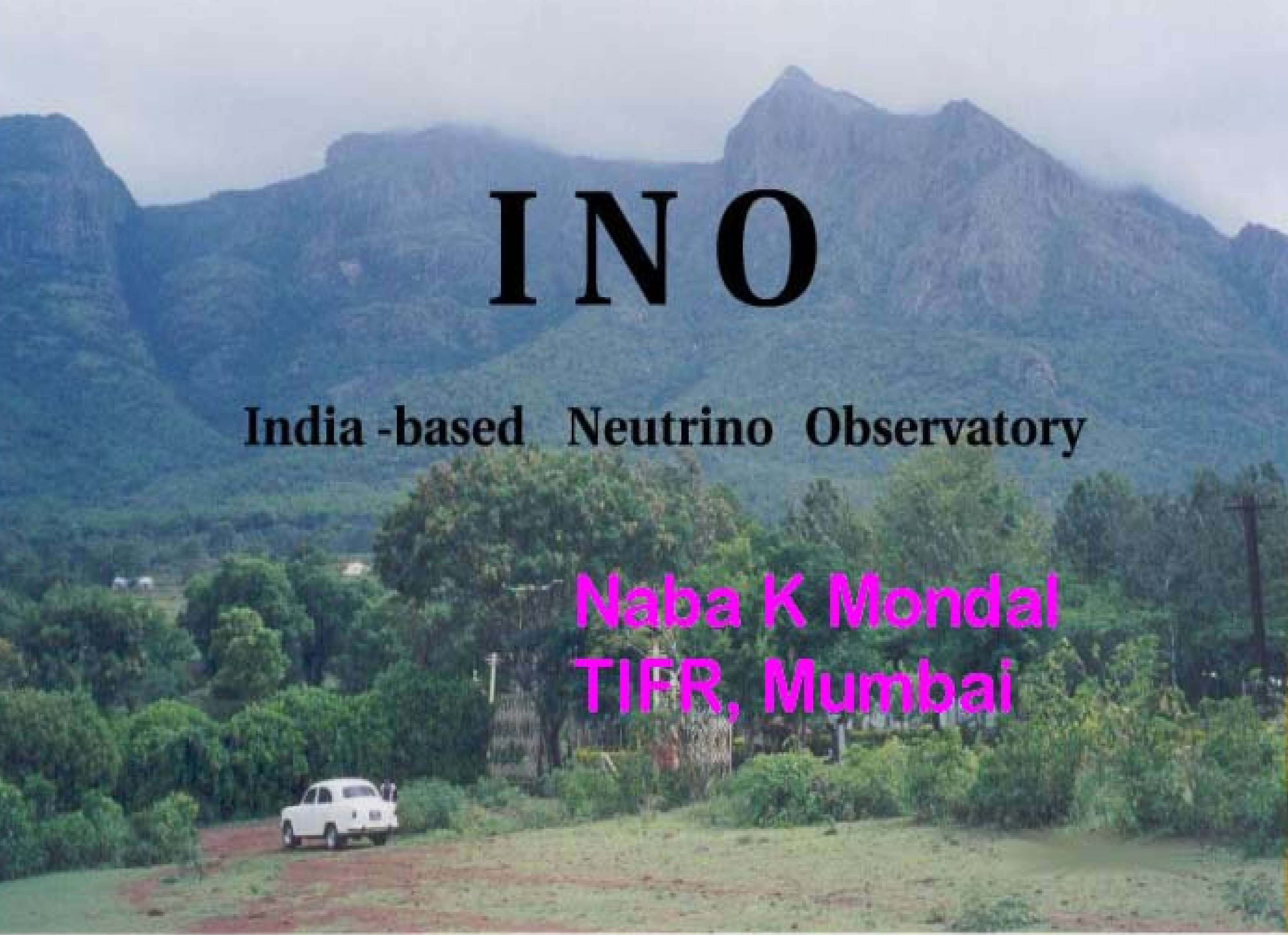
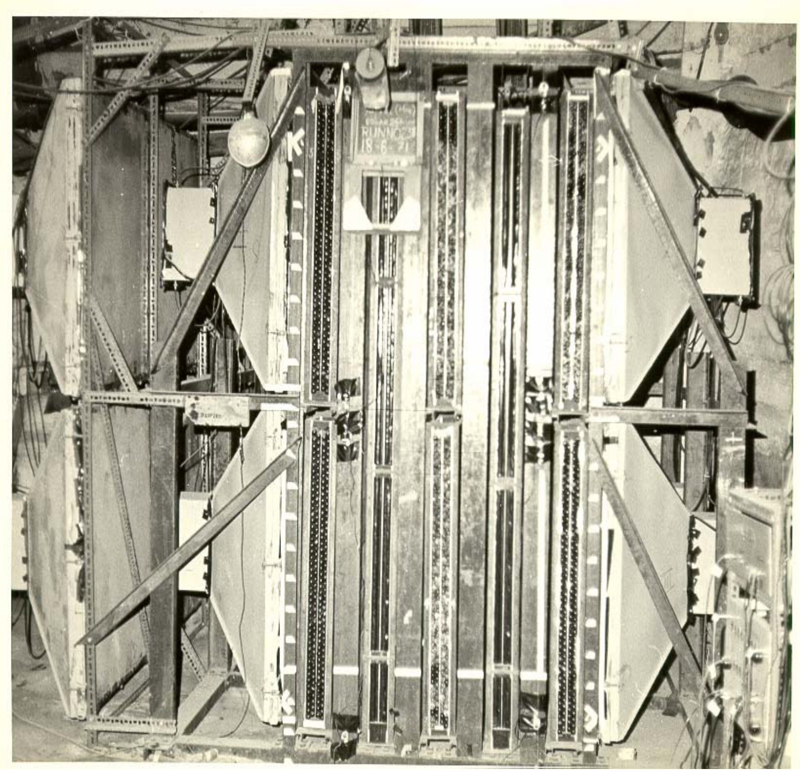
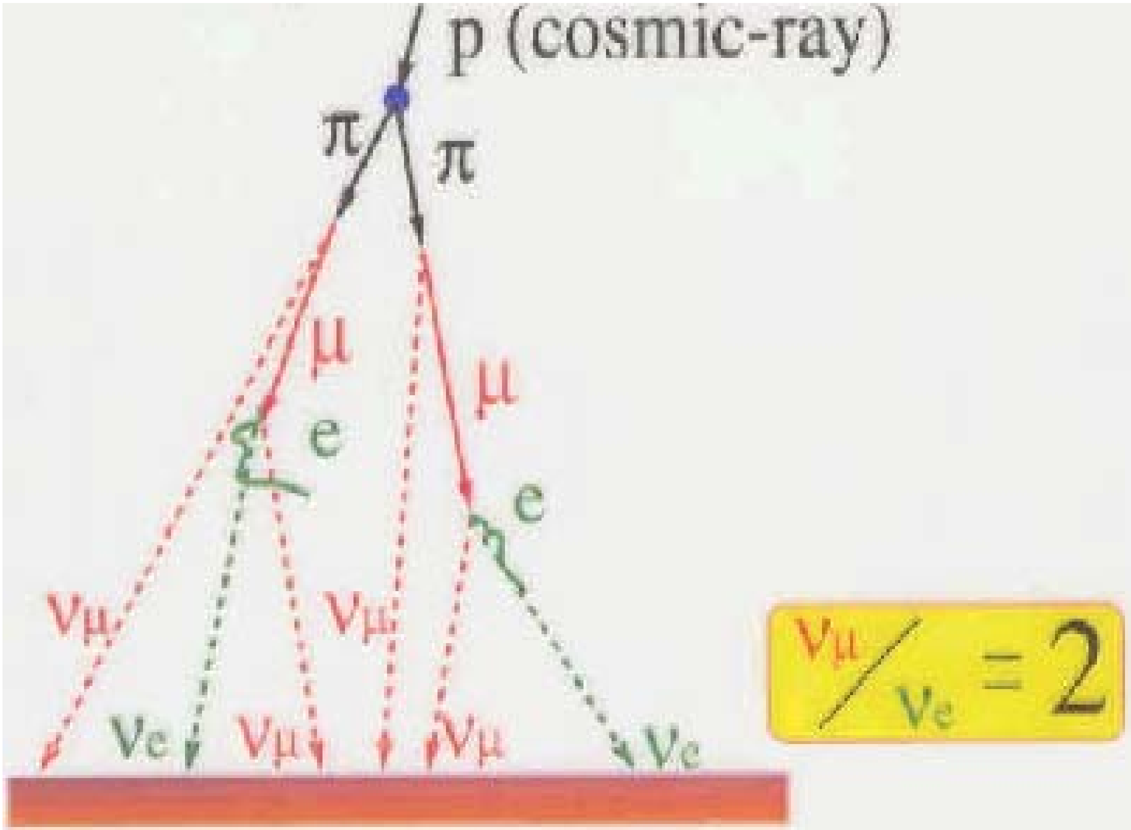

INO
India -based Neutrino Observatory
Naba K Mondal
TIFR, Mumbai

Atmospheric Neutrinos

Atmospheric neutrino detector at Kolar Gold Field –1965





DETECTION OF MUONS PRODUCED BY COSMIC RAY NEUTRINO DEEP UNDERGROUND

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University of Durham, Durham, U.K.

Received 12 July 1965

More on KGF

KGF Proton Decay Experiment

INO Collaboration

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S.Umasankar
IIT, Mumbai

S.K.Singh
AMU

41 Experimentalists + Engineers
22 Theorists

Scientific Advisors: G.Rajasekaran, Bikash Sinha, Ramnath Cowsik,V.S.Narasimham, H.S.Mani, Amit Roy

Current Initiative

- **Two phase approach:**
  - **Phase I ~ 2 Yrs.**
    - Detector R & D
    - Site survey
    - Human resource development through training and workshops
  - **Phase II**
    - Construction of the detector

- **Detector Possibilities:**

  - **Magnetised iron with RPCs or glass spark chambers.**
  - **Alternate detector design.**

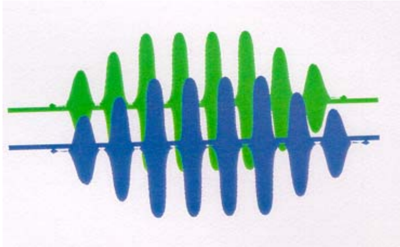
- **Should be an international facility**

Neutrino Oscillations

For neutrinos, weak eigenstates may be different from mass eigenstates.

$$\nu_e = \nu_1 \cos\theta + \nu_2 \sin\theta$$

$$\nu_\mu = -\nu_1 \sin\theta + \nu_2 \cos\theta$$



In a weak decay one produces a definite weak eigenstate $\nu(0) = \nu_e$

Then at a later time t

$$\nu(t) = \nu_1 e^{-iE_1 t} \cos\theta + \nu_2 e^{-iE_2 t} \sin\theta$$

$$= C_e(t)\nu_e + C_f \nu_f$$

$$P(\nu_e \to \nu_f; t) = \sin^2 2\theta \sin^2[\frac{1}{2}(E_2 - E_1)t]$$

$$E_2 - E_1 = \frac{m_2^2 - m_1^2}{2E} = \frac{\Delta m^2}{2E}$$

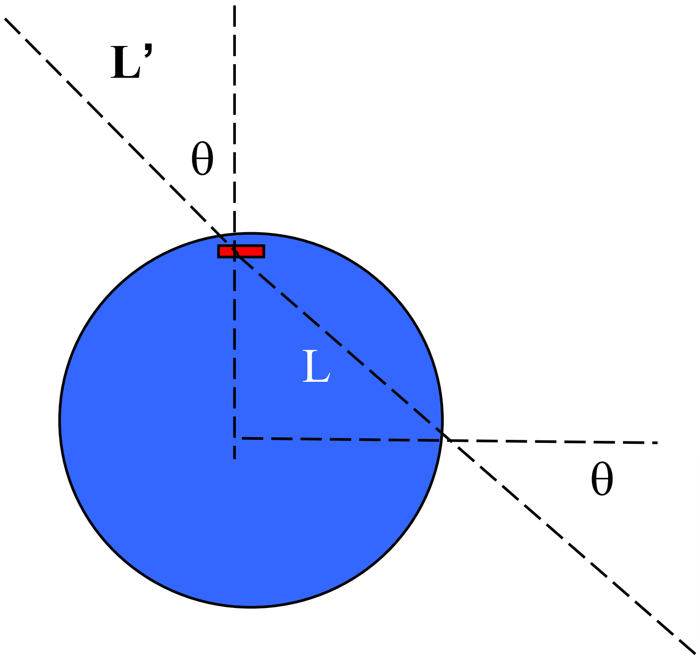
$$P(\nu_e \to \nu_f; L) = \sin^2 2\theta \ \sin^2 \frac{1.27 \Delta m^2 L}{E}$$

Choice of Neutrino Source and Detector

- **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)**
    - **Ease of construction**
  - **Use magnetised iron as target mass and RPC as active detector medium**

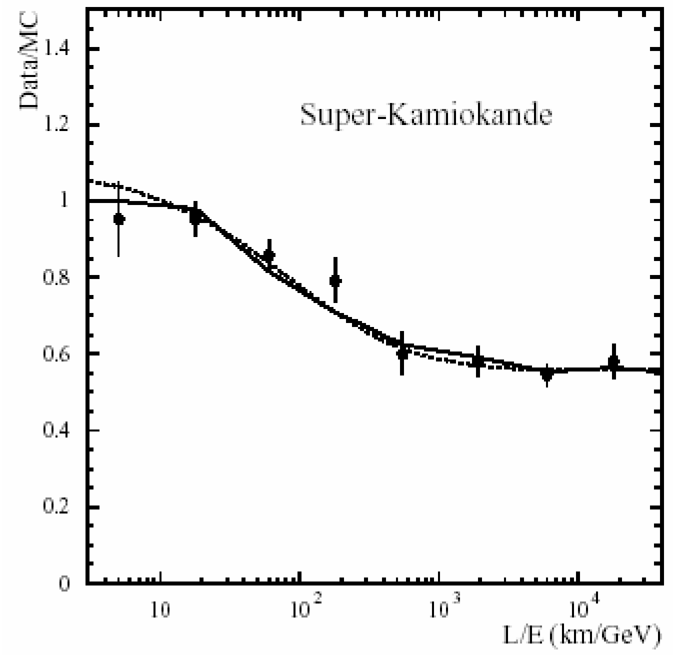
Disappearance of ν_μ Vs. L/E

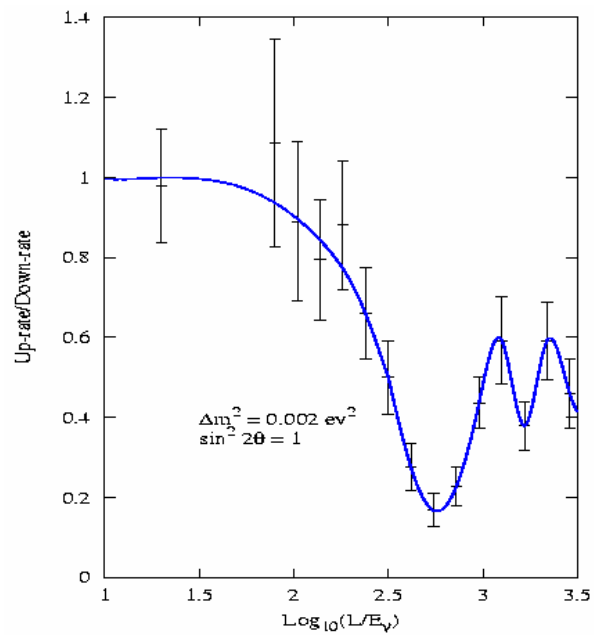


The disappearance probability can be measured with a single detector and two equal sources:

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

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

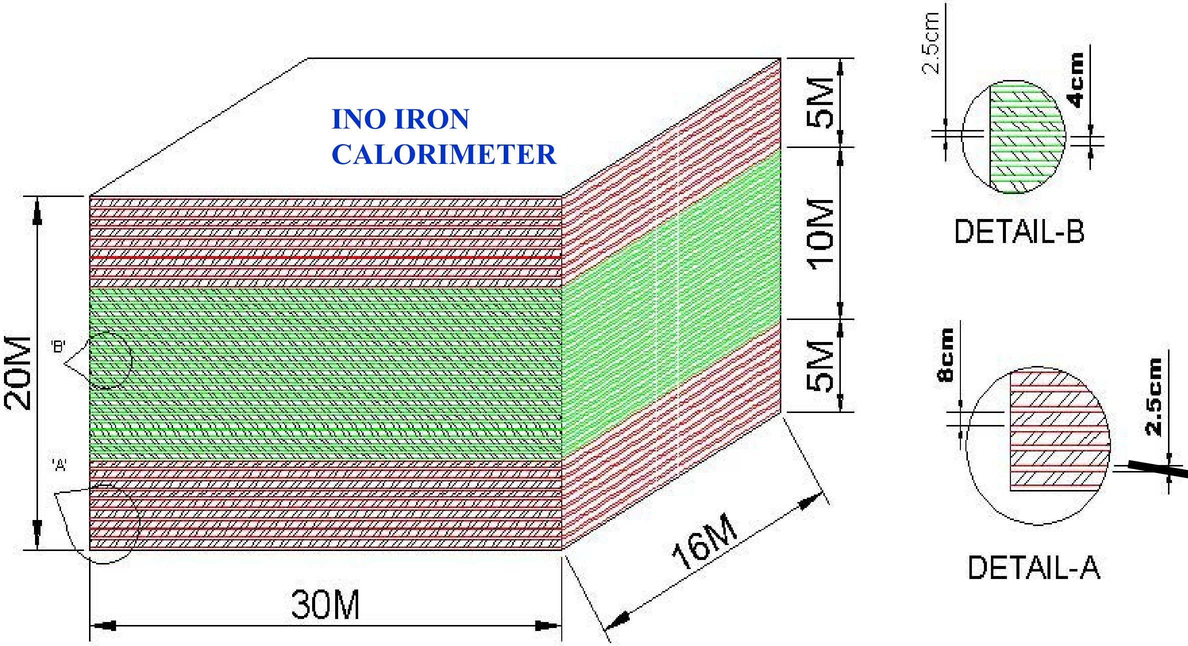


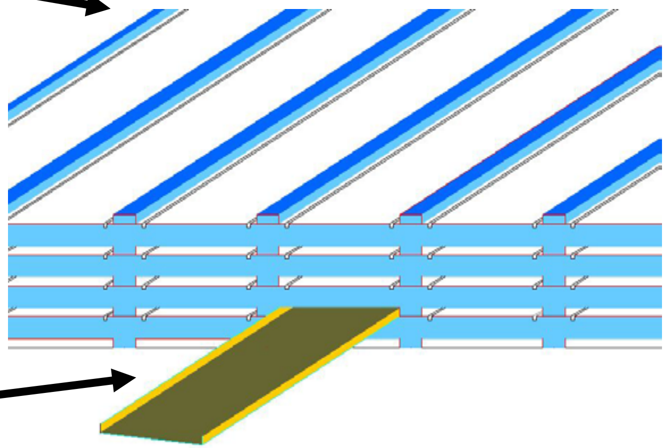


Current Activities

- **Detector Development.**
- **Detector Simulation.**
- **Physics Studies.**
- **Data Acquisition System.**
- **Site Survey.**
- **International Collaboration.**

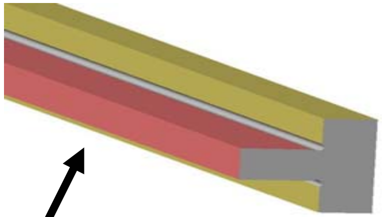
INO Detector Concept



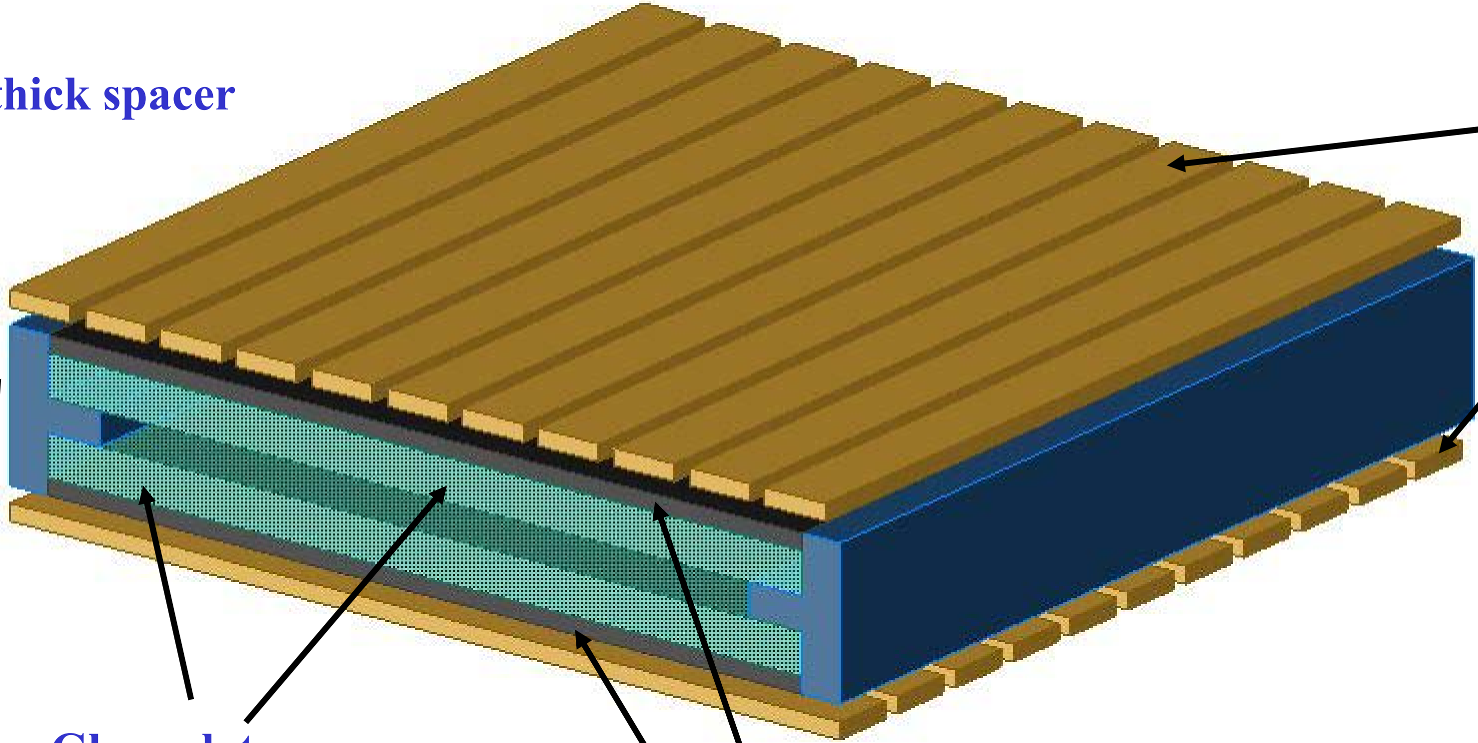


RPC Trays

Construction of RPC

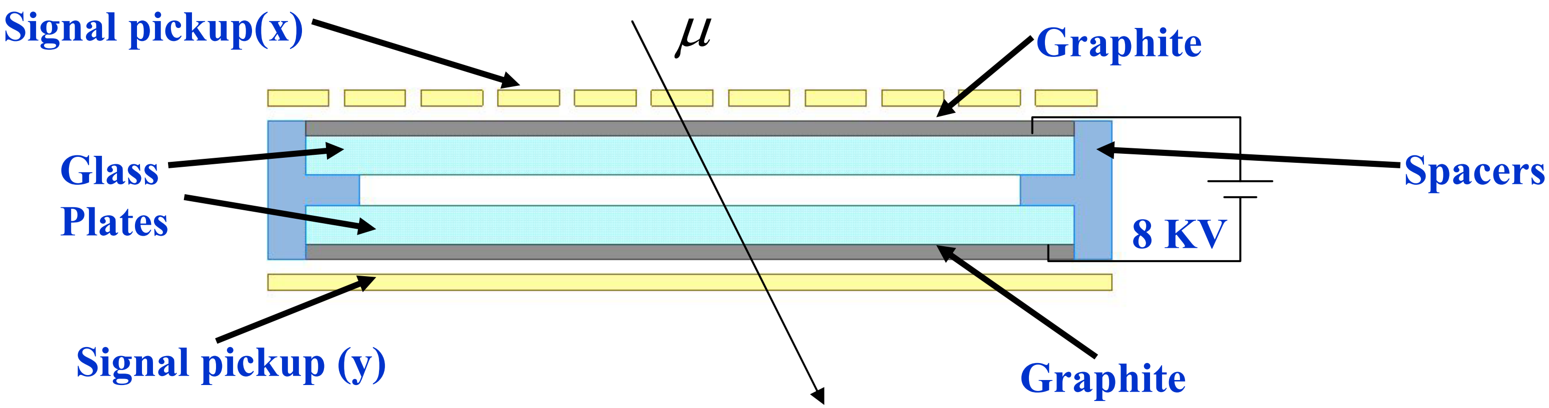


Two 2 mm thick float Glass
Separated by 2 mm spacer



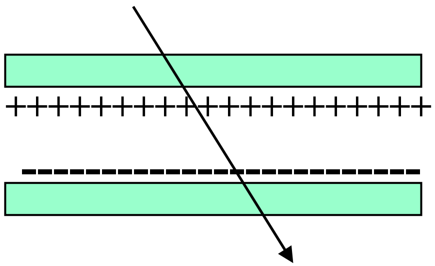
Complete RPC

RPC Principles of Operation

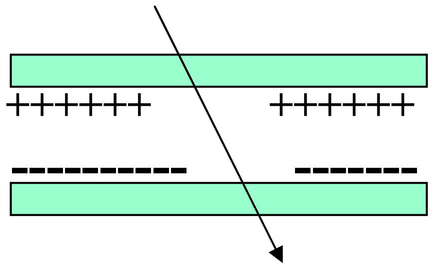


A passing charged particle induces an avalanche, which develops into a spark. The discharge is quenched when all of the locally $(r \approx 0.1\,\mathrm{cm}^2)$ available charge is consumed.

Before

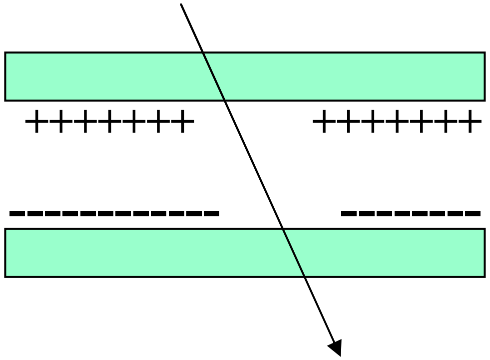


After



The discharged area recharges slowly through the high-resistivity glass plates.

Principles of Operation: Rate Capability



Each discharge locally deadens the RPC. The recovery time is approximately

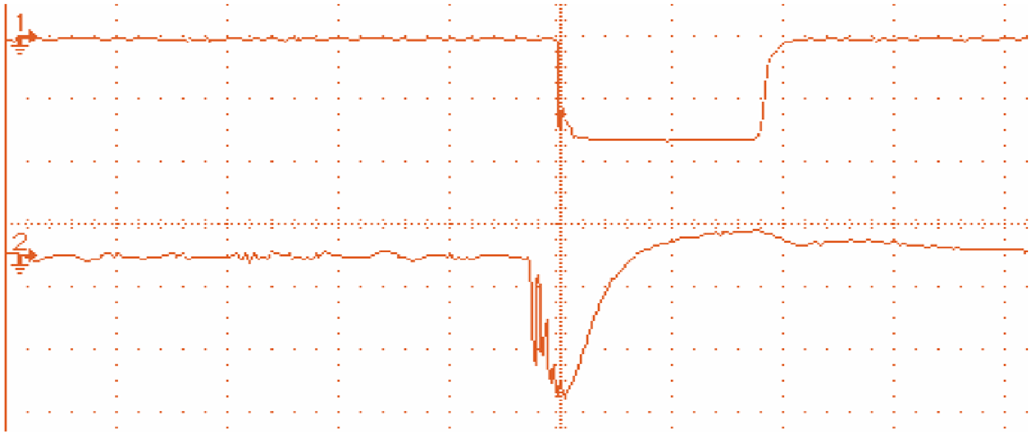
$$\tau = RC \cong \left(\frac{\rho\, l}{A}\right)\left(\frac{\kappa \varepsilon_0 A}{l}\right) = \rho \kappa \varepsilon_0$$

Numerically this is (MKS units)

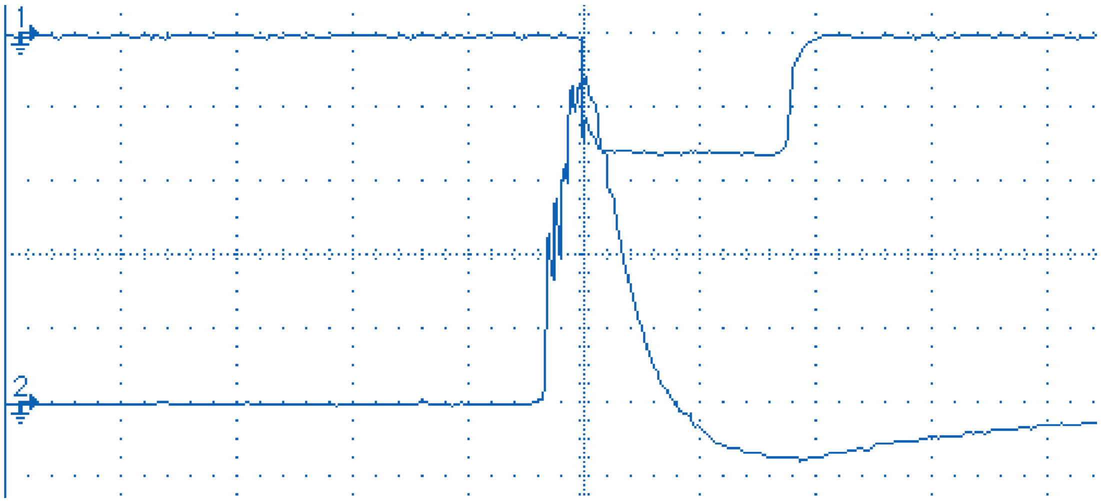
$$\tau = (5 \text{ x } 10^{10}) \text{ x } 4 \text{ x } (8.85 \text{ x } 10^{-12}) = 2 \text{ s}$$

Assuming each discharge deadens an area of $0.1\,\text{cm}^2$**, rates of up to** $500\,\text{Hz/m}^2$ **can be handled with 1% deadtime or less. This is well below what is expected in our application.**

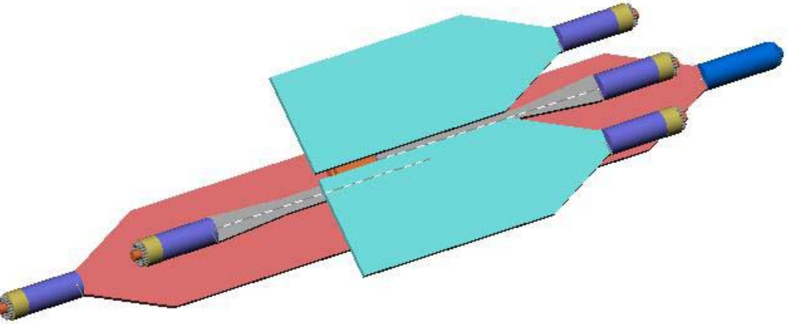
Pulse Height from RPC



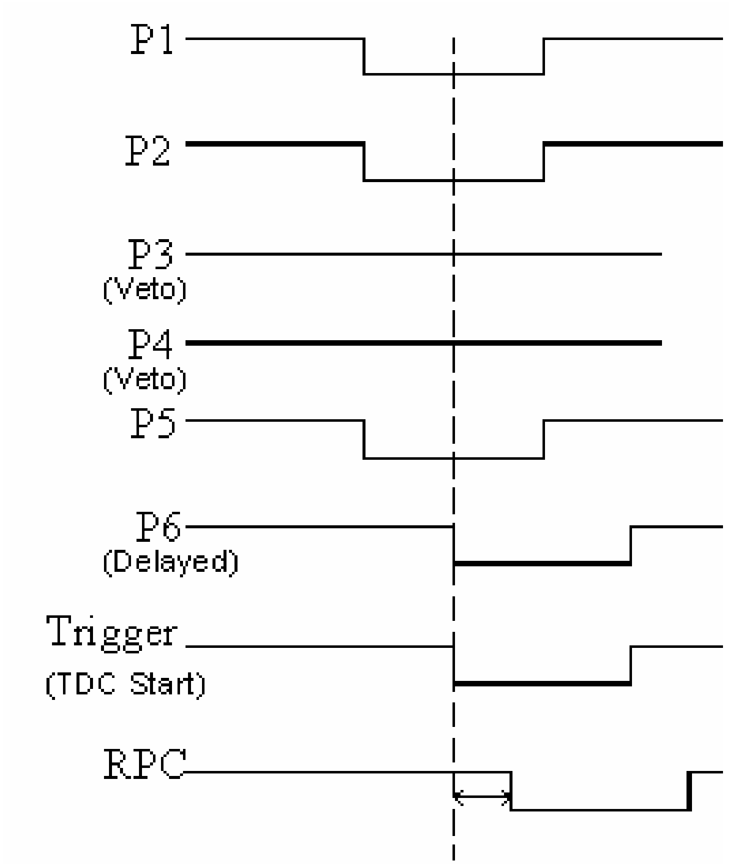
In streamer mode of operation, pulses are large (~100 mV into 50 ohms) and fast (FWHM ~ 15ns)



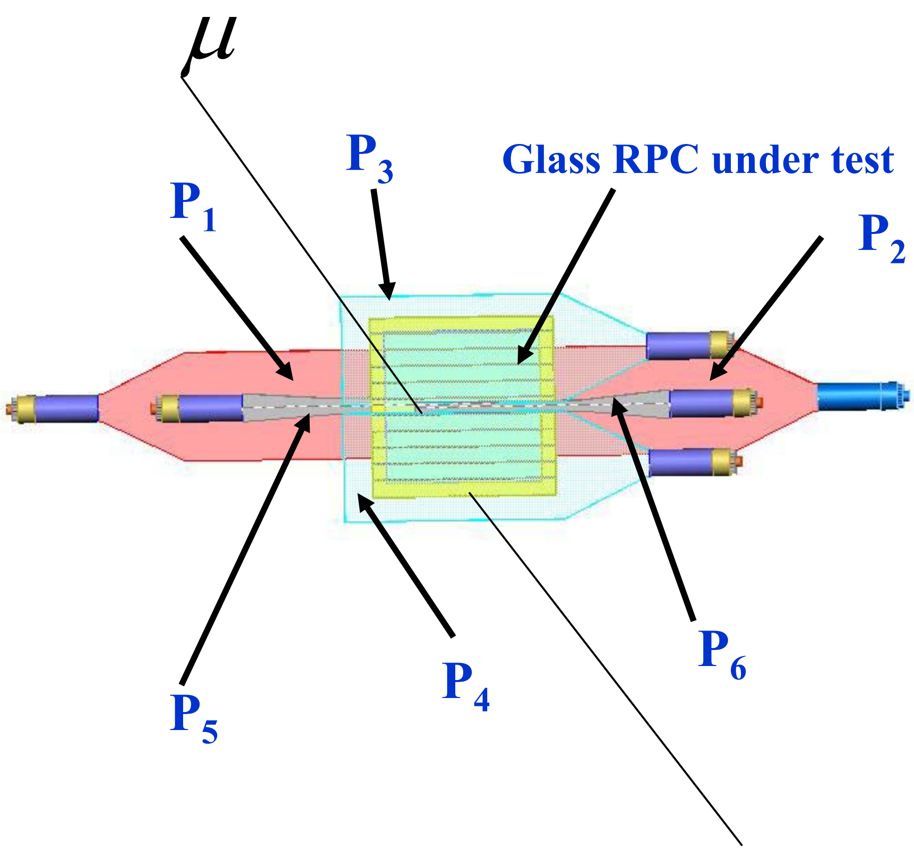
Test of RPC



Glass Spark Chamber R & D

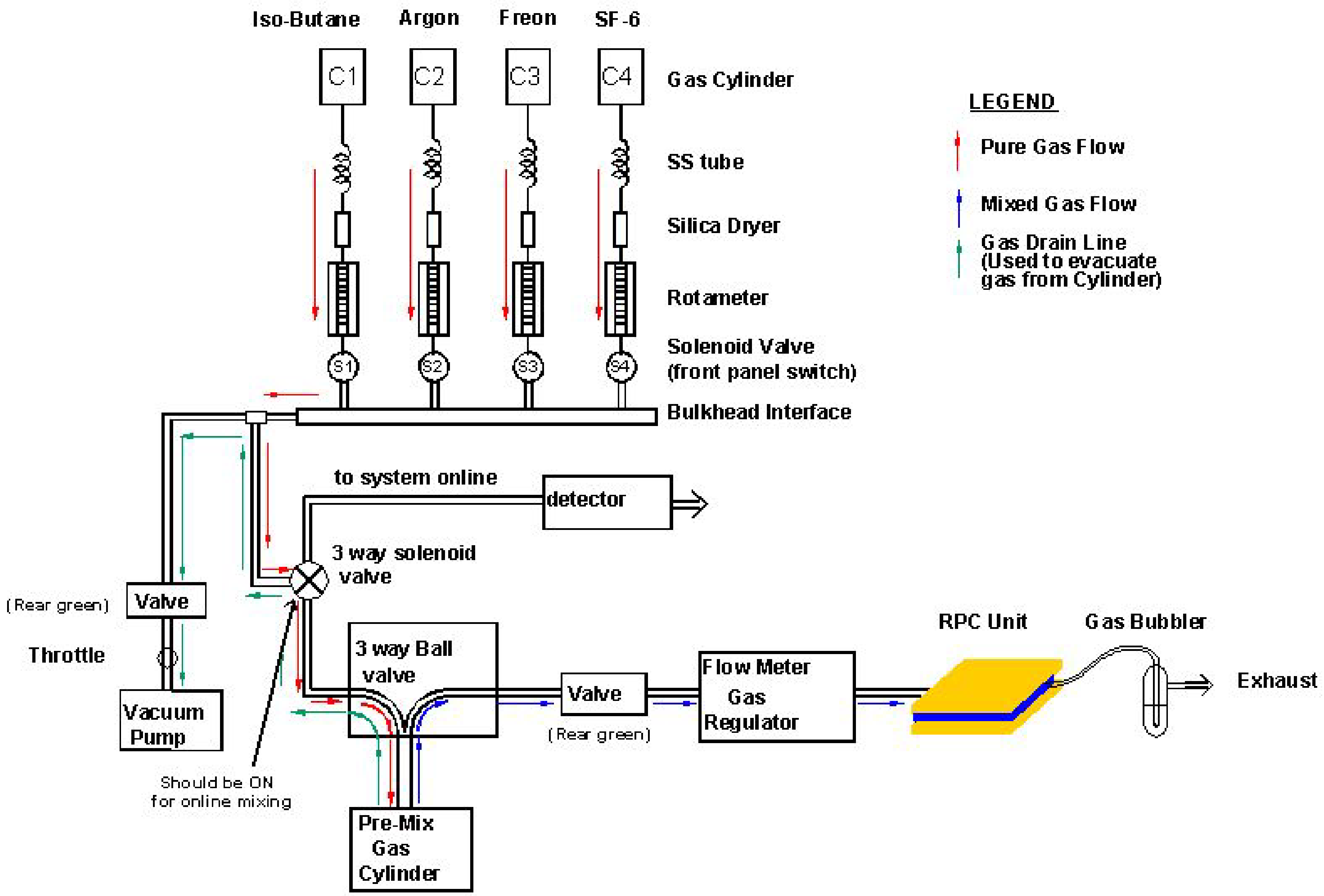


Schematic of the RPC test setup at TIFR

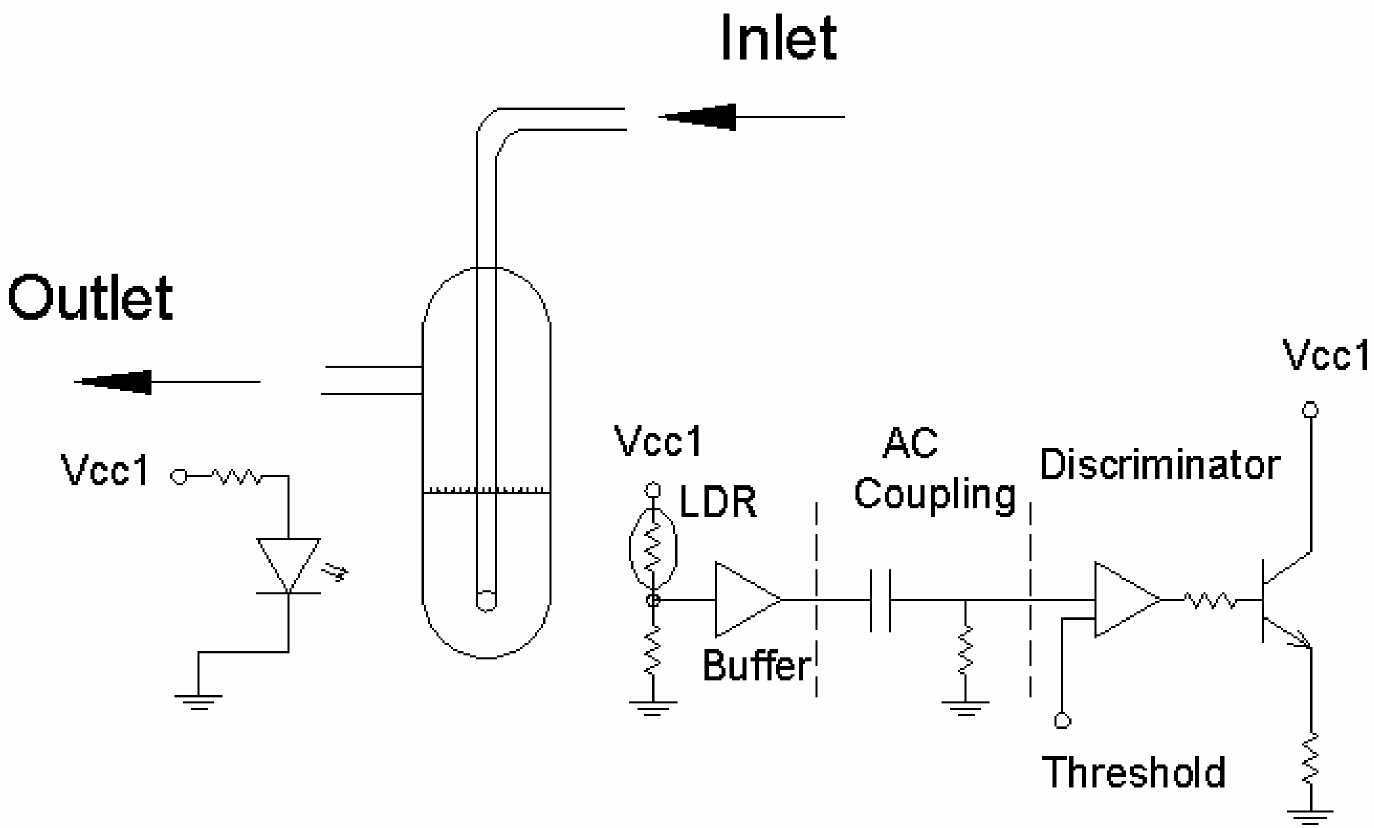


Muon Trigger = $P_1 \bullet P_2 \bullet \overline{P_3} \bullet \overline{P_4} \bullet P_5 \bullet P_6$

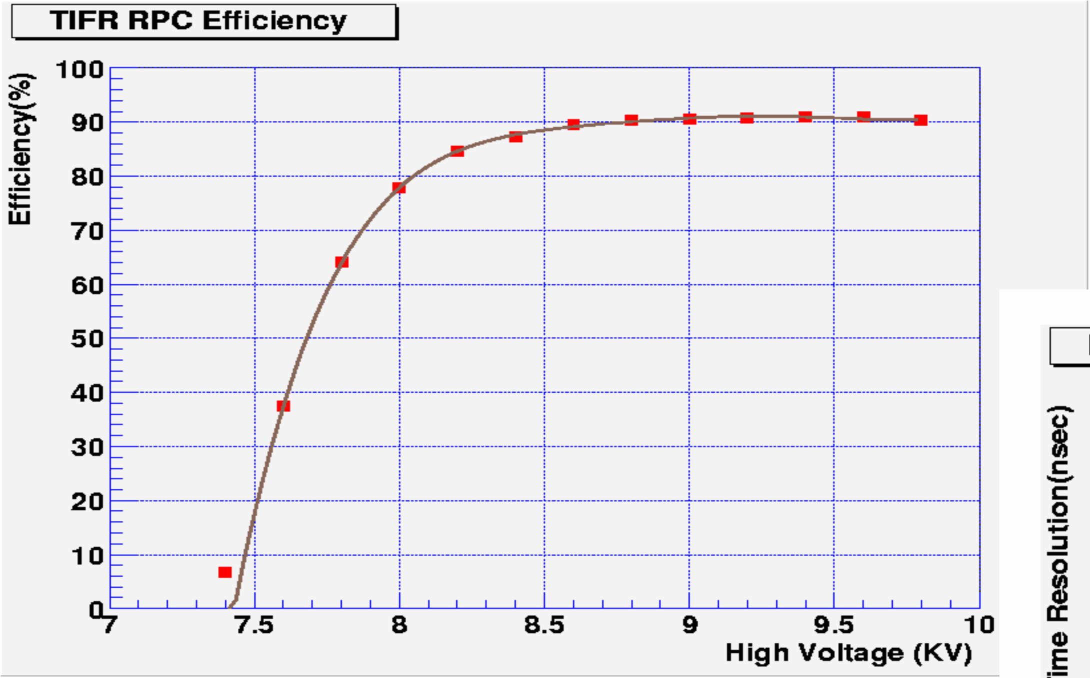
Gas Mixing Unit



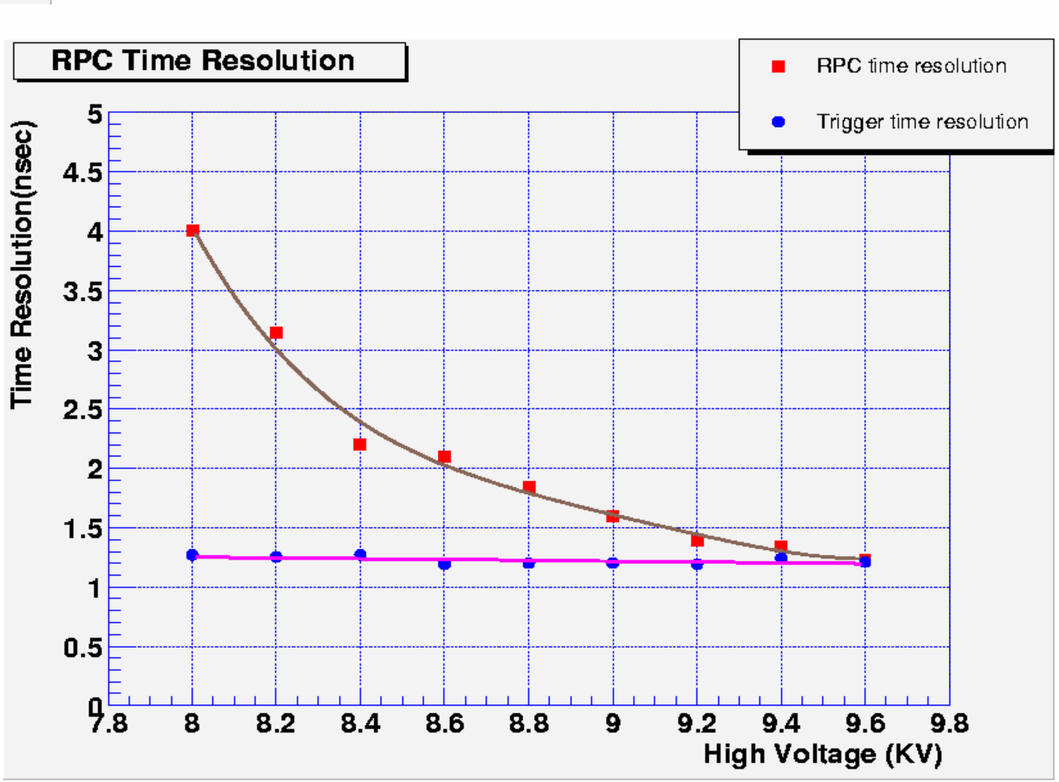
Bubble Counter as flow rate monitor

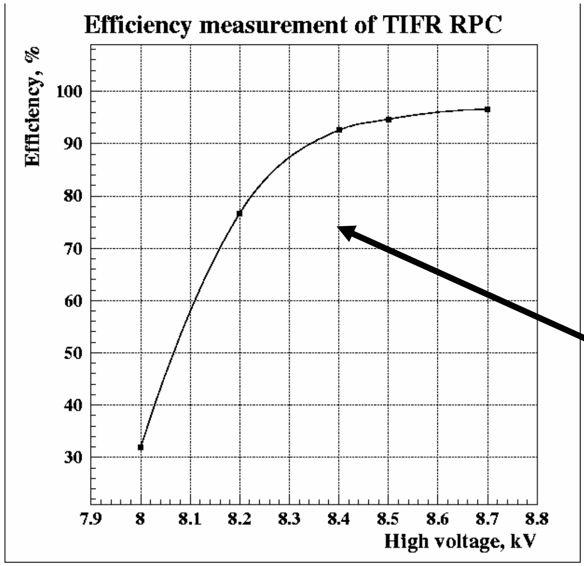


RPC Efficiency and Time resolution



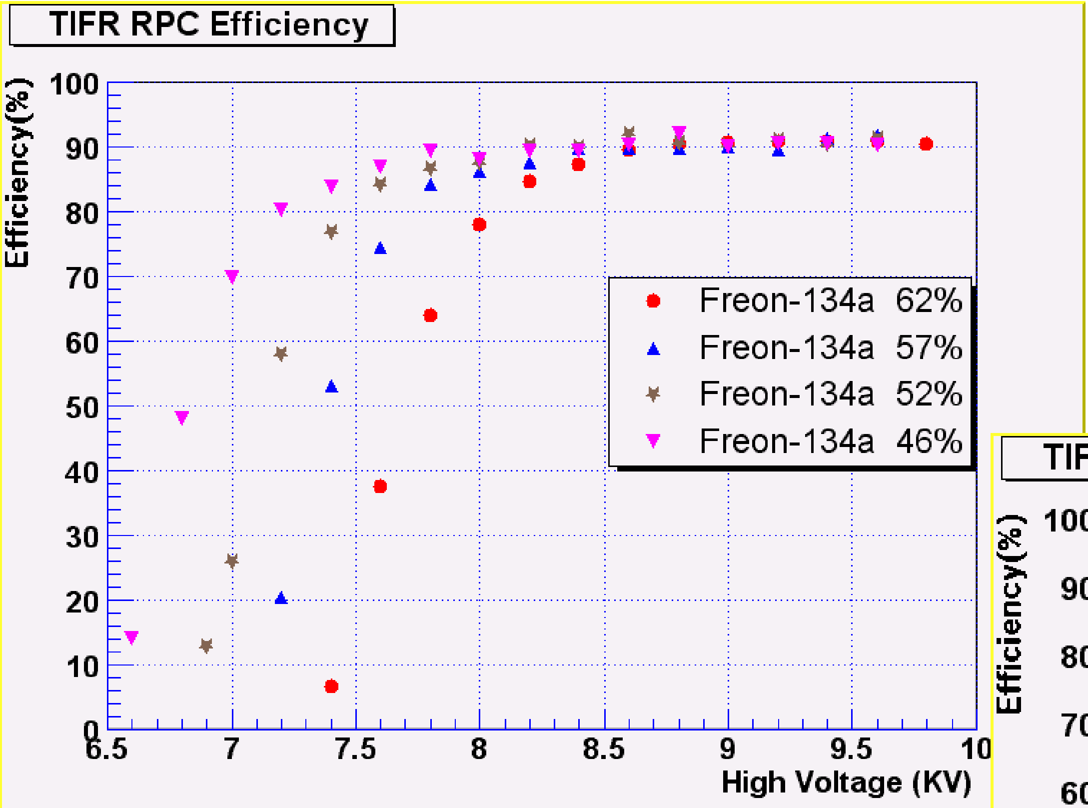
Freon 134a : 62%
Argon : 30%
Isobutane : 8%

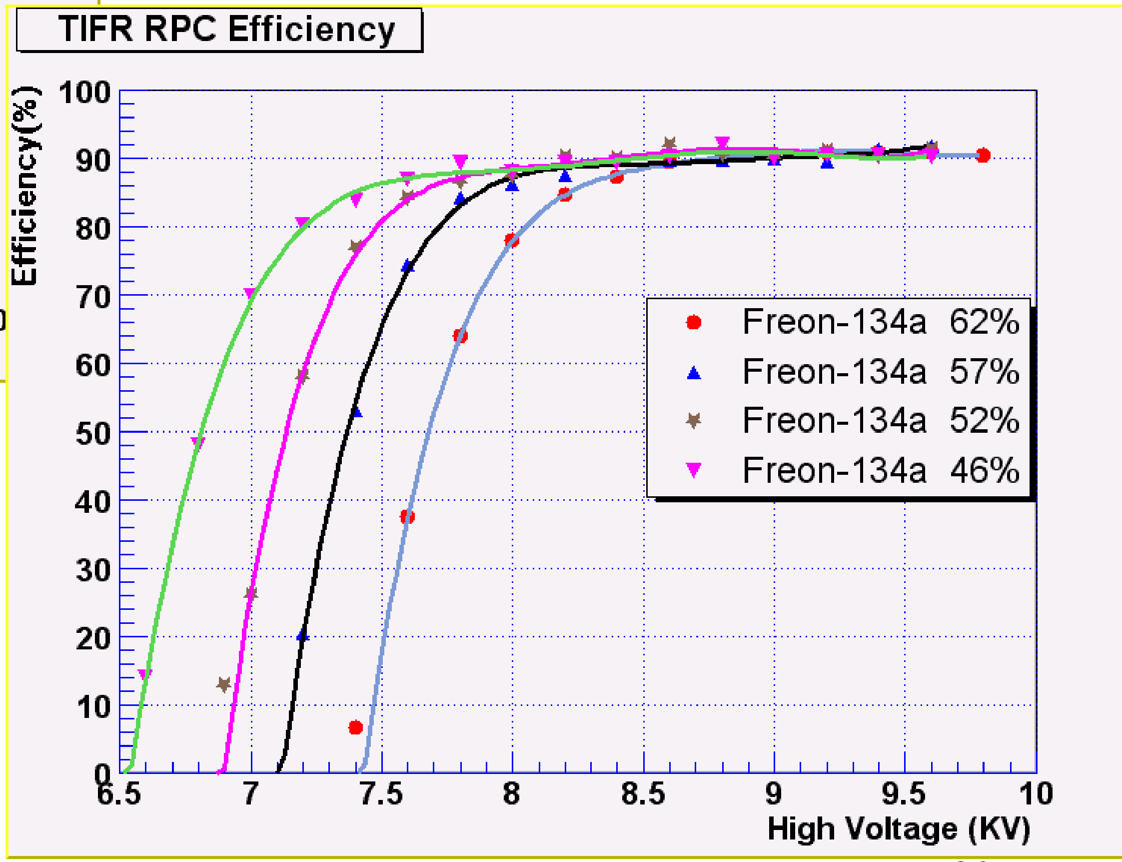




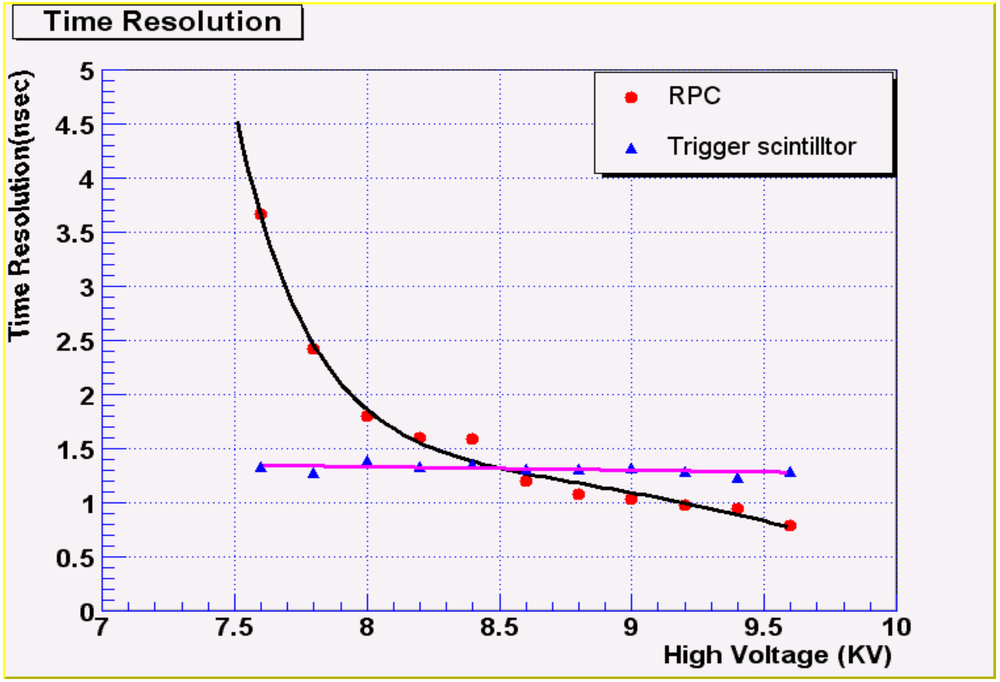
Fermi Lab measurement

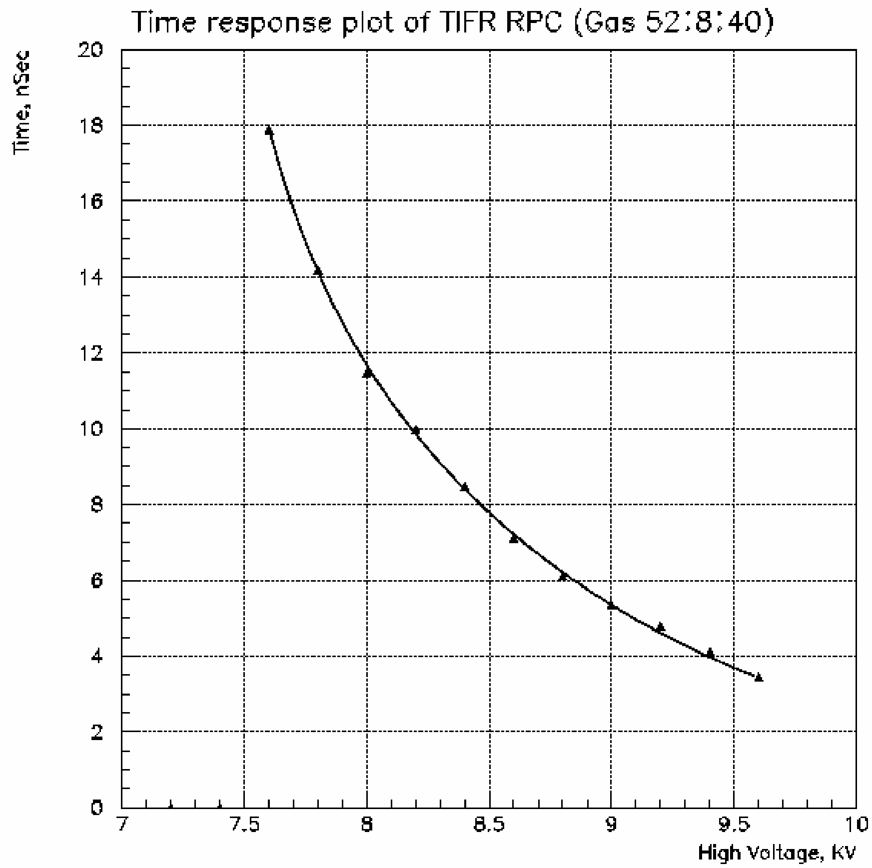
RPC Efficiency Studies

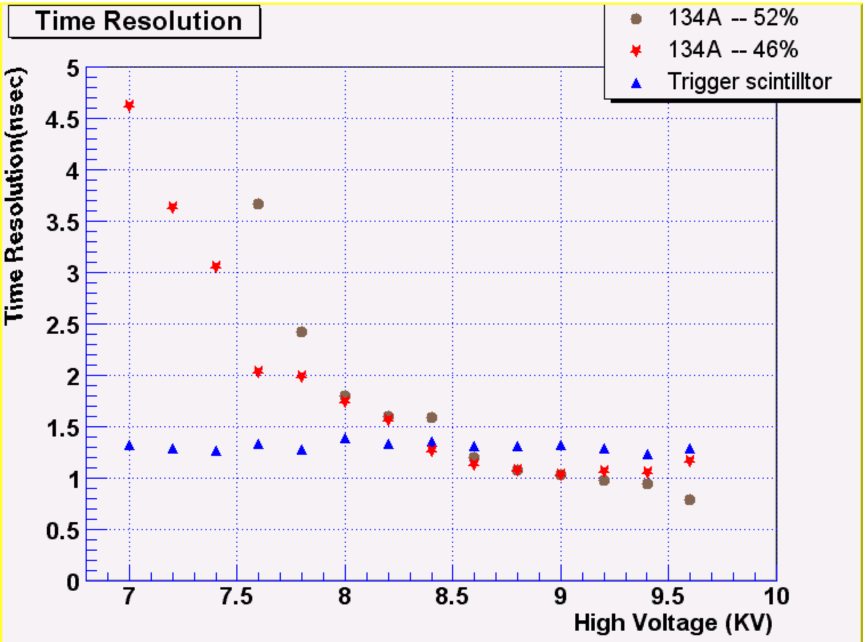




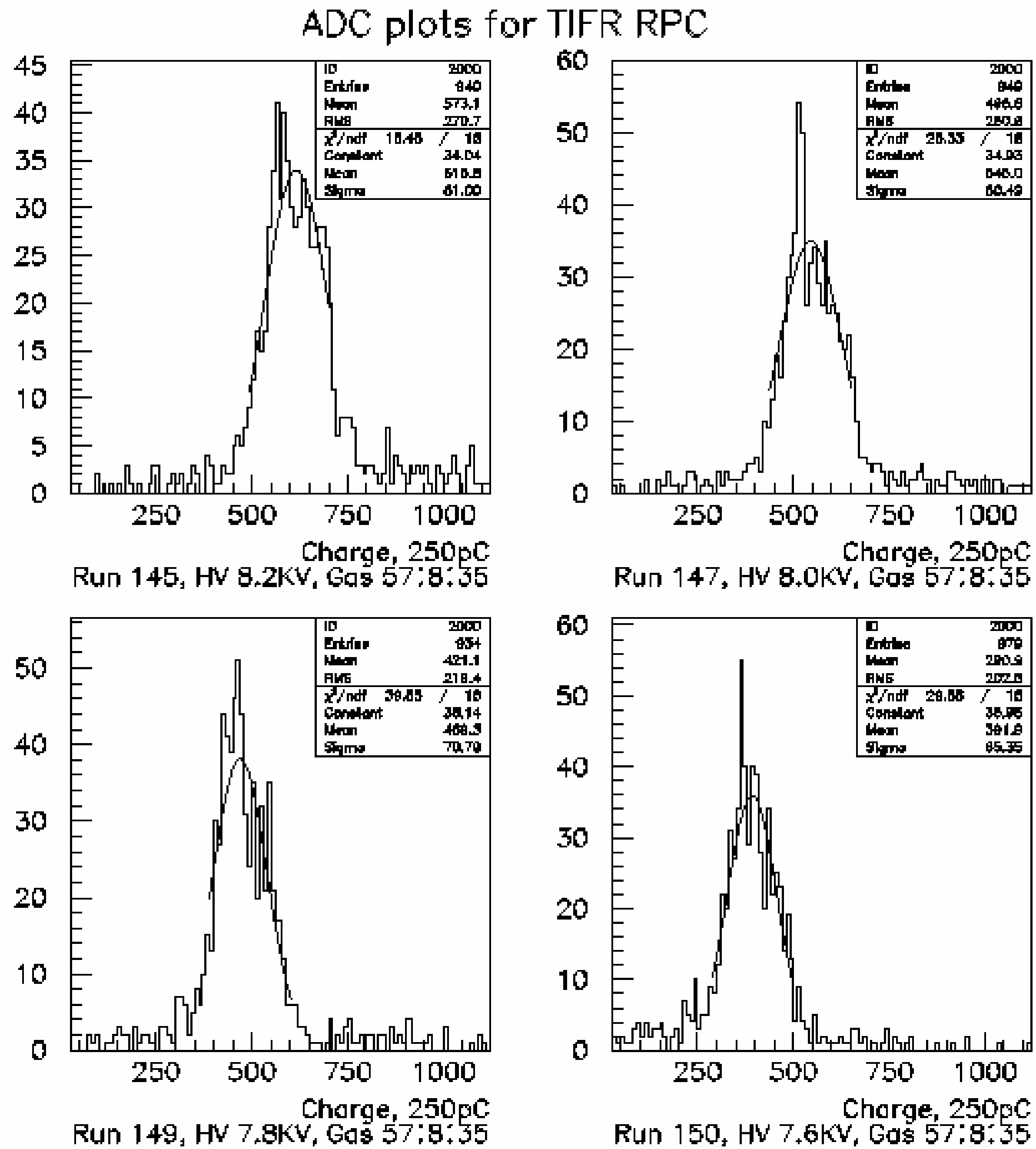
RPC Timing Studies



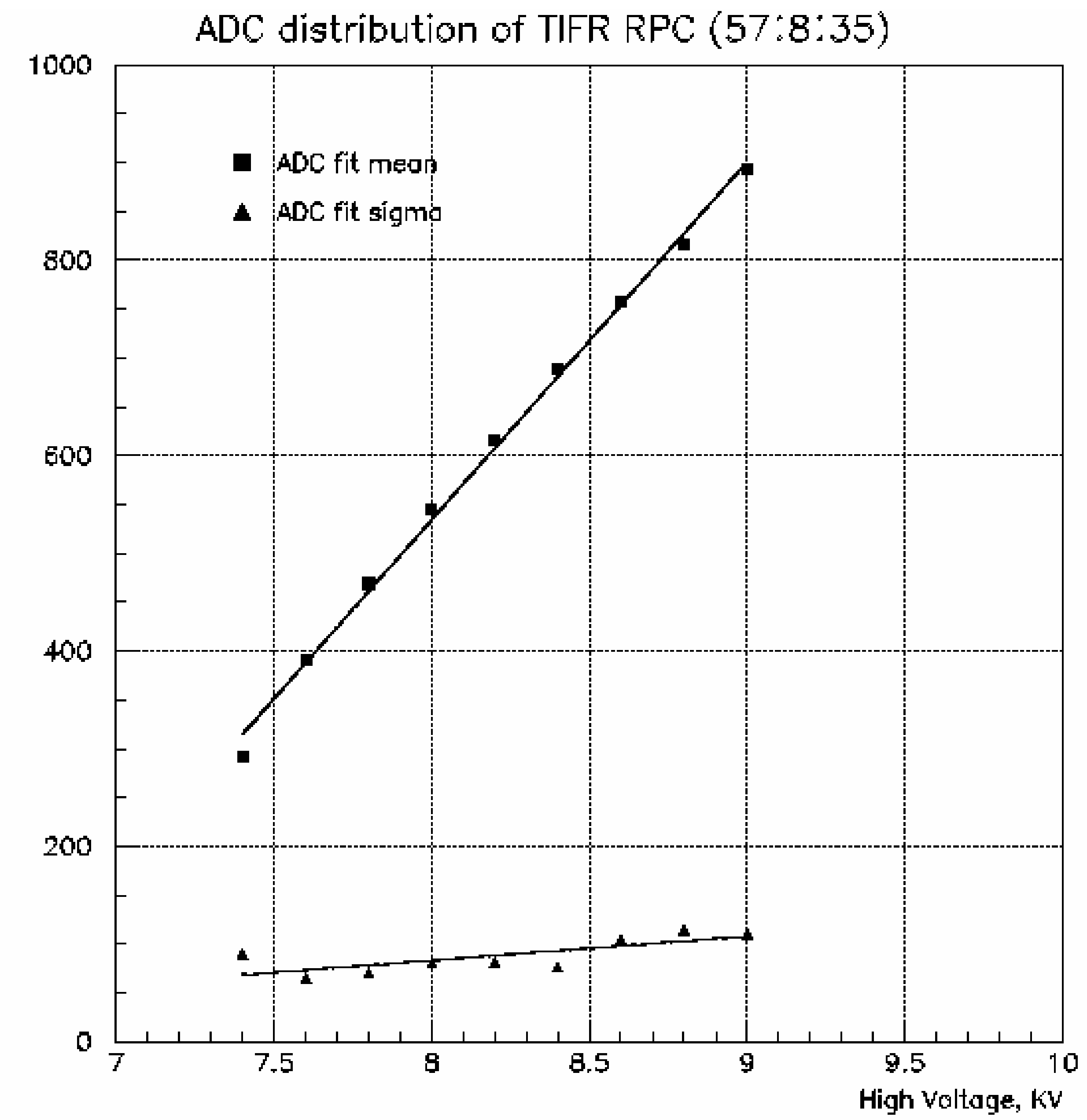




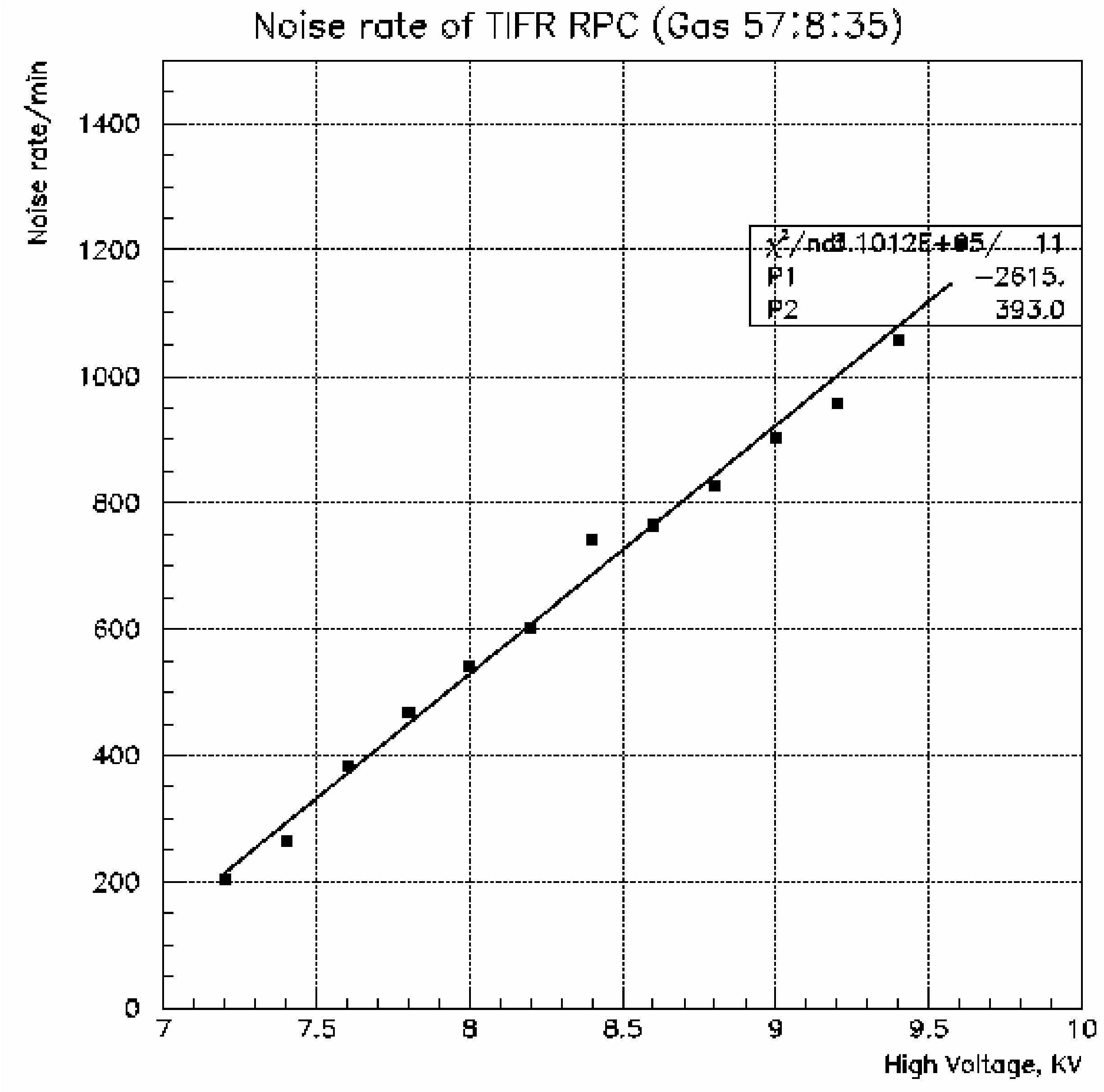
RPC Charge distribution



RPC Mean Charge Vs. Voltage



RPC Noise Pulse rate

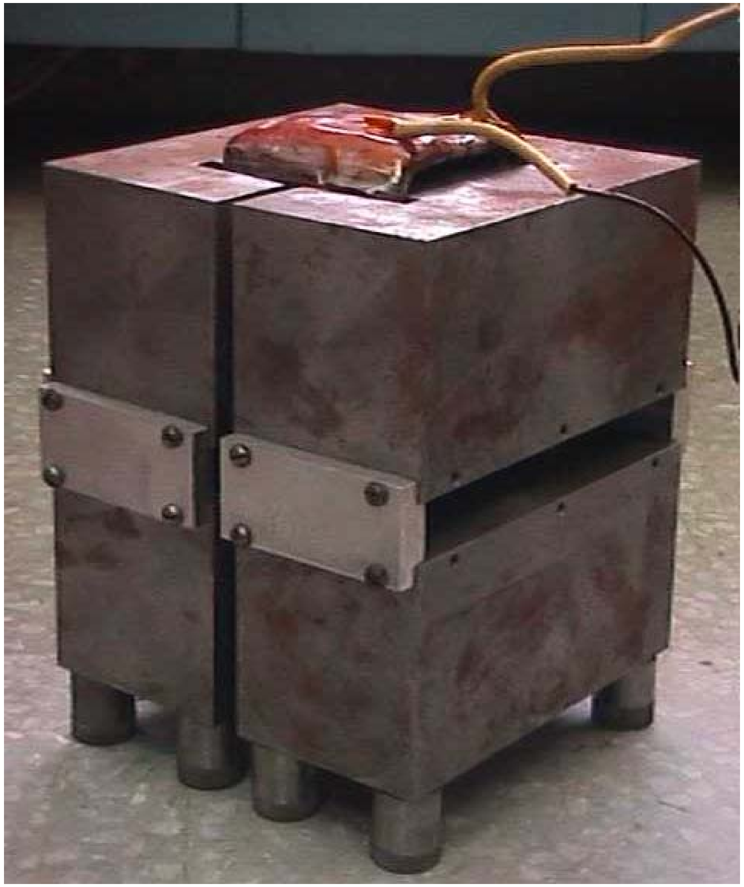


RPC Cross talk

Gas Mixture $C_2H_2F_4 : C_4H_{10} : Ar$	Slit Size (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

Magnet Model at VECC

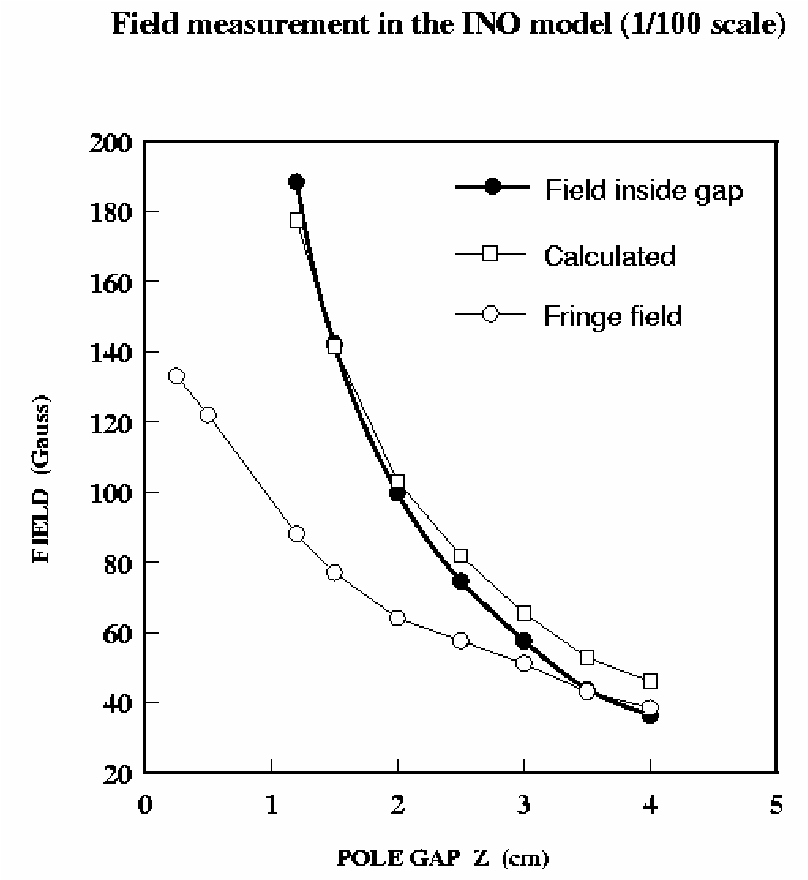
- **A model of the INO magnet has been fabricated at VECC to understand –**



If the measured field agrees with calculation.

Whether 2D calculation is OK

To understand magnet energizing time



Expected field inside iron 14 KG

Detector and Physics Simulation

- **NUANCE Event Generator:**
  - Generate atmospheric neutrino events inside INO detector
- **GEANT Monte Carlo Package:**
  - Simulate the detector response for the neutrino event
- **Event Reconstruction:**
  - Fits the raw data to extract neutrino energy and direction
- **Physics Performance of the baseline INO detector.**
  - Analysis of reconstructed events to extract physics.

These studies are going on at all the collaborating institutes

Physics Performance

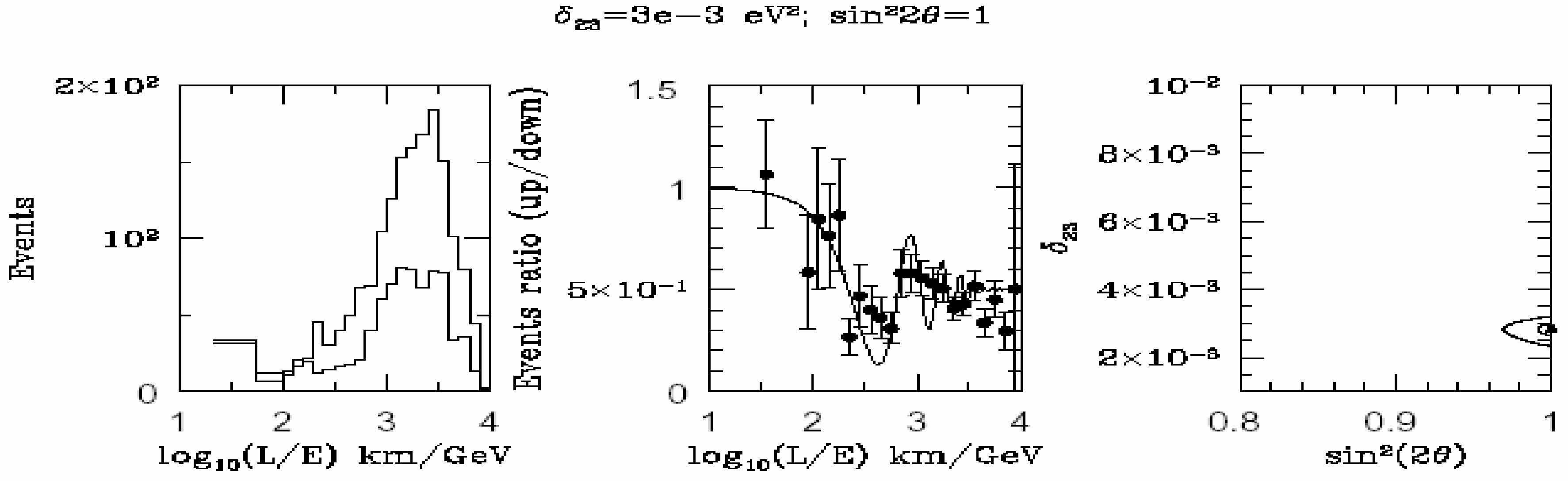


Figure 5: Analysis of 5 years up/down events with two-flavour oscillations $\delta_{23} = 3 \times 10^{-3}$ eV^2 and $\tan\psi = 1$.

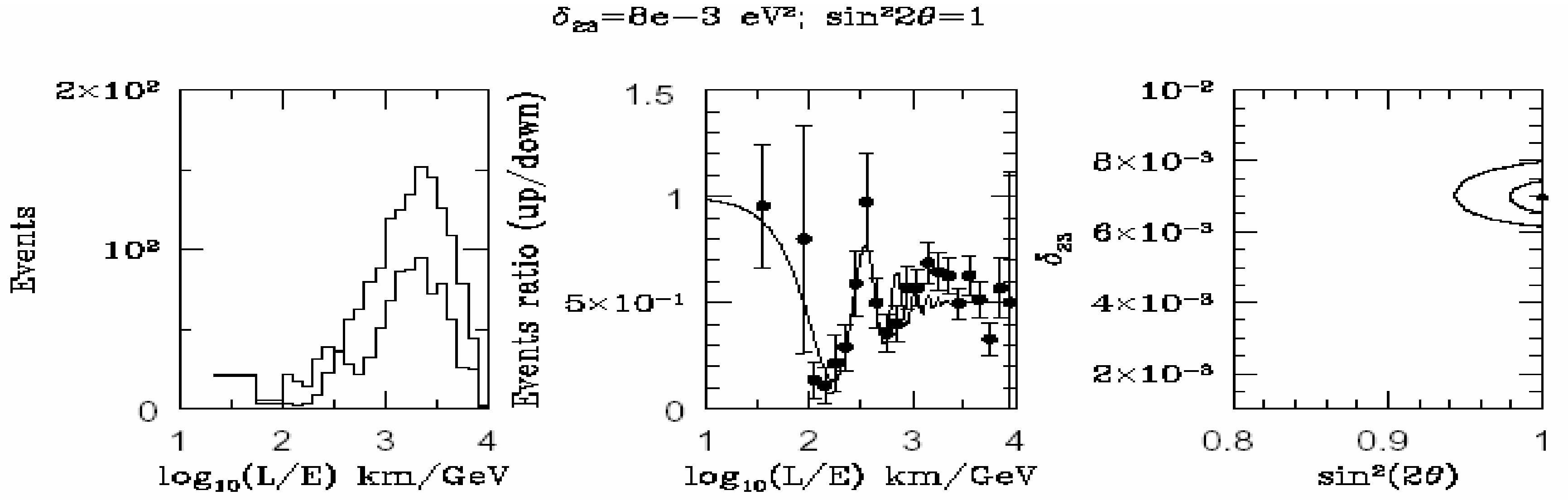


Figure 7: Analysis of 5 years up/down events with two-flavour oscillations $\delta_{23} = 8 \times 10^{-3}$ eV^2 and $\tan\psi = 1$.

Other Physics potential

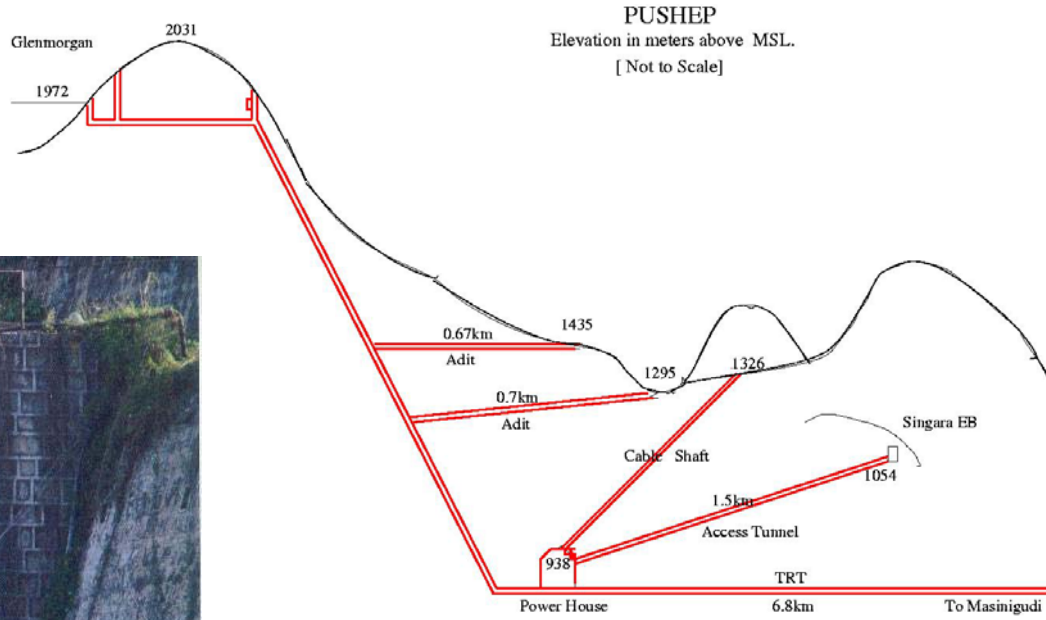
- Cosmic ray studies using multiple muon + air shower on surface
- Search for magnetic monopoles
- Search for WIMPs
- Additional studies on Kolar Events, Double core events, anomalous cascades
- Neutrinos from factories

Possible INO sites

- **PUSHEP (Pykara Ultimate Stage Hydro Electric Project) in South India**

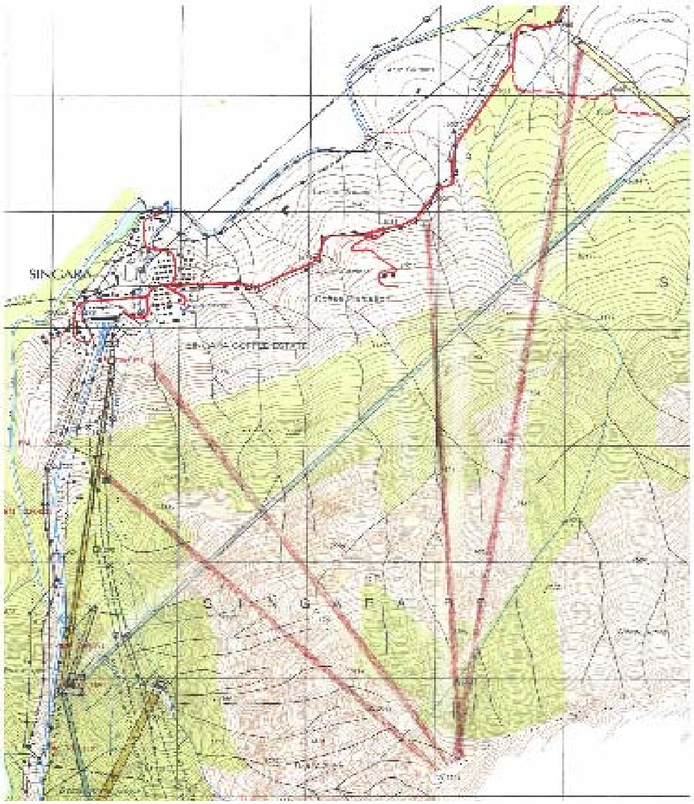
  or

- **RAMMAM Hydro Electric Project Site**



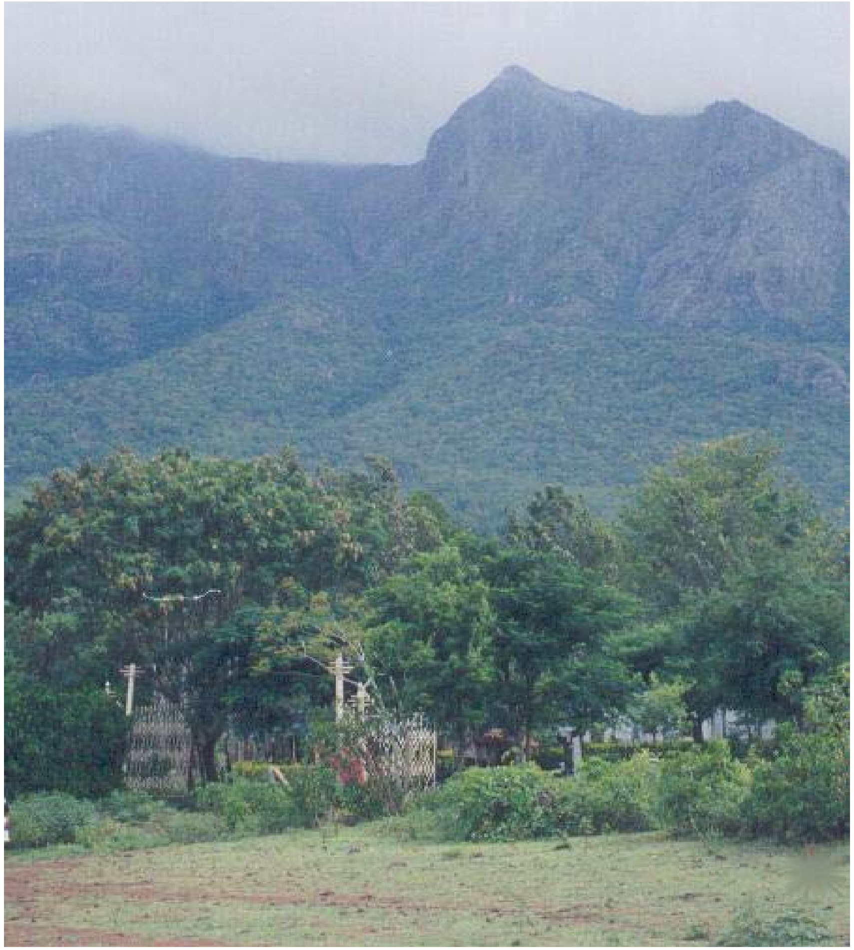
Possible tunnel alignments at PUSHEP

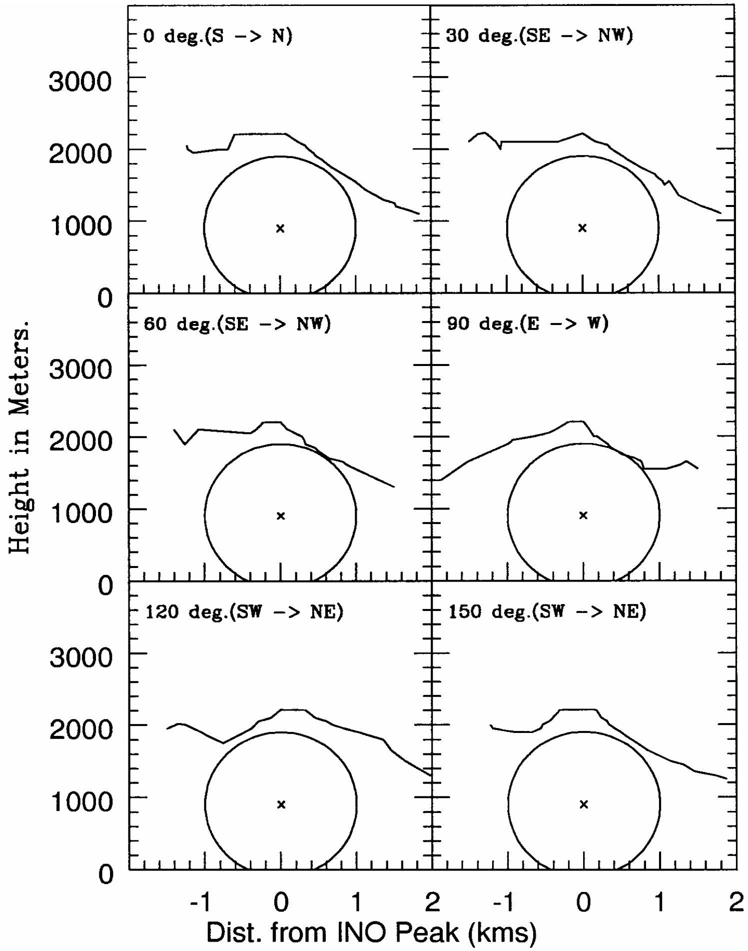
4 possible allignments of INO tunnel at PUSHEP



Alignment location	Length	Portal level	Cavern base	Vertical Cover	Cover at TRT
1. From access Tunnel 450 ms from PUSHEP portal	1867 ms	1019 ms	894 ms	1313 ms	+51 ms
2. Next to access Tunnel 187 ms east of PUSHEP portal	2129 ms	1050 ms	908 ms	1299 ms	+63 ms
3. South of Adit 4	2380 ms	1025 ms	867 ms	1340 ms	+61 ms
4. Around Adit 4 inlet	3194 ms	966 ms	753.5 ms	1453.5 ms	-18.9 ms

PUSHEP

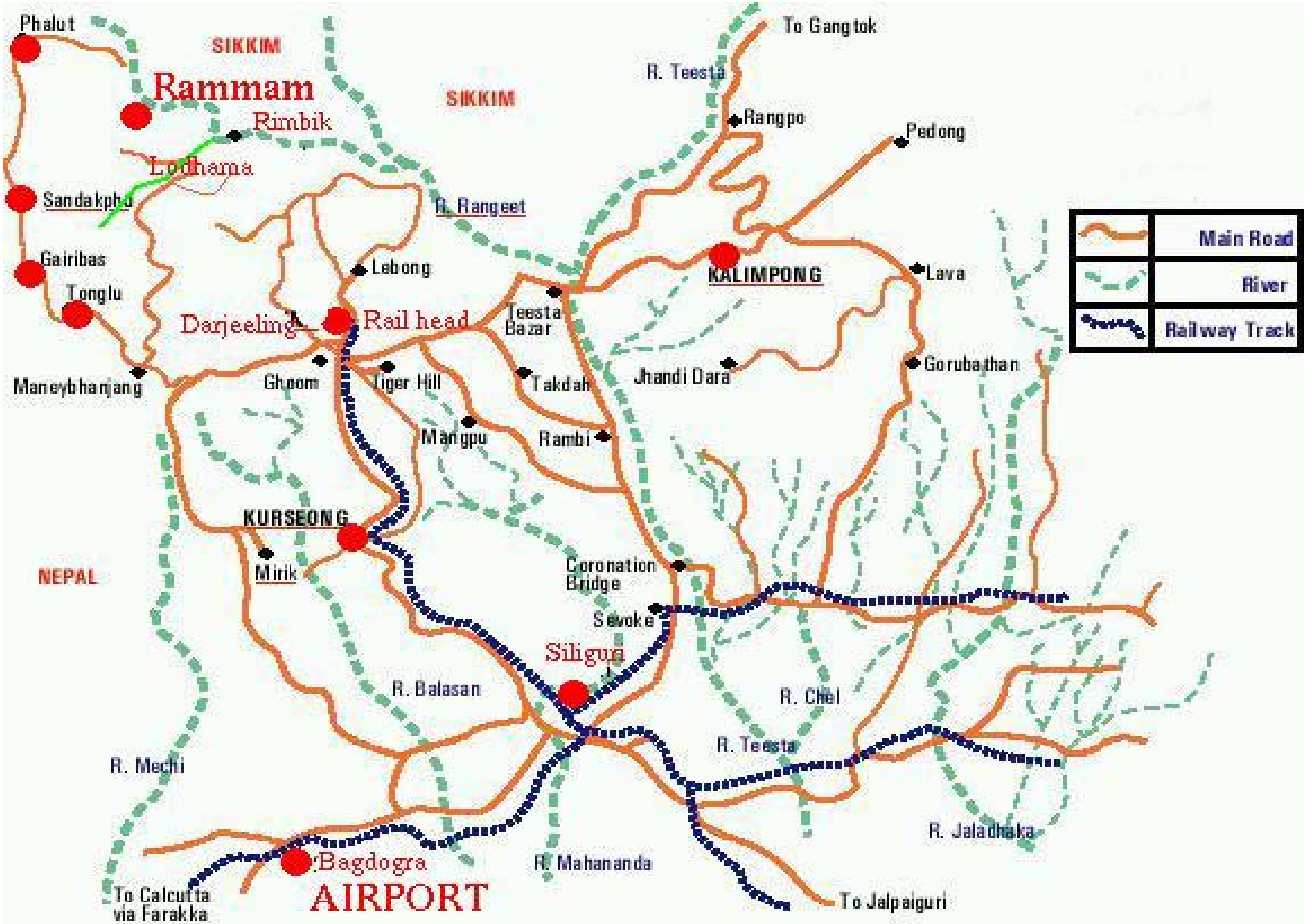




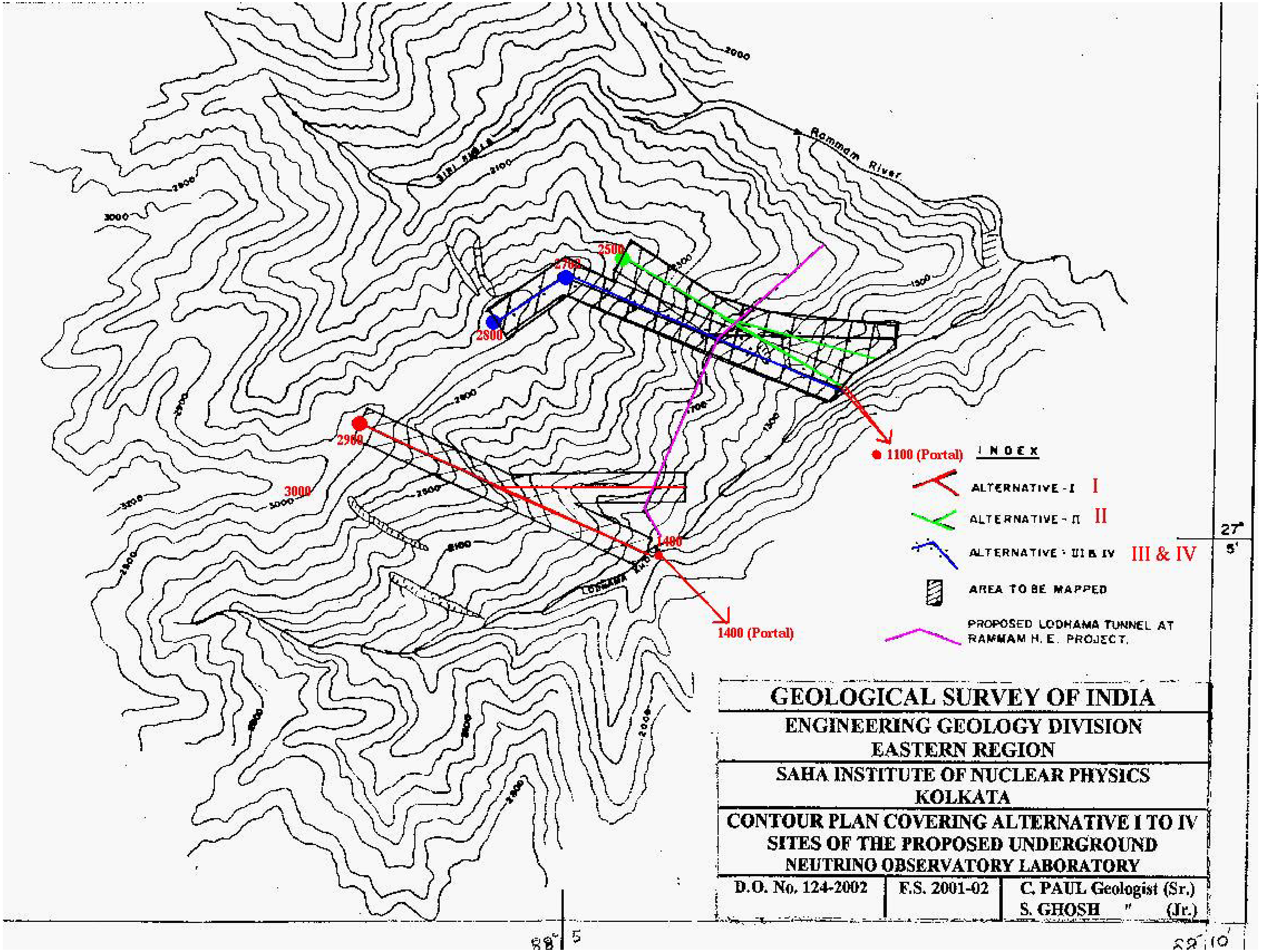
Action Items:

- Stress measurement at depths of 1000m
- Permissions to conduct tests and approval for locating INO at PUSHEP
- Possibility of building exploratory tunnel

Location of Rammam



Possible tunnel alignment at Rammam



International Collaboration

- Such a facility has to be an international effort.
- A small beginning in detector collaboration with Gran Sasso Laboratory and Fermilab.
- Discussing with JHF proponents on a possible very long base line beam towards INO. Ultimate Long base line neutrino experiment should have a beam from USA to India.
- US has long term commitment towards neutrino physics. India has started R & D effort in this direction. There are lot of scope for collaboration.
- There are lot more to achieve
  - Detector R & D
  - Associated Electronics
  - Simulation software and event reconstruction