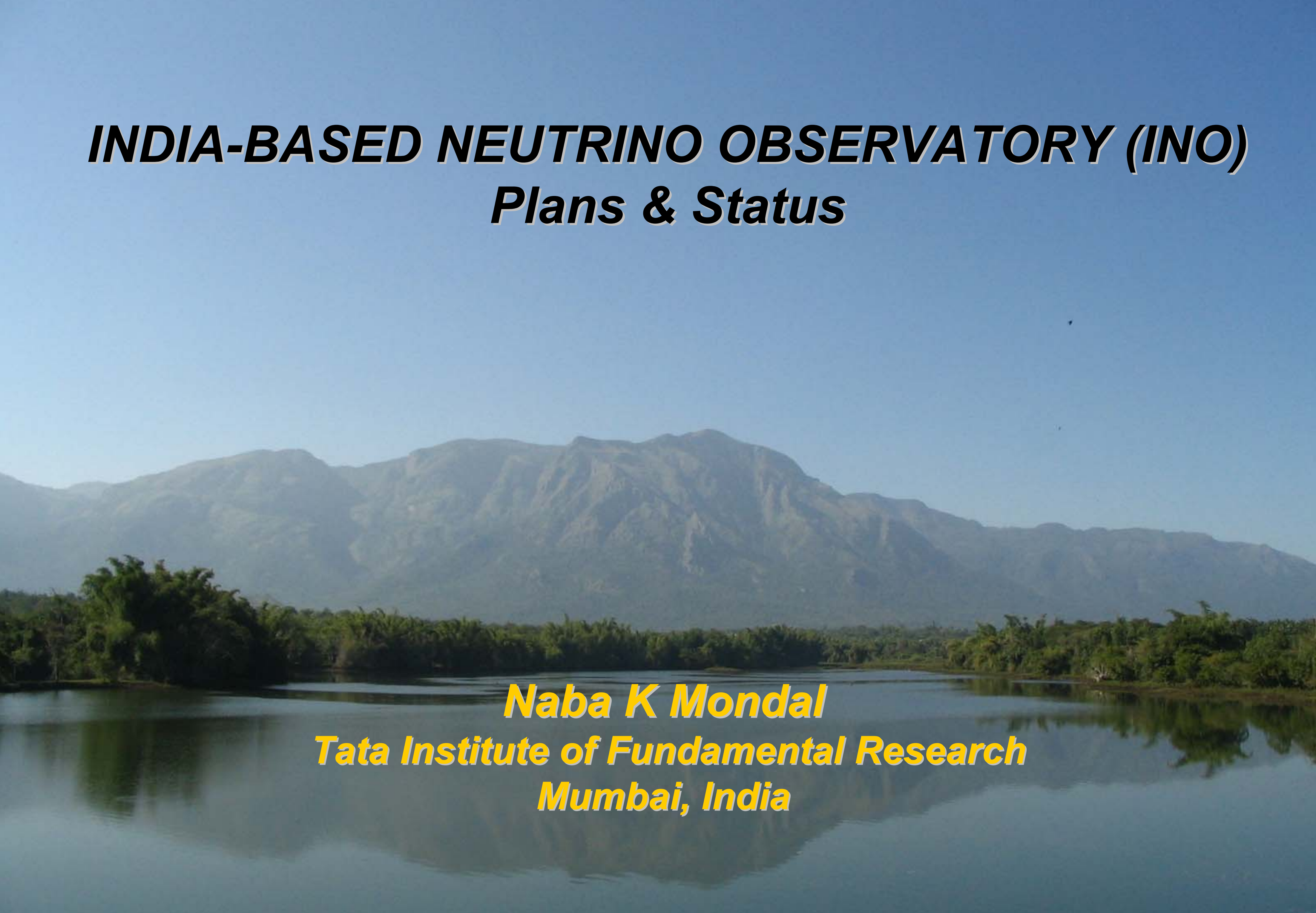
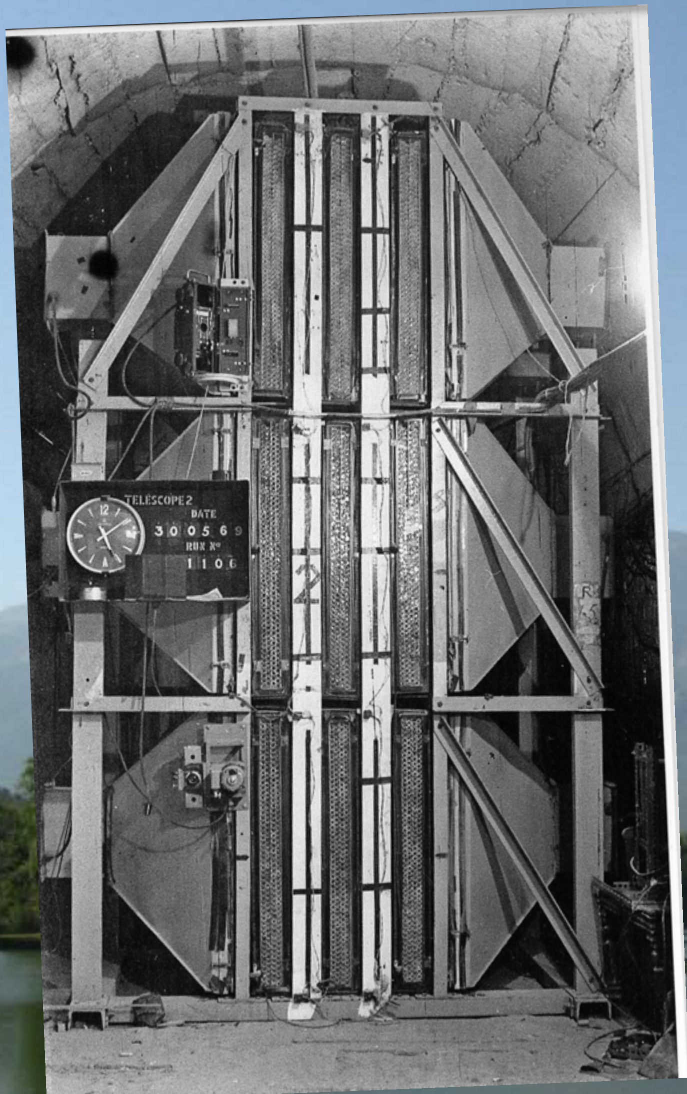
INDIA-BASED NEUTRINO OBSERVATORY (INO)
Plans & Status



Naba K Mondal
Tata Institute of Fundamental Research
Mumbai, India

Atmospheric neutrino detection in 1965



Atmospheric neutrino detector at Kolar Gold Field –1965

DETECTION OF MUONS PRODUCED BY COSMIC RAY NEUTRINO DEEP UNDERGROUND

C. V. ACHAR, M. G. K. MENON, V. S. NARASIMHAM, P. V. RAMANA MURTHY and B. V. SREEKANTAN,
Tata Institute of Fundamental Research, Colaba, Bombay

K. HINOTANI and S. MIYAKE,
Osaka City University, Osaka, Japan

D. R. CREED, J. L. OSBORNE, J. B. M. PATTISON and A. W. WOLFENDALE
University of Durham, Durham, U.K.

Received 12 July 1965

Physics Letters 18, (1965) 196, dated 15th Aug 1965

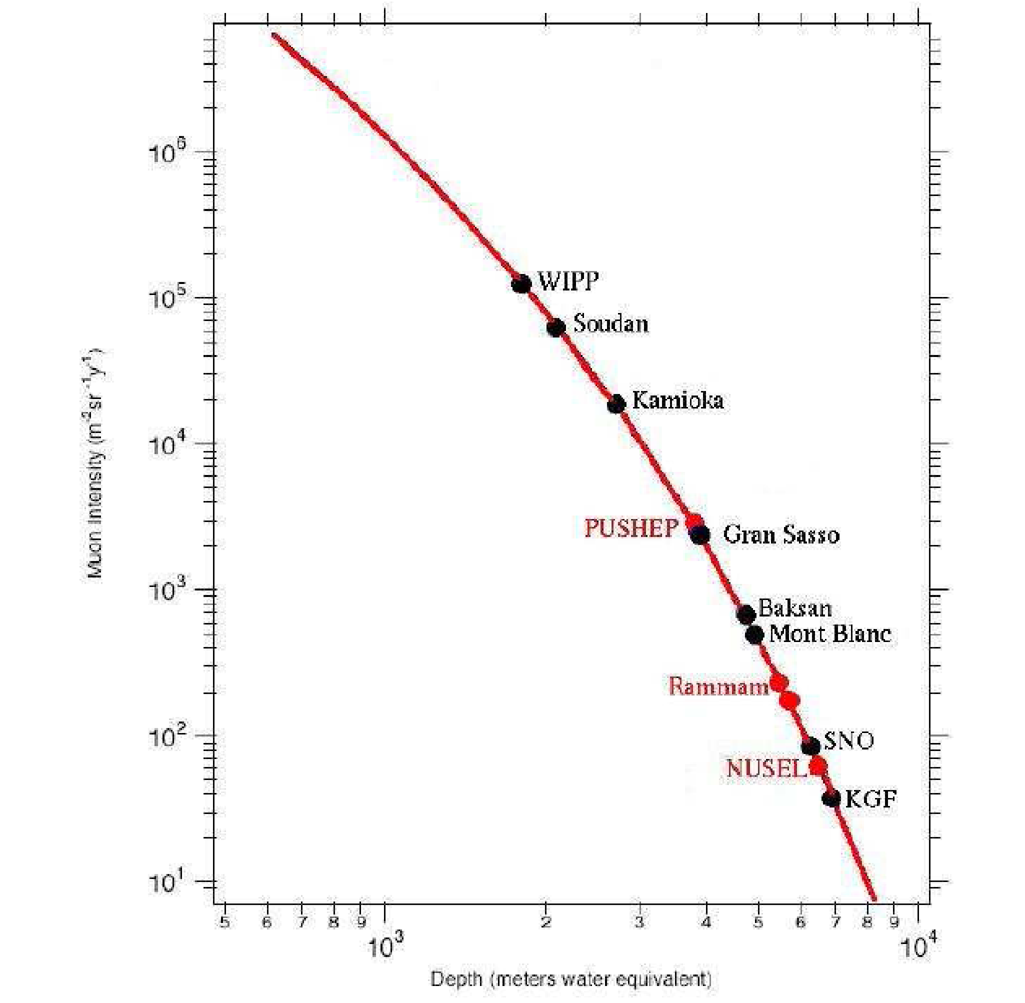
EVIDENCE FOR HIGH-ENERGY COSMIC-RAY NEUTRINO INTERACTIONS*

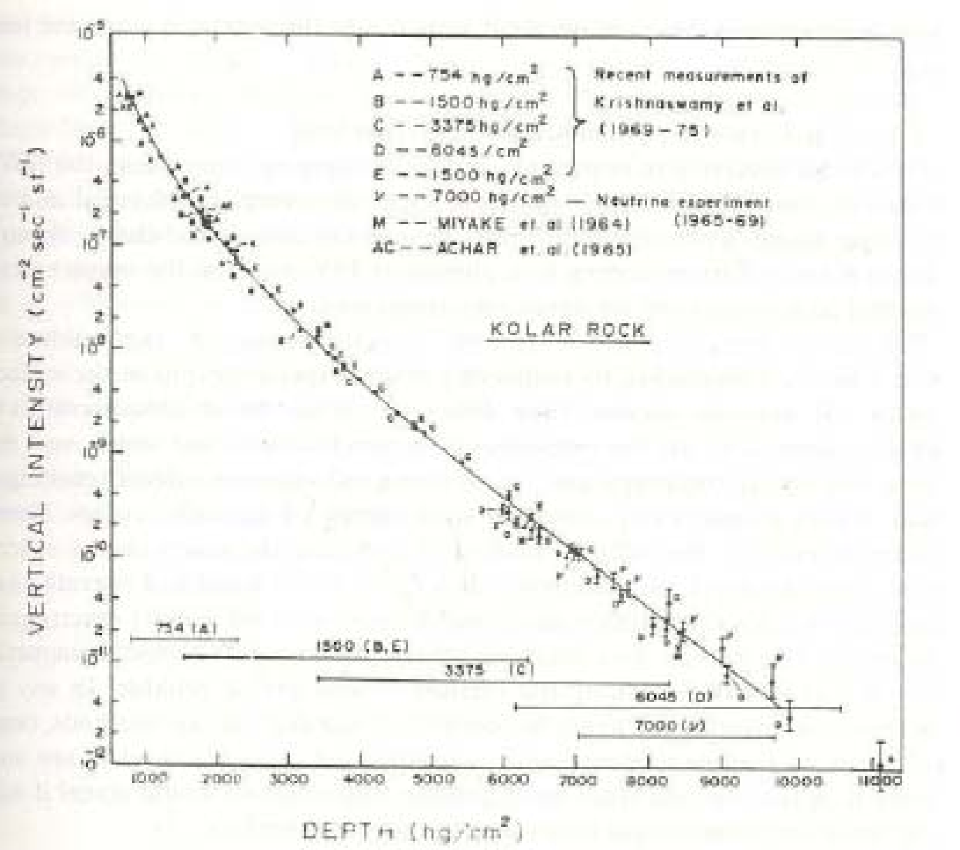
F. Reines, M. F. Crouch, T. L. Jenkins, W. R. Kropp, H. S. Gurr, and G. R. Smith
Case Institute of Technology, Cleveland, Ohio
and
J. P. F. Sellschop and B. Meyer
University of the Witwatersrand, Johannesburg, Republic of South Africa

(Received 26 July 1965)

PRL 15, (1965), 429, dated 30th Aug. 1965

KGF





THE CONSOLIDATED DEPTH-INTENSITY RELATION FROM ALL WORKS DONE UNDER KOLAR ROCK

INO Initiative

- *In early 2002, a document was presented to the Dept. of Atomic Energy (DAE), Govt of India with a request for fund to carry out feasibility study for setting up an underground neutrino laboratory in India.*
- *In August 2002, an MoU was signed by the directors of seven participating DAE institutes towards working together on the feasibility study for such a laboratory.*
- *A neutrino collaboration group was established with members mostly from Indian Institutes and Universities.*
- *A sum of 50 million INR (1 M USD) was allotted by DAE to carry out the feasibility study.*
- *Considering the physics possibilities and given the past experience at Kolar, it was agreed to carry out the feasibility study for a large mass magnetised iron calorimeter which will compliment the already existing water cherenkov based Super-K experiment in Japan.*

INO activities during feasibility study period

- **Detector R & D:**
  - Choice of active detector
  - Design of the magnet
  - Prototyping
  - Electronics front end and DAQ system
  - Gas recirculation system
  - Cost estimate for various components

- **Site Survey:**
  - History of the site.
  - Cost factors.
  - Risk factors and safety issues.
  - Ownership & site sharing.
  - Depth
  - Outreach potential
  - Local support & awareness

INO activities during feasibility study period

- Numerical simulation:
  - Development of GEANT3 & GEANT4 based codes for proposed detector geometry
  - Neutrino generator
  - Analysis to evaluate physics potential.
- Human Resource development:
  - INO training school
  - Joint universities training program
  - Direct recruitment
  - INO positions/ INO fellowships at various institutions
  - Ph. D. degree for instrument building

India-based Neutrino Observatory Proposal

Goal: *A large mass detector with charge identification capability*

- *Two phase approach:*

R & D and Construction	*Operation of the Detector*
Phase I	***Phase I***
Physics studies, *Detector R & D,* *Site survey,* *Human resource development*	*Physics with Atmospheric Neutrinos*
Phase II	***Phase II***
Construction of the detector	*Physics with Neutrino beam from a factory*

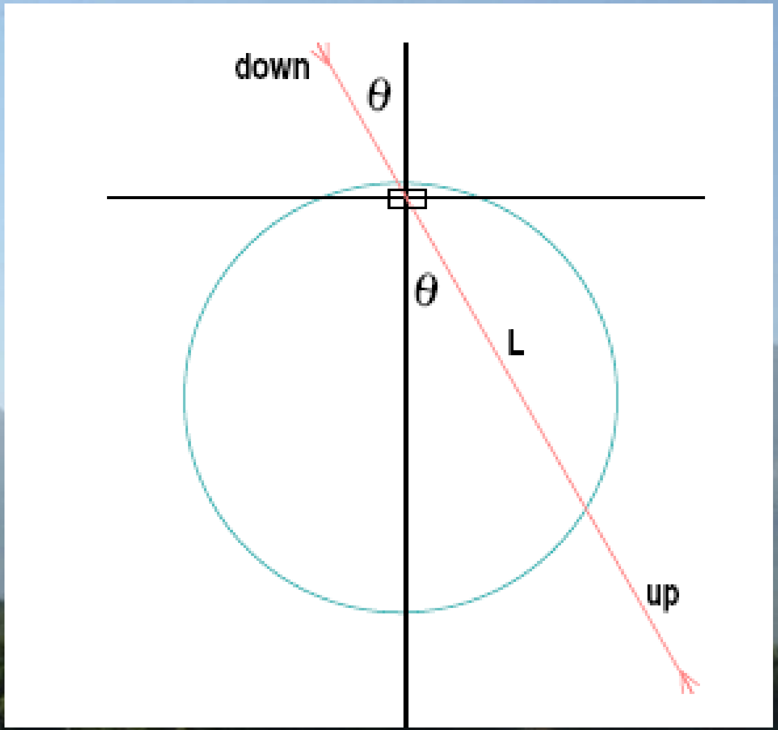
Neutrino Physics using INO

Physics using atmospheric neutrinos during Phase I

- *Reconfirm atmospheric neutrino oscillation*
- *Improved measurement of oscillation parameters*
- *Search for potential matter effect in neutrino oscillation*
- *Determining the sign of Δm^2_{23} using matter effect*
- *Measuring deviation from maximal mixing for θ_{23}*
- *Probing CP and CPT violation*
- *Constraining long range leptonic forces*
- *Ultra high energy neutrinos and muons*

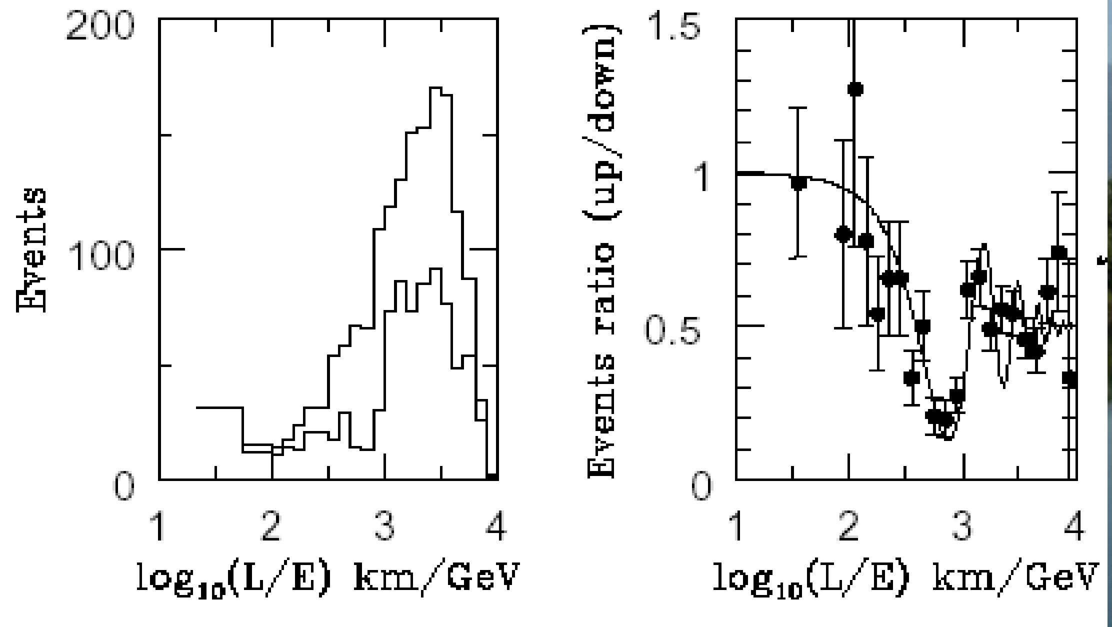
Disappearance of ν_μ Vs. L/E

The disappearance probability can be measured with a single detector and two equal sources:



$$\frac{N_{up}(L/E)}{N_{down}(L'/E)} = P(\nu_\mu \rightarrow \nu_\mu; L/E)$$

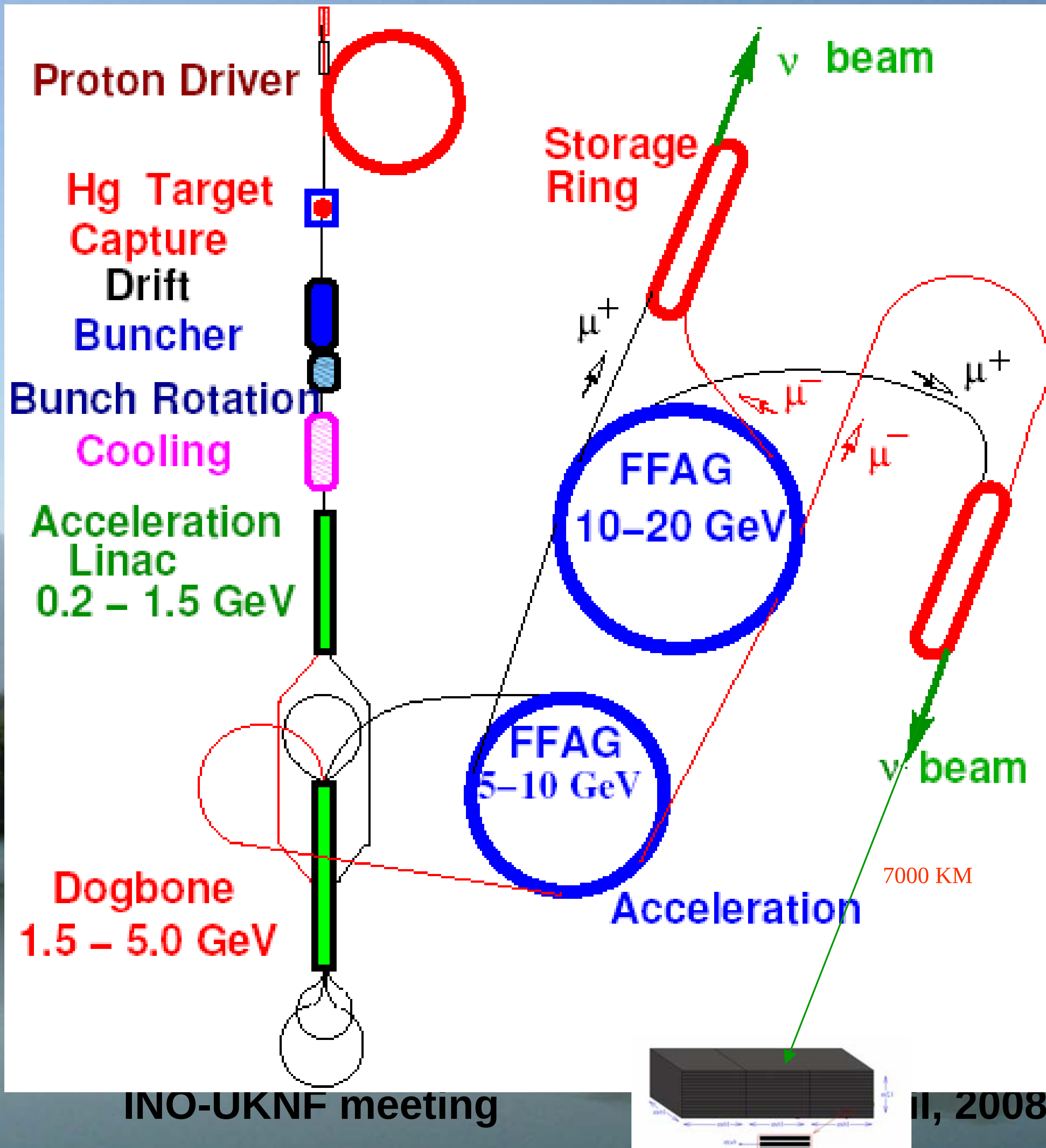
$$= 1 - \sin^2(2\Theta)\,\sin^2(1.27\,\Delta m^2\, L/E)$$

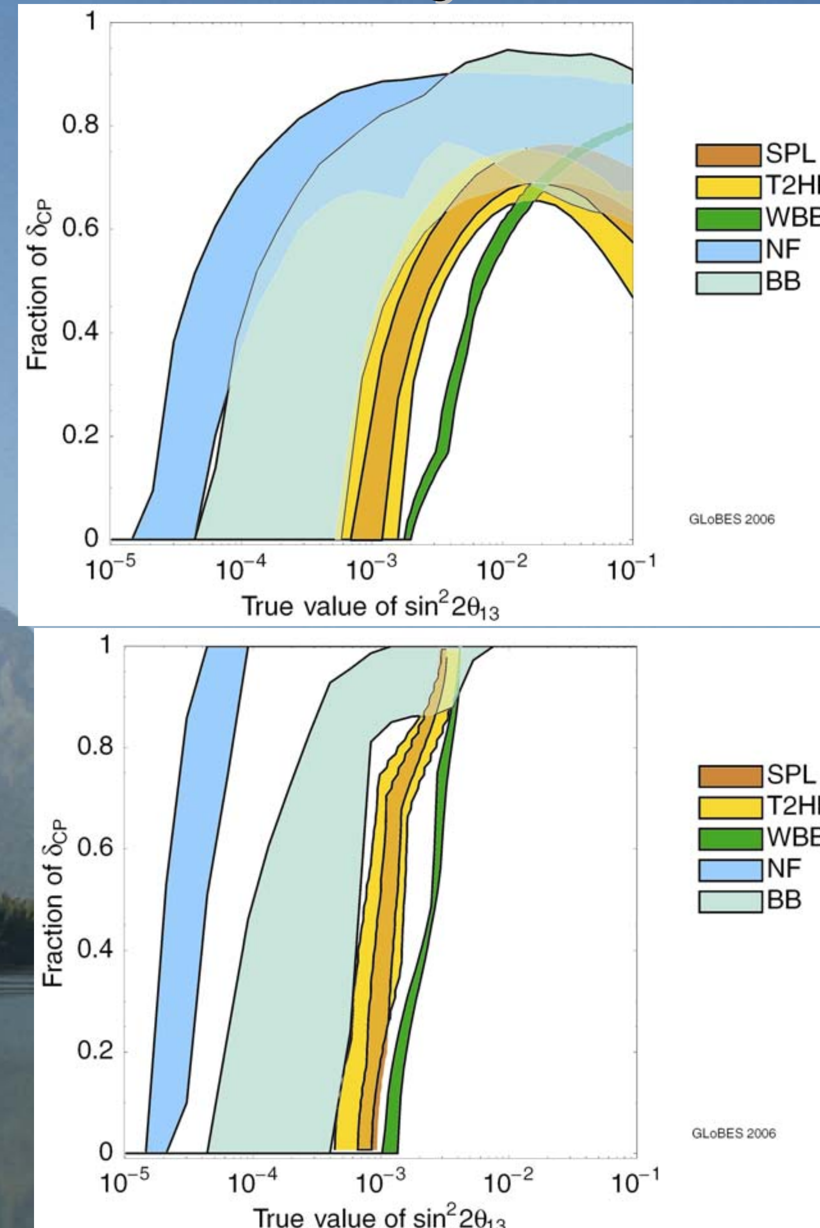


Precision measurement of Δm^2_{31} and θ_{23}

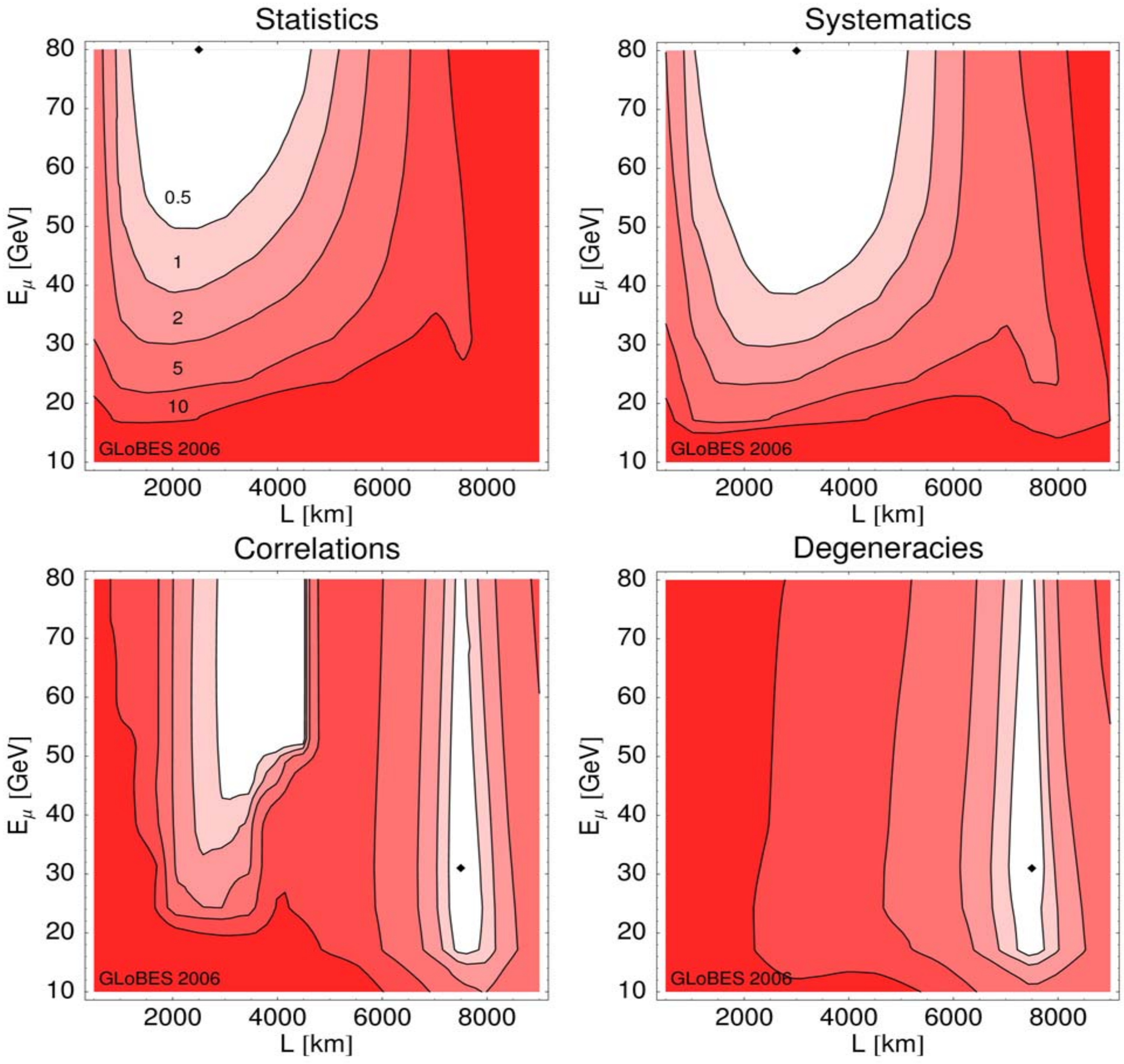
Experiment	$\|\Delta m^2_{31}\|$	$Sin^2\theta_{23}$
Current	30%	34%
MINOS + CNGS	13%	38%
T2K (5 yrs)	6%	22%
NOνA (5 yrs)	13%	42%
SK20 (1.84 MTy)	17%	24%
INO (250 KTy)	10%	30%

Beyond Superbeam - Neutrino Factory





NF: Golden channel optimisation



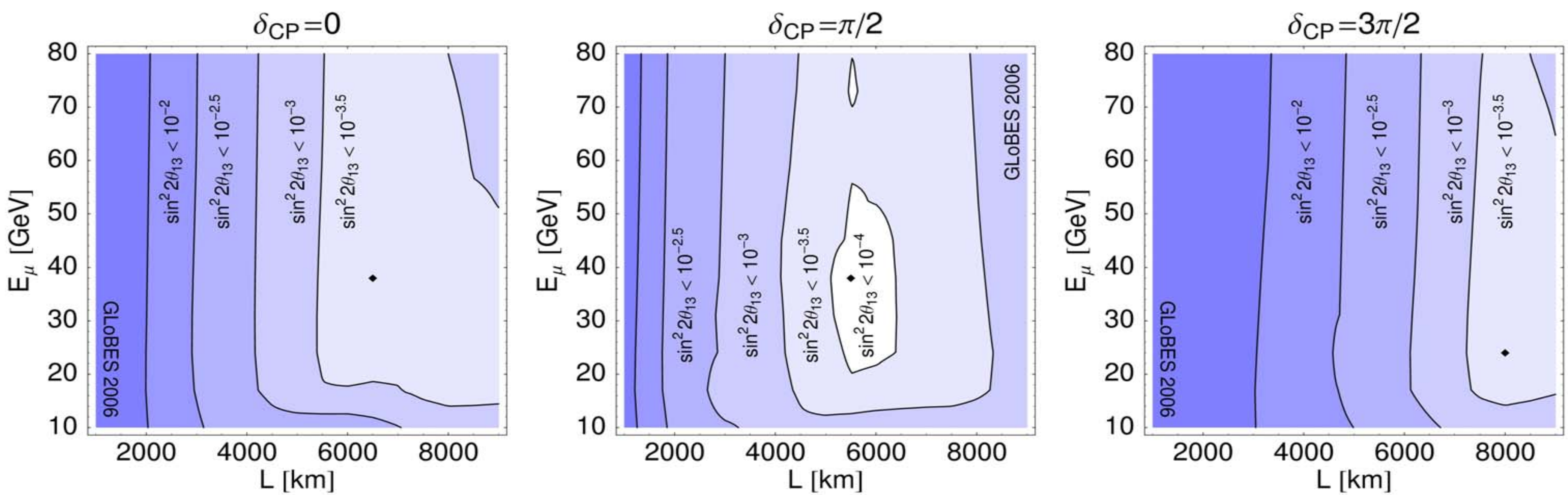
$\sin^2 2\theta_{13}$: 5σ sensitivity

- *Magic baseline (7500 km) good degeneracy solver*
- *Stored muon energy > 20 GeV*

Patrick Huber: NUFACT06

NF: Golden channel optimisation

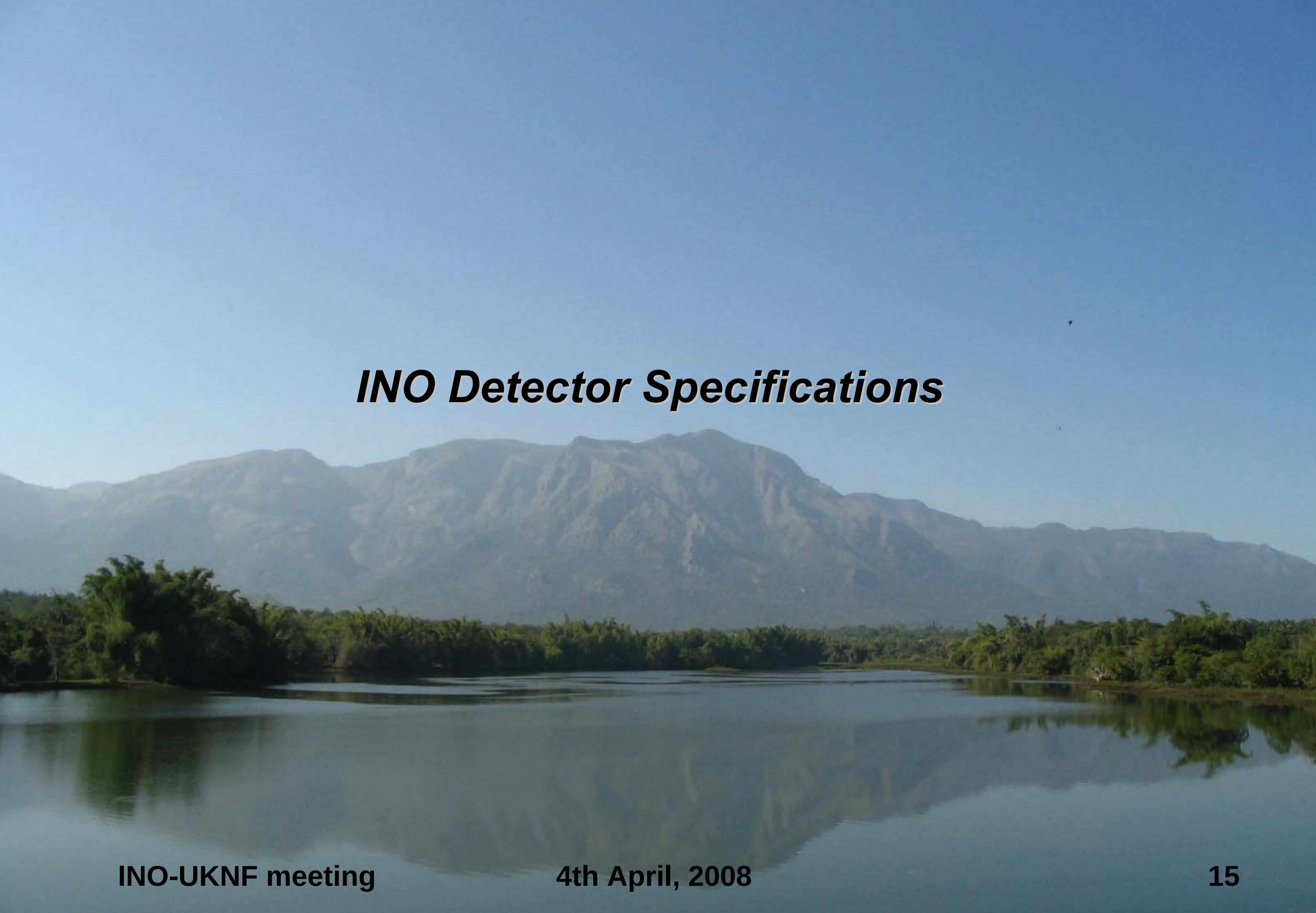
Mass hierarchy: 3σ sensitivity



- *Baseline: ~7500 km*
- *Stored muon energy 20 – 50 GeV*

Patrick Huber- NUFACT06

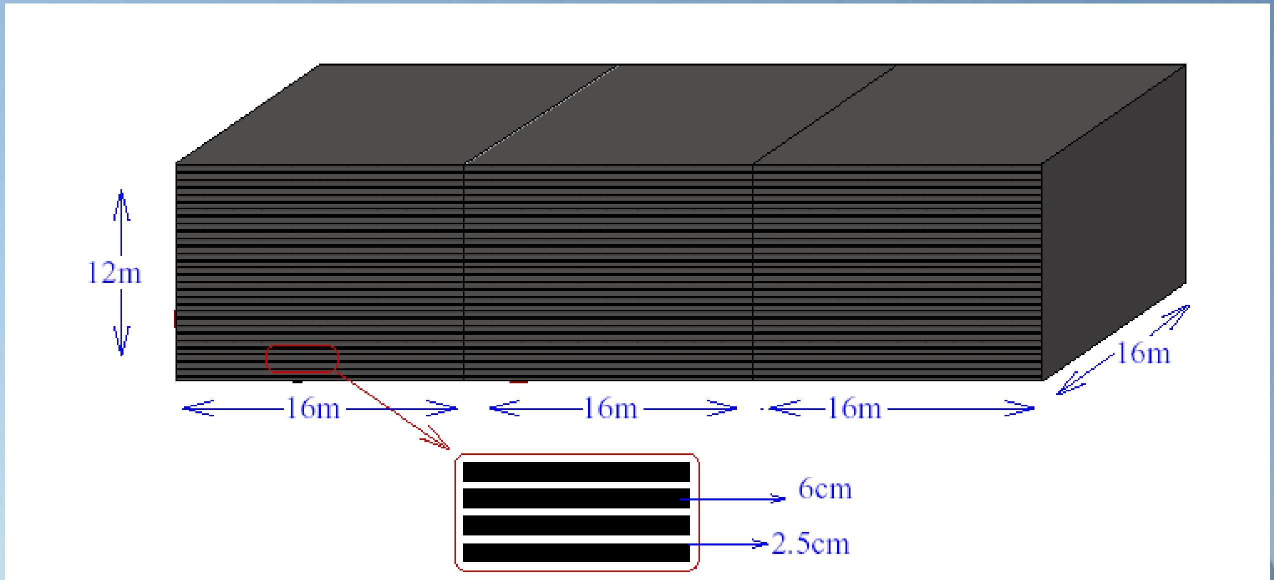
INO Detector Specifications

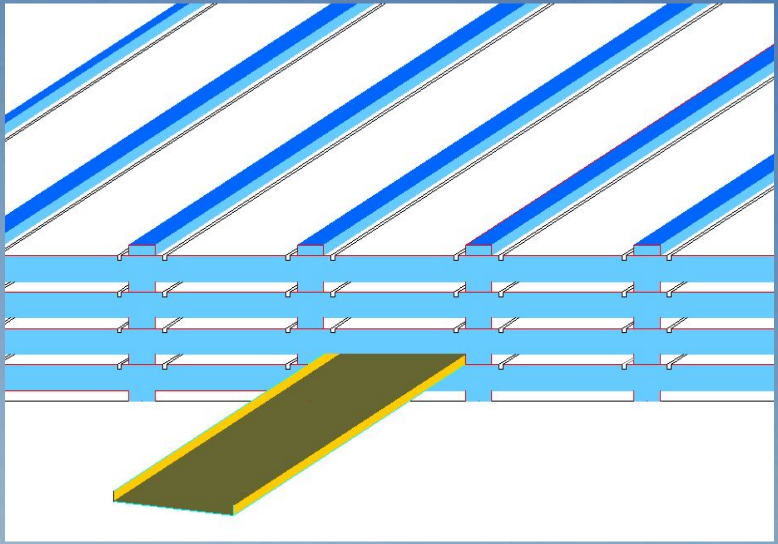


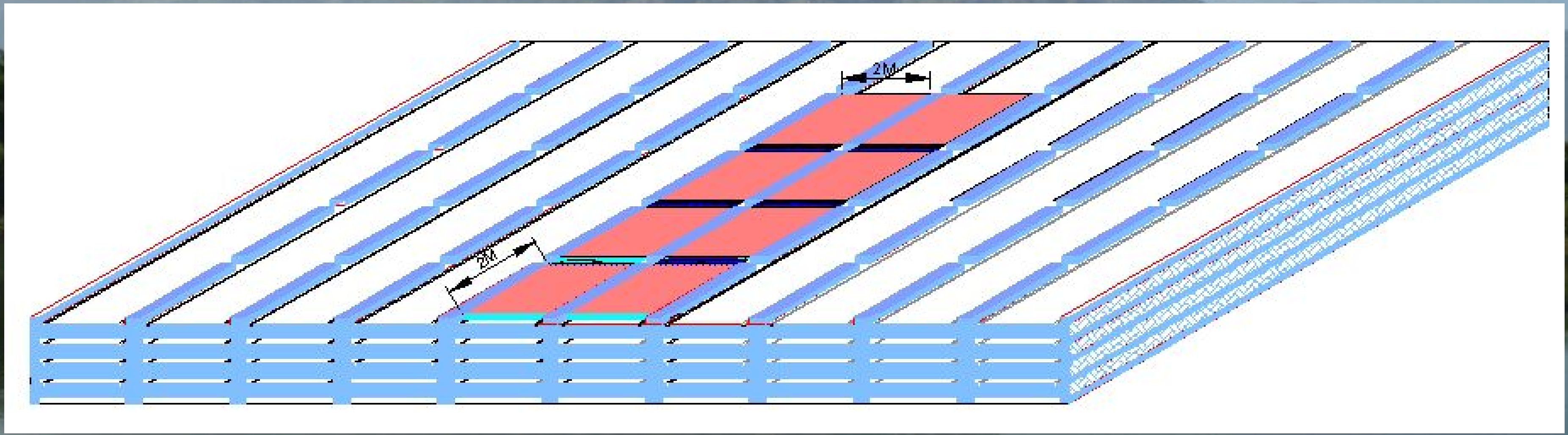
INO Phase 1

- *Neutrino Source*
  - *Need to cover a large L/E range*
    - *Large L range*
    - *Large E_{ν} Range*
  - *Use Atmospheric neutrinos as source*
- *Detector Choice*
    - *Should have large target mass (50-100 kT)*
    - *Good tracking and Energy resolution (tracking calorimeter)*
    - *Good directionality (<= 1 nsec time resolution)*
    - *Charge identification*
    - *Ease of construction*
    - *Modularity*
    - *Complimentarity with other existing and proposed detectors*
  - *Use magnetised iron as target mass and RPC as active detector medium*

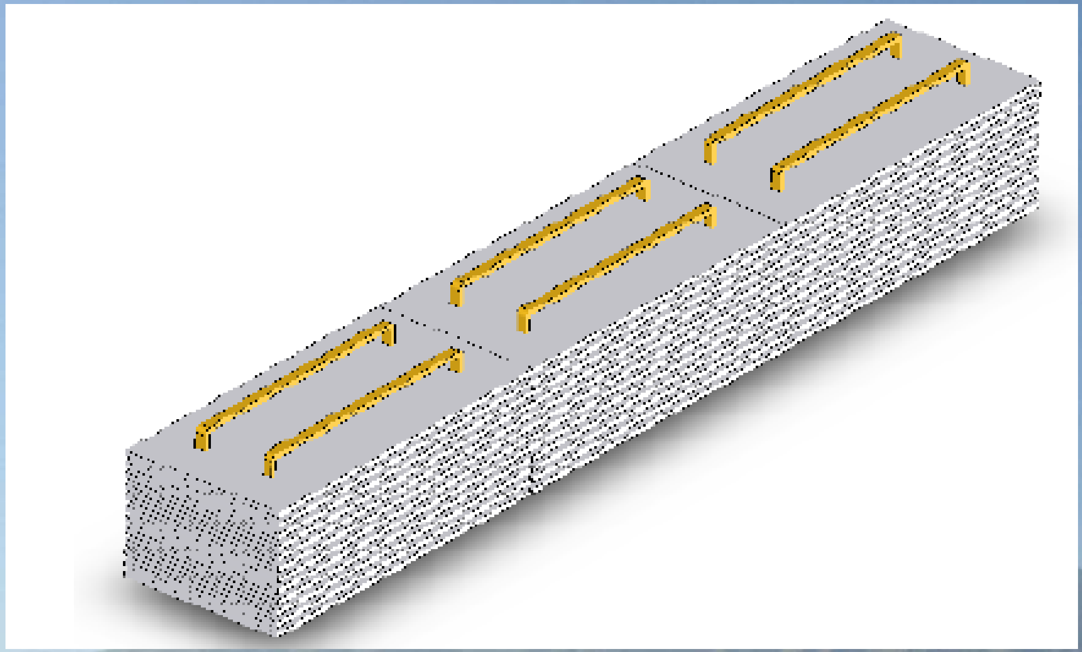
INO Detector Concept

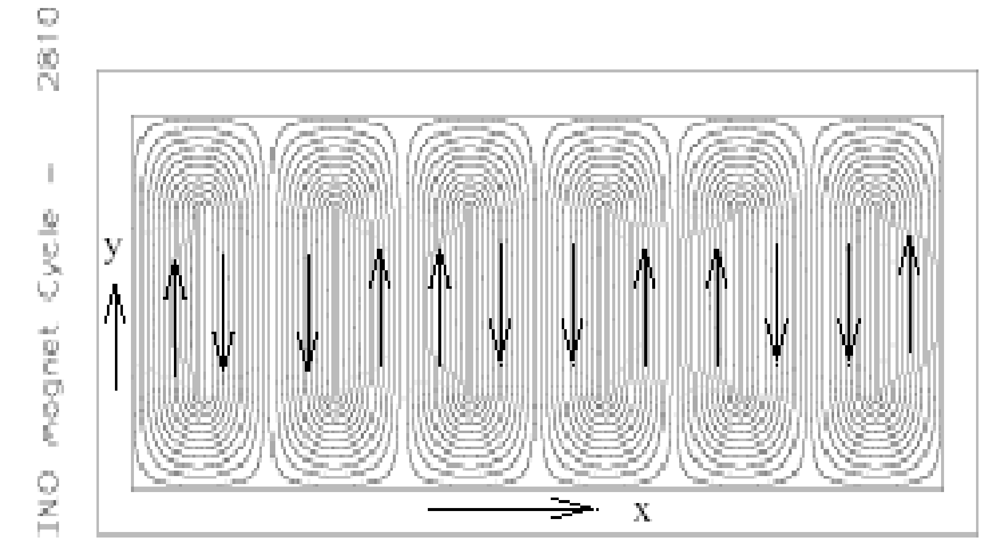






The Magnet

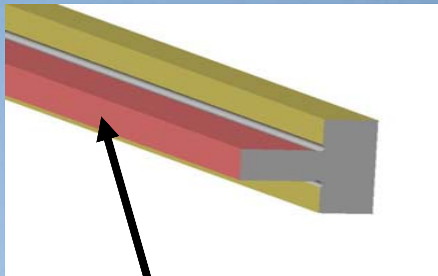




ICAL Detector Specifications

No of modules	3
Module dimension	16 m X 16 m X 12 m
Detector dimension	48 m X 16 m X 12 m
No of layers	140
Iron plate thickness	6 cm
Gap for RPC trays	2.5 cm
Magnetic field	1.5 Tesla
RPC unit dimension	2 m X 2 m
Readout strip width	2 cm
No. of RPCs/Road/Layer	8
No. of Roads/Layer/Module	8
No. of RPC units/Layer	192
Total no of RPC units	27000
No of Electronic channels	3.6×10^6

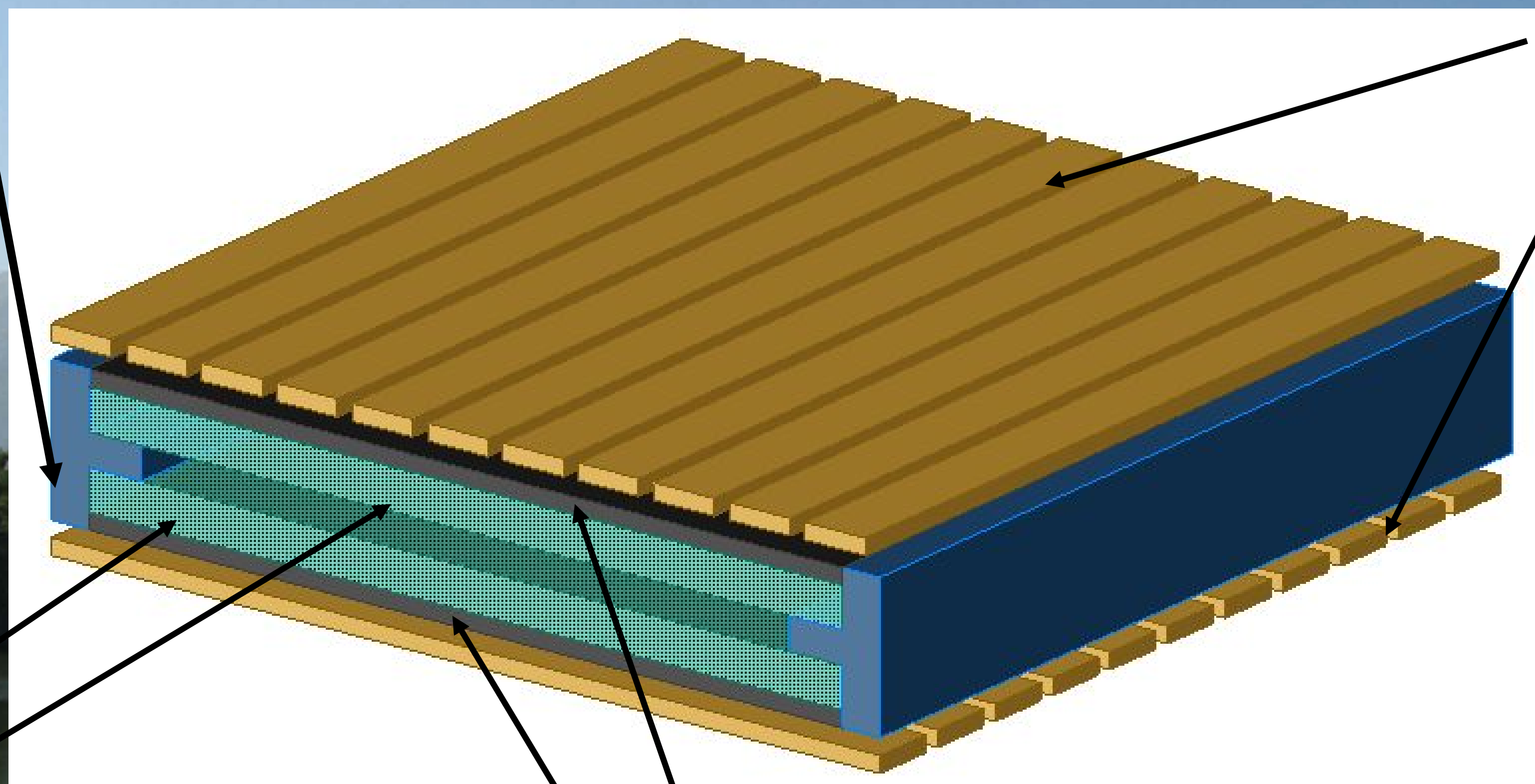
Construction of RPC



2 mm thick spacer

Two 2 mm thick float Glass
Separated by 2 mm spacer

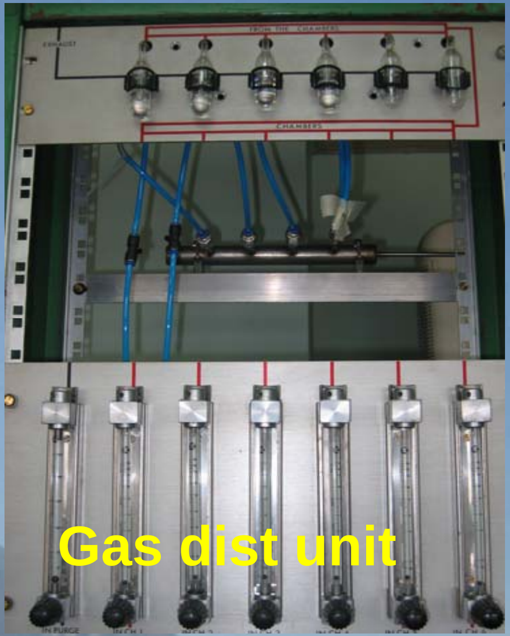
Pickup strips

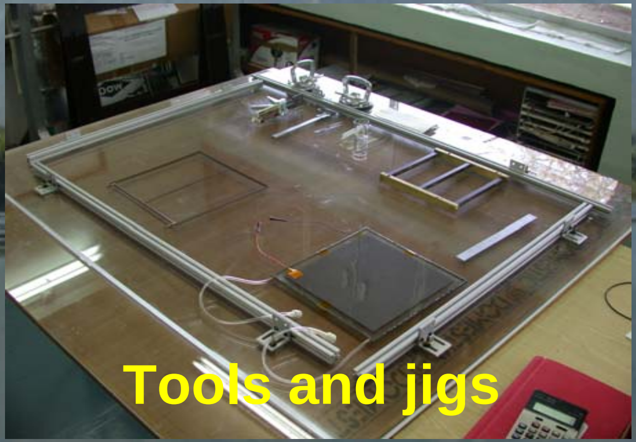


Glass plates

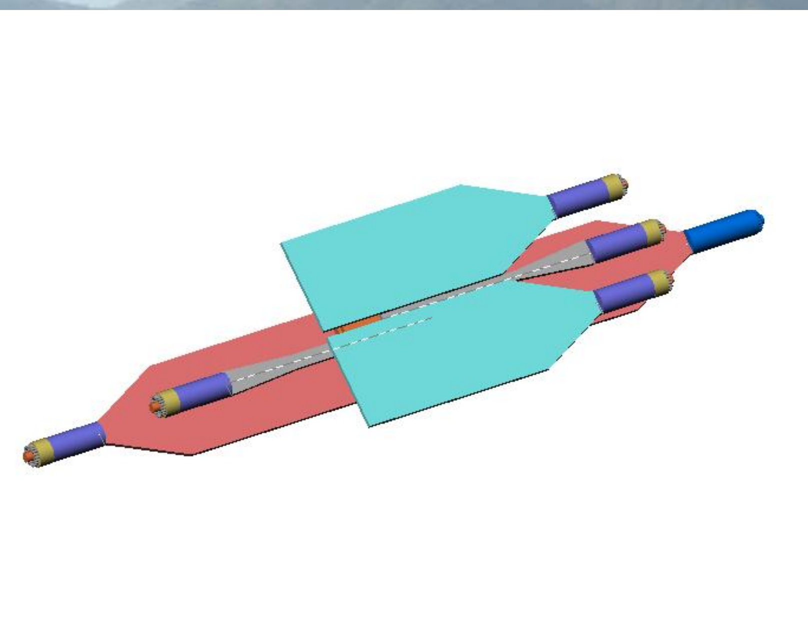
Resistive coating on the outer surfaces of glass

First RPC lab at TIFR

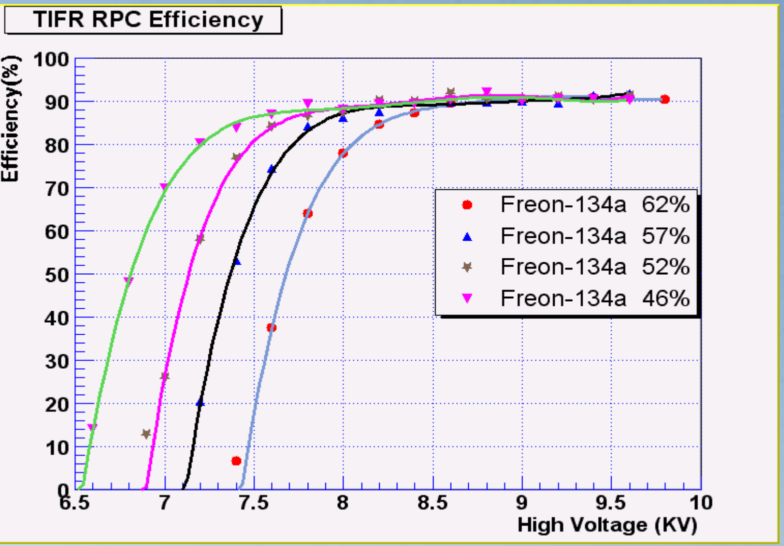


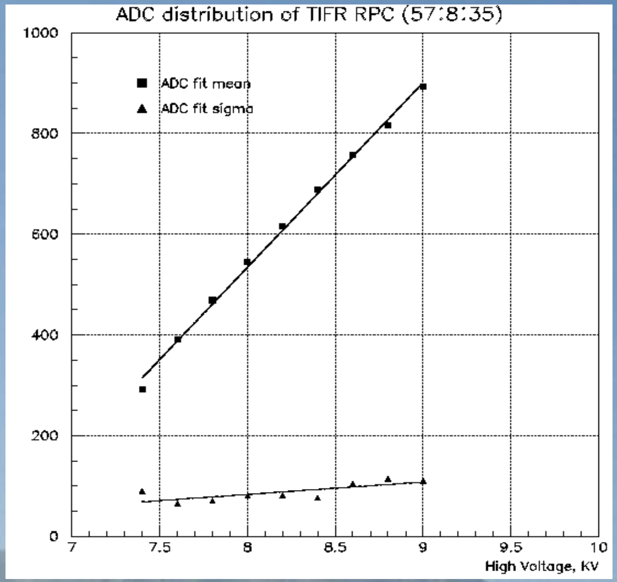


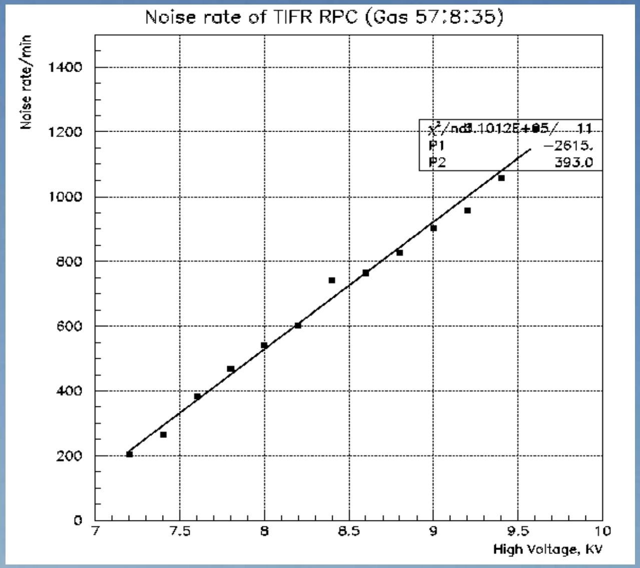
RPC Test Stand

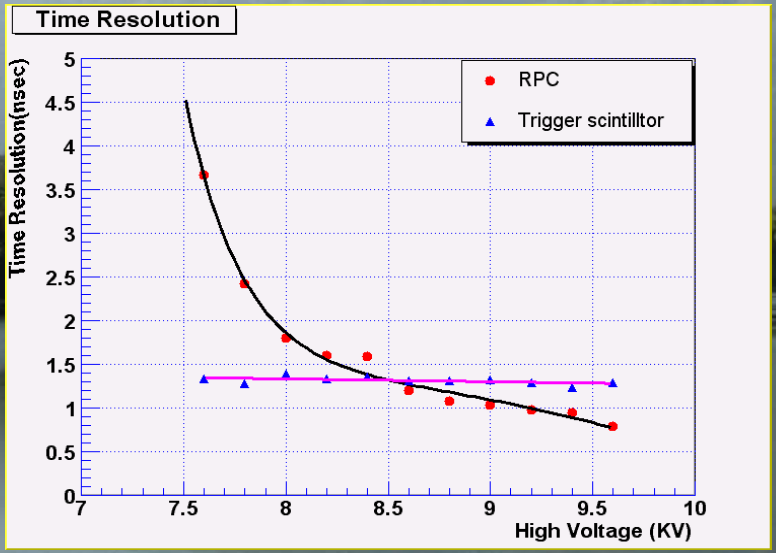


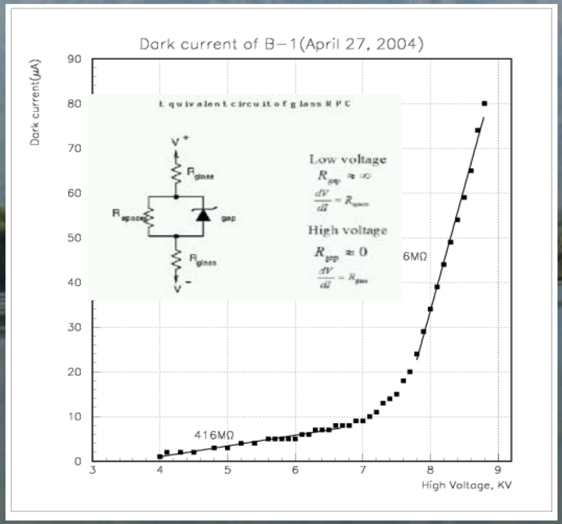
Early results





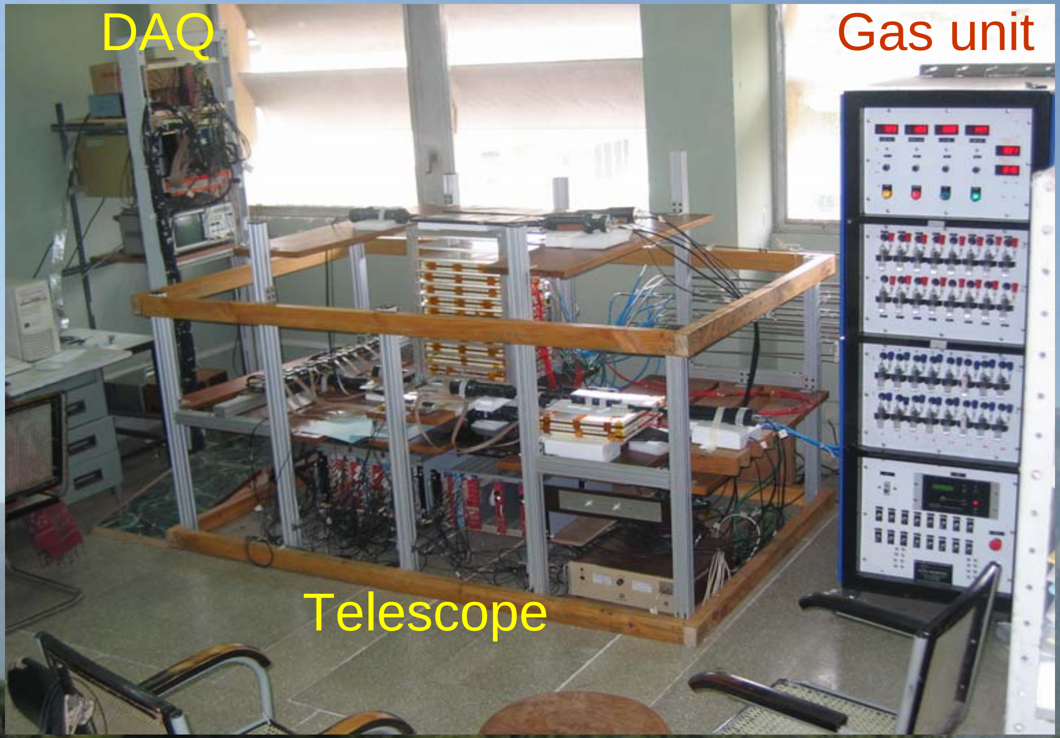


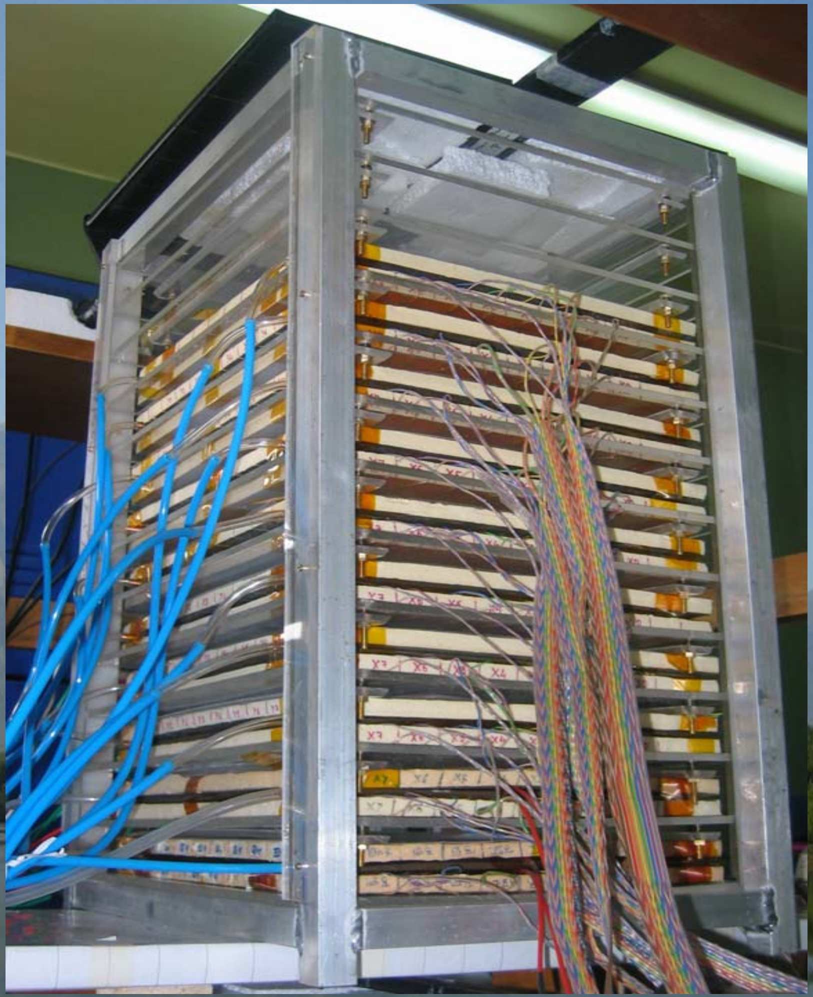




Gas Mixture	Tele window (mm)	Cross talk (%)
62:8:30	10	6.8
62:8:30	15	6.7
62:8:30	20	6.2
57:8:35	20	6.5
52:8:40	20	5.9
46:8:46	20	6.3

Cosmic Muon Test using small RPCs

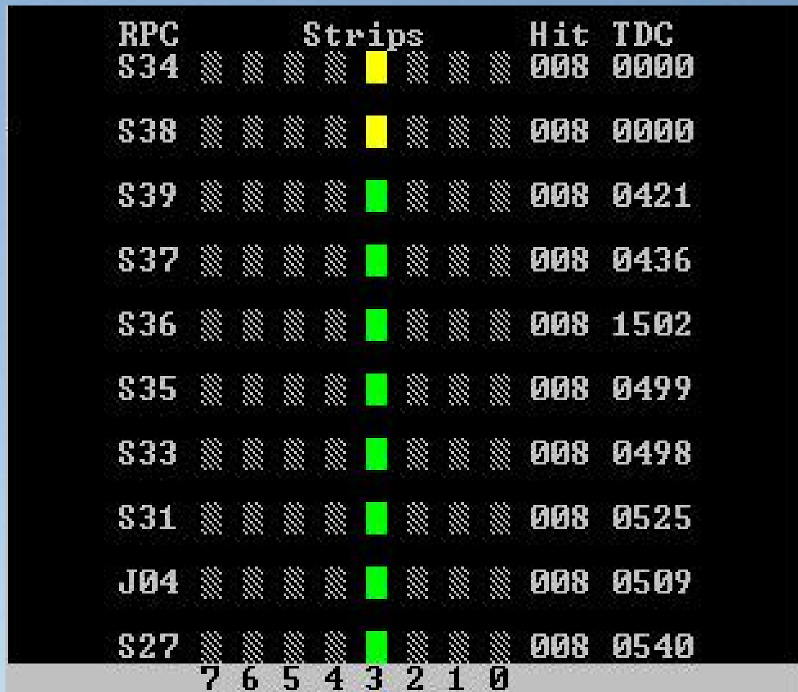


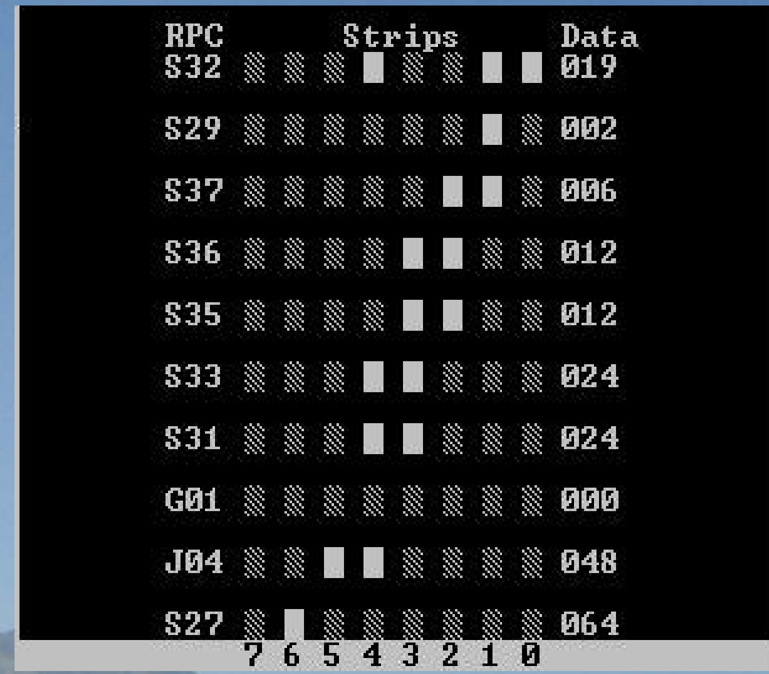


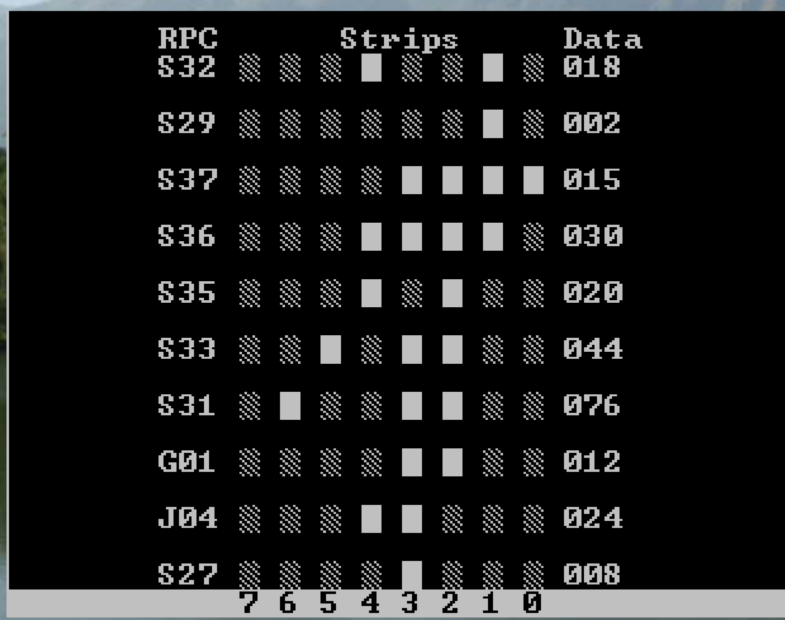
Stack of 10 RPCs

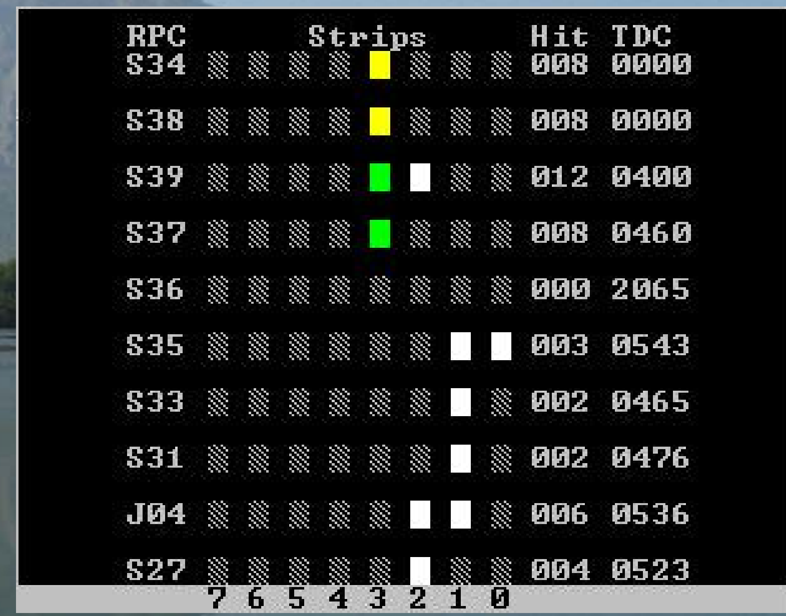
- Streamer mode (R134a=62%, Argon=30% and the rest Iso-Butane)
- Recording hits, timing, noise rates etc

Some interesting events tracked

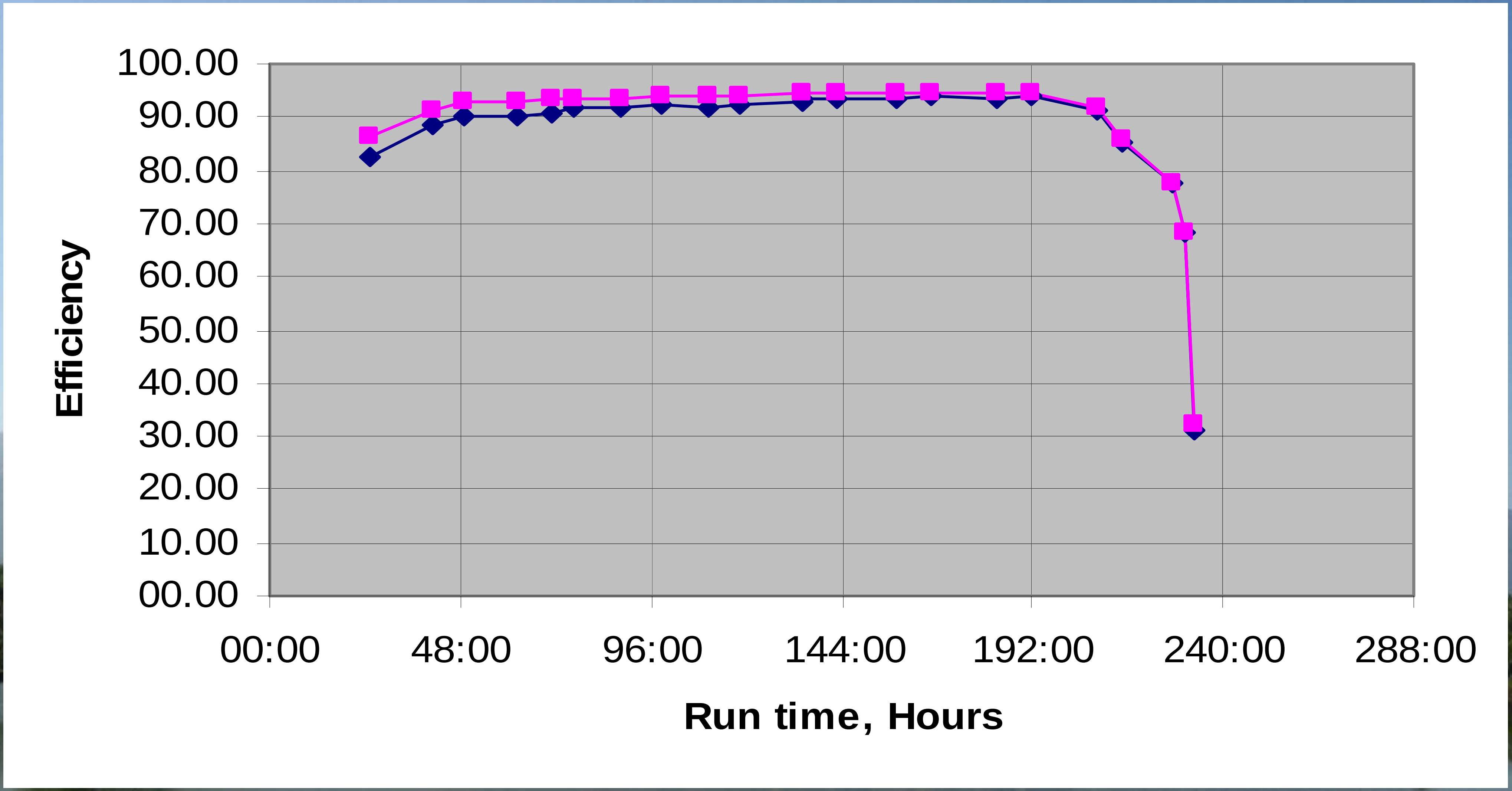






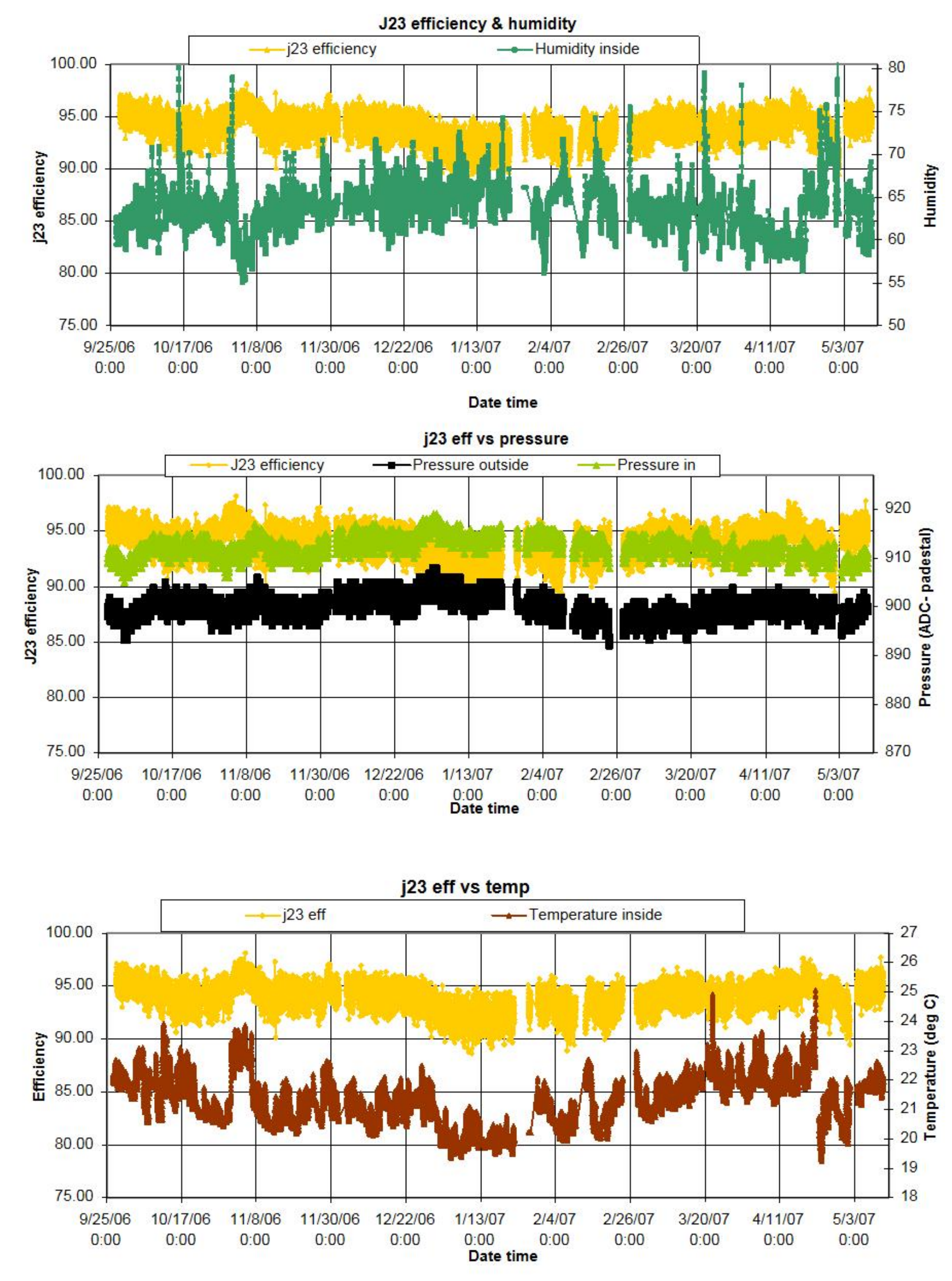


Aging: Efficiency drop of a RPC



Long-term stability tests of RPCs

- Two RPCs (J2 & J3) built using 2mm Japanese glass for electrodes
- Readout by a common G-10 based signal pickup panel sandwiched between the RPCs
- Operated in avalanche mode (R134a: 95.5% and the rest isobutene) at 9.3KV
- Round the clock monitoring of RPC and ambient parameters – Temperature, Relative humidity and Barometric pressure
- Under continuous operation for more than two years.
- Chamber currents, noise rate, combined efficiencies etc are stable



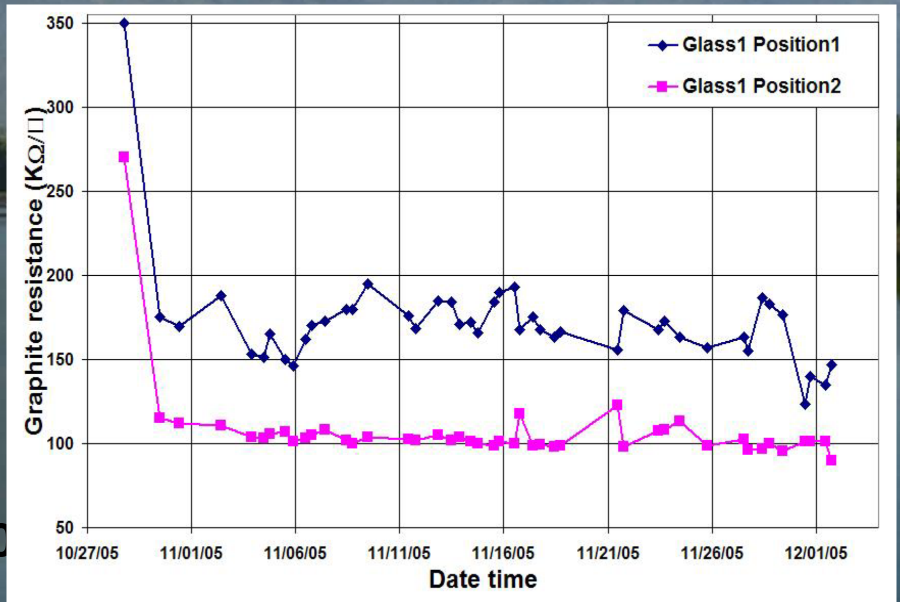
Painting with conductive paint on Glass

Paint developed by KANSAI-NEROLAC composition :

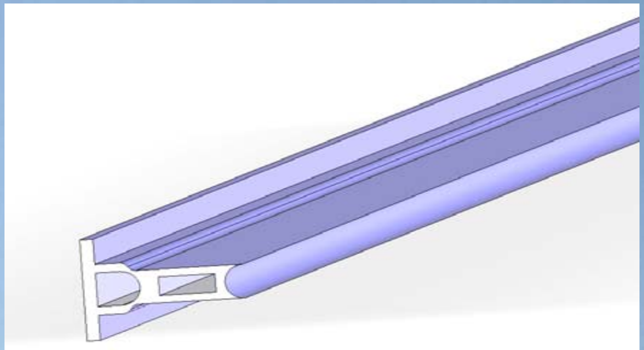
(i) Binder (acrylic resin),

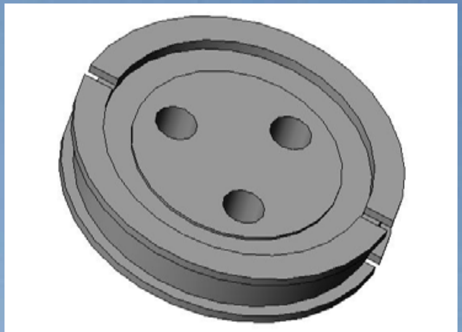
(ii) Pigments (conductive black),

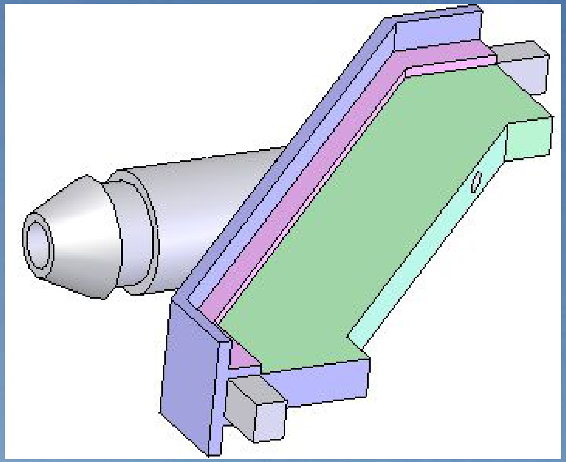
(iii) solvents (Aromatic hydrocarbons and alcohols).

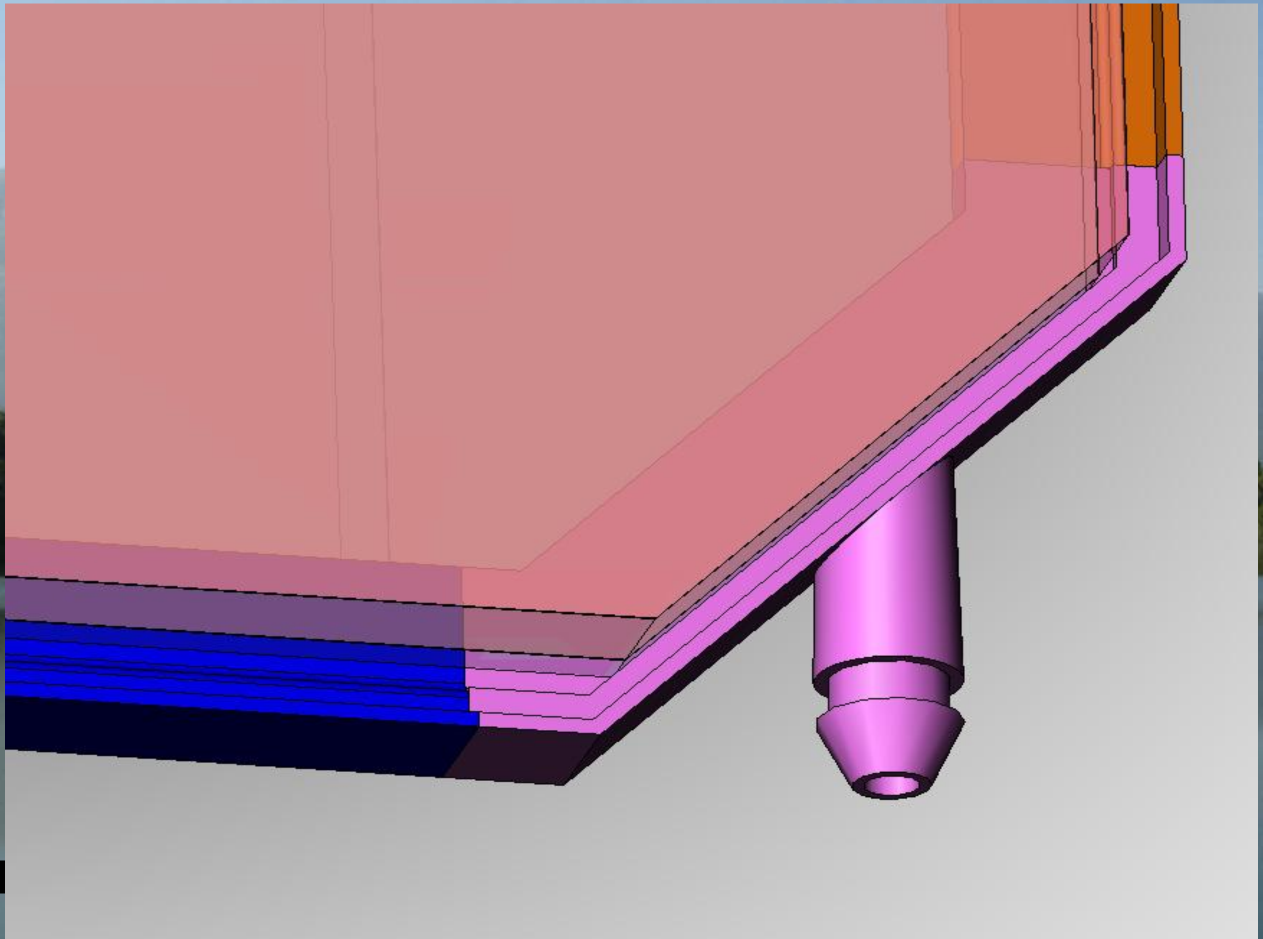


RPC building blocks



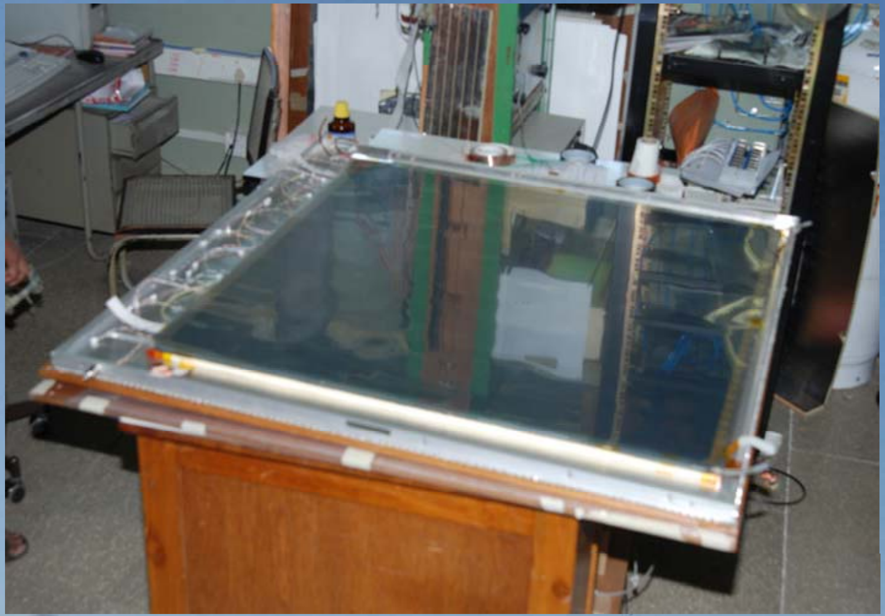




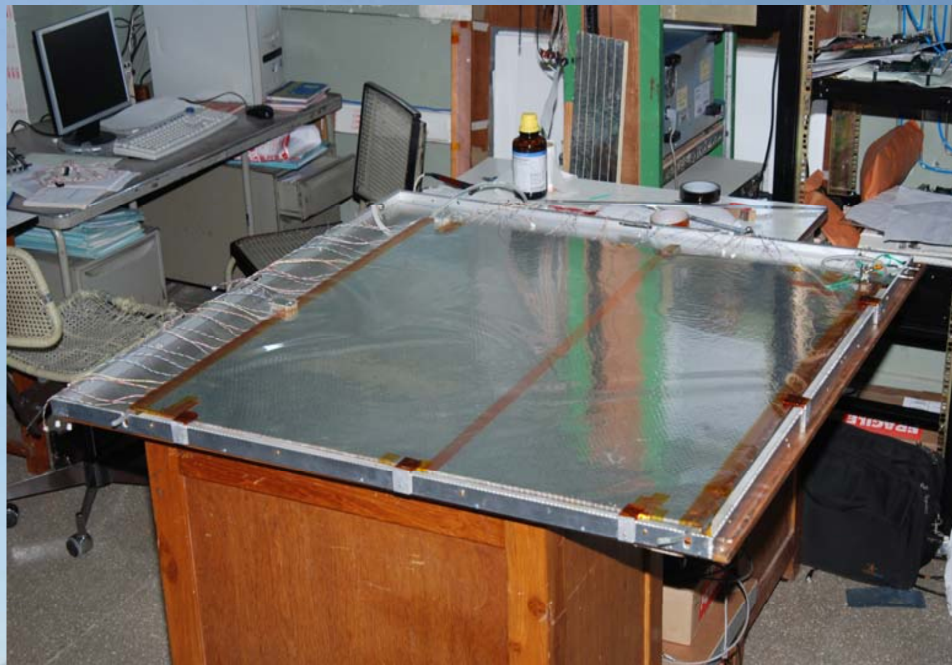


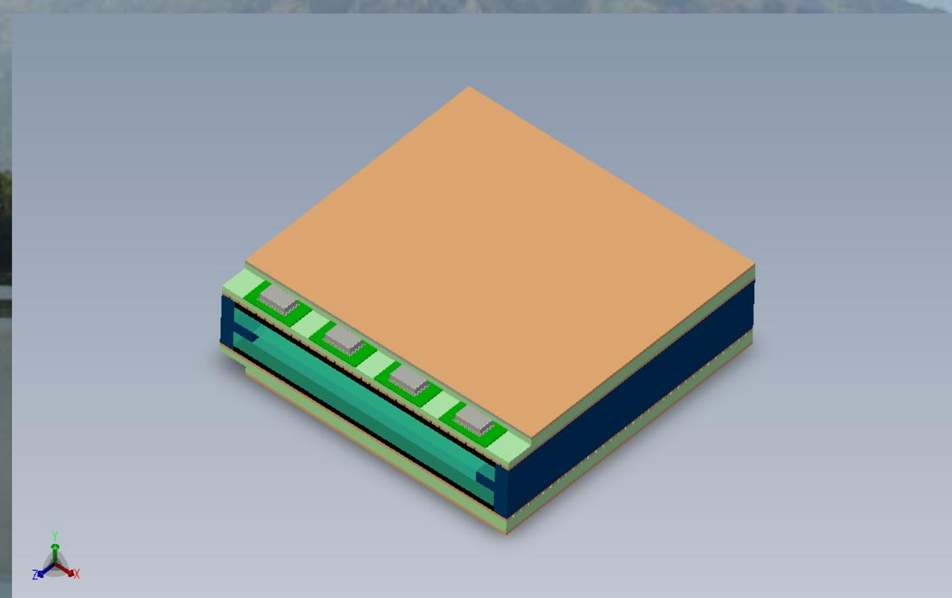
Making of RPC gap

RPC fabrication

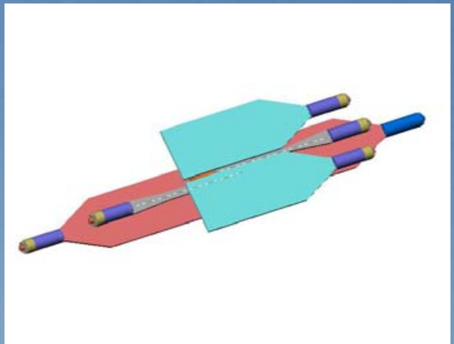


RPC Fabrication



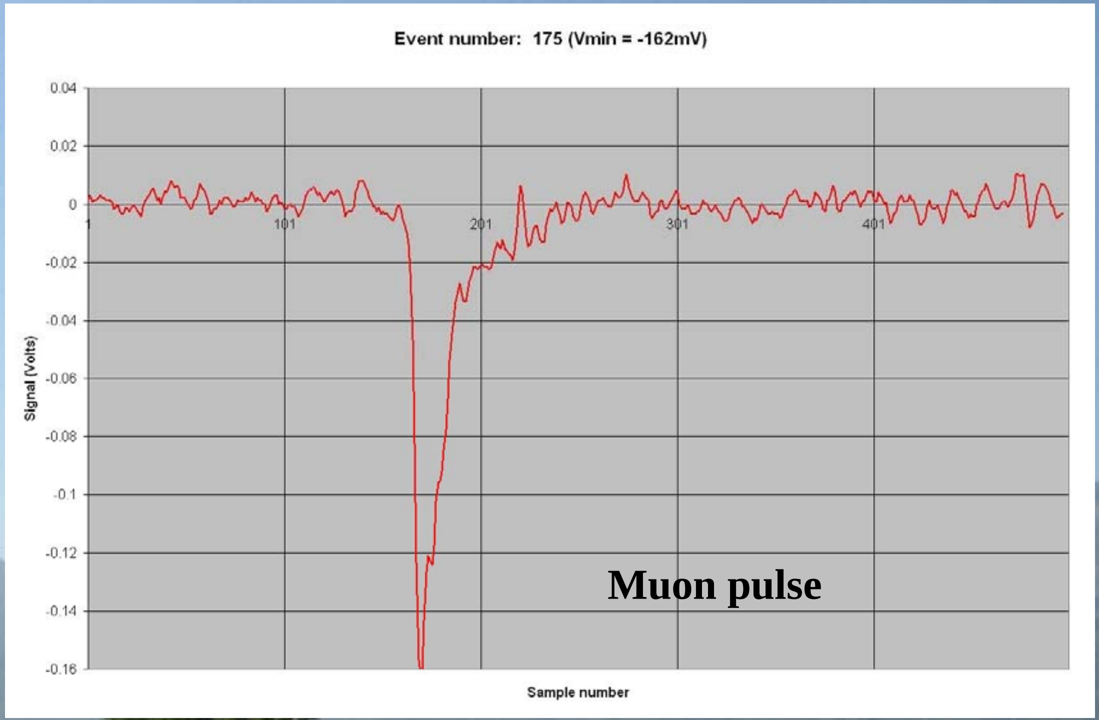


Testing of Large Area RPCs using cosmic ray muons

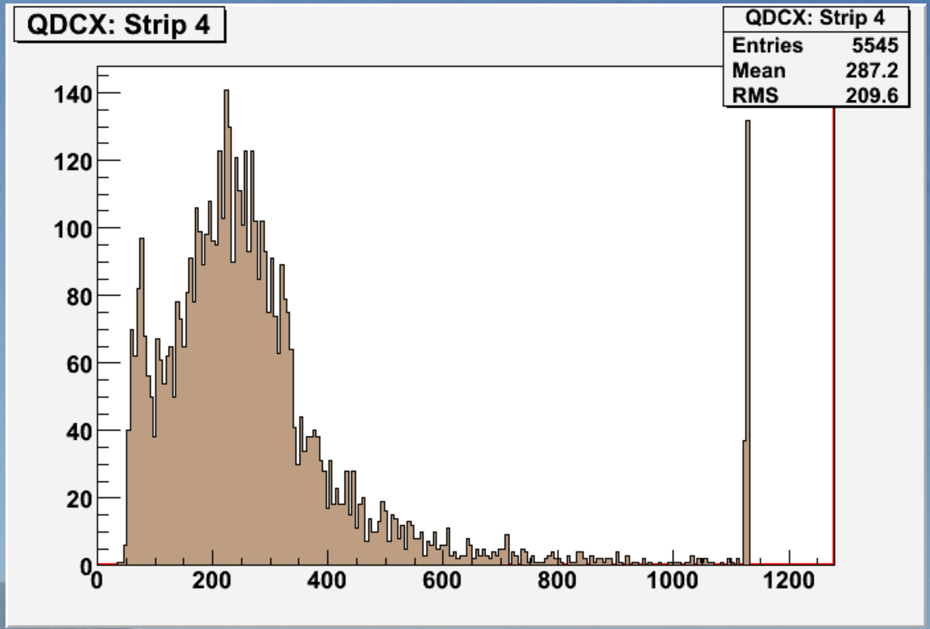


Trigger Scintillators

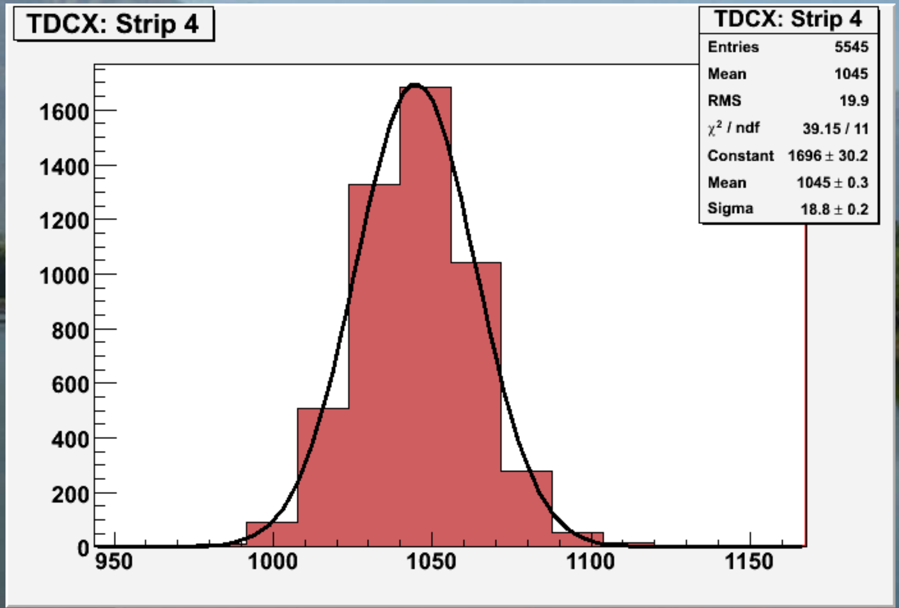
Signal from RPC



Muon pulse

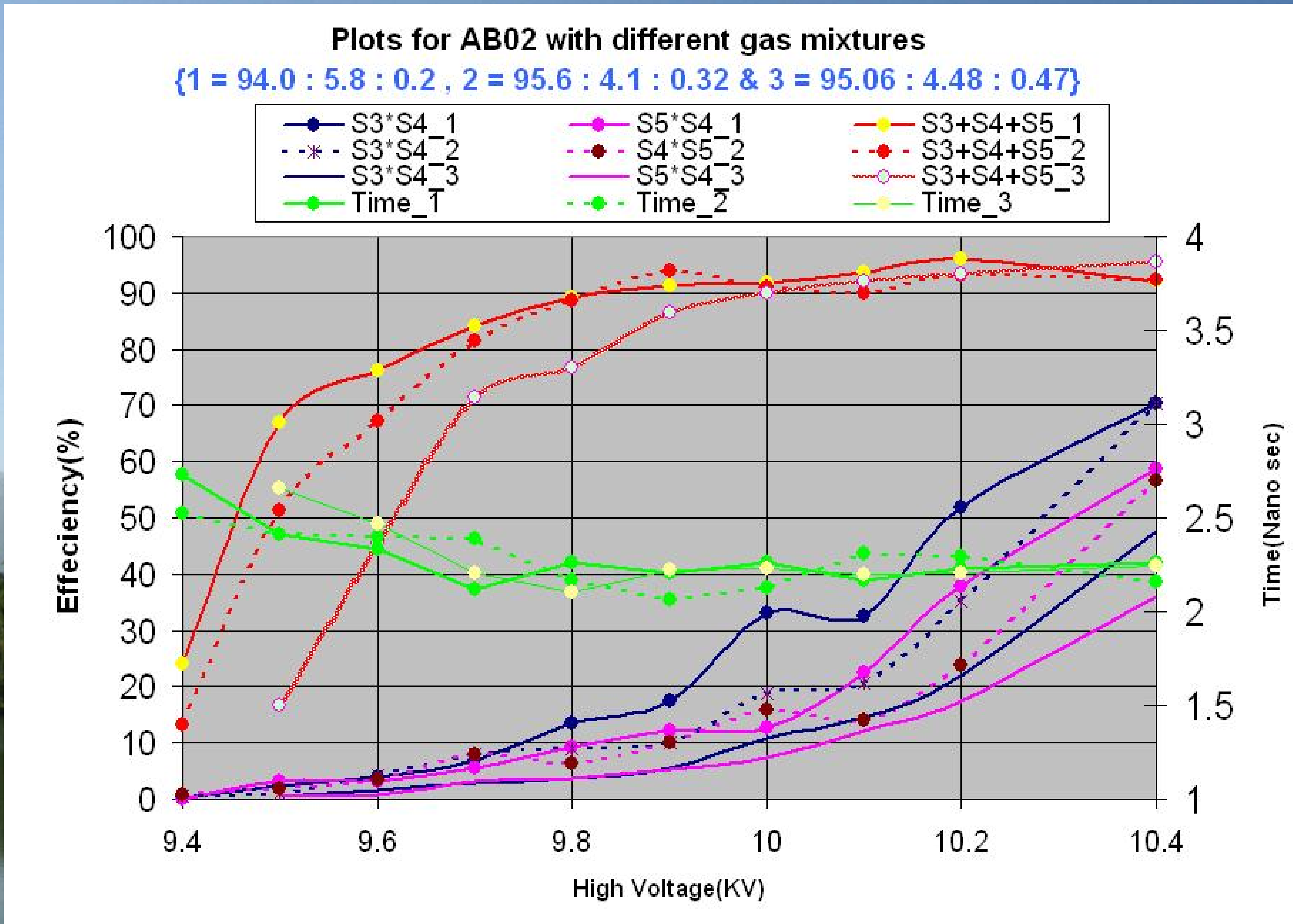


Charge distribution

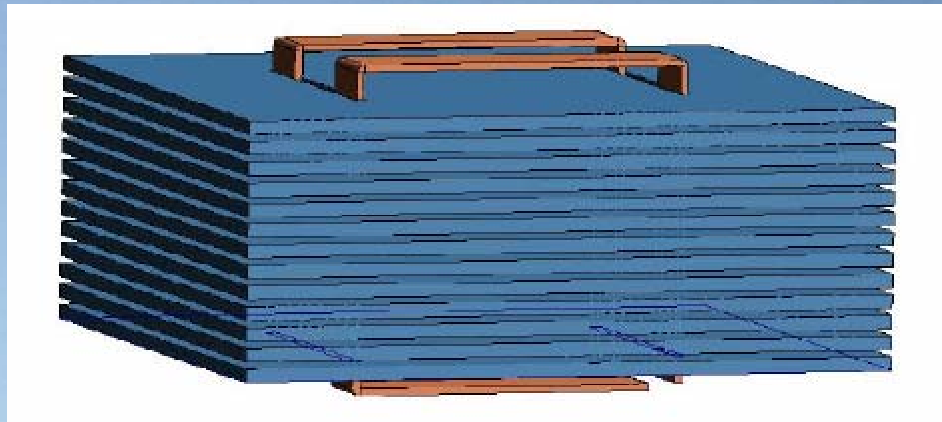


Timing distribution

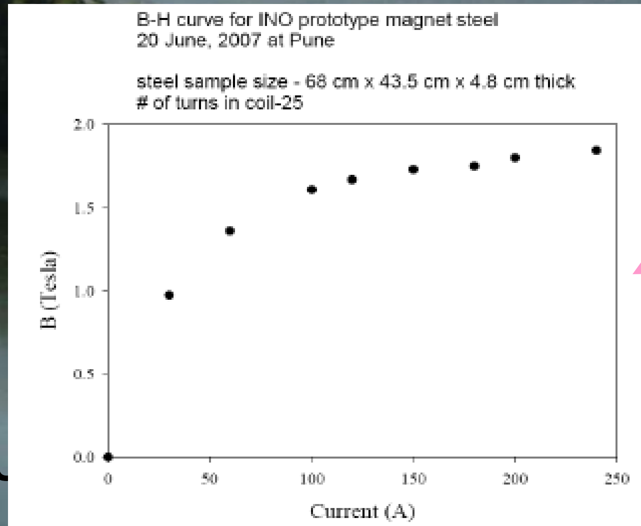
Effect of SF_6 on efficiency & cross talk



INO Prototype



- *12, 1m^2 RPC layers*
- *13 layers of 5 cm thick magnetised iron plates*
- *About 1000 readout channels*
- *RPC and scintillation paddle triggers*
- *Hit and timing information*

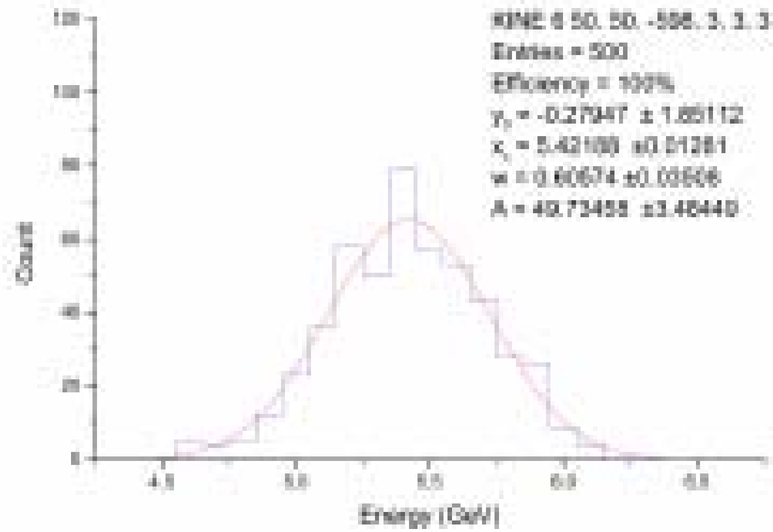


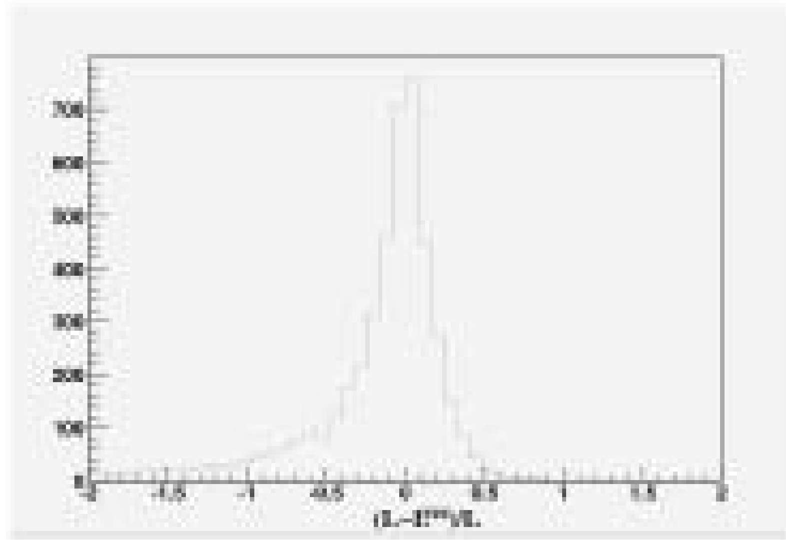
INO Simulations

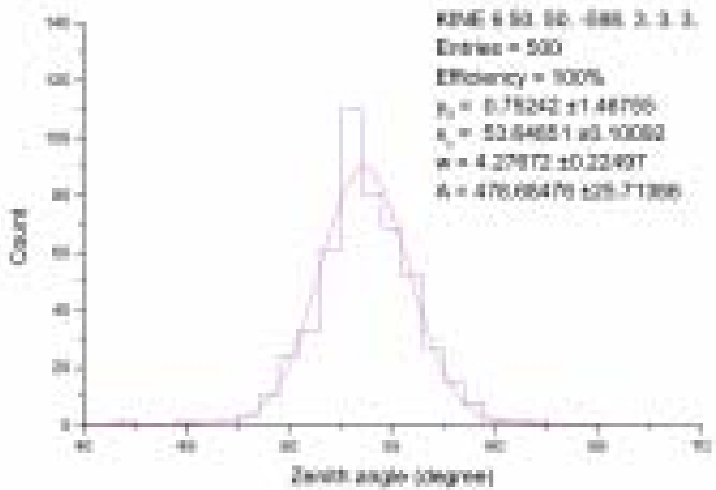
Detector Simulation

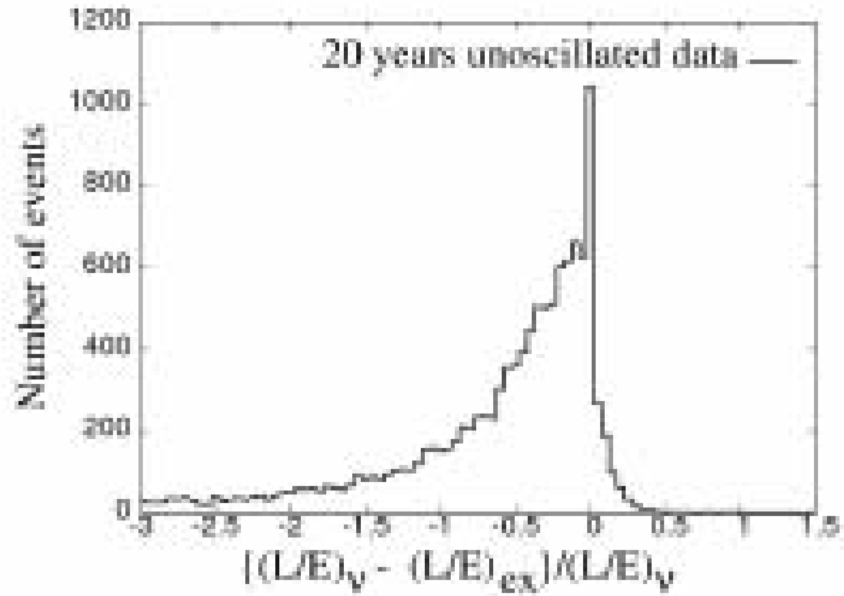
- *Used NUANCE Neutrino Event Generator*
  - *Generate atmospheric neutrino events inside INO detector*
- *Used Atmospheric Neutrino Flux of Honda et. al.*
- *GEANT detector simulation package*
  - *Simulate the detector response for the neutrino even*
- *Analysed oscillation data at two levels*
  - *Using NUANCE output and kinematic resolution function*
  - *Using full detector simulation*
- *Obtained preliminary results so far. Detailed simulation is underway.*

Some simulation results

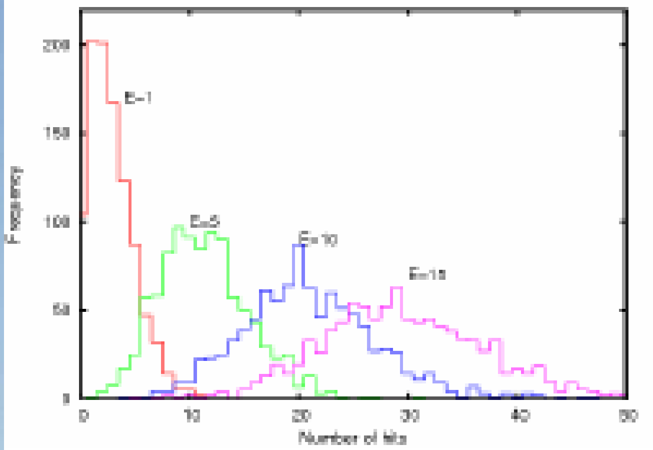


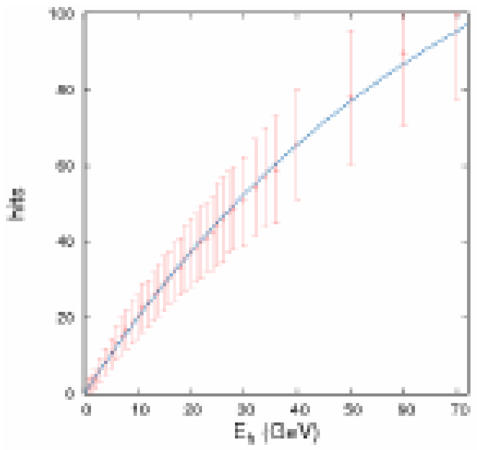


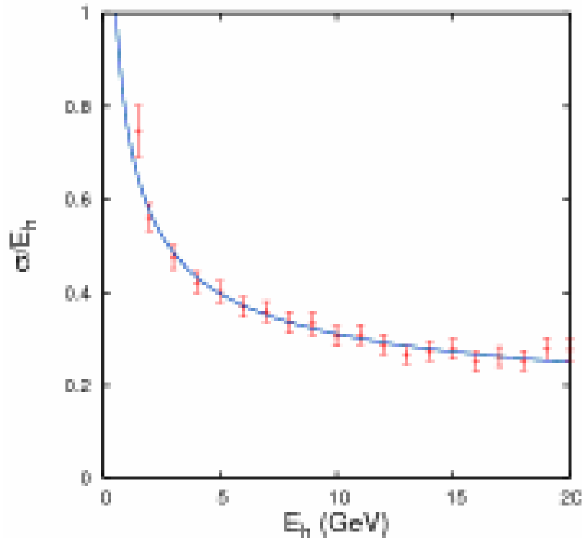




Hadron Response

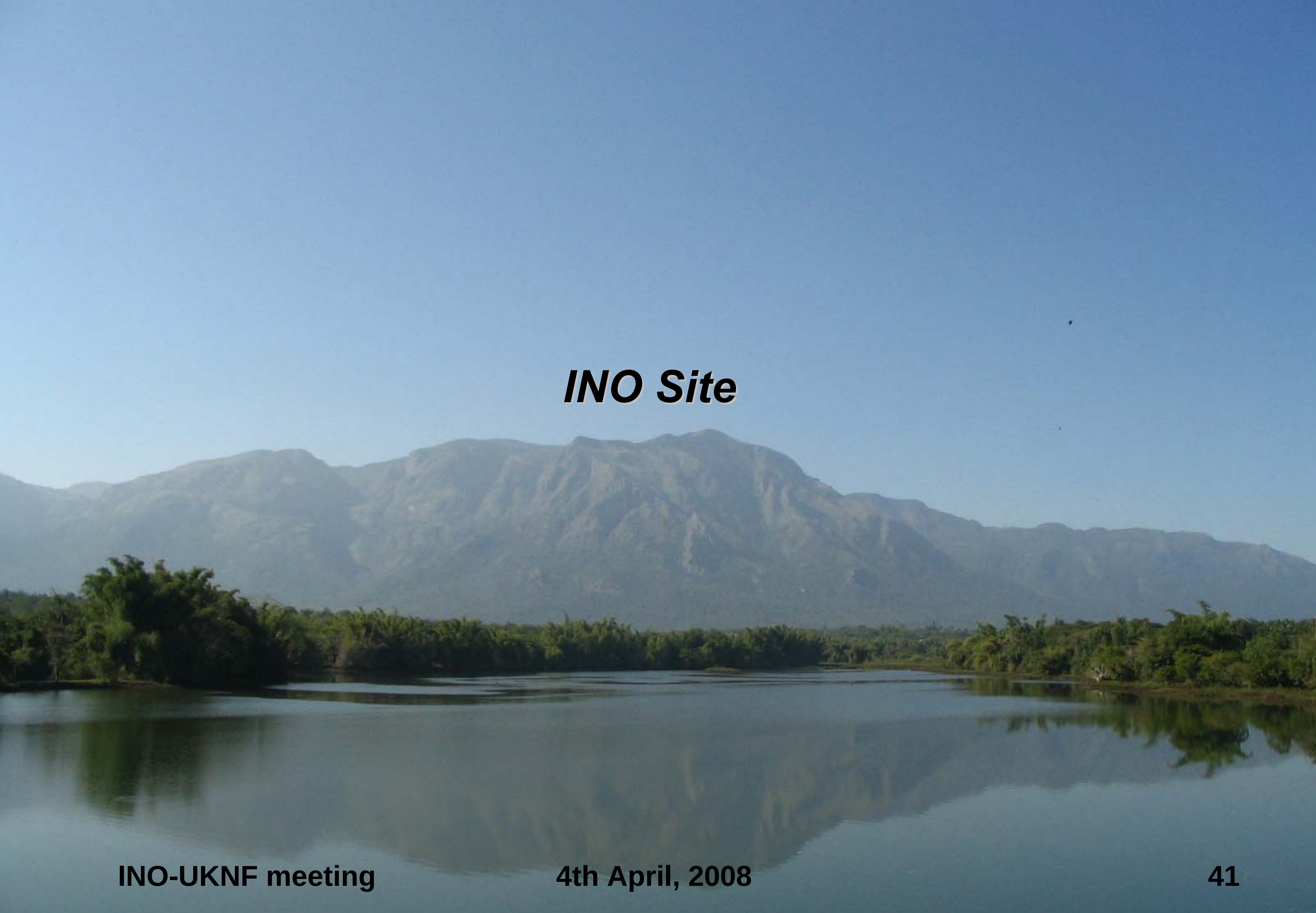






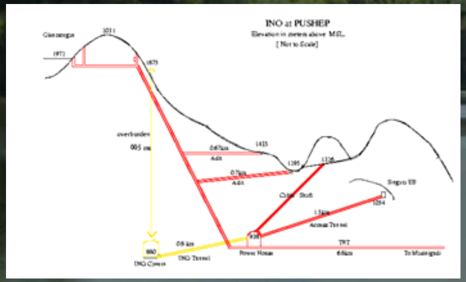
Pions of different fixed energies but random directions (1 K events)

INO Site



Location of the Underground Laboratory

- ***Studies were performed on two potential sites.***
  - ***Pykara Ultimate Stage Hydro Electric Project (PUSHEP) at Masinagudi, Tamilnadu***
  - ***Rammam Hydro Electric Project Site at Darjeeling District in West Bengal***
- ***INO Site Selection Committee after thorough evaluation have now recommended PUSHEP at Tamilnadu as the preferred site for the underground lab.***




INDIA
States and Union Territories
N
PAKISTAN
CHINA (TIBET)
NEPAL
BHUTAN
BANGLADESH
MYANMAR
ARABIAN SEA
BAY OF BENGAL
JAMMU & KASHMIR
Srinagar
HIMACHAL PRADESH
Shimla
Chandigarh
PUNJAB
UTTARANCHAL
Dehradun
HARYANA
DELHI
RAJASTHAN
Jaipur
UTTAR PRADESH
Lucknow
SIKKIM
Gangtok
ARUNACHAL PRADESH
Itanagar
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Aizawl
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DIU
DAMAN
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Hyderabad
ANDHRA PRADESH
YANAM (Pondicherry)
Panaji
GOA
KARNATAKA
Bangalore
Chennai (Madras)
PONDICHERRY (Puduchchery)
KARAIKAL (Pondicherry)
TAMILNADU
LAKSHADWEEP
MAHE (Pondicherry)
KERALA
Thiruvananthapuram
Port Blair
ANDAMAN & NICOBAR ISLANDS
Location of INO
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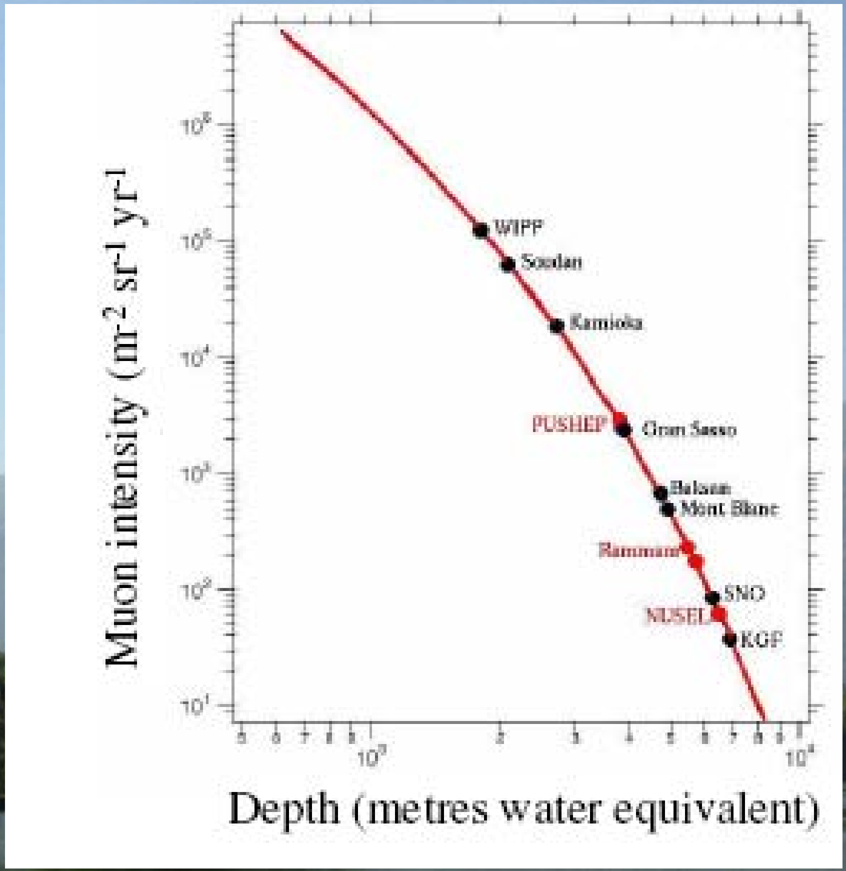
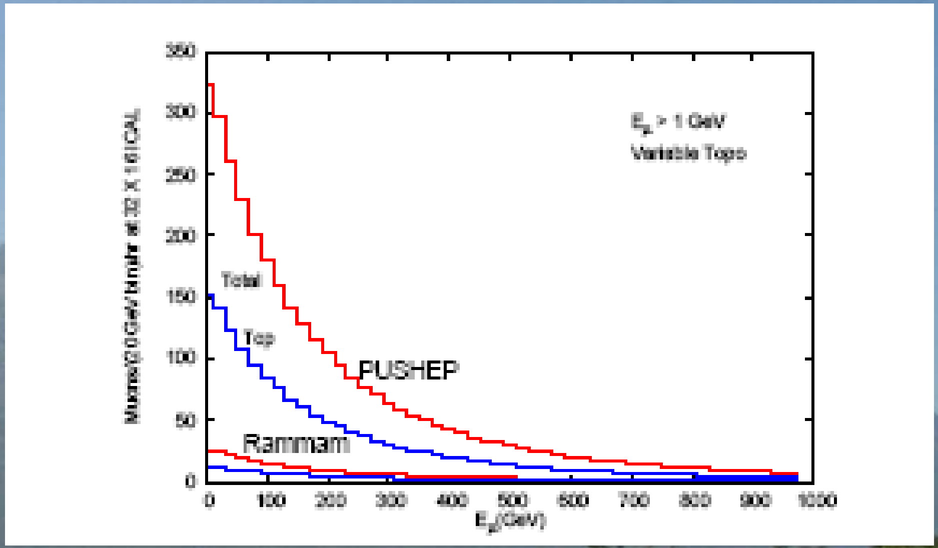
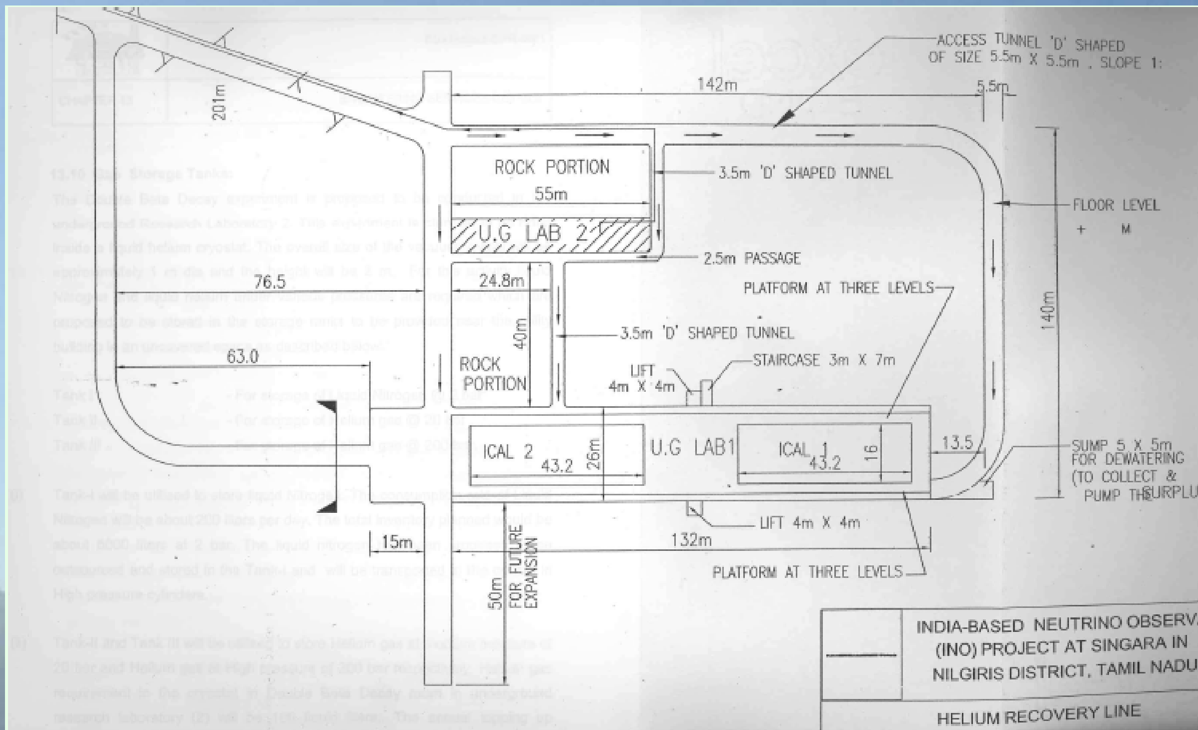
Map not to Scale

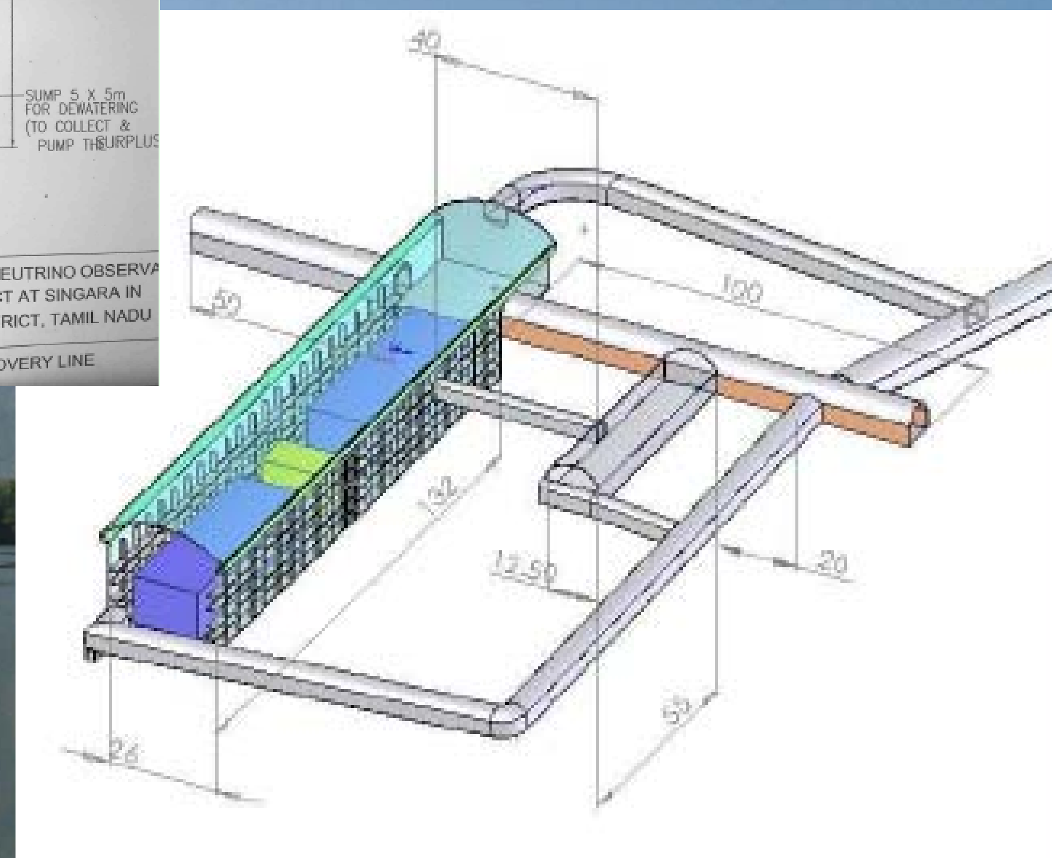
Expected Background





Underground Caverns: Schematics





Time Scale

- **Phase I: 12-18 months:**
  - *Draw up detailed design report for tunnel and cavern*
  - *Detailed design report on detector structure, RPCs, pickup electrodes, electronics & power supply system*
- **Phase II : 22-40 months:**
  - *Tunnel & cavern construction*
  - *RPC R & D and construction*
  - *Tendering and procurement of iron, magnet coil*
  - *Electronics and gas mixing unit procurement and fabrication*
- **Phase III: 12-18 months**
  - ***Laboratory outfitting***
  - ***Transporting of materials***
  - ***Assembly***
  - ***Data taking of first module start early while assembly of other modules continue***

Expected to start the first module by 2012

Center for Detector Development

- *Particle detectors developed by High Energy & Nuclear Physicists have found application in medical imaging, material science, industrial control, geological survey.*

- *Apart from exciting physics, detector development itself will be a major activity of this centre.*

- *Need a focused approach with a well coordinated group of people working on detector development.*

- *INO Centre can play the role of coordinating such activities through joint R & D efforts on detector development with other laboratories around the world.*

- *Need close interaction with industry.*

INO Graduate Training Programme

- ***A large number of well trained Physicists and Engineers will be needed to lead the experimental activities in high energy and astroparticle physics to be carried out using INO facility.***
- ***We plan to start a graduate training programme from August 2008.***
- ***Selected students will be initially trained for one year at TIFR, Mumbai in both experimental techniques and theory.***
- ***Successful candidates after the training will be attached to Ph.D. guides at various collaborating institutions for a Ph. D. degree.***

INO Time Line

- *INO Interim Project Report was presented to DAE and DST on 1 May, 2005.*
- *A presentation on INO proposal was made to SAC-PM in August 2005.*
- *The proposal was recommended by the Indian HEP-NP community at a meeting at Mumbai in March 2006 sponsored jointly by DAE and DST to define the road map for High Energy and Nuclear Physics research in India.*
- *It was discussed in the Mega Science Committee set up by Planning Commission in September, 2006 and recommended for funding in the XI th 5 year plan starting from April 07.*

International review

- *INO proposal was sent for review to a panel of international referees consisting of.*
- *Prof. Yoji Totsuka KEK, Japan*
- *Prof. A. Betini INFN, Padova*
- *Prof. John Learned Univ. of Hawaii*
- *Prof. Raju Raghavan Verginia Tech.*
- *Dr. S. S. Kapoor BARC, Mumbai*
- *Prof. Subir Sarkar Oxford University*

Project Status

- *INO-Engineering task force has prepared a Detailed Project Report (DPR) on the INO cavern and surface lab . We have approached environment and forest departments for necessary clearances.*
- *An Engineering consulting firm is preparing the DPR for the detector structure. It is at the final stage.*
- *A prototype magnet is now ready .*
- *Identification of sources for various components needed for mass production of glass RPCs is in progress.*
- *DAQ system for the prototype detector is now under test.*
- *Long term stability test of RPCs both in avalanche mode and in streamer mode will continue.*
- *A new centre will take charge of the INO related activities soon.*

Approval Status

- *DAE has given its approval for the project. This is an "in principle" approval.*
- *The requested funding for the current plan period ending in March 2012 has been allocated by Indian Planning Commission.*
- *Detailed Project Report giving our year wise funding request is required for the sanction of the construction money.*
- *DPR is in the approval chain.*
- *Expected to take few more months.*

Summary

- *A large magnetised detector of 50-100 Kton is needed to achieve some of the very exciting physics goals using atmospheric neutrinos.*
- *Physics case for such a detector is strong.*
- *It will complement the existing and planned water cherenkov detectors.*
- *Can be used as a far detector during neutrino factory era.*
- *We will soon complete the R & D phase and begin construction of the INO facility and the ICAL detector.*
- *Looking forward for international participation.*

For more information on INO please visit the website www.imsc.res.in/~ino

Thank You