Possible Indian Participation at EPIC collaboration in EIC

Shuddha Shankar Dasgupta
On behalf of
EIC INDIA COLLABORATION

Outline

- **Indian participation in QCD Physics experiments.**
- **Indian interests in EIC.**

Indian groups: HI collision experiments

Institution	Experiment/Facility	Approx number of persons
Univ. of Jammu	STAR@RHIC, ALICE@LHC, CBM@FAIR	10
Univ. of Panjab	STAR@RHIC, ALICE@LHC, CBM@FAIR	10
Univ. of Rajasthan	STAR@RHIC, ALICE@LHC	2
Inst. of Phy. BBSR	STAR@RHIC, ALICE@LHC, CBM@FAIR	4
NISER, BBSR	STAR@RHIC, ALICE@LHC, CBM@FAIR	12
VECC, Kolkata	STAR@RHIC, ALICE@LHC, CBM@FAIR	15
IIT, Bombay	STAR@RHIC, ALICE@LHC	8
SINP, Kolkata	ALICE@LHC	8
Bose Inst. Kolkata	ALICE@LHC, CBM@FAIR	8
IIT, Indore	ALICE@LHC CBM@FAIR	10
BHU, Varanasi	PHENIX@RHIC, CBM@FAIR	3
AMU, Aligrah	ALICE@LHC, CBM@FAIR	6
BARC, Mumbai	PHENIX@RHIC, CMS@LHC, ALICE@LHC	10
Gauhati Univ.	ALICE@LHC, CBM@FAIR	3
Univ. Calcutta	CBM@FAIR	4
IISER, Tirupati	STAR@RHIC	3
IISER, Berhampur	STAR@RHIC	2
IIT, Patna	STAR@RHIC	2
IIT Madras	CMS@LHC	4
19 Institutes	**RHIC, LHC, FAIR**	**124**

Indian groups: Contributions

Institution	Physics, Detector, Experiment (selected list only)
Univ. of Jammu	Heavy Flavour Physics, PMD, DCS, Trigger, GRID computing, STAR HFT, ALICE-FOCAL, **EIC**
Panjab University	Fluctuation and correlations, photon multiplicity, nuclei production, BES-II-RHIC, CBM, **EIC**
Univ. of Rajasthan	Anisotropic flow, photon multiplicity
Inst. of Phy. BBSR	Light hadron spectra, PMD, GEM, CBM, **EIC**
NISER, BBSR	Spectra, fluctuations, azimuthal anisotropy, RHIC-BES, CBM-RPC, GEM, ALICE-FOCAL, **EIC**
VECC, Kolkata	PMD, MUCH, fluctuations, correlations, Jet physics, ALICE-TPC, ALICE-FOCAL, CBM-MUCH, CRU, Electronics, Grid Computing
IIT, Bombay	Resonance, fluctuations, correlations, simulations, ALICE-FOCAL, **EIC**
SINP, Kolkata	Muon Spectrometer ALICE, High Level trigger, RAA, J/Psi, Upsilon
Bose Inst. Kolkata	ALICE-TPC upgrade, photon multiplicity, ALICE-FOCAL, CBM
IIT, Indore	Photon Multiplicity, HBT, Freeze-out dynamics, CBM, **EIC**
BHU, Varanasi	Non-photonic electrons PHENIX@RHIC, CBM@FAIR, detector R&D **EIC**
AMU, Aligrah	Heavy-quark Measurements, ALICE-Muon Detector, **EIC**
BARC, Mumbai	Heavy-quark Measurements, Fluctuations and Correlations, jets, UPC, ALICE-FOCAL, GEM, RPC, Electronics
IISER Tirupati and Berhampur IIT Patna	Physics Analysis at RHIC and **EIC**

Indian groups: Vibrant Theory Community

Institution	Theoretical Physics (selected list only)
Tata Institute of Fundamental Research	QCD, Electroweak Physics and Physics Beyond the Standard Model
Harish Chandra Research Institute	QCD, Physics beyond the Standard Model
The Institute of Mathematical Sciences	QCD, Particle physics phenomenology and non-perturbative QFT
Inst. of Phy. BBSR	QCD, Collider physics, neutrino physics, and dark matter.
NISER, BBSR	QCD
VECC, Kolkata	QCD
IIT, Bombay	QCD and Physics beyond standard model
SINP, Kolkata	QCD
Bose Inst. Kolkata	QCD
AMU, Aligrah	QCD
IIT Madras	QFT
IIT Delhi	QCD and Physics beyond standard model
IIT Kanpur	QCD, QFT, Particle Physics, beyond standard model
IISER – Bhopal, Pune, Berhampur	QCD and Physics beyond standard model
Indian Institute of Sciences	QCD, QFT and physics beyond standard model

Selected hardware Publications (NON EIC)	
Photon Multiplicity Detector: STAR @ RHIC	**Muon Spectrometer: ALICE @ LHC**
Physical Review Letters 95 (2005) 062301	Physics Letters B 734 (2014) 314
Physical Review C 73 (2006) 034906	JHEP 1402 (2014) 073
Nuclear Physics A 832 (2010) 134	Physical Review Letters 111 (2013) 162301
NIM A 499 (2003) 751	Physical Review Letters 109 (2012) 112301
NIM A 488 (2002) 131	Physical Review Letters 109 (2012) 072301
Eur.Phys.J. C75 (2015) no.4, 146	Physics Letters B 708 (2012) 265
	Physics Letters B 704 (2011) 442

Experimental participation to achieve science goals

Experiments/Facility	Nature of participation and time line
STAR Experiment Beam Energy Scan Phase – II – Relativistic Heavy Ion Collider, BNL, USA	*Data taking and Physics Analysis* ***2014-2024***
Compressed Baryonic Matter Experiment, FAIR facility, GSI, Germany	*Detector for muon identification in CBM (RPC and GEM based) Physics Analysis and Data Taking* ***2025 Onwards***
LHC	*Data taking, Physics Analysis Detector and Electronics R&D – upgrades coping with higher luminosity and building radiation hard detectors (silicon based).* ***2010 - 2030***

Indian Participation in EIC progress

- **International Representative for Steering Committee**: Asmita Mukherjee (IIT Bombay, India)
- Member of "**Diversity and Inclusion Committee**": Asmita Mukherjee (IIT Bombay, India)
- Member of "**Elections and Nominating Committee**": Bedangadas Mohanty (NISER, India)
- Member of "**Integration Committee (ATHENA)**": Bedangadas Mohanty (NISER, India)
- Member of "**Bye laws and Charter Committee**": Bedangadas Mohanty (NISER, India)

- EIC finds place in the Indian "Mega Science Vision (MSV) – 2035" document.
- MSV 2035: A roadmap prepared by the Indian Nuclear Physics Community for long term future.
- Recommendations for participation in Electron – Ion Collider experiments to address the fundamental questions in nuclear physics and participate in detector development.

EIC physics contribution: Theory Colleagues

- Initiated joint IITB – CFNS (theory) postdoc fellowship (50% funding from CFNS)

SciPost (Selected publication only) SciPost Phys. Proc. 8, 017 (2022)

Sivers asymmetry in inelastic J/ψ leptoproduction at the EIC

S. Rajesh[1*], U. D'Alesio[1,2], A. Mukherjee[3], F. Murgia[1] and C. Pisano[1,2]

$\cos 2\phi_t$ azimuthal asymmetry in back-to-back J/ψ-jet production in $ep \to eJ/\psi$ jet X at the EIC

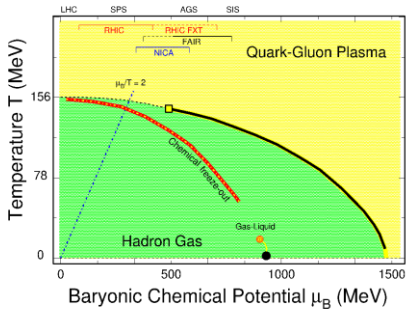
Raj Kishore, Asmita Mukherjee, Amol Pawar, and Mariyah Siddiqah
Phys. Rev. D **106**, 034009 – Published 10 August 2022

- International workshop on QCD with Electron-Ion Collider (QEIC), January 4-7, 2020, IIT Bombay, Mumbai
- The next workshop QEIC II will be held by IIT Delhi during Dec 18 – 20, 2022. **Everyone here are invited to attend.** https://indico.cern.ch/event/1196913/
- There is a possibility to receive seed funds from DAE and DST for next 3 years → under discussion.

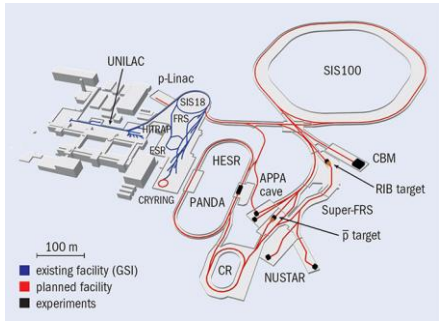
QCD: Recommendations

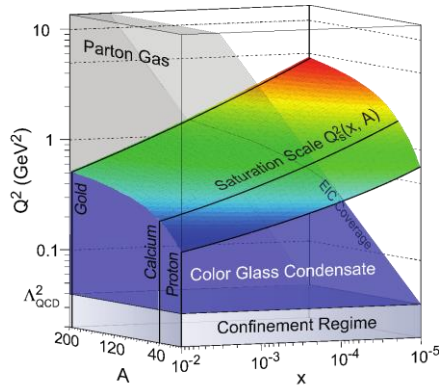
The study of the emergent properties of QCD matter is one of the most compelling science problems in nuclear physics. It includes mapping the phase diagram of the QCD matter, measuring the properties of the QCD matter subjected to extreme conditions of temperature, pressure, baryon density, electromagnetic fields and angular momentum, finding out the partonic content of a nucleus and the fundamental mechanisms behind the properties of nucleons, such as its mass and spin.

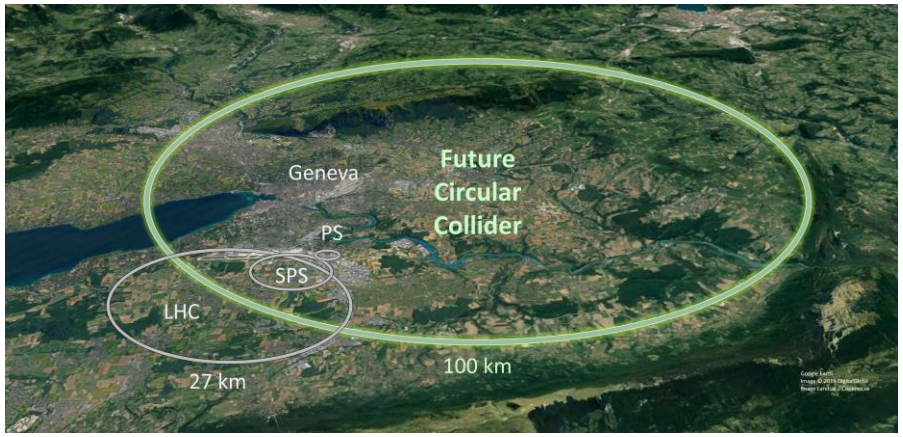
We recommend continued participation in heavy-ion programs at LHC, RHIC and FAIR, the collision energies of which, only when taken together, allow to map the QCD phase diagram. While the CBM experiment, which is under construction at FAIR, should be the focus for the high-energy nuclear collisions in the near future, we also recommend participation in the upcoming Electron-Ion Collider experiments to address the fundamental questions in nuclear physics.



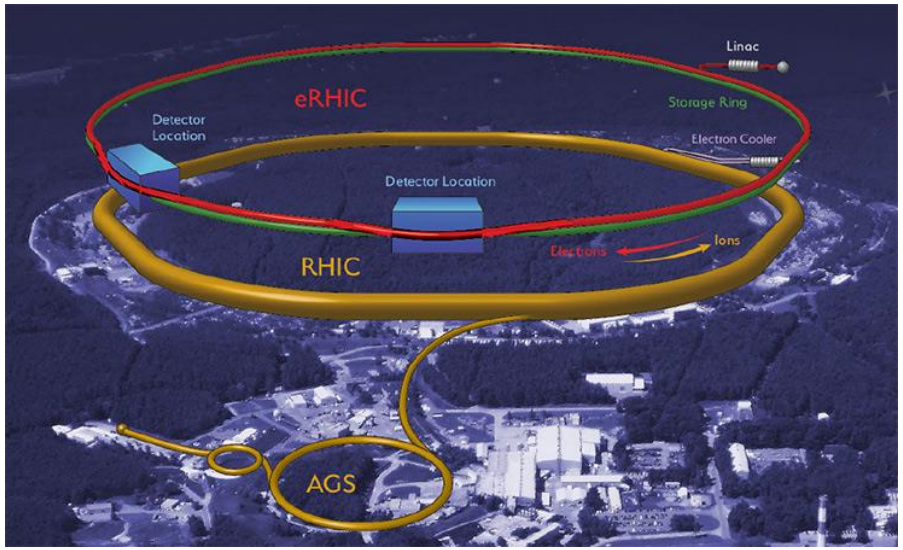
What are the phase structures of Quantum Chromodynamic (QCD) matter?







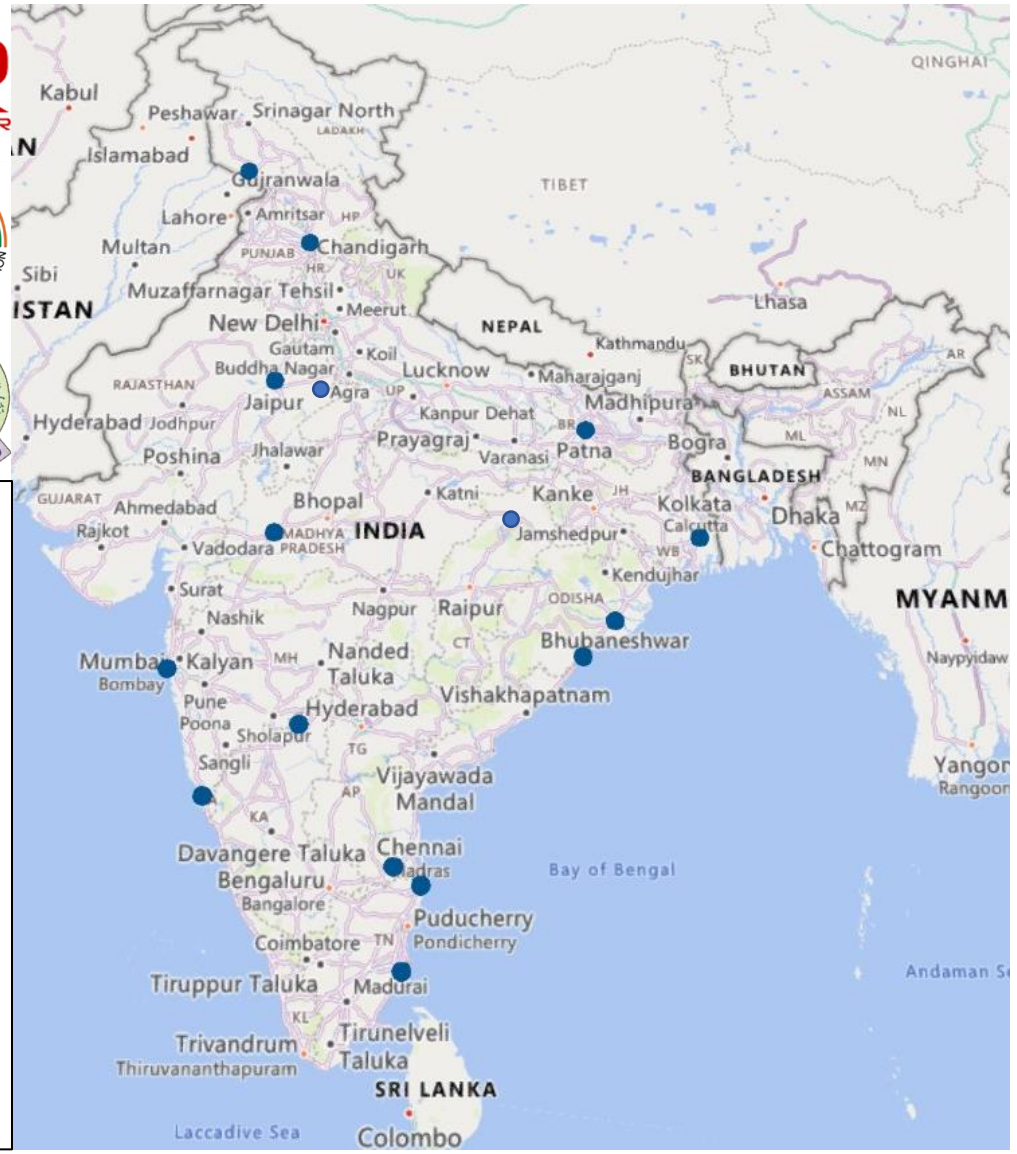
How do the strong interactions amongst quarks and gluons inside the nucleons result in confinement and collectively result in their properties such as mass and spin?



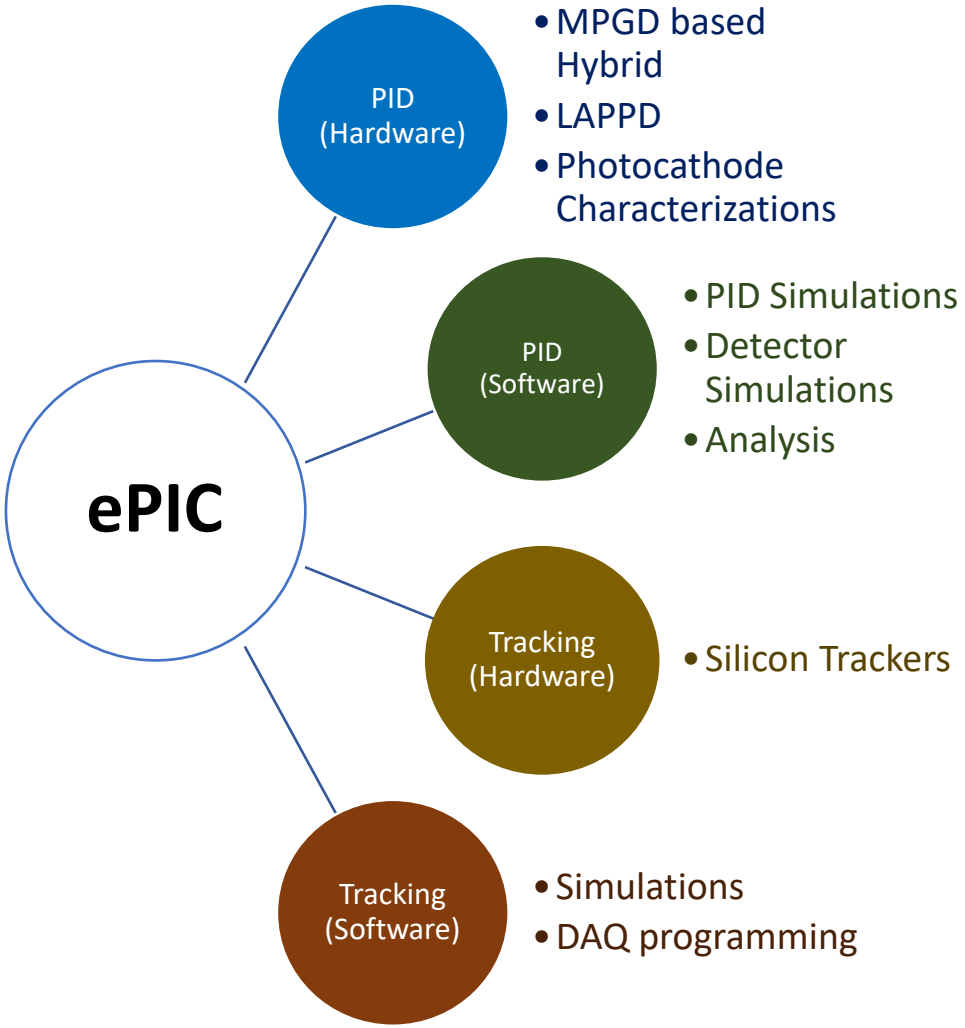
How does a nucleus look in terms of its partonic content? Does the gluon density saturate to gluonic matter of universal properties?

Indian Institutes interested in EIC

- 18 Institutes from all around India have shown interest.
- Interests in Software as well as in hardware activities.
  - **Vertex tracking detectors and PID detectors.**
  - **Physics simulations related to the above detector systems, dominantly related to heavy flavor production.**
  - **Detector Simulation.**



Indian Institutes interested in EIC HW



SI NO.	Institute Name
1	Banaras Hindu University
2	Central University of Haryana
3	Central University of Karnataka
4	Central University of Tamil Nadu, Thiruvarur
5	Goa University
6	Indian Institute of Science Education and Research, Berhampur
7	Indian Institute of Science Education and Research, Tirupati
8	Indian Institute of Technology Bombay
9	Indian Institute of Technology Indore
10	Indian Institute of Technology Madras
11	Indian Institute of Technology Patna
12	Institute of Physics
13	Malaviya National Institute of Technology Jaipur
14	National Institute of Science Education and Research
15	Panjab University
16	Ramakrishna Mission Residential College, Narendrapur, Kolkata
17	Tata Institute of Fundamental Research
18	University of Jammu

Interested institutes in India for PID

Particle Identification Detector (BHU, NISER, and IOP) – Prof. Bhartendu Singh	
Institute	Interest
University of Goa	Track finding and fitting, MPGD Tracker/PID
Panjab University	MPGD Tracker/PID
MNIT	PID and Tracker
RMRCK	PID and Tracker

(i) In kind labour contributions for detector R&D, detector simulations, testing, quality assurance, commissioning and operations.

(ii) Provide access to other EIC groups to existing facilities in our laboratory for detector related work.

Main Interests

- **The focus is to participate in the PID group, mainly focusing on Photon detector development and studies.**
- Work is ongoing for setting up the basics: Lab space, organizing people, giving responsibilities, etc.
  - 3 Scientists are present in NISER (2 Gaseous Detector experts and 1 Silicon Detector Expert), along with 2 Scientific Assistants and 1 Scientific Officer with expertise in electronics.
  - **In NISER, A huge lab space of ~ 400m^2 [~ 4000 sq feet] is currently under preparation. Including class 1000 cleanrooms -> aiming for Cryogenic detectors, Gaseous Detectors, Photon detectors, MPGD-based detectors, and Silicon Devices.**
  - **Banaras Hindu University has a photocathode coating and characterization setup based on the VUV monochromator system.**
  - Institute of Physics, Bhubaneswar, has facilities for Detector R&D and simulations studies.
- **People are getting organized for Simulation, Software Studies…**

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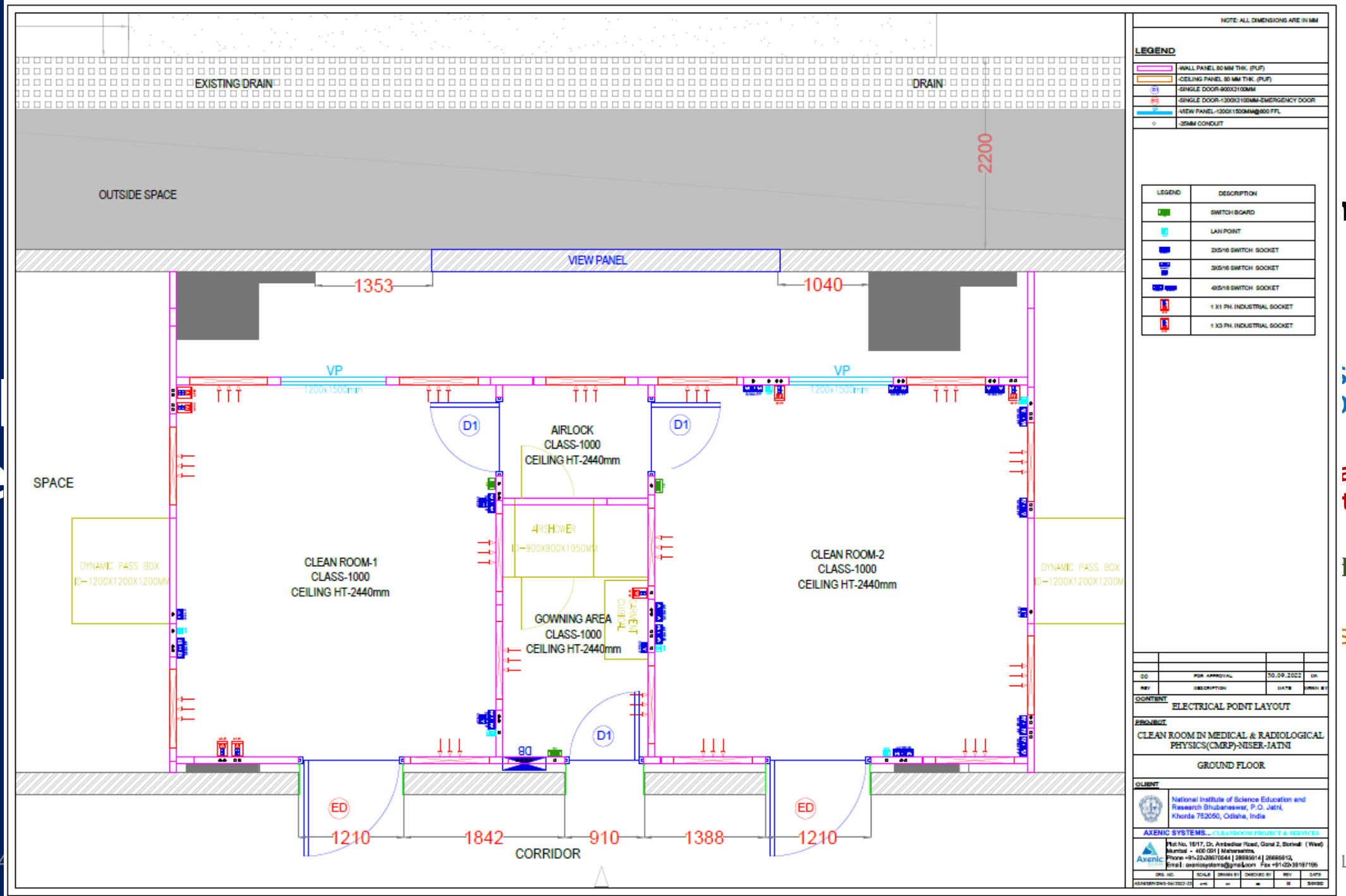

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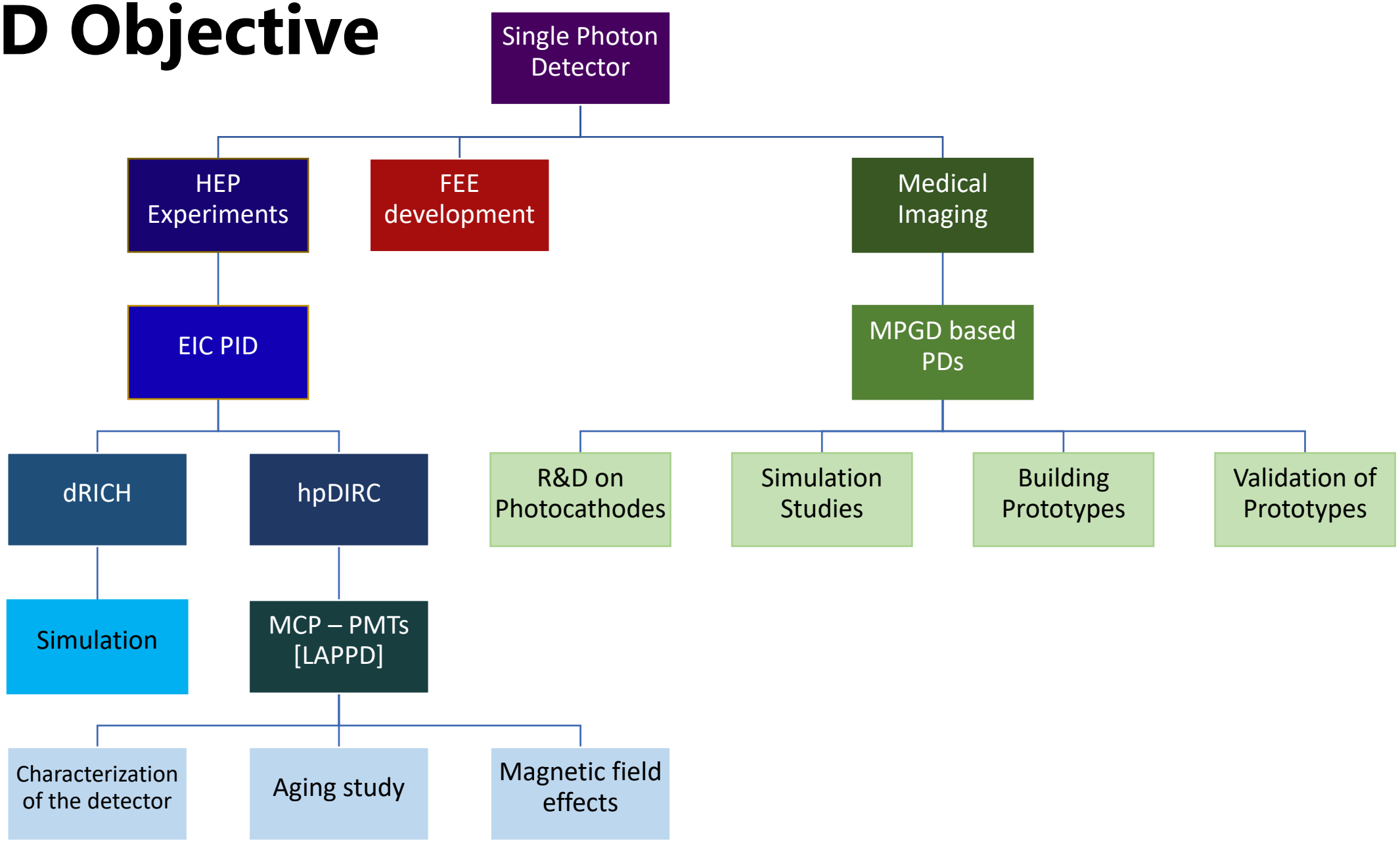
Existing facilities for Detector Development and Photocathode Characterization

R&D Objective



R&D Objective

CAEN Digitizer V1742B with DRS4 Chip to have 50 ps timing

- Single Photon Detector
  - HEP Experiments
    - EIC PID
      - dRICH
        - Simulation
      - hpDIRC
        - MCP – PMTs [LAPPD]
          - Characterization of the detector
          - Aging study
          - Magnetic field effects
  - FEE development
  - Medical Imaging
    - MPGD based PDs
      - R&D on Photocathodes
      - Simulation Studies
      - Building Prototypes
      - Validation of Prototypes

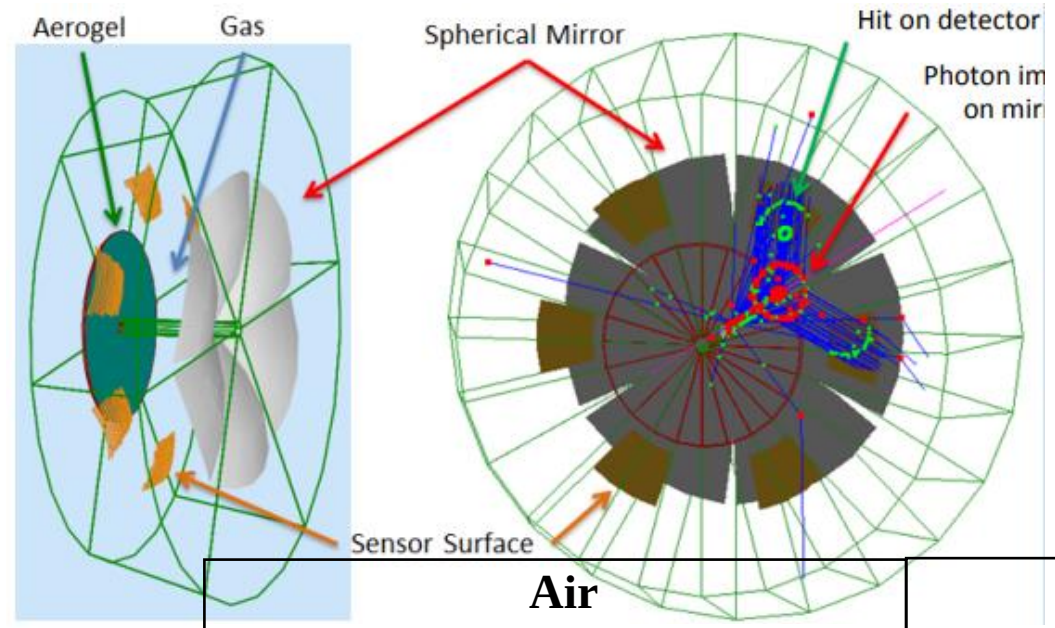
Pulsed Laser Drive PDL 800 – D, LDH series 375 nm laser head with 20 ps pulse width and PLS series 245 nm laser head with 600 ps pulse width.

LAPPD will not come as USA declined the export license → Searching for new R&D possibilities.

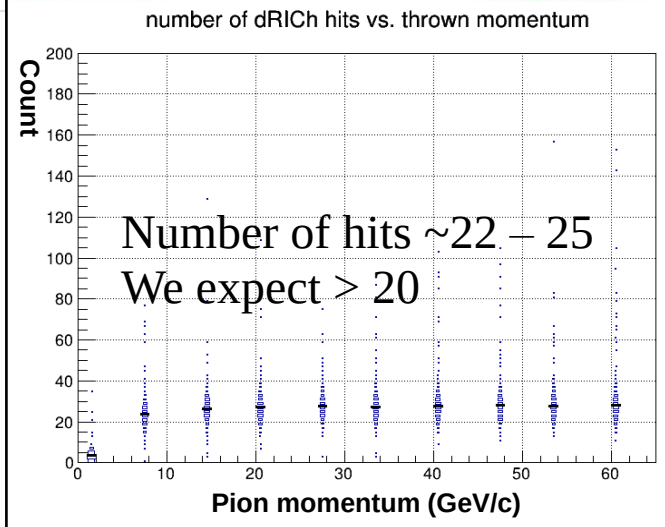
EIC Simulation effort @ NISER

dRICH detector system	Radiator, mirror, and other component
Transport of particle through dRICH	Particles are transported trough detector material
Sensors for photons	Detector for single photon detection
Photon hits on sensor	Hits on Sensor

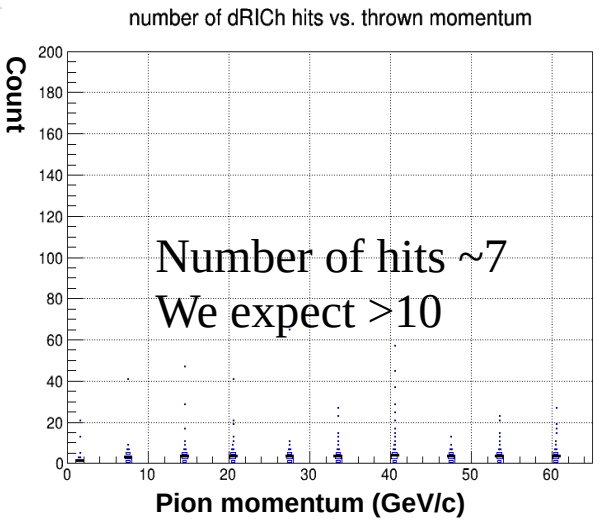
Simulation goal is to implement the realistic sensor material and check the number of photons for given incident particle and given momentum



Air



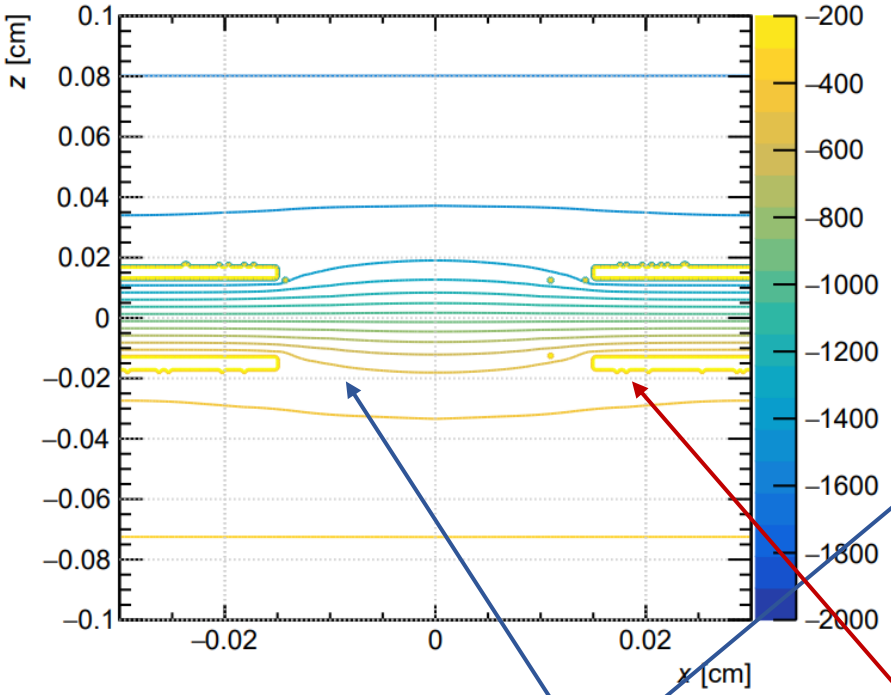
Si sensor

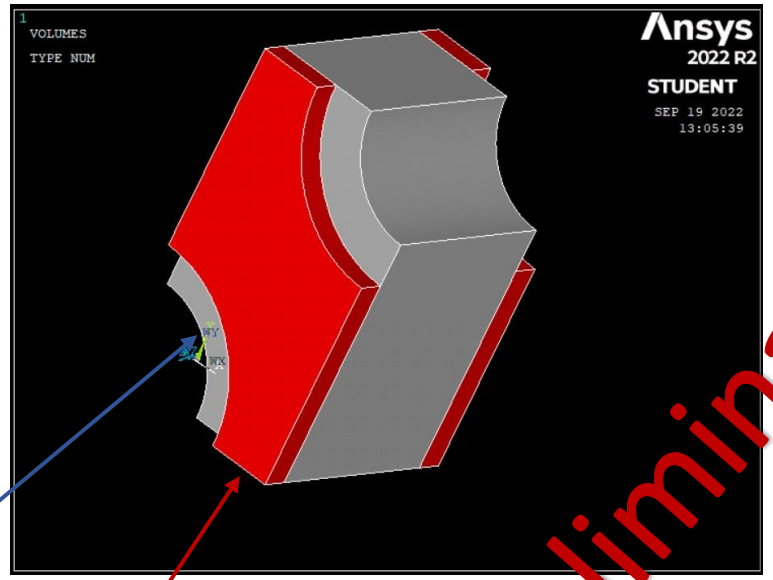


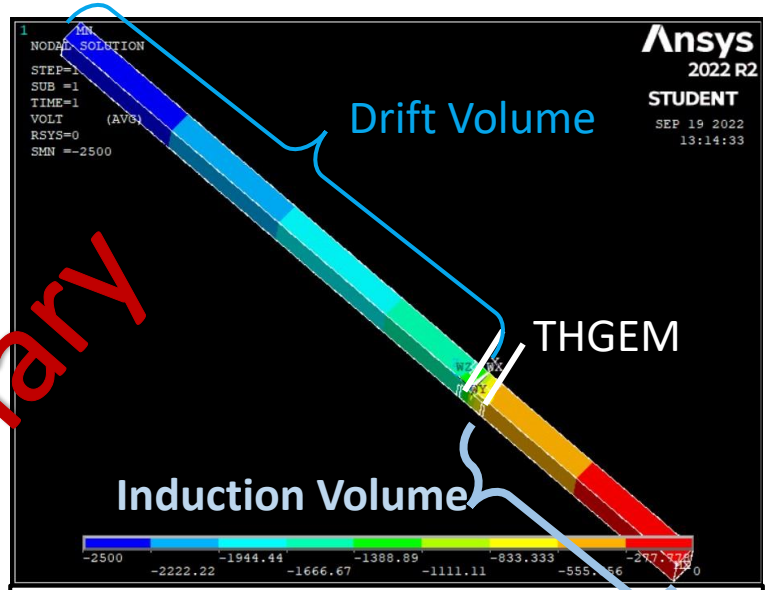
Work by Ajit Kumar Post Doctoral Fellow

Simulation of THGEM detector @ NISER

- Field calculation was done by ANSYS and then the results were imported to Garfield++ for further calculations.
- The tool to simulate Electric Field configurations for the available THGEM setup is ready.
- The same tool can be used for simulating new designs.
- Very Preliminary efforts. The tools are getting ready. People are getting trained.







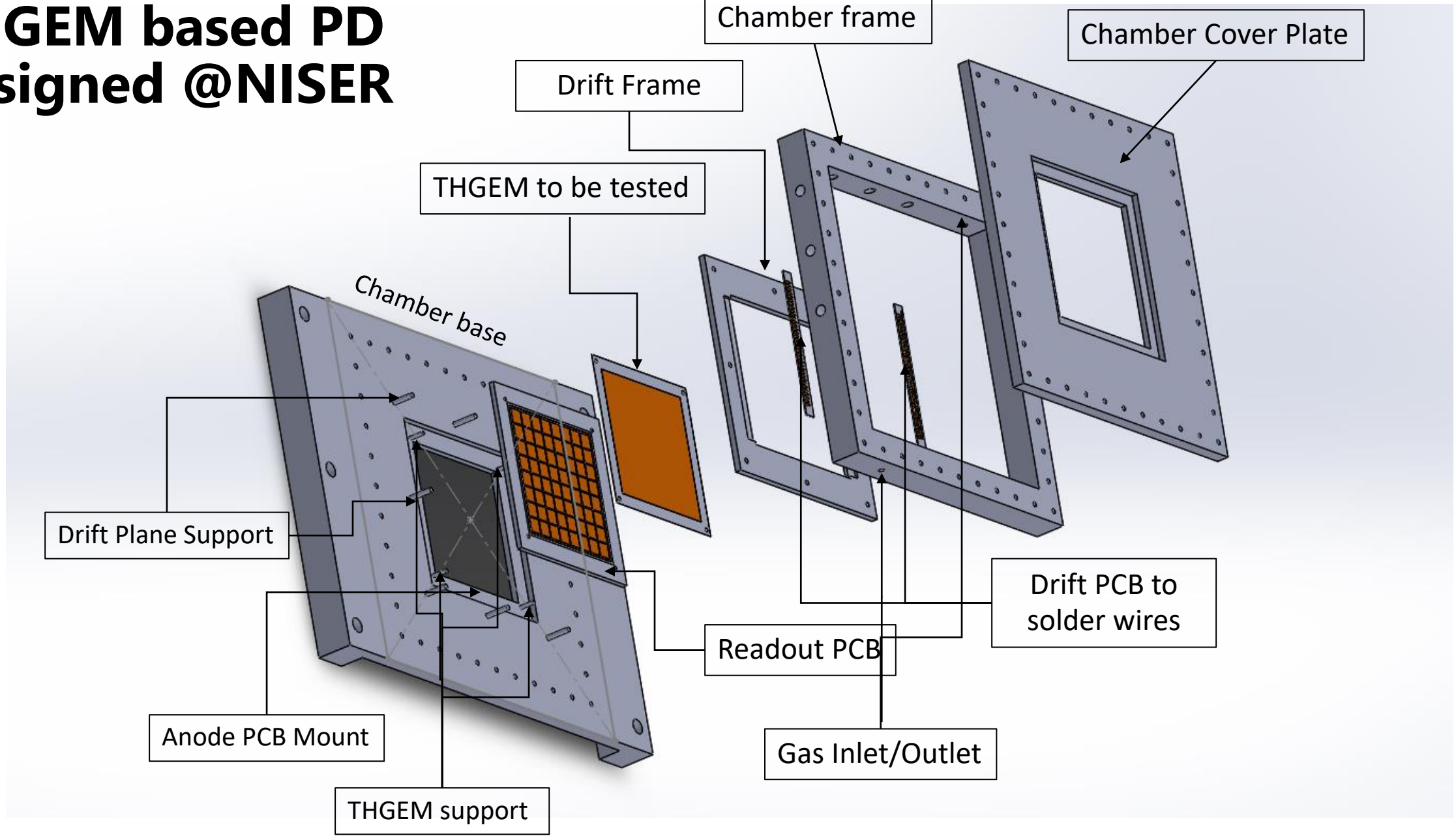
Preliminary

THGEM hole

THGEM Cu layer

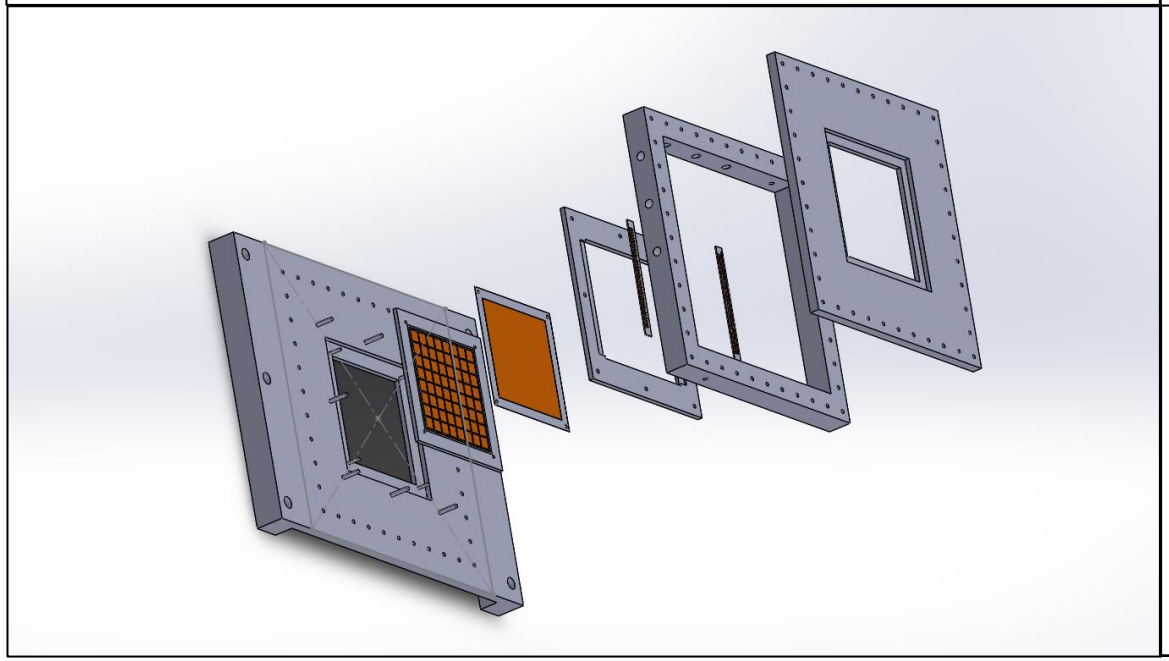
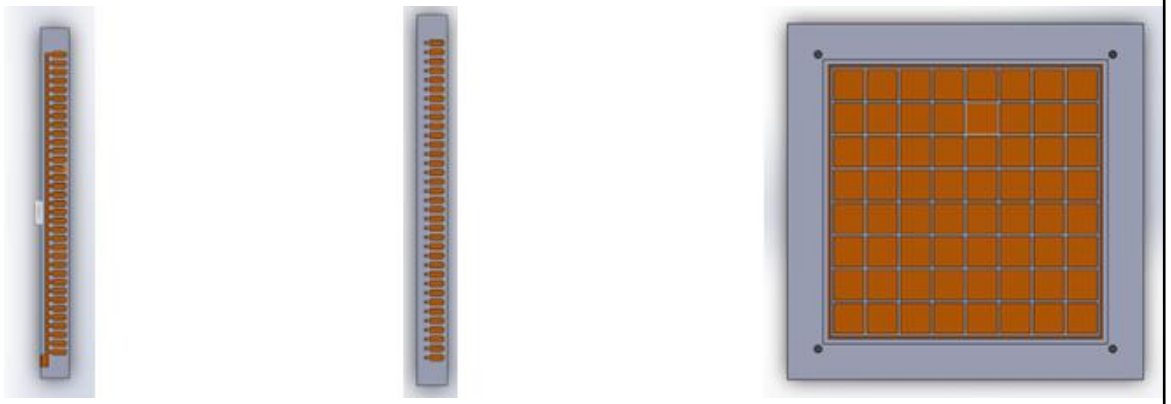
Electric Potential configuration for all the stages of a THGEM unit cell inside the gas volume.

THGEM based PD designed @NISER



THGEM based PD development progress

- Test Chamber for Prototypes design has been finalized.
- THGEMs from Micropack India
  - Foil Thickness = 0.25 mm fiberglass with 0.035 mm copper on each side.
  - Hole diameter = 0.25 mm
  - Hole pitch = 0.50 mm
  - RIM (etched open area around hole) = 0.050 mm
- CREMAT CSP with ORTEC 672 Spectroscopy amplifier and Ar:CO_2 80:20 gas mixture is used.

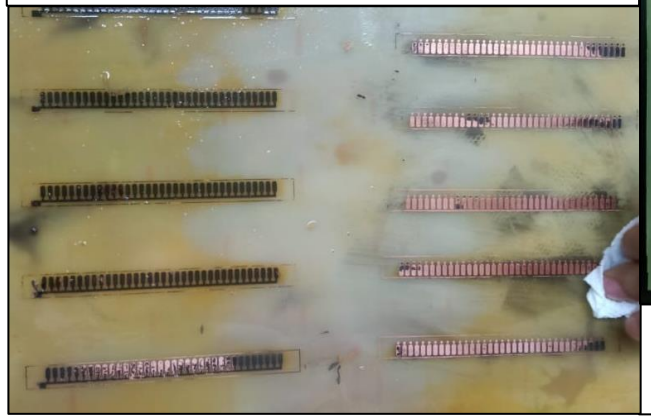
Test Chamber exploded view	Drift PCBs for having transparent drift and pad segmented R/O
	

Designed in Solid works Scientific Assistant, Mr. Debasish Barik

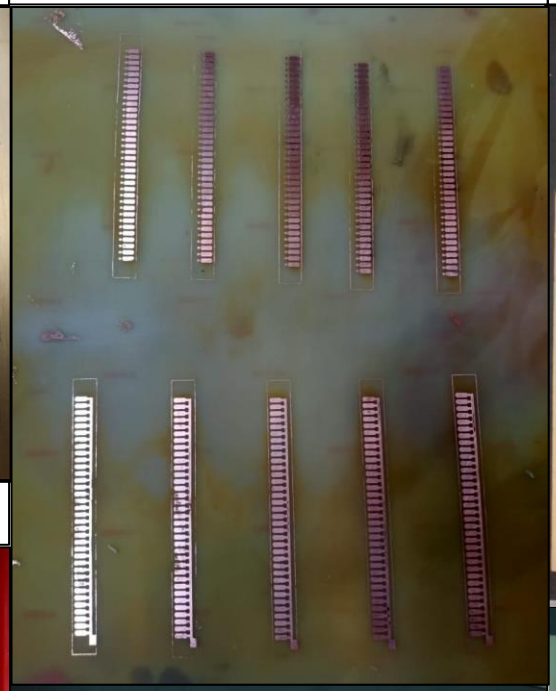
Mask transfer

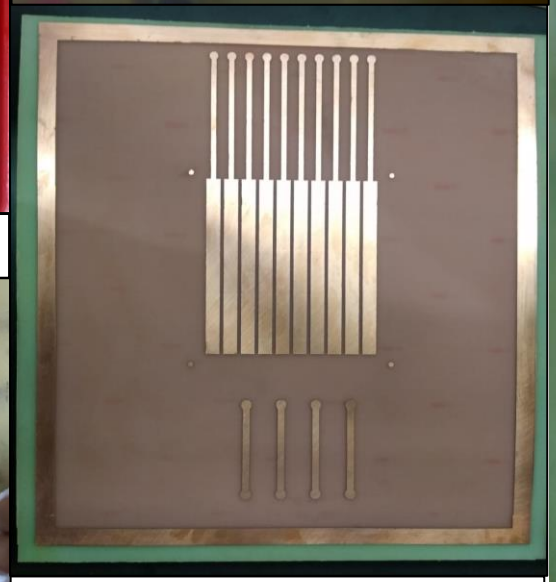
$FeCl_3$ solution preparation and etching

After etching removing the mask



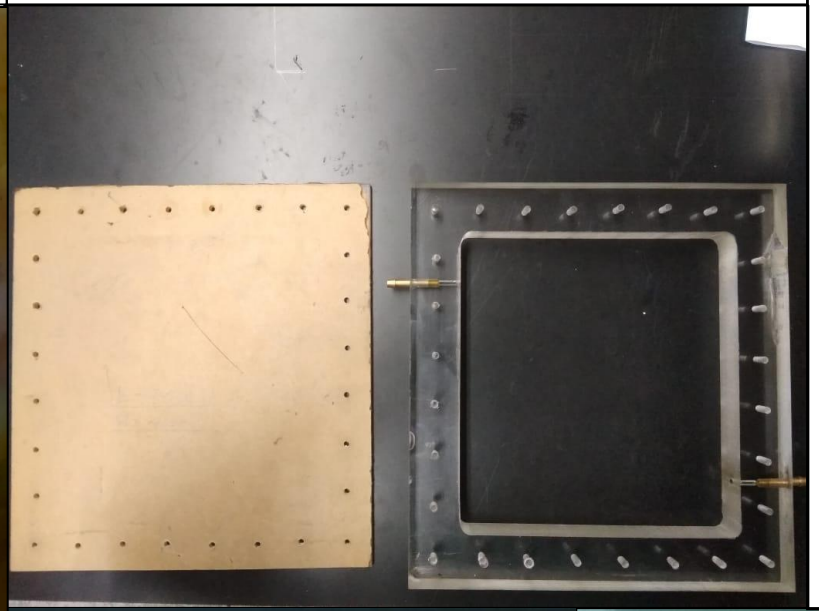
Final PCBs

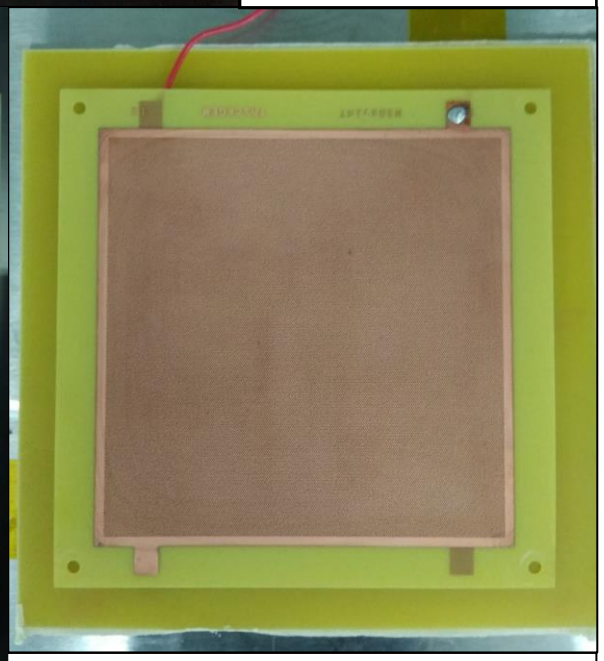




Work done by Scientific Assistant Mr. Deepak Kumar

Test chamber made in NISER

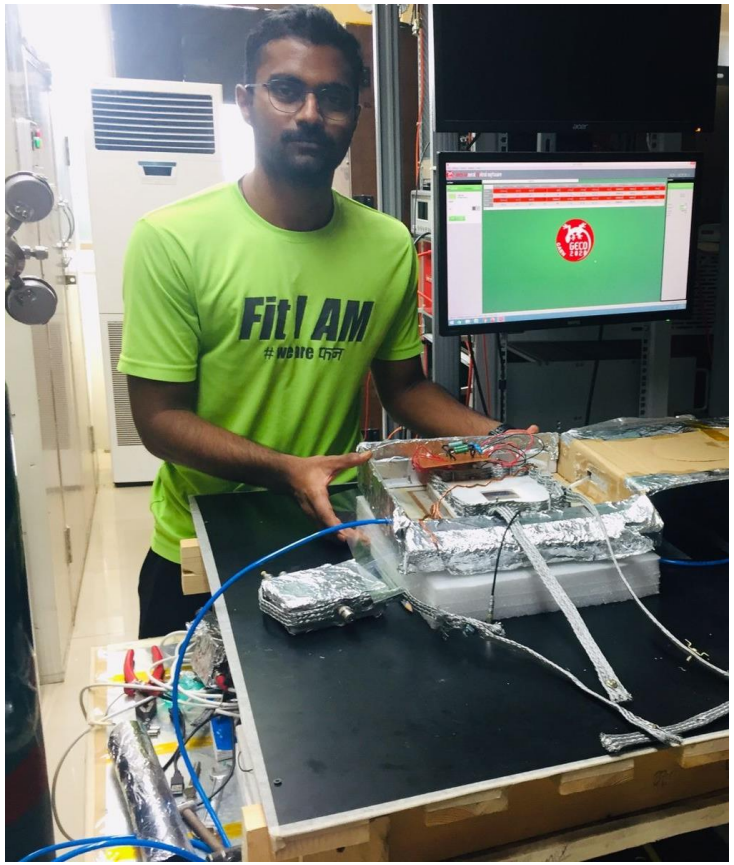


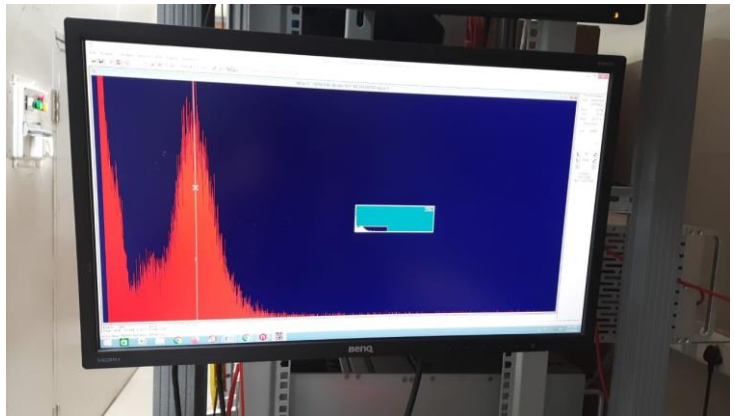


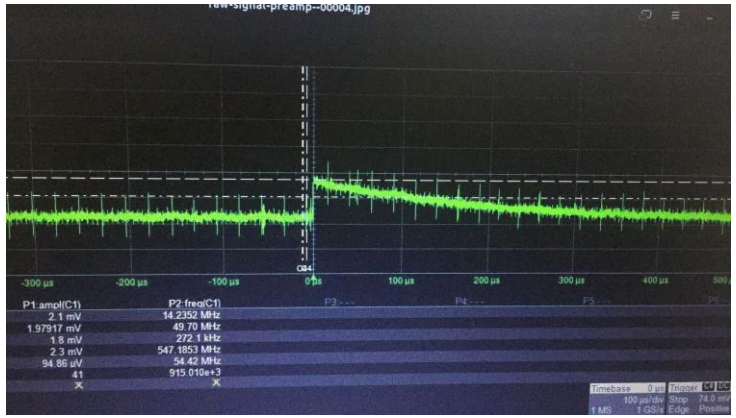
THGEM prepared by Micropack Bangalore

- Test chamber pieces are made
- Quality check ongoing
- First trial we made stripped readout but in future the goal is to make Pad segmented readout from industry

First Results



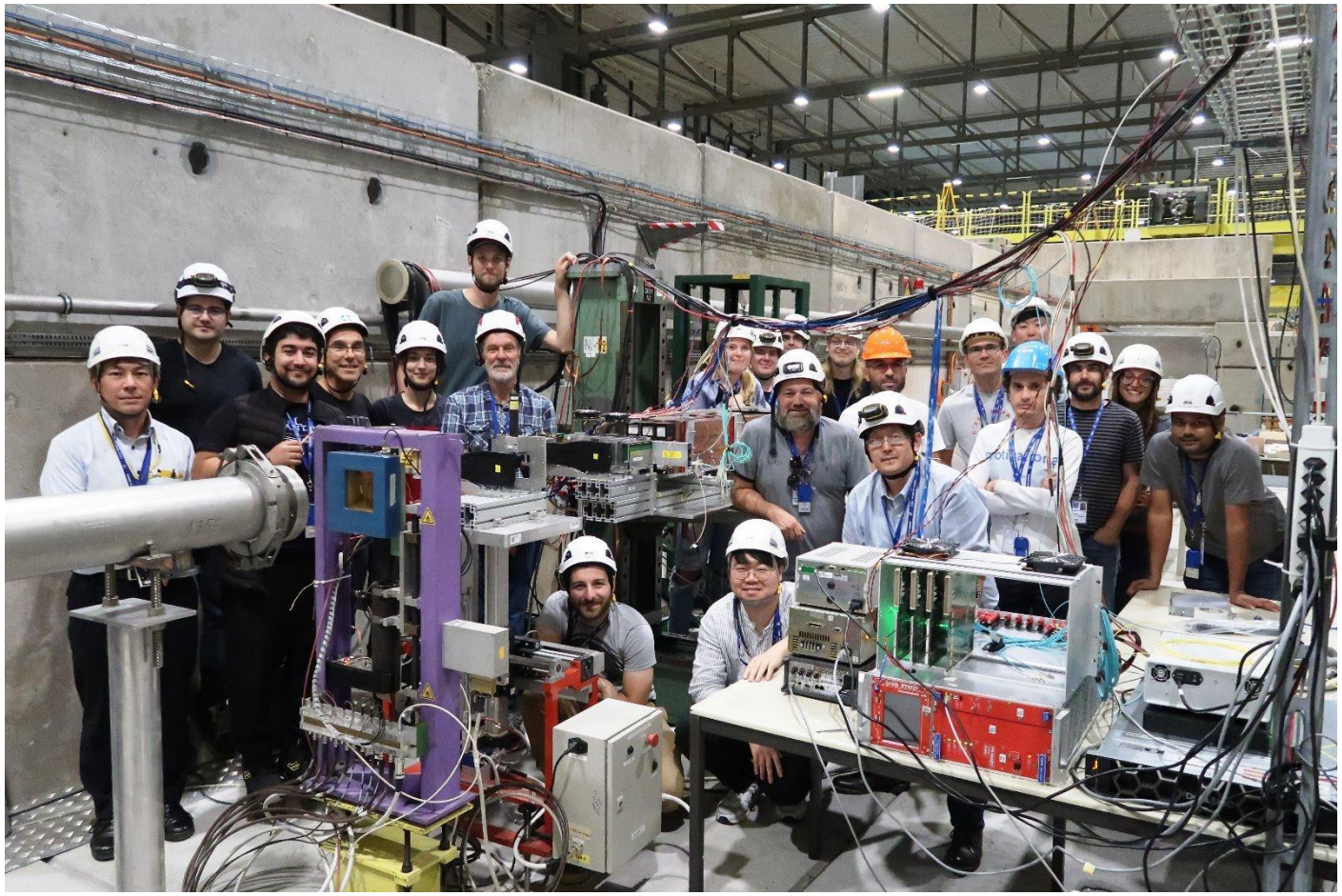




- Our master student Danush Sekhar with the first THGEM test chamber prototype at NISER
- The First Pre–Amplifier Signal in DSO has been shown in the figure at right along with THGEM Spectra from MCA.

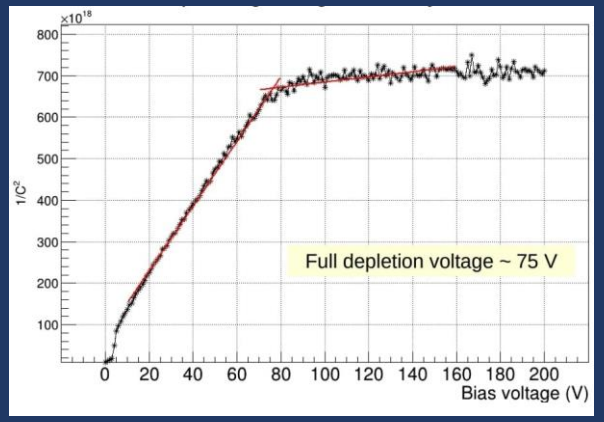
NISER Si group and background

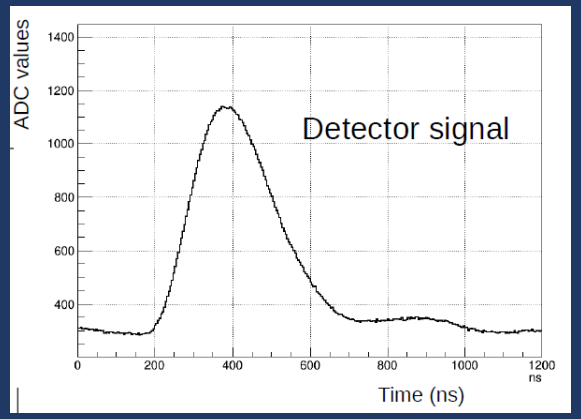
- Team of 6 people: Interested in working on the EPIC-TOF project: two scientists (Ganesh Jagannath Tambave → Si hardware and Mriganka → physics simulations), one electronics engineer (Kirti Prasad Sharma), plus the support staff as mentioned on the last slide.
- The group is currently part of the ALICE FOCAL project
  - Design, development, and production: n-and p-type pad array (8x9) on 6" wafer
  - Qualification studies of pad arrays (lab test, test beam experiments), ordered 25 pads
  - Focal physics simulations
- Dr. Tambave has a background in ALICE TPC upgrade (SAMPA ASIC tests) and ALICE ITS2 upgrade (ALPIDE MAPS tests, system integration), currently working on the ALICE FOCAL project
- 20 m^2 ISO-6 clean room, 40 m^2 workspace for silicon research lab, and various instruments required for detector qualification studies.
- Working on collective funding proposal for EIC – EPIC, includes 18 national institutes in India

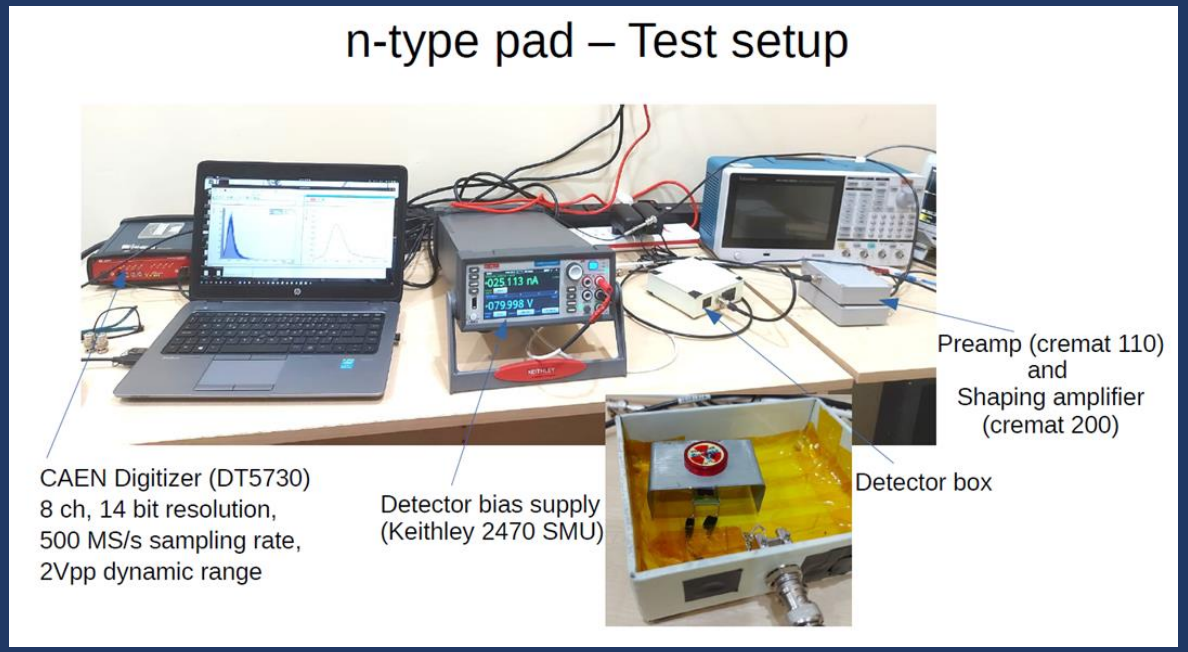


FoCAL Test beam at CERN, September 2022.

Slides from Dr. Ganesh Jagannath Tambave



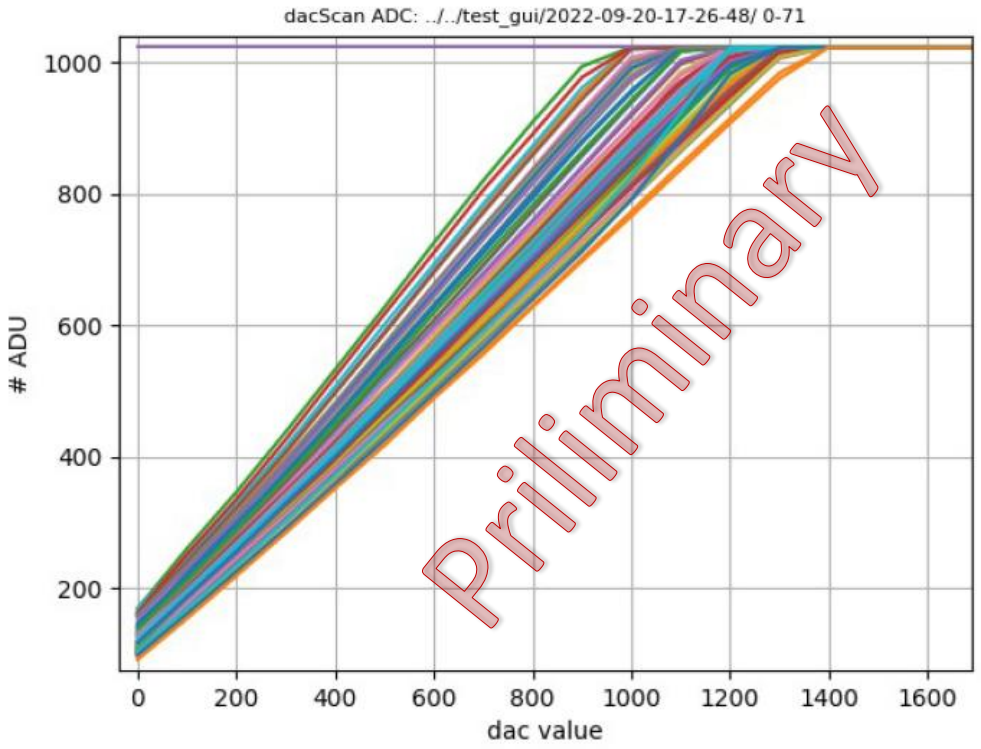


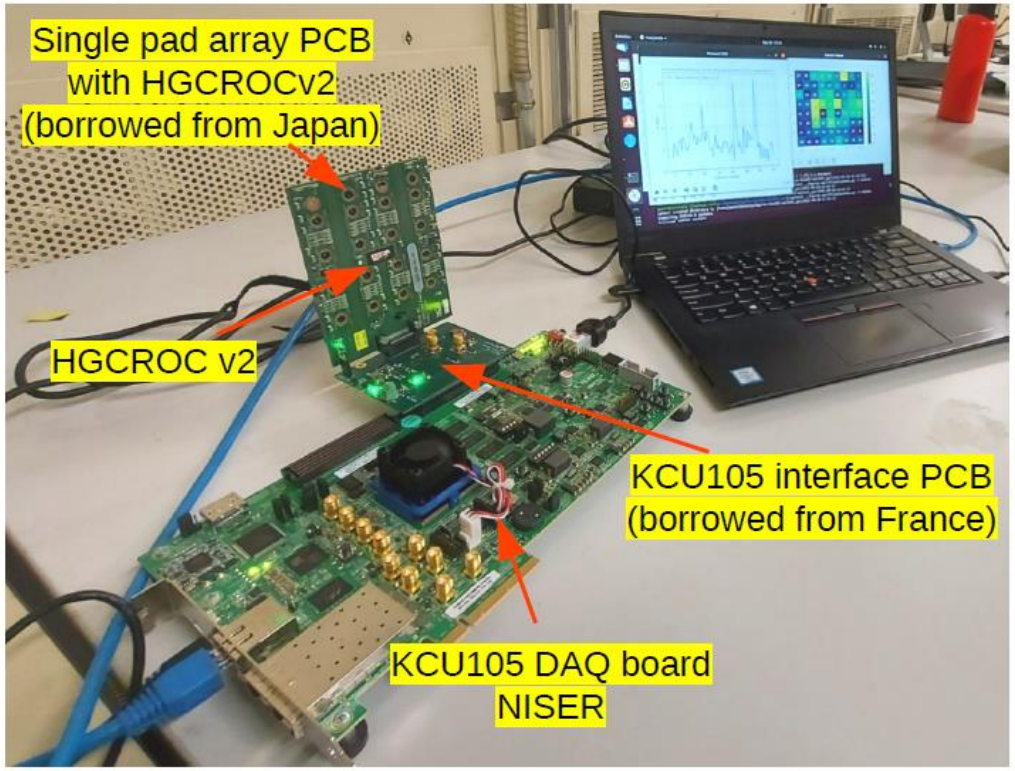


Si pad test setup @ NISER

- Pad size: 1x1 cm^2: detector operated at 80 V bias.
- Sr90 beta source emits electrons upto 2.2 MeV, activity ~ 3.7 kBq.

- Noise study by analysing the pedestal and ADC linearity are getting tested for HGCROC chip we get.
- All 71 Channels were happen to be linear fo the test.





NISER possible contribution – EPIC - TOF

- Could design and develop AC LGAD in Indian Fab
  - BEL Bangalore (6'' wafer), and SCL Mohali (8'' wafer, 180 nm process)
  - SiPMs were produced in India for CMS exp. in 2012 [Ref1] by SITAR*
- Could possibly contribute in simulations
  - TCAD (Process and Geometry),
  - MC (Garfield++) on detectors with gain as AC-LGAD
- LGADs require dedicated ASIC (FEE, TDC) to readout sensors
  - Either design or borrow or purchase such ASIC
  - Explore the possibilities to produce simple ASICs in Indian Si fab
- AC LGAD qualification studies: in lab (with sources, lasers, cosmic rays) and participate in test bea

SiPM produced on 6'' wafers at SITAR, I

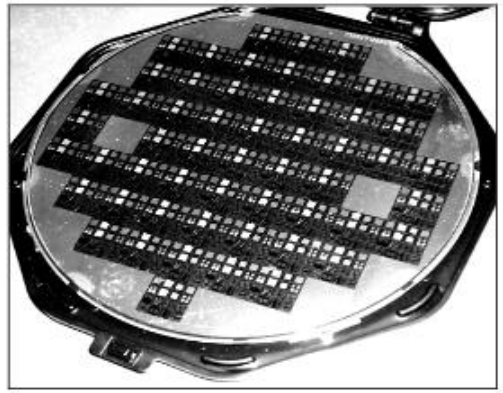


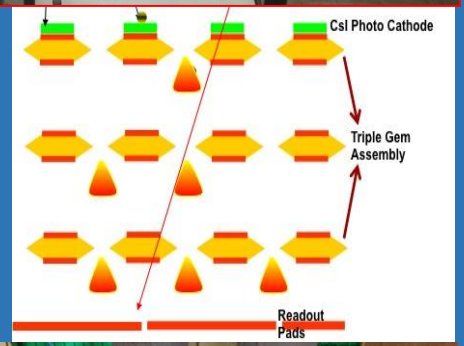
Fig. 1 Fabricated wafer showing SiPMs

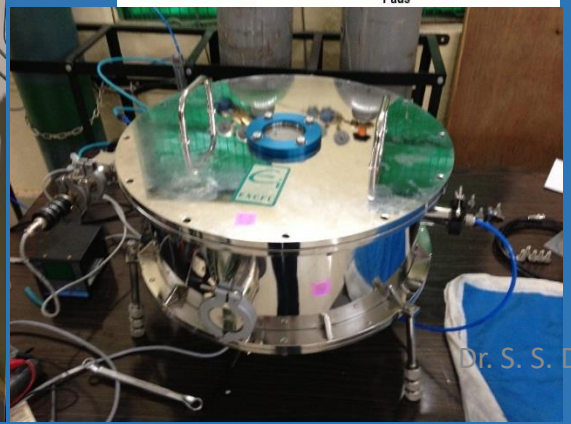
LGAD + ASIC

*Society For Integrated Circuit Technology And Applied Research (SITAR)

[Ref1] Anita Topkar et al., Development of SiPM in India using CMOS Technology, https://inspirehep.net/files/2f05f40e82377fddbcaff41ae24635d1

GEM-based photo detector for PID @ BHU





1. Photocathodes:

Conversion of photons into photo-electrons

High QE CsI/KBr/Diamond photocathode may be used.

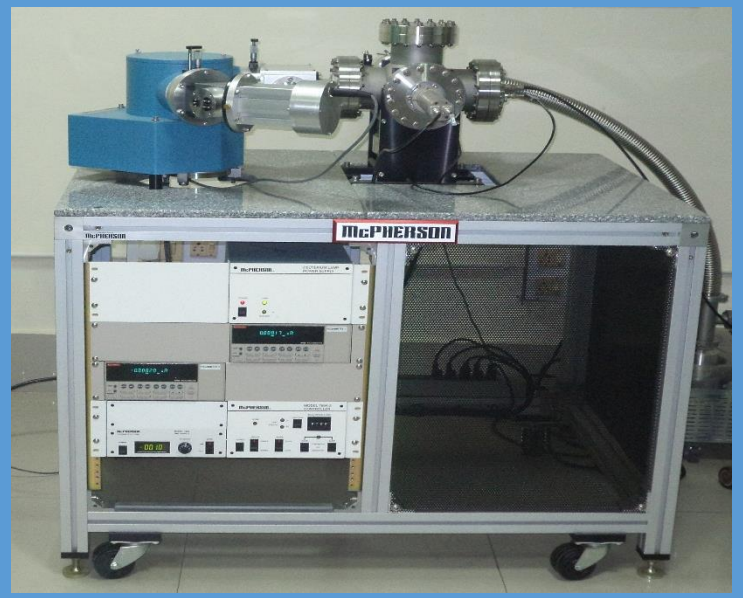
R & D simulation for Meta-materials for PID application

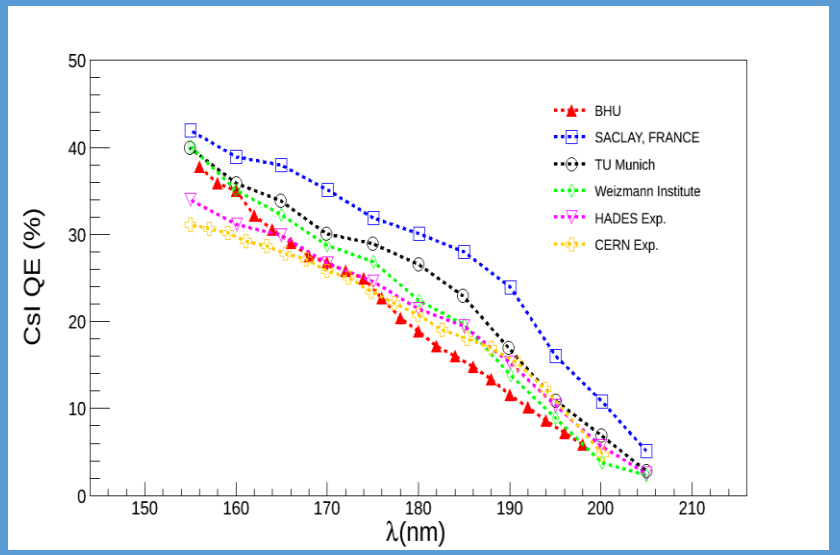
2. Gas Electron Multiplier:

Gas amplification will be done inside the GEM, THGEM or Micromegas.

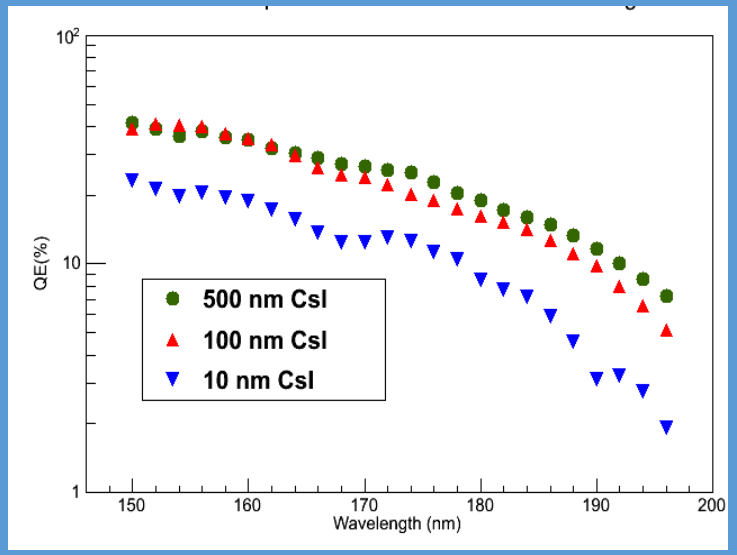
Gain from 1000 to 10000 may be achieved by using a cascade of GEM/THGEM.

302/234 VUV Monochromator – QE measurement:

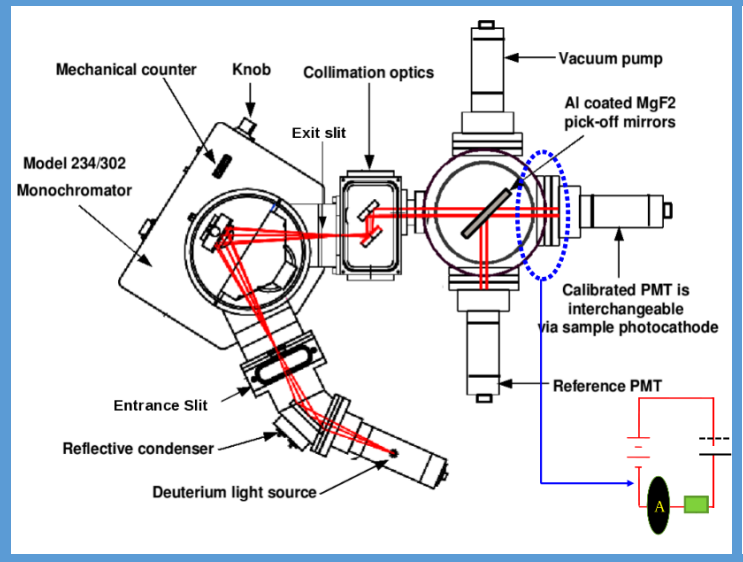




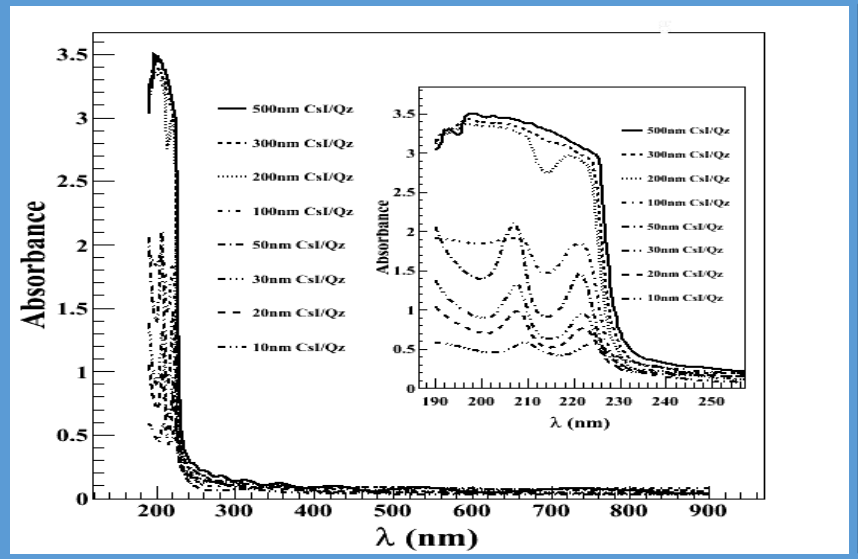
Comparative QE results of 500 nm thick CsI photocathode.



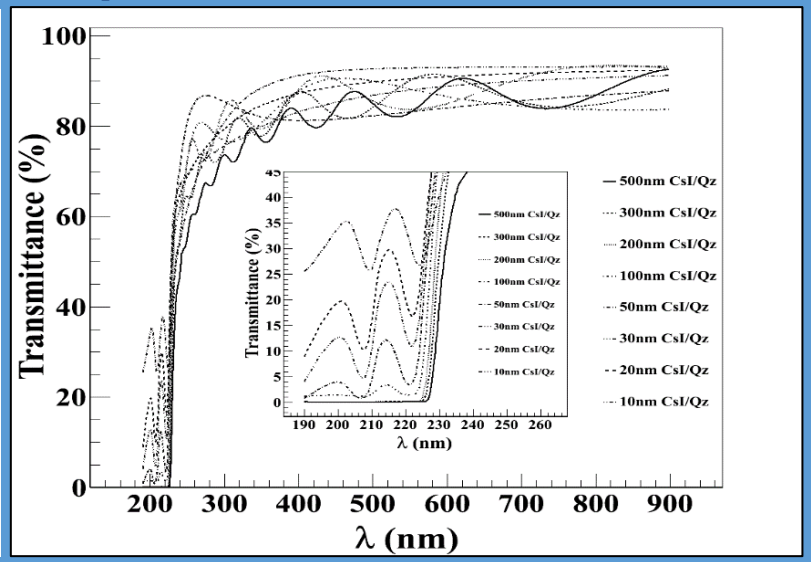
QE as a function of thickness for CsI thin film photocathodes.



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



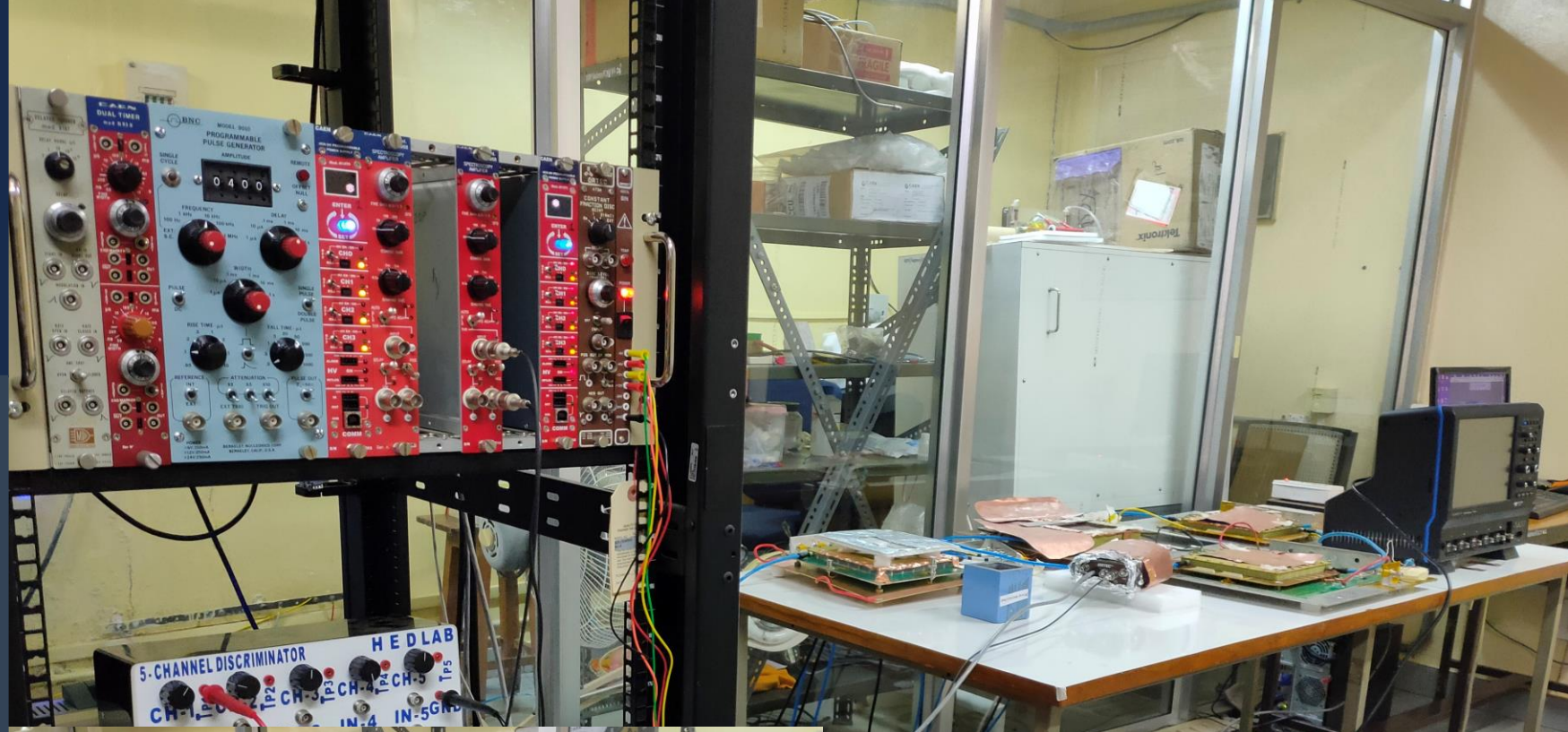
Absorbance of CsI thin film photocathodes deposited on quartz substrate.



Transmittance of CsI thin film photocathodes deposited on quartz substrate.

Facility at IoP Bhubaneswar

Available Setup in **IoP Bhubaneswar, India**



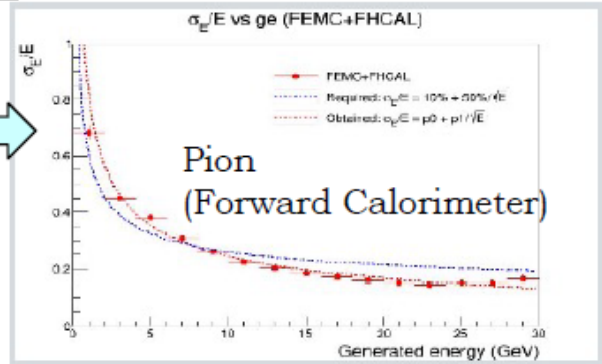
A dedicated 150 ft^2 clean room for detector assembly is available.

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

EIC India

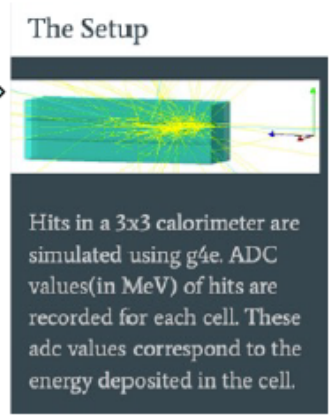
Software Contributions: Benchmarking

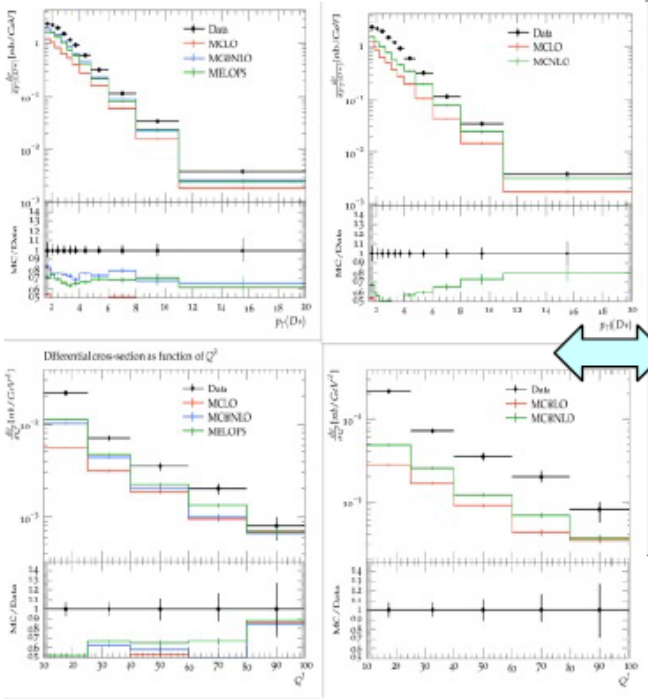
Fun4ALL (PU, IITI) : Parameterization of energy resolution of Calorimeters



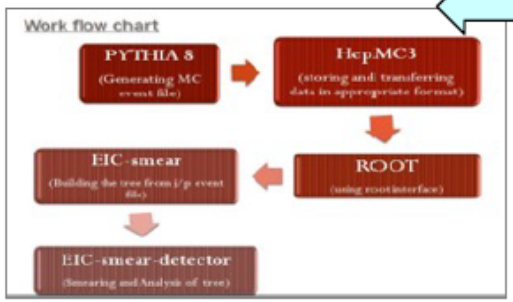
$\sigma_E/E = 2\% + 83\%/E$

Escalate-ML (IITI): Create a framework that read and write generated particle interaction events





MC-data Validation (IITB, IITM, Goa Univ.): Study the global properties of hadronic final states in DIS events and other observables at EIC energies using different event generators.

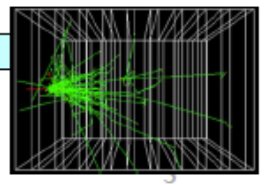


EIC Smear (IITP, IITM, MNIT): Get the smearing for fast-simulation and from Geant4, develop unit tests for the repository using Catch2

Project EAST (IITB, IITM, Goa Univ.): Develop a HepMC3 interface to read event record and pass the information to Geant4

Barrel Imaging Calorimeter (ATHENA): Optimization of Clustering Parameters (PU)

dRICH (NISER): Photo-sensors optimization simulation with JUGLER



Conclusion

- India is willing to be involved in designing, simulating, building and commissioning ePIC.
- India has a large already trained community working on QCD experiments around the world interested to join EIC effort.
- India has both hardware and software expertise → already started participation → in future we are aiming to contribute much more.
- The main hardware interest is to be involved in PID hardware activities → not possible to buy LAPPD → searching for new R&D possibilities.
- We are open to any possible collaborations or for any collaborator thinks that we can be part of.

THANK YOU