Indian participation in Electron Ion Collider

Bedanga Mohanty (NISER) on
behalf of Indian group

Outline:
Indian participation in QCD based physics program (Selected)
Indian participation Electron Ion collider (tentative)

Science Goal – I

What is the phase diagram of strong interactions ?

-- Search for the critical point

Physics analysis
Detector R&D
Grid Computing

RHIC
LHC
FAIR
EIC

Science Goal – II

What are the properties of de-confined state of quarks and gluons ?

--- Establish the perfect fluid

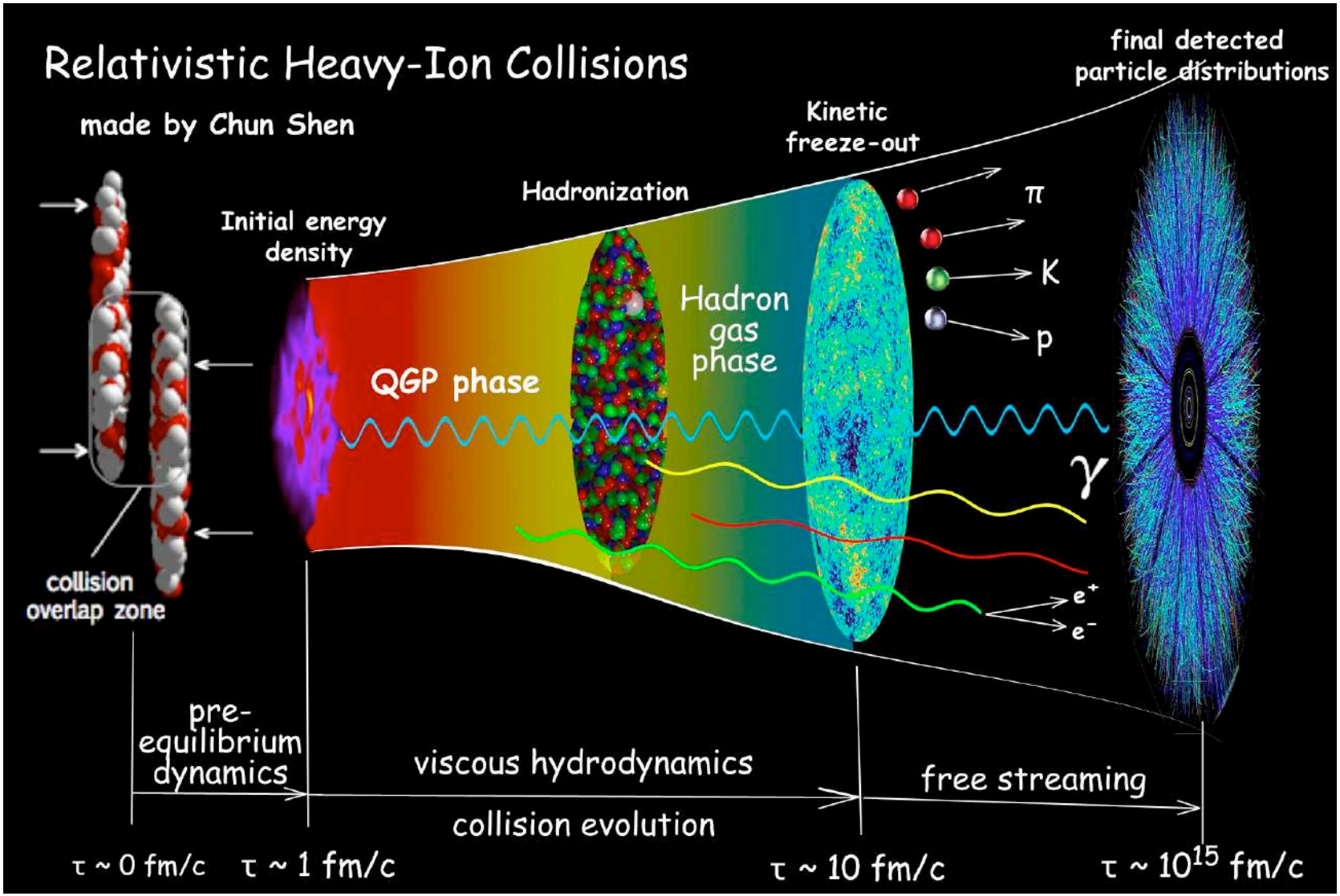
Science Goal – III

Initial conditions – Where does Saturation of gluon density happens ?

-- Search for CGC state of matter

Some of the science goals that various experimental groups are pursuing

Heavy-Ion Collisions



Indian groups: HI collisions experiment

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

Contributions

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

Recent Indian detector highlights

Photon Multiplicity Detector : STAR @ RHIC
ALICE @ LHC

Publications:
Physical Review Letters 95 (2005) 062301
Physical Review C 73 (2006) 034906
Nuclear Physics A 832 (2010) 134
NIM A 499 (2003) 751
NIM A 488 (2002) 131
Eur.Phys.J. C75 (2015) no.4, 146

Muon Spectrometer : ALICE @ LHC

Publications:
Physics Letters B 734 (2014) 314
JHEP 1402 (2014) 073
Physical Review Letters 111 (2013) 162301
Physical Review Letters 109 (2012) 112301
Physical Review Letters 109 (2012) 072301
Physics Letters B 708 (2012) 265
Physics Letters B 704 (2011) 442
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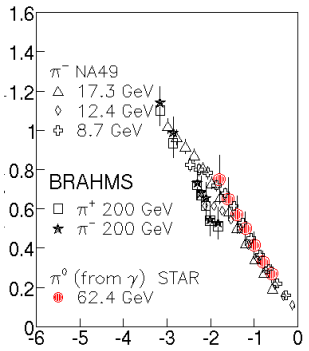
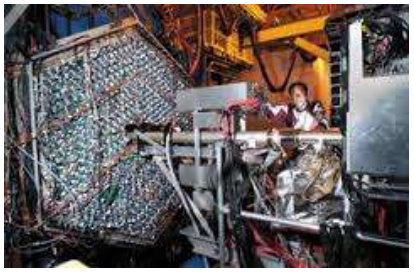
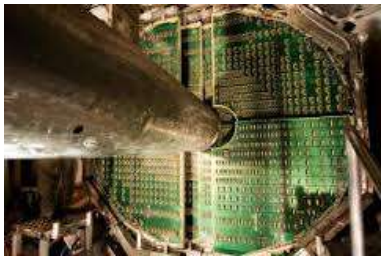
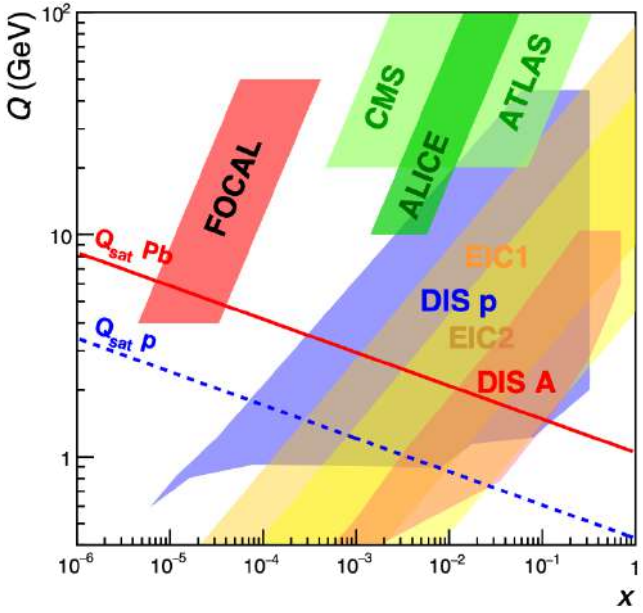




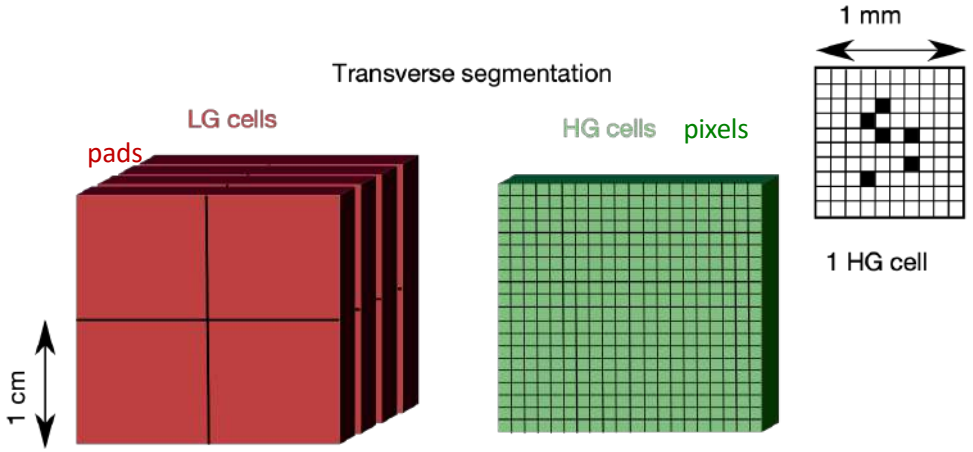


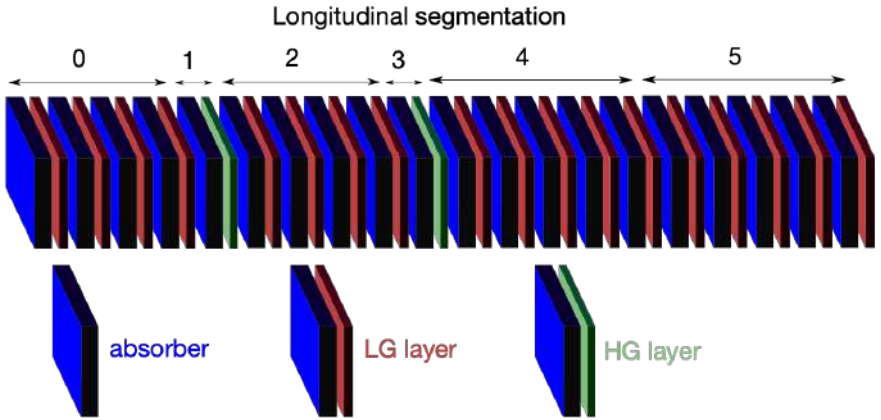
EM probes - kinematic coverage



x-Q^2-Sensitivity

$$x \approx \frac{2p_T}{\sqrt{s}}\exp(-y)$$





20 layers:
W (3.5mm ≈ 1 X_0) + Si-sensors

hybrid design (2 types of sensors)

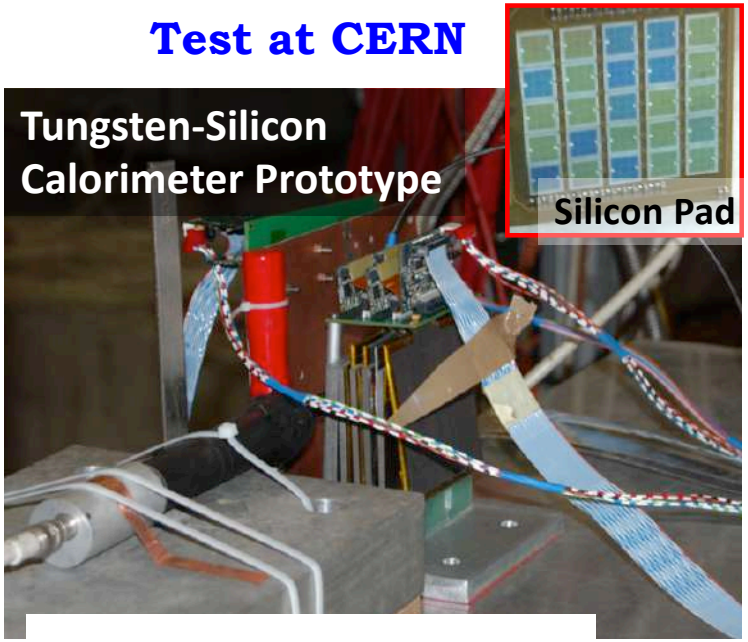
- **Si-pads** (≈ 1 cm²):
  energy measurement, timing(?)
- **CMOS pixels** (≈ 30x30 μm²):
  two-shower separation, position resolution
- at $z \approx 7$m: $3.2 < \eta < 5.8$

Silicon Sensors:

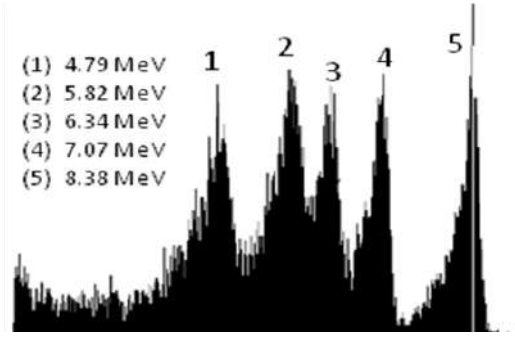
ALICE-India with BEL, Bangalore

Test at India

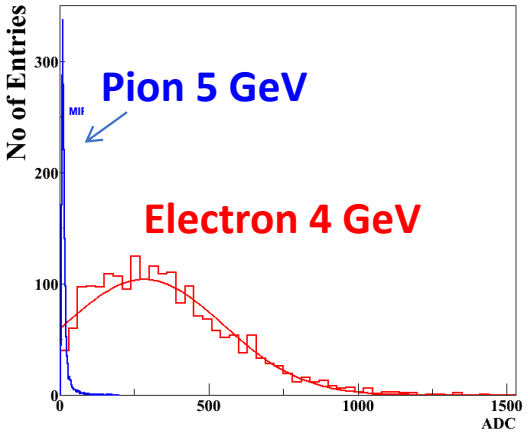
Test at CERN



Thorium Alpha Spectra



ALICE UPGRADE



Experimental participation to achieve science goals

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

Also gives an idea of the current involvement and future commitment of the group ….
This is taken into account while distributing core responsibilities to various groups for EIC

Vibrant high energy theory community

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

EIC-India participation

Institutes in Institutional Board from India in EIC

Sl No	Institutes	Area
1	Aligarh Muslim University	Theory
2	University of Jammu	Experiment
3	National Institute of Technology, Jalandhar	Theory
4	Saha Institute of Nuclear Physics	Experiment
5	Harischandra Research Institute	Theory
6	Indian Institute of Science Education and Research, Tirupati	Experiment
7	Panjab University	Experiment
8	Akal University	Experiment
9	Malaviya National Institute of Technology Jaipur	Experiment
10	Tata Institute of Fundamental Research	Experiment
11	National Institute of Science Education and Research	Experiment

Sl No	Institutes	Area
12	Indian Institute of Technology Bombay	Theory & Experiment
13	Indian Institute of Science Education and Research, Berhampur	Experiment
14	The Institute of Mathematical Sciences	Theory
15	Bhabha Atomic Research Centre	Experiment
16	Indian Institute of Technology Indore	Experiment
17	Institute of Physics	Experiment
18	Central University of Karnataka	Experiment
19	Indian Institute of Technology Patna	Experiment
20	Banaras Hindu University	Experiment
21	Indian Institute of Technology Delhi	Theory
22	Ramakrishna Mission Residential College, Narendrapur, Kolkata	Experiment

EIC India is expected to be led by younger faculty who were trained at RHIC and LHC

Expression of Interest (EOI) Progress …

Every Thursday, 4:30 PM the experimental group discusses on three broad aspects related to our participation and EOI formulation.

(a) Detector building and testing

(b) Detector related simulations

(c) Physics analysis and related simulations

- Theory group colleagues are invited to participate
- Abhay is also a regular participant in our meetings

Summary so far ..

Interest to participate in

- Vertex Tracking Detector and Hadron PID Detector
- Physics simulations related to above detector systems, dominantly related to heavy flavor production
- Detector simulations

We are interested in contributing to the Software Working Group requesting assistance with cross-validation. One round of meetings already carried out last Thursday with participation of Markus, Douglas and Andrea

EOI Progress ..

Area	Interest for Primary Participation	Interest for Secondary active Participation (due to current time, manpower, resources constraints)	Facility (existing)	Expertise (existing)
Detector Silicon based Tracker Hadron PID	University of Jammu Banaras Hindu University *No other major hardware commitments* We are identifying possible collaboration with outside India collaborating institutes	Indian Institute of Technology Indore Institute of Physics National Institute of Science Education and Research	Facility: Clean Rooms; Characterization setups; Electronics for testing.	Expertise: Detector slow control Si-sensors, proportional counters, RPC, GEM. Experience: ALICE, STAR, WA98
Physics and Detector Simulations	**Panjab University, Indian Institute of Technology Bombay**, Central University, Karnataka, Indian Institute of Science Education and Research, **Indian Institute of Technology Patna**, **MNIT Jaipur** and **RKMRC Narendrapur, Kolkata**	University of Jammu Banaras Hindu University Indian Institute of Technology Indore Institute of Physics National Institute of Science Education and Research, , **Indian Institute of Technology Delhi**	Computing clusters or basic computing facility exists	GEANT 3 and 4 Correlation analysis Spectra analysis Fast simulations Event generators

** Most institutes have possibility of taking Masters students, PhD scholars and PDF. Later two require funding. Some are hiring new faculty.*

** Institutes in Bold have confirmed their interests for participation in Software Group Call for help*

Some existing facilities

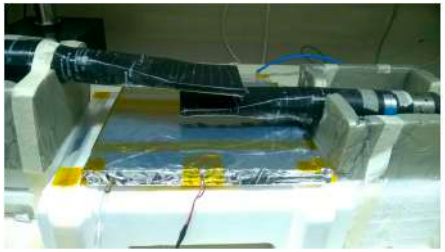
NISER

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

EIC-India-Theory

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.	First principles 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

EIC-India-Theory

R. Kishore, **A. Mukherjee**, S. Rajesh; PRD 101 (2020), 5 054003

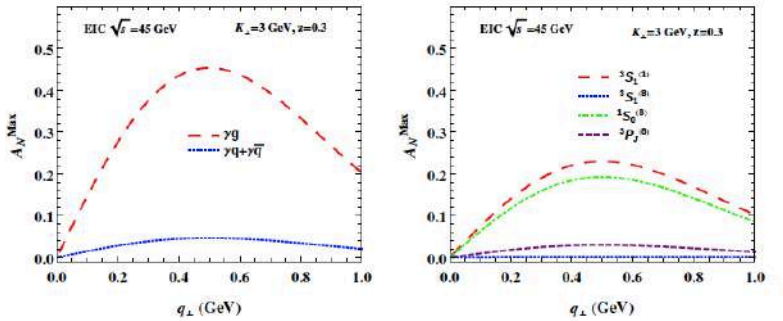
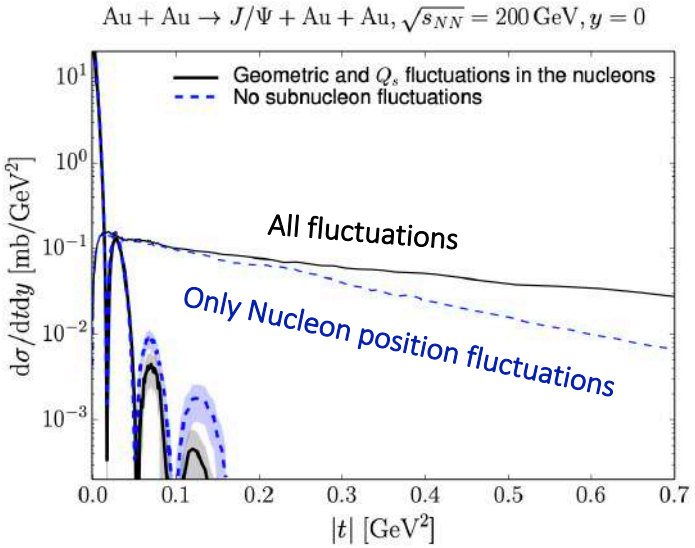


FIG. 2: (color online) Maximized Sivers asymmetry in $e + p^\uparrow \to J/\psi + \text{jet} + X$ process as a function of $q_\perp$ at EIC $\sqrt{s} = 45$ GeV. The Sivers function is saturated by adopting $\mathcal{N}_g(x) = 1$ and $\rho = 2/3$ for the parametrization of Sivers function given in Eq.(16).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

Incoherent Cross Section=
Gluon Fluctuations as a Direct Probe for Virtual Particles!

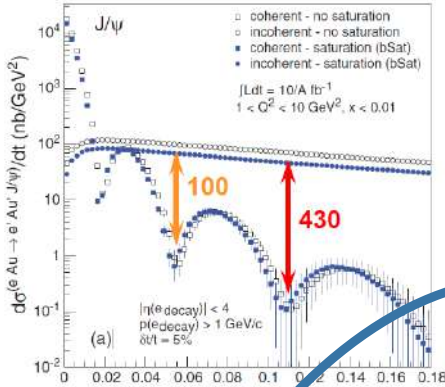
Two different fluctuations:
Nucleon Position + Subnucleon



Heikki Mäntysaari, Björn Schenke (Brookhaven Natl. Lab.) Phys.Lett. B772 (2017) 832-838

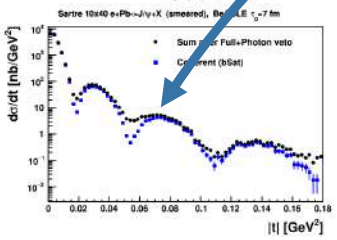
Measuring the Spatial gluon distribution with Sartre

Tobias Toll et al.

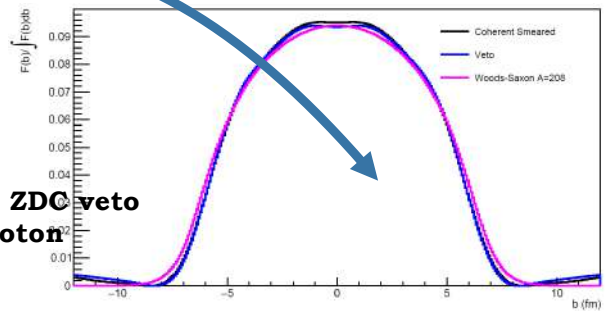


Fourier Transform

Reject Incoherent



Central + ZDC veto +photon



Plans

- Prepare and submit EOI timely
- Contribute to Software Group request for help on cross validation
- Contact outside Indian EIC institutes related to our hardware plans
- Formalize the EIC-India group and start planning for applying for funding to Indian funding agencies – DAE and DST

Thanks