Making of Detectors

सत्यमेव जयते
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Radiation Detection

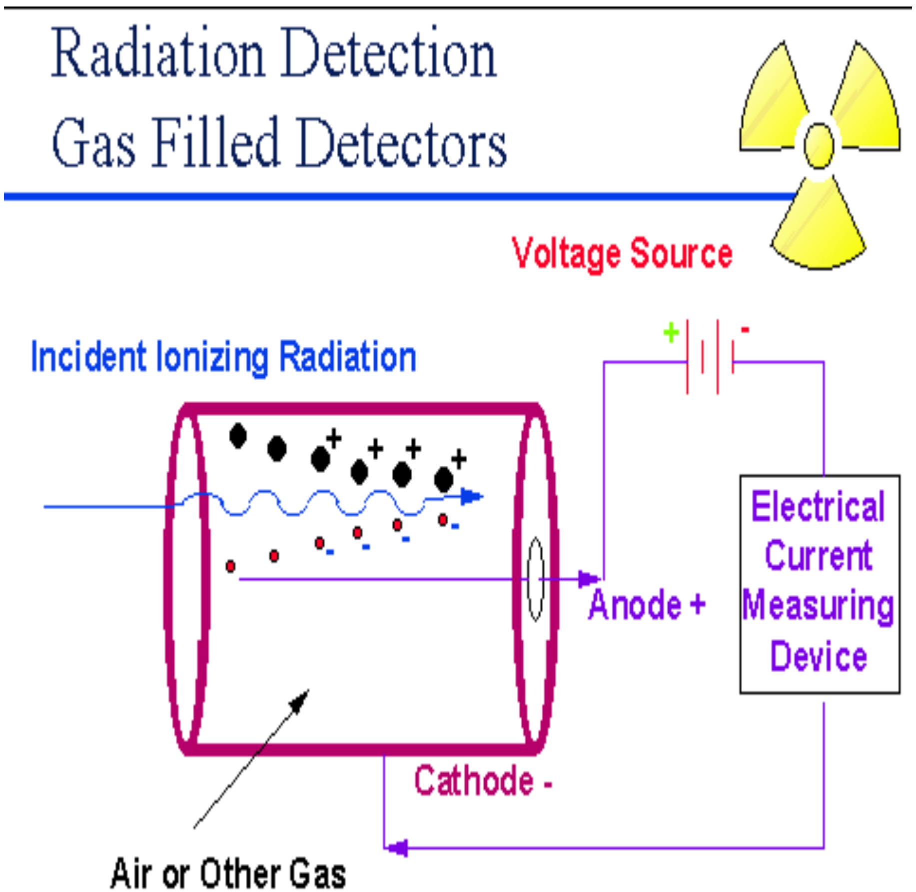
- Basic operation principles of different types of radiation detectors
- Physical processes underlying the principles of operation of these devices
- Comparing and selecting instrumentation best suited for different applications

Classification

- Gas-Filled Detectors
- Scintillation Detectors
- Solid State Detectors

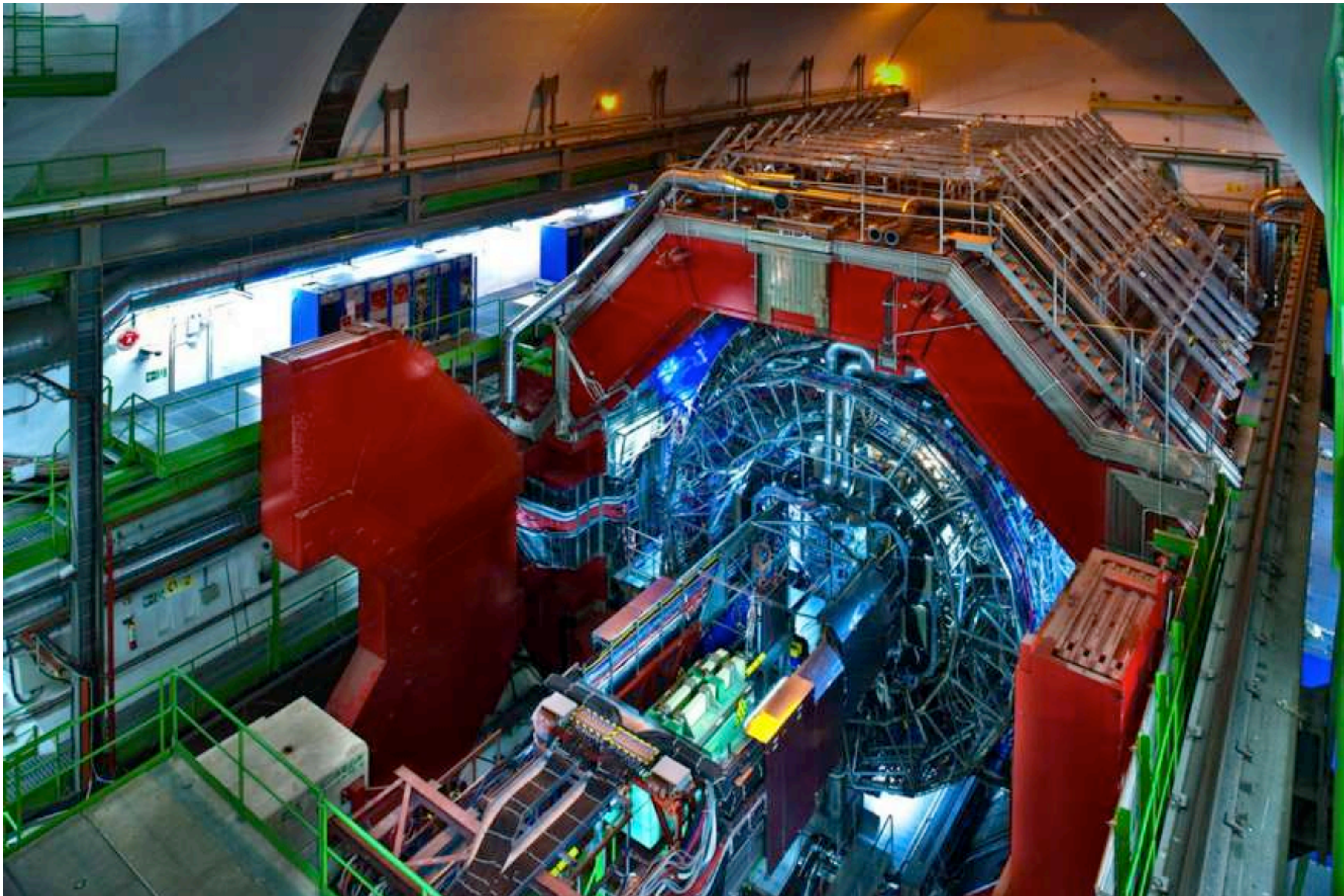
Gas filled detectors

Basic principle of Gaseous Detectors



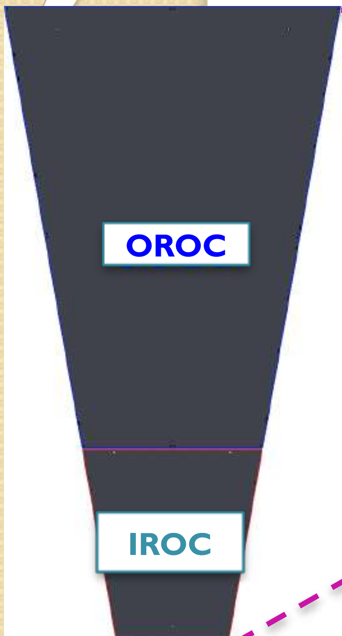
- ***Primary ionisation:*** An incident particle ionizes atoms /molecules.
- ***Secondary ionisation:*** The electron kicked out of the atom gains kinetic energy under the applied electric field and ionizes other atoms on its way.
- ***Avalanche:*** The process continues and suddenly a large number of electrons are freed and they travel towards the anode.
- ***Signal:*** When these electrons reach the anode, a signal is obtained.

ALICE detector



ALICE TPC

2 x 18
Outer **R**ead **O**ut **C**hambers

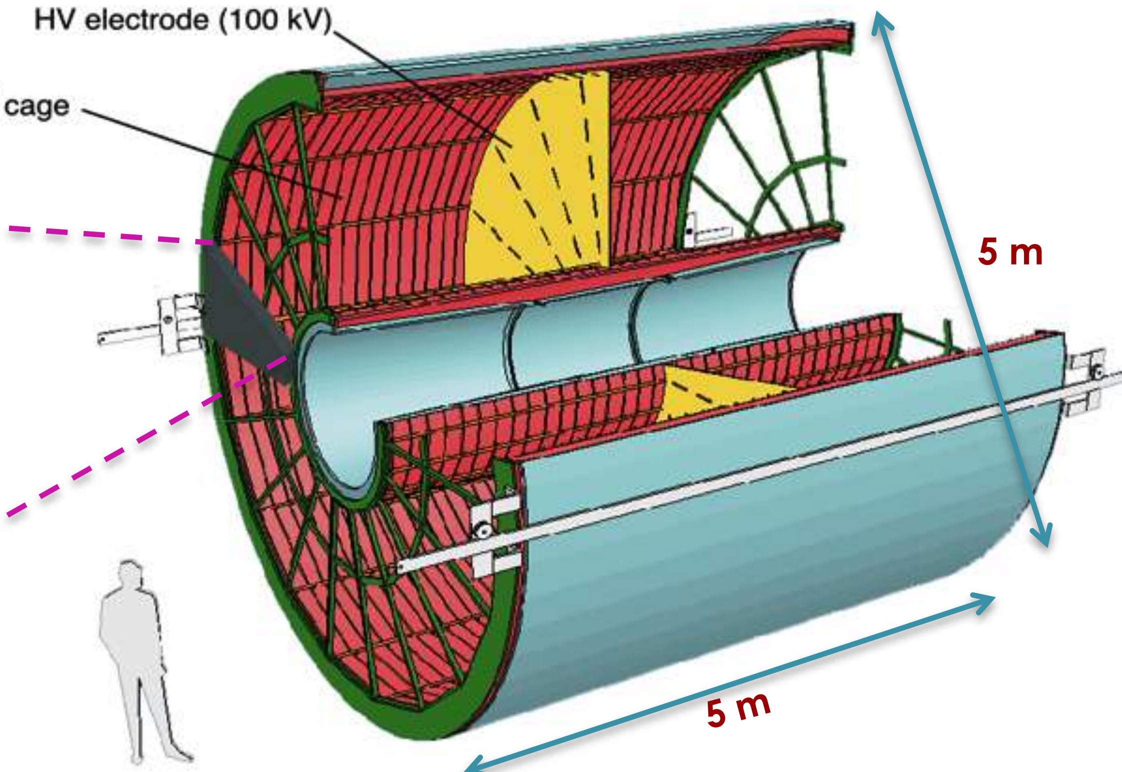


2 x 18
Inner **R**ead **O**ut **C**hambers

557568 pads

4 x 7.5 mm^2 (IROC)
6 x 10 mm^2 (OROC)
6 x 15 mm^2 (OROC)

Drift field: 400 V/cm

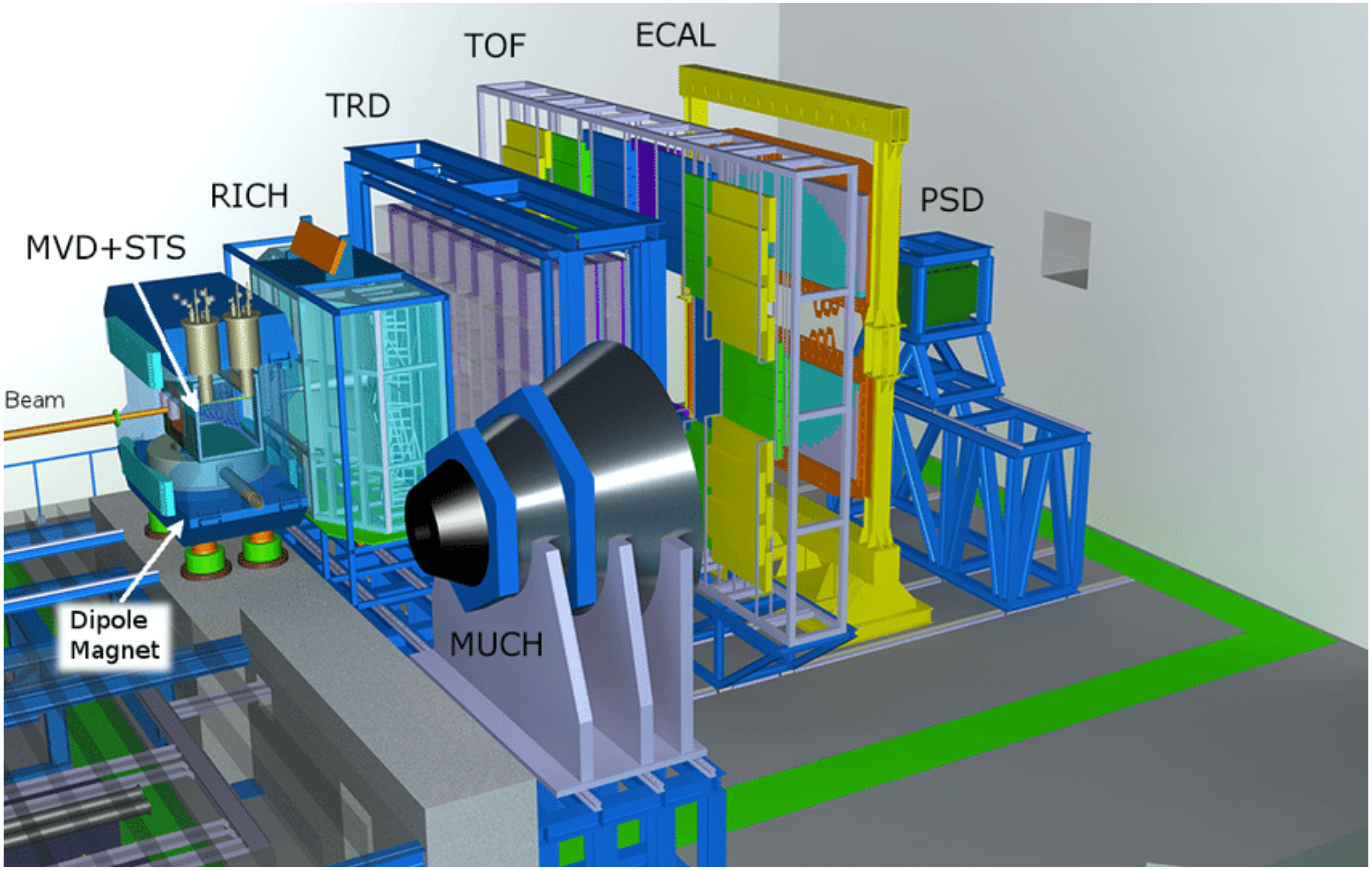


GAS:
~90 m^3
Ne-CO_2 (90-10) in RUN1
v_{drift} = 2.73 cm/μs (@ 400 V/cm)
Maximum drift time: ~92 μs

- Designed for charged-particle tracking and d*E*/dx measurement in Pb-Pb collisions with **$dN_{ch}/d\eta$=8000, σ(d*E*/dx)/(d*E*/dx)<10%**

- Employs gating grid to block backdrifting ions
- Rate limitations: < 3.5 kHz (in p-p), ~500 Hz (in Pb-Pb)

CBM Experimental set-up

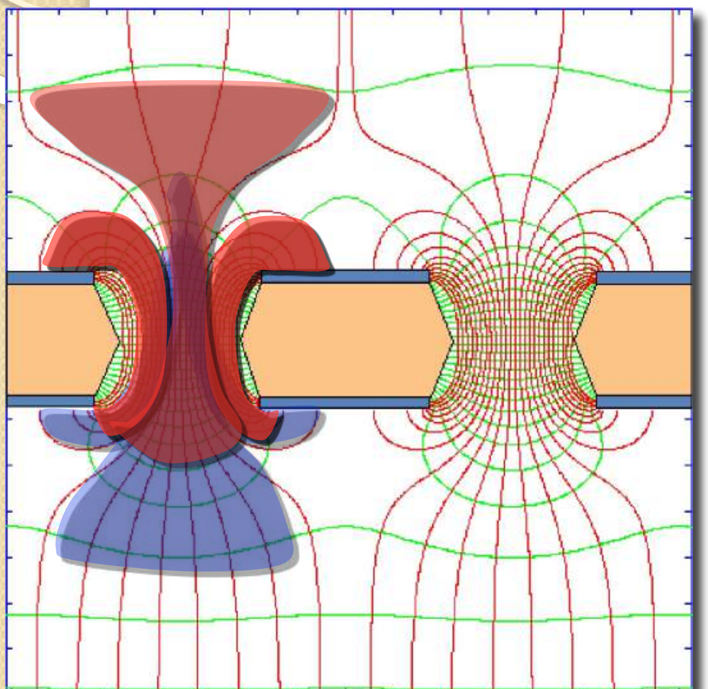


Schematic diagram of the Compressed Baryonic Matter (CBM) experiment

GEM

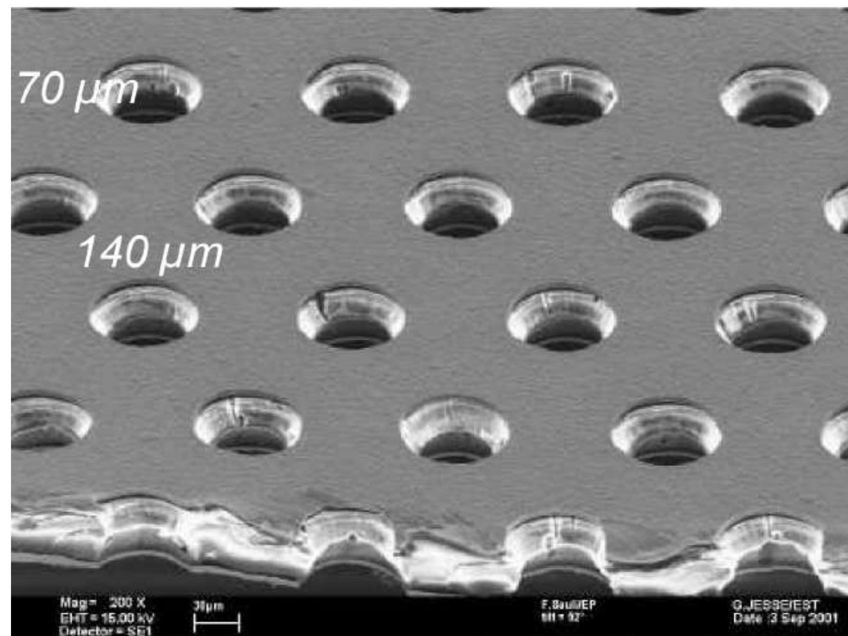
GAS ELECTRON MULTIPLIER (GEM):

THIN METAL-COATED POLYMER FOIL CHEMICALLY ETCHED WITH 50÷100 HOLES/mm²



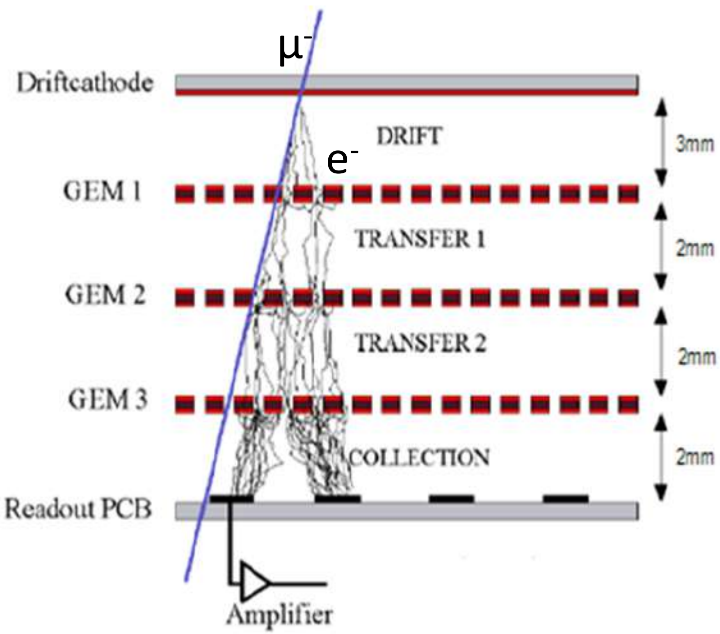
STANDARD GEM:

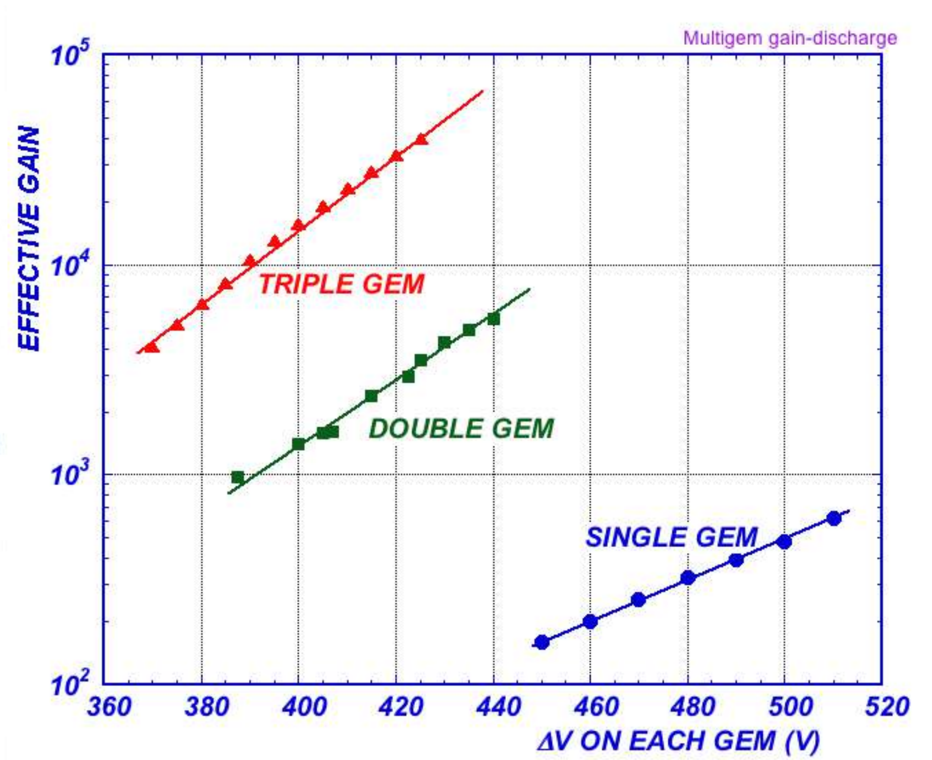
50 μm Kapton
5 μm Copper
70 μm holes at 140 μm pitch



F. Sauli,
Nucl. Instr. and Meth. A386(1997)531

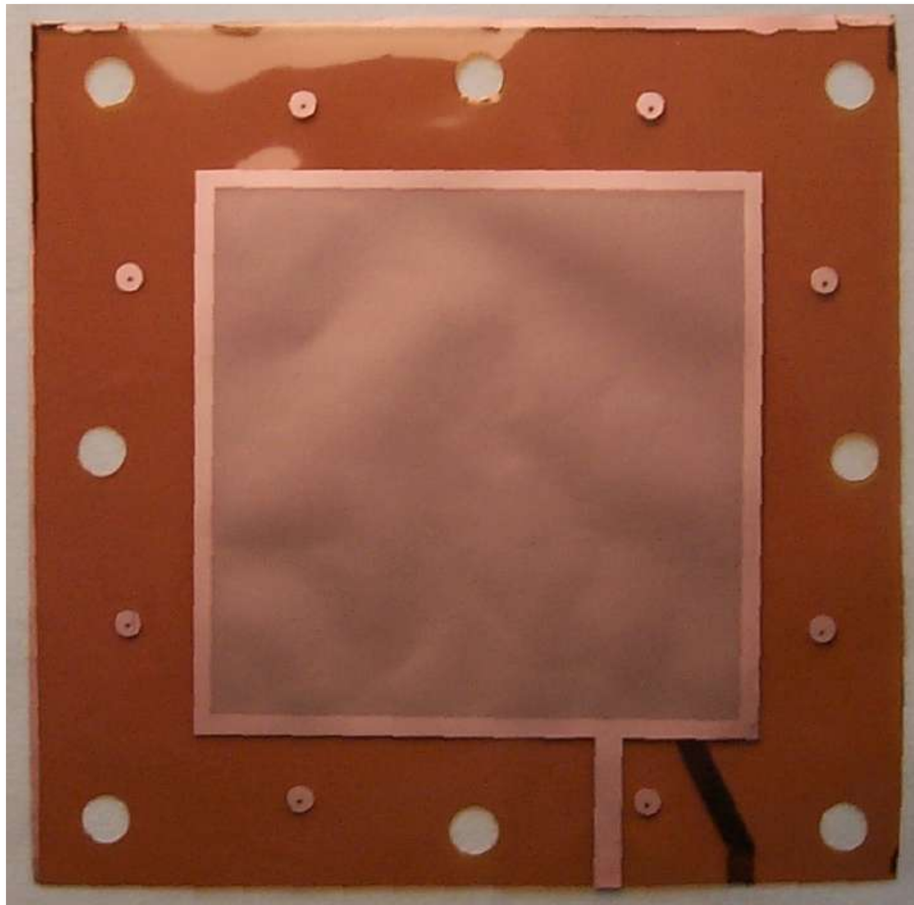
MULTIPLE CASCADED GEM DETECTORS:





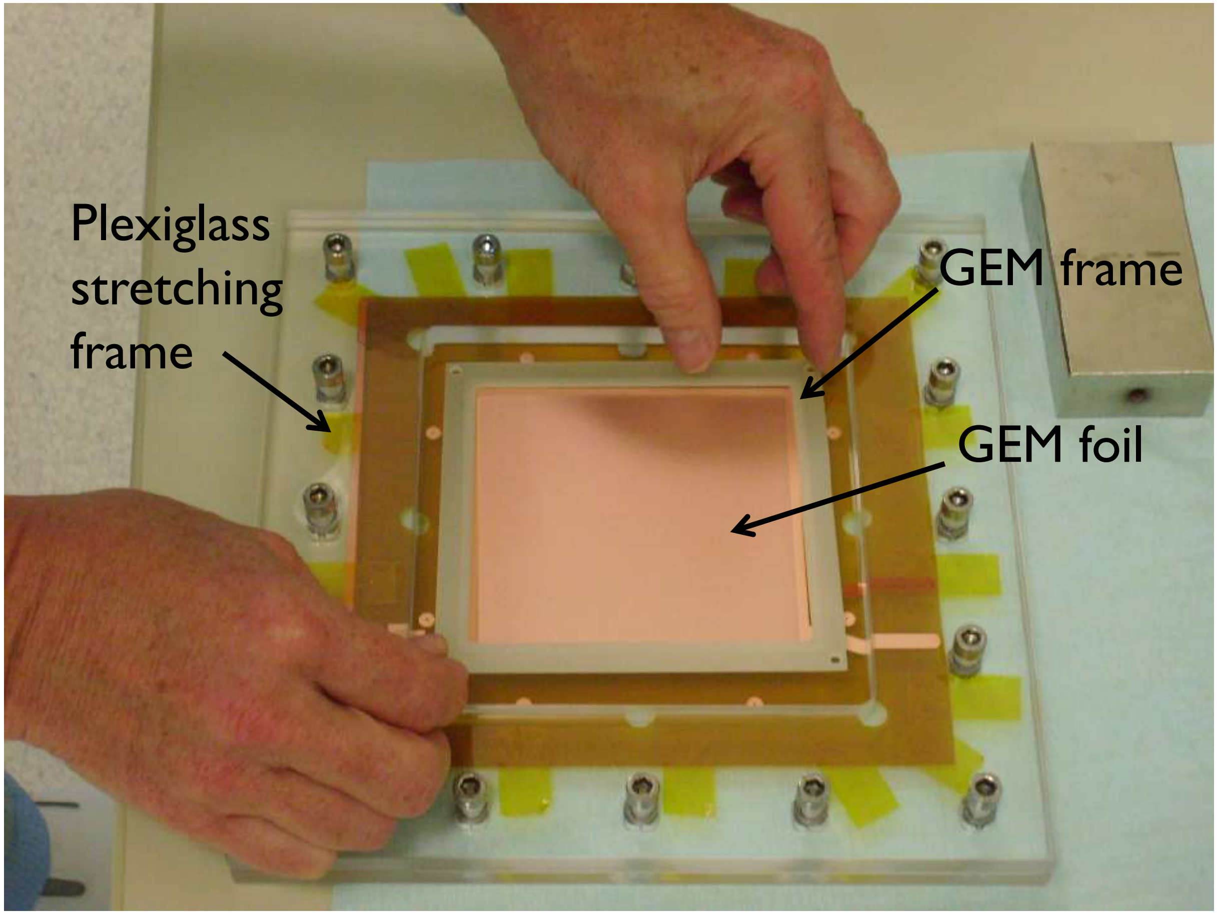
S. Bachmann et al, Nucl. Instr. and Meth. A479(2002)294

GEM FOIL



STANDARD SMALL GEM: 10x10 cm²

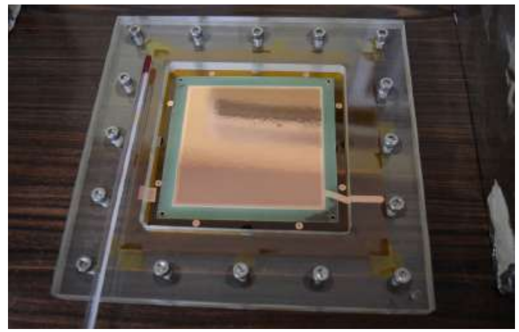
Stretching frame



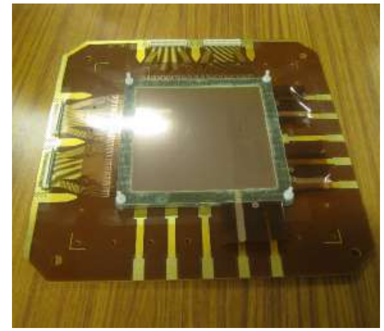
Components used in fabrication of a triple GEM detector

Building of a GEM detector

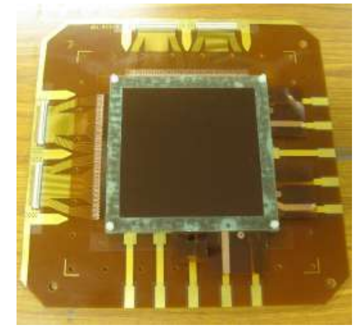
GEM FOIL



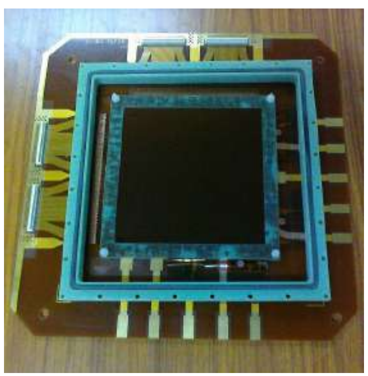
Stretching



GEM foils on Read-out plane

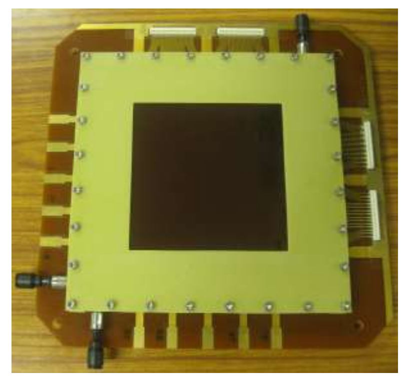


Drift plane is placed

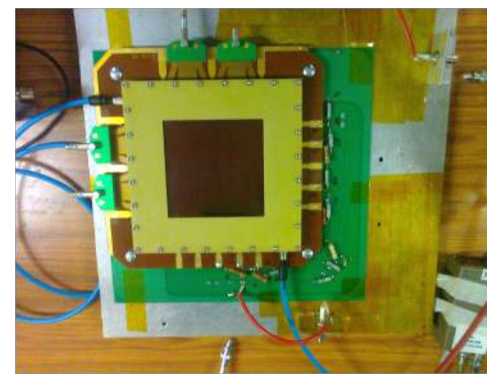


Frame is placed with O-ring

Gluing at the bottom



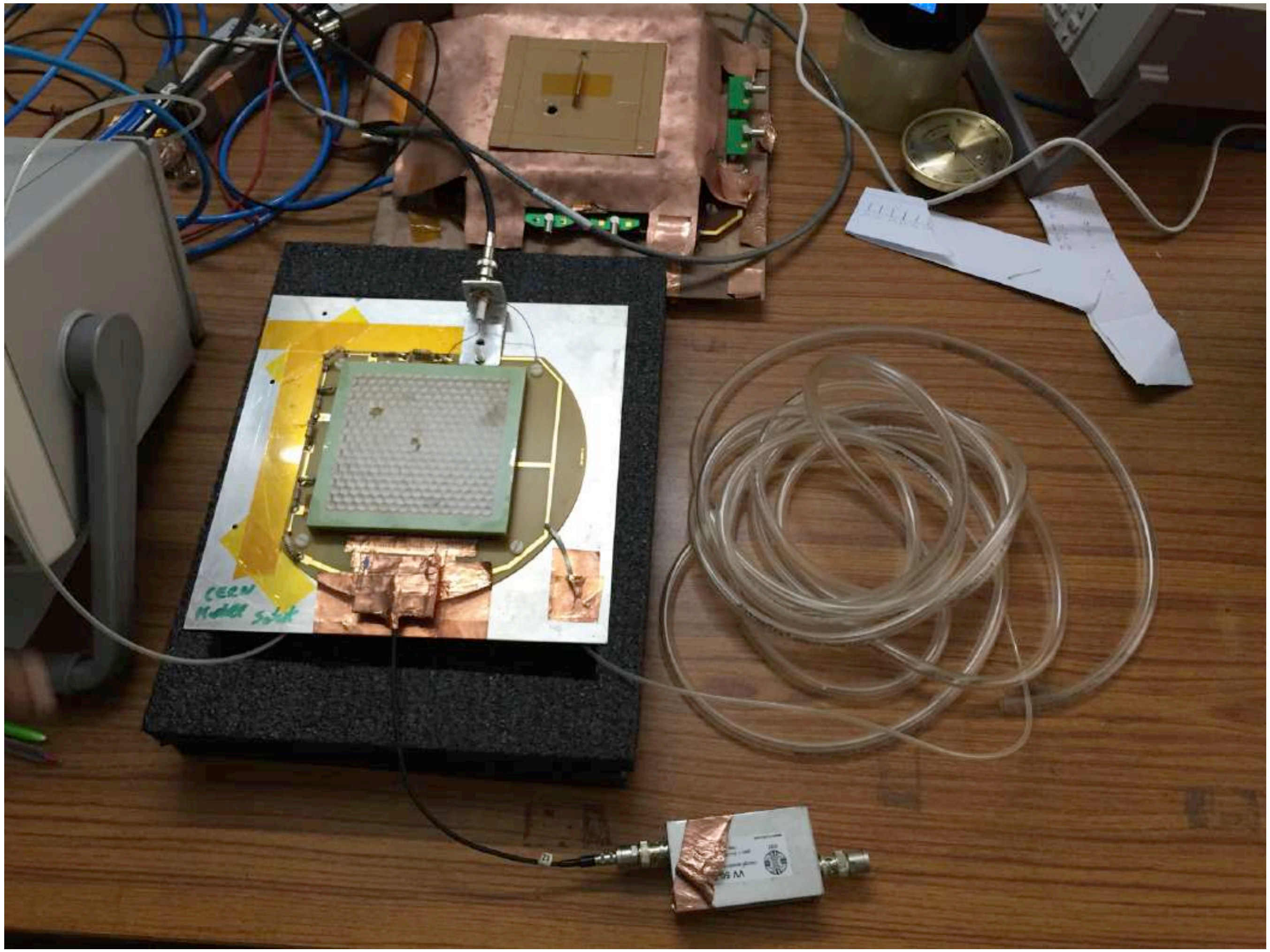
Assembled GEM



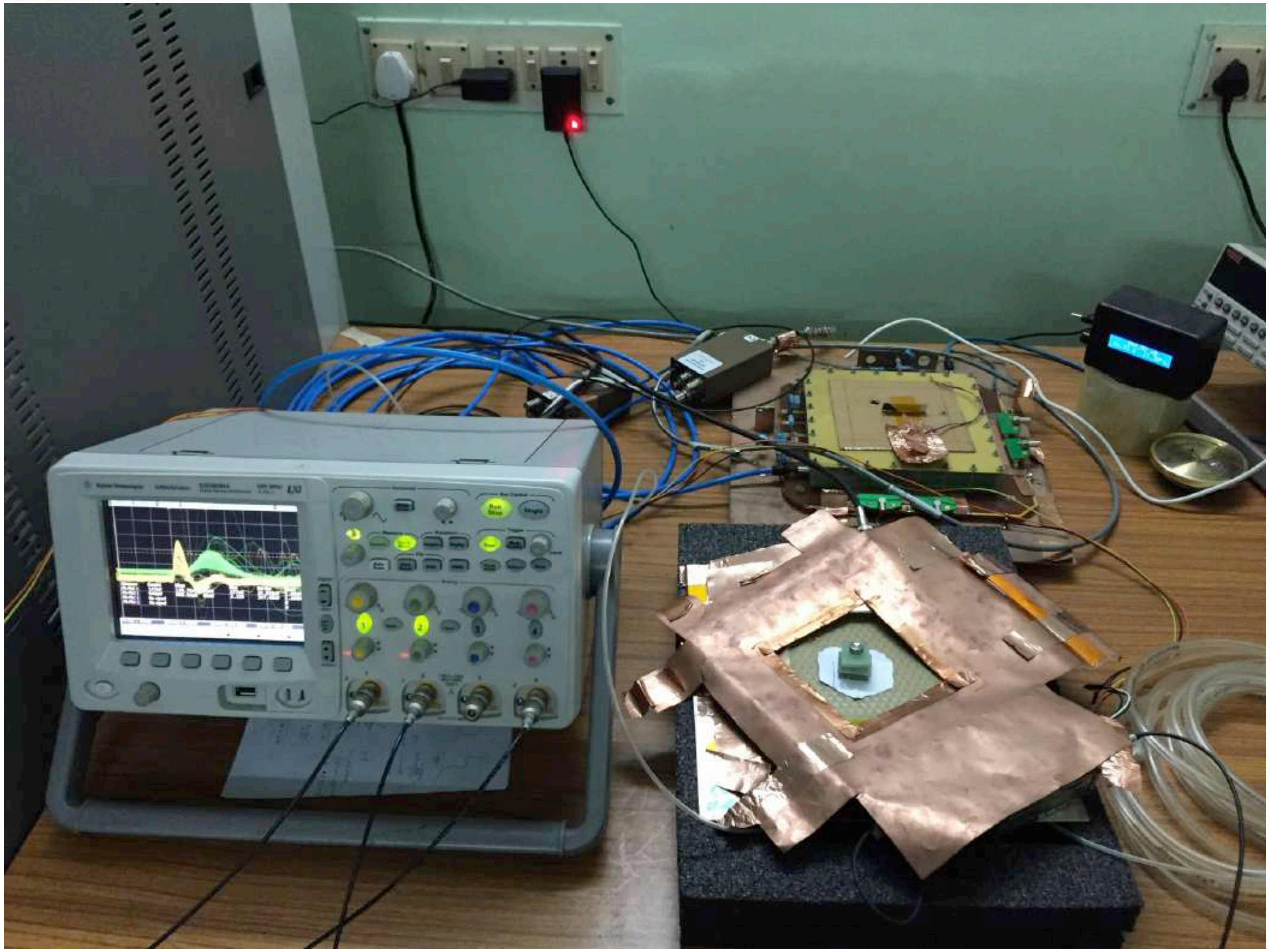
Completely assembled GEM with HV-divider and gas-flow inlet and outlet

Set-up at Bose Institute

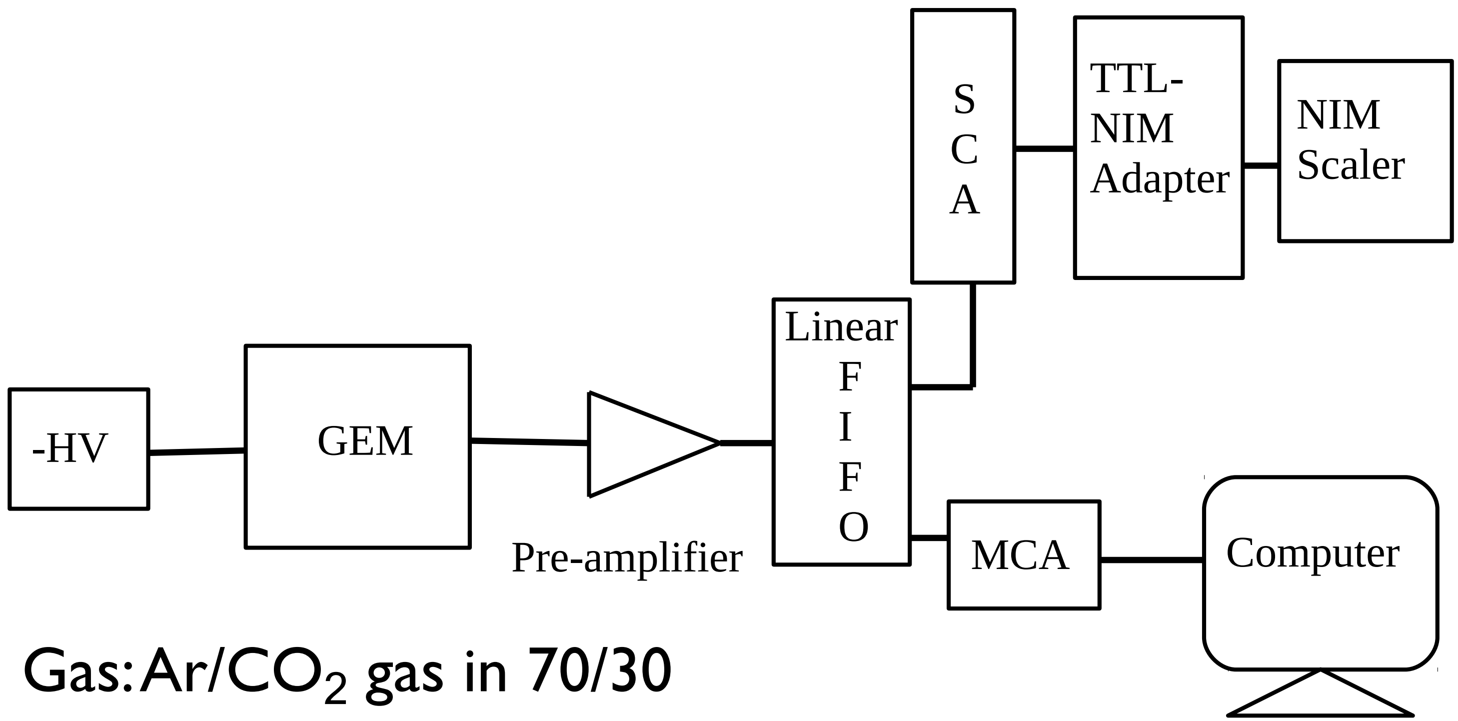
Triple GEM detector



Triple GEM detector

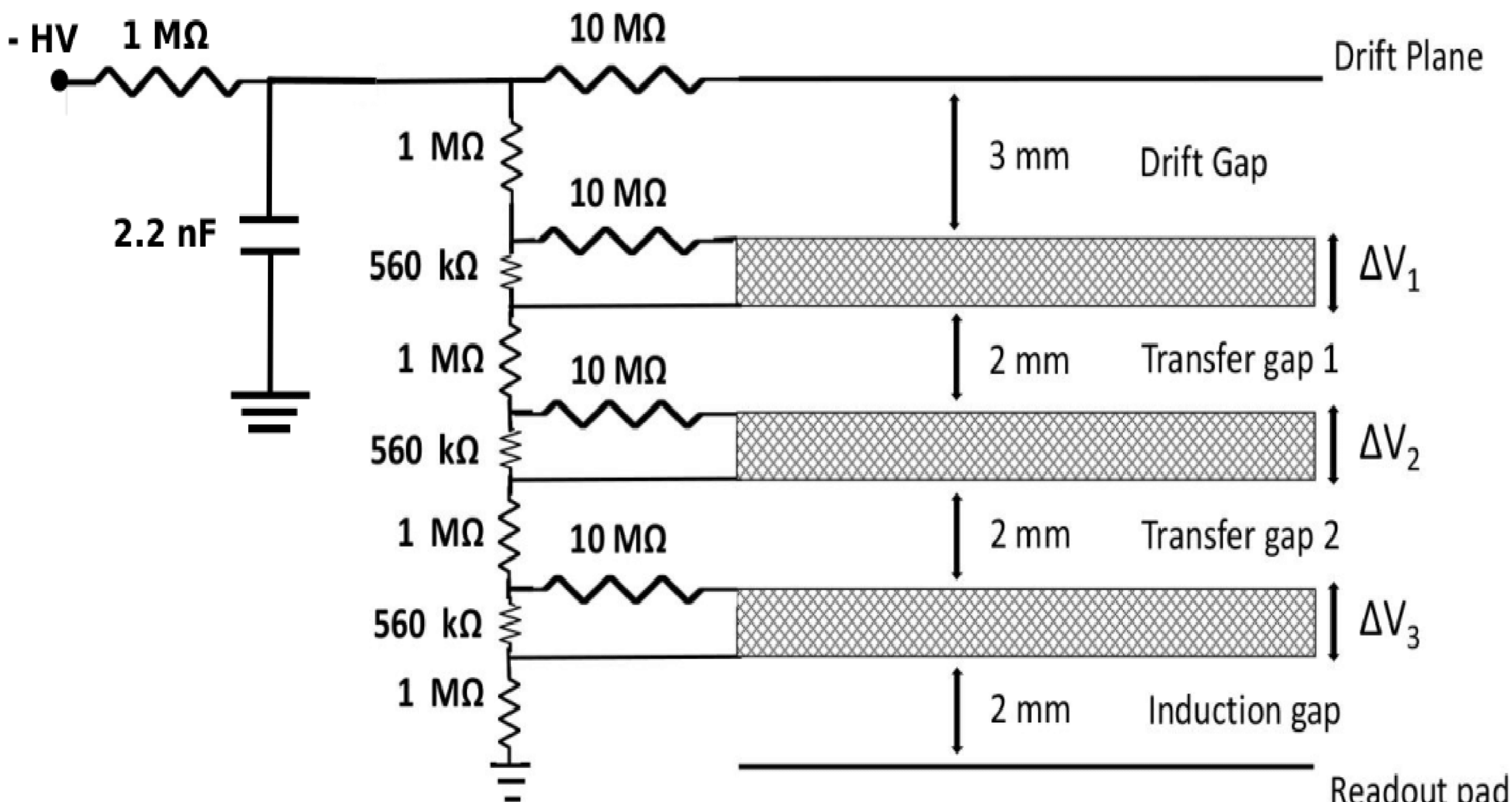


Schematic representation of the electronics setup

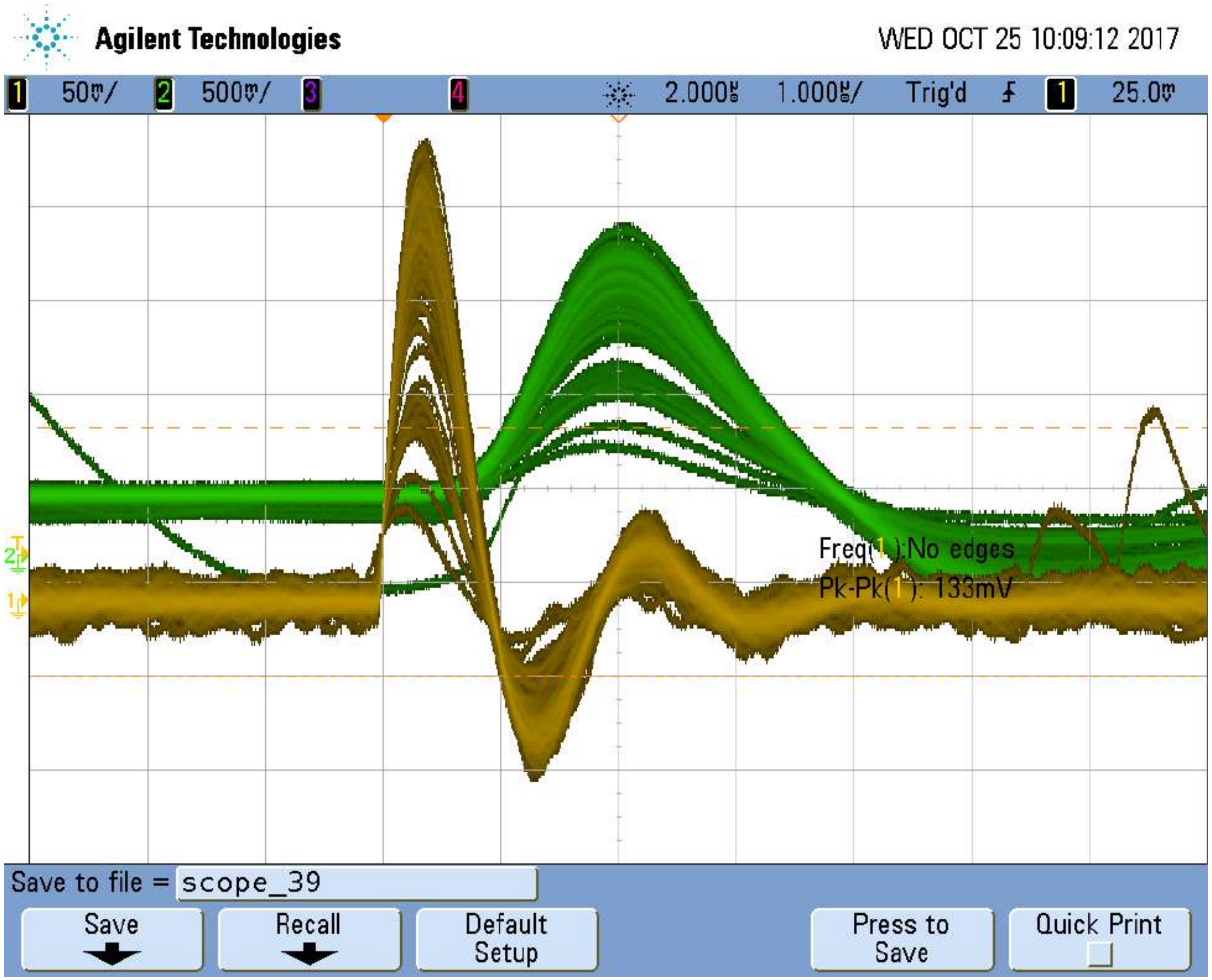


- Gas: Ar/CO_2 gas in 70/30
- Flow rate: 3 lt/hr
- Conventional NIM electronics
- Pre-amplifier: VV 50-2 (Heidelberg)

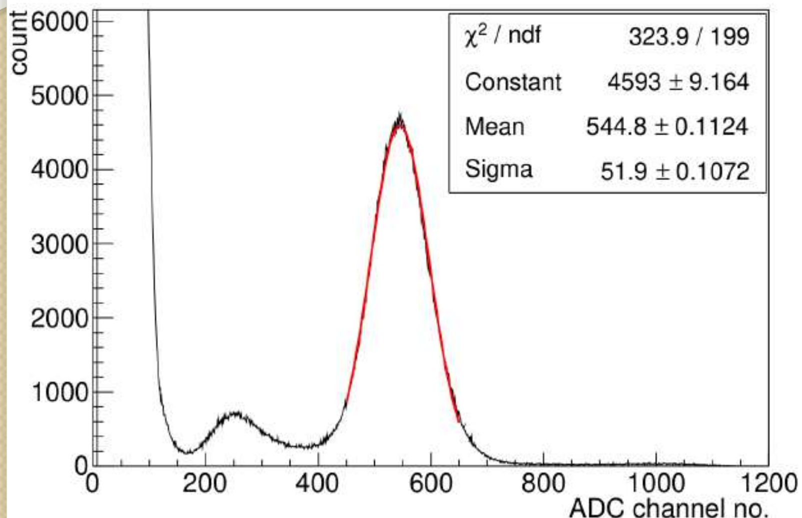
Schematic of the High Voltage distribution of the triple GEM chamber of dimension 10 x10 cm^2



Fe^{55} Signals from GEM



Gain and energy resolution



Fe^{55} spectra at ΔV ~ 410 V and with Ar/CO_2 gas mixture at 70/30 volume ratio

- **Dimension of the chamber:** 10 x 10 cm^2
- **GEM:** Single Mask (SM) triple GEM chamber
- **Source:** Same Fe^{55} X-ray (5.9 keV) source is used for irradiation and monitoring the spectrum
- **Gas mixture:** Ar/CO_2 in 70/30 volume ratio
- **Flow rate :** 3 lt/hr
- **Preamplifier gain:** 2 mV/fC (charge sensitive)

$$\textbf{Gain} = \frac{\text{Output charge}}{\text{Input charge}} = \frac{\text{(Mean pulse height/ 2 mV) fC}}{\text{No of primary electrons} \times \text{e C}}$$

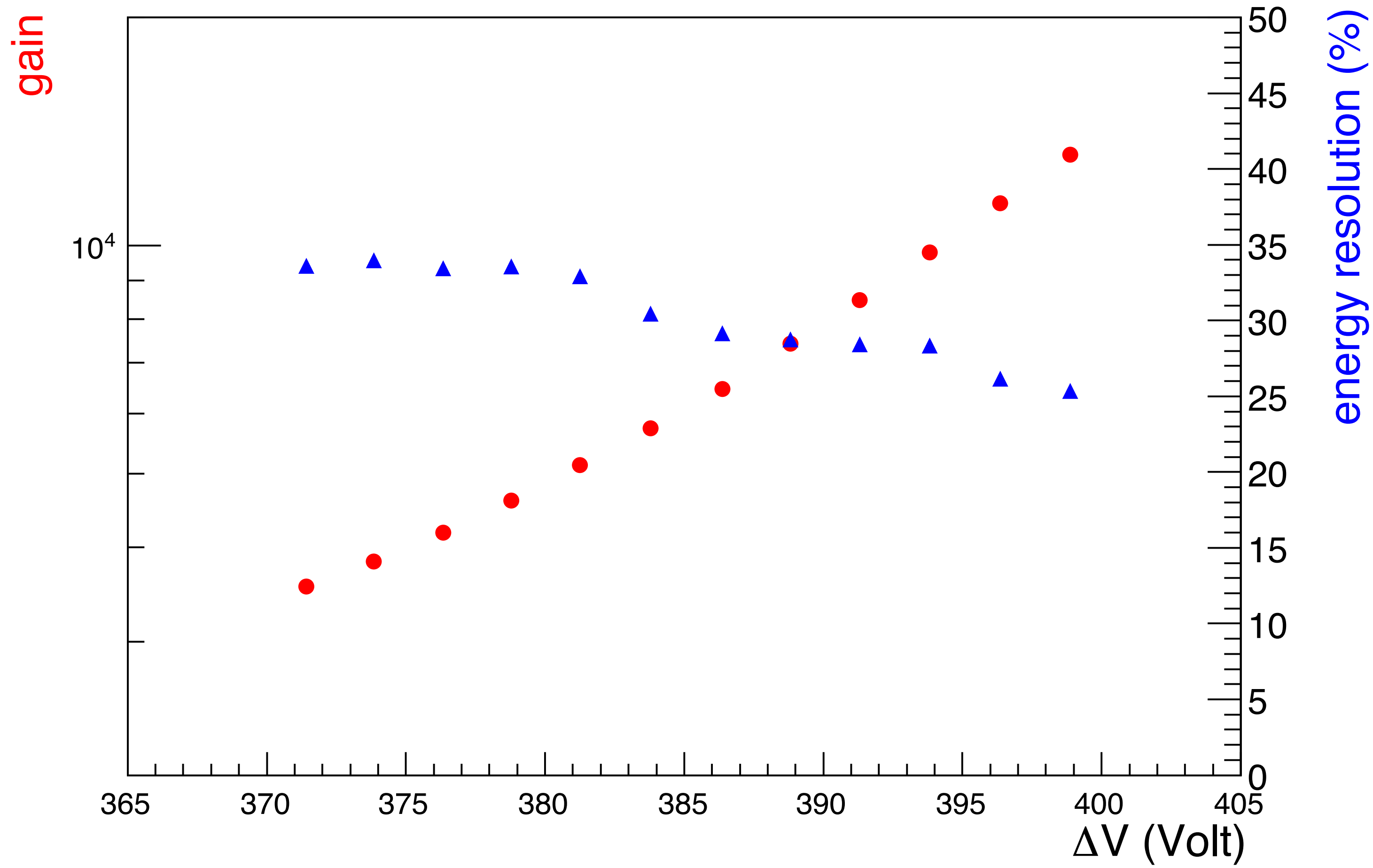
$$\textbf{Energy resolution} = \frac{\text{Sigma} \times 2.355}{\text{Mean}} \times 100$$

Number of primary electrons (n)

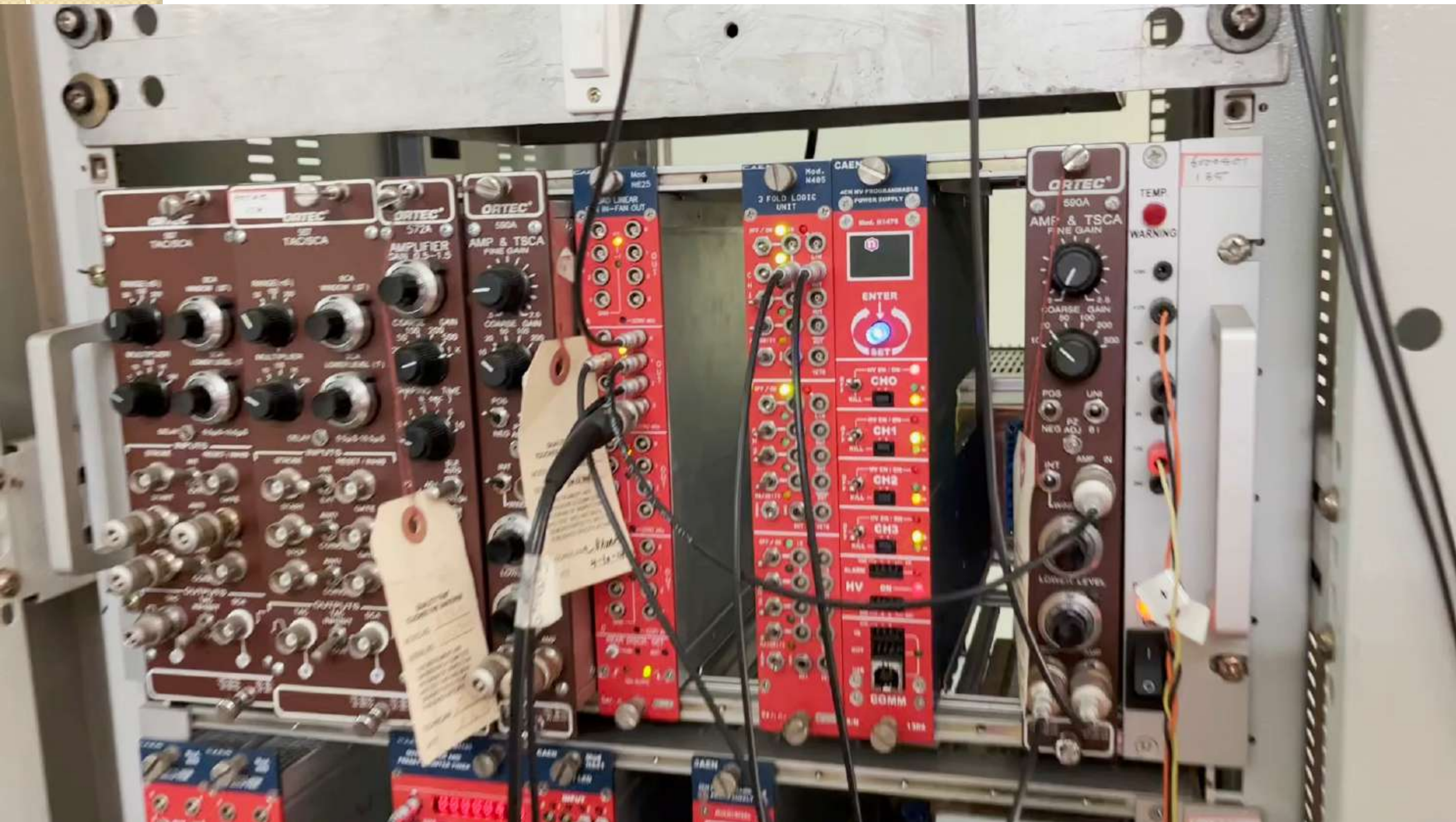
$$\mathbf{n} = \text{E}_{\text{gamma}}\left(\frac{\%\text{ of Ar}}{\text{W}_{\text{Ar}}} + \frac{\%\text{ of CO}_2}{\text{W}_{\text{CO2}}}\right)$$

For Ar/CO_2 in 70/30 volume ratio, the number average of the primary electrons is 212 with the 5.9 keV X-ray source

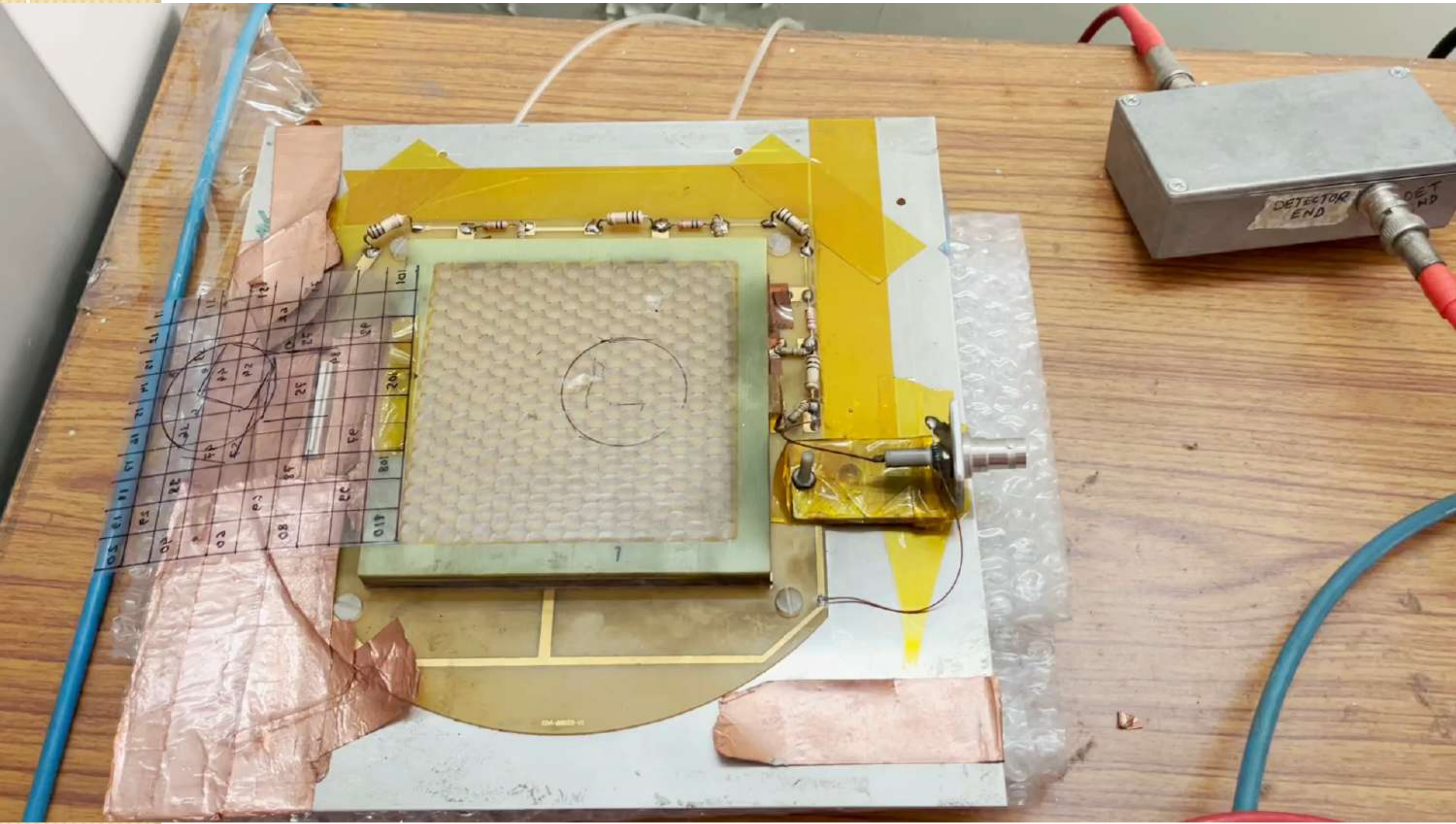
Gain and Energy resolution Vs. GEM voltage



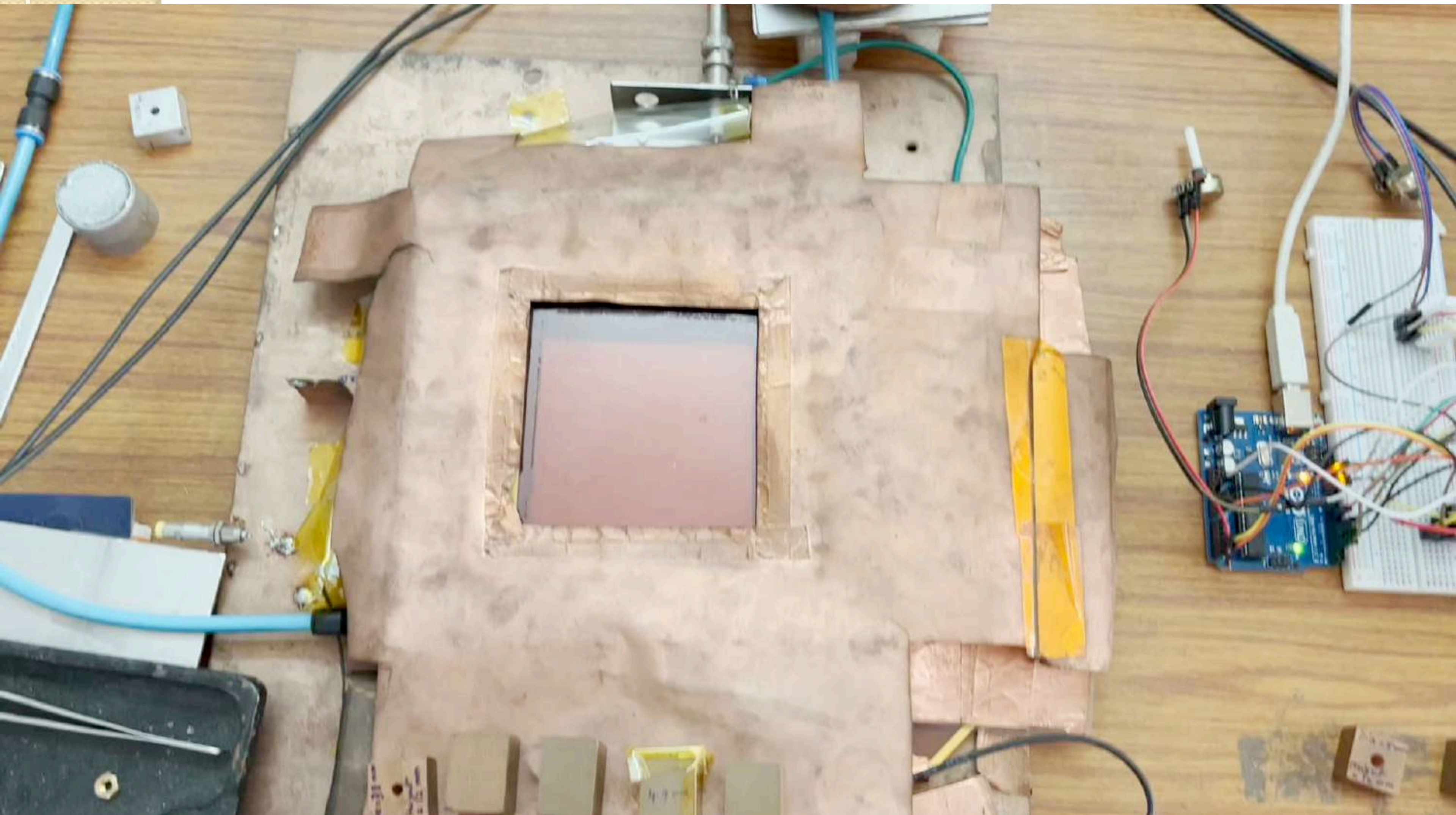
NIM electronic modules



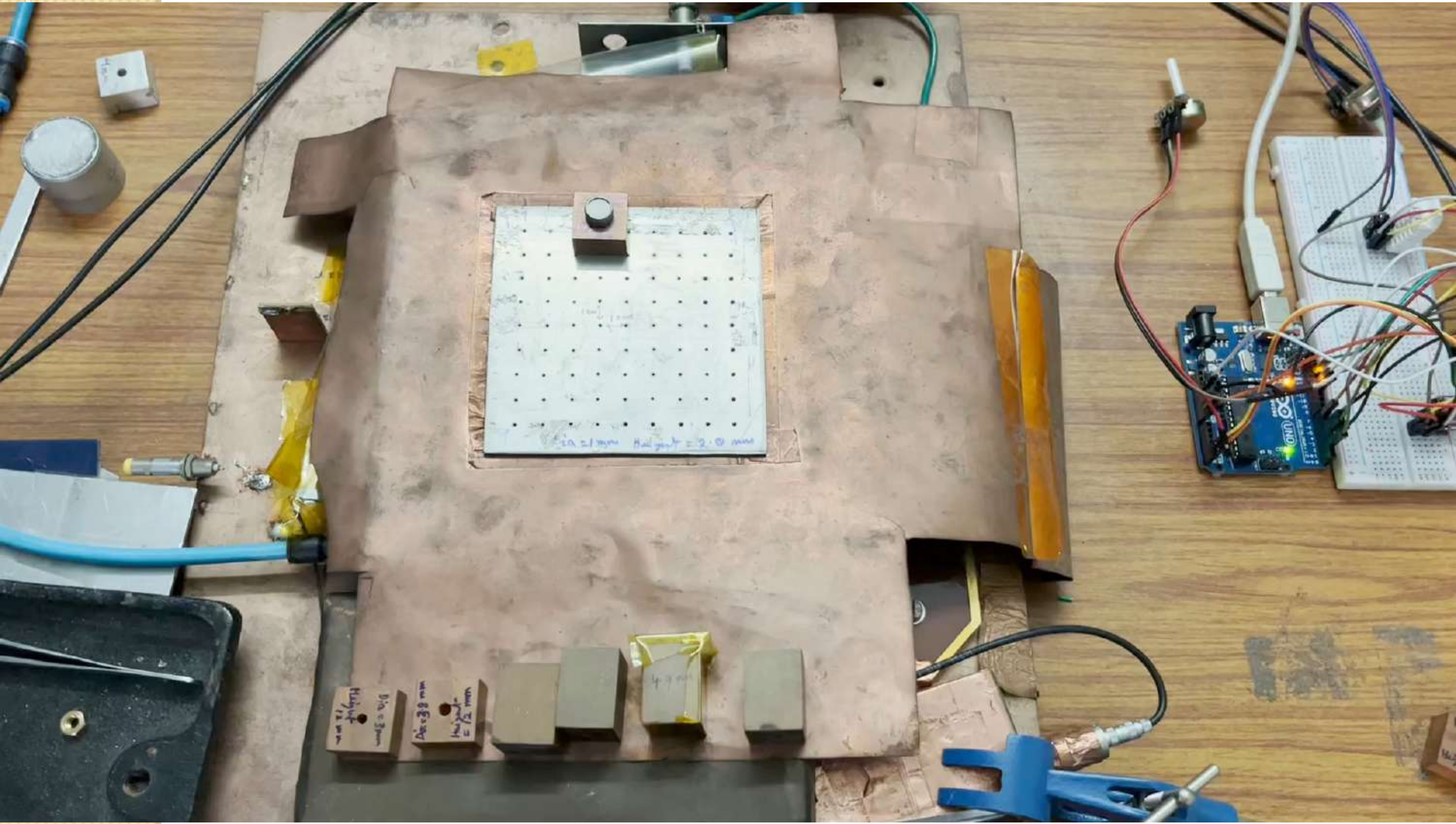
GEM detector



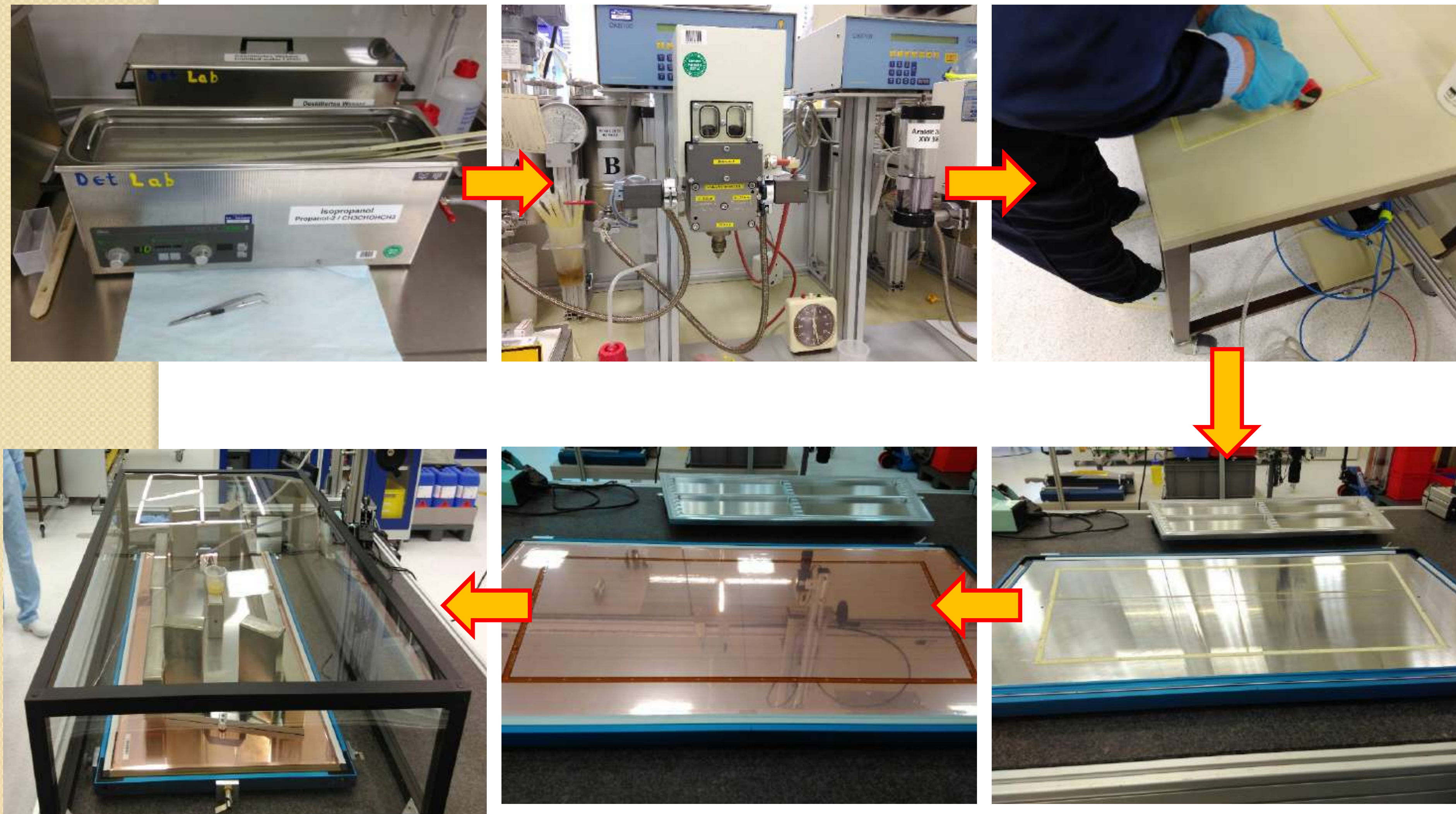
GEM detector



GEM signal

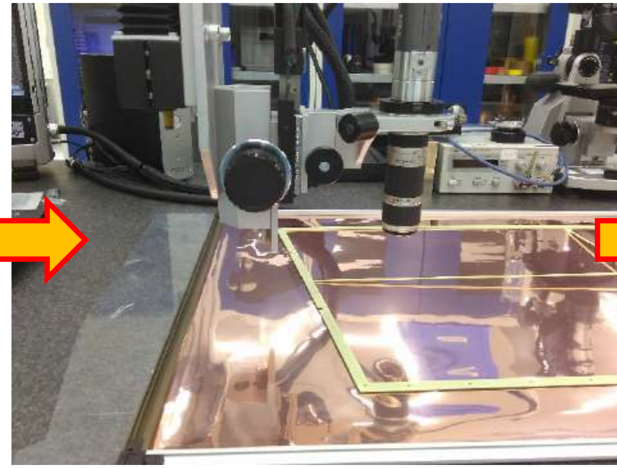


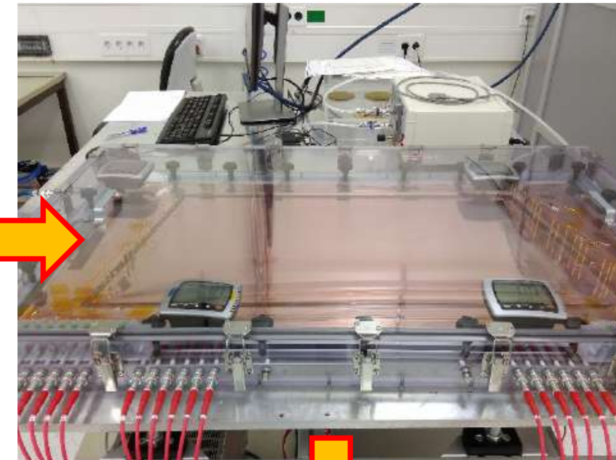
Pictorial steps of the OROC GEM framing

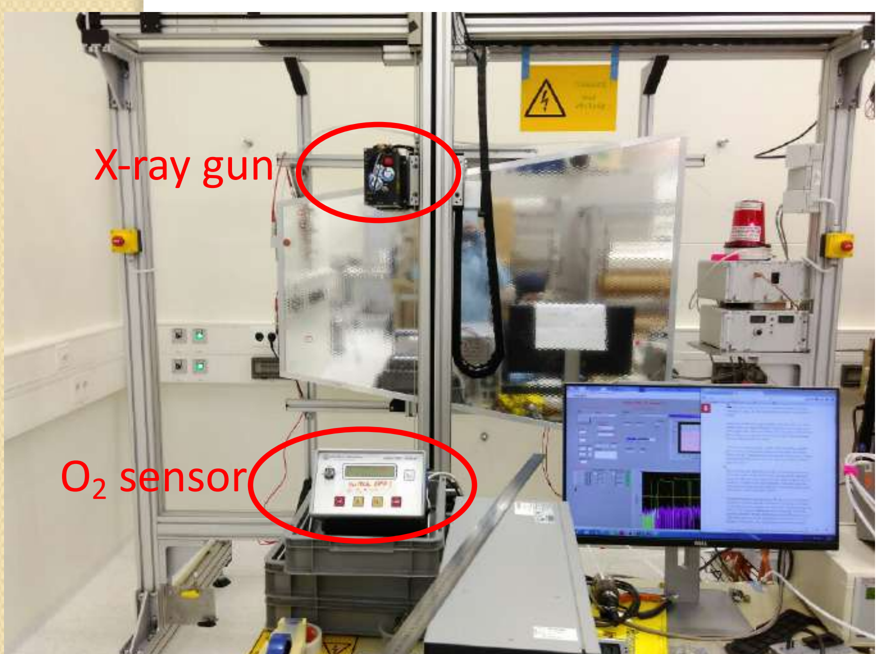


R. N. Patra

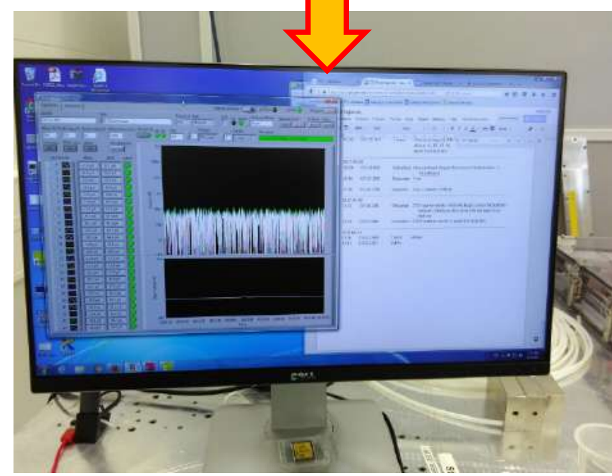
Pictorial steps of the OROC GEM testing





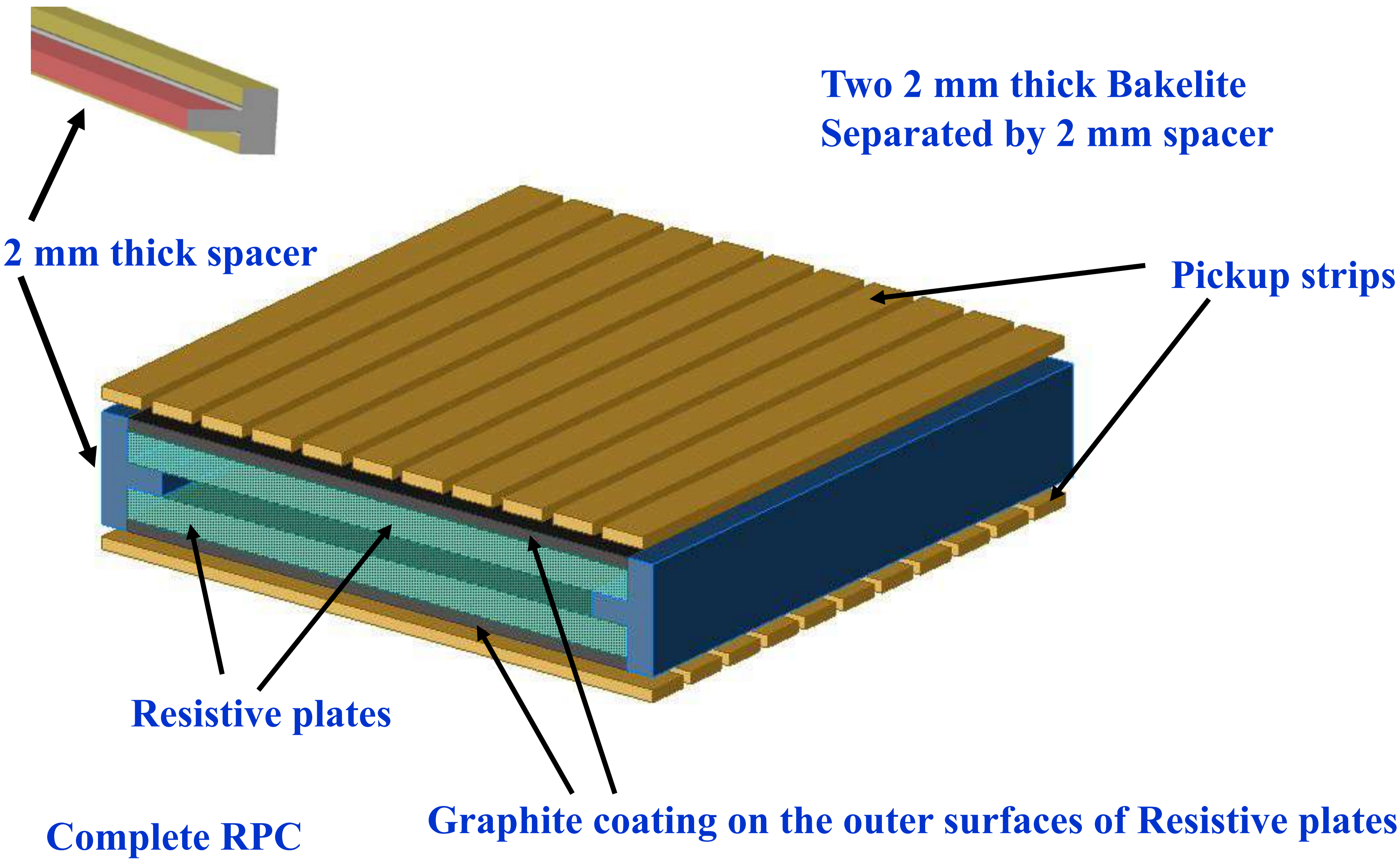


X-ray scanning of OROC chamber



R. N. Patra

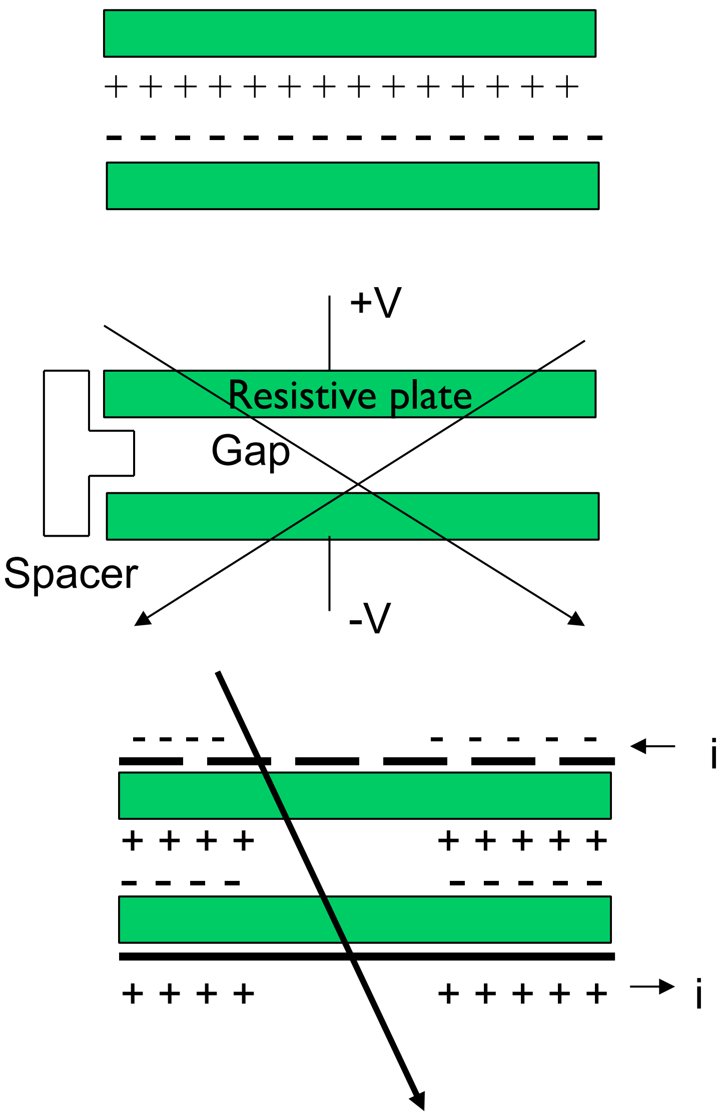
Resistive Plate Chamber



Why RPC?

- Built from simple and common materials.
- Low fabrication cost per unit area.
- Easy to construct and operate.
- Simple signal pick up and readout system.
- Large detector area coverage.
- High efficiency (>90%) and good time resolution (~2ns).
- Particle tracking capability and good position resolution.
- Two dimensional (x and y) readout from the same chamber.
- Long term stability.

Basic principle of RPC

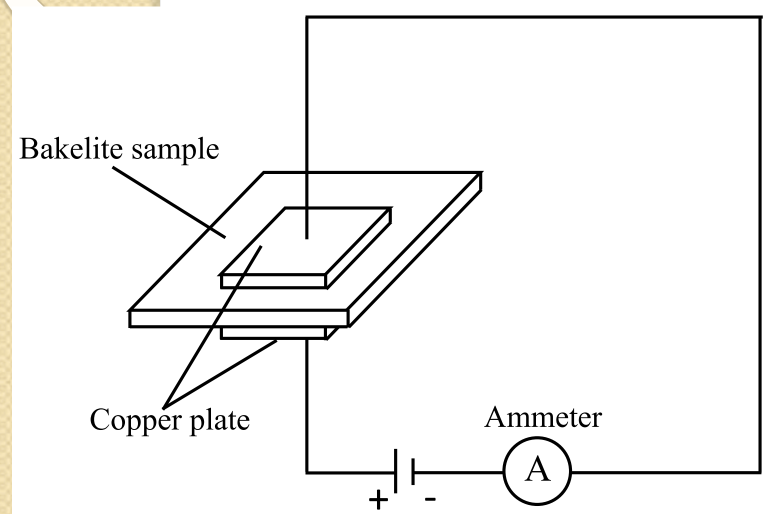


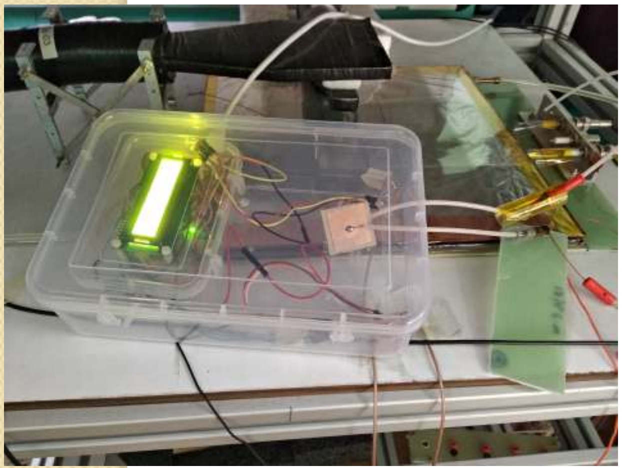
Surface of resistive electrodes are charged from power supply. Charge-up process is slow due to high resistivity of the material.

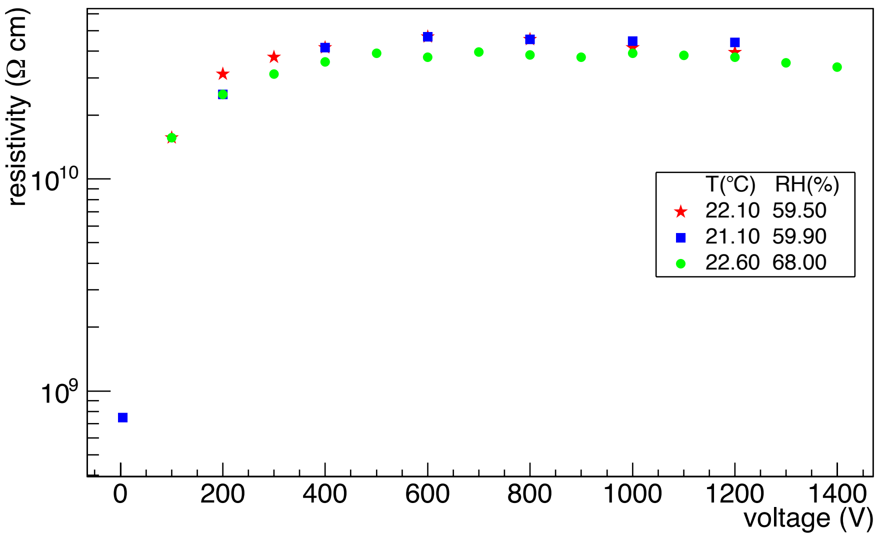
A passing charged particle induces an avalanche, which develops into a spark. The discharge stops when local charge is used up. This region is dead until re-charged through the bulk resistivity of the plates (10^{11} Ω cm.)

When readout strips are placed, induced charge is either drawn in or drawn out from the readout board, generating voltage signals of opposite polarities.

Measurement of bulk resistivity

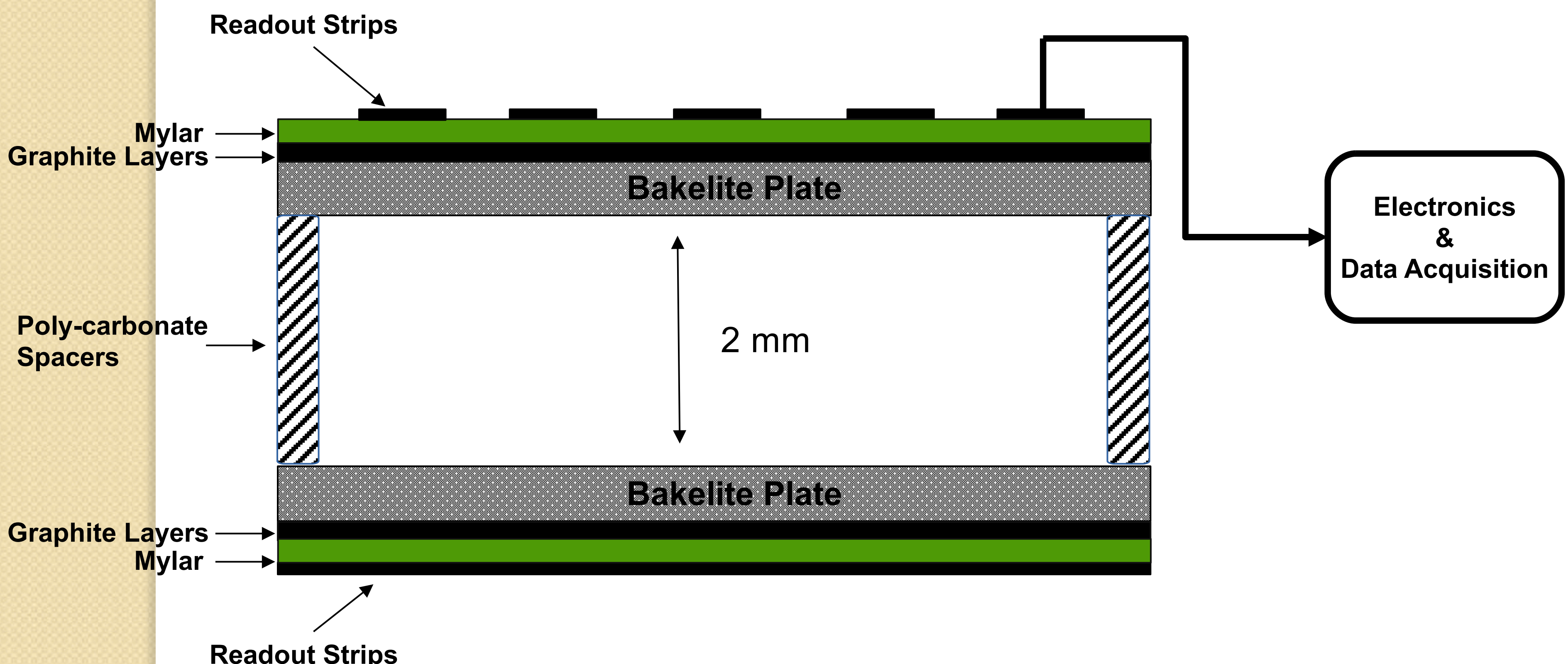






- Bulk resistivity $3 \times 10^{10}\ \Omega$ cm

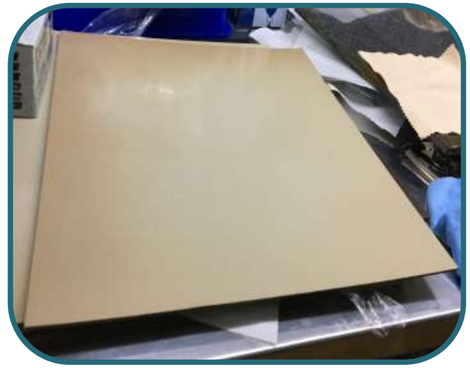
Fabrication steps



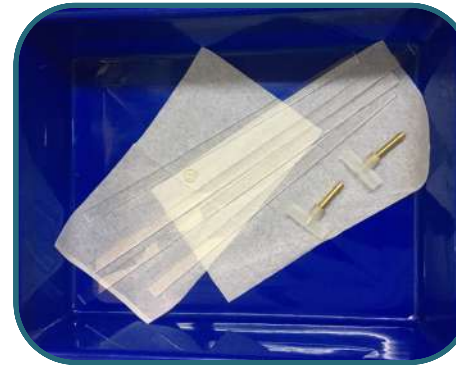
A. Sen

Fabrication steps of the prototype

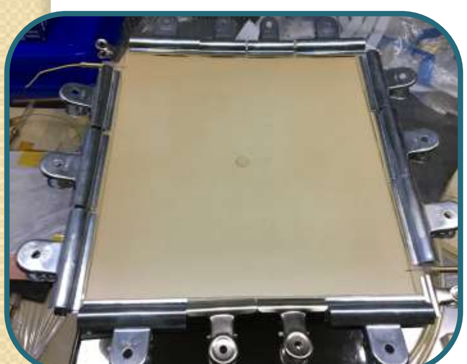
Application of linseed oil on the bakelite surface



Cured linseed oil coated bakelite surface

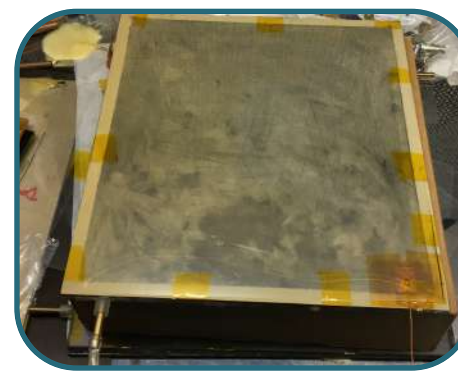


Gas nozzles and spacers



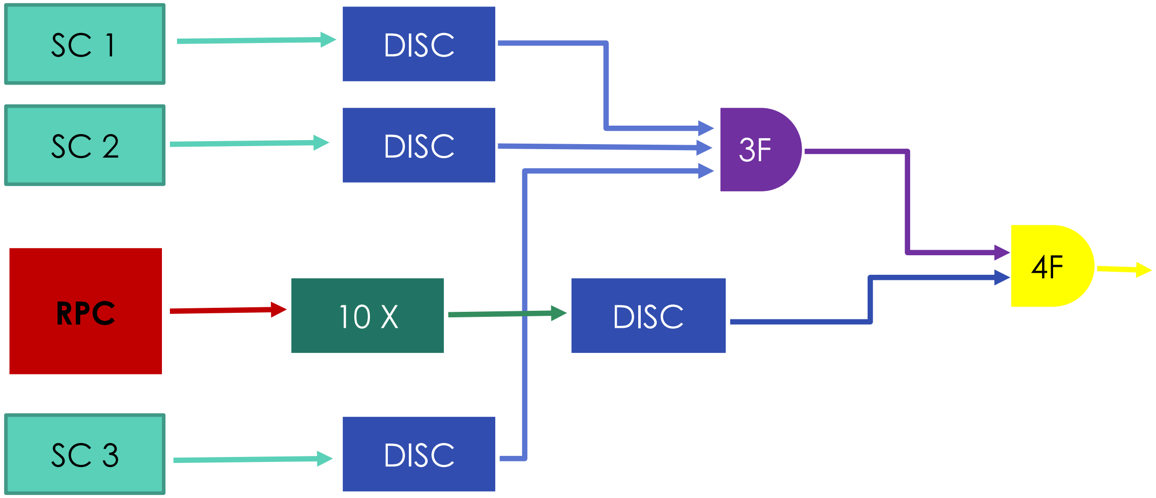
Gluing of spacers and nozzles

Making of gas gap



Complete RPC module after graphite coating

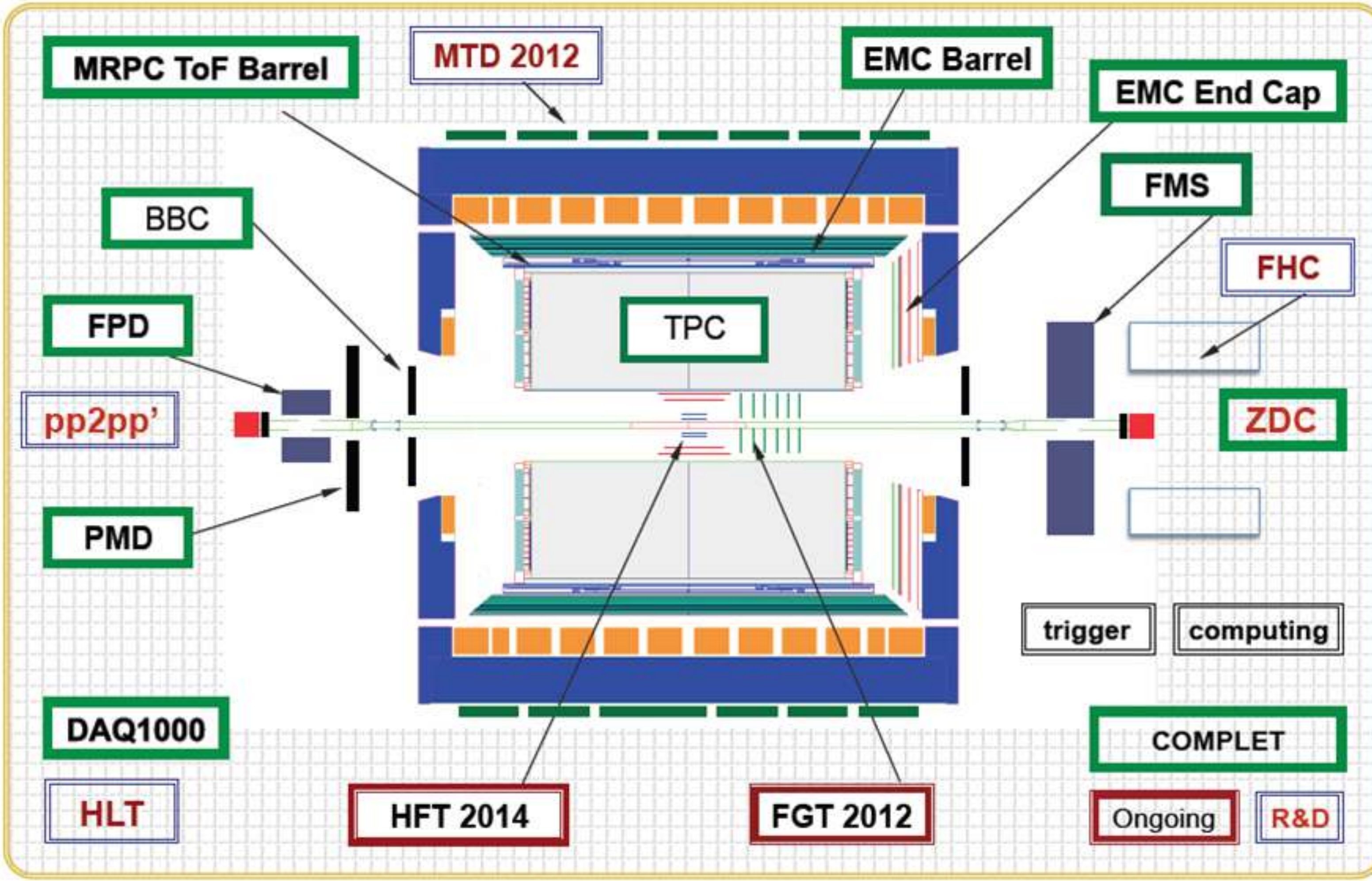
Efficiency and time resolution



- The module is fabricated with resistivity $3 \times 10^{10}\ \Omega$ cm.
- With 100% tetrafluroethane gas, an efficiency ~ 70% is obtained at 10.2 kV onwards.
- The time resolution of the chamber is found to be ~ 1 ns (sigma).

Development of Muon Telescope Detector (MTD) for STAR experiment

MTD at STAR



MRPC ToF Barrel
MTD 2012
EMC Barrel
EMC End Cap
FMS
BBC
FHC
FPD
TPC
pp2pp'
ZDC
PMD
trigger
computing
DAQ1000
COMPLET
HLT
HFT 2014
FGT 2012
Ongoing
R&D

Materials used

- Graphite coated outer glass, spacers and screws: obtained from China
- Inner glass plates: procured by VECC
- Fishing line (250 ± 2 μm) obtained from Germany
- Mechanical supports (paper honey-comb & G10 board): made in VECC
- Pick-up strip: procured by VECC

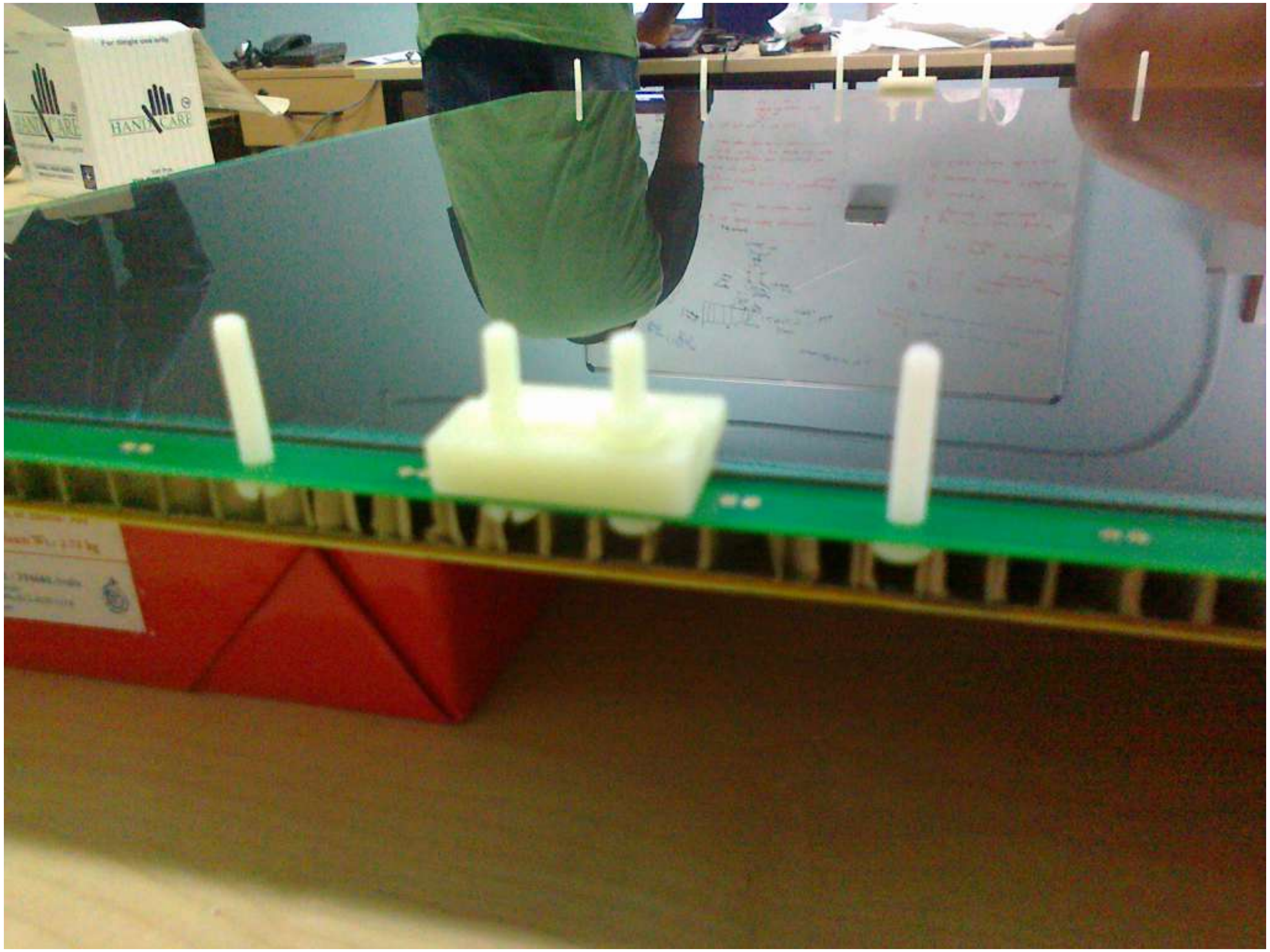
Pick-up strip

Arnab Banerjee

Outer glass placed on pick-up strips

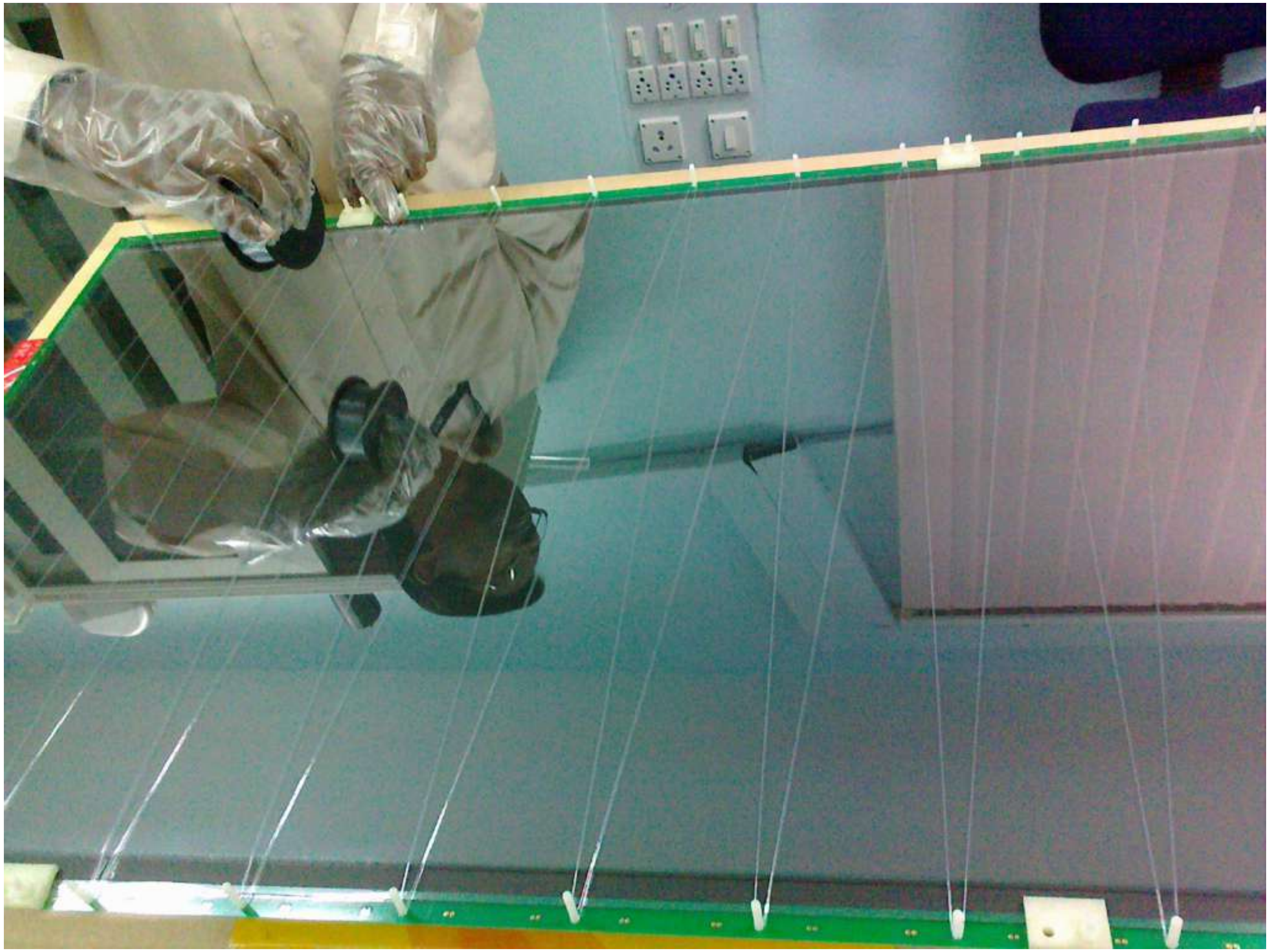
Arnab Banerjee

Screws to support the glass plates



Fishing lines (250 μm) to make uniform gas gap

Fishing lines (250 μm) to make uniform gas gap

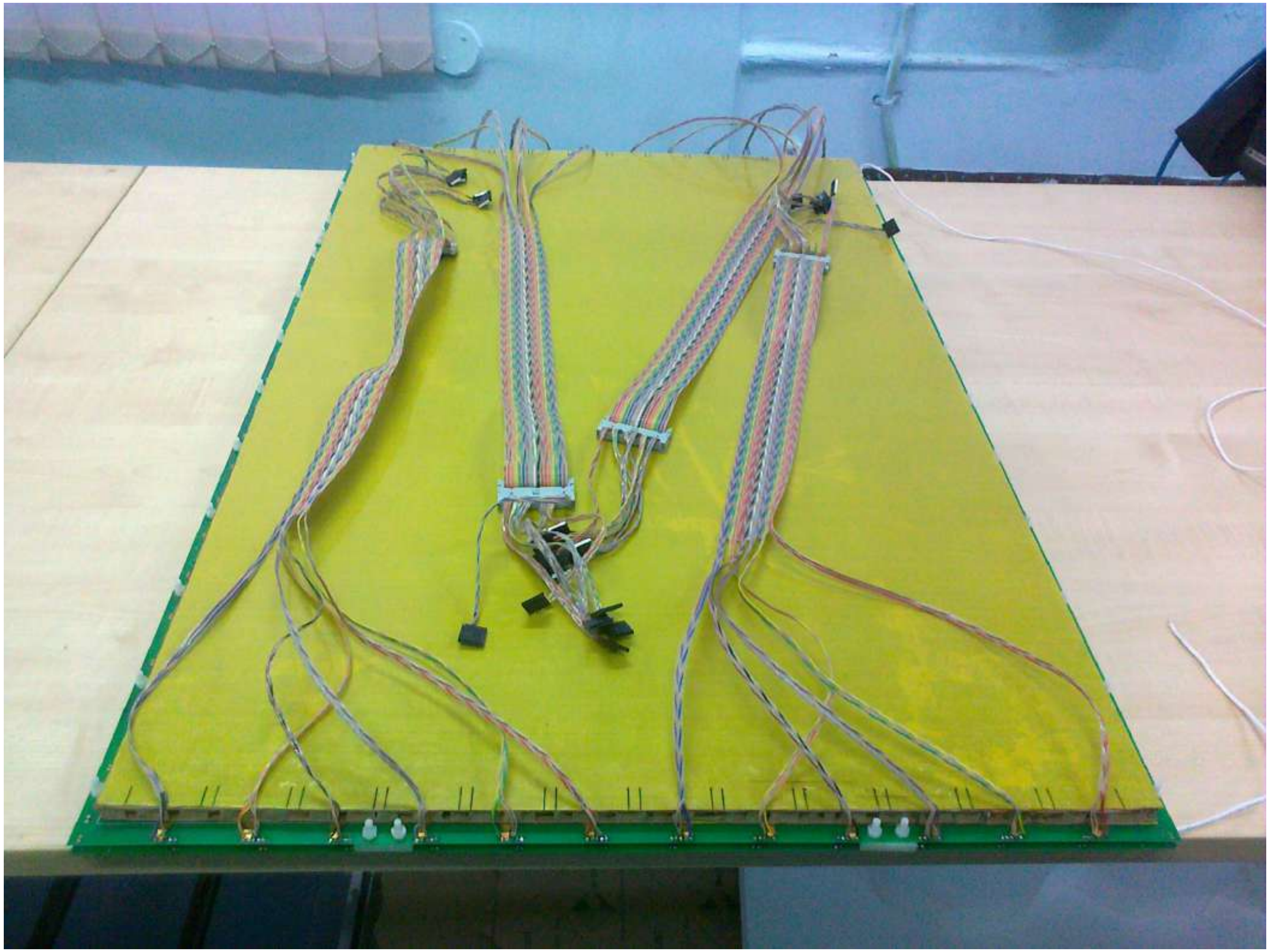


Fishing lines (250 μm) to make uniform gas gap

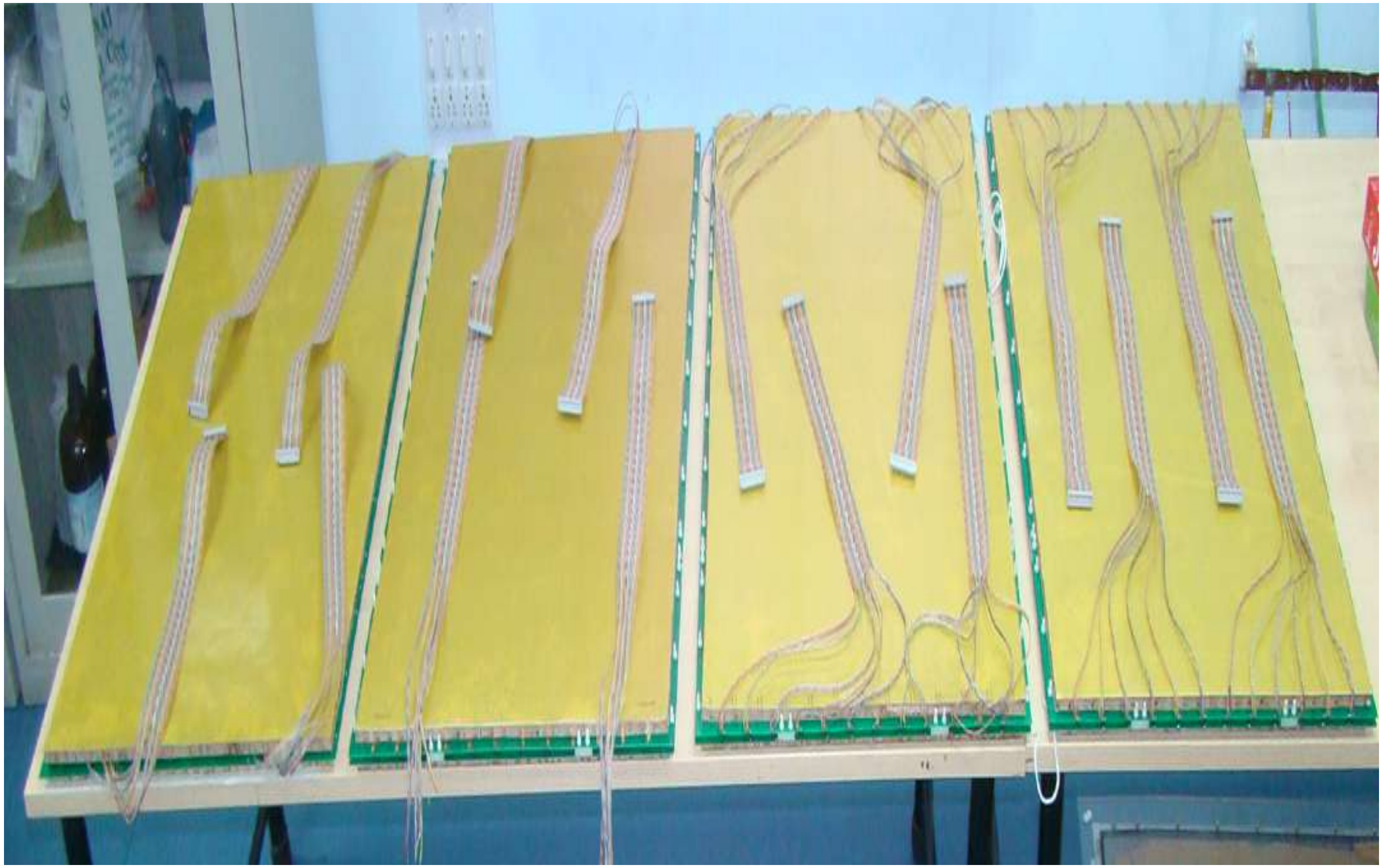
Gas gap with pick-up strip and support structure

Gas gap with pick-up strip and support structure

Complete module

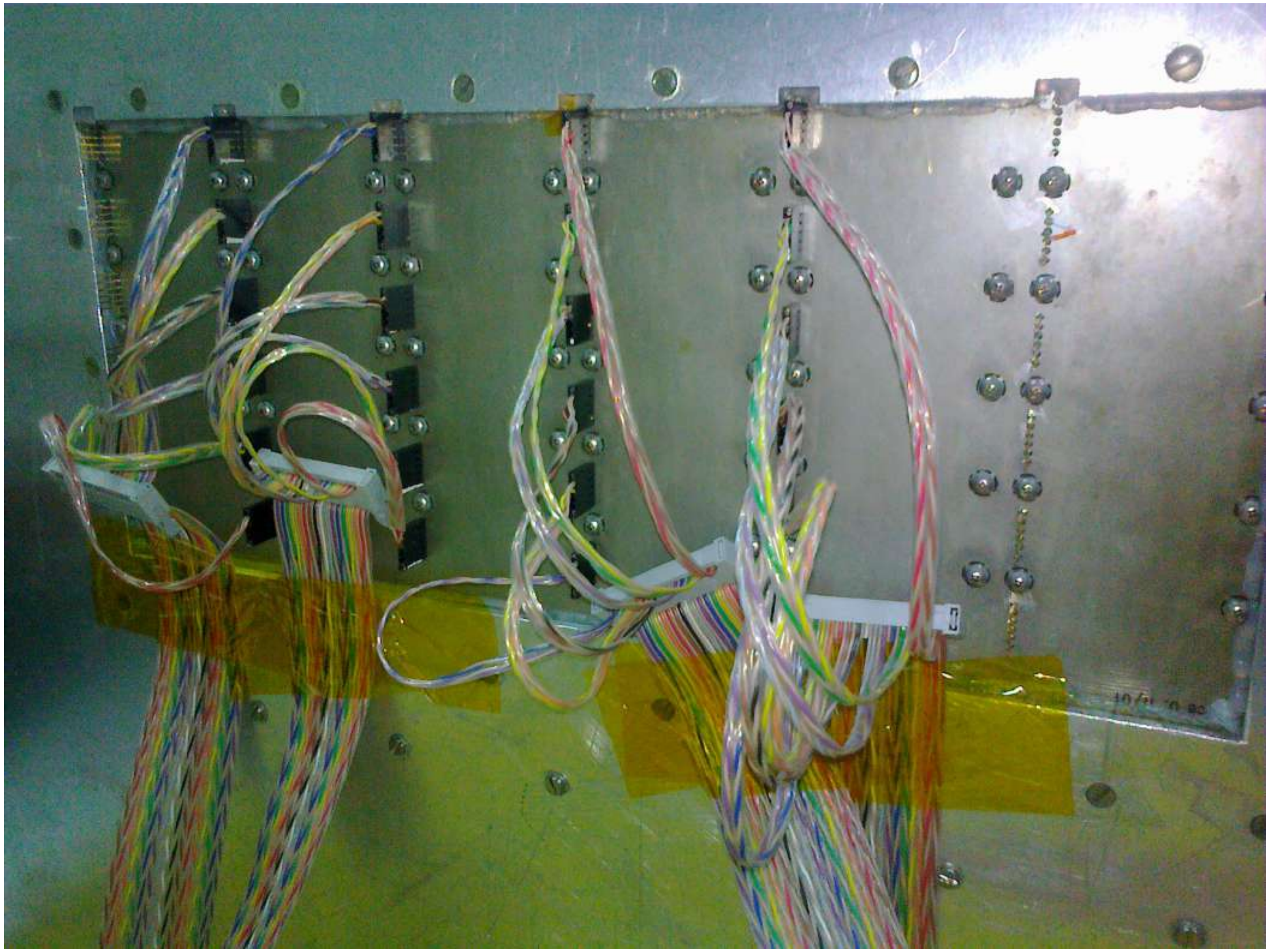


Complete module



Cable connection

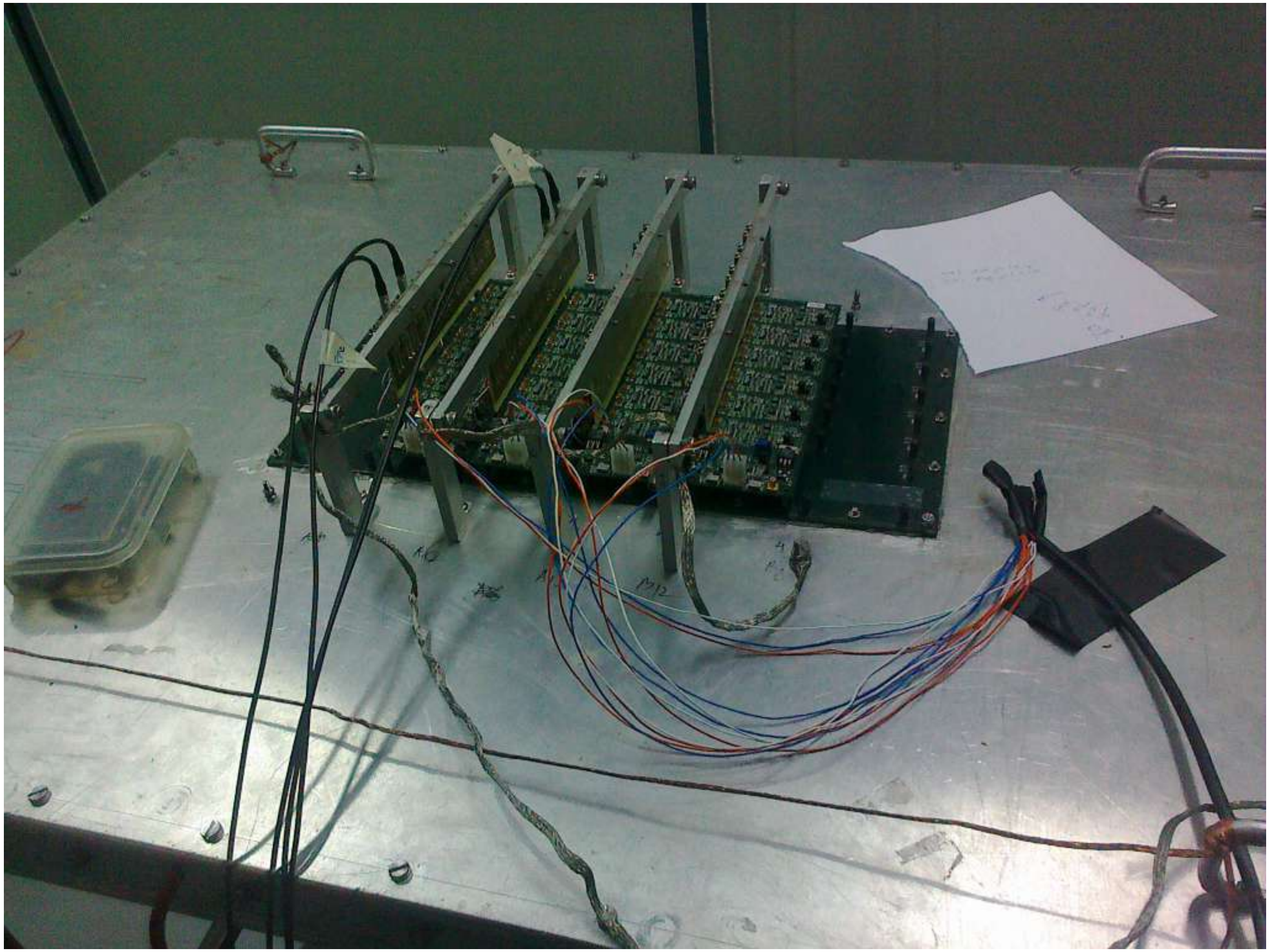
Cable connection



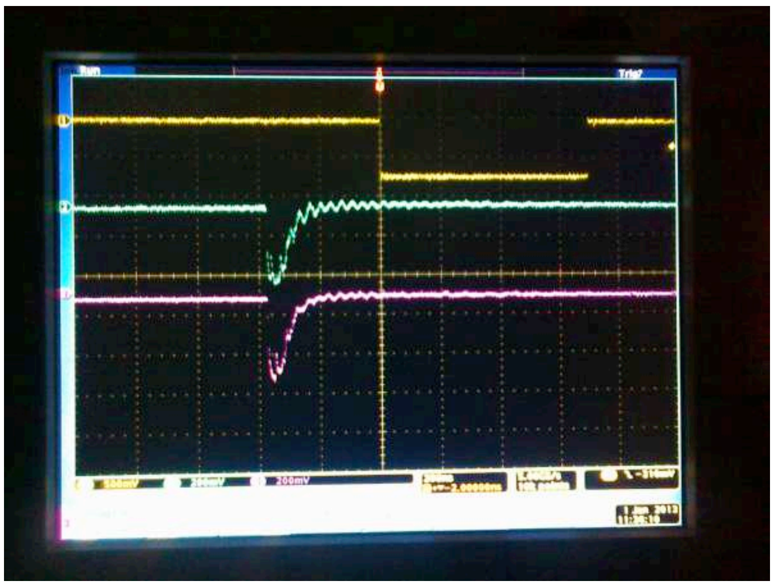
Closing the box

Closing the box

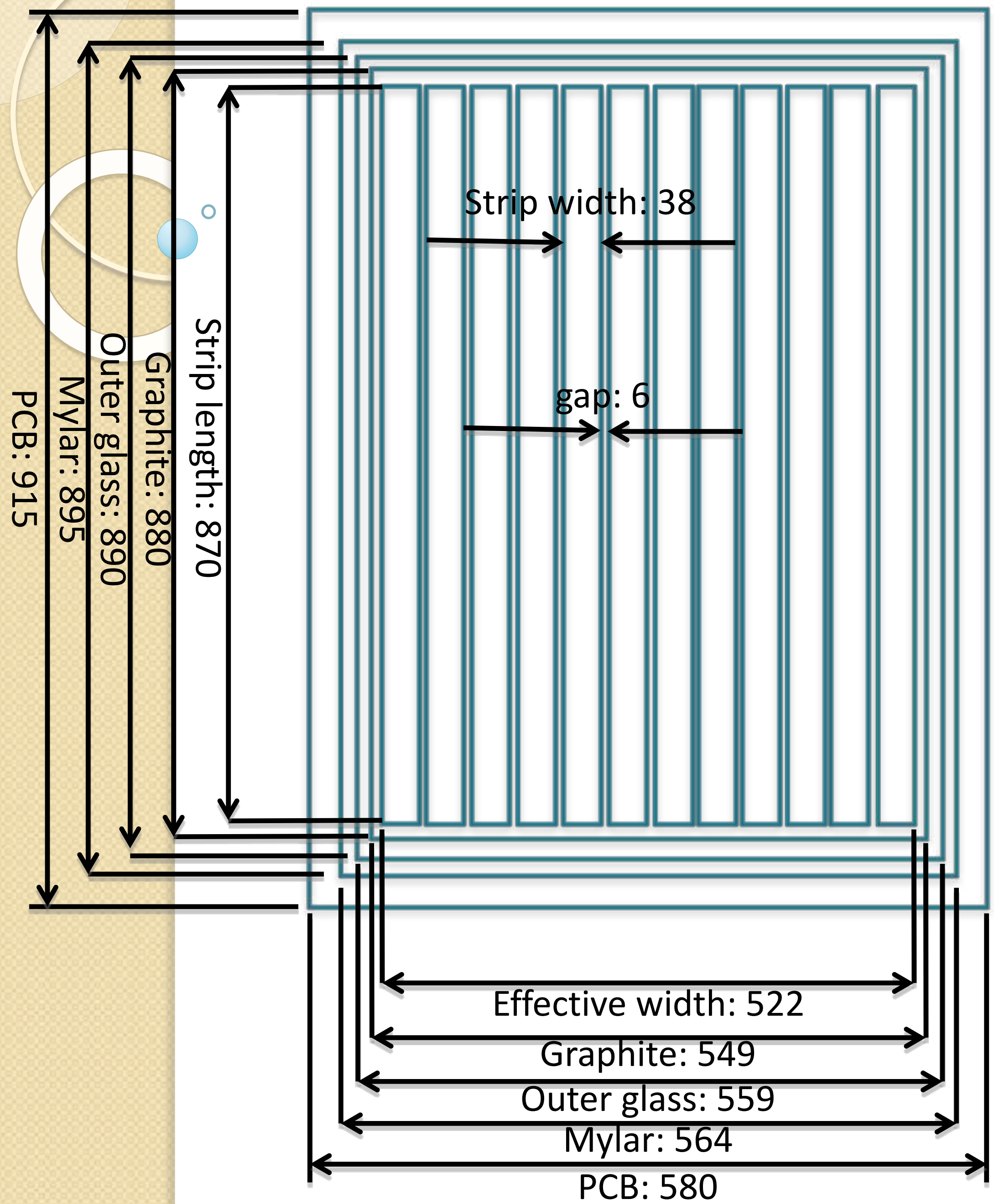
Closed box



Signal



- Signal observed in oscilloscope with trigger
- Yellow digital signal is the three fold scintillator coincidence signal
- Green and purple are the analog signal obtained from two sides of the same strip

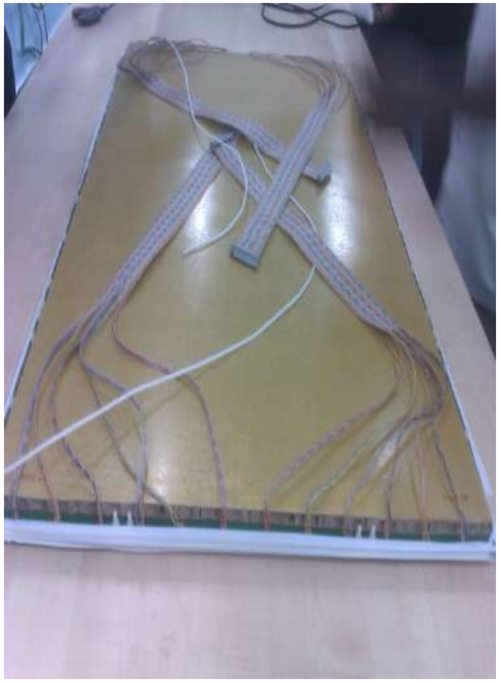


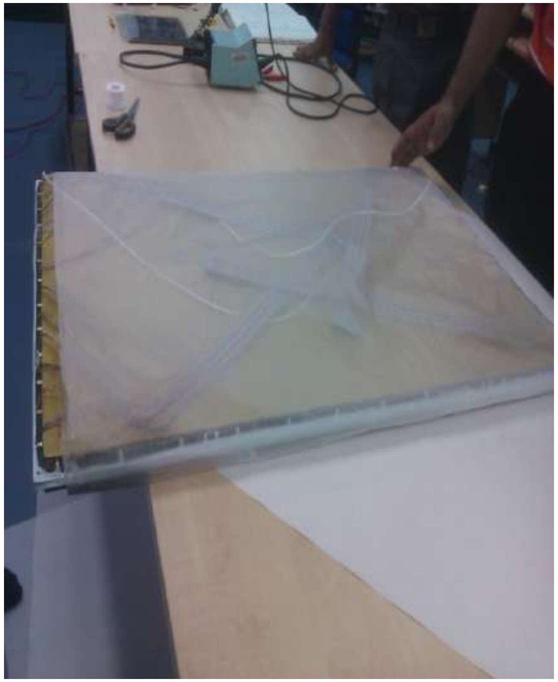
Honeycomb with G10 board support dimension:
890 × 559 × 12.1

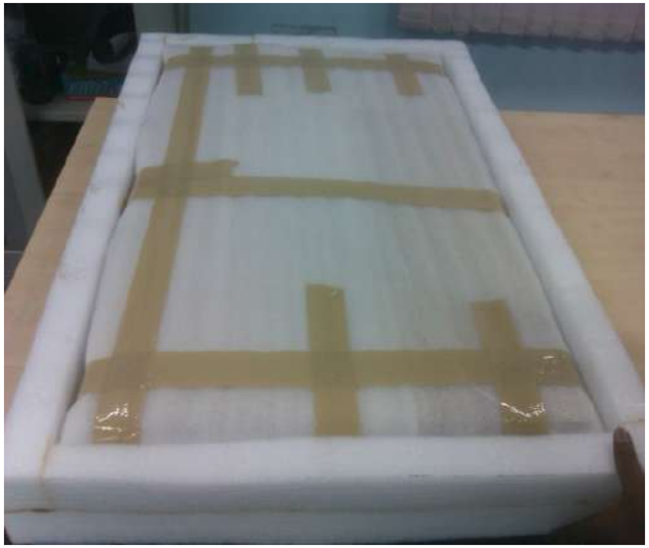
PCB thickness: 1

All dimensions are in mm

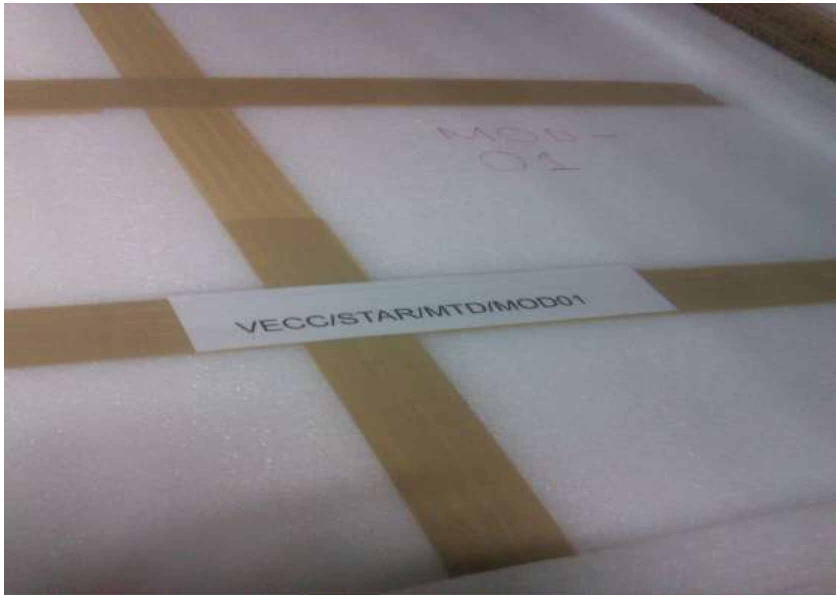
Packing







Packing



Scintillation detectors

Scintillators

- Emit light when irradiated
  - promptly ($<10^{-8}$s)
    - fluorescence
  - delayed ($>10^{-8}$s)
    - phosphorescence
- Can be
  - liquid
  - solid
  - gas
  - organic
  - inorganic

Principle of scintillation detectors

1) Incident radiation interact with material
2) Atoms are raised to excited states
3) Excited states emit visible light: fluorescence
4) Light strikes photosensitive a surface
5) Release of a photoelectron

↓

multiplication

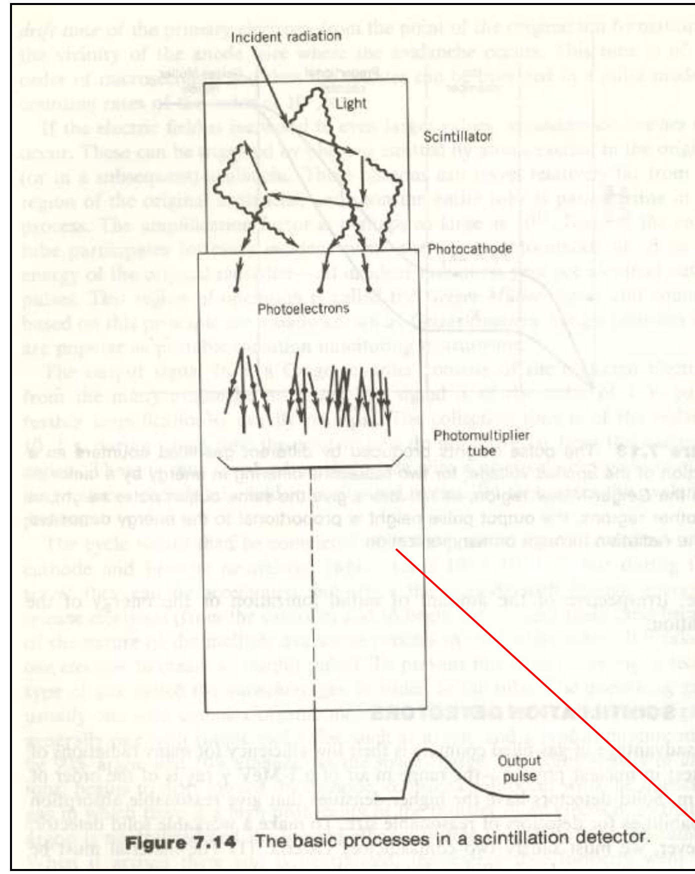
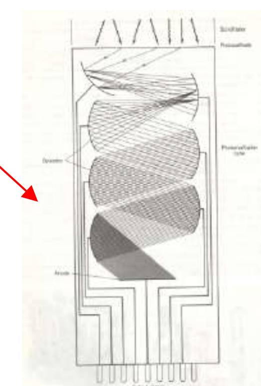
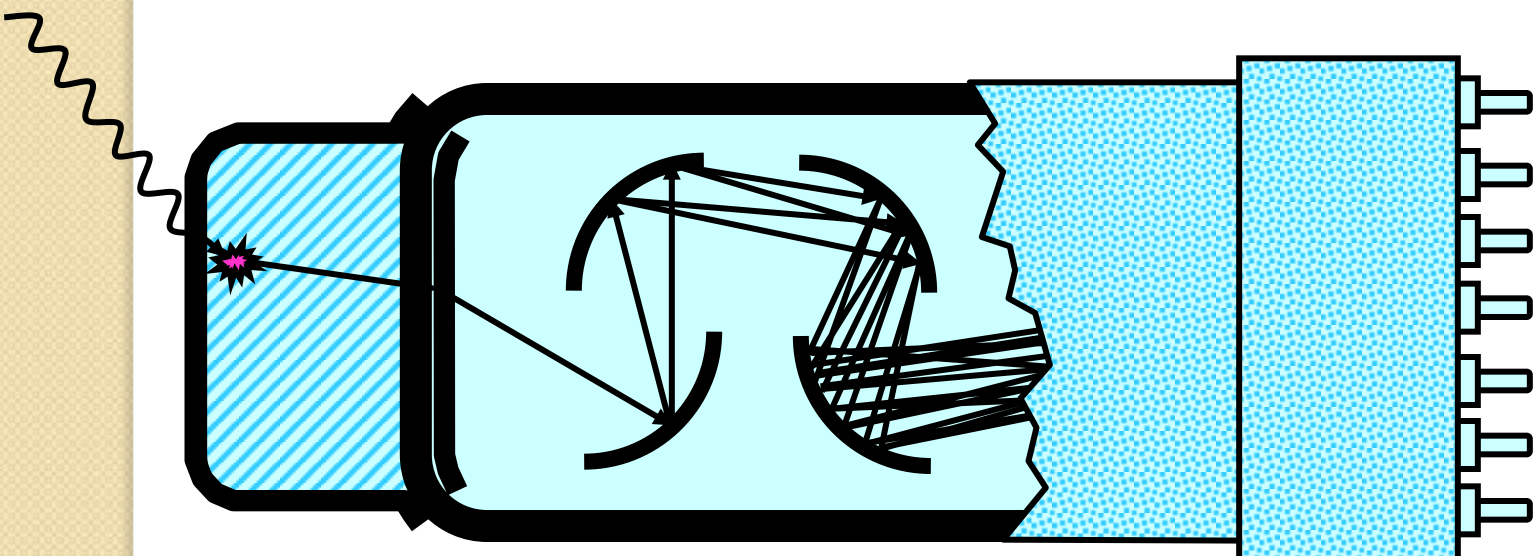


Figure 7.14 The basic processes in a scintillation detector.

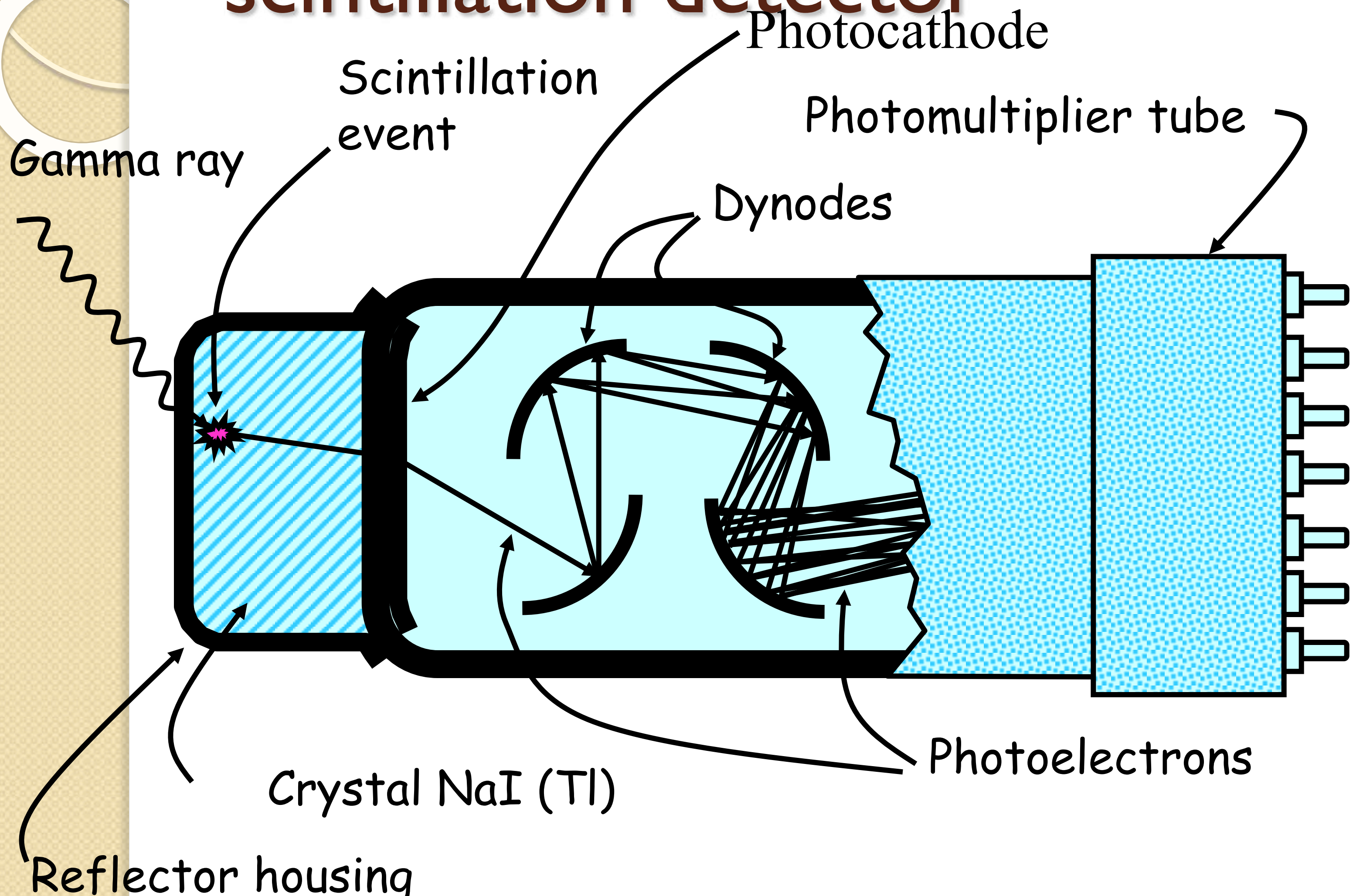


There are organic (plastic) and inorganic scintillators (NaI)

Cross sectional view of a scintillation detector



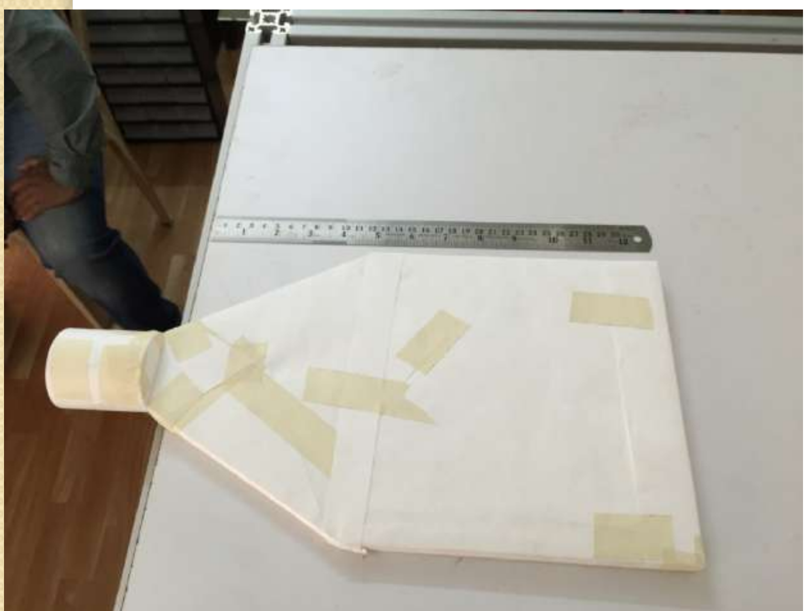
Cross sectional view of a scintillation detector



Gluing of different parts

- Scintillator is first glued with the light guide
- The glue used is BC-600 optical cement mixed with BC-600 hardener in the ratio 5:1
- The scintillator modules were left for the glue to harden for 24 hours at room temperature

Wrapping with tyvek paper



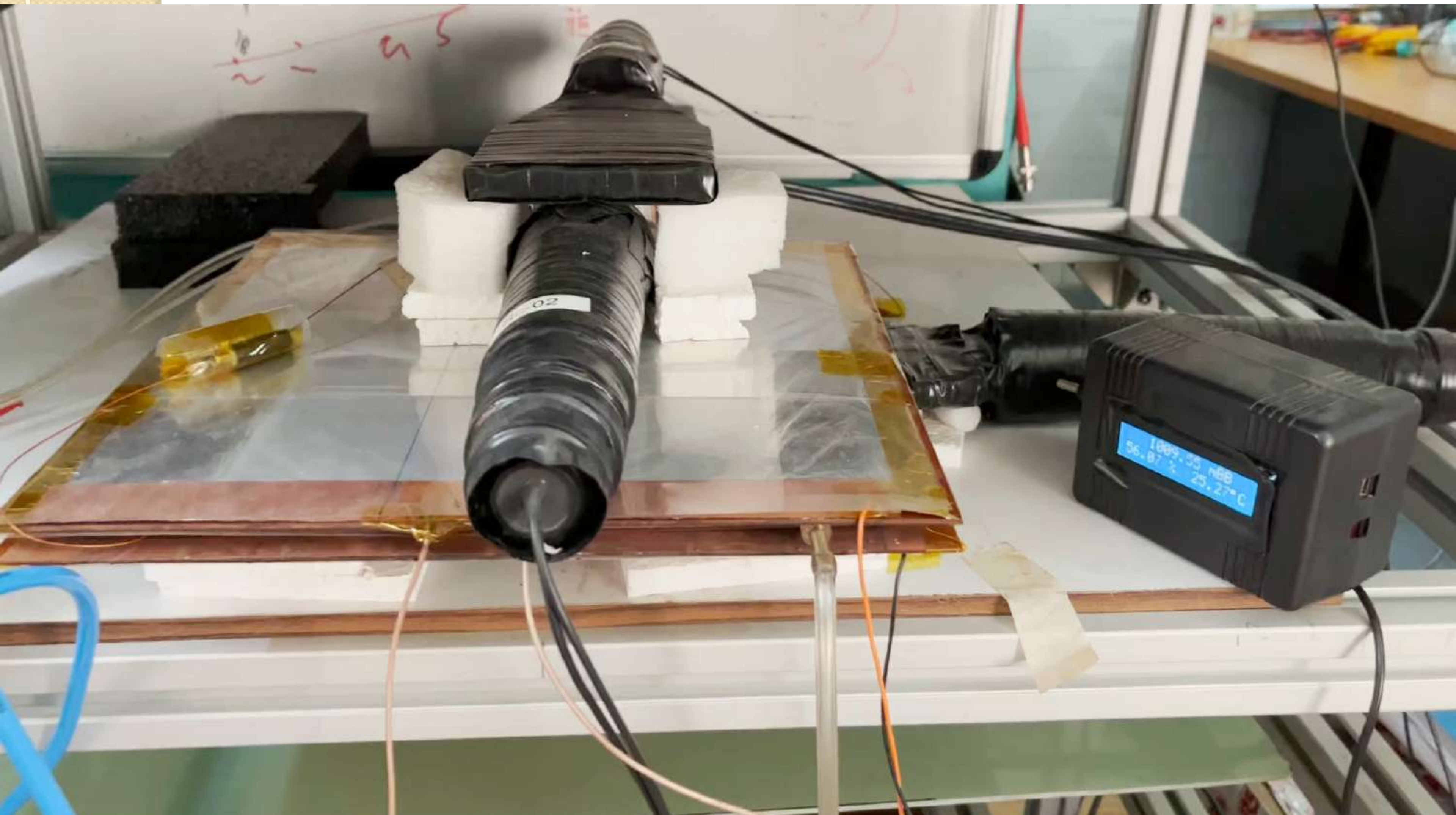
- Before wrapping with Tyvek paper the scintillator module is cleaned with alcohol and water.
- The smooth side of the Tyvek paper faces the scintillator while wrapping

Wrapping with black tape

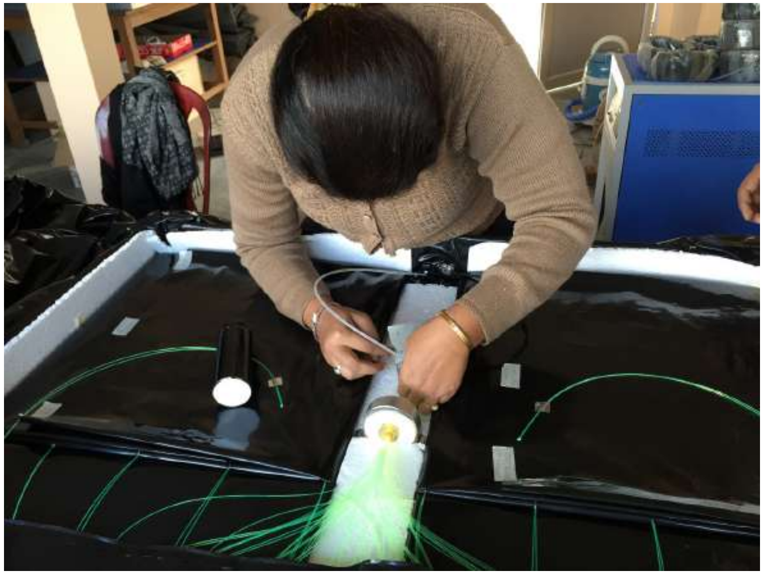
Coupling PMT and light guide with optical glue

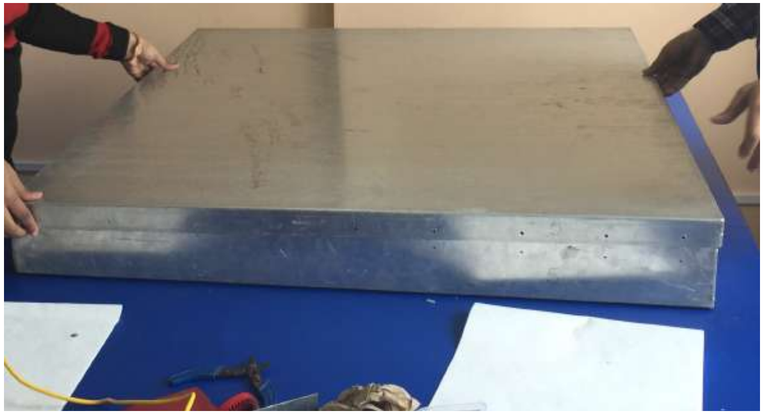
Completed scintillator paddle

Scintillator & Straw tube detector



Detector assembly

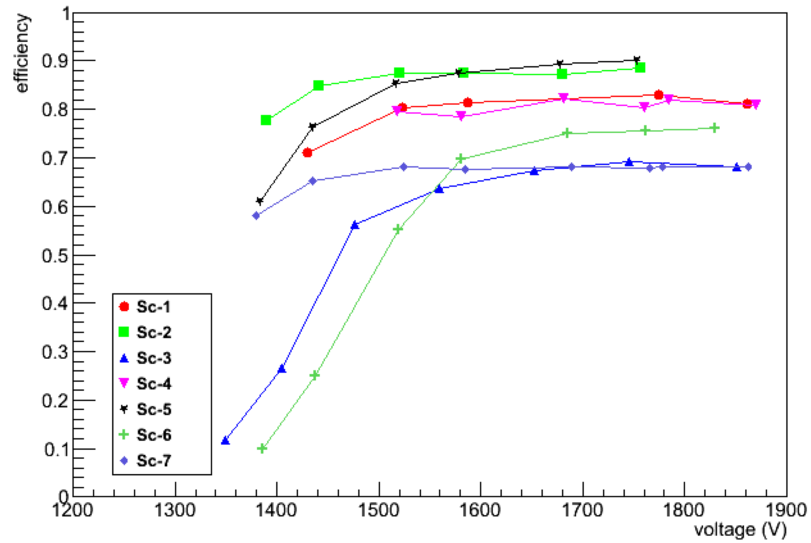




Dimension of each scintillator block: 0.5 m x 0.5 m
One detector consists of 4 such blocks

Testing of the scintillator detectors

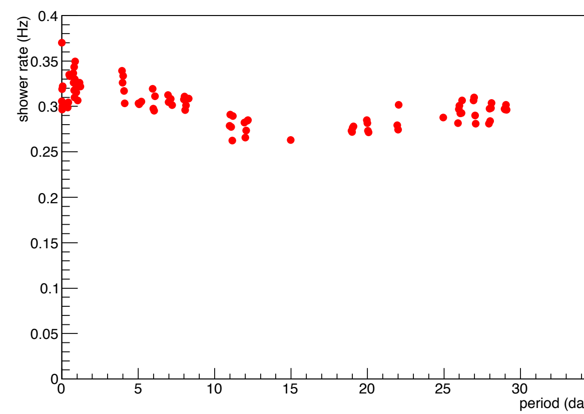
Stack of Scintillator detectors



Efficiency as a function of applied voltage

Set-up with 3 detectors

Coincidence signals



3F rate vs. time during mid November - mid December, 2016

Steps towards the 7-detector array

Fixing of stand

Cabling

Placing of detector

Sealing

Calibration

Cable and electronics

7-detector array @ Darjeeling campus, BI

Summary

- Wide range of detection equipment available
- Understand strengths and weaknesses of each
- No single detector will do everything

Workforce

Thank you

Suggested Reading

- Glenn F. Knoll, *Radiation Detection and Measurement*, John Wiley & Sons.
- W Leo, Techniques for Nuclear and Particle Physics Hernam Cember, *Introduction to Health Physics*, McGraw Hill.