Optimisation of the Magnetised Iron Neutrino Detector for a Neutrino Factory

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Neutrino oscillations

- Flavour transition of neutral leptons confirmed.
- Experiments observing reduction in expected fluxes have made significant measurements.
- Future experiments will look for appearance via subdominant channels.

$\sin^2(2\theta_{12})=0.87^{+0.03}_{-0.03}$ $\Delta m^2_{12}=(7.59\pm 0.2)\,x\,10^{-5}\ eV^2$

$\sin^2(2\theta_{23})>0.92$ $\Delta m^2_{32}=(2.43\pm 0.13)\,x\,10^{-3}\ eV^2$

$\sin^2(2\theta_{13})<0.19$

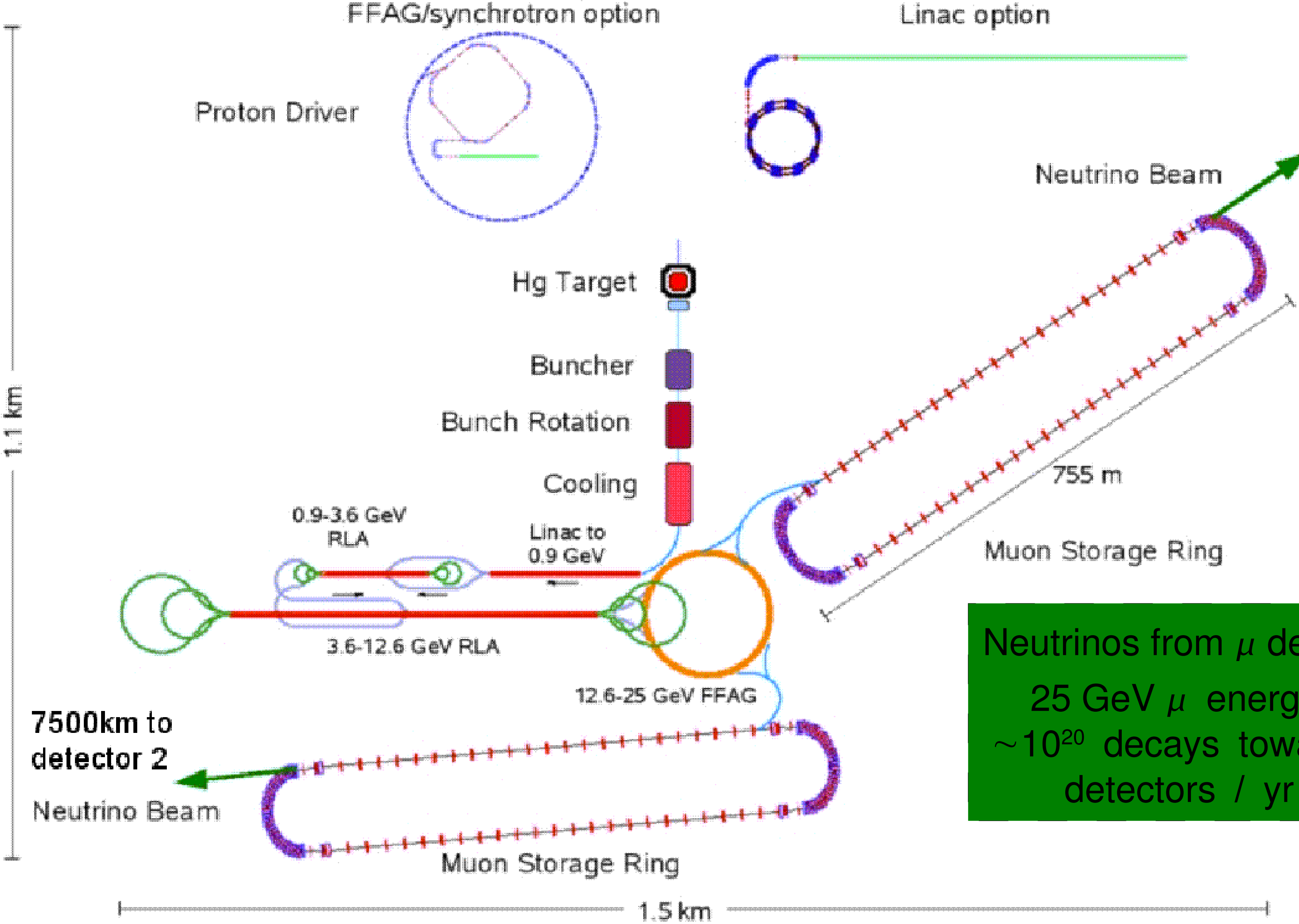
PDG, 2010

GOLDEN CHANNEL

$$P_{\nu_e\to\nu_\mu}=s^2_{23}\sin(2\theta_{13})\left(\frac{\Delta_{13}}{B}\right)^2\sin^2\left(\frac{BL}{2}\right)+c^2_{23}\sin(2\theta_{12})\sin^2\left(\frac{AL}{2}\right)+\tilde{J}\left(\frac{\Delta_{12}}{A}\frac{\Delta_{13}}{B}\right)\sin\left(\frac{AL}{2}\right)\sin\left(\frac{BL}{2}\right)\cos\left(\pm\delta-\Delta_{13}\frac{L}{2}\right)$$

(Cervera et al 2000)

The Neutrino Factory



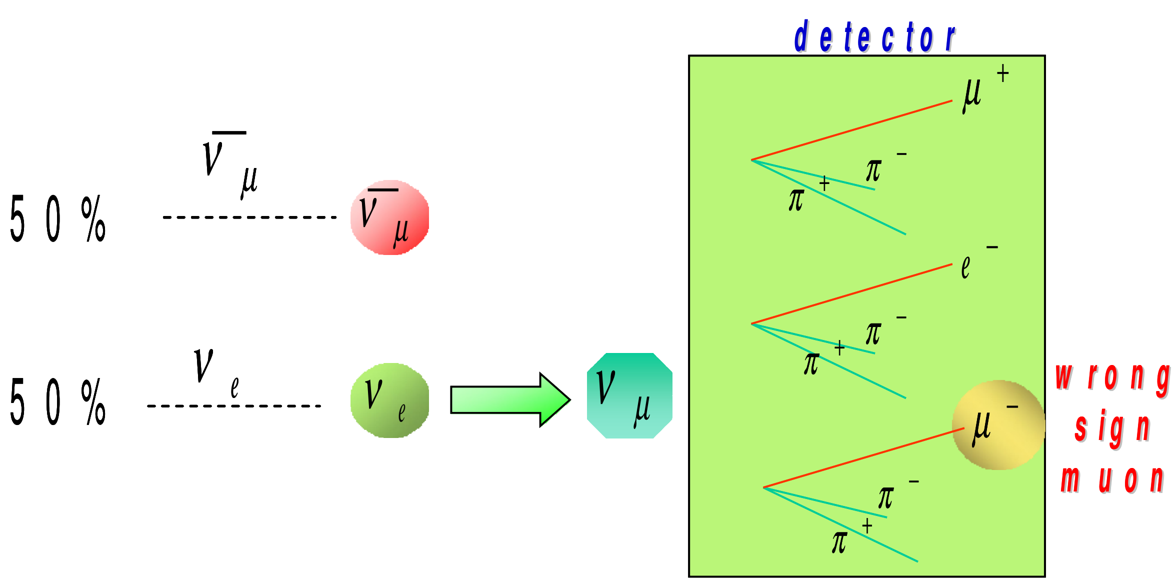
Neutrinos from μ decay.

25 GeV μ energy.

$\sim 10^{20}$ decays towards detectors / yr

Magnetised Iron Neutrino Detector

- Golden channel signature: "wrong-sign" muons in magnetised calorimeter (Cervera et al. 2000)
- Far detector (3000-7000 km) can search for "wrong-sign" muons in appearance mode (for example, Large Magnetic Detector)



Wrong sign Muon analysis

- 'Wrong sign' muon sensitivity must be maximised while suppressing backgrounds.
- Correct sign muon backgrounds:
  - Fitting the wrong charge
  - Fitting a hadron or decay muon
- Neutral Currents.
- Electrons.

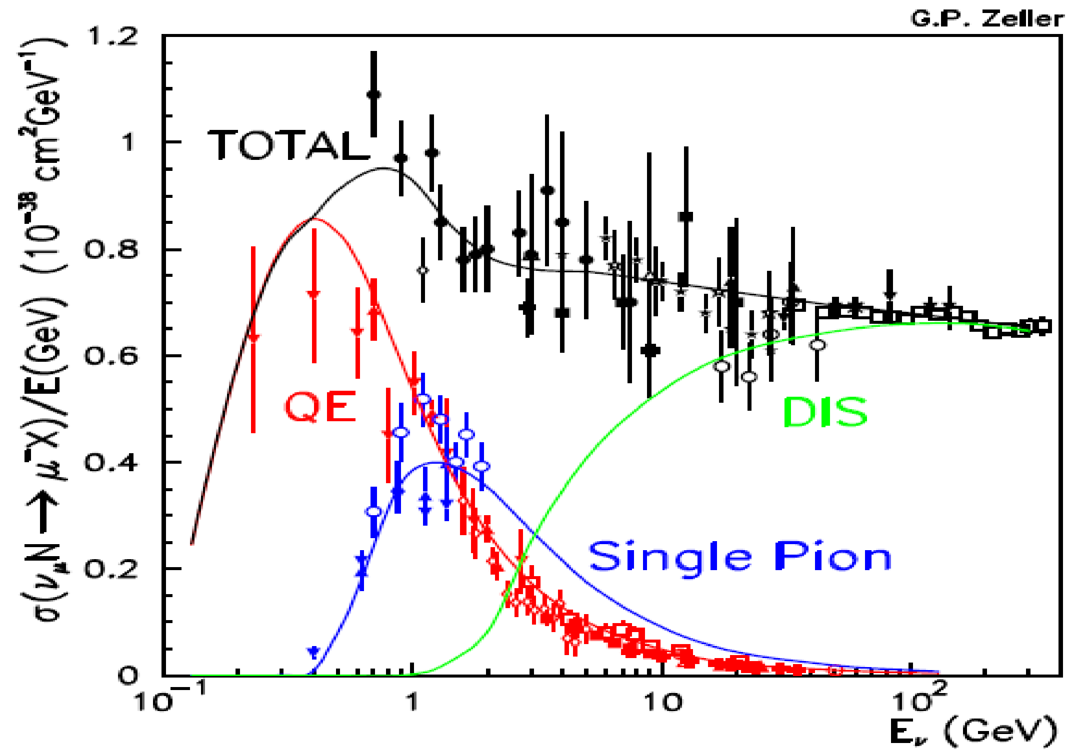
$\overline{\nu}_\mu$ CC	ν_e CC	$\overline{\nu}_\mu + \nu_e$ NC	ν_μ (Signal)
1.22×10^5	3.34×10^5	1.48×10^5	5.56×10^3

Expected interactions at 4000km distance in a 50ktonne detector for 5 yr running with 25GeV muons. Measured parameters as in PDG with δ = 45° and θ_{13} = 5.7°

A new simulation and analysis

- Need to prove that under full simulation, digitization and reconstruction MIND can suppress backgrounds and maintain efficiency.
- What is the effect of Quasi-elastic and resonance?

Expected impact of Quasi-elastics

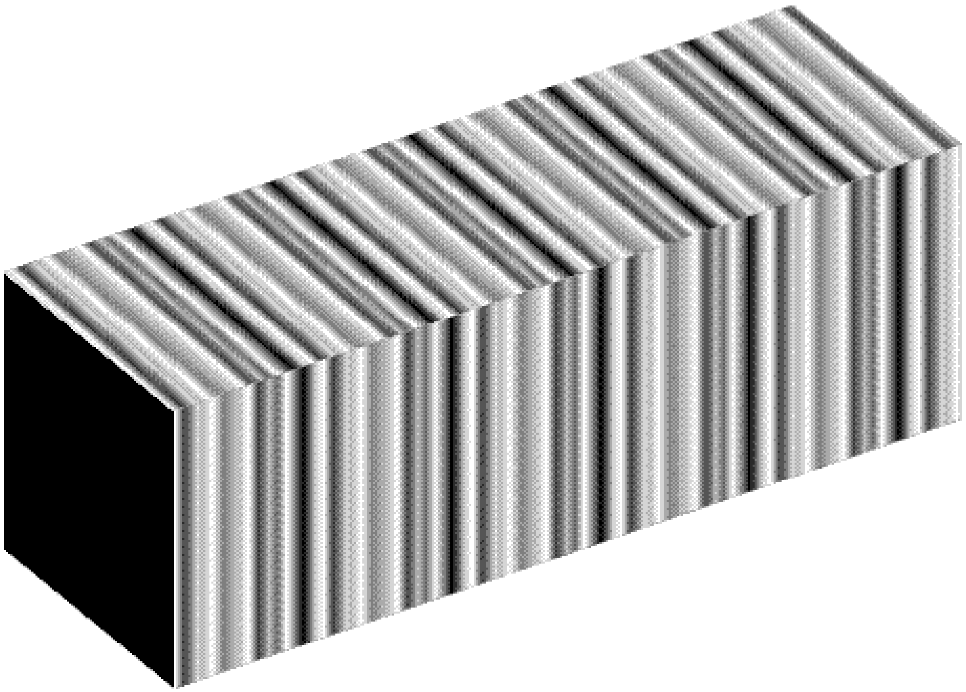


Non-DIS processes dominate at low energies.

Lower multiplicity should make pattern recognition easier and hence improve efficiency at low energy.

However, could also increase backgrounds at low energies.

Simulation



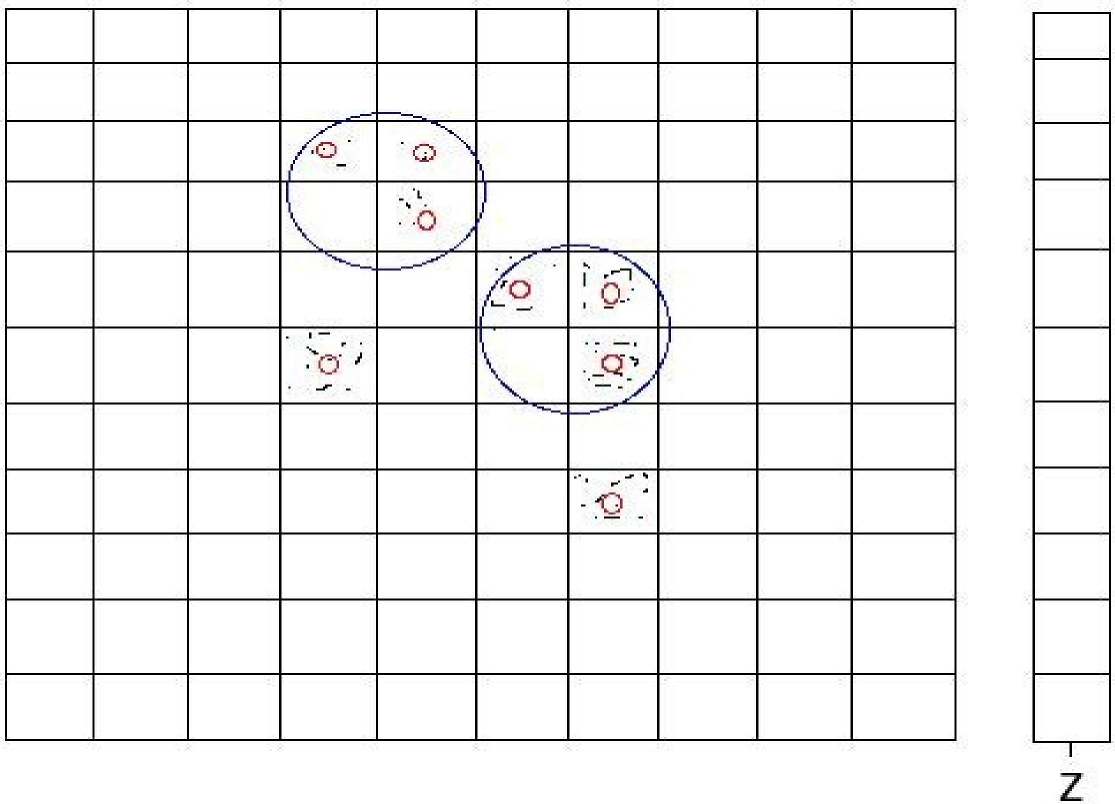
Geant4 simulation of MIND:

- Cuboidal structure
- Dipole field*
- Physics via QGSP_BERT

Control over all external and internal dimensions as well as the number of scintillator planes per sandwich.

*Will be developed in the future to include a toroidal field. Sensitivities are not expected to change significantly.

Digitization



Parameterization of scintillator response. Assumes WLS with λ = 5m.

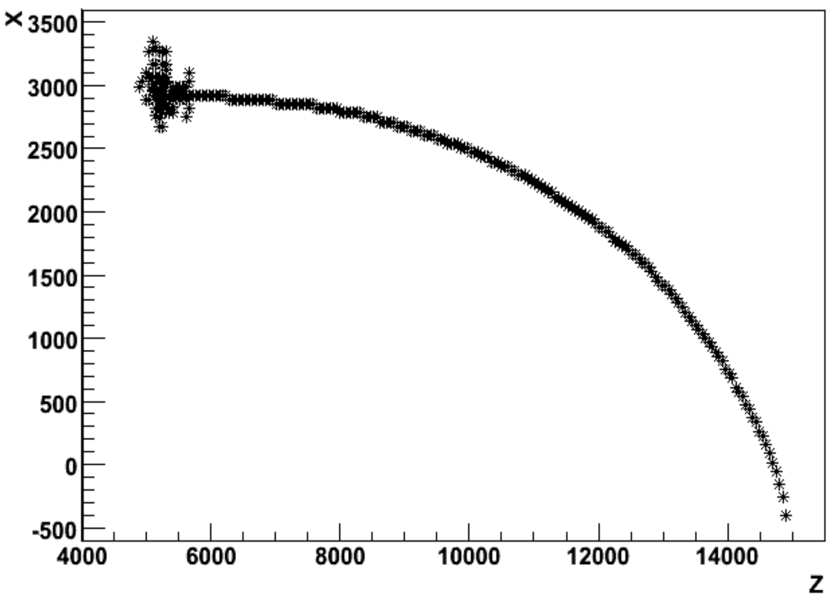
Views assumed matched with low energy in one view giving a larger error to that dimension at fitting.

Keeping it simple while being realistic leads us to:

- Boxes to represent view matched x,y readout planes with the x,y,z at the centre of a box.
- Clustering of adjacent boxes at analysis around the largest signal with weighted mean for x,y position.

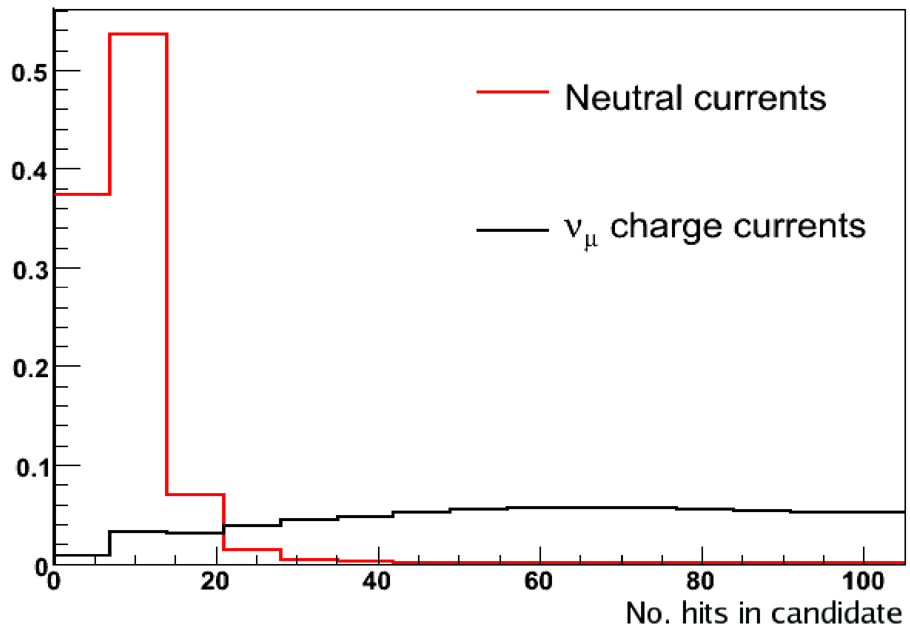
Selection of signal events

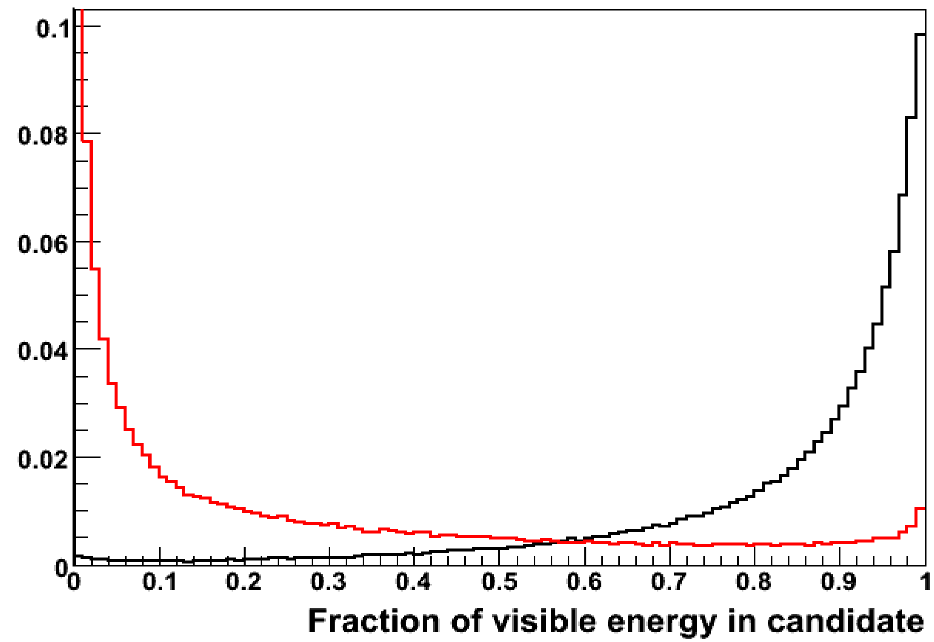
- Muons tend to penetrate beyond other particles. Use longest track as starting point.
- Model Helix to look back through the activity and form a candidate muon.
- Cuts on the fit quality can remove backgrounds with incorrect curvature.



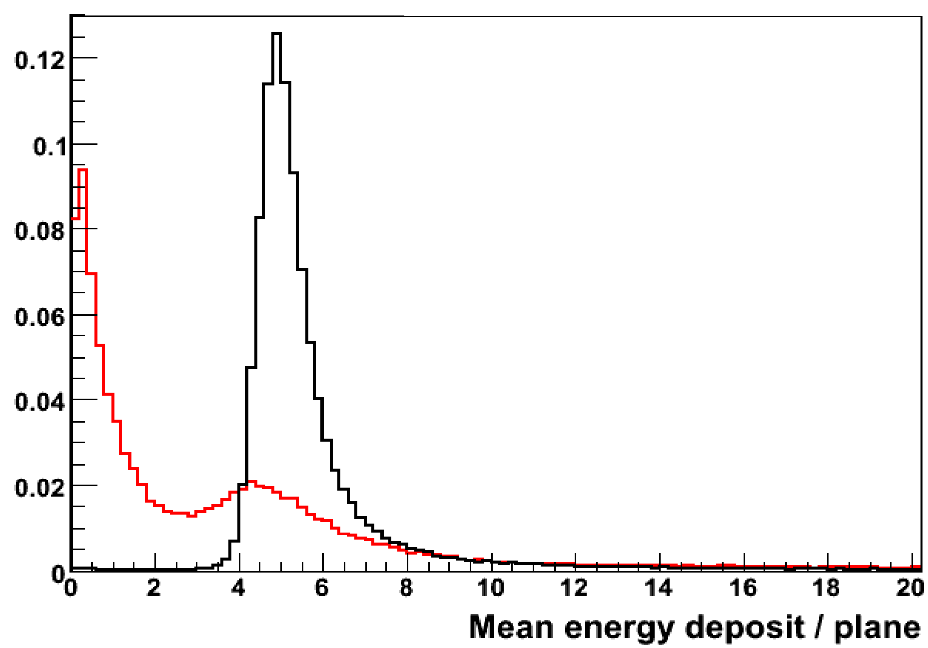
More complex events can be reconstructed using a cellular automaton to 'walk' back through the activity and test possible trajectories to find the most likely muon.

Likelihood analysis





Likelihood analysis using these parameters serves to reject additional background from NC



Parameters inspired by MINOS analysis

Hadron reconstruction

- Hadron energy must be reconstructed to calculate the neutrino energy of DIS events.
- Development of algorithms for this and to reconstruct the direction vector underway
- Smear on the true quantities for now:

$$\frac{\delta E}{E}=\frac{0.55}{\sqrt{E}}+0.03$$

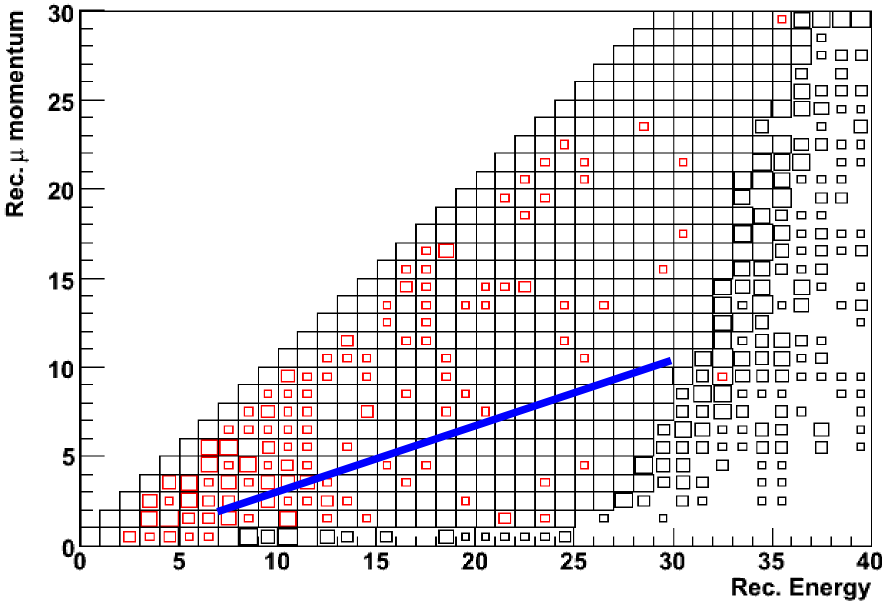
From MINOS CalDet result.

$$\delta\theta=\frac{10.4}{\sqrt{E}}+\frac{10.1}{E}$$

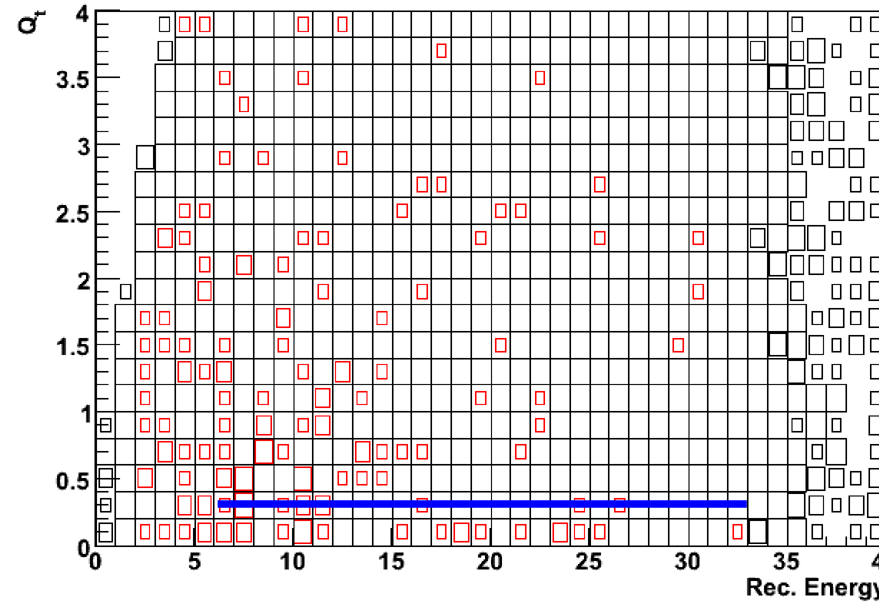
From Monolith proposal.

Kinematic cuts

$P_\mu \geq 0.3E_\nu$



$Q_t = P_\mu \sin^2\theta_{had} \geq 0.3$



Neutrino energy reconstructed as $E_\nu = E_\mu + E_{had}$.

For now true hadron energy smeared, a good reconstruction algorithm important for kinematic cuts.

μ^+ wrong sign signal background

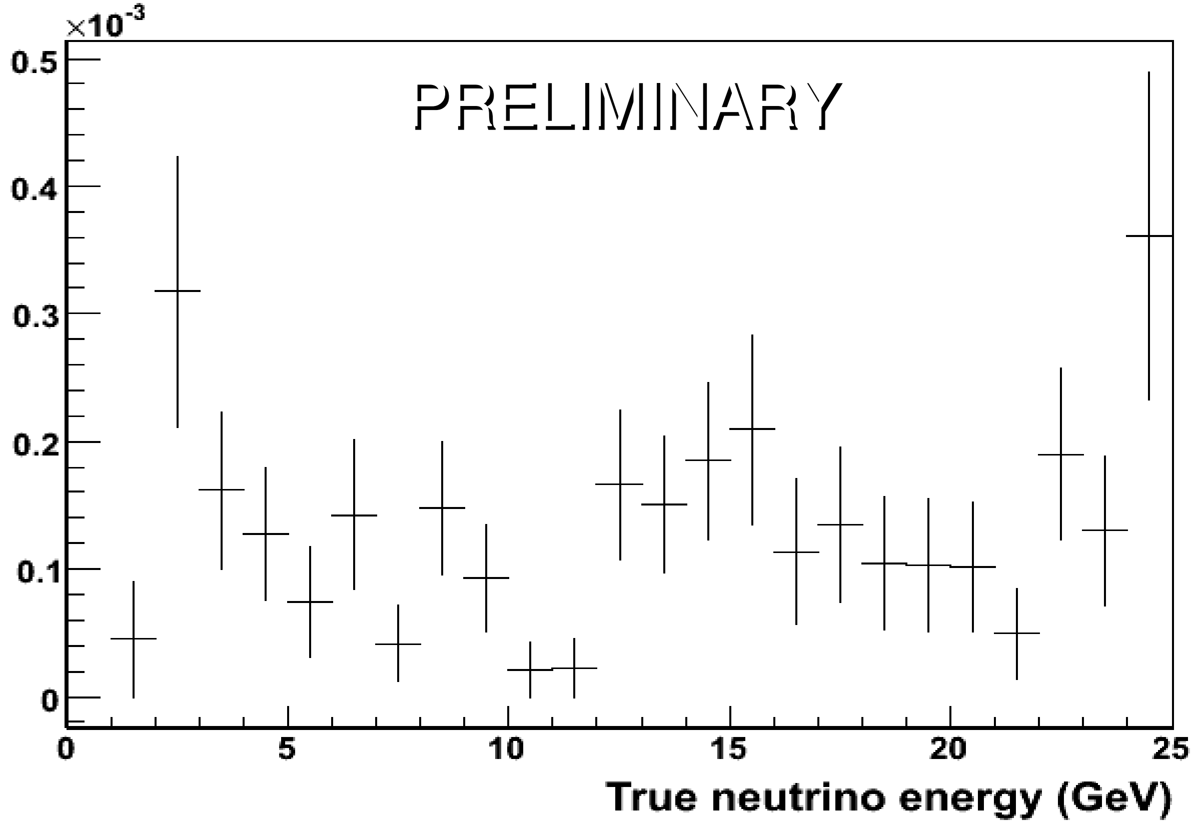
Need to quantify:

1) how often ν_μ interaction reconstructed as CC event with μ^+,

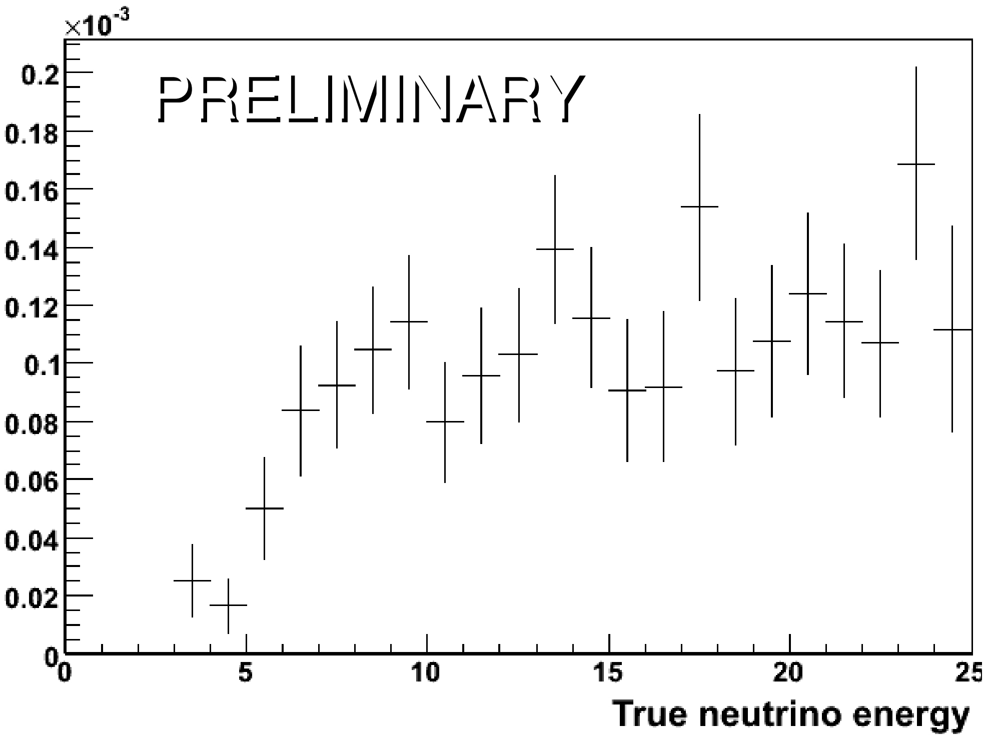
2) how often NC interactions reconstructed as CC event with μ^+,

3) how often $\bar{\nu}_e$ interaction reconstructed as CC event with μ^+.

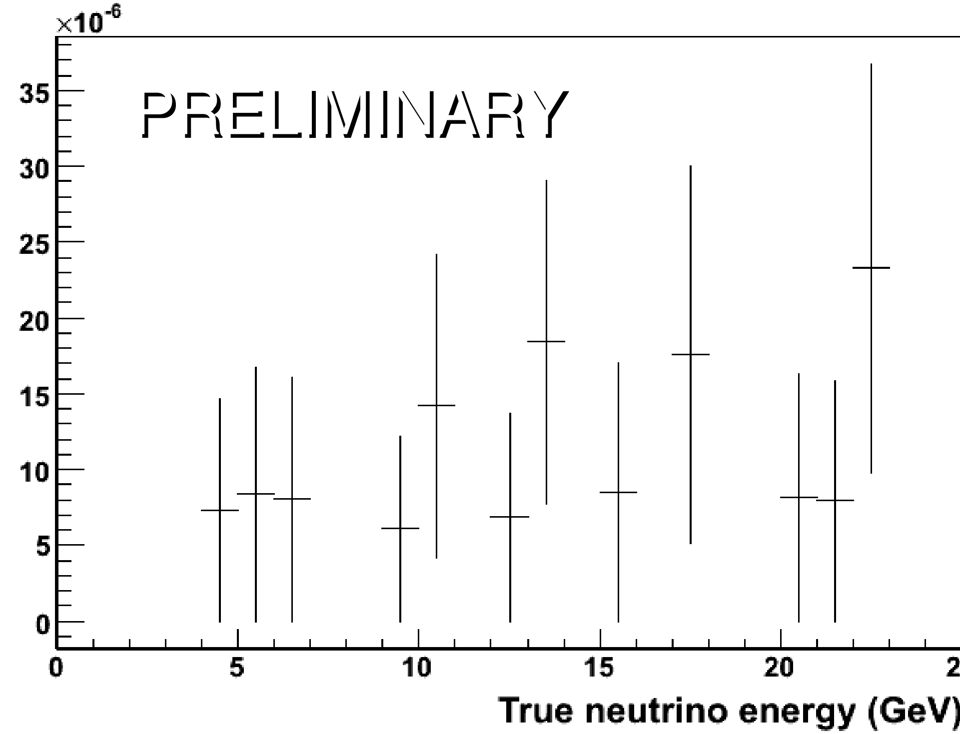
1) Charge background



Background (cont.)

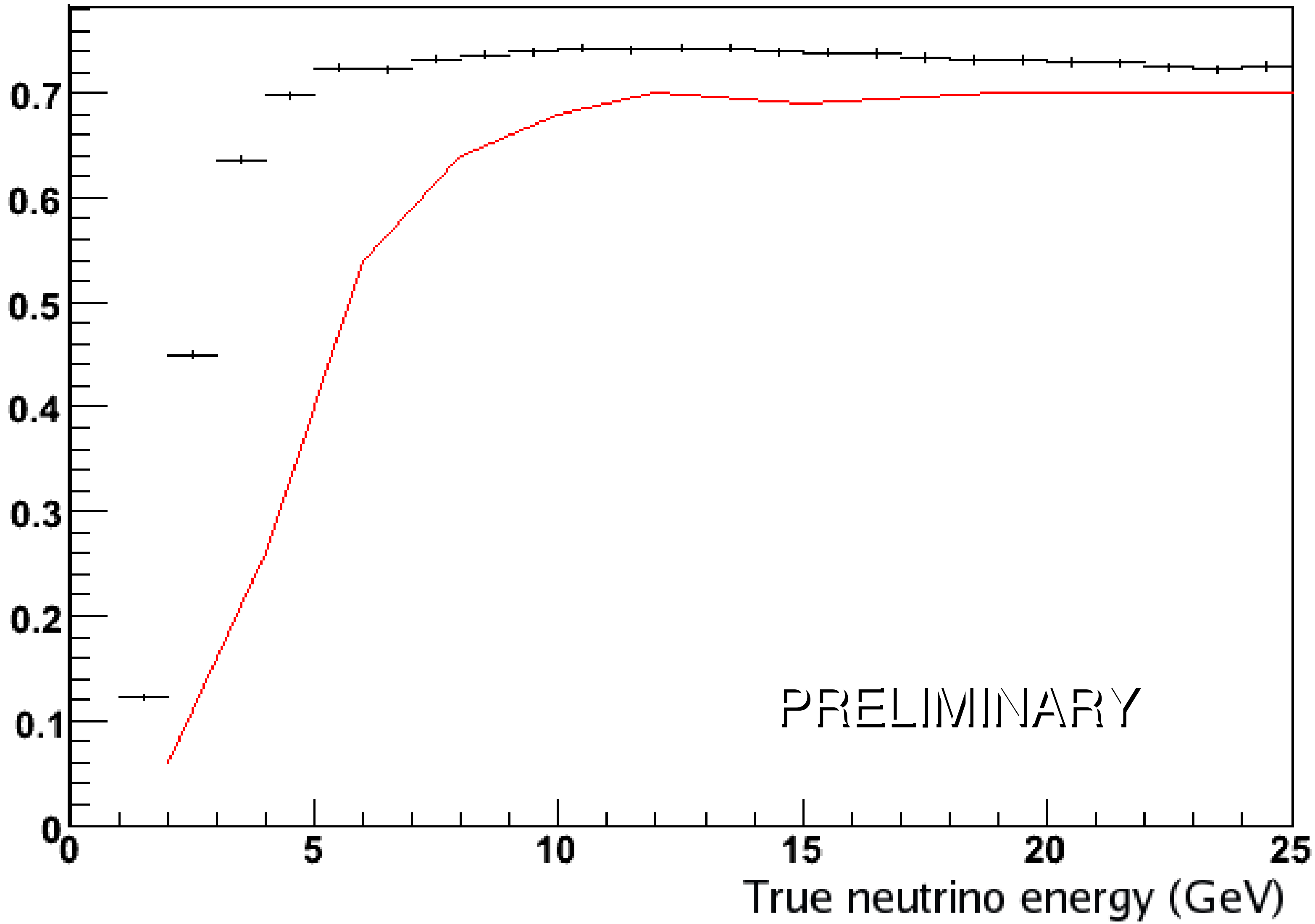


2) Neutral current



3) Electron

Signal efficiency



Red curve follows the efficiency curve for MIND as published in:

T. Abe et al, JINST, 4:T05001, 2009.

Conclusion

- New simulation and analysis show that the MIND detector has the potential to perform the wrong-sign muon analysis at NF.
- Work ongoing to fully optimise the detector.