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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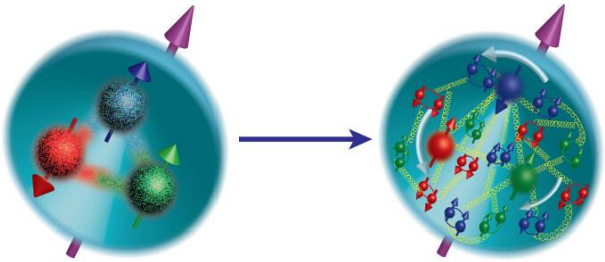
The Sixth Workshop on Hadron Physics in China and Opportunities in US
July 21~24, 2014 at Lanzhou

EIC@China Project

- IMP 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
- 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

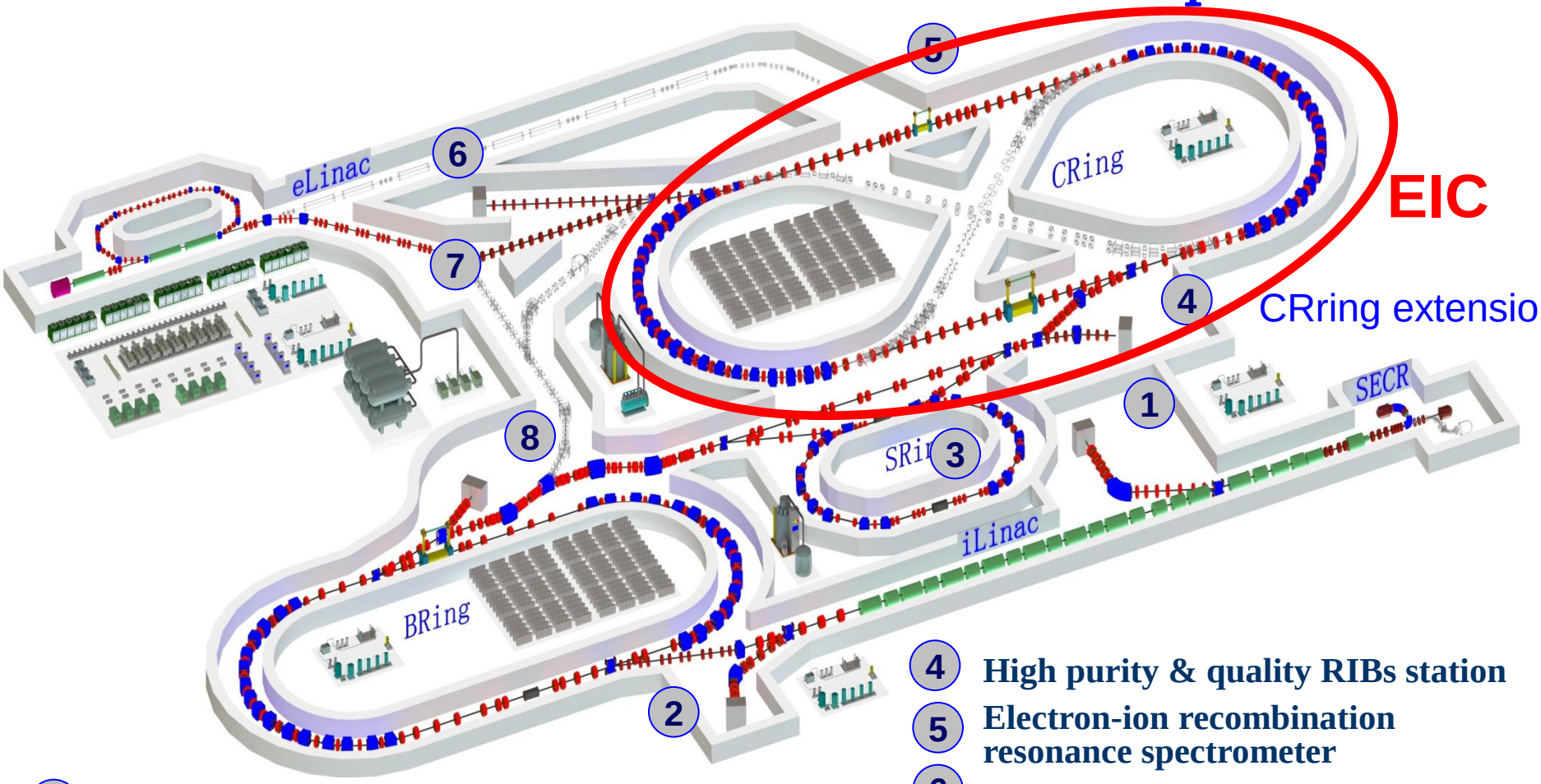
12th five-year plan: Mid- to long-term projects ranked by priority

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 >= $4x10^{32}$

Time: significantly before US EIC (5 ~10 years)

- **Many discussions on China EIC plan:**
  - 2^{nd} Int. Conf. on "QCD and Hadron Physics", March, 2013, Lanzhou
  - Symposium on EIC @ China, July, 2013, Weihai, China

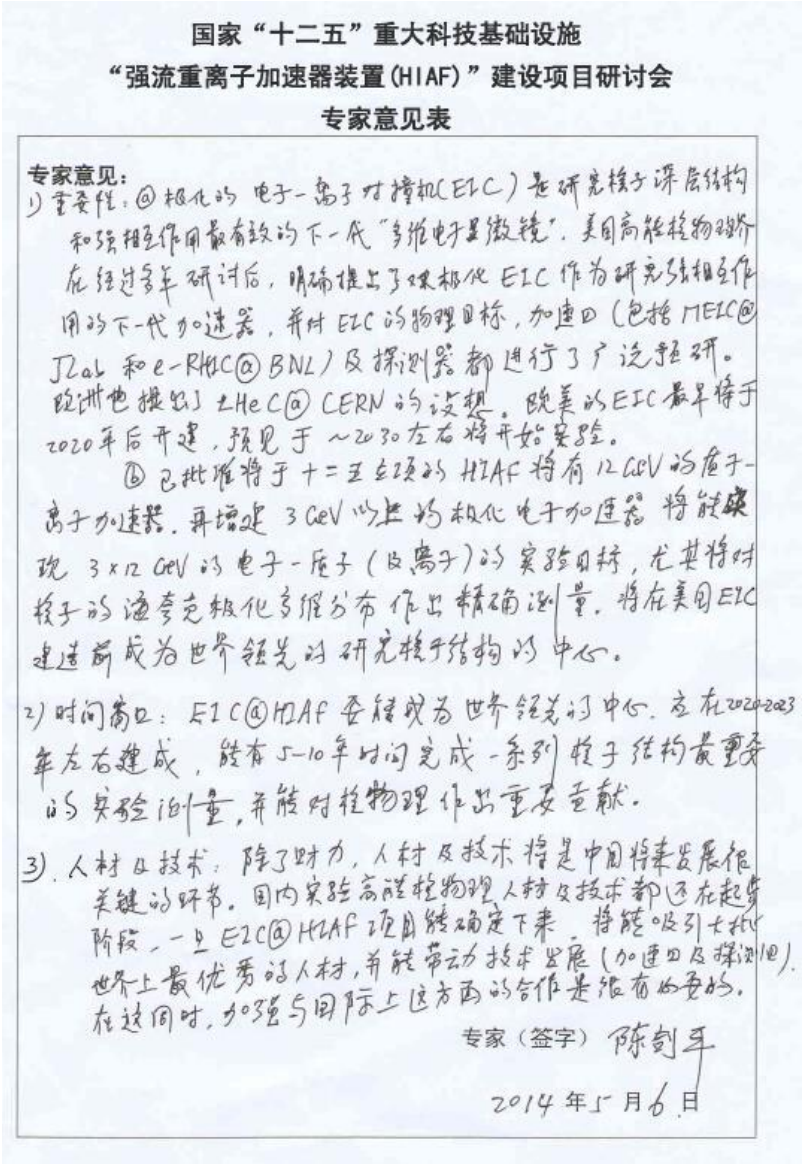
strong support for EIC@HIAF

Symposium on EIC @ HIAF
May 6, 2014, Beijing

- A special and key important symposium on the EIC@HIAF 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 EIC@HIAF 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.



国家“十二五”重大科技基础设施
“强流重离子加速器装置(HIAF)”建设项目研讨会
专家意见表

专家意见：

1) 重要性：@ 极化的 电子-离子对撞机(EIC)是研究核子深层结构和强相互作用最有效的下一代“多维电子显微镜”。美国高能核物理界在经过多年研讨后，明确提出了以极化 EIC 作为研究强相互作用的下一代加速器，并对 EIC 的物理目标，加速器(包括 MEIC@JLab 和 e-RHIC@BNL)及探测器都进行了广泛的研究。欧洲也提出了 LHeC@CERN 的设想。跟美的 EIC 最早将于 2020 年后开建，预见于 ~2030 左右将开始实验。

⑥ 已批准将于十三五立项的 HIAF 将有 12 GeV 的质子-离子加速器，再增建 3 GeV 以上的极化电子加速器，将能实现 3×12 GeV 的电子-质子(及离子)的实验目标，尤其将对核子的海夸克极化分布作出精确测量，将在美国 EIC 建造前成为世界领先的研究核子结构的中心。

2) 时间窗口：EIC@HIAF 要能成为世界领先的中心，应在 2020-2023 年左右建成，能有 5-10 年时间完成一系列核子结构最重要的实验测量，并能对理论作出重要贡献。

3) 人材及技术：除了财力，人材及技术将是中国将来发展很关键的环节。国内实验高能核物理人材及技术都还在起步阶段，一旦 EIC@HIAF 项目能确定下来，将能吸引大批世界上最优秀的人材，并能带动技术发展(加速器及探测器)。在这同时，加强与国际上这方面的合作是很有必要的。

专家(签字) 陈剑平

2014 年 5 月 6 日

JP Chen’s opinion

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	

Part 3

Unique Opportunities for EIC@HIAF

Future EIC Projects

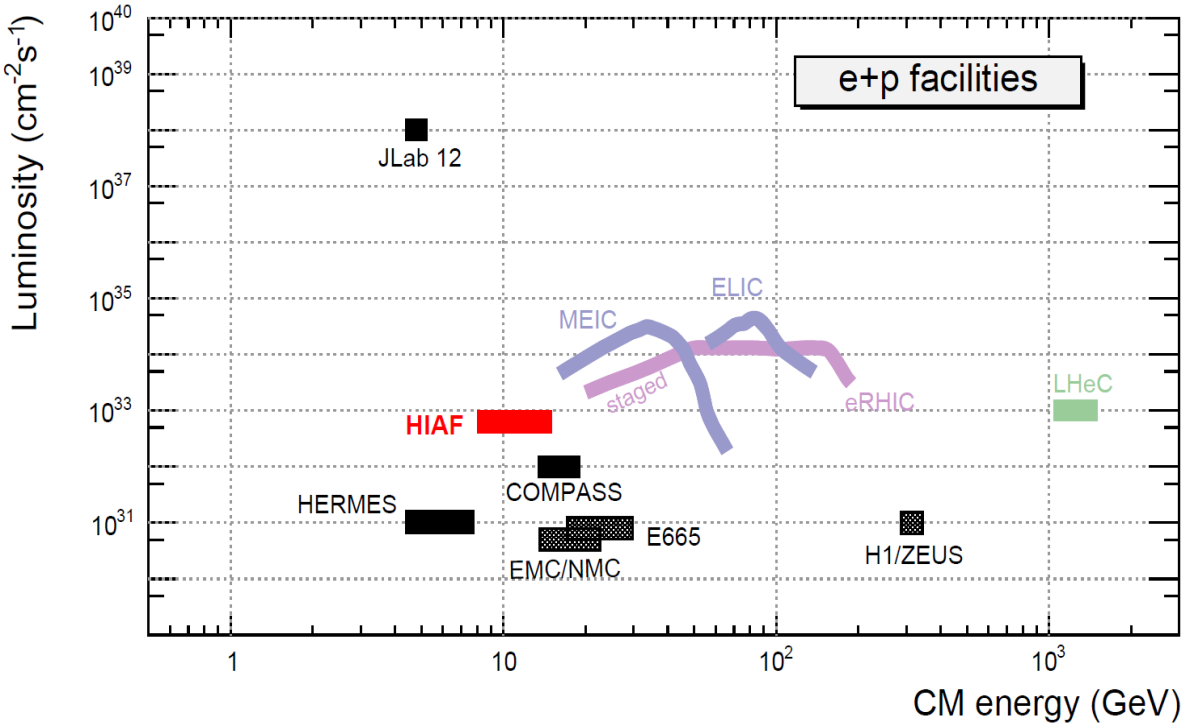
- **Electron-Ion collider @ Ion Accelerator Facilities**:
  - -ENC @ FAIR, Germany
  - -EIC @ HIAF, China

- **Dedicated Electron-Ion collider projects for QCD exploration**
  - -eRHIC @ BNL, U.S.A. [Collider, polarization]
  - -MEIC @ JLab, U.S.A. [Collider, polarization]
  - -MESA @ U Mainz, Germany (polarized, gas target)

- **Energy Frontier**:
  - -LHeC @ CERN using 7 TeV protons from LHC
  - -FCC-eh @ CERN using 50TeV protons

Lepton-Nucleon Facilities

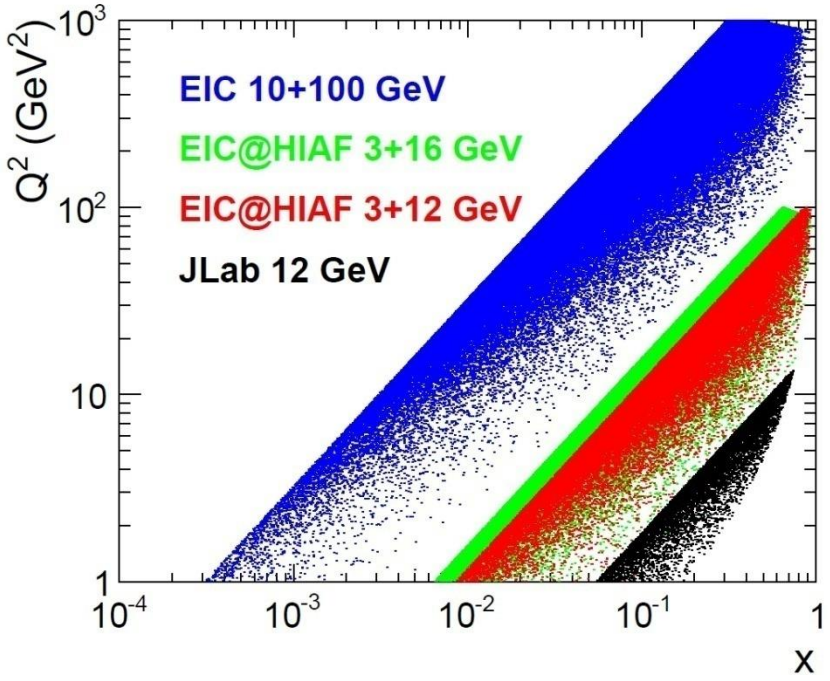
HIAF: e(3GeV) +p(12~16 GeV), both polarized, L>= 4*10^{32}cm^2/s

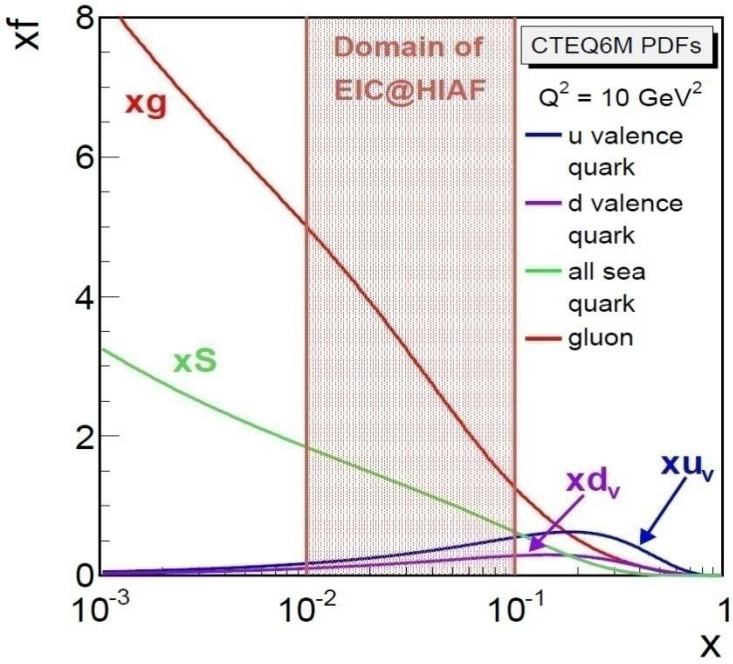


- The energy reach of the EIC@HIAF is significantly higher than JLab12 but lower than the full EIC being considered in US
- COMPASS has similar (slightly higher) energy, but significantly lower polarized luminosity (about a factor of 200 lower, even though the unpolarized luminosity is only a factor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

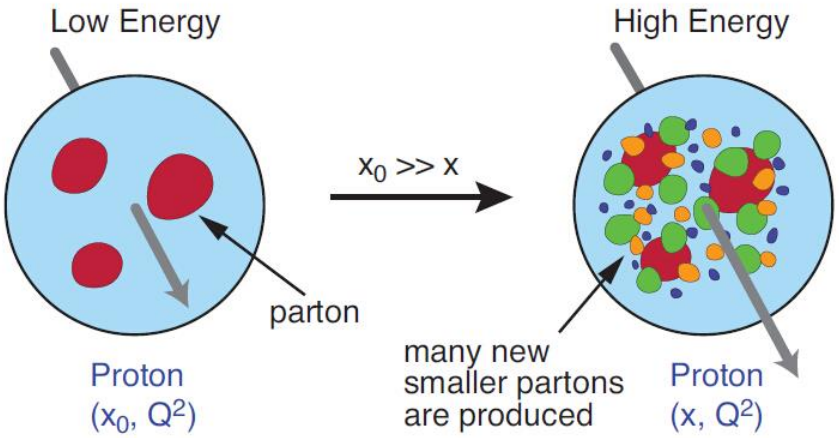
EIC@HIAF's Advantages

- 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
- EIC@HIAF will also be very good in study the fragmentation process, complementary to the e+e-machines.

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

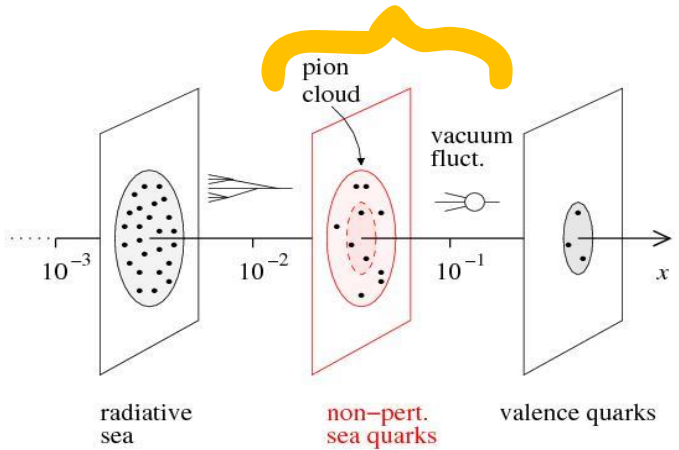


1. Spin-Flavor Study at EIC@HIAF

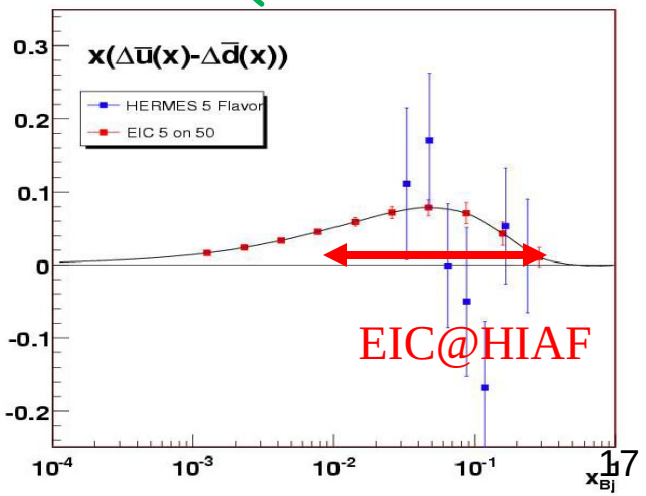
- **EIC@HIAF, combination of energy and luminosity：**
- ✓ Significant improvement for Δubar, Δdbar from SIDIS
- ✓ By SIDIS, in particular, for Kaons , EIC@HIAF energy reaches the current fragmentation region for Kaon tagging in SIDIS, will help to identify strange quark helicity (For Δs , one needs to 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 Bergen‘s criteria) to be in the current fragmentation region)
- ✓ Increase in Q^2 range/precision for g_1 (and g_2): constraint on Δg.

Unique opportunity for Δs

We are doing the sea-quark polarization simulation (Baiyang Zhang’s talk on July 24)



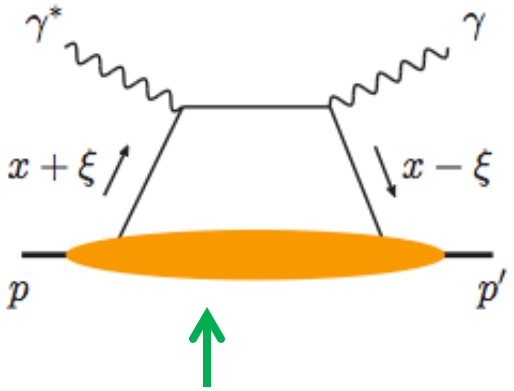
Sea Quark Polarization



2. GPD Study at EIC@HIAF

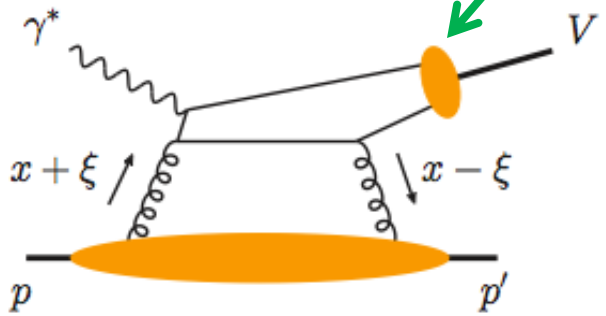
Deeply virtual Compton Scattering (DVCS) and deeply virtual exclusive meson production (DVMP)

DVCS



DVMP

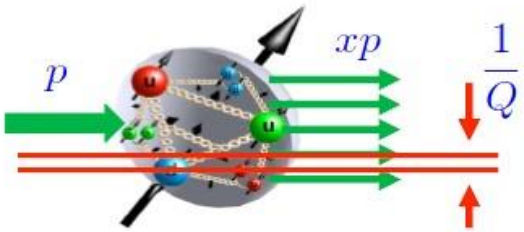
Meson



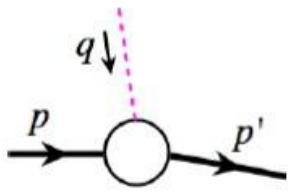
GPD

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

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



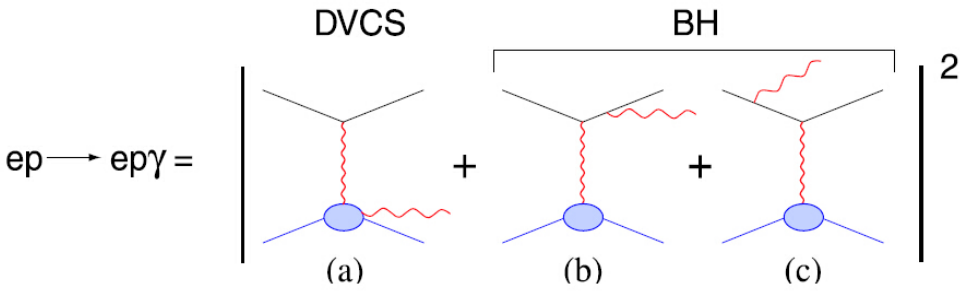
- ✧ Need a localized probe
- ✧ Scan in transverse direction
- ✧ Spatial imaging

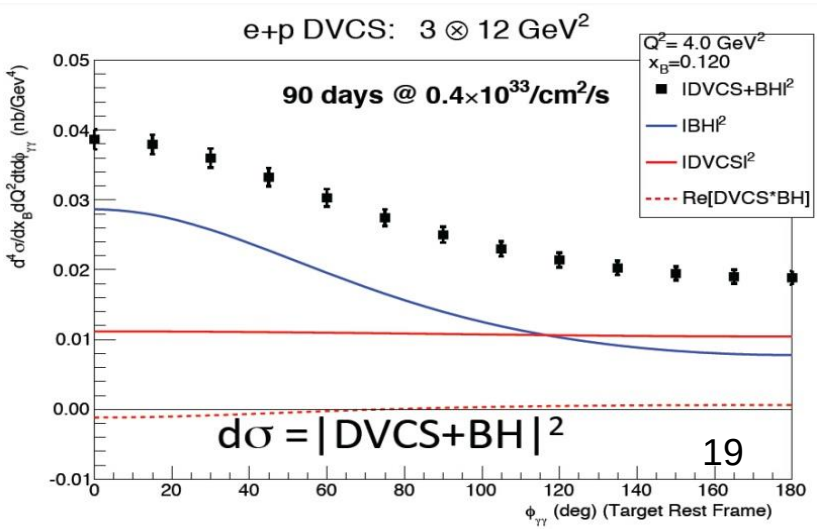


GPD Study at EIC@HIAF

- 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 $Q^2 > 5\sim10\ GeV^2$, scaling region for exclusive light meson production

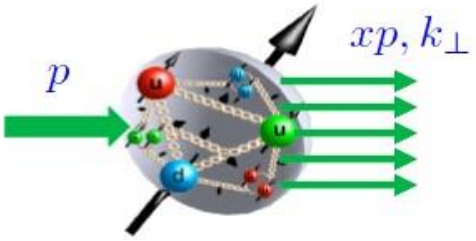
DVCS Simulation by Charles Hyde (ODU)





3. TMD Study at EIC@HIAF

❑ TMDs – 3D momentum distributions (semi-inclusive):

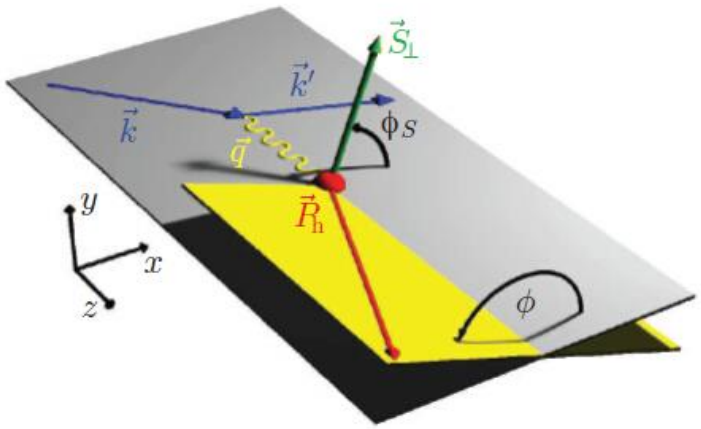


✧ SIDIS: Q >> P_T (> or ~ 1/fm)

$$\ell + p \to \ell' + h(p') + X$$

✧ Two scales, two planes, and two hadrons

- Measure TMD in DIS process



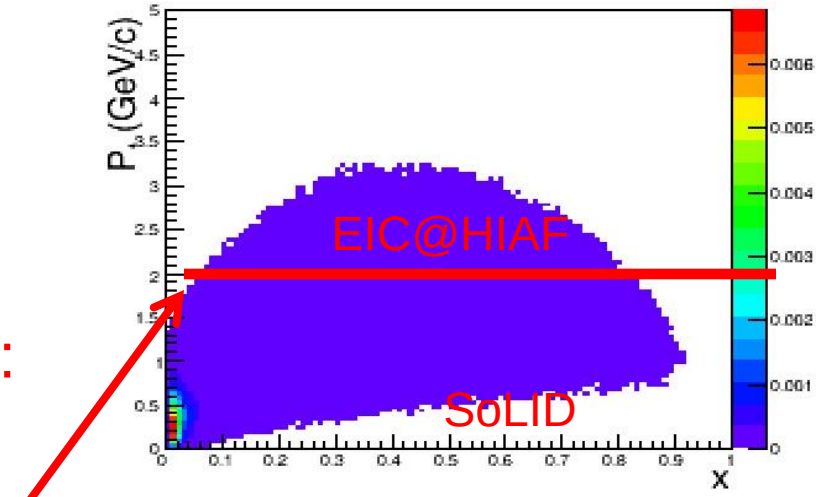
Leading Twist TMDs

: Nucleon Spin : Quark Spin

Nucleon Polarization	Quark polarization: Un-Polarized (U)	Longitudinally Polarized (L)	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; $h_{1T}^\perp$ = → − →

TMD Study at EIC@HIAF

- 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:



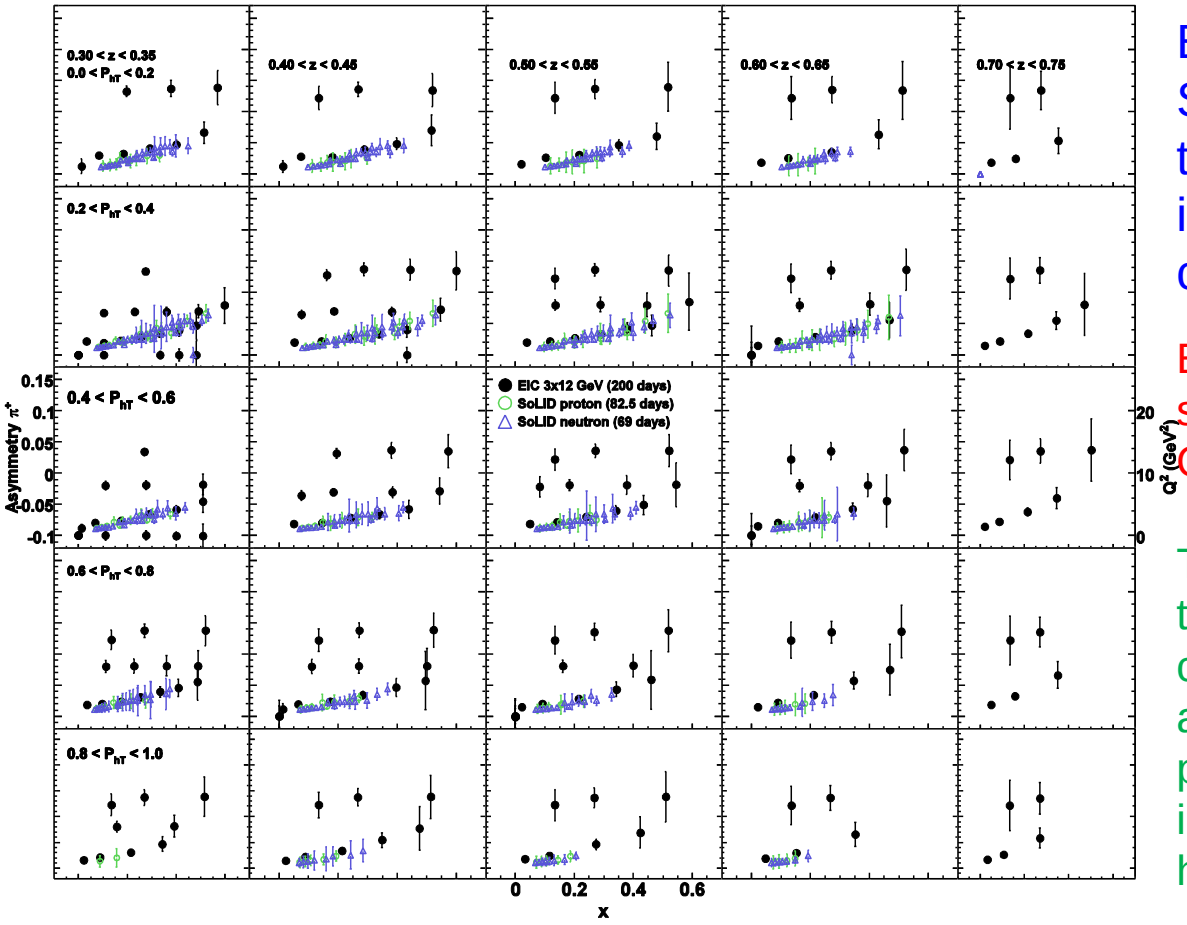
➢ The region around 2 GeV is the overlap region for TMD factorization and collinear factorization (X. Ji, etc., Phys. Rev. D73 (2006) 094017)

➢ 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.

The TMD simulation: Projections for SIDIS Asymmetry π^+



Exploration of the sea quark Sivers function will provide, for the first time, the unique information on the spin-orbital correlation in the small-x region

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

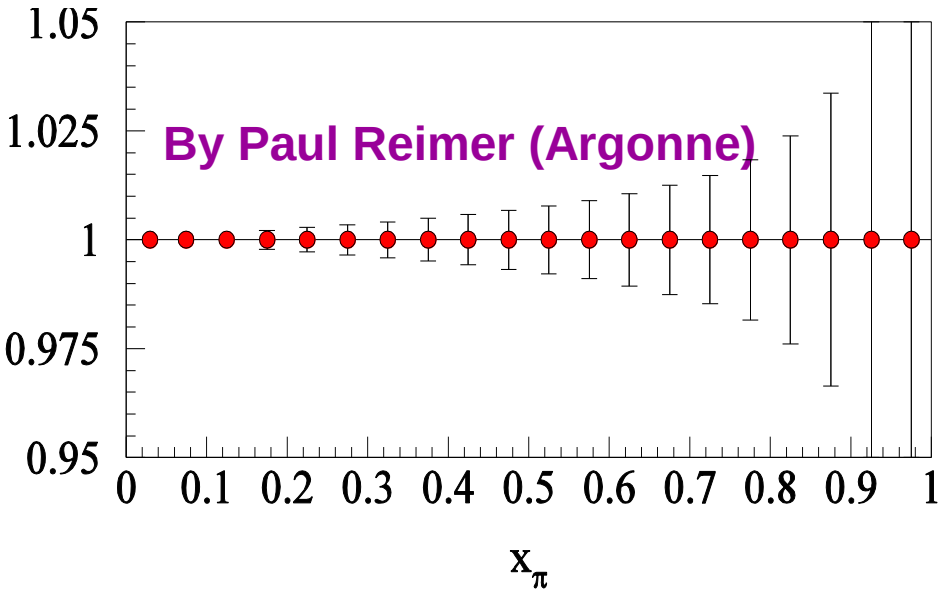
This precision is not only crucial for the fundamental QCD test of the sign change between the Sivers asymmetries in the DIS and Drell-Yan processes, but also important to investigate the QCD dynamics in the hard processes in SIDIS

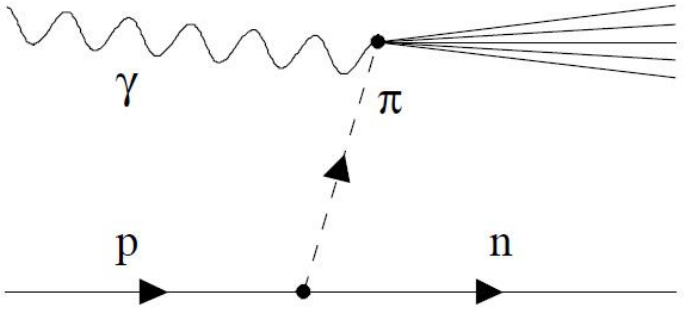
Green (Blue) Points: SoLID projections for polarized NH_3 (^{3}He/n) target
Luminosity: 10^{35} (10^{36}) (1/cm^2/s); Time: 120 (90) days

By Haiyan Gao (Duke)

Black points: EIC@HIAF projections for 3 GeV e and 12 GeV p
Luminosity: 4 x 10^{32} /cm^2/s; Time: 200 days

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.

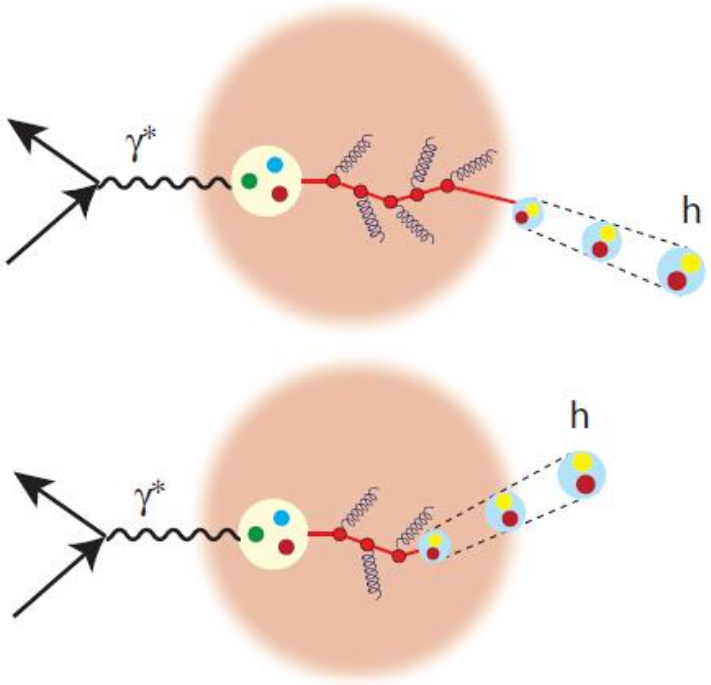
5. Hadronization

- Hadronization or fragmentation process refer to the transition from colored partons to colorless hadrons
- The EIC@HIAF 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 (Xin-nian Wang (BNL)

A cartoon for the interactions of the parton moving through cold nuclear matter when the produced hadron is formed:

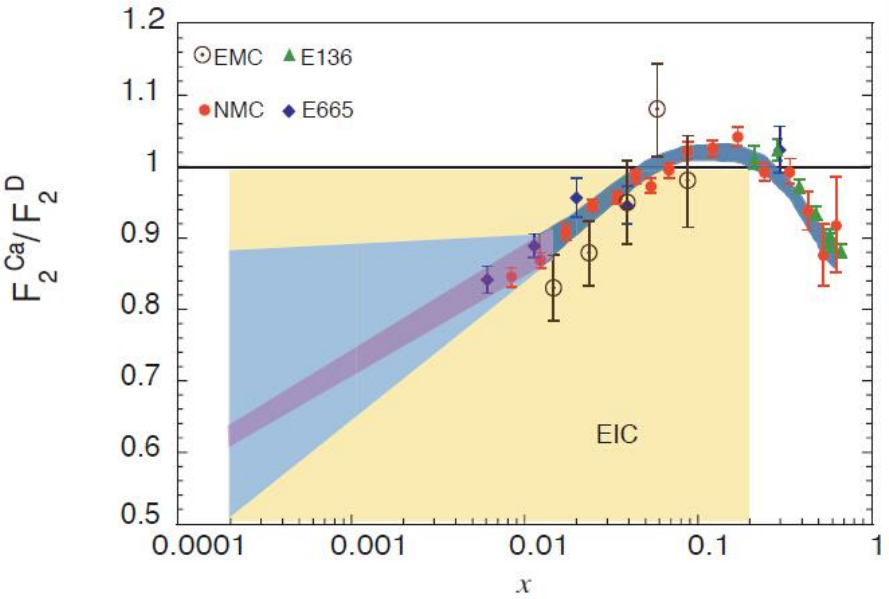
➢outside (upper)

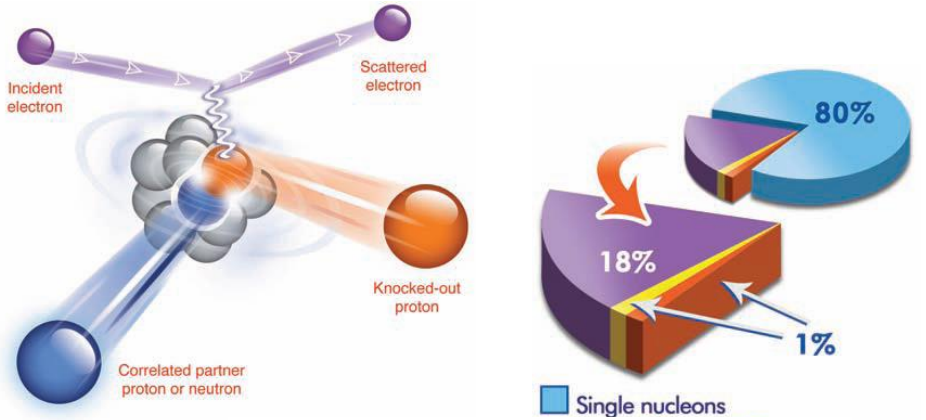
➢inside (lower) the nucleus.



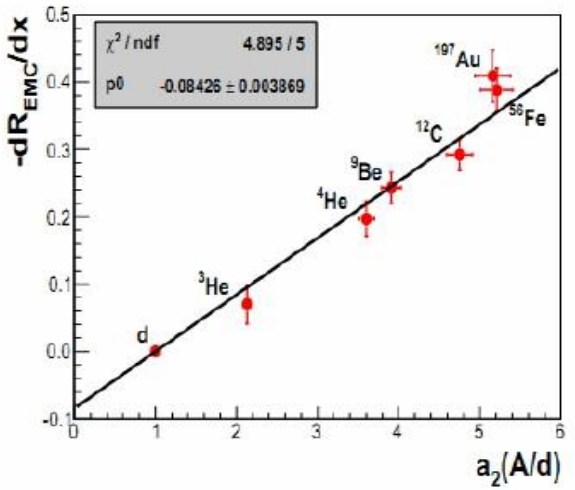
6. EMC and SRC

- The A-dependence of the EMC effect at large x indicates that the main contribution to the EMC effect is due to scattering off the short-range correlations (SRC) in nuclei
- The EIC@HIAF can shed light on the origin of the EMC effect





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



Other Physics Programs for EIC@HIAF?

- **Form Factor Measurements at EIC@HIAF?**
  - Fast Falling of Form Factors and Elastic Cross Sections

    Needs very high luminosity
  - Luminosity comparison:

    JLab: $>10^{38}$ unpolarized, $>10^{36}$ polarized, EIC@HIAF: 10^{33}
  - Limited role for EIC@HIAF in nucleon form factor study
- **Hadron Spectroscopy Measurements with an EIC?**
  - e+e- (Bella, BaBar, BES): charmonium states: x-y-z

    search for new states.
  - JLab12: GlueX search for gluon excitation

    Search for new hadron states
  - No obvious advantage, probably limited role for EIC, including EIC@HIAF

Part 4

Status and Summary

Current Status of HIAF

- The HIAF project was proposed in 2009, approved in principle by the central government in Jan 2013
- A conceptual machine design will be completed recently and provide a base for performance evaluation, cost estimation, and technical risk assessment.
- HIAF parameters will be chosen to optimize science, technology development, and project cost. The final design of first stage will maintain a well defined path for future upgrade to higher energies and luminosities.
- The timing of HIAF construction depends on the design optimization and accelerator technology R&D. We hope we can start construction in 2015. Project completion is expected in 2023.
- The total budget of HIAF (no EIC) is about $ 400 million, if the EIC cost is included , the total budget is about $ 700 million
- We are seeking for international collaborations for key supporting technologies of HIAF

EIC@HIAF Location: Huizhou, Guangdong

Current EIC@HIAF Status

- J.P. Chen from JLab is organizing the six golden experiments simulations and detector simulations
- J.W. Qiu and F. Yuan (BNL), etc., are organizing the China EIC whitepaper writing (in English)
- EIC@China Webpage:

  http://snst-hu.lzu.edu.cn/wiki/index.php/Eic

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
- The Chinese 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!

Any comments are welcome!