Electron Ion Collider in China, EicC

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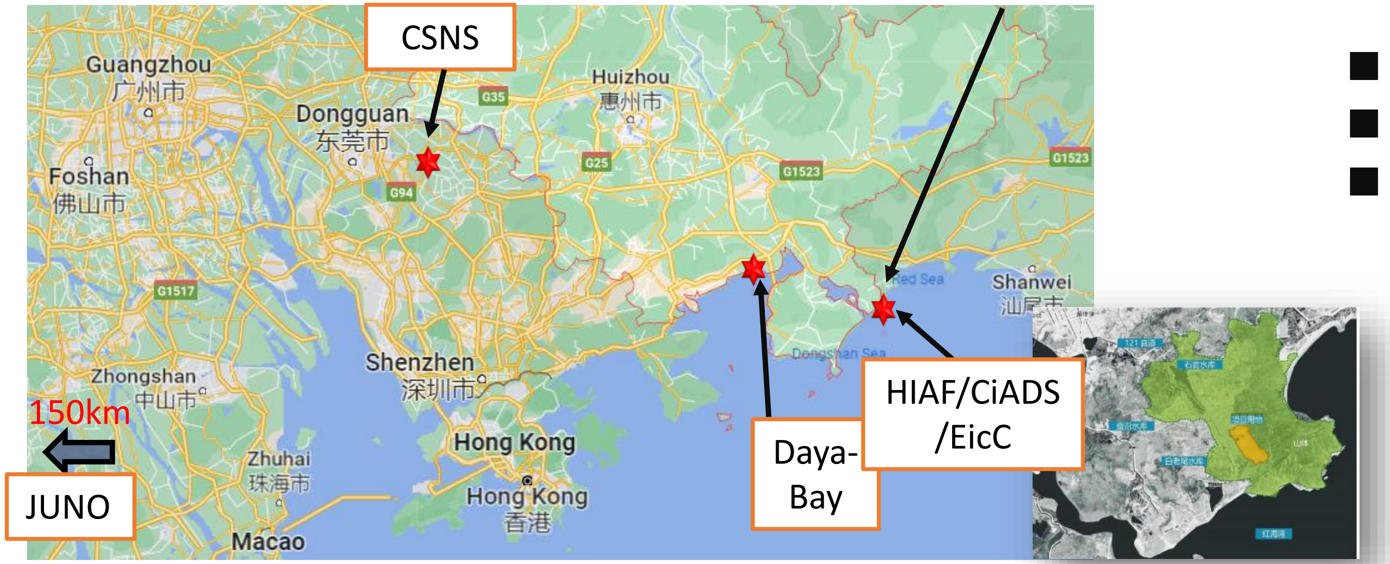
On behalf of EicC Collaboration

Towards improved hadron femtography with hard exclusive reactions
Virginia Tech 2022/07/18-22

清華大學
Tsinghua University

➢High Intensity heavy-ion Accelerator Facility (HIAF):

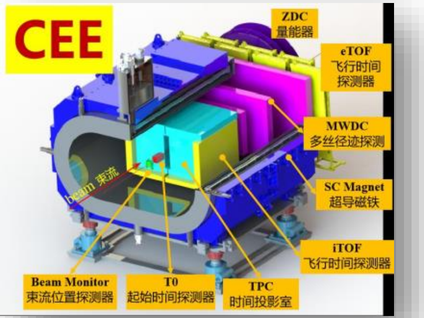


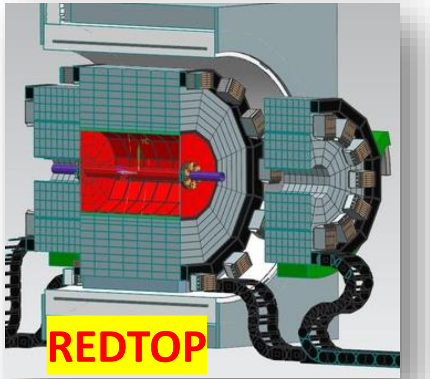
- First phase ~0.6 km^2 ; Construction area ~ 0.12 km^2
- +2 km^2 is reserved for future development
- Total budget:~ 6.8 billion CNY (~1billion US Dollars)
  - ✓ 3.5 billion comes from the central government.
  - ✓ 1.0 billion from The China National Nuclear Corporation (CNNC) for CiADS
  - ✓ 2.35 billion from local government for infrastructure

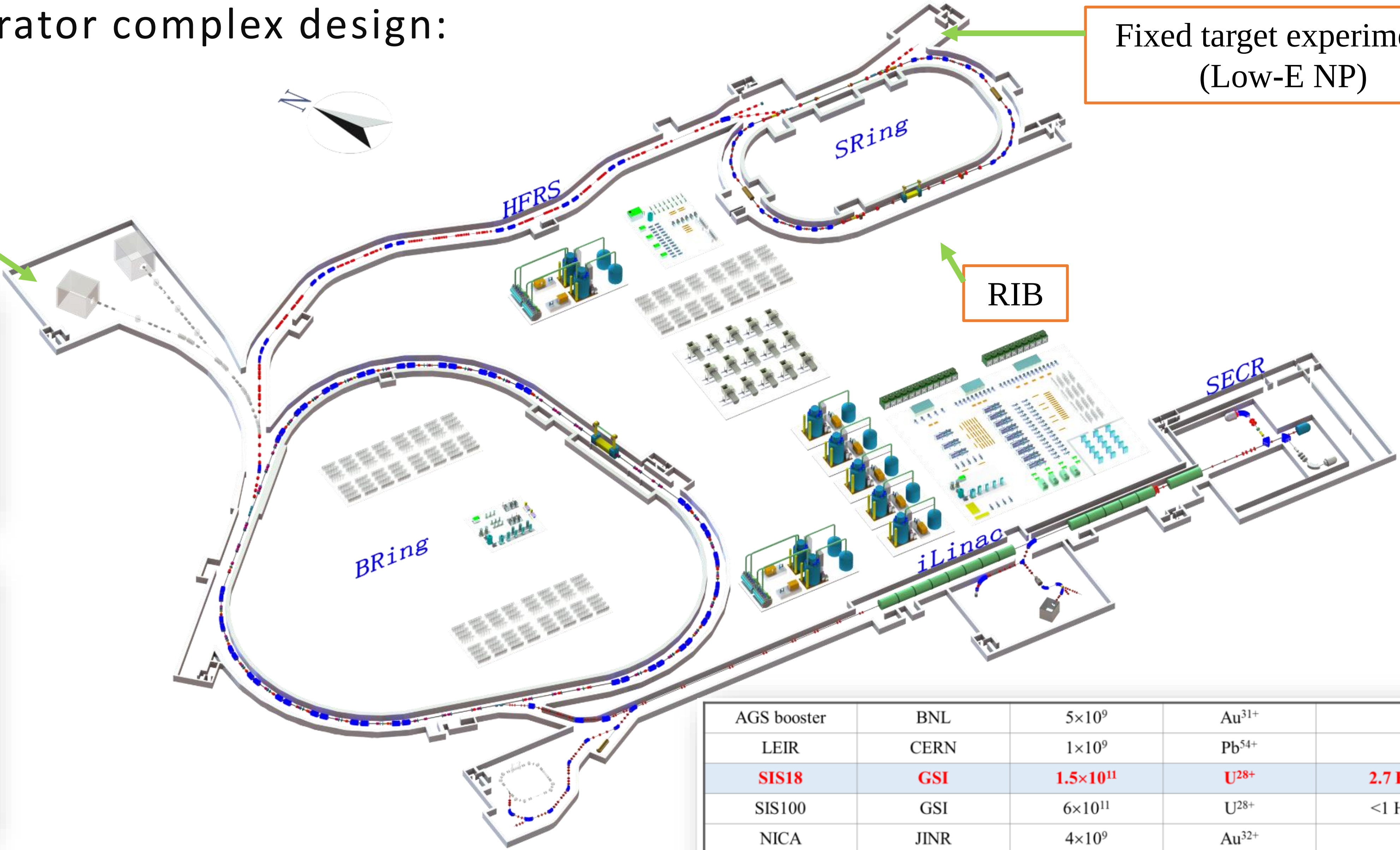
HIAF

➢HIAF accelerator complex design:

Fixed target experiments (Mid/High-E NP)







Fixed target experiments (Low-E NP)

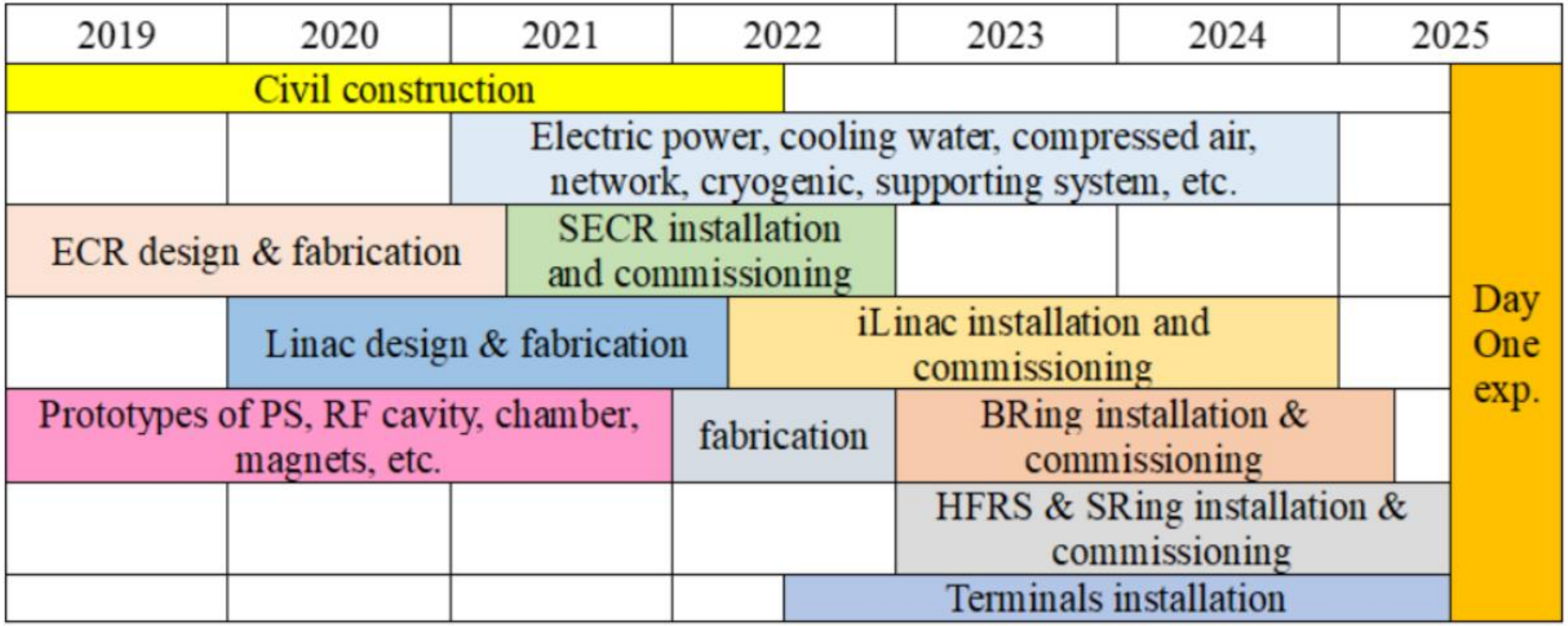
RIB

AGS booster	BNL	5×10^9	Au^{31+}	
LEIR	CERN	1×10^9	Pb^{54+}	
SIS18	**GSI**	**1.5×10^{11}**	**U^{28+}**	**2.7 Hz**
SIS100	GSI	6×10^{11}	U^{28+}	<1 Hz
NICA	JINR	4×10^9	Au^{32+}	
HIAF	**IMP**	**2×10^{11}**	**U^{35+}**	**3-10 Hz**

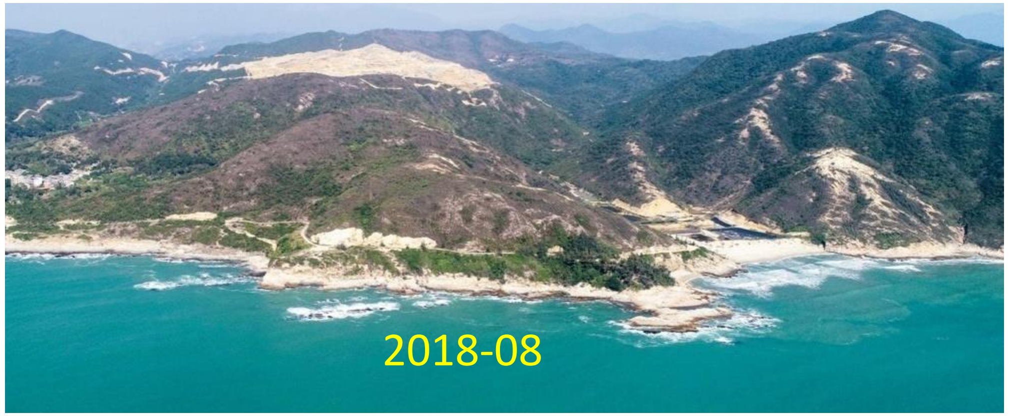
➢High Intensity heavy-ion Accelerator Facility (HIAF):

- Road Map:

- Construction Plan:

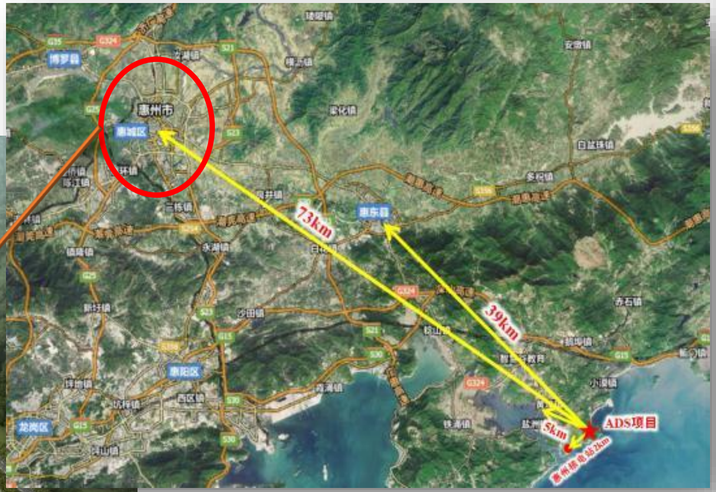


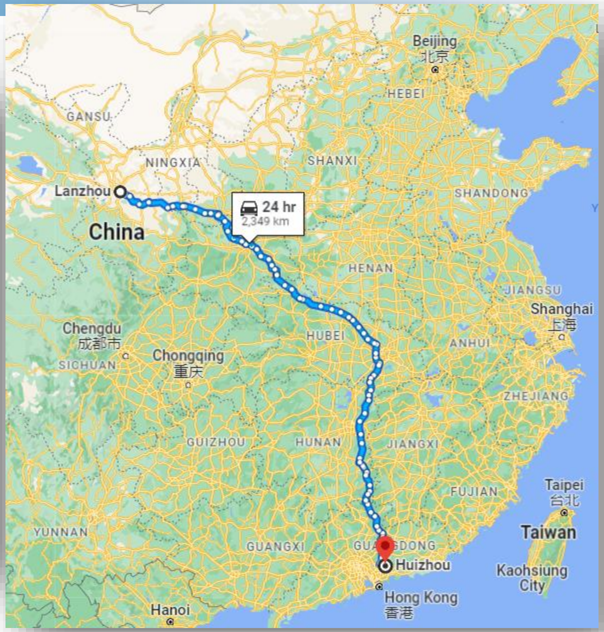
➢Accelerator Site Construction:



➢IMP Office Site Construction:

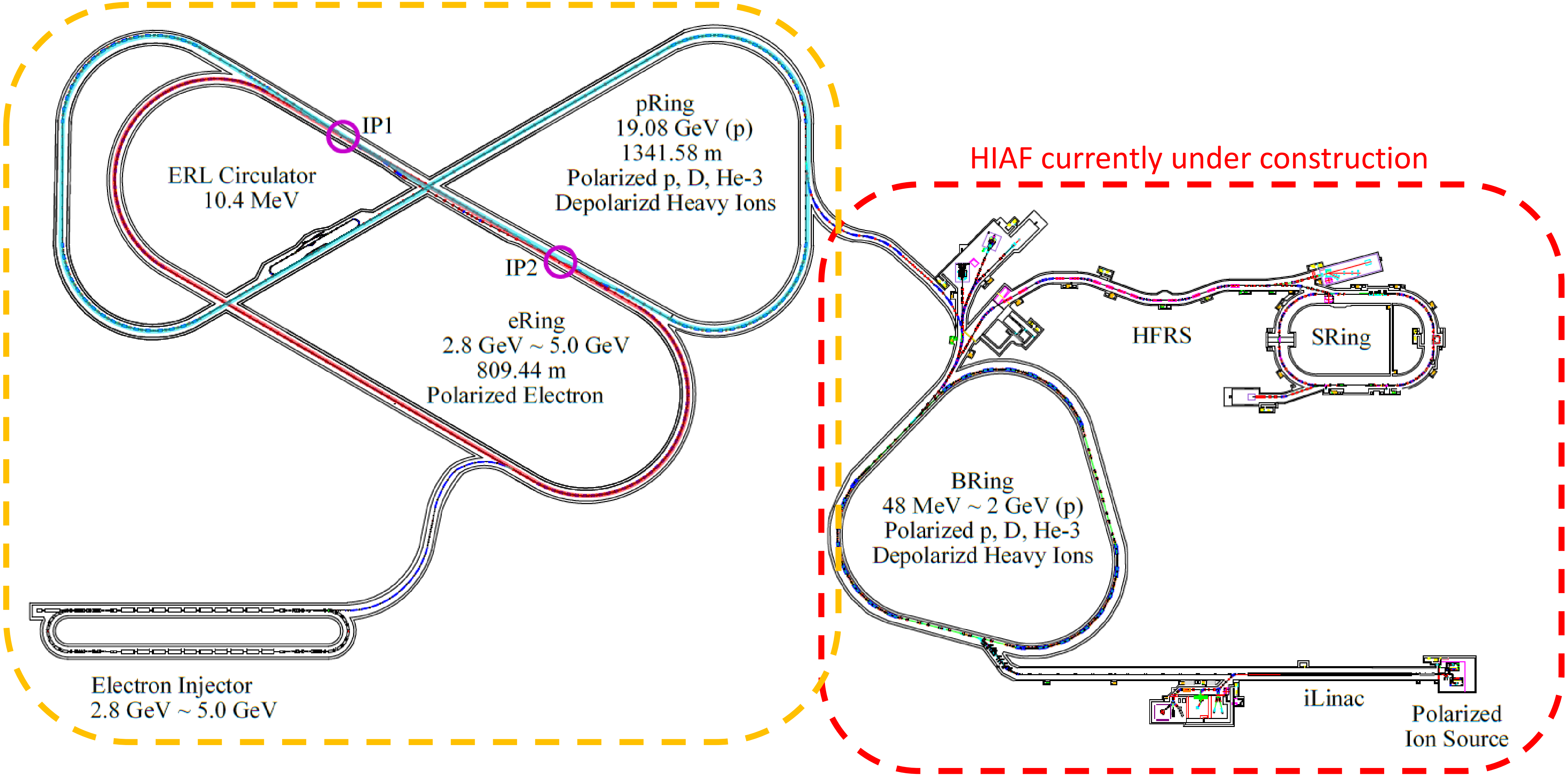
New IMP branch in Huizhou downtown (73km from HIAF)





➢Upgraded Accelerator complex layout:

NEW: Electron injector and collider rings



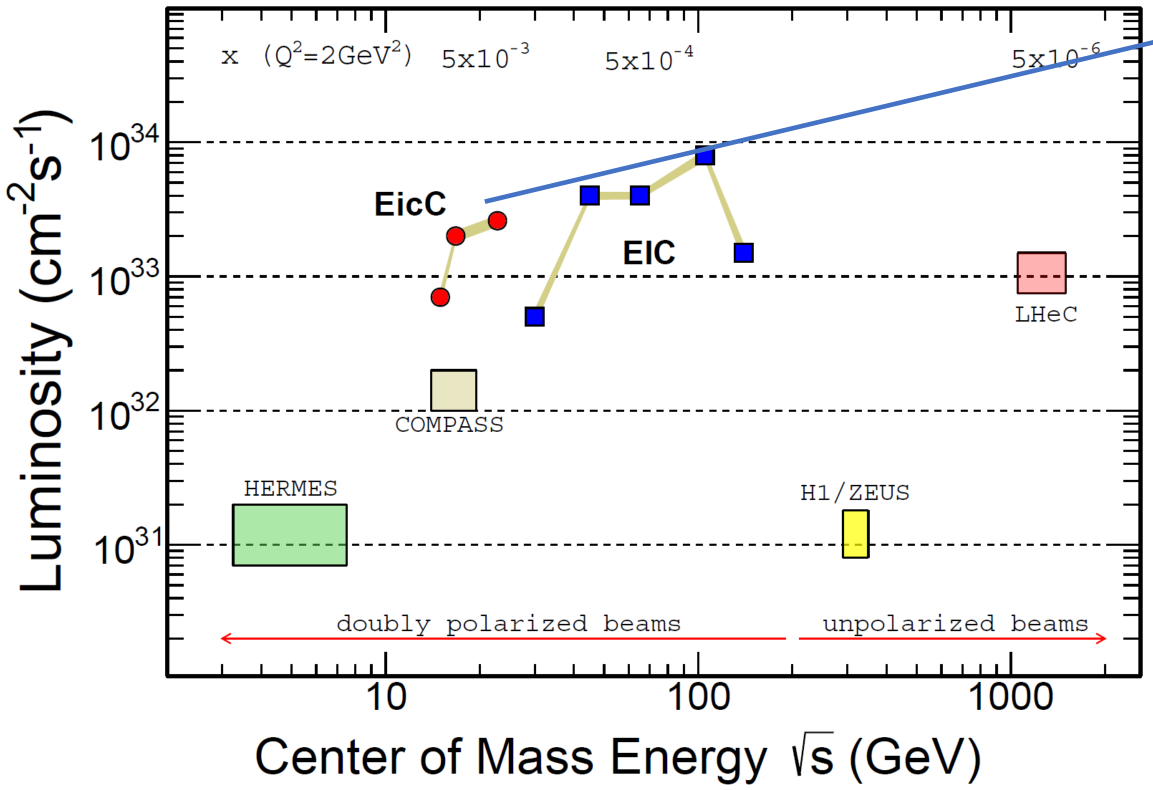
EicC

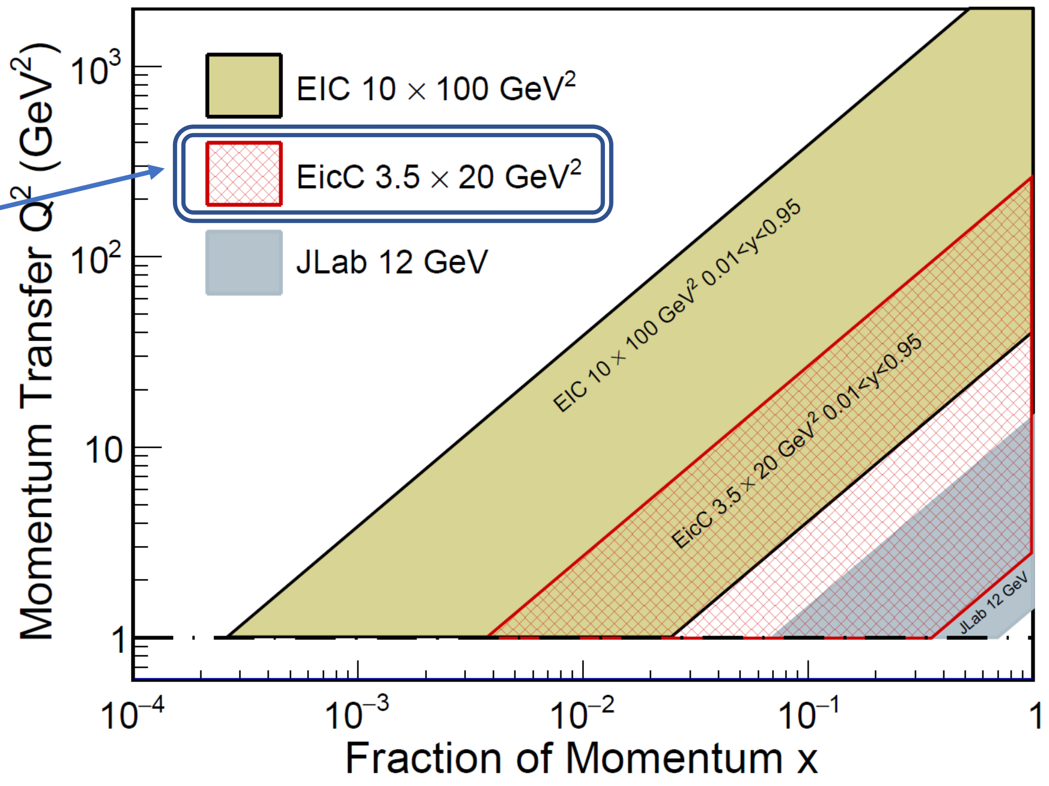

SRing
HFRS
Polarized
Ion Source
iLinac
pRing
19.08 GeV (p)
1341.58 m
Polarized p, D, He-3
Depolarizd Heavy Ions
BRing
48 MeV ~ 2 GeV (p)
Polarized p, D, He-3
Depolarizd Heavy Ions
IP1
IP2
eRing
2.8 GeV ~ 5.0 GeV
809.44 m
Polarized Electron
ERL Circulator
10.4 MeV
Electron Injector
2.8 GeV ~ 5.0 GeV

EicC

➢Complementary to JLab@12GeV and US-EIC:

- ✓ Luminosity: $10^{33}cm^{-2}s^{-1}$;
- ✓ Polarization: electrons →70%, ^{2}D & ^{3}He



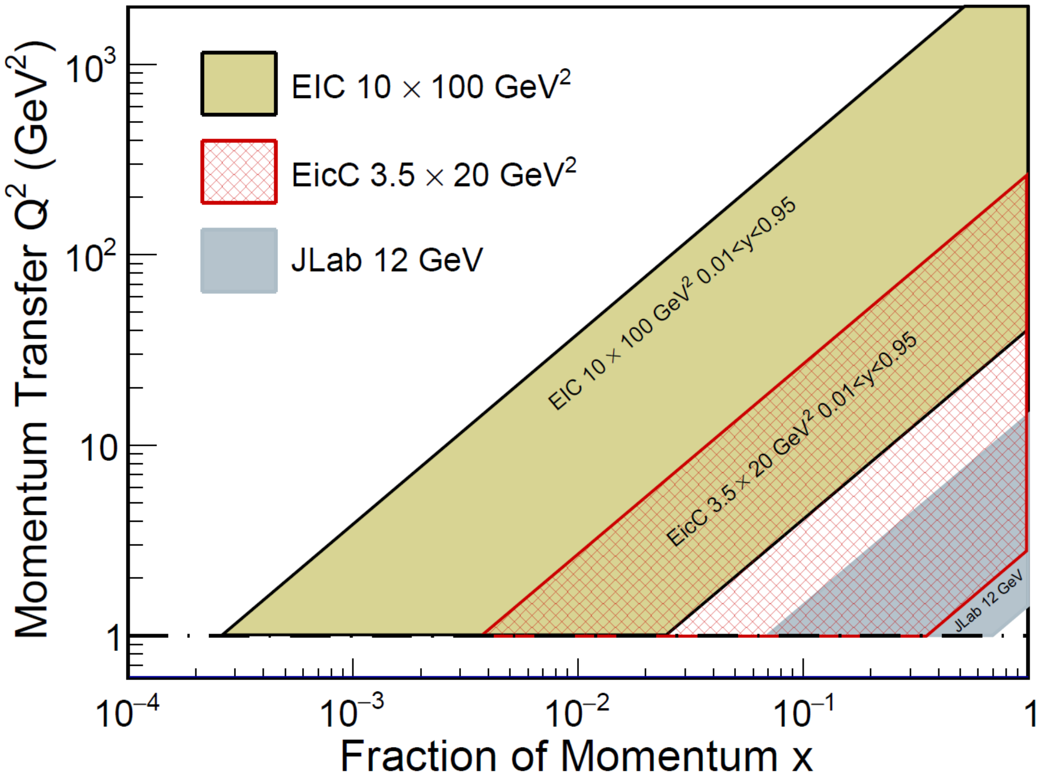


√s ~ 17GeV, $2x10^{33}/s/cm^2$

◆ Some overlap with JLab@24GeV

➢Complementary to JLab@12GeV and US-EIC:

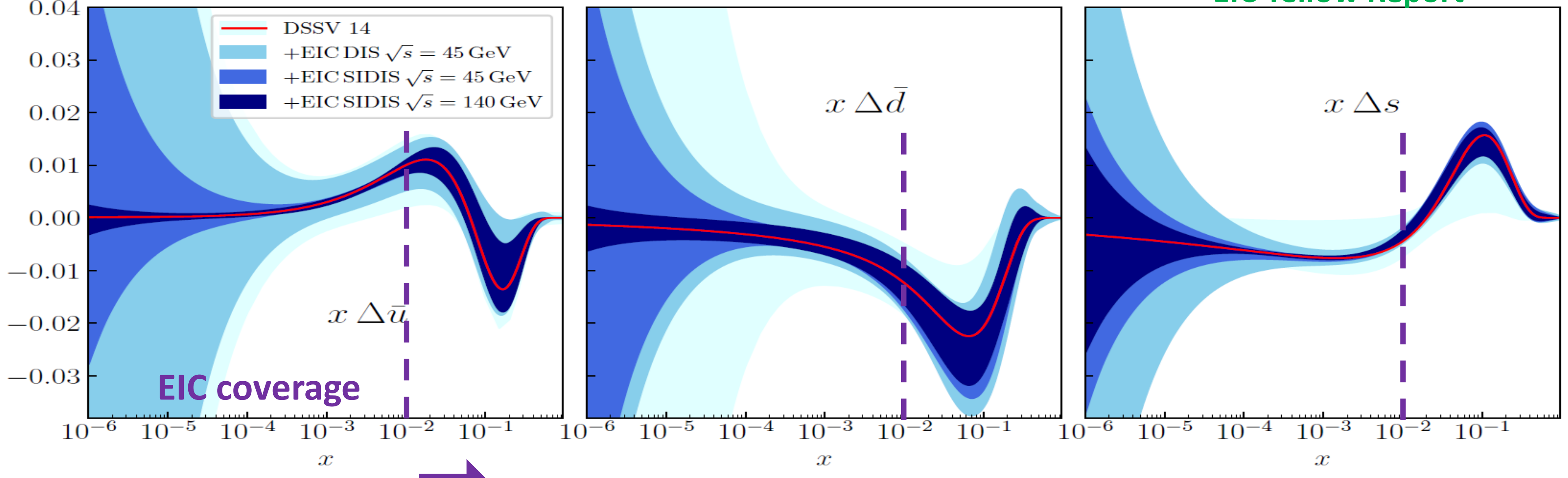
- Spin of the nucleon: 1D, 3D
  - Polarized electron + Polarized proton/light nuclei
  - Valance and see quarks TMDs and GPDs
- Partonic structure of nuclei and the parton interaction with the nuclear environment
  - Unpolarized electron + unpolarized various nuclei
  - Well developed heavy-ion community
- Mass of the nucleon
  - J/Psi and Upsilon Production
- Exotic states with c/cbar, b/bbar
  - Strong BESIII community in China



Physics Highlight

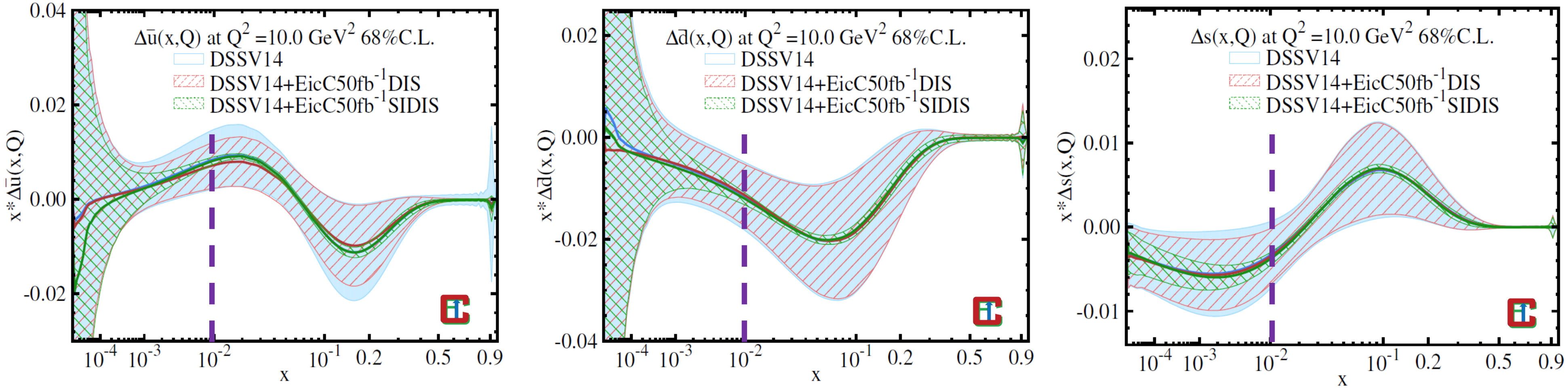
➢Spin of the nucleon-helicity distribution

EIC Yellow Report



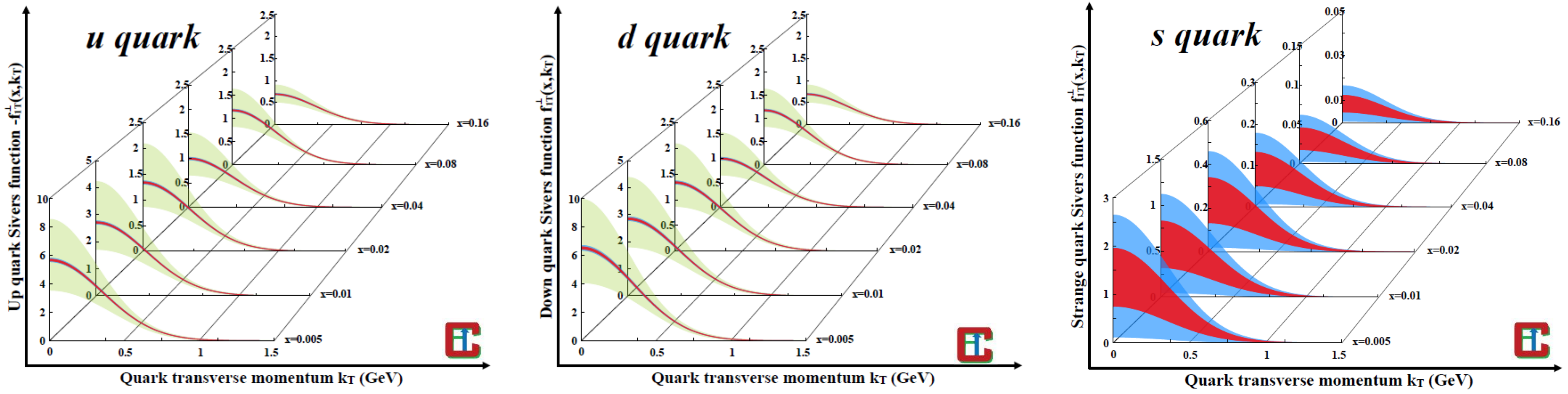
EicC coverage

EicC white paper



arXiv:2103.10276
JHEP08(2021)034

➢Spin structure of the nucleon-TMDs



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

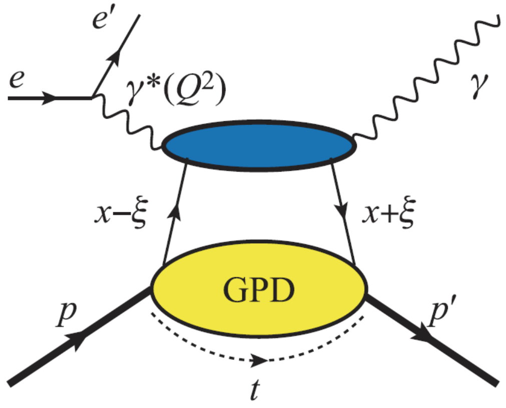
H. Dong, D. X. Zheng, J. Zhou, 2018

EicC SIDIS MC Data:

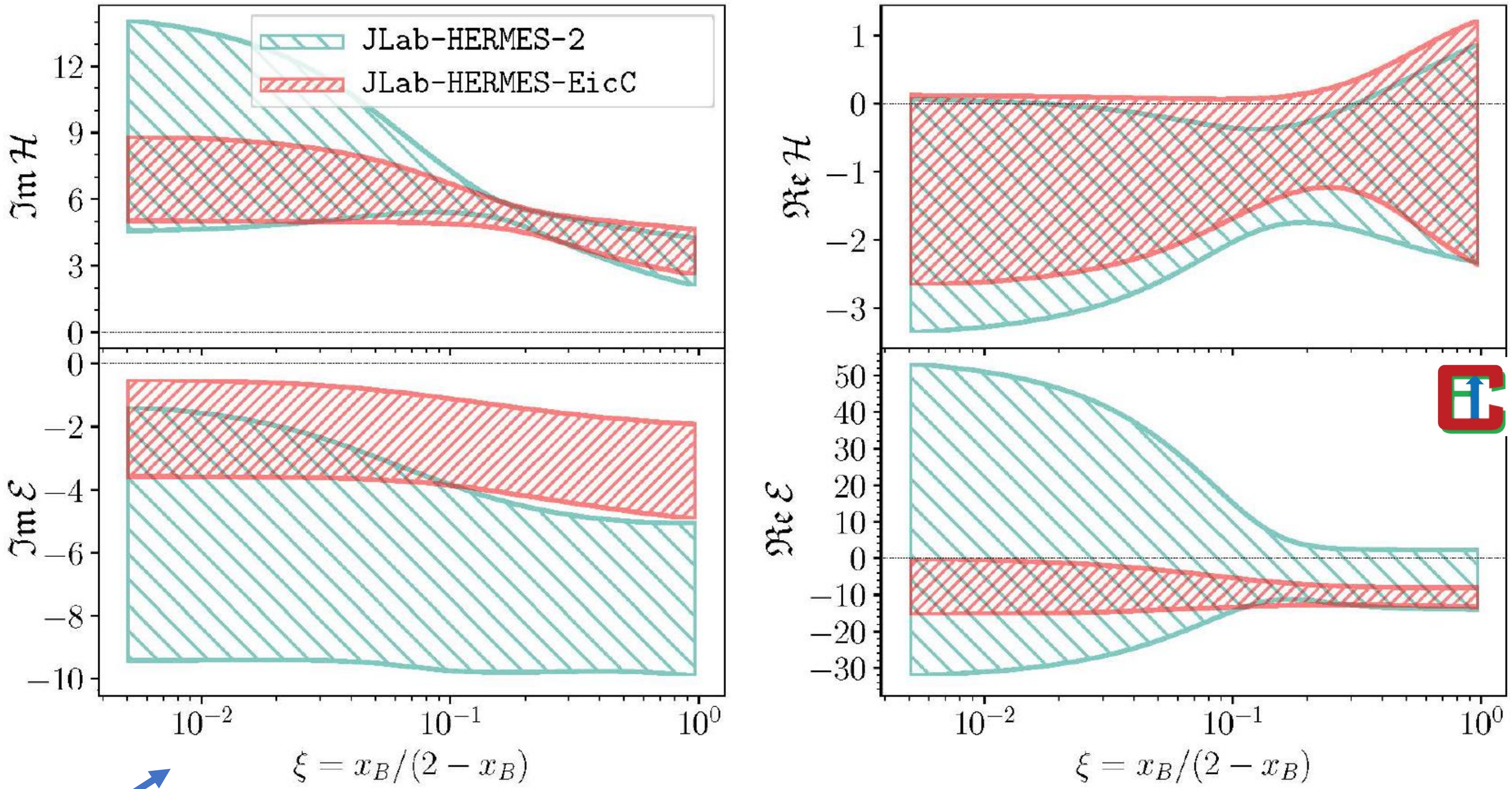
- ➢ Pion(+/-), Kaon(+/-)
- ➢ ep: 3.5 GeV X 20 GeV
- ➢ eHe-3: 3.5 GeV X 40 GeV
- ➢ Pol.: e(80%), p(70%), He-3(70%)
- ➢ Lumi: ep 50 fb^{-1}, eHe-3 50 fb^{-1}

Physics Highlight

➢Spin structure of the nucleon-GPDs



The extraction of CFF with neural network methods



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)

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

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 with this azimuthal angular modulation

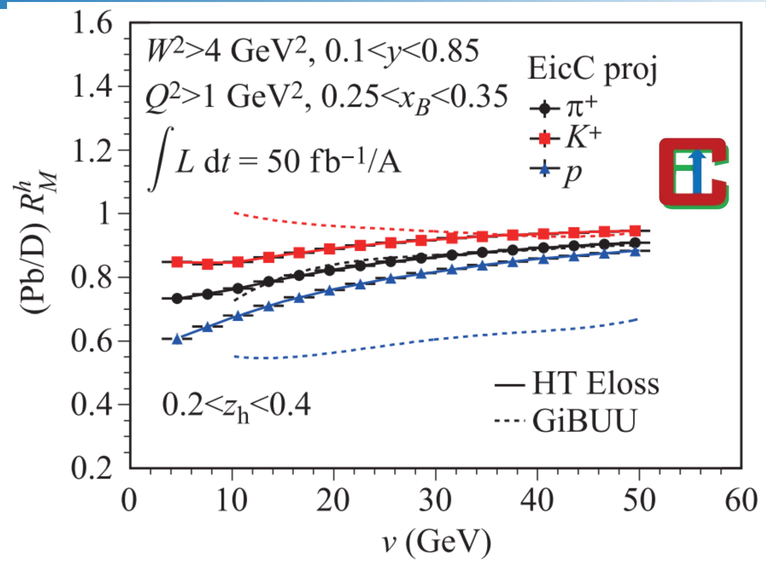
Strong support from PARTONS collaboration

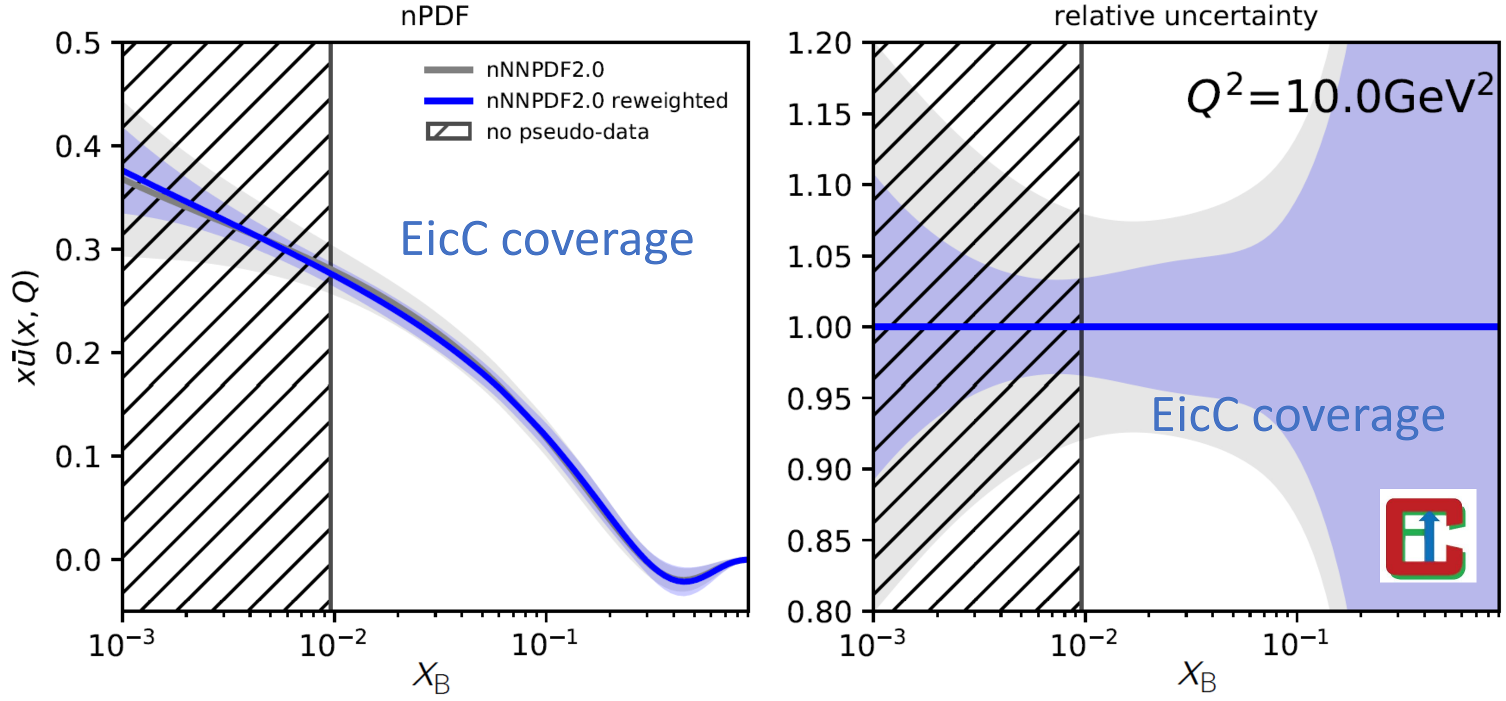
[Kumericki, 19]

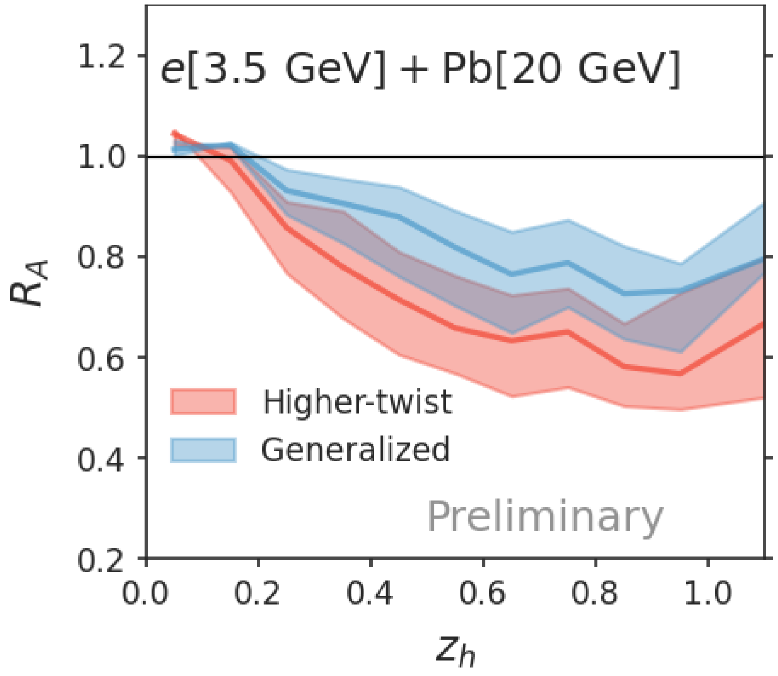
➢Nuclear medium effect

eA Physics:

- ➢ EMC / Anti-shadowing
- ➢ Nuclear-PDF
- ➢ Hadronization
- ➢ Nuclear-TMD, Nuclear-FF, Nuclear-GPD







Physics Highlight

➢Proton Mass Study

Mass decomposition [Ji, 95]

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

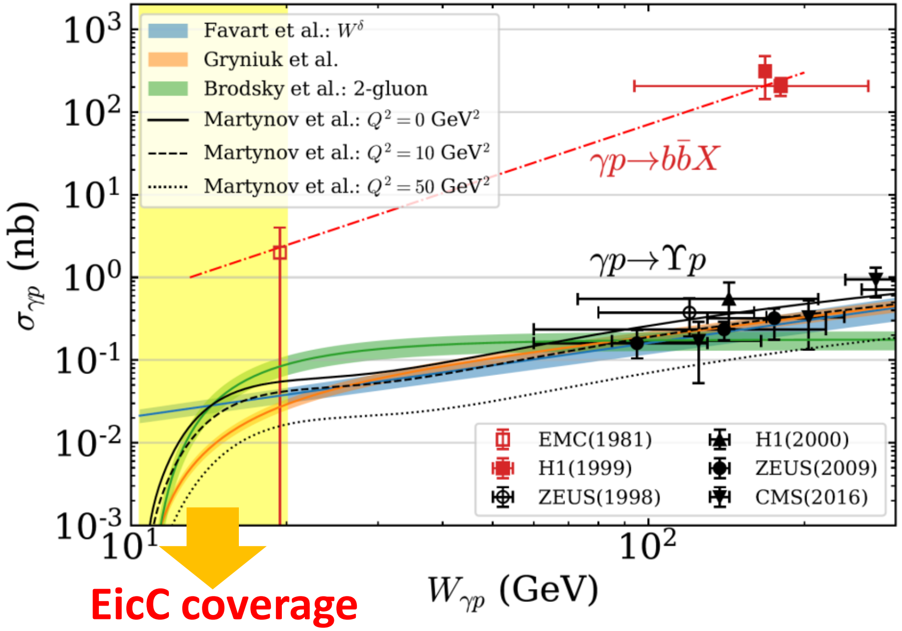
M_q : quark energy

M_m : quark mass (condensate)

M_g : gluon energy

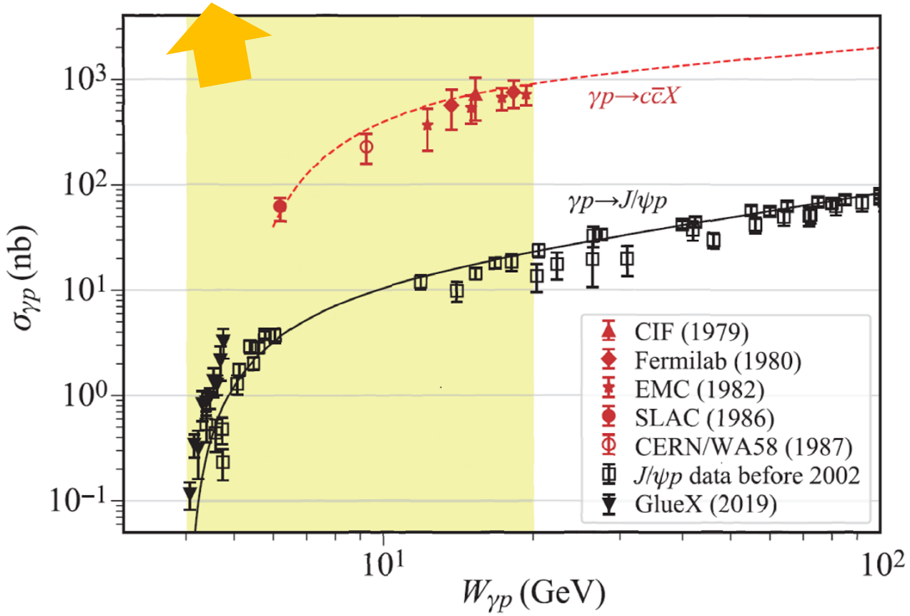
M_a : trace anomaly

- 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);



Upsilon production

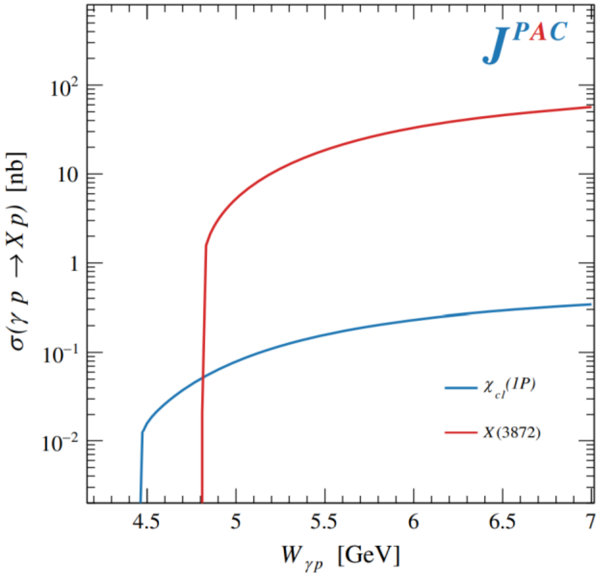
EicC coverage

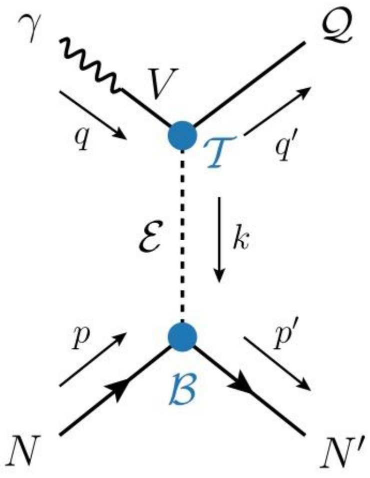


J/Psi production

➢Exotic hadronic states

- Search for hidden-charm pentaquarks P_c
  - So far observed only by LHCb
  - No signal in GlueX
- Search for hidden-charm tetraquarks Z_c
- Search for doubly-charmed tetraquark T_{cc} family



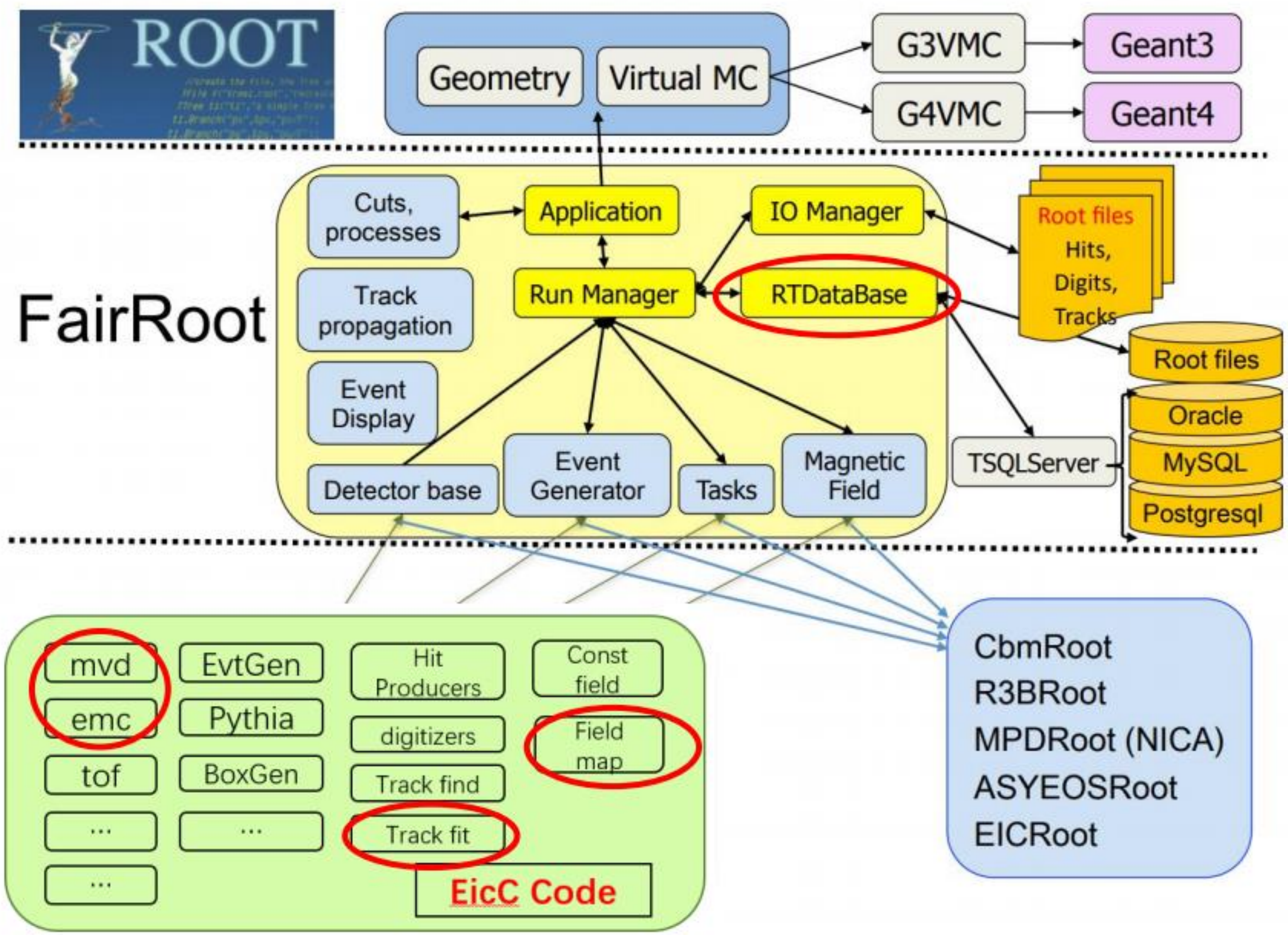


EicC 50/fb Z. Yang, F.-K. Guo, CPC45(2021)123101

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)	$ep \to eP_b$(narrow) P_b(narrow) $\to p\Upsilon$ $\Upsilon \to l^+l^-$	~30%	0–20
P_b(wide)	$ep \to eP_b$(wide) P_b(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

Software

➢EiccRoot in the FairRoot framework:



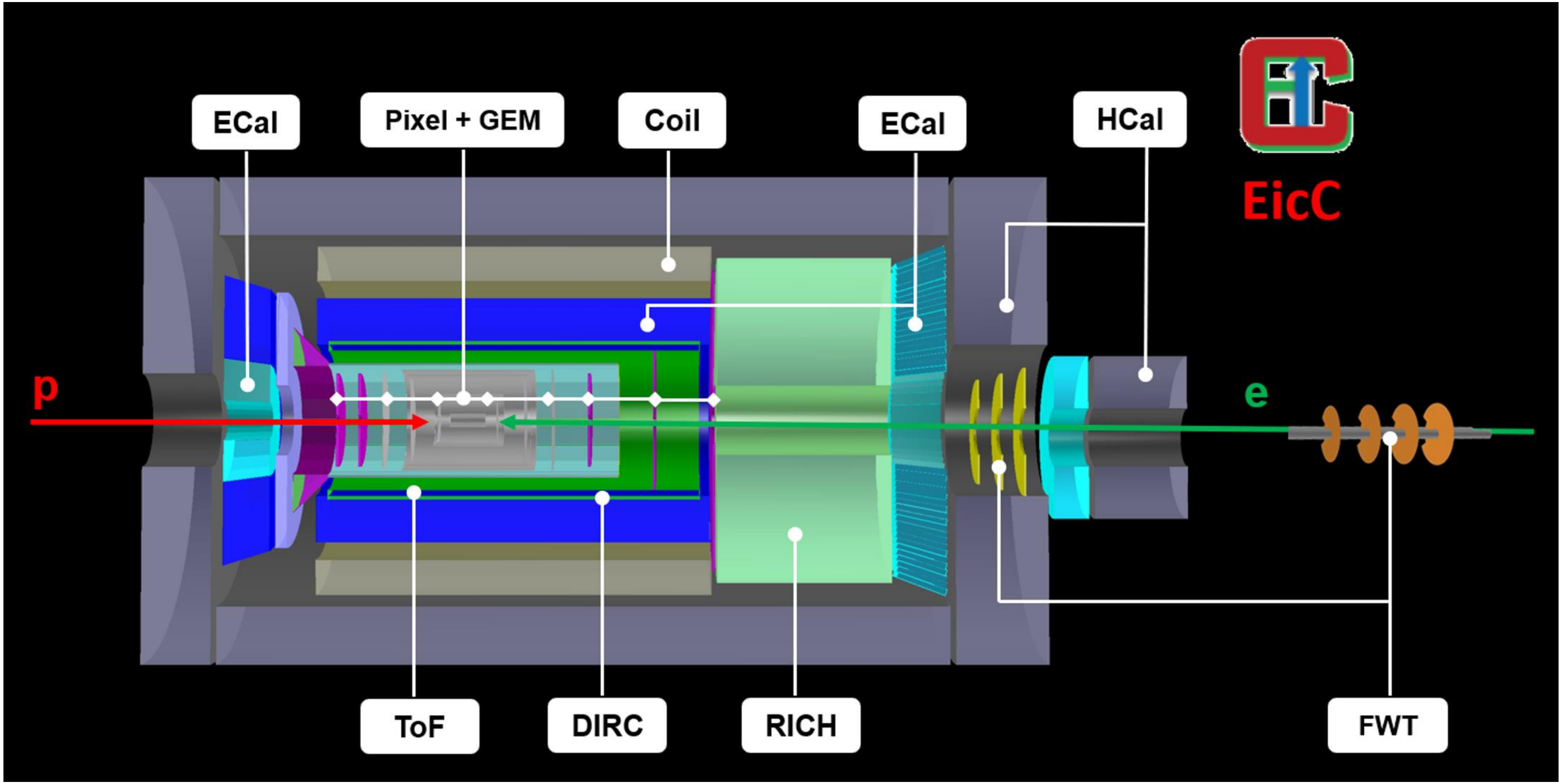
Top level: ROOT, Virtual MC, etc.

Middle level: FairRoot framework manages the general infrastructure with simulation and tasks

EiccRoot: implementation of the EicC detector sim. and rec. inside FairRoot framework

IP Detector Layout

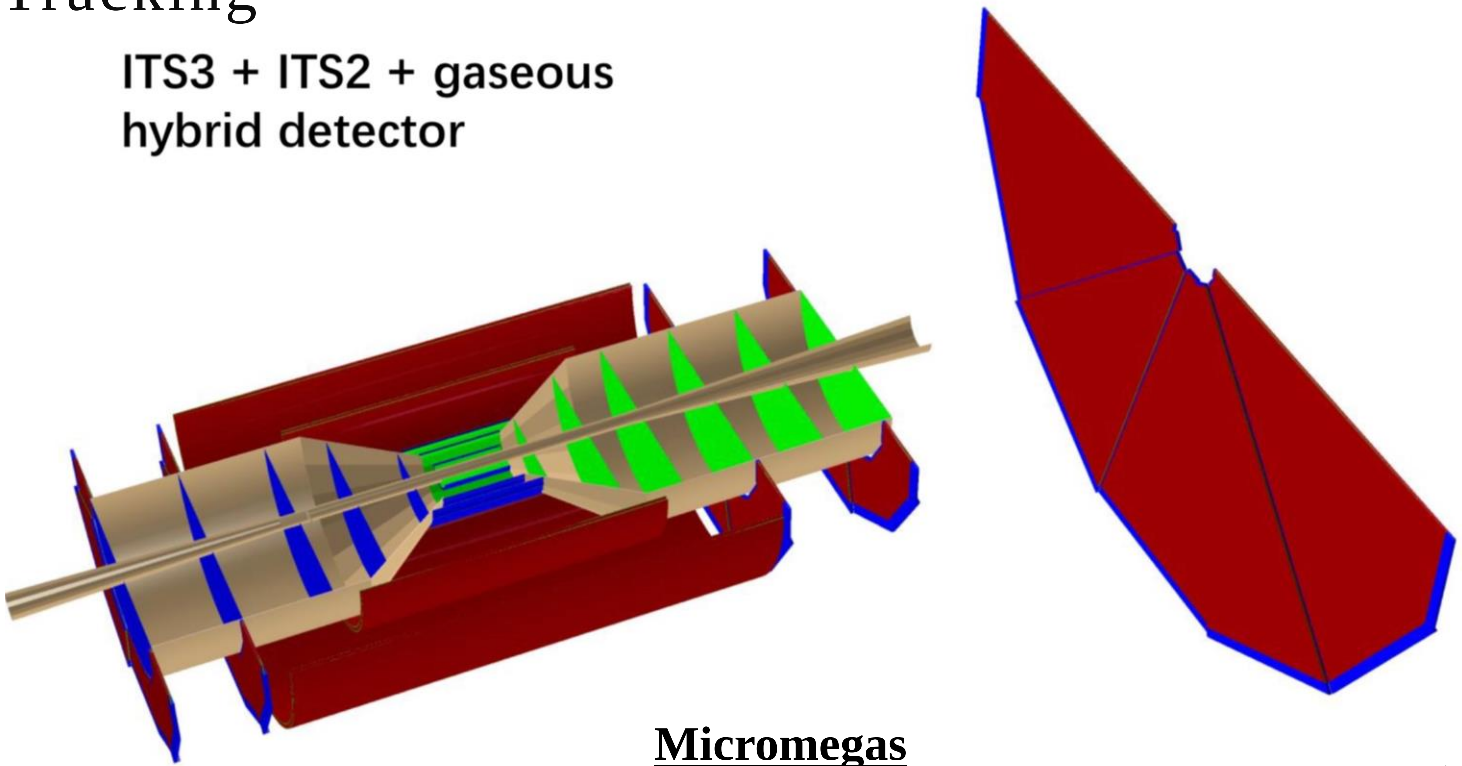
➢Very Preliminary Design: Ongoing full Geant4 simulation



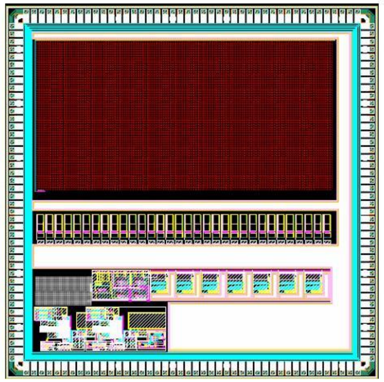
Detector Designs and R&D

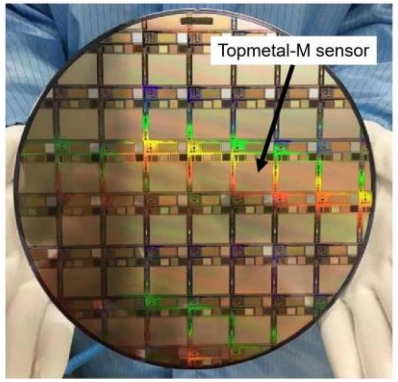
➢Tracking

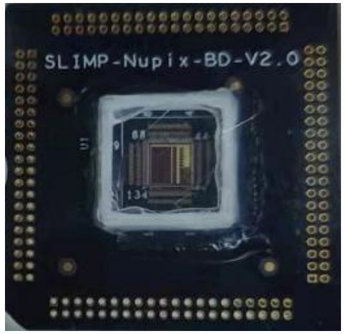
ITS3 + ITS2 + gaseous hybrid detector



Nupix-A1: First Protype MAPS in China

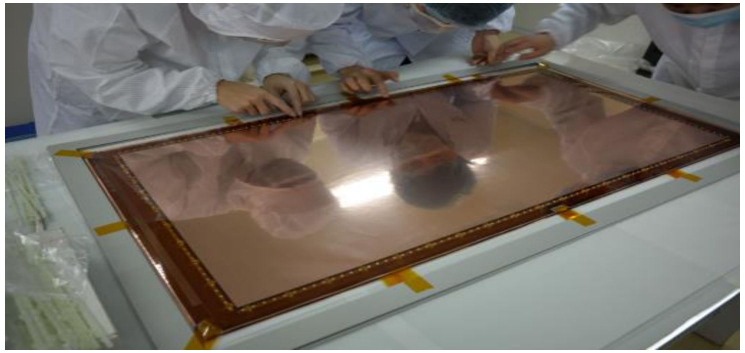




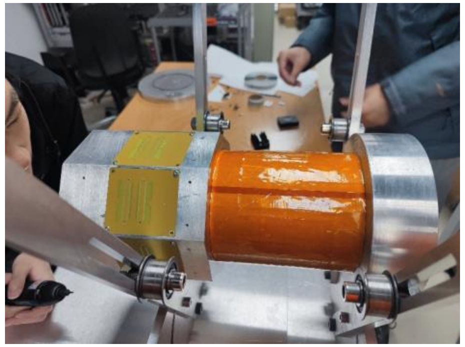


Micromegas

GEM (self-stretching)

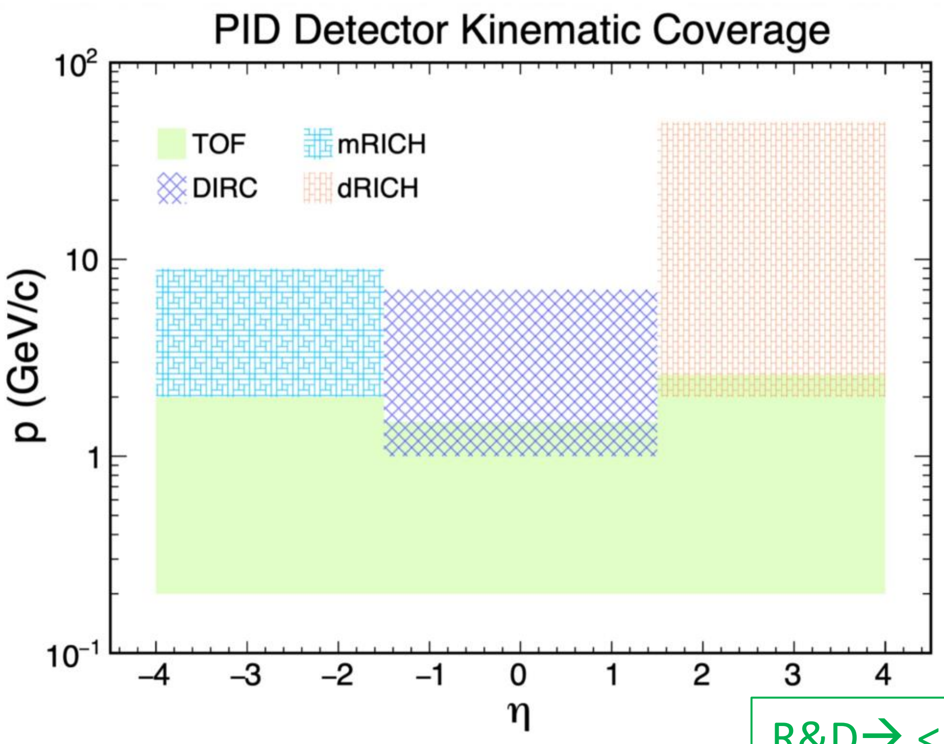


uRWELL



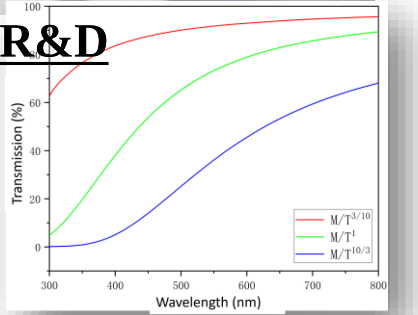
Detector Designs and R&D

➢PID



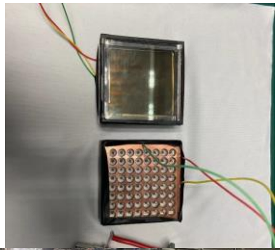
R&D→ < 20ps

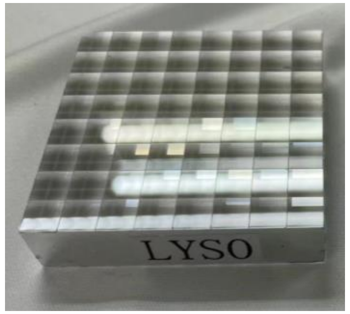
	AC-LGAD	MRPC	MCP
Timing resolution	30-50 ps	~50 ps	~50 ps
Spatial resolution	A few to hundreds μm	a few mm to 1 cm	1 mm
Overall thickness	2 cm	10 cm	2 cm
High B field tolerant	Yes	Yes	No
Cost	High	No	High

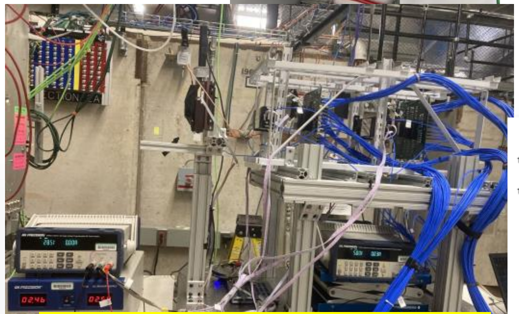


Aerogel R&D

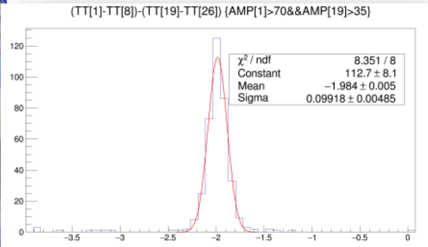
MCP+LYSO





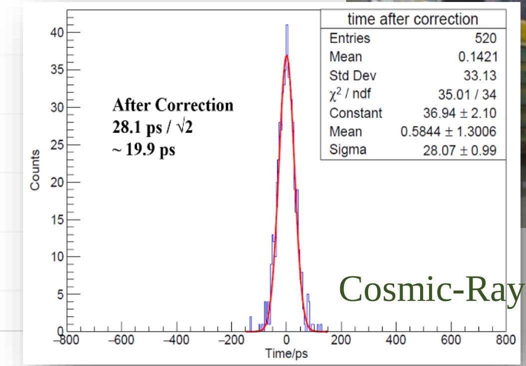


MCP+LYSO Beam Test at FermiLab

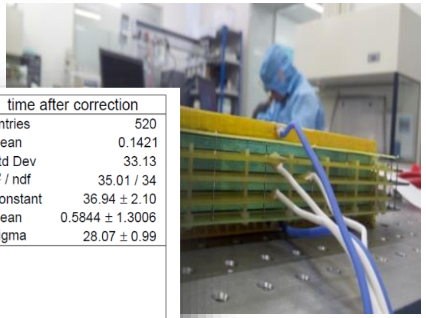


Prelim:<100ps

MRPC



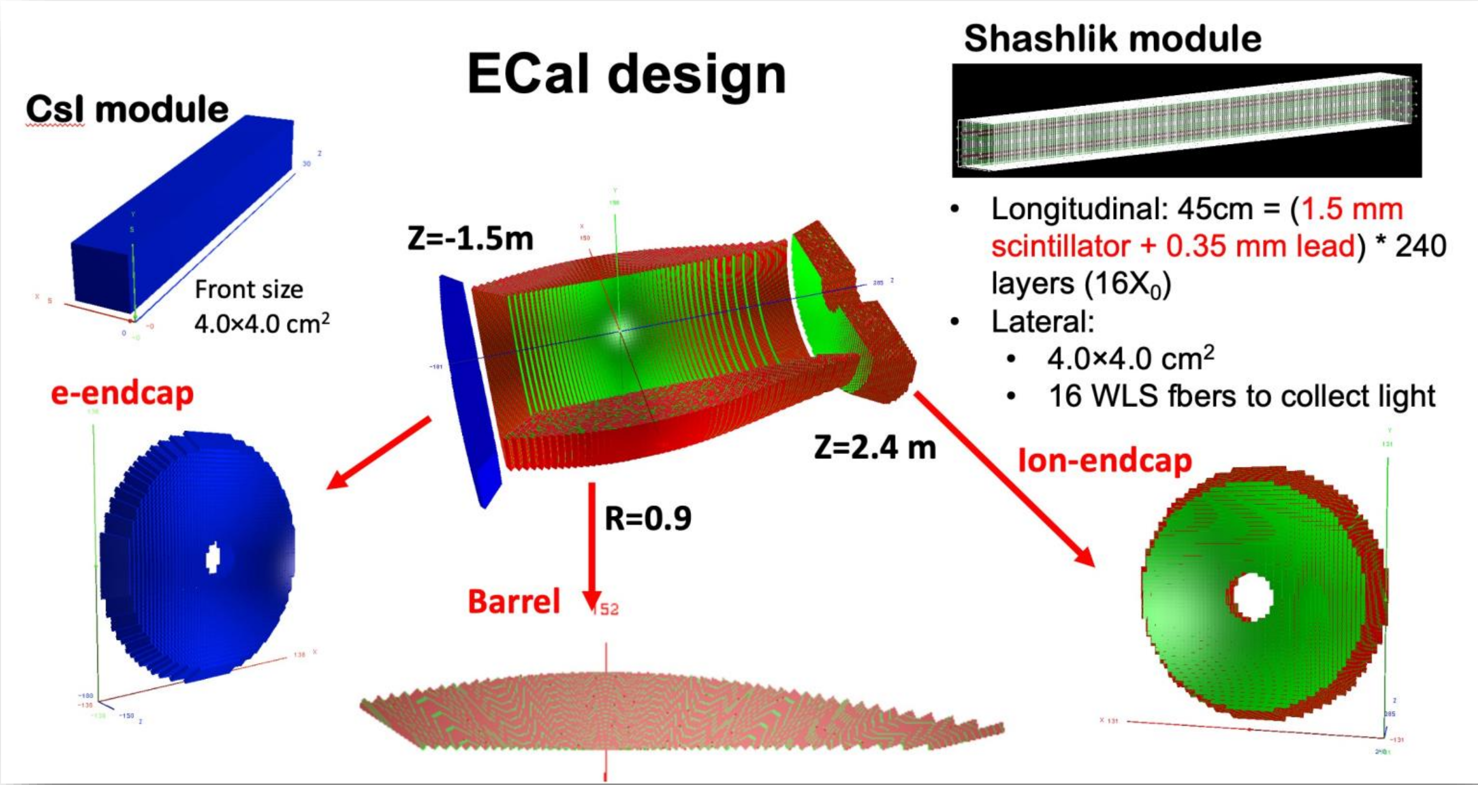
Cosmic-Ray~20ps



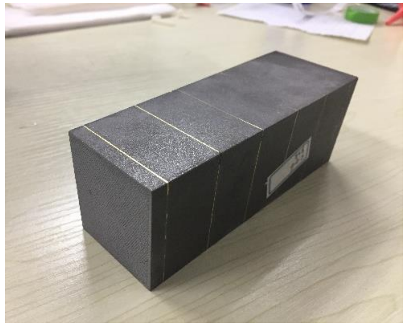
Sealed MRPC Beam Test at FermiLab

Detector Designs and R&D

➢Calorimeters

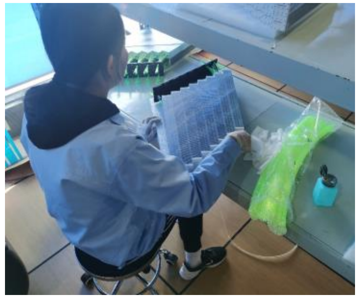


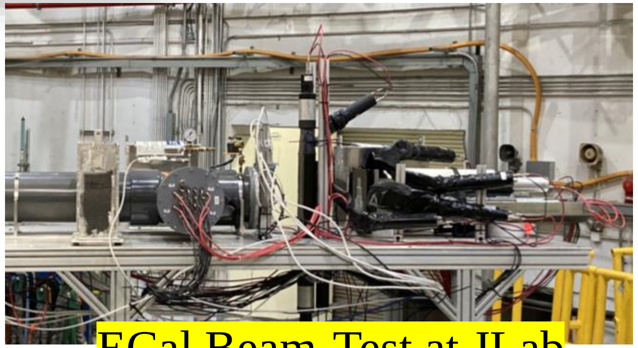
W-Powder+ScFi



Shashlyk ECal

Strong mass production capability

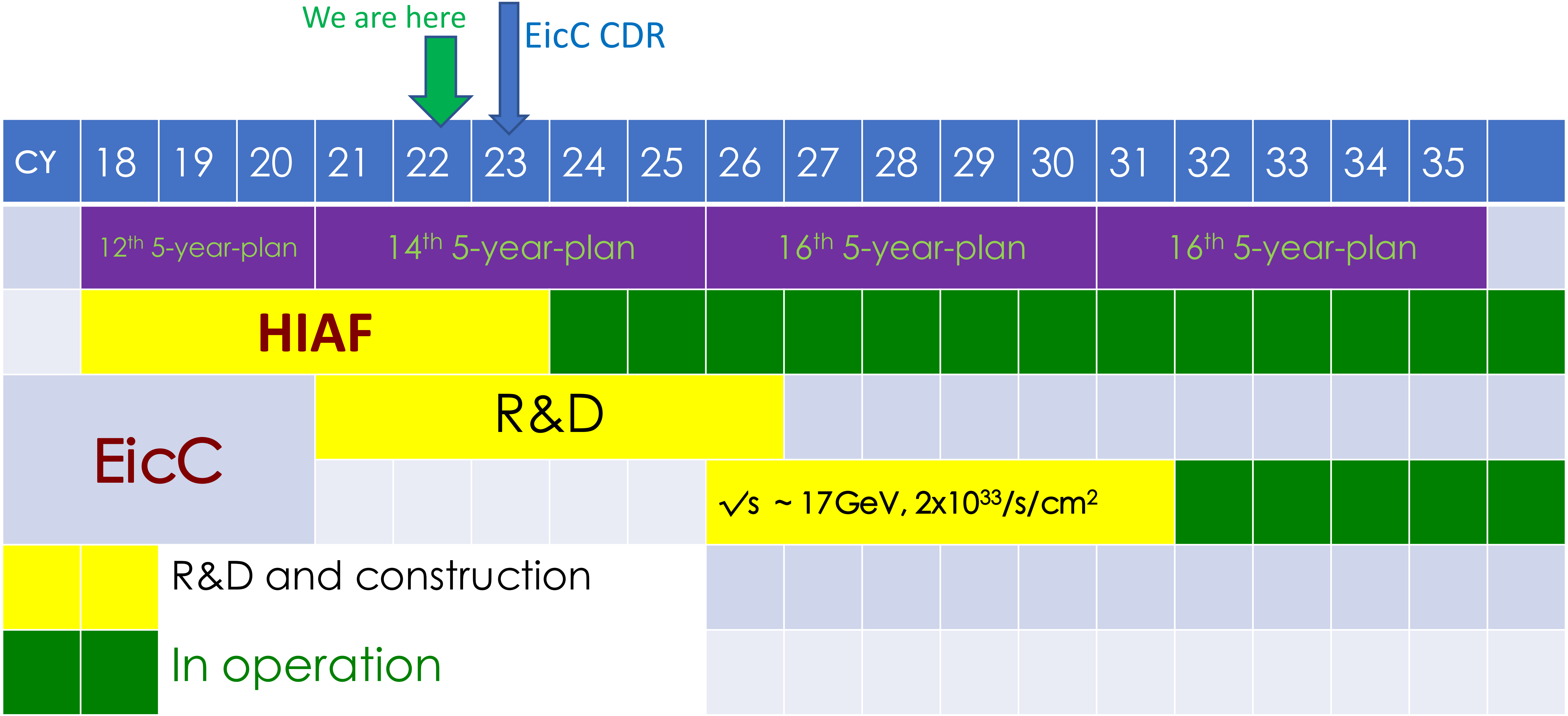




ECal Beam-Test at JLab

Front End Board for SiPM-based Ecal

Projected Timeline



Collaboration

➢An International Effort:

EicC Current Collaborators:

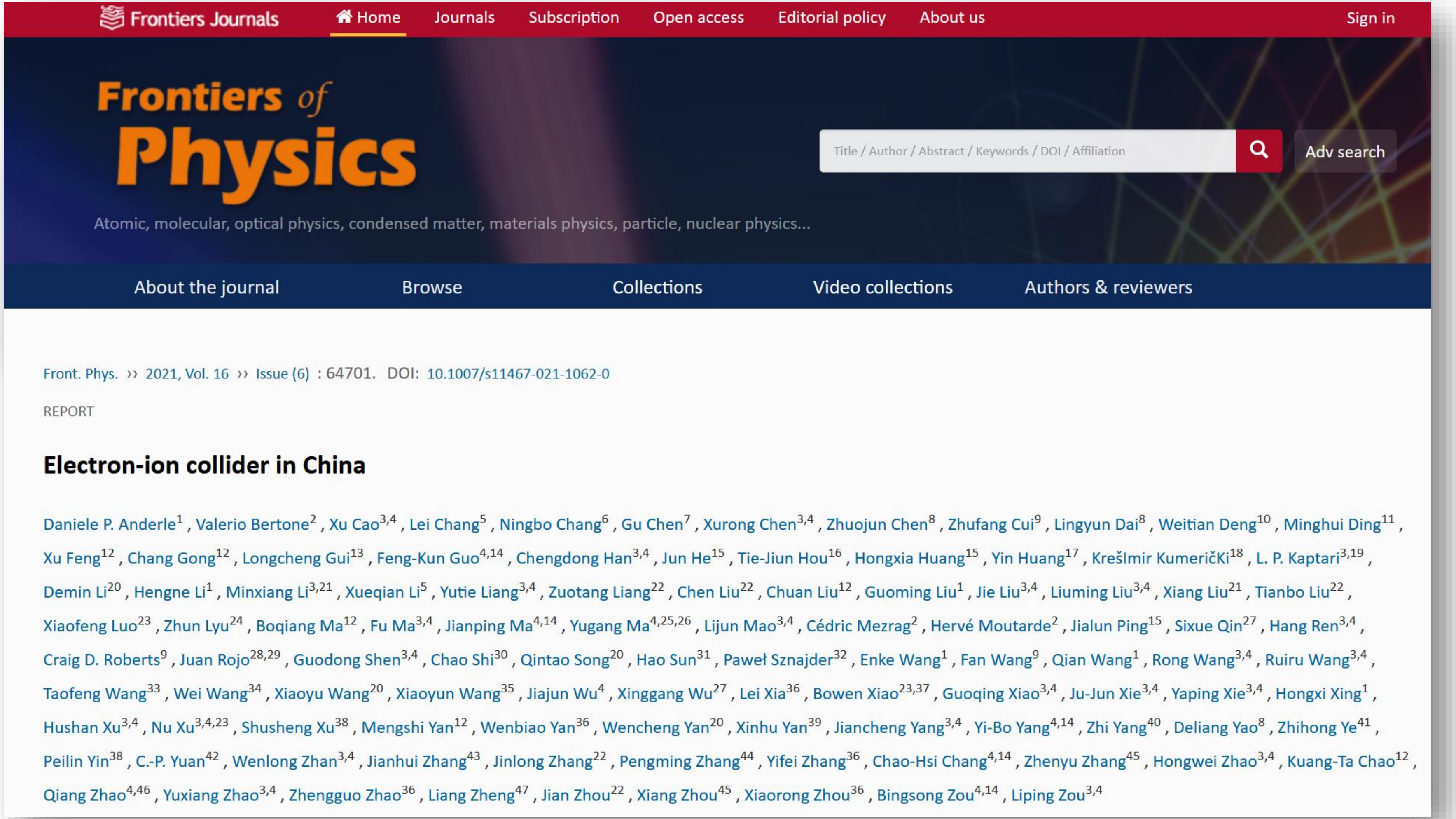
- 102 scientists
- 47 institutes
- 8 countries

EIC User Group:

- 1330 members
- 266 institutions
- 36 countries (7 world regions)

➢ Need strong supports from international collaborators!

EicC White Paper (arXiv: 2102.09222)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REPORT

Electron-ion collider in China

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Summary

- HIAF is under construction → Day#1 experiment in 2025
- From HIAF to EicC → Complementary to JLab@12GeV and US-EIC
  - Add new electron Injector and collider rings
  - White-Paper released in 2021
  - CDR in 2023 → Aim for 15^{th} "5-year-plan" (construction in 2026~2030)
  - Active physics simulations, accelerators & detectors R&D

- Existing Experience & Expertise:
  - ✓ Accelerator: good in ion beams; limited in electron beams & polarizations
  - ✓ Theory: strong in hadron spectroscopies & nuclear medium; accumulating in hadron-structure
  - ✓ Experiment: good in tracking/calorimeters; enhancing other detector technologies
  - ✓ Participating in and learning form US-EIC project

EicC will be an international facility →Welcome to join and build together!

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J/Psi production at EicC

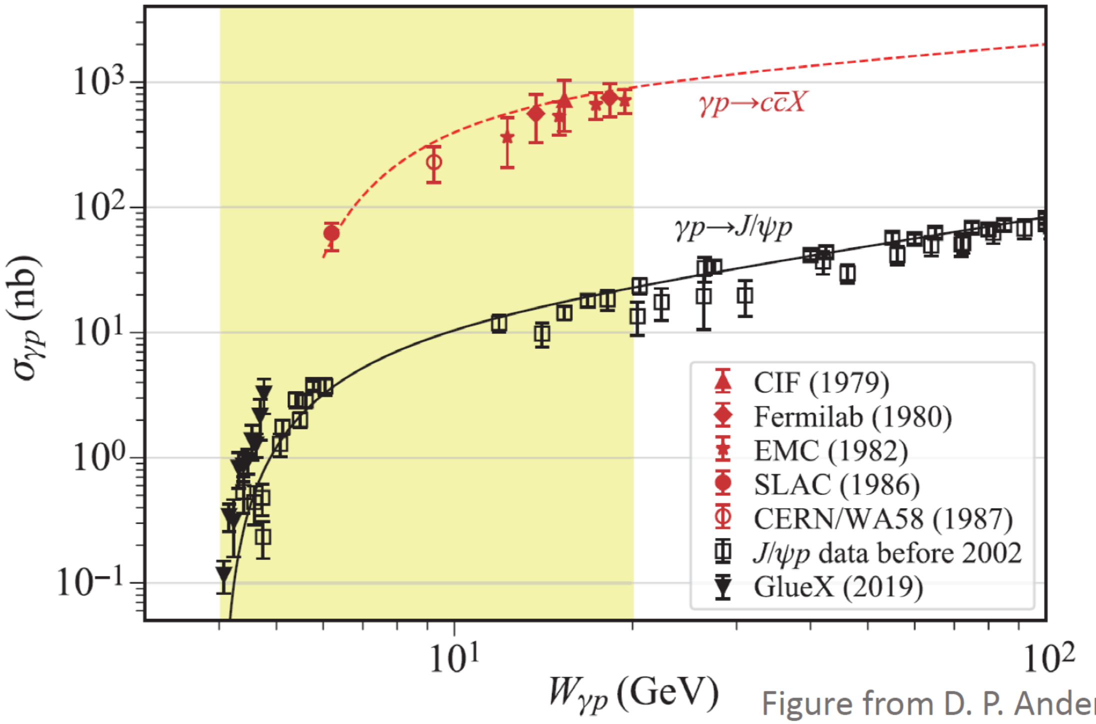


Figure from D. P. Anderle et al. Front.Phys.16(2021)64701

For W=10-20 GeV,

- Photoproduction: $\sigma(\gamma p \to J/\psi p) \sim O(10\text{ nb})$, (no resonant enhancement considered), $\sigma(\gamma p \to c\bar{c}X) \sim 50\sigma(\gamma p \to J/\psi p)$
- Leptoproduction: cross sections are roughly two orders of magnitude (α) smaller
- For an integrated luminosity of 50 fb^{-1}, no. of J/ψ is $\sim O(10^7 - 10^8)$; many more open-charm hadrons D and Λ_c

Upsilon production at EicC

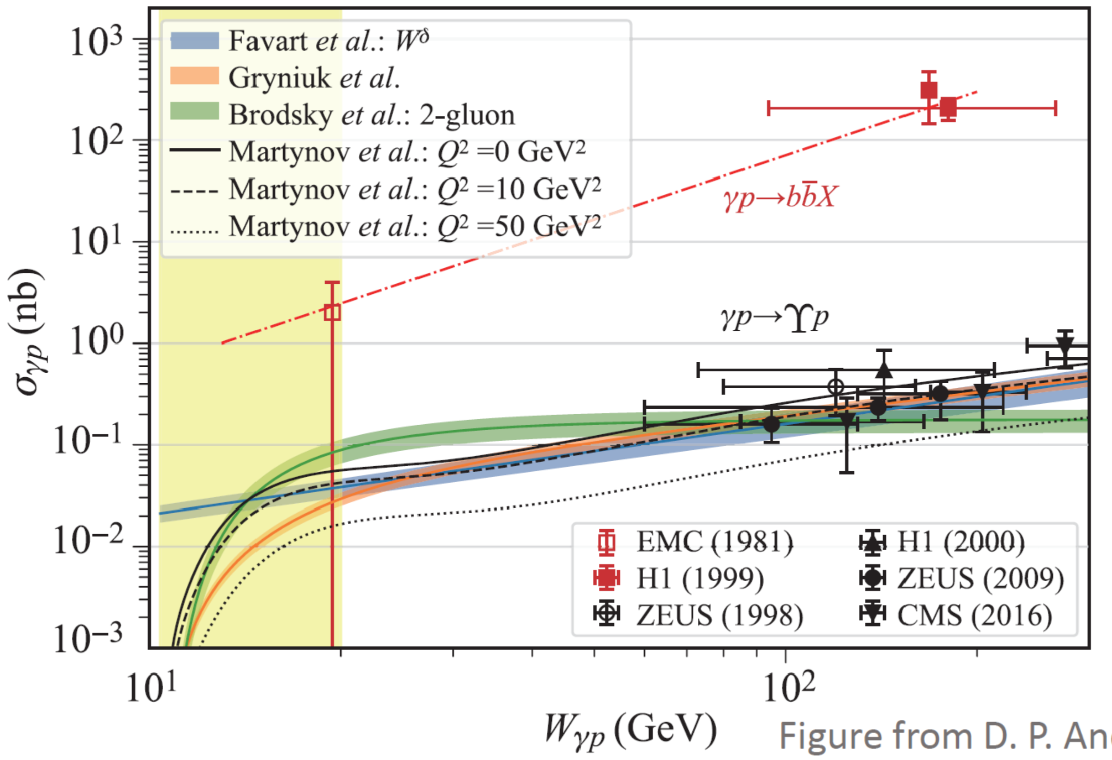


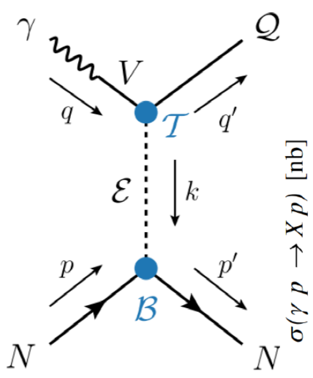
Figure from D. P. Anderle et al. Front.Phys.16(2021)64701

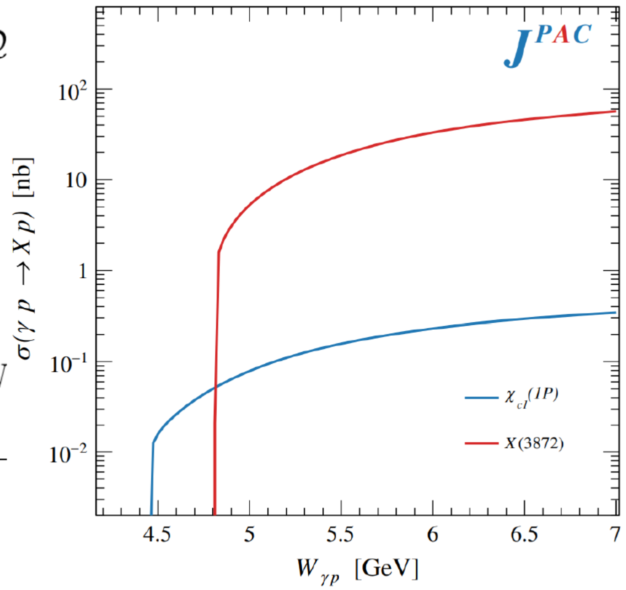
For W=15-20 GeV,

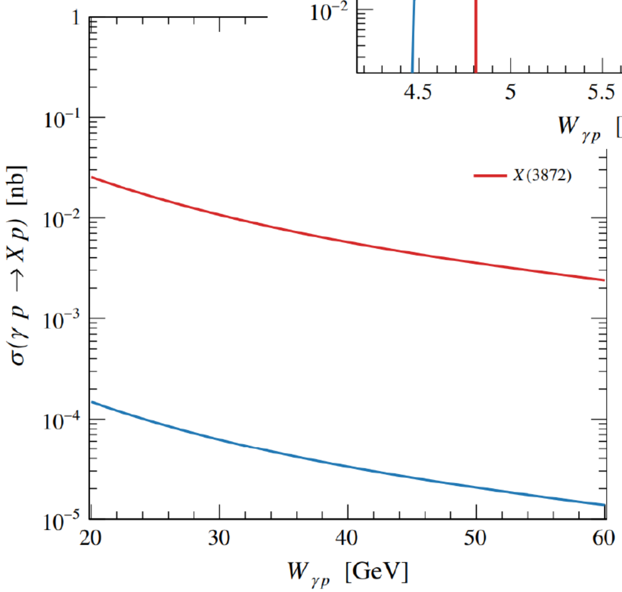
- Photoproduction: $\sigma(\gamma p \to \Upsilon p) \sim O(10\text{ pb})$ (no resonant enhancement considered), $\sigma(\gamma p \to b\bar{b}X)$ is about two orders higher
- Electroproduction: roughly two orders of magnitude (α) smaller, $\sim O(0.1\ pb)$
- For an integrated luminosity of 50 fb^{-1}, no. of Υ is $\sim O(10^4)$;

Exotic states production at EicC

- Cross section estimates for exclusive reactions assuming VMD (highly model-dependent)







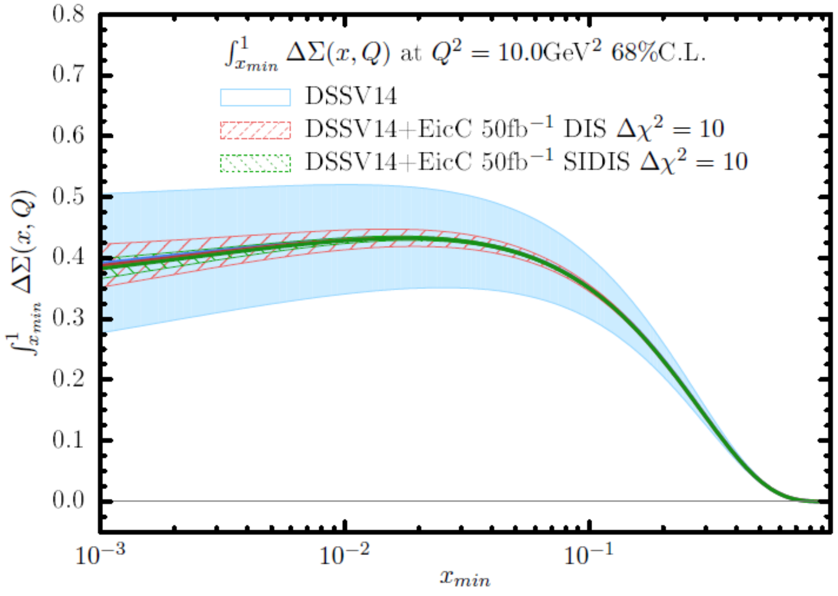
JPAC, PRD102(2020)114010

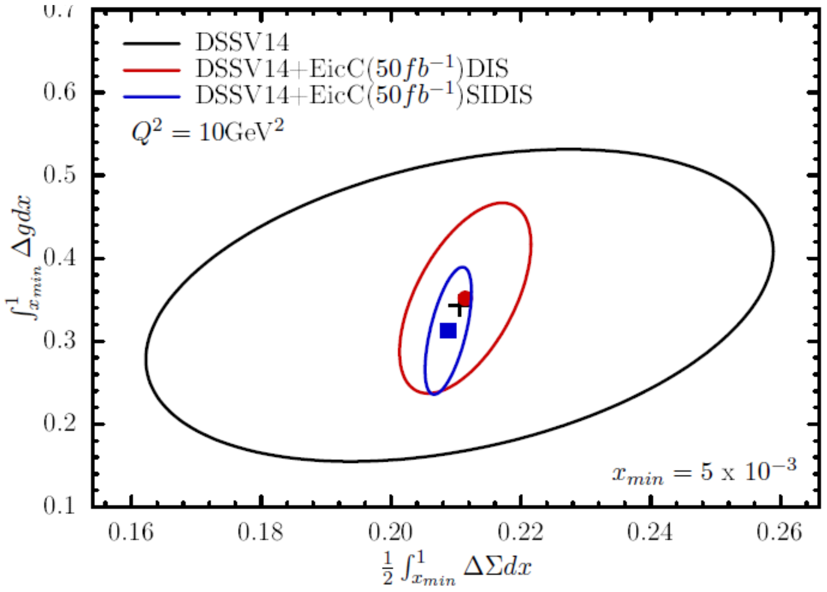
➢ Estimated events for EicC (50 /fb)

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)	$ep \to eP_b$(narrow) P_b(narrow) $\to p\Upsilon$ $\Upsilon \to l^+l^-$	∼30%	0−20
P_b(wide)	$ep \to eP_b$(wide) P_b(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

Highlighted physics topics

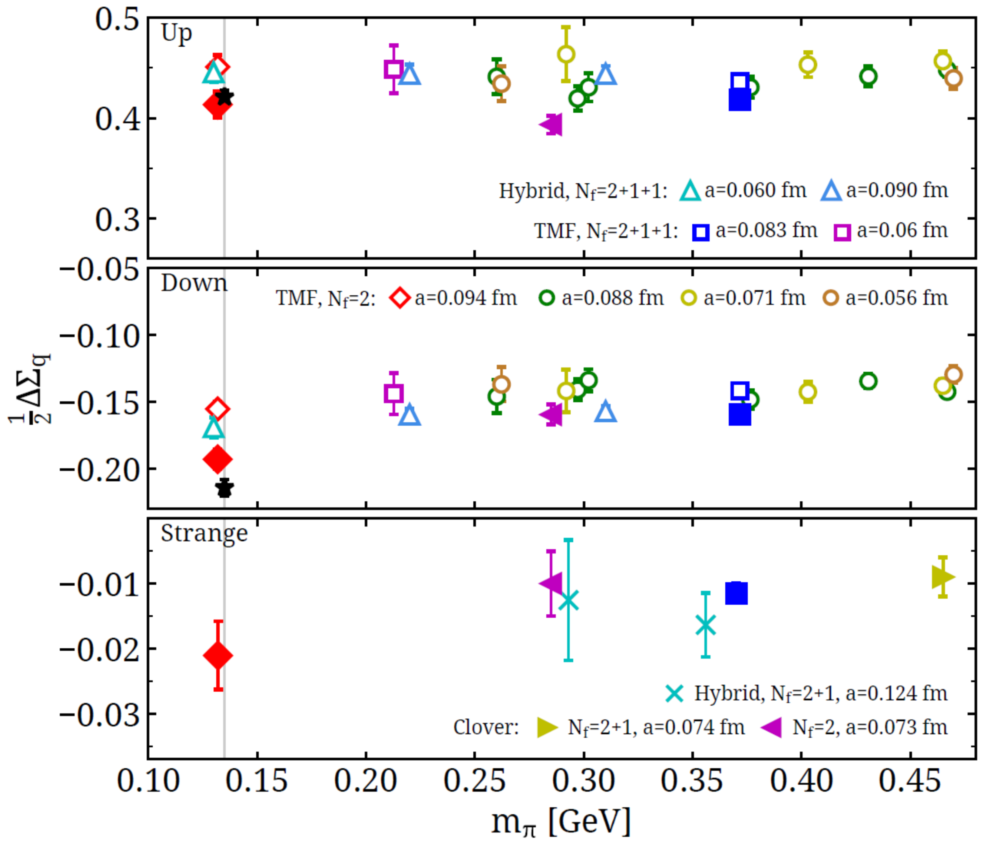
- Quark/gluon spin contributions to the





Lattice QCD simulations

PRL119.142002, 2017



Also, LQCD is able to do quasi-PDF calculations