第二届核子三维结构研讨会暨第二届高扭度核子结构研讨会

青岛，2024年10月17日至20日

Electron-ion collider in China (EicC)

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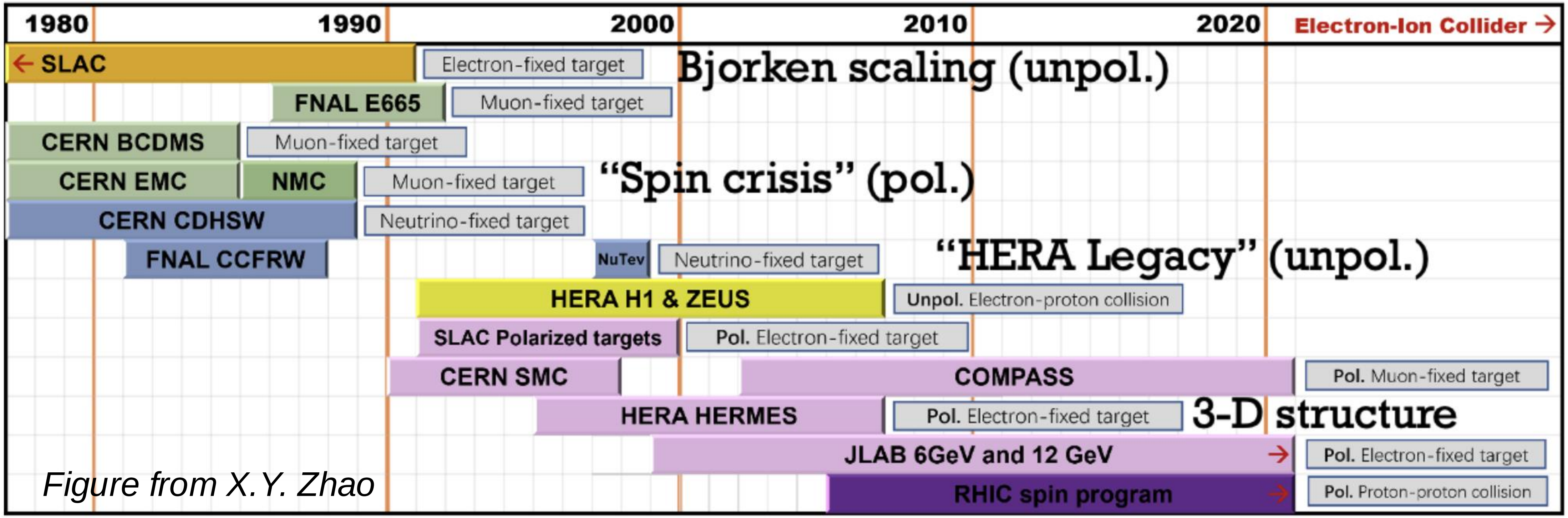
On behalf of the EicC working group

Lepton scattering: an ideal tool



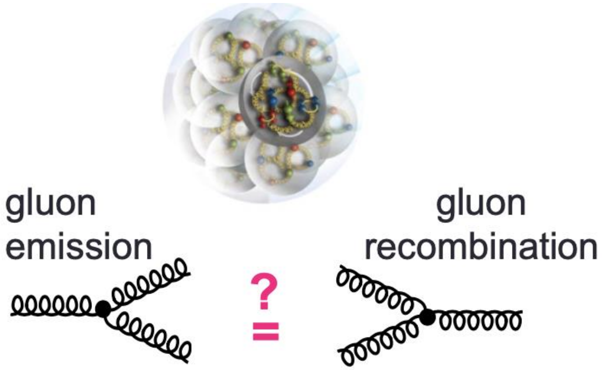
Modern "Rutherford Scattering" Experiment

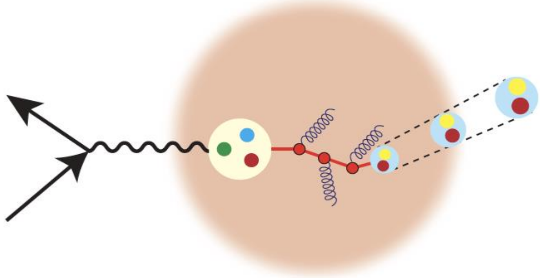
- Start from unpolarized fixed targets
- Extended unpolarized collider experiments
- and polarized fixed-target experiments

Need polarized electron-ion collider

- High luminosity: 100~1000 × HERA lumi.
- High polarization: both electron and ion beams
- Large acceptance: nearly full detector coverage

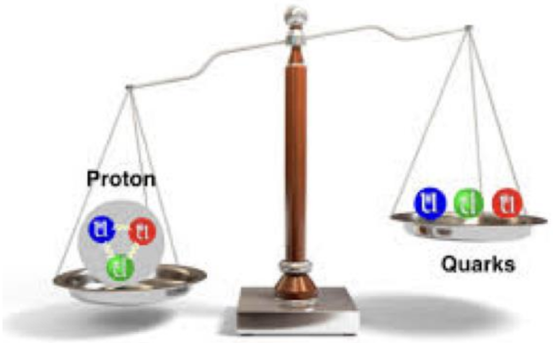
Questions expecting electron-ion colliders to answer

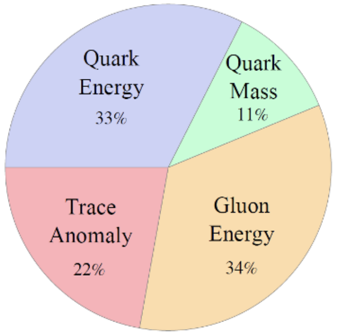


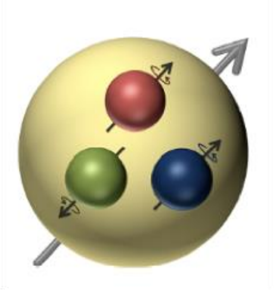


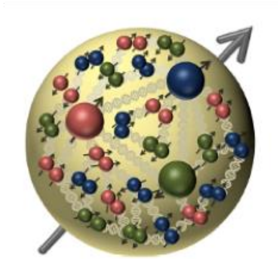
Does gluon saturate at high energy?
How does a dense nuclear environment affect the quarks and gluons, their correlations, and their interactions?

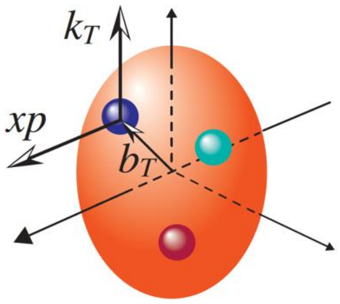
How do the nucleon properties (mass & spin) emerge from their interactions?











How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?

Proposed electron-ion colliders (incomplete list)

FAIR ➔ ENC

RHIC ➔ eRHIC/EIC

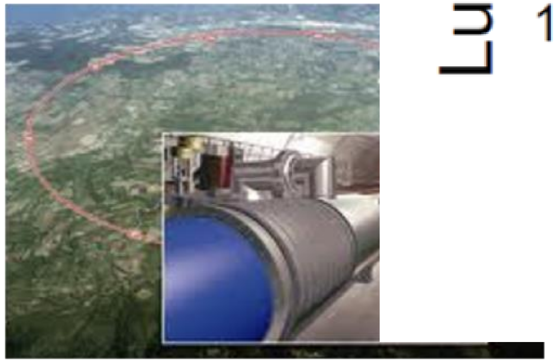
LHC ➔ LHeC

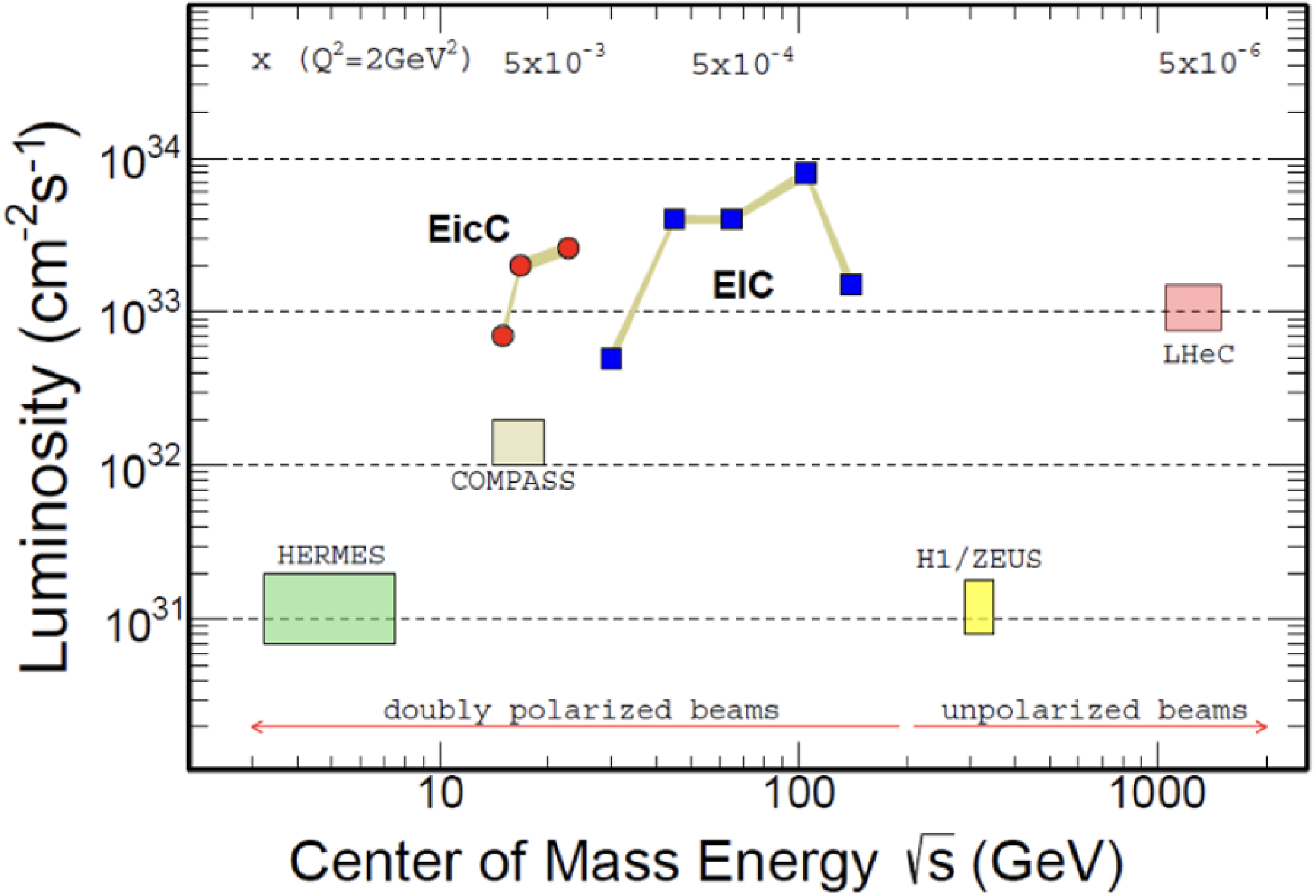
HIAF ➔ EicC

Proposed electron-ion colliders (incomplete list)

FAIR ➔ EN

LHC ➔ LH





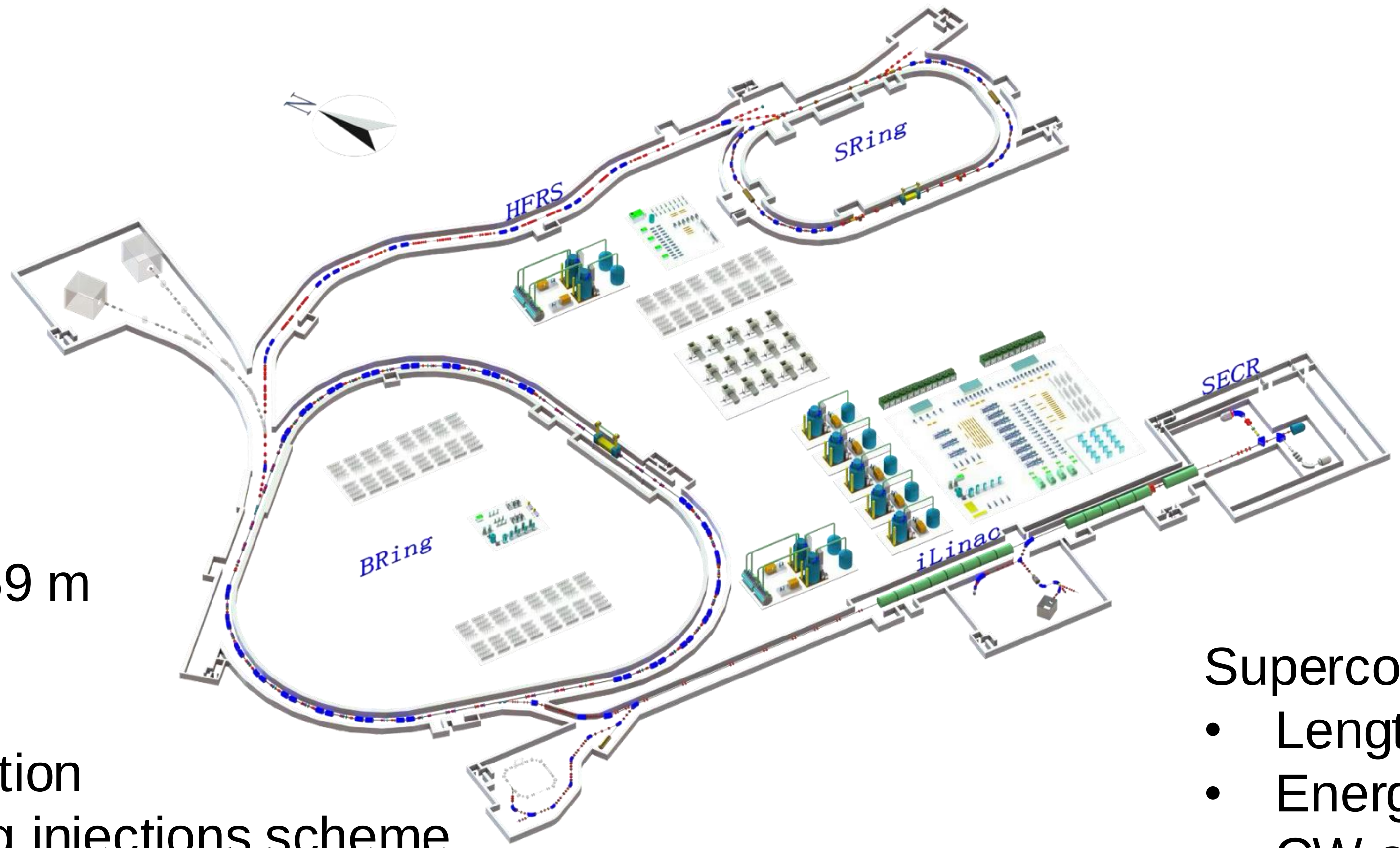
IC ➔ eRHIC/EIC

HIAF ➔ EicC

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

Under construction
(2018 - 2025)



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 (U34+)
- CW and pulsed modes

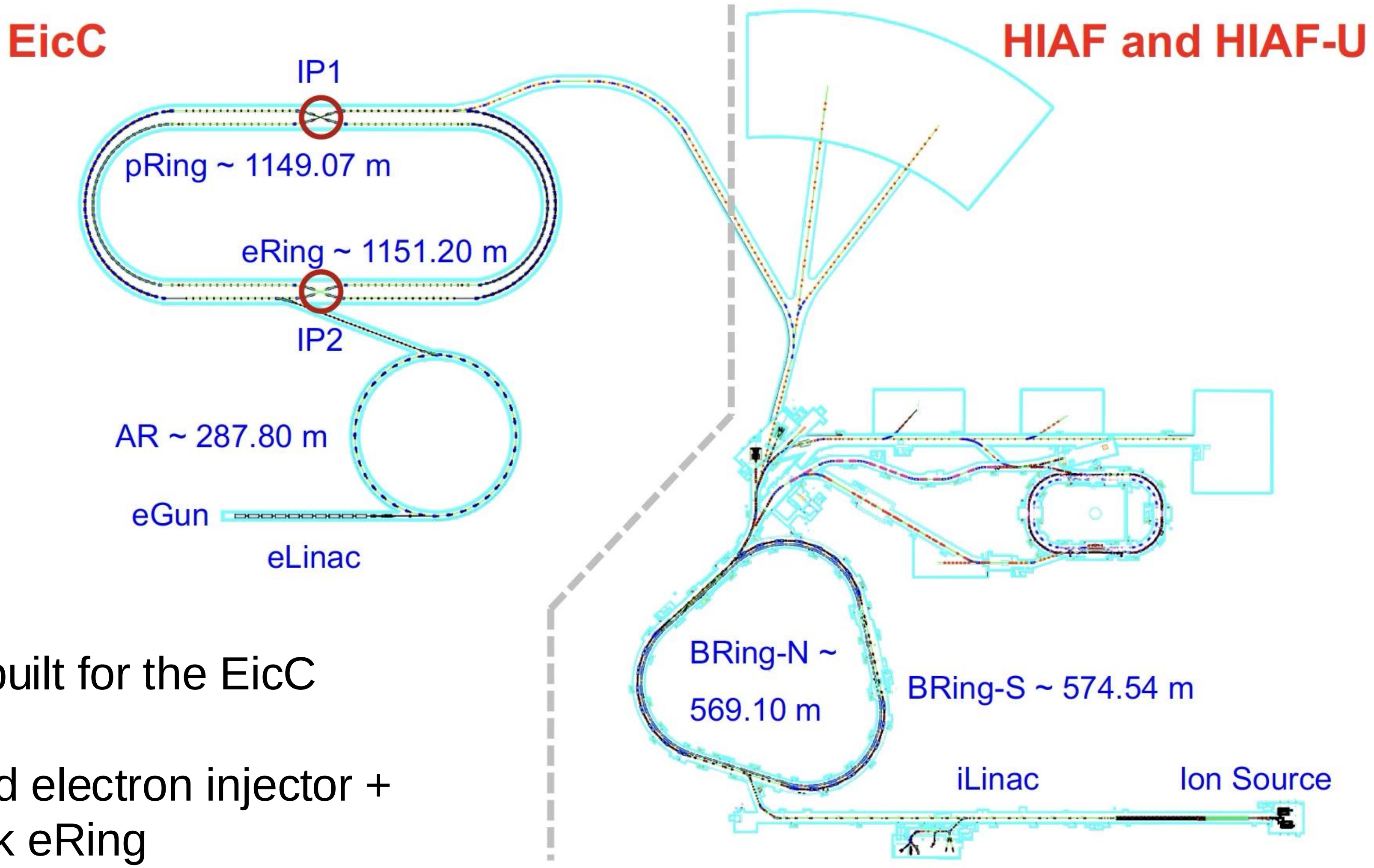
HIAF - High Intensity heavy-ion Accelerator Facility

Location: Huizhou, Guangdong Province, South coast of China

HIAF - High Intensity heavy-ion Accelerator Facility

Picture in May 2024
- Deliver the first heavy ion beam in 2025

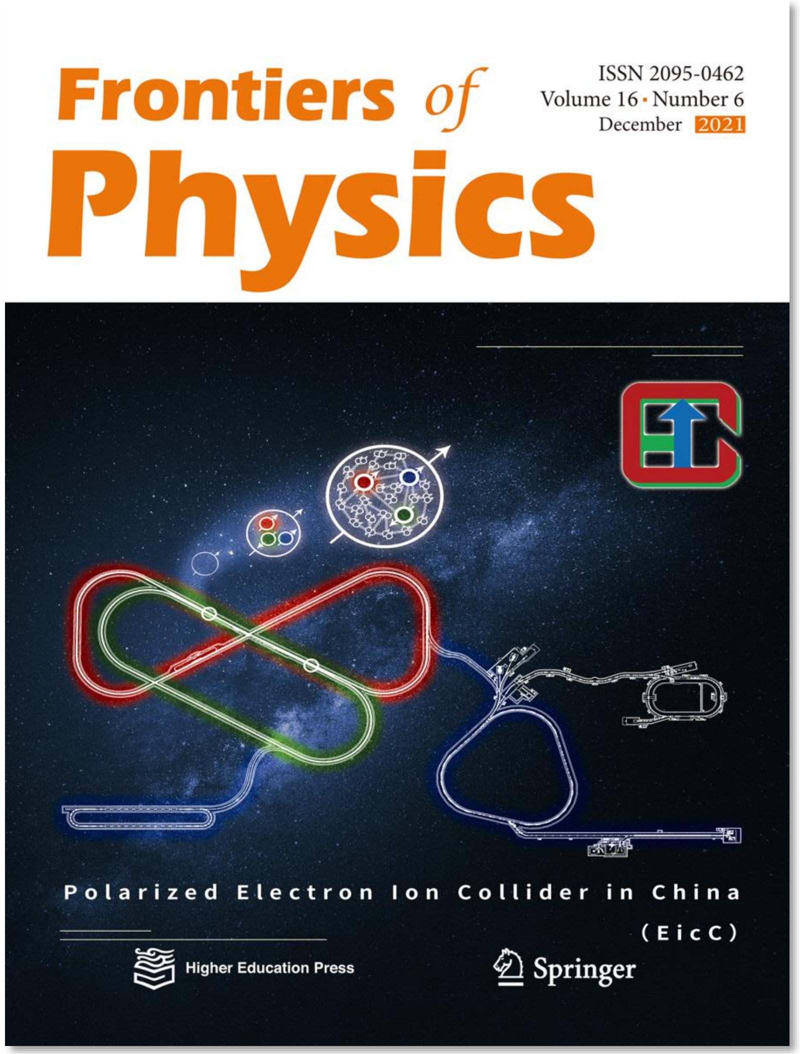
Layout of Electron-ion Collider in China



Need to be built for the EicC

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

EicC white-paper



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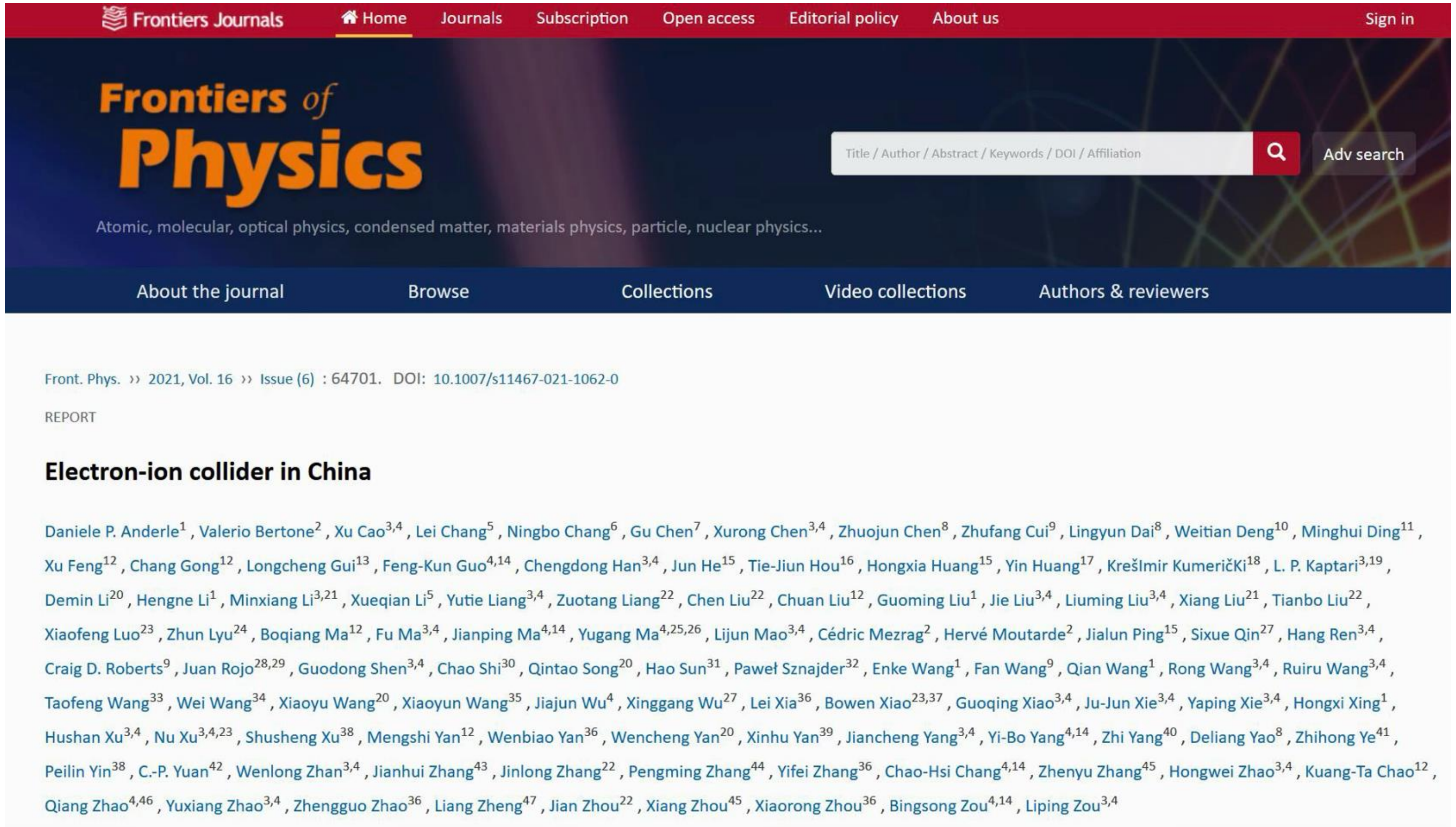
100+ physicists from 46 institutes



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REPORT

Electron-ion collider in China

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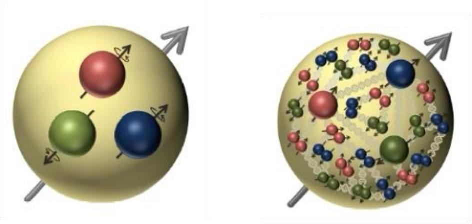
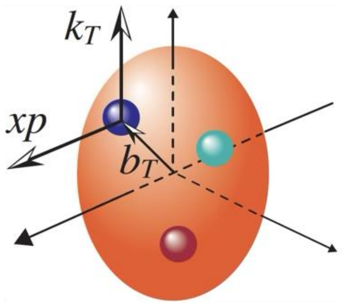
Highlighted physics topics

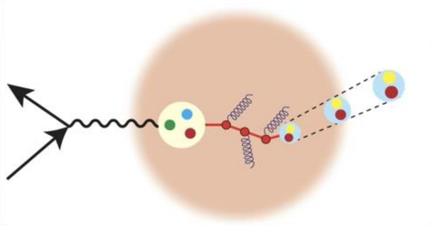
1D spin structure of nucleon



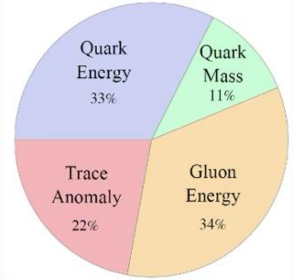
3D and 2+1D tomography of nucleon



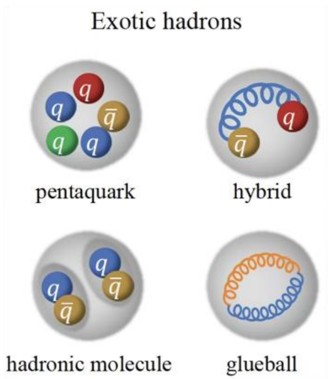
Partonic structure of nucleus



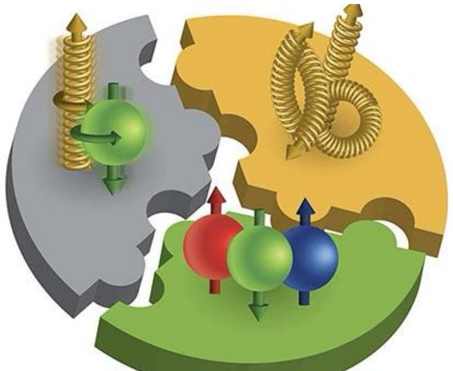
Proton mass



Exotic hadron states



1D spin structure of nucleon

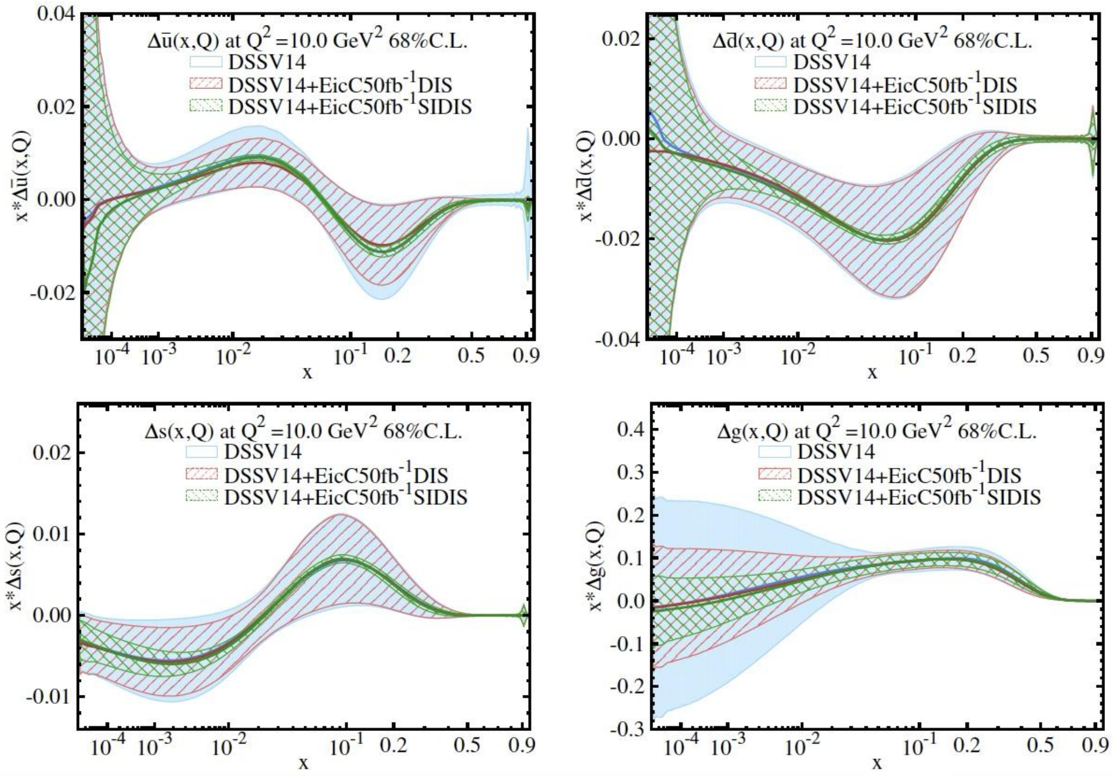


$$< S_p > = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

Jaffe-Manohar 1990

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

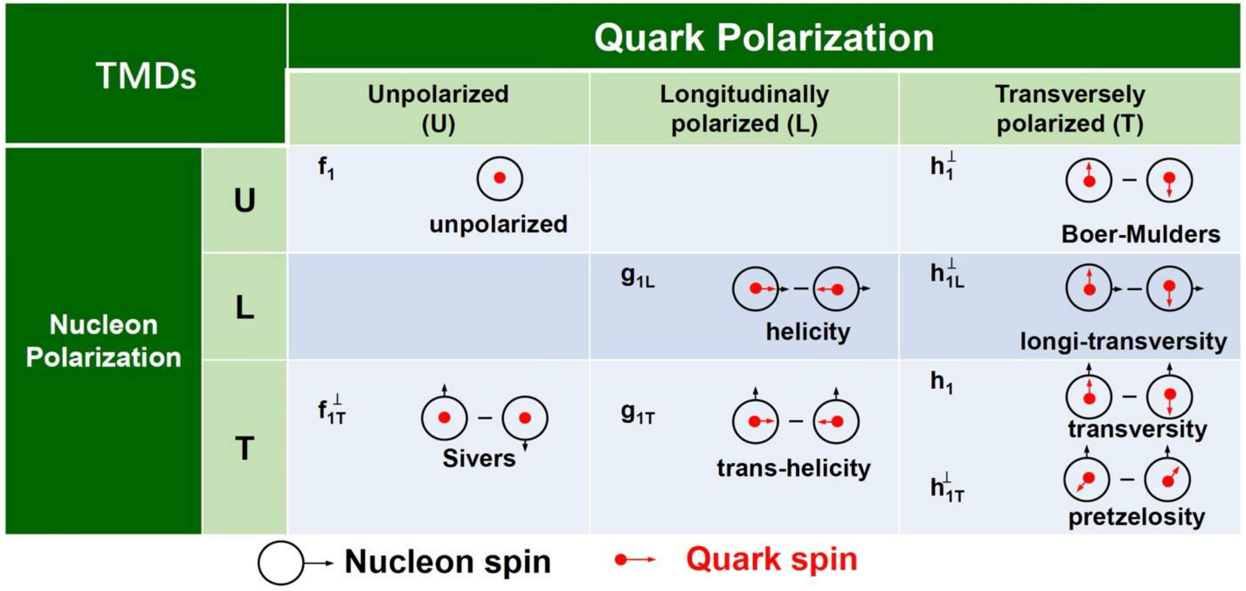
D. Anderle, T. Hou, H. Xing, M. Yan, C. -P. Yuan, Y. X. Zhao, JHEP08, 034 (2021)



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

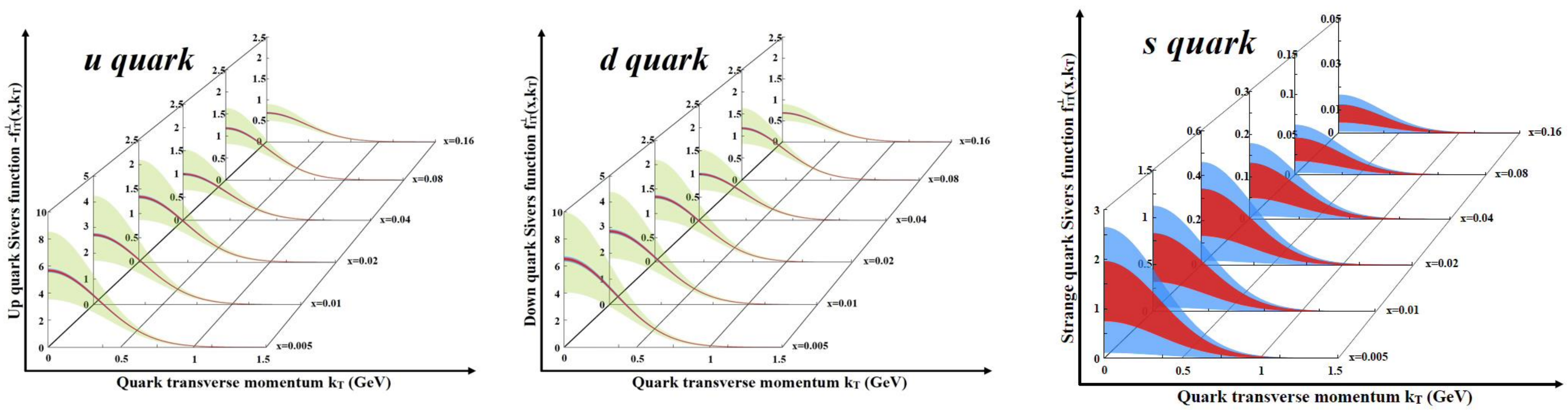
3D spin structure at momentum space



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

LO analysis of EicC projection

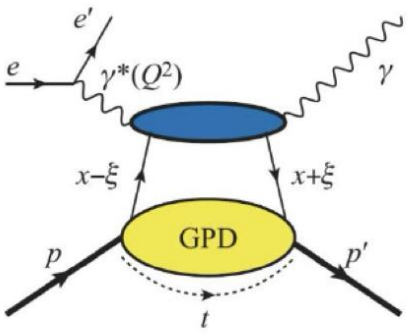
- Pion(+/-), Kaon(+/-)
- ep: 3.5 GeV x 20 GeV
- eHe-3: 3.5 GeV x 40 GeV
- Lumi: ep 50 fb-1, eHe-3 50 fb-1
- Stat. Error vs Sys. Error



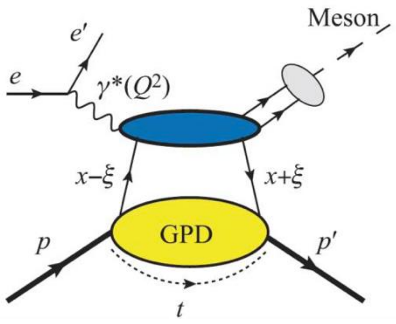
2+1 structure at momentum+spatial space

- 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

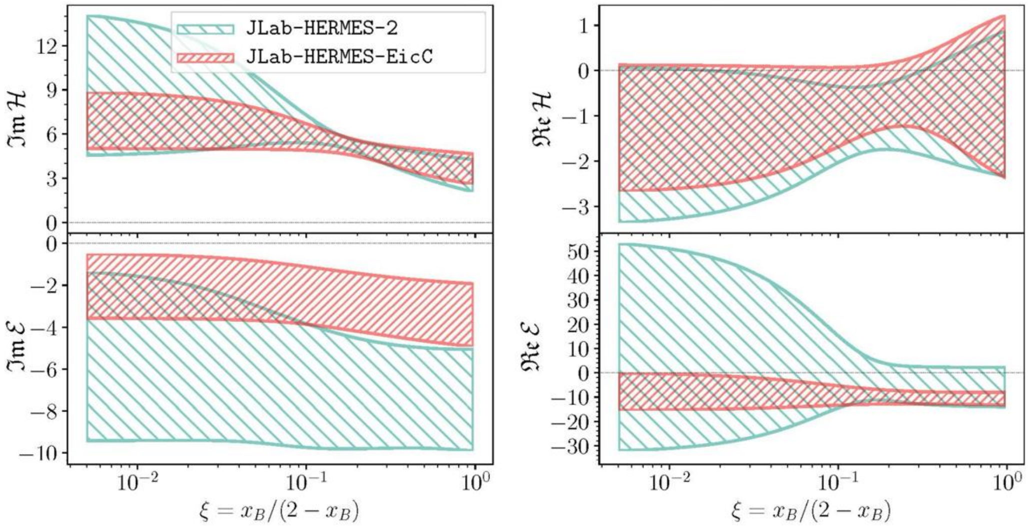
DVCS



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)

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

Unpolarized beam, transverse target (tTSA)

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

Polarized beam, longitudinal target (DSA)

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

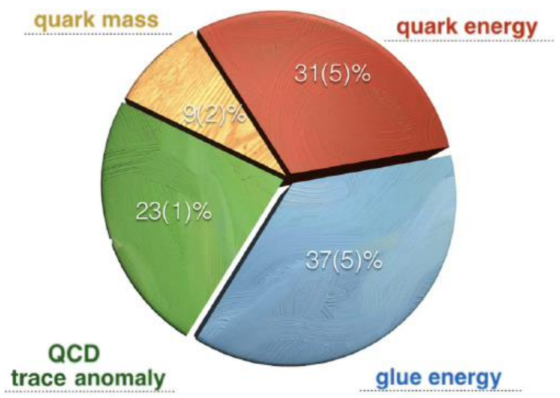
Only this azimuthal angular modulation

Understanding Proton Mass

Mass decomposition [Ji, 95]

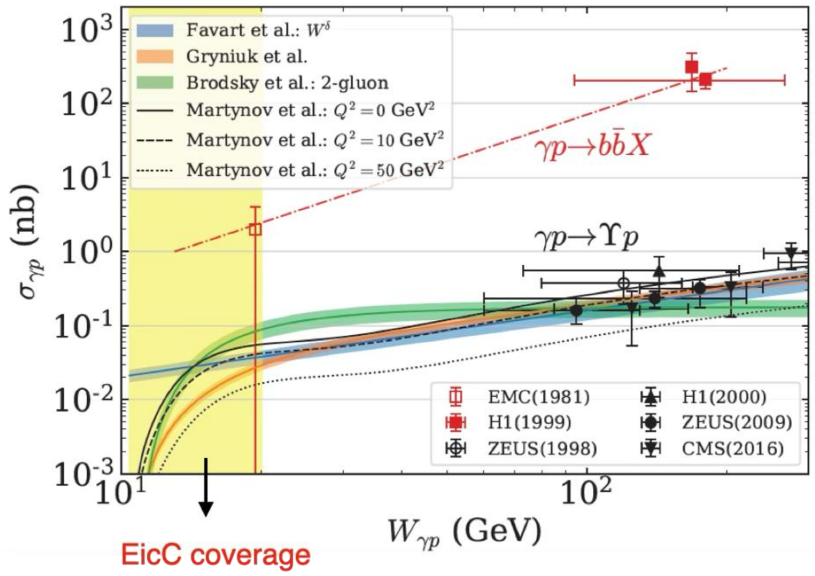
$$M = M_q + M_m + M_g + M_a$$

M_q : quark energy
M_m : quark mass (condensate)
M_g : gluon energy
M_a : trace anomaly



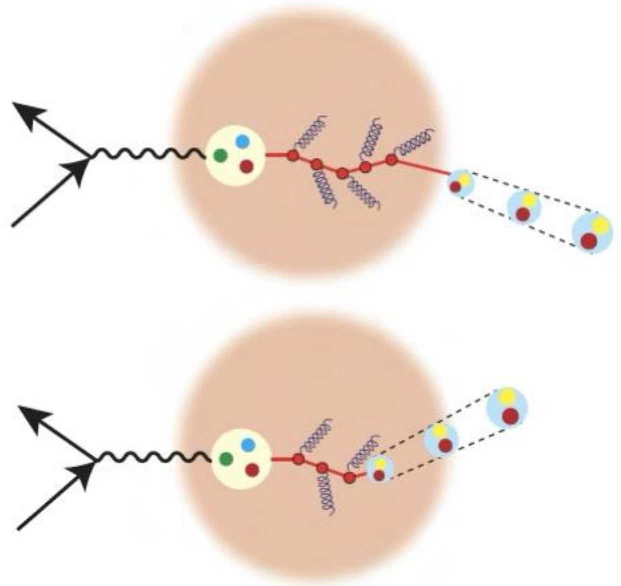
Lattice QCD, Yang et al 2018

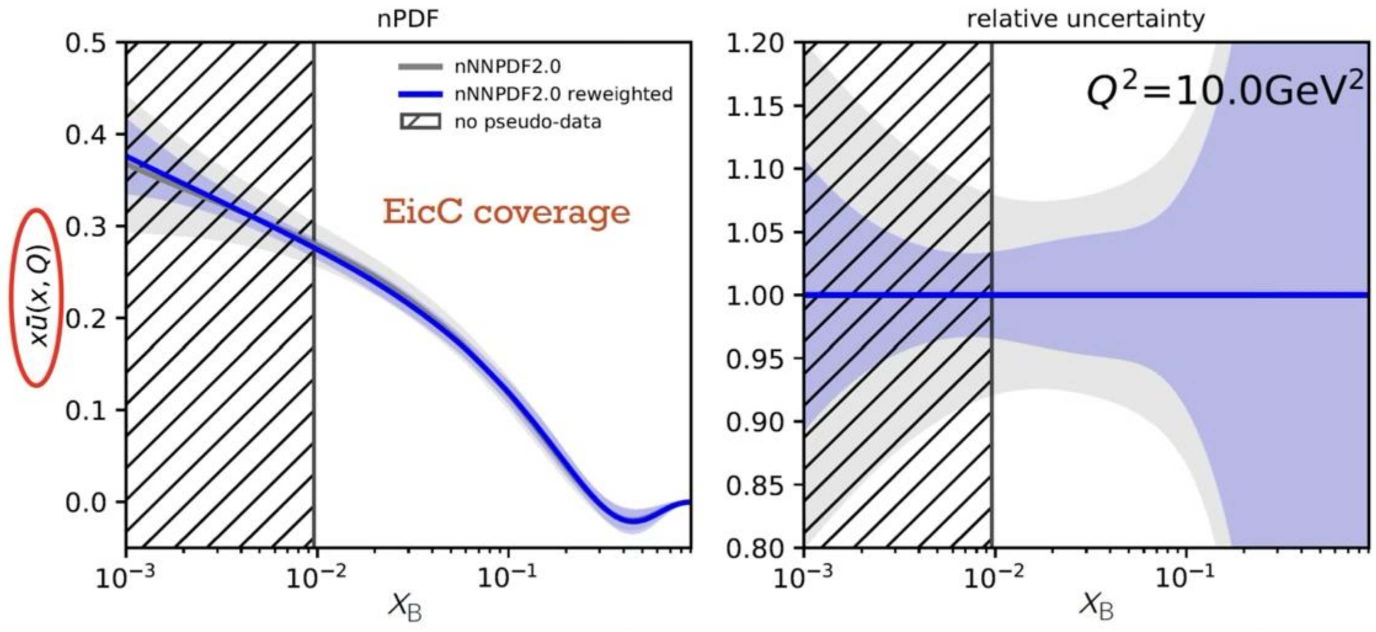
- M_q and M_g : constrained by PDFs
- M_m via πN scattering
- M_a via threshold production of J/ψ (8.2 GeV, JLab) and Υ (12 GeV)
- Threshold requires low CoM energy (low y at EIC)
- Complementarity between EicC (and EIC) and Lattices.



Partonic structure of nucleus

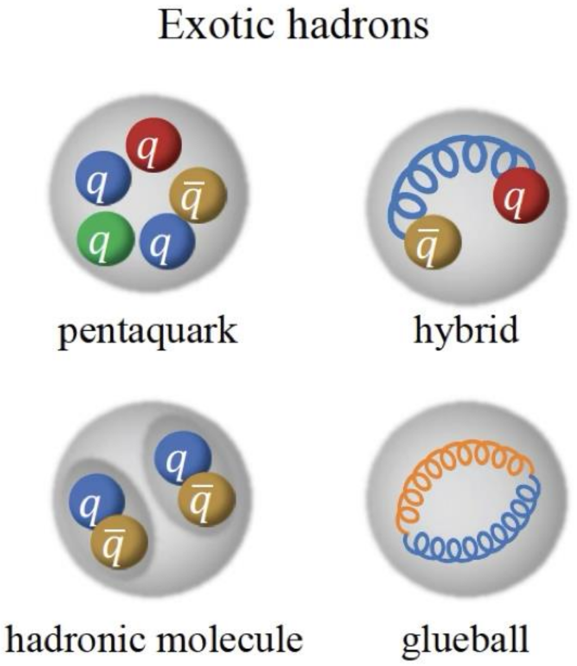
- Use heavy nuclei to study parton energy loss in cold nuclear medium
- Hadronization inside and outside medium. (Nucleus as a lab at the fm scale)
- Medium modification of light meson and heavy meson in SIDIS.
- Precision study of nuclear PDFs with heavy ion beams.





With only a few hours of running

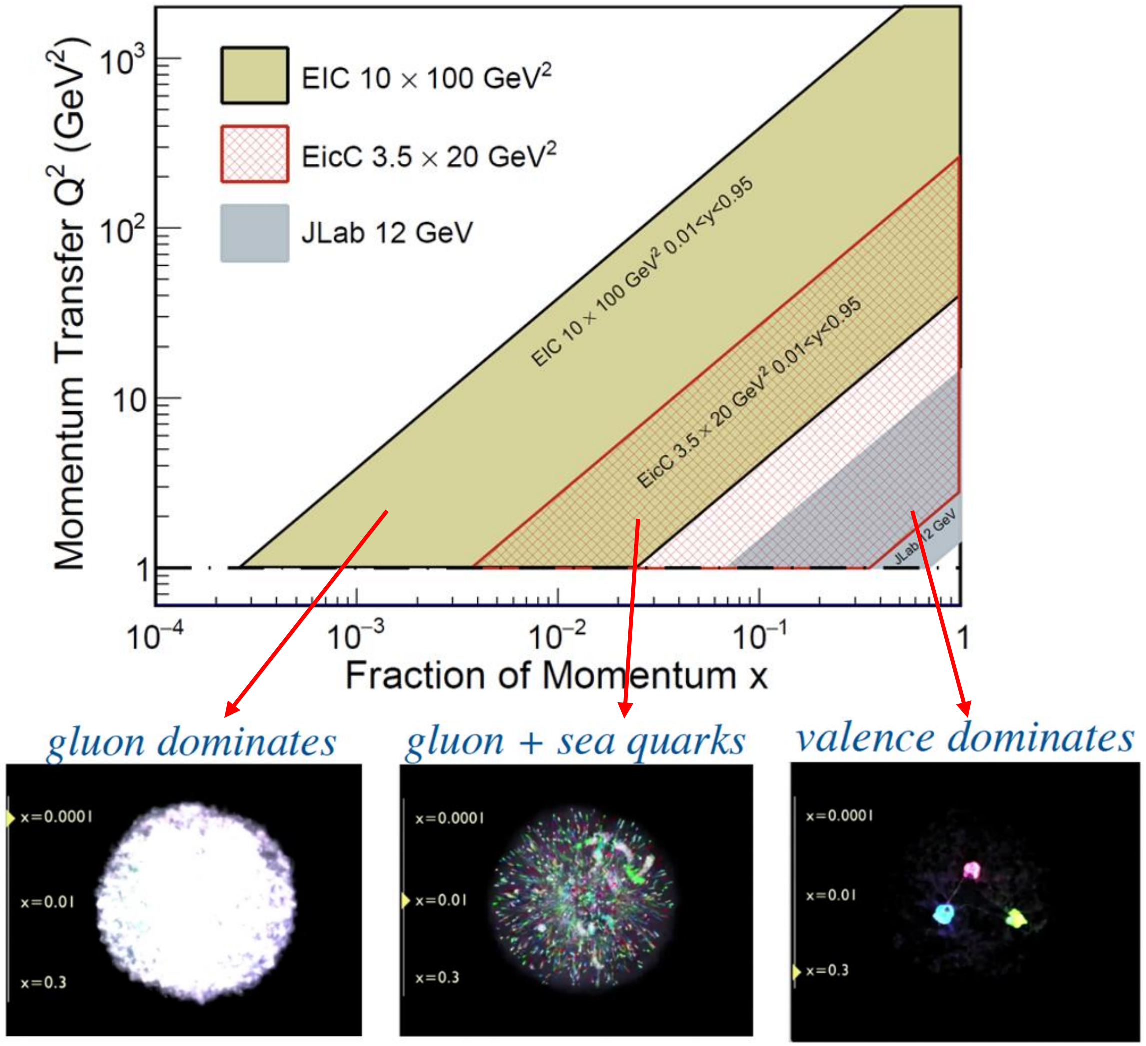
Exotic hadron states



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.

Complementarity of US-EIC and EicC



R.G. Milner and R. Ent, *Visualizing the proton* 2022

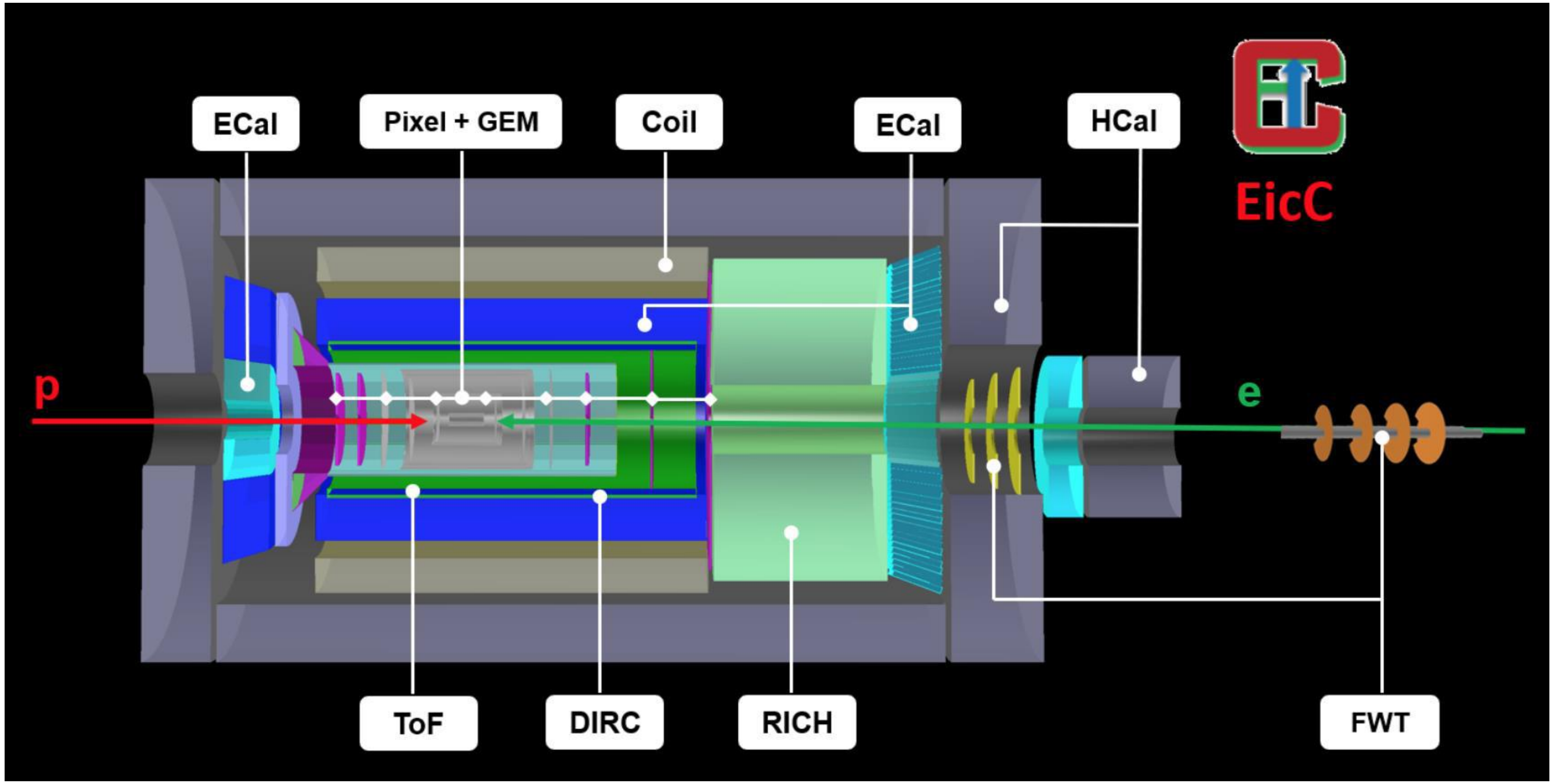
Common physics goal:

- nucleon 1D, 3D spin structure
- Nucleon mass origin
- Nuclear environment effect

Complementary QCD phase space:

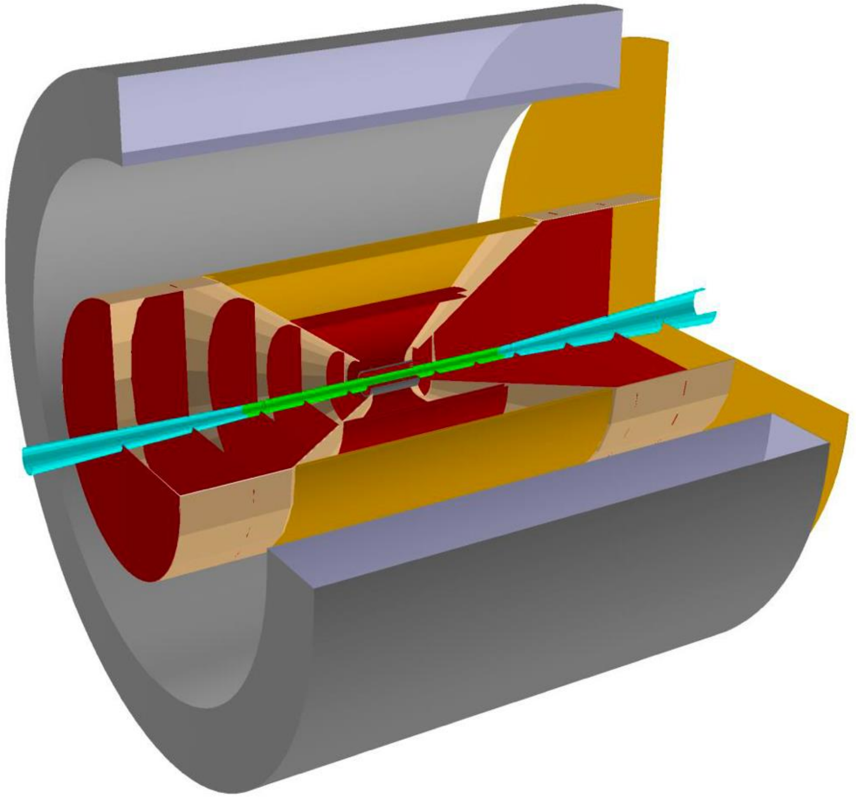
- US-EIC: small-x gluon dominated region; saturation behavior; etc.
- EicC: moderate x sea quark region; exotic hadron states, especially those with heavy flavor quark contents; etc

EicC detector design



- Hermetic detector, low mass inner tracking, good PID (e and π/K/p) in wide range, calorimetry
- Moderate radiation hardness requirements, low pile-up, low multiplicity.

Tracking: Silicon + MPGD



Physics requirements for EicC tracking

Assume B ~ 1.5 T

- Barrel (*-1* < η < 1.6): $\sigma(p)/p$ ~ 1% @ 1GeV
- e-endcap (-3 < η < -1): $\sigma(p)/p$ ~ 2% @ 1GeV
- h-endcap (1.6 < η < 3): $\sigma(p)/p$ ~ 2% @ 1GeV

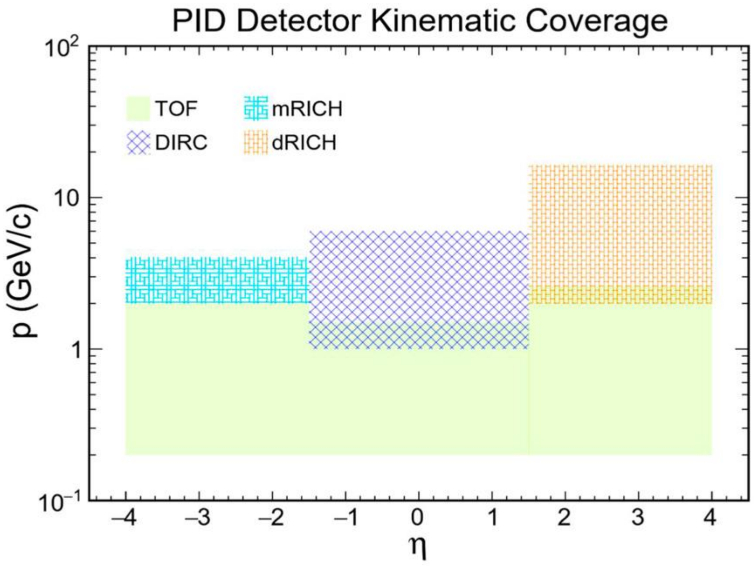
Silicon detector conceptual design

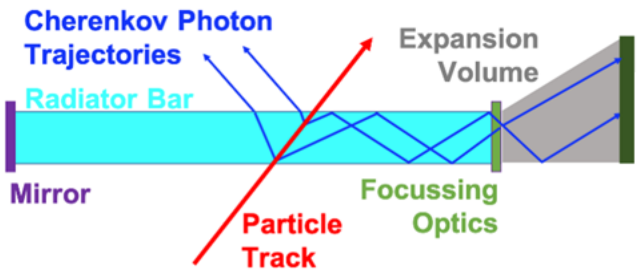
- Reduced Material budget is ~0.26%
- Optimal Pixel size: 10 to 20 mircon
- Thickness: 50 micron

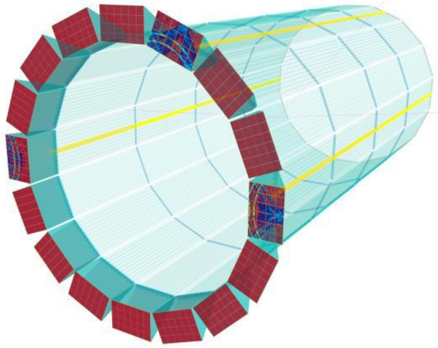
PID detectors: ToF + DIRC + RICH

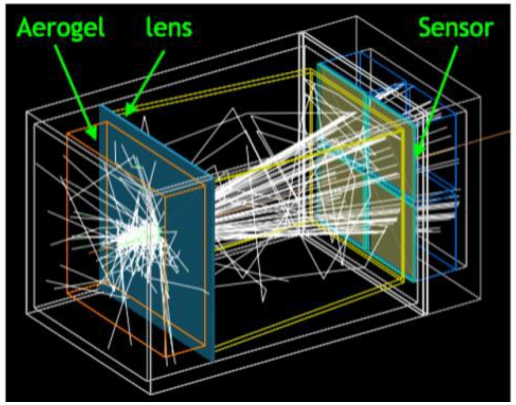
PID design concept:
- Barrel region: DIRC+TOF
- Backward e-Endcap: mRICH
- Forward ion-Endcap: dRICH

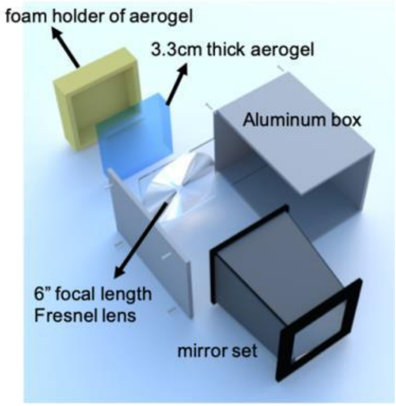
PID momentum coverage:
- <6 GeV/c at Barrel
- <4 GeV/c at e-Endcap;
- <15 GeV/c at ion-Endcap







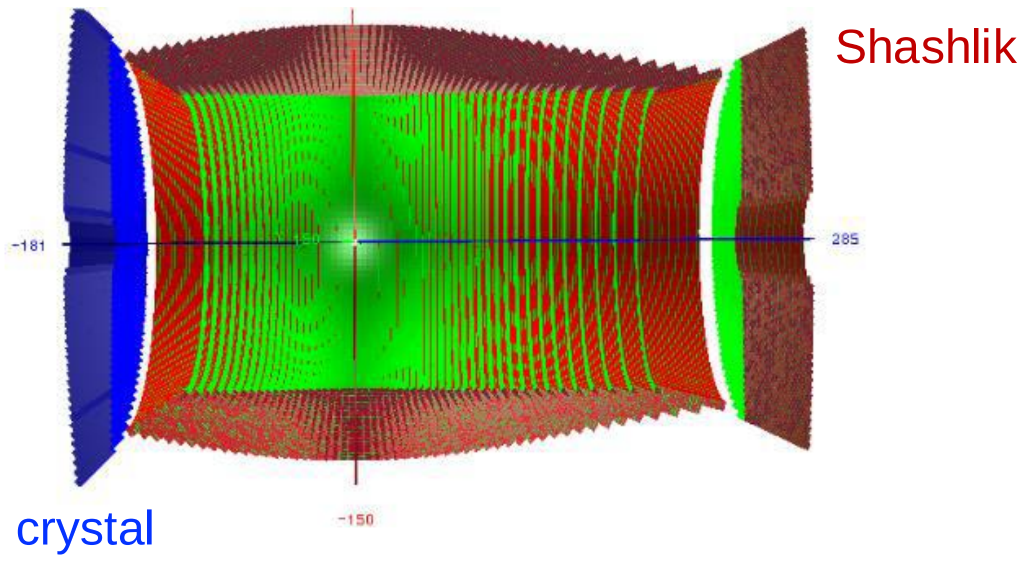




Calorimeter system: Shashlik + CsI crystal

General EMCal requirement:

- E-endcap: energy resolution, 2.5%/√E
- Barrel: good angle resolution, 5.0%/√E
- Ion-endcap: angle resolution, 5.0%/√E



	EMC	type	z/r[m]	Length[cm], X_0	Coverage[cm]	pseudorapidity	Tower size
EicC	e-endcap	CsI/crystal	Z=-1.5	30, $16X_0$	15.0<r<128	(-3.0, -1.0)	4.0*4.0(front)
	barrel	Shashlik	R=0.9	45, $16X_0$	-105.8<z<187.5	(-1.0, 1.5)	4.0*4.0 (front)
	Ion-endcap	Shashlik	Z=2.4	45, $16X_0$	24.0<r<113	(1.5, 3.0)	

EicC organization

Accelerator:

- EicC Accelerators
- Ion Sources
- Ion Machine
- Electron Machine
- Polarization
- Cooling
- IR
- Common System

Detector:

- Tracking
- PID
- Calorimetry
- IR+Magnet
- Luminosity and polarimetry
- Far-Forward detector
- DAQ
- Simulations

Physics:

- Inclusive
- SIDIS
- Heavy Flavor
- Exclusive

Software: EicCRoot

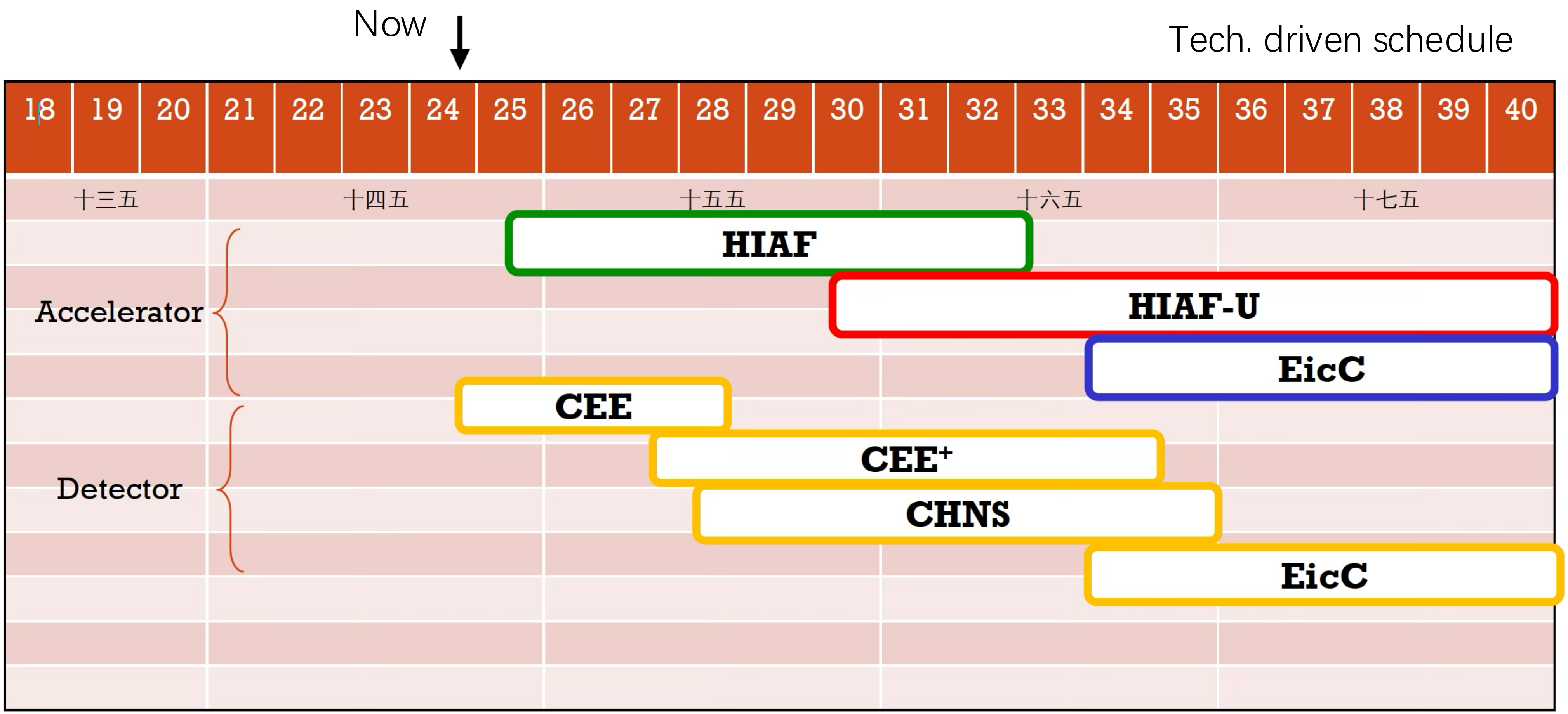
Computing (at SCNU):

Southern Nuclear Science Computing Center

Towards to the Conceptual Design Report

Accelerator	Physics	Detector
1) EicC Accelerators	1) 1D spin	1) Vertexing + tracking
2) Ion Sources	2) 3D spin (TMDs + GPDs)	2) PID
3) Ion Machine	3) Exotic states	3) Calorimetry
5) Electron Machine	4) EHM and proton mass	4) IR + Magnet
5) Polarization	5) Nuclei	5) Luminosity and polarimetry
6) Electron cooling	6) LQCD	6) Forward detector
7) IR	7) DSE	7) DAQ
8) Common System	8) New ideas	8) Simulations
		Software: EicCRoot
EicC CDR Volume I	**EicC CDR** Volume II	

Timeline



HIAF construction is near complement
Finishing EicC Conceptual Design Report

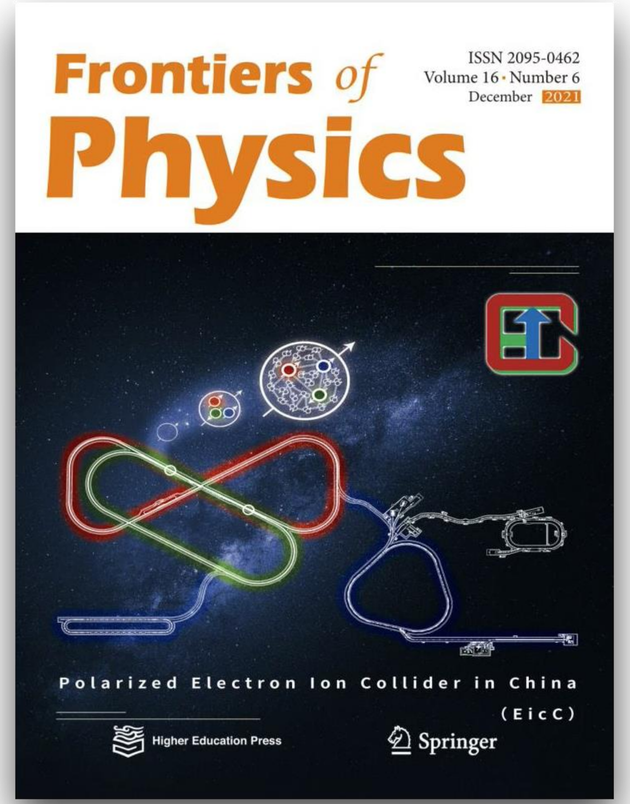
Summary

Electron-ion collider in China — EicC

- Focused on sea-quark/gluon at moderate/large-x region
- Complements EICs at higher energies

Conceptual design report by 2024

- Geant4 simulations and detector R&D
- More physics topics under development



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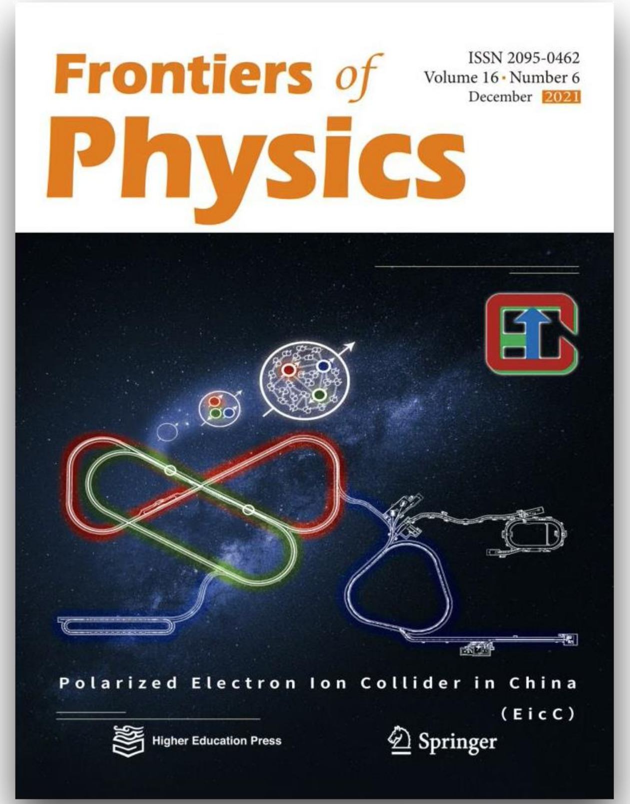
Welcome to join us !



Thanks for your attention!