Detector possibilities: scintillator based detectors

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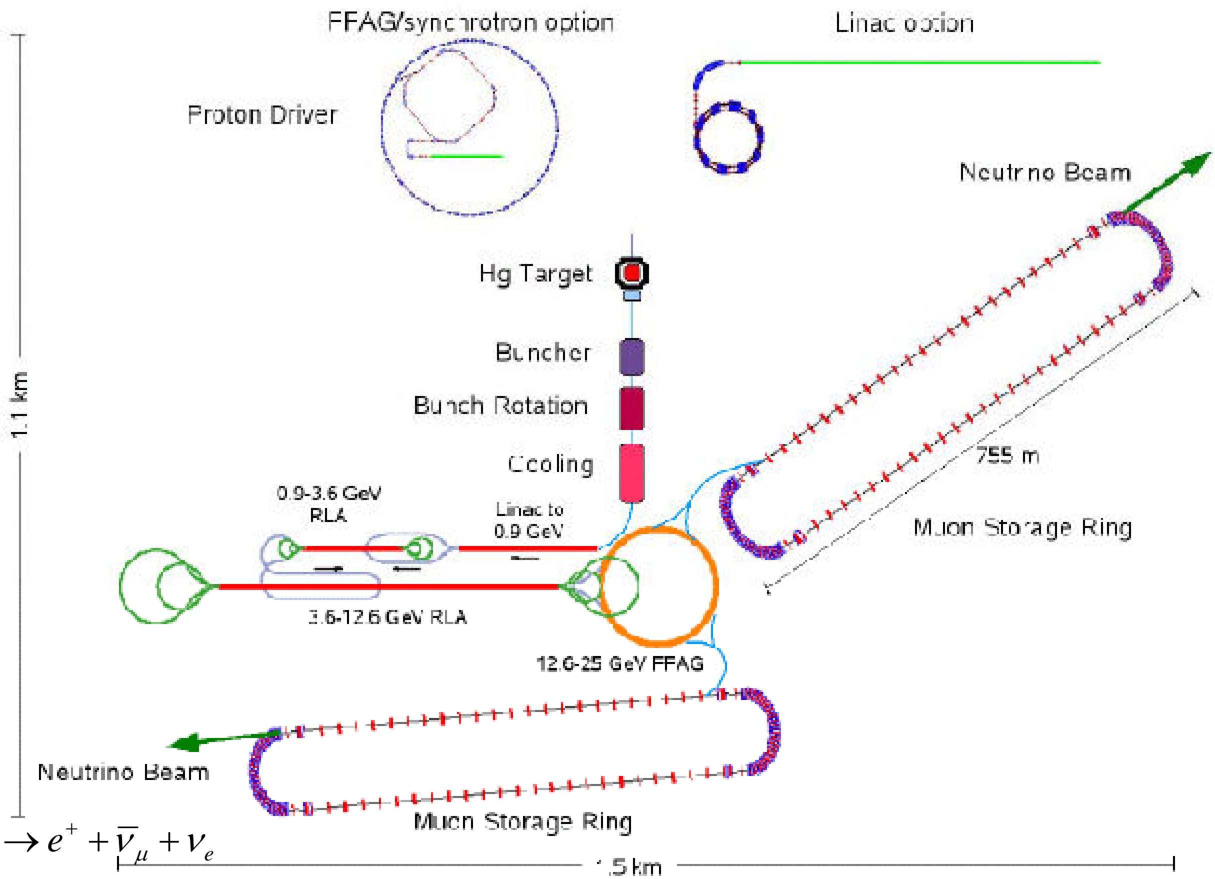
Scintillator based detectors

- Scintillator based detectors are widely used in neutrino experiments
- Many examples from past and present: CDHS, CHARM, CHARM-II, CCFR, NuTeV, MINOS, ND280, Minerva, NOVA…
- There are two examples that are being looked at in the context of detectors at a Neutrino Factory:
  - Magnetised Iron Neutrino Detector (MIND) of 50-100 kton – comprising layers of iron and scintillator
    - This is the default option at a Neutrino Factory (10-20 times bigger than MINOS)
  - Totally Active Scintillating Detector (TASD) - layers of scintillator making up 100% of target

Neutrino Factory

- Baseline design for a Neutrino Factory: two different detectors at two different baselines (~4000km, 7500km)

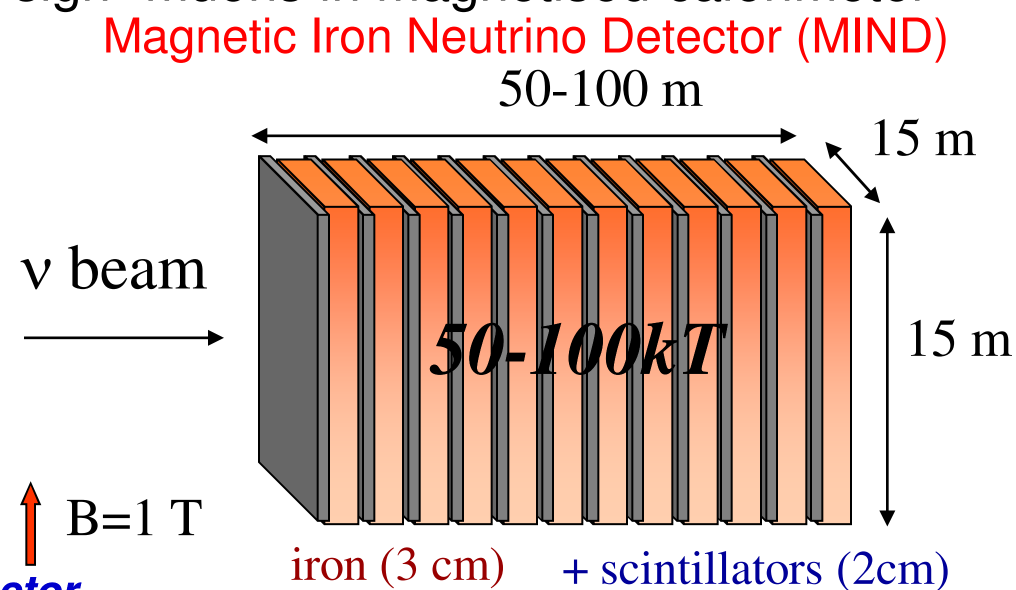


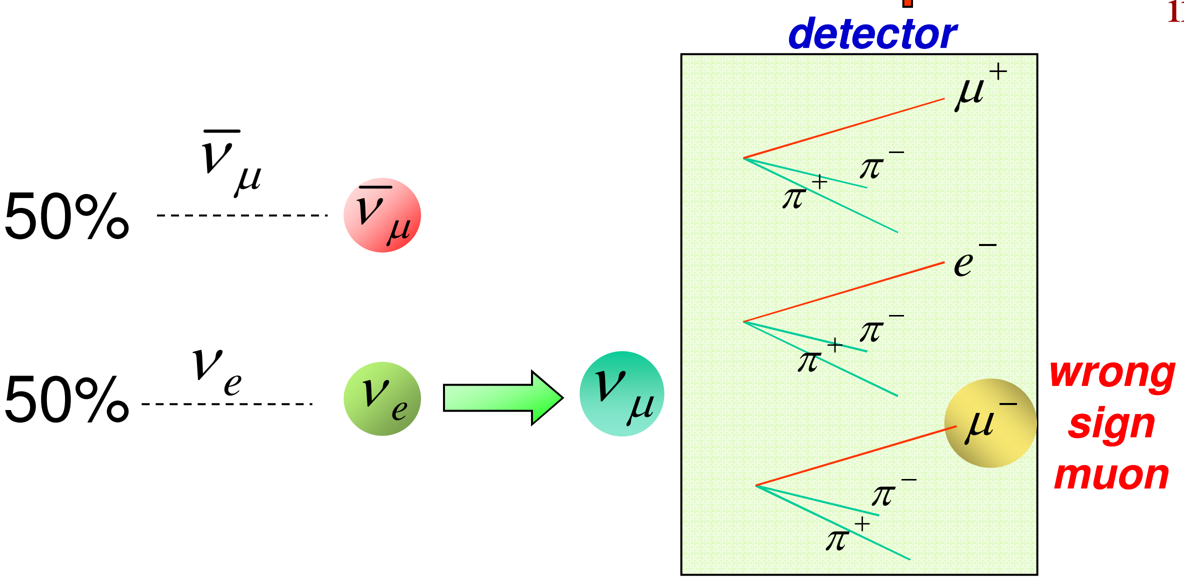
$$\mu^+ \to e^+ + \bar{\nu}_\mu + \nu_e$$
$$\mu^- \to e^- + \nu_\mu + \bar{\nu}_e$$

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

Magnetised Iron Neutrino Detector (MIND)

- Golden channel signature: “wrong-sign” muons in magnetised calorimeter **(Cervera et al. 2000)**
- Far detector (2000-7600 km) can search for “wrong-sign” muons in appearance mode



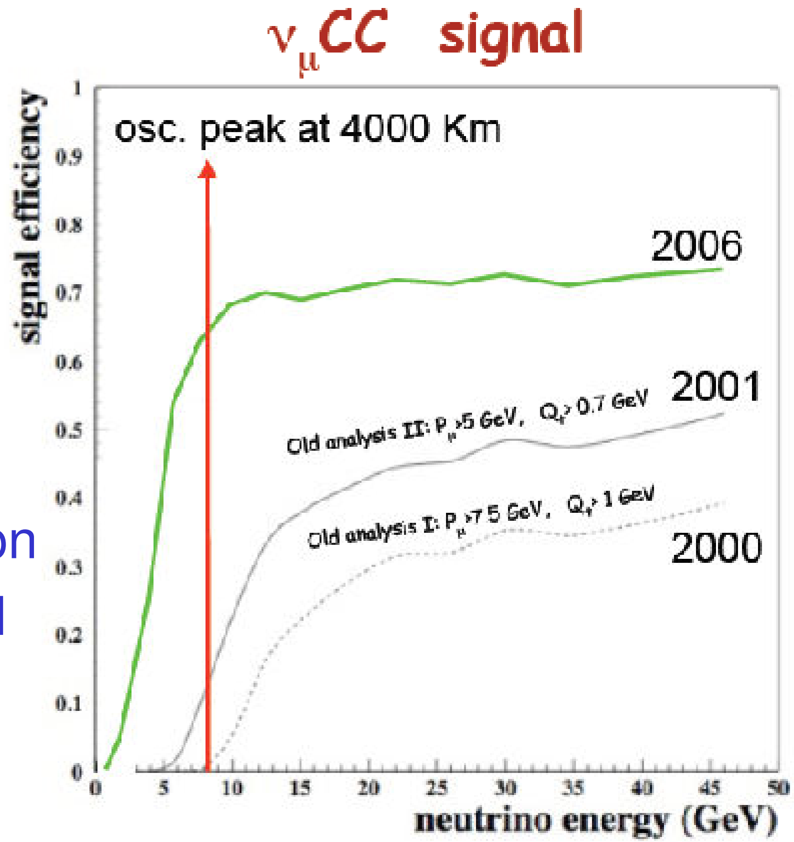


5-10 ×

History of MIND analysis

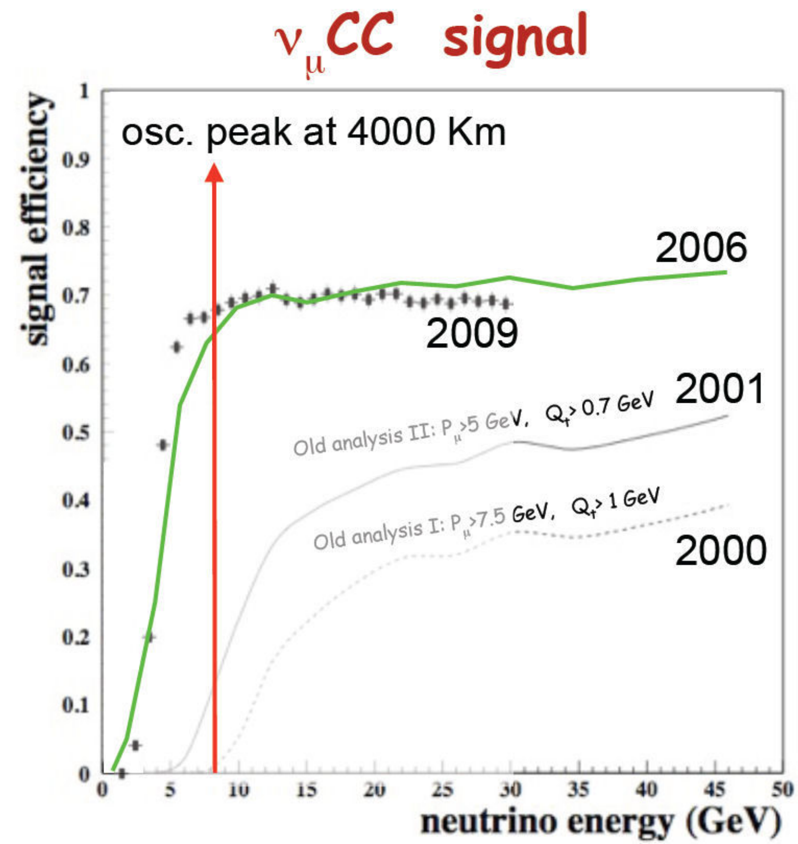
- "Golden" paper (Cervera et al, 2000) was optimised for a small value of θ_{13}, so efficiency at low energy cut severely
- Used fast simulations and detector parameterisation
- MIND analysis redone for ISS (Cervera 2006)
  - Improved event selection,
  - Fast simulation
  - Perfect pattern recognition
  - Parameterisation based reconstruction
  - 1T dipole field instead of toroidal field
  - Fully contained muons by range
  - Scraping muons by curvature
  - Hadron shower: $E_{\nu}^{recon} = E_{had} + E_{\mu}$

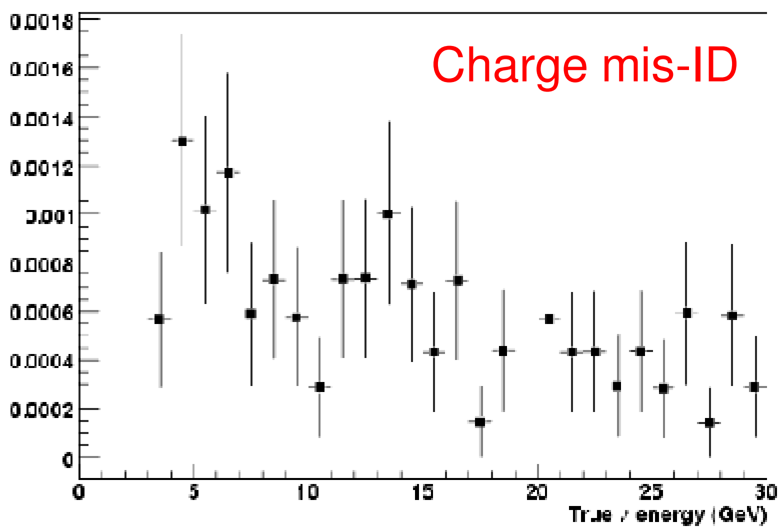
$$\left(\frac{\delta E}{E}\right)_{had} = \frac{0.55}{\sqrt{E_{had}}}$$



History of MIND analysis

- "Golden" paper (Cervera et al, 2000) was optimised for a small value of θ_{13}, so efficiency at low energy cut severely
- New analysis: **arXiV:1004.0358**
  - Full reconstruction Kalman filter
  - Full pattern recognition
  - GEANT3 (LEPTO DIS)
  - Analysis chain using full likelihood functions
  - Still dipole field and hadron shower



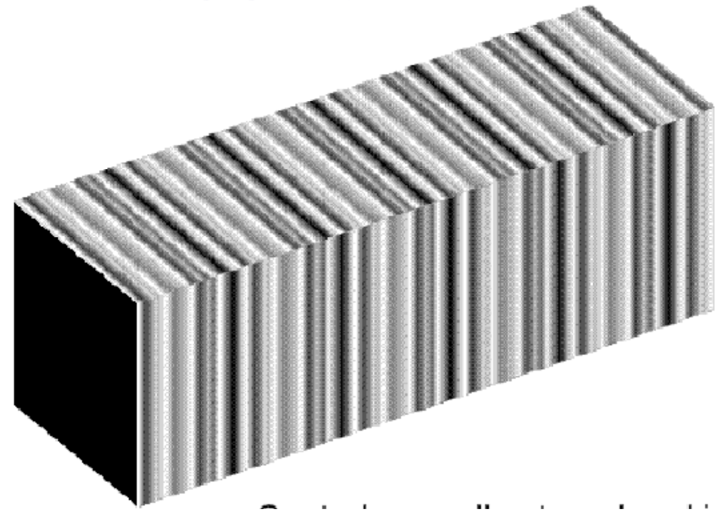


MIND: new developments

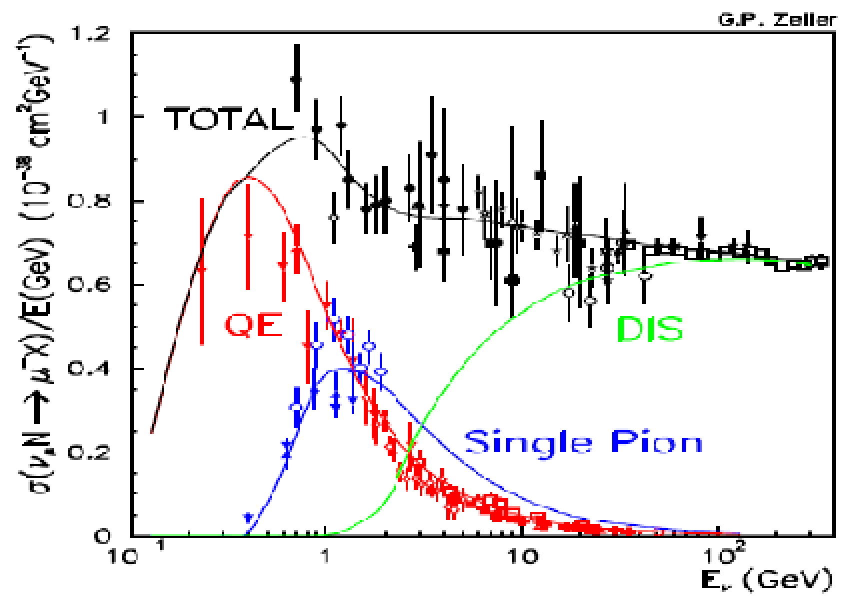
Results to be shown use 3 cm of iron and one 2 cm thick polystyrene plane.

- Improvements MIND analysis with full GEANT4 simulation

Laing, Cervera, PS – 5th IDS Meeting Apr10



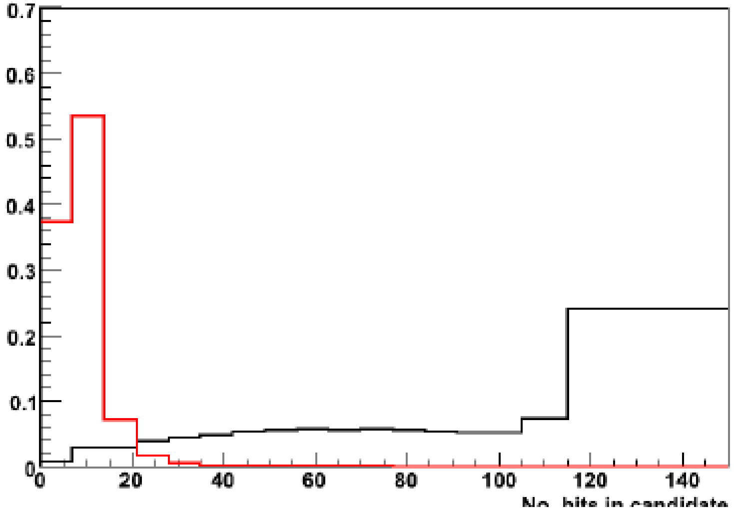
- Add quasi-elastics and resonance production (NUANCE): Non DIS processes dominate at low energies and should improve efficiency at low energies

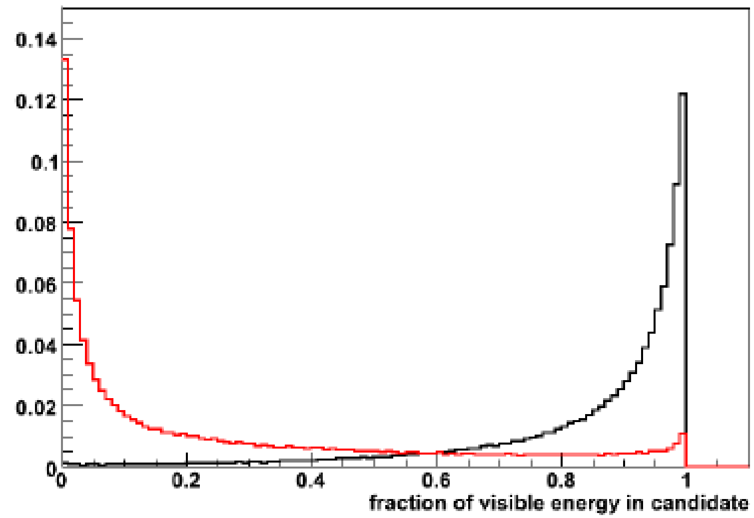


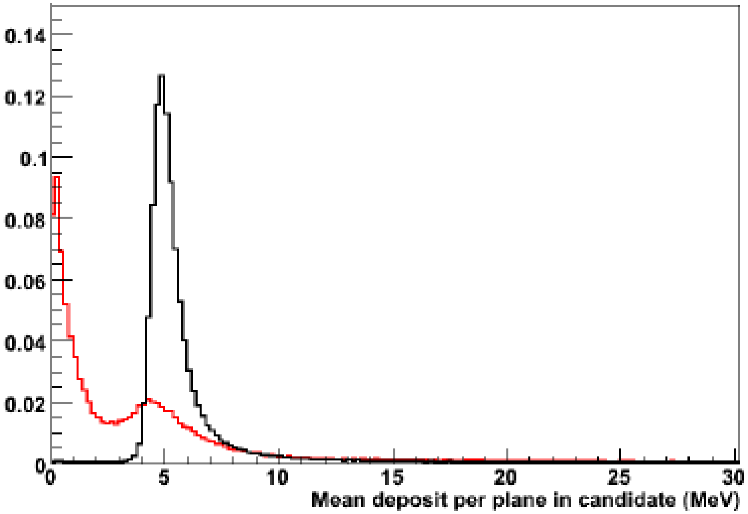
MIND: likelihood analysis

- Likelihoods: number hits in candidate, fraction visible energy, mean energy deposit per plane

Preliminary







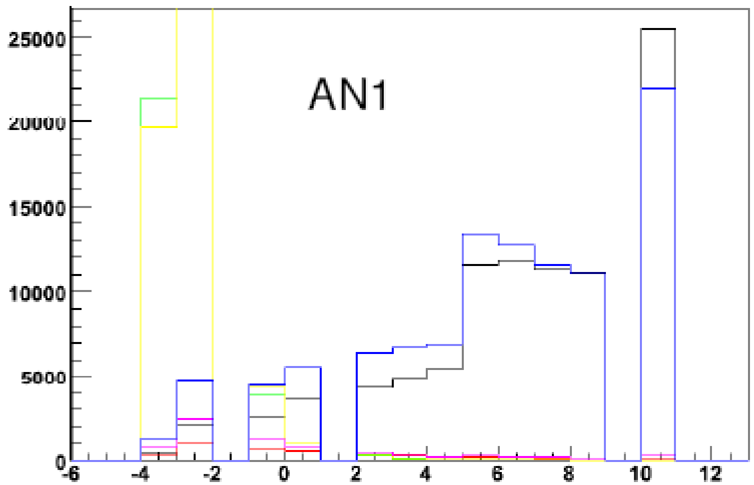
Parameters taken from MINOS.

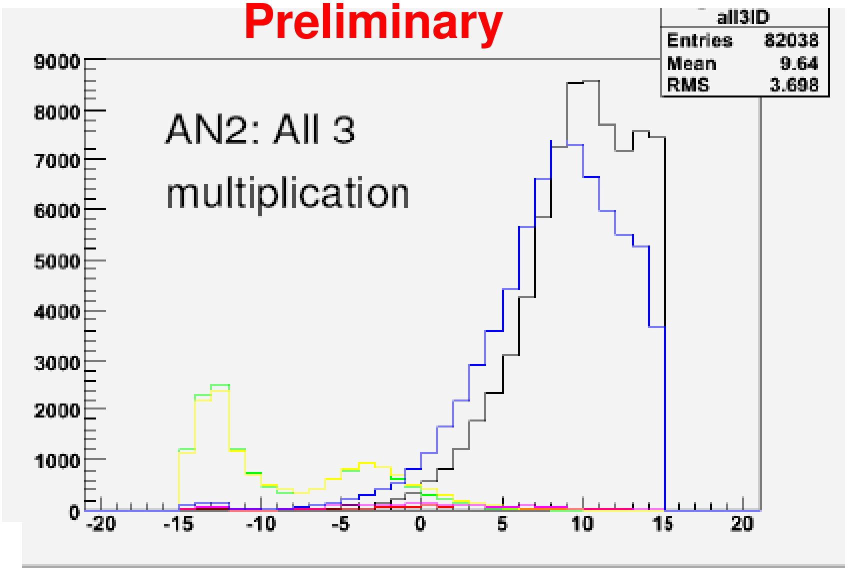
Since energy deposit involves assumptions define two likelihood analyses:

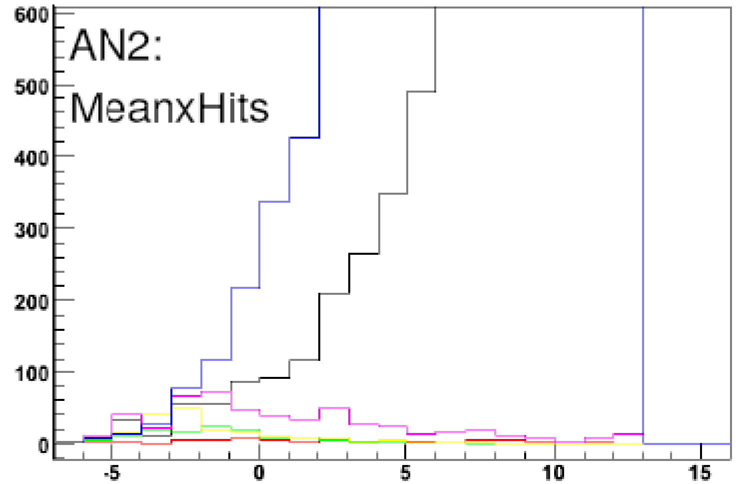
1) Use hit parameter only.
2) Use combination of all three where available.

MIND: likelihood analysis

- Two analyses: different combinations of likelihood functions







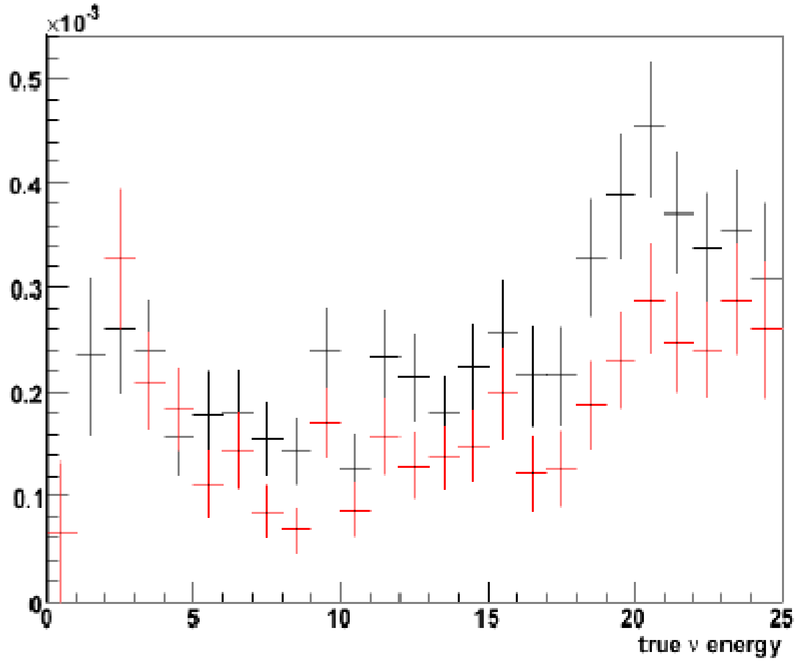
Analysis 2 requires more than one log parameter.
Tuning can achieve better efficiency or better background suppression.

Blue and Black signal. Other colours background

MIND: likelihood analysis

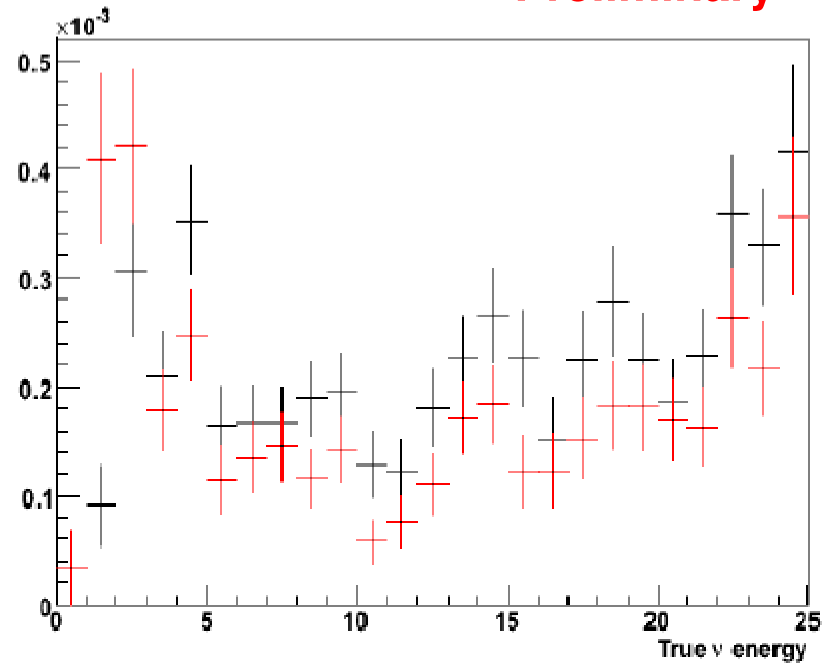
- ν_μ Charged current background

Background to μ^- appearance



Background to μ^+ appearance

Preliminary



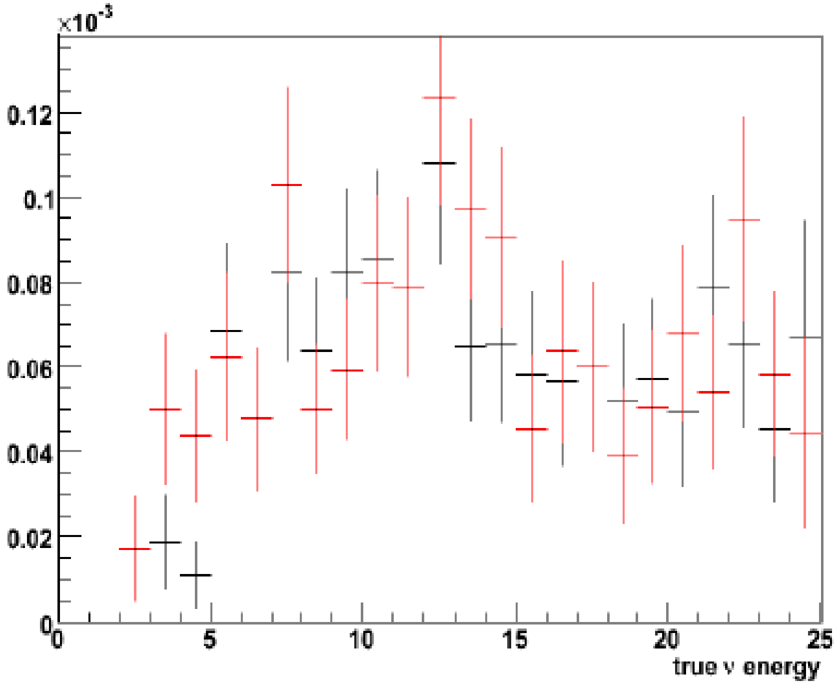
Analysis1 Black. Analysis 2 red

MIND: likelihood analysis

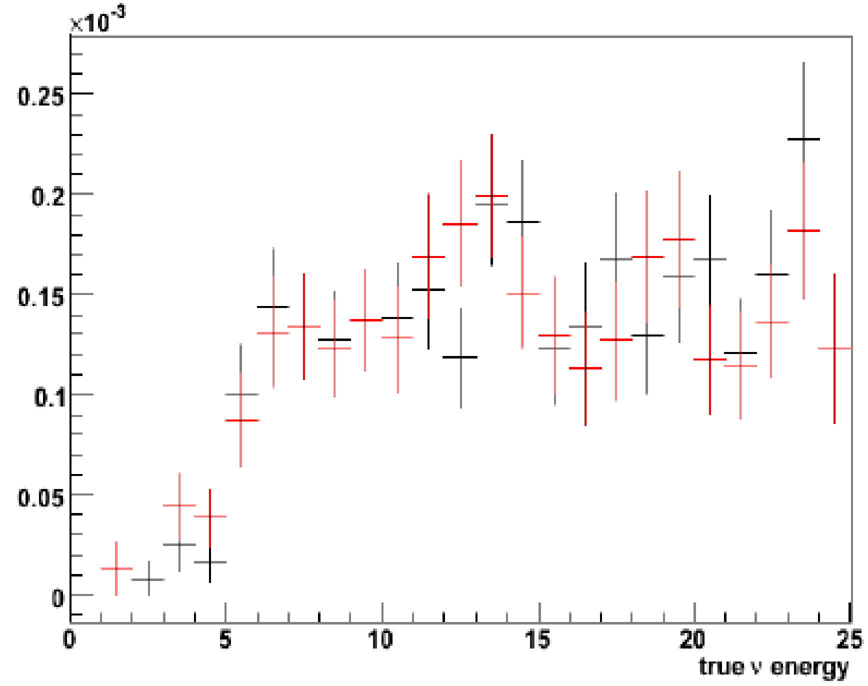
- Neutral current background

Preliminary

Background to μ^- appearance



Background to μ^+ appearance

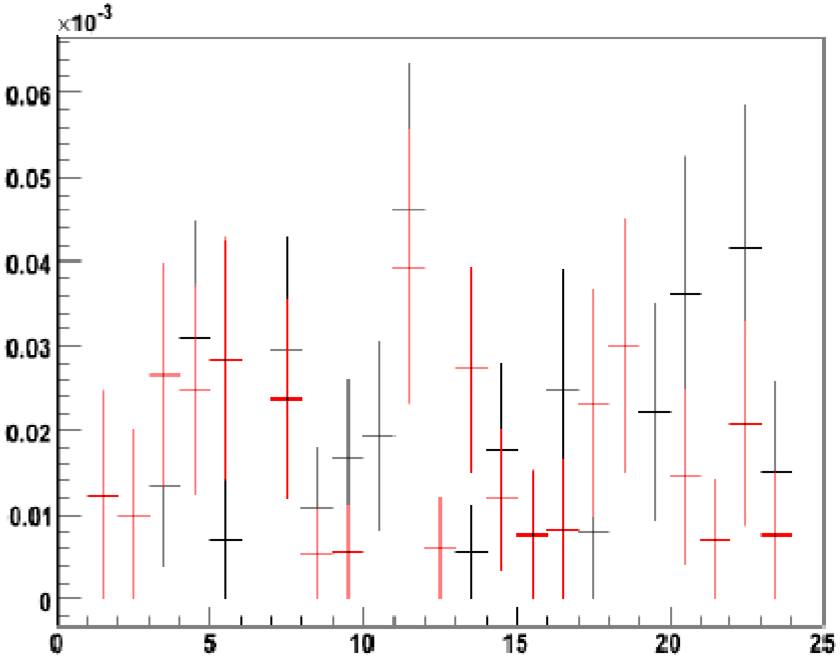


MIND: likelihood analysis

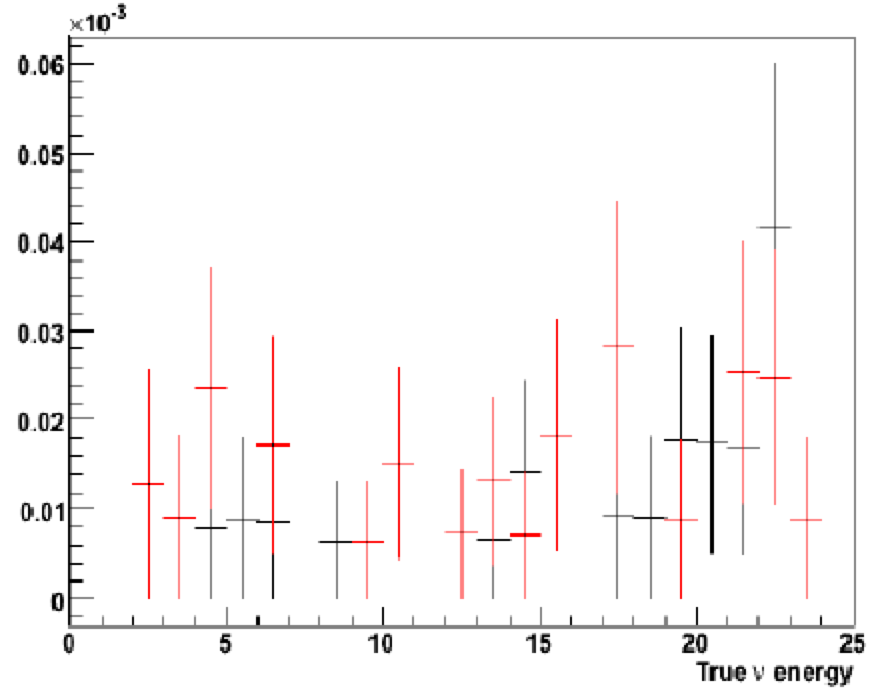
- ν_e Charged current background

Preliminary

Background to μ^- appearance



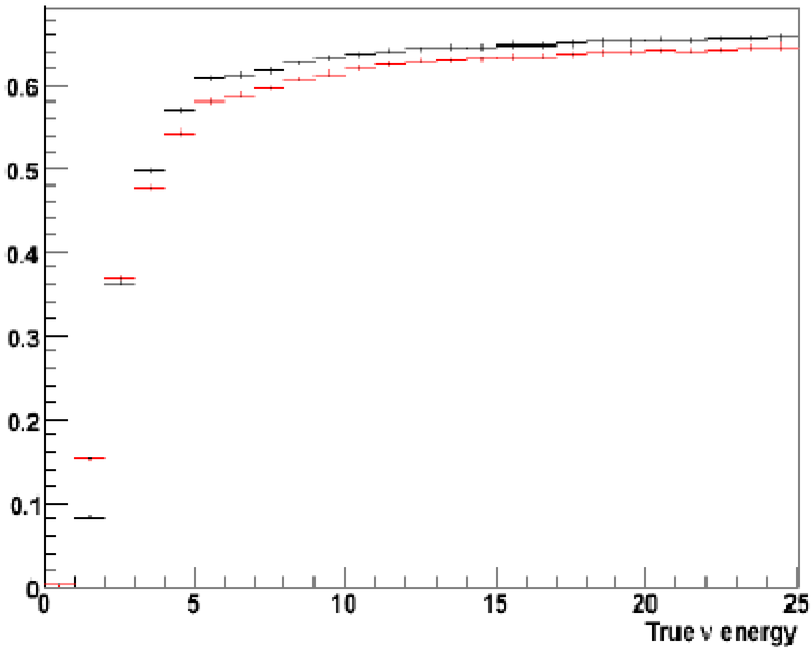
Background to μ^+ appearance



MIND: likelihood analysis

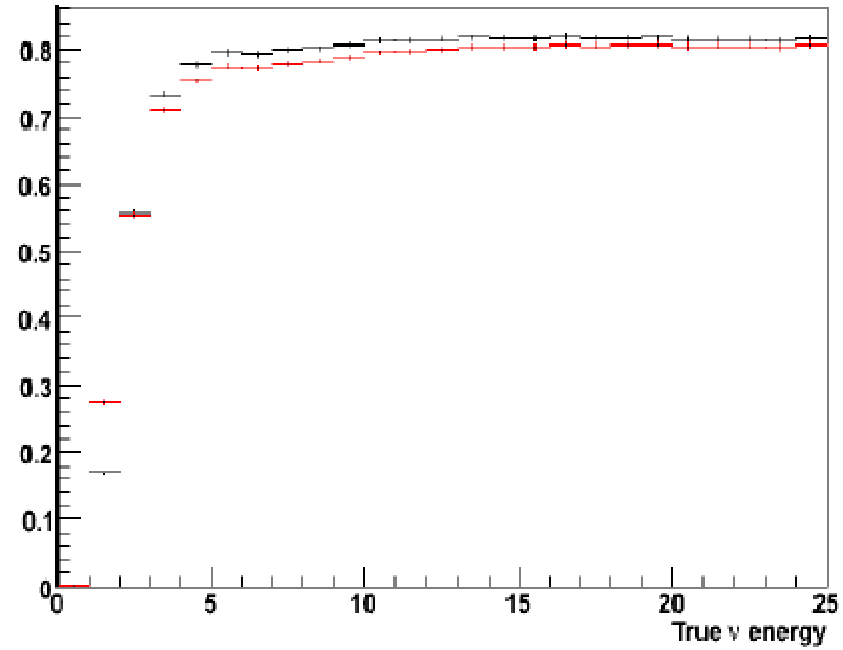
- Two analyses: different combinations of likelihood functions

Identification of μ^-



Identification of μ^+

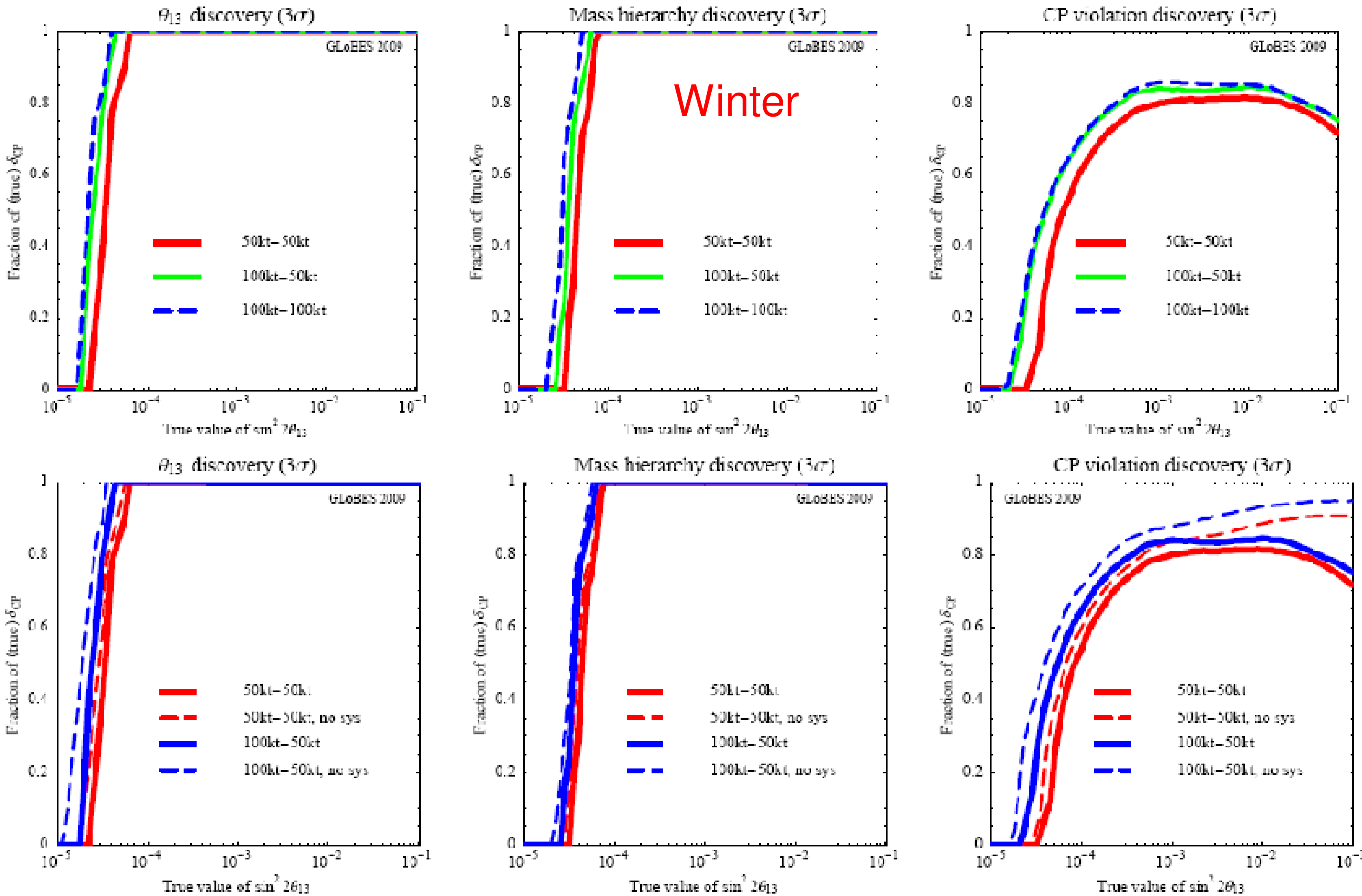
Preliminary



Efficiency is clearly better for anti neutrino channel. While this is fine in principle it has to be understood.

MIND at NF sensitivity

- Best sensitivity/cost with 100 kton at 4000 km and 50 kton at 7500 km



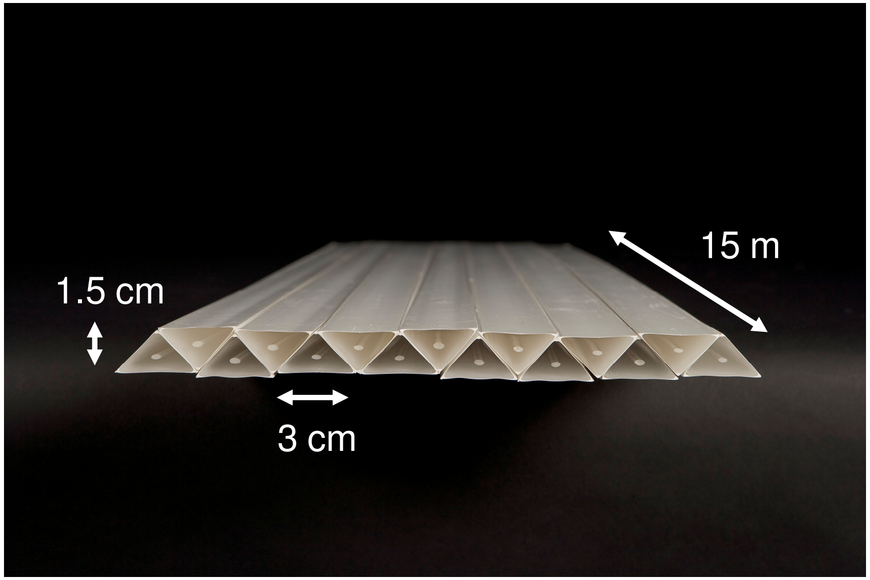
However, minimising systematics should be one of the main goals!!

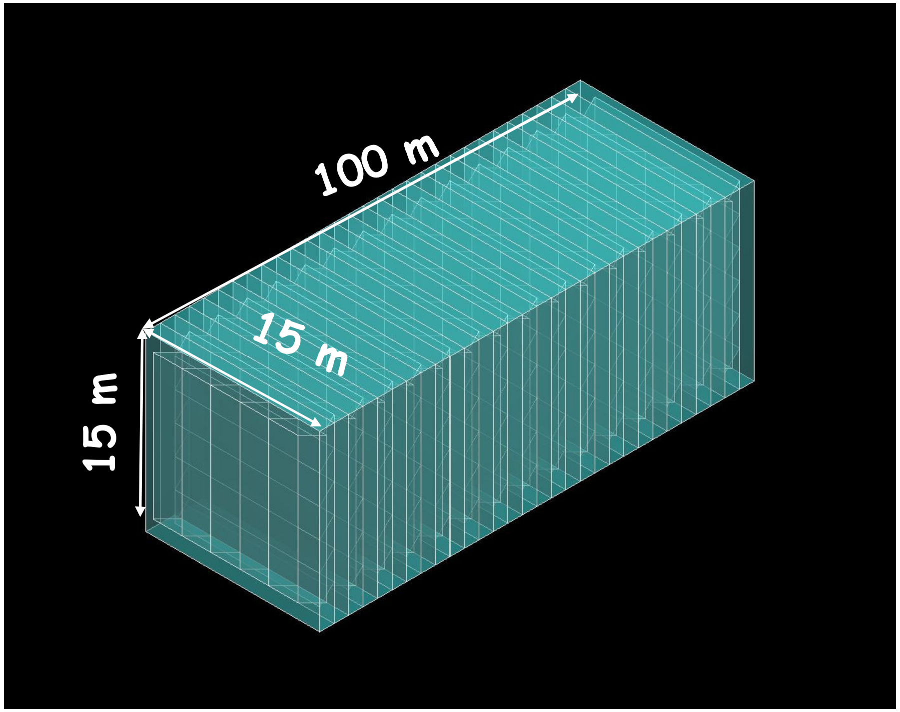
Totally Active Scintillating Detectors (TASD)

Possible improvement: Totally Active Scintillating Detector (TASD) using Noνa and Minerνa concepts

Ellis, Bross

- 3333 Modules (X and Y plane)
- Each plane contains 1000 slabs
- Total: 6.7M channels



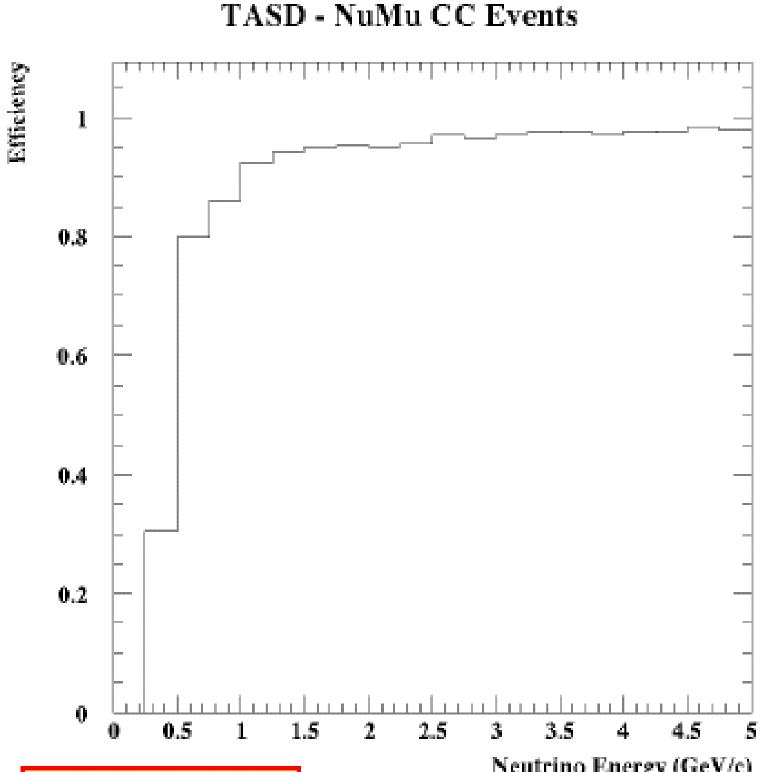


- Momenta between 100 MeV/c to 15 GeV/c
- Magnetic field considered: 0.5 T
- Reconstructed position resolution ~ 4.5 mm

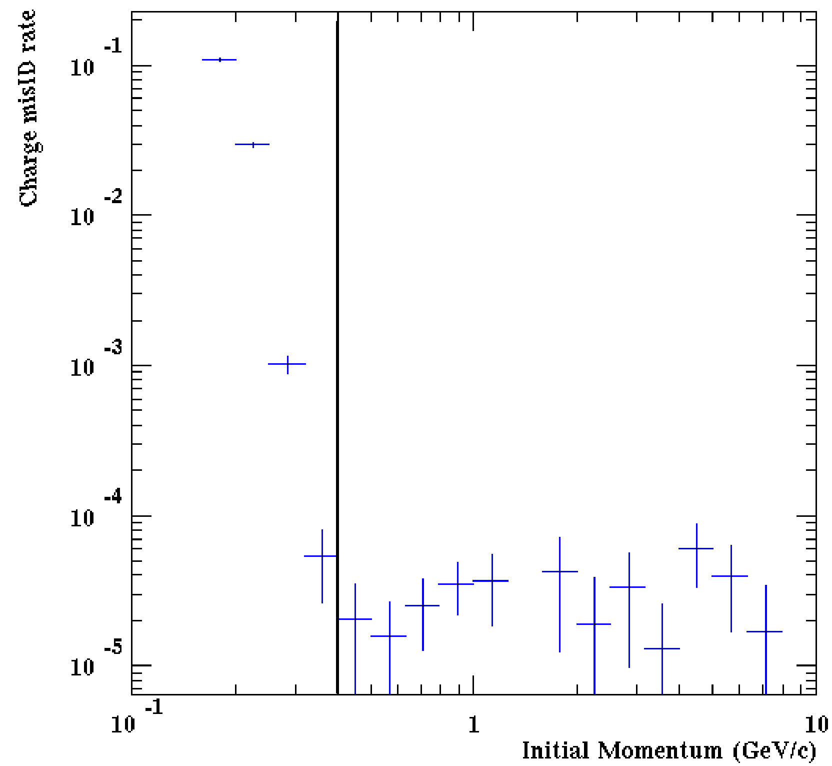
Reduction threshold: access second oscillation maximum and electron identification

Totally Active Scintillating Detectors (TASD)

Neutrino CC reconstructed efficiency



Muon charge mis-ID rate



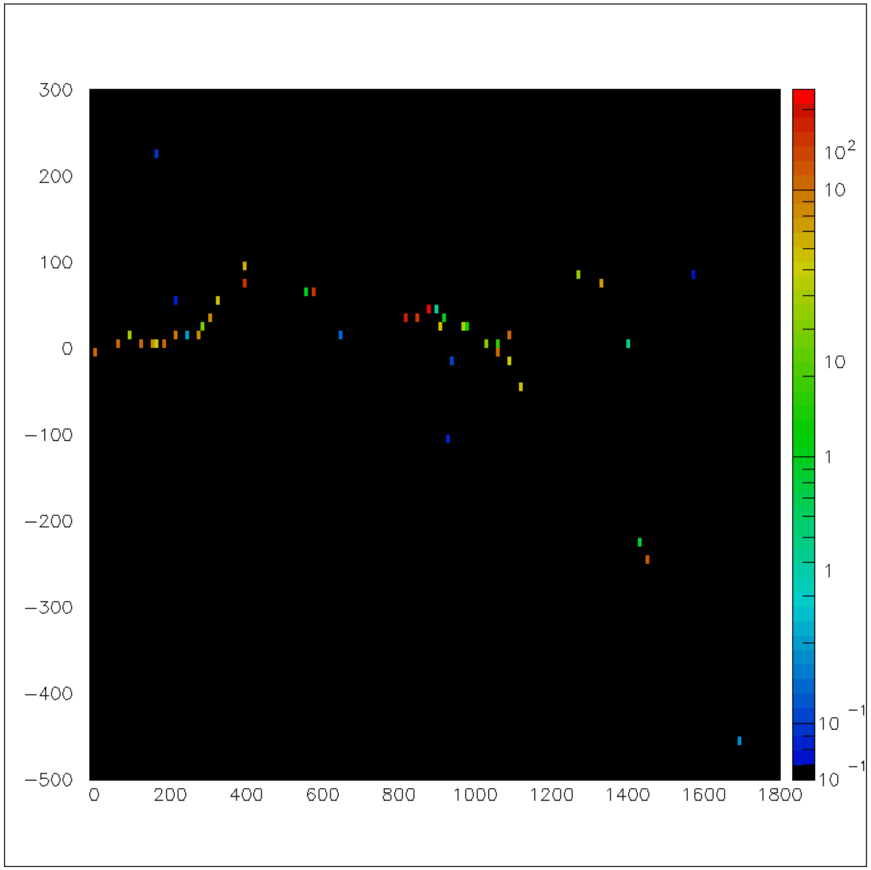
Excellent σ_E

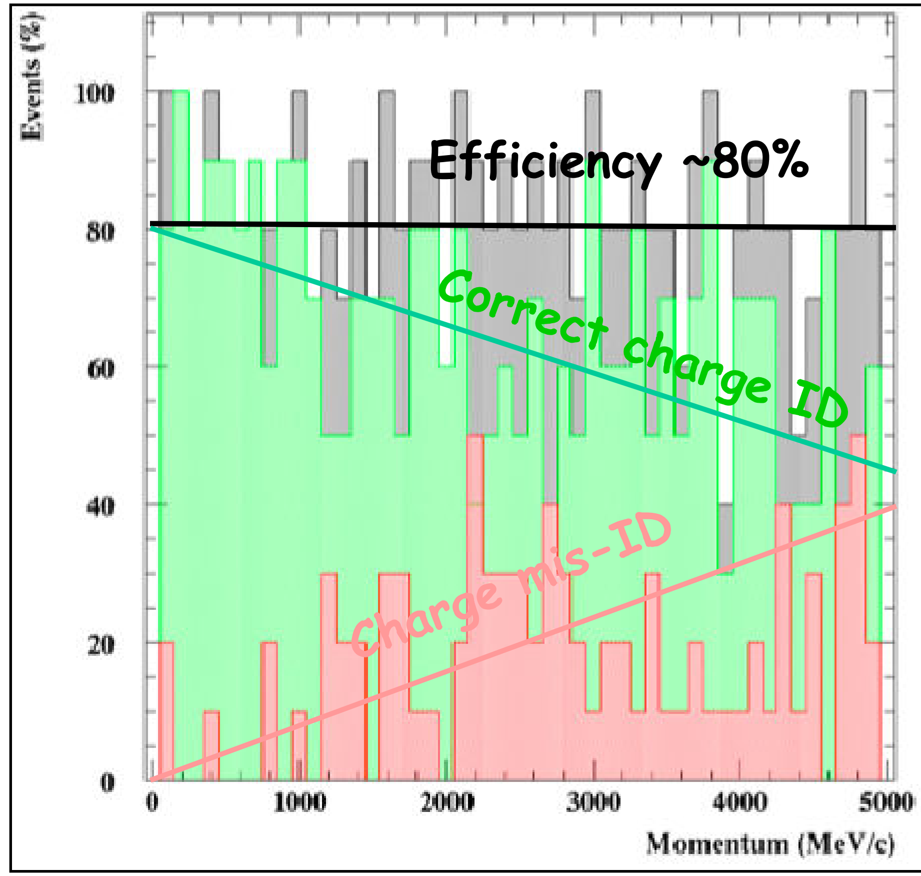
- Considered as default option for a low energy neutrino factory (muon energy 5 GeV): excellent charge mis-ID and efficiency above 0.5 GeV/c

Totally Active Scintillating Detectors (TASD)

Electron/positron identification by visual scanning

400 MeV/c e⁻





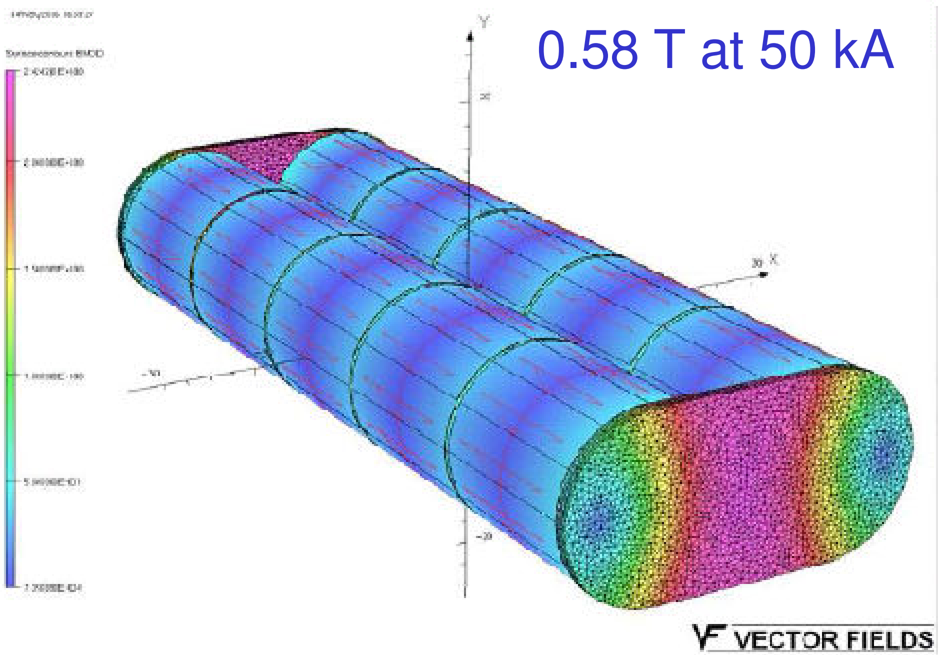
Totally Active Scintillating Detectors (TASD)

Main problem: magnetisation of huge volume (difficulty and cost)

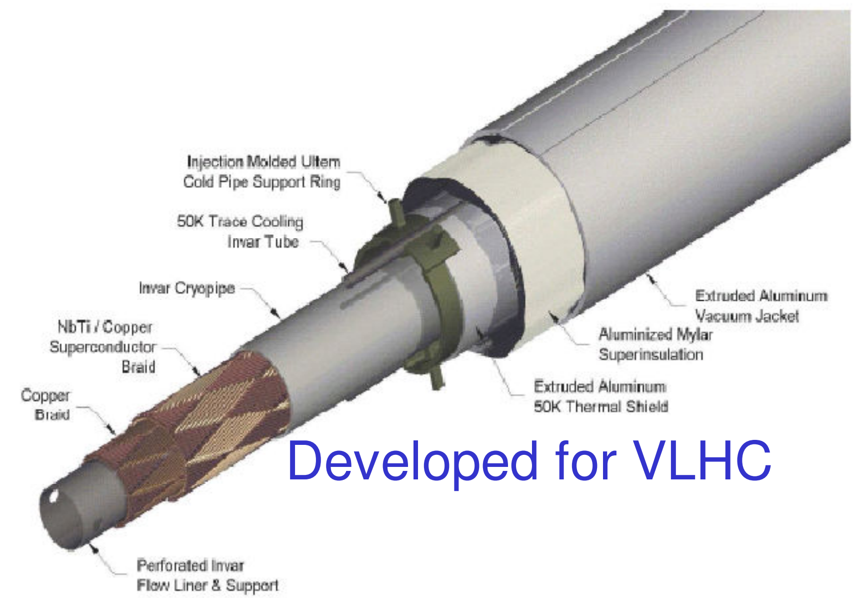
However, possible magnetisation can be achieved using magnetic cavern concept (10 modules with 15m x 15 m diameter)

Bross

0.58 T at 50 kA



Use Superconducting Transmission Line (STL): cable has its own cryostat!



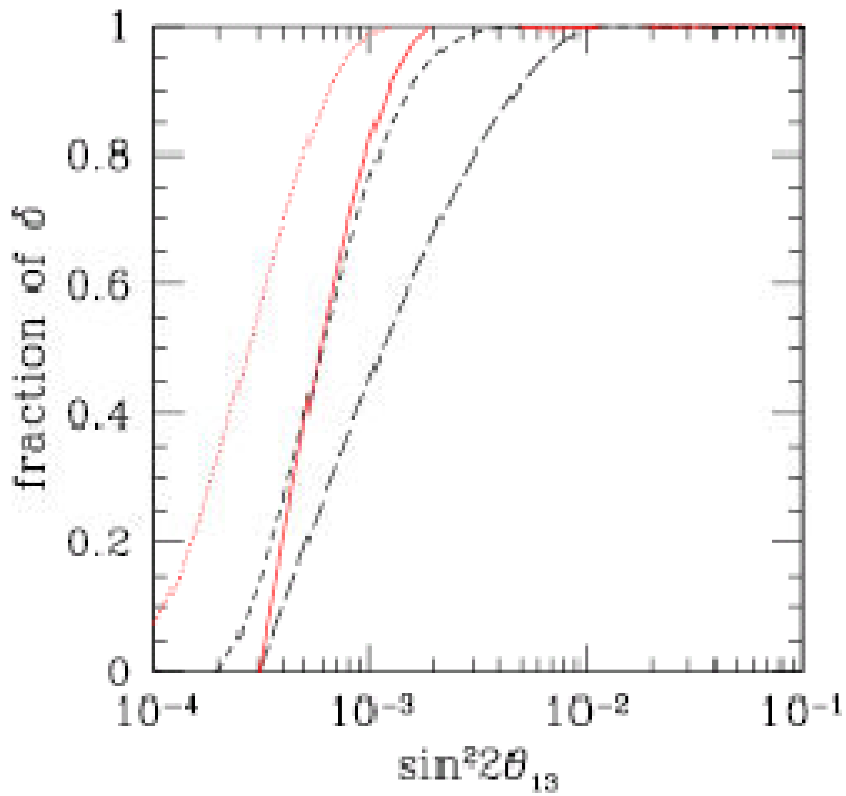
Developed for VLHC

R&D needed to develop concept!!

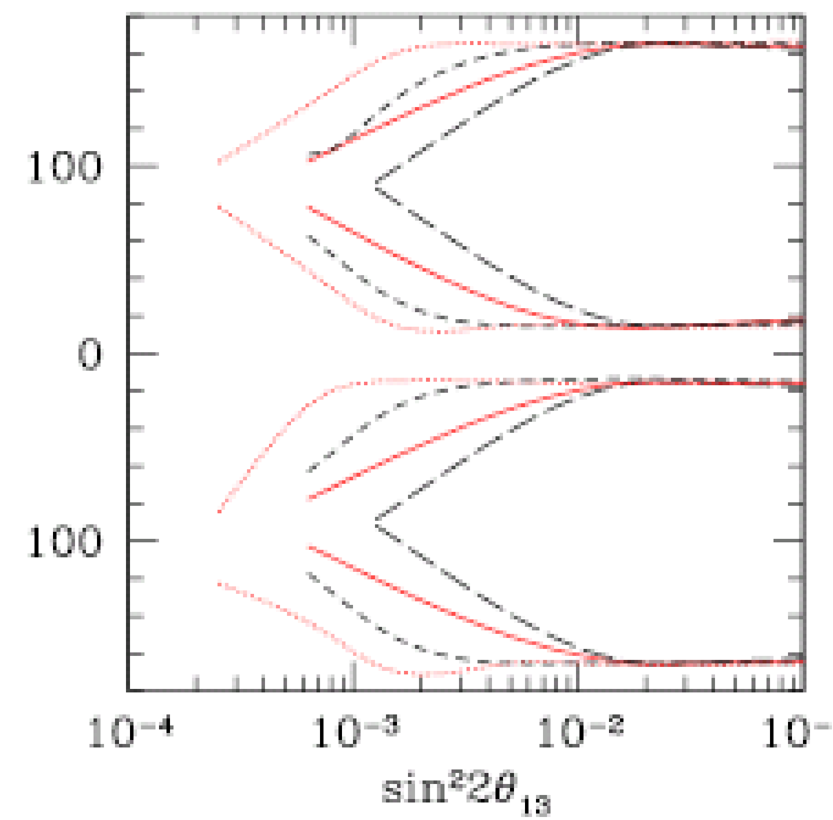
Totally Active Scintillating Detectors (TASD)

- Possible use of TASD opens up possibility of running at a low energy neutrino factory (4 GeV) Bross, Ellis, Geer, Mena, Pascoli

95% CL mass hierarchy at 1480 km



95% CL CP violation at 1480 km



Conclusions

- Scintillator based detectors have a proven track record in neutrino experiments and can be scaled up in size
- Golden channel (wrong sign muon) has the best statistical power – other channels have small contribution to standard oscillation physics
- Hence, two MIND detectors at 4000 km with100 kton mass and 7500 km (magic baseline) with 50 kton gives best performance at standard neutrino factory (25 GeV)
- TASD detectors offer very good performance at low energy neutrino factory (~5 GeV)