Neutrino is the most tiny quantity of reality ever imagined by a human being.

Frederick Reines
Co-discoverer & Nobel Laureate

Detector and instrumentation for the INO's ICAL experiment

Dr. B.Satyanarayana ▪ Scientific Officer (G)
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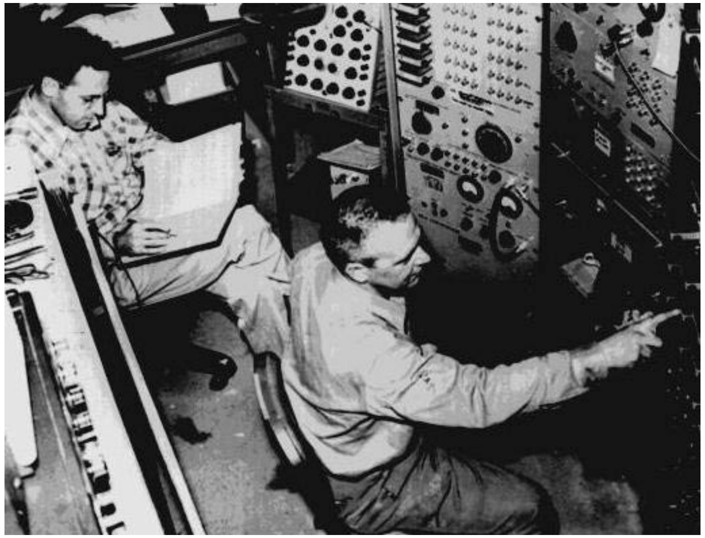
Neutrino (ν)

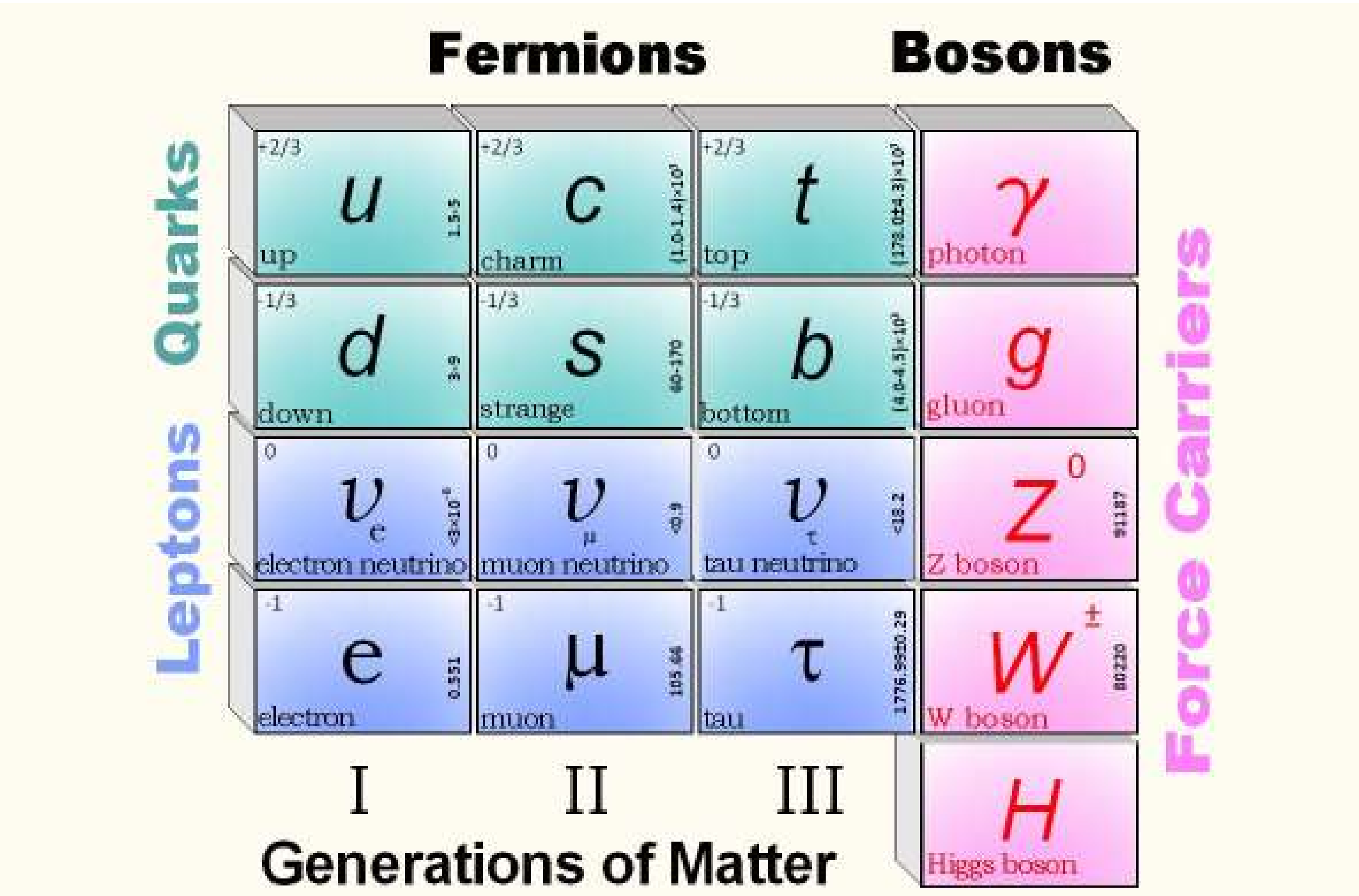
- Proposed by Wolfgang Pauli in 1930 to explain beta decay.
- Named by Enrico Fermi in 1931.
- Discovered by Frederick Reines and Clyde Cowan in 1956.
- Created during the Big Bang, Supernova, in the Sun, from cosmic rays, in nuclear reactors, in particle accelerators etc.
- Interactions involving neutrinos are mediated by the weak force.



Unique features of neutrinos

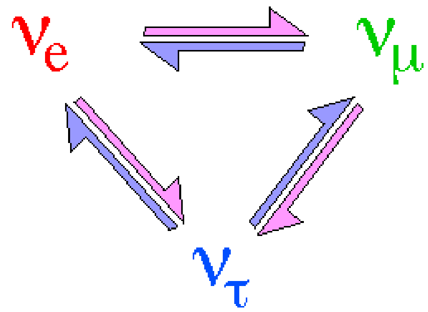
- The second most abundant particles in the universe
  - Cosmic microware background photons: 400/cm^3
  - Cosmic microware background neutrinos: 300/cm^3
- The lightest massive particles
  - A million times lighter than the electron
  - No direct mass measurement yet
- The most weakly interacting particles
  - Invisible: Do not interact with light
  - Stopping α, β, γ radiation: 50cm lead shielding
  - Stopping neutrinos from the sun: Several light years!
- About 100 trillion neutrinos from the sun and other such objects are going through our body every second without doing any harm.

Standard model of particle physics



Neutrino oscillations

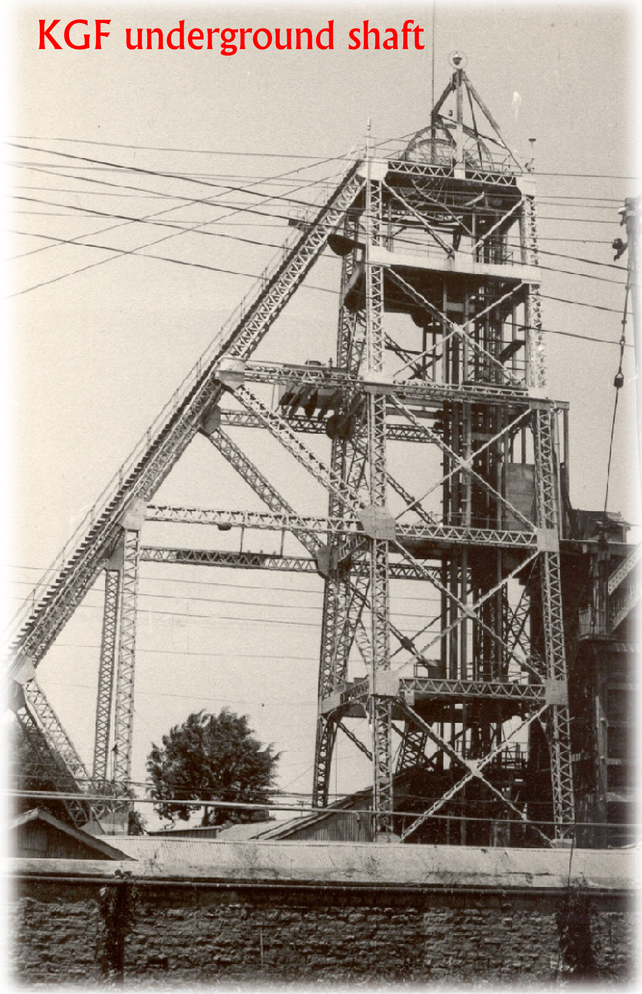
- It is now known that neutrinos of one flavour oscillate to those of another flavour.
- The oscillation mechanism is possible only if the neutrinos are massive.



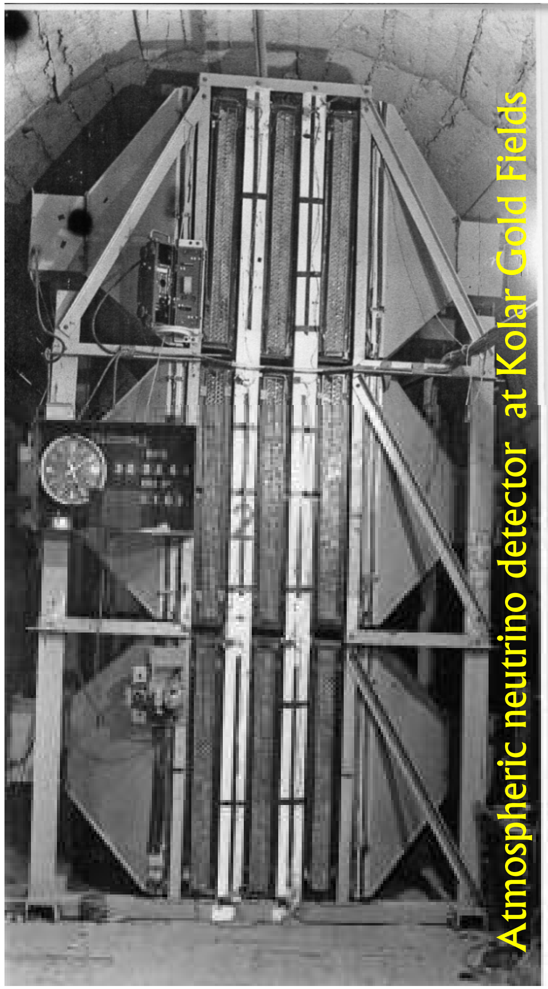
- Neutrino experiments are setting the stage for extension of Standard Model itself.
- One of the main goals of the INO experiment is to precisely measure the parameters that govern the neutrino oscillations.

History of neutrino physics in India

- India had a long tradition of carrying out High Energy Physics research using deepest underground laboratories in the world at Kolar Gold Fields during 1952-92.
- Indian initiative in neutrino physics goes back to nearly 50 years.
- Demonstrated for the first time, the feasibility of doing neutrino experiments at KGF.
- International collaboration experiment to detect atmospheric neutrinos started at KGF in 1964.
- First atmospheric neutrino was detected at KGF at a depth of 2.3km way back in 1965 by the TIFR-Osaka-Durham group.
- During early 80s dedicated detectors were setup at KGF by TIFR-Osaka collaboration to look for proton decay.



Tradition of underground physics



Atmospheric neutrino detector at Kolar Gold Fields

Proton decay experiments

India-based Neutrino Observatory (INO) project

- The primary goal of INO is neutrino physics.
- A national collaboration of scientists from more than 26 groups belonging to DAE institutions, IITs and Universities.
- The total cost of the project is expected to be about Rs.1500 crores.
- The project includes:
  - construction of an underground laboratory and associated surface facilities,
  - construction of a Iron Calorimeter (ICAL) detector for neutrinos,
  - setting up of National Centre for High energy Physics (NCHEP).
- The project is expected to be completed within seven years beginning April 2012.
- A successful INO-Academia-Industry interface is expected to develop because of the large scale of experimental science activity involved.
- INO Graduate Training Programme under the umbrella of Homi Bhabha National Institute (HBNI) - a deemed-to-be University within DAE, is in its fifth year (25 Ph.D. students in Physics, detectors and electronics).

Physics possibilities with ICAL

- ICAL is capable of shedding light on the neutrino mass hierarchy, or the ordering of neutrino masses, due to its unique capability to identify lepton charge.
- Determining the hierarchy would be a crucial pointer to the physics that lies beyond the Standard Model.
- ICAL can significantly aid in improving the precision of the atmospheric mass squared difference and the associated mixing angle.
- Using effects primarily due to earth's matter, it can also shed light on the octant of the atmospheric mixing angle.
- ICAL is capable of substantially adding to our present knowledge of very high energy cosmic ray muons due to its unique capability to access hitherto unexplored energy regions in this sector.
- Several studies have also explored ICAL's capabilities as an end detector for a neutrino factory or a beta beam. This would allow precise measurements of very important parameters like the CP phase and the small mixing between two of the neutrino mass states.

Possible new proposals at INO

- Search for neutrino less double beta decay (NDBD) using Tin (^{124}Sn) via cryogenic bolometer.
- Cryogenic Silicon/Germanium based dark matter experiment at INO (DINO).
- Measurement of nuclear cross sections of astrophysical interest using 500kV accelerator; utilising the low back-ground environment inside the INO facility.
- The INO facility will develop into a centre for other studies in physics, biology, geology, material research etc., which will exploit the special conditions existent deep underground.

National Centre for High Energy Physics (NCHEP)

- To be setup on a 13 hectares land very close to the Madurai Kamaraj University (Vadapalanchi and Karadipatti Village) in the city of Madurai.
- Will act as the nodal centre for all INO activities. Responsible for operation of the INO facilities.
- Will develop full-fledged manpower to operate and maintain the INO laboratory. Human resource development in basic experimental science research. INO Graduate Training program will move to NCHEP when ready.
- Will have a major detector development laboratory. Development of detector technology and its varied applications, such as in medical imaging, material science, industrial control and geological survey.

INO Collaboration

Spokesperson: N.K. Mondal, TIFR, Mumbai
Home page: http://www.ino.tifr.res.in

Ahmedabad: Physical Research Laboratory (PRL)
S. Goswami, A.S. Joshipura

Aligarh: Aligarh Muslim University (AMU)
S. Ahmed, M. Sajjad Athar, R. Hasan, S.K. Singh

Allahabad: Harish Chandra Research Institute (HRI)
S. Choubey, R.Gandhi, A.Raychaudhuri

Calicut: University of Calicut (UC)
B.R.S. Babu, A.M. Vinodkumar

Chandigarh: Panjab University (PU)
V.K. Bhandari, V. Bhatnagar, M.M. Gupta, A. Kumar, J.S. Shahi, B. Singh, J.B. Singh

Chennai: Indian Institute of Technology, Madras (IITM)
N. Chandrachoodan, N. Krishnapurna, J. Libby, A. Prabhakar

Chennai: The Institute of Mathematical Sciences (IMSc)
D. Indumathi, H.S. Mani, M.V.N. Murthy, G. Rajasekaran, N.Sinha

Delhi: Delhi University (DU)
S.K. Chamoli, B.C. Choudhary, D. Choudhury, D. Kaur, A. Kumar, S. Kumar, S. Mandal, Md. Naimuddin, Shahnawaz, S. Verma, S.K. Verma

Guwahati: Indian Institute of Technology (IITG)
B.Bhuyan, P. Paulose, A. Sil

Hawaii (USA): University of Hawaii (UHW)
S. Pakvasa

Indore: Indian Institute of Technology (IITI)
S. Rakshit

Jammu: University of Jammu (JU)
A. Bhasin, A. Gupta, R. Gupta, S. Mahajan, S.S. Sambyal

Kalpakkam: Indira Gandhi Center for Atomic Research (IGCAR)
J. Jayapandian, C.S. Sundar

Kolkata: Ramakrishna Mission Vivekananda University (RMVU)
Abhijit Samanta

Kolkata: Saha Institute of Nuclear Physics (SINP)
P. Bhattacharya, S. Bhattacharya, Kamales Kar, D. Majumdar, S. Saha

Kolkata: University of Calcutta (CU)
S. Bandyopadhyay, A. Banerjee, D. Jana, G. Gangopadhyay

Kolkata: Variable Energy Cyclotron Centre (VECC)
R.K. Bhandari, S. Chattopadhyay, A.K. Dubey, S.A. Khan, S. Muhuri, T.K. Nayak, S. Saha, J. Saini, P.R. Sarma, R.N. Singaraju, V. Singhal, S.K. Thakur, Y.P. Viyogi

Lucknow: Lucknow University (LU)
Jyotsna Singh

Madurai: American College (AC)
S.P.M. Deborrah, K. Gnanasekar, S.R. Inbanathan, K. Moorthy

Mumbai: Bhabha Atomic Research Centre (BARC)
V. Arumugam, Anita Behere, M.S. Bhatia, V.B. Chandratre, V.M. Datar, M.P. Diwakar, G. Gouthaman, Suresh Kumar, P.K. Mukhopadhyay, L.M. Pant, B.J. Roy, K. Srinivas, V. Sugadan

Mumbai: Indian Institute of Technology, Bombay (IITB)
Basanta Nandi, S. Uma Sankar, Raghav Varma

Mumbai: Tata Institute of Fundamental Research (TIFR),
B.S. Acharya, S. Banerjee, M.Bhuyan, A. Dighe, K.S. Gothe, S.D. Kalmani, S. Lahamge, G.Majumder, N.K. Mondal, P. Nagaraj, B.K. Nagesh, S.K. Rao, L.V. Reddy, A. Redij, D. Samuel, M. Saraf, B. Satyanarayana, S. Upadhya, P. Verma

Mysore: University of Mysore (MU)
S. Krishnaveni, C. Ranganathaiah, H.B. Ravikumar

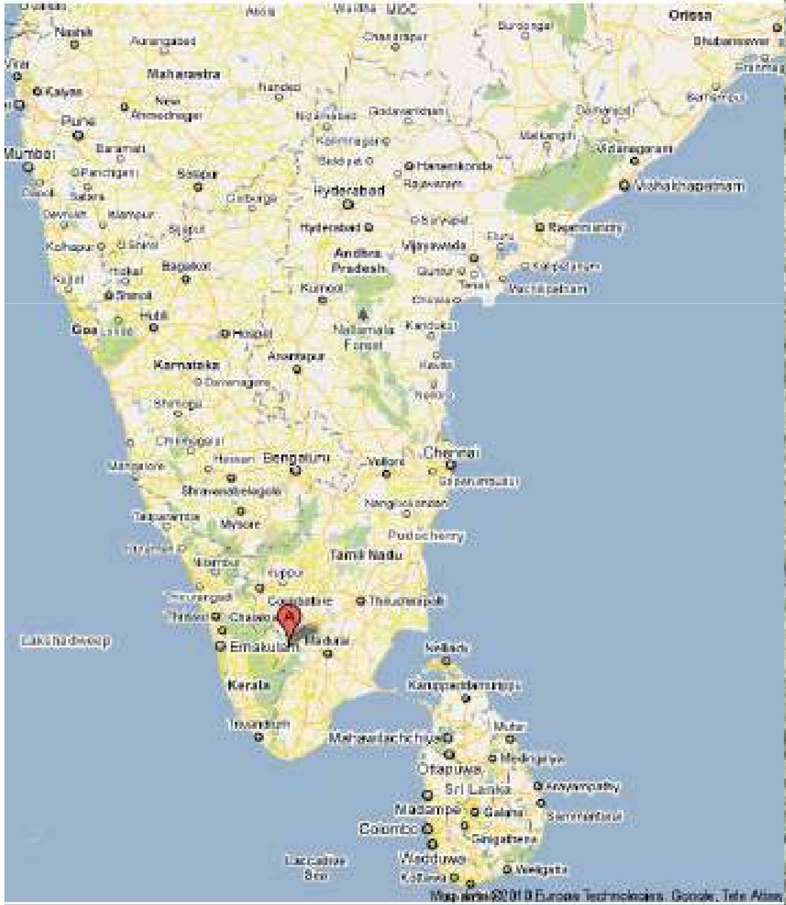
Sambalpur: Sambalpur University (SU)
S. N. Nayak

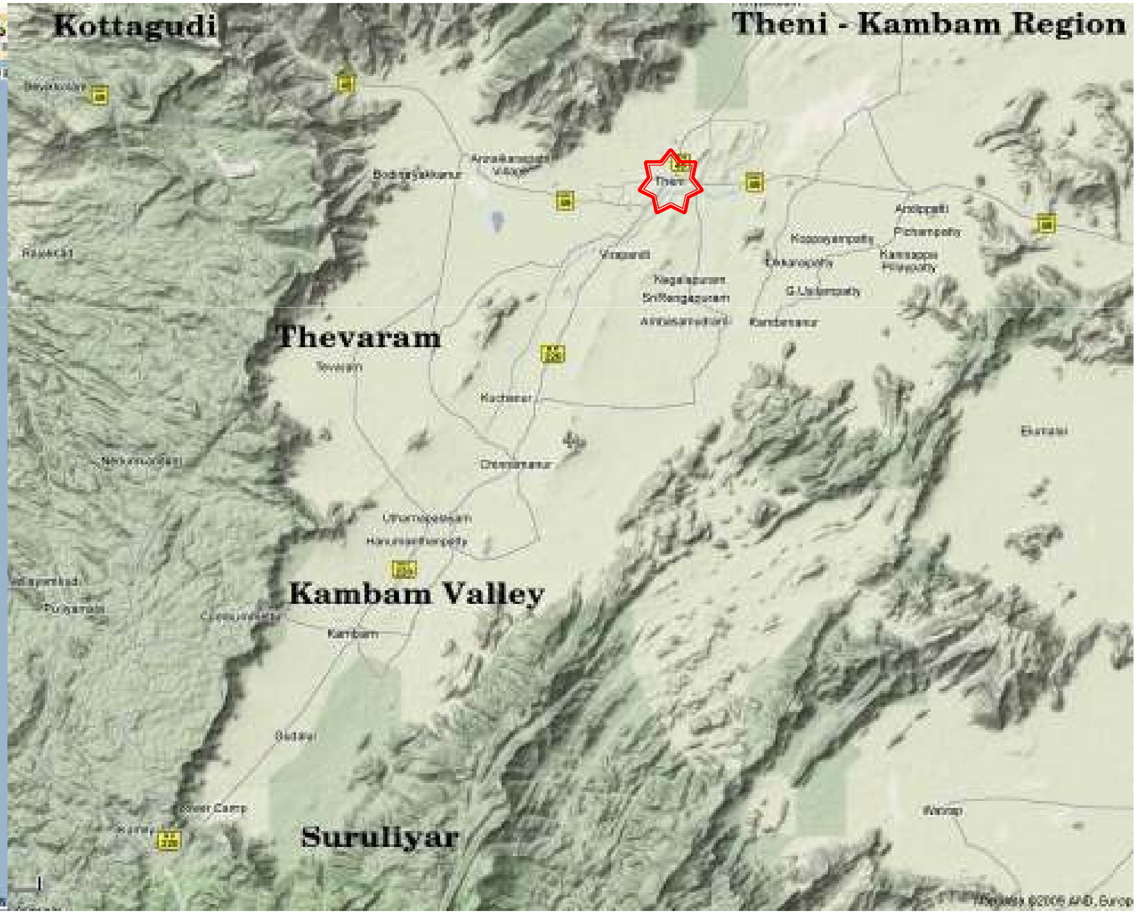
Srinagar: University of Kashmir (UK)
W. Bari, N. Iqbal

Varanasi: Banaras Hindu University (BHU)
B.K. Singh, C.P. Singh, V. Singh

INO coming soon:
Inside a mountain near you!

Location: 9°58′ North; 77°16′ East, 110km from Madurai (South India)





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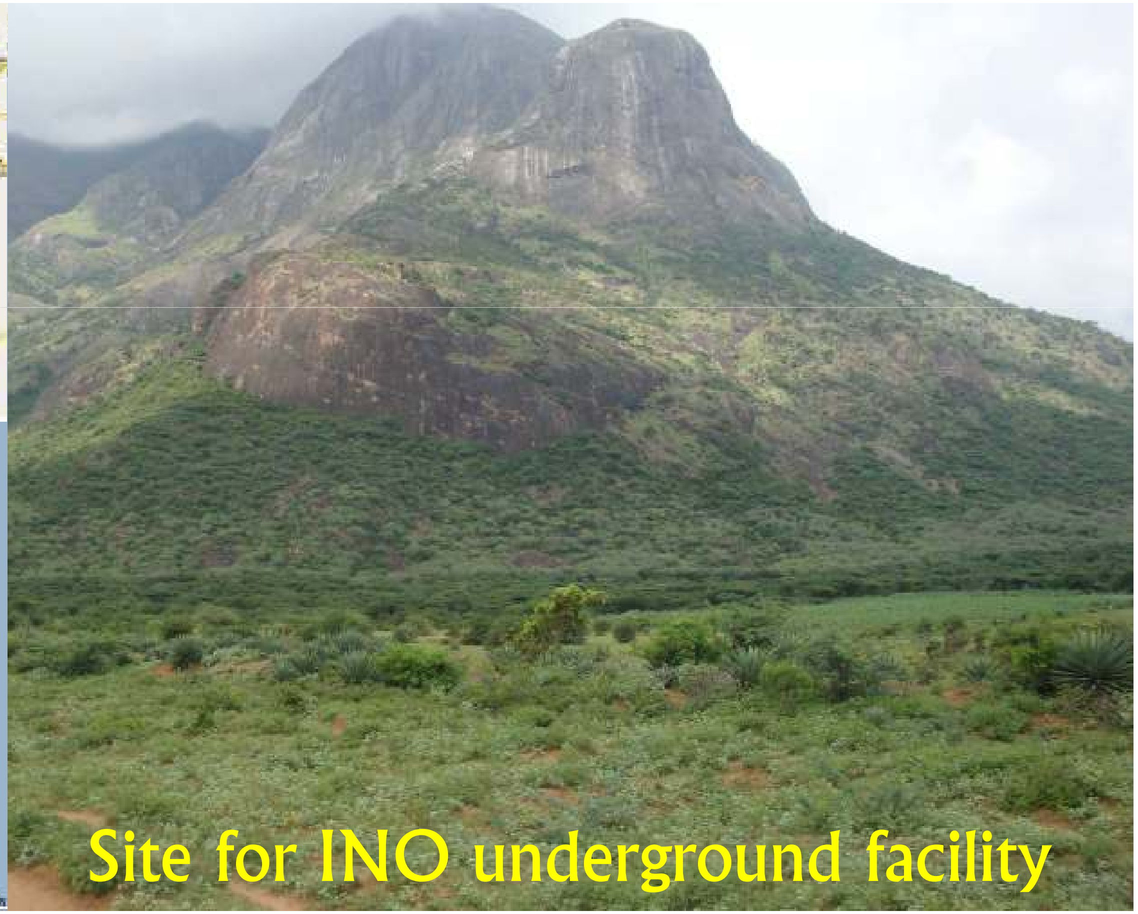


Location and site for National Centre for High Energy Physics

Ownership and Management

- Infrastructural facilities to be created at Pottipuram (underground lab & surface facilities) as well as those at Madurai (NCHEP) will be under the Department of Atomic Energy (DAE).
- National Centre for High Energy Physics (NCHEP) will be the nodal unit of DAE for administrative control of underground laboratory, project monitoring, HRD, Detector R&D etc. TIFR to act as the host institute.
- ICAL detector will be funded jointly by DAE and DST.
- ICAL detector will be constructed by the members of INO-ICAL collaboration from various research institutes, universities and IITs.

INO Management Structure

- Apex Committee chaired jointly by Secretary DAE and Secretary DST and having Directors/Heads of major participating institutes/universities including HBNI.
- NCHEP Management Board chaired by Director of the INO host institute (TIFR).
- Project Management Committee chaired by the NCHEP Centre Director.
- Project Implementation committees at major participating institutes.
- Scientific Advisory Committee chaired by the Director of the INO host institute (TIFR).

Status of INO sites

- Forest land above the INO tunnel and cavern
  - Received stage II clearance to use 4.12 hectares of forest land to construct the cavern and the access tunnel under the Bodi West Hill reserve forest from Ministry of Environment and Forests.
- Land at Pottipuram
  - 26.82.5 hectares of revenue land at Pottipuram village to establish the INO surface facilities was transferred to the DAE.
  - Transfer document signed on December 28, 2011.
- Land at Madurai
  - 12.5.5 hectares of land at Madurai to establish the National Centre for High Energy Physics (NCHEP) against a payment of Rs. 17.14 crores was transferred to the DAE on November 17, 2012.

Civil construction activities

- Tendering process on for
  - Detailed survey work and clearing of jungle at NCHEP site at Madurai and INO site at Pottipuram.
  - Construction of barbed wire fencing with RCC posts over random rubble masonry wall around NCHEP site at Madurai and INO site at Pottipuram.
- Tender documents under preparation for
  - Architectural/Engineering services consultancy for INO surface facility buildings at Pottipuram and NCHEP building at Madurai including landscape and horticulture.
  - Geotechnical survey at Pottipuram and Madurai.
- Tender documents yet to be prepared for
  - Prefabricated laboratory buildings at NCHEP site.
- Initial activities of the project to start soon in the rented premises in Madurai.

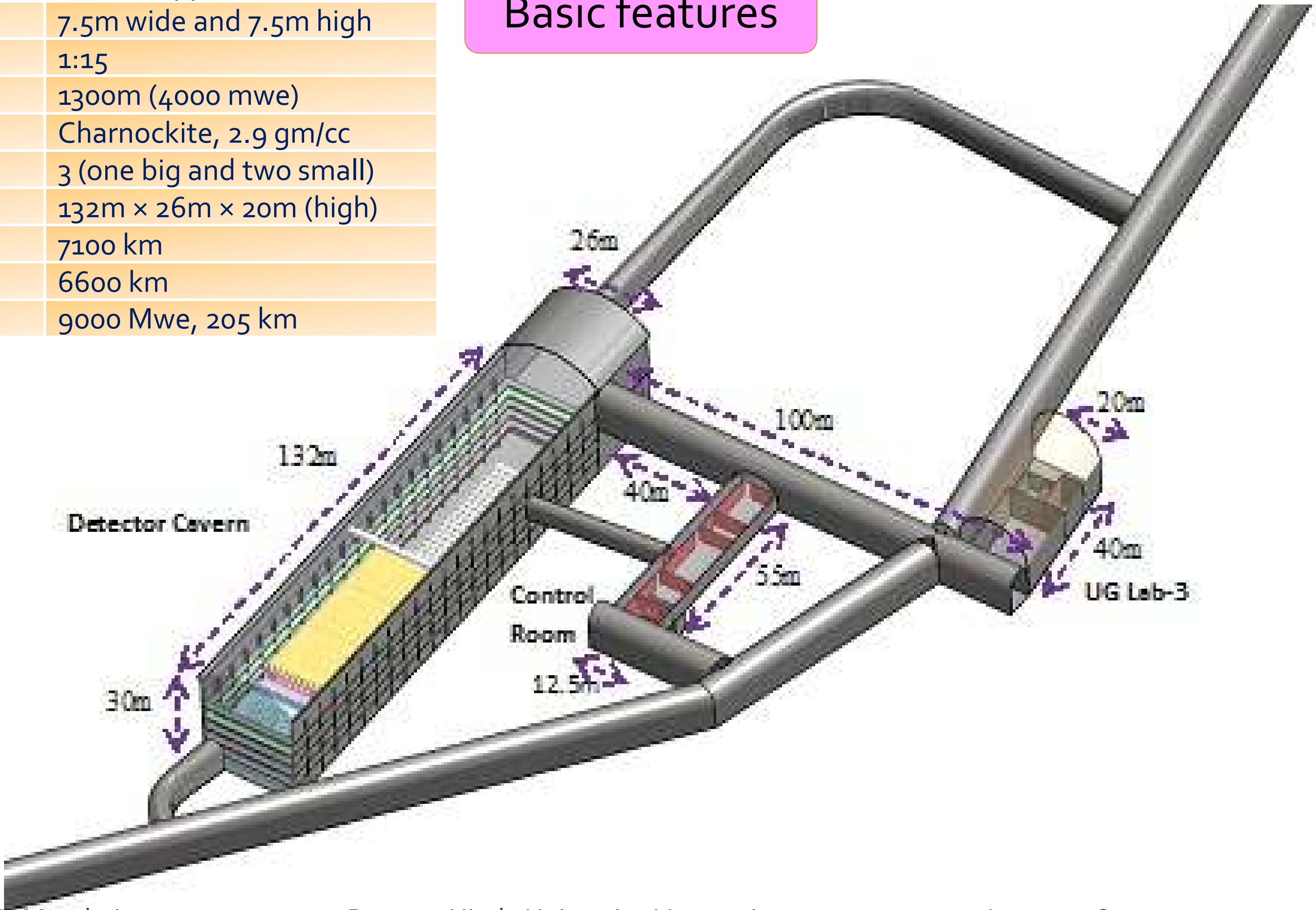
Civil works carried out through TN government agencies

- MoU with the Tamil Nadu Water Supply and Drainage Board (TWAD) signed for water supply infrastructure development for Pottipuram site. Cost of the work package: 592 Lakhs.
- Improvement/construction of 9km approach road to INO site from Rasingapuram to Pottipuram (Km. 21/10 of Palayam-Bodi Road (SH100), 0/0 – 10/6). To be taken up by Tamil Nadu Highways Department. Cost of the work package Rs. 2045 Lakhs.
- Funds also approved for the temporary electricity connection by TNEB for the Pottipuram site.
- Rs. 300 Lakhs approved for local area and community development.

Underground Laboratory Layout

Length of the tunnel	2.1 km (approx.)
Tunnel cross-section	7.5m wide and 7.5m high
Tunnel gradient	1:15
Rock overburden	1300m (4000 mwe)
Rock type and density	Charnockite, 2.9 gm/cc
Number of caverns	3 (one big and two small)
Size of the main cavern	132m × 26m × 20m (high)
Distance from CERN	7100 km
Distance from JPARC	6600 km
Future nuclear reactor	9000 Mwe, 205 km

Basic features

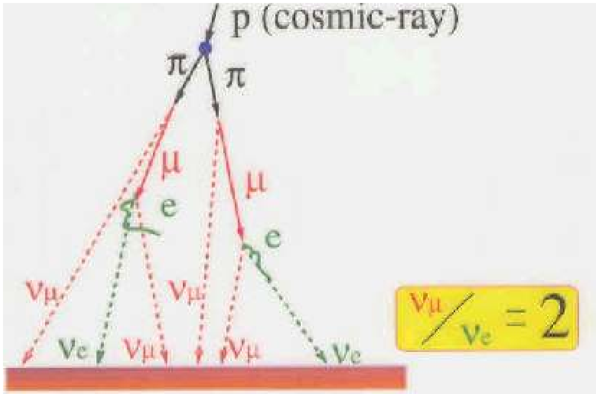


Neutrino sources and detector choice

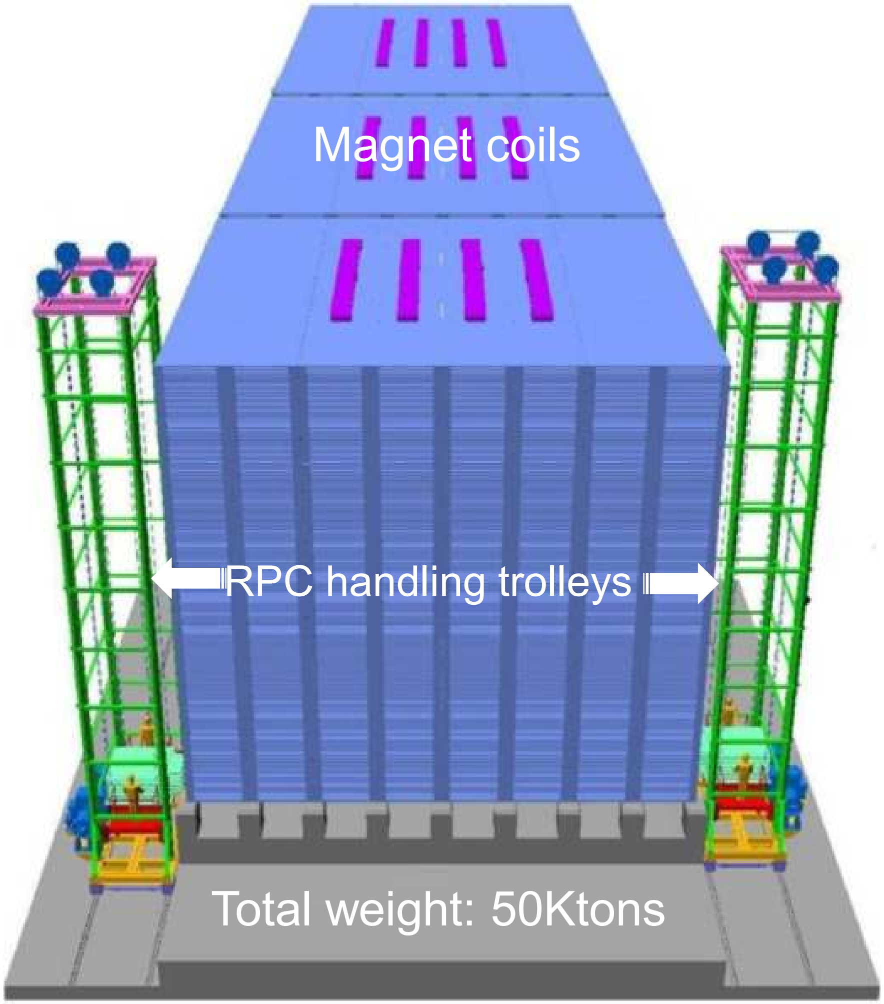
- Source of neutrinos
  - Use atmospheric neutrinos as source
  - Need to cover a large L/E range
    - Large L range
    - Large E_ν range
  - Upto 20 GeV muons contained in fiducial volume; most interesting region for observing matter effects in 2–3 sector is 5–15 GeV
  - ICAL is sensitive to muons only, very little sensitivity to electrons; Electrons leave few traces (radiation length 1.8 (11) cm in iron (glass))
- Physics driven detector requirements
  - Should have large target mass (50-100 kT)
  - Good tracking and energy resolution (tracking calorimeter)
  - Good directionality, up/down discrimination (< 1 nSec time resolution)
  - Nearly 4π coverage in solid angle (except near horizontal)
  - Good charge identification capability (magnetic field ~1.5 Tesla)
  - Modularity and ease of construction (3 modules of ~17 kTons each)
  - Compliment capabilities of existing and proposed detectors
- Use magnetised iron as target mass and RPC as active detector medium

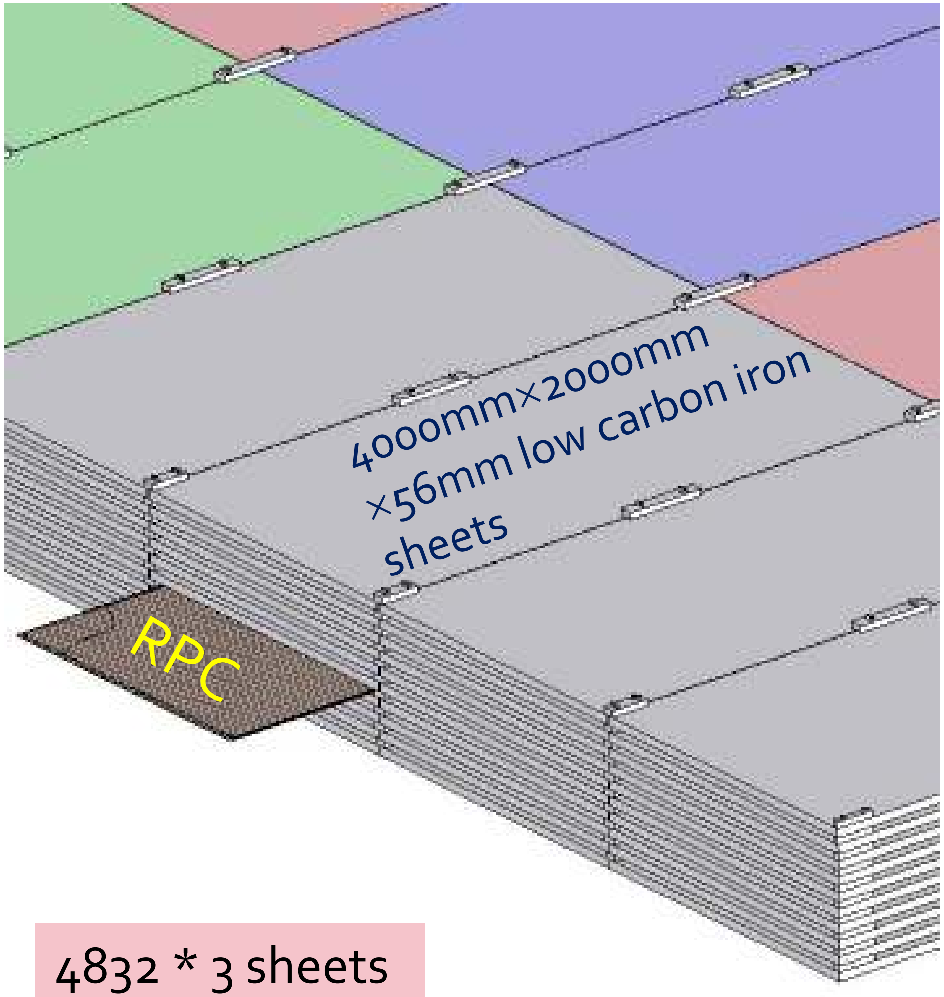
$$\nu_\mu + n \rightarrow \mu^- + p^+$$

$$\bar{\nu}_\mu + p \rightarrow \mu^+ + n$$



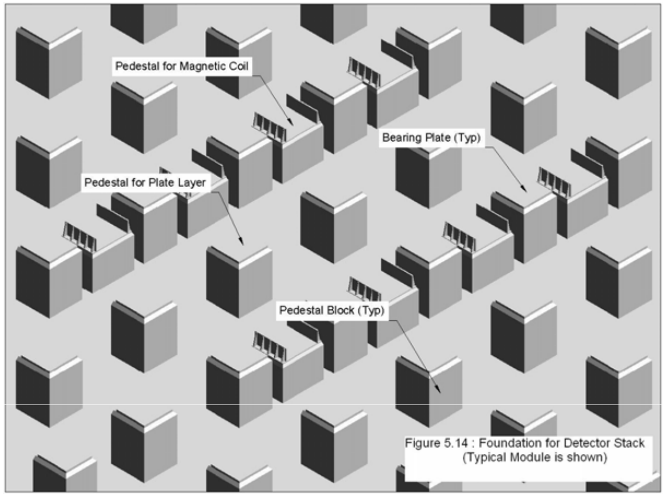
ICAL detector and construction

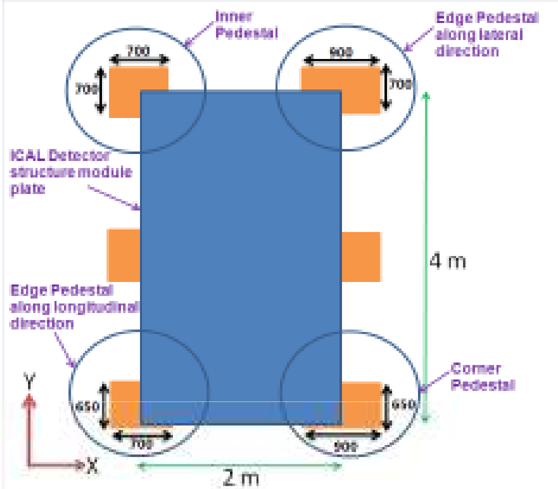


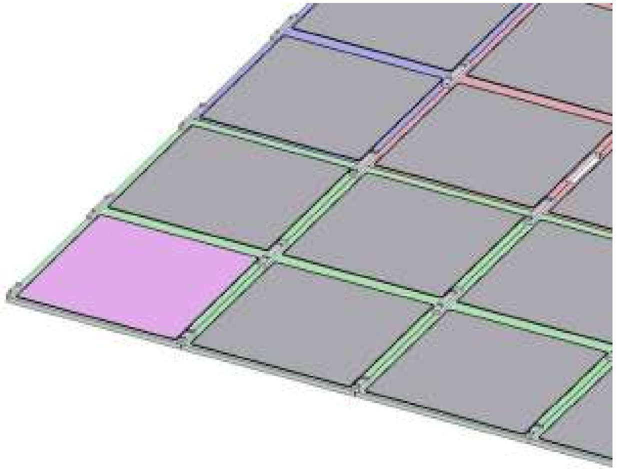


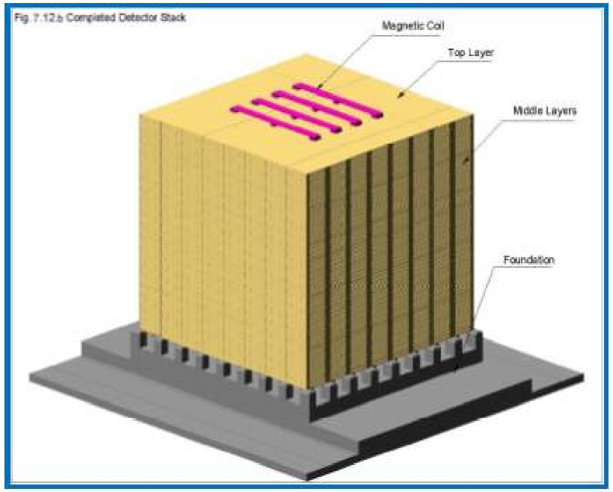
4832 * 3 sheets

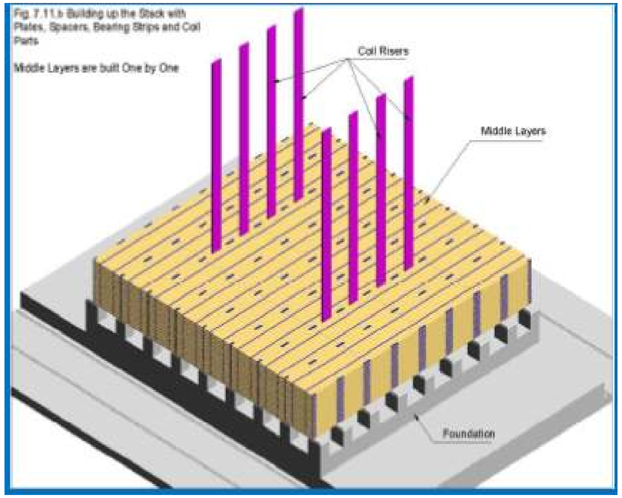
Construction of ICAL Magnet

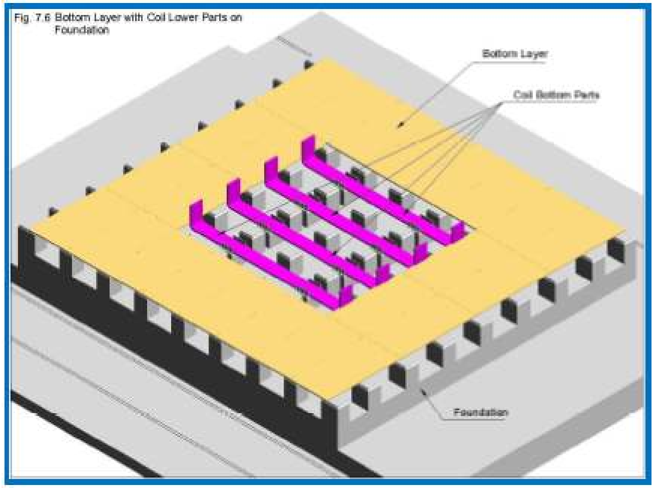




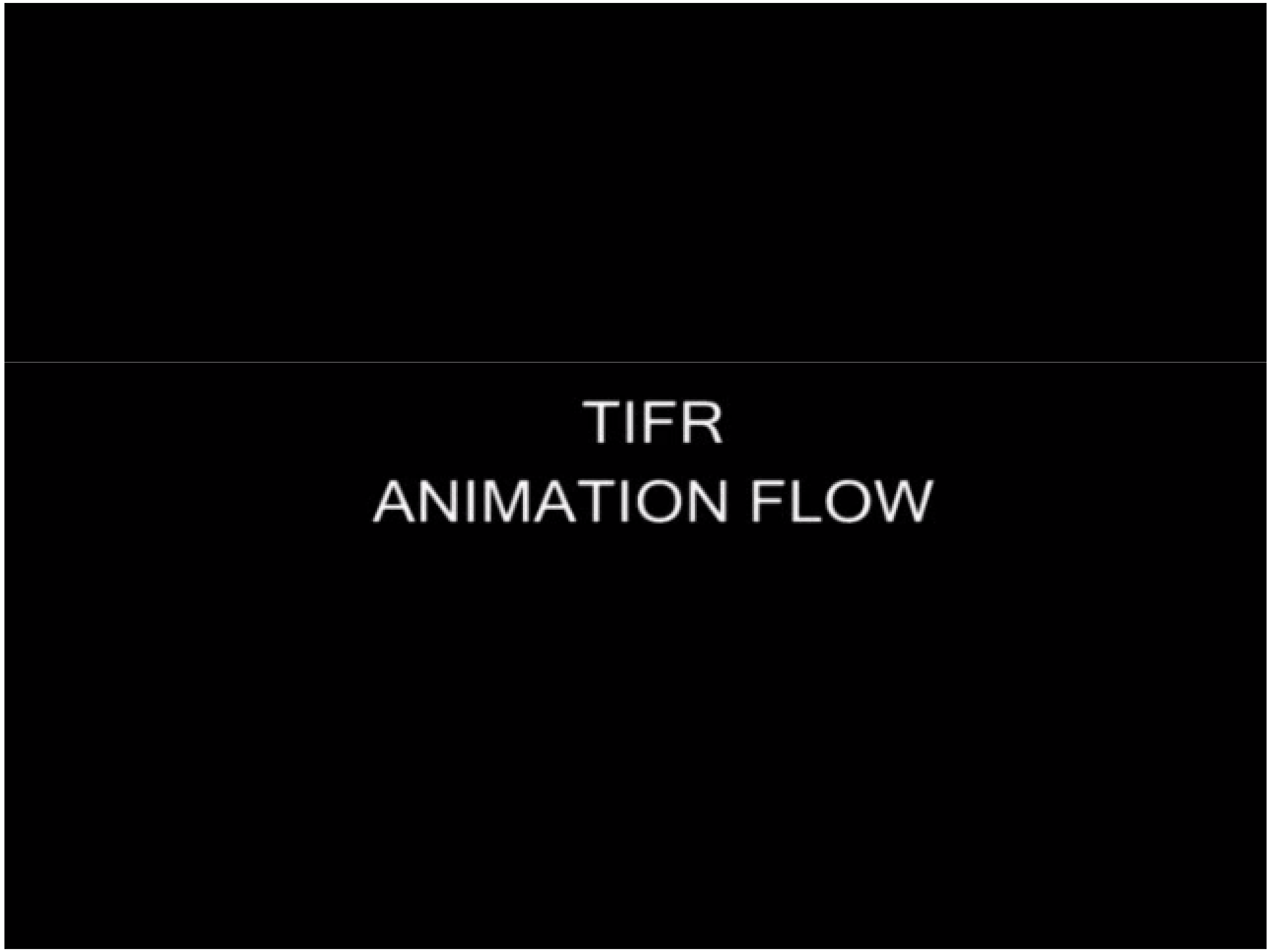








Animation of ICAL construction



Factsheet of ICAL detector

No. of modules	3
Module dimensions	16m × 16m × 14.5m
Detector dimensions	48.4m × 16m × 14.5m
No. of layers	150
Iron plate thickness	56mm
Gap for RPC trays	40mm
Magnetic field	1.3Tesla
RPC dimensions	1,950mm × 1,840mm × 24mm
Readout strip pitch	3 0mm
No. of RPCs/Road/Layer	8
No. of Roads/Layer/Module	8
No. of RPC units/Layer	192
No. of RPC units	28,800 (97,505m^2)
No. of readout strips	3,686,400

Power requirement

- Main Hall
  - 200KW for cooling electronic circuits of one 50 kton detector assembly (4 million channels, each consuming 50mW). That is 400KW for 100 kton detector.
  - The magnet power requirements is about 450KW for 50 kton detector i.e. 900KW for 100 kton detector.
- Control room/lab
  - Neutrino-less Double Beta Decay (NDBD) experiment will require about 20KW for cooling of associated electronics.
  - The NDBD experimental set up requires a helium compressor of 10litre/day capacity, which will be driven by a 50KW motor.
- The AC, ventilation, mechanical, material handling and lighting loads.

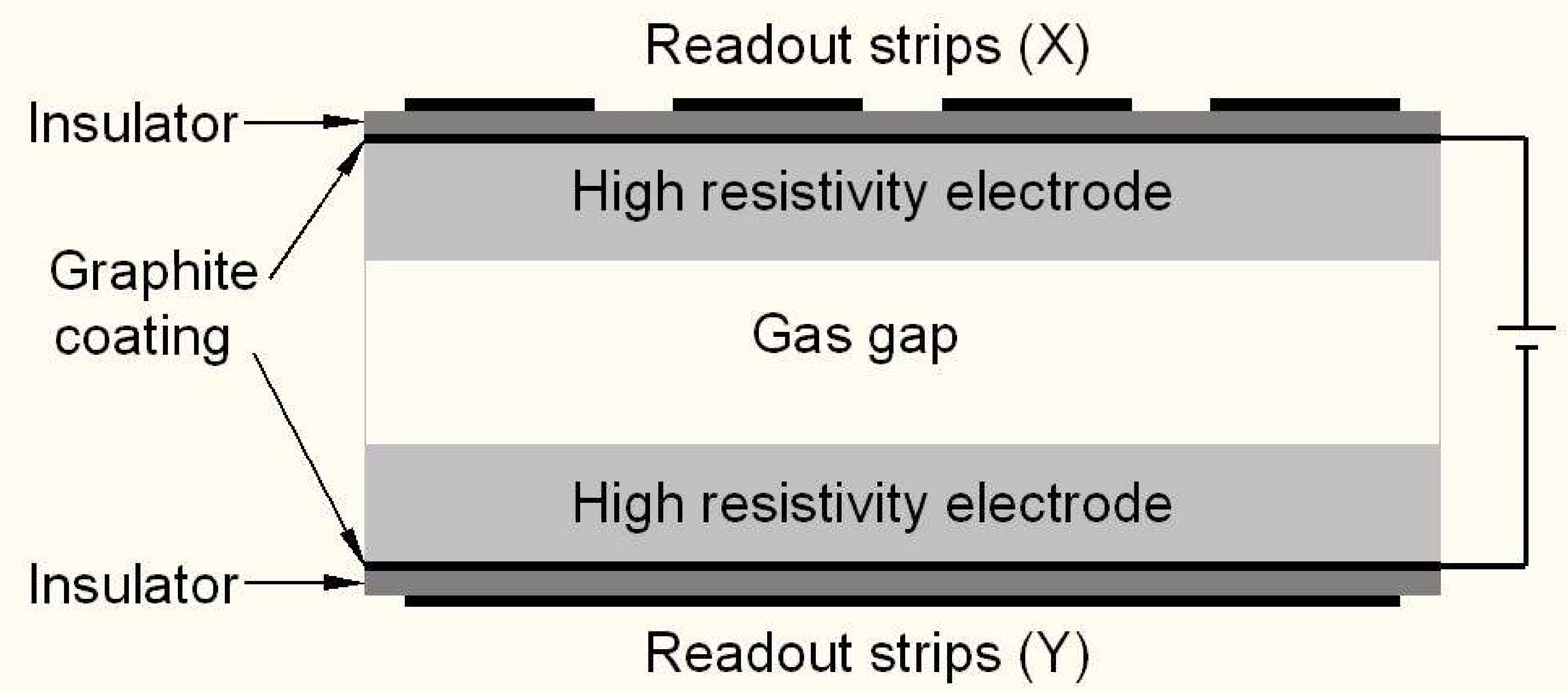
Mains power

- The electric power will be received from nearby TNEB substation through two, 11KV feeders at the utility building. This will in turn feed two, 11KV/433V dry type transformers of adequate capacity located in the same building and two transformers at the cavern.
- Further distribution will be at 415Volts .
- The Transformers will be sized to meet all the loads including emergency, DC and UPS.
- Emergency power
  - 2 silent DG sets of adequate capacity, will be located in the utility building.
  - Emergency loads will be restricted to 10KW for NDBD experiment (Dilution refrigerant equipment.), high voltage supply to the detectors and gas flow monitors.
- Magnets and Detector electronics do not require emergency power.
  - No common UPS will be provided.
  - Small independent UPS will be procured and installed wherever required, as part of scientific equipment.
  - Similarly DC supply for the magnets also will be procured separately. The DC system and UPS systems must be capable of receiving 415V, 50Hz, 3 phase supply.

Air conditioning and Ventilation

- The main experimental hall will be maintained at 21 $\pm$ 3 ^{o}C and RH <55%.
- Isobutane - being denser than air, may collect at the floor level. A separate duct system (or return grills at his level) for sucking this may be designed.
- It would be desirable, if simple ventilation system with air washers can be designed to meet the ambient conditions required in the main hall, considering the lower temperature in the cavern interior, which is about 1300m below ground and has a earth cover of 1000m all around.
- The NDBD area need not be air conditioned. Normal human comfort level AC may be maintained in the control room. All other areas will have minimum air changes required for human comfort.

Schematic of a basic RPC

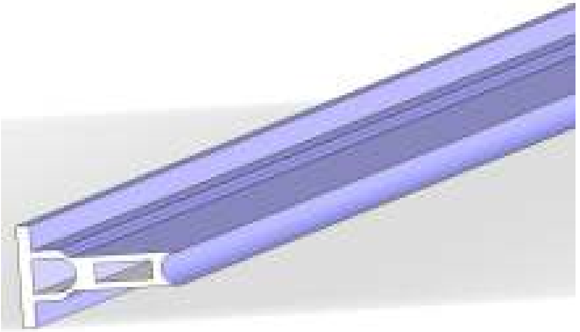


Deployment of RPCs in running experiments

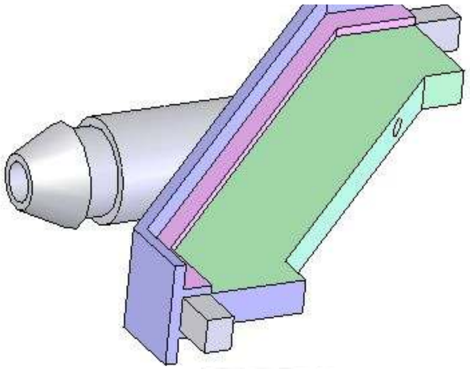
Experiment	Area (m^2)	Electrodes	Gap(mm)	Gaps	Mode	Type
PHENIX	?	Bakelite	2	2	Avalanche	Trigger
NeuLAND	4	Glass	0.6	8	Avalanche	Timing
FOPI	6	Glass	0.3	4	Avalanche	Timing
HADES	8	Glass	0.3	4	Avalanche	Timing
HARP	10	Glass	0.3	4	Avalanche	Timing
COVER-PLASTEX	16	Bakelite	2	1	Streamer	Timing
EAS-TOP	40	Bakelite	2	1	Streamer	Trigger
STAR	50	Glass	0.22	6	Avalanche	Timing
CBM TOF	120	Glass	0.25	10	Avalanche	Timing
ALICE Muon	140	Bakelite	2	1	Streamer	Trigger
ALICE TOF	150	Glass	0.25	10	Avalanche	Timing
L3	300	Bakelite	2	2	Streamer	Trigger
BESIII	1200	Bakelite	2	1	Streamer	Trigger
BaBar	2000	Bakelite	2	1	Streamer	Trigger
Belle	2200	Glass	2	2	Streamer	Trigger
CMS	2953	Bakelite	2	2	Avalanche	Trigger
OPERA	3200	Bakelite	2	1	Streamer	Trigger
YBJ-ARGO	5630	Bakelite	2	1	Streamer	Trigger
ATLAS	6550	Bakelite	2	1	Avalanche	Trigger
ICAL	97,505	Both	2	1	Both	Trigger

Materials for gas volume fabrication

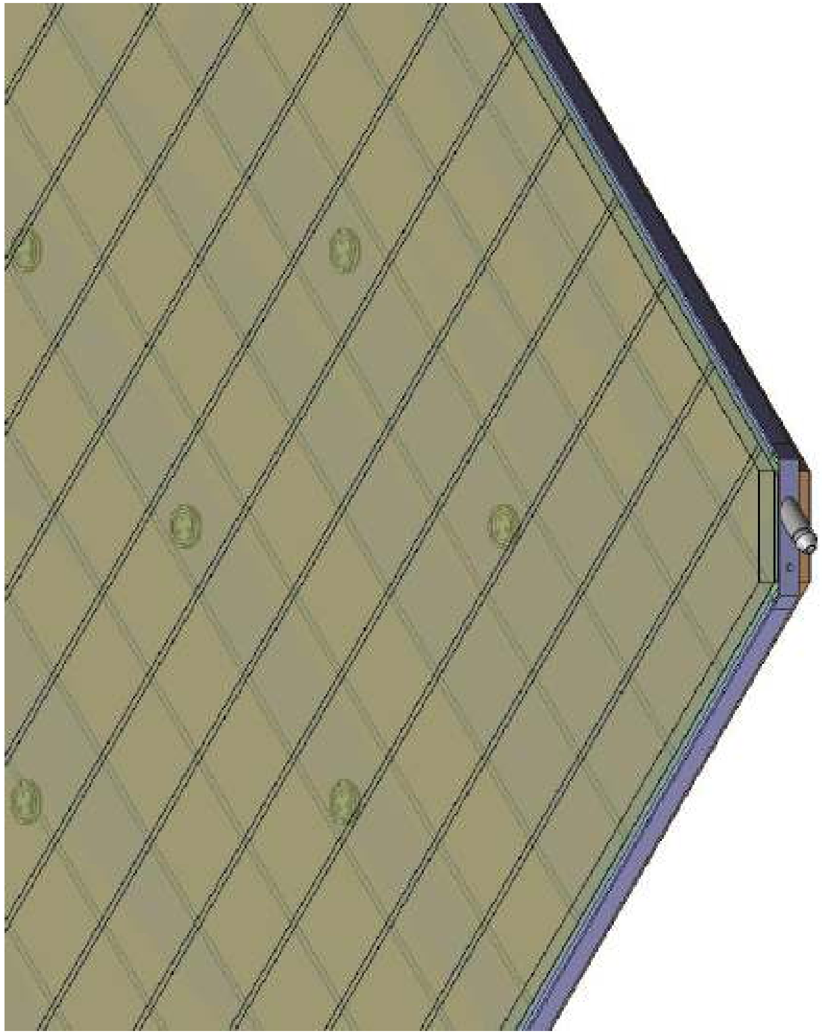
Edge spacer



Gas nozzle

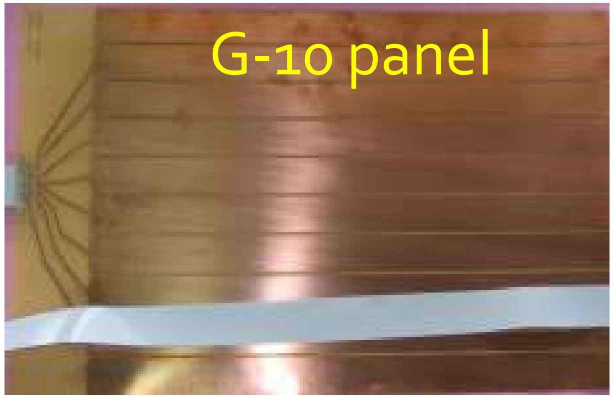


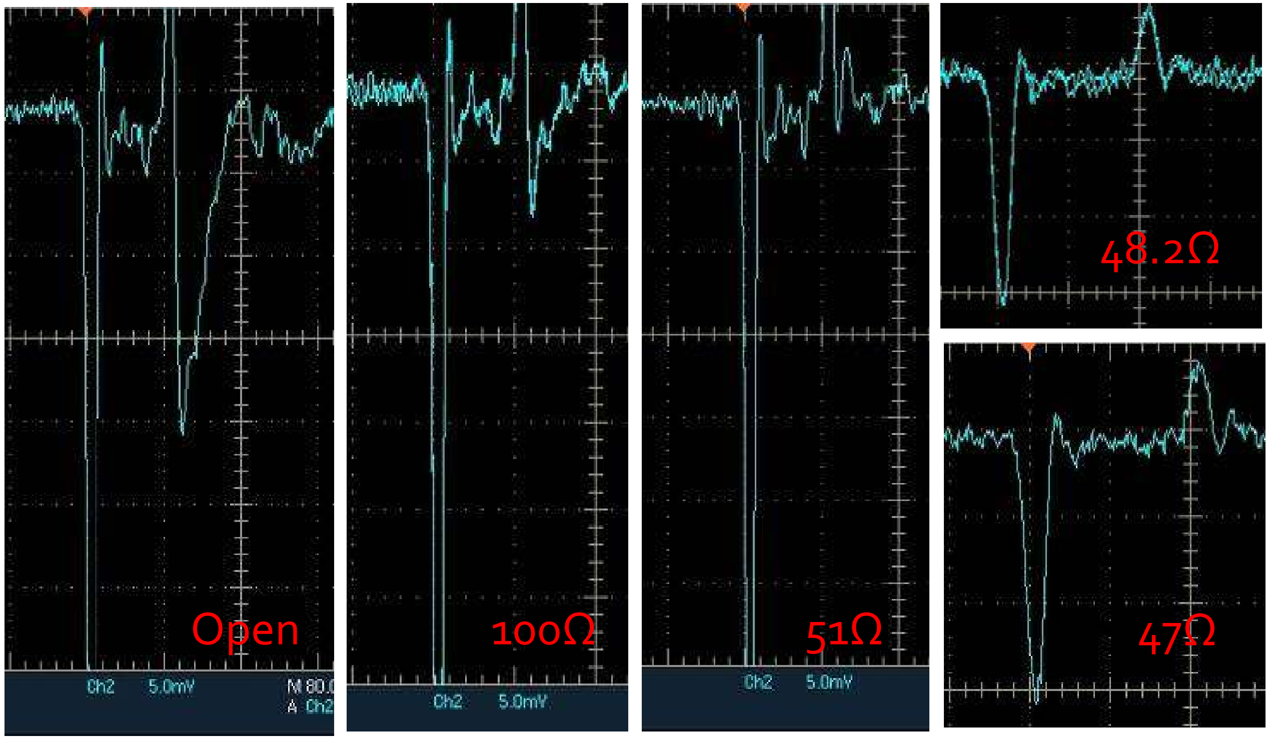
Glass spacer



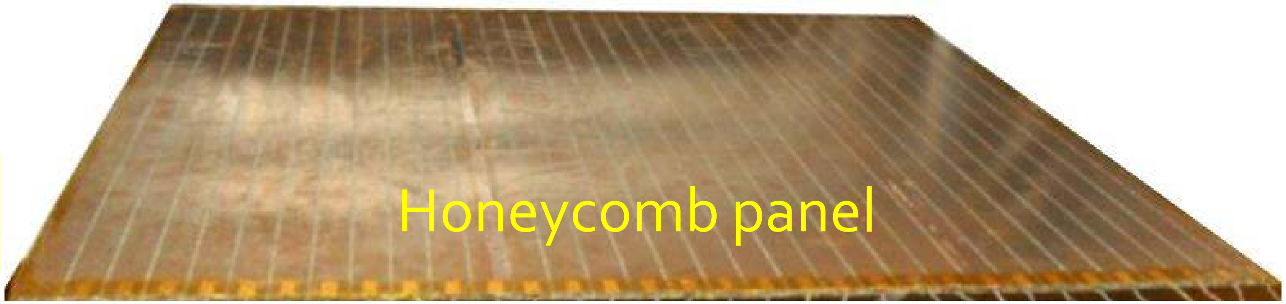
Schematic of an assembled gas volume

Development and characterisation of signal pickup panels

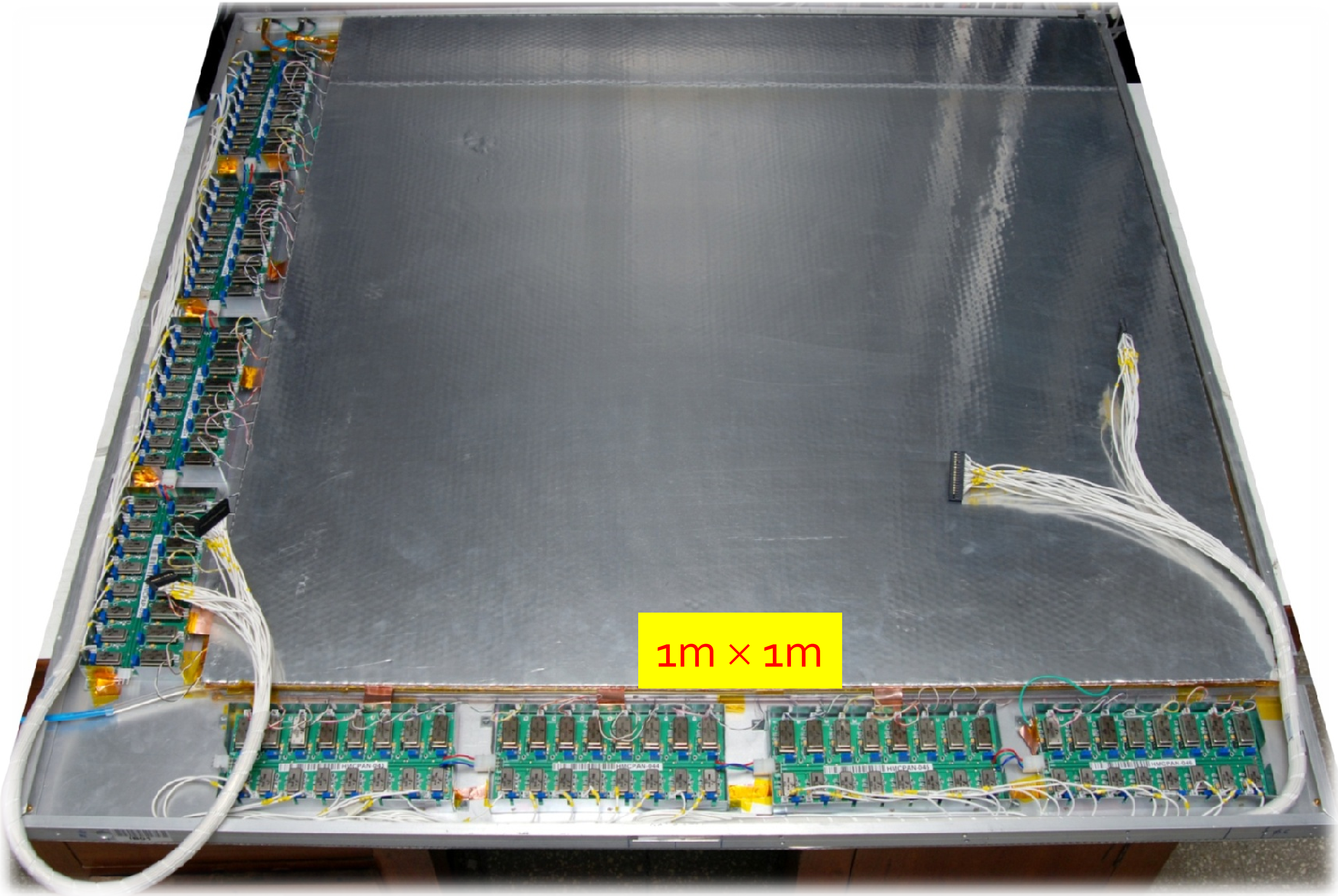




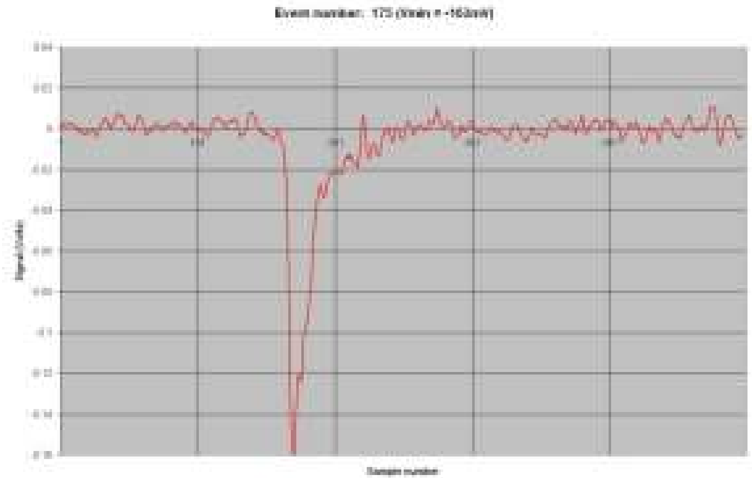
Z_0: Inject a pulse into the strip; tune the terminating resistance at the far end, until its reflection disappears.

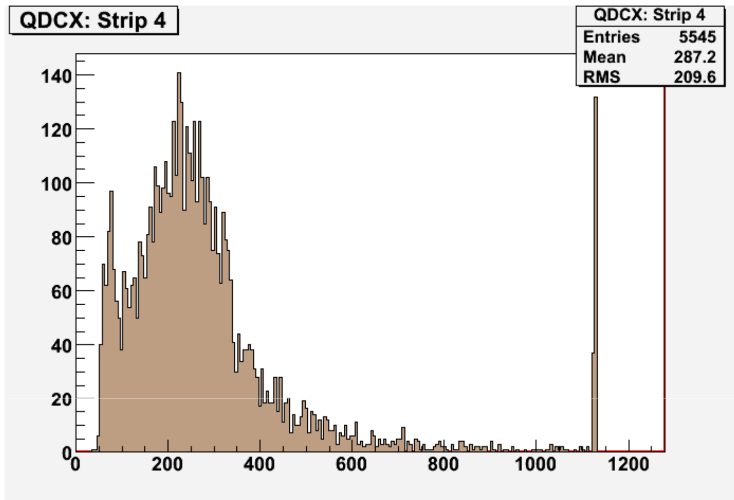


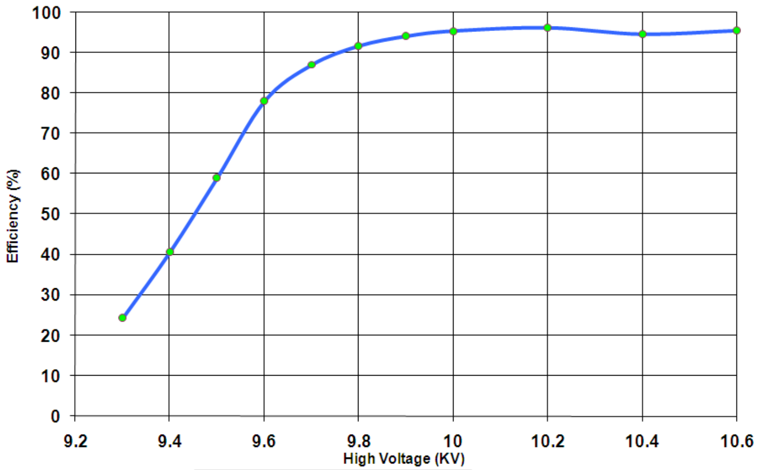
Fully assembled large area RPC

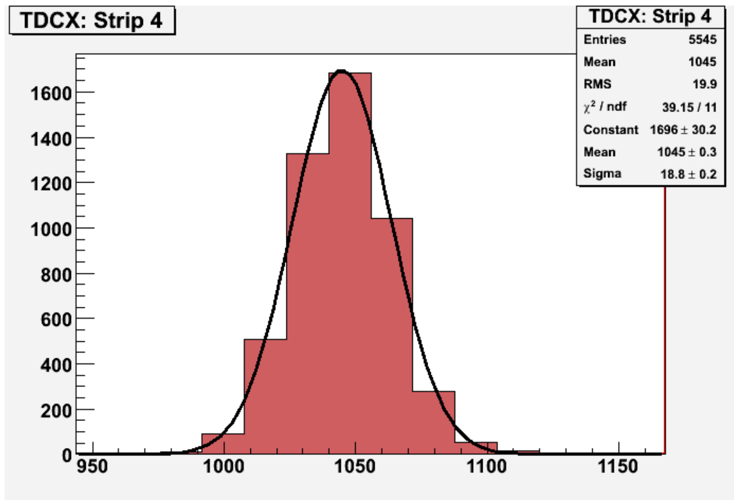


RPC parameter characterisation

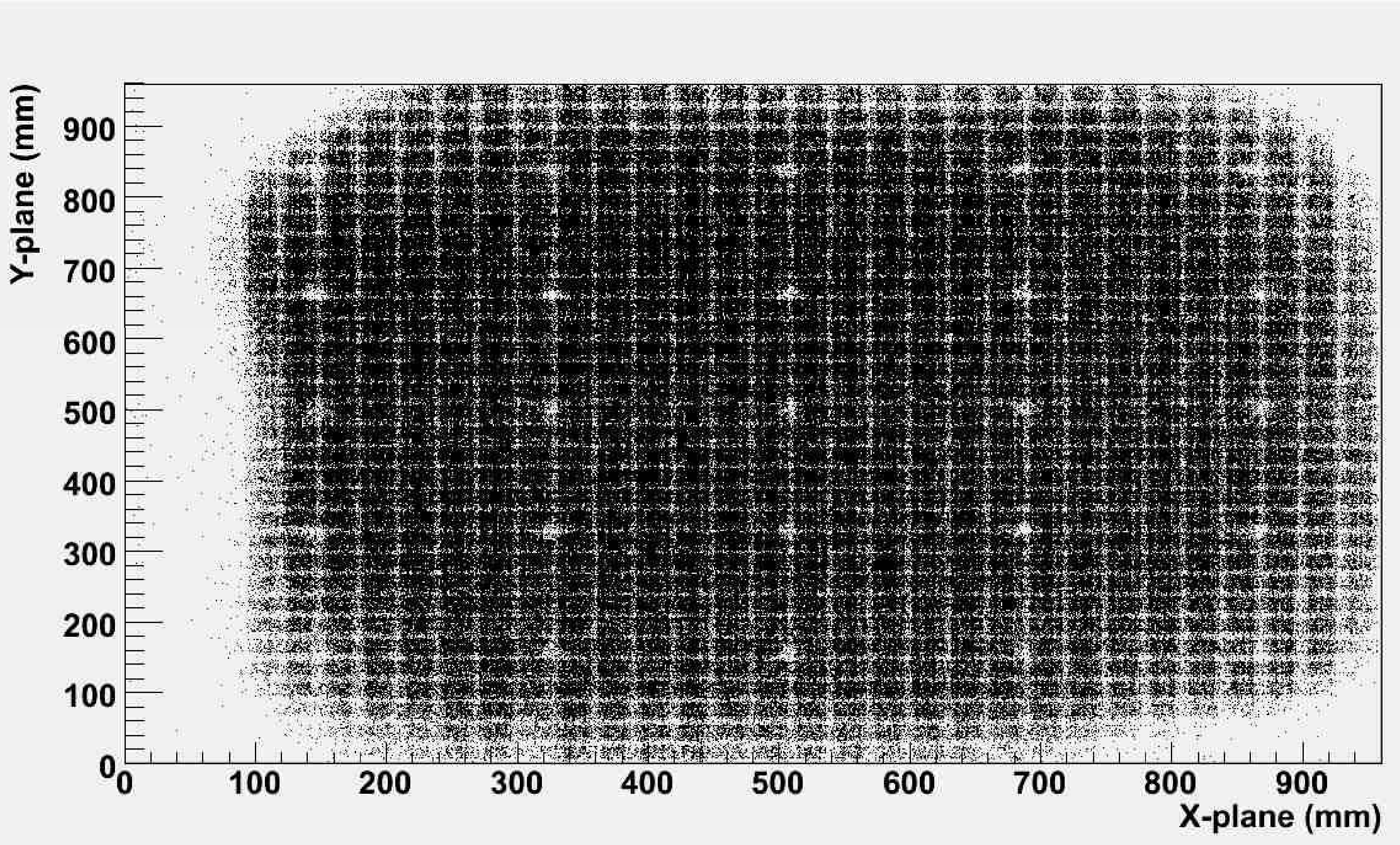




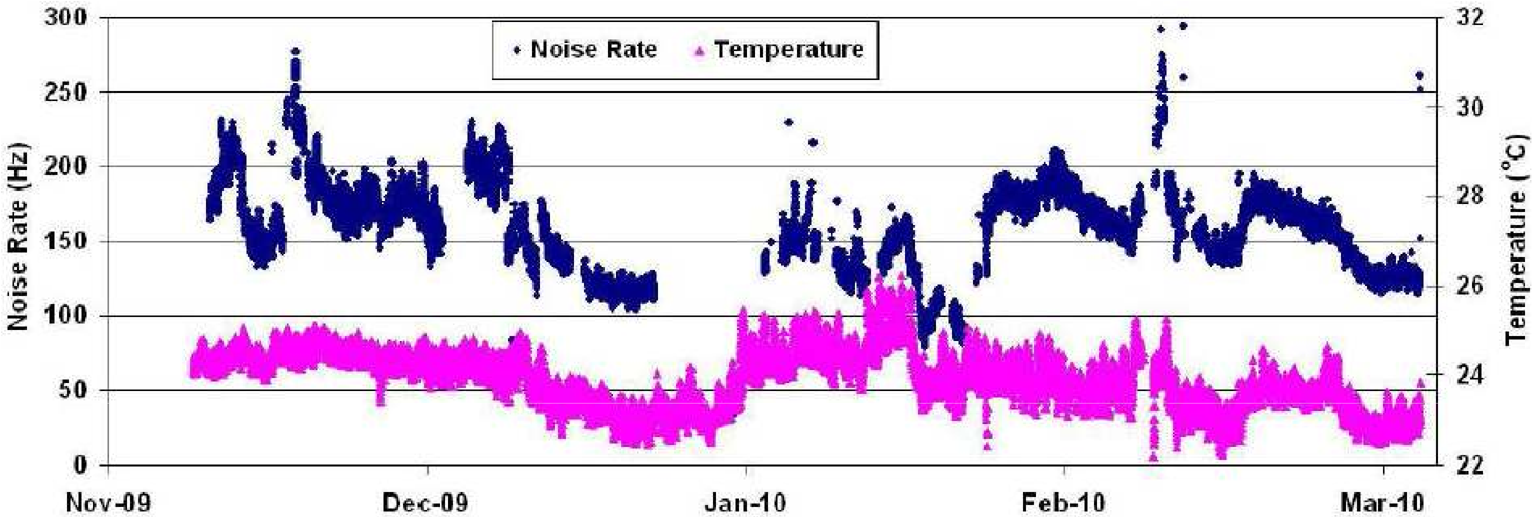


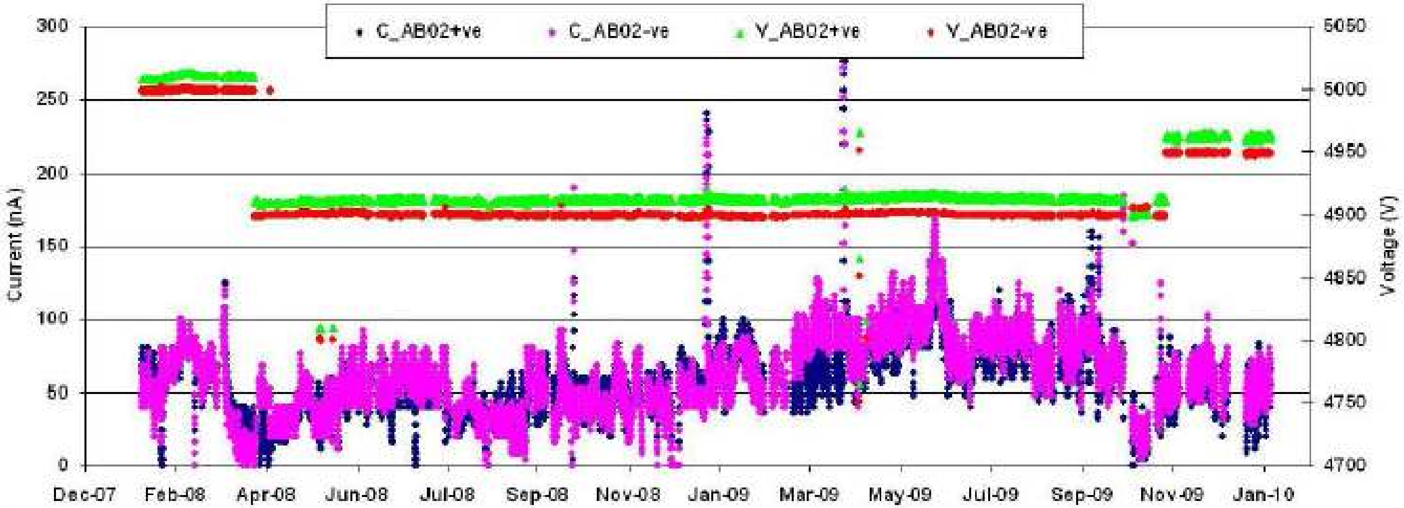


RPC *tomography* using cosmic ray muons



Studying long-term stability



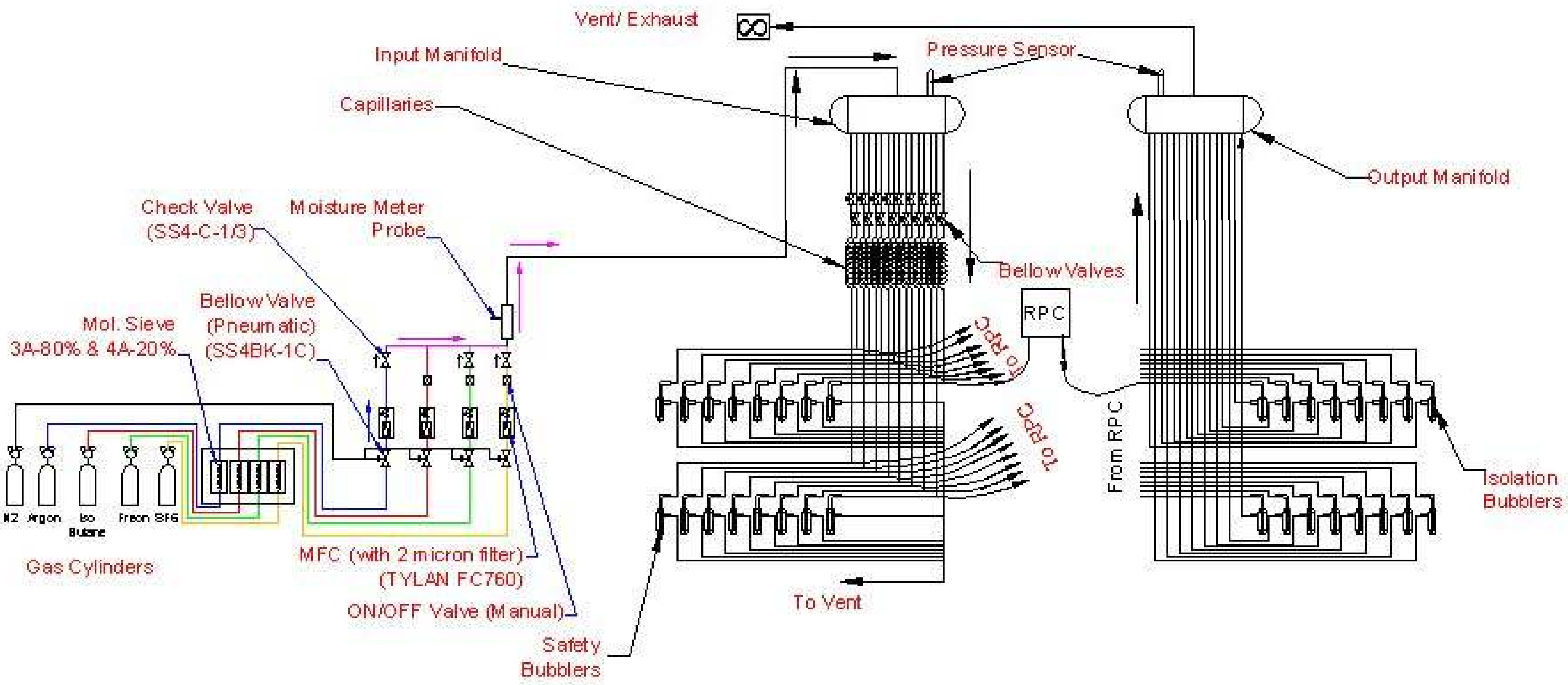


Requirement of gases in ICAL

Total number of RPCs in ICAL = 3 × 150 × 64 = 28,800
Total gas volume = 28,800 × 184cm × 184cm × 0.2cm = 195,010 litres
For ex: One volume change/day with 10% gas top-up in a re-circulating scheme
Approximate running gas cost = Rs 30,000/day

Gas	Avalanche (%)	Streamer (%)	Maximum (%)	Volume (L)	Density (g/L)	Weight (Kg)	Cost (Rs/Kg)
Argon	0.0	30.0	30.0	58,503	1.784	104.4	
R134a	95.5	62.0	95.5	186,234.6	4.25	791.5	
Isobutane	4.3	8.0	8.0	15,600.8	2.51	39.16	
SF_6	0.2	0.0	0.2	390	6.164	2.40	

Schematic of gas system



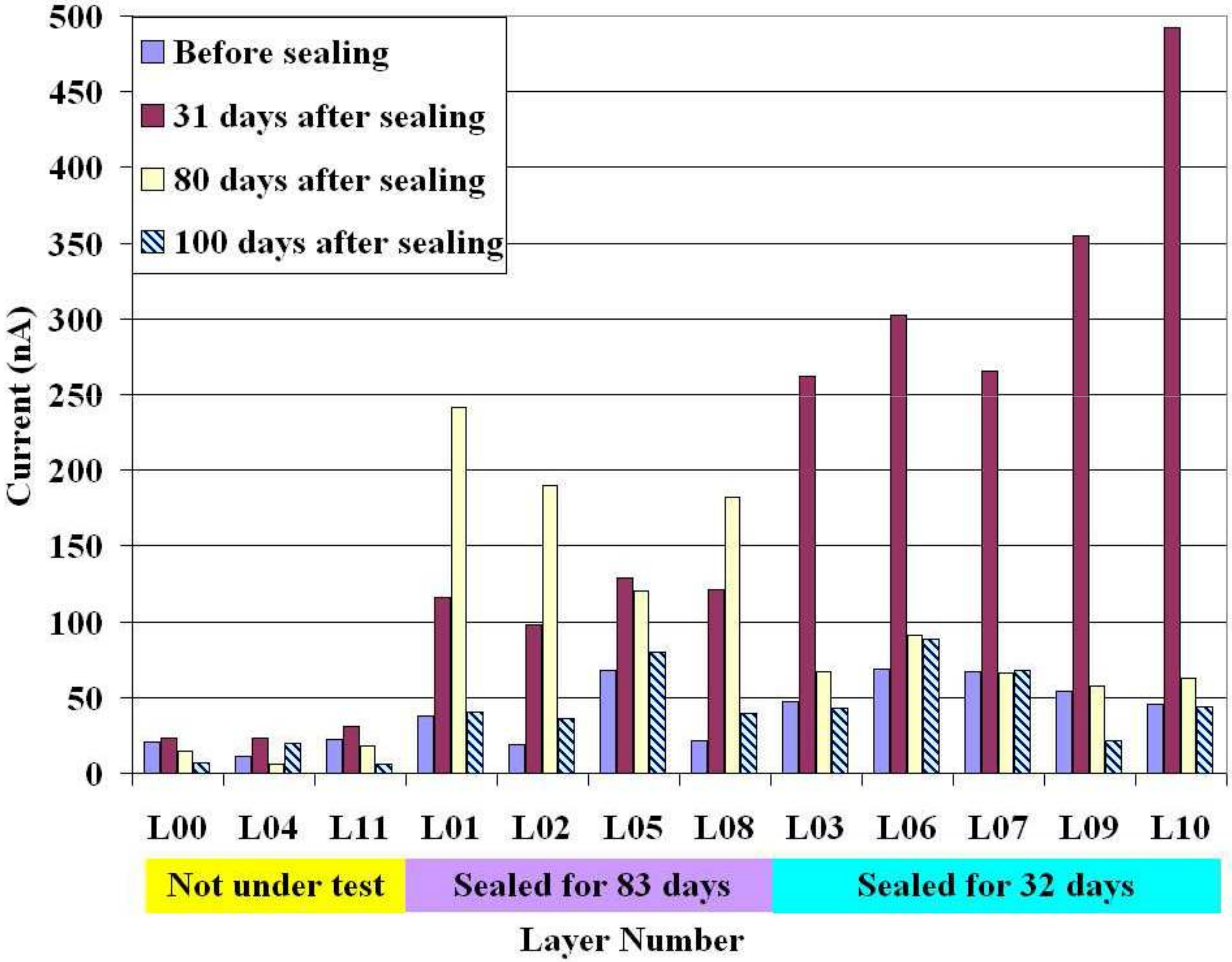
Constructional details of the gas system

Front view

Internal view

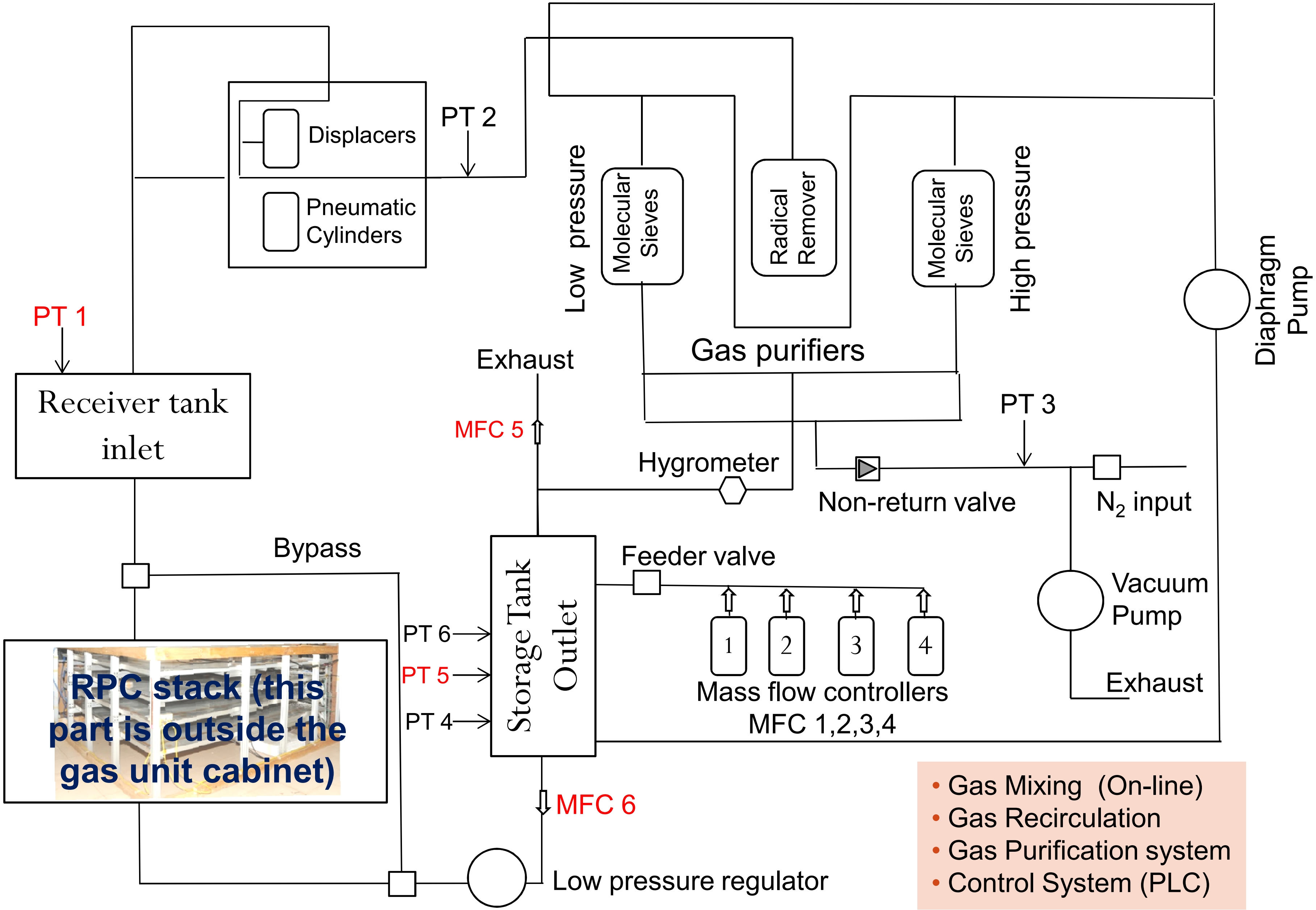
Rear view

Study of gas sealed RPCs



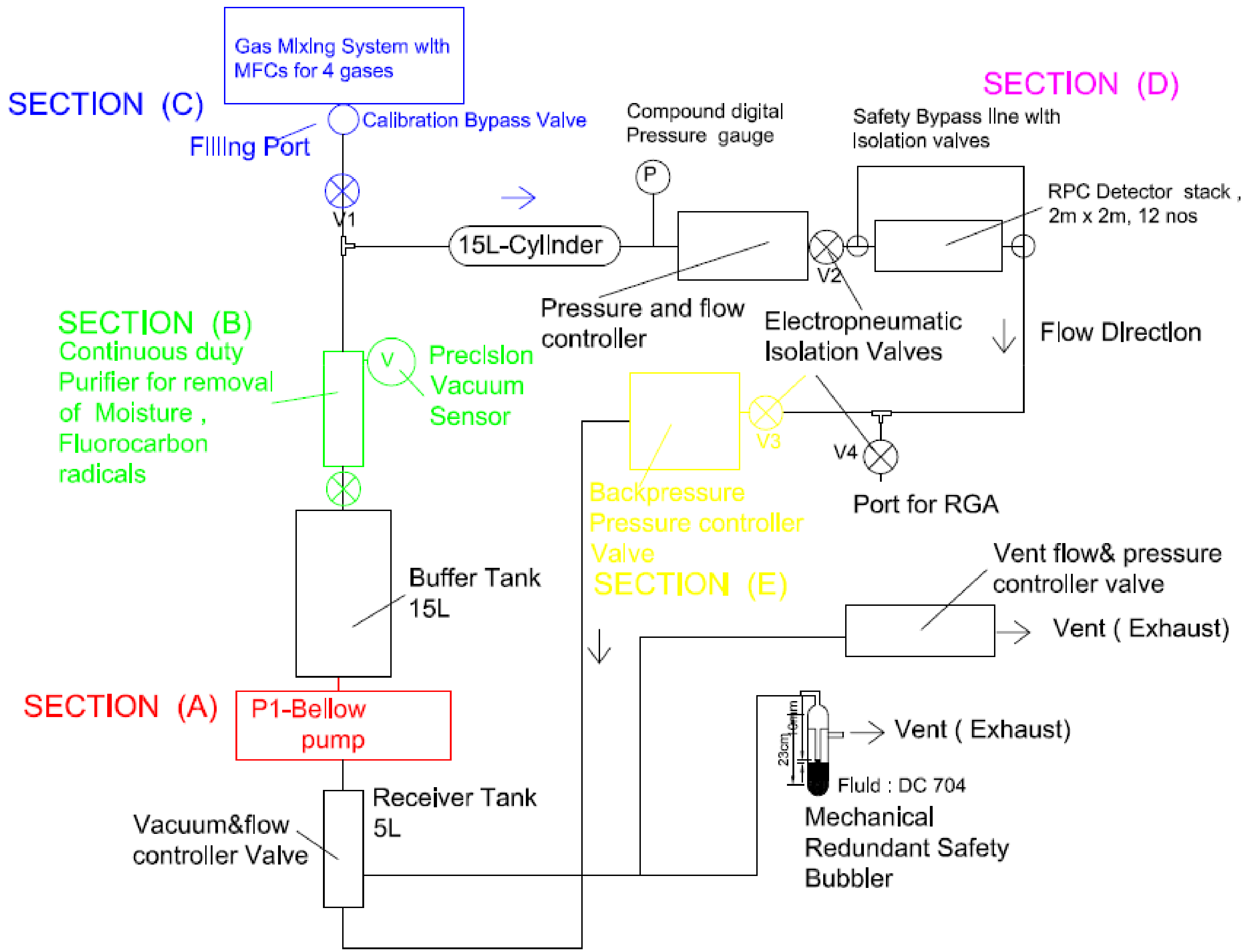
If the RPC gas gaps are produced without leaks (less than 1.75 mm WC in more than 33 hours), then the detectors can be operated without appreciable degradation in their performance for more than a month with a single gas fill. The cost of gas replenishing could thus be reduced considerably, by up to a factor of 30.

Line diagram of the close loop gas recirculation and purification system



- Gas Mixing (On-line)
- Gas Recirculation
- Gas Purification system
- Control System (PLC)

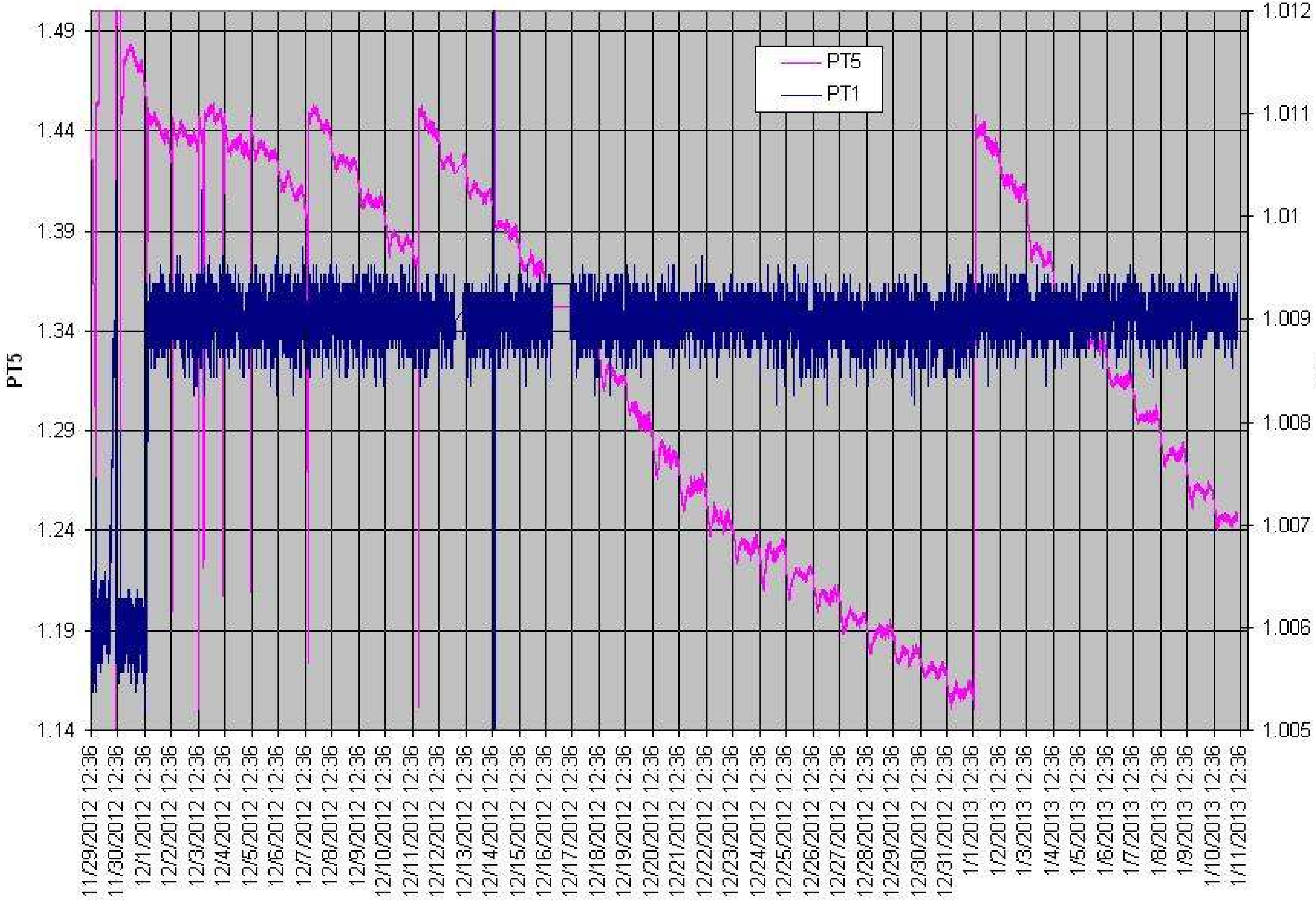
Closed-loop gas recirculation system



- 4 channel gas mixing module (filling/top-up of Iso-butane, Freon R134A, Argon and SF6)
- Total Capacity: 140 litres
- Continuous duty gas purification system to remove moisture, and other radicals
- Contamination removal up to 2ppm.

Newly developed gas recirculation system

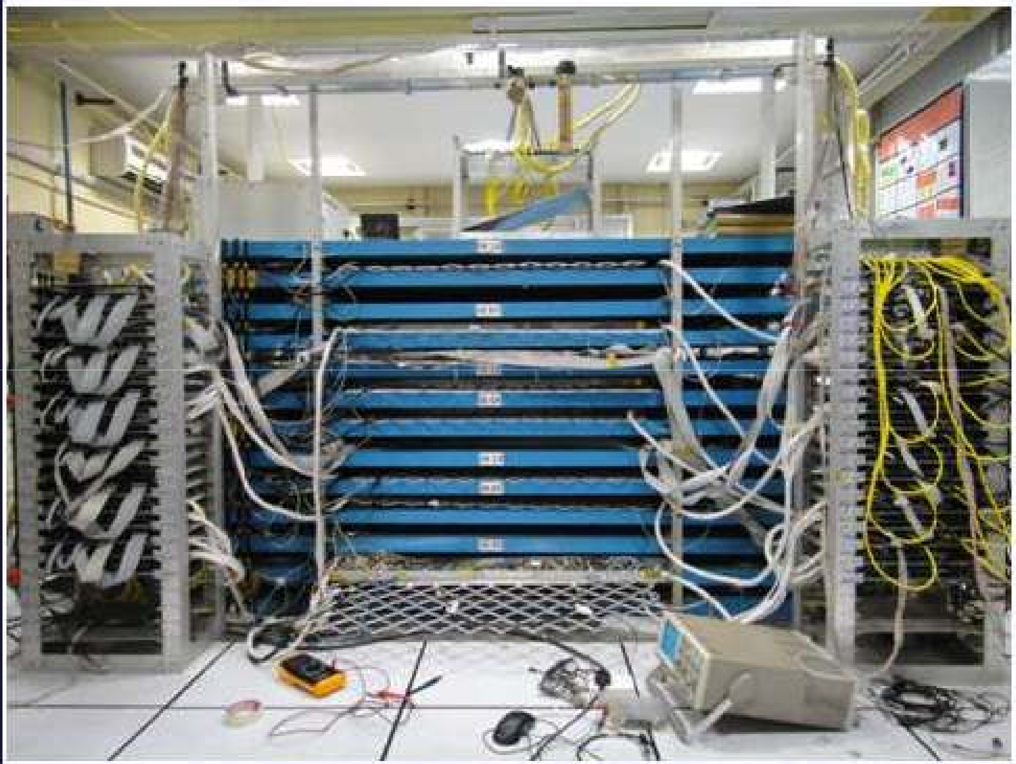
System with 2 RPCs auto-refill in 20 days



1m × 1m RPC stack at TIFR, Mumbai

2m × 2m RPC stack at TIFR, Mumbai

ICAL prototype at VECC, Kolkata



12 1m x 1m RPCs
- 4-Bakelite

13 Iron Plates
- ~ 5 cm Thickness

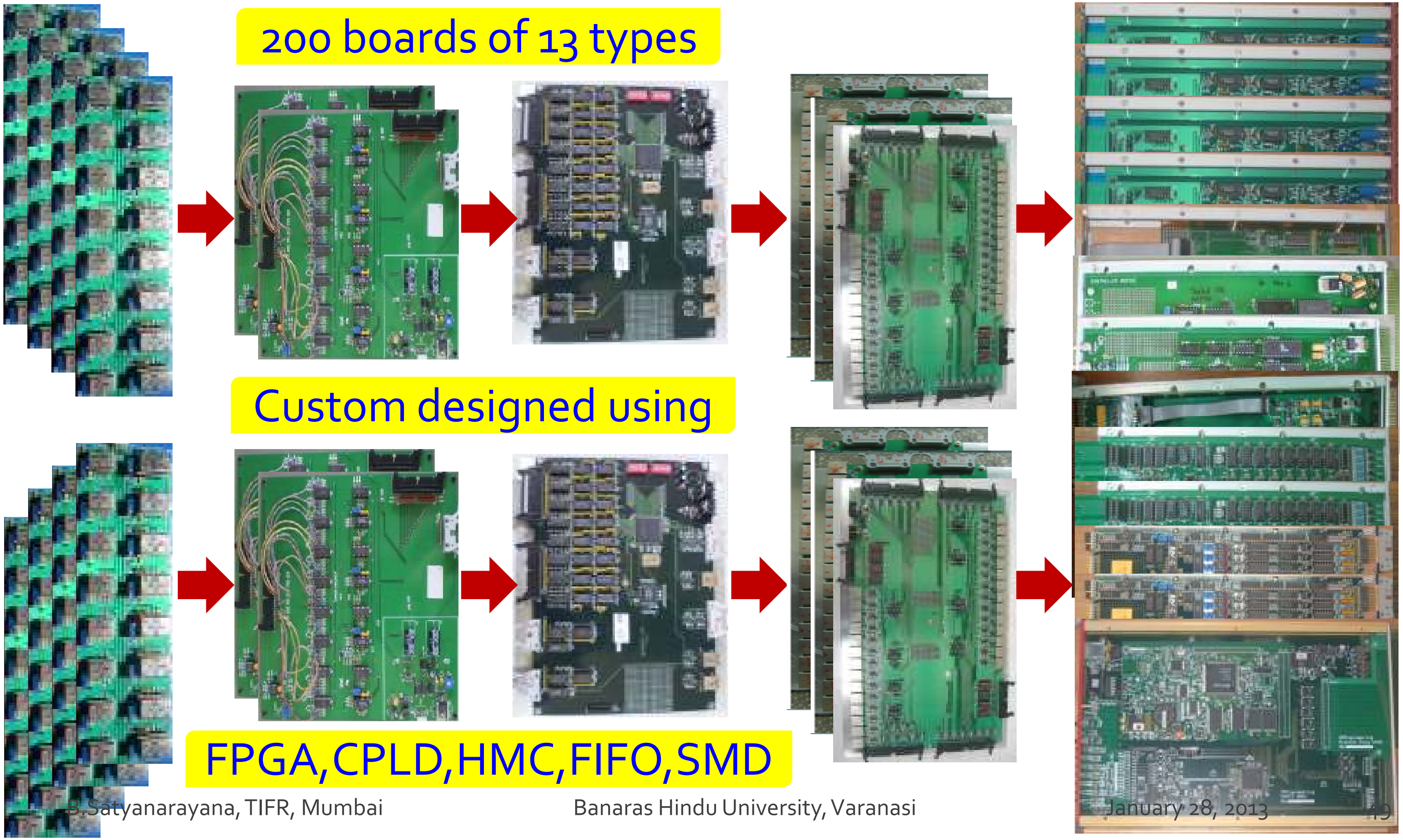
4 Coils, 5 turns each
- 1.5 T Max
- Field along Y

Design and implementation of the data acquisition system

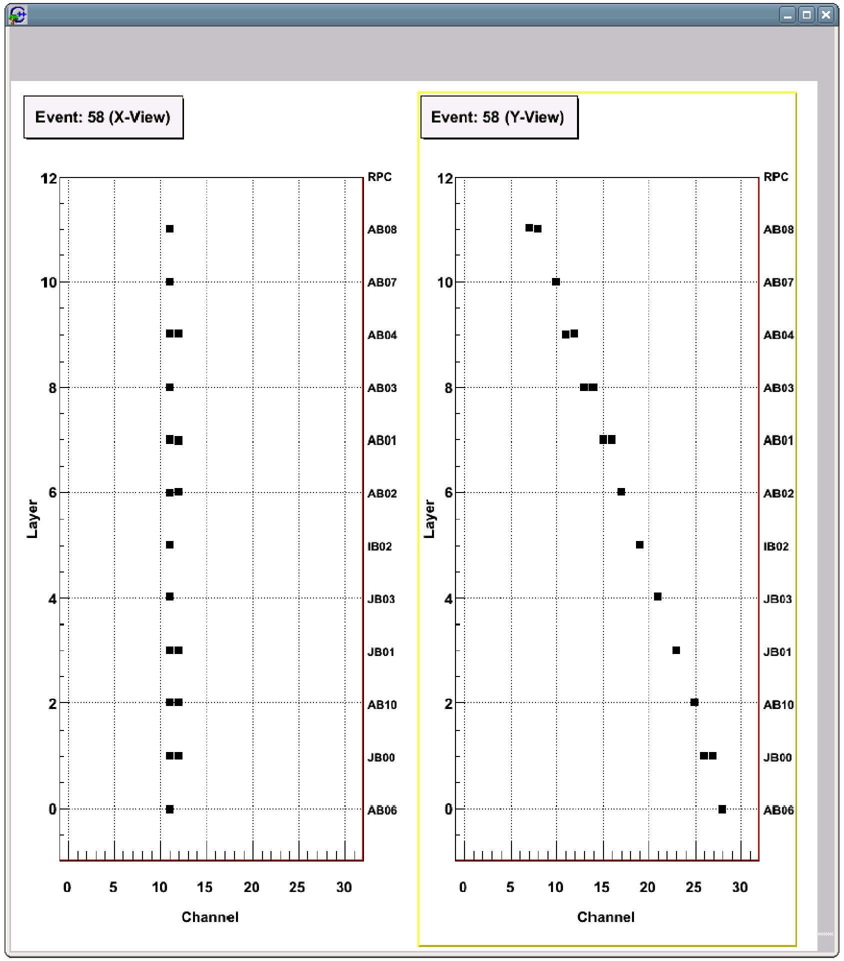
200 boards of 13 types

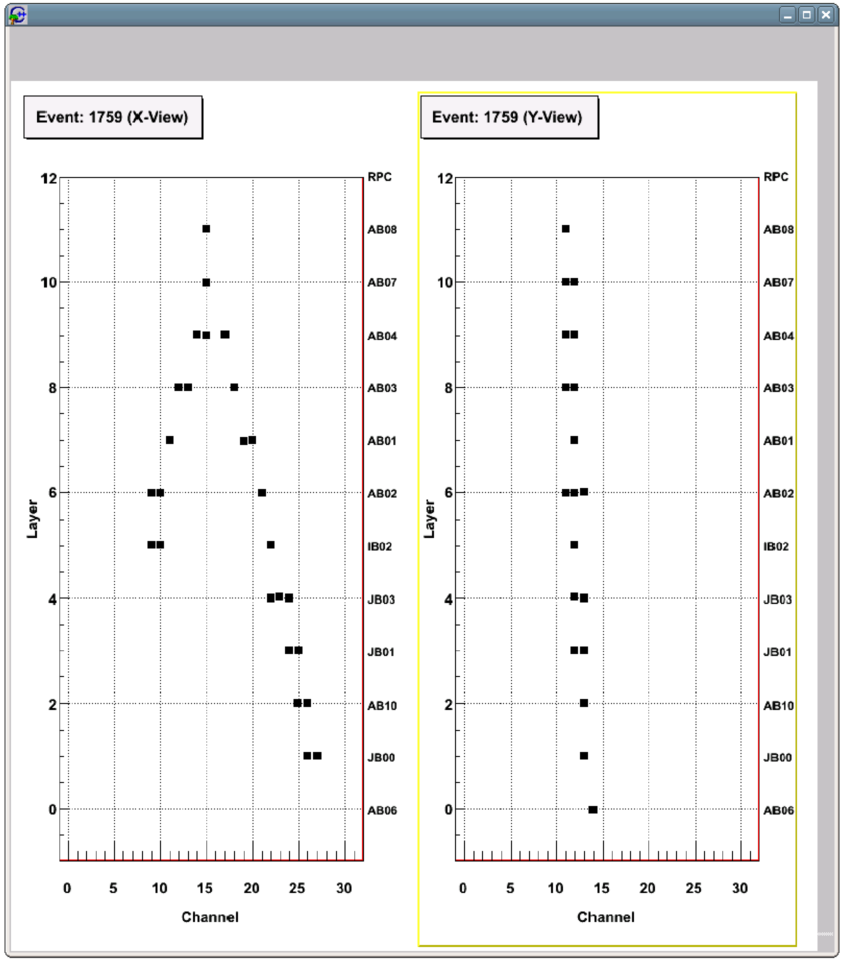
Custom designed using

FPGA,CPLD,HMC,FIFO,SMD

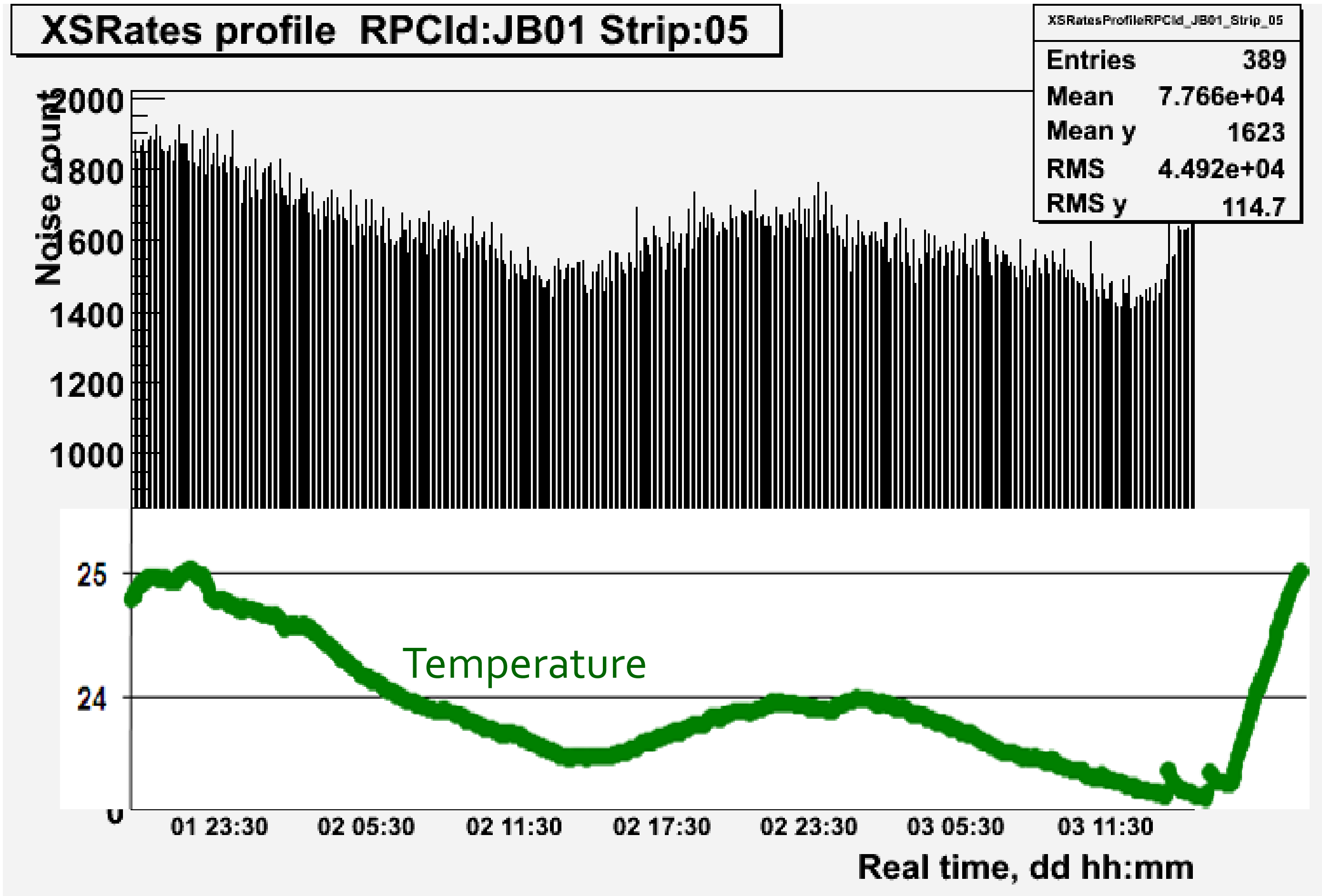


A couple of interesting events





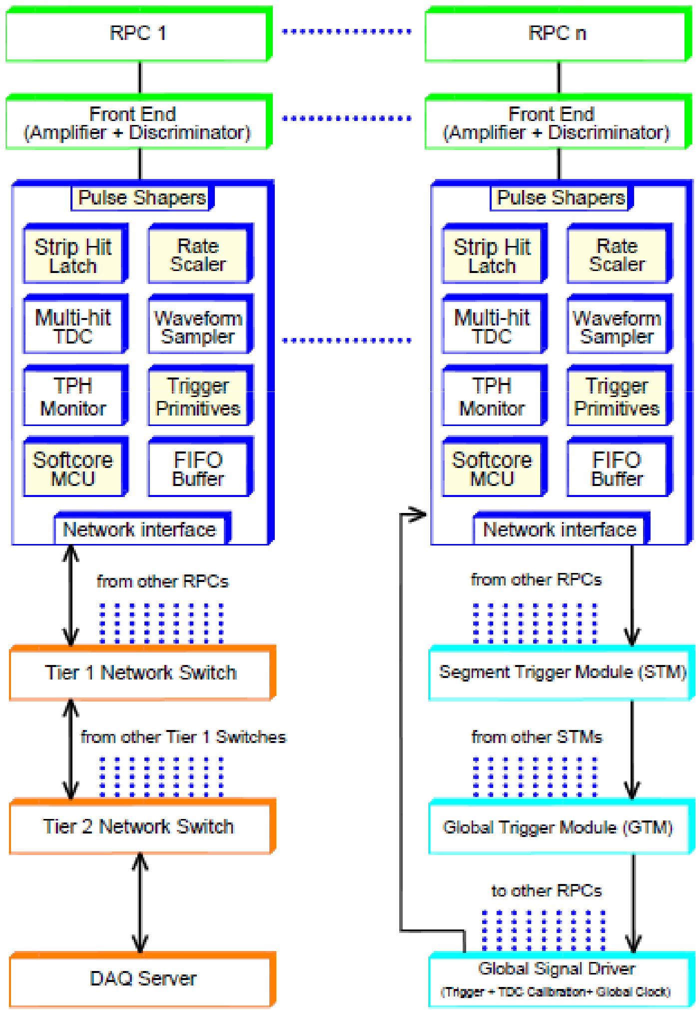
RPC strip rate time profile



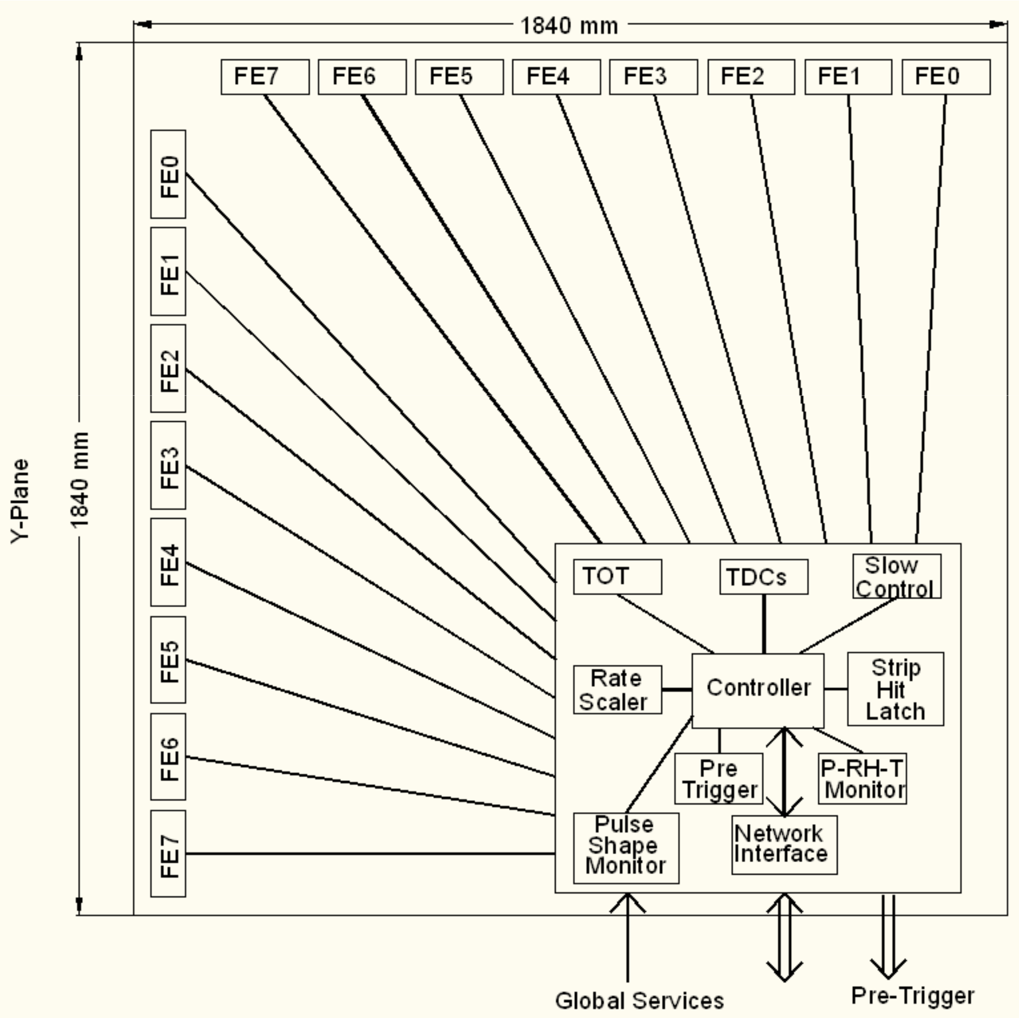
Overall scheme of ICAL electronics

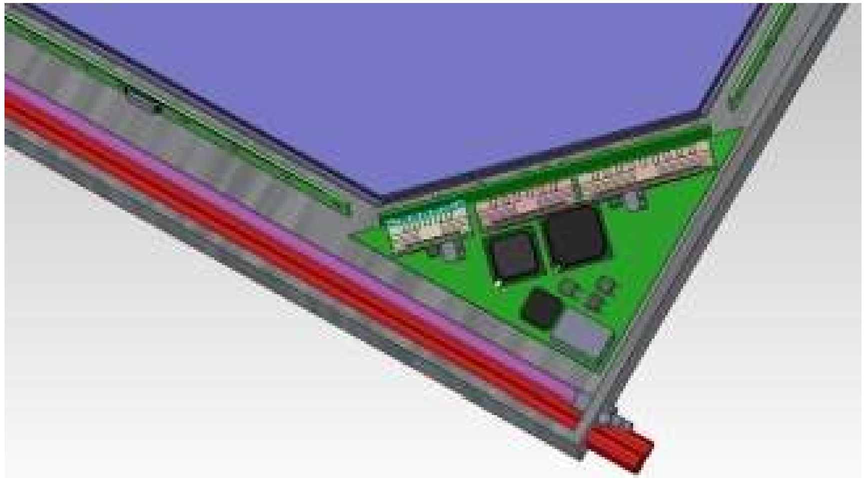
❖ Major elements

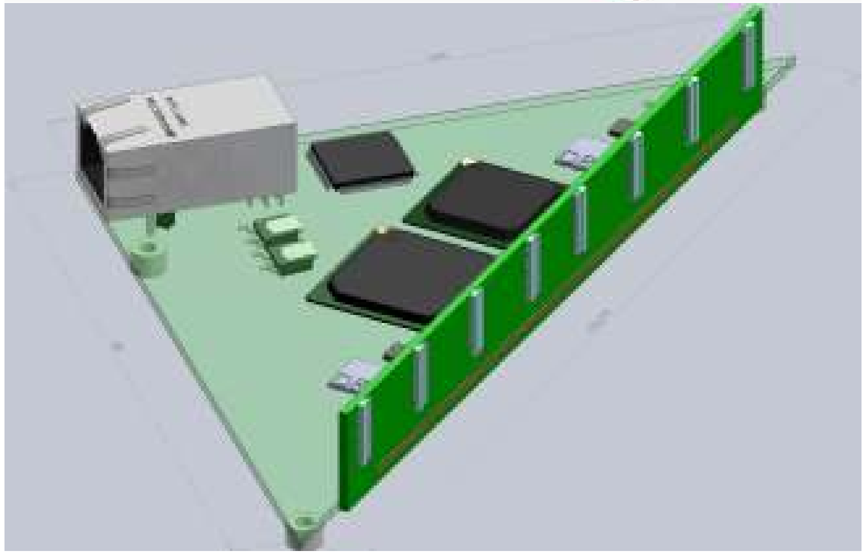
- Front-end board
- RPCDAQ board
- Segment Trigger Module
- Global Trigger Module
- Global Trigger Driver
- Tier1 Network Switch
- Tier2 Network Switch
- DAQ Server



Functions & integration of FE-DAQ

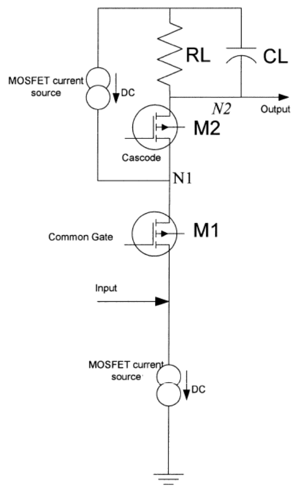


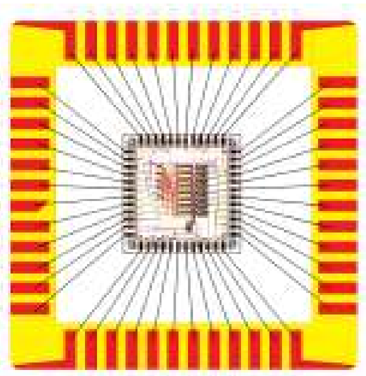


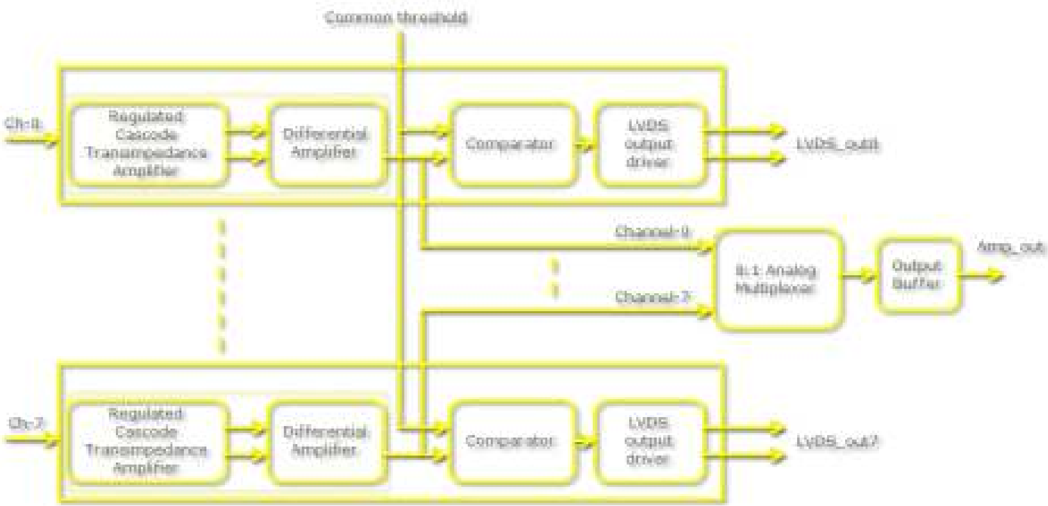


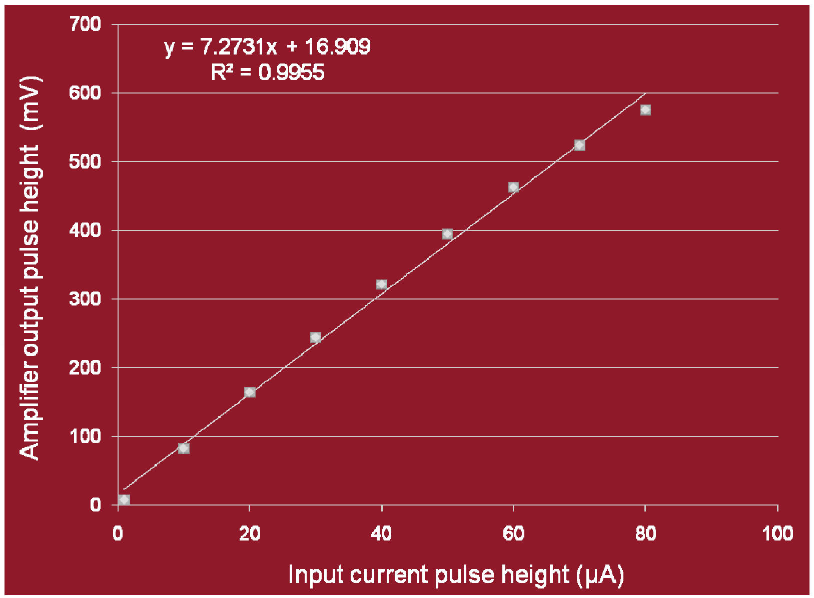
Picking up the tiny charges

- Process: AMSc35b4c3 (0.35um CMOS)
- Input dynamic range:18fC – 1.36pC
- Input impedance: 45Ω @350MHz
- Amplifier gain: 8mV/μA
- 3-dB Bandwidth: 274MHz
- Rise time: 1.2ns
- Comparator's sensitivity: 2mV
- LVDS drive: 4mA
- Power per channel: < 20mW
- Package: CLCC48(48-pin)
- Chip area: 13mm²









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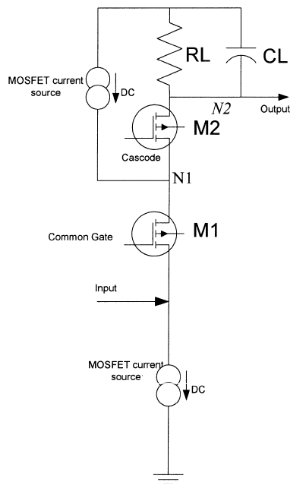
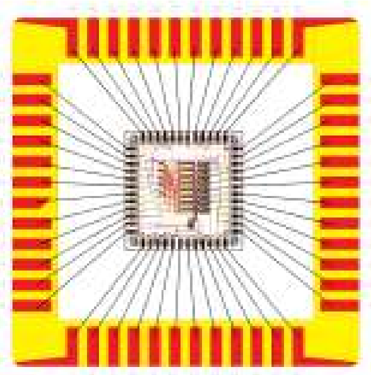
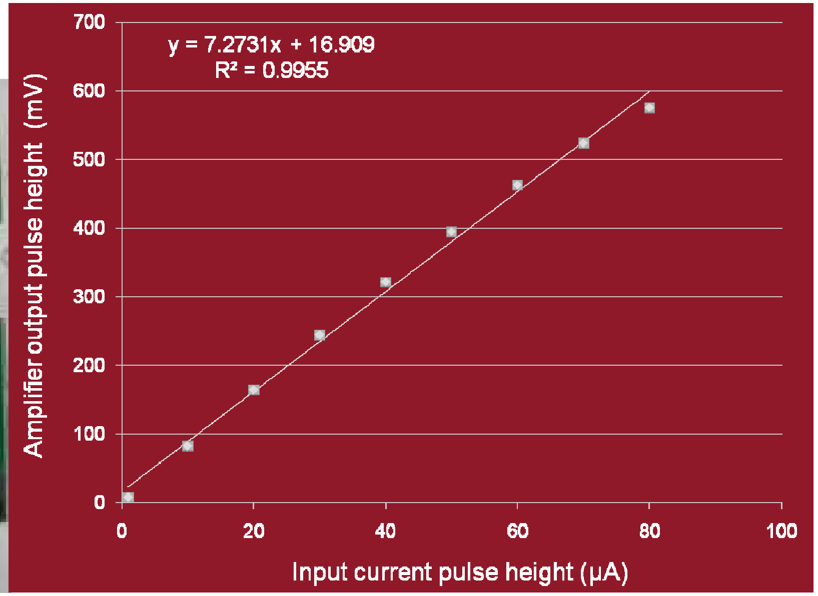
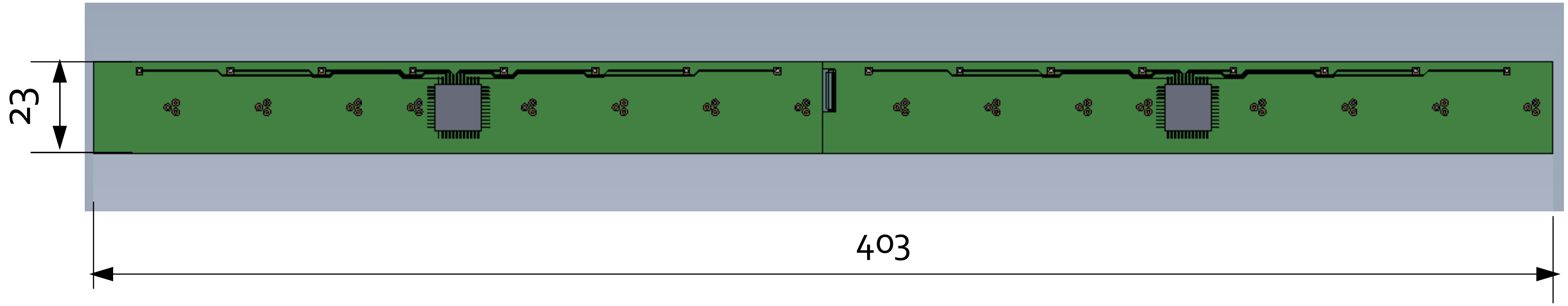






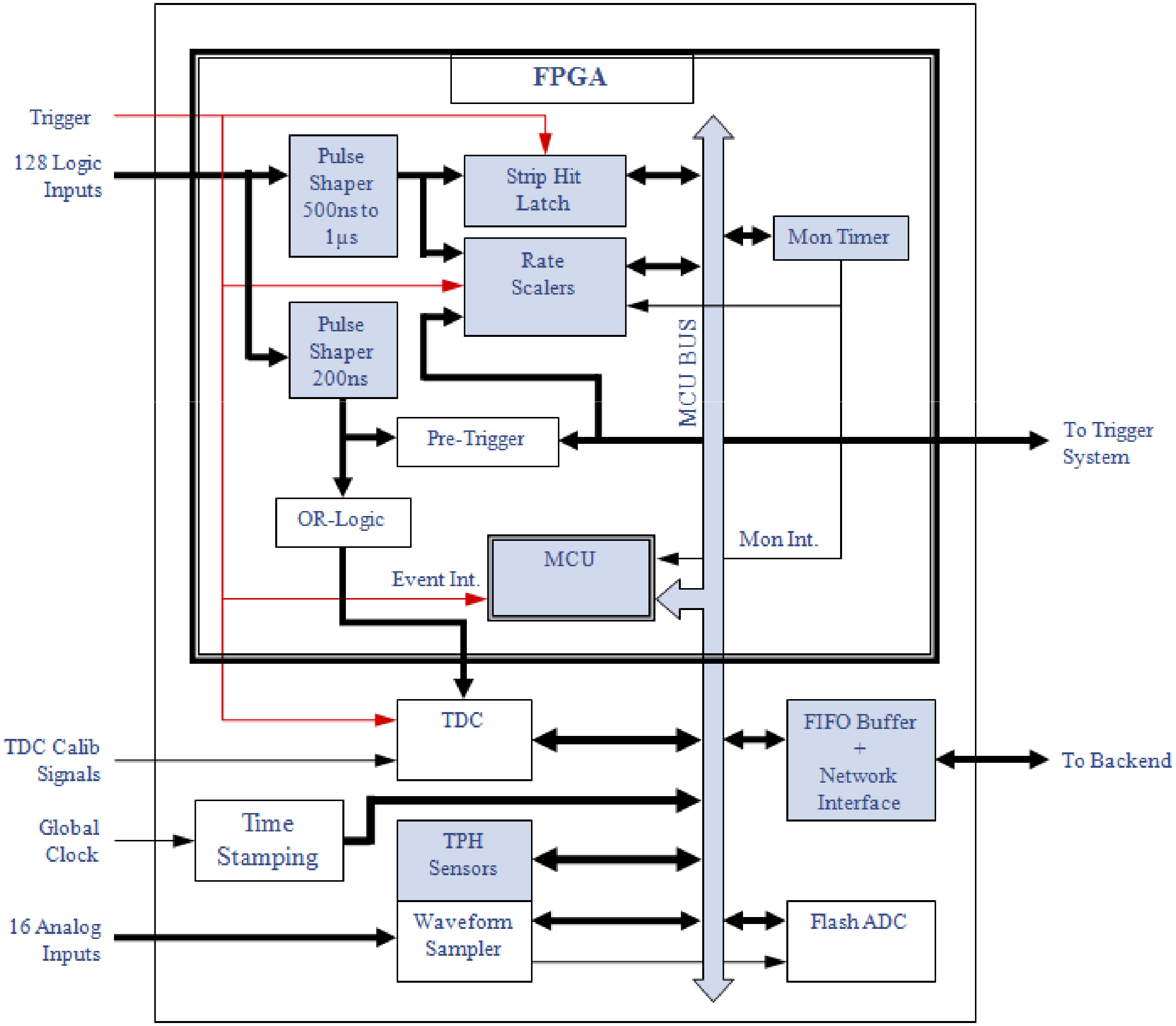
Preamplifier Board



- Current Anusparsh-2 chip dimensions does not fit to this design
- Next iteration might shrink the size
- Package the chip in the rectangular shape
- Go for chip bonding (for example: ATLAS's RPC front-end)

RPCDAQ module – the workhorse

- Unshaped, digitized, LVDS RPC signals from 128 strips (64x + 64y)
- 16 analog RPC signals, each signal is a summed or multiplexed output of 8 RPC amplified signals.
- Global trigger
- TDC calibration signals
- TCP/IP connection to backend for command and data transfer



Design considerations & constraints

- Data rates are low.
- Physical dimensions: Owing to severe space constraints on the RPC, triangular space of about $160cm^2$ only is available for this extremely high density board.
- Service life of the electronics is expected to be more than15 years, component spares availability/replaceability is a concern.
- Since the temperature and humidity inside the cavern will be controlled for RPCs, the electronic components need not be even of industrial grade - Commercial grade will do.
- Low power consumption. It is highly desirable to have minimum power consumption.
- Cost: Since the volumes are high, cost is also a major consideration

Data sizes and rates – Event

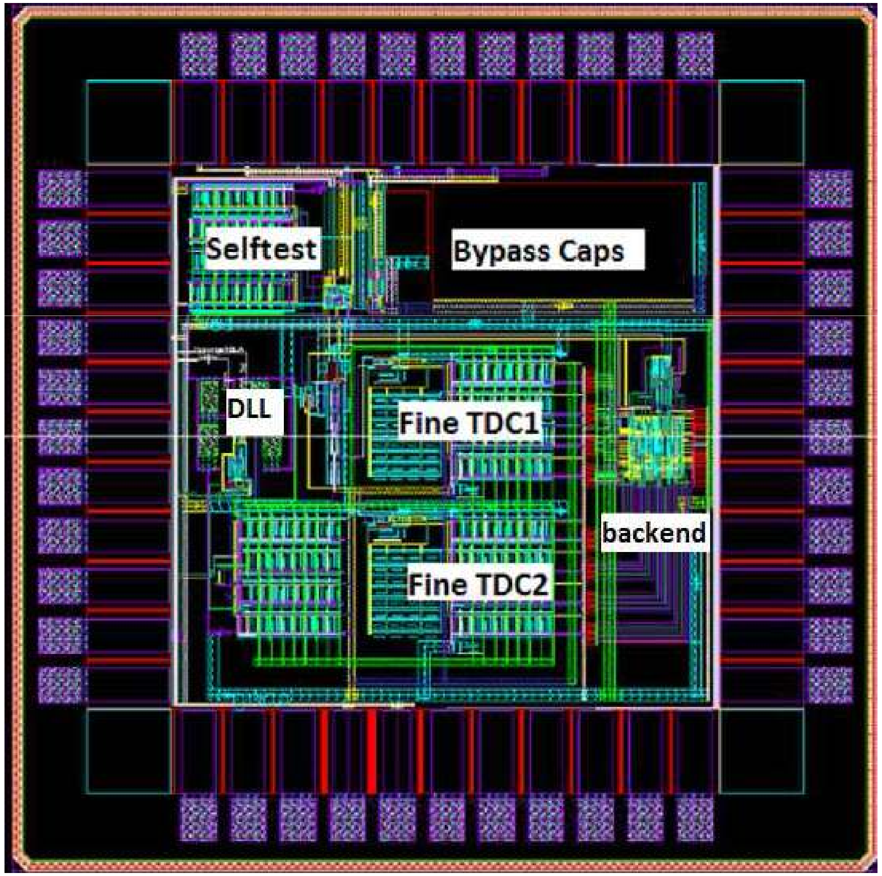
- Event header = 32 bits
- TDC data = 1 channel for 8 strips and both the edges per hit, up to 4 hits per channel per event = 16 channels x 2 edges x 4 hits x 32 bits = 4096 bits
- Hit data per RPC = 128 bits
- RPC ID = 32 bits
- Event ID = 32 bits
- Time Stamp = 64 bits
- DRS data = 16 channels x 1000 samples x 16 bits = 256000 bits
- (DRS data comes in event data only if we get summed analog outputs from the preamplifier)
- Data size per event per RPC
  - With DRS data, DR = 32 + 4096 + 128 + 32 + 32 + 64 + 256000 = 260,384 bits
  - Without DRS data, DR = 32 + 4096 + 128 + 32 + 32 + 64 = 4,384 bits
- Considering 1Hz trigger rate, Maximum data rate per RPC = 254.25 kbps
- Considering 10Hz trigger rate, Maximum data rate per RPC = 2.5425 Mbps

Data sizes and rates - Monitoring

- We require to monitor 16 pick-up strips per RPC.
- Monitor header = 32 bits
- Monitor data = 32 bits/strip x 16 strips = 512 bits
- Channel ID = 32 bits
- RPC ID = 32 bits
- Mon Event ID = 32 bits
- Ambient Sensors' data = 3 x 16 bits = 48 bits
- Time Stamp = 64 bits
- DRS data = 1000 pulses (if noise rate is 100Hz) x 16 bits x 100 samples x 16 strips = 25600000 bits
- (DRS data comes in monitoring data only if we get multiplexed analog outputs from the preamplifier)
- Data size per 10 seconds per RPC
  - With DRS data = 32 + 512 + 32 + 32 + 32 + 48 + 64 + 25600000 = 25600752 bits
  - Without DRS data = 32 + 512 + 32 + 32 + 32 + 48 + 64 = 752 bits
- Maximum data rate with 10 second monitoring period per RPC = 2.500 Mbps

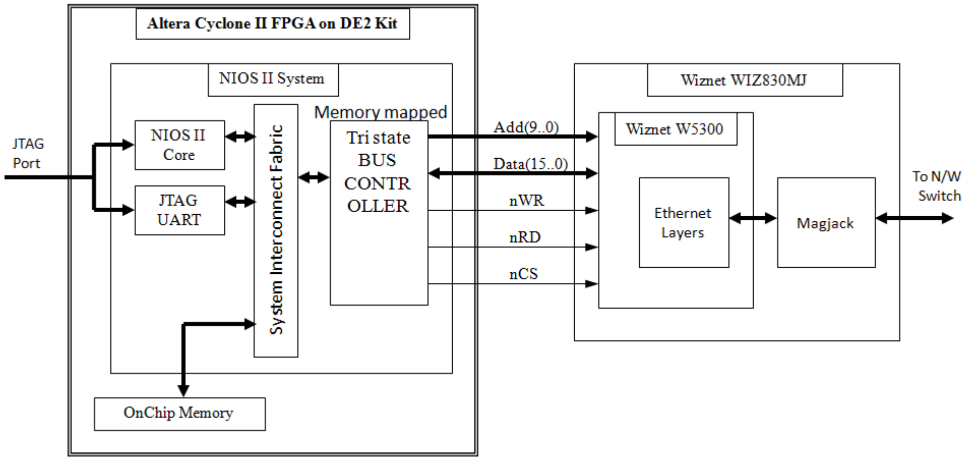
ASIC based TDC device

- Principle
  - Two fine TDCs to measure start/stop distance to clock edge (T_1, T_2)
  - Coarse TDC to count the number of clocks between start and stop (T_3)
  - TDC output = $T_3+T_1-T_2$
- Specifications
  - Currently a single-hit TDC, can be adapted to multi-hit
  - 20 bit parallel output
  - Clock period, T_c = 4ns
  - Fine TDC interval, $T_c/32$ = 125ps
  - Fine TDC output: 5 bits
  - Coarse TDC interval: $2^{15} * T_c$ = 131.072μs
  - Coarse TDC output: 15 bits
- The chip has arrived, evaluation tests are in progress it IITM



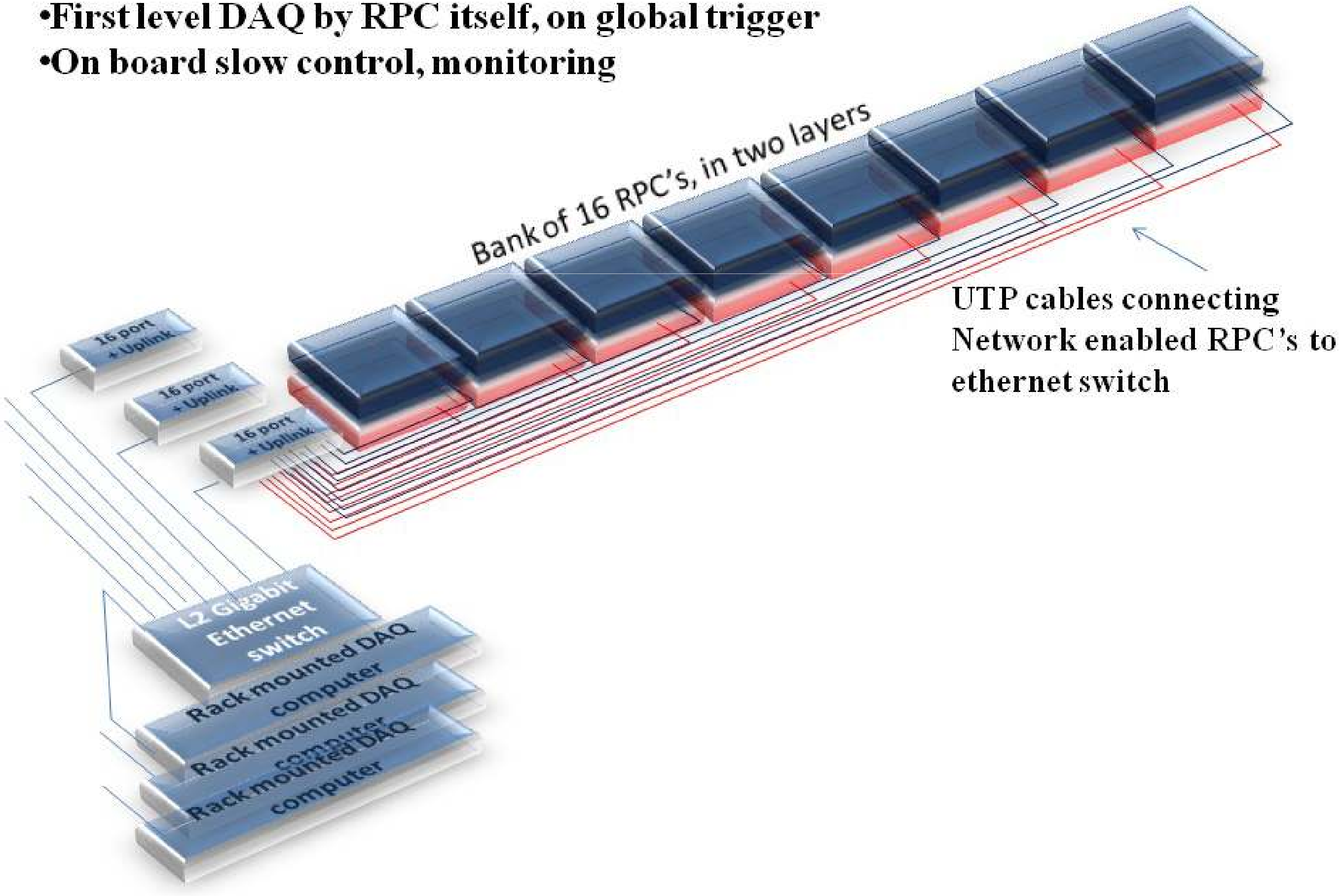
Network interface specifications

- Data traffic into RPC-DAQ is Configuration/ commands – Beginning or rarely Broad cast/ Multicast – UDP protocol with/higher layer check
- Data traffic out of RPC-DAQ is relatively high (45/332kbps)
- We will use a TCP/IP based network interface to send and receive data from front-end to the back-end. TCP/IP over UTP or optical fiber is a reliable protocol over long distances.
- Hardwired network protocol – Wiznet 5300 chip is used



Data network schematic

- RPC's designed as network devices
- Each RPC will have Embedded μP + Linux + TCP/IP
- First level DAQ by RPC itself, on global trigger
- On board slow control, monitoring



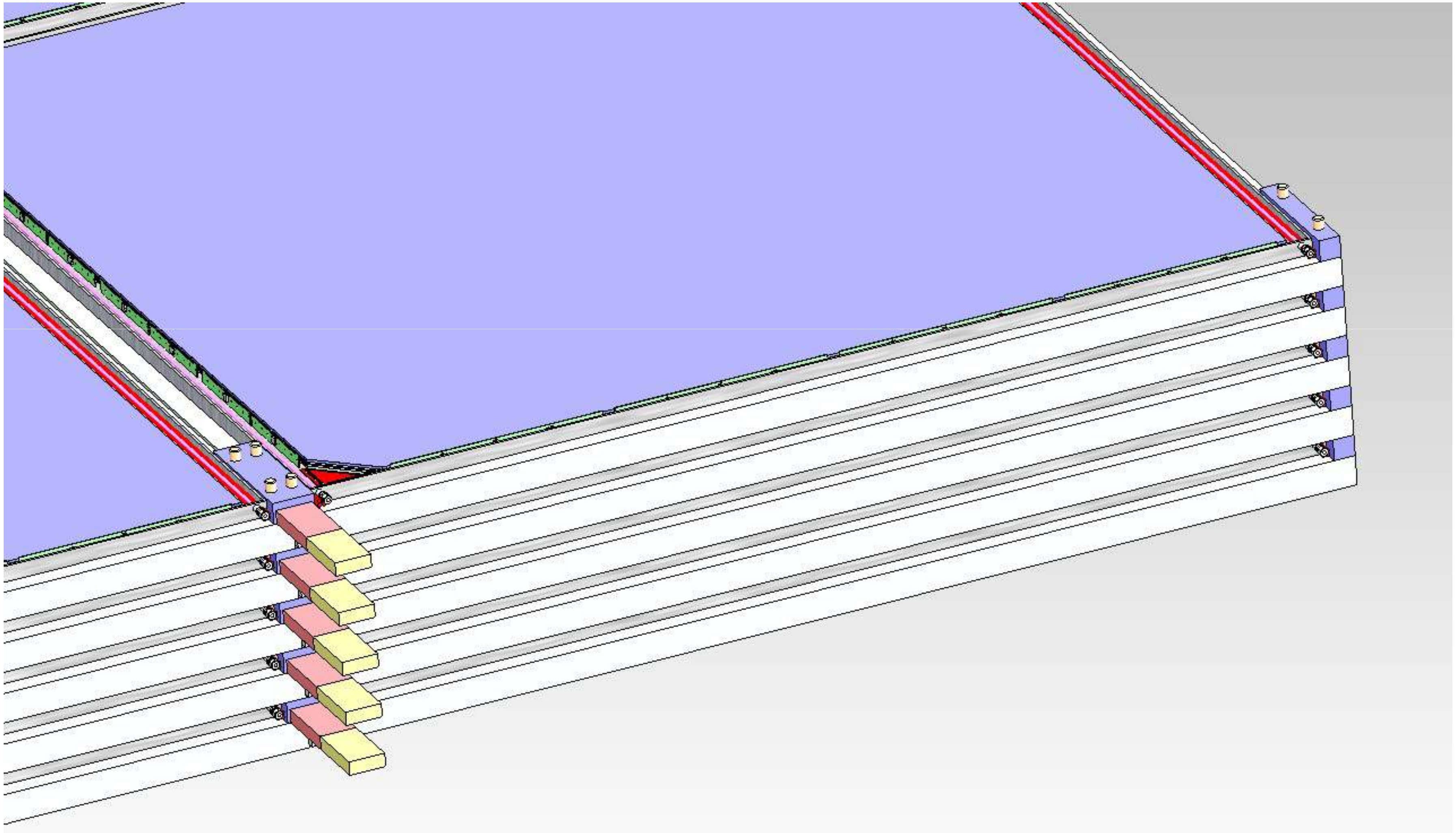
Front-end switches

- Atleast 16 (24, preferable) 1G copper ports PLUS a 1G fiber uplink ports, all duplex capable
- Layer 2, unmanaged Ethernet switch with “store and forward” non-blocking architecture.
- Atleast 512KB packet buffer, 1K MAC address table
- Fan-less design, dc power supply
- Severe constraints on place for mounting FE Switch, (40cm x 60cm x ~200cm)
- Next gen 8 port switches in market will fit our size requirement
- Present day chipsets small enough, only limited by size of RJ45 connectors
- Contacted couple of Ethernet chip set makers, positive response for 16+1 port switch

Back-end Ethernet switches

- Proposal is for up-linking the FE Switches to back end switches to which the computers are also connected.
- BE Switches: Commercial 48 port gigabit switches (copper/fiber) with atleast 4 10G uplink ports
- Rack size is 1U (all current models)
- Many models have MAC address table exceeding 10k, so can store location information of all RPC's of one ICAL module. Implications are (to be tested):
  - the Master computer can quickly address any RPC
  - no need of L3 functionality, L2 functionality will do
  - but time taken to gather the MAC table.. to be understood
- IP segmentation using separate class C subnet for each 3 layers

N/W switches on the face of spacers



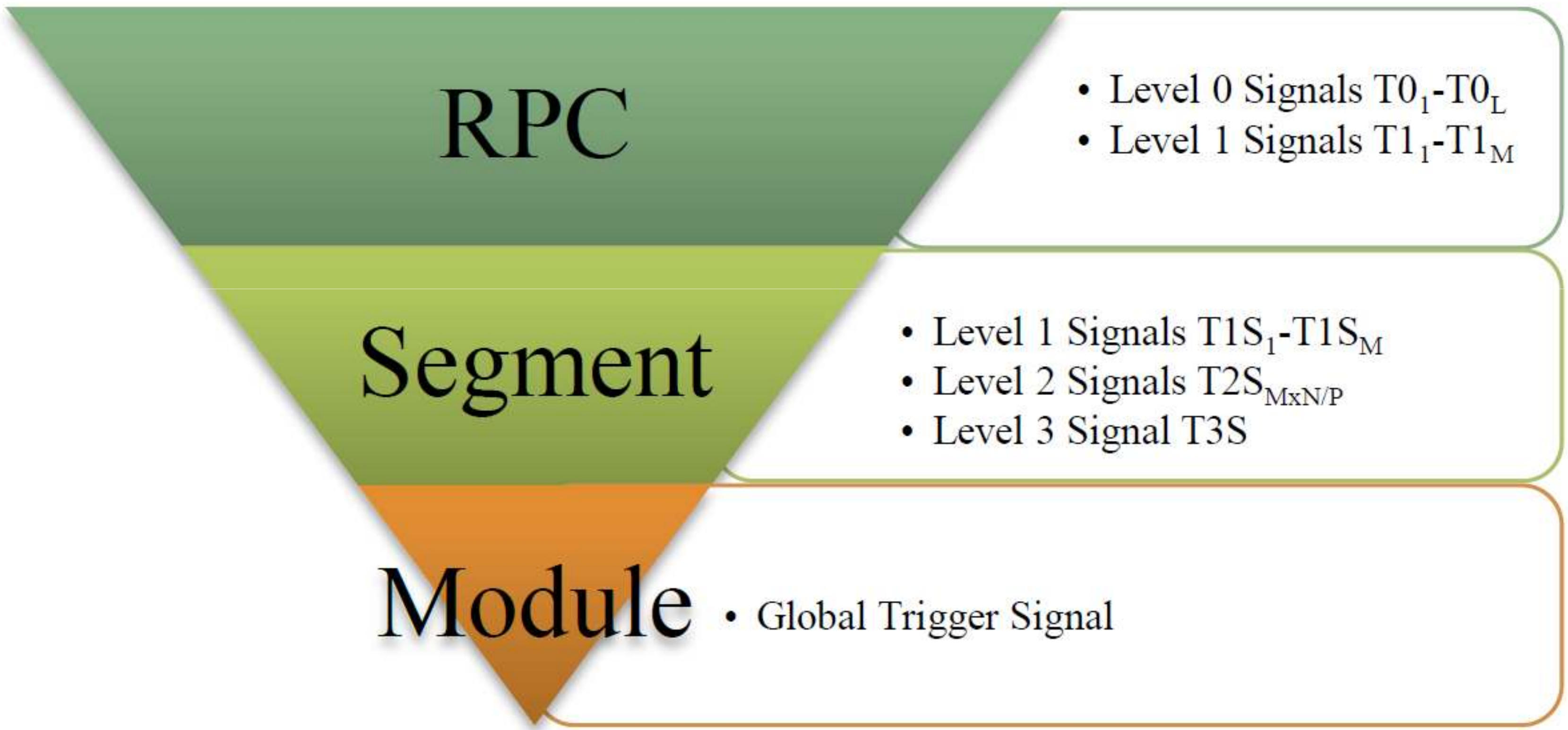
Data collecting computers

- Worst case data rate from even 4 layers together is within the capacity of modern multi core CPUs (real case tests to be done)
- Broadly, the specs are:
  - High density 1U rack mountable servers
  - diskless, remote OS installation/configuration (Quattor, ROCKS, or even Kickstart)
  - one gigabit port for RPC's + one 10G port for networking with other DCCs and upstream event builder/master computer
  - Example: rack space requirement 3U for 12 RPC layers
    - with 3 layers RPC for each DCC – 3U rack space
    - 1U for 48 port switch, 2U for 4 high performance servers

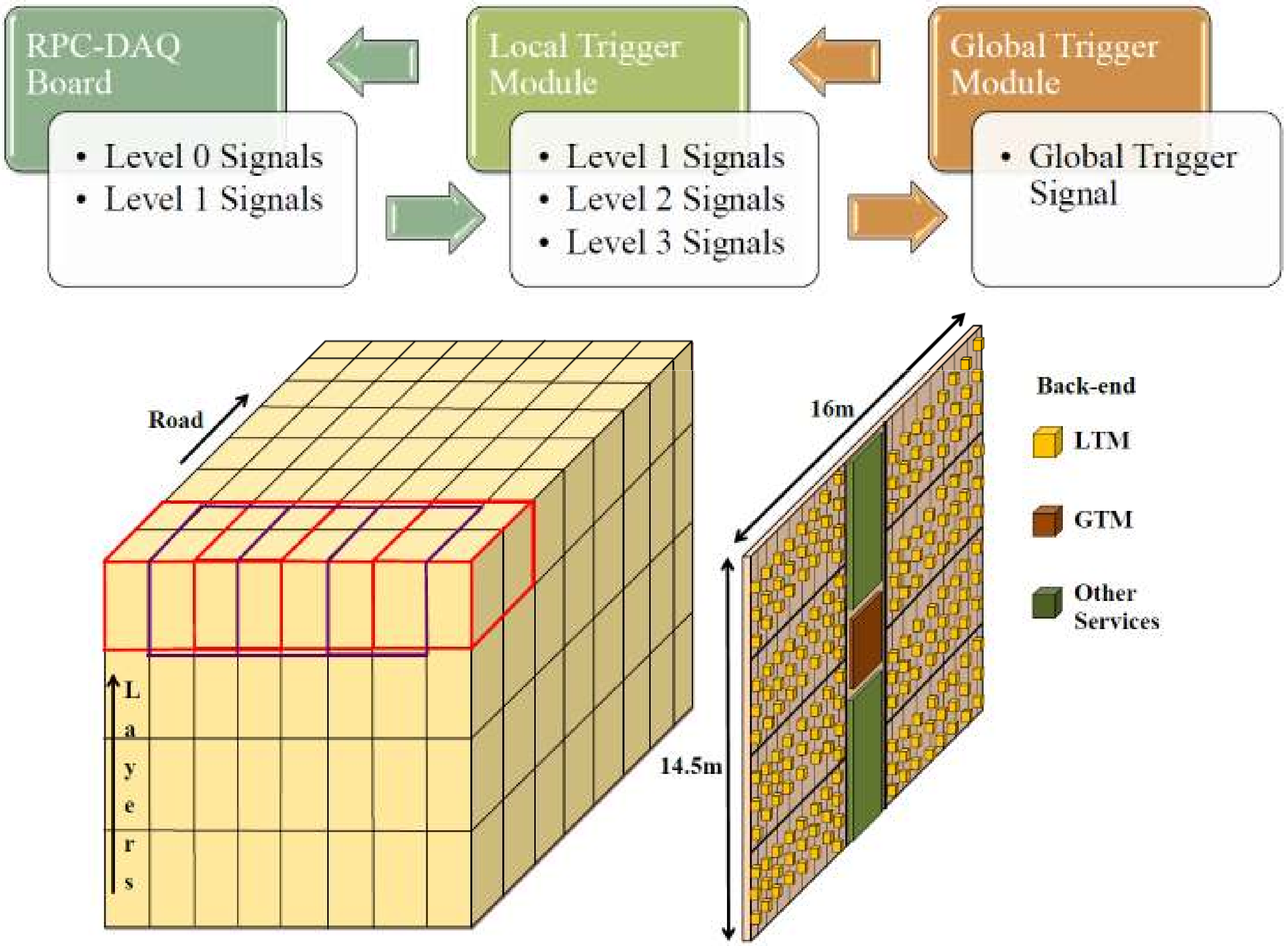
Features of ICAL trigger system

- *Physicist's mind* decoded!
- *Insitu* trigger generation
- Autonomous; shares data bus with readout system
- Distributed architecture
- For ICAL, trigger system is based only on topology of the event; no other measurement data is used
- Huge bank of combinatorial circuits
- Programmability is the game, FPGAs, ASICs are the players

ICAL Trigger Scheme

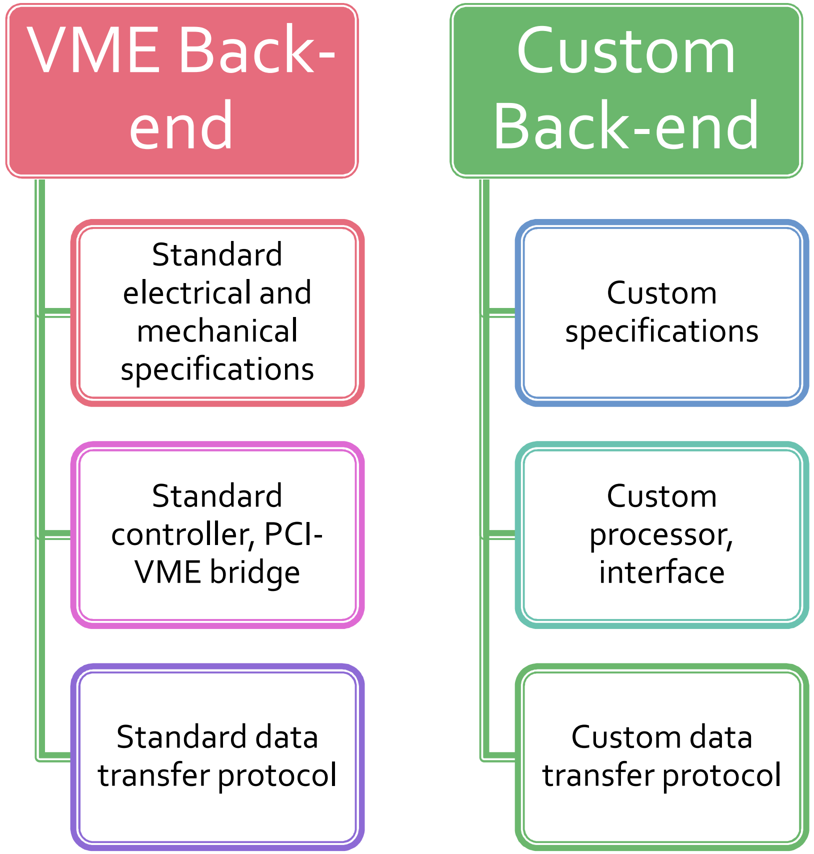


Implementation layout



Back-end communication for trigger modules

- Configuration of the LTM FPGAs to implement new trigger criteria.
- User specifications
  - Selective masking of signals at different levels of trigger generation.
- Data readout
  - Trigger rates
  - Latch information



Studying suitability of FPGAs

Vendor	RPC-DAQ board		Trigger system	
	Family	**Device**	**Family**	**Device**
Altera	Cyclone 4	EP4CE115F29	Cyclone 5	5CEBA7F31
Xilinx	Spartan 6	XC6SLX100FGG676	Spartan 6	XC6SLX100FGG676

Power supply options

- High voltage (Central scheme)
  - Two options: a channel at 12kV or two channels at ±6kV (Imax ~2mA)
  - Consider powering 4 RPC with a single HV channel (10μA current)
  - Cable diameter an integration issues, connectors a cost issue
  - Ripple less than a volt at 6KV
- High voltage (Distributed scheme)
  - DC-DCHV converters (proportional – high ripple or regulated)
  - Each RPC has to be identical to the others?
  - Each RPC will have its own DC-HVDC converter for generating HV and LV
  - Control and monitoring modules interfaced to the RPCDAQ module
- Low voltage
  - Power budget 25W per RPC – for the purpose of power supply design
  - How many low voltages? – one for now.
  - Voltage Set/Monitor resolution 5 mV
  - Current Set/Monitor resolution10 mA
  - Voltage ripple ~20mV PP
  - Input, topology, efficiency and size
  - Voltage Drop compensation via sense wires?
  - Load regulation ±0.3 %
- Fringe magnetic fields and space for DC-DC converters inside the RPC unit are the design and integration issues

"Innovation, not imitation"

A SERIES

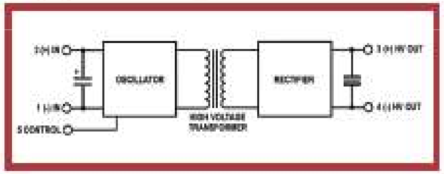
ISOLATED, PROPORTIONAL DC TO HV DC CONVERTERS

100V to 6000V @ 1.0 and 1.5 Watts

Extremely Low Profile: 0.25 inches and volume of < 0.100 cubic inches

PRODUCT DESCRIPTION

The A Series is a new line of ultra-miniature, DC to HV DC converters that set an industry standard in high voltage miniaturization. This unique package occupies less than one tenth of a cubic inch of volume, and features an extremely low profile of only 0.250 inches (6.35mm)! Controllable output voltages range from 100 volts to 6000 volts. These component-sized converters are ideal for applications requiring minimal size and weight.



APPLICATIONS

Avalanche Photodiodes
Capacitor Charging
Electrophoresis
Photomultiplier Tubes
Piezo Devices
Mass Spectrometry
Sustaining Ion Pumps

OPTIONS

1 Watt and 1.5 Watt Versions Available (A/AH)
Available in Three Standard Input Voltage Ranges: 0 to 5, 12 or 24VDC
Polarity: Choose Positive or Negative Output (P/N)
Extended Operating Temperature (T Suffix)
Alternate Input / Output Voltages (Consult Factory)
See Ordering Information (Page 10)

PRODUCT SELECTION TABLE

VDC	STANDARD 1 WATT - A MODEL		1.5 WATT OPTION - AH MODEL	
	MODEL	MAXIMUM OUTPUT CURRENT*1	MODEL	MAXIMUM OUTPUT CURRENT*1
100 VDC	A01	10 mA	AH01	15 mA
200 VDC	A02	5 mA	AH02	7.5 mA
250 VDC	A025	4 mA	AH025	6 mA
300 VDC	A03	3.33 mA	AH03	5mA
400 VDC	A04	2.5 mA	AH04	3.75 mA
500 VDC	A05	2 mA	AH05	3 mA
600 VDC	A06	1.67 mA	AH06	2.5 mA
700 VDC	A07	1.43 mA	AH07	2.15 mA
800 VDC	A08	1.25 mA	AH08	1.87 mA
900 VDC	A09	1.1 mA	AH09	1.67 mA
1000 VDC	A10	1 mA	AH10	1.5 mA
1200 VDC	A12	0.83 mA	AH12	1.25 mA
1500 VDC	A15	0.66 mA	AH15	1 mA
2000 VDC	A20	0.5 mA	AH20	0.75 mA
3000 VDC	A30	0.32 mA	AH30	0.5 mA
4000 VDC	A40	0.24 mA	AH40	0.375 mA
5000 VDC	A50	0.2 mA	AH50	0.3 mA
6000 VDC	A60	0.167 mA	AH60	0.25 mA

Complete List of Models on page 2

FEATURES

- Proportional Input/Output
- Low Noise Quasi-sinewave Oscillator
- Control Pin
- Low Leakage Current
- Low Input/Output Capacitance
- Input to Output Galvanic Isolation
- Short Circuit Protection, 1 Minute Minimum
- No Minimum Load Required
- No External Components Required
- Designed to meet RoHS and REACH Directives
- MTBF > 1,862,000 hours, per Bellcore TR 332

EMCO HIGH VOLTAGE CORPORATION
www.emcohighvoltage.com
e-mail: sales@emcohv.com
phone: 1-800-546-3680, fax (209) 267-0282
70 Forest Products Rd, Sutter Creek, CA 95685 USA

ELECTRICAL SPECIFICATIONS*3

OUTPUT VOLTAGE*2 (To select polarity, see pg. 8 - How to Order)	STANDARD 1 WATT - A MODEL			1.5 WATT OPTION - AH MODEL		
	MODEL	MAXIMUM OUTPUT CURRENT*1	RIPPLE P-P*4	MODEL	MAXIMUM OUTPUT CURRENT*1	RIPPLE P-P*4
0 to 100 VDC	A01	10 mA	1%	AH01	15 mA	2%
0 to 200 VDC	A02	5 mA	1%	AH02	7.5 mA	2%
0 to 250 VDC	A025	4 mA	1%	AH025	6 mA	2%
0 to 300 VDC	A03	3.33 mA	1%	AH03	5 mA	2%
0 to 400 VDC	A04	2.5mA	1%	AH04	3.75 mA	2%
0 to 500 VDC	A05	2 mA	1%	AH05	3 mA	2%
0 to 600 VDC	A06	1.67 mA	1%	AH06	2.5 mA	2%
0 to 700 VDC	A07	1.43 mA	1%	AH07	2.15 mA	2%
0 to 800 VDC	A08	1.25 mA	1%	AH08	1.87 mA	2%
0 to 900 VDC	A09	1.1 mA	1%	AH09	1.67 mA	2%
0 to 1000 VDC	A10	1 mA	1%	AH10	1.5 mA	2%
0 to 1200 VDC	A12	0.83 mA	1%	AH12	1.25 mA	2%
0 to 1500 VDC	A15	0.67 mA	1%	AH15	1 mA	2%
0 to 2000 VDC	A20	0.5 mA	1%	AH20	0.75 mA	2%
0 to 3000 VDC	A30	0.33 mA	1%	AH30	0.5 mA	2%
0 to 4000 VDC	A40	0.25 mA	1%	AH40	0.37 mA	2%
0 to 5000 VDC	A50	0.2 mA	1%	AH50	0.3mA	2%
0 to 6000 VDC	A60	0.167 mA	1%	AH60	0.25 mA	2%

	INPUT CURRENT			
	A MODELS - 1 Watt		AH MODELS - 1.5 Watt	
VIN	NO-LOAD	FULL-LOAD	NO-LOAD	FULL-LOAD
5 VDC	<200mA	<470mA	<300mA	<550mA
12 VDC	<100mA	<185mA	<125mA	<250mA
24 VDC	<25mA	<60mA	<40mA	<120mA

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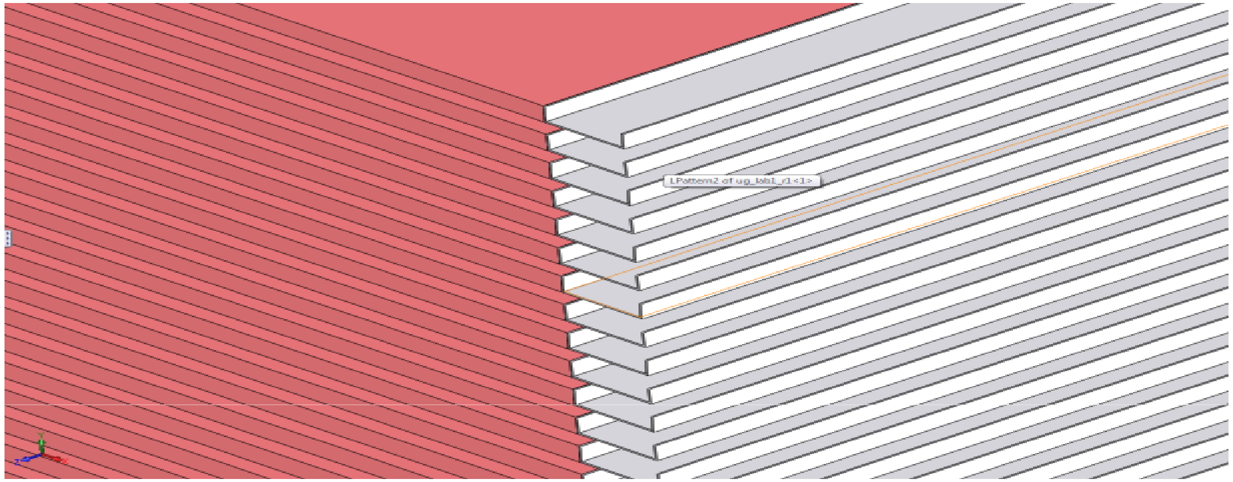
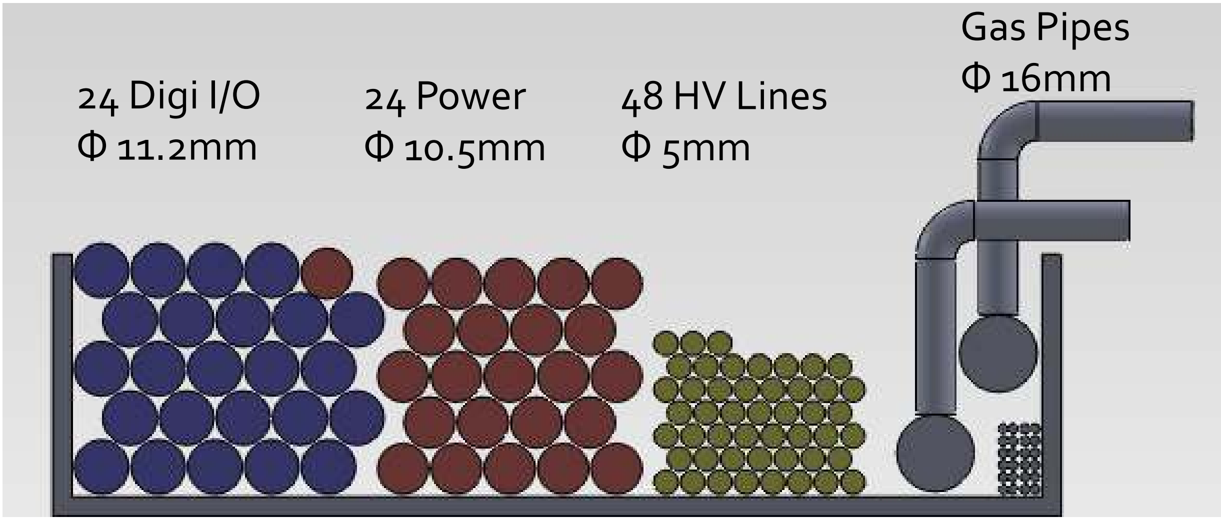
DC-HVDC supply control & monitoring

- Controls and monitors 2 channels
- A µC (with built in 12-bit ADCs and DACs) based.
- Communicates with RPCDAQ module on SPI.
- Controls high voltage, ramp rate etc.
- Monitors voltages and currents
- Compact and small form-factor

Cable trays




Gas Pipes
Φ 16mm
24 Digi I/O
Φ 11.2mm
24 Power
Φ 10.5mm
48 HV Lines
Φ 5mm

Software requirements

- RPC-DAQ controller firmware
- Backend online DAQ system
- Local and remote shift consoles
- Data packing and archival
- Event and monitor display panels
- Event data quality monitors
- Slow control and monitor consoles
- Database standards
- Data analysis and presentation software standards
- Operating System and development platforms

Technology development for Industrial production of RPCs

- Development of graphite coating by automatic spray painting.
- Demonstration of successful operation of automatic button and glue dispenser.
- Development of glass chamfering and glass Engraving.
- Pickup panel development.
- Tray design.
- Computer modeling of RPC & its assembly in ICAL.
- Physical RPC models to study push-pull assembly in ICAL magnet gap.
- Some of these items are at advanced stages of development.

QC procedures for RPC gap

- Visual inspection: All the glasses, buttons, spacers etc. are to be inspected before taking up the fabrication work. This should be done by an experienced staff and the same person need to certify the acceptance of the material provided with proper documentation.
- Dimension conformance
- Leak test of Gaps*: A RPC-gap "leak test system" should be developed, so that the RPC gaps so produced are qualified for the required pressure test.
- The QC sheets (traveler sheet) need to be filled at each and every step and should be carried forward along with gap.

- *Leak test:
- The gaps need to be checked for any leak and the leak rate should be less then 10^{-4} SCCM and the gaps should hold at least 6mbar pressure.

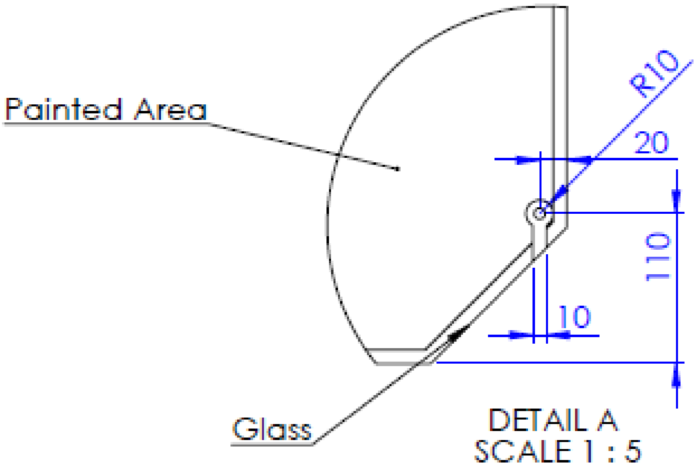
Steps towards Industrial production of RPCs

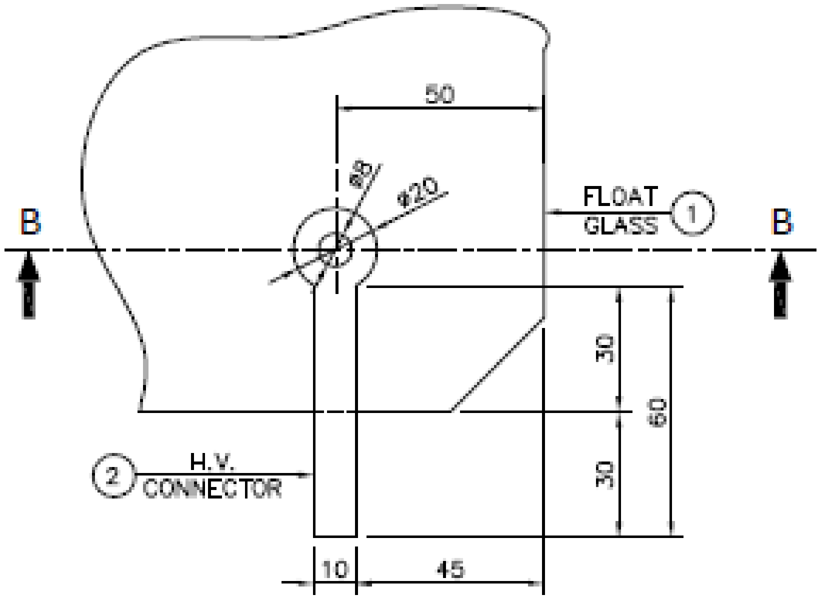





RPC fabrication at Asahi Float Glass

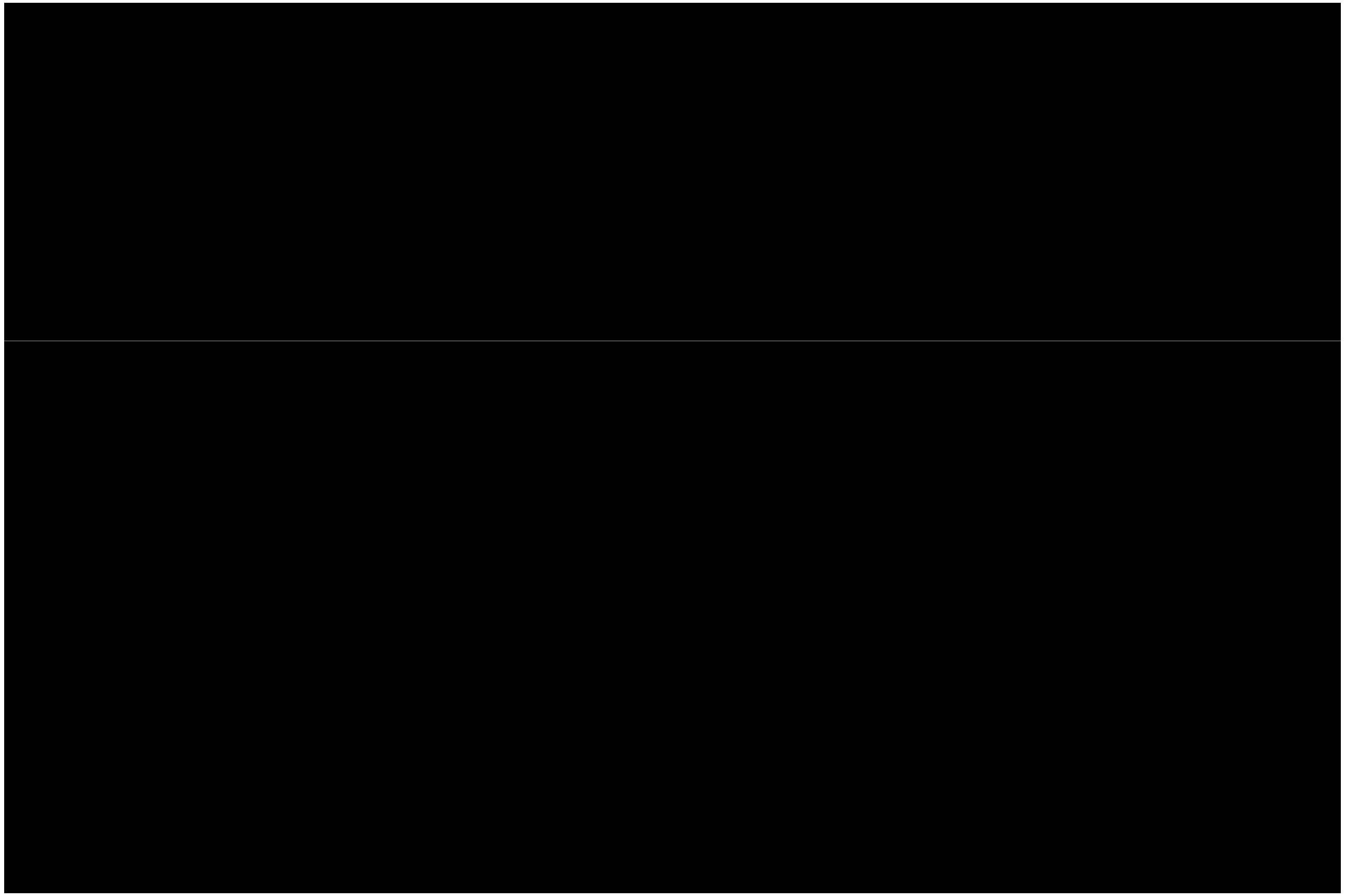
Chamfering and engraving of glass





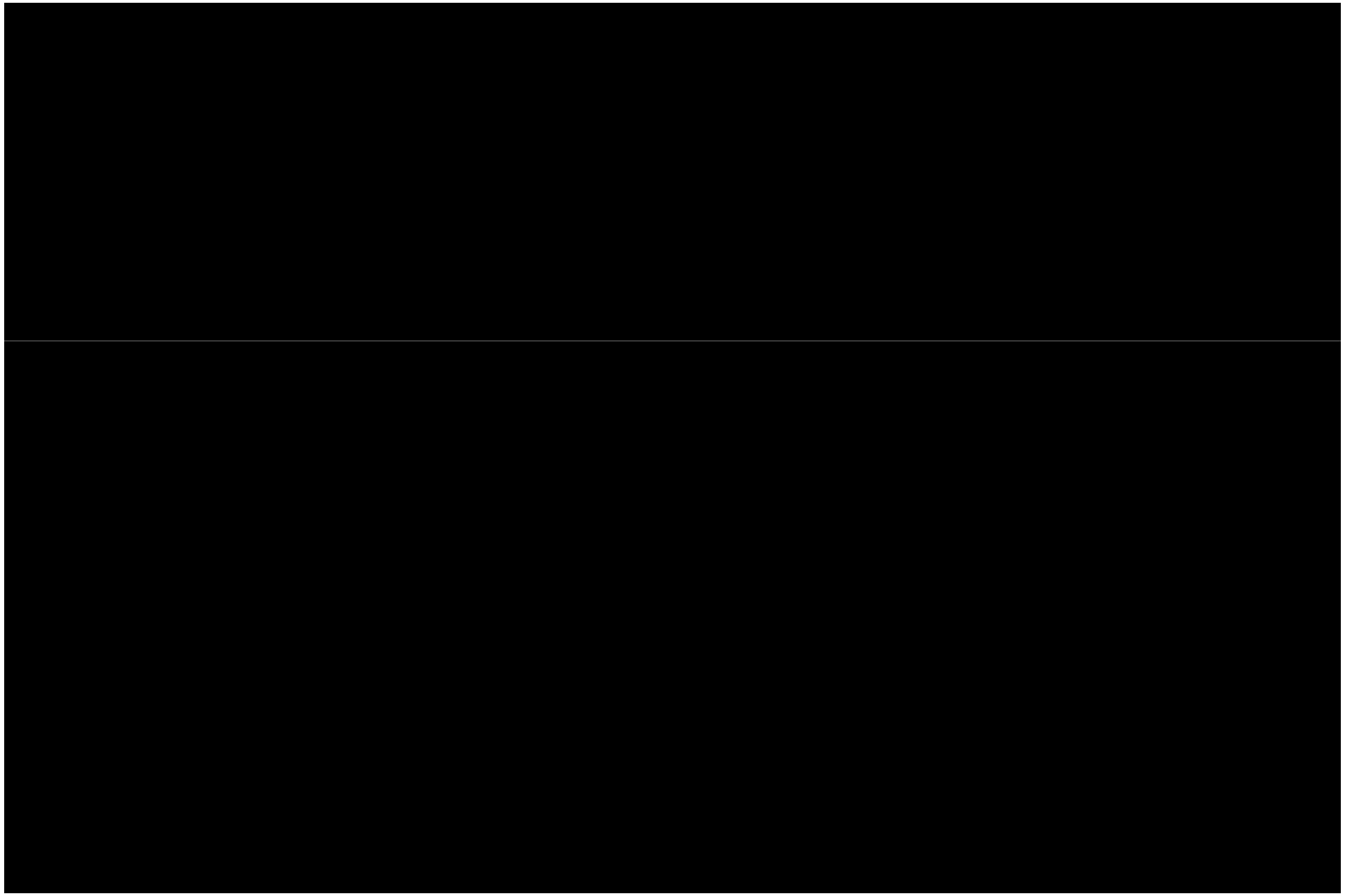
Painting/curing of glass plates

Animation of glass painting



Automatic RPC gap making

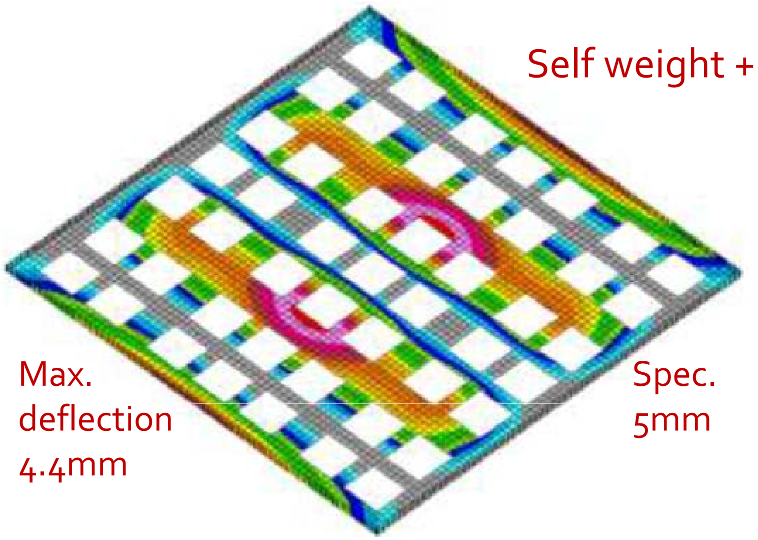
Animation of RPC gap fabrication



RPC holding tray

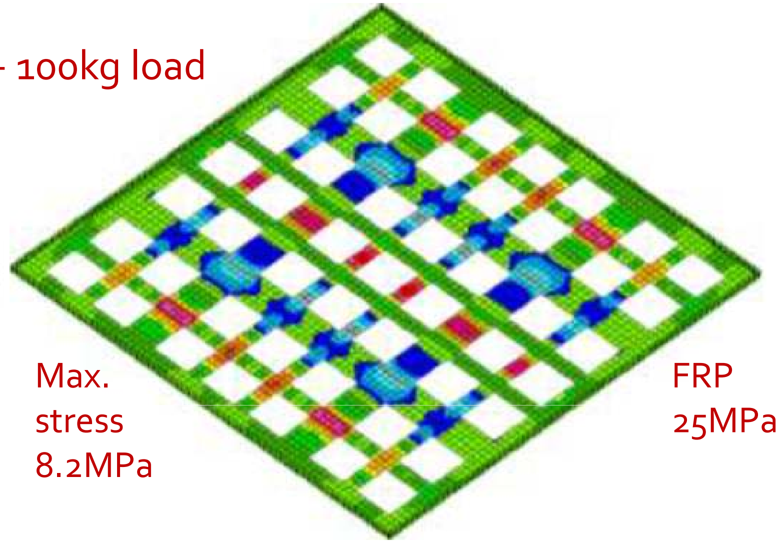
Finite Element Analysis

Self weight + 100kg load



Max. deflection 4.4mm

Spec. 5mm



Max. stress 8.2MPa

FRP 25MPa

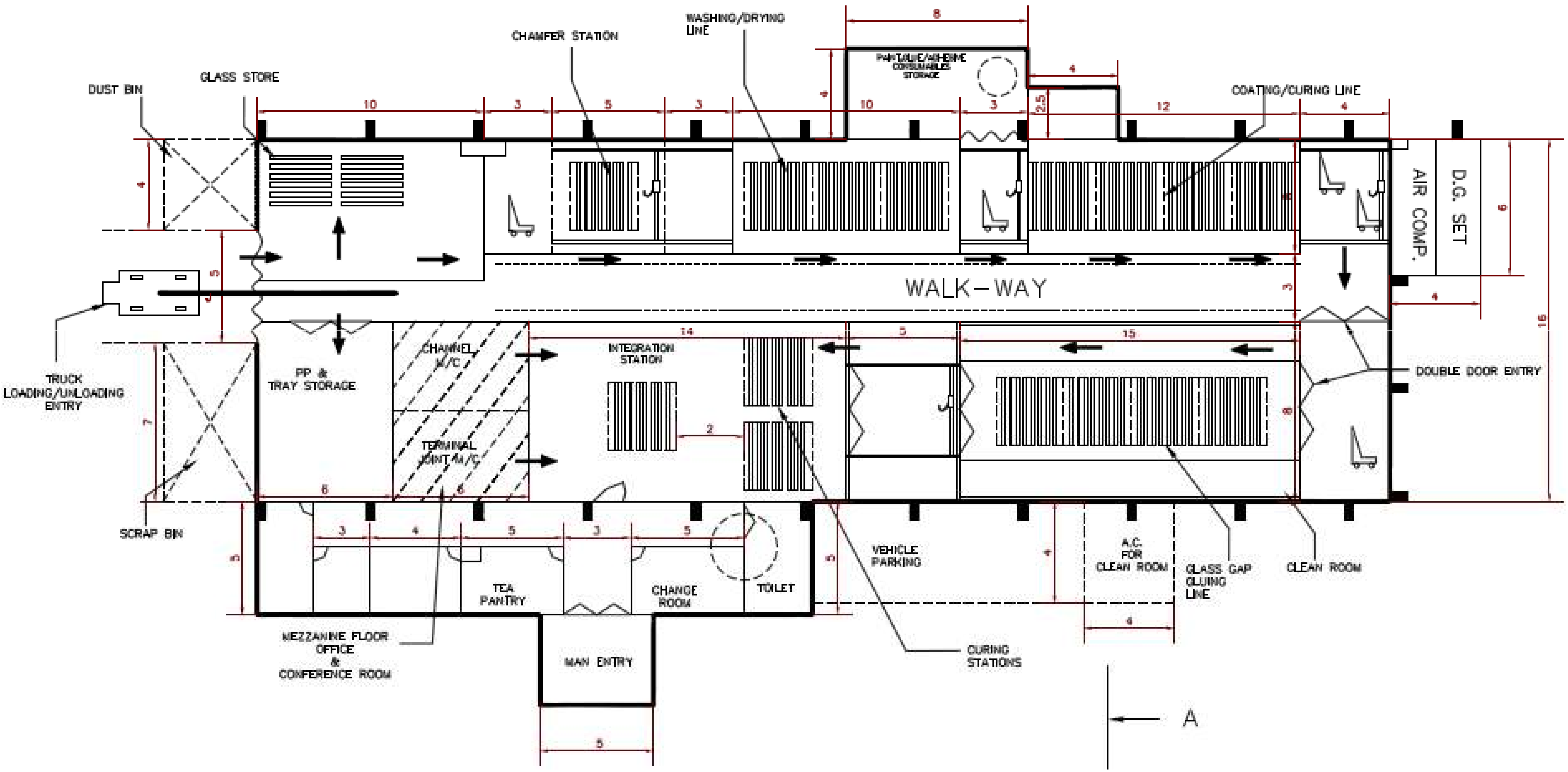
Extra thickness in selected sections

Fabricated tray

Down side view

Three-line support

RPC fabrication facility



Career opportunities in INO

- Research Scholars
  - Applicants must have a minimum qualification of M.Sc. degree in Physics or B.E./B.Tech. degree in any one of Electronics, E & CE, Instrumentation and Electrical Engineering subjects with strong motivation for and proficiency in Physics.
  - The selected candidates will be enrolled as Ph.D. students of the Homi Bhabha National Institute (HBNI), a Deemed to be University, with constituent institutions that include BARC, HRI, IGCAR, IMSc, SINP and VECC.
  - They will take up 1 year course work at TIFR, Mumbai in both theoretical and experimental high energy physics and necessary foundation courses specially designed to train people to be good experimental physicists.
  - Successful candidates after the course work will be attached to Ph.D. guides at various collaborating institutions for a Ph. D. degree in Physics on the basis of their INO related work.
- Career opportunities for bright engineers in Electronics, Instrumentation, Computer Science, Information technology, Civil, Mechanical and Electrical engineers

Current status

- RPC detector R&D concluded quite a while ago. The RPC stacks are being used even for some physics studies.
- Scaling up and industrial adaptation of lab technology – by an industry, is almost complete.
- Extensive vendor development for material fabrication, process development, design of SPMs and for large scale production of RPCs.
- Overall electronics scheme finalised
- ASICs are being validated on the detector
- Electronic boards are being designed and prototyped
- FPGAs, other components, cables and connectors are being finalised and procured

Closing remarks

- INO is an exciting mega basic science project
- It is being planned on an unprecedented scale and budget
- ICAL and other experiments will produce highly competitive physics
- Beyond neutrino physics, INO is going to be an invaluable facility for many future experiments
- It provides wonderful opportunities for science and engineering professionals and students
- Detector and instrumentation R&D, scientific human resource development are INO's major trust areas
- It offers a large number of engineering challenges and many spin-offs such as medical applications

Thank you

- To the organisers of the Winter School on High Energy Physics - Prof. Venktesh Singh in particular, for giving me this wonderful opportunity to share the excitement of building this unique mega science project.
- To you all for your kind attention.

Backup slides

5.1 Concrete Foundation for Detector

5.1.1 ICAL detector structure consists of three detector modules, each of size 17.140 m × 16.015 m × 14.40 m. The assembly of the three modules in the longitudinal direction will form the combined detector of size (51.420 m× 16.015 m × 14.4 m). The horizontal distance between the vertical edges of the adjacent detector modules will be 200 mm.

5.1.2 ICAL detector structure assembly will be constructed in the underground cavern at proposed PUSHEP site having size of 26 m width, 132 m length and clear height of about 20 m under the EOT 25/5 T Crane. The portion of width of 5 m on both side of detector module assembly shall be kept for walkway on side of detector structure as well as RPC handling crane structure, which moves on cart rail along the longitudinal direction of cavern.

5.1.3 ICAL Detector Structure consists of 150 layers of 56 mm thick low carbon steel detector plates (4 m × 2 m),magnetic coils (625 mm × 80 mm) and other fixtures for supporting gas lines, wires, teflon guides for RPC Trays, etc. Each layer of detector plates is separated through 40 mm thick SS304 spacers.

5.1.4 The bottom layer of the detector plates is supported on the base plates provided on the discrete concrete pedestals. The magnetic coils are also supported on the SS304 mounting brackets fixed on the coil supporting concrete pedestals. The construction details of the concrete pedestals are as given below (Refer Drg. No. TCE-5352A-853-RC-6001).

5.1.5 The Detector structure is supported on 81 nos. of concrete pedestals. Each pedestal is provided with 40 mm thick MS base plates. The height of each pedestal is 900 mm.

5.1.6 The Concrete pedestals supporting the detector stack are categorized into following four categories based on the location in the detector modules as well as supporting arrangement of detector plates.

a) Corner Pedestals (900 mm × 650 mm)
b) Edge Pedestals along the longitudinal direction (700 mm × 650 mm)
c) Edge Pedestals along the lateral direction (900 mm × 700 mm)
d) Inner Pedestals (700 mm × 700 mm)

5.1.7 In addition to detector plate supporting pedestals, 8 nos. of separate pedestals are provided for mounting 4 nos. of magnetic coils in the central 8 m × 8 m portion with spacing of 1 m.

5.1.8 The dimensions of the corner as well as edge pedestals as indicated in section 5.1.6 above will enable to accommodate the adjacent detector modules to have a clear gap of 200 mm between their vertical edges.

5.1.9 Common concrete pedestal strip between adjacent detector modules comprising 2 corner pedestals & 7 edge pedestals along lateral direction together forms the 9 nos. of concrete pedestals on the edge grid of ICAL detector structure module.

ICAL detector construction

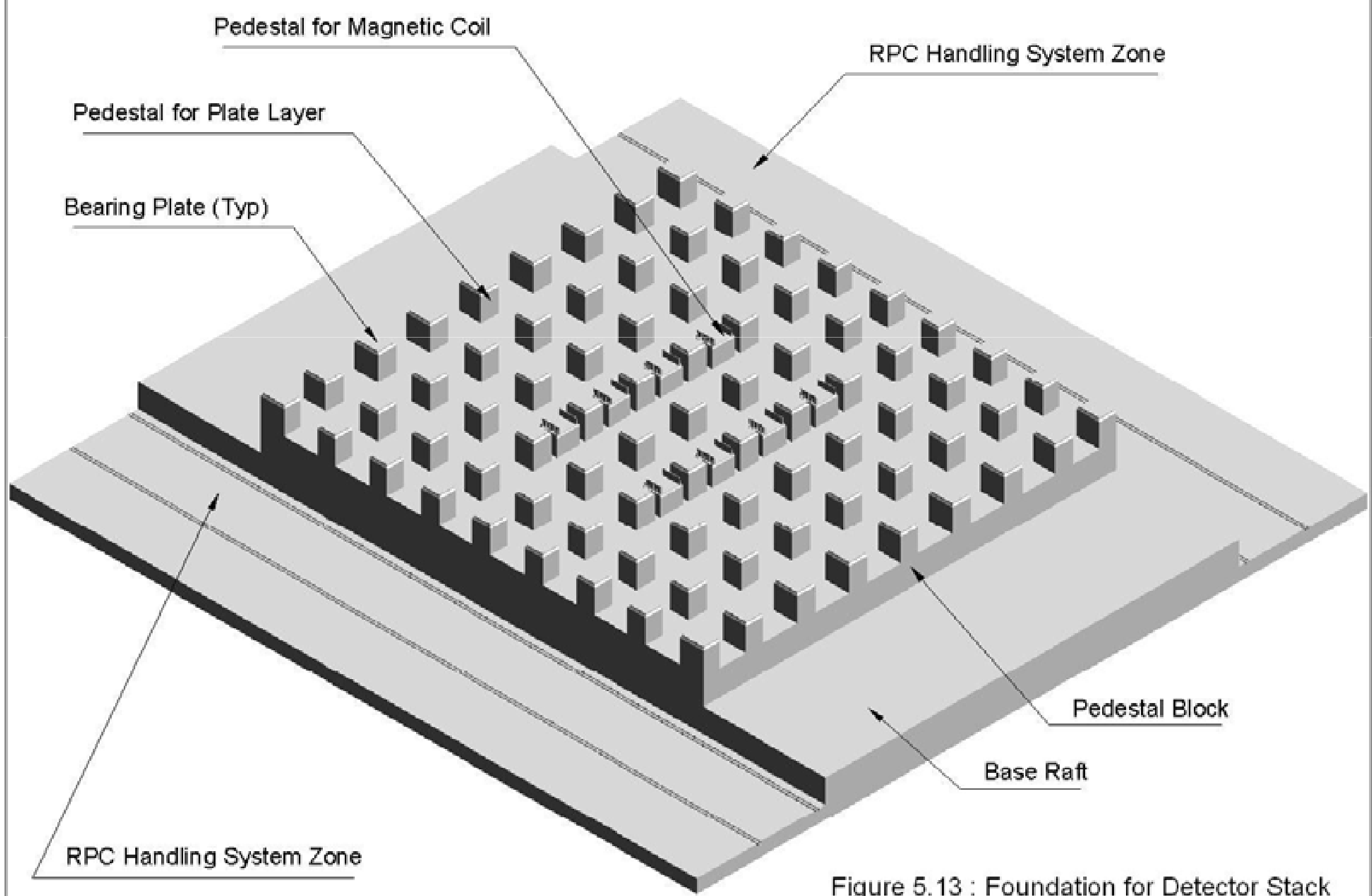


Figure 5.13 : Foundation for Detector Stack
(Typical Module is shown)

ICAL detector construction

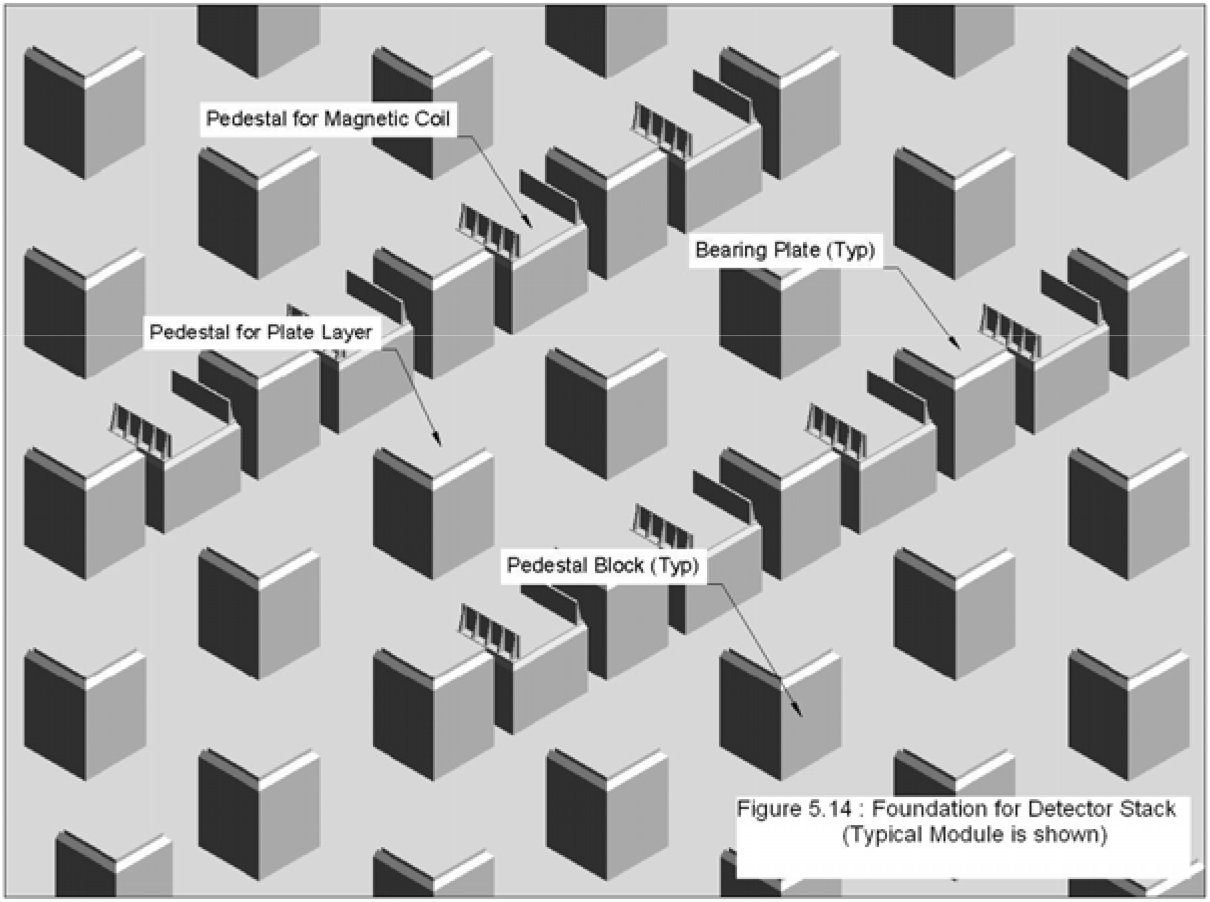
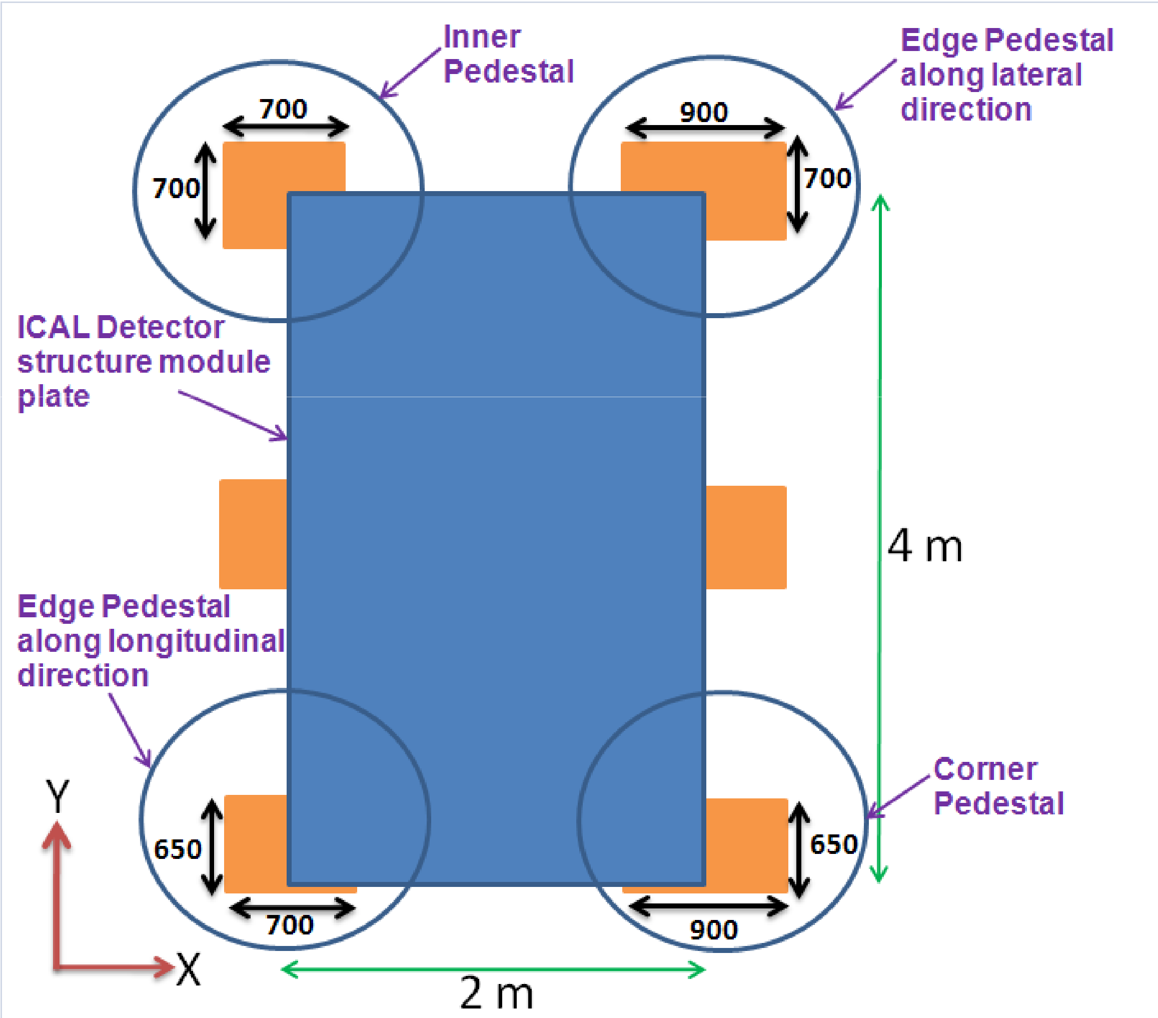
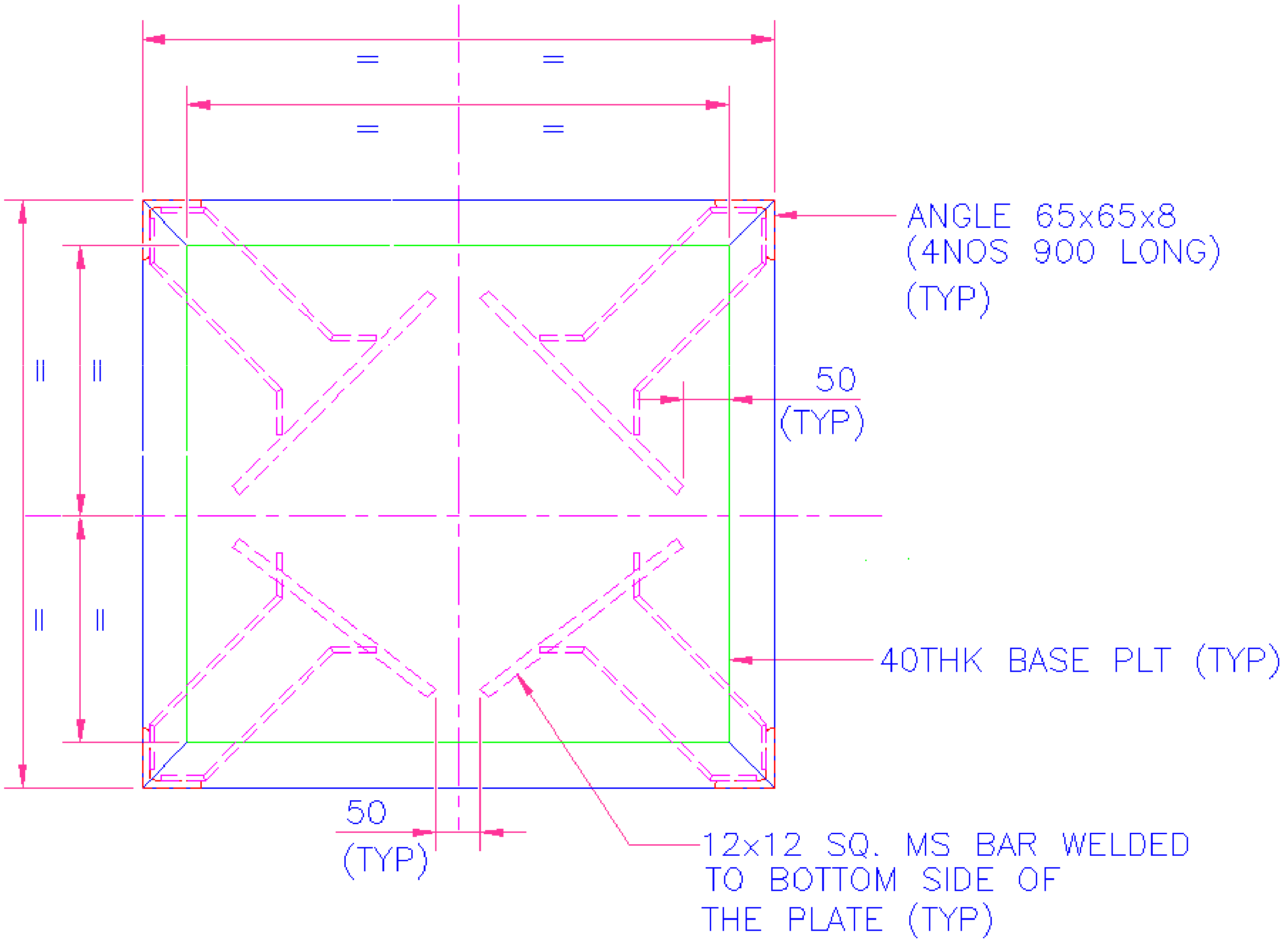


Figure 5.14 : Foundation for Detector Stack (Typical Module is shown)

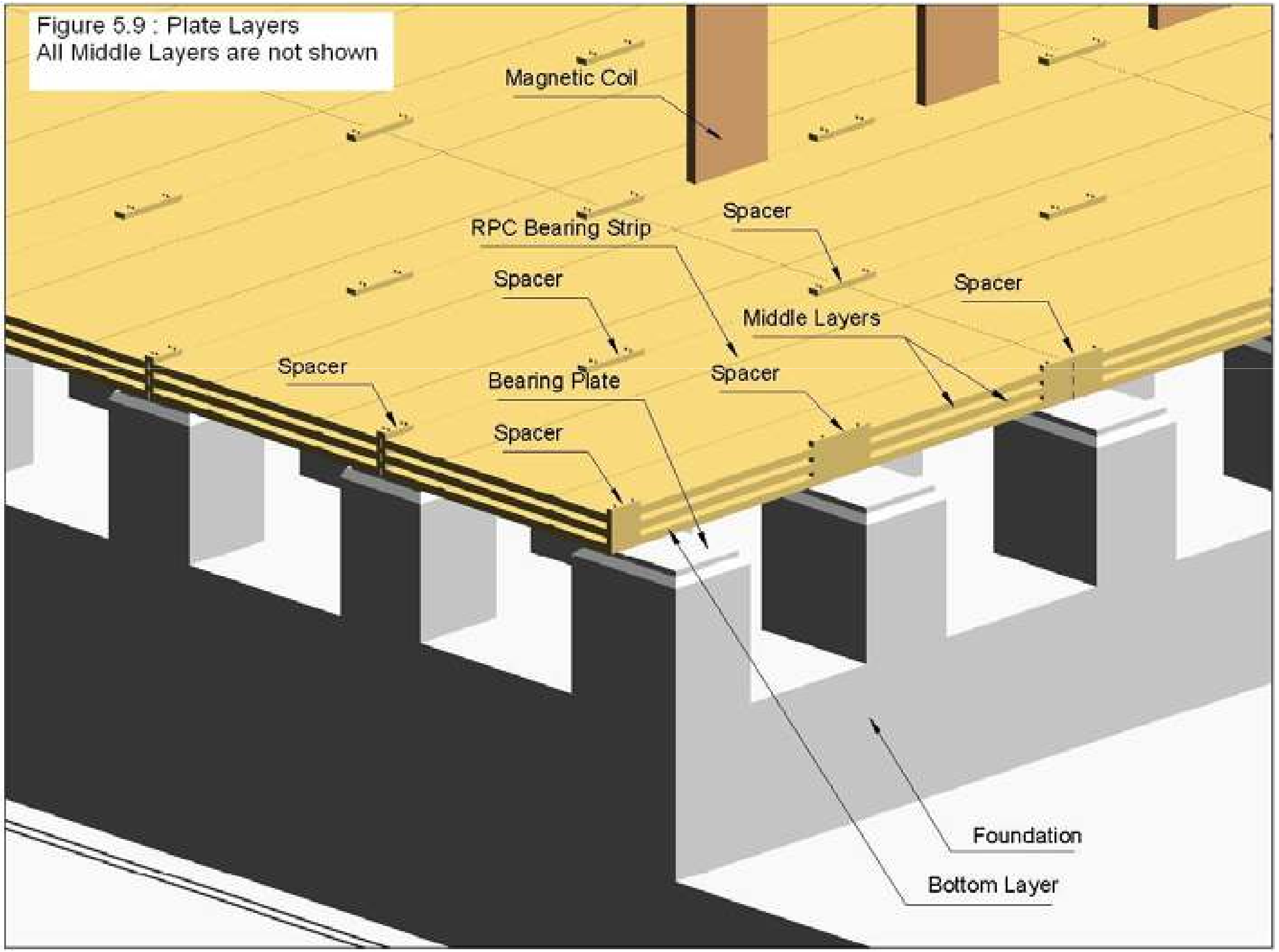
ICAL detector construction



ICAL detector construction



ICAL detector construction



ICAL detector construction

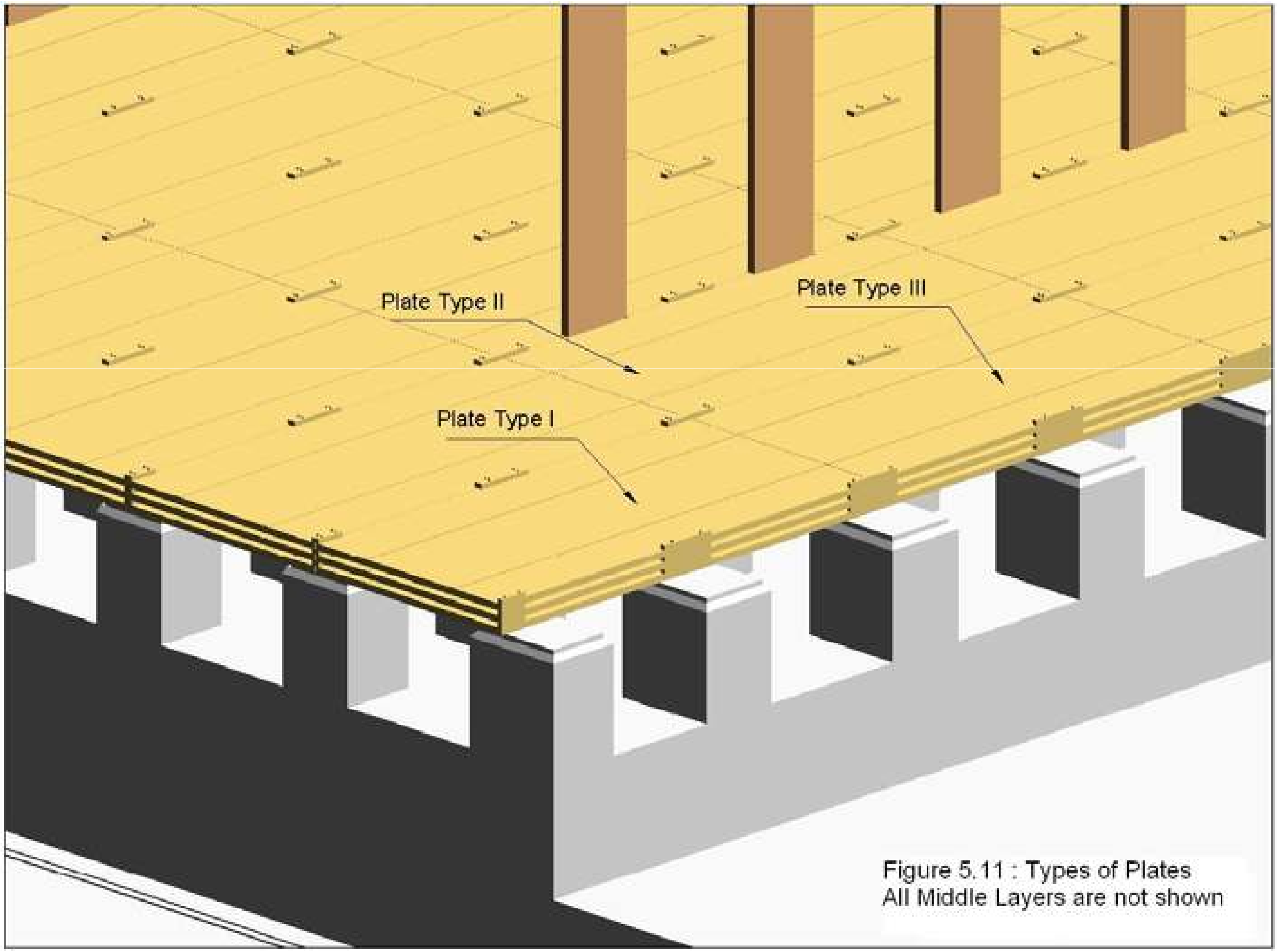
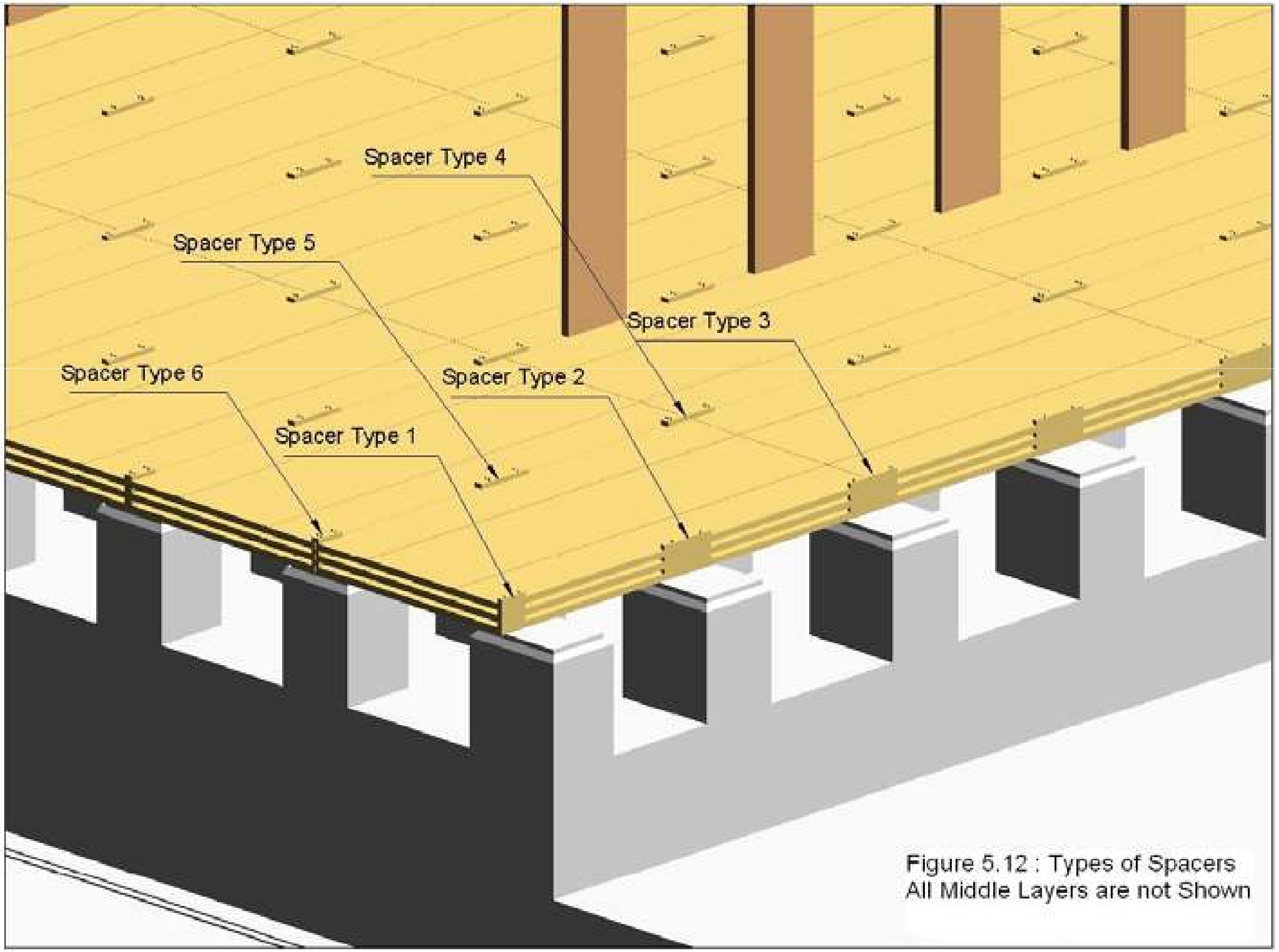
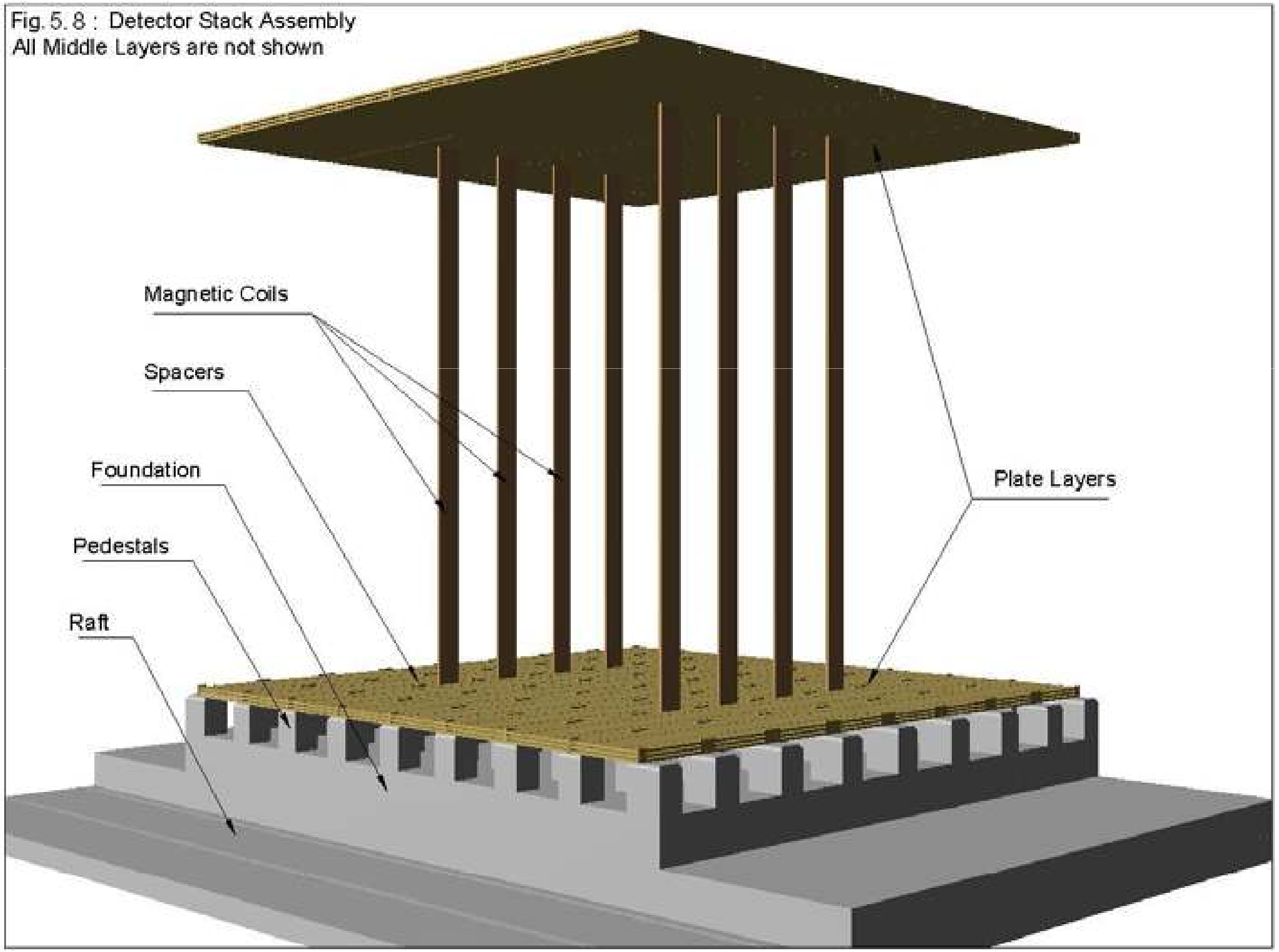


Figure 5.11 : Types of Plates
All Middle Layers are not shown

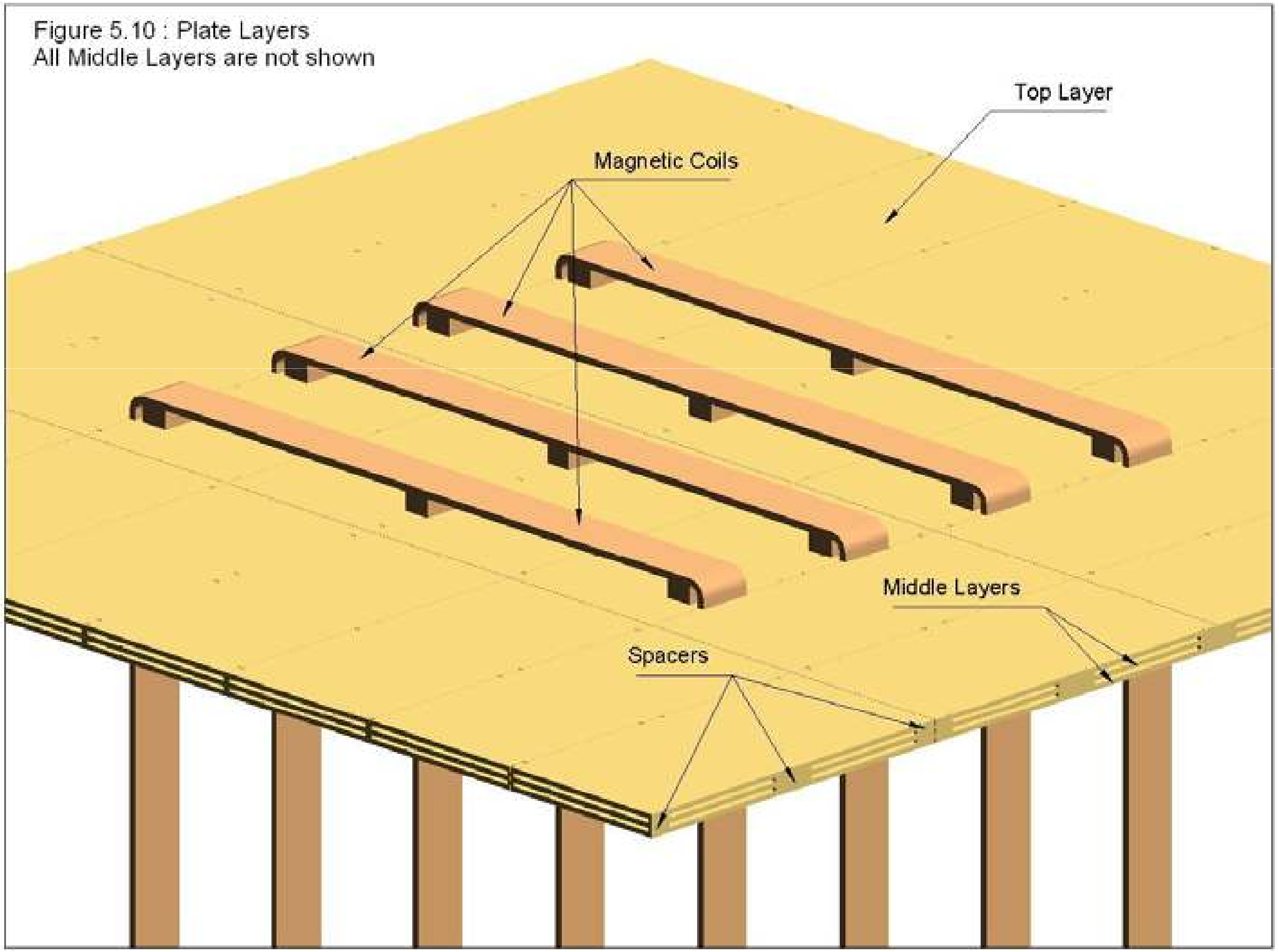
ICAL detector construction



ICAL detector construction



ICAL detector construction



ICAL detector construction