

MIND Systematic Errors

EuroNu Meeting, RAL
18 January 2010
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Introduction

- A comprehensive analysis for MIND at a Neutrino Factory has been carried out (A. Laing, PhD thesis)

- Features of analysis:

Full description analysis
in talk by Anselmo

- Nuance: event generation
- GEANT4: detector simulation in 1 T dipole field
- Smearing position resolution
- Simple detector digitisation and clustering
- Smearing of hadronic energy: $\frac{\delta E_{had}}{E_{had}} = \frac{0.55}{\sqrt{E_{had}}} + 0.03$
- Smearing hadron angular resolution: $\delta\theta = \frac{10.4}{\sqrt{E_{had}}} + 10.1$
- Full pattern recognition and reconstruction (Kalman filter and Cellular Automaton)
- Likelihood function analysis
- Generation of full detector response matrices for ν_{μ} and $\bar{\nu}_{\mu}$

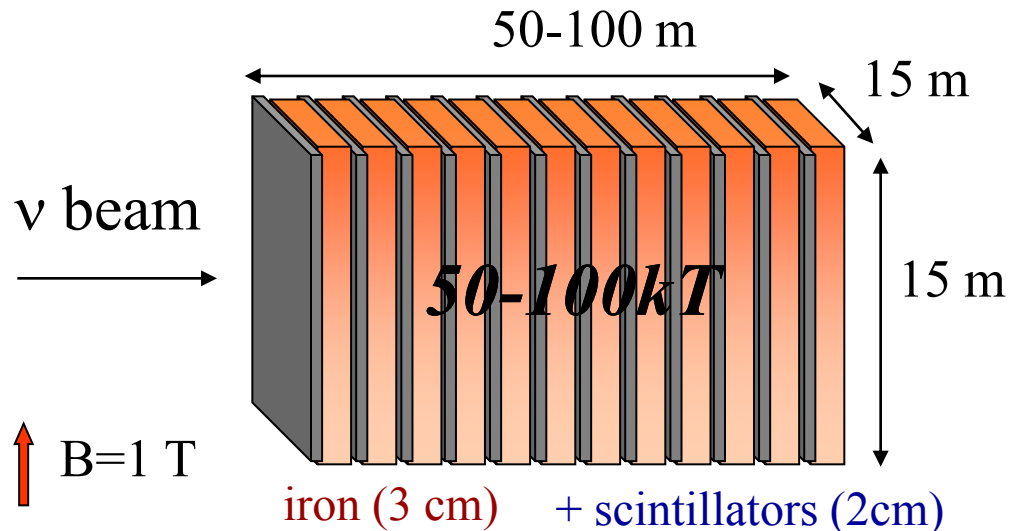
- Estimation of systematic errors

- Hadronic energy and hadron resolution
- Relative proportion of QEL, RES and DIS interactions

Baseline detector at a Neutrino Factory: MIND

- Golden channel signature: “wrong-sign” muons

IDS-NF baseline for 25 GeV NuFact: MIND



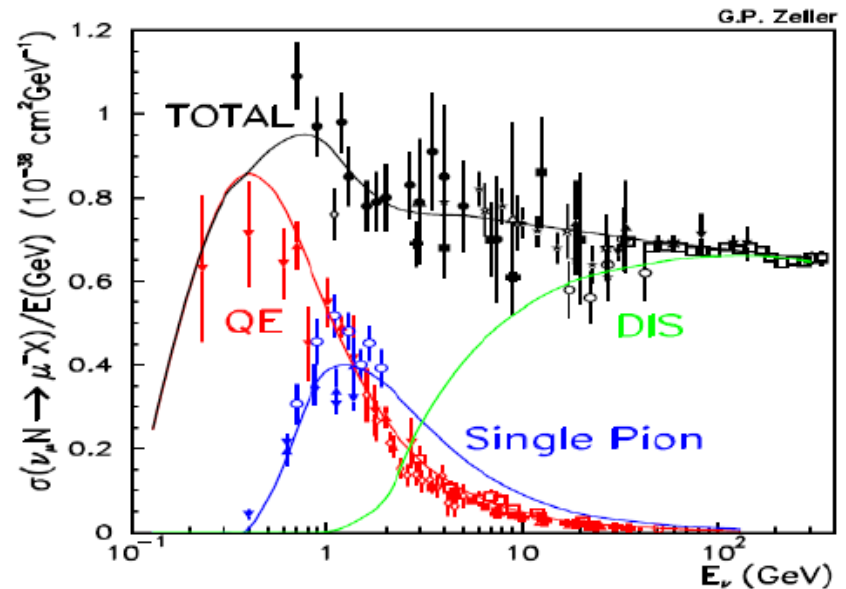
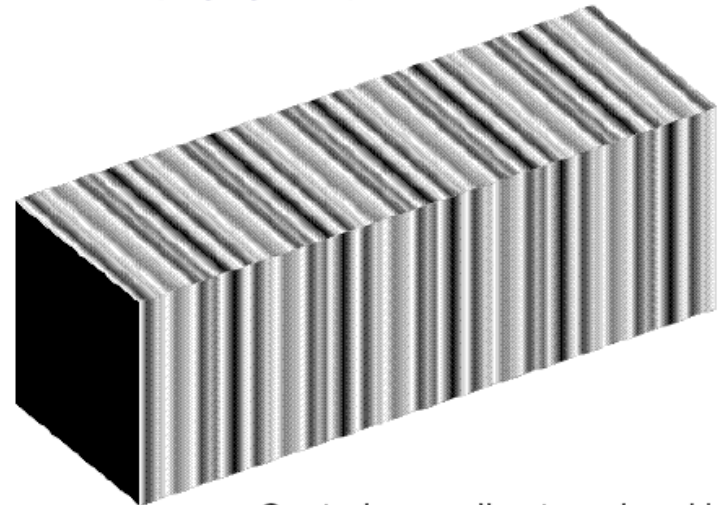
- Far detector: 100 kton at 2000-4000 km
- Magic detector: 50 kton at 7500 km
- Appearance of “wrong-sign” muons
- Segmentation: 3 cm Fe + 2 cm scintillator
- 1 T magnetic field

MIND: new analysis

- Improvements MIND analysis with full GEANT4 simulation
- Add quasi-elastics and resonance production (NUANCE): Non DIS processes dominate at low energies and should improve efficiency at low energies

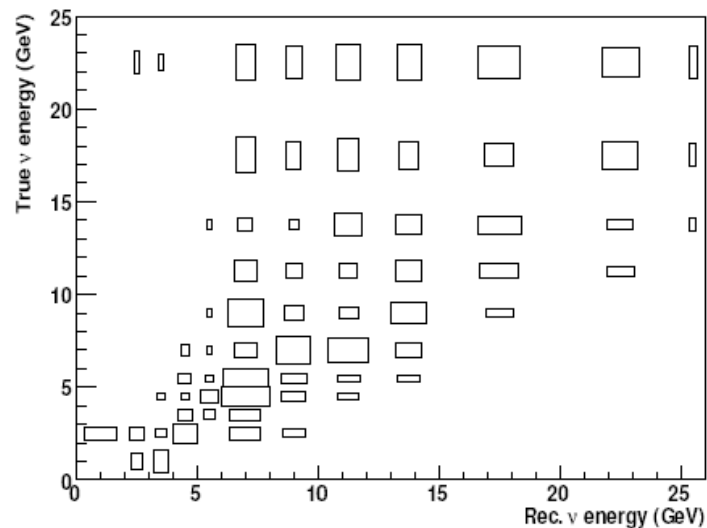
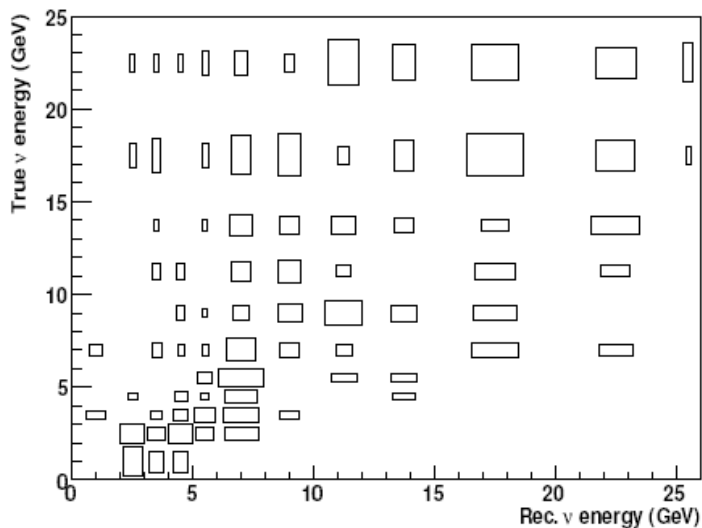
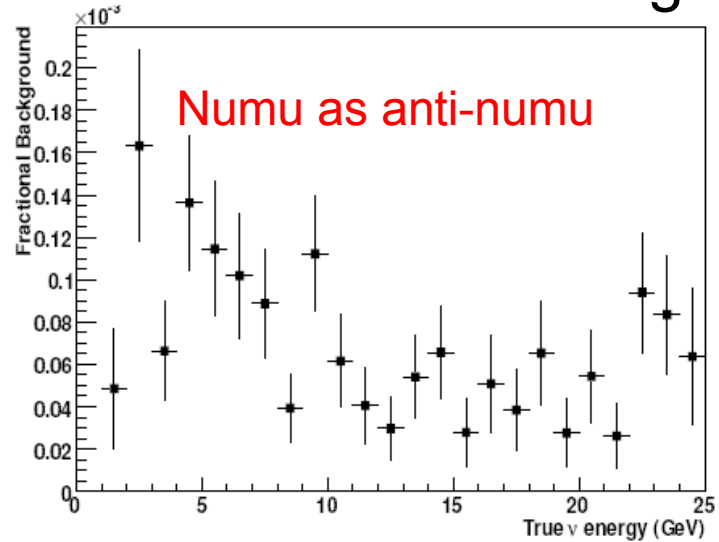
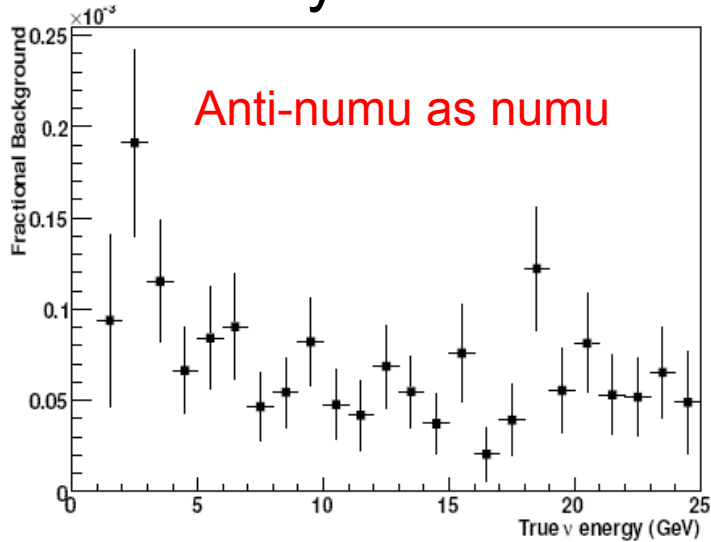
Benchmark of NUANCE with data

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



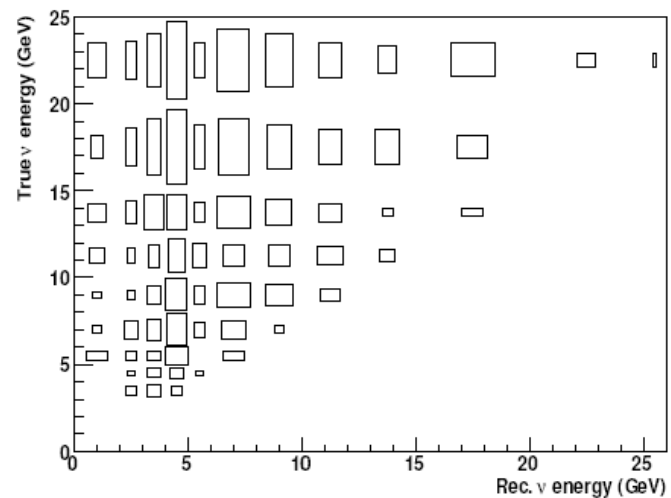
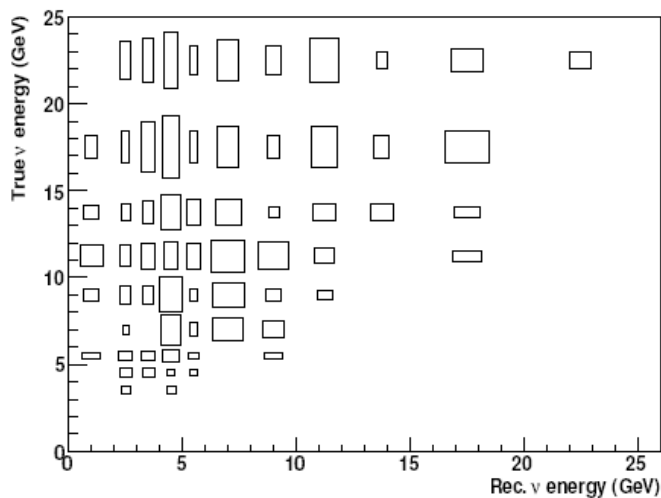
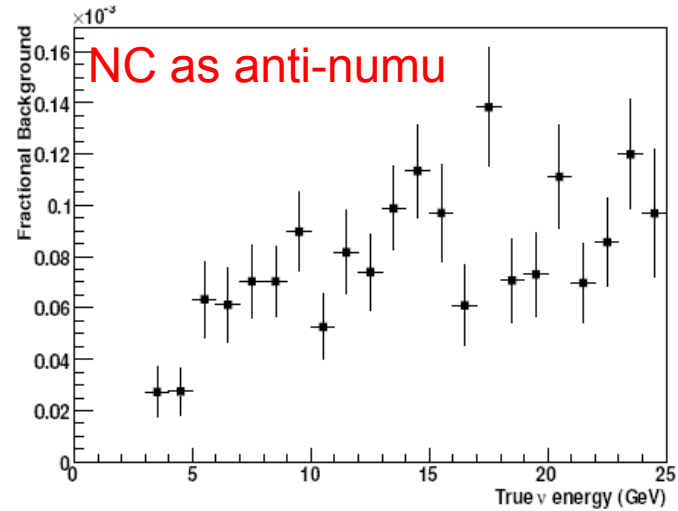
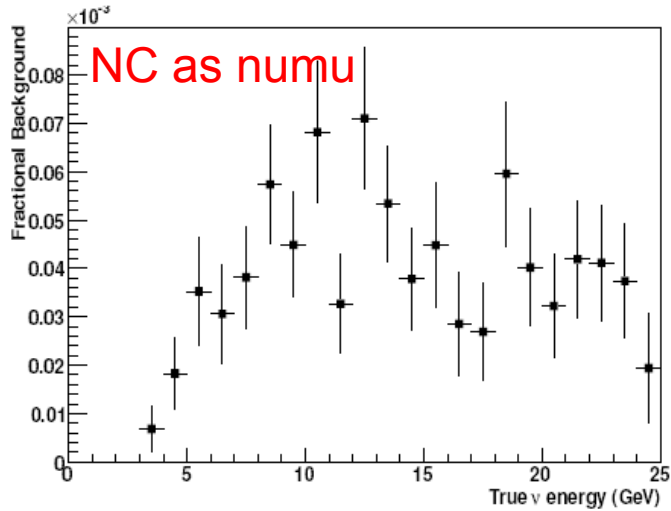
MIND: new analysis

- o New analysis with Nuance and GEANT4: CC background



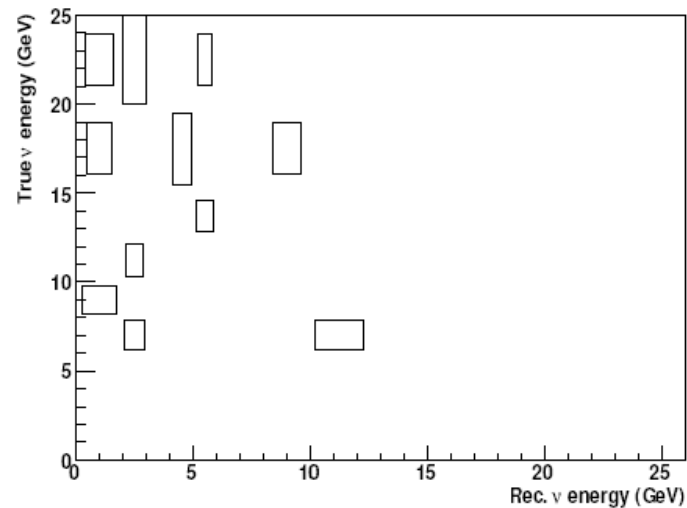
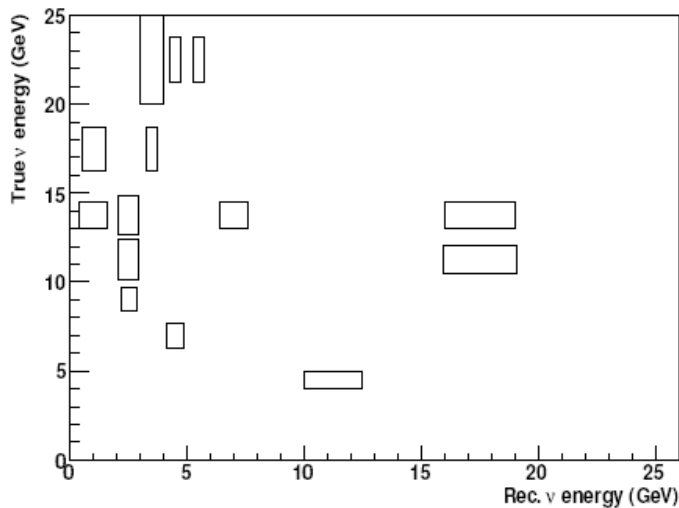
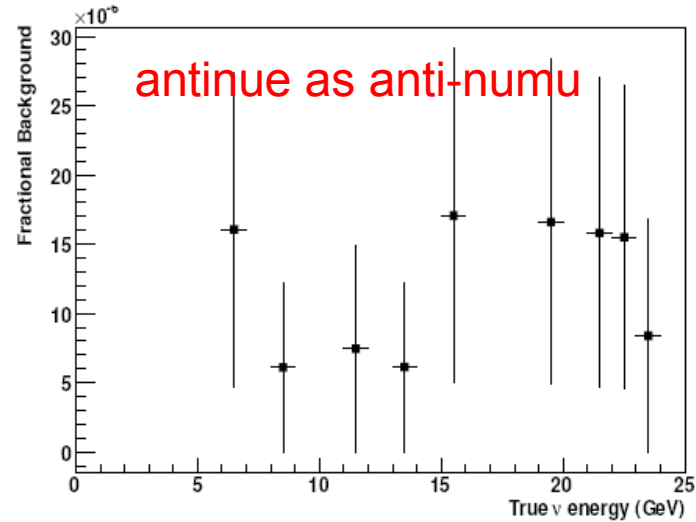
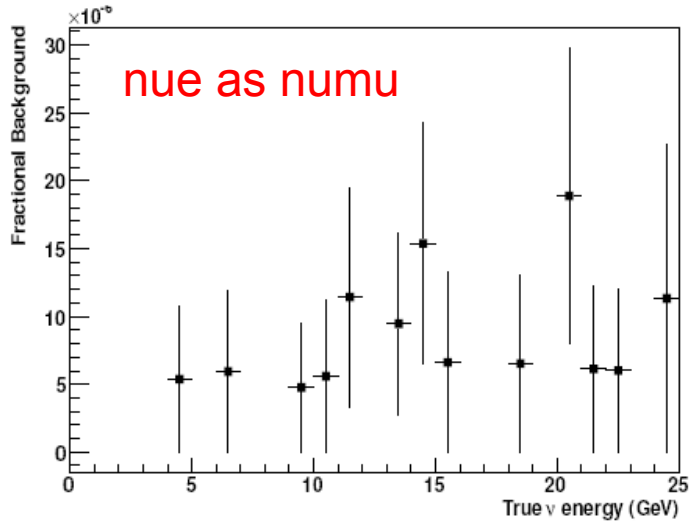
MIND: new analysis

- o New analysis with Nuance and GEANT4: NC background



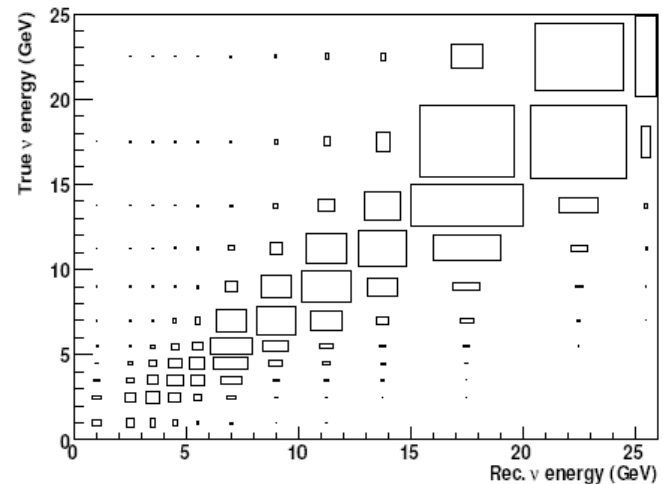
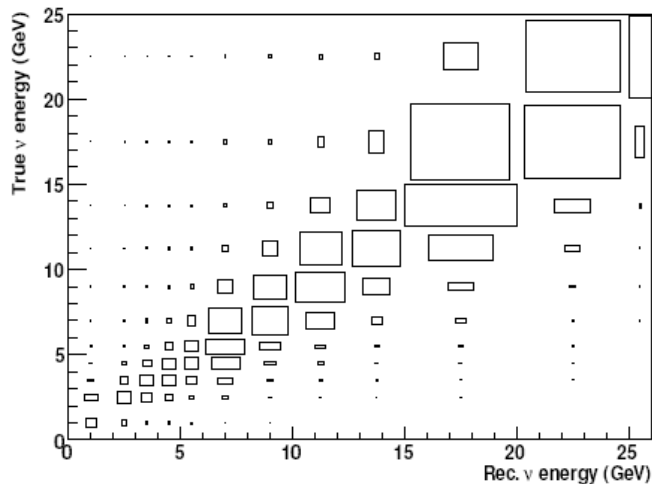
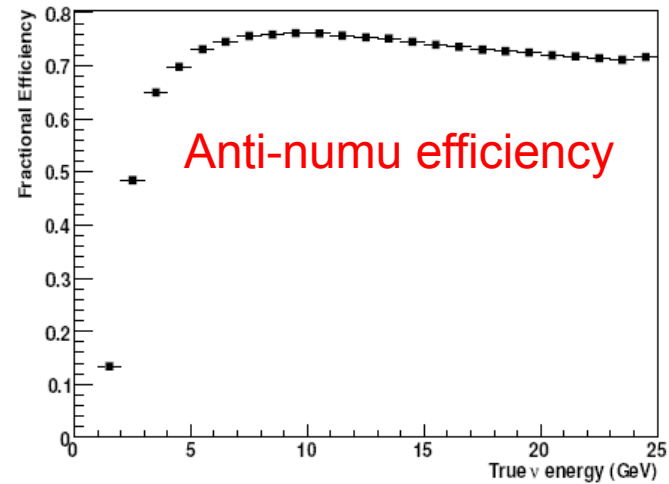
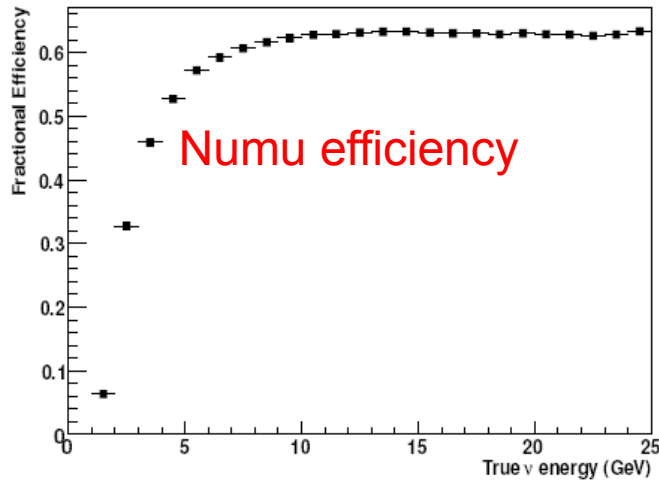
MIND: new analysis

- o New analysis with Nuance and GEANT4: ν_e background



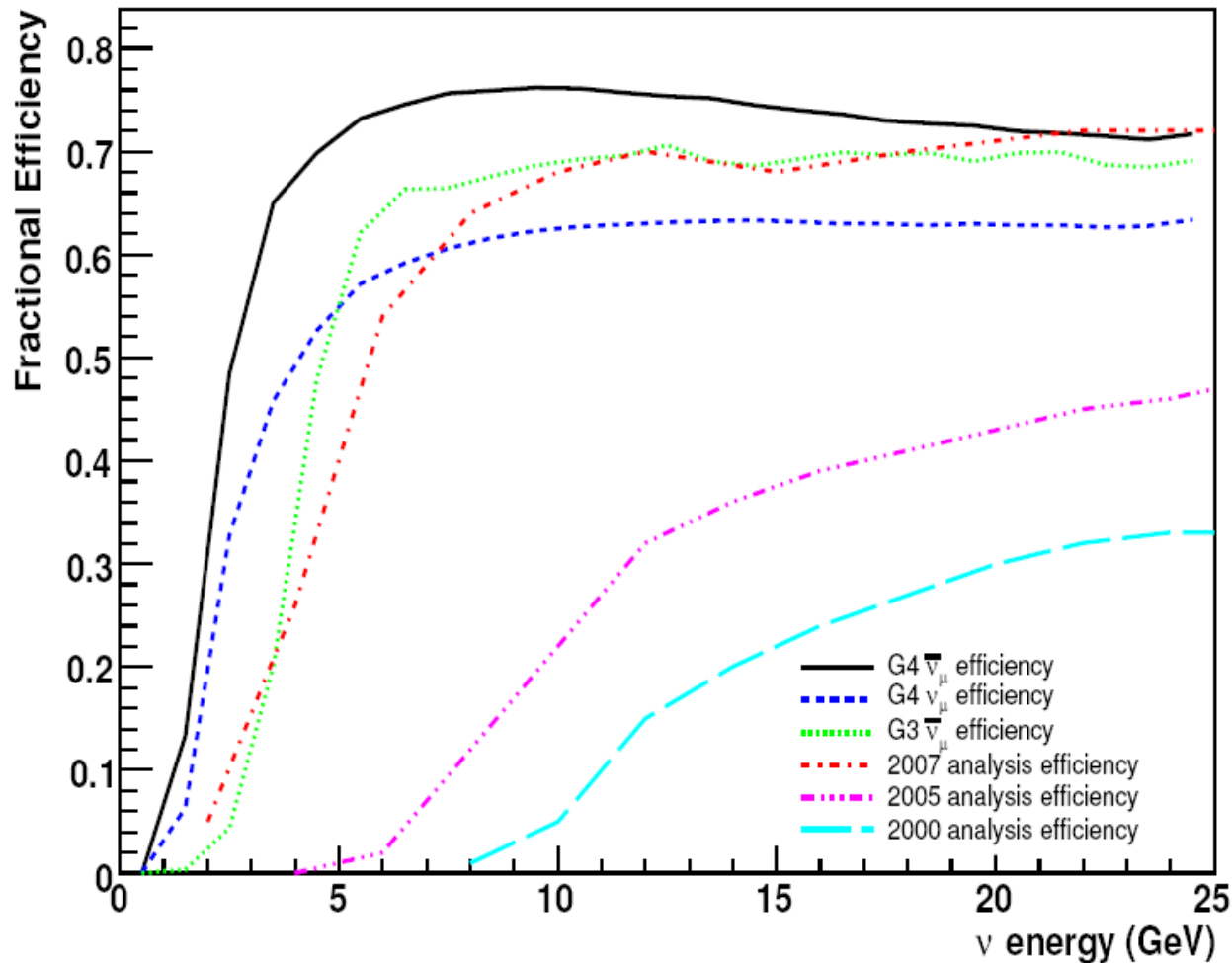
MIND: new analysis

- New analysis with Nuance and GEANT4: signal efficiencies



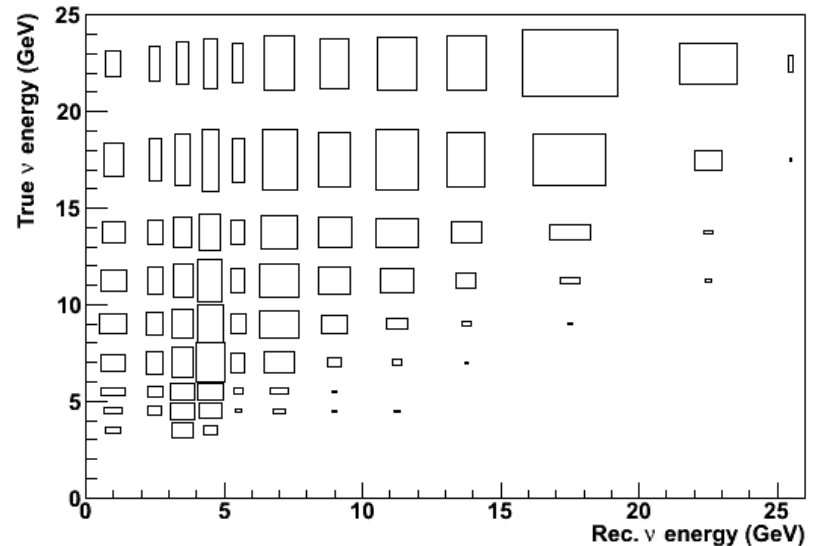
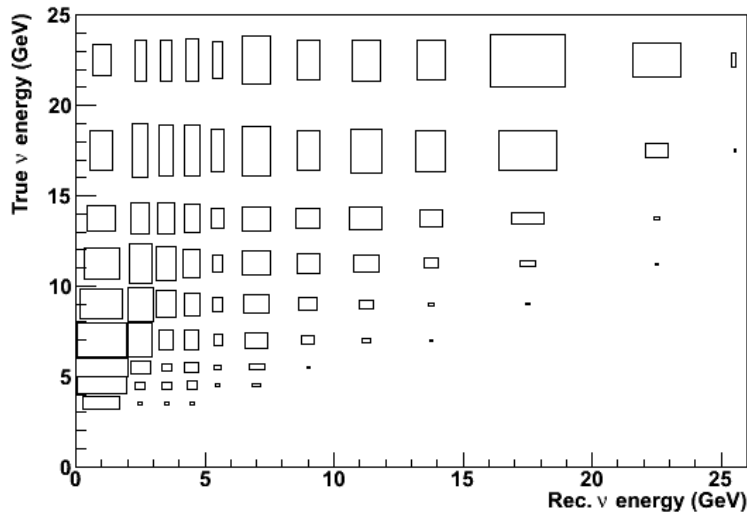
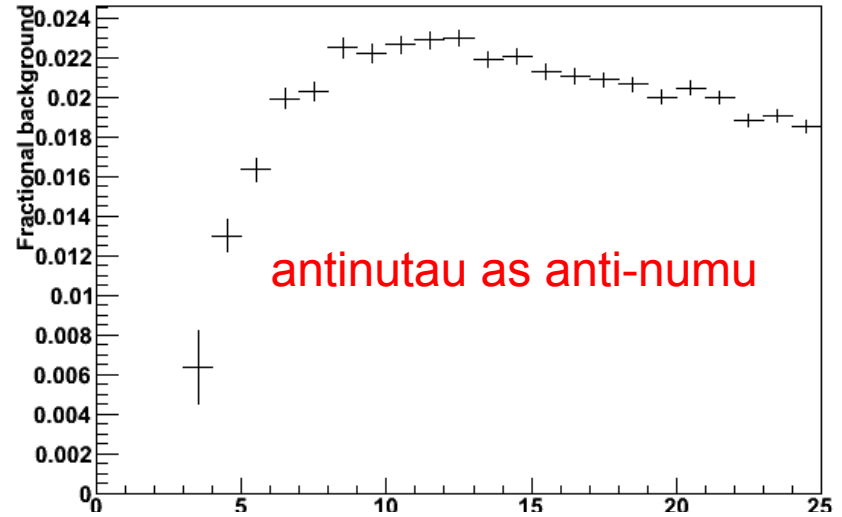
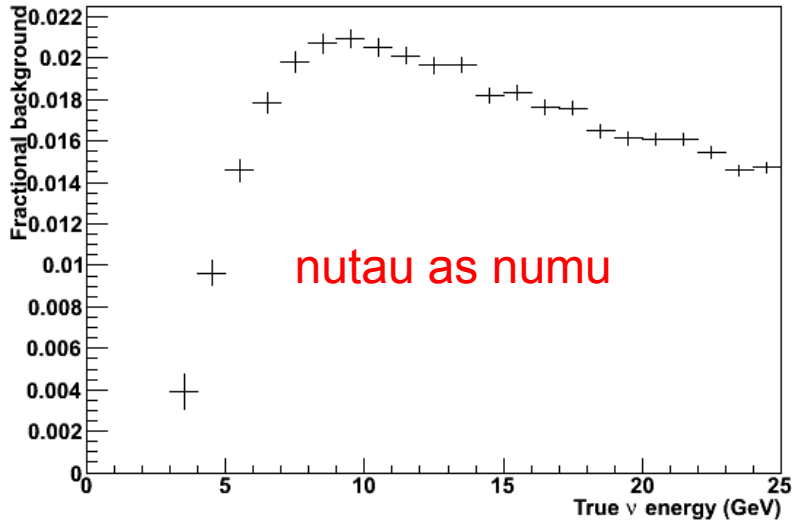
MIND: new analysis

- New analysis with Nuance and GEANT4: better efficiencies at low energies, due to addition of QES and RES events



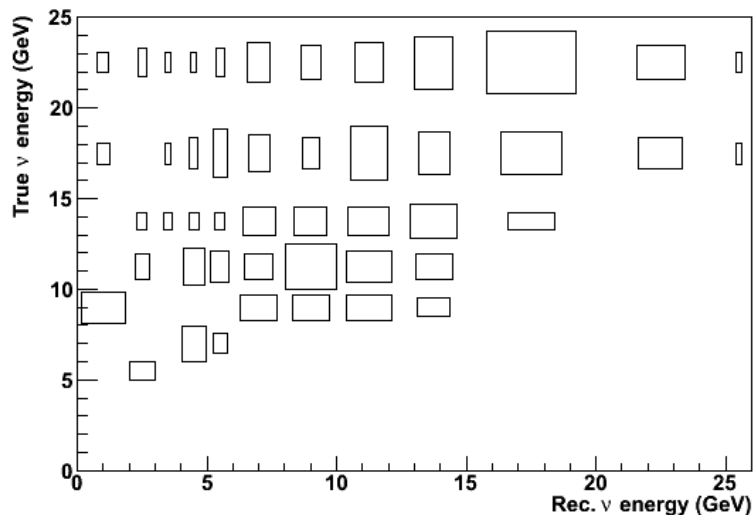
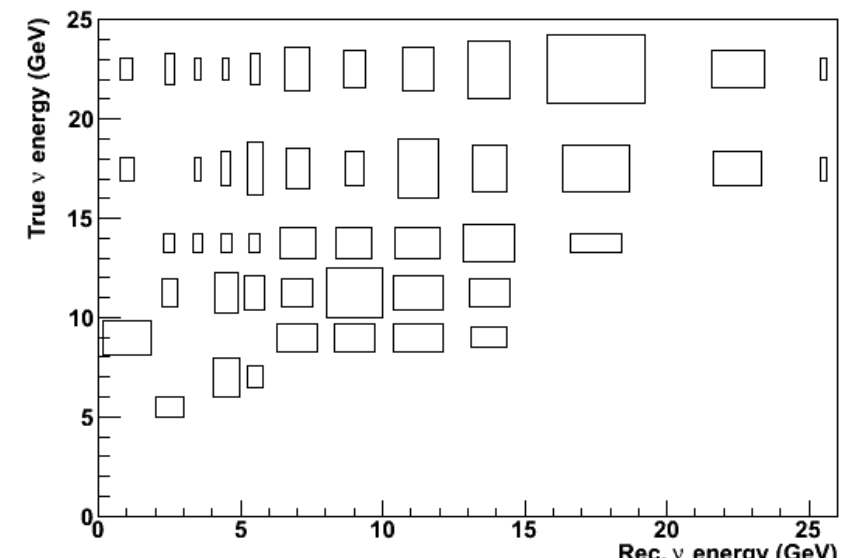
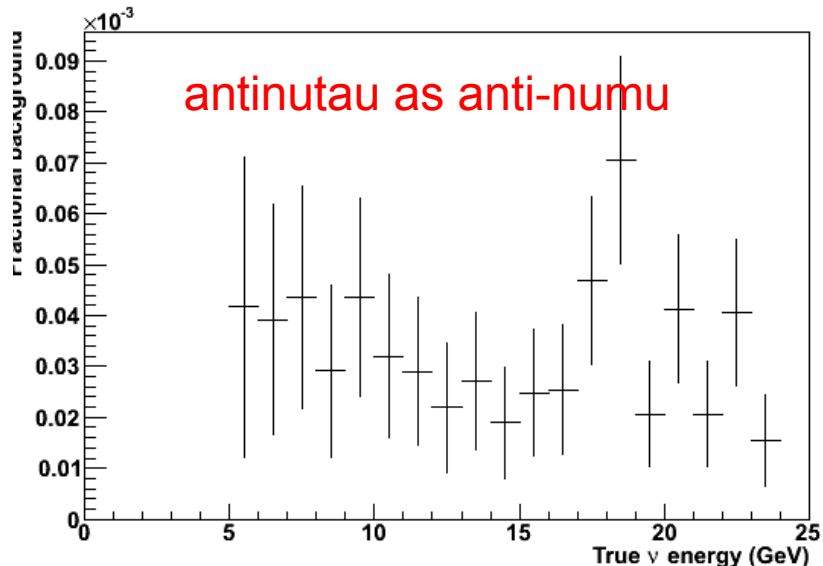
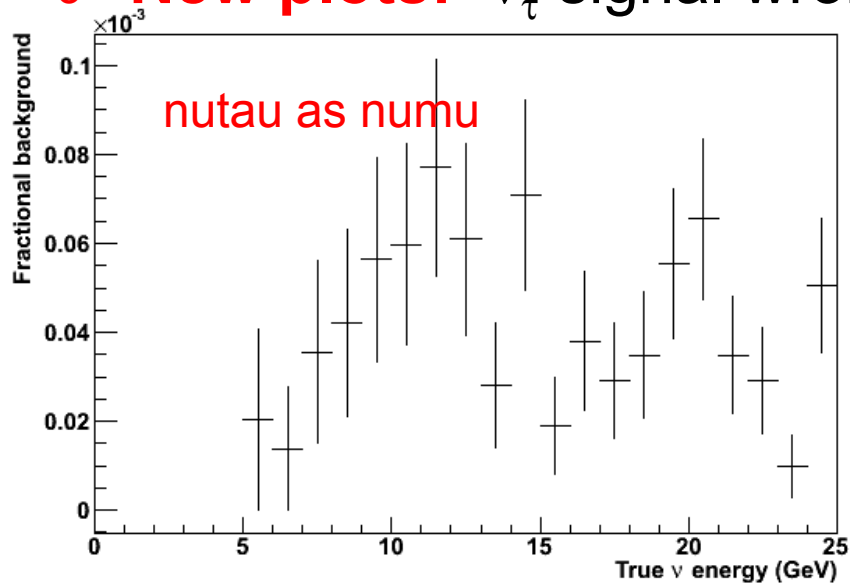
MIND: new analysis

- o **New plots:** ν_τ signal right-sign



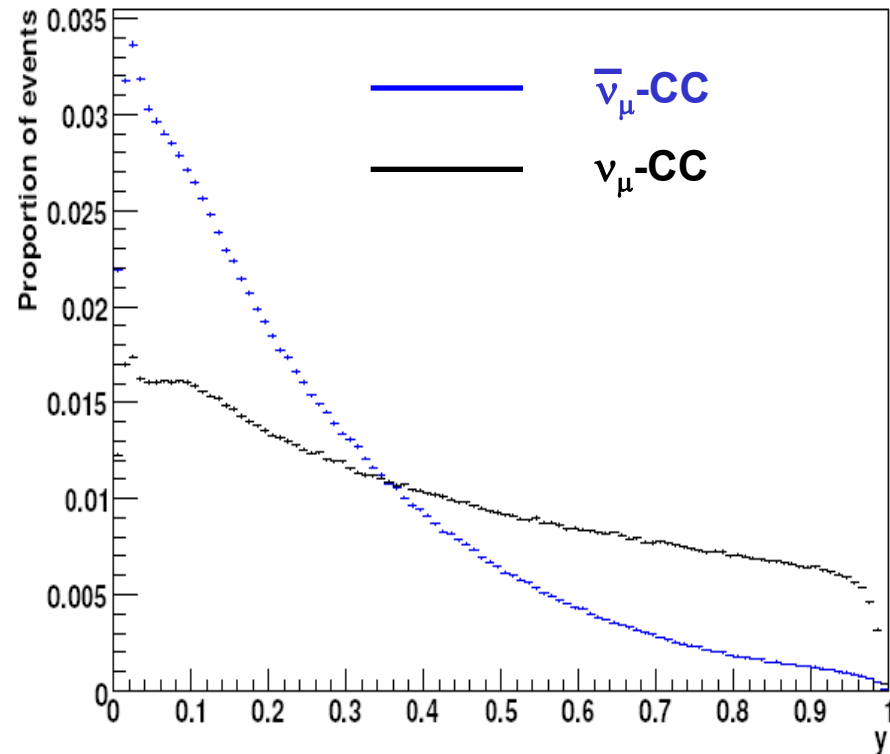
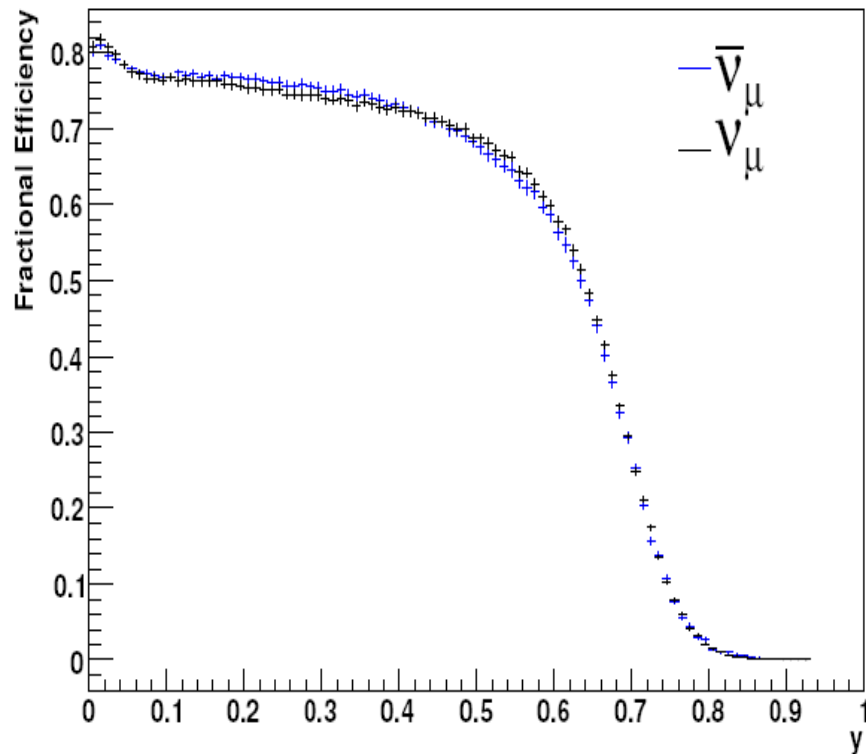
MIND: new analysis

o New plots: ν_τ signal wrong-sign



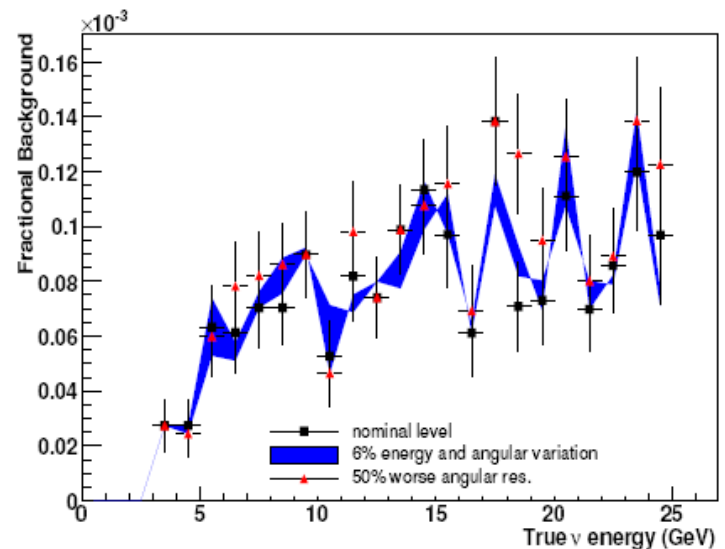
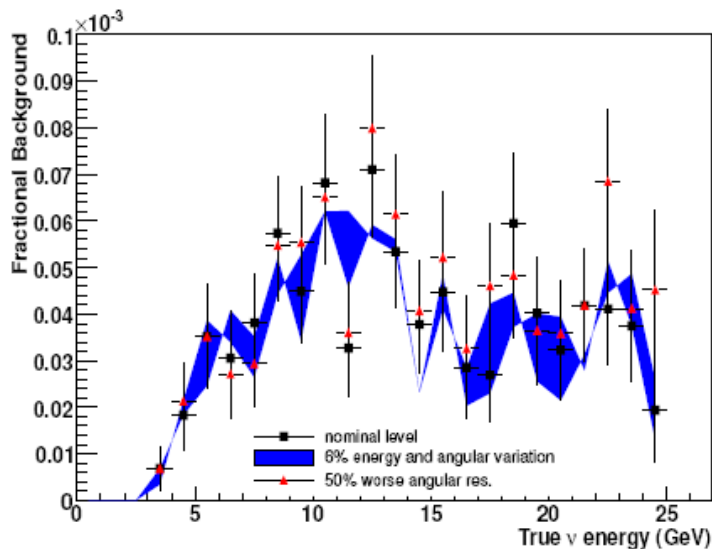
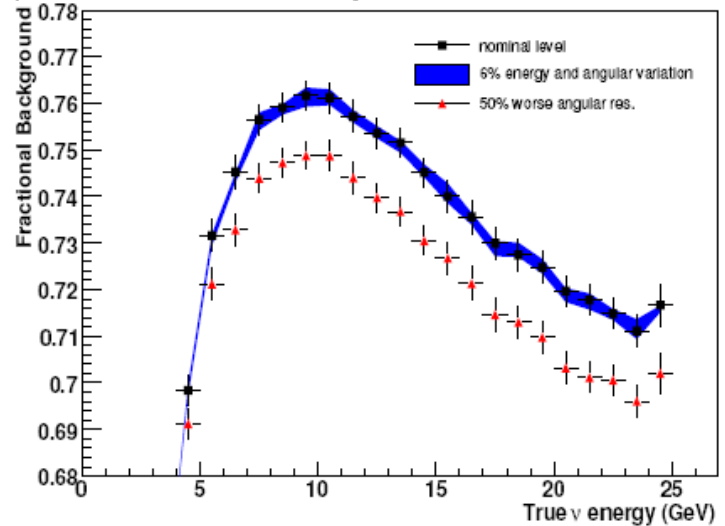
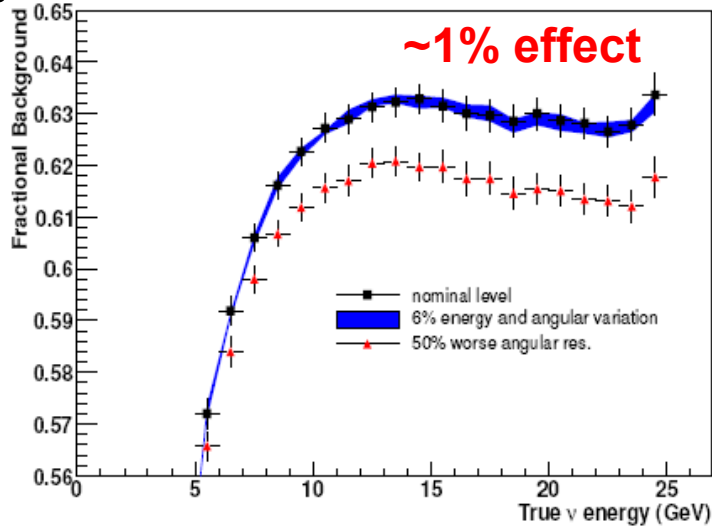
MIND: new analysis

- o Difference in numu and anti-numu efficiencies: effectively only because of Bjorken y distribution (inelasticity) of neutrinos and antineutrinos



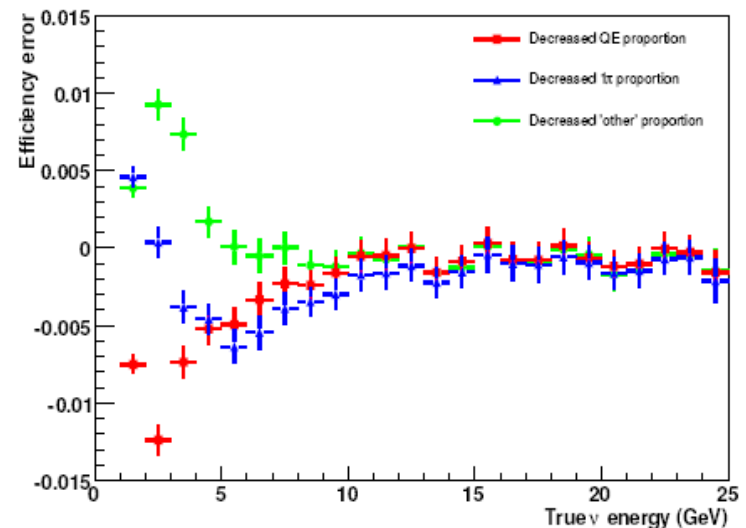
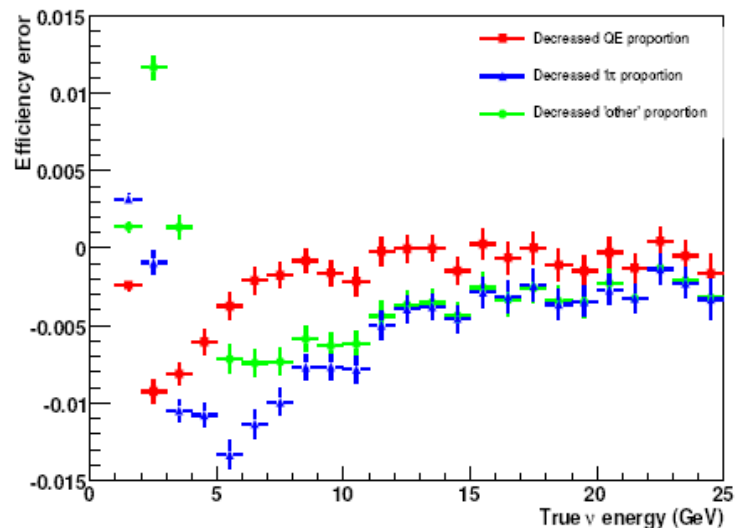
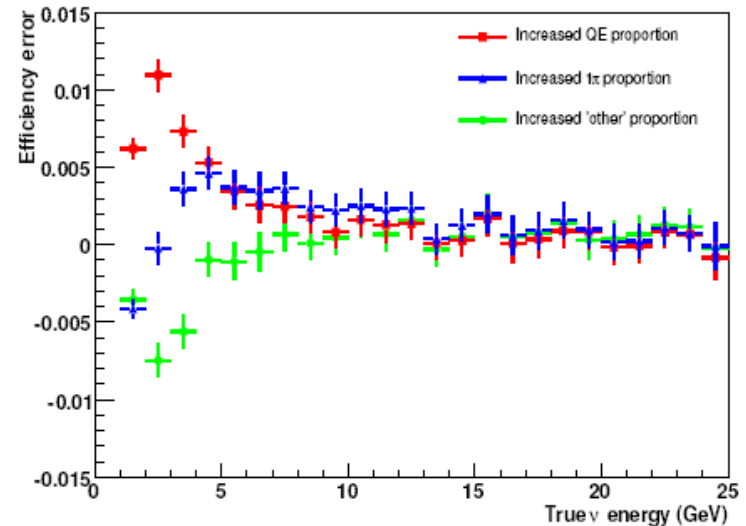
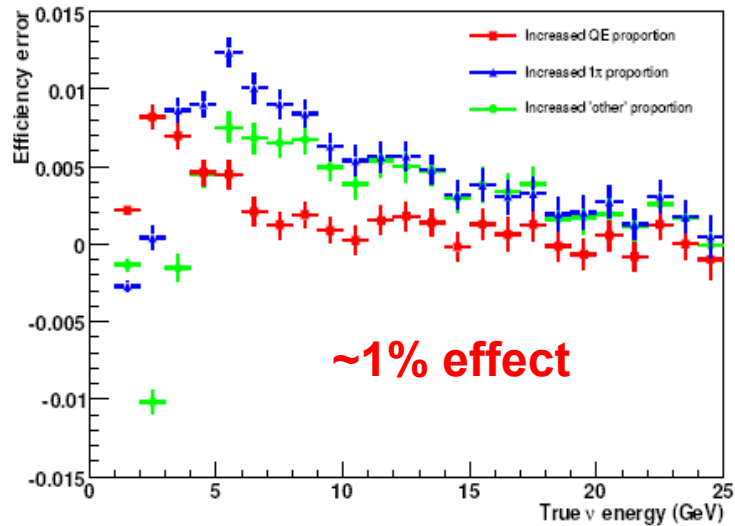
MIND: new analysis

- Systematic errors: hadronic energy & hadron angular resolution



MIND: new analysis

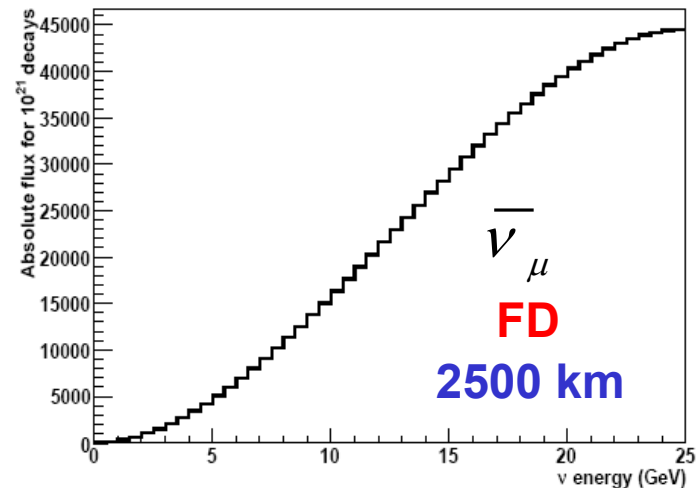
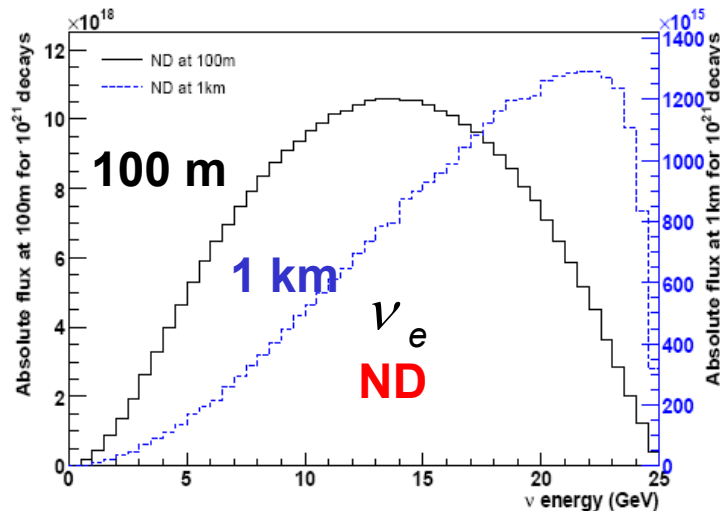
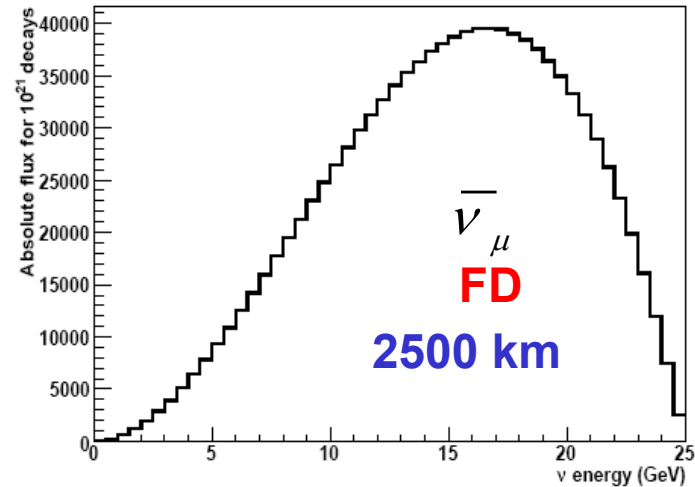
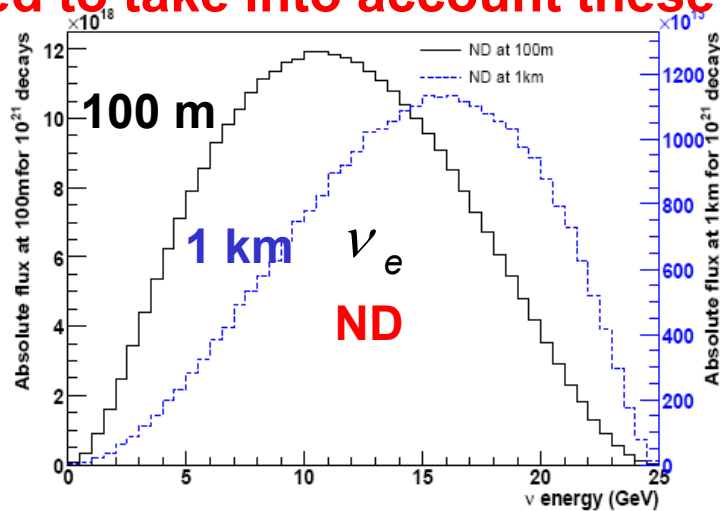
- Systematic errors: ratio of QES/DIS, 1π /DIS, “Other”/DIS



Flux Near Detector at Neutrino Factory

- Near Detector sees a line source (600 m long decay straight)
- Far Detector sees a point source

Need to take into account these differences for flux measurement

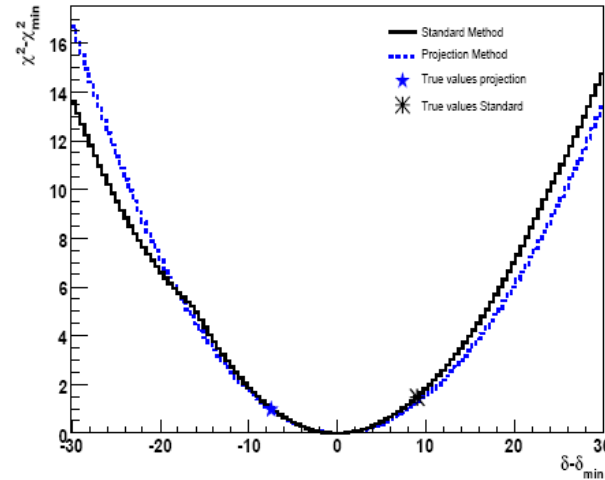
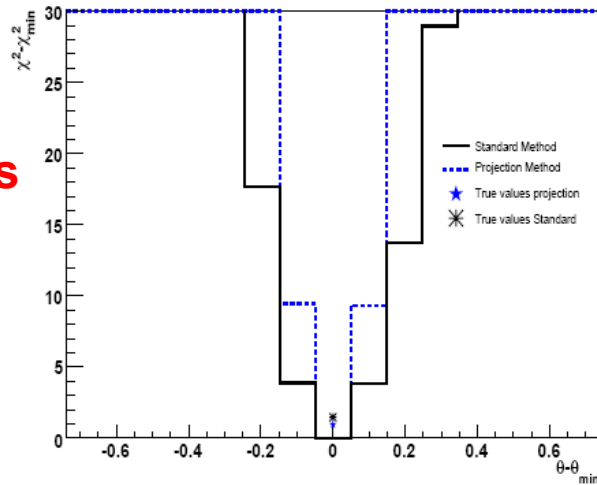


Flux extrapolation

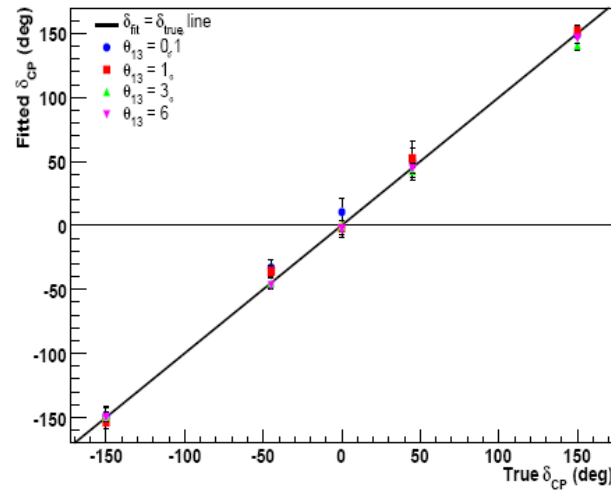
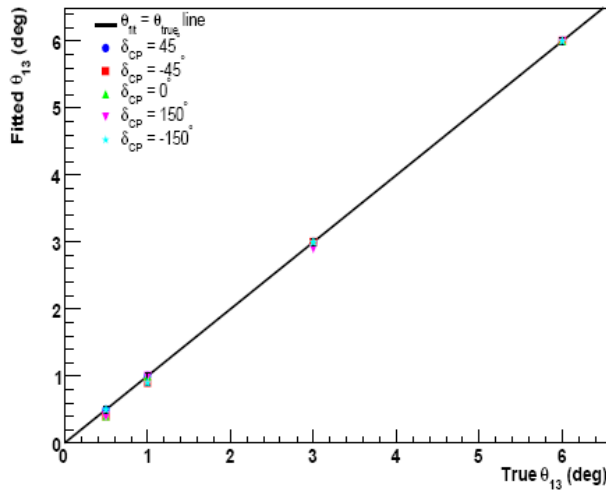
○ Extrapolation near-to-far at Neutrino Factory: **Laing, PS**

- Matrix method similar to MINOS: $N_{FD} = M_{FD} P_{osc}(\theta_{13}, \delta_{CP}) M_{nOsc} M_{ND}^{-1} N_{ND}$
- Fit FD spectrum to predicted spectrum from ND: $\chi^2 = \sum_i \sum_j (N_{ij} - n_{ij}) V_{ij}^{-1} (N_{ij} - n_{ij})^T$

**Fit improves
at 3σ level**

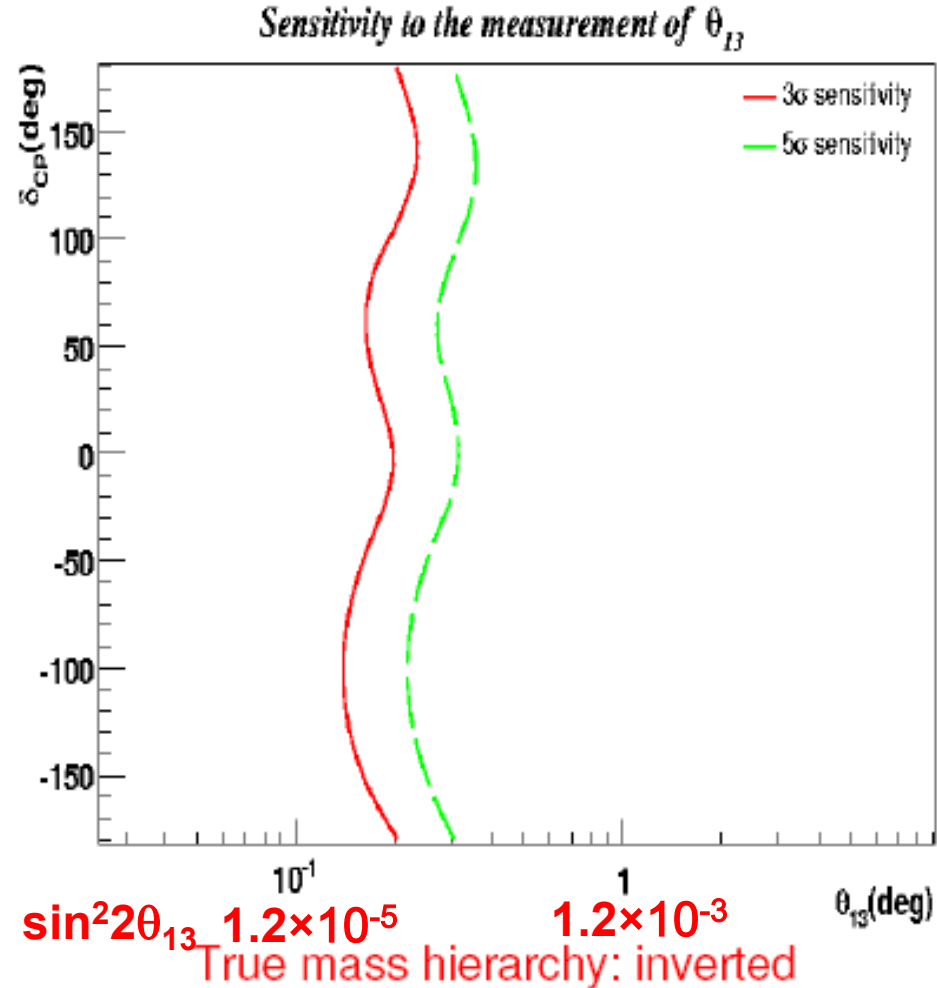
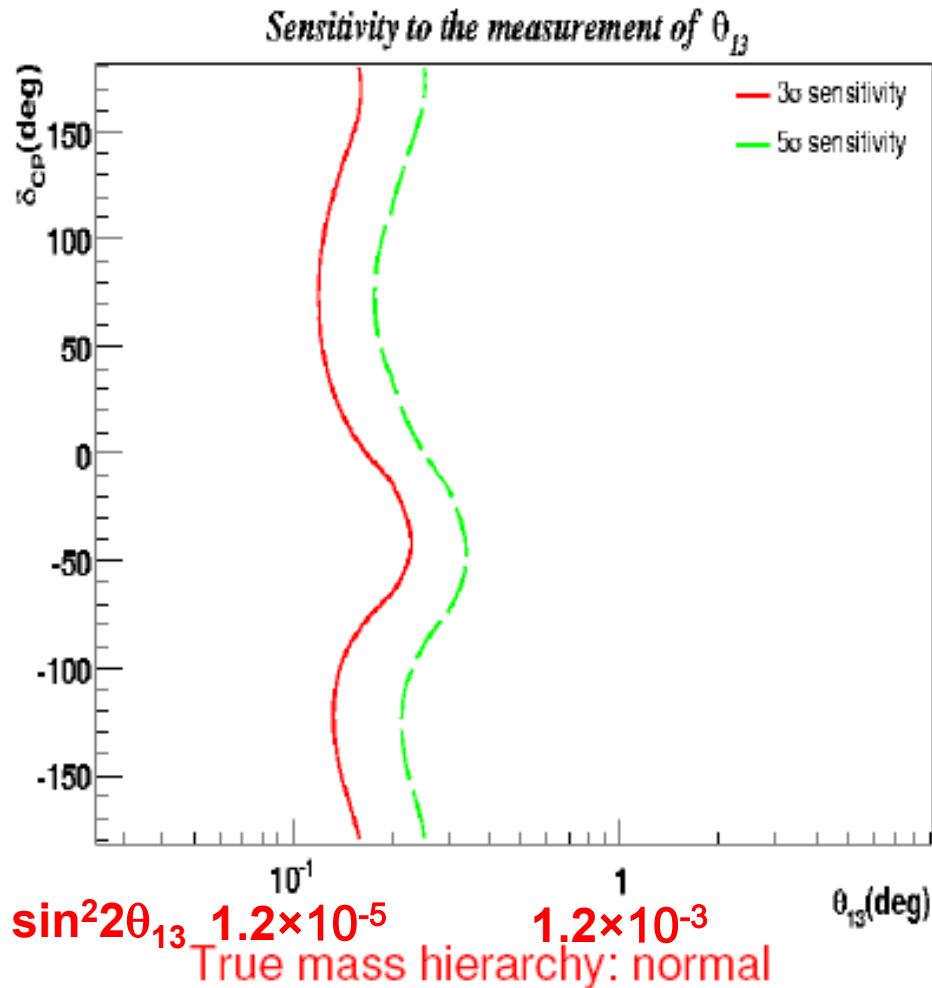


**Comparison
fitted θ_{13} and
 δ with true
values**



MIND: new analysis sensitivities with NuTS

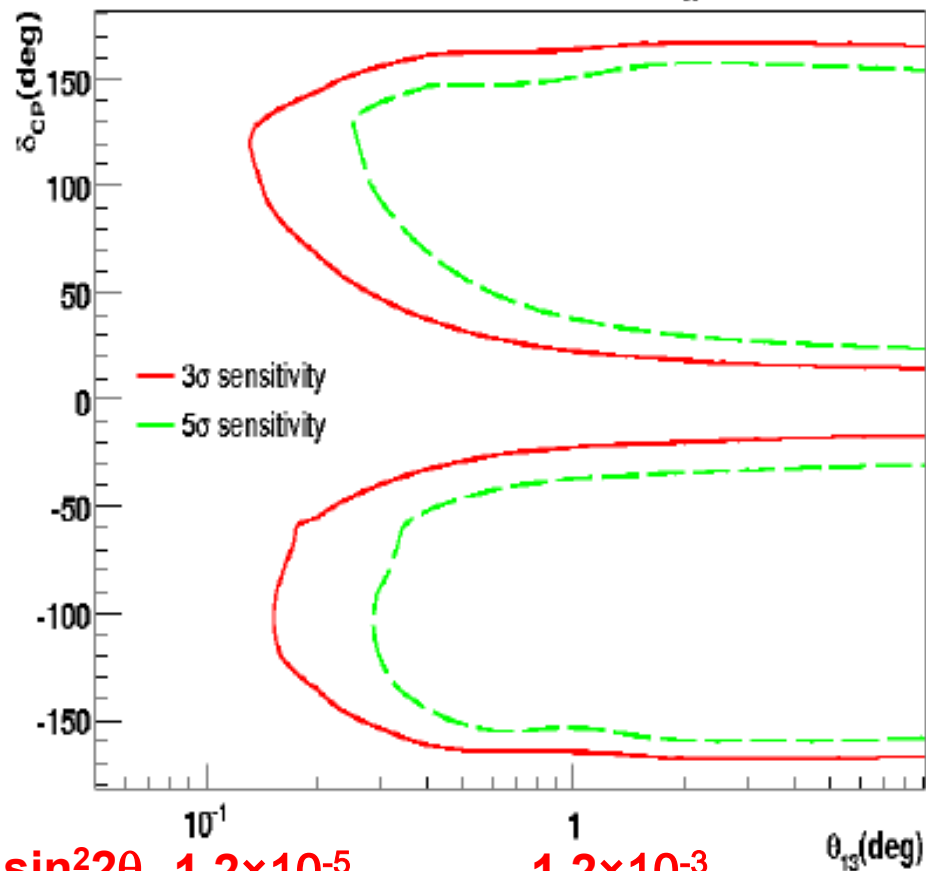
- θ_{13} sensitivities:



MIND: new analysis sensitivities with NuTS

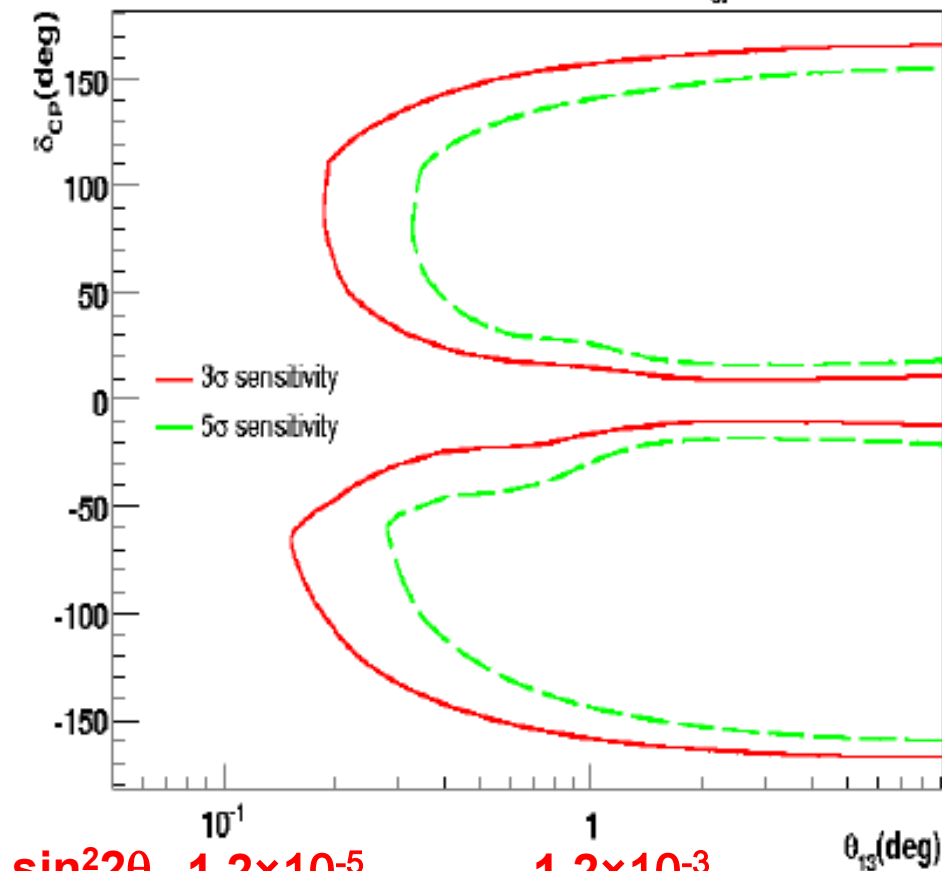
- δ_{CP} sensitivities:

Sensitivity to the discovery of δ_{CP}



True mass hierarchy: normal

Sensitivity to the discovery of δ_{CP}

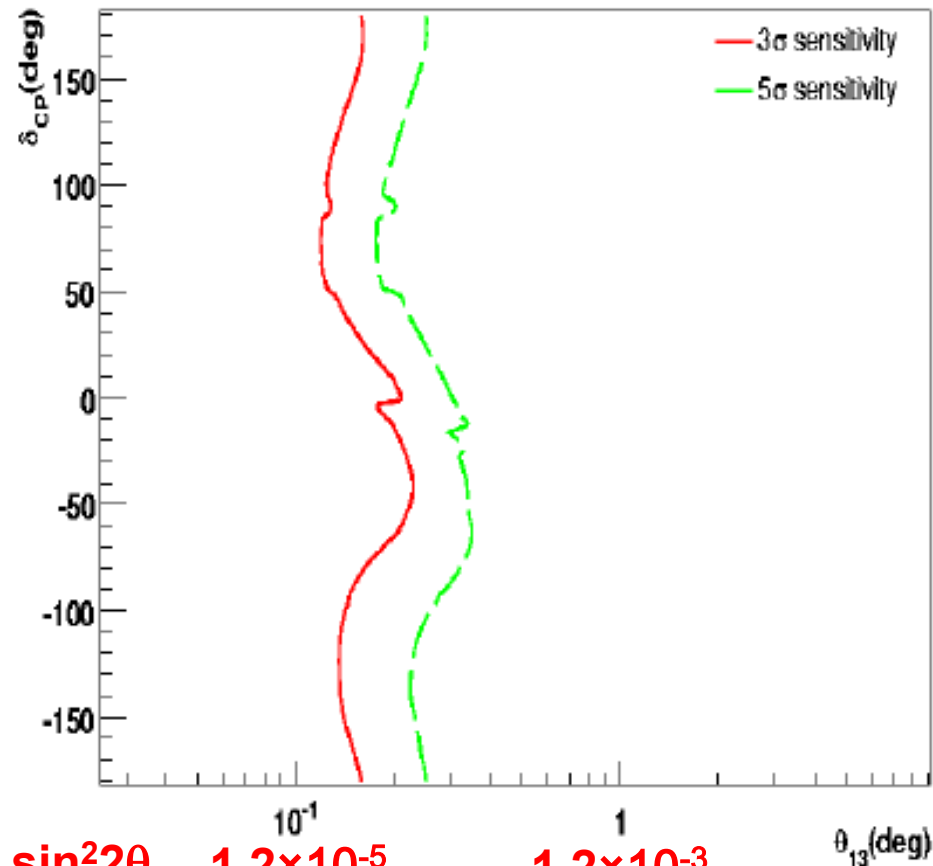


True mass hierarchy: inverted

MIND: new analysis sensitivities with NuTS

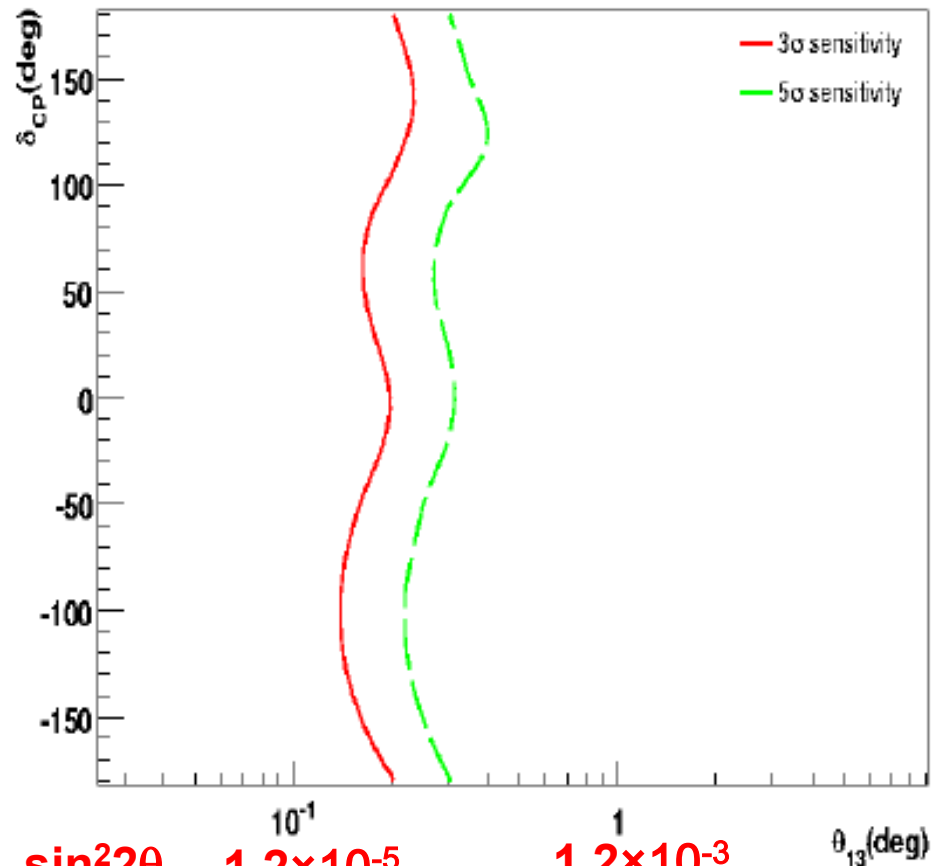
- Mass hierarchy sensitivities:

Sensitivity to the discovery of the true mass hierarchy



True mass hierarchy: normal

Sensitivity to the discovery of the true mass hierarchy



True mass hierarchy: inverted

How to treat systematics?

- Globes systematics:
 - We have response (migration) matrices
 - Should we calculate error in each term response matrix?
 - Systematics take into account current knowledge
 - What is expected error in cross-sections by the time NuFACT?
 - Analysis not optimised for ν_τ signal
 - No systematic errors done for analysis cuts yet
- R&D effort:
 - Develop realistic B-field
 - Measure charge mis-ID rate in test beams – can this be used to improve errors?
 -

Future directions

- Analysis and simulations:
 - Improve digitisation and optimise geometry
 - Add toroidal field
 - Move to GENIE for neutrino interactions (nearly done)
 - Improve hadronic reconstruction: energy and angular resolution
 - Final sensitivity plots and systematic errors
- R&D effort:
 - Prototype detectors with SiPM and extruded scintillator
 - Develop realistic B-field
 - Measure charge mis-ID rate
 - Develop CERN test beam for neutrino detector R&D – European AIDA proposal to make H8 into low E beam

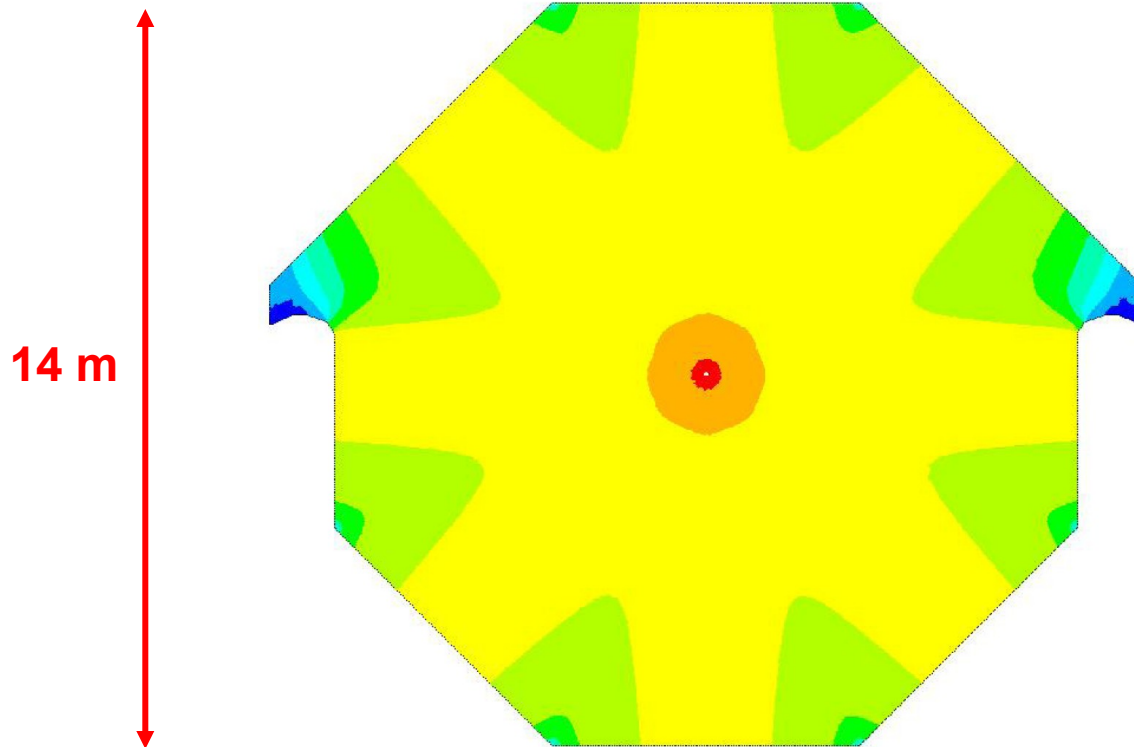
Systematics due to knowledge of B-field?

Add toroidal field: need to go to MINOS-like geometry to avoid low B-field corners

Preliminary field map for 14 m plates from ANSYS simulation

(Bob Wands, FNAL): ~ 1 T - 2.2 T with 92 kA-turn

```
ANSYS 12.1  
DEC 23 2010  
04:43:40  
NODAL SOLUTION  
STEP=1  
SUB =1  
TIME=1  
BY (AVG)  
RSYS=1  
PowerGraphics  
EFACET=1  
AVRES=Mat  
SMN =-.154342  
SMX =2.42  
-.154342  
.131729  
.417801  
.703873  
.989944  
1.276  
1.562  
1.848  
2.134  
2.42
```



Need to know how accurately we can determine B-field inside iron

Azimuthal B-field

Conclusions

- New MIND analysis with Nuance, Geant4, full pattern recognition and reconstruction provides 3σ discovery of θ_{13} , δ and mass hierarchy down to $\theta_{13} \sim 0.25^\circ$: **lower threshold**
- Preliminary systematic errors include hadronic energy (6%) and angular resolution (50%): affects efficiency by $<1\%$ above 5 GeV
- Relative weight of QEL, RES and DIS reactions by their known cross-section errors affects efficiency by $\sim 1\%$ below 5 GeV
- Near Detector flux normalisation known to $\sim 1\%$
- Matrix extrapolation method can reduce systematic errors on fits by 30% (probably due to correlated errors between near and far?)
- Need to understand how Globes will include systematics and what do they need from us