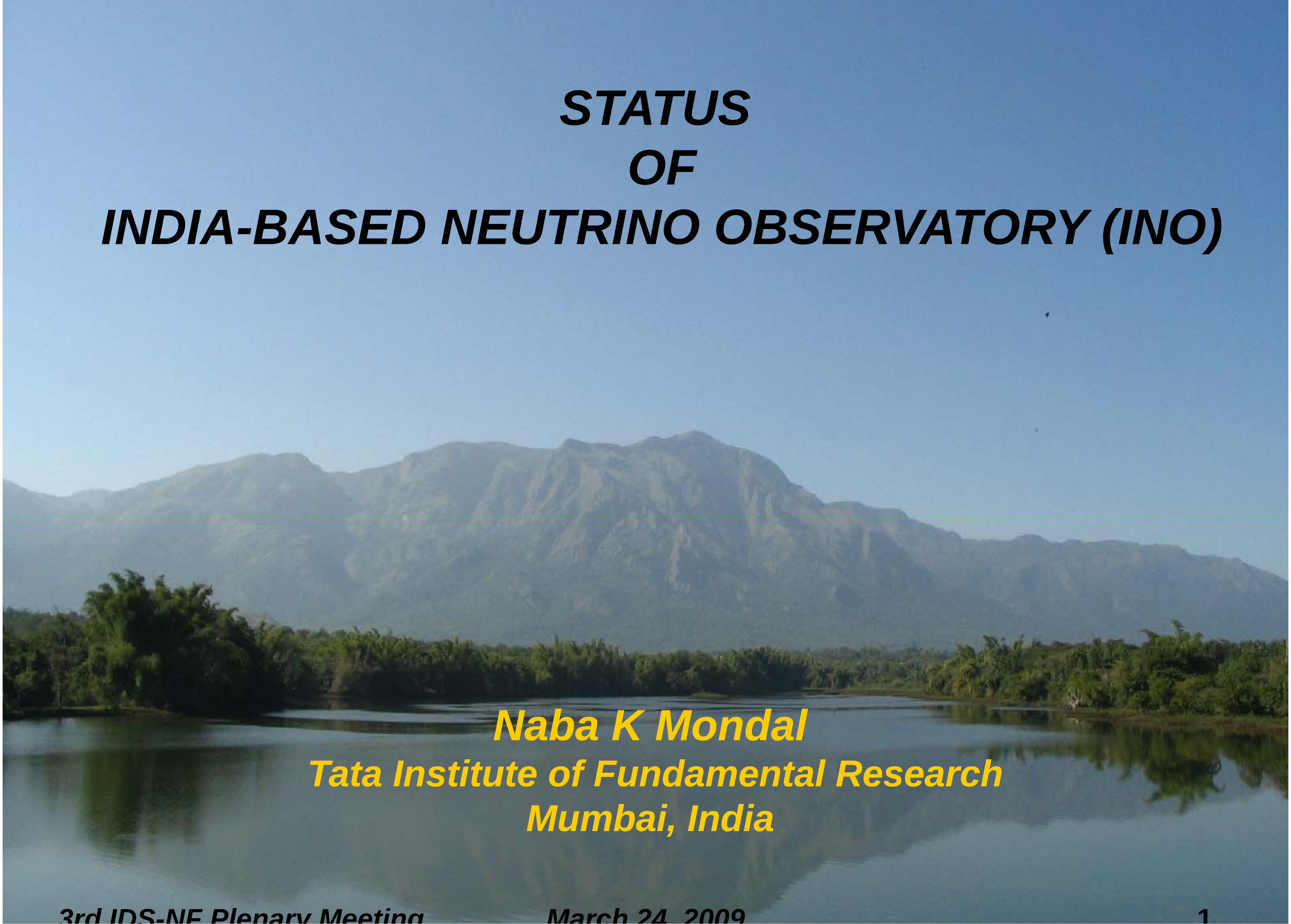


STATUS
OF
INDIA-BASED NEUTRINO OBSERVATORY (INO)

Naba K Mondal
Tata Institute of Fundamental Research
Mumbai, India

India-based Neutrino Observatory Project

- India-based Neutrino observatory is a Mega Science Project funded by Dept. of Science & Technology and Dept. of Atomic Energy, Govt. of India . The project will lead to:
- Creation of an underground laboratory in India for carrying out research in the emerging field of neutrino physics. Will develop into a full fledged underground laboratory over the years for other studies in physics, biology & geology.
- Involvement of Universities in a big way for carrying out large basic science projects- healthy development of University-Research lab partnership.
- A Centre for particle physics and detector technology and its varied applications in areas like medical imaging.
- INO graduate training program will lead to Ph.D. in particle physics and more importantly creating highly skilled scientific manpower for experimental high energy and nuclear physics. Hands on training on all aspect of experiments with strong emphasis on detector development.

INO-ICAL Collaboration

- *Aligarh Muslim University*
- *Banaras Hindu University*
- *Bhabha Atomic Research Centre*
- *Calcutta University*
- *Delhi University*
- *Harish Chandra Research Institute*
- *University of Hawaii*
- *Himachal Pradesh University*
- *Indian Institute of Technology, Chennai*
- *Indian Institute of Technology, Guwahati*
- *Indian Institute of Technology, Mumbai*
- *Indira Gandhi Center for Atomic Research,*
- *The Institute of Mathematical Sciences*
- *Institute of Physics*

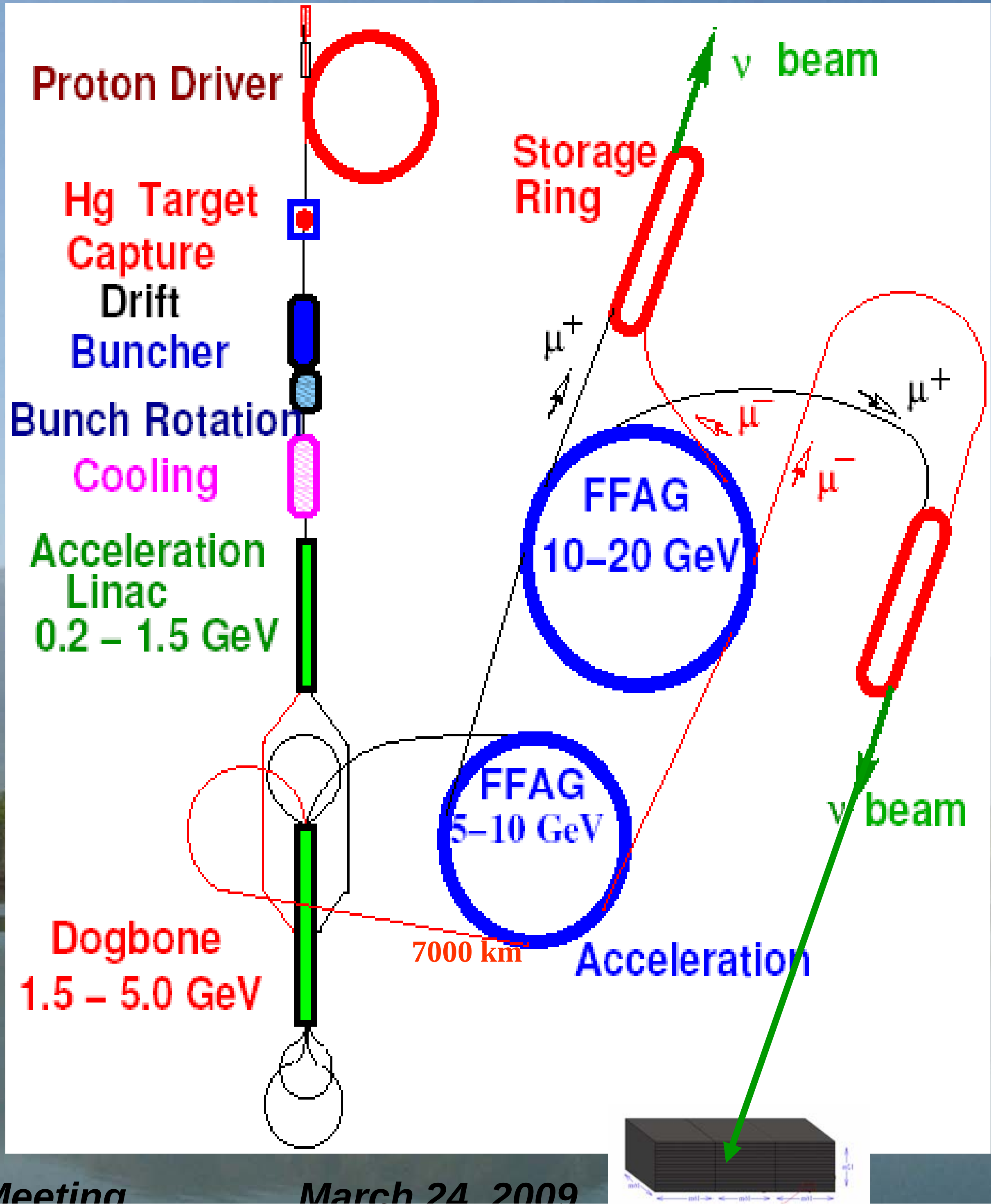
- *University of Jammu*
- *Jamia Millia Islamia University*
- *University of Kashmir*
- *University of Mysore*
- *Panjab University*
- *Physical Research Laboratory*
- *Saha Institute of Nuclear Physics*
- *Sambalpur University*
- *Sikkim Manipal Institute of Technology*
- *Tata Institute of Fundamental Research*
- *Variable Energy Cyclotron Centre*

25 institutions currently in INO-ICAL collaboration

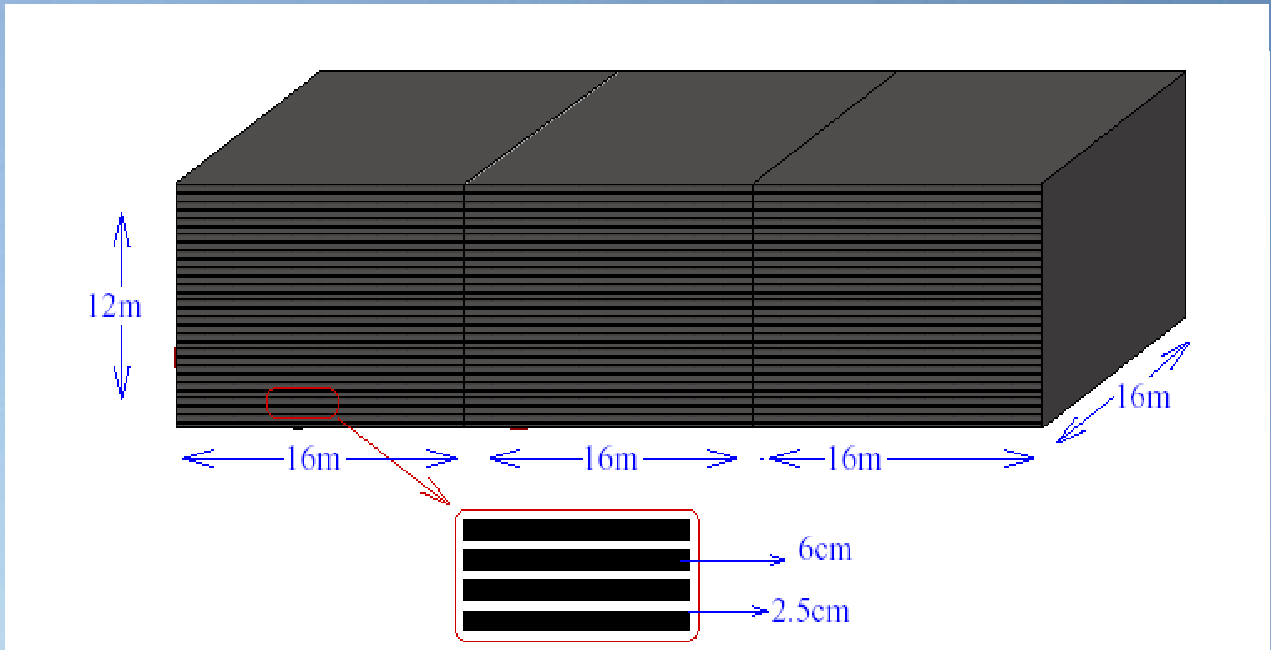
Physics using atmospheric neutrinos during Phase I

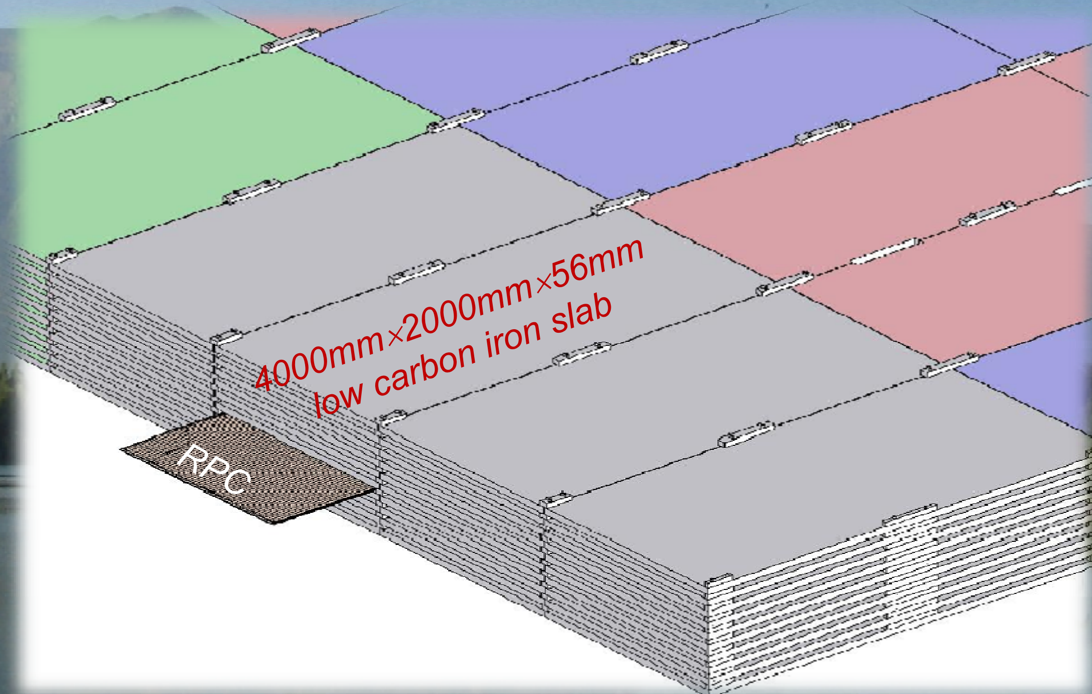
- *Reconfirm atmospheric neutrino oscillation*
- *Improved measurement of oscillation parameters*
- *Search for potential matter effect in neutrino oscillation*
- *Determining the sign of Δm^2_{23} using matter effect*
- *Measuring deviation from maximal mixing for θ_{23}*
- *Probing CP and CPT violation*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

Beyond Superbeam - Neutrino Factory



INO ICAL Detector Concept





ICAL detector Structure

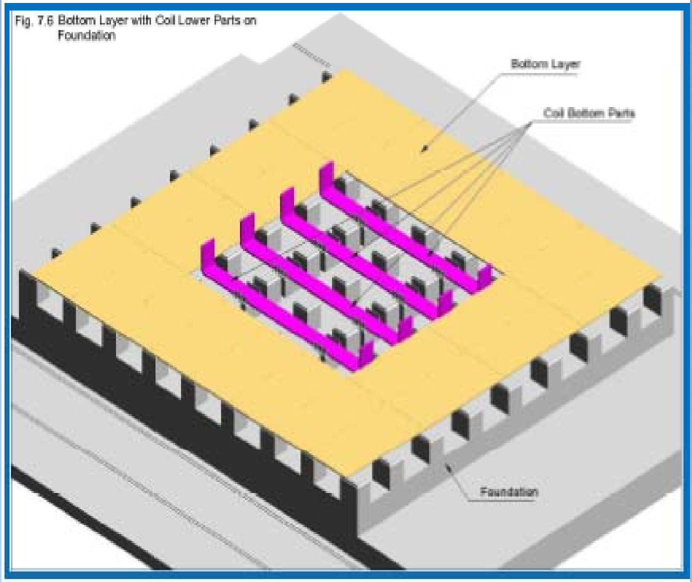


Fig. 7.6 Bottom Layer with Coil Lower Parts on Foundation

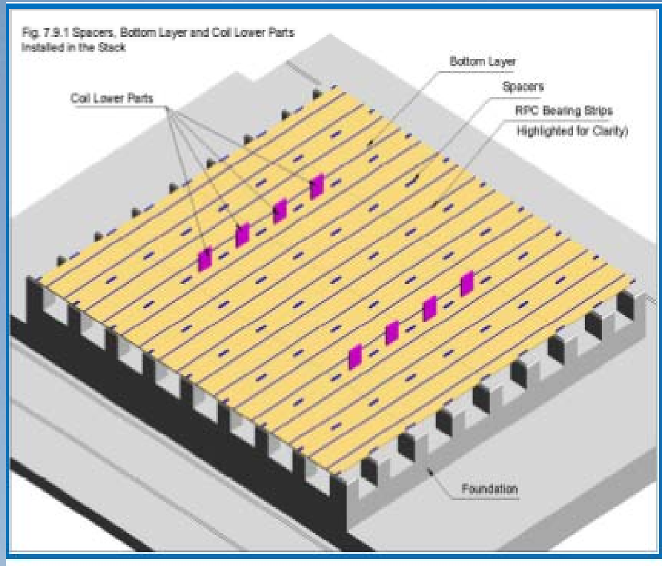


Fig. 7.9.1 Spacers, Bottom Layer and Coil Lower Parts Installed in the Stack

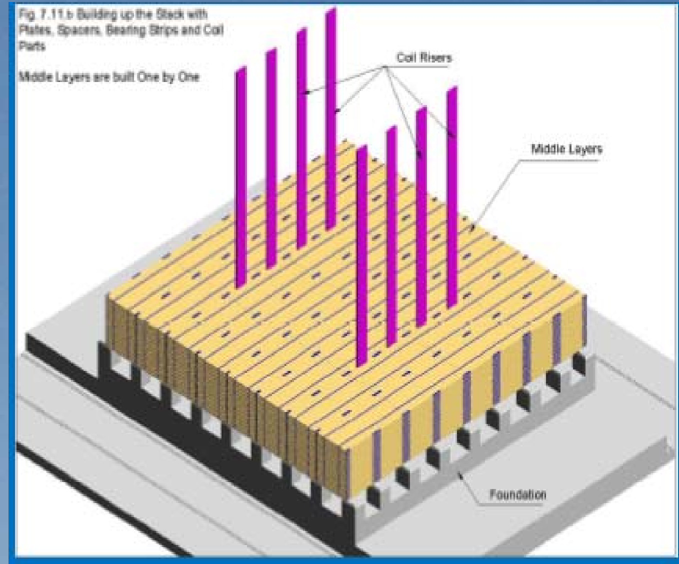


Fig. 7.11.b Building up the Stack with Plates, Spacers, Bearing Strips and Coil Parts

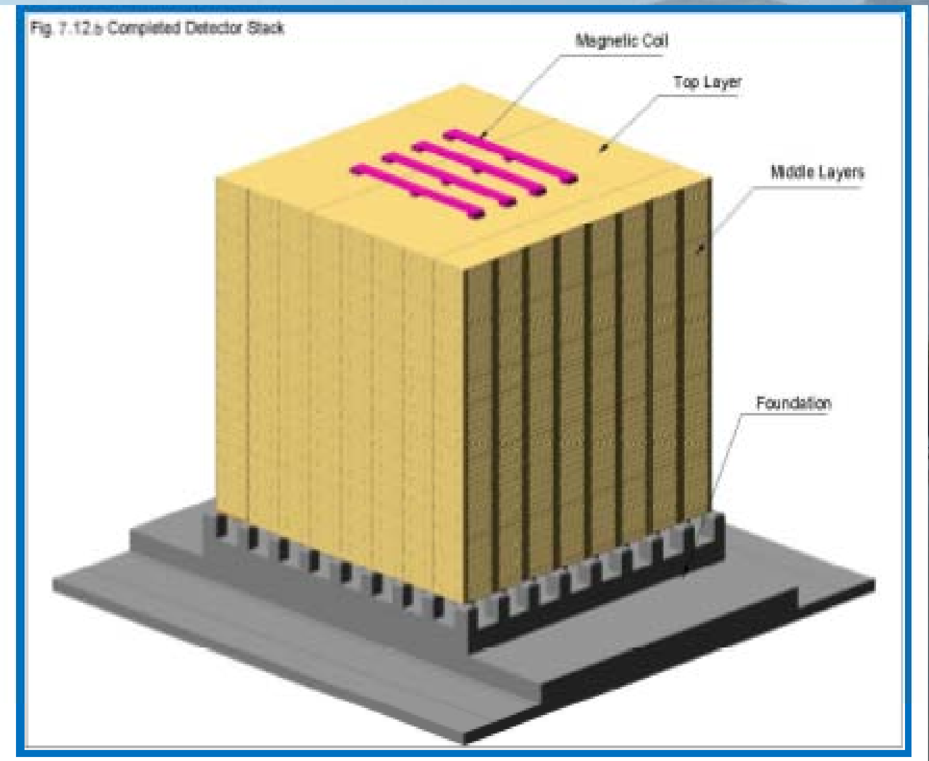


Fig. 7.12.b Completed Detector Stack

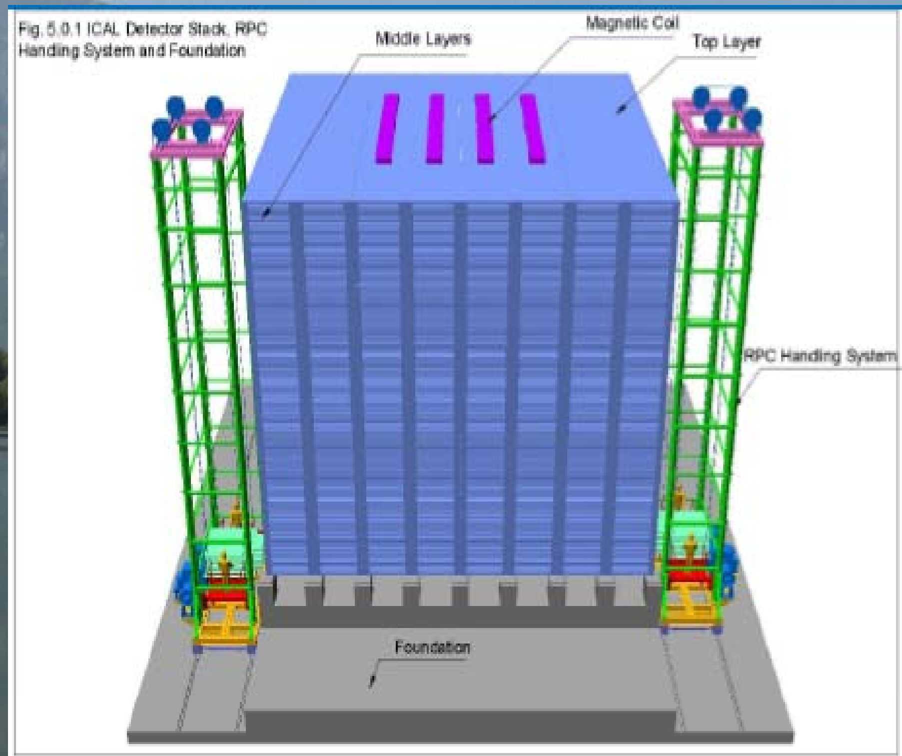
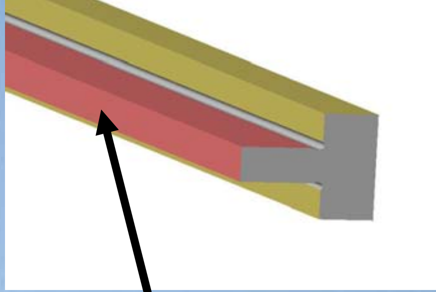


Fig. 5.0.1 ICAL Detector Stack, RPC Handling System and Foundation

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	$3.6 X 10^6$

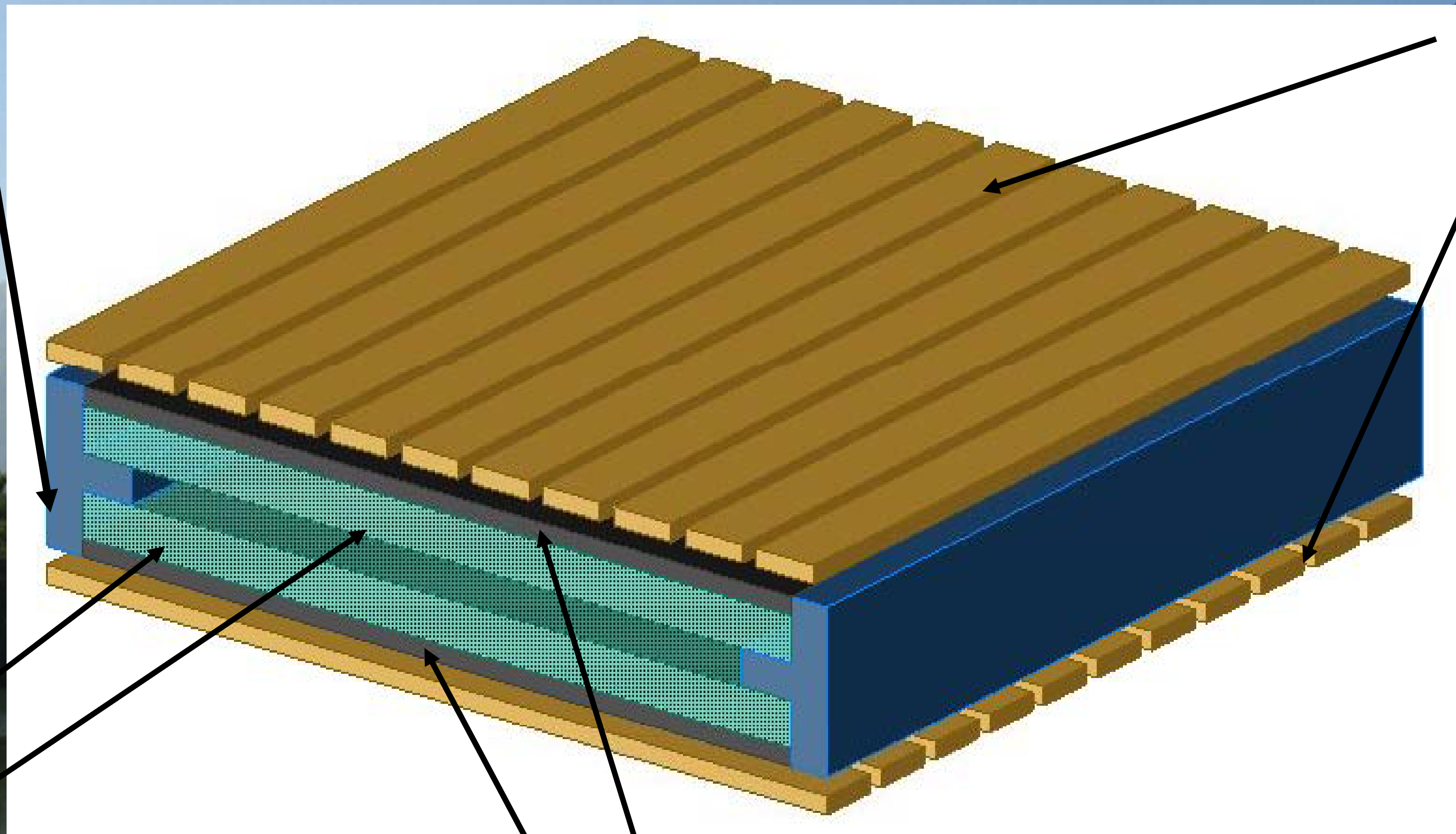
Construction of RPC



Two 2 mm thick float Glass
Separated by 2 mm spacer

2 mm thick spacer

Pickup strips

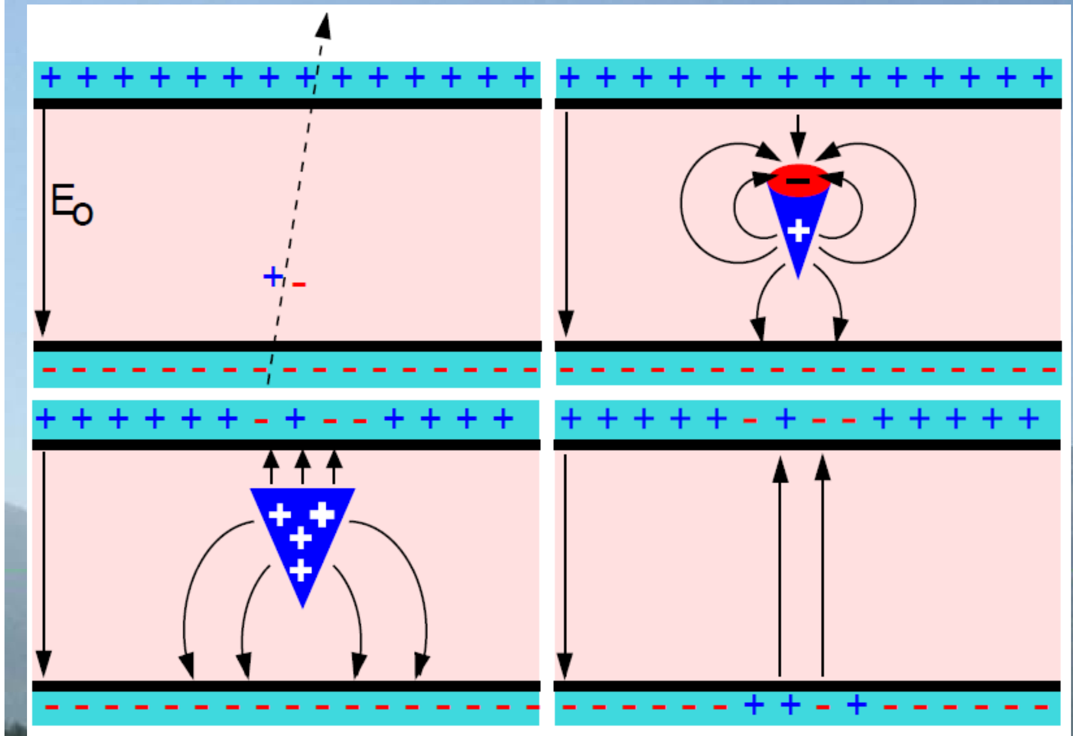


Glass plates

Resistive coating on the outer surfaces of glass

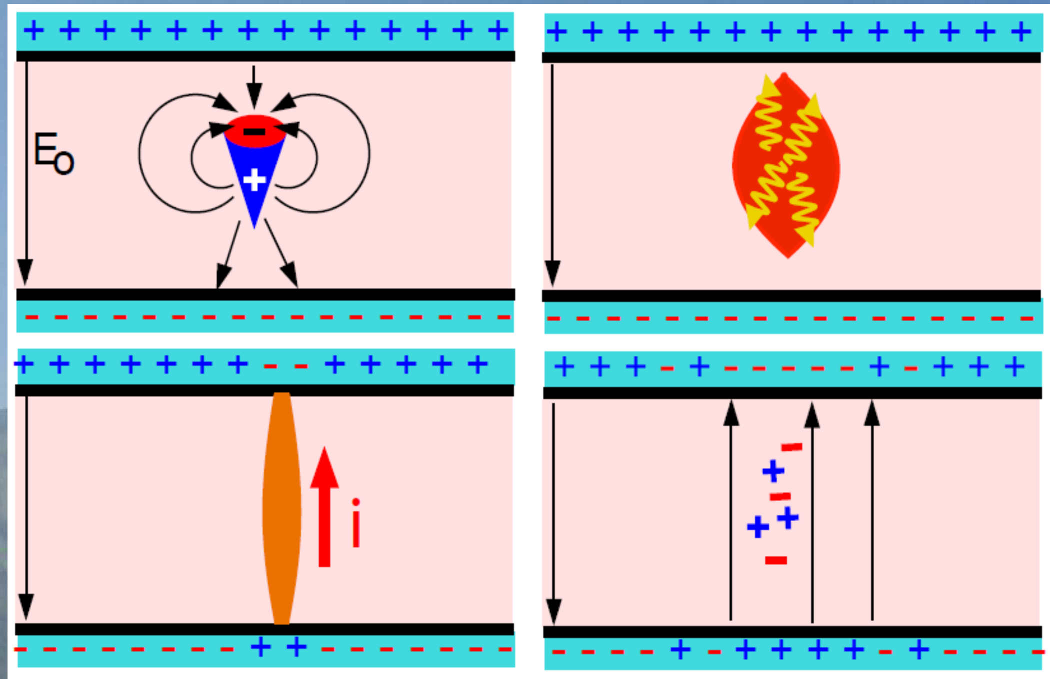
Two modes of RPC operation

Avalanche mode



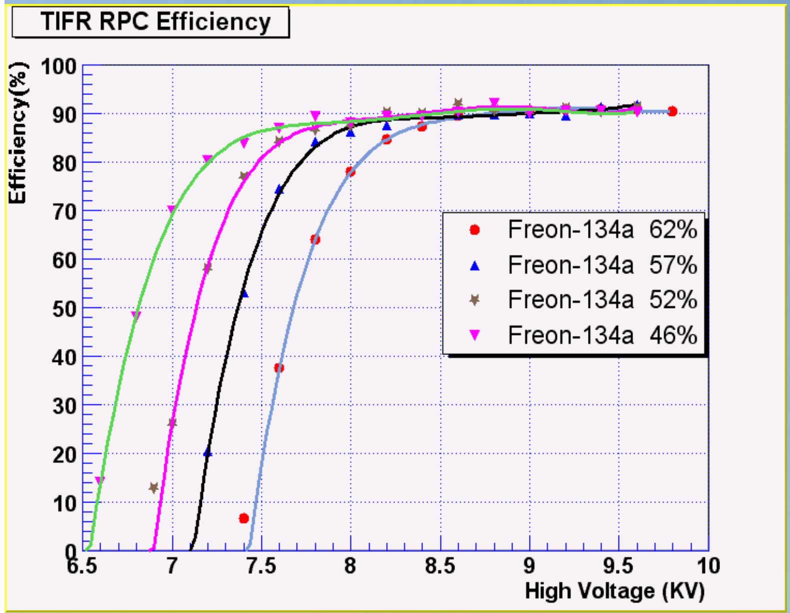
- *Gain of the detector << 10^8*
- *Charge developed 1-2pC*
- *Needs a preamplifier*
- *Longer life*
- *Typical gas mixture Fr:iB:SF6::94.5:4:0.5*
- *Moderate purity of gases*

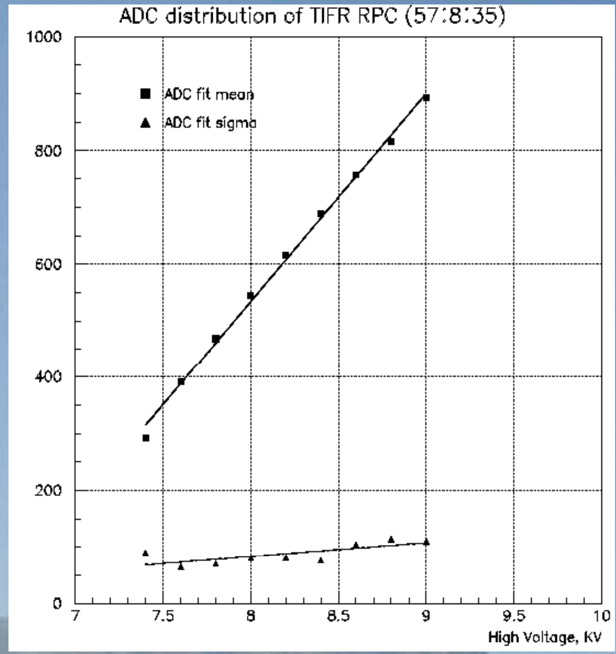
Streamer mode

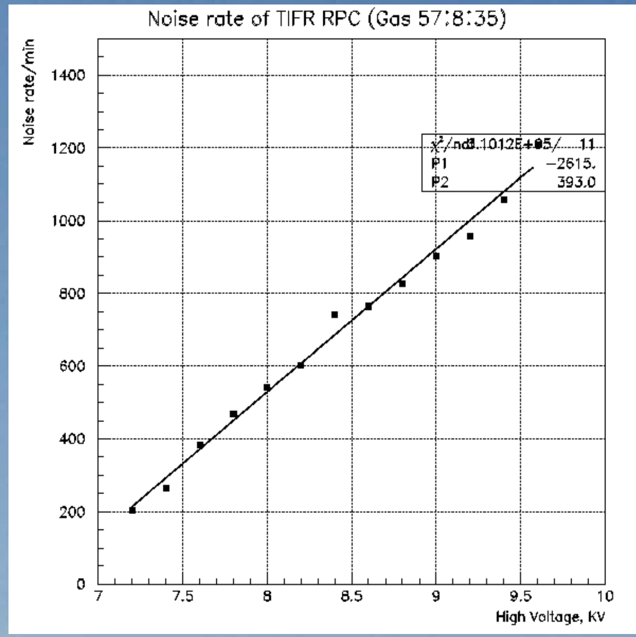


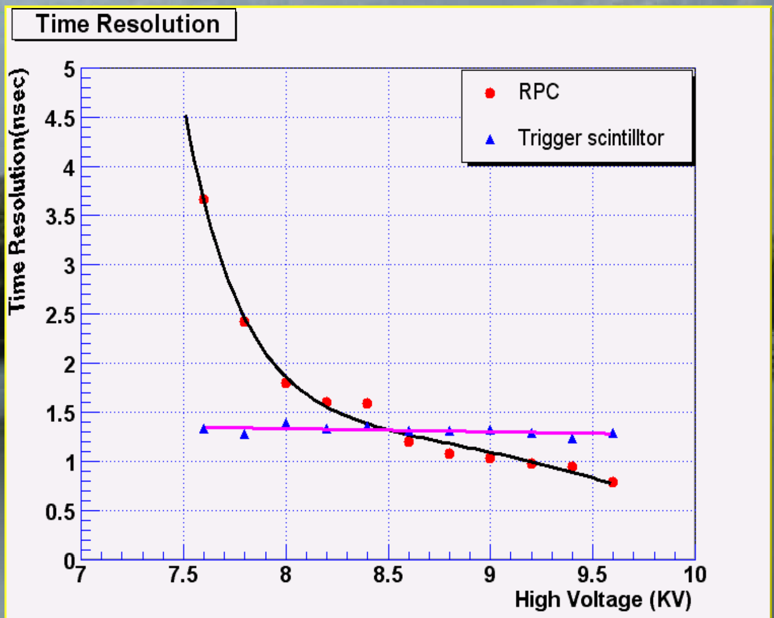
- *Gain of the detector > 10^8*
- *Charge developed 100-200pC*
- *No need for a preamplier*
- *Relatively shorter life*
- *Typical gas mixture Fr:iB:Ar::62.8:30*
- *High purity of gases*
- *Low counting rate capability*

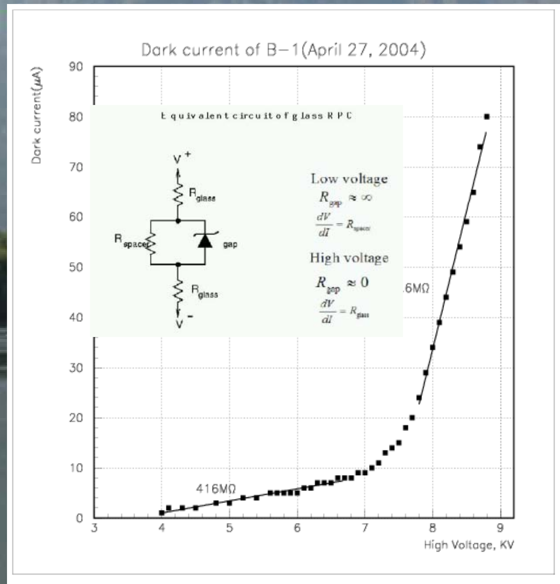
Early results







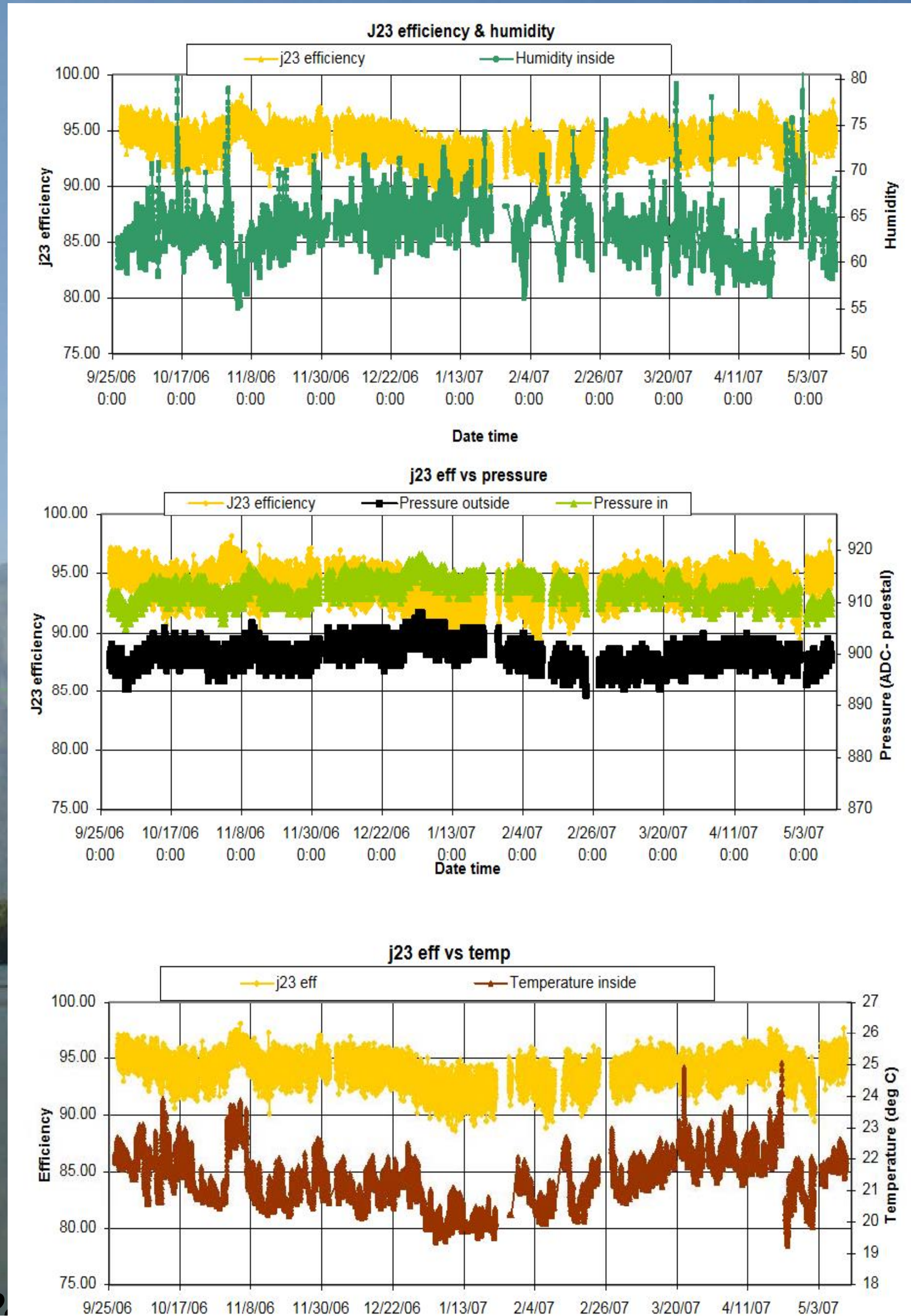




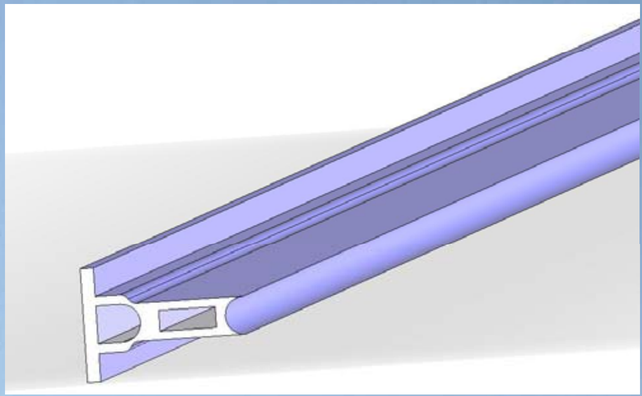
Gas Mixture	Tele window (mm)	Cross talk (%)
62:8:30	10	6.8
62:8:30	15	6.7
62:8:30	20	6.2
57:8:35	20	6.5
52:8:40	20	5.9
46:8:46	20	6.3

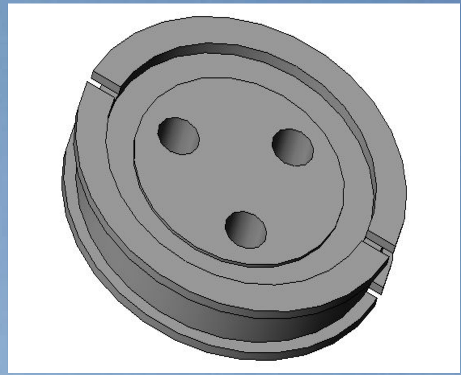
Long-term stability tests of RPCs

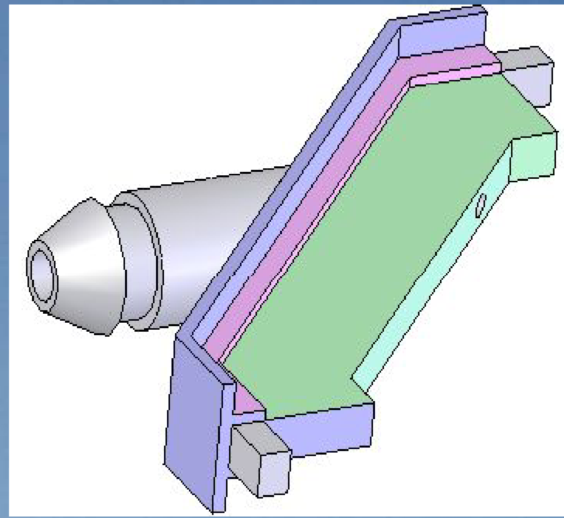
- Two RPCs (J2 & J3) built using 2mm glass for electrodes
- Readout by a common G-10 based signal pickup panel sandwiched between the RPCs
- Operated in avalanche mode (R134a: 95.5% and the rest isobutene) at 9.3KV
- Round the clock monitoring of RPC and ambient parameters – Temperature, Relative humidity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

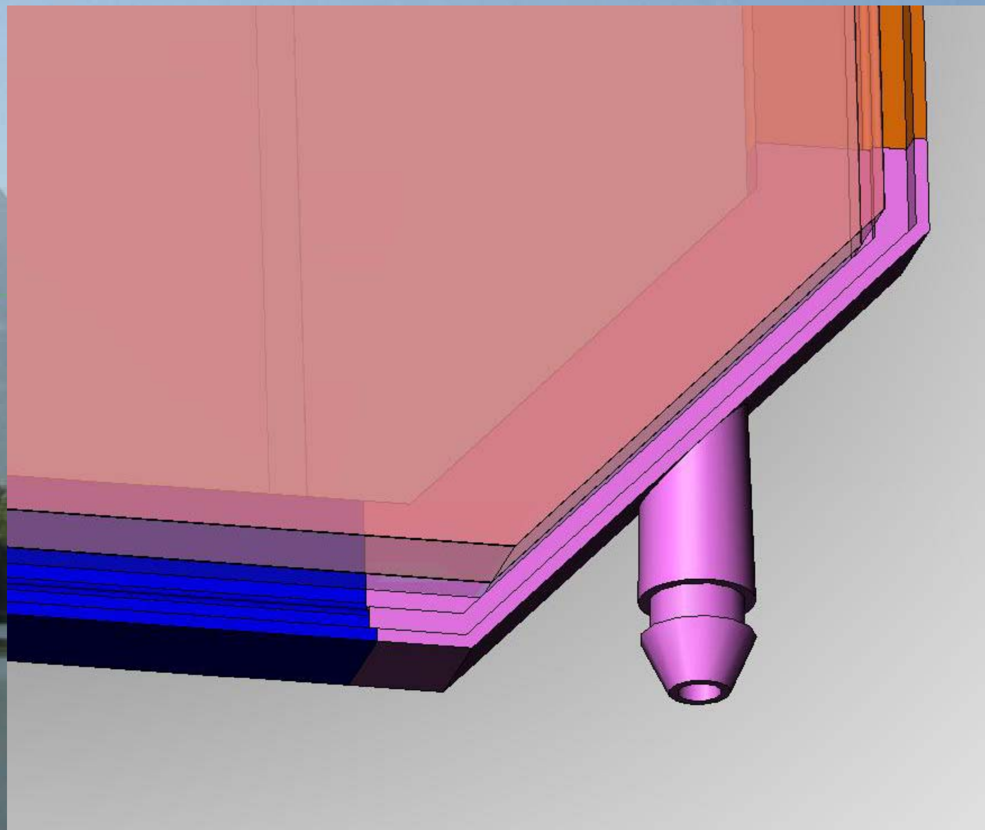


RPC building blocks



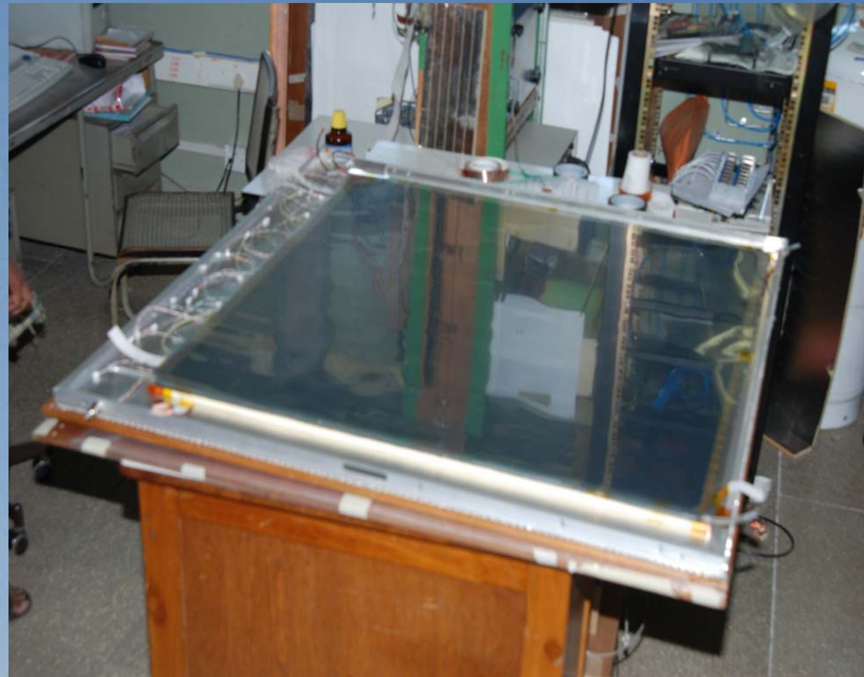




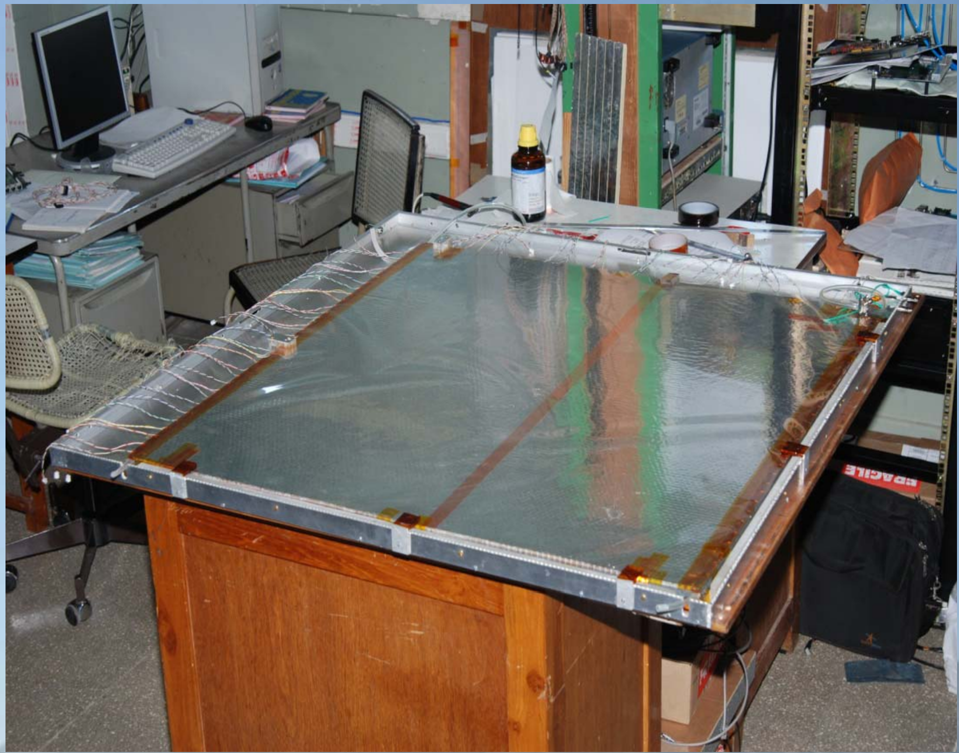


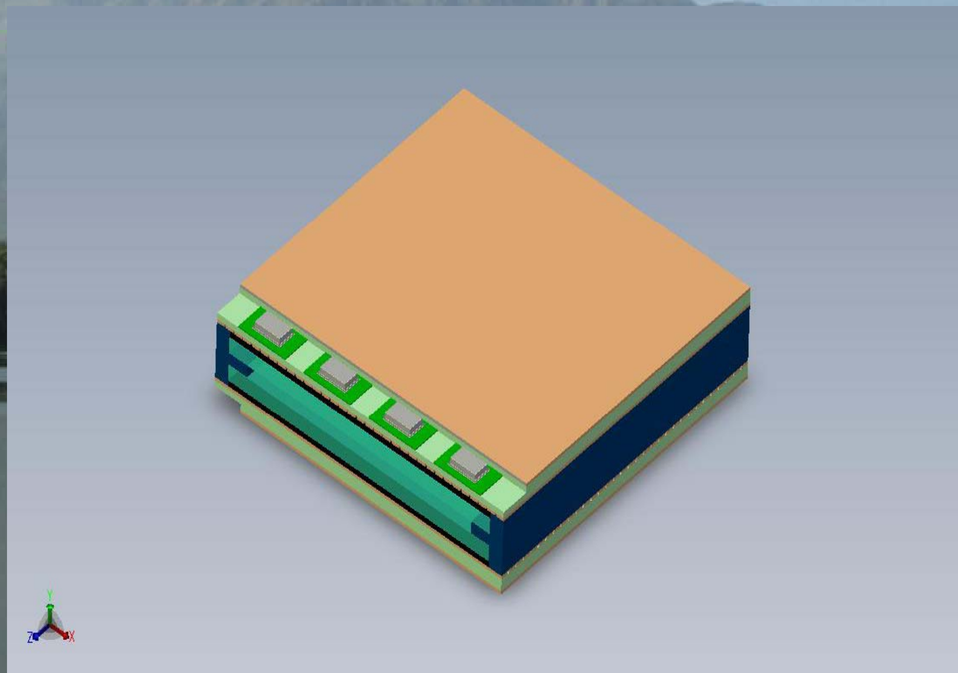
Making of RPC gap

RPC fabrication

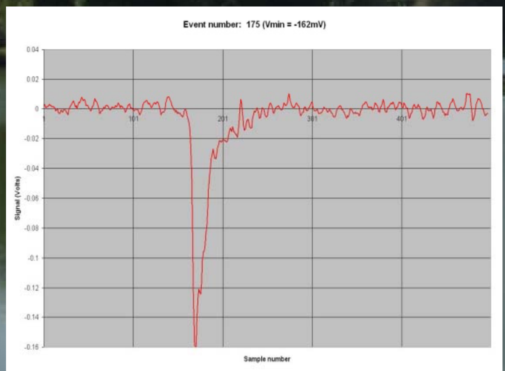


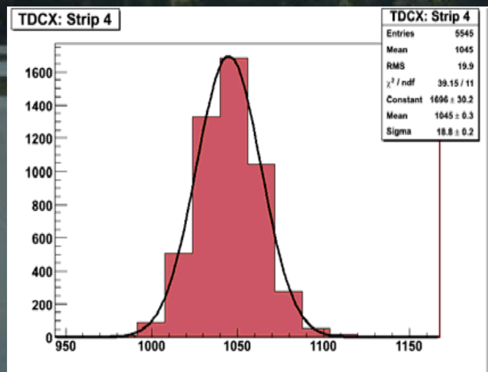
RPC Fabrication

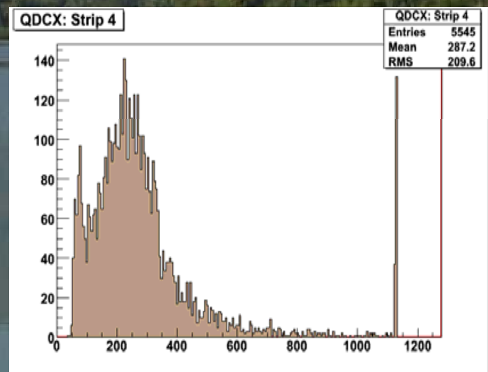




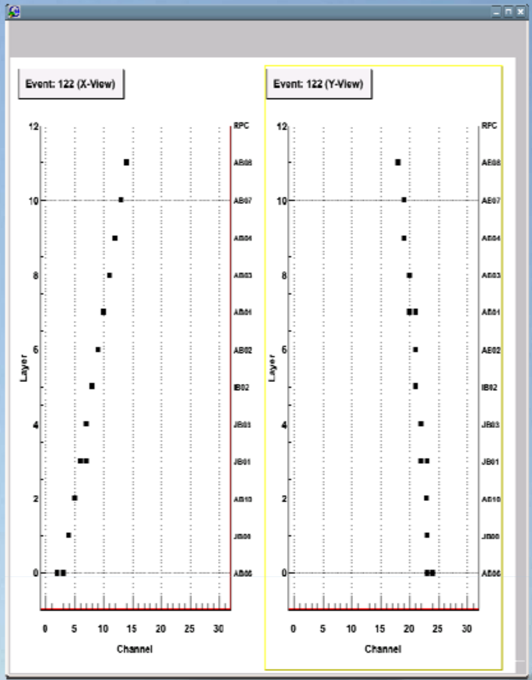
Prototype RPC Stack at TIFR tracking Muons

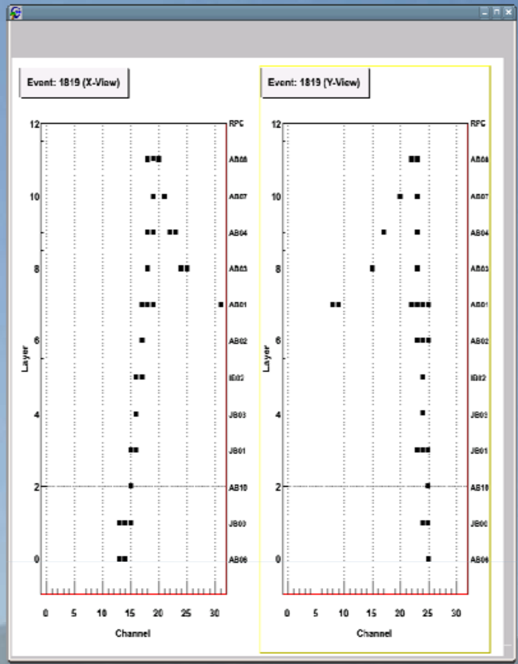


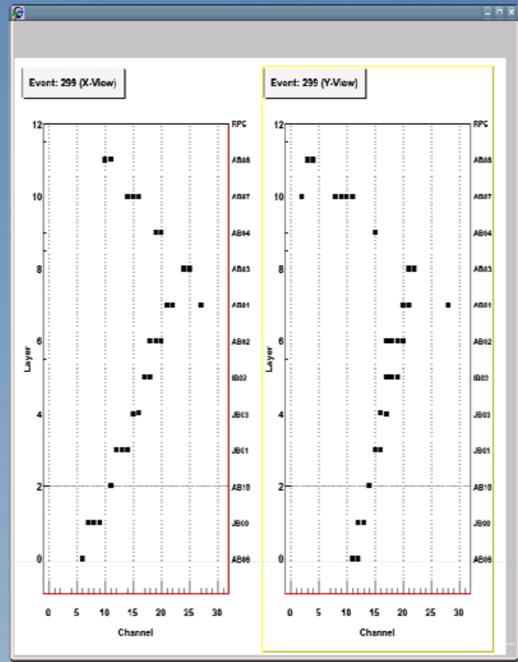


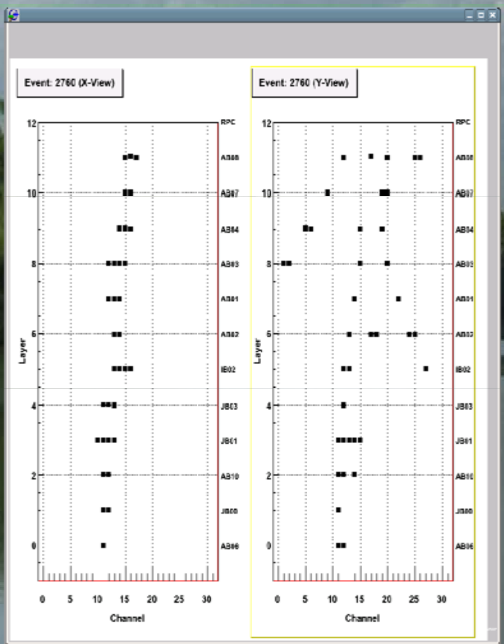


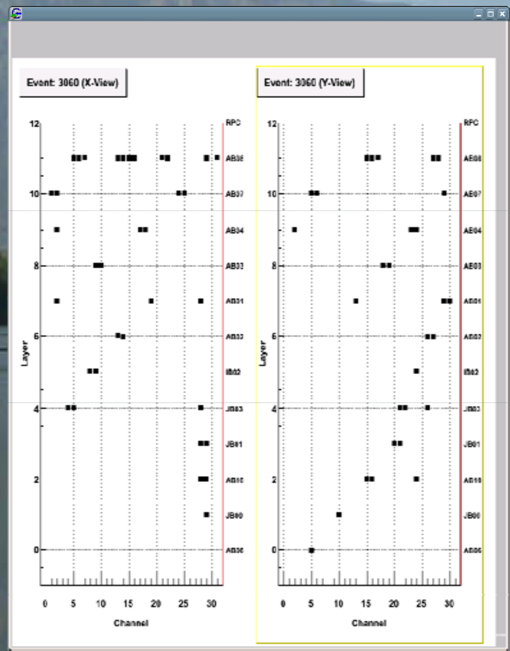
Some interesting cosmic ray tracks



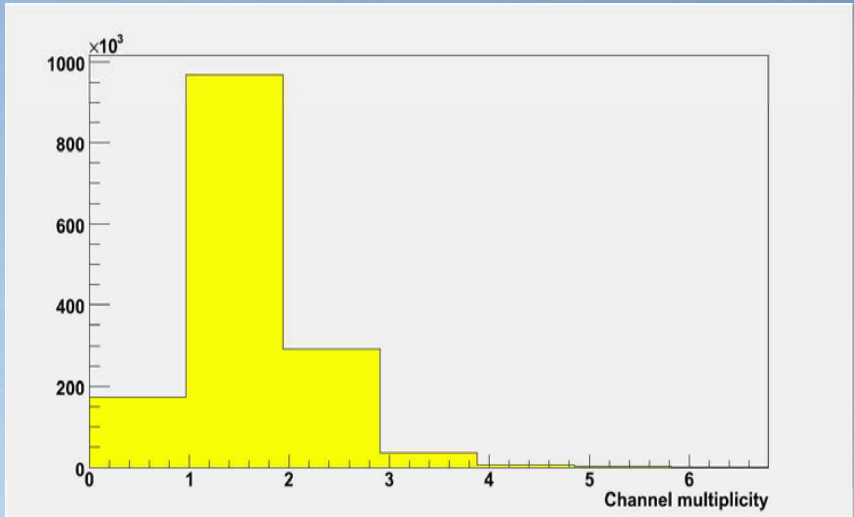


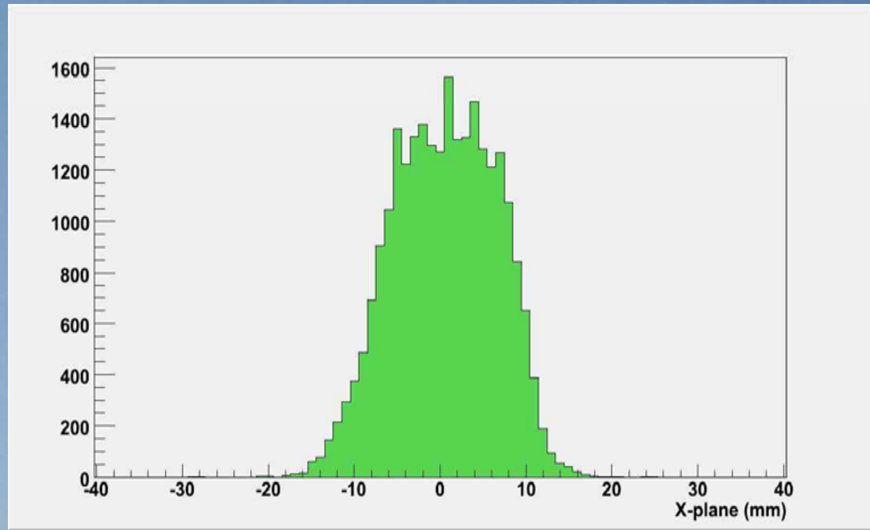


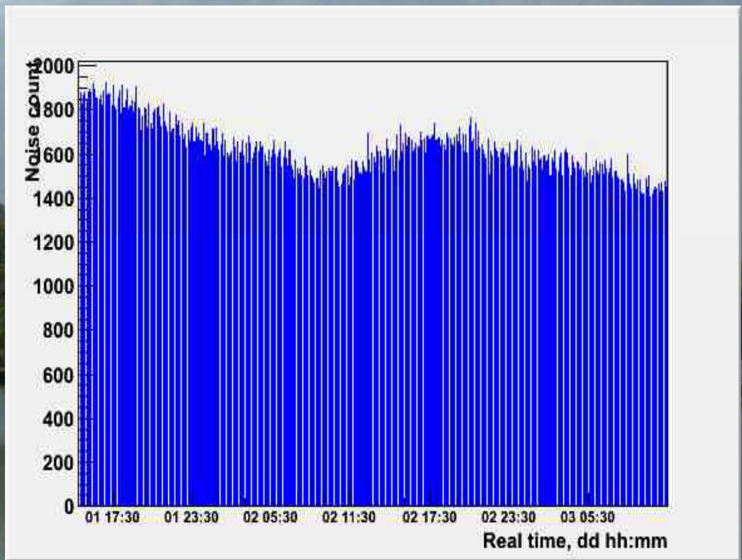


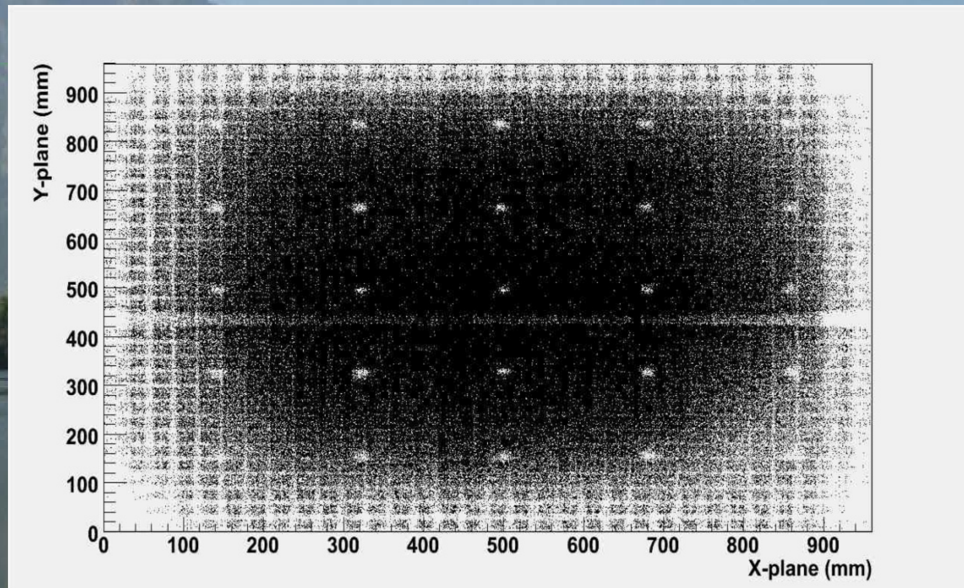


Performances of RPCs

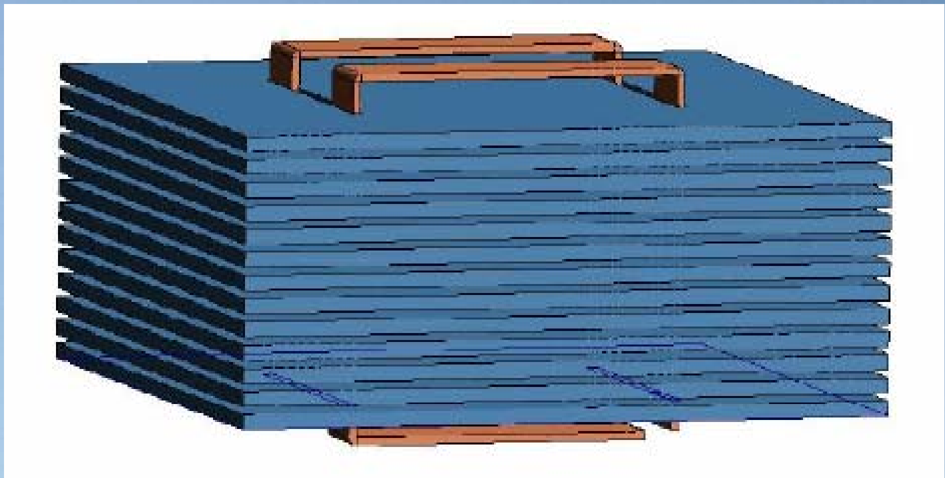




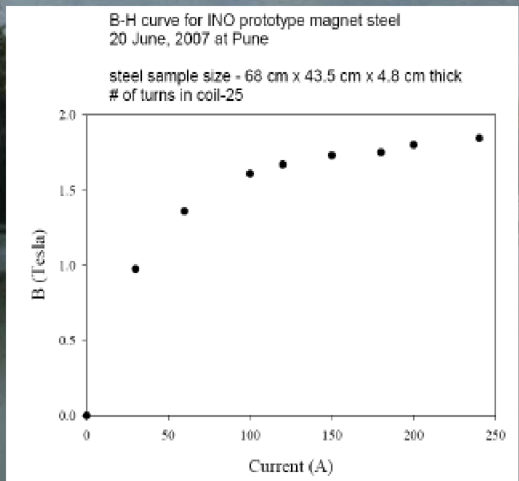




INO-ICAL Prototype Magnet now at VECC



- 12, 1m² RPC layers
- 13 layers of 5 cm thick magnetised iron plates
- About 1000 readout channels
- RPC and scintillation paddle triggers
- Hit and timing information



Making 2m × 2m RPCs

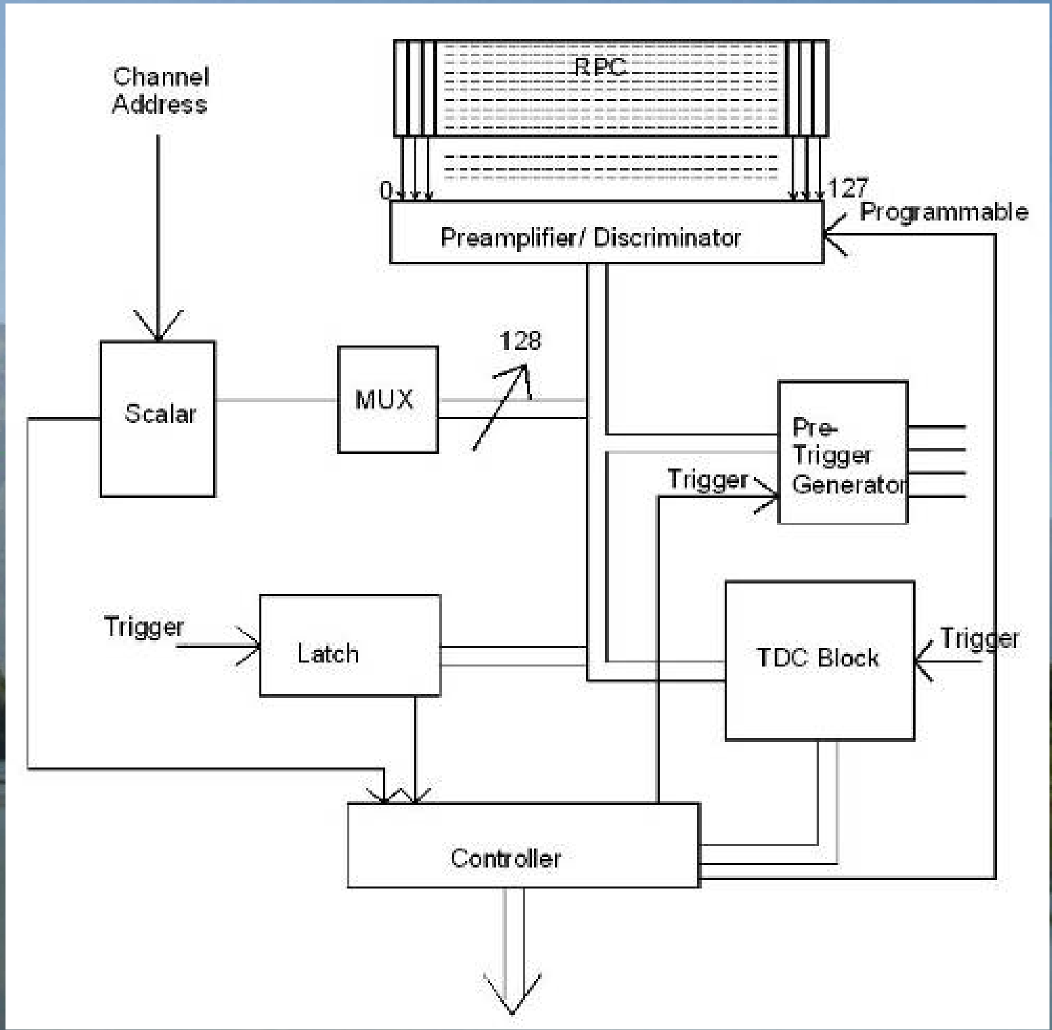
Status of RPC R & D

- *R & D for Large size glass RPC is in good shape.*
- *1 m^2 size RPCs are now made routinely in the lab.*
- *100 % success rate.*
- *All the components needed are locally developed.*
- *Prototype electronics including FPGA based self trigger system is operational.*
- *A stack of 12 RPCs are continuously recording cosmic muon tracks (~ 90K/day).*
- *Trigger rate is currently limited by the DAQ band width.*
- *Data available on line on the Web.*

Proposed Front End Electronics: Triggered scheme

RPC , a unit for front-end processing

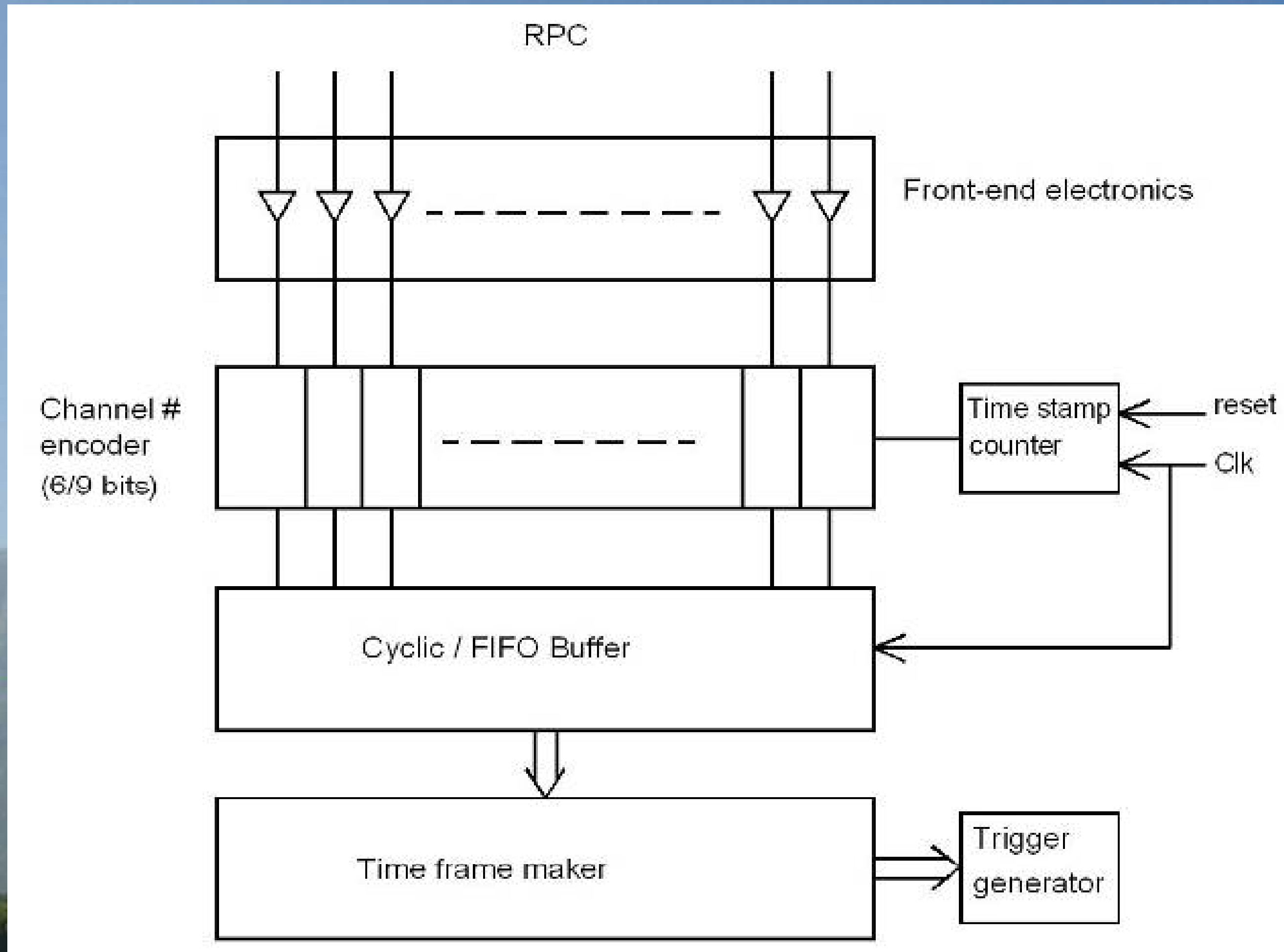
- *Conventional architecture*
- *Dedicated sub-system blocks for performing various data readout tasks*
- *Need for Hardware based on-line trigger system*
- *Trigger latency issues and how do we take care in implementation*
- *Synchronisation of trigger/global clock signals*



Trigger-less scheme

Suitable for low event rate and low background/noise rates

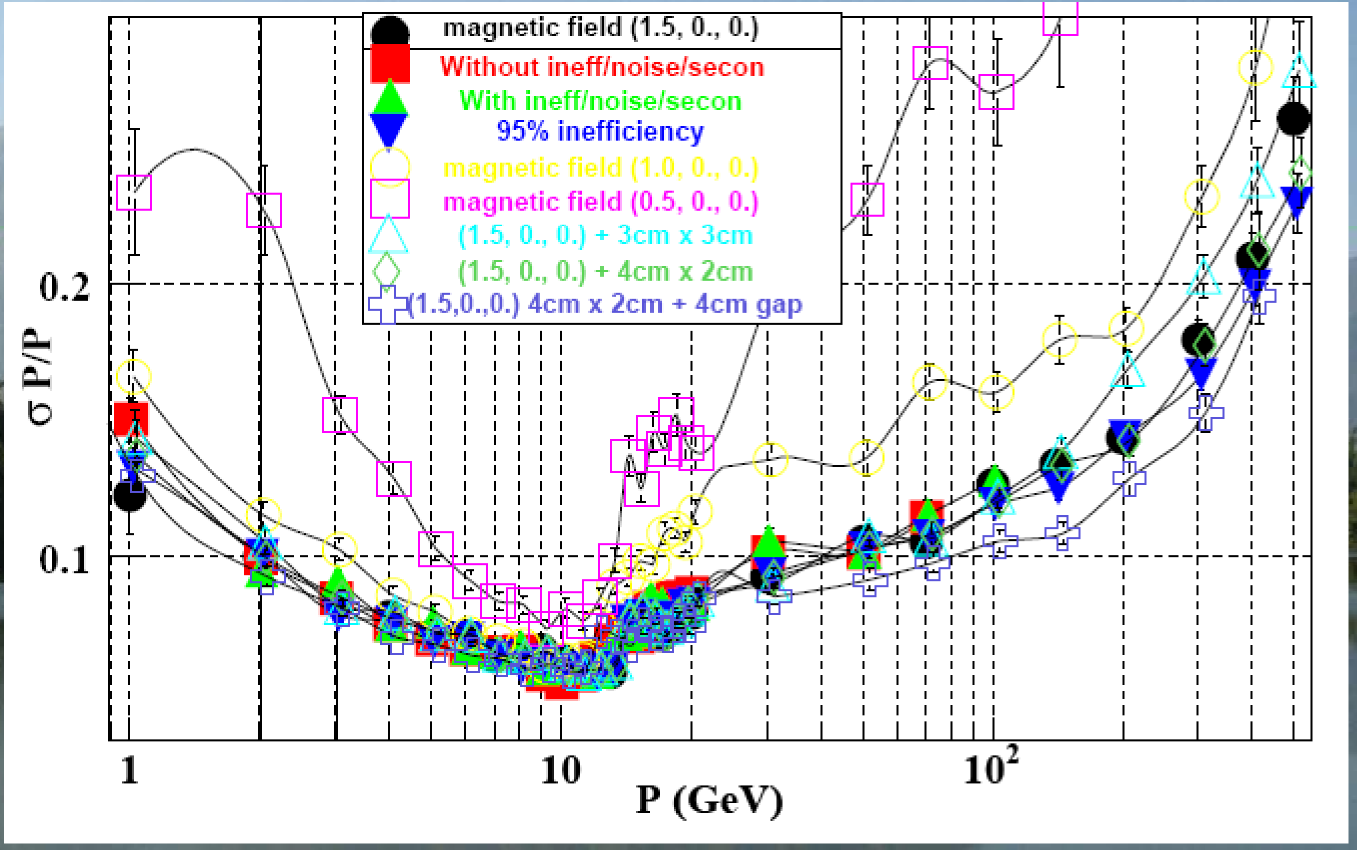
On-off control and V_{th} control to disable noisy channels



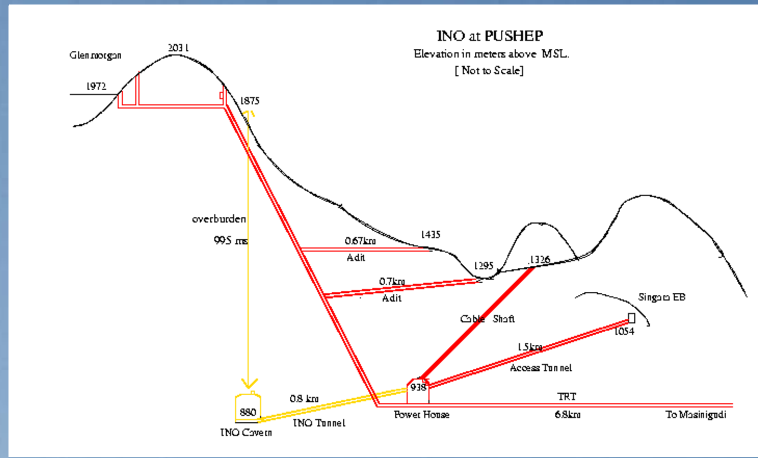
Clock frequency considerations

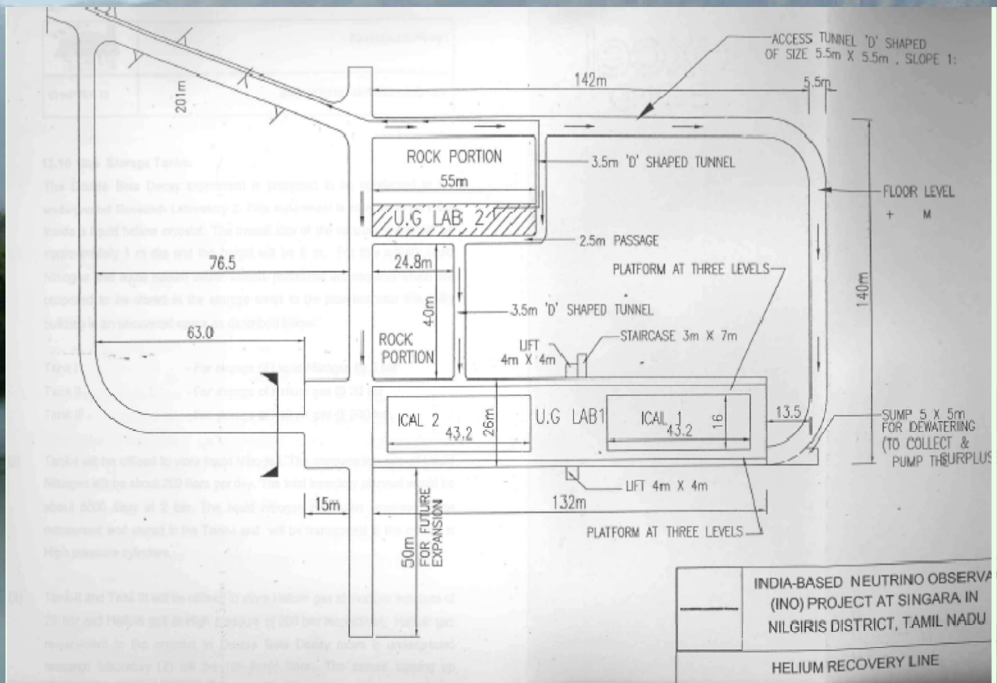
INO Detector simulation & reconstruction

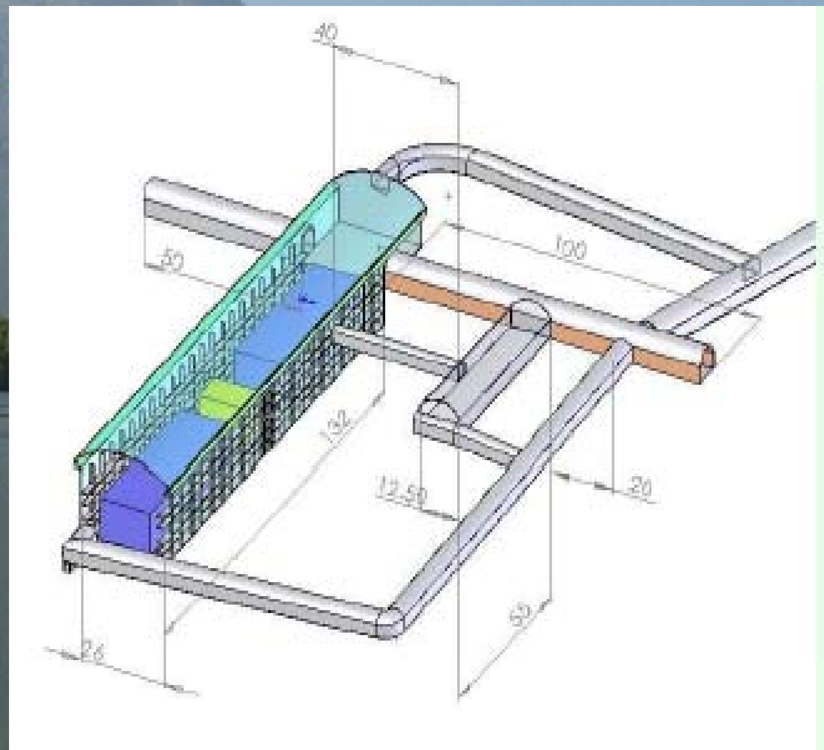
- *Nuance Event Generator.*
- *GEANT4 for simulation.*
- *Track finder algorithm based on triplet formation.*
- *Kalman filter based track fitting algorithm.*

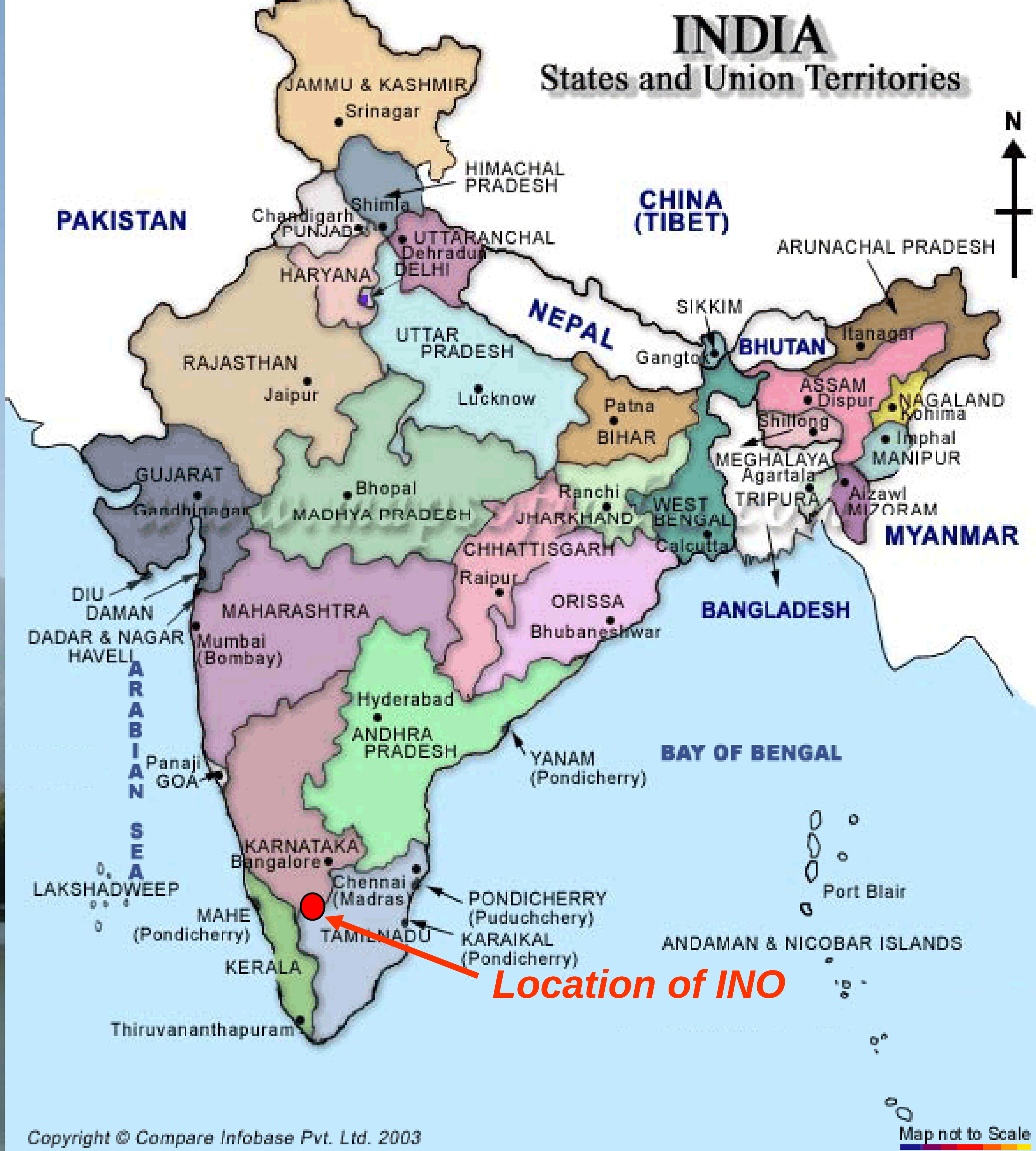


INO Underground Laboratory





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States and Union Territories
N
JAMMU & KASHMIR
Srinagar
HIMACHAL PRADESH
Shimla
Chandigarh
PUNJAB
UTTARANCHAL
Dehradun
DELHI
HARYANA
PAKISTAN
CHINA (TIBET)
ARUNACHAL PRADESH
Itanagar
NEPAL
SIKKIM
Gangtok
BHUTAN
RAJASTHAN
Jaipur
UTTAR PRADESH
Lucknow
Patna
BIHAR
ASSAM
Dispur
NAGALAND
Kohima
Shillong
MEGHALAYA
Imphal
MANIPUR
Agartala
TRIPURA
Aizawl
MIZORAM
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ARABIAN SEA
Hyderabad
ANDHRA PRADESH
YANAM (Pondicherry)
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Panaji
GOA
KARNATAKA
Bangalore
Chennai (Madras)
LAKSHADWEEP
MAHE (Pondicherry)
PONDICHERRY (Puduchchery)
TAMIL NADU
KARAIKAL (Pondicherry)
KERALA
Thiruvananthapuram
Port Blair
ANDAMAN & NICOBAR ISLANDS
Location of INO
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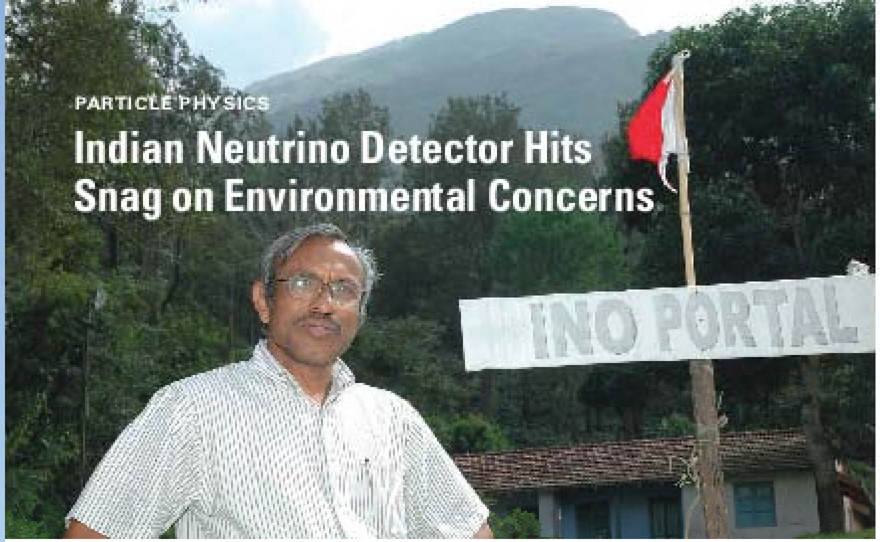
Map not to Scale



PARTICLE PHYSICS

Indian Neutrino Detector Hits Snag on Environmental Concerns

Waiting game. Naba Mondal at INO's proposed site.

MASINAGUDI, INDIA—The rosewood and teak forest here in southern India's Nilgiri Biosphere Reserve is prime elephant habitat. It's also where Indian particle physicists hope to install a massive detector to stalk a more exotic quarry: neutrinos. But concerns about the well-being of the heaviest land animals have so far blocked plans to tune in to the lightest known fundamental particles.

The $167 million India-based Neutrino Observatory (INO), slated for completion in 2012, is the country's most expensive science facility ever. The magnetized iron detector would be nestled in a cavern 2 kilometers deep inside a granite mountain in Tamil Nadu state, some 250 kilometers southeast of Bangalore. Neutrinos are produced in stars as well as on Earth, in nuclear reactors and when cosmic rays smash into the upper atmosphere. They have the slightest mass and are elusive because they interact with other particles only by means of the weak nuclear force. The granite in Nilgiri would absorb most cosmic rays that at the surface would swamp any neutrino signal, but neutrinos will readily pass through to the detector.

A 100-strong team of physicists has conducted site surveys and has begun fabricating detector components at Tata Institute of Fundamental Research (TIFR) in Mumbai and at collaborating institutions. The initiative is "unique and important," says Maury Goodman, a neutrino specialist at Argonne National Laboratory in Illinois. INO, adds Anil Kakodkar, chair of the Atomic Energy Commission, is a "perfect launching pad" for attracting fresh blood into basic sciences in India.

Before work at Nilgiri can begin, INO must obtain a permit from Tamil Nadu's forestry department. State officials say the physicists have not yet made a convincing case. "INO would be detrimental to the ecological balance of the area," says a senior forestry official, who cites two chief concerns: damage to fragile habitat as equipment and materials are hauled through the forest, and debris from tunneling choking the watershed. The World Wide Fund for Nature–India also opposes the facility, arguing that Nilgiri "is already under pressure, and INO will lead to permanent detrimental impacts on wildlife."

Last month, forestry officials and INO scientists met in Chennai, capital of Tamil Nadu, to seek common ground. Kakodkar and project staff outlined their strategy for minimizing INO's environmental impact. The discussions were "positive," says INO spokesperson Naba K. Mondal, a particle physicist at TIFR. But as *Science* went to press, it was unclear whether the state government would issue a permit.

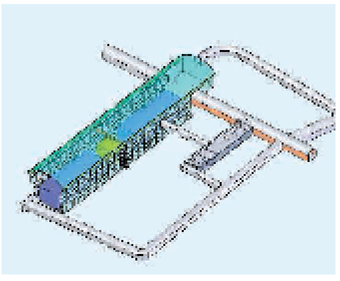
A few decades ago, India was at the forefront of neutrino research. In 1964, a TIFR team led by B. V. Sreekantan and M. G. K. Menon, using an iron calorimeter in a gold mine shaft, were the first in the world to detect neutrinos created in the atmosphere. The facility was shuttered in 1992 when Kolar Gold Fields closed and the experiment became too costly to maintain. "Many of us in the international community grieved over the termination of that line of work," says John Learned, a physicist at the University of Hawaii, Manoa.

India hopes INO will help it secure a leading position in the next generation of neutrino research. For instance, more robust estimates of neutrino mass could shed light on an enduring mystery: why there is more matter than antimatter in the universe. The project entails delving an underground laboratory and installing a 50,000-ton detector for studying atmospheric neutrinos and antineutrinos. Down the road, the detector could be doubled in size to study neutrinos beamed through the planet from particle accelerators in Europe or Japan. Both experiments aim to yield more precise calculations of neutrino masses. "No large dedicated experiment to study atmospheric neutrinos has ever been built," Goodman says. "The INO design is certainly a better way to study atmospheric neutrinos than has been done before."

According to Mondal, the Nilgiri site is ideal in part because the geology was well-characterized during preparation for a hydroelectric project at the mountain. (The waterworks were built a decade ago, when India's environmental movement was weaker than it is today.) Mondal acknowledges that excavating the tunnel will require hauling huge amounts of materials and rubble through elephant habitat. "No doubt there will be some pain," says Raman Sukumar, an elephant biologist at the Indian Institute of Science in Bangalore who has worked in the area for 3 decades. But he argues that "INO can also be converted into an opportunity" if the project funds conservation efforts in Nilgiri. INO plans to create just such a fund, Mondal says.

In that case, Sukumar says, "both neutrinos and elephants can be winners." Mondal and his colleagues are anxiously waiting to see if Tamil Nadu officials agree.

—PALLAVA BAGLA



Taking the measure. INO aims to make precise calculations of neutrino mass.

CREDITS (TOP TO BOTTOM): PALLAVA BAGLA; INO

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Project Status

- *A prototype RPC stack is now operational at TIFR. A second prototype with the magnet is getting ready at VECC.*
- *Electronics DAQ for the prototype is operational. Final electronics for the 50 Kton detector is under design.*
- *A gas purification & recirculation system is under test.*
- *Long term stability test of RPCs continuing.*
- *INO-Engineering task force has prepared a Detailed Project Report (DPR) on the INO cavern and surface lab .*
- *Detailed Project Report for the detector structure with all engineering details is ready.*
- *We have approached environment and forest departments for necessary clearances.*
  - *MOEF clearance obtained.*
  - *State forest clearance awaited.*
- *Environmental Impact Assesment & Enviornmental Management Plan for the INO lab at Singara, Masinagudi has been prepared by reputed enviornmental organisations.*
- *EMP compliance report submitted to local state Government.*
- *Identification of sources for various components needed for mass production of glass RPCs is in progress.*
- *Land for INO centre at Mysore will be provided by Karnataka Govt.*