Proposal by the IIFC to participate in the LBNE Experiment

(Report on the DPR)

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(DPR Editors: Brajesh Choudhary, Raj Gandhi, Sanjib Mishra, Shekhar Mishra, Jim Strait)

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Neutrinos.......................................Some properties

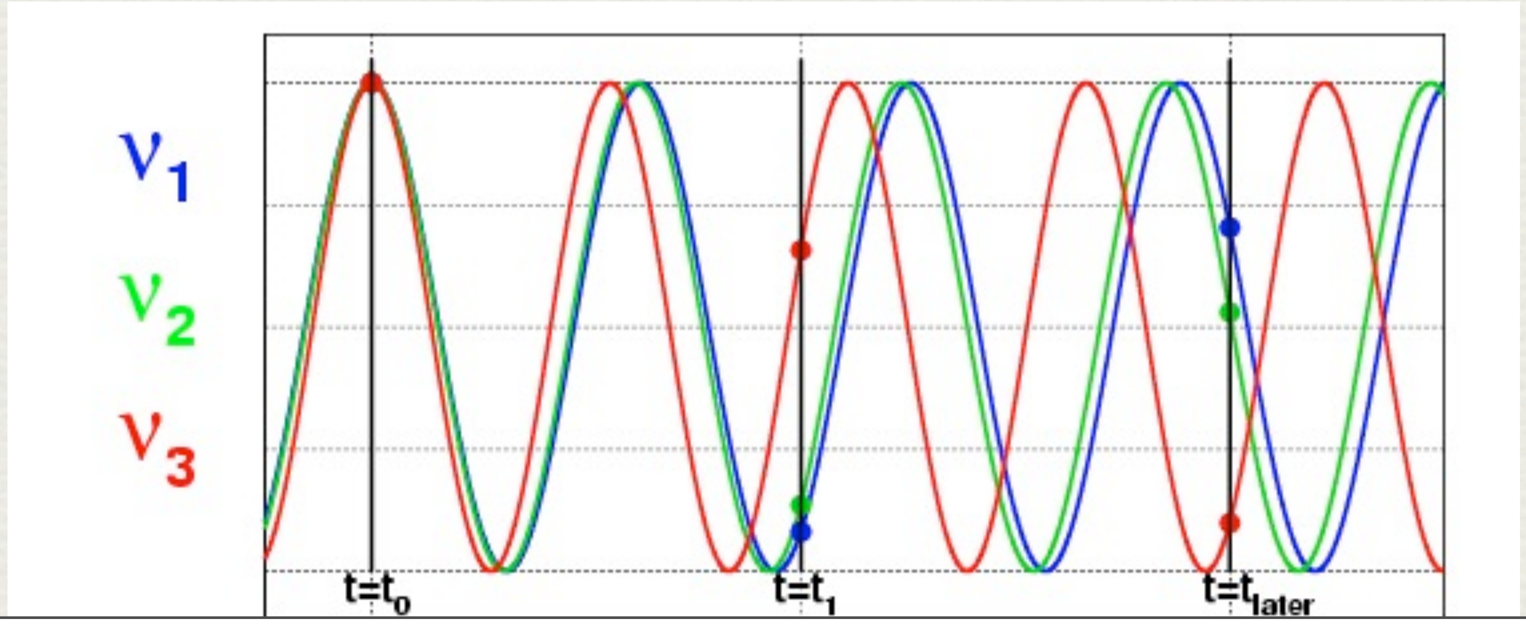
Neutrinos barely interact, having a mean free path length of 1 light year even when passing thru lead

Thus very large volume detectors are necessary to observe them, and detection of a signal over backgrounds is a challenge

Neutrinos have tiny masses, about 10^-7 times (or less)the mass of the lightest charged particle (the electron).

Absolute mass values not exactly known.

Neutrinos oscillate, i.e change flavour, as they propagate



Neutrinos............Why are they important?

Measuring the mass hierarchy of neutrinos will provide crucial clues to the nature of physics beyond the Standard Model.

The search for CP violation in the neutrino sector could provide important information on the matter-antimatter asymmetry of the Universe

Both the hierarchy and the CP violating parameter are major physics goals of LBNE

(For Physics goals and description of LBNE, pl refer to Jim Strait's talk in this meeting)

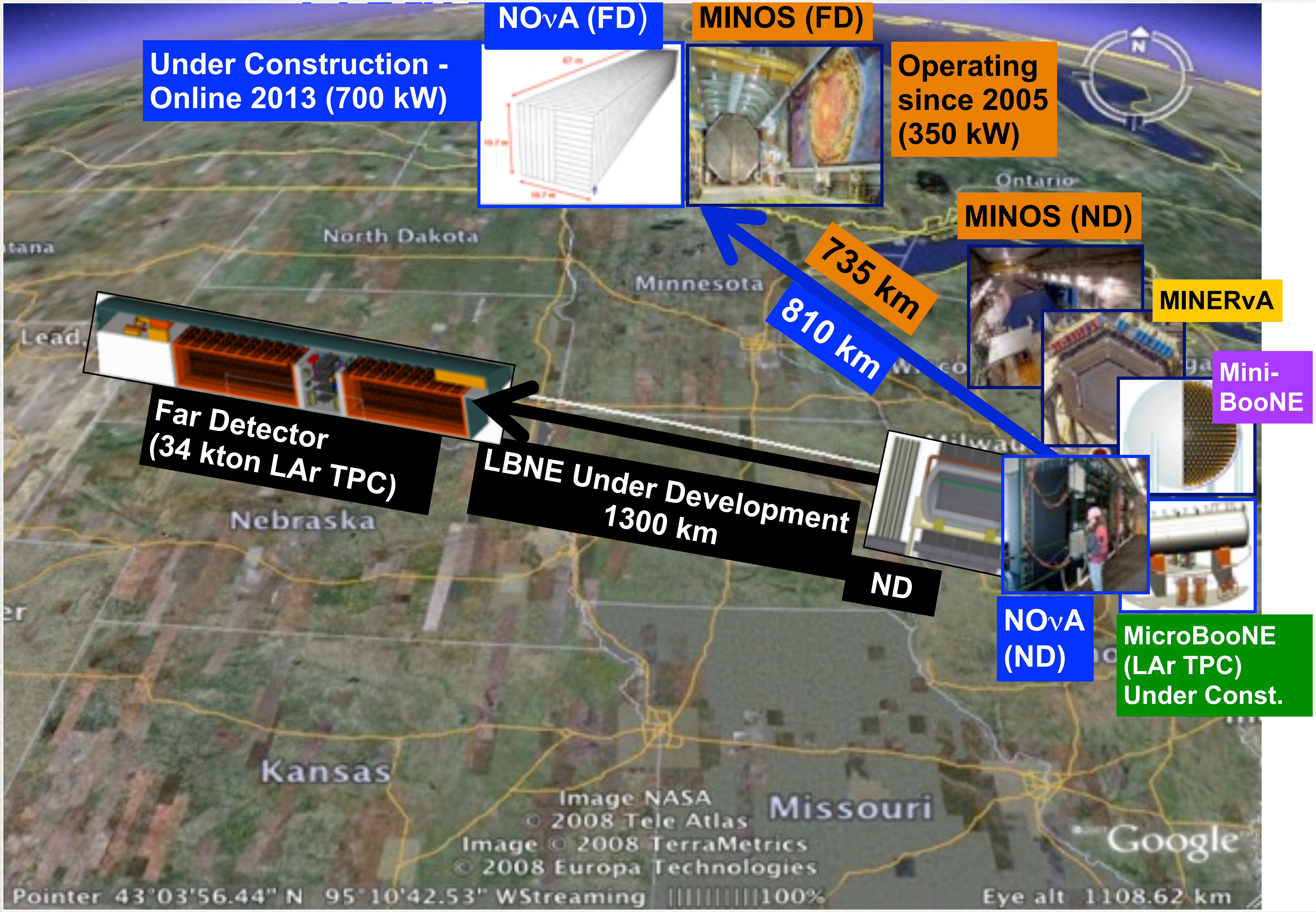
India and LBNE...... The DAE mandate for participation

In May 2010, Dr. Srikumar Banerjee, then Secretary of the DAE, gave the Indian institutions and Fermilab Collaboration (IIFC) a mandate to develop a physics program to complement the accelerator collaboration.

He specifically asked that we develop a program that:

- **Provides rich physics and is capable of producing 50–100 Ph.Ds from the Indian Institutions;**
- **Strengthens India's scientific infrastructure;**
- **Constitutes a significant contribution to the Fermilab project with a DAE/DST ownership;**
- **Shares synergy with the ongoing research programs in India, including the INO program.**

LBNE...... Schematic



Under IIFC, institutions already involved in MINOS, NOνA, MIPP. These are BHU, Delhi, Panjab, Jammu, University of Hyderabad, CUSAT, IIT-Guwahati and IIT-Hyderabad.

SINP and HRI to join.

The Long Baseline Neutrino Experiment (LBNE)

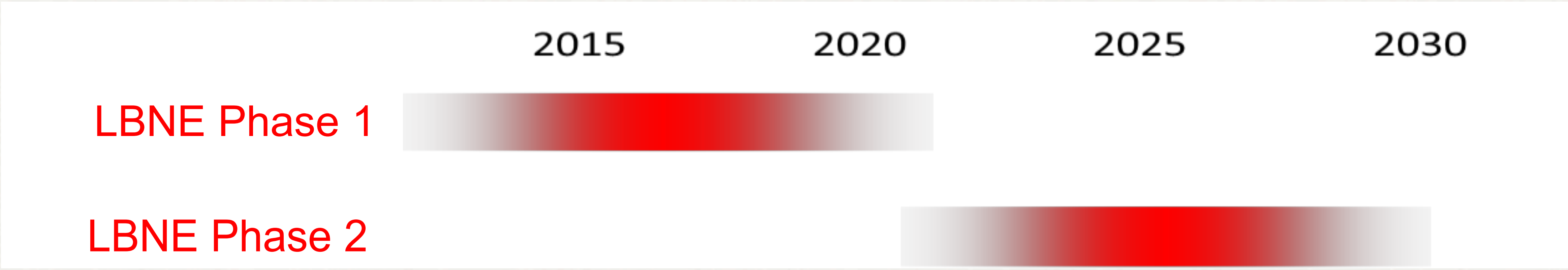
Beam from Fermilab to a Liq Ar TPC Far Detector 1300 km away at the Sanford Underground Research Facility (SURF), Homestake mine in South Dakota

LBNE will take physics data in 2023, first using a 708 kW beam and later, with Project X, using a 2.3 MW beam

India already part of Project X via the Accelerator Collaboration

Adding a strong and substantial neutrino component would allow for complete participation in the world's premier long baseline facility

LBNE...... Phases and Timelines



At present, in Phase I, no near detector (ND) planned.

We propose to design and build a high-resolution near detector (ND) in India that will not only significantly add to the capabilities of the overall LBNE oscillation program, but will also:

- make precision measurements of neutrino-nucleon and neutrino nucleus cross-sections and other electro-weak parameters with previously unachieveable precision ;
- allow searches for non-standard interactions which could lead to new discoveries in neutrino physics

We have also proposed that we contribute to the design and construction of the liquid argon detector at the far site and conduct analyses and physics studies.

LBNE-India DPR......

On Nov 22, 2012, the DPR (Final-2 version) was submitted to the DAE for consideration and evaluation.

The DPR contains a carefully thought-out and detailed design for one possible ND detector technology that:

- **Will meet the scientific goals of LBNE and satisfy the mandate given by DAE to the IIFC;**
- **Will, over the next several months, be the subject of study within the LBNE collaboration with full and equal Indian participation;**

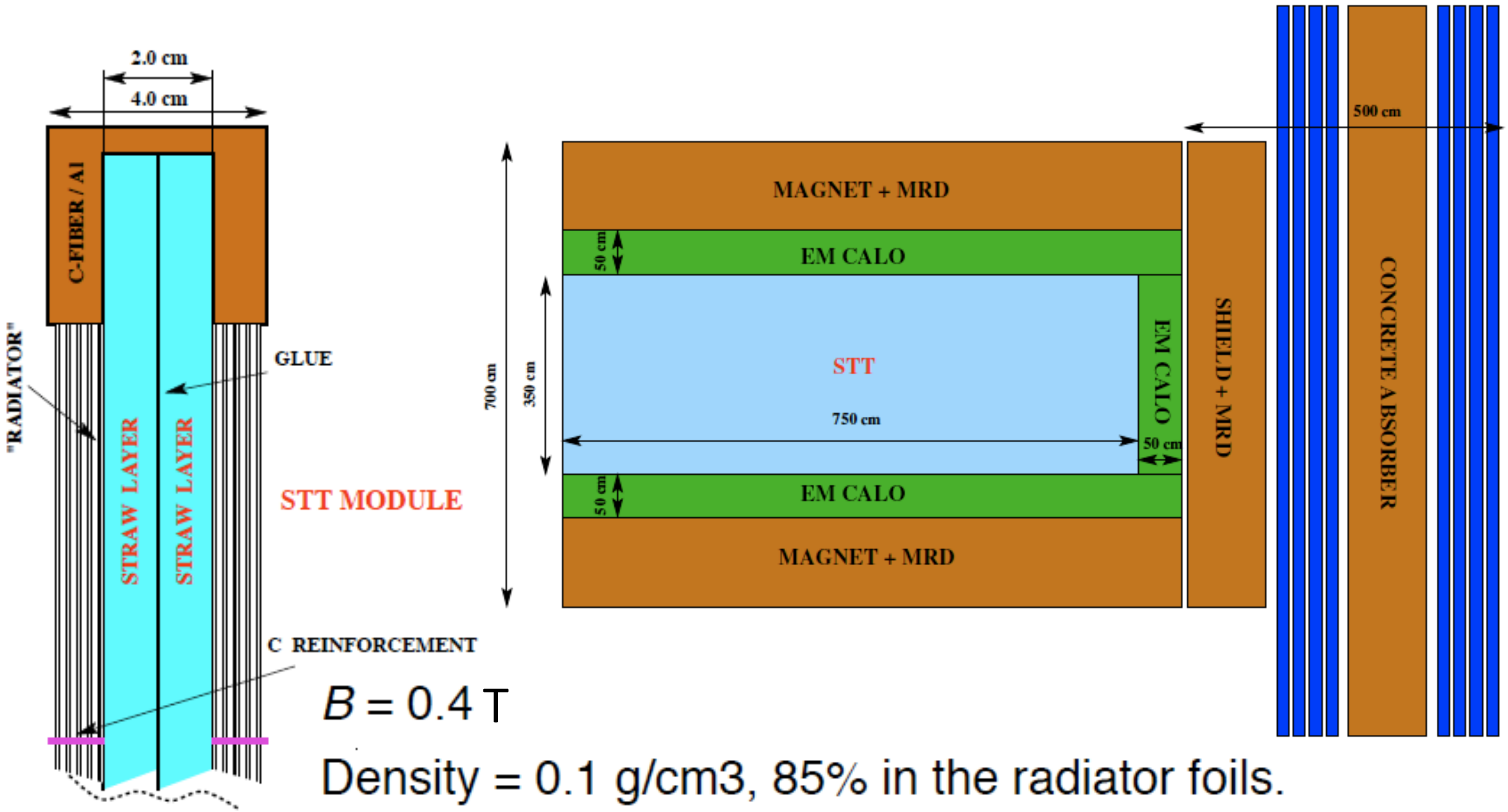
Due to these studies, the design may improve and evolve from what is described in the DPR

The final design will be subject to a review called jointly by the LBNE-India and LBNE-USA Project Managers, to evaluate the detector conceptual design in light of the DAE mandates, LBNE Scientific goals, technical feasibility, cost and schedule

We stress that a ND would be very important for enhancing precision and reducing errors and uncertainties for the ambitious planned FD oscillation physics program. In addition it adds a substantial number of other physics-rich projects.

The remainder of this talk will focus on describing salient features of the proposed ND in the DPR, and how it will meet both the physics goals and DAE mandate

LBNE-ND (HIRESMNU)........................ Schematic



$B = 0.4$ T

Density = 0.1 g/cm3, 85% in the radiator foils.

Transition Radiation ⤜ Electron ID ⇒ γ (w. Kinematics)

dE/dx ⤜ Proton, π, K ID

Magnet/Muon Detector ⤜ μ

Photons and other charged particle energies measured in ECAL

HIRESMNU design comprises 4 sub-detectors.

✴**Straw Tube Tracker** (inside the B-Field)
☙Based on ATLAS, COMPASS, and the NOMAD-TRD designs ☙A critical part ⇒ with Transition Radiation (TR) Capability

✴**ECalorimeter** (inside the B-Field): ☙Based on T2K ECAL
☙Downstream , Barrel (Up/Dw, Left/Right), & Upstream (UP)

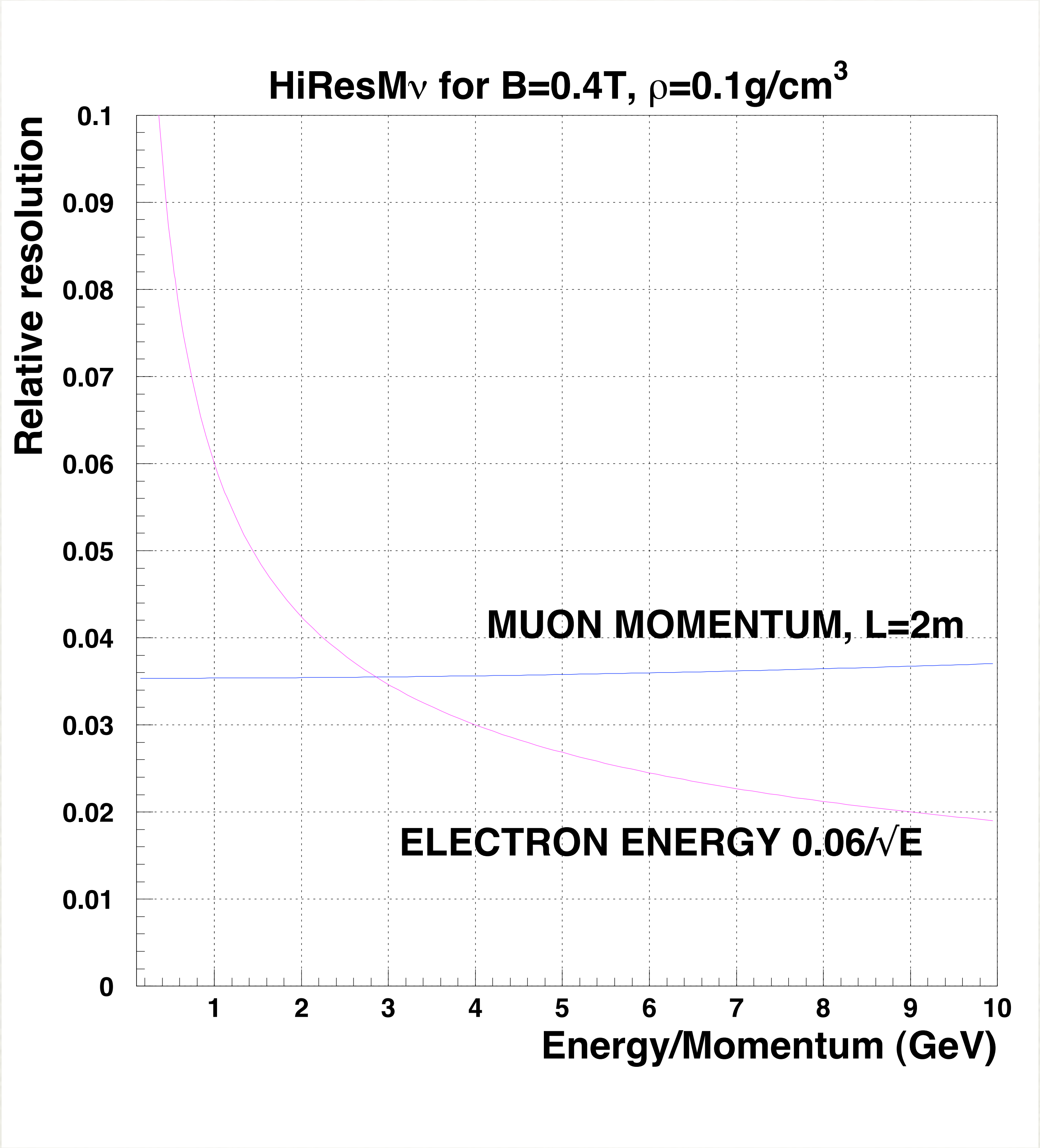
✴**Muon Detector:**
☙RPC's and Absorbers ☙Instrumenting the dipole & two muon stations, outside the magnet, at the downstream end

✴**Dipole Magnet:** ☙Based on UA1 (& LHCb) designs (but no beam-tube)
☙Design linked to the STT and ECal

LBNE-ND...............A precision detector

Resolutions in HiResMν:

- $\rho \simeq$ 0.1gm/cm^3
- Space point position ≃ 200μ
- Time resolution ≃ 1ns
- CC-Events Vertex: Δ(X,Y,Z) ≃ O(100μ)
- Energy in Downstream-ECAL ≃ 6%/√E
- μ-Angle resolution (~5 GeV) ≃ O(1 mrad)
- μ-Energy resolution (~3 GeV) ~ 3.5%
- e-Energy resolution (~3 GeV) ~ 3.5%



ND PHYSICS GOALS

- *Determination of the relative abundance, the energy spectrum, and the detailed topology (complete hadronic multiplicity) of the four neutrino species in NuMI:* ν_μ, $\bar{\nu}_\mu$, $\boxed{\nu_e}$, *and* $\boxed{\bar{\nu}_e}$ *CC-interactions.* ⇐Absolute ν-Flux & Eν-scale; Cross-Sections

- *An 'Event-Generator Measurement' for the LBL*ν *experiments including single and coherent* π^0 (π^+) *production,* $\pi^\pm/K^\pm/p$ *for the* ν_e*-appearance experiment, and a quantitative determination of the neutrino-energy scale.* ⇐Backgrounds to Oscillation

- *Measurement of the weak-mixing angle,* $\sin^2\theta_W$, *with a precision of about 0.2%, using independent measurements:*
  - $\nu(\bar{\nu})$*-q (DIS);*
  - $\nu(\bar{\nu})$*-*e^- *(NC).*

  ⇐Example of Precision Measurement

  Direct probe of the running of $\sin^2\theta_W$ *within a single experiment.*

- *Precise determination of the exclusive processes such as* ν *quasi-elastic, resonance,* $K^0/\Lambda/D$ *production, and of the nucleon structure functions.*

- *Search for weakly interacting massive particles with electronic, muonic, and hadronic decay modes with unprecedented sensitivity.*

Credit:Sanjib Mishra

LBNE-ND will bring precision detection capability to an important energy range.

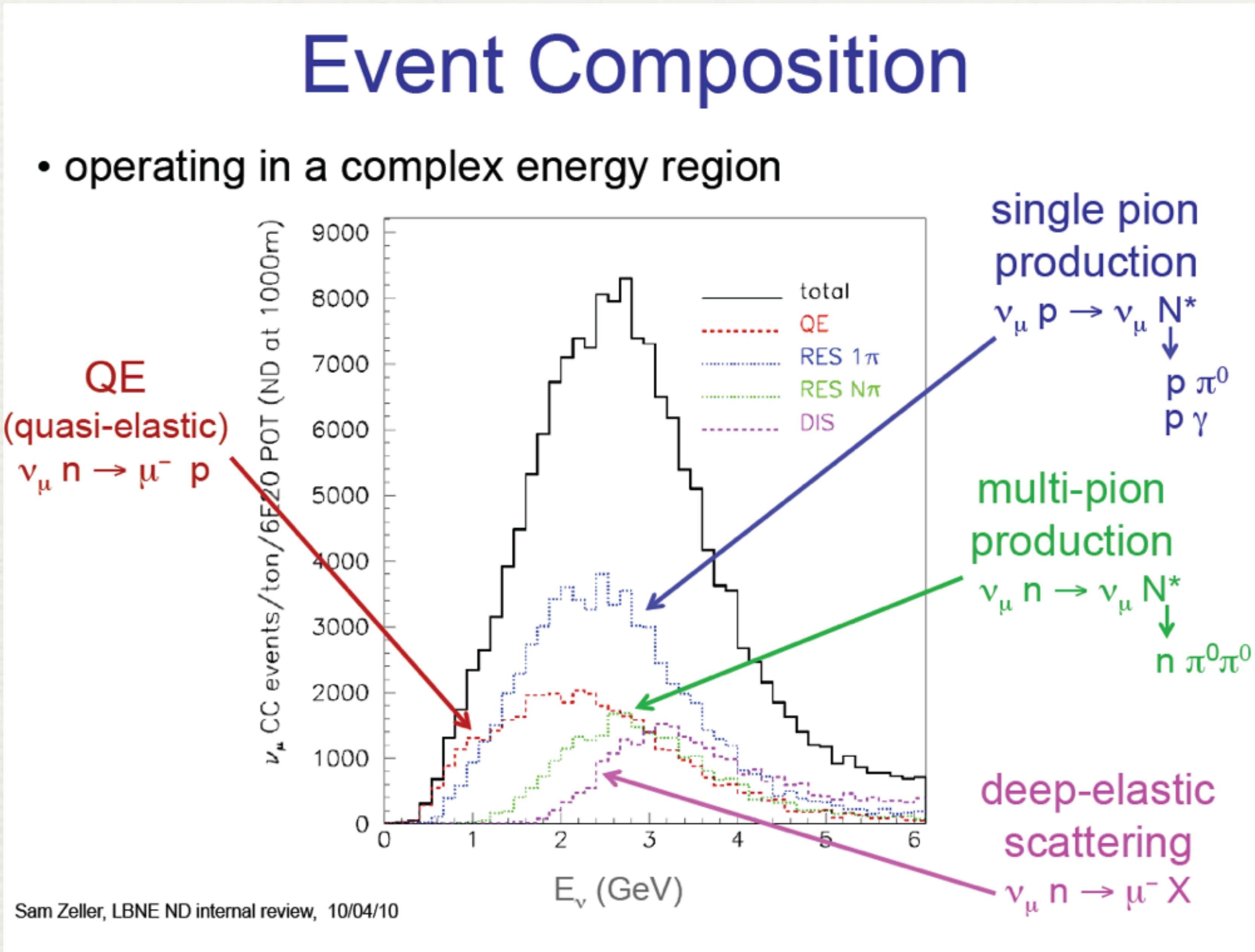
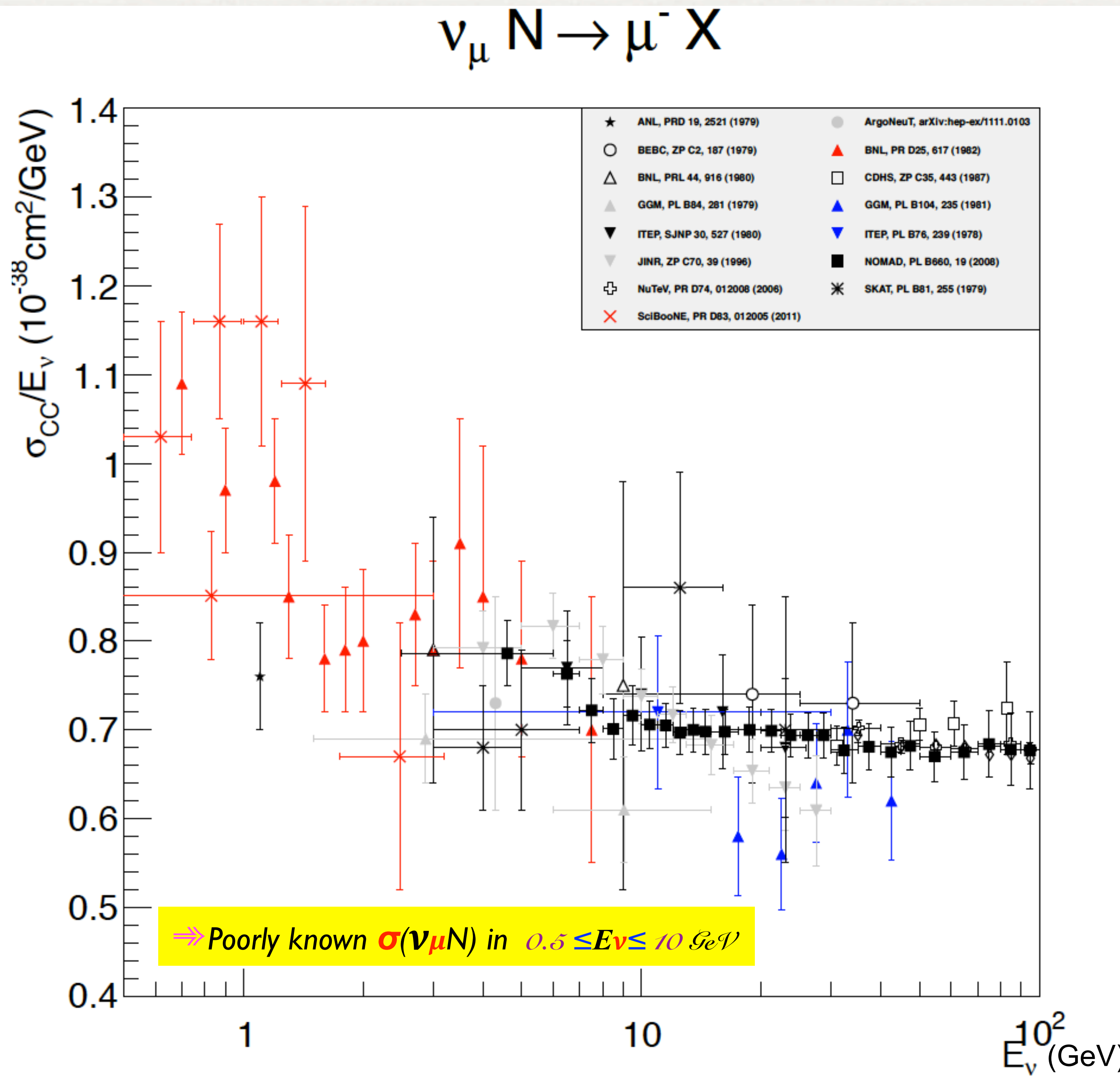
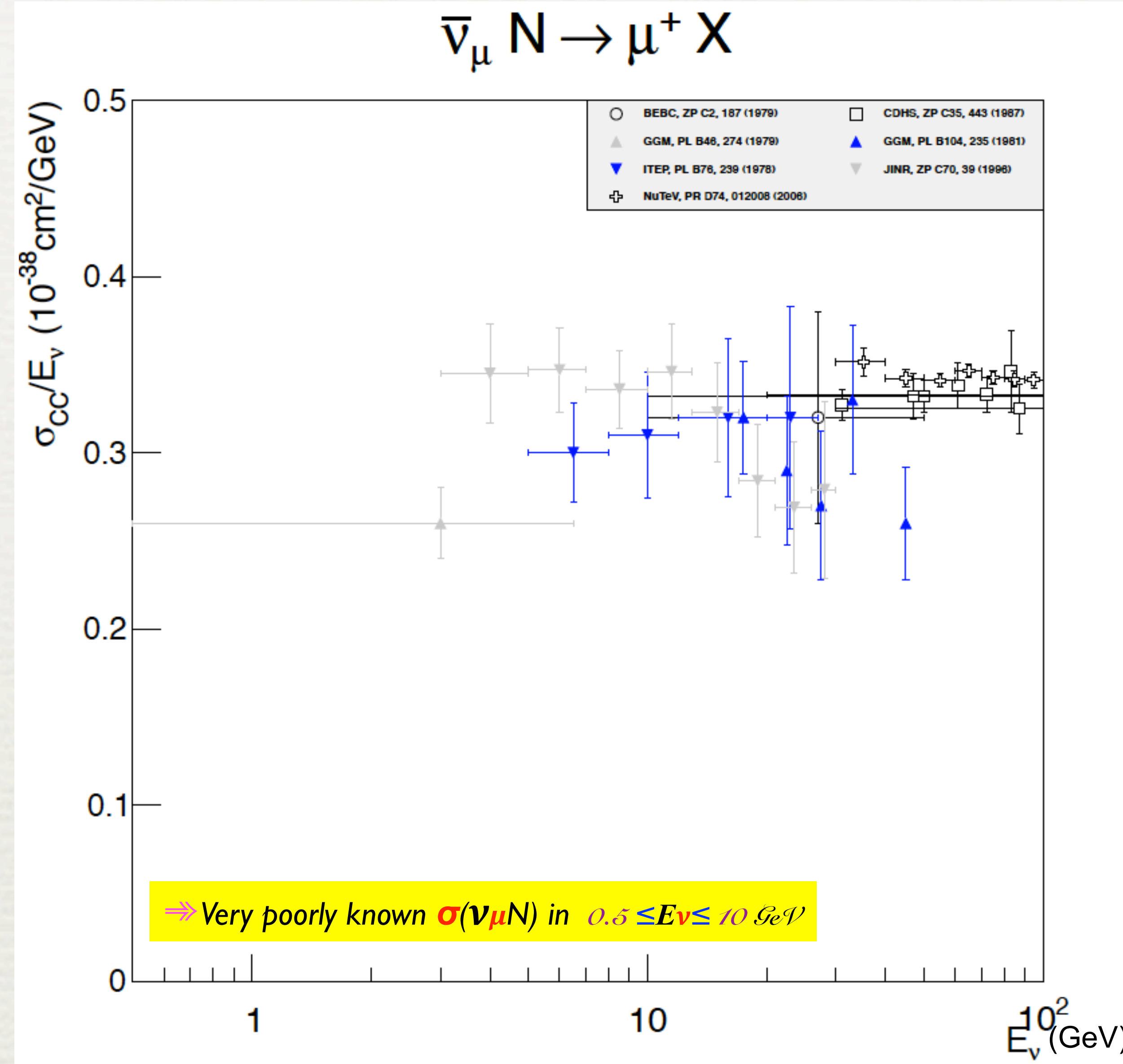


Figure 3–10: Composition of ν_μ-CC, $\mu^- X$, at a Near Location: QE, Single-pion resonance, multi-pion resonance, Coherent-pion, and DIS channels compose the inclusive ν_μ-CC in LBNE. Credit: G. Zeller, FNAL

Nu, Anti-Nu Cross-section poorly known at low energies





QE Cross-section anomaly

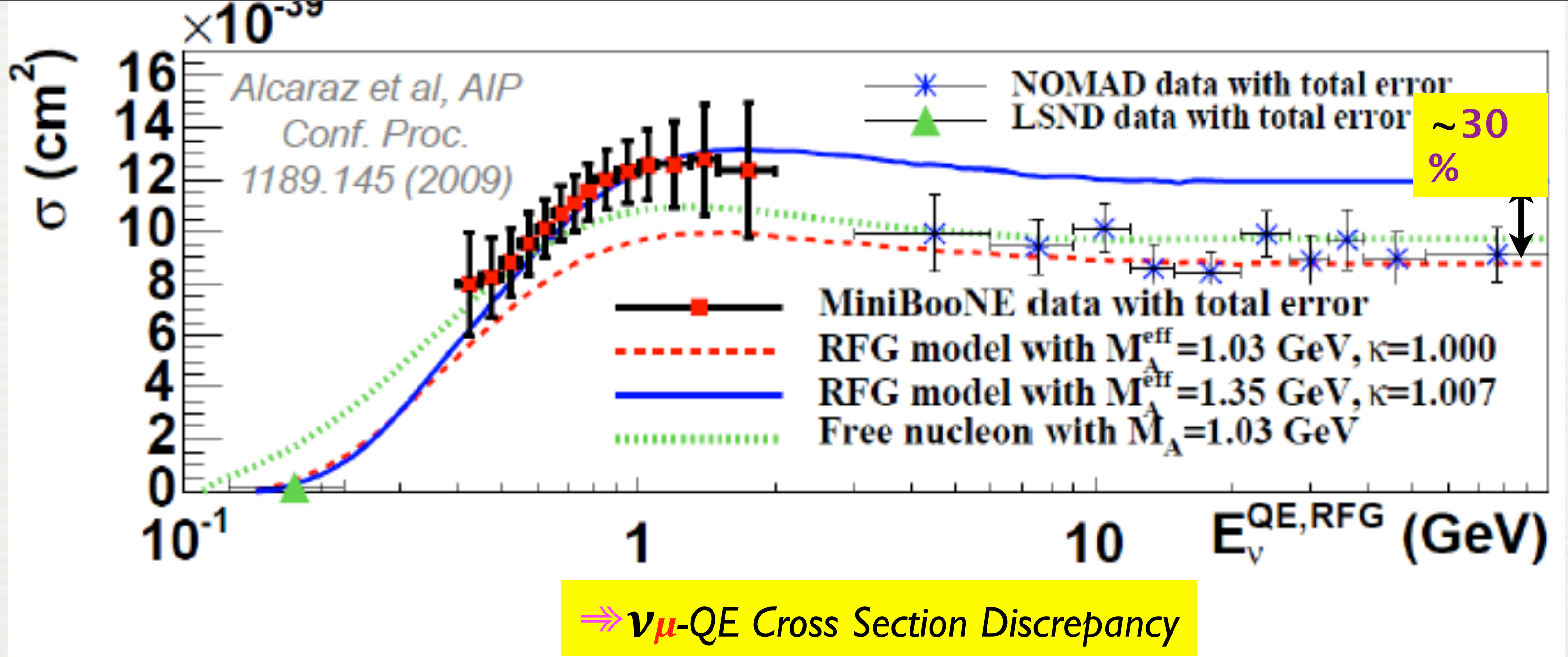


Figure 3–13: Neutrino quasi elastic cross section by NOMAD and MiniBOONE experiments

Table 3–2: Expected Events in a 5-Year ν-Run: Events in the fiducial volume for various interactions are shown.

Interaction	Events	Cuts
Inclusive ν_μ-CC	38.2×10^6	FV
ν_μ-QE	8.1×10^6	FV
ν_μ-Res	11.0×10^6	FV
ν_μ Coherent-π^+	0.63×10^6	FV
Inclusive ν_μ-NC	4.1×10^6	FV & $E_{Had} \geq 3$ GeV
Coherent-π^0	0.32×10^6	FV
IMD	1944	FV ($E_\nu \geq 11$ GeV)
ν_μ-e NC	4700	FV
Contaminant CC's		
ν_e-CC	4.2×10^5	FV
$\bar{\nu}_e$-CC	4.2×10^4	FV
$\bar{\nu}_\mu$-CC	2.5×10^6	FV

Significant event rates and low S/B ratio

LBNE-ND and the DAE mandate............

- *It will provide rich physics and is capable of producing **50-100** Ph.Ds from Indian Institutions;*

1: The energy scale and relative flux of the muon-neutrino in the beam

2: The Anti-NuMu to NuMu ratio as a function of neutrino energy in the beam

3: Abundance of NuE and Anti-NuE relative to NuMu (NuMuBar) as a function of energy

4: Empirical determination of the Pi+, Pi-, K+, and K- yields in p-C interaction using neutrino data: a check of the hadro-production experiment.

108: Search for anomaly mediated (anti)neutrino induced photons

109: Search for the magnetic moment of neutrinos

110: A test of NuMu–NuE universality down to 10–4

111: A test of NuMuBar–NuEbar universality down to 10–3 level 112: Search for right-handed current in CC interaction

LBNE-ND and the DAE mandate............

- *Strengthens India's scientific infrastructure;*
  - The entire effort, from design to prototype to fabrication of the ND subdetectors, will be done by the Indian institutions over the coming decade.
  - Physics and sensitivity studies will be concurrently done .
  - The subdetectors will be shipped to and assembled at Fermilab, and installed in the LBNE beamline.
  - The IIFC-νP will lead the data-taking and analysis tasks.
  - Participation in FD physics which uses the cutting edge liquid argon technology will enhance the cryogenic expertise in India which could be of immense potential use in future DAE-DST scientific research.

Such a composite endeavor will generate ≃100 Ph.Ds in particle, nuclear and engineering physics, and the hardware R&D and fabrication will greatly enhance India's infrastructure capability in these fields

LBNE-ND and the DAE mandate............

- *Constitutes a significant contribution to the Fermilab project with a DAE/DST ownership;*

- The LBNE detector is made up of LBNE-ND and LBNE-FD complexes.

- This proposal would enable India scientists and engineers (DAE-DST) to have a significant ownership of the LBNE-ND detector, while making significant (10%) contribution to the full LBNE Project.

LBNE-ND and the DAE mandate............

- *Shares synergy with the ongoing research programs in India, including the INO program.*
- Scintillator detectors for the muon and/calorimeter will be required
- Prof Brajesh Choudhary has extensive experience in the scintillator and fibre R&D and fabrication from the MINOS (– the largest solid scintillator detector in the world) and NOvA experiments. He has participated in building the MINOS FD and been the L3 fiber manager for NOvA.
- TIFR has made scintillator detectors for the D0 and CMS experiments. (Prof.Shashi Dugad)
- Panjab University built part of the HO for CMS. Collaborated with the industry. (Prof. J. B. Singh and Dr. Vipin Bhatnagar)
- Scintillator arrays built indigenously in Ooty. (Profs. Sunil Gupta, Shashi Duggad)

Thus initiation and extension of scintillator detector expertise will naturally follow and percolate

LBNE-ND and the DAE mandate............

- *Shares synergy with the ongoing research programs in India, including the INO program.*

- RPC Expertise and synergy with INO (For the Muon System)
- TIFR has produced glass-based RPCs for INO. The process has been industrialized.(Prof Naba Mondal)
- Panjab University is producing Bakelite based RPCs for the CMS muon system. (Prof. J. B. Singh and Dr. Vipin Bhatnagar)
- BARC is producing Bakelite based RPCs for the CMS muon system.(Dr. L. M. Pant)
- SINP is leading the R&D efforts in development of Bakelite based RPCs in India. (Prof. Sunanda Banerjee)
- DU plans to setup a R&D lab for the RPC as well. (Prof Brajesh Choudhary)
- BHU plans to setup a R&D lab for the RPC as well. (Prof V Singh)

LBNE-ND and the DAE mandate............

- *Shares synergy with the ongoing research programs in India, including the INO program.*

- **Magnet**

- Experience exists at SINP and BARC. (Prof Vivek Datar and Sanjay Malhotra). INO prototype has been build and tested at these places.
- The full scale magnet will be built by industry. Can lead to close synergy between the EHEP needs and industry.

This DPR reflects the vision and hard work of several people on both the US and the Indian side

(Brajesh Choudhary, Shekhar Mishra, Sanjib Mishra, Jim Strait,......)

We seek your help in making it a reality

We request timely approval of this proposal, which would enable us to prepare a Project Execution Plan by May 31st 2013 for approval by DAE-DST.

◆ *THANK YOU!* ◆