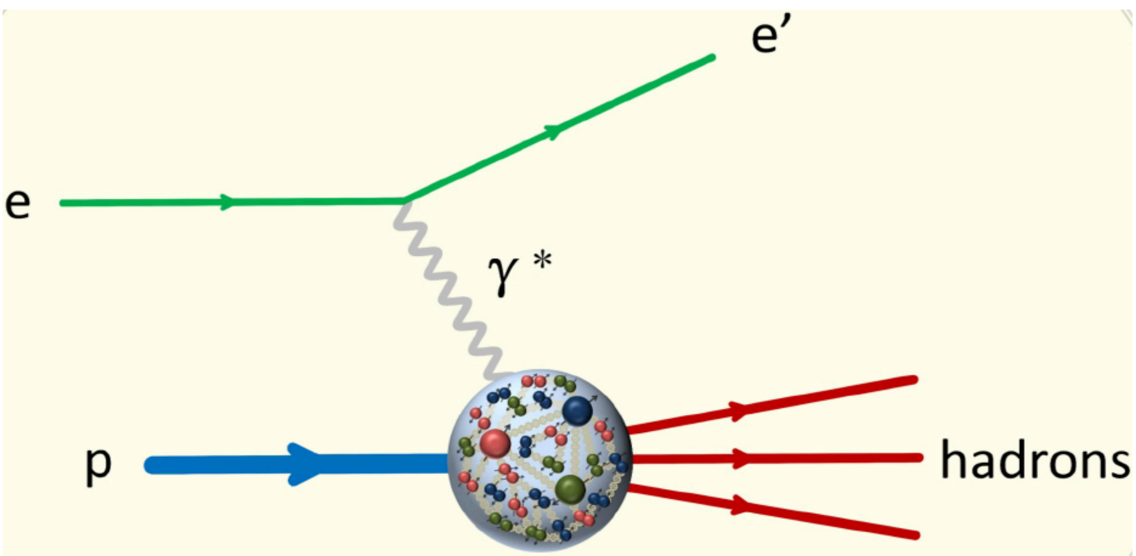
Overview of Electron-ion collider in China

Jinlong Zhang (张金龙), Shandong University

On behalf of the EicC working group

Deeply Inelastic Scattering



Precision microscope with superfine control

Q^2 : Resolution/scale

y : Scattering inelasticity

x : Momentum fraction of struck quark

s : center of mass energy

$$Q^2 = sxy$$

- **Inclusive events:** $e + p/A \rightarrow e' + X$

  Detect the scattered lepton only

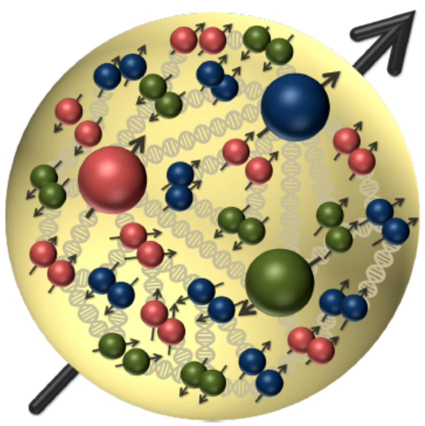
- **Semi-Inclusive events:** $e + p/A \rightarrow e' + h(\pi, K, p, jet, etc) + X$

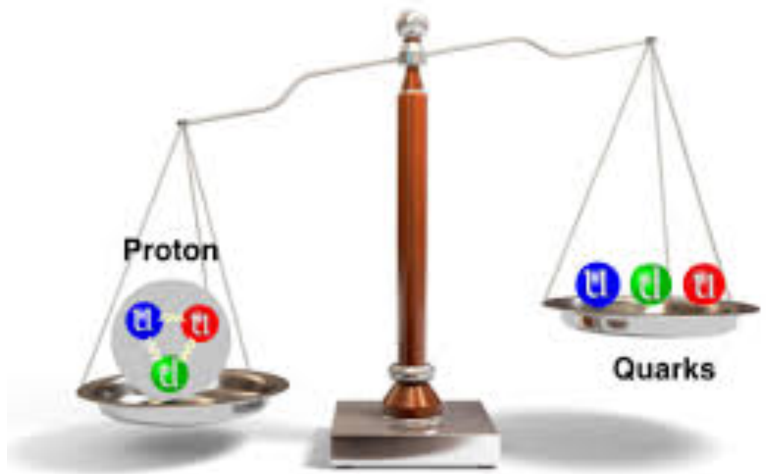
  Detect the scattered lepton + identified hadrons/jets

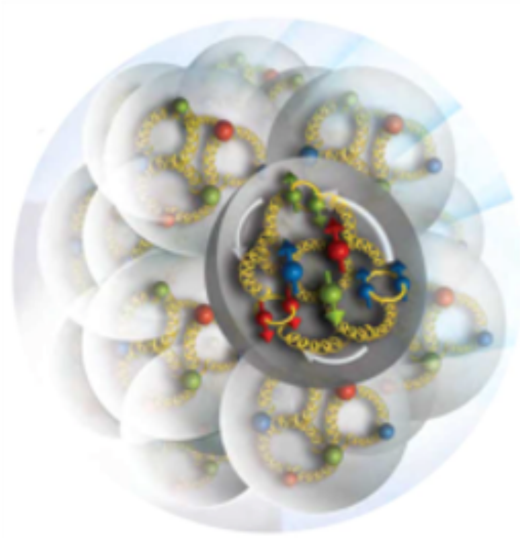
- **Exclusive events:** $e + p/A \rightarrow e' + p'/A' + h(\pi, K, p, jet, etc)$

  Detect everything

Questions expecting EIC to answer







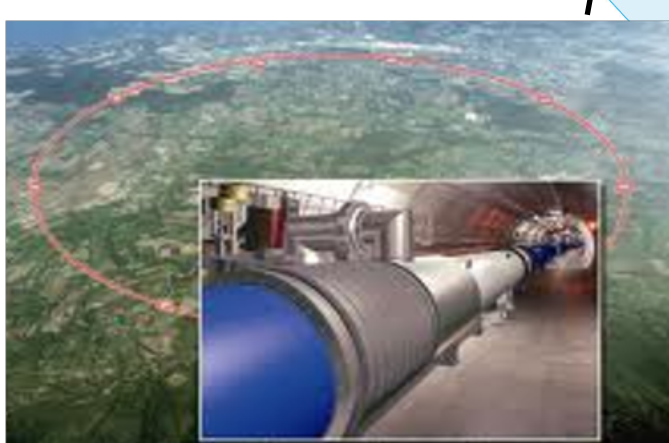
- How does the spin of proton arise?
- How does the mass of proton arise?
- How does gluon bind quarks and gluons inside proton?
- What are the emergent properties of dense gluon system?
- Can we map the quark and gluon inside the proton in 3D?

Proposed Electron-ion colliders

FAIR ➔ ENC

RHIC ➔ eRHIC/EIC

LHC ➔ LHeC



HIAF ➔ **EicC**

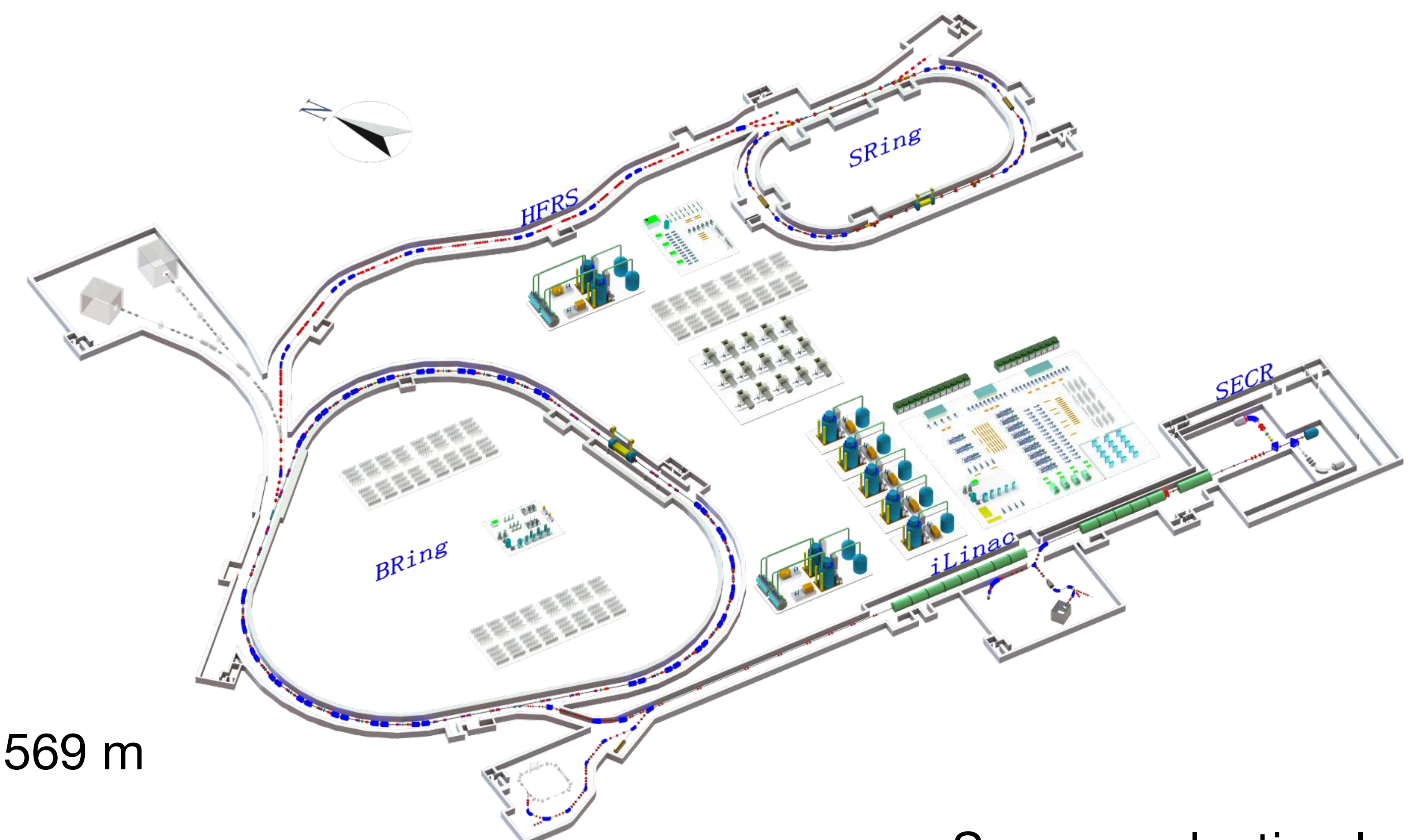
Electron-ion colliders in China

Location: <u>Huizhou</u>, south coast of China

HIAF ➔ EicC: Take use of facility under construction

HIAF - High Intensity heavy-ion Accelerator Facility

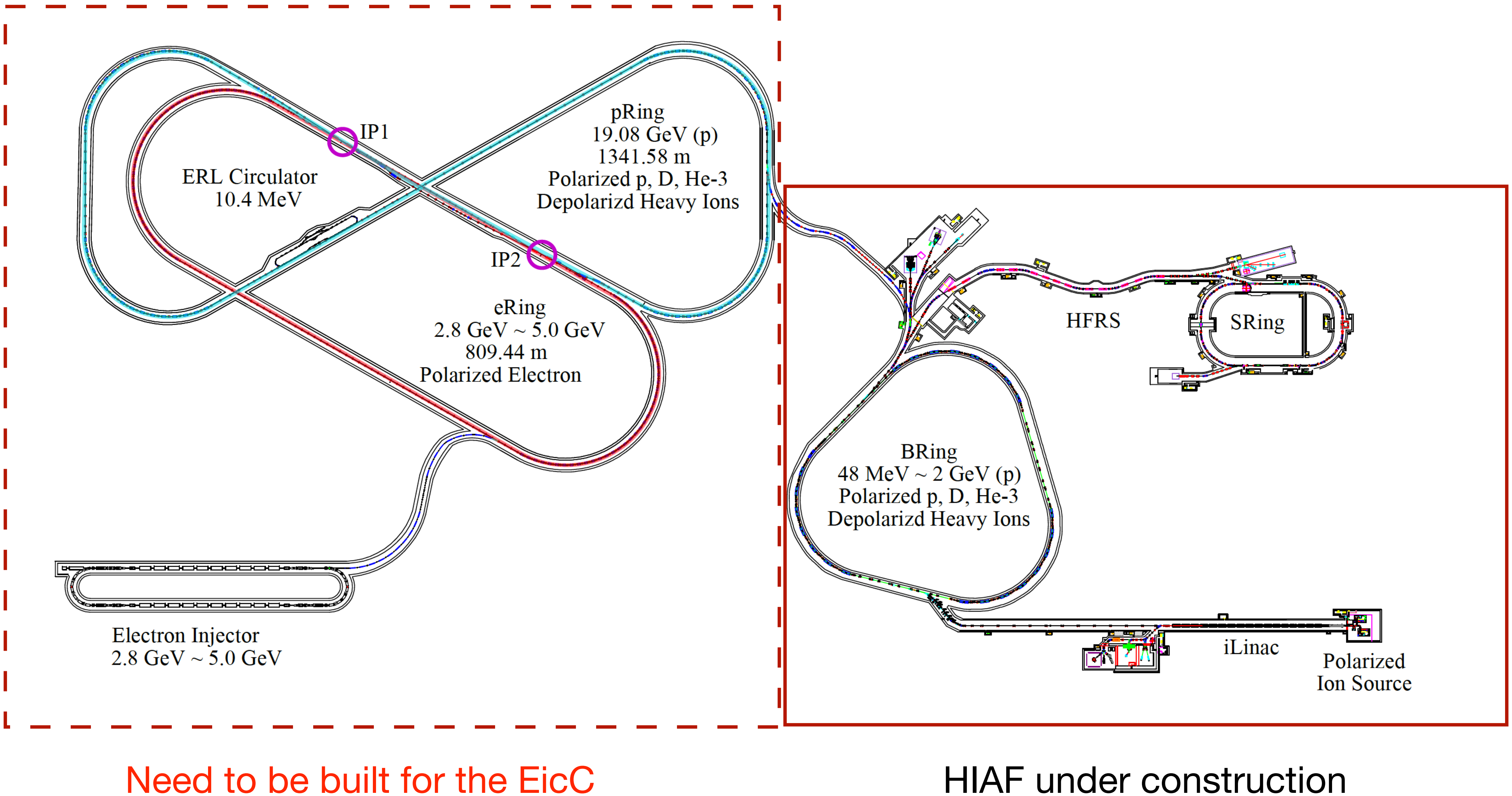
- Funded 2.5 billion RMB, under construction
- for atomic physics, nuclear physics, applied research in biology and material science etc.
- Upgrades to EicC taken into consideration during the design stage



Booster Ring:
- Circumference: 569 m
- Rigidity: 34 Tm
- A accumulation
- Colling & acceleration
- Two-plane painting injections scheme
- Fast ramping rate operation

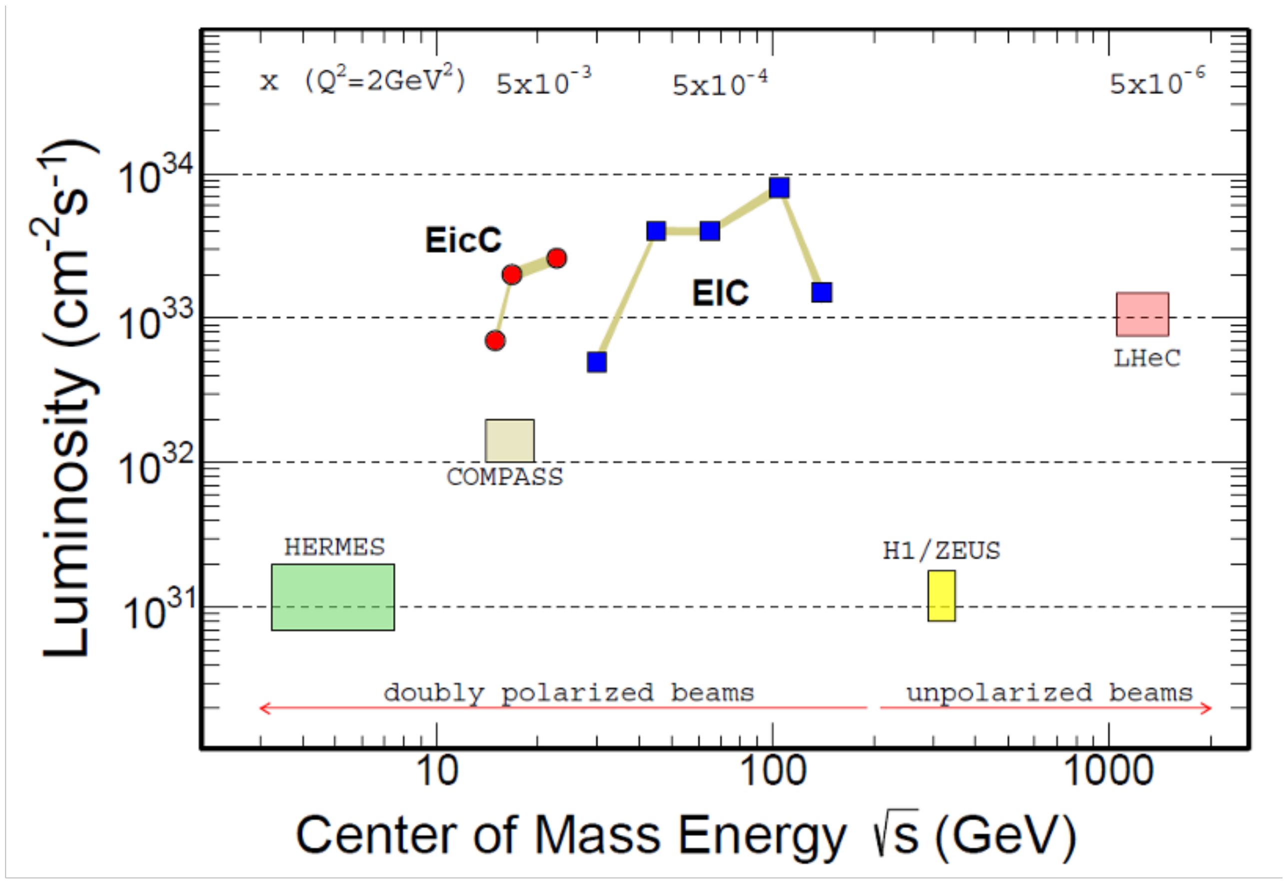
Superconducting Ion Linac:
- Length: 180 m
- Energy: 17 MeV/u (U^{34+})
- CW and pulsed modes

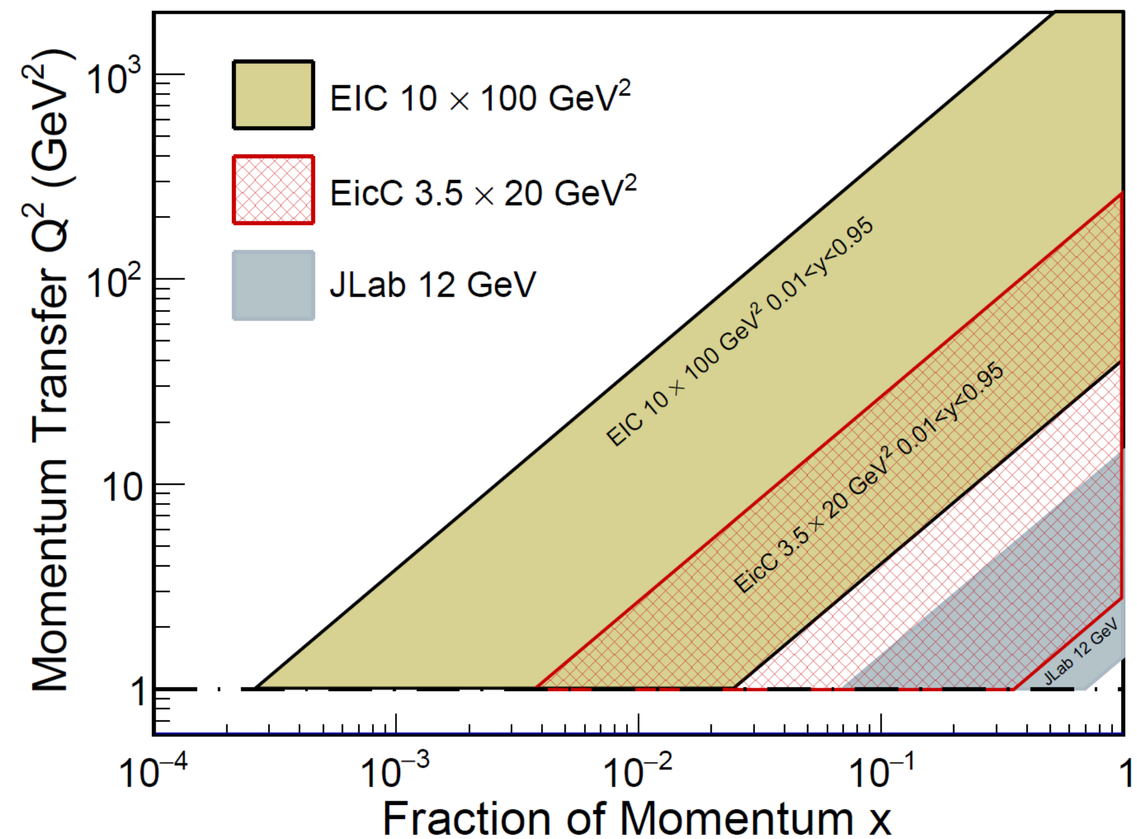
Layout of EicC



- Polarized electron injector + racetrack eRing + Figure 8 pRing
- 2 interaction regions
- 3.5 GeV (e) x 20 GeV (p)

EicC Parameters



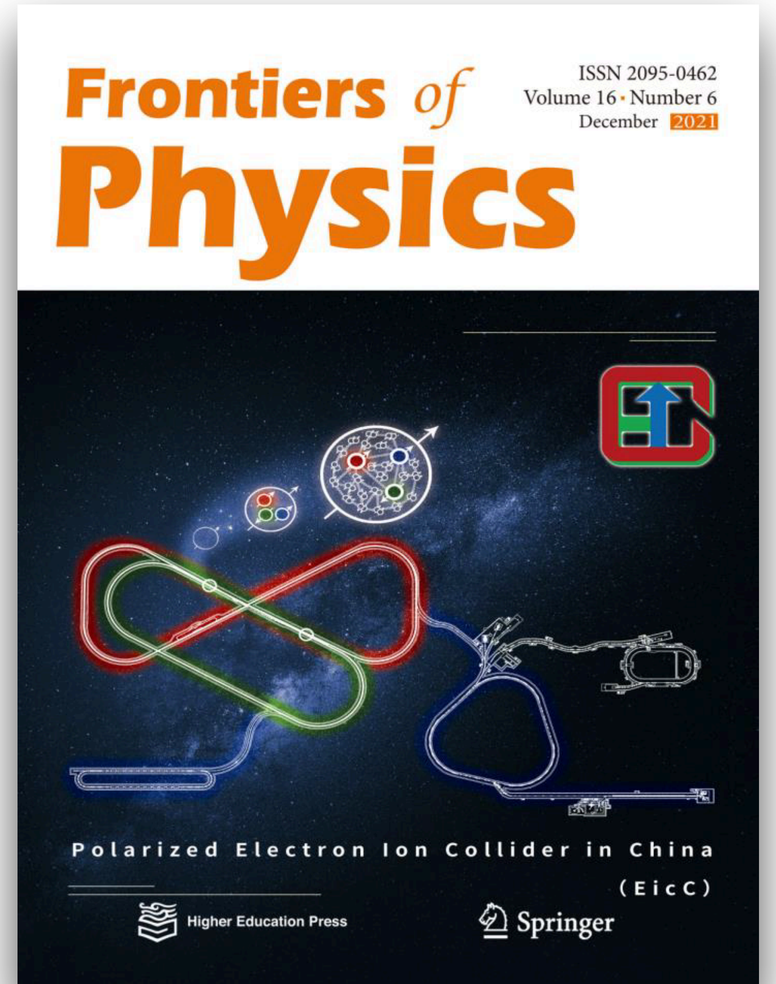


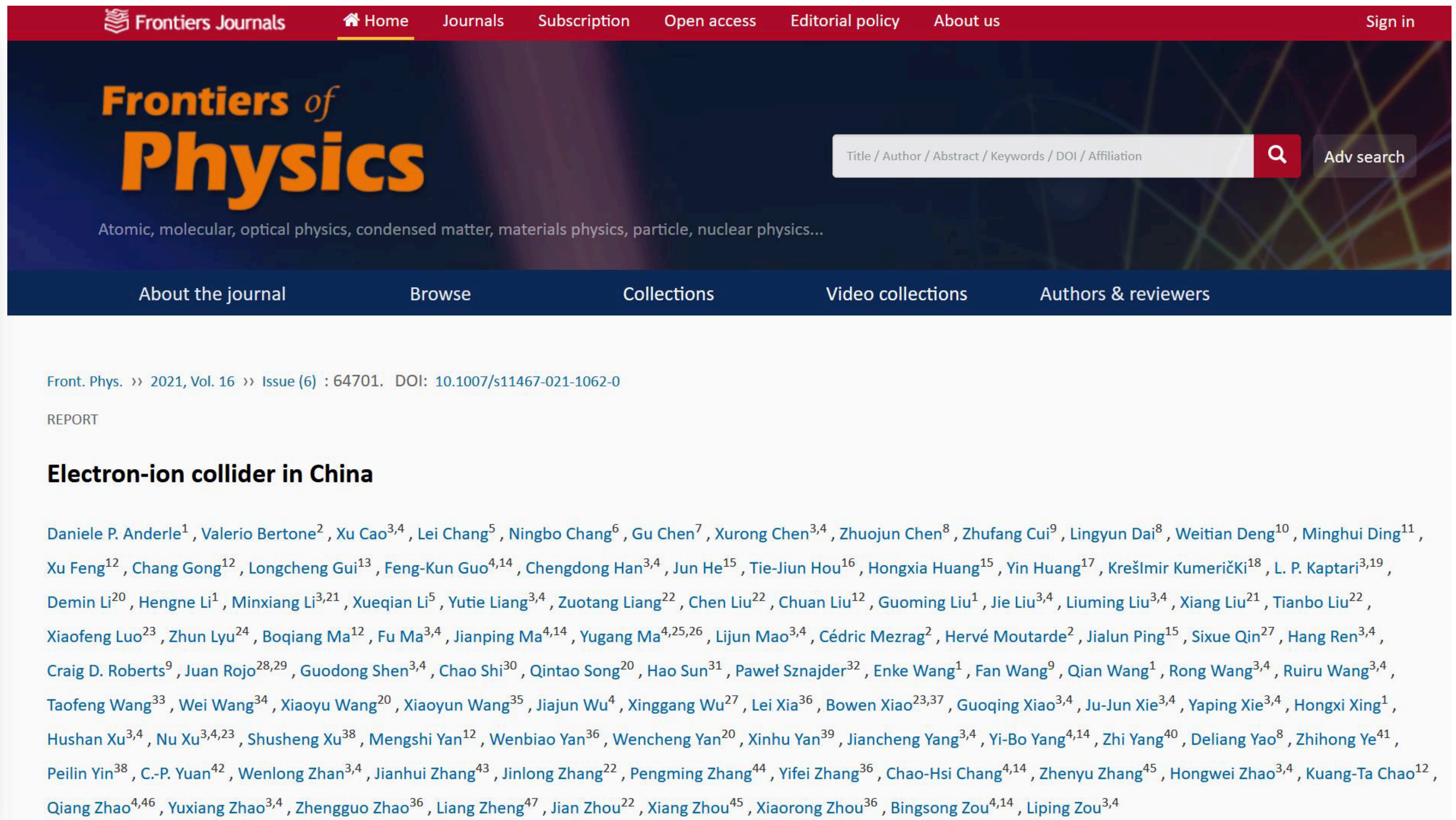
Facility	CoM energy	lum./10^{33}cm^{-2}s^{-1}	Ions	Polarization
EicC	15 - 20	2 - 3	$p \to$U	e^-, p, and light nuclei
EIC-US	30 - 140	2 - 15	$p \to$U	e^-, p, ^{3}He, Li

- EicC covers the kinematic region between JLab experiments and US-EIC.
- EicC complements the ongoing scientific programs at JLab and future EIC project.
- EicC focus on moderate x and sea-quark for spin, exotic hadrons and nuclear modification.
- EicC can systematically study Υ near threshold and shed lights on proton mass origin.

EicC white-paper

EicC white paper: ***Front. Phys., 2021, 16(6): 64701*** arXiv: 2102.09222





Front. Phys. ›› 2021, Vol. 16 ›› Issue (6) : 64701. DOI: 10.1007/s11467-021-1062-0

REPORT

Electron-ion collider in China

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], Zhenguo Zhao[36], Liang Zheng[47], Jian Zhou[22], Xiang Zhou[45], Xiaorong Zhou[36], Bingsong Zou[4,14], Liping Zou[3,4]

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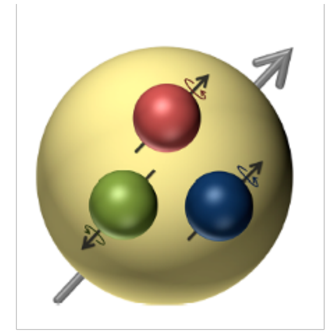
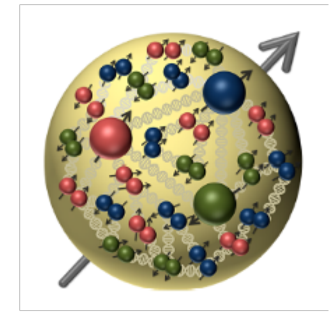
100+ physicists from 46 institutes

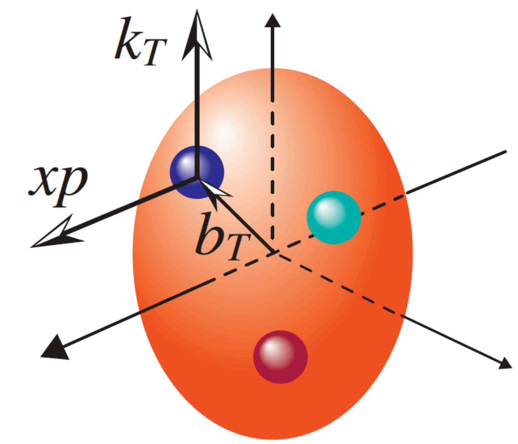
Highlighted physics topics

1D spin structure of nucleon

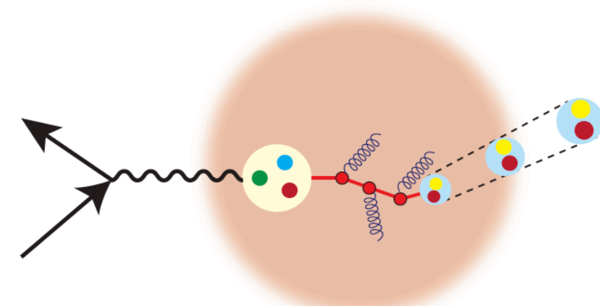




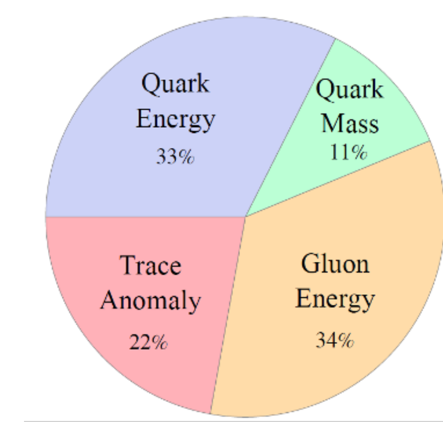
3D and 2+1D tomography of nucleon



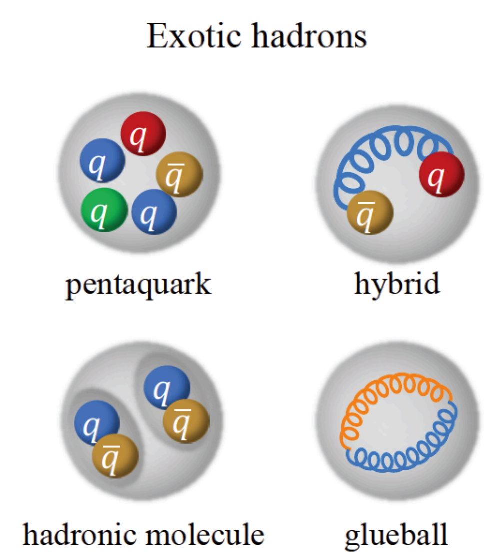
Partonic structure of nucleus



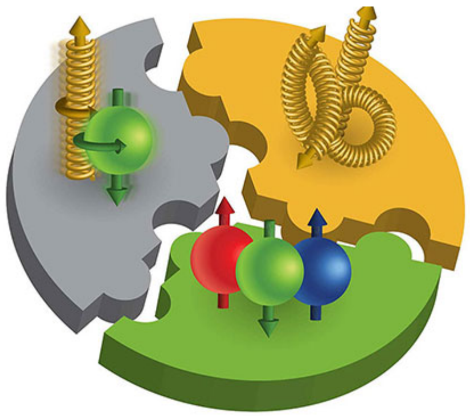
Proton mass



Exotic hadron states



1D spin structure of nucleon



$$< S_p > = \frac{1}{2} = \frac{1}{2}\,\Delta\Sigma + \Delta G + L_q + L_g$$

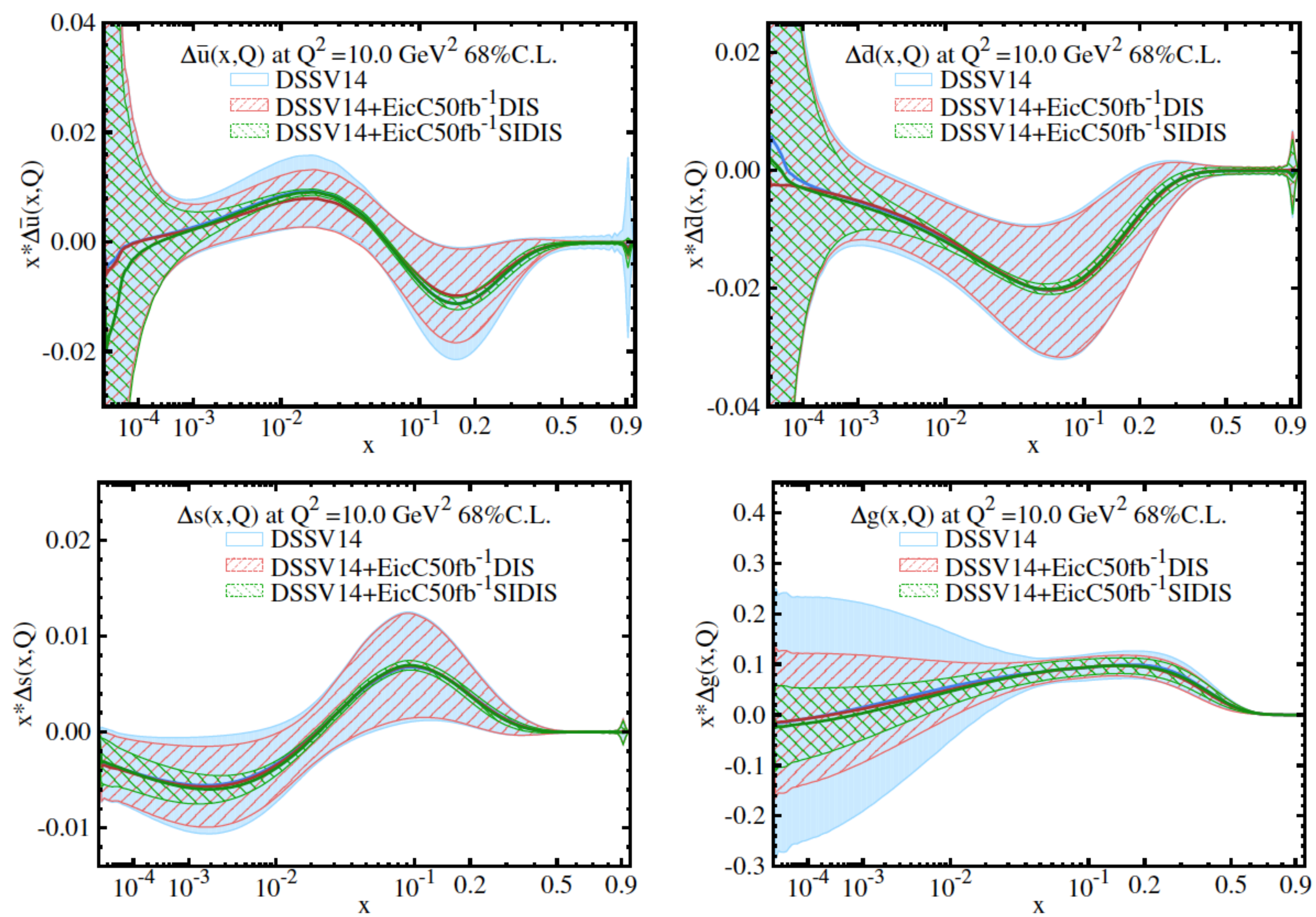
Jaffe-Manohar 1990

$\Delta\Sigma$ ***Quark spin*** ΔG ***gluon spin*** $L_{q,g}$ ***Orbital angular momentum***

NLO EicC SIDIS projection:

- 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}

Significantly reduce uncertainties of spin contribution from the sea

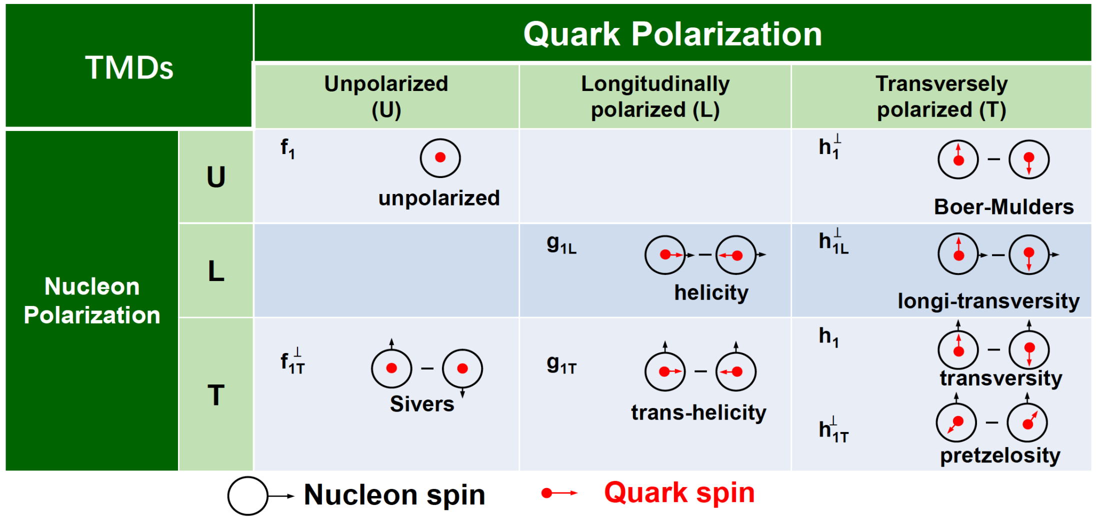


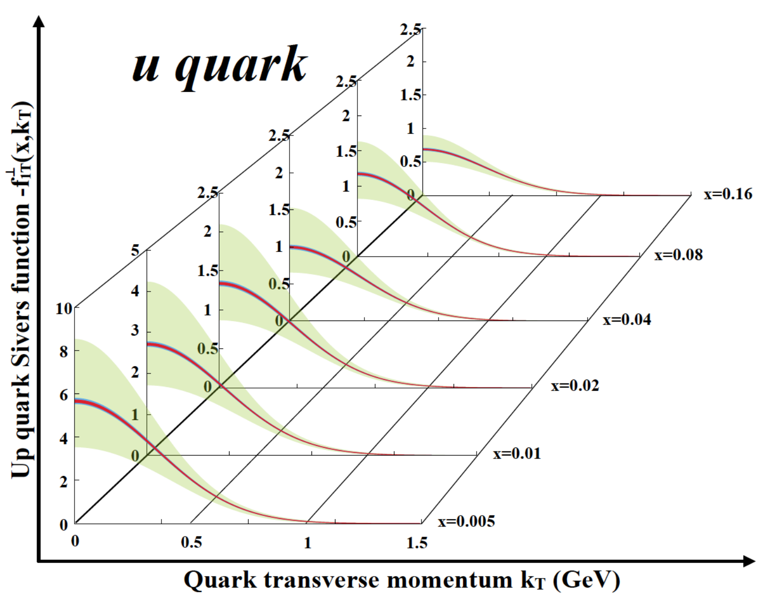
3D spin structure at momentum space

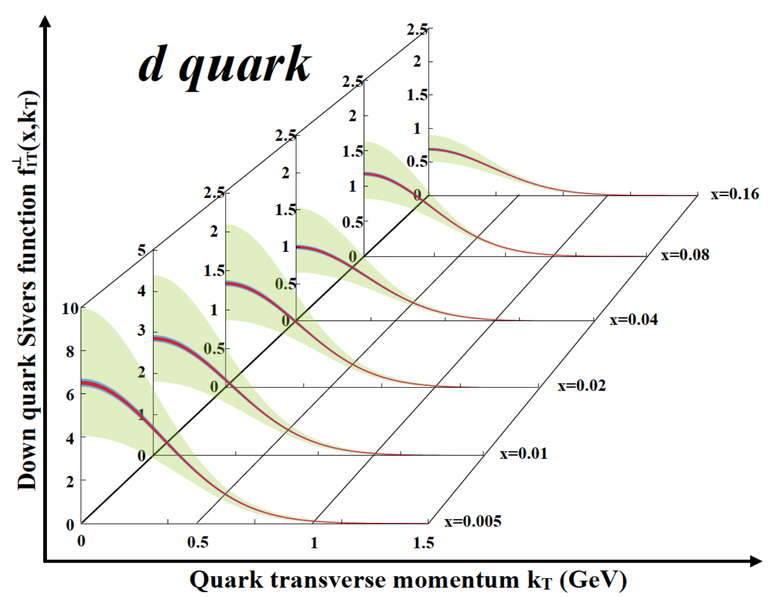
Access to quark Sivers function, especially the strange quark Sivers via SIDIS

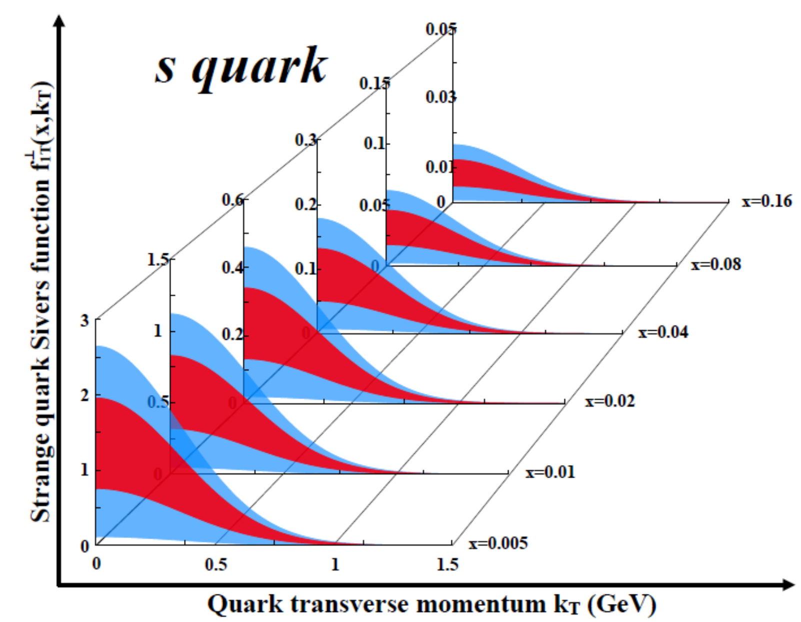
LO analysis of EicC projection

- Pion(+/-), Kaon(+/-)
- ep: 3.5 GeV x 20 GeV
- eHe-3: 3.5 GeV x 40 GeV
- Lumi: ep 50 fb^{-1}, eHe-3 50 fb^{-1}
- Stat. Error vs Sys. Error

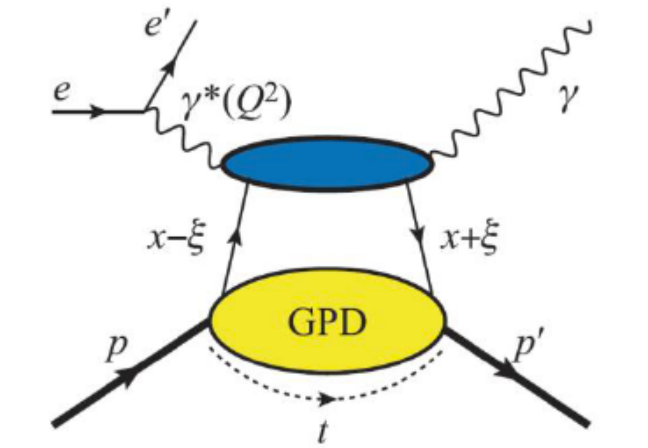


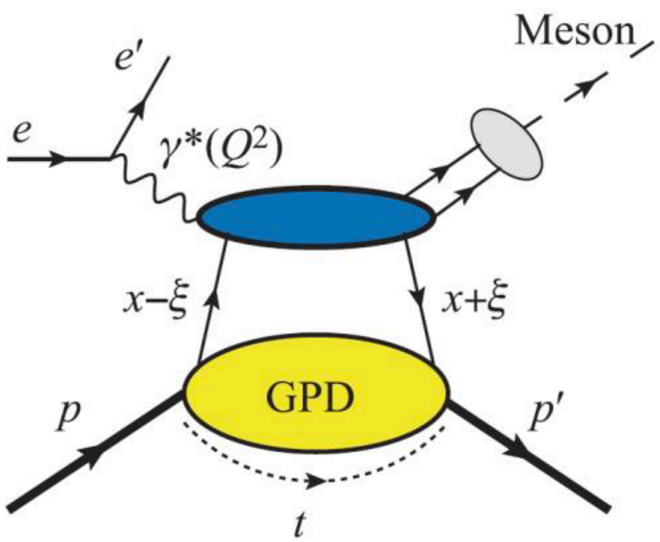






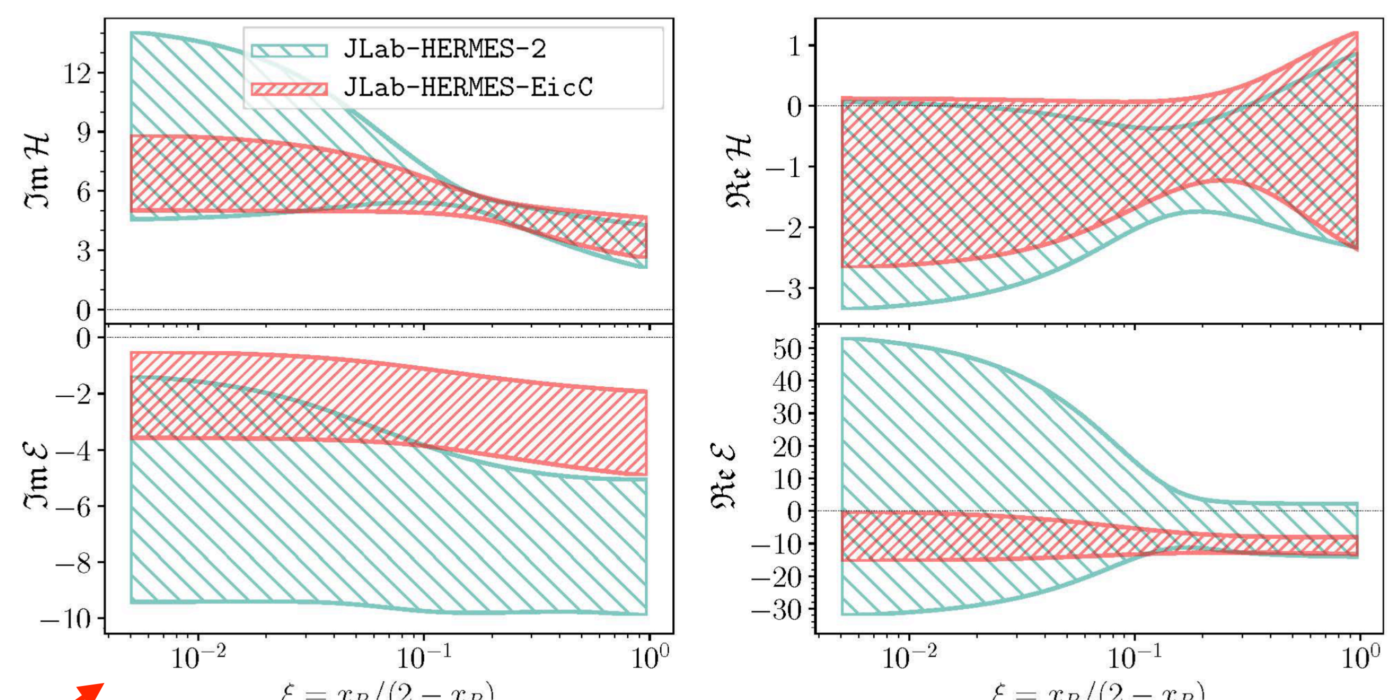
GPDs





- Spatial distribution of partons encoded in GPDs
- GPD is related to quark angular momentum [Ji, 95]
- Access to GPDs via exclusive reactions DVCS, DVMP, etc
- Flavor separation and sea quark GPD in DVMP

Extraction of CFF with neutral network methods [Kumericki, 19]



Polarized beam, unpolarized target (SSA)

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

Unpolarized beam, longitudinal target (lTSA)

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

Unpolarized beam, transverse target (tTSA)

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

Polarized beam, longitudinal target (DSA)

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

Only this azimuthal angular modulation

Understanding Proton Mass

Mass decomposition [Ji, 95]

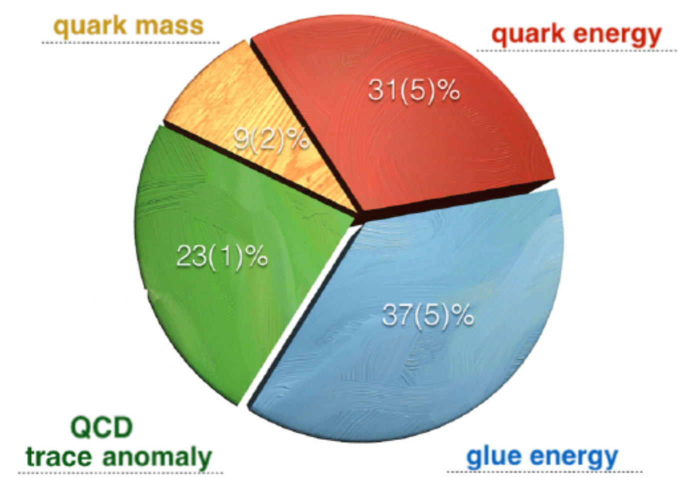
$$M = M_q + M_m + M_g + M_a$$

M_q : quark energy

M_m : quark mass (condensate)

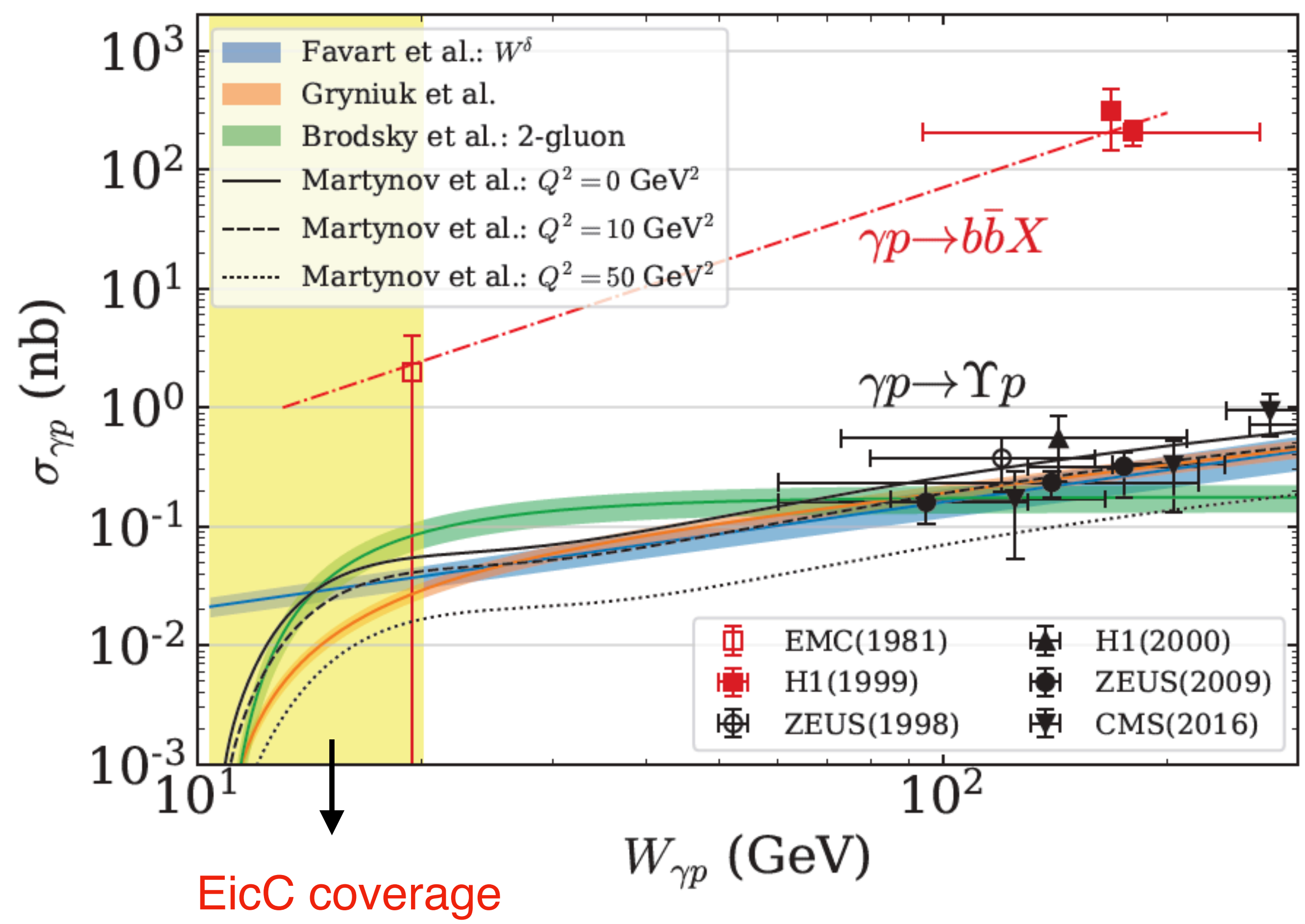
M_g : gluon energy

M_a : trace anomaly



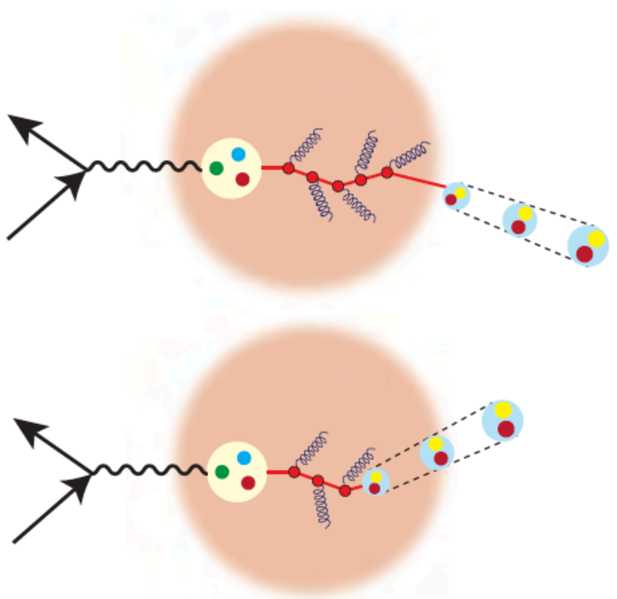
Lattice QCD, Yang et al 2018

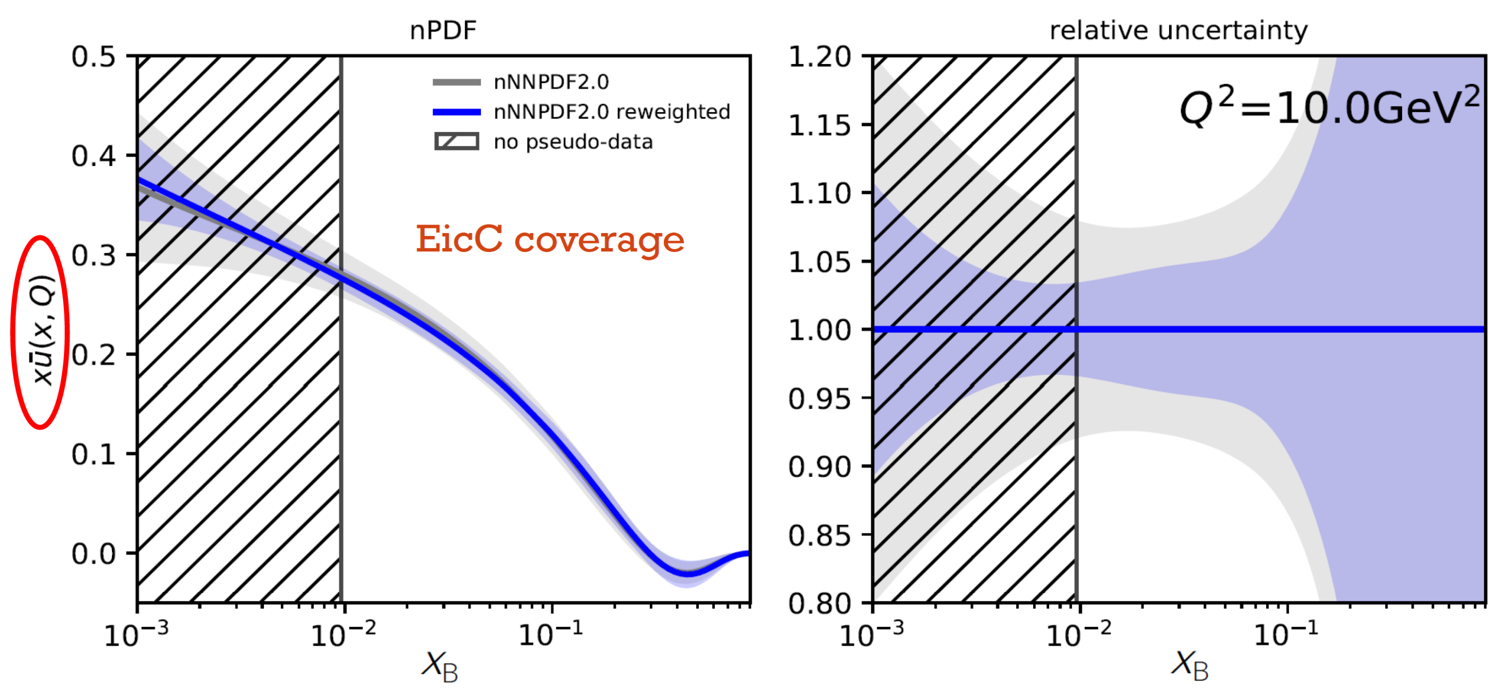
- M_q and M_g : constrained by PDFs
- M_m via πN scattering
- M_a via threshold production of J/ψ (8.2 GeV, JLab) and Υ (12 GeV)
- Threshold requires low CoM energy (low y at EIC)
- Complementarity between EicC (and EIC) and Lattices.



Partonic structure of nucleus

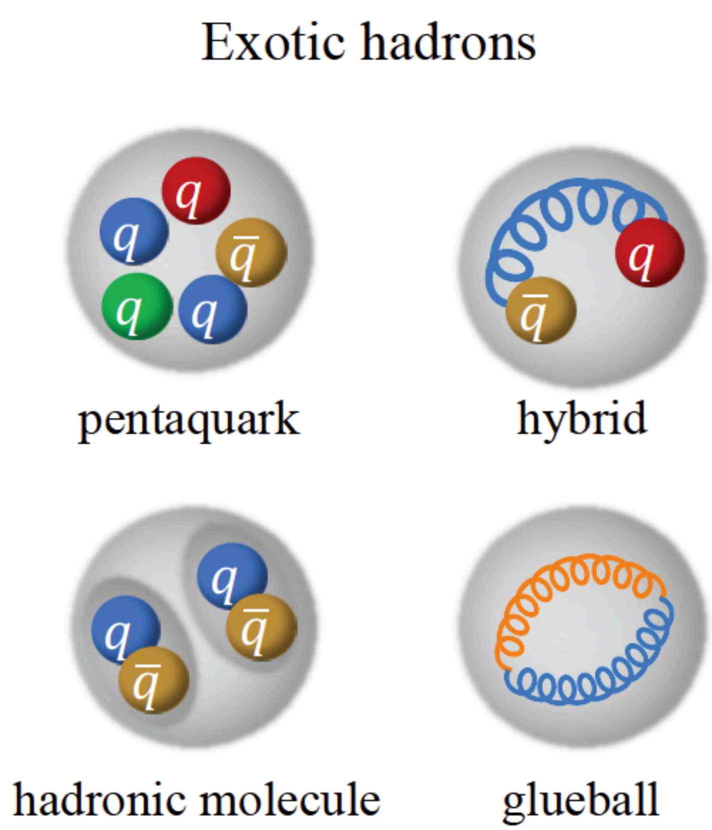
- Use heavy nuclei to study parton energy loss in cold nuclear medium
- Hadronization inside and outside medium. (Nucleus as a lab at the fm scale)
- Medium modification of light meson and heavy meson in SIDIS.
- Precision study of nuclear PDFs with heavy ion beams.





With only a few hours of running

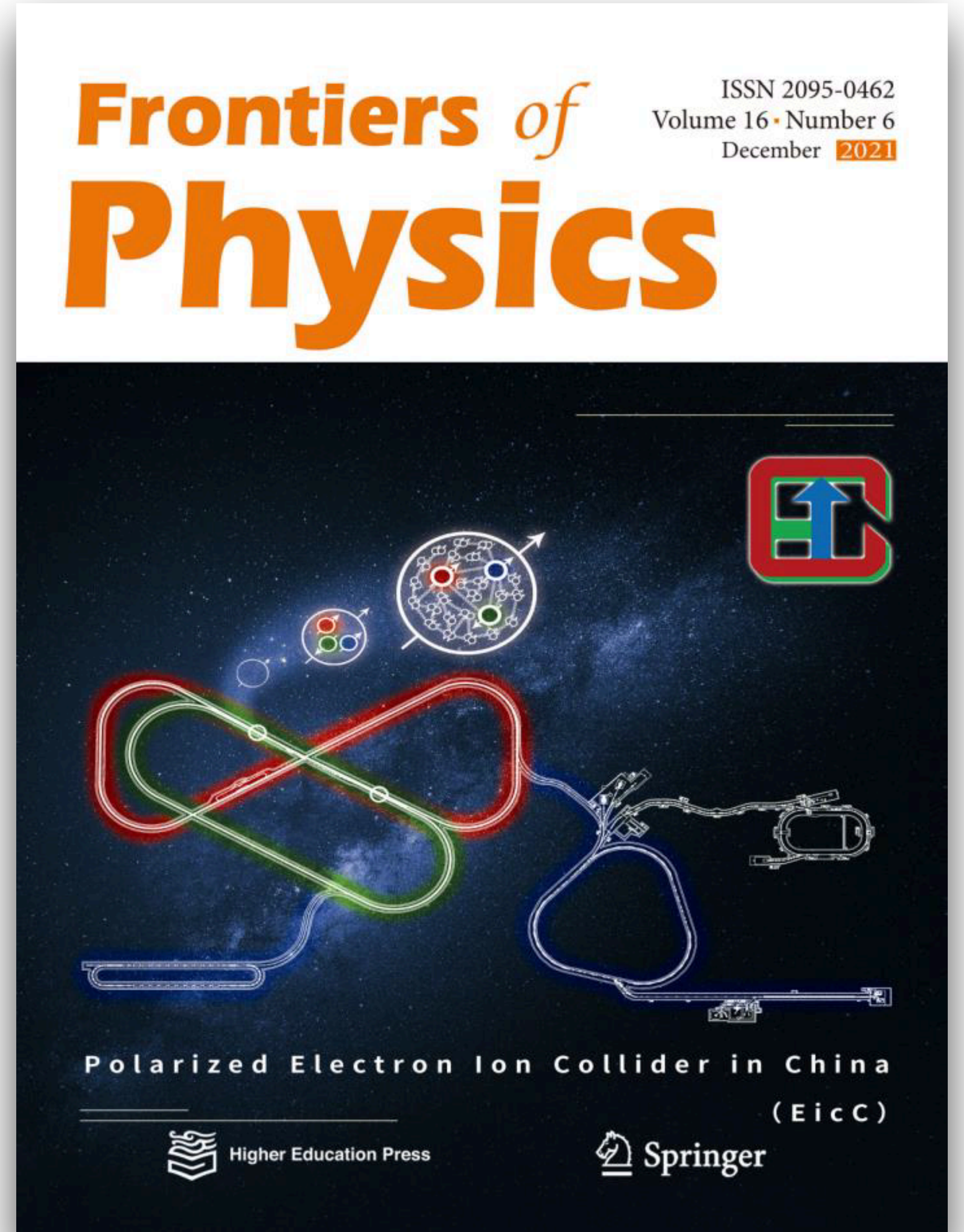
Exotic hadron states



Exotic states	Production/decay processes	Detection efficiency	Expected events
$P_c(4312)$	$ep \to eP_c(4312)$ $P_c(4312) \to pJ/\psi$ $J/\psi \to l^+l^-$	~30%	15–1450
$P_c(4440)$	$ep \to eP_c(4440)$ $P_c(4440) \to pJ/\psi$ $J/\psi \to l^+l^-$	~30%	20–2200
$P_c(4457)$	$ep \to eP_c(4457)$ $P_c(4457) \to pJ/\psi$ $J/\psi \to l^+l^-$	~30%	10–650
P_b(narrow)	$ep \to eP_b(\text{narrow})$ $P_b(\text{narrow}) \to p\Upsilon$ $\Upsilon \to l^+l^-$	~30%	0–20
P_b(wide)	$ep \to eP_b(\text{wide})$ $P_b(\text{wide}) \to p\Upsilon$ $\Upsilon \to l^+l^-$	~30%	0–200
$\chi_{c1}(3872)$	$ep \to e\chi_{c1}(3872)p$ $\chi_{c1}(3872) \to \pi^+\pi^- J/\psi$ $J/\psi \to l^+l^-$	~50%	0–90
$Z_c(3900)^+$	$ep \to eZ_c(3900)^+n$ $Z_c^+(3900) \to \pi^+ J/\psi$ $J/\psi \to l^+l^-$	~60%	90–9300

- Complementary to e+e- and pp collisions.
- Larger acceptance, exotic hadrons produced at middle rapidity.
- Heavy-flavor exotic hadrons, in particular to charmonium-like states and hidden charm pentaquarks.
- Polarization helps to determine the quantum numbers.

Towards Conceptual Design Reports



EicC white paper

Volume I: Accelerator

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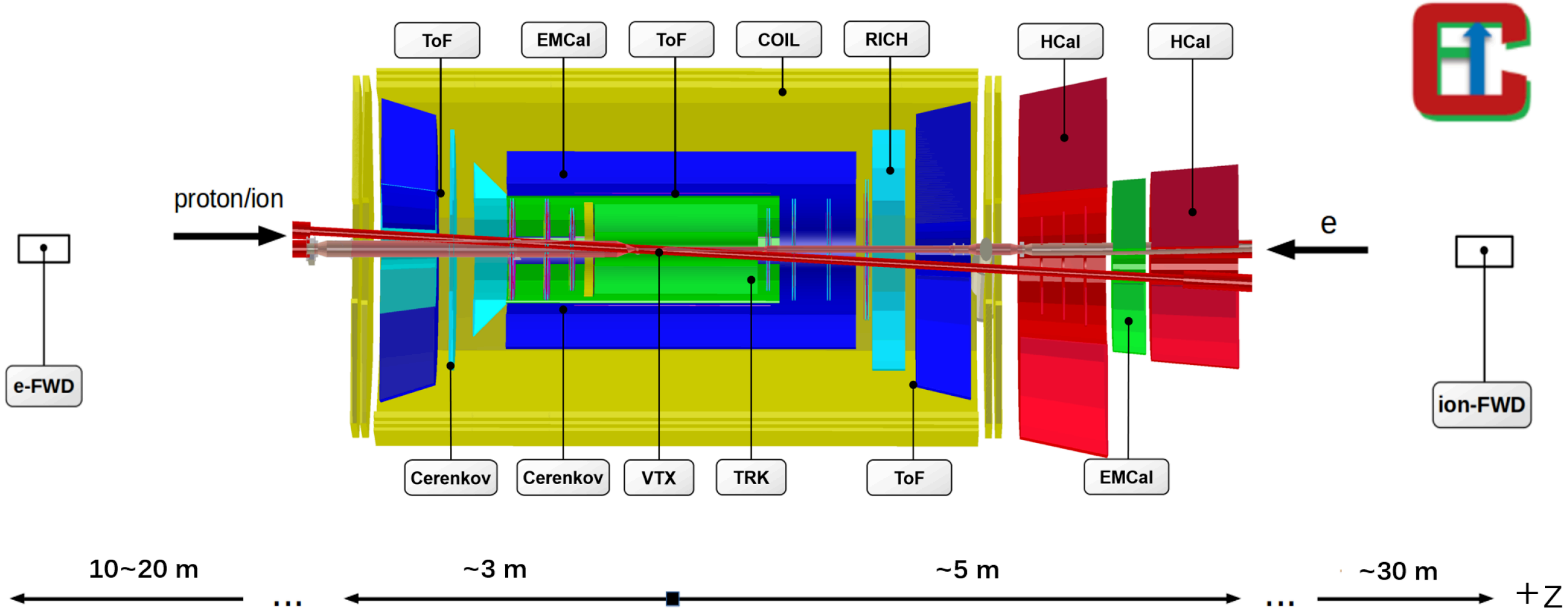
- 5.4 HCal . . . .

EicC Conceptual Design Reports

Conceptual design of the EicC detector



A general purpose detector with:

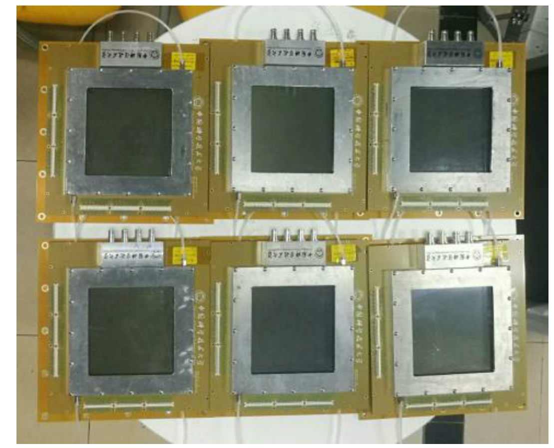
- Vertex detector;
- Tracking detector;
- Particle Identification detector (ToF & RICH);
- Calorimeter (EM & Hadron)

Detailed full Geant4 simulation is ongoing

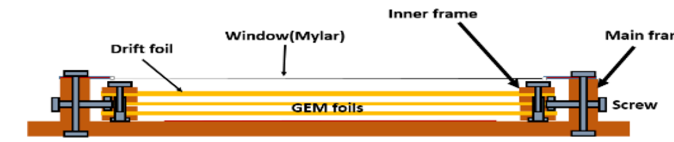
Detector R&D

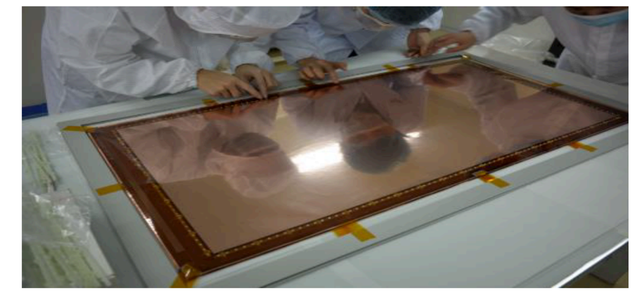
Clean room (200 m^2) for detector assembling

Micromegas 25cm x 25cm



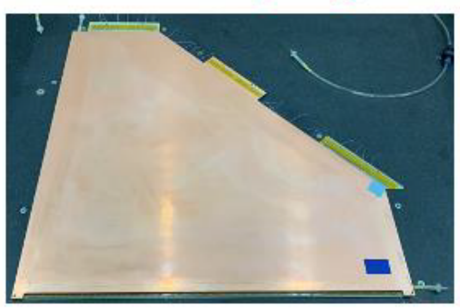
GEM 1m x 0.5m

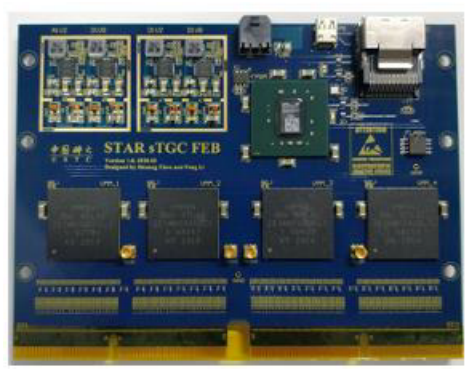




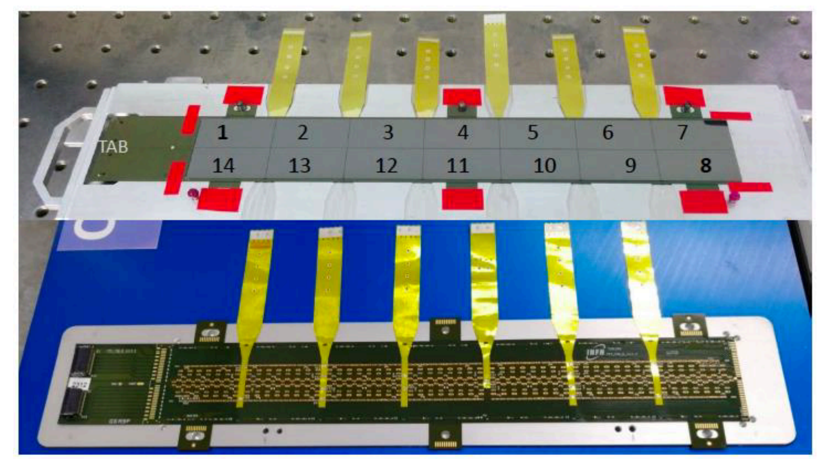
sTGC @SDU

~55cm * 55cm pentagon

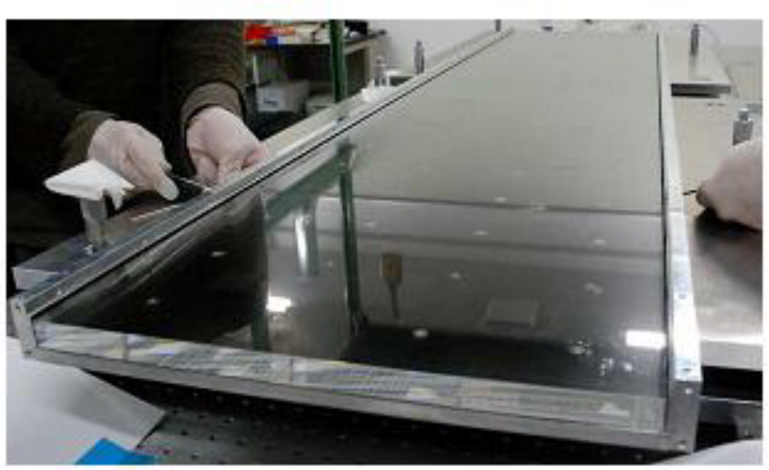




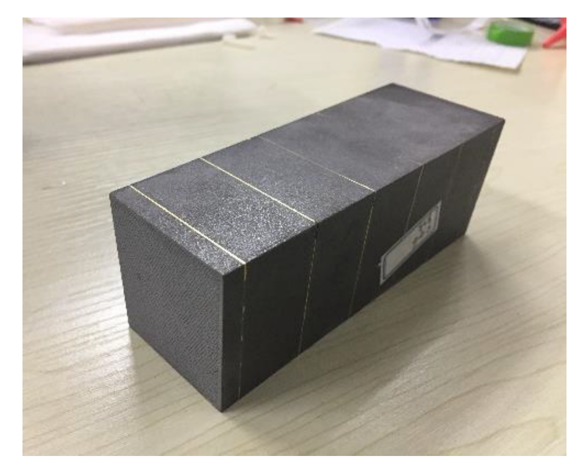
ALICE style ITS2 MAPS pixel detector



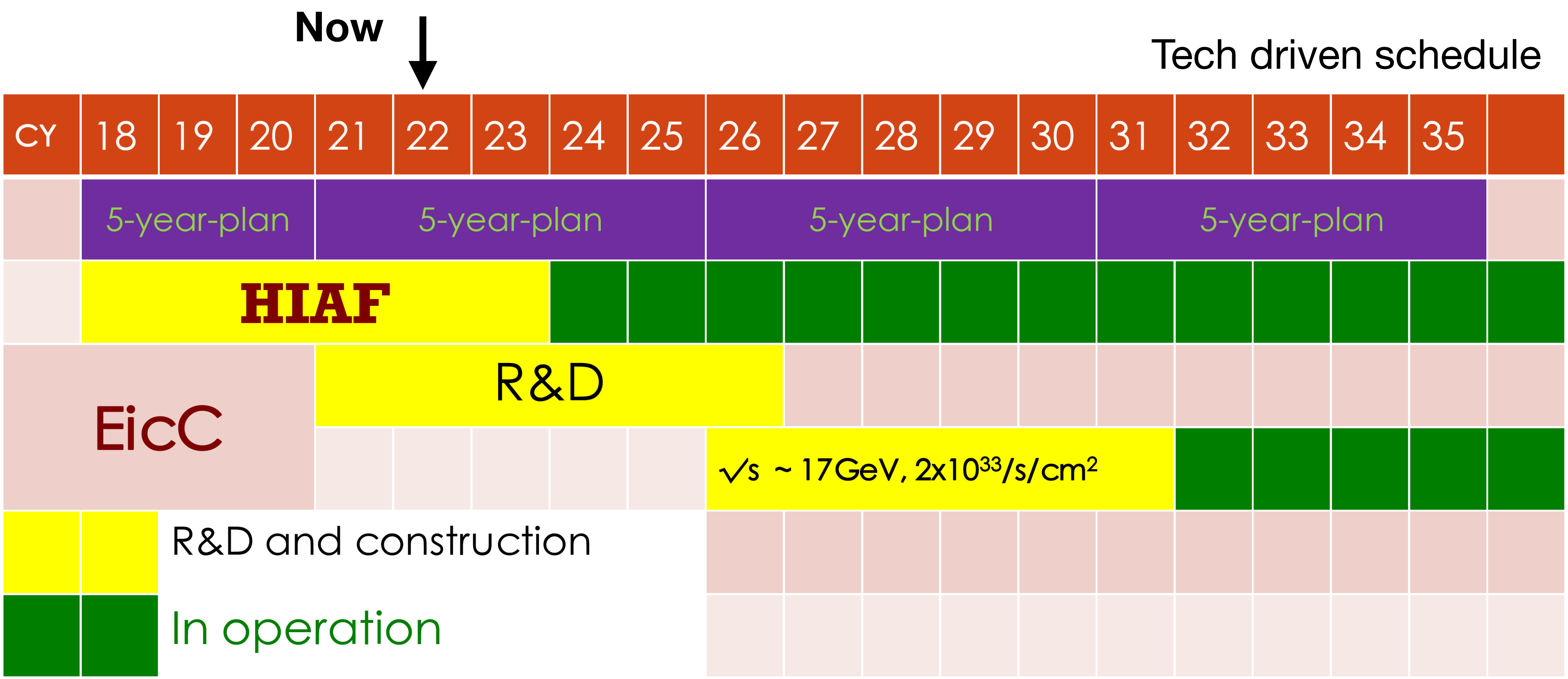
DIRC prototype @IMP



Shashlik and W-powder+SciFi EMCal



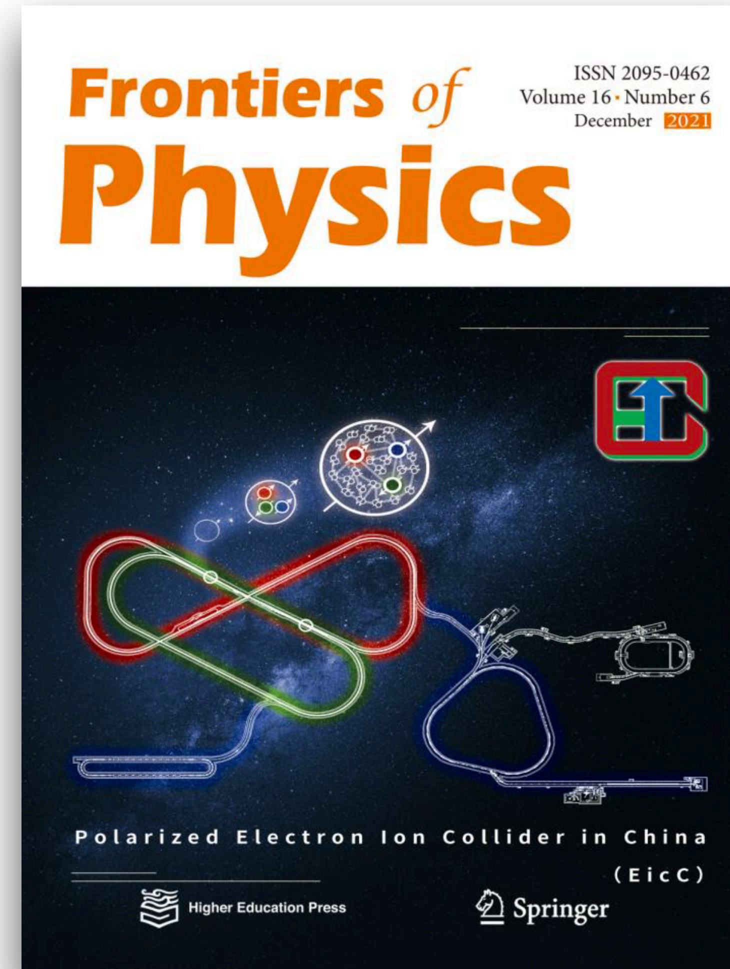
Timeline



- HIAF construction is near complement
- Aiming to finish EicC CDR by 2023
- Hope to get support in the next 5-year-plan and first collision in 2032

Summary

- Electron-ion collider in China — EicC
  - Focused on sea-quark/gluon at moderated/large-x region
  - Complements EICs at higher energies
- Conceptual design report by 2023
  - Geant4 simulations and detector R&D
- More physics topics under development



EicC white paper: <u>Front. Phys., 2021, 16(6): 64701</u>

Thanks for your attention and welcome to join us!