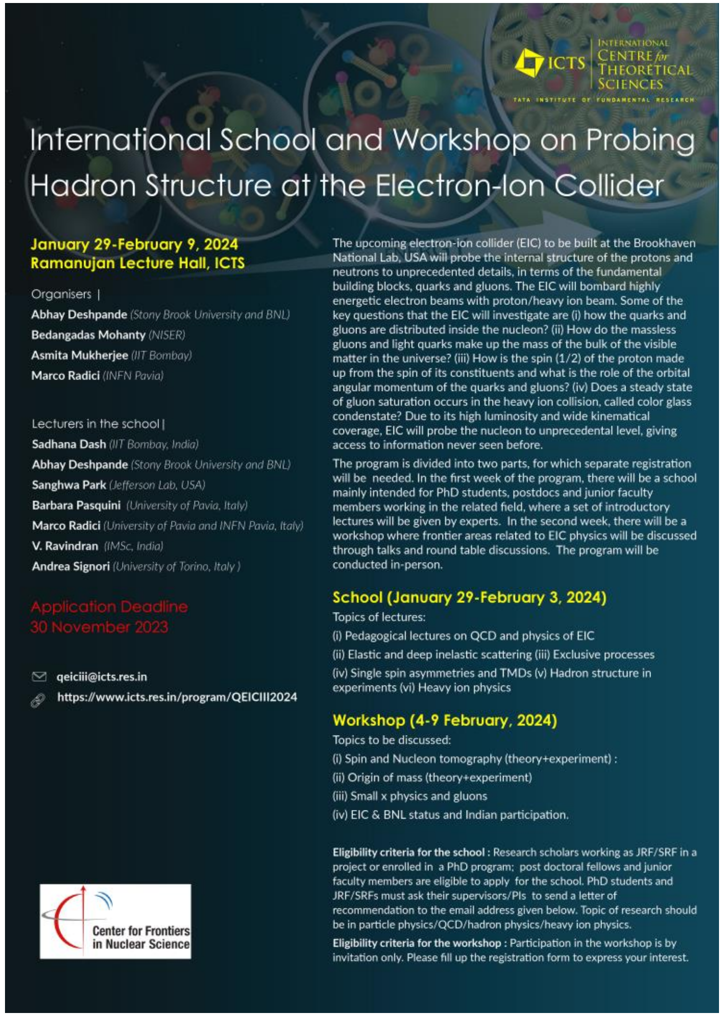
Electron Ion Collider – Indian Participation

IIT Bombay, Jan 2020

Bedanga Mohanty

(NISER)



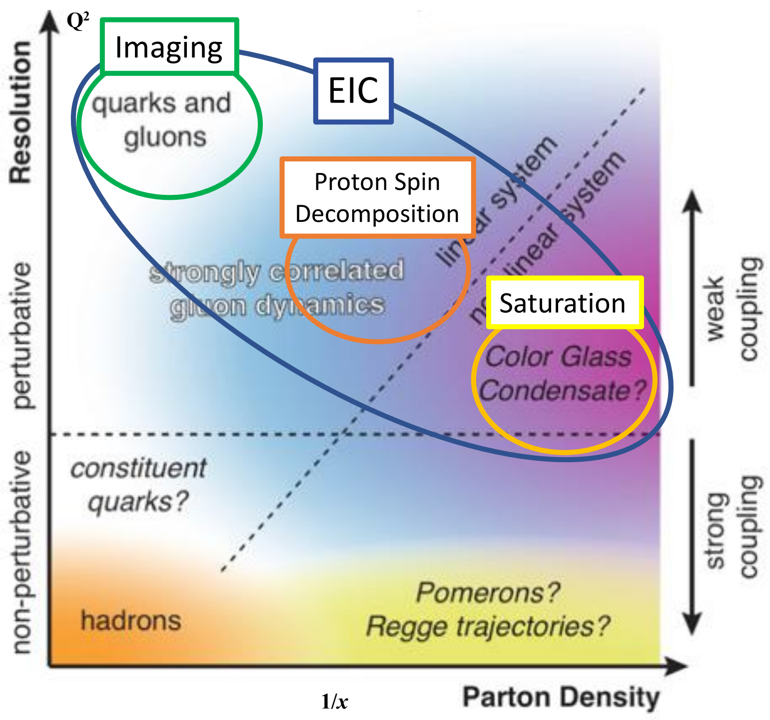
Outline

- Physics at EIC and India in ePIC
- EIC in India's long-range plan
- Indian group experience (experiment & theory)
- Plans for the detailed project report for ePIC
- Summary

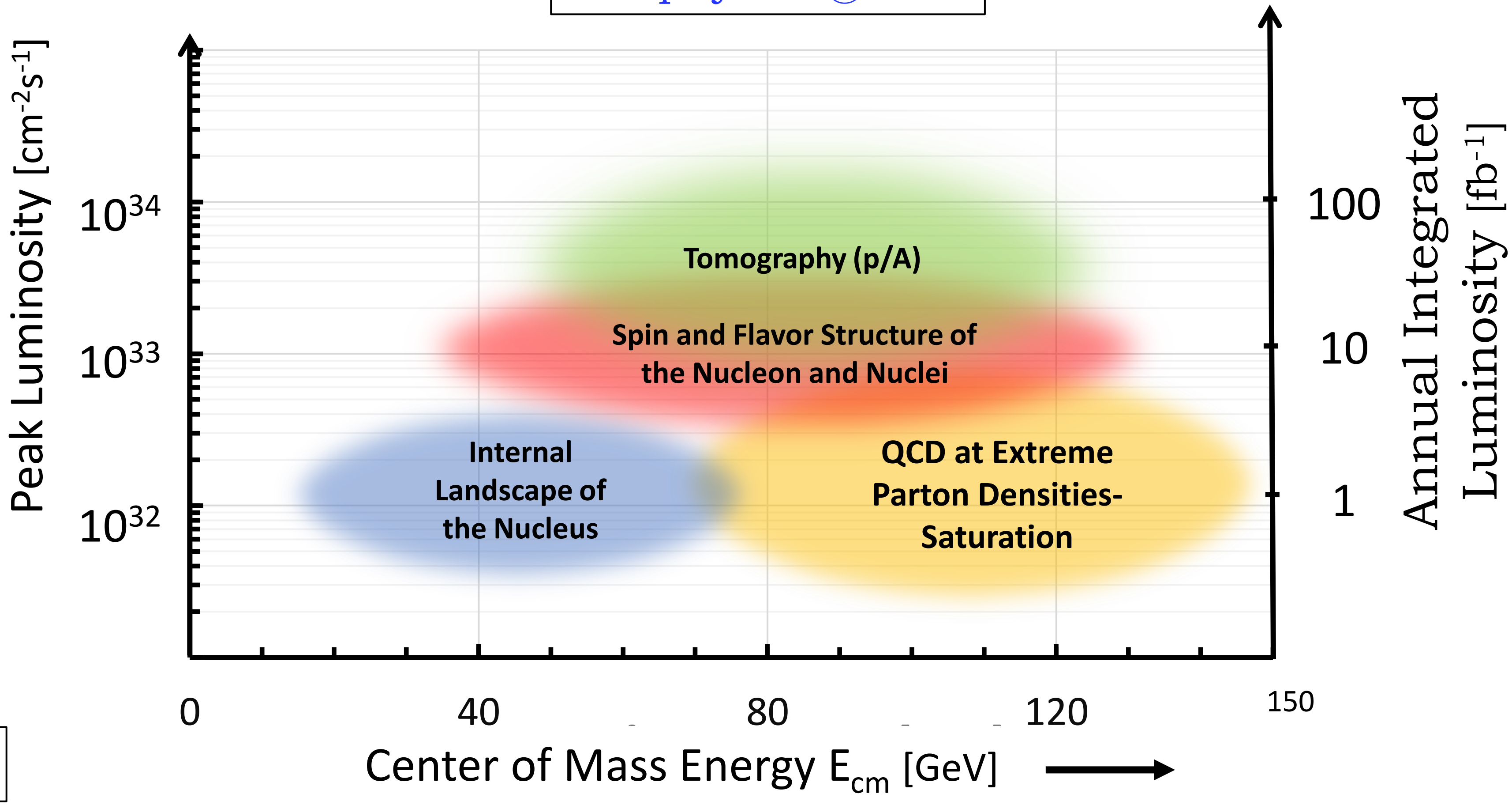
More in talks by
Dr. Lokesh Kumar
D. Shuddha Sankar Dasgupta

Electron Ion Collider – study QCD at new level

The next phase diagram



EIC physics @ BNL



4 important questions - EIC

How do quarks and gluons form nuclei?

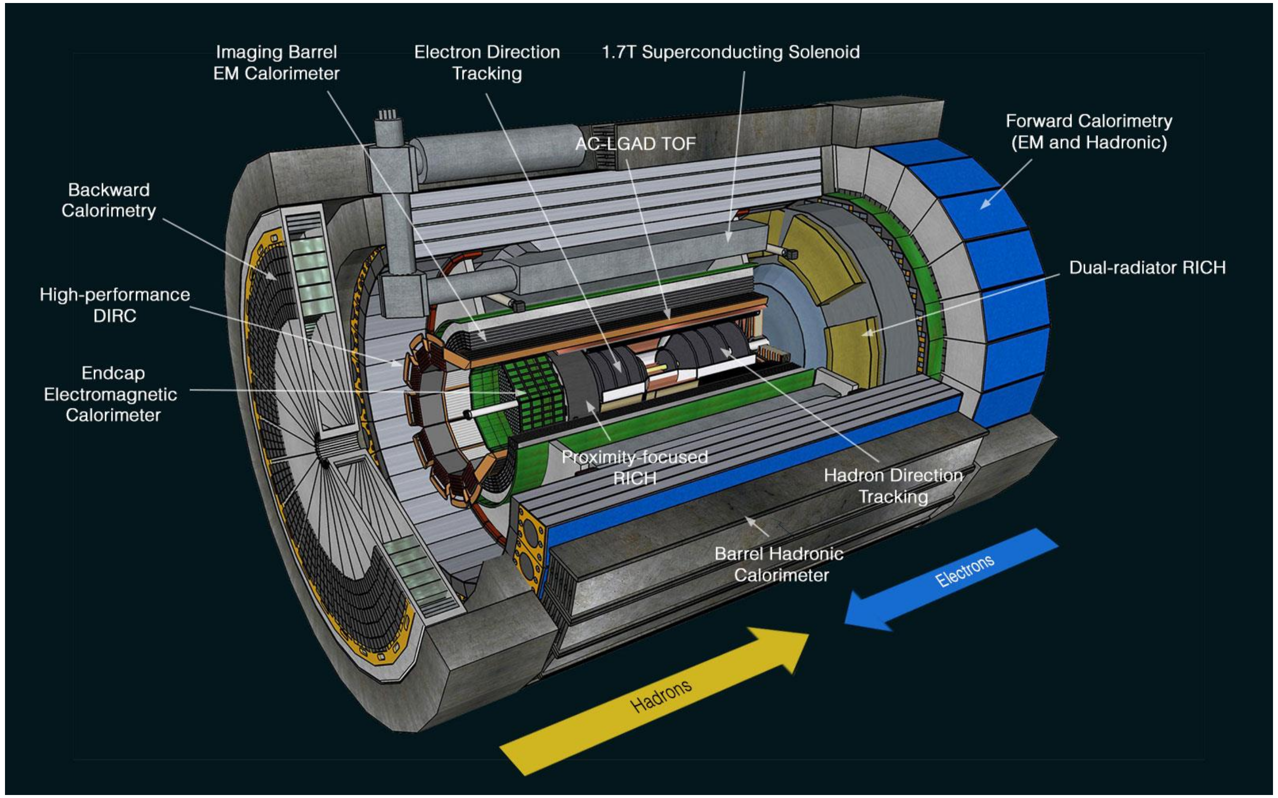
How does the proton get its spin?

How does the proton get its mass?

What is the nature of dense gluon matter?

ePIC @ EIC, BNL

EPIC-INDIA



https://www.bnl.gov/eic/images/epic-cutaway-labeled.jpg

20 Institutes

May join soon

Indian long range plan report

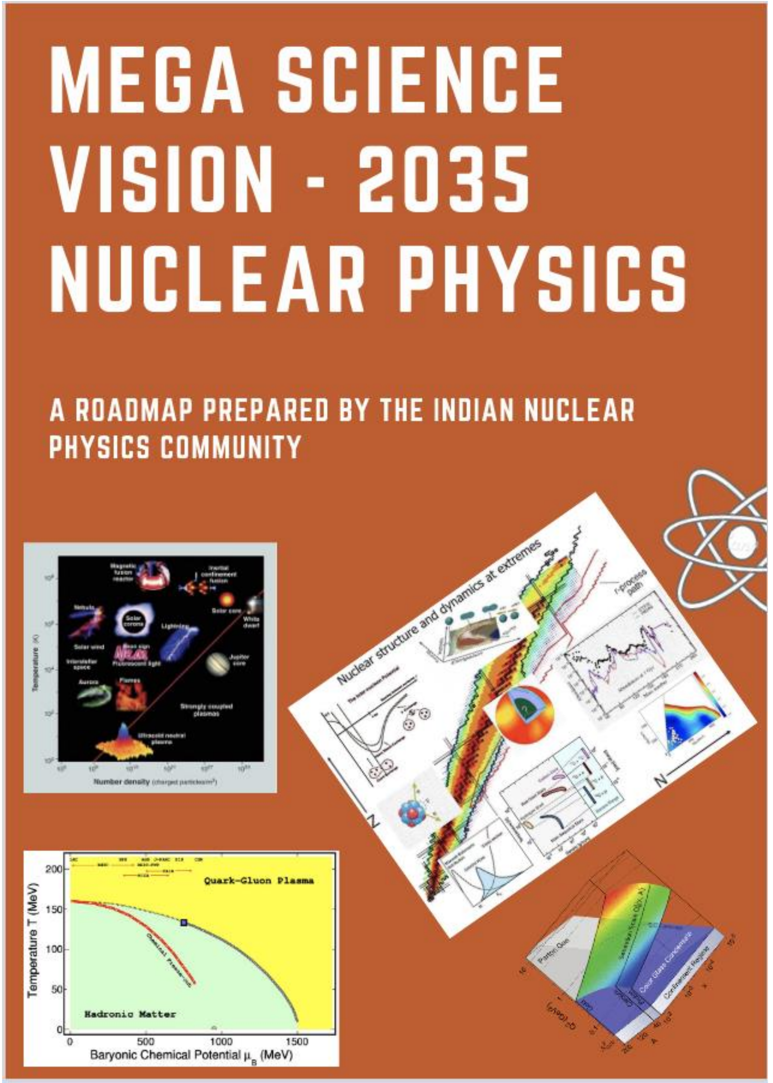
MEGA SCIENCE VISION – 2035

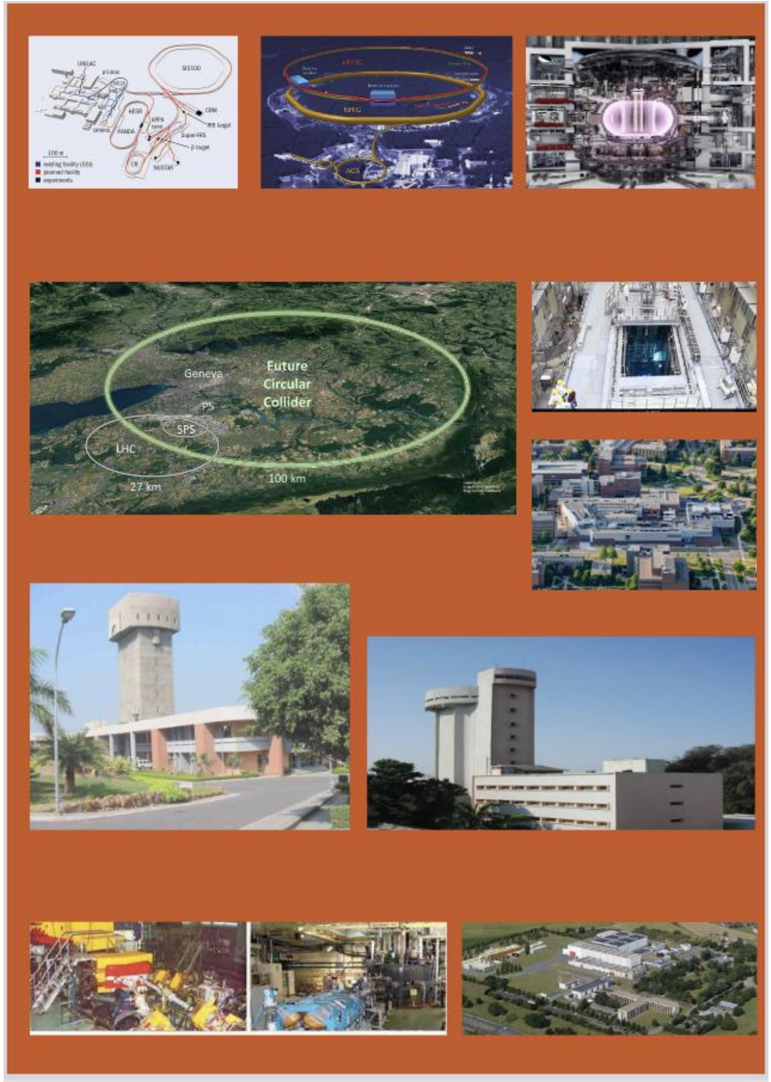
NUCLEAR PHYSICS

A roadmap prepared by
the Indian Nuclear Physics Community
with TIFR, Mumbai
as the Nodal Scientific Institution

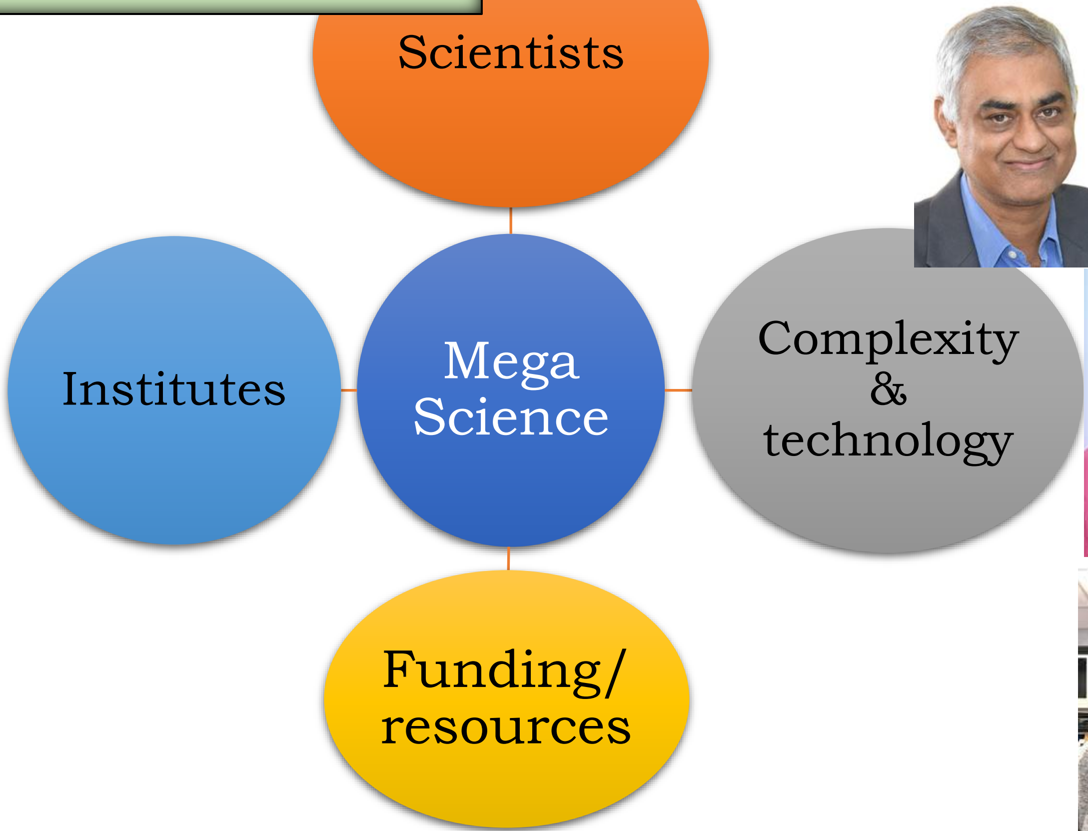
and

submitted to
The Office of the Principal Scientific Adviser to the
Government of India





Mega Science

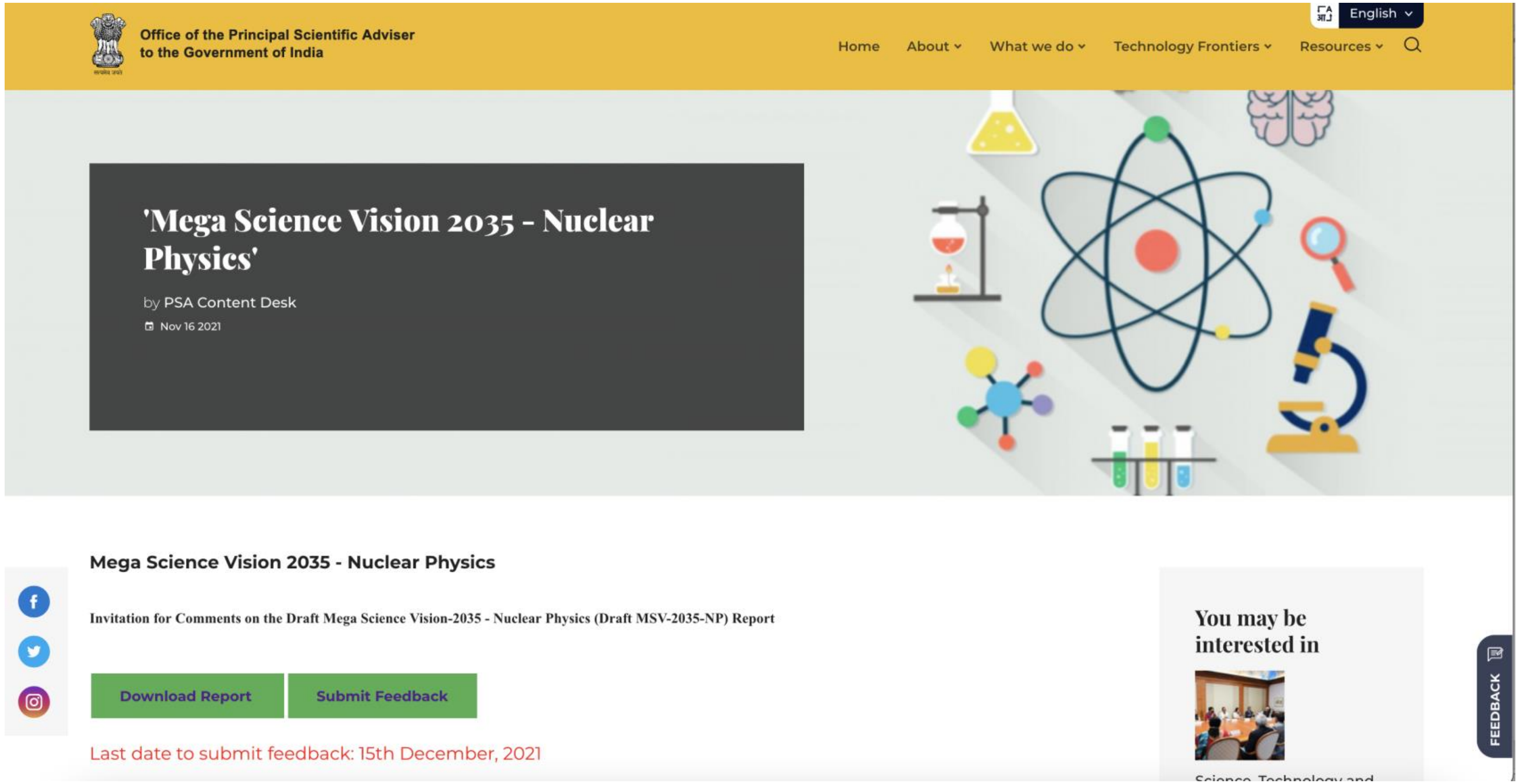


- *Drafting group met regularly for last 2.0 years.*
- *Regular consultations with working group.*
- *Inputs obtained from individual, institutes, facilities, collaborations.*
- *4000+ scientific members from across various areas contacted for inputs.*
- *National and International expert consultation.*
- *Consulted STIP document, Vision 2014 & LR-US-Eur.*
- *Professional editing work by Chandani Palshetkar.*

Team for MSV2035-NP

Initial Inputs

Community Input Exercise



- *4000+ scientific members from across various areas were contacted for inputs.*
- *About 60 written detailed comments received.*
- *Those were discussed point-by-point and several suggestions incorporated.*

Community response overall enthusiastic.

National and International Expert Consultations

- *Feedback taken via a dedicated online meeting.*
- *Additionally, 9 very detailed written feedbacks were received.*
- *Point-by-point the comments were discussed and several suggestions incorporated.*

Experts were very positive about the draft report.
SWOT (strengths, weaknesses, opportunities, and threats) analysis was noted.

Indian long range plan document and EIC

SCIENCE QUESTIONS (2 out of the 14 questions listed)

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

How does a nucleus look in terms of its partonic content? Do nucleons and nuclei, viewed at near-light speed, behave as gluonic matter with universal properties?

Indian long range plan document and EIC

RECOMMENDATIONS ON MEGA PROJECTS

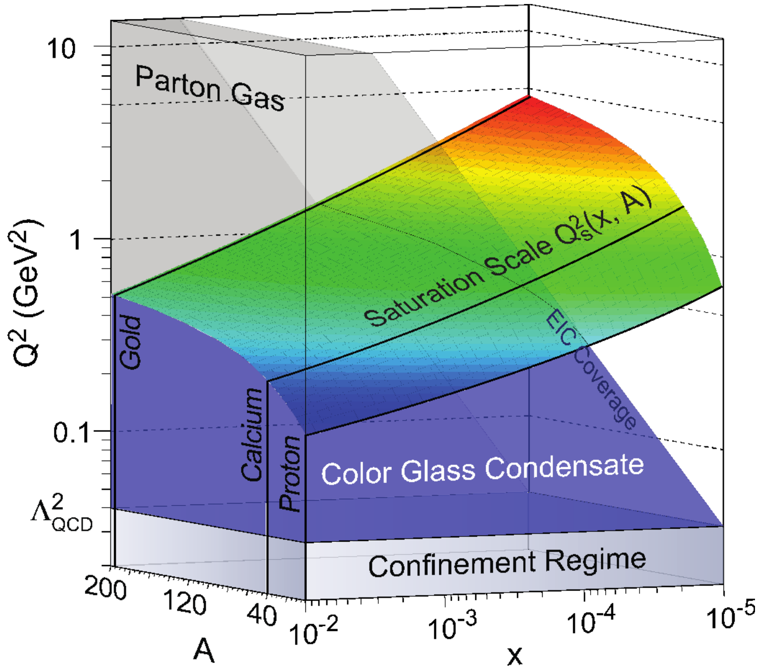
RECOMMENDATIONS FOR QCD

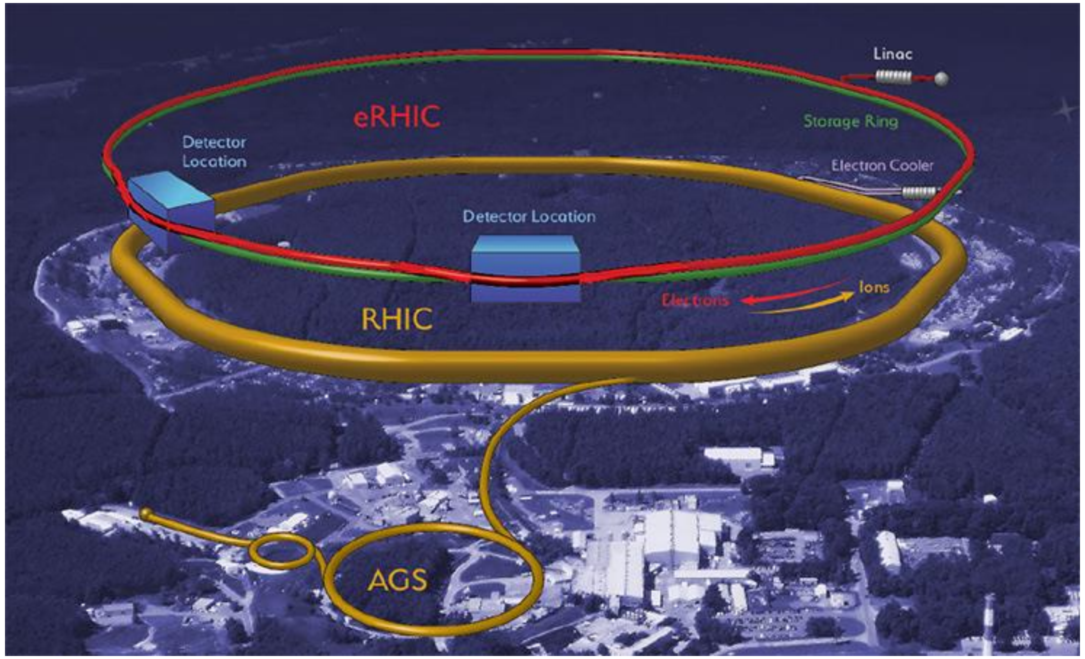
The study of the emergent properties of QCD matter is one of the most compelling science problems in nuclear physics. It includes mapping the phase diagram of the QCD matter, measuring the properties of the QCD matter subjected to extreme conditions of temperature, pressure, baryon density, electromagnetic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

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

Indian long range plan document and EIC

Features in : SCIENCE GOALS OF NUCLEAR PHYSICS IN THE NEXT DECADE





The conjectured QCD landscape showing the resolving power of the probe (increasing upward) vs. energy (increasing toward the right), as a function of the atomic number of the nucleus being probed.

Indian Long Range Plan Document and EIC

Features in NUCLEAR AND PLASMA PHYSICS FACILITIES

Facility	Features	Experiments	Science	Users
EIC	Will be commissioned around 2032.Highly polarized (~ 70%) electron and nucleon beams. Ion beams from deuteron to the heaviest nuclei (U or Pb). Variable center-of-mass energies from $\sqrt{ss} \approx 20$ to 100 GeV, upgradable to ~140 GeV. High collision luminosity of L ~10^{33-34} cm^{-2} s^{-1}	Separate detectors at two different interaction regions are expected.	Precisely image gluons in nucleons and nuclei. Understand the origin of the nucleon spin and explore a new QCD frontier of ultra-dense gluon fields, with the potential to discover a new form of gluon matter predicted to be common to all nuclei.	Multi-institute and multi-country collaboration. Collaboration is in the formation stage.

Indian long range plan document and EIC

Efforts from theory side features in the section on THEORETICAL NUCLEAR PHYSICS

Emergence of mass and spin: The investigation of the emergence of mass and spin in all visible composite matter is of utmost importance in our understanding of nature. Lattice QCD methods provide a unique tool to study it from first principles with controlled systematics. Lattice QCD methods can already calculate the nucleon mass with an accuracy at a percent level. However, it is still intriguing how the collective interactions of tiny quarks and gluons emerge into a massive hadron. It is of fundamental interest to find how the mass of a composite subatomic particle, through the dynamics of strong interactions, decomposes into various parts, namely contributions from the quark condensate, the quark energy, the gluon field energy and the trace anomaly. Similarly, one can also study the emergence of spin of a composite particle from a combination of various parts, namely, quark spin contribution, gluon angular momentum contribution and the orbital motion of quarks.

The vibrant theoretical community in India has made remarkable advances in studying the motion of the confined partons in the fast-moving nucleon and the transverse momentum-dependent distributions (TMDs) of partons. These give the distribution of the quarks and gluons inside a nucleon in the 3D momentum space. There also is evidence of correlations between the parton momentum and spin, and the origin of such correlations are yet to be understood.

Indian long range plan document and EIC

Features in CURRENT AND PLANNED MEGA PROJECTS AND FACILITIES

Indian Participation:

Although the realization of the EIC is expected to evolve over time, Indian participation at this early stage is highly desirable for the following reasons:

(i) The participation in EIC will enable us to continue our pursuit in nuclear science research through the quest for understanding the unique gluon-dominated nature of visible matter in the Universe. The Indian research program should not miss on this fundamental quest of hadron physics.

(ii) The EIC requirements will push the accelerator and detector designs to the limits of current technology. The detector designing concepts contain assessments of the current state of the art in technologies, services, mechanical support and other components. It can therefore provide enormous platform for training the younger generation to be skilled scientists, engineers and technicians in cutting-edge technology that can have later societal applications in terms of application in medical sciences, indigenous development of technology, energy, etc.

(iii) It will inspire and attract new generations of young talented people in the pursuit of careers in science and technology

Indian long range plan document and EIC

Already lays down the goals for Indian Scientists in EIC

There are three primary goals for the Indian scientists that are relevant to their participation in the EIC program:

1. To participate and contribute to the physics program of EIC. As the physics program would offer answers to a number of key questions in hadron physics, the long-term plan of Indian groups should be to focus primarily on the following studies:

A. Global properties and parton structure of hadrons
B. Multi-dimensional imaging of nuclei, nucleons and mesons
C. QCD at gluon saturation densities
D. Color charge in QCD matter

2. To participate and contribute to detector research and development
A. Silicon tracking and vertex system and ToF detector
B. Particle identification detector:
C. Participation and contribution to EIC software developments

3. Computational Resources – Both Lattice QCD and experiments

Indian long range plan document and EIC

SWOT analysis

Strengths:

- Large pool of young physicists, engineers and technicians with international expertise in data analysis and detector developments
- Active and effective participation in RHIC and LHC experiments with significant contribution in data analysis, software development etc.
- Successful development and installation of detectors in STAR and ALICE experiment
- Excellent collaboration between experimental and theoretical high energy communities.
- Availability of high-end computing facilities

Opportunities:

- Continue to participate and contribute to fundamental physics
- Attract and inspire the next generation to pursue research in basic sciences
- Develop a pool of highly skilled scientific and technical manpower
- Excellent opportunity to become world leaders in hadron physics
- Create job/fellowship opportunities for young researchers beyond 2030

Indian Long Range Plan Document and EIC

Tentative funding projections

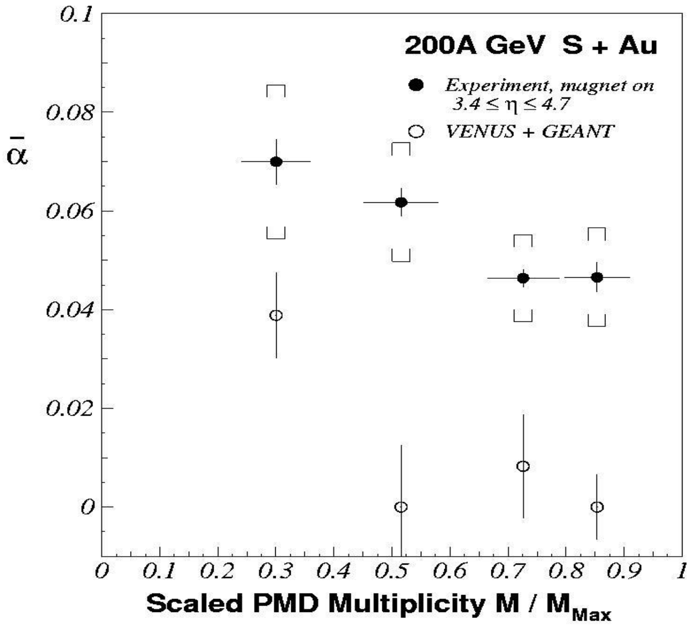
Project	2020-2025		2025-2030		2030-2035	
EIC	FTE Scientists	Funding in Rs. Cr per year (USD per year)	FTE Scientists	Funding in Rs. Cr per year (USD per year)	FTE Scientists	Funding in Rs. Cr per year (USD per year)
	45	10 (USD 1.2 Million)	90	25 (USD 3 Million)	130	30 (3.6 Million USD)
Total in 5 years		Rs. 50 Crs (6.0 Million USD)		Rs. 125 Crs (15 Million USD)		Rs. 150 Crs (18 Million USD)

Funding includes – Salary for human resources, travel, machinery and equipment and supplies & materials

India Group Experience – Experiment (selected)

WA93 – CERN SPS

Physics contribution



Photon multiplicity detector

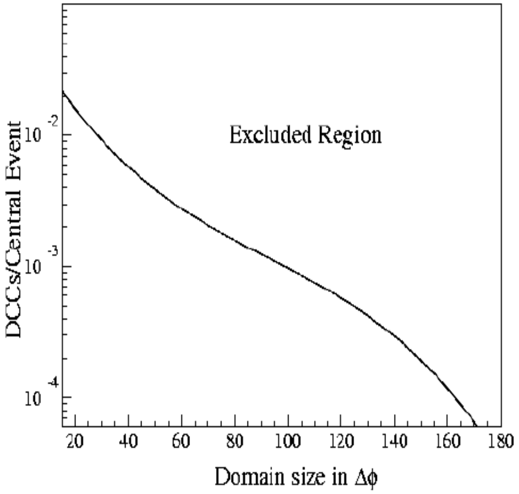
7600 scintillator pads covering 3 m^2

First observation of Collective Flow at CERN SPS: Phys. Lett. B403 (1997) 390

Nucl.Instrum.Meth.A 372 (1996) 143-159

WA98 – CERN SPS

Physics contribution



Photon multiplicity detector

50000+ scintillator pads covering 21 m^2

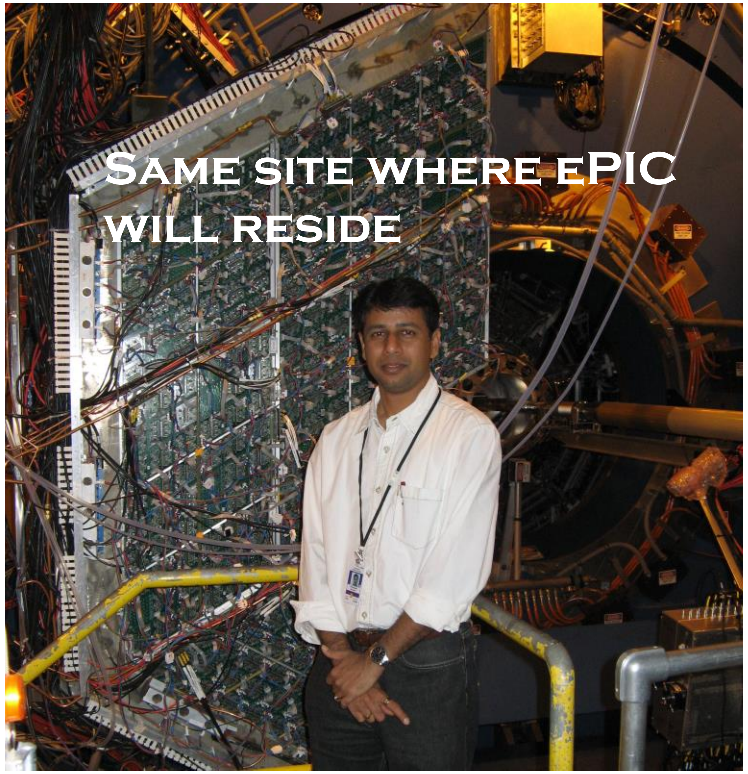
Search for disoriented chiral condemsates: Phys.Rev.C64 (2001) 011901

Nucl.Instrum.Meth.A 424 (1999) 395-413

India Group Experience – Experiment (selected)

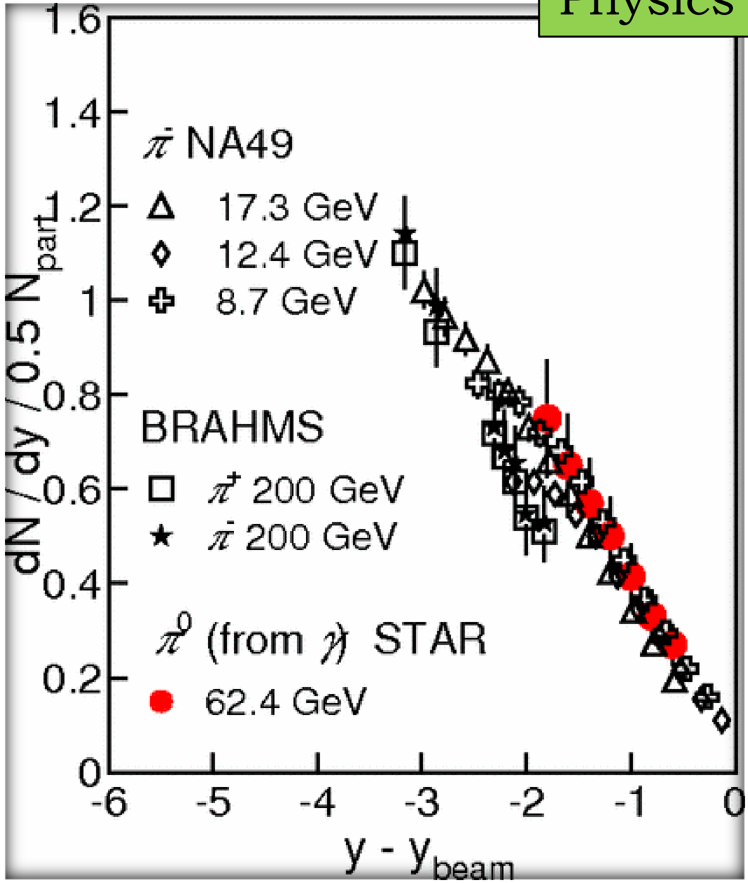
STAR – RHIC BNL

Photon multiplicity detector

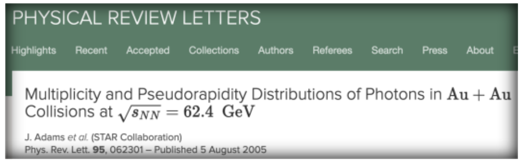


82944 gas based proportional counters

Nucl.Instrum.Meth.A 499 (2003) 751-761



Observation of a novel longitudinal scaling


PHYSICAL REVIEW LETTERS

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Multiplicity and Pseudorapidity Distributions of Photons in Au + Au Collisions at $\sqrt{s_{NN}} = 62.4$ GeV

J. Adams *et al.* (STAR Collaboration)

Phys. Rev. Lett. 95, 062301 – Published 5 August 2005

Physics contribution


PHYSICAL REVIEW LETTERS

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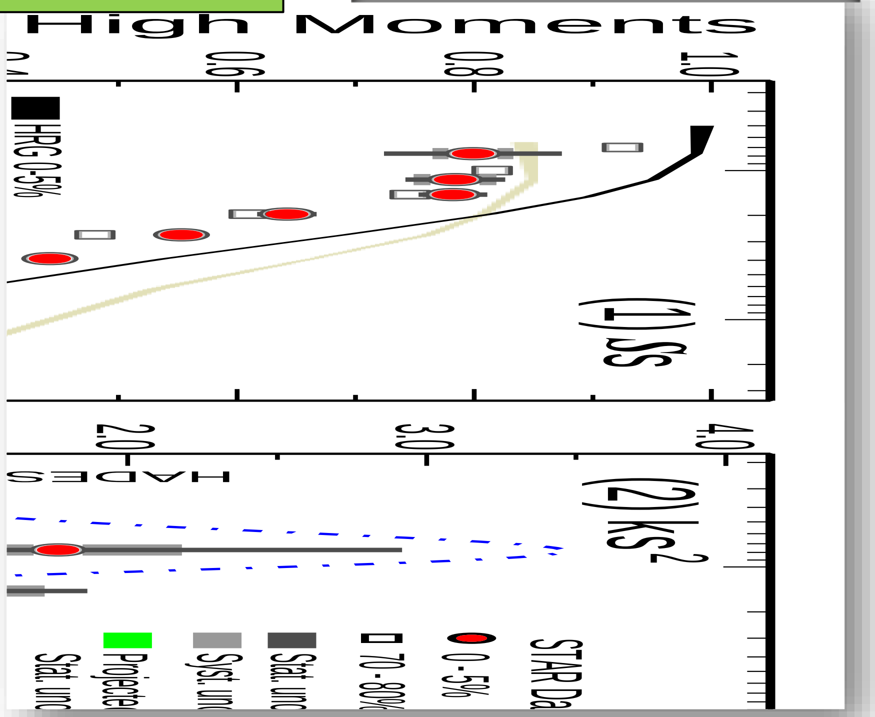
Nonmonotonic Energy Dependence of Net-Proton Number Fluctuations

J. Adam *et al.* (STAR Collaboration)

Phys. Rev. Lett. 126, 092301 – Published 5 March 2021



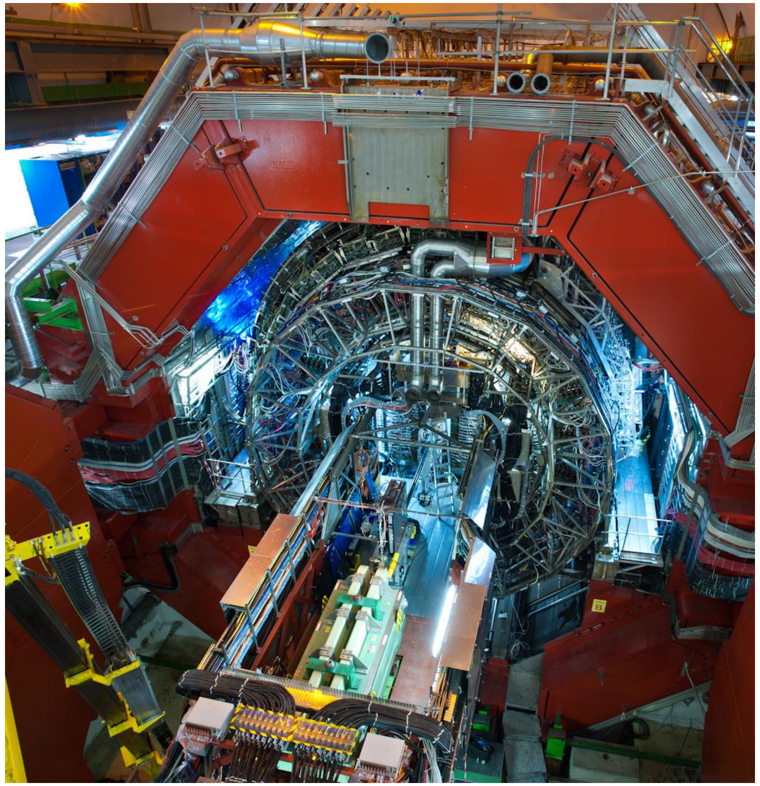
Collision energy (GeV)

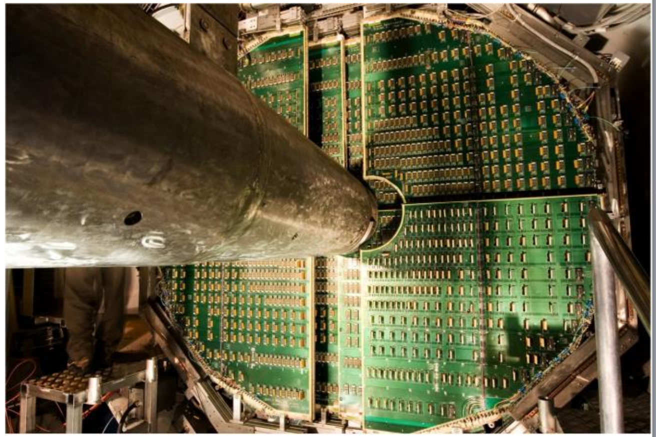
Search for the QCD Critical Point and Phase Diagram

India Group Experience – Experiment (selected)

ALICE – LHC CERN

Photon multiplicity, muon detector, MANAS ASIC

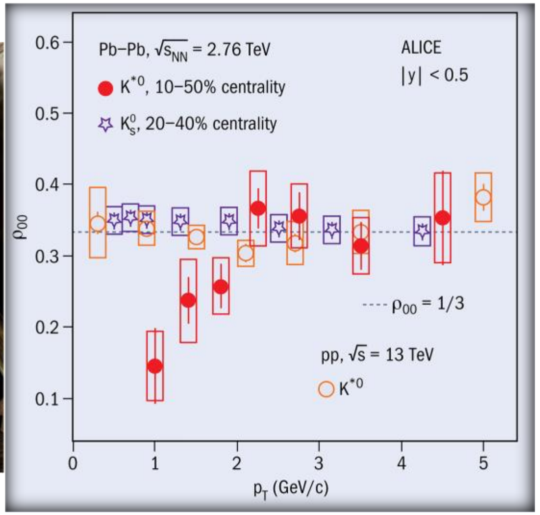


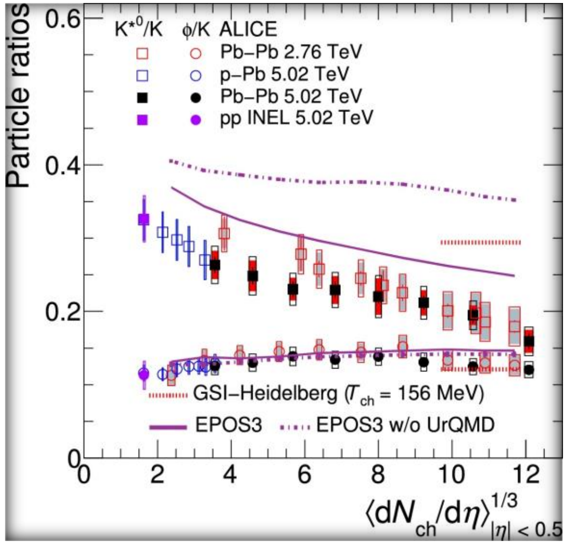


270,000 gas based proportional counters

Nucl.Instrum.Meth.A 488 (2002) 131-143

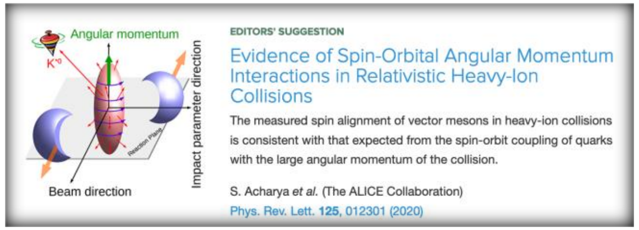
Physics contribution





Evidence of spin-orbit interactions

Evidence: rescattering effect



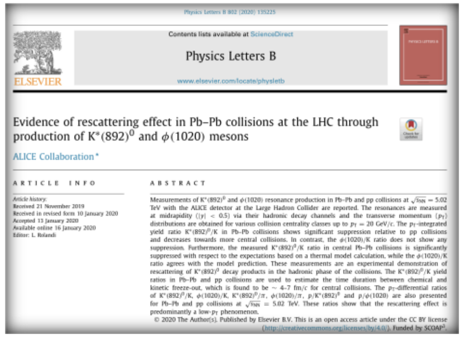
EDITORS' SUGGESTION

Evidence of Spin-Orbital Angular Momentum Interactions in Relativistic Heavy-Ion Collisions

The measured spin alignment of vector mesons in heavy-ion collisions is consistent with that expected from the spin-orbit coupling of quarks with the large angular momentum of the collision.

S. Acharya *et al.* (The ALICE Collaboration)

Phys. Rev. Lett. 125, 012301 (2020)


Contents lists available at ScienceDirect

Physics Letters B

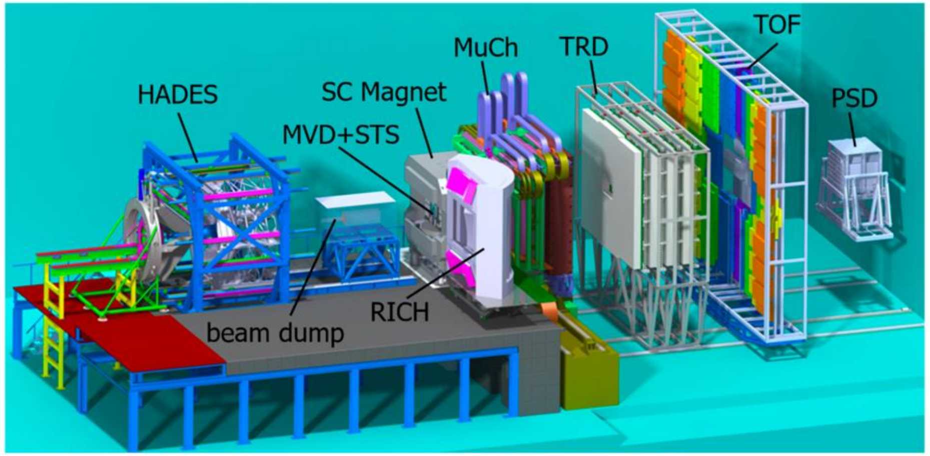
Evidence of rescattering effect in Pb–Pb collisions at the LHC through production of $K^*(892)^0$ and $\phi(1020)$ mesons

ALICE Collaboration

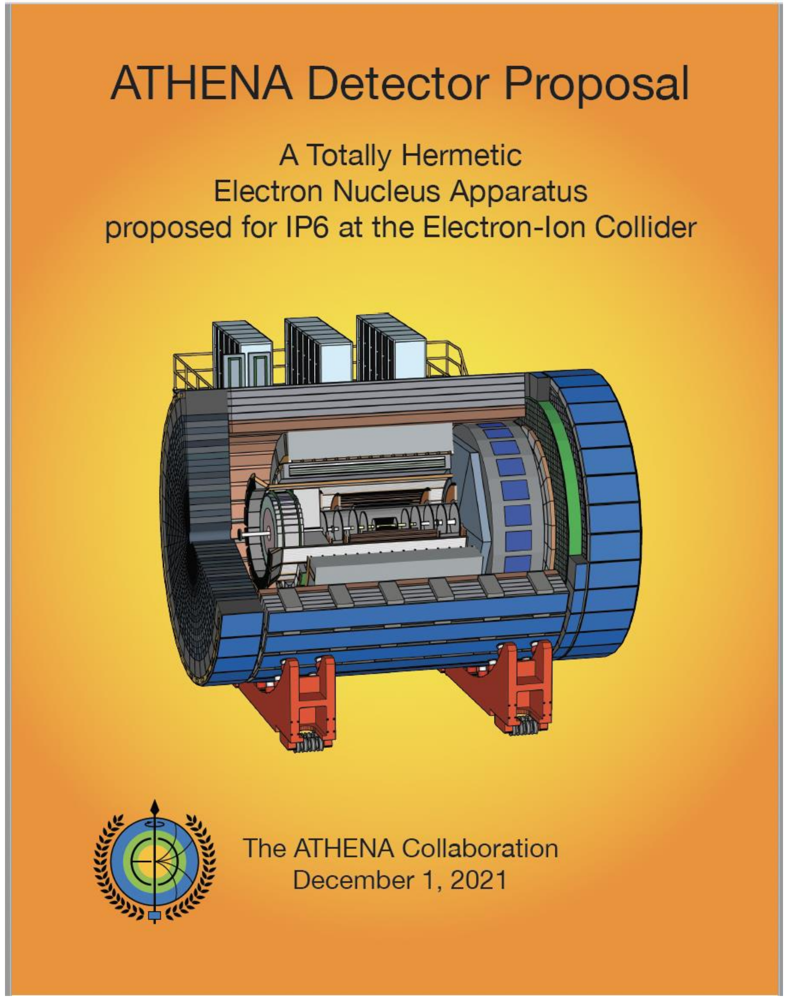
India Group Experience – Experiment (selected)

Other experimental projects

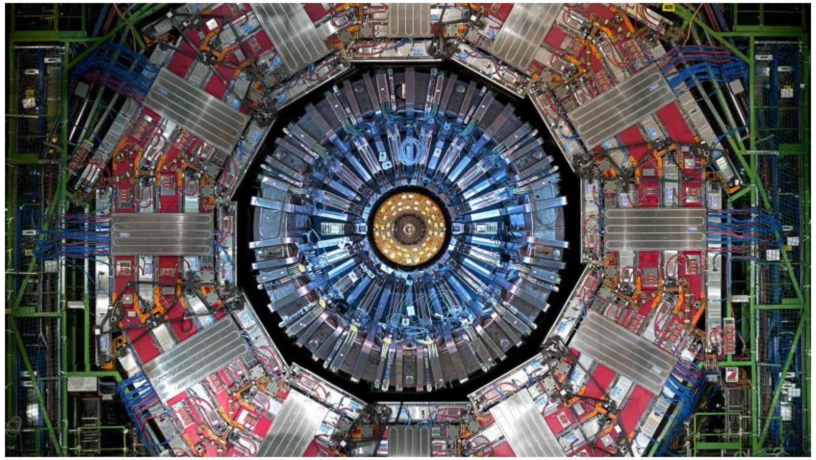
CBM – FAIR, GSI



BELLE - KEK



CMS, LHC, CERN



India Group Experience – THEORY (selected)

Group	EIC related work	EIC related publications recent work
Aligarh Muslim University Raktim Abir et al.	Small-x physics Gluon Saturation at high energy Color Glass Condensate BK-JIMWLK equations TMD PDFs	Nucl. Phys. B953 (2020) 114961 Phys. Rev. D99 (2019) 094017 Phys. Rev. D97 (2018) 054009 Phys. Rev. D95 (2017) 074035 Phys. Lett B748 (2015) 467-471
Tata Institute of Fundamental Research Nilmani Mathur et. al.	Lattice QCD method to calculate: 1. Quark and gluon angular momenta including their orbital angular momentum components 2. Parton distribution functions, generalized parton distribution functions as well as various distribution amplitudes 3. To probe high density regimes of QCD in an effective way.	Physical Review D 62 (11), 114504 (2000) : This is the first lattice QCD calculation on quark gluon angular momenta.
Indian Institute of Technology Bombay Asmita Mukherjee et al.	Single Spin Asymmetry for J/Ψ and jet production at EIC Can help to understand the gluon Sivers function Theoretical estimate of asymmetry in NRQCD including Color singlet and Color octet contributions Maximal asymmetry by maximizing Sivers function saturating the positivity bound	R. Kishore, A. Mukherjee, S. Rajesh; PRD 101 (2020), 5 054003
Indian Institute of Technology Delhi Tobias Toll et al.	Small-x physics, Gluon Saturation at high energies. Exclusive diffraction with Sartre, Measuring the spatial gluon distribution with Sartre Direct probe for virtual particles	B. Sambasivam, T. Toll, T. Ullrich; Phys.Lett.B 803 (2020) 135277 S. Anand, T. Toll; Phys.Rev.C 100 (2019) 2, 024901 T. Toll, T. Ullrich; Comput.Phys.Commun. 185 (2014) 1835-1853 T. Toll, T. Ullrich; Phys.Rev.C 87 (2013) 2, 024913

India Group Experience – THEORY (selected)

Single Spin Asymmetry for J/Ψ and jet production at EIC

Quark orbital angular momentum from lattice QCD

Spin-flip gluon GTMD $F_{1,2}$ at small-x

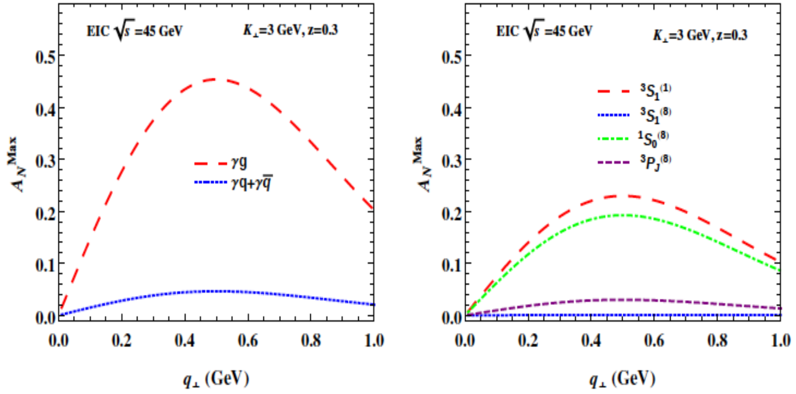


FIG. 2: (color online) Maximized Sivers asymmetry in $e+p^\uparrow \to J/\psi + \text{jet} + X$ process as a function of $q_\perp$ at EIC $\sqrt{s} = 45$ GeV. The Sivers function is saturated by adopting $\mathcal{N}_g(x) = 1$ and $\rho = 2/3$ for the parametrization of Sivers function given in Eq.(16). Left panel: for gluon and quark (antiquark) initiated subprocesses contribution to the asymmetry. Right panel: for different CS and CO states contribution to the maximum asymmetry.

TABLE I. The breakdown of quark angular momentum.

	J_q	$\frac{1}{2}\Sigma$	L_q
$u+d(CI)$	0.44(7)	0.31(4)	0.13(7)
$u/d(DI)$	−0.047(12)	−0.062(6)	0.015(12)
s	−0.047(12)	−0.058(6)	0.011(12)
$u+d+s(DI)$	−0.14(4)	−0.18(3)	0.041(36)
Total	0.30(7)	0.13(6)	0.17(6)

Analytically solved the small-x evolution equation for spin-flip Gluon GTMD. S. Agrawal, N. Vasim, R. Abhir arXiv: 2312.04132

NRQCD framework
Help understand the gluon Sivers function
R. Kishore, A. Mukherjee, S. Rajesh; PRD 101 (2020), 5 054003

Quark orbital angular momentum ~ 34% of the proton spin; predict gluon angular momentum is ~ 40% of the proton spin. N. Mathur et al., PRD 62 (2000) 114504

Indian EIC-THEORY group part of theory alliance

[Submitted on 23 May 2023]

The case for an EIC Theory Alliance: Theoretical Challenges of the EIC

Raktim Abir, Igor Akushevich, Tolga Altinoluk, Daniele Paolo Anderle, Fatma P. Aslan, Alessandro Bacchetta, Baha Balantekin, Joao Barata, Marco Battaglieri, Carlos A. Bertulani, Guillaume Beuf, Chiara Bissolotti, Daniël Boer, M. Boglione, Radja Boughezal, Eric Braaten, Nora Brambilla, Vladimir Braun, Duane Byer, Francesco Giovanni Celiberto, Yang-Ting Chien, Ian C. Cloët, Martha Constantinou, Wim Cosyn, Aurore Courtoy, Alexander Czajka, Umberto D'Alesio, Giuseppe Bozzi, Igor Danilkin, Debasish Das, Daniel de Florian, Andrea Delgado, J. P. B. C. de Melo, William Detmold, Michael Döring, Adrian Dumitru, Miguel G. Echevarria, Robert Edwards, Gernot Eichmann, Bruno El-Bennich, Michael Engelhardt, Cesar Fernandez-Ramirez, Christian Fischer, Geofrey Fox, Adam Freese, Leonard Gamberg, Maria Vittoria Garzelli, Francesco Giacosa, Gustavo Gil da Silveira, Derek Glazier, Victor P. Goncalves, Silas Grossberndt, Feng-Kun Guo, Rajan Gupta, Yoshitaka Hatta, Martin Hentschinski, Astrid Hiller Blin, Radja Boughezal, Timothy Hobbs, Alexander Ilyichev, Jamal Jalilian-Marian, Chueng-Ryong Ji, Shuo Jia, Zhong-Bo Kang, Bishnu Karki, Weiyao Ke, Vladimir Khachatryan, Dmitri Kharzeev, Spencer R. Klein, Vladimir Korepin, Yuri Kovchegov, Brandon Kriesten, Shunzo Kumano, Wai Kin Lai, Richard Lebed, Christopher Lee, Kyle Lee, Hai Tao Li, Jifeng Liao, Huey-Wen Lin, Keh-Fei Liu, Simonetta Liuti, Cédric Lorcé, Magno V. T. Machado, Heikki Mantysaari, Vincent Mathieu, Nilmani Mathur, Yacine Mehtar-Tani, Wally Melnitchouk, Emanuele Mereghetti, Andreas Metz, Johannes K.L. Michel, Gerald Miller, Hamlet Mkrtchyan, Asmita Mukherjee, Swagato Mukherjee, Piet Mulders, Stéphane Munier, Francesco Murgia, P. M. Nadolsky et al. (71 additional authors not shown)

We outline the physics opportunities provided by the Electron Ion Collider (EIC). These include the study of the parton structure of the nucleon and nuclei, the onset of gluon saturation, the production of jets and heavy flavor, hadron spectroscopy and tests of fundamental symmetries. We review the present status and future challenges in EIC theory that have to be addressed in order to realize this ambitious and impactful physics program, including how to engage a diverse and inclusive workforce. In order to address these many-fold challenges, we propose a coordinated effort involving theory groups with differing expertise is needed. We discuss the scientific goals and scope of such an EIC Theory Alliance.

Comments: 44 pages, ReVTeX, White Paper on EIC Theory Alliance
Subjects: **High Energy Physics - Phenomenology (hep-ph)**; High Energy Physics - Experiment (hep-ex)
Cite as: arXiv:2305.14572 **[hep-ph]**
(or arXiv:2305.14572v1 **[hep-ph]** for this version)
https://doi.org/10.48550/arXiv.2305.14572

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5. Department of Physics, Indian Institute of Technology Delhi, India

Indian Detail Project Report - ePIC

Depends on expertise, facility, synergy with existing experiments and Indian industry

Currently expertise and facility with hardware available with

- National Institute of Science Education and Research
- Institute of Physics
- Jammu University
- Banaras Hindu University
- Central University of Karnataka (DAQ)

(In near future)
- Indian Institute of Science Education and Research Mohali*
- Delhi University*

- Indian Institute of Science Education and Research, Tirupati
- Indian Institute of Technology Bombay

Current links with industry partners (selected)

भारत इलेक्ट्रॉनिक्स BHARAT ELECTRONICS

SCL Semi-Conductor Laboratory
Department of Space, Government of India

mp Micropack Private Limited

Some existing facilities

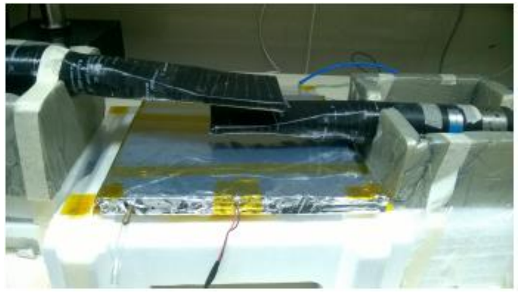
NISER

Gas Mixture System


NIM and VME Electronics

Clean Room ISO-5, 200 sqft
With X-ray irradiation facility


RPC being tested



Gas mixing

BHU

Trigger setup

Electronics

IOP

Clean Room

Probe Station

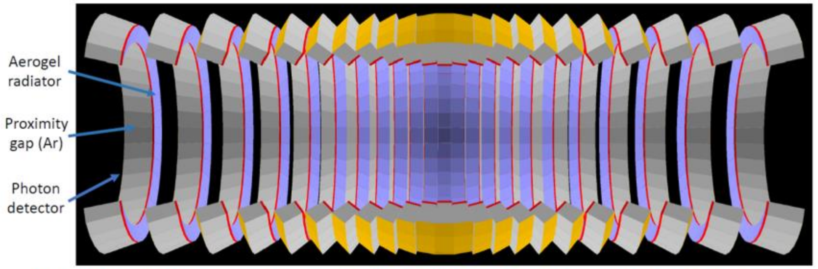
CV measurements

CAEN HV supply

Jammu University

Synergy with hardware efforts in existing Experiments (selected)

ALICE3 RICH

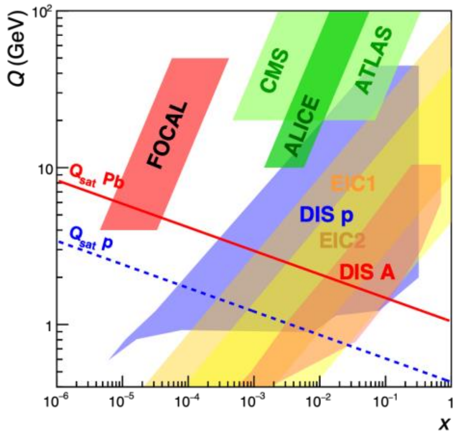


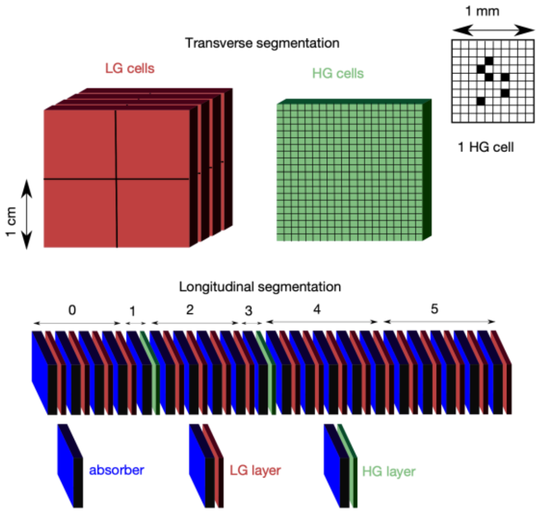
Ref: ALICE 3 RICH Updates on simulations and preliminary test beam results by N. Nicassio and M. N. Mazziotta in ALICE Week, October 16-20, 2023

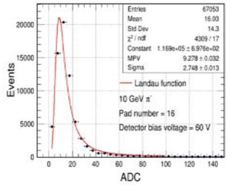
Identify hadrons (e, π, K, p) in $0 < \eta < 2$:

- π/e upto $p \cong 2.0\ GeV/c$
- k/π upto $p \cong 10.0\ GeV/c$
- p/π upto $p \cong 16.0\ GeV/c$
- Time resolution 1 ns - 50 ps
- Custom production of **SiPMs.**
- Angular resolution ~ 15 mrad
- Refractive Index: n~1.03
- Aerogel (hydrophobic)

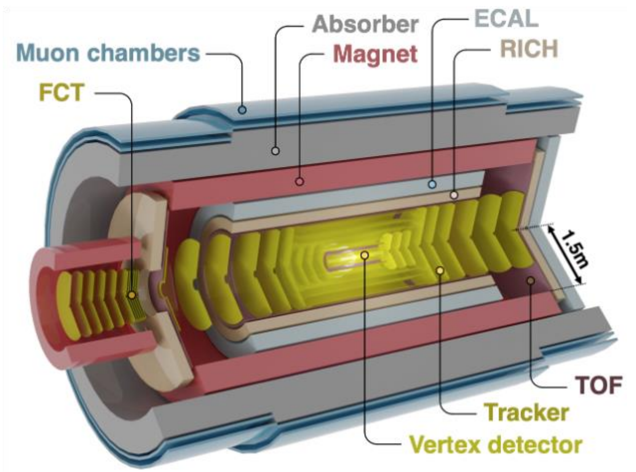
ALICE FOCAL





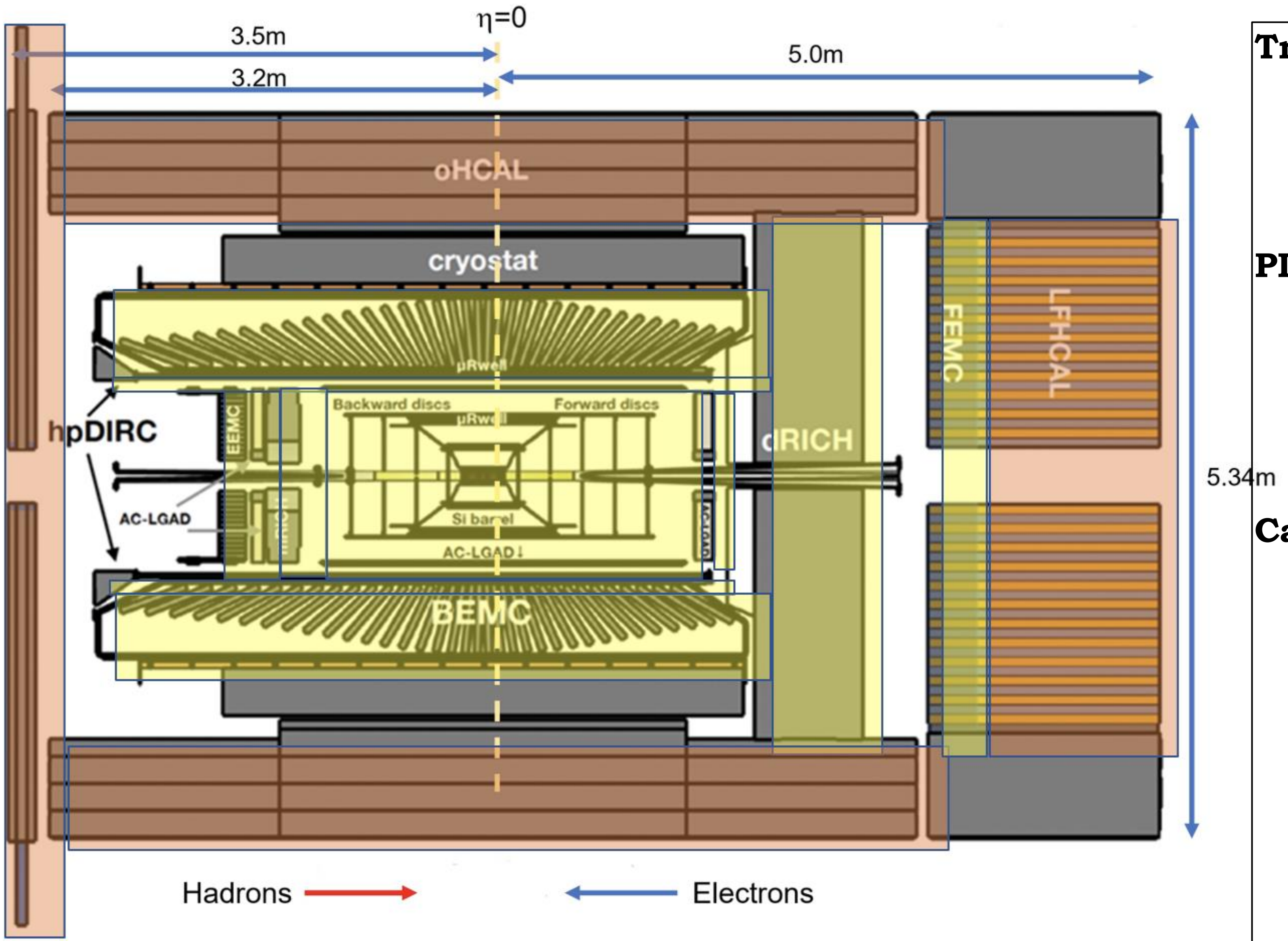


Muon detection (ALICE3/CBM)



- MuonID is 100% efficient in p_T > 1.5 GeV/c,
- pion and kaon rejection factors of 50-100.
- **SiPM based readouts**

ePIC DETECTOR SYSTEM



Tracking:
- New 1.7T solenoid
- Si MAPS Tracker
- MPGDs (□RWELL/□Megas)

PID:
- hpDIRC
- mRICH/pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

Calorimetry:
- SciGlass/Imaging Barrel EMCal
- PbWO4 EMCal in backward direction
- Finely segmented EMCal +HCal in forward direction
- Outer HCal (sPHENIX re-use)
- Backwards HCal (tail-catcher)

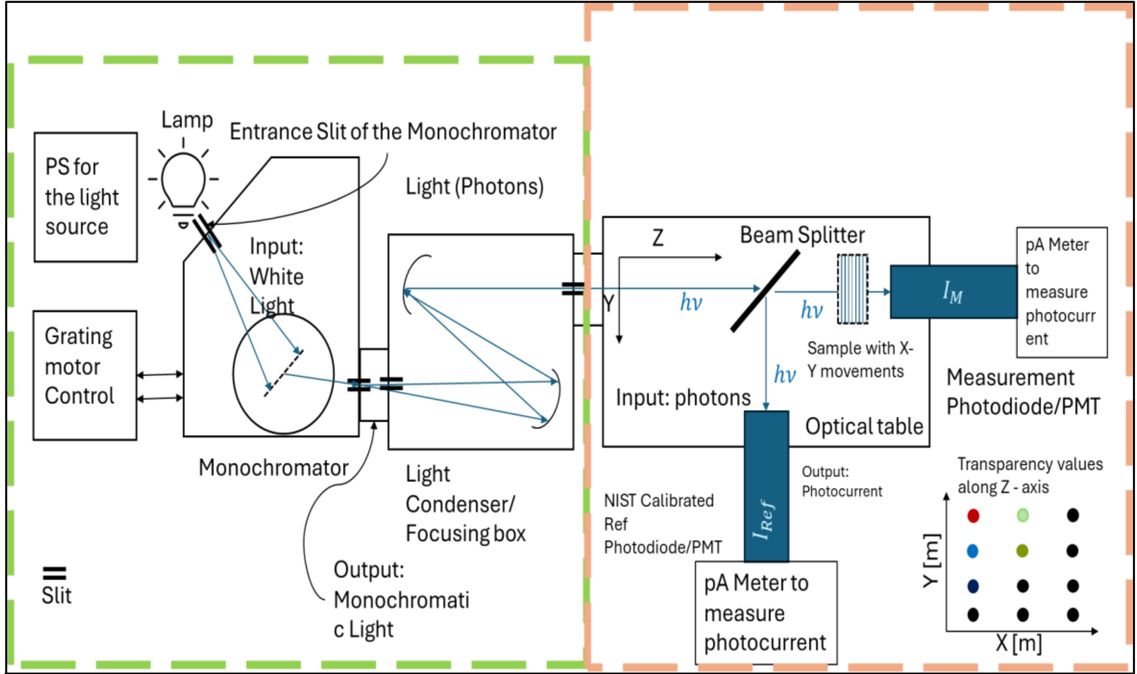
Indian Group Detail Project Report

Particle identification - Dual-radiator RICH - Aerogel + SiPM

Scopes

1. **Aerogel characterization**
   I. **Study of refractive index uniformity**
   II. **Transmittance, reflectance**
   III. Raleigh scattering in UV domain, chromaticity,
   IV. Aging effects due to water absorption: difference in response between different size and thickness of aerogel blocks
2. **SiPM characterizations**
   I. **PDE (normal value ~ 40%)**
   II. **Dark count Suppression**
   III. Timing studies
3. **Technical studies**
   I. Design aspects of the gas tight vessel
   II. Integration in the existing detector, routing of service lines etc
   III. Integration with radiator
4. **Simulation studies**

Typical aerogel characterization set-up



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

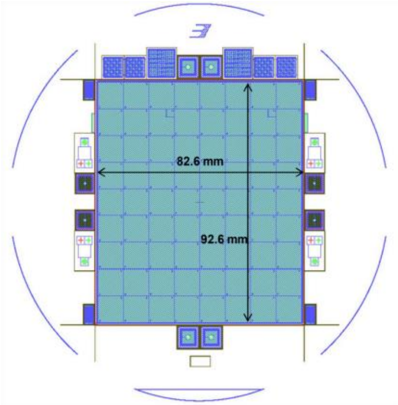
$$Transparency = \left[\frac{\{(I_M - I_{MDC})/(I_{Ref} - I_{RefDC})\}_{With\ Obj}}{\{(I_M - I_{MDC})/(I_{Ref} - I_{RefDC})\}_{WO\ Obj}}\right] \times 100\%$$

Indian Group Detail Project Report

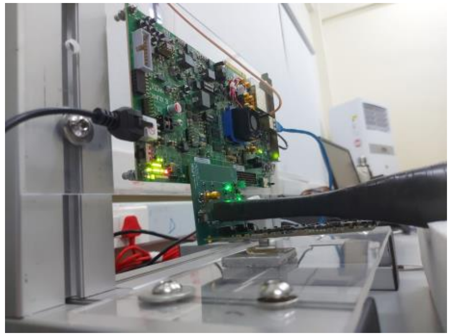
Zero degree Calorimeter (ZDC) – Silicon pads and SiPMs

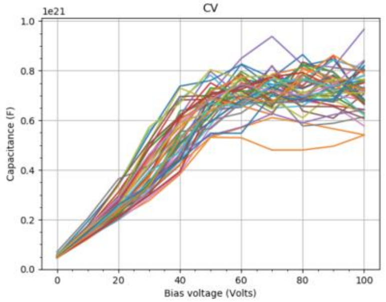
ePIC plans

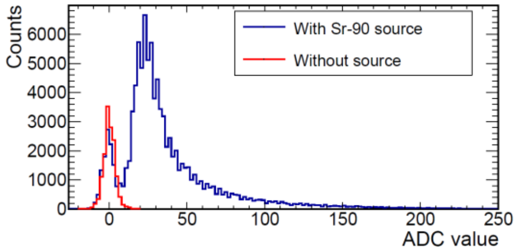
The ZDC is planned to detect neutrons as well as photons in the far forward region with the energy range from 100 MeV to 40 GeV. The proposed ZDC design is a composition of four different calorimeter types starting with crystal ($PbWO_4$ / LYSO) calorimeter, Sampling calorimeter based on an alternating layer of Tungsten and Silicon and then Lead (Pb) and scintillating fiber (instrumented using SiPM) based calorimeter (Hadron calorimeter or HCAL). In the ZDC sampling calorimeter, it is proposed to use **p-type Si pad array** (8 × 9 or 8 × 8) with each pad size of (1 × 1 cm^2).

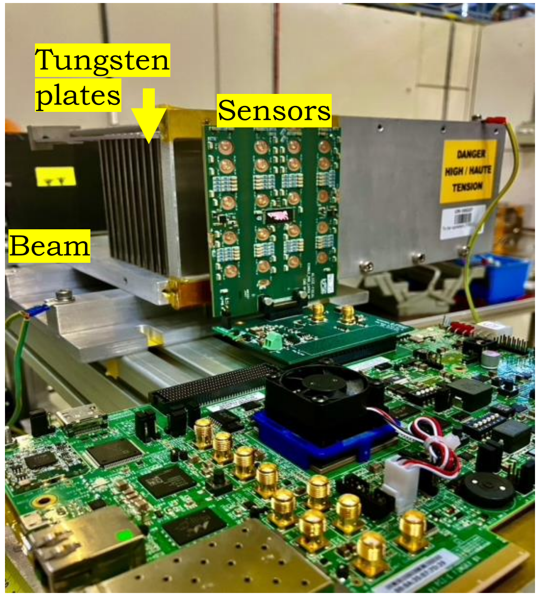


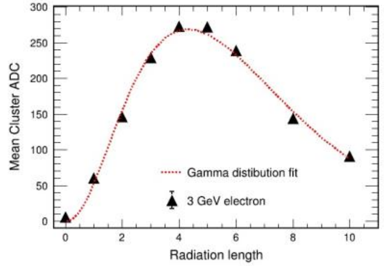
Si-pad detectors @ BEL and tested at NISER and CERN PS 2023

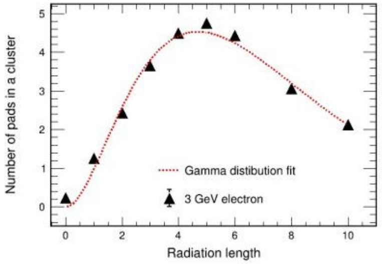












Indian Group Detail Project Report

SiPM

What is available in Indian industry – willing to do further R&D

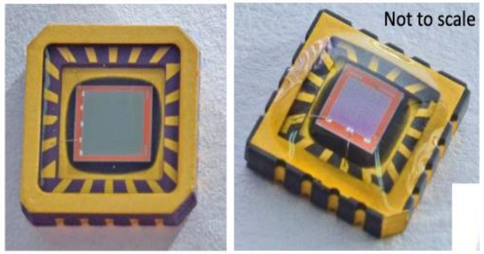
Sr. No	Parameter (targeted by design)	Specifications		
		BARC/SCL	SCL	BEL
1	Effective active area	1.5 & 3 mm^2	1.5 mm^2	3.3 mm^2
2	Micro-cell count	676 & 2704	1156	4836
3	Micro-cell size	50 μm^2	35 μm^2	
4	Micro-cell fill factor	20% & 75%	61%	55%
5	Capacitance (Cathode - anode)	1000 pF	-	~100pF/cell and (500 pF @25.5V)
6	Recharge time constant	120 ns – 150 ns		-
7	Spectral response range	350 nm – 900 nm		
8	Peak sensitivity wavelength	~ 500 nm	~ 510 nm	420 – 450 nm
9	Photon detection efficiency	-	-	-
10	Breakdown voltage (V_{BD})	22 V	15 V - 21 V	23 V
11	Overvoltage range (OV)	2 V – 3 V	3 V	2 V – 5 V
12	Dark count rate	~ 500 kHz (@ V_{BD}+2.0 V and 0.5 p.e. thr.	20 Hz/ μm^2 at 1V OV	-
13	Gain	2 x 10^6 @ V_{BD}+1V	~10^5 - 10^6	~5.2 x 10^5 @V_{BD}+2V
14	V_{BR} temp. coefficient	20.0 mV/ ºC	15.0 mV/ºC	-
15	Package type	LCC* 16, 20 pin	TO-8/6 pin	On PCB
16	Package dimension	~ 3.5 mm^2		
17	Dark current	< 5 nA/cm^2 @ 20V	< 10 nA/cm^2	-
18	Quenching resistor (R_q)	300-500 kΩ		R_{eq} = 6.6 kΩ and R_q = ~ 32 MΩ
19	Cross-talk	< 5 % @V_{BD}+2.0 V	-	-

*Lead-Less Chip Carriers (LCC)

Technical Specifications of SiPM

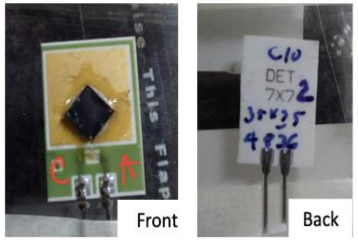
2

Bhabha Atomic Research Center (BARC), Mumbai

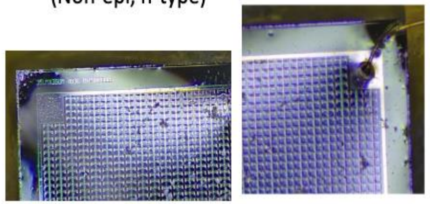


BARC/SCL
(epi., p-type)

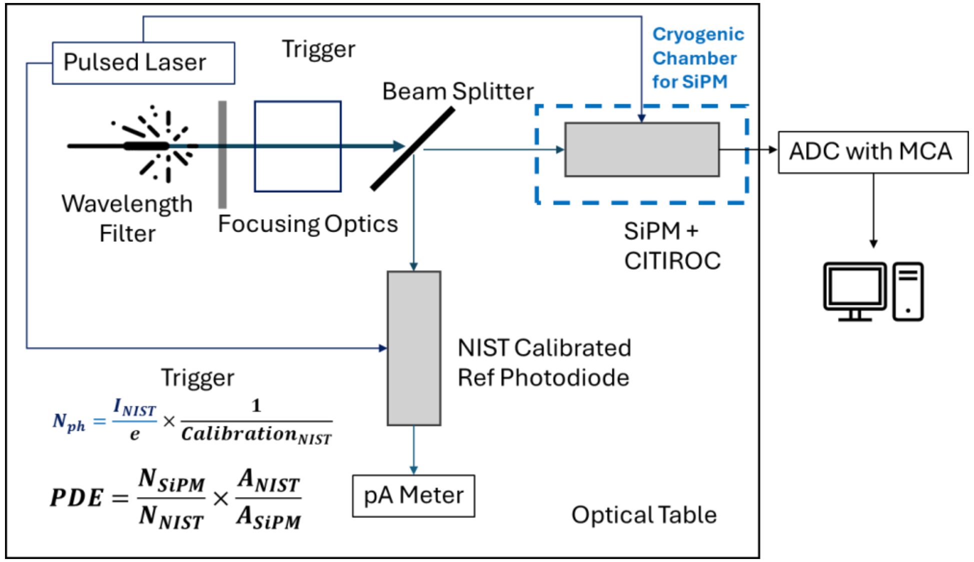
SCL sample
(epi., p-type)



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



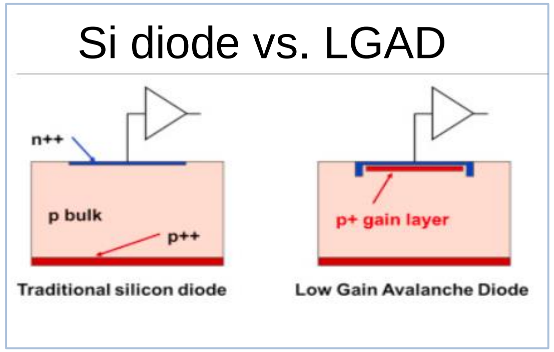
Typical SiPM characterization set-up

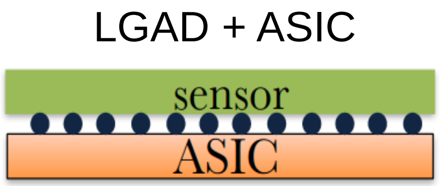


Indian Group Detail Project Report (Preliminary ideas)

Time of Flight – AC-LGAD

- Focal like pad design: Develop LGAD and SiPM in India
- LGAD - slight modification in Si diode
  - Work with BEL Bangalore (6” wafer), and SCL Mohali (8” wafers, 180 nm process)
- Simulations using
  - TCAD (Process and Geometry), MC (Garfield++ and Allpix^2) on monolithic detectors with gain as LGAD
- LGADs require dedicated ASIC





SiPM produced on 6” wafers at SITAR, India

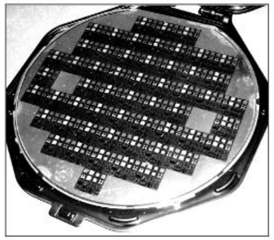


Fig. 1 Fabricated wafer showing SiPMs

Possible contributions to DAQ

DAQ system will read digitized data containing spatial, temporal or charge information from a range of sub detector systems. The streaming readout technique, suppression of noise caused by dark currents from SiPM, as well as data reduction to write all collision data on tape, are the main challenges foreseen in DAQ design. Data reduction, employing machine learning methods implemented on a FPGA, for example, offers significant scope for R & D.

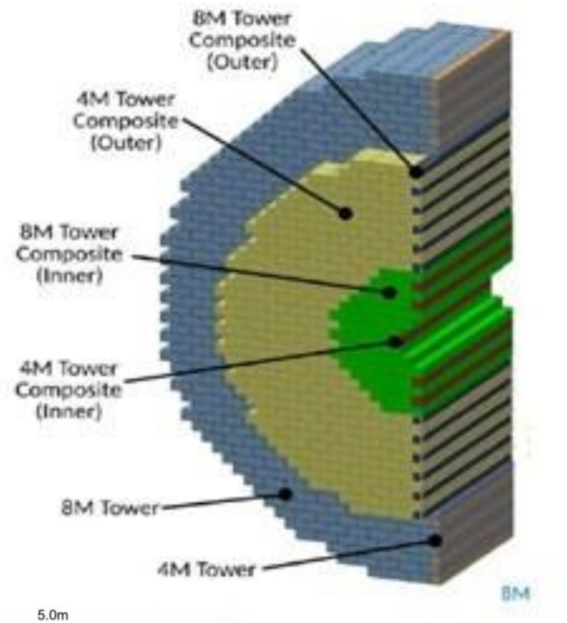
Indian group can also contribute in the implementation of software for various operations throughout the DAQ chain, including slow controls.

Suggestions from ePIC Management

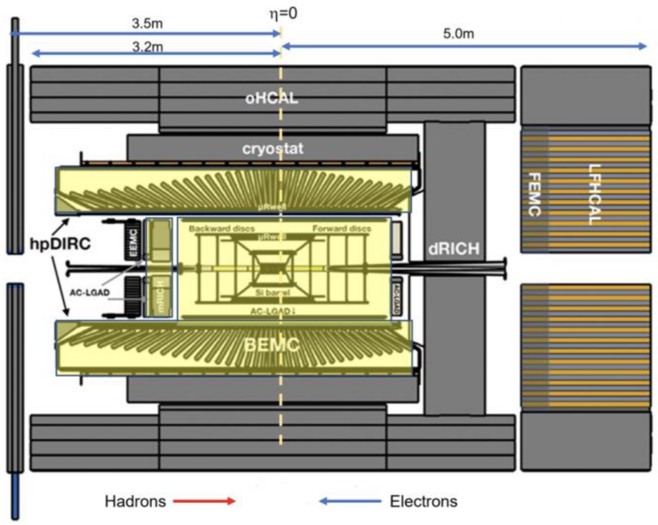
(1) NISER is a member of the dRICH DSC, so this is certainly welcome

(2) Become one of the two production lines for the forward EM calorimeter. Part of EIC-Asia in collaboration with China/Fudan colleagues

W-powder / Scintillating Fiber (WScFi) technology for the default choice of pECal.



(3) Take part in module assembly and testing of forward AC-LGAD detector. Part of EIC-Asia in collaboration with Taiwan colleagues



(4) Lead the infrastructure how to integrate the reference time T_0 of the AC-LGAD in the streaming readout model. T_0 is critical for the streaming readout assumption in ePIC - DAQ

Summary

- Strong community support for Indian groups being part of EIC
- EIC features prominently in several places of Indian long range plan document – MSV-NP 2035
- Indian experimental groups (20+2) and theory groups (4) have scientific interest and expertise in the physics of EIC
- Based on science interest, expertise, facilities and Indian industry, Indian groups formulating a DPR with following potential contribution areas to ePIC

  - RICH
  - ~~ZDC~~ Forward EMCal
  - SiPMs
  - TOF (AC-LGAD*) Forward
  - Physics and detector simulations
  - Data Acquisition

Workshop can be used to arrive at a consensus on hardware contributions from ePIC-India

ATHIC meeting to be held between Jan 10-20, 2025 at NISER. We can have one/two days dedicated discussion in EIC

Thanks to ePIC and ePIC-India