Overview of future facilities for nucleon spin studies

Pacific Spin 2019

Miyazaki, Japan

August 30th, 2019

Yuji Goto (RIKEN)

Physics topics for future facilities

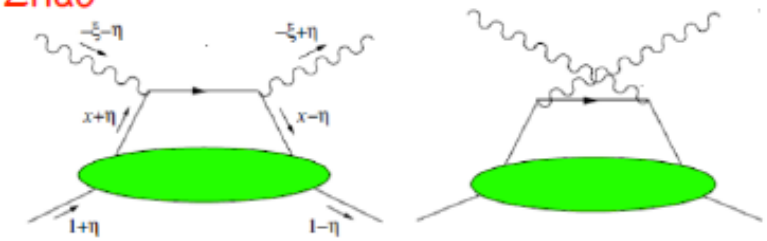
- Precision measurement of components of spin of the nucleon
  - Gluon polarization after discovery of positive ΔG at RHIC
  - At small-*x*
- TMD distributions & fragmentations
  - Drell-Yan vs SIDIS after pioneering measurements at COMPASS and RHIC
  - Gluon's TMD
- Transversity to tensor charge
- Tomography
  - GPD & GDA
- Extending our scope to measure components of mass of the nucleon

Future facilities

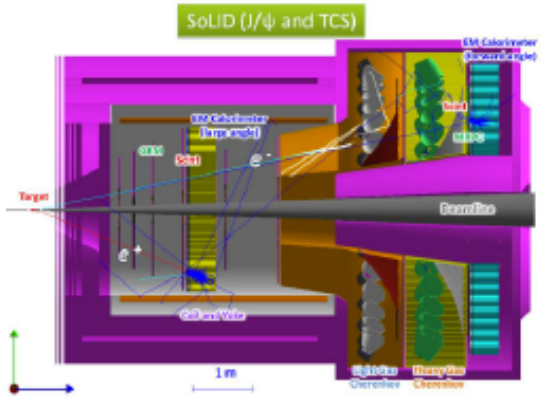
- Fixed target experiments
  - JLab 12GeV: SoLID
  - COMPASS++/AMBER (A. Bressan)
  - Fixed target at LHCb & ALICE
  - J-PARC (K. Tanaka, S. Sawada)
- Colliders
  - RHIC: STAR upgrade (A. Ogawa), sPHENIX (M. Liu)
  - NICA: SPD
  - EIC (USA)
  - EicC (China)

3D Nucleon Structire with the Solenoidal Large Intensity Device (SoLID) at JLab

Zhiwen Zhao



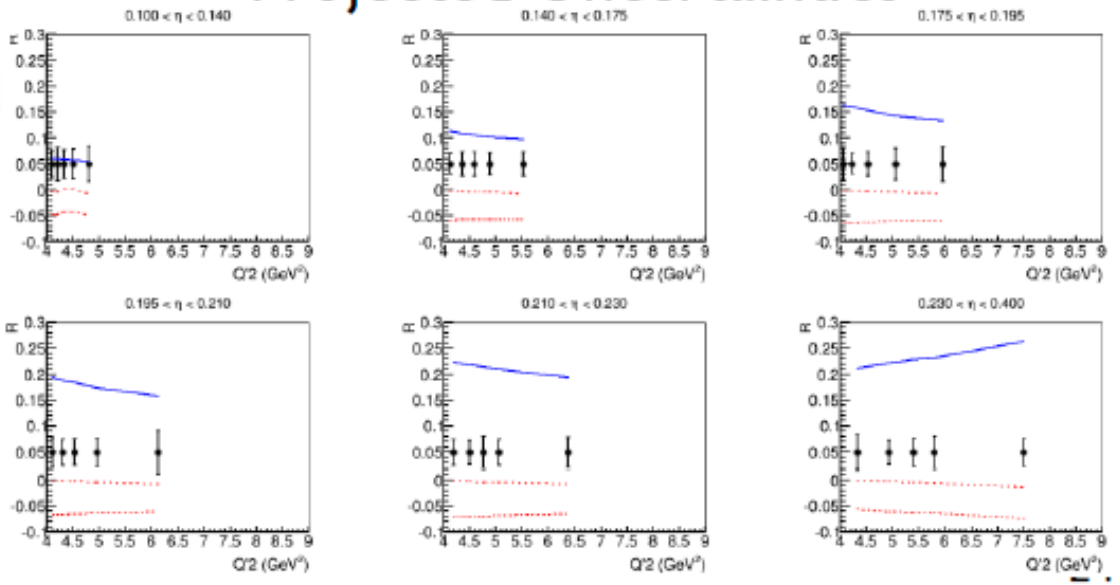
DVCS	$(\gamma' \rightarrow \gamma)$
TCS	$(\gamma \rightarrow \gamma')$
DDVCS	$(\gamma' \rightarrow \gamma')$



Lumi ~1e^{37}/cm^2/s (open geometry)

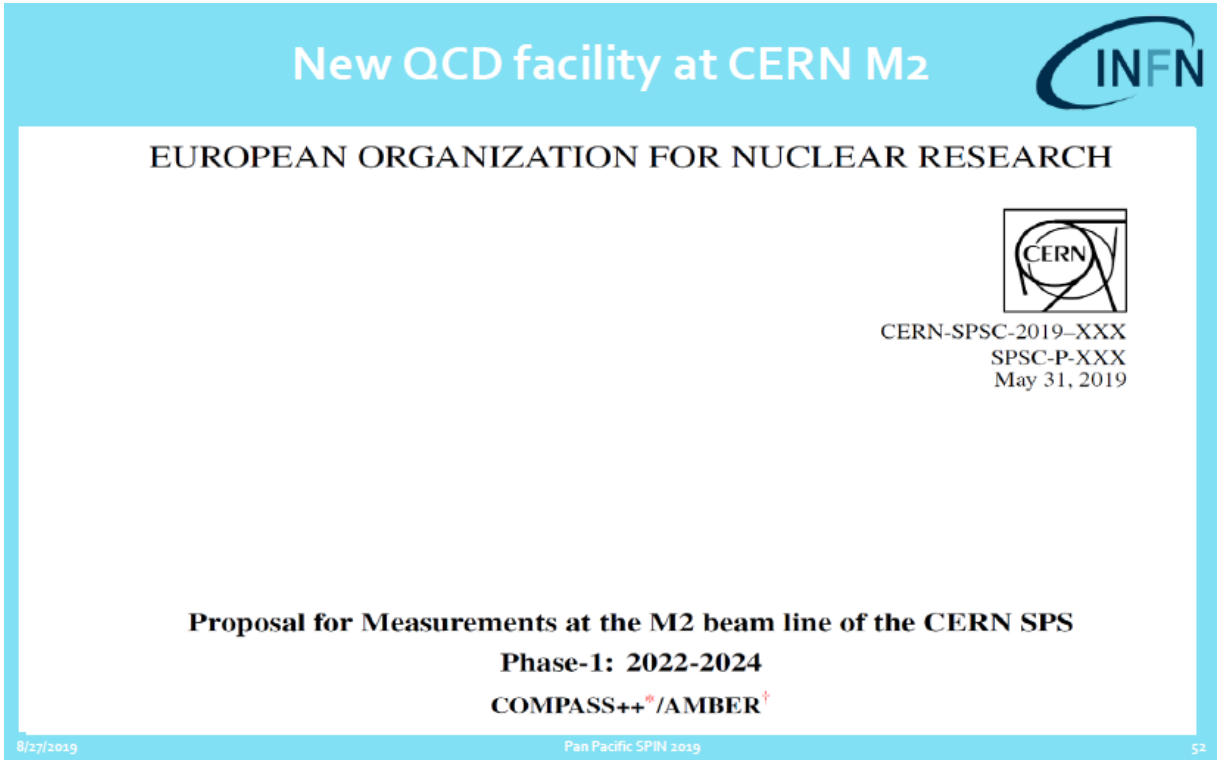
- 3D hadron structure
  - TMD (SIDIS on both neutron ar proton)
  - GPD (TCS, DEMP)
- Gluon and nucleon mass
  - J/ψ production at threshold

Projected Uncertainties



COMPASS++ / AMBER

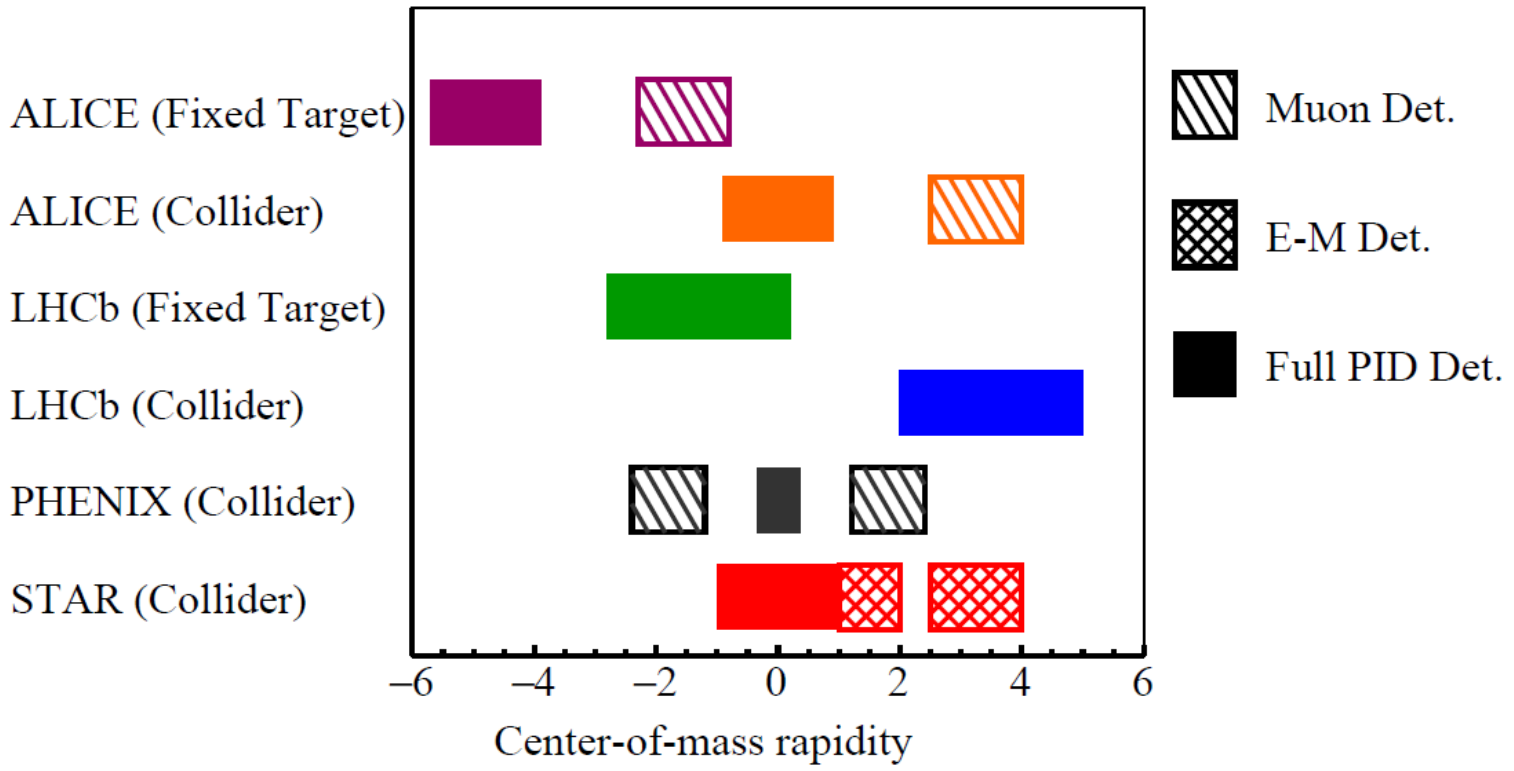
- Proposal phase-1: focus on Run3 (2021-2024)
  - Proton radius
  - Antiproton production cross sections
  - Pion-induced Drell-Yan and charmonium production mechanisms



A. Bressan
8/27 (Mon)

Fixed target at LHCb & ALICE

- C. Aidala et al., arXiv:1901.08002
- M. Echevarria et al., arXiv:1903.03379
- Polarized storage cell internal target



J-PARC

- Exclusive meson-induced Drell-Yan for time-like GPD

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GPD with pion beams at J-PARC

PHYSICAL REVIEW D 93, 114034 (2016)

Accessing proton generalized parton distributions and pion distribution amplitudes with the exclusive pion-induced Drell-Yan process at J-PARC

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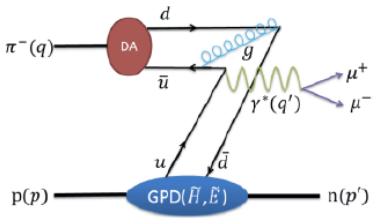

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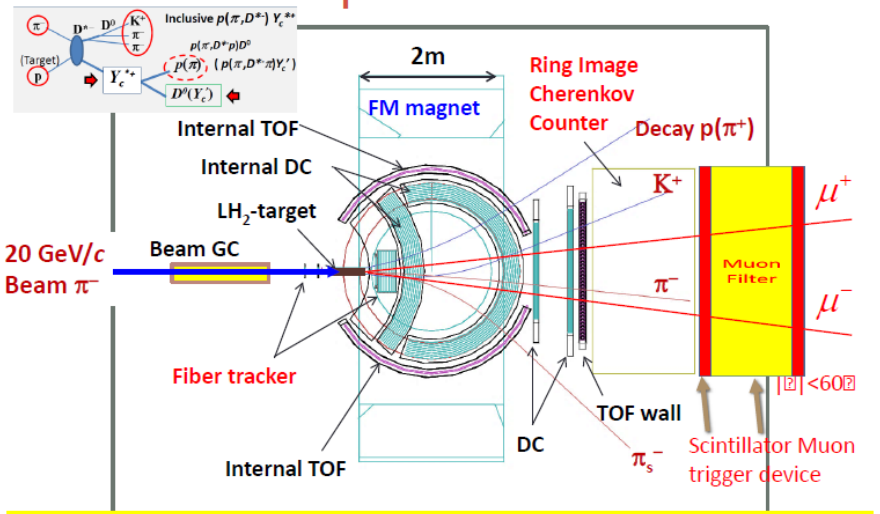
J-PARC E50 Spectrometer + MuID



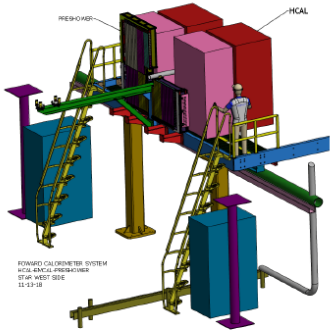
DY trigger rate is expected to be very low, so that the DY measurement can be a "by-product" of the main E50 experiment.

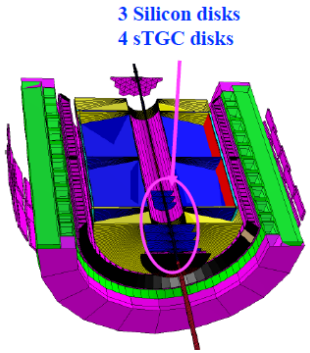
K. Tanaka 8/28 (Tue)
S. Sawada 8/29 (Wed)

STAR forward upgrade

STAR Forward Upgrade

ECal: PHENIX PbSC calorimeter with new readout
HCal: Fe/Sc (20mm/3 mm) sandwich.
Preshower: Reuse existing FMS-pre-shower





Replace FMS with
a compact Ecal and
add Hcal + Tracking

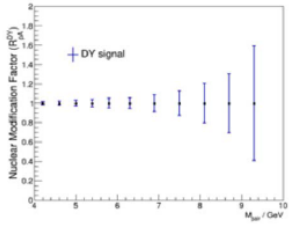
Small scale system test @ run19

Project is fully approved
and funded

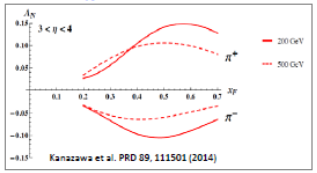
On schedule for first data
taking with 500 GeV polarized pp
in fall 2021

Physics with STAR forward upgrade

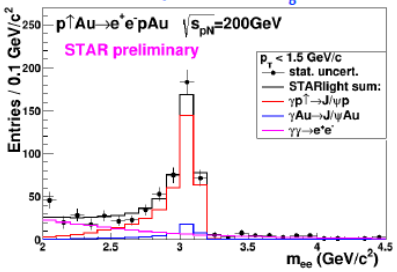
DY: Sivers sign change/TMD evolution



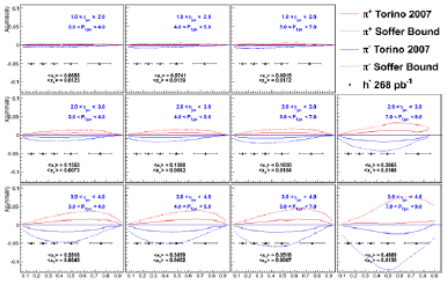
A_N : forward $h^{+/-}$



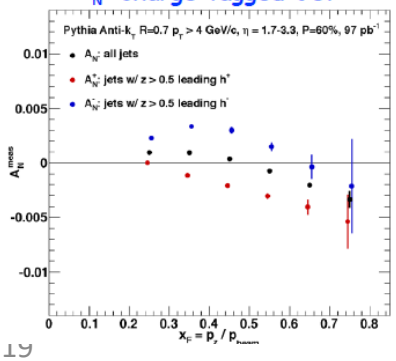
UPC J/psi for GPD E_g



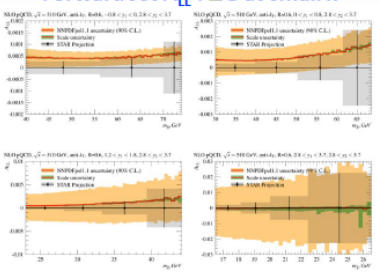
Transversity * Collins/IFF at forward



A_N: charge tagged Jet



Forward Jet A_{LL} : ΔG at small x

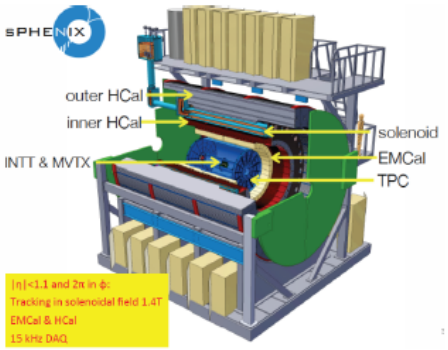


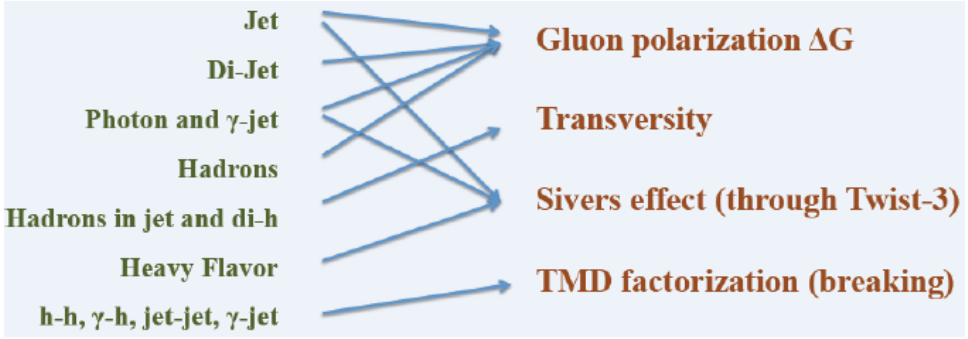
And more physics on both cold
and hot QCD with pp, pAu,AuAu

A. Ogawa
8/27 (Mon)

Spin Physics with sPHENIX

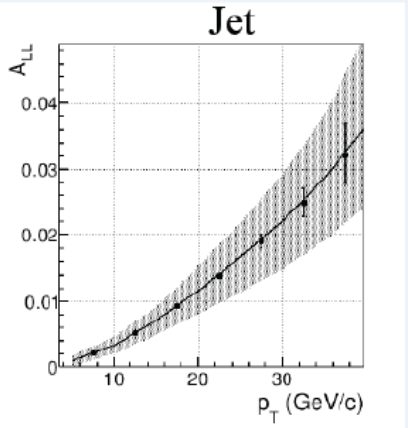
Alexander Bazylevsky

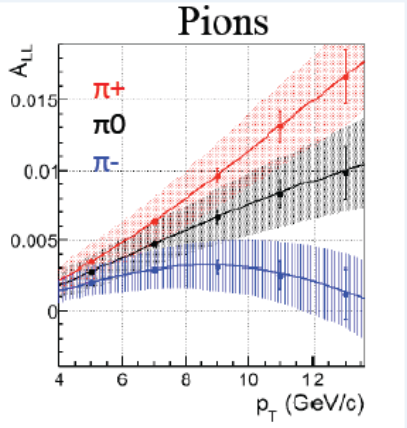


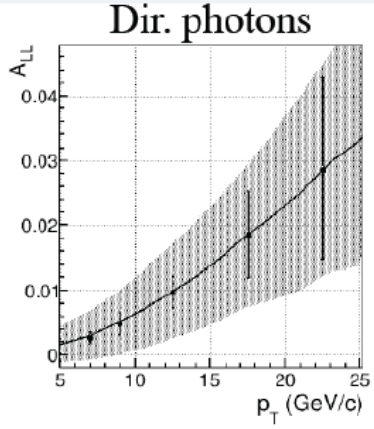


ΔG projection

√s=200 GeV |η|<1.1
L=700 pb^{-1} P=0.6
Theory curve and band: NNPDF







High-precision ΔG measurements (at x> 0.05, ΔGdx-integral precision improvement by a factor of 4

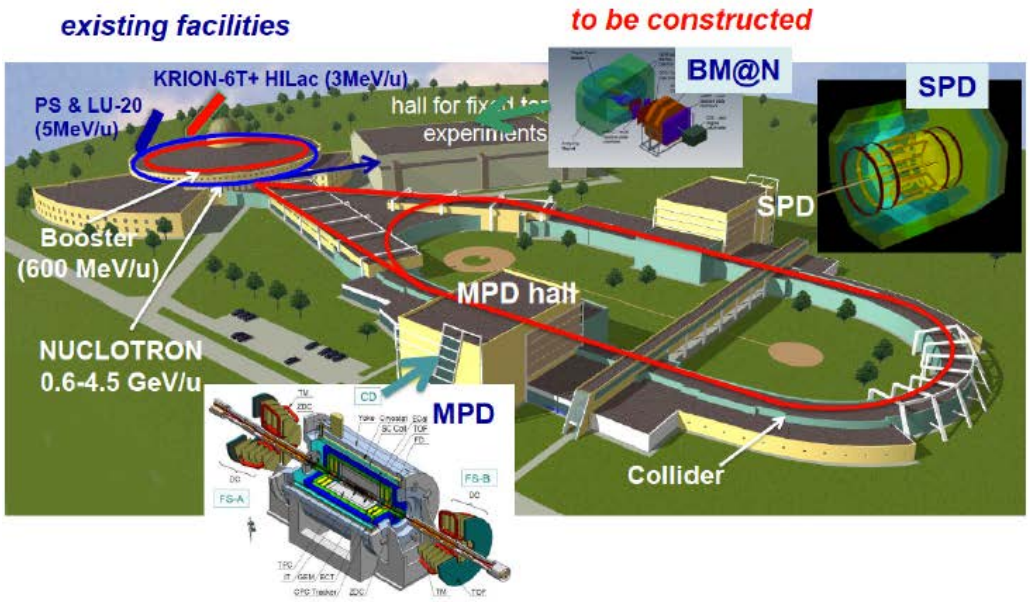
Multiple channels

Complementary to future EIC

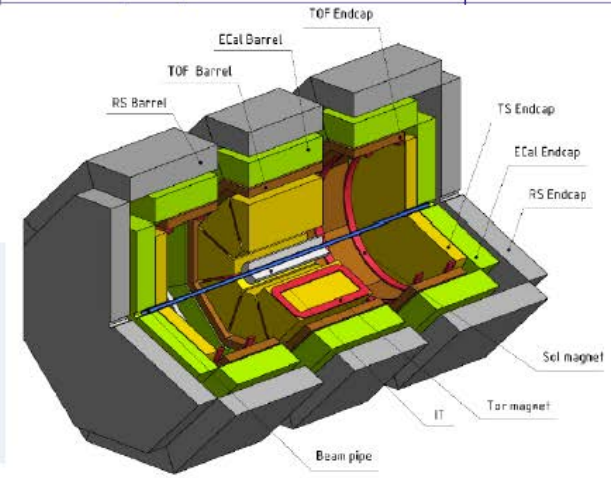
The SPD Project at NICA

Roumen Tsenov

The Nuclotron based Ion Collider fAcility (JINR, Dubna)



Ring circumference, m	**503.04**
heavy ions	
energy range for Au^{79+}: $\sqrt{s_{NN}}$, GeV	**4 - 11**
r.m.s. $\Delta p/p$, 10^{-3}	**1.6**
Luminosity for Au^{79+}, $cm^{-2}\ s^{-1}$	**$1x10^{27}$**
polarized particles	
*max. $\sqrt{s}$ for polarized **p**, Gev*	**27**
*Luminosity for **p**, $cm^{-2}\ s^{-1}$*	**$1x10^{32}$**



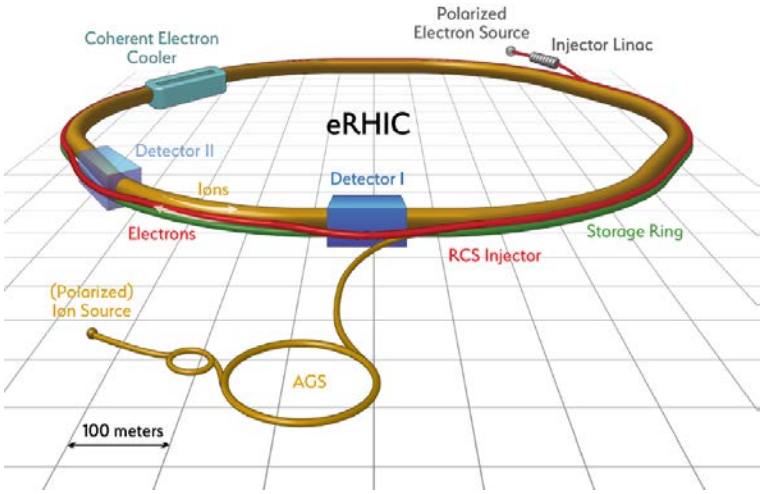
Physics Highlight: Nucleon Spin Structure

- Drell-Yan Production
- Direct Photons
- Nucleon PDFs via J/ψ Production

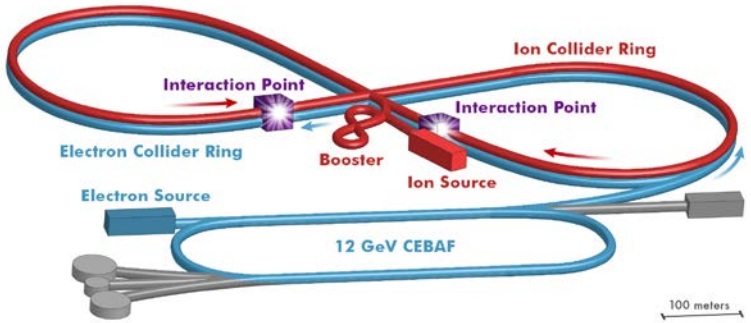
EIC (USA)

- High-energy QCD frontier to study nucleon (hadron) and nucleus (cold nuclear matter) from quarks and gluons
- World's first polarized electron + proton / light-ion / heavy-ion collider
  - Wide (Q^2, x) region
- Electron + proton / light-ion collision
  - Polarized beam
    - e, p, d/^{3}He
  - High luminosity
    - $L_{ep} \sim 10^{33\text{-}34}\ cm^{-2}s^{-1}$
    - 100-1000 times HERA
  - Collision energy
    - $\sqrt{s}$ = 20 – 100 (140) GeV
- Electron + heavy-ion collision
  - Wide range in nuclei

eRHIC at BNL



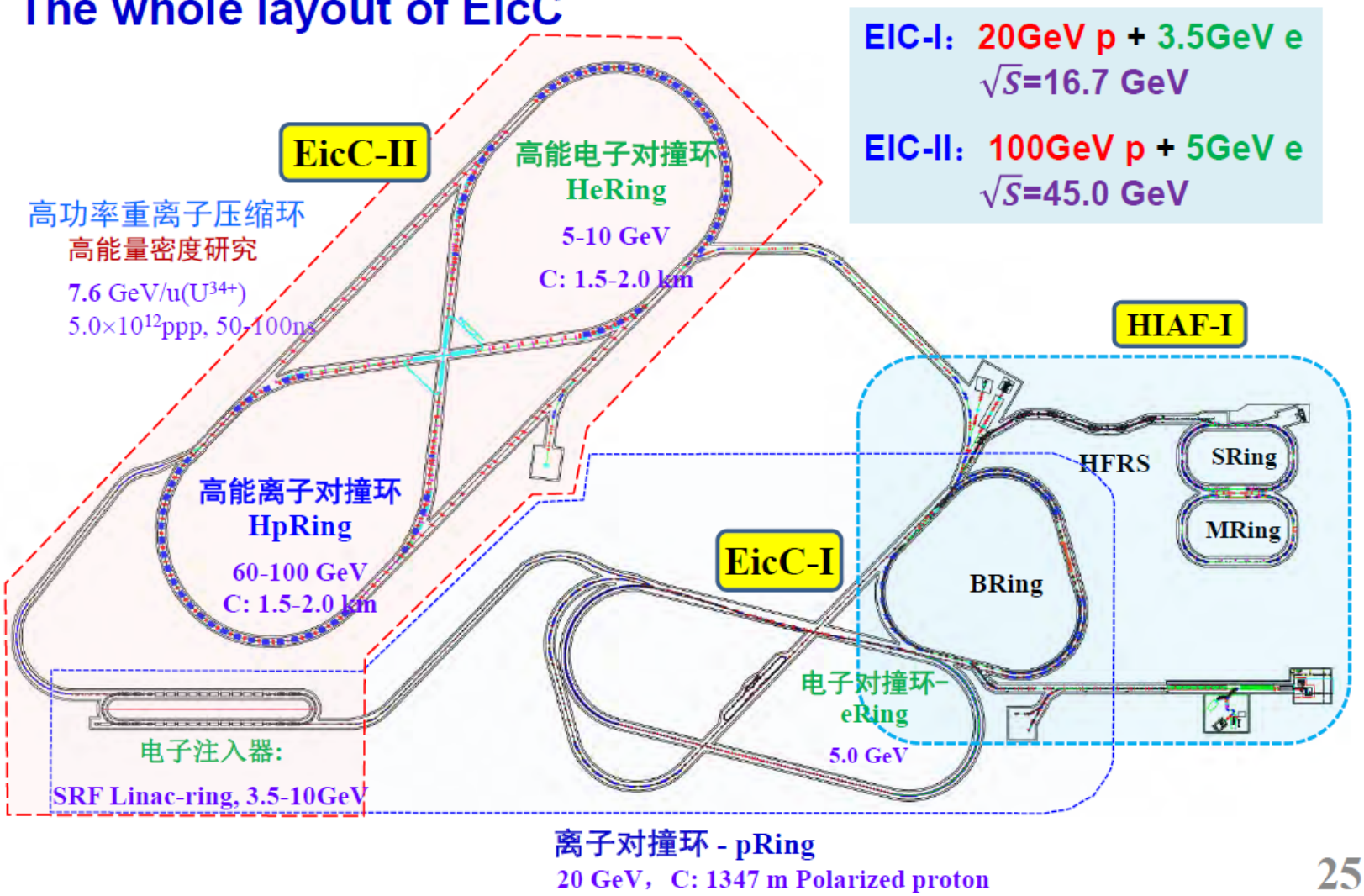
JLEIC at Jefferson Lab



EicC (China)

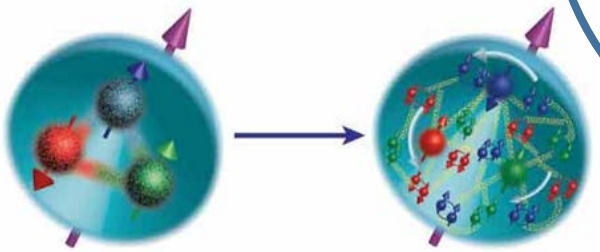
The preliminary concept design of EicC

The whole layout of EicC



Physics at EIC

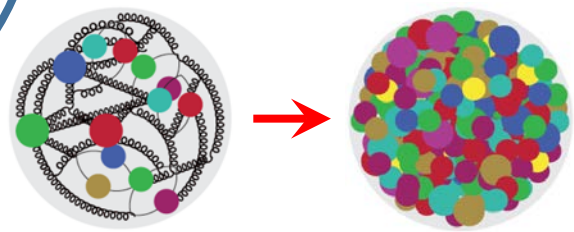
Understanding how the nucleon structure and properties emerge from quarks and gluons and their interactions from QCD



3D Picture of the Nucleons and Nuclei

- *Transverse -Momentum Distribution and Spatial Imaging*
- *Orbital Motion of Quarks and Gluons Inside*
- *Mass of the Nucleon*

Systematic understanding of the structure of nucleons and nuclei covering the wide kinematic range



New Picture

Precision Measurement

Discovery

Luminosity

Collision Energy

Spin and Flavor Structure of the Nucleons and Nuclei

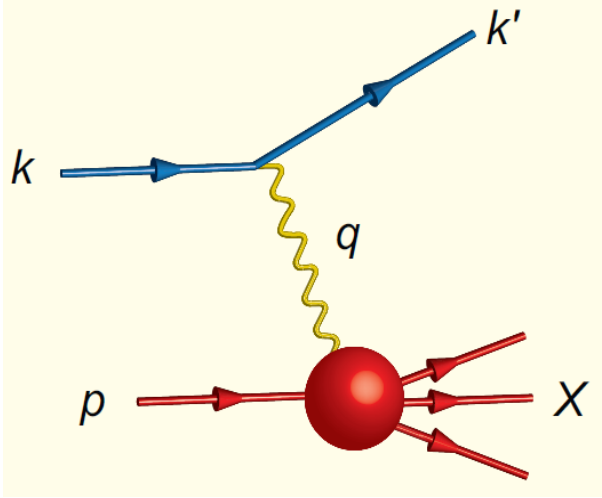
- *Gluon Polarization*
- *Quarks and Gluons Inside the Nuclei*
- *Hadronization*

Gluon Saturation at Extreme Density

- *Emergent Properties of Dense System of Gluons*
- *Initial State of the QGP (Quark-Gluon Plasma)*

Precision measurement of PDFs

- Inclusive DIS
  - Large Q^2 ($Q^2 = -q^2$) provides a hard scale to resolve quarks and gluons in the proton
  - 1D longitudinal motion of partons
- Spin puzzle
  - Gluon polarization measurement with polarized DIS
    - Small Bjorken-x region with QCD evolution (DGLAP equation)



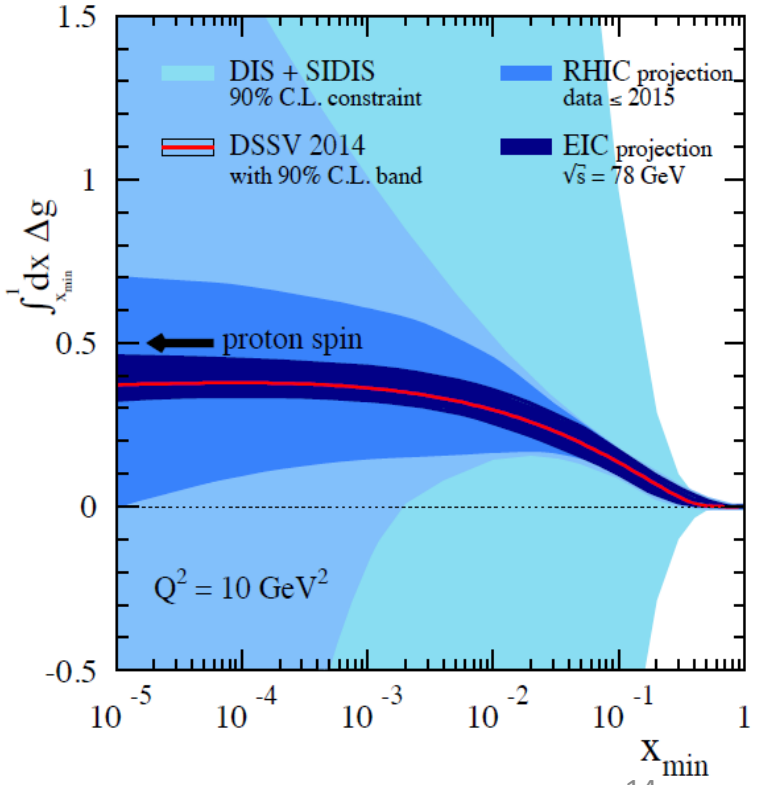
$$\frac{1}{2} = \left[\frac{1}{2}\Delta\Sigma + L_Q\right] + \left[\Delta g + L_G\right]$$

$\Delta\Sigma/2$ = Quark contribution to Proton Spin

L_Q = Quark Orbital Ang. Mom

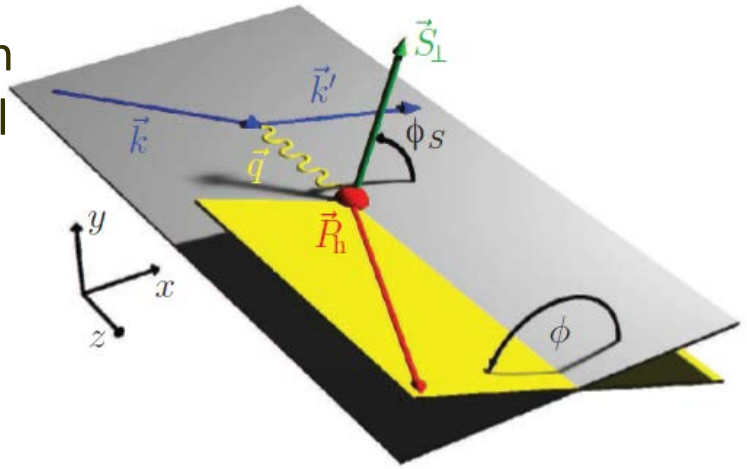
Δg = Gluon contribution to Proton Spin

L_G = Gluon Orbital Ang. Mom



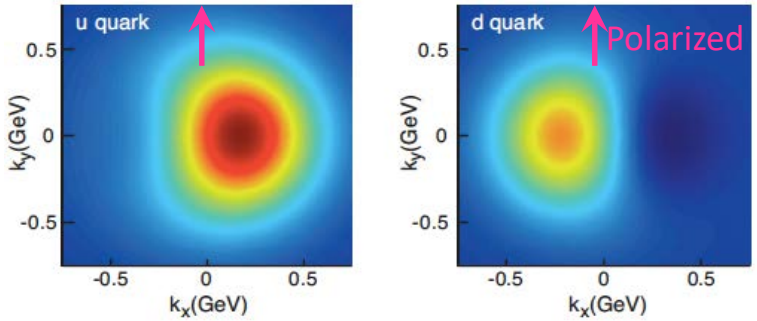
Precision measurement of PDFs

- Semi-Inclusive DIS (SIDIS)
  - Flavor dependence of the quark polarization
  - Transverse-momentum dependence (orbital motion)
- TMD distribution function
  - TMD = Transverse Momentum Dependent
  - Quark, anti-quark, gluon
  - 3D distribution incl. transverse momentum
  - Correlation of spin and parton orbital motion

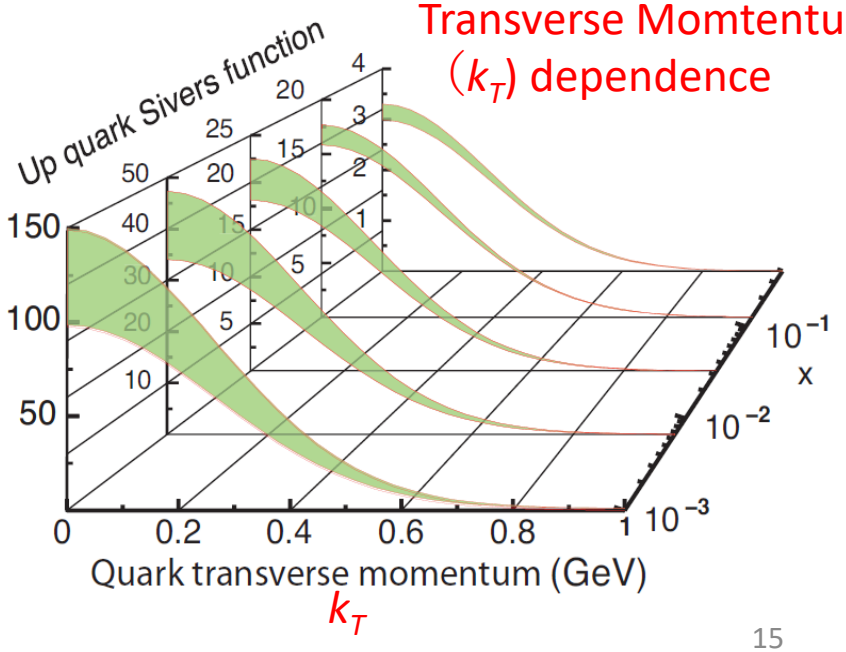


Sivers function:
Correlation of the nucleon spin and the parton transverse momentum

Sivers function at x = 0.1

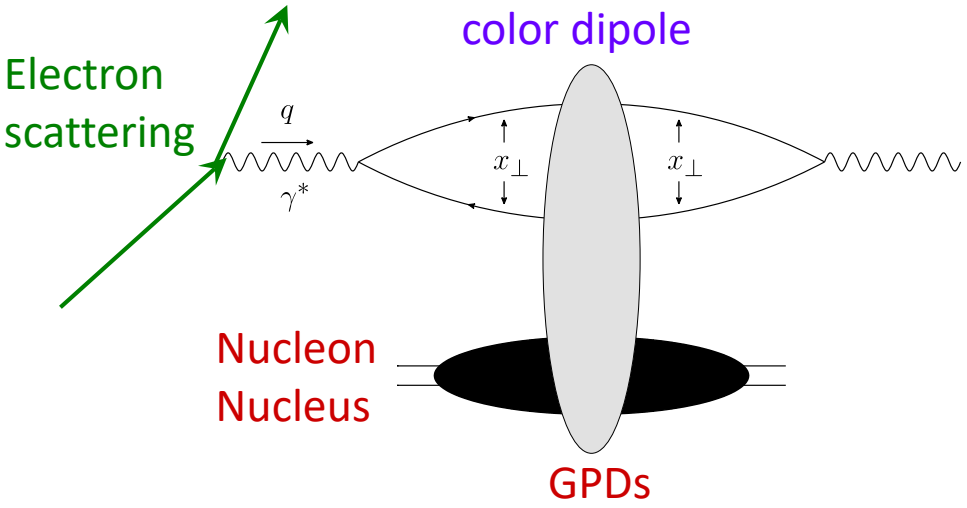


Transverse Momtentum (k_T) dependence

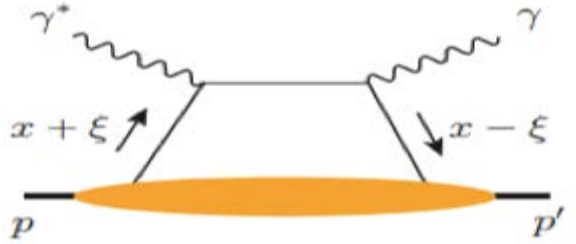


Tomography of the nucleon / nucleus

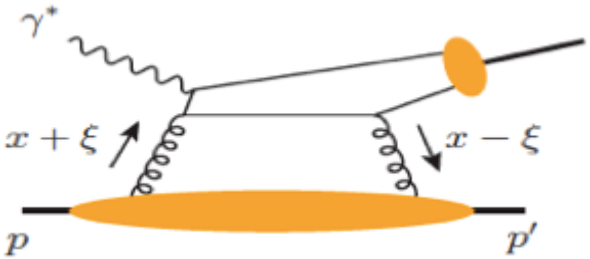
- EIC = color dipole microscope
  - Exclusive process and diffractive process



DVCS (Deeply Virtual Compton Scattering)



Meson Production



J/ψ, ϕ, ρ, etc.

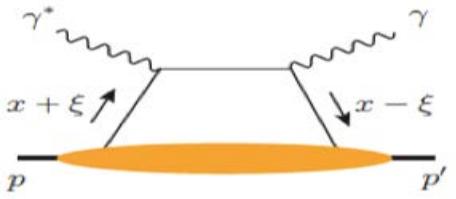
- GPD (Generalized Parton Distribution)
  - Spatial imaging of gluons and quarks = tomography
    - HERA: 1st generation
    - EIC: 2nd generation (high luminosity, heavy ion, polarization)
  - Orbital angular momentum
    - Ji's sum rule

$$J_q^z = \frac{1}{2}\sum_q \Delta q + \sum_q L_q = \frac{1}{2}\left(\int_{-1}^{1} x dx (H^q + E^q)\right)_{t\to 0}$$

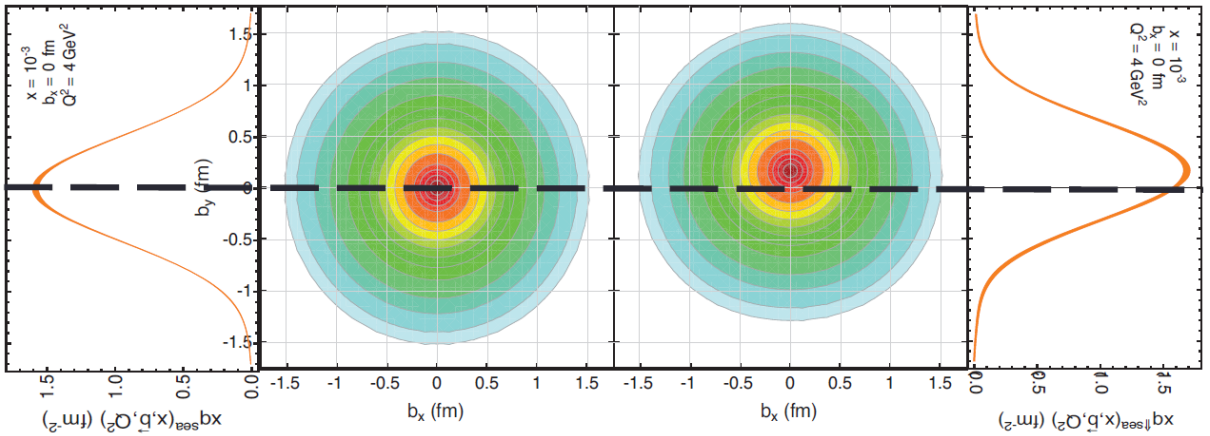
Tomography of the nucleon / nucleus

- DVCS
  - Deeply virtual Compton scattering

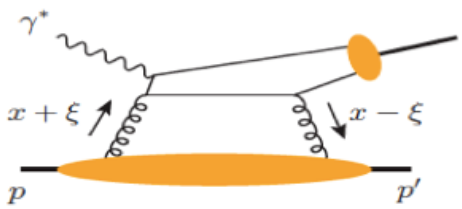
Spatial distribution of sea quarks at EIC 100 fb^{-1} and corresponding density of partons in the transverse plane



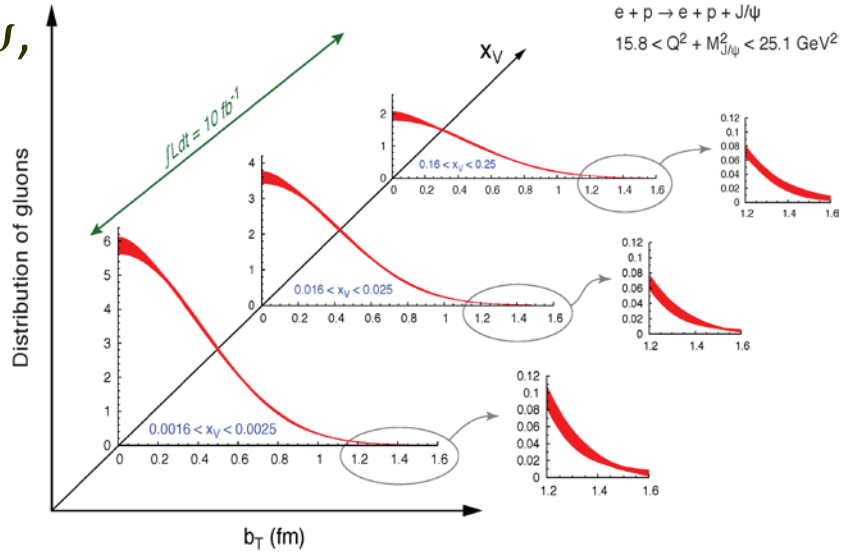
Unpolarized Polarized



- Meson production
  - Gluon tomography by measuring J/ψ, ϕ, ρ, etc.
  - Precision measurement at large radius with high luminosity

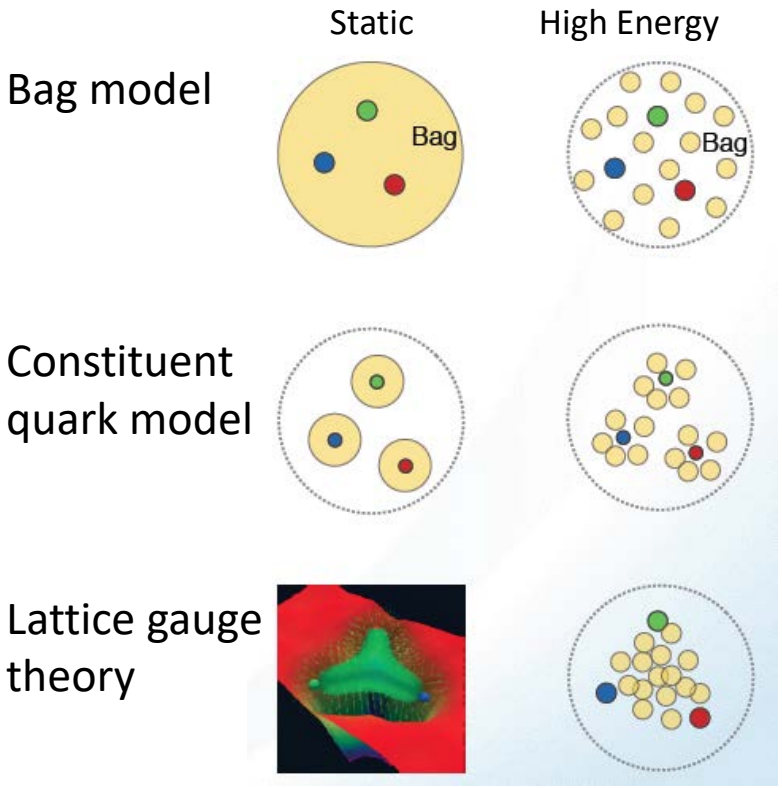


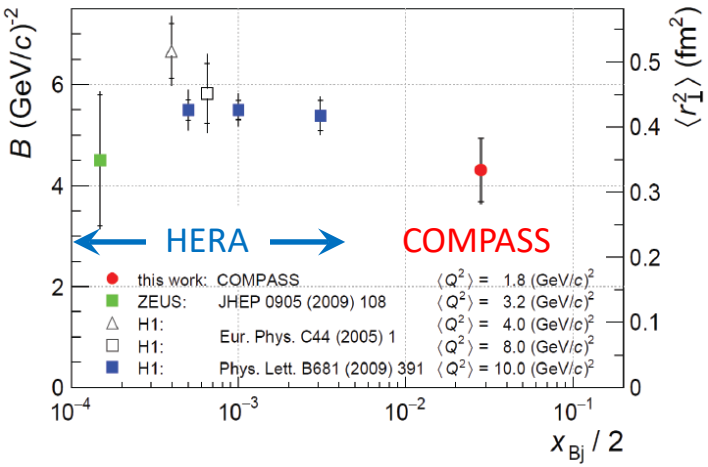
J/ψ, ϕ, ρ, etc.



3D structure of the nucleon

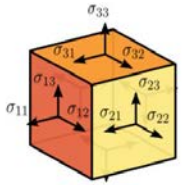
- How are quarks and gluons confined inside the nucleon?
  - Bag model
    - gluon radius > charged radius
  - Constituent quark model
    - gluon radius ~ charged radius
  - Lattice gauge theory (with slow moving quarks)
    - gluon radius < charged radius
- Need measurement of transverse images of the quarks and gluons in the nucleon
- Proton tomography with GPD measurement
  - R = 0.6 – 0.7 fm for gluon (HERA) and sea quark (COMPASS)
  - Smaller than 0.85 fm with EM interaction

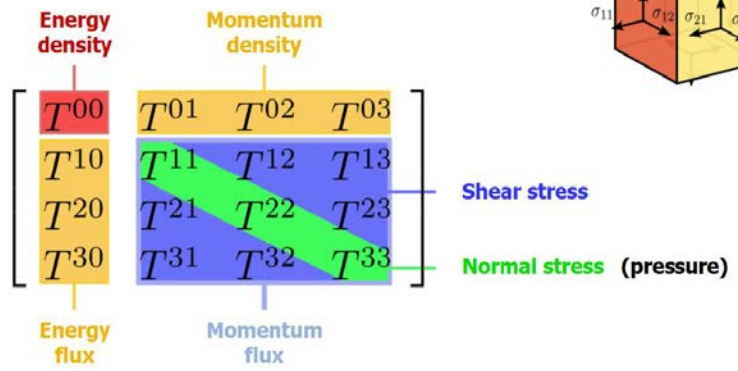




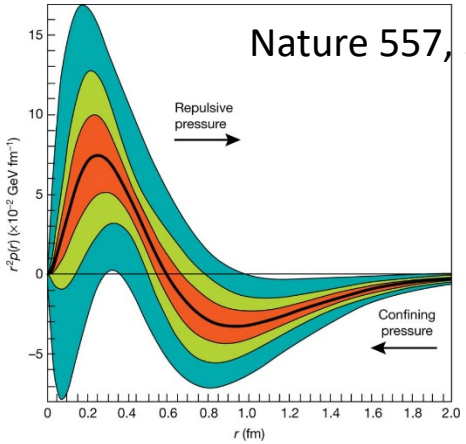
New picture of the nucleon structure

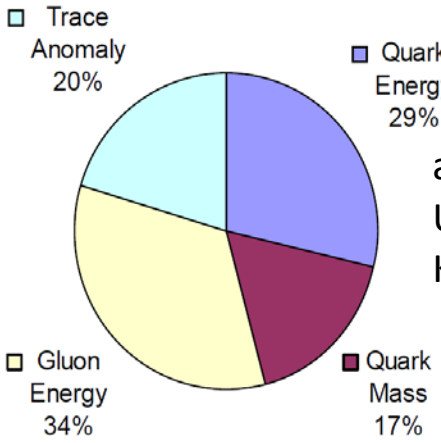
- Energy Momentum Tensor (EMT)
  - 3D distribution of mass, spin, pressure, etc. in the nucleon from GPD measurement
  - Pressure in the proton using GPD data from Jefferson Lab
- Sum rule for the nucleon mass
  - Lattice QCD calculation
  - Discussing how to determine each contribution
- Precision comparison of experiment and theory in the future
  - Mass, spin, pressure, radius,…





Nature 557, 396–399 (2018)



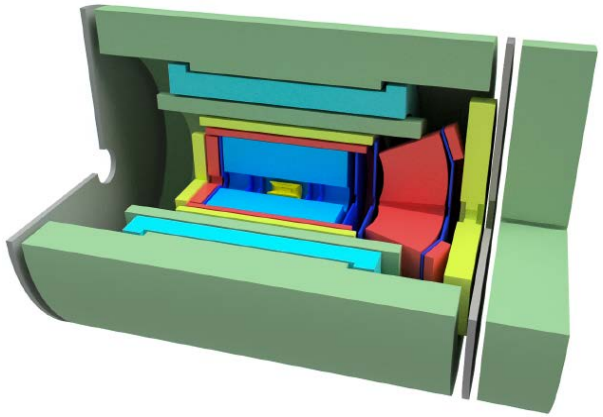


arXiv:1710.09011
Updated by
K.-F Liu et al.

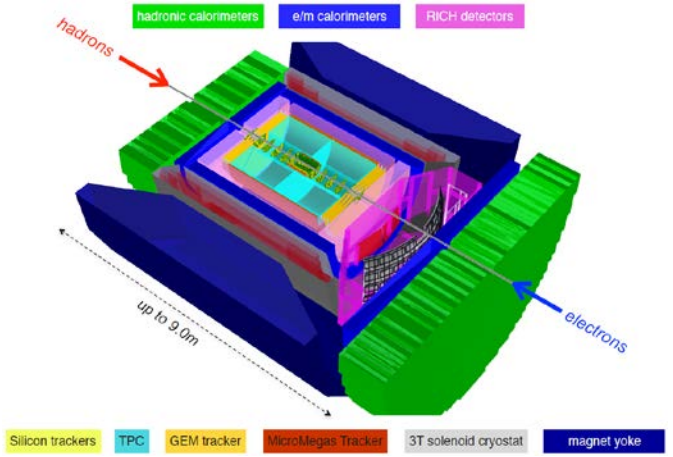
EIC detector

- Many opportunity and need for additional contributions and collaborators

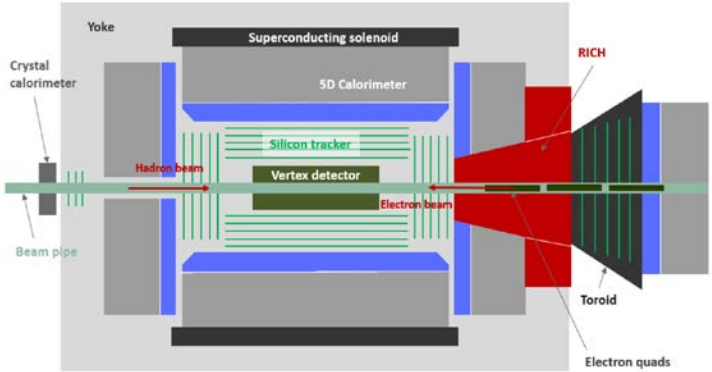
EIC Day-1 detector with BaBar Solenoid
(aka EIC-sPHENIX)



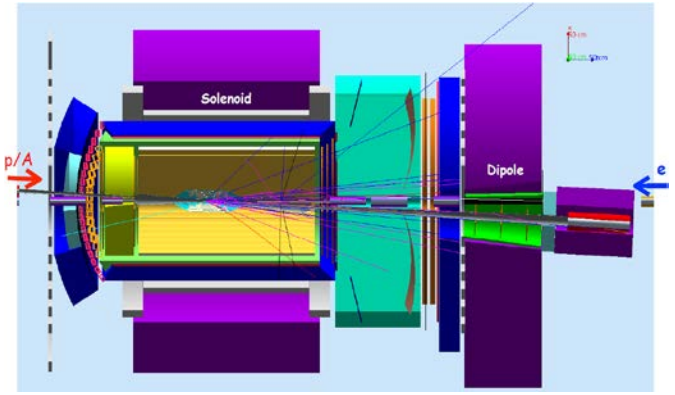
BeAST at BNL



TOPSiDE
(Time Optimized PID Silicon Detector for EIC)



JLEIC Detector Concept with CLEO Solenoid

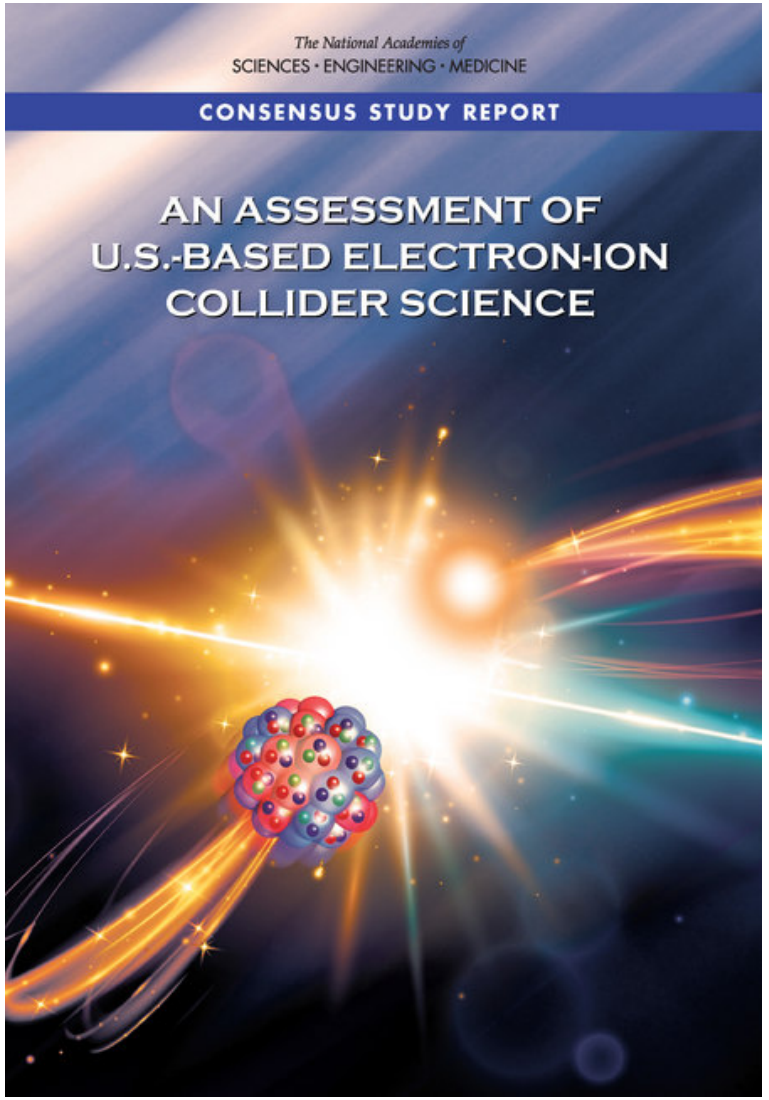


Status of the EIC project

- NSAC 2015 Long Range Plan
  - We recommend a high-energy high luminosity polarized Electron Ion Collider as the highest priority for new facility construction after the completion of FRIB.
- NAS (National Academies of Sciences, Engineering, and Medicine) review requested by DOE
  - US-based EIC Science Assessment
- NAS webinar and NAS report release 7/24/2018
  - EIC science endorsed unanimously by the NAS

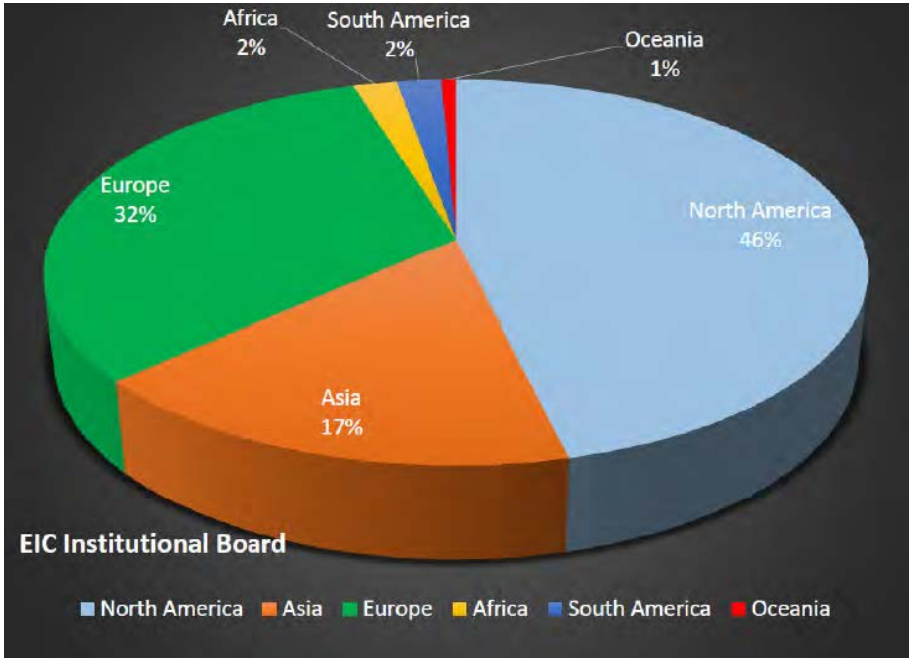
Status of the EIC project

- NAS assessment of a U.S.-Based Electron-Ion Collider Science
  - EIC can uniquely address three profound questions
  - How does the mass of the nucleon arise?
  - How does the spin of the nucleon arise?
  - What are the emergent properties of dense systems of gluons?
- Cost review underway
- CD-0 (US mission need statement) anticipated very soon
- EIC detector R&D program operated by BNL with ~$1.3M / year since 2011
  - Increase anticipated soon after project officially begins
- EIC accelerator R&D already assigned ~$7M / year since FY2017



EIC Users Group (EICUG)

- EIC Users Group
  - Established in summer 2016
  - 864 members
  - 184 institutes
  - 30 countries
- EICUG structures in place and active
  - Steering Committee
  - Institutional Board
  - Conference & Talks Committee
  - Working groups
    - software
    - polarimetry
    - IR & luminosity
  - Annual meetings
    - SBU (2014), Berkeley (2015), ANL (2016), Trieste (2017), CAU (2018), Paris (2019)



Summary

- Physics for future facilities
  - Precision measurement of components of the nucleon spin
  - TMD distributions & fragmentations
  - Transversity to tensor charge
  - Tomography: GPD & GDA
  - Measurement of components of the nucleon mass
- EIC project
  - EIC science endorsed by the NAS
  - CD-0 (approve mission need) anticipated very soon
  - Active EIC User Group and R&D

SPIN2020 at Matsue, Japan

- 24th International Spin Symposium
  - September 21 – 25, 2020 (after Tokyo Olympic/Paralympic)

Where is Matsue

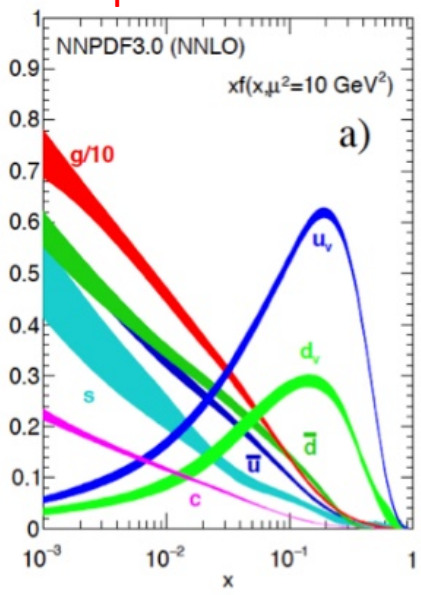
- Famous and interesting area for 2,000 years of Japanese history from creation myth era to present day
- Two domestic airports near Matsue city, Izumo airport and Yonago airport
- About 30 to 45 minutes from both airports to Matsue city by airport shuttle bus
- Connected with Haneda international airport in Tokyo by more than 10 daily flights

Backup Slides

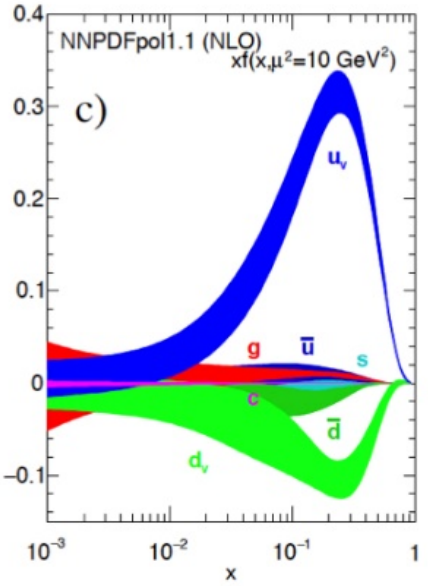
Quark-gluon structure

- 1-D picture
  - Parton distribution function (PDF) of quarks and gluons
  - *x*: momentum fraction of quarks and gluons
  - Significant improvement of precision of the polarized PDF at EIC
    - especially gluon polarization
- 3-D picture
  - Generalized parton distribution (GPD) function
    - charge distribution
    - magnetic-moment distribution
    - mass distribution
  - Comparison of radii (R)
  - Orbital motion / orbital angular momentum
    - origin of the nucleon spin
  - New picture to be established at EIC

Unpolarized PDF

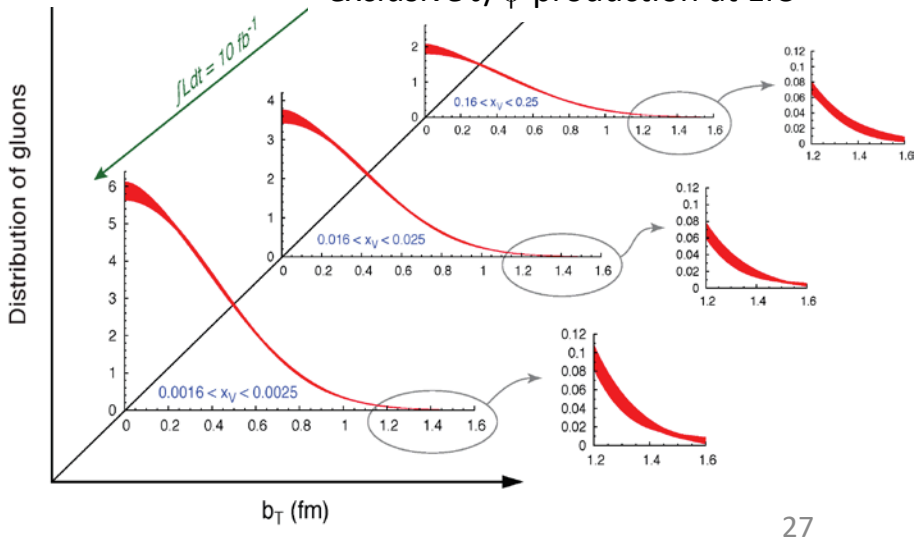


Polarized PDF



GPD measurement

x-dependence of spatial distribution of gluons to be obtained by the exclusive J/ψ production at EIC

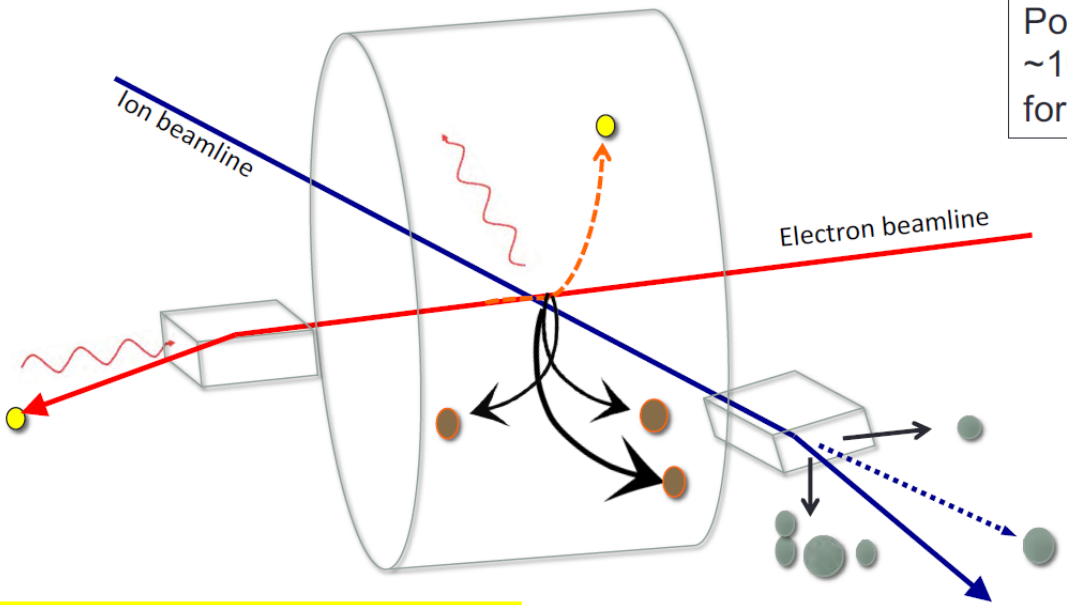


Other physics at EIC

- Discovery of the gluon saturation
  - Emergent properties of dense system of gluons
- Hadronization in the nuclei
  - Hadron and jet production from quarks and gluons in the cold nuclear matter
- Hadron spectroscopy
  - Exotics
- Tensor charge of the nucleon
  - Transversity measurement
- Polarized e + d/^{3}He collisions
  - Polarized structure of the neutron
  - “n+p” wave function of the deuteron
- Short range correlations
  - EMC effect by high-momentum “n+p” pairs in nuclei
- High-energy cosmic-ray/neutrino reaction
  - Energy flow in the very forward region
  - Event generator for shower evolution

EIC detector & integration with the IR

- EIC detector
  - Mid and forward rapidity detectors
  - Scattered electron detector, backward and mid rapidity
  - Low angle trigger
  - Absolute and relative luminosity measurement
  - Polarization measurement



Possible to get ~100% acceptance for the whole event

Total acceptance detector (and IR)

Crossing angles:
eRHIC: 25 mrad
JLEIC : 50 mrad

Figure Courtsey: Rik Yoshida