Hyperon-Nucleon Spectrometer at HIAF

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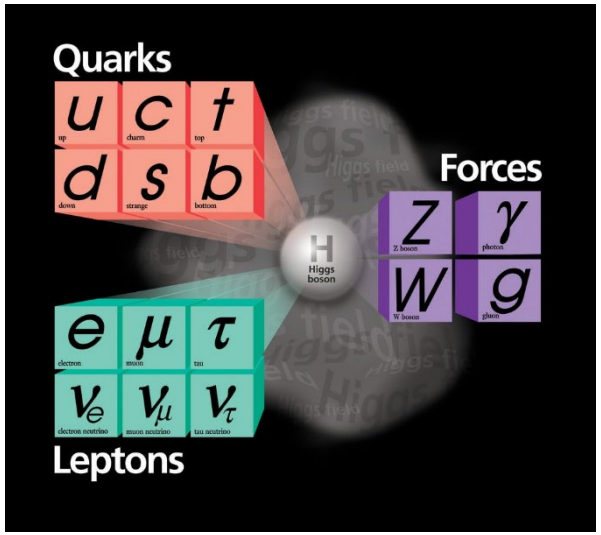
AFAD2026
2026.10.13-17 Shanghai

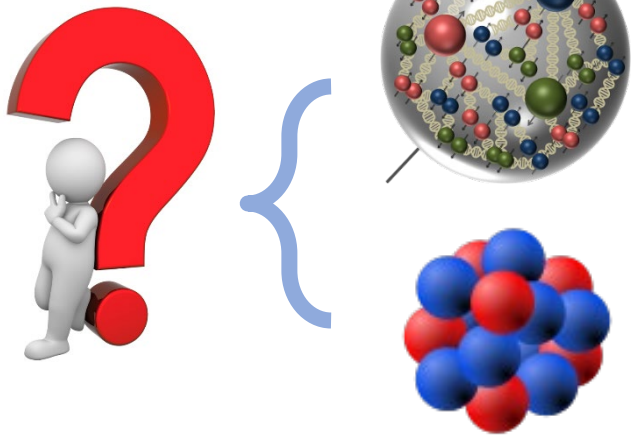
Phys. Rev. D 112, L031502
arXiv: 2512.02804, NST in press
arXiv: 2601.21325, NST in press
arXiv: 2606.06553, NST in press
arXiv: 2607.19927

Outline

- **Introduction**
- **Hyperon-Nucleon spectrometer (H-NS)**
- **Performance study and physics potentials**
- **Status and plan**
- **Summary**

One of the fundamental question：Nucleon internal structure



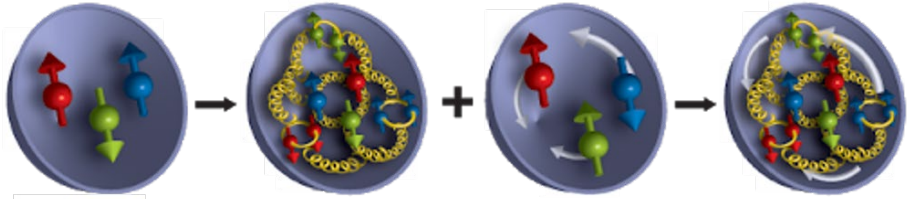


Proton spin structure?

Origin of proton mass?

Spin

Gell-Mann
Quark model

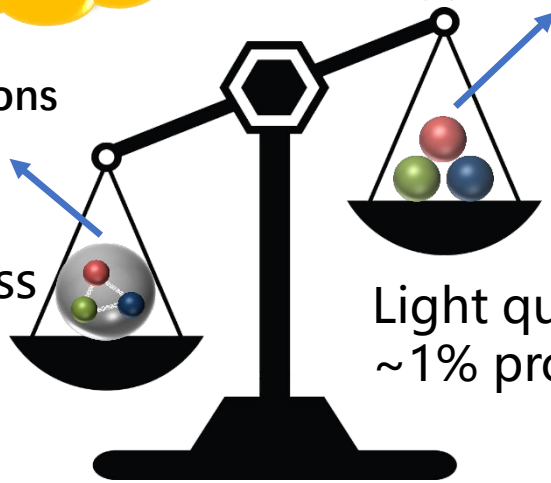


Mass

Higgs mechanism

Dynamics of gluons

~99%
Proton mass



Light quark
~1% proton mass

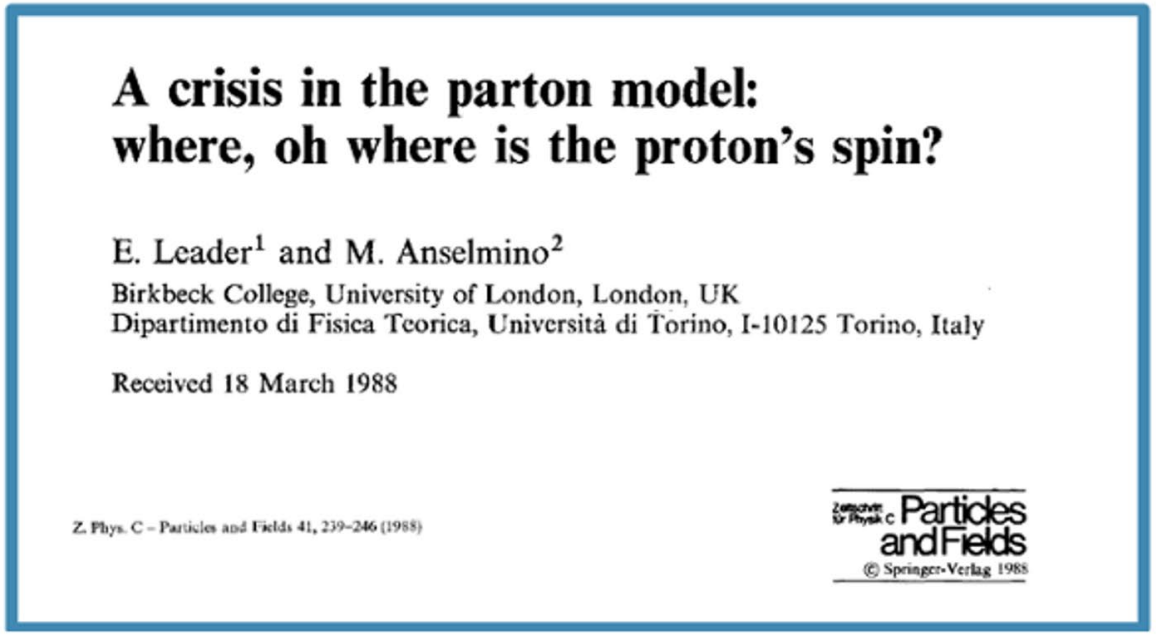
Proton spin structure VS hyperon polarization

Nucleon spin structure – 1988

Crisis of proton spin

EMC at CERN – J. Ashman et. al., NPB 328, 1(1989)

$\Delta\Sigma = \Delta u + \Delta d + \Delta s = 12 \pm 9 \pm 14\ \%$



A crisis in the parton model:
where, oh where is the proton's spin?

E. Leader[1] and M. Anselmino[2]

Birkbeck College, University of London, London, UK
Dipartimento di Fisica Teorica, Università di Torino, I-10125 Torino, Italy

Received 18 March 1988

Z. Phys. C – Particles and Fields 41, 239–246 (1988)

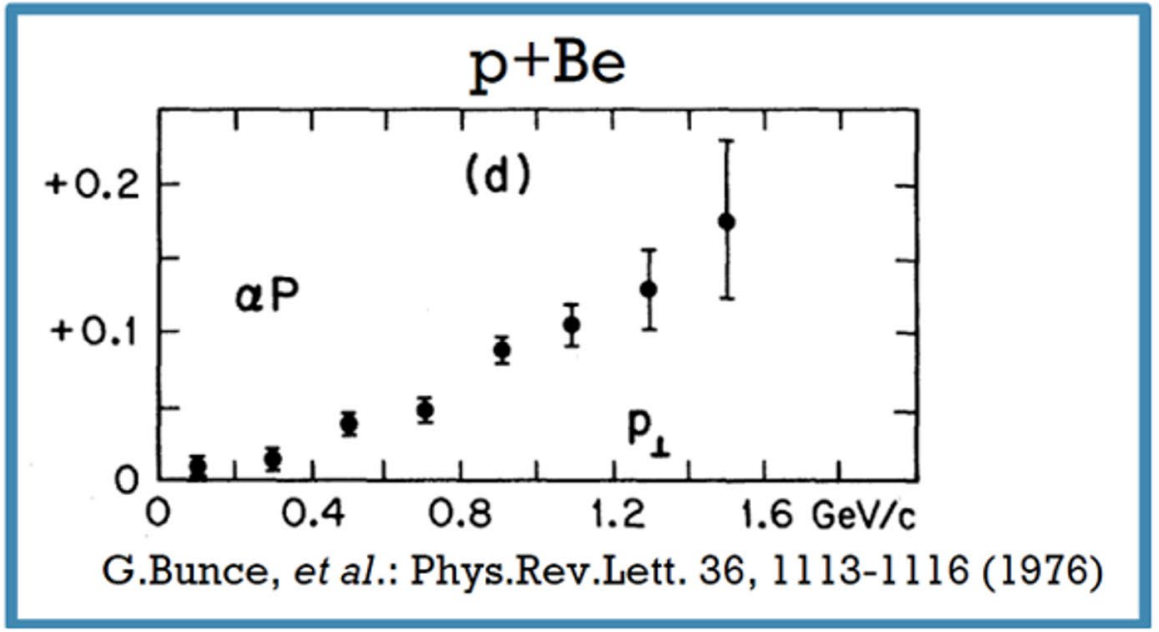
Zeitschrift für Physik C Particles and Fields

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First observation of Λ polarization – 1976

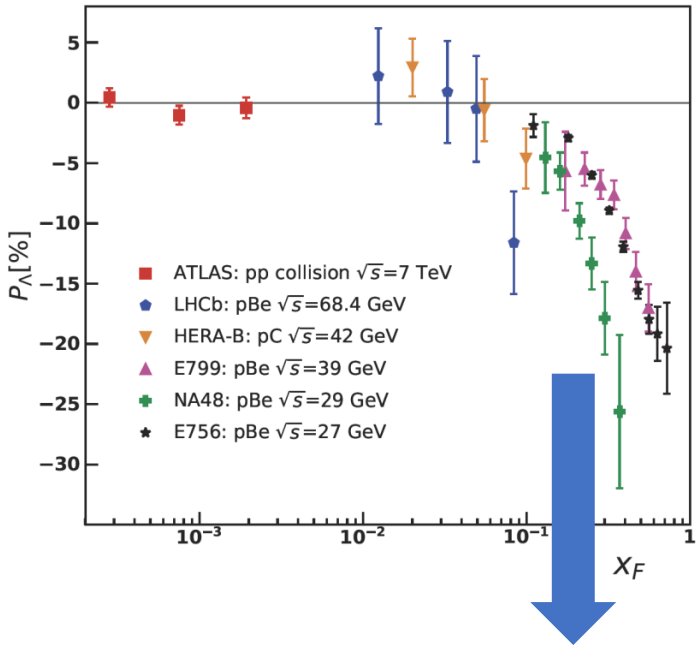
Origin of hyperon polarization

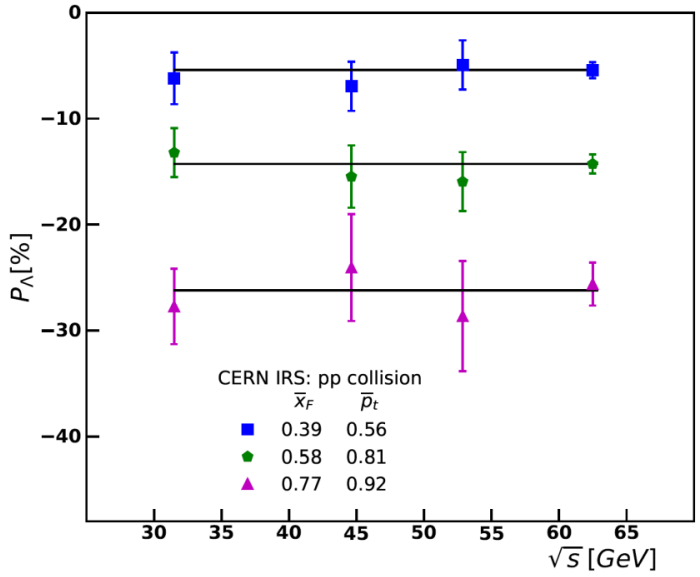
Fermi Lab: 300 GeV proton on Be target. Final state Λ polarization from unpolarized initial states

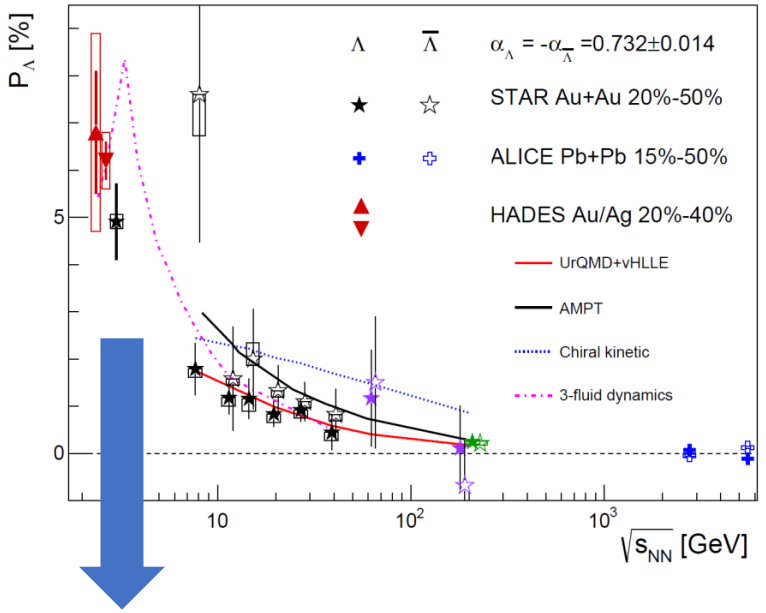


G.Bunce, *et al.*: Phys.Rev.Lett. 36, 1113-1116 (1976)

Experiments on Λ polarization







polarization dependence on x_F

Strong polarization at HIAF energy

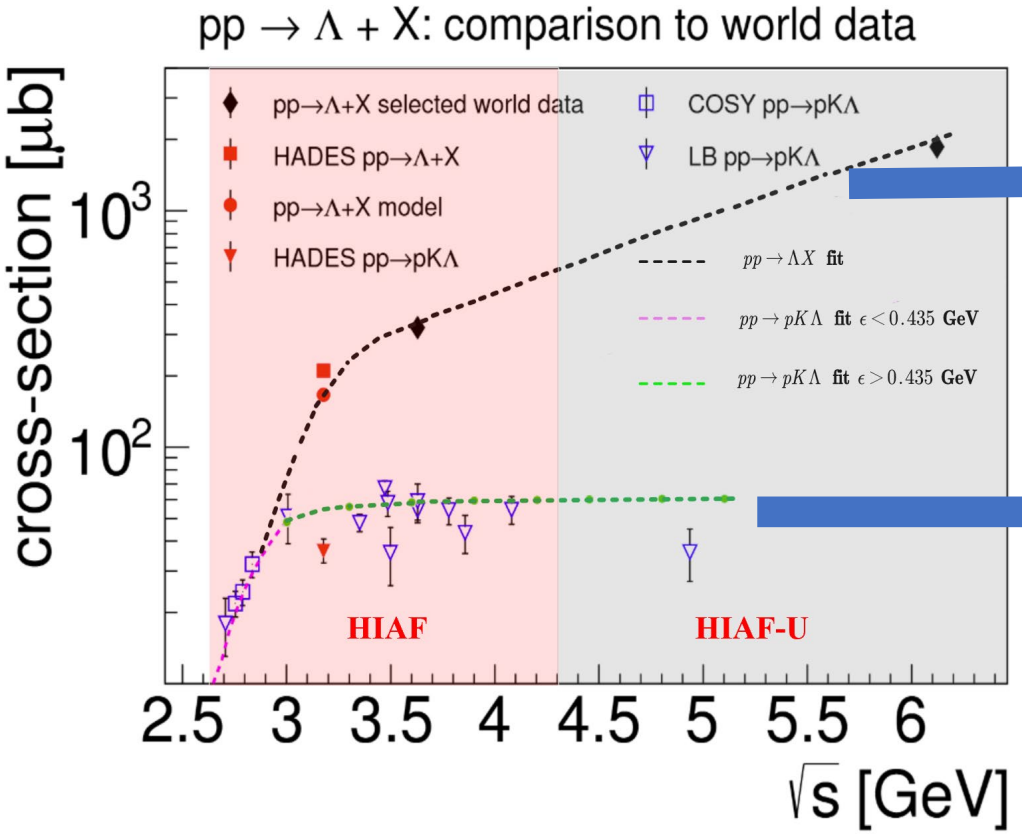
Scaling?

Global polarization in AA

Strong polarization at HIAF energy

Research status: scare experimental data, lack of systematic studies (in terms of kinematic coverage, energy range, and different reaction processes)

Potentials at HIAF

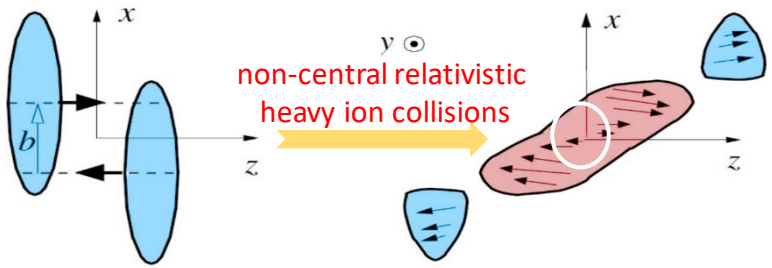


$pp(A) \rightarrow \Lambda + X$ **polarization through hadronization**

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).

$pp \rightarrow \mathrm{p} + \mathrm{K} + \Lambda$ **Λ polarization in exclusive processes**

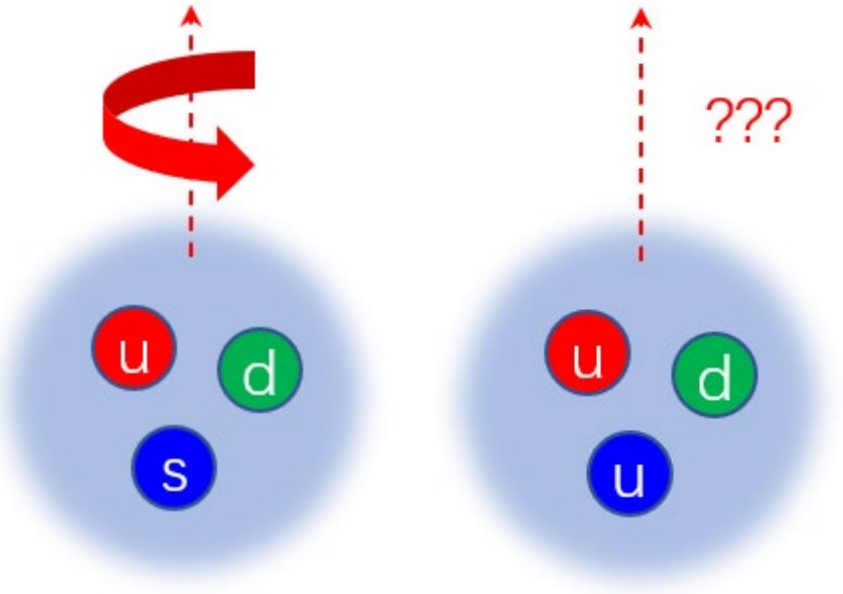
R. Machleidt, K. Holinde and C. Elster, Phys. Rept. 149, 1 (1987).
B. C. Liu, B. S. Zou, PRL 96, 042002 (2006).



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

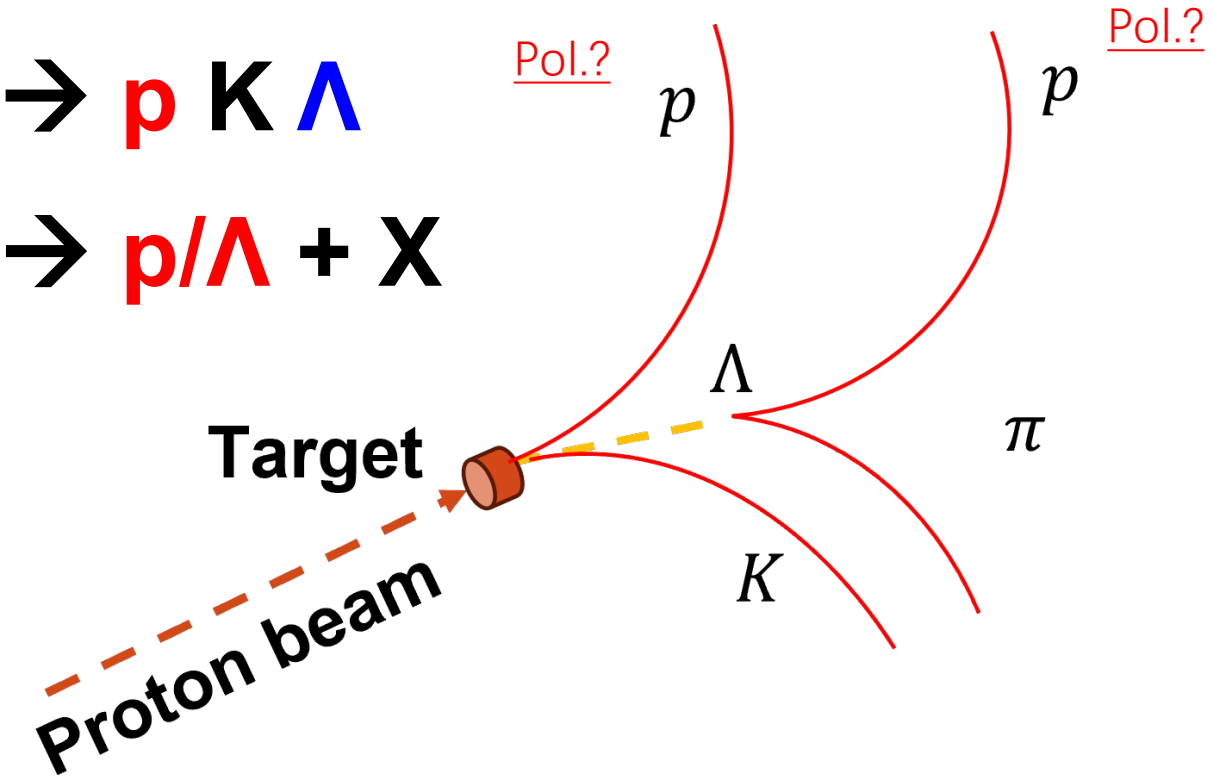
Zuo-Tang Liang, Xin-Nian Wang, PRL 94,102301 (2005); PLB 629, 20 (2005).
Jian-Hua Gao, Shou-Wan Chen, Wei-tian Deng, Zuo-Tang Liang, Qun Wang, Xin-Nian Wang, PRC 77, 044902 (2008).

Question: is the proton also polarized?



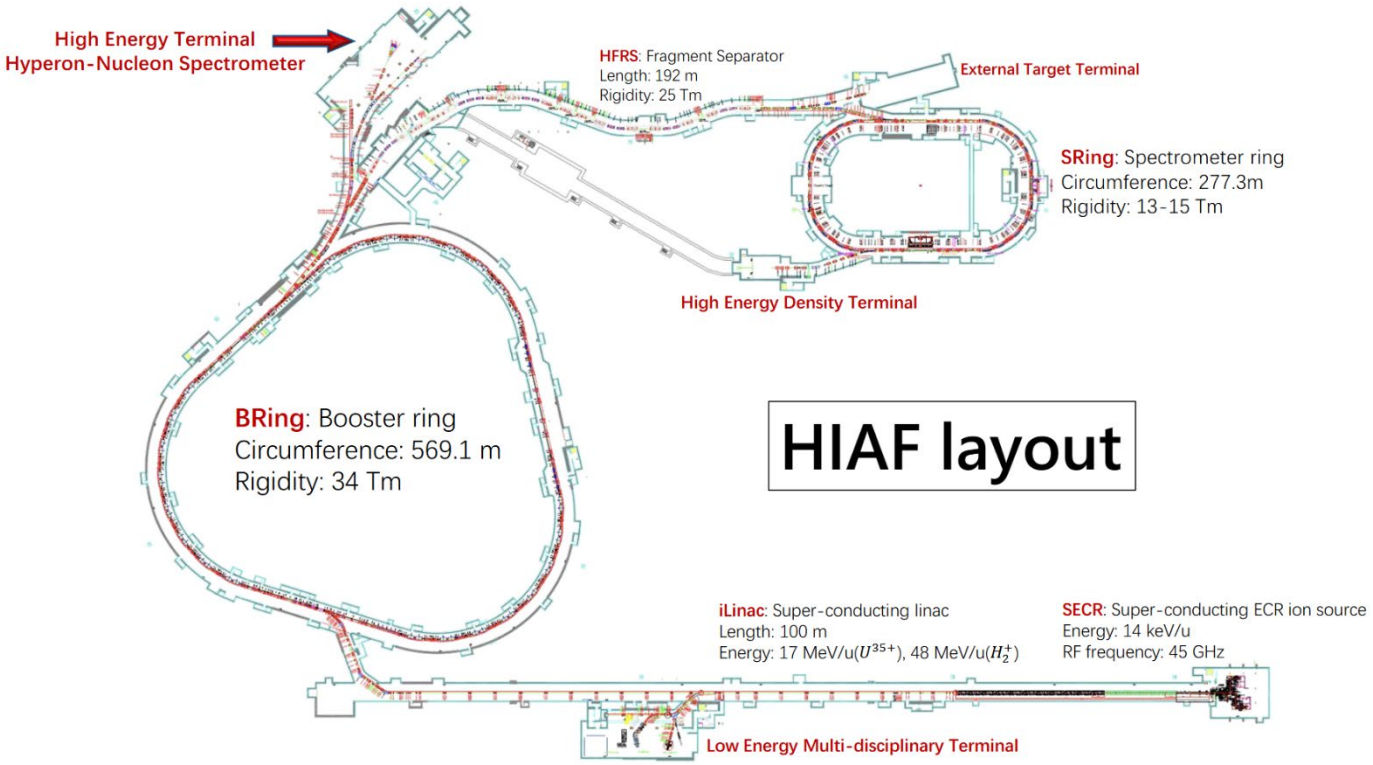
pp → p K Λ

pp → p/Λ + X



Dedicated proton polarimeter at H-NS

High energy nuclear physics at HIAF



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}

- **p → p**
- **p → A**
- **A → A**

Construction: 2019-2025

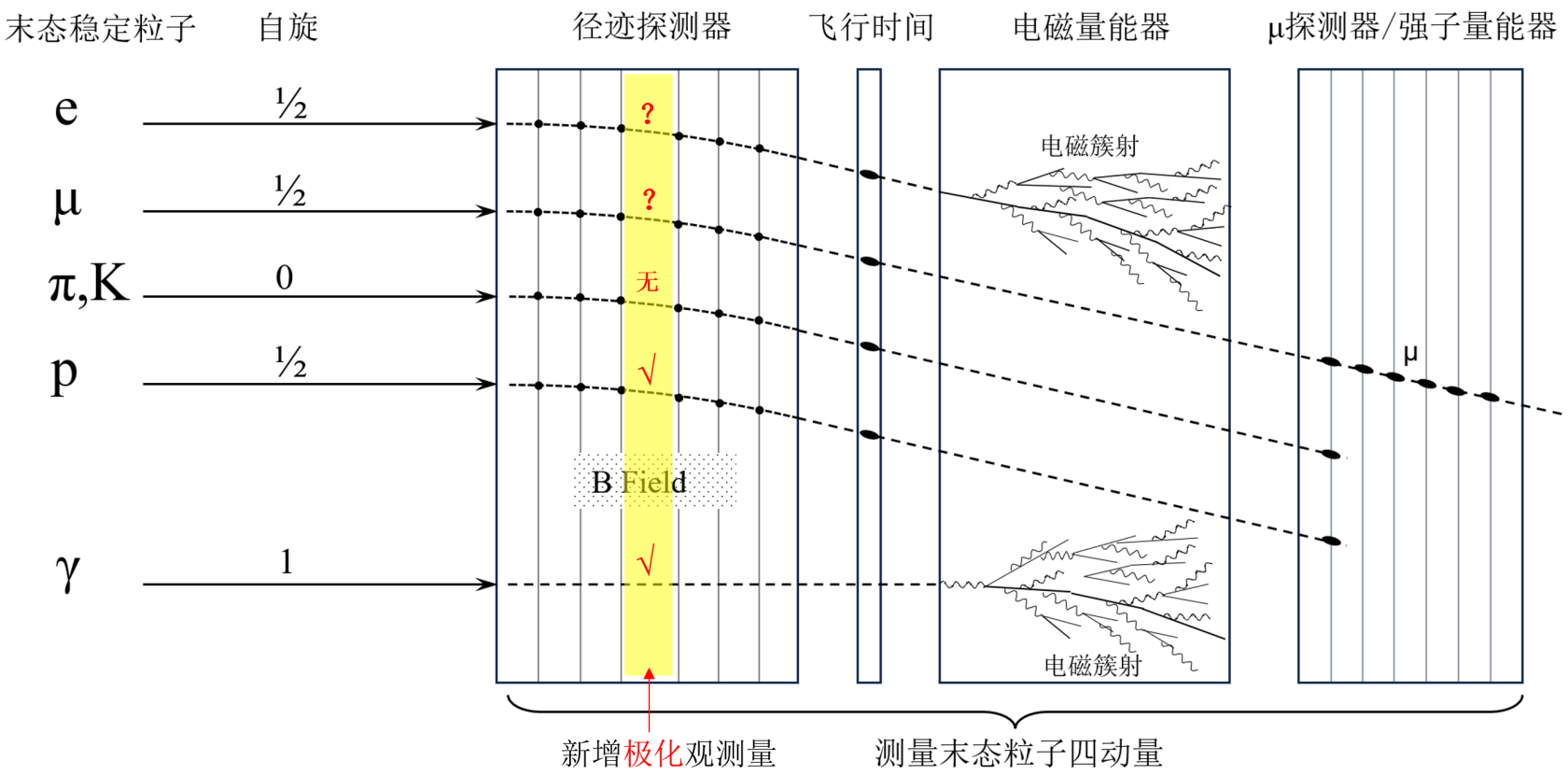
First beam: 2025

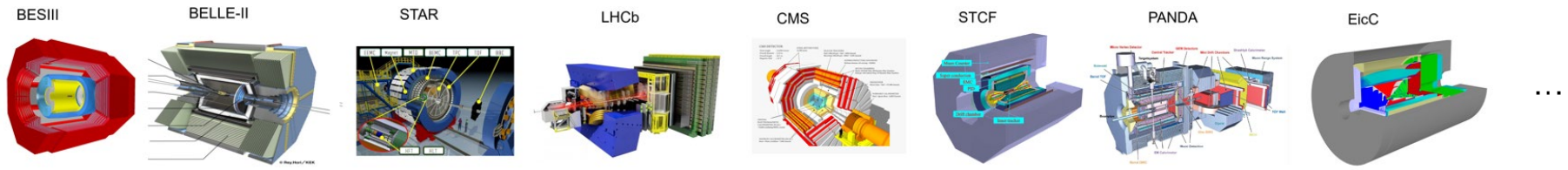
Near future:

fixed target experiments at HIAF

Hyperon-Nucleon spectrometer

General-use spectrometer + polarimeter?





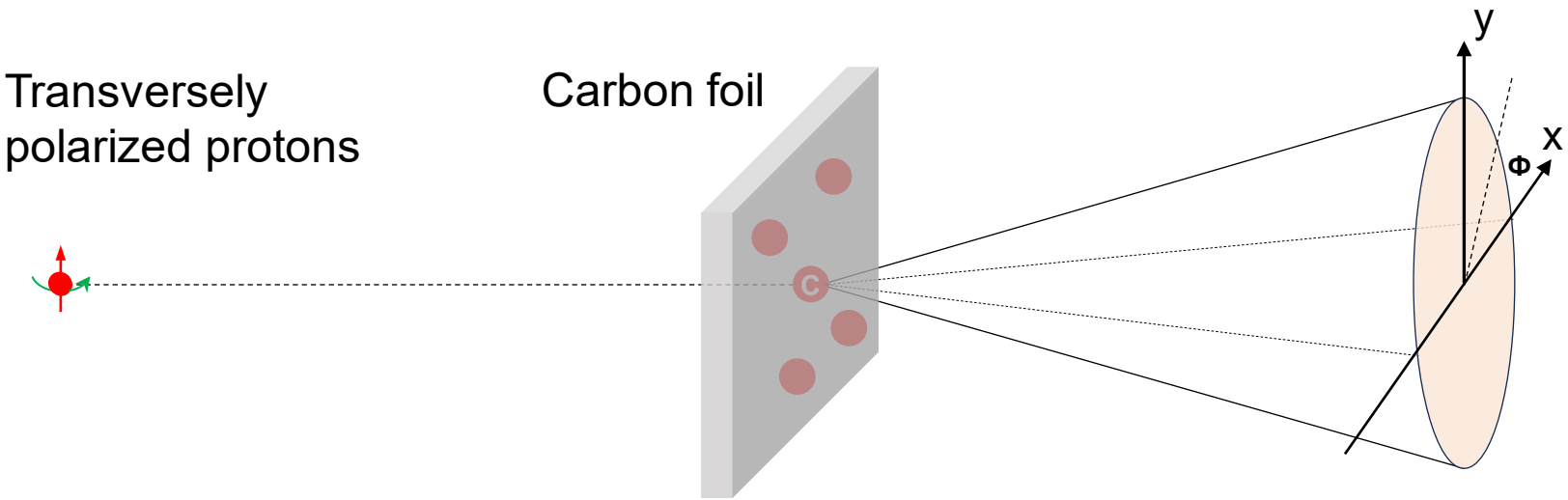
Principle of proton polarimeter

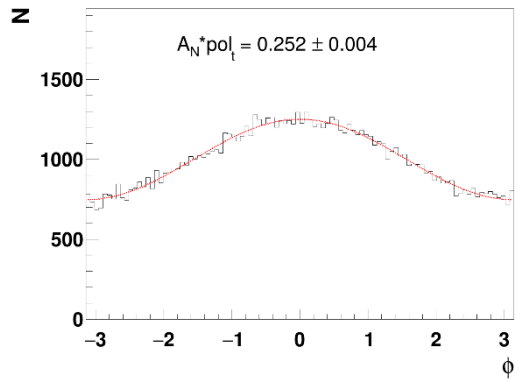
Relation between the **spin-dependent cross-section** of p + p/C scattering and the **asymmetries**

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

Transversely polarized protons

Carbon foil

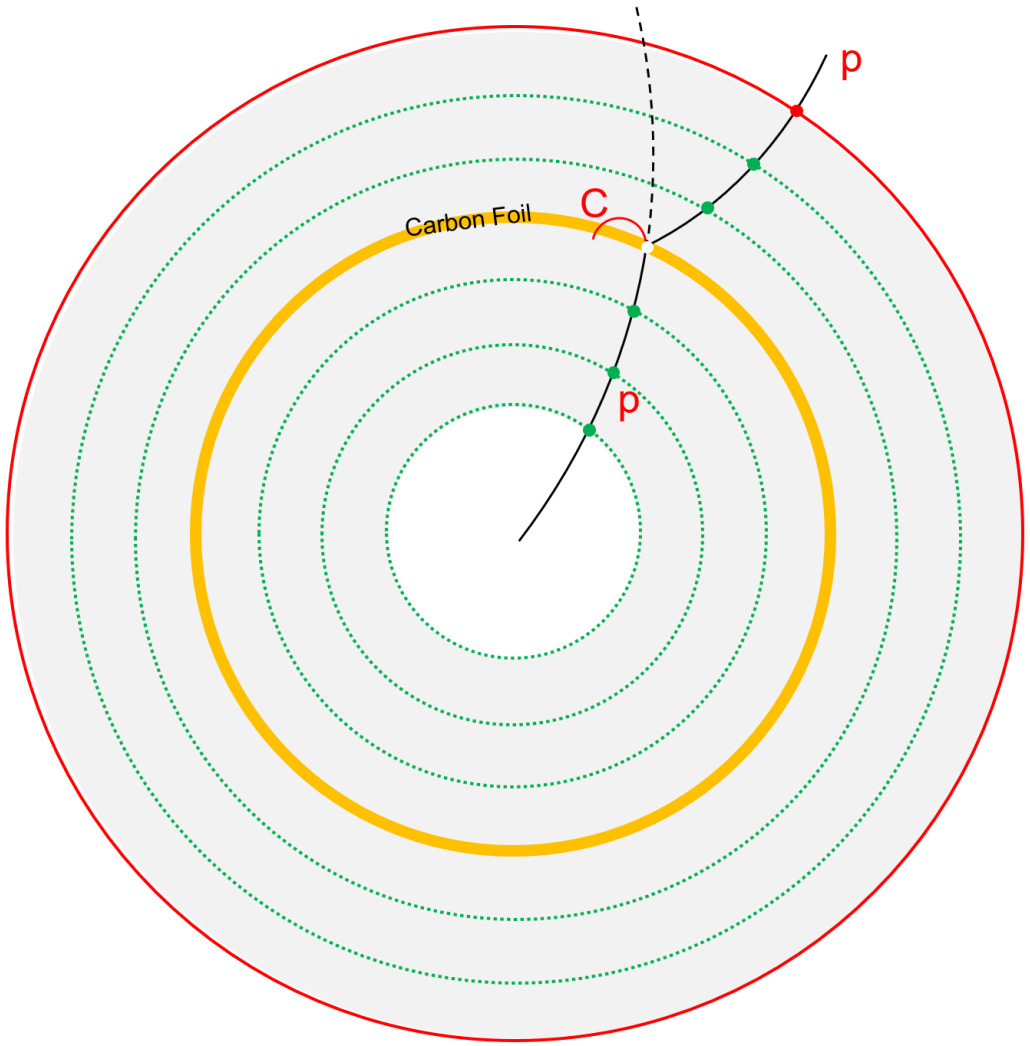




More protons to the left:
Left-right asymmetry

Widely used as polarimetric reaction to measure proton beam polarization (PSI, TRIMUF, LAMPF, COSY, SATURNE, ZGS, KEK-PS, AGS, RHIC …)

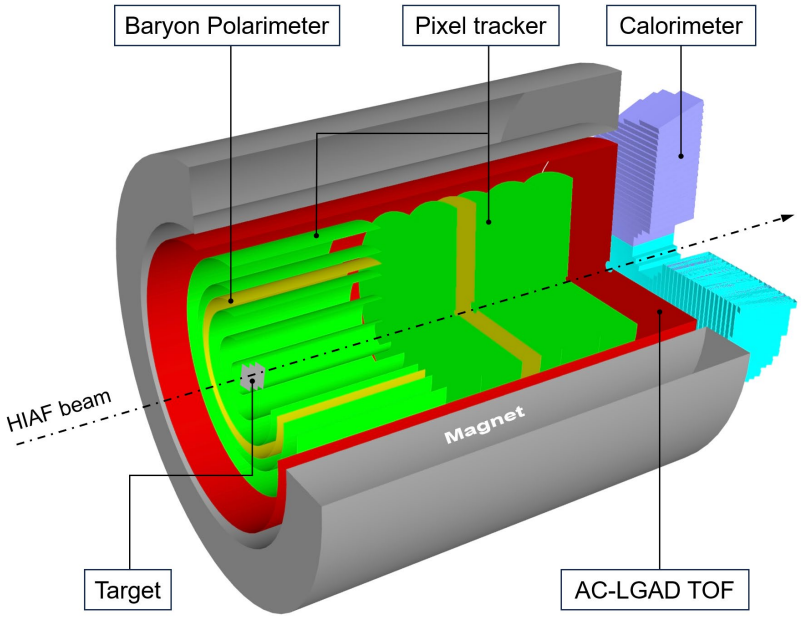
An extra carbon layer serve as baryon polarimeter



- **Carbon layer**
  - **~1 mm thickness**
  - **Material budget: <1% X/X_0**
  - **Probability: pC (1E-3)**
  - **Tiny influence to the conventional performance**
- **Position : in-between the tracking devices**
  - **Appliable in all reactions: ee/ep/pp/pA/AA**
  - **Appliable in high energy machines**

Yutie Liang, et. al., Phys. Rev. D 112, L031502

Hyperon-Nucleon Spectrometer (H-NS)



Mag. Field: 1.5 Tesla

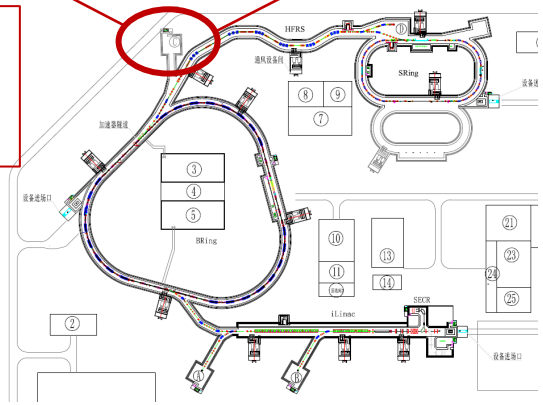
Tracker: MIC6, 30X30 μm^2, 0.8%X/X_0

LGAD: σ_t ~ 30 ps , 300X300 μm^2

Calorimeter: σ_E ~ 3% @ 1GeV

Polarimeter: nucleon and photon polarization

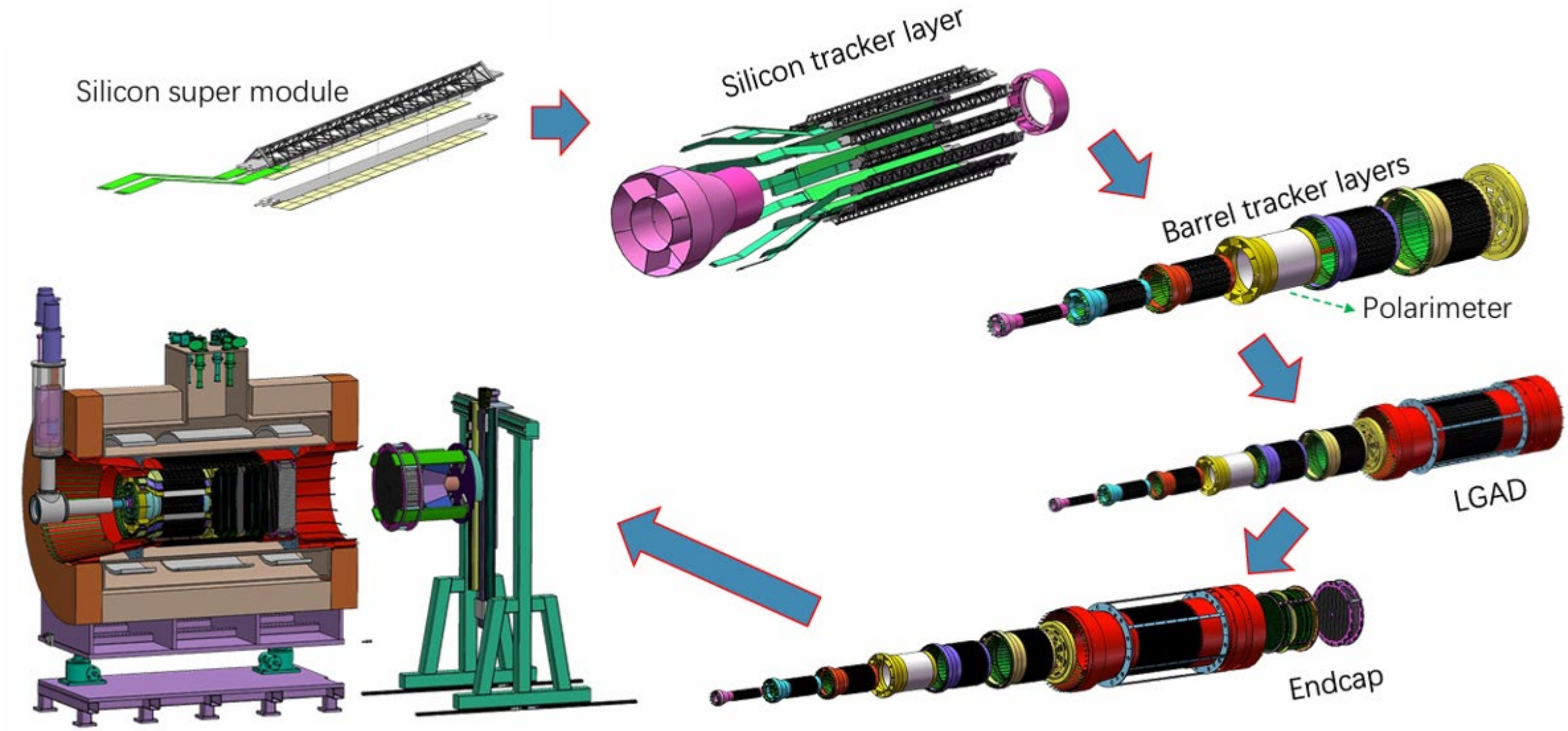
High Energy Nuclear Physics Terminal



H-NS Detector requirements:

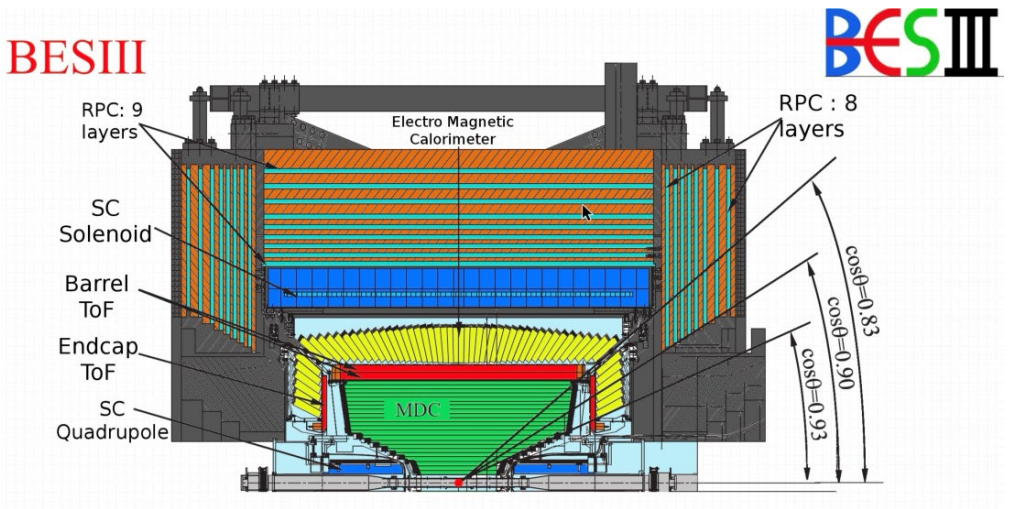
- Large acceptance:
  - 5 to 100 deg
- High event rate:
  - 1MHz (pp / pA)
- Momentum resolution:
  - ~2% @1GeV ($\eta < 2$)
- Vertex resolution:
  - < 500 um
- PID
  - K, π separation (~3σ) up to 2 GeV/c
  - K, p separation (~3σ) up to 5 GeV/c

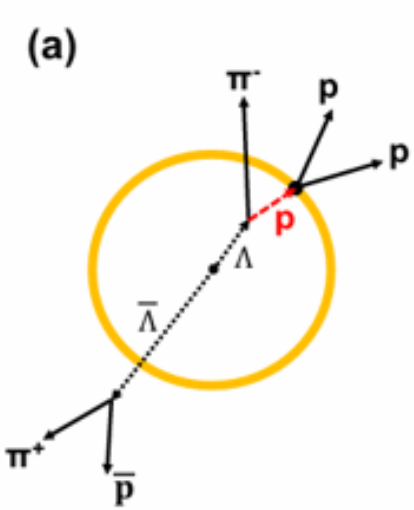
H-NS detector integration

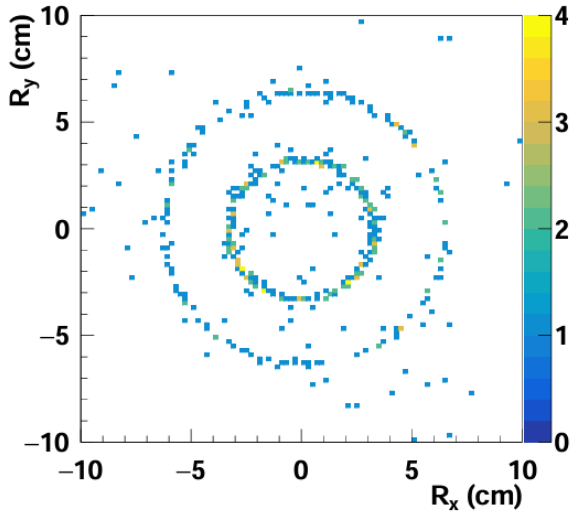


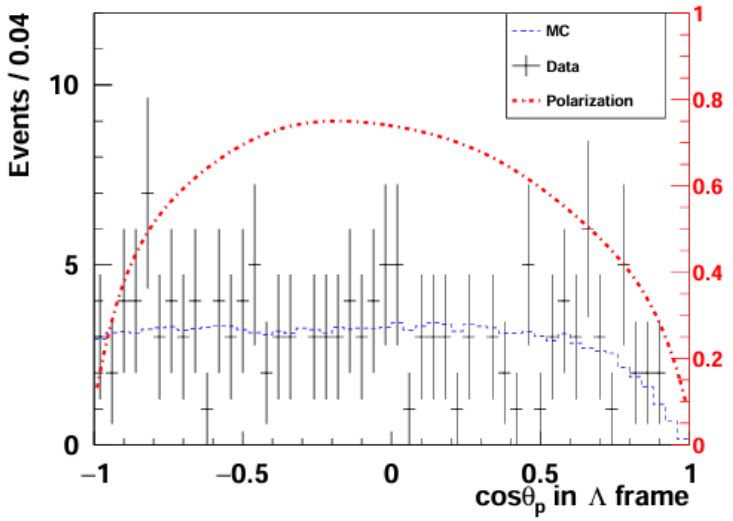
Performance and physics potentials

Validation of proton polarimeter at BESIII



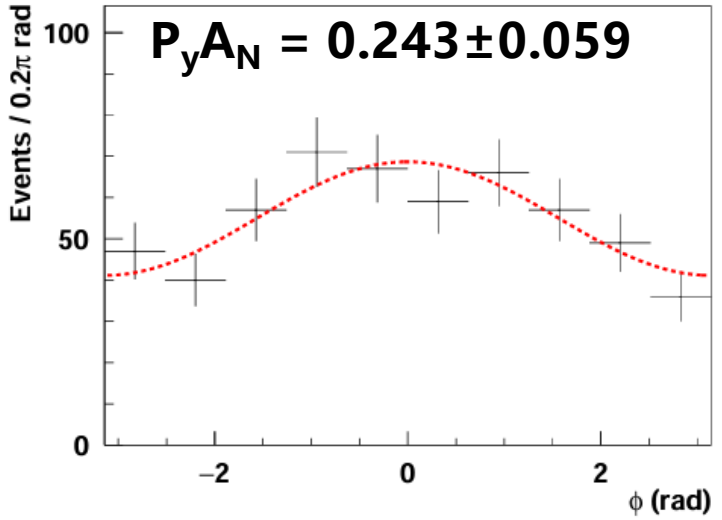






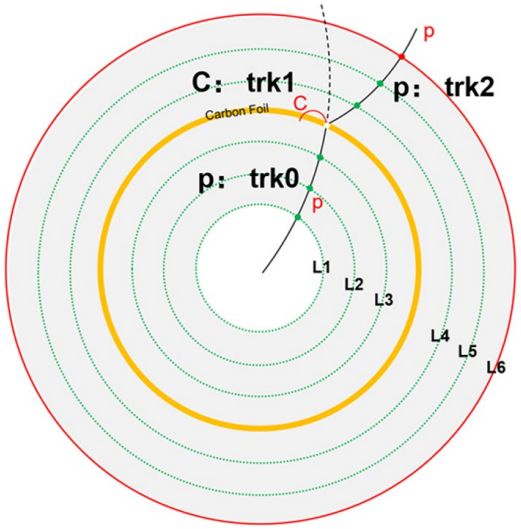
→ **expected**
$P_y A_N = 0.22 \pm 0.01$

→ **measured**
$P_y A_N = 0.243 \pm 0.059$

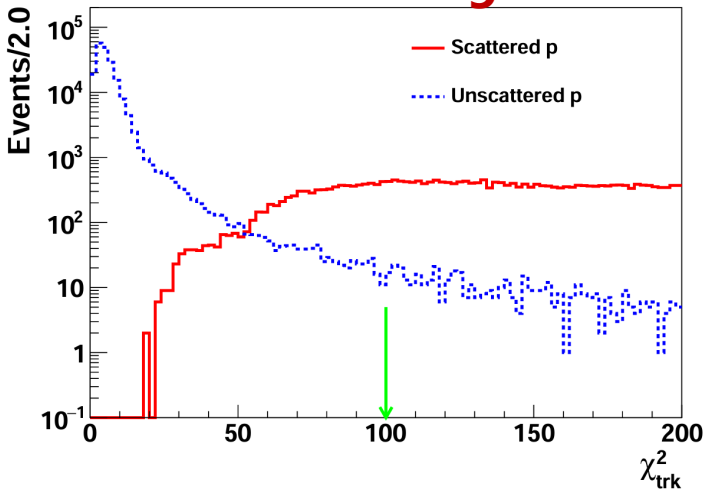


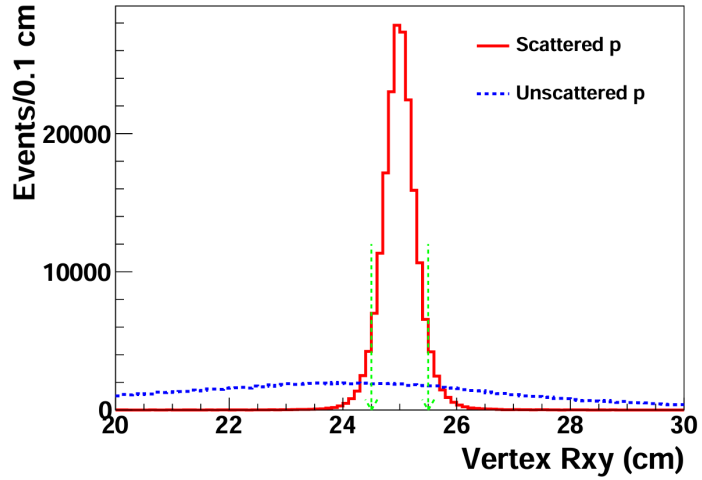
arXiv: 2607.19927

Precision measurement of proton polarization

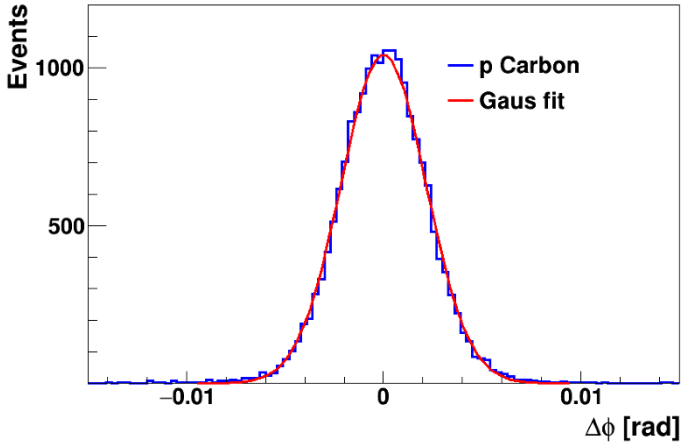


Signature of signal/background

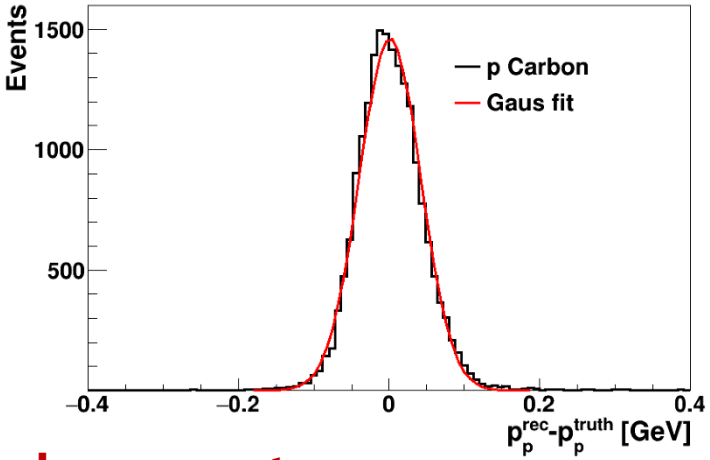




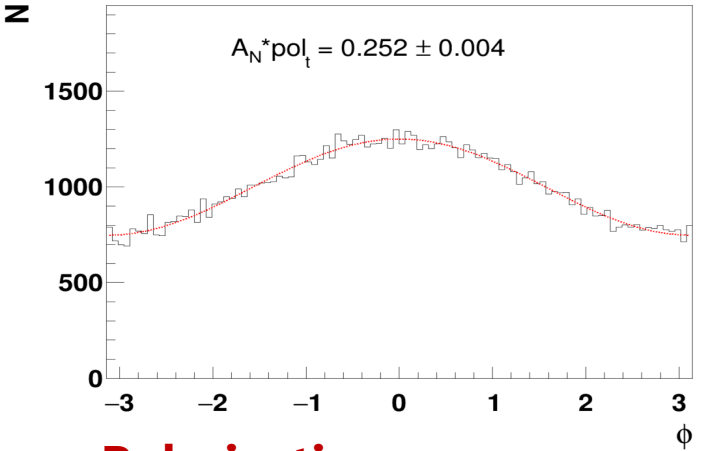
$\sigma = 2.16$ mrad



$\sigma = 0.041$ GeV



Input: 0.250



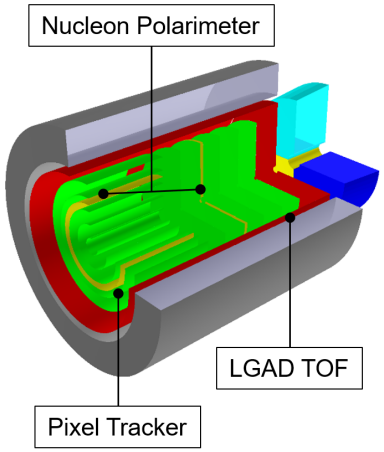
Measuring track segments

Polarization measurement

NST in press, arXiv: 2512.02804

Physics potentials at H-NS

➢ **Spin structure of baryon?**



H-NS

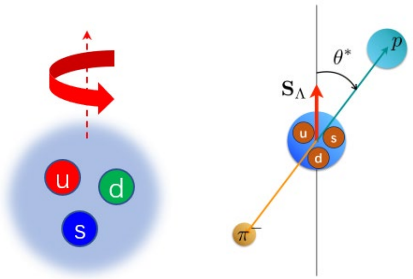
Reaction: p+p

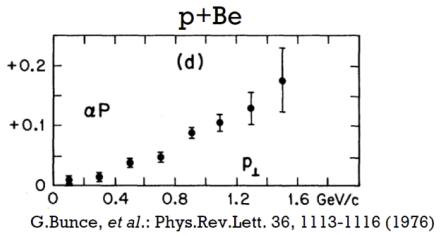
Event rate:1MHz

Time: 3 months

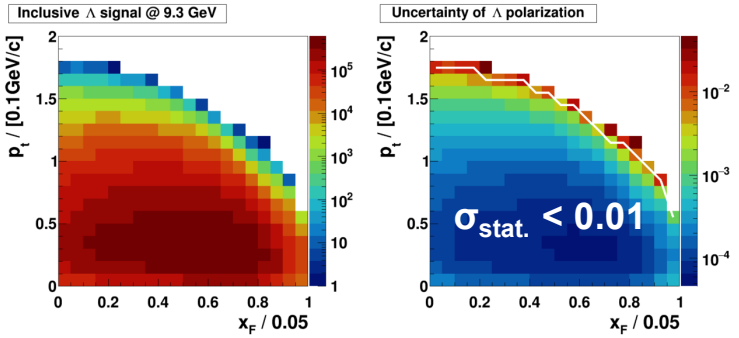
- pp → Λ+X N ~ 10^{11}
- pp → p+X N ~ 10^{13}
- pp → pKΛ N ~ 10^{10}

p p → Λ + X $\sigma_{stat.}$ < 0.01 2D:400 bins



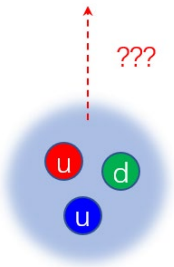


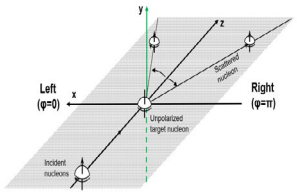
Λ polarization

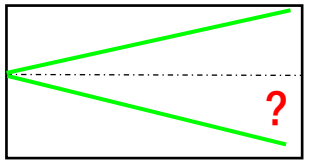


p p → p + X $\sigma_{stat.}$ < 0.02 2D:400 bins

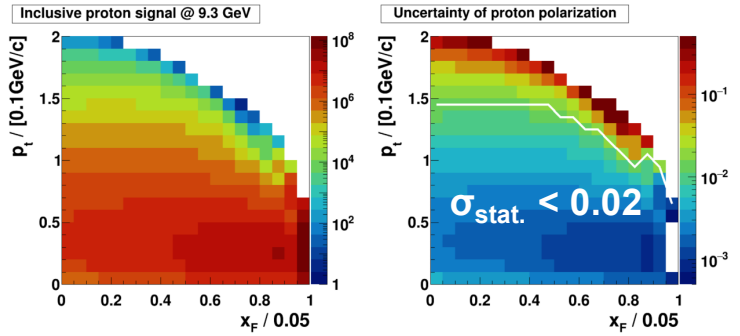
pC scattering ~ 10^{13} * $4*10^{-4}$ = $4*10^{9}$





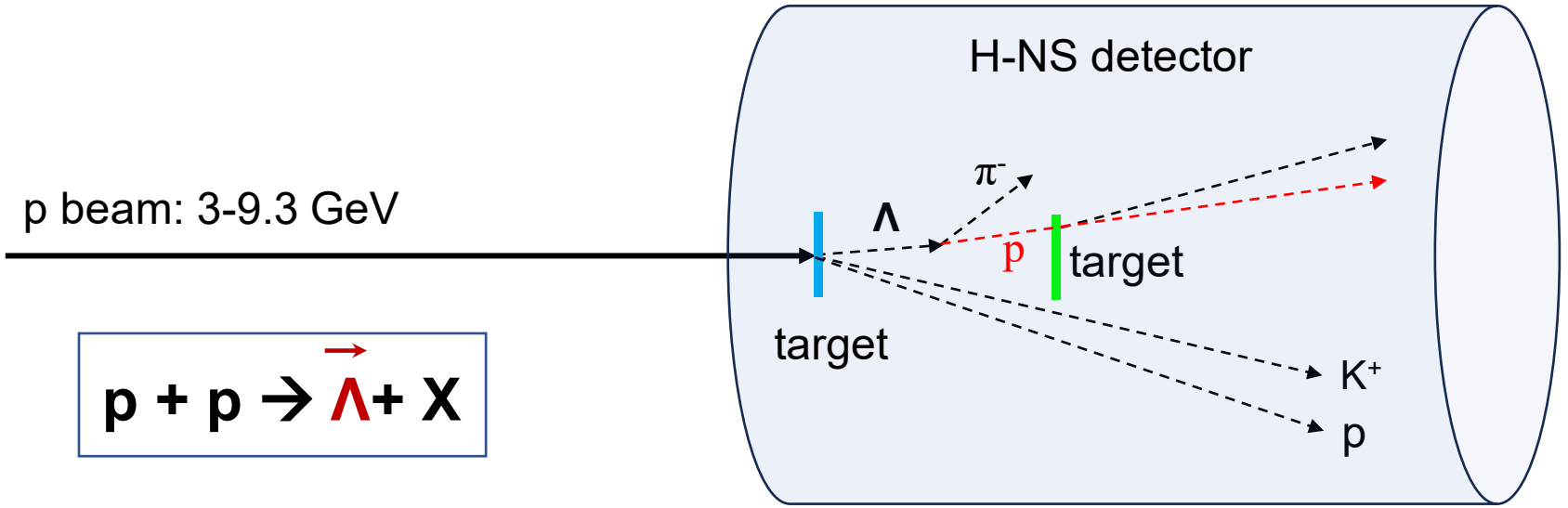


proton polarization



Polarized experiments at H-NS

➢ **Potential at H-NS**

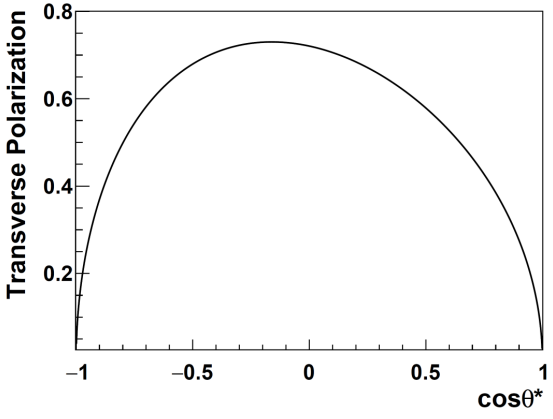


$p + p \rightarrow \vec{\Lambda} + X$

$\vec{p} + p \rightarrow \vec{\Lambda} + X$

Polarized proton experiment: polarization transfer from beam?

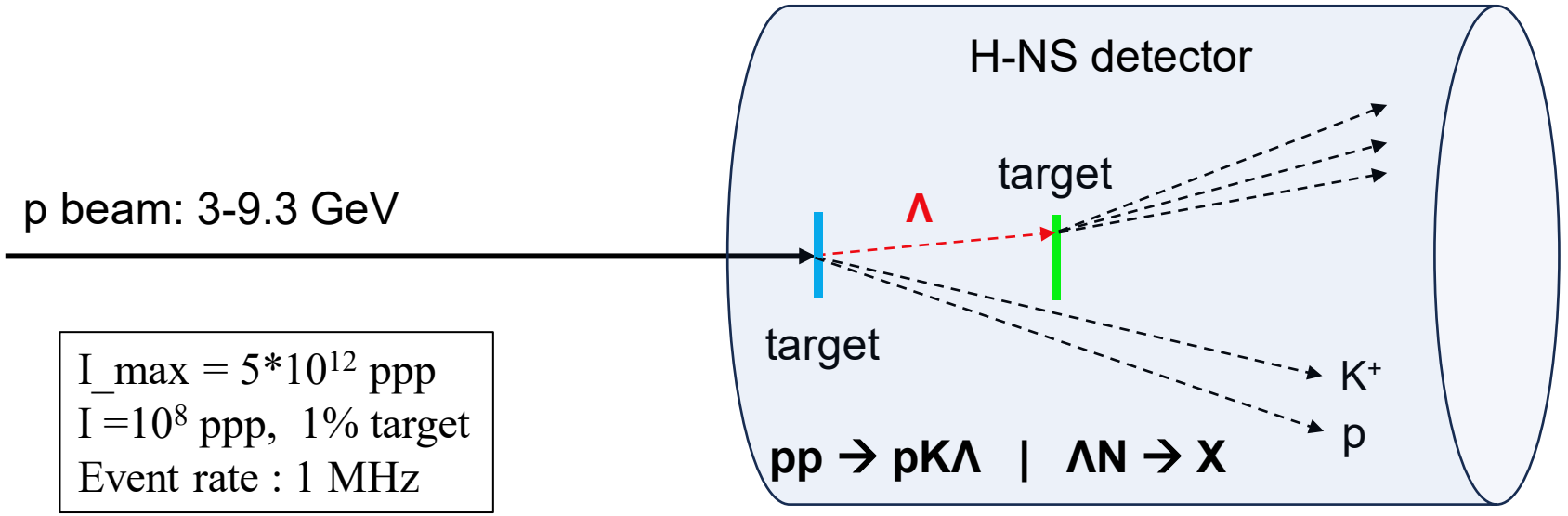
- **Average transverse polarization of proton, pol = 0.57**
- **Polarized proton beam intensity: 1 KHz**
- **Calibrate the pC analyzing power**



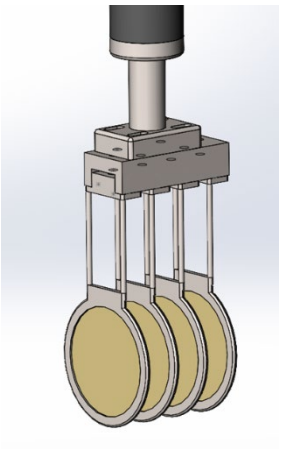
Yutie Liang, et. al., Phys. Rev. D 112, L031502

N-Y interaction

➢ **Potential at H-NS**



I_max = $5*10^{12}$ ppp
I =10^{8} ppp, 1% target
Event rate : 1 MHz



参考CEE 4层靶设计

- **Event rate : 1 MHz → Λ beam from pKΛ : 1 KHz**
- **Λ N interaction (0.1% target): 1 Hz**
- **N ~ 10^{7} signals in 3 months; N_obs ~ 10^{6} (assuming efficiency of 10%)**
- **Statistics can be improved by implementing a hyperon trigger**

Hadron physics

✓ Λ*, Σ*, Ξ*, Ω*, resonance

$\frac{1}{2}^+$	$\frac{1}{2}^-$	$\frac{3}{2}^+$	$\frac{3}{2}^-$	$\frac{5}{2}^+$	$\frac{5}{2}^-$	$\frac{7}{2}^+$	$\frac{7}{2}^-$	$\frac{9}{2}^+$	$\frac{9}{2}^-$	$\frac{11}{2}^+$
$N(939)$	$N(1535)$	$N(1720)$	$N(1520)$	$N(1680)$	$N(1675)$	$N(1990)$	$N(2190)$	$N(2220)$	$N(2250)$	
$N(1440)$	$N(1650)$	$N(1900)$	$N(1700)$	$N(1860)$	$N(2060)$					
$N(1710)$	$N(1895)$		$N(1875)$	$N(2000)$	$N(2570)$					
$N(1880)$			$N(2120)$							
$N(2100)$										
$N(2300)$										
$\Delta(1910)$	$\Delta(1620)$	$\Delta(1232)$	$\Delta(1700)$	$\Delta(1905)$	$\Delta(1930)$	$\Delta(1950)$	$\Delta(2200)$	$\Delta(2300)$	$\Delta(2400)$	$\Delta(2420)$
	$\Delta(1900)$	$\Delta(1600)$	$\Delta(1940)$	$\Delta(2000)$						
		$\Delta(1920)$								
$\Lambda(1116)$	$\Lambda(1380)$	$\Lambda(1890)$	$\Lambda(1520)$	$\Lambda(1820)$	$\Lambda(1830)$	$\Lambda(2085)$	$\Lambda(2100)$	$\Lambda(2350)$		
$\Lambda(1600)$	$\Lambda(1405)$		$\Lambda(1690)$	$\Lambda(2110)$						
$\Lambda(1810)$	$\Lambda(1670)$									
	$\Lambda(1800)$									
$\Sigma(1189)$	$\Sigma(1750)$	$\Sigma(1385)$	$\Sigma(1670)$	$\Sigma(1915)$	$\Sigma(1775)$	$\Sigma(2030)$				
$\Sigma(1660)$	$\Sigma(1900)$		$\Sigma(1910)$							
$\Sigma(1880)$										
$\Xi(1315)$		$\Xi(1530)$	$\Xi(1820)$							
		$\Omega(1672)$								

m < 3.1 GeV/c²

m < 3.1 GeV/c²

m < 2.6 GeV/c²

m < 2.1 GeV/c²

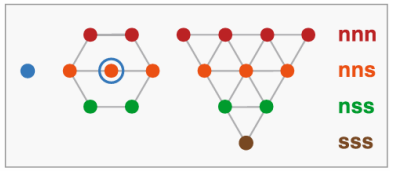
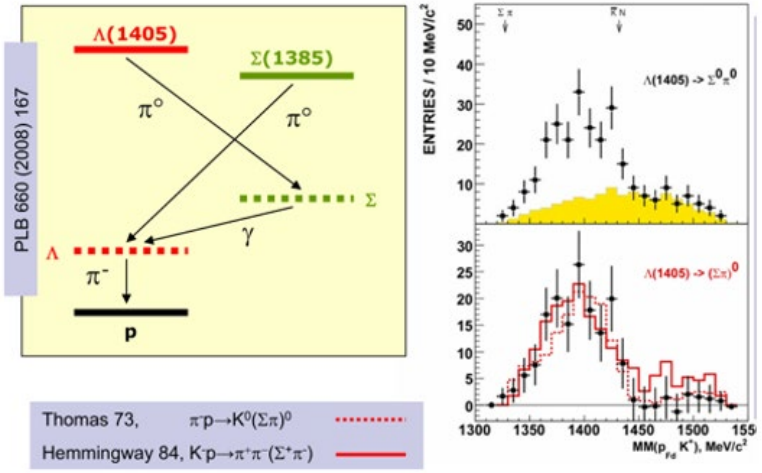


Fig. 1 Light and strange baryon spectrum from the PDG [1] up to $J^P = 11/2^+$. The columns correspond to different J^P and the colors to isospin and hypercharge. The different font weights represent four-, three- and two-star resonances

https://doi.org/10.1007/s00601-022-01756-y

■ Reaction (p_{beam}=3.65 GeV/c):

$$pp \rightarrow pK^+\Sigma^0(1385) \rightarrow pK^+(p\pi^-)\pi^0$$
$$pp \rightarrow pK^+\Lambda(1405) \rightarrow pK^+(\Sigma^0\pi^0) \rightarrow pK^+(p\pi^-)\gamma\pi^0$$

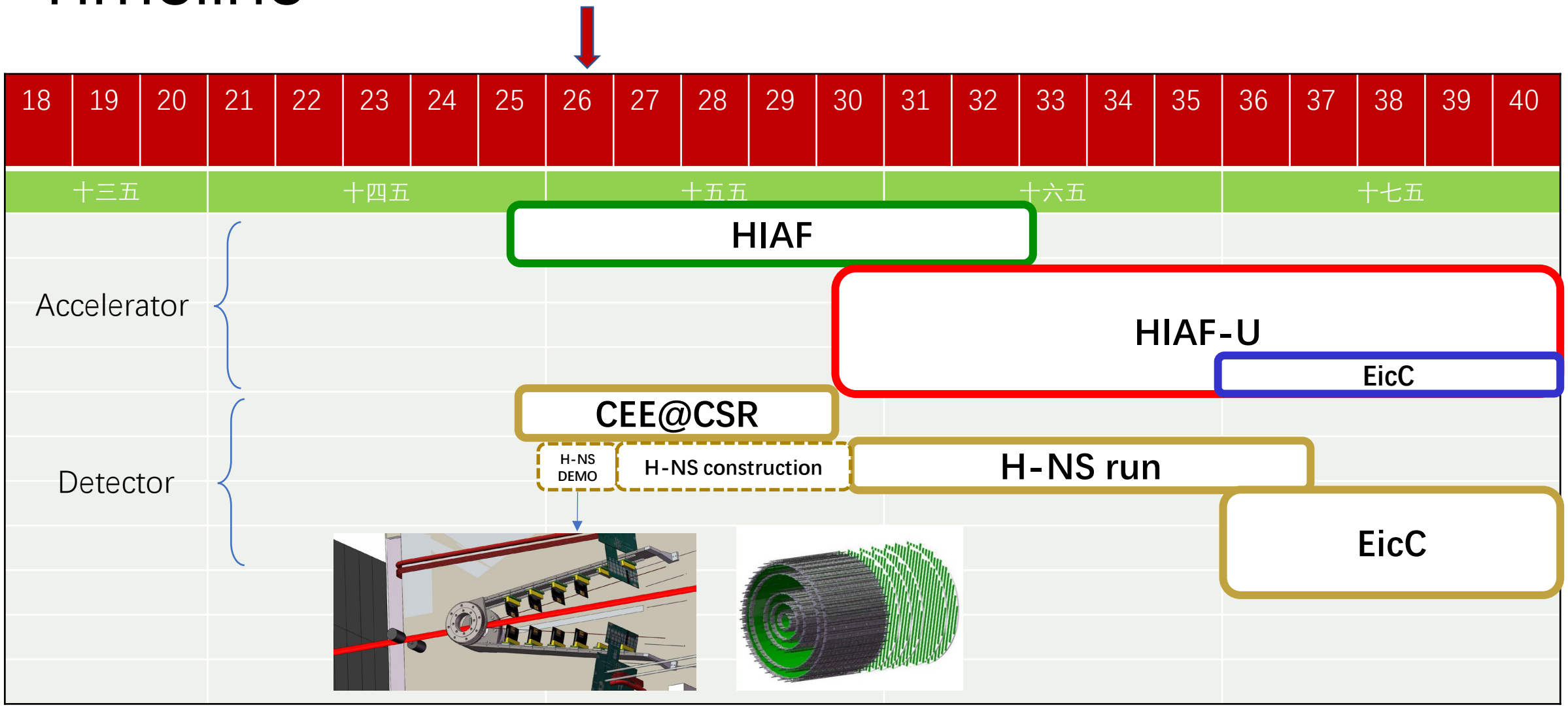


- $\sqrt{s}$ = **4.6 GeV** @ E_{beam} = 9.3 GeV
- $\sqrt{s}$ = 7.1 GeV @ E_{beam} = 25 GeV

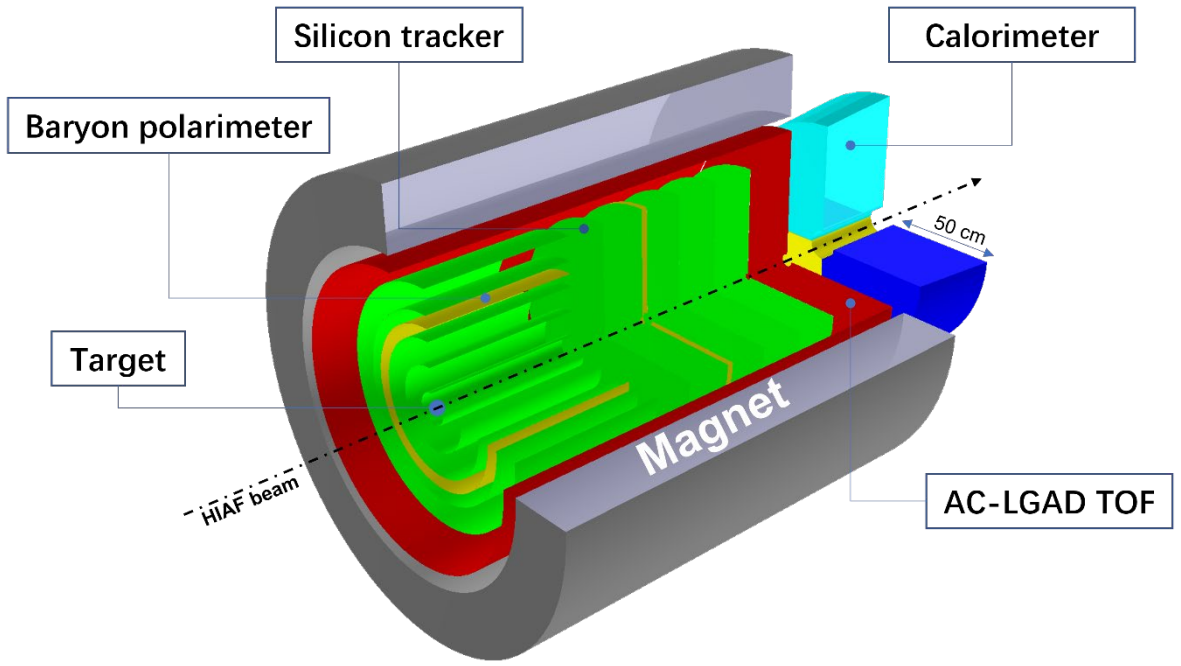
□ s-sbar, complementary to the c-cbar at BESIII

Status and Plan

Timeline


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
Detector
HIAF
HIAF-U
EicC
CEE@CSR
H-NS DEMO
H-NS construction
H-NS run
EicC

Hyperon-Nucleon Spectrometer



Participating Institute： 近代物理研究所、高能物理研究所、清华大学、山东大学、北京航空航天大学、复旦大学、国科大、华中师范大学、华南师范大学、北京师范大学、香港中文大学（深圳）、中科大、 中国原子能研究院、中山大学、湖州师范学院、 …

Subsystems： Silicon tracker, AC-LGAD, Target, Baryon polarimeter, Calorimeter, Electronics, DAQ, Magnet, Beamline, Mechanics + Engineering

I. Physics：

- Λ production and polarization (*p*+*p*)
  - Medium effect (*p*+*A*)
  - Global polarization of Λ hyperon (*A*+*A*)
- Hadron physics via *p*+*p*

II. Community：

- Supports both communities of hadron structure and heavy-ion physics
- International participations are expected

III. Detector R&D

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

Summary

➢ Physics：Baryon Spin Structure

- Utilizing HIAF's high-quality beams, to study **baryon polarization**, explore the deep structure of matter, and connecting to the future major direction of high-energy nuclear physics: electron-ion collider physics.
- Conducting energy scans at the HIAF energy range to study the **nuclear matter phase diagram** in the high-baryon-density region and search for the **liquid-gas phase transition** critical point.

➢ Detector Technology：

- Domestically-produced silicon detectors. All silicon detector (silicon tracking and LGAD).
- First proposal of a novel spectrometer concept with **final-state proton polarization measurement capability**, applied to H-NS, enabling simultaneous determination of **proton and hyperon polarization**.

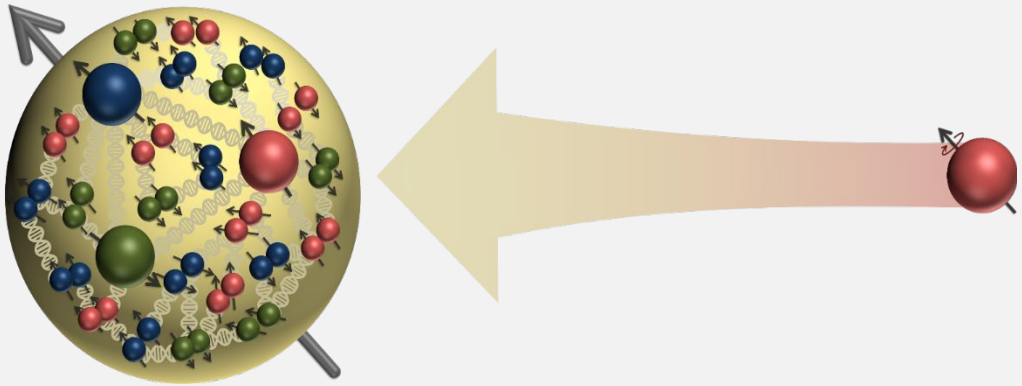
➢ Accelerator：

- Unpolarized beams at HIAF are already world-leading.
- Polarized beam R&D ongoing, not only for the H-NS but also for future EicC experiments.

Thank You

Spin structure and spin polarization

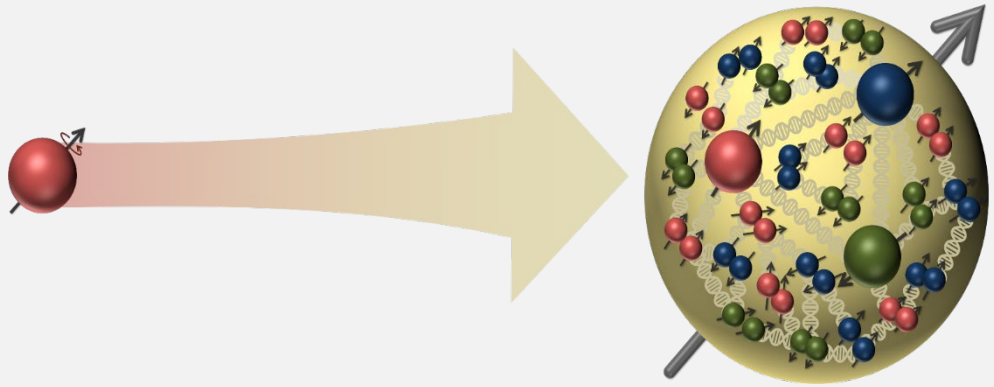
EIC: **Initial state** is polarized
-How do partons form up a polarized nucleon?



Initial state

Polarized by device

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

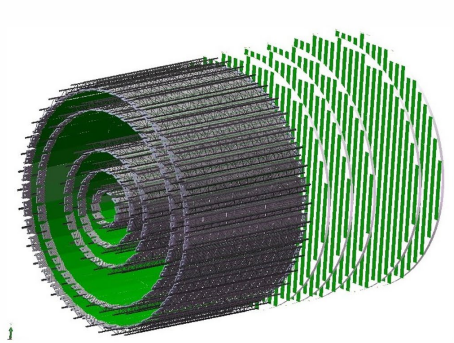


Final state

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

origin of nucleon spin VS origin of Λ or p polarization

Silicon tracker design



- The key detector of H-NS: MAPS Tracker
- 5.2 m² MAPS in total
  - ✓ Barrel: 5 stave layers, ~2.9 m²
  - ✓ Endcap: 5 disc layers, ~2.3 m²

➢ Barrel

R (cm)	Length (cm)	Pitch Size (μm)	Material Budget (X/X_0)	Tech.
5.0	42	30	< 0.8%	MIC6
11.0	42	30	< 0.8%	MIC6
17.0	42	30	< 0.8%	MIC6
29.0	42	30	< 0.8%	MIC6
35.0	42	30	< 0.8%	MIC6

➢ Endcap

In R (cm)	Out R (cm)	Z (cm)	Pitch Size (μm)	Material Budget (X/X_0 %)	Tech.
2.0	38	30	30	< 0.8%	MIC6
2.0	38	39	30	< 0.8%	MIC6
2.0	38	48	30	< 0.8%	MIC6
2.0	38	66	30	< 0.8%	MIC6
2.0	38	75	30	< 0.8%	MIC6

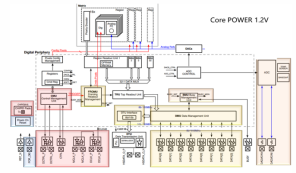
Chip development

✓ **MIC6_V4 chip tape-out completed, under characterization testing**

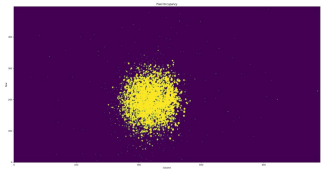
MIC6_V4 Features	
Process	GSMC 130 nm
Core Voltage	1.2V
Chip Size	30 mm×15 mm
Pixel Array	980×497
Pixel Size	30.53 um×26.8 um
Readout	AERD
Output Rate	1.2Gbps
Encoder	8B10B
Slow Control	MLVDS Control Bus
Parallel Data Interface	master-slave data aggregation and transmission

- ➢ Add control management unit (CMU) to replace SPI interface
- ➢ Add on-chip LDO

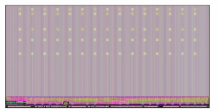
MIC6_V4 Architecture



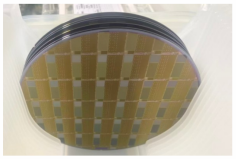
Alpha source test



MIC6_V4 Layout

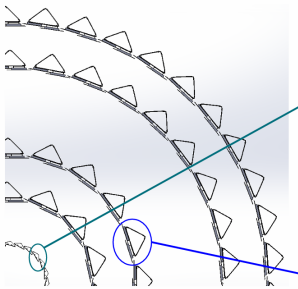


MIC6_V4 Chip

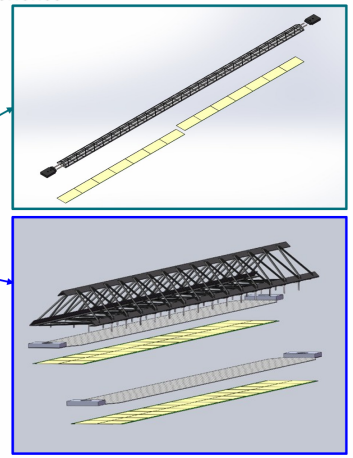


Barrel stave module design

Designed based on ALICE ITS2 experience



Layer No.	R (cm)	Nr. Of Staves
L0	5.0	24
L1	11.0	14
L2	17.0	20
L3	29.0	34
L4	35.0	42



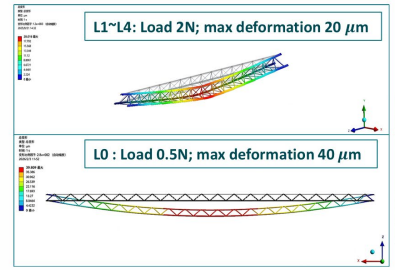
STAVE module:
Carbon frame + Cooling System + MIC6 chips + Flexible PCB

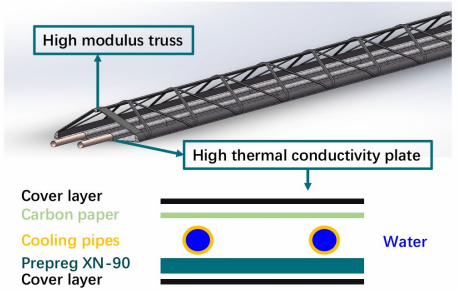
Innermost stave module:
- Each stave is formed by 2 chip modules(CM)
- Each CM is assembled from 1×7 MIC6 chips and a FPC
- All chips on the CM operate in master mode

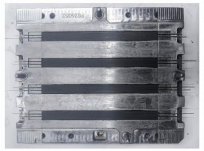
Stave module for the outer 4 layers:
- Each stave is composed of 2 half-staves
- Each half-stave consists of 2 chip modules(CM)
- Each CM is assembled from a 2×7 array of MIC6 chips and a FPC
- 2 chips on each CM operate in master mode, and the rest operate in slave mode

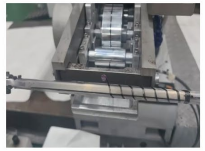
Mechanical structure and prototype

- ✓ FEA simulations were performed based on the material selection and structure, and the mechanical performance of the current design was verified
- ✓ Mature production and processing conditions for the carbon fiber materials and processes required for the stave are currently available domestically
- ✓ Completed the fabrication of the carbon fiber mechanical prototype






Cooling tube & plate

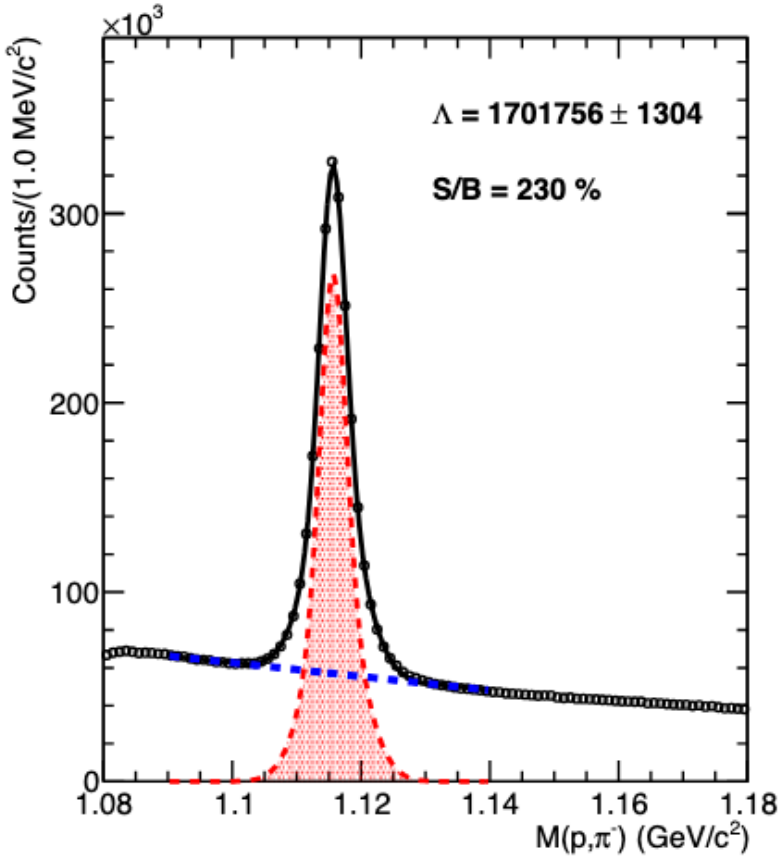

Frame machining

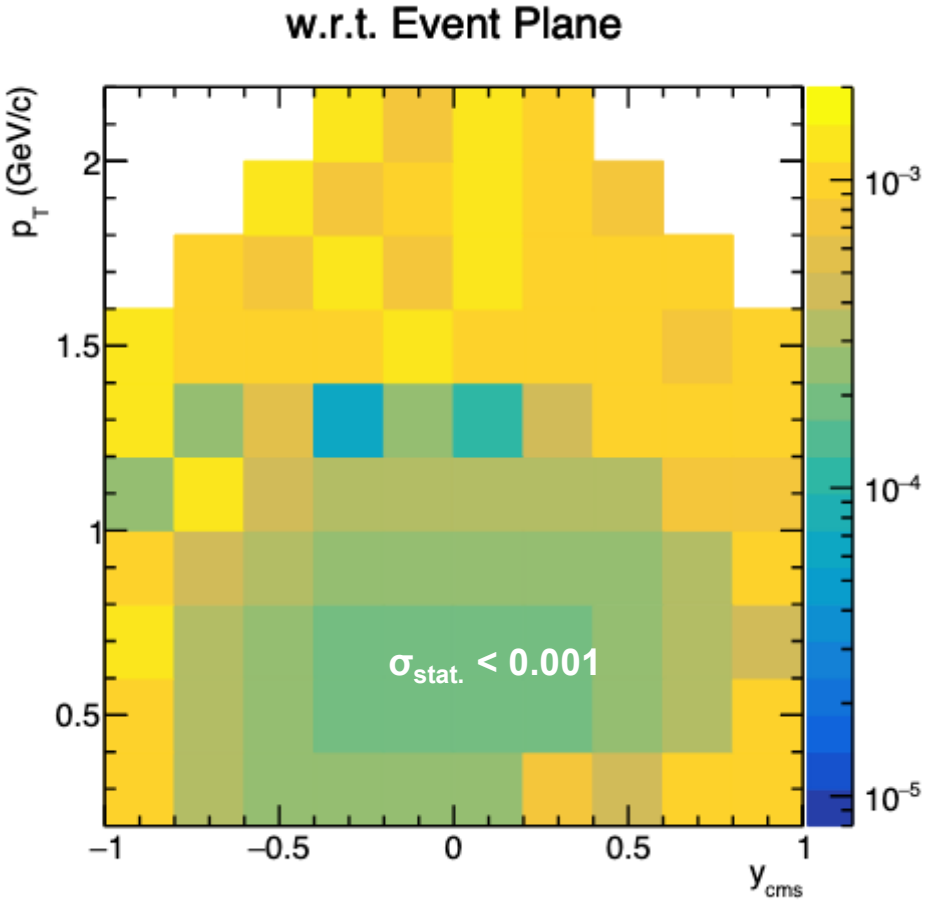

Mechanical Structure prototype

Physics potentials at H-NS

Au+Au → Λ + X

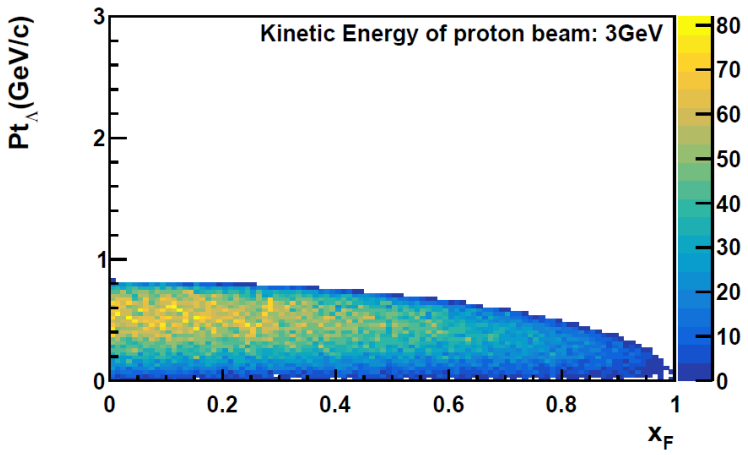
beam kinetic energy of 2.8 GeV/u

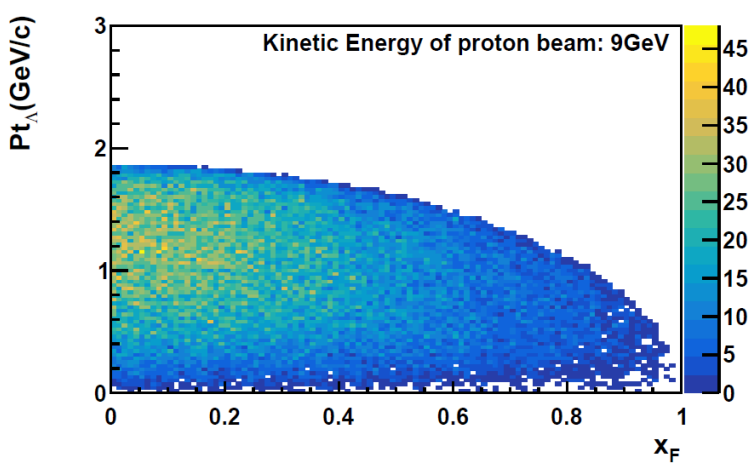


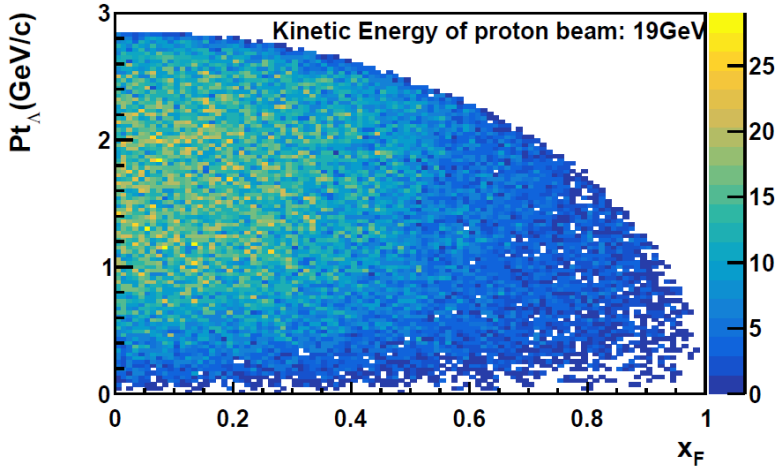


2D uncertainty of Λ polarization using 10^{11} Au+Au events, few weeks data taking

Kinematic of hyperon production at HIAF







3 GeV → 9 GeV → 20 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

Polarized experiments at H-NS



General Partial Wave Analysis of the Decay of a Hyperon of Spin ½

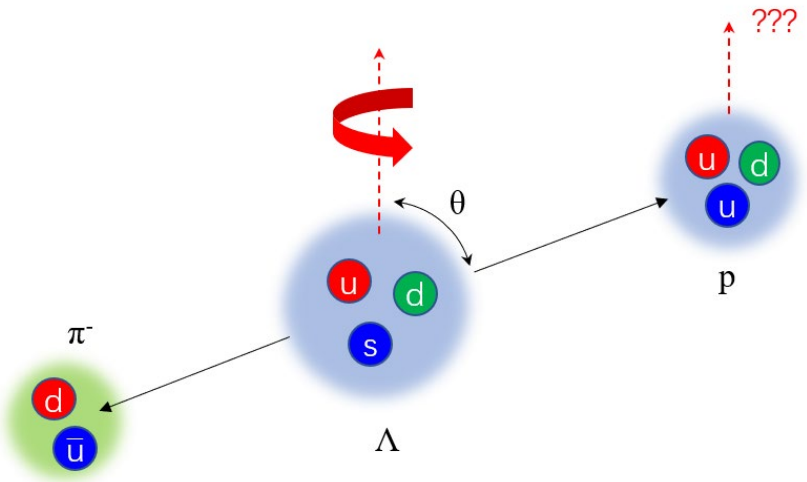
T. D. Lee* and C. N. Yang
Institute for Advanced Study, Princeton, New Jersey
(Received October 22, 1957)
Phys. Rev. 108, 1645 (1957)

The amplitude of spin ½ baryon B_i decay to a spin ½ baryon B_f and π:

$$\mathcal{A} \sim S\sigma_0 + P\boldsymbol{\sigma}\cdot\hat{\boldsymbol{n}}$$

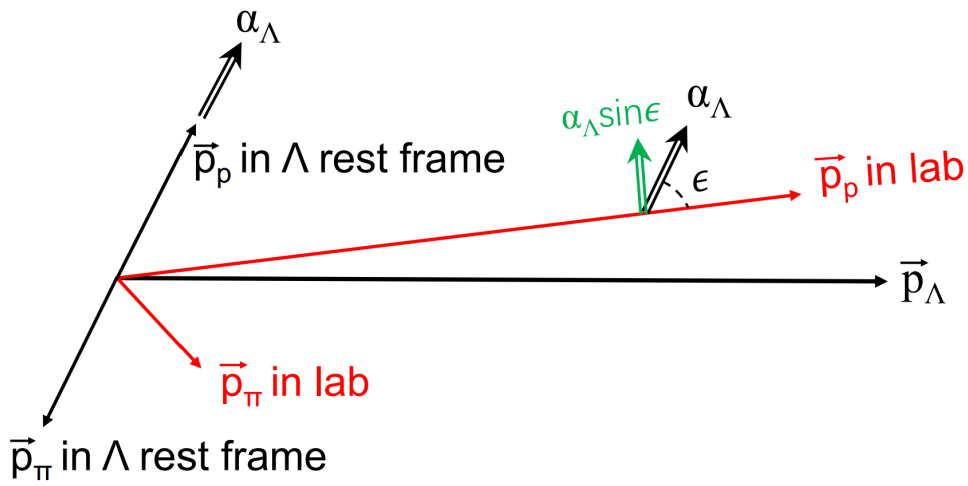
The decay parameters are defined as:

$$\alpha = \frac{2\mathrm{Re}(S^*\cdot P)}{|S|^2+|P|^2} \qquad \beta = \frac{2\mathrm{Im}(S^*\cdot P)}{|S|^2+|P|^2} \qquad \gamma = \frac{|S|^2-|P|^2}{|S|^2+|P|^2} \qquad \alpha^2+\beta^2+\gamma^2 = 1$$



$$dw(\theta) = \frac{1}{4\pi}(1+\alpha P_\Lambda\cdot\hat{q})\,d\Omega$$

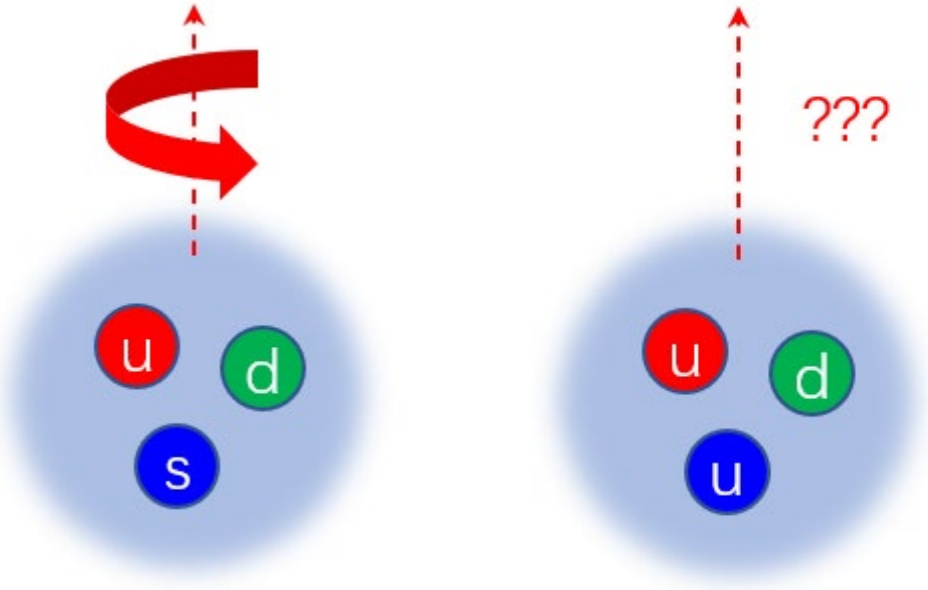
$$P_p = \frac{(\alpha+P_\Lambda\cdot\hat{q})\hat{q} + \beta(P_\Lambda\times\hat{q}) + \gamma(\hat{q}\times[P_\Lambda\times\hat{q}])}{1+\alpha P_\Lambda\cdot\hat{q}}$$

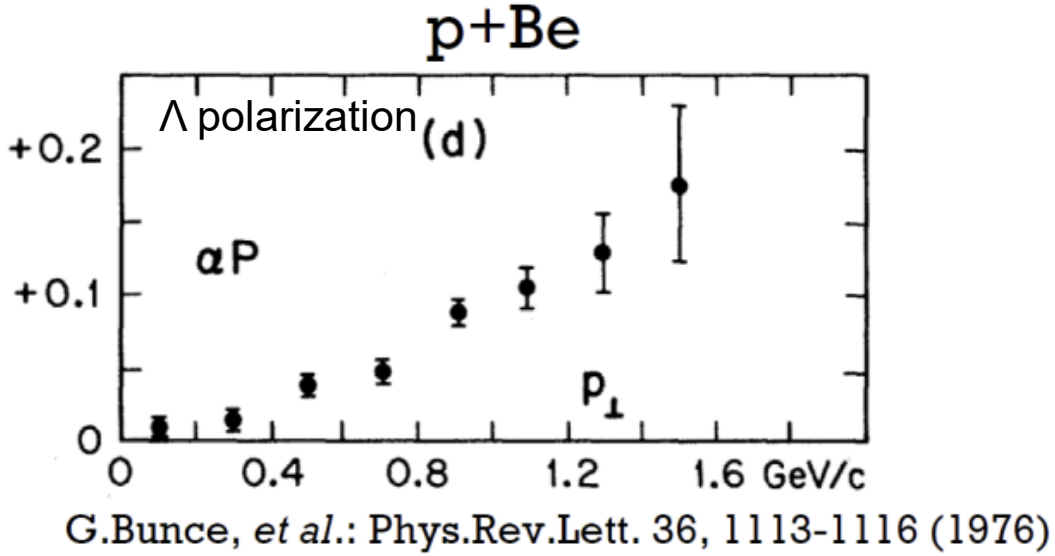


T. D. Lee, C. N. Yang Phys. Rev. 108,1645 (1957)

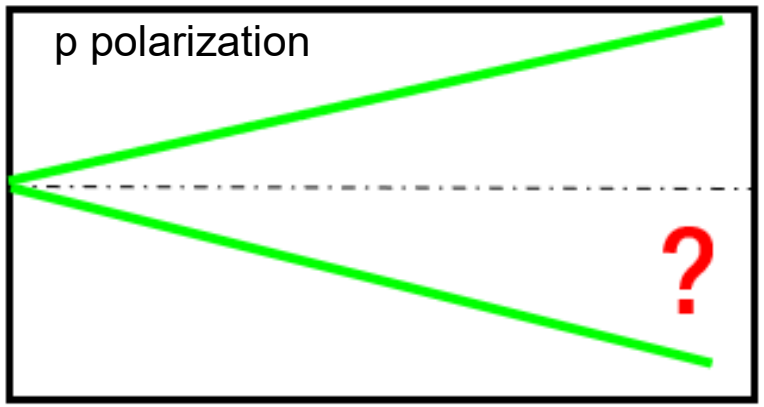
Baryon spin structure – polarization of p/Λ

pp → p/Λ + X





G.Bunce, *et al.*: Phys.Rev.Lett. 36, 1113-1116 (1976)



Hyperon-Nucleon Spectrometer (H-NS)

Mag. Field: 1.5 Tesla

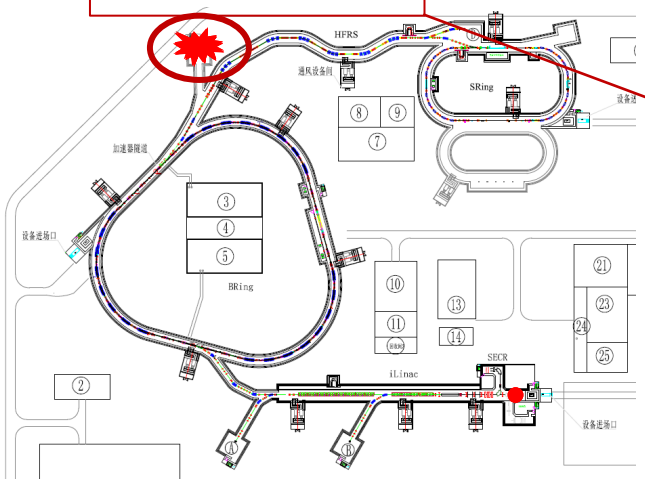
Tracker: MIC6, 30X30 μm^2, 0.8%X/X_0

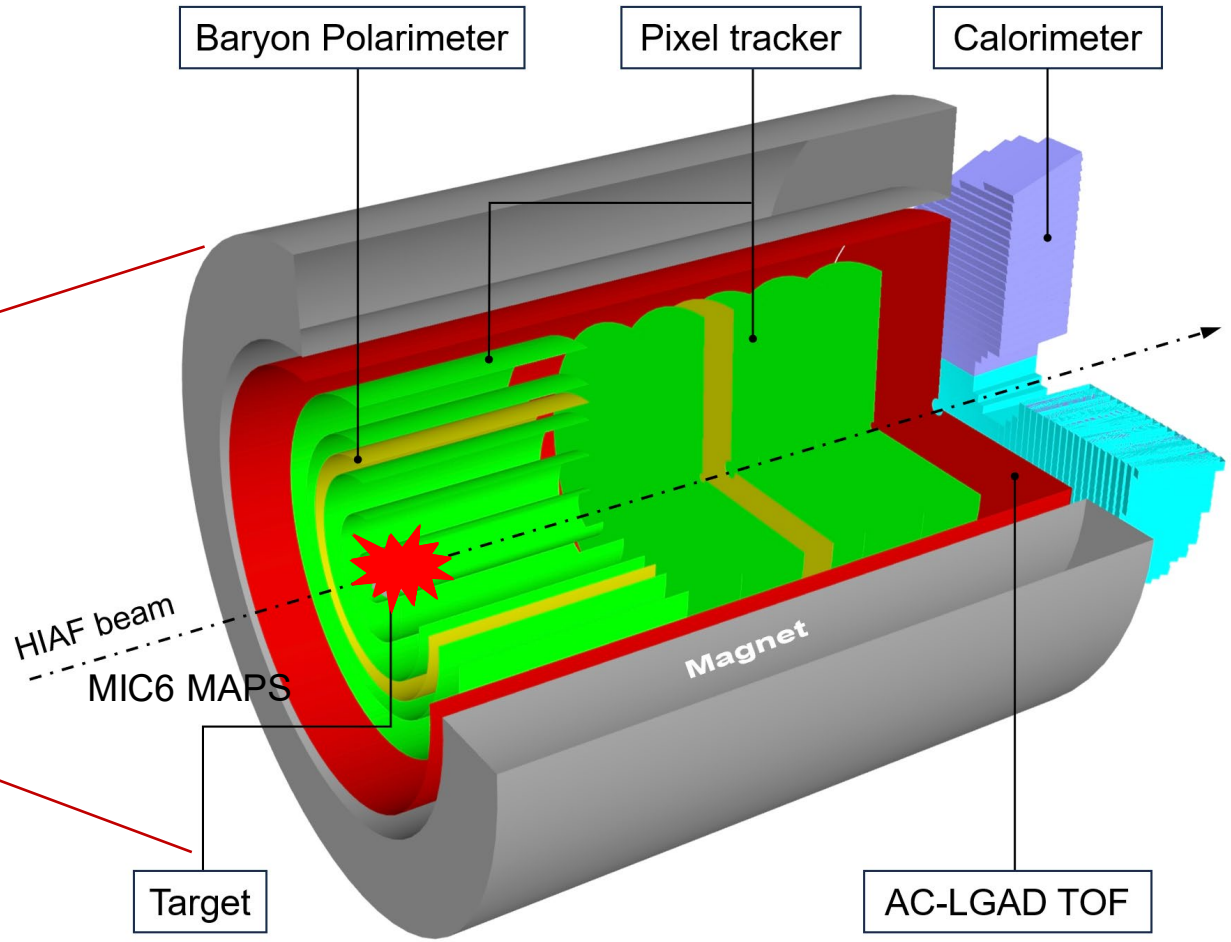
LGAD: σ_t ~ 30 ps , 300X300 μm^2

Calorimeter: σ_E ~ 3% @ 1GeV

Polarimeter: nucleon and photon polarization

High Energy Nuclear Physics Terminal

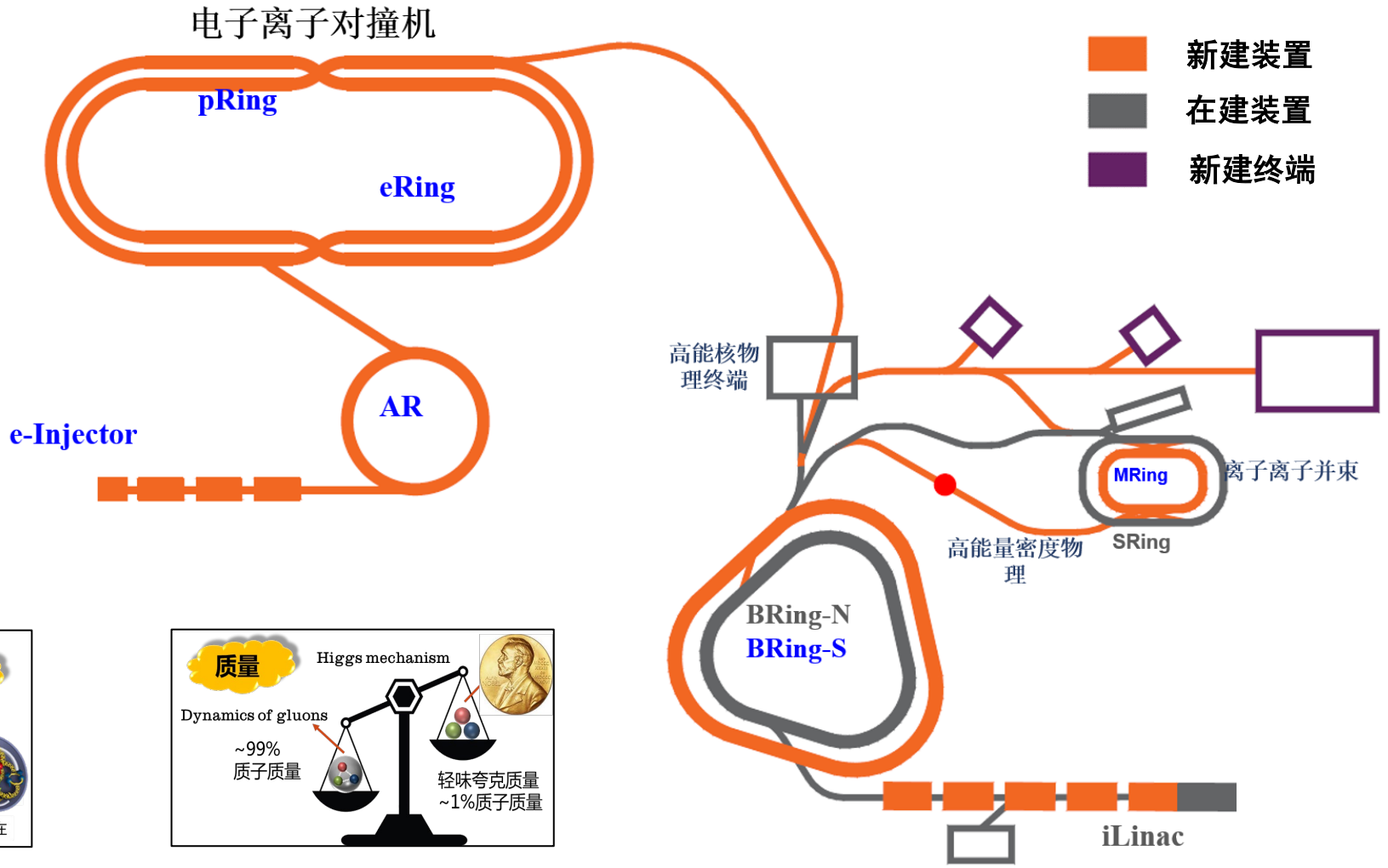


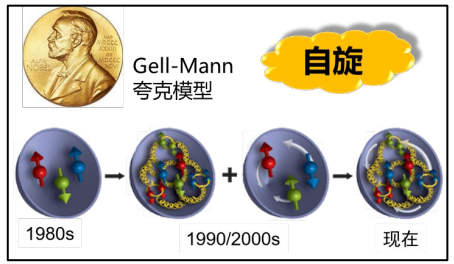


Electron ion collider in China (EicC)

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

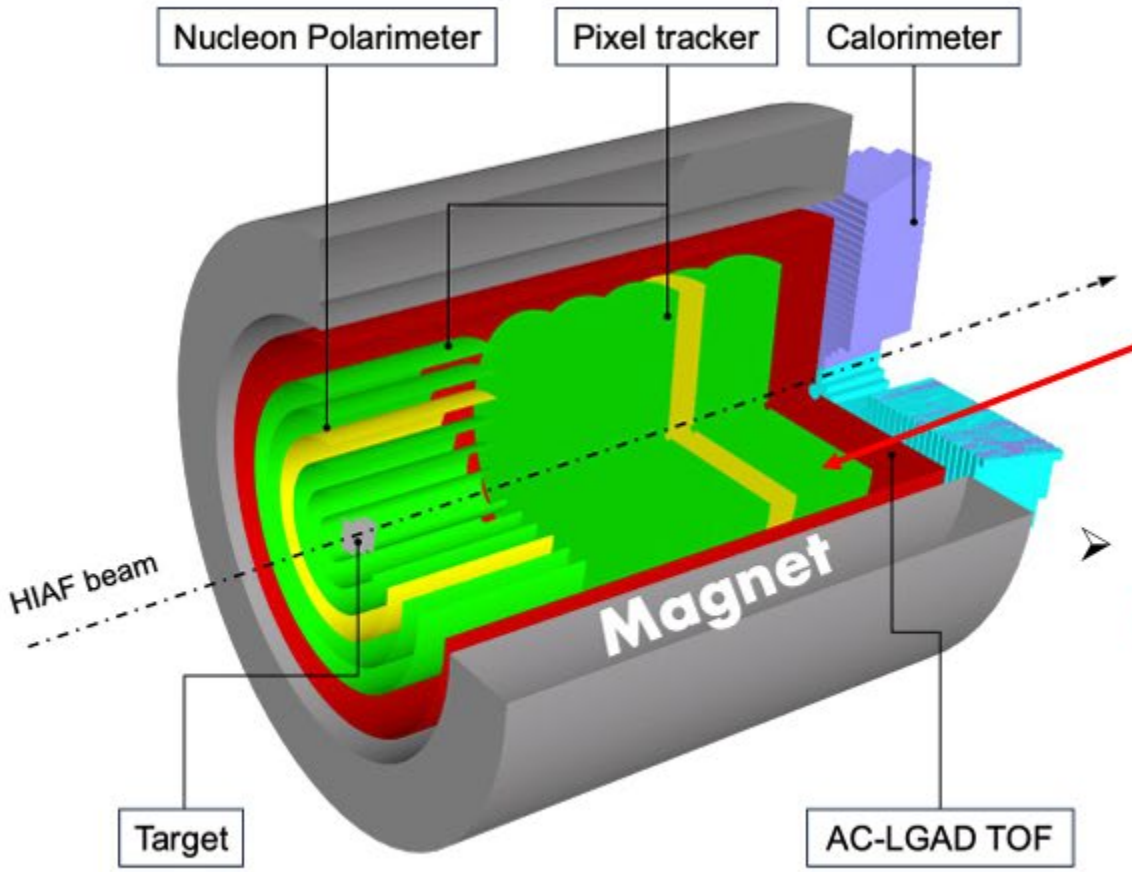
  2-4 x10^{33} cm^{-2}s^{-1}
- Polarized beams

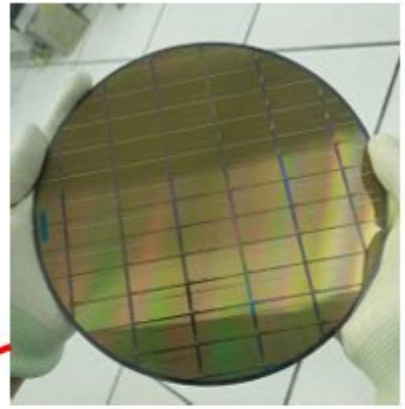




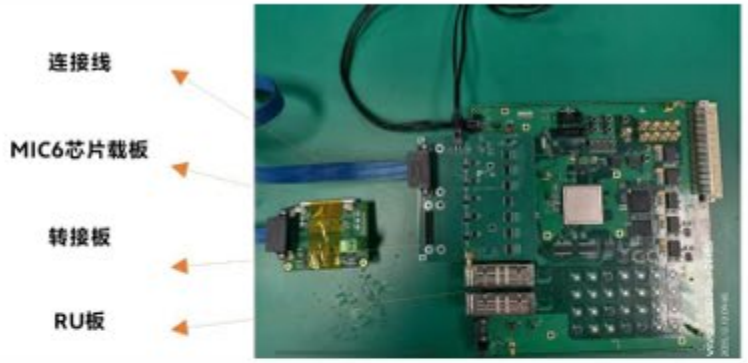
- We have a framework for the understanding of the spin structure of the nucleon
- EIC/EicC is the future

H-NS Tracking detector



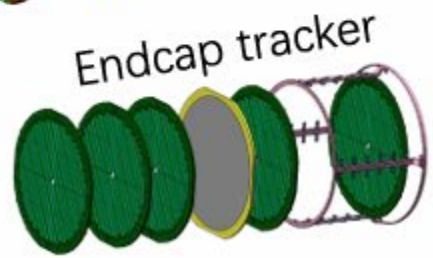


MIC6 V3测试系统



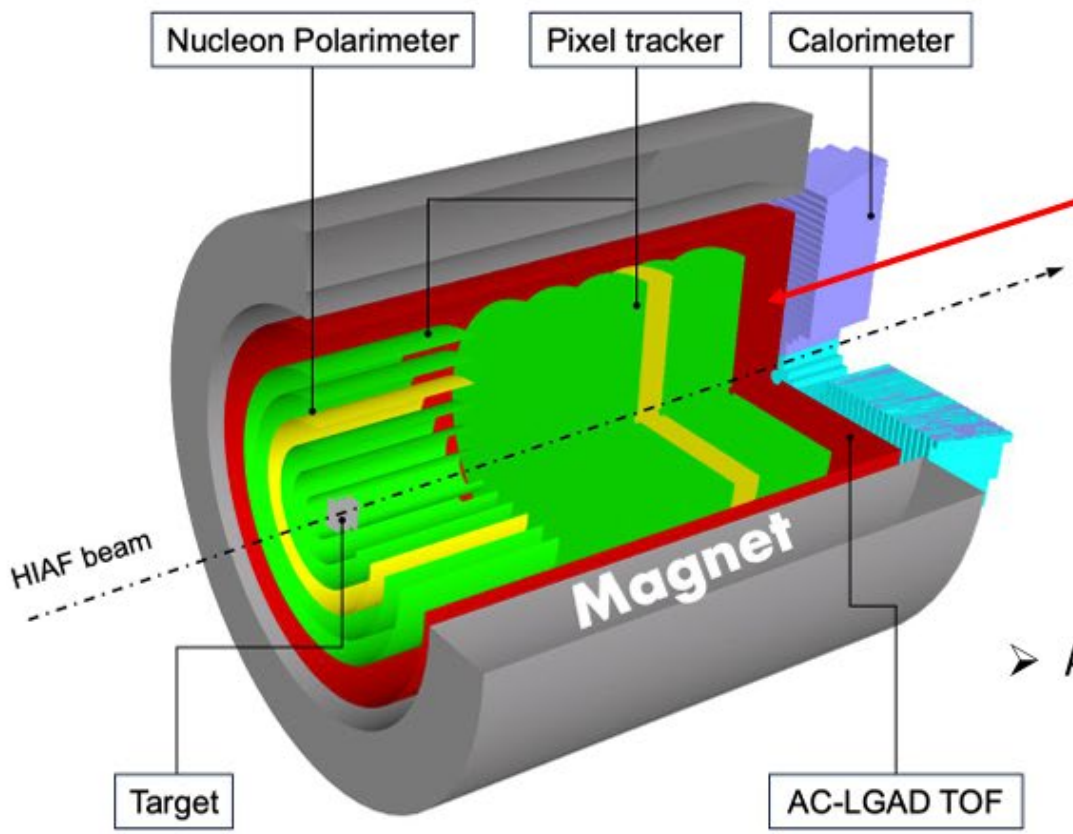
- MIC6 MAPS像素芯片：采用国产工艺开发与制造
  - 像素尺寸：30 μm
  - 物质量：0.8% X/X_0
  - 积分时间：5–10 μs

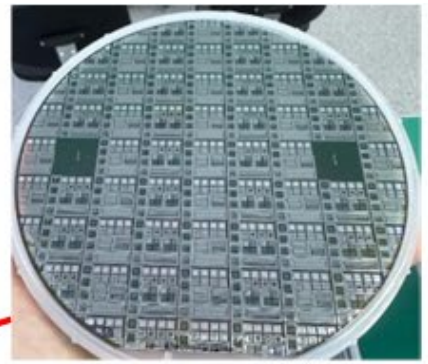


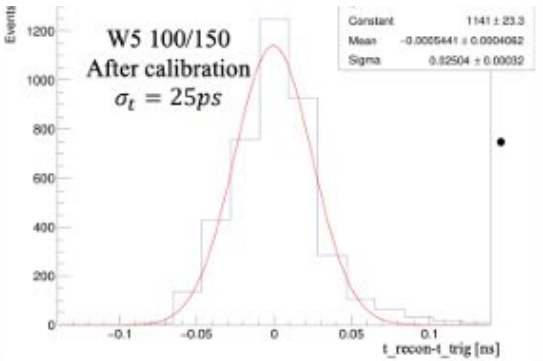


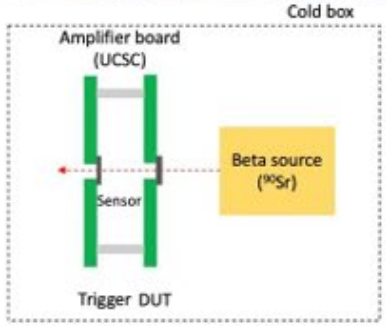
华中师范大学 + 中科大 + 近物所 + 西工大

H-NS PID detector

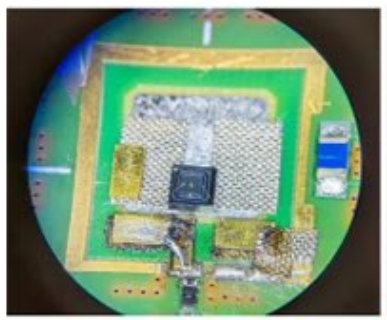




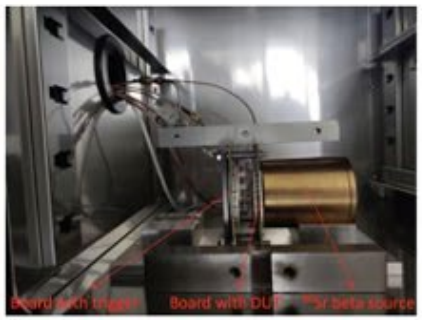




(a)

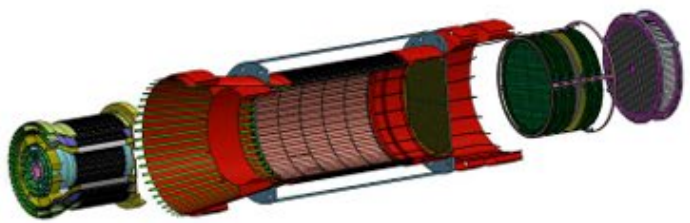


(b)



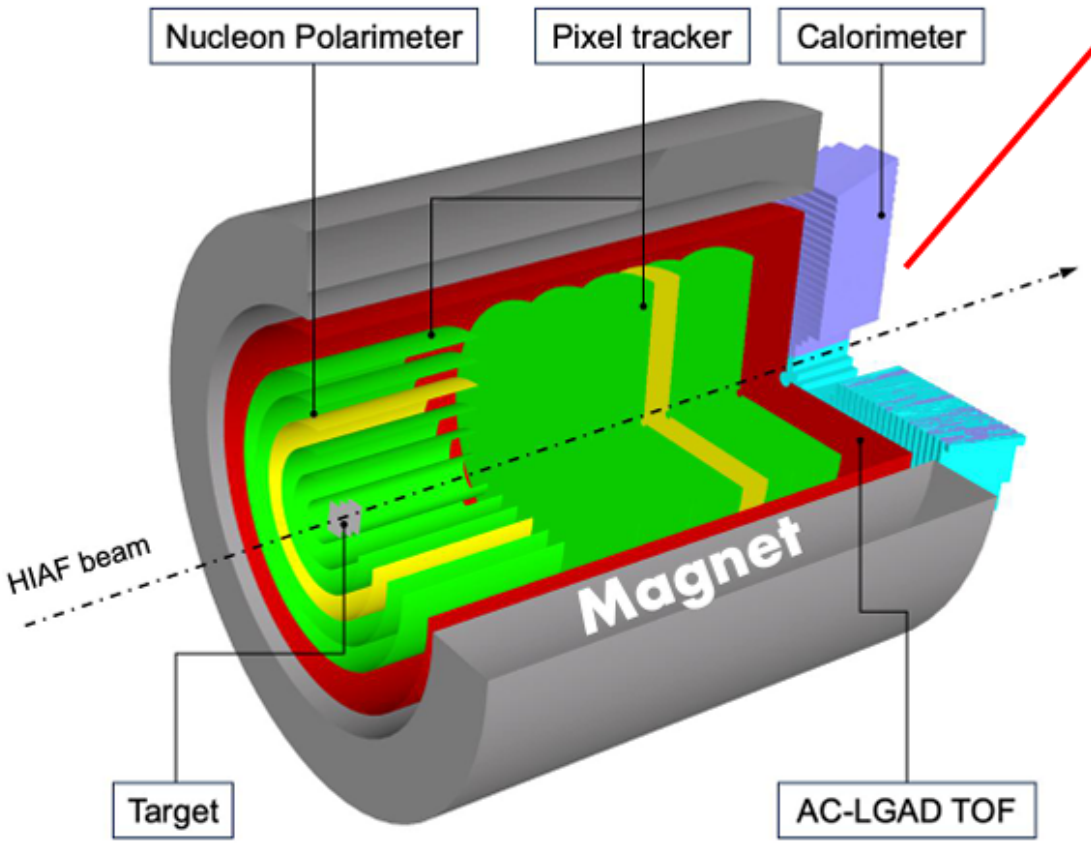
(c)

- AC-LGAD
  - 结构紧凑
  - 时间分辨率: ~30 ps
  - 空间分辨率: ~100μm



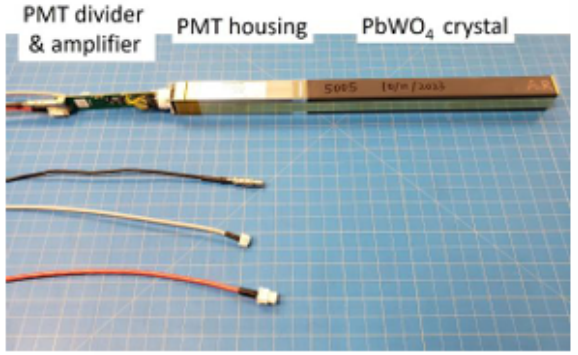
中科大 + 山东大学 + 清华大学 + 近物所

H-NS 量能器系统



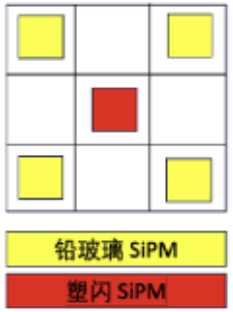
量能器系统双重功能：

1. 重建中性粒子γ, π^0 等，服务物理研究
2. 高性能量能器R&D 平台，支撑未来实验



- PbWO4晶体：体积紧凑，能量分辨率良好
  - 能量分辨：$3\%/\sqrt{E}$
  - 空间分辨：～3mm

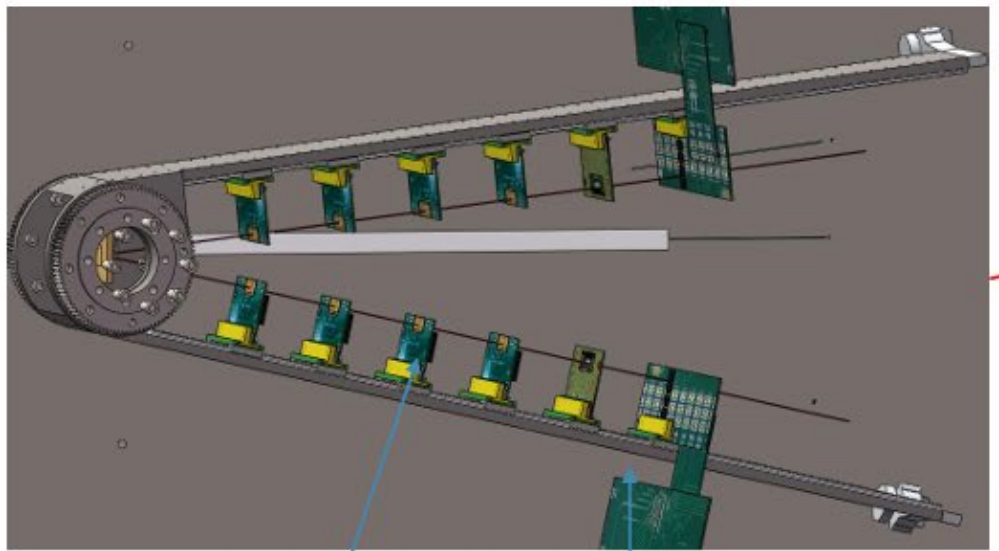


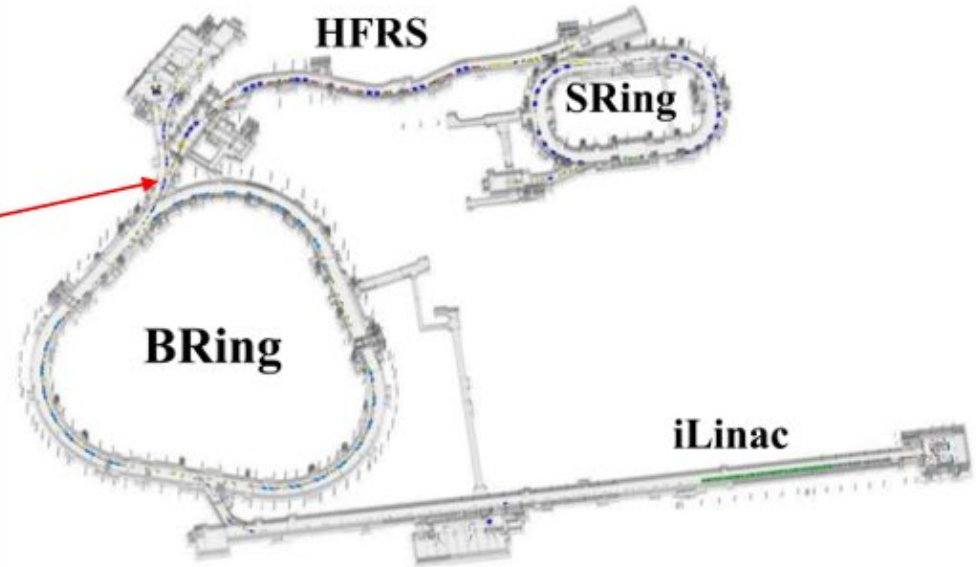


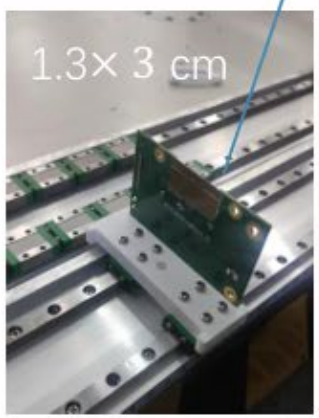
切伦科夫光和闪烁光双读出量能器预研

清华大学 + 复旦大学 + 近物所

H-NS0 prototype

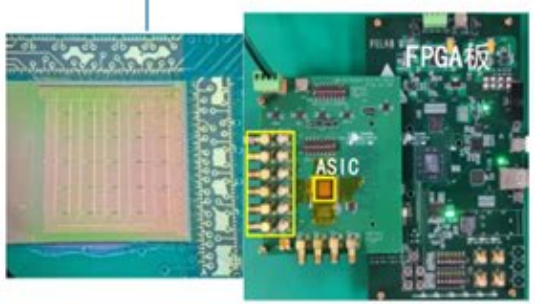






MAPS

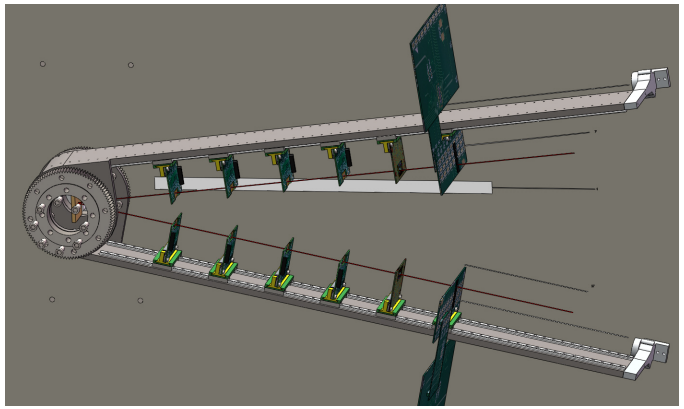
目前正在惠州整体集成，2026年完成!

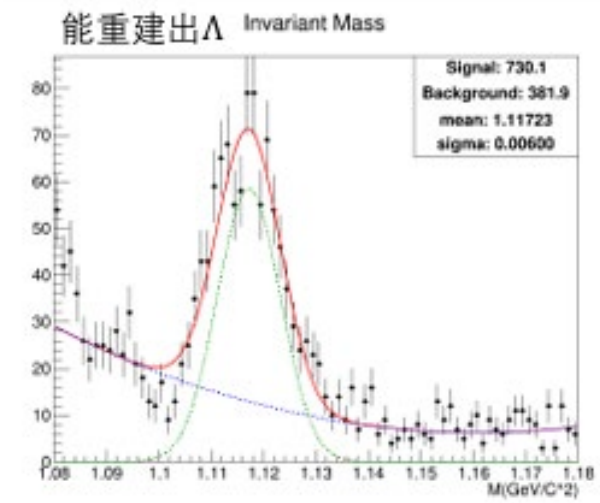


LGAD

H-NS0: DEMO 验证关键技术
detector + electronics + DAQ + control system

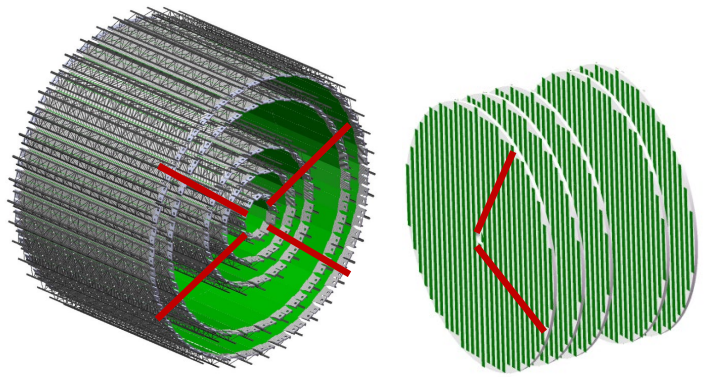
H-NS 阶段规划





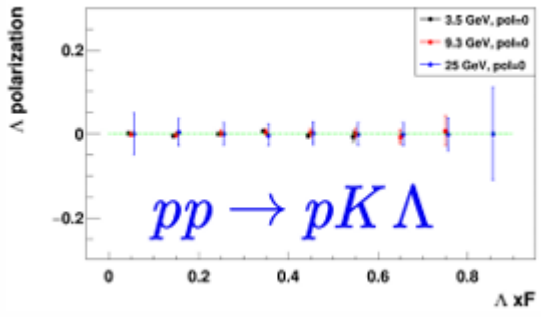
MIC6/LGAD芯片验证

2026



TOF，ECal 未显示

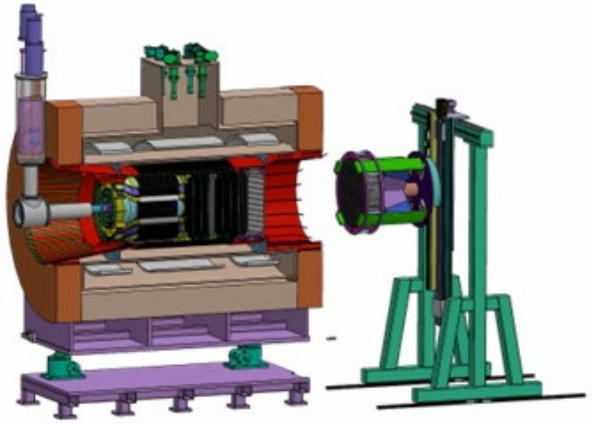
部分探测器，可扩展性



全尺寸磁铁，部分立体角覆盖探测器；可运行，用于物理产出

部分经费支持

2026-2030



全尺寸探测器

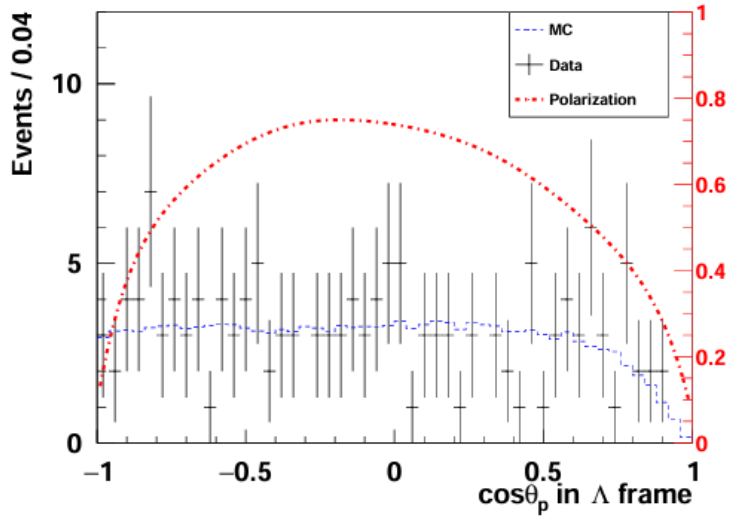
丰富的物理：

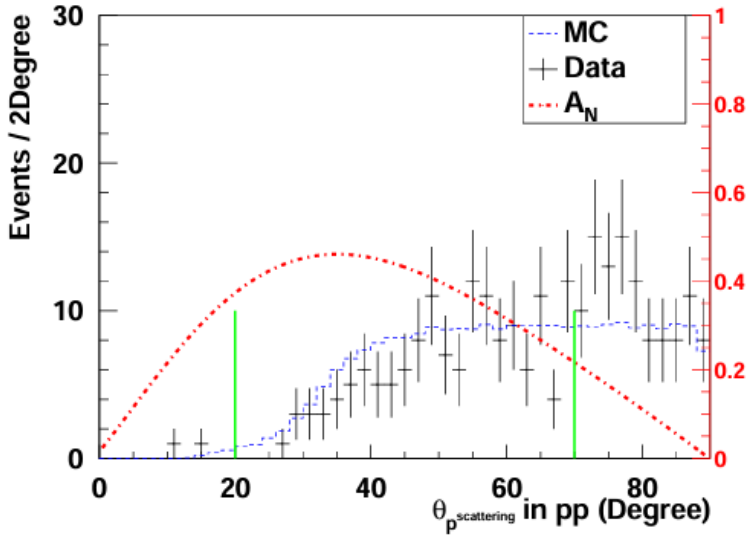
- 高精度、多维度超子极化测量
- 轻强子物理、奇特强子态…
- 核介质效应
- 超核物理
- 核物质相结构
- …

全额支持

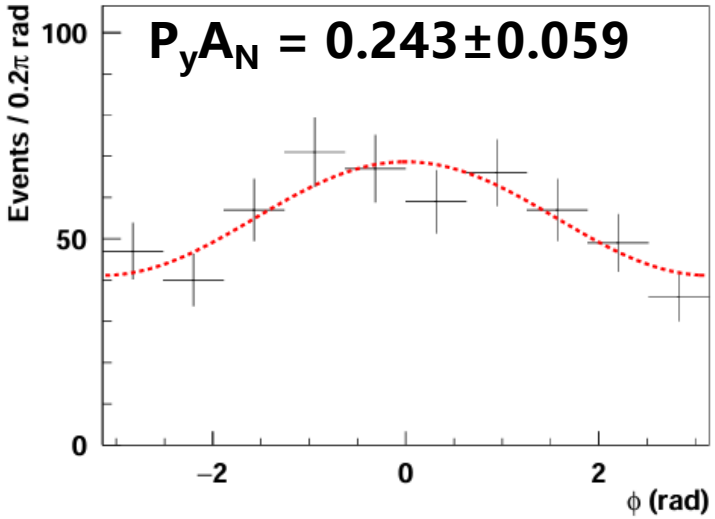
2030-

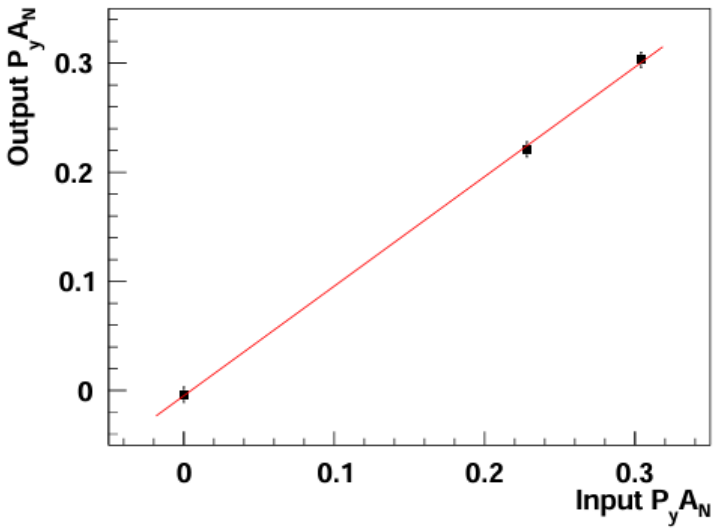
H-NS 核子极化测量仪--BESIII验证





→ expected
$P_yA_N = 0.22 \pm 0.01$

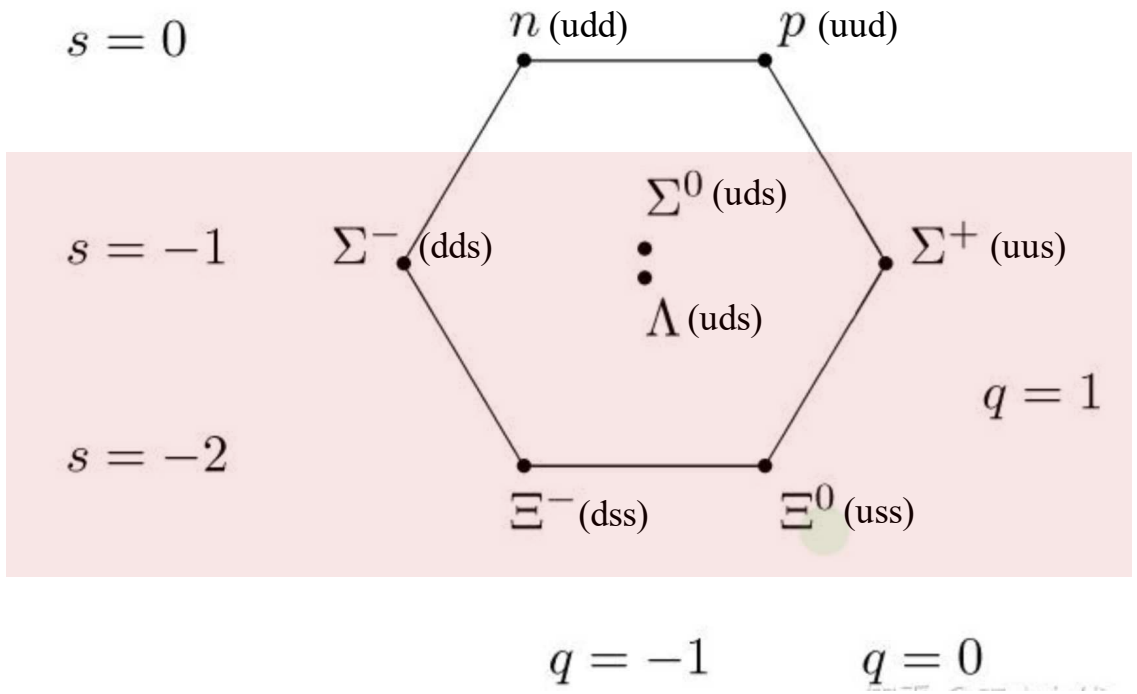




→ measured
$P_yA_N = 0.243 \pm 0.059$

arXiv: 2607.19927

Various baryons at H-NS



Beam energy @ 9.3 GeV

- Number of hyperons relative to Λ

Σ^- ~ 0.05 Σ^0 ~ 0.15 Σ^+ ~ 0.25 2D √

Ξ^- ~ 1E-2 Ξ^0 ~ 1E-2 1D √

- Number of anti-hyperons relative to Λ

$\bar{\Lambda}$ ~ 5E-4

$\bar{\Sigma}^+$ $\bar{\Sigma}^0$ $\bar{\Sigma}^-$ ~ 1E-4 1D √

$\bar{\Xi}^+$ ~ 1E-6

- Number of anti-proton relative to p

$\bar{p}$ ~ 1E-4 1D √