Overview of EicC

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Outline

- Introduction
- EicC physics
- Detector design
- Accelerator design
- Summary

Development in China-HIAF&EicC

EicC

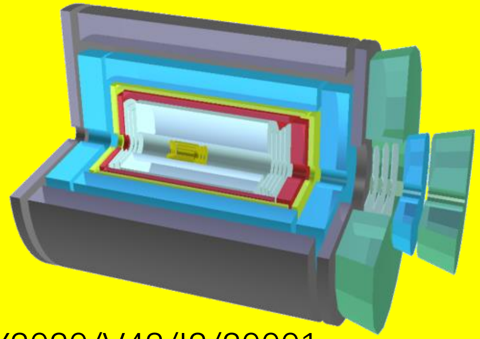
2012:Discussion in community

2020.2,2021.6:white paper(CN,EN)

2021-2024:CDR

(213 authors from 69 institutes)

As part of the long-term planning project for major scientific and technological infrastructure in particle physics and nuclear physics, the project has undergone two international expert reviews and one domestic expert review.



http://www.j.sinap.ac.cn/hjs/CN/Y2020/V43/I2/20001
https://journal.hep.com.cn/fop/EN/10.1007/s11467-021-1062-0

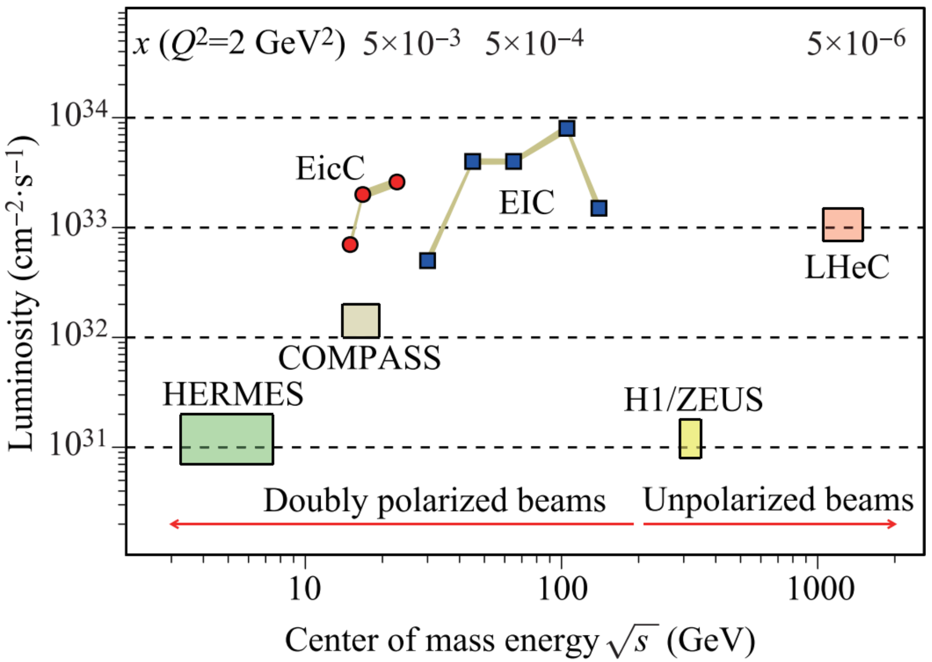
EicC's advantages (to EIC-US):

1) The energy is in the sea quark region, closer to nuclear physics
2) Nearer to the threshold for the production of heavy quarkonium

HIAF:

Completed by the end of 2025, it will provide the world's highest-intensity pulsed heavy ion beams, creating unique conditions for the construction of the EicC

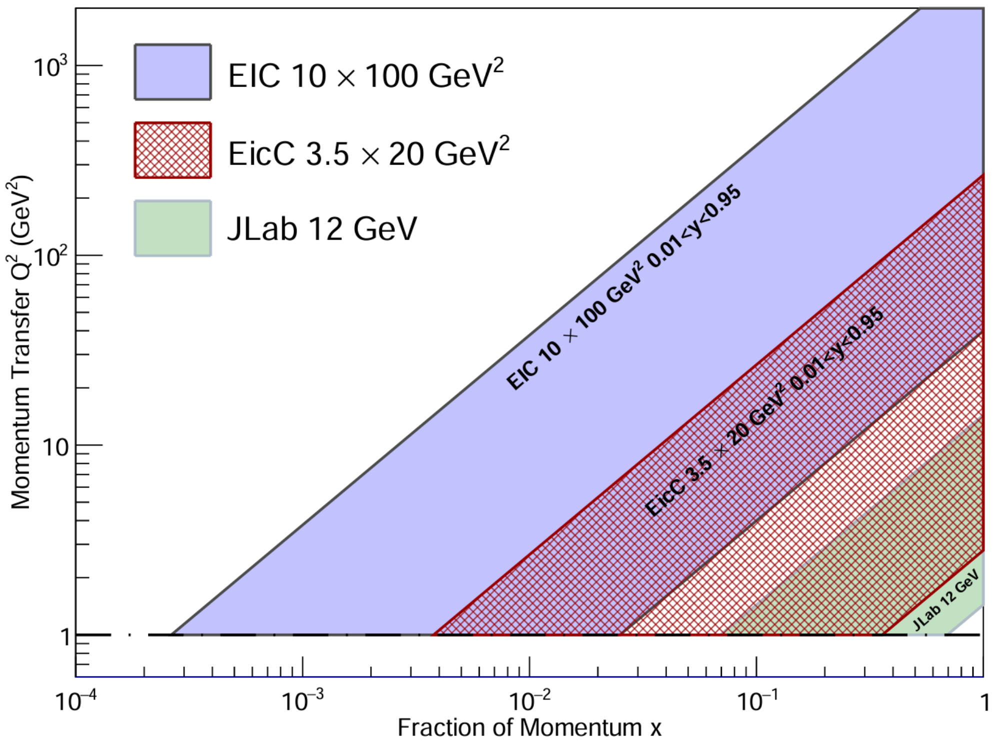
Machine Kinematics



Facilities	Main goals
JLab 12 GeV	Valence quark
EicC	Valence and Sea
US and Europe EIC	gluon

EicC, √s : 15 ~ 20 GeV

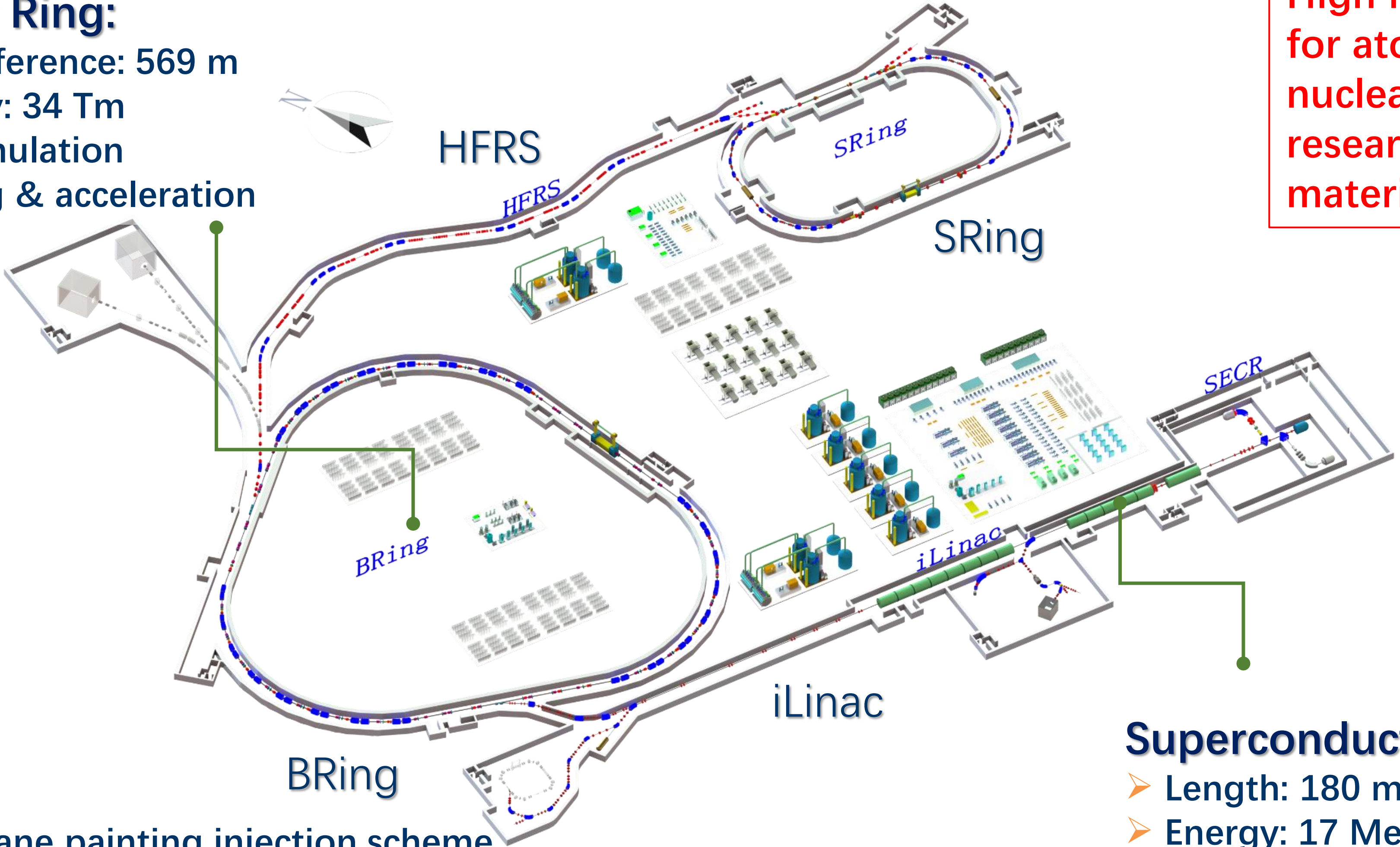
1) The energy is in the sea quark region, closer to nuclear physics
2) Nearer to the threshold for the production of heavy quarkonium



High Intensity heavy-ion Accelerator Facility (HIAF)

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

High intensity ion beams 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

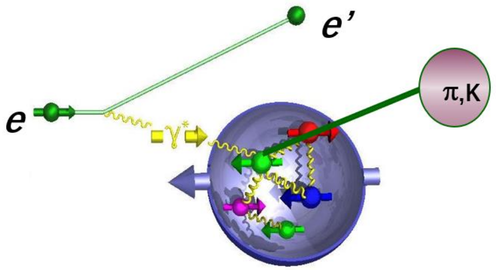
EicC accelerator complex overview

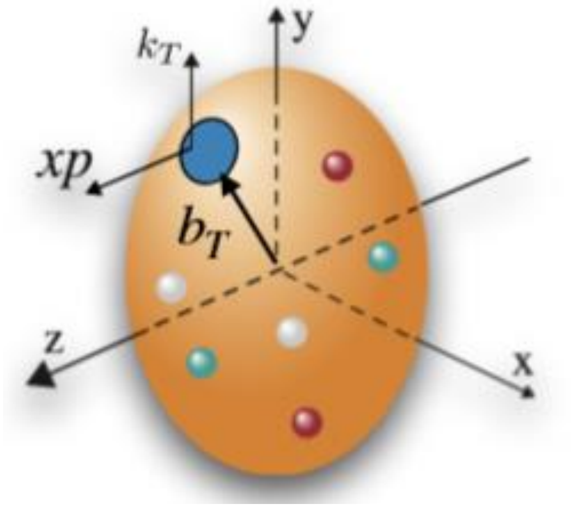
- 20 GeV p + 3.5 GeV e
- $\sqrt{S}$: 16.7GeV
- High Lumi.:

  2-4 x10^{33} cm^{-2}s^{-1}
- Polarized beams

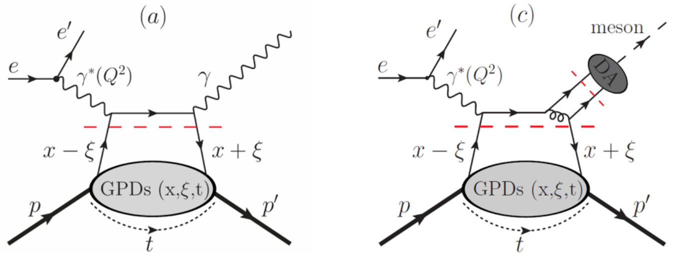
EicC Physics

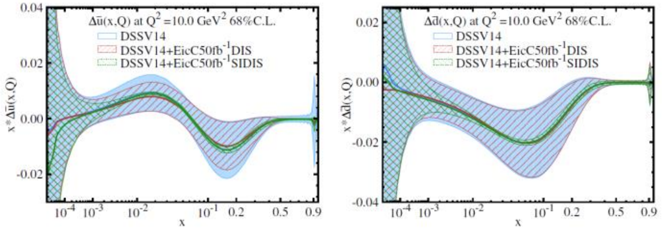
(Semi)-Inclusive DIS

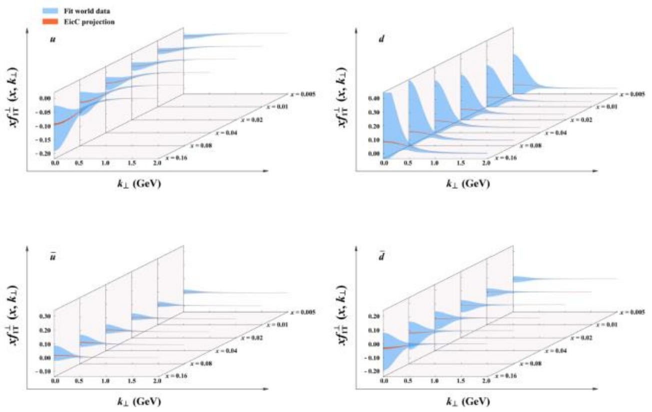




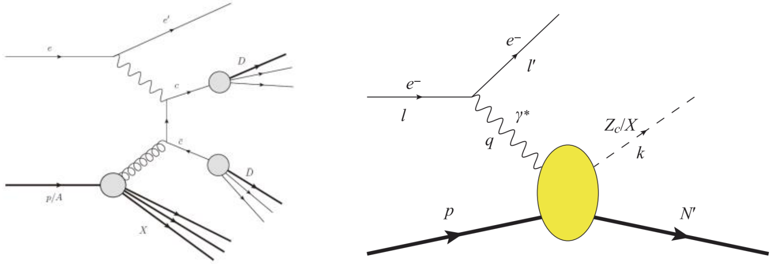
Exclusive process

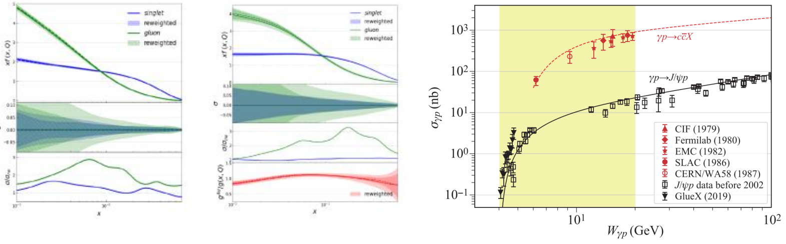


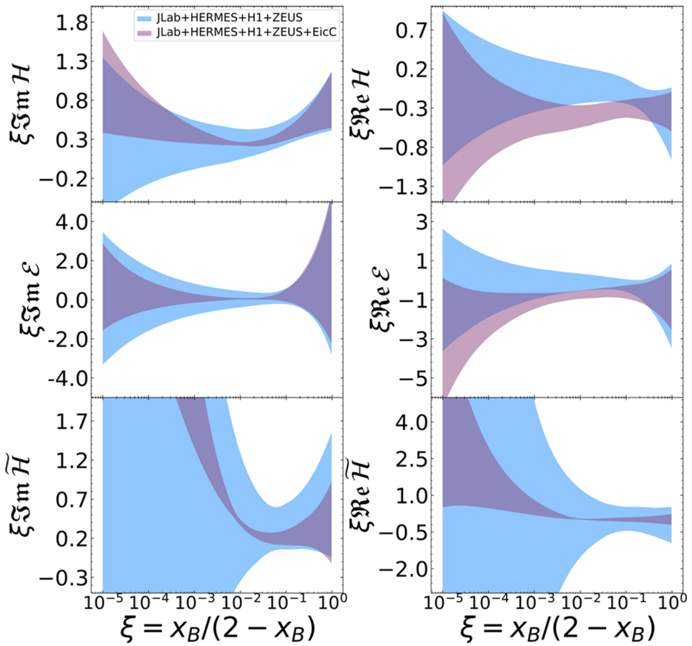




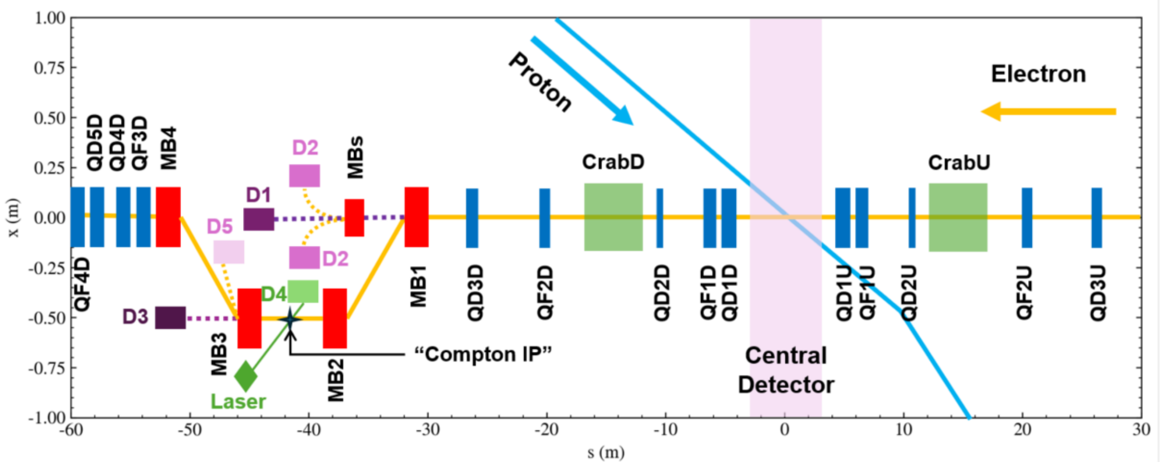
Heavy flavor

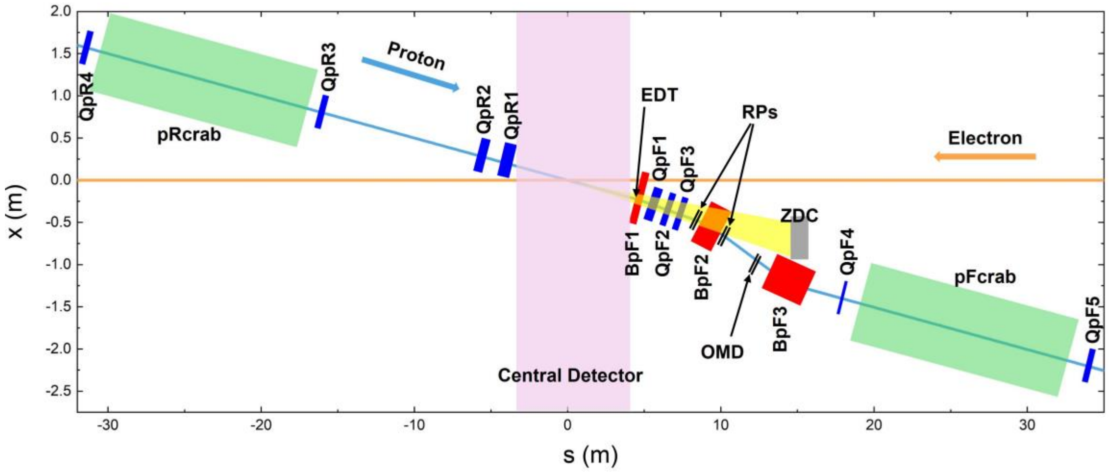






EicC Detector

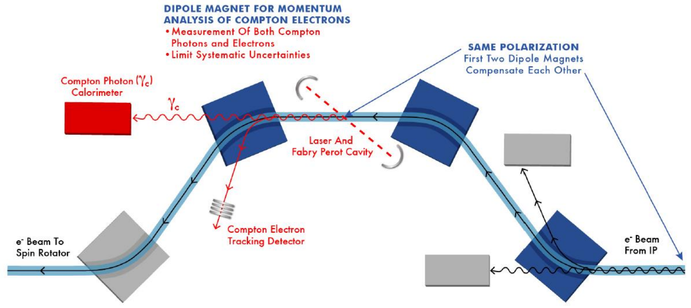


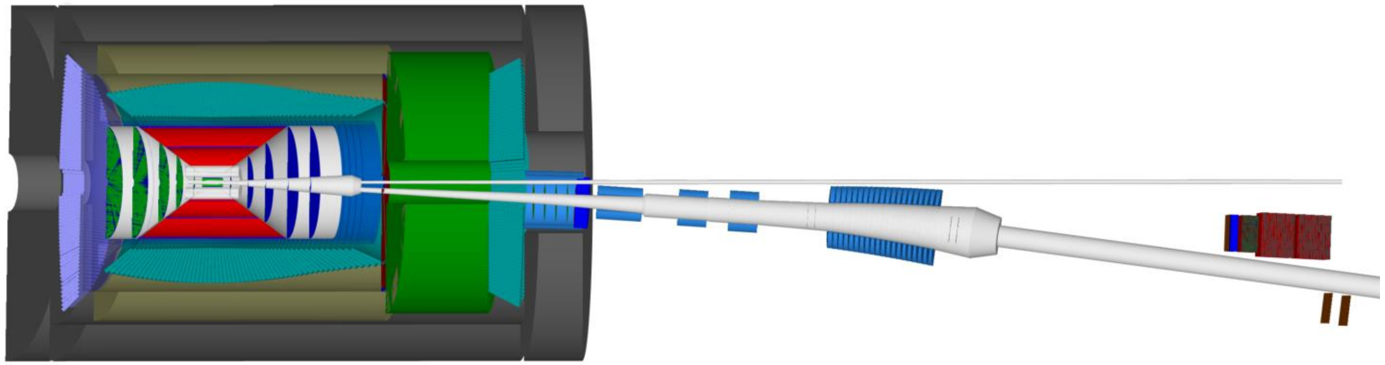


e far-forward detectors

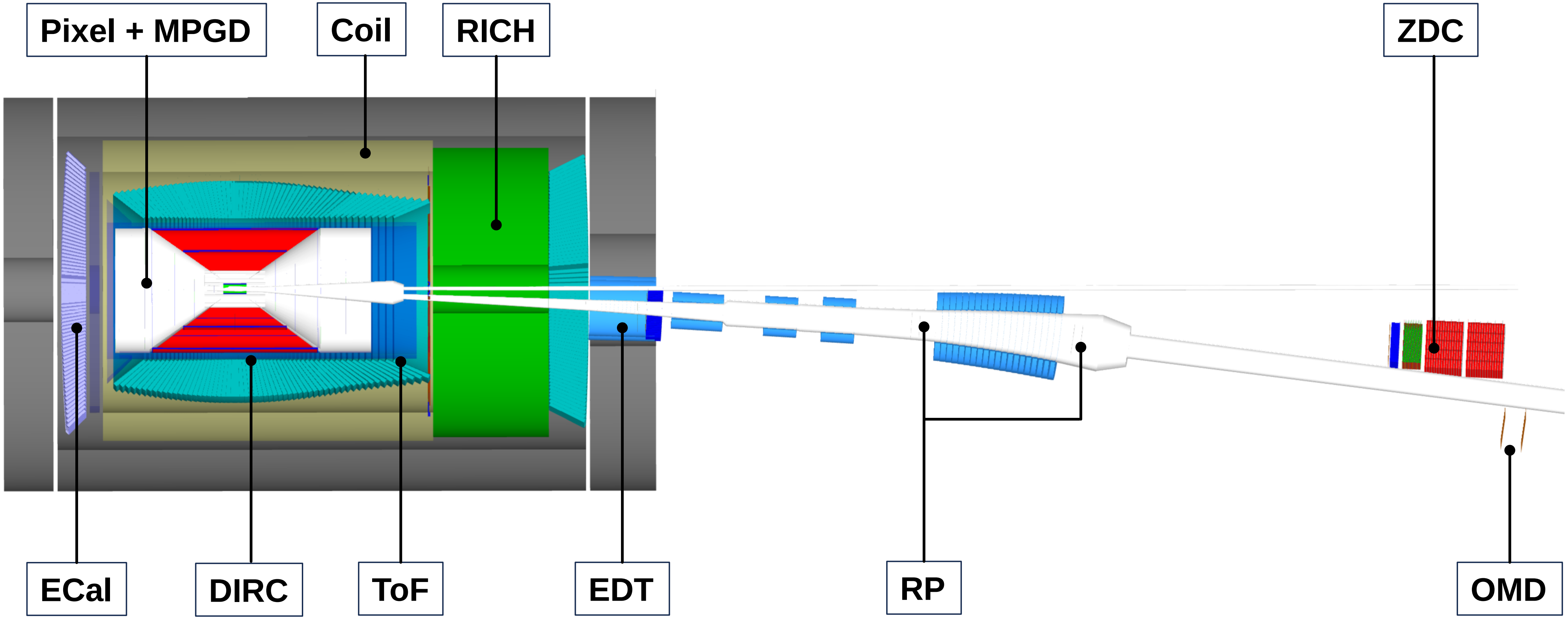
Central detector

Ion far-forward detectors

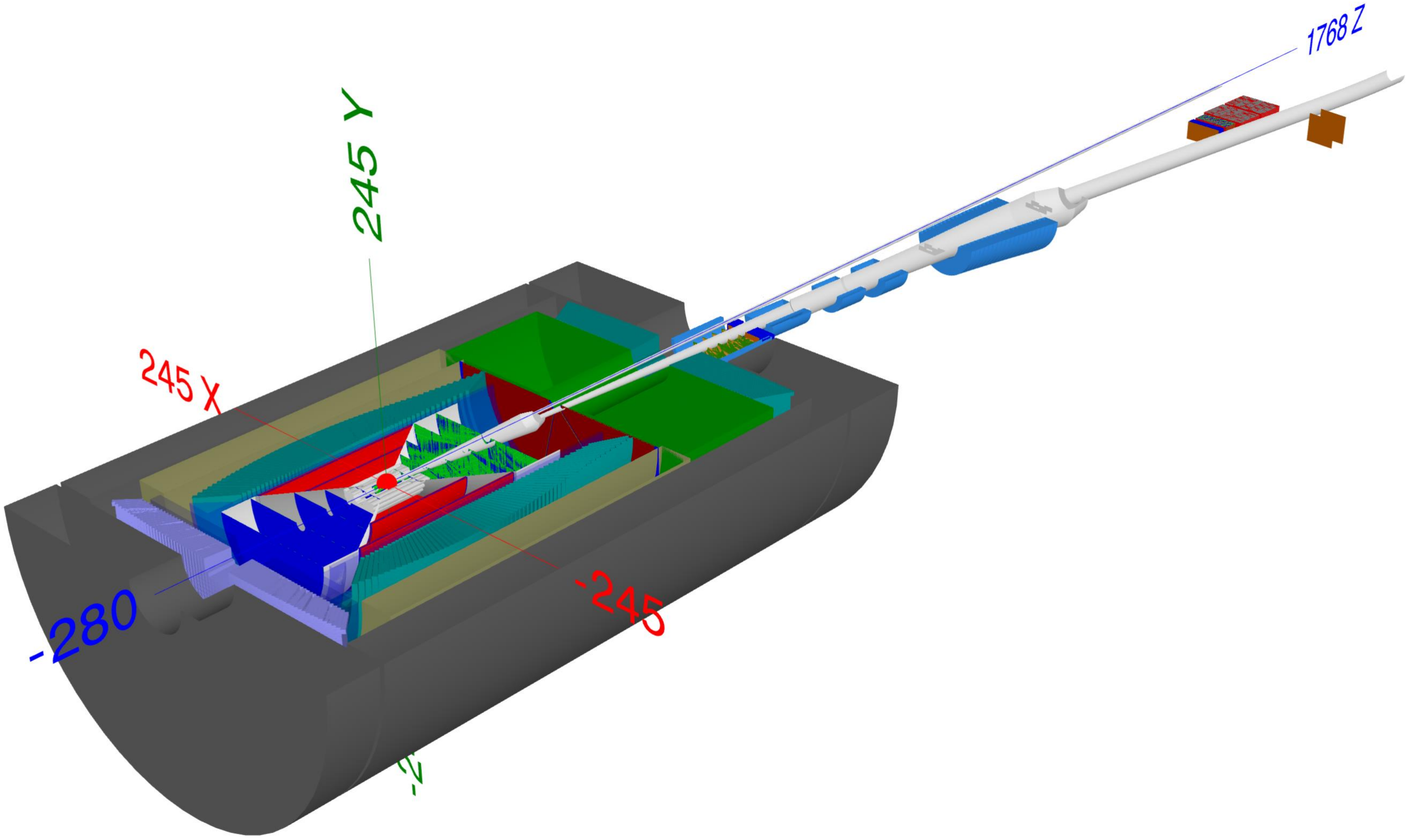




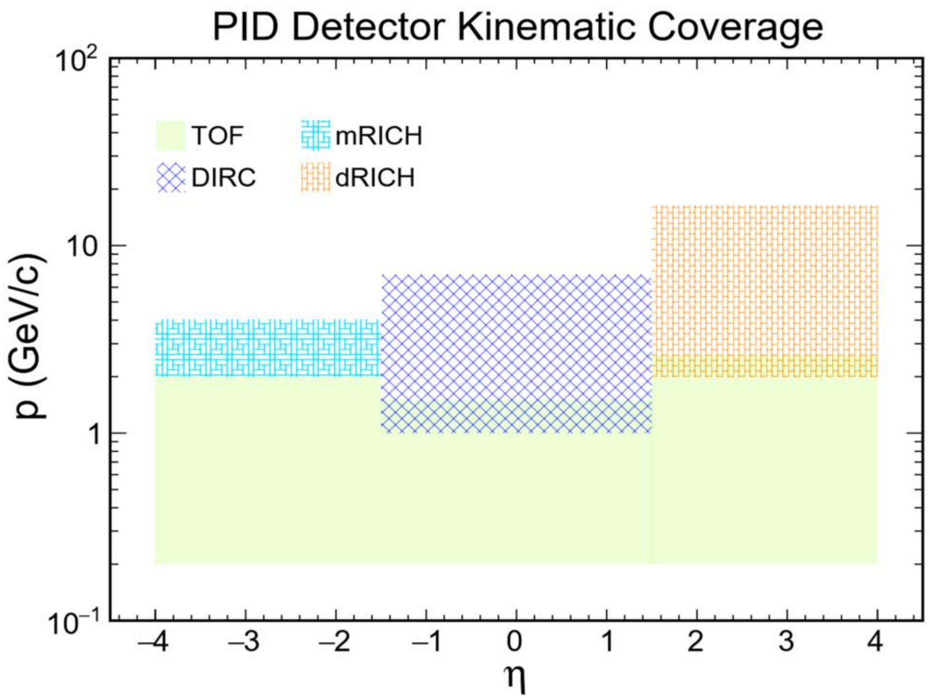
EicC Detector (central + ion far-forward)



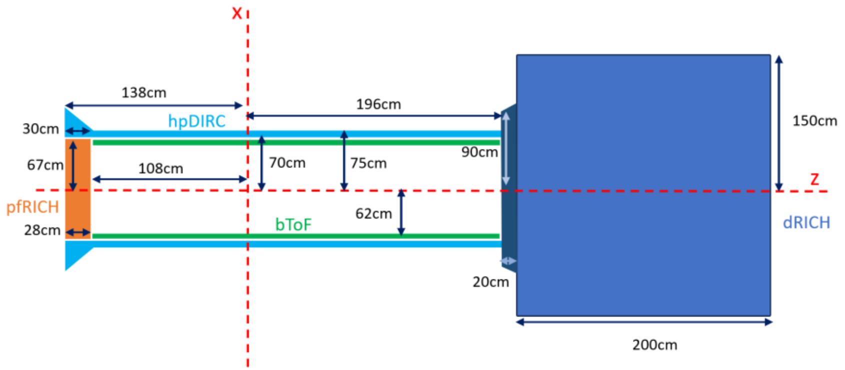
EicC Detector (central + ion far-forward)

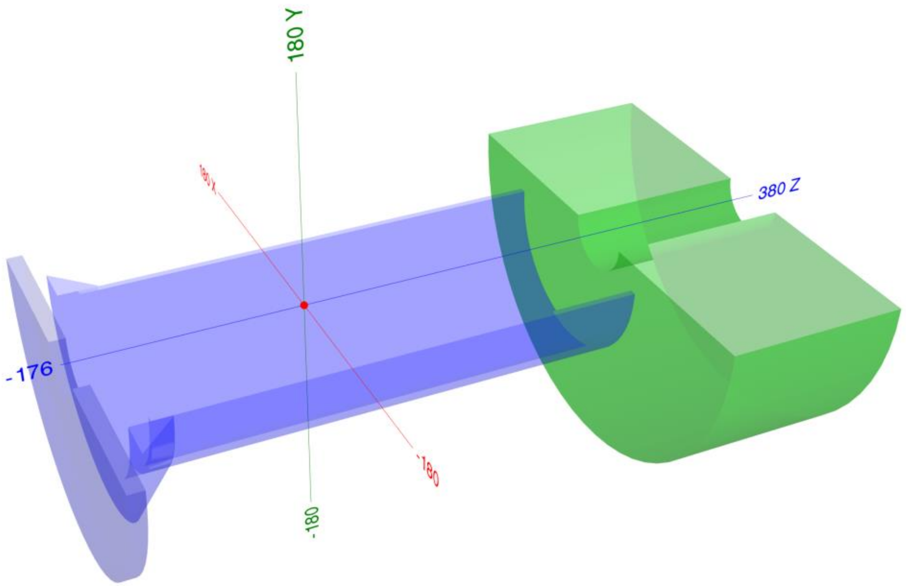


PID detectors

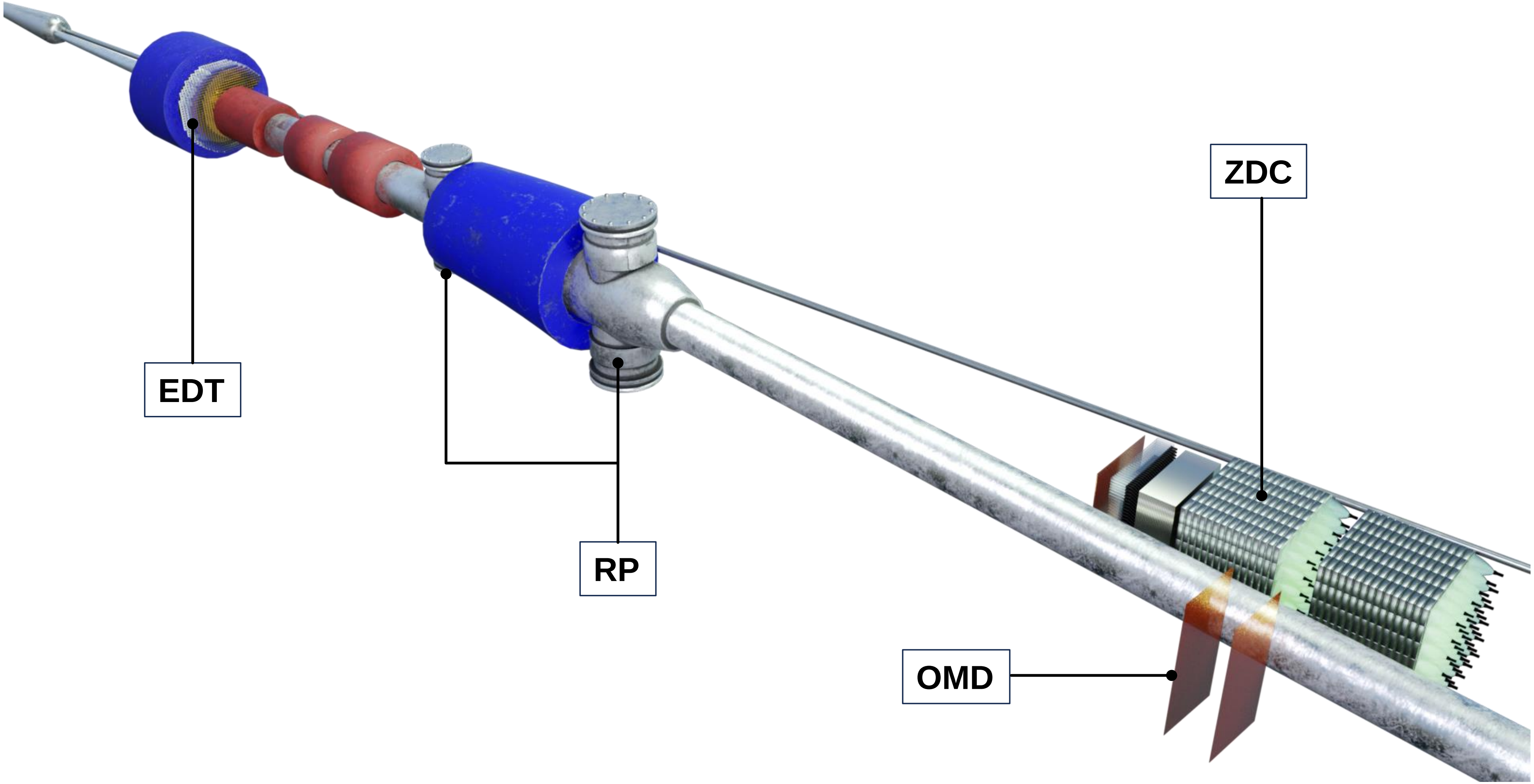


- TOF based (low p)
  - MRPC
  - LGAD
- Cherenkov based (high p)
  - DIRC
  - RICH



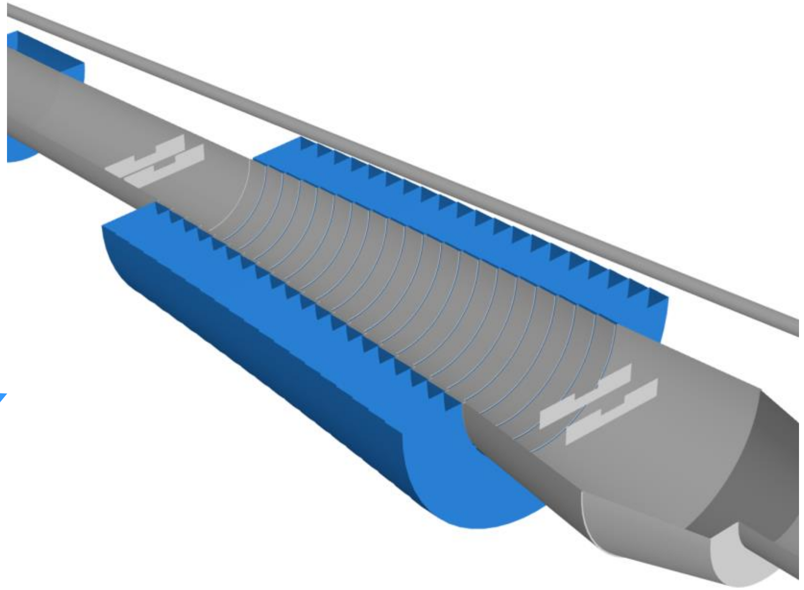


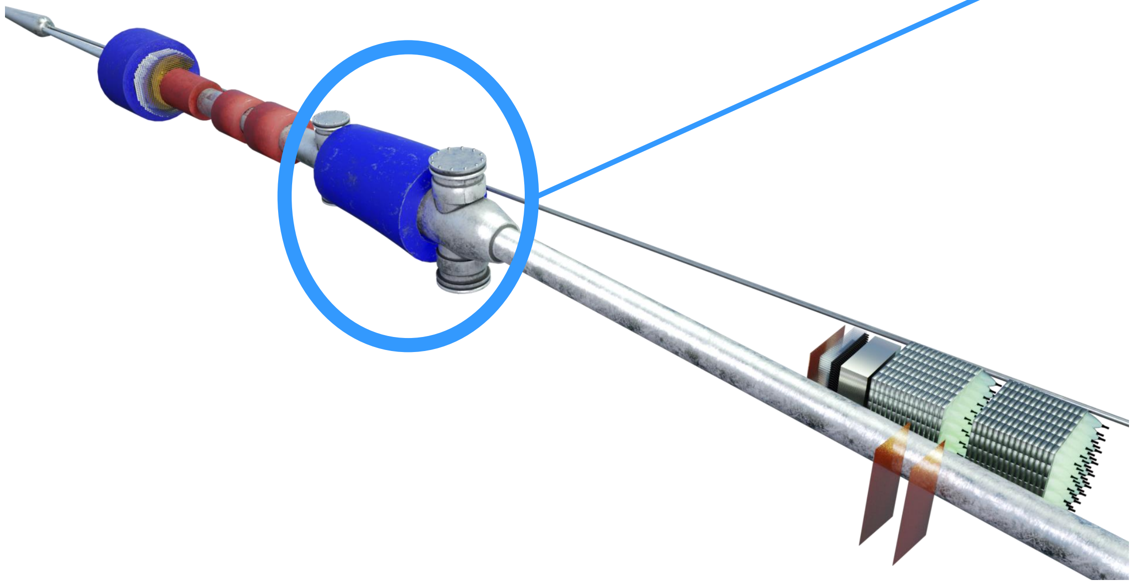
Ion Far-forward detectors

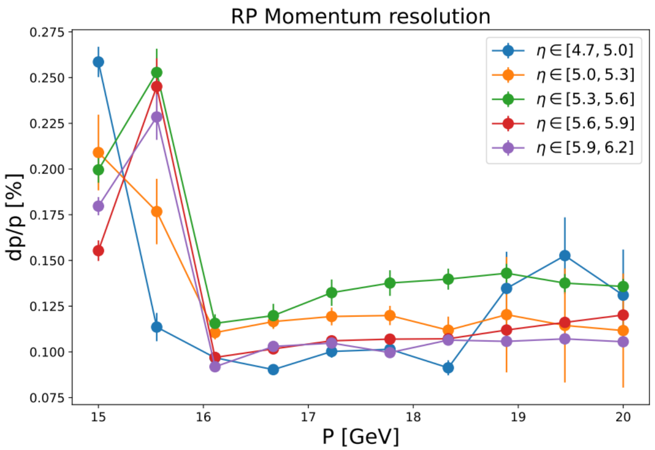


Roman Pot Stations

- Roman pot station: 2 silicon trackers (MAPS + AC-LGAD) placed inside the ion beam pipe
- Small holes in the middie to allow ion beam passes through
- Each tracker made of two movable L-shape planes, making the hole size tunable
- ~ 0.3% resolution

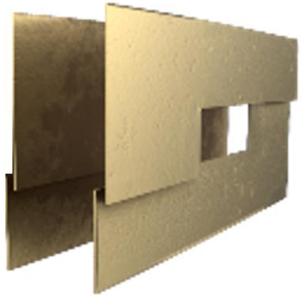


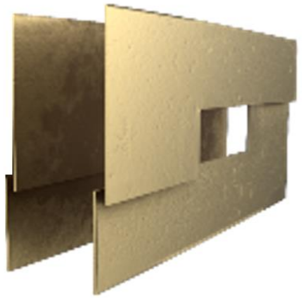




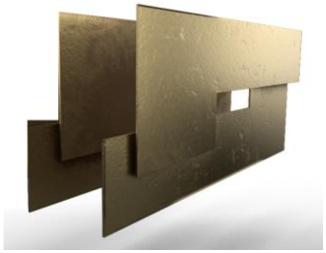
Roman Pot Stations

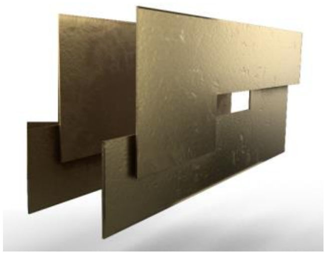
High lumi. configuration





Low lumi. configuration





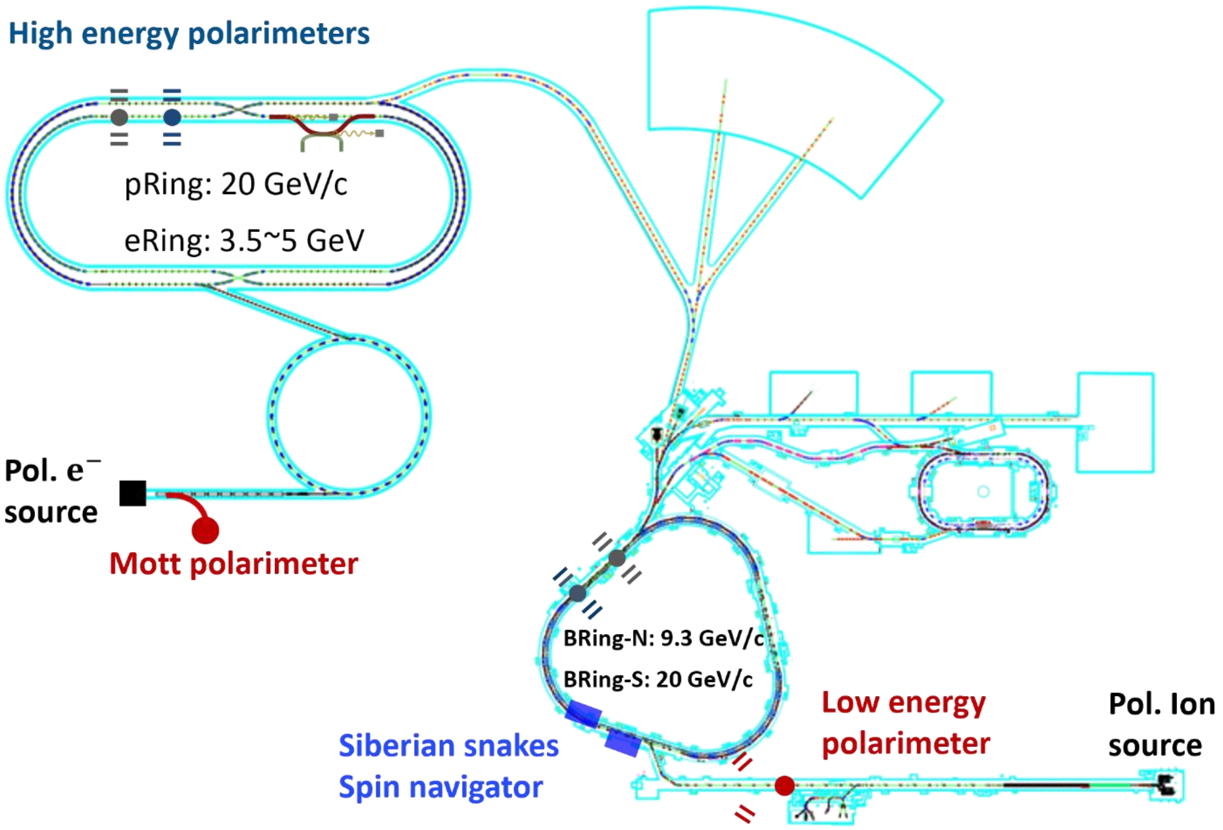
- With EicC high luminosity ~4x10^{33} cm^{-2} s^{-1}
  - larger beam spot size at RPS
  - central hole needs minimum (18cm / 10cm in x / y)
  - Only cover down to ~10 mrad
- With EicC high luminosity ~1x10^{33} cm^{-2} s^{-1}
  - smaller beam spot size at RPS
  - central hole needs minimum (8cm / 4cm in x / y)
  - Can cover down to 5 mrad
- Possible way to reach ultra-forward angles:
  - spend 10~20% of run time to run low-lumi. setting, reaching angles ~5 mrad

EicC accelerator

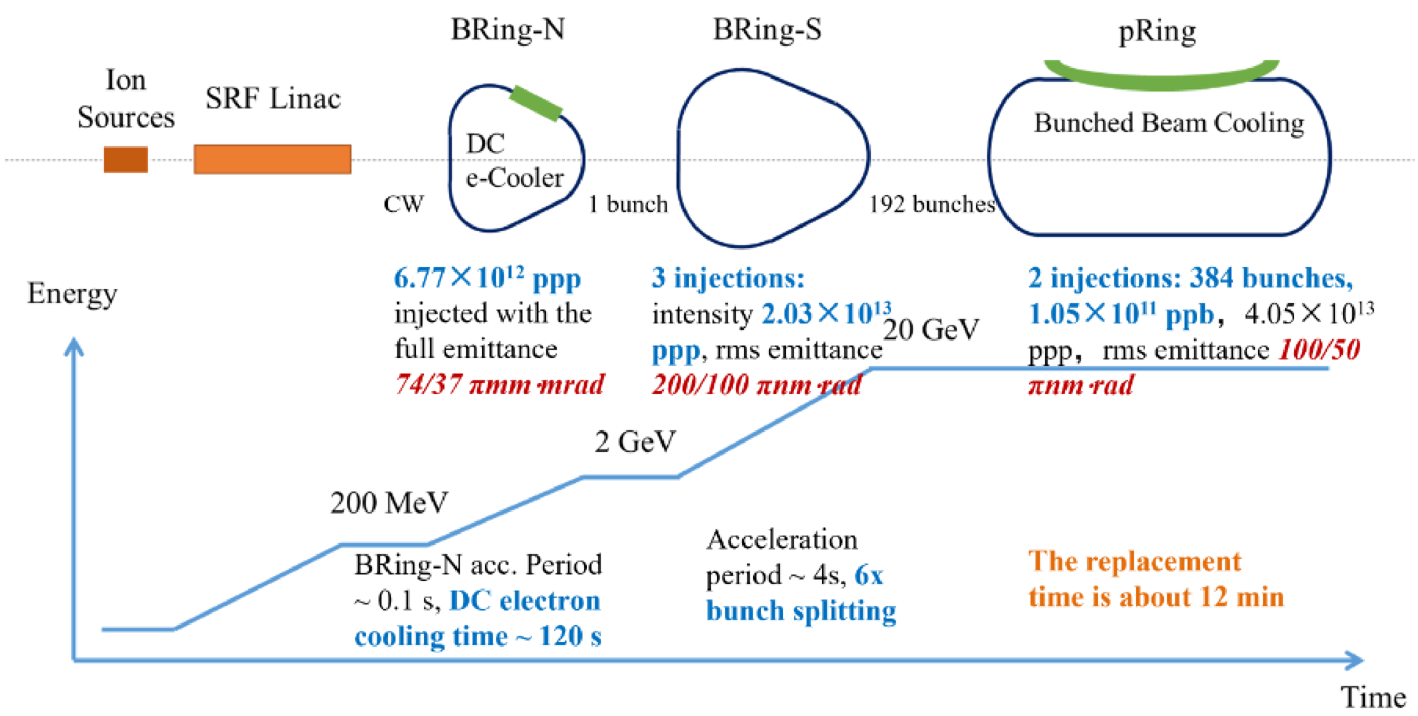
High Lumi. (HIAF-U-New, V0) — **Low Lumi.** (V1)

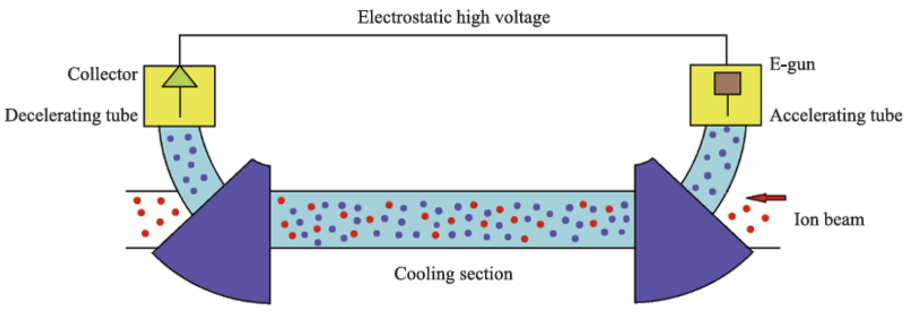
Designs	HIAF-U-New, V0		V1	
Particle	e	p	e	p
Circumference(m)	1151.20	1149.07	1151.20	1149.07
Kinetic energy (GeV)	3.5	19.08	3.5	19.08
Momentum (GeV)	3.5	20	3.5	20
Total energy (GeV)	3.5	20.02	3.5	20.02
CM energy (GeV)	16.76			
$f_{\text{collision}}$ (MHz)	100			
Polarization	80%	70%	80%	70%
$B\rho$ (T·m)	11.7	67.2	11.7	67.2
Bunch intensity($\times 10^{11}$)	1.7	1.05	0.44	0.27
$\varepsilon_x/\varepsilon_y$ (nm·rad, rms)	50/15	100/50	12.5/3.75	25/12.5
β_x^*/β_y^* (cm)	10/4	5/1.2	10/4	5/1.2
RMS divergence (mrad)		1.4/2.0		0.7/1.0
6×RMS size @ BpF2 (cm)		9.3/4.6		4.6/2.3
8×RMS size @ BpF2 (cm)		12.4/6.2		6.2/3.1
10×RMS size @ BpF2 (cm)		15.5/7.7		7.8/3.9
Bunch length (cm, rms)	0.75	8	0.75	8
BB parameter ξ_x/ξ_y	0.102/0.118	0.0144/0.01	0.105/0.121	0.015/0.010
Laslett tune shift	-	0.066/0.105		0.065/0.10
Energy loss (MeV/turn)	0.32	-		
Total SR power (MW)	0.86	-		
Average Current (A)	2.7	1.68		
Crossing angle (mrad)	50			
Luminosity ($cm^{-2}\cdot s^{-1}$)	4.25×10^{33} (H=0.52)		1.13×10^{33} (H=0.52)	

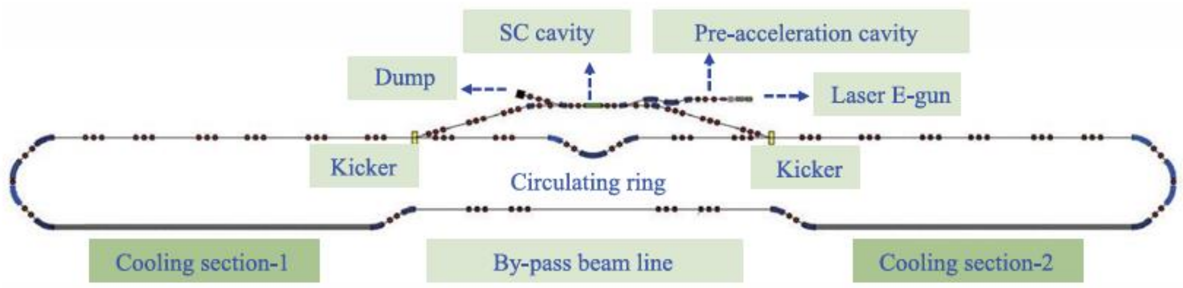
Two running modes to meet physics requirements



Efforts to increase the luminosity

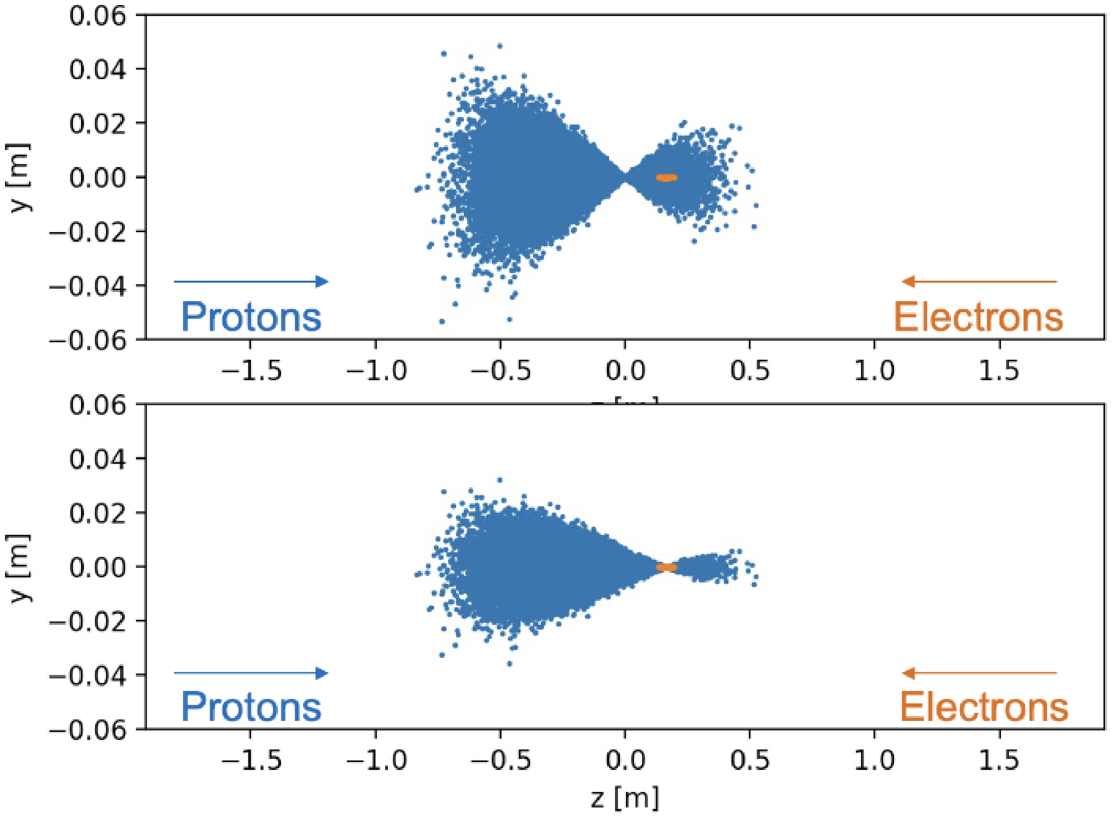




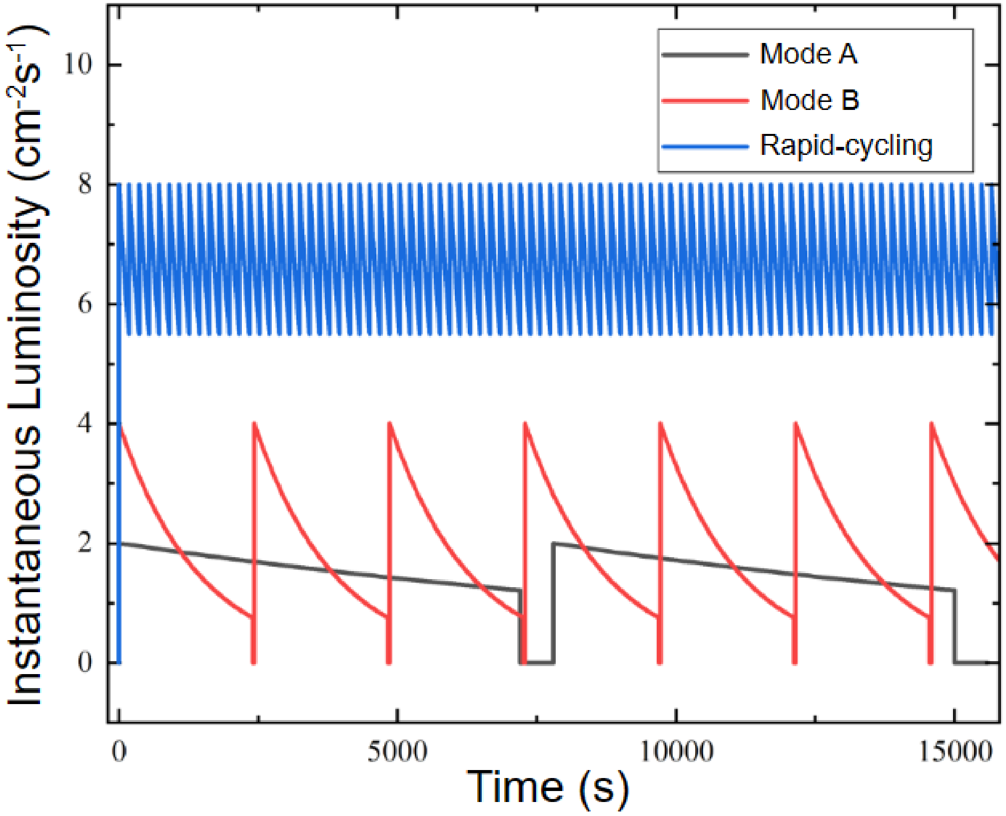


Efforts to increase the luminosity

Floating-waist Collision Method

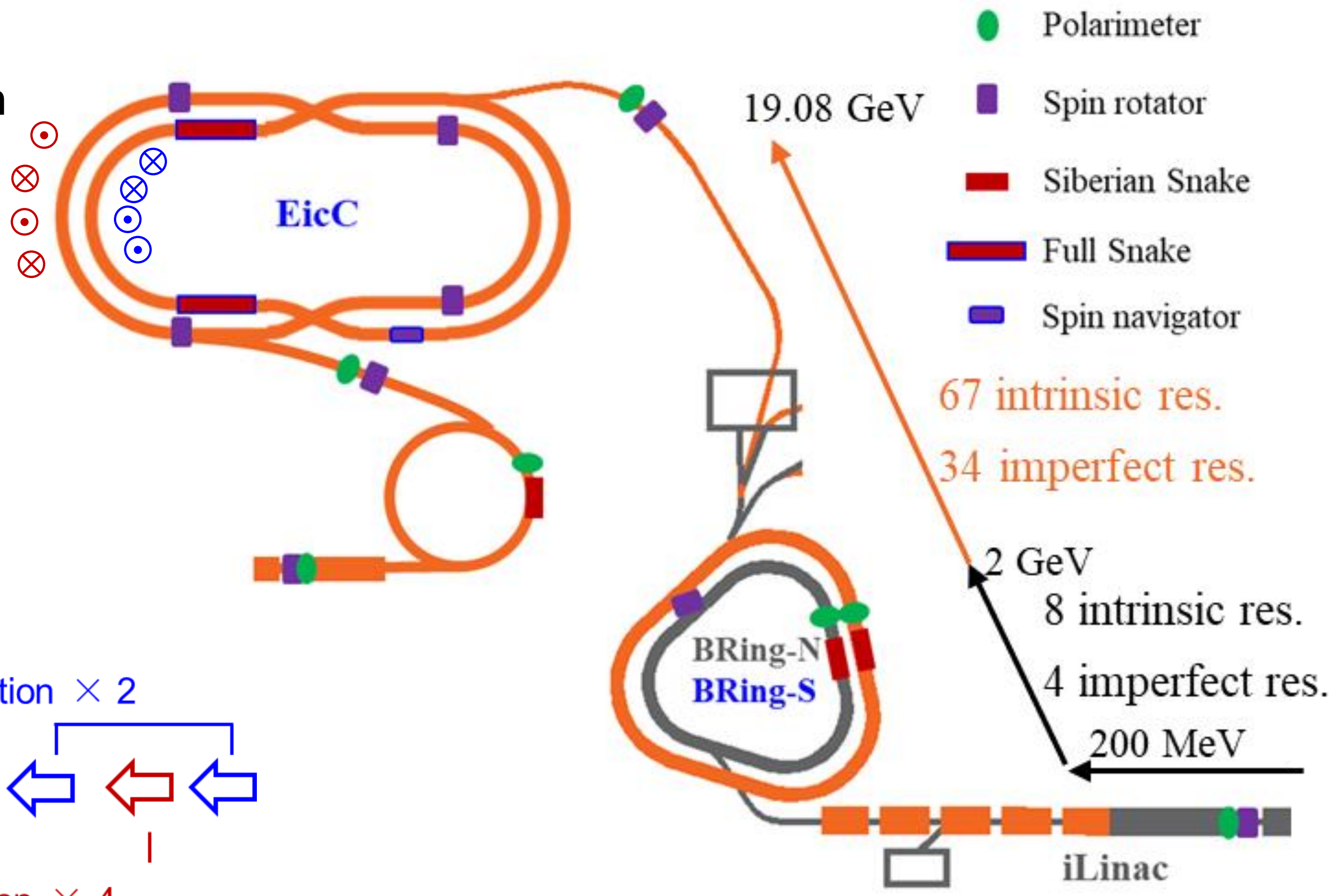


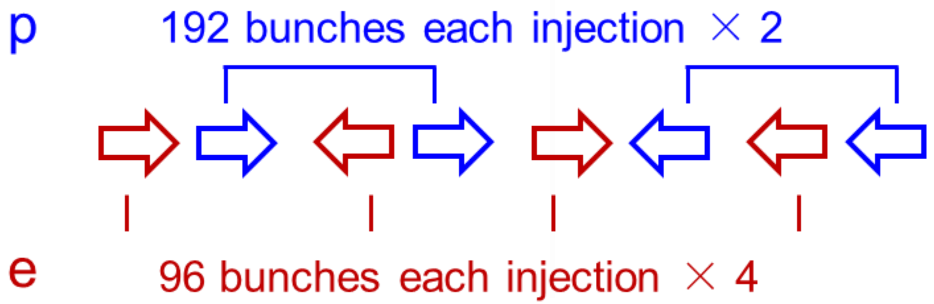
Rapid cycling collision scheme



Spin flip

- **The spin flip frequency in the collisions of the electron beams and the proton beams is about 1.04 MHz, decided by the number of bunch trains with opposite spin directions in the collision rings.**

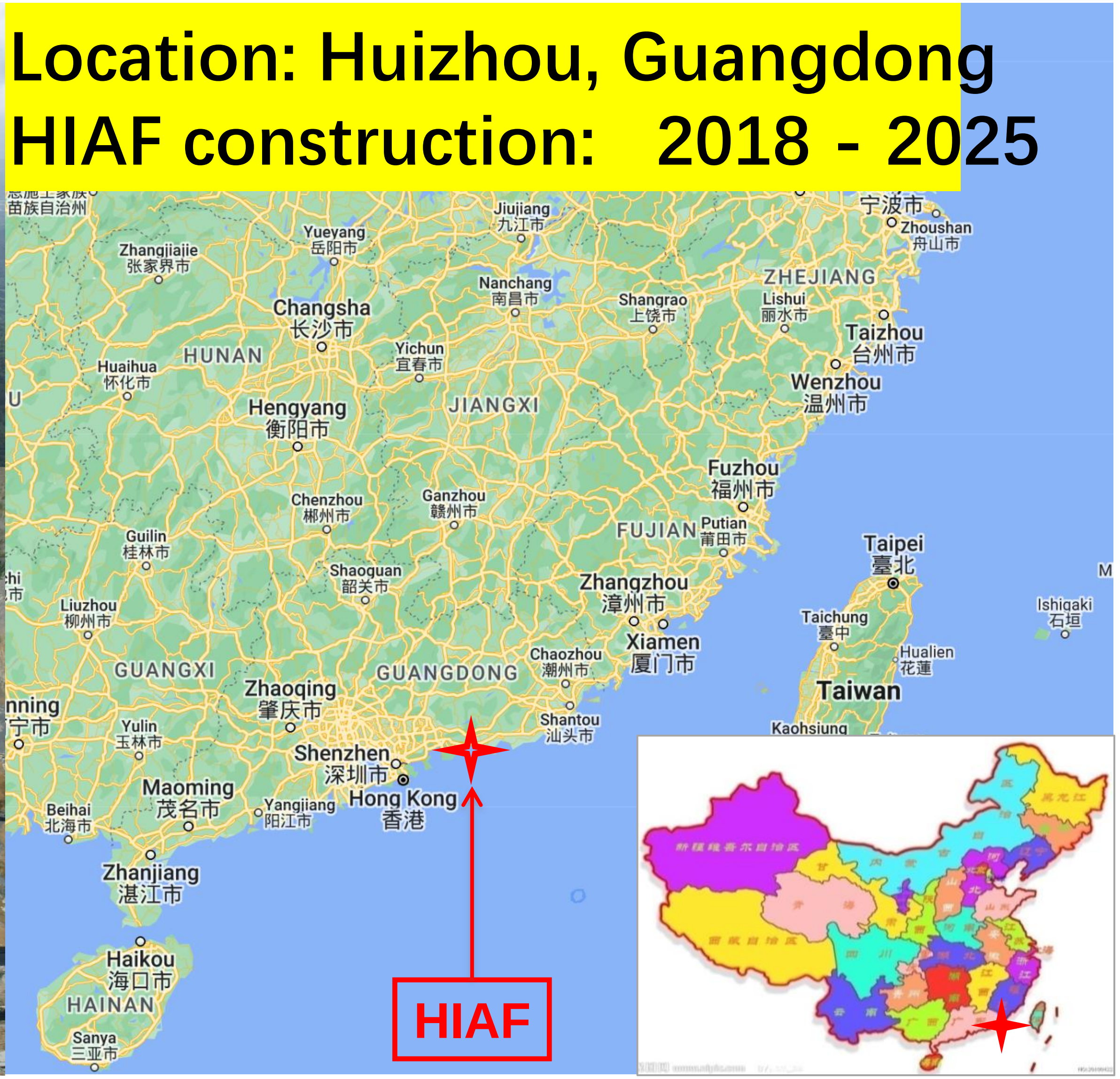




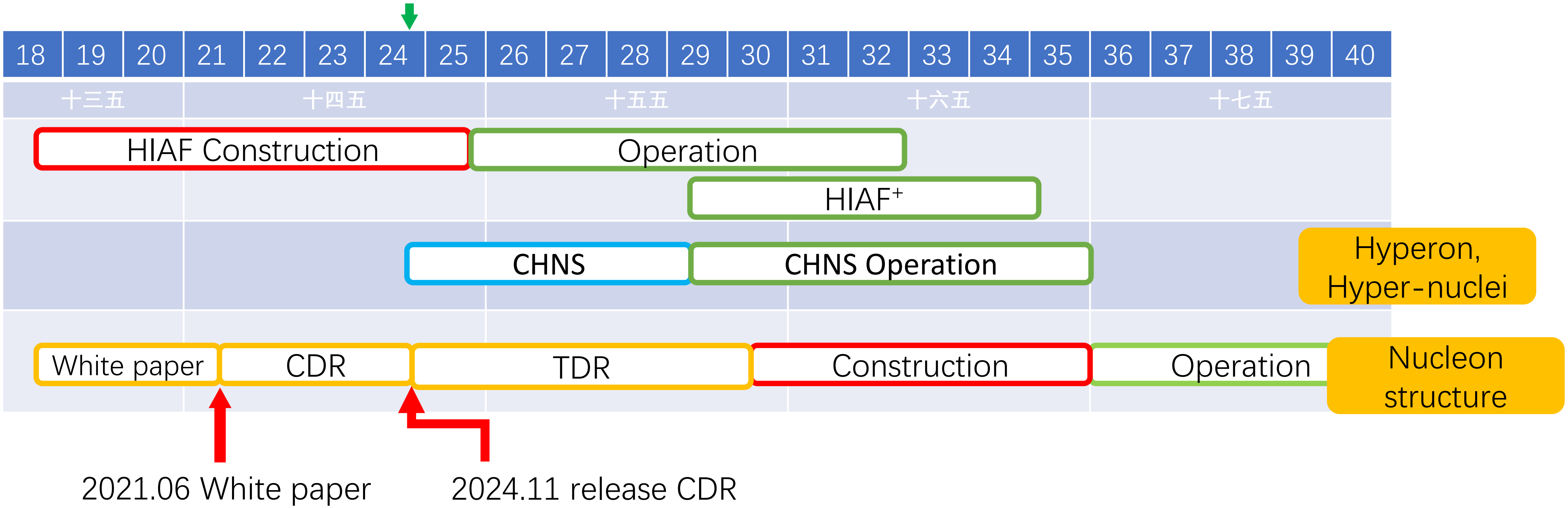
Status of HIAF

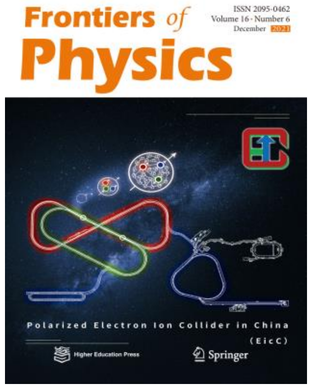
Location: Huizhou, Guangdong

HIAF construction: 2018 - 2025



Project status





Fundings for detector and accelerator R&D:

Forward detectors: ZDC, OMD, EDT

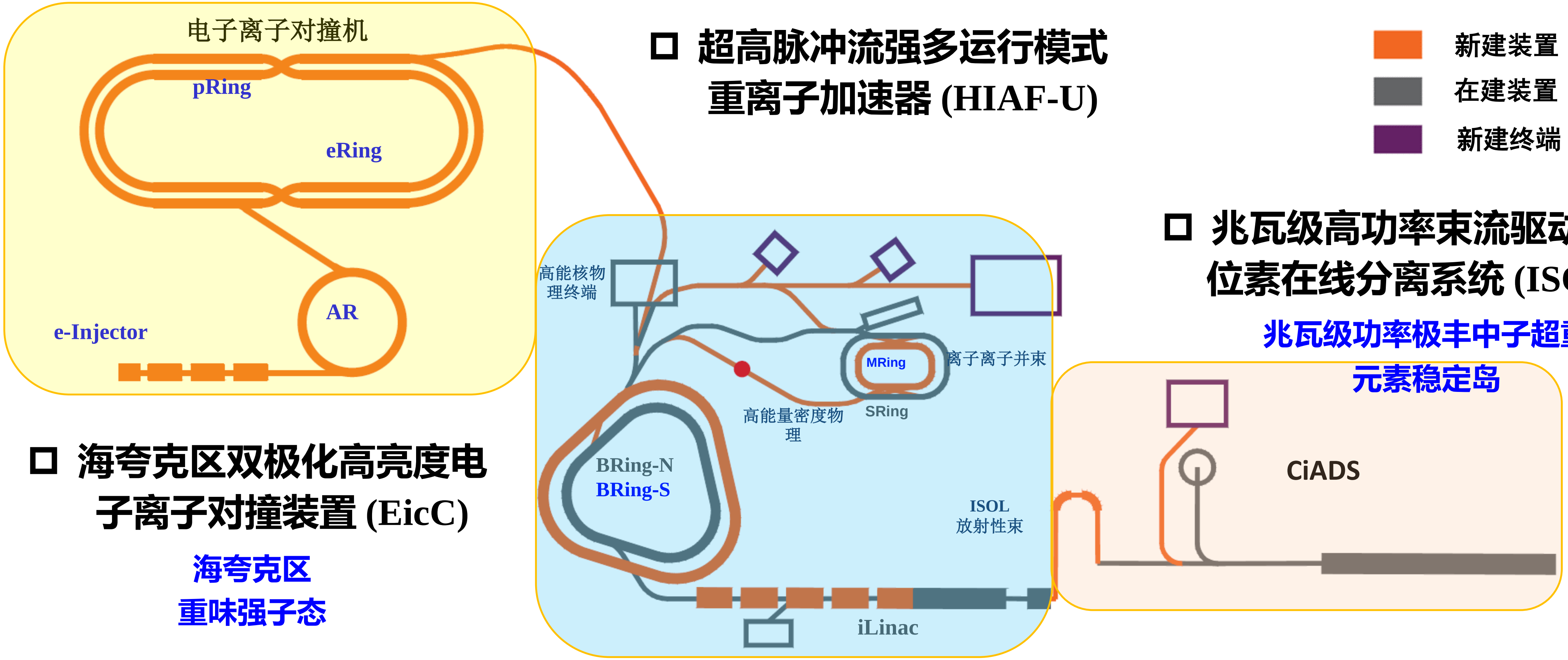
proton polarimetry

Polarized proton beam

中国先进核物理研究装置（CNUF）

CNUF-China advanced NUclear physics research Facility

综合性、多功能、性能先进的离子加速器大科学装置集群



- 超高脉冲流强多运行模式重离子加速器 (HIAF-U)
- 兆瓦级高功率束流驱动同位素在线分离系统 (ISOL)

兆瓦级功率极丰中子超重元素稳定岛

- 海夸克区双极化高亮度电子离子对撞装置 (EicC)

海夸克区
重味强子态

Summary

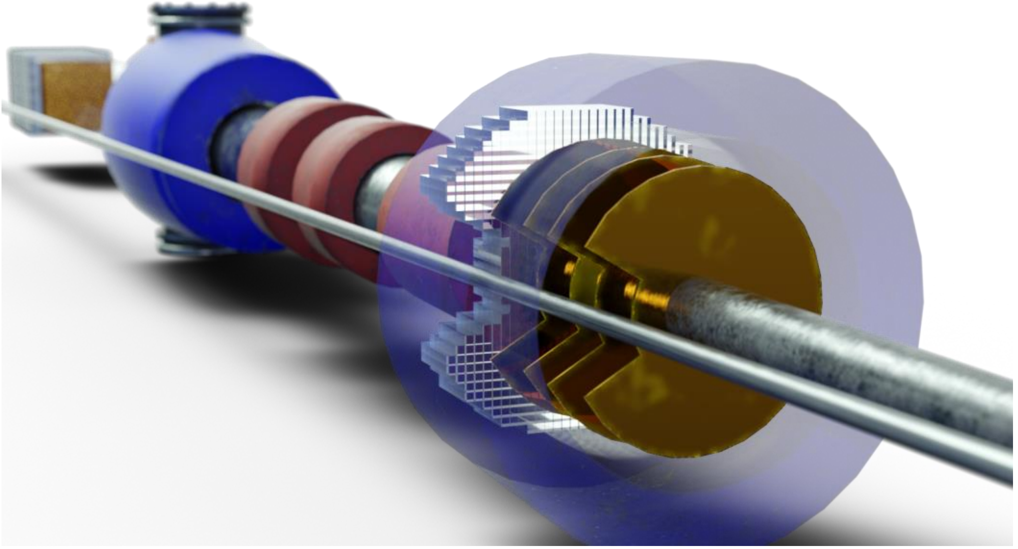
- **EicC proposed based on the HIAF facility.**
  - **-- polarized electron beam (3.5 GeV)**
  - **-- polarized proton beam (20 GeV) and ion beams**
- **High precision measurements for 1D (helicity), 3D (TMDs/GPDs) nucleon structure study with flavor separation in the valence and sea quark dominated region. Physics potential on exotic hadron, meson structure etc. are also investigated in EicC.**
- **EicC CDR will be released at 2024.**
- **Accelerator and detector R&Ds are on-going.**

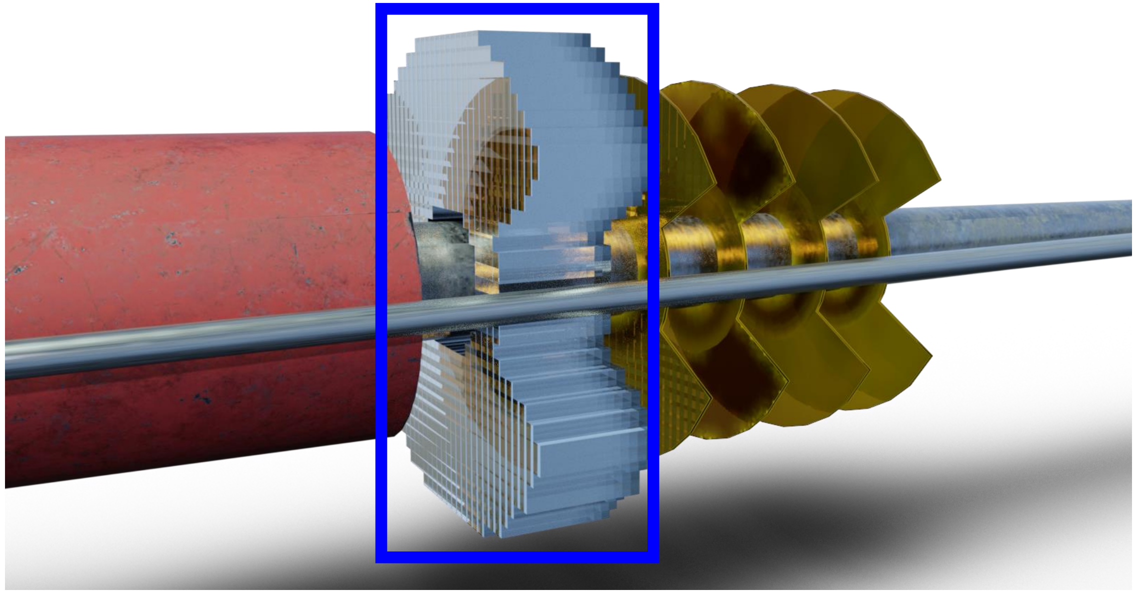
Thank You

Endcap Dipole Trackers (EDT)

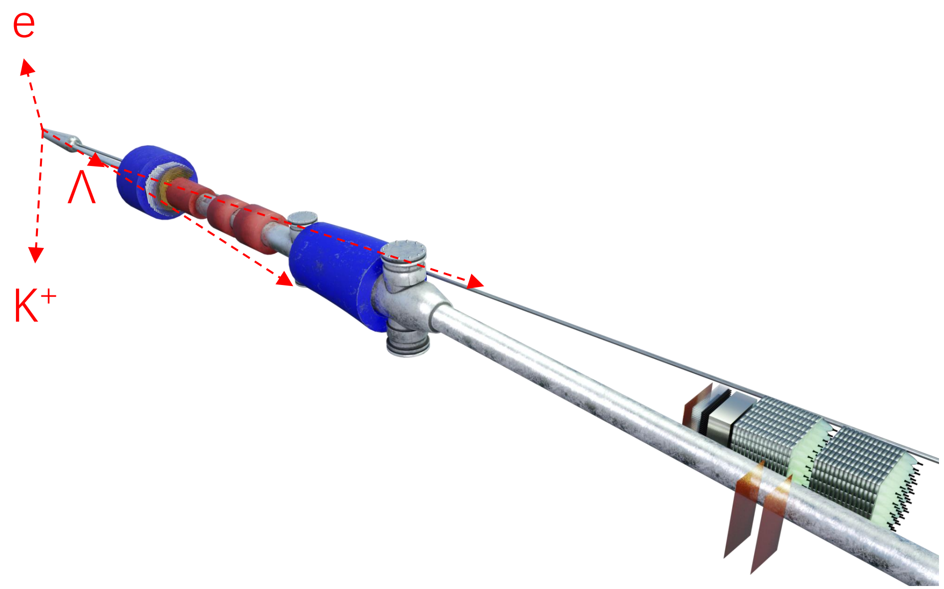
- Four silicon trackers (MAPS, AC-LGAD)
- Charged particle in 16 mr < θ < 60 mr
- Full ϕ coverage for θ < 35 mr
- gaps for θ > 35 mr and -30º < ϕ < 30º to allow electron beam pass through
- ~ 0.5% resolution

- Motivation: many meson decay photons peak in this range
- Compact EM calorimeter (only ~30cm available space in z due to quad. magnets)
- Reasonable candidate: $PbWO_4$
- Acceptance: 20 mr < θ < 60 mr

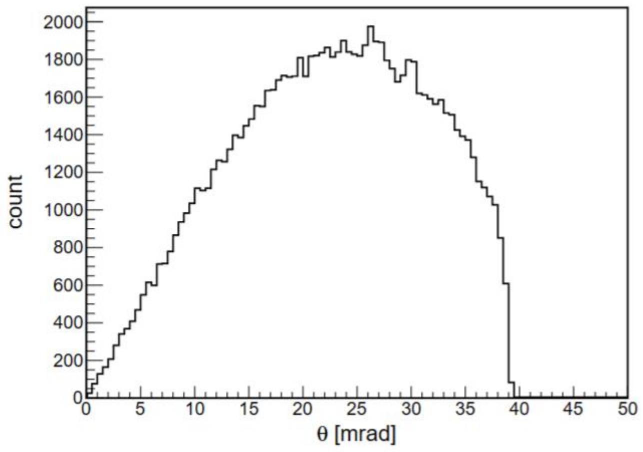




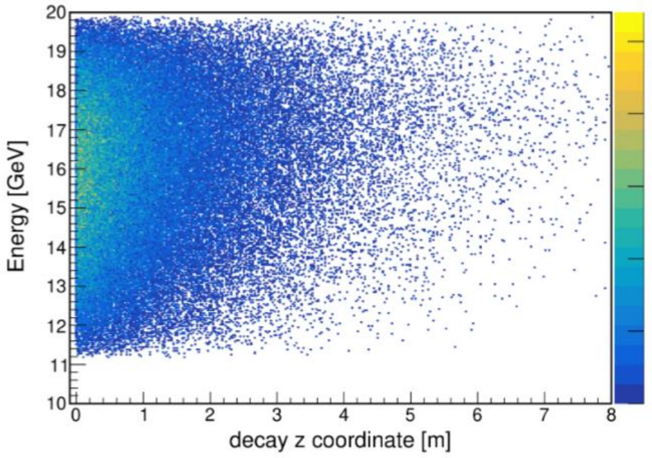
Forward Λ detection



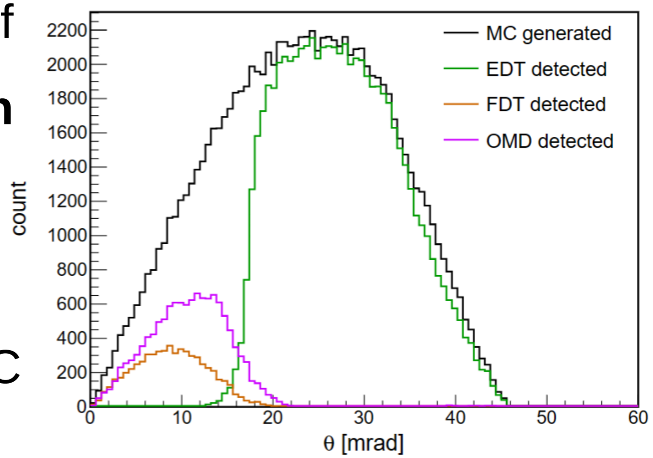
polar angle of Λ



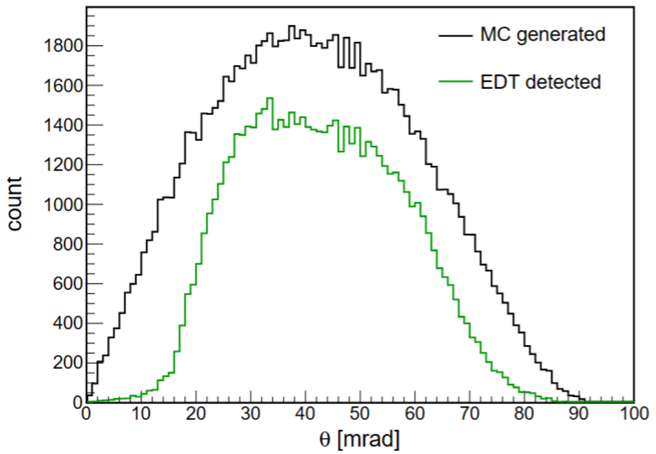
Energy vs decay z-vertex of Λ



polar angle of p from Λ



polar angle of π^- from Λ



Detection of Λ is essential for measurement of the **kaon form factor** and **structure function using the Sullivan process.**

$e + p \rightarrow e' + K^+ + \Lambda$

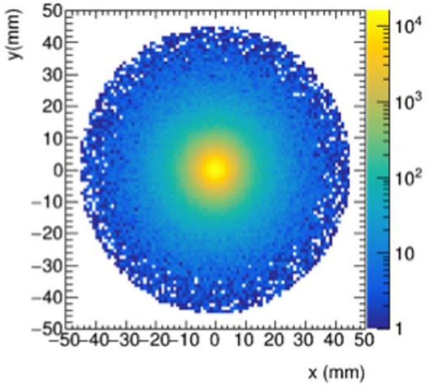
Obvious advantage for EicC, compared to EIC

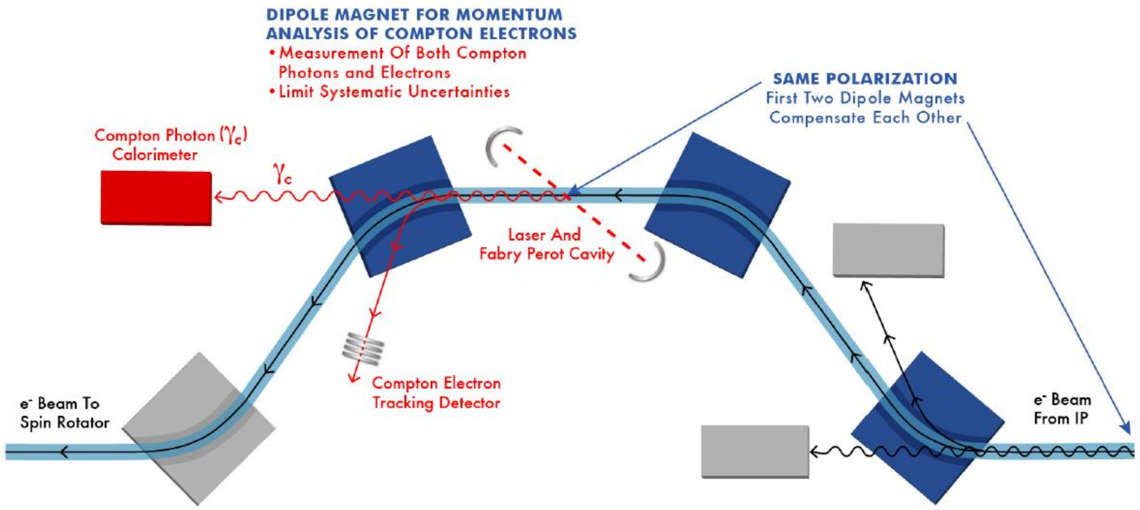
Efficiency of Λ ~ 40% (EIC 1% ~ 20%)

Luminosity Monitors

- via elastic bremsstrahlung off electrons; large and well-know cross section ~mb
- Detect bremsstrahlung photons downstream electron beam
  - Photon conversion to e+e- for precise luminosity calibration
  - Direct photon detection for instantaneous luminosity monitoring

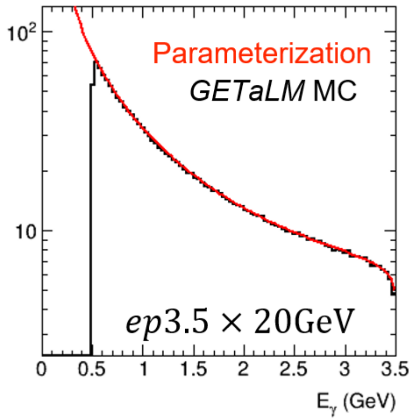
Photon spot at z=30m



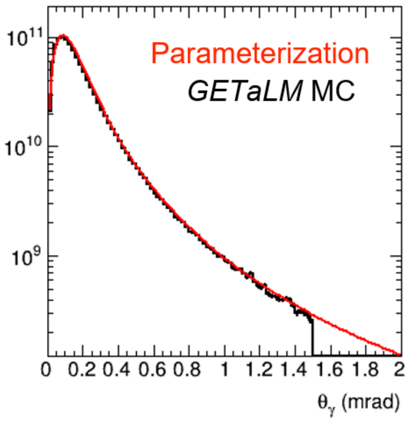


Luminosity monitor

Photon energy

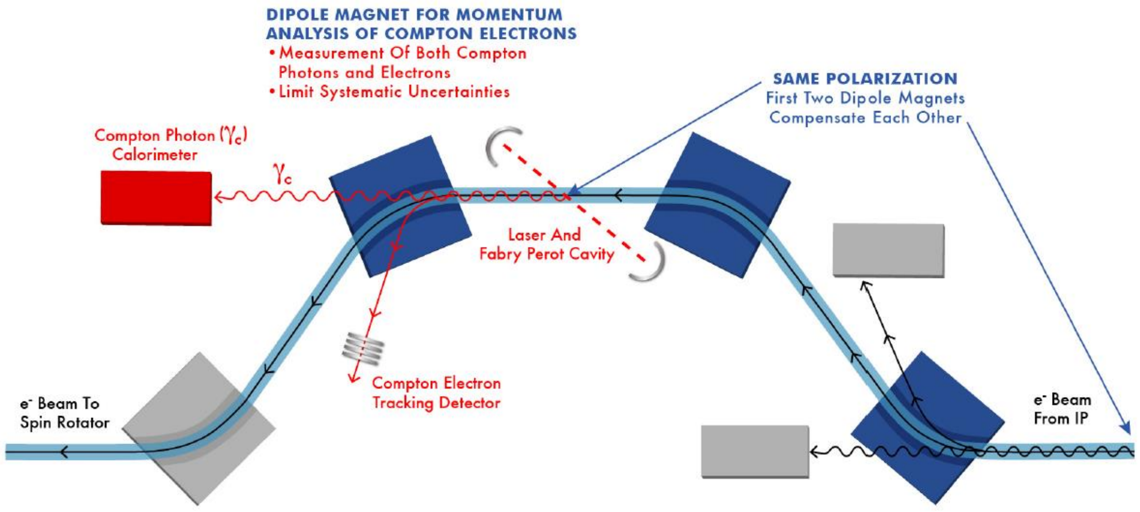


Photon angle



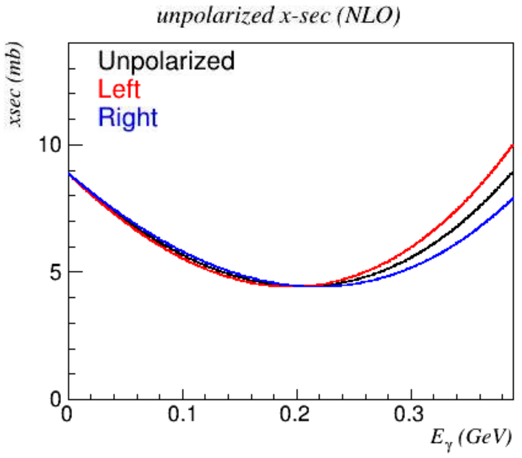
Electron Compton Polarimeter

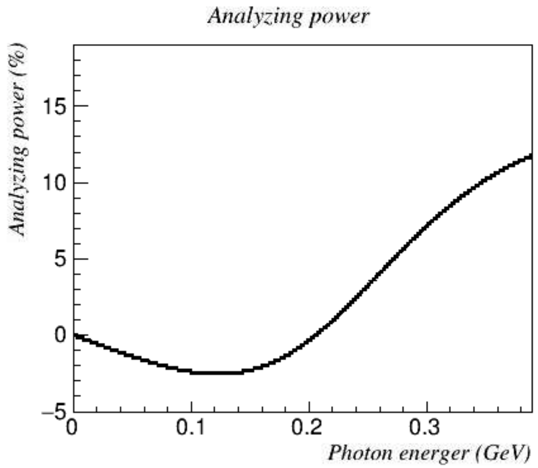
- Quasi-head-on collision with high-power 100% circularly polarized laser
- Independent detectors for electron and photon of $\vec{e}\vec{\gamma} \rightarrow e\gamma$
- Noninvasive and continuous measurement of asymmetries between left and right handed laser polarization states



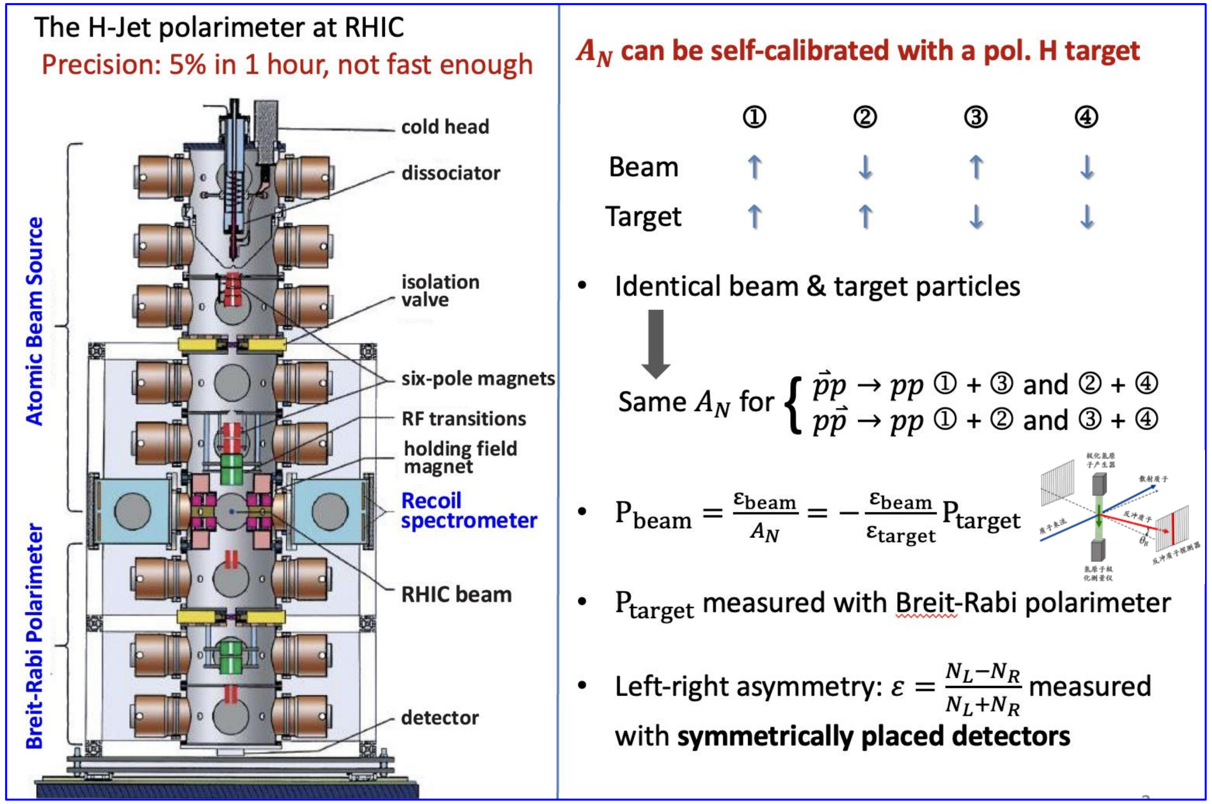
Luminosity monitor

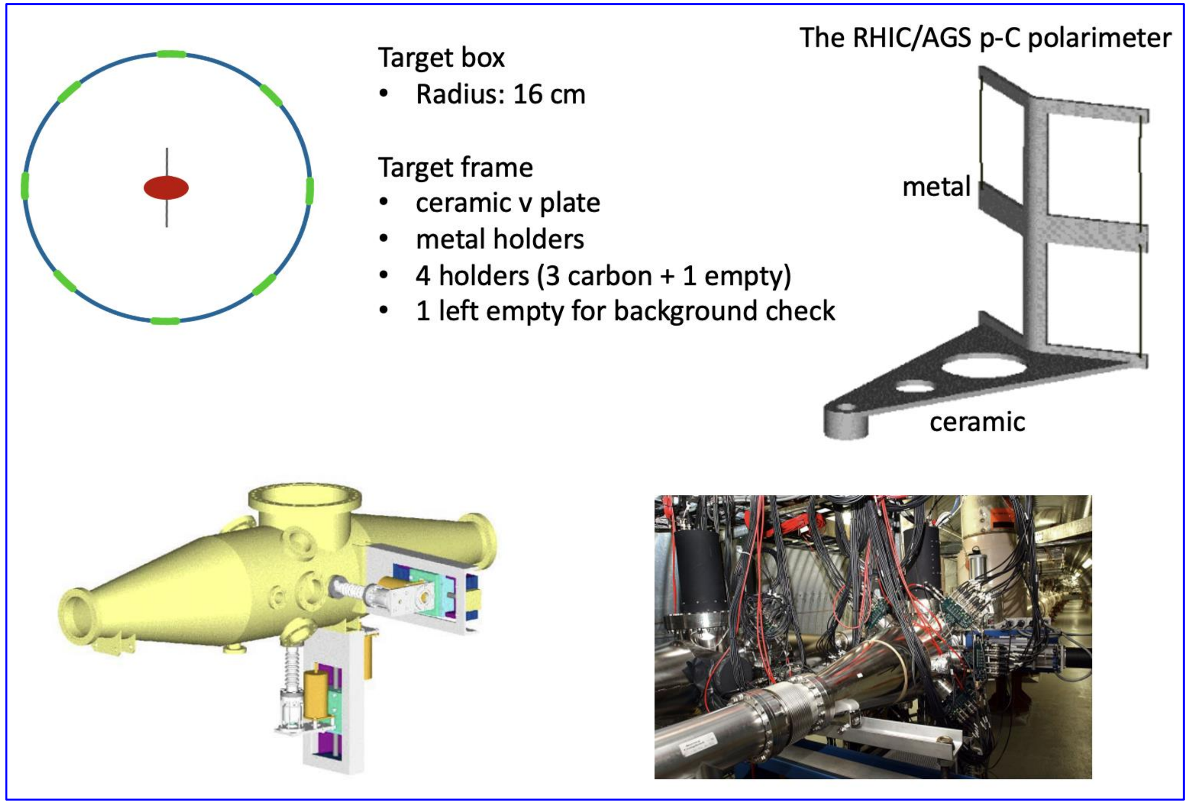
- Geant4 simulation is ongoing





Proton polarimetry scheme

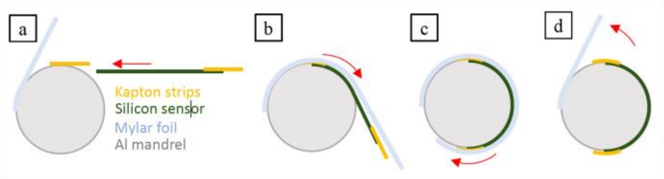


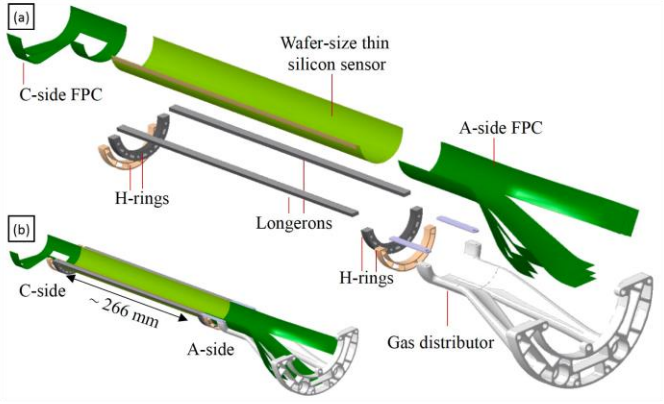


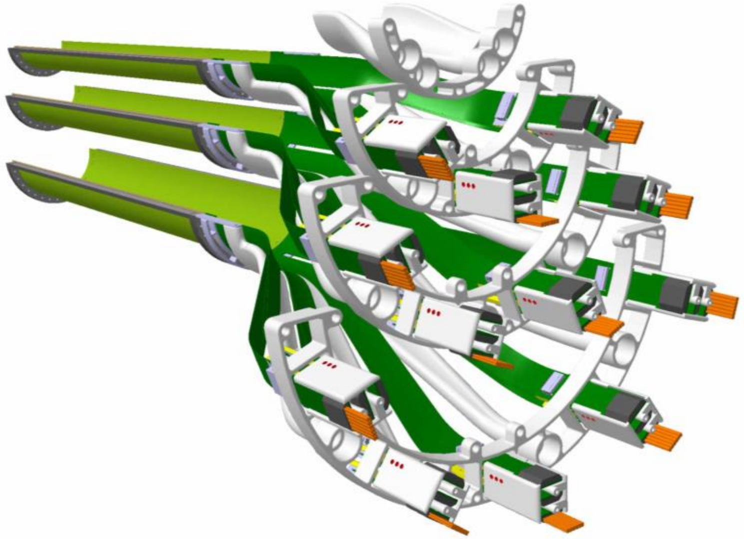
Technologies are rather mature in the world. However, critical R&D needs to be identified from our side.

Structure of the EicC barrel silicon tracker

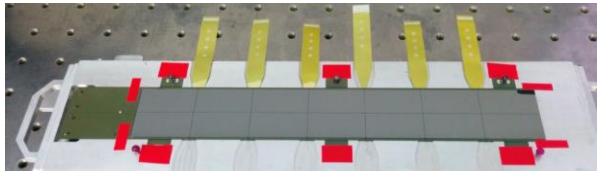
- **ITS3-based Vertexer (3 IB layers)**



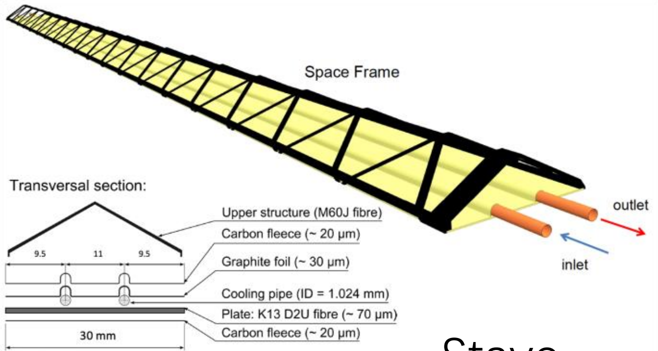




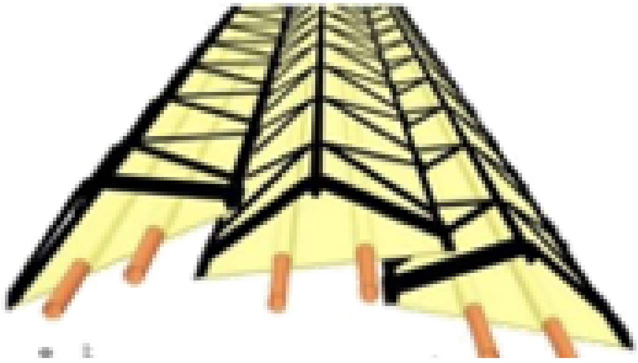
- **ITS2-based Silicon Tracker (2 OB layers)**



Hybrid Integrated Circuits (HIC)



Stave



7th EicC CDR Meeting - Y.P. Wang

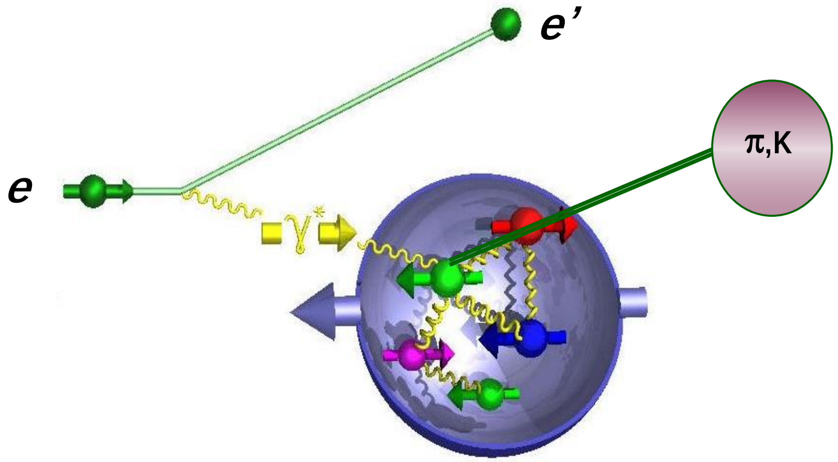
➢ 针对EicC，尽快启动MAPS探测器设计与仿真，开展柔性PCB、碳纤维机械支撑等关键器部件的市场调研

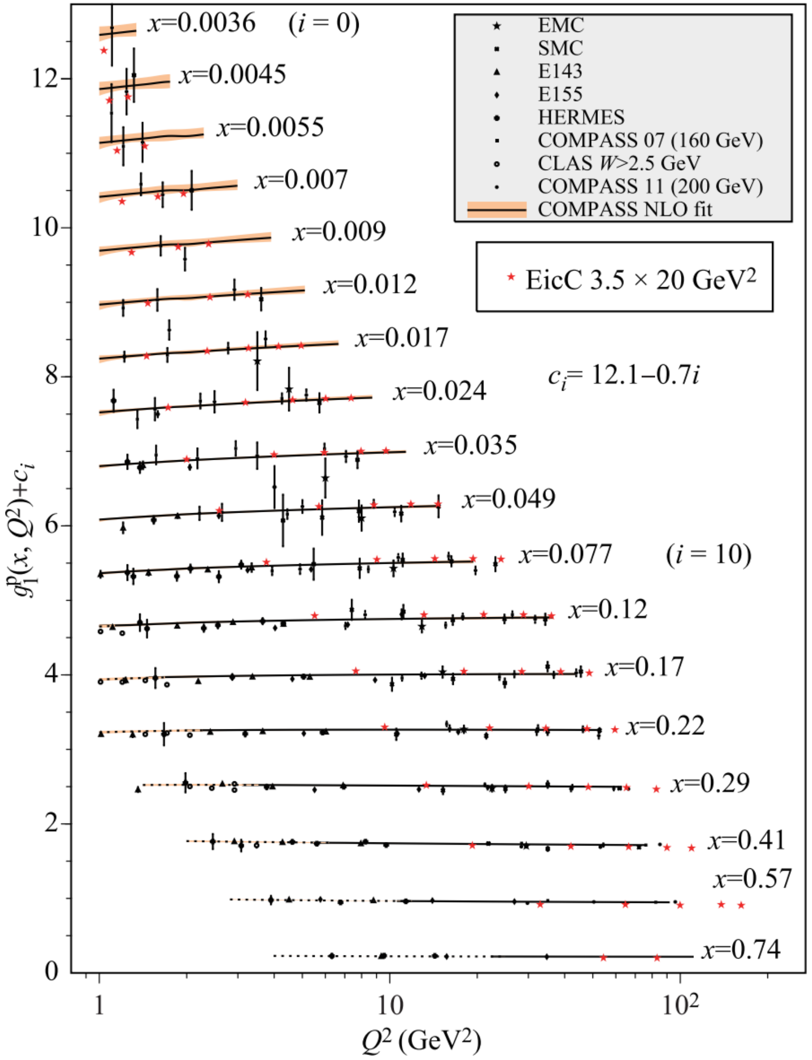
The Longitudinal Spin of the Nucleon

$$\frac{1}{2} = S_q + L_q + S_g + L_g$$

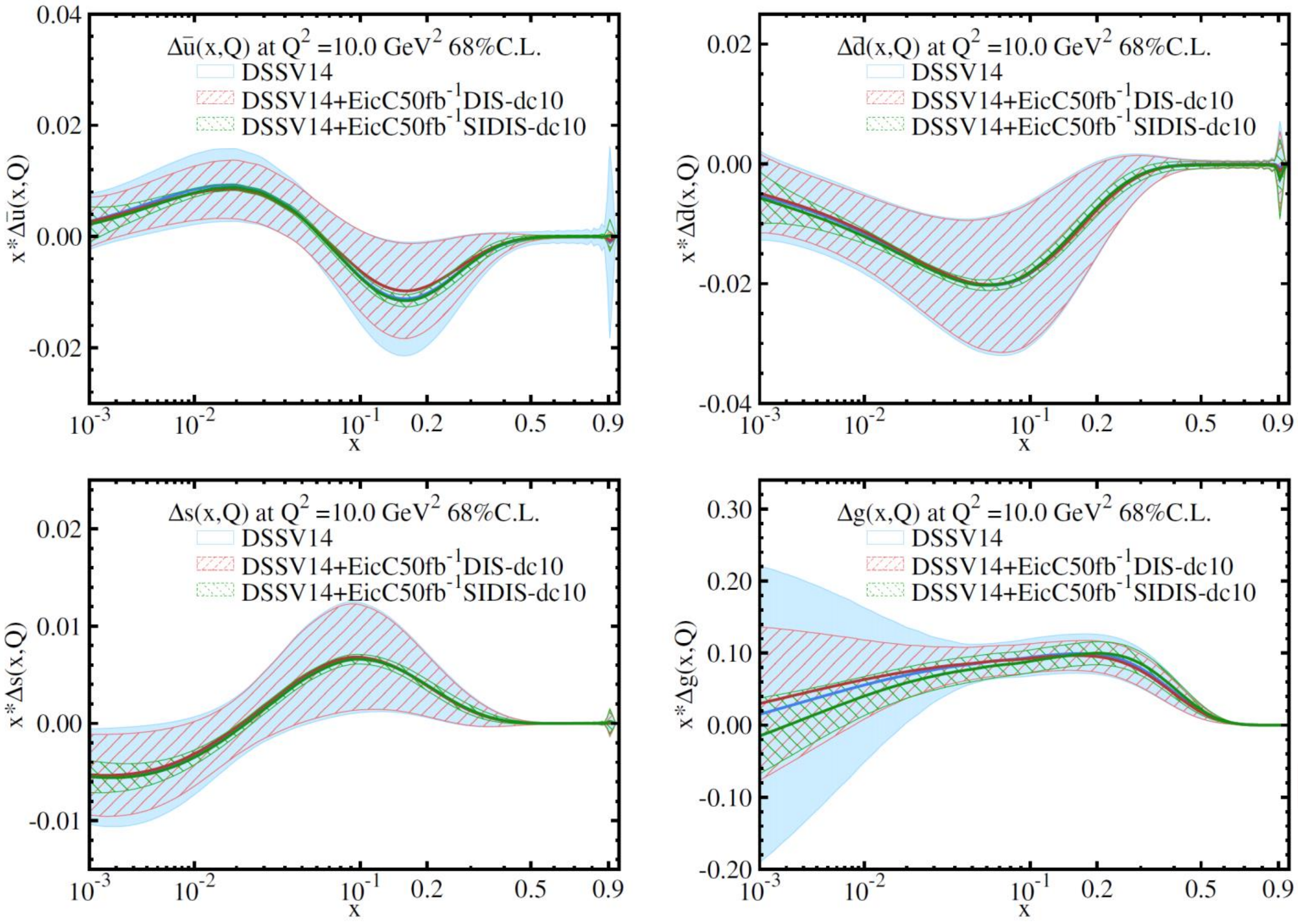
$$\frac{1}{2}\left[\frac{d^2\sigma^{\rightleftarrows}}{dx\,dQ^2} - \frac{d^2\sigma^{\rightrightarrows}}{dx\,dQ^2}\right] \simeq \frac{4\pi\,\alpha^2}{Q^4} y\,(2-y)\,g_1(x,Q^2)$$

$$g_1(x,Q^2) = \frac{1}{2}\sum e_q^2\left[\Delta q(x,Q^2) + \Delta\bar{q}(x,Q^2)\right]$$





Projections on helicity distributions



EicC SIDIS data:

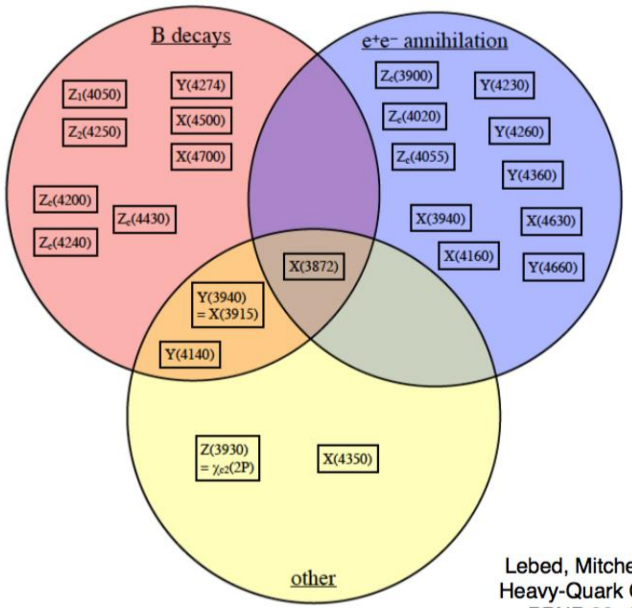
- Pion(+/-), Kaon(+/-)
- ep: 3.5 GeV X 20 GeV
- eHe-3: 3.5 GeV X 40 GeV
- Pol.: e(80%), p(70%), He-3(70%)
- Lumi: ep 50 fb^{-1} eHe-3 50 fb^{-1}

- SIDIS is much more powerful
- EicC significantly improve the precision in sea qurak region

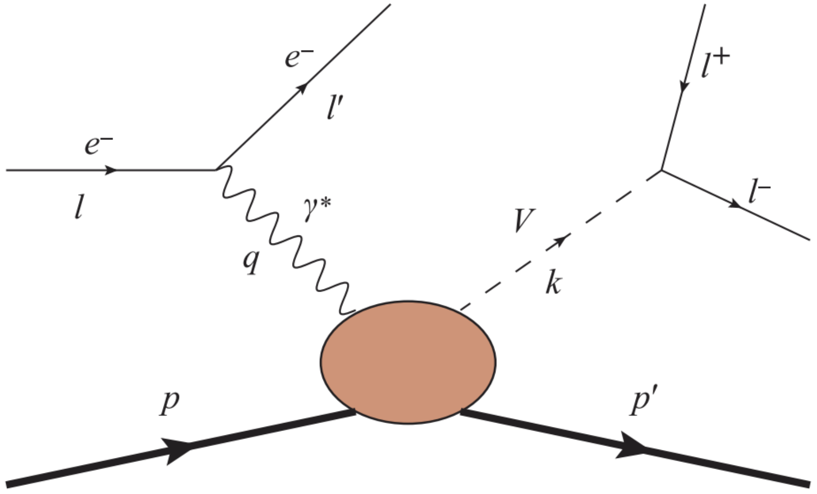
Fragmentation function used: DSS

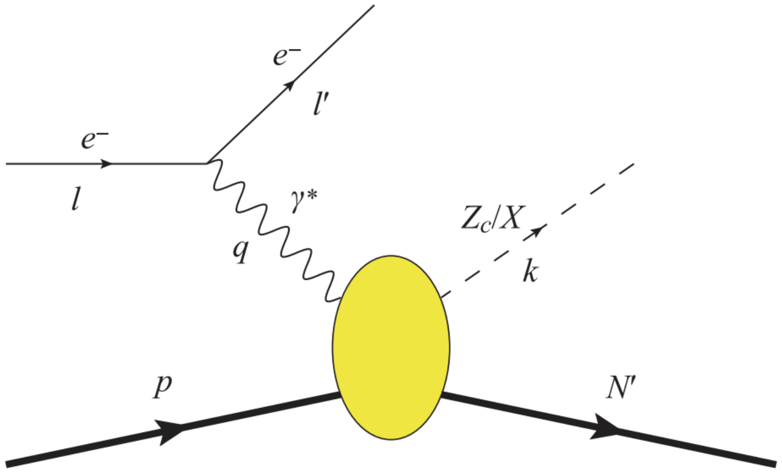
Exotic hadrons

- Study the exotic states from **new production mechanism** is crucial to pin down their nature
- EicC as a unique electron-ion collider has many advantages
  - ➢ Larger cross section compared to e+e- collision
  - ➢ Smaller background compared to pp and pA collisions
  - ➢ Polarized beams: pin down the quantum numbers
  - ➢ **No triangle singularity**

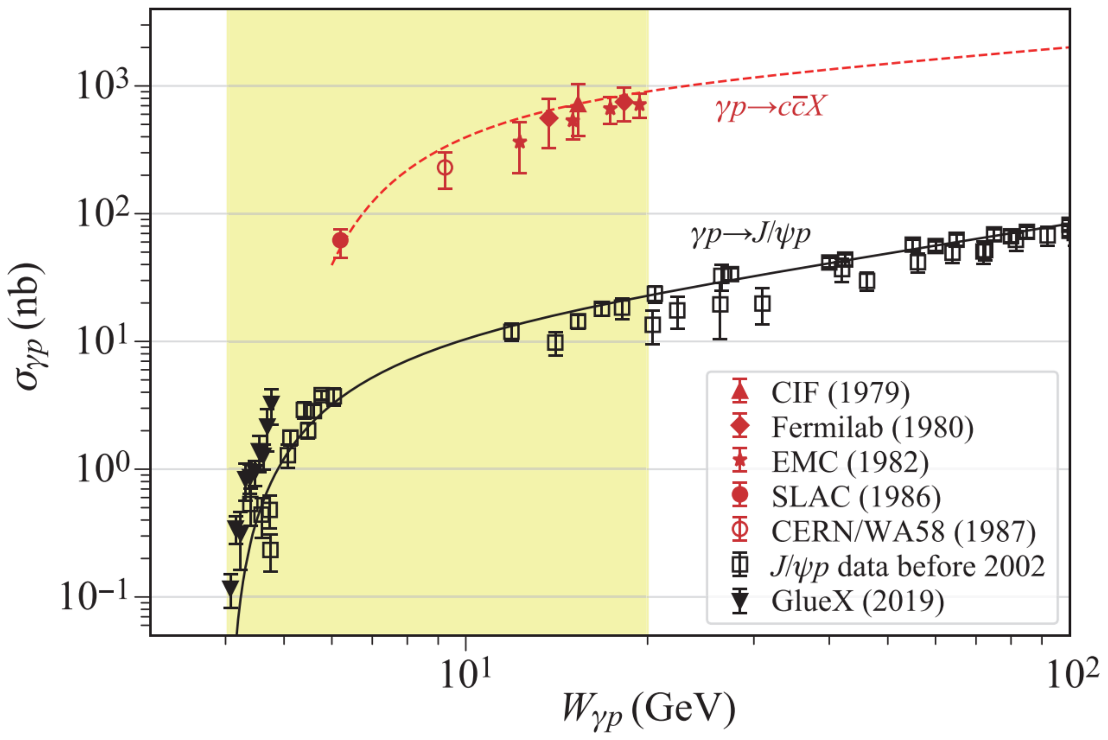


Lebed, Mitchell, Swanson, Heavy-Quark QCD Exotica, PPNP 93, 143 (2017)





J/psi production at EicC



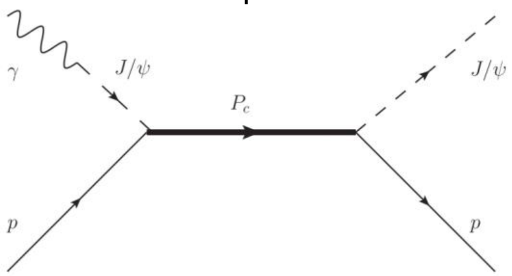
For s ~ 10-20 GeV

- Photoproduction σ(γp→ J/ψp) ~ O(10 nb)

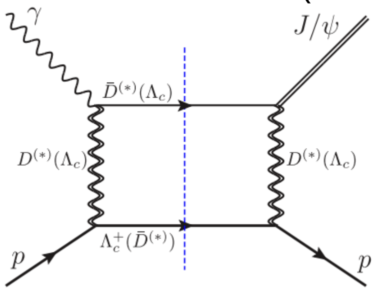
σ(γp→ $c\bar{c}$ p) ~ O(500 nb)

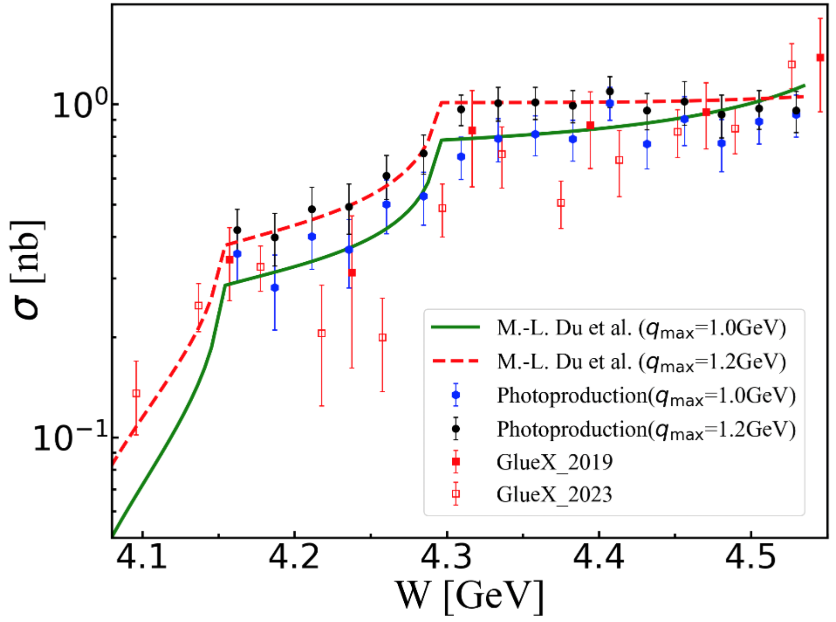
- Cusp structures at $\Lambda_c \overline{D}^*$ thresholds in the energy dependence cross section.

Multi-quark states

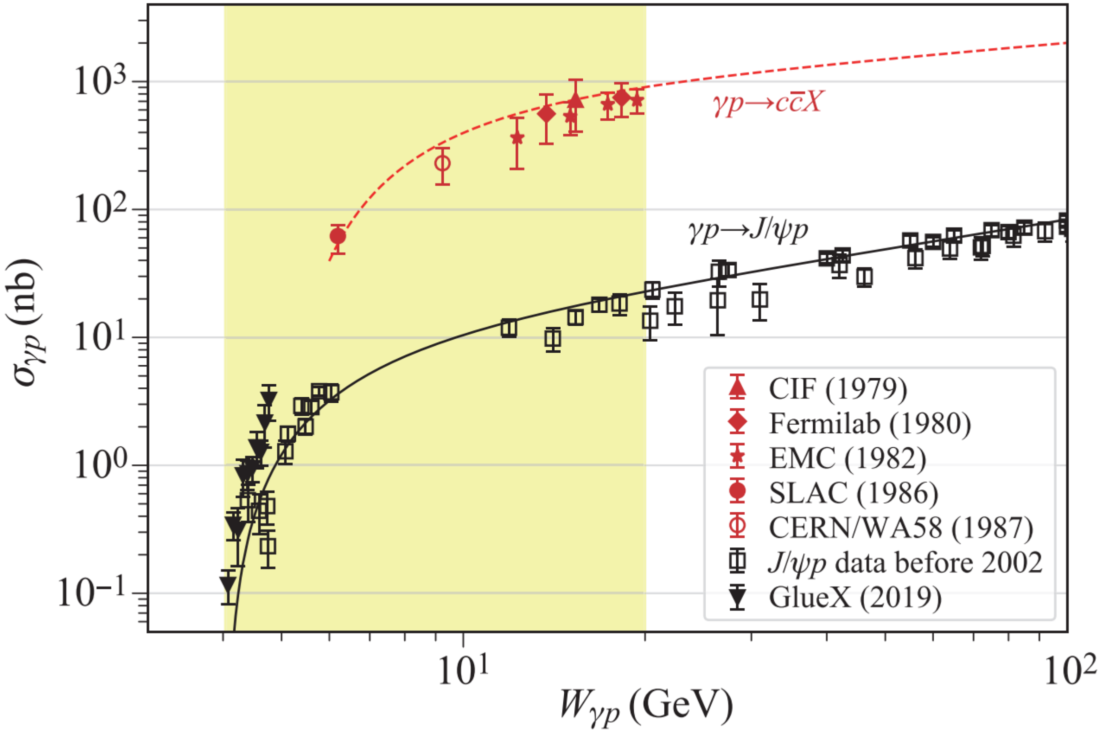


Kinematic effect (CUSP)

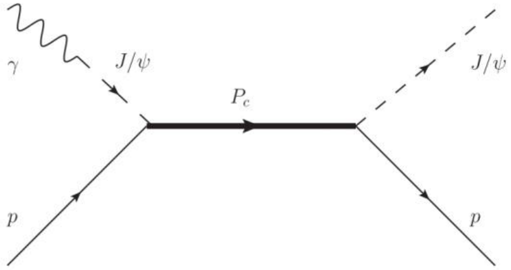




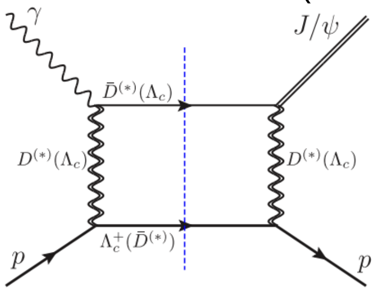
J/psi production at EicC



Multi-quark states



Kinematic effect (CUSP)

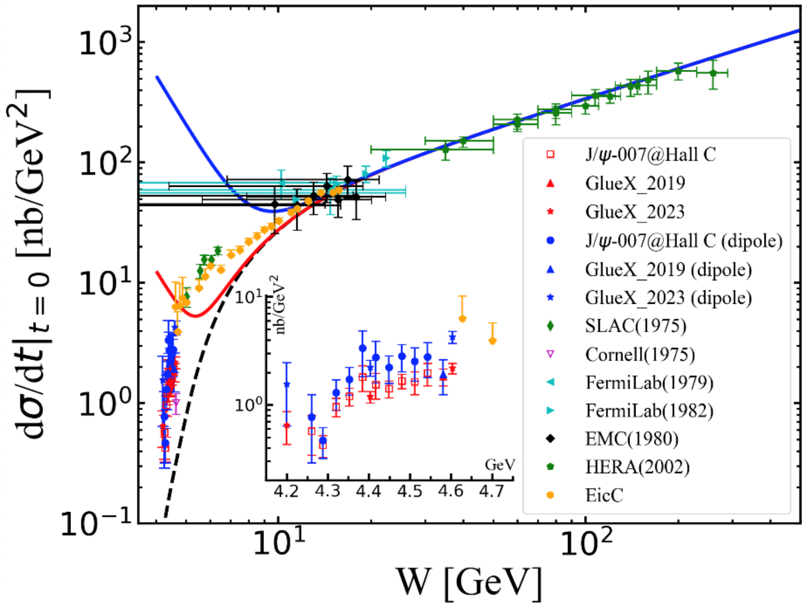


For W ~ 10-20 GeV

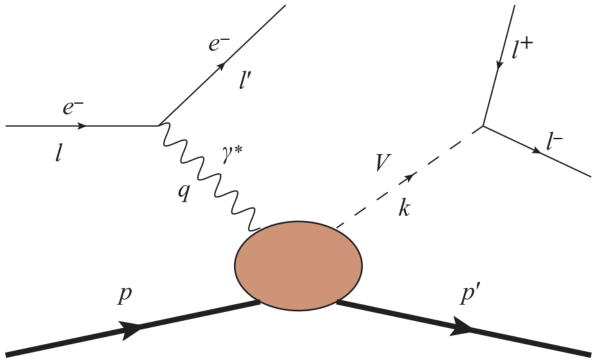
- Photoproduction σ(γp→ J/ψp) ~ O(10 nb)

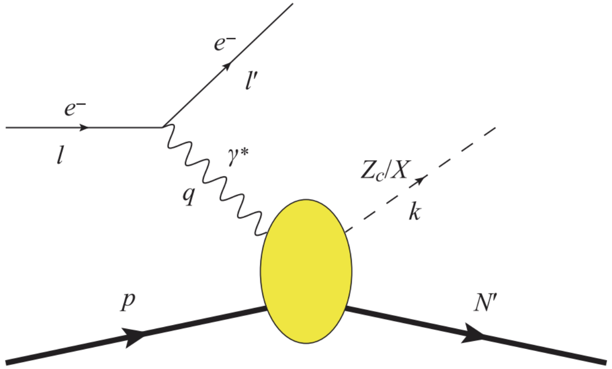
σ(γp→ $c\bar{c}$ p) ~ O(500 nb)

For an integrated luminosity of 50 fb^{-1}, number of J/ψ ~ O(10^7-10^8), many more open-charm hadron



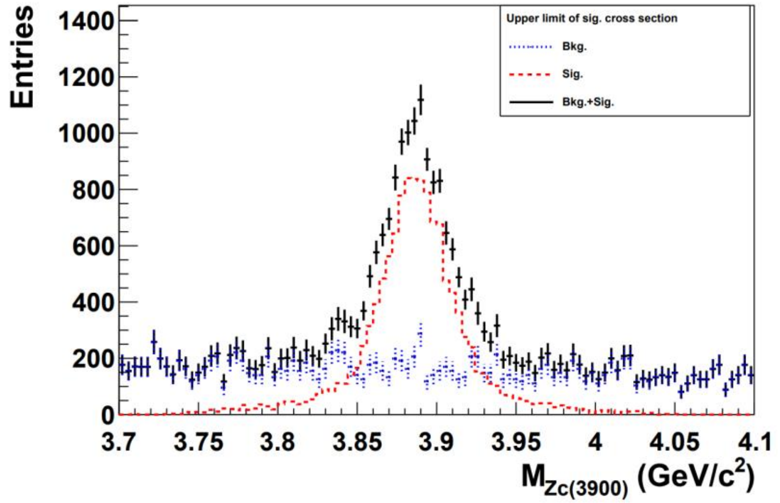
Exotic hadrons

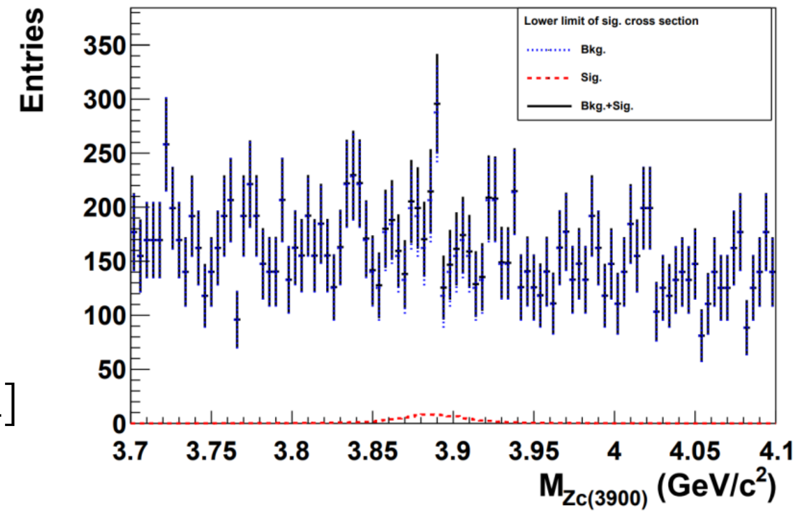




Exotic states	Production/decay processes	Detection efficiency	Expected events
$P_c(4312)$	$ep \to eP_c(4312)$ $P_c(4312) \to pJ/\psi$ $J/\psi \to l^+l^-$	$\sim$30%	15–1450
$P_c(4440)$	$ep \to eP_c(4440)$ $P_c(4440) \to pJ/\psi$ $J/\psi \to l^+l^-$	$\sim$30%	20–2200
$P_c(4457)$	$ep \to eP_c(4457)$ $P_c(4457)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

[1]





[1] C. Adolph, et. Al., COMPASS, Phys. Lett. B 742, 330 (2015)