THE INTERNATIONAL DESIGN STUDY FOR THE NEUTRINO FACTORY

Detector working group: status and plans for IDS-NF#9

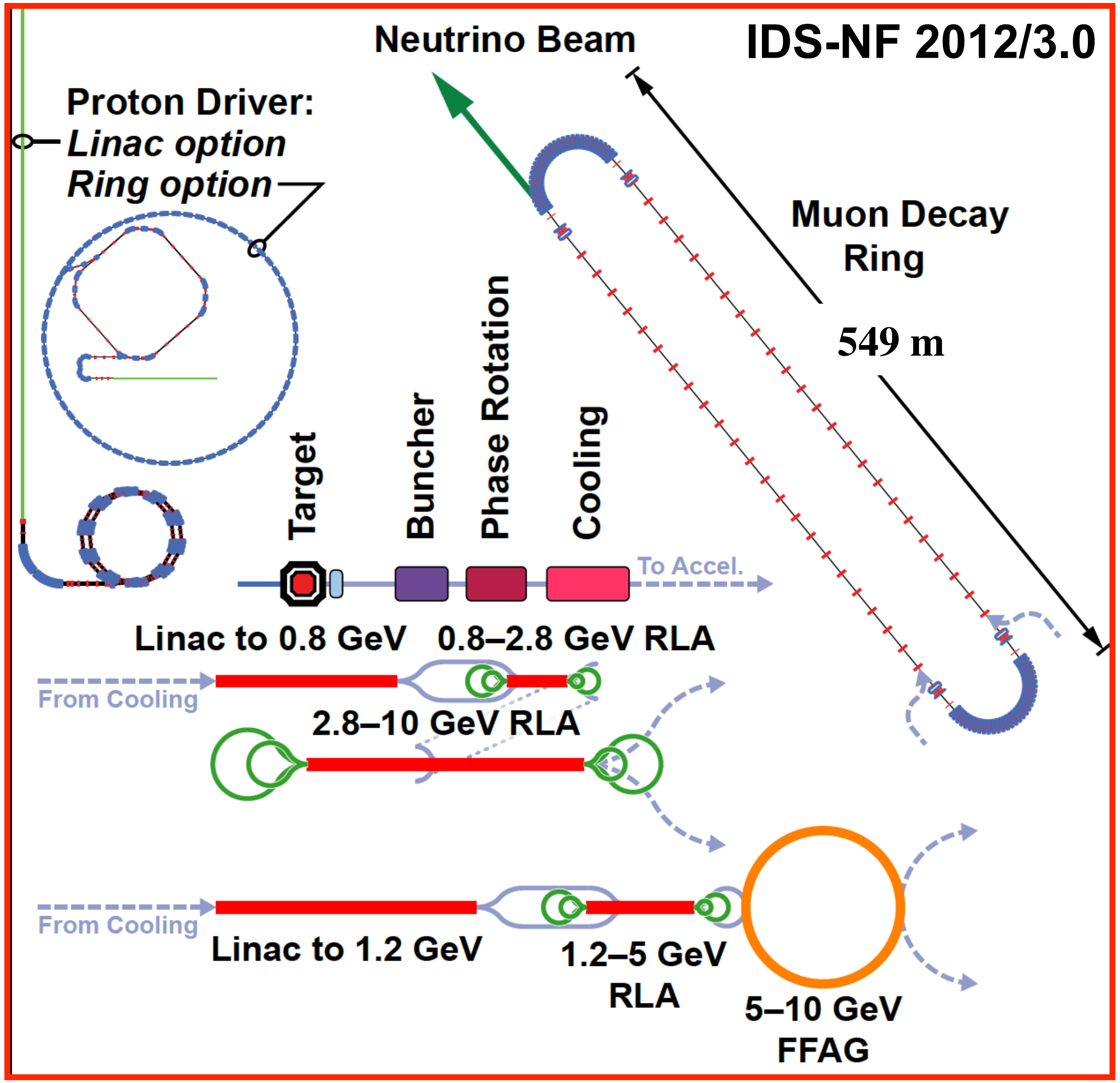
9th IDS-NF Meeting

Fermilab

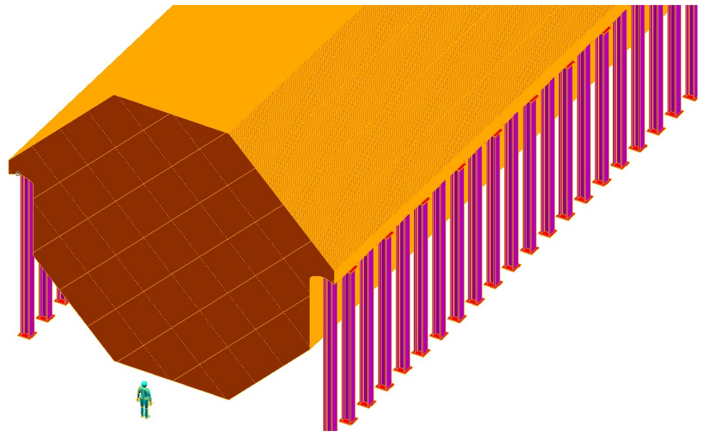
Paul Soler, 8 October 2012

University of Glasgow

MIND baseline (reminder)



- Magnetised Iron Neutrino Detector (MIND):
  - 100 kton at ~2000 km

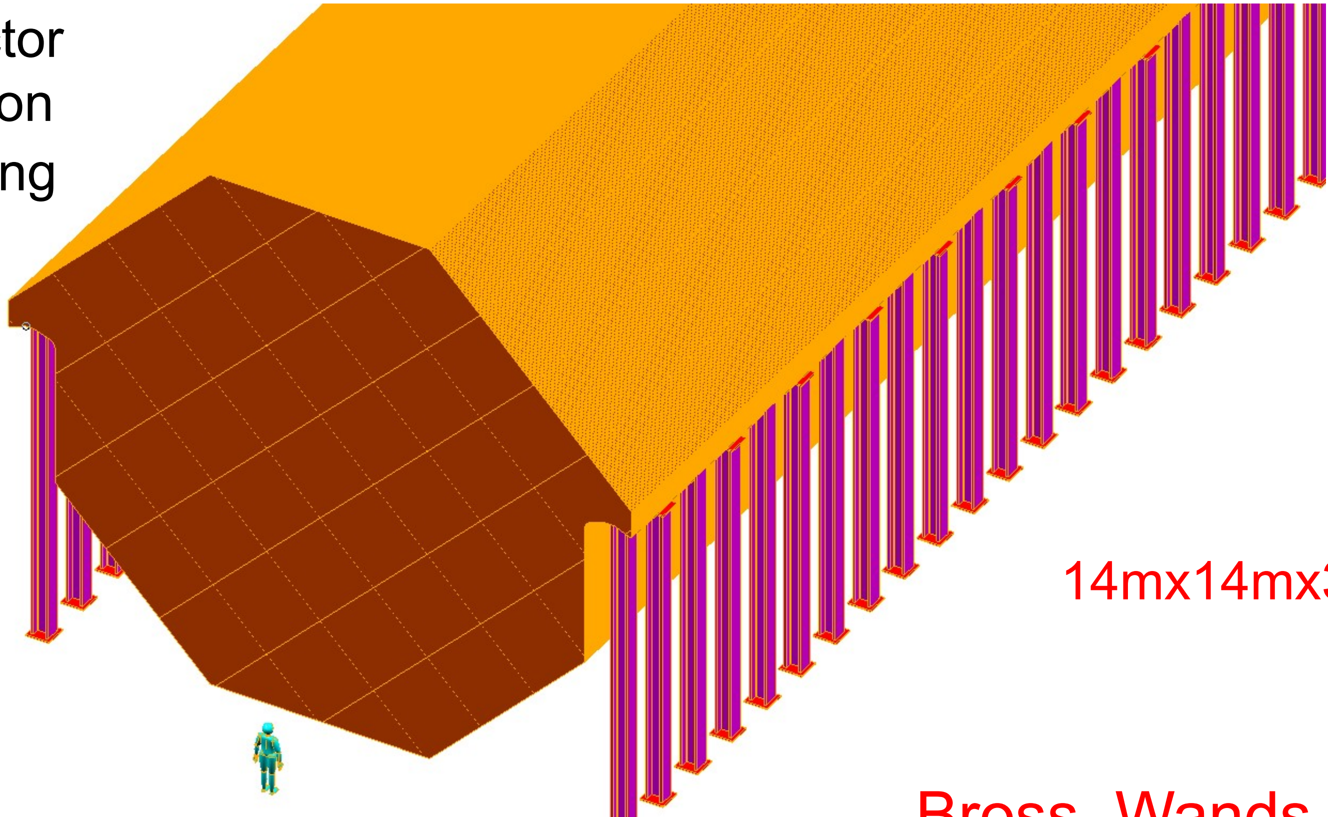


Baseline reviewed in Glasgow: from 25 GeV to 10 GeV muons in light of large θ_{13} results

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



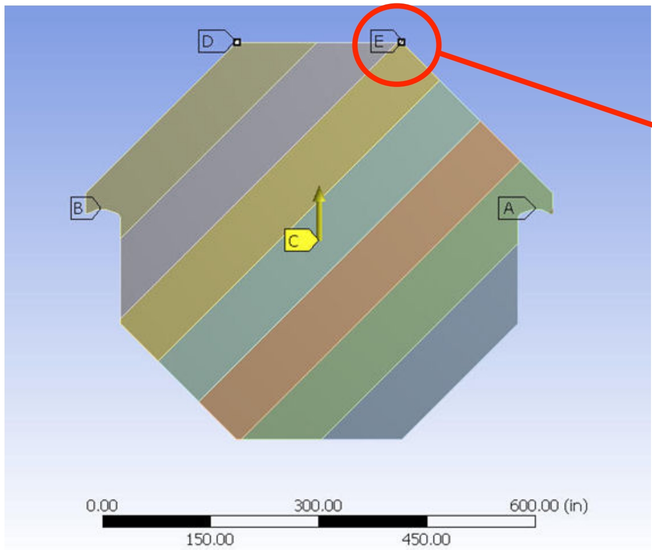
14mx14mx3cm plates

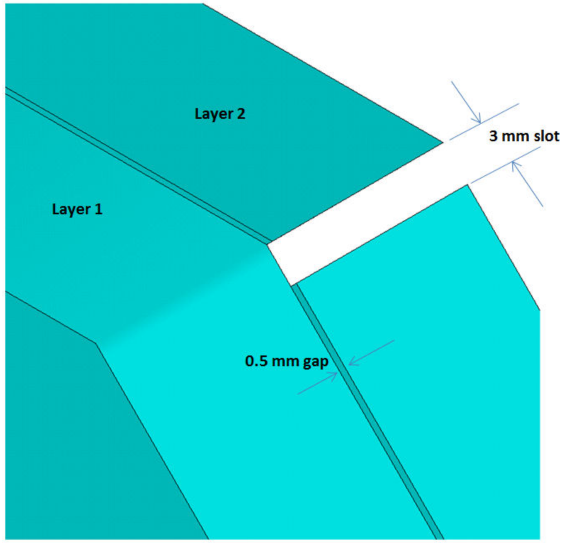
Bross, Wands (FNAL)

MIND baseline (reminder)

- Plate engineering:

Plates: two welded layers (0.5mm gaps) 3 mm slots between Plates (2 m wide)

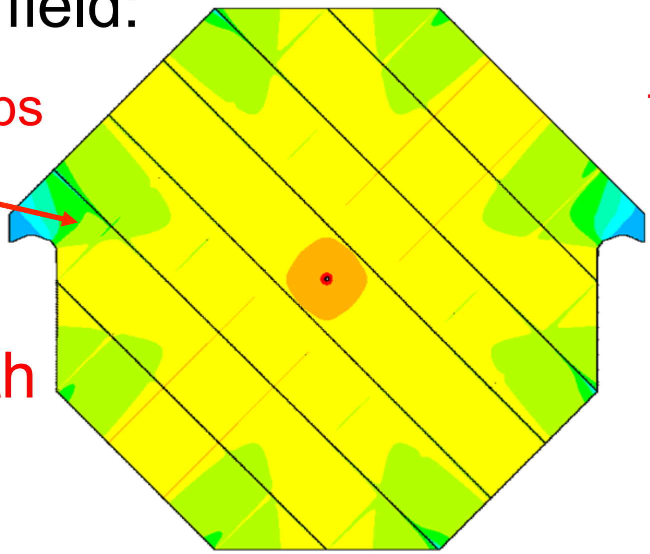




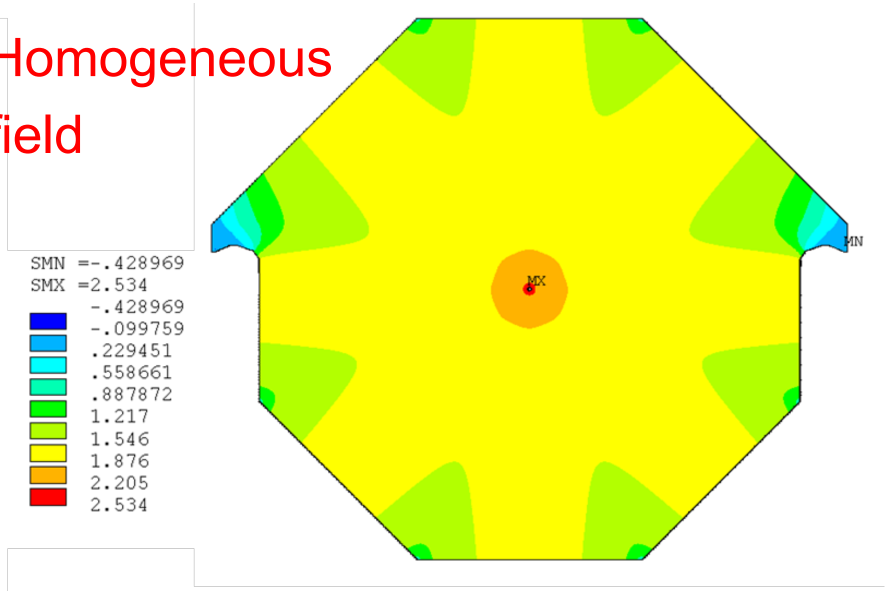
- Toroidal field:

Small field gaps and jumps

1.2-2.2 T with 100 kA turn

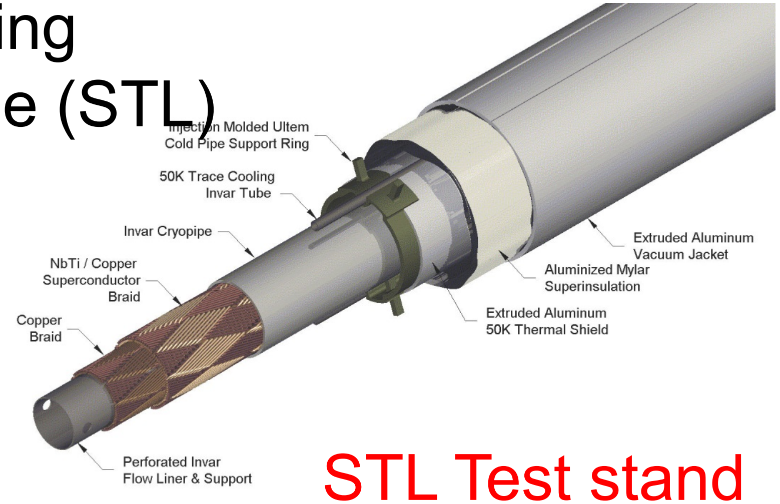


Homogeneous field

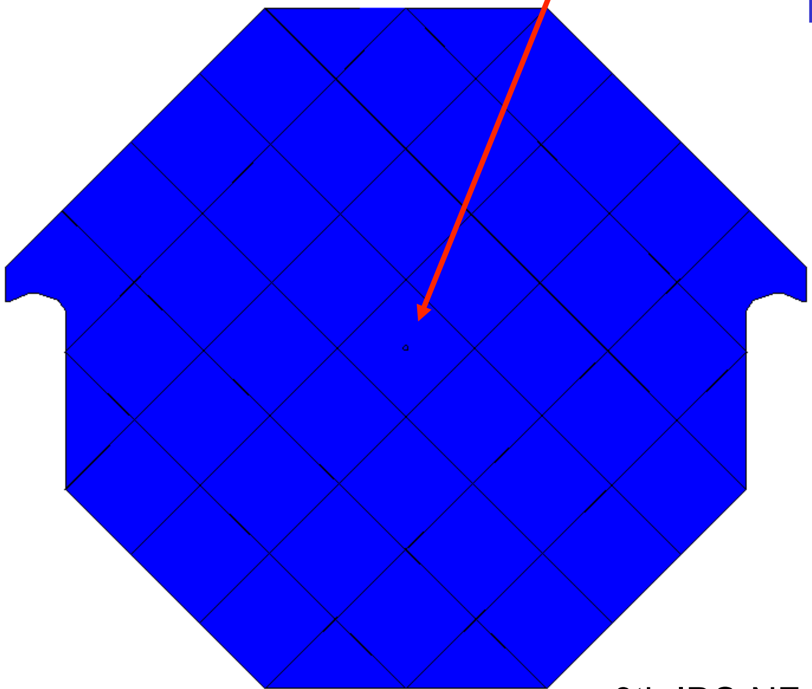


MIND baseline (reminder)

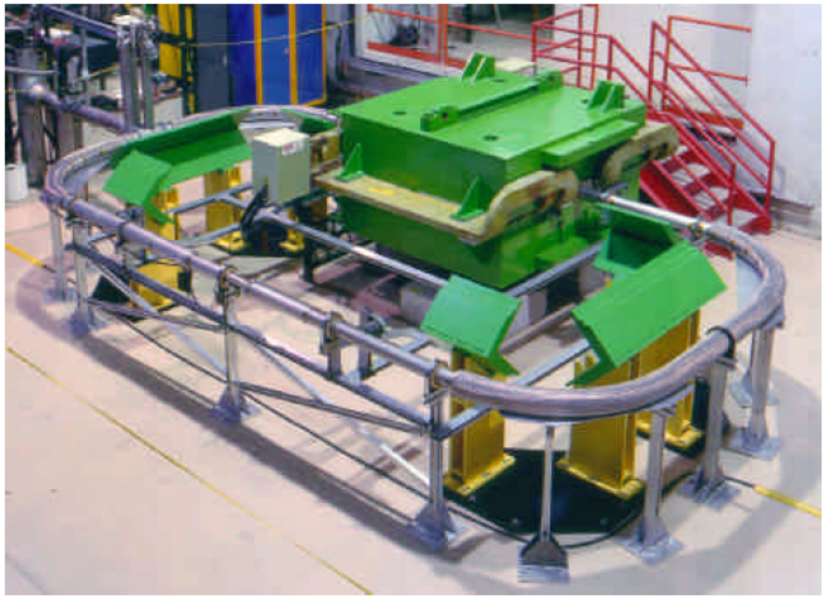
- Magnetisation can be achieved using Superconducting Transmission Line (STL) developed for VLHC:
  - Can carry 100 kA turn
  - Only need 10 cm diameter hole



Bross



STL Test stand



The test apparatus used at MW-9 for developing the transmission line.

MIND: likelihood analysis

- Analysis is mature: use of GENIE and GEANT4 **Ryan Bayes**
- Adapted for new situation with large value of θ_{13}
- Analysis with toroidal field requires to take into account two possible scenarios: focusing positive and focusing negative
- Analysis follows seven steps:

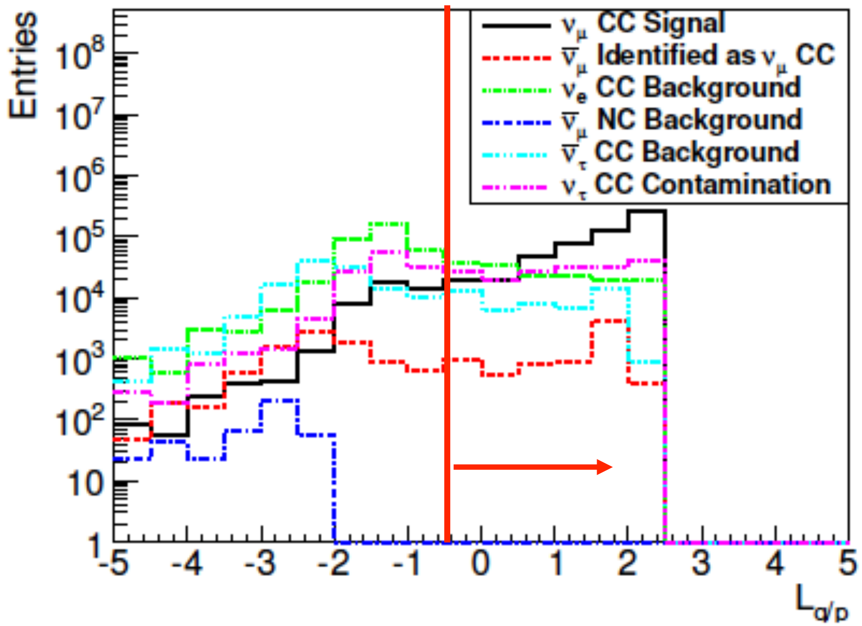
Event Cut	Description
Successful Reconstruction	Failed Kalman reconstruction of event removed
Fiducial	First hit of event is more than 1.5 m from end of detector
Maximum Momentum	Muon momentum less than $1.6 \times E_\nu$
Fitted Proportion	60% of track nodes used in final fit.
Track Quality	$\log(P(\sigma_{q/p}/(q/p)\|CC)/P(\sigma_{q/p}/(q/p)\|NC)) > -0.5$
CC Selection	$\log(P(N_{hit}\|CC)/P(N_{hit}\|NC)) > 1.0$
Kinematic	$Q_t > 1.5 GeV$

MIND analysis: track quality

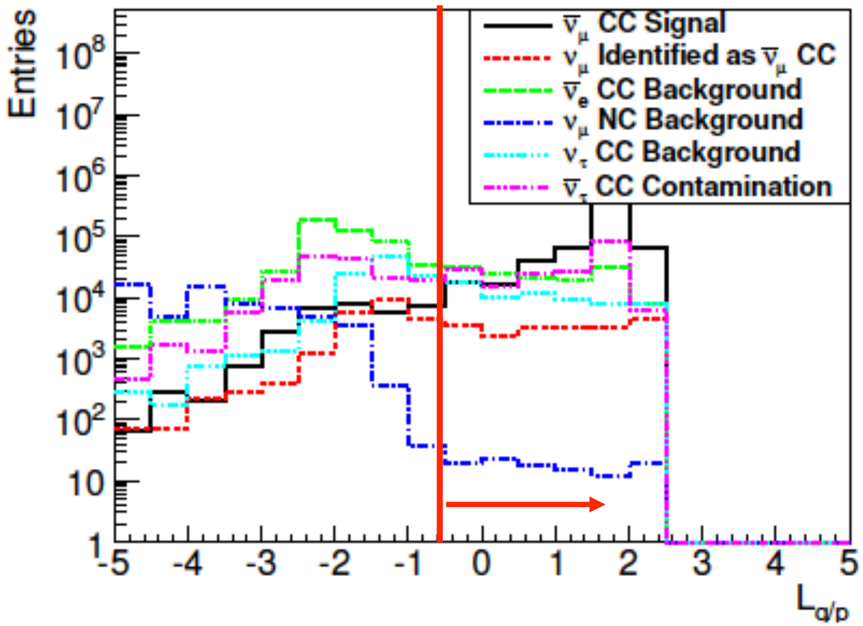
- Track quality cut:

$$L_{q/p} = \log\left(P\left(\frac{\sigma_{q/p}}{q/p}\middle|CC\right)\right) - \log\left(P\left(\frac{\sigma_{q/p}}{q/p}\middle|NC\right)\right) > -0.5$$

Curvature is more charged-current like than neutral-current like



Stored μ^+



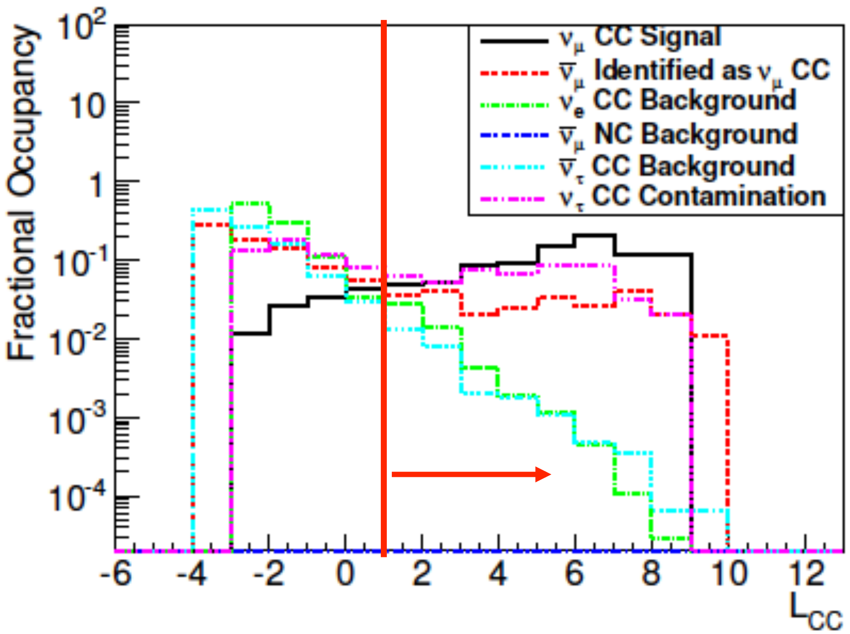
Stored μ^-

MIND analysis: CC selection

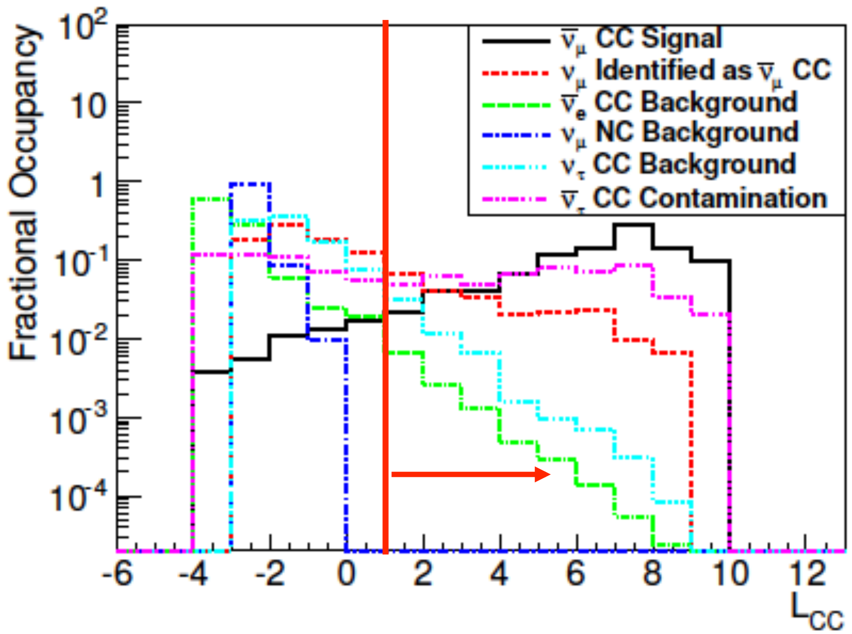
- CC selection:

$$L_{CC} = \log\left(P\left(N_{hit}\middle|CC\right)\right) - \log\left(P\left(N_{hit}\middle|NC\right)\right) > 1.0$$

Likelihood of number of hits is most efficient CC discriminator



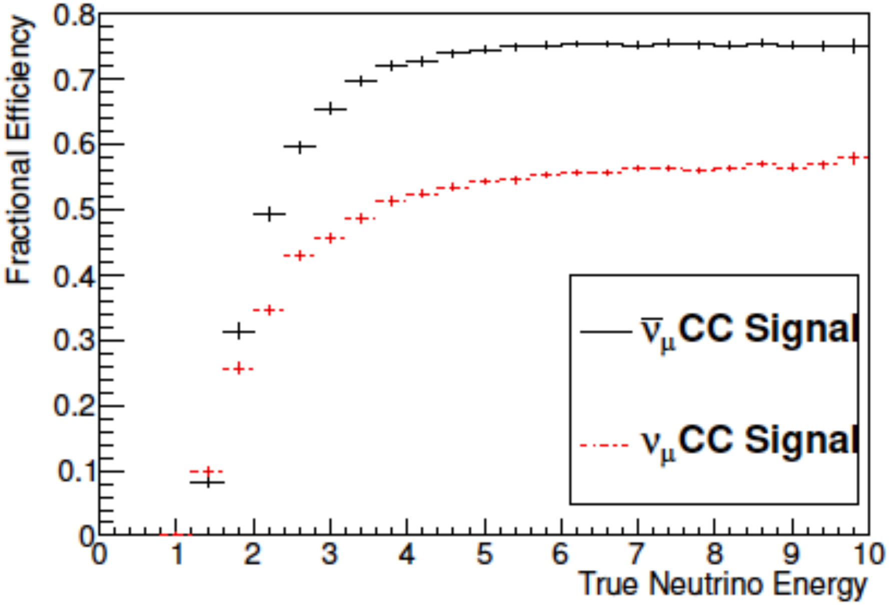
Stored μ^+



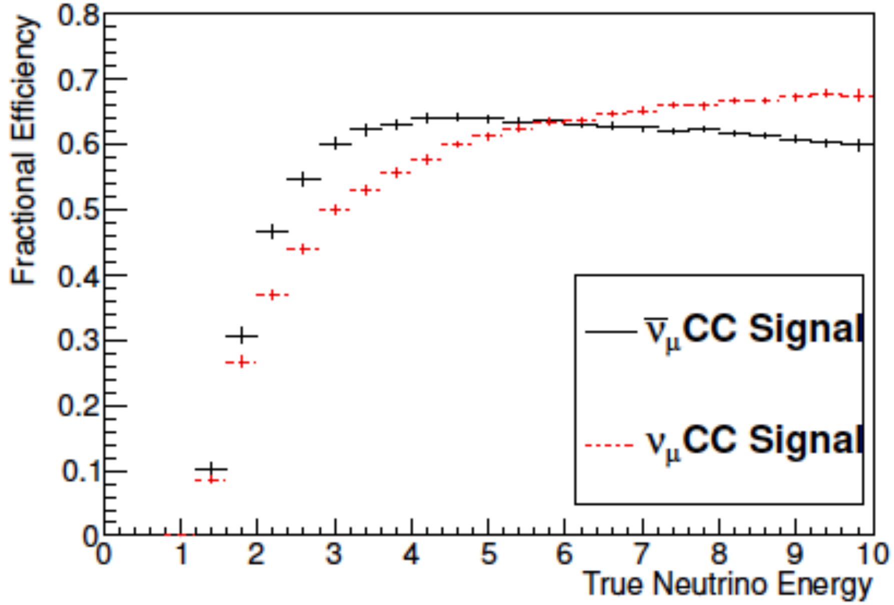
Stored μ^-

MIND: efficiency

- Two efficiencies: one for positive focusing field and one for negative focusing field



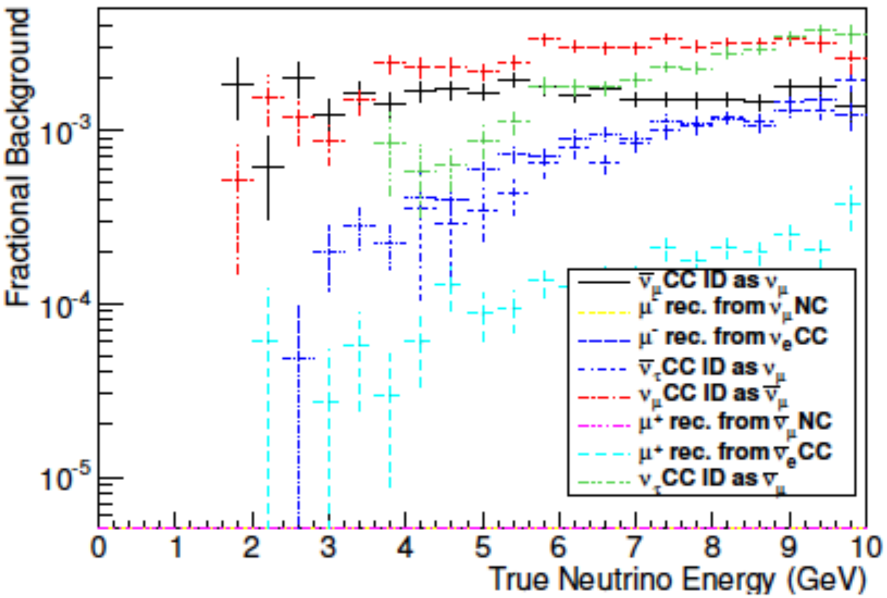
With μ^+ as focusing field



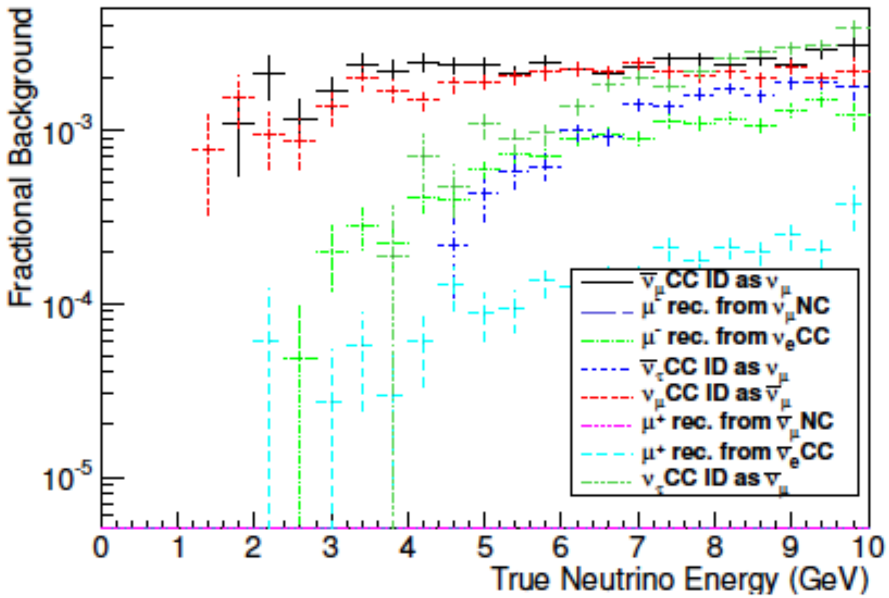
With μ^- as focusing field

MIND: backgrounds

- Backgrounds: all kept at around 10^{-3}



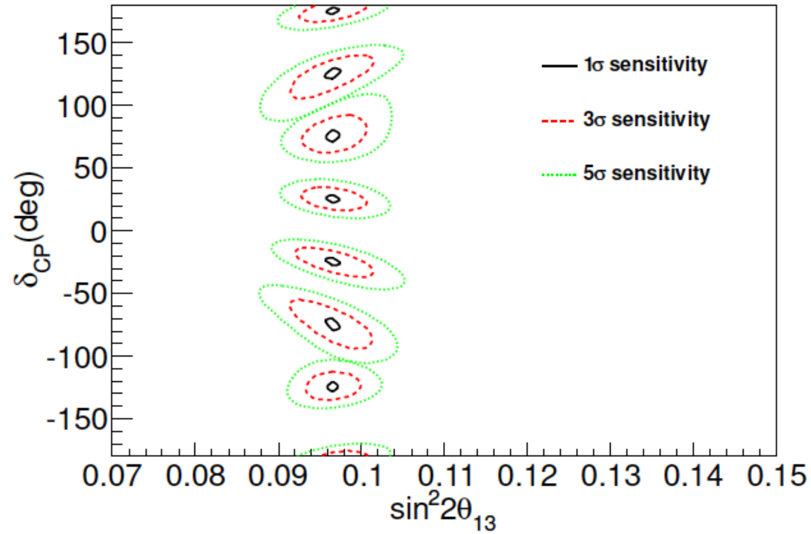
With μ^+ as focusing field



With μ^- as focusing field

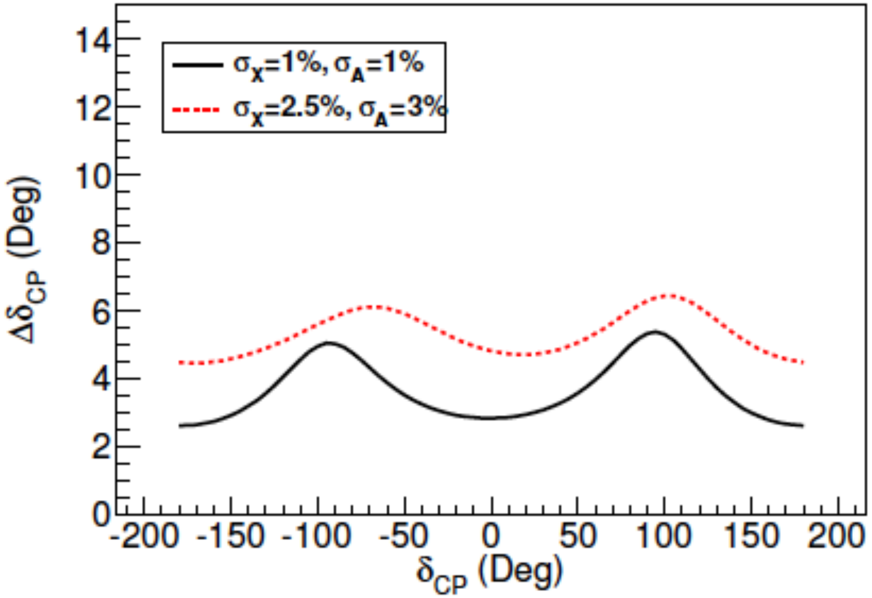
MIND: sensitivities

- Fits to δ around $\sin^2 2\theta_{13} \sim 10^{-1}$

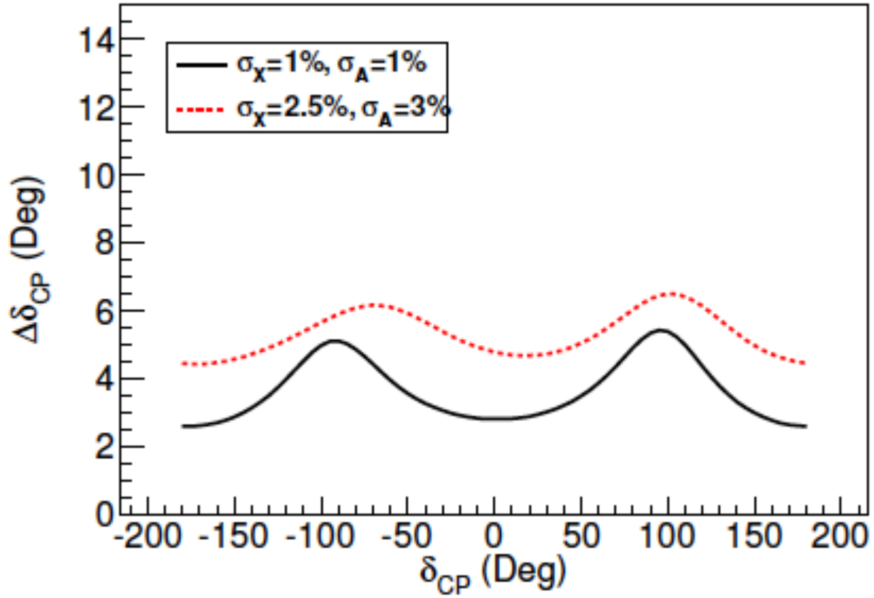


- Accuracy of δ fits: 3-6%

(depending on syst. error and δ)



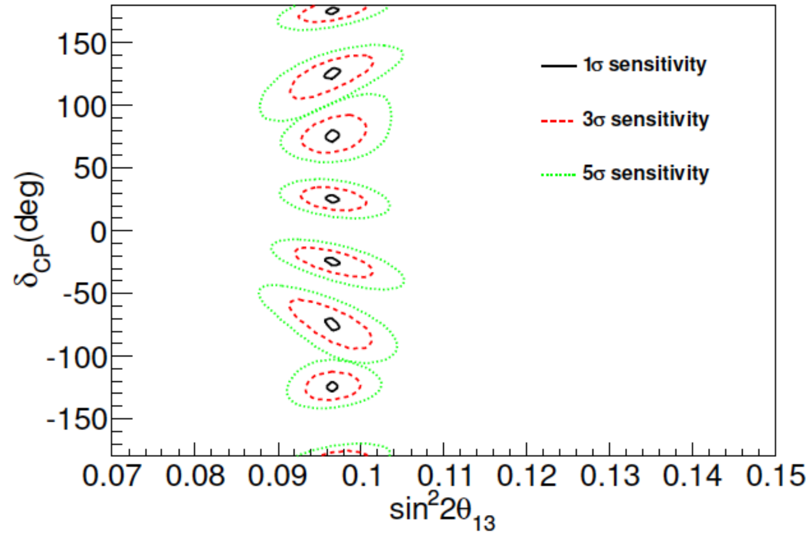
With μ^- as focusing field

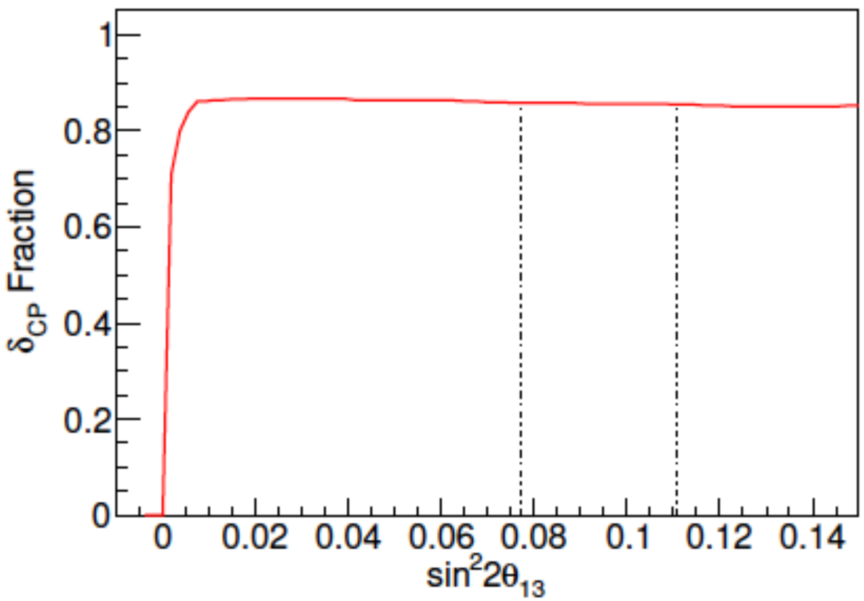


With μ^+ as focusing field

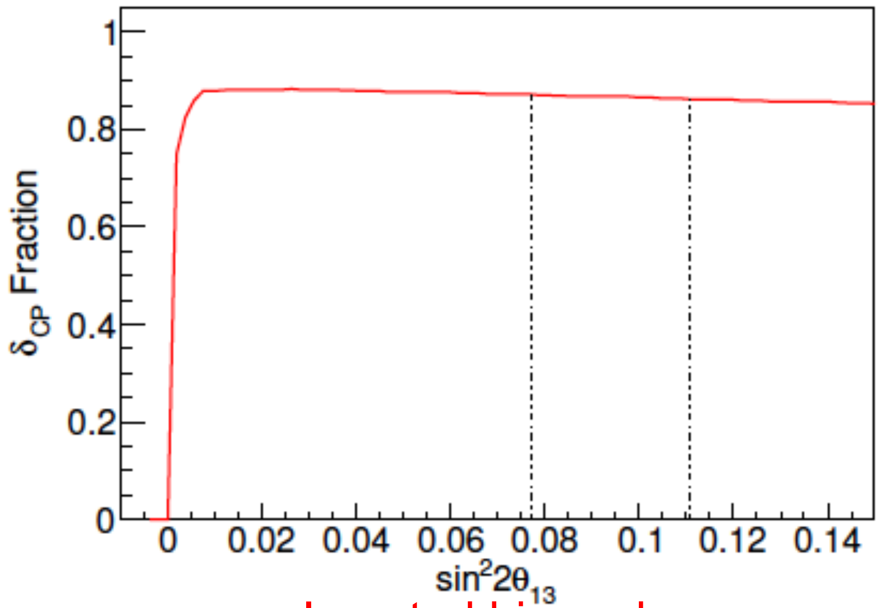
MIND: sensitivities

- Fits to δ around $\sin^2 2\theta_{13} \sim 10^{-1}$
- Coverage of δ_{CP} fits: ~ 85%





Normal hierarchy



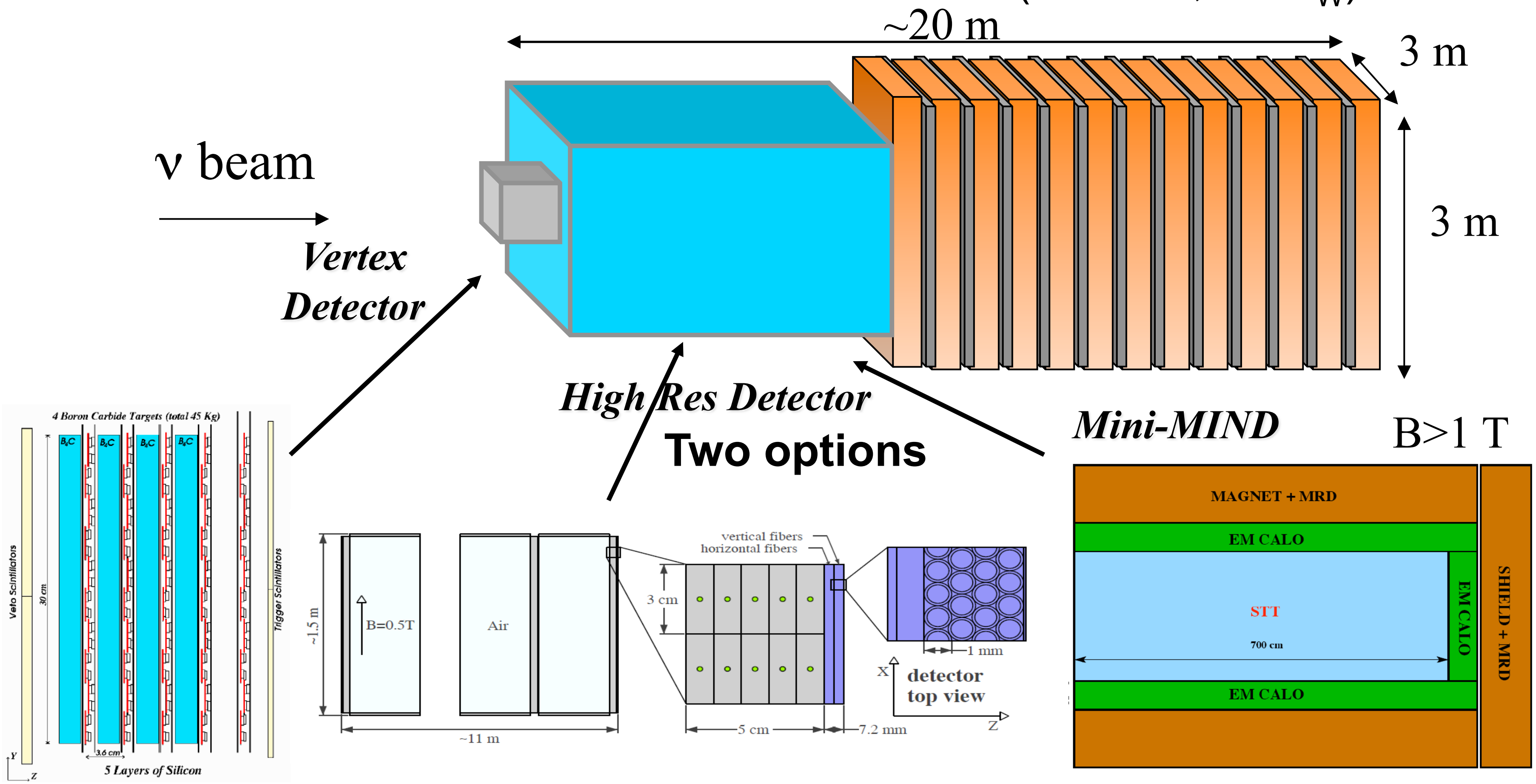
Inverted hierarchy

MIND: task list of things left to do

- Perform multi-variate analysis with other CC-like variables
- Finalise hadron reconstruction in MIND
- Perform full systematic error analysis
- Include backgrounds due to cosmic rays to determine whether MIND can be placed on surface (or near surface)
- Perform disappearance analysis to determine accuracy of in measurement of θ_{23} (and whether θ_{23} quadrant may be determined)
- Other …. ?

Near Detectors

- Near detector tasks:
  - Neutrino flux (<1% precision) and extrapolation to far detector
  - Charm production (main background) and taus for Non Standard Interactions (NSI) searches - this requirement is now weaker at large θ_{13}
  - Cross-sections and other measurements (ie PDFs, $\sin^2\theta_W$)

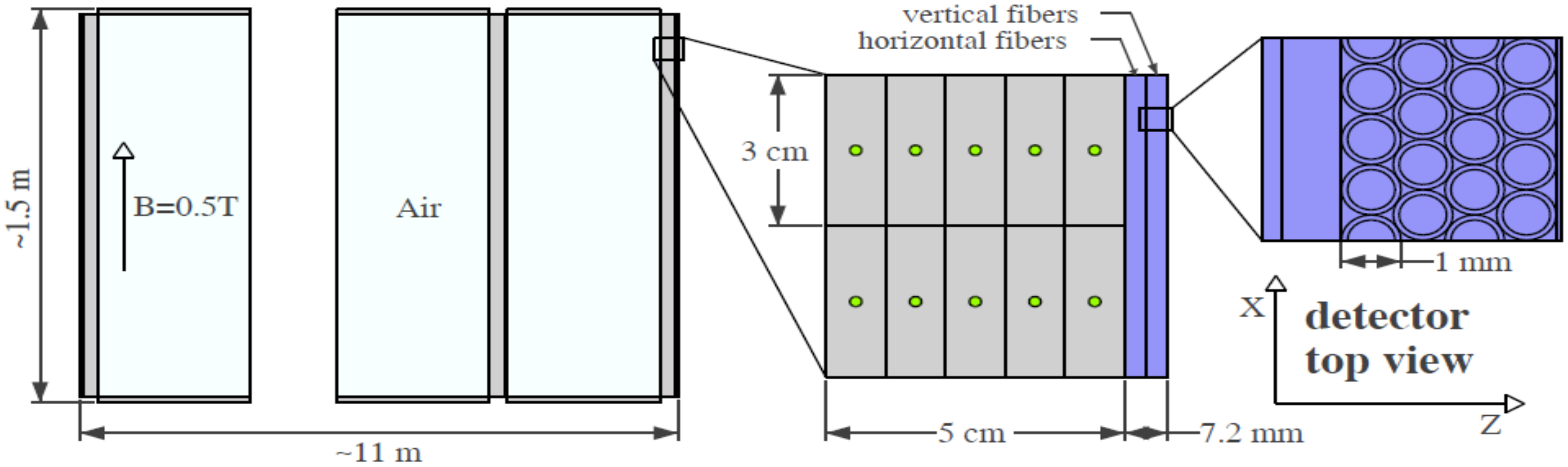


Scintillating Fibre design

Roumen Tsenov, Rosen Matev

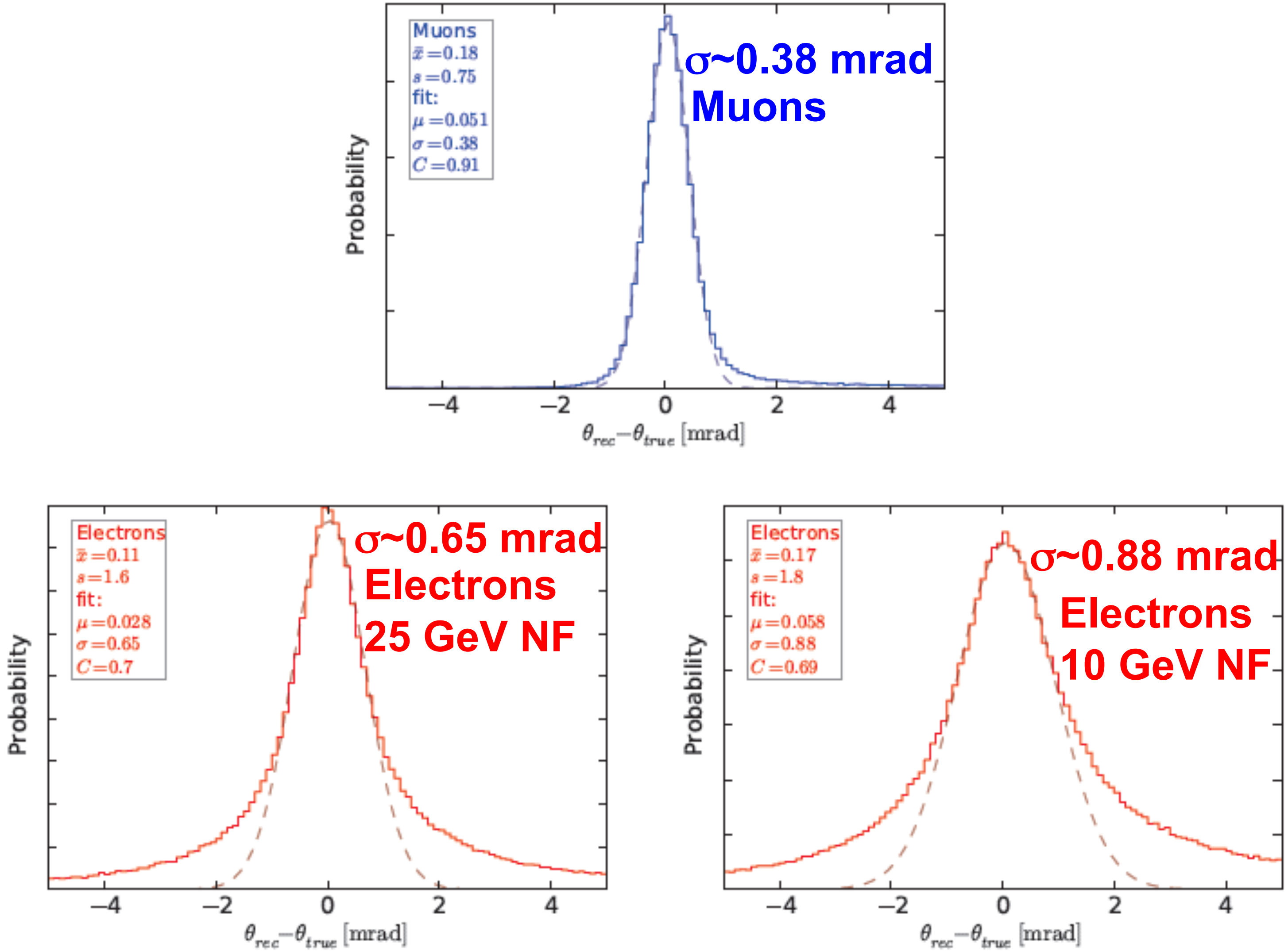
- **20 tracker stations**
  - **each consists of 4 horizontal and 4 vertical layers of 1 mm diameter scintillating fibres shifted with respect to each other and 5 cm thick active absorber, divided into 5 slabs to allow for more precise measurement of recoil energy near the event vertex;**
- **12 000 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



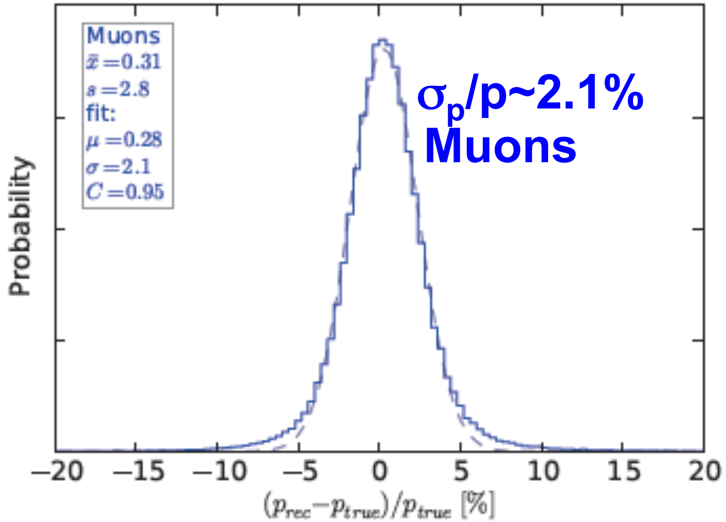
Scintillating Fibre performance

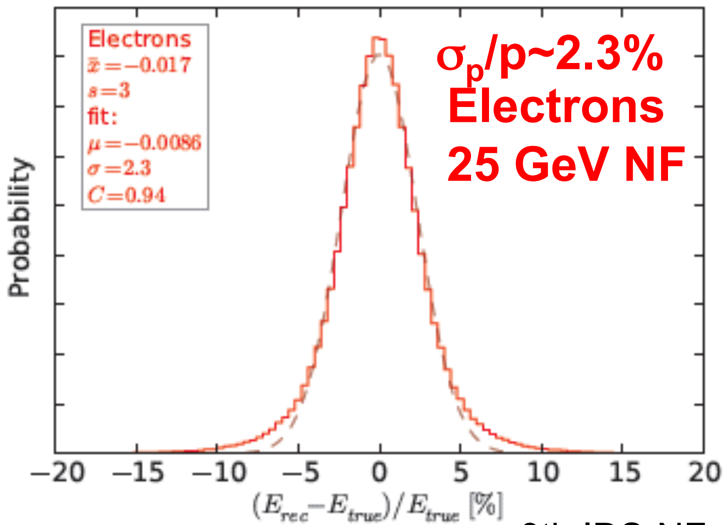
- **Angular resolution scintillating fibre tracker**

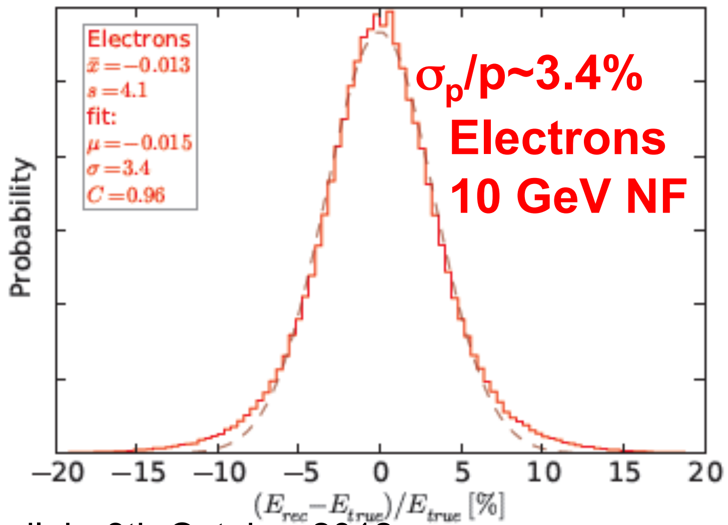


Scintillating Fibre performance

- **Momentum resolution scintillating fibre tracker**

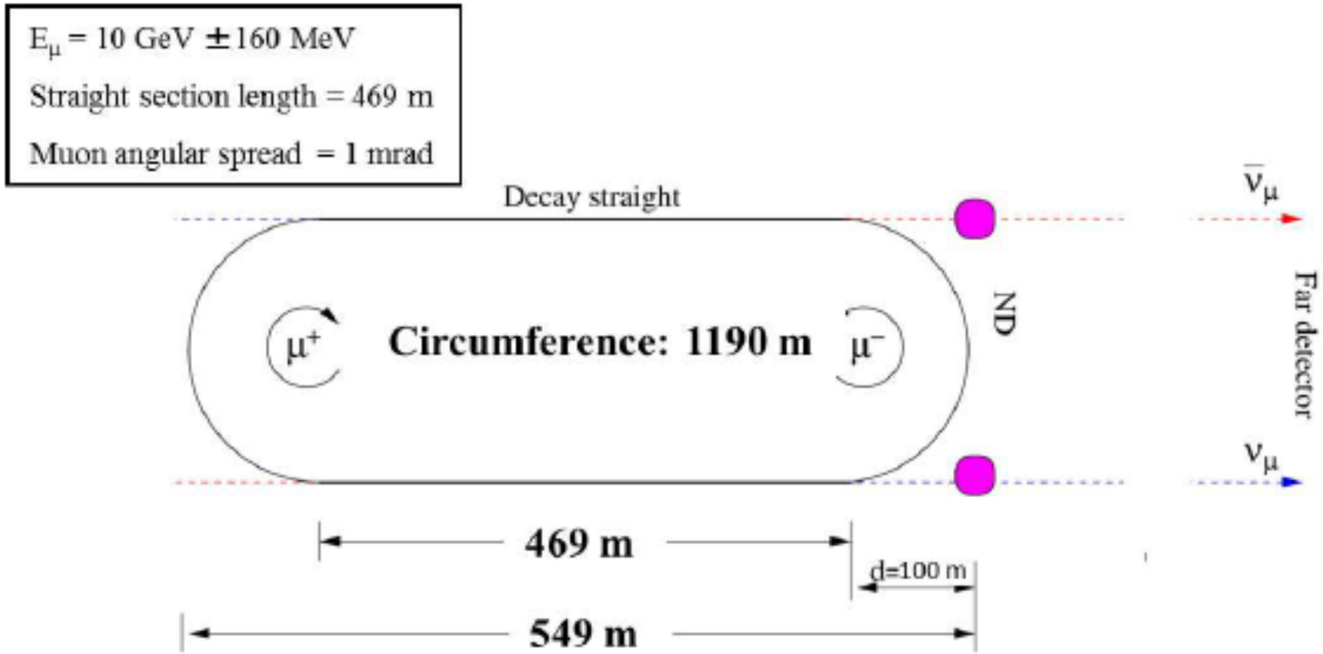






Near Detector Location

- For new 10 GeV Neutrino Factory, we need one Near Detector per decay straight (ie 2 detectors)

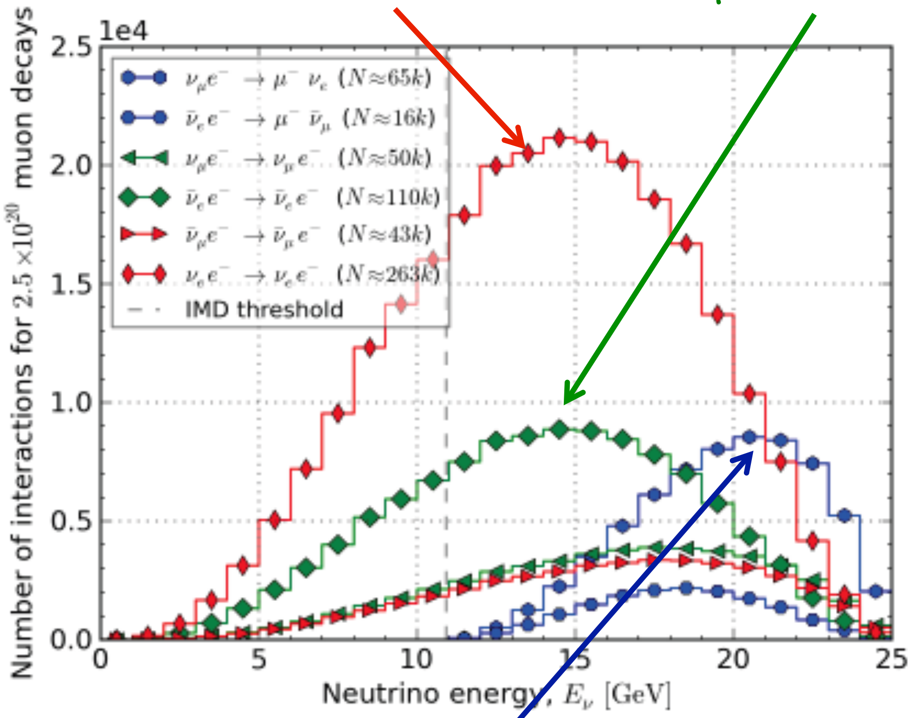


- We have lost capability to measure inverse muon decay (threshold = 11 GeV) at lower 10 GeV muon energy
  - However, can use electron scattering for flux measurement

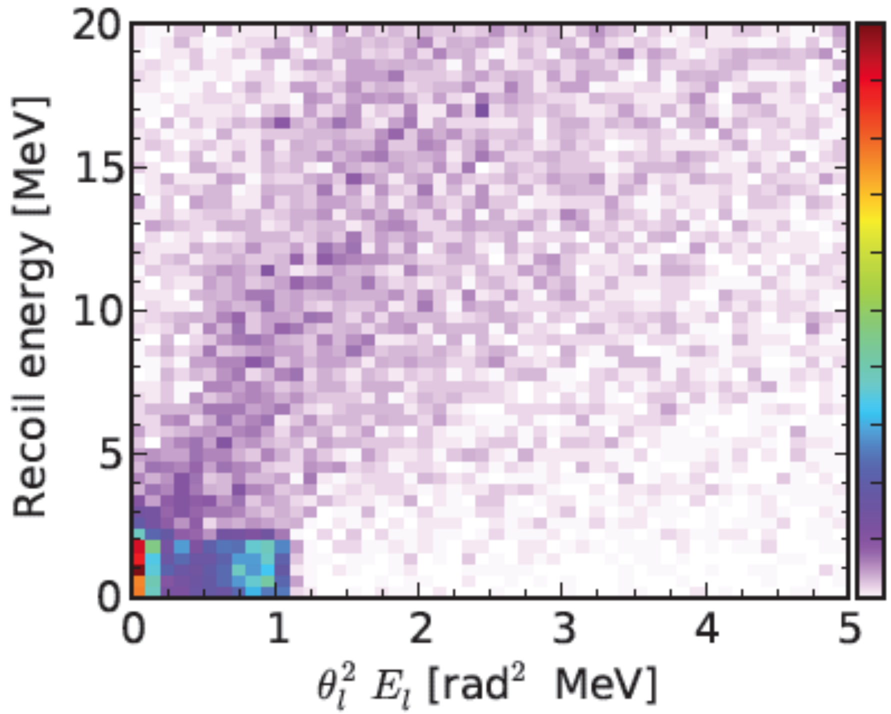
Neutrino electron scattering

- Neutrino electron interactions at 25 GeV 0.25×10^{20} μ^- decays
  - Different neutrino electron scattering interactions

ν-e with μ^+ beam   ν-e with μ^- beam



IMD with μ^- beam

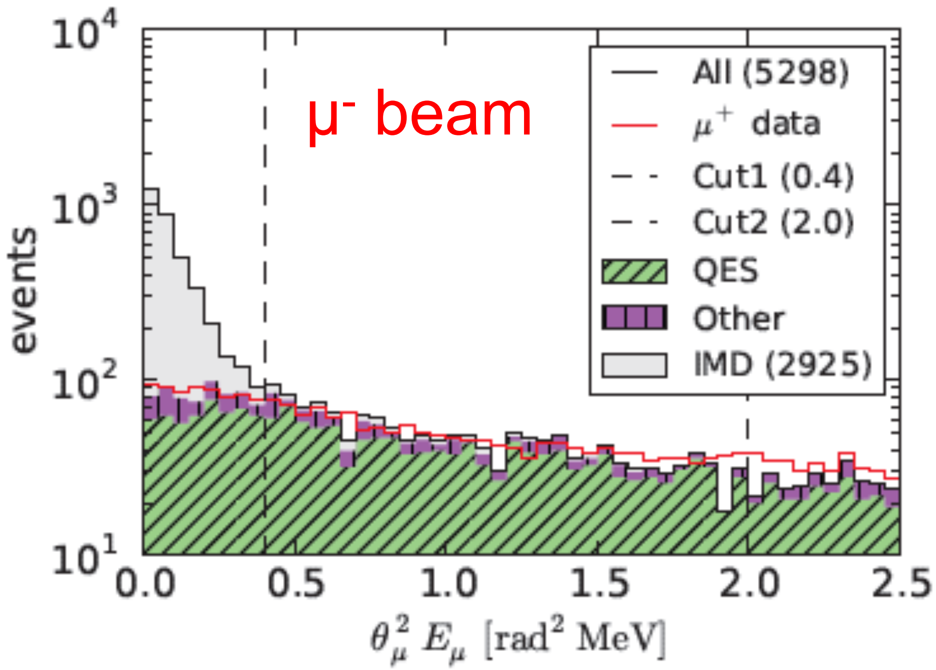


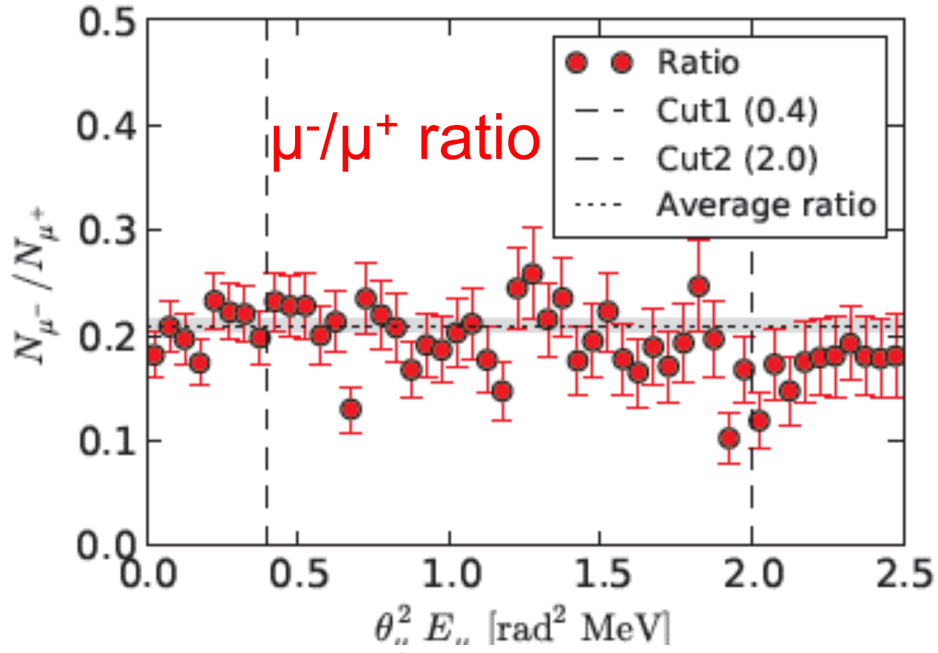
$$E_\mu \theta_\mu^2 = 2m_e(1-y)$$

Near detector IMD at 25 GeV

- Extract IMD signal in μ^- beam by subtracting background determined by μ^+ beam

Roumen Tsenov, Rosen Matev





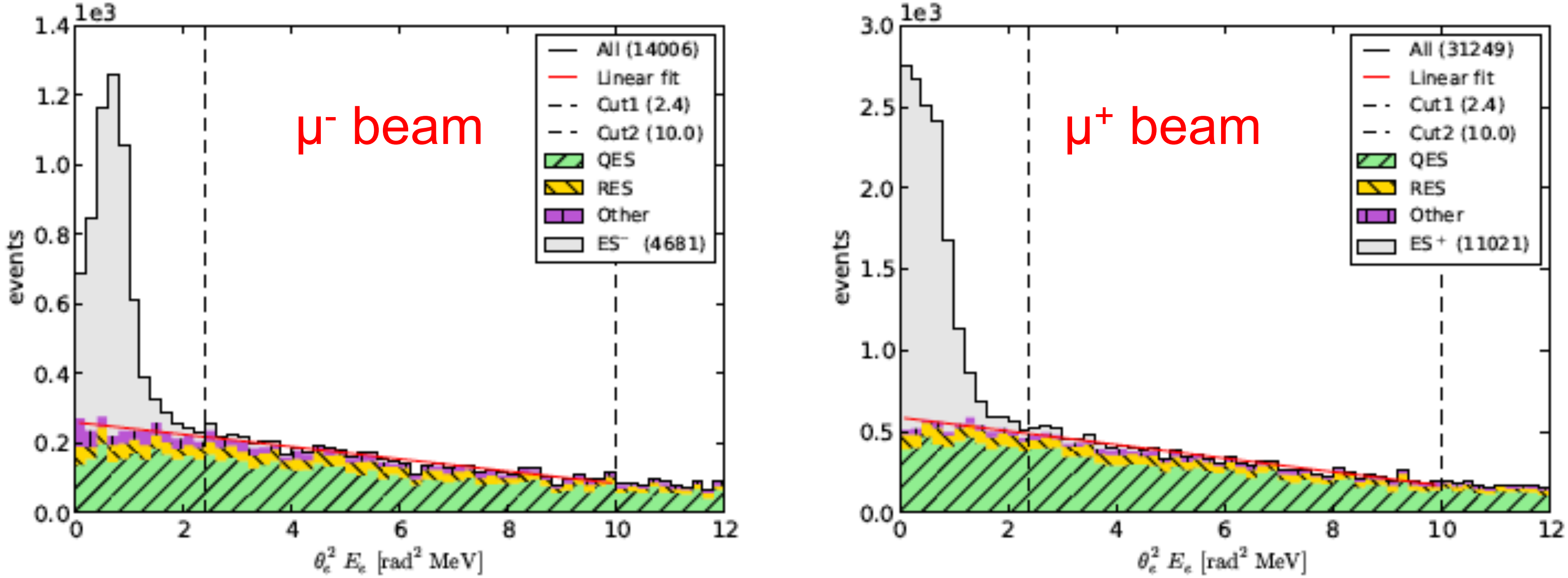
$$R = \frac{N^{\Delta}_{\mu-}}{N^{\Delta}_{\mu+}} = 0.210 \pm 006,$$

Near Detector ν-e scattering

- But near detector can do ν-e scattering equally well:
  - Can be used to measure the flux and can be used for both ν and $\bar{\nu}$ at both 25 GeV and 10 GeV

Roumen Tsenov, Rosen Matev

25 GeV Neutrino Factory



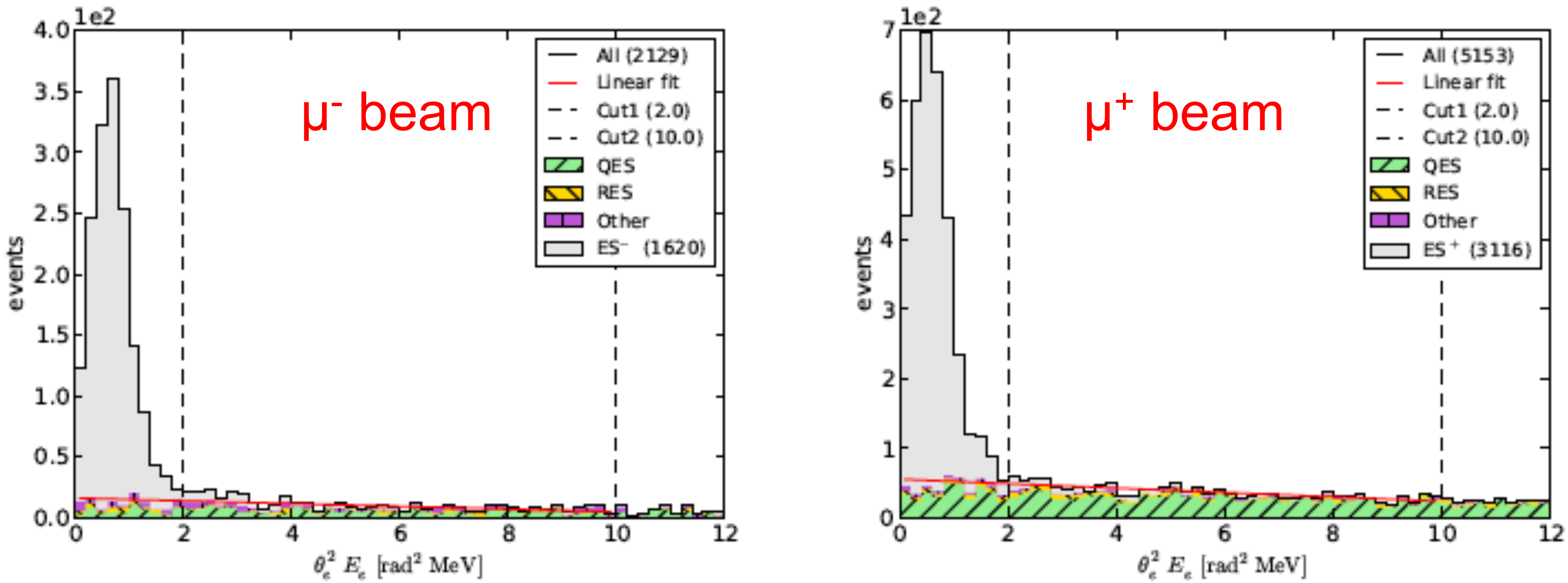
Total flux accuracy ~1% in one year.

Near Detector ν-e scattering

- But near detector can do ν-e scattering equally well:
  - Can be used to measure the flux and can be used for both ν and $\bar{\nu}$ at both 25 GeV and 10 GeV

Roumen Tsenov, Rosen Matev

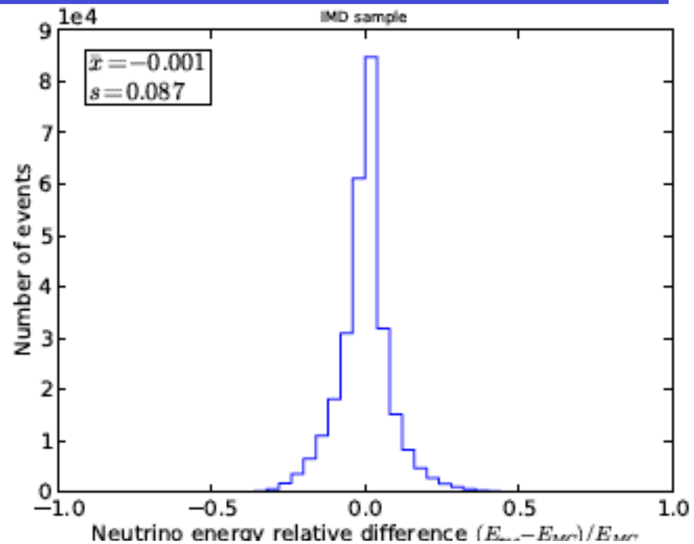
10 GeV Neutrino Factory



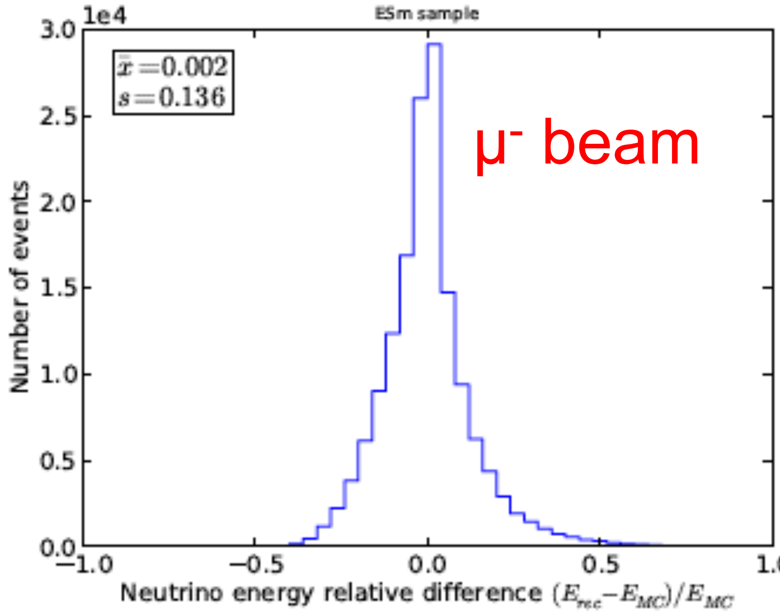
Total flux accuracy ~1% in one year.

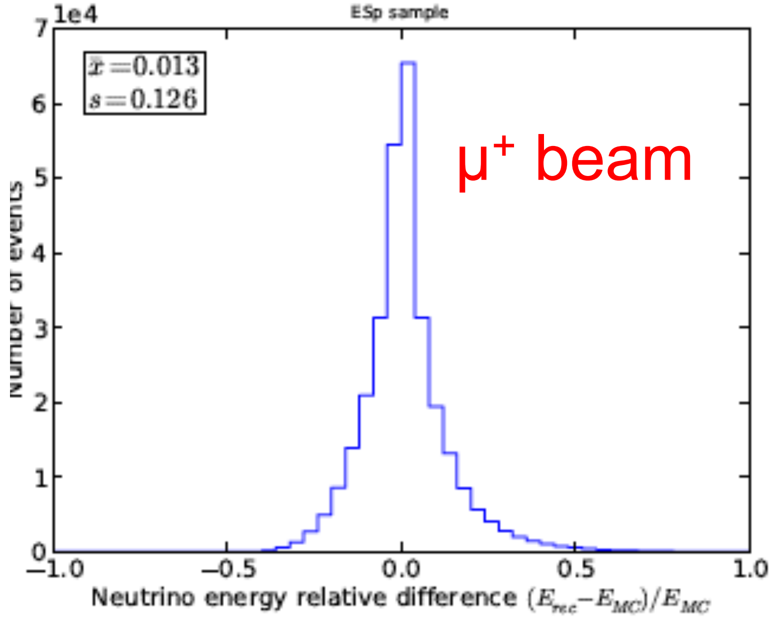
Energy reconstruction ν-e scattering

- Constrained fit reduces energy resolution from 28% to 8.7% for IMD events 25 GeV NF



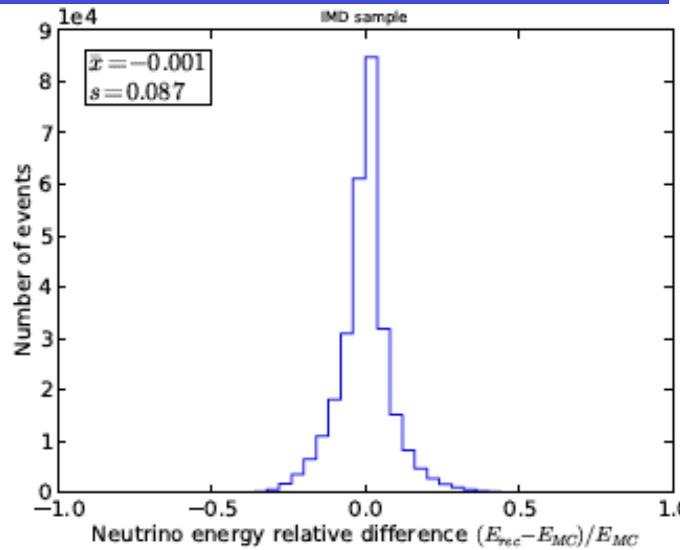
- For ν-e scattering events resolution is ~13% 10 GeV NF

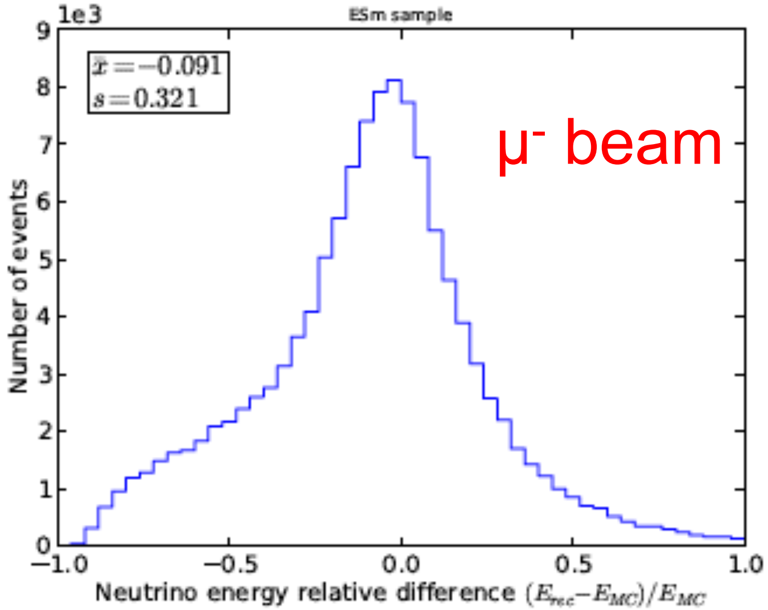


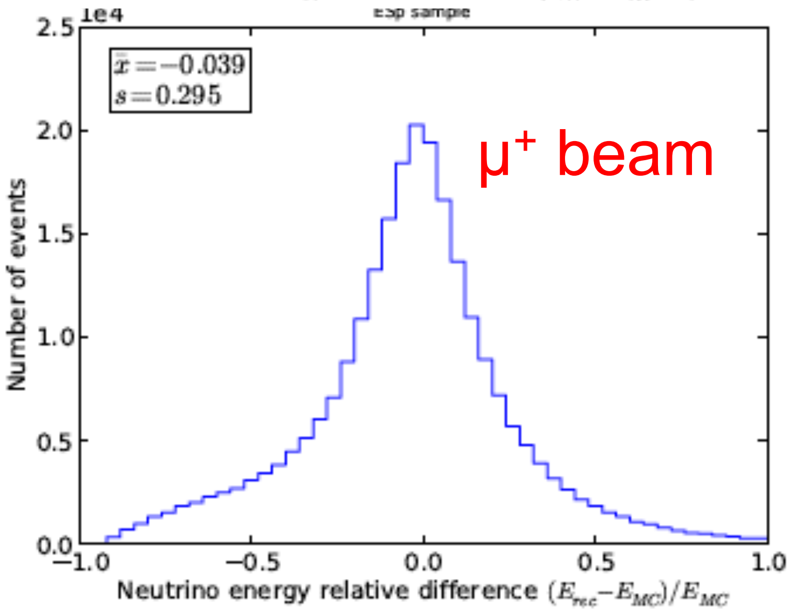


Energy reconstruction ν-e scattering

- Constrained fit reduces energy resolution from 28% to 8.7% for IMD events 25 GeV NF
- For ν-e scattering events resolution with smearing is ~30% 10 GeV NF



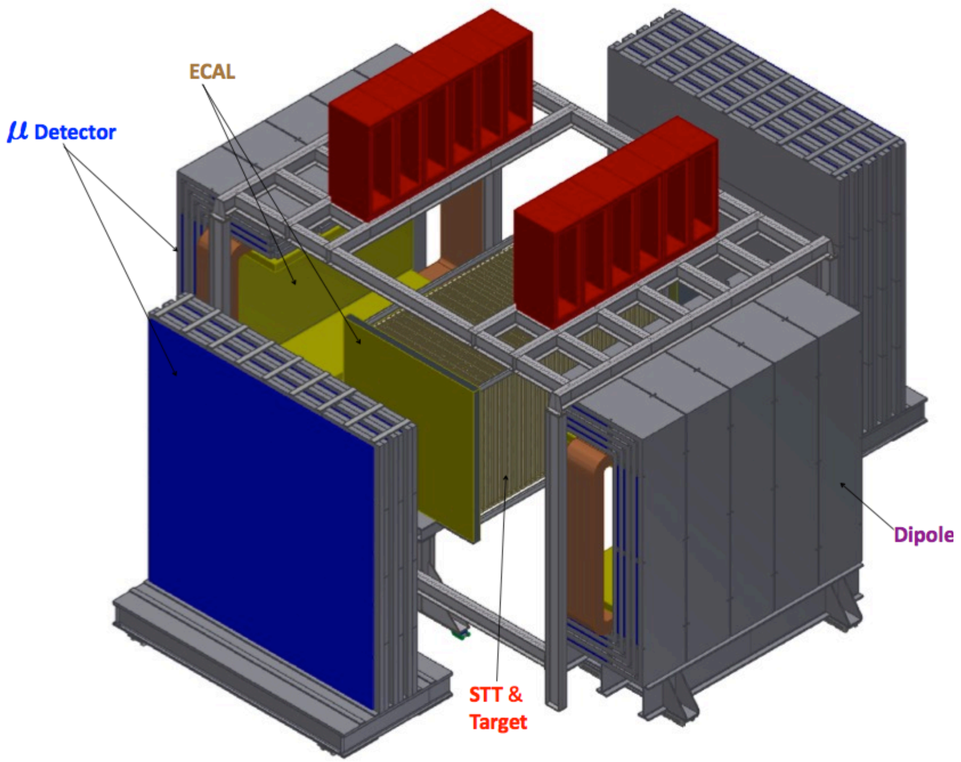


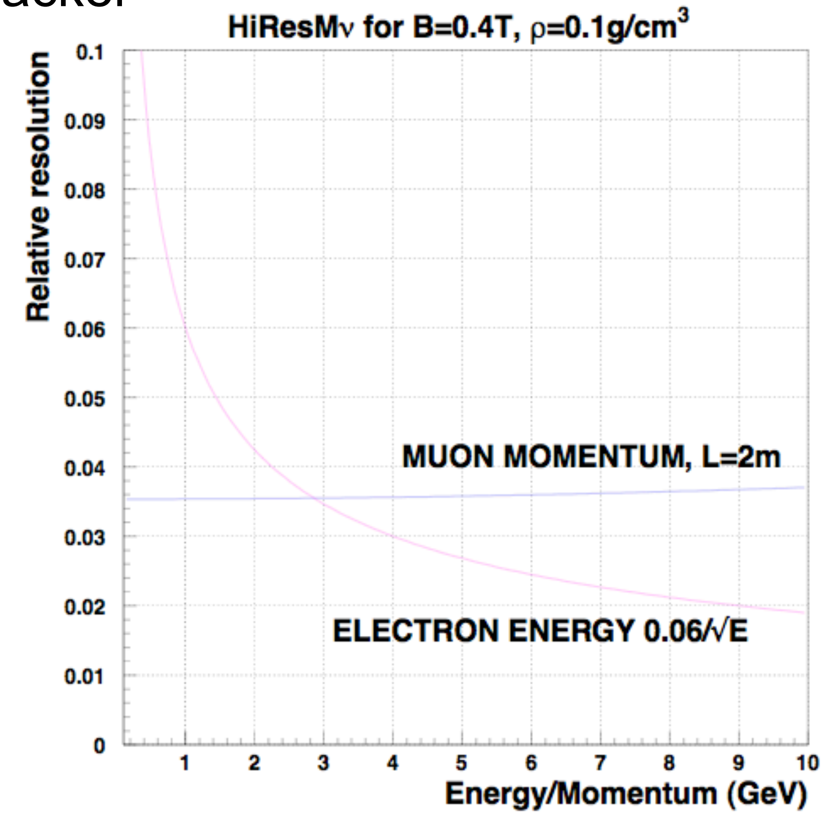


HiRes Near Detector

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

Sanjib Mishra



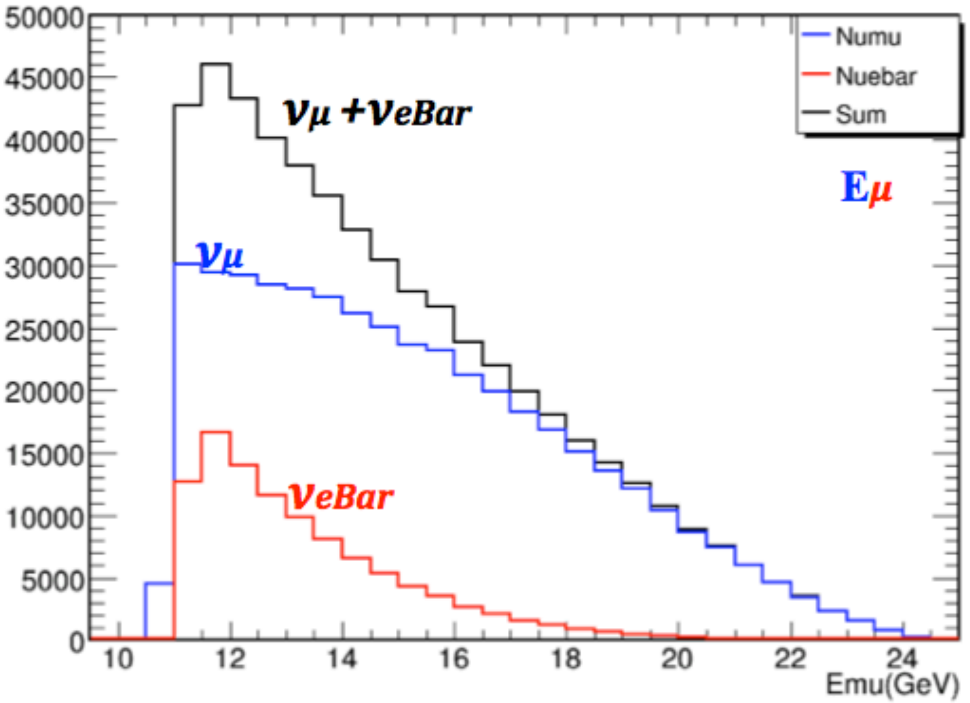


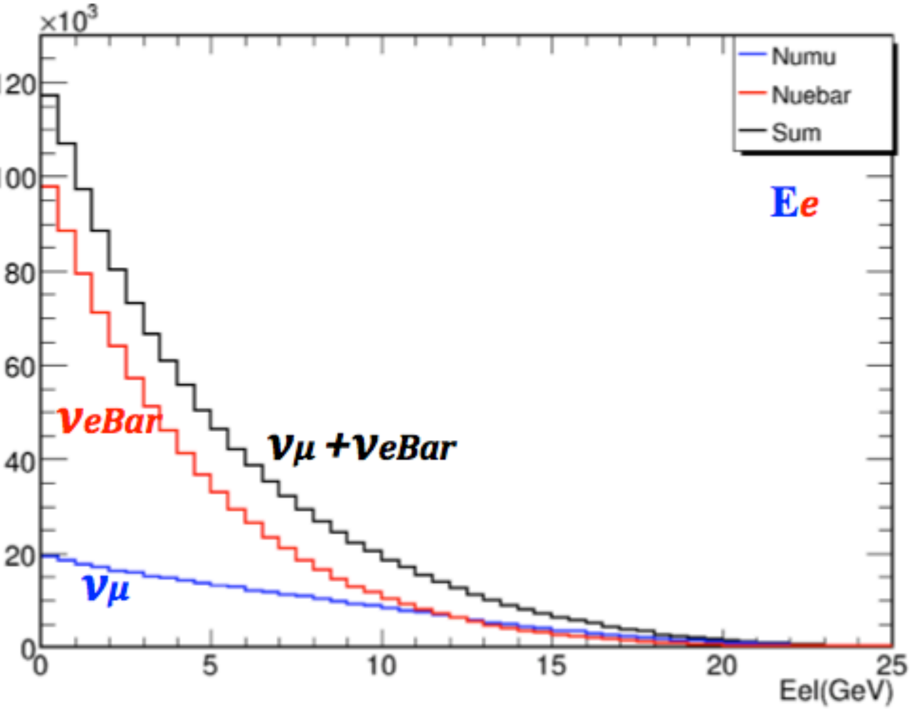
Momentum resolution ~3.5%
Angular resolution ~ 1 mrad

HiRes Near Detector

- Fit simultaneously ν_μ IMD and ν_e channels to extract flux:

  See Sanjib Mishra's talk tomorrow





Can the same flux accuracy be achieved if we do not have the IMD channel?

Near Detector: list of things left to do

- Decide on Near Detector baseline for RDR
- Finalise ν-e scattering for HiRes detector
- Flux extrapolation from near to far detector
- Tau and charm analysis? (lack of manpower)
- Near detector shielding – design?
- Neutrino scattering cross-section requirements
- Influence of near detector on systematic errors
- Other …. ?

Conclusions

- A Magnetised Iron Neutrino Detector (MIND) is baseline for Neutrino Factory (10 GeV):
  - 2000 km with 100 kton mass
- Analysis is being re-optimised – robust sensitivity results ~85% coverage
- Since only one storage ring – only two near detectors
- Either Scintillating Fibre or HiRes Straw Tube tracker could do the job – Sci Fi adopted as baseline for EUROnu report but need to define final baseline for RDR
- Flux can still be measured with < 1% precision at a 10 GeV NF but systematic errors and accuracy of fits need to be determined.
- More tasks missing to finalise near detector and near-to-far extrapolation