Potential detector and hardware participation of Indian groups in ePIC at EIC

Shuddha

On behalf of

EIC India group

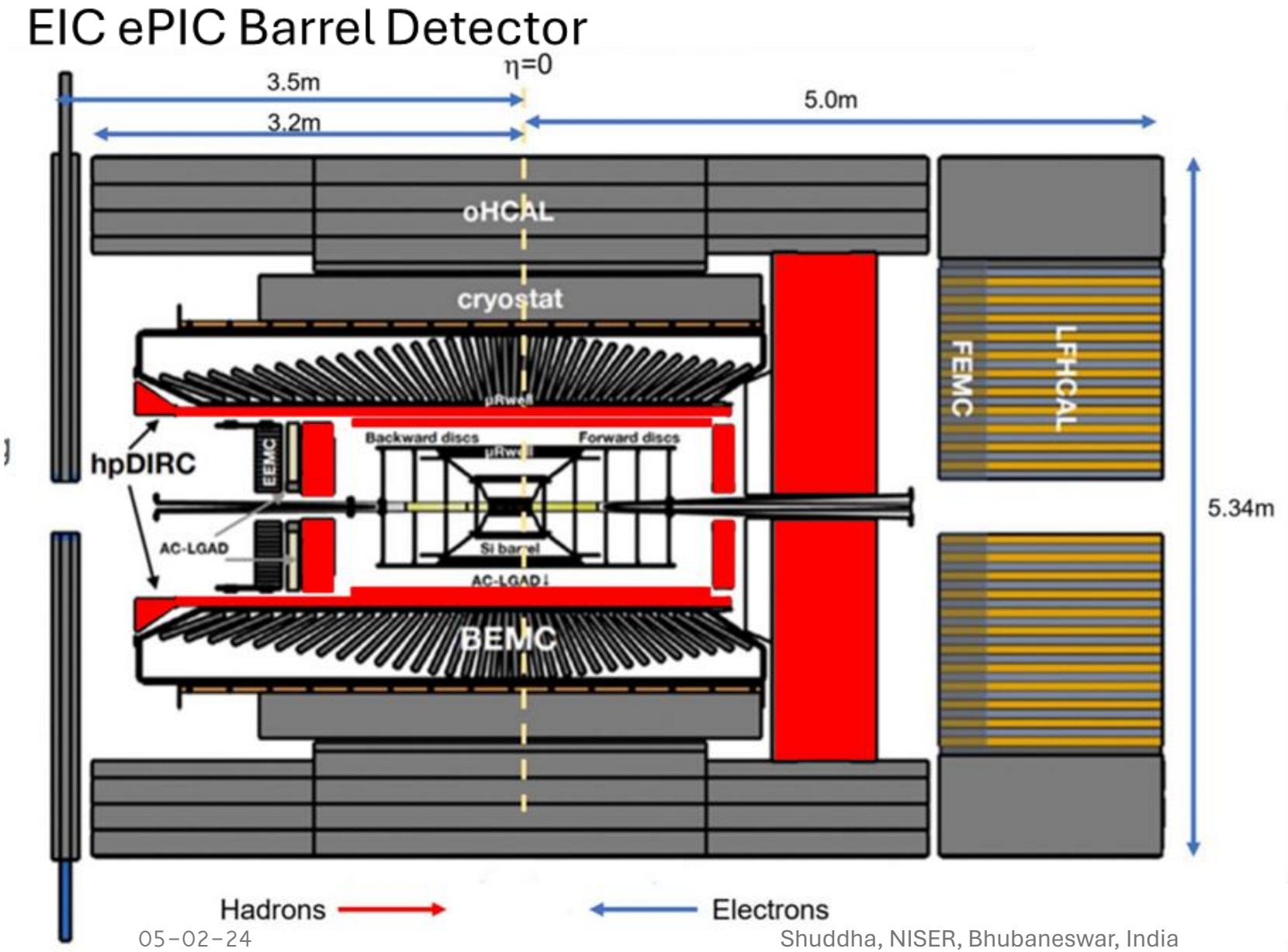
Outline

- EIC India Collaboration and interest
- RICH (Radiator Studies and SiPM)
- Calorimeter experience
- AC – LGAD test setup
- Software Interests
- Conclusion

Indian Institutes interested in ePIC at EIC

- 20 Institutes from all around India have shown interest. Two more are willing to join.
- Interests in hardware as well as in software activities.
  - **PID.**
  - **Calorimeter.**
  - **ToF.**
  - **Simulation studies.**

Indian Interest in ePIC



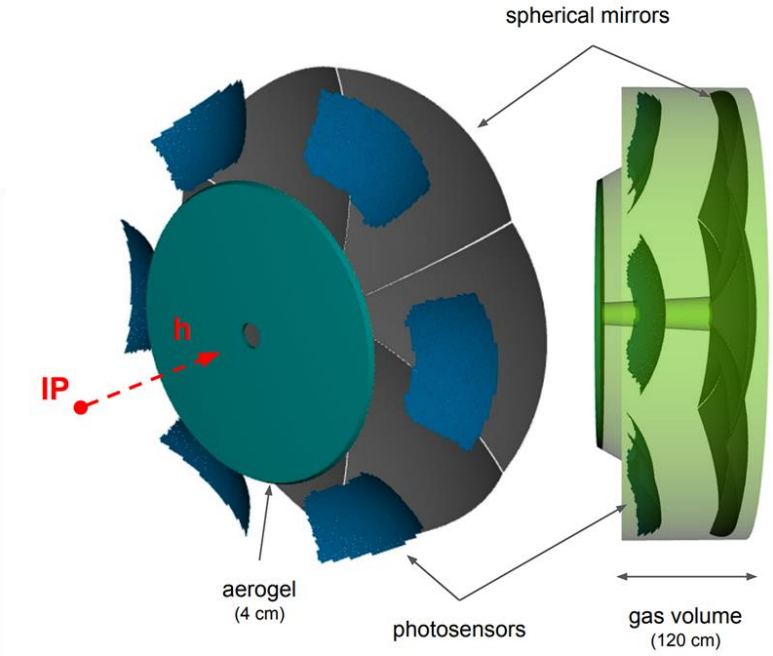
- Calorimetry
- Particle ID
  - ToF: LGAD
  - dRICH: Radiator characterization and SiPMs
- DAQ/DCS and Slow Control Software
- Simulation studies

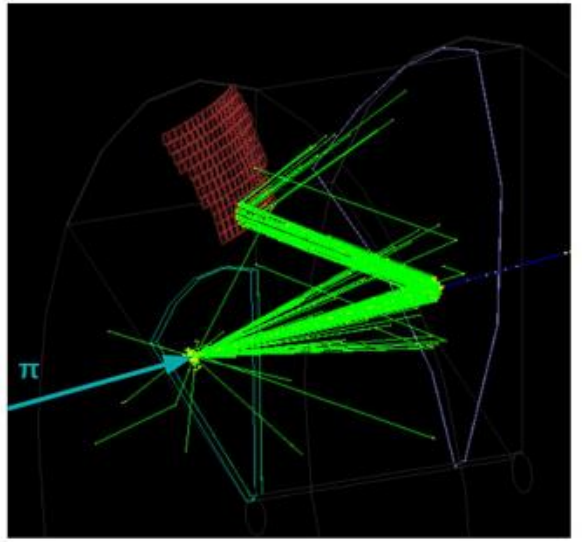
dRICH Requirements

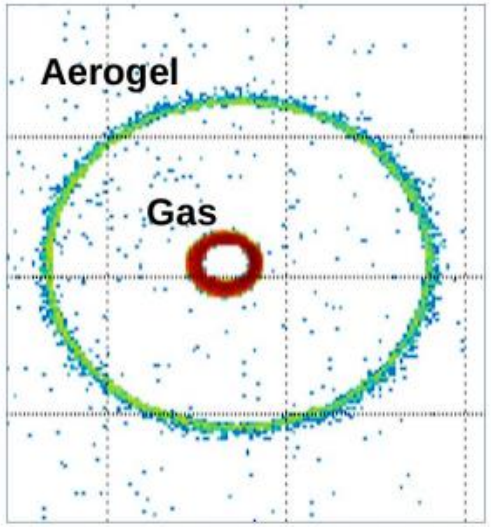
- **Requirements**
  - **Wide acceptance:** $(1.5 < |\eta| \leq 3.5)$
  - **High momentum coverage: upto** $50\ GeV/c$ $\pi - K$ separation.
  - **Dual Radiator RICH: (Aerogel n~1.02 + C_2F_6 gas n~1.0008)**
- **Large photo sensor surface to be covered in magnetic field.**
  - **Choice of Photo Sensor is SiPMs due to more number of detected photons.**

Our Interests

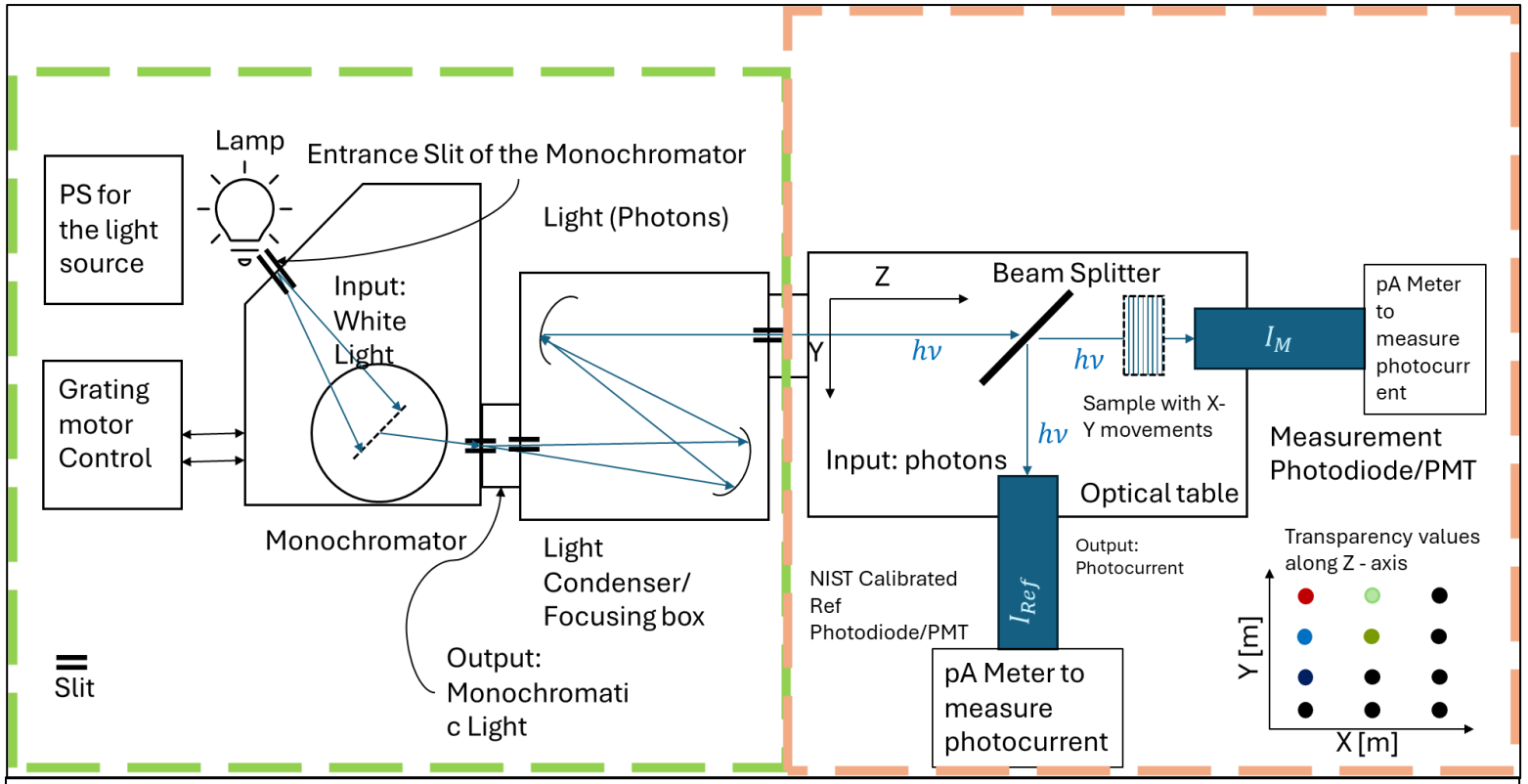
1. **Aerogel characterization**
   - I. **Study of refractive index uniformity.**
   - II. **Transmittance and reflectance studies.**
   - III. Raleigh scattering in UV domain, chromaticity.
   - IV. Aging effects due to water absorption: difference in response between different size and thickness of aerogel blocks.
2. **SiPM characterizations**
   - I. **PDE (normal value ~ 40%).**
   - II. **Dark count Suppression.**
   - III. Timing studies.
3. **Simulation studies.**







Typical Aerogel Characterization Setup



Transparency is the ratio of photocurrents with and without the object between the beam splitter and measurement detector ratio.

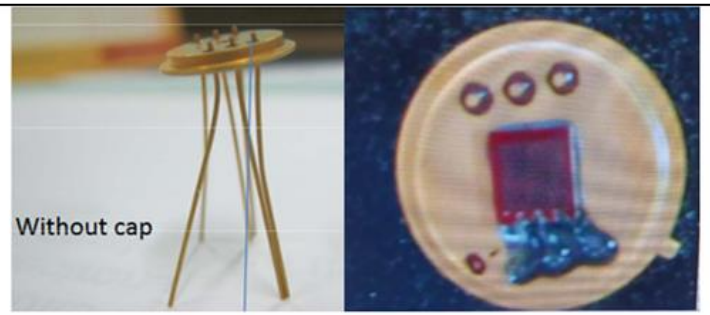
$$Transparency = \left[\frac{\{(I_M - I_{MDC})/(I_{Ref} - I_{RefDC})\}_{With\ Obj}}{\{(I_M - I_{MDC})/(I_{Ref} - I_{RefDC})\}_{WO\ Obj}}\right] \times 100\%$$

- This setup has synergies with ALICE3 pfRICH Aerogel characterization activities.
- Setup is ongoing. It will be ready in the 1.5-year timeline.

SiPMs in India

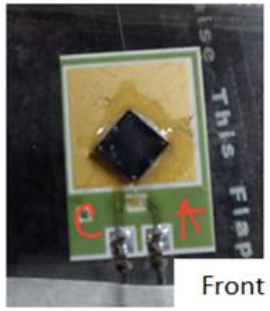
Two semiconductor fabs in India

- Semiconductor Lab (SCL) in Chandigarh, Punjab
- Bharat Electronics Ltd. (BEL) in Bengaluru, Karnataka

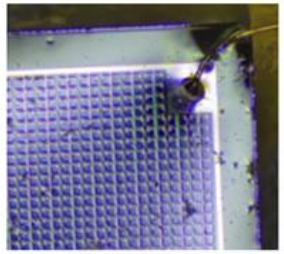


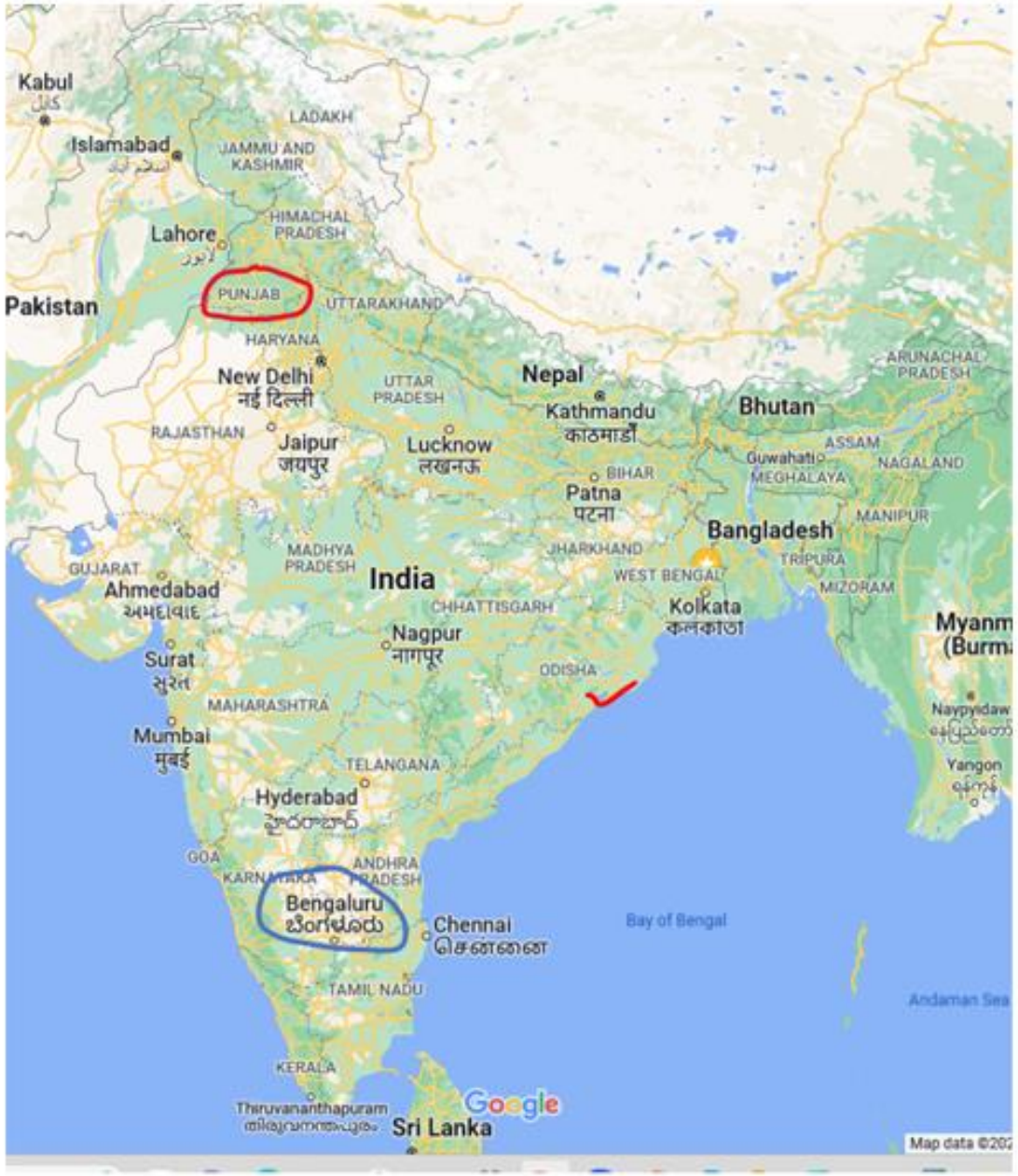
SCL sample
(epi., p-type)

Not to scale



BEL sample:
(Non-epi, n-type)





SiPMs in India

Sr. No	Parameter (targeted by design)	Specifications		
		BARC/SCL	SCL	BEL
1	Effective active area (mm^2)	1.5 x 1.5 & 3 x3	1.5 x 1.5	3.3 x 3.3
2	Micro-cell count	676 & 2704	1156	4836
3	Micro-cell size	50 x 50 μm^2	35 x 35 μm^2	
4	Micro-cell fill factor	20% & 75%	61%	55%
5	Capacitance (Cathode - anode)	1000 pF	~330 pF	~100pF/cell and (500 pF @25.5V)
6	Recharge time constant	120 ns – 150 ns	-	-
7	Spectral response range	350 nm – 900 nm	-	350 nm – 900 nm
8	Peak sensitivity wavelength	~ 500 nm	-	420 – 450 nm
9	Photon detection efficiency	-	-	-
10	Breakdown voltage (V_{BD})	22 V	18 V	23 V
11	Overvoltage range (OV)	2 V – 3 V	2.5 V	2 V – 5 V
12	Dark count rate	~ 500 kHz (@ V_{BD}+2.0 V and 0.5 p.e. thr.	20 Hz/ μm^2 at 1V OV	-
13	Gain	2 x 10^6 @ V_{BD}+1V	~ 10^6	~5.2 x 10^5 @V_{BD}+2V
14	V_{BR} temp. coefficient	20.0 mV/°C	15.0 mV/°C	-
15	Package type	LCC* 16, 20 pin	TO-8/6 pin	On PCB
16	Package dimension	~ 3.5 x 3.5 mm^2		
17	Dark current	< 5 nA/cm^2 @ 20V	< 10 nA/cm^2	-
18	Quenching resistor (R_q)	300-500 kΩ	360 kΩ	R_{sq} = 6.6 kΩ and R_q = ~ 32 MΩ
19	Cross-talk	< 5 % @V_{BD}+2.0 V	-	-

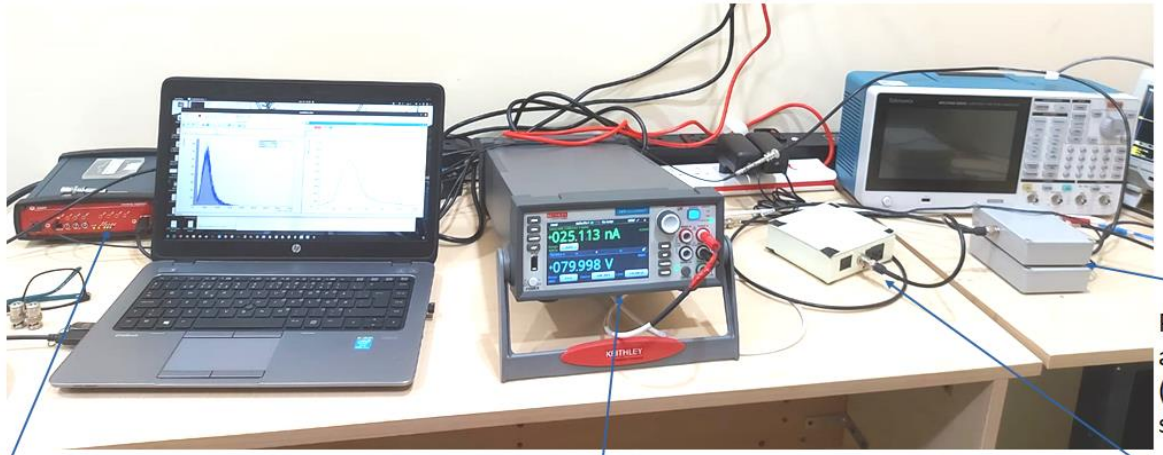
*Lead-Less Chip Carriers (LCC)

Sl No.	Sensitive area – 3 $mm \times 3$ mm, Pixel size – 50 $\mu m \times 50$ μm		
	Properties	On Semiconductor C – Series 30050	SCL Sample
1	Breakdown Voltage	24.2 V	22.0 V
2	No of Pixels	2668	2704
3	Fill factor	72%	75%
4	Gain	6×10^6 @ $V_{BD} = +2.5\ V$	~2×10^6 @ $V_{BD} = +1.0\ V$
5	Temperature dependence of V_{BD}	21.5 $mV/°C$	20.0 $mV/°C$
6	Capacitance (Cathode - Anode)	920 pF	1000 pF
7	Dark count rate	@ $V_{BD} = +2.5\ V$ Typ. 300 kHz	@ $V_{BD} = +2.0\ V$ Typ. 500 kHz
8	Cross Talk	@ $V_{BD} = +2.5\ V$ 10%	@ $V_{BD} = +2.0\ V < 5\%$

- Specifications are similar to some commercially available SiPMs

SiPM test setup at NISER

Test setup @ NISER: Few channels



Preamp (cremat 110) and Shaping amplifier (cremat 200) with shaping time 100 ns

CAEN Digitizer (DT5730) 8 ch, 14 bit resolution, 500 MS/s sampling rate, 2Vpp dynamic range With DPP firmware

Detector bias supply (Keithley 2470 SMU)

SiPM inside the detector box

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LED Driver available at NISER

SP5601

LED Driver

Request a quote

Manual Downloads

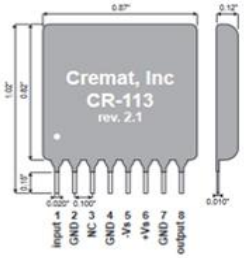
Features

- Pulse width: 8 ns
- LED color: violet (400 nm) 1500 mcd
- Pulse generator: internal/external
- Optical output connectors: FC
- Optical fiber included
- Dimension: 79 x 42 x 102 mm³ (WxHxD

- Cremat fast preamp order in process

Detector coupling

The CR-113-R2.1 can be used either in a direct coupled (DC) mode or an AC coupled mode. If the detector current exceeds



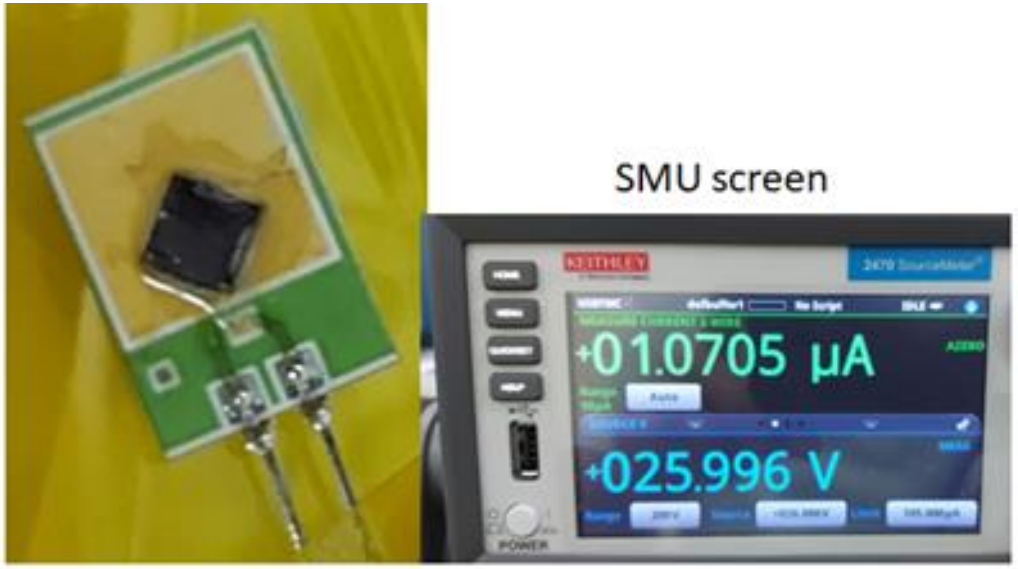
CAEN PETIROC based DAQ

- PETIROC-based test setup is at NISER
- CITIROC DAQ is under procurement

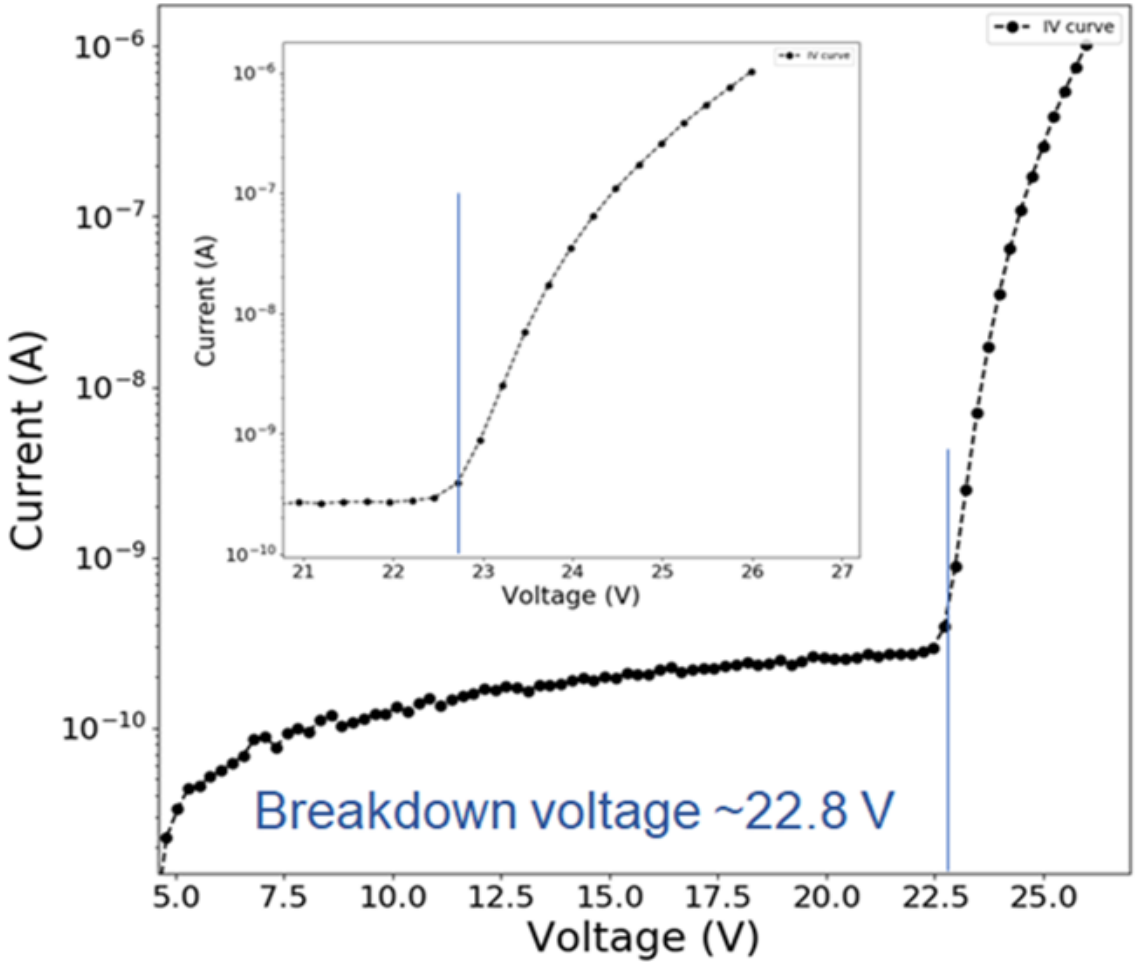
SiPM test results:

BEL Sample

- SiPM fabricated in CMOS 180 nm process
- SiPM was mounted on DIP package
  - Pixel size: $35 \times 35\ \mu m^2$;
  - Effective area: $3 \times 3\ mm^2$;
  - No. Of Cells: 4836;
  - Fill Factor: 55%; and
  - Breakdown voltage: $\sim 23\ V$;



- Connected in Reverse bias mode
- Reverse voltage applied using Keithley 2470
  - Sweep: 0 to 26 V with (0.25 V step)

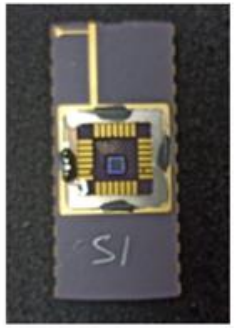


SiPM test results:

SCL Sample

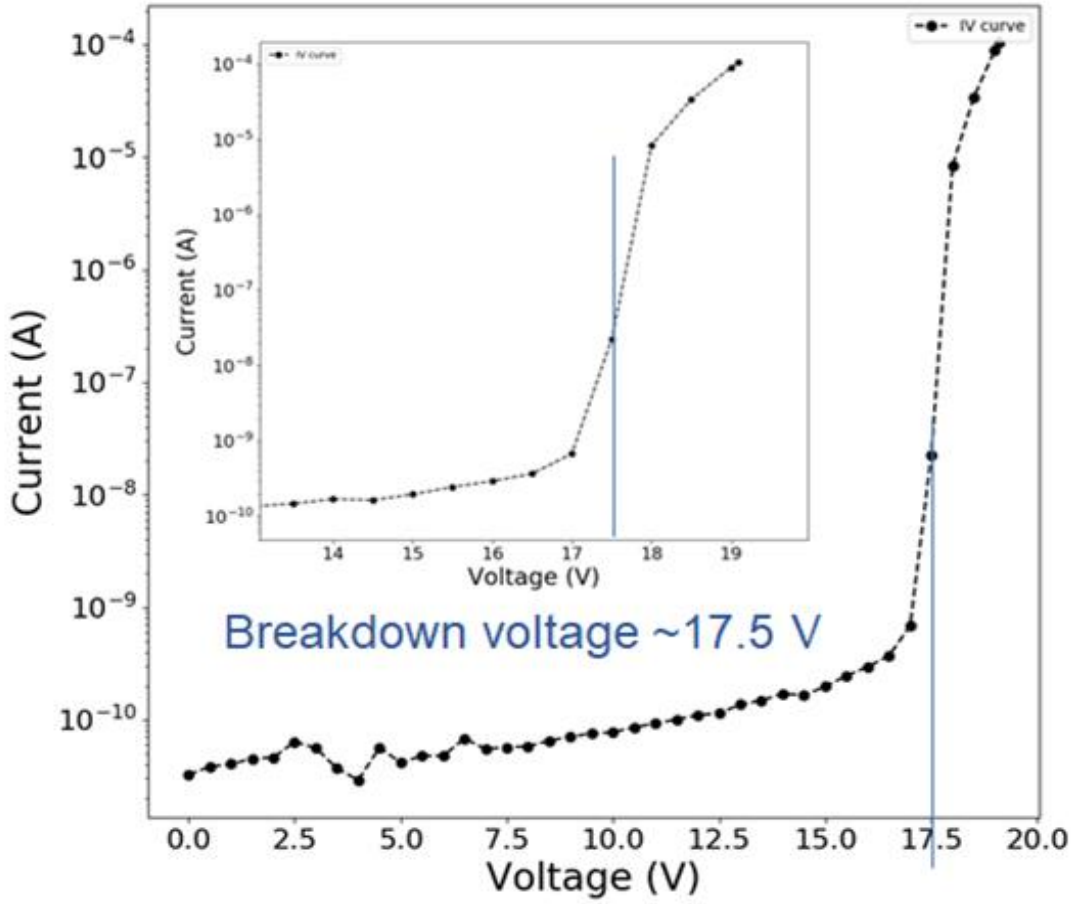
- SiPM fabricated in CMOS 180 nm process
- SiPM was mounted on DIP package
  - Pixel size: $35 \times 35\ \mu m^2$;
  - Effective area: $1.5 \times 1.5\ mm^2$;
  - No. Of Cells: 1156;
  - Fill Factor: 61%; and
  - Breakdown voltage: $\sim 17.5\ V$;

SiPM sample on DIP



SMU screen

- Connected in Reverse bias mode
- Reverse voltage applied using Keithly 2470
  - Sweep: 0 to 20 V with (0.5 V step)



SiPM Specifications for dRICH

SiPM technical specs

Slides presented by Roberto Preghenella from INFN Bologna on behalf of the dRICH Collaboration in TIC meeting, 6 November 2023: Slide Number 8.

baseline sensor device
64 (8x8) channel SiPM array
3x3 mm² / channel

Parameters	Value	Notes (all parameters at the recommended operating voltage and T = 25 C, unless specified)
Device type	SiPM array	
Number of channels	64	8 x 8 matrix
Active Area	3 x 3 mm²	active area of one channel, total active area is 64 x 3 x 3 mm²
Device Area	< 28 x 28 mm²	device area should be small such as to have > 75% fraction of active area over device total area
Pixel Size	40 - 80 um	pitch of the microcell SPAD
Package Type	surface mount	
Operating voltage	< 64 V	
Peak Sensitivity	400 - 450 nm	
PDE	> 35%	at peak sensitivity wavelength
Gain	> 1.5 10^6	
DCR	< 1.5 MHz	
Temperature coefficient of Vop	< 60 mV / C	
Direct crosstalk probability	< 10%	
Terminal capacity	< 600 pF	
Packing granularity		
Vop variation within a tray	< 300 mV	Vop variation between channels in one device
Recharge Time	< 100 ns	ctau recharge time constant
Fill Factor	> 70%	
Protective Layer	silicone resin (n = 1.5 - 1.6)	radiation resistant, heat resistant (up to T = 180 C)
DCR at low temperature	< 10 kHz	at T = -30 C
DCR increase with radiation damage	< 1 MHz / 10^9 neq	at T = -30 C, after a radiation damage corresponding to 10^9 1-MeV neutron equivalent / cm² (neq)
Residual DCR after annealing	< 25 kHz / 10^9 neq	at T = -30 C, after a radiation damage of 10^9 neq and a 150 hours annealing cycle at T = 150 C
Single photon time resolution	< 200 ps FWHM	corresponding to < 85 ps RMS

very important parameters to ensure detector performance over the years

we will evaluate as part of QA, testing sensor samples in received batches

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Ref: [20231106][EPIC][TIC] dRICH photosensor status (bnl.gov)

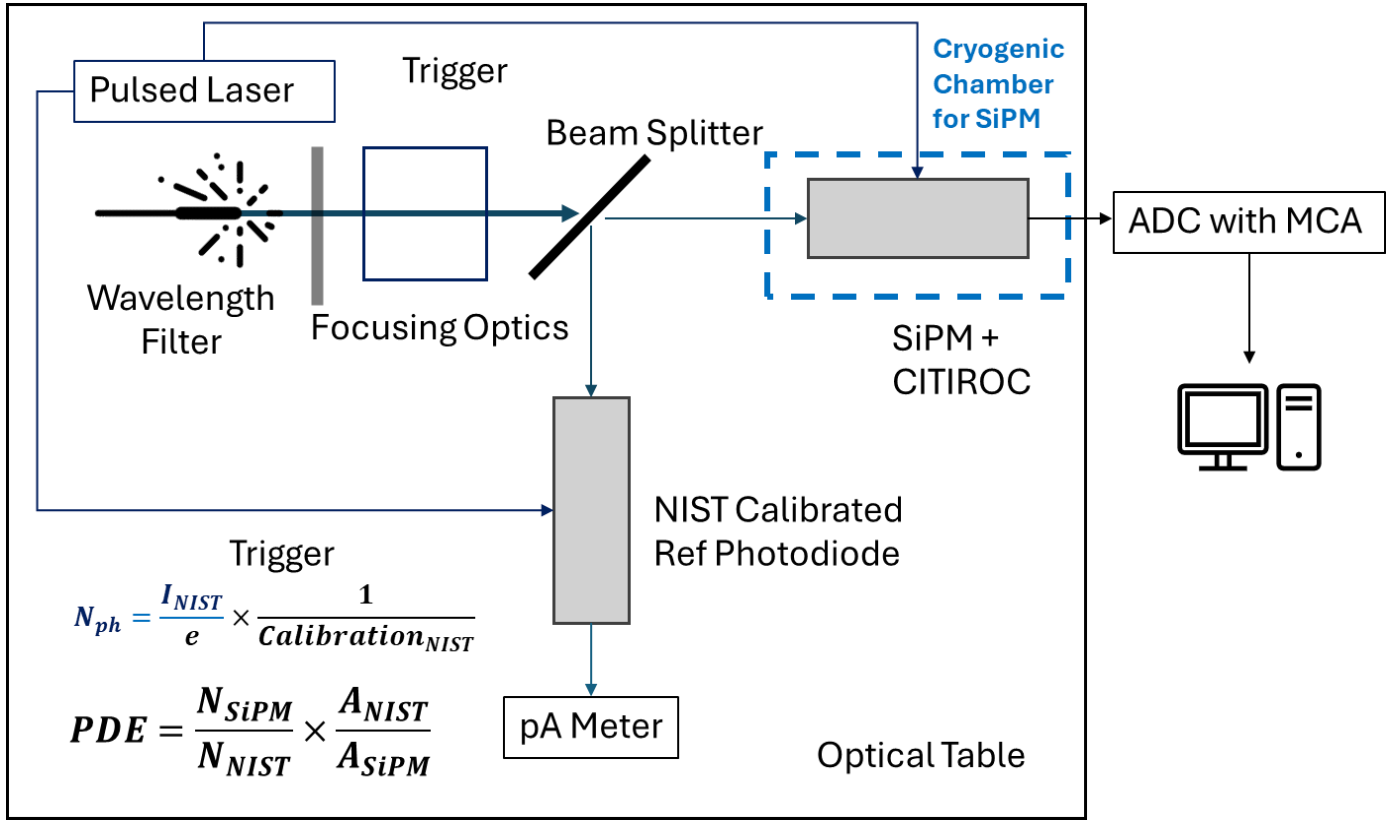
SiPM Specifications

Parameters	**dRICH (array of 8x8 with TSV)**	**FW EMCal (Hamamatsu S12572-015P) - Japan**	**SCL/BARC (India)**
Active area	3x3 mm^2	3x3 mm^2	1.5x1.5 mm^2 / 3x3 mm^2
No. of Pixels	4000 – 1000	40,000	1156 / 2704
Peak wavelength	400-450 nm	460 nm	500 nm
Pixel pitch	40-80-µm	15-µm	50-µm
Photon detection efficiency (PDE)	35%	25%	unmeasured
Gain	>1.5x10^6	2.3x10^5	~10^6
Fill factor	>70%	53%	61% / 75%

SiPM in India: Future Setup

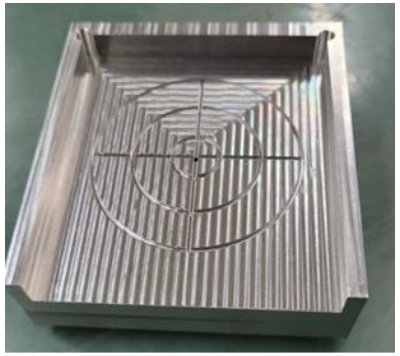
- Photo Detection Efficiency (PDE) measurement setup under preparation.
- New designs and ideas are under way as this work is in synergies with ALICE3 barrel pfRICH activities.

Possible SiPM characterization setup

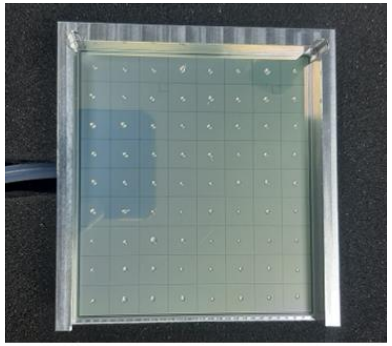


Si PAD Array detector in India

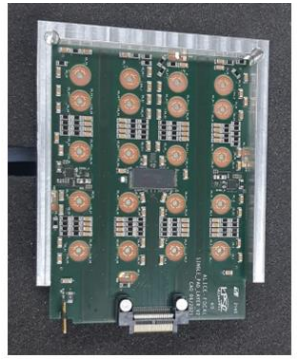
- India is currently part of ALICE FoCAL upgrade and developing Si PAD Array detectors.
- Currently n – type 8×9 Si pad arrays are fabricated in BEL, Bengaluru, India and has been tested in the lab and in Test Beam facility at CERN



Jig, holds detector with vacuum



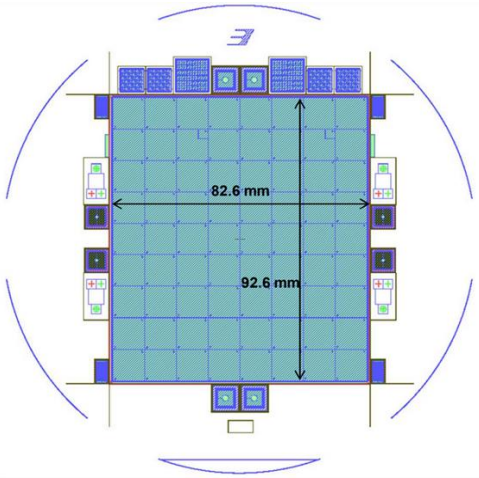
Detector in jig
Then add glue dots at the center of each pad

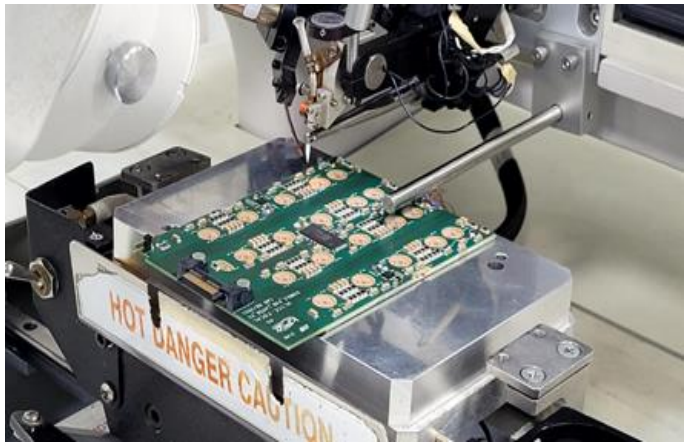


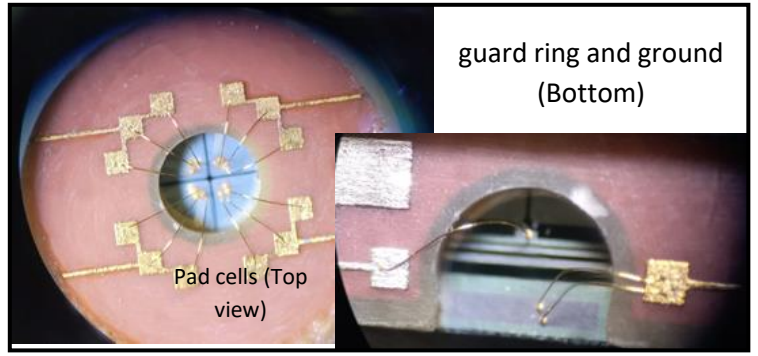
Place PCB on top of the detector and add some weight and keep it overnight

- Wafers glued to PCB
- Used automated wire bonding (~250 wire bonds per detector)
- The jig was kept at 90 degree C while wire bonding

High resistivity (~7kohm.cm), ~325 um thick Si wafer

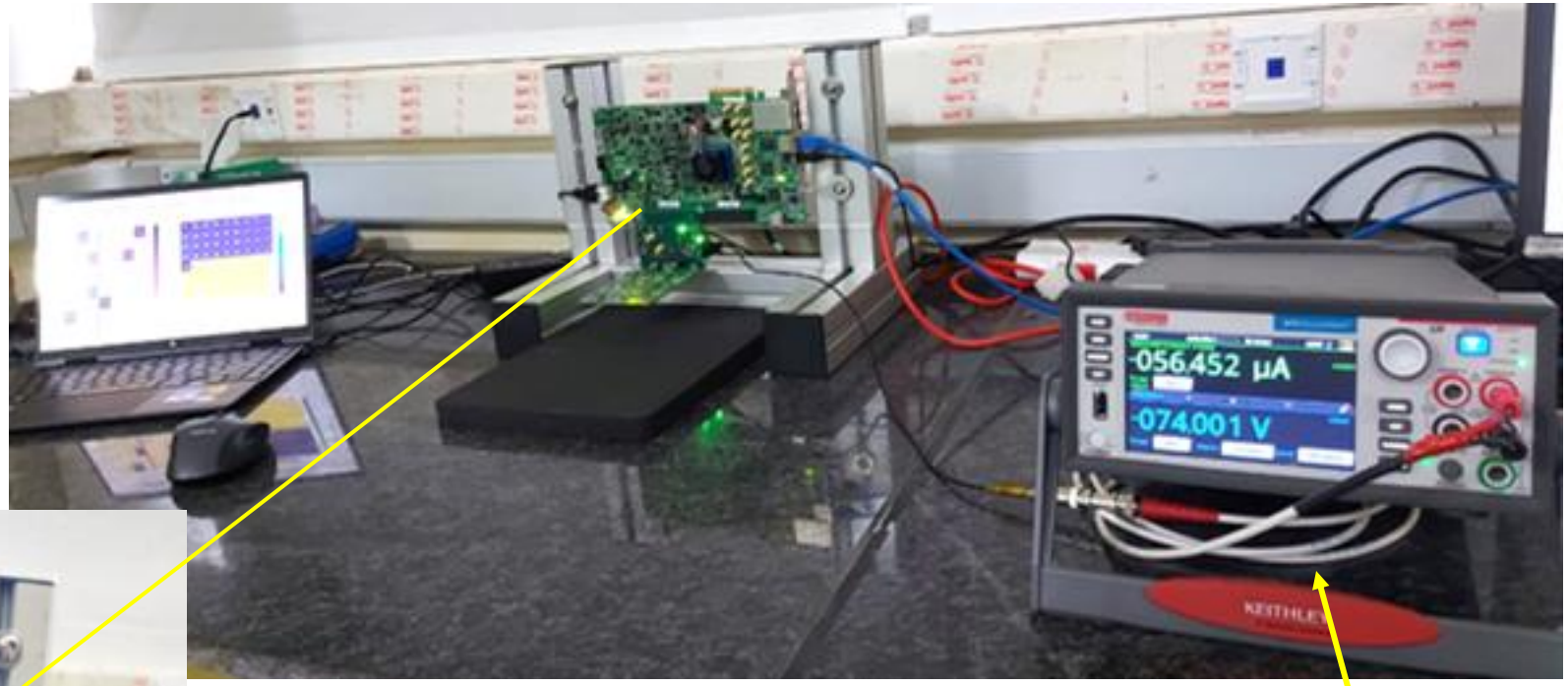




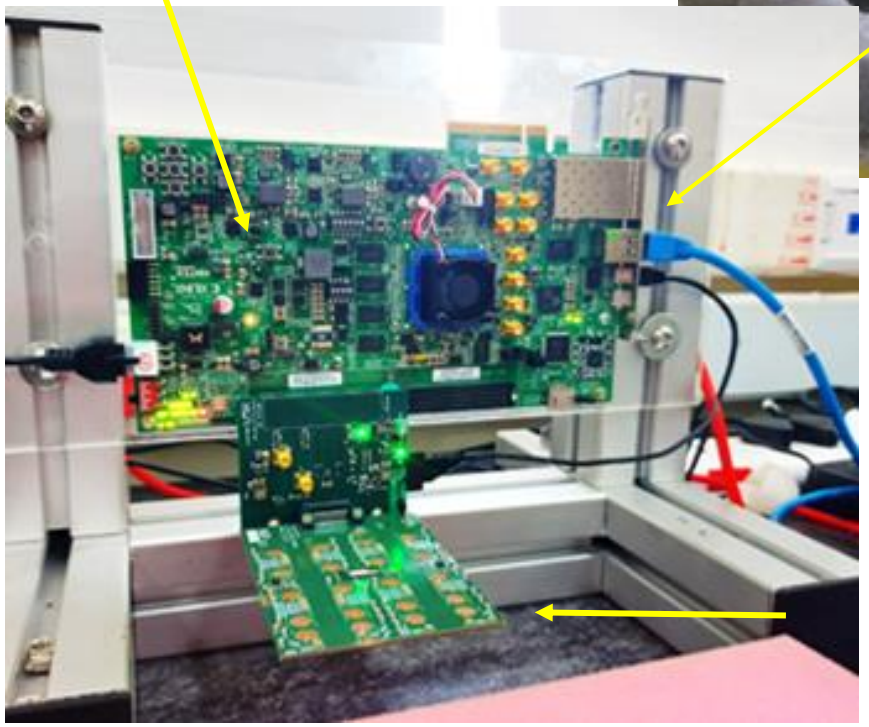


Si pad array detector readout printed circuit board fabricated by Micropack Private Limited, Bangalore, India

Test setup



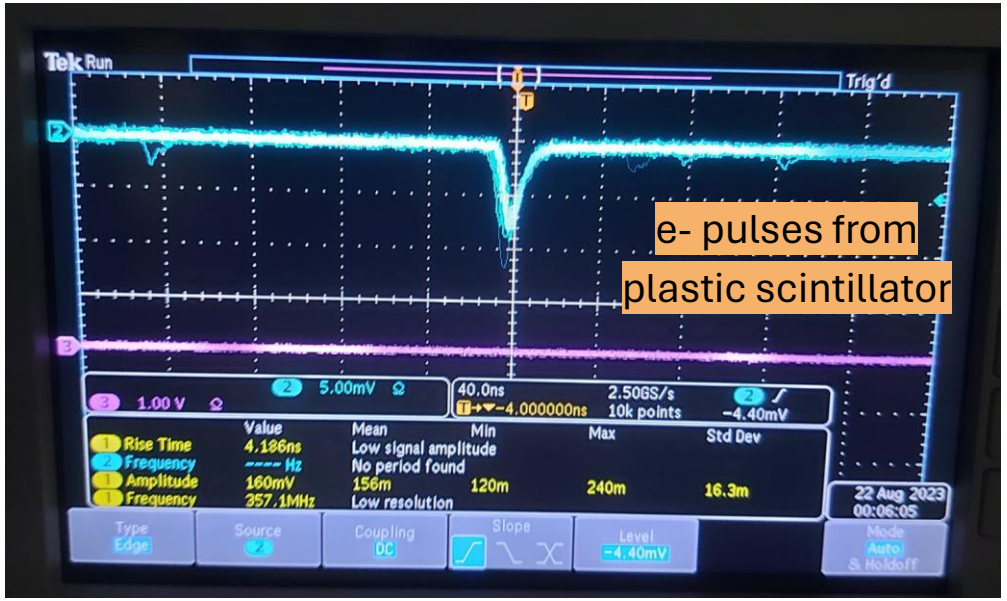
DAQ board



Detector bias
Power supply

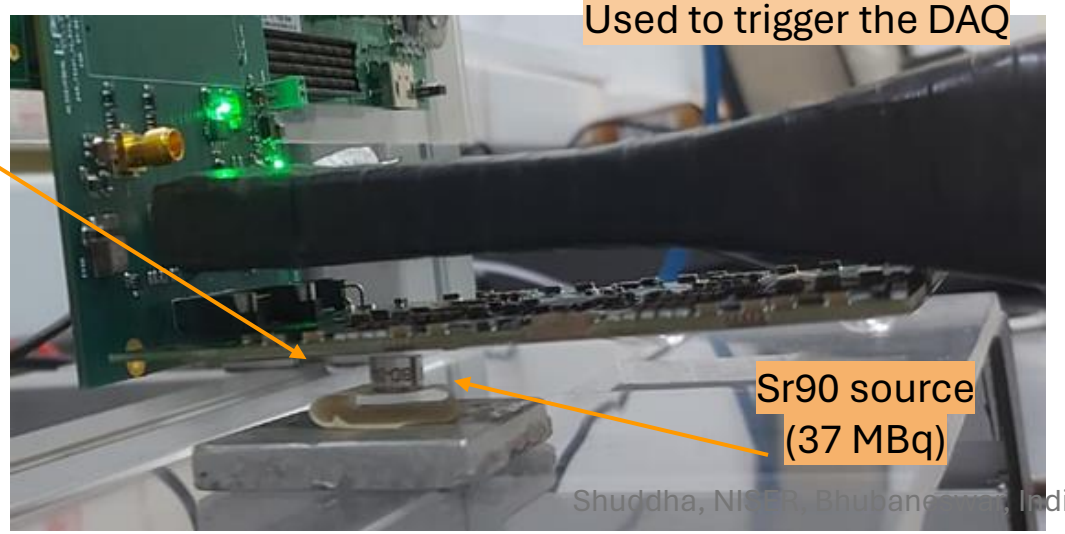
Detector connected
with HGCROCv2 PCB

Test setup: detector response to Sr90 source

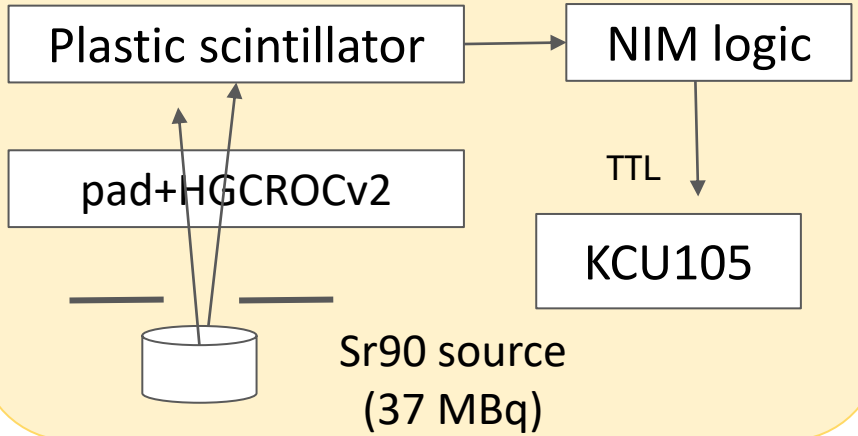


Plastic scintillator
Used to trigger the DAQ

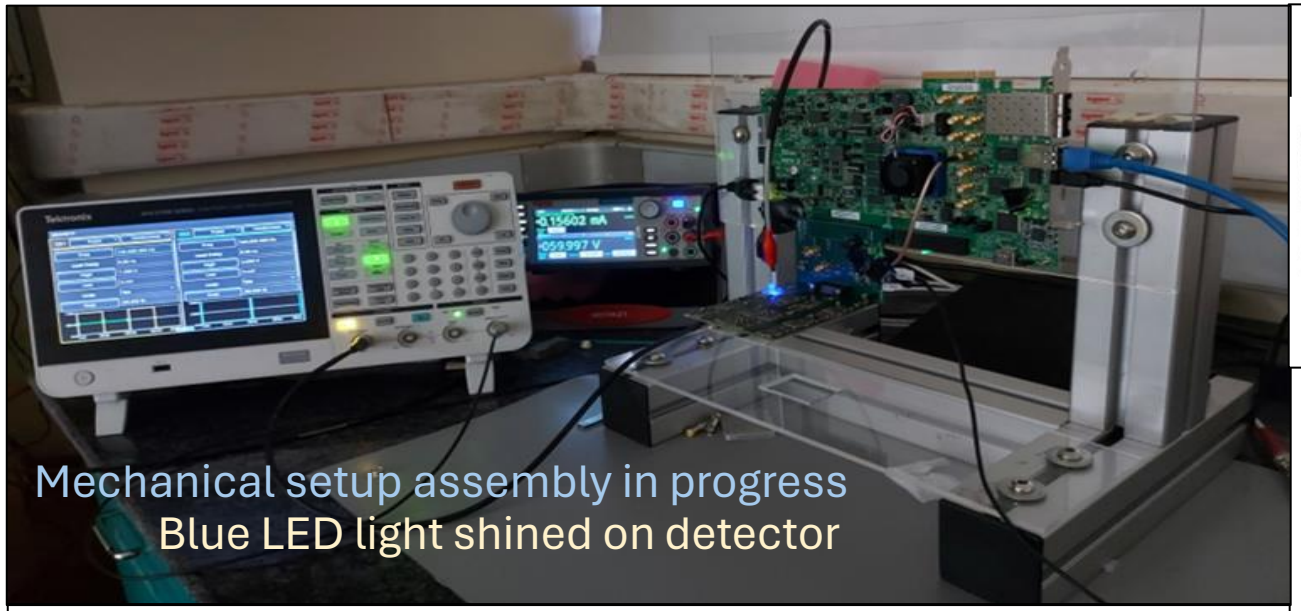
Detector connected
with HGCROCv2 PCB

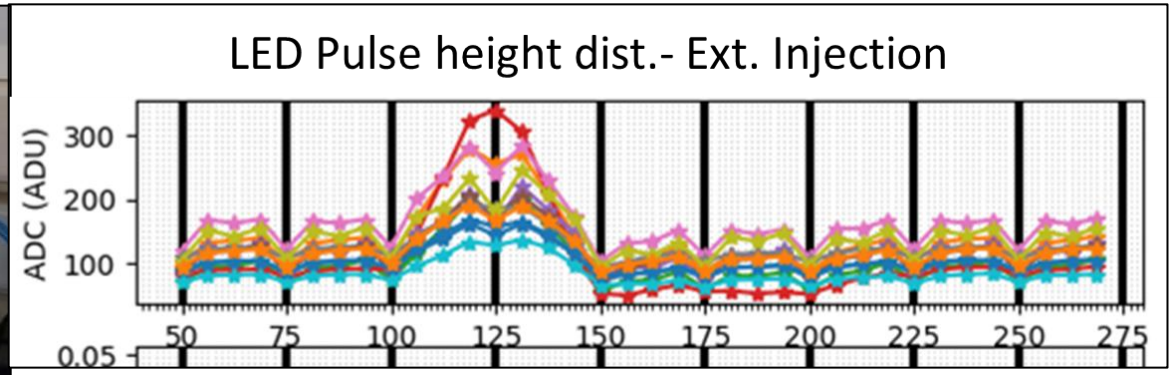


Schematic

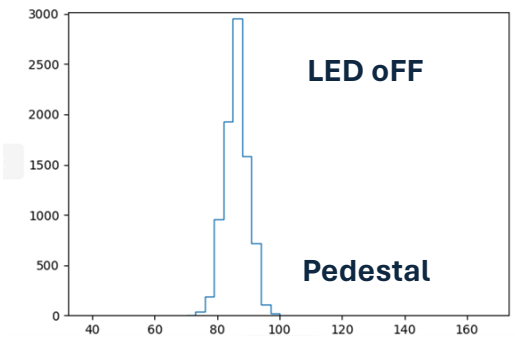


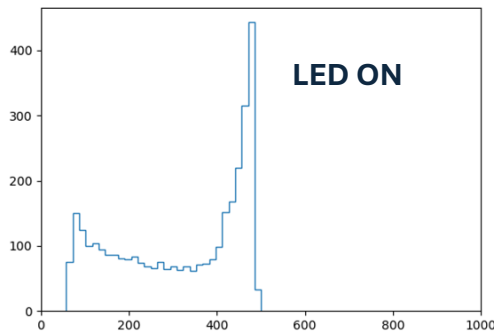
Si PAD Array detector in India: Lab tests at NISER



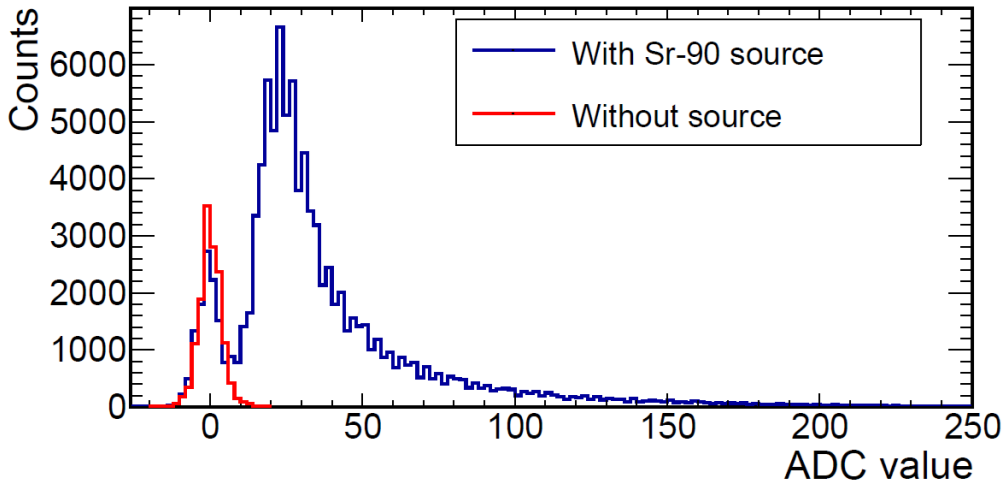


LED pulse amplitude distribution





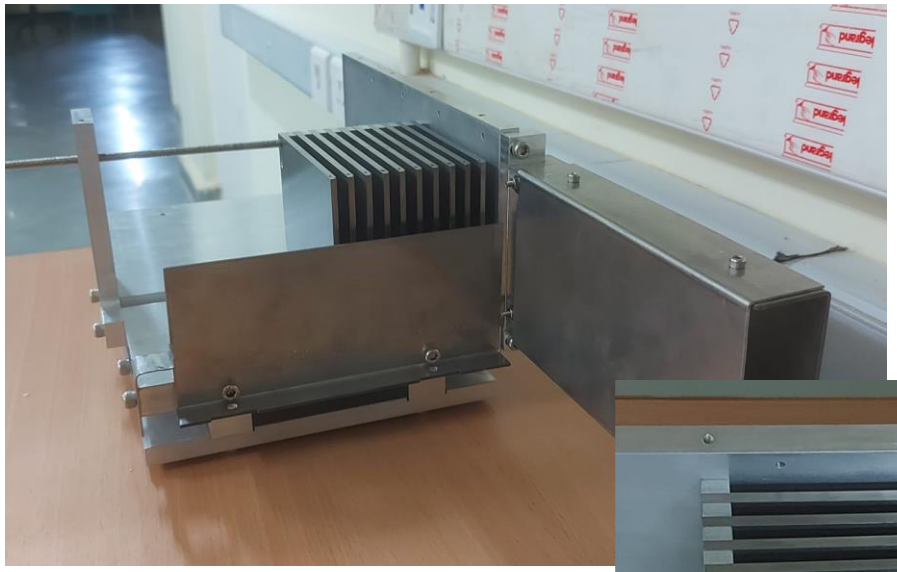
Bias = 75V

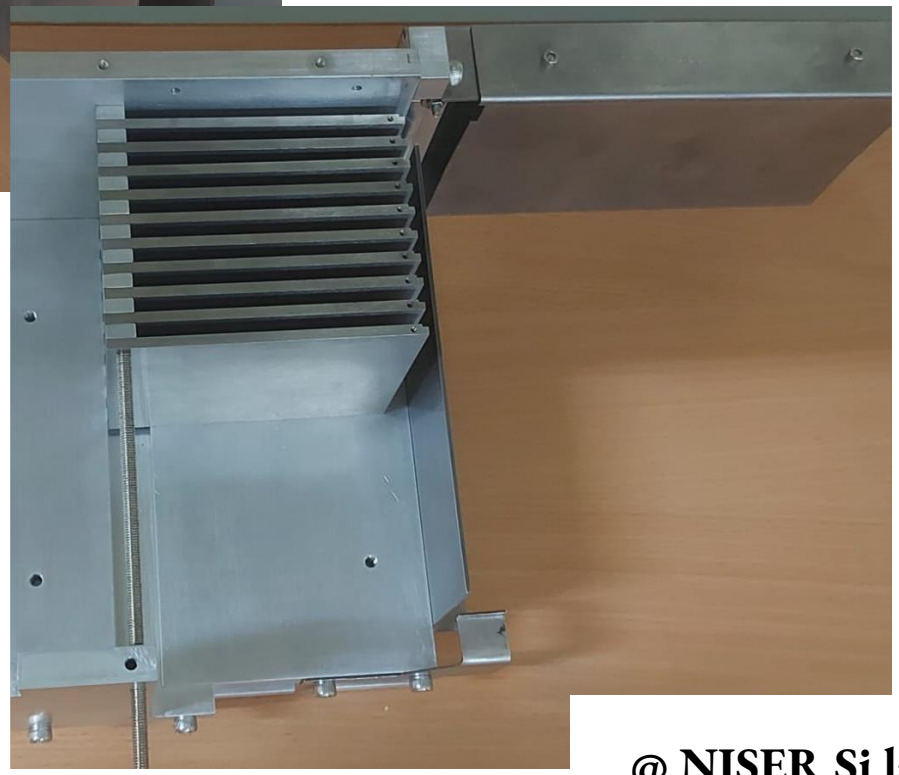


Mechanical setup assembly for test beam at CERN

@ NISER Si lab, made by Central workshop NISER

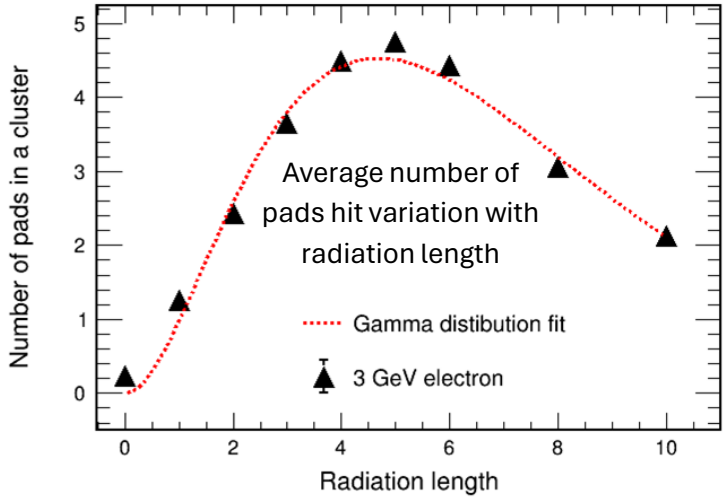
Mechanical setup assembly for test beam at CERN

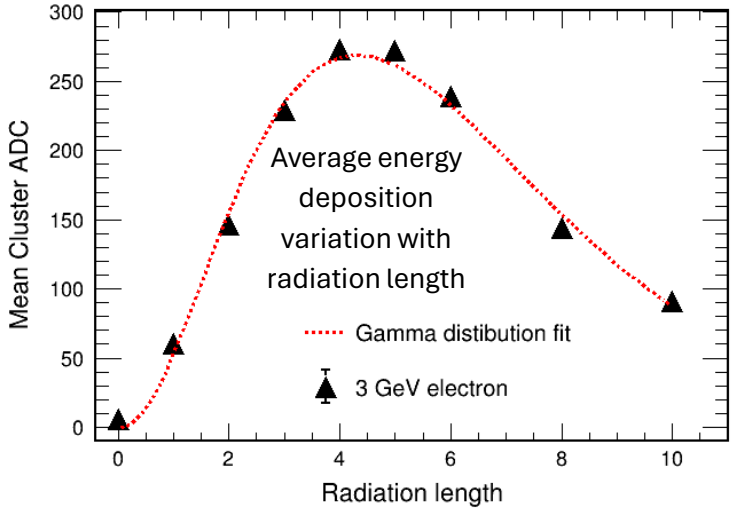


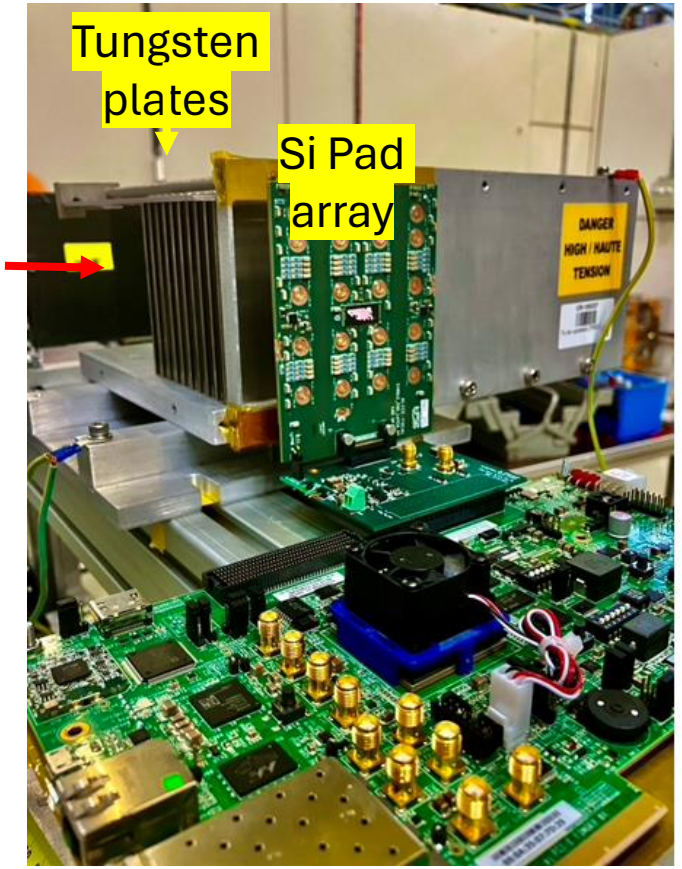


@ NISER Si lab, made by Central workshop NISER

Alice FoCAL test beam at CERN PS T9

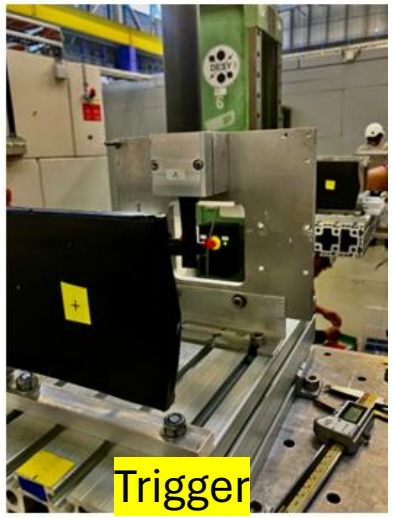


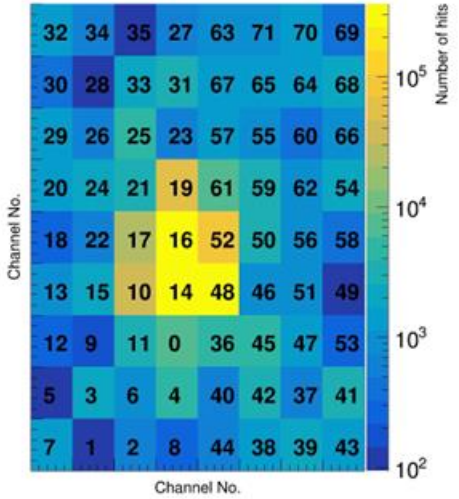




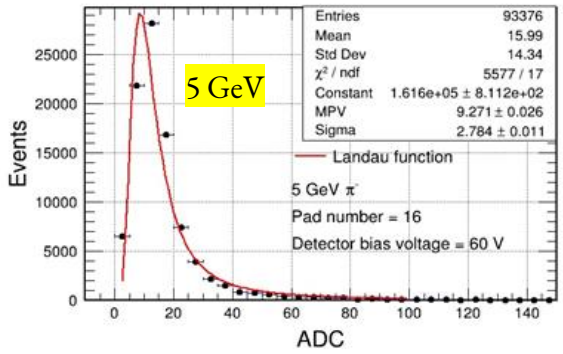
6 days beam time: (11.10.2023 to 18.10.2023)

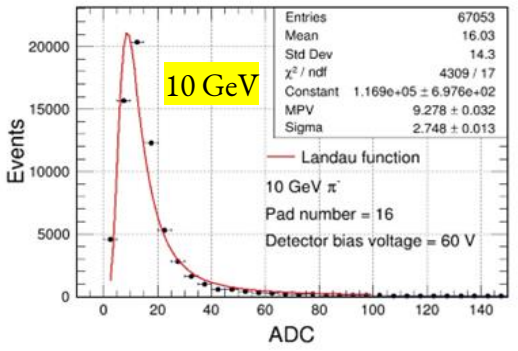
- 5 GeV, 10 GeV and 15 GeV pion(-ve) runs to record MIP response
- Position Scan of each pad element of pad array and Bias voltage scan
- 1- 5 GeV (step of 1) e- beam with Cherenkov trigger 6 to 1 tungsten plates to measure electron

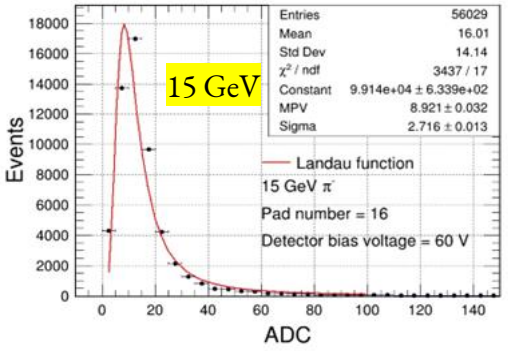




10 GeV pion beam Hit Map

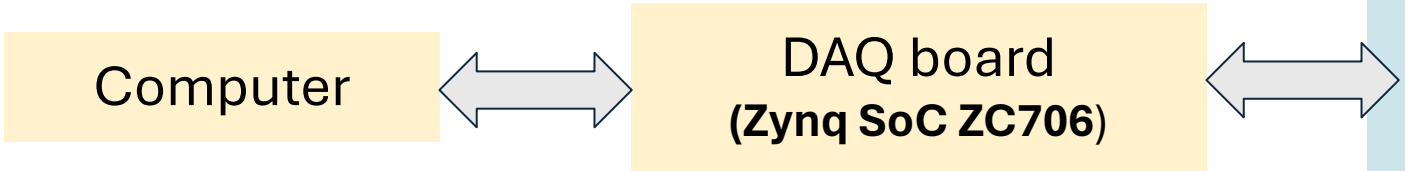


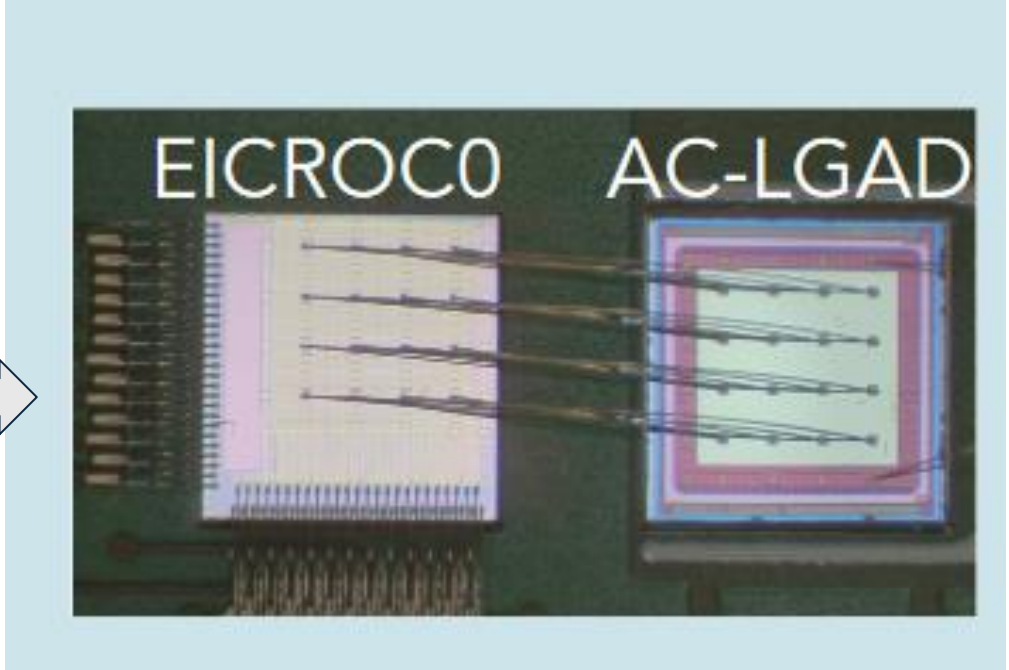




AC – LGADs test setup preparation

- Interested to contribute mostly to test and characterization work of AC-LGADs and readout ASIC (EICROC)
- Plan to purchase test equipment such as,
  - Zynq evaluation board (ZC706), Picosecond laser, high-precision oscilloscope (e.g. LeCroy 9404M-MS 4 GHz, 40 GS/s)
- Earlier experience:
  - SAMPA readout chip for ALICE TPC
  - HGCROCv2 ASIC for ALICE FoCal





DAQ/DCS Slow Control contribution

Crucial input to the DAQ team: Background rates of each detector arising out of various sources.
Used for: Calculating data volumes and corresponding bandwidths

CUK: Estimation of background rates due to synchrotron radiation

Ran simulation for two different setups (with gold and without gold coating) and analyzed the photon and electron counts for a specific beam current.

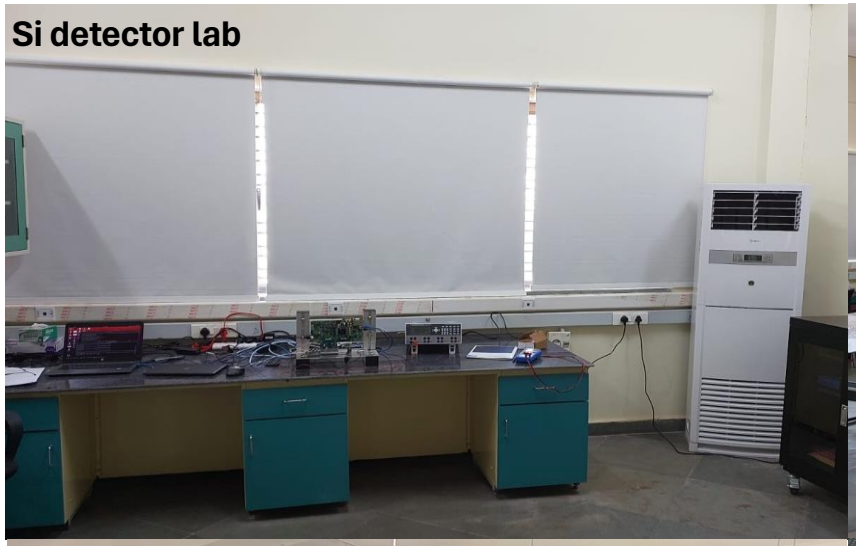
Results were used in ATHENA white paper to calculate maximum data volumes

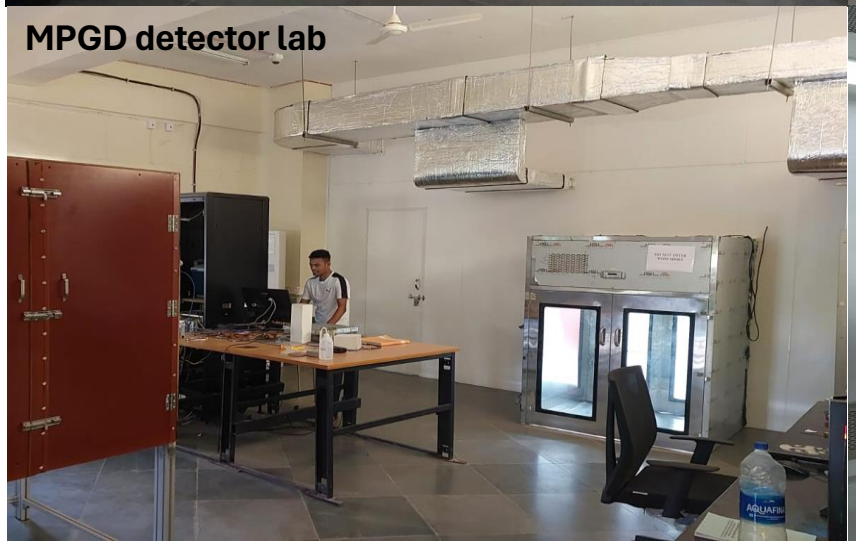
Adam, J., et al. *Journal of Instrumentation* 17, P10019 (2022)

Table 7: Maximum data volume by detector.

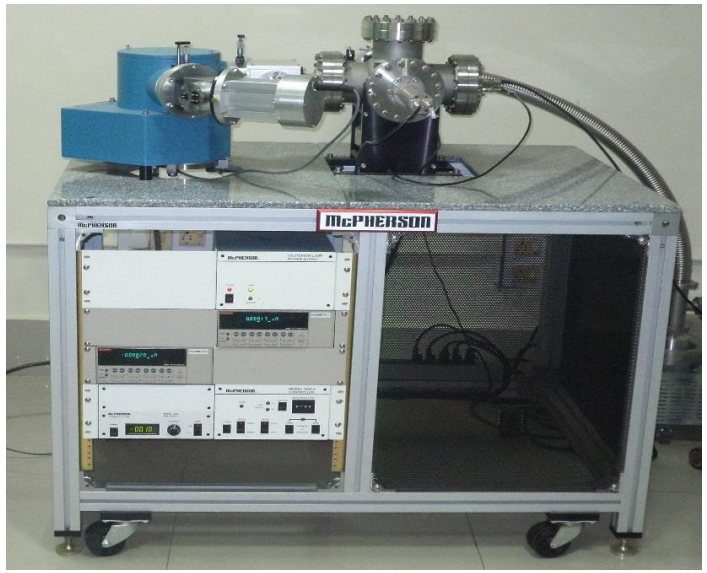
Detector	Channels	DAQ Input (Gbps)	DAQ Output (Gbps)
B0 Si	400M	<1	<1
B0 AC-LGAD	500k	<1	<1
RP+OMD+ZDC	700k	<1	<1
FB Cal	4k	80	1
ECal	34k	5	5
HCal	39k	5.5	5.5
Imaging bECal	619M	4	4
Si Tracking	60B	5	5
Micromegas Tracking	66k	2.6	.6
GEM Tracking	28k	2.4	.5
µRWELL Tracking	50k	2.4	.5
dRICH	300k	1830	14
pfRICH	225k	1380	12
DIRC	100k	11	11
TOF	332k	3	.8
Total		3334	62.9

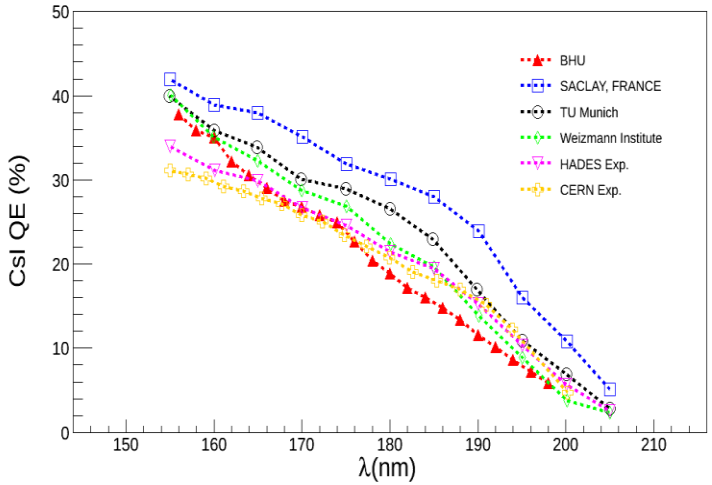
Facilities at NISER



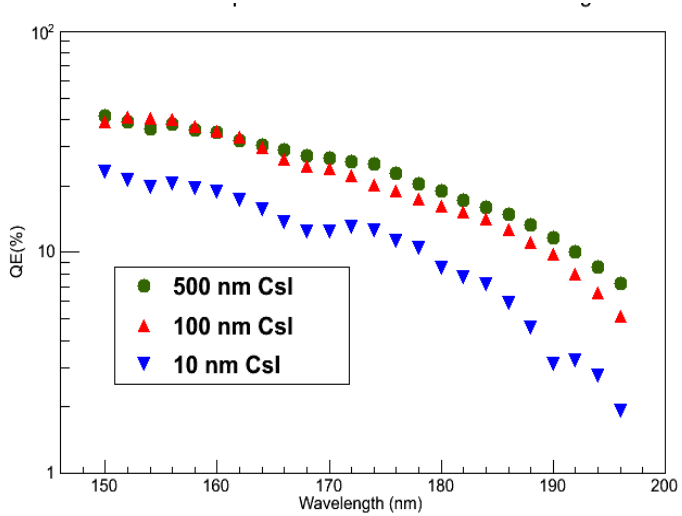


BHU: 302/234 VUV Monochromator – QE measurement:

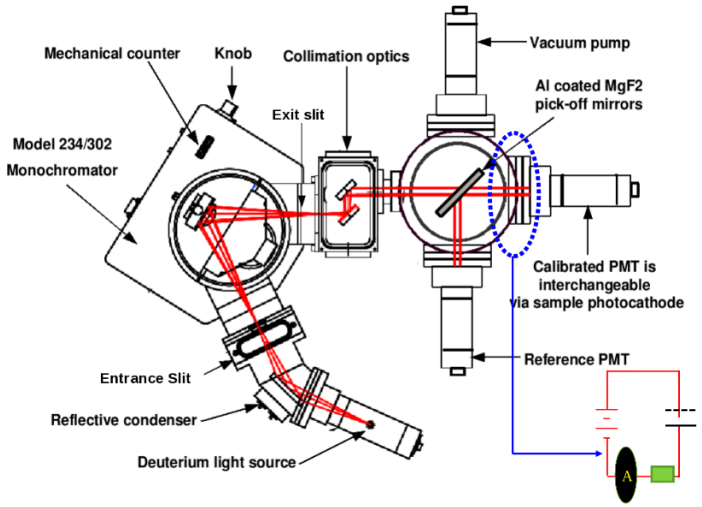




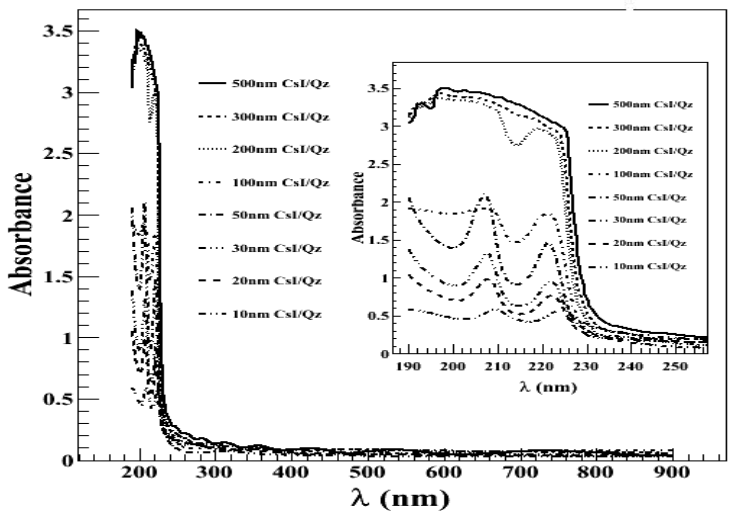
Comparative QE results of 500 nm thick CsI photocathode.



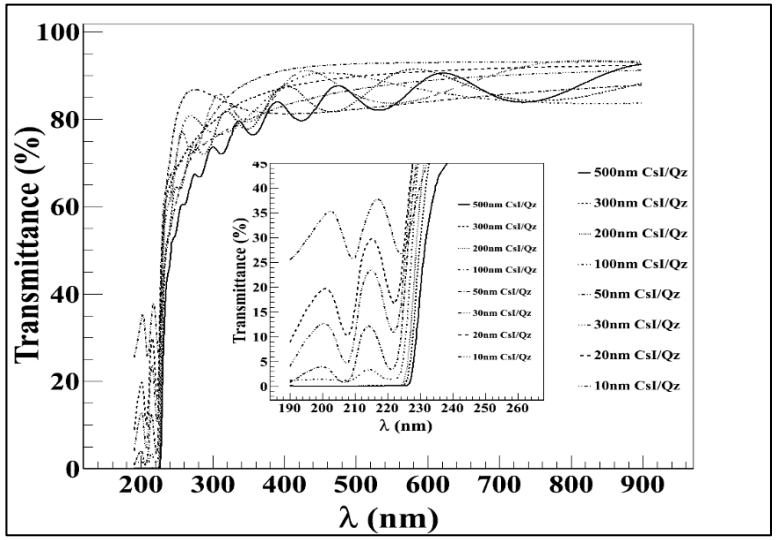
QE as a function of thickness for CsI thin film photocathodes.



Real view (top panel) and schematic diagram (bottom panel) of 0.2-meter VUV monochromator.



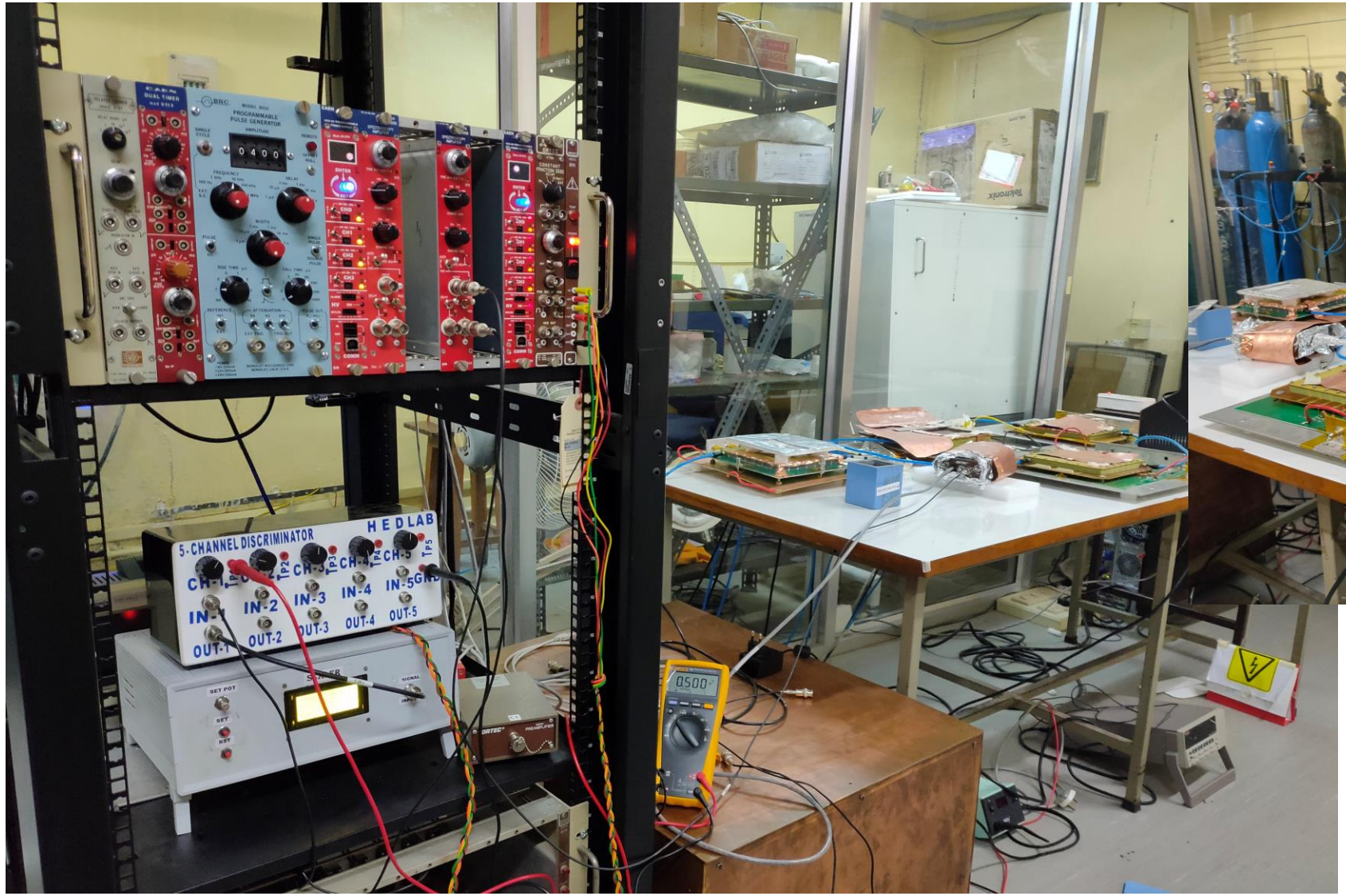
Absorbance of CsI thin film photocathodes deposited on quartz substrate.



Transmittance of CsI thin film photocathodes deposited on quartz substrate.

Facility at IoP Bhubaneswar

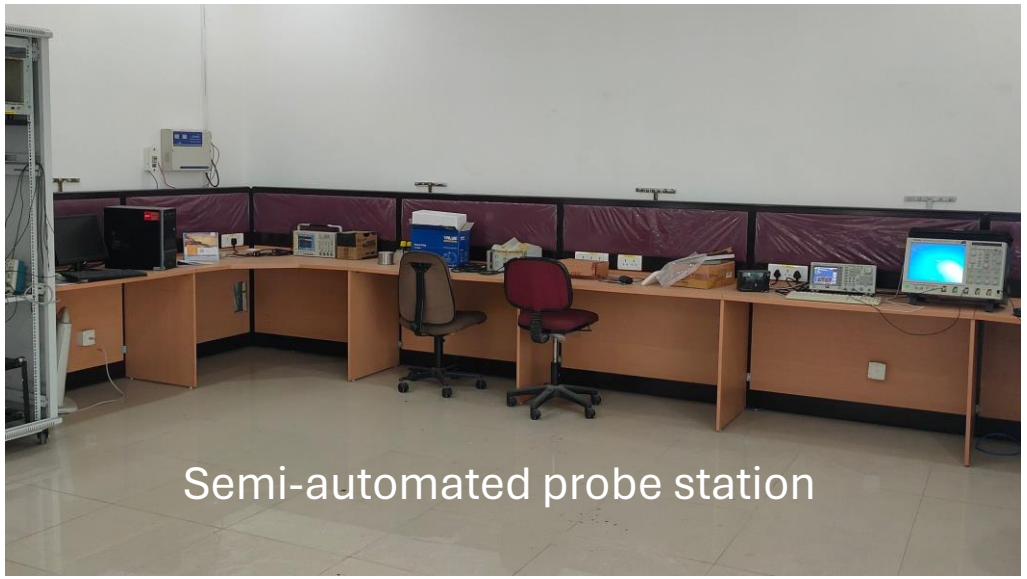
Available Setup in IoP Bhubaneswar, India



- A dedicated 150 ft^2 clean room for detector assembly is available.

P.C. Dr. Rupamoy Bhattacharya, Institute of Physics, Bhubaneswar, India

Facilities at University of Jammu



Silicon detector testing facilities

- Two Detector laboratories (area ~100 sq m, ~ 100 sq m)– one with a clean room.
- Facilities for Silicon and Gas detector testing and characterizing
  1. Semi-automatic Probe Station
  2. LabView for interfacing different instruments
  3. For Noise and I-V test: LV and HV Power supply, Kiethley source meter (mod 2410), LCR meter, Oscilloscopes
  4. For Efficiency and spectrum study: Low-rate radioactive sources (beta, gamma), Scintillator paddle detectors (2), HV module (1) (mod CAEN 470, 4 Ch), HV crate (SY2527), Pre-Amp (2), Amplifier, MCA, TAC, Discriminator, Delay module, NIM logic modules, NIM crates(2), ORTEC MASTERO DAQ, VME crates and modules

Suggestions from ePIC management

- **Recently (last week), we received some suggestions from ePIC managements about possible participation topics:**
  - Forward EM Calorimeter.
  - AC – LGAD assembly and test facilities for Forward ToF.
  - dRICH studies.
  - Software for streaming DAQ studies.
- **We are discussing within EIC India about the possible contributions.**

Summary

- Thanks to DAE, DST, and the EIC community for their support.
- EIC India group interests in hardware is being defined.
- The funding proposal is in progress.
- The interests are
  - dRICH aerogel characterization
  - SiPM studies for dRICH and Forward EM Calorimeter
  - DAQ/DCS
  - Software and Simulation studies

THANK YOU

BACK UP

SiPM Specifications

Parameters	Value (dRICH)	Value (SCL)
Device Type	SiPM array	SiPM
Number of Channels	64	1
Active Area	$3 \times 3\ mm^2$	$3 \times 3\ mm^2$
Device Area	$< 28 \times 28\ mm^2$	$\sim 3.5 \times 3.5\ mm^2$
Pixel Size	$40\ -80\ \mu m$	$50\ \mu m$
Package Type	Surface mount	LCC* 16, 20 pin
Operating Voltage	$< 64\ V$	Break Down Voltage $V_{BD} = 22\ V$
Peak Sensitivity	$400\ -450\ nm$	$500\ nm$
PDE	$> 35\%$	---
Gain	$> 1.5 \times 10^6$	$2 \times 10^6 @\ V_{BD} + 1V$
DCR	$< 1.5\ MHz$	$\sim 500\ kHz\ @V_{BD} + 2.0\ V\ and\ 0.5\ p.e.thr$
Temperature coefficient of V_{OP}	$< 60\ mV/°C$	$V_{BD} < 20.0\ mV/°C$
Direct crosstalk probability	$< 10\%$	$< 5\% @ V_{BD} + 2.0\ V$
Terminal Capacity	$< 600\ pF$	$1000\ pF$
Packaging granularity		
V_{OP} variation within a tray	$< 300\ mV$	
Recharge Time	$< 100\ ns$	
Fill Factor	$> 70\%$	75%
Protective Layer	Silicon resin ($n = 1.5\ -1.6$)	
DCR at low temperature	$< 10\ kHz$	$Dark\ current < 5\ nA/cm^2$
DCR increase with radiation damage	$< 1\ MHz/10^9 neq$	---
Residual DCR after annealing	$< 25\ kHz/10^9 neq$	---
Single photon time resolution	$< 200\ ps\ FWHM$	---

FW ToF Assembly Flow

AC-LGAD + ASIC
Bump bonding

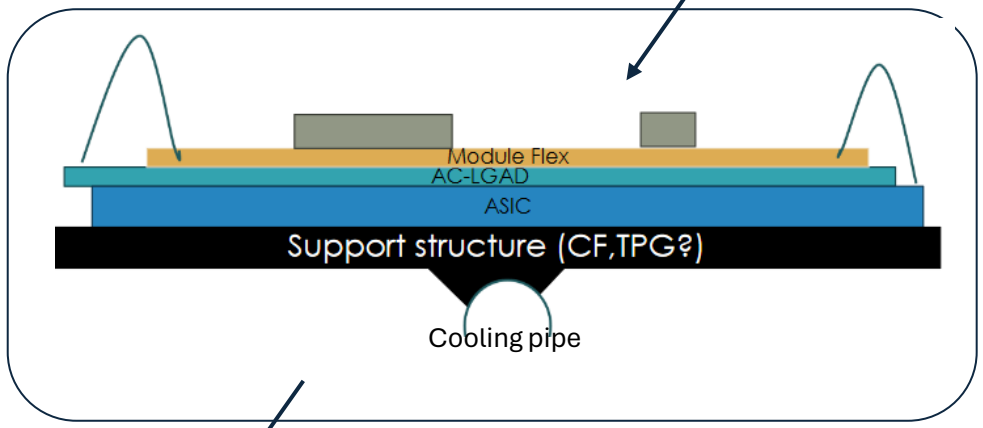
ASIC to Flex
100+ wire bonds

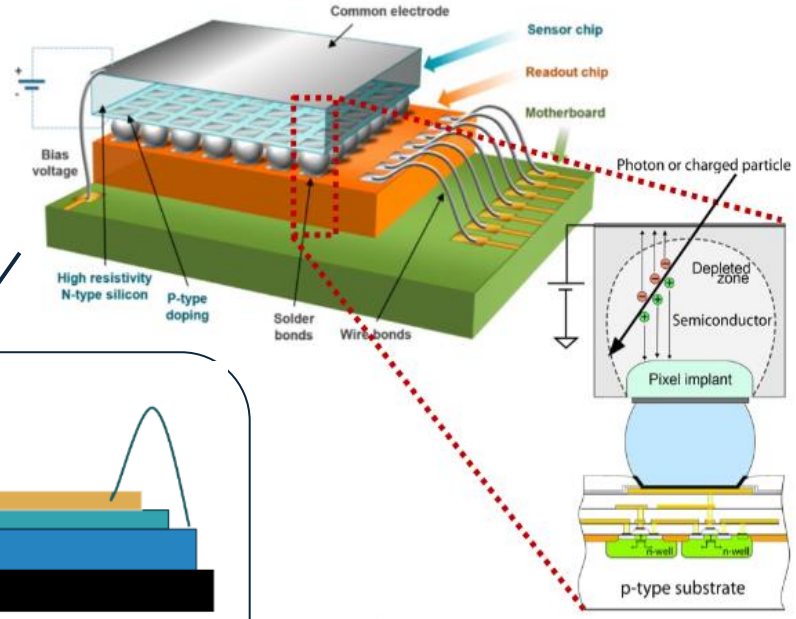
Flex connection
to
Service Hybrid
(Readout and power board)

connector

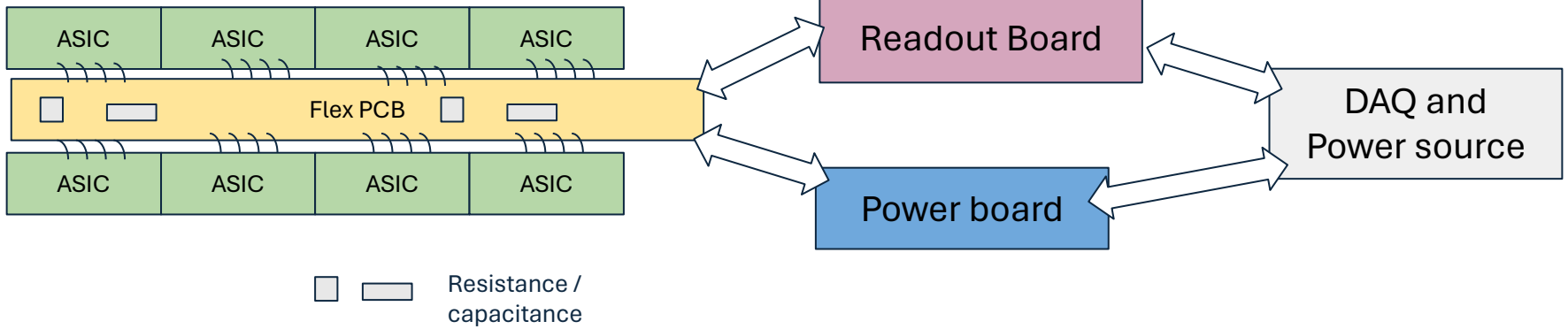
DAQ and Power source
Optical links and connectors

AC-GAD + ASIC
32x32 ch or 64 x32 ch





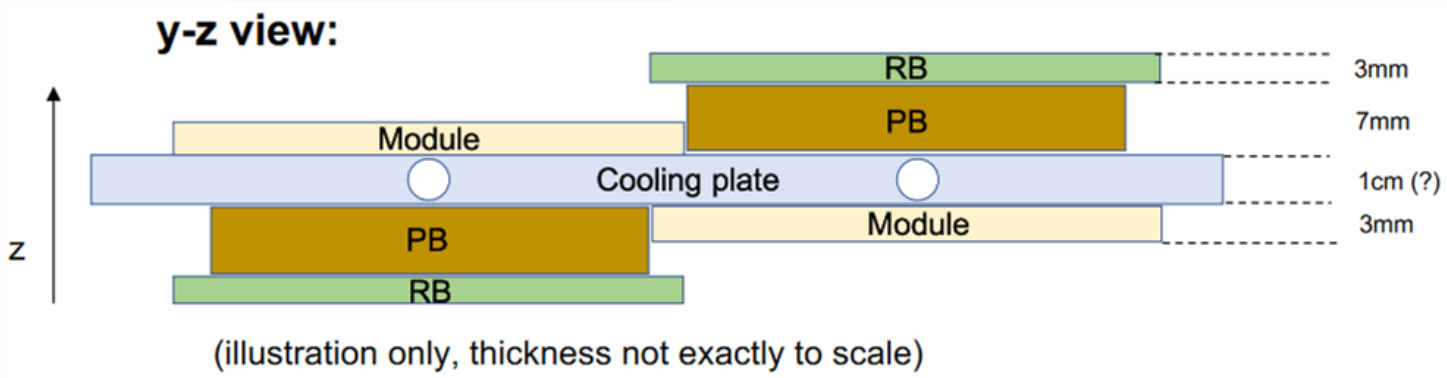
AC-GAD + ASIC
32x32 ch or 64 x32 ch

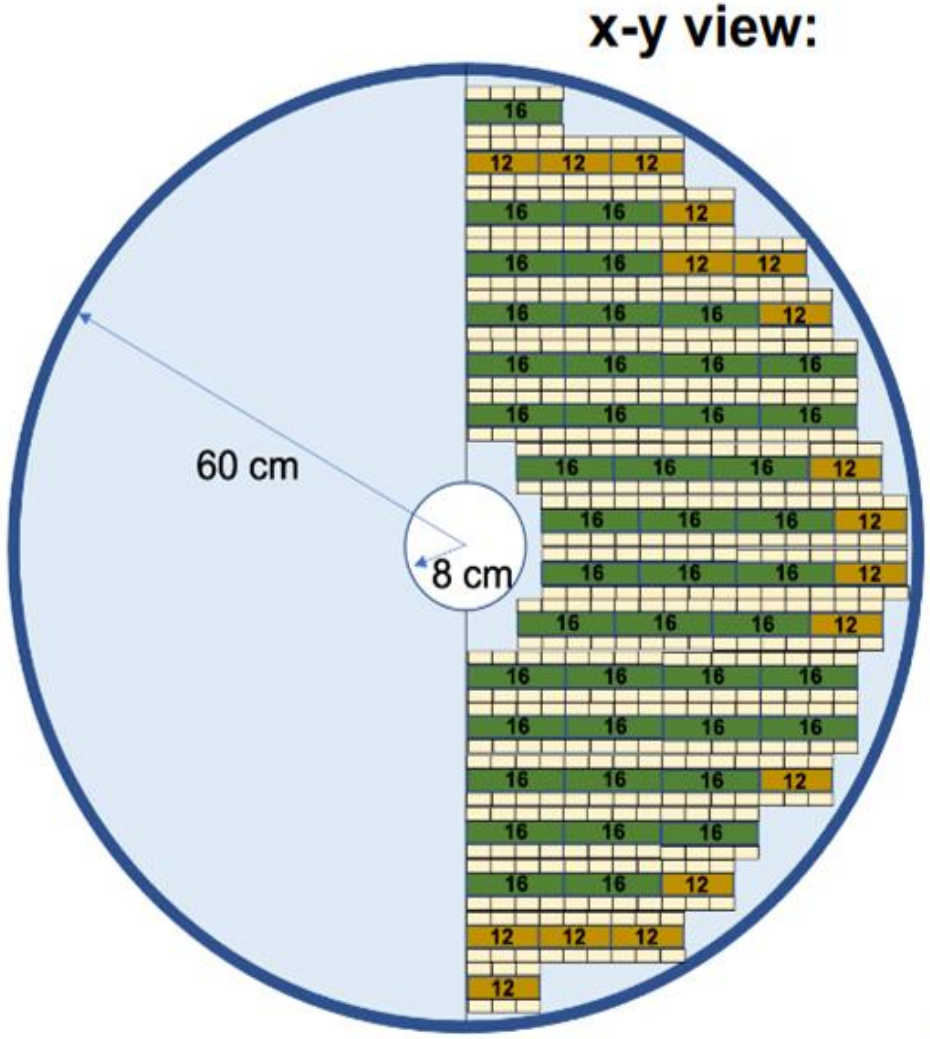


FW ToF layout proposal

Service Hybrids: Data+power lines

Detector module (AC-LGAD+EICROC)





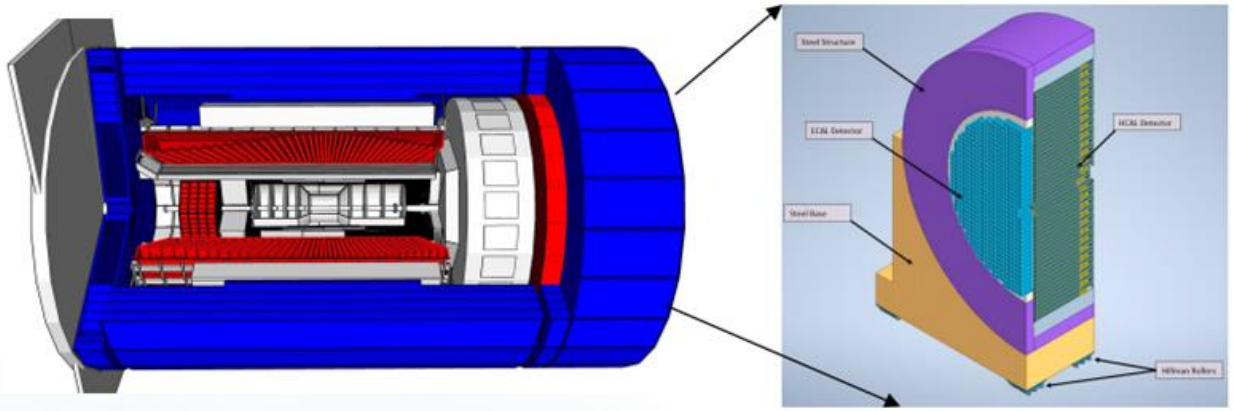
~ 2000 modules
3.8 M readout channels

talks @ AC-LGADs Workfest@ePIC collab meeting, Jan. 9-10, 2024:
Ref.: Wei Li (Rice University) wl33@rice.edu

(2) Production Line for the “Forward EMCal”

Forward E-Cal

22



High granularity W/SciFi EMCal
Longitudinally separated HCAL with high-η insert
Steel/Sc & W/Sc sandwich

China (Fudan, Shandong, Tsinghua) is responsible for 2/3 WScFi block production.

- On Pb/Sc Shashlyk EMCal, both Tsinghua and Shandong University have lot of R&D experiences based on the Jlab-SOLID project, and several prototypes already.
- On W powder/ScFi EMCal, Fudan/PKU/CIAE responsible for sPHENIX high-eta (0.8-1.1) EMCal Blocks .
- the infrastructure for the construction of such W-powder/ScFi ECal blocks, including block production and testing

W/ScFi EMCal blocks

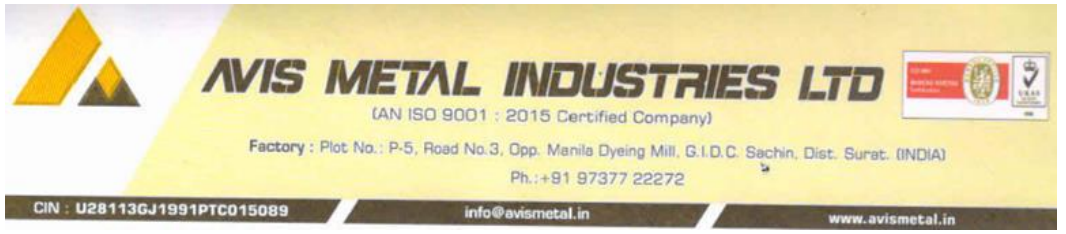
Pb/Sc Shashlyk module

Shashlyk module testing

Comments/points to work on

After meeting on 28/01/2024 at NISER

(1) Name and Address of Companies:



a) Tungsten powder company:
INNOMET ADVANCED MATERIALS LTD
B-31, BHEL Ancillary Estate, Ramachandrapuram,
Hyderabad – 502 032
Email: **sales@innomet.net** https://www.innomet.net/tungsten-heavy-alloys.html
->Two companies who make powder in India [Surat (GJ) and Ahmadnagar (MH)], sent email to inquire about required specs.

b) Scintillating Fiber Contact:(Fibers are made in USA)
Luxium Solutions India Pvt Ltd
(formerly Saint-Gobain India Pvt Ltd - Crystals)
email: Shanthi.Shanmugam@luxiumsolutions.com

-> They can import and supply us!