THE INTERNATIONAL DESIGN STUDY FOR THE NEUTRINO FACTORY

Detector working group: summary from IDS-NF#9 and plans

9th IDS-NF Meeting

Fermilab

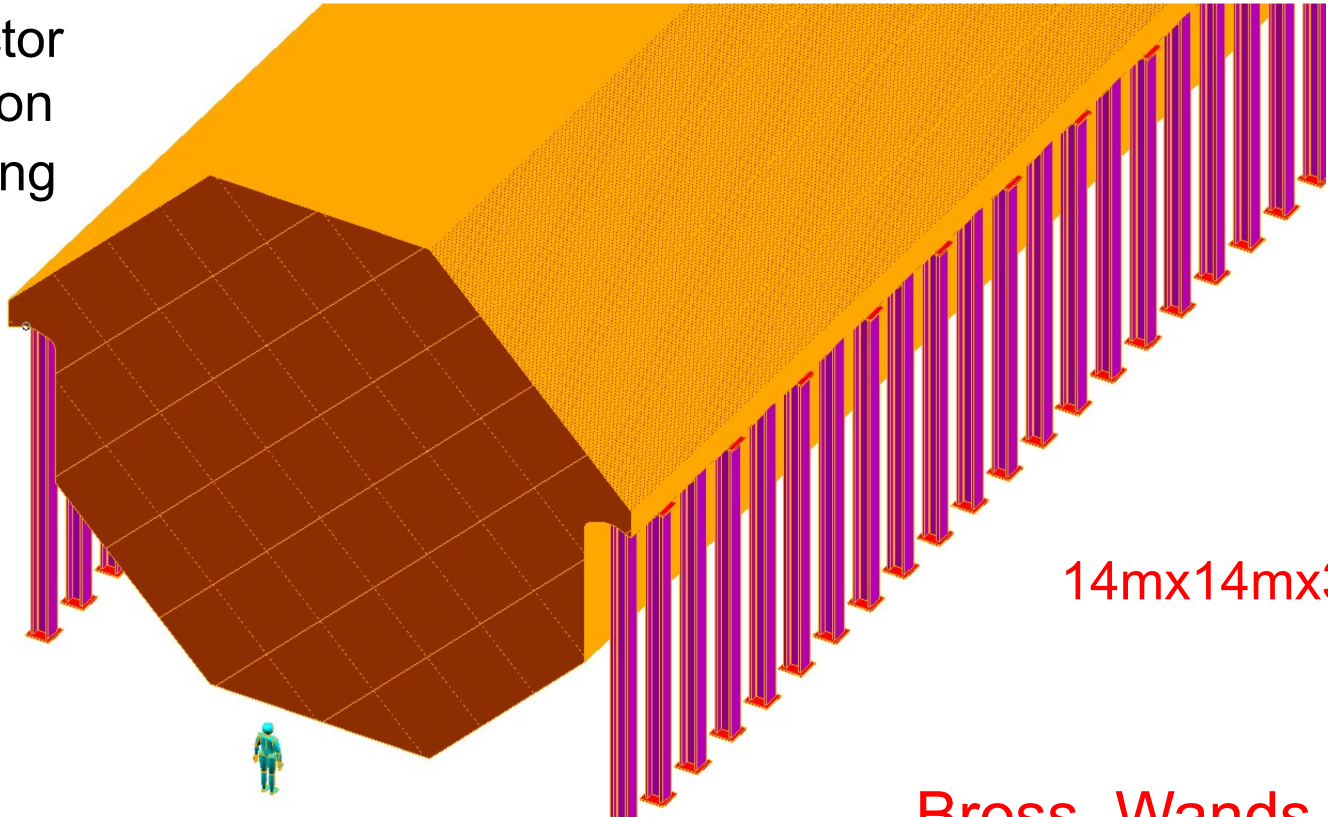
Paul Soler, 10 October 2012

University of Glasgow

MIND baseline (reminder)

- Toroidal field and octagonally shaped detector (as in MINOS)
  - Feasible engineering and known magnetic field map

One detector
M~100 Kton
~100 m long



14mx14mx3cm plates

Bross, Wands (FNAL)

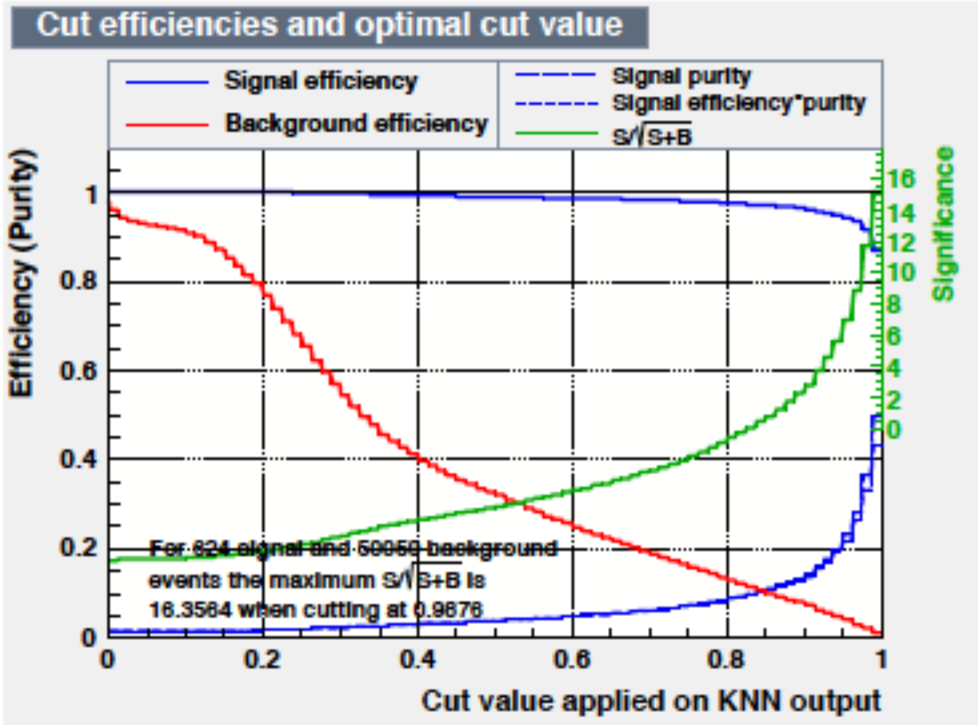
MIND: changes in analysis

- Developments in analysis: multivariate analysis **Ryan Bayes**
- Variables for CC selection: **Work in progress: not converged yet**
  - Muon trajectory
  - Hadron reconstruction
  - Energy deposition
  - Deposition fraction
  - Deposition variation

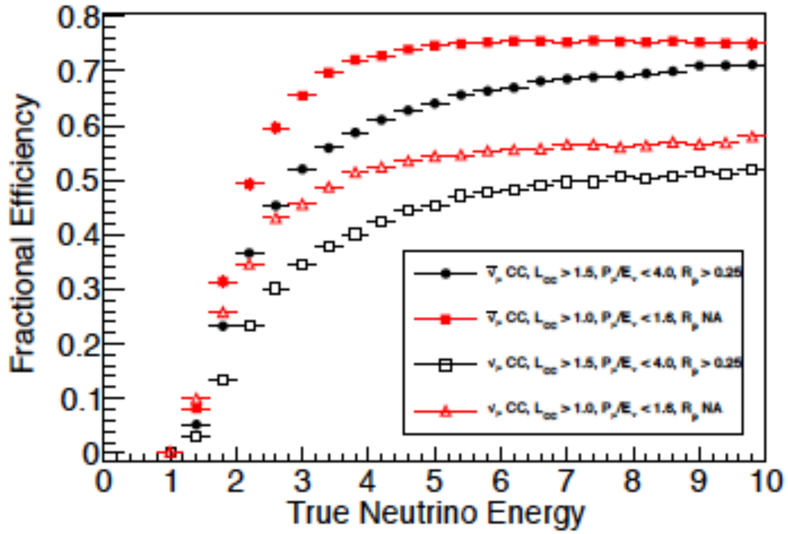
NC Rejection of Muon Track

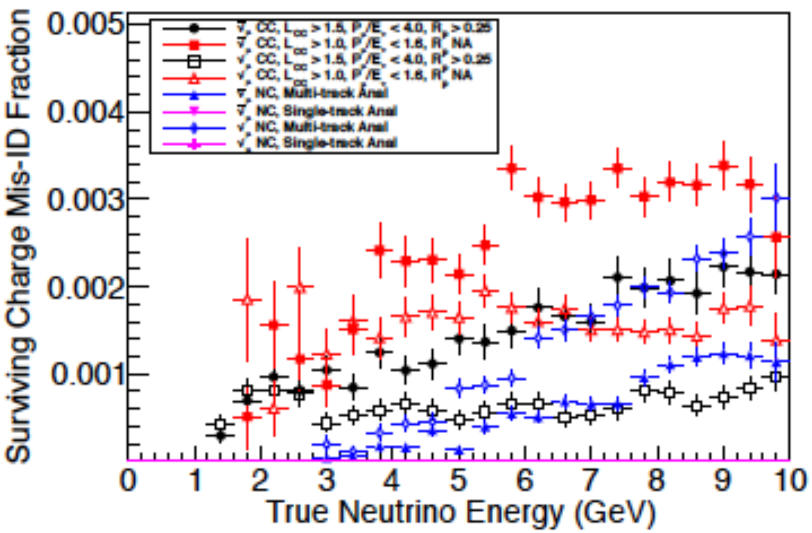
- Muon track fit successful
- $p_\mu < 4.0 \times E_\mu$
- $z_{length} - z_{vertex} > 1$ m
- $\frac{N_{fit}}{N_{cand.}} < 60\%.$
- $R_p = \frac{q_{fit}}{p_{fit}} \times \frac{p_{init}}{q_{init}} > 0.25$
- $\log \frac{P(\sigma_{qp}/qp|CC)}{P(\sigma_{qp}/qp|NC)} > -0.5$
- $\log \frac{P(N_{hit}|CC)}{P(N_{hit}|NC)} > 1.5$

Example KNN Method



MIND reanalysis: effect of changes





Ryan Bayes

- Red for Single track reconstruction
- Black for Multiple track reconstruction.

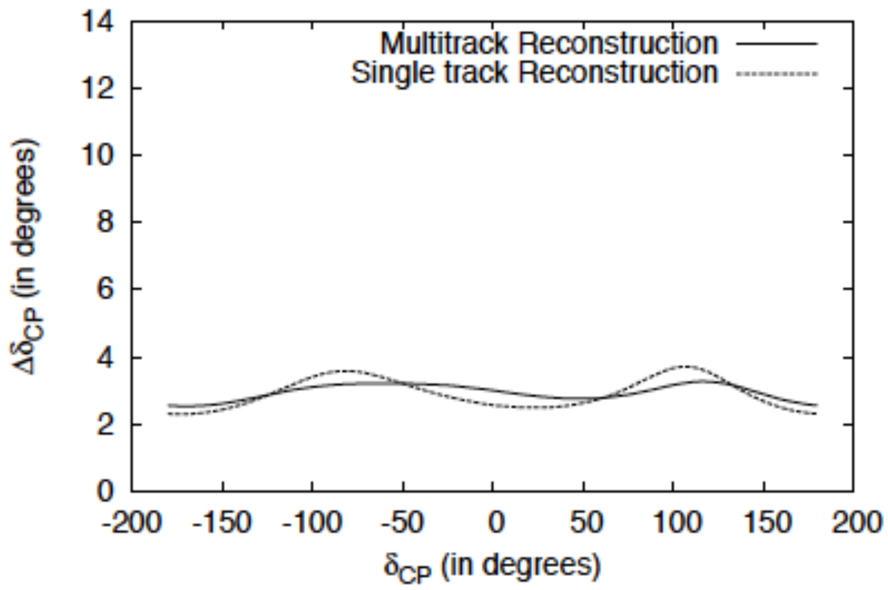
Result of Changes

- Reduced signal efficiency.
- Reduced background fraction.
- Energy threshold unchanged.
- Need to calculate $\Delta\delta_{CP}$
- Neutral current backgrounds are significant in multiple track reconstruction.

MIND reanalysis: effect of changes

Ryan Bayes

- Default definition of χ^2 assumed.
- Compare new analyses to EUROnu analysis.



- Decreases sensitivity to δ_{CP} by $< 1\%$
- Precision increases on average
- Have tested $\mathcal{L}_{CC} > 1$
  - No significant difference
  - background larger (not shown).

Energy staging question

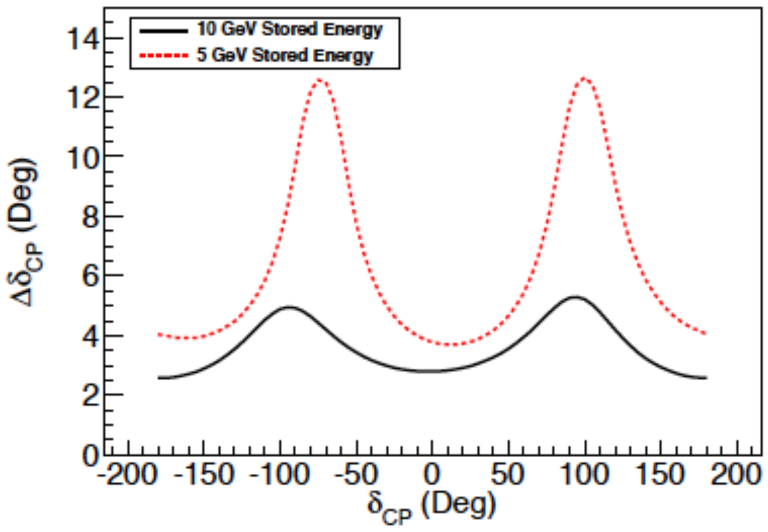
5 GeV Staging

Ryan Bayes

- Used EUROnu MM, Consider 5 GeV at 1300 km and 2000 km.
- Taken from private e-mail,"Re:Break points in muon acceleration", 31 July, 2012

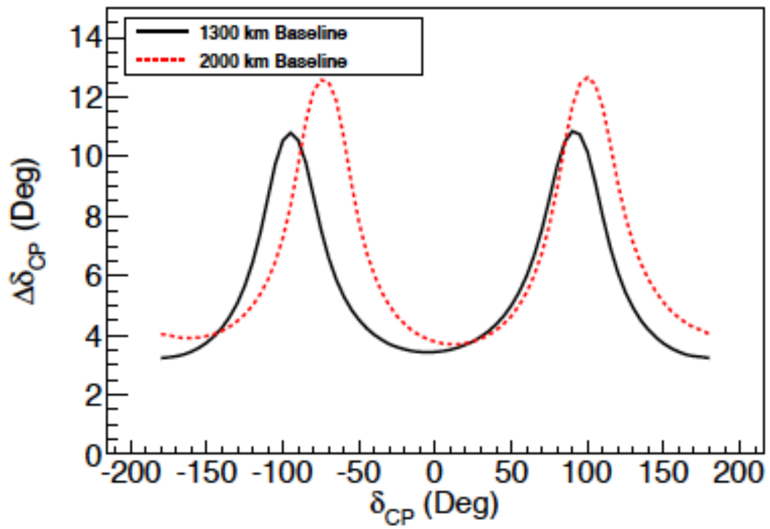
Energy staging not recommended

Fixed 2000 km Baseline



- 5 GeV: 66% 5σ CP Coverage.

Fixed 5 GeV Energy



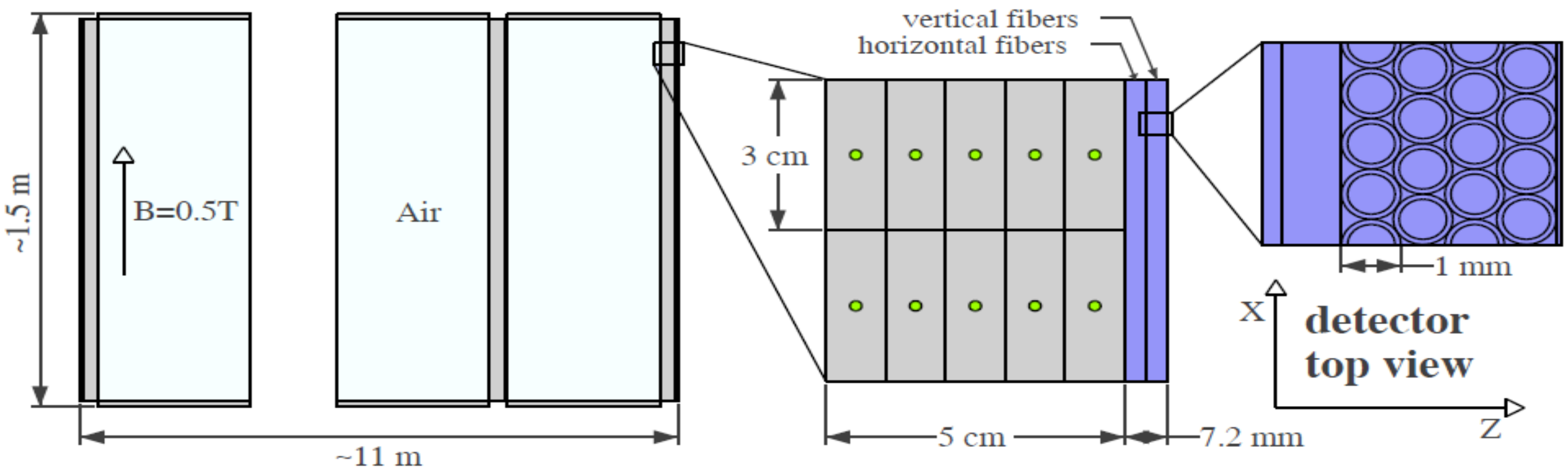
- 1300 km: Covers 80% 5σ CP.

Scintillating Fibre design

Roumen Tsenov, Rosen Matev

- 20 tracker stations
  - each consists of 4 horizontal and 4 vertical layers of 1 mm diameter scintillating fibres shifted with respect to each other and 5 cm thick active absorber, divided into 5 slabs to allow for more precise measurement of recoil energy near the event vertex;
- 12 000 fibres per station (240 000 in total);
- Air gaps are closed by a layer of scintillating bars;
- Overall detector dimensions: 1.5 x 1.5 x 11 m^3 (2.7 tons of polystyrene);

Adopted as baseline for EUROnu report



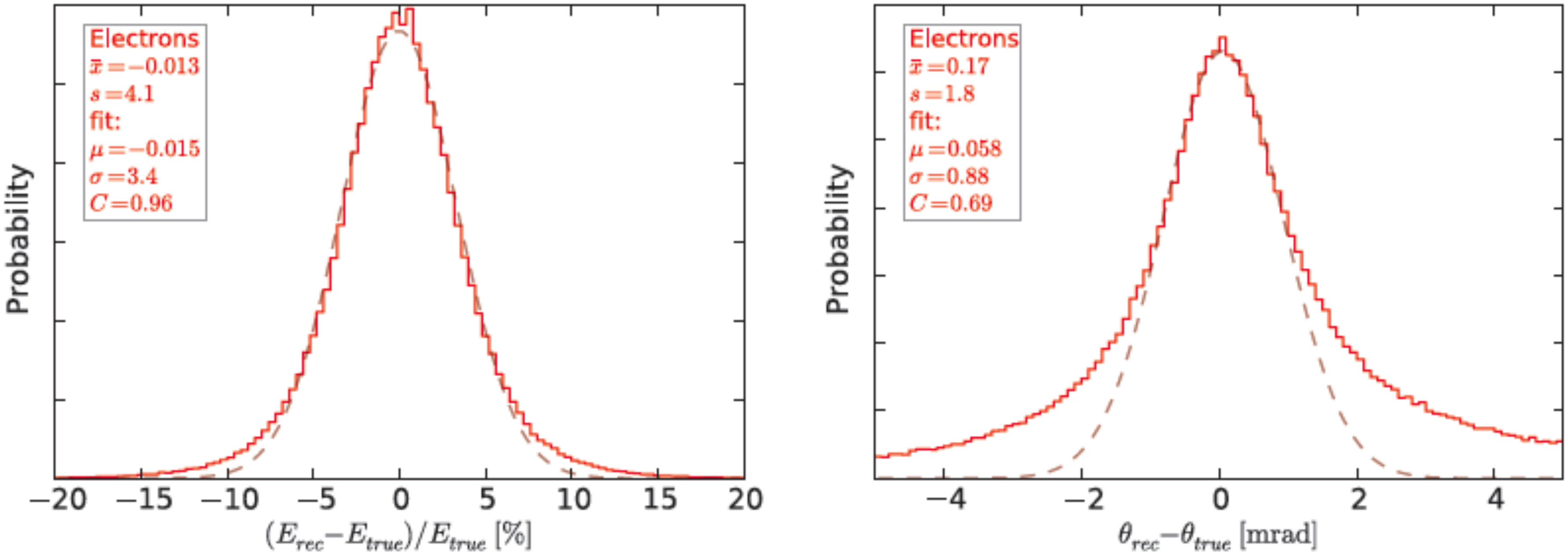
Scintillating Fibre performance

- 10 GeV resolutions:
- No IMD, only electron scattering

Update from Rosen Matev

$$\nu_\mu + e^- \rightarrow \nu_\mu + e^- \quad \bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$$

$$\nu_e + e^- \rightarrow \nu_e + e^- \quad \bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$$



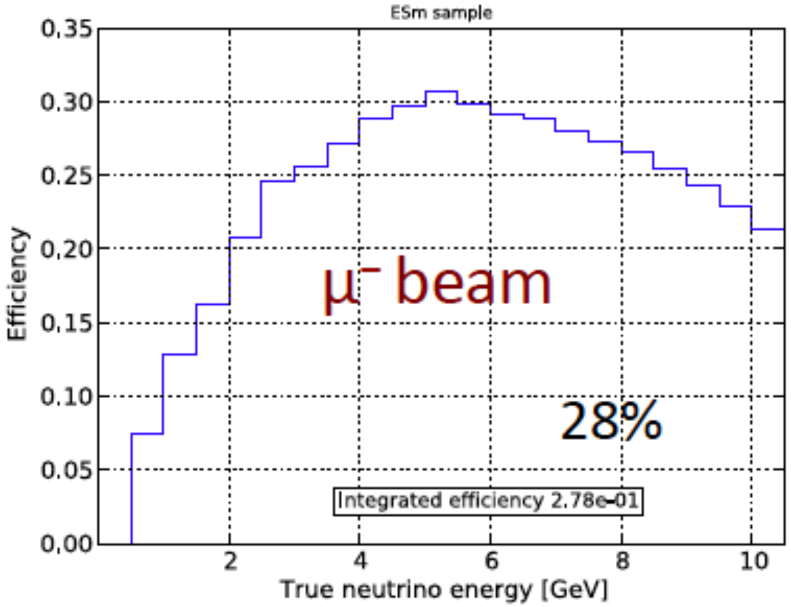
- Electron energy **σ(E)/E = 3.4%** (from ECAL)
- Electron angle **σ(θ) = 0.88 mrad**

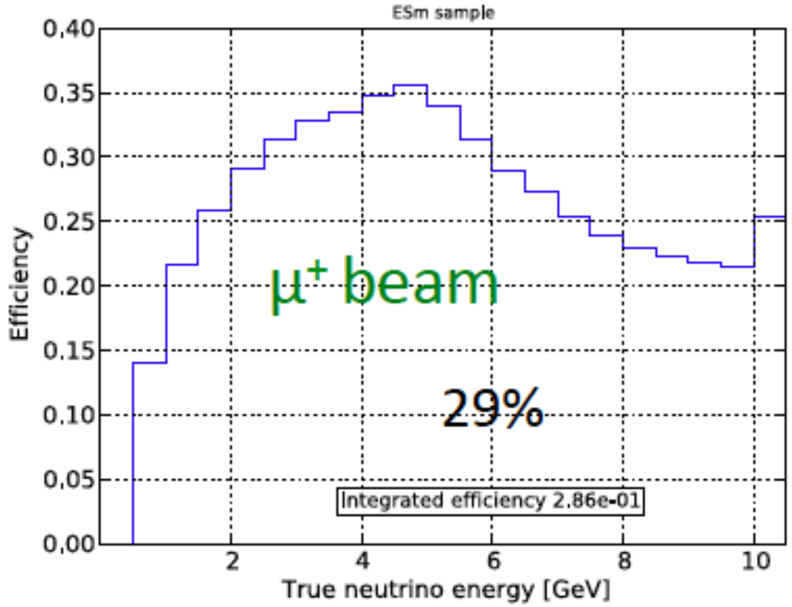
Scintillating Fibre performance

- 10 GeV resolutions:
- No IMD, only electron scattering

Update from Rosen Matev

$$\nu_\mu + e^- \to \nu_\mu + e^- \quad \bar{\nu}_\mu + e^- \to \bar{\nu}_\mu + e^-$$
$$\nu_e + e^- \to \nu_e + e^- \quad \bar{\nu}_e + e^- \to \bar{\nu}_e + e^-$$





- Reconstruction efficiency ~43%
- Selection cuts ~66%

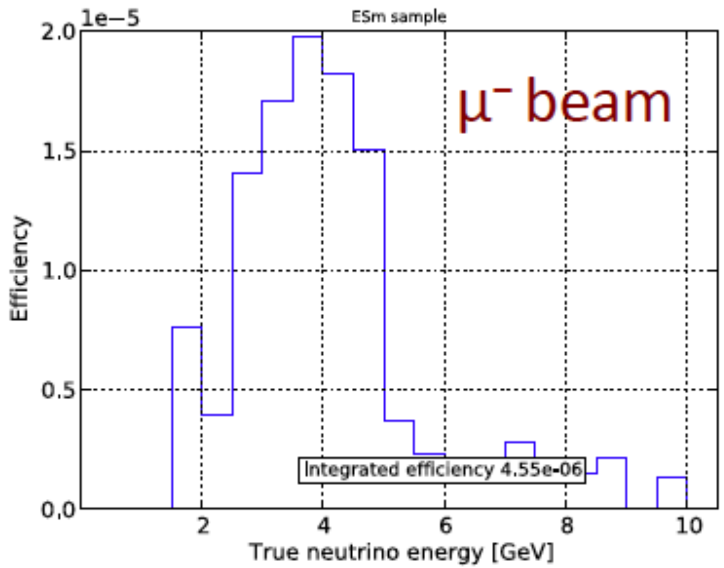
Scintillating Fibre performance

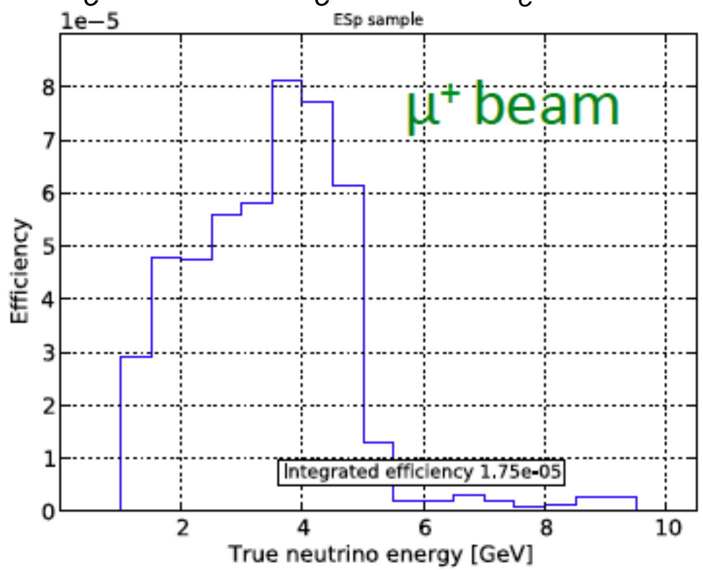
- 10 GeV resolutions:
- No IMD, only electron scattering

Update from Rosen Matev

$$\nu_\mu + e^- \rightarrow \nu_\mu + e^- \quad \bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$$

$$\nu_e + e^- \rightarrow \nu_e + e^- \quad \bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$$



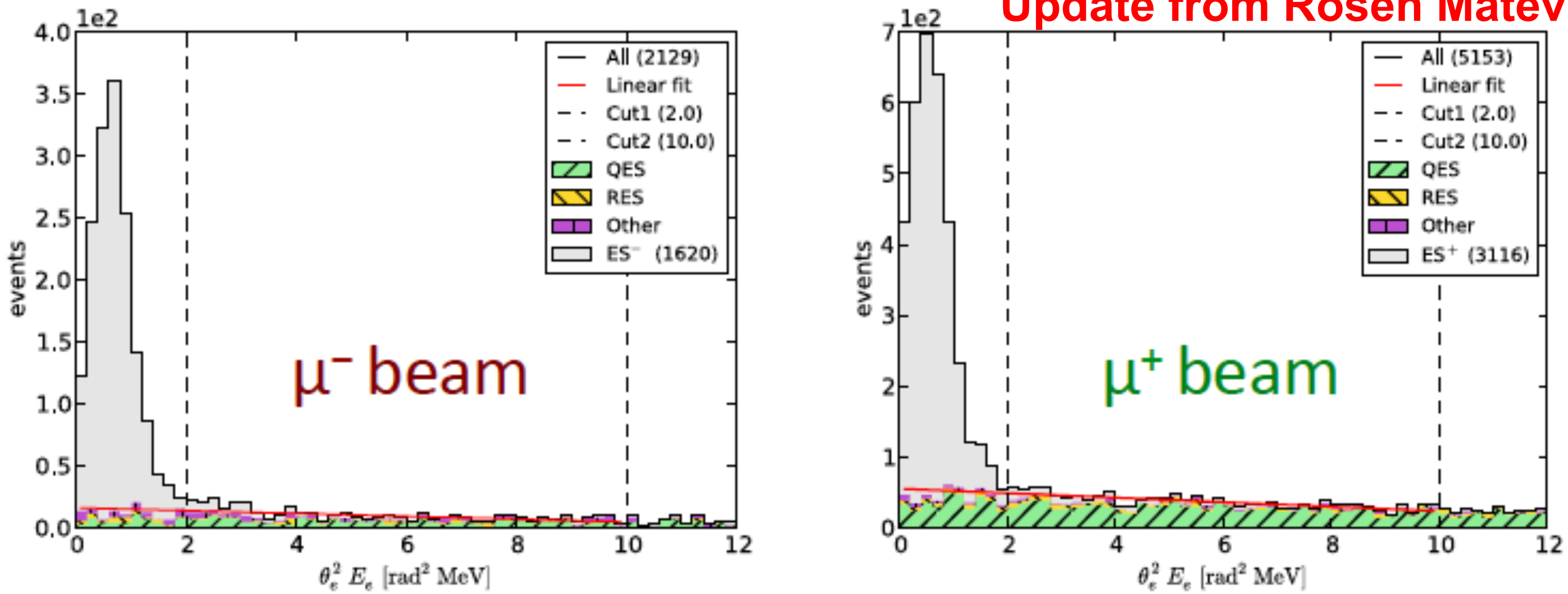


(fluctuations due to low statistics)

- Substantial background rejection
- μ^- beam – $5\text{x}10^{-6}$
- μ^+ beam – $2\text{x}10^{-5}$

Scintillating Fibre performance

Update from Rosen Matev



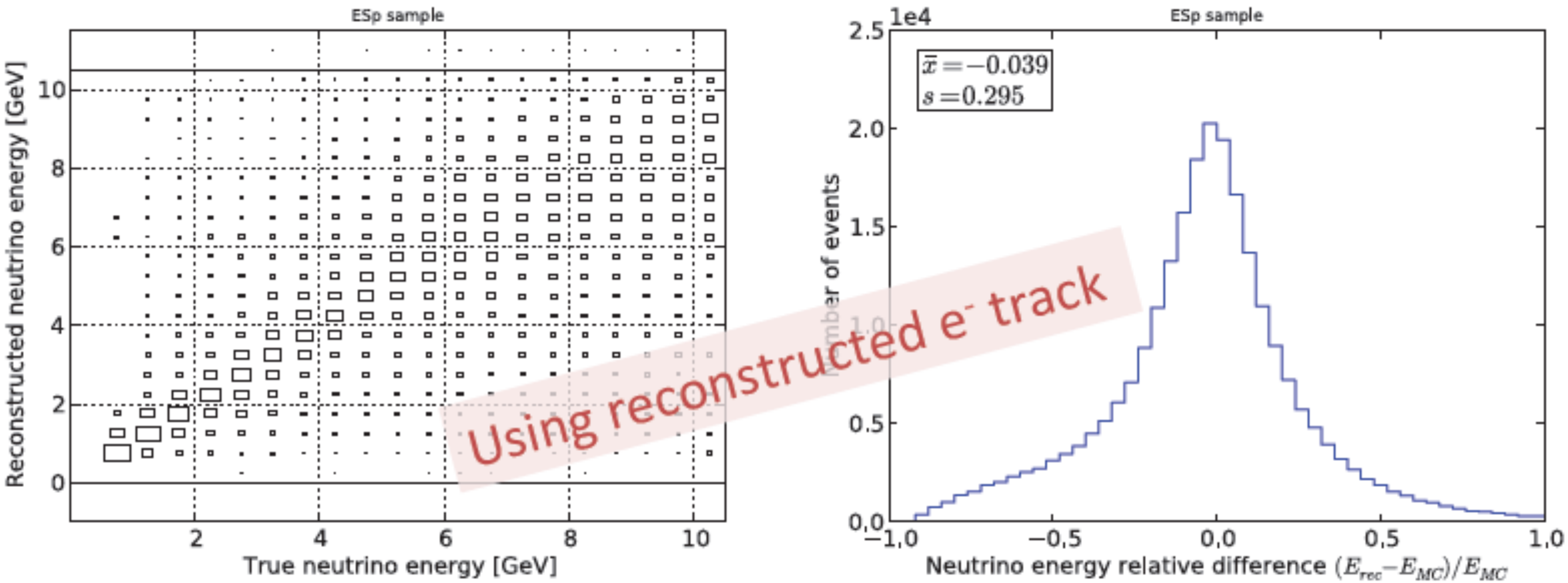
Statistics correspond to 2/10 of a nominal year (5×10^{19} μ^- decays and as many μ^+ decays)

Sample	Efficiency	Purity	Signal + Bgr	# signal	# signal linear fit
ES^-	29%	92%	1637	1511	1486 ± 40
ES^+	28%	86%	3414	2951	2892 ± 58

Need to estimate number of background events with 10% precision to have 1% uncertainty on number of signal events

Scintillating Fibre performance

Update from Rosen Matev



- Theoretical performance of method – 12%

  (with current NF neutrino flux Monte Carlo)

- Best achieved performance – 30%

Flux extrapolation simulation

A Laing, PS

- Extrapolation near-to-far at Neutrino Factory:
  - Matrix extrapolation method: $N_{FD} = M_{FD} P_{osc}(\theta_{13}, \delta_{CP}) M_{nOsc} M_{ND}^{-1} N_{ND}$

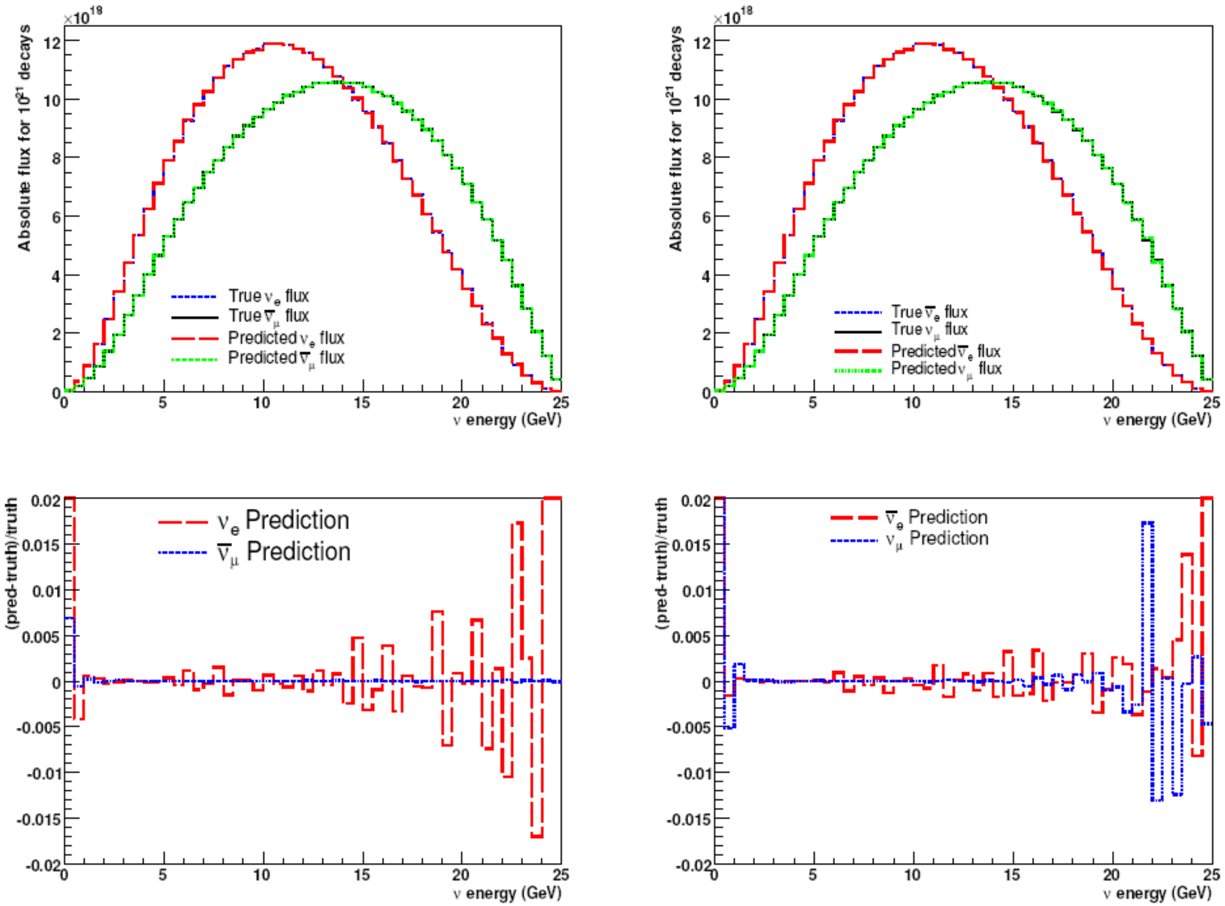
$$\frac{\Delta E(\nu_\mu)}{E(\nu_\mu)} = \frac{20\%}{\sqrt{E(GeV)}}$$

$$\frac{\Delta E(\nu_e)}{E(\nu_e)} = \frac{35\%}{\sqrt{E(GeV)}}$$

$$\varepsilon(\nu_\mu) = \begin{cases} 60\% & E > 4\,GeV \\ 15\%E & E < 4\,GeV \end{cases}$$

$$\varepsilon(\bar{\nu}_\mu) = \begin{cases} 80\% & E > 4\,GeV \\ 20\%E & E < 4\,GeV \end{cases}$$

$$\varepsilon(\nu_e) = \begin{cases} 70\% & E > 4\,GeV \\ 17.5\%E & E < 4\,GeV \end{cases}$$

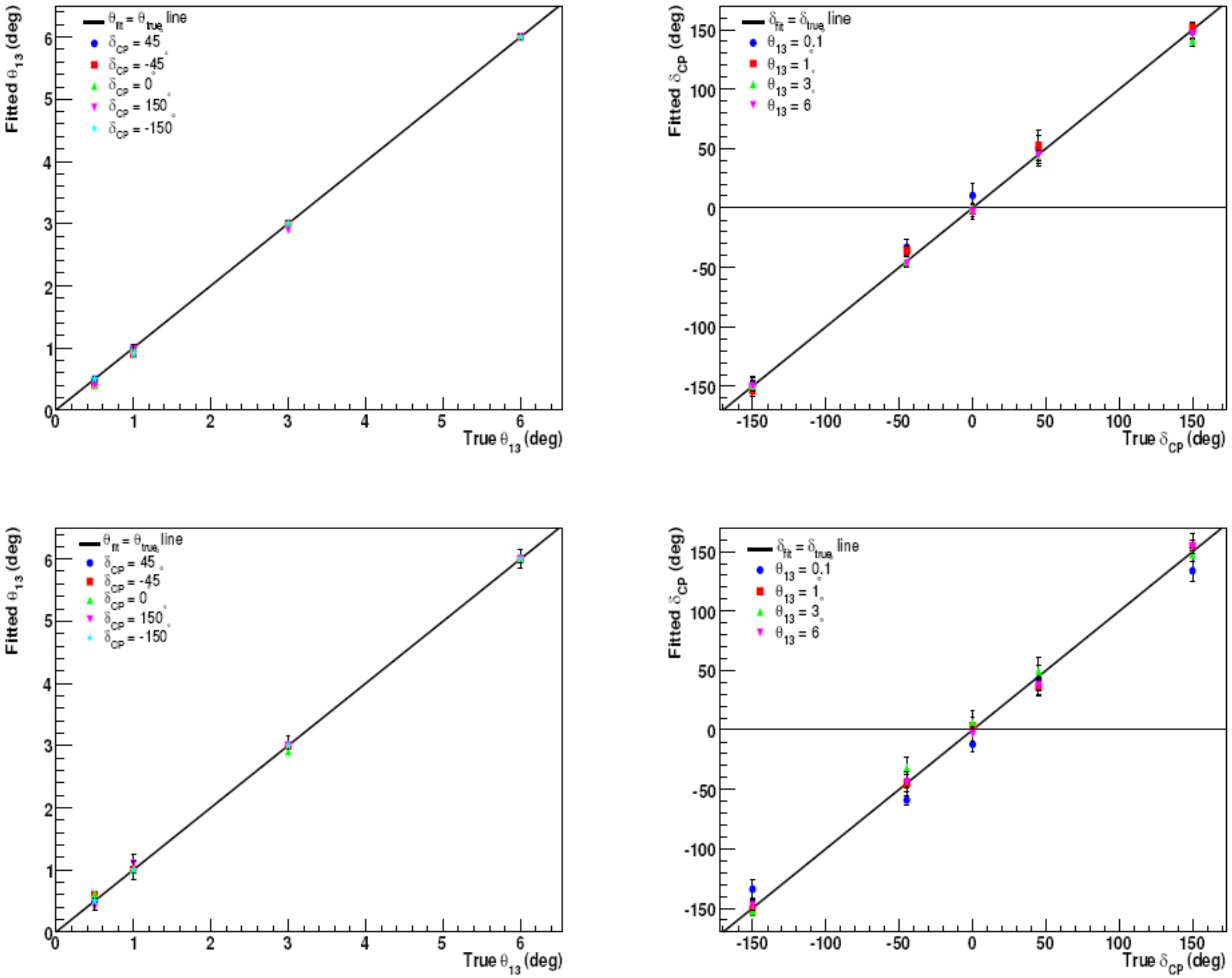


Prediction of flux from response matrices

Flux extrapolation results

- Fitted vs true values of θ_{13} and δ_{CP}: no observed biases

Fitted θ_{13} vs true value



Fitted δ_{CP} vs true value

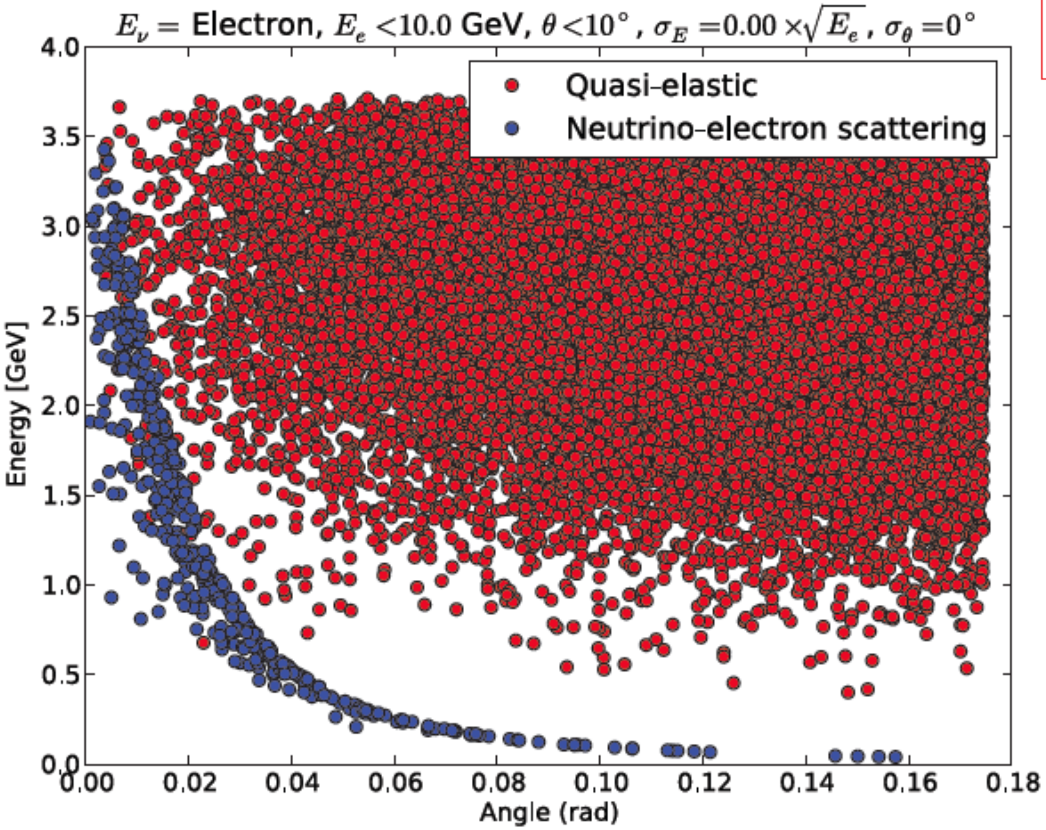
- Need to reproduce these results with 10 GeV NF

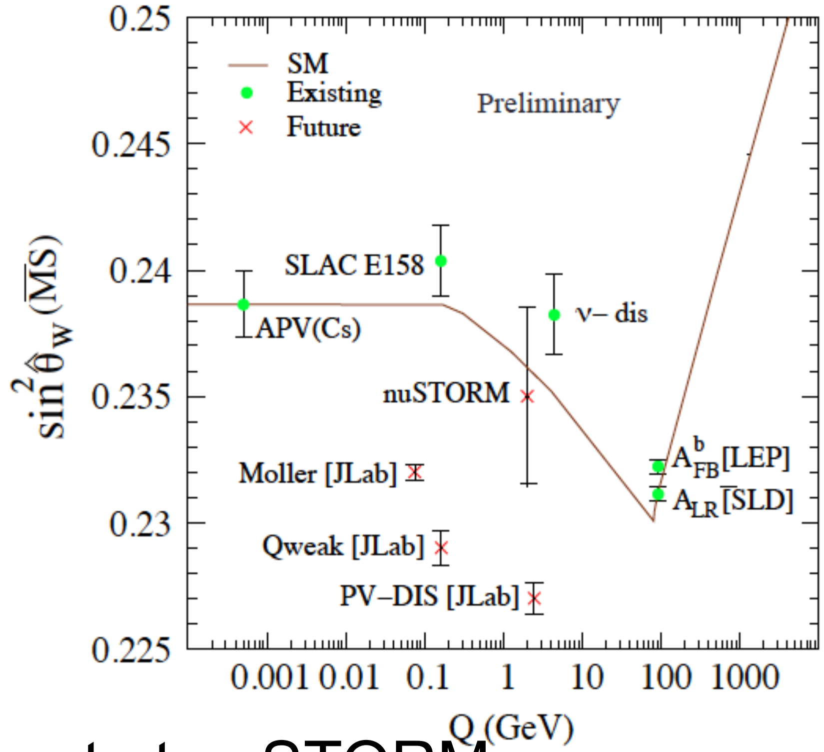
Electroweak measurement in νSTORM

- Measurement of $\sin^2\theta_W$ from leptonic processes in nuSTORM

$$\frac{d\sigma}{dT} = \frac{2G_F^2 m_e}{\pi E_\nu^2}\left[\alpha^2 E_\nu^2 + \beta^2 (E_\nu - T)^2 - \alpha\beta m_e T\right]$$

	$\nu_e e \to \nu_e e$	$\nu_\mu e \to \nu_\mu e$	$\bar{\nu}_\mu e \to \bar{\nu}_\mu e$
α	$\frac{1}{2} + \sin^2\theta_W$	$-\frac{1}{2} + \sin^2\theta_W$	$\sin^2\theta_W$
β	$\sin^2\theta_W$	$\sin^2\theta_W$	$-\frac{1}{2} + \sin^2\theta_W$





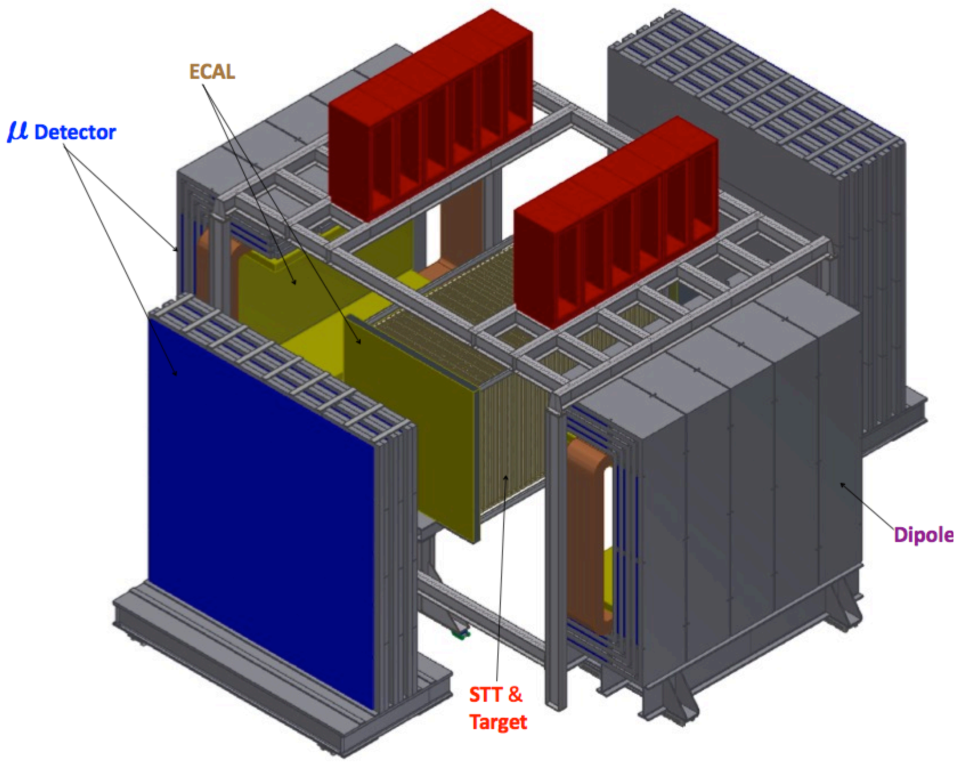
Sanjib Agarwala
Chris Tunnel

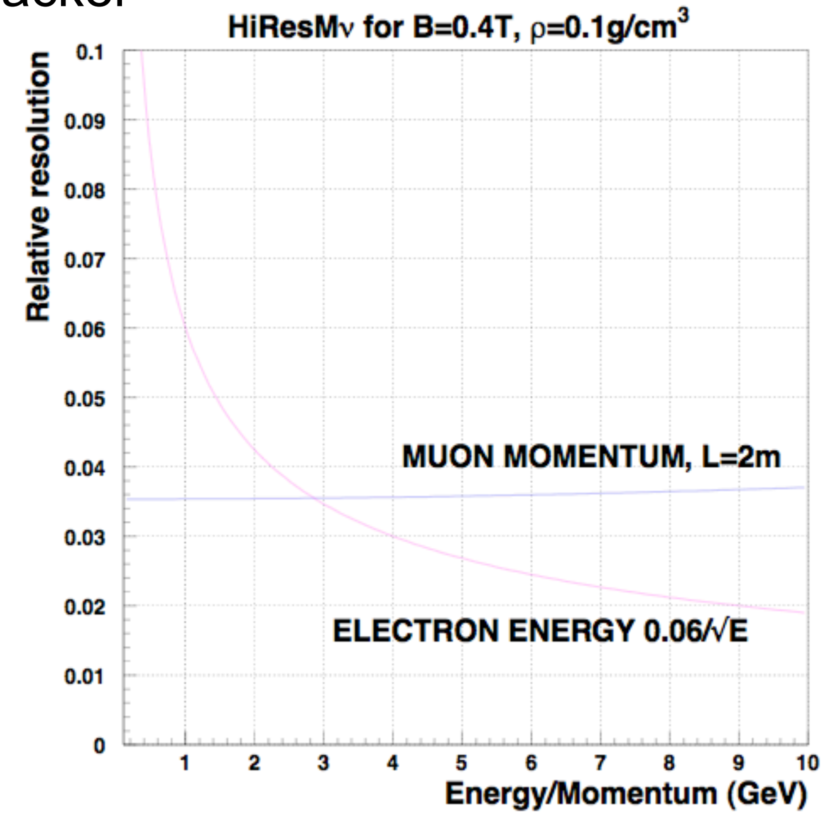
- Results in 1.5% $\sin^2\theta_W$ measurement at nuSTORM

HiRes Near Detector

Sanjib Mishra

- Concept from LBNE:
  - Main difference: TRT straw tube tracker



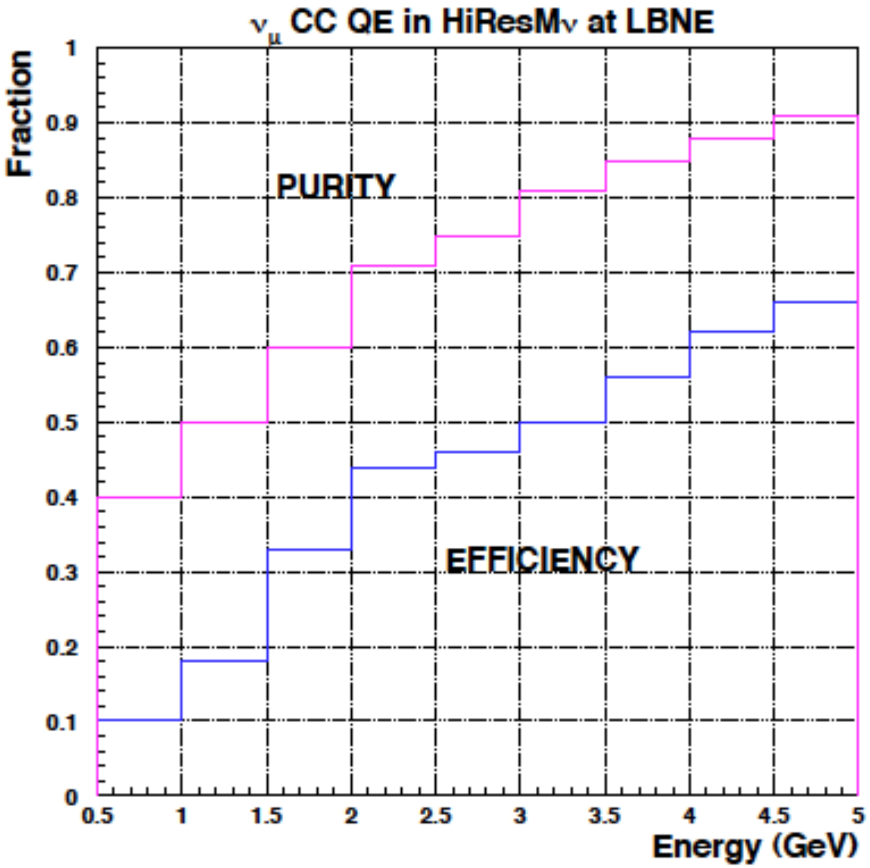


Momentum resolution ~3.5%
Angular resolution ~ 1 mrad

HiRes Near Detector

- QEL interaction efficiency and purity:

Sanjib Mishra



- *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*

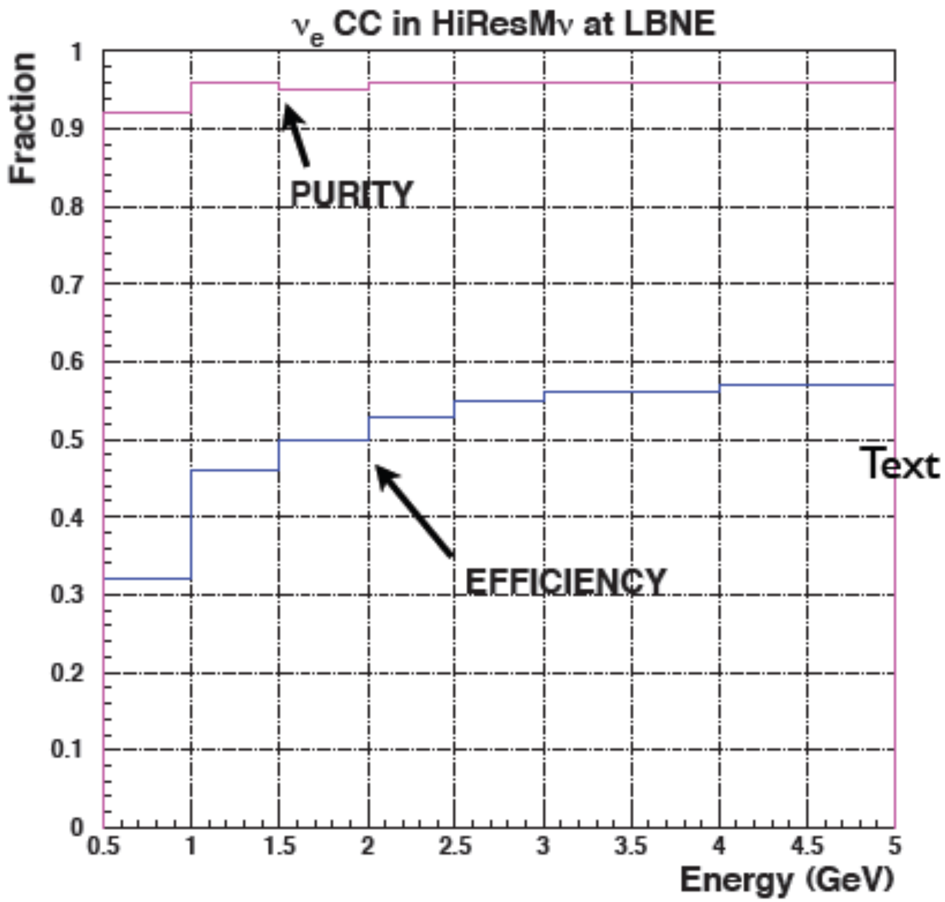
  $\Longrightarrow$ *On average* $\varepsilon = 52\%$ *and* $\eta = 82\%$ *for CC QE at LBNE*

Expect ⇒ For ν-Factory, Eff ~ 60% with 90%-purity

HiRes Near Detector

- Nue CC efficiency and purity:

Sanjib Mishra

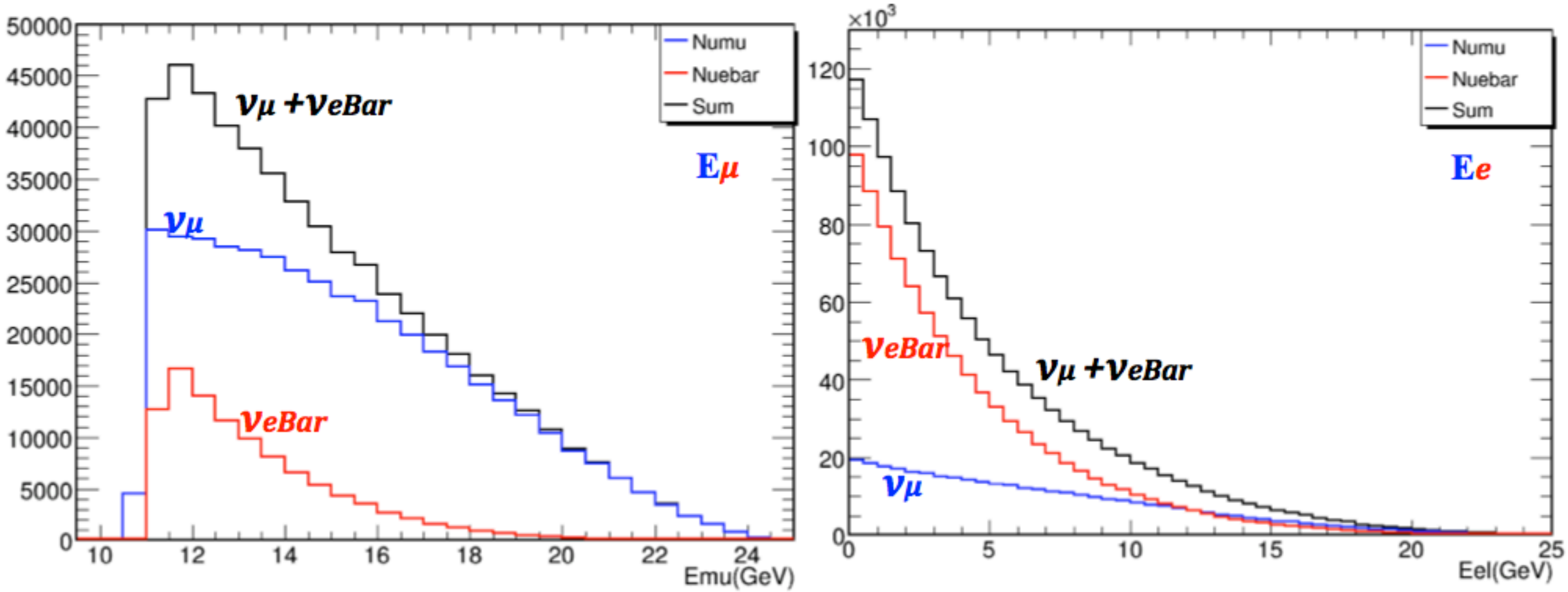


- *The HiResMν detector can distinguish electrons from positrons in STT*
  $\Longrightarrow$ *Reconstruction of the e's as bending tracks NOT showers*
- *Electron identification against charged hadrons from both TR and dE/dx*
  $\Longrightarrow$ *TR π rejection of 10^{-3} for $\varepsilon \sim 90\%$*
- *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*

VeBar-CC Sensitivity: Eff ~55% and Purity ~ 99%

HiRes Near Detector

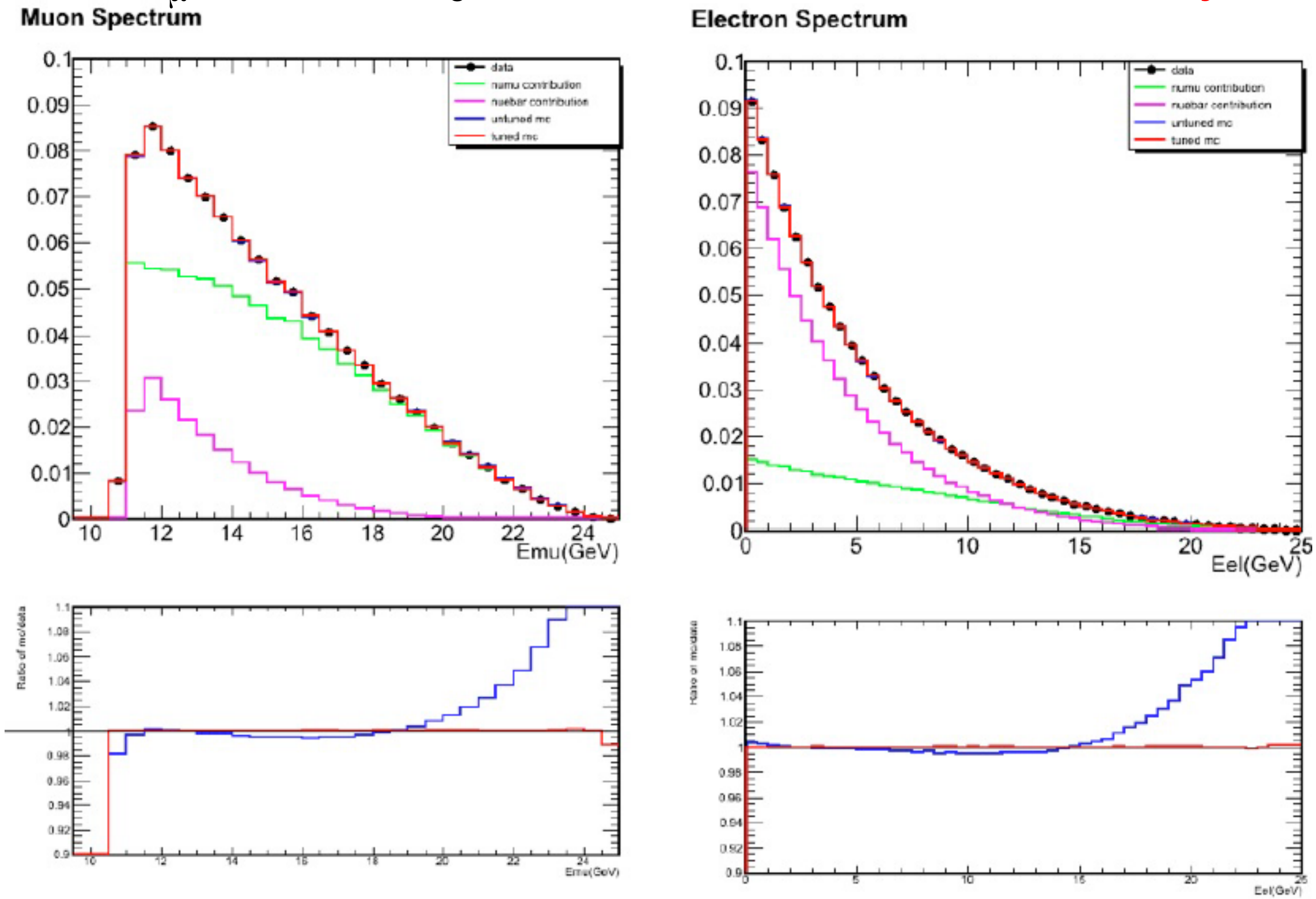
- Fits to ν_μ IMD and ν_e channels to extract flux: Sanjib Mishra



Can the same flux accuracy be achieved if we do not have the IMD channel? Yes, since ν_e channel better

HiRes Near Detector

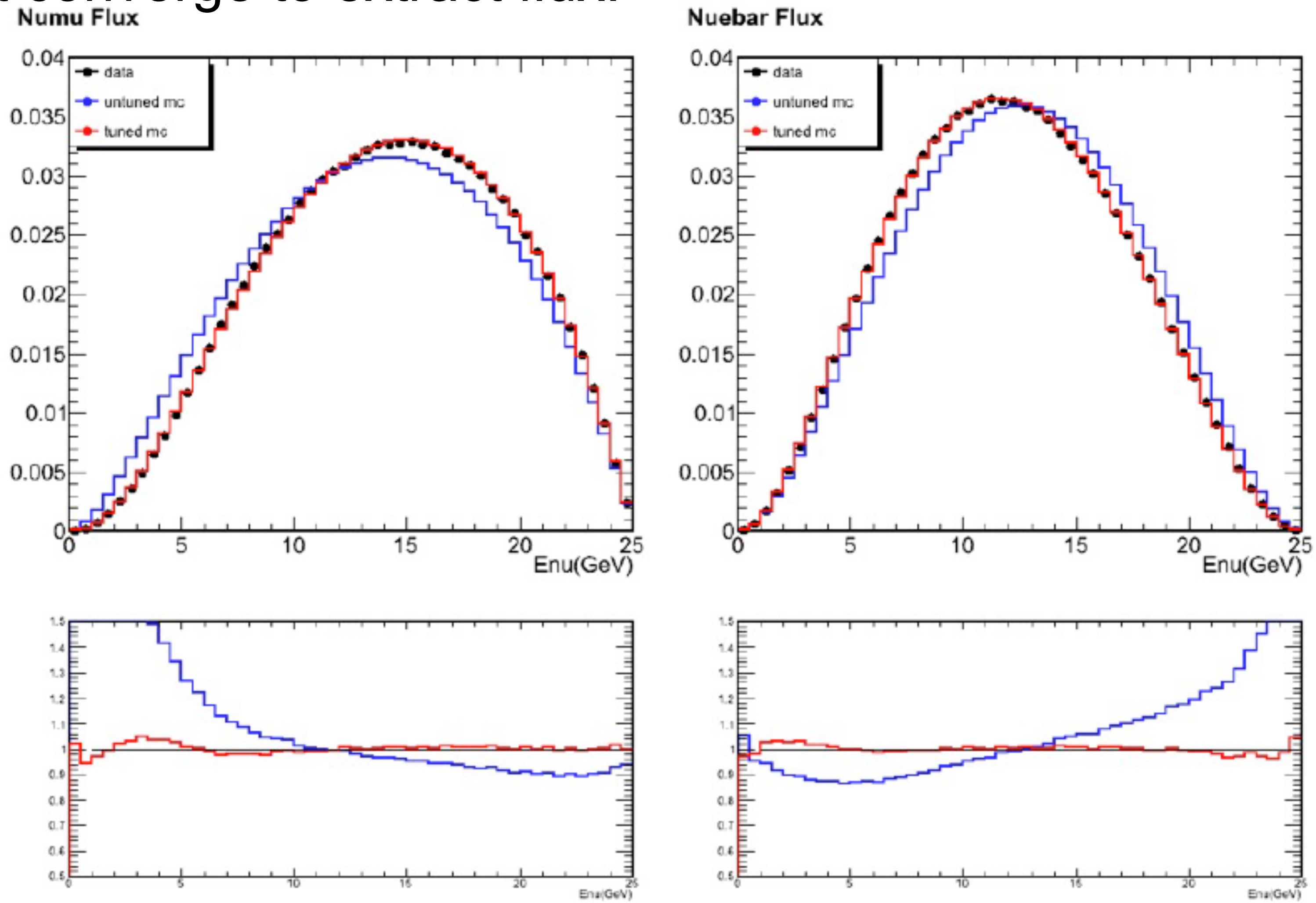
- Fits to ν_μ IMD and ν_e channels to extract flux: Sanjib Mishra



HiRes Near Detector

Sanjib Mishra

- Start with different ν_μ and ν_e functional form, iterate and let fit converge to extract flux:



Low-ν method

- Flux ambiguity at 10 GeV NF can be resolved with Low-ν method
- What is low-ν method?
  - By selecting low ν=E−E' interactions, the error associated to the hadronic energy is small, and the interaction rate becomes proportional to the flux, except for a correction to be determined

$$N(E_\nu : E_{had} < \nu_0) = C\phi(E_\nu) f\left(\frac{\nu_0}{E_\nu}\right) = C\phi(E_\nu)\left(A + B\left(\frac{\nu_0}{E_\nu}\right) + C\left(\frac{\nu_0}{E_\nu}\right)^2 + \ldots\right)$$

- Normally used in DIS interactions but A. Bodek (NUFACT12) showed that it can also be used in the context of quasi-elastic, resonant and coherent interactions

Low-ν method

Sanjib Mishra

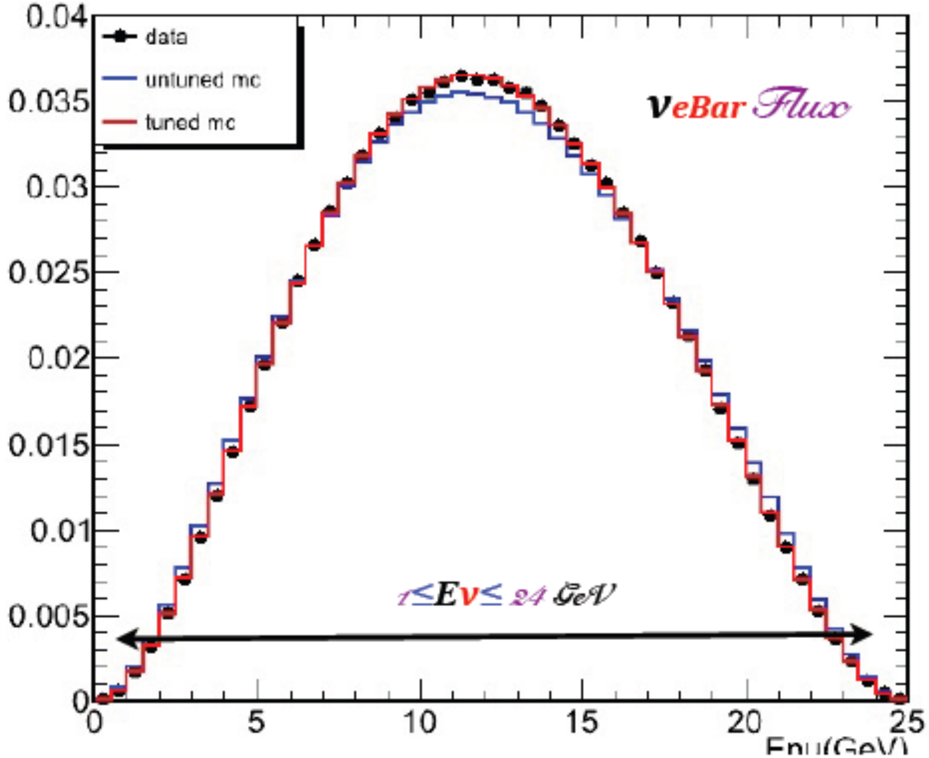
Low-ν0:

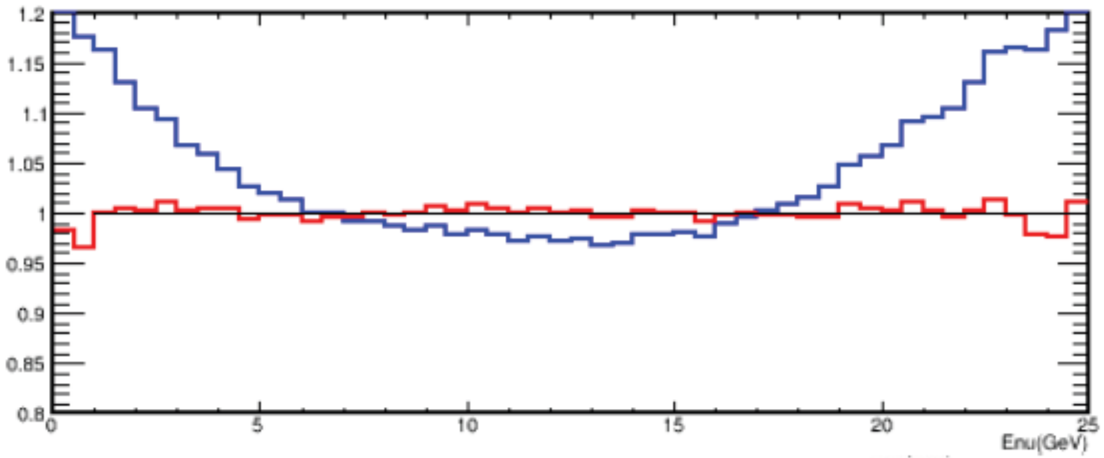
$\nu_e Bar + N \rightarrow e^+ + X$ (Ex<0.5 GeV)

Observation ⇒ The Low-ν0 method should permit flux determination of ν_μ and ν_eBar within ± ~1-% at ND;

Ditto for (ν_e and ν_μBar).

⇒ FD/ND will be more precise

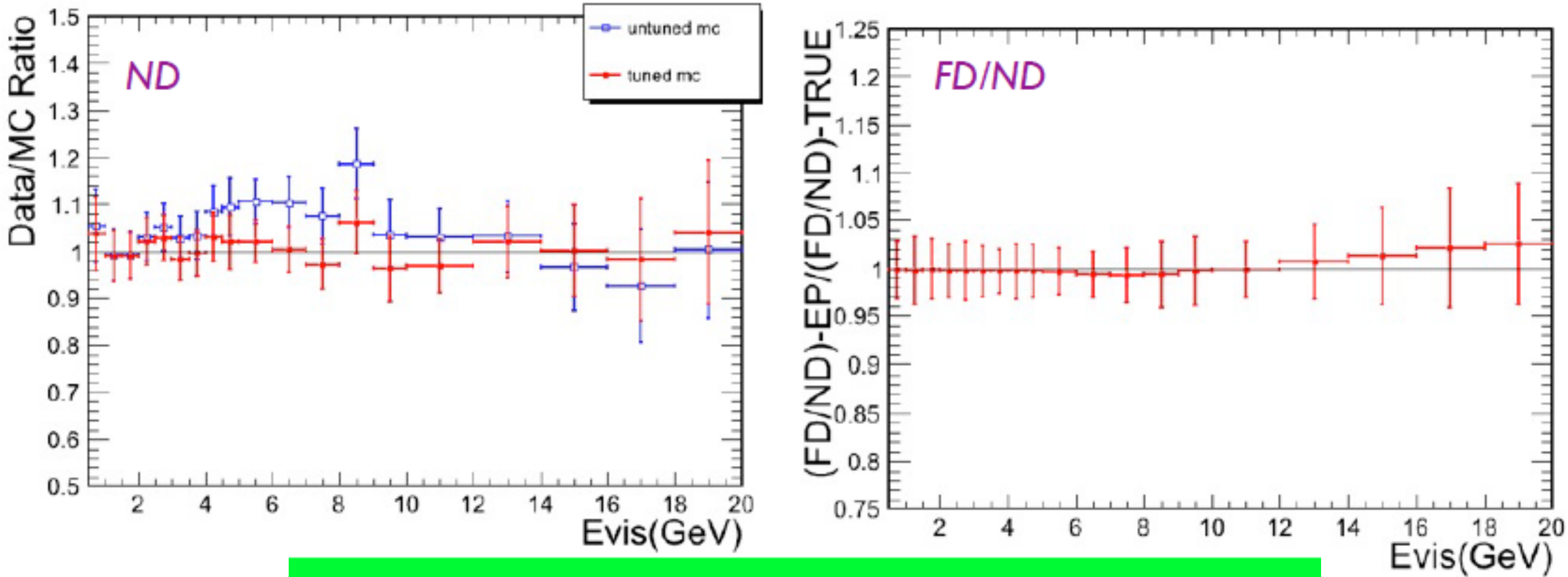




Low-ν method

Sanjib Mishra

Shape of Anti-ν_μ Flux using Low-ν_0 Method @ LBNE



Conclusion ⇒

Predict FD/ND flux-ratio with high precision

Detector task list from IDR

	Year 1												Year 2											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Neutrino detectors																								
MIND																								
Tau background		■		✓																				
Realistic MIND geometry with toroidal magnetic field map									■		✓													
Muon momentum measurement by range											■		✓											
Hadronic reconstruction													■		✗									
Multi-variate likelihood analysis																	■		✗					
Cosmic backgrounds																				■	✗			
Costing of MIND																							■	✓
Near Detector																								
Neutrino electron scattering				■		✓																		
Performance of near detector for neutrino scattering physics							■		✗															
Tau and charm analysis										■		✗												
Near detector shielding														■		✗								
Choice of near detector baseline geometry																		■		✗				
Choice of tau/charm detector																		■		✓				
Flux extrapolation from near to far detector and systematics																					■		✗	
Costing of near detectors																							■	✓

MIND: task list for RDR

1. Investigate multi-variate analysis with other CC-NC separation variables to see if improvement in efficiency achieved
2. Finalise hadron reconstruction in MIND – we can probably live with parametrisation (lower priority)
3. Include backgrounds due to cosmic rays to determine whether MIND can be placed on surface (or near surface) – CryGenerator now in Glasgow so need to run analysis on cosmic ray data scaled down by duty factor
4. Finalise analysis and freeze efficiencies and migration matrices
5. Perform full systematic error analysis – simplest way of delivering results is to give one 1σ error matrix
6. Influence of disappearance analysis is being considered by Pilar – useful to normalise appearance channel but also to be used to determine accuracy of θ_{23} (and whether θ_{23} quadrant may be determined)
7. Neutral current Near/Far ratio to search for new physics (ie. sterile neutrinos but also non-unitarity, etc.) – new analysis with new selection cuts
8. Other …. ?

Near Detector: task list for RDR

1. Finalise ν-e scattering for SciFi and HiRes detectors – need to document
2. Decide on Near Detector baseline for RDR – define performance parameters and make decision
3. Flux extrapolation from near to far detector – done at 25 GeV but need to redo at 10 GeV - Use matrix method and stick it into Globes
4. Influence of near detector on systematic errors for oscillation search
5. Distance from straight to near detector – discuss with accelerator (take into account muon contamination from arcs)
6. Near detector shielding design – photon background known but need to know muon leakage – discuss with accelerator and make decision
7. Neutrino scattering cross-section requirements – desirable to demonstrate an example of an analysis (ie QEL, …) to show accuracy
8. Other EW measurements like $\sin^2\theta_W$, …– example analysis and create list
9. Tau and charm analysis in vertex detector – less important at 10 GeV – low priority and lack of manpower
10. Other …. ?