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Electron Ion Collider Plan in China

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Outline

1. Introduction
2. EIC@HIAF Project
3. Unique Physics Opportunities for EIC@HIAF
4. Current Status and Summary

(Physics Today, May 2013)

China prepares to spend billions (US Dollars) on science & technology

12th five-year plan: Mid- to long-term projects ranked by priority

China National Mid- to long-term projects:

- 12th five-year plan: 2011~2015
- 13th five-year plan: 2016~2020

1. Ocean-floor scientific survey network
2. High-energy synchrotron test facility
3. Accelerator-driven subcritical reactor research facility
4. Synergetic Extreme Condition User Facility
5. High-flux heavy ion accelerator ---> HIAF
6. High-efficiency, low-carbon gas turbine testing facility
7. Large High Altitude Air Shower Observatory
8. Future network experimental facility
9. Outer-space environment simulating facility
10. Translational medicine research facility
11. China Antarctic Observatory
12. Precision gravity measurement research facility
13. Large-scale low-speed wind tunnel
14. Shanghai Synchrotron Radiation Facility Phase-II Beamline Project
15. Model animal phenotype and heredity research facility
16. Earth system digital simulator

HIAF and Its EIC Plan

◆ **HIAF initial goals:**

- Nuclear Physics (rare isotope)
- high-energy-density matter
- applications…

◆ **New: add collision physics –EIC**

Discussions, 2012- 2015: inputs from Chinese and international communities

Phase I: 3~5 GeV (pol. e) x 20 ~25 GeV (pol. p), L >= 10^{33}

Overview of the HIAF Complex

HIAF II

- 3GeV SRF Linac-ring
- "8" electron 3GeV
- "8" proton 12GeV
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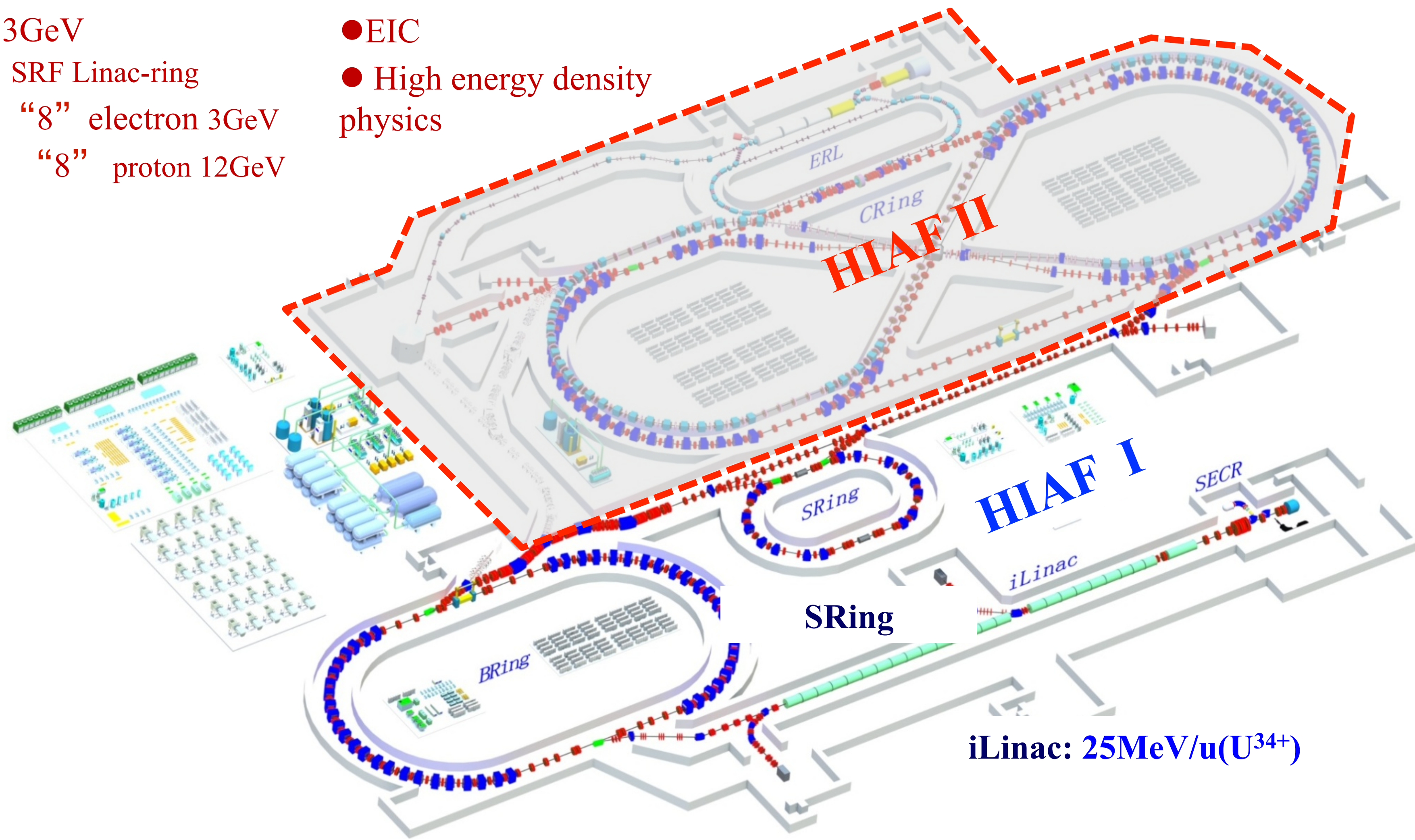
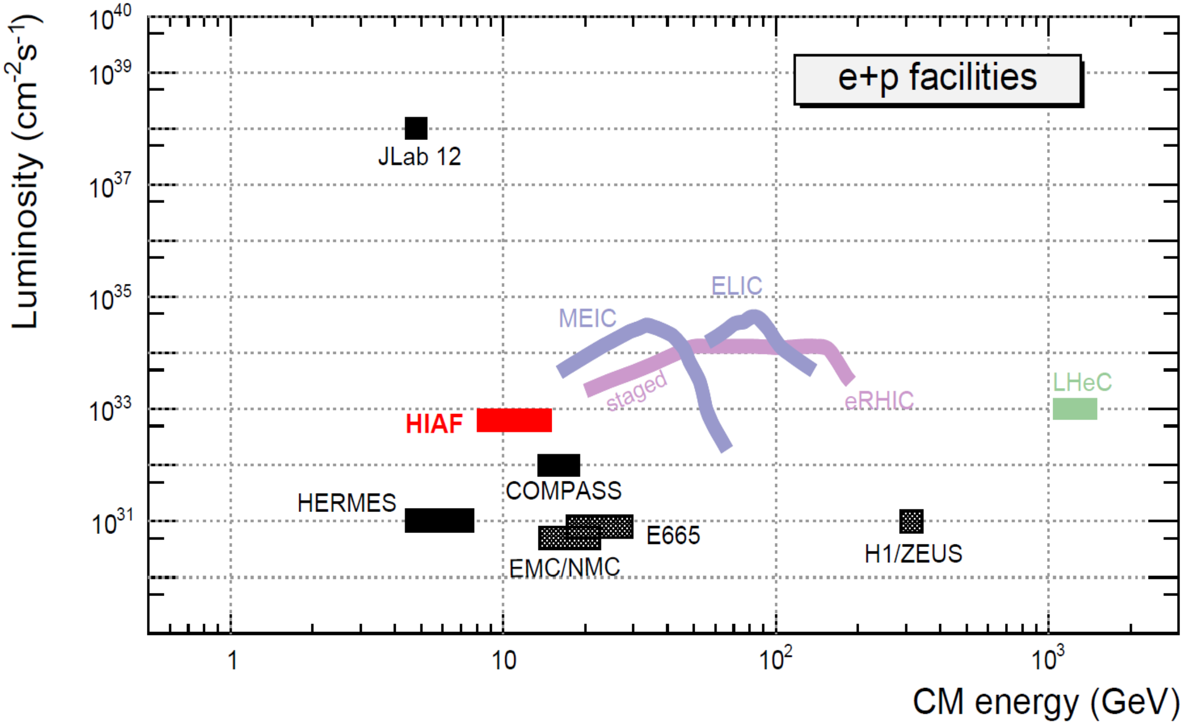
- EIC
- High energy density physics



Lepton-Nucleon Facilities

HIAF: e(3GeV) +p(12~16 GeV), both polarized, L>= $4*10^{32} cm^2/s$



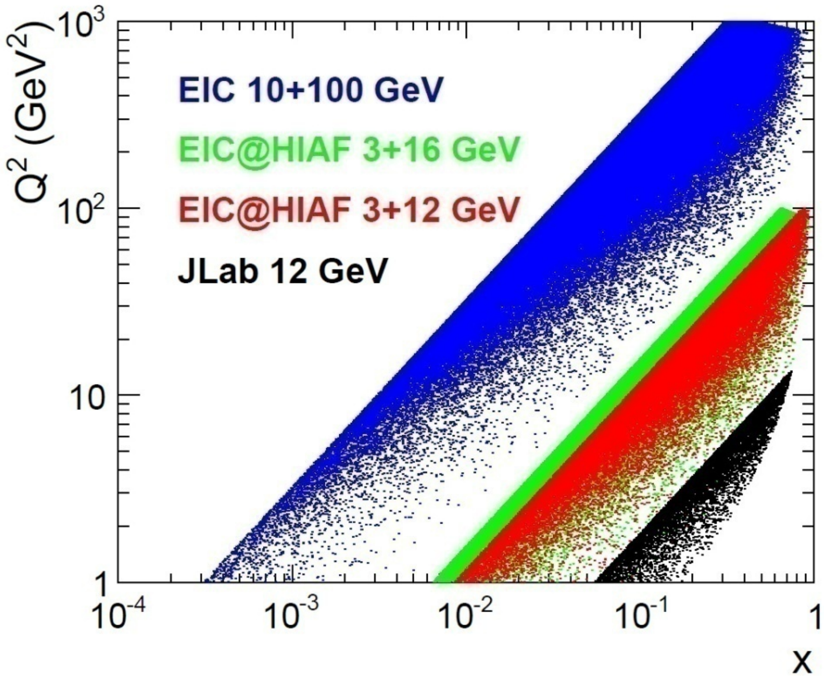
●The energy reach of the EIC@HIAF is significantly higher than JLab12 but lower than the full EIC being considered in US

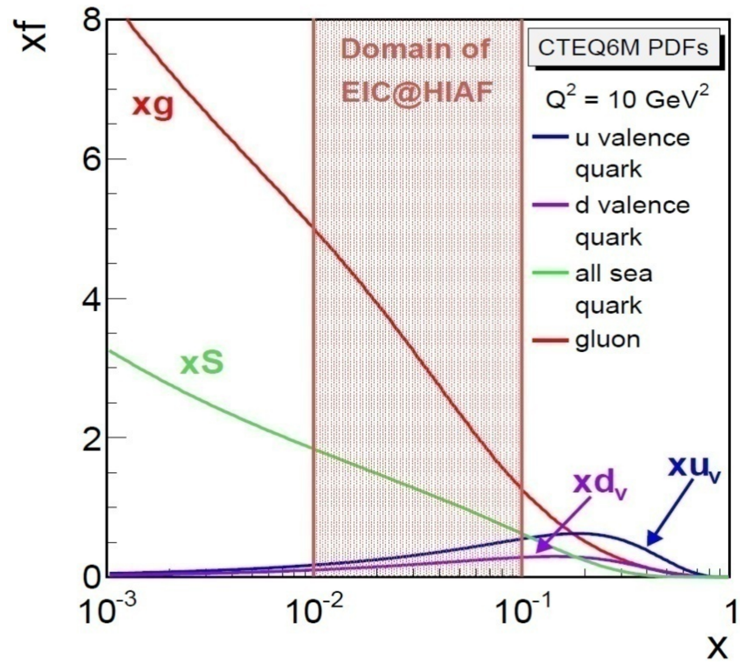
●COMPASS has similar (slightly higher) energy, but significantly lower polarized luminosity (about a factor of 200 lower, even though the unpolarized luminosity is only a factor of 4 lower)

●HERA only has electron and proton beams collision, but no electron and light or heavy ion beams collision, no polarized beams and its luminosity is low (10^31).

EIC@HIAF Kinematic Coverage

Comparison with JLab 12 GeV





EIC@HIAF :

Explore the spin and spatial structure of valence & sea quarks in nucleons

The best region for studying sea quarks ($x > 0.01$)

higher Q^2 in valance region, Allows some study gluons

EIC@HIAF's Advantages

- Many aspects of parton structure can be uniquely addressed by an EIC, especially an EIC with polarization, such as EIC@HIAF
- The main theme for the future full EIC machines (eRHIC, MEIC, LHeC) is to understand the gluons
- The Phase-I of EIC@HIAF will fill the gap between the existing facilities (HERA, JLab…) and future high energy facilities
- EIC@HIAF will provide a broad range of opportunities to explore new frontier research of QCD dynamics which is key to the visible matter

Physics Programs at EIC@HIAF

Six golden experiments

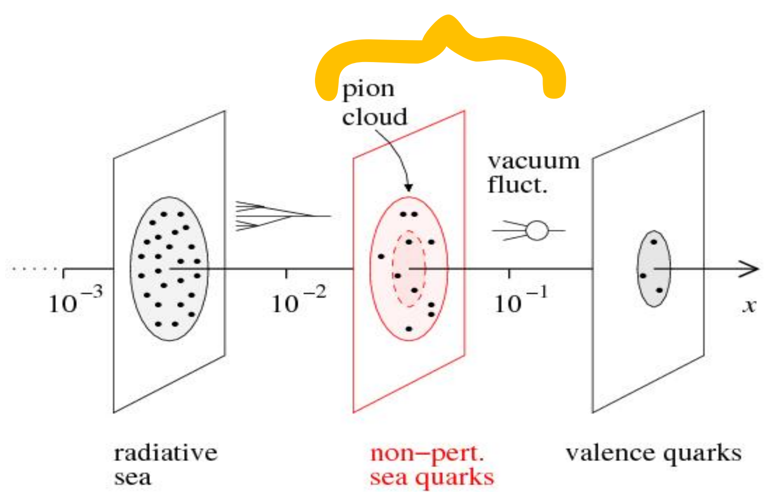
- Nucleon spin-flavor structure (polarized sea, Ds)
- GPDs (Deep-Virtual Meson Production, pion/Kaon)
- TMD in "sea quark" region and significant increase in Q^2 / P_T range for valence region
- Pion/Kaon structure functions in the high-x (valence) region
- e-A to study hadronization
- EMC-SRC in e-A

1. Spin-Flavor Study at EIC@HIAF

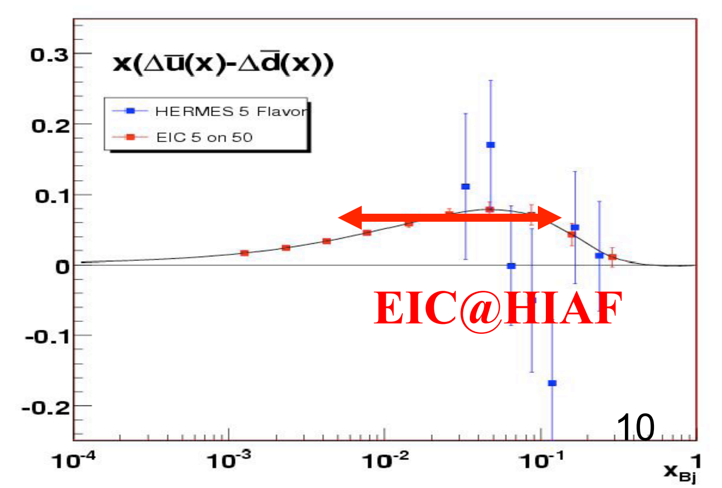
- **Understanding the spin structure of the nucleon in terms of constituent partons, i.e. quarks and gluons, has been and still is an essential task of subatomic physics**
- The electron ion collider(EIC) provides unique opportunities to study the inner structure of the nucleon, especially the polarized distribution functions of sea quarks
- **EIC@HIAF, combination of energy and luminosity**

Significant improvement for Δubar, Δdbar from SIDIS

Unique opportunity for Δs

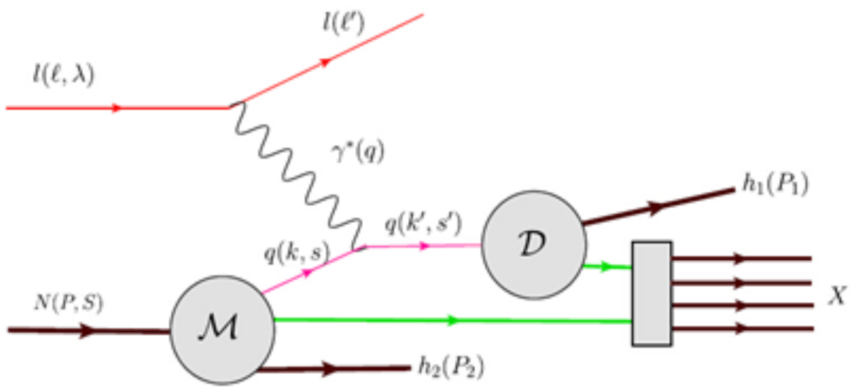


Sea Quark Polarization



1. Spin-Flavor Study at EIC@HIAF

- Current fragmentation can be factorized into distribution and fragmentation functions.
- Target fragmentation involves a more complex soft part.
- To study the struck quark fragmentation one need disentangle the regions
- Due to the complexity in theoretical interpretations, the target fragmentation is generally less explored



Fragmentation Function:

Lepto-production of two hadrons:

- **h1 in the current fragmentation region**
- **h2 in the target fragmentation region**

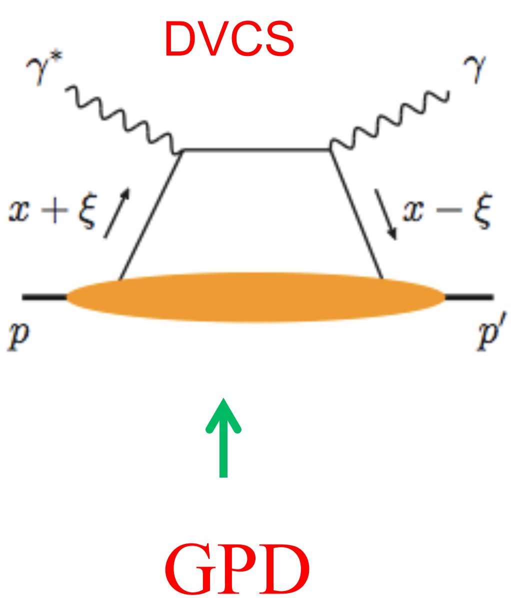
1. Spin-Flavor Study at EIC@HIAF

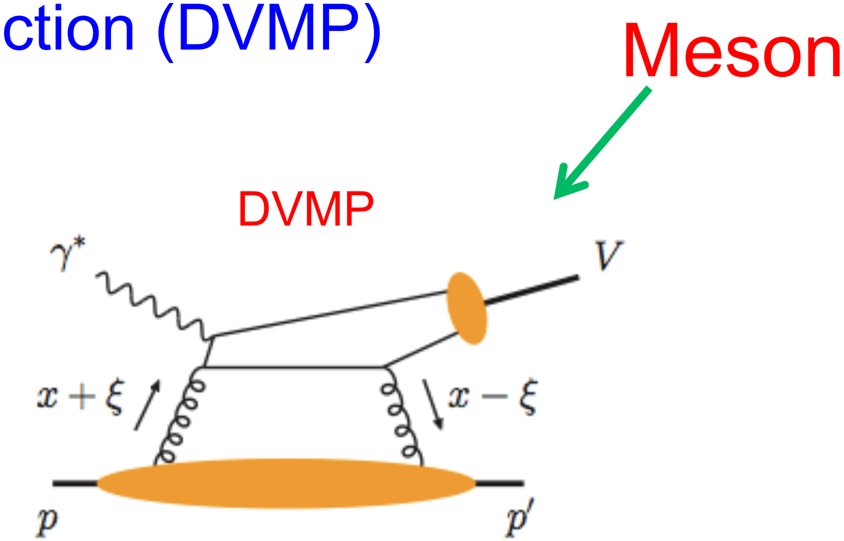
- By SIDIS, in particular, for Kaons , EIC@HIAF energy reaches the current fragmentation region for Kaon tagging in SIDIS, will help to identify strange quark helicity
- For Δs , one needs to tagging Kaon in the current fragmentation region. To separate current fragmentation from target fragmentation, it requires high energy. But JLab 12 GeV is not high enough to satisfy simple criteria， such as Berger's criteria， to be in the current fragmentation region)
- Increase in Q^2 range/precision for g_1 (and g_2): constraint on Δg
- Simulations are almost done

E.L.Berger, Nucl.Phys. B85 (1975) 61; P.Mulders arXiv:hep-ph/0010199

2. GPD Study at EIC@HIAF

- GPDs – Spatial imaging of quarks and gluons
- GPDs can be extracted from suitable exclusive scattering processes in ep collisions
- Deeply virtual Compton Scattering (DVCS) and deeply virtual exclusive meson production (DVMP)

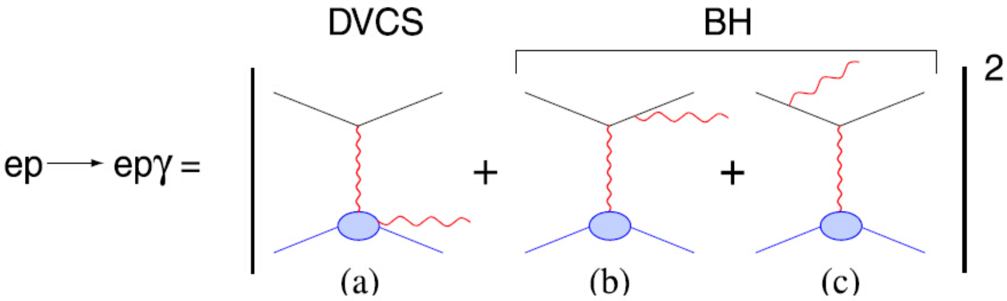




What's the use of GPDs?

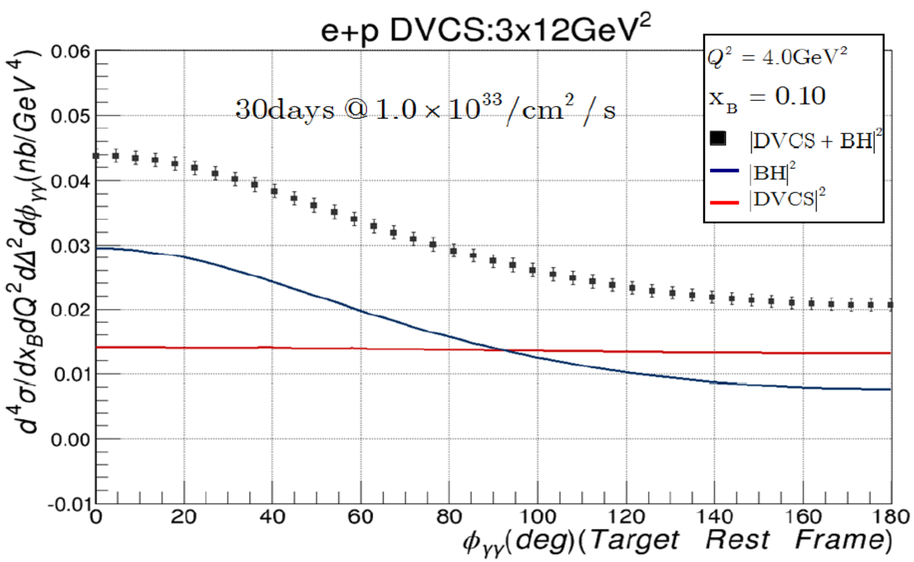
1. GPD Allows for a unified description of form factors and parton distributions
2. Describe correlations of quarks/gluons
3. Allows for Transverse Imaging
4. Allows access to quark angular momentum (in model-dependent way)

DVCS simulations

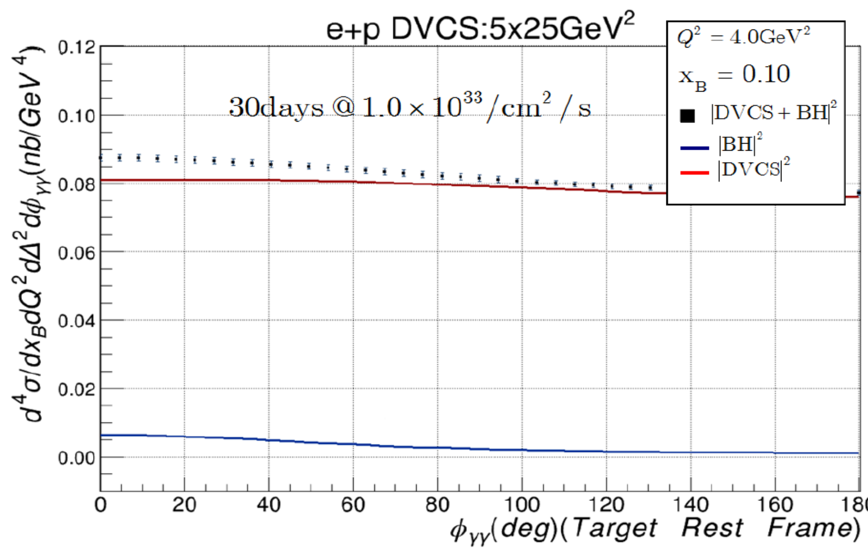


DVCS/DVMP interferes with the Bethe-Heitler process

3 x 12 GeV



5 x 25 GeV



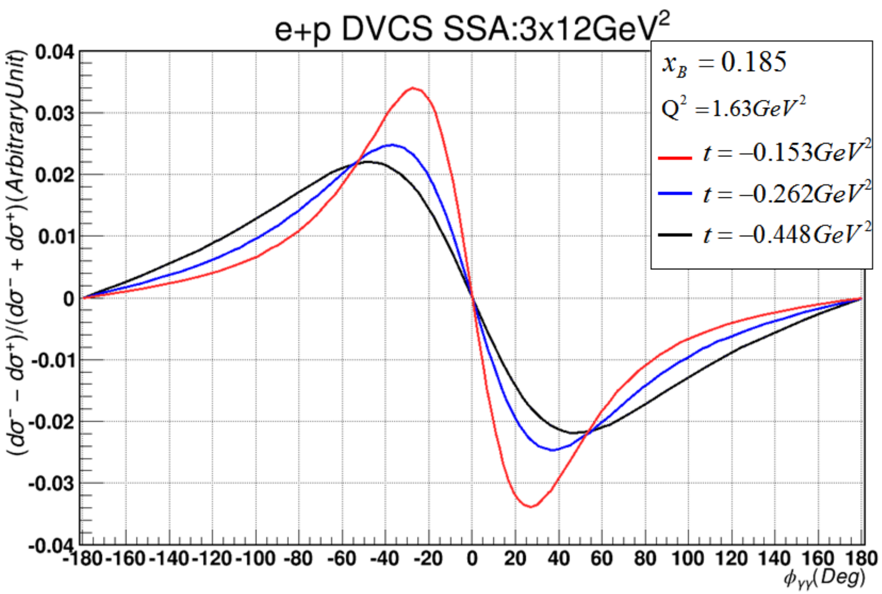
- flavor decomposition needs DVMP
- energy reaches $Q^2 > 5\sim10\ GeV^2$, scaling region for exclusive light meson production
- JLab12 energy is not high enough to have clean meson deep exclusive process
- EIC@HIAF: significant increase in range for DVCS; Unique opportunity for DVMP (pion/Kaon)

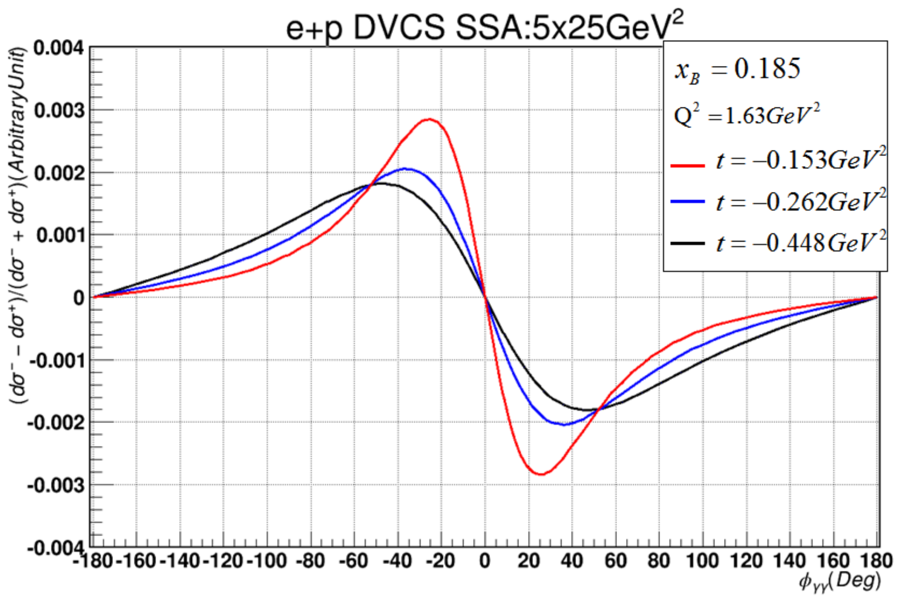
Simulated by MILOU

DVCS simulations: SSA

3 x 12 GeV

5 x 25 GeV





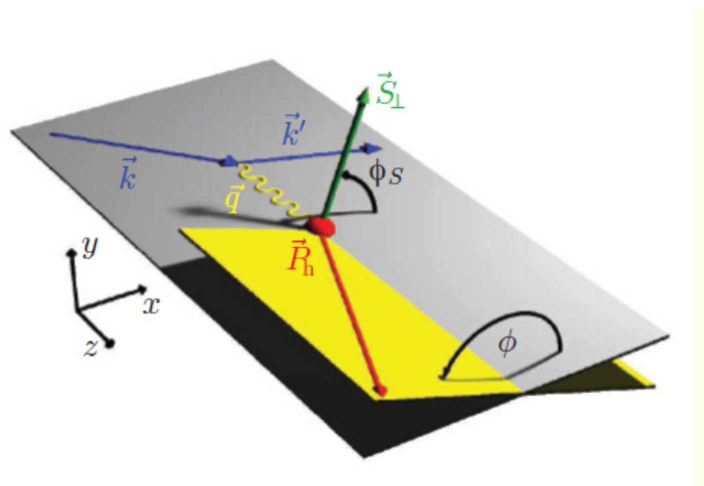
beam-helicity asymmetry:

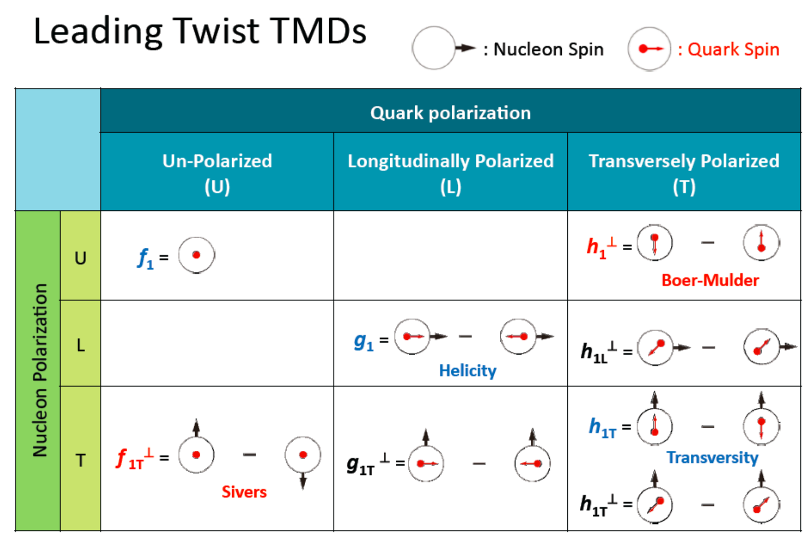
Lower energy has larger SSA

Smaller t has larger SSA

3. TMD Study at EIC@HIAF

- compared to the 1D parton distributions, the TMDs are much less understood
- In order to improve our understanding on the TMDs, it is important to perform precision measurements
- **SIDIS** provides a powerful probe of 3D TMD quark distributions

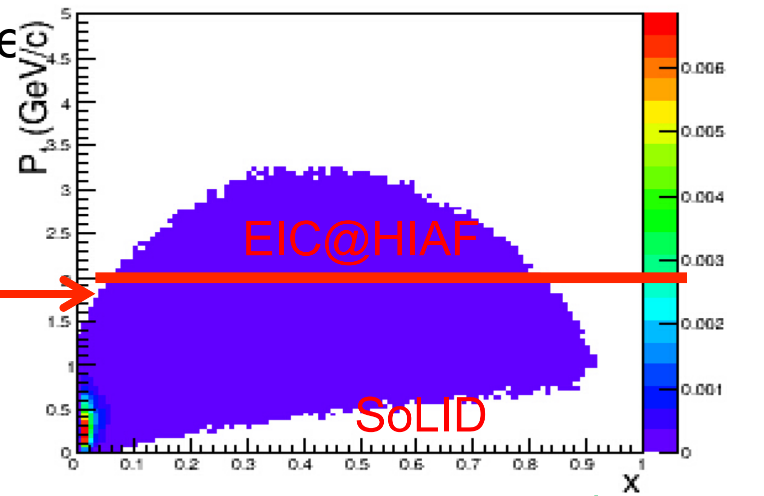




- At the leading twist, there are **8** different TMD quark distributions
- These distributions represent various correlations between the transverse momentum of the quark k_T , the nucleon momentum P, the nucleon spin S, and the quark spin s_q

Compared to the fixed target experiments, EIC will be able to probe much larger phase space in x, Q2 and p_T

- Unique opportunity for TMD in "sea quark" region: reach $x \sim 0.01$
- Significant increase in Q^2 range for valence region: energy reach $Q^2 \sim 40\ GeV^2$ at $x \sim 0.4$
- Significant increase in P_{hT} range:

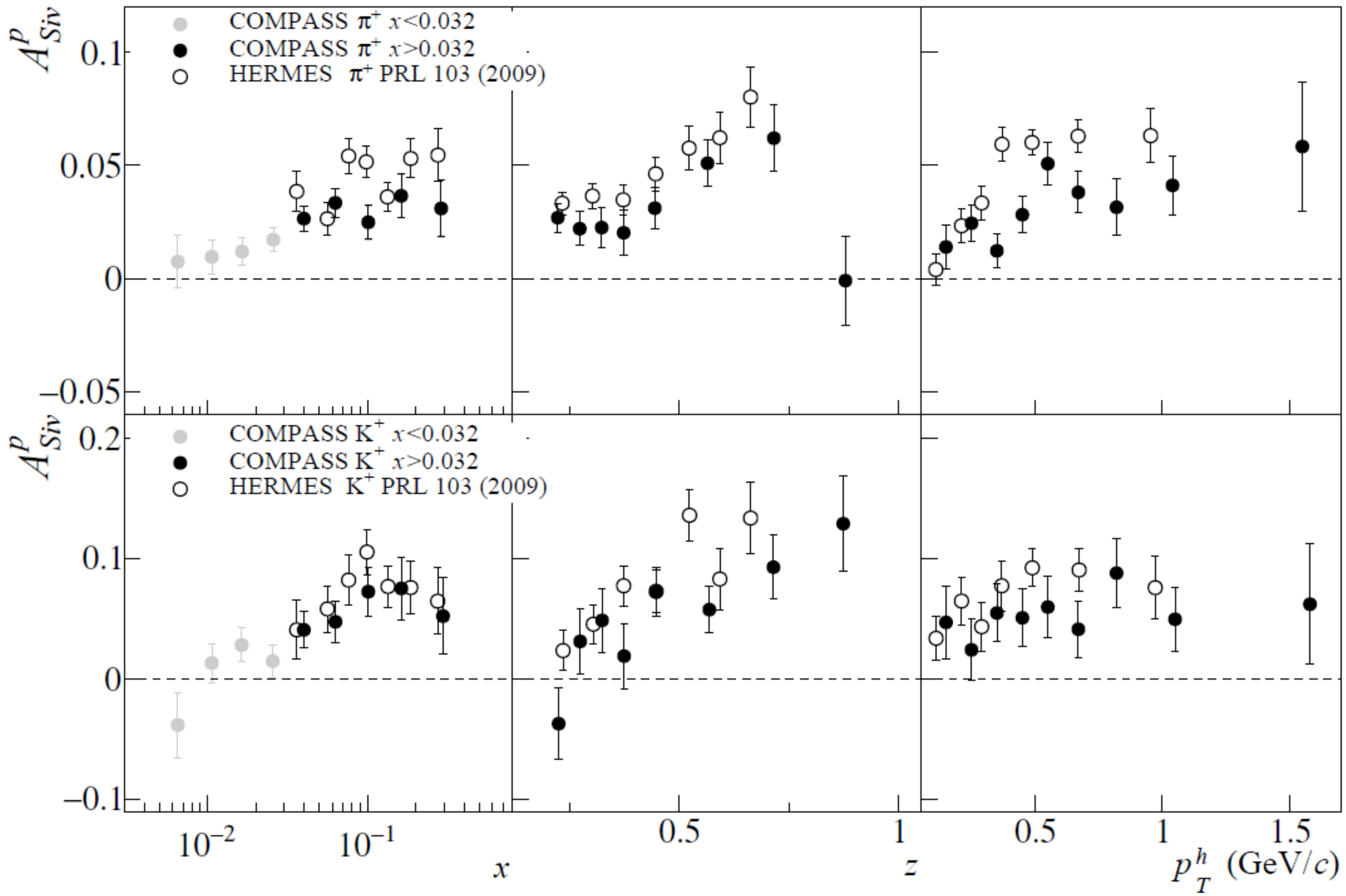


The region around 2 GeV is the overlap region for TMD factorization (low $P_{hT} << Q$) and collinear factorization (high$P_{hT} \sim Q$) (X. Ji, J. P. Ma and F. Yuan, Phys. Rev. D 71, 034005 (2005); Phys. Lett. B 597, 299 (2004); JHEP 0507, 020 (2005).)

- SoLID has P_T coverage slightly higher than 1 GeV/c (up to 1.2~1.4)
- For EIC@HIAF, it reaches up to 2~3 GeV/c
- So observation in this region will help to check/test the QCD factorization theory predictions.

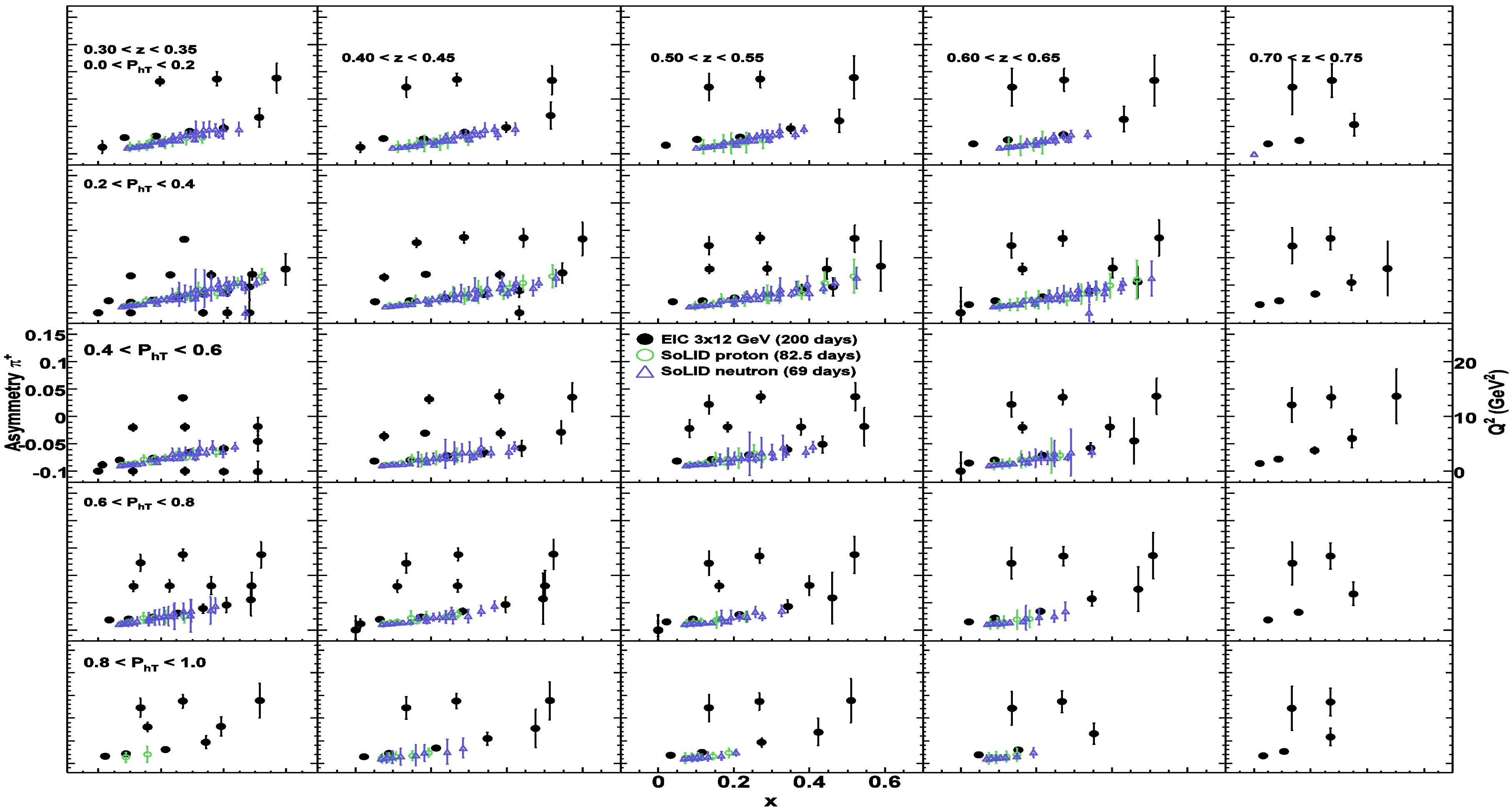
It will be interested to see if it works for Jlab energies and future EIC hadron's transverse momentum distributions --- J. Qiu

TMD Sivers From COMPASS and HERMERS



Many new and interesting results were obtained in last decade. Basic contributions came from the COMPASS,HERMES and JLab experiments

The TMD simulation: Projections for SIDIS Asymmetry π^+



π+ Sivers asymmetries for all kinematic bin in terms of different z and Q2 bin ***(x, Q^2, z and P_T)***

Green (Blue) Points: SoLID projections for polarized NH_3 (^3He/n) target

Luminosity: 10^{35} (10^{36}) (1/cm^2/s); Time: 120 (90) days;

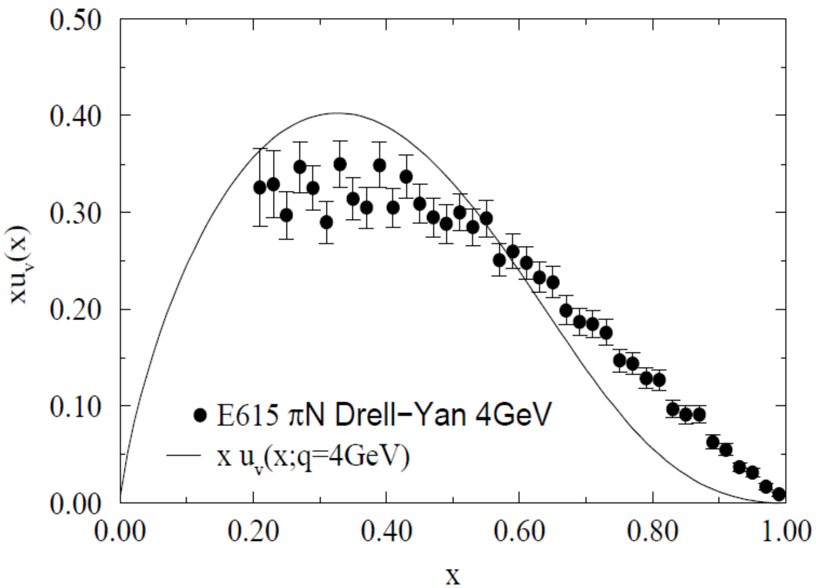
Black points: EIC@HIAF projections for 3 GeV e and 12 GeV p

Luminosity: 4 x 10^{32} /cm^2/s; Time: 200 days

By Haiyan Gao (Duke)

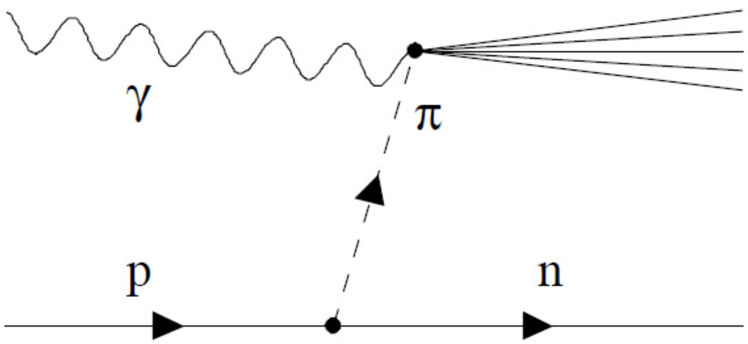
4. π/K Parton Distribution Function in Valence Quark Region

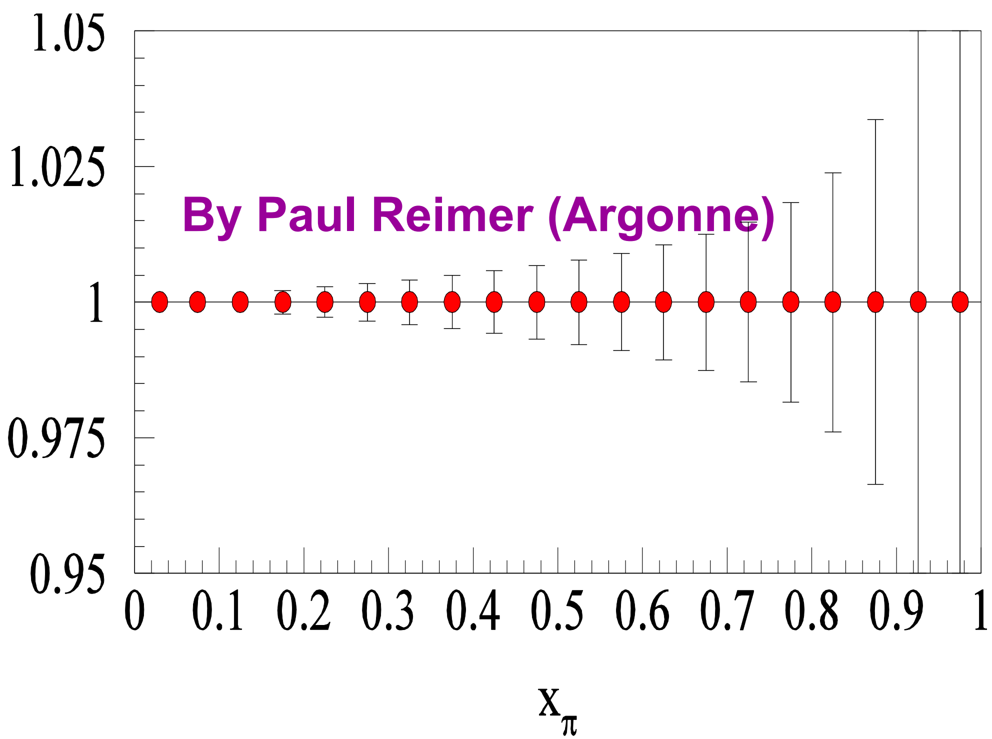
- The pion, being the lightest meson, is particularly interesting not only because of its importance in chiral perturbation theory, but also because of its importance in explaining the quark sea in the nucleon and the nuclear force in nuclei
- π contains a valence quark and antiquark as well as a partonic sea
- Theoretical calculations in the valence region: Dyson-Schwinger and NJL models
- The general features of the valence structure of the pion are qualitatively understood. However, there is no good understanding of the pion sea.



◆Existing data for the π structure function from Drell-Yan scattering, compared to the calculation of DSE.

◆discrepancy between the data and the theoretical calculation at very high x, another measurement using a different technique at high x would be important.





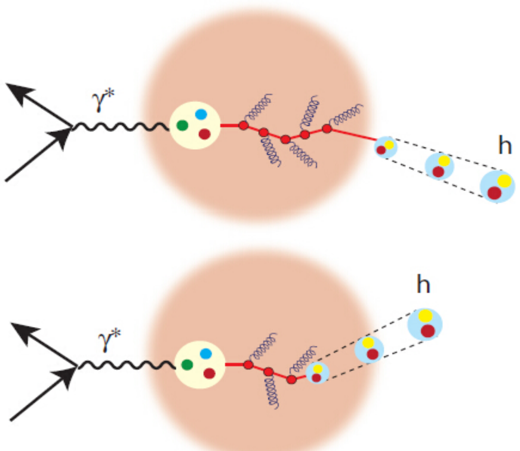
π structure simulation for EIC@HIAF

- 3 GeV e and 12 GeV p
- Luminosity: 5 x 10^{32} /cm^2/s;
- Time:10^6 seconds

EIC@HIAF will be able to extract pion PDFs with a high precision. These, together with the Kaon PDFs, will provide benchmark tests of theoretical calculations, such as Lattice QCD and the Schwinger-Dyson equations approach.

5. Hadronization in the Nuclear Medium

- Hadronization or fragmentation process refer to the transition from colored partons to colorless hadrons
- Although QCD calculations are consistent with hadron production in high energy collisions, knowledge about the dynamics of the hadronization process remains limited and model dependent
- The process could take place entirely inside the nuclear medium, or outside the medium, or somewhere in-between
- Two mechanisms lead to different predictions on the hadron yield on nuclei as compared to that on free nucleons (multiplicity ratio R^h_A)



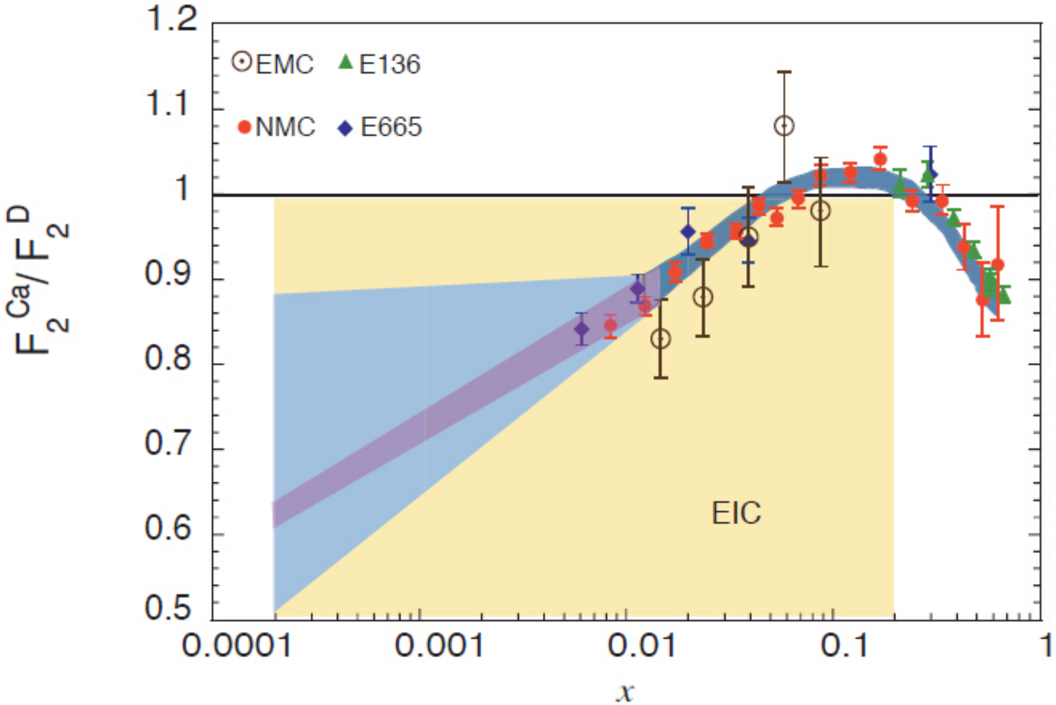
When hadronization takes place inside the nucleus, semi-inclusive deep inelastic lepton-nucleus collisions can provide the important information on the space-time development of the hadronization process in the nuclear medium

More Precise Measurements Need

- Many new and interesting results were obtained in the last decade (HERMES, JLab， …).
- Phenomenological models can not describe the whole set of new results. New, more precise measurements are required
- Future precise experimental results will help unravel the space-time dynamics of the hadronization process
- EIC would able to contribute considerably into this field
- The EIC@HIAF would have a capability of colliding many ion species at a wide energy, it can shed light on the hadronization process and provide new information about the mechanism of hadronization
- Simulations are going on.

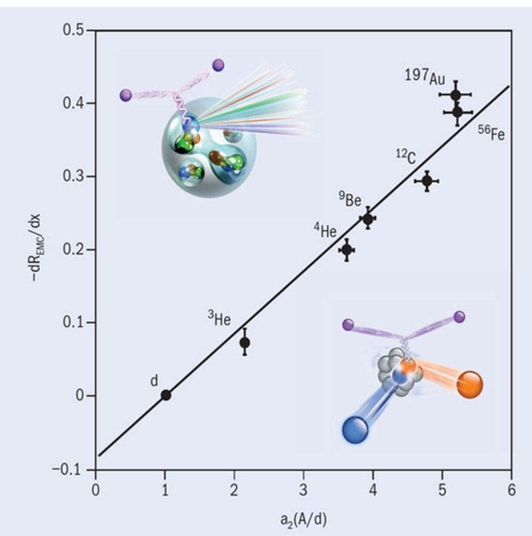
6. EMC and SRC

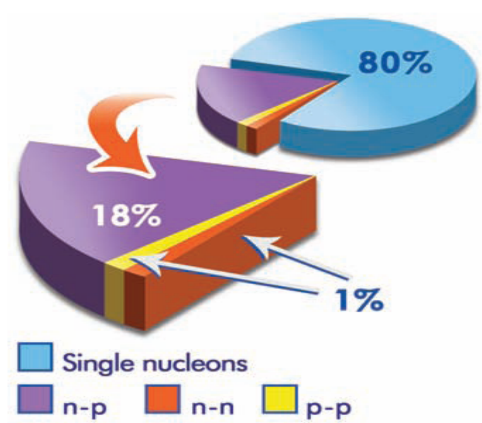
- EMC effect: the nucleon structure in a bound state is different from the one in free space in 0.3 < x < 0.7
- A lot of theoretical efforts have been made aimed at understanding the underlying the effect. However, there is no generally accepted model for the effect over all A and x_B

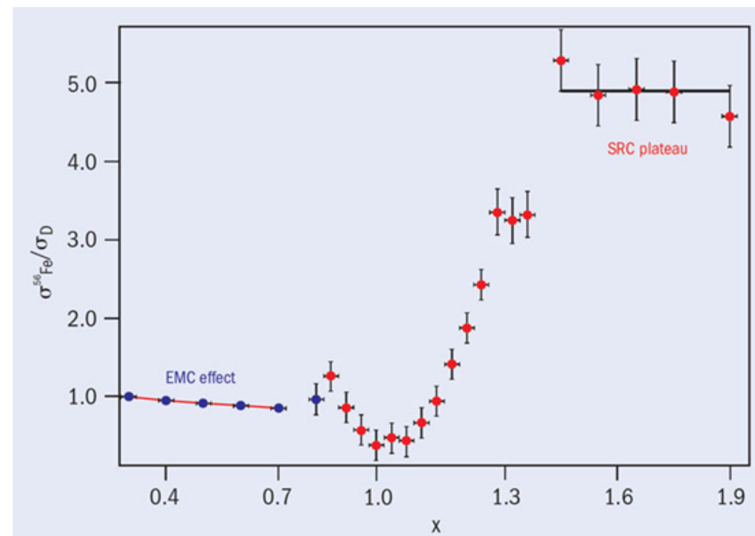


The ratio of nuclear over nucleon F2 structure function, R2, as a function of Bjorken x

- The SRC occur between pairs of nucleons with high relative momentum but low center of mass momentum (where low and high are relative to the Fermi momentum in heavy nuclei)
- the magnitude of the EMC effect measured in electron DIS at intermediate x_B is linearly related to the short range correlation (SRC) scaling factor obtained from electron inclusive scattering at $x_B > 1$
- The EIC@HIAF can shed light on the origin of the EMC effect and SRC study







The SRC scaling factor $a_2 = (2/A)(\sigma_A/\sigma_d)$

Hadron Physics for EIC@HIAF?

- The systematics of the hadron excitation spectrum is important to our understanding of the effective degree of freedom underlying nucleon matter
- The e+e- machine, such as Belle, BaBar and BES, search for new states charmonium states: x, y and z particles
- The JLab12 GlueX searches for gluon excitation, as well as Search for new hadron states
- The EIC@HIAF, as ep machine, higher CM energy than Jalb 12, should have some advantages in this field, but more study is needed!

EIC@HIAF Location

Huizhou, Guangdong

Current Status of HIAF-EIC

- EIC@HIAF opens up a new window to study/understand nucleon structure, especially the sea quark
- There are 6 possible "Golden Experiments"
- We will continue to apply for the HIAF-EIC program in the earliest possible time (HIAF II)
- Its cost will be around US $ 300 Million
- With help from international community, simulations of the six golden experiments and initial detector study are ongoing; a whitepaper on China EIC is under preparation.
- International collaborations for HIAF-EIC are very welcome!

Thanks for your attention!