Near Detector for NuStorm

✴ *Neutrino Source*

❧Search for large $\Delta m^{**}2$ Oscillation

❧Violation of Universality

⇒ *Need systematic precision to reach 10^-4*

✴ *Neutrino Cross-Section*

❧CC: QE, Res, DIS (0.5--4 GeV)

❧NC/CC

❧Form factors and Nuclear effect

❧Sum rules and Isospin Physics

...

$\mathcal{ND}$ PHYSICS GOALS

- *Determination of the relative abundance, the energy spectrum, and the detailed topology (complete hadronic multiplicity) of the four neutrino species* ν_μ, $\bar{\nu}_\mu$, $\boxed{\nu_e}$, *and* $\boxed{\bar{\nu}_e}$ *CC-interactions.* ⇐Absolute ν-Flux & Eν-scale; Cross-Sections

- *An 'Event-Generator Measurement' for the LBLν experiments including single and coherent π^0 (π^+) production, $\pi^\pm/K^\pm/p$ for the ν_e-appearance experiment, and a quantitative determination of the neutrino-energy scale.* ⇐Backgrounds to Oscillation

- *Precision measurements of Neutrino & Anti-Neutrino Cross-sections and Electroweak physics*
  - *Inclusive CC & Exclusive QE, Resonance*
  - *Neutral Current; NC-QE*
  - *ν-e scattering*

  ⇐Example of Precision Measurement

- *Precise determination of the exclusive processes such as ν quasi-elastic, resonance, $K^0/\Lambda/D$ production, and of the nucleon structure functions.*

- *Search for weakly interacting massive particles with electronic, muonic, and hadronic decay modes with unprecedented sensitivity.*

THE HiResMν CONCEPT

- *Evolution from the NOMAD experiment;*

- *High resolution spectrometer with a dipole magnetic field:*

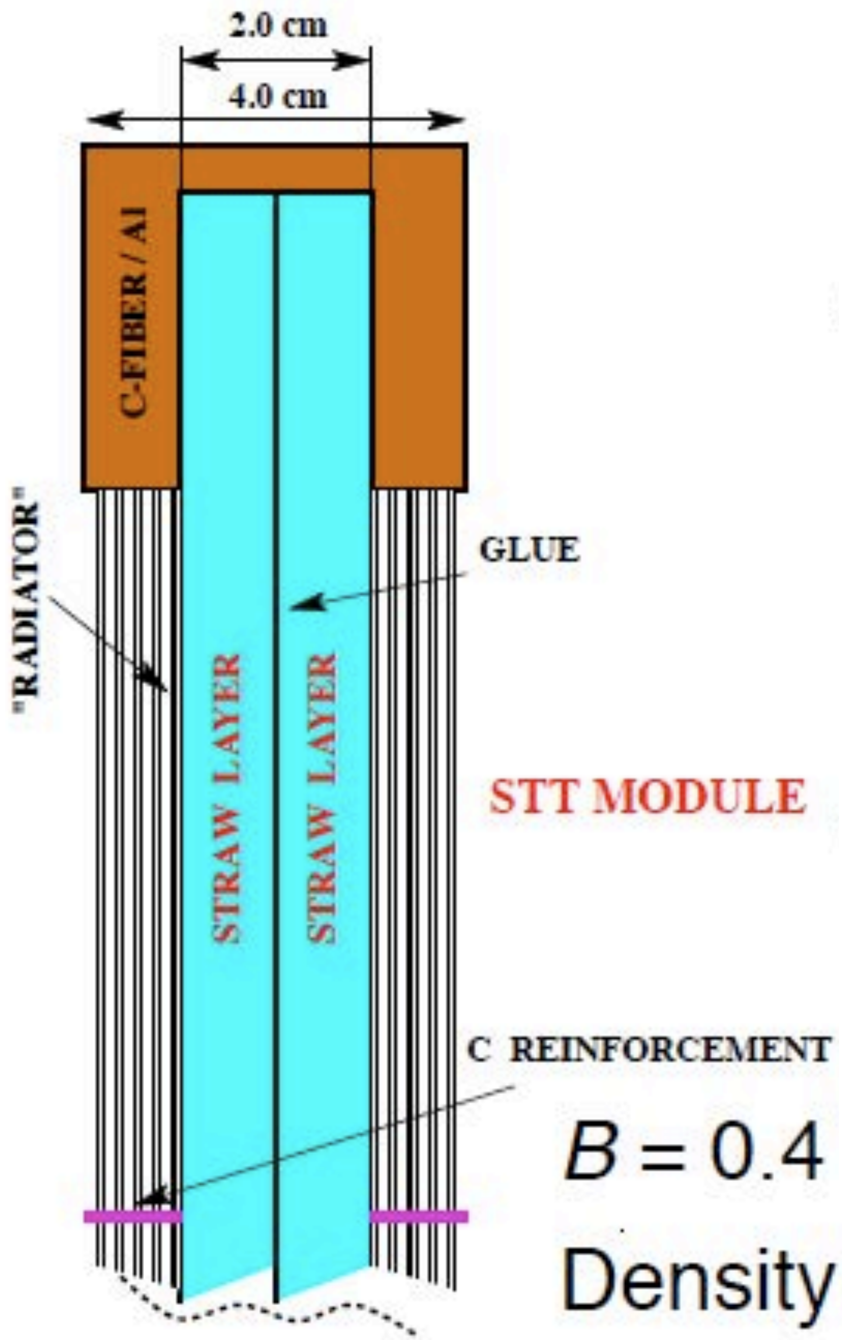
$$B = 0.4T$$

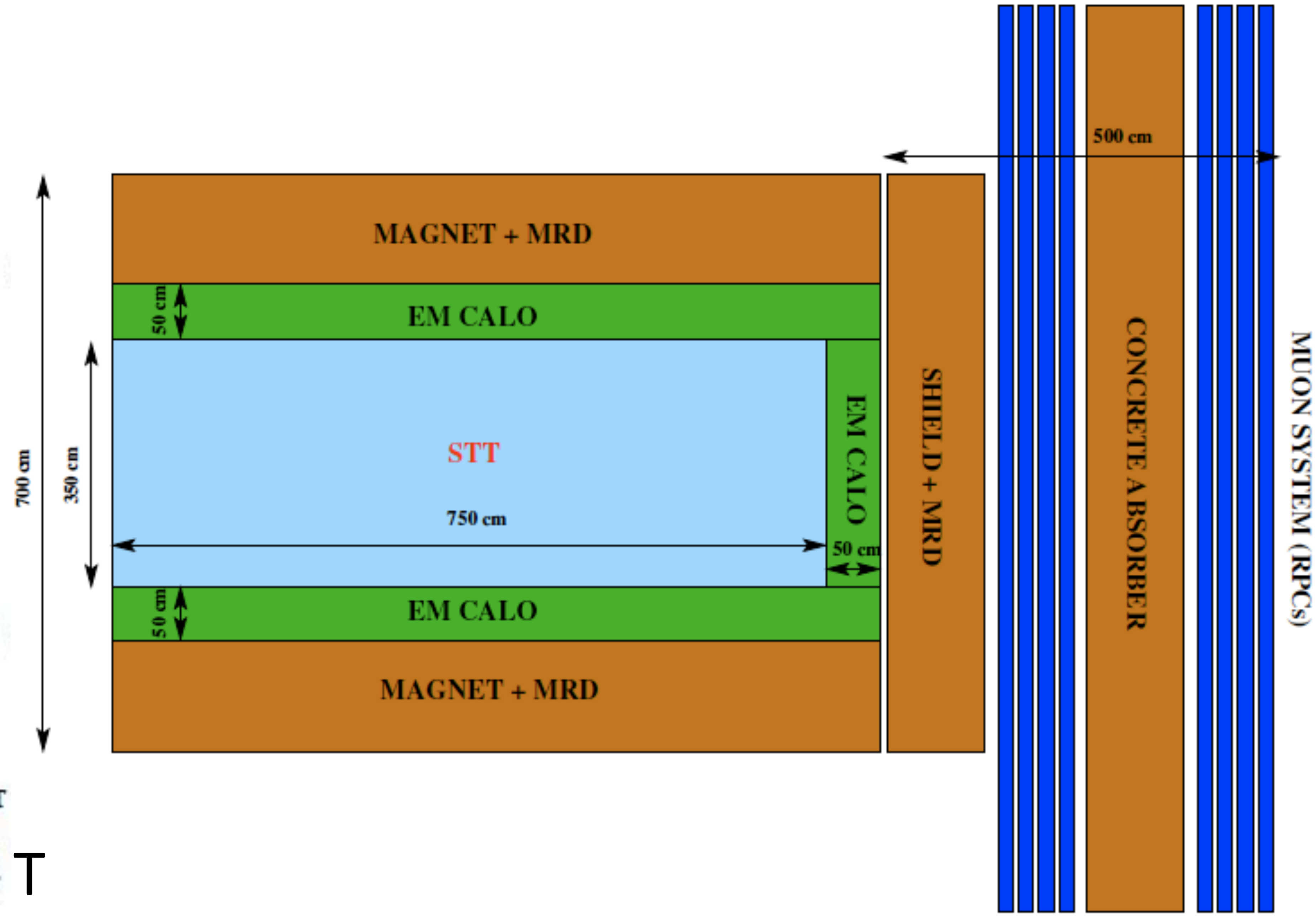
- *Low density "transparent" tracking with target embedded:*

$$1X_0 \sim 5m \quad \rho \sim 0.1g/cm^3$$

- *Combined particle identification & tracking to reconstruct all charged particles and γs produced in neutrino interactions;*

Electronic Bubble Chamber with 10^6 Events





$B = 0.4$ T

Density = 0.1 g/cm3, 85% in the radiator foils.

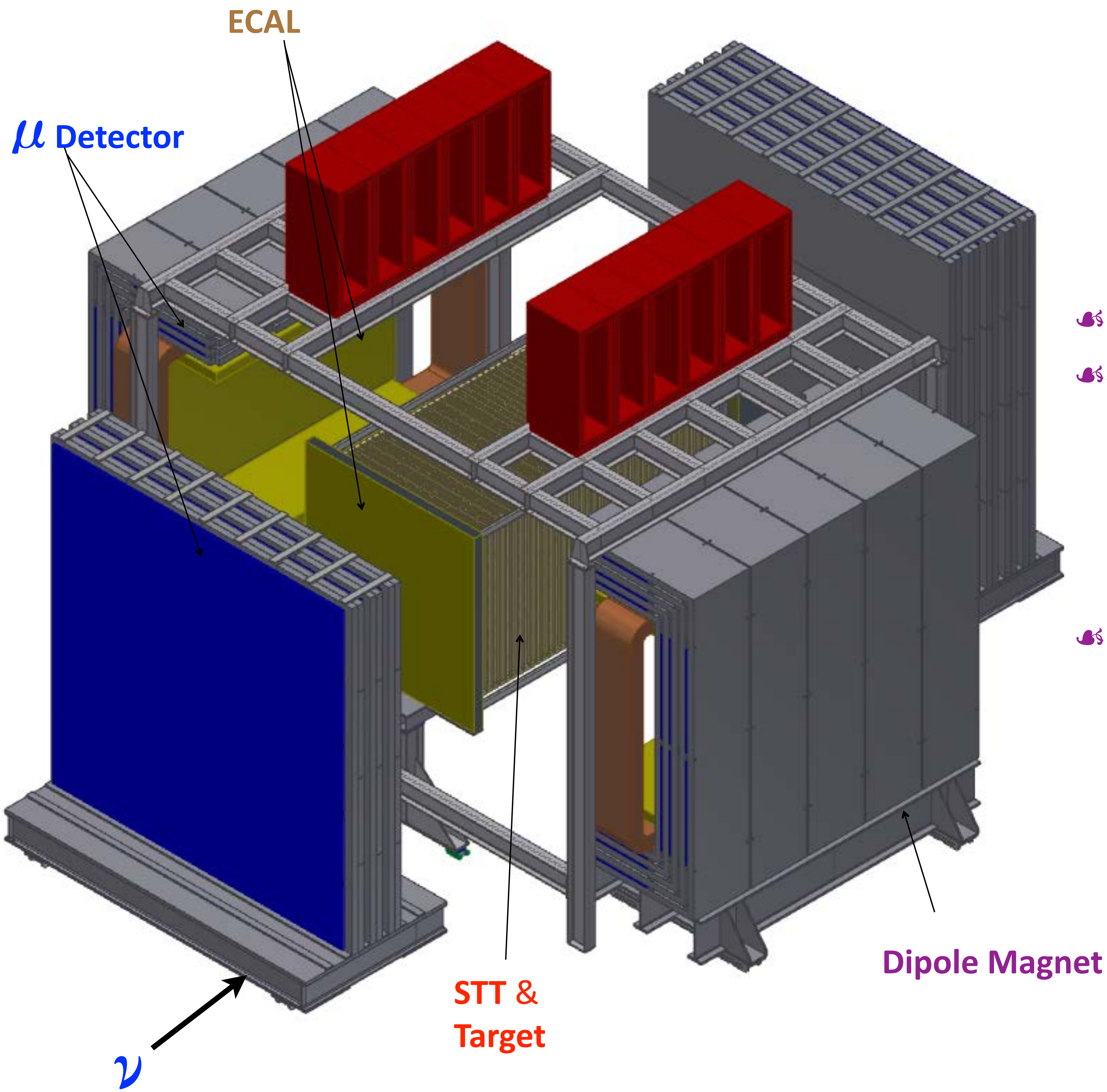
Transition Radiation ⤀ Electron ID ⇒ γ (w. Kinematics)

dE/dx ⤀ Proton, π, K ID

Magnet/Muon Detector ⤀ μ

ν-e ⇒ Absolute Flux measurement

HiRESMNU: Near Detector option for *LBNE*



- Best performance among the 4-options
- ~3.5m x 3.5m x 7.5m STT ($\rho \simeq 0.1 gm/cm^3$)

  4 π -ECAL in a Dipole-B-Field (0.4T)

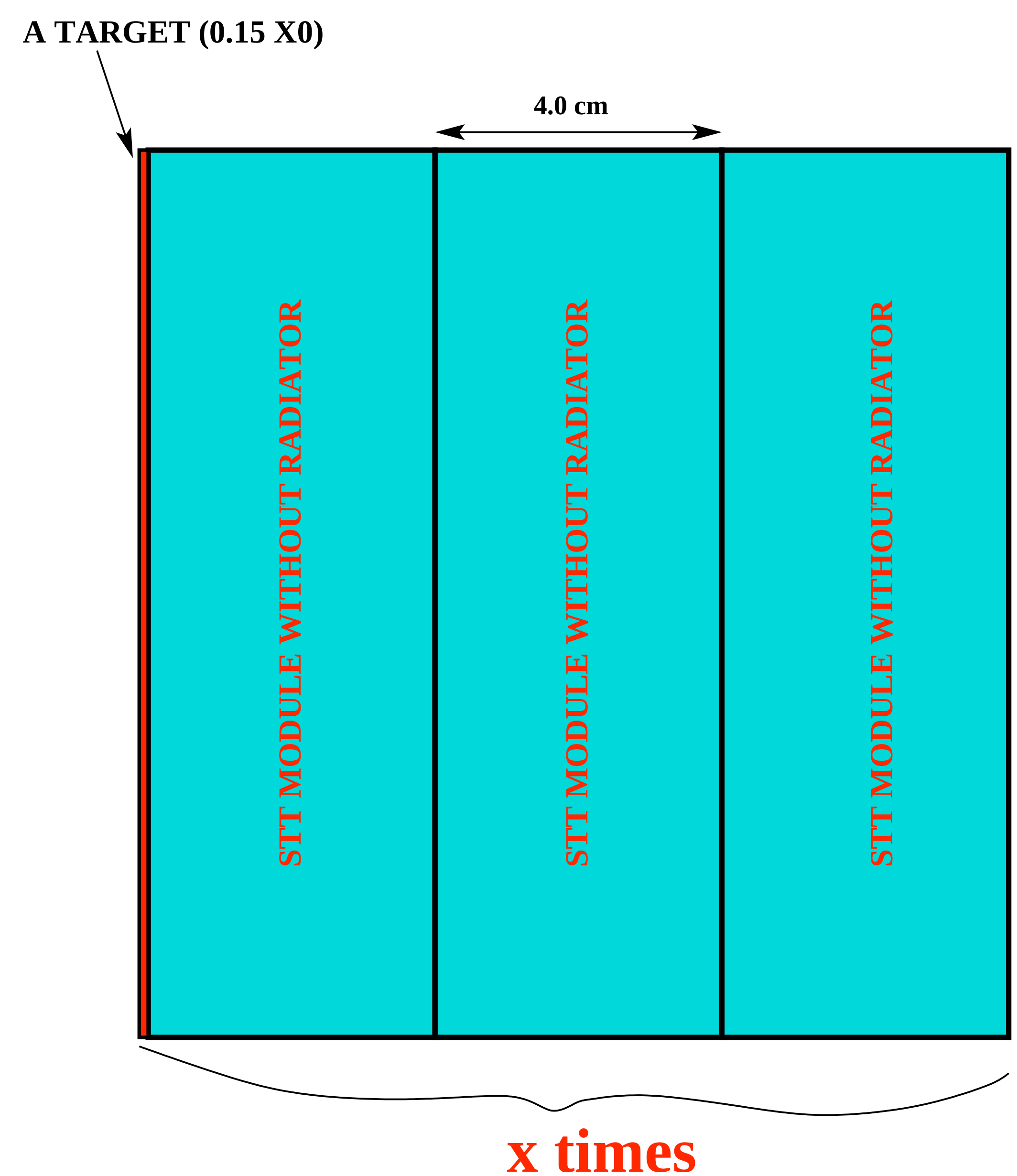
  4 π -μ-Detector (RPC) in Dipole and Downstream
- Pressurized Ar Target (≃x5 FD-Stat)

  ⇛ *LAr-FD*

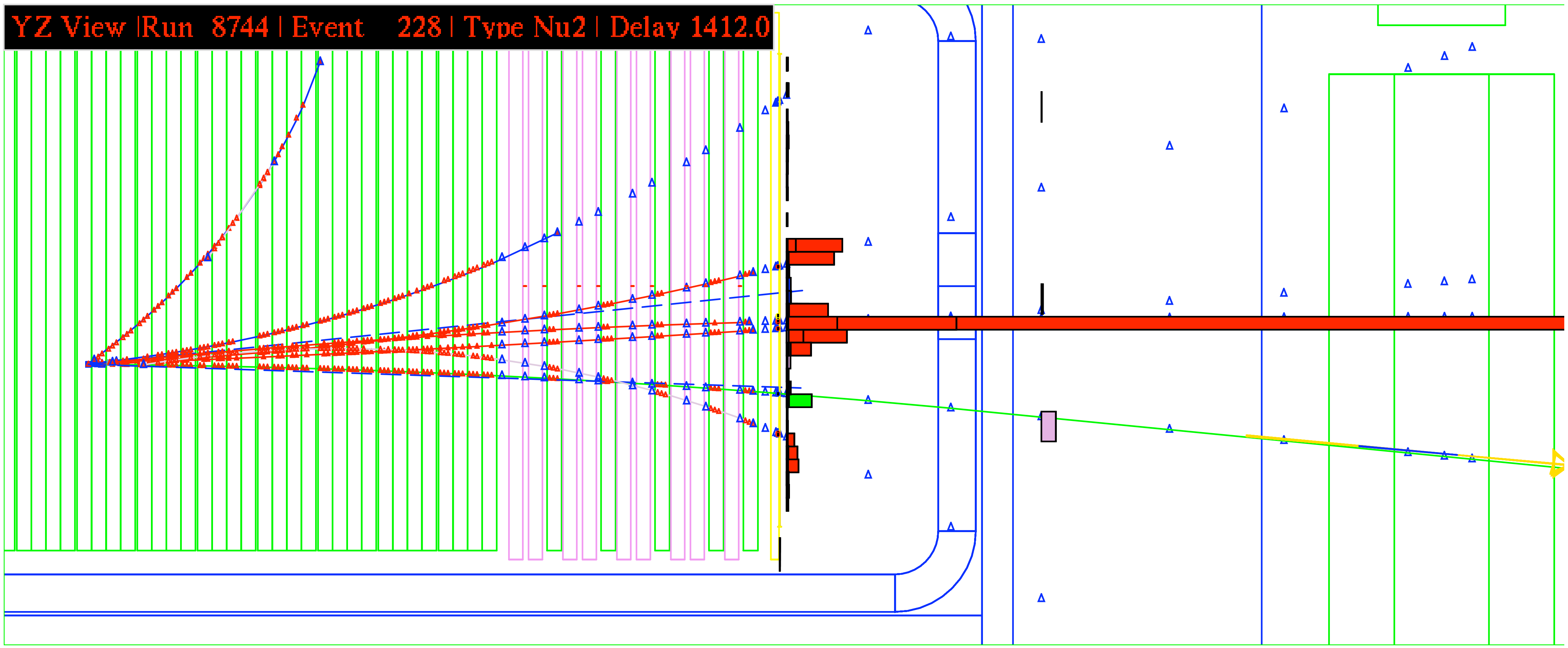
MEASURING NUCLEAR EFFECTS *(Fe, Ar, ..)*

- *Measure the A dependence (Ca, Cu, H_2O, etc.) in addition to the main C target in STT:*
  - *Ratios of F_2 AND xF_3 on different nuclei;*
  - *Comparisons with charged leptons.*

- *Use 0.15X_0 thick target plates in front of three straw modules (providing 6 space points) without radiators. Nuclear targets upstream.*
  - *For Ca target consider CaCO$_3$ or other compounds;*
  - OPTION*: possible to install other materials (Pb, etc.).*

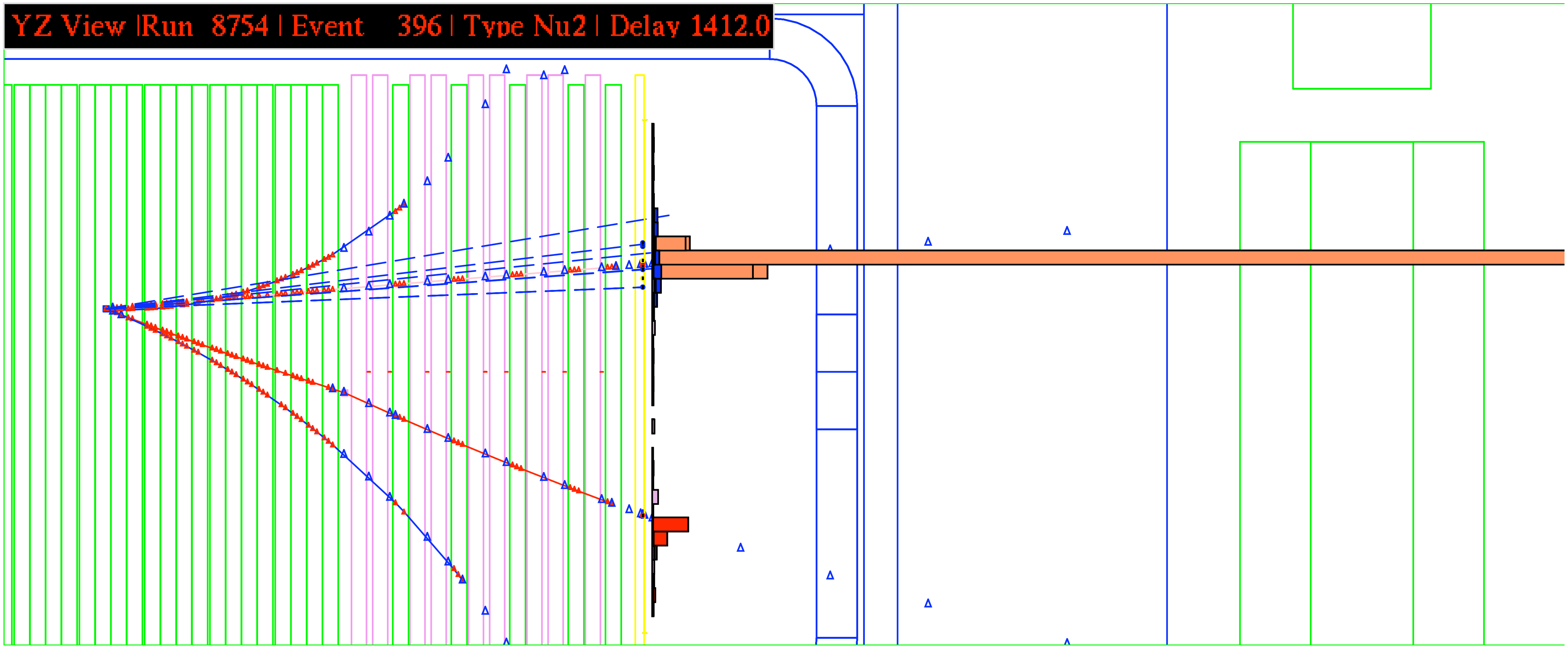


A ν_μ CC candidate in NOMAD



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

e-/e+ ID *using* TRD, ECAL



Conclusion ⇛

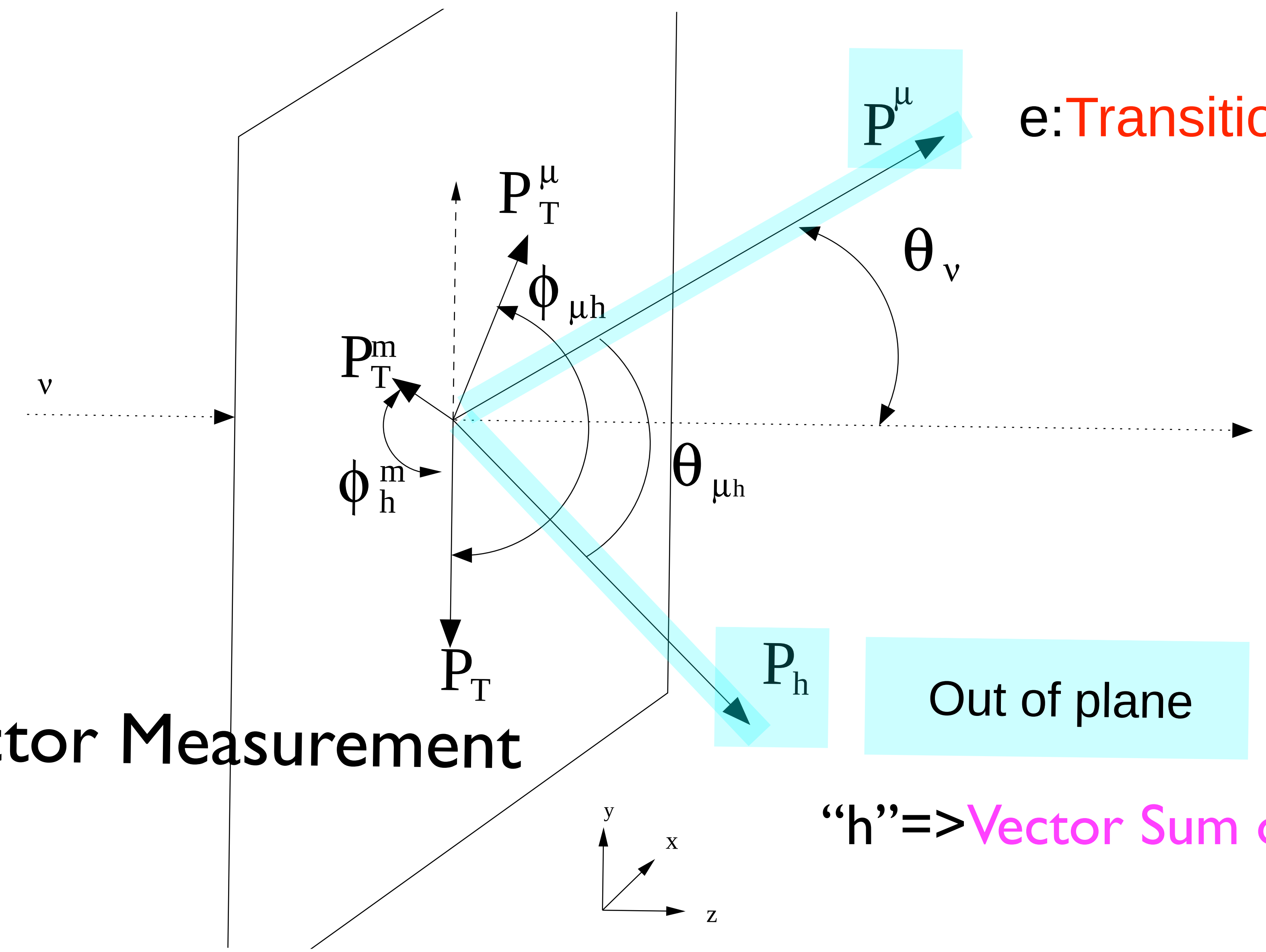
(1) μ *from* $\boldsymbol{\nu}\mu$ *and* e *from* $\boldsymbol{\nu}e$ *are Tracks: Determined with very high precision*

(2) Universality equivalence: μ -$\boldsymbol{\nu}\mu$ ↔ e -$\boldsymbol{\nu}e$

(3) Uniquely resolve $\mu^-(\boldsymbol{\nu}\mu)$ *from* $\mu^+(\bar{\boldsymbol{\nu}}\mu)$ **&** $e^-(\boldsymbol{\nu}e)$ *from* $e^+(\bar{\boldsymbol{\nu}}e)$

Kinematics in HiResMnu

USC HEP
University of South Carolina
High Energy Physics



e:Transition Radiation

Out of plane

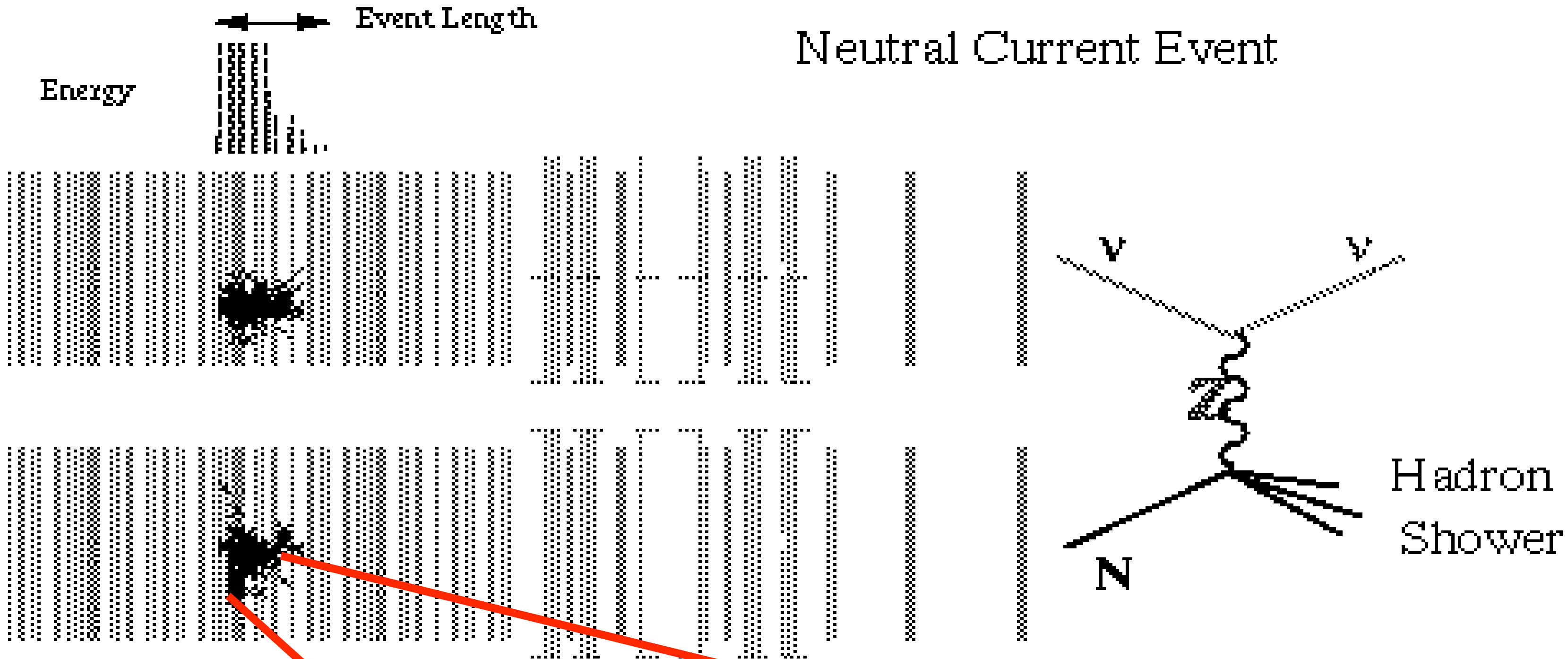
Pt-Vector Measurement

"h"=>Vector Sum of Tracks

Pt-Vector ⇛

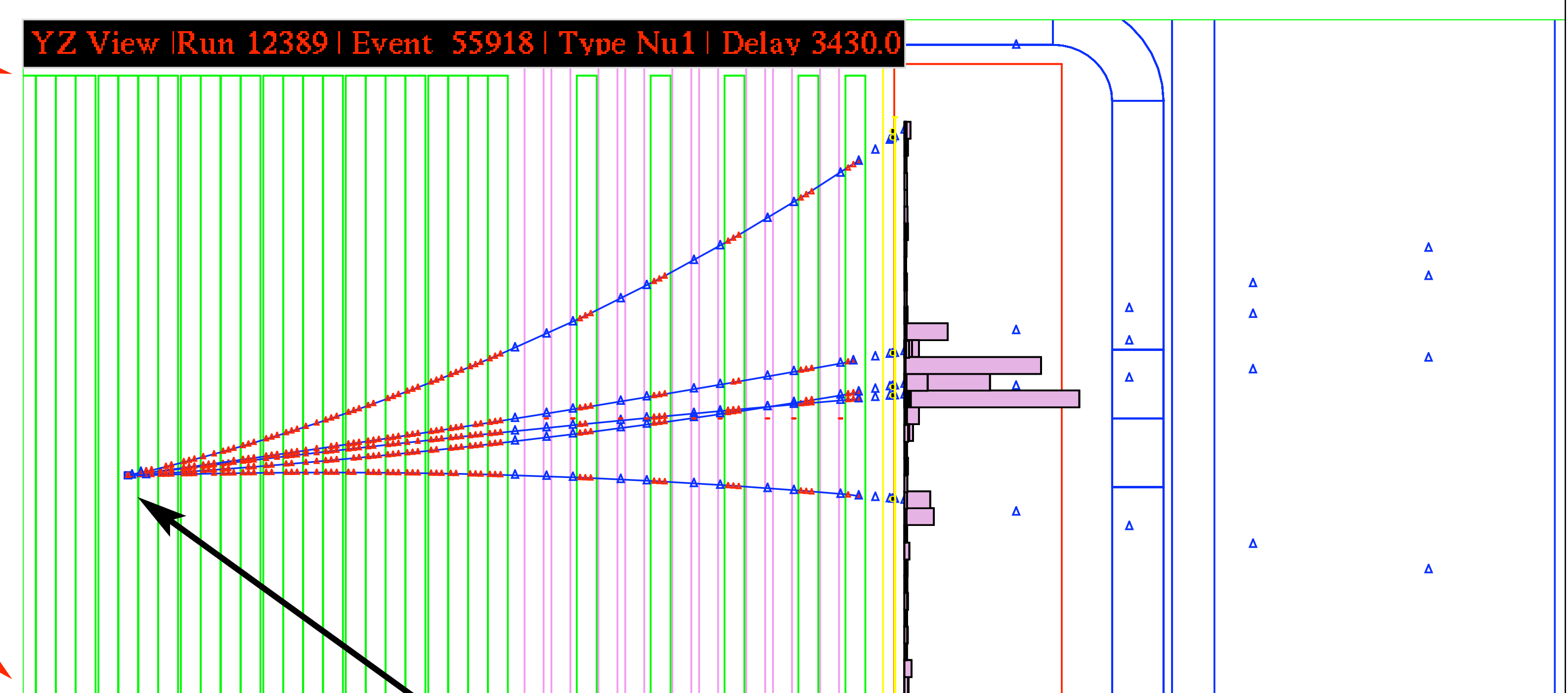
(1) Powerful constraint on Eν-Scale & Nu -vs- NuBar Interactions

(2) NC -vs- CC ID



MASSIVE CALO

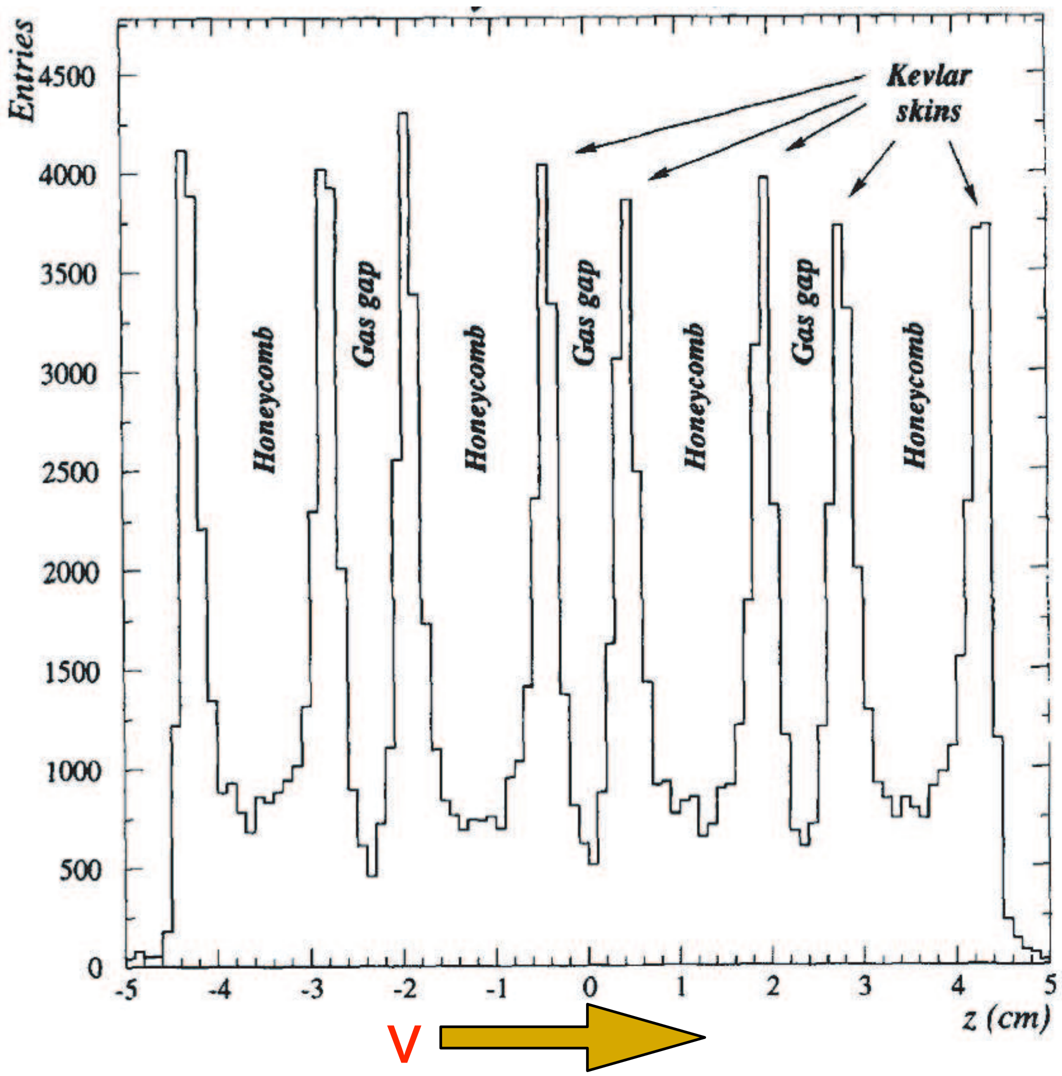
PRECISE TRACKER
(NOMAD)



Missing transverse momentum

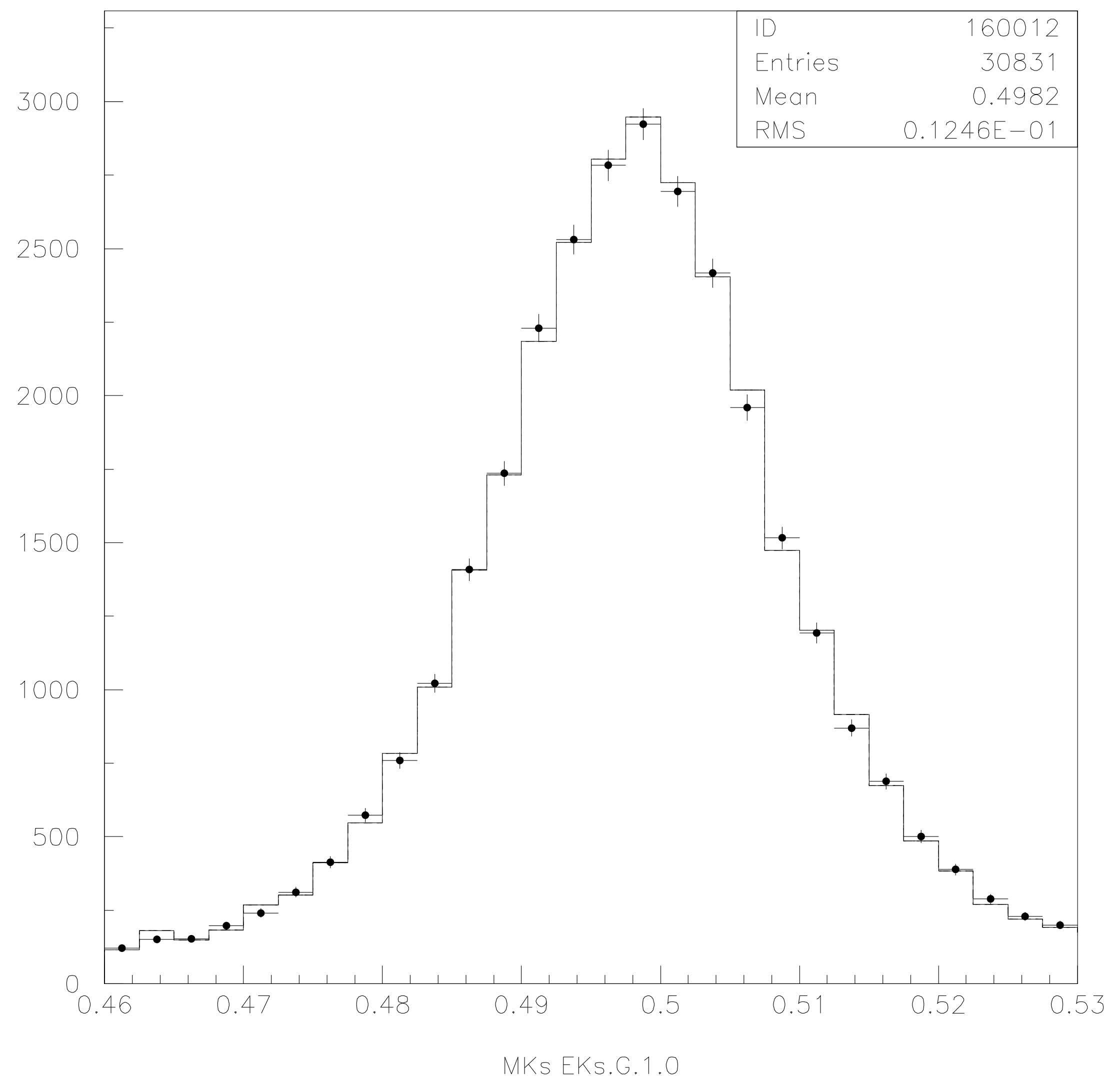
HiResMν : order of mag. higher segmentation

What we build on: NOMAD DATA



Neutrino radiography of one drift chamber

Momentum Scale of μ



Reconstructed K^0 mass

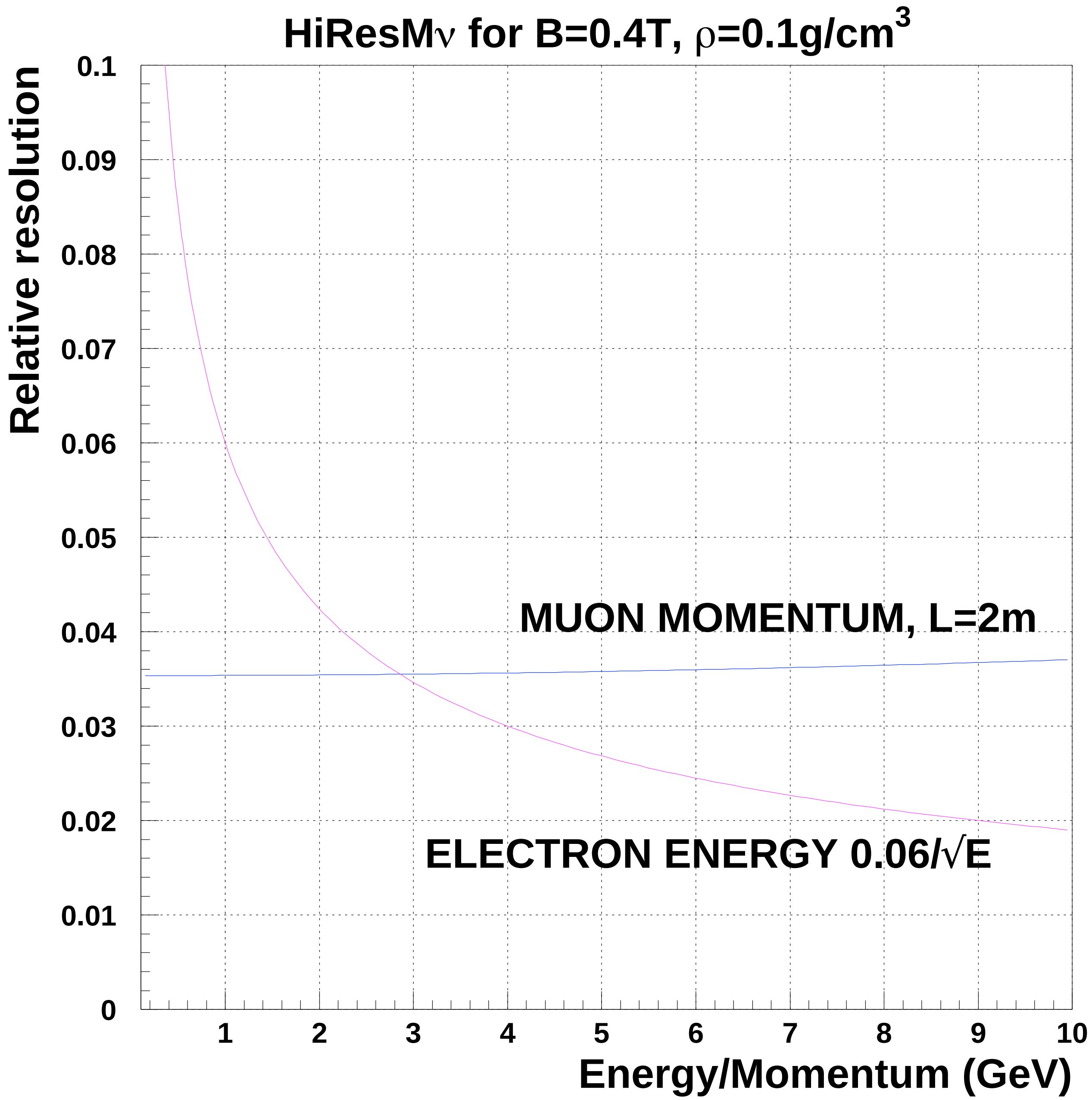
- ✦ *NOMAD: charged track momentum scale known to* $< 0.2\%$
  hardonic energy scale known to $< 0.5\%$
- ✦ *HiResMν:* $\boxed{200\times}$ *more statistics and* $\boxed{12\times}$ *higher segmentation*

Resolutions in HIRESMNU

- $\rho \simeq$ 0.1gm/cm^3
- Space point position $\simeq$ 200μ
- Time resolution $\simeq$ 1ns

- CC-Events Vertex: Δ(X,Y,Z) $\simeq$ *O*(250μ)
- Energy in Downstream-ECAL $\simeq$ 6%/$\sqrt{E}$
- μ-Angle resolution (~2 GeV) $\simeq$ *O*(3 mrad)

- μ-Energy resolution (~2 GeV) ~ 3.5%
- e-Energy resolution (~2 GeV) ~ 4.5%



HIRESMNU (with STT) Idea:

- *Proposed at the 1st. Project-X Workshop (2008)*
  - Measure all *4* species ν_μ ν_e Anti-ν_μ Anti-ν_e
  - Emphasis on resolution and precision Measurements
- *Near Detector Candidate for LBNE (since 2009)*
  - Sensitivity studies conducted with the LBNE Flux
  - Colleagues from India began collaborating; proposal submitted to DAE
  - Sub-detector specifications, R&D, Cost, Schedule
- *Neutrino Factory, IDS* (since *2010*)
  - Synergy with LBNE: HIRESMNU as ND
  - Sensitivity studies conducted with 25 GeV Muon-Ring
- *NuStorm*
  - 4 GeV Muon-Ring --- sensitive (<10^-3) search for large Del-M^2
  - Quantify the neutrino-source, measure ν & Anti-ν cross-section, detailed topologies

A fine grain tracker such as HIRESMNU should perform well for NuStorm

Near Detector Sensitivity Studies for Neutrino Factory $\mu \twoheadrightarrow \nu_e\, \nu_\mu$ *with* E_μ=25 GeV

with Xinchun Tian, Chris Kullenberg, H. Duyang

✴ *Flux*

- Inverse Muon Decay $\nu_x + e^- \twoheadrightarrow \nu_x + \mu^-$ (Single, forward μ^-)
  - ν_μ (t-channel) or Anti-ν_e (s-channel)
- ν-Elas $\nu_x + e^- \twoheadrightarrow \nu_x + e^-$ (Single, forward e^-)
  - ν_e-CC, Anti-ν_e-CC, & all flavor $\nu_x e$-NC
- E_ν-Dependence
  - Fixed-ν_0 Method
  - Combined fit of Single, forward μ^- & Single, forward e^-
  - *E_ν-Scale*

Working on:

Determination of Beam-Divergence using ν -Data

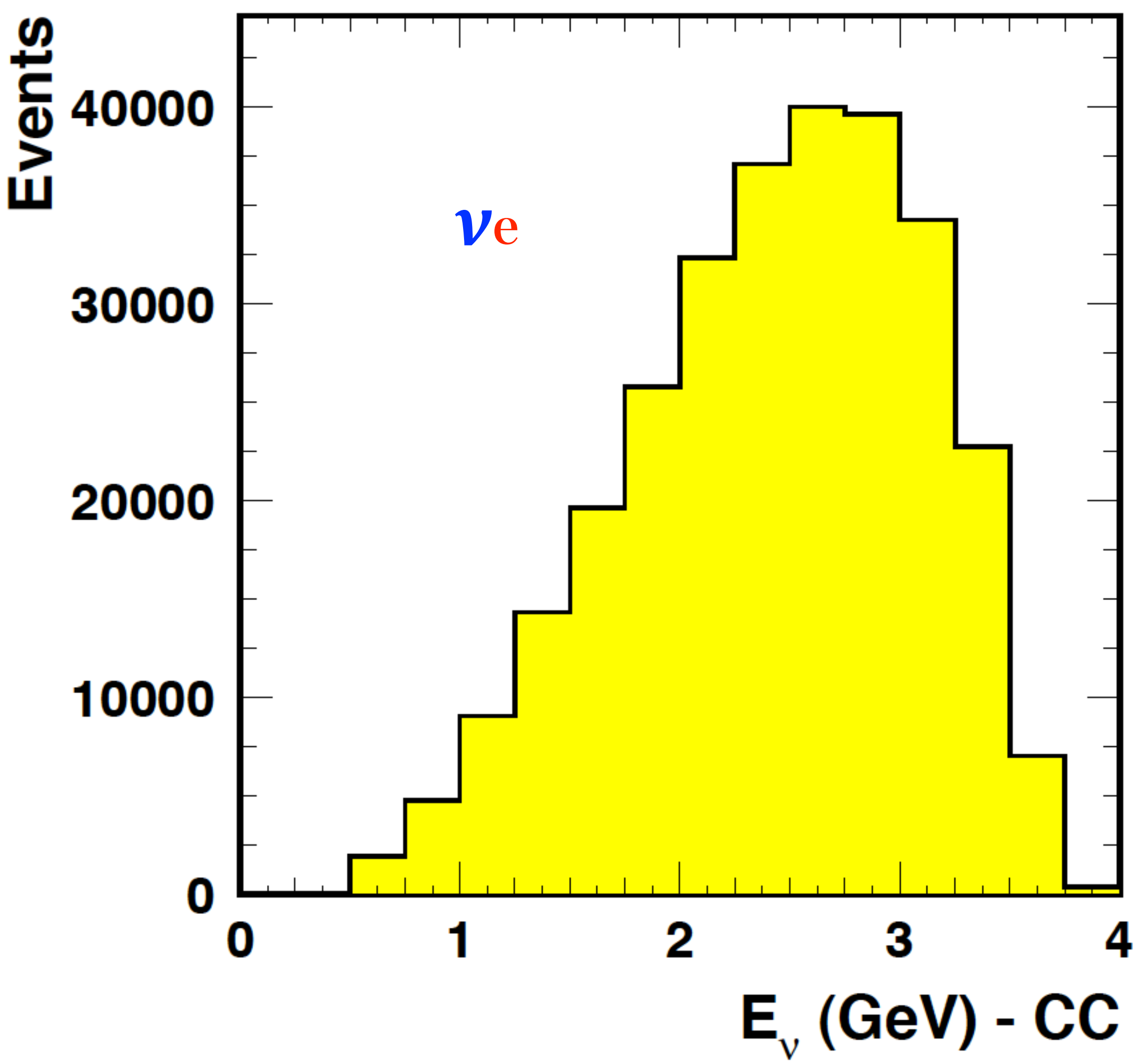
✴ *Interactions*

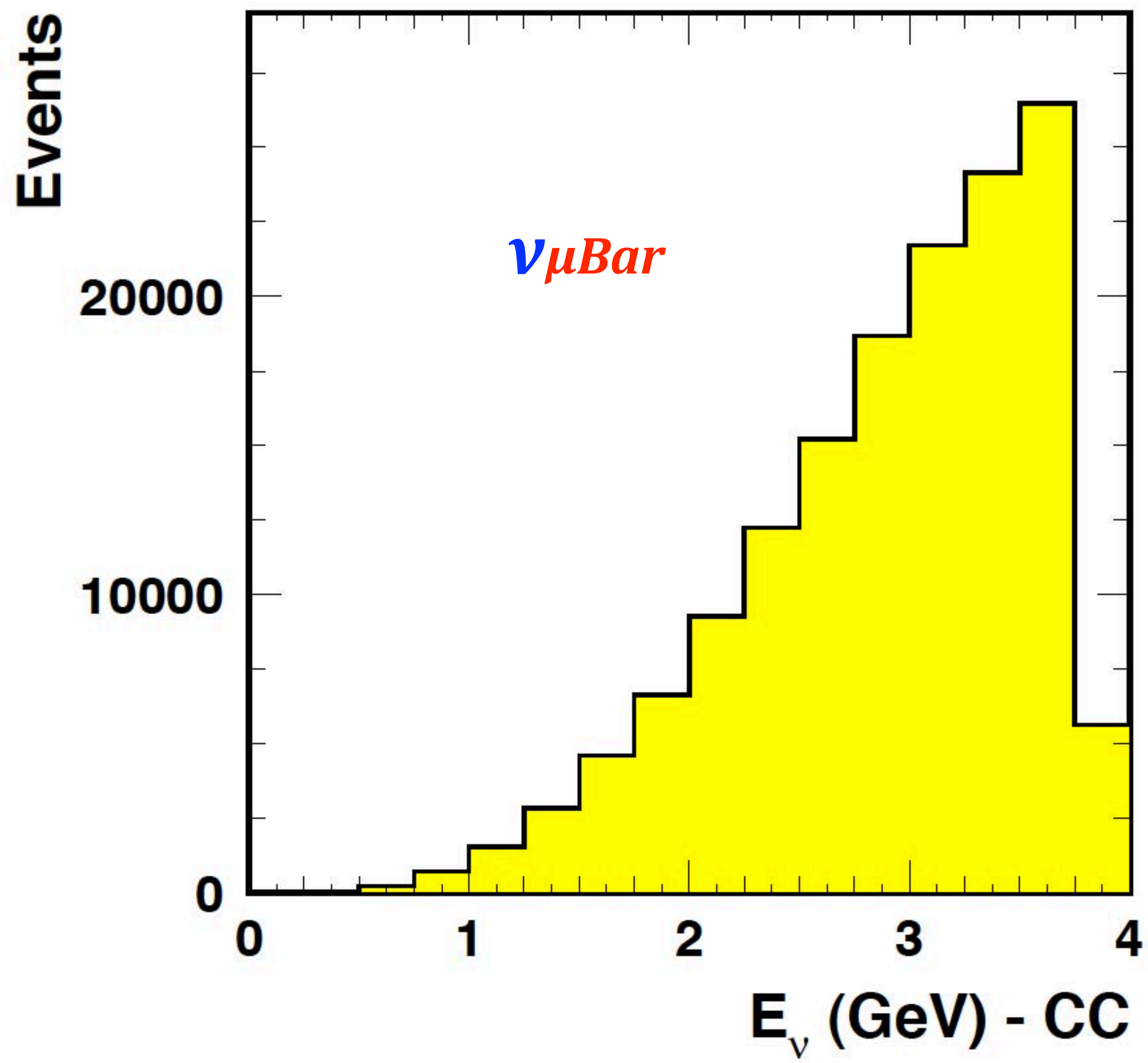
- ν_μ-QE Analysis:
  - ⇛ *For ν-Factory, Eff ~ 60% with 90%-purity*
- ν_e-CC *(inclusive)* Analysis:
  - ⇛ *For ν-Factory, ν_e-CC: Eff ~ 55% with 99%-purity*
  - ⇛ *For ν-Factory, ν_{eBar}-CC: Eff ~ 55% with 99%-purity*
- π^0-Reconstruction:
  - ⇛ *with one $\gamma \twoheadrightarrow e^+e^-$, Eff ~ 55% from 0.5--20 GeV*
- Event by Event Separation of NC -vs- CC: $1.0 \le E_{HAD} \le 20$ GeV
- Precision Measurement of the *Weak Mixing Angle:* $\delta(\sin^2\theta_W) \twoheadrightarrow$ Collider-like

Expected Statistics in NuStorm:

- 10^21 PoT
- Fiducial Mass: 7 Tons

			QE	Res	Dis
μ+:	ν_{μ}Bar-CC:	1.5 x 10**5	34%	56%	10%
	ν_e-CC:	2.8 x 10**5	33%	65%	2% (?)





ν_e-CC Sensitivity Study (LBNE Spectrum)

ν_e-CC ➳ Signal
NC and CC(without Mu-ID) ➳ Background

Two Steps to Analysis
✳Electron-ID:TR
✳ Kinematic Isolation of NuE-induced e- from the Hadron-Vector

NOMAD data as a benchmark

HiResMnu	NuE	NuMu-CC	Nu-NC
Fiducial Volume	1,500	100,000	34,000
$p_\mu < 0.5$GeV	1,500	8,273	34,000
Electron-Sel against -ve Hadrons			
≥20-Mod(-Ve)	1,228	1,738	11,213
P-ve>0.5 GeV	1,192	1,319	8,662
TR-Cut	911	1.3	8.7
Pi0-Backgound			
Phton➢e-(e+)		5.5	24.1
TR-Cut		5.0	21.7
e- Sample	911	6.3	30.4

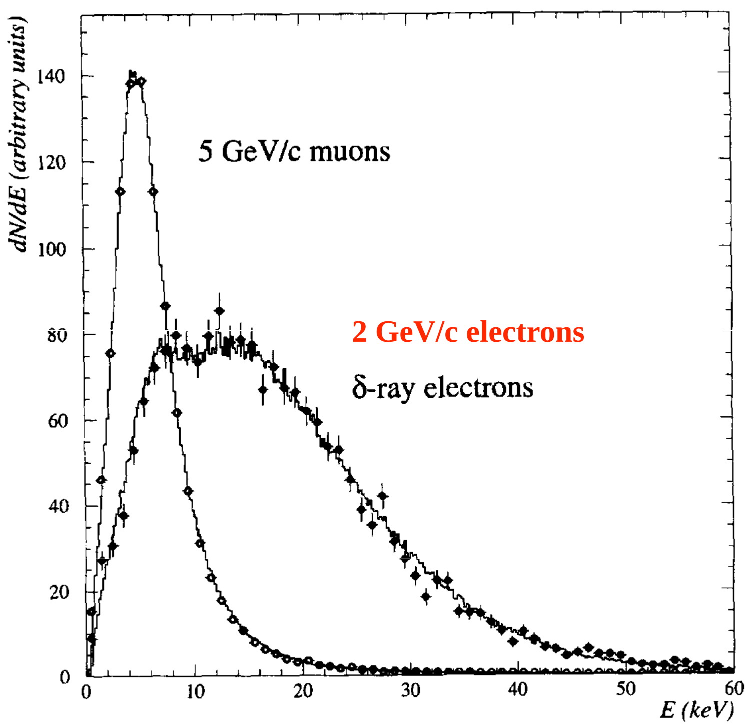
HiResMnu:
⇐NuE-Eff ➳ 60.8%
NuE-Purity ➳ 96.1%

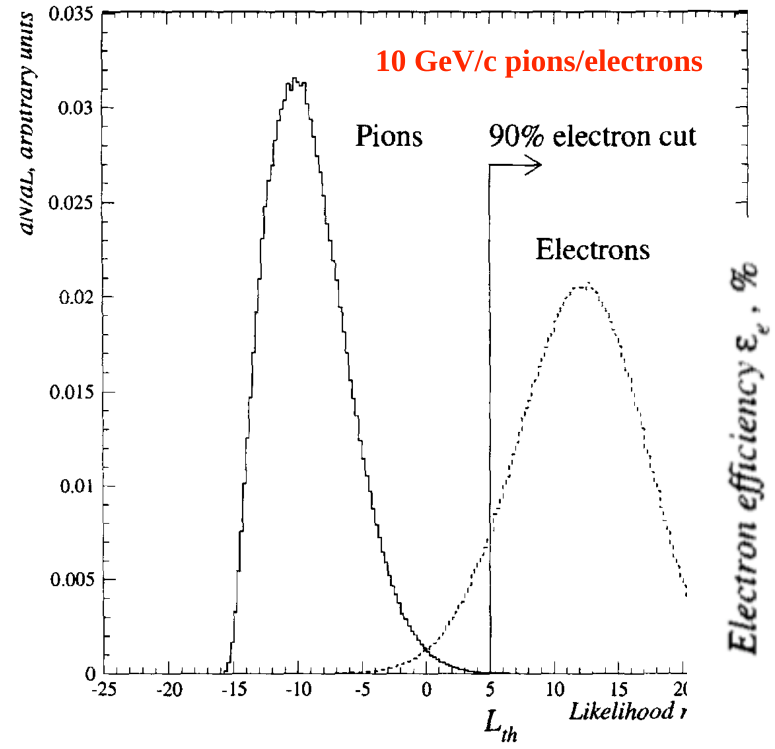
Check: For Nomad
NuE-Eff ➳ 48.8%

Actual: Eff ➳ 45.0%
Pur ➳ 80.0%

Electron ID

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

Electron TR-Eff as a function of Ee for 10**-3 rejection of μ/π

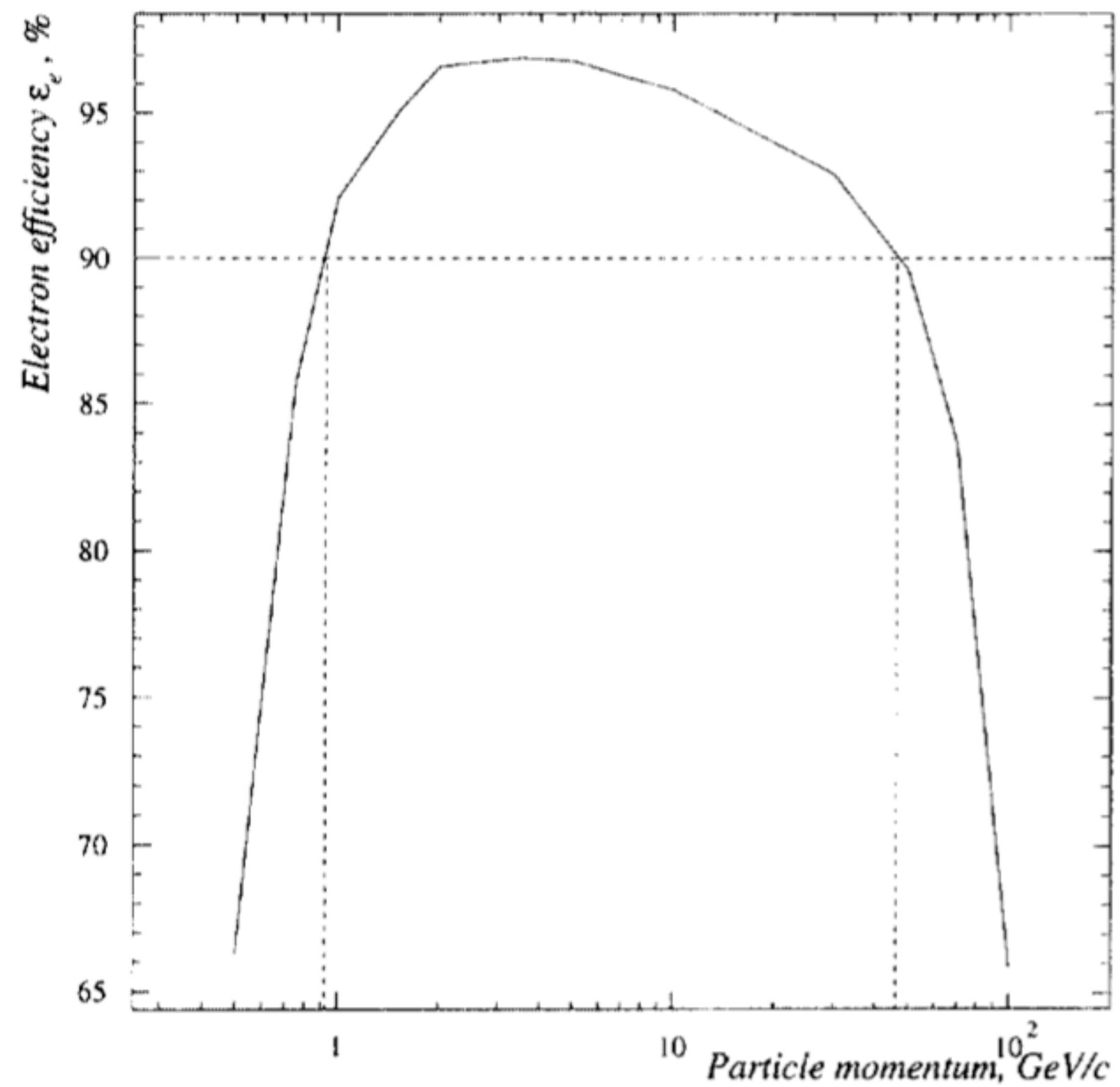
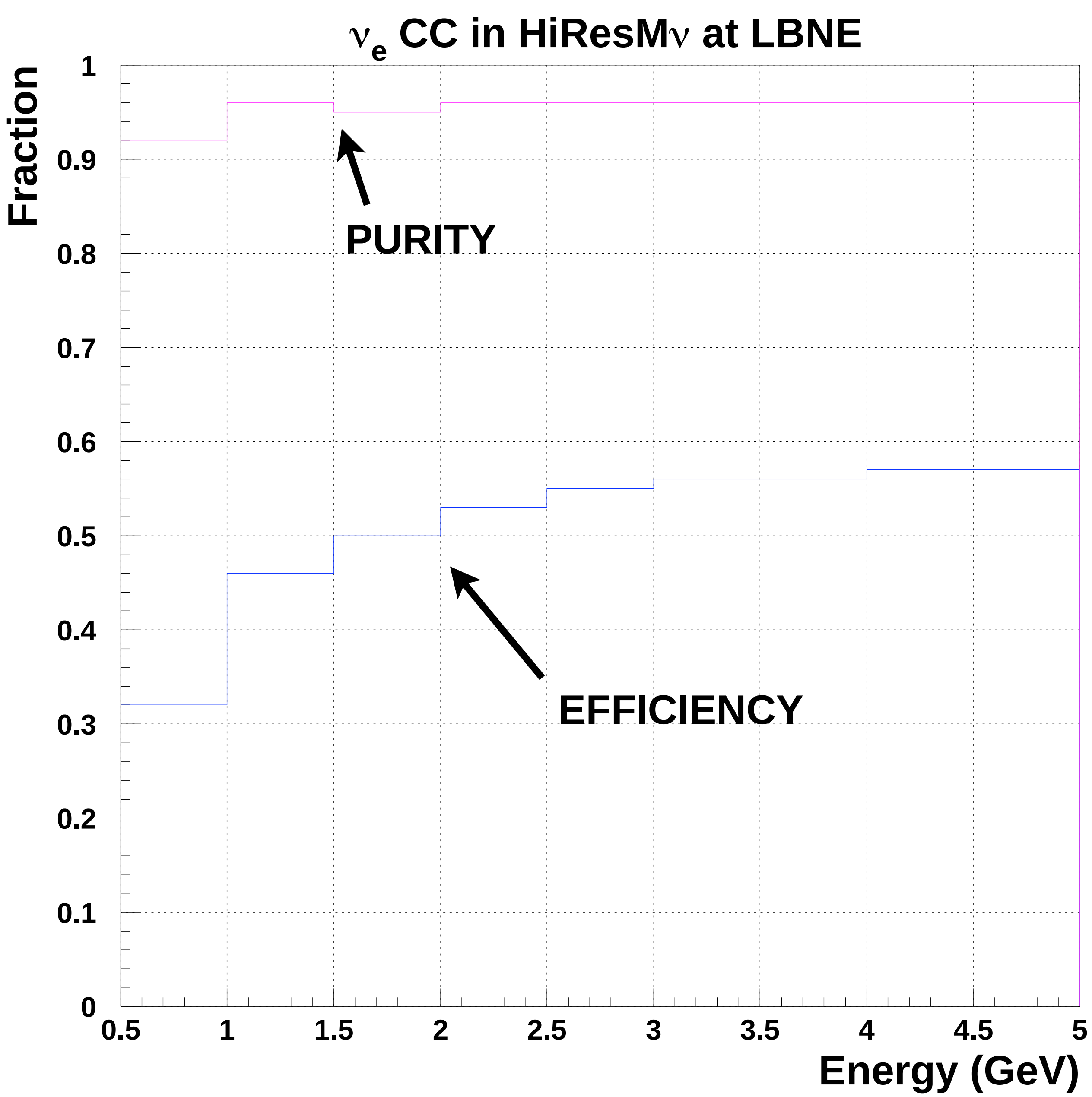


Fig. 8. Monte Carlo predicted electron efficiency ε_e corresponding to $\varepsilon_\pi = 10^{-3}$ as a function of the momentum of the particle for 9 associated hits.

- Atlas-TRT's Geant4 simulation conducted for the HiResMnu-config. verifies the e/μ-π separation assumed for the STT ➢ (See P.Nevski DocDB#432-V1)

IDENTIFICATION OF ν_e CC INTERACTIONS



- *The HiResMν detector can distinguish electrons from positrons in STT*

  $\Longrightarrow$ *Reconstruction of the e's as bending tracks NOT showers*

- *Electron identification against charged hadrons from both TR and dE/dx*

  $\Longrightarrow$ *TR π rejection of 10^{-3} for $\varepsilon \sim 90\%$*

- *Use multi-dimensional likelihood functions incorporating the full event kinematics to reject non-prompt backgrounds (π^0 in ν_μ CC and NC)*

  $\Longrightarrow$ *On average $\varepsilon =$ 55% and $\eta =$ 99% for ν_e CC at LBNE*

***ν*e-CC ⇛**

At Eν=2 GeV, Eff ~ 50% & Purity ~ 95%

ν_μ-QE Analysis

✶ Example of a ν-interaction in a high-resolution ND as a calibration of FD

✶ Key is 2-Track (μ, p) signature ✺*Proton reconstruction: the critical issue*
(✺*dE/dx in but not used in the analysis*)

✶ Parametrized Calculation: Nomad data as check

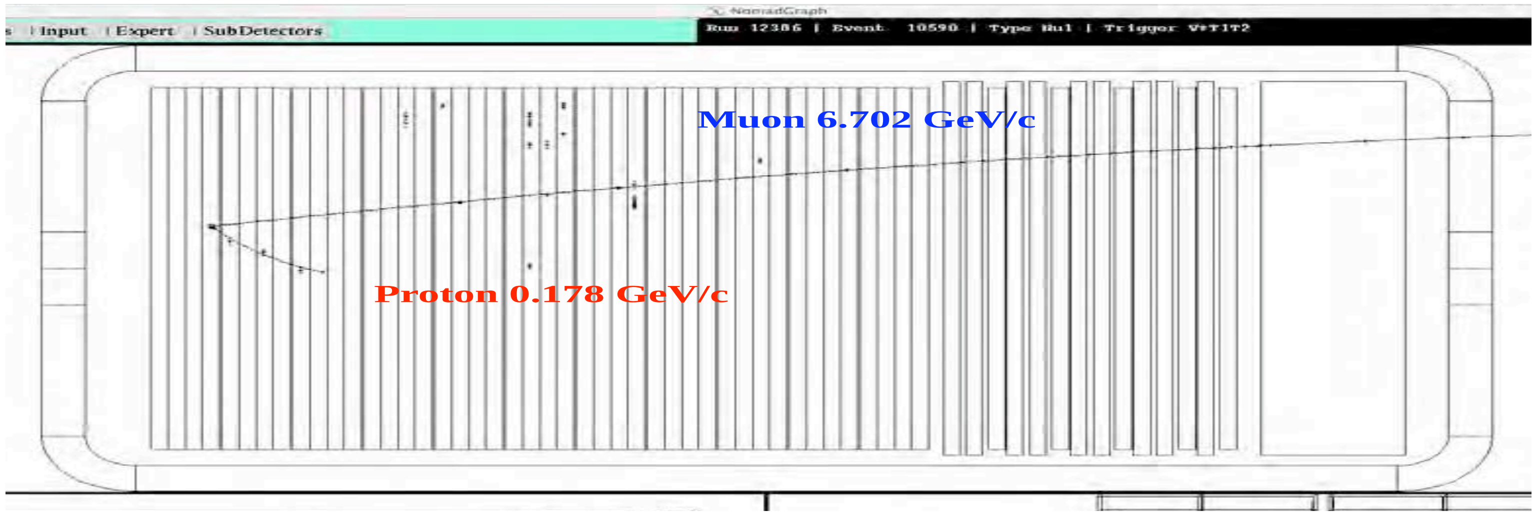


Figure 14: A ν_μ-QE candidate in NOMAD

QE Candidates in NOMAD

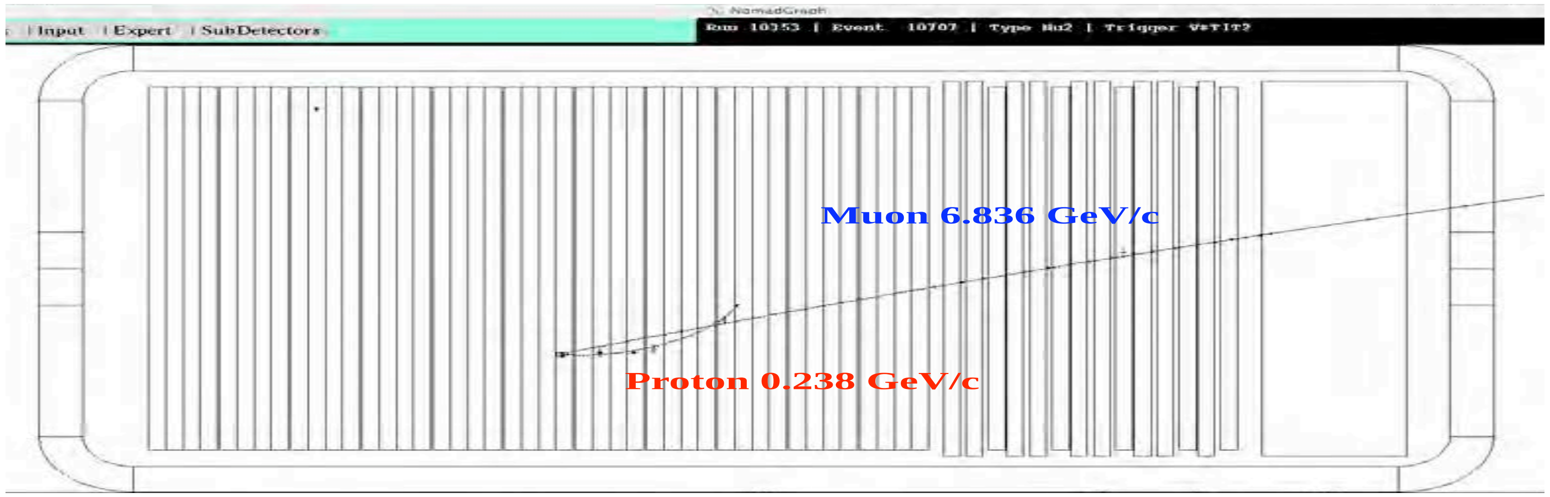
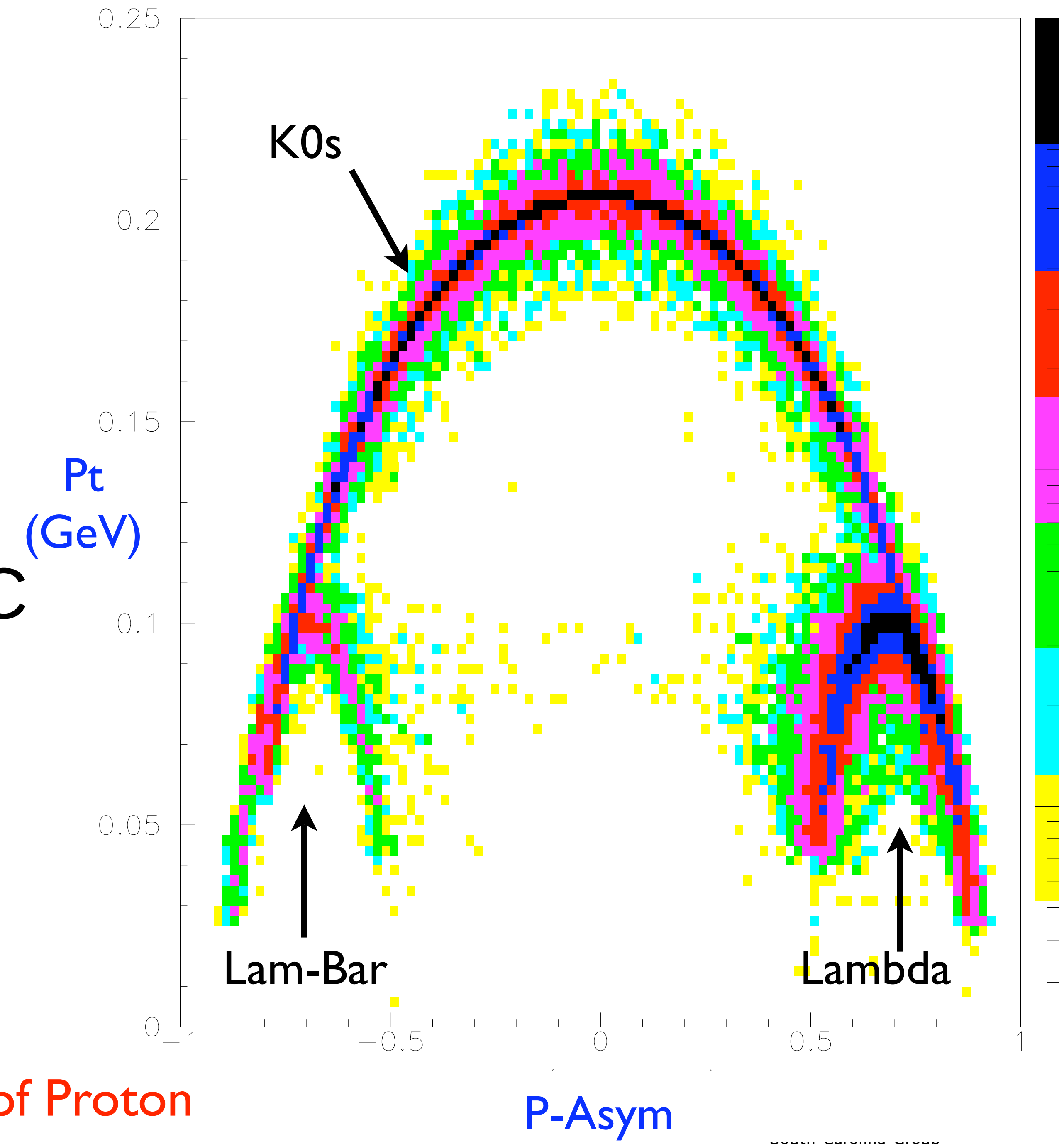


Figure 15: A ν_μ-QE candidate in NOMAD

Measurement of exclusive topologies

- ✦ High resolution allows excellent reconstruction of exclusive decay modes
- ✦ NOMAD performed detailed analysis of strange particle production: $\Lambda, \bar{\Lambda}$
- ✦ Δ resonances in CC & NC are easier to reconstruct
- ✦ Constraints on NC decay mode $\Delta \rightarrow N\gamma$

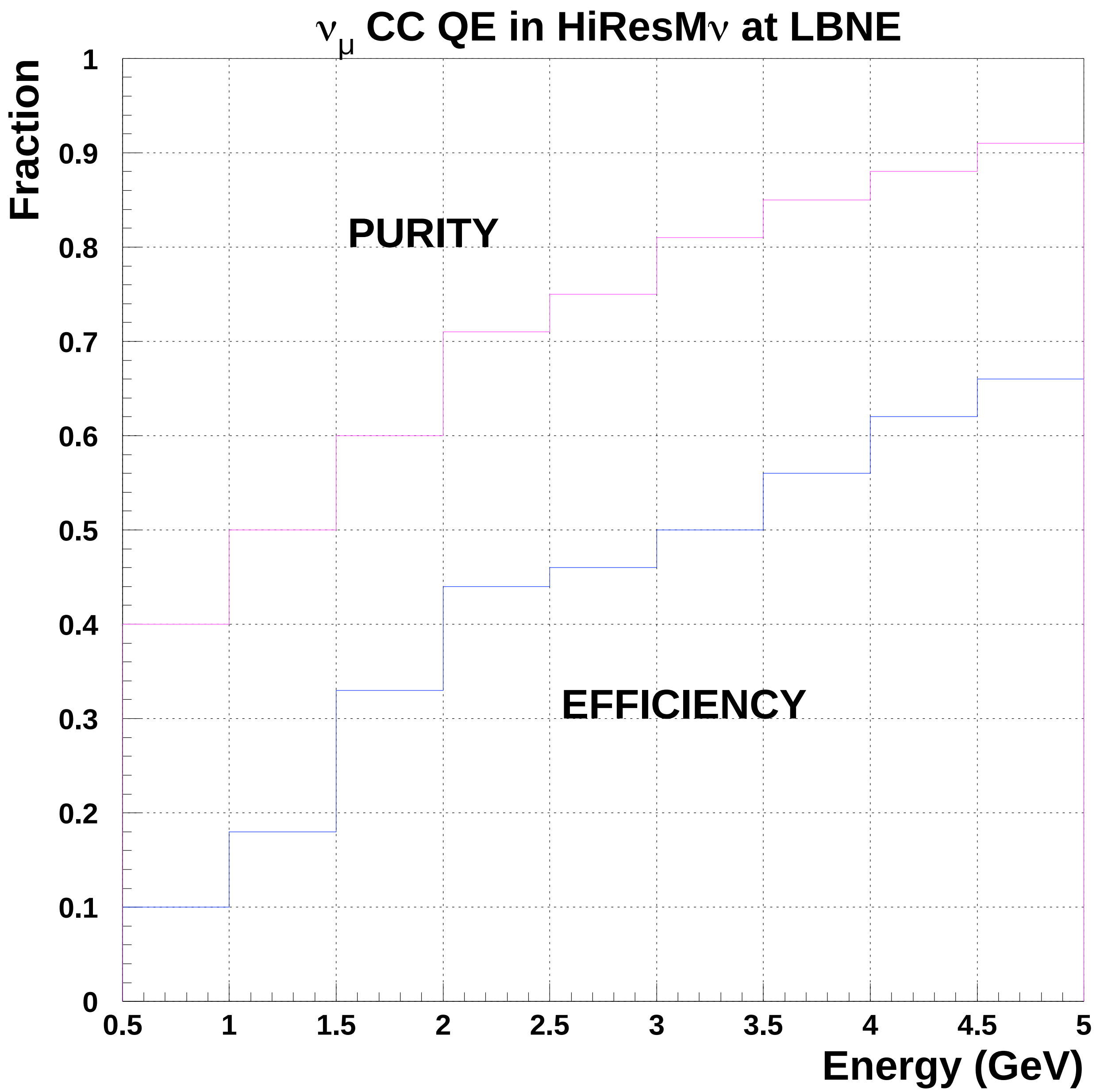
CC-Data: Armenteros Plot



✴ Λ ↠ Calibration of Proton Reconstruction

RECONSTRUCTION OF CC QUASI-ELASTIC INTERACTIONS

LBNE Spectrum



- *Protons easily identified by the large dE/dx in STT & range*

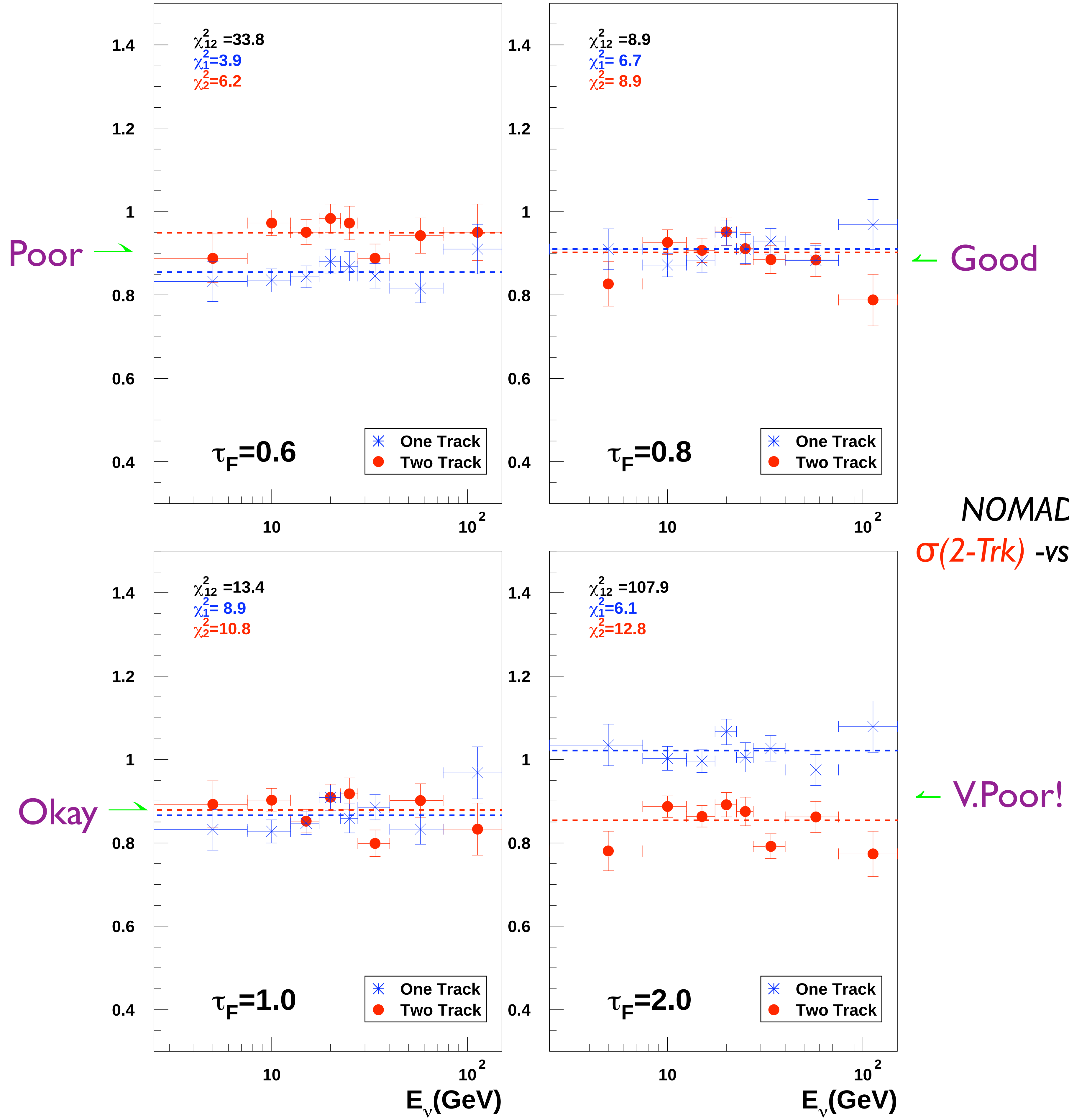
  $\Longrightarrow$ *Minimal range to reconstruct p track parameters 12cm* $\Rightarrow 250\ MeV$

- *Analize BOTH 2-track and 1-track events to constrain FSI, Fermi motion and nuclear effects* Fig.

- *Use multi-dimensional likelihood functions incorporating the full event kinematics to reject DIS & Res backgrounds*

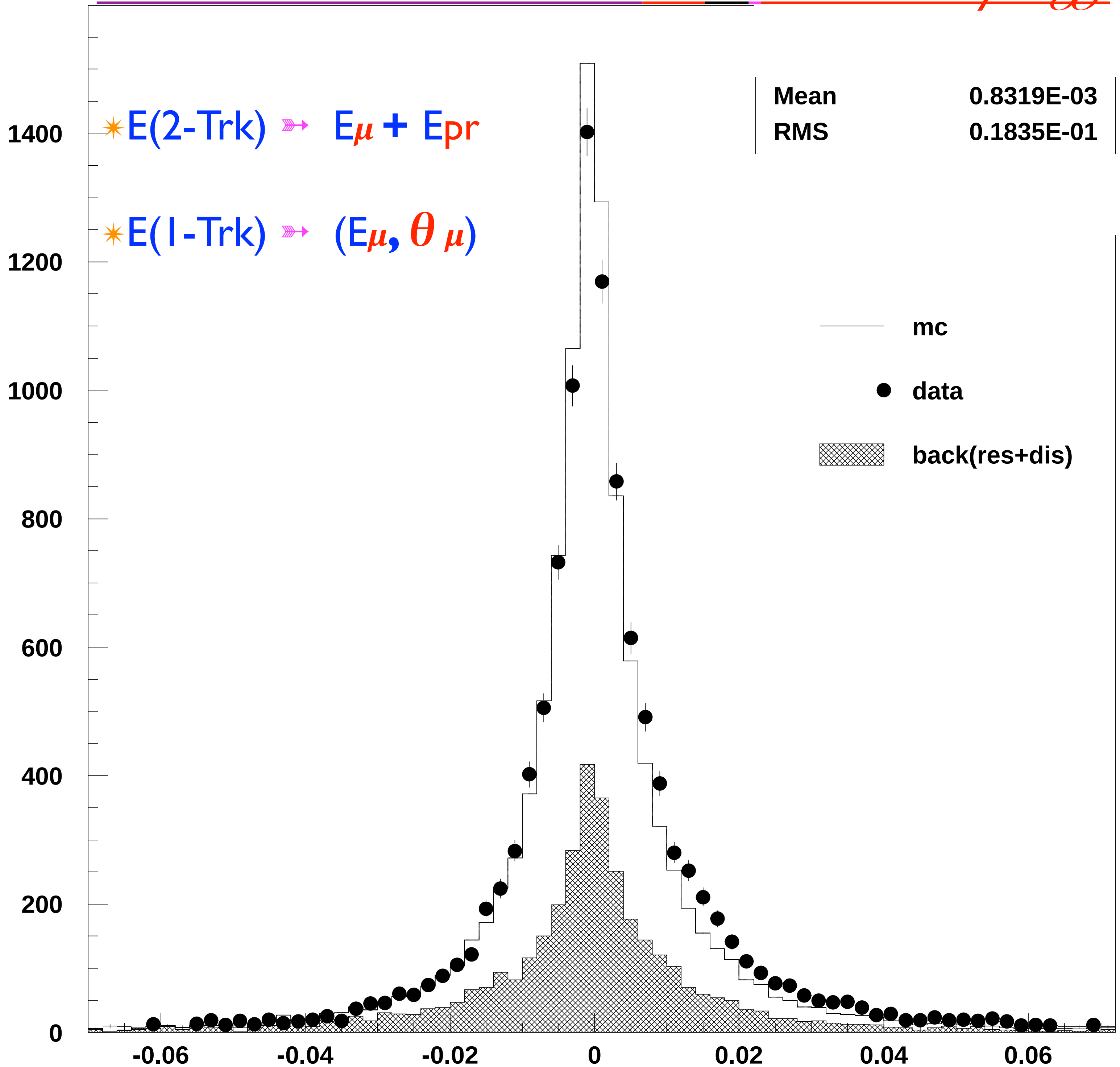
  $\Longrightarrow$ *On average* $\varepsilon = 52\%$ *and* $\eta = 82\%$ *for CC QE at LBNE*

Expect $\Rrightarrow$ *For NuStorm Eff* $\sim$ *40% with 70%-purity*



NOMAD-Data:
σ(2-Trk) -vs- σ(1-Trk)

NOMAD Data: QE ⇒ 2-Track Topology

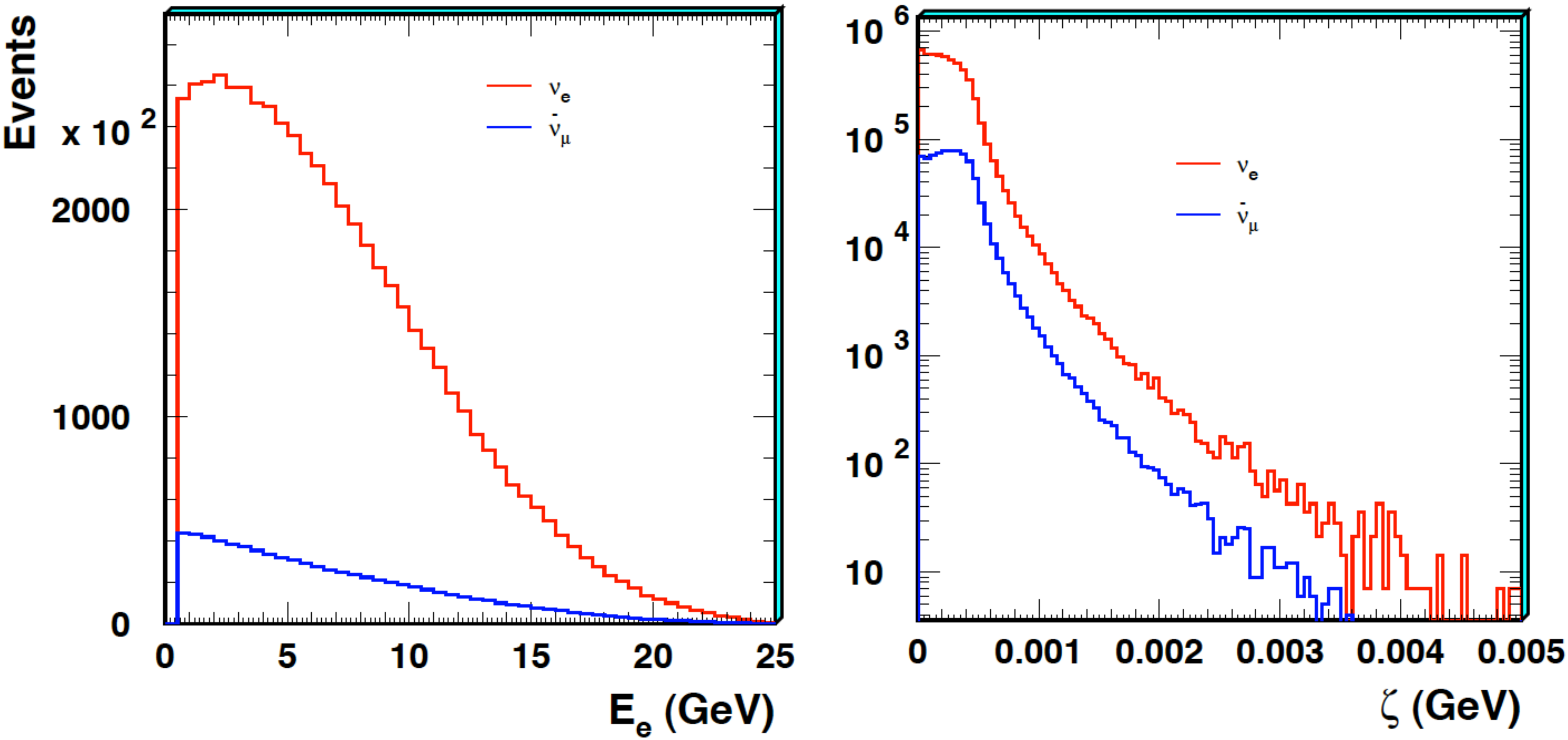


Evis(2-Trak) - Enu(1-Trk w. PFermi=0) (GeV)

⇒Experimental check on Fermi Motion

Sensitivity Analysis **νEl:** ***μ⁺ Beam*** **νe(μbar)** + e- ↠ e- + **ν**e (*Single, forward e-*)

✶ **ν**e(μbar)-N NC background dominated by single, asymmetric $\gamma \to e^- e^+$ and $\pi^- / \mu^- \Rightarrow$



Conclusion ⇛ *The cleanest separation of* **ν**e−e *interaction*

..but in NuStorm, it is statistically ~10%

Calibration of ν_e and $\nu_{\bar{\mu}}$ Flux Measurement Techniques and of the $E\nu$-Scale

(1) Low-ν_0 Method

(2) Neutrino-Electron Scattering: ***e***-sample (Statistically limited)

(3) Quasi-Elastic and Coherent-$\pi^{+/-/0}$

For Relative flux determination

LOW-ν_0 METHOD ⇐Shape of ν_μ or Anti-ν_μ Flux

✦ *Relative flux vs. energy from low-ν_0 method:*

$$N(E_\nu : E_{\text{HAD}} < \nu^0) = C\Phi(E_\nu) f(\frac{\nu^0}{E_\nu})$$

⇐SRM(1989): Used by CCFR, NOMAD, NuTeV, MINOS..

the correction factor $f(\nu^0/E_\nu) \to 1$ *for* $\nu^0 \to 0$.

$\Longrightarrow$ *Need precise determination of the muon energy scale and good resolution at low ν values*

✦ *Fit Near Detector $\nu_\mu, \bar{\nu}_\mu$ spectra:*

- *Trace secondaries through beam-elements, decay;*
- *Predict $\nu_\mu, \bar{\nu}_\mu$ flux by folding experiental acceptance;*
- *Compare predicted to measured spectra $\Longrightarrow \chi^2$ minimization*

$$\frac{d^2\sigma}{dx_F dP_T^2} = f(x_F)g(P_T)h(x_F, P_T)$$

- *Functional form constraint allows flux prediction close to $E_\nu \sim \nu^0$.*

✦ *Add measurements of $\pi^\pm/K^\pm$ ratios from hadro-production experiments to the empirical fit of the neutrino spectra in the Near Detector*

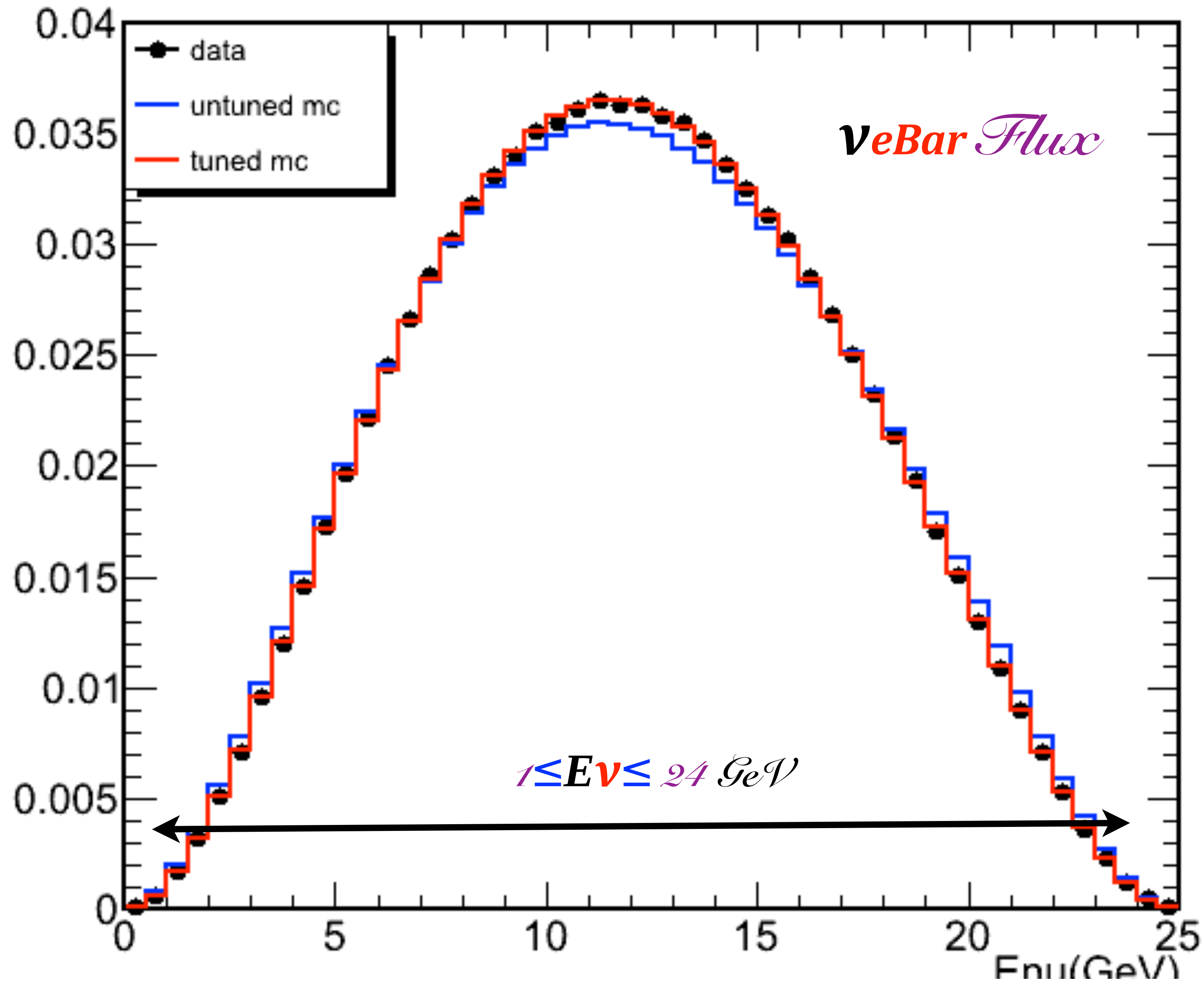
Low-ν0:

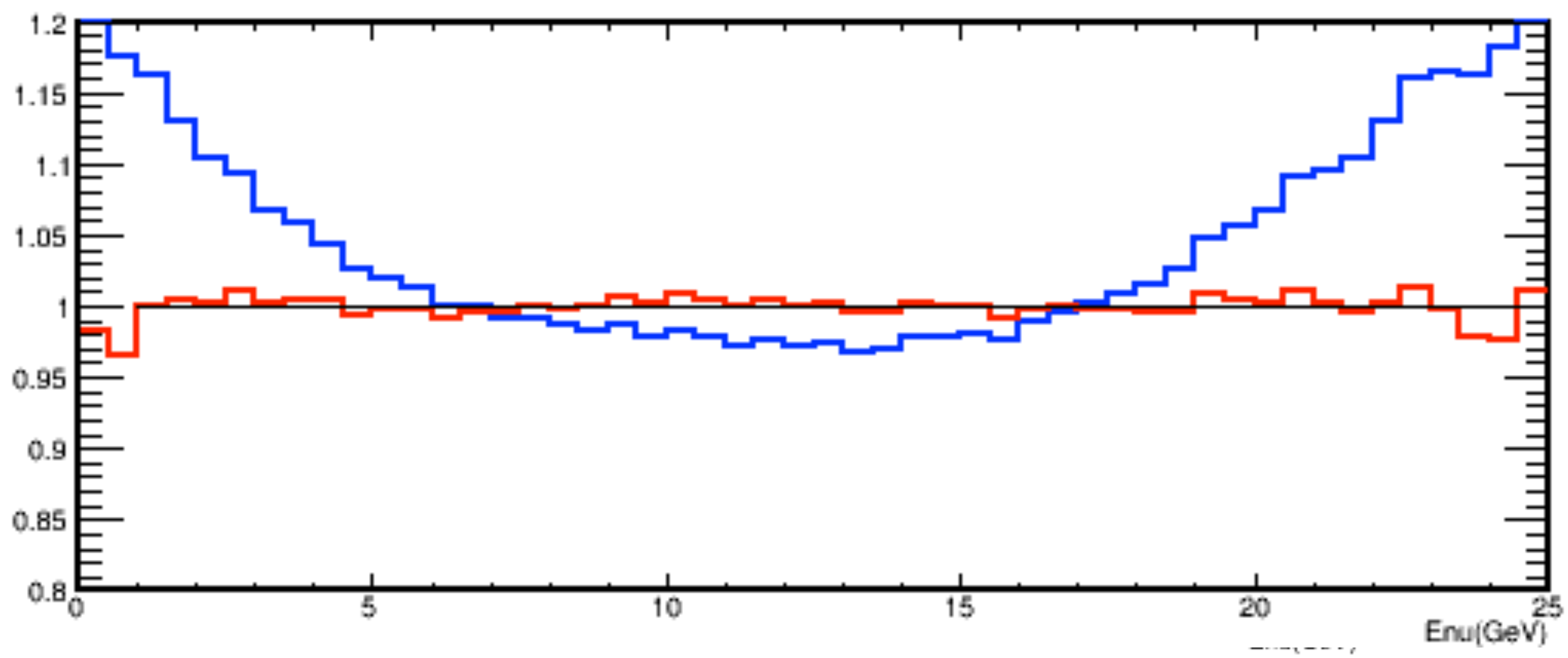
ν*eBar* + N ⇛ e^+ + X (*Ex<0.5 GeV*)

Observation ⇛ *The Low-ν0 method should permit calibration of the flux determination of* ν_μ *and* ν*eBar* *within* ± *~2-3% at ND;*

Ditto for (ν_e *and* ν*μBar*).

⇛ *FD/ND will be more precise*





Coherent Processes:

- Coherent π^0 ❧
- Coherent π^+ ❧
- Coherent π^-
- Coherent ρ^0 ❧
- Coherent ρ^+ ❧
- Coherent ρ^-

⇒ *Not accessible at NuStorm*

(❧ ➳ Different Analyses)

⇛ ***Structure of Weak-Current and its Hadronic-Content***

Partially conserved axial current (PCAC) & Adler's theorem
Conserved vector current (CVC)
Vector meson dominance (VMD)

⇛ ✳ Cohπ^-/Cohπ^+ ⇒ Identical signatures ($\mu\,\pi$)

Constraint on the Anti-Nu/Nu flux?

✳ Coh ρ^0 ⇒ If/Since CVC and VMD are at work, using γ -induced Coh ρ^0

get an independent measure of the Absolute-Neutrino Flux;?
Coh ρ^+ and Coh ρ^- provide additional redundancies.

*A matrix of measurements leading to a much better modeling of Low-Q**2 processes and provide independent constraints on Flux.*

Particle Multiplicity: ν-induced Hardon-jet

✴ ν_μ-CC identified by μ^- in the FD

However in ν-NC interactions:

⇒ π/K/D-hadron ➾ e/μ form an irreducible background

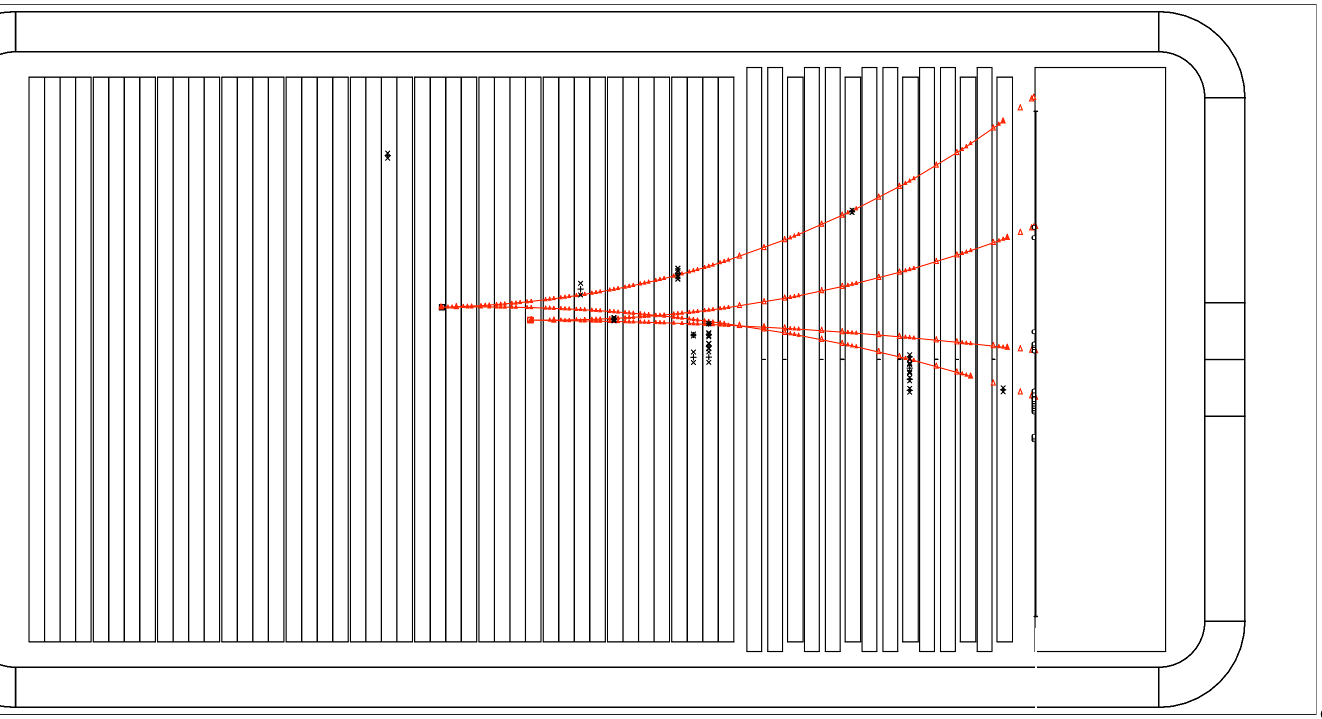
✴ Anti-$\nu_{\mu/e}$ CC identified by μ^+/e^+ in the FD: Still higher backgrounds

✴ π^0's in NC ⇒ Largest backgrounds to (Anti)ν_e-appearance

✴ ≃30% of the Non-Prompt background ($\pi^{0+-}/K^{0+-}/D$ ⇒ μ, EM-shower)

arise from "short" ν_μ-CC

➢➢ *Measure ($\pi^{0+-}/K^{0+-}/D$ ⇒ μ, EM-shower) in NC & in CC*



π0-Reconstruction

✴ Clean Π0- and γ-signatures in STT

✴ ν-NC & CC ➹ π0 ➹ γγ

~50% of the γ ➹ e+e- will convert in the STT, away from the primary vertex.

✴ γ-Identification:

✺ e-/e+ ID:TR

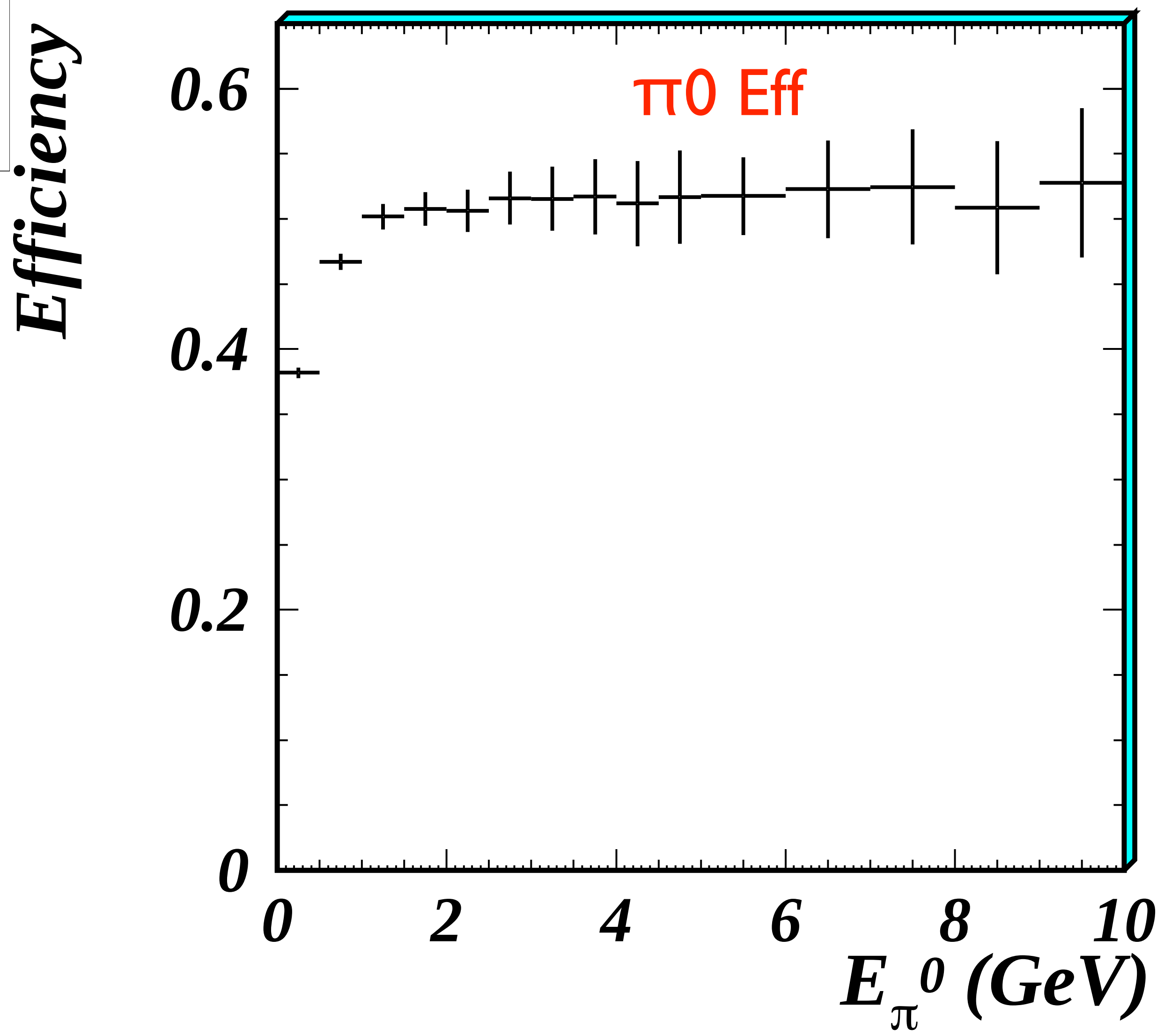
✺ Kinematic cut: Mass, Opening angle

➢ At least one converted γ in STT

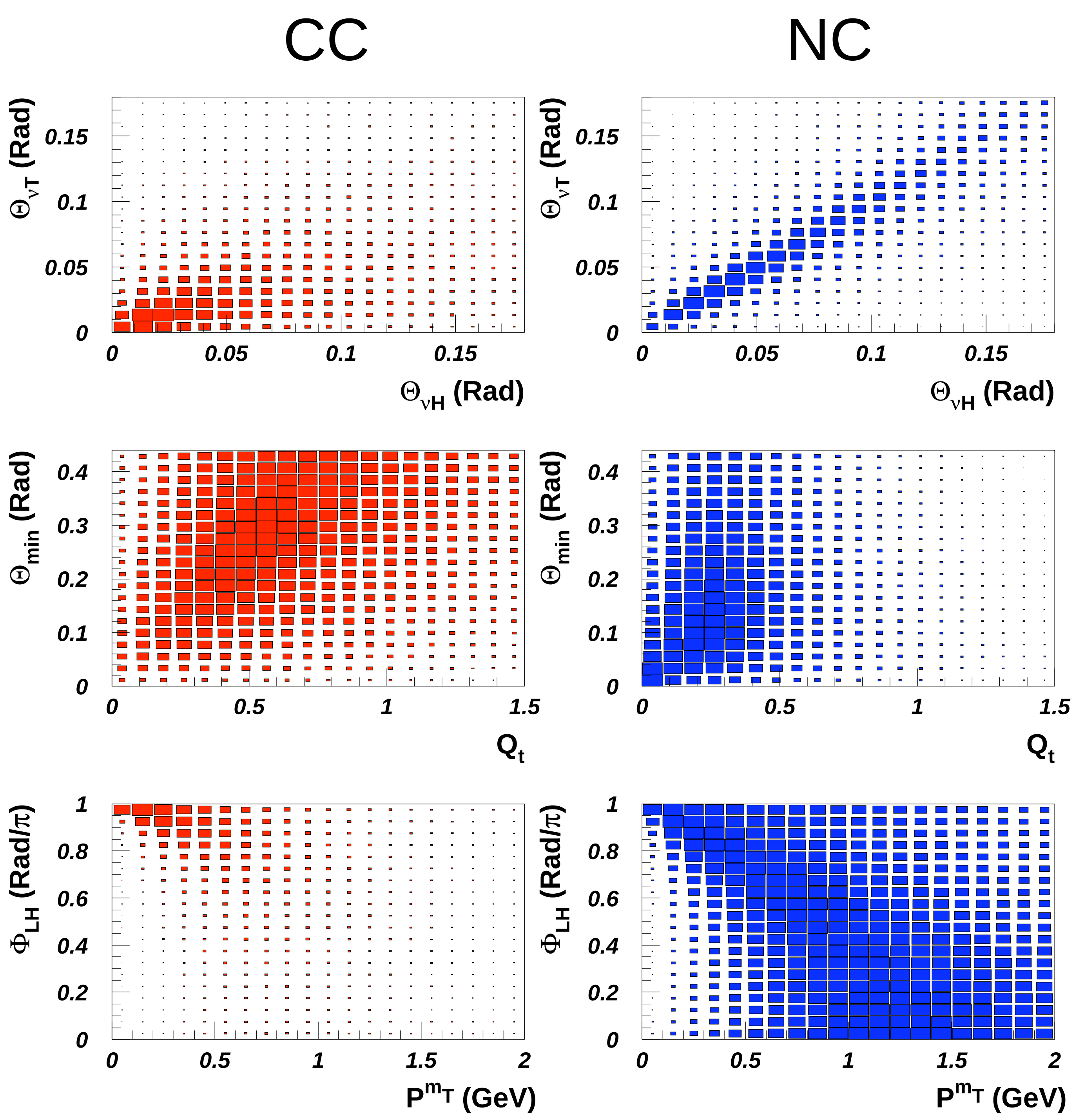
(Reconstructed e- & e+;

e- or e+ traverse ≥6 Mods)

➢Another γ in the Downstream & Side ECAL



Identification of NC interactions in NOMAD



✦ Difficult to measure NC cross-section in conventional detectors

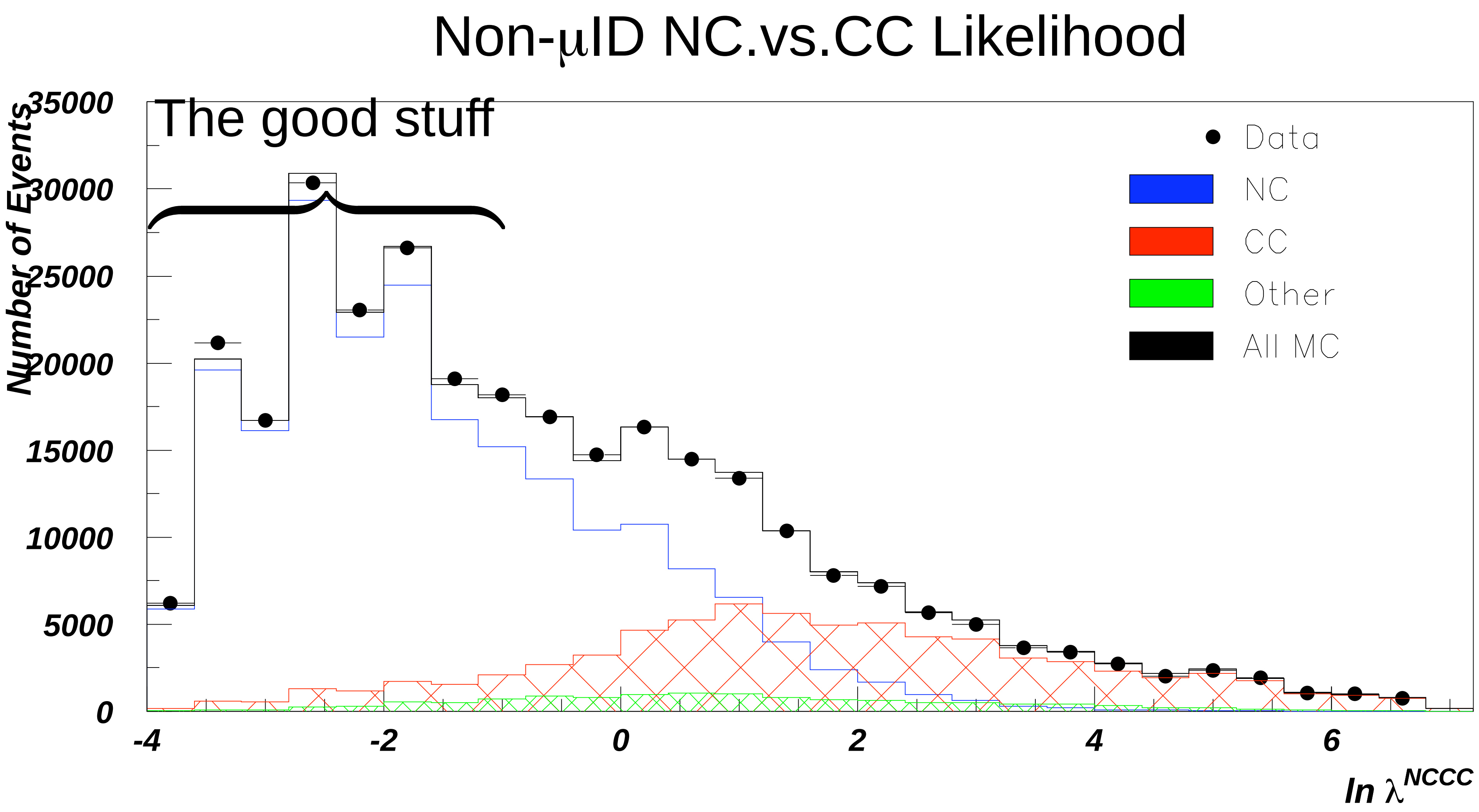
✦ NOMAD can identify NC events from kinematics with a purity of 90%

✦ Plots show NC/CC separation for events failing the muon identification

⇐Non-μID Events

NC *vs* CC

Kinematic separation of NC events in NOMAD. The abscissa variable is a likelihood.



Physics Potential of HIRESMNU (STT) in NuSTORM

Below we enumerate some physics topics which can be studied with the proposed experiment and can be the subject of PhD theses. The list is not complete. It is intended to illustrate the outstanding physics potential of HIRESMNU and the many theses it will engender.

Service to Oscillation Studies

1: Relative flux of ν_e and $\overline{\nu}_\mu$

2: Measurement of the difference in the energy-scale of $\overline{\nu}_\mu$- versus ν_e-induced charged-current (CC) events

Neutral-Pion Production in ν-Interactions

3: Coherent and quasi-exclusive single π^0 production in ν_e-induced neutral current interactions

4: Coherent and quasi-exclusive single π^0 production in $\overline{\nu}_\mu$-induced neutral current interactions

5: Multiplicity and energy distribution π^0 production in neutral current and charged current processes as a function of neutrino and hadronic energy

6: The cross section of π^0 production as a function of X_F and P_T in the ν-CC interactions

Charged-Pion & Kaon and Proton & Neutron Production in ν-Interactions

7: Coherent and quasi-exclusive single π^+ production in ν-induced charged current interactions

8: Coherent and quasi-exclusive single π^- production in $\overline{\nu}$-induced charged current interactions

9: Charged π/K/Proton production in the the neutral current and charged current interactions as a function of hadronic energy

10: The cross section of $\pi^\pm$/K$^\pm$/proton production as a function of X_F and P_T in the ν-CC interactions

11: Measurement of neutron production via charge-exchange process in the CC and NC interactions

Neutrino-Electron Scattering

12: The ν_e-e^- and $\overline{\nu}_\mu$-e^- Interactions and search for lepton number violating process

ν-Nucleon Neutral Current Scattering

13: Measurement of neutral current to charged current ratio, R^ν, as a function of hadronic energy in the range $0.25 \leq E_{Had} \leq 4$ GeV

14: Measurement of neutral current to charged current ratio, R^ν and $R^{\overline{\nu}}$, for $0.25 \leq E_{Had} \leq 4$ GeV

Non-Scaling Charged and Neutral Current Processes

15: Measurement of ν_e quasi-elastic CC interaction

16: Measurement of $\overline{\nu}_\mu$ quasi-elastic CC interaction

17: Determination of M_A from the QE cross section and the shape of the kinematic variables (Q^2, Y_{bj}, etc.)

18: Measurement of the axial form-factor of the nucleon from quasi-elastic interactions

19: Measurement of ν_e induced resonance processes

20: Measurement of $\overline{\nu}_\mu$ induced resonance processes

21: Measurement of resonant form-factors and structure functions

22: Study of the transition between scaling and non-scaling processes

23: Constraints on the Fermi-motion of the nucleons using the 2-track topology of neutrino quasi-elastic interactions

24: Measurement of the $\overline{\nu}_\mu/\nu_e$ flux ratio using the coherent-pion events

25: Neutral Current elastic scattering on proton $\nu(\overline{\nu}_\mu)p \to \nu(\overline{\nu}_\mu)p$ and the strange quark contribution to the nucleon spin ΔS

Inclusive Charged Current Processes

26: Measurement of the inclusive ν_e charged current cross-section in the range $0.5 \leq E_\nu \leq 4$ GeV

27: Measurement of the inclusive $\overline{\nu}_\mu$ charged current cross-section in the range $0.5 \leq E_\nu \leq 4$ GeV

28: Measurement of the inclusive ν_e and $\overline{\nu}_\mu$ charged current cross-section in the range $0.5 \leq E_\nu \leq 40$ GeV

29: Measurement of the differential ν_e charged current cross-section as a function of x_{bj}, y_{bj} and E_ν.

30: Measurement of the differential $\overline{\nu}_\mu$ charged current cross-section as a function of x_{bj}, y_{bj} and E_ν.

31: Determination of xF_3 and F_2 structure functions in ν_e charged current interactions and the QCD evolution

32: Determination of xF_3 and F_2 structure functions in $\overline{\nu}_\mu$ charged current interactions and the QCD evolution

33: Measurement of the longitudinal structure function, F_L, in ν_e and $\overline{\nu}_\mu$ charged current interactions and test of QCD

34: Tests of sum-rules in QPM/QCD

35: Verification of quark-hadron duality in (anti)neutrino interactions

36: Checking the Partially Conserved Axial Current (PCAC) hypothesis at low momentum transfer

37: Determination of the behavior of $R = \sigma_L/\sigma_T$ at low momentum transfer

38: Measurement of the hadronic content of the weak current in neutrino-CC interaction

CC interaction

40: Measurement of the hadronic content of the weak current in neutrino(bar)-NC interaction

Nuclear Effects

41: Measurement of nuclear effects on F_2 in (anti)neutrino scattering from ratios of Pb,Fe and C targets

42: Measurement of nuclear effects on xF_3 in (anti)neutrino scattering from ratios of Pb,Fe and C targets

43: Study of (anti)shadowing in neutrino and antineutrino interactions and impact of axial-vector current

44: Measurement of axial form-factors for the bound nucleons from quasi-elastic interactions on Pb, Fe and C

45: Measurement of hadron multiplicities and kinematics as a function of the atomic number

@@@

Semi-Exclusive and Exclusive Processes

46: Measurement of K^0_S, Λ and $\overline{\Lambda}$ production in neutrino CC processes

47: Measurement of K^0_S, Λ and $\overline{\Lambda}$ production in antineutrino CC processes

48: Measurement of K^0_S, Λ and $\overline{\Lambda}$ production in (anti)neutrino NC processes

49: Measurement of exclusive strange hadron and hyperon production in (anti)neutrino charged and neutral current

50: Measurement of the Λ and $\overline{\Lambda}$ polarization in neutrino charged current interactions

51: Measurement of the Λ and $\overline{\Lambda}$ polarization in antineutrino charged current interactions

52: Measurement of the Λ and $\overline{\Lambda}$ polarization in (anti)neutrino neutral current interactions

53: Search for inclusive production of rho0(770), f0(980) and f2(1270) mesons in (anti)neutrino charged current interactions

54: Measurement of backward going protons and pions in neutrino CC interactions and constraints on nuclear processes

55: Search for K*(892)+- vector mesons and their spin alignment in neutrino interactions

Search for New Physics and Exotic Phenomena

56: Search for heavy neutrinos using electronic, muonic and hadronic decays

57: Search for eV (pseudo)scalar penetrating particles

58: Search for an anomalous gauge boson in pi0 decays at the 120 GeV p-NuMI target

59: Search for anomaly mediated neutrino induced photons

60: Search for the magnetic moment of neutrinos

61: A test of ν_μ–ν_e universality down to 10^{-4} level

62: Search for right-handed current in CC interaction

- *>60 Topics listed*
- *Many topics are pertinent to oscillation physics*
- *Some non-oscillation topics might lead to discovery*

A High Resolution ND for Neutrino Factory/LBNE/NuStorm

The Familiar, Beautiful Neighborhood

❧Cross-section

❧Precision measurements in 0.5--4 GeV

❧Sum rules

❧Isospin Physics

❧Searches

❧........

☙Rewriting the ν-text-book

Backup Slides

Improvements over the NOMAD: HiResMnu-Concept

- ✴ Tracking Charged Particles
  - ❧ x6 more hits in the Transverse-Plane (X-Y)
  - ❧ x2 more hits along Z-axis
- ✴ Electron/Positron ID
  - ❧ Continuous TR providing e+/e- ID
- ✴ Calorimetry: 4π-Coverage
  - ❧ Downstream ECAL: fine Longitudinal & Transverse segmentation
  - ❧ Barrel & Upstream ECAL
- ✴ μ-ID
  - ❧ 4π-Coverage: min-P_μ ➾ 0.3 GeV

Fitting ν_e and ν_μBar flux as a function of $E\nu$

✳ *(i)* Mock Data: simulate a signal/back --- IMD (μ-sample), or νe (e-sample), or ν_μ-N CC

✳ *(ii)* Reconstruct (parametric smearing)

✳ *(iii)* Subject it to analysis

✳ *(a)* Start with a Trial Flux

✳ *(b)* Fold in Cross-section

✳ *(c)* Fold in Acceptance (Efficiency-Smearing); add background

✳ *(1)* Compare samples *(iii)* with *(c)* : From χ^2

✳ *(2)* Vary Flux parameter; Go to *(a)*; arrive at *(c)*; go to *(1)*

✳ *(3)* Minimize χ^2: $\Rightarrow$ Fitted Flux

Missing:

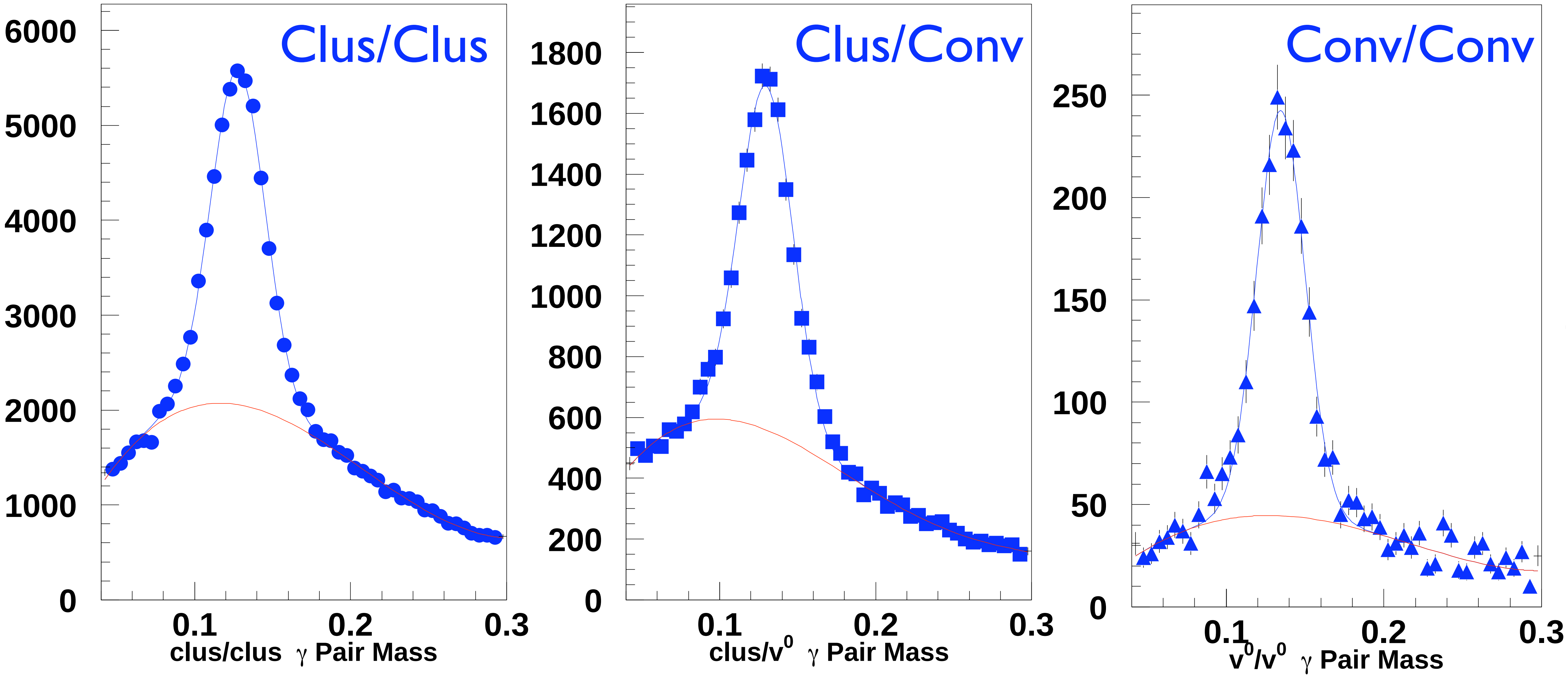
Determination of Beam-Divergence using ν -Data

Systematic-Errors in Low-ν_0 Relative Flux: ν_μ & Anti-ν_μ

- Variation in ν_0-cut
- Variation in ν_0-correction
- Systematic shift in Ehad-scale
- Vary σ(QE) $\pm$10%
- Vary σ(Res) $\pm$10%
- Vary σ(DIS) $\pm$10%
- Vary functional-forms
- Systematic shift in Emu-scale

- Beam-Transport $\Leftarrow$ Missing

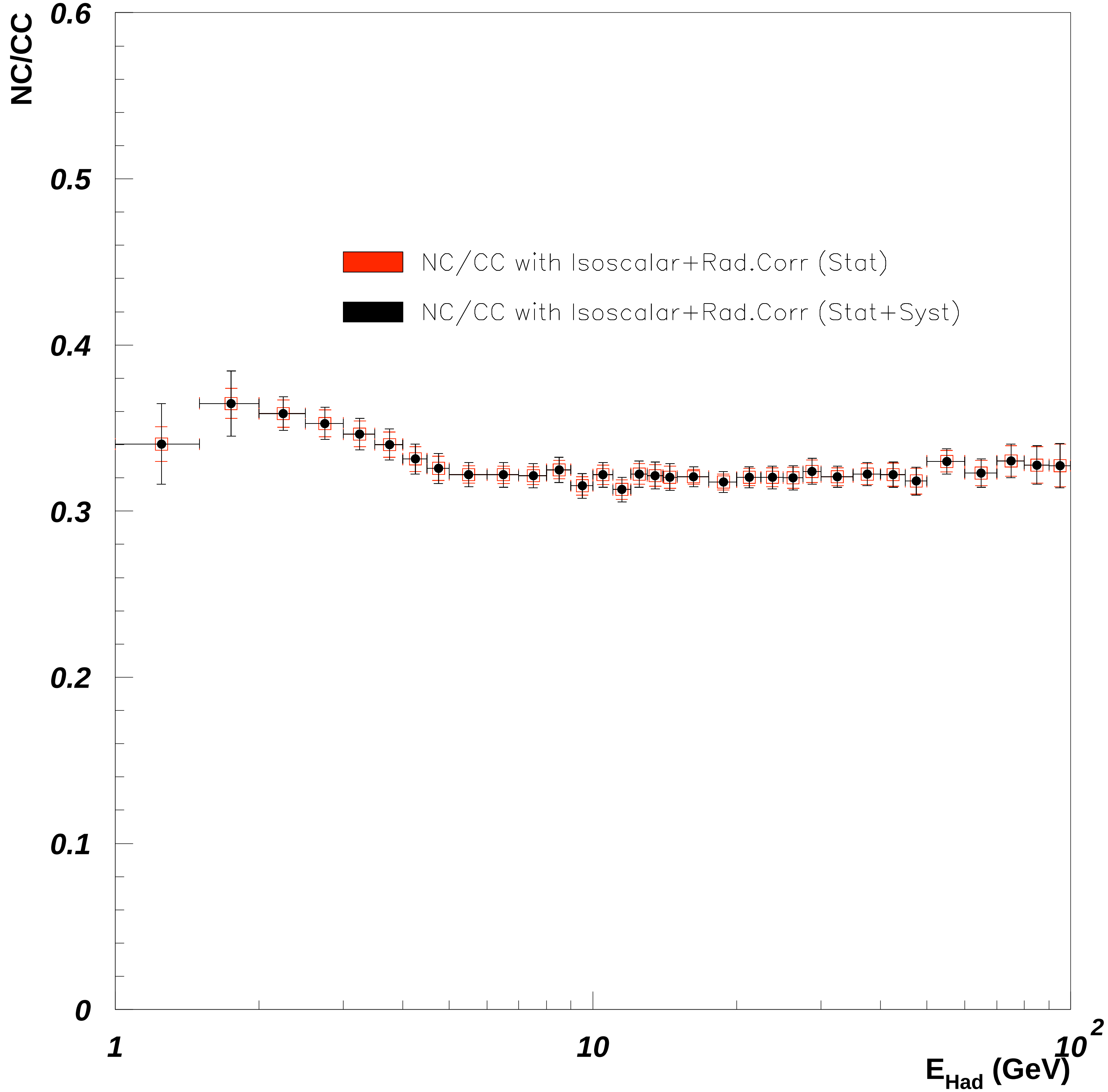
Reconstructed π^0 in NC interactions in NOMAD



Overall more than 33k reconstructed events. Three topologies:

- *Cluster/Cluster 24k events*
- *Cluster/Conversion 7k events*
- *Conversion/Conversion 2k events*

South Carolina Group



Measurement of the Rate of NC/CC(Ehad):
1<Ehad<100 GeV (NOMAD)