India-based Neutrino Observatory (INO)

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(On behalf of the INO Collaboration)
http://www.ino.tifr.res.in/ino/

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INO Collaboration

Ahmadabad: Physical Research Lab.
Aligarh: Aligarh Muslim University
Allahabad: HRI
Calicut: University of Calicut
Chandigarh: Panjab University
Chennai: IIT, Madras IMSc
Delhi: University of Delhi
Guwahati: IIT, Guwahati
Hawaii (USA): University of Hawaii
Indore: IIT, Indore
Jammu: University of Jammu
Kalpakkam: IGCAR
Kolkata: Ramakrishna Mission Vivekananda University, SINP, VECC, University of Calcutta
Lucknow: Lucknow University
Madurai: American College
Mumbai: BARC
Mumbai: IIT, Bombay TIFR
Mysore: University of Mysore
Sambalpur: Sambalpur University
Srinagar: University of Kashmir
Varanasi: Banaras Hindu University
INO: the physics
INO: The physics motivation

- Atmospheric neutrinos provide a wider range for $E$ and $L$ than any artificial neutrino source
- An ability to discriminate between neutrinos and antineutrinos enables efficient determination of neutrino mass ordering
- Magnetized iron calorimeter (ICAL): excellent muon energy measurement, muon direction reconstruction and charge identification
- Hadron shower reconstruction allows access to neutrino energy and high-energy cosmic rays
INO: the physics goals

- Accurate determination of the atmospheric parameters (theta23 octant, deviation of theta23 from maximality)
- Determination of neutrino mass hierarchy (large theta13 is good news!)
- Determination of CP violation in the lepton sector (with a future long baseline experiment with a neutrino factory)
- Non-standard interactions, CPT violation, long range forces, ultrahigh-energy muon fluxes, ...
INO phase II: with a neutrino factory?

- Charge-ID crucial for identification of wrong-sign muons
INO: the location
The nearest major city: Madurai

- South India, 120 km from the temple city of Madurai (has airport)
The site: Bodi West Hills

- (9 58' N, 77 16' E)
- Pottipuram village
- Theni district
- Tamil Nadu state
The caverns

- Accessible through a 2km tunnel
- Cavern 1 will host 50kt ICAL (space for 100 kt)
- Other caverns available for multiple experiments (NDBD, dark matter, ...)

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ACCESS TUNNEL 7.5m, 'D' SHAPE: 1966.0m
ADDITIONALLY DRIVEN INT. TUNNEL 5.5m 'D' SHAPE: 128.4m
AUXILIARY TUNNEL 7.5m 'D' SHAPE: 224.6m
INTERCONNECTING TUNNEL 3.5m 'D' SHAPE: 72.5m
ADDITIONAL TUNNEL 7.5m 'D' SHAPE (future expn): 50.0m

CAVERN -1: 132m x 26m x 32.5m
CAVERN -2: 55m x 12.5m x 8.6m
CAVERN -3: 40m x 10m x 10m
CAVERN -4: 10m x 10m x 10m
Geography of the site

- Cavern set in Charnockite rock under the 1589 m peak
- Vertical cover: 1289 m, all-round cover ~1000 m
- Warm, low-rainfall area, low humidity throughout the year, unusual wind speed in some seasons
Organization at the site

- Flat terrain with good access to major roads
- All major components to be located underground, Small surface lab on the outside (Pottipuram)
- Tunnel and cavern under forest on the surface, but the portal outside the reserve forest boundary
- Surface facilities not on the forest land, so no forest clearing required.
 Updates on the site front

- INO project approved by the Indian funding agencies

- Environmental and Forest Clearance for the site obtained. 26 hectares of land provided free by Tamil Nadu state government

- Site preparation works are being tendered

- Plans are being prepared for construction of approach roads, water and electricity connections to the INO site

- Construction of an INO Centre: National Centre for High Energy Physics (NCHEP) planned at Madurai, land available against payment
INOICAL: The detector
Magnetized Iron calorimeter (ICAL)

- Iron plates separated by resistive plate chambers (RPCs): 150 layers
**Salient features of the detector**

- Magnetized iron as target mass and glass RPCs as the active detector
- Modularity and ease of construction
- Good energy measurement through tracking of muons bending in the magnetic field
- Directionality through tracking and timing (~1ns resolution)
- Charge identification through bending of muons
- Complementarity to existing and future detectors
# Detector factsheet

<table>
<thead>
<tr>
<th>No. of modules</th>
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<tbody>
<tr>
<td>Module dimensions</td>
<td>16m x 16m x 14.5m</td>
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<tr>
<td>Detector dimensions</td>
<td>48.4m x 16m x 14.5m</td>
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<tr>
<td>No. of layers</td>
<td>150</td>
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<tr>
<td>Iron plate thickness</td>
<td>56mm</td>
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<tr>
<td>Gap for RPC trays</td>
<td>40mm</td>
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<tr>
<td>Magnetic field</td>
<td>1.3 Tesla</td>
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<tr>
<td>RPC dimensions</td>
<td>1,950mm x 1,840mm x 24mm</td>
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<tr>
<td>Readout strip pitch</td>
<td>30mm</td>
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<tr>
<td>No. of RPCs/Road/Layer</td>
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<tr>
<td>No. of Roads/Layer/Module</td>
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<tr>
<td>No. of RPC units/Layer</td>
<td>192</td>
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<tr>
<td>No. of RPC units</td>
<td>28,800 (97,505m²)</td>
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<tr>
<td>No. of readout strips</td>
<td>3,686,400</td>
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</table>
Construction of RPC

- Two 2 mm thick float Glass
- Separated by 2 mm spacer
- Pickup strips
- 2 mm thick spacer
- Glass plates
- Resistive coating on the outer surfaces of glass
Construction of the ICAL
ICAL Front End Electronics chip developed at BARC Electronics Division
ICAL Electronics: schematic
Testing the RPCs

RPC stack being used for cosmic ray measurements

Muon Pulse in RPC

RPC timing resolution

RPC Pulse ht. resolution
Cosmic ray tracks in the RPC stand

- Demonstrates tracking capability of the INO RPC system
RPC performance with cosmic rays

Strip Multiplicity due to crossing muons

Track residue in mm

Strip noise rate vs time

Image of a RPC using muons
Fabricating 2mx2m glass RPC in the lab
2m x 2m glass RPC test stand
Bakelite RPC R&D

- SINF and VECC groups in Kolkata developing bakelite RPCs in streamer mode
- Inner surface of bakelite coated with PDMS (silicone) to make the surface smooth
- Efficiency plateau over 96% obtained with reduced noise rate and long term stability
- INO-ICAL being modular, can use both, glass and/or bakelite RPCs
Detector prototype (40 ton) in Kolkata

- Both, glass and bakelite RPCs tested in this magnetized ICAL prototype
Status of detector development

- **RPC development for ICAL:**
  - R&D almost complete
  - Full size RPCs (2m x 2m) are being fabricated not just in the INO labs but also by the industry
  - Methods, machinery and production optimisation for large scale production of RPCs are being developed with the help of an industry

- **Electronics for ICAL**
  - Design and prototyping of electronics, trigger and data acquisition systems progressing well.
  - First batch of ASIC front end designed by the INO electronics team & fabricated by Euro Practice IC Services being tested in the RPC lab
  - TDC ASIC developed at IIT Madras

- **Magnet for ICAL**
  - Prototype magnet running at VECC, Kolkata

  8m x 8m x 20 layer engineering module (800 ton) being planned
INO: Simulations
Overview of simulation framework

**Simulation Framework**

**NUANCE**
- Neutrino Event Generation
  \[ \nu_a + X \rightarrow A + B + \ldots \]
  Generates particles that result from a random interaction of a neutrino with matter using theoretical models.

**GEANT4**
- Event Simulation
  \[ A + B + \ldots \text{ through RPCs + Mag.Field} \]
  Simulate propagation of particles through the detector (RPCs + Magnetic Field)

**Event Digitisation**
- (x,y,z,t) of A + B + \ldots + noise + detector efficiency
  Add detector efficiency and noise to the hits

**Event Reconstruction**
- \((E,p)\) of \(\nu + X = (E,p)\) of A + B + \ldots
  Fit the tracks of A + B + \ldots to get their energy and momentum.

**Output**
- i) Reaction Channel
- ii) Vertex Information
- iii) Energy & Momentum of all Particles

Output:
- i) x,y,z,t of the particles at their interaction point in detector
- ii) Energy deposited
- iii) Momentum information

Output:
- i) Digitised output of the previous stage (simulation)

Output:
- i) Energy & Momentum of the initial neutrino
The status of INO simulations

- Inhomogeneous magnetic field implemented
- Muon track reconstruction: good understanding of energy and direction resolution, but improvements still possible
- Hadron energy resolutions available (but not used in the results shown in this talk)
- Neutrino energy reconstruction using muon and hadron momenta possible
- Optimization of iron plate thickness in progress
Detector performance: efficiencies
Detector performance: resolutions
Atmospheric parameters with INO-ICAL

- Priors used on $|\Delta m_{32}|$, theta23, theta13 projected reach
- Precision complementary to LBL experiments: better for theta23, but worse for $|\Delta m_{32}|$. 
Mass hierarchy with INO-ICAL

- Events generated using NUANCE and ICAL resolutions in $E$ and $\cos(\theta_{\text{zenith}})$

- For $\sin^2(\theta_{23})=0.5$, $\sin^2(2\theta_{13})=0.1$:
  - In 5 years (2022), 2 sigma sensitivity to MH
  - In 10 years (2027), 2.7 sigma sensitivity to MH
Impact of CP phase on MH sensitivity

- Data generated at $\Delta \text{CP}=0$ and fitted to nonzero $\Delta \text{CP}$
- MH sensitivity almost independent of the CP phase
INO: Timeline
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<td>Transportation of machined plates at site</td>
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<td>Transportation to site and tests</td>
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Thank You

Collaborators are welcome!

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