THE INTERNATIONAL DESIGN STUDY
FOR THE NEUTRINO FACTORY

Detectors for leptonic CP violation at the Neutrino Factory

35th International Conference on High Energy Physics

A. Laing, 24 July 2010

on behalf of the IDS-NF collaboration

University of Glasgow | Experimental Particle Physics

Acknowledgements:

- Many thanks to those who provided information or material:
  - And in particular the International Design Study for the Neutrino Factory (the IDS-NF) collaboration and the EUROnu collaboration: http://www.ids-nf.org/

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YORK UNIVERSITÉ UNIVERSITY redefine THE POSSIBLE.
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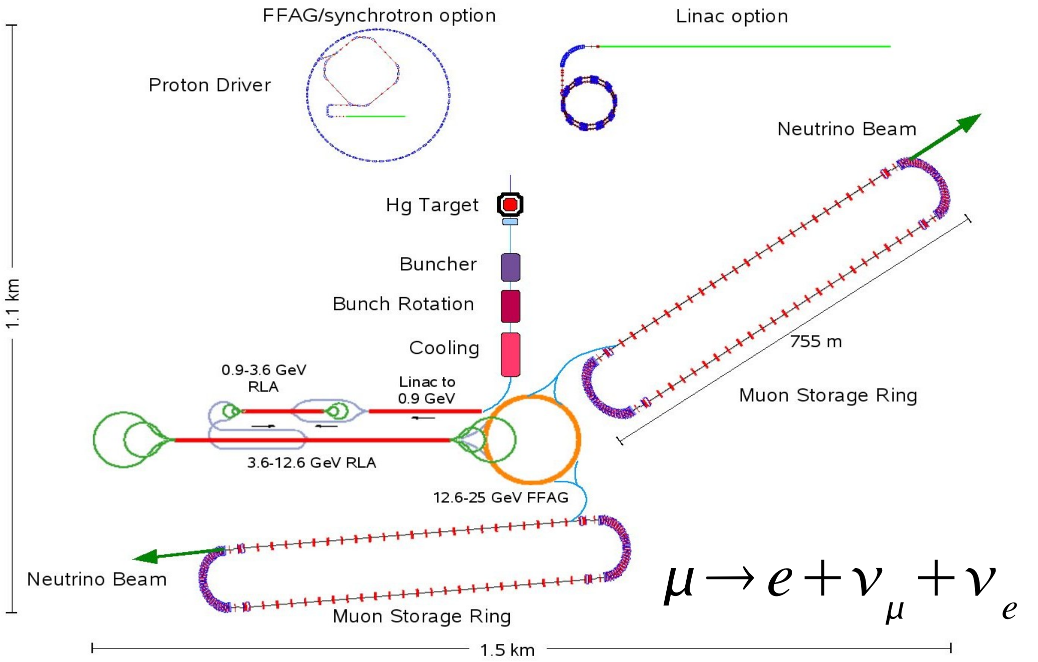
Contents

- The neutrino factory and motivations for CP violation measurement.
- Near detector at a neutrino factory.
- Possible technologies for far detectors.
- The baseline and its simulation status.
- R&D

The Neutrino Factory and leptonic CP violation



$$\mu \rightarrow e + \nu_\mu + \nu_e$$

Measurement requires the study of appearance channels.

Spectral information greatly improves resolution.

Multiple detector baselines and/or channels advantageous.

GOLDEN CHANNEL

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

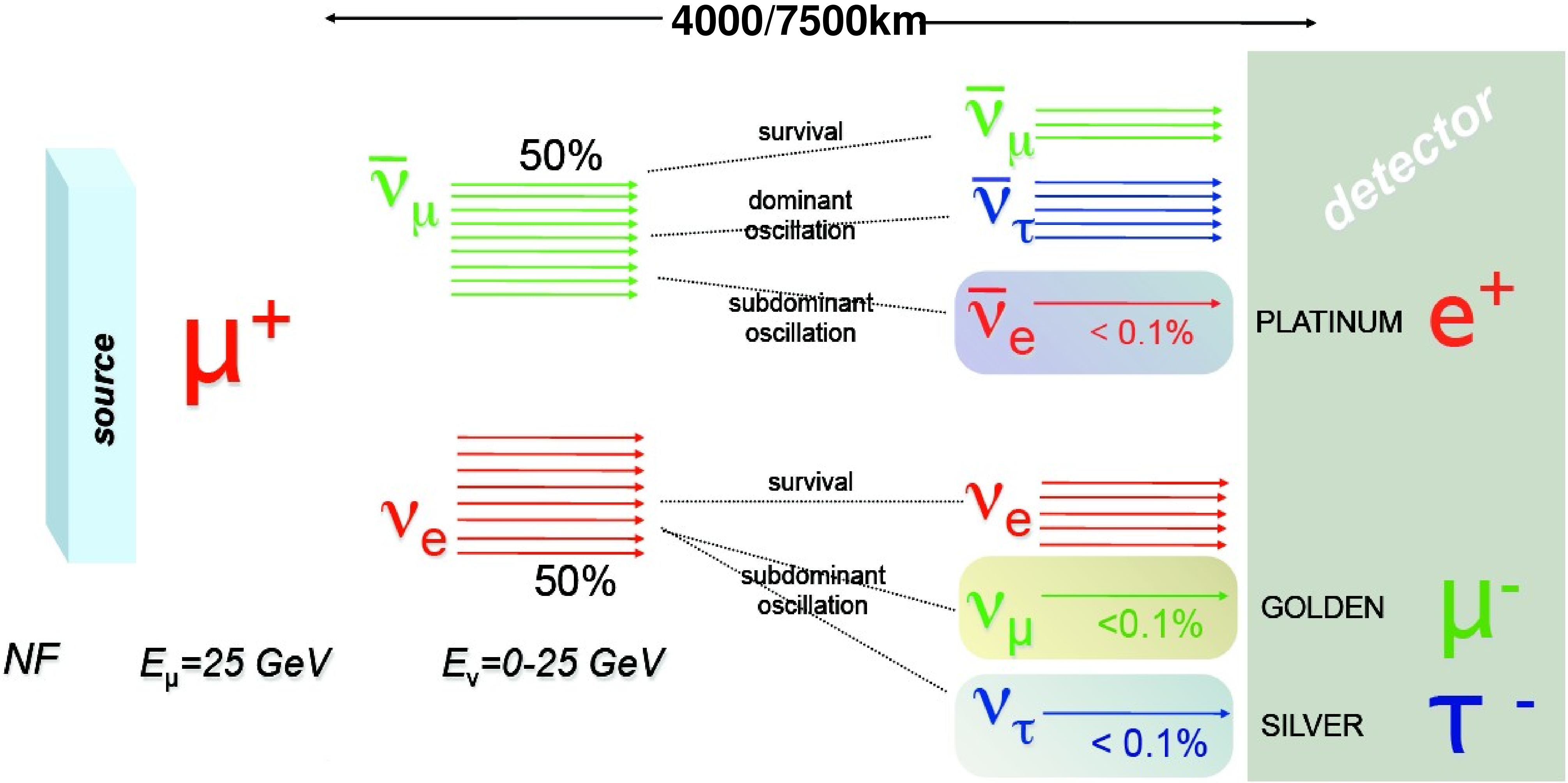
The measurement of CP violation in neutrino oscillations opens a potential window on leptogenesis.

Related presentations at ICHEP 2010

K. Long, “The International design study for the neutrino factory”, track 14, 16.40 24/7.

Y. Karadzhov, “Status of MICE...”, Poster 345.
M. Bonesini, “MICE PID System”, Poster 803.
V. Verguilov, “Emittance reduction in MICE”, Poster 727.
N. Mondal, “India Neutrino observatory”, Poster 394.

The Neutrino Factory as a neutrino source



Subdominant oscillations contain most information.

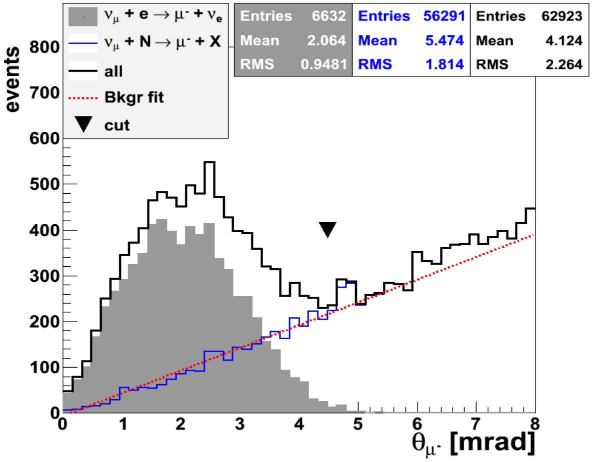
Golden channel identified as most important signal due to relative ease of detection.

Requirements for the detection of subdominant oscillations

- Magnetic field to separate the charge of the primary lepton.
  - High interaction rate of surviving beam neutrinos.
- High suppression of hadronic particles.
  - Pions, Kaons and decay leptons can act as background.
- Measure flux and cross-sections to a high degree of accuracy.

Near Detector

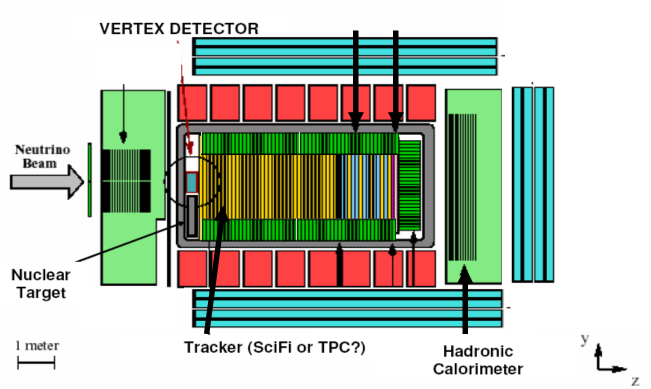
- A near detector facility placed within 1 km of the source would have a number of functions:

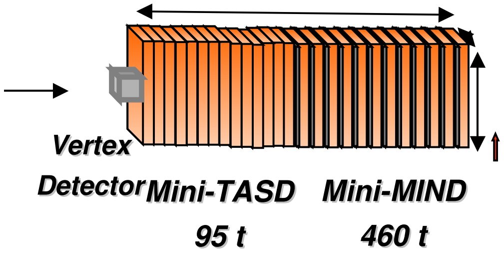


Karadzhov, Matev, Tsenov, Uni. Sofia.

Absolute flux measurement:

- Inverse muon decay for purity.
- Full spectral reconstruction with multiple channels.

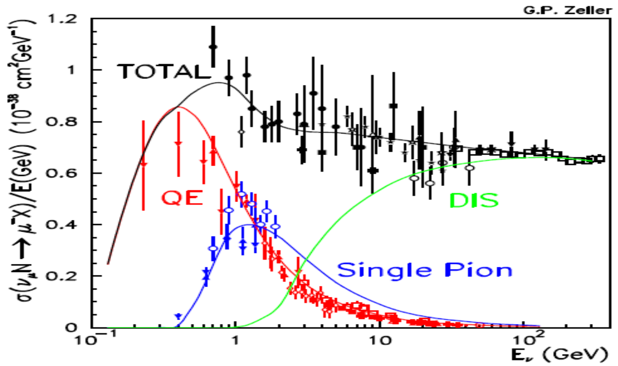


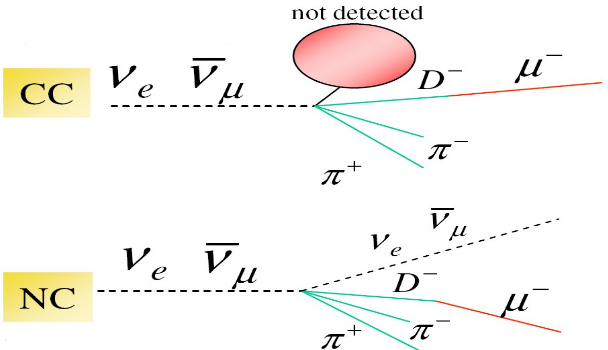


Multiple subdetectors or small scale FD?

High granularity possible.

Huge flux means unprecedented interaction rate.



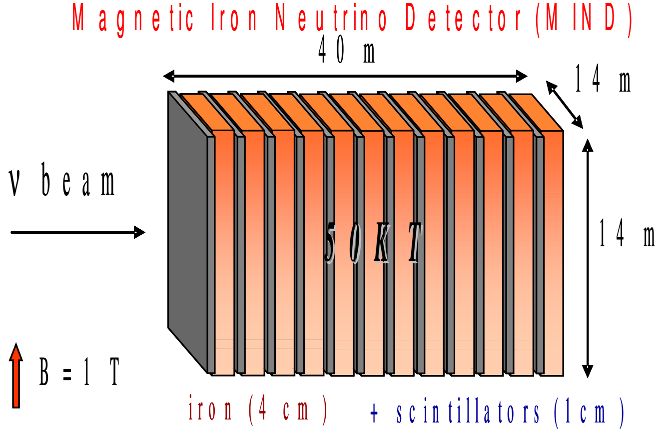


Cross-section measurement:

- All channels measured to 1% level?
- Unprecedented understanding of suppressed processes.

Possible Far detector technologies

Magnetised Iron Neutrino Detector



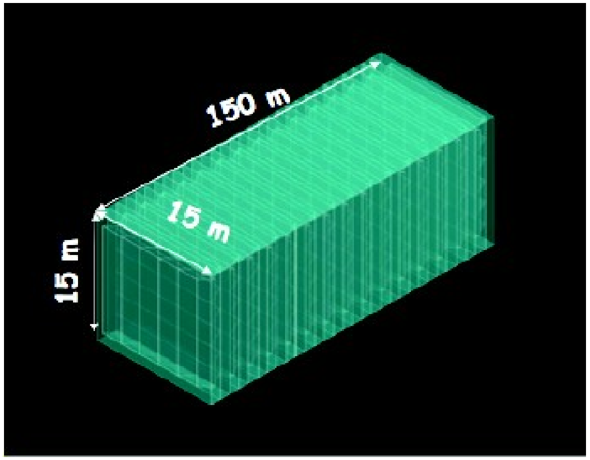
Pros:

- Large mass
- high hadronic suppression
- Easily magnetised

Cons:

- Only for golden channel
- High energy threshold

Totally active scintillator



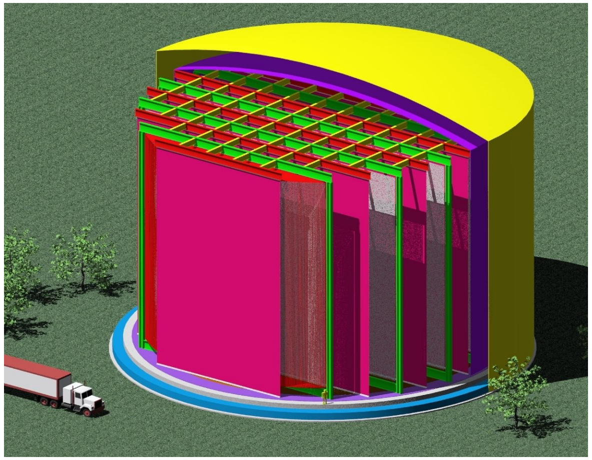
Pros:

- Low energy threshold
- High resolution
- Possible silver channel

Cons:

- Lower mass
- Difficult to magnetise

Liquid Argon TPC



Pros:

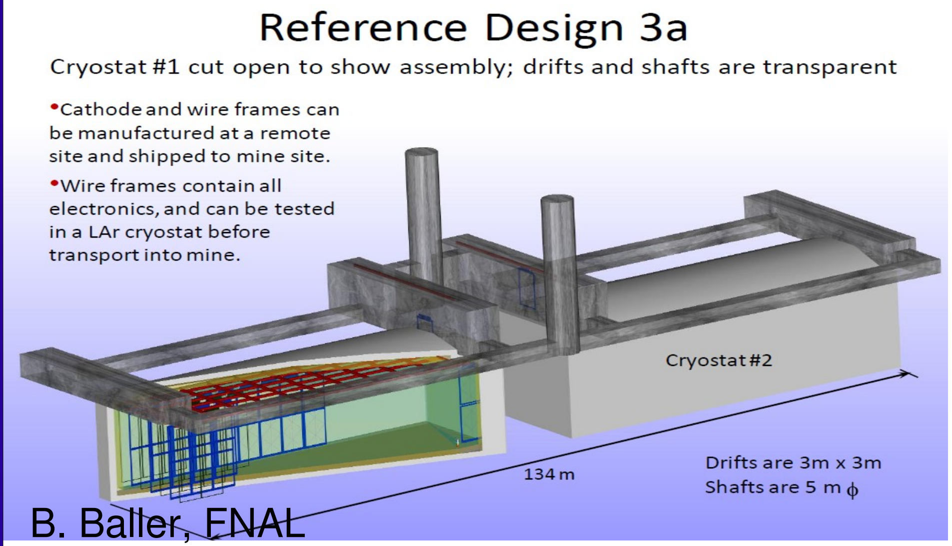
- V. high resolution
- V. low energy threshold
- Multi-channel

Cons:

- New technology
- Difficult to magnetise
- Large mass difficult

MIND has been chosen as the baseline detector technology for IDS-NF.

Large scale liquid argon



Reference Design 3a

Cryostat #1 cut open to show assembly; drifts and shafts are transparent

- Cathode and wire frames can be manufactured at a remote site and shipped to mine site.
- Wire frames contain all electronics, and can be tested in a LAr cryostat before transport into mine.

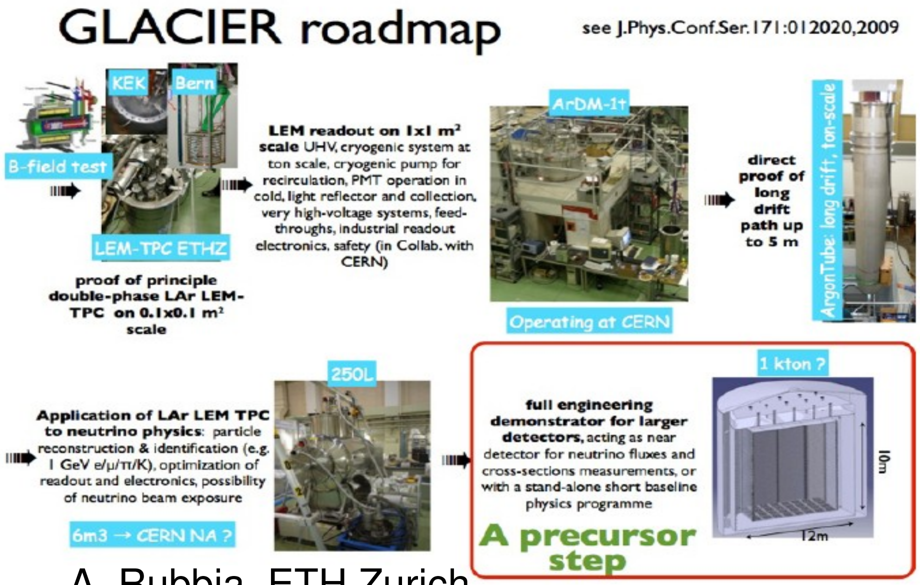
B. Baller, FNAL

A number of R&D programs exist to realise a high mass LAr TPC.

- The Laguna project is studying sites and engineering in Europe.
- LBNE in USA are looking into designs for a 20kT detector.
- Other efforts in Japan etc. looking at technology.

Challenges include:

- Engineering of the vessel.
- Cooling and maintaining purity.
- Drift distances.
- Magnetisation.



GLACIER roadmap

see J.Phys.Conf.Ser.171:012020,2009

proof of principle double-phase LAr LEM-TPC on 0.1x0.1 m² scale

LEM readout on 1x1 m² scale UHV, cryogenic system at ton scale, cryogenic pump for recirculation, PMT operation in cold, light reflector and collection, very high-voltage systems, feed-throughs, industrial readout electronics, safety (in Collab. with CERN)

direct proof of long drift path up to 5 m

Application of LAr LEM TPC to neutrino physics: particle reconstruction & identification (e.g. 1 GeV e/μ/π/K), optimization of readout and electronics, possibility of neutrino beam exposure

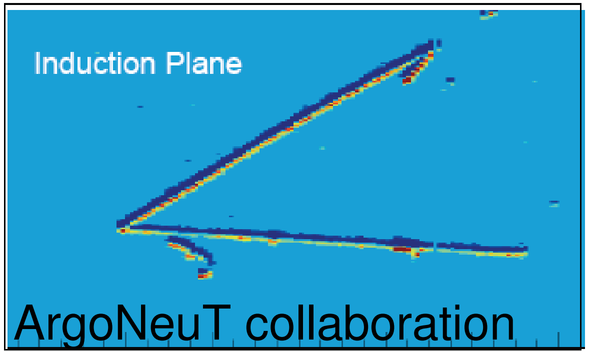
full engineering demonstrator for larger detectors, acting as near detector for neutrino fluxes and cross-sections measurements, or with a stand-alone short baseline physics programme

A precursor step

A. Rubbia, ETH Zurich

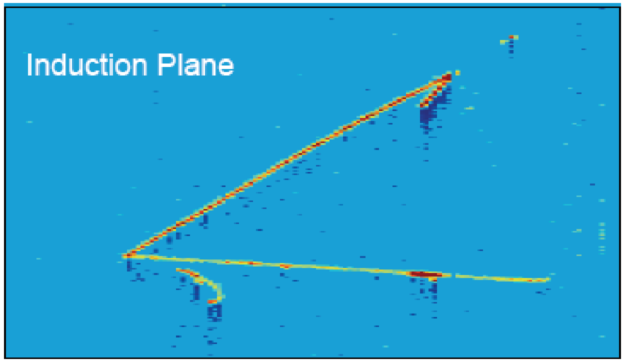
LAr TPC (cont.)

- The spacial resolution of a LAr TPC is similar to that of a bubble chamber.
- Proof of the feasibility of the technology and of magnetisation required.
- Has the potential to study other neutrino sources and perform other physics studies.



Raw Data

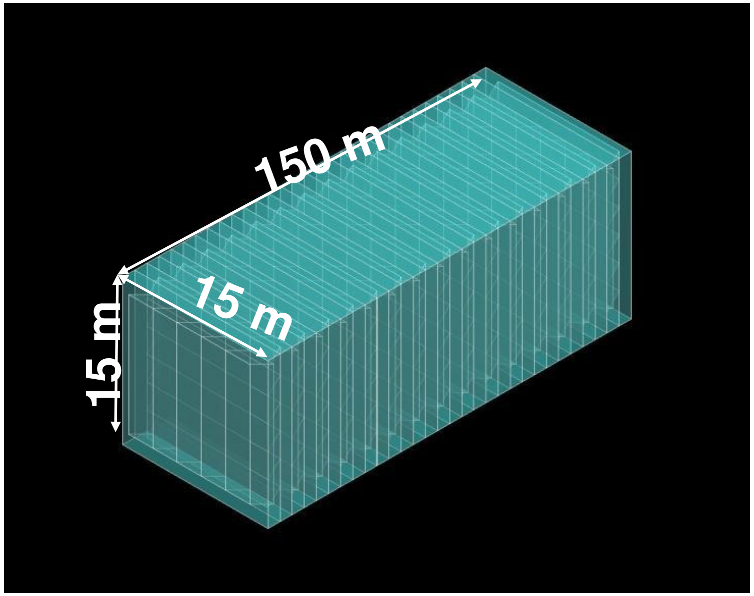
ArgoNeuT collaboration



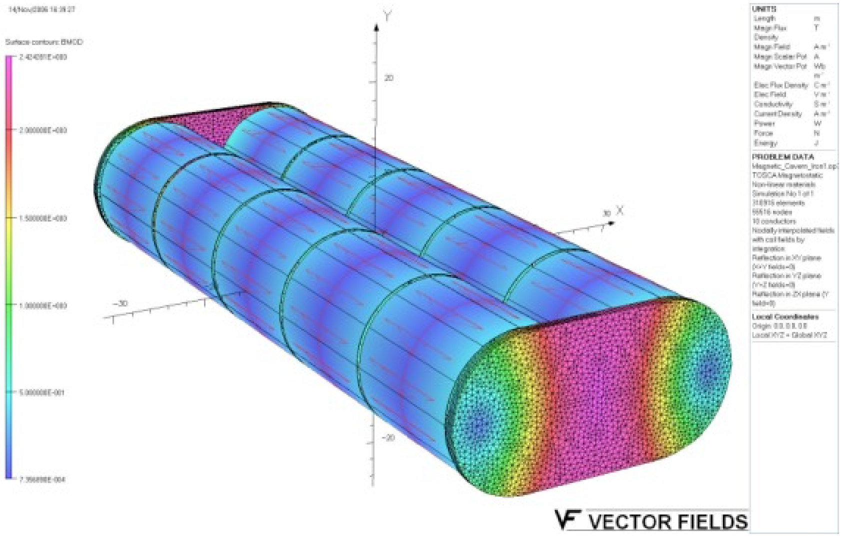
Deconvolution

Antonello M., “ArgoNeuT and MicroBooNE: LAr-TPC's at Fermilab”, *AIP conf. Proc.*, 1222 (2010) pp. 257-261.

Totally Active Scintillator Detector

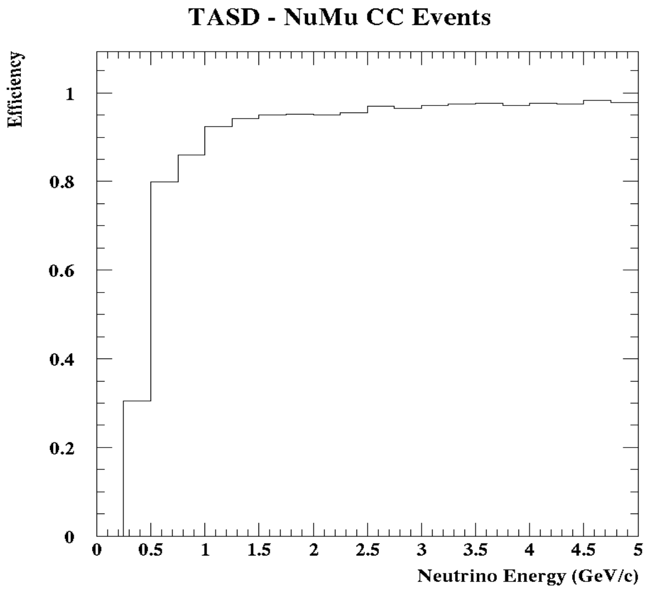


- Like Nova but made from extruded plastic scintillator decreasing dead area.
- Triangular cross-section bars similar to Minerva for increased spacial resolution.

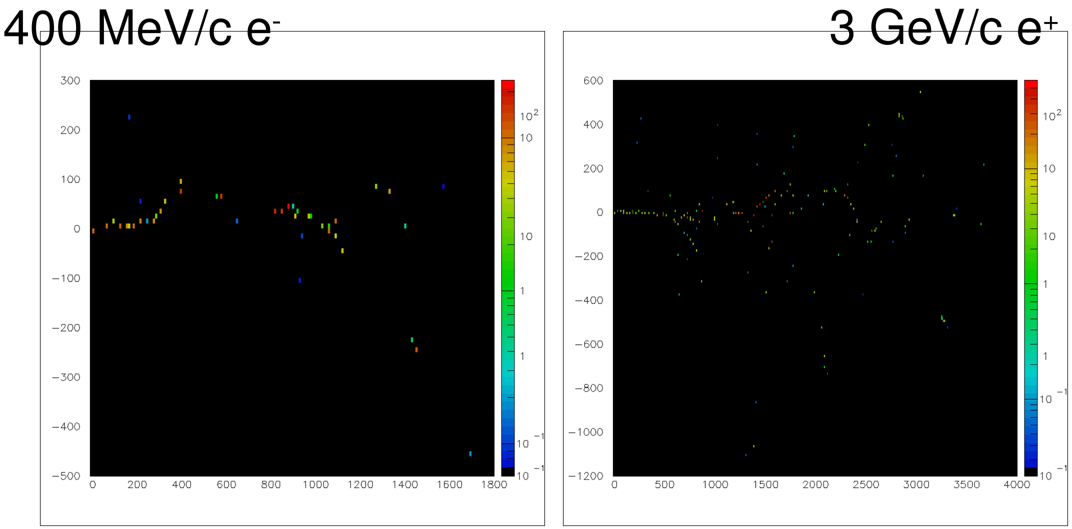


- R&D required to achieve magnetic field.
- Possibility of Magnetised cavern using superconducting transmission lines.

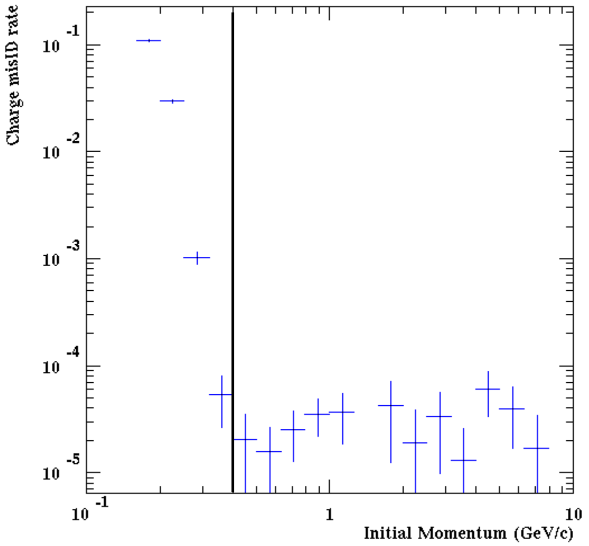
TASD (cont.)



Initial studies simulating free muons indicate a low energy threshold for golden channel signal identification.


400 MeV/c e^-

3 GeV/c e^+

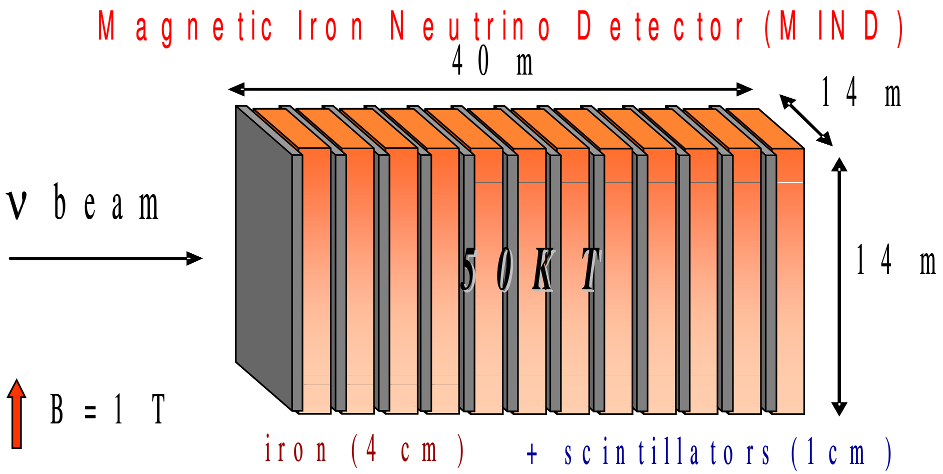


Indication also of potential platinum channel sensitivity through electron identification

Bross, A. D. *et al*, “A Neutrino factory for both large and small θ_{13}”, *Phys. Rev.* **D**77 (2008).

Magnetised Iron Neutrino Detector

- High suppression of hadronic backgrounds.
- Easily magnetised.
- High mass.
- Technology well understood



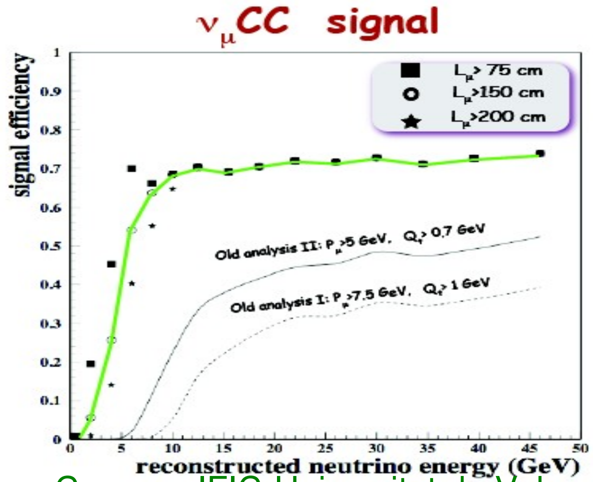
50-100kT

Chosen as the baseline detector for IDS-NF for these reasons.

Need to prove that an energy threshold of 3 GeV or lower can be maintained without high backgrounds.

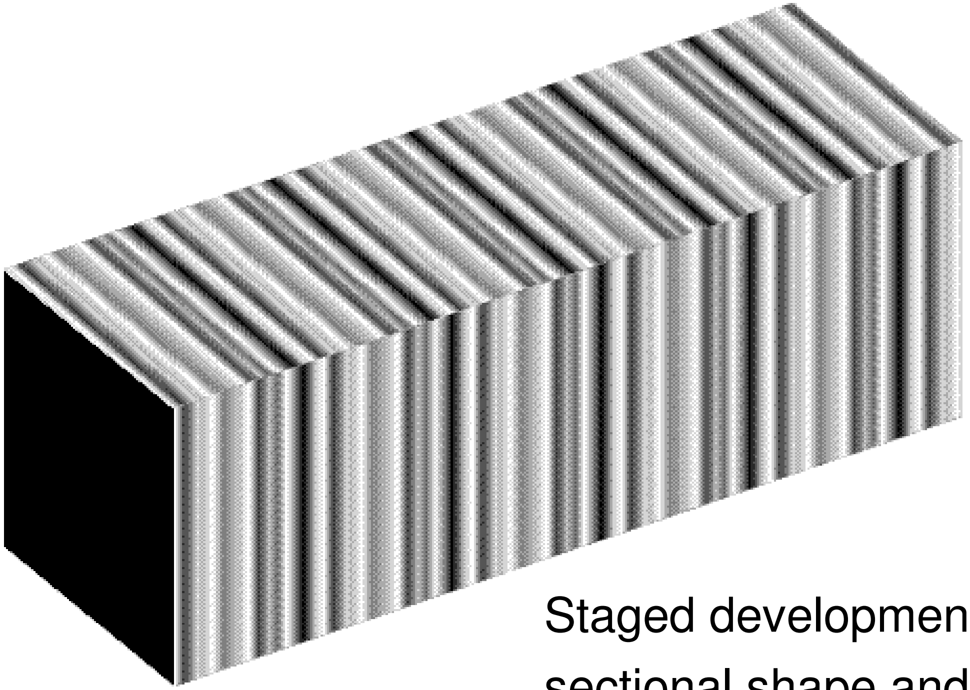
Are the electronics to overcome cross-talk affordable?

Is only the Golden Channel enough?



Cervera, IFIC-Universitat de Valencia

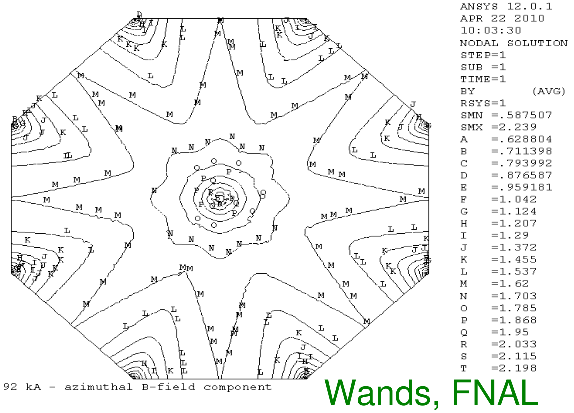
Simulation status



Geant4 simulation of MIND:

- Cuboidal structure
- 1T uniform dipole field*

Staged development to include toroidal field, optimise cross-sectional shape and scintillator segmentation. Can ultimately be used for studies of TASD using the same framework.



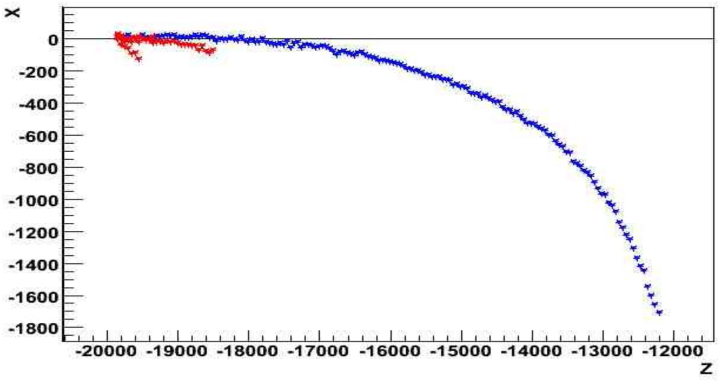
Wands, FNAL

*Studies underway into a realistic toroidal fieldmap and octagonal cross section.

Field strength likely to be achieved using a Superconducting Transmission Line (SCTL) developed originally for the VLHC.

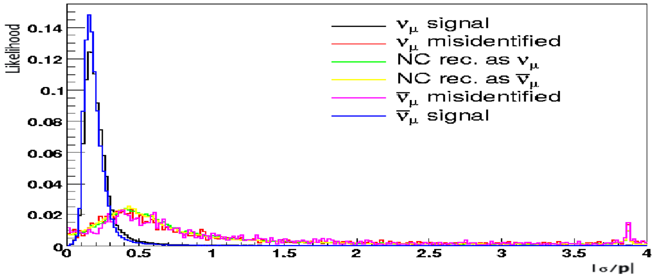
Analysis

- All detectors require dedicated studies of reconstruction and analysis to suppress beam inherent backgrounds.

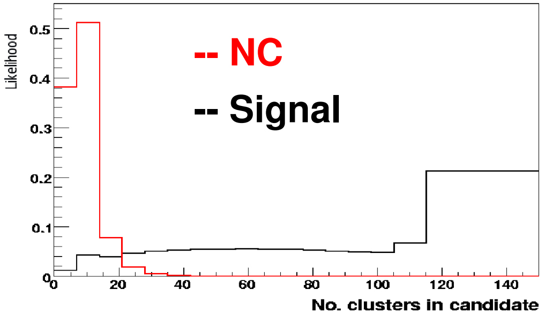


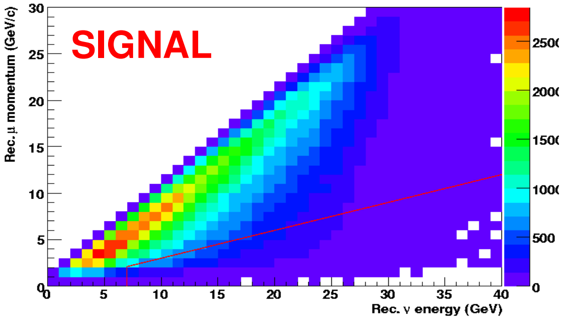
Kalman filter/Cellular automaton to reconstruct candidate muons from events.

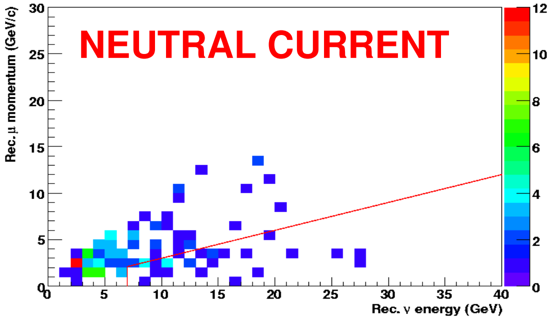
Helix fit of candidates using Kalman filter to reconstruct Charge and momentum.



Separation of signal and background using fit quality, event topology and kinematics.







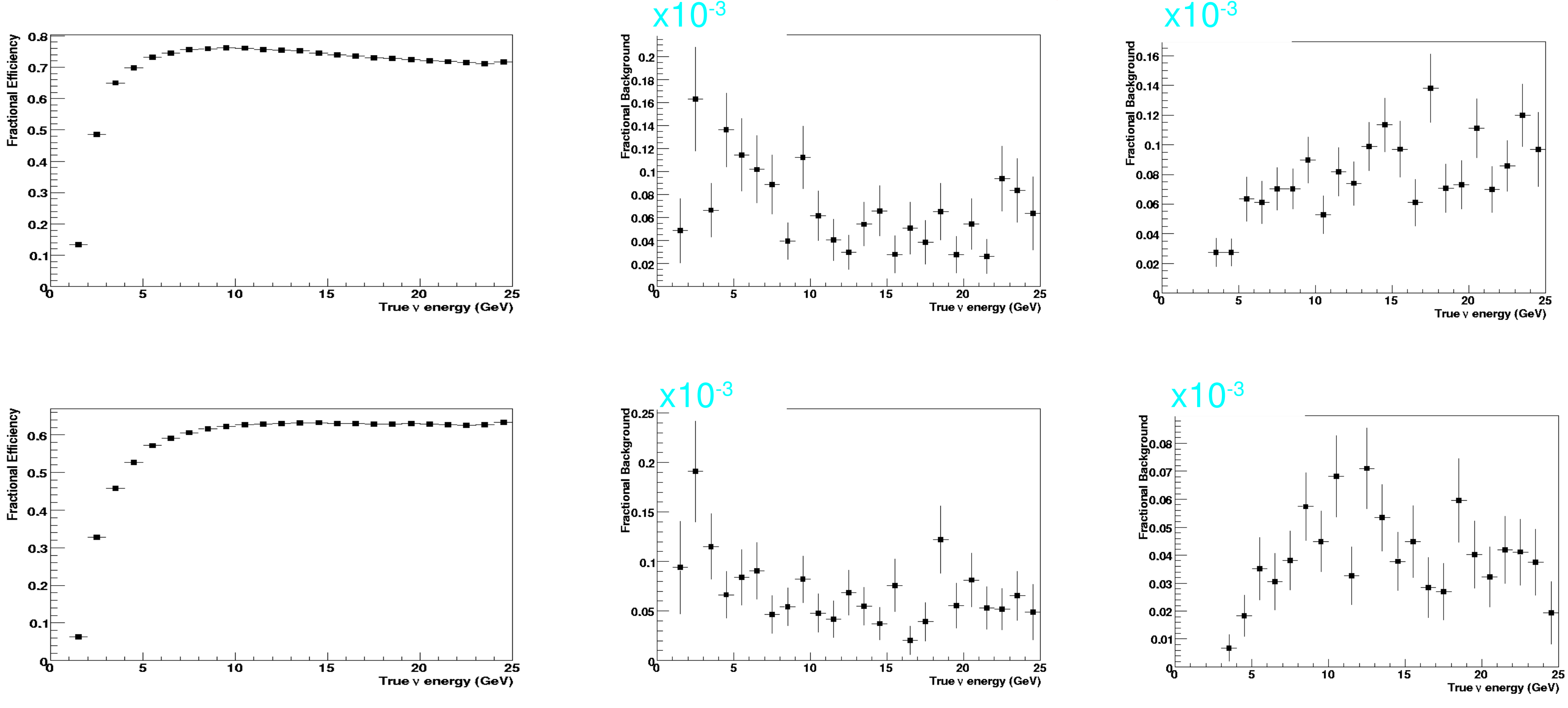
Current status of MIND

- Signal efficiency and background for the appearance of ν_μ and $\bar{\nu}_\mu$ have been studied under current assumptions.

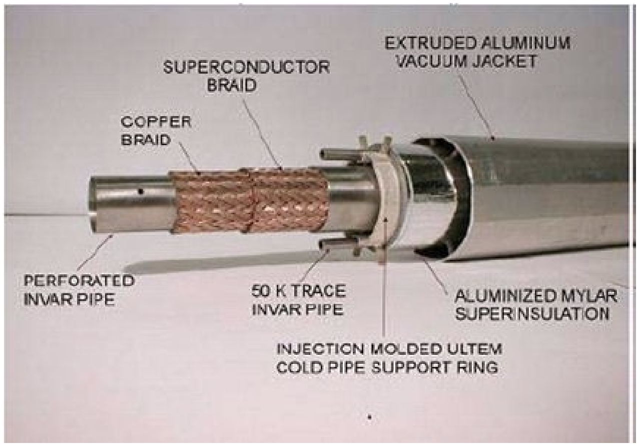
Signal Efficiency | **Background from beam ν_μ** | **Background from NC**

Antineutrino appearance

Neutrino appearance

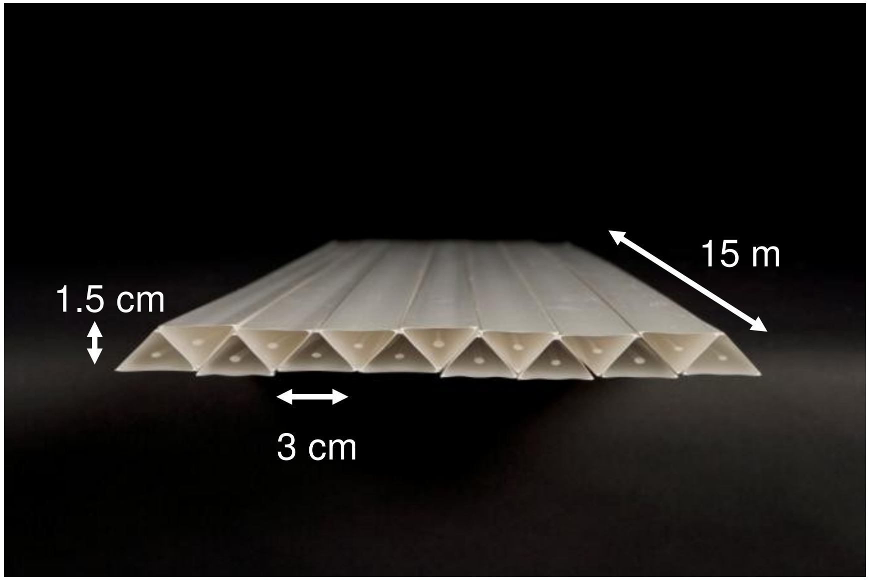


Required R&D



Testing of SCTL technology in the context of the magnetic cavern.

Optimisation of cable geometry for toroidal field for MIND.



Testing of very long scintillator bars for mechanical strength and attenuation.

Double or single sided read-out, electronics technologies.

Mondal *et al*, TIFR.

MIND has large amount of synergy with the Indian Neutrino Observatory detector.

Work with INO colleagues on prototyping using RPC and scintillator read-out.

Summary

- Measurement of leptonic CP violation at the neutrino factory requires optimisation of detectors.
- A number of technologies are under study.
- Simulations indicate required efficiency and background suppression is possible
- Interim design report within the year. Reference design report to be published by 2013.

Backup

Efficiency and inelasticity