March 19, 2026

Hyperon-Nucleon Spectrometer at HIAF

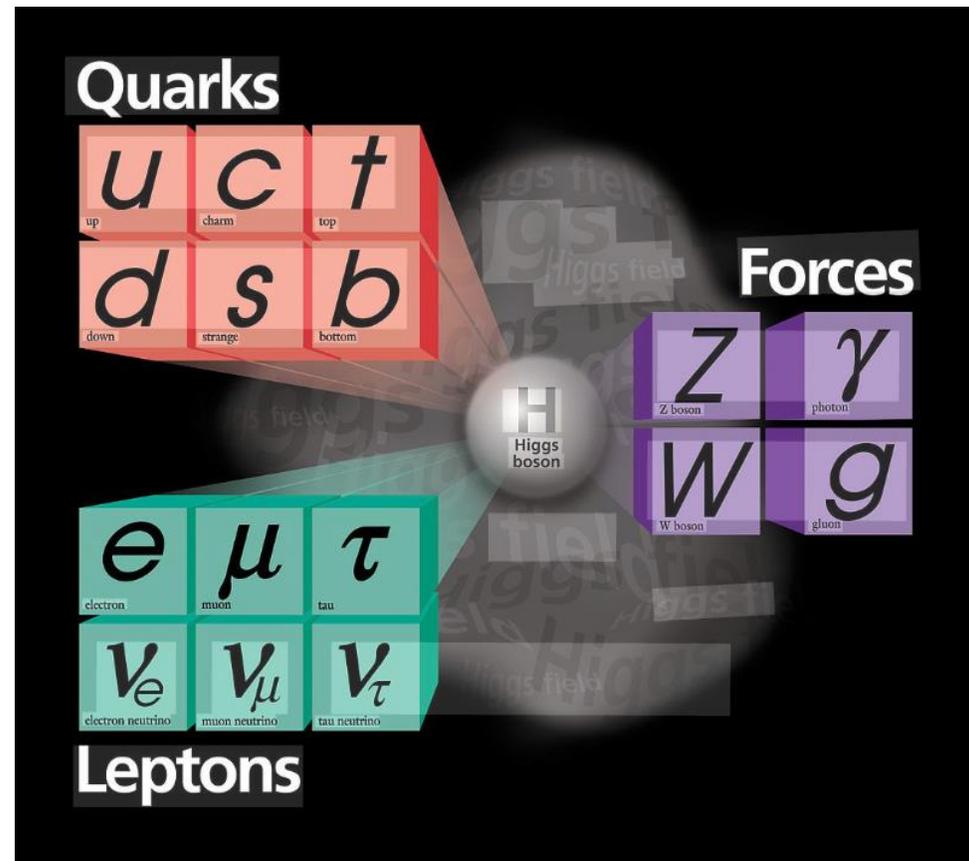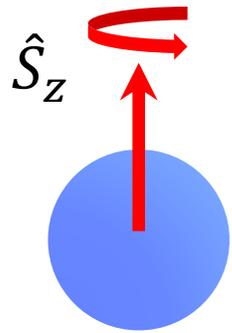Aiqiang Guo (guoaq@impcas.ac.cn)

Institute of Modern Physics, Chinese Academy of Sciences

Outline

➢ Introduction of physics
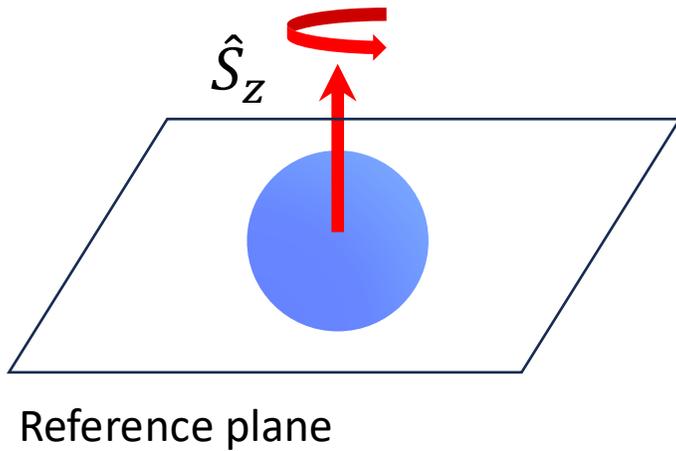
➢ H-NS at HIAF

➢ Summary and Outlook

Spin and its polarization

Spin: fundamental degree of freedom for element particles, an intrinsic property of all quantum particles
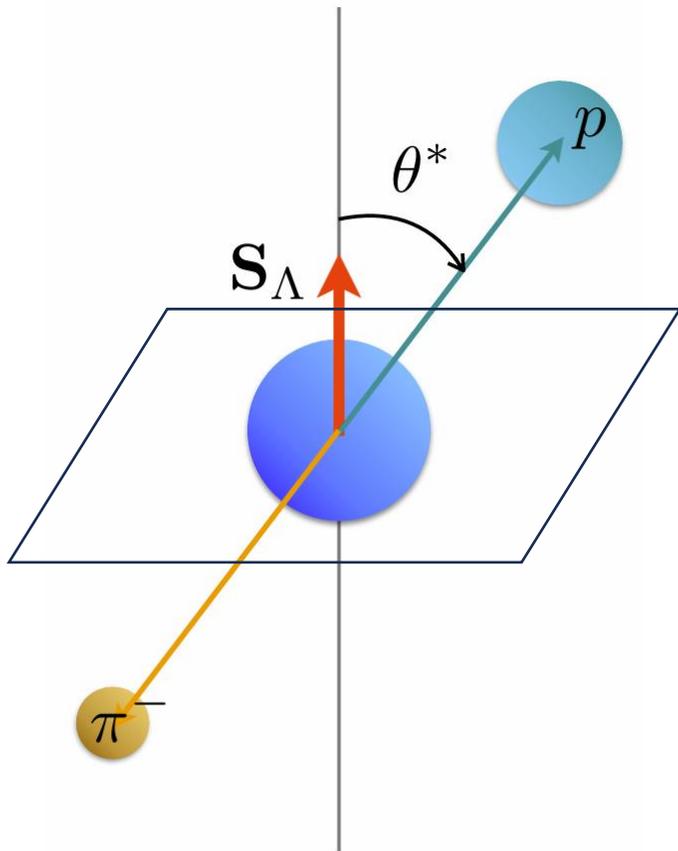
$\hat{S}_z$

Spin and its polarization

Polarization: spin of particles in a system is aligned in a preferred direction.

$\hat{S}_z$

Reference plane

Measurement of polarization

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

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

branch ratio: $64.1 \pm 0.5\%$

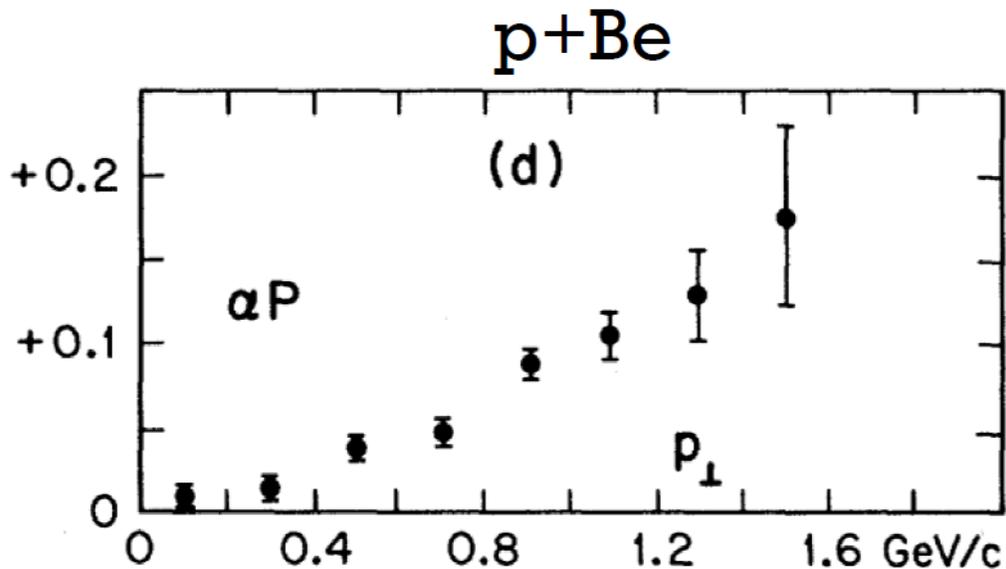parity violating weak decay

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

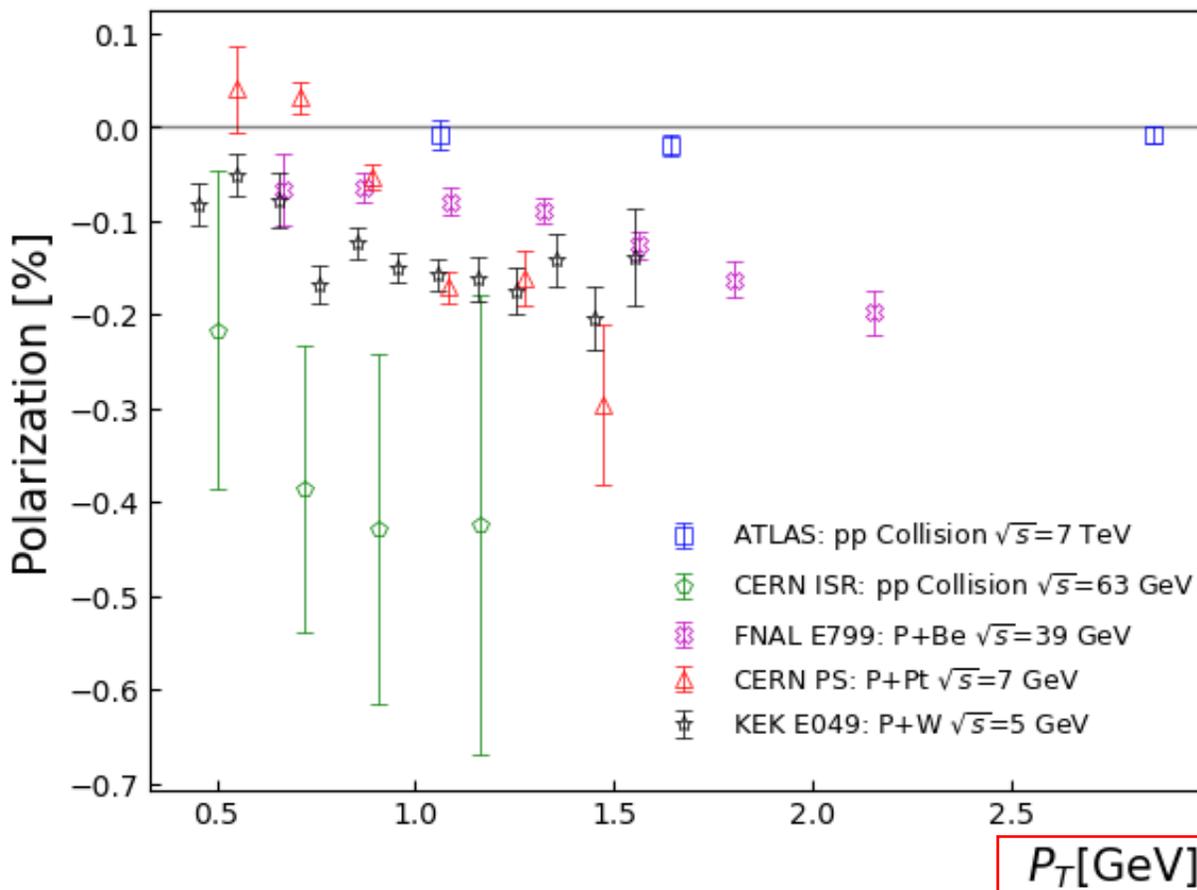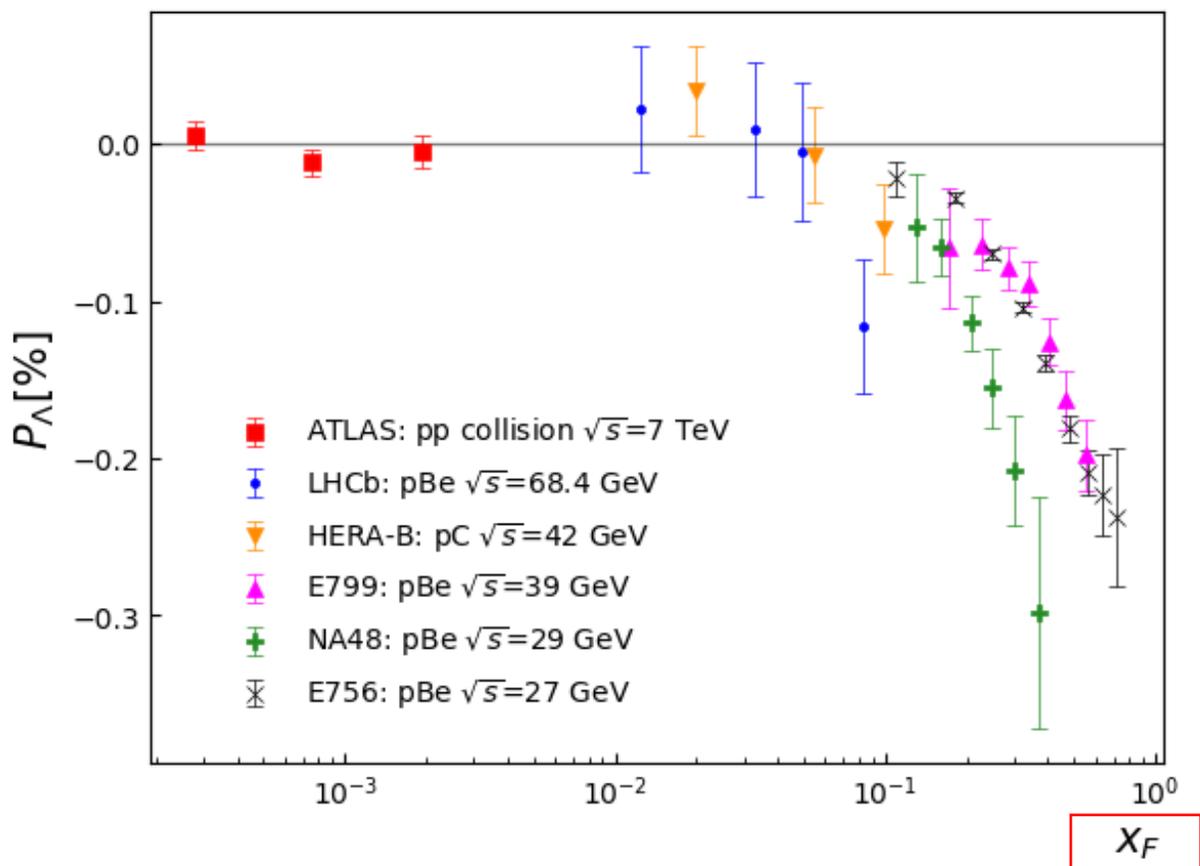decay parameter: $\alpha_\Lambda = 0.748 \pm 0.007$

[Current PDG value]

First observation of Λ^0 polarization in the 1970's

p+Be

(d)

αP

$p_\perp$

+0.2

+0.1

0

0   0.4   0.8   1.2   1.6 GeV/c

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

➢ Hyperons can be produced polarized in collisions of **unpolarized particles**

➢ Discovered at Fermilab in the 1970's in *p* + Be collisions: 300 GeV protons on Beryllium
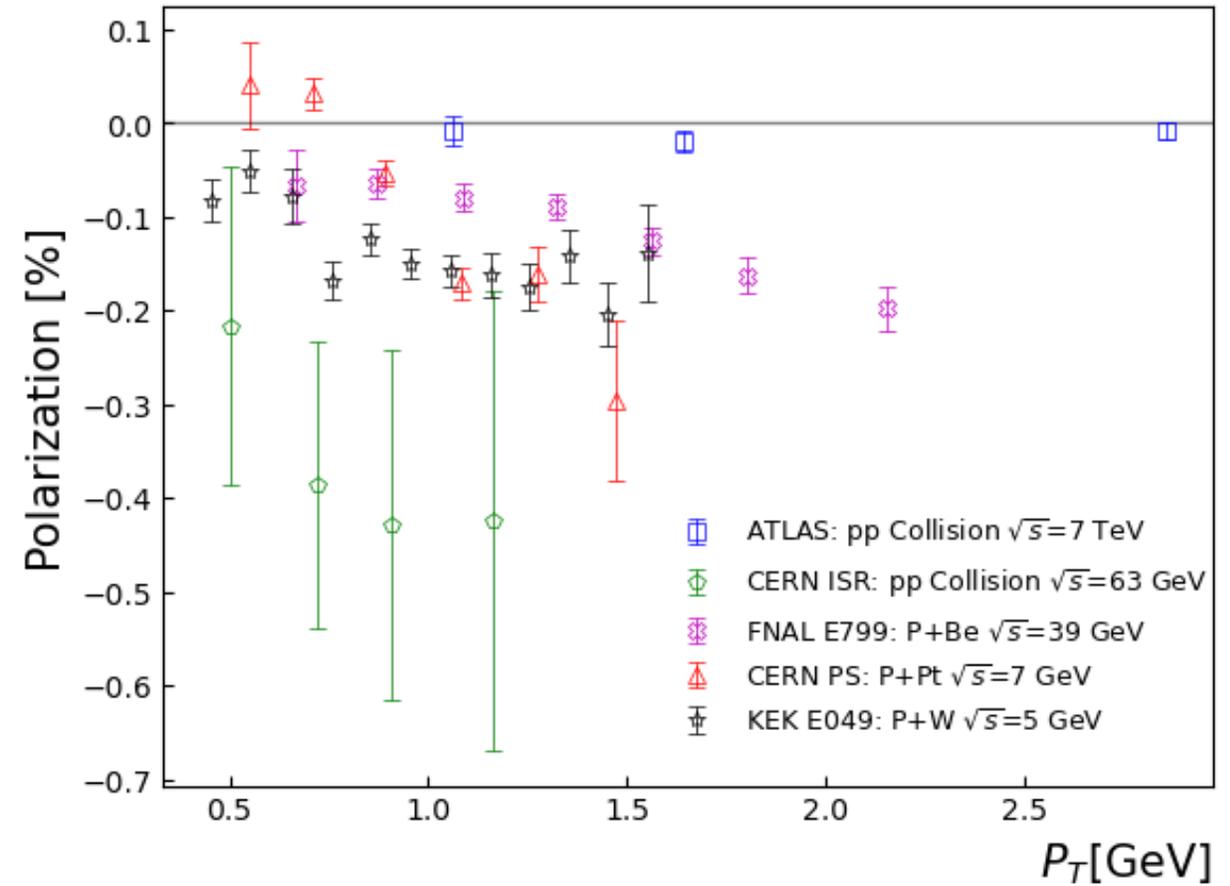
Λ^0 polarization measurements

In standard collinear pQCD, the single quark polarization P from hard scattering follows the scaling relation:

$$P \propto \alpha_s \frac{m_q}{Q}$$

[Phys.Rev.Lett. 41 (1978) 1689]

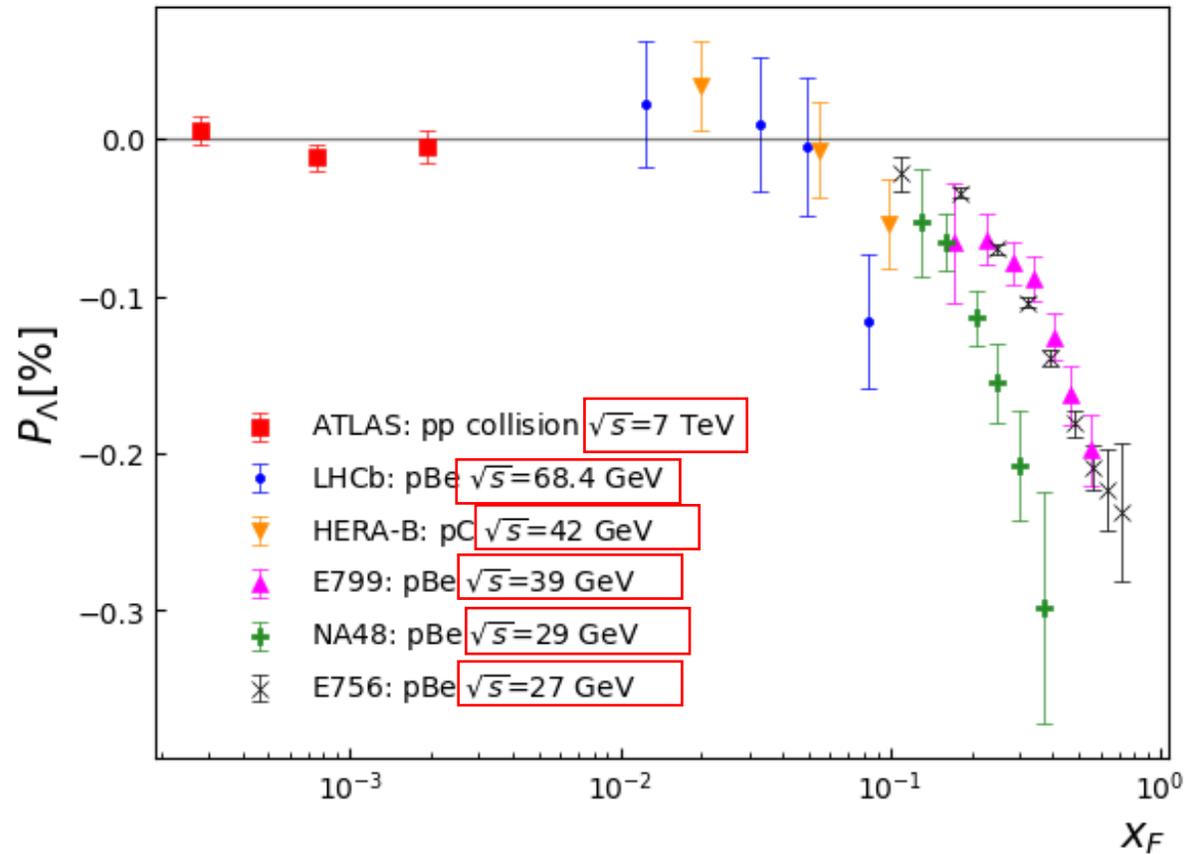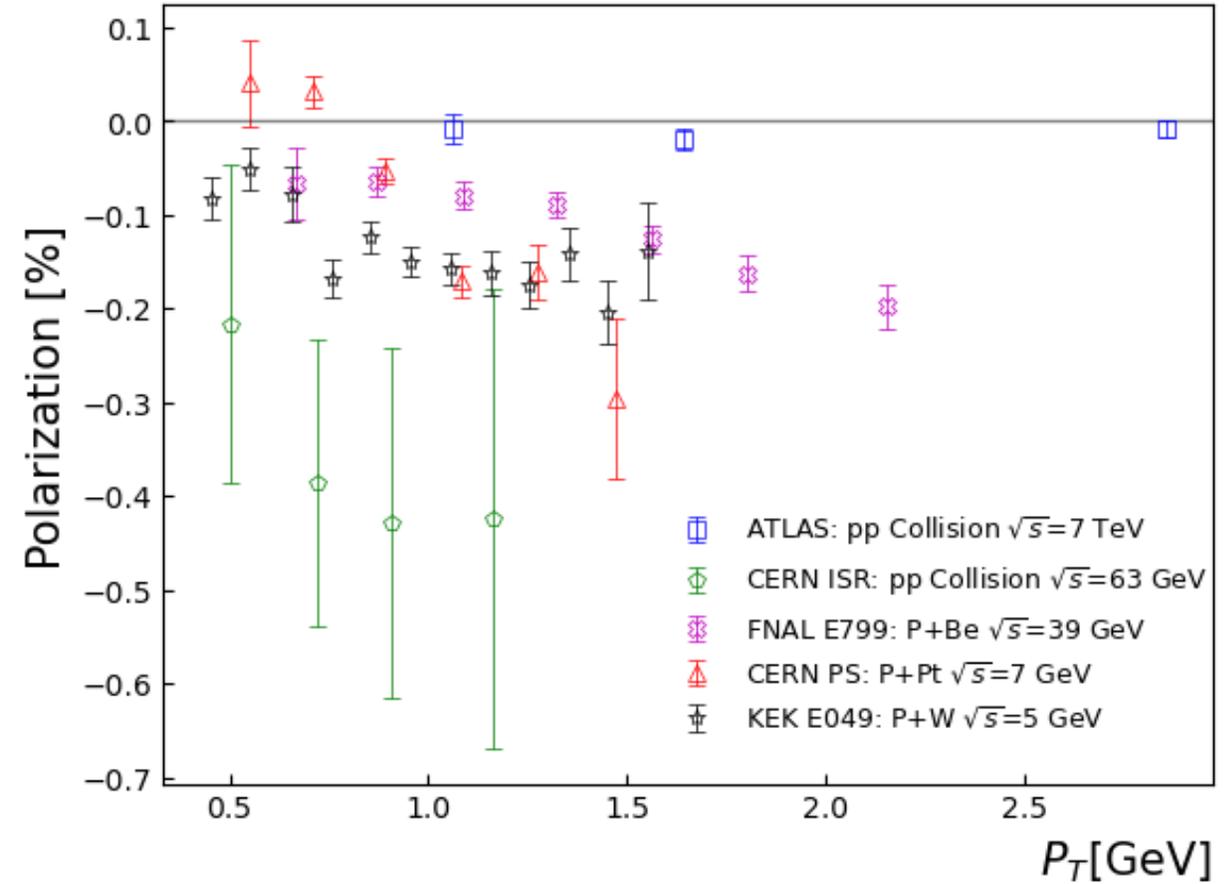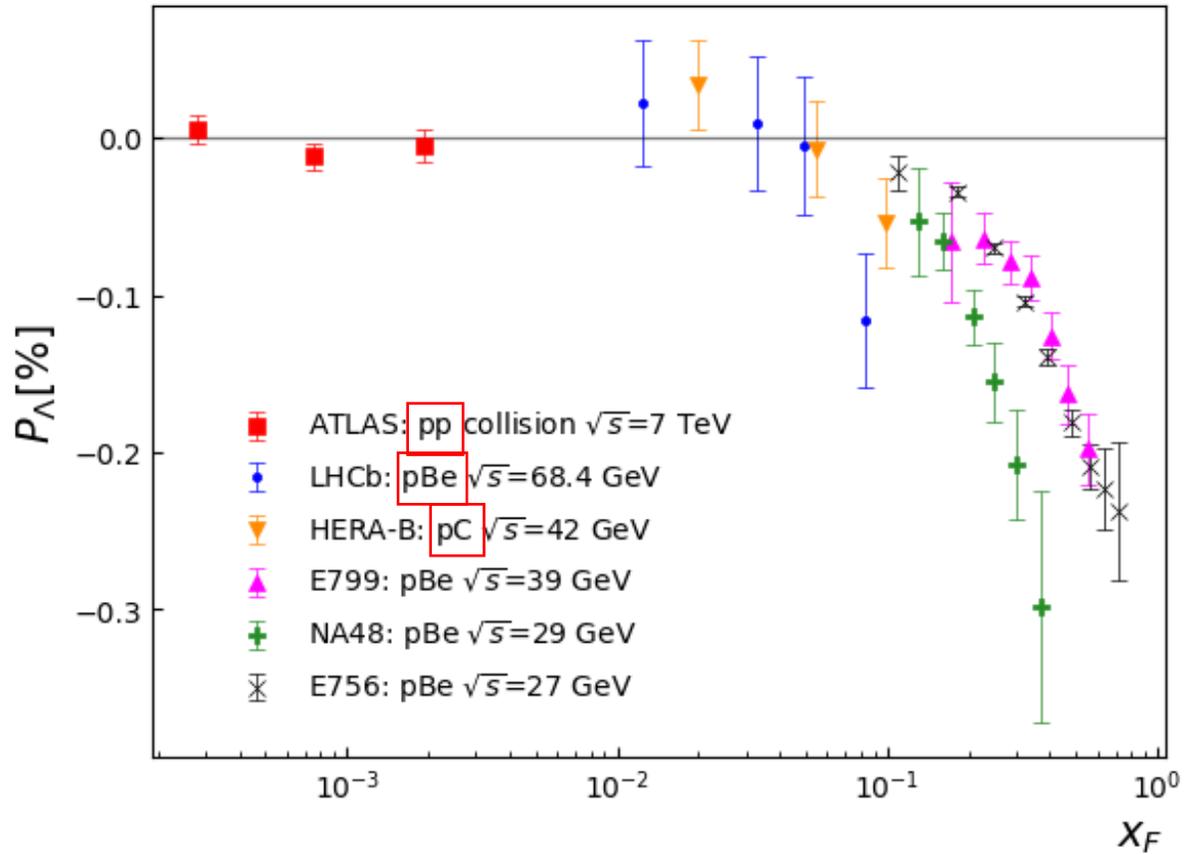# Λ^0 polarization measurements

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[Phys.Rev.Lett. 41 (1978) 1689]

Λ^0 polarization measurements

Left panel legend:
- ATLAS: pp collision $\sqrt{s}$=7 TeV
- LHCb: pBe $\sqrt{s}$=68.4 GeV
- HERA-B: pC $\sqrt{s}$=42 GeV
- E799: pBe $\sqrt{s}$=39 GeV
- NA48: pBe $\sqrt{s}$=29 GeV
- E756: pBe $\sqrt{s}$=27 GeV

Right panel legend:
- ATLAS: pp Collision $\sqrt{s}$=7 TeV
- CERN ISR: pp Collision $\sqrt{s}$=63 GeV
- FNAL E799: P+Be $\sqrt{s}$=39 GeV
- CERN PS: P+Pt $\sqrt{s}$=7 GeV
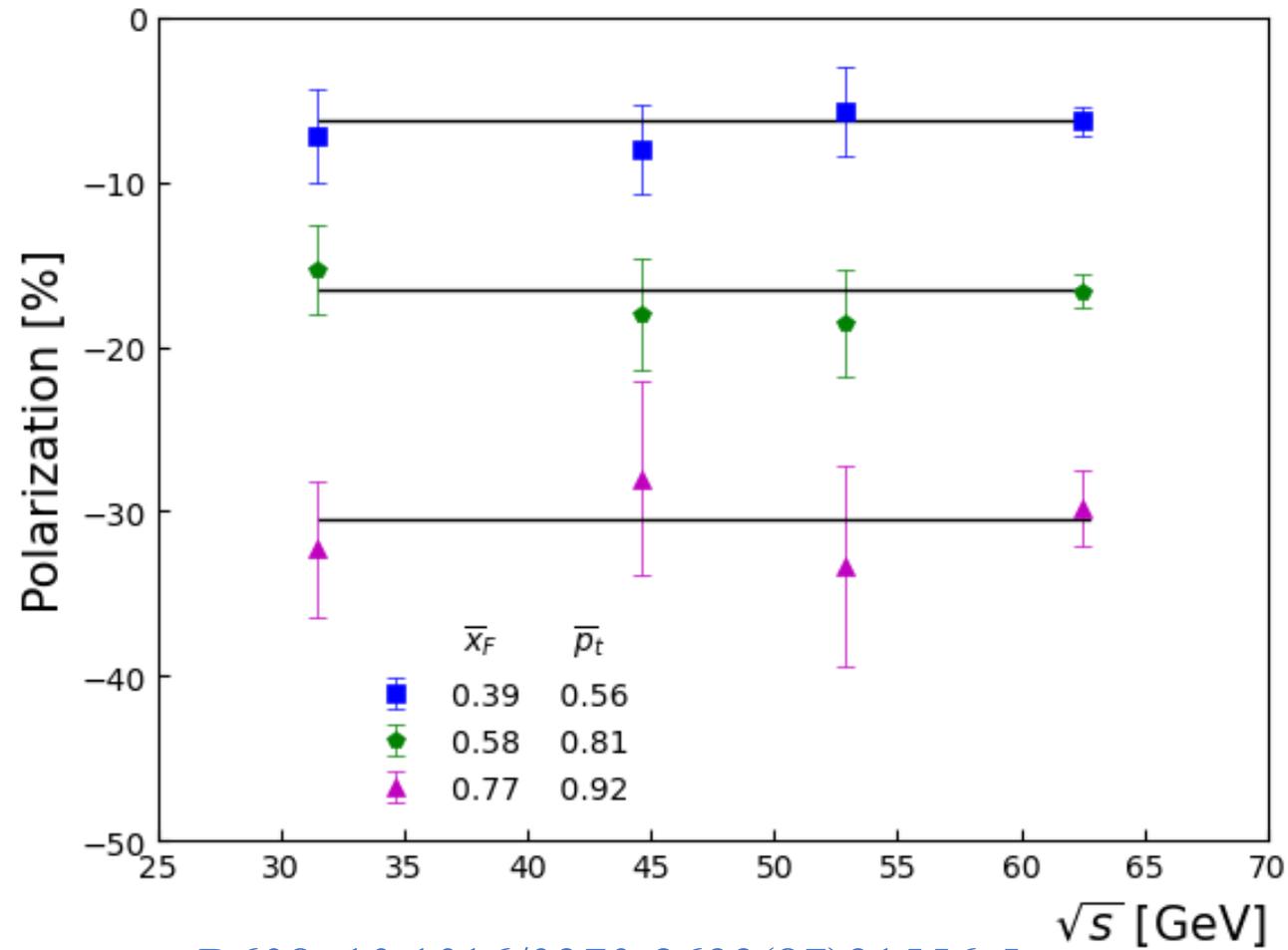- KEK E049: P+W $\sqrt{s}$=5 GeV

In standard collinear pQCD, the single quark polarization P from hard scattering follows the scaling relation:

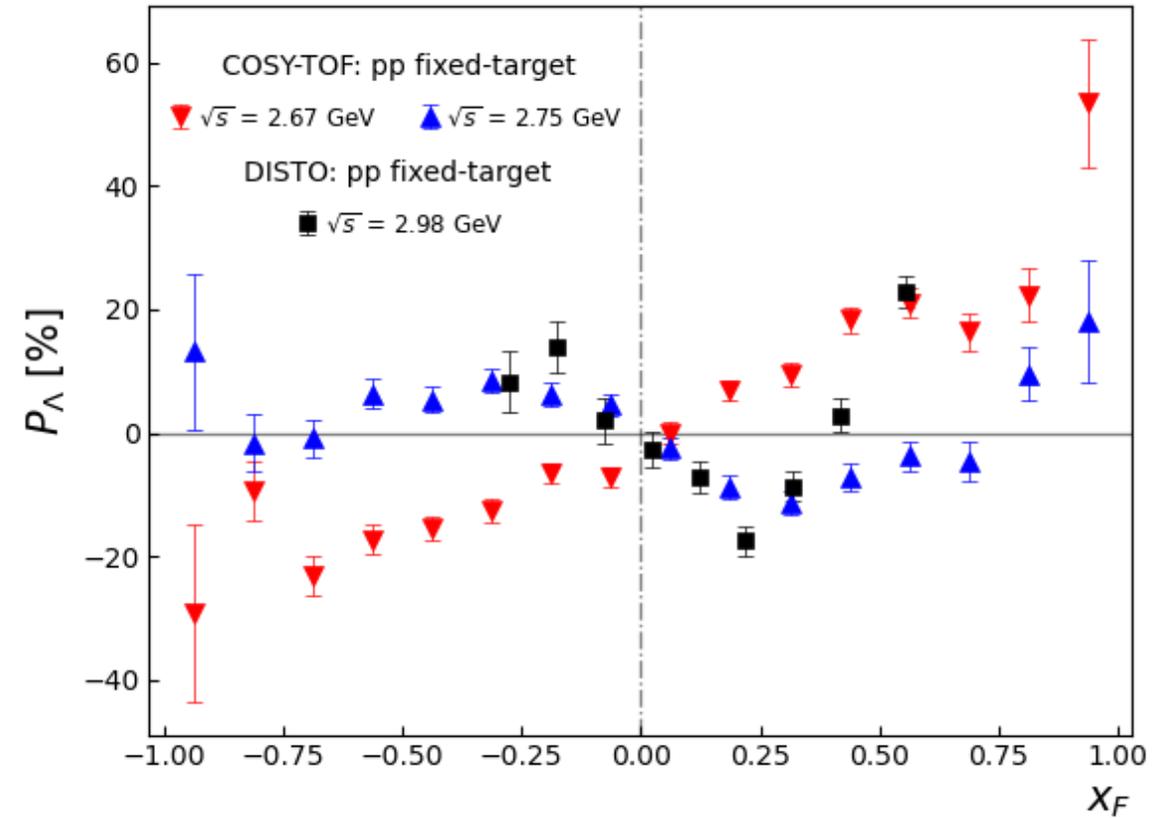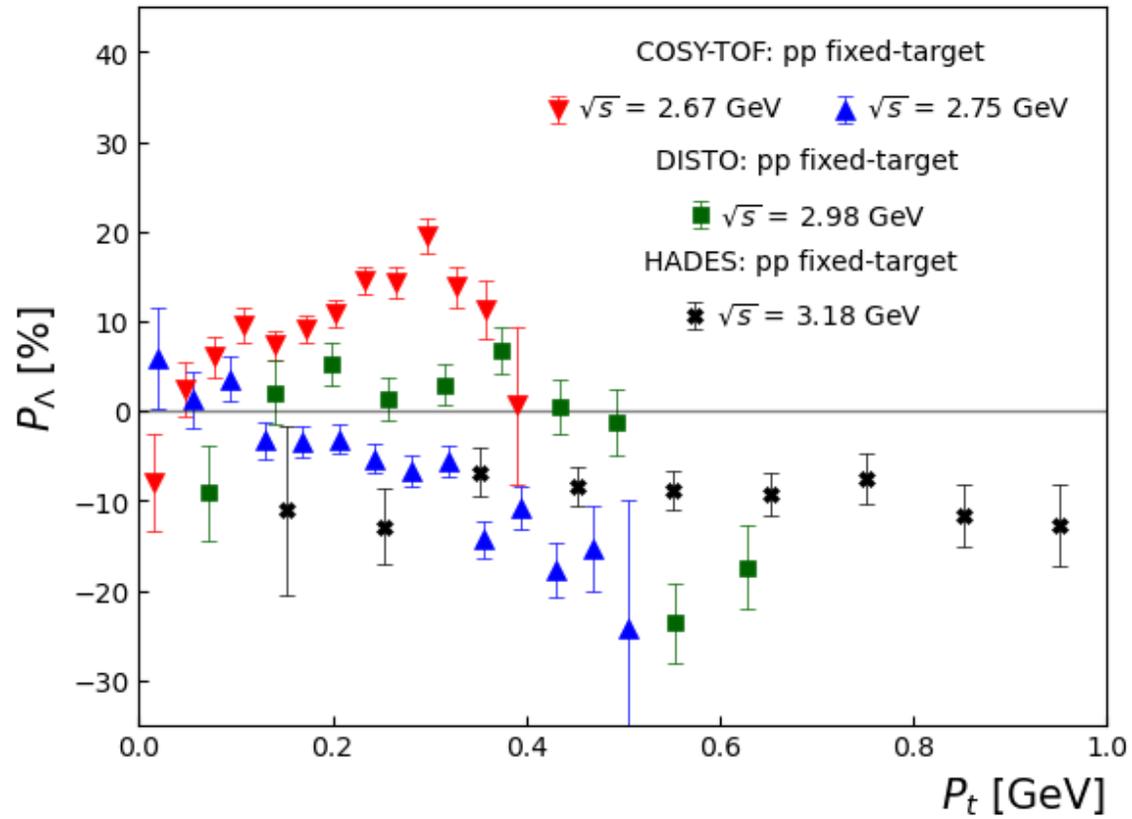$$P \propto \alpha_s \frac{m_q}{Q}$$
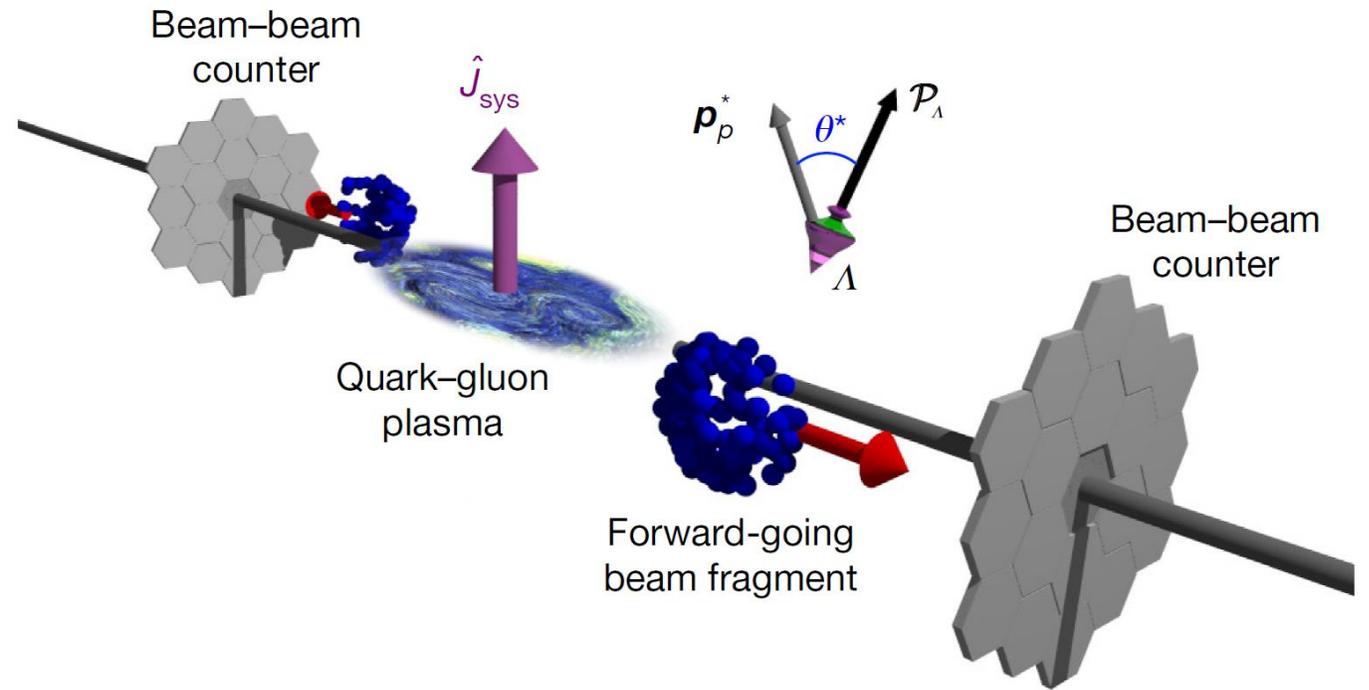
[Phys.Rev.Lett. 41 (1978) 1689]

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"Scaling" of Λ^0 polarization ?

R608: 10.1016/0370-2693(87)91556-5

pQCD predicts that the polarization will be decreasing as energy increases

Puzzle in low energy collisions

What's more?   with A-A
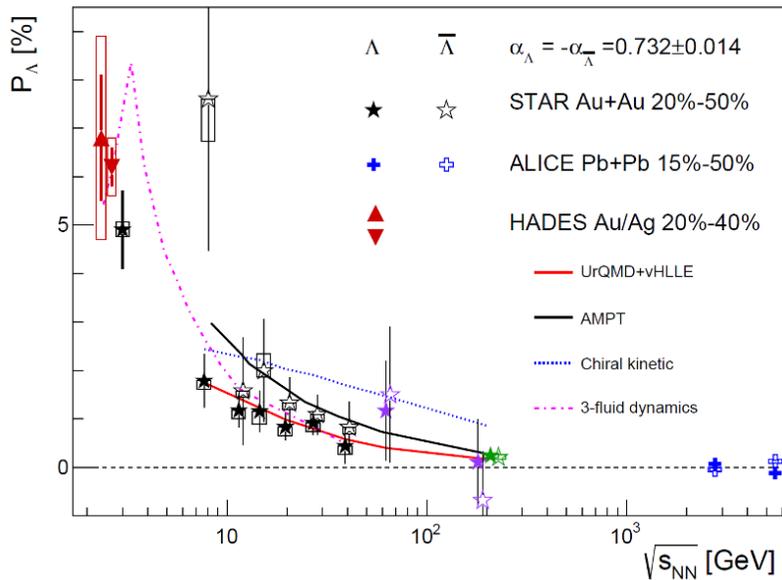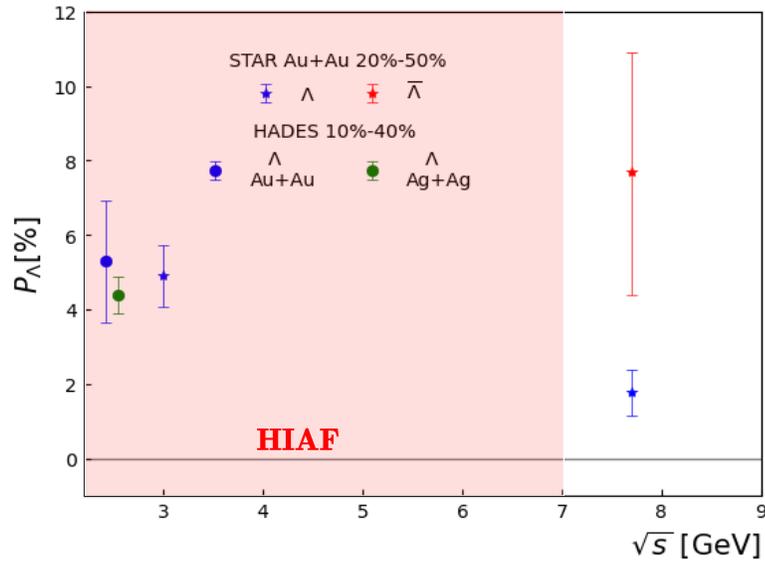
In non-central heavy-ion collisions, large initial orbital angular momentum is transferred to the medium, inducing particle spin alignment known as **global polarization**.

One has to take into account the production mechanism
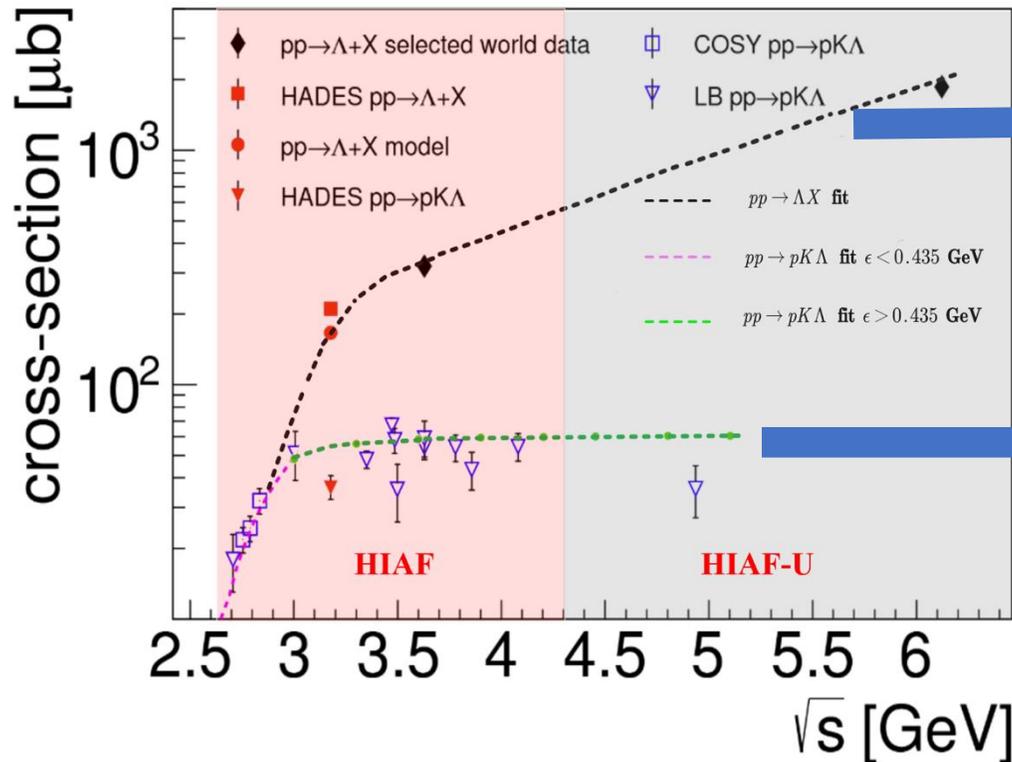
- across energy region and collision system

non-central relativistic heavy ion collisions
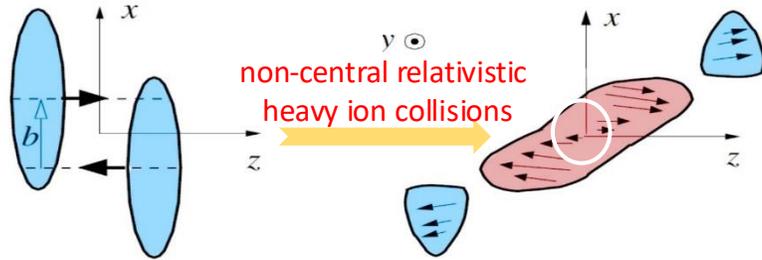
① $AA \rightarrow \Lambda X$ **Global polarization**

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).

pp → Λ + X: comparison to world data

- ◆ pp→Λ+X selected world data
- ■ HADES pp→Λ+X
- ● pp→Λ+X model
- ▼ HADES pp→pKΛ
- ⊡ COSY pp→pKΛ
- ▽ LB pp→pKΛ
- - - - $pp \rightarrow \Lambda X$ **fit**
- - - - $pp \rightarrow pK\Lambda$ **fit** $\epsilon < 0.435$ **GeV**
- - - - $pp \rightarrow pK\Lambda$ **fit** $\epsilon > 0.435$ **GeV**

HIAF **HIAF-U**

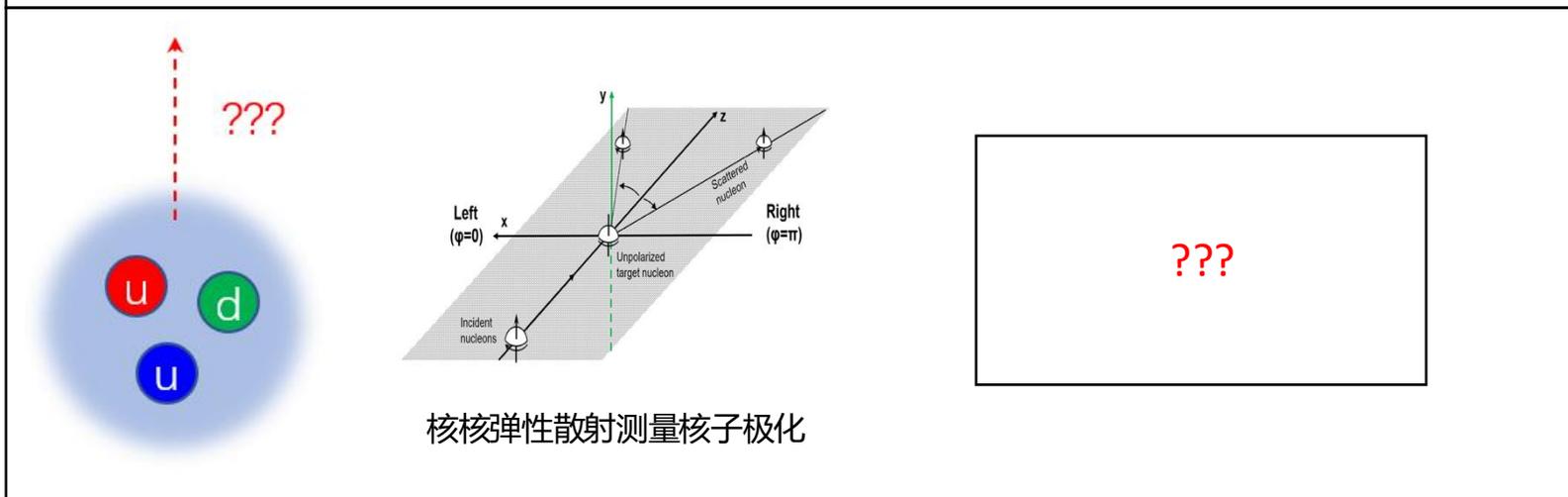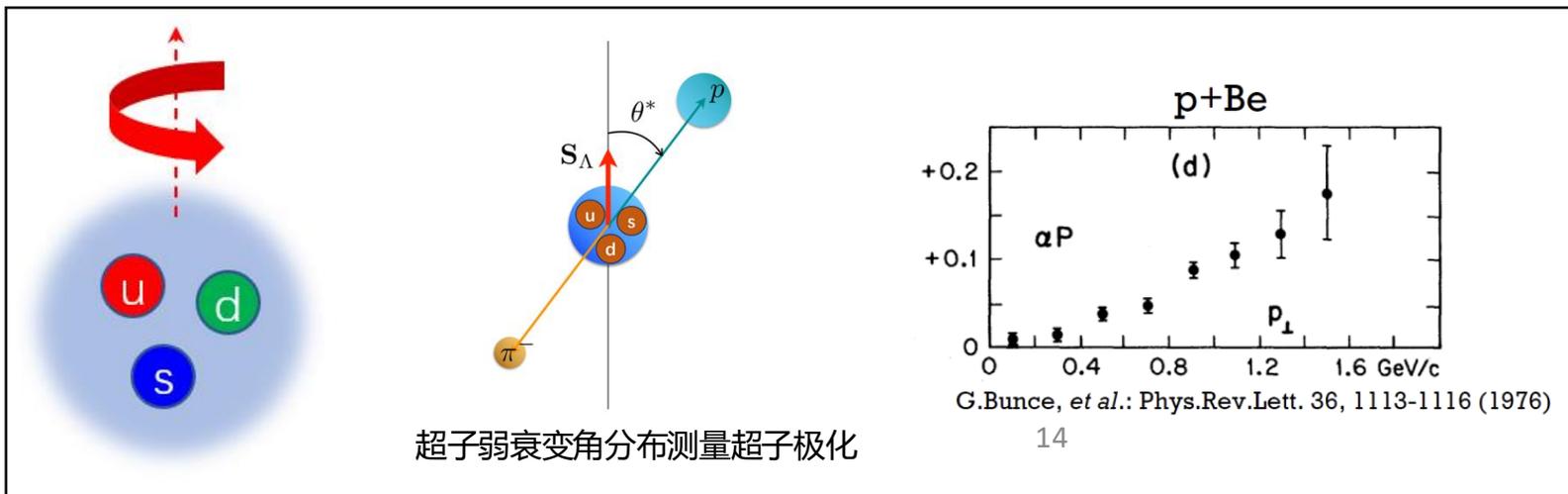② $pp\,(A) \rightarrow \Lambda X$ **polarization through hadronization**

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).
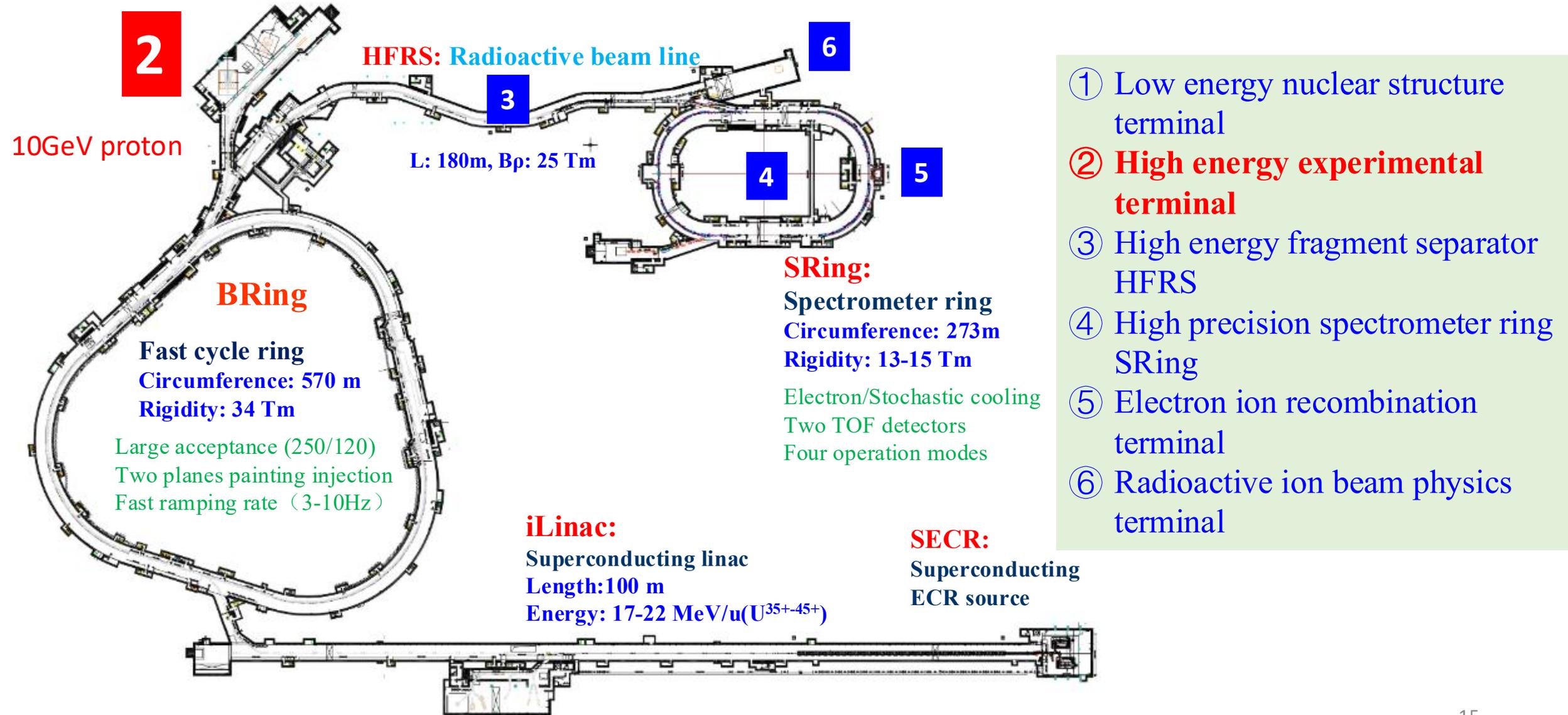
③ $pp \rightarrow pK\,\Lambda$ **Λ polarization in exclusive processes**

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

An interesting question: Is proton polarized as well?

pp → p K Λ

超子弱衰变角分布测量超子极化

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

pp → p + X

核核弹性散射测量核子极化

High Intensity heavy-ion Accelerator Facility (HIAF)

2

10GeV proton

HFRS: Radioactive beam line

3

L: 180m, Bρ: 25 Tm

6

4

5

BRing

Fast cycle ring
Circumference: 570 m
Rigidity: 34 Tm

Large acceptance (250/120)
Two planes painting injection
Fast ramping rate（3-10Hz）

SRing:
Spectrometer ring
Circumference: 273m
Rigidity: 13-15 Tm

Electron/Stochastic cooling
Two TOF detectors
Four operation modes

iLinac:
Superconducting linac
Length:100 m
Energy: 17-22 MeV/u($U^{35+-45+}$)

SECR:
Superconducting
ECR source

① Low energy nuclear structure terminal
② **High energy experimental terminal**
③ High energy fragment separator HFRS
④ High precision spectrometer ring SRing
⑤ Electron ion recombination terminal
⑥ Radioactive ion beam physics terminal

Budget ~3 billion CNY (including civil construction), start from Dec. 2018, installation finished in Sept. 2025, located in Huizhou.
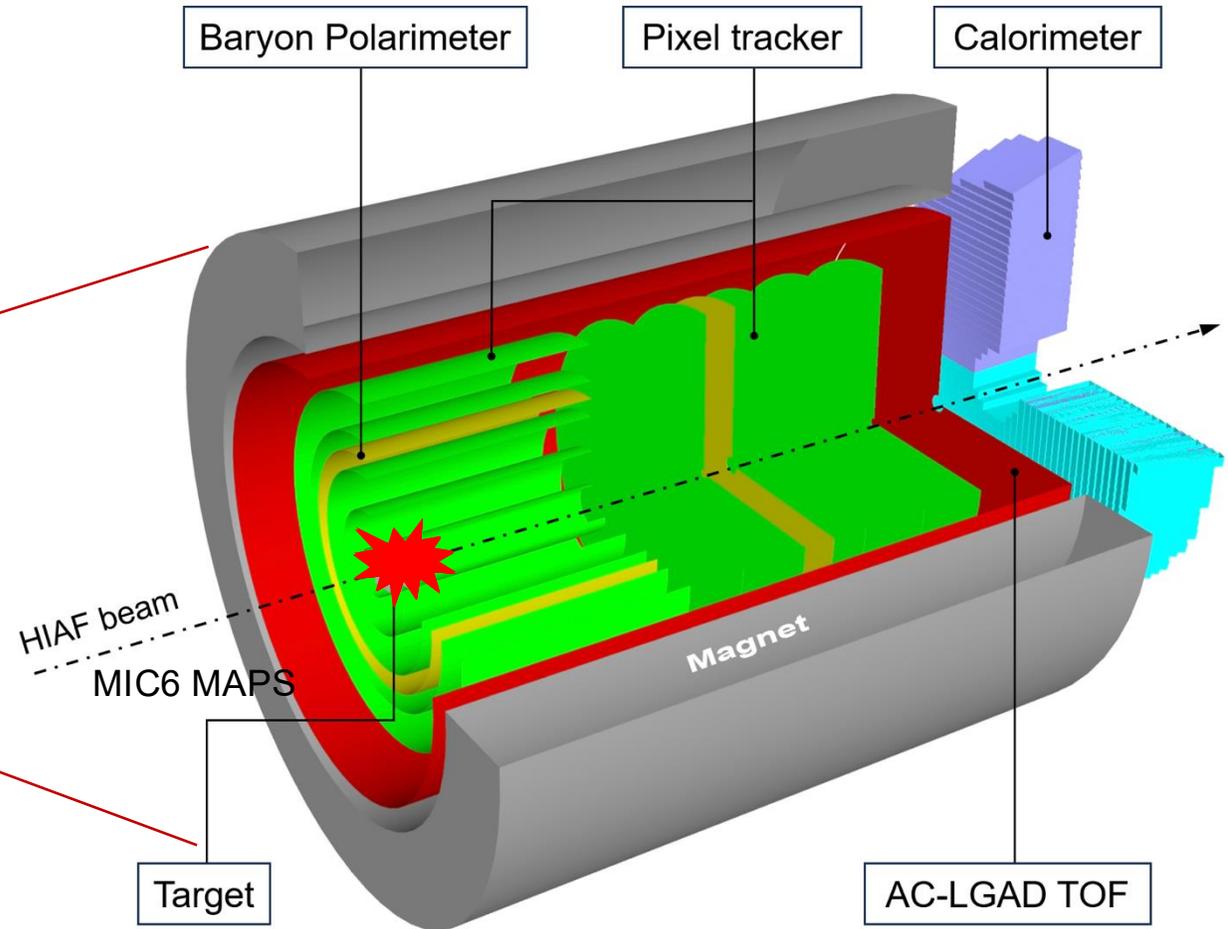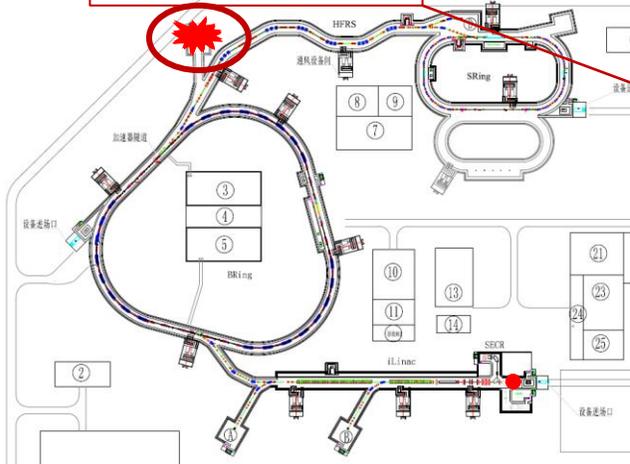
Hyperon Nucleon Spectrometer (H-NS)

proton beam up to 9.3 GeV
ion beam up to 4.25 GeV/u
- p + p
- p + A
- A + A

High Energy Nuclear Physics Terminal

Baryon Polarimeter

Pixel tracker

Calorimeter

HIAF beam

MIC6 MAPS

Magnet

Target

AC-LGAD TOF

10:45 Oct. 28   Aiqiang Guo's talk

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HIAF beam parameters

Ion	Intensity (ppp)	Kine_Energy (GeV/u)
$^{238}U^{35+}$	2.0×10^{11}	0.84
$^{238}U^{76+}$	5.0×10^{10}	2.5
$^{129}Xe^{27+}$	3.6×10^{11}	1.4
$^{78}Kr^{19+}$	5.0×10^{11}	1.7
$^{40}Ar^{12+}$	7.0×10^{11}	2.3
$^{18}O^{6+}$	8.0×10^{11}	2.6
p	5.0×10^{12}	9.3

HIAF beam parameters

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p	5.0×10^{12}		9.3

研究所	装置	重复频率	离子种类	设计流强	达到流强
BNL	AGS Booster	/	Au^{32+}	/	5×10^9
CERN	LEIR	/	Pb^{54+}	/	9×10^8
JINR	NICA	/	Au^{32+}	4×10^9	/
GSI	SIS18	2.7Hz	U^{28+}	1.0×10^{11}	3×10^{10}
FAIR	SIS100	2.7Hz	U^{28+}	$(1.0\text{-}2.0)\times10^{11}$	/
IMP	HIAF-BRing	3-5Hz	U^{45+}	2.0×10^{11}	/
IMP	HIAF-SRing	/	U^{45+}	1.0×10^{12}	/

HIAF kinematics coverage
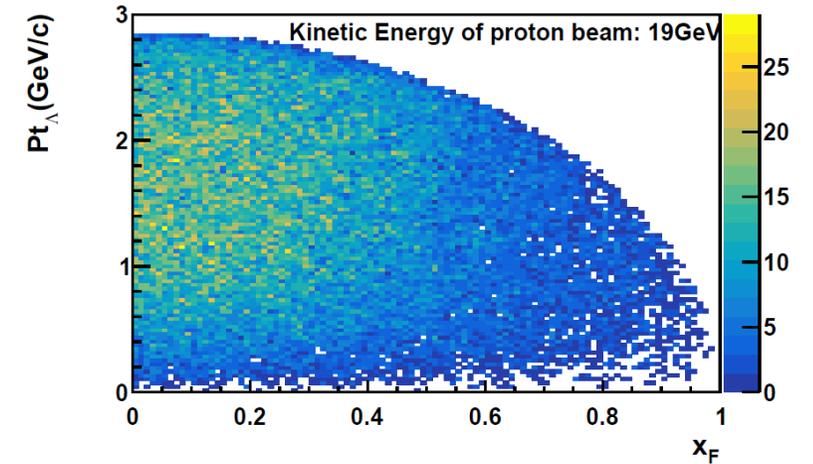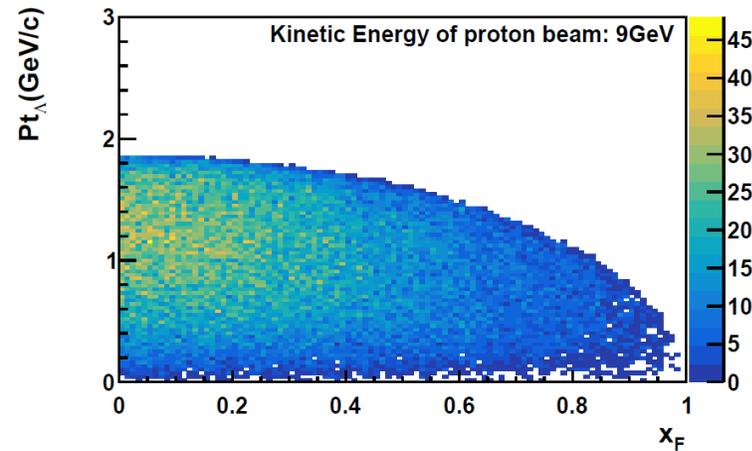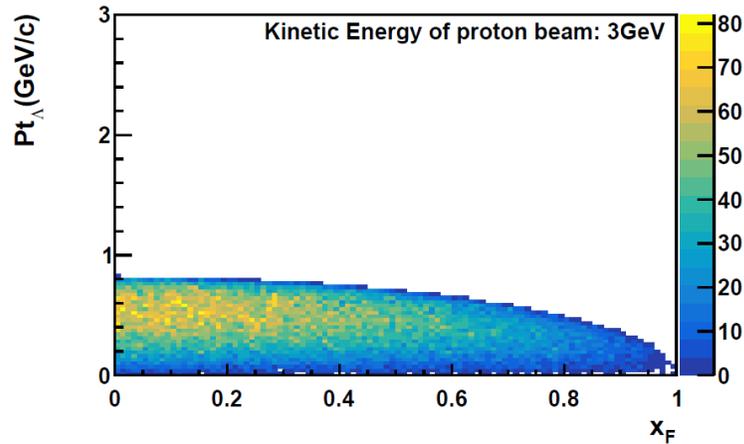
3 GeV → 9 GeV → 20 GeV

Allow for a multi-dimensional mapping of the Λ^0 polarization and production
  ➢ Beam energy scan
  ➢ p→p, p→A, A→A data taking

The challenge

All the momentum, angular distributions and the Λ decay length are beam energy-dependent

Momentum of p from Λ | θ of p from Λ | Decay length of Λ
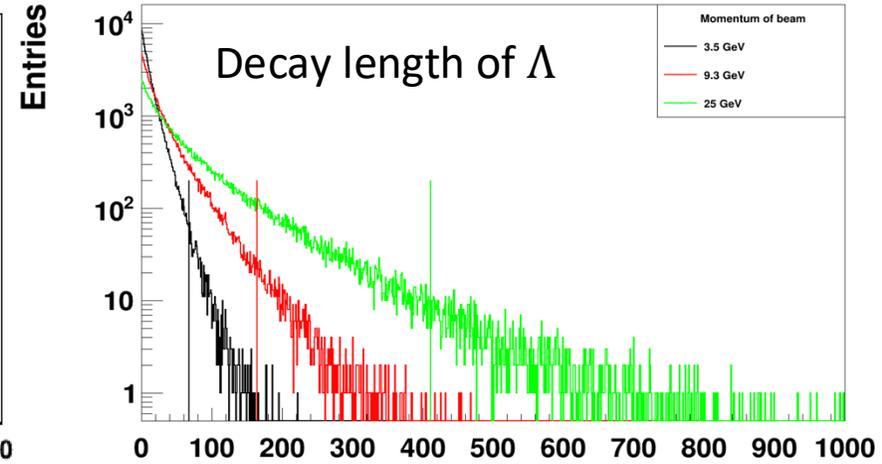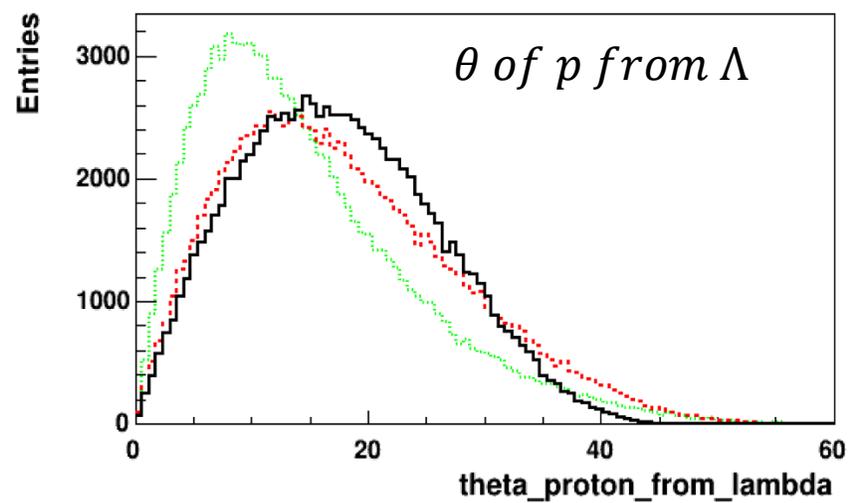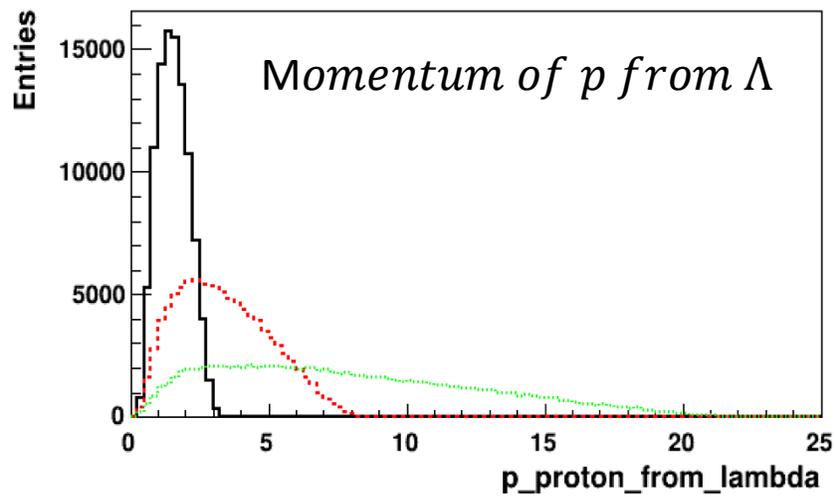
The conceptual design of H-NS detector
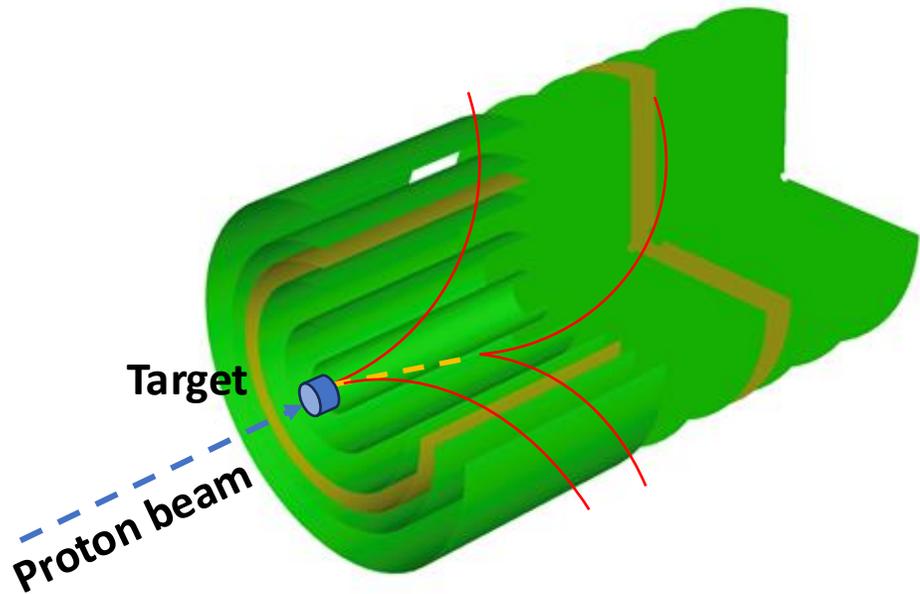
➤ **Good tracking/vertexing detector:**
  • Good granularity
    • Compact design ~0.5m in radius
    • Measure the vertex precisely
  • Low material
    • **Vertex** resolution is crutial for BG suppression
    • Good **angular resolution** is the key requirement for proton polarization measurement
  • Fast
    • Handle the event rate ~1MHz
➤ **Tech. choice:**
  • MAPS
    • Pixel size: 30 micron
    • Material budget: 0.4 % X/X_0
   • Integration time: 5-10 μs

The conceptual design of H-NS detector
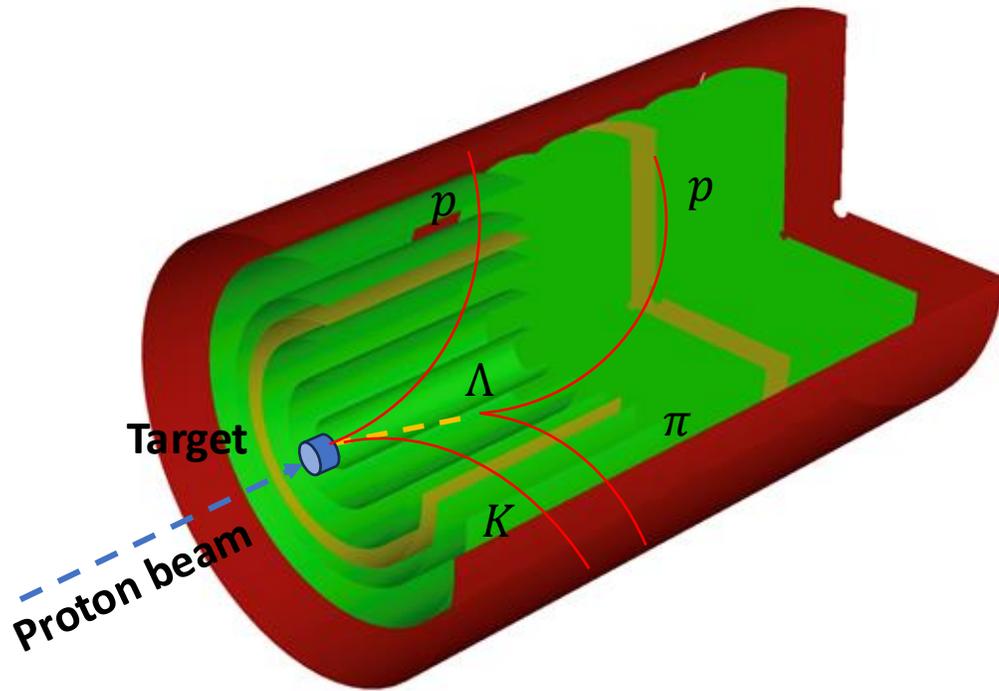
- ➤ **PID:**
  - Compact design
  - Wide range of momentum coverage
    - K, π separation (~3σ) up to 2 GeV/c .
    - K, p separation (~3σ) up to 5 GeV/c
- ➤ **Tech. choice:**
  - LGAD
    - Time resolution: 20~30 ps
    - Spatial resolution: ~100 micron

The conceptual design of H-NS detector
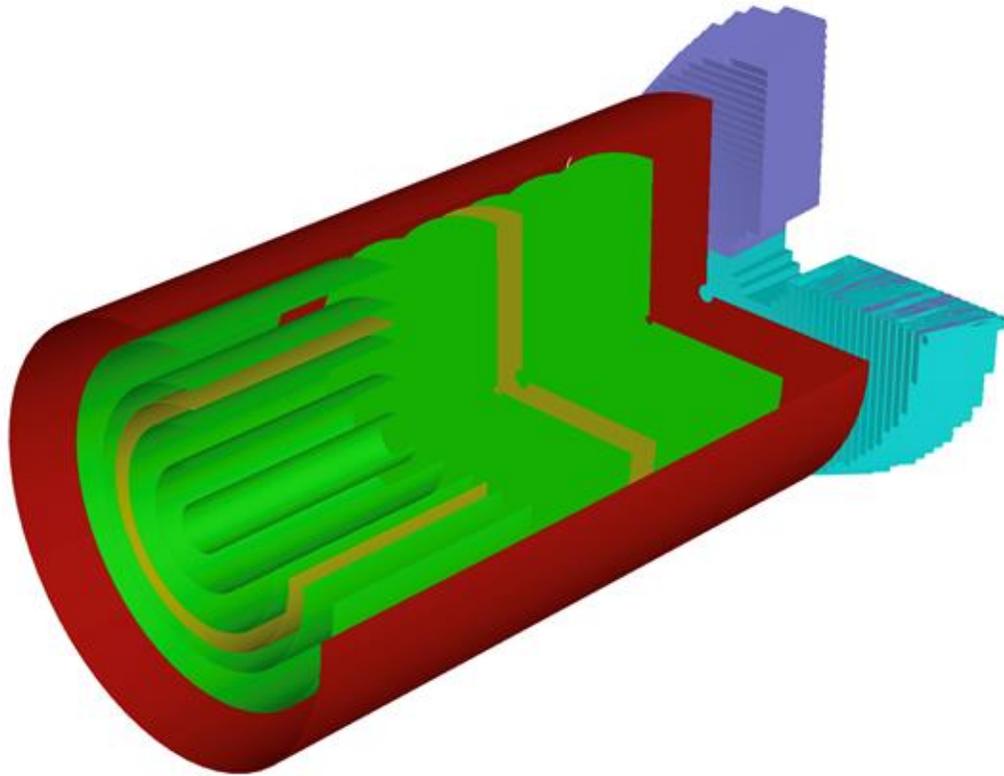
➢ **Calorimeter for Σ, Ξ rec.:**
  - Good spatial and energy resolution
  - Fast
  - Radiation hardness
➢ **Tech. choice:**
  - PbWO4 crystal
    - Energy resolution: $3\%/\sqrt{E}$
    - Spatial resolution: $3mm/\sqrt{E}$ (20X20 mm)
  - Dual readout sampling type calorimeter
    - Energy resolution: $5\%/\sqrt{E}$

The conceptual design of H-NS detector
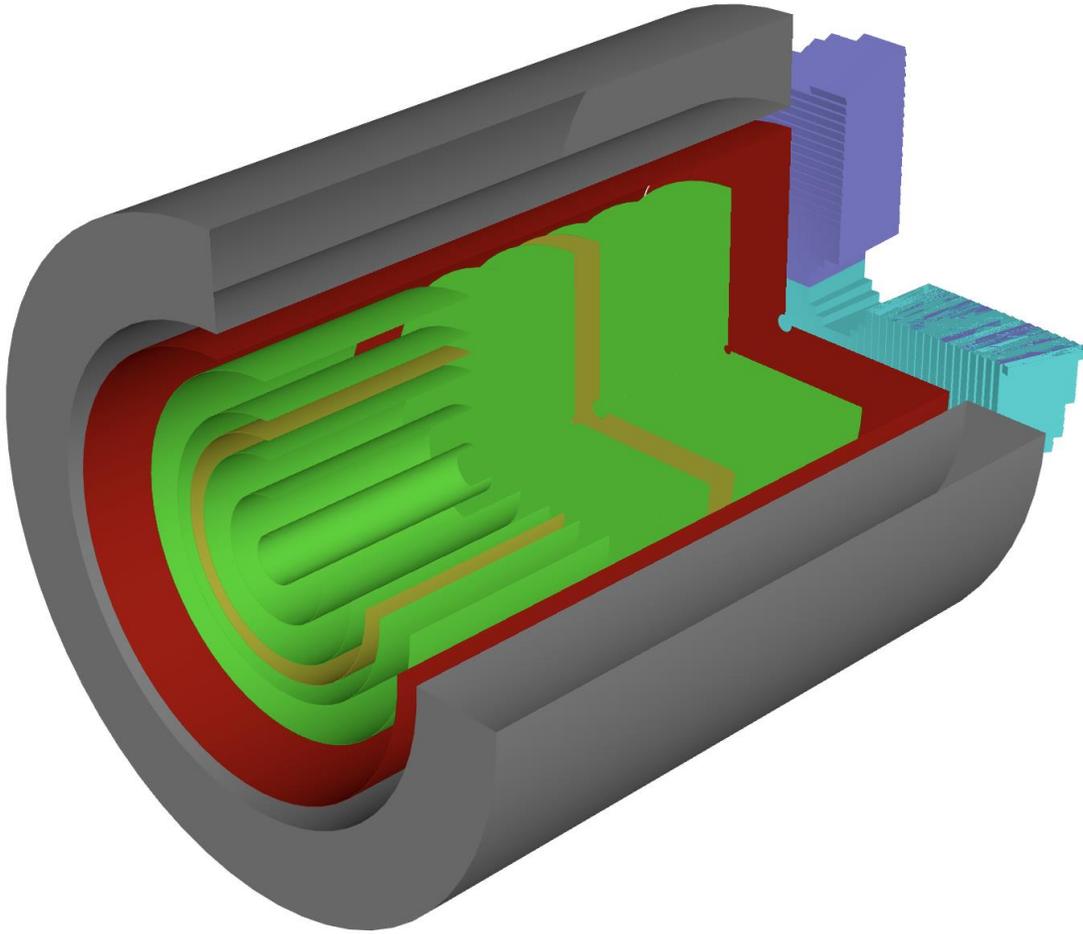
➢ **Magnet:**
  • Be able to measure the track with high Pz and low Pt
➢ **Tech. choice:**
  • Superconducting Solenoid @ Bz = 1.5T
  • Or dipole @ By = 1.5 T

The conceptual design of H-NS detector
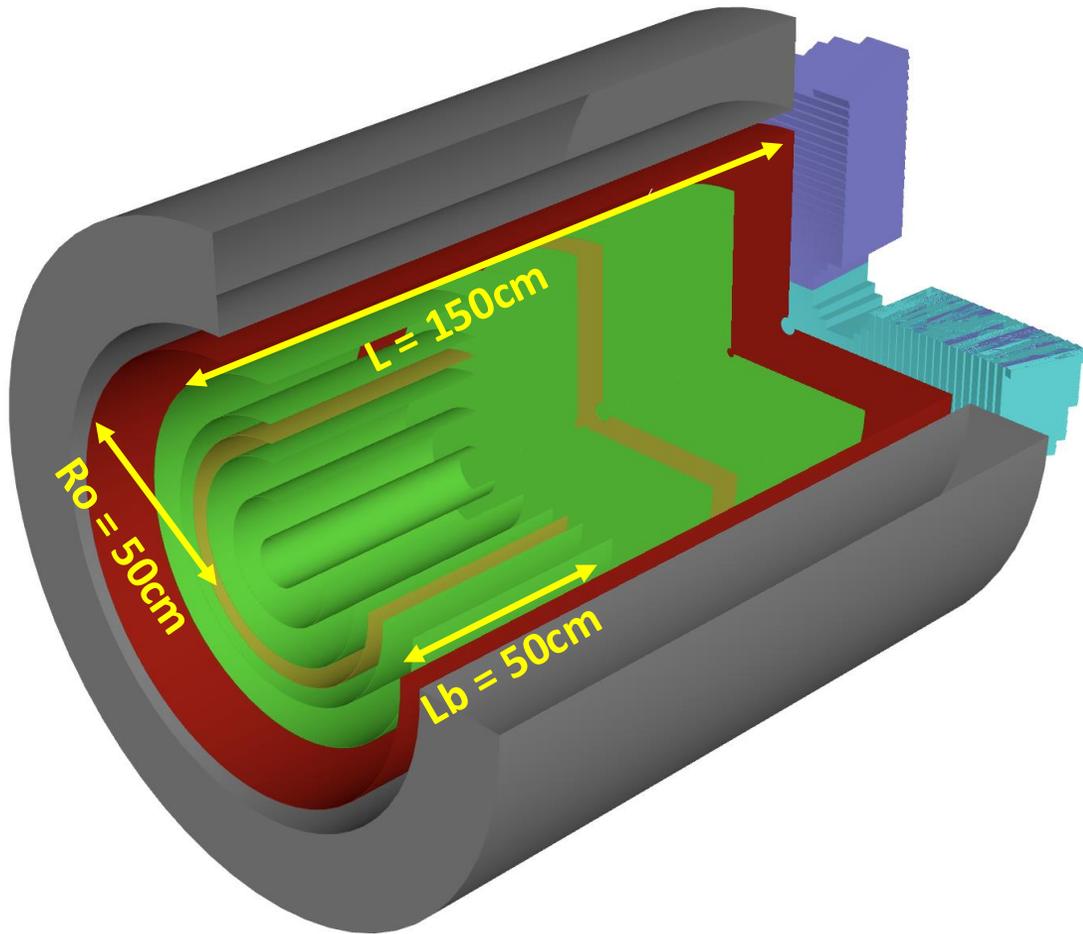
- ➢ **Momentum resolution:**
  - ~2%@1GeV when η<2.5
- ➢ **PID:**
  - K, π separation (~3σ) up to 2 GeV/c
  - K, p separation (~3σ) up to 5 GeV/c
- ➢ **Vertex resolution:**
  - Excellent vertex resolution for background suppression
  - Material budget (<10%)
- ➢ **Acceptance:**
  - 5 to 100 degree
- ➢ **High event rate**
  - 1MHz
- ➢ **Baryon Polarimeter → determine final state proton's polarization**

Λ^0 reconstruction in H-NS

Uncertainty projection of the polarization measurement

pp → pKΛ

pp → Λ+X
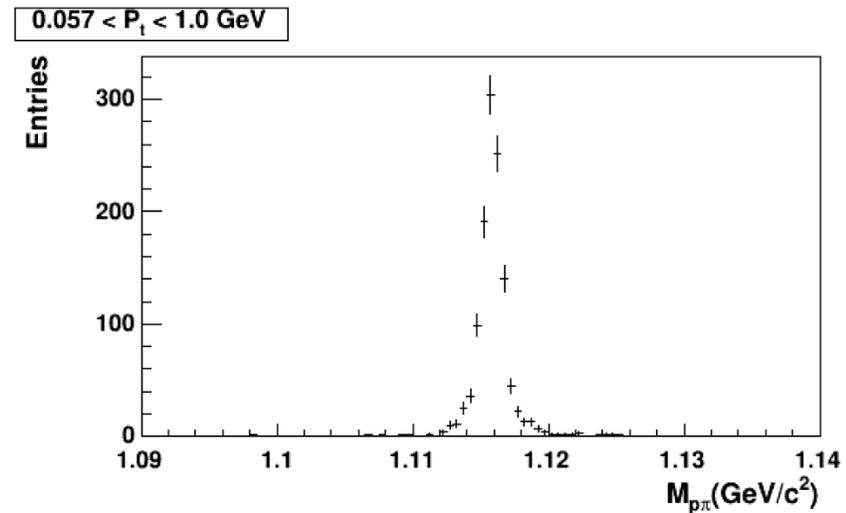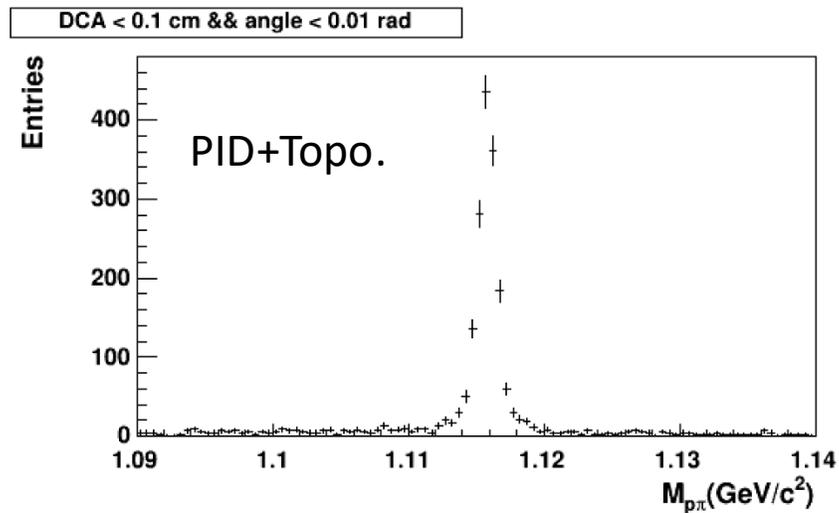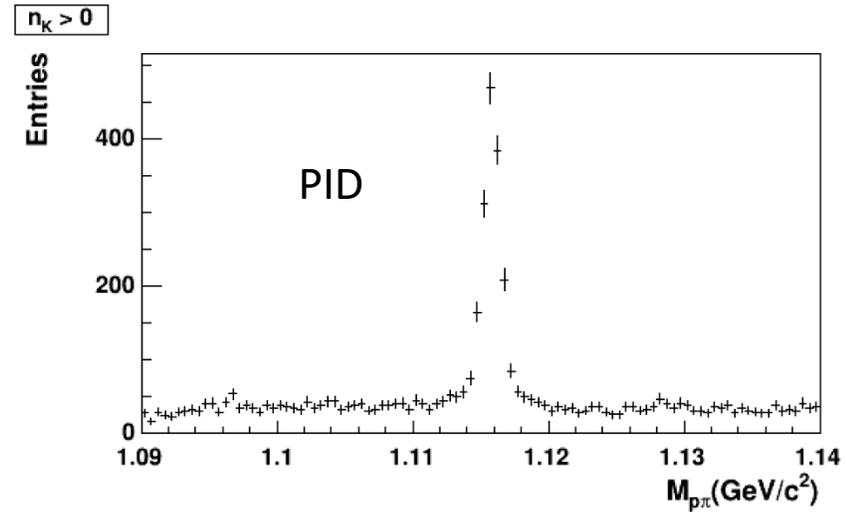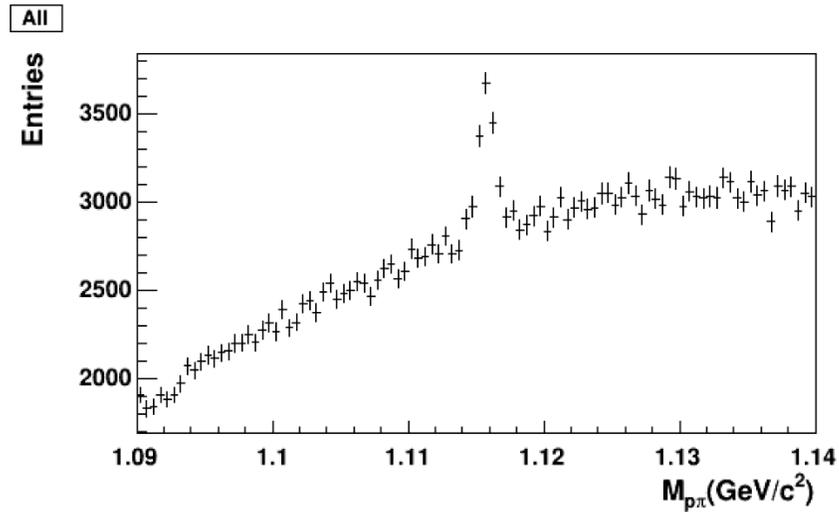
$\sigma_{stat.} < 0.01$ for Λ 100 bins $\sigma_{stat.} < 0.01$ for Λ 400 bins

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}

Exclusive measurement

Uncertainty of Λ polarization

Inclusive measurement

Uncertainty of Λ polarization

Baryon polarimeter

Determining proton polarization via elastic scattering

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

Transversely polarized protons

Carbon foil

More protons to the left: Left-right asymmetry

$A_N \cdot pol = 0.252 \pm 0.004$
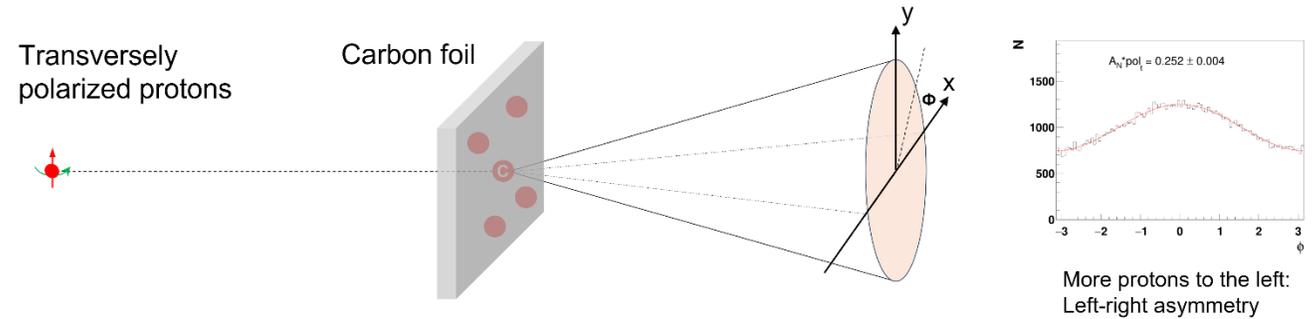
➢ **Carbon Foil layer**

- **~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)

Background from Non-scattering tracks
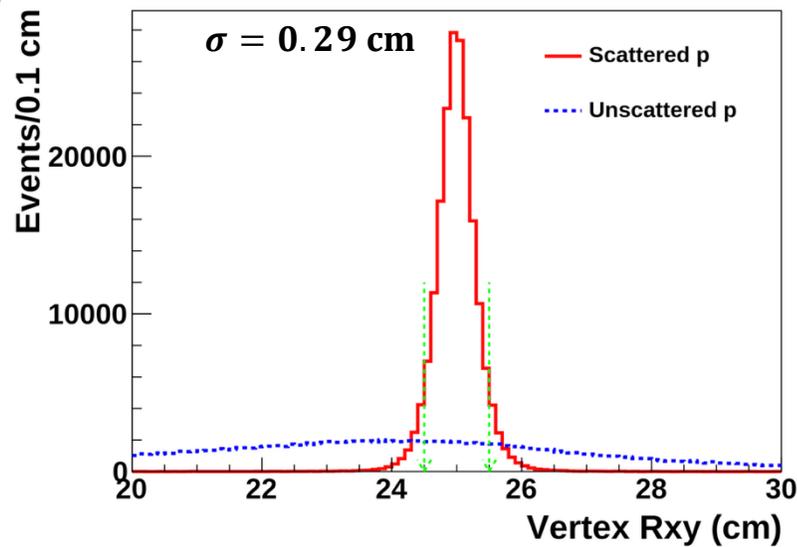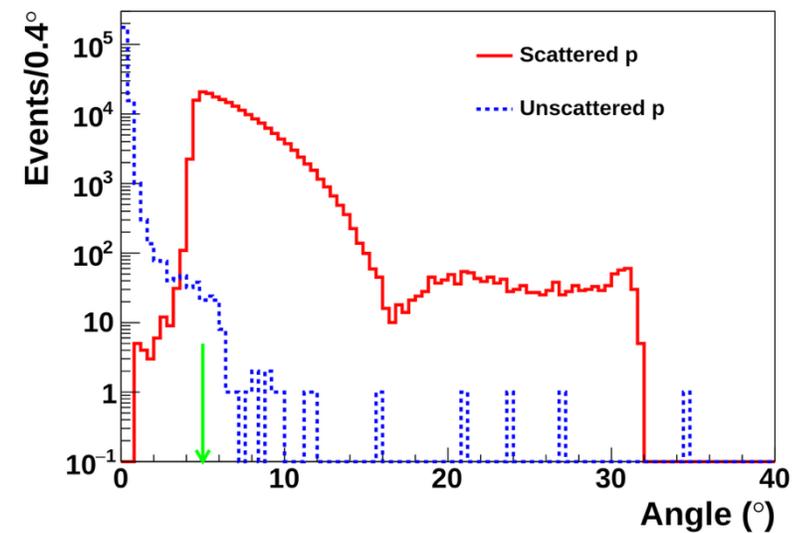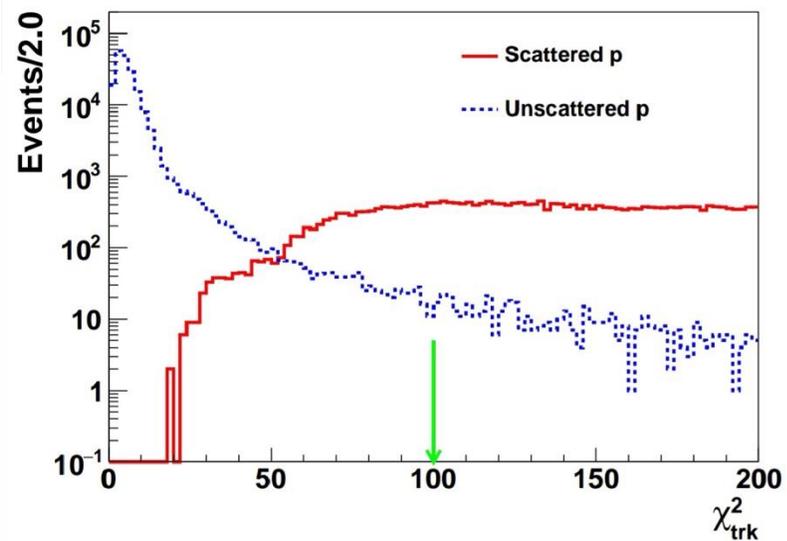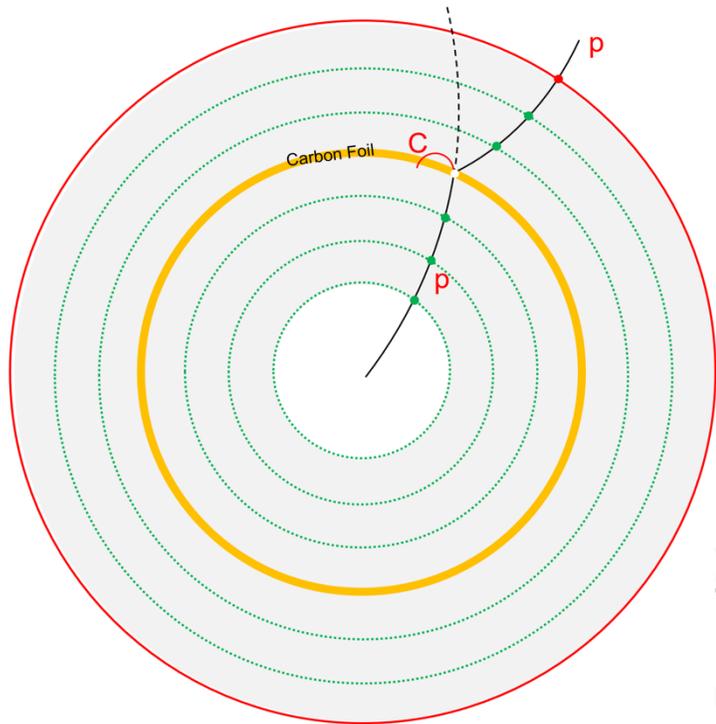
✓ Reconstruction effi: > 70%
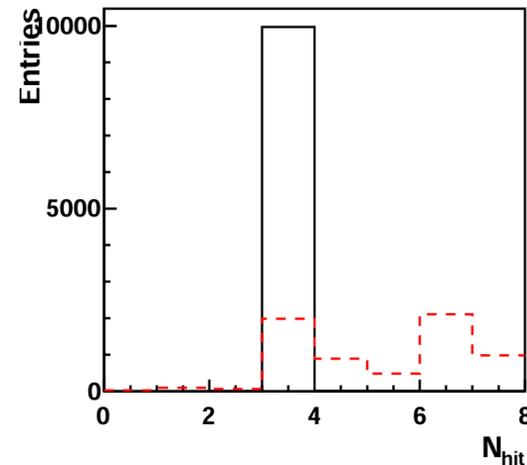
✓ Bkg. contimation: <1%

Background from inelastic scattering
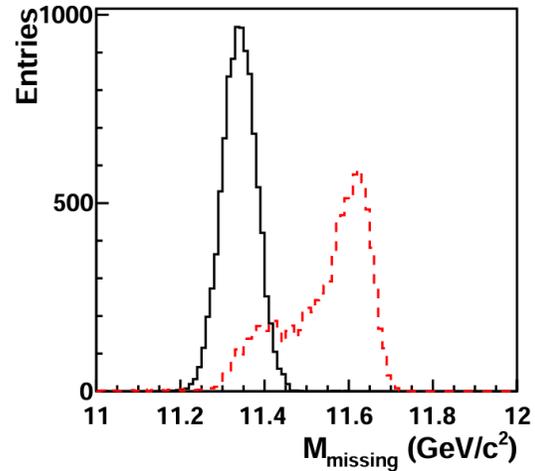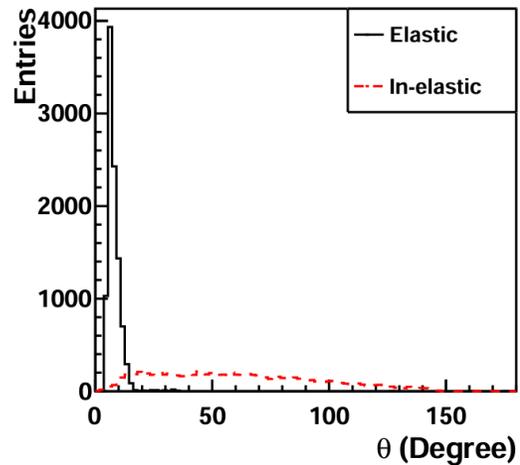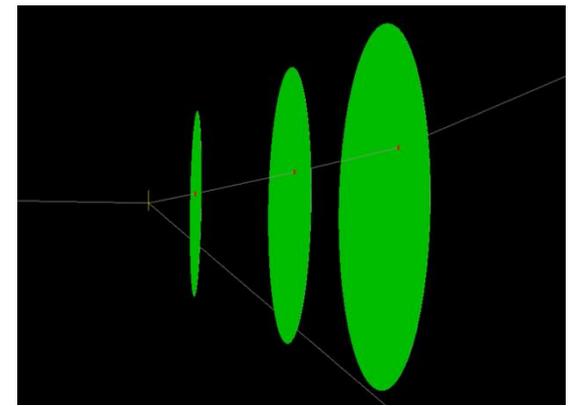
Signal: $p + C \rightarrow p + C$
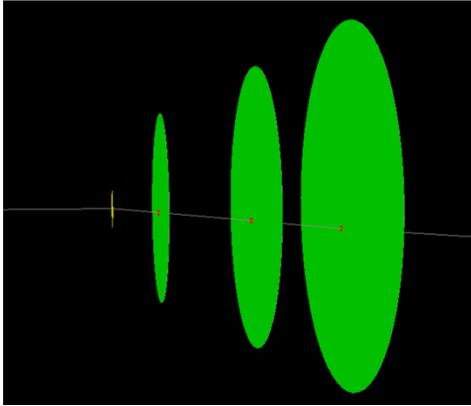
Bkg: $p + C \rightarrow p + p + \ldots$
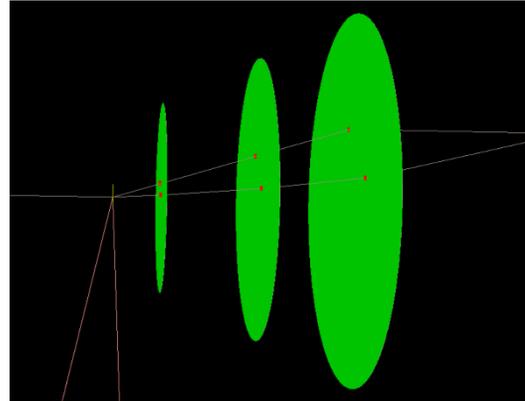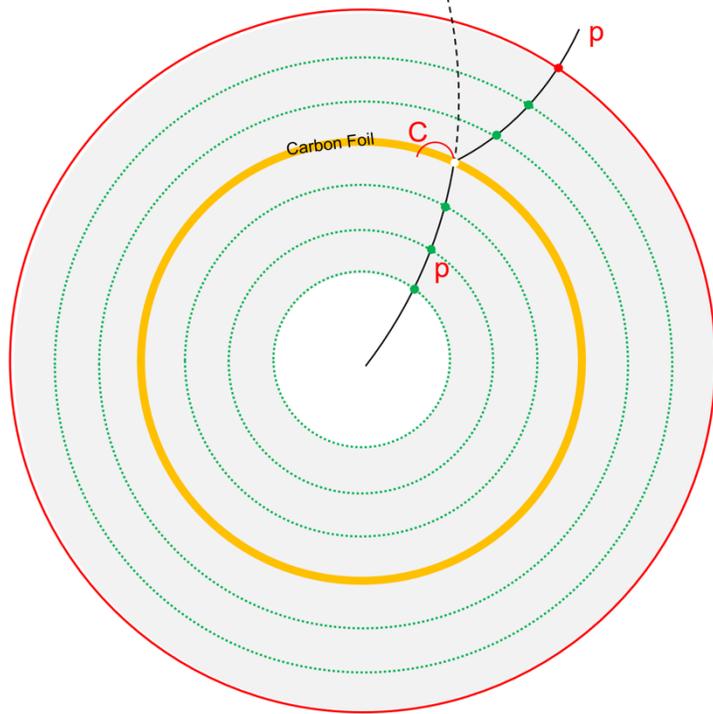
$p + C \rightarrow p + d + \alpha + He^3$
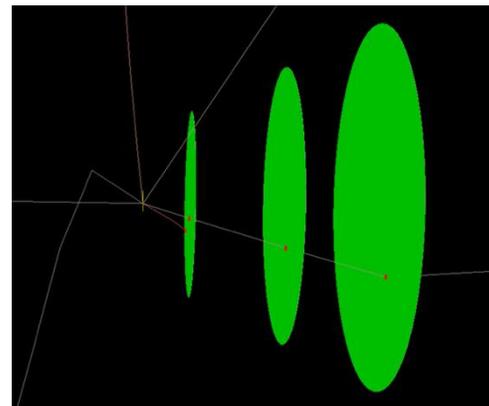
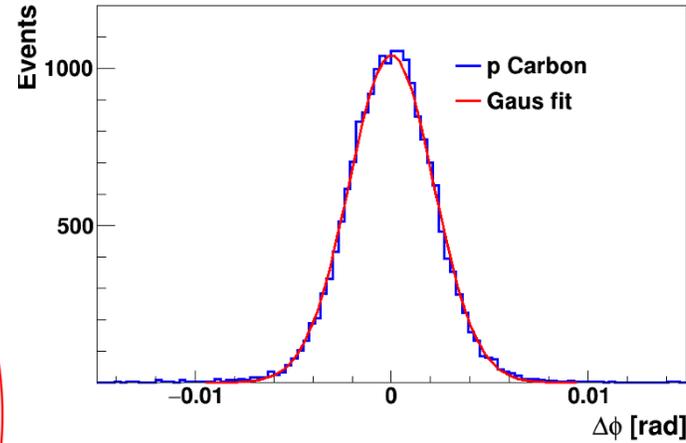$p + C \rightarrow p + n + C^{11}$

$p + C \rightarrow p + d + \alpha + He^3$
$p + C \rightarrow p + n + C^{11}$
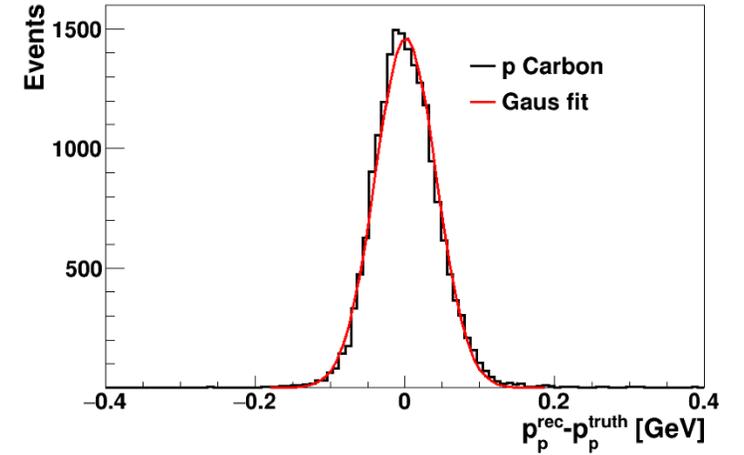$p + C \rightarrow p + p + B^{11}$
…

Background level: 2-5%

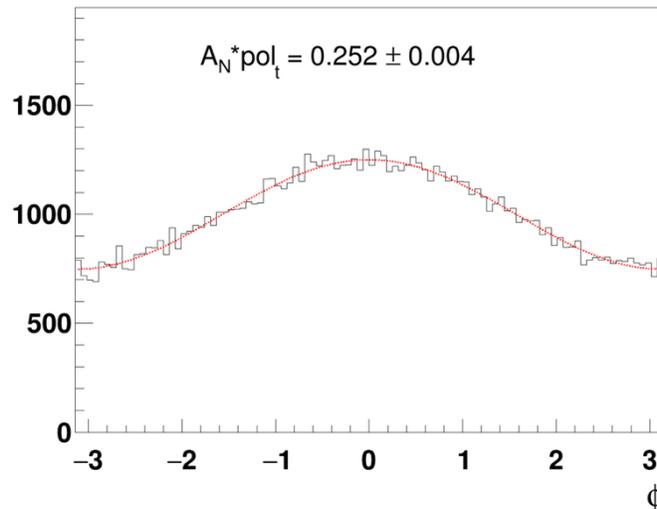# Precision measurement of proton polarization

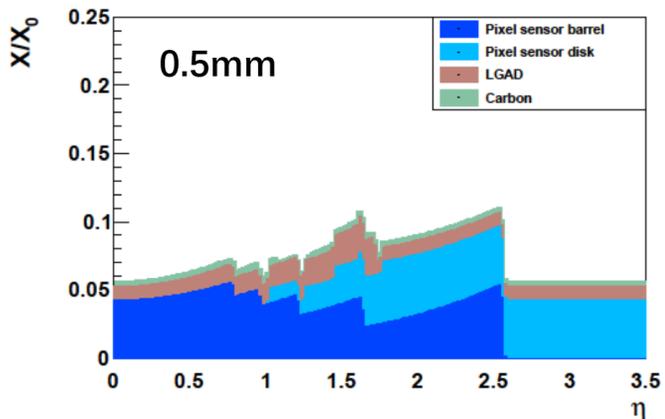$$\sigma = 2.16 \text{ mrad}$$

$$\sigma = 0.041 \text{ GeV}$$
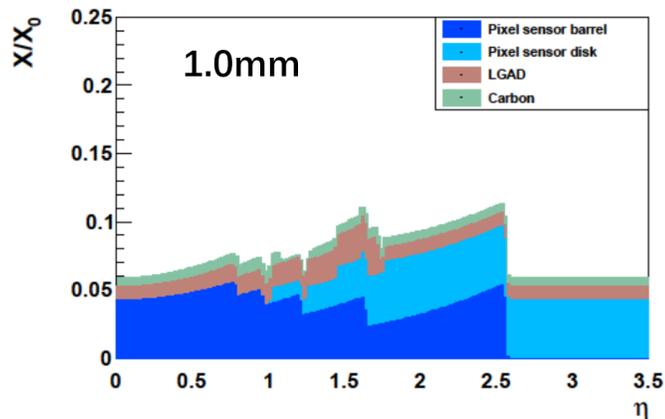

Input: 0.250

$A_N * pol_t = 0.252 \pm 0.004$

- ✓ Reconstruction effi: > 70%
- ➢ Low background contamination!
- ➢ High precision measurement!

Material budget of carbon layer

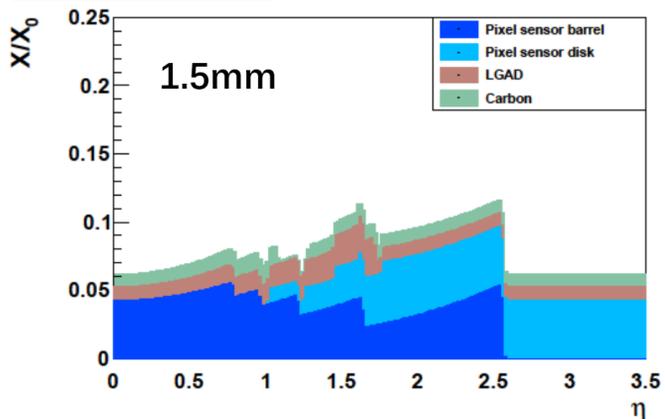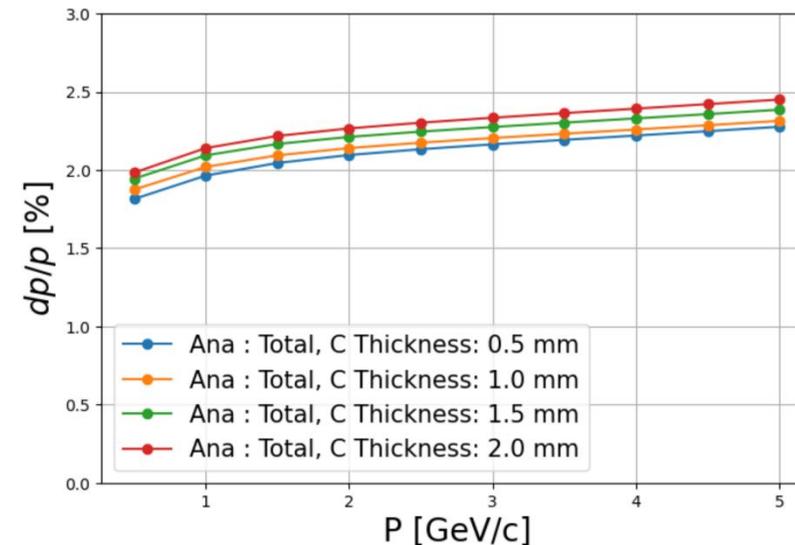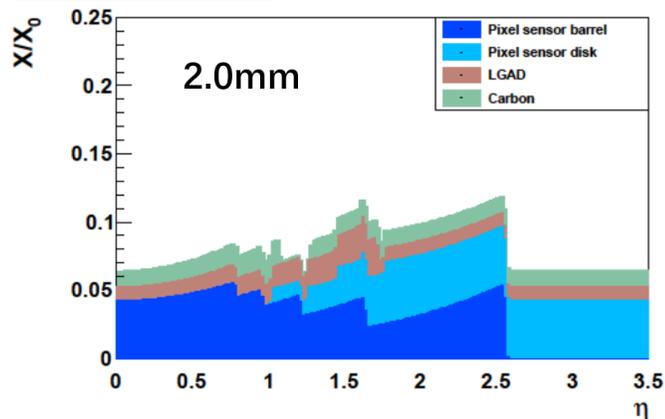> Tiny influence on the conventional performance

Baryon spin structure -- inclusive production of p/Λ

pp → p/Λ + X

p+Be

Λ polarization (d)

αP

+0.2

+0.1

0

$p_\perp$

0   0.4   0.8   1.2   1.6 GeV/c

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

???

u   d

s

u   d

u

p polarization

?

Uncertainty projection of the polarization measurement

pp → pKΛ

pp → p + X

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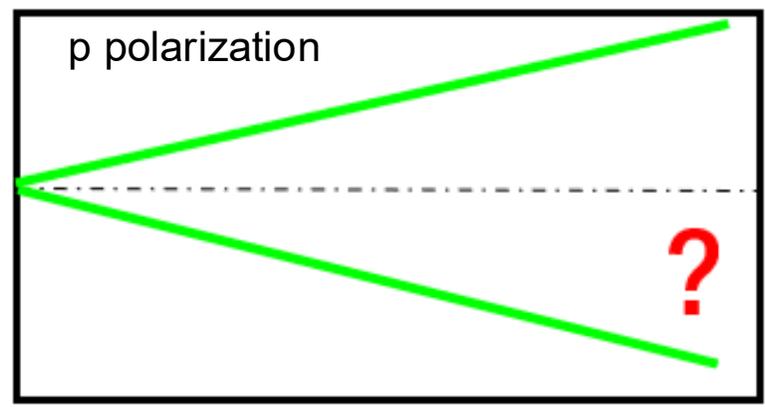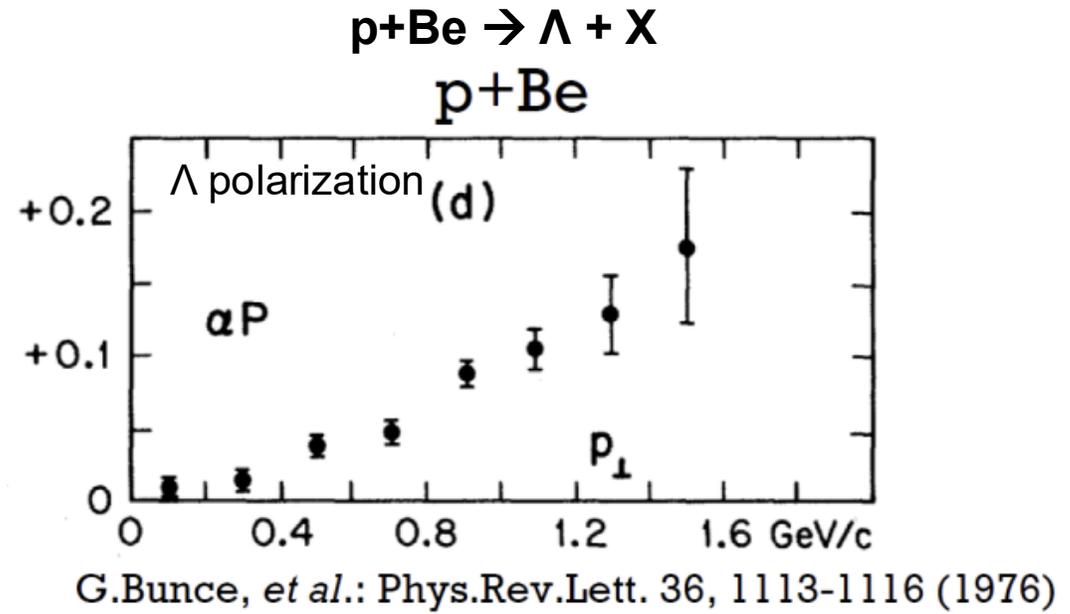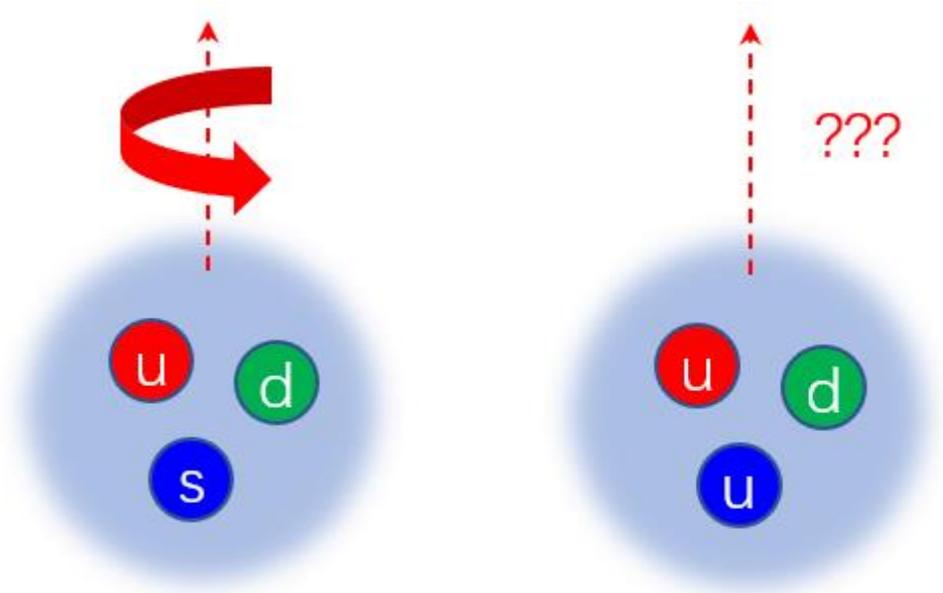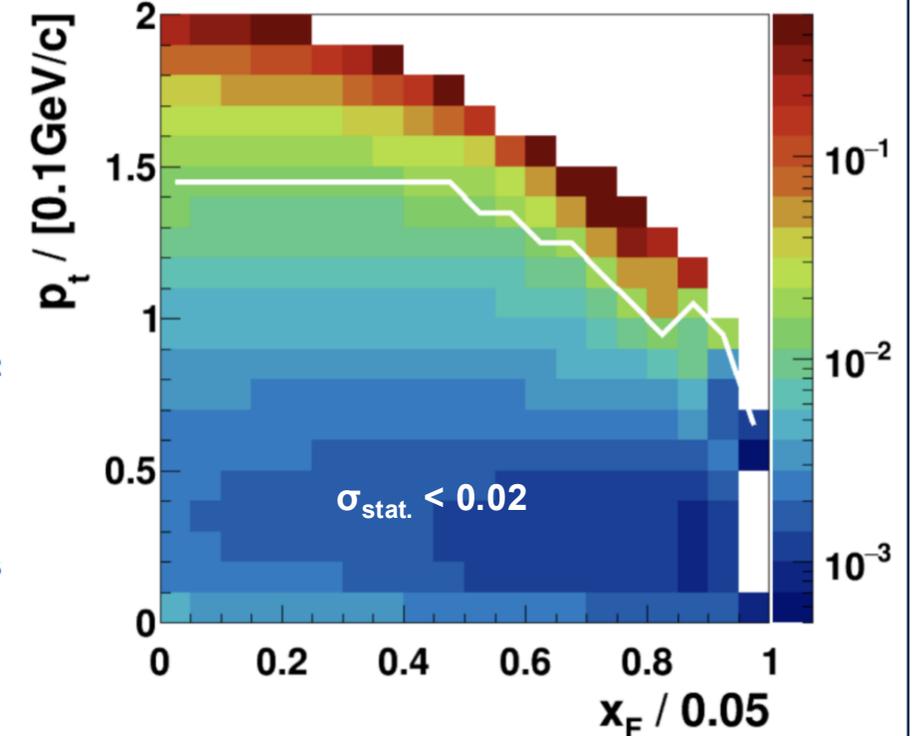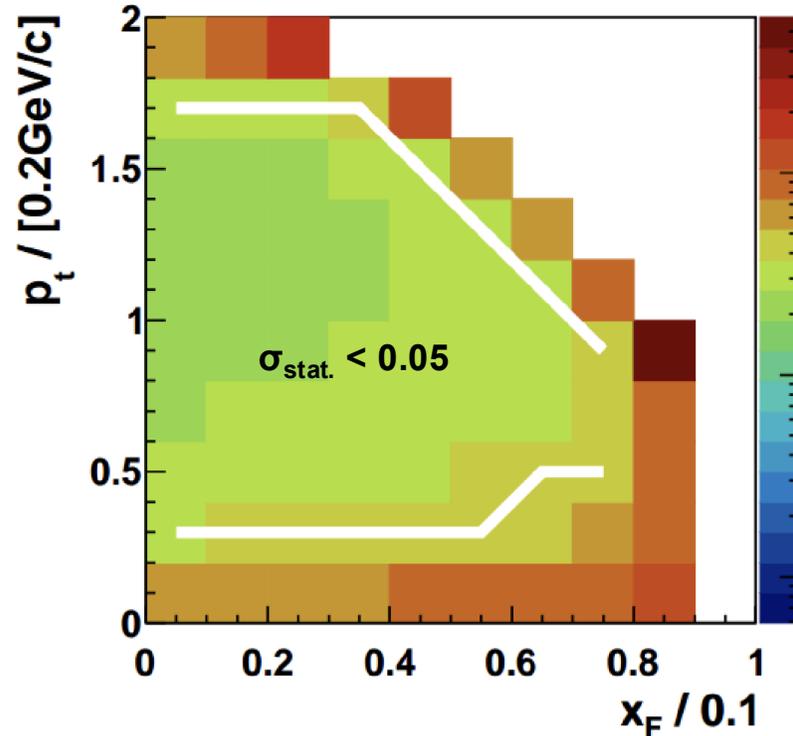
$\sigma_{stat.} < 0.05$ for p $_{100\ bins}$

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

Exclusive measurement

Inclusive measurement

Uncertainty of proton polarization

Uncertainty of proton polarization

$\sigma_{stat.} < 0.05$

$\sigma_{stat.} < 0.02$

p_t / [0.2GeV/c]

p_t / [0.1GeV/c]

x_F / 0.1

x_F / 0.05

Uncertainty projection of the Global polarization in A-A

Au+Au events at beam kinetic energy of 2.8 GeV/u
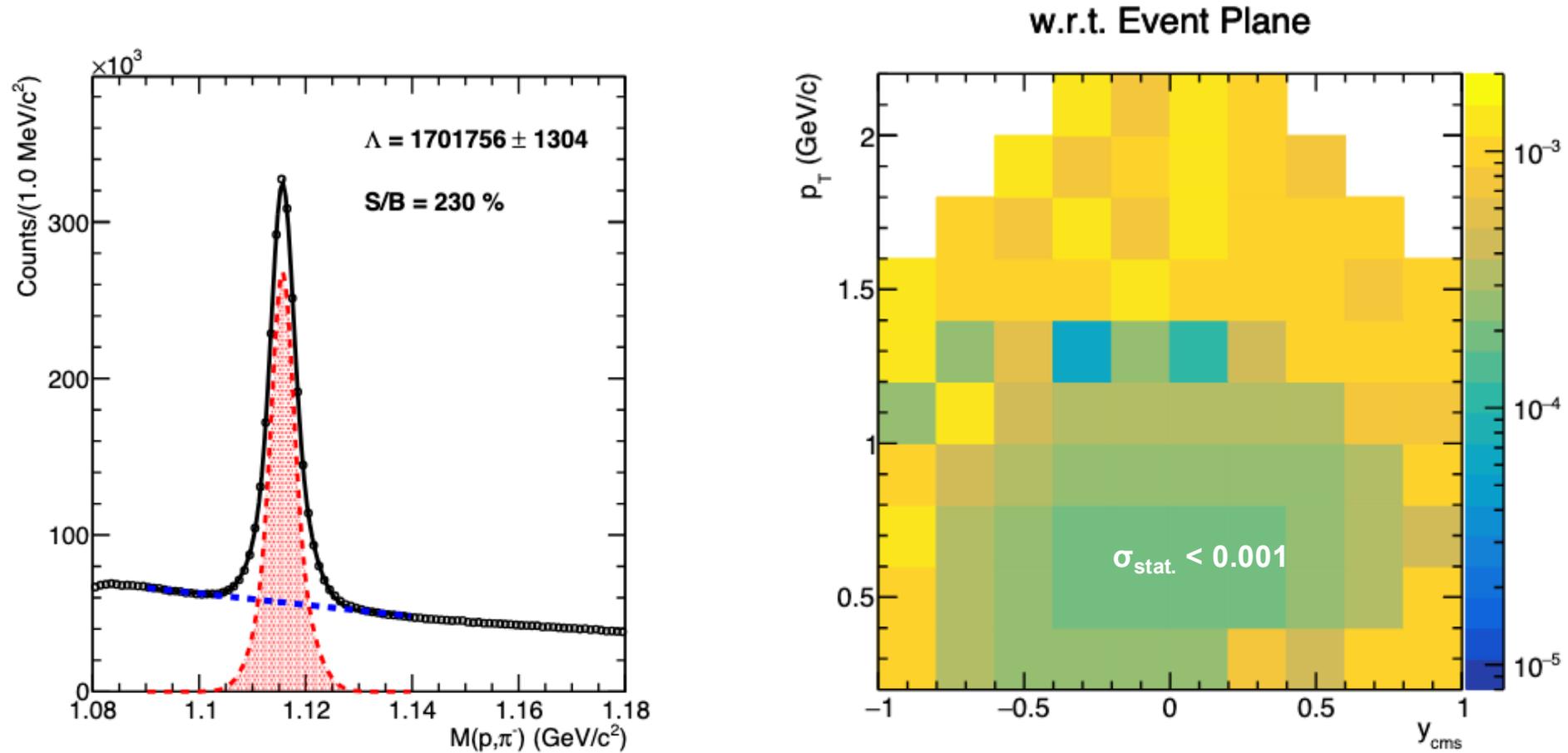
2D uncertainty of Λ polarization using 10^{11} Au+Au events, few weeks data taking

Silicon tracker at H-NS

MIC6 development at CCNU

- **MIC6 MAPS pixel chip:** development and manufacture with the domestic process
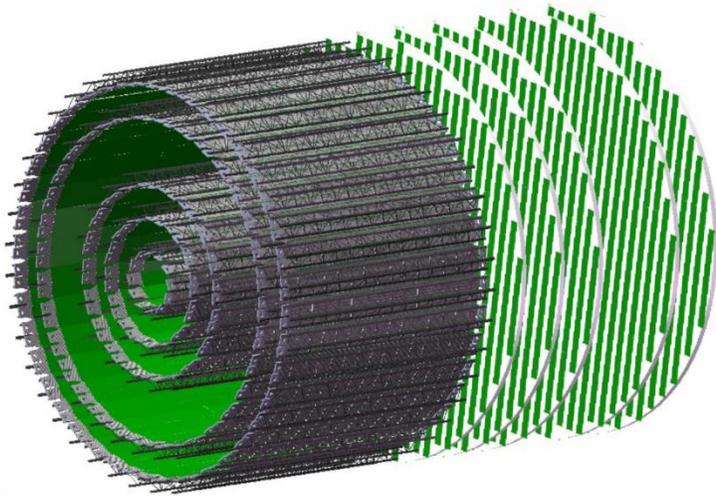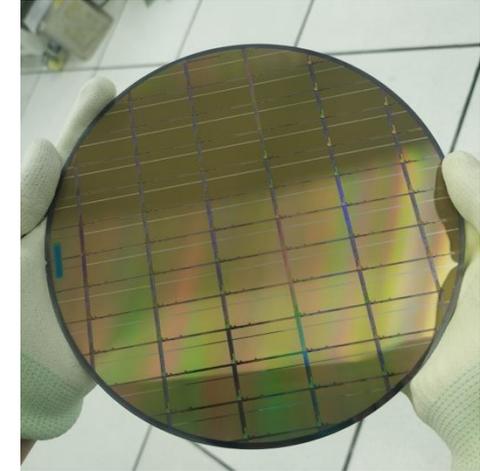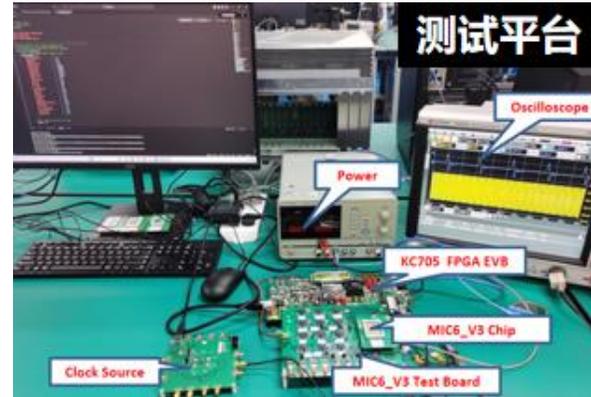- **Readout electronics** (ITS2 based design) **and DAQ** (ALICE CRU/FELIX protocol, GBTx, …)
- **Detector assembly and integration:**
  - ➢ **Vertex detector:** Stave module design (spatial resolution: ~ 5 μm with pixel size 30 μm, total material < 0.35%X/X_0 per layer)
  - ➢ **Forward tracker:** Ladder module aligned to disc super-module (spatial resolution: ~ 5 μm with pixel size 30 μm, total material < 0.45%X/X_0 per layer)

Conceptual design of HNS silicon pixel detector

桶部：

Active area: ~3.9 cm²

30mm

15mm
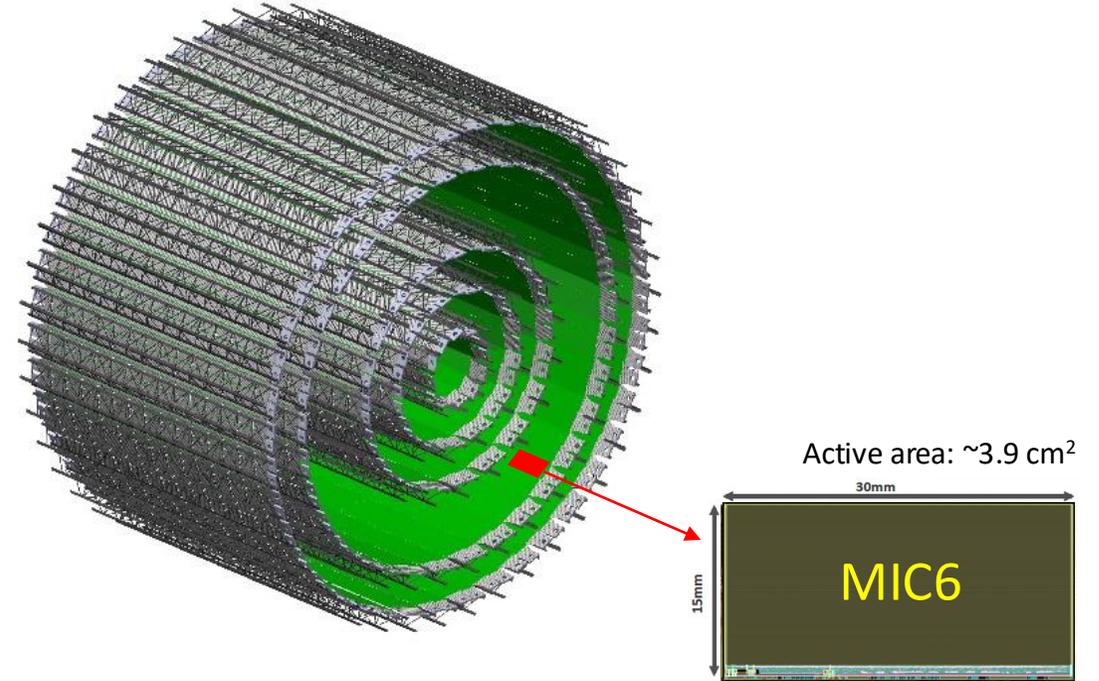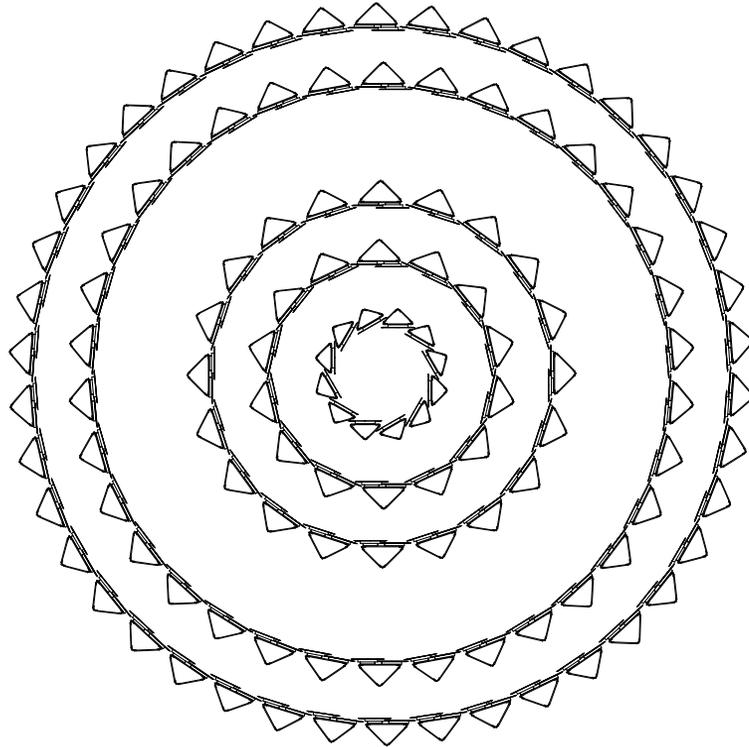
MIC6

Layer No.	No. of MIC6 chips	MIC6 dimensions (mm²)	Nr. Of Staves	Stave overlap in rφ (mm)	Active area (cm²)
L0	336		12	2.35	1310.4
L1	784		14	3.37	3057.6
L2	1120	15×30	20	3.37	4368.0
L3	1904		34	3.37	7425.6
L4	2352		42	3.37	9172.8

Conceptual design of HNS silicon pixel detector

端盖：

Active area: ~3.9 cm²

30mm

15mm
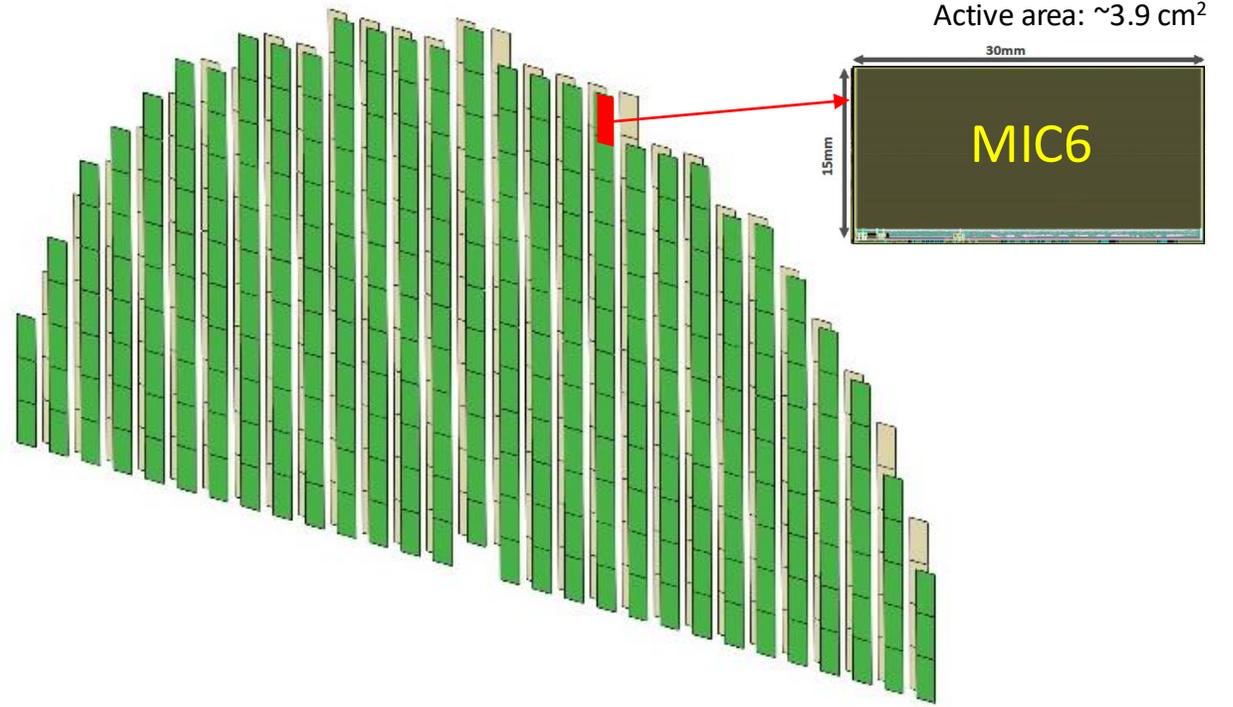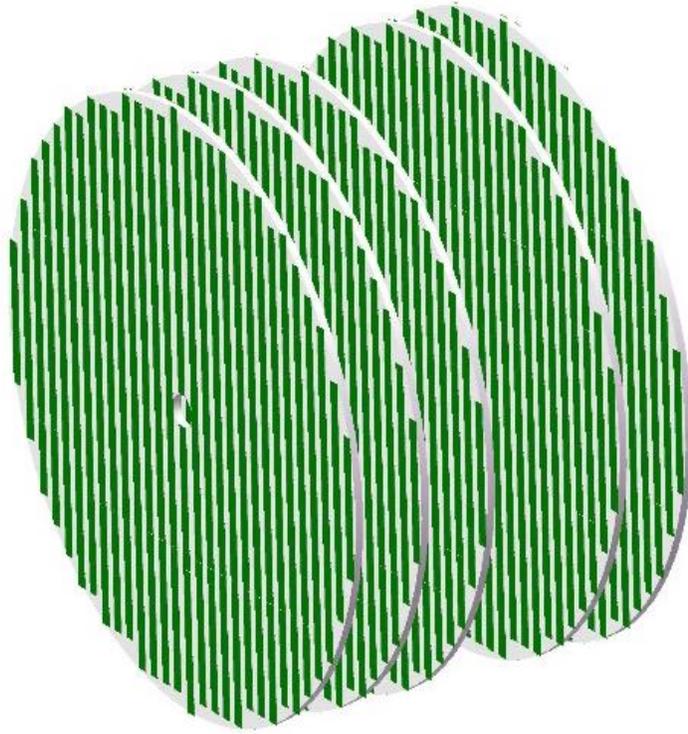
MIC6

Layer No.	No. of MIC6 chips	MIC6 dimensions (mm²)	Nr. of ladders	ladder overlap (mm)	Active area (cm²)
D0	1028		114	2.0	4009.2
D1	1028		114	2.0	4009.2
D2	1028	15×30	114	2.0	4009.2
D3	1028		114	2.0	4009.2
D4	1028		114	2.0	4009.2

AC-LGAD at H-NS

Recent development at USTC:

- Two wafers with different n+ dose: W5 high n+ dose and W6 low n+ dose.
- Sensor size : 1300×1300×50 μm.
- Sensor with different pad-pitch size: Large pad size/pitch: 100/150 μm, Small pad (Strip) size/pitch: 50/75 μm.
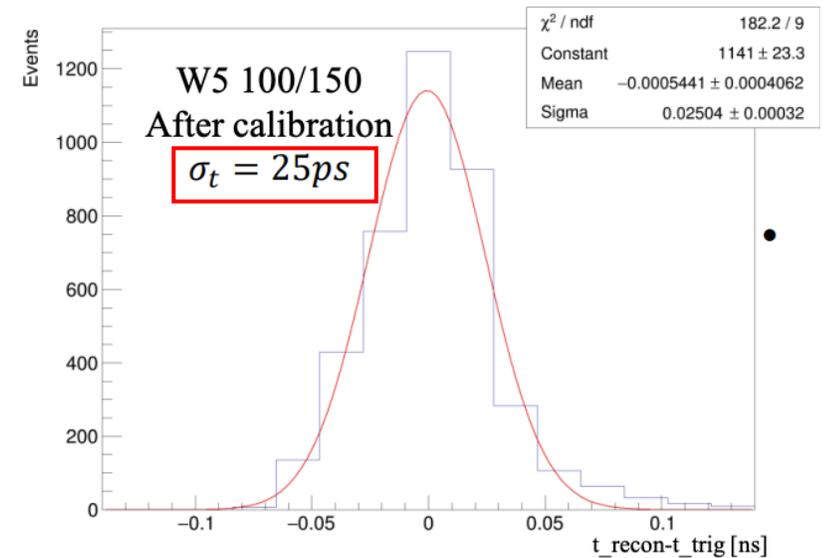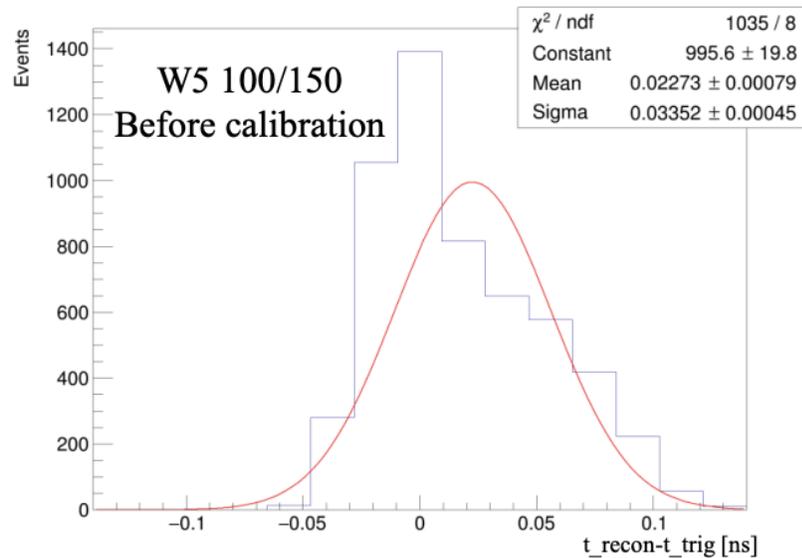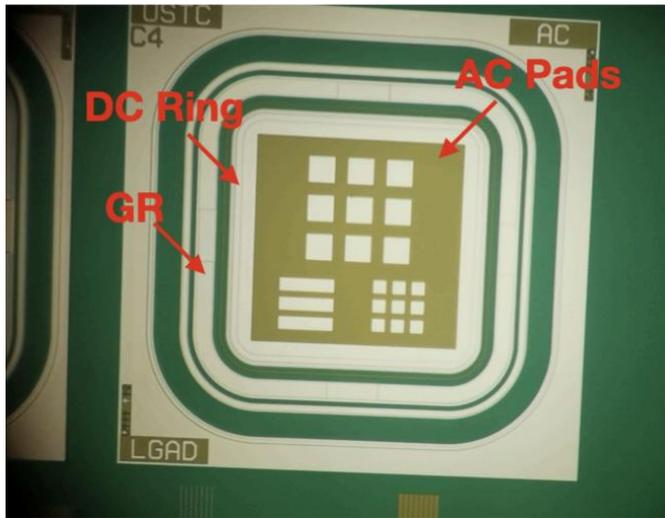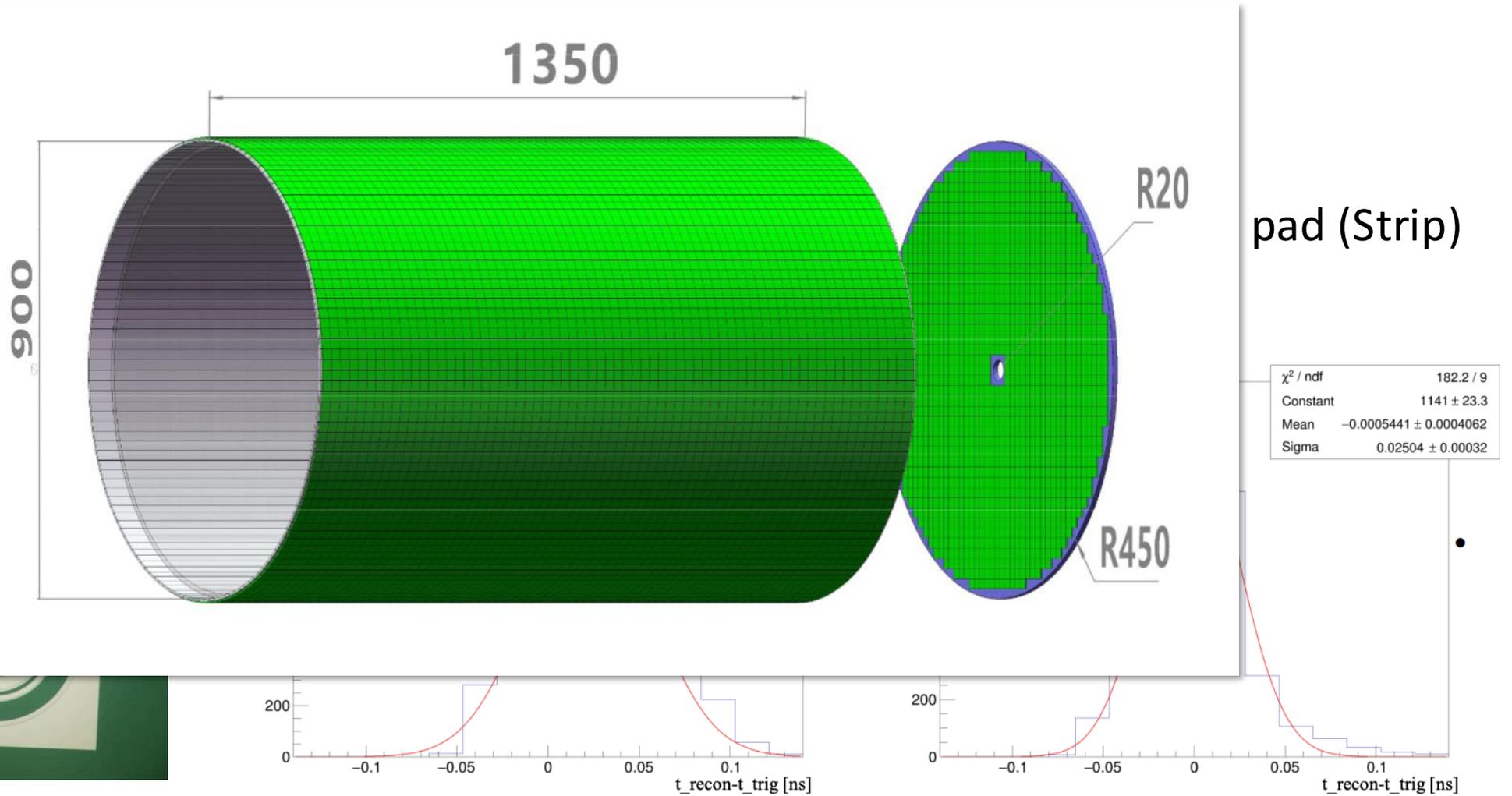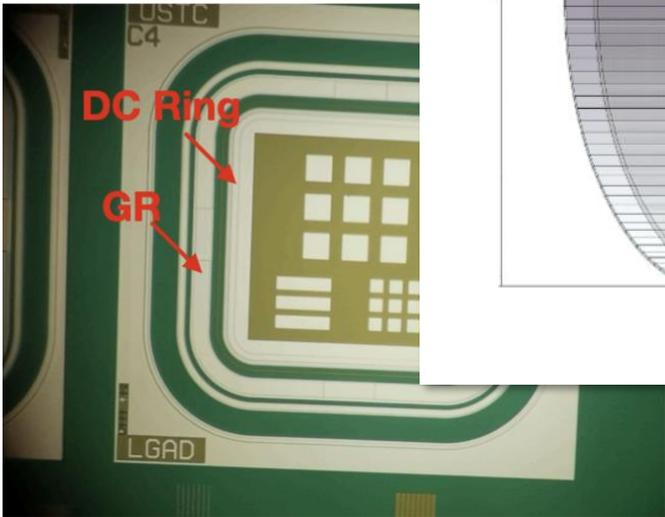
AC-LGAD at H-NS

Recent develo
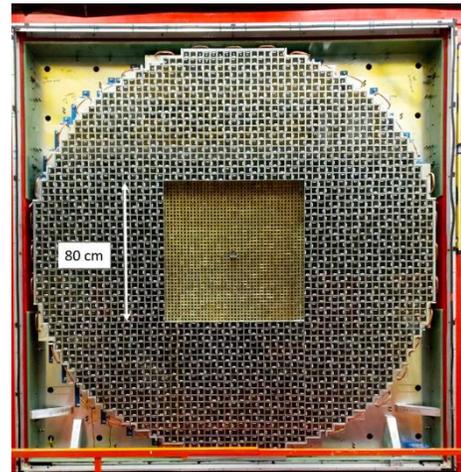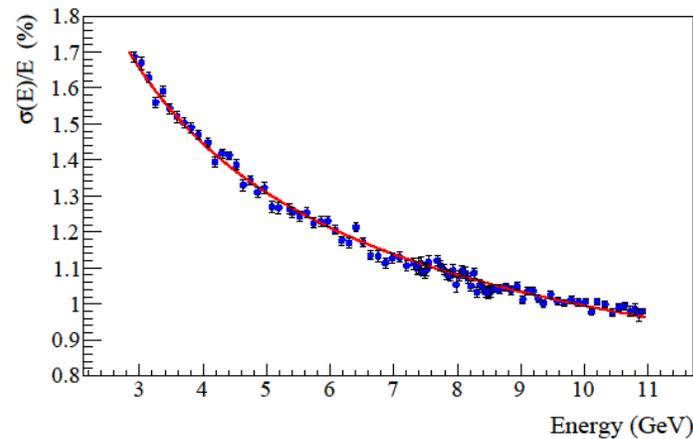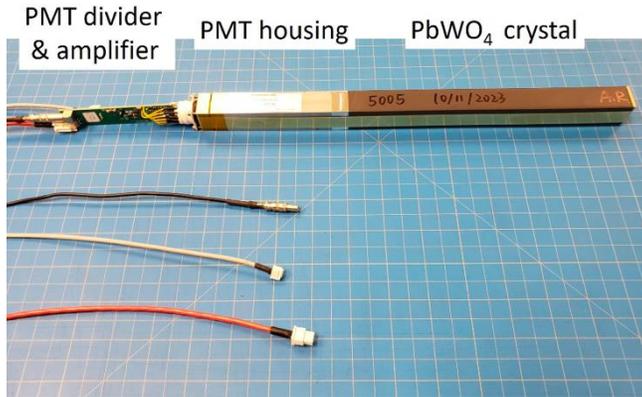
- Two wafers wi
- Sensor size : 1
- Sensor with di   pad (Strip)
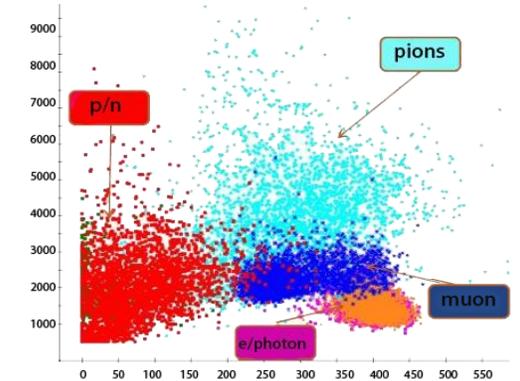 size/pitch: 50/

End cap energy meter design

➢ **PbWO4 crystal**: compact size, good energy resolution

➢ **Dual-Read out**: better hadron shower resolution, PID capability

环氧树脂与金属微颗粒   铜网

SiP M   SiP M

闪烁光纤   切伦科夫光纤（塑料/石英）
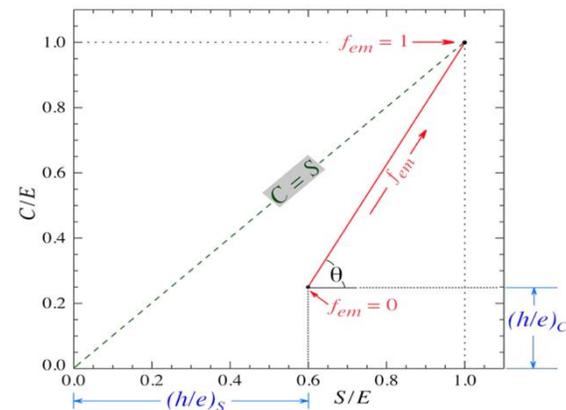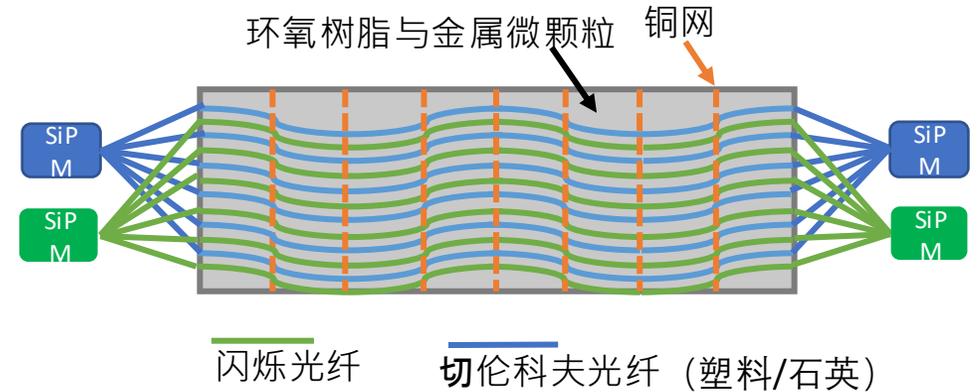
End cap energy meter design

- ➤ Σ+ and Σ0 generation process γ/π0 detection, etc
- ➤ The expected number of modules is 1225
- ➤ Analog detector setup:
- ➤ Front end size: 2.05x2.05 cm^2
- ➤ The length is 18cm
- ➤ The detector is located at ~140 cm
- ➤ Beam hole radius is 5 cm, outer diameter is 45 cm (maximum angle 18 degrees)
- ➤ Two different design arrangements are simulated

长方体
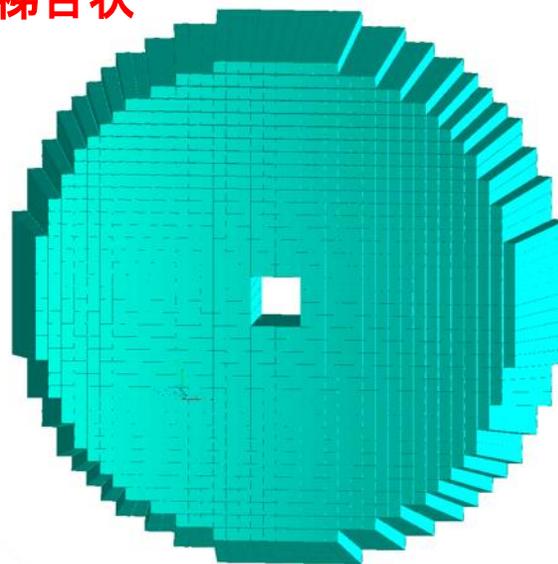
40 cm 设计

半径 [cm]	PbWO4数量
40	1152
43	1324
45	1436
50	1764
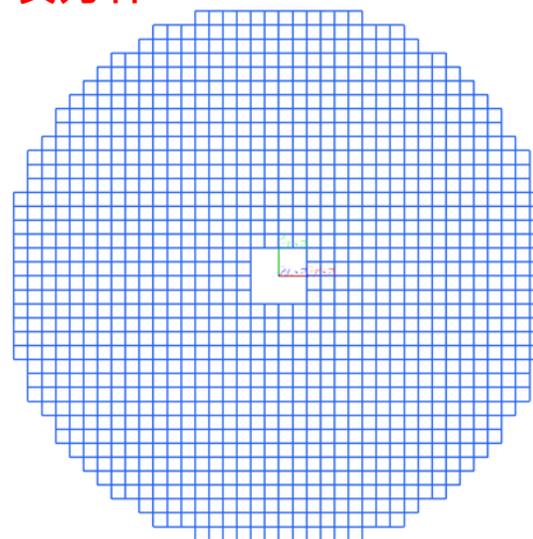
半径 [cm]	PbWO4数量
40	1244
43	1340
45	1464
50	1852

The effect of PWO length on performance

- A 5x5 array simulation is used, and the simulation only considers energy deposition
- At present, the irradiation length of detectors using PWO crystals is generally about 20cm (=22.5X0, X0=0.89cm), and the length can be optimized to reduce the cost.

Energy resolution
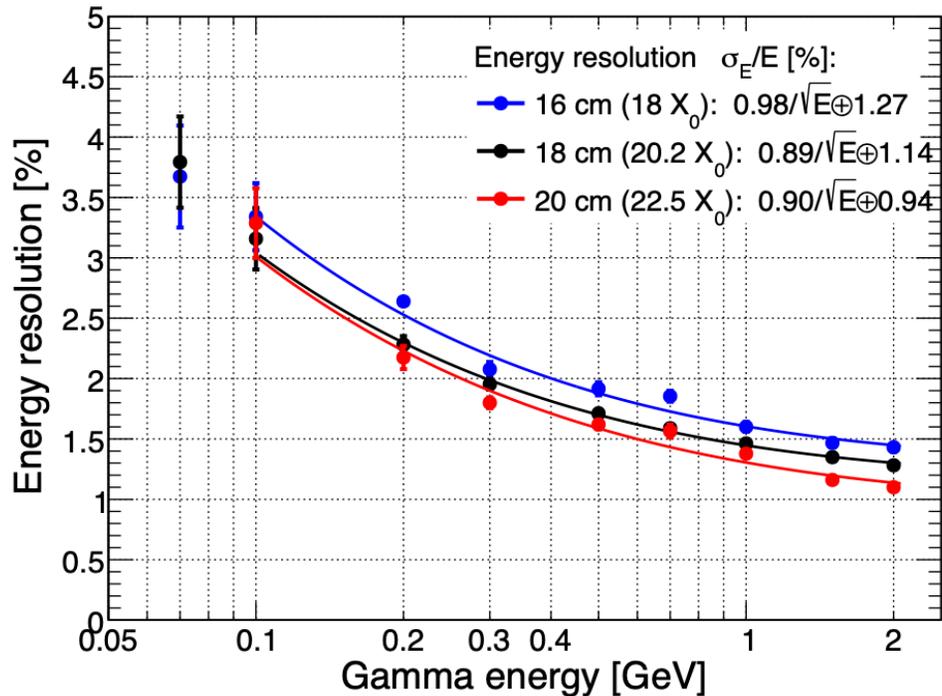
Energy resolution σ_E/E [%]:
- 16 cm (18 X_0): $0.98/\sqrt{E} \oplus 1.27$
- 18 cm (20.2 X_0): $0.89/\sqrt{E} \oplus 1.14$
- 20 cm (22.5 X_0): $0.90/\sqrt{E} \oplus 0.94$

Position resolution

Position resolution [mm]:
- 16 cm (18 X_0)
- 18 cm (20.2 X_0)
- 20 cm (22.5 X_0)

44

The mechanical design of $HNS\emptyset$

1.3× 3 cm

ASIC

FELAB

FPGA板

The mechanical design of *HNS∅*

1.3× 3 cm
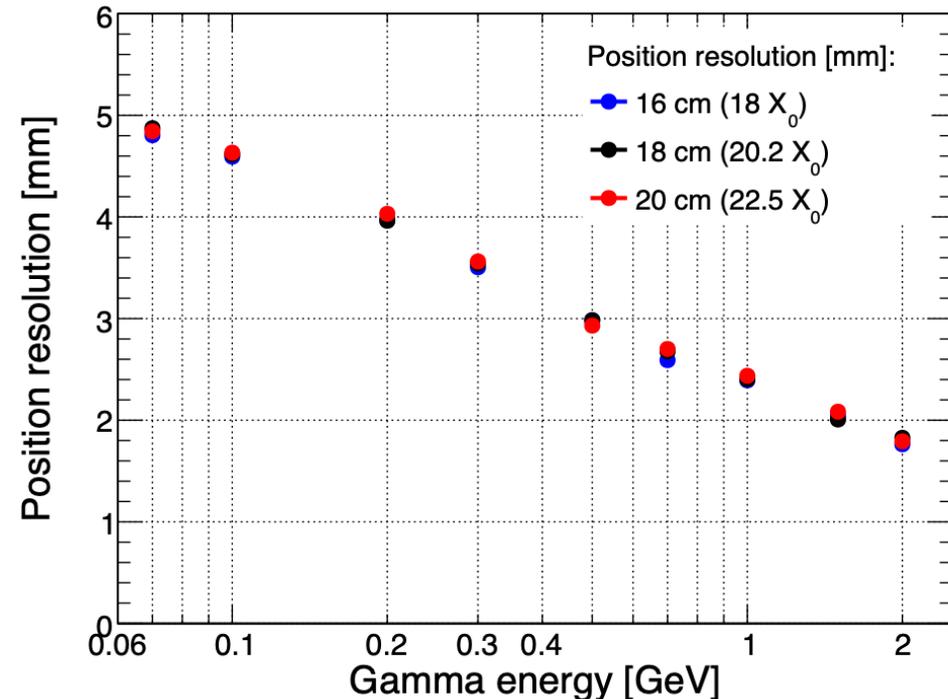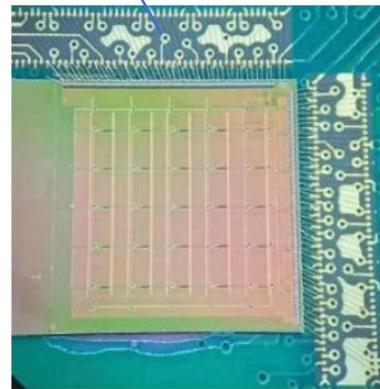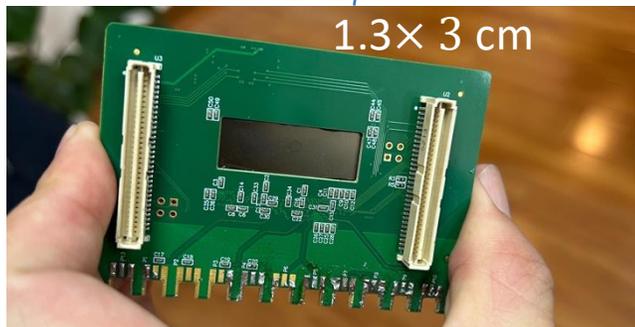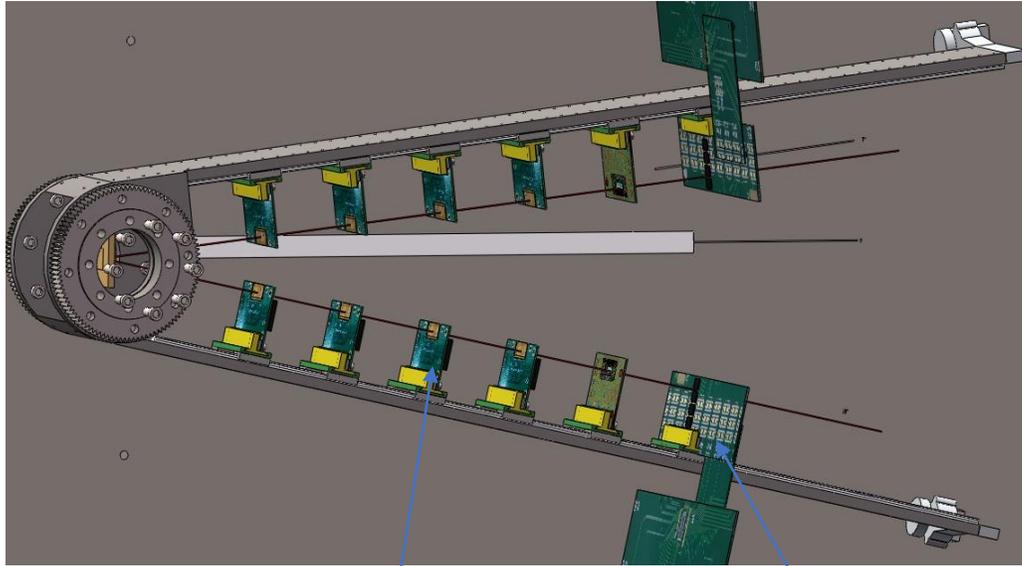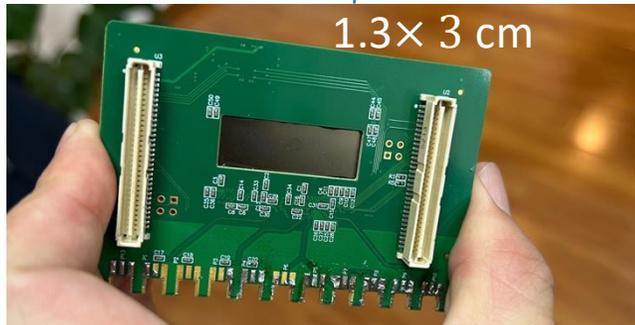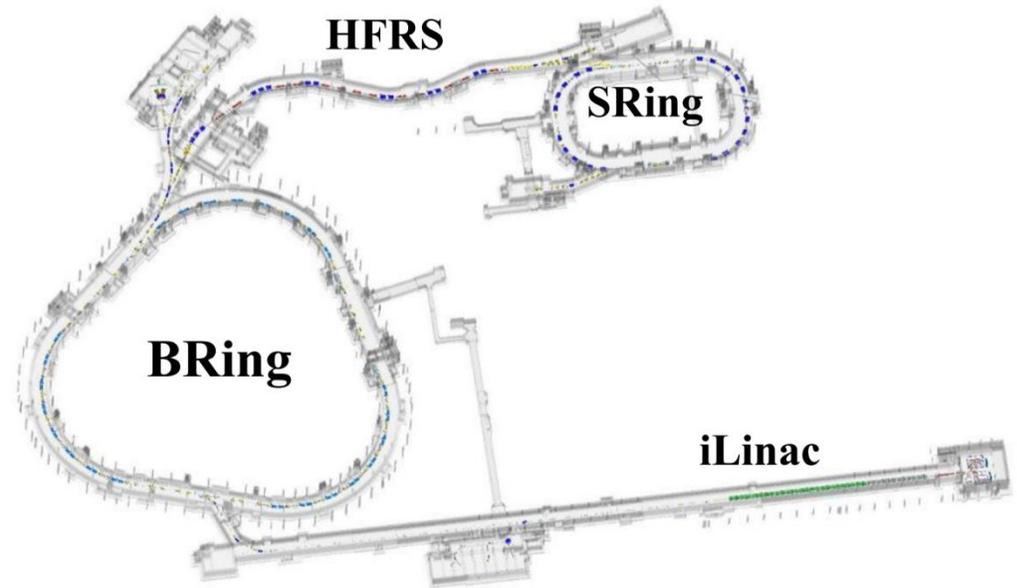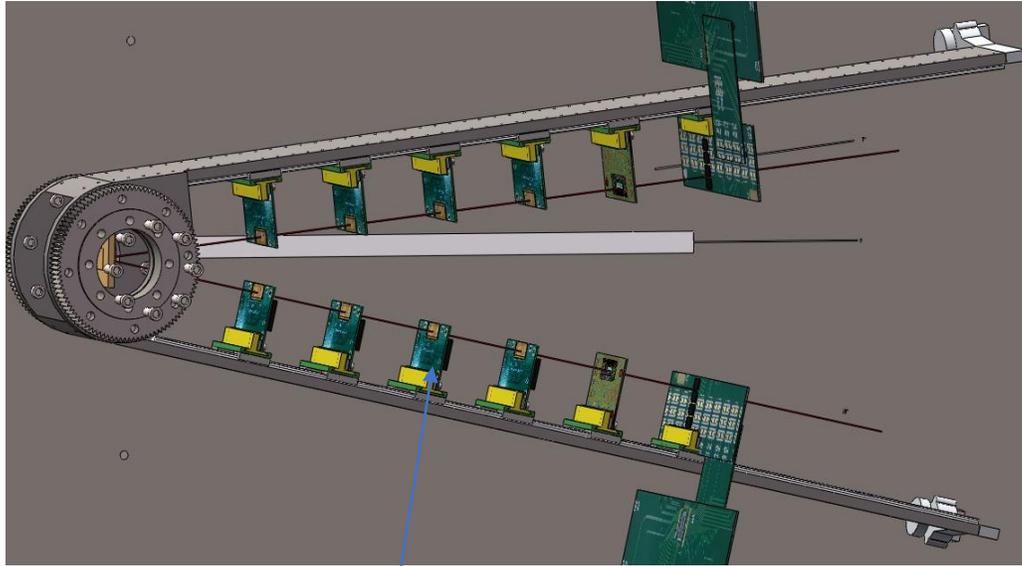
表 1-3 HIAF 验收束流指标

离子		最高能量(GeV/u)	脉冲流强(ppp)
非金属 $^{18}O^{6+}$ 或 $^{78}Kr^{19+}$ 任选一	$^{18}O^{6+}$	2.6	1.0×10^{10}
	$^{78}Kr^{19+}$	1.7	7.5×10^{9}
金属 $^{209}Bi^{31+}$ 或 $^{238}U^{35+}$ 任选一	$^{209}Bi^{31+}$	0.85	3.0×10^{9}
	$^{238}U^{35+}$	0.8	3.0×10^{9}

Invariant mass of $p\pi$

Flight distance **0.5m**

Nsig = 2423.5 ± 116.9

Nbkg = 3722.5 ± 122.3

μ = 1.11627 ± 0.00033

σ = 0.00944 ± 0.00040

Significance: 36
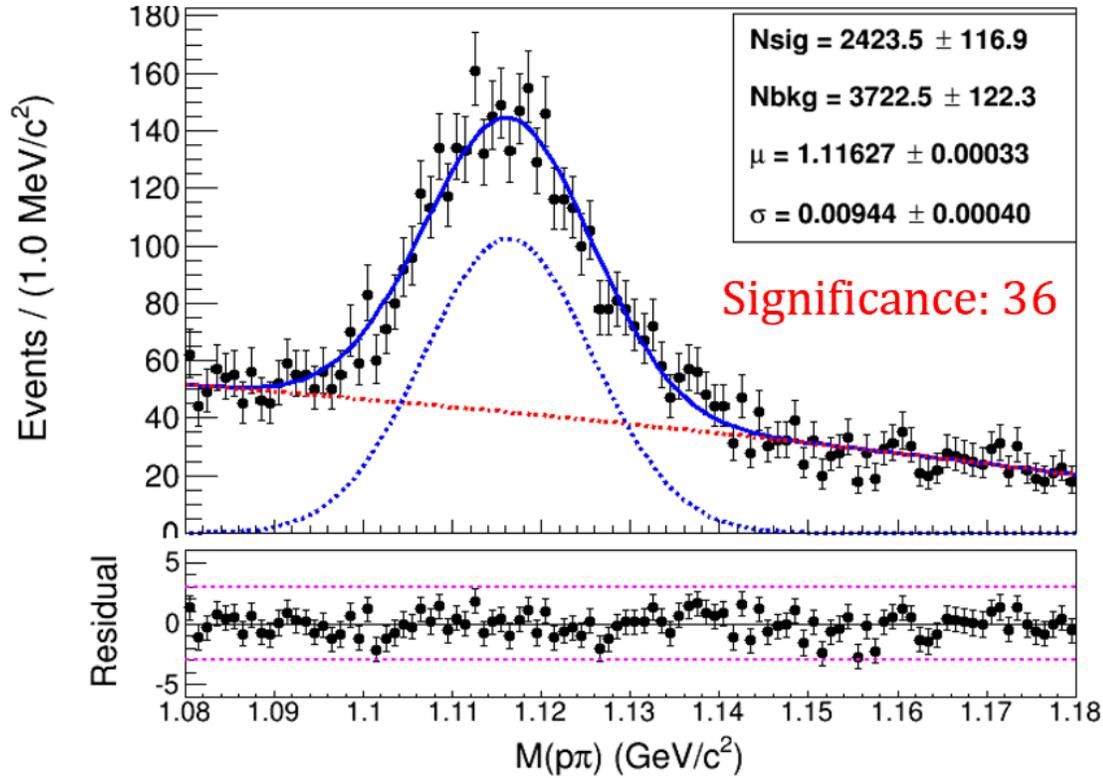
➢ 10000 Lambda in few weeks

Beam direction

Proton arm

Pion arm

7° 12°

$v = L/t$
$p = \gamma m v$

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

HIAF

Accelerator

HIAF-U

EicC

CEE@CSR

H-NS DEMO　　H-NS construction　　**H-NS run**

Detector

EicC

H-NS DEMO running at HIAF

A smooth transition from H-NS to EicC, in terms of both physics and hardware

48

Summary

Silicon tracker

Baryon polarimeter

Calorimeter

Target

Magnet

HIAF beam

50 cm

AC-LGAD TOF

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, T0+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 interests are expected: Japan

III. Detector R&D

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

Thank you !

backups

About nucleon spin structure

1988 EMC experiment → "Spin crisis"

1970s   1980s/2000s   Now
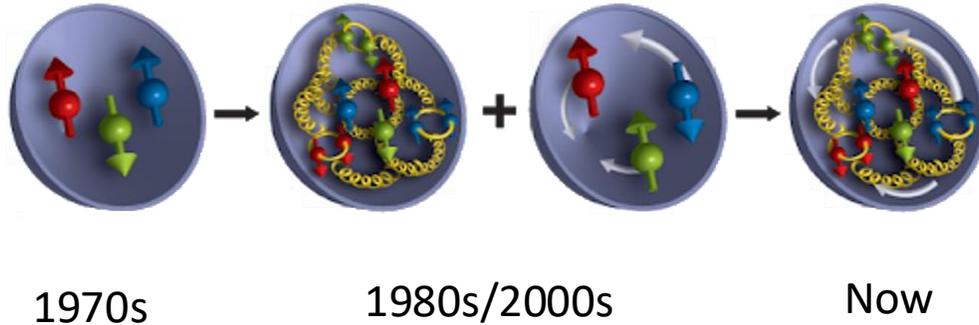
Spin decomposition:

$$S_{tot} = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \mathcal{L}_q + \mathcal{L}_g$$
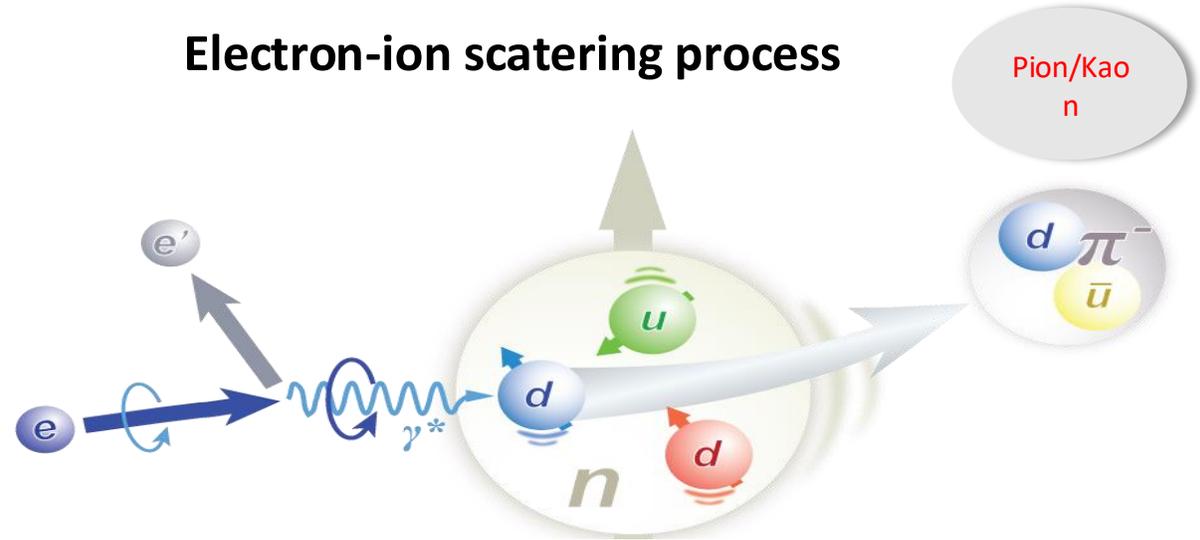
| Quark spin | Gluon Spin | Quark OAM | Gluon OAM |

Electron-ion scatering process

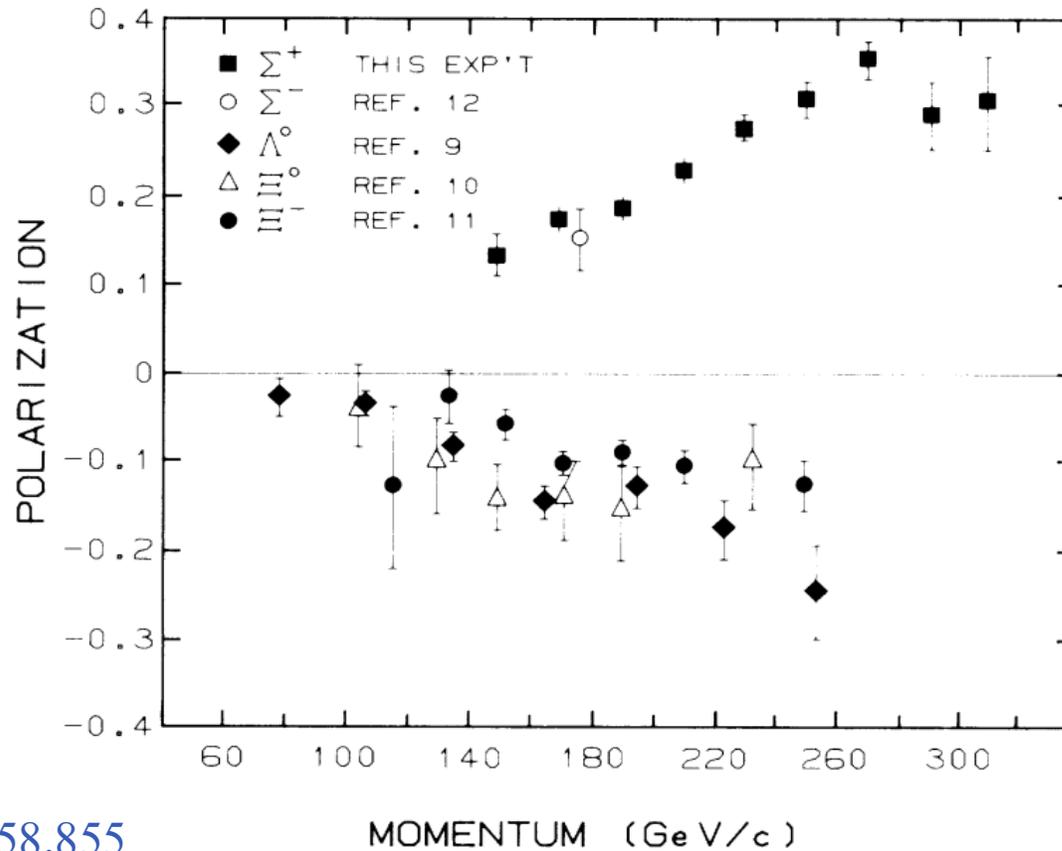Pion/Kaon

➤ We have a framework for the understanding of the spin structure of the nucleon

Polarization of other hyperons

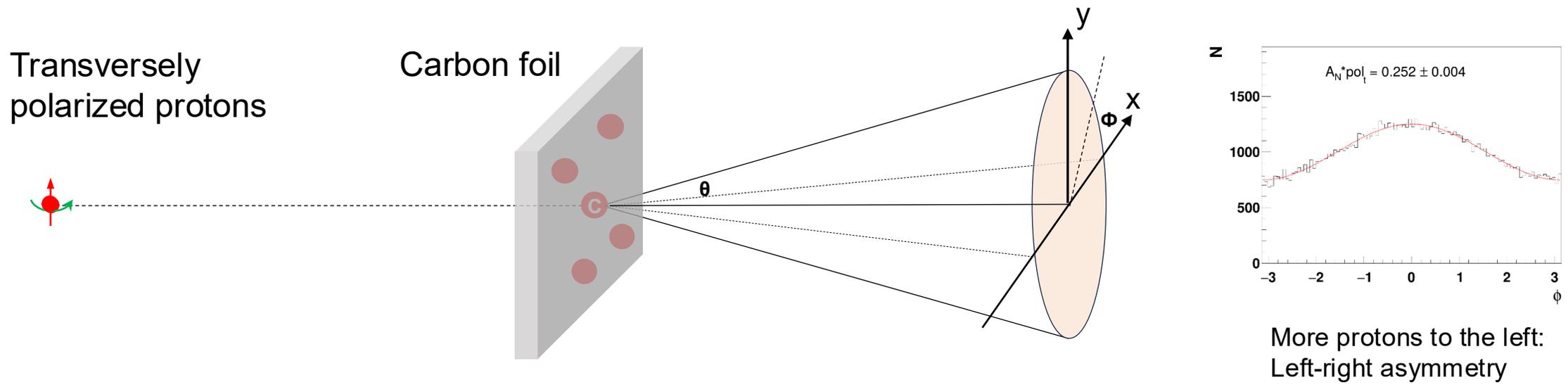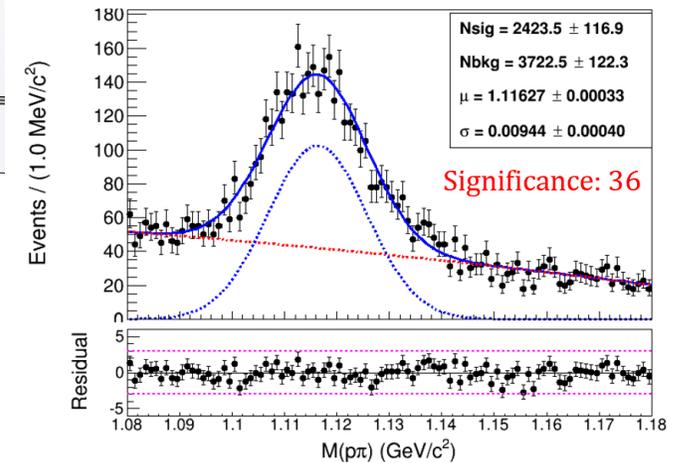| Λ	Σ^+	Σ^0	Σ^-	Ξ^0	Ξ^-
P_s	$\dfrac{4P_u-P_s}{3}$	$\dfrac{2(P_u+P_d)-P_s}{3}$	$\dfrac{4P_d-P_s}{3}$	$\dfrac{4P_s-P_u}{3}$	$\dfrac{4P_s-P_d}{3}$

PhysRevLett.58.855

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

$A_N^* pol_t = 0.252 \pm 0.004$

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 …)

H-NS demo: H-NS0

Nsig = 2423.5 ± 116.9
Nbkg = 3722.5 ± 122.3
μ = 1.11627 ± 0.00033
σ = 0.00944 ± 0.00040

Significance: 36
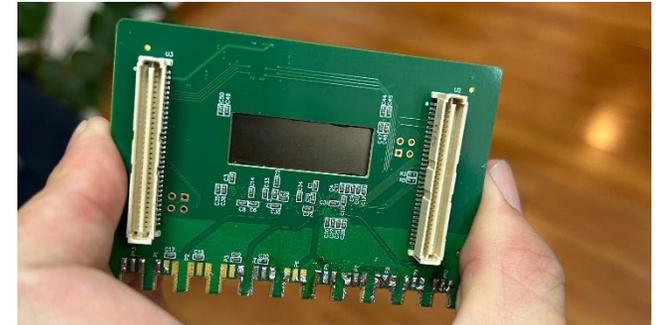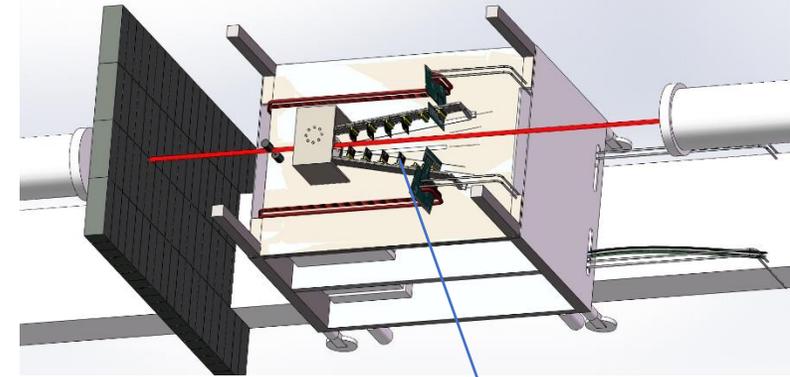
H-NS0 will be ready and tested at HIAF next year

Efficiency due to tracking

E beam=3.5GeV

E beam=9.3GeV

E beam=25GeV
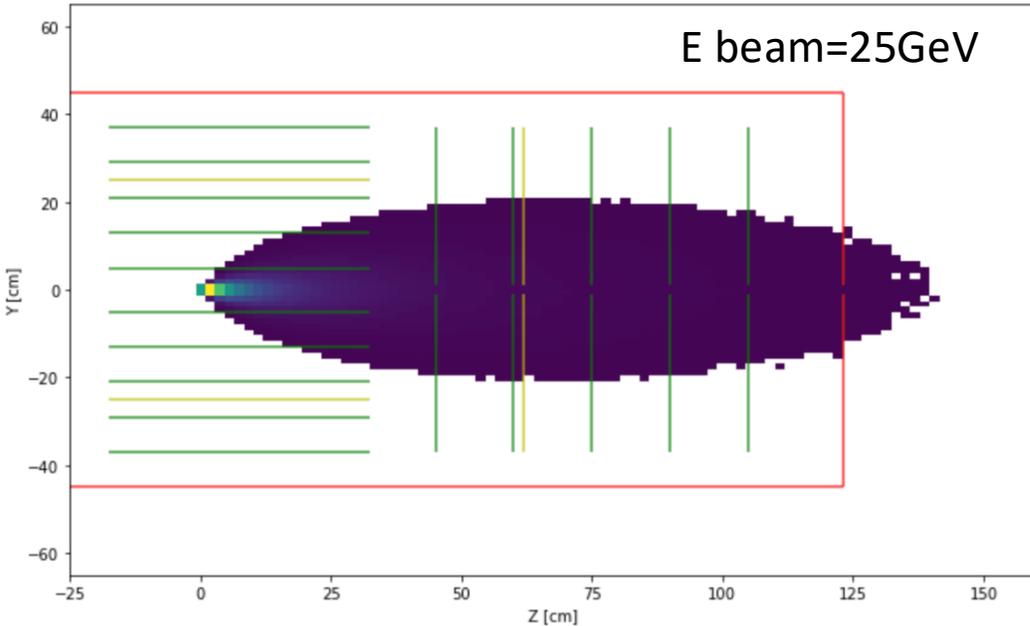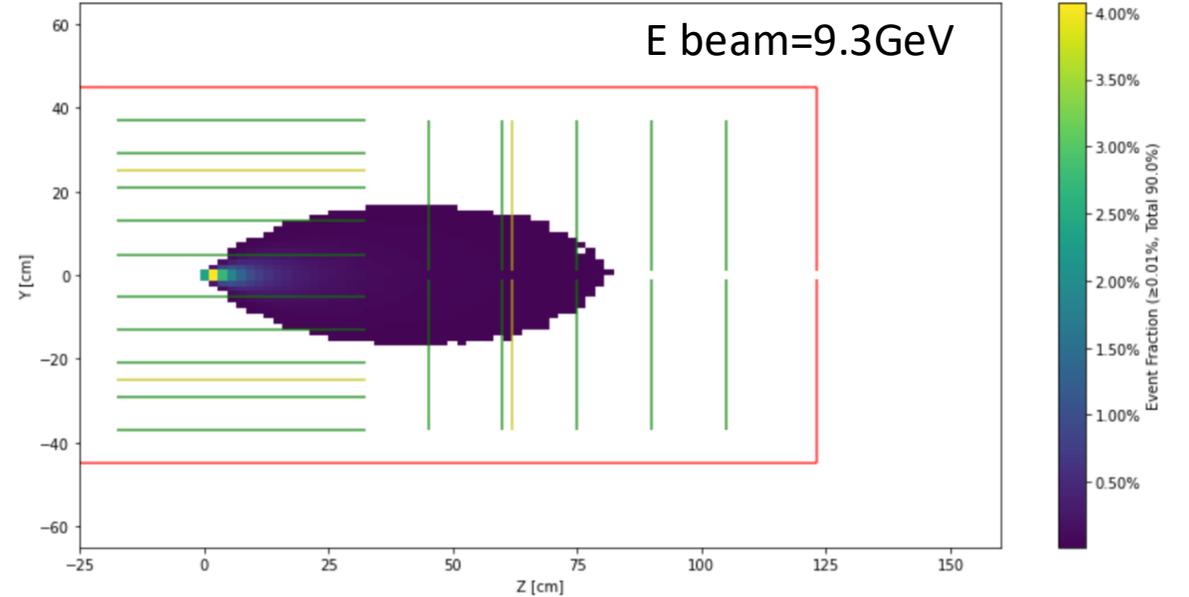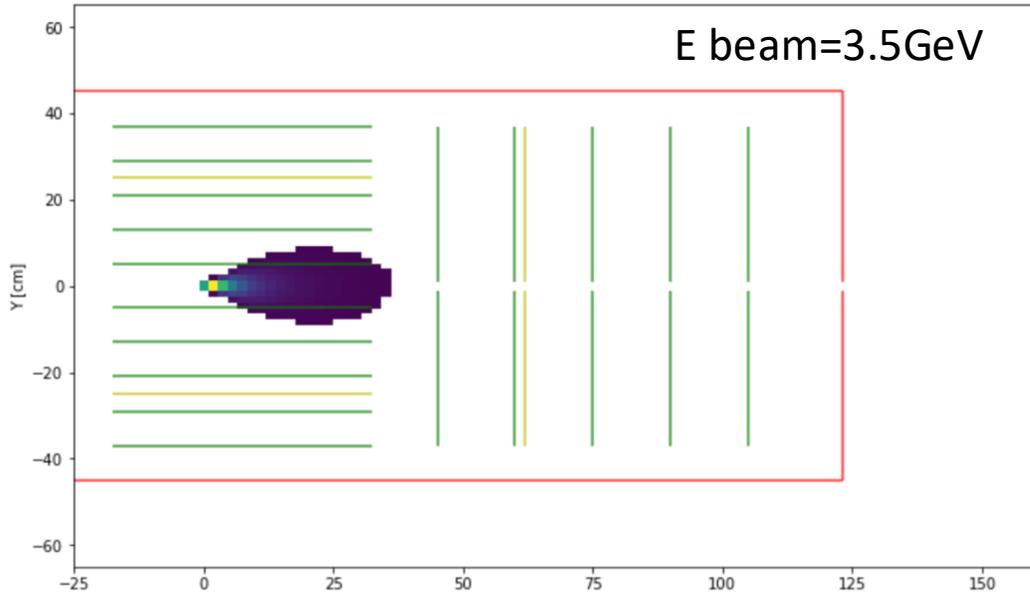
➢ Λ **decay vertex distribution**
➢ **90% of all event**
➢ **Normalized to total event**

An extra scattering layer serve as baryon polarimeter
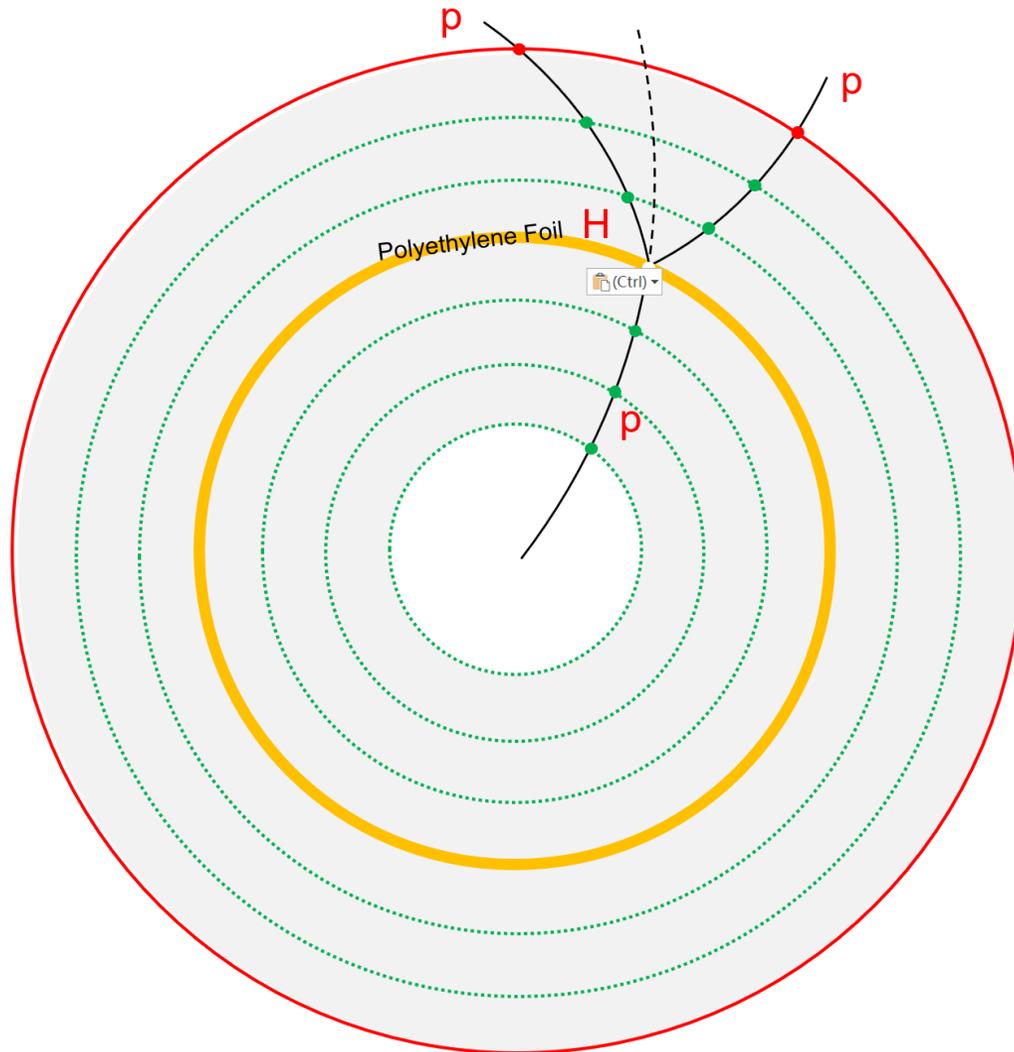
p

p

H

Polyethylene Foil

(Ctrl)

p

➢ **Carbon foil / Polyethylene foil**

- **~1 mm thickness**

- **Material budget: <1% X/X$_0$**

- **Probability: pC / pp (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

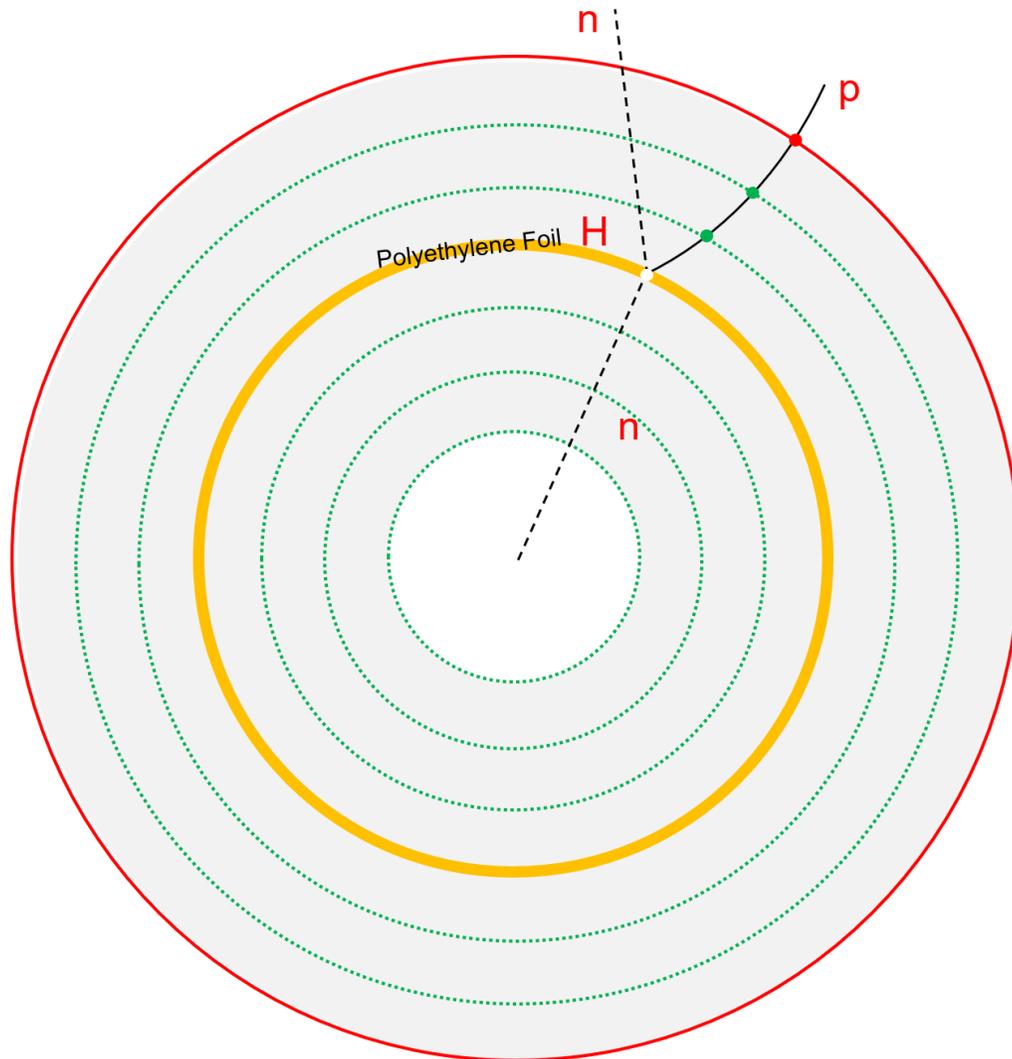# An extra scattering layer serve as baryon polarimeter
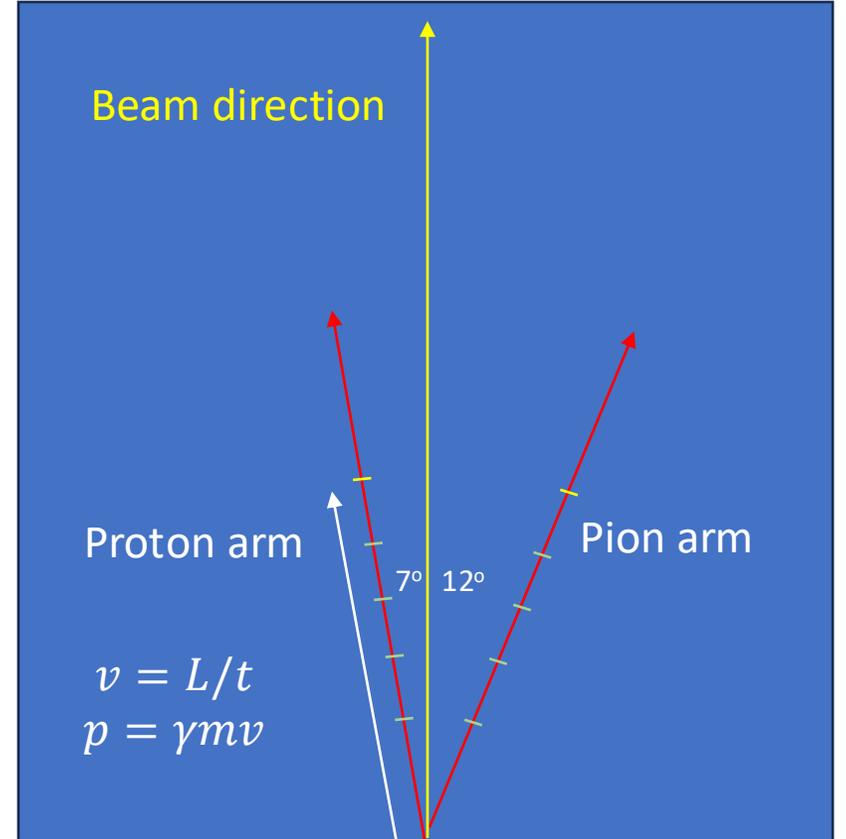

> **Carbon foil / Polyethylene foil**

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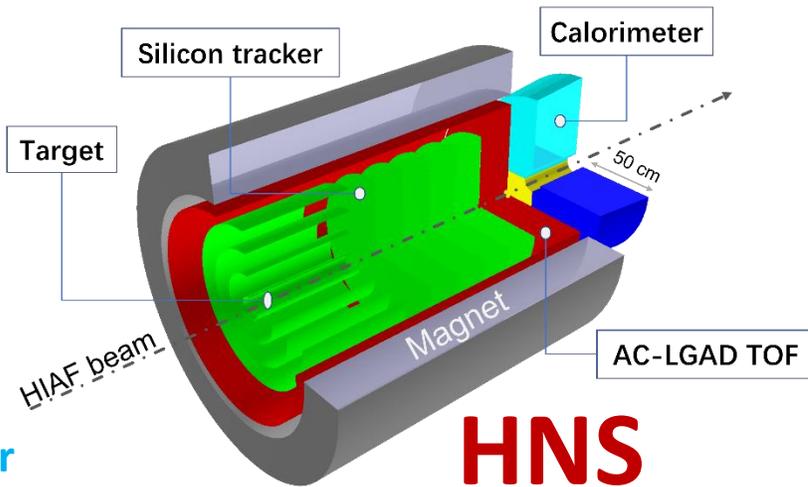
- Tiny influence to the conventional performance

> **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

Procedure of Λ reconstruction

- Select the event, in which there are track on both the proton and pion arm

- Assume the track on proton arm is proton, and pion on another arm

- Determine the momentum according to the measured velocity by LGAD

- Calcaulate the invariant mass of the found two particles

Beam direction

Proton arm

Pion arm

7° 12°

$$v = L/t$$
$$p = \gamma m v$$

HNS

Silicon tracker
Calorimeter
Silicon tracker
Target
50 cm
Magnet
AC-LGAD TOF
HIAF beam

EicC

RICH
ToF+DIRC
Pixel + MPGD
ECal
Coil
ECal
ECal

STCF

Muon Counter
Super conduction
EMC
PID
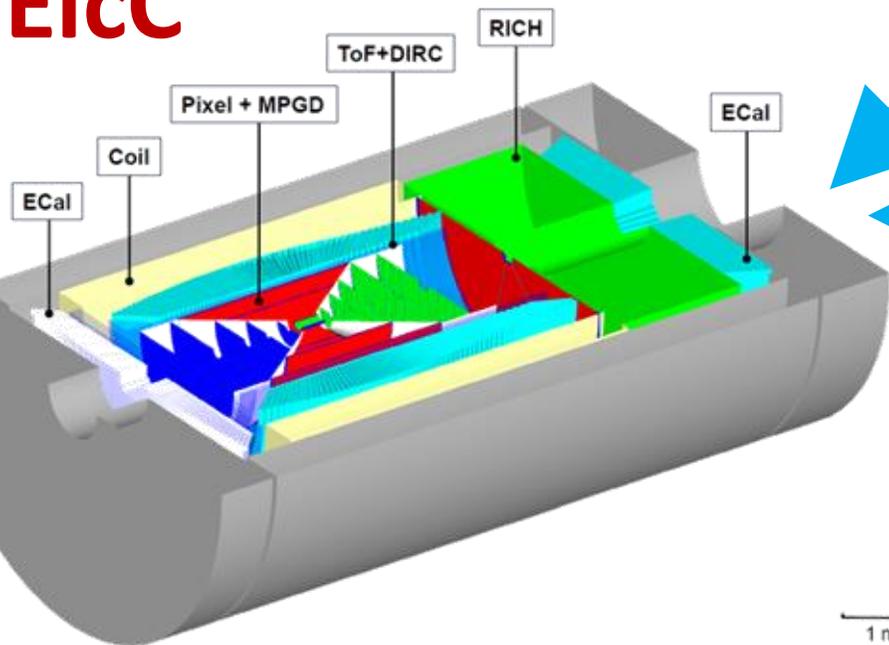Drift chamber
Inner tracker

Silicon tracker
AC-LGAD (PID)
Ecal.
Super-conducting Solenoid

Silicon tracker
Ecal.
Super-conducting Solenoid

Silicon tracker
MPGD tracker
DIRC (PID)
RICH (PID)
Ecal
Super-conducting Solenoid

1 m