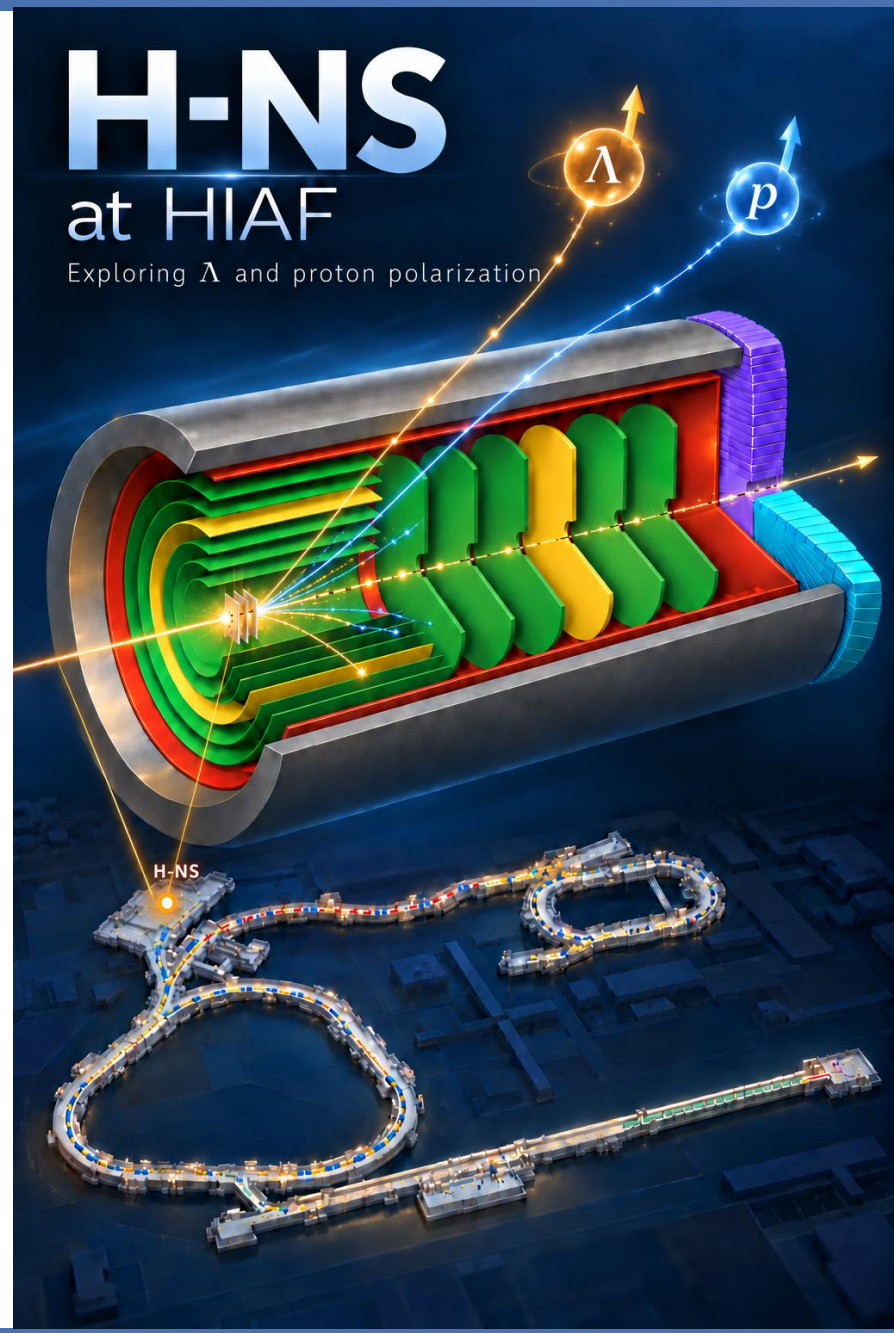
超子-核子谱仪
Hyperon-Nucleon Spectrometer at HIAF

Yuxiang Zhao

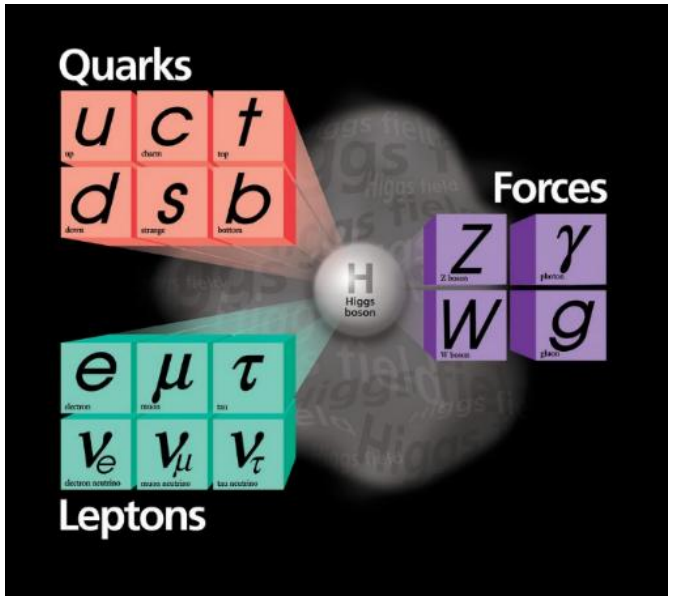
Institute of Modern Physics, CAS

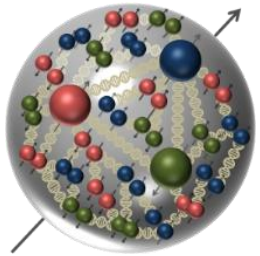


Outline

1. Introduction of highlighted physics
2. Hyperon-Nucleon Spectrometer (H-NS) at HIAF
3. Long range plan of high energy nuclear physics based on HIAF: from **H-NS** to **EicC**
4. Summary

Understand the Visible Matter: Hadrons





Spin structure?

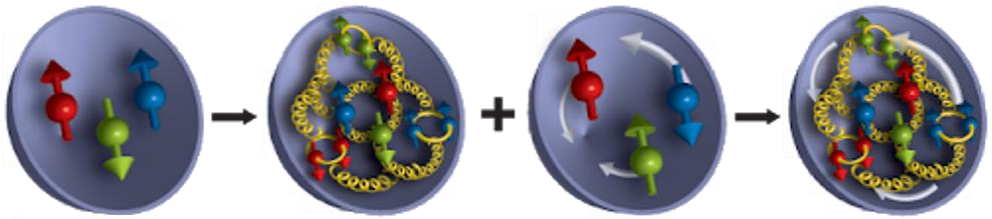


Origin of mass?

V.M.

Spin

Gell-Mann
Quark model



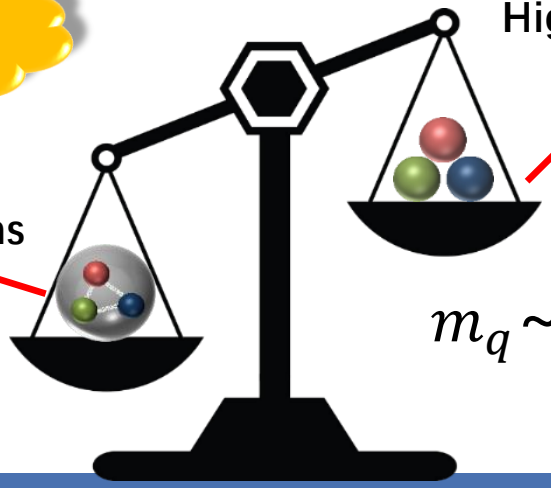
Mass

Higgs mechanism

Dynamics of gluons

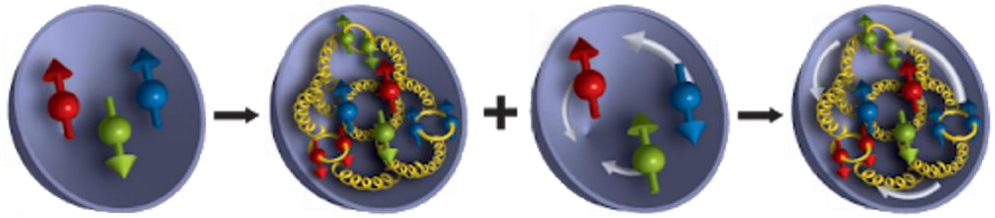
~99% m_p

m_q~1% m_p



About nucleon spin structure

1988 EMC experiment → "Spin crisis"

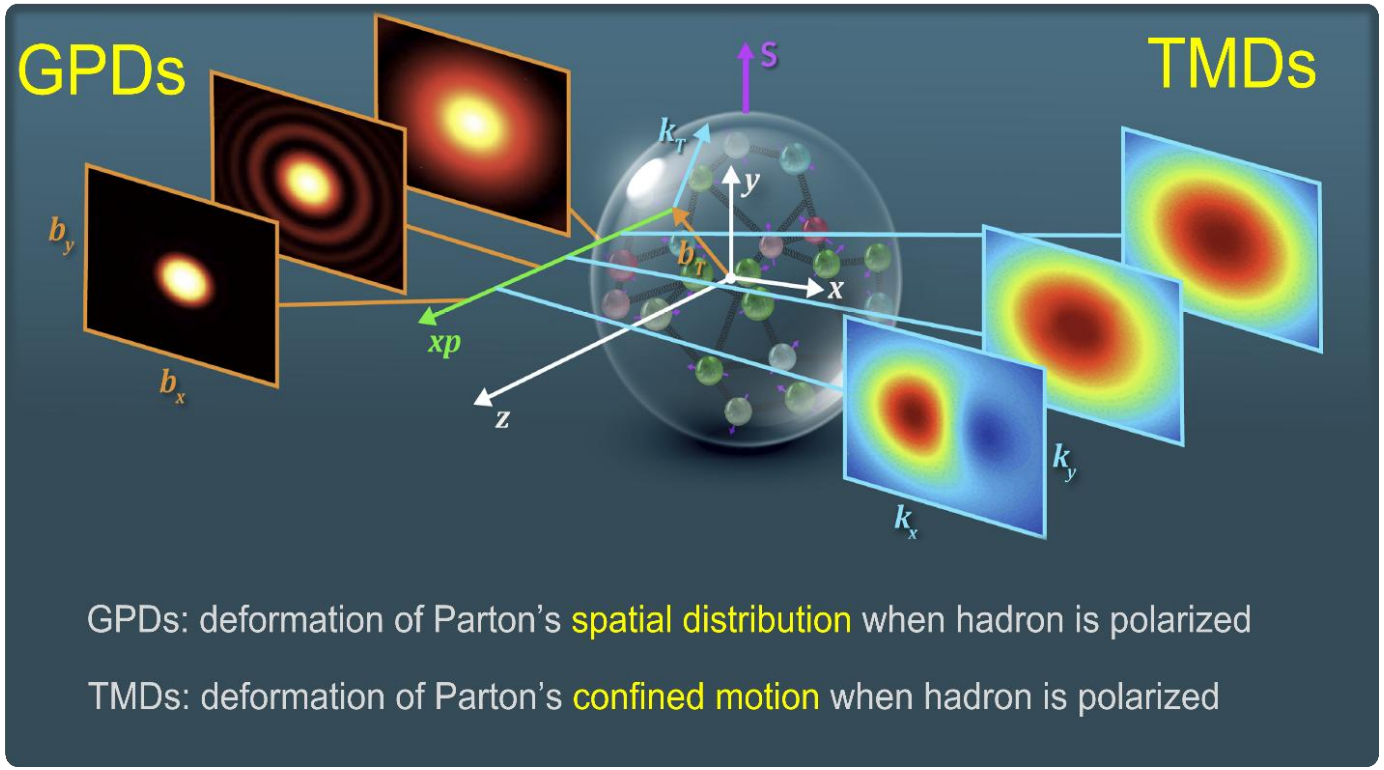


1970s 1980s/2000s Now

Spin decomposition:

$$S_{tot} = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \mathcal{L}_q + \mathcal{L}_g$$

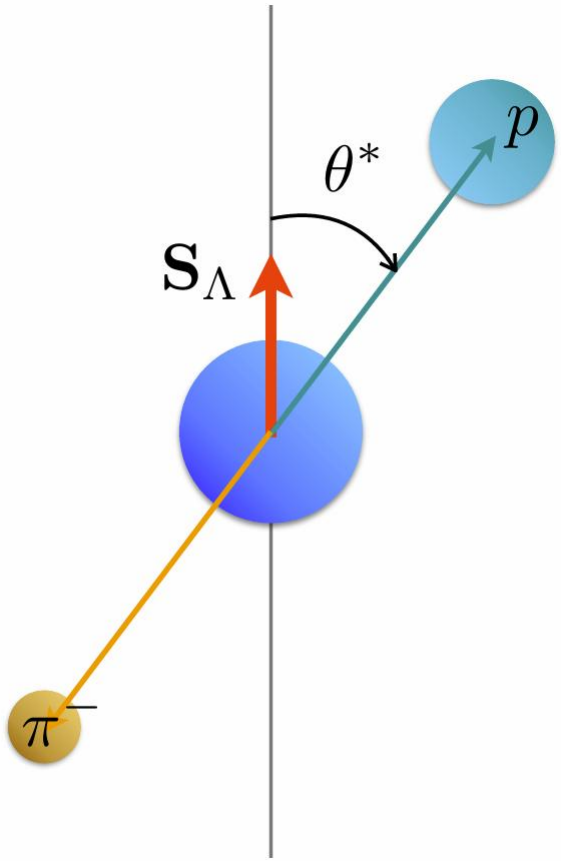
Quark spin | Gluon Spin | Quark OAM | Gluon OAM



- We have a framework for the understanding of the spin structure of the nucleon
- EIC/EicC is the future

From nucleon to hyperon

Λ^0 serves as its own spin analyzer through the decay $\Lambda^0 \rightarrow p + \pi^-$



Decay channel: $\Lambda \rightarrow p\pi^-$

branch ratio: $64.1 \pm 0.5\%$

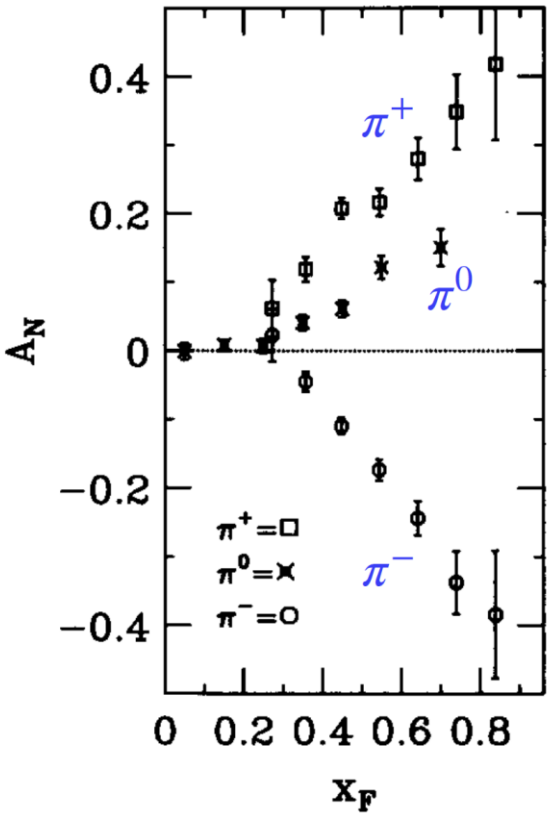
parity violating weak decay

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} \propto \mathcal{A}\left(1 + \alpha_\Lambda P_\Lambda \cos\theta^*\right)$$

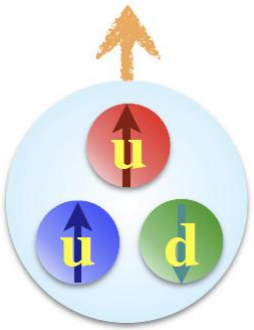
decay parameter: $\alpha_\Lambda = 0.748 \pm 0.007$

Relation of Λ polarization and nucleon spin structure – Liang-Boros model

$p^{\uparrow}p \rightarrow \pi X$



J. Antille *et al.*, PLB 94, 523 (1980)



VOLUME 79, NUMBER 19 PHYSICAL REVIEW LETTERS 10 NOVEMBER 1997

Hyperon Polarization and Single Spin Left-Right Asymmetry in Inclusive Production Processes at High Energies

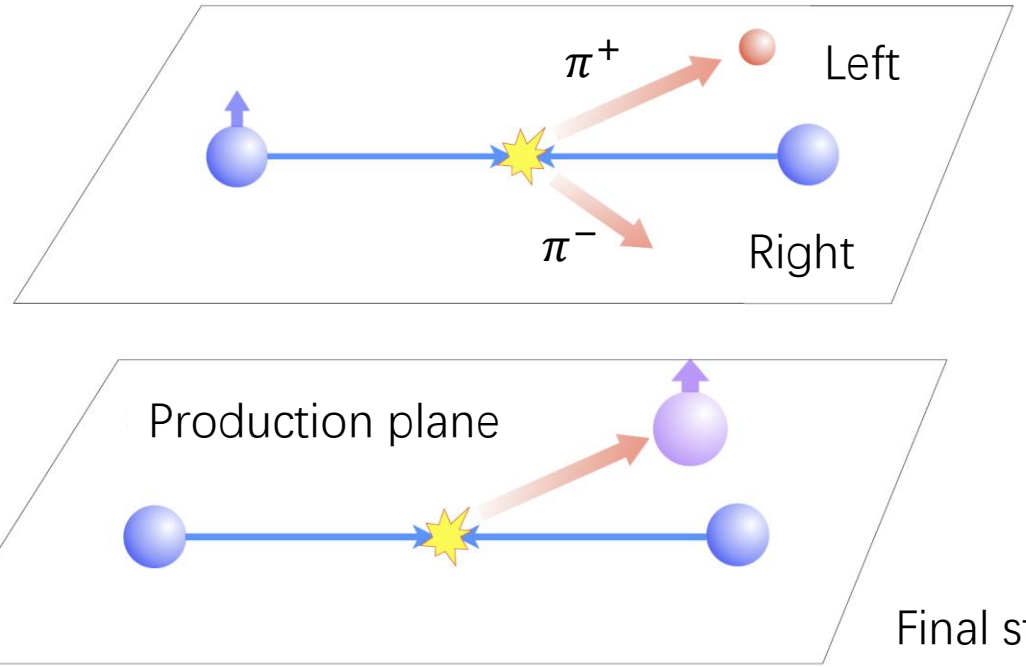
Liang Zuo-tang[1] and C. Boros[2,3]

[1]*Department of Physics, Shandong University, Jinan, Shandong 250100, China*

[2]*Institut für Theoretische Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany*

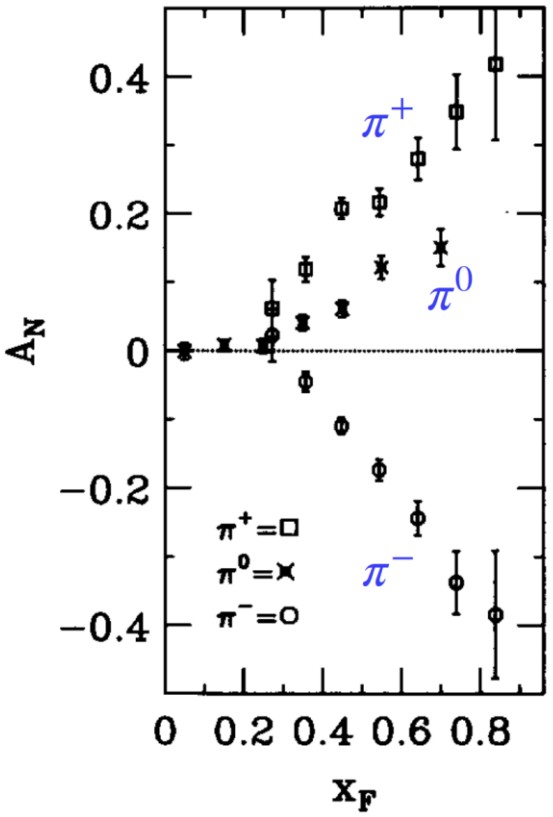
[3]*Special Research Centre for the Subatomic Structure of Matter, University of Adelaide, Adelaide, Australia 5005*

(Received 16 May 1997)



Relation of Λ polarization and nucleon spin structure – Liang-Boros model

$p^{\uparrow}p \to \pi X$



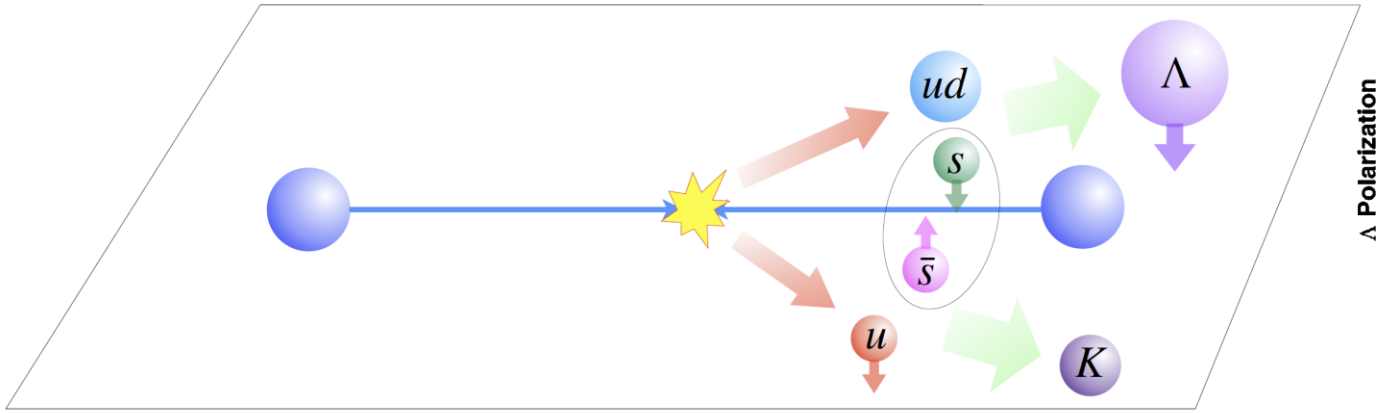
J. Antille *et al.*, PLB 94, 523 (1980)

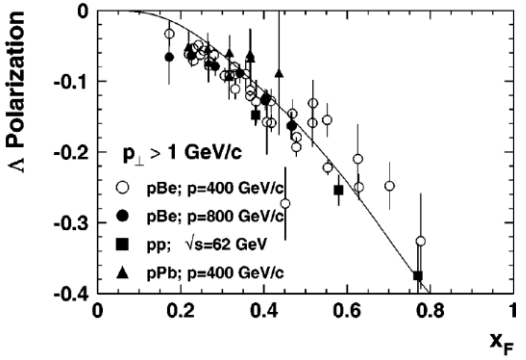
VOLUME 79, NUMBER 19 PHYSICAL REVIEW LETTERS 10 NOVEMBER 1997

Hyperon Polarization and Single Spin Left-Right Asymmetry in Inclusive Production Processes at High Energies

Liang Zuo-tang[1] and C. Boros[2,3]
[1]*Department of Physics, Shandong University, Jinan, Shandong 250100, China*
[2]*Institut für Theoretische Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany*
[3]*Special Research Centre for the Subatomic Structure of Matter, University of Adelaide, Adelaide, Australia 5005*
(Received 16 May 1997)

Correlation of quark spin and momentum → Essential part of nucleon 3D imaging

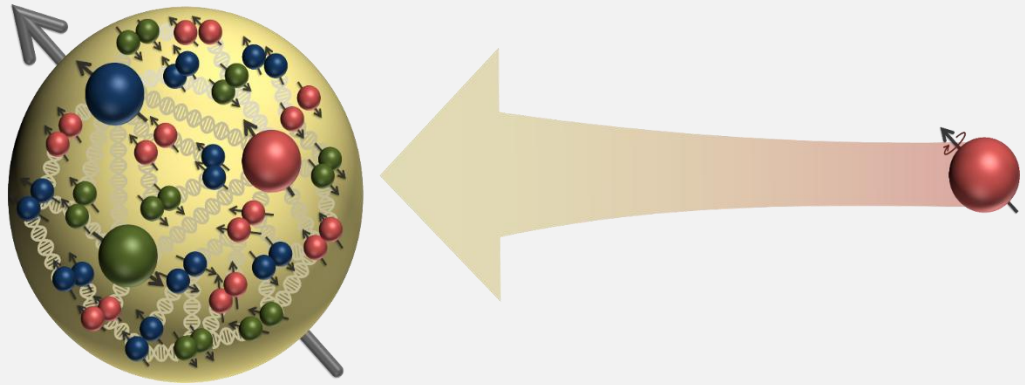




Refer to Tianbo Liu's talk in August H-NS workshop (NKU)

EicC

Nucleon spin structure: **Initial state** is polarized
-How do partons form up a polarized nucleon?

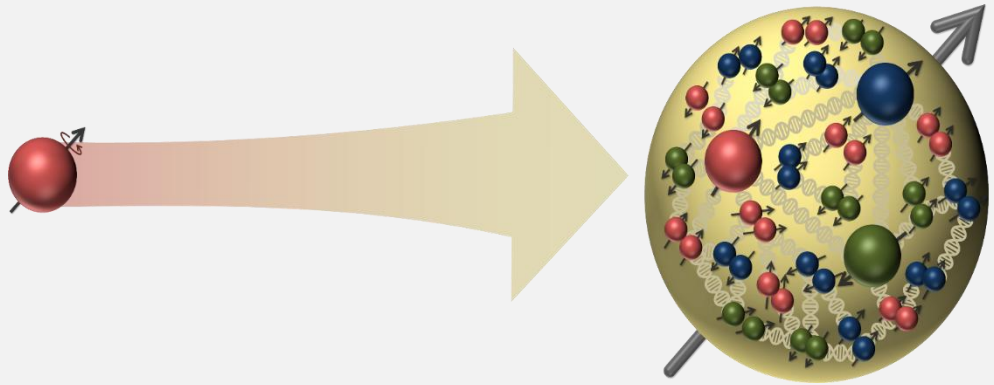


Initial state

Polarized by device

Hyperon-Nucleon Spectrometer

Λ polarization: **Final state** is polarized
-How do partons form up a polarized Λ?



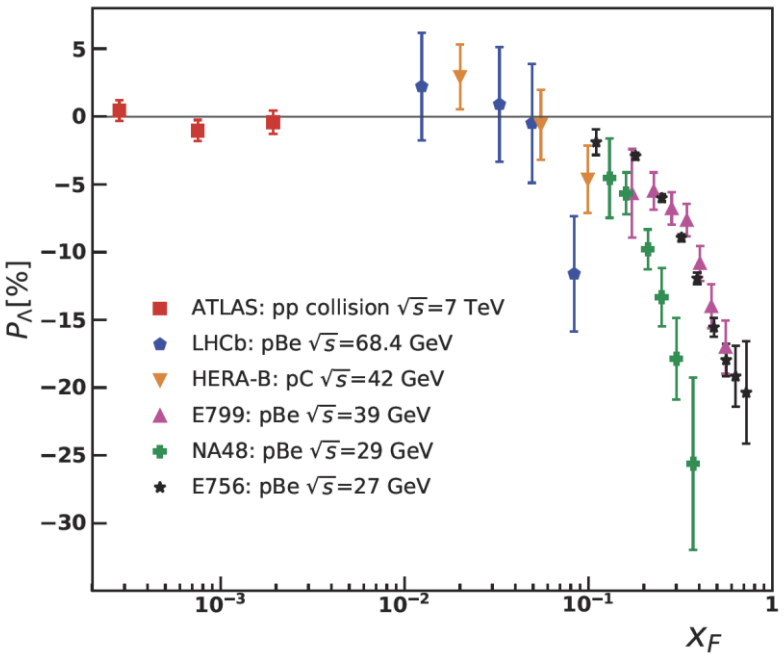
Final state

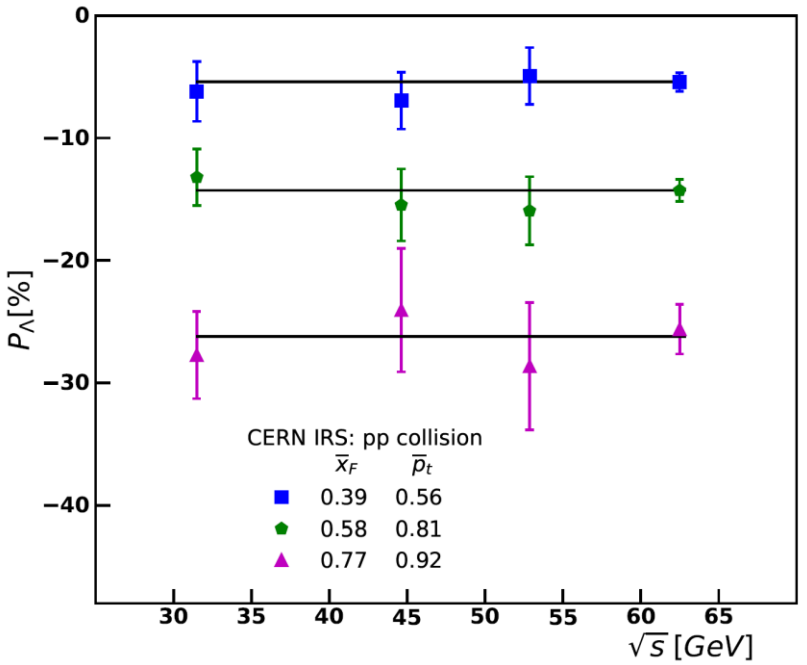
Λ serves as its own spin analyzer through the decay $\Lambda^0 \rightarrow p + \pi^-$

Understand Baryon spin structure

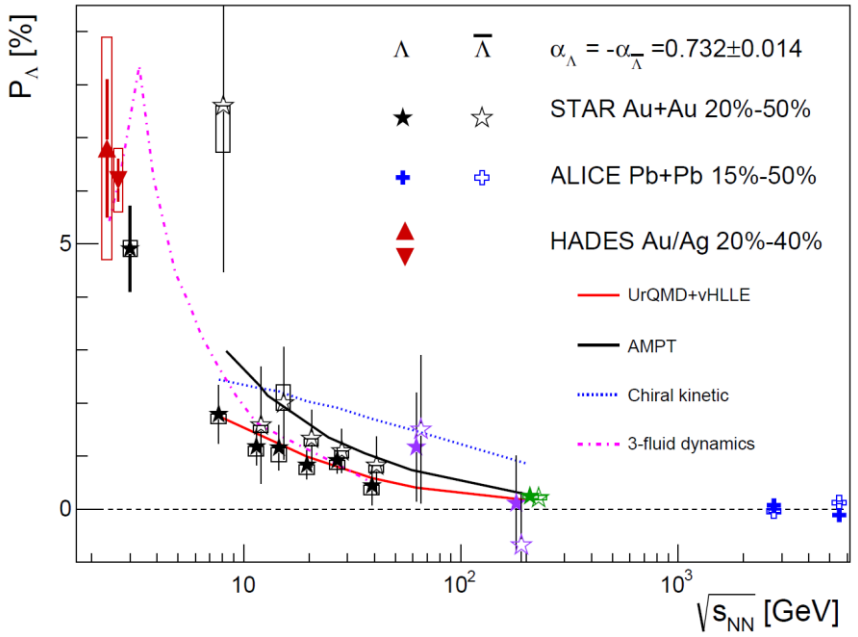
Λ polarization measurements

Transverse polarization





Global polarization

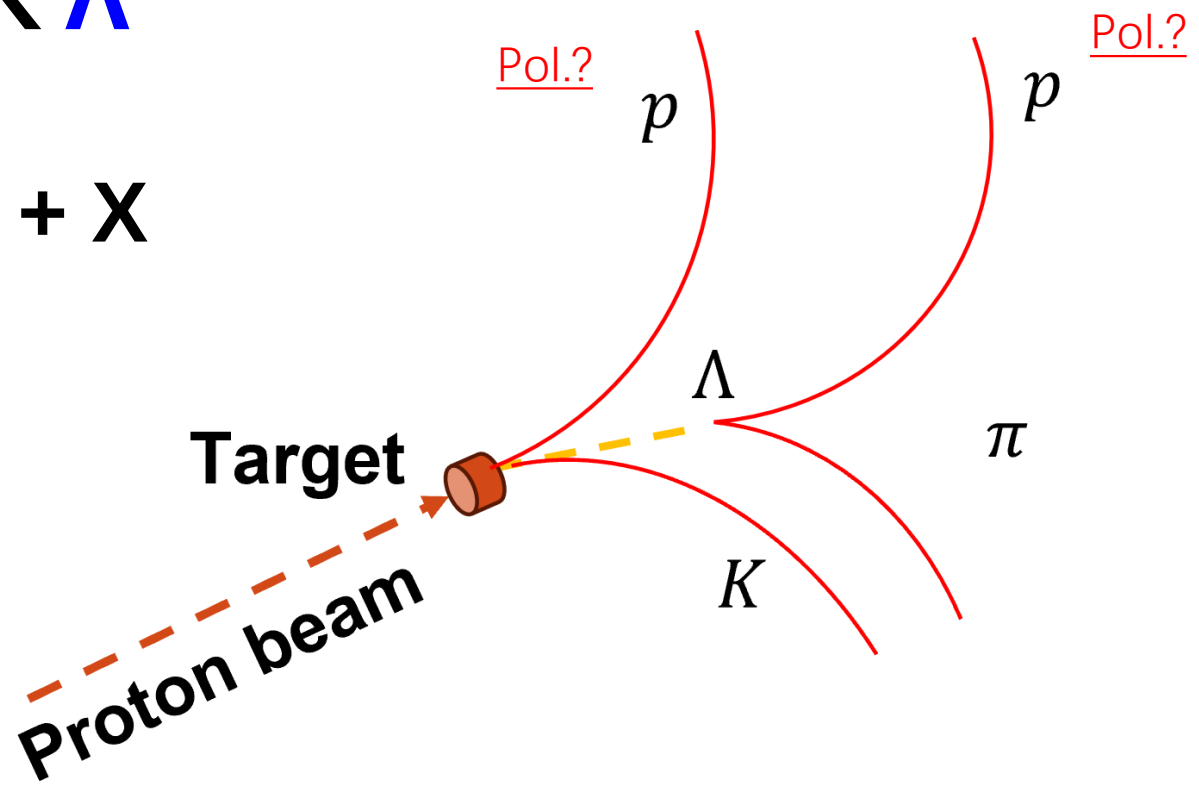


1) Strong transverse polarization of Λ at large x_f in its production frame; scaling behavior?
2) Global polarization increases as the collision energy decreases

An interesting question: Is proton polarized?

pp → p K Λ

pp → p/Λ + X



Outline

1. Introduction of highlighted physics
2. Hyperon-Nucleon Spectrometer (H-NS) at HIAF
3. Long range plan of high energy nuclear physics based on HIAF: from **H-NS** to **EicC**
4. Summary

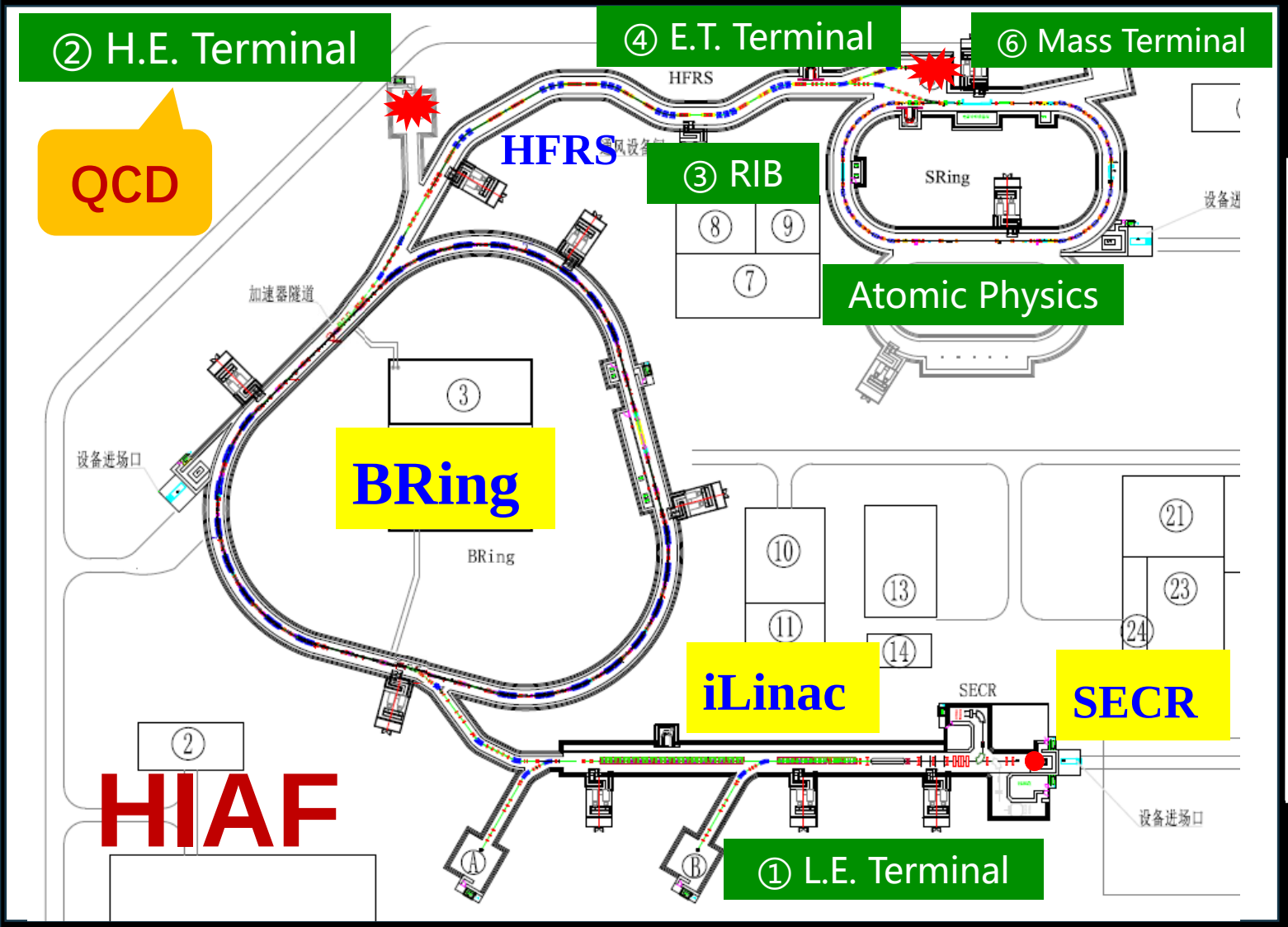
强流重离子加速器装置 （Huizhou，Guangdong）

High Intensity Heavy-ion Accelerator Facility (HIAF)



High Intensity heavy-ion Accelerator Facility

(HIAF, Huizhou, China)



HIAF Physics：

(i) Atomic physics;
(ii) Nuclear physics;
(iii) Applied research in biology and material science etc.

低能综合研究终端

HIAF Commission started in 2025



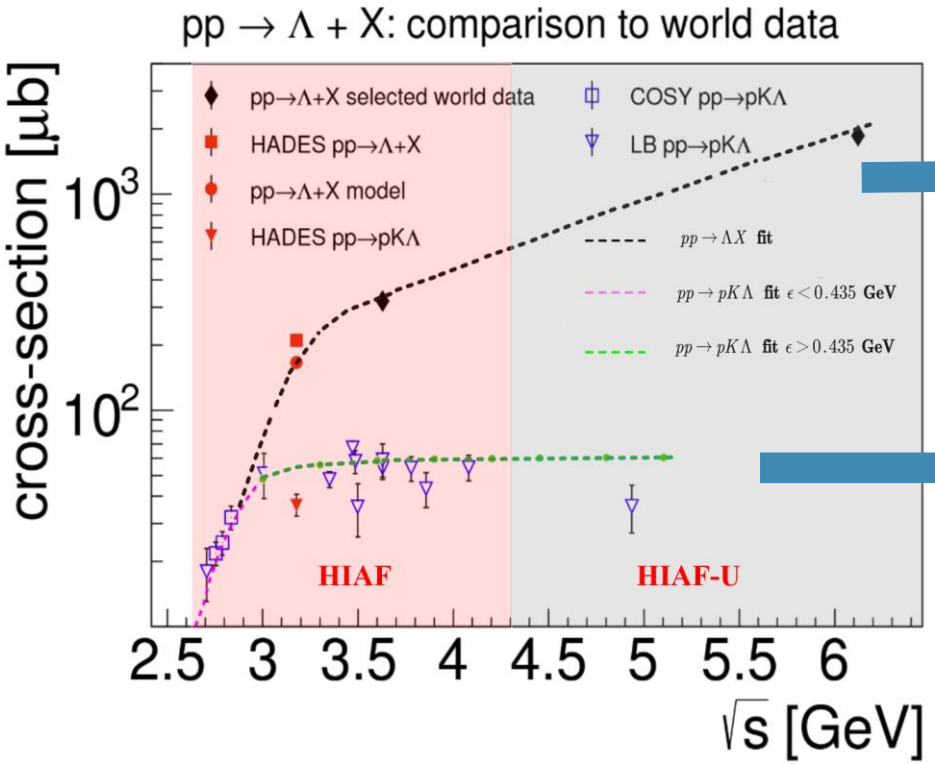
Science
Volume 390, Issue 6773
Nov 2025

HIAF beam parameters

Ion species	Kinetic Energy (GeV/u)	Beam intensity (ppp)
p	9.3	6.0×10^{12}
$^{16}O^{8+}$	4.25	6.0×10^{11}
$^{18}O^{6+}$	2.6	6.0×10^{11}
$^{78}Kr^{19+}$	1.7	3.0×10^{11}
$^{209}Bi^{31+}$	0.85	1.2×10^{11}
$^{238}U^{35+}$	0.835	1.0×10^{11}
$^{238}U^{78+}$	2.6	1.0×10^{10}

Rich hadron physics and heavy ion physics

- across energy region and collision system

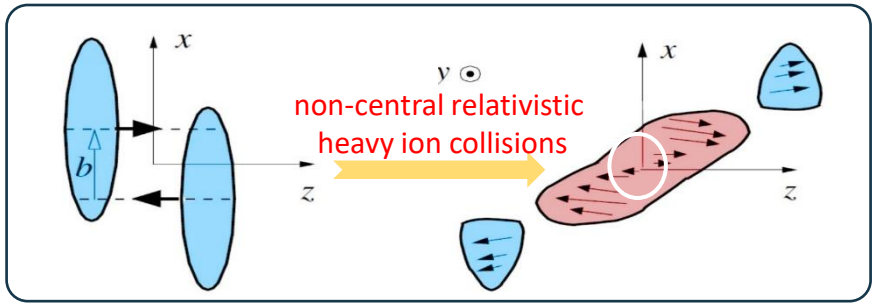


$pp(A) \rightarrow \Lambda + X$ **polarization through hadronization**

Zuo-tang Liang, and C. Boros, Phys. Rev. Lett. 79, 3608 (1997); PRD 61, 117503 (2000).
H. Dong and Zuo-tang Liang, PRD 70, 014019 (2004); PRD 72, 033006 (2005).

$pp \rightarrow \mathrm{p} + \mathrm{K} + \Lambda$ **polarization through intermediate state**

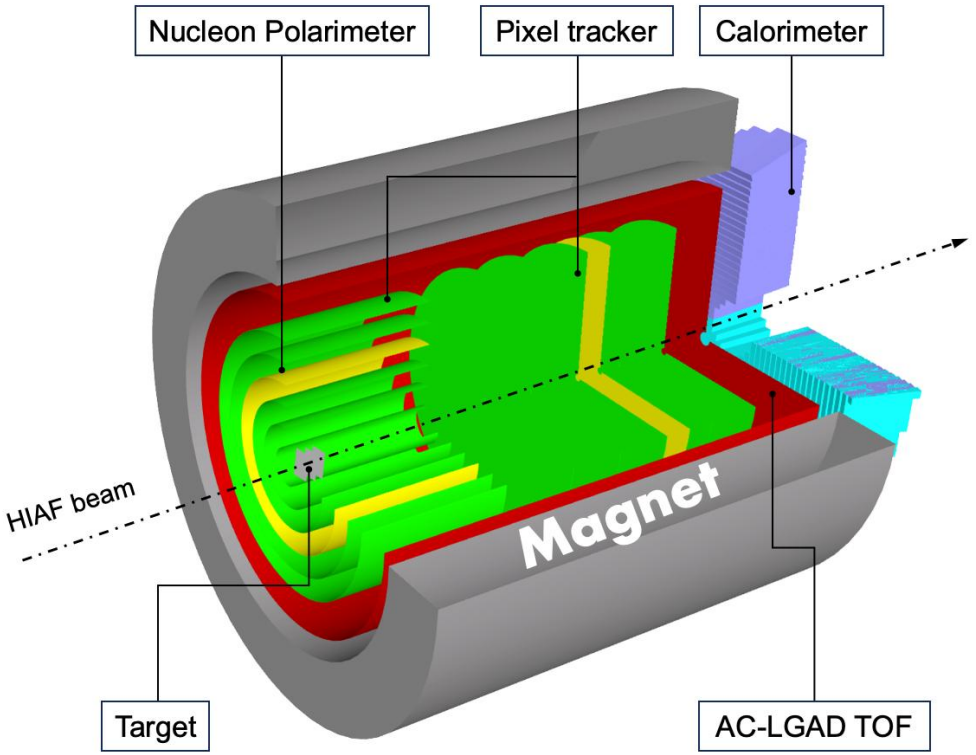
R. Machleidt, K. Holinde and C. Elster, Phys. Rept. 149, 1 (1987).
B. C. Liu, B. S. Zou, PRL 96, 042002 (2006).



$AA \rightarrow \Lambda + \mathrm{X}$ **global polarization**

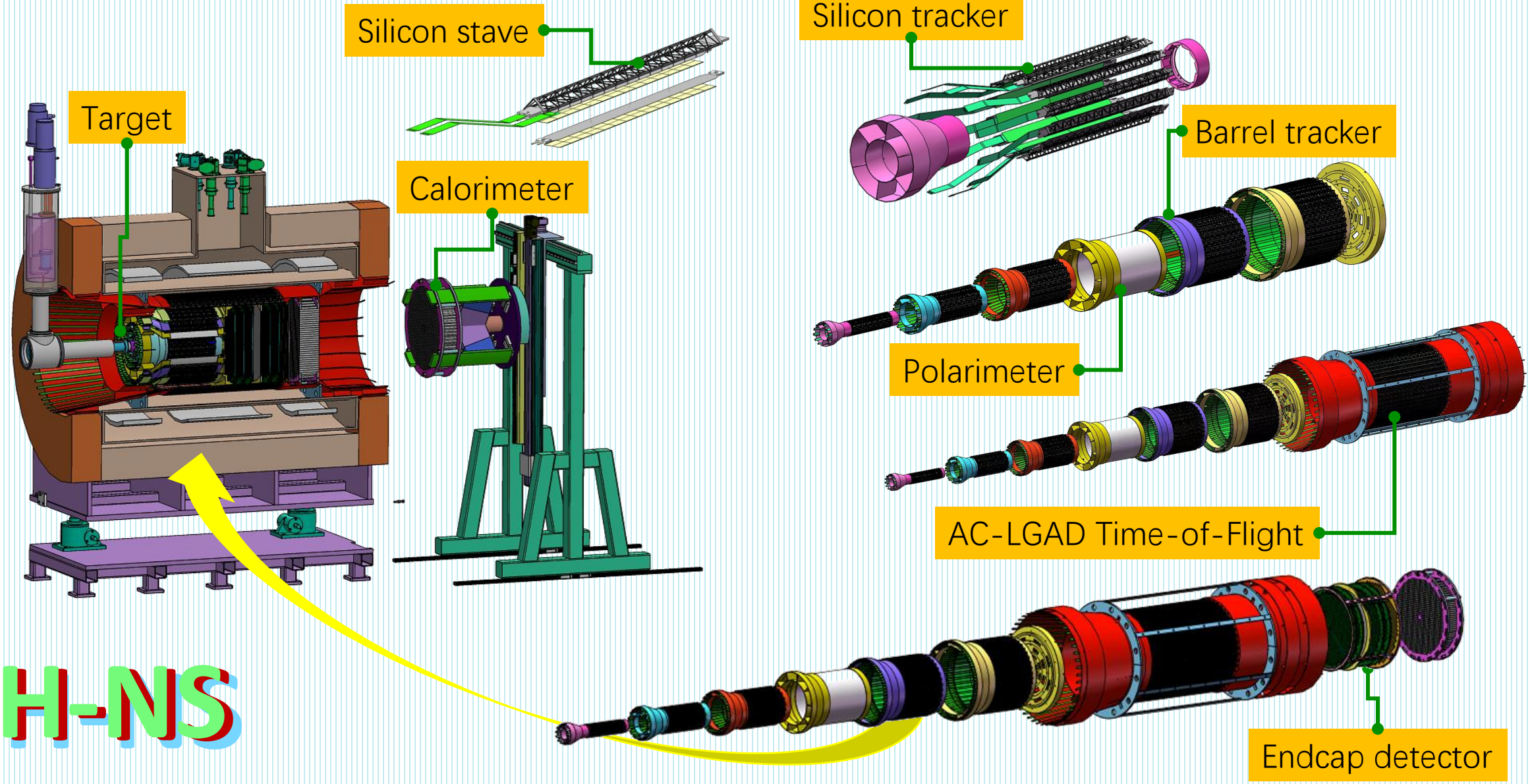
Zuo-Tang Liang, Xin-Nian Wang, PRL 94,102301 (2005); PLB 629, 20 (2005).
Jian-Hua Gao, Shou-Wan Chen, Wei-tian Deng, Zuo-Tang Liang, Qun Wang, Xin-Nian Wang, PRC 77, 044902 (2008).

Hyperon-Nucleon Spectrometer (H-NS) at HIAF



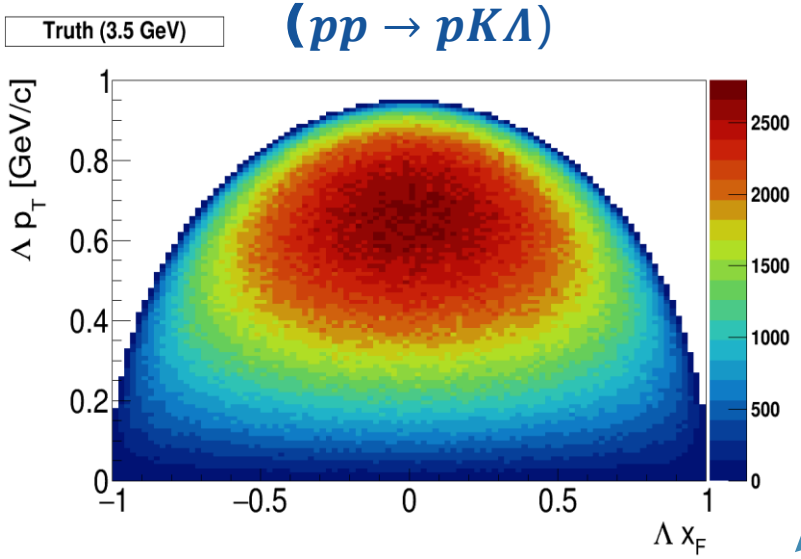
Subsystem / Category	Parameter	Design Requirement
Tracker & Vertex	Momentum resolution ($\Delta p/p$)	~2% @ 1 GeV/c
	Vertex resolution (σ_{vtx})	< 500 μm
	Material budget (per layer)	< 0.5% X/X_0
PID Detector	π/K separation	3σ up to 2 GeV/c
	p/K separation	3σ up to 5 GeV/c
ECal	Spatial resolution	~3 mm
	Energy resolution	3%/ $\sqrt{E}$
Others	Polar angle acceptance (θ)	5° to 100°
	Event rate capability	Up to 1 MHz (fast, radiati
	Baryon polarimeter target	Thin carbon foil (for protc

H-NS: A Conceptual Design

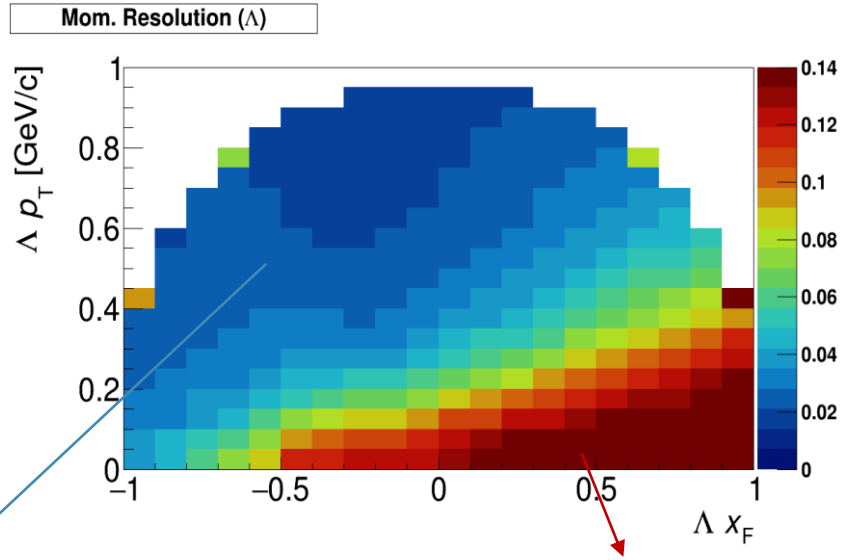


H-NS performance

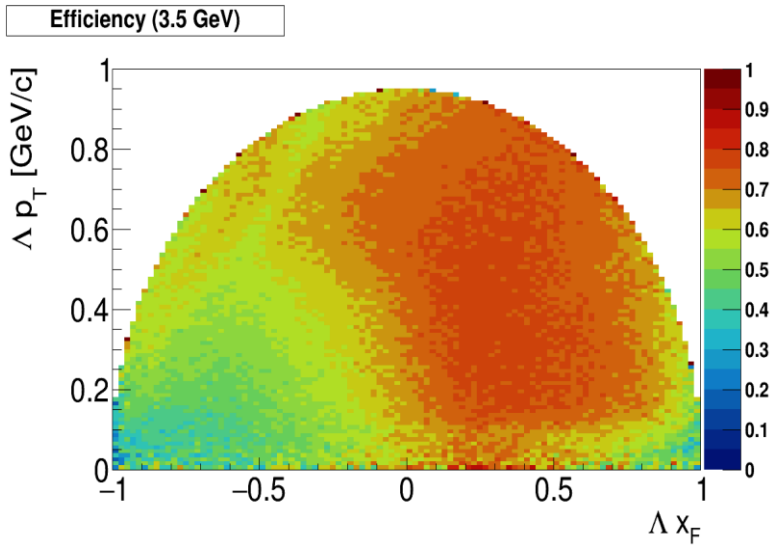
Signal distribution ($pp \rightarrow pK\Lambda$)

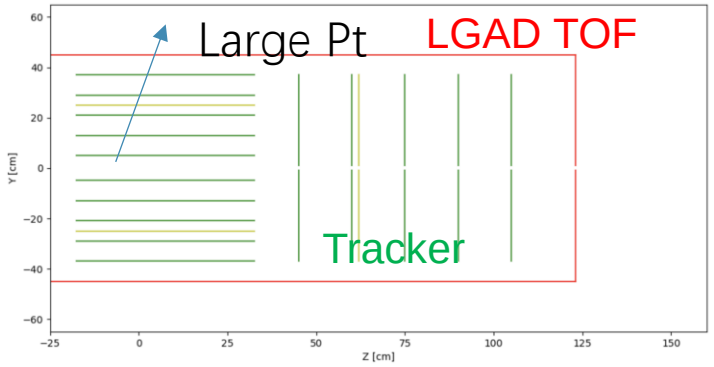


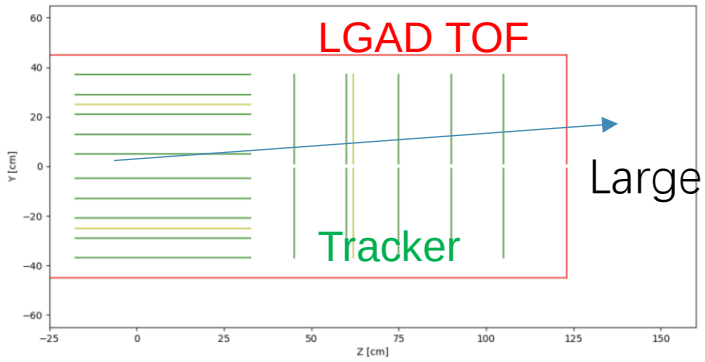
Momentum resolution



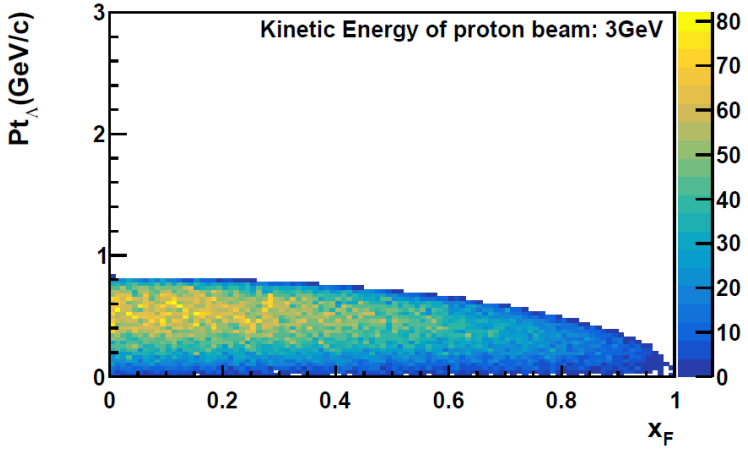
Reconstruction efficiency

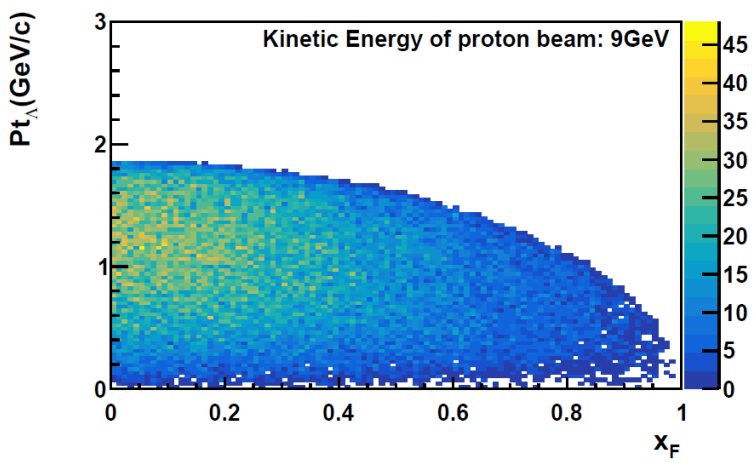


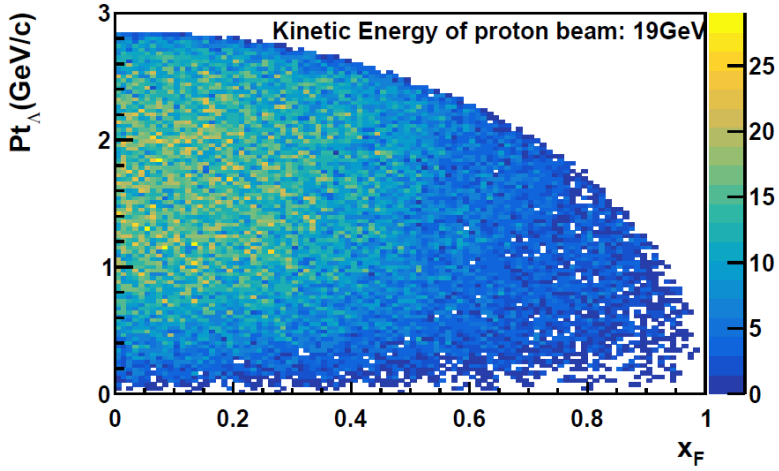




The opportunity of H-NS







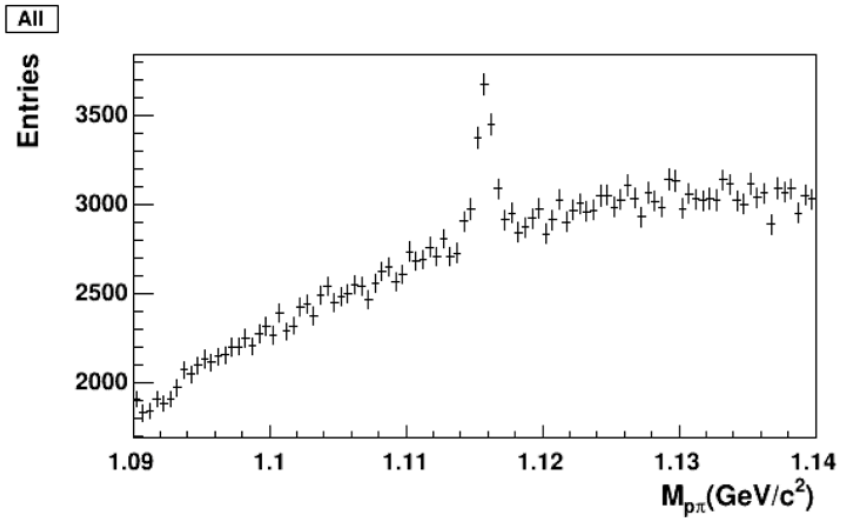
3 GeV → 9 GeV → 20 GeV → 32 GeV (?)

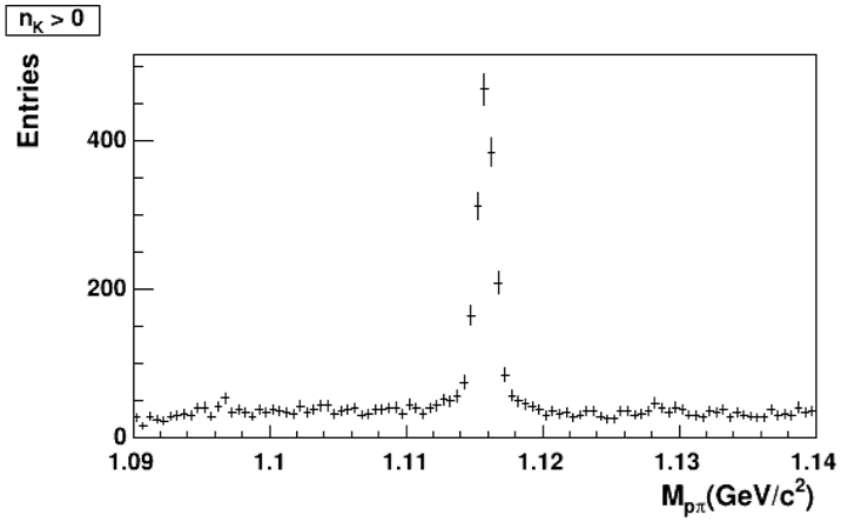
Allow for a multi-dimensional mapping of the Λ^0 polarization and production

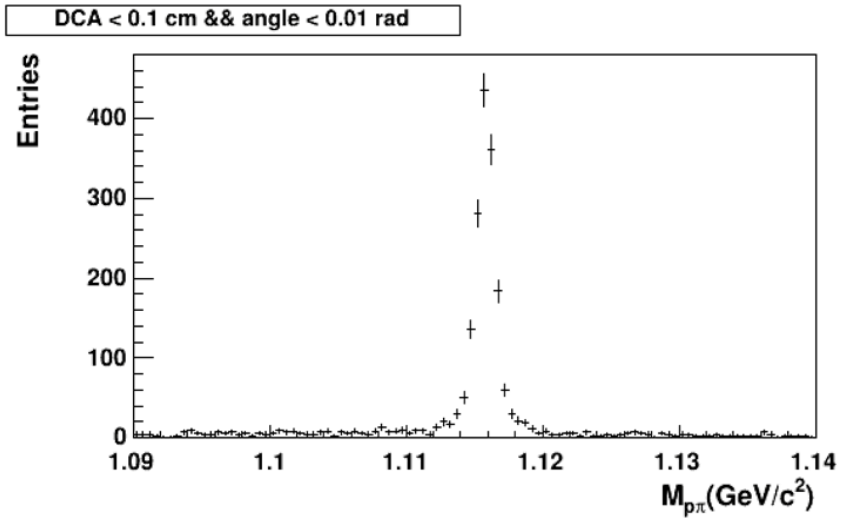
1. Beam energy scan
2. p→p, p→A, A→A data taking

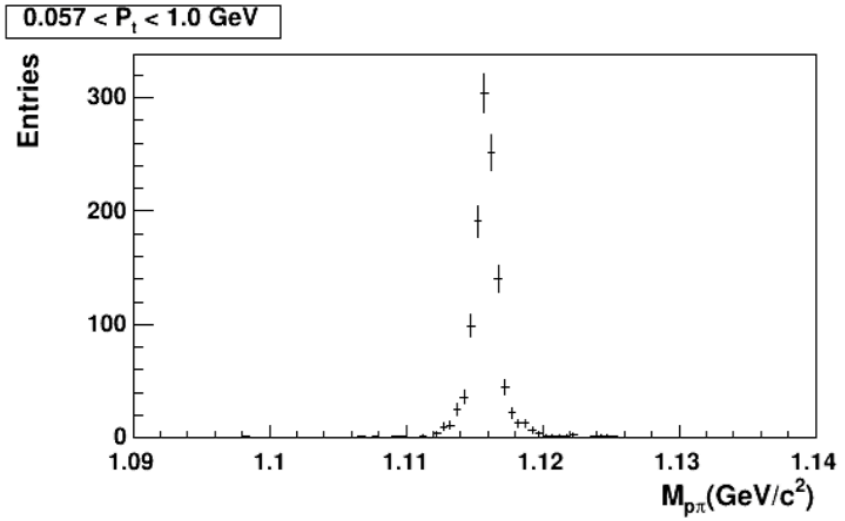
H-NS Λ reconstruction

$pp \rightarrow pK\Lambda$: Low background + High efficiency

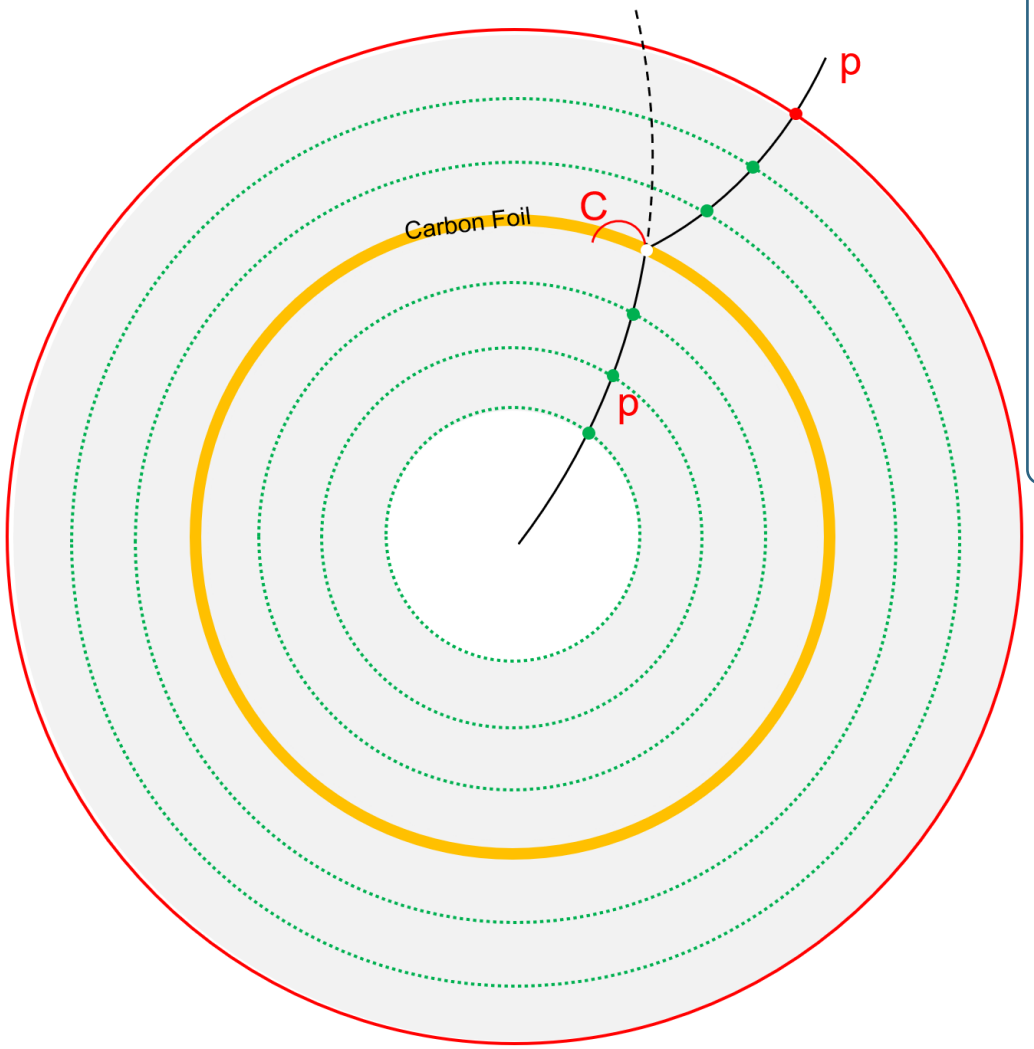




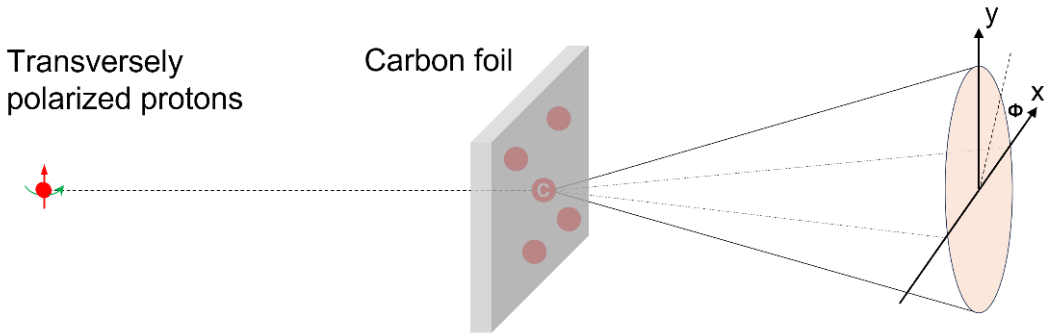


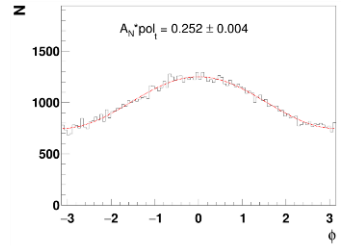


Baryon polarimeter: determining proton polarization via elastic scattering



$$\frac{d\sigma}{d\phi d\cos\theta} = \frac{1}{2\pi}\frac{d\sigma_0}{d\cos\theta}\left[1 + P_y A_N(\theta)\cos\phi\right]$$



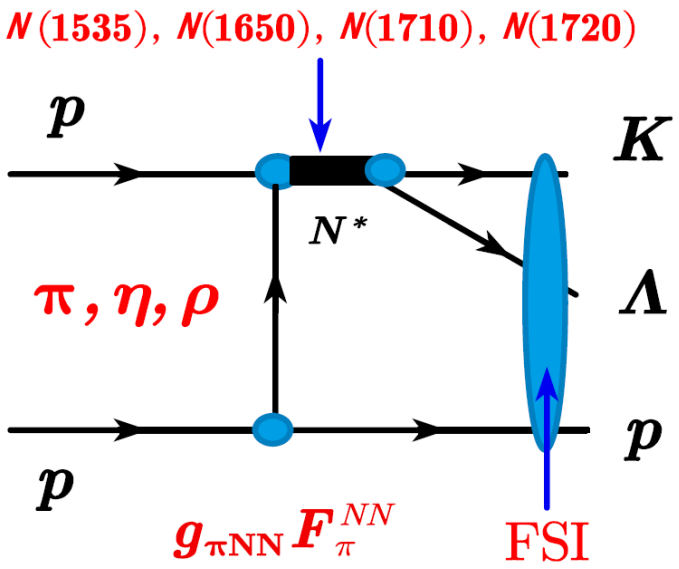


More protons to the left:
Left-right asymmetry

- **Carbon Foil layer**
  - **~1 mm thickness**
  - **Material budget: <1% X/X_0**
  - **Probability: pC (1E-3)**
- **Position : in-between the tracking devices**

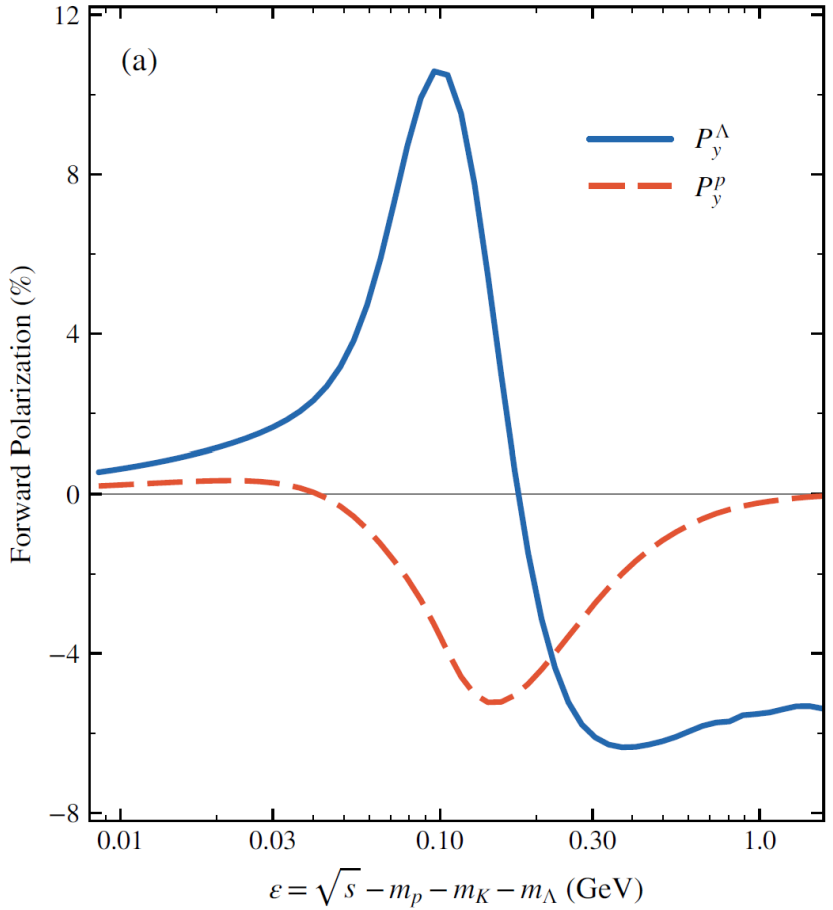
Y. T. Liang et. al. Phys. Rev. D 112, L031502 (2025)

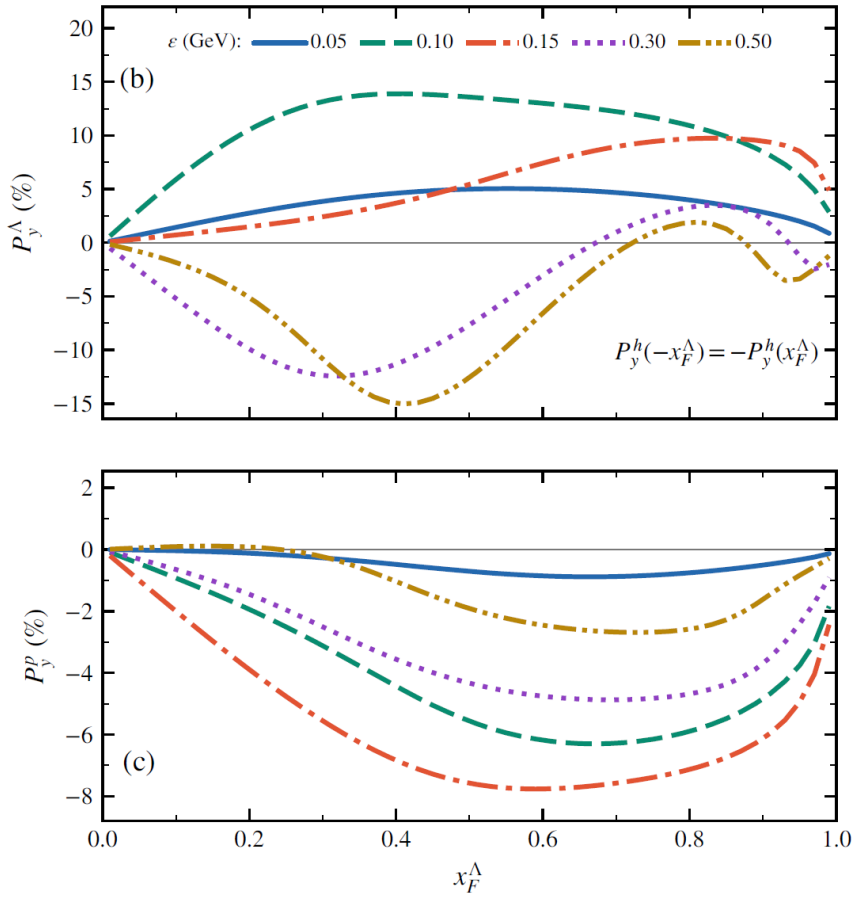
Proton is predicted to be polarized at HIAF



B. S. Zou, et. al.

Zhe Zhang, to be published





Projection of Λ polarization measurements

H-NS projection

Reaction: p+p

Beam time: 3 months

pp → Λ+X N ~ 10^{11}

pp → p+X N ~ 10^{13}

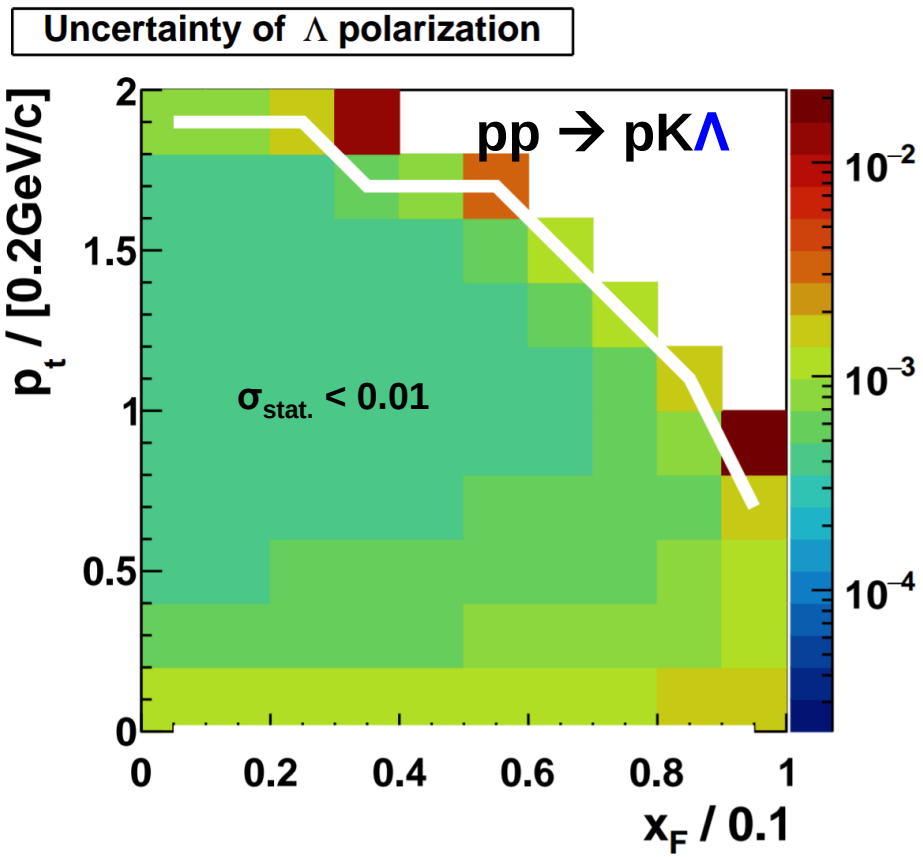
pp → pKΛ N ~ 10^{10}

Beam energy scan
pp/pA/AA data taking

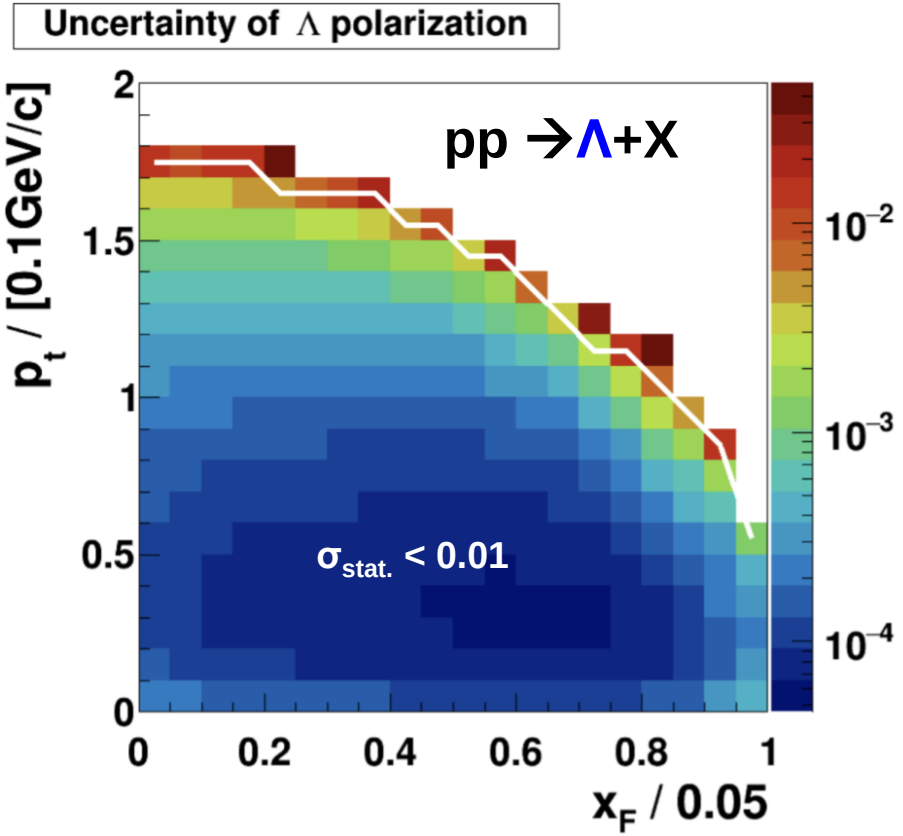
$\sigma_{stat.}$ < 0.01 for Λ 100 bins

$\sigma_{stat.}$ < 0.01 for Λ 400 bins

Exclusive measurement



Inclusive measurement



Projection of proton polarization measurements

H-NS projection

Reaction: p+p

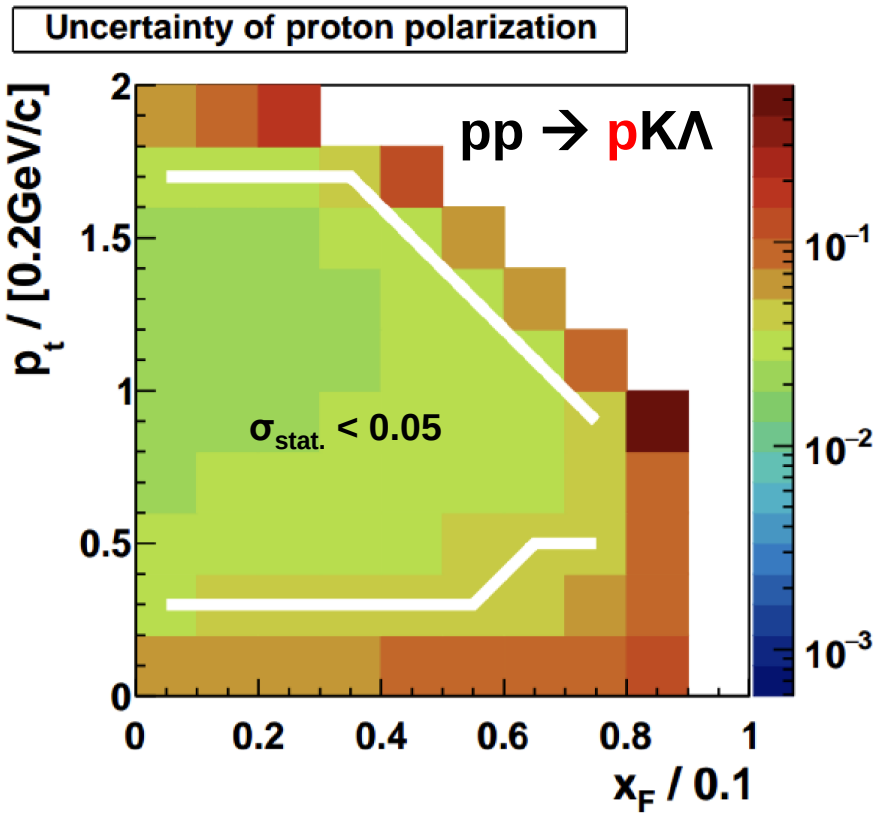
Beam time: 3 months

- pp → Λ+X N ~ 10^{11}
- pp → p+X N ~ 10^{13}
- pp → pKΛ N ~ 10^{10}

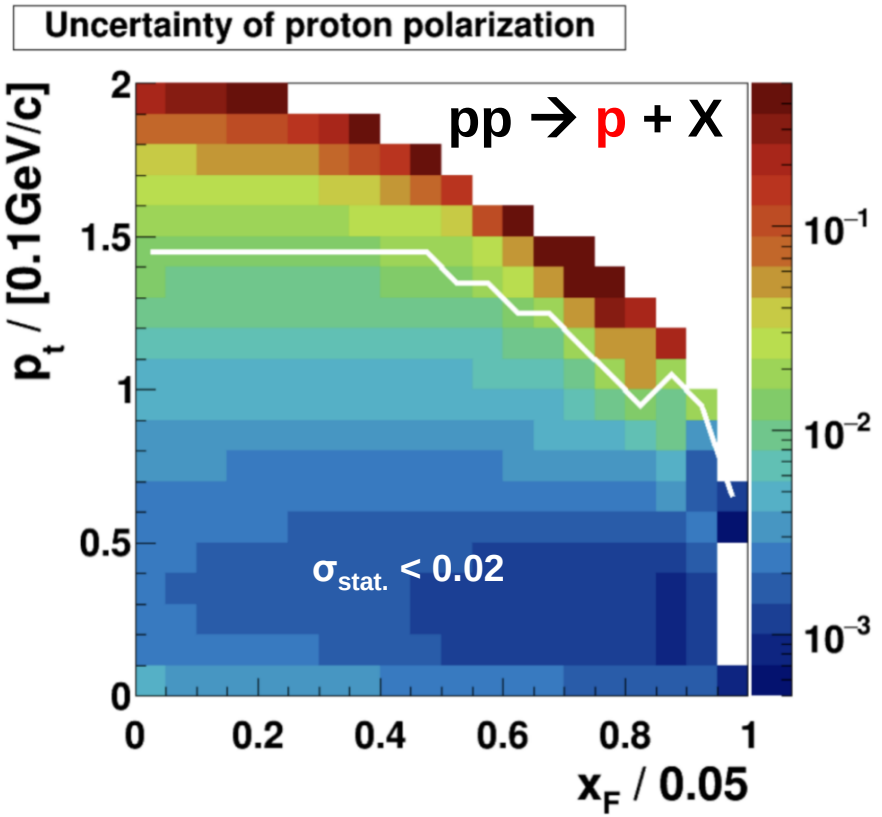
Beam energy scan
pp/pA/AA data taking

$\sigma_{stat.}$ < 0.05 for p 100 bins $\sigma_{stat.}$ < 0.02 for p 400 bins

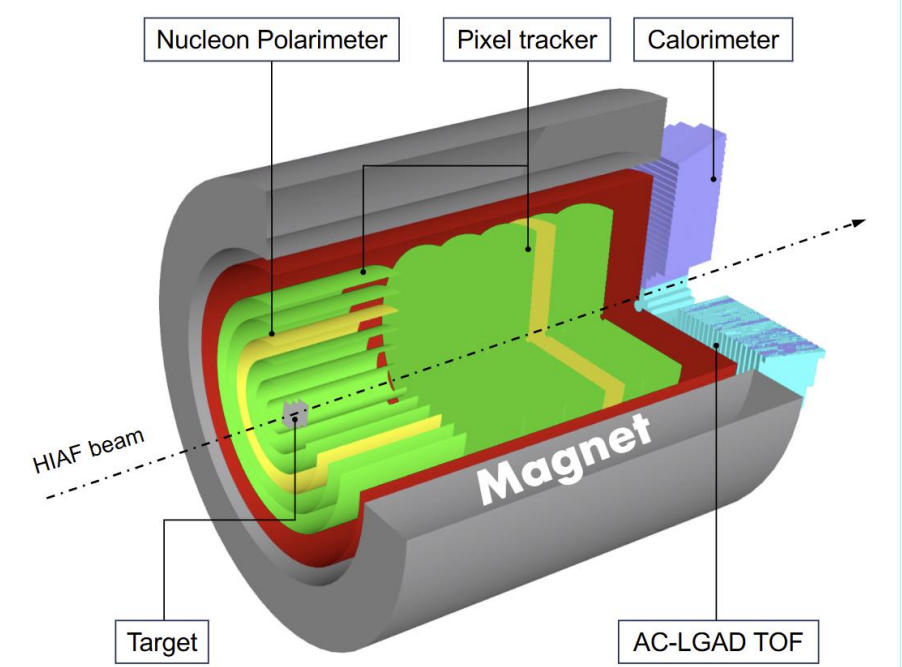
Exclusive measurement



Inclusive measurement



Hyperon-Nucleon Spectrometer (H-NS)



Participating Institute (30):

BNU, BUAA, **CCNU**, CIAE, **CUHK-SZ**, ECNU, **FDU**, HFUT, HMFL, HTU, HZU, IHEP-CAS, **IMP-CAS**, ITP-CAS, LZU, NKU, NWPU, PKU, **SCNU**, **SDU**, SHNU, SYSU, **THU**, UCAS, **USTC**, WHU, XBMU, XJTU, YNU, ZZU

H-NS Whitepaper: 2606.06553

I. Physics:

- Λ production and polarization ($p+p$)
  - Medium effect ($p+A$)
  - Global polarization of Λ hyperon ($A+A$)
- Hadron physics via $p+p$ (with polarization as extra constraints)

II. Community:

- Supports both communities of hadron structure and heavy-ion physics
- International participation: Germany, Japan

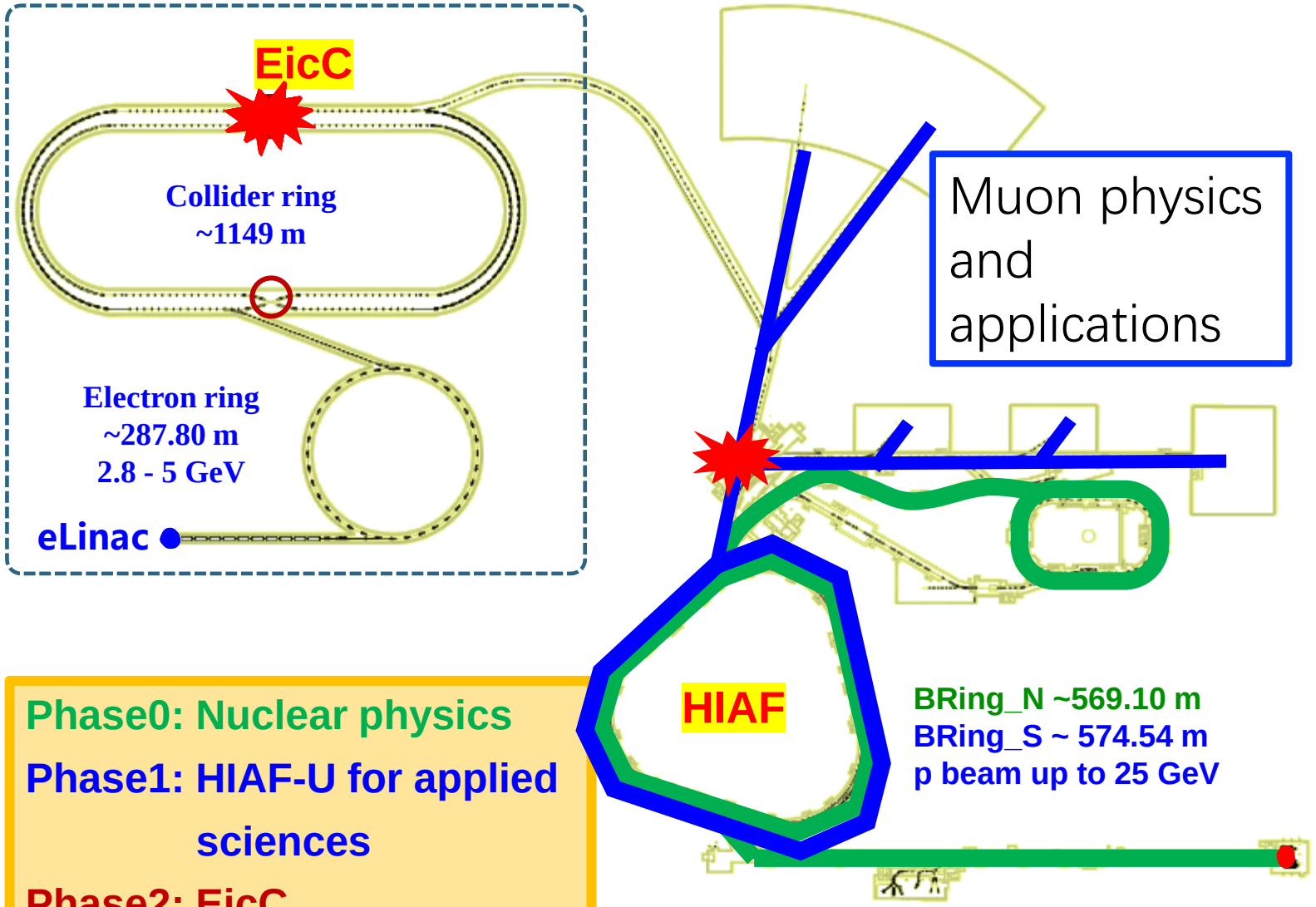
III. Detector R&D:

- Many parts are similar for CEPC, EicC, H-NS, and STCF. Save resources!
- H-NS: a detector R&D platform for EicC (½ EicC)

Outline

1. Introduction of highlighted physics
2. Hyperon-Nucleon Spectrometer (H-NS) at HIAF
3. Long range plan of high energy nuclear physics based on HIAF: from **H-NS** to **EicC**
4. Summary

HIAF and its upgrade plan



Phase0: Nuclear physics

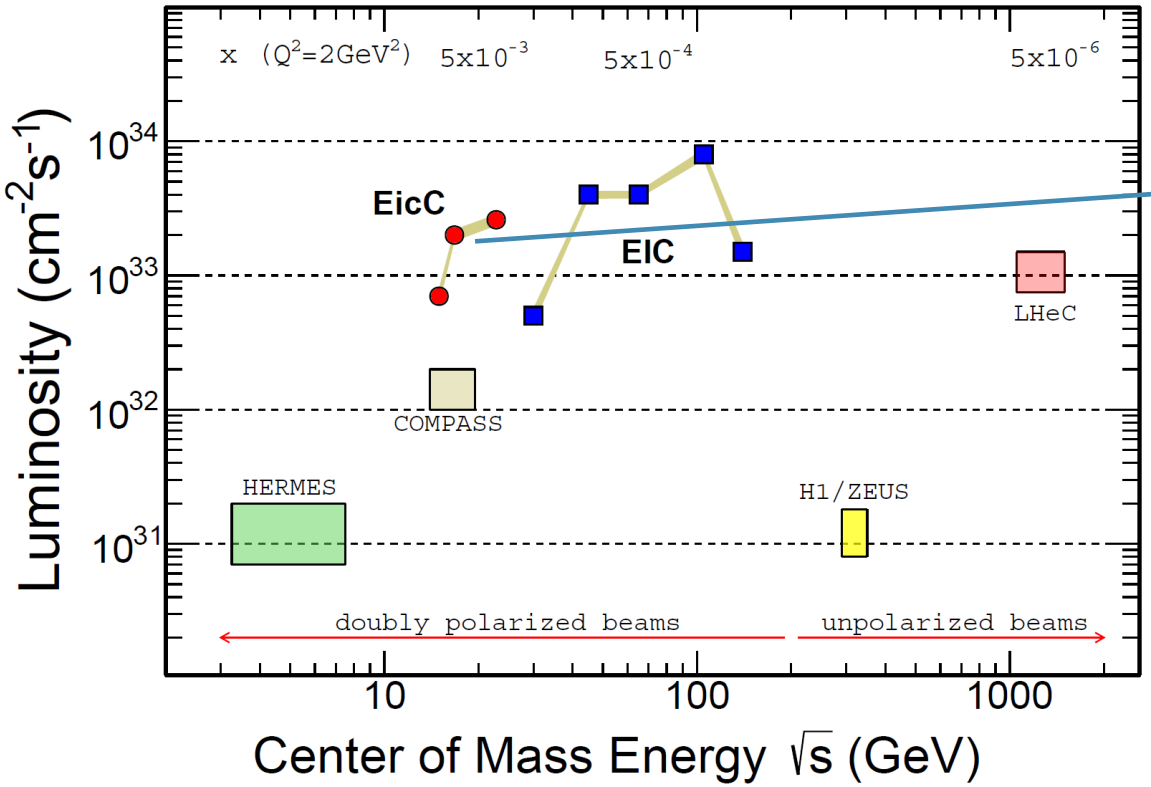
Phase1: HIAF-U for applied sciences

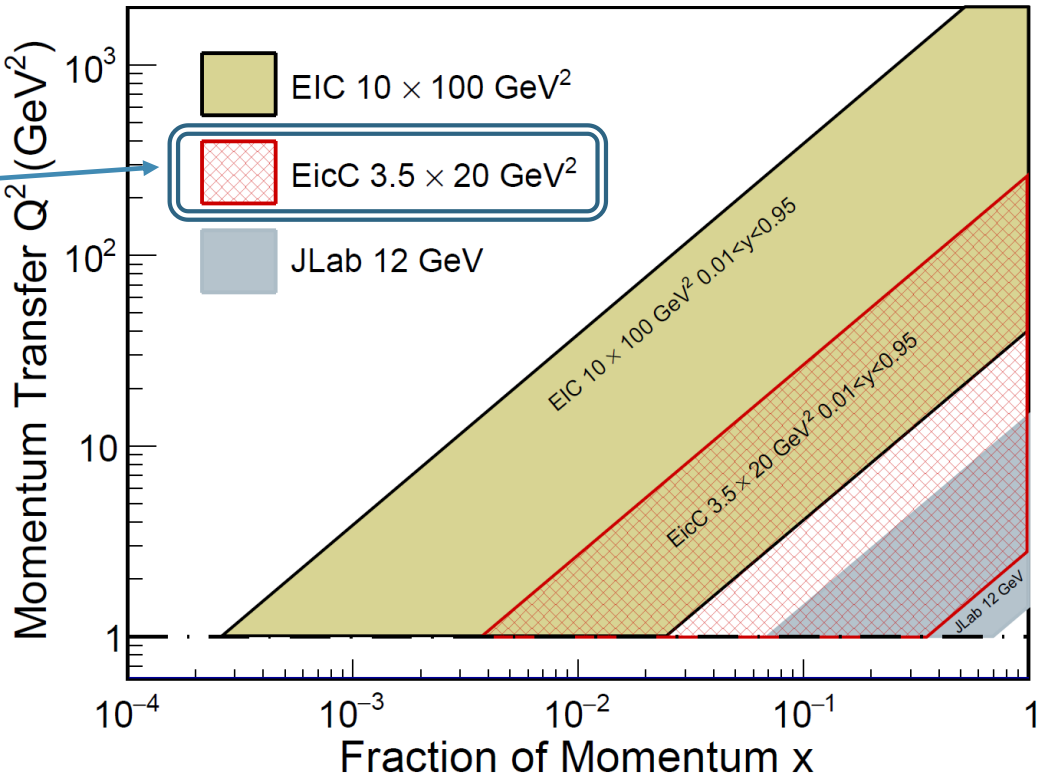
Phase2: EicC

EicC beam parameters

Parameter	electron	proton
Circumference (m)	1151	1149
Kinetic energy (GeV)	3.5	19.08
CM energy (GeV)	**16.76**	
$f_{collision}$ (MHz)	100	
Polarization	80%	70%
Bunch intensity (x10^{11})	1.7	1.05
$\varepsilon_x, \varepsilon_y$ (nm·rad, rms)	50/15	**100/50**
β_x^*/β_y^* (cm)	10/4	5/1.2
RMS divergence (mrad)	-	**1.4/2.0**
Bunch length (cm, rms)	0.75	8
Average current (A)	2.7	1.68
Crossing angle (mrad)	50	
Luminosity($cm^{-2}s^{-1}$)	**4.25×10^{33}**	

EicC parameters





EicC:

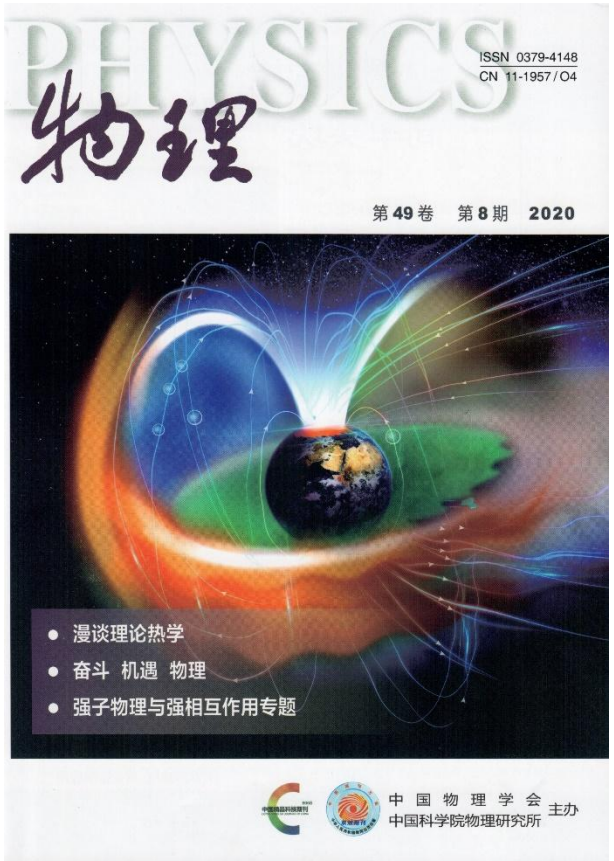
1) Focuses on moderate x and sea-quark region;
2) Complements the ongoing scientific programs at JLab and future EIC project

EicC milestones after the idea been proposed in 2012

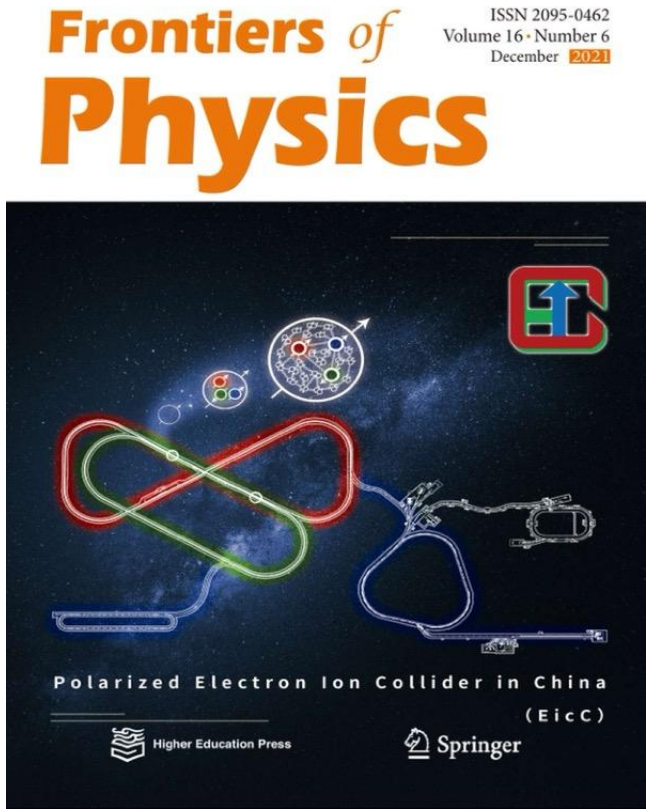
EicC Chinese WP(2020)



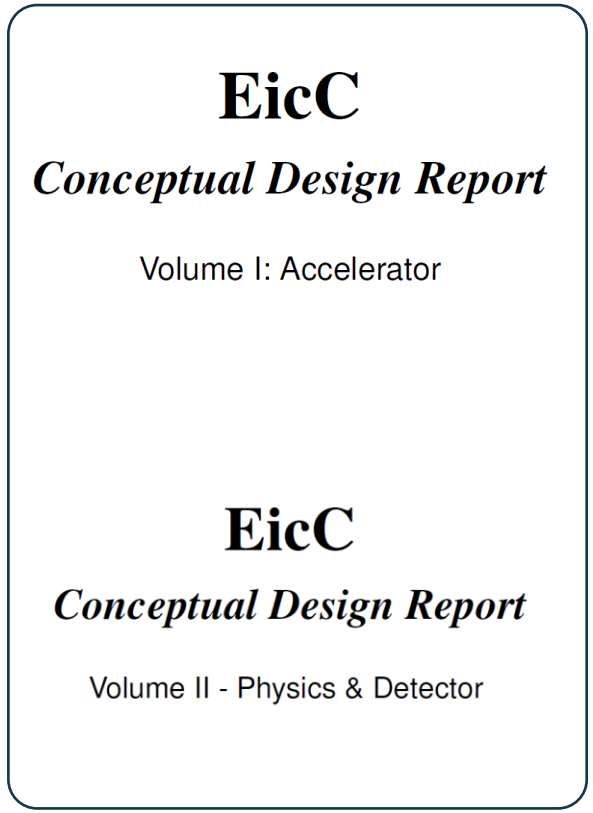
Physics (2020)



EicC English WP(2021)



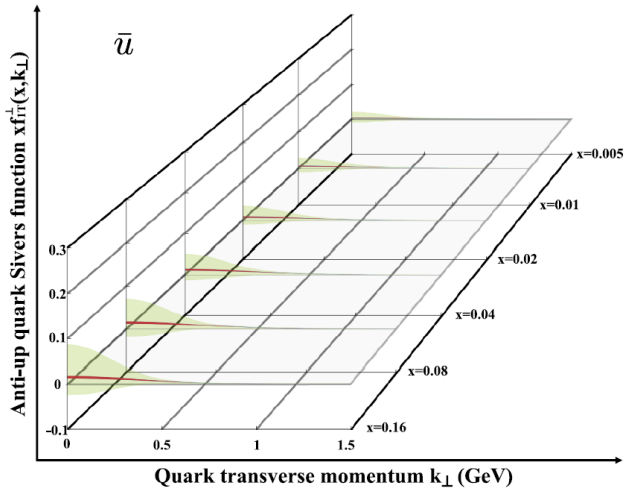
EicC CDR(2024)

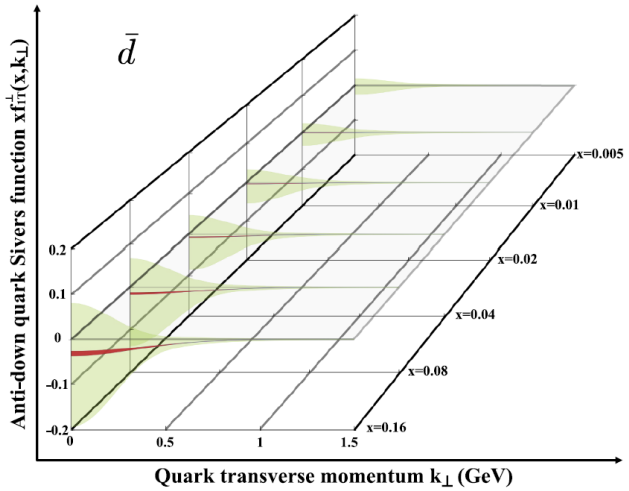


Efforts of around 71 institutes and more than 250 physicists

Key physics of EicC

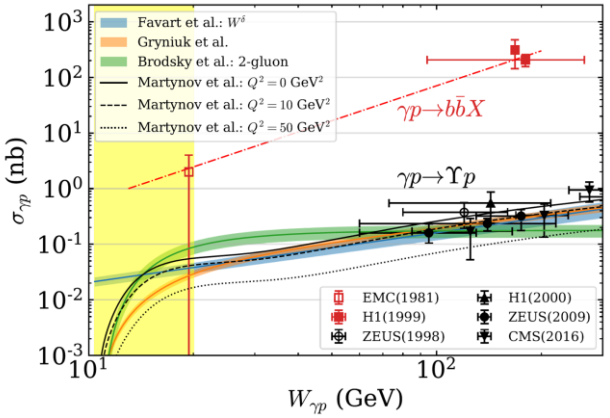
1) **High luminosity at $\sqrt{s}$ ~17 GeV → well suited for 3-D imaging**



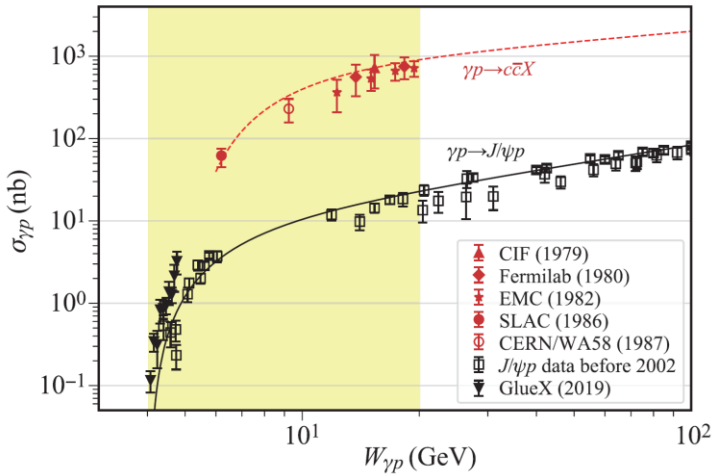


2) **Near threshold production of Υ and J/ψ → origin of proton mass**

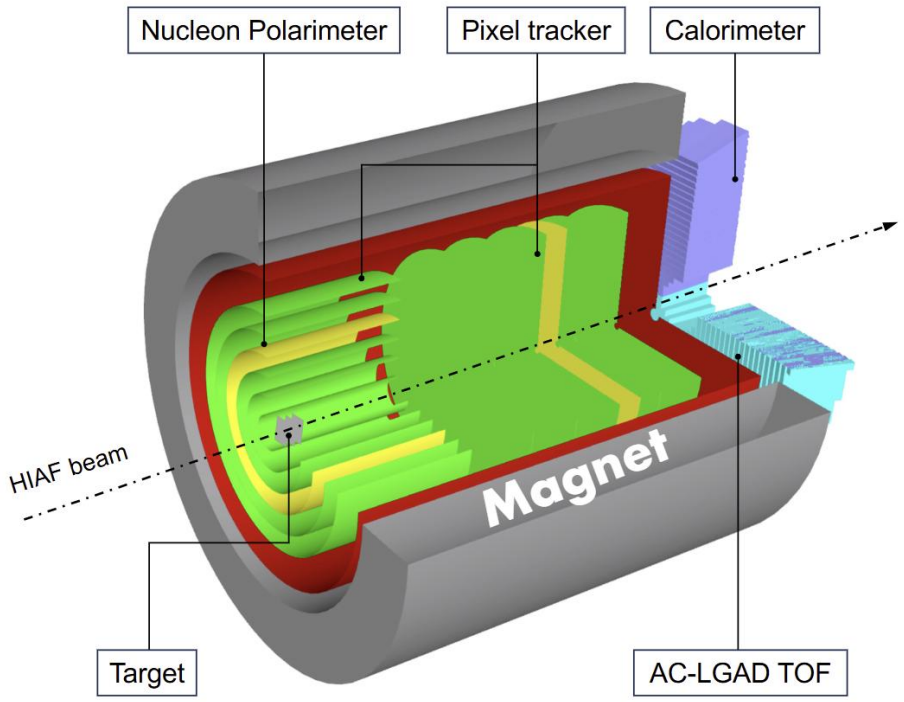
Near threshold Upsilon production



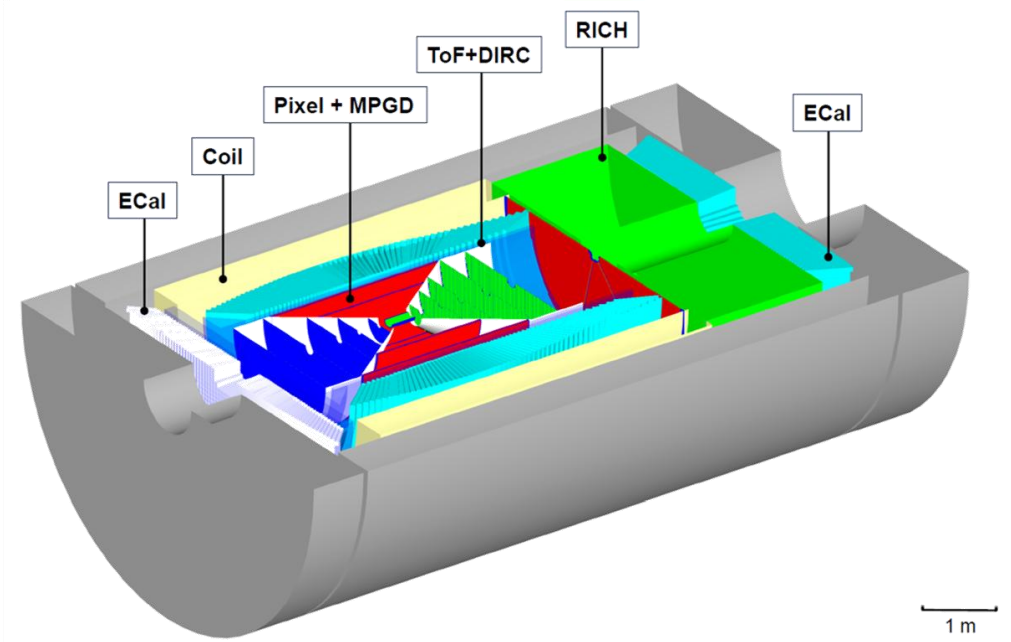
Near threshold J/Psi production



H-NS detector = ½ EicC detector



H-NS



EicC

H-NS → EicC

18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40

十三五 十四五 十五五 十六五 十七五

Accelerator

HIAF

HIAF-U

EicC

Detector

CEE@CSR

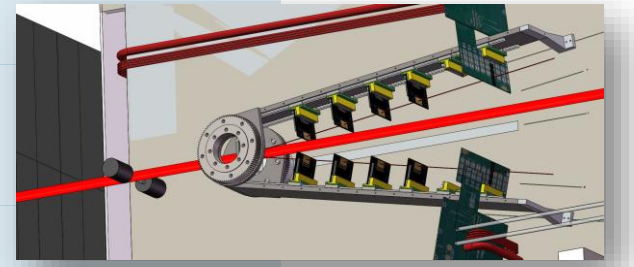
H-NS DEMO

H-NS construction

H-NS run

EicC

H-NS prototype



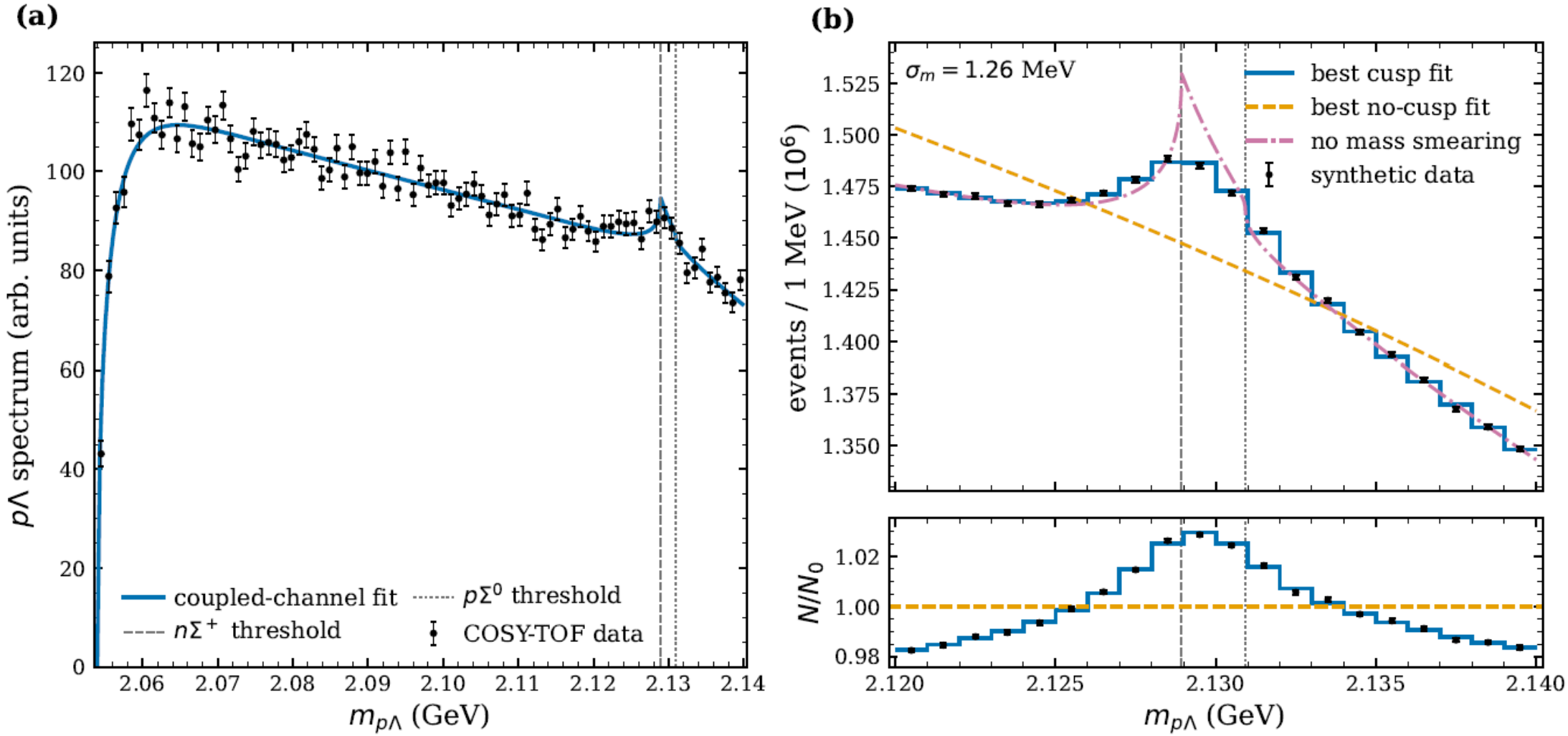
Summary

1) **H-NS at HIAF:**
   a) pp, pA, AA experiments: Measure $\boldsymbol{p}$ and $\boldsymbol{\Lambda}$ polarizations;
   b) Support both hadron physics and heavy-ion physics community;
   c) Smooth transition, both physics and detectors, to EicC
2) **Long range plan for high energy nuclear physics based on HIAF:** H-NS → EicC
3) **Exploring internal structure of the visible matter**

Everyone is invited: Join us and have fun!

Backups

Y-N low-energy scattering at threshold at H-NS



10^9 particle/s * **0.02g/cm2** * **100000* 10^-30 cm^2** * 6.02*10^23 = 1MHz

