Physics Case for the Straw-Tube Tracker (STT): DUNE-ND

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Unique Features of STT as DUNE-ND Tracker

⟸ *STT offers ~2mrad resolution on* θe
(1) Low background; (2) Positron Analysis
⇛ ***Error** on Beam Divergence?*

✦ $\nu(\bar{\nu})$-e *elastic scattering:*

- *Statistics in STT enough for* $\sim 2.5\%$ *absolute flux;*
- *Excellent electron ID (TR) & angular resolution to reduce backgrounds;*
- *Could be used for* E_ν *shape & energy scale if beam divergence can be constrained in-situ;*
- *Complementary Inverse Muon Decay (IMD) channel (CC) at* $E_\nu > 11$ *GeV not sensitive to* $\bar{\nu}_\mu$.

✦ *Coherent* $\pi^\pm$ *production:*

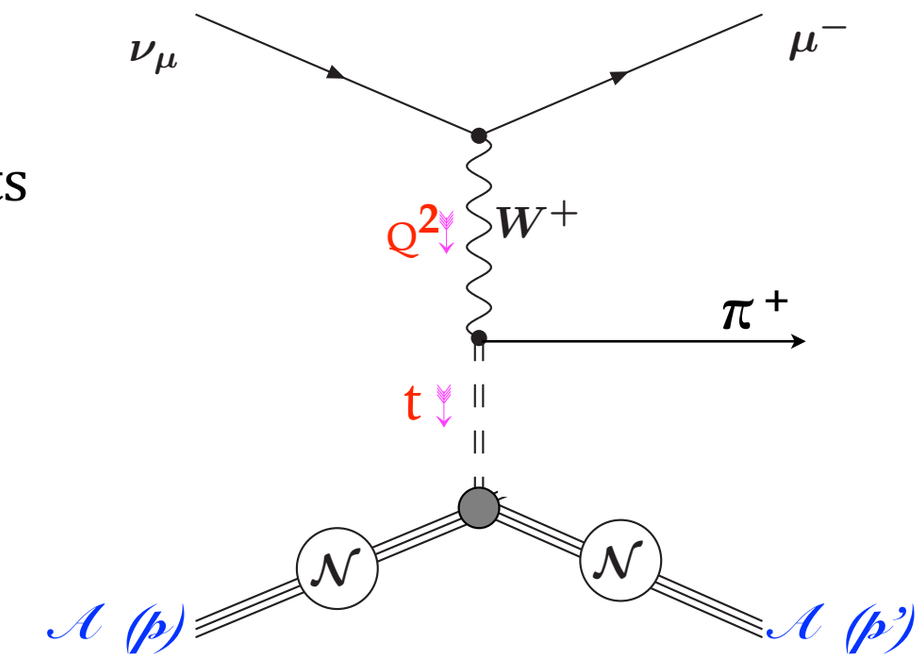
- *High statistics samples in STT: expect* $5(2.5) \times 10^5$ $\nu_\mu(\bar{\nu}_\mu)$ *CC reconstructed events;*
- *Excellent angular & momentum resolution (*t *resolution) for background rejection;*
- *Same cross-section for* ν_μ *&* $\bar{\nu}_\mu$ *in carbon (isoscalar)*
  $\Longrightarrow$ *Most promising channel to measure* $\bar{\nu}_\mu/\nu_\mu$ *flux ratio;*
- *Promising channel to constrain beam divergence (e.g. NOMAD).*

$\Longrightarrow$ *Ongoing studies at DUNE energies*

⟸ *short update*

Neutrino-Induced Coherent $\pi^{+/-}$ *Production*

$\nu_\mu/\bar{\nu}_\mu\ \mathcal{A} \rightarrow \mu^{-/+}\ \pi^{+/-}\ \mathcal{A}$



Coherent-π^+/π^- ⇒ almost independent of Nuclear effects

- with $|t| < \sim 0.05$
- To the first order, little nuclear-effect
- The emergent particles, μ^+ & π^+, well measured
  ⇒ *Small Missing-Pt*
- The ONLY channel where the **topology** is IDENTICAL for $\nu\ (\mu^-, \pi^+) \Leftrightarrow \bar{\nu}(\mu^+, \pi^-)$ & **cross-section**, to the first order, is *identical* for ν & $\bar{\nu}$

⇒ *Precise determination of*

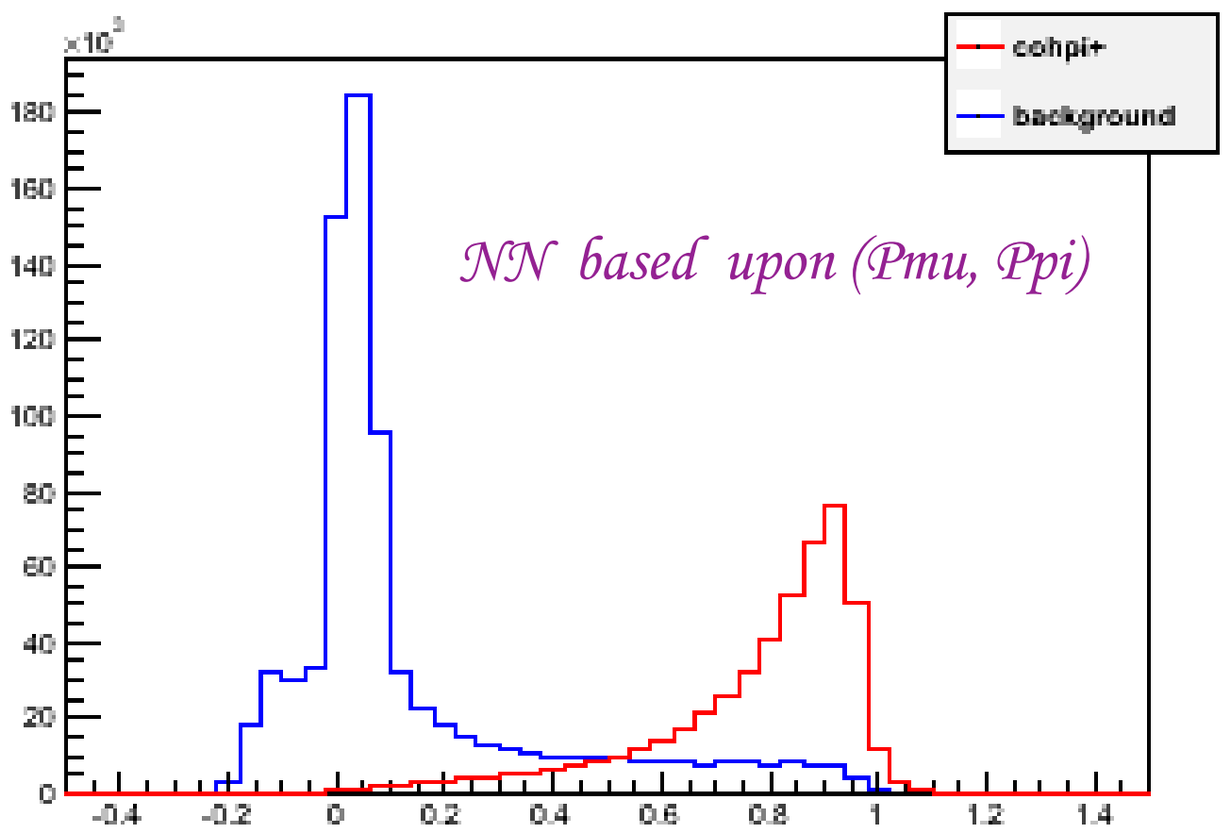
⇒ *Ev-Scale* ⇒ $\bar{\nu}/\nu$ *Flux* ⇒ *constraint on Beam-divergence*

Coherent-π + Analysis in STT
(Very Preliminary! Details @ NG-WG)

Bing Guo

Cuts	Cohpi+	DIS	QE	Res	Bkg
Total	675000	28300000	19500000	25500000	73300000
$p_\mu > .35$	602748	25177206	18732366	22631916	66541488
hadtrk=1	602748	7967242	14387020	4639338	26993600
γ Veto	602748	4037671	14290440	2251178	20579290
Neutral Veto	602748	1106276	13443473	758261	15308009
$\pi+$ ID	602319	957391	6331	617578	1581300
$p_\pi > .25$	500178	780122	3290	497639	1281052
$\zeta < .2$	491138	481551	2492	320230	804274
$NN > .5$	435935	34296	0	63743	98039

Eff *64%*



Assumptions:

*Smearing functions similar/identical to those in the fast MC: |p|, Theta, Photons

*Hadrons: Sigma/E = 1% + 100%/Sqrt(E)

*Pi-ID: Assumed perfect ID

*Soft cuts on Zeta and NN

*Purity can be improved by x2 at the cost of an additional 10% loss of signal.

Salient Variables: (analysis validated by NOMAD data)

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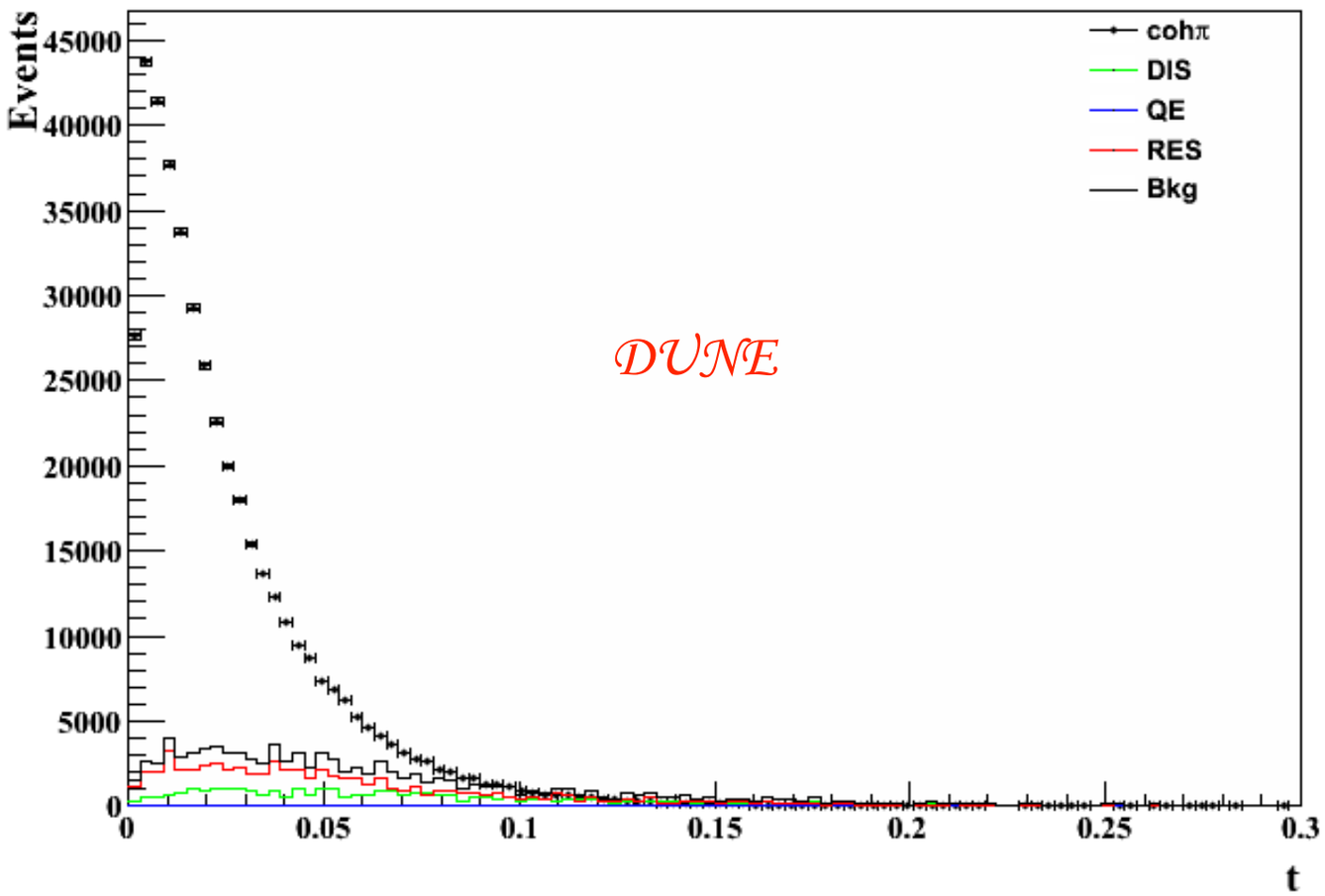

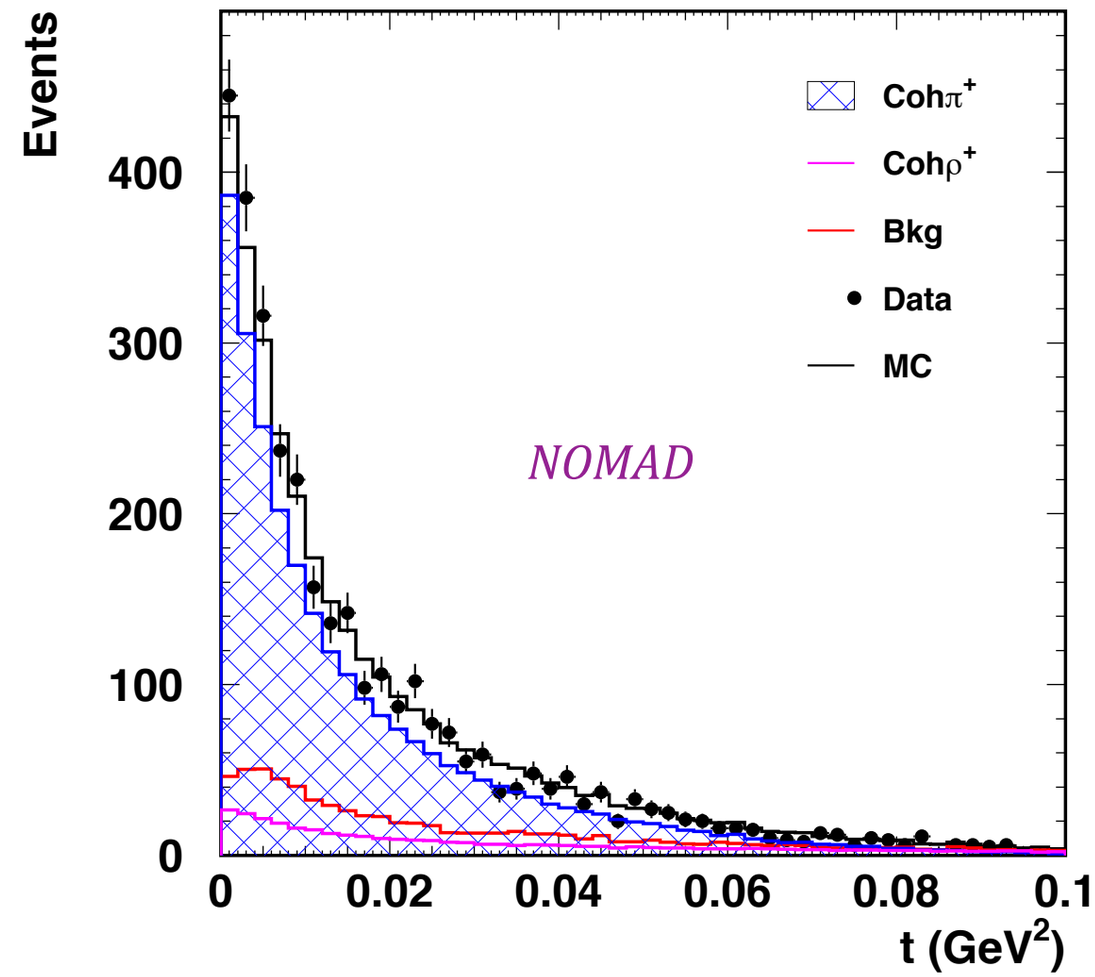

Figure 132: The t distribution in [**2.3**,**7.5**] region.

⇛ *Consistent with Expectation*

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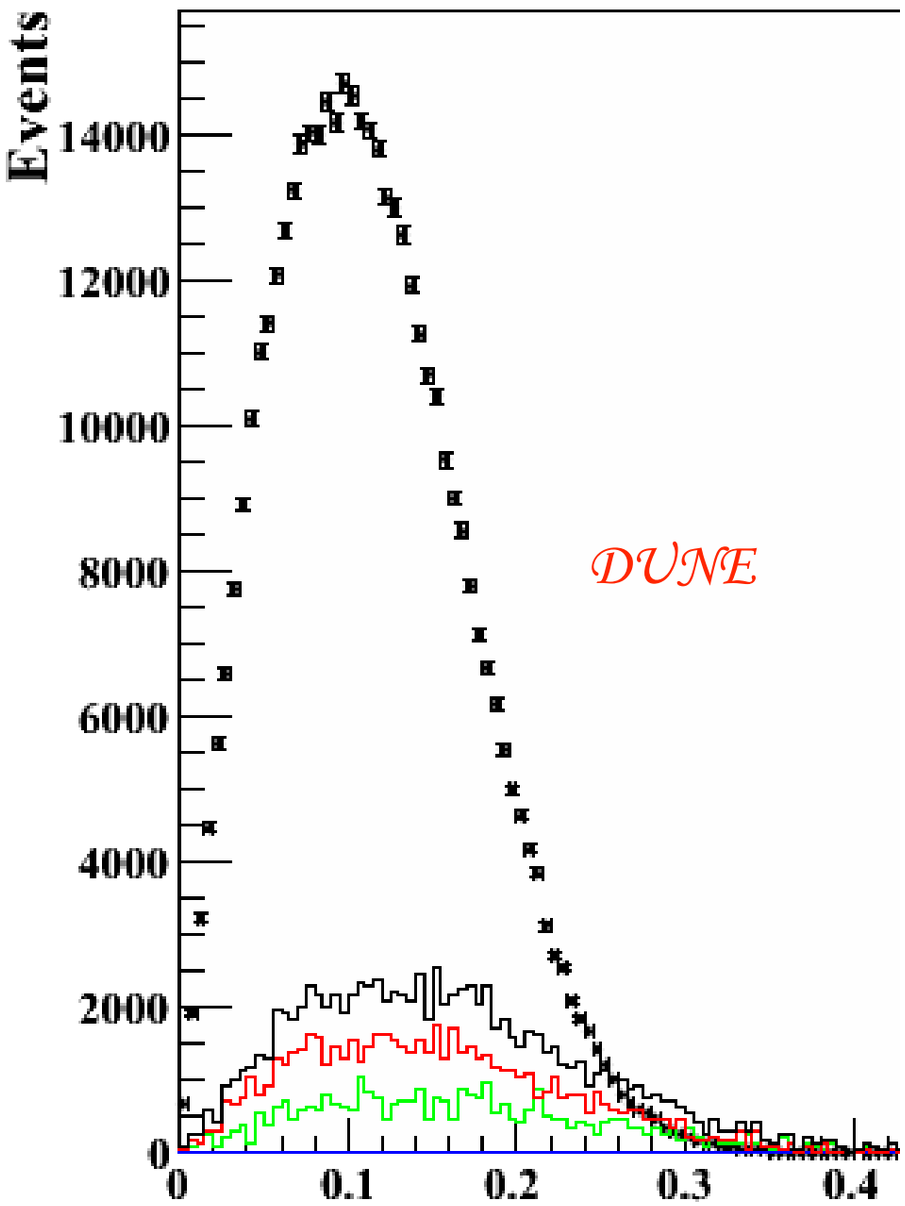
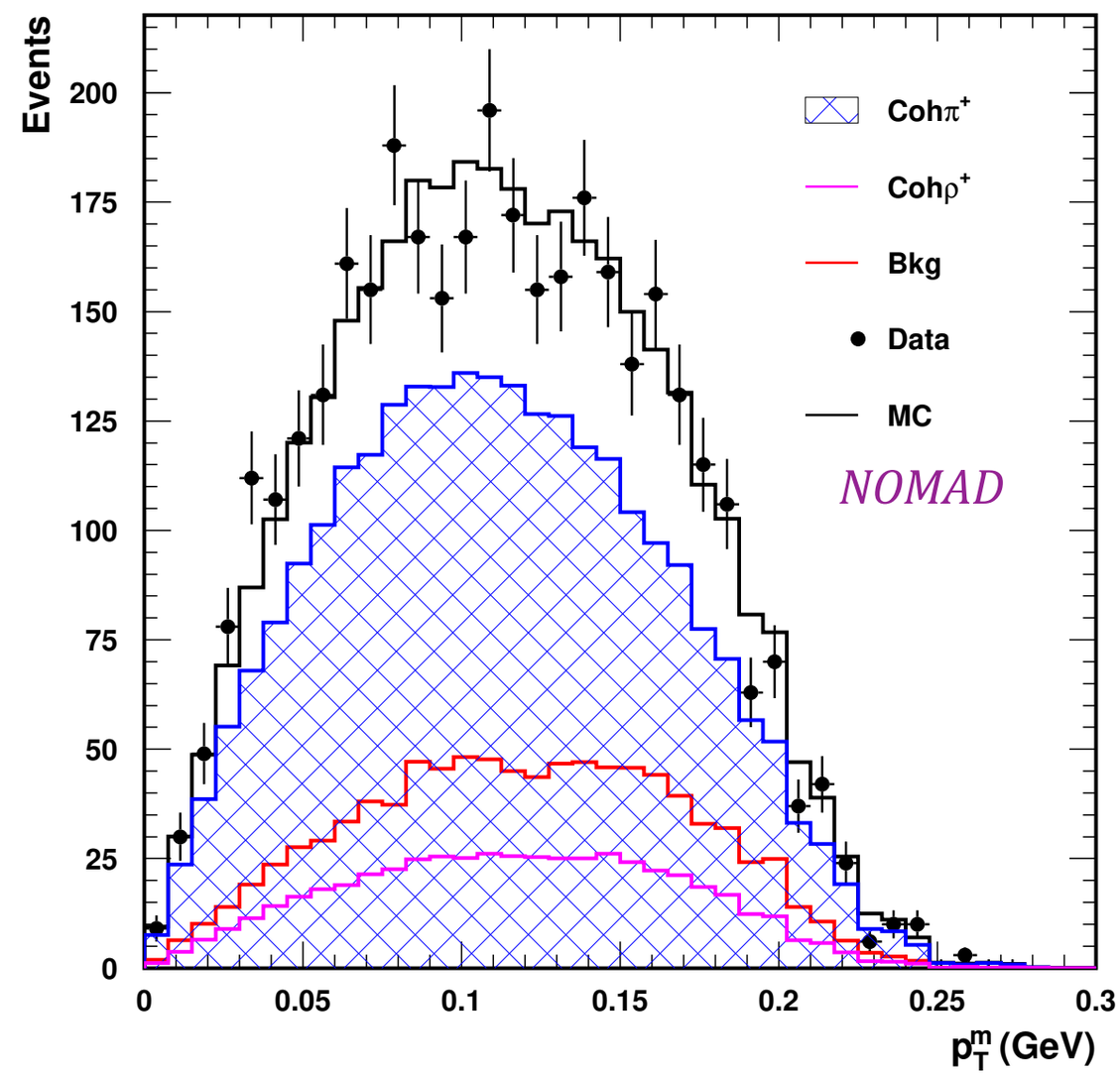
Missing Pt





⇛ Coh π in DUNE should provide the most sensitive measure of:

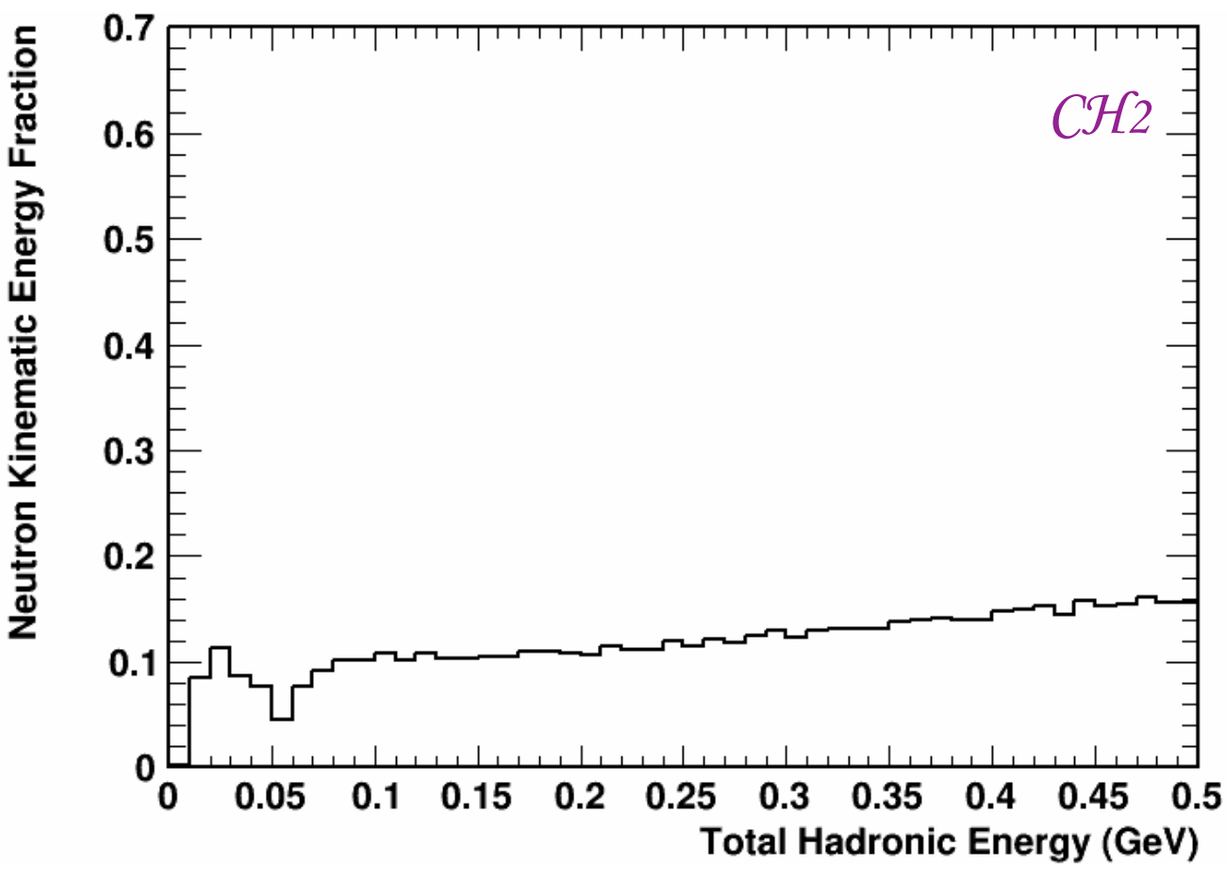
(a) Enu-Scale, (b) $\bar{\nu}/\nu$ Flux, (c) the beam divergence

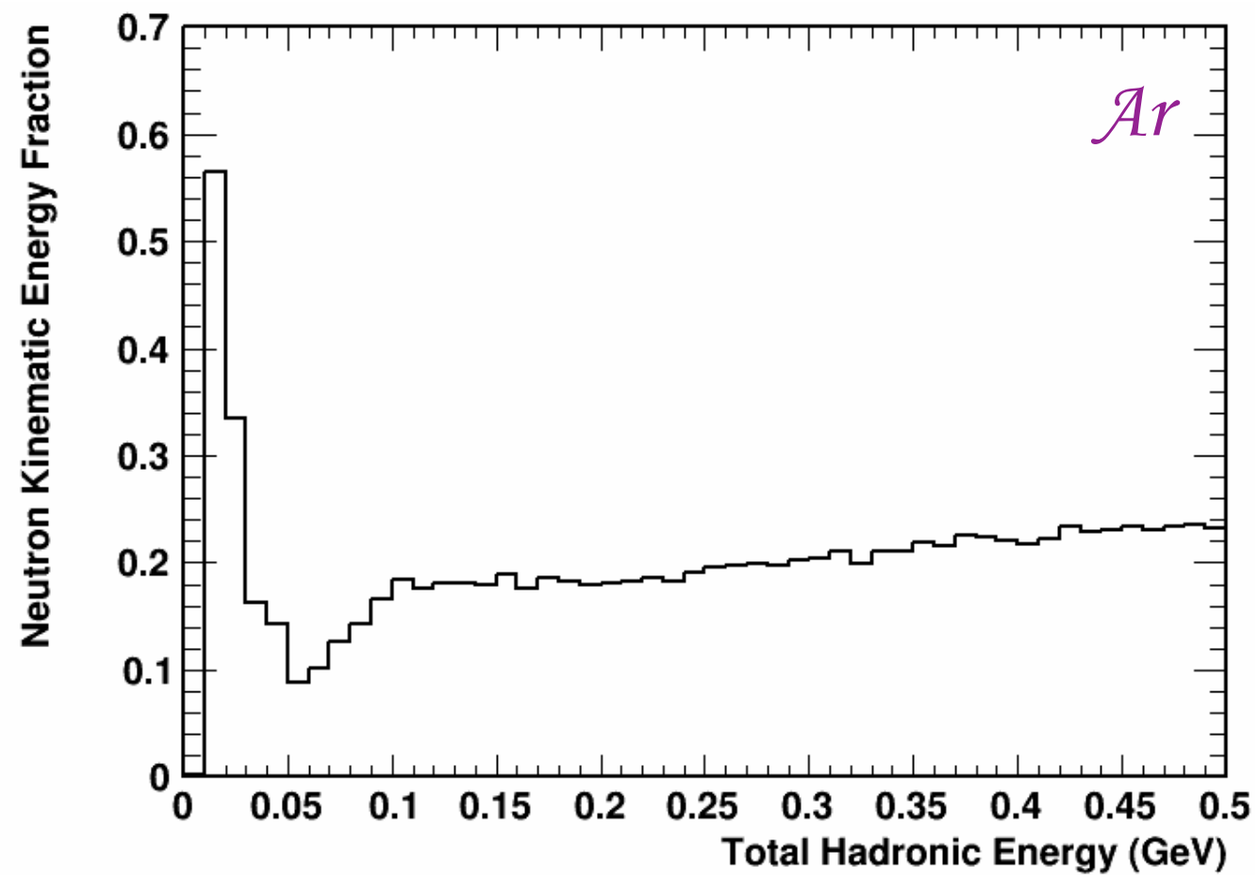
(Very Preliminary! Details @ NG-WG)

Unique Features of STT as DUNE-ND Tracker

- *Low-ν_0 measurement of relative fluxes:*
  - *Small muon energy scale uncertainty in STT* $\sim 0.2\%$;
  - *Fractional energy carried by neutrons in* $(C_3H_6)_n$ *smaller than in Ar (GENIE);*
  - *Use kinematics in transverse plane* (p_T) *to reduce neutron impact;*
  - *Constrain production of primary neutrons by measuring exclusive resonance production;*
  - *Calibrate neutrons in-situ with charge exchange interactions?*

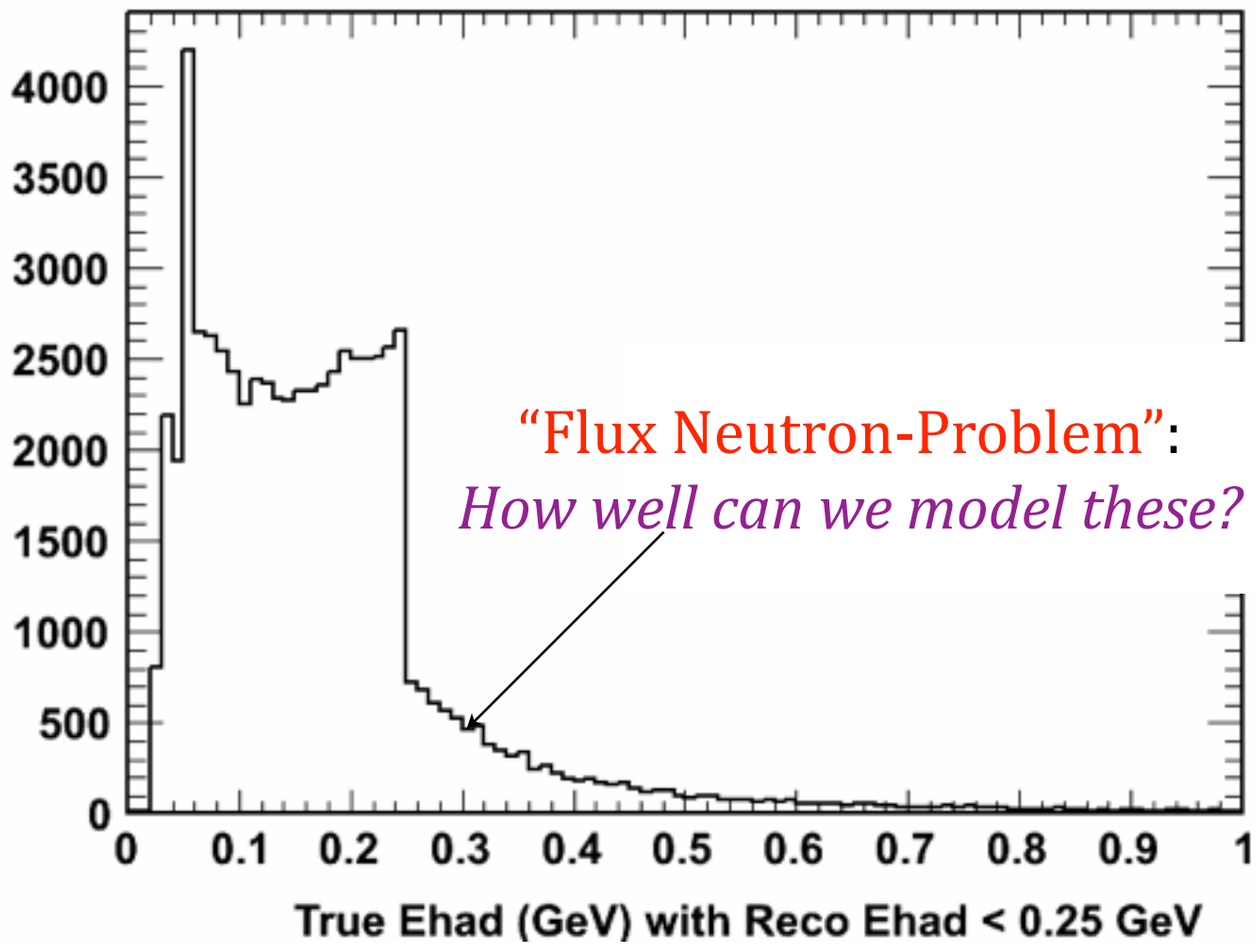
$\Longrightarrow$ *Ongoing studies to assess STT precision and redundancy* $\Longleftarrow$ *short update*





H. Duyang

True Ehad for Rec-ν < 0.25



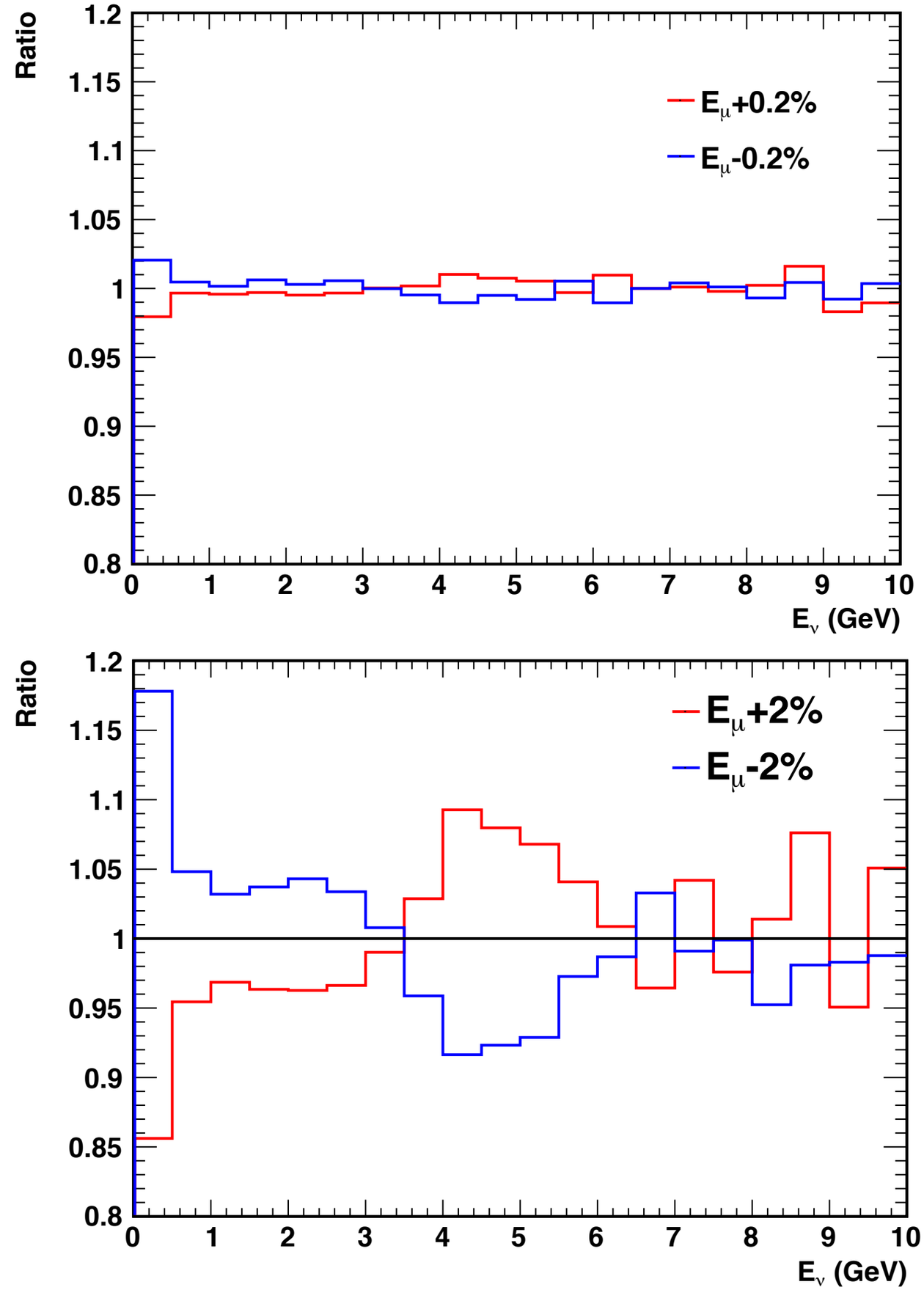
"Flux Neutron-Problem":
How well can we model these?

Constraining "n"

(a) in situ constraints on FSI using QE & Res
(b) in situ constraint on "n" using charge-ex
(c) Kinematic cuts to isolate n-rich events
(d) MC modeling

see presented talks

One of the largest sources of Error:
Systematic error on the E_μ-scale



Hybrid Detector & Size of STT

(1) Synergy between LAr & STT Detectors:

⇒ Use STT as the spectrometer for LAr

⇒ LAr provides an in-situ check of STT prediction for the FD (on Ar)

⇒ Combined LAr & STT provide the most precise ν-e measurement
(Proposed by Petti in 2012!)

(2) We do not fully understand the complementarity between STT & Others ?

(3) We do not fully understand the "size" issue at this point ?

⇛ *Nevertheless, some thoughts …*

(A) CRITICAL Dimension of STT: Transverse dimension

⇒ **3.5m** x **3.5m** is about the minimum to attain the goals

⇒ It is NOT matter of statistics:

π^0-Reconstruction, proton & $\pi^{+/-}$ (from QE & Res) emitted at large angles, need a large aperture detector

Smaller detector would adversely effect the systematic precision

⇒ Spectrometer for LAr benefits from large aperture

(B) Longitudinal Dimension of STT:

⇒ We can live with 4.5m long STT … Price ⇒ (electron ID, pi0 reconstruction, muon-momentum resolution, statistics, etc.).

⇒ ..However, before changing to make room for GAr, physics justification should be made.

(C) STT & GAr-TPC:

⇒ GAr-TPC does provide better measurement of low-momenta, charged hadrons

⇒ …But for all other particles, esp. above ~2 GeV, STT does better e-ID

⇒ Assuming an LAr, the need for *same-A* is obviated

⇒ STT provides the "unsmearing of A-effects" that neither LAr or GAr can

⇛ Even when ND carries a FRACTION (5%!!) of the cost of the program, in every single Long Baseline Experiment, the ND — *upon whose shoulders lays the burden of systematic error* — is compromised.

Let us not do this to DUNE (at the outset)!

Backup

Salient Variables: (analysis validated by NOMAD data)

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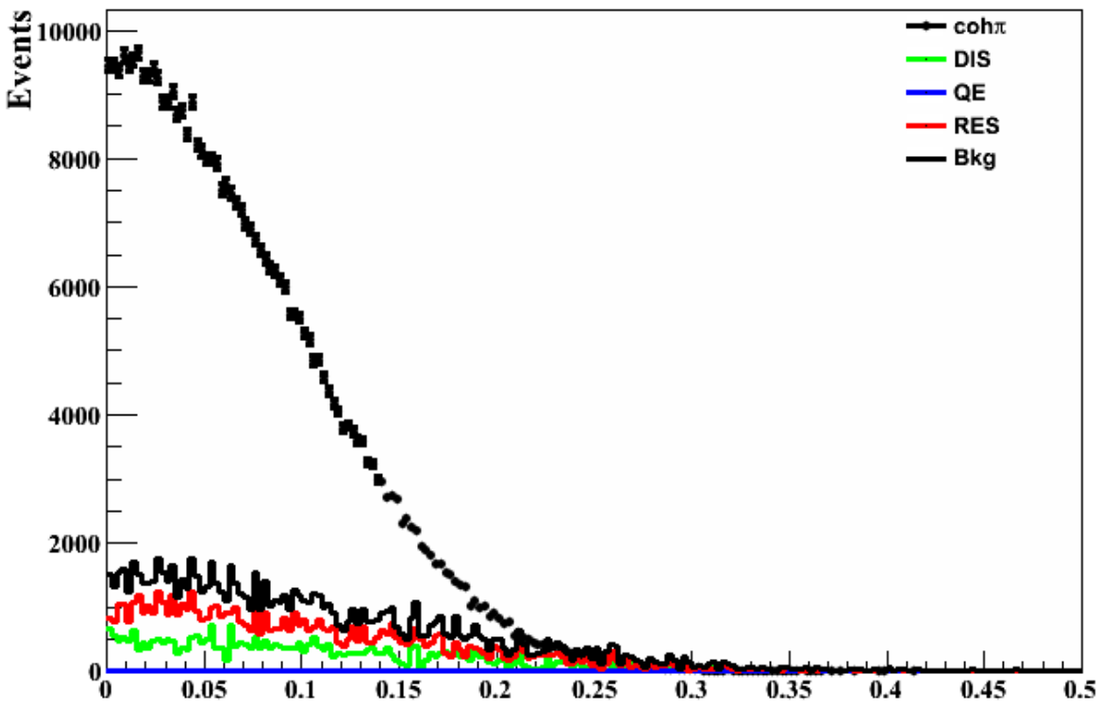
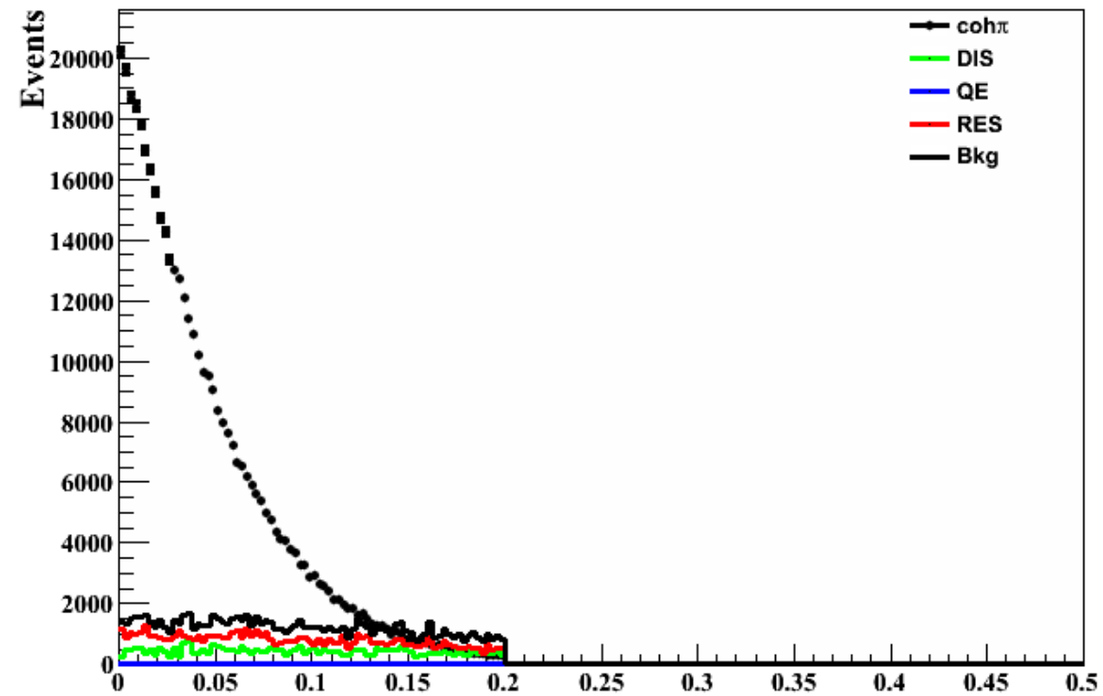
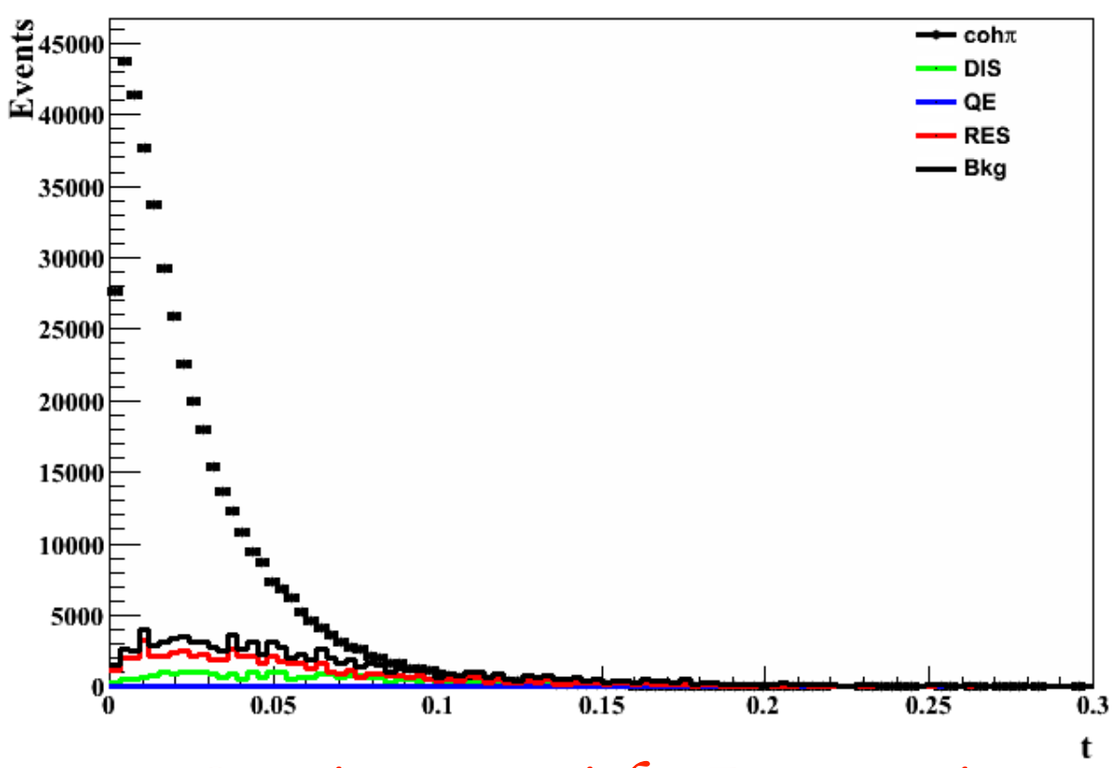
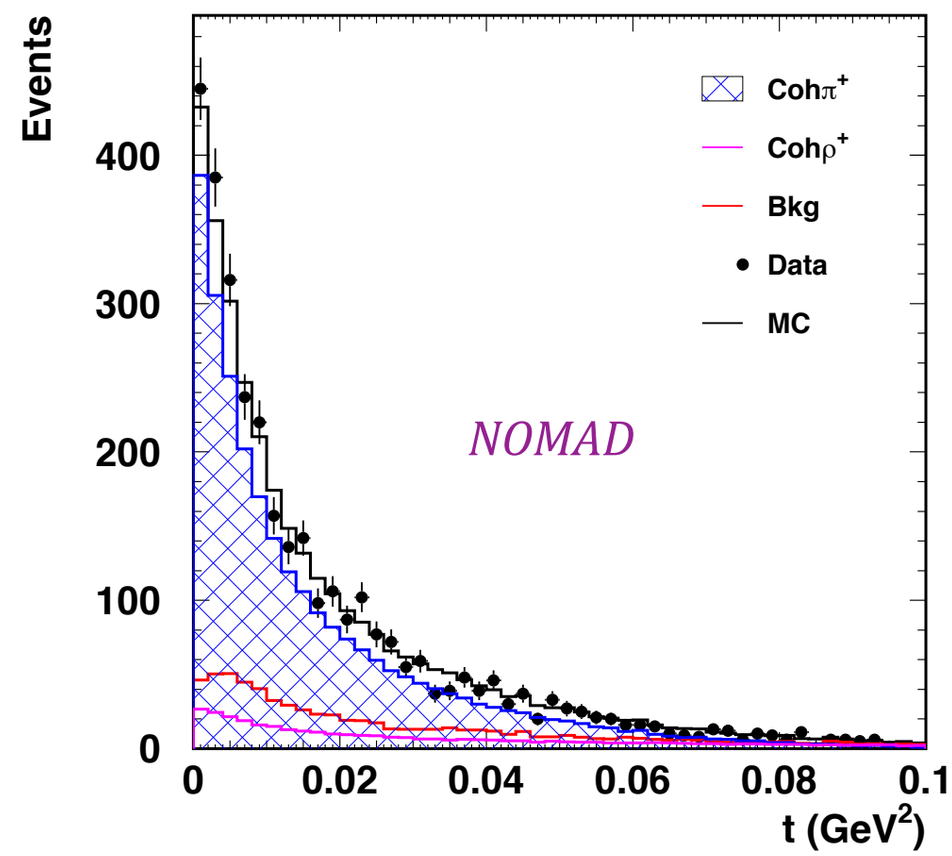


Pi-Pt wrt Muon ρ



Ppi*ThPi**2 ζ





⇛ *Consistent with Expectation*

Low-ν Flux & Empirical Parametrization of π^+/K^+

(1) Determine the Flux-Shape using Low-ν data in ND in Radial-bins

(2) Using this Low-ν flux and the Beam-MC, fit the differential cross-section of the π^+/K^+ production: $d\sigma / dx\, dPt = f(x) * g(Pt) * h(x,Pt)$

⇛

(a) Fully correlated FD flux, relative to ND, which is driven by data

(b) ν_e / ν_μ, & $\bar{\nu}_e / \bar{\nu}_\mu$

(c) Additional uncertainty due to the functional forms

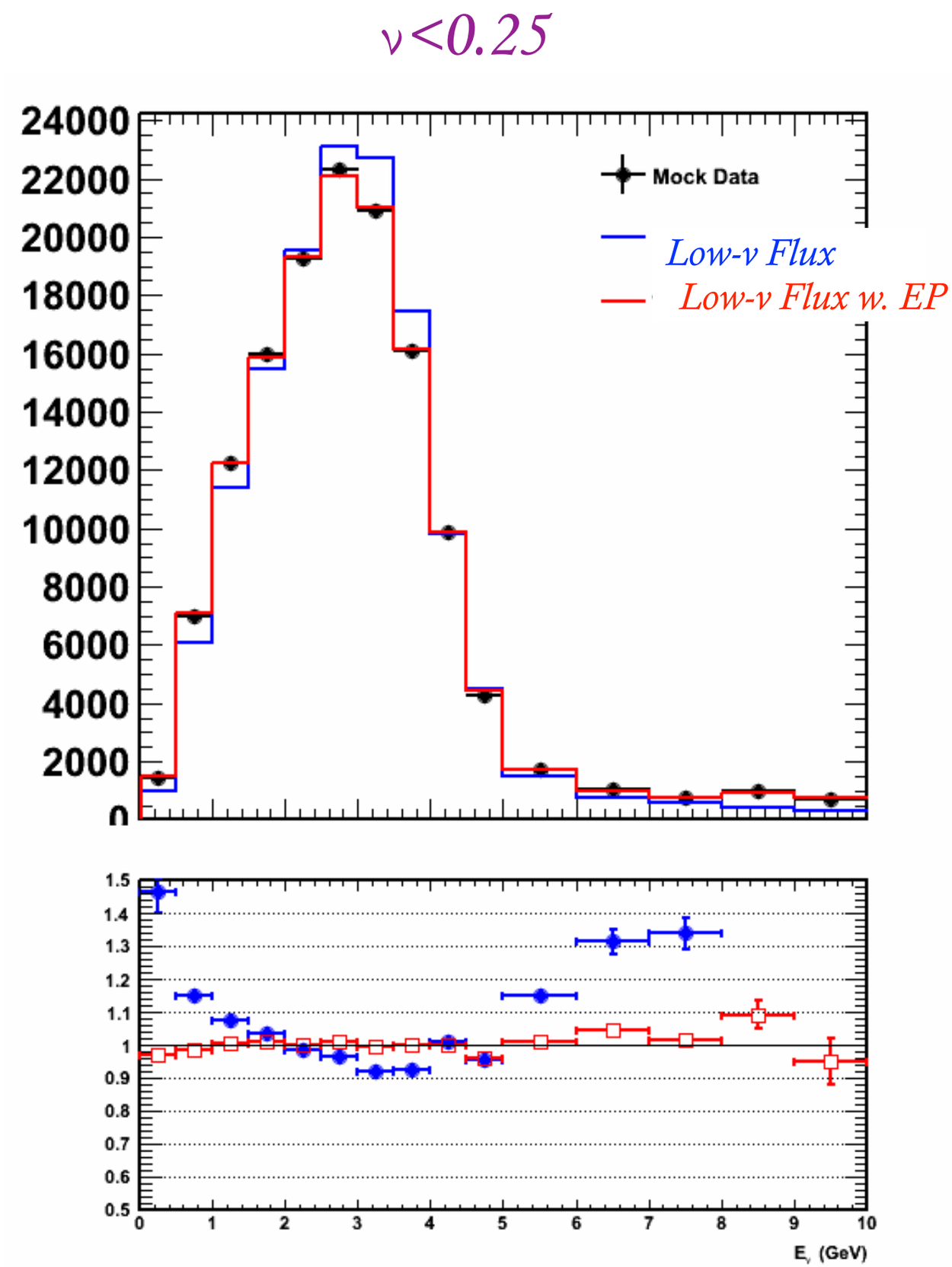


Figure 31: EP fit result with $E_{neutron} > 0.1$ GeV, and $100\%/\sqrt{E}$ smearing.