TMDs study at the Electron-Ion Collider in China

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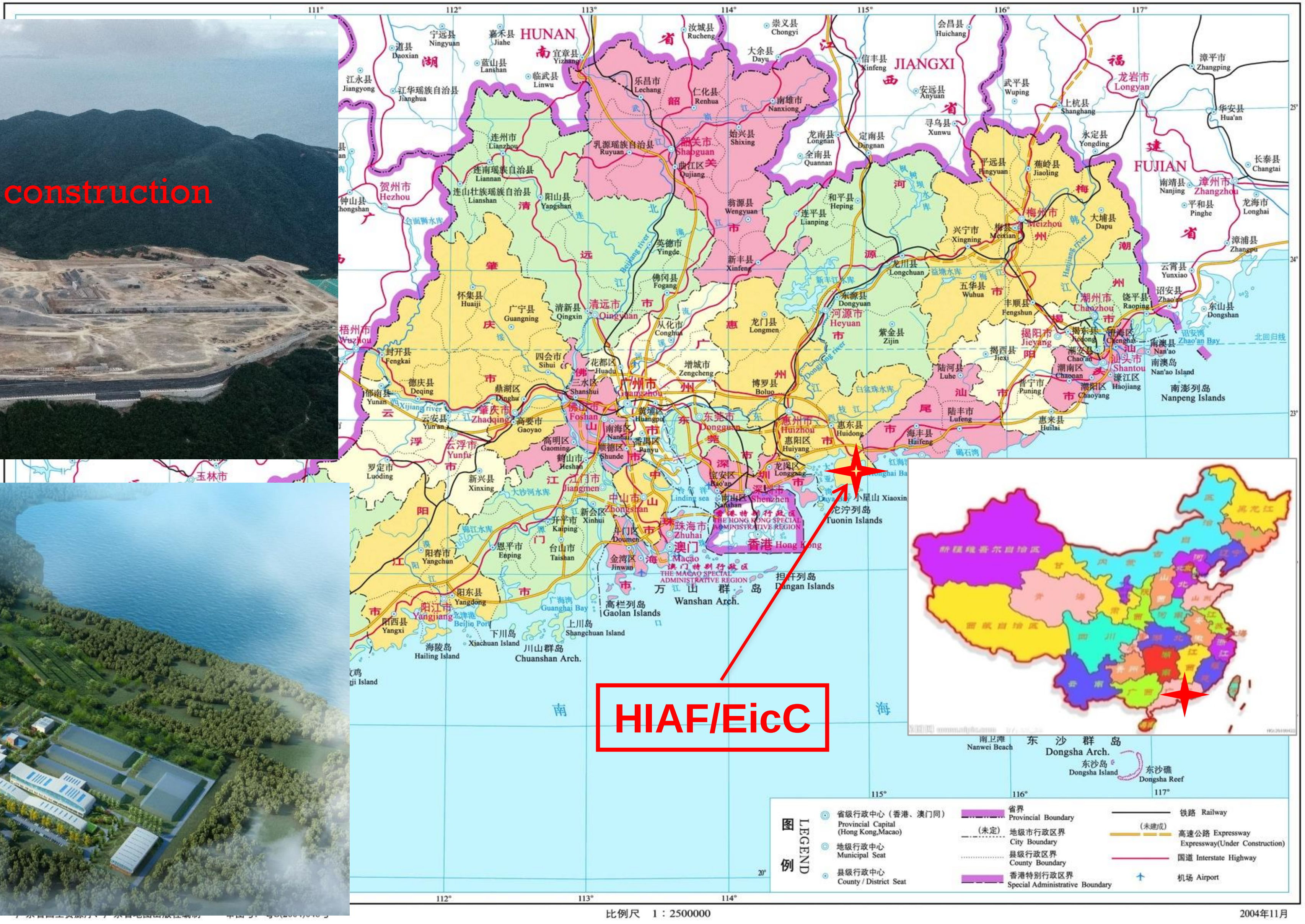
Yuxiang Zhao (IMP), on behalf of the EicC working group

Special thanks to Tianbo Liu and Jian Zhou

Outline

- General introduction of the Electron-Ion Collider in China
- TMDs study at the EicC
- Summary

Where we are talking about…Huizhou(惠州) in Guangdong province

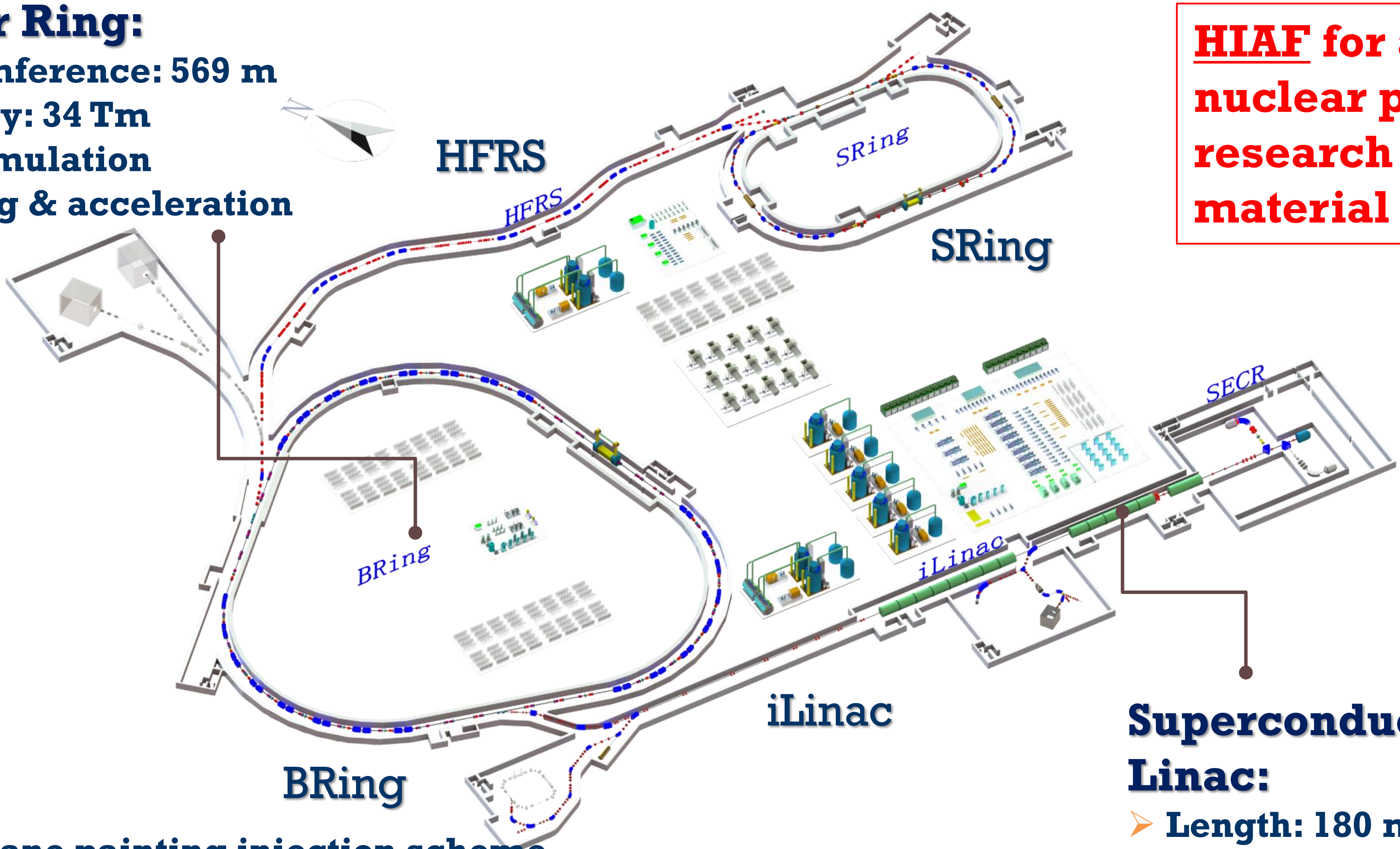


High Intensity heavy-ion Accelerator Facility (HIAF)

HIAF total investment: 2.5 billion RMB

Booster Ring:

- Circumference: 569 m
- Rigidity: 34 Tm
- Aaccumulation
- Cooling & acceleration



HIAF for atomic physics, nuclear physics, applied research in biology and material science etc.

- Two-plane painting injection scheme
- Fast ramping rate operation

Superconducting Ion Linac:

- Length: 180 m
- Energy: 17 MeV/u (U^{34+})
- CW and pulse modes

Electron Ion Collider in China, EicC

EicC white paper (arXiv: 2102.09222)

Also in production in the *Frontiers of Physics* Journal

arXiv.org > nucl-ex > arXiv:2102.09222

Search...

Help | Advance

Nuclear Experiment

[Submitted on 18 Feb 2021]

Electron-Ion Collider in China

Daniele P. Anderle, Valerio Bertone, Xu Cao, Lei Chang, Ningbo Chang, Gu Chen, Xurong Chen, Zhuojun Chen, Zhufang Cui, Lingyun Dai, Weitian Deng, Minghui Ding, Xu Feng, Chang Gong, Longcheng Gui, Feng-Kun Guo, Chengdong Han, Jun He, Tie-Jiun Hou, Hongxia Huang, Yin Huang, Krešimir Kumerički, L. P. Kaptari, Demin Li, Hengne Li, Minxiang Li, Xueqian Li, Yutie Liang, Zuotang Liang, Chen Liu, Chuan Liu, Guoming Liu, Jie Liu, Liuming Liu, Xiang Liu, Tianbo Liu, Xiaofeng Luo, Zhun Lyu, Boqiang Ma, Fu Ma, Jianping Ma, Yugang Ma, Lijun Mao, Cédric Mezrag, Hervé Moutarde, Jialun Ping, Sixue Qin, Hang Ren, Craig D. Roberts, Juan Rojo, Guodong Shen, Chao Shi, Qintao Song, Hao Sun, Paweł Sznajder, Enke Wang, Fan Wang, Qian Wang, Rong Wang, Ruiru Wang, Taofeng Wang, Wei Wang, Xiaoyu Wang, Xiaoyun Wang, Jiajun Wu, Xinggang Wu, Lei Xia, Bowen Xiao, Guoqing Xiao, Ju-Jun Xie, Yaping Xie, Hongxi Xing, Hushan Xu, Nu Xu, Shusheng Xu, Mengshi Yan, Wenbiao Yan, Wencheng Yan, Xinhu Yan, Jiancheng Yang, Yi-Bo Yang, Zhi Yang, Deliang Yao, Peilin Yin, C.-P. Yuan, Wenlong Zhan, Jianhui Zhang, Jinlong Zhang, Pengming Zhang, Chao-Hsi Chang, Zhenyu Zhang, Hongwei Zhao, Kuang-Ta Chao, Qiang Zhao, Yuxiang Zhao, Zhengguo Zhao, Liang Zheng, Jian Zhou, Xiang Zhou, Xiaorong Zhou et al. (2 additional authors not shown)

Lepton scattering is an established ideal tool for studying inner structure of small particles such as nucleons as well as nuclei. As a future high energy nuclear physics project, an Electron-ion collider in China (EicC) has been proposed. It will be constructed based on an upgraded heavy-ion accelerator, High Intensity heavy-ion Accelerator Facility (HIAF) which is currently under construction, together with a new electron ring. The proposed collider will provide highly polarized electrons (with a polarization of \sim80%) and protons (with a polarization of \sim70%) with variable center of mass energies from 15 to 20 GeV and the luminosity of (2-3) \times 10^{33} cm^{-2} s^{-1}. Polarized deuterons and Helium-3, as well as unpolarized ion beams from Carbon to Uranium, will be also available at the EicC.

The main foci of the EicC will be precision measurements of the structure of the nucleon in the sea quark region, including 3D tomography of nucleon; the partonic structure of nuclei and the parton interaction with the nuclear environment; the exotic states, especially those with heavy flavor quark contents. In addition, issues fundamental to understanding the origin of mass could be addressed by measurements of heavy quarkonia near-threshold production at the EicC. In order to achieve the above-mentioned physics goals, a hermetical detector system will be constructed with cutting-edge technologies.

This document is the result of collective contributions and valuable inputs from experts across the globe. The EicC physics program complements the ongoing scientific programs at the Jefferson Laboratory and the future EIC project in the United States. The success of this project will also advance both nuclear and particle physics as well as accelerator and detector technology in China.

Comments: EicC white paper, written by the whole EicC working group

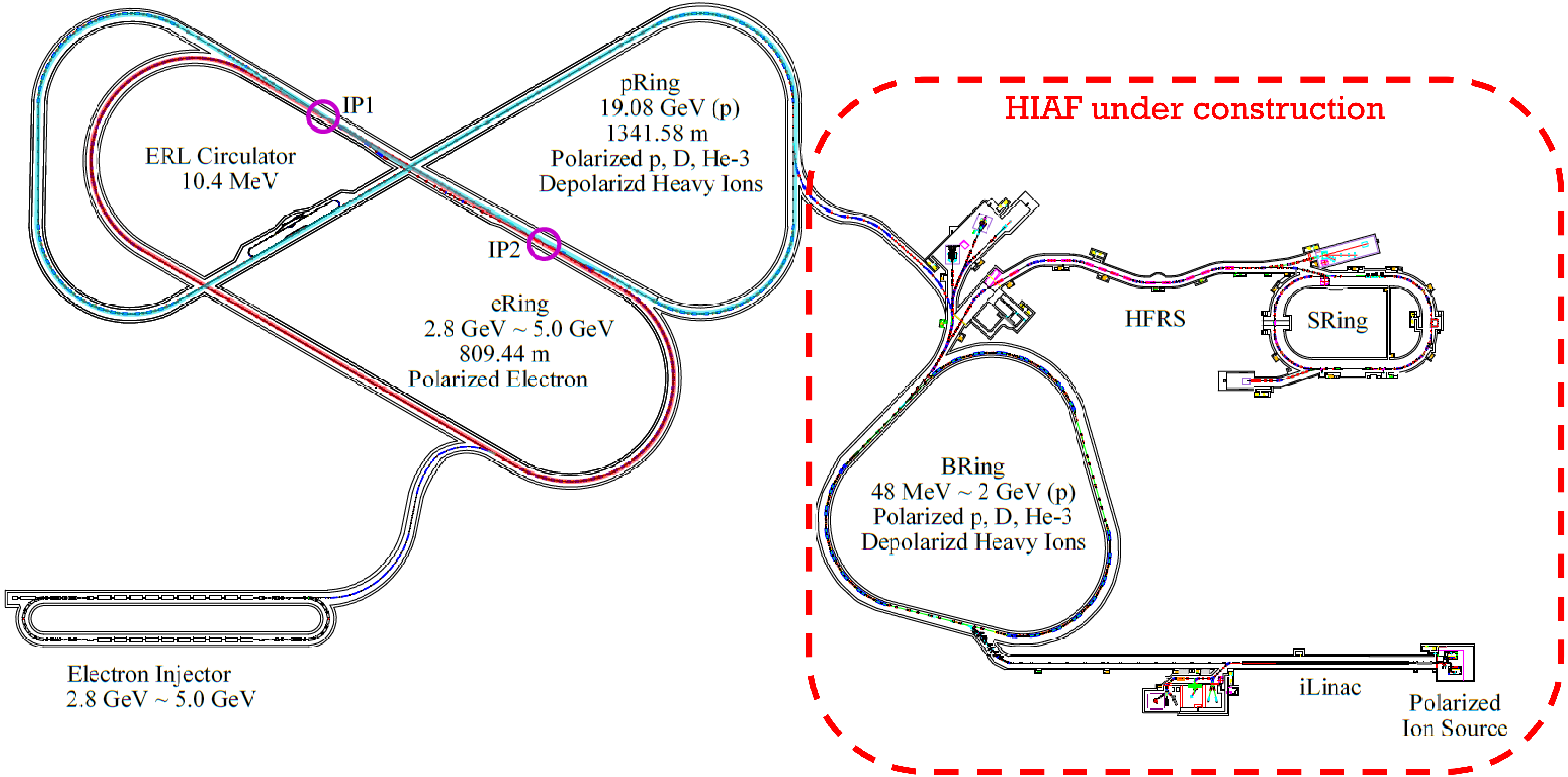
Subjects: **Nuclear Experiment (nucl-ex)**; High Energy Physics - Experiment (hep-ex); High Energy Physics - Phenomenology (hep-ph); Nuclear Theory (nucl-th)

Cite as: arXiv:2102.09222 **[nucl-ex]**

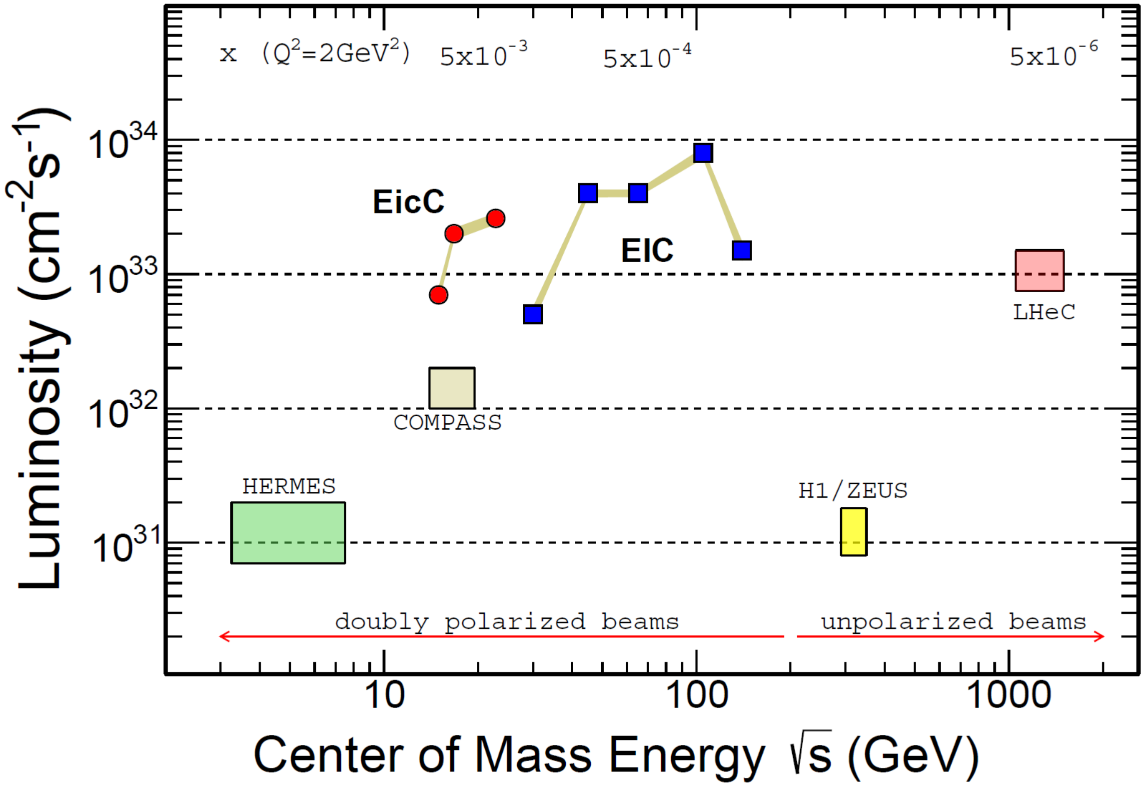
(or arXiv:2102.09222v1 **[nucl-ex]** for this version)

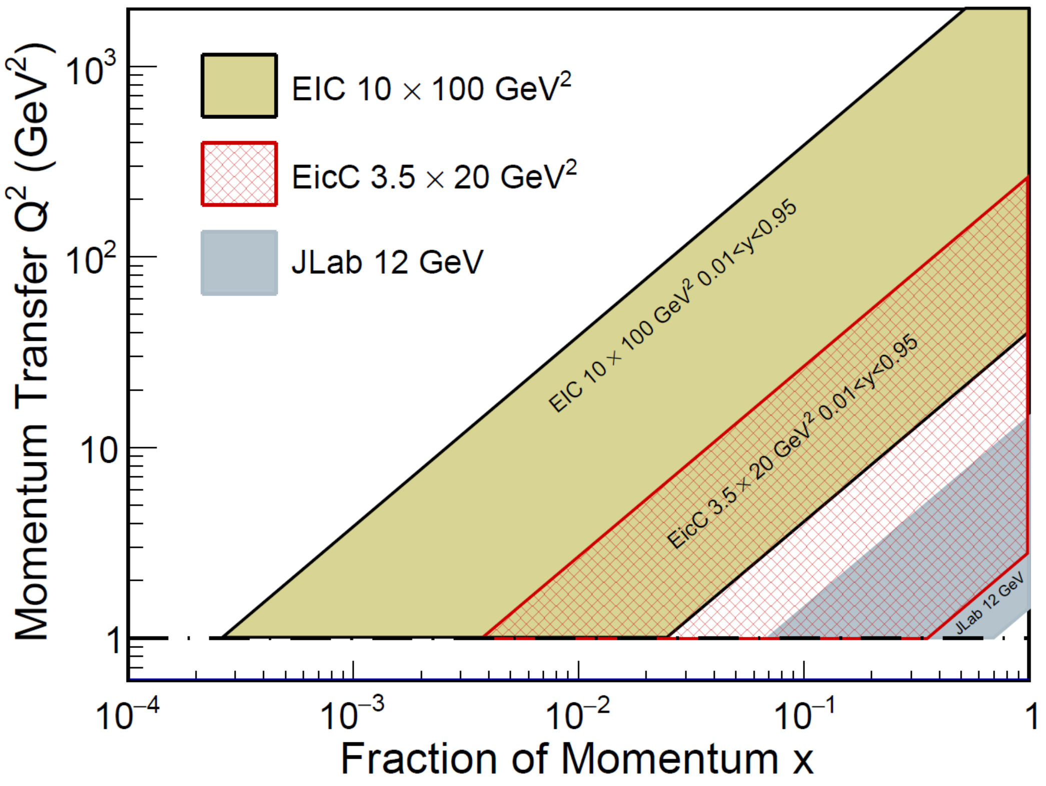
Now we have 46 institutes and >100 physicists

EicC Accelerator complex layout



EicC Specs





- EicC covers the kinematic region between JLab experiments and US-EIC
- EicC complements the ongoing scientific programs at JLab and future EIC project
- EicC focuses on moderate x and sea-quark region

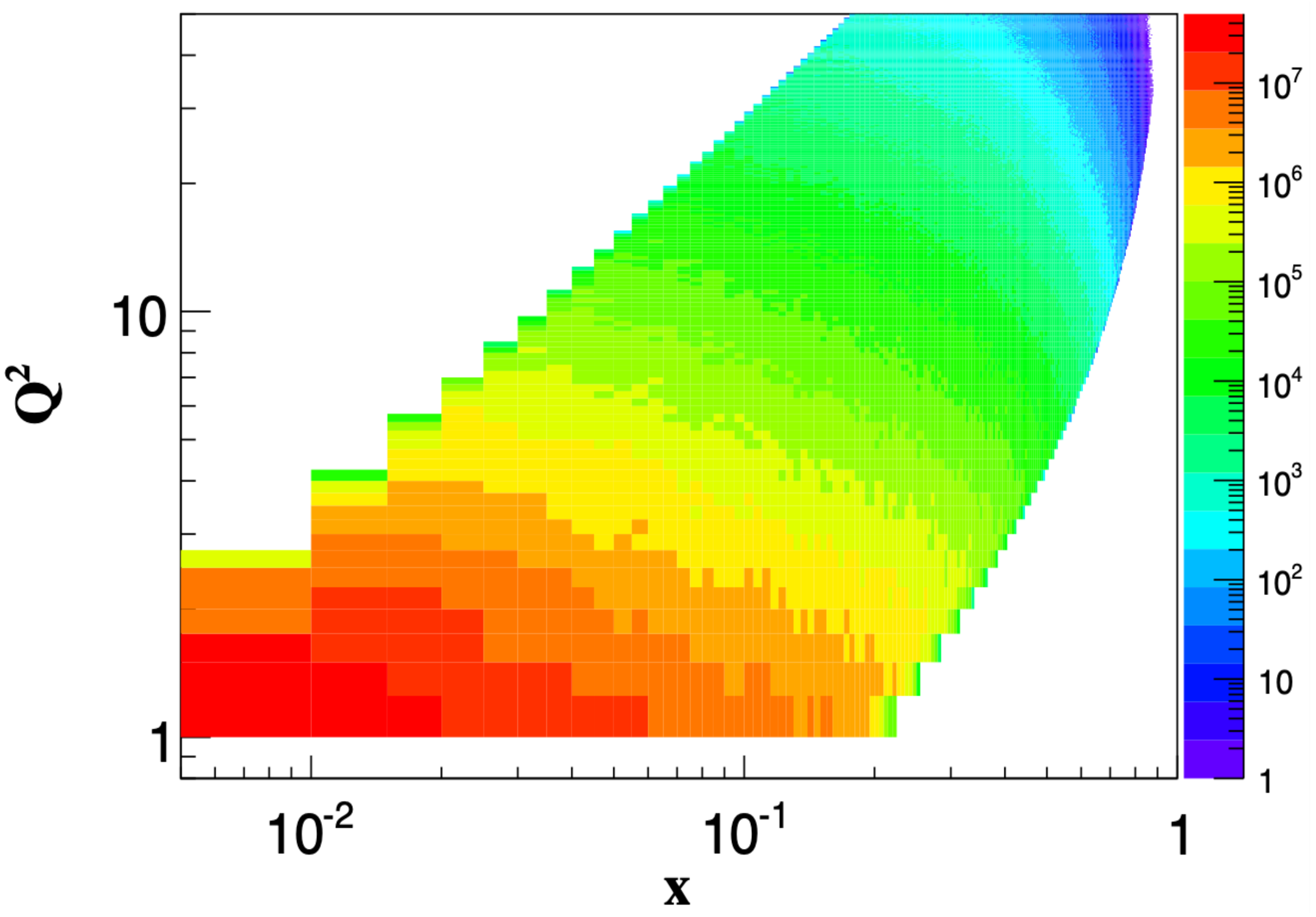
Outline

- General introduction of the Electron-Ion Collider in China
- TMDs study at the EicC

Using Sivers function as an example

- Summary

Q^2 VS x coverage



Electron beam: 3.5 GeV, polarization ~80%

Proton beam: 20 GeV, polarization ~70%

Helium-3 beam: 40 GeV (40/3 GeV per nucleon), polarization ~70%

Center of mass energy: 15 ~ 20 GeV

Luminosity: 2 ~ 4 × 10^{33} cm^{-2} s^{-1}

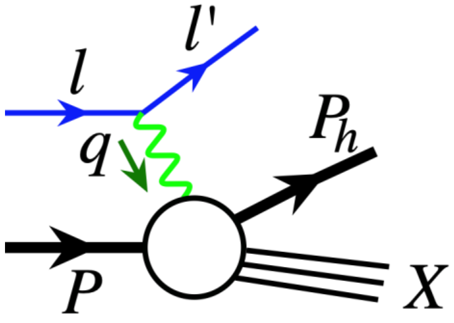
Cuts:

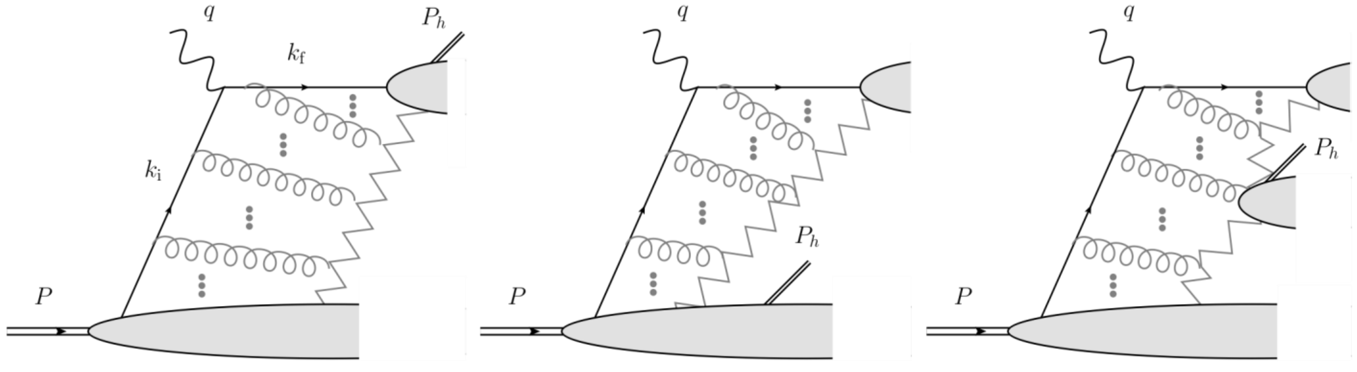
Q^2>1GeV^2, W>5GeV, W'>2GeV, 0.3<z<0.7

P_e > 0.35GeV, P_h>0.3GeV

SIDIS Kinematic Regions

M. Boglione *et al.*, Phys. Lett. B 766, 245 (2017).





(a) (b) (c)

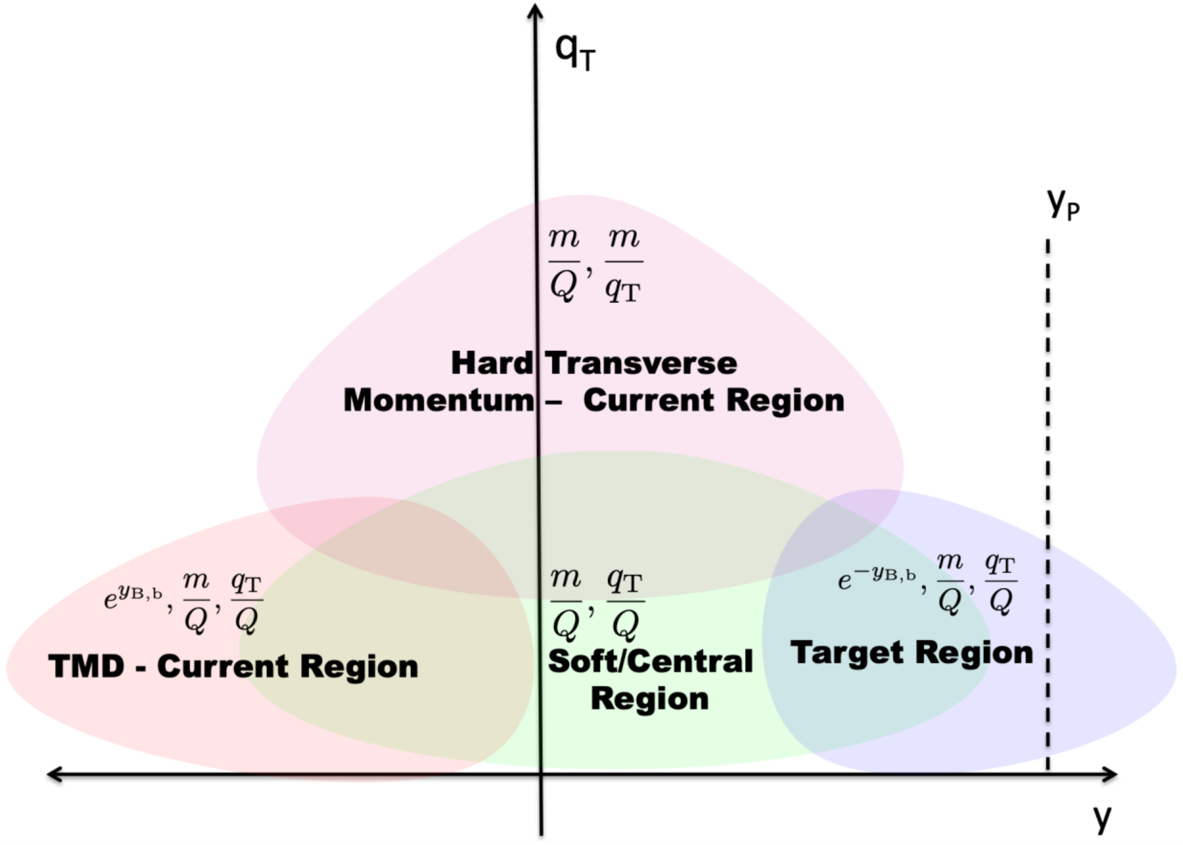
(a) Current fragmentation region; (b) Target fragmentation region; (c) Central fragmentation region

Regions overlap with each other. Classification boundaries are not sharp.

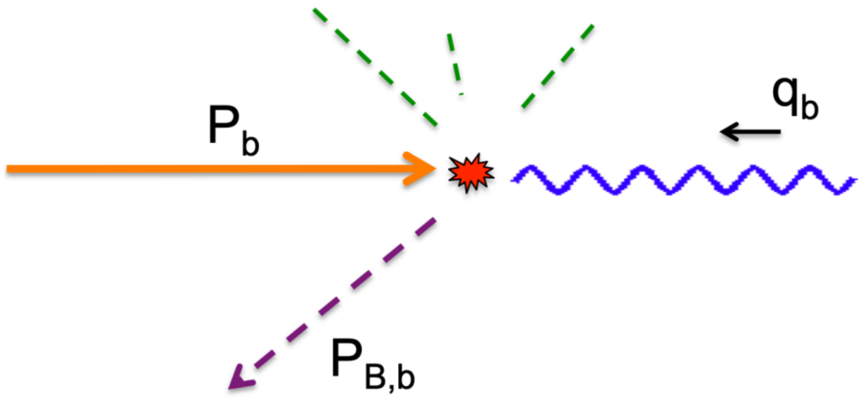
Some criteria may help to select events in the kinematic region dominated by current/target fragmentation.

SIDIS Kinematic Regions

Sketch of kinematic regions of the produced hadron



[Figure from arXiv:1904.12882]

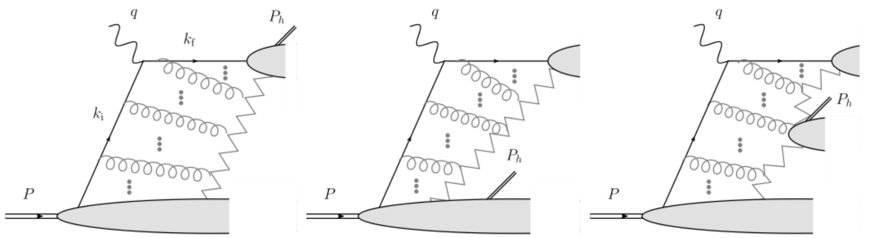


Nucleon-photon frame / Breit frame:

y: rapidity

$q_T = P_{hT} / z$: transverse momentum

The proposed R1 parameter



M. Boglione, J. Collins, L. Gamberg, J.O. Gonzalez-Hernandez, T.C. Rogers, N. Sato, Phys. Lett. B 766 (2017) 245.
and further communications with T.C. Rogers.

$$R_1 = \frac{P_h \cdot k_f}{P_h \cdot k_i}$$

current fragmentation: R_1 is small

$$k_{\rm i}^{\rm b} = \left(\frac{Q}{\hat{x}_{\rm N}\sqrt{2}}, \frac{\hat{x}_{\rm N} k_{\rm i}^2}{\sqrt{2}Q}, \mathbf{0}_{\rm T} \right), \qquad k_{\rm f}^{\rm b} = \left(\frac{\mathbf{k}_{\rm f,b,T}^2 + k_{\rm f}^2}{\sqrt{2}\hat{z}_{\rm N} Q}, \frac{\hat{z}_{\rm N} Q}{\sqrt{2}}, \mathbf{k}_{\rm f,b,T} \right)$$

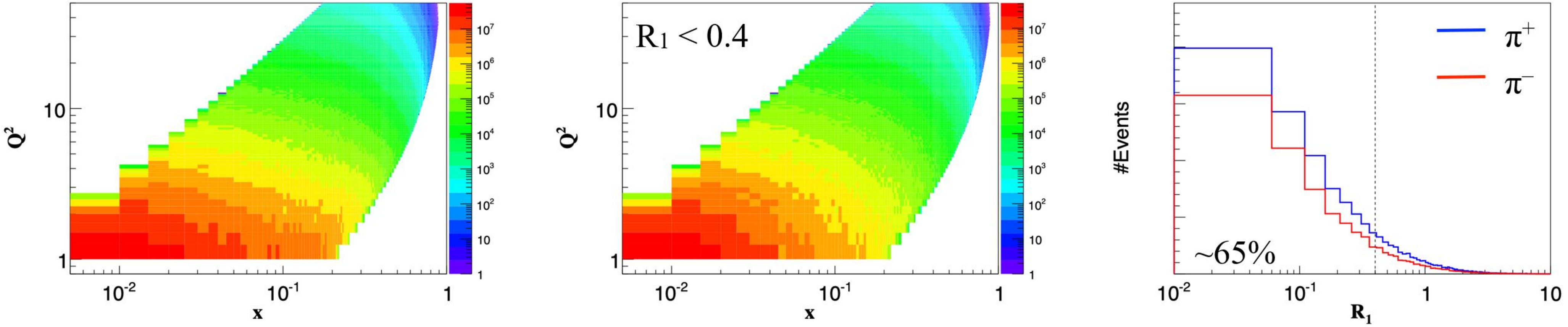
$$\hat{x}_{\rm N} \equiv -\frac{q_{\rm b}^+}{k_{\rm i,b}^+} = \frac{x_{\rm N}}{\xi} \qquad \hat{z}_{\rm N} \equiv \frac{k_{\rm f,b}^-}{q_{\rm b}^-} = \frac{z_{\rm N}}{\zeta} \qquad \mathbf{k}_{\rm f,b,T} = -\hat{z}_{\rm N} \boldsymbol{q}_{\rm T} + \delta \boldsymbol{k}_{\rm T}$$

$$x_{\rm N} = -\frac{q^+}{P^+} = \frac{2x_{\rm Bj}}{1 + \sqrt{1 + \frac{4x_{\rm Bj}^2 M^2}{Q^2}}}$$

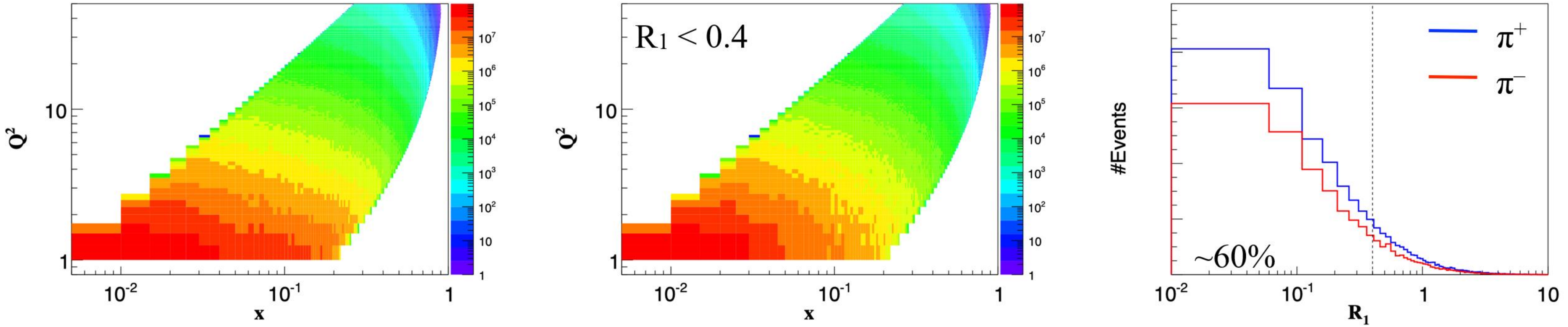
$$z_{\rm N} = \frac{P_{\rm B}^-}{q^-} = \frac{Q^4 x_{\rm N} z_{\rm h} \left(1 + \sqrt{1 - \frac{4M^2 M_{\rm B}^2 x_{\rm Bj}^2 (Q^4 + x_{\rm N}^2 M^2 \mathbf{q}_{\rm T}^2)}{Q^8 z_{\rm h}^2}} \right)}{2x_{\rm Bj}(Q^4 + x_{\rm N}^2 M^2 \mathbf{q}_{\rm T}^2)}$$

EicC-SIDIS Kinematic Regions
---Pion

Proton beam (20 GeV):

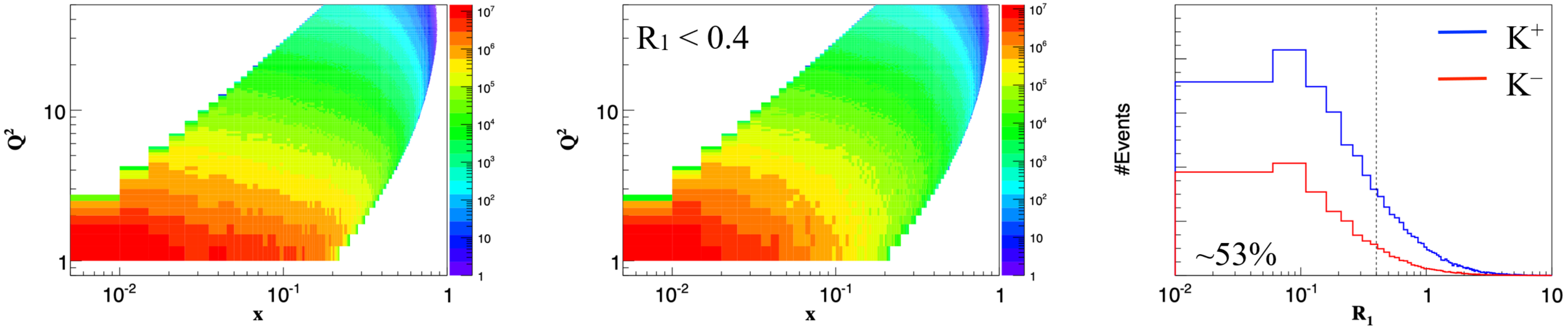


Helium-3 beam (40/3 GeV per nucleon):

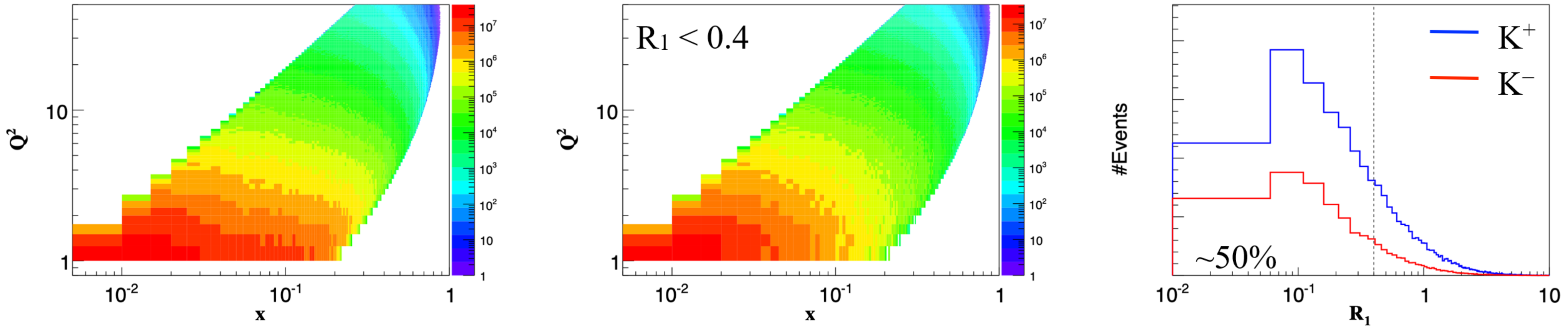


EicC-SIDIS Kinematic Regions ---Kaon

Proton beam (20 GeV):



Helium-3 beam (40/3 GeV per nucleon):



Sivers asymmetry Modeling and Parametrization

Sivers asymmetry:

$$A_{UT}^{\sin(\phi_h-\phi_S)} \sim f_{1T}^{\perp}(x,k_\perp) \bigotimes D_1(z,p_\perp)$$

Parametrization:

M. Anselmino, M. Boglione, U. D'Alesio, F. Murgia, A. Prokudin and B.-L. Valley
J. High Energy Phys. 04 (2017) 046.

unpolarized functions:

$$f_1(x,\mathbf{k}_T^2,Q^2) = \frac{1}{\pi\langle k_\perp^2\rangle} f_1(x,Q^2)\exp\left(-\frac{\mathbf{k}_T^2}{\langle k_\perp^2\rangle}\right) \qquad \langle k_\perp^2\rangle = 0.57\ \mathrm{GeV}^2$$

$$D_1(z,\mathbf{p}_T^2,Q^2) = \frac{1}{\pi\langle p_\perp^2\rangle} D_1(z,Q^2)\exp\left(-\frac{\mathbf{p}_T^2}{\langle p_\perp^2\rangle}\right) \qquad \langle p_\perp^2\rangle = 0.12\ \mathrm{GeV}^2$$

collinear PDF set: CJ15, collinear FF set: DSS

Sivers functions:

$$f_{1T}^{\perp}(x,\mathbf{k}_T^2,Q^2) = -\frac{\sqrt{2e}M_p}{M_1}\mathcal{N}(x)f_1(x,Q^2)\frac{1}{\pi\langle k_\perp^2\rangle}\exp\left(-\frac{\mathbf{k}_T^2}{k_s^2}\right) \qquad k_s^2 = \frac{M_1^2\langle k_\perp^2\rangle}{M_1^2+\langle k_\perp^2\rangle}$$

$$\mathcal{N}_{u_v}(x) = N_{u_v}x^{a_{u_v}}(1-x)^{b_{u_v}}\frac{(a_{u_v}+b_{u_v})^{a_{u_v}+b_{u_v}}}{a_{u_v}^{a_{u_v}}b_{u_v}^{b_{u_v}}} \qquad \mathcal{N}_{d_v}(x) = N_{d_v}x^{a_{d_v}}(1-x)^{b_{d_v}}\frac{(a_{d_v}+b_{d_v})^{a_{d_v}+b_{d_v}}}{a_{d_v}^{a_{d_v}}b_{d_v}^{b_{d_v}}}$$

$$\mathcal{N}_{\bar{u}}(x) = N_{\bar{u}} \qquad \mathcal{N}_{\bar{d}}(x) = N_{\bar{d}}$$

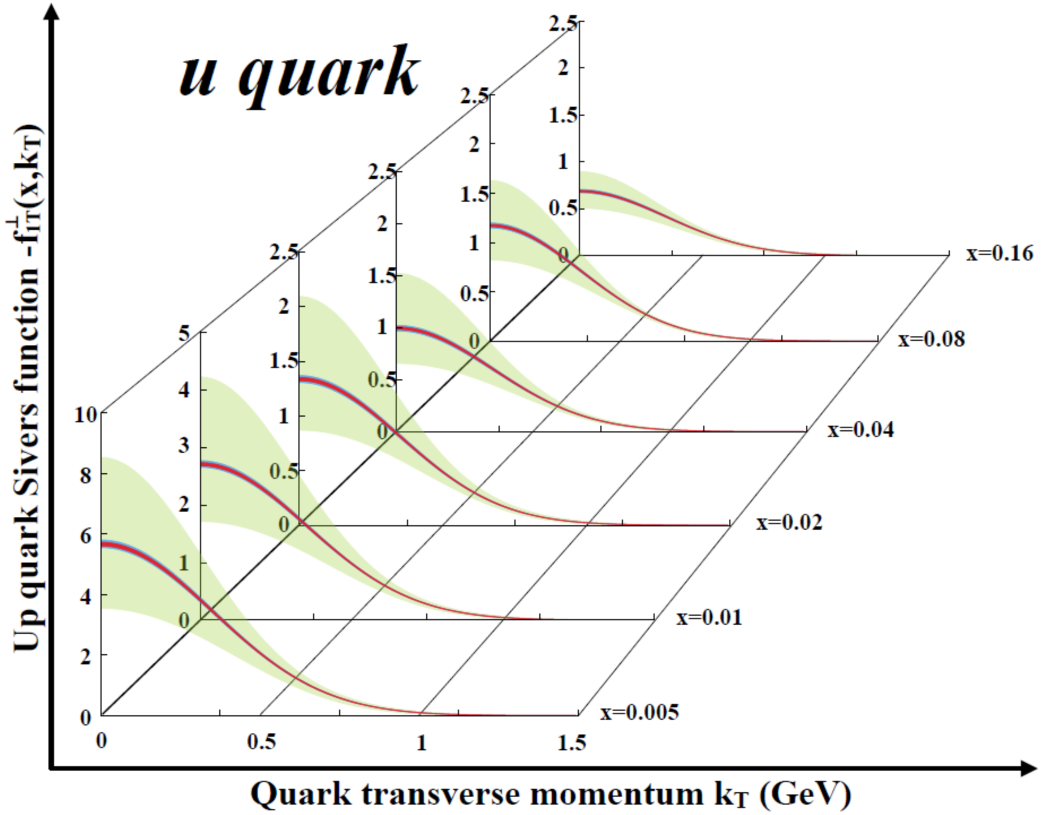
parameters: $N_{u_v},\ a_{u_v},\ b_{u_v},\ N_{d_v},\ a_{d_v},\ b_{d_v},\ N_{\bar{u}},\ N_{\bar{d}},\ M_1$

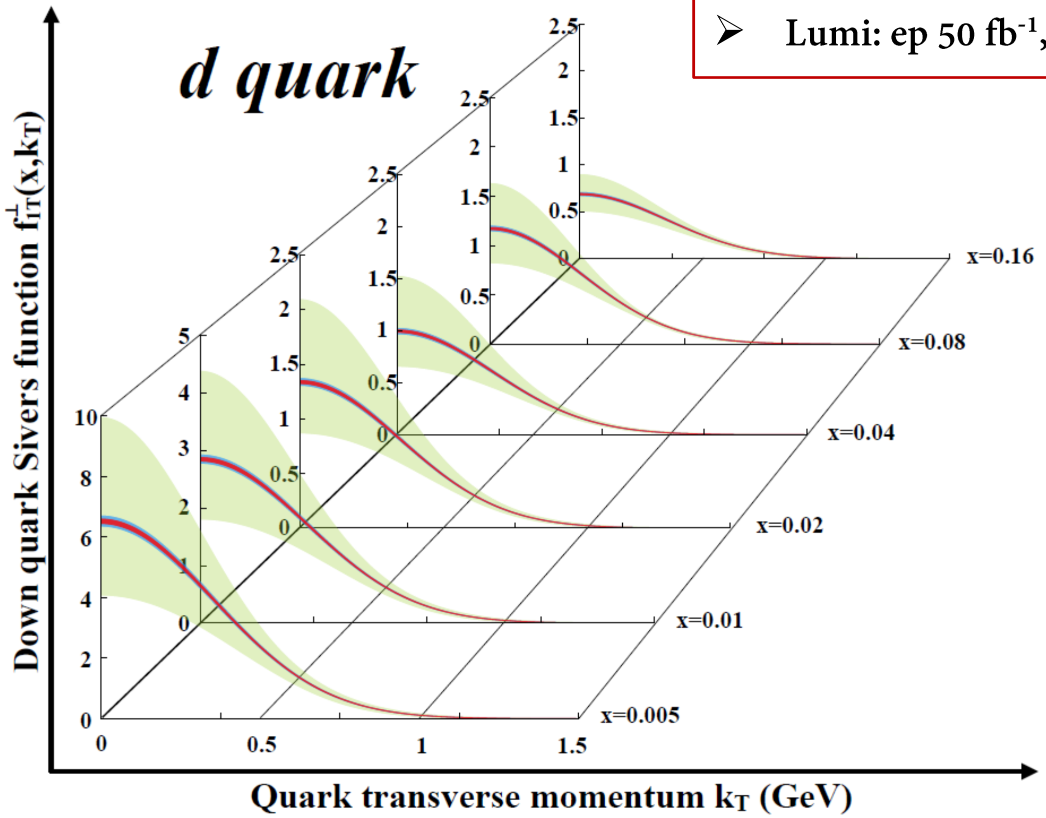
Projections on Sivers function

Green: Current accuracy
Red: stat. error only
Blue: sys. Error included

EicC SIDS data:

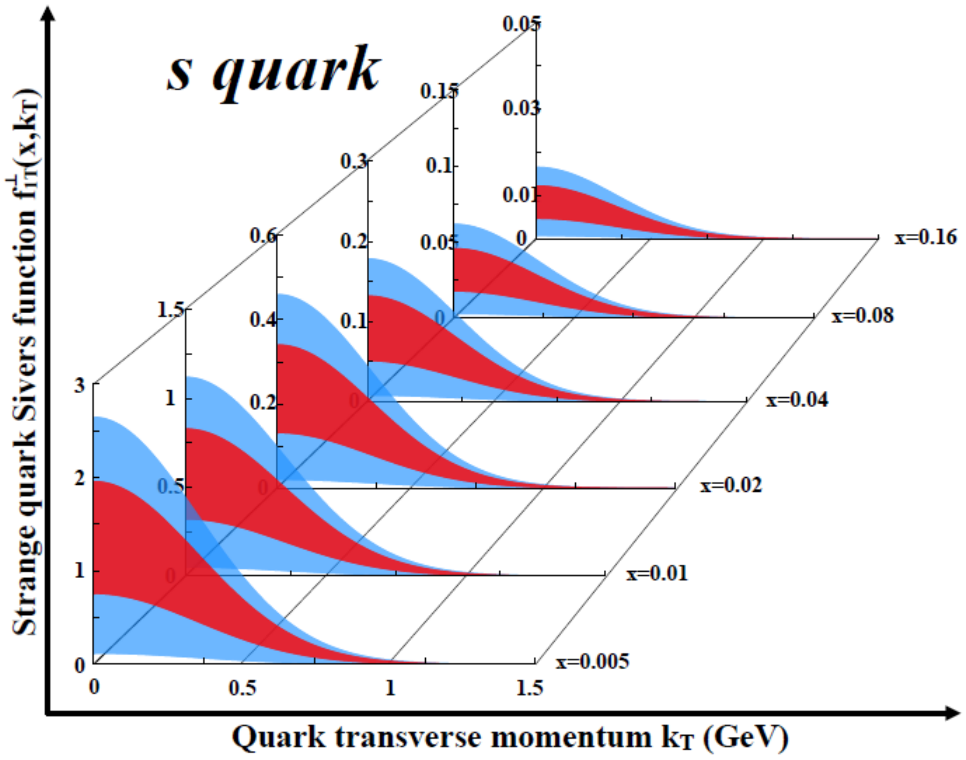
- Pion(+/-), Kaon(+/-)
- ep: 3.5 GeV X 20 GeV
- eHe-3: 3.5 GeV X 40 GeV
- Pol.: e(80%), p(70%), He-3(70%)
- Lumi: ep 50 fb^{-1}, eHe-3 50 fb^{-1}





Courtesy of Tianbo Liu

First trial to look at s-quark Sivers function



- sea quark Sivers function dynamically generated via Spin dependent odderon
- leads to a unique predication for s-quark: quark and anit-quark Sivers functions flip sign

Spin dependent odderon

Hard part

$$x f_{1T}^{\perp,s}(x,l_\perp^2) = -x f_{1T}^{\perp,\bar{s}}(x,l_\perp^2) = \frac{N_c}{8\pi^4}\int d\xi \int d^2k_\perp \frac{k_\perp \cdot l_\perp}{l_\perp^2} O_{1T}^{\perp}(x_g,k_\perp^2) A(l_\perp,k_\perp)$$

Courtesy of Tianbo Liu

H. Dong, D. x. Zheng, J. Zhou, 2018

A few more words about TMDs study at the EicC

Constrain the non-perturbative part of TMD evolution kernel

It is of great importance to unambiguously determine TMD evolution effects

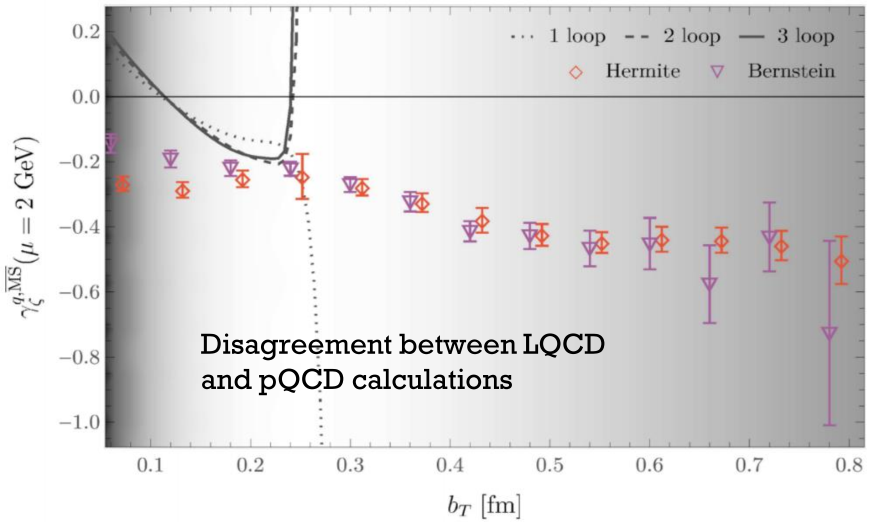
$$\exp\left[\int_{\mu_0}^{\mu}\frac{d\mu'}{\mu'}\gamma_{\mu}^{i}(\mu',\zeta_0)\right]\exp\left[\frac{1}{2}\gamma_{\zeta}^{i}(\mu,b_T)\ln\frac{\zeta}{\zeta_0}\right]$$

large b_T

- Considerable efforts to constrain the non-perturbative part of TMD evolution kernel

- Disagreement among model dependent parameterizations
  C. A. Aidala, B. Field, L. P. Gamberg and T. C. Rogers, 2014
  J. Collins and T. Rogers. 2015
  Alexey A. Vladimirov, 2020

- Exploratory LQCD study: P. Shanahan, M. Wagman, Y. Zhao,2020



- Less sensitive to the non-perturbative part at high energy
- Provide wide/moderate Q^2 leverage at EicC

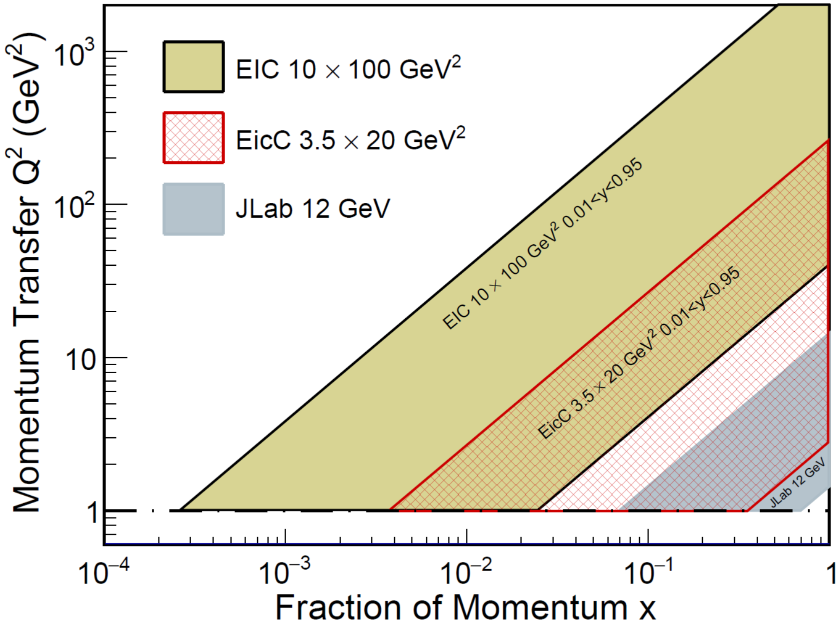
Summary

- EicC (3.5 GeV x 20 GeV) offers an opportunity to study the TMDs via the SIDIS process with a wide Q^2 coverage in the $x>0.005$ region
- A combination of pion and kaon events from e-p and e-^{3}He allows the flavor separation for light quarks (more kaon data in the current fragmentation region comparing to Jlab data)
- EicC-SIDIS kinematics fill the gap between Jlab and a higher energy EIC@BNL, hence in together provide a more complete kinematic coverage for TMDs studies

Thanks

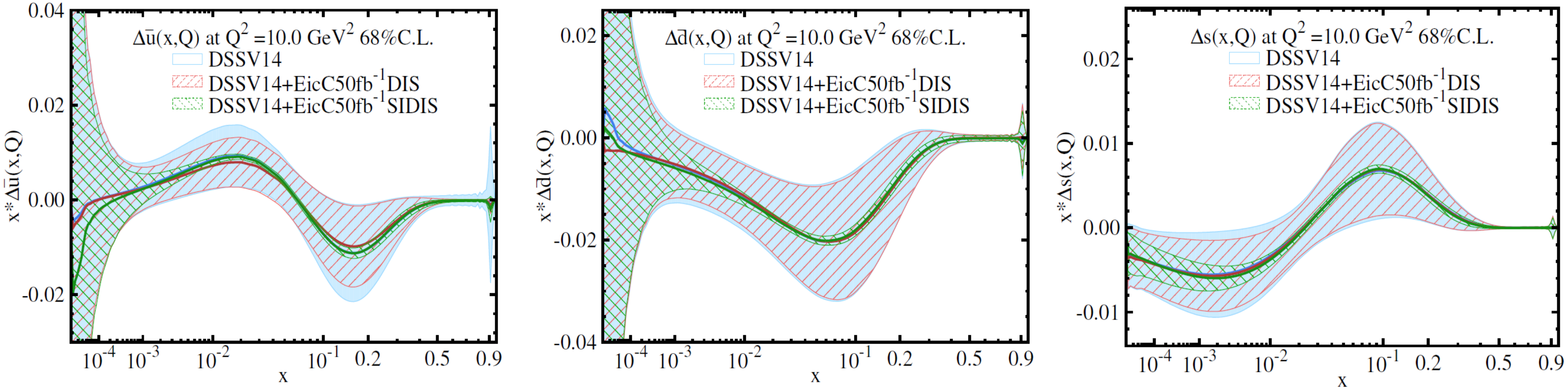
Backups

Highlighted physics topics



- Spin structure of the nucleon: 1D, 3D
  - polarized electron + polarized proton/light nuclei
- Partonic structure of nuclei and the parton interaction with the nuclear environment
  - unpolarized electron + unpolarized various nuclei
- Exotic states with c/cbar, b/bbar
- Origin of the proton mass study via heavy quarkonium near-threshold production

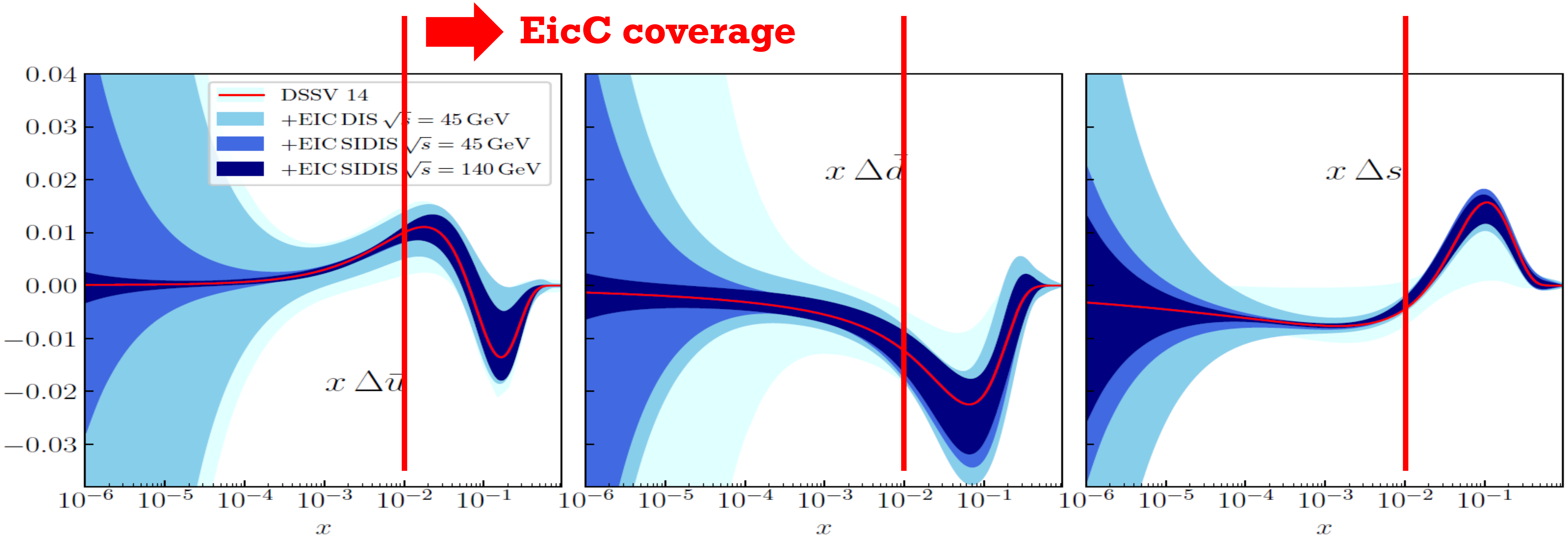
Spin structure of the nucleon-helicity distribution



A NLO impact study
See arXiv:2103.10276

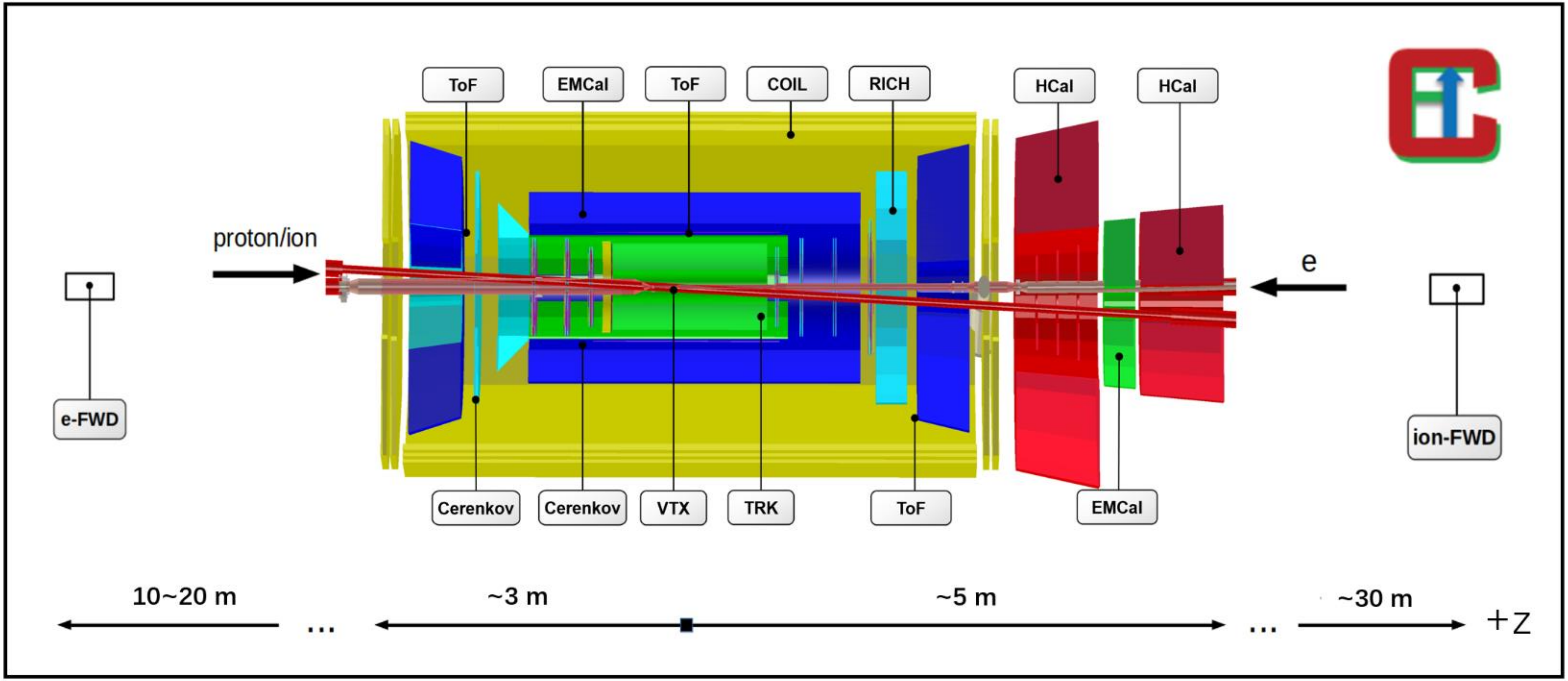
EicC white paper

EicC coverage



EIC Yellow Report

EicC detector considerations

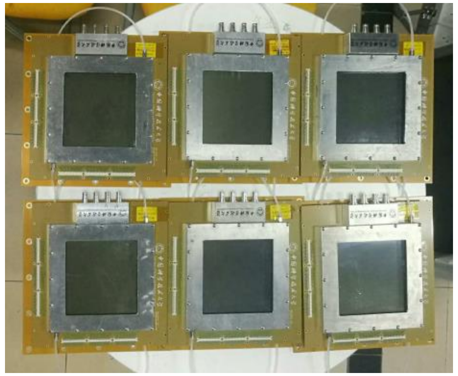


Full Geant4 simulation is ongoing

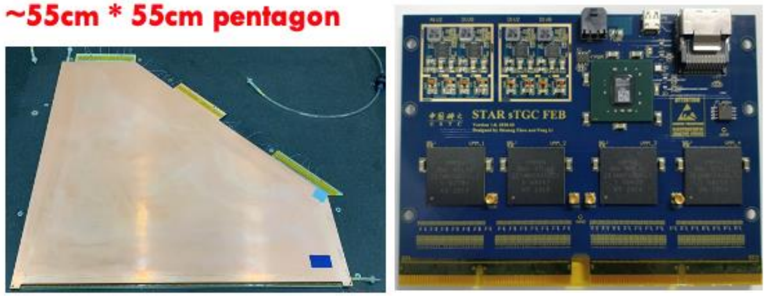
Detector R&Ds

Clean rooms of ISO6 and ISO7 (in total of 200 m^2) for detector assembling

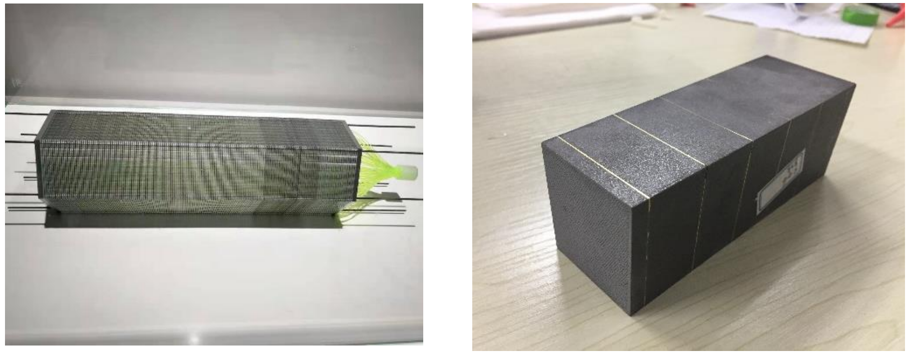
- 25cm x 25 cm Micromegas mass production
- R&D on 0.4m x 0.4m



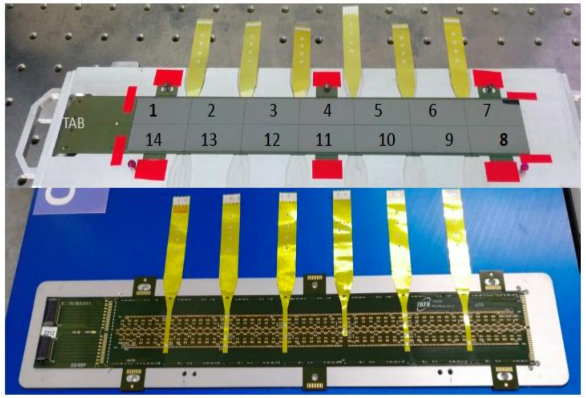
sTGC detector



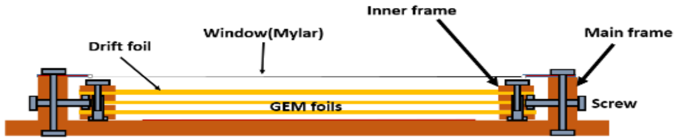
Shashlyk and W-powder+ScFi EMCal

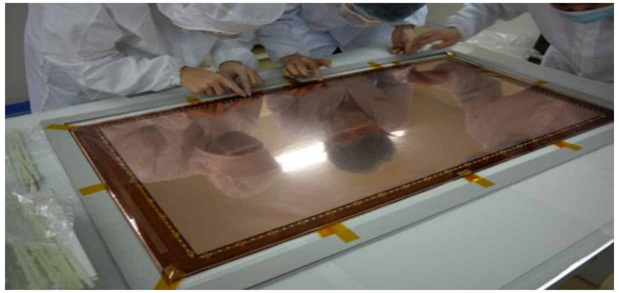


ALICE style ITS2 MAPS pixel detector



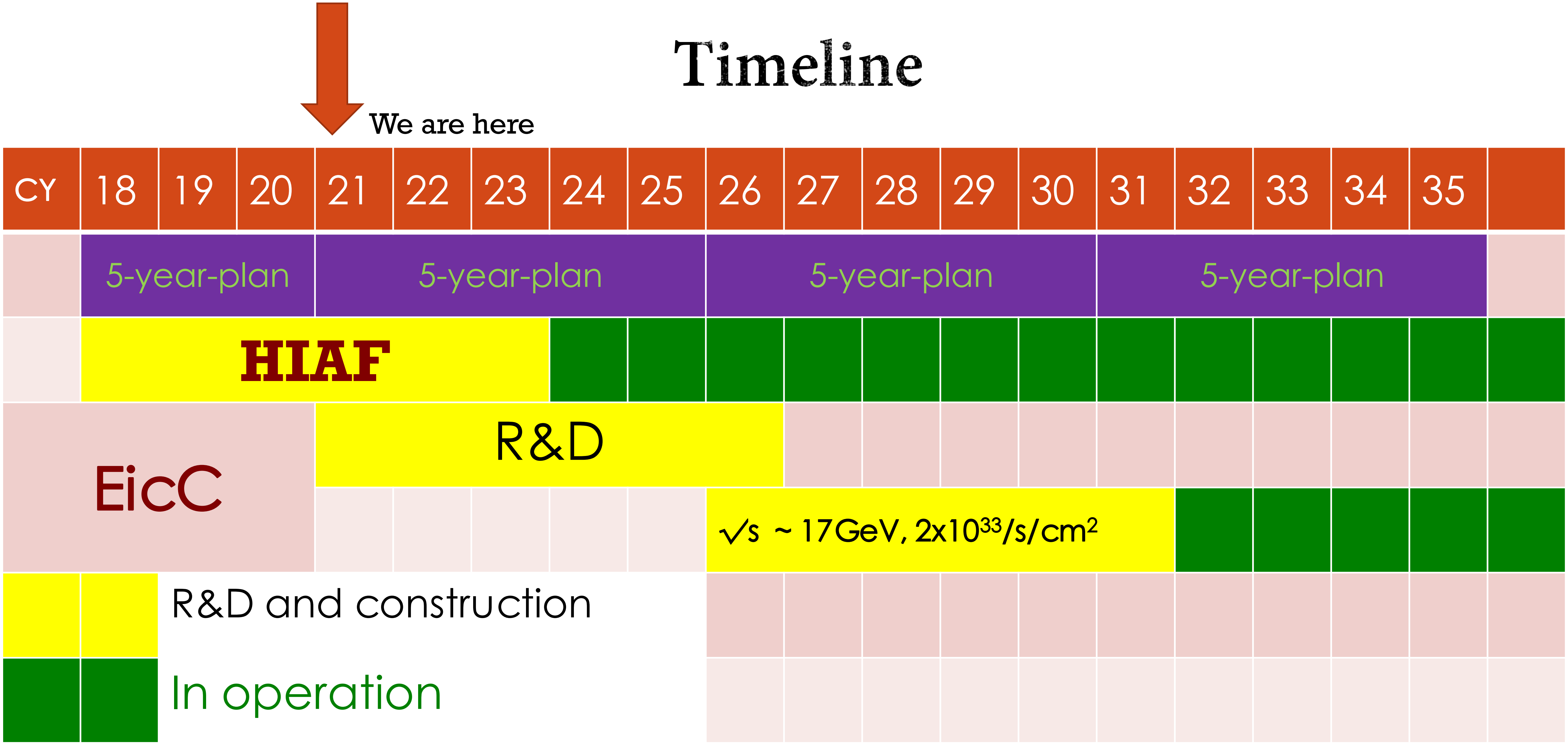
1m x 0.5 m **GEM (self-stretching)**





Others such as DIRC and RICH R&Ds will be followed …

Timeline



We are here
CY
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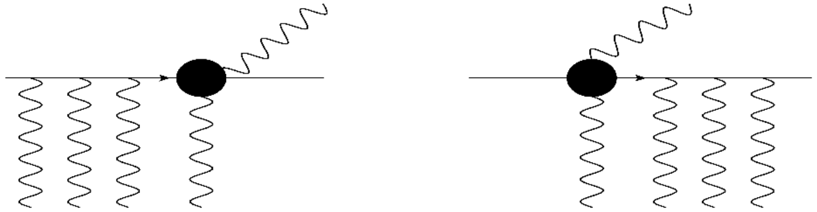
5-year-plan
5-year-plan
5-year-plan
5-year-plan
HIAF
EicC
R&D
$\sqrt{s}$ ~ 17GeV, 2×10^{33}/s/cm^2
R&D and construction
In operation

Process dependent photon TMD at EicC

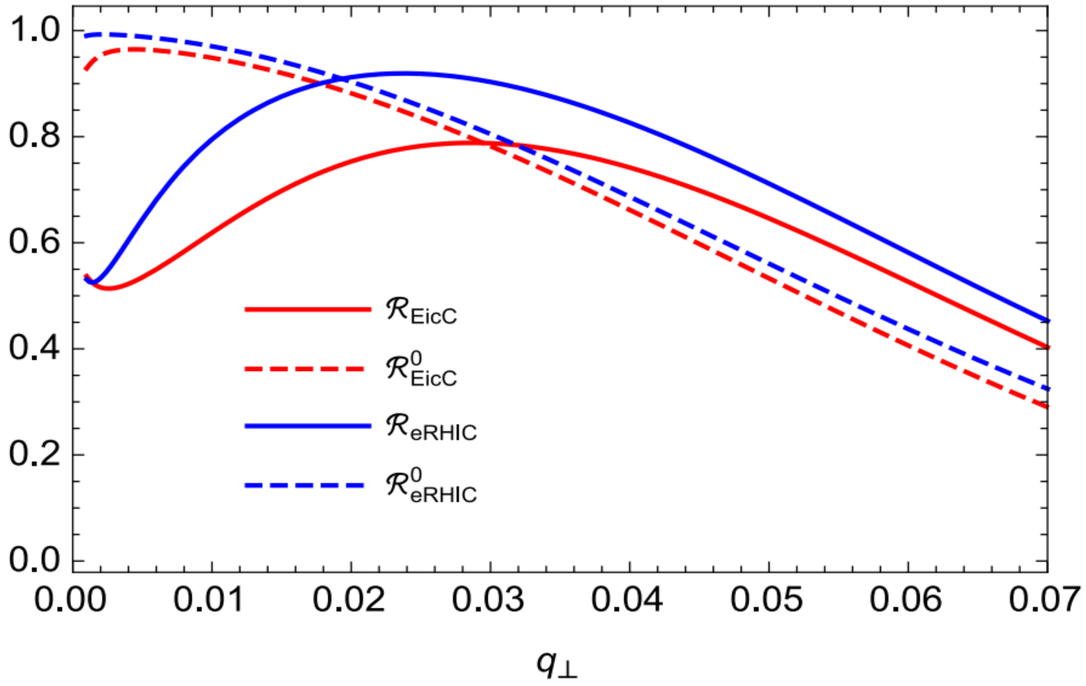
Multiple photon exchange enhance by a factor Z in eA collions

The ratios between the BH cross sections in ep and eA collisions



$$\mathcal{R}(q_\perp) = \frac{d\sigma_{eA}}{Z^2 d\sigma_{ep}} \qquad \mathcal{R}^0(q_\perp) = \frac{d\sigma^0_{eA}}{Z^2 d\sigma^0_{ep}}$$

Z.h. Sun, D.x. Zheng, J. Zhou, Y.j. Zhou, 2020



- Requires high momentum resolution!
- It is more promising to observe Coulomb correction at EicC as compared to EIC.