中国科学院近代物理研究所
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An Electron Ion Collider in China

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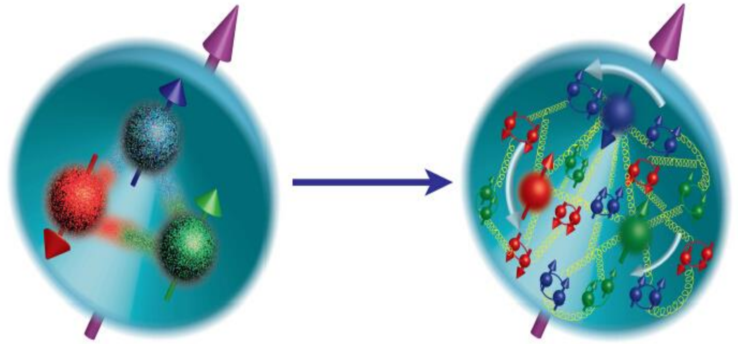
9th APCTP - BLTP JINR Joint Workshop at Kazakhstan

Modern problems of nuclear and elementary particle physics

June 27 - July 4, 2015, Almaty, Kazakhstan

EIC@China Project

- ◆ **IMP Introduction and HIAF Project**
- ◆ **EIC@HIAF Project**
  - **3 GeV (pol. e) X 12 GeV (pol. p), L= 4×10^{32}**
- ◆ **Unique Opportunities for EIC@HIAF**
  - ➢ **Spin-Flavor Structure (sea quark polarization)**
  - ➢ **3-d Structure of the Nucleon (GPDs/TMDs)**
  - ➢ **π/K Structure Functions**
  - ➢ **Hadronization/EMC/SRC**
- ◆ **Current Status and Summary**



Part 1

IMP and HIAF

Institute of Modern Physics (IMP)

- 1957: The institute of Modern Physics(IMP) was founded. It is affiliated with the Chinese Academy of Sciences (CAS)
- 1991: Heavy Ion Research Facility in Lanzhou (HIRFL).
- 2007: Cooler Storage Ring (HIRFL-CSR) : ~2 GeV for p, ~1 GeV/u for heavy ion, up to U
- Research center for low-to-intermediate energy physics in China.
- More than 800 scientists and engineers
- 2011New Proposal: High Intensity Heavy Ion Accelerator Facility (HIAF)

(Physics Today, May 2013)

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

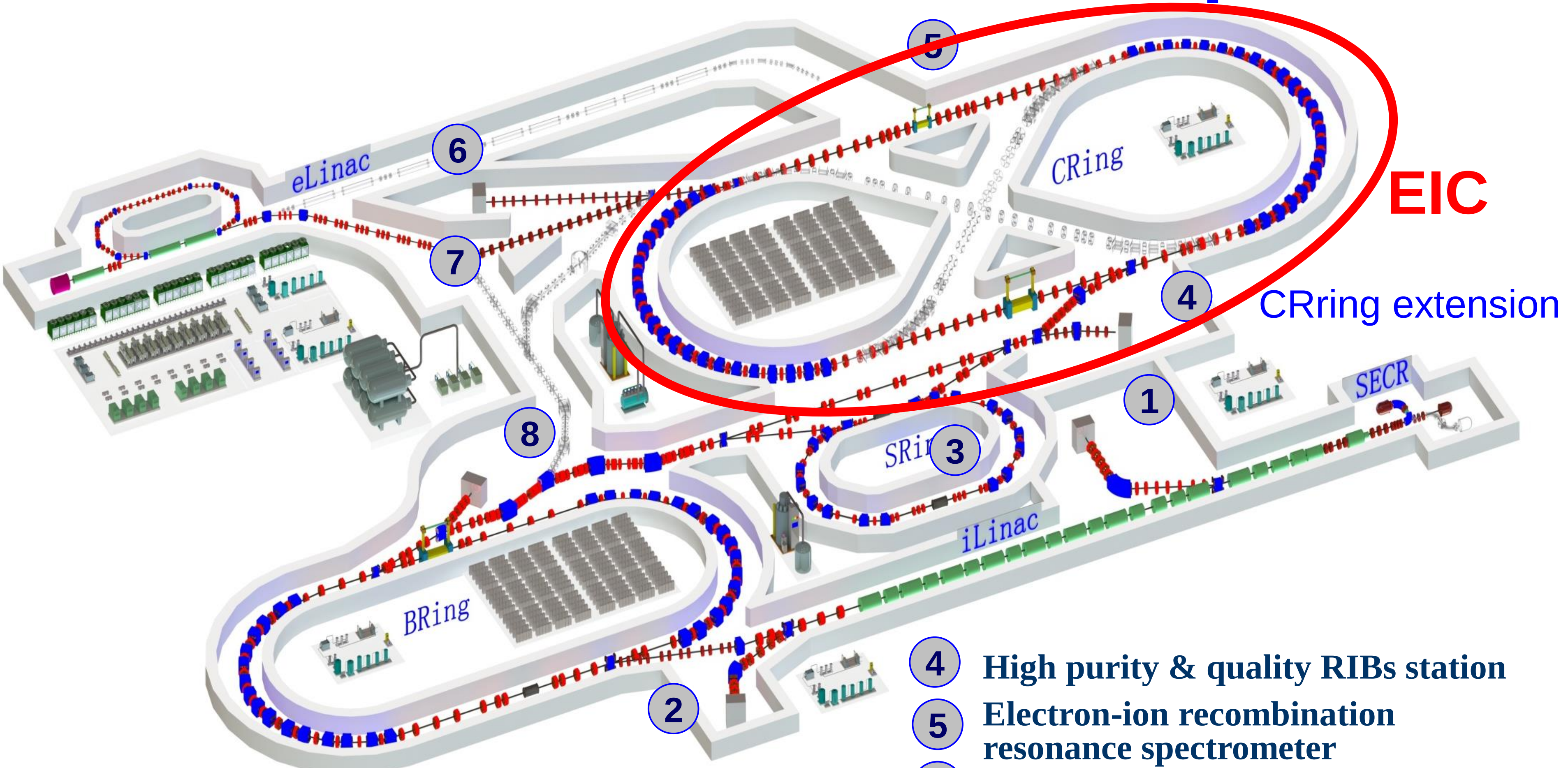
12th five-year plan: Mid- to long-term projects ranked by priority

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**

Overview of the HIAF Complex



1. Low energy nuclear structure spectrometer
2. Low energy RIBs beam station
3. High precision spectrometer
4. High purity & quality RIBs station
5. Electron-ion recombination resonance spectrometer
6. High energy irradiation terminal
7. High-Energy-Density Matter terminal
8. External target station

Part 2

EIC@HIAF Project

EIC@ HIAF Propose

- **Initial goals for HIAF:**
  1) Nuclear Physics (rare isotope)
  2) high-energy-density matter
  3) applications …
- **New:** add collision physics –EIC

  Discussions, 2012- 2014: inputs from Chinese and international communities

  Phase one: 3 GeV (pol. e) x 12 ~16 GeV (pol. p), L >= 4×10^{32}

  Time: significantly before US EIC (5 ~10 years)
- **Many discussions on China EIC plan:**
  - 2nd Int. Conf. on "QCD and Hadron Physics", March, 2013, Lanzhou
  - Symposium on EIC @ China, July, 2013, Weihai, China

    strong support for EIC@HIAF

Luminosity consideration of EIC

		Proton	Electron
Beam energy	GeV	12	3.0
Collision frequency	MHz	500	
Particles per bunch	10^{10}	0.54	3.7
Beam Current	A	0.43	3
Polarization	%	> 70	~ 80
Energy spread	10^{-4}	3	3
RMS bunch length	cm	2	1
Horizontal emittance, geometric	nm•rad	150	30
Vertical emittance, geometric	nm•rad	50	10
Horizontal β*	cm	2	10
Vertical β*	cm	2	10
Vertical beam-beam tune shift		0.0048	0.015
Laslett tune shift		0.045	Very small
Luminosity per IP, 10^{32}	$cm^{-2}s^{-1}$	4.0	

Under considering: Energy: 5 x 25 GeV, Lumi = 10^{33}

HIAF Budgets

HIAF phase 1: USD$400M， +EIC: extra USD$300M

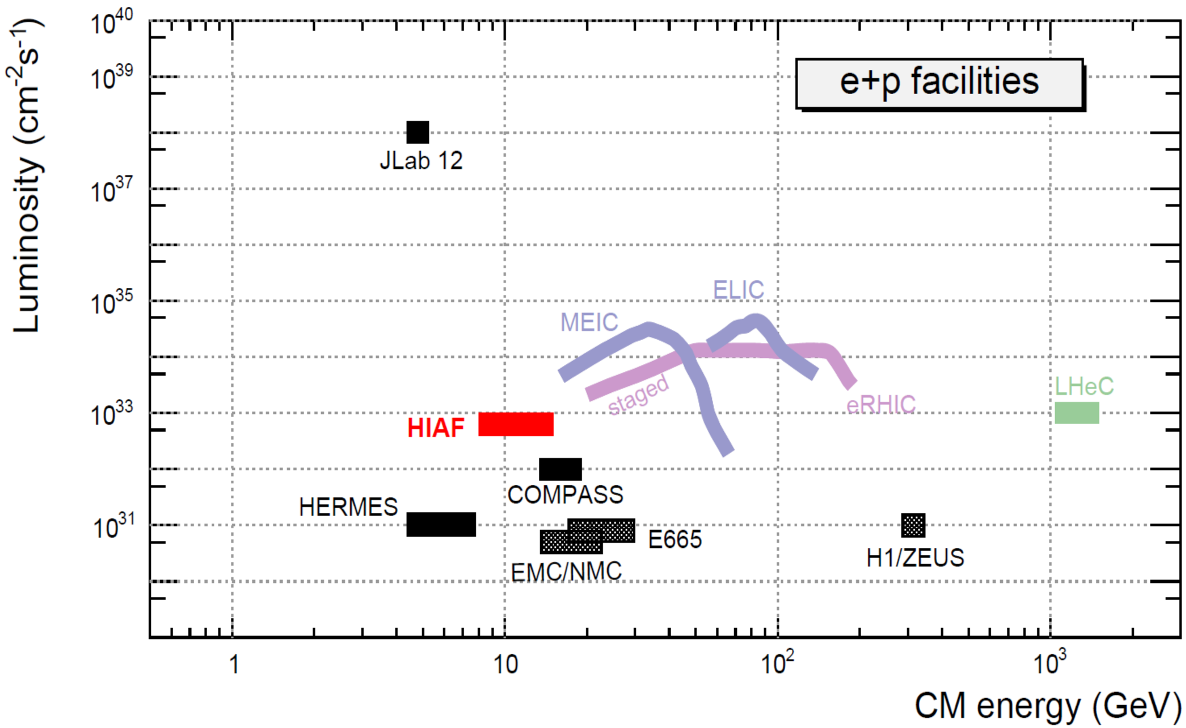
Items	1st phase (100M RMB)	EIC Budget(100M RMB)
iLinac	0.4+5.1	
BRing	3.2	0.1
CRing	3.7	1.9
eLinac	0.5	3.57
ERing		4.0
High energy electron cooling		1.0
Beam transfer line	0.5	0.25
Experiment setups	3.3	3.1 (EIC Detector)
Cryogenics	2.05	1.2
Civil engineering	2.45	1.73
Tunnel construction	1.8	0.9
Contingency cost	0.7	1.3
Total	23.7	19.35

Part 3

Unique Opportunities for EIC@HIAF

Lepton-Nucleon Facilities

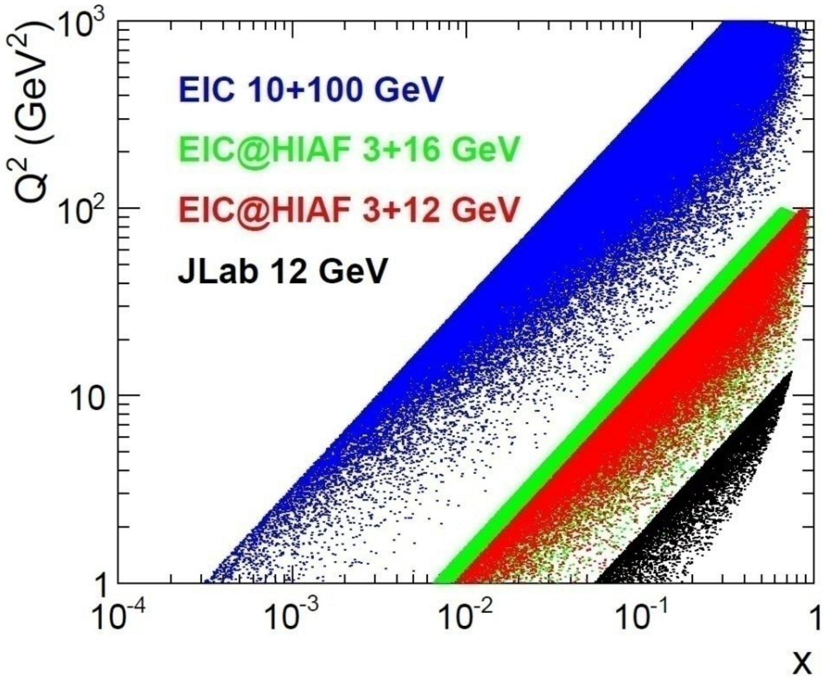
HIAF: e(3GeV) +p(12~16 GeV), both polarized, L>= $4*10^{32} cm^2/s$

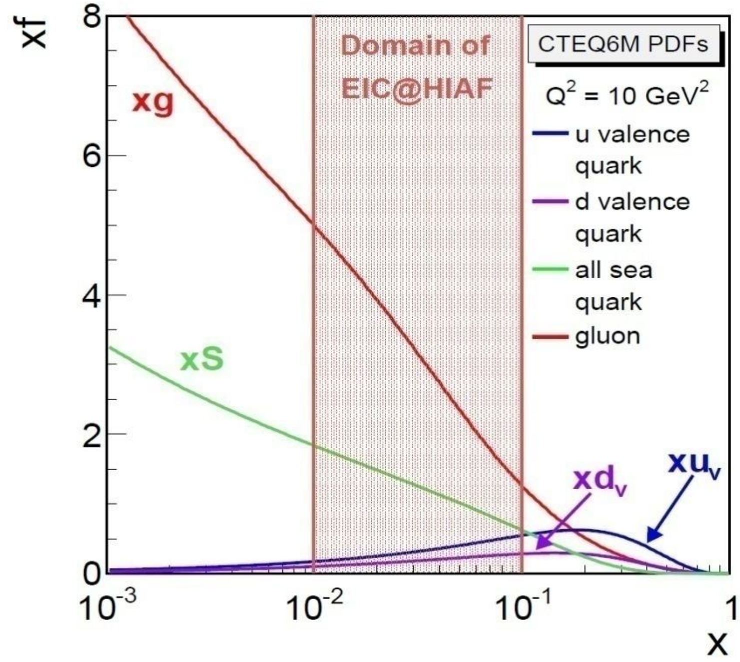


- The energy reach of the EIC@HIAF is significantly higher than JLab12 but lower than the full EIC being considered in US
- COMPASS has similar (slightly higher) energy, but significantly lower polarized luminosity (about a factor of 200 lower, even though the unpolarized luminosity is only a factor 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

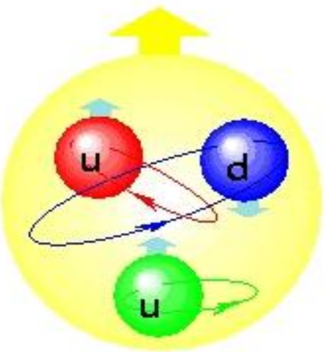
EIC@HIAF's Advantages

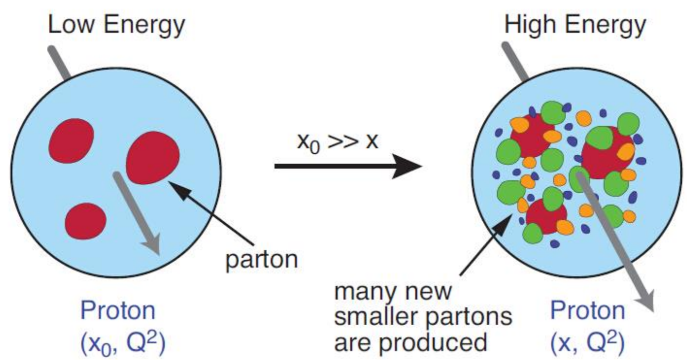
- **Many aspects of parton structure can be uniquely addressed by an EIC, especially an EIC with polarization, such as EIC@HIAF**
- **The main theme for the future full EIC machines (eRHIC, MEIC, LHeC) is to understand the gluons**
- **The Phase-I of EIC@HIAF will fill the gap between the existing facilities (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

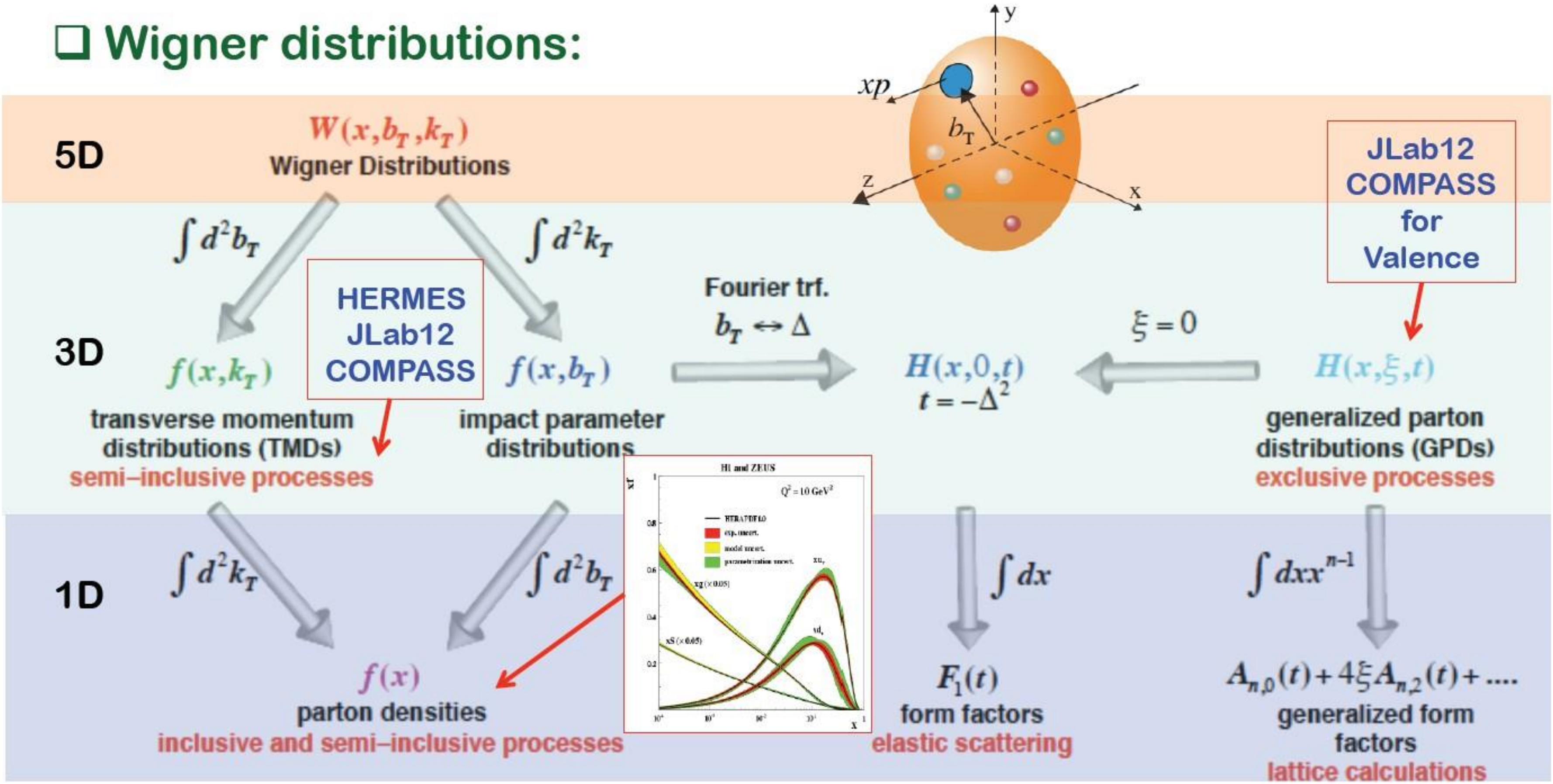
Six golden experiments

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





Unified view of nucleon structure



EIC – 3D imaging of nucleon structure:

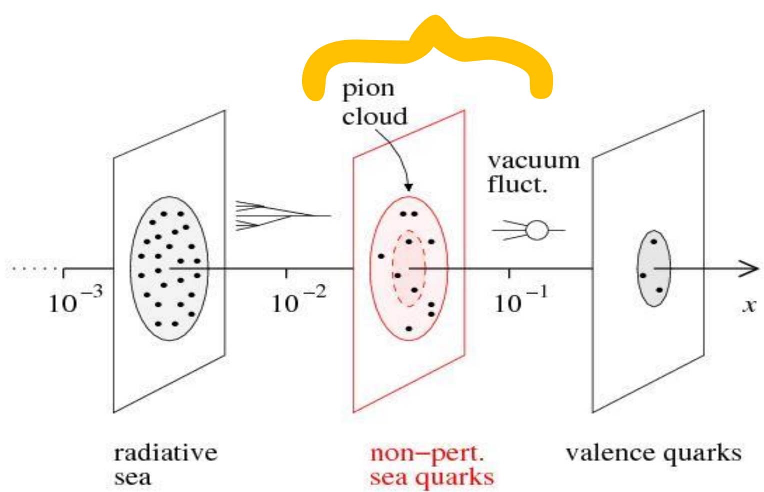
- ➢TMDs – confined motion in a nucleon (semi-inclusive DIS)
- ➢GPDs – Spatial imaging of quarks and gluons (exclusive DIS)

1. Spin-Flavor Study at EIC@HIAF

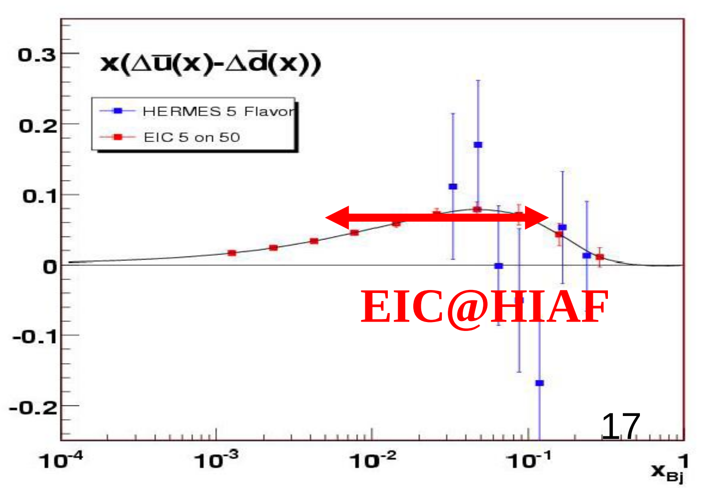
- **Understanding the spin structure of the nucleon in terms of constituent partons, i.e. quarks and gluons, has been and still is an essential task of subatomic physics**
- The electron ion collider(EIC) provides unique opportunities to study the inner structure of the nucleon, especially the polarized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

Significant improvement for Δubar, Δdbar from SIDIS

Unique opportunity for Δs

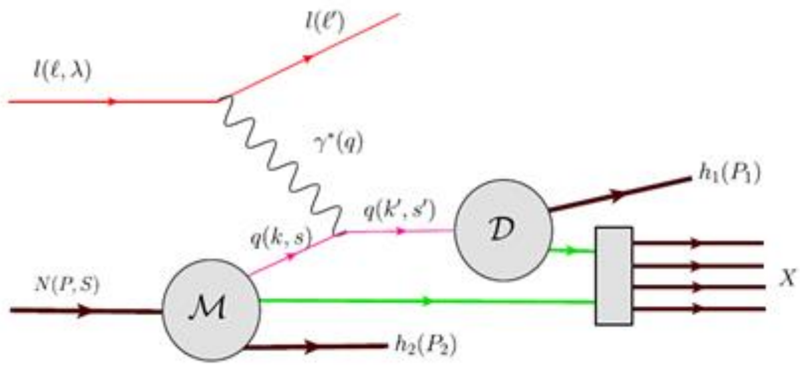


Sea Quark Polarization



1. Spin-Flavor Study at EIC@HIAF

- 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



Fragmentation Function:

Lepto-production of two hadrons:

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

Due to the complexity in theoretical interpretations, the target fragmentation is generally less explored

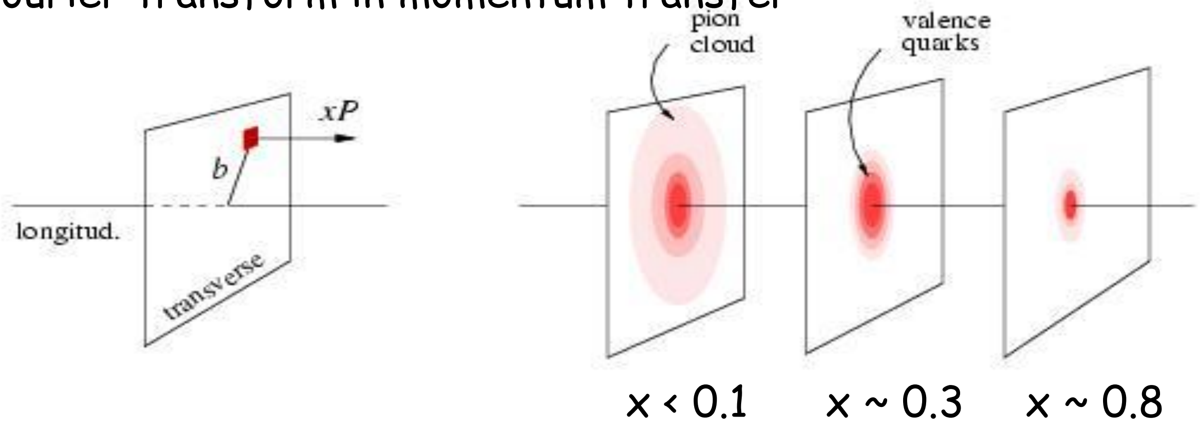
2. GPD Study at EIC@HIAF:
What's the use of GPDs?

1. Allows for a unified description of form factors and parton distributions

2. Describe correlations of quarks/gluons

3. Allows for Transverse Imaging

Fourier transform in momentum transfer



gives transverse spatial distribution of quark (parton) with momentum fraction x

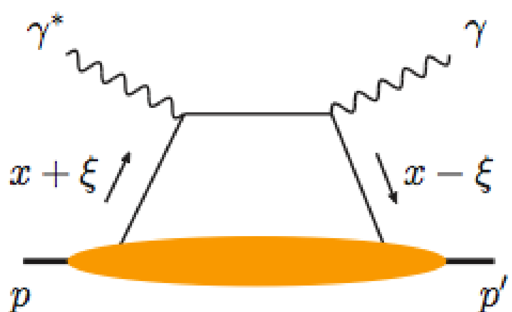
4. Allows access to quark angular momentum (in model-dependent way)

2. GPD Study at EIC@HIAF

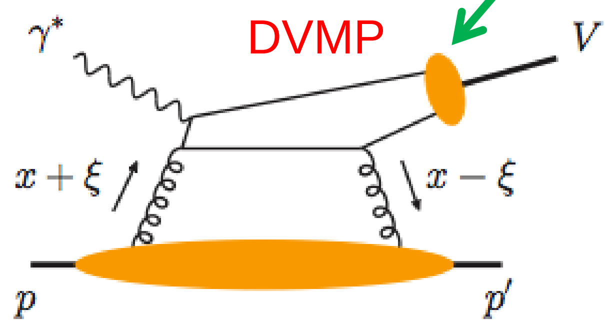
- **GPDs can be extracted from suitable exclusive scattering processes in ep collisions**
- **Deeply virtual Compton Scattering (DVCS) and deeply virtual exclusive meson production (DVMP)**

Meson

DVCS



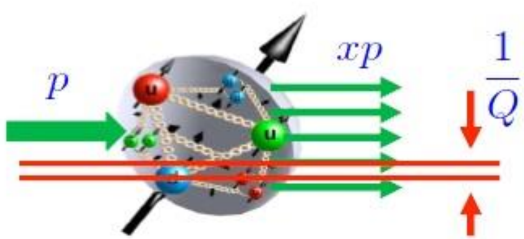
DVMP



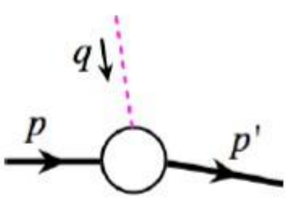
GPD

In the Bjorken limit: $Q^2 >> (-t), \Lambda^2_{QCD}, M^2$

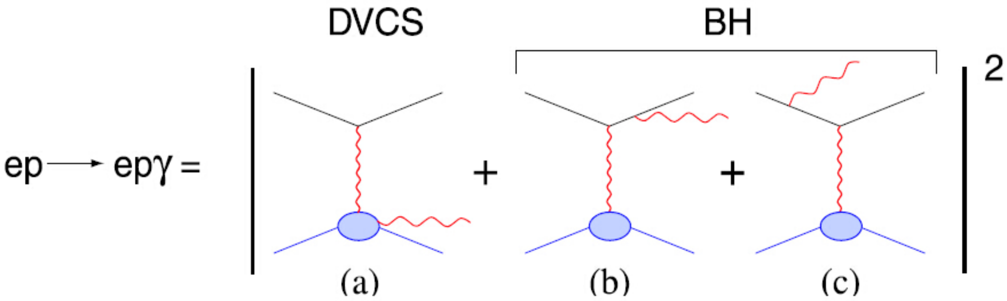
❑ GPDs – 1D momentum + 2D space distributions (exclusive):



✧ Need a localized probe
✧ Scan in transverse direction
✧ Spatial imaging

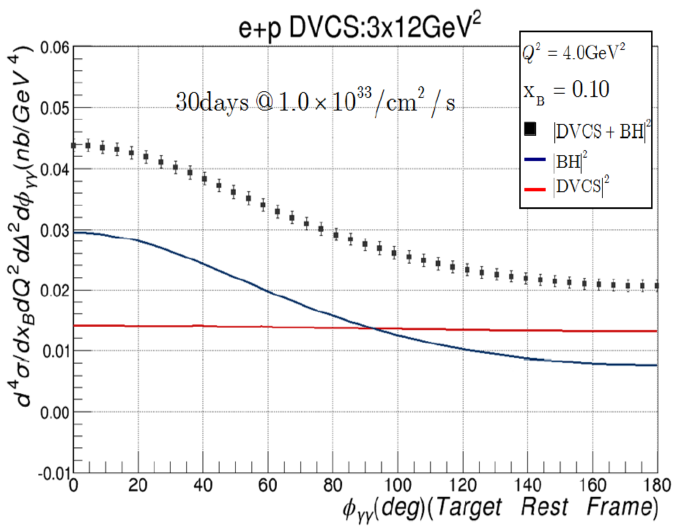


DVCS simulations

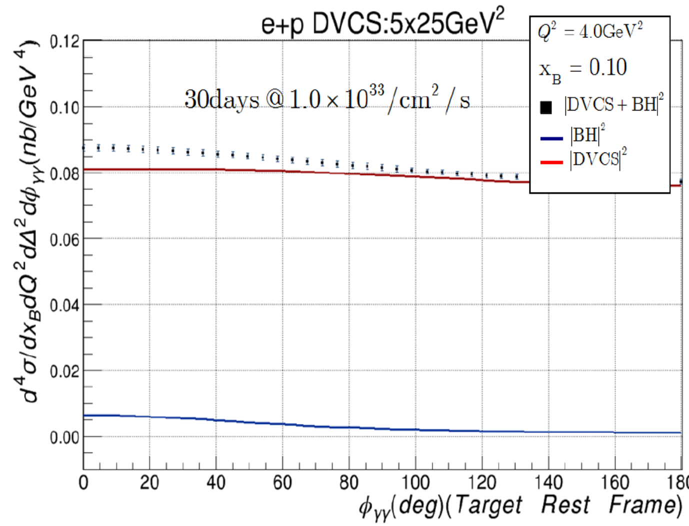


DVCS/DVMP interferes with the Bethe-Heitler process

3 x 12 GeV



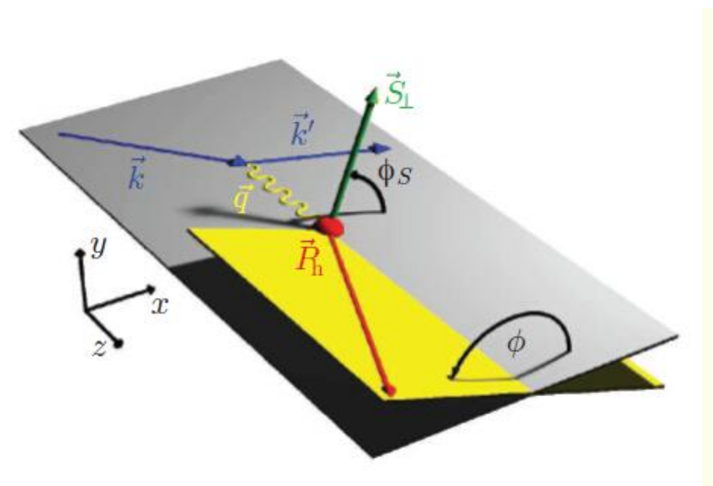
5 x 25 GeV



- flavor decomposition needs DVMP
- 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)
- energy reaches Q^2 > 5~10 GeV^2, scaling region for exclusive light meson production

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



Leading Twist TMDs — : Nucleon Spin — : Quark Spin

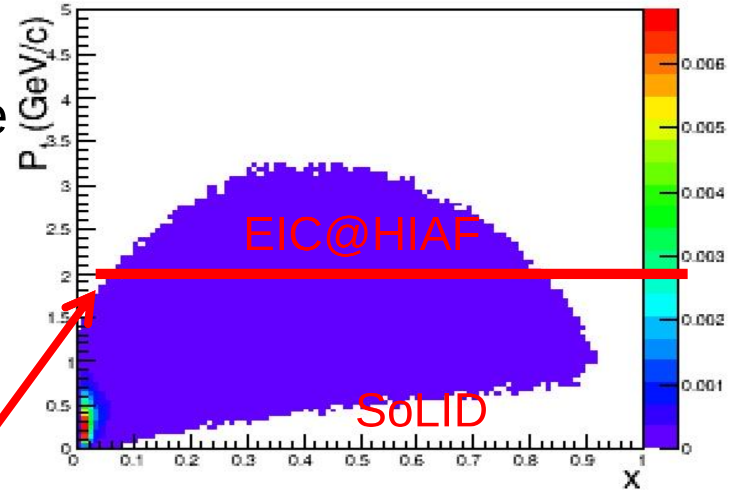
Nucleon Polarization	Quark polarization: Un-Polarized (U)	Quark polarization: Longitudinally Polarized (L)	Quark polarization: Transversely Polarized (T)
U	f_1 =		$h_1^\perp$ = − Boer-Mulder
L		g_1 = − Helicity	$h_{1L}^\perp$ = −
T	$f_{1T}^\perp$ = − Sivers	$g_{1T}^\perp$ = −	h_{1T} = − Transversity; $h_{1T}^\perp$ = −

- 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

TMD Study at EIC@HIAF

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 ~ 0.01
- Significant increase in Q^2 range for valence region: energy reach Q^2 ~40 GeV^2 at x ~ 0.4

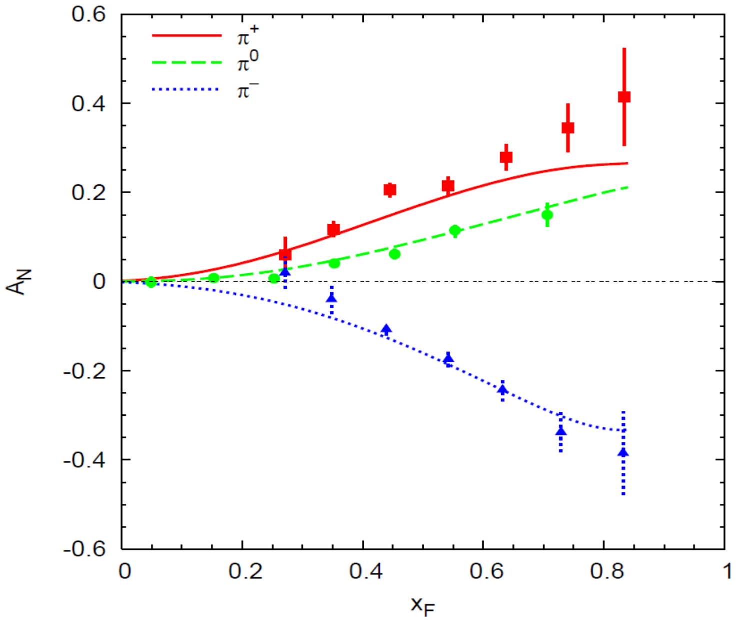


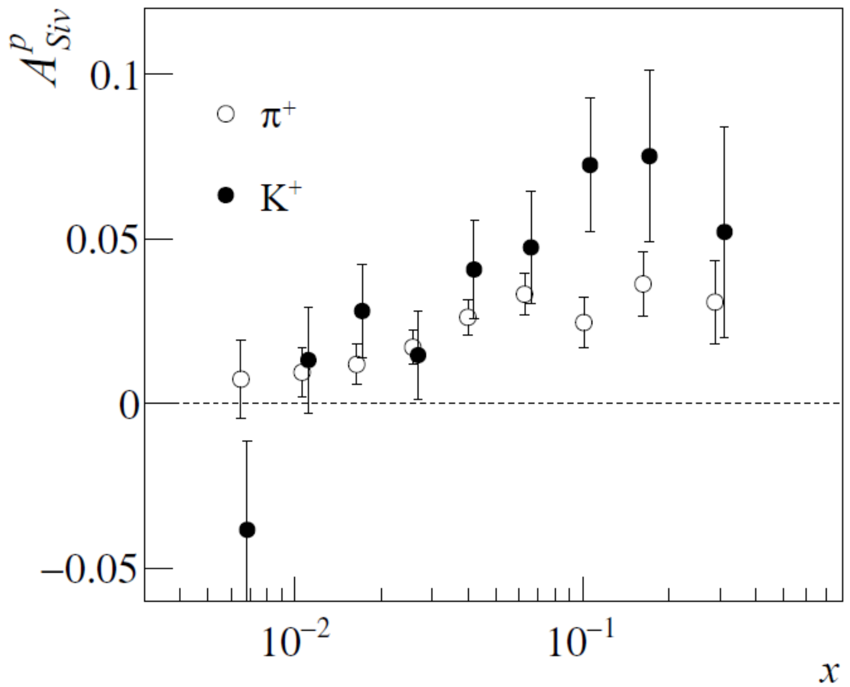
- Significant increase in P_T range:

➢ The region around 2 GeV is the overlap region for TMD factorization and collinear factorization (X. Ji, etc., Phys. Rev. D73 (2006) 094017)
➢ 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.

TMD Asymmetry

●Common belief: the asymmetry (polarization effects) is calculable perturbatively in QCD. The result is zero for $m_q = 0$ and is numerically small if we calculate Mq/sqrt(s) corrections for light quarks.(G.L.Kane, J.Pumplin, W.Repko, Phys.Rev.Lett. 41(1978)1689). The problem was that the conclusion was got in framework of the "collinear" QCD.



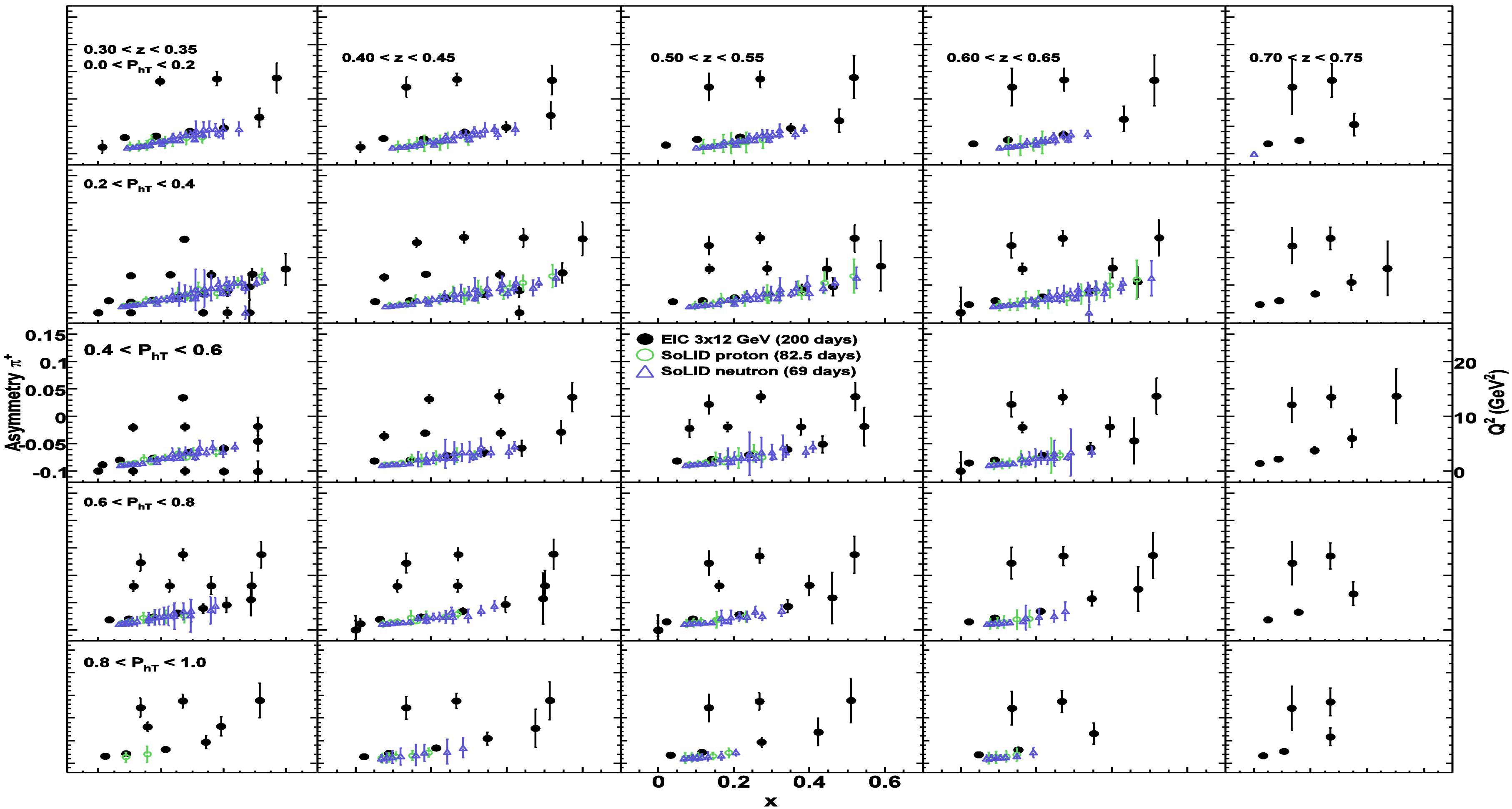


Experiment E704, Fermilab, 200 GeV polarized proton beam

D. L. Adams et al., E704 Coll., Phys.Lett. B261(1991)201; B264(1991)462; Z.Phys. C56(1992)181

C.Adolph et al.,COMPASS Coll. Phys.Lett. B744 (2015) 250

The TMD simulation: Projections for SIDIS Asymmetry π^+



π+ Sivers asymmetries for all kinematic bin in terms of different z and Q2 bin

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

(x, Q^2, z and P_T)

By Haiyan Gao (Duke)

Sea Quark TMD Sivers Function

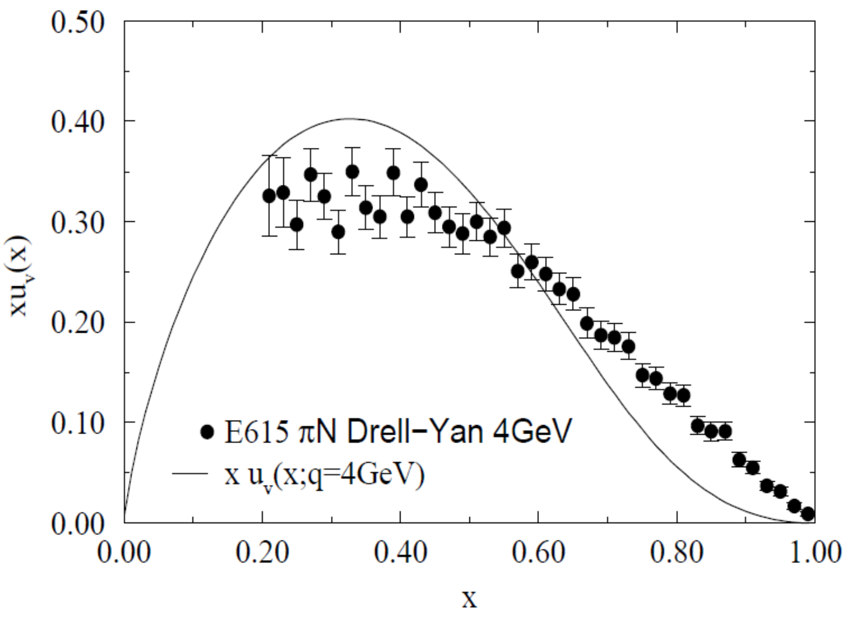
- **EIC@HIAF reaches high precision similar to SoLID at lower x, higher Q2 region**

- The EIC will be a powerful facility enabling access to TMDs with unprecedented precision, and particularly in the currently unexplored sea quark region

- This precision is not only crucial for the fundamental QCD test of the sign change between the Sivers asymmetries in the DIS and Drell-Yan processes, but also important to investigate the QCD dynamics in the hard processes in SIDIS

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

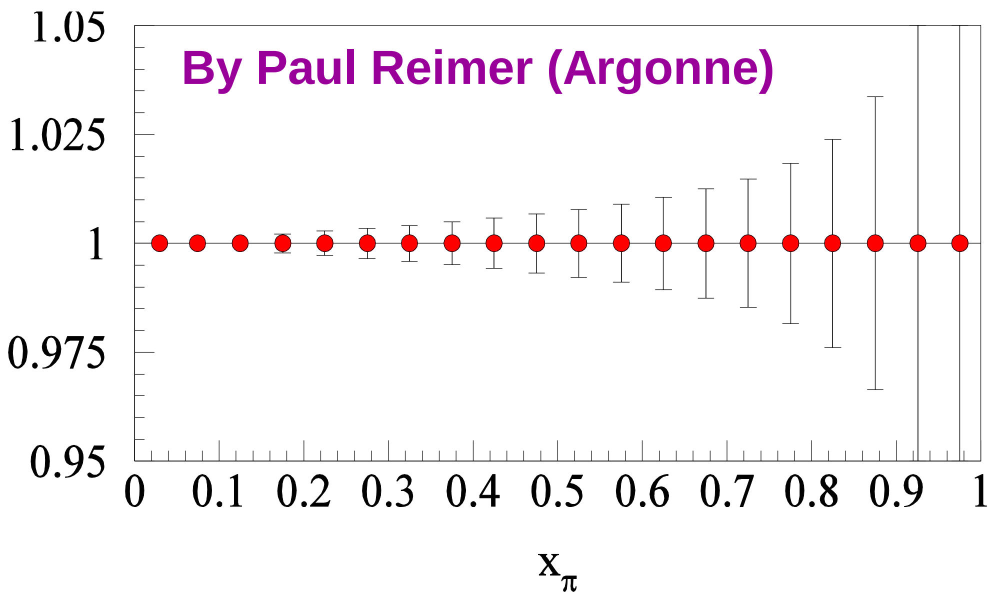
- The pion, being the lightest meson, is particularly interesting not only because of its importance in chiral perturbation theory, but also because of its importance in explaining the quark sea in the nucleon and the nuclear force in nuclei
- π contains a valence quark and antiquark as well as a partonic 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.

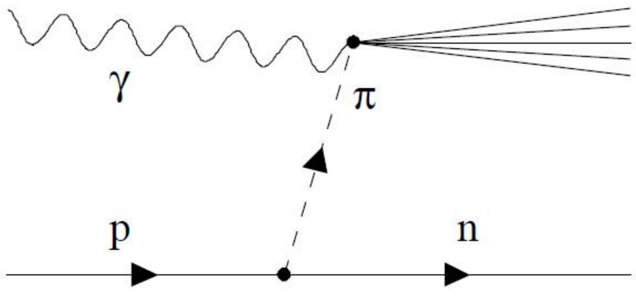


◆Existing data for the π structure function from Drell-Yan scattering, compared to the calculation of DSE.

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

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





π structure simulation for EIC@HIAF

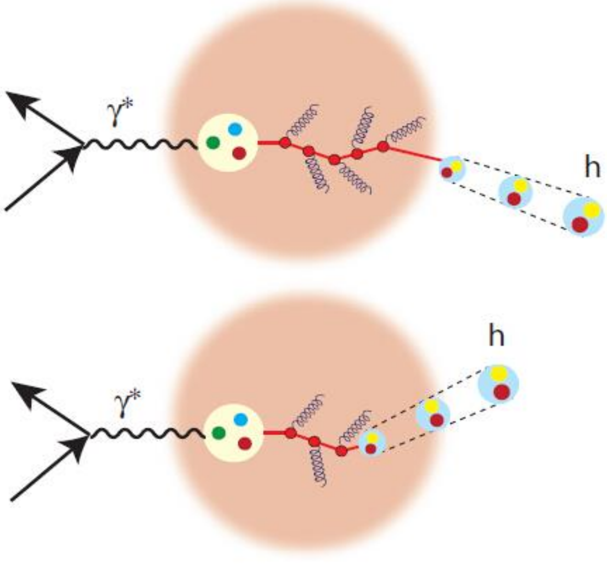
- 3 GeV e and 12 GeV p
- Luminosity: 5 x 10^{32} /cm^2/s;
- Time:10^6 seconds

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

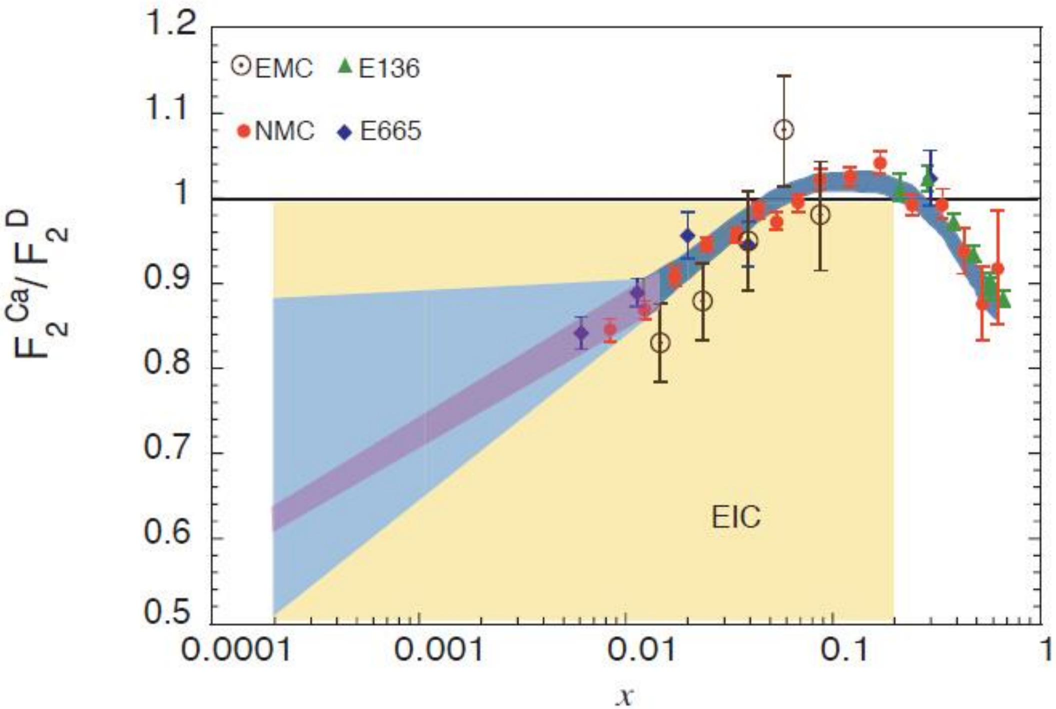
- Hadronization or fragmentation process refer to the transition from colored partons to colorless hadrons
- Although QCD calculations are consistent with hadron production in high energy collisions, knowledge about the dynamics of the hadronization process remains limited and model dependent
- The EIC@HIAF 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
- Measurements with hadronization in electron and ion collision processes are under simulating

The process could take place entirely inside the nuclear medium, or outside the medium, or somewhere in-between



6. EMC and SRC

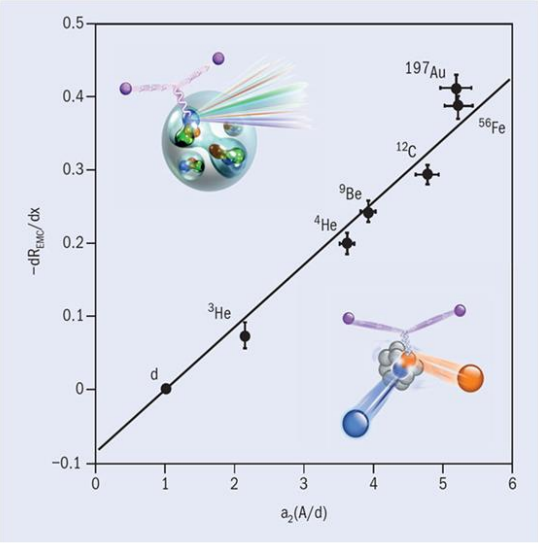
- EMC effect: the nucleon structure in a bound state is different from the one in free space in $0.3 < x < 0.7$
- A lot of theoretical efforts have been made aimed at understanding the underlying the effect. However, there is no generally accepted model for the effect over all A and x_B

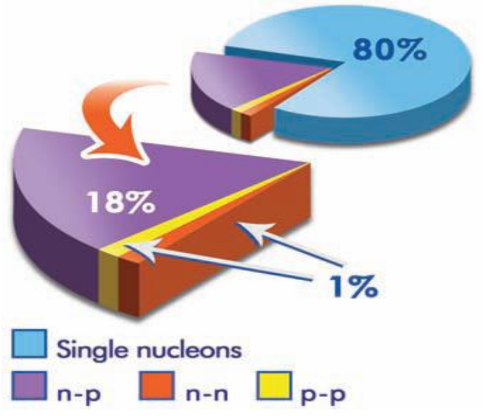


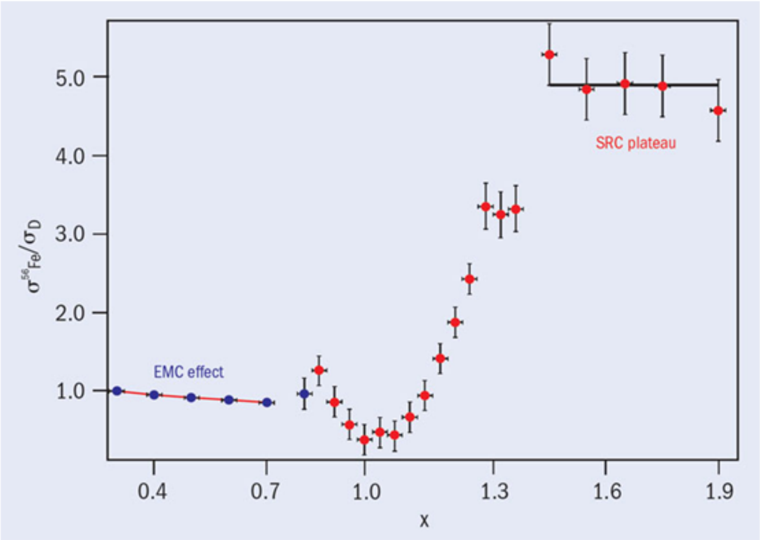
The ratio of nuclear over nucleon F2 structure function, R2, as a function of Bjorken x

6. EMC and SRC

- 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!

Part 4

Current Status and Summary

Current Status of HIAF-EIC

- The HIAF project initially was proposed in 2009, approved in principle by the central government in Jan 2013, should be finally approved some time in 2015. Hopefully we can start construction in 2016. Project completion is expected in 2022. The total budget of HIAF (no EIC) is about US $ 400 Million

- IMP will submit the EIC proposal. Its cost will be around US $ 300 Million

- The Chinese high energy and nuclear physics communities strongly support this EIC project. A special and key important symposium on the HIAF-EIC was held in Beijing between the Chinese government and high energy physics communities in May 6, 2014. Both the Chinese government and experts strongly support the HIAF-EIC plan and think the EIC program should be started up in the earliest time of the Chinese 13th five-year (2016-2020). The possibility of combination of Super Tau and Charm machine was also being proposed
- 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!**

EIC-14 Jefferson Lab, March 17-24

※ Discussed the possible four future EIC machines over the world （EIC@HIAF, MEIC-J-Lab, eRHIC-BNL, LHeC-CERN）

※ EIC@HIAF has great advantages in technique and time window than the other three

※ EIC-18 will be held in China (2018)

EIC@HIAF Location

Huizhou, Guangdong

Summary

- EIC@HIAF opens up a new window to study/understand nucleon structure, especially the sea quark. Examples of Possible "Golden Experiments":
  - Nucleon spin-flavor structure (polarized sea, Δs)
  - 3-d structure: GPDs (DVMP) and DVCS
  - 3-d structure: TMDs (sea, range in Q^2, P_T)
  - Meson (pion/Kaon) structure function at high-x
  - Hadronization/EMC/SRC
- There are wonderful Physics and Time windows for EIC@HIAF machine
- Both the Chinese and international high energy and nuclear physics communities strongly support this EIC project
- Opportunity to bring Chinese hadron physics to the forefront in the world

Thanks for your attention!

Co-operations are very welcome!

Any comments are very welcome!