Indian Participation in the ePIC experiment at EIC

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HSF-India / ePIC Workshop
IIT Bombay, Mumbai
May 13 -17, 2025

Outline

- **Journey of EIC-India group**
- **Indian Group Activities at EIC**
  - **Highlights of Previous Efforts**
  - **Current Efforts**
- **Summary**

Journey of Indian Groups Toward the EIC

First Formal Interaction:

Workshop on High Energy Physics Phenomenology (WHEPP XIV) at IIT Kanpur, India (Dec. 4-13, 2015)

Dedicated Session: Heavy-ion and QCD (WG-IV) [half-day session on EIC]

First Event:

QCD with Electron-Ion Collider (QEIC) at IIT Bombay, India (Jan 4 – 7, 2020)

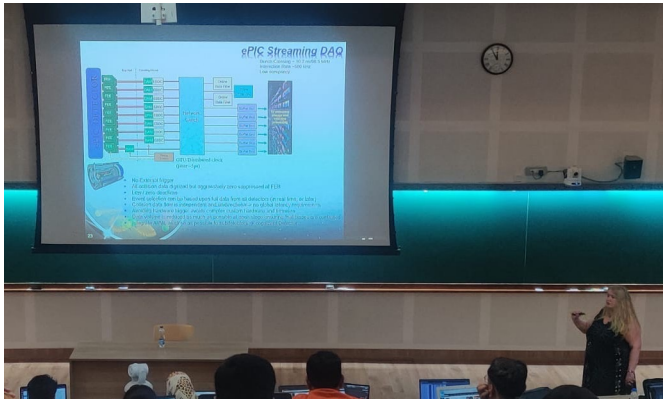
One-to-one interaction and planning

Courtesy: B. Mohanty & L. Kumar

Journey of Indian Groups Toward the EIC

Second Event:

QCD with Electron-Ion Collider (QEIC) II at IIT Delhi, India (Dec 18 - 20, 2022)



Third Event:

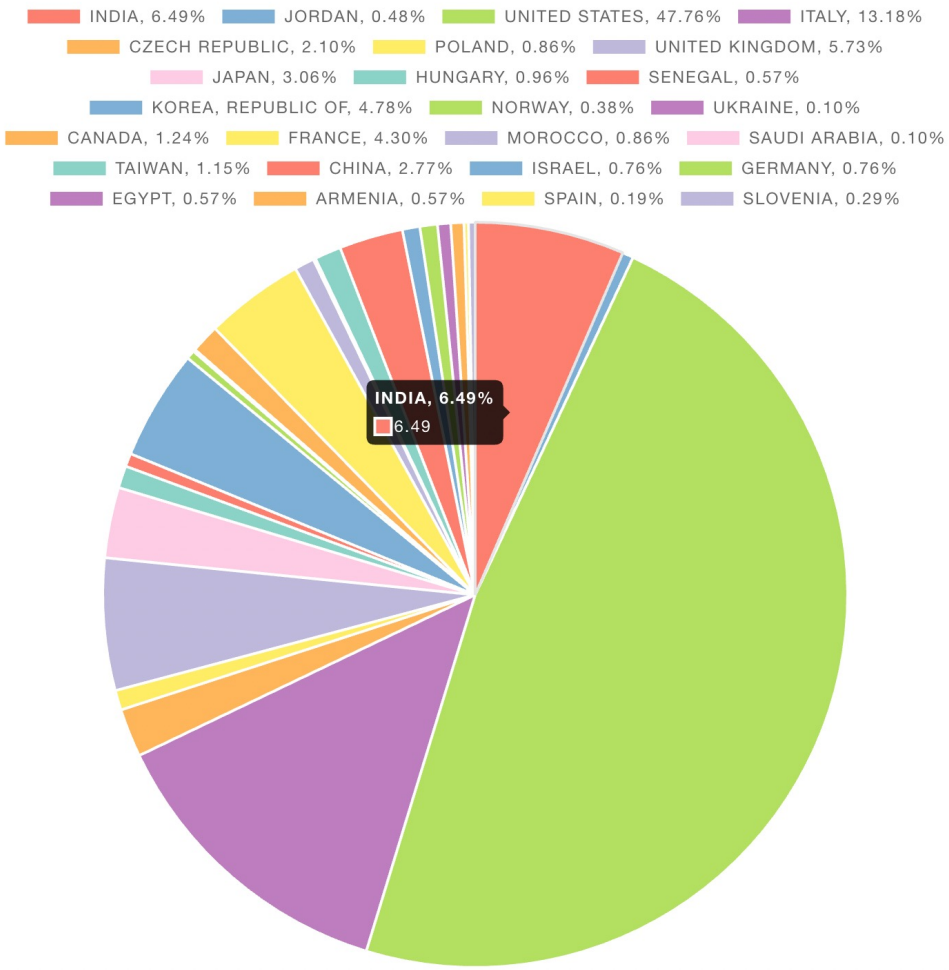
International School and Workshop on Probing Hadron Structure at the Electron- Ion Collider (QEIC) III at ICTS Bangalore, India (Feb 5 - 9, 2024)

EIC-India Groups

Sl.No.	Institution	Council Member	Contact
1	Aligarh Muslim University	Abir, Raktim	raktim.ph@amu.ac.in
2	Banaras Hindu University	Singh, B. K.	bksingh@bhu.ac.in
3	Central University of Karnataka	Samuel, Deepak	deepaksamuel@cuk.ac.in
4	Central University of Tamil Nadu	Behera, Nirbhay Kumar	nirbhaykumar@cutn.ac.in
5	NIT Jalandhar	Dahiya, Harleen	dahiyah@nitj.ac.in
6	Indian Institute of Technology (IIT) Madras	Pujahari, Prabhat	p.pujahari@gmail.com
7	IISER Berhampur	Nasim, Md	nasim@iiserbpr.ac.in
8	IISER Tirupati	Jena, Chitrasen	cjena@iisertirupati.ac.in
9	Indian Institute of Technology (IIT) Bombay	Mukherjee, Asmita	asmita@phy.iitb.ac.in
10	Indian Institute of Technology (IIT) Delhi	Toll, Tobias	tobiastoll@iitd.ac.in
11	Indian Institute of Technology (IIT) Indore	Roy, Ankhi	ankhi@iiti.ac.in
12	Indian Institute of Technology (IIT) Patna	Shah, Neha	neau2802@gmail.com
13	Institute of Physics, Bhubaneswar	Sahu, Pradip Kumar	pradip@iopb.res.in
14	MNIT Jaipur	Kavita Lalwani	kavita.phy@mnit.ac.in
15	NISER	Mohanty, Bedangadas	bedanga@niser.ac.in
16	Panjab University Chandigarh	Kumar, Lokesh	lokesh@pu.ac.in
17	Ramaiah University of Applied Sciences	Ghosh, Tapasi	tapasi03@gmail.com
18	Central University of Haryana	Thakur, Meenu	meenuthakur@cuh.ac.in

Other Institutions: University of Jammu, Indian Institute of Technology (IIT) Mandi, Indian Institute of Science Education and Research (IISER) Mohali

EIC-India Groups



https://phonebook.sdcc.bnl.gov/ePIC/#/worldmap

Indian Group Expertise

Sl.No.	Institution	Available expertise	Remarks
1	Aligarh Muslim University	Theory	
2	Banaras Hindu University	Detector	Worked in detector building
3	Central University of Karnataka	DCS and DAQ	Worked in INO experiment and experienced in developing DAQ and DCS.
4	Central University of Tamil Nadu	Simulation, Physics analysis	Worked in STAR and ALICE data analysis
5	NIT Jalandhar	Theory	
6	Indian Institute of Technology (IIT) Madras	Simulation, Physics analysis	Worked in STAR, ALICE and CMS analysis
7	IISER Berhampur	Simulation, Physics analysis	Worked in STAR and ALICE data analysis
8	IISER Tirupati	Simulation, Physics analysis	Worked in STAR and ALICE data analysis
9	Indian Institute of Technology (IIT) Bombay	Simulation, physics analysis	Worked in STAR and ALICE experiments
10	Indian Institute of Technology (IIT) Delhi	Theory	
11	Indian Institute of Technology (IIT) Indore	Simulation, physics analysis	Worked in ALICE experiment
12	Indian Institute of Technology (IIT) Patna	Simulation, Physics analysis	Worked in STAR and WASA experiments
13	Institute of Physics, Bhubaneswar	Detector control, Simulation	Worked in STAR and ALICE experiments
14	MNIT Jaipur	PID, Simulations	working in BELLE-II experiment
15	NISER	RPC detector, MPGDs, PID, Silicon Trackers, simulation, physics analysis	Worked in STAR, ALICE, CMS, CBM and INO experiments and experienced in gas detectors, and silicon detectors.
16	Panjab University Chandigarh	Simulation, Physics analysis	Worked in STAR and ALICE data analysis
17	Ramaiah University of Applied Sciences	Simulation, Physics analysis	Worked in INO experiment
18	Central University of Haryana	Simulation, Physics analysis	Worked in CMS experiment

EIC-India Theory Alliance (EITA)

Efforts from the Indian theory groups towards EIC-Science

Sl. No.	Institutions	Primary Research Area
1	Aligarh Muslim University, Aligarh	▪ Generalized Parton Distributions (GPDs) and Nucleon Spin ▪ Transverse Momentum Dependents (TMDs) ▪ Color Glass Condensate (CGC) and Gluon Saturations ▪ Small-x physics ▪ Jets in EIC ▪ Precision eP physics ▪ Hadron spectroscopy in lattice
2	Indian Institute of Technology (IIT), Bombay	
3	Indian Institute of Technology (IIT), Kanpur	
4	Indian Institute of Science Education and Research (IISER), Berhampur	
5	National Institute of Science Education and Research (NISER), Jatni	
6	National Institute of Technology (NIT), Kurukshetra	
7	National Institute of Technology (NIT), Jalandhar	
8	Tata Institute of Fundamental Research (TIFR), Mumbai	
9	The Institute of Mathematical Sciences (IMSc), Chennai	
10	Vellore Institute of Technology (VIT), Vellore	

Webpage: https://sites.google.com/view/eic-india-theory/home

Previous Contributions: Simulations

Sl.No.	Task-Name	Collaboration	Study-performed
1	Geant4 Simulations based on sPHENIX solenoid	sPHENIX	Momentum resolution for pion and electron tracks with and w/o truth vertex constraint Institution: Panjab University
2	Fun4All Simulation	ATHENA	Energy resolution and parameterization of energy resolution using pions and electrons for different calorimeters Institutions: Panjab University and IIT Indore
3	MC-data validation	ATHENA	Study of global properties of hadronic final states in DIS events using different event generators ; Compare simulations output with existing HERA data Institutions: IIT Bombay, IIT Madras, Goa University (IIT Mandi)
4	ESCALATE	ATHENA	Software tool to work full simulation of EIC Institutions: RKMRC (IIT Mandi), IIT Indore
5	EIC-Smear	ATHENA	Study smearing effect for exclusive physics with EIC Institutions: IIT Patna, IIT Madras, MNIT Jaipur, CUK Karnataka
6	Contribution to DAQ group	ATHENA	Calculate photon rates of Synchrotron Radiation (SR) on various detectors; results included in ATHENA white paper Institutions: CUK Karnataka

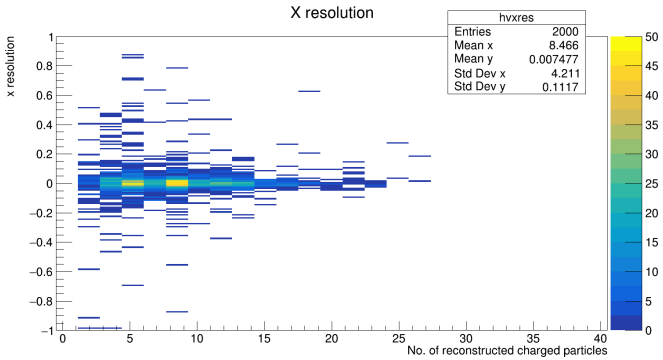
Vertexing @ ePIC

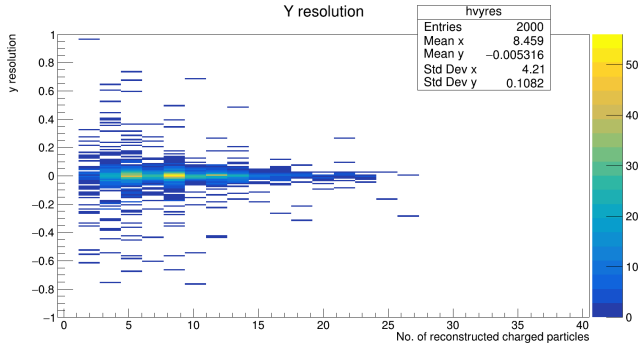
Task: Evaluate the vertexing algorithm performance of ePIC

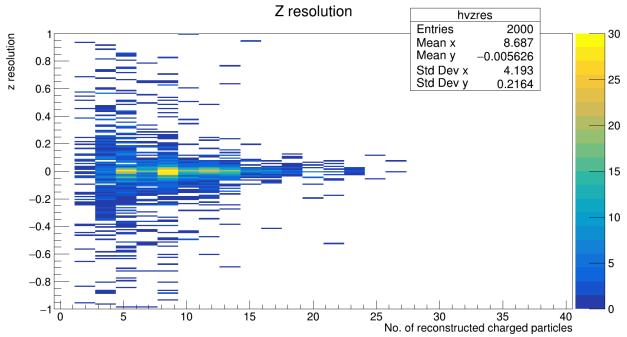
Institution: Panjab University, Chandigarh

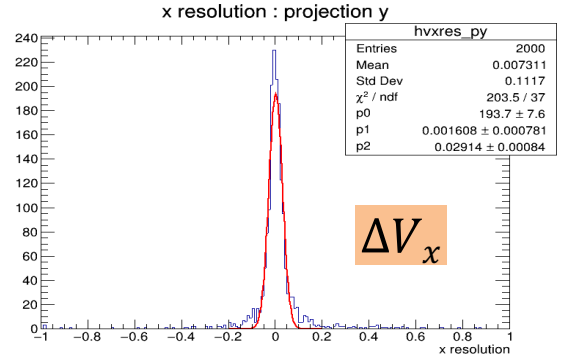
Simulated 2000 events using Pythia 8:

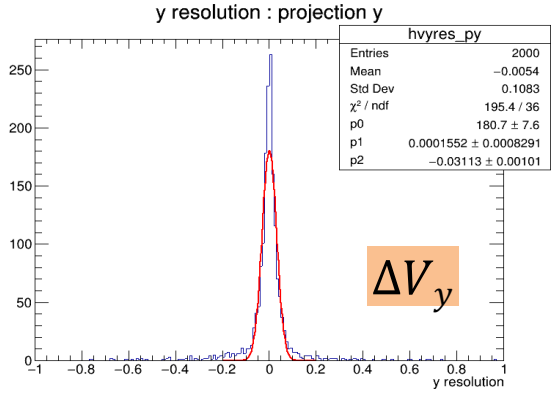
- Electron Beam Energy = 18 GeV
- Proton Beam Energy = 275 GeV

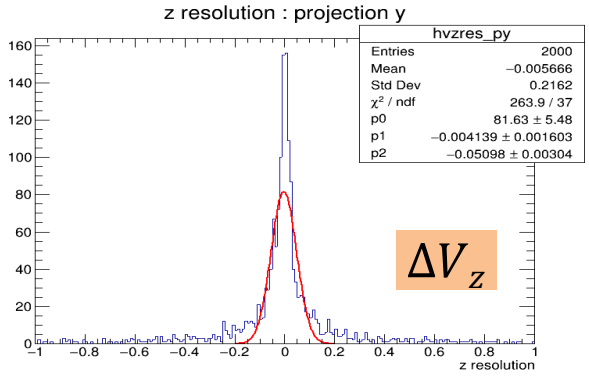






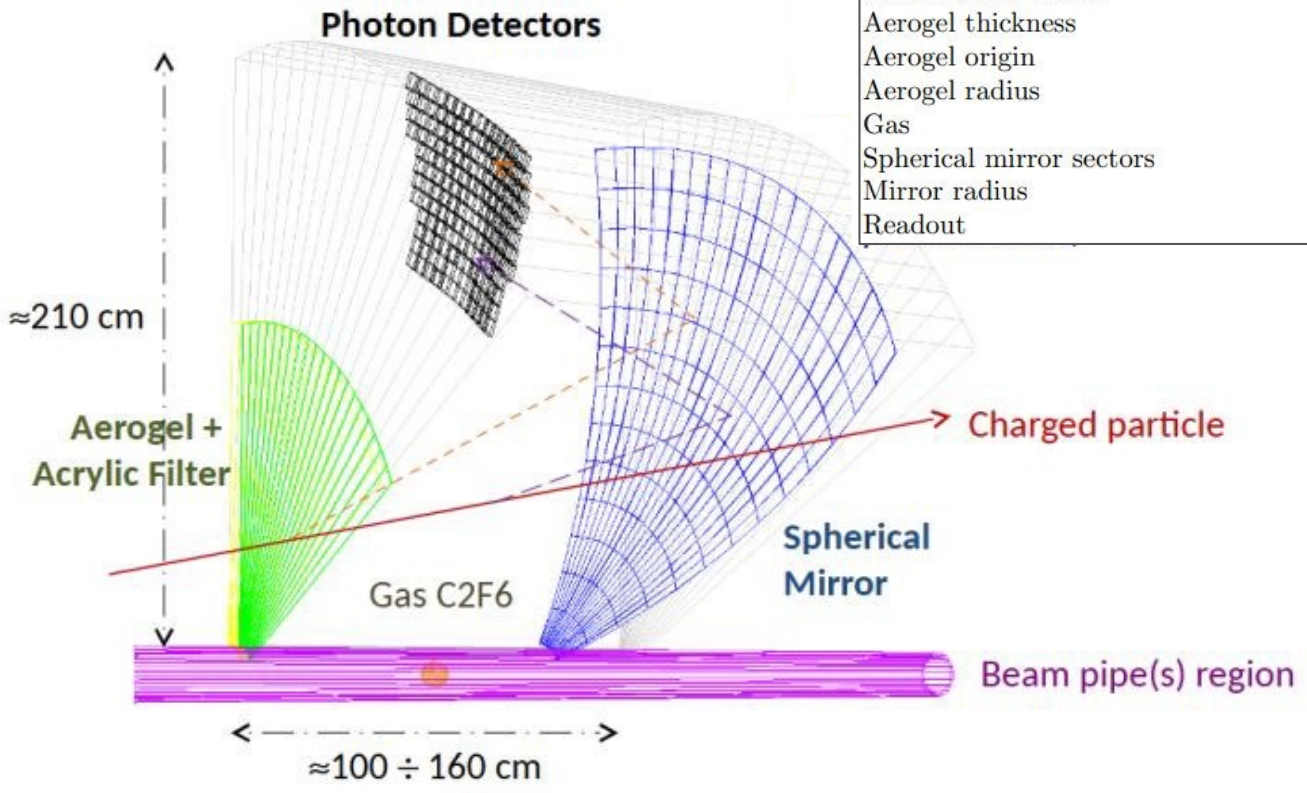






PID studies for dRICH @ ePIC

Institutions: Central University of Karnataka (CUK) and Central University of Haryana (CUH) in association with INFN

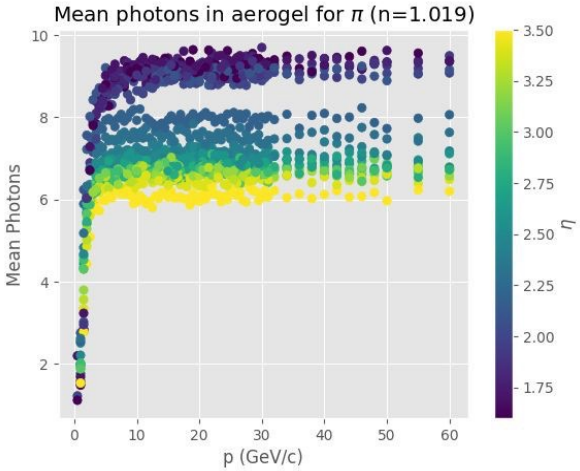


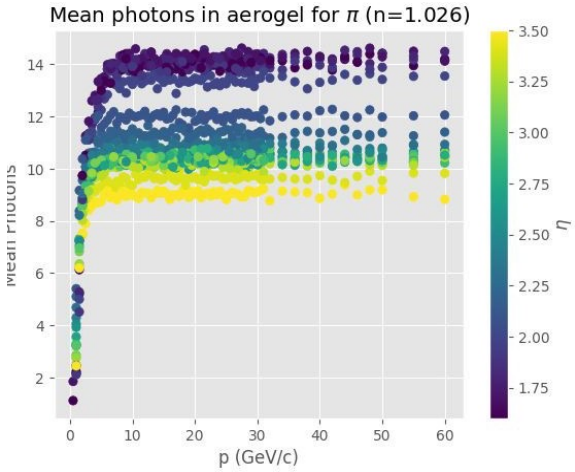
Vessel length	120 cm	baseline design
dRICH outer radius	180 cm	
Aerogel thickness	4 cm	n= 1.019/1.026
Aerogel origin	198 cm from IP	
Aerogel radius	90 cm	η coverage: 1.5 to 3.5
Gas	160 cm C_2F_6	n=1.008
Spherical mirror sectors	$6 \times 60°$	160 cm from Aerogel
Mirror radius	R≈ 2.9 m	
Readout	SiPM	

PID studies for dRICH @ ePIC

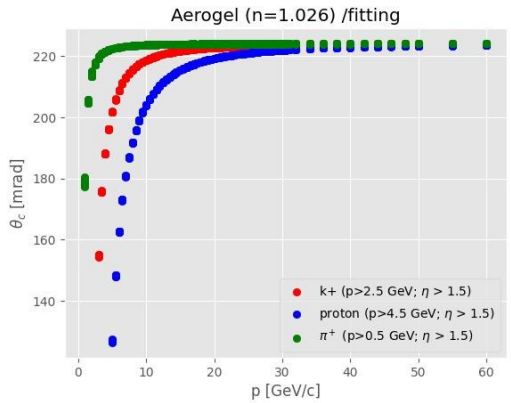
Task: Estimation of separation powers for pions, kaons and protons in aerogel and gas as a function of momentum and pseudorapidity.

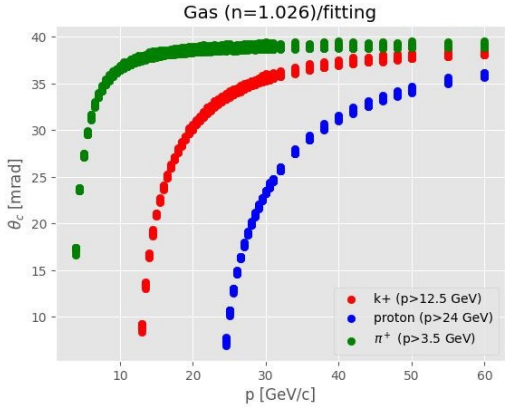
Institutions: CUK and CUH





- Increase in the mean photon count with increasing aerogel refractive index
- Beneficial for improving the S/N ratio





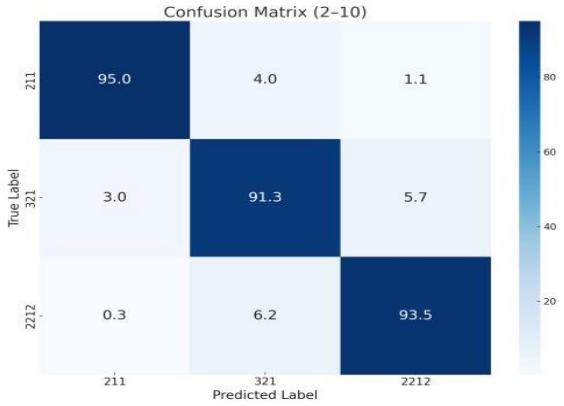
- Due to the dual radiators, PID efficiency is seen to be above 85% for pions and kaons protons up to a momentum of 60 GeV/c
- Protons are clearly separated in the entire kinematic range

✓ Submitted for pre-TDR draft

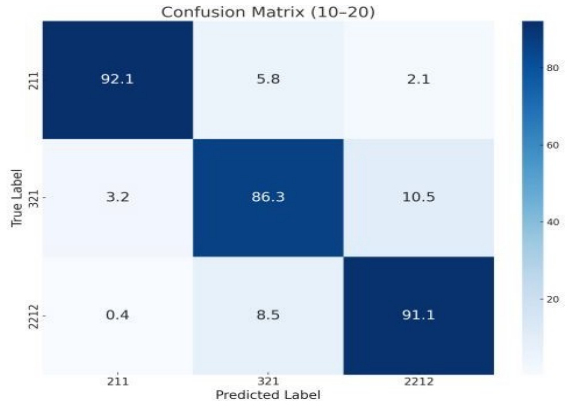
PID studies for dRICH @ ePIC

Task: CNN-based PID - Alternatives to Inverse Ray Tracing algorithm

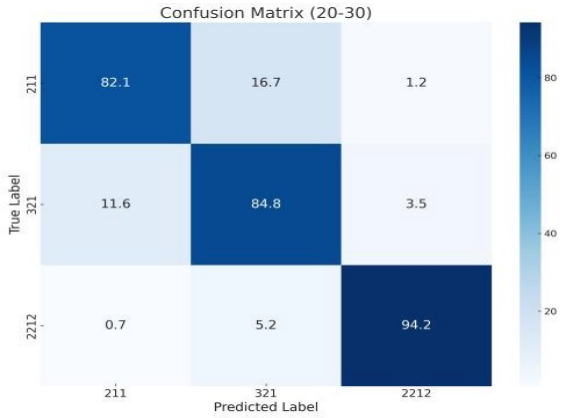
Institutions: Central University of Karnataka



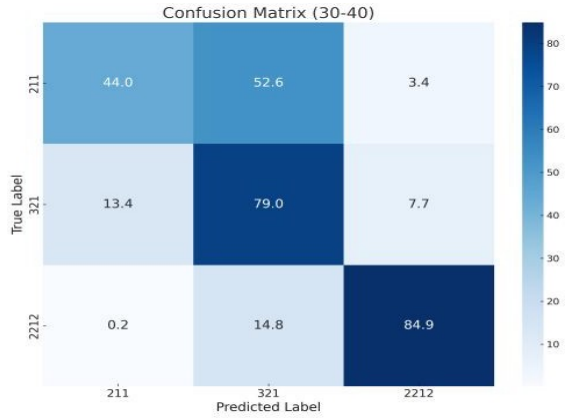
(a) p = 2–10 GeV/c, η = 3.1–3.5



(b) p = 10–20 GeV/c, η = 3.1–3.5



(c) p = 20–30 GeV/c, η = 3.1–3.5

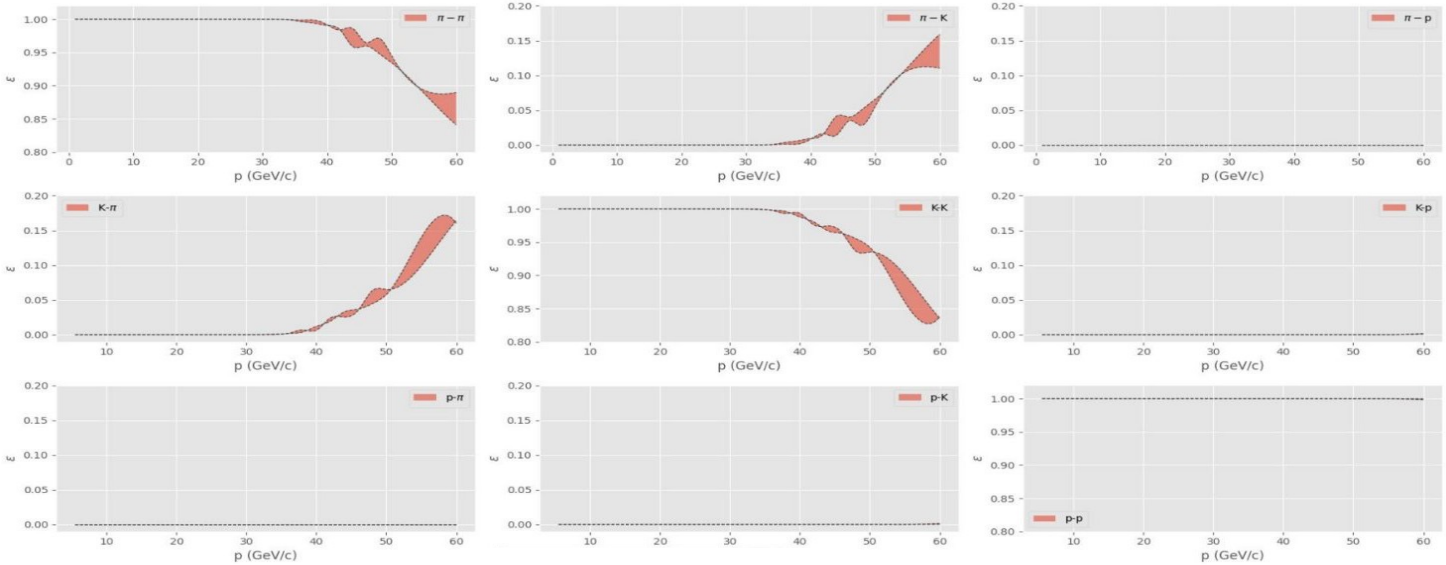


(d) p = 30–40 GeV/c, η = 3.1–3.5

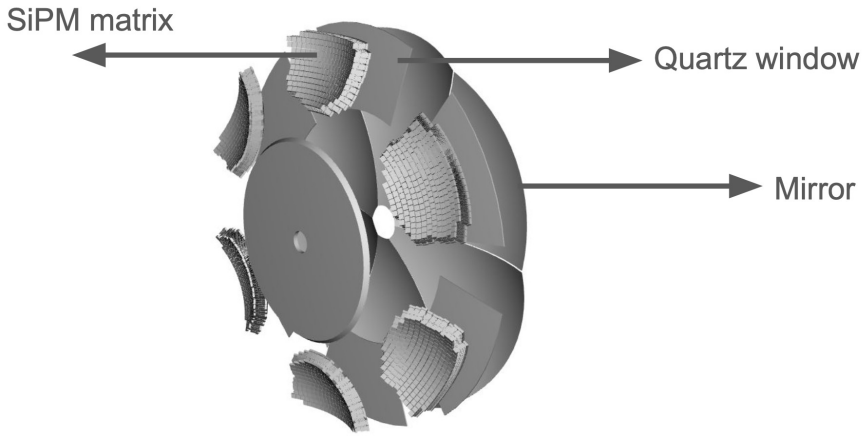
PID studies for dRICH @ ePIC

Task: Preparation of Look-up tables

Institutions: CUK and CUH



Task: Quartz window implementation in Geant4

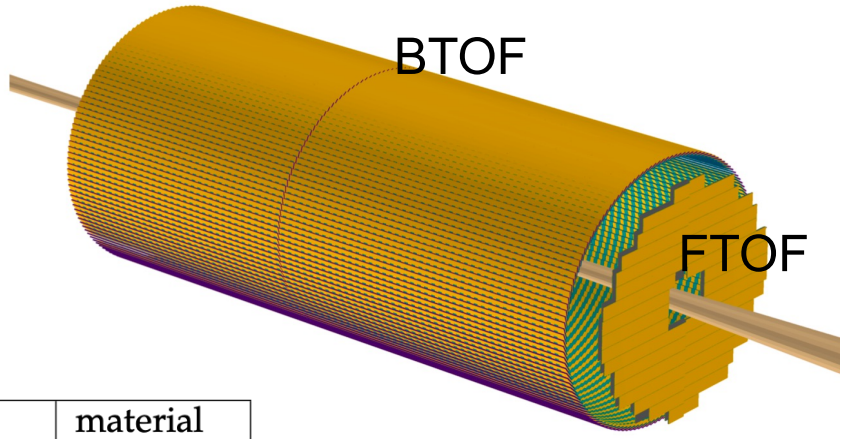


✓ Submitted for pre-TDR draft

Forward Time of Flight (FTOF) simulation

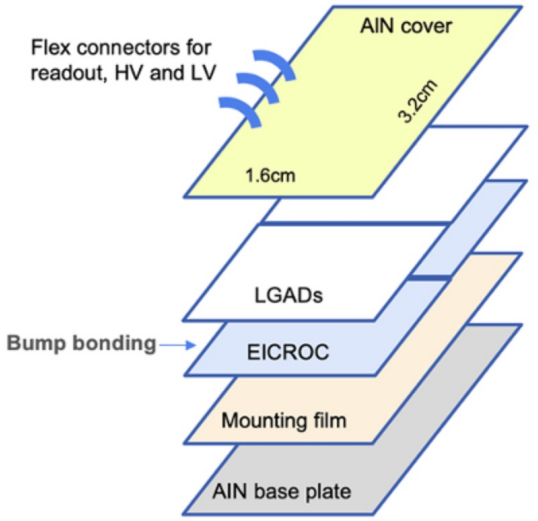
Institution: IIT Madras

- TOF can provide particle identification for charged particles up to a few GeV
  - π-K separation at the 3σ level for p_T < 1.2 GeV/c for $-1.2 < \eta < 1.6$, and p < 2.5 GeV/c for $1.9 < \eta < 3.6$



Subsystem	Area (m^2)	dimension (mm^2)	channel count	timing σ_t (ps)	spatial σ_x (μm)	material budget (X/X_0)
Barrel TOF	12	0.5*10	2.4M	35	30 ($r \cdot \phi$)	3%
Forward TOF	1.1	0.5*0.5	3.2M	25	30 (x, y)	5%

Module



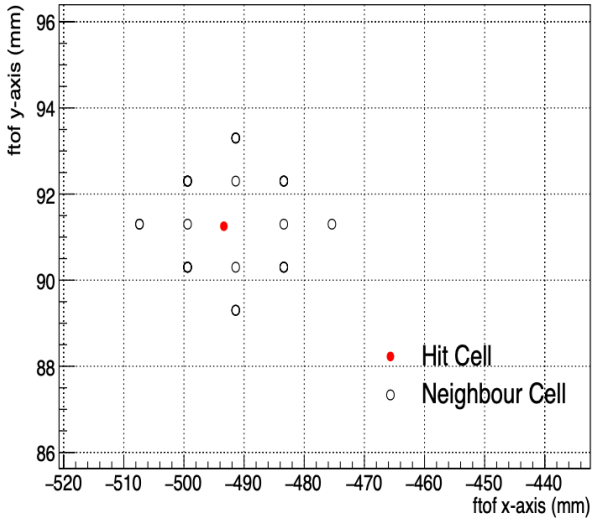
Total Number of FTOF Modules: 780

Forward Time of Flight (FTOF) simulation

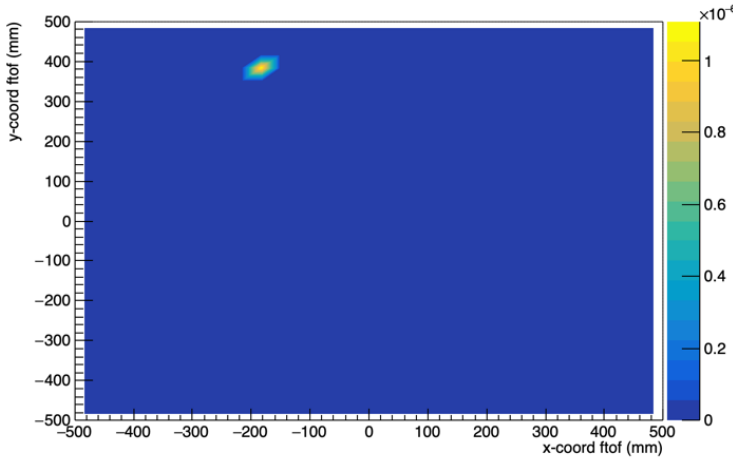
Tasks:

- Extracting hit information from 20 bit cell ID
- Finding neighbouring cells of the hit Cell
- Implementing 2-D gaussian among the neighbouring cell to smear the energy deposited in the hit Cell
- Implementation of digitisation of timing and energy information
- Adding noise in the simulated data

Institution: IIT Madras



Neighbouring cells using second iteration



2-D Gaussian distribution of energy of hit cell.

- ✓ DD4HEP Simulations for FToF
- ✓ Using segmentation to get neighbour Cell ID.

Possible Hardware Contribution

Sl. No.	Possible Project	Measurements	Remarks
1	Dual Radiator Ring Imaging Cherenkov **(dRICH)**	Particle Identification	Use Aerogel + SiPM
2	Forward Electromagnetic Calorimeter **(F-ECal)**	Energy Measurements	Use W-powder / Scintillating Fiber (WScFi) and SiPMs
3	Forward Time-of-Flight **(FTOF)**	Particle Identification	Use AC-LGAD
4	Data Acquisition **(DAQ)**	Streaming Readout	Data reduction using ML techniques on FPGA…

Groups Interested in Hardware Activities:

NISER (ongoing), IIT Bombay, IIT Madras, IIT Mandi, IISER Tirupati, …

Facilities Available

Lab facilities available at: NISER, BHU, IOP, Jammu

NISER

- Clean room
- RPC lab
- Silicon det. lab
- NIM and VME electronics
- Gas mixing
- …

BHU

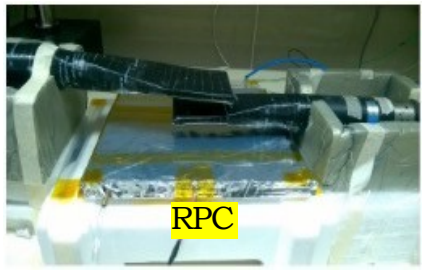
- Working lab
- Gas tight GEM chamber
- VUV-UV Spectro-photometer
- Gas mixing
- ….

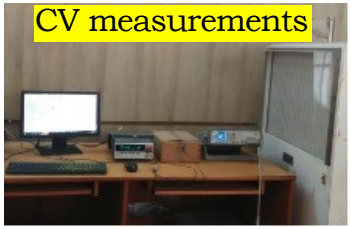
IOP

- Working lab
- Clean room
- GEM-testing
- Electronics
- ….

Jammu

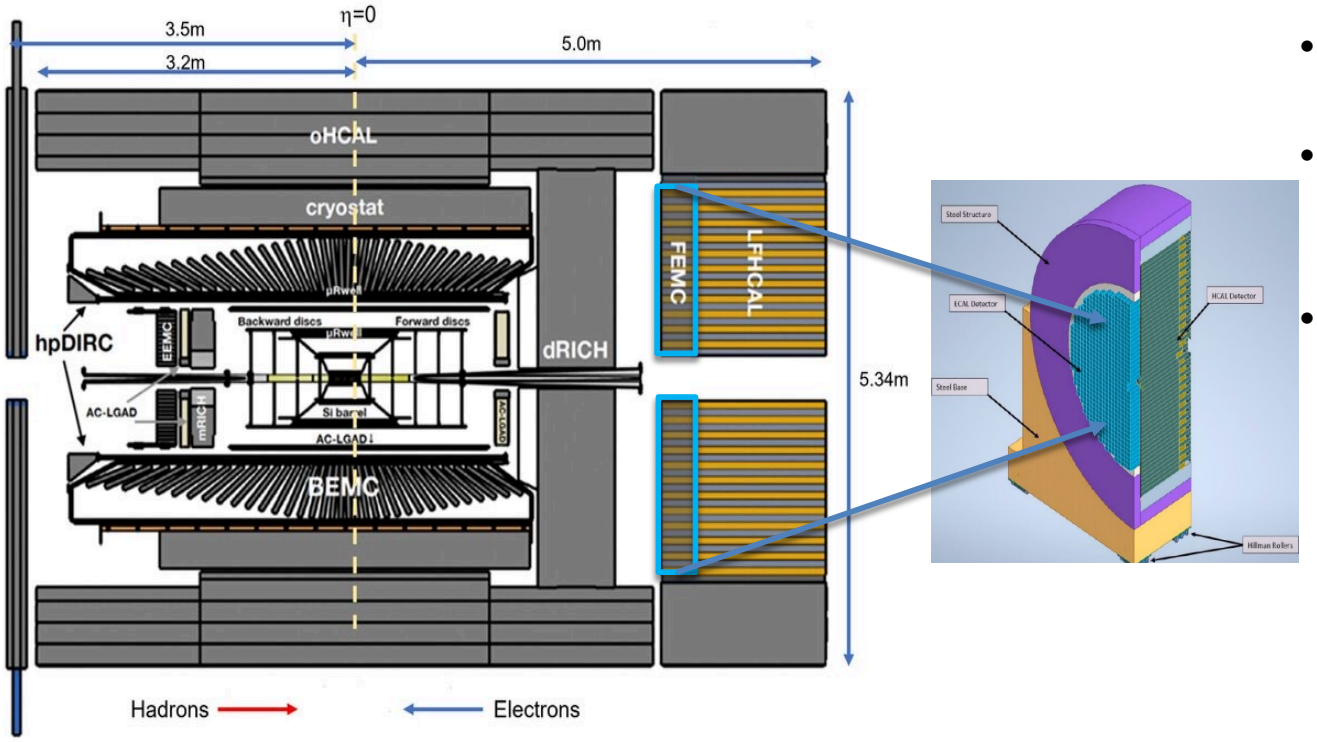
- Working lab
- Probe station
- Electronics
- ….





Possibilities to extend the lab facilities at other places

Forward EM Calorimeter @ ePIC



- Pseudo-rapidity (η) coverage: $1 < \eta < 4$.
- Technology: Tungsten powder / scintillating fiber (W/SciFi).
- Forward EMCAL block prototype built at Fudan University [2].

Figure: Schematic of the proposed detector at EIC [1]. Left: Side view; Right: Forward ECAL [2].

Dimensions: 20 × 5 × 5 cm^3

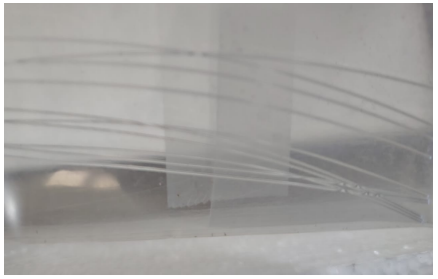
- NISER is planning to participate in the production of the forward EMCAL blocks for ePIC.

[1] J. K. Adkins et al., Design of the ECCE Detector for the Electron Ion Collider, arXiv:2209.02580v2.
[2] Weihu Ma, ePIC Forward ECal: Status and Plan, presented at EIC Asia Workshop, National Cheng Kung University, 29-31 January 2024.

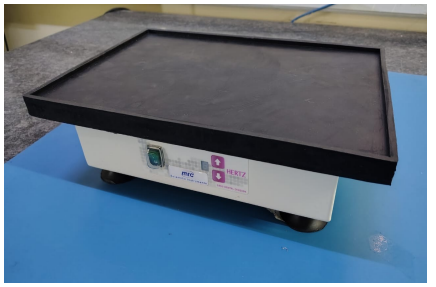
Forward EM Calorimeter @ ePIC

The following required materials to produce a prototype block @ NISER

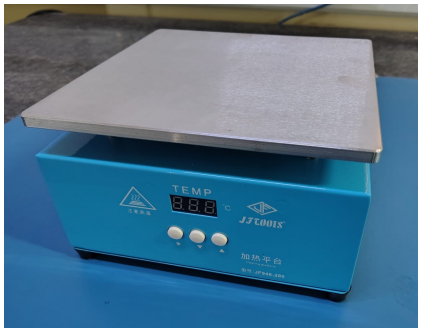
Sl. No.	Material	Properties
1	Scintillation fibres	0. 47 mm diameter, 435 nm emission peak
2	Tungsten powder	Particle size: 90 - 100 µm, tap density: 11.5 g/cm^3
3	Denepox I-40 Epoxy	Long-term stability, high shear strength
4	Mold	Delrin®Polyformaldehyde (POM)
5	Light guide	PMMA/Acrylic
6	Brass screens	To hold the scintillation fibres
7	Optical glues	EPO-TEK 301 and DOWSIL 3145 RTV Silicone Adhesive
8	SiPMs	Hamamatsu S14160-6015PS
9	Vibration platform	
10	Heater	A hot plate which can heat around 60-70 °C
11	Vacuum pump	



Scintillation fibres



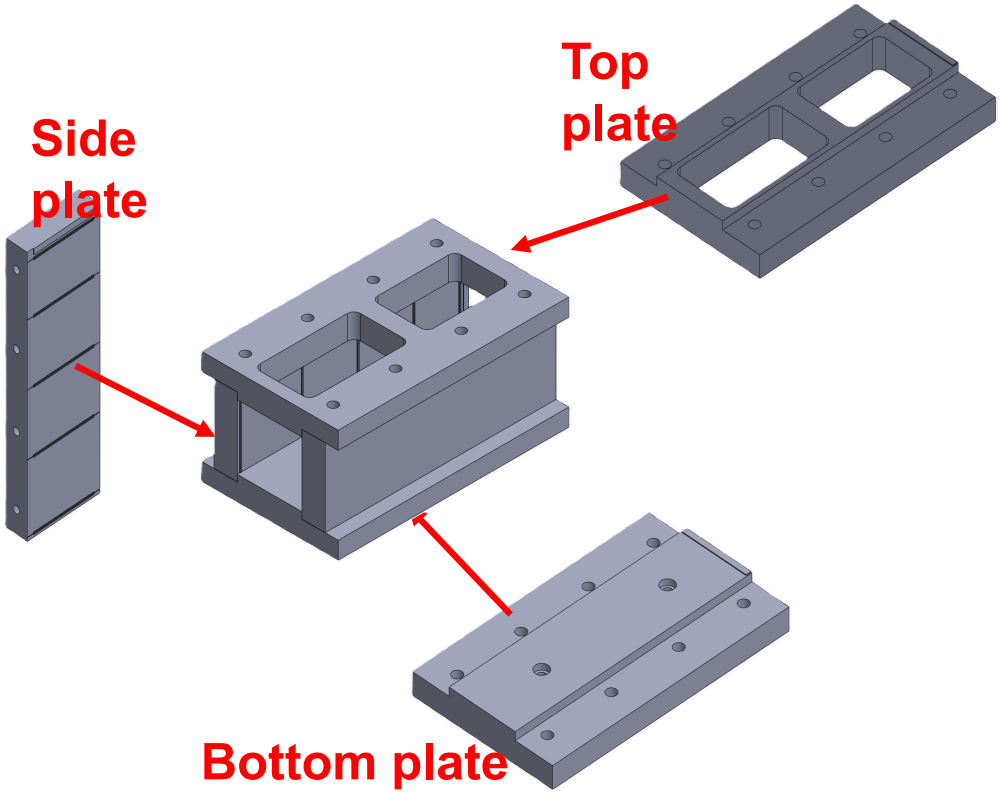
Vibration platform



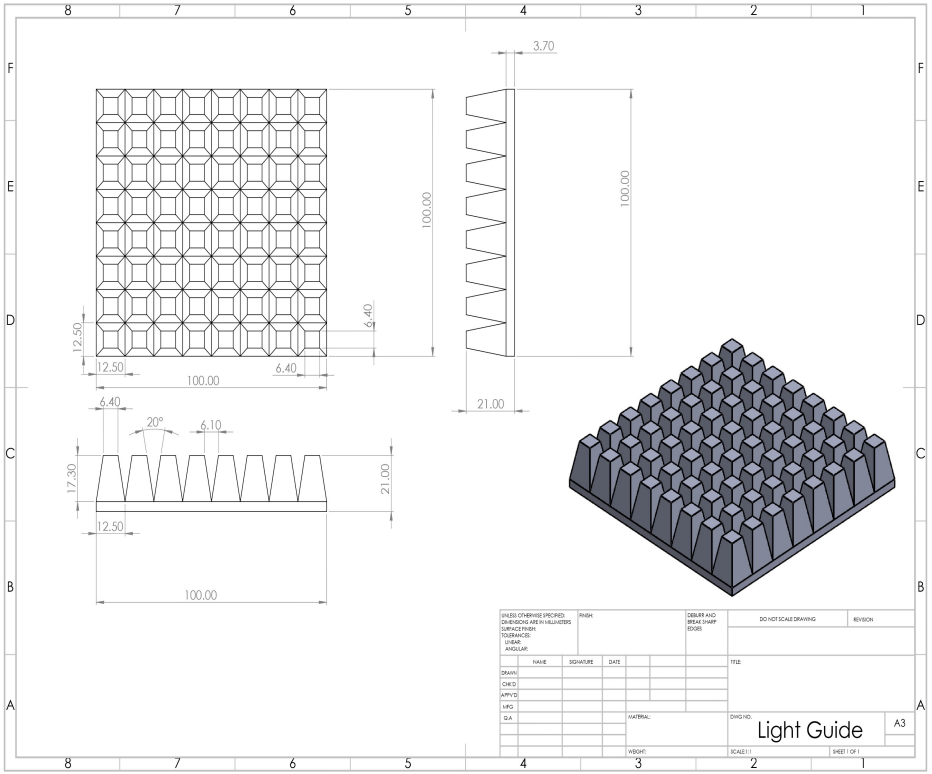
Hot plate

Forward EM Calorimeter @ ePIC

Designs of Mold form and light guide @ NISER



Conceptual design of the Mold form

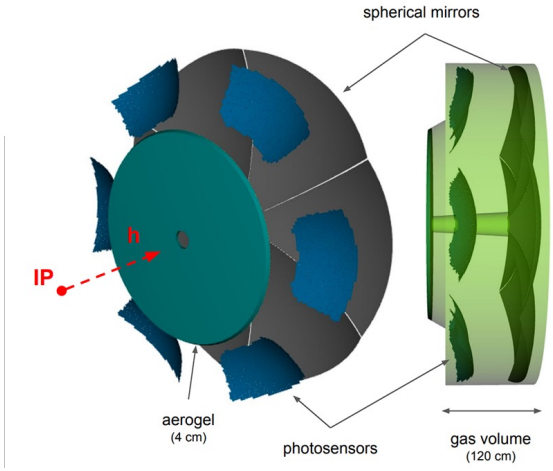


Conceptual design of the light guide

- The components of Mold forms and light guides will be designed at **Central Tool Room & Training Centre (CTTC) Bhubaneswar**.
- Block machining will be conducted at CTTC Bhubaneswar.

dRICH @ ePIC

- **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 large number of detected photons.



Interests of NISER group:

1. Aerogel characterization

I. Study of refractive index uniformity.

II. Transmittance and reflectance studies.

III. Rayleigh scattering in UV domain, chromaticity.

IV. Aging effects due to water absorption: difference in response between different size and thickness of aerogel blocks.

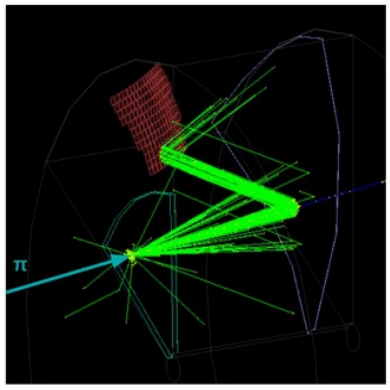
2. SiPM characterizations

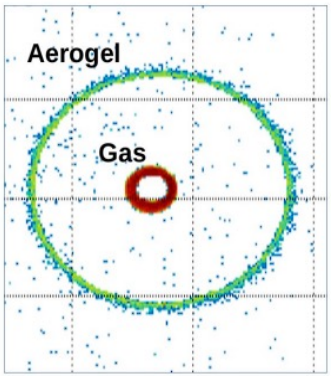
I. Photodetection efficiency (PDE) [normal value ~ 40%]

II. Dark count Suppression.

III. Timing studies.

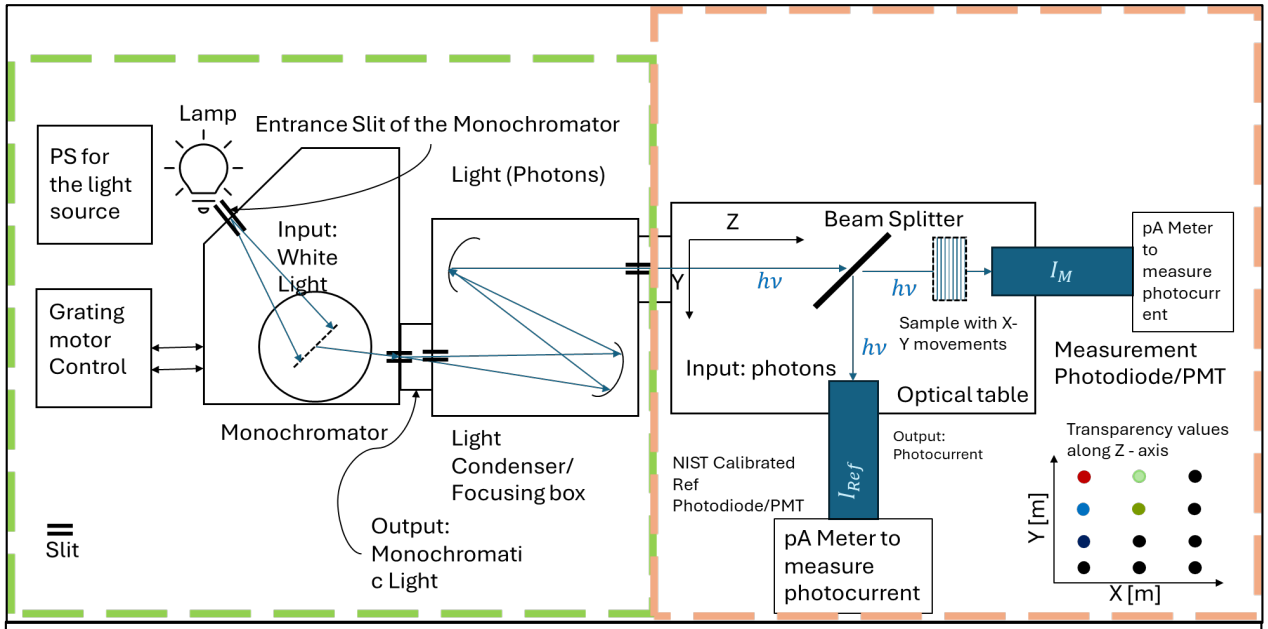
3. Simulation studies





dRICH @ ePIC

Aerogel Characterization Setup @ NISER



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

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

- The Aerogel characterization has 3 different measurement methods.
  1. Thickness uniformity measurement → CMM machine
  2. Refractive Index measurements → by Prism Method
  3. Transmittance length, Absorption length, and Scattering length → Spectrophotometer
- An Integrating sphere can be used with the spectrophotometer to estimate the dispersion of the light within aerogel tile to correct the optical lengths measurements.
- This setup has synergies with ALICE3 pfRICH Aerogel characterization activities.
- Setup is ongoing. It will be ready in the 1.5-year timeline.

Indian Contributions: Various Committees

Contributions toward ATHENA-EIC collaboration:

- ATHENA-EOI preparation, review and submission
- ATHENA-logo design competition
- Various Surveys related to EIC
- Contributed in EIC software (benchmarking, etc.)

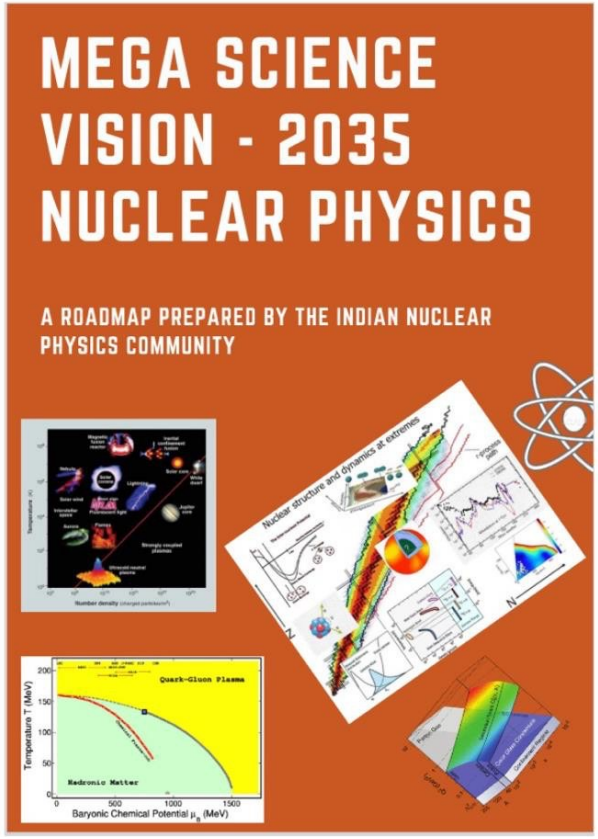
Important Responsibilities in ePIC-EIC collaboration:

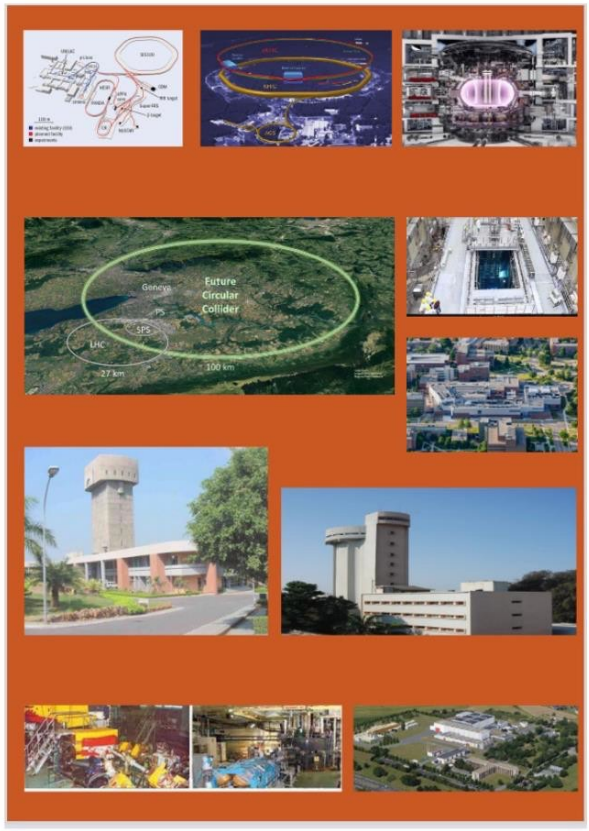
- International Representative for Steering Committee
- Diversity, Equity, and Inclusion Committee
- Elections and Nominating Committee
- Integration Committee (ATHENA)
- Bye laws and Charter Committee

- ePIC Membership Committee
- ePIC Publication Committee

EIC-Science In Indian Long Range Plan

- Mega Science Vision – 2035 (Nuclear Physics) Document:
  A Roadmap Prepared by the Indian Nuclear Physics Community
- The document is released by the Principal Scientific Advisor of Govt. of India in December 2023.





- EIC is mentioned as one of the important Mega Science Project in Indian context.
- Favourable environment for getting funding for EIC

Step Towards Funding Application

- Preparation of a Detailed Project Report (DPR) is ongoing and to be submitted to the Indian funding agency soon.

Indian participation in the electron-Proton/Ion-Collider (ePIC) collaboration at the Electron Ion Collider (EIC) facility, Brookhaven National Laboratory (BNL), USA

Detailed Project Report

1. Project Title: Indian participation in the ePIC collaboration at the EIC, BNL
2. Duration (Normal duration of such projects is 5 years): 3 years
3. Total cost (in Rupees): 25 Cr
4. Foreign Exchange (FE) Component:
5. Proposal Category: Physical Sciences
6. Project Coordinator (PC) details: Prof. Bedangadas Mohanty
7. Co-Principal Investigator/s* details:
8. Keywords: Heavy Ion-Collisions, Hadronic Structure, Quantum Chromo-Dynamics, Particle Identification detectors, Tracking detectors

9. Introduction

9.1 Origin of the proposal:

Many secrets about the building blocks of matter have been already revealed through different world-class facilities like RHIC@BNL, LHC@CERN, and many other particle physics experiments. In 2012 LHC experiments discovered the Higgs boson, which is required to understand mass generation through the Higgs mechanism. However, one still needs to understand how the building blocks of matter, quarks, and gluons, add up to make proton mass and the origin of the spin of the proton. Major objectives of Nuclear Science which are not yet understood by the existing experiments are the following:

Summary

- Indian groups are actively participating in the ePIC–EIC collaboration, with many more expressing strong interest in contributing
- Several groups are already involved in detector development and simulation work for ePIC
- Most participating institutions bring rich experience in detector hardware and physics analysis from other major high-energy experiments
- Discussions are ongoing to finalize specific hardware contributions to the ePIC detector by Indian groups
- A Detailed Project Report (DPR) is under preparation and will be submitted soon to Indian funding agencies to get initial financial support

Thank You!

Acknowledgements:
EIC-India Collaboration
ePIC Collaboration

EIC-India Collaboration Mailing List:
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