Indian Participation in ePIC at EIC

Lokesh Kumar

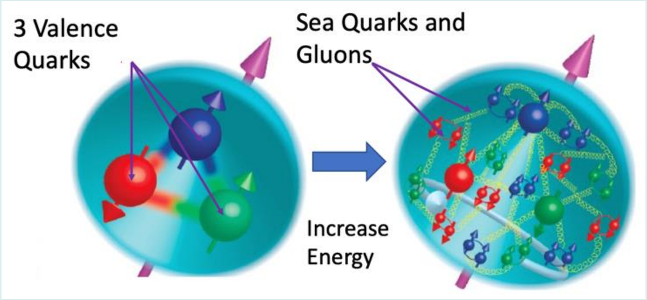
Panjab University Chandigarh

Outline

- Introduction
- Electron Ion Collider
- Physics Goals, Methodology, and Detector Requirement
- Indian Participation
- Summary

Introduction

Structure of the proton



Introduction

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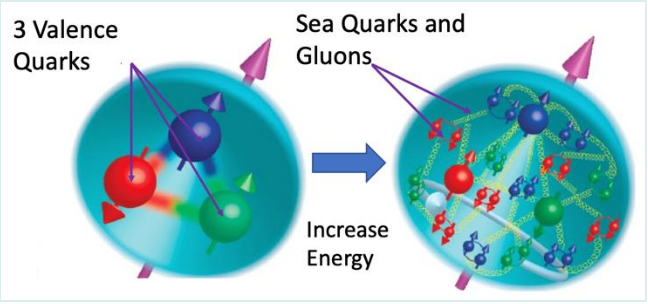
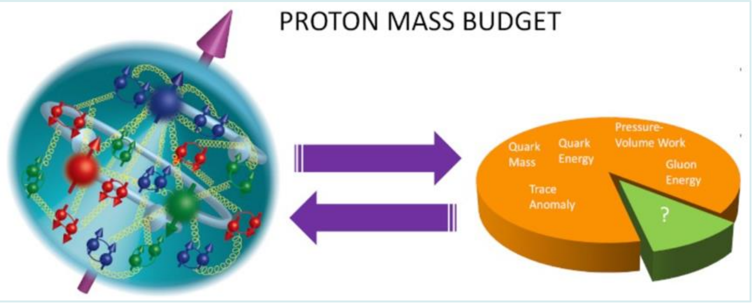


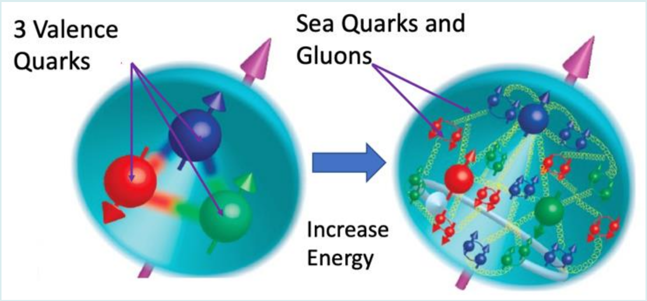
Proton Mass Issue



Mass is driven by a complicated sum of various QCD interactions!

Introduction

Structure of the proton



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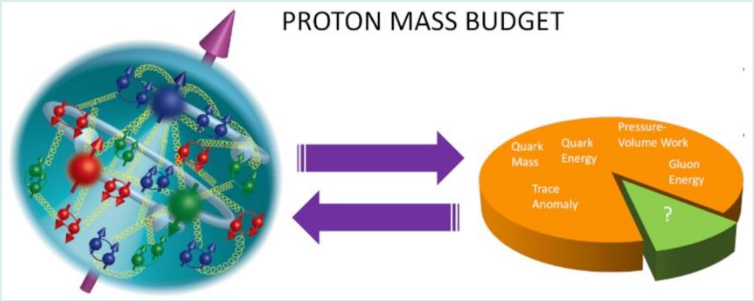

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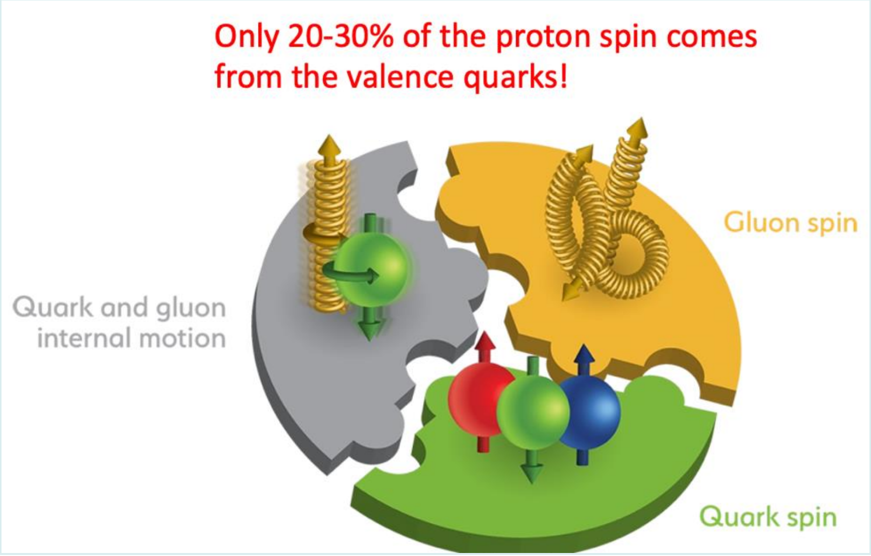
Proton Spin Issue



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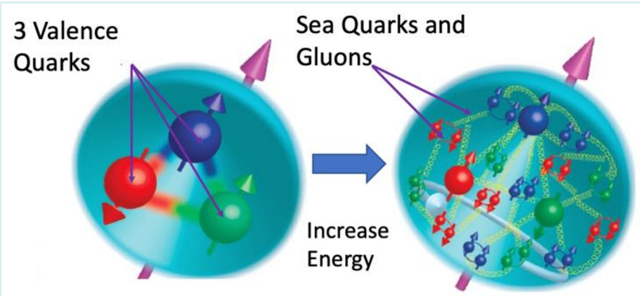

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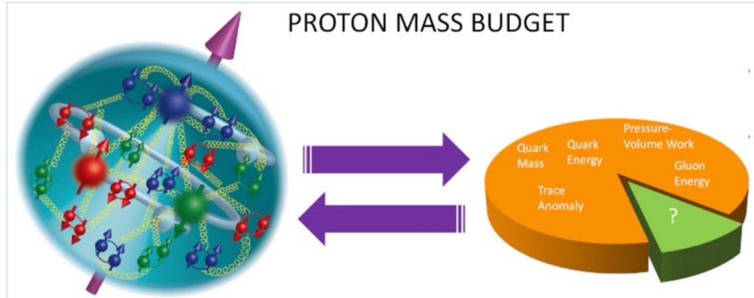

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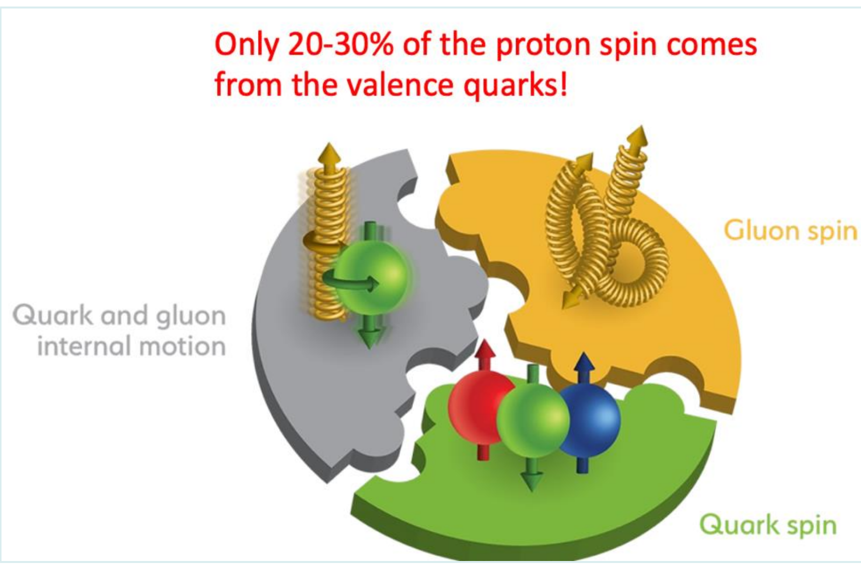


Even after hundred years of discovery of proton, we do not know its internal structure completely!

Need multidimensional imaging of the proton structure

Electron Ion Collider (EIC) @ Brookhaven National Laboratory, USA

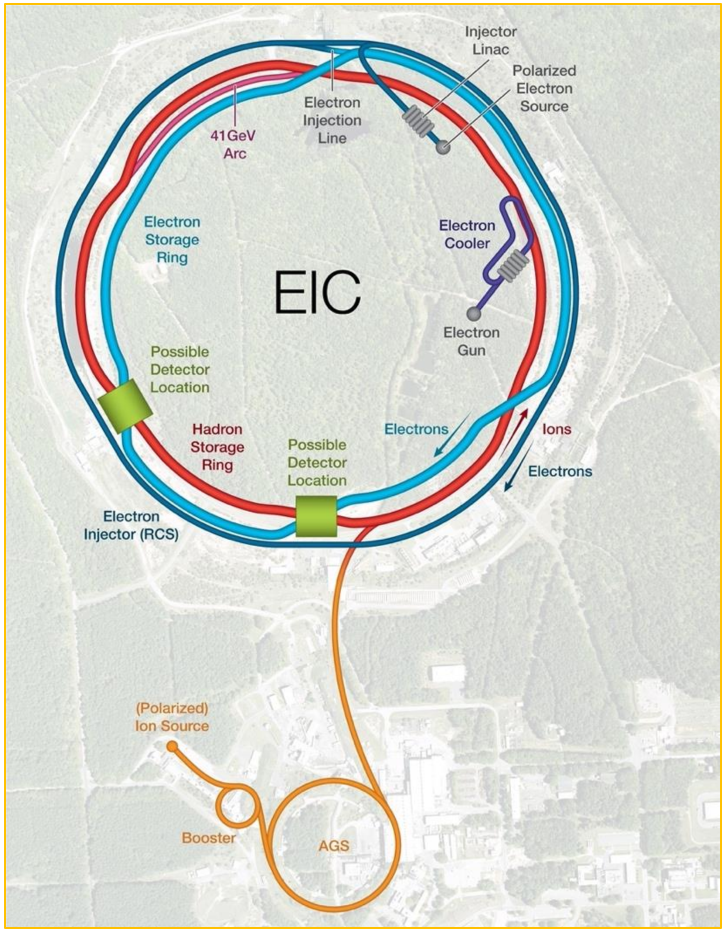
Electron Ion Collider (EIC)

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

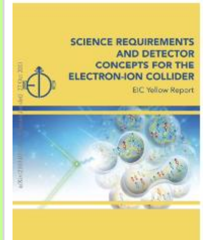
EIC Yellow Report



Only new collider in foreseeable future – will remain at frontier of accelerator S&T

EIC Project Design Goals

- High **Luminosity**: L= $10^{33} - 10^{34} cm^{-2} sec^{-1}$,
  $10 - 100\ fb^{-1}$/year
- Highly **Polarized** Beams: 70%
  -- *requires high precision polarimetry*
- Large Center of Mass **Energy Range**:
  $E_{cm} = 29 - 140$ GeV
  -- *large detector acceptance*
- Large **Ion Species Range**: proton-Uranium
  -- *requires forward detectors integrated in beam lattice*
- Good **Background Conditions**
- Accommodate a **Second Interaction Region** (IR) -- *IR-8*



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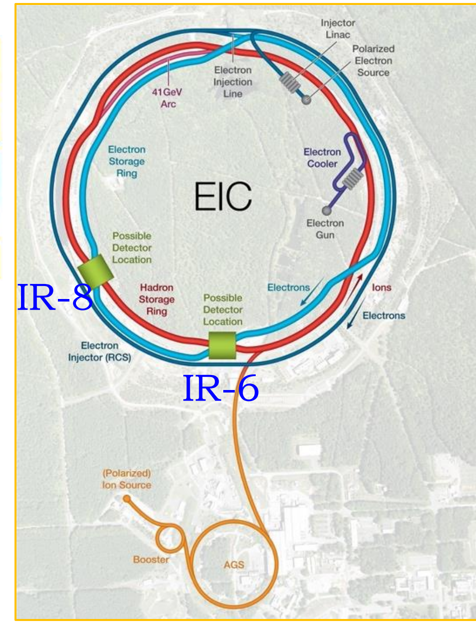


EIC:

- 1st high-luminosity e-p collider
- 1st polarized target collider
- 1st electron-nucleus collider

← Backward

p: 41 GeV, 100 to 275 GeV

p/A beam →

← e beam

Forward →

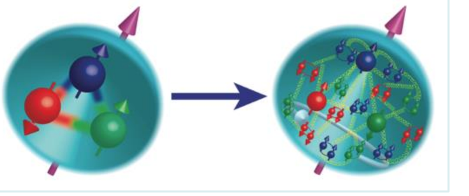
e: 5 GeV to 18 GeV

→ z

EIC Physics Goals

Nucleon structure & its properties

- How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?
- How do the nucleon properties (mass, spin..) emerge from them and their interactions?



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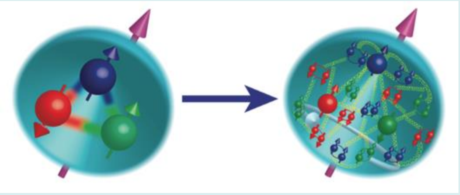
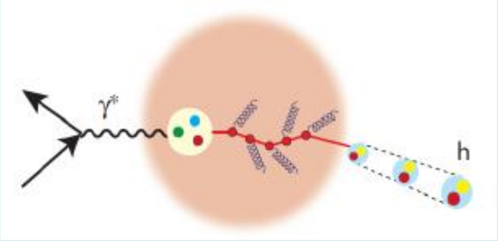


Partons' interactions with nuclear medium; nuclear binding



- How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium?
- How do the confined hadronic states emerge from these quarks and gluons?
- How do the quark-gluon interactions create nuclear binding?

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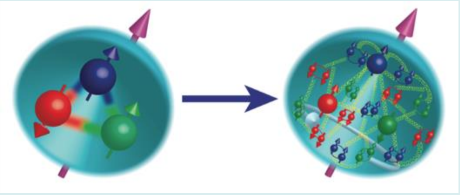

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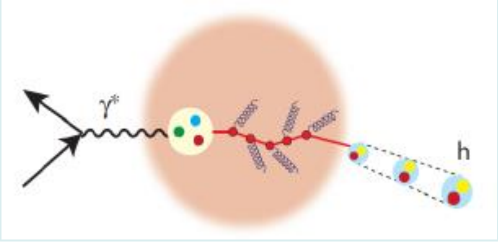

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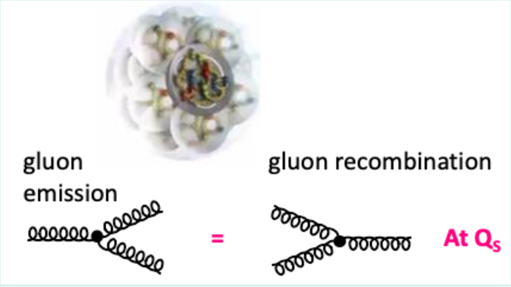
Effect of dense nuclear environment; gluon saturation

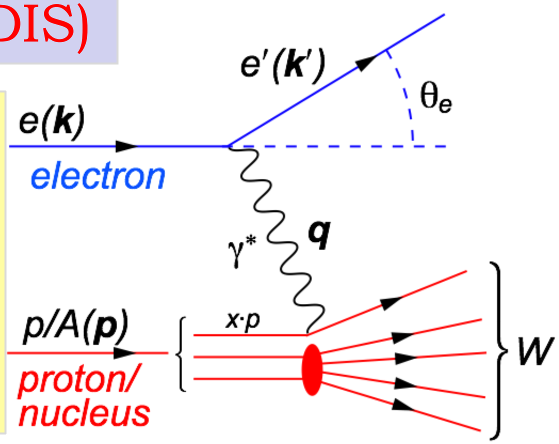
- How does a dense nuclear environment affect the dynamics of quarks and gluons, their correlations and interactions?
- Does the gluon density in nuclei saturate at high energy, giving rise to a gluonic matter or phase with universal properties in all nuclei, even in the proton?



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

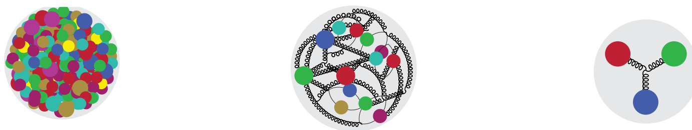


Terminology: $q = k - k'$ $-Q^2 = (k - k')^2$ $s = (k + p)^2$ $W = (p + q)^2$

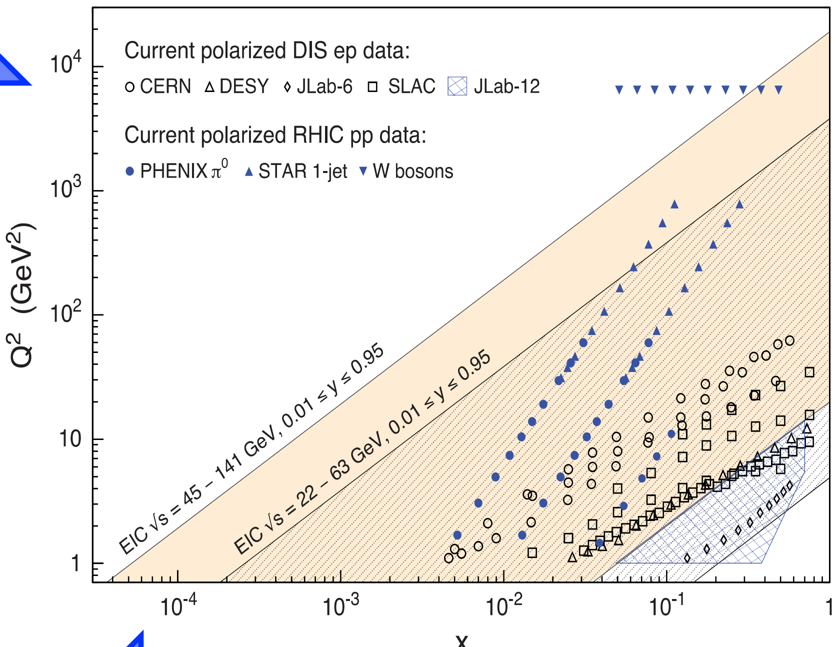
s: Center-of-mass energy squared for DIS system
Q²: Square of the momentum transfer between the electron and proton; inversely proportional to the resolution
y: inelasticity $(0 \leq y \leq 1)$
x: the fraction of the nucleon's momentum carried by the struck quark $(0<x<1)$
W: Center-of-mass energy for photon-nucleon system

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

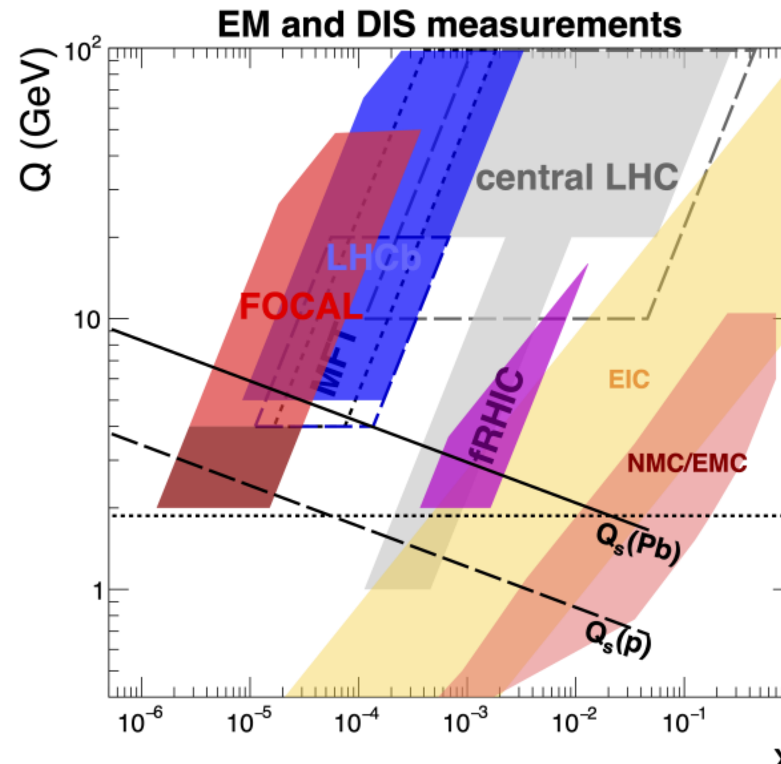
Kinematic Range



increasing luminosity and center of mass energy



increasing center of mass energy



EIC covers large kinematic coverage:

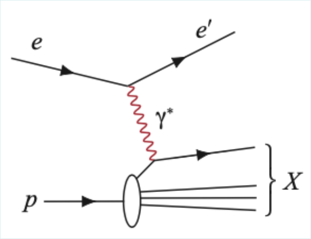
- Access to x and Q^2 over a wide range

- 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*

Physics Processes Measured @ EIC

Neutral-current inclusive DIS ⇐ Inclusive DIS ⇒ Charged-current inclusive DIS

$e + p/\mathrm{A} \longrightarrow e' + \mathrm{X}$



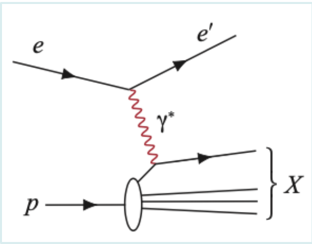
- Essential to detect the scattered electron, e′, with high precision.
- All other final state particles (X) are ignored.
- The scattered electron is crucial for all processes to determine the event kinematics.

Initial state: *Colliding electron (e), proton (p), and nuclei (A).*
Final state: *Scattered electron (e′), neutrino (ν), photon (γ), hadron (h), and hadronic final state (X).*

Physics Processes Measured @ EIC

Neutral-current inclusive DIS ⇦ **Inclusive DIS** ⇨ **Charged-current inclusive DIS**

$e + p/A \longrightarrow e' + X$



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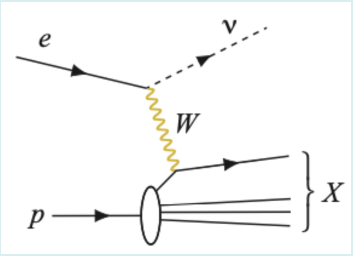
- Event kinematic cannot be reconstructed from the scattered electron; reconstructed from the final state particles.

$e + p/A \longrightarrow \nu + X$



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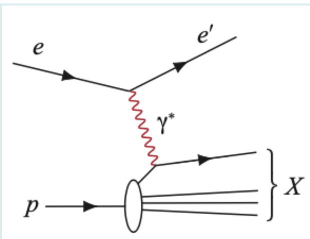

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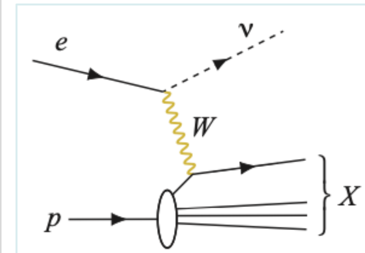
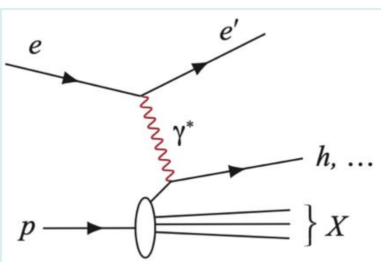


Semi-inclusive DIS

$e + p/A \longrightarrow e' + h^{\pm,0} + X$



Requires measurement of at least one identified hadron in coincidence with the scattered electron.

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Physics Processes Measured @ EIC

Inclusive DIS

Neutral-current inclusive DIS

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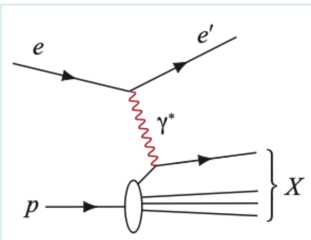

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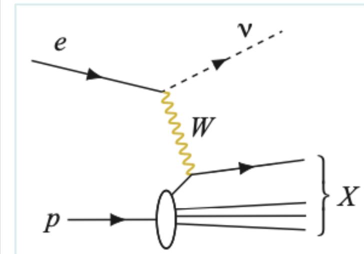

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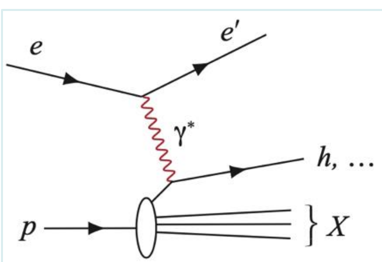

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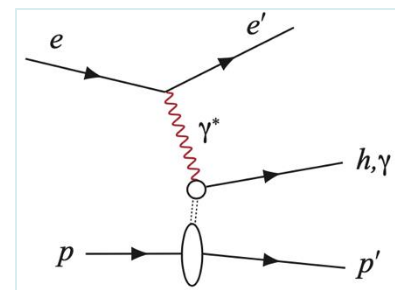
Exclusive DIS

$e + p/A \longrightarrow e' + p'/A' + \gamma/h^{\pm,0}/VM$

Requires the measurement of all particles in the event with high precision.



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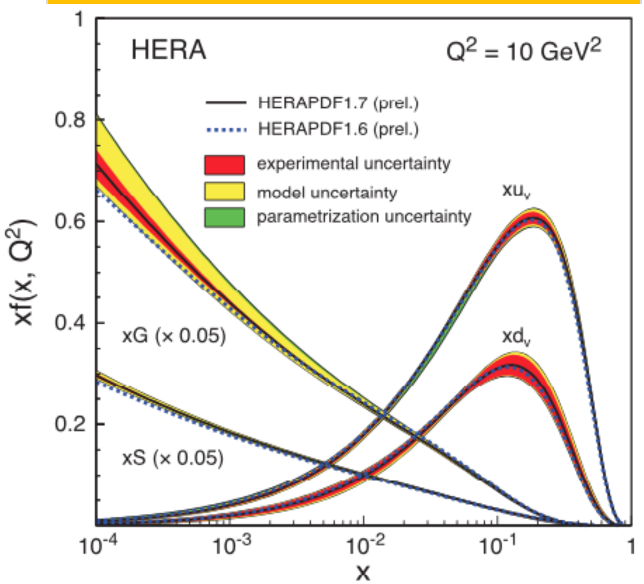
Gluon Saturation @ EIC

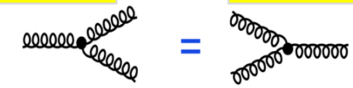
Parton Distribution Functions



F.D. Aaron, et al., H1 Collaboration, ZEUS Collaboration, JHEP 01 (2010) 109

At high energies, gluon density is high at low-x
-- Cannot continue to rise & must saturate!
-- Saturation of parton density called Color Glass Condensate (CGC)

gluon emission | gluon recombination

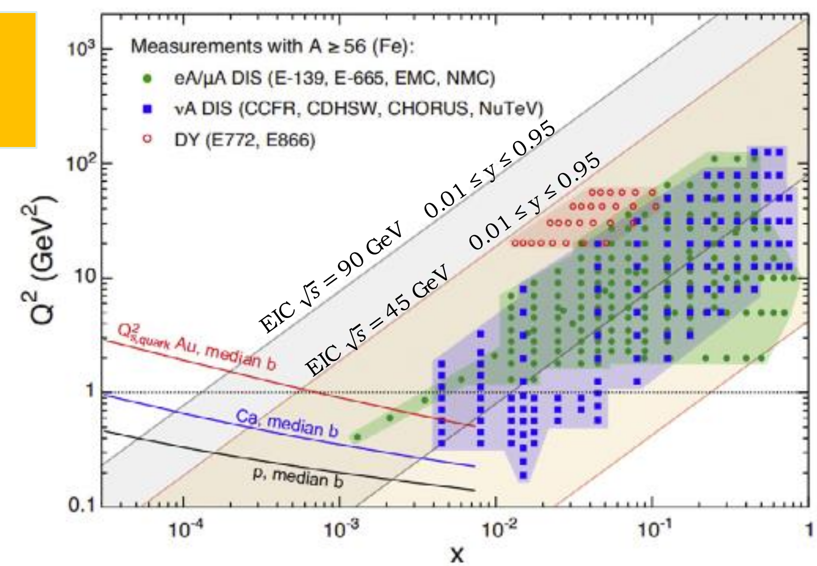


No. of hard gluons splitting into softer gluons

No. of soft gluons recombining into harder gluons

Gluon saturation

Possibility at EIC:



Saturation scale:

$$Q^2_{\rm sat} \approx \frac{x g_A(x, Q^2)}{\pi R_A^2} \propto A^{1/3} x^{-\lambda}$$

Large A => Enhance Q_{sat} scale

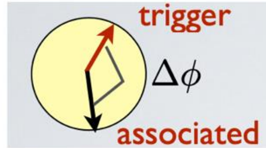
$$x_{1,2} \approx \frac{2p_T \exp(\pm y)}{\sqrt{s}}$$

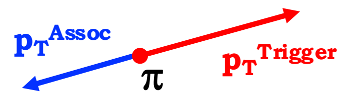
Low-x => forward rapidity

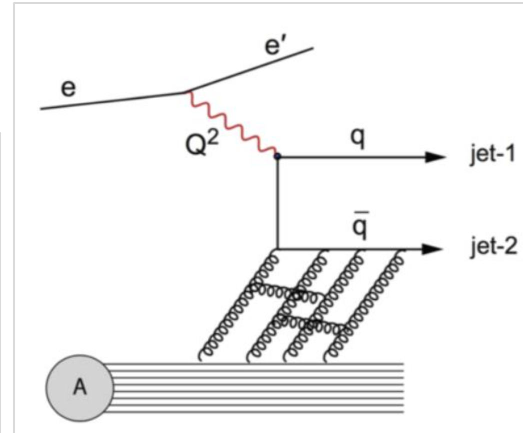
Gluon Saturation effects accessible at EIC!

Gluon Saturation @ EIC

Dihadron Correlations:





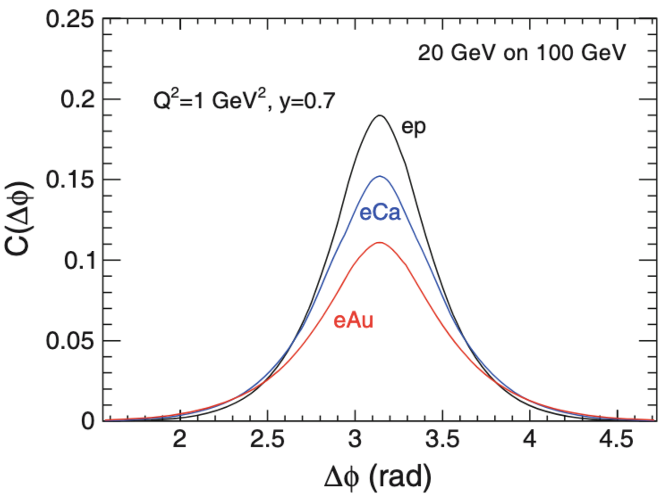


E. Sichtermann, NPA 956, 233 (2016)

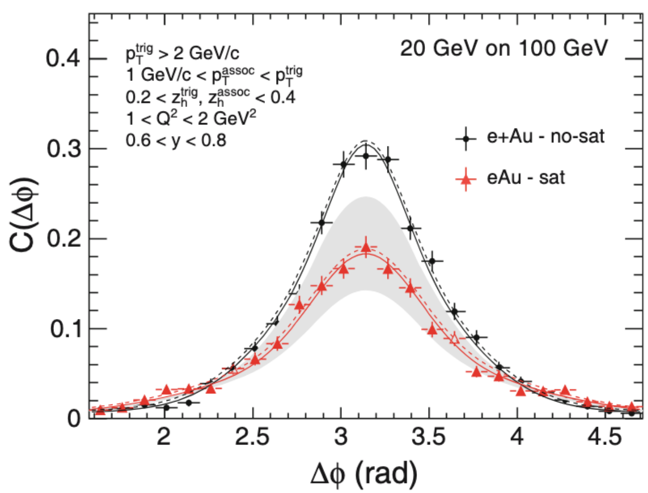
Measure: Azimuthal correlation between two hadrons produced in lepton-nucleus DIS

Sensitive to: p_T-dependence of gluon distribution and their correlations

Expectation: Disappearance of back-to-back correlations with increasing A (in dense gluonic matter)



A. Accardi et. al, EPJA 52, 268 (2016)



L. Zheng et al. Phys. Rev. D 89, 074037 (2014)

Away side peak is suppressed in dense gluonic matter: Melting of back-to-back correlation with increasing A

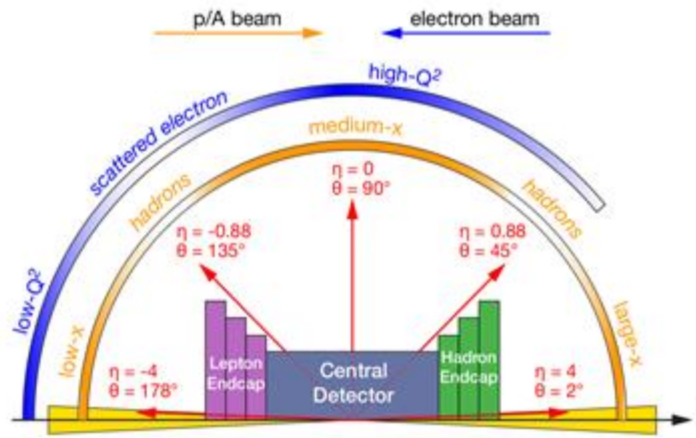
Demonstrates: Discrimination power of these measurements!

EIC Detector Requirements

Radius/Distance from IP

- **Vertex detector:** ***Identify primary and secondary vertices***
  - Low material budget: 0.05% X/X_0 per layer
  - High spatial resolution: 20 μm pitch CMOS Monolithic Active Pixel Sensor

- **Central and Endcap tracker:** ***High precision low mass tracking***
  - MAPS – tracking layers in combination with micro pattern gas detectors
- **Particle identification:** ***High performance single track PID for π, K, p separation***
  - RICH detectors (RICH, DIRC)
  - Time-of-Flight high resolution timing detectors (HRPPDs, LGAD)
  - Novel photon sensors: MCP-PMT / HRPPD

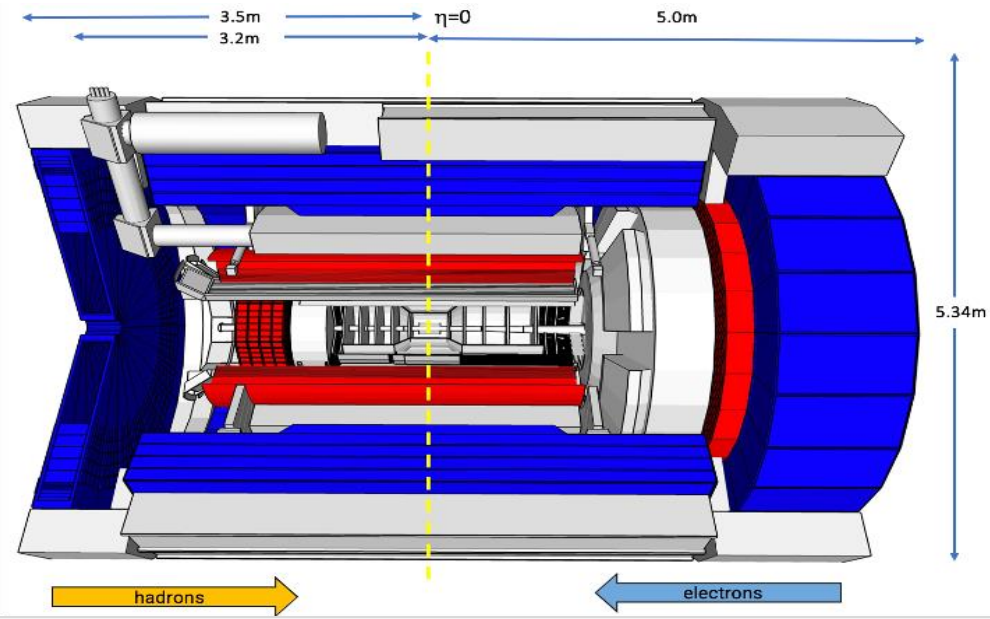


- **Electromagnetic Calorimetry:** ***Measure photons (E, angle), identify electrons***
  - $PbWO_4$ Crystals (backward), W/ScFi (forward)
  - Barrel Imaging Calorimeter (Si + Pb/ScFi)
- **Hadron Calorimetry:** ***Measure charged hadrons, neutrons and K_L^0***
  - Achieve ~70%/$\sqrt{E}$ + 10% for low E hadrons (~ 20 GeV)
  - Fe/Sc sandwich with longitudinal segmentation
- **Very forward and backward detectors:** ***Large acceptance for diffraction, tagging, neutrons from nuclear breakup***
  - Silicon tracking layers in lepton and hadron beam vacuum
  - Zero-degree high resolution electromagnetic and hadronic calorimeters

- **DAQ & Readout Electronics:** ***Trigger-less/ streaming DAQ, integrate AI/ML into DAQ***

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

EIC detector requirements push the technology limit!



Tracking:

- New 1.7T solenoid
- Si MAPS Tracker
- MPGDs (μRWELL/μMegas)

PID:

- hpDIRC
- pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

Calorimetry:

- Imaging *Barrel* EMCal
- $PbWO_4$ EMCal in *backward* direction
- Finely segmented EMCal + HCal in *forward* direction
- *Outer* HCal (sPHENIX re-use)
- *Backwards* HCal (tail-catcher)

MAPS: Monolithic Active Pixel Sensor
MPGD: Micropattern Gaseous Detector
LGAD: Low Gain Avalanche Detector
hpDIRC: High-performance Detection of Internally Reflected Cherenkov
pfRICH: Proximity Focussed Ring Imaging Cherenkov Detector
dRICH: Dual-Radiator Ring Imaging Cherenkov Detector

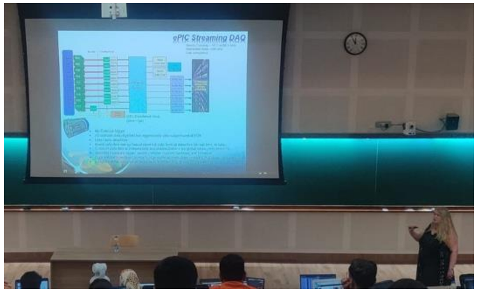
Activities within India

First discussion: *Workshop on High Energy Physics Phenomenology (WHEPP)*, WHEPP-XIV, Dec. 4-13, 2015, **IIT Kanpur**, India
Half-day dedicated session on EIC: Heavy-ion and QCD (WG-IV)

Conference: *QCD with Electron-Ion Collider (QEIC)*, Jan. 4-7, 2020, **IIT Bombay**, India
One-to-one interaction and planning (US-Indian groups) -- *QEIC is now regular event!*

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

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



EIC-India Collaboration: Biweekly meeting; Mailing list: eic_india@googlegroups.com

EIC-India Groups

Collaboration Council Members

Both Theory and Experimental Groups

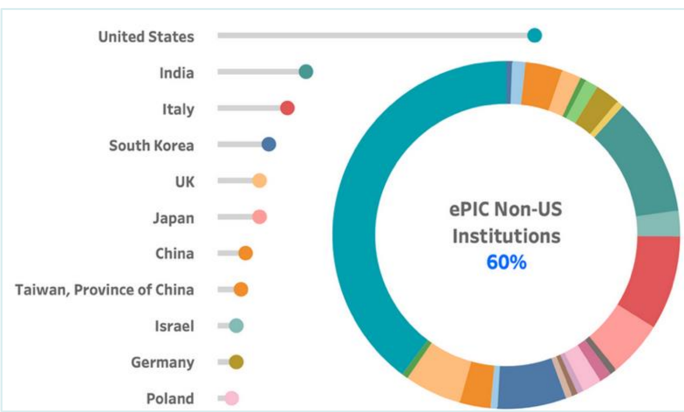
S.No.	Institution	Council Member	Contact
1	Aligarh Muslim University	Abir, Raktim	raktim.ph@amu.ac.in
2	Banaras Hindu University	Singh, B. K.	bksingh@bhu.ac.in
3	Central University of Karnataka	Samuel, Deepak	deepaksamuel@cuk.ac.in
4	Central University of Tamil Nadu	Behera, Nirbhay Kumar	nirbhaykumar@cutn.ac.in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

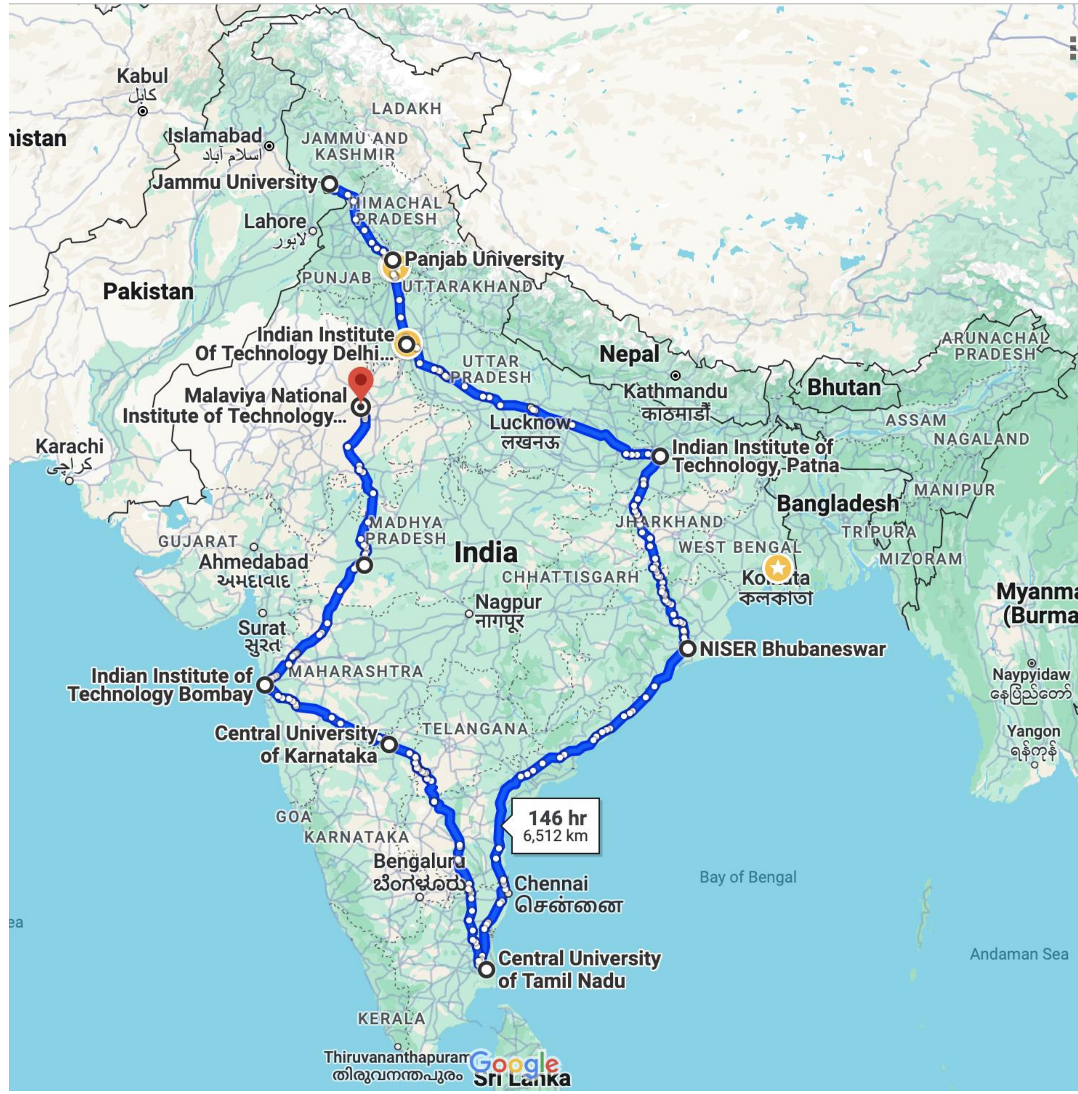
EIC-India Groups

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 Theory Alliance (EITA)

Efforts from the Indian theory groups towards EIC-Science

S. 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

Contributions: Various Committees

- 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
- ePIC Publication Committee

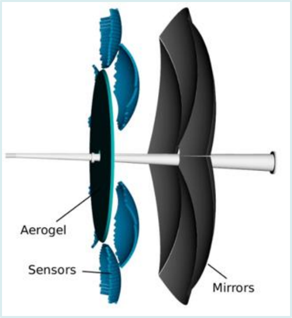
In 2022, ATHENA and EIC Collider Experiment (ECCE) collaborations resulted to a new collaboration: ePIC (Electron Proton Ion Collider)

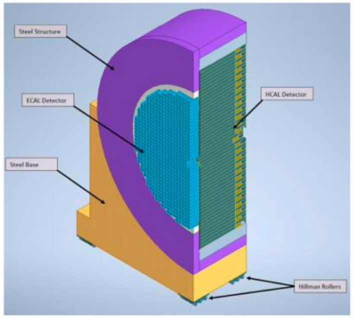
Contributions: Simulations

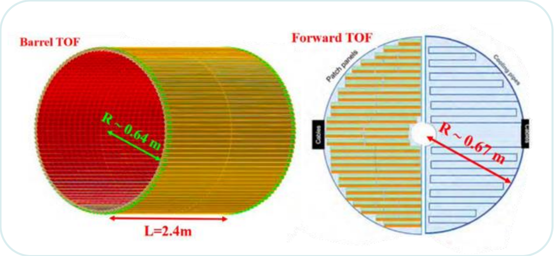
S.No.	Task-Name	Collaboration	Study-performed
1	Geant4 Simulations based on sPHENIX solenoid	sPHENIX	Momentum resolution for pion and electron tracks with and w/o truth vertex constraint
2	Fun4All Simulation	ATHENA	Energy resolution and parameterization of energy-resolution using pions and electrons for different calorimeters
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
4	ESCALATE	ATHENA	Software tool to work full simulation of EIC
5	EIC-Smear	ATHENA	Study smearing effect for exclusive physics with EIC
6	Contribution to DAQ group	ATHENA	Calculate photon rates of Synchrotron Radiation (SR) on various detectors; results included in ATHENA white paper
7	Vertexing @ ePIC	ePIC	Evaluate the existing Vertexing algorithm and check its performance
8	dRICH @ ePIC	ePIC	PID performance studies for dRICH@ePIC
9	TOF Simulation	ePIC	Angular resolution of reconstructed tracks

Possible Hardware Contribution

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

In addition: interested in R&D of SiPMs

ATHIC Institutions in EIC

S.No.	Asian-Country	Institutions	Detector Hardware Interests
1	China	1) Central China Normal University (CCNU) 2) Fudan University 3) Shandong University (SDU) 4) South China Normal University (SCNU) 5) Tsinghua University THU) 6) University of Science and Technology of China (USTC)	▪ Forward EmCal (fECal) ▪ RICH/sMRPC ▪ LGAD
2	Japan	1) Hiroshima University 2) Kobe University 3) Nara Woman's University 4) Nihon University 5) Riken Nishina Center 6) Shinshu University 7) The University of Tokyo 8) Tsukuba University of Technology 9) University of Tsukuba 10) Yamagata University	▪ AC-LGAD-TOF ▪ Streaming DAQ/Computing ▪ ZDC

Green color: Common interest with EIC-India

ATHIC Institutions in EIC

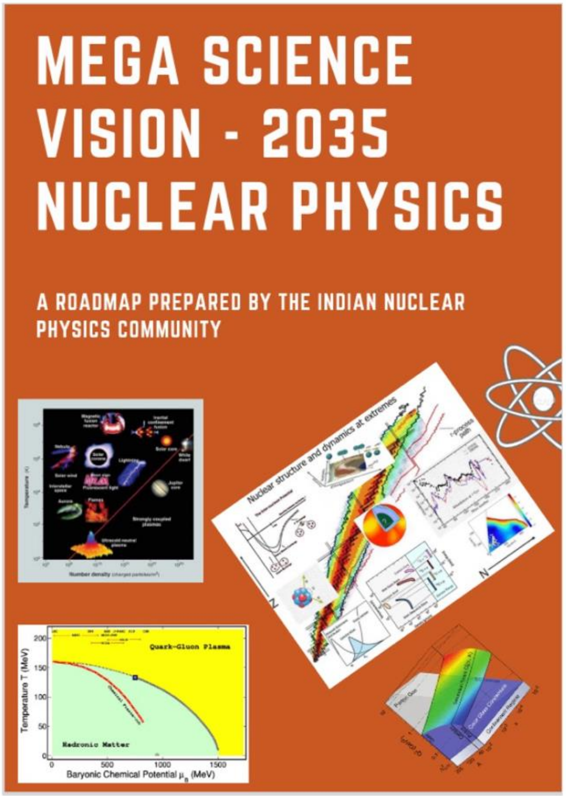
S.No.	Asian-Country	Institutions	Detector Hardware Interests
3	Korea	1) Gangneung-Wonju National University 2) Hanyang University 3) Inha University 4) Korea University 5) Kyungpook National University 6) Pusan National University 7) Sejong University 8) Sungkyunkwan University 9) University of Seoul 10) Yonsei University	▪ Barrel Imaging Calorimeter (BIC) ▪ ZDC Further interests: ▪ MPGD ▪ endcap tracker ▪ LGAD
4	Taiwan	1) Academia Sinica 2) National Taiwan University 3) National Central University 4) Chung Yuan Christian University 5) National Tsing Hua University 6) National Yang-Ming Chiao-Tung University 7) National Cheng Kung University	▪ AC-LGAD-TOF ▪ ZDC

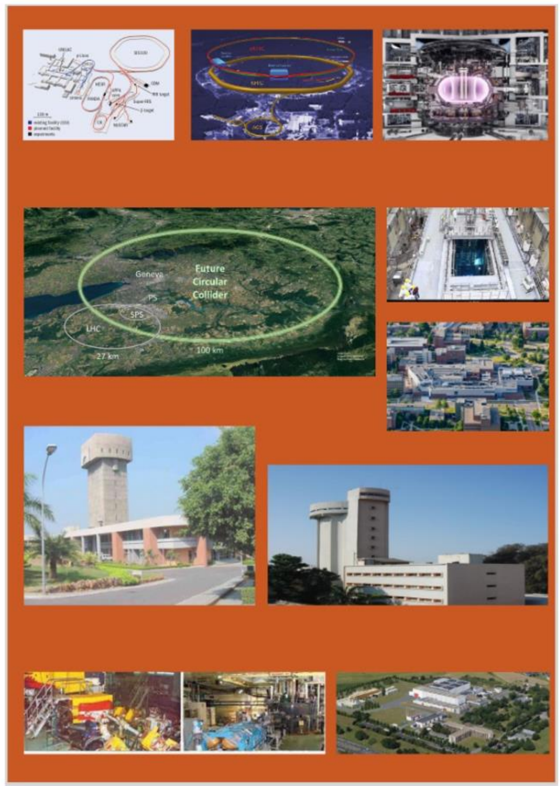
Green color: Common interest with EIC-India

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

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

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

Summary

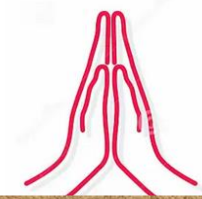
Electron Ion Collider (ePIC)

EIC is a QCD laboratory for discovery science

ePIC is a new Collaboration formed in 2022 – extraordinary progress since then

Consolidation and Optimization of detector layout – almost mature & use innovative technologies

Indian side: Good contribution in simulations; Detector hardware project finalization; DPR writing for funding!

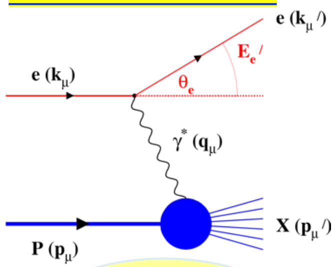


Acknowledgement: ePIC-India Collaboration

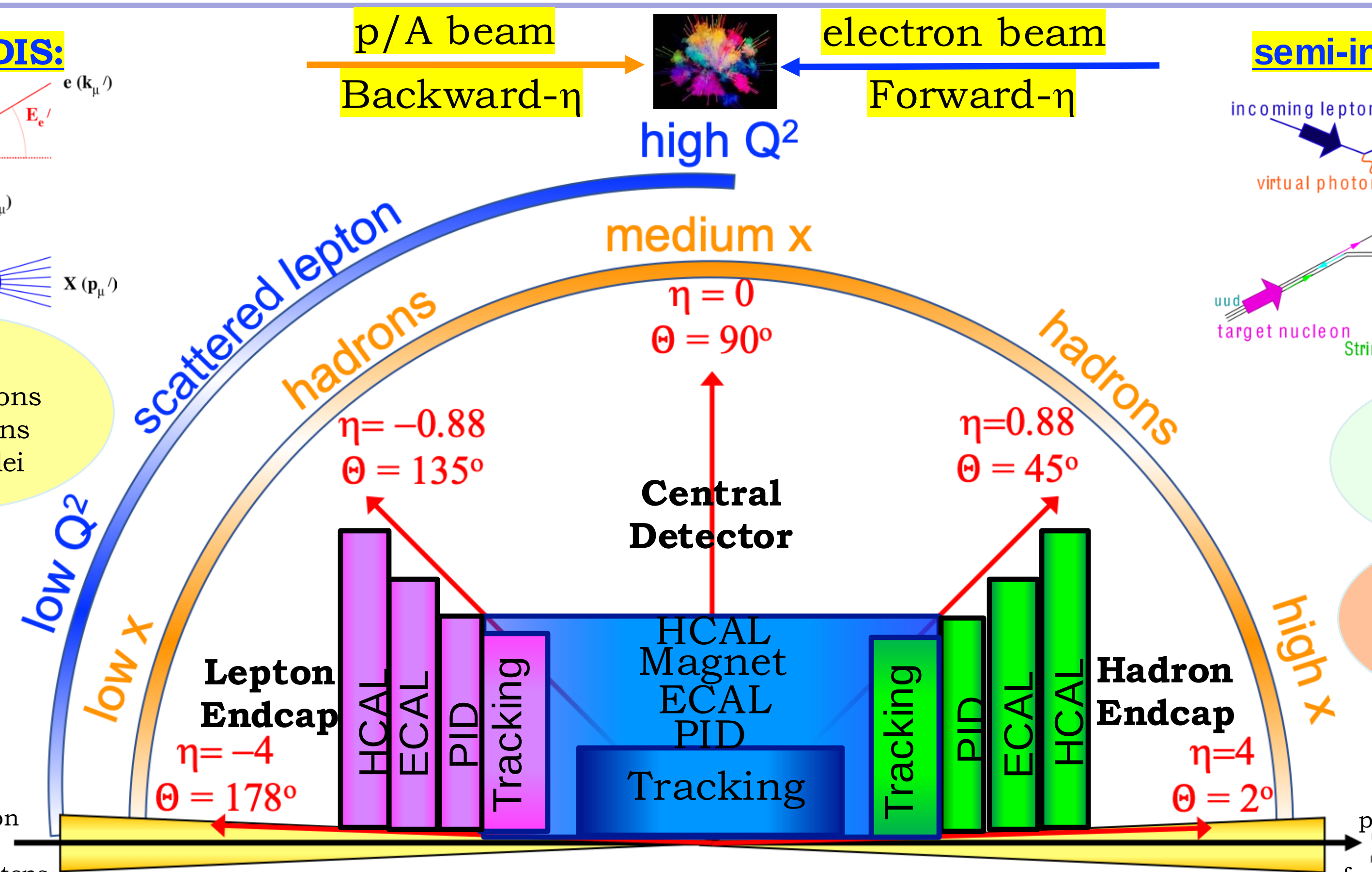
Back-up

Detector Requirements

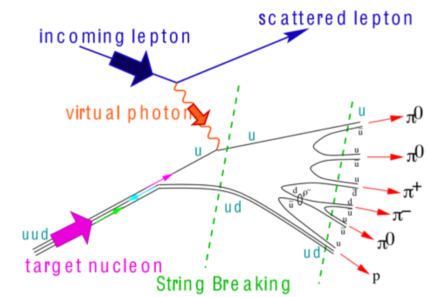
inclusive DIS:



Parton Distributions in nucleons and nuclei



semi-inclusive DIS



Spin and Flavor structure of nucleons and nuclei

Tomography Transverse Momentum Dist.

very low Q^2 scattered lepton

Bethe-Heitler photons for luminosity

particles from nuclear breakup and from diffractive reactions

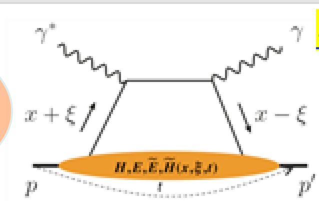
Distribution of hadrons & scattered lepton (in x – Q^2 & detector η)

Luminosity Detector

Low Q^2-Tagger

QCD at Extreme Parton Densities - Saturation

Tomography Spatial Imaging

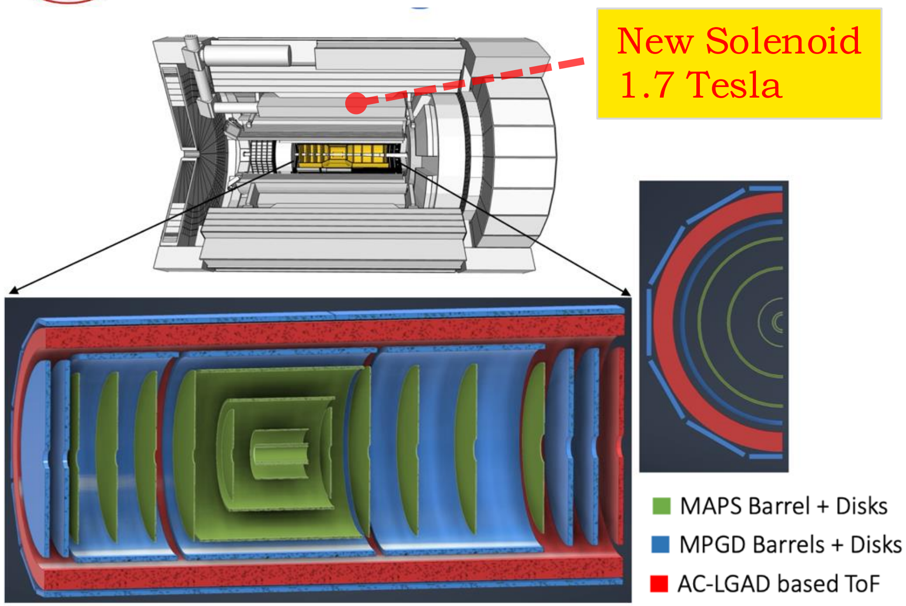


exclusive DIS

ZDC

Forward Tracking

Central Region: Tracking Detectors



MAPS Tracker:

- Ultra thin bent silicon around beampipe
- Small pixels (20 μm), low power consumption (<20 mW/cm^2) and material budget (0.05% to 0.55% X/X0) per layer
- Based on ALICE ITS-3 development
- Vertex layers optimized for beam pipe bakeout and ITS-3 sensor size
- Barrel layers based on EIC LAS development
- Forward and backwards disks

MPGD Layers:

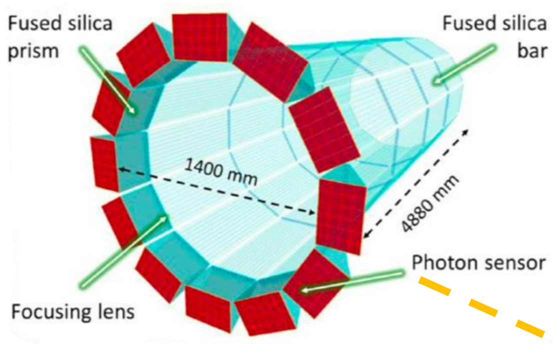
- Provide timing and pattern recognition redundancy
- Cylindrical barrel μMEGAs
- Planar End cap μRWells+single GEM before hpDIRC
- Impact point and direction for ring seeding

AC-LGAD based TOF (BECal):

- Additional space point for pattern recognition / redundancy.

MAPS: Monolithic Active Pixel Sensor
MPGD: Micro Pattern Gaseous Detector
LGAD: Low Gain Avalanche Detector

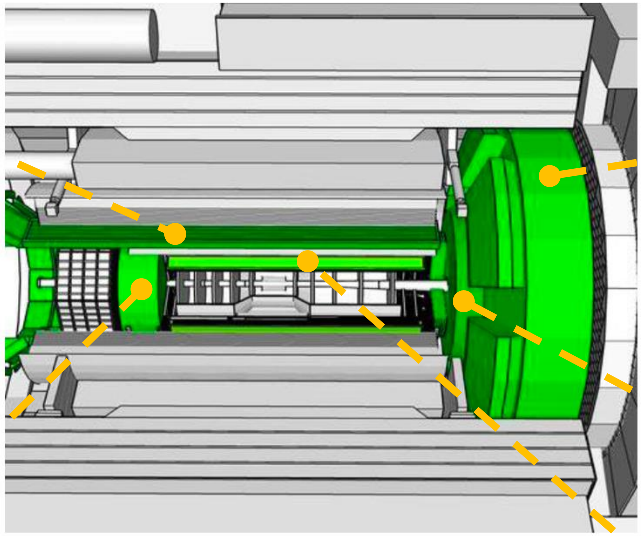
Central Region: PID Detectors

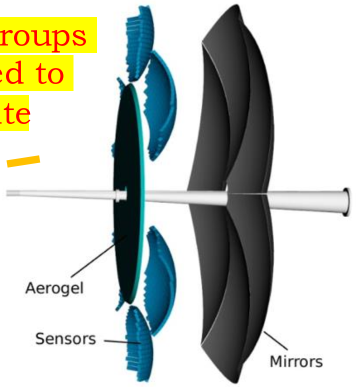


High-Performance DIRC (hpDIRC)
- Quartz bar radiator (reuse BaBAR bars)
- Sensors: HRPPDs
- π/K separation up to 6 GeV/c

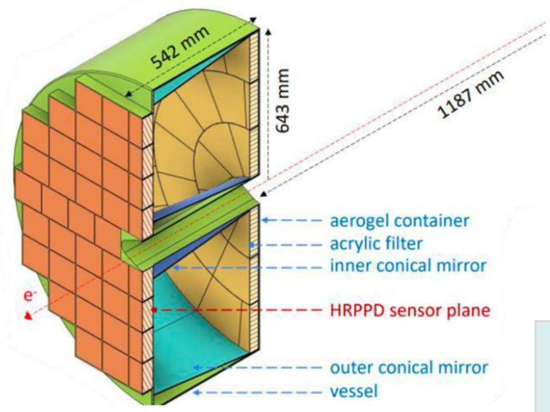
Dual-Radiator RICH (dRICH)
- C_2F_6 gas volume and Aerogel
- Sensors: SiPMs tiled on spheres
- π/K separation up to 50 GeV/c

Indian groups interested to contribute

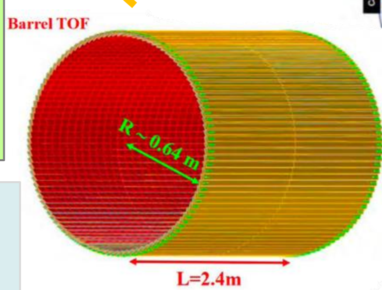


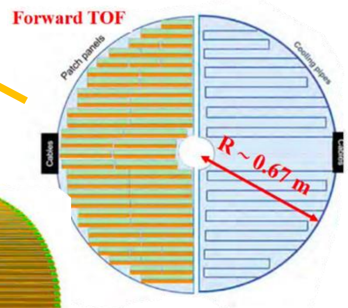


Proximity Focused RICH (pfRICH)
- Long Proximity gap (~40 cm)
- Sensors: HRPPDs (also provides timing)
- π/K separation up to 10 GeV/c
- e/π separation up to 2.5 GeV/c



AC-LGAD based TOF:
- t ~30 ps
- Accurate space point for tracking
- Forward disk and central barrel

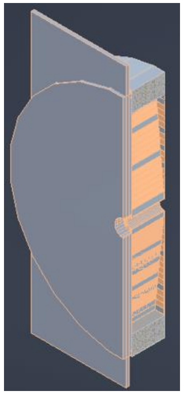




Indian groups interested to contribute

DIRC: Detection of Internally Reflected Cherenkov
RICH: Ring Imaging Cherenkov Detector
TOF: Time Of Flight

Central Region: Calorimetry

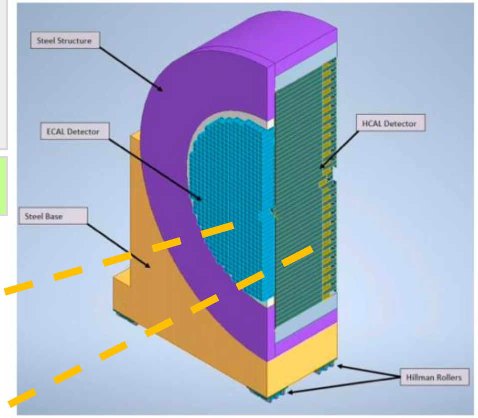


Electron Endcap HCal
Steel/Sc sandwich

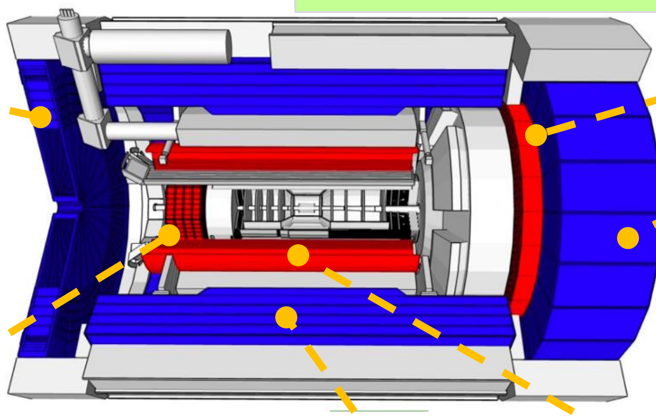
Electron going direction

Hadron Endcap EMCal
High granularity W-powder/SciFi
Hadron Endcap HCal
Longitudinally segmented Steel/Sc

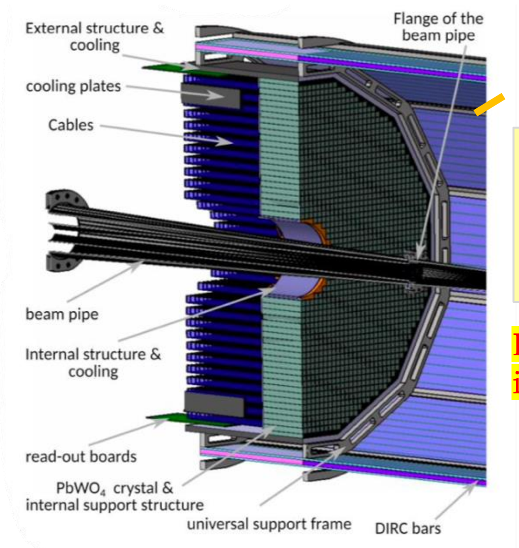
Indian groups interested to contribute



Hadron going direction



Electron Endcap EMCal
- Lead tungstate ($PbWO_4$) crystals



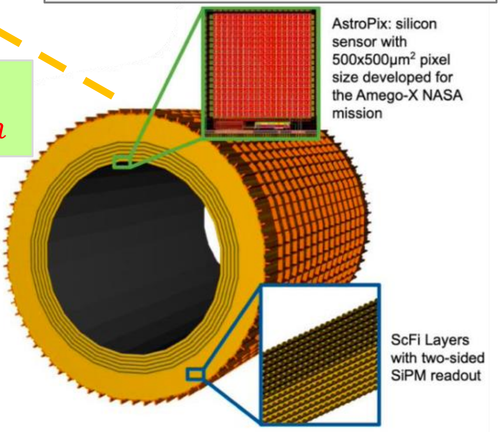
All Calorimeters are readout using SiPM

Indian groups interested in R&D of SiPM

Barrel Region

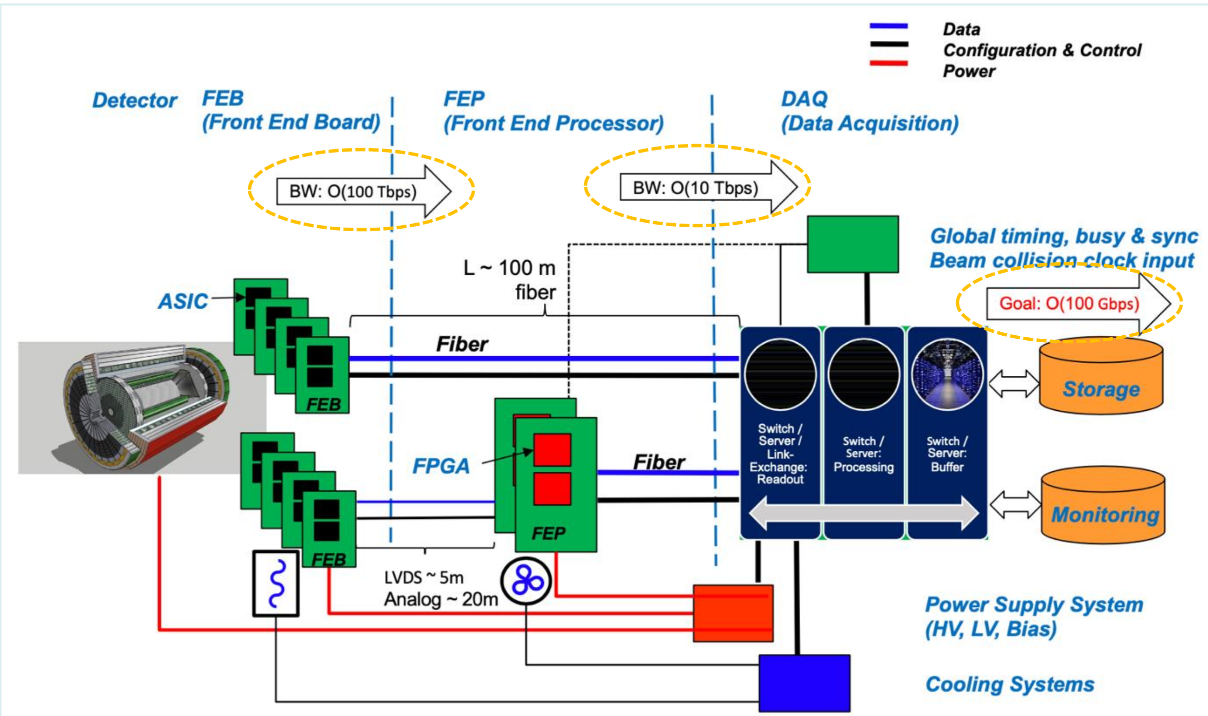
Barrel Hcal:
sPHENIX re-use (with increased granularity)

Barrel Imaging EMCal
Pb/SciFi with a hybrid imaging part (AstroPix Si Sensors)



ePIC Streaming DAQ

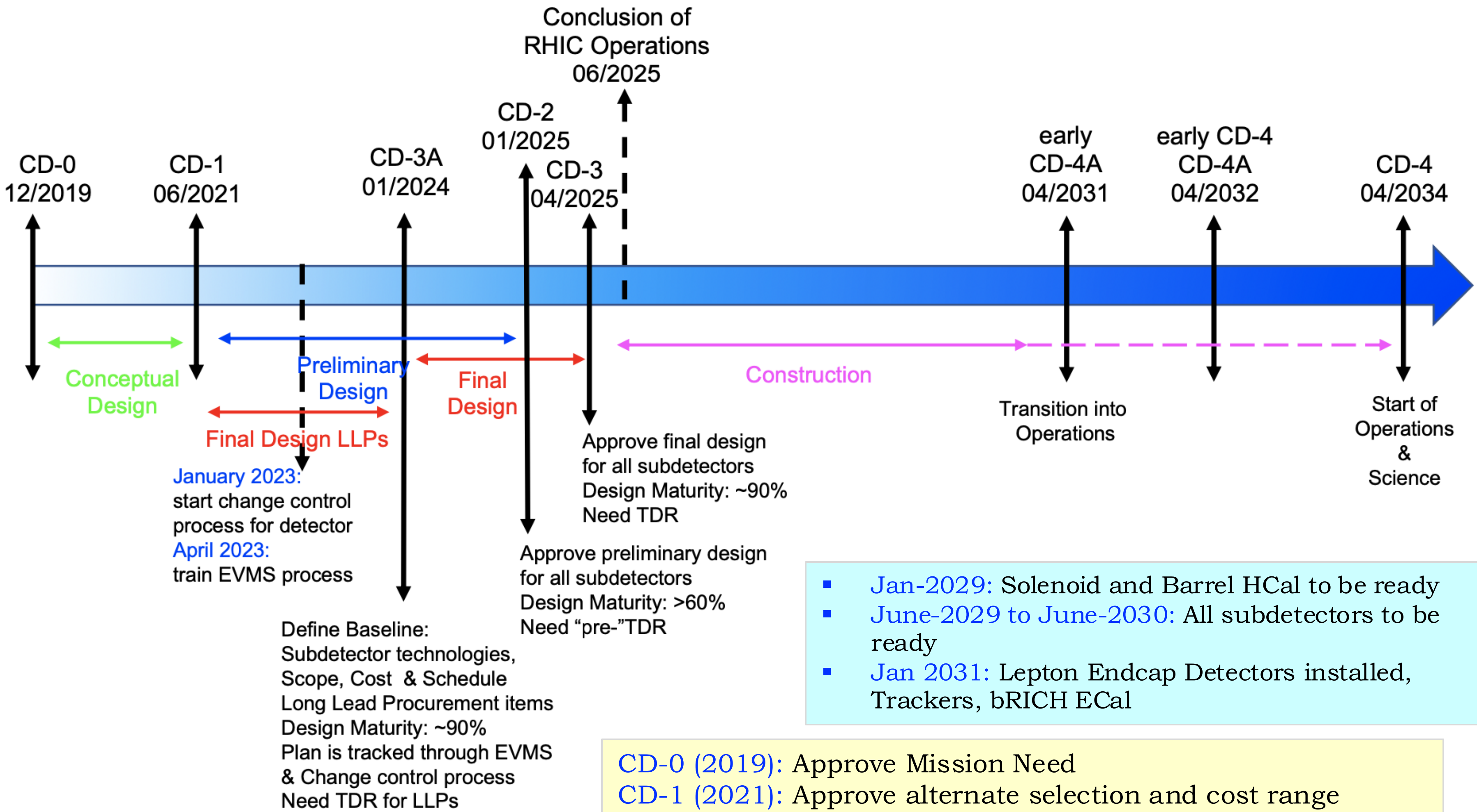
- Triggerless streaming architecture gives much more flexibility to do physics
- Integrate AI/ML as close as possible to subdetectors → cognizant Detector



Indian groups interested to contribute

- No external trigger
- All collision data digitized but aggressively zero suppressed at FEB
- Low / zero deadtime
- Event selection can be based upon full data from all detectors (in real time, or later)
- Collision data flow is independent and unidirectional-> no global latency requirements
- Avoiding hardware trigger avoids complex custom hardware and firmware
- Data volume is reduced as much as possible at each stage

EIC Project Schedule



- Jan-2029: Solenoid and Barrel HCal to be ready
- June-2029 to June-2030: All subdetectors to be ready
- Jan 2031: Lepton Endcap Detectors installed, Trackers, bRICH ECal

CD-0 (2019): Approve Mission Need
CD-1 (2021): Approve alternate selection and cost range
CD-2 (2025): Approve performance baseline
CD-3 (2025): Approve start of construction or execution
CD-4 (2034): Approve start of operations & project completion

Beam Energies, Parameters

Species	p	e	p	e	p	e	p	e	p	e
Beam energy [GeV]	275	18	275	10	100	10	100	5	41	5
$\sqrt{s}$ [GeV]	140.7		104.9		63.2		44.7		28.6	
No. of bunches	290		1160		1160		1160		1160	
	High divergence configuration									
RMS $\Delta\theta$, h/v [μrad]	150/150	202/187	119/119	211/152	220/220	145/105	206/206	160/160	220/380	101/129
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9	6.8	5.8	9.7	5.8	9.7	6.8	10.3	6.8
Luminosity [10^{33}cm^{-2}s^{-1}]	1.54		10.00		4.48		3.68		0.44	
	High acceptance configuration									
RMS $\Delta\theta$, h/v [μrad]	65/65	89/82	65/65	116/84	180/180	118/86	180/180	140/140	220/380	101/129
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9	6.8	5.8	9.7	5.8	9.7	6.8	10.3	6.8
Luminosity [10^{33}cm^{-2}s^{-1}]	0.32		3.14		3.14		2.92		0.44	

Table 10.1: Beam parameters for e+p collisions for the available center-of-mass energies $\sqrt{s}$ with strong hadron cooling. Luminosities and beam effects depend on the configuration. Values for high divergence and high acceptance configurations are shown.

Species	Au	e	Au	e	Au	e	Au	e
Beam energy [GeV]	110	18	110	10	110	5	41	5
$\sqrt{s}$ [GeV]	89.0		66.3		46.9		28.6	
No. of bunches	290		1160		1160		1160	
	Strong hadron cooling							
RMS $\Delta\theta$, h/v [μrad]	218/379	101/37	216/274	102/92	215/275	102/185	275/377	81/136
RMS $\Delta p/p$ [10^{-4}]	6.2	10.9	6.2	5.8	6.2	6.8	10	6.8
Luminosity [10^{33}cm^{-2}s^{-1}]	0.59		4.76		4.77		1.67	
	Stochastic cooling							
RMS $\Delta\theta$, h/v [μrad]	77/380	109/38	136/376	161/116	108/380	127/144	174/302	77/77
RMS $\Delta p/p$ [10^{-4}]	10	10.9	10	5.8	10	6.8	13	6.8
Luminosity [10^{33}cm^{-2}s^{-1}]	0.14		2.06		1.27		0.31	

Table 10.2: Beam parameters for e+Au collisions for the available center-of-mass energies $\sqrt{s}$. Luminosities and beam effects depend on the cooling technique. Values for strong hadronic and stochastic cooling are shown.