Electron-Ion Collider in China

Yuxiang Zhao (Institute of Modern Physics, Chinese Academy of Sciences)

On behalf of the EicC working group

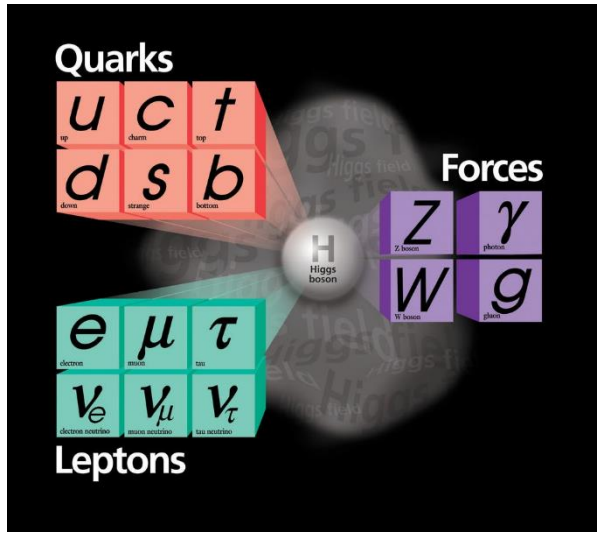
Celebration of Higgs boson discovery

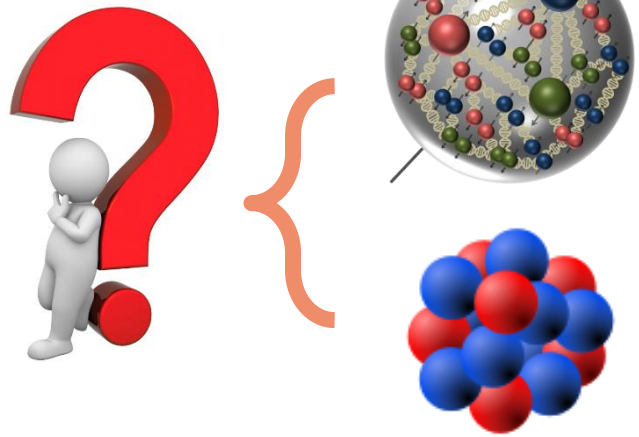
2013 Nobel prize in physics

… for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles …

However… do we really understand the building blocks of our visible world?

We know very little…

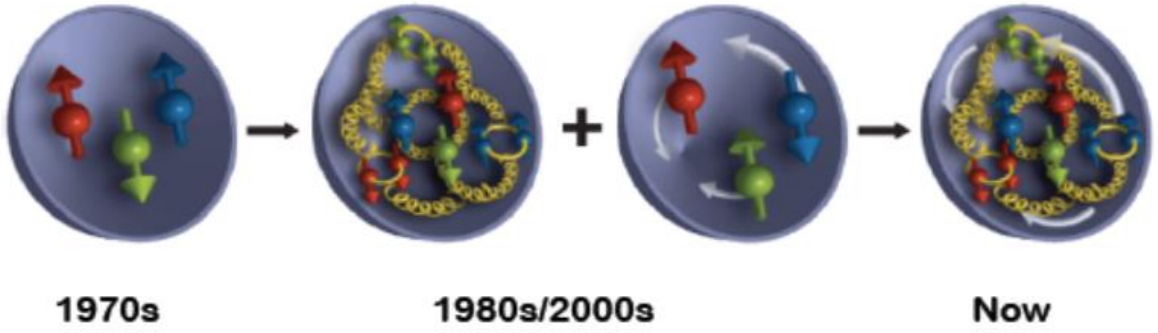




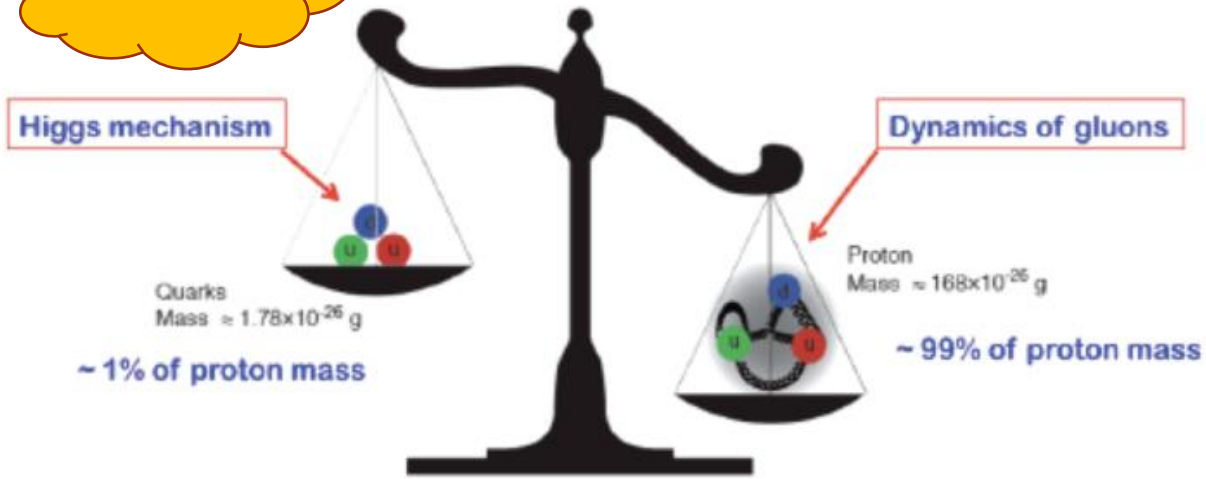
Spin structure

Mass structure

spin

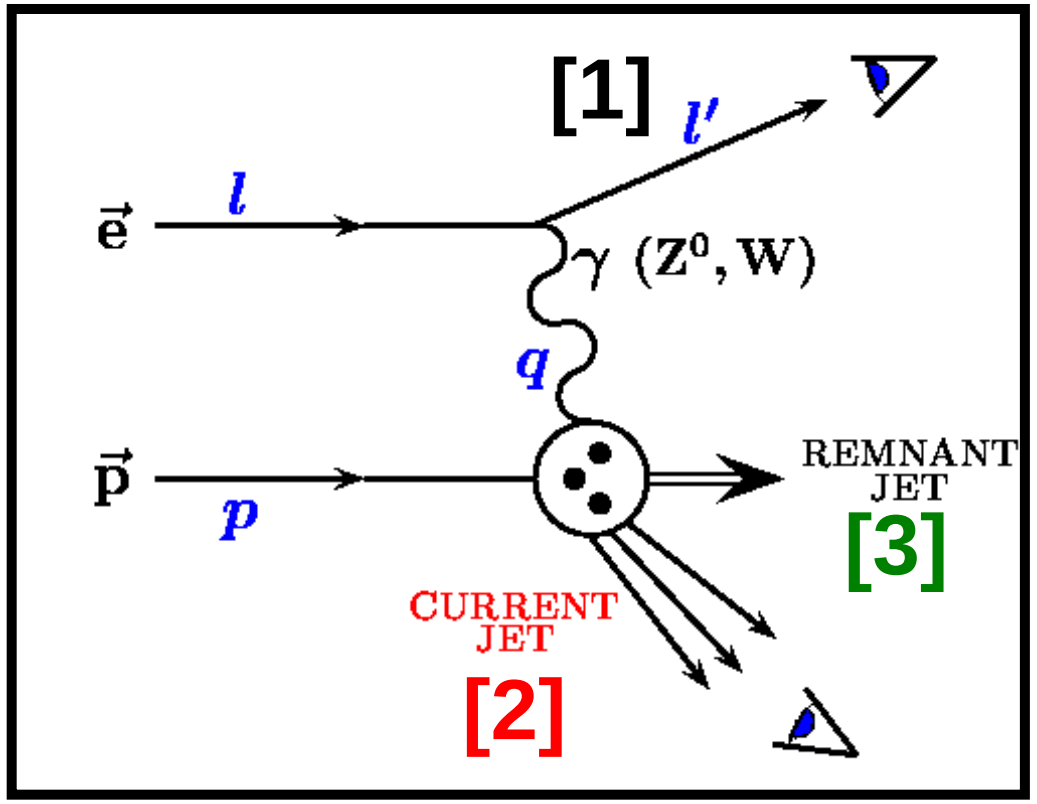


mass



Lepton-Nucleon Scatterings

QED tool to study QCD nature of the nucleon



$$Q^2 = -q^2 = sxy$$

$$x = \frac{Q^2}{2p \cdot q}$$

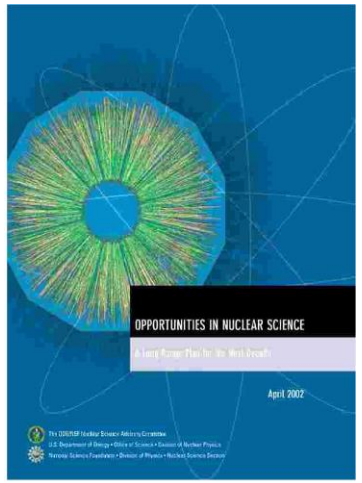
$$y = \frac{p \cdot q}{p \cdot l}$$

$$s = 4E_e E_p$$

$$W = (q + p)^2$$

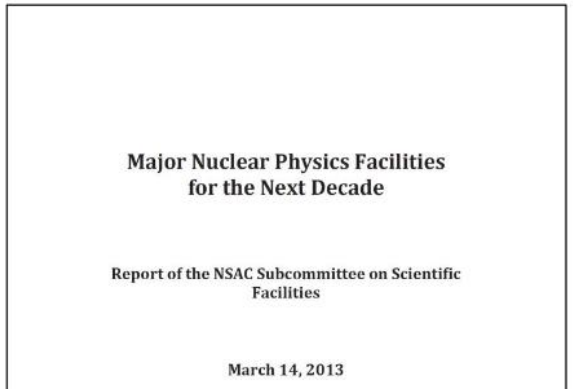
- QED probe is clean
- α_{EM} ~1/137 with broad Q coverage
- One-photon exchange approximation: ~1% accuracy
- Detection scale is determined by Q^2: $1GeV^2$ ~ nucleon size

Observe scattered electron/muon	**[1]**	**→ inclusive**
Observe current jet/hadron	**[1]+[2]**	**→ semi-inclusive**
Observe remnant jet/hadron as well	**[1]+[2]+[3]**	**→ exclusive**



2002 Long Range Plan in the US

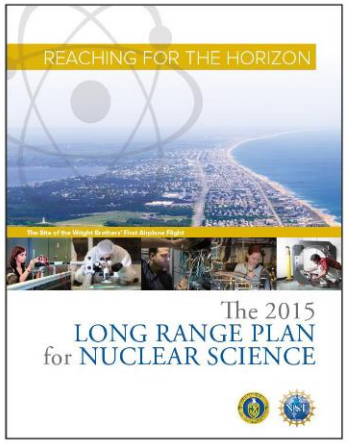
The Electron-Ion Collider (EIC). The EIC is a new accelerator concept that has been proposed to extend our understanding of the structure of matter in terms of its quark and gluon constituents. Two classes of


Major Nuclear Physics Facilities
for the Next Decade

Report of the NSAC Subcommittee on Scientific Facilities

March 14, 2013

The 2013 NSAC *Subcommittee on Future Facilities* identified an Electron-Ion Collider as ***absolutely central*** to the nuclear science program of the next decade.



- Gluons…generate nearly all of the visible mass in the universe. Despite their importance, fundamental questions remain…. These can only be answered with a powerful new electron ion collider (EIC). ***We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.***

2002

2013

2015

2020:CD-0
Approved project!

2021:CD-1

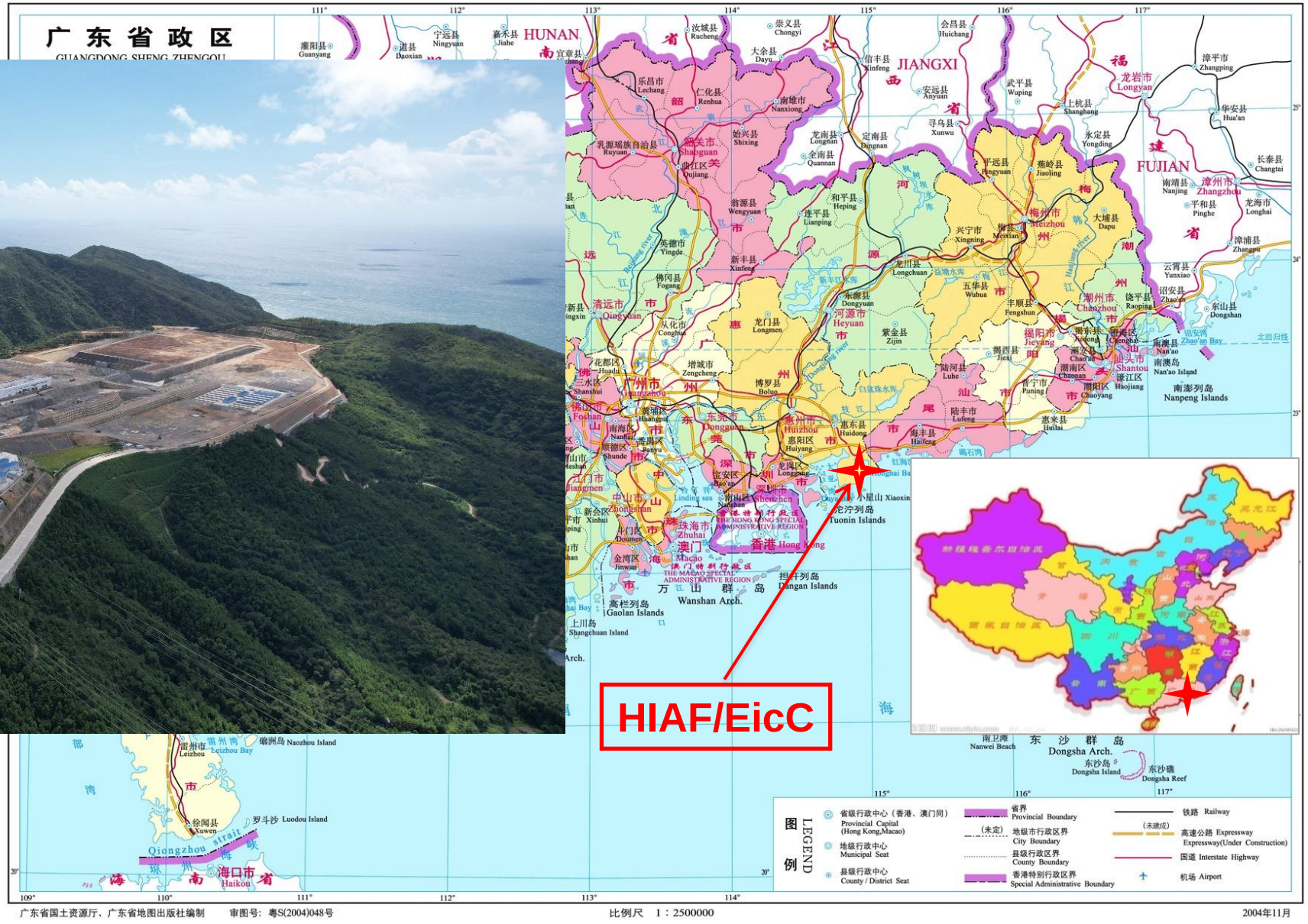
~2030:operation

Outline

- General introduction of the Electron-Ion Collider **in China**
- Physics highlights
- Project status
- Summary

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

HIAF under construction

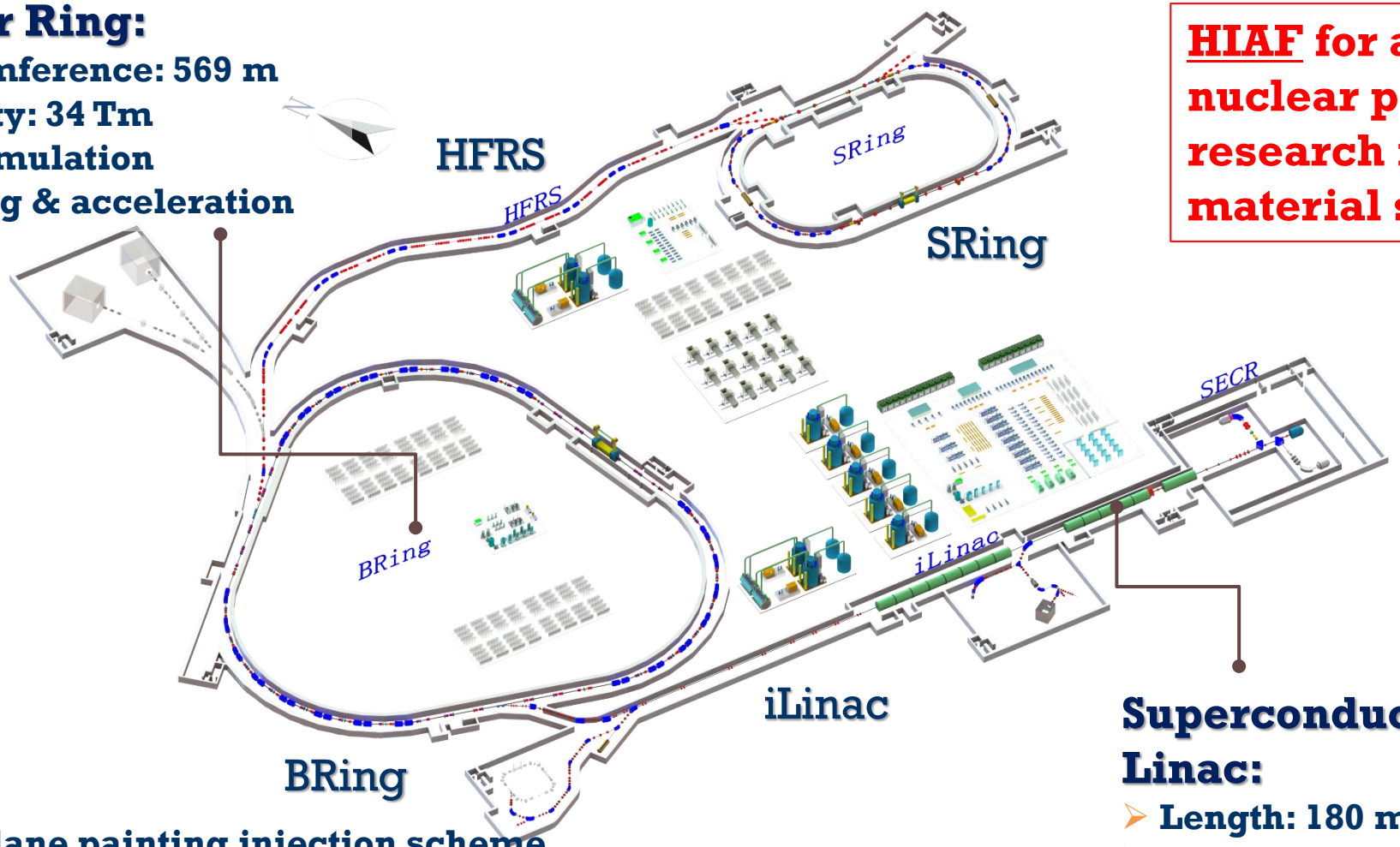


High Intensity heavy-ion Accelerator Facility (HIAF)

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

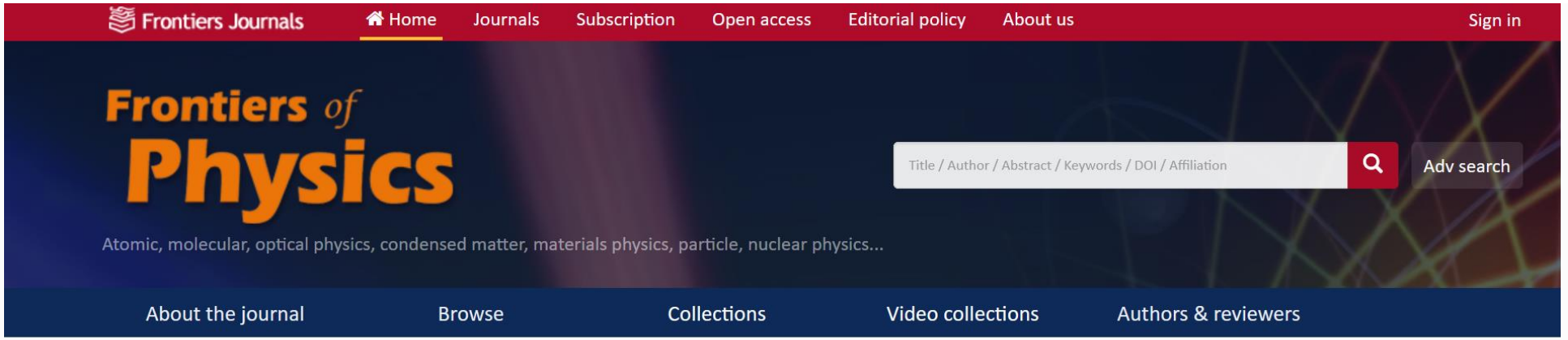
Superconducting Ion Linac:

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

Electron **I**on **C**ollider in **C**hina, EicC

EicC white paper (arXiv: 2102.09222)

Published in the *Frontiers of Physics* Journal (open access)



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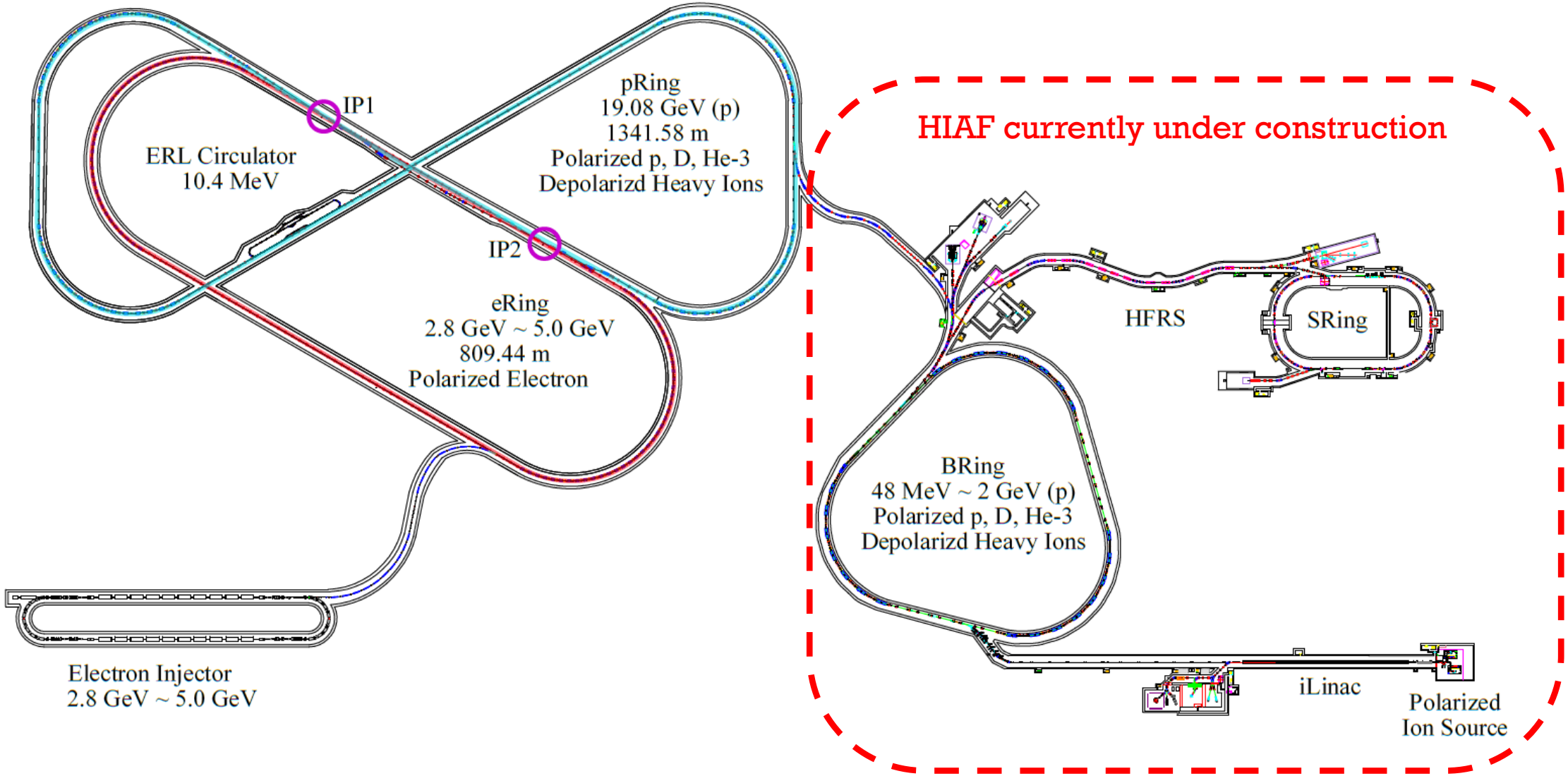
REPORT

Electron-ion collider in China

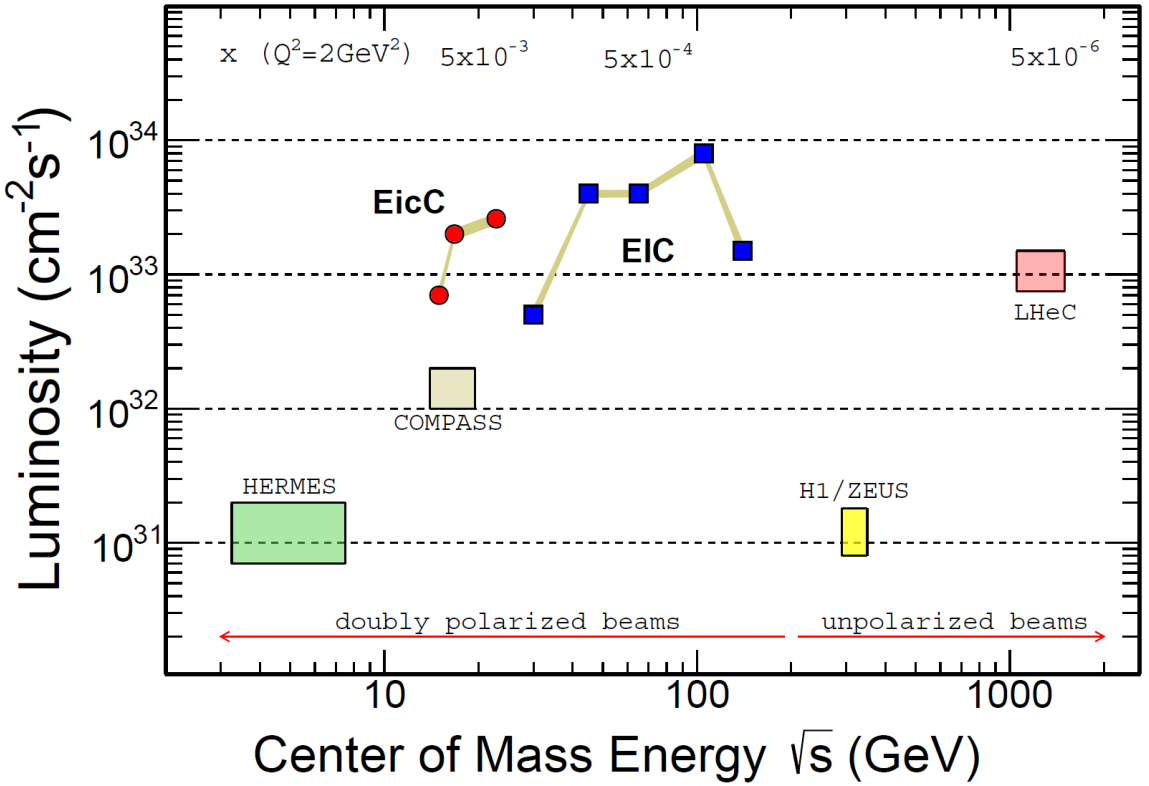
Now we have 46 institutes and >100 physicists

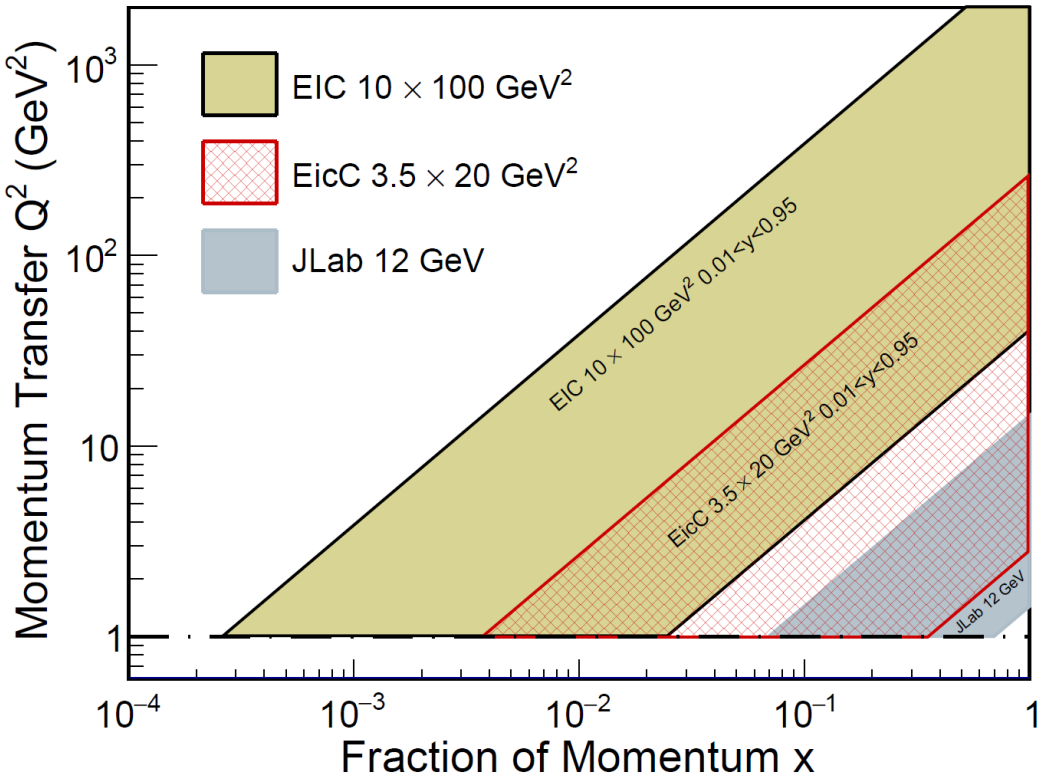
Daniele P. Anderle[1] , Valerio Bertone[2] , Xu Cao[3,4] , Lei Chang[5] , Ningbo Chang[6] , Gu Chen[7] , Xurong Chen[3,4] , Zhuojun Chen[8] , Zhufang Cui[9] , Lingyun Dai[8] , Weitian Deng[10] , Minghui Ding[11] , Xu Feng[12] , Chang Gong[12] , Longcheng Gui[13] , Feng-Kun Guo[4,14] , Chengdong Han[3,4] , Jun He[15] , Tie-Jiun Hou[16] , Hongxia Huang[15] , Yin Huang[17] , KrešImir KumeričKi[18] , L. P. Kaptari[3,19] , Demin Li[20] , Hengne Li[1] , Minxiang Li[3,21] , Xueqian Li[5] , Yutie Liang[3,4] , Zuotang Liang[22] , Chen Liu[22] , Chuan Liu[12] , Guoming Liu[1] , Jie Liu[3,4] , Liuming Liu[3,4] , Xiang Liu[21] , Tianbo Liu[22] , Xiaofeng Luo[23] , Zhun Lyu[24] , Boqiang Ma[12] , Fu Ma[3,4] , Jianping Ma[4,14] , Yugang Ma[4,25,26] , Lijun Mao[3,4] , Cédric Mezrag[2] , Hervé Moutarde[2] , Jialun Ping[15] , Sixue Qin[27] , Hang Ren[3,4] , Craig D. Roberts[9] , Juan Rojo[28,29] , Guodong Shen[3,4] , Chao Shi[30] , Qintao Song[20] , Hao Sun[31] , Paweł Sznajder[32] , Enke Wang[1] , Fan Wang[9] , Qian Wang[1] , Rong Wang[3,4] , Ruiru Wang[3,4] , Taofeng Wang[33] , Wei Wang[34] , Xiaoyu Wang[20] , Xiaoyun Wang[35] , Jiajun Wu[4] , Xinggang Wu[27] , Lei Xia[36] , Bowen Xiao[23,37] , Guoqing Xiao[3,4] , Ju-Jun Xie[3,4] , Yaping Xie[3,4] , Hongxi Xing[1] , Hushan Xu[3,4] , Nu Xu[3,4,23] , Shusheng Xu[38] , Mengshi Yan[12] , Wenbiao Yan[36] , Wencheng Yan[20] , Xinhu Yan[39] , Jiancheng Yang[3,4] , Yi-Bo Yang[4,14] , Zhi Yang[40] , Deliang Yao[8] , Zhihong Ye[41] , Peilin Yin[38] , C.-P. Yuan[42] , Wenlong Zhan[3,4] , Jianhui Zhang[43] , Jinlong Zhang[22] , Pengming Zhang[44] , Yifei Zhang[36] , Chao-Hsi Chang[4,14] , Zhenyu Zhang[45] , Hongwei Zhao[3,4] , Kuang-Ta Chao[12] , Qiang Zhao[4,46] , Yuxiang Zhao[3,4] , Zhengguo Zhao[36] , Liang Zheng[47] , Jian Zhou[22] , Xiang Zhou[45] , Xiaorong Zhou[36] , Bingsong Zou[4,14] , Liping Zou[3,4]

EicC Accelerator complex layout



EicC Specs



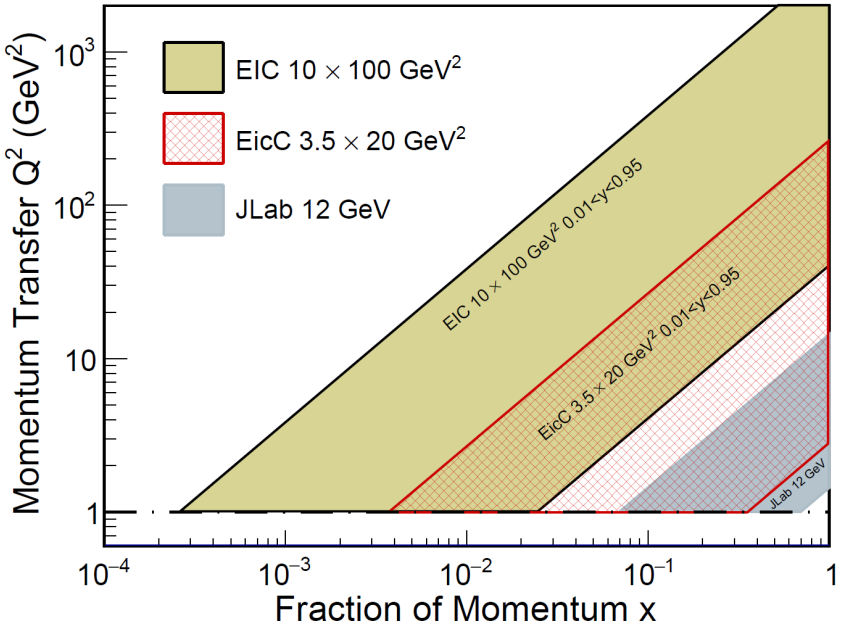


- EicC covers the kinematic region between JLab experiments and US-EIC
- EicC complements the ongoing scientific programs at JLab and future EIC project
- EicC focuses on moderate x and sea-quark region

Outline

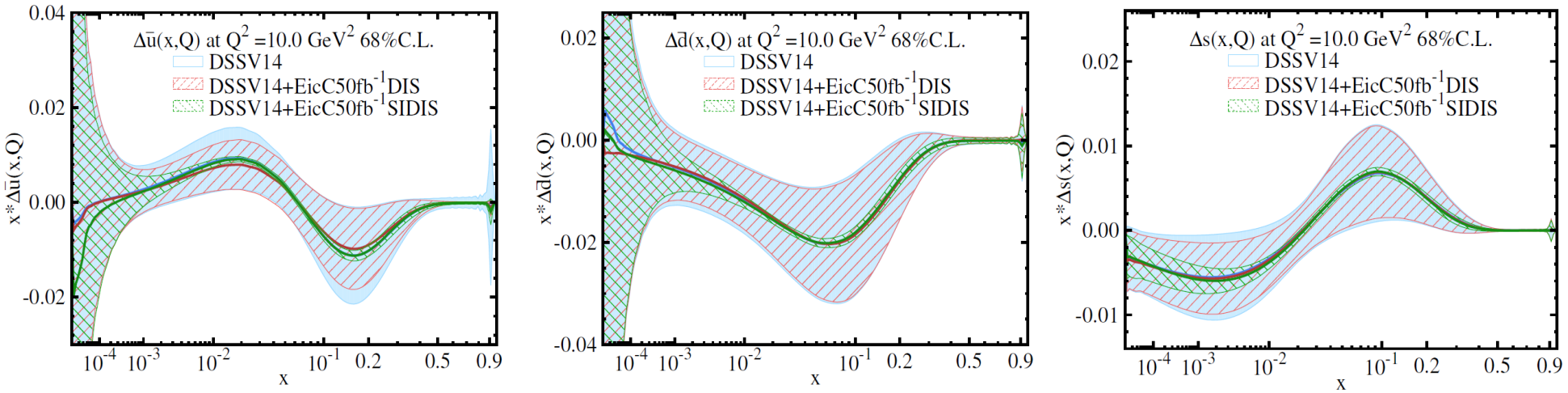
- General introduction of the Electron-Ion Collider in China
- Physics highlights
- Project status
- Summary

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 (BESIII community in China)
- Origin of the proton mass study

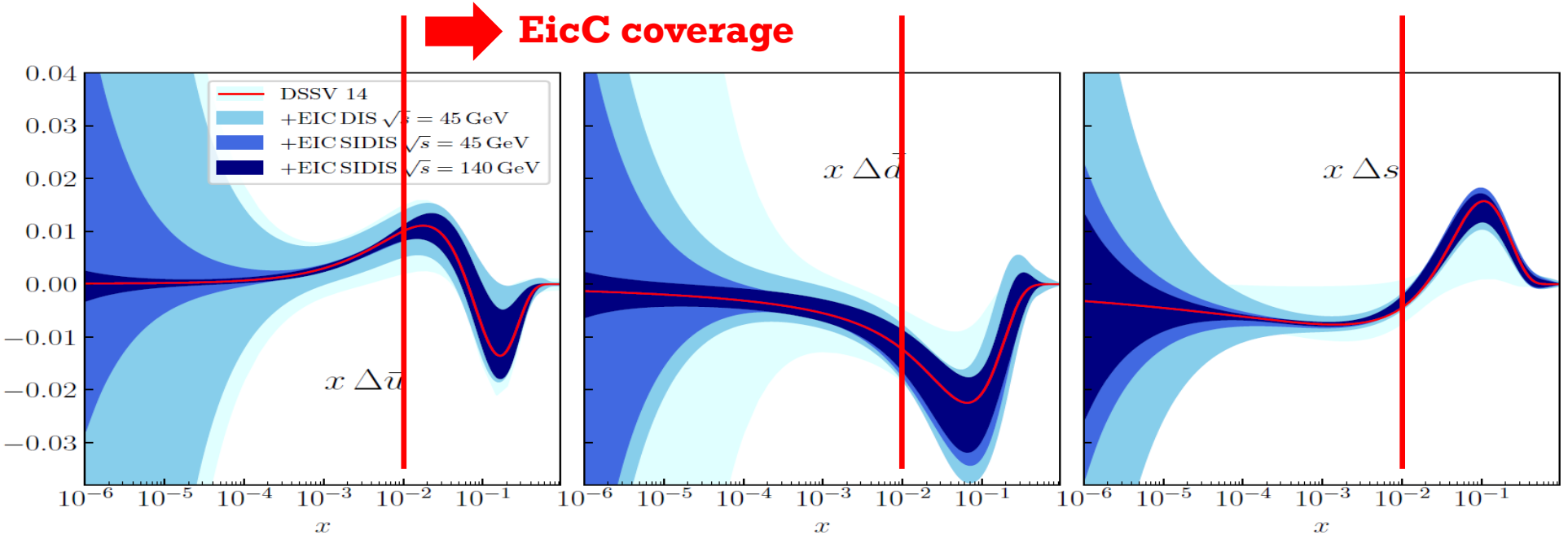
Spin structure of the nucleon-helicity distribution



A NLO impact study
See arXiv:2103.10276
JHEP08(2021)034

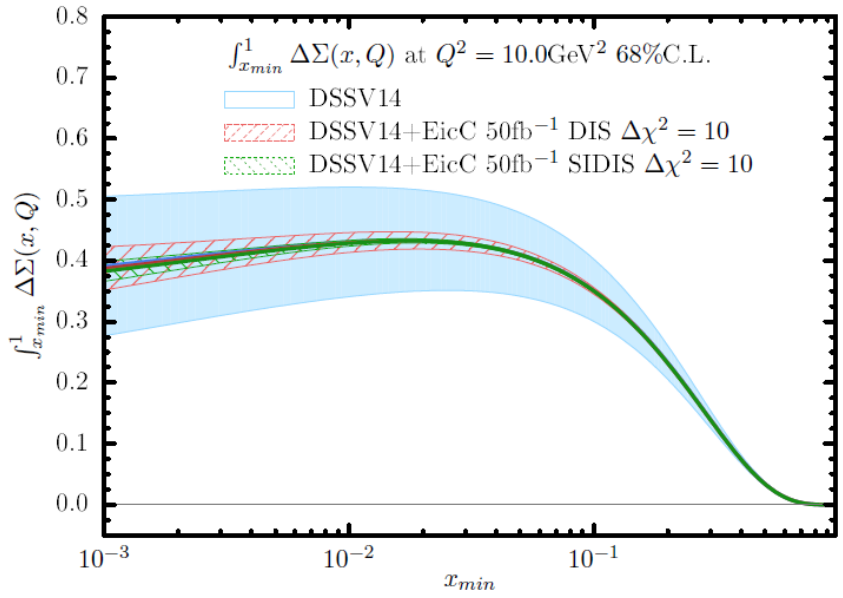
EicC white paper

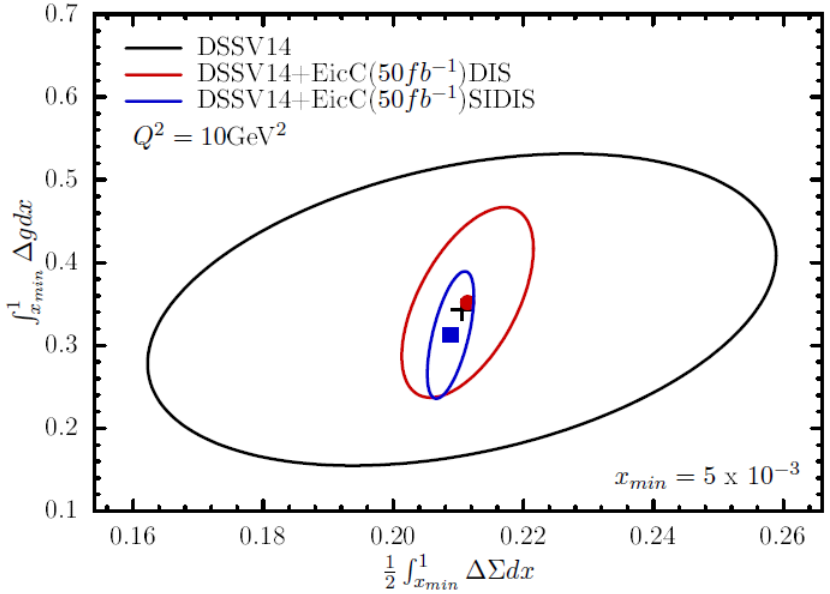
EicC coverage



EIC Yellow Report

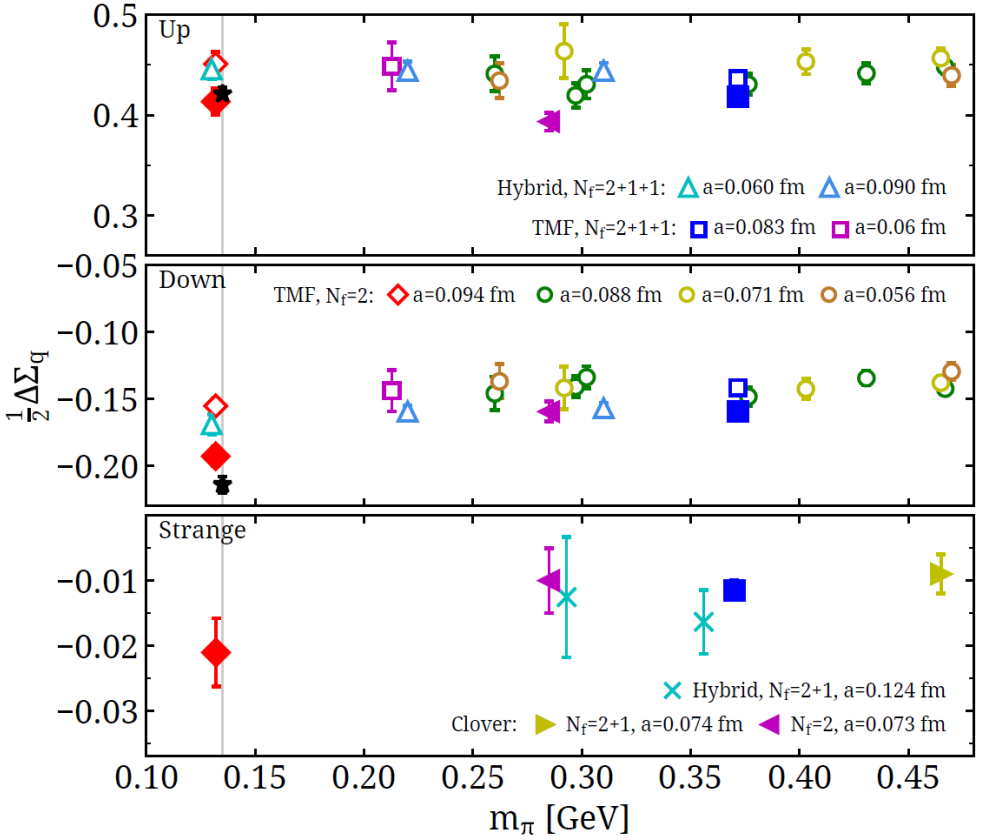
Quark/gluon spin contributions to the proton spin





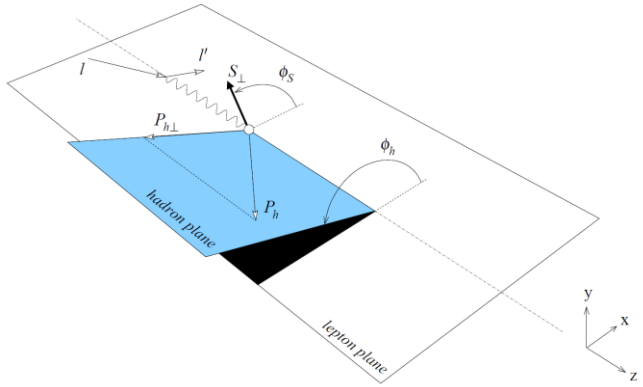
Lattice QCD simulations

PRL119.142002, 2017



Also, LQCD is able to do quasi-PDF calculations

Spin structure of the nucleon-TMDs



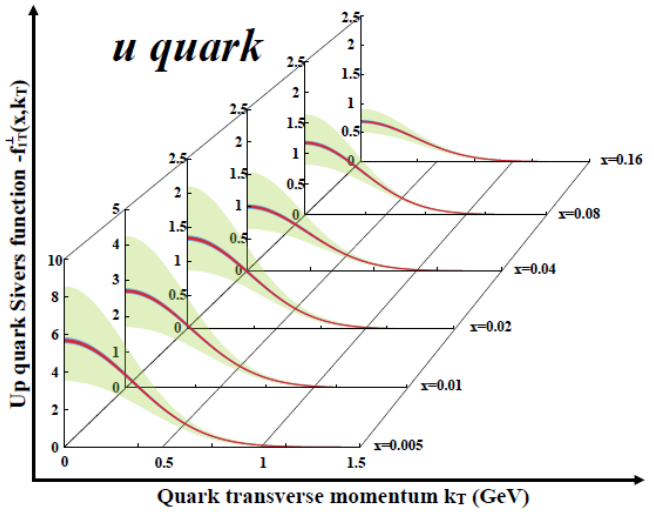
u/d Sivers EicC vs world data

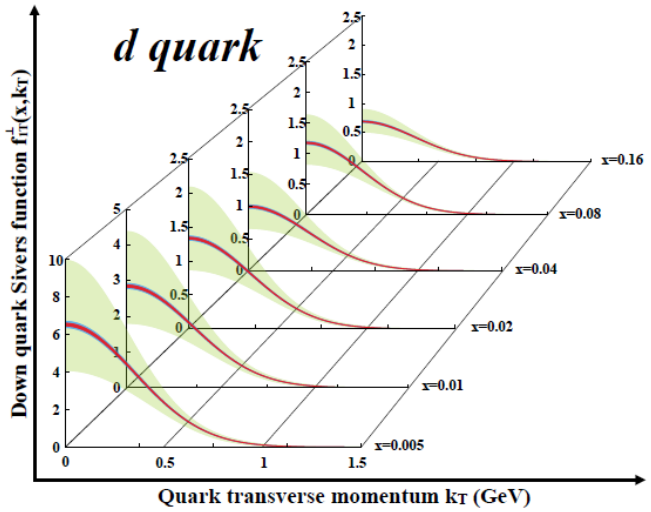
LO analysis

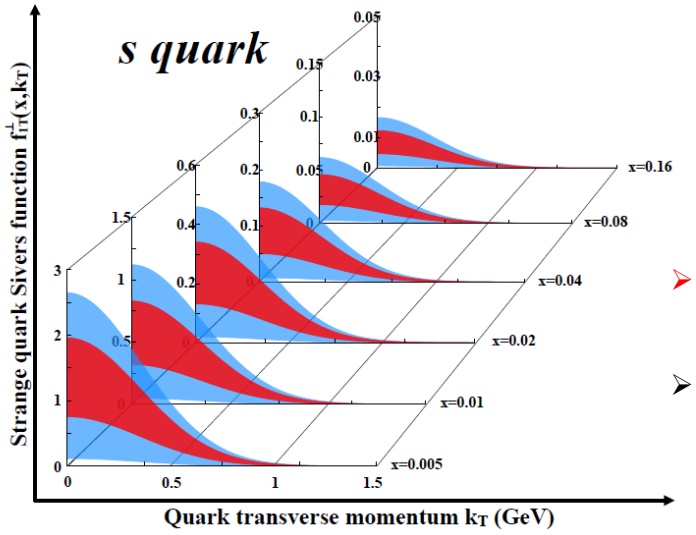
EicC SIDS data:

- 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}

EicC, precise measurements.







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

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

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

A few more words about TMDs study at the EicC

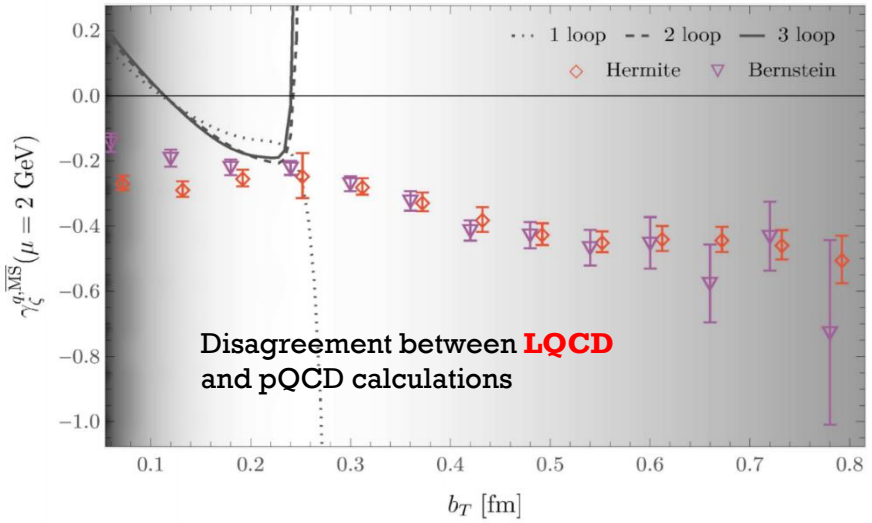
Constrain the non-perturbative part of TMD evolution kernel

It is of great importance to unambiguously determine TMD evolution effects

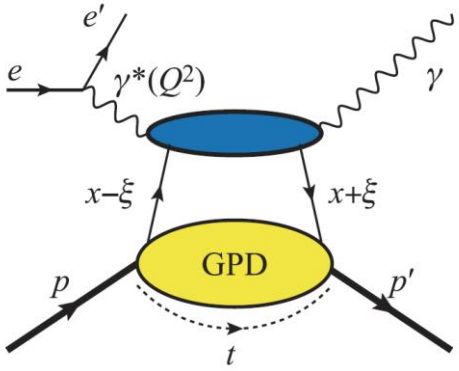
$$\exp\left[\int_{\mu_0}^{\mu}\frac{\mathrm{d}\mu'}{\mu'}\gamma_\mu^i\left(\mu',\zeta_0\right)\right]\exp\left[\frac{1}{2}\gamma_\zeta^i\left(\mu,b_T\right)\ln\frac{\zeta}{\zeta_0}\right]$$

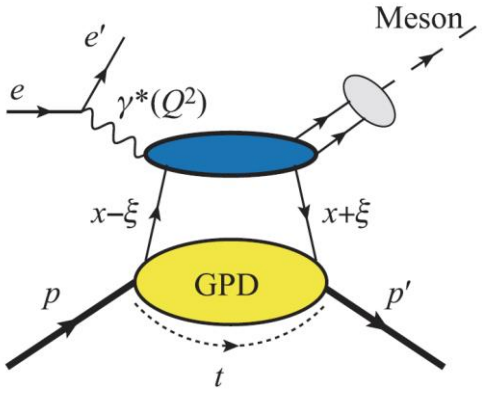
large b_T

- 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



Spin structure of the nucleon-GPDs





Polarized beam, unpolarized target (SSA)

$$A_{LU}^{\sin\phi} \propto \frac{y\sqrt{1-y}}{2-2y-y^2}\sqrt{\frac{-t}{y^2Q^2}} \times x_B Im\left[F_1\mathcal{H} + \xi(F_1+F_2)\widetilde{\mathcal{H}} - kF_2\mathcal{E} + ...\right](x_B, t, Q^2),$$

Unpolarized beam, longitudinal target (lTSA)

$$A_{UL}^{\sin\phi} \propto \frac{\sqrt{1-y}}{2-y}\sqrt{\frac{-t}{y^2Q^2}} \times x_B Im\left[F_1\widetilde{\mathcal{H}} + x_B(F_1+F_2)(\widetilde{\mathcal{H}} + \frac{x_B}{2\mathcal{E}}) - x_B kF_2\widetilde{\mathcal{E}} + ...\right](x_B, t, Q^2),$$

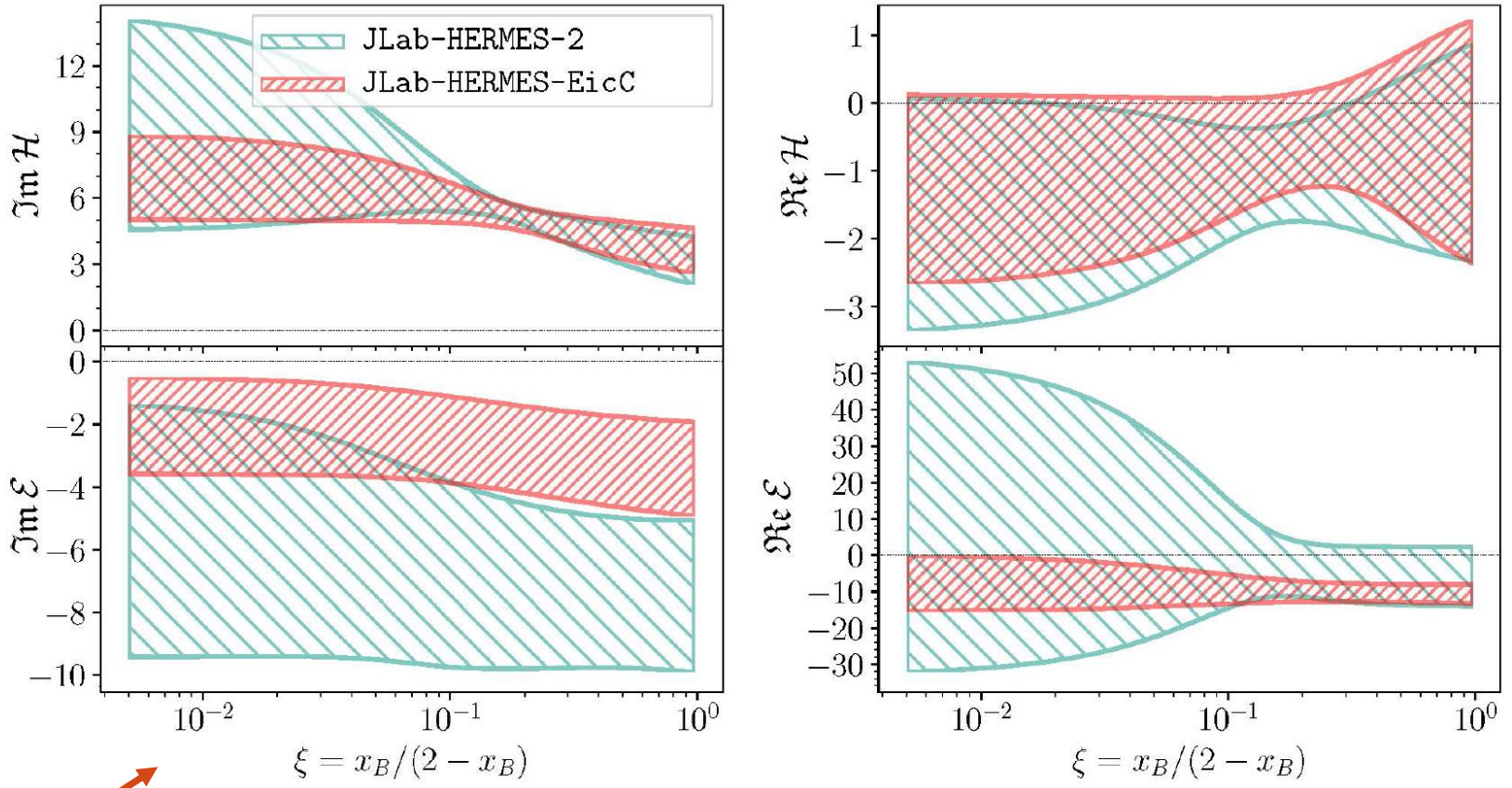
Unpolarized beam, transverse target (tTSA)

$$A_{UT}^{\sin(\phi-\phi_S)\cos\phi} \propto \frac{\sqrt{1-y}}{2-y}\frac{-t}{2yM_NQ} \times x_B Im\left[F_1\mathcal{H} + \xi(F_1+F_2)(\widetilde{\mathcal{H}} + \frac{x_B}{2}\mathcal{E}) - \xi kF_2\widetilde{\mathcal{E}} + ...\right](x_B, t, Q^2),$$

Polarized beam, longitudinal target (DSA)

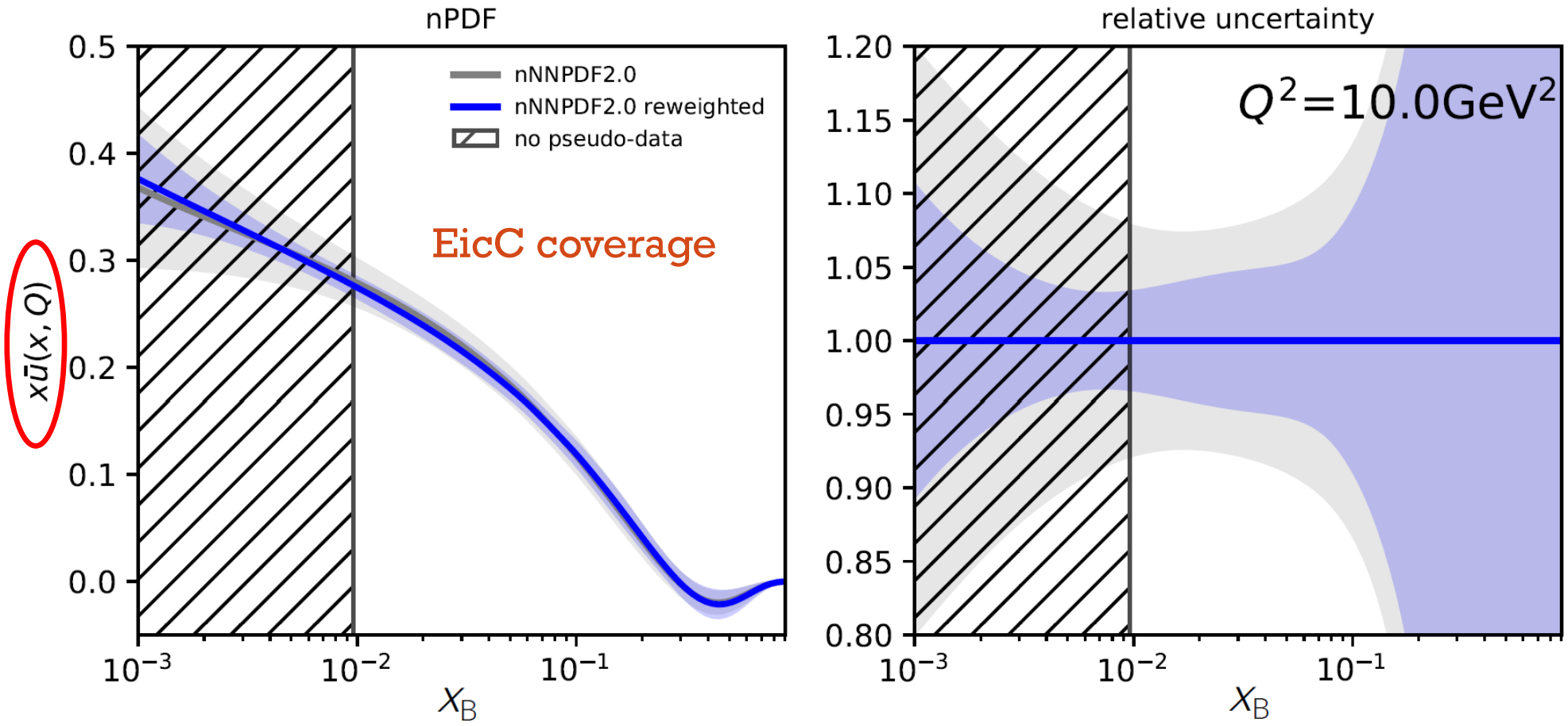
$$A_{LL} \propto (A + B\cos\phi)\, Re\left[F_1\mathcal{H} + \xi(F_1+F_2)(\mathcal{H} + \frac{x_B}{2}\mathcal{E}) + ...\right],$$

The extraction of CFF with neural network methods [Kumericki, 19]



Only with this azimuthal angular modulation

Nuclear PDFs study with ion beam



With only a few hours of running

Proton mass study

Mass decomposition [Ji, 95]

$$M = \underbrace{M_q + M_m}_{\text{Quark}} + \underbrace{M_g + M_a}_{\text{Gluon}}$$

M_q : quark energy

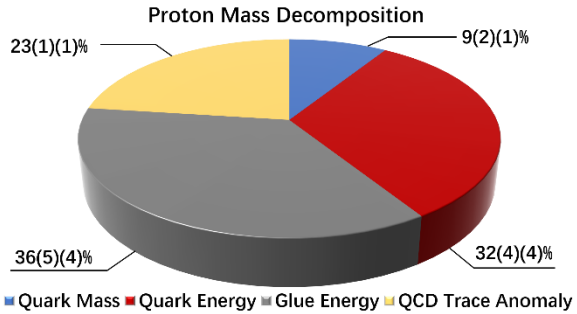
M_m : quark mass (condensate)

M_g : gluon energy

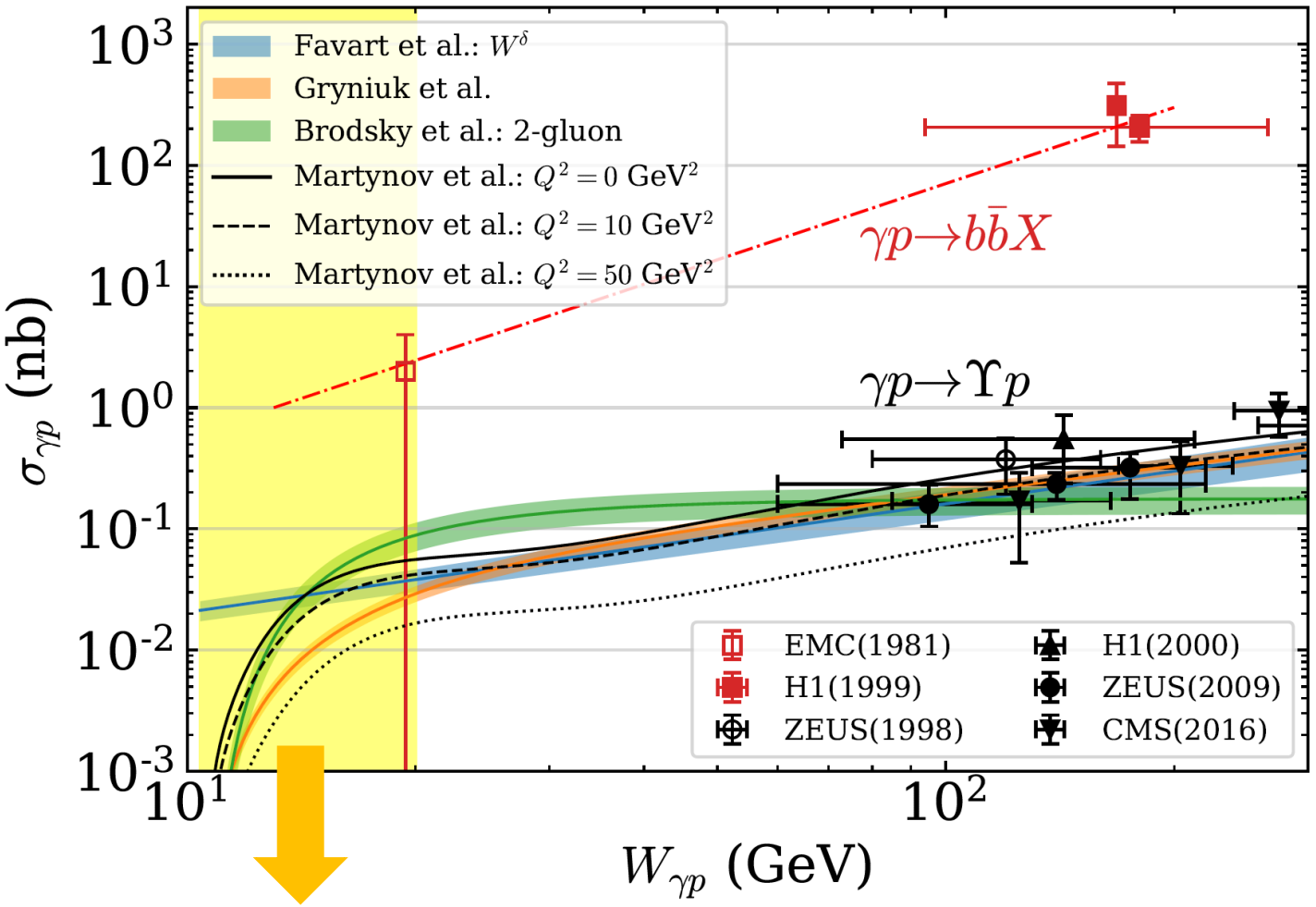
M_a : trace anomaly

- M_q and M_g constrained by PDFs.
- M_m via πN low energy scattering.
- M_a via threshold production of J/Ψ (8.2 GeV; JLab) and Υ (12 GeV);
- Threshold requires low CoM energy. (Low y at EIC).
- Complementarity between EicC (and EIC) and lattice. Guideline

?



Lattice QCD calculation by Yang et al, 2018



EicC coverage

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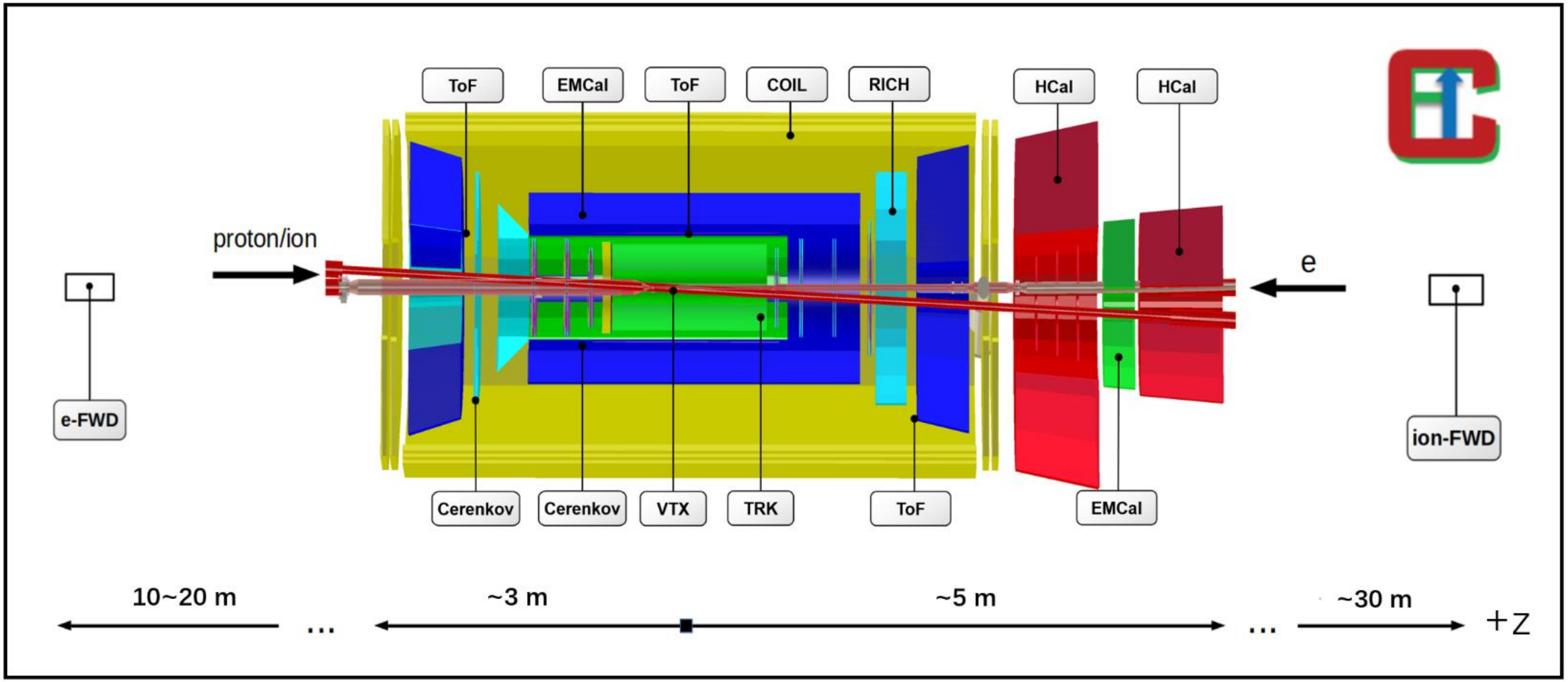
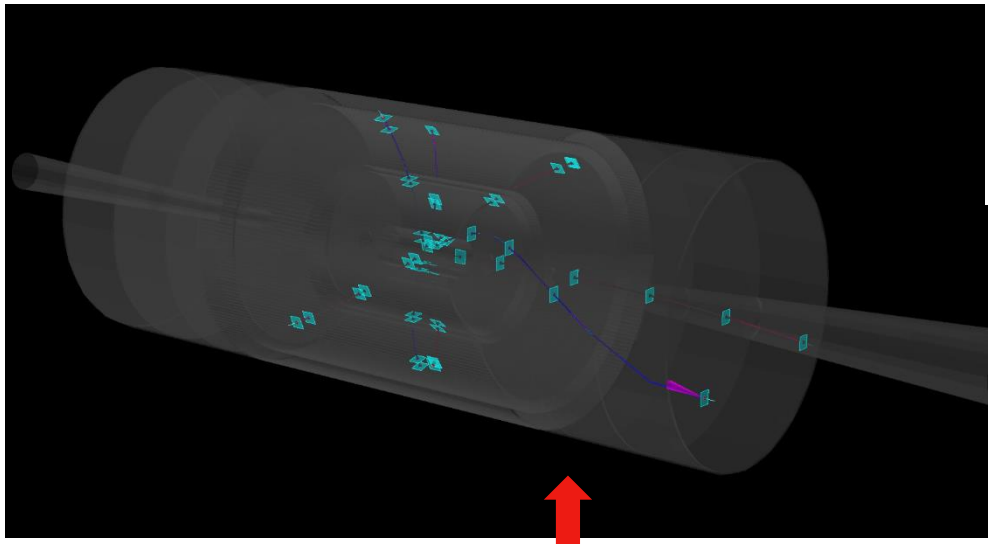
EicC detector considerations

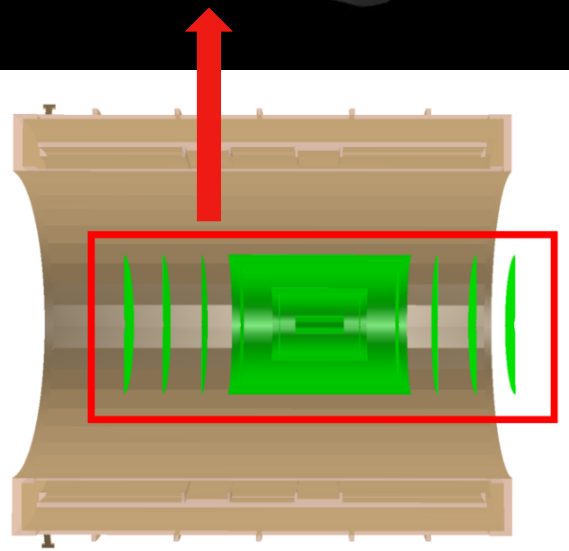


Detailed full Geant4 simulation is ongoing

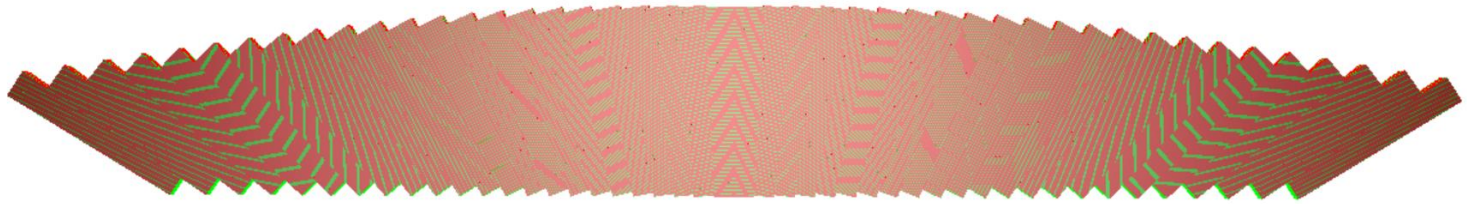
Subsystem simulations---an example

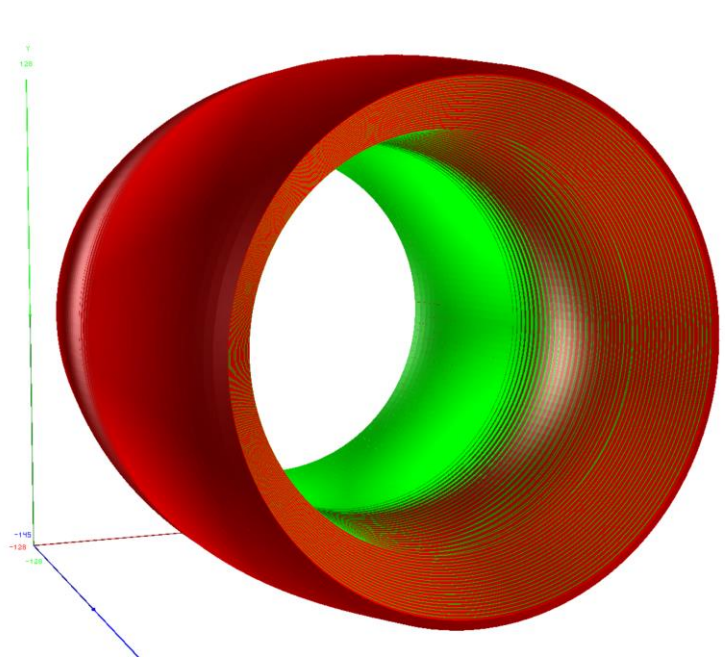
Tracking with all-silicon design

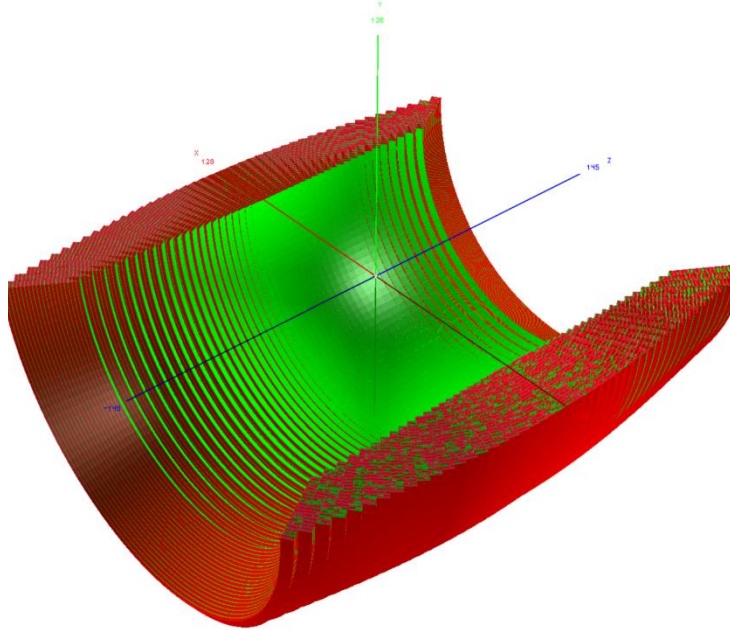




arXiv:2102.08337







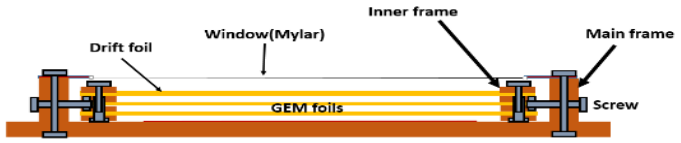
Calorimetry system

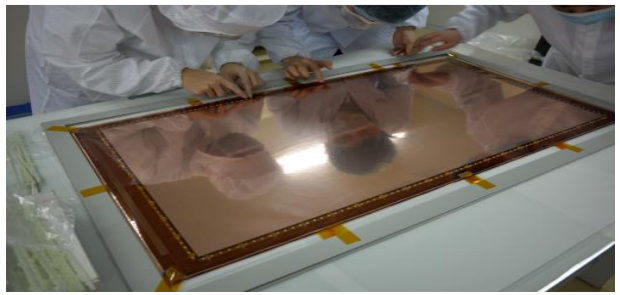
Detector R&Ds

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

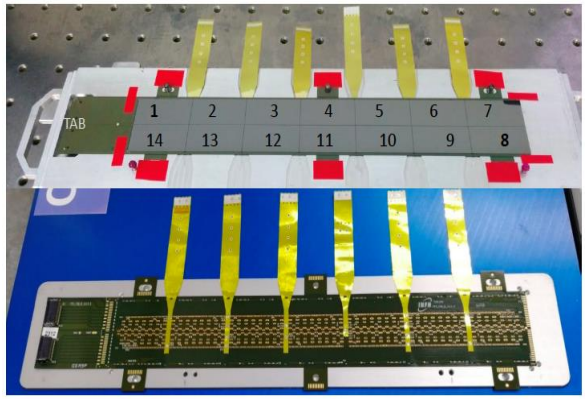
- 25cm x 25 cm Micromegas mass production
- R&D on 0.4m x 0.4m

1m x 0.5 m GEM (self-stretching)

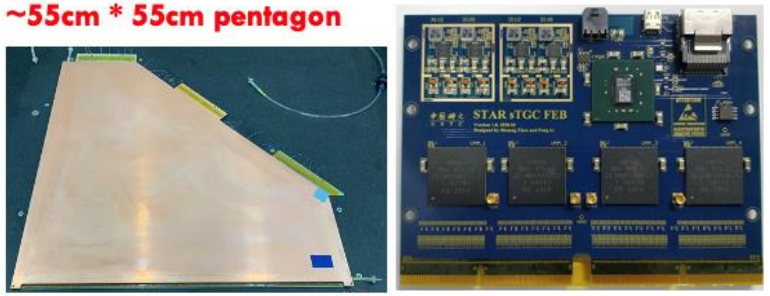




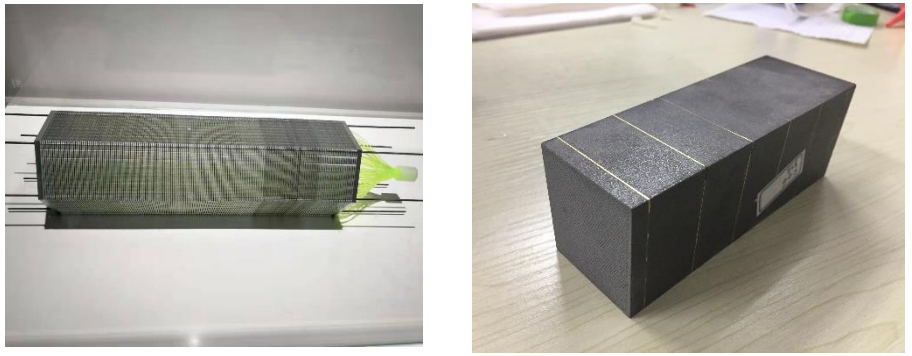
ALICE style ITS2 MAPS pixel detector



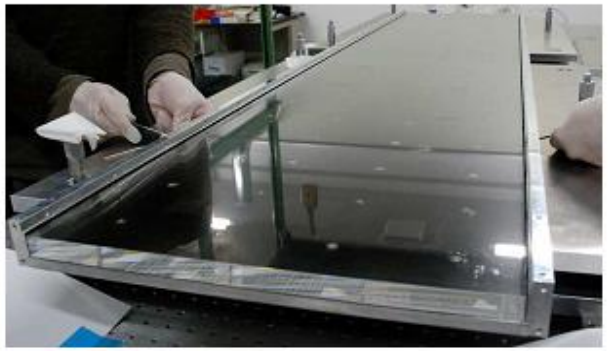
sTGC detector



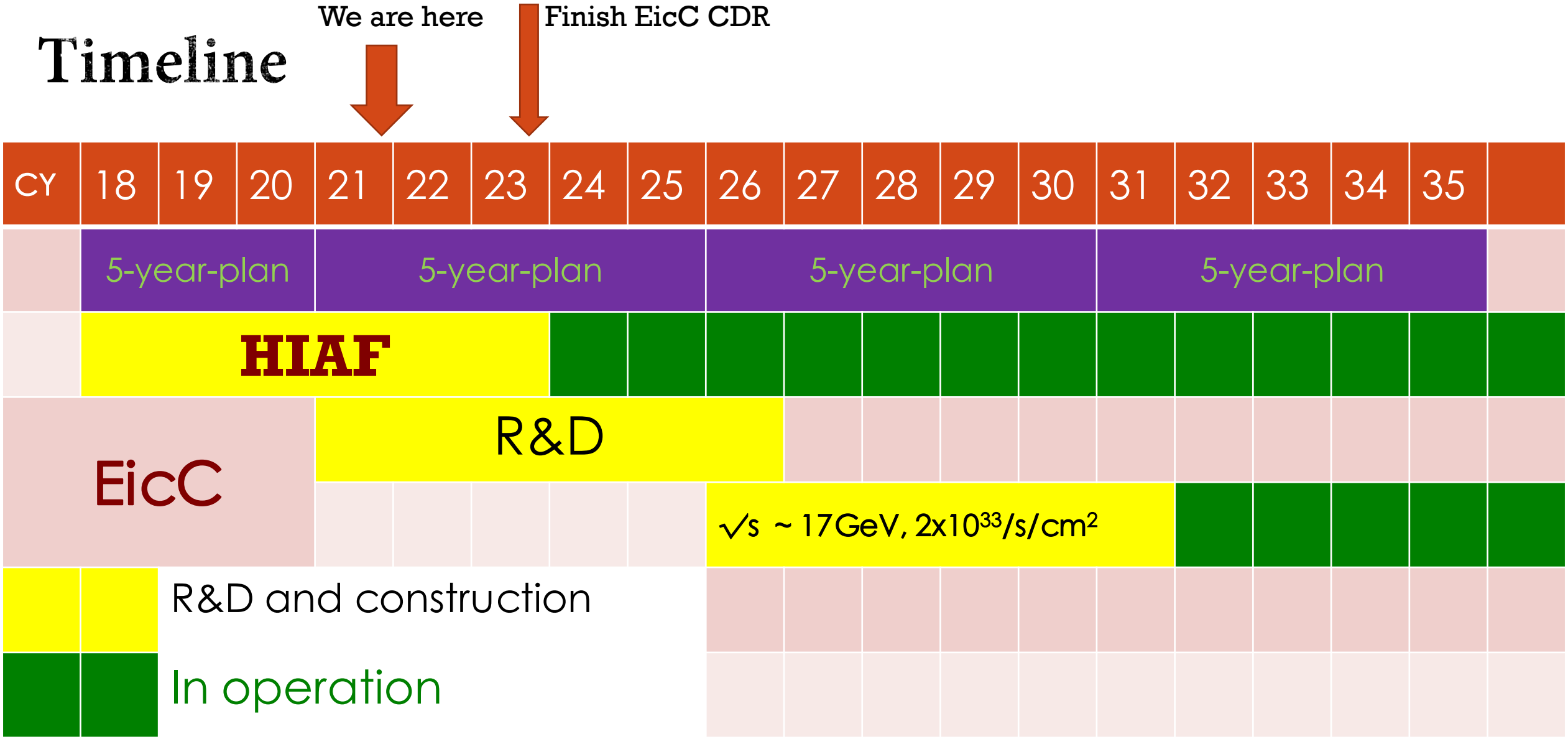
Shashlyk and W-powder+ScFi EMCal



DIRC prototype



Timeline


We are here
Finish EicC CDR
CY
18
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31
32
33
34
35
5-year-plan
5-year-plan
5-year-plan
5-year-plan
HIAF
EicC
R&D
√s ~ 17GeV, 2x10^33/s/cm^2
R&D and construction
In operation

To follow our regular meetings/workshops

- For subscription to the **eicc_member** mail list, please do it in the following link:

http://lists.ustc.edu.cn/sympa/subscribe/eicc_member?previous_action=info

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http://lists.ustc.edu.cn/sympa/subscribe/eicc_physics?previous_action=info

- For subscription to the **eicc_detector** mail list, please do it in the following link:

http://lists.ustc.edu.cn/sympa/subscribe/eicc_detector?previous_action=info

- For subscription to the **eicc_accelerator** mail list, please do it in the following link:

http://lists.ustc.edu.cn/sympa/subscribe/eicc_accelerator?previous_action=info

Summary

- EicC is briefly introduced
  - EicC focuses on sea-quark/gluon related study at moderate/large-x region
- Full Geant4 simulation and detector R&Ds are ongoing
- More physics topics are under study and development

- **EicC complements EIC physics program at higher energy**

Thanks and you are more than welcome to join the effort!


Office area in Huizhou, Guangdong will be available soon