Efforts and Current Status of Electron Ion Collider (EIC) – India Group

Lokesh Kumar

Panjab University Chandigarh

International Workshop on Probing Hadron Structure at the Electron-Ion Collider
5-9 February 2024

Outline

EIC-India Initiation & Introduction

Highlights of Previous Efforts in EIC Software (ATHENA…)

Current Efforts (ePIC-Simulation), Detector Hardware Possible Project & Future Directions

Summary

EIC-India Initiation
&
EIC-Introduction

Little History in Indian Context

First Formal Interaction:

Workshop on High Energy Physics Phenomenology (WHEPP), WHEPP-XIV,
Dec. 4-13, 2015, **IIT Kanpur**, India
Dedicated session: Heavy-ion and QCD (WG-IV) [half-day session on EIC]

First full-fledged discussion:

QCD with Electron-Ion Collider (QEIC),
Jan. 4-7, 2020, **IIT Bombay**, India
One-to-one interaction and planning

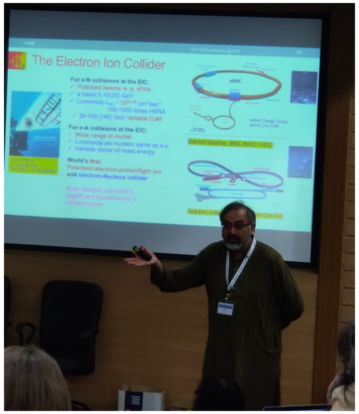


Photo courtesy: B. Mohanty

Little History in Indian Context

Few Outcomes from the 1st QEIC:

- Master student started working in EIC (sPhenix) simulation (Thanks to Christine).
- Biweekly meeting planned within Indian group. (eic_india@googlegroups.com)

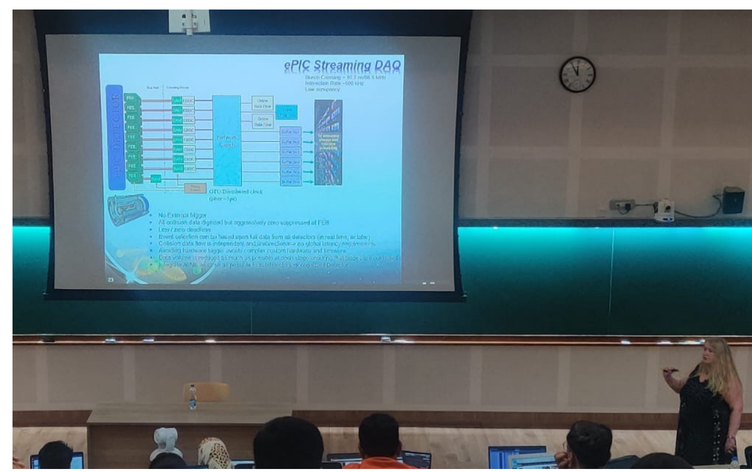
QEIC now a Regular Assignment within India:

2nd Meeting:

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

3rd Meeting:

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



EIC-India Group

Collaboration Council Members

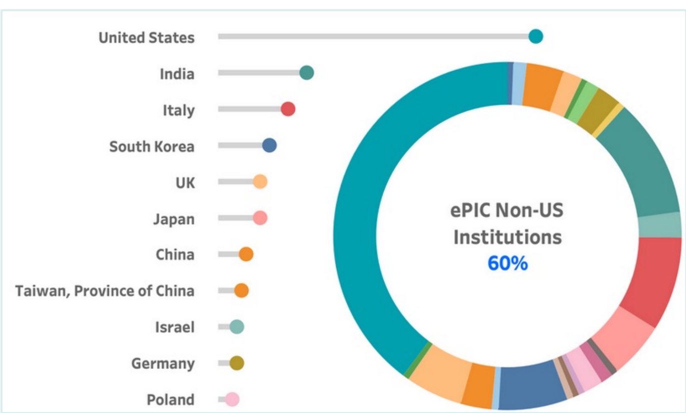
Both Theory and Experimental Groups

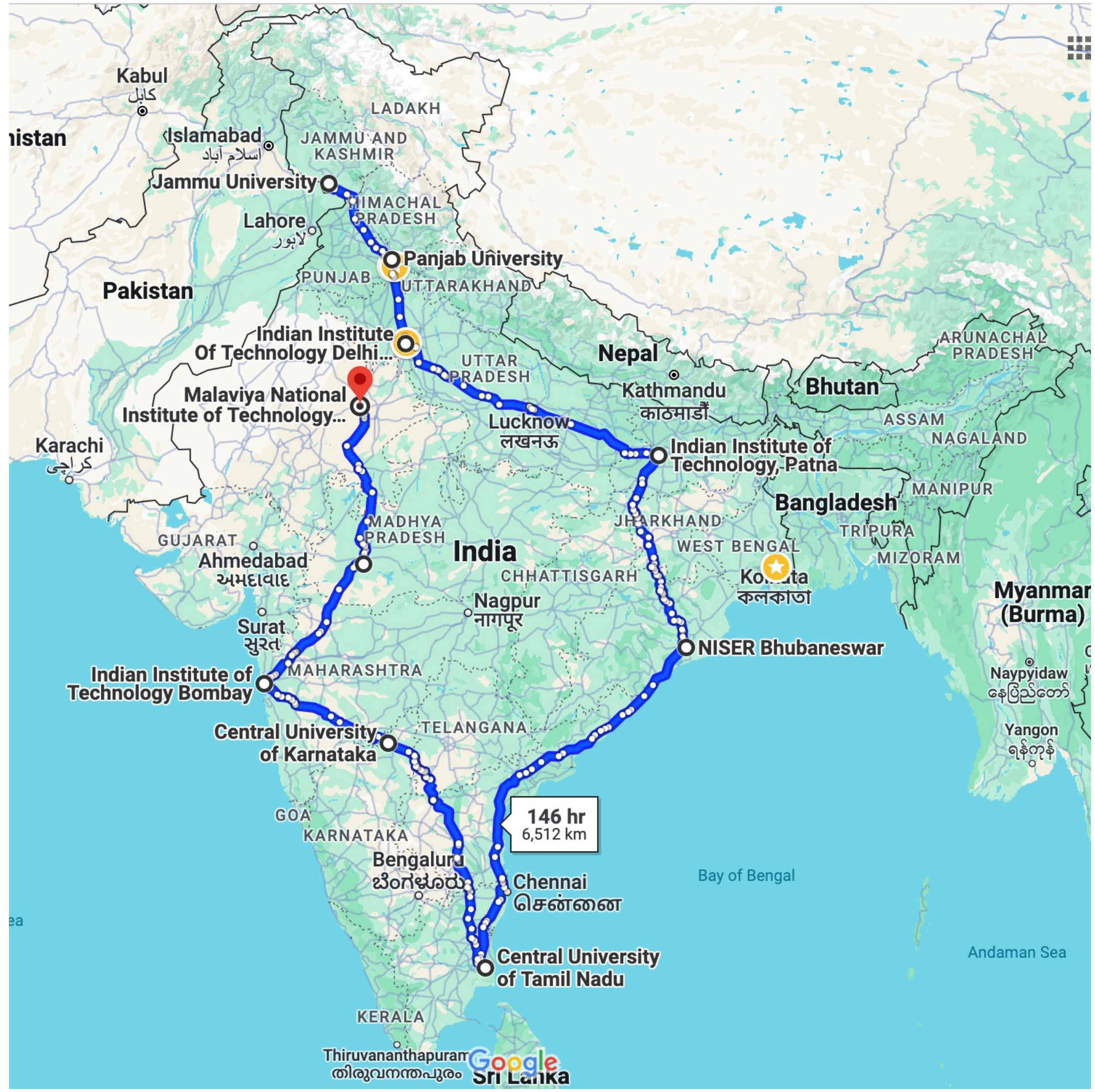
S.No.	Institution	Council Member	Contact
1	Aligarh Muslim University	Abir, Raktim	raktim.ph@amu.ac.in
2	Banaras Hindu University	Singh, B. K.	bksingh@bhu.ac.in
3	Central University of Karnataka	Samuel, Deepak	deepaksamuel@cuk.ac.in
4	Central University of Tamil Nadu	Behera, Nirbhay Kumar	nirbhaykumar@cutn.ac.in
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

EIC-India Group

Other EIC-India Institutions	
S.No	Institution
1	University of Jammu
2	Indian Institute of Technology (IIT) Mandi
3	Indian Institute of Science Education and Research, Mohali

List covers almost every region of India!





Courtesy: Google Maps

EIC-India Group: Expertise

Previous Experience of Different Groups:

From the Heavy-ion and Particle Physics experiments at INO, COSY, KEK, RHIC, LHC, and FAIR

Expertise:

Physics analyses, Simulation, Detector Hardware.. etc.

Detector Hardware etc:

- ✓ *DCS, Trigger, HLT, & Electronics, GRID computing…*
- ✓ ALICE: PMD, TPC, GEM, FOCAL, CRU, Muon Spectrometer…
- ✓ STAR: PMD, HFT…
- ✓ CBM: RPC, GEM, MUCH…
- ✓ CMS: HO, Si-PSD (EMCal), Muon Detector RPC…

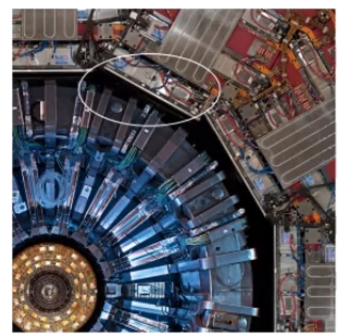
Physics Analyses:

Fluctuation and correlations, HBT, Anisotropic flow, LF Particle/nuclei Production, Photon multiplicity, Light hadron spectra, Nuclei production, Freeze-out dynamics, Resonance Production, Strangeness Production, Jet physics, R_{AA}, Heavy Flavour Physics, J/Psi, Upsilon, Non-photonic electrons, UPC…

Simulation: Detector and Physics simulations -- PMD, FOCAL, CBM…

STAR-ALICE

PMD



CMS

Outer Hadronic Calorimeter (HO)

ALICE

Muon Spectrometer

Indian Participation Since Then

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

(ATHENA: A Totally Hermetic Electron-Nucleus Apparatus)

J. Adam *et al* 2022 *JINST* **17** P10019

Important Responsibilities (from India) within 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

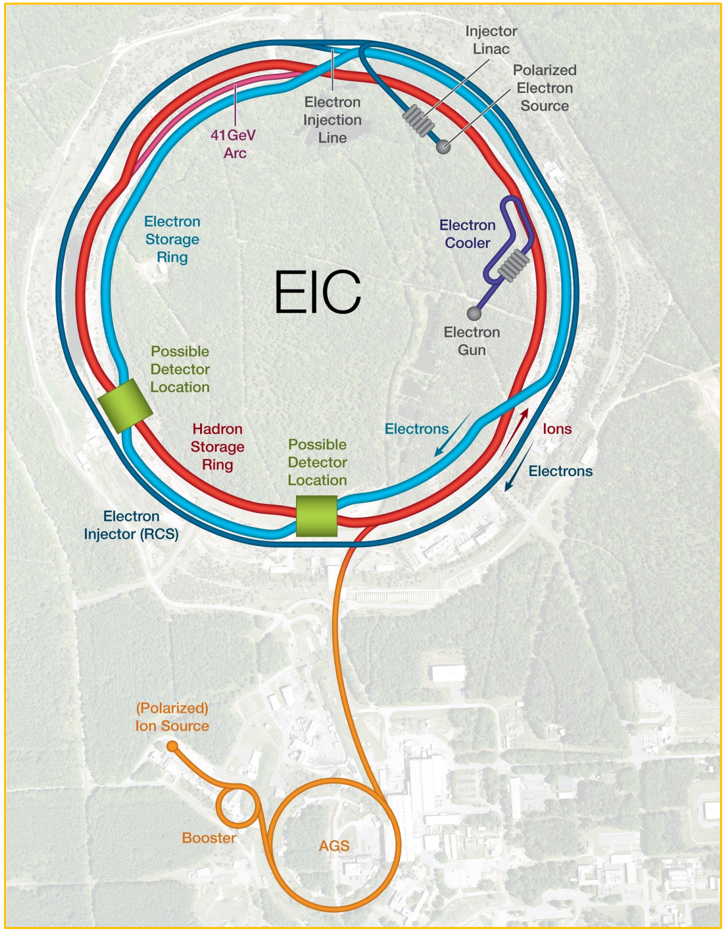
In 2022, ATHENA and EIC Collider Experiment (ECCE) collaborations resulted to a new collaboration: ePIC (Electron Proton Ion Collider)

Electron Ion Collider (EIC)

EIC:

- A new, innovative, large-scale particle accelerator facility planned for construction at Brookhaven National Laboratory (BNL), New York, USA.
- Highest priority project appeared in the 2015 & 2023 US Nuclear Physics Long Range Plan.
- Favorably endorsed by a committee established by the National Academy of Sciences (US) in 2018.
- Granted Critical Decision Zero (CD0) [2019] by the US Department of Energy (DOE) – marked as the official project of the US government.

US-NSAC Long Range Plan, 2015
US-NSAC Long Range Plan, 2023



EIC Yellow Report

See also:
talk by Elke Aschenauer

Physics Goals and Technical Details

Physics Program: Addresses three profound questions about nucleons (neutrons and protons), and how they are assembled to form the nuclei of atoms

- How does the mass of the nucleon arise?
- How does the spin of the nucleon arise?
- What are the emergent properties of dense systems of gluons?

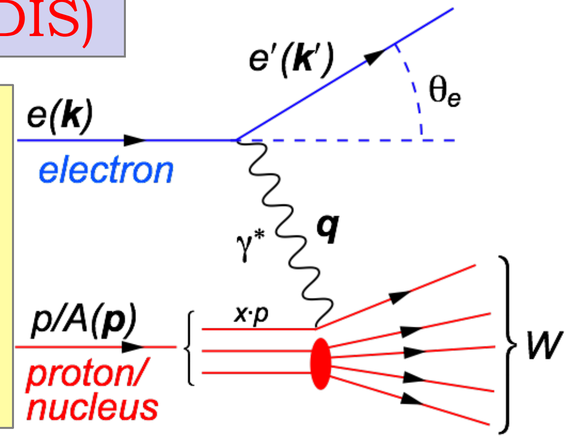
Technical Details:

- A high luminosity ($10^{33} – 10^{34}$ $cm^{-2}s^{-1}$) polarized electron proton/ion collider with $\sqrt{s_{ep}}$ = 20 – 140 GeV
- Only new collider in foreseeable future – will remain at frontier of accelerator S&T

Methodology

Physics Methodology: Deep Inelastic Scattering (DIS)

- As a probe, electron beams provide unmatched precision of the electromagnetic interaction
- Direct, model independent determination of parton kinematics of physics processes



Terminology: $q = k - k'$ $-Q^2 = (k - k')^2$ $s = (k + p)^2$ $W = (p + q)^2$

s: Center-of-mass energy squared for DIS system

Q^2: Square of the momentum transfer between the electron and proton; inversely proportional to the resolution

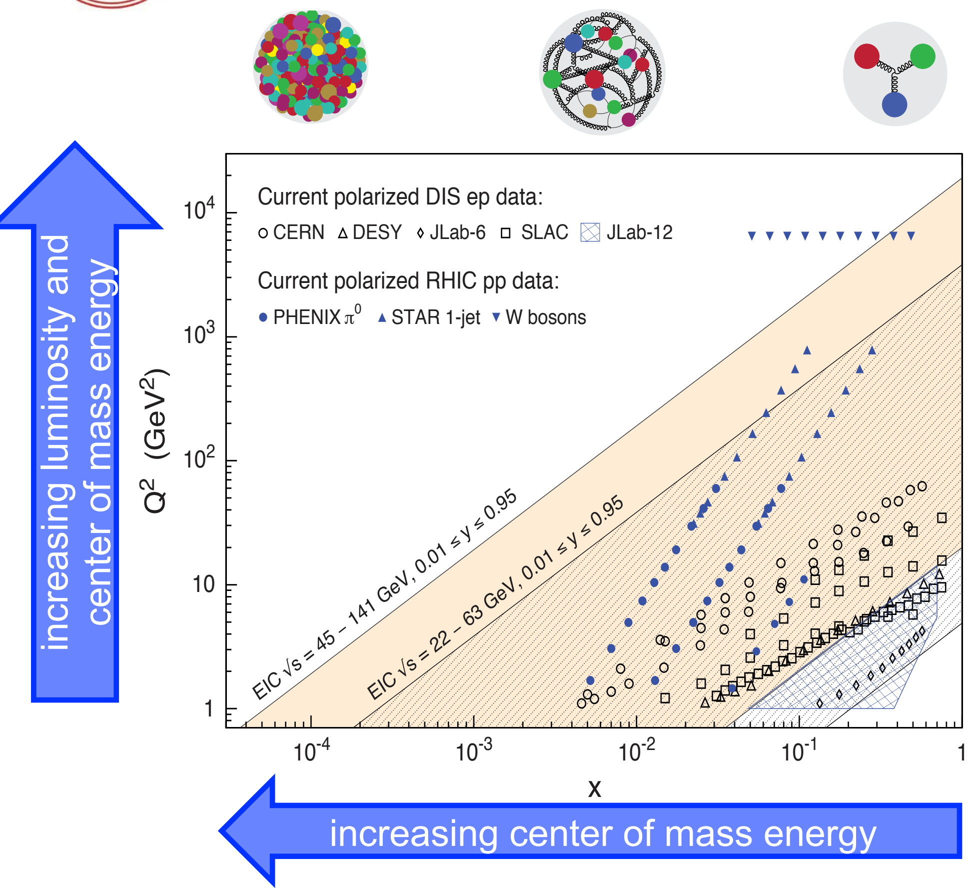
y: inelasticity ($0 \leq y \leq 1$)

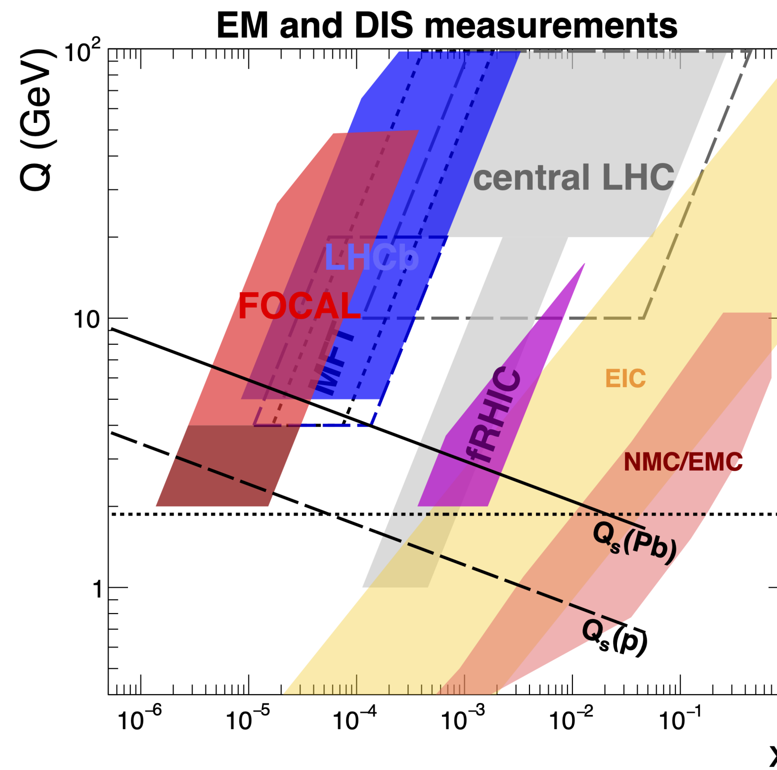
x: the fraction of the nucleon's momentum carried by the struck quark ($0<x<1$)

W: Center-of-mass energy for photon-nucleon system

Variables x, Q^2, s are related through the equation: $Q^2 = s \cdot x \cdot y$

Kinematic Range Comparison





EIC covers large kinematic coverage:

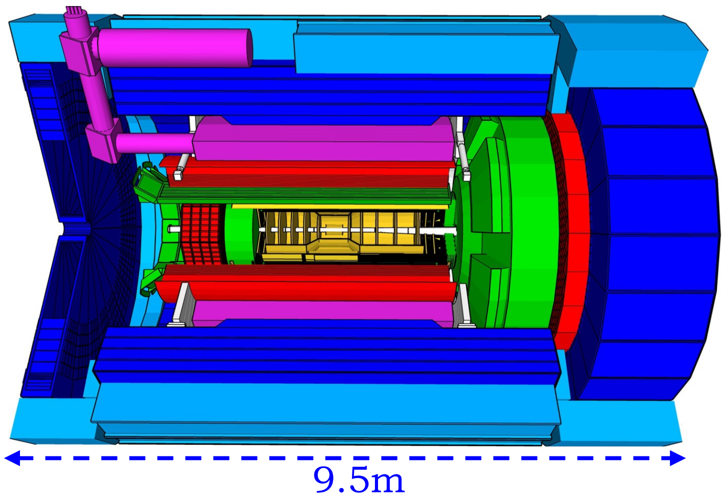
- Center-of-mass energy – $\sqrt{s}$: 20 – 140 GeV
- Access to x and Q^2 over a wide range

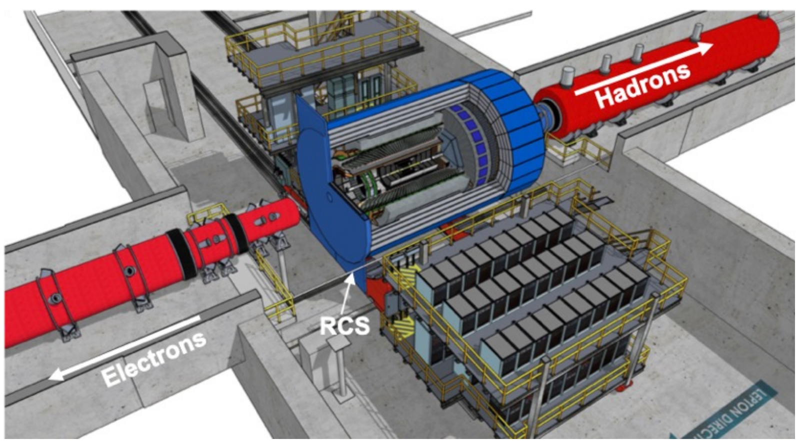
- EIC – Bridge the gap b/w LHC and HERA experiments
- EIC + other experiments give almost full and complementary access to x and Q^2 – *comprehensive data set*

The Detector: **e**lectron **P**roton **I**on **C**ollider

hadronic calorimeters | solenoid coils | ToF, DIRC, RICH detectors

e/m calorimeters | MPG & MAPS trackers





Overall detector requirement

- Large rapidity ($-4 < \eta < 4$) coverage; and far beyond especially in far-forward detector regions
  - Large acceptance for diffraction, tagging, neutrons from nuclear breakup: critical for physics program, Many ancillary detector along the beam lines: low-Q^2 tagger, Roman Pots, Zero-Degree Calorimeter, ….
- High precision low mass tracking
  - small (m-vertex Silicon) and large radius (gaseous-based) tracking
- Electromagnetic and Hadronic Calorimetry
  - equal coverage of tracking and EM-calorimetry
- High performance PID to separate e, π, K, p on track level
  - good e/h separation critical for scattered electron identification
- Maximum scientific flexibility
  - Streaming DAQ → integrating AI/ML

Details about ePIC
https://wiki.bnl.gov/EPIC/index.php?title=Main_Page

These requirements push the technology limit

Highlights of Some Previous Efforts towards the EIC Software

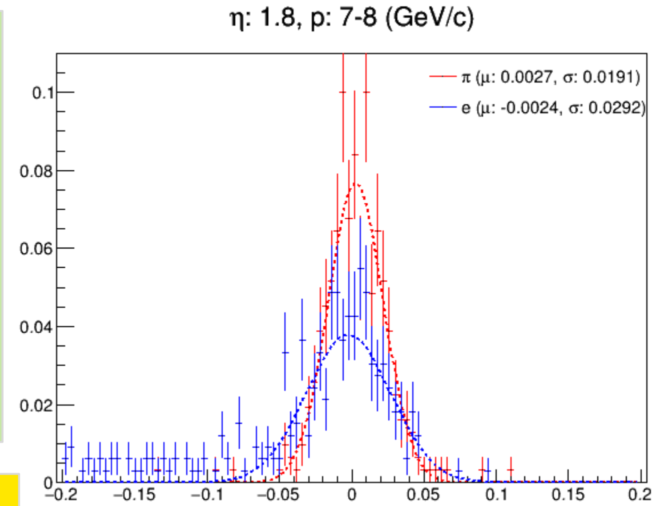
(Workforce: Master Students)

EIC Geant4 Simulation based on sPHENIX Solenoid

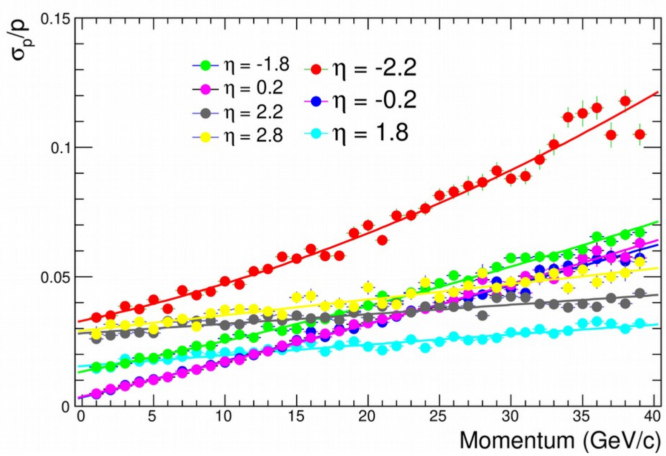
Institution: Panjab University, Chandigarh
In collaboration with: Christine Aidala, Jin Huang

Task: Including silicon tracker & new beampipe

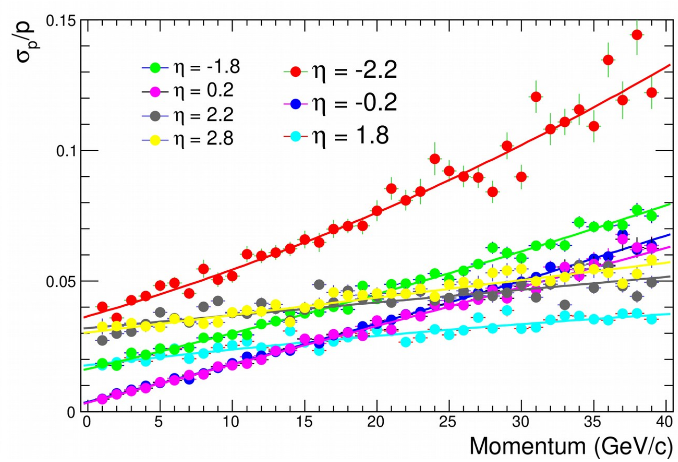
- Obtain momentum resolution for pion tracks
  - with constraint on the vertex tracking by using the smeared truth vertex for tracking
  - with relaxing the truth vertex constraint
- Do similar study for electrons
  - with constraint vertex tracking



Pion track w/ vert. constraint



e- w/ vert. constraint



- Including Si-trackers improve mom. res. at higher η
- Constraint of truth vertex leads to better mom. res.
- Mom. res. of e is worse than that of π – Bremsstrahlung radiation.

Fun4All Simulation

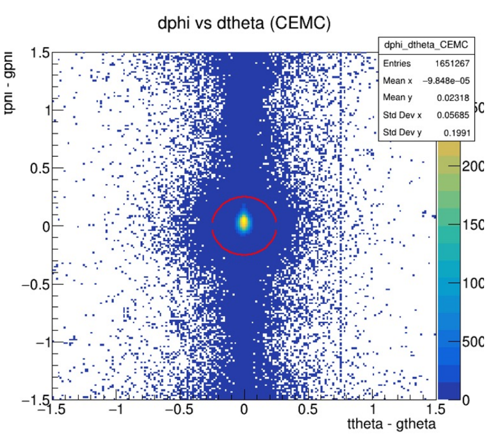
Institutions: Panjab University, Chandigarh & IIT Indore
In collaboration with: Chris Pinkenburg, Kolja Kauder

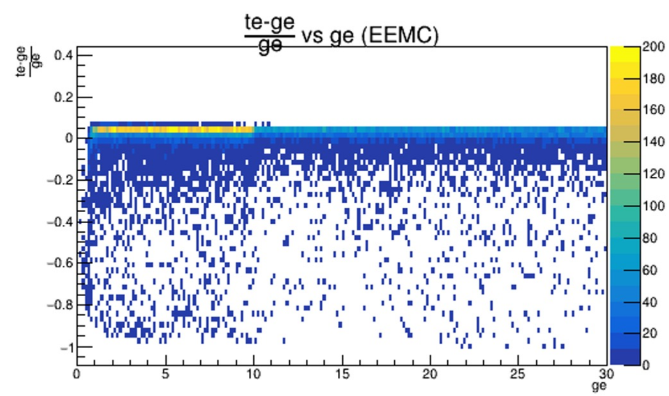
Task: Obtain energy resolution and parameterization of energy-resolution using pions and electrons for

- Electromagnetic Calorimeters (EMCAL): Lead Tungstate (PWO) crystals
  - Midrapidity (Barrel) (CEMC): $-1.5 < \eta < 1.2$
  - Forward rapidity (Ion/forward direction) (FEMC): $1.3 < \eta < 3.3$
  - Backward rapidity (Electron/backward direction) (EEMC): $-3.5 < \eta < -1.7$
- Hadronic Calorimeters (HCAL): Steel absorber (inner), Al Absorber (outer) + plastic scintillator
  - Forward region (FHCAL): $1.2 < \eta < 3.5$
  - Barrel (HCALIN, HCALOUT): $-1.1 < \eta < 1.1$

Ref: EIC Yellow Report

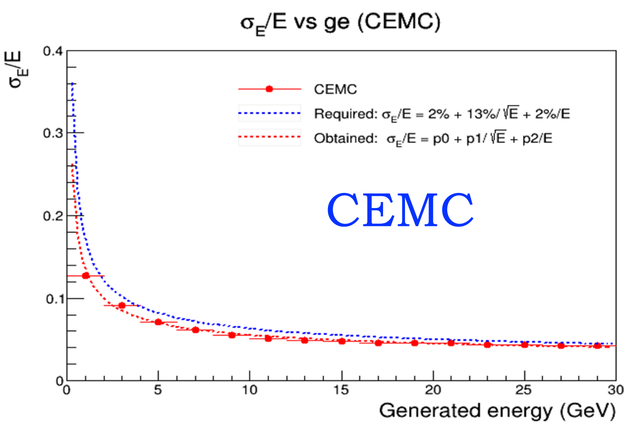
Simplest case considered:
- Photon digitization noise turned off.
- Manual clustering performed on towers – circular cuts phi vs eta differences.

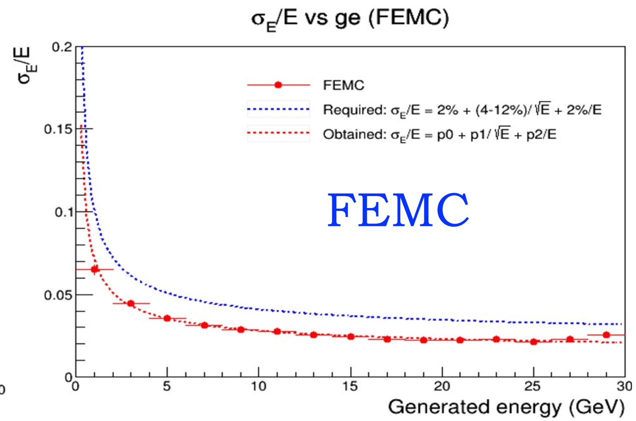


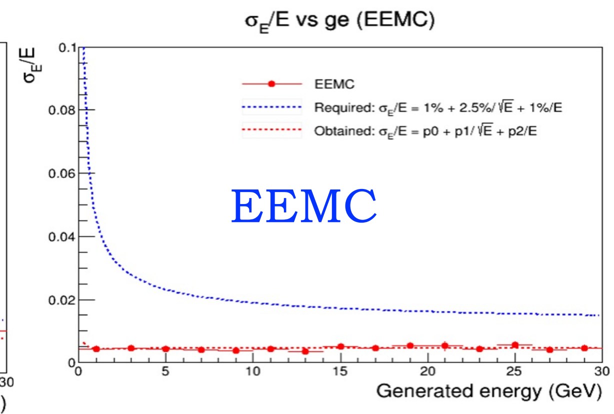


Fun4All Simulation

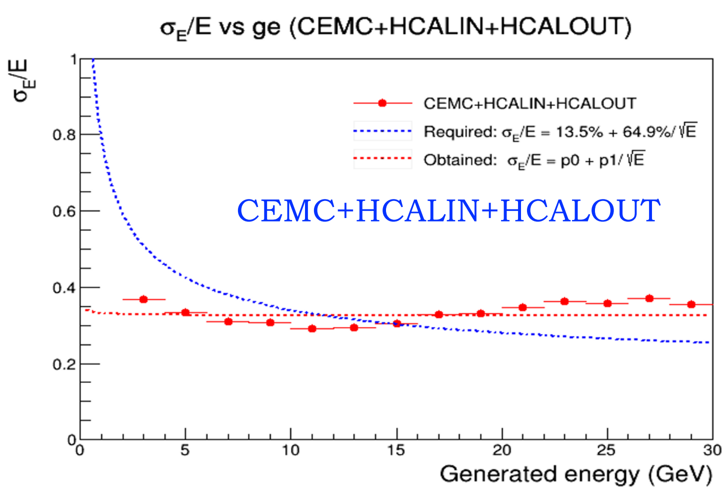
Electron energy resolution

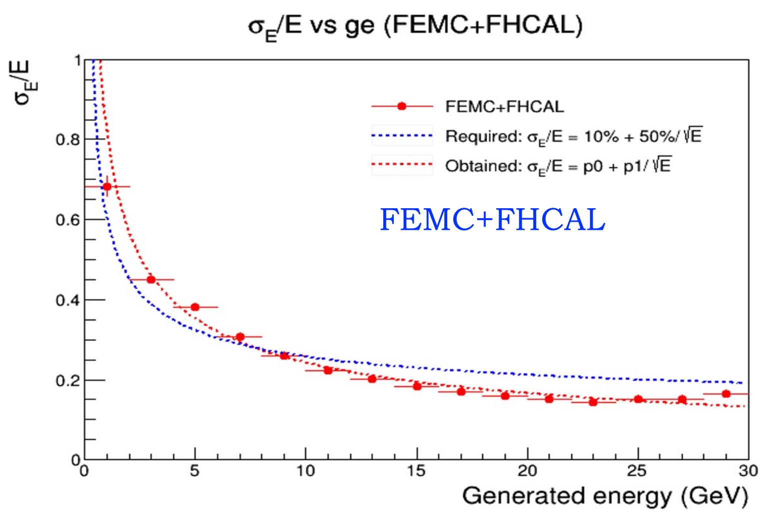






Pion energy resolution





MC-Data Validation

Institutions: IIT Bombay, IIT Madras, Goa University (IIT Mandi)
In collaboration with: Markus Diefenthaler

Task:

- Study global properties of hadronic final states in DIS events and other interesting observables at EIC energies by using different event generators
- Compare simulations output with existing HERA data and improvise the models to account for the differences/discrepancies, if any.

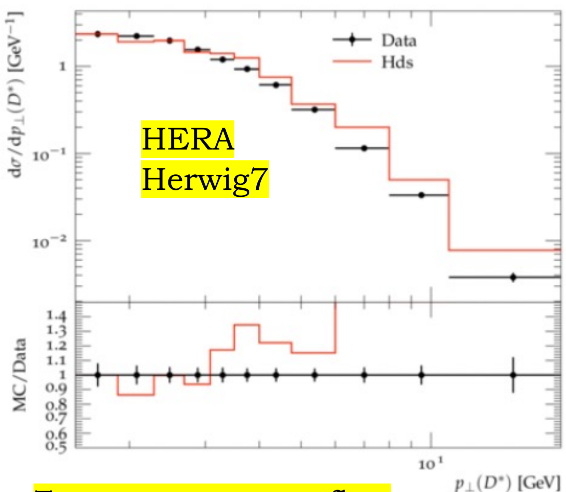
Work: Comparison of available data with events generated using Pythia8, Herwig7 and Sherpa event generators; topics/measurements include:

- Charged particle multiplicities in DIS at HERA (H1).
- Measurement of charged particle transverse momentum spectra in DIS (H1).
- Inclusive ϕ-meson production in neutral current DIS at HERA.
- Measurement of inelastic J/Psi production in DIS at HERA.
- Diffractive Dijets in Photoproduction and inclusive jet production.
- Transverse energy-energy correlations.
- Observation of scaling violations in scaled momentum distributions at HERA.
- Energy flow and charged particle spectra.
- Single differential cross-section of D*-meson production.

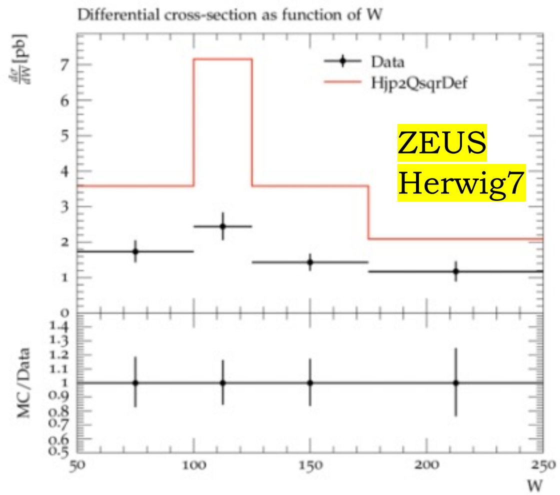
MC-Data Validation

Few Examples

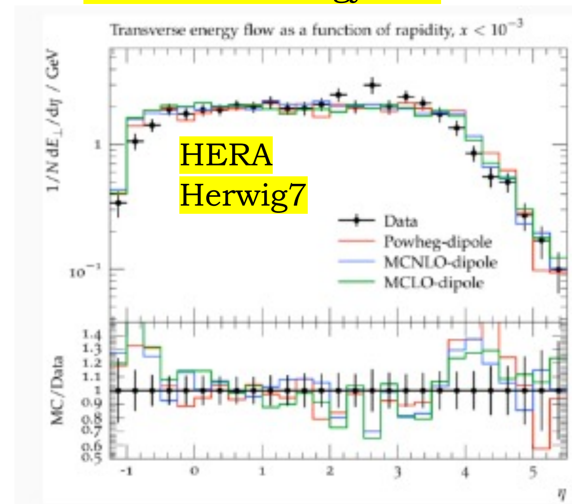
D*+- production cross-section



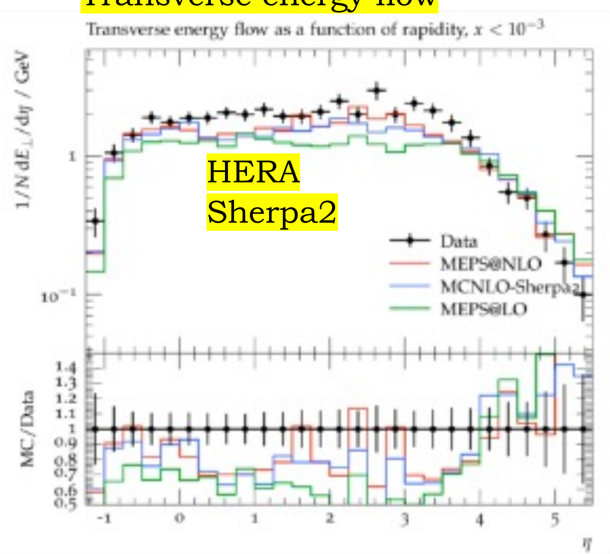
J/Psi production cross-section



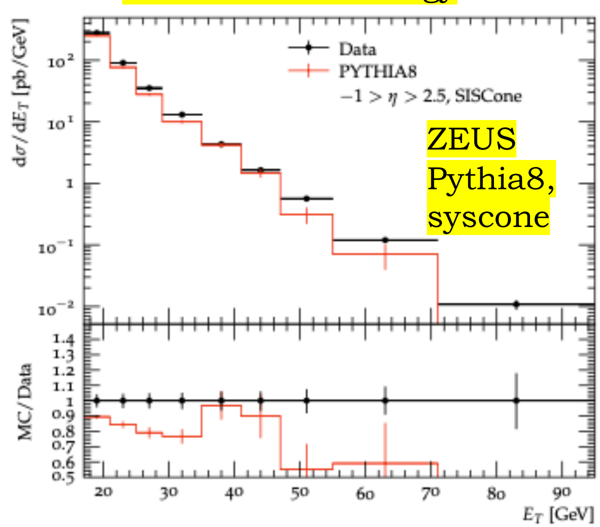
Transverse energy flow



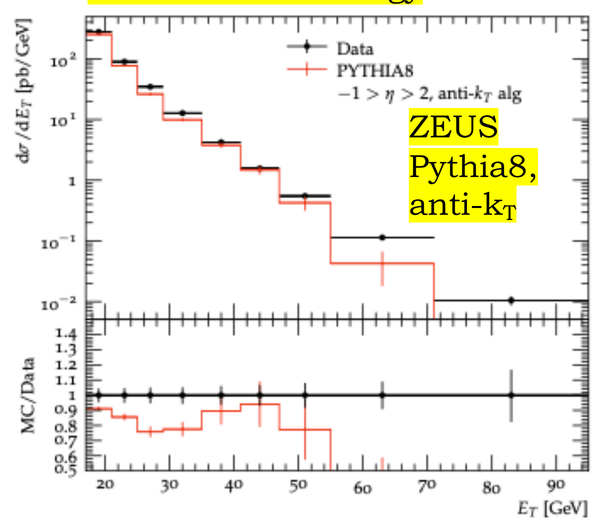
Transverse energy flow



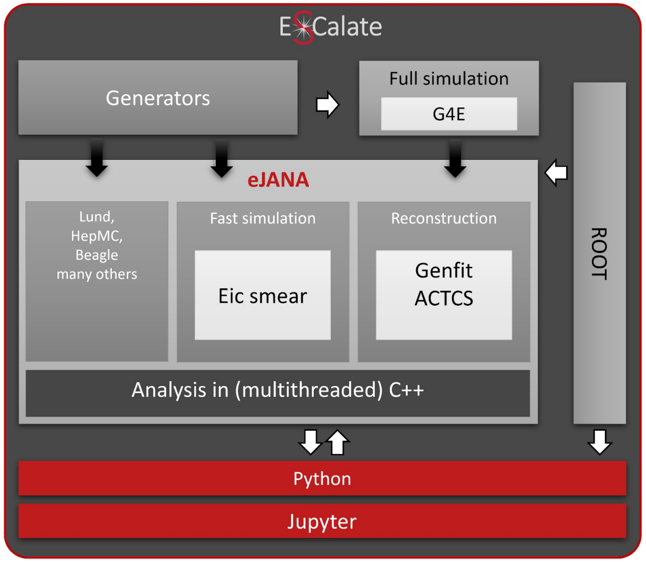
Jet transverse energy



Jet transverse energy



Escalate



Institutions: RKMRC (IIT Mandi), IIT Indore
In collaboration with: Dmitry Romanov

- Software to work full simulation of EIC.
- Both python and c++ can be coded.
- Complete pkg of ROOT, (Geant4 for EIC (g4e) etc - all are inbuild

Validation Plots

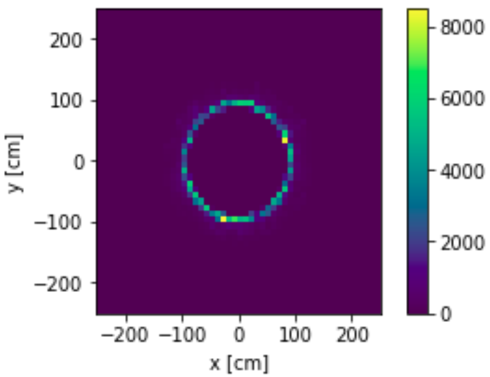
Validation plots for different calorimeters and sensitive detectors.

Beamline Construction

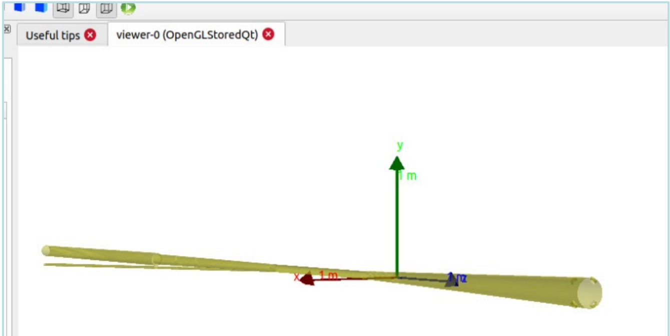
- Detached Beamline construction from the detector construction. Constructed Beampipe from CAD files.

Calorimeter ML

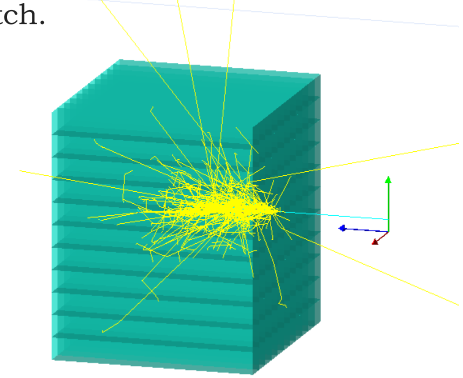
Using Machine Learning to Separate pion and electron, based on energy deposited in 3x3 and 10x10 calorimeters, carry out analysis of mismatch.



cb_EMCAL occupancy Plot



Beampipe Construction



Electron shower (10x10 calorimeter)

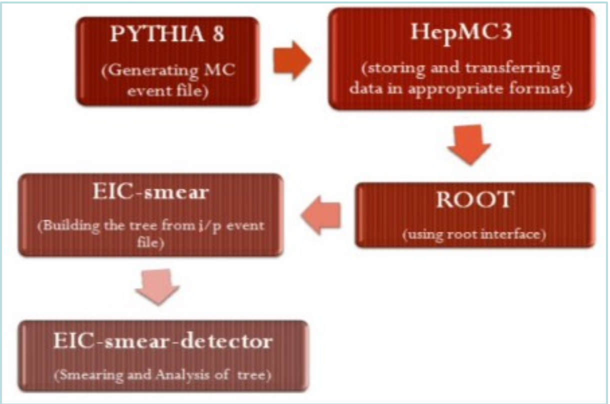
EIC-Smear

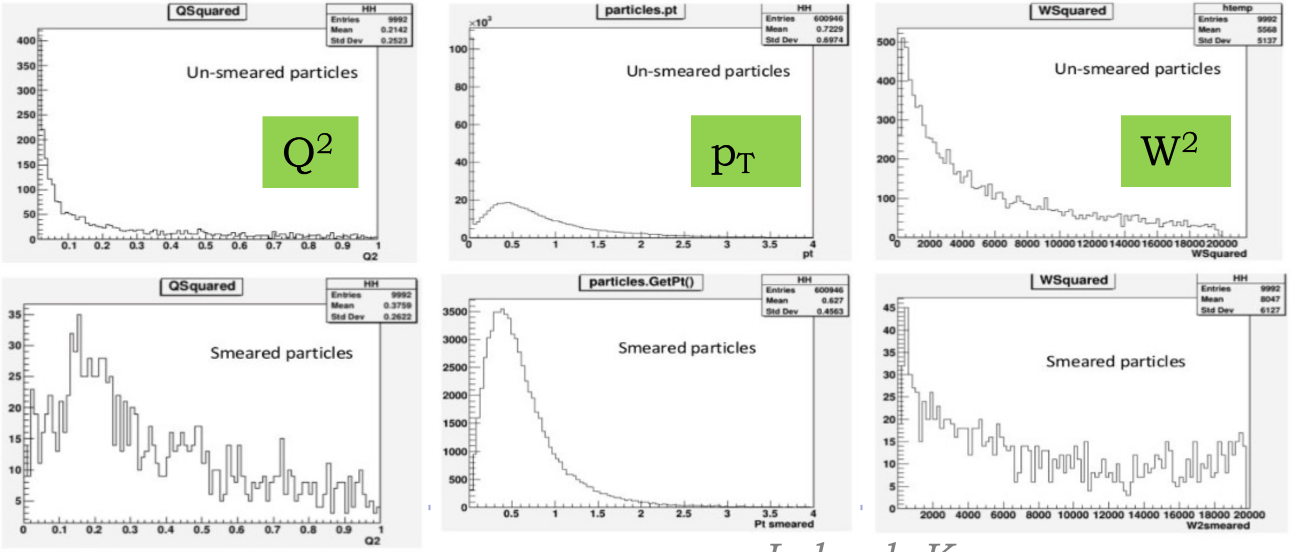
Institutions: IIT Patna, IIT Madras, MNIT Jaipur, CUK Karnataka
In collaboration with: Kolja Kauder

Task: Study smearing effect for Exclusive Physics with EIC

- Input MC event file is generated using Pythia8 giving input parameters corresponding to exclusive reaction, i.e. J/Psi photo-production
- The input event file is stored in root format to ease reading and smearing process
- Fast simulation is performed effectively by using eic-smear software and eic-smear detector scripts.
- Smearing effect on different parameters of exclusive reactions are analyzed

Work flow chart





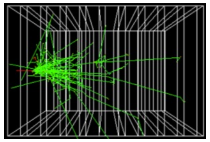
Un-smeared

Smeared

e-p @ 18 x 275 GeV

Makota Asai

In addition : Project eAST



Contribution to DAQ Group

Institutions: CUK Karnataka

Crucial input to the DAQ team: Background rates of each detector arising out of various sources.

Used for: Calculating data volumes and corresponding bandwidths

Task for CUK: Calculate the photon rates of Synchrotron Radiation (SR) on various detectors.

SynRad: Well-established machine simulation tool to generate SR photons.

- Simulated 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

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

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

Current Efforts and Future Plan

Vertexing @ ePIC

Institution: Panjab University Chandigarh (master students)

Task: Evaluate the vertexing algorithm performance of ePIC

Strategy:

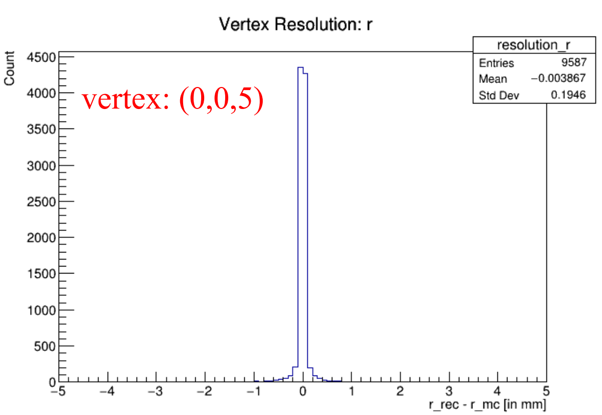
- Few-track simulation, check single track performances (resolution, efficiency, DCA), then move away from (0,0) in (x,y)
- PYTHIA DIS simulation, starting from (0,0,0)

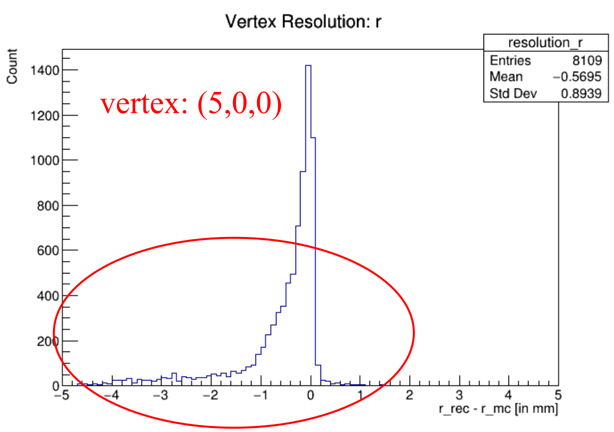
Simulation detail:

10 muons per event, flat theta, p_T

Simulation was run for 4 different Gun Positions i.e. vertices (1000 events each):
Gun Position: (0.0 0.0 0.0) //r = 0 mm, z = 0 mm
Gun Position: (0.0 0.0 5.0) //r = 0 mm, z = 5 mm
Gun Position: (5.0 0.0 0.0) //r = 5 mm, z = 0 mm
Gun Position: (3.0 4.0 5.0) //r = 5 mm, z = 5 mm

The analysis is done using assoc. particles
p_{rec} : Reconstructed total momentum
p_{mc} : Truth(MC) total momentum
r_{rec} : Reconstructed vertex position r
r_{mc} : Truth(MC) vertex position r
z_{rec} : Reconstructed vertex position z
z_{mc} : Truth(MC) vertex position z





Δr distributions are distorted for non-zero (x,y)

Quick fix: re-calculate rPCA (point of closest approach)

Work in progress

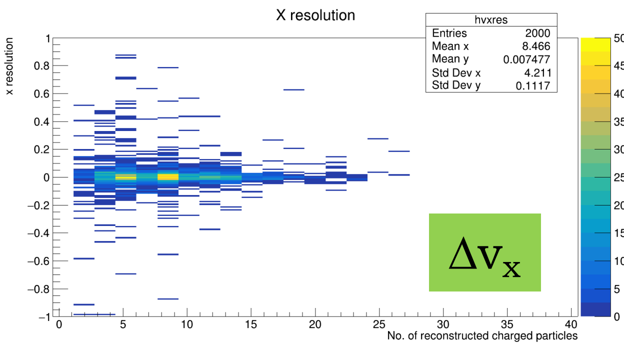
Vertexing @ ePIC

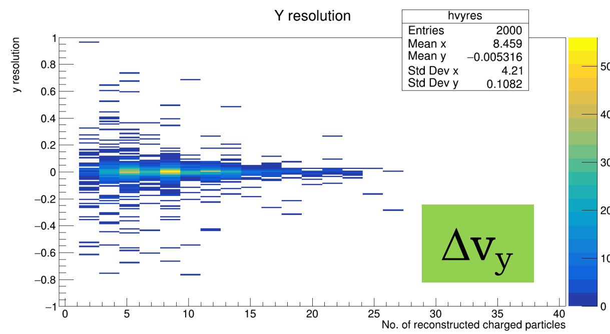
Pythia8 Simulation detail:

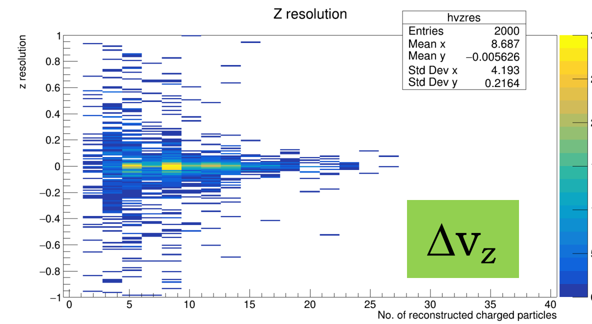
Simulated 2000 events:
- Electron Beam Energy = 18 GeV
- Proton Beam Energy = 275 GeV

- Min Q square = 10 GeV^2
- With Neutral Current

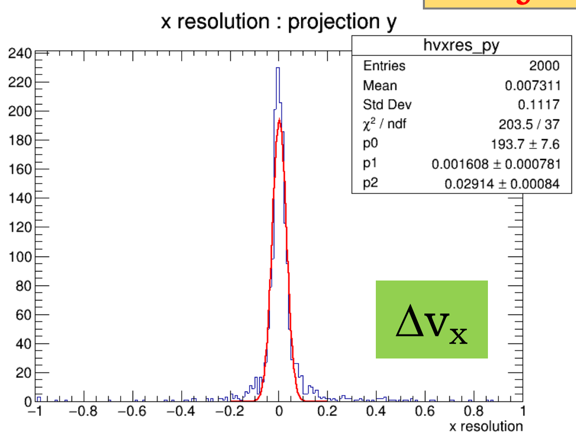
Vertex resolution vs. no. of reconstructed tracks

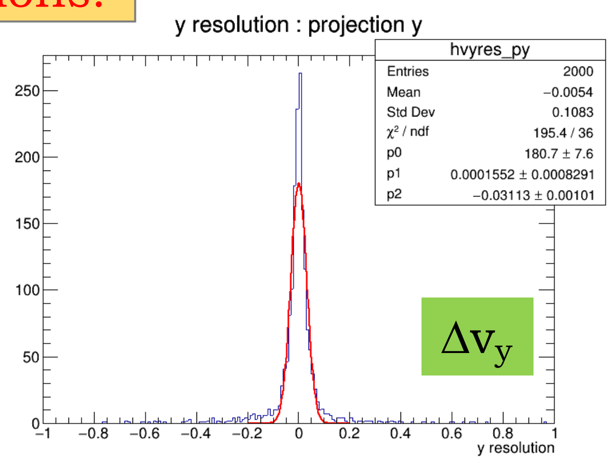


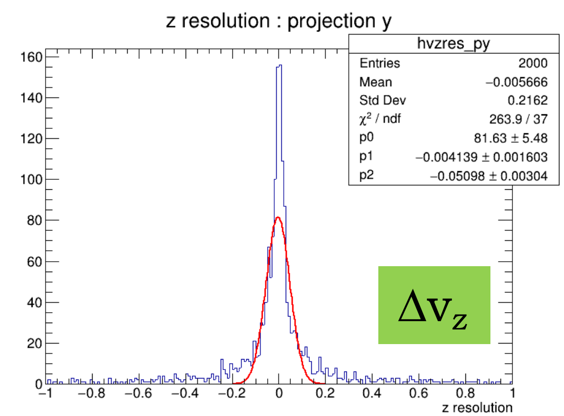




Projections:





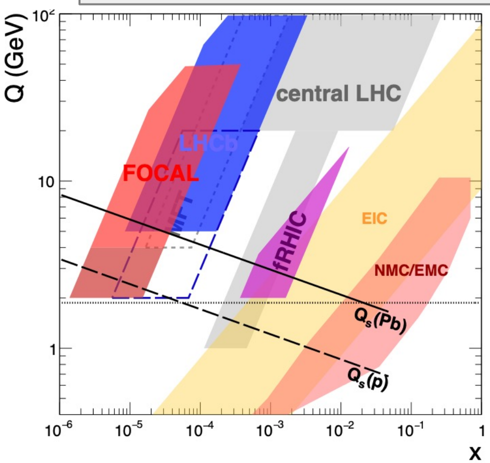


Work in progress

Current Indian Hardware Effort

Forward Calorimeter (FOCAL) @ ALICE

High granularity forward calorimeter to explore small-x structure of nucleons and nuclei.



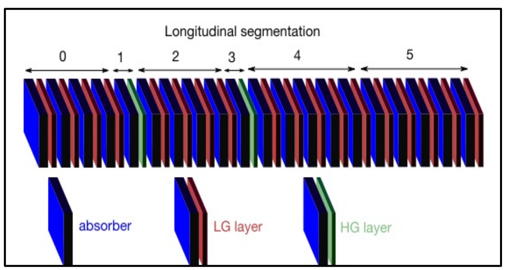
Indian groups to contribute to Si-pad array (FOCAL-E) detectors

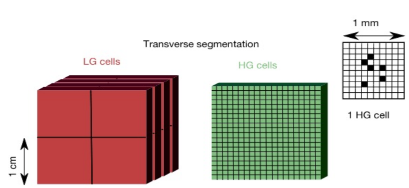
- 18 layers, each layer: 110 Si pad arrays
- Each Si pad array (8x9) has 72 pads (1x1 cm^2)

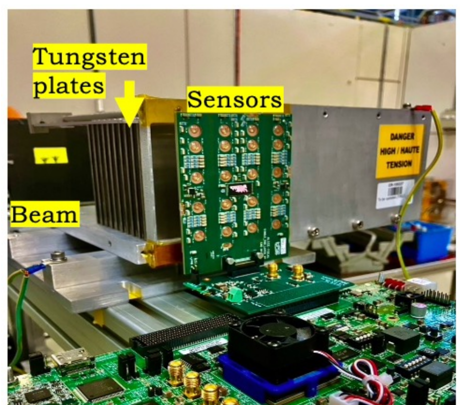
Main Goals:

- Measure the gluon density in protons and lead nuclei and quantify its nuclear modification at small x and Q^2
- Explore the physical origin of shadowing effects
- Investigate the origin of long range flow-like correlations in pp and p–Pb collisions
- Explore jet quenching at forward rapidity in Pb–Pb collisions

Ref.: LOI (CERN-LHCC-2020-009)







India-ALICE-FOCAL test beam setup @ PS CERN

India-ALICE-FOCAL test beam team @PS CERN

Possible Hardware Contribution in EIC

Very Preliminary Discussions

S.No.	Possible Project	Measurement	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	Time-of-Flight (TOF)	Particle Identification	Use AC-LGAD
4	Data Acquisition (DAQ)	Streaming Readout	Data reduction using ML techniques on FPGA…

Possible DAQ software contribution: Evaluate timing synchronization feasibility amongst various subsystems and incorporating streaming readout in simulations

More Details: talk by B. Mohanty and S.S. Dasgupta

Interests of Indian Groups at EIC

S. No.	Institute Name	Interest
1	Banaras Hindu University	PID Detector Hardware
2	Central University of Karnataka	DAQ + DCS
3	Central University of Tamil Nadu	Hardware + related SW
4	Institute of Physics Bhubaneswar	R&D for PID + DCS
5	Indian Institute of Science Education and Research (IISER) Berhampur	Detector and Physics Simulations
6	Indian Institute of Science Education and Research (IISER) Tirupati	Detector and Physics Simulations
7	Indian Institute of Technology (IIT) Bombay	Hardware + Detector Simulations
8	Indian Institute of Technology (IIT) Indore	Detector and Physics Simulations
9	Indian Institute of Technology (IIT) Madras	Hardware + JETs and HF mainly Simulation
10	Indian Institute of Technology (IIT) Mandi	PID Detector+ Simulations and Analysis
11	Indian Institute of Technology (IIT) Patna	Detector and Physics Simulations
12	Malaviya National Institute of Technology Jaipur	PID Detector + Simulations and Analysis
13	National Institute of Science Education and Research (NISER) Bhubaneswar	dRICH radiator, FEMCal, TOF, photo sensor
14	Panjab University Chandigarh	Detector Hardware and Software
15	University of Jammu, Jammu	Hardware + Simulations

Tentative, inputs being collected

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

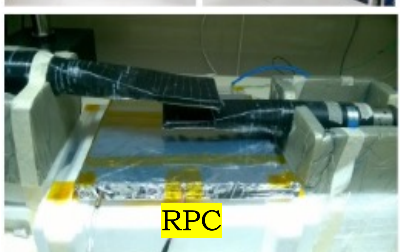
- Working lab
- Gas tight GEM chamber
- VUV-UV Spectro-photometer
- Gas mixing
- ....

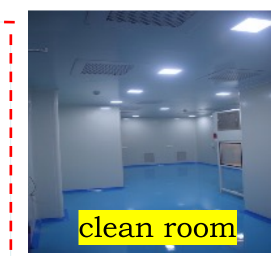
IOP

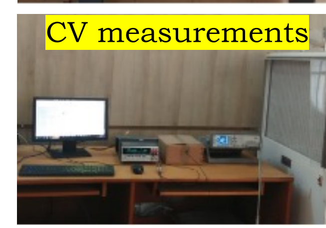
- Working lab
- Clean room
- GEM-testing
- Electronics
- ....

Jammu

- Working lab
- Probe station
- Electronics
- ....





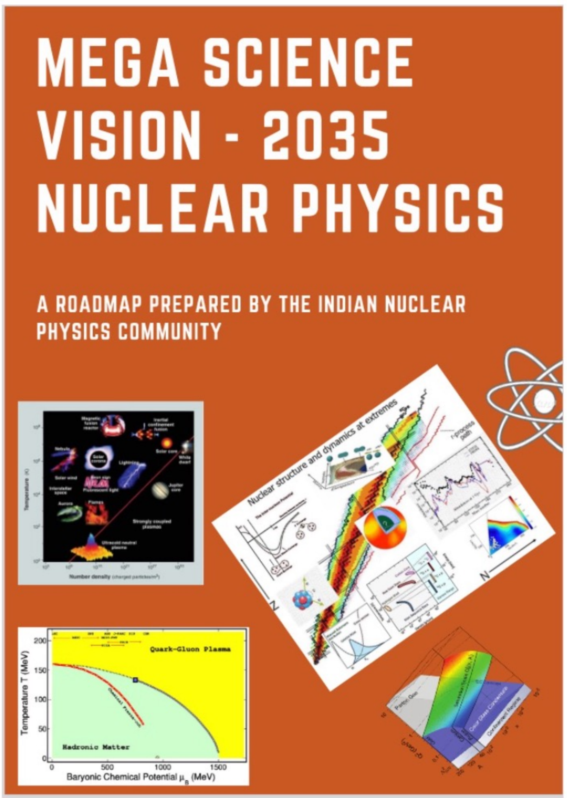


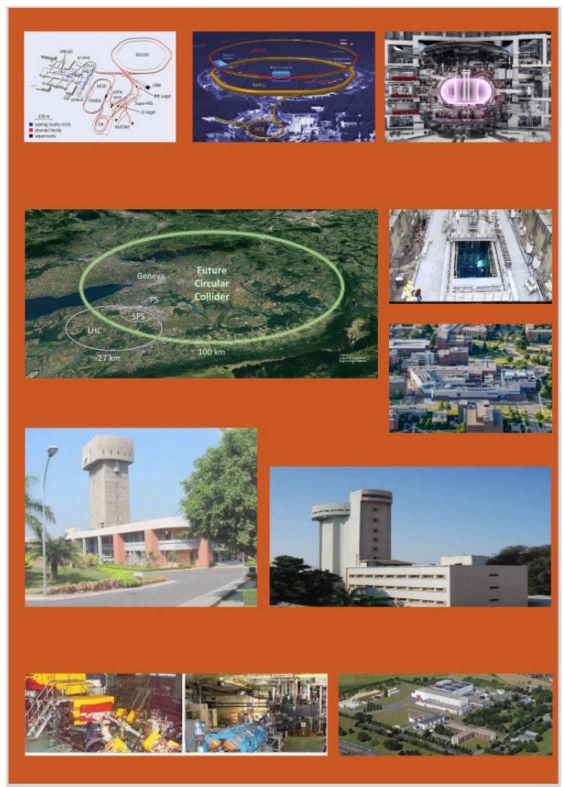
Possibilities to extend the lab facilities at other places

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 environ-ment for getting funding for EIC

More Details:
talk by B. Mohanty

Step Towards Funding Application

Ongoing: Writing of Detailed Project Report (DPR) to be submitted to Indian funding agency

- *Inputs being collected from participating institutes*
- *Aim to finish within couple of month*

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:

10.4 Review of expertise available with proposed investigating group/institution in the subject of the project (Lokesh)

The table below shows the expertise available with the member institutions:

Sl. No	Name of the Institution	Available expertise	Remarks
1	NISER-Bhubaneswar, Jatni	RPC detector, MPGDs, PID, Silicon Trackers, simulation, analysis	Worked in STAR, ALICE, CMS, CBM and INO experiments and experienced in gas detectors, and silicon detectors.
2	IISER-Berhampur, Berhampur	Simulation, physics analysis	Worked in STAR data analysis
3	IISER-Tirupati, Tirupati	Simulation, physics analysis	Worked in STAR data analysis
4	IIT-Patna, Patna	Simulation, Physics analysis	Worked in STAR and WASA experiments
5	Central University of Karnataka, Kalaburagi	DCS and DAQ	Worked in INO experiment and experienced in developing DAQ and DCS.
6	IIT-Bombay, Mumbai	Simulation, physics analysis	Worked in STAR and ALICE experiments
7	Goa University IIT-Mandi, Mandi		Worked in ALICE
8	IIT-Indore, Indore	Simulation, physics analysis	Worked in ALICE experiment
9	Benaras Hindu University, Varanasi		
10	IIT-Madras, Chennai	Simulation, analysis	Worked in STAR analysis and simulation

See also:
talk by B. Mohanty

Summary

Indian participation in EIC (ePIC)

- Indian groups have experiences at KEK, RHIC, LHC, FAIR, INO in detector hardware, simulation and analysis
- Contributed in EIC software group (mostly benchmarking the software)
- Finalizing options for a detector hardware project in ePIC
- Writing a Detailed Project Report (DPR) to be submitted to funding agency for funding

Acknowledgement:

- EIC-India
- ePIC Collaboration

Back-up

Indian Groups in World Experiments

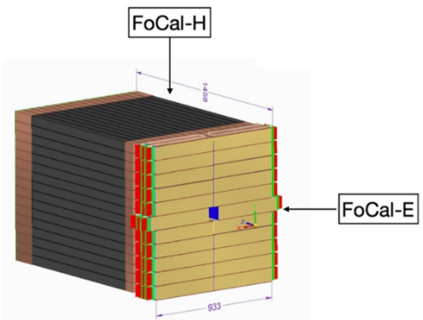
Facility	Laboratory	Experiment	Country	Status
Relativistic Heavy-Ion Collider (RHIC)	Brookhaven National Laboratory (BNL)	STAR, PHENIX	New York, USA	Running
Large Hadron Collider (LHC)	European Organization for Nuclear Research (CERN)	ALICE, CMS	Geneva, Switzerland	Running
Facility for Antiproton and Ion Research (FAIR)	Gesellschaft für Schwerionenforschung (GSI)	Compressed Baryonic Matter (CBM)	Darmstadt, Germany	Future
The High Energy Accelerator Research Organization (KEK)	Kō Enerugī Kasokuki Kenkyū Kikō (KEK)	BELLE	Tsukuba, Japan	BELLE II running
Cooler synchrotron and storage ring (COSY)	Nuclear Physics Institute (IKP)	Wide Angle Shower Apparatus (WASA)	Julich, Germany	Not running
India-based Neutrino Observatory (INO)	INO	Iron Calorimeter (ICAL) Detector	Tamil Nadu, India	Future

Indian Groups Experience

Institution	Physics, Detector, Experiment (selected list only)
Univ. of Jammu	Heavy Flavour Physics, PMD, DCS, Trigger, GRID computing, STAR HFT, ALICE-FOCAL
Univ. of Panjab	Fluctuation and correlations, photon multiplicity, nuclei production, BES-II-RHIC, CBM
Inst. of Phy. BBSR	Light hadron spectra, PMD, GEM, CBM
NISER, BBSR	Spectra, fluctuations, azimuthal anisotropy, RHIC-BES, CBM-RPC, GEM, ALICE-FOCAL
IIT, Bombay	Resonance, fluctuations, correlations, simulations, ALICE-FOCAL
IIT, Indore	Photon Multiplicity, HBT, Freeze-out dynamics, CBM
BHU, Varanasi	Non-photonic electrons PHENIX@RHIC, CBM@FAIR, detector R&D
IISER Tirupati	Physics Analysis at RHIC
IISER Berhampur	Physics Analysis at RHIC
IIT Patna	Physics Analysis at RHIC

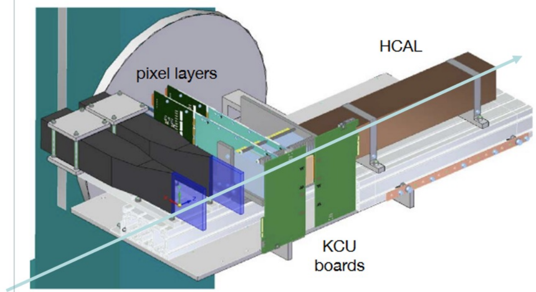
ALICE FoCal – detector overview

complete detector

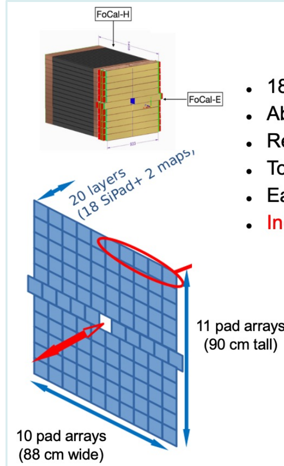


Dimension: ~ 94 cm x 145 cm

demonstrator prototype

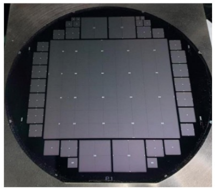


ALICE Forward Calorimeter (FoCal): FoCal-E and FoCal-H



- 18 layers, each layer will have 110 Si pad arrays
- About 2000 Si pad arrays or 2000 Si 6" wafers
- Readout by ~ 2000 HGCROC ASICs (72 ch), 1 chip/pad array
- Total readout channels: ~143k
- Each Si pad array (8x9) has 72 pads (1x1 cm^2)
- Indian groups are contributing in Si pad array detectors

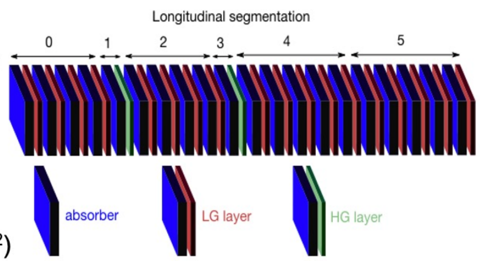
Si pad array (8x9) on 6" wafer



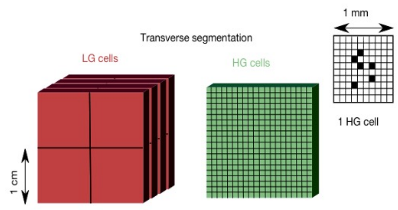
- FoCal-E (Si-W design):

  (i) 18 layers of **Si pad arrays** with low granularity (~1 cm^2)
  - Measure shower profile and energy
  - 3.5 mm thick W, it has high melting point (3422 ^{0}C), high density 19.3 g/cm^3 (Pb 11.34 g/cm^3), 94% purity (pure W is hard to machine, expensive)

  (ii) 2 layers of **Si pixels** with high granularity (~30 × 30 μm^2)
  - Enable two-photon separation with high spatial precision to discriminate direct photons and merged showers of π^0 photon pairs



- The total silicon sensor area for FoCal-E is about 12 m^2 (150K individual pad channels) and about 4K pixel sensors
- FoCal-H (Cu/scintillating fiber+SiPM):
  - provides good hadronic resolution

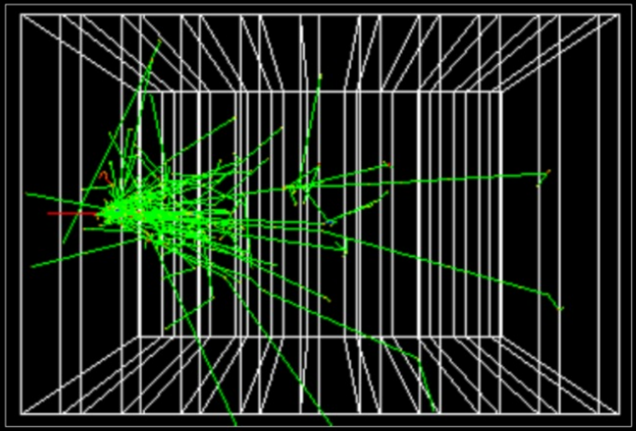


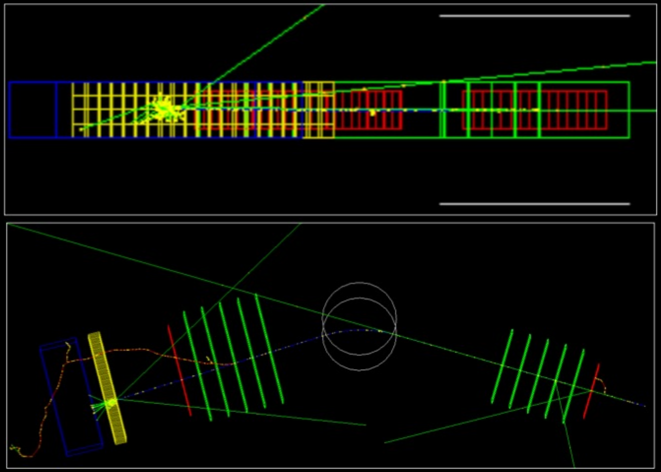
Ref.: LOI (CERN-LHCC-2020-009)

Project eAST (eA Simulation Technique)

Project eAST (IITB, IITM, Goa University)

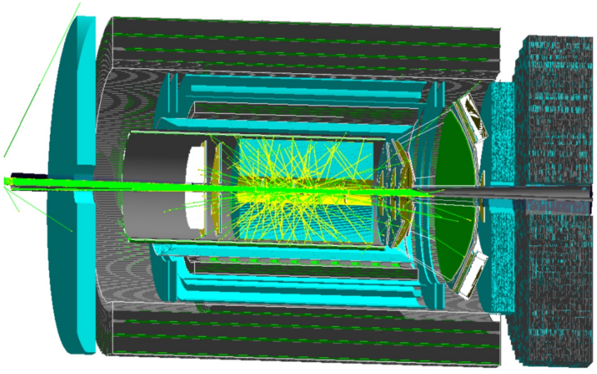
- Present task: develop a HepMC3 interface which can read event record & pass the information to Geant4
- Vashishtha Kochar, Aryan Borker, Pranjal Verma, Chinmay Seth, Suvarna Patil, and other colleagues incorporated the HepMC3 package in Project eAST by getting familiar with HepMC3 and Geant4 tutorials
- They are working on testing and debugging the HepMC3 interface to read the event record by understanding the existing HepMC2 interface with Geant4
- Thanks to Makoto Asai for introductory lecture with some excellent hands-on exercises to get familiar with Geant4. This would help in development of eAST (following pictures are from some basic examples)





SynRad Simulation Tool

SynRad - simulates the generation of SR photons.



- In the simulation, a "virtual cylinder", comprised of rectangular facets, is placed just inside the IR beampipe
- Photons which pass through this facet are tracked.
- The Synrad particle logger is used to get a table of simulated photons with position, direction and energy information for each facet.

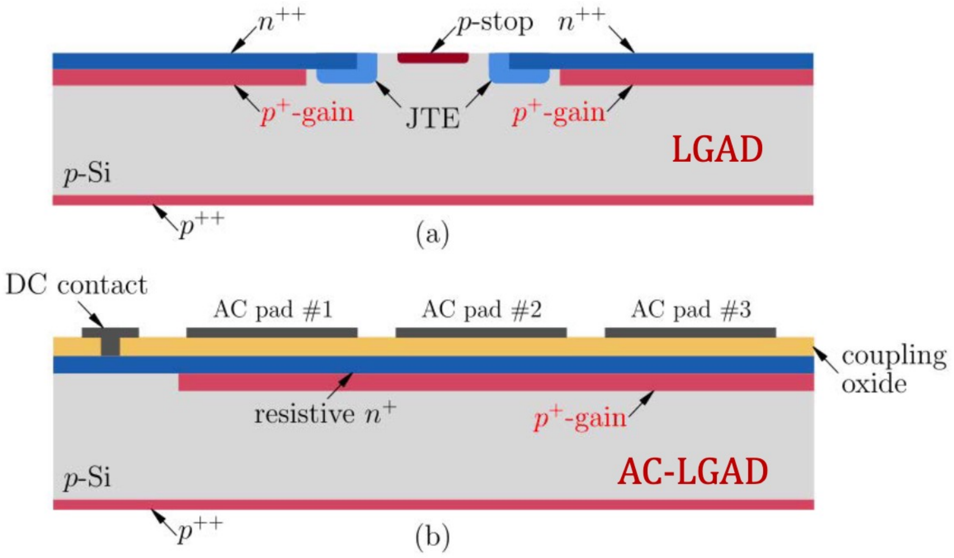
This table will have a set number of simulated photon hits (50K or 100K), so the total hits on the facet *need to be normalized to a flux (photons/sec) related to the beam current* used in the simulation.

- These photons are propagated through the detector volume and the hits in the individual detectors were counted.
- In order to understand the effectiveness of a "gold coating" in minimizing SR photons, the study was repeated again with a gold layer of 5 um.

AC-LGAD

LGAD: Low Gain Avalanche Detector

Novel silicon technology -- allowed timing resolution of few tens of picoseconds for number of particle tracks emerging from the interaction regions in high energy physics experiments



Due to the presence of Junction Termination Edges (JTE) and the gap between LGAD cells, 100% fill factor can not be achieved in LGAD.

AC-LGAD: replacement of the segmented n++ layer by a less doped but continuous n+ layer. Electrical signals in the n+ layer are AC-coupled to neighboring metal electrodes that are separated from the n+ layer by a thin insulator layer.

AC-LGAD not only provides a timing resolution of a few tens of picoseconds, but also 100% fill factor and a spatial resolution that are orders of magnitude smaller than the cell size. Therefore, it is a good candidate for 4D detectors at future high energy experiments.