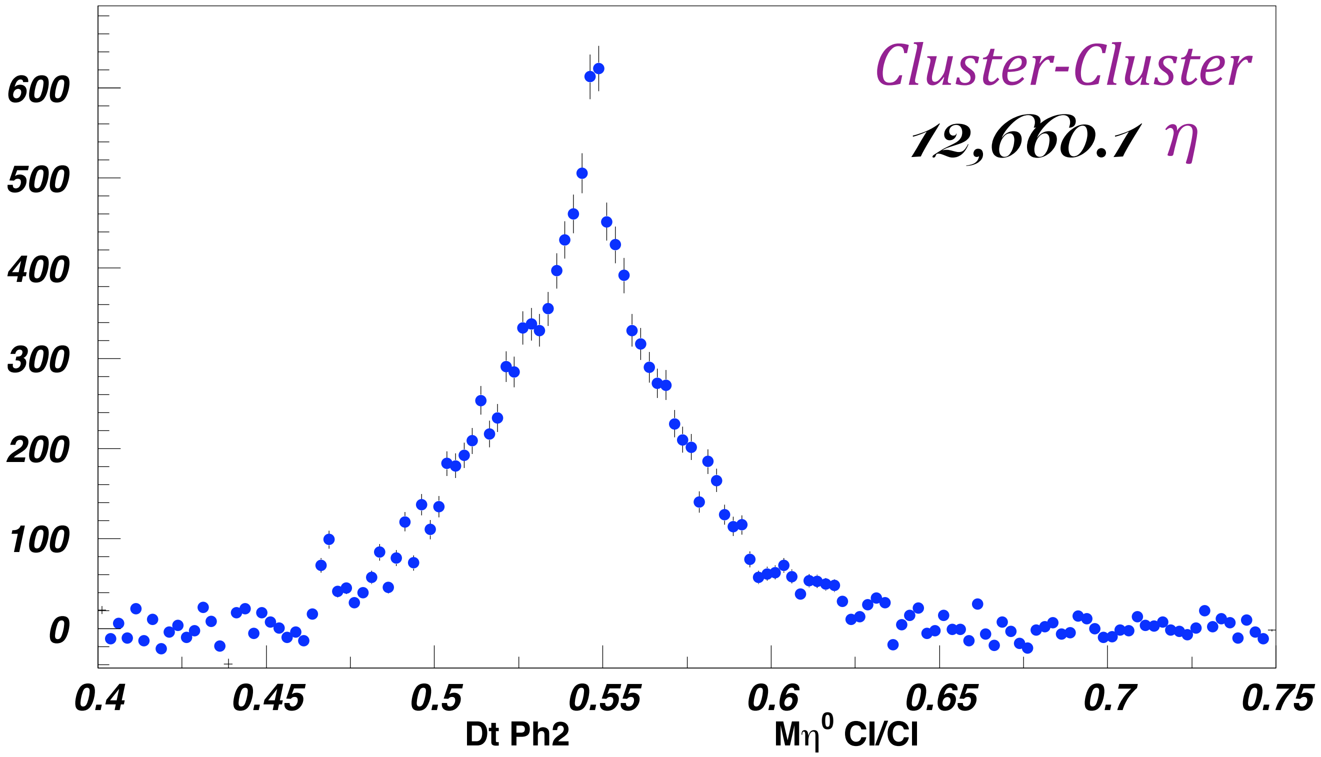


η Reconstruction using NOMAD Data (ν_μ-CC Sample)

(background: fit data excluding 475< Mγγ <625 MeV)







Summary/Outlook: Electron Measurement in FGT ... in progress

(1) *100%* distinction between e^- .vs. e^+ in *~0.3 - 50 GeV*

(3) Measure **Pe** in STT

⇒ Direction-cosines using the track-fit

⇒ Resolution of |**Pe**| ~ 12% using curvature

⇒ Resolution of |**Ee**| ~ 6%/√Ee

⇒ Resolution of θ e ~ 3 mrad (*3 GeV* e^-)

(4) Electron-ID measurement via

⇒ TR (Transition Radiation) in STT

⇒ Shower-shape in ECAL

⇒ Patter of Energy-Loss (track-fit) in STT

(5) in situ constraints on the electron-ID efficiency using e^+/e^- tracks originating from the reconstructed $\gamma \twoheadrightarrow e^+e^-$

(6) in situ constraints on the electron-energy using reconstructed

⇒ ~$\mathcal{O}$(10M) π^0 using γ-conversion and γ-clusters

⇒ ~$\mathcal{O}$(200k) $K^0 \twoheadrightarrow \pi^0 \pi^0$ & ~$\mathcal{O}$(400k) $\eta \twoheadrightarrow \gamma\gamma$

Backup