

HEP Program & Planning – Next Decade in India



Brajesh Choudhary
University of Delhi, Delhi, INDIA

DPF organized COMMUNITY PLANNING MEETING (CPM2012)
For Community Summer Study (CSS2013) of APS
Fermi National Accelerator Laboratory, Batavia, IL, USA
11 – 13 October, 2012

Supported by DST and DAE, Govt. of India

India is participating in the following areas of mega science:

Experimental High Energy & Nuclear Physics

Astrophysics & Astronomy

Material Research and Intense Light Sources

The mega projects in India are supported by:

Department of Atomic Energy (DAE)

Department of Science & Technology (DST)

Department of Space (DOS)

➤ Energy Frontier/Collider/Nuclear Physics

- ✓ Collaboration at CERN – LHC, CMS & ALICE, CLIC
- ✓ Collaboration at KEK - KEK-B
- ✓ Collaboration at GSI – FAIR – CBM & PANDA

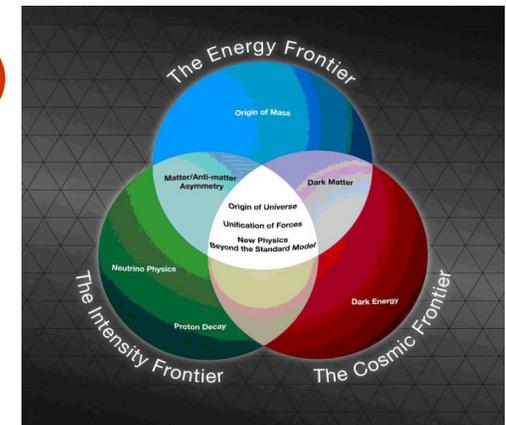
➤ Intensity Frontier

✓ India-based Neutrino Observatory (INO)

- ❖ ICAL at INO
- ❖ $0\nu\beta\beta$ Decay
- ❖ Search for the Dark Matter

✓ Collaboration at FERMILAB

- ❖ ProjectX
- ❖ Neutrino Program (MIPP, MINOS+, NOvA, LBNE)
- ❖ Material Science
- ❖ Detector R&D and Human Resource Development



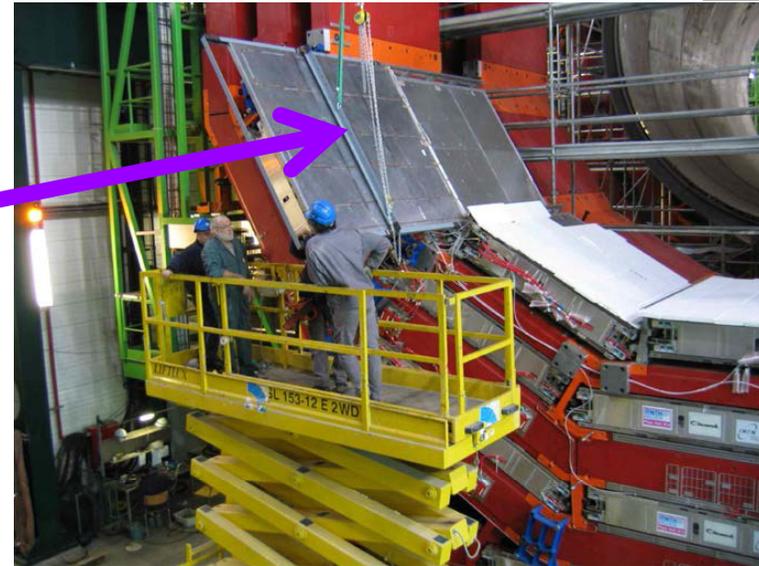
➤ Cosmic Frontier - γ -ray Astronomy

- GRAPES3, PACT, TACTIC, HAGAR, & MACE
Brajesh Choudhary, University of Delhi

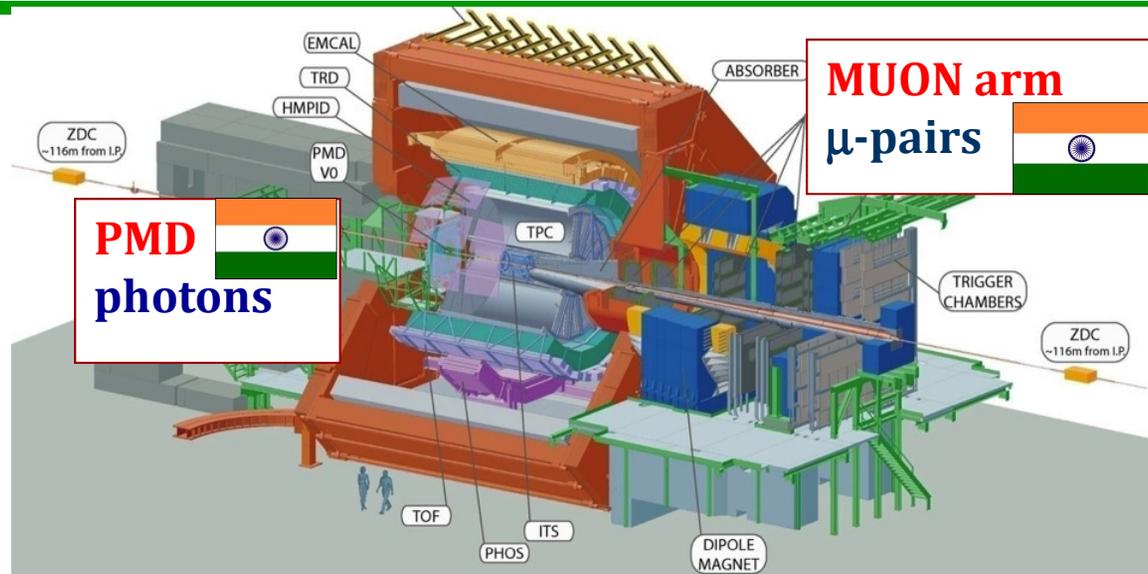
ENERGY
FRONTIER,
COLLIDER &
NUCLEAR PHYSICS

- ❖ **Participation in LHC machine, GRID, CMS & ALICE Experiments**
- ❖ **In-kind and man power related support for LHC machine & GRID related activities, ~60 MCHF (50% outright contribution, 50% in India-fund)**
- ❖ **WLCG activities in India: networking to CERN, domestic networking, Two Tier2 centres, ..., ~18 MCHF + ongoing**
- ❖ **Participation in CMS & ALICE experiments, hardware, M&O, ongoing and future upgrades**

- **Outer hadron (HO) Calorimeter – Scintillator tiles + Fibre – 450 sq. meters**
- **Silicon Pre-Shower Detectors – Si strip sensors fabricated & mounted on support – 1000 pieces**
- **Tier-2 Activities**
- **Physics Analysis**
 - **30+ Faculty/Scientist**
 - **30+ PhD students**



- ❖ *Involved in Muon RPC upslope. India will provide 50 RPCs and cooling accessories for 200 RPC.*
- ❖ *Long Shutdown I*
- ❖ *HO and HF Consolidation - SiPMs to replace HPDs*
- ❖ *Characterize front-end readout modules for SiPMs*
- ❖ *For HF – Replace Photo-detectors with thin-window PMTs.*
- ❖ *Long Shutdown II*
- ❖ *Indian groups in HCAL front-end and back-end electronics overhaul – for higher luminosity*
- ❖ *HCAL SiPM activities – in future with indigenous SiPM*
- ❖ *Indian groups interested in upgrade of Si tracker*
- ❖ *Large eta muon coverage – possibly with GEM detectors*



● at the core of the technology:

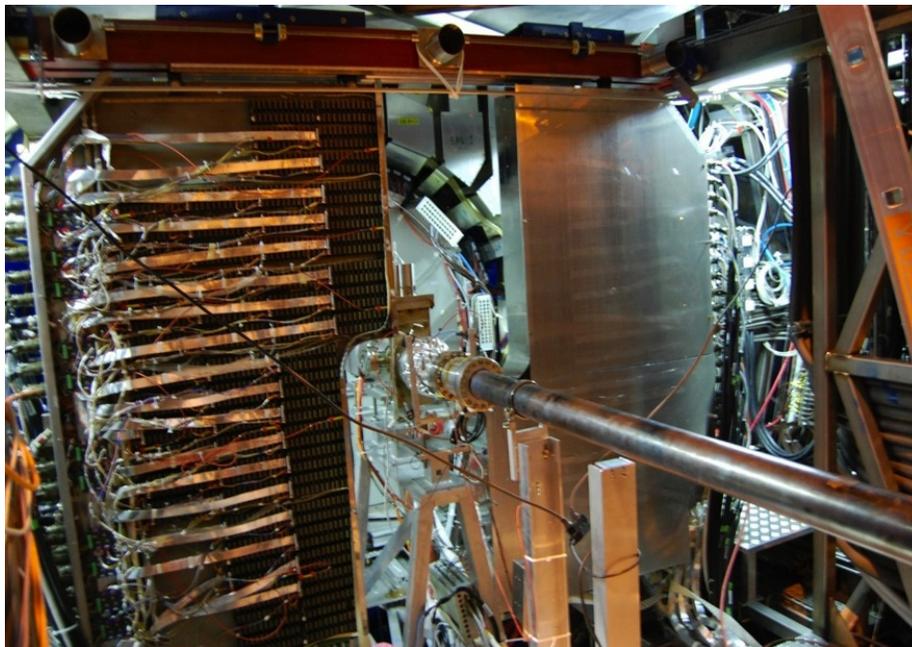
- ⇒ Front-end electronics VLSI full-custom design and manufacturing: the **MANAS** chip (for PMD and MS)
- ⇒ high tech PMD:
 - ★ 100% Indian Project
- ⇒ **Muon Spectrometer:**
- ⇒ worldwide collaboration, with India as major player
- > Station 2 construction
- > High Level Trigger Development
- ⇒ **ALICE Upgrades: Forward Calorimeter**

● at the core of the Physics:

- ⇒ **PMD:**
 - ★ on the track of flow
 - ★ chase surprises (DCC)
- ⇒ **Luminosity project (cross sections)**
- ⇒ **Muon Spectrometer:**
 - ★ solving the Quarkonia puzzle
- ◆ **Physics at small Bjorken-x**

***Fully Indian effort: from conception to commissioning
(Design, Fabrication, Installation, Detector Control and
Data Acquisition)***

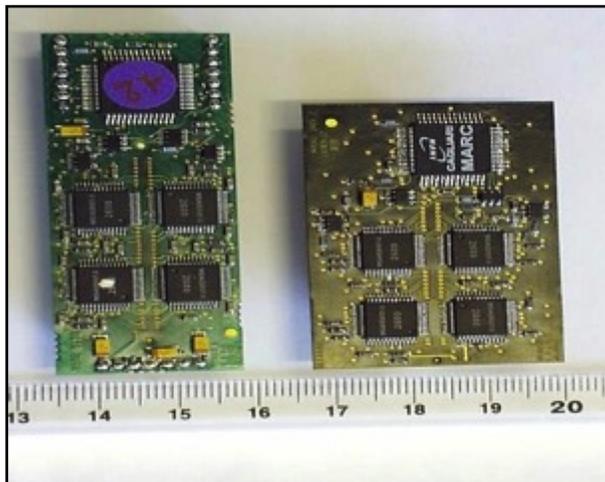
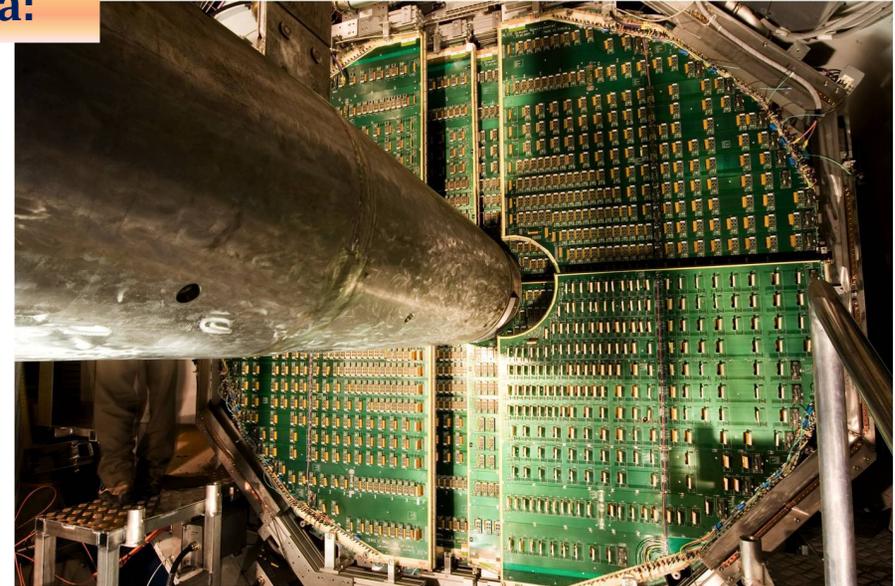
***Measurement of photon multiplicity and distribution of
photons in the forward region on an event-by-event
basis***



- Total no of honeycomb cells = 221184
- Cell depth = 0.5 cm
- Cell Cross section = 0.23 cm²
- 1 module = 4608 cells read
- 1 module read by 72 FEE boards
- 1 FEE board = 64 cells (4 MANAS Chips).
- Each MANAS reads 16 channels
- Sensitive medium : Gas (Ar+CO₂ in the ratio 70:30)
- Total no of Modules = 48

Collaboration France, India, Italy, Russia:

- 5 stations of two Cathode Pad Chambers $\sim 100 \text{ m}^2$
- 1.1×10^6 channels, occupancy $< 5\%$ (in Pb+Pb) \rightarrow Read out at 1 kHz
- Chamber thickness $\sim 3\% X_0$
- Beam test results for the spatial resolution : $50 \mu\text{m}$ for a required resolution $< 100 \mu\text{m}$



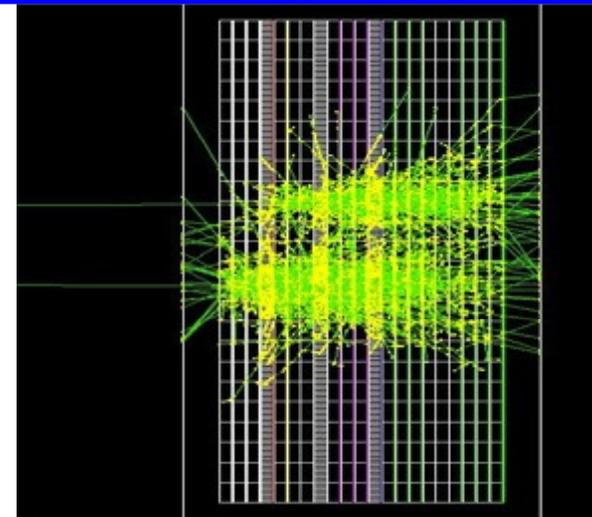
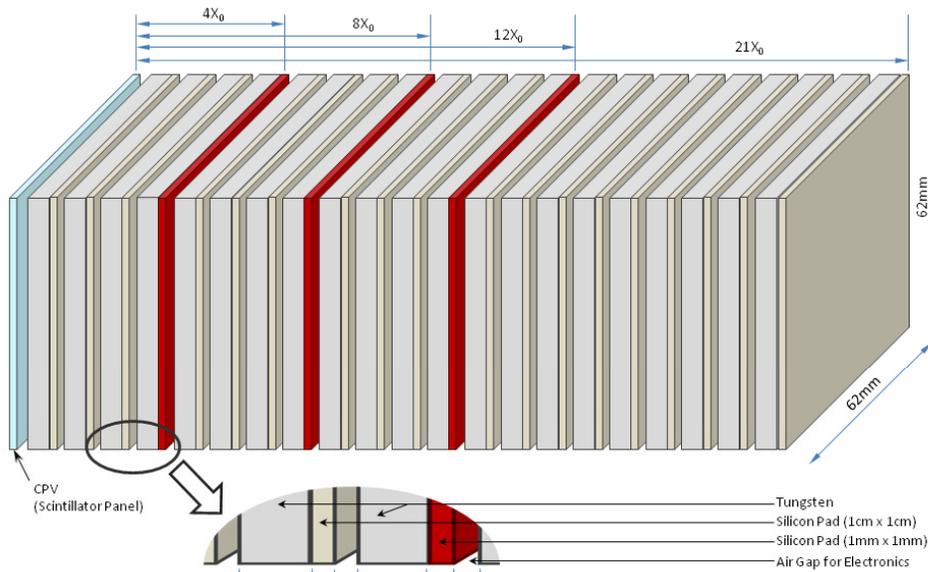
**MANAS electronics chip:
16-channel Amplifier,
shaper, track-and-hold**

**Reads 1.1 million pads of
tracking chambers of
ALICE**



Tungsten – Silicon Calorimetry

A new initiative using Silicon Detectors made in India



25 Layers (each 1m² area)

- **22 layers of 1cm x 1cm silicon pads**
- 500 K channels
- **3 layers of 1mmx1mm silicon pads -**
3M channels

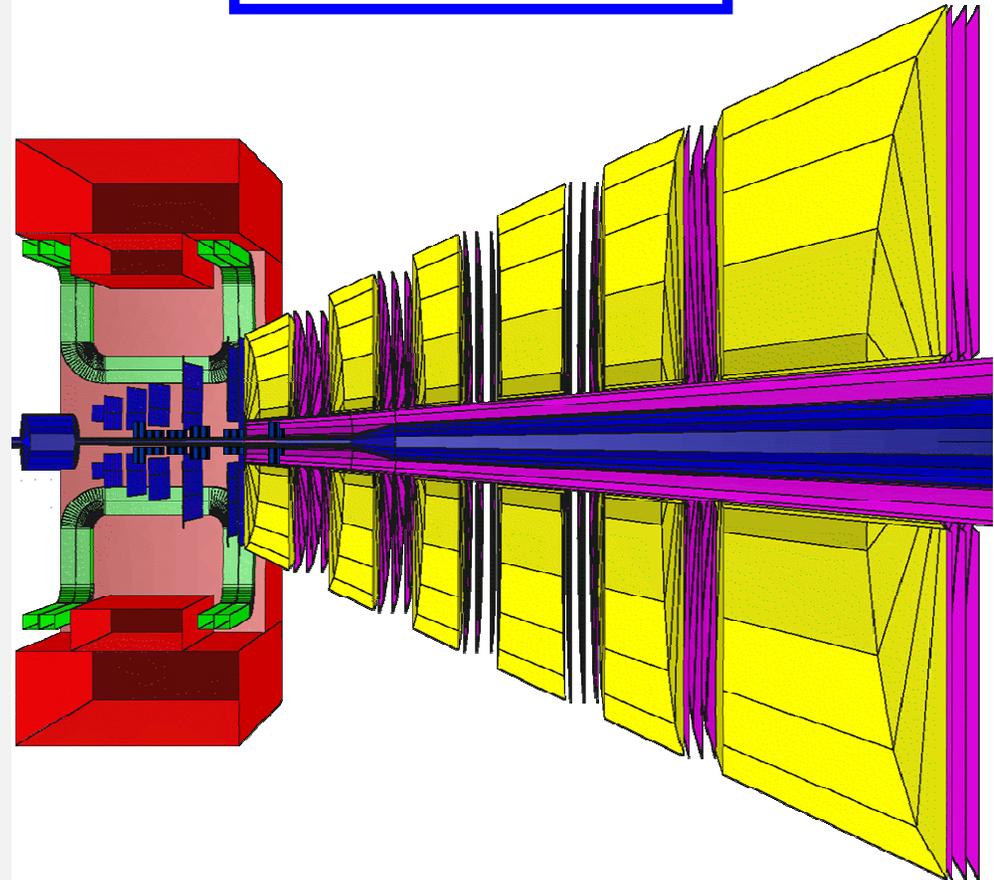
1. *Beam : 2017*
2. *Distance : 2.6 m*
3. *Chambers : high resolution gas detectors (entirely Indian effort)*

Challenges:

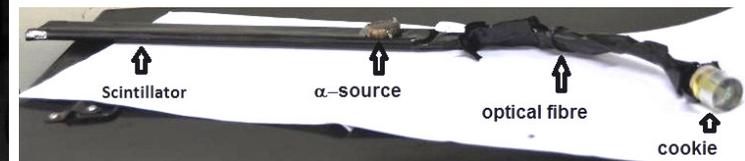
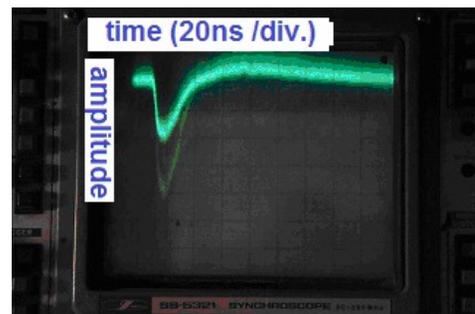
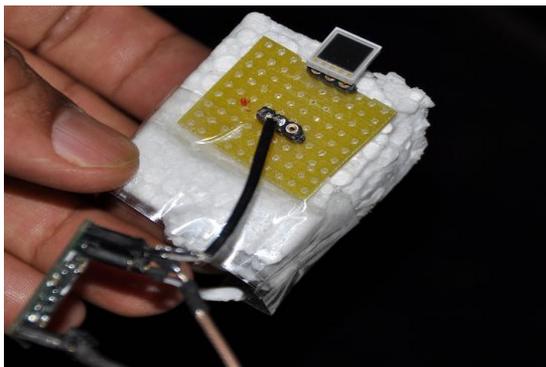
1. *High Rate : >10 MHz/cm²*
2. *High density : 1M channels*
3. *Large background : (1 J/Psi in 10⁵ events)*

Large size GEM-based gas detectors are most suitable candidates

MUON SETUP



- **Multi Institutional effort from India**
- **Deliverables:**
 - **Luminosity Monitor**
 - **Development of SiPM based Fast Scintillation Detector (Direct Ring Imaging Cherenkov Counter)**



SciTil/SiPM Activities at BARC

- **Participation in Construction of the LHC**
 - ✓ **Hardware contribution**
 - ✓ **Participation in Commissioning**
 - ✓ **Software Development**

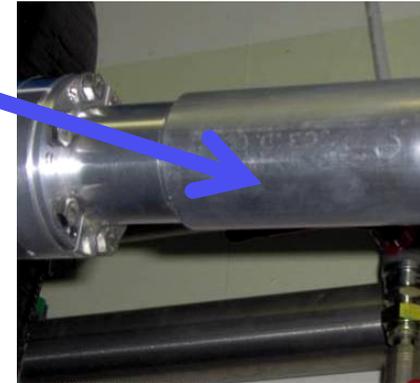
- **Beyond LHC: Novel Accelerator Technology**
 - ✓ **Compact Linear Collider (CLIC) – Begin with CTF3**
 - ✓ **Delivered - 2 Long & 3 Short Dipoles for TL2**
 - ✓ **Delivered – 31 cylindrical, 22 race track & 3 cylindrical bent vacuum chambers**
 - ✓ **Optics design studies for TL2**
 - ✓ **Control system commissioning for CTF3**
 - ✓ **Superconducting Proton LINAC (SPL) Front End – LINAC4 – for LHC luminosity upgrade**

- **Future Participation – Discussion in Progress**



Race Track Profile Vacuum Chambers Installed

Circular Profile Vacuum Chambers installed



End part of TL2 entering TL2' in CLEX area at CERN CTF3 Site

NEUTRINOS

INDIA-BASED

NEUTRINO

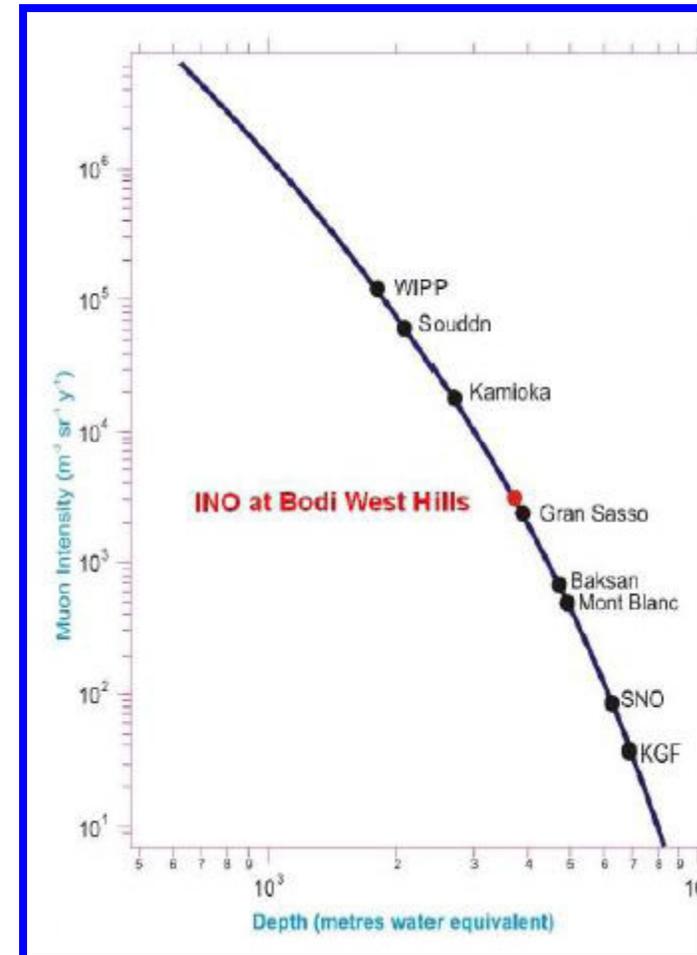
ONSERVATORY

Salient Features

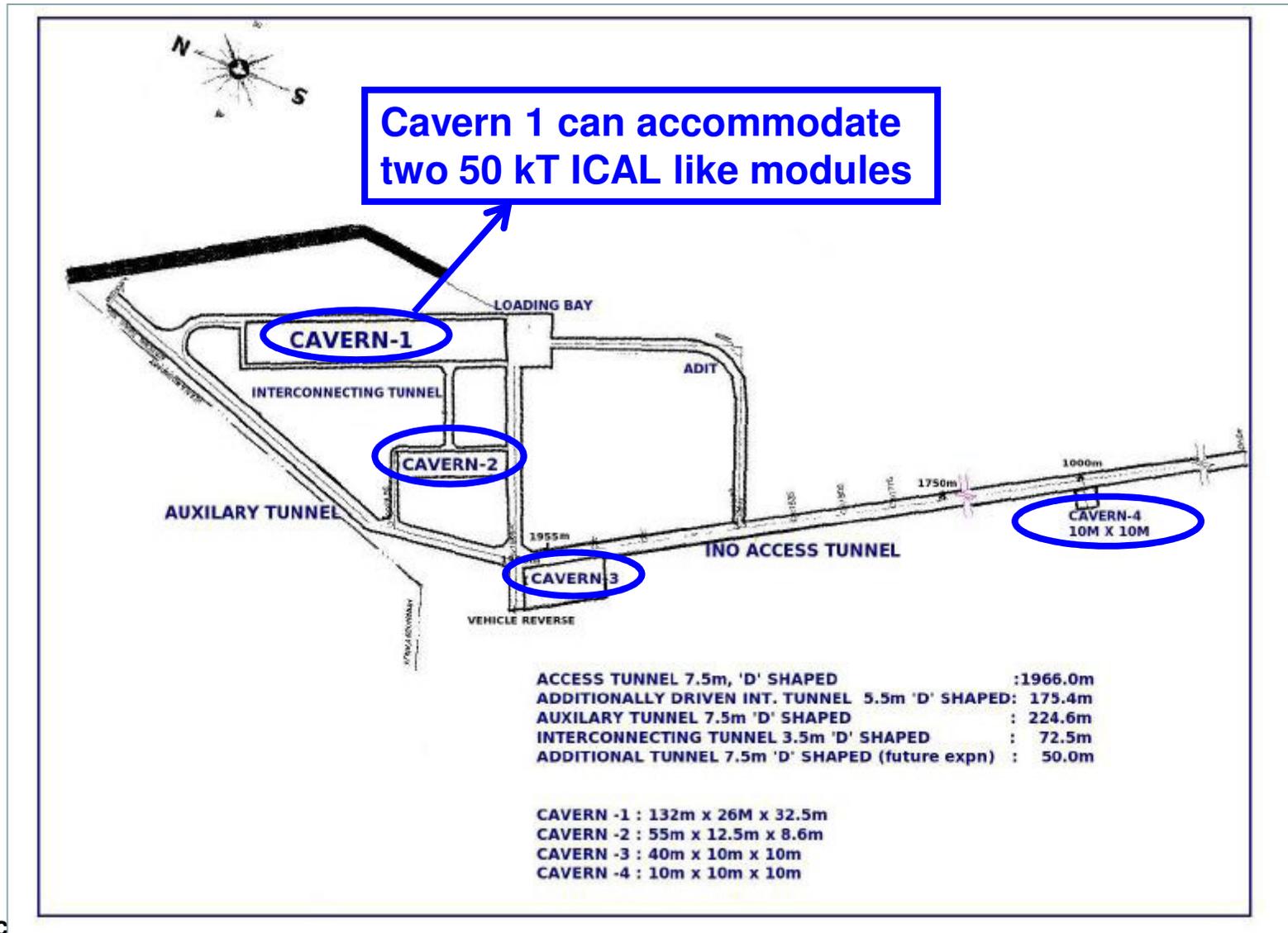
- ✓ **Underground laboratory in South India ($9^{\circ} 58' N, 77^{\circ} 16' E$)**
- ✓ **With ~ 1 km - rock cover - through a 2 km long tunnel.**
- ✓ **One large and several smaller caverns**
- ✓ **A national underground laboratory**
- ✓ **Important neutrino issues, especially – mass parameters and other properties, will be explored in a manner complementary to on-going efforts in different parts of the world.**
- ✓ **Once operational, in addition to ICAL, will support several other experiments, such as $0\nu\beta\beta$ decay and DM search experiments.**
- ✓ **INO facility - available to “International Community” for setting up experiments. You are MOST स्वागतम WELCOME**

- ***Project approved by the Indian funding agencies. Environment & forest clearance obtained. 26 hectares of land acquired at the detector site. Construction of lab & surface facility to begin.***
- ***Construction of a 50kT magnetized Iron Calorimeter (ICAL) detector to study properties of neutrinos.***
- ***Development of INO center (a Detector R&D center) at Madurai (~100Km from INO).***
- ***Human resource development (INO graduate training program).***
- ***Detector R & D almost complete.***

- All major components to be located underground. Flat terrain with good access from major roads.
- Rock quality is good. Cavern set in massive charnockite under the 1589 m peak. Vertical cover ~1289 meters. Tunnel length 1.97 km to reach the laboratory caverns from portal.
- Portal set outside the reserve forest boundary, hence no disturbance to forest . Tunnel and cavern under forest on the surface. Surface facilities not on forest land so no clearing of forest.
- Warm, low rainfall area and low humidity throughout the year. Unusual wind speeds during certain seasons.



Layout of the Underground Laboratory



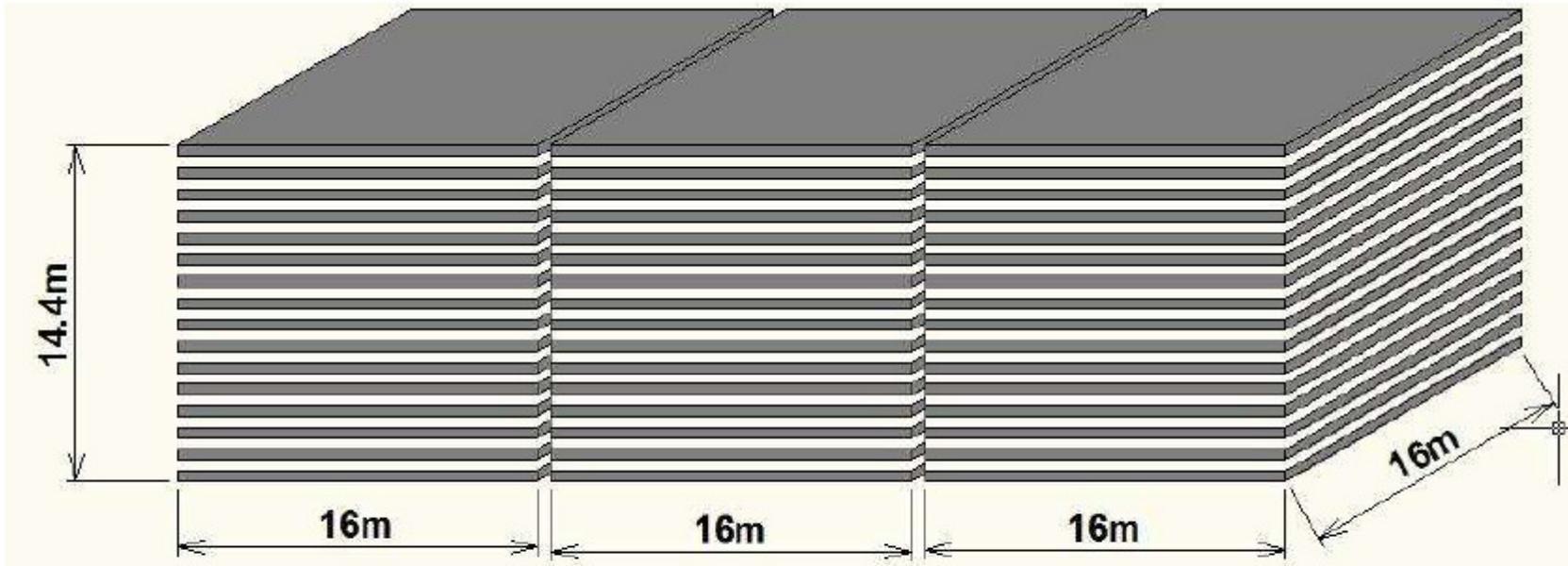
A 50 kT magnetized Fe-RPC detector with charge identification

Physics Goals:

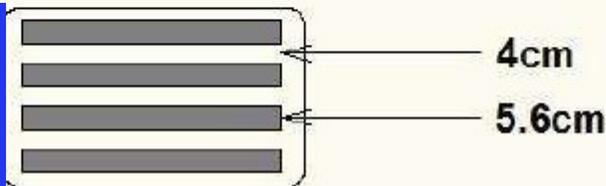
- ✓ **Measure atmospheric neutrino parameters from distortion in L/E**
- ✓ **Determine the sign of $|\Delta m^2_{31}|$ using matter effect**
- ✓ **Measure the deviation of θ_{23} from 45° and its octant**
- ✓ **Other Physics:**
 - **Probe CP and CPT violation**
 - **Constrain long range leptonic forces**
 - **Study ultra high energy neutrinos and muons**

INO-ICAL DETECTOR

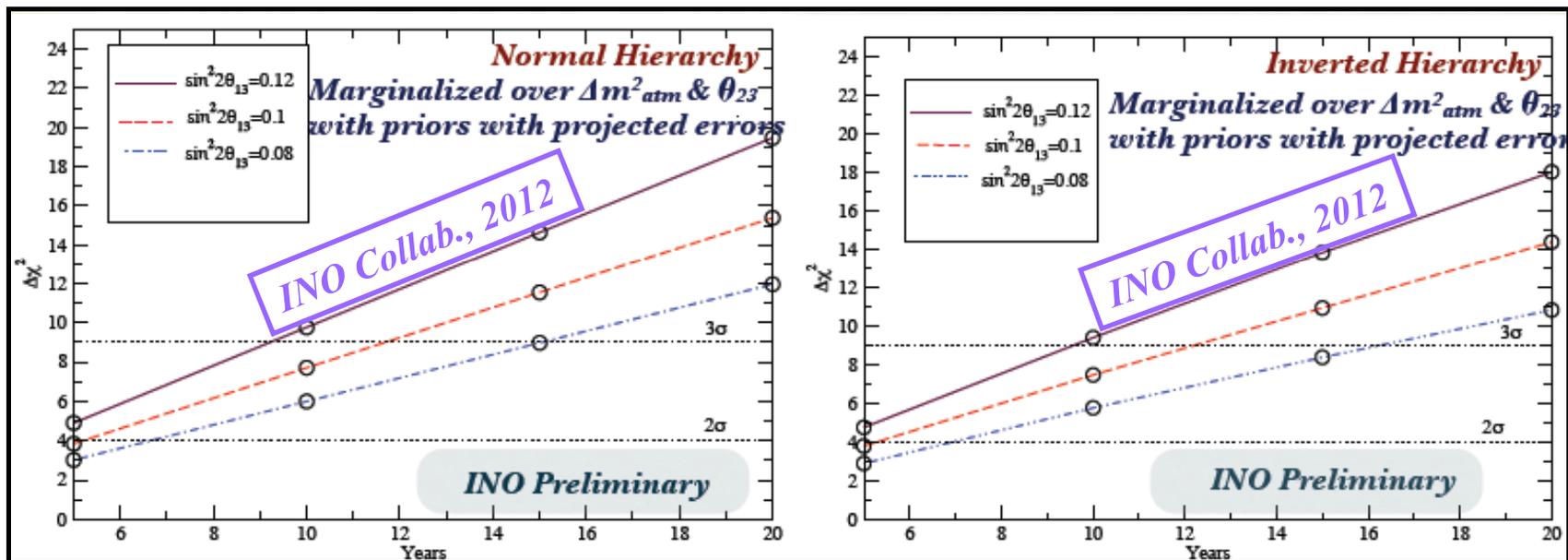
Number of Institutions ~ 26 + 1



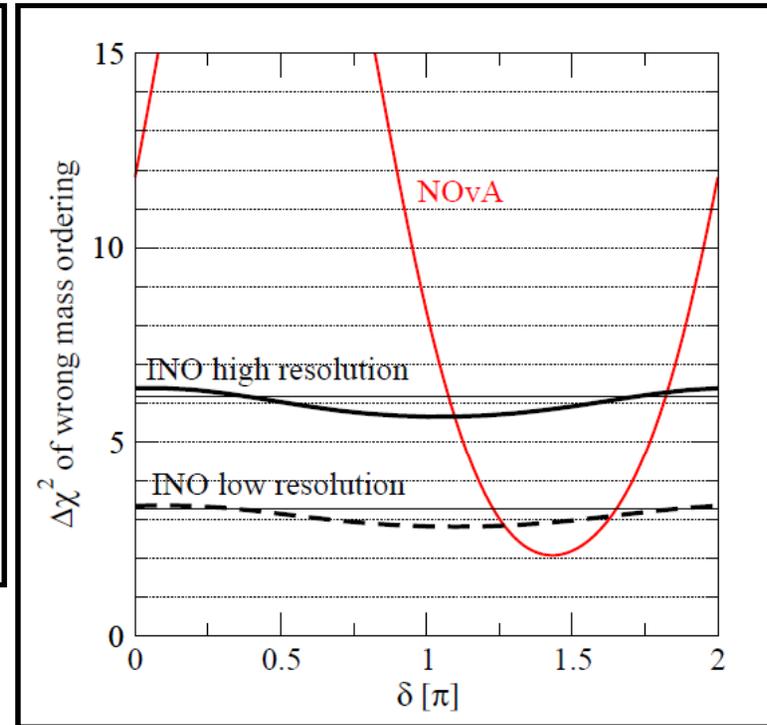
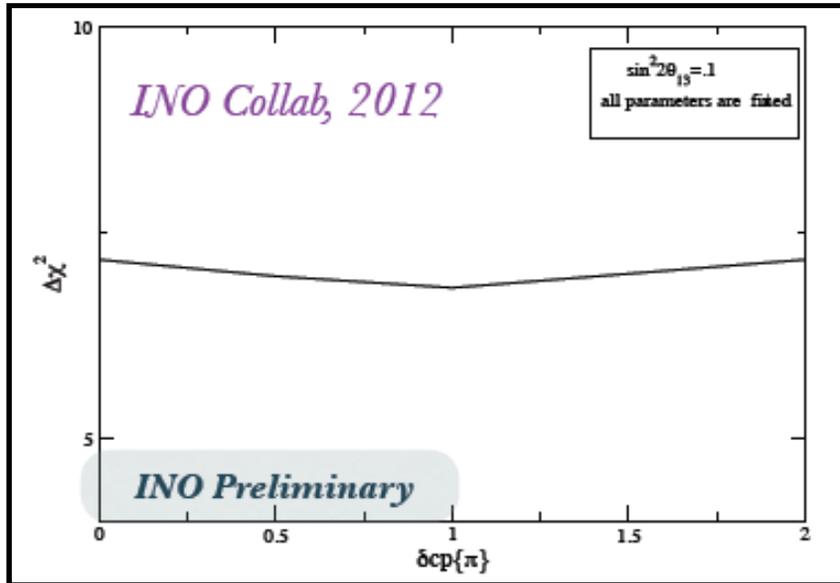
- ✓ # of layers = 140
- ✓ Fe thickness = 5.6 cm
- ✓ Magnetic Field ~ 1.3T
- ✓ # of RPCs ~ 27K
- ✓ # of channels ~ 3.6M



Events generated using Nuance & ICAL resolution in E and $\cos\theta_{zenith}$



$\sim 2.0\sigma$ sensitivity for $\sin^2\theta_{23} = 0.5$, $\sin^2 2\theta_{13} = 0.1$ in 5 yrs
 $\sim 2.7\sigma$ sensitivity for $\sin^2\theta_{23} = 0.5$, $\sin^2 2\theta_{13} = 0.1$ in 10 yrs



arXiv:1203.3388v1 - Blennow, Schwetz

*Data generated at $\delta_{CP} = 0$ and fitted at non-zero δ_{CP}
INO will give MH sensitivity almost independent of δ_{CP}*

Proposal for an Experiment in INO cavern

⇒ ^{124}Sn Bolometer

⇒ $^{124}\text{Sn} \Rightarrow Q = 2.28 \text{ MeV}$ (5.8% abundance)

⇒ High Q-value ⇒ decay rate $\propto Q^5$ ($0\nu\beta\beta$)

⇒ Z = 50 Close Shell

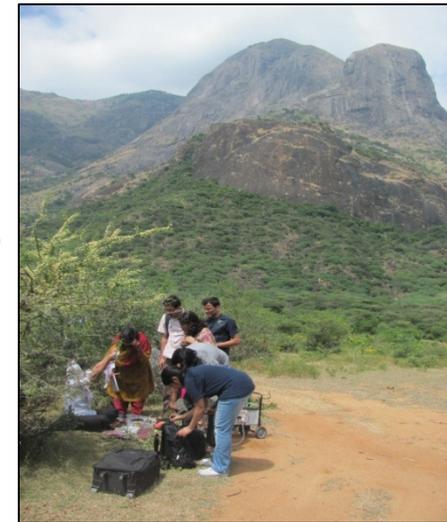
⇒ Sn ⇒ $T_C \sim 3.7^0 \text{ K}$

⇒ Simple Metallurgy

⇒ Electronic specific heat falls off exponentially below T_C

⇒ ^{124}Sn : $T_{1/2} > (0.8 - 1.2) \times 10^{21} \text{ yrs.}$

Nucl. Phys. A 807, 269(2008)



A Multi Institutional Effort

THE INDIA'S TIN DETECTOR



<http://www.tifr.res.in/~tin.tin/>

- ✓ *Make a Natural Sn Bolometric Device ~ 1.0 Kg*
- ✓ *Detector & Background Simulation*
- ✓ *Develop Sensors*
- ✓ *Reliable NTME Calculations*
- ✓ *Precision Q Value Measurement*
- ✓ *Enrichment of ^{124}Sn*
- ✓ *Constraining NTME, GT matrix element measurement in NDBD Nuclei*

FUTURE

Build a Large Scale Detector (~1 Ton) at INO Lab
With 90% enrichment, bkg ~ 0.01 counts/keV.kg.yr
 $m\nu \sim 50 - 100 \text{ meV}$ in 1yr

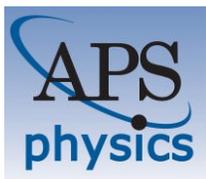
***SINP – Member of the PICASSO Collaboration at SNO Lab
– Detector R&D, Fabrication, Simulation & Physics***

Indigenous DM Effort - DARK MATTER @ INO – DINO

SINP + Texas A&M + TIFR + BARC + VECC + PRL + IITB +...

- ***Si/Ge based Cryogenic Experiment***
- ***Search for WIMP candidate for DM –***
- ***Focus on low mass < 20 GeV WIMPs.***
- ✓ ***Phase 1 – Mini-DINO, ~ 30-50 Kg. Cost \$6M.***
 - ✓ ***At UCIL mine in Jaduguda. Depth ~ 550m.***
 - ✓ ***Fully operational by 2014. First result by ~2015.***
- ✓ ***Phase 2 – DINO. 100Kg scale.***
- ✓ ***Phase 3 – DINO. Scale it to ~1 Ton (~1000 Kg). \$50M.***
- ✓ ***Expect to be operational by ~2018 in INO cavern.***

INTENSITY
FRONTIER
COLLABORATIONS
AT
FERMILAB



DAE-INDIA & DOE-USA IMPLEMENTING AGREEMENT



IMPLEMENTING AGREEMENT

BETWEEN

THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF AMERICA

AND

THE DEPARTMENT OF ATOMIC ENERGY

OF THE REPUBLIC OF INDIA

FOR COOPERATION

IN THE AREA OF ACCELERATOR AND PARTICLE DETECTOR

AND DEVELOPMENT FOR DISCOVERY SCIENCE



Handwritten text: *New Delhi*
DONE at _____, in duplicate, this 19th day of July, 2011, in the English and Hindi languages, each text being equally authentic.

Signature: *Brikumar Banerjee*
FOR THE DEPARTMENT OF ENERGY OF THE REPUBLIC OF INDIA:

Signature: _____
FOR THE DEPARTMENT OF ENERGY OF THE UNITED STATES OF AMERICA:

Discovery Science: The United States' Department of Energy and India's Department of Atomic Energy signed an Implementing Agreement on Discovery Science that provides the framework for India's participation in the next generation particle accelerator facility at Fermilab.

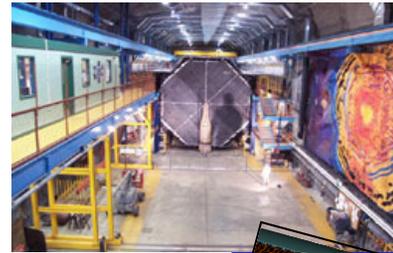
<http://www.state.gov/r/pa/prs/2011/07/168740.htm>

- ❖ **Collaboration on ProjectX**
- ❖ **Physics Working Groups Exists For:**
 - ✓ ***Neutrino Physics***
 - ✓ ***Rare Processes***
 - ✓ ***Nuclear Physics***
 - ✓ ***Nuclear Energy***
 - ✓ ***Detector and Electronics Development***
 - ✓ ***Particle Production & Hyper-Nuclei Expt.***

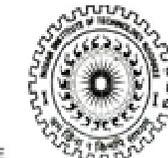
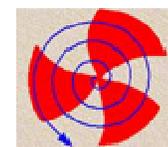
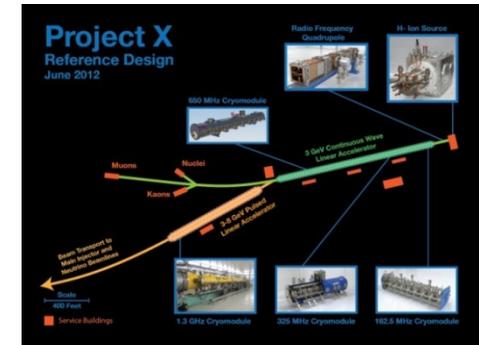
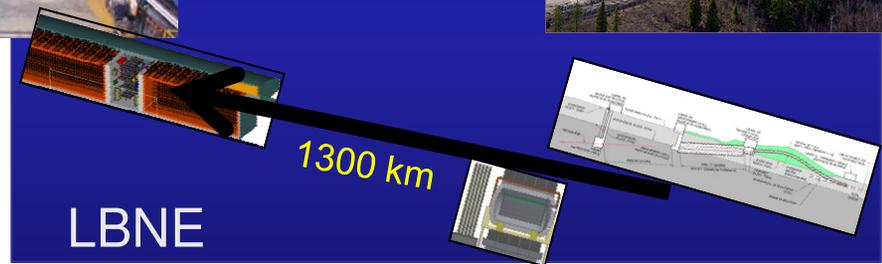
INDIAN INSTITUTIONS AT FERMILAB



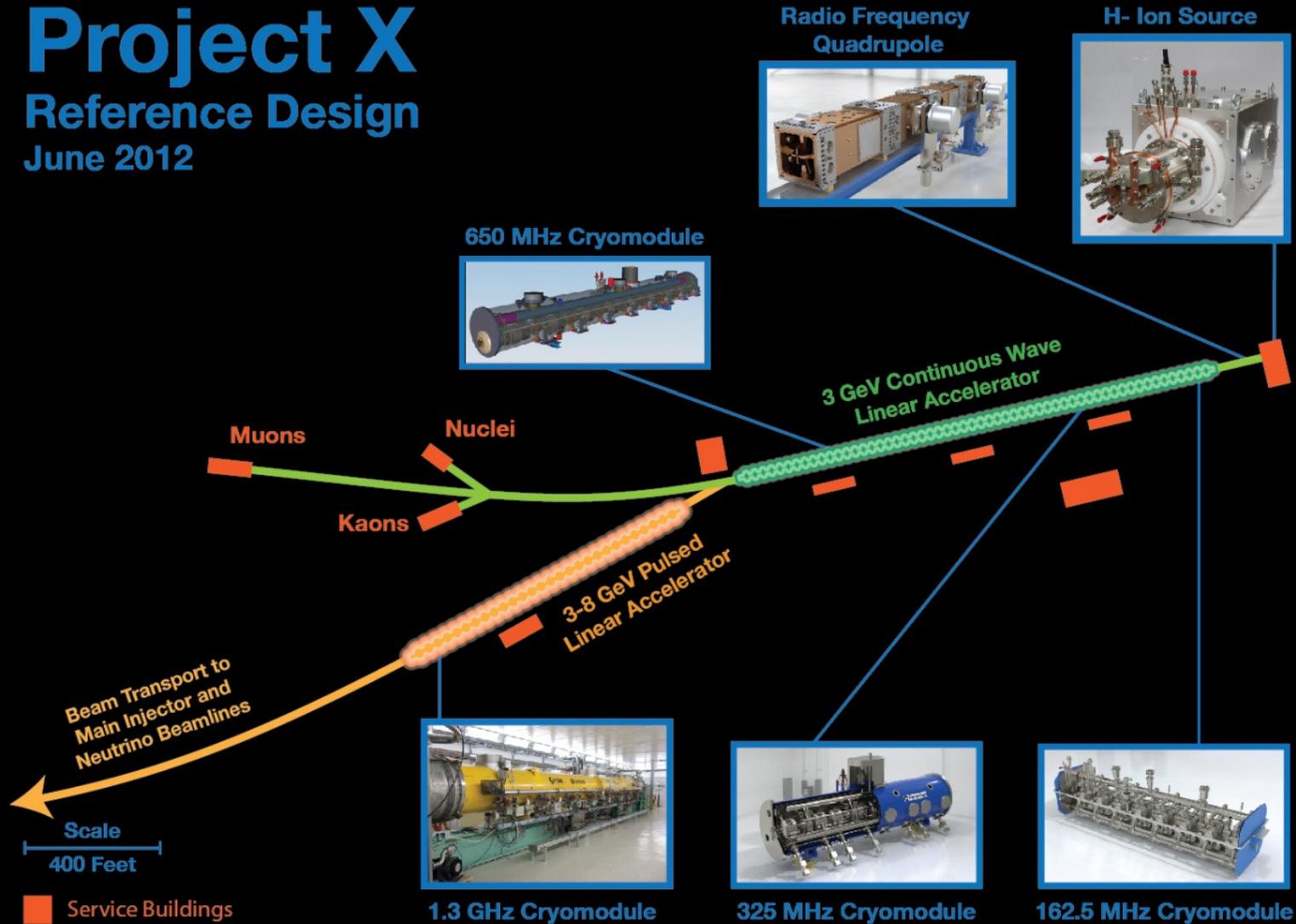
Before 2006



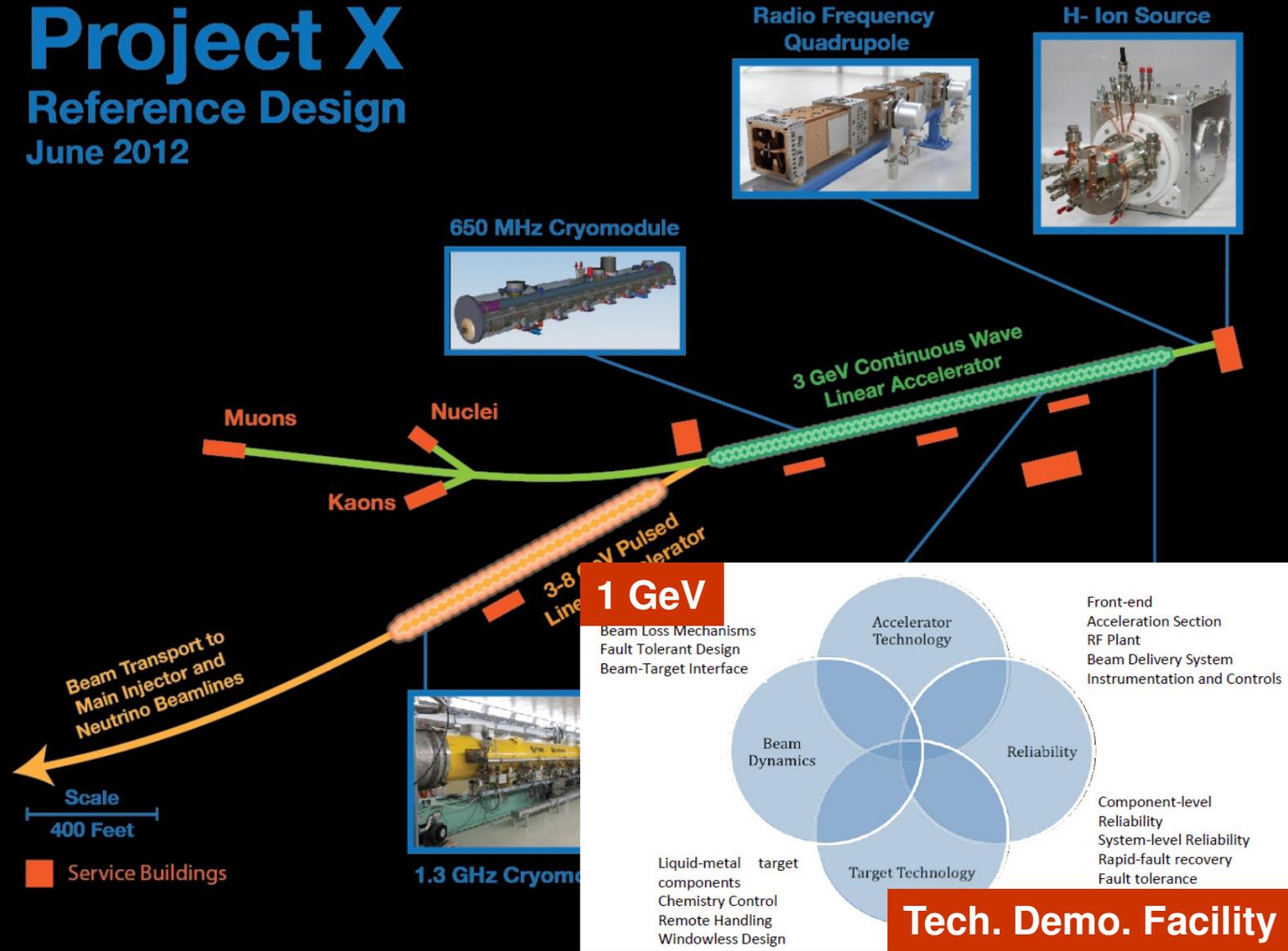
Now



Project X Reference Design June 2012



Project X Reference Design June 2012



1 GeV

- Beam Loss Mechanisms
- Fault Tolerant Design
- Beam-Target Interface



- Front-end Acceleration Section
- RF Plant
- Beam Delivery System
- Instrumentation and Controls

- Component-level Reliability
- System-level Reliability
- Rapid-fault recovery
- Fault tolerance

- Liquid-metal target components
- Chemistry Control
- Remote Handling
- Windowless Design

Tech. Demo. Facility

S1&2:

Next generation muon-to-electron conversion experiment

S1&2:

$K^+ \rightarrow \pi^+ \nu \nu$: >1000 events, Precision rate and form factor

Stage 1-3:

Neutrino Physics:

- **Mass Hierarchy**
- **CP violation**
- **Precision measurement**

Radio Frequency Quadrupole



H- Ion Source



650 MHz Cryomodule



3 GeV Continuous Wave Linear Accelerator

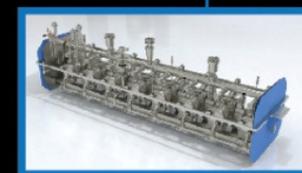


S1&2:

Nuclear edm experiments

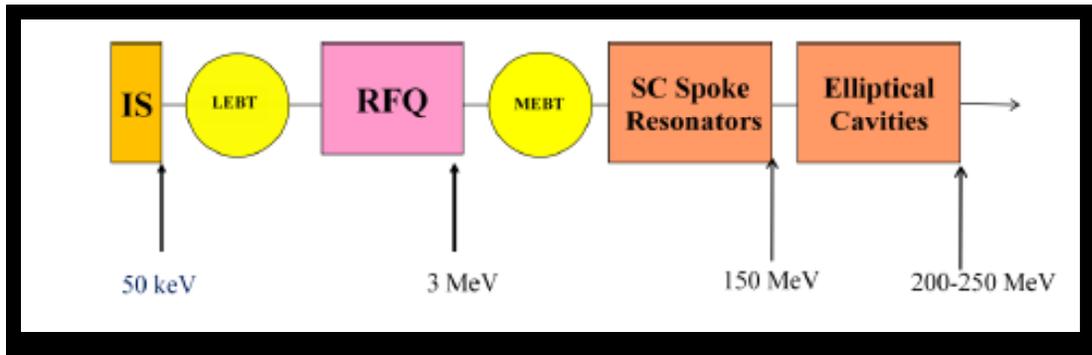


325 MHz Cryomodule



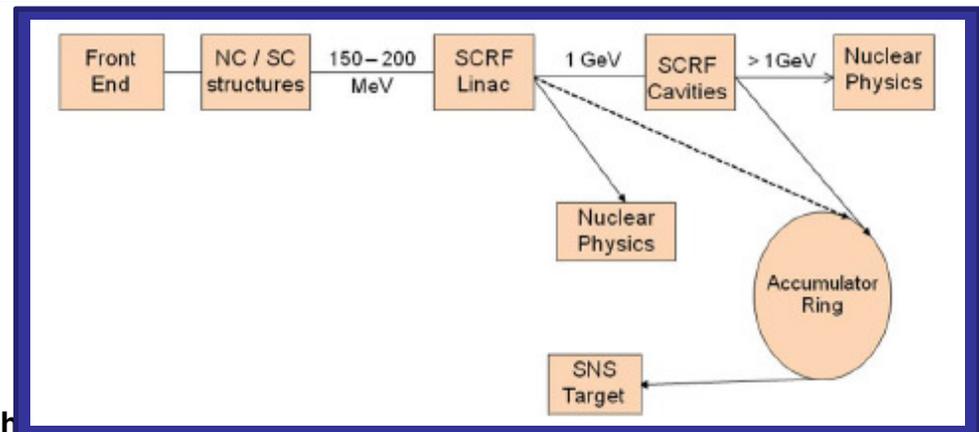
162.5 MHz Cryomodule

- *DAE laboratories (RRCAT & BARC) in collaboration with other DAE labs and Fermilab have proposed:*
 - ✓ *Physics Studies & Enabling Technology Development for Ion Accelerators, a CW SRF LINAC*
 - ✓ *High power proton LINAC based Spallation Neutron Source*

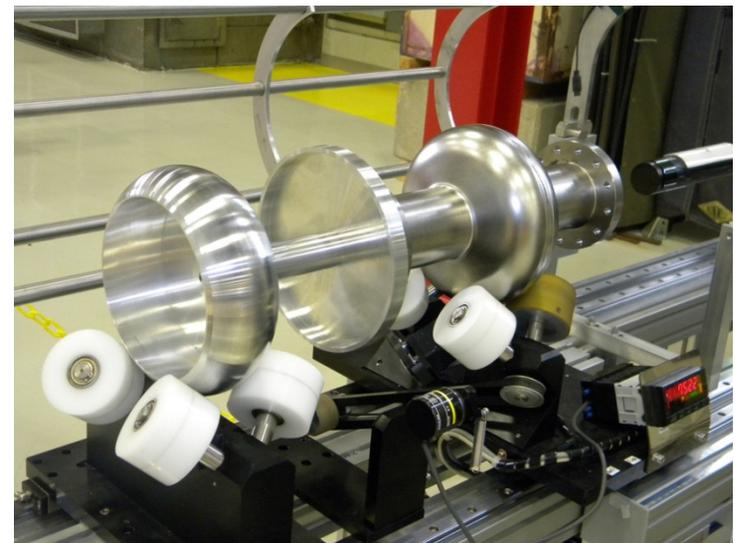


BARC
CW SRF LINAC

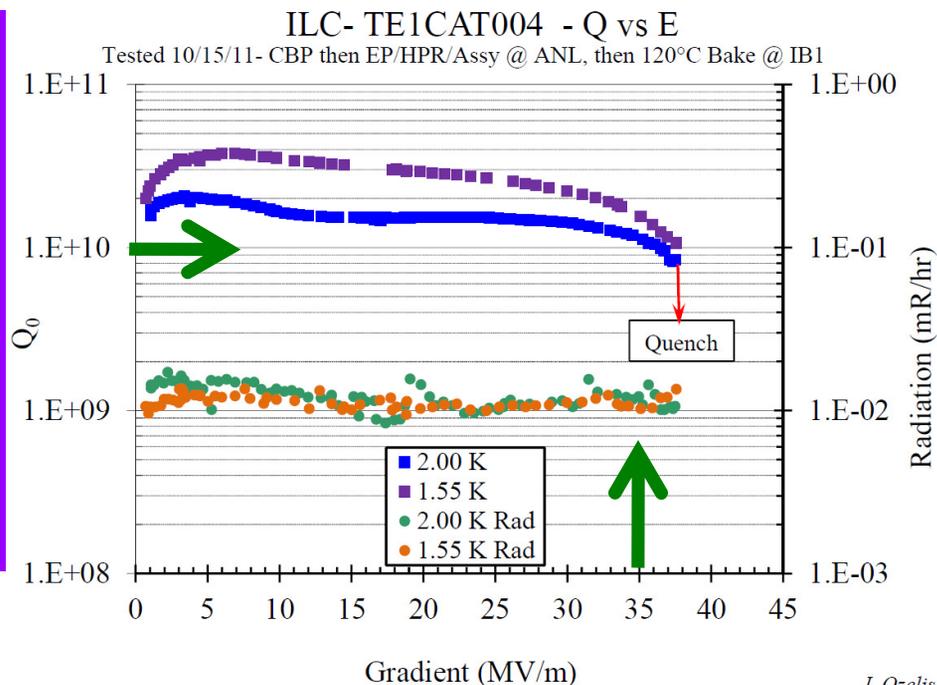
RRCAT
LINAC based Spallation Neutron Source

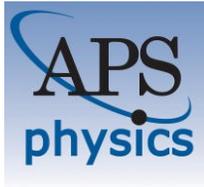


- ❖ **FABRICATION of 1.3 GHz cavity at RRCAT in collaboration with IUAC – For last 2 years only**
- ❖ **Processing and testing at FNAL & ANL – Meets Specifications**



Quality Factor Q_0





UNIQUENESS OF INDIA – FNAL COLLABORATION



Unlike other accelerator collaborations in the world, Fermilab and Indian Institutions are collaborating on full SRF accelerator from source to dump.

ADDENDUM
to the
Memorandum of Understanding
between
US Universities & Accelerator Laboratories
and
Indian Universities & Accelerator Laboratories
concerning
Collaboration on R&D for Accelerator Physics and High Energy Physics Projects

Addendum IV: "US and Indian Institutions Collaboration on Neutrino Physics, Related Experiments and Detector Development."

Nov 10, 2009

1. Authority and Limitations

Pursuant to the Memorandum of Understanding ("MOU") between the U.S. Universities & Accelerator Laboratories and Indian Universities & Accelerator Laboratories dated January 9, 2006, Fermilab and Indian Accelerator Laboratories (the "Parties") intend to undertake the work described in this Addendum IV. The Parties acknowledge that their intended work shall be consistent with the terms and conditions of the MOU, the terms and conditions of their respective contracts and programs, and subject to the availability of appropriated funds as provided to them. The Parties further acknowledge and understand that their agreement with and signature to Addendum IV does not create a legal, contractual obligation for either Party nor may form the basis of a claim for reliance thereon. The Parties agree to comport their activities under Addendum IV in conformance with all applicable U.S. and Indian laws and regulations, including those related to export control.

2. Introduction

The work detailed in this document falls within the scope of the MOU cited above. It addresses two key areas of collaboration mentioned in the main MOU. These are: (i) Neutrino Physics; and (ii) Development of Novel and Large Particle Detectors. All terms and conditions under which the work will be carried out are found within the main MOU.

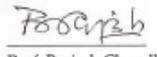
The following concur on the terms of this Memorandum of Understanding Addendum:


Dr. Amit Roy Date
Director
IUAC


Dr. Piermaria Oddone Date
Director,
Fermilab


Dr. Vinod Sahni Date
Collaboration Coordinator
DAE, India


Dr. Shekhar Mishra, Date
Collaboration Coordinator,
Fermilab


Prof. Brajesh Choudhary, Date
Technical Project Manager
University of Delhi, India

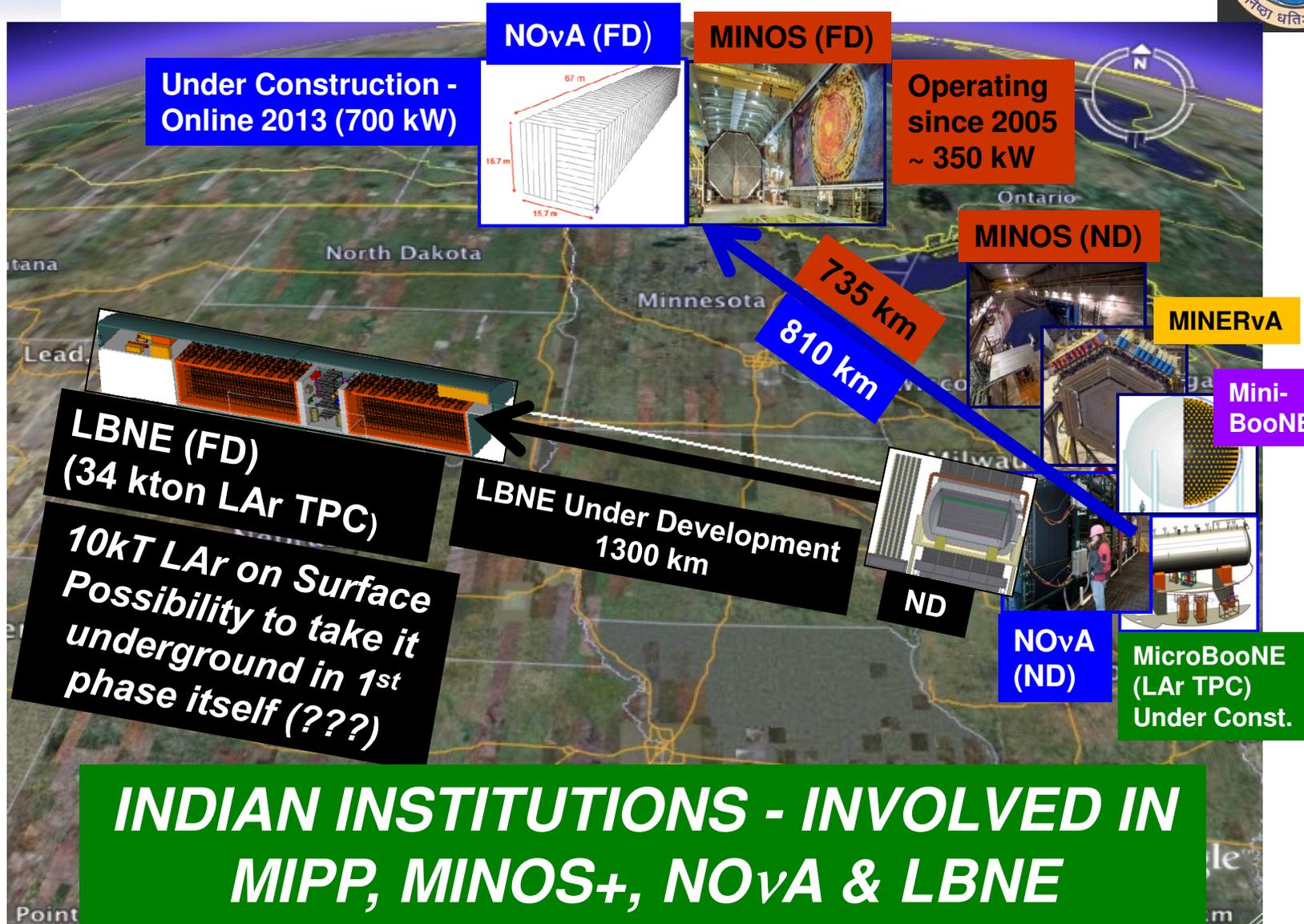

Prof. Sanjib Mishra Date
Technical Project Manager
University of South Carolina, Columbia

IIFC-vP Collaborating Institutions:

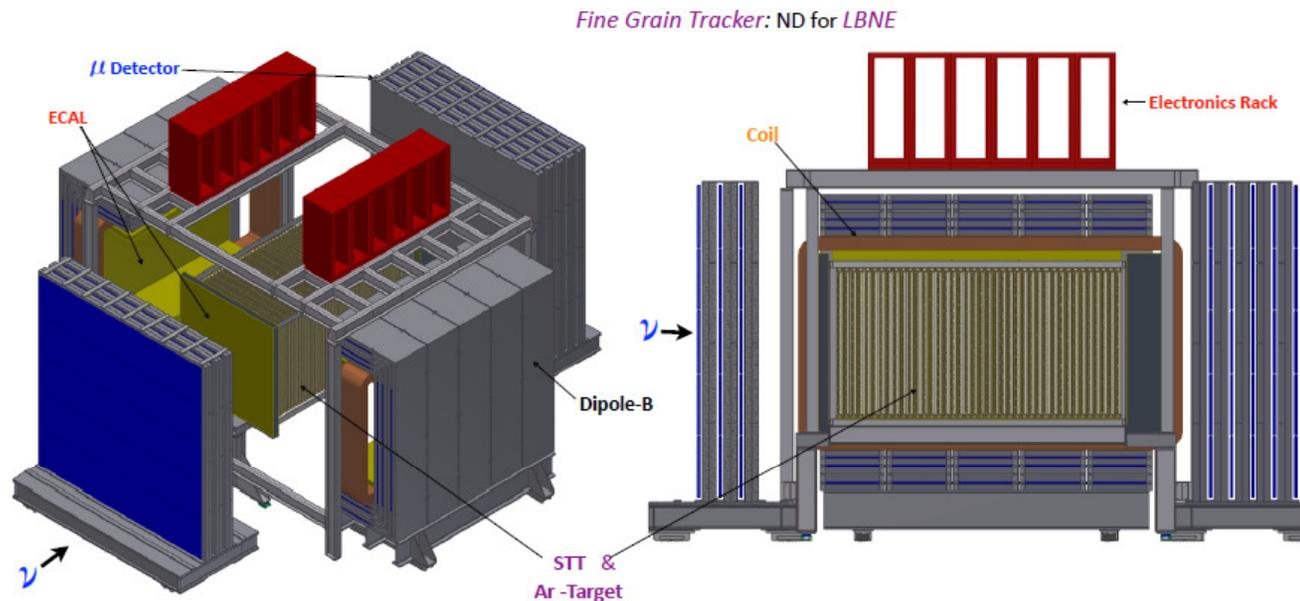
1. Banaras Hindu University, Varanasi
2. Cochin University of Science & Tech., Cochin
3. University of Delhi, Delhi
4. IITG, Guwahati
5. IITH, Hyderabad
6. Jammu University, Jammu-Tawi
7. Hyderabad University, Hyderabad
8. Panjab University, Chandigarh
9. SINP + Other Institutions to join.

**Seed
Funding
\$2.2M**

FERMILAB NEUTRINO PROGRAM



- ✓ **Mass Hierarchy - whether “normal or “inverted?**
- ✓ **CP violation**
- ✓ **Measure precise values of - $|\Delta m^2_{23}|$, θ_{23} and θ_{13} ---
Octant Degeneracy**
- ✓ **High precision ND needed to provide constraints on the systematic affecting the neutrino oscillation physics. Will measure large Δm^2 (LSND, MiniBooNE) anomaly and other new physics searches such as NSI, Sterile neutrinos, etc.**



- Best performance among the 4-options
- $\sim 3.5\text{m} \times 3.5\text{m} \times 7.5\text{m}$ STT ($\rho = 0.1\text{ gm/cm}^3$)
 - 4 π -ECAL in a Dipole-B-Field (0.4T)
 - 4 π - μ -Detector (RPC) in Dipole and Downstream
- Pressurized Ar Target (≈ 5 FD-Stat) \Rightarrow LAr-FD

Transition Radiation $\Rightarrow e^-/e^+ \text{ ID} \Rightarrow \gamma$
 $dE/dx \Rightarrow$ Proton, $\pi^{+/-}$, $K^{+/-}$
 Magnet/Muon Detector $\Rightarrow \mu^{+/-}$
 { ν -e \Rightarrow Absolute Flux measurement }

**INDIAN INSTITUTIONS in Indo-US neutrino program
 have Proposed to DAE to Build LBNE-ND and more.
 HOPE TO GET THE SUPPORT.**

What it does:

- ❑ Flux –
 - ✓ Measure the four species of neutrinos
 - ✓ Absolute and relative neutrino and anti- ν flux
- ❑ Energy Scale –
 - ✓ Charged particle momentum – 4π calorimetric coverage – missing Pt - Neutrino Energy Scale
- ✓ Measurement of secondary $\pi^{+/-/0}$ in ν -hadron shower in CC and NC – proton/K/ π ID
- ❑ Measurement of ν -Ar Interactions
- ❑ 40M $\nu\mu$ -CC events

Possible Physics Topics ~100
Expected PhD Thesis ~200

COSMIC FRONTIER

Gamma Ray Astronomy at PeV Energies – GRAPES3 An Indo-Japanese Collaboration, Ooty, South India

- 1. The origin, acceleration and propagation of UHE (>100 TeV) particles in the galaxy and beyond.*
- 2. “Knee” in energy spectrum of UHE particles and their nuclear composition.*
- 3. Production/acceleration of highest energy particles in cosmic rays.*
- 4. Astronomy of UHE gamma-rays from neutron stars and other compact object (muon poor showers).*

- ✓ ***A total of 400 (each 1 m²) plastic scintillator (fabricated in India) detectors with a separation of 8m, to record the density of particles in cosmic ray showers.***
- ✓ ***Also associated with a 560 m² area tracking muon detector - the largest tracking detector.***



Gamma-ray Astronomy – using atmospheric Cherenkov radiation - for detecting Extensive Air Showers below “Few TeV”

An array of 25 telescopes at Panchamarhi - PACT

An array of 4 telescopes at Mt. Abu – TACTIC

Threshold Energy for detecting γ -ray \sim 850 GeV.



- ✓ **Altitude – 4.3 Km**
- ✓ **Phase-One - 7 Telescopes (3m dia.) – HAGAR
Since 2008**
- ✓ **Energy Threshold ~ 200 GeV**
- ✓ **Phase-II – a 21m diameter imaging telescope MACE
Being built – Expected to be fully operational by 2013.**
- ✓ **Energy Threshold ~ 50 GeV or lower**

**Future Efforts – “Cherenkov Telescope Array (CTA)”
A Global Effort -
India to Participate**



- India has built its own large science projects indigenously, and with international collaboration and welcomes international partners.***
- India has been participating meaningfully in large science facilities outside the country for last couple of decades and the present emphasis is on challenging and equal partnerships.***
- India has joined (or will be joining) partnership in many of the large international projects and plan to be an important stake holder.***
- Indian Institutions and Fermilab Collaboration is jointly building infrastructure, accelerator and physics program(s) in India and at Fermilab for the programs of vital interest to both countries.***

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