



Development and Performance of a MAPS-Based Silicon Tracker for the Hyperon–Nucleon Spectrometer at HIAF

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2026/10/12

- Physics motivation
- H-NS concept design
- H-NS silicon tracker design
 - MAPS chip
 - Detector module
 - Mechanical structure
 - Flexible PCB
- Simulation and performance
- H-NS prototype
- Summary

Physics Motivation – Hadron structure with spin & polarization

➤ 1988 Proton Spin Crisis

EMC experiment: Quarks carry only a small fraction of the proton spin

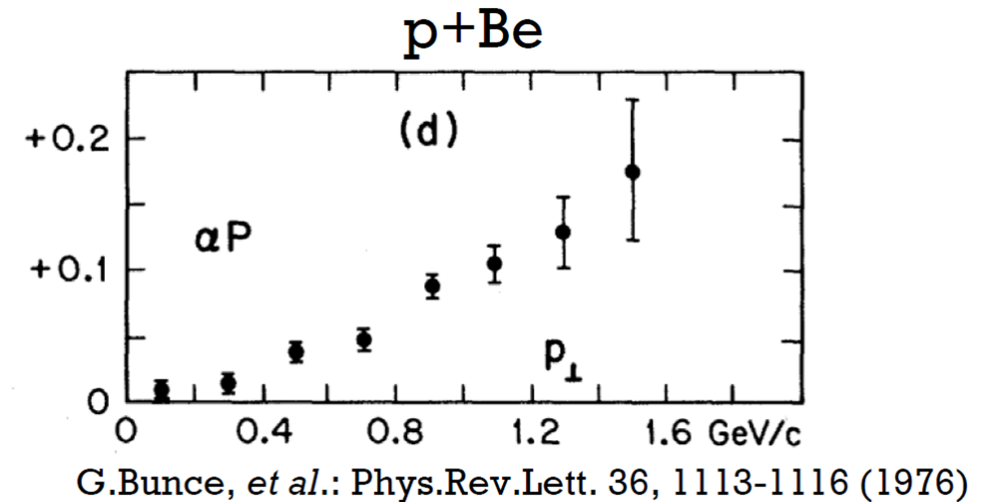
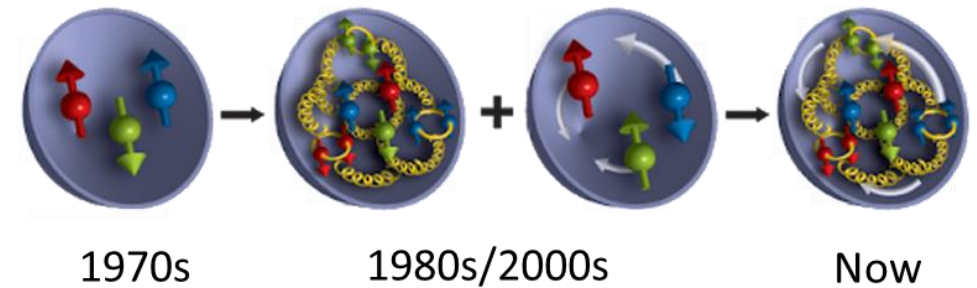
$$S_{tot} = \frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + \mathcal{L}_q + \mathcal{L}_g$$

➤ 1976 First observation of Λ polarization

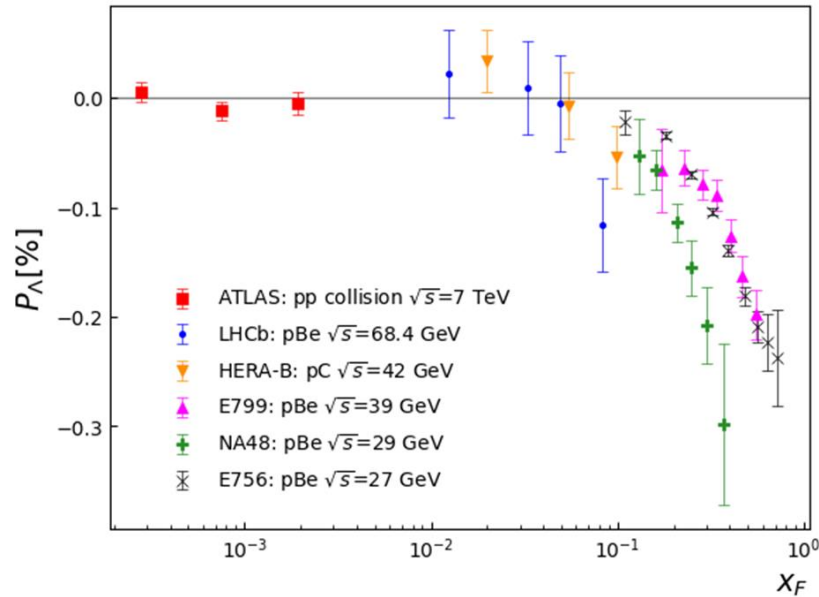
Fermilab: 300 GeV p + Be, Λ can be transversely polarized in collisions with unpolarized beams and targets

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

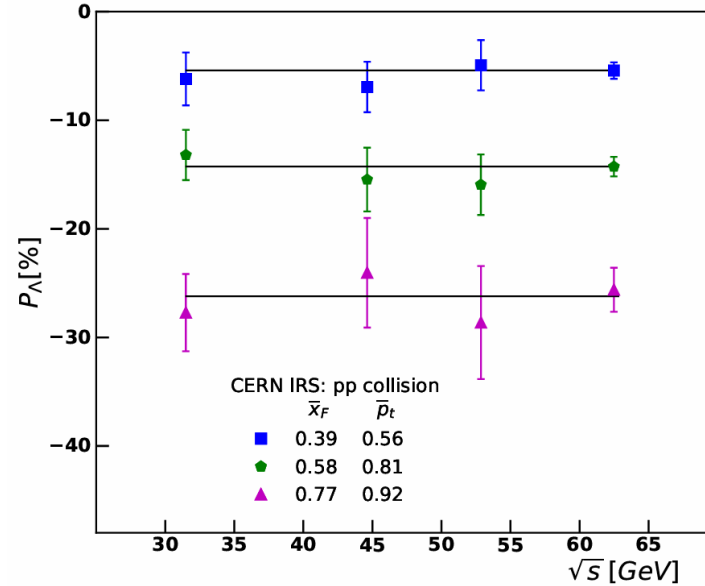
$$P = \frac{(N \uparrow - N \downarrow)}{(N \uparrow + N \downarrow)}$$



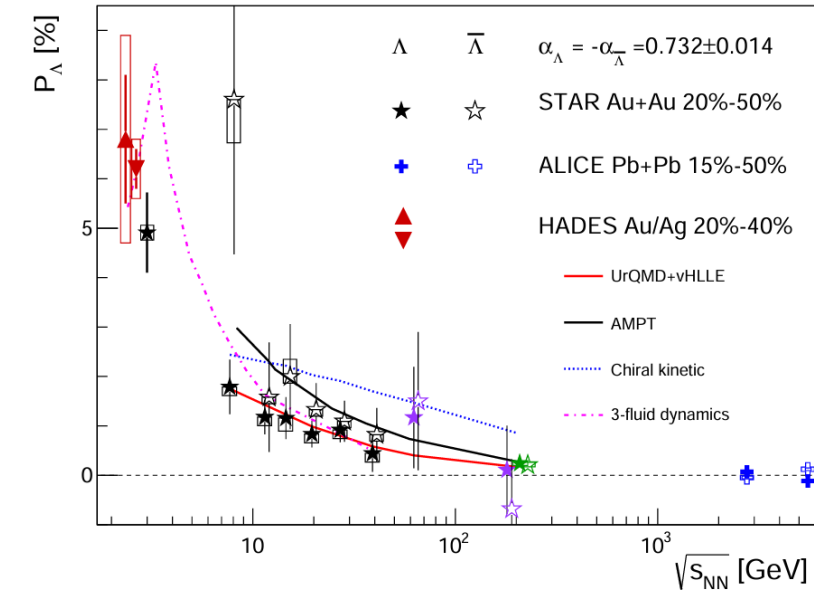
Physics Motivation - Experimental studies of Λ polarization



- The underlying mechanism for spontaneous polarization



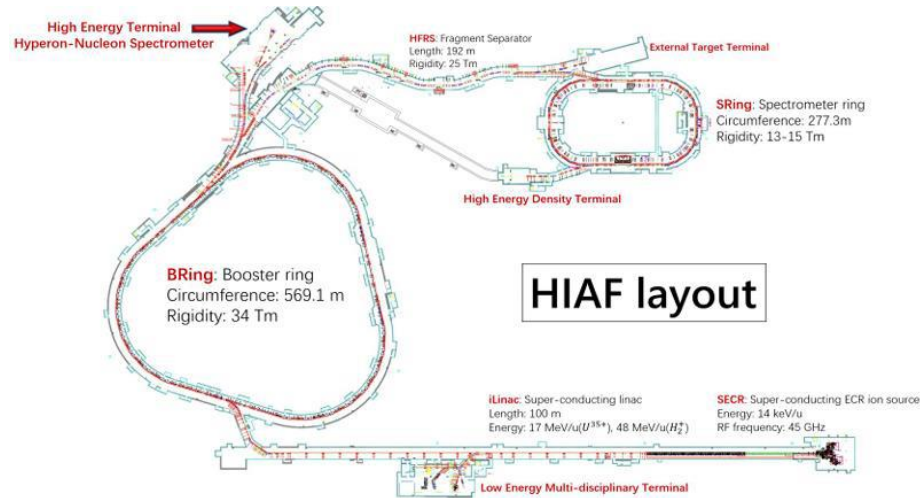
- Λ polarization exhibits scaling in $\sqrt{s}$



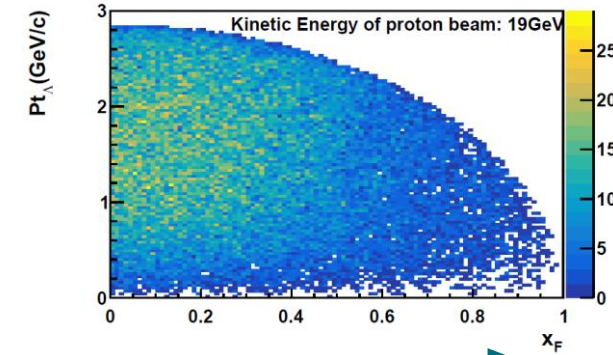
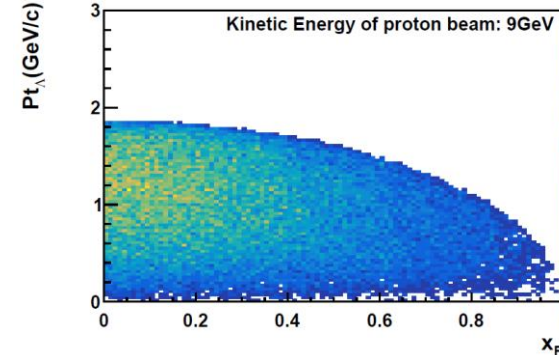
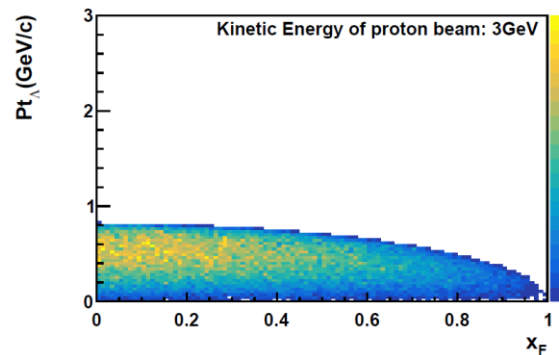
- Global polarization of hyperon in heavy-ion collisions

Overall status: Limited experimental data and lack of systematic studies (kinematic coverage, energy range, and different reaction processes)

The High Intensity heavy-ion Accelerator Facility



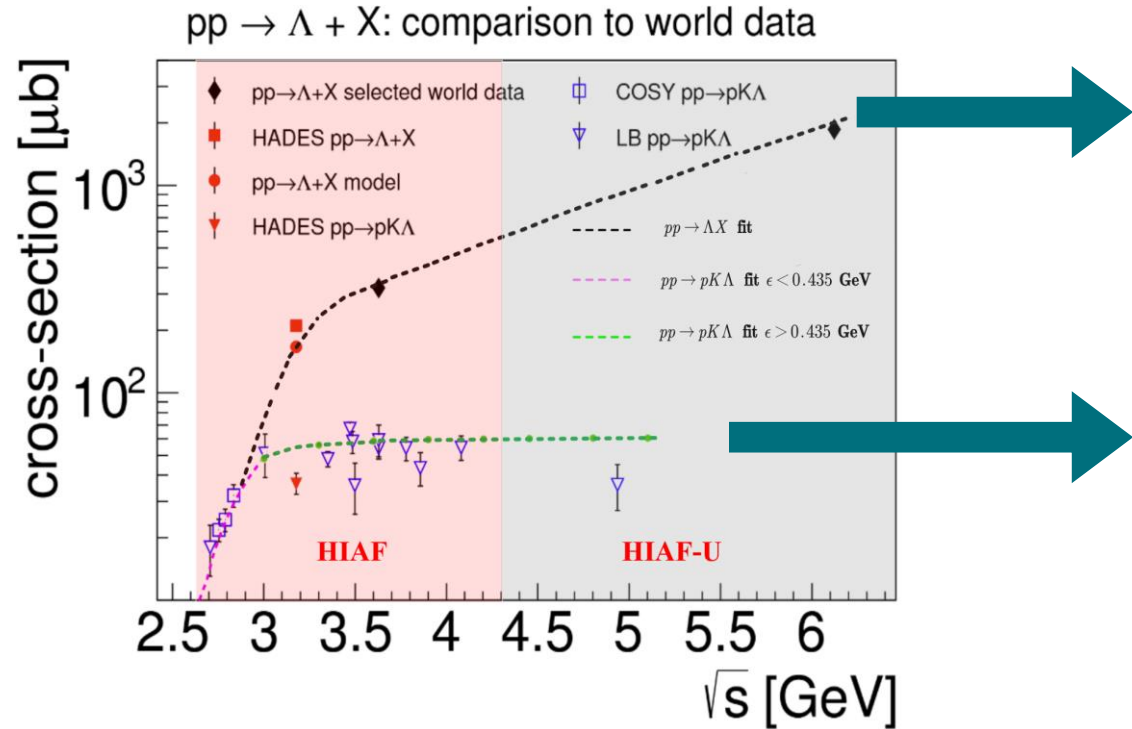
Ion species	Kinetic Energy (GeV/u)	Beam intensity (ppp)
p	9.3	6.0×10^{12}
$^{16}\text{O}^{8+}$	4.25	6.0×10^{11}
$^{18}\text{O}^{6+}$	2.6	6.0×10^{11}
$^{78}\text{Kr}^{19+}$	1.7	3.0×10^{11}
$^{209}\text{Bi}^{31+}$	0.85	1.2×10^{11}
$^{238}\text{U}^{35+}$	0.835	1.0×10^{11}
$^{238}\text{U}^{78+}$	2.6	1.0×10^{10}



3 GeV → 9 GeV → 20 GeV

- HIAF allows for a multi-dimensional mapping of the Λ polarization and production
- ✓ Beam energy scan
- ✓ pp, pA, AA data taking

Rich Hadron and Heavy-Ion Physics on HIAF



① $pp(A) \rightarrow \Lambda + X$

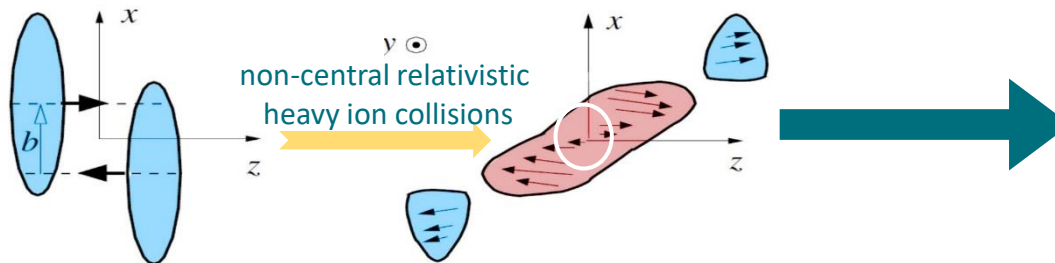
polarization through hadronization

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).

② $pp \rightarrow p + K + \Lambda$

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).

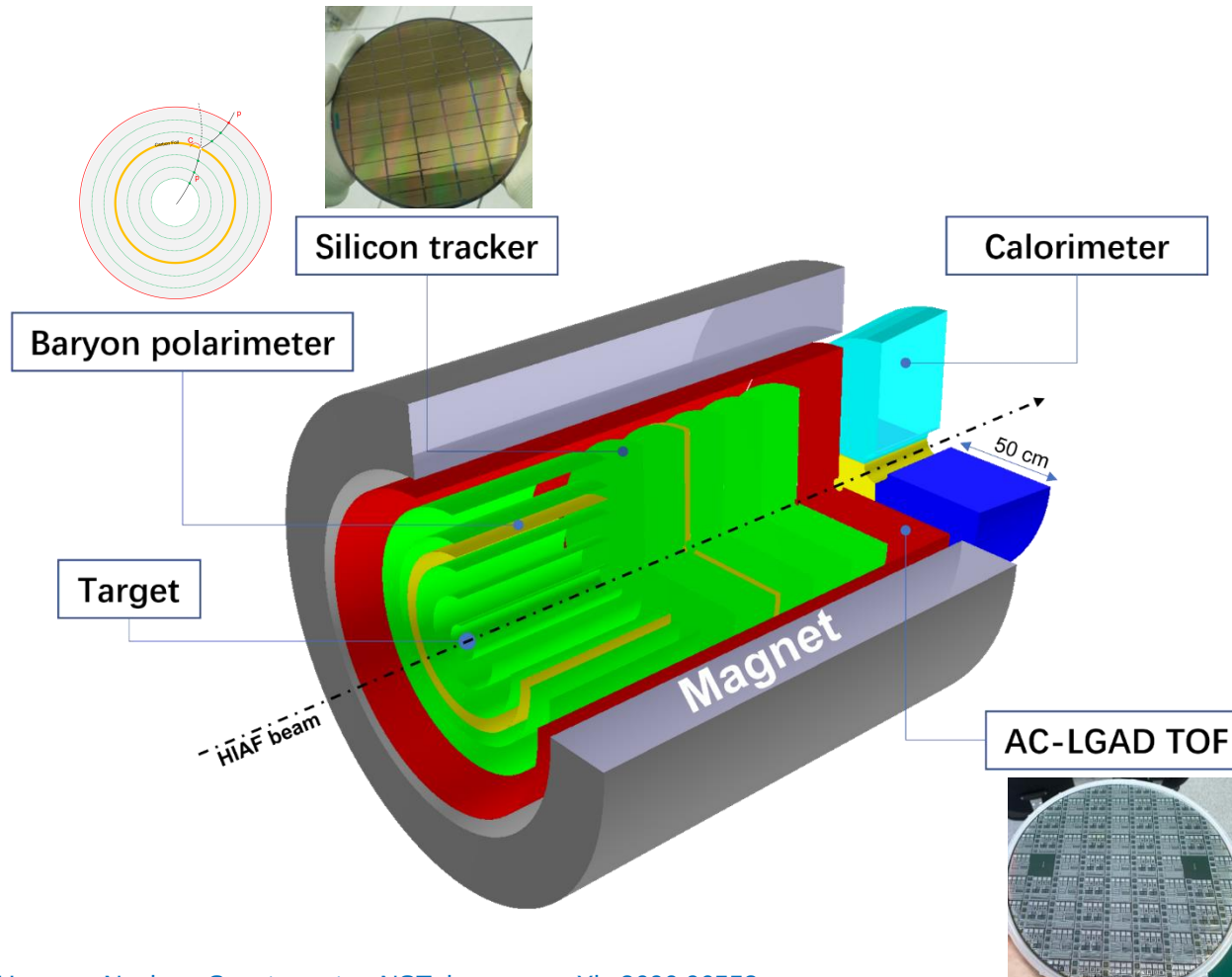


③ $AA \rightarrow \Lambda + X$

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).

Hyperon-Nucleon Spectrometer (H-NS)

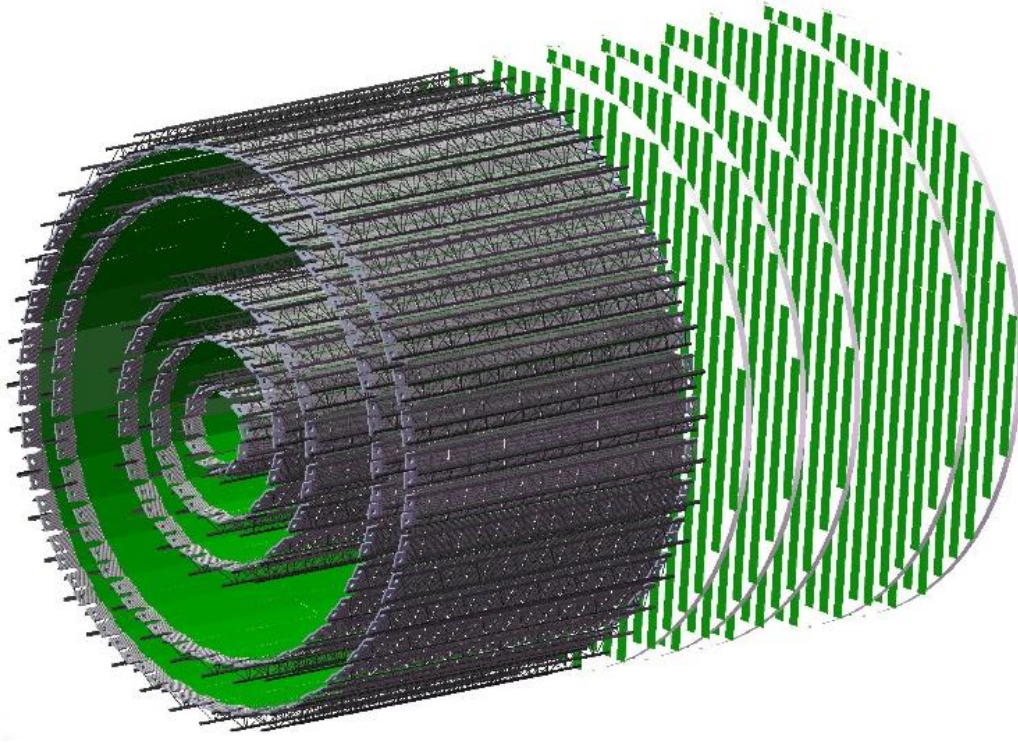


H-NS Detector requirements:

- Large acceptance:
 - 5 to 100 deg
- High event rate:
 - 1MHz (pp / pA)
- Momentum resolution:
 - $\sim 2\%$ @1GeV ($\eta < 2$)
- Vertex resolution:
 - $< 500 \mu\text{m}$
- PID
 - K, π separation ($\sim 3\sigma$) up to 2 GeV/c
 - K, p separation ($\sim 3\sigma$) up to 5 GeV/c
- Baryon Polarization Measurement

Hyperon-Nucleon Spectrometer. NST, in press. arXiv:2606.06553.
Lin, C.-X., Liang, Y.-T., et al. (2026). A novel design of general-purpose spectrometer with nucleon polarimeter function. NST, in press. arXiv:2512.02804.

H-NS 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

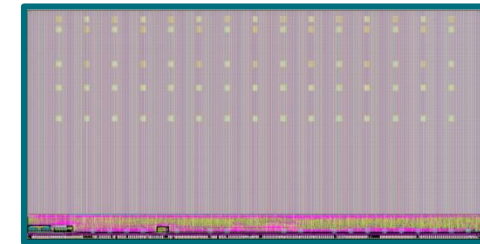
R (cm)	Length (cm)	Pitch Size (μm)	Material Budget (X/X ₀)	Tech.
5.0	42	30	< 0.8%	MIC6
11.0	42	30	< 0.8%	MIC6
17.0	42	30	< 0.8%	MIC6
29.0	42	30	< 0.8%	MIC6
35.0	42	30	< 0.8%	MIC6

➤ 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

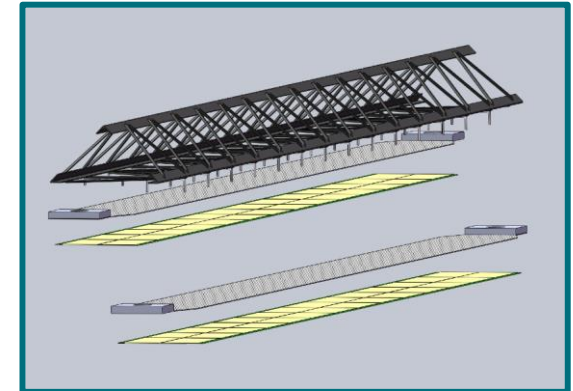
H-NS Silicon Tracker Design

- To achieve momentum resolution ($\sim 2\%$ @ $1 \text{ GeV}/c$) and high SNR in Δ reconstruction, **material budget below $0.8\% X/X_0$ per layer** is required
- ✓ **MAPS-based MIC6 pixel chip:** MIC6-v4 (CCNU), **spatial resolution $\sim 10 \mu\text{m}$** with pixel size $30 \mu\text{m}$, developed and manufactured with the domestic process
- ✓ **Mechanics:** Carbon fiber mechanics, water cooling, low mass flexible PCB
- ✓ **Detector assembly and integration:**
 - Barrel tracker: Stave module design
 - Forward tracker: Ladder module aligned to disk super-module
- ✓ **Readout electronics and DAQ**

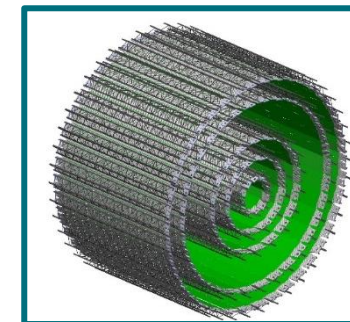


➤ MIC6-v4

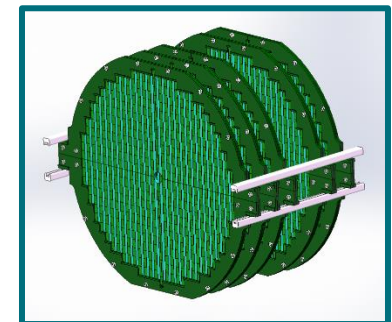
➤ Detector module



➤ Barrels



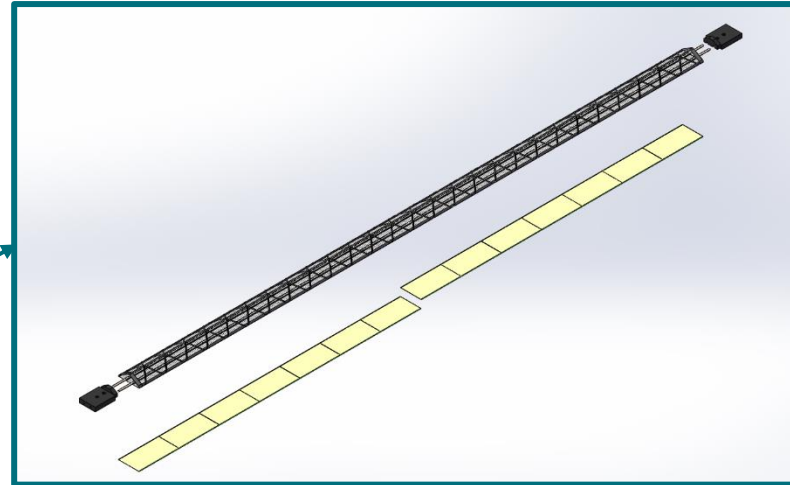
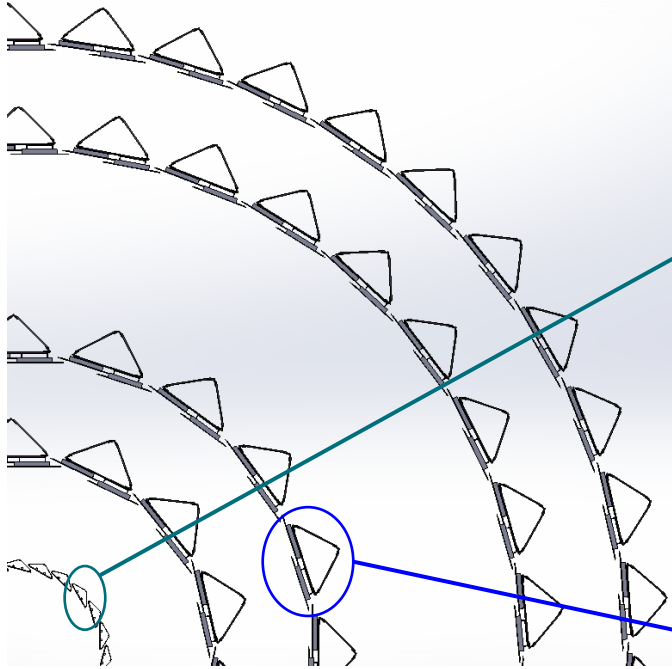
➤ Disks



- 

Barrel Stave Module Design

Designed based on ALICE ITS2 experience

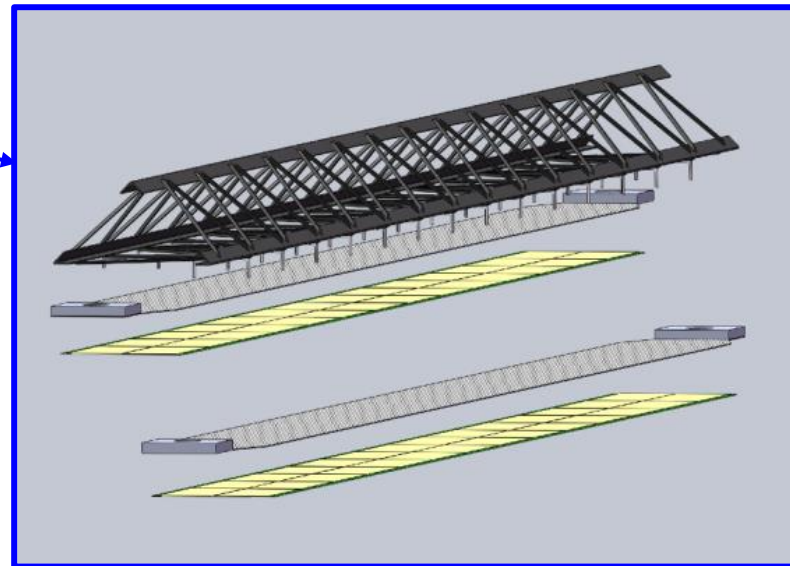


STAVE module:

**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



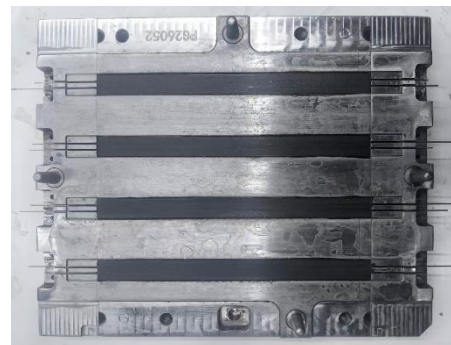
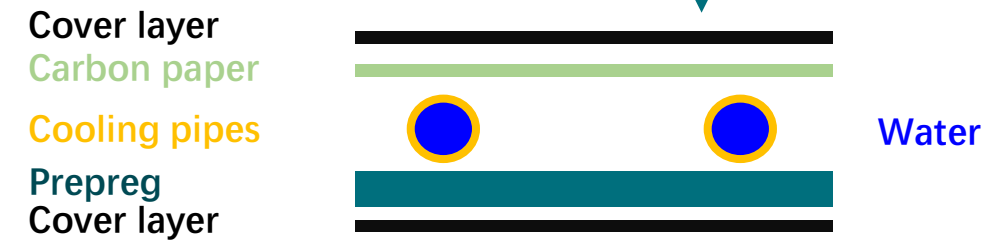
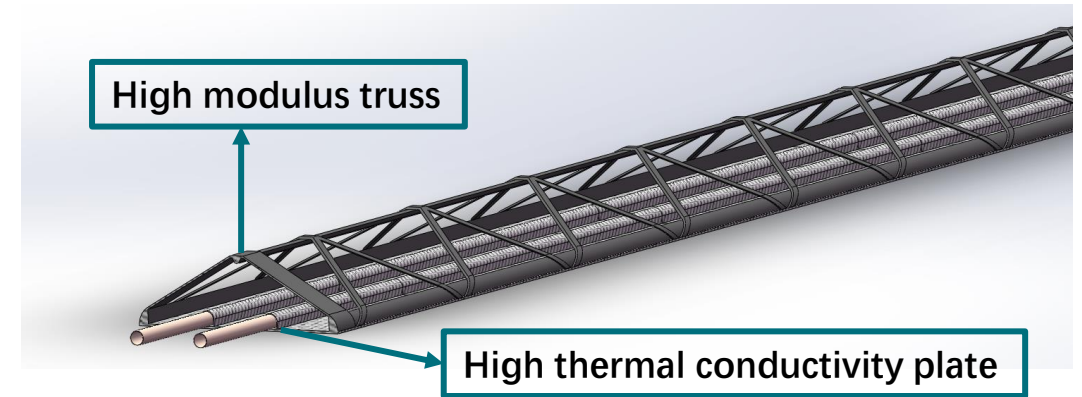
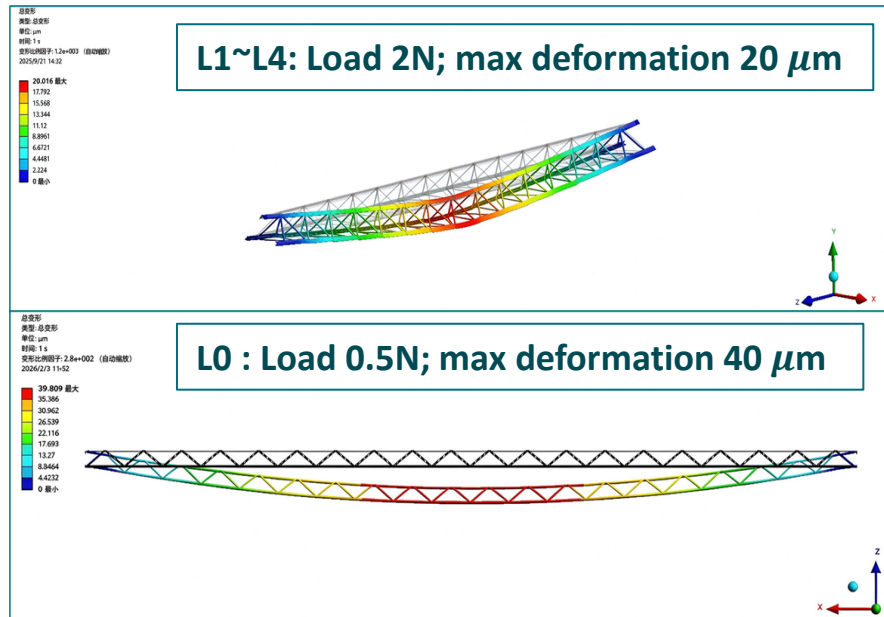
Stave module for the outer 4 layers:

- 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

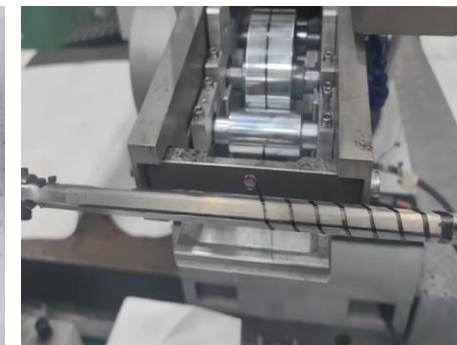
Layer No.	R (cm)	Nr. Of Staves
L0	5.0	24
L1	11.0	14
L2	17.0	20
L3	29.0	34
L4	35.0	42

Mechanical Structure Design and Prototype

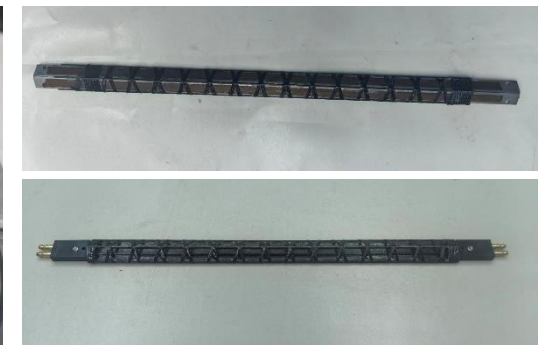
- ✓ FEA simulations were performed based on the material selection and structure, and the mechanical performance of the current design was verified
- ✓ Mature production and processing conditions for the carbon fiber materials and processes required for the stave are currently available domestically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



Cooling tube & plate

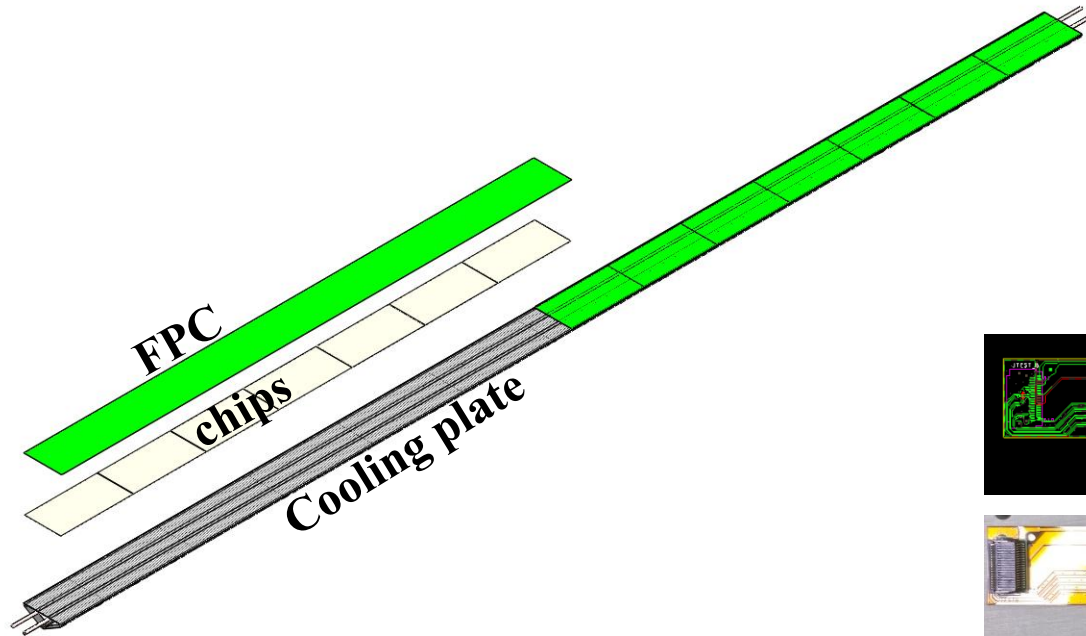


Frame machining

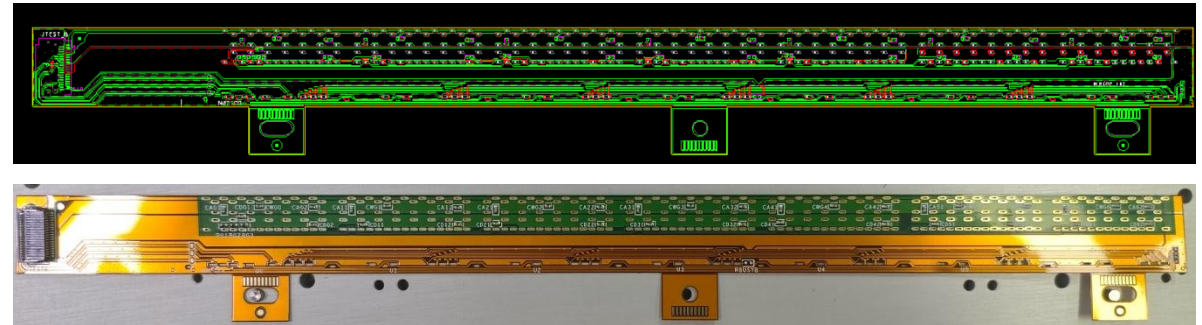


Mechanical Structure prototype

Flexible PCB Design and Prototype



Coverlayer PI 12.5μm
Coverlayer AD 15μm
Copper 18+4μm
Polyimide 75μm
Copper 18+4μm
Coverlayer AD 15μm
Coverlayer PI 12.5μm

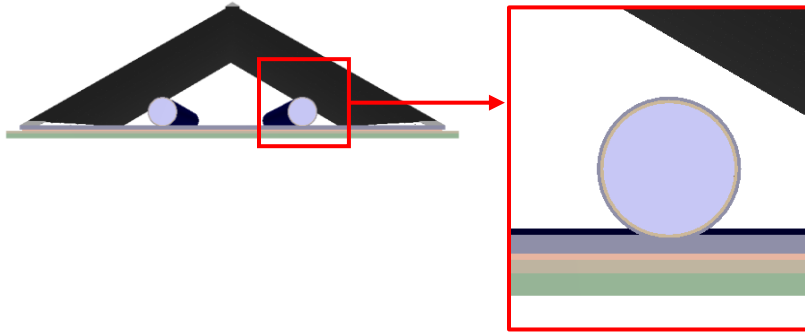


FPC Prototype

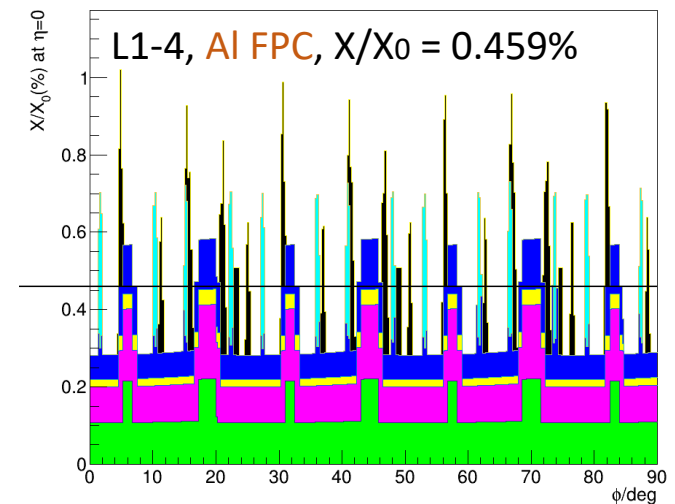
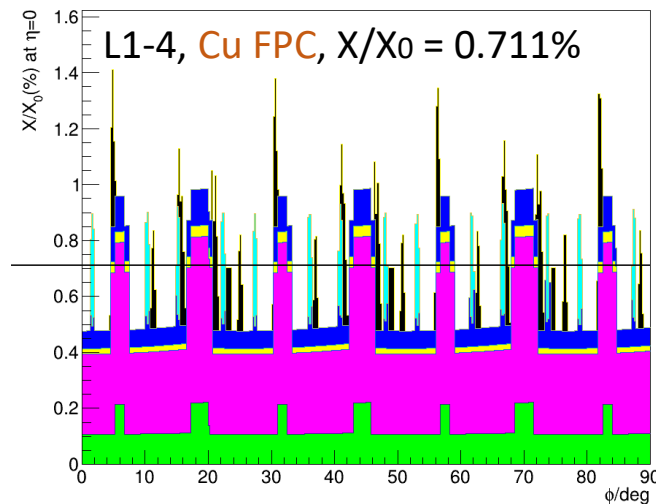
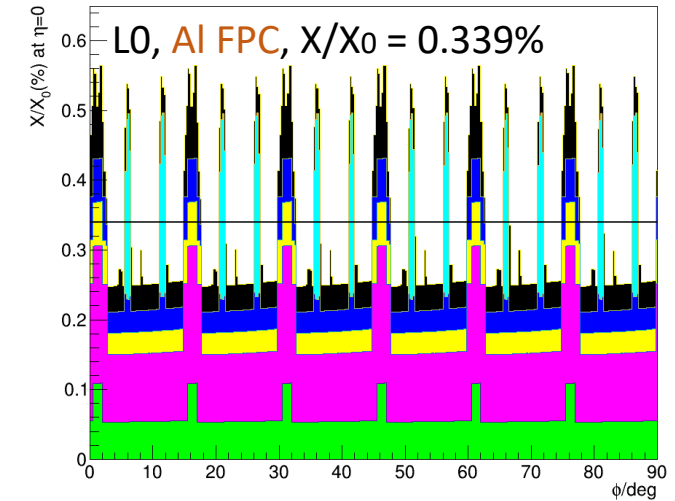
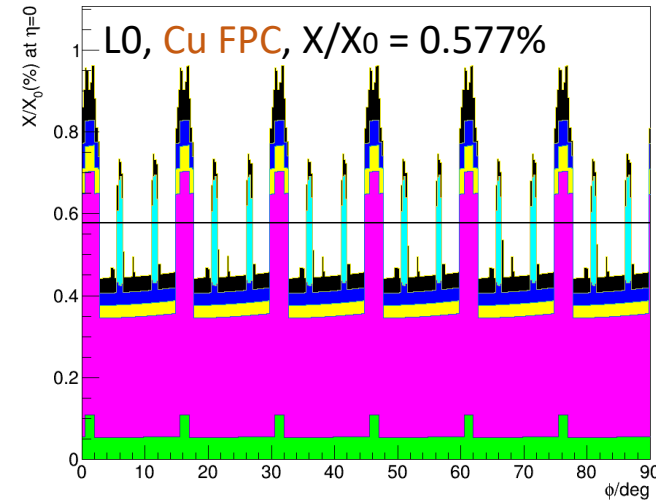
- The Flexible PCB based on the MIC6 chip was designed
- Meeting the requirements of low voltage drop and high-fidelity signal transmission
- The metal layer of the FPC largely determines the detector's material budget
 - Copper: higher material budget, mature fabrication technology
 - Aluminum: lower material budget, but more difficult to fabricate
- Completed the fabrication of the copper-based FPC prototype

Material Budget Simulation

- ✓ Based on Geant4 + DD4hep, simulated single-layer material budget distribution for Cu-based and Al-based FPCs



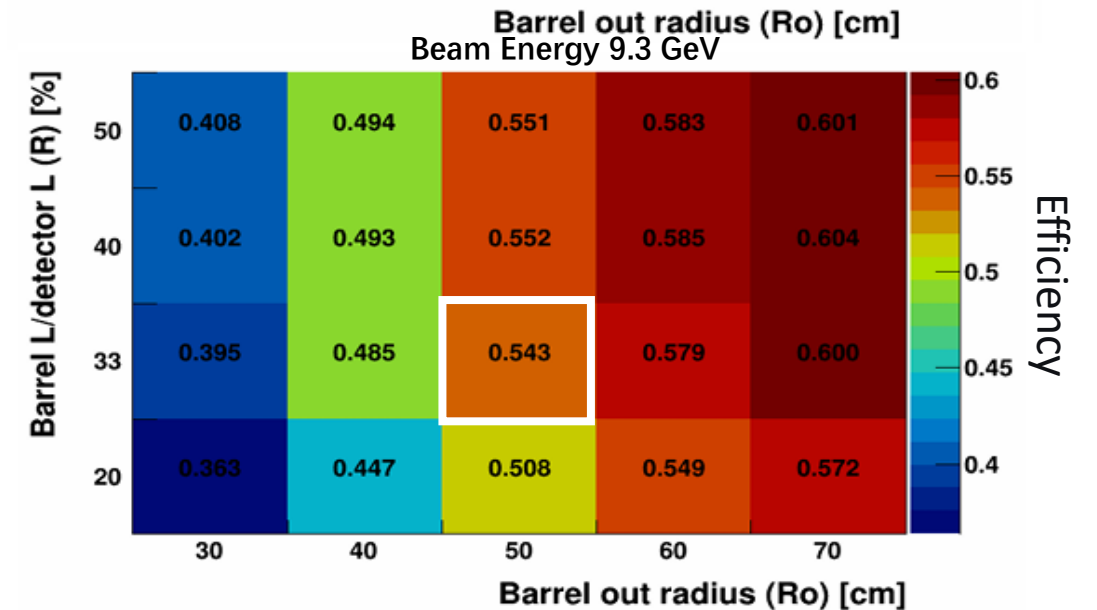
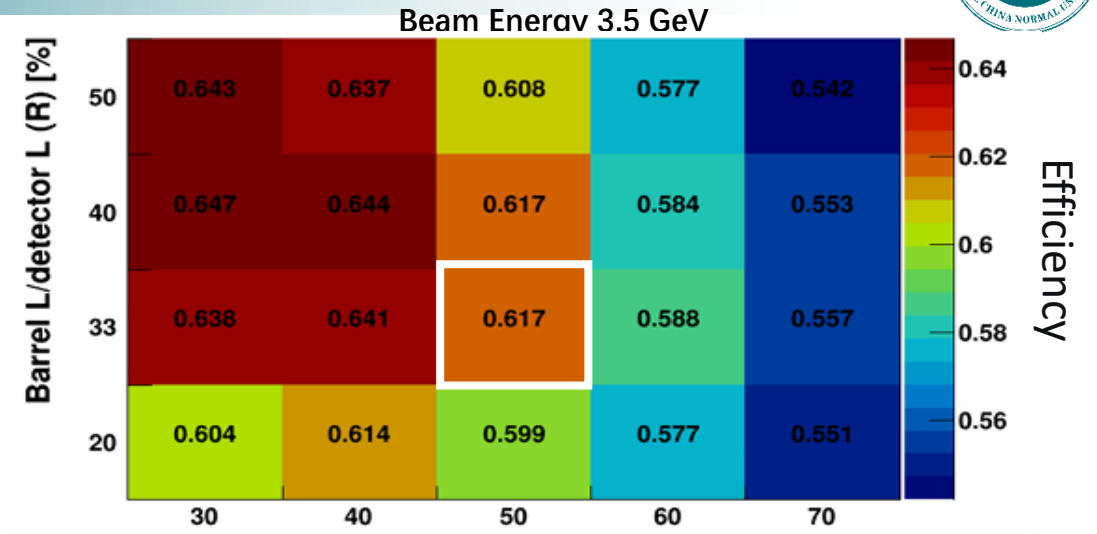
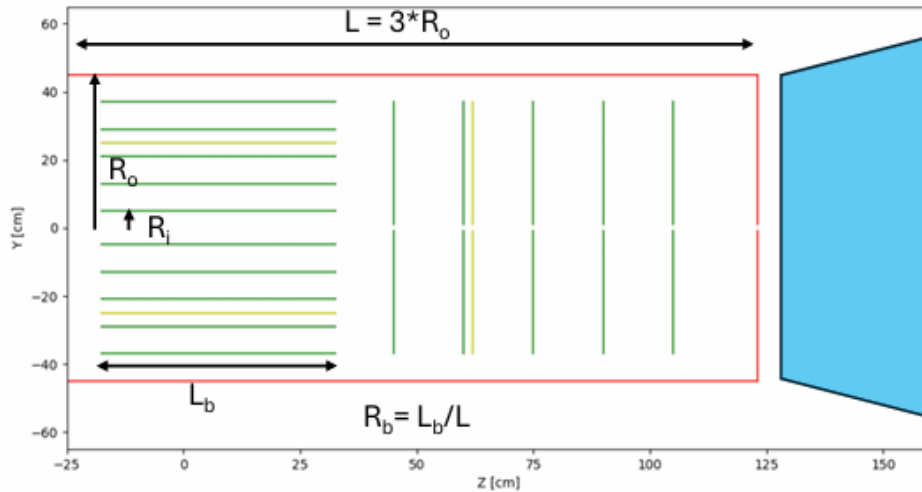
Component	Material
 Frame	Carbon Fiber
 Cooling Tube	Polyimide
 Cooling Plate	Carbon Fiber & Graphite
 Coolant	Water
 MAPS Chip	Si
 Glue	Epoxy
 FPC metal layer	Cu or Al
 FPC non-metal layer	Polyimide & Epoxy



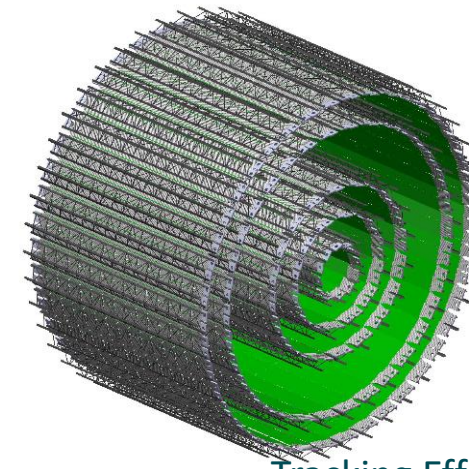
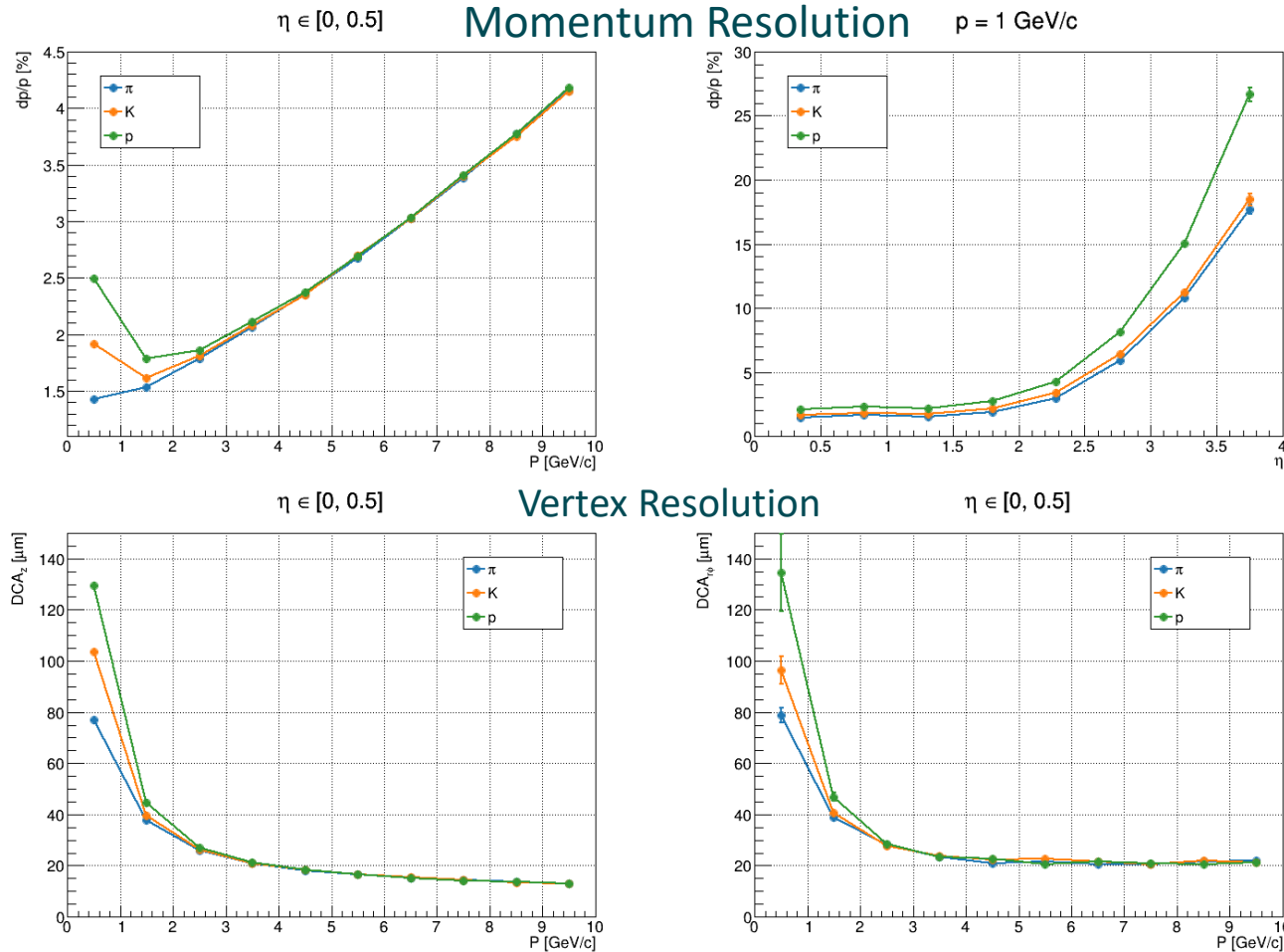
Single-layer material budget distribution along ϕ for the L0 and L1-4 layers with Al/Cu-based FPC ($\eta = 0$)

Performance simulation of MAPS Tracker

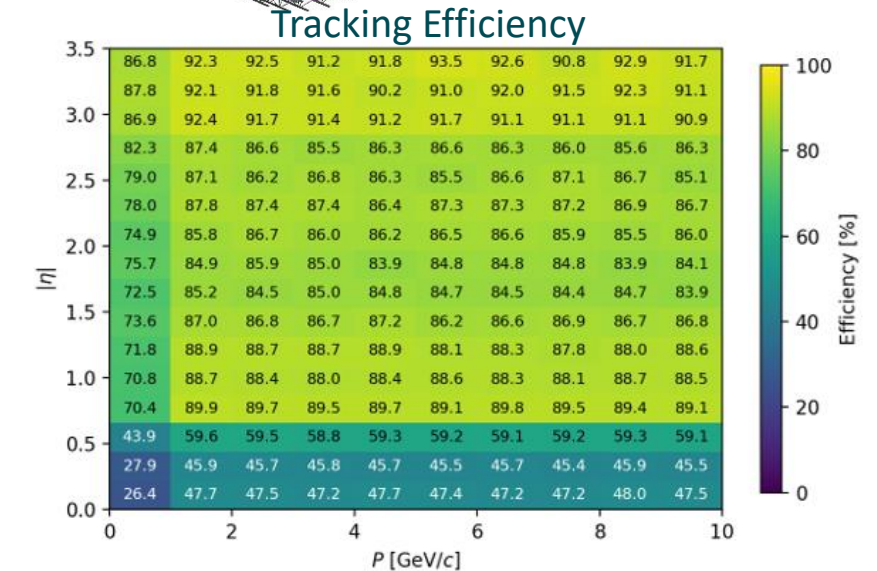
- Simulated tracking detector system(MAPS Tracker & LGAD TOF) performance under different geometric parameters to optimize key performance parameters
- Two parameters considered: outer barrel radius R_o ; barrel fraction along Z, $R_b = L_b/L$
- Simulated Λ hyperon detection efficiency in proton collisions at 3.5 and 9.3 GeV
- **Pluto** generator, 2M $pp \rightarrow pK\Lambda$ events for each configurations
- **Balancing performance and technical feasibility, $R_o = 50$ cm, $R_b = 0.33$ was selected**



Performance simulation of MAPS Tracker



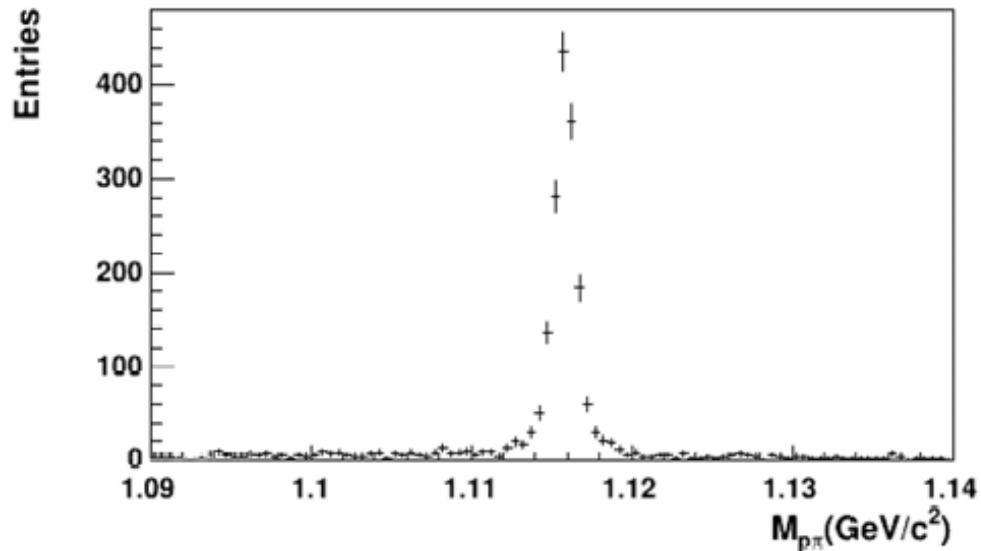
The realistic geometry and material budget of the barrel stave modules were taken into account



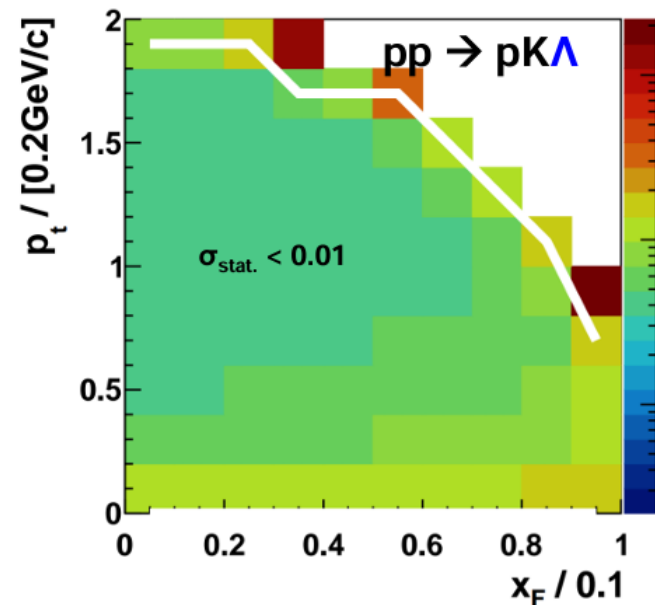
- Generate 1M **single $\pi/K/p$** tracks
- Simulation results show that momentum resolution is around 2% @ 1GeV ($0 < \eta < 2$)
- DCA resolution better than 100 μm @ 1GeV ($0 < \eta < 0.5$)

Physics projection simulation - Λ polarization in pp

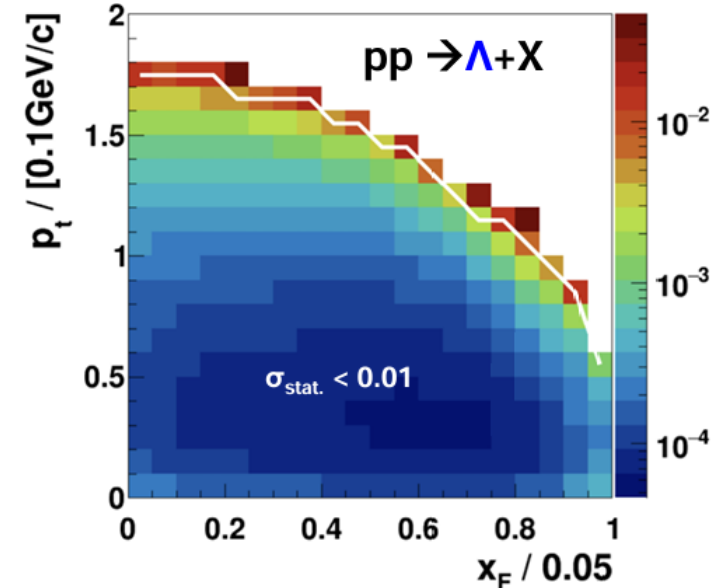
- With the current detector design, Λ has been reconstructed with an extremely low background in $pp \rightarrow pK\Lambda$
- Simulated the measurement precision of Λ polarization in inclusive and exclusive processes at a beam energy of 9.3 GeV.
 - **Pluto** generator for $pp \rightarrow pK\Lambda$ events, **JAM2** generator for $pp \rightarrow \Lambda X$ events
 - Scale 20M events to 10^{10} ($pp \rightarrow pK\Lambda$) & 10^{11} ($pp \rightarrow \Lambda X$) events in total (data will take 3 months from H-NS/HIAF)
 - Uncertainty of the Λ polarization measurement can reach the level of 1%



The Invariant mass spectrum from $pp \rightarrow pK\Lambda$

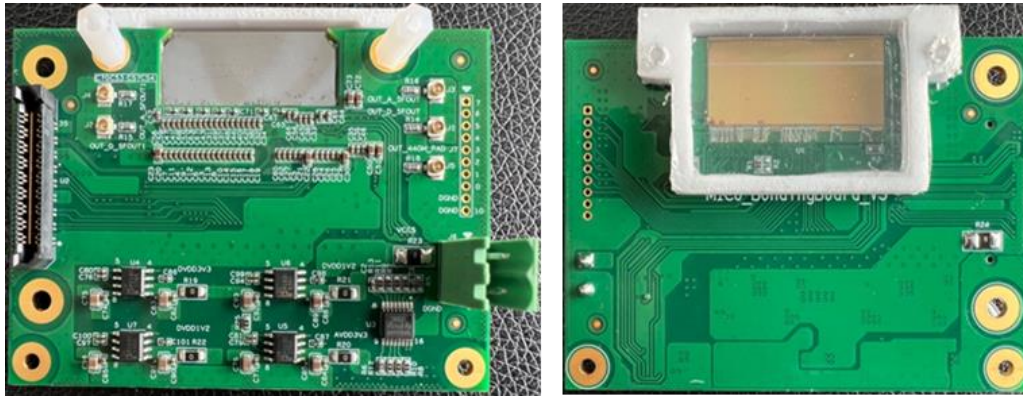


The 2D uncertainty of Λ polarization

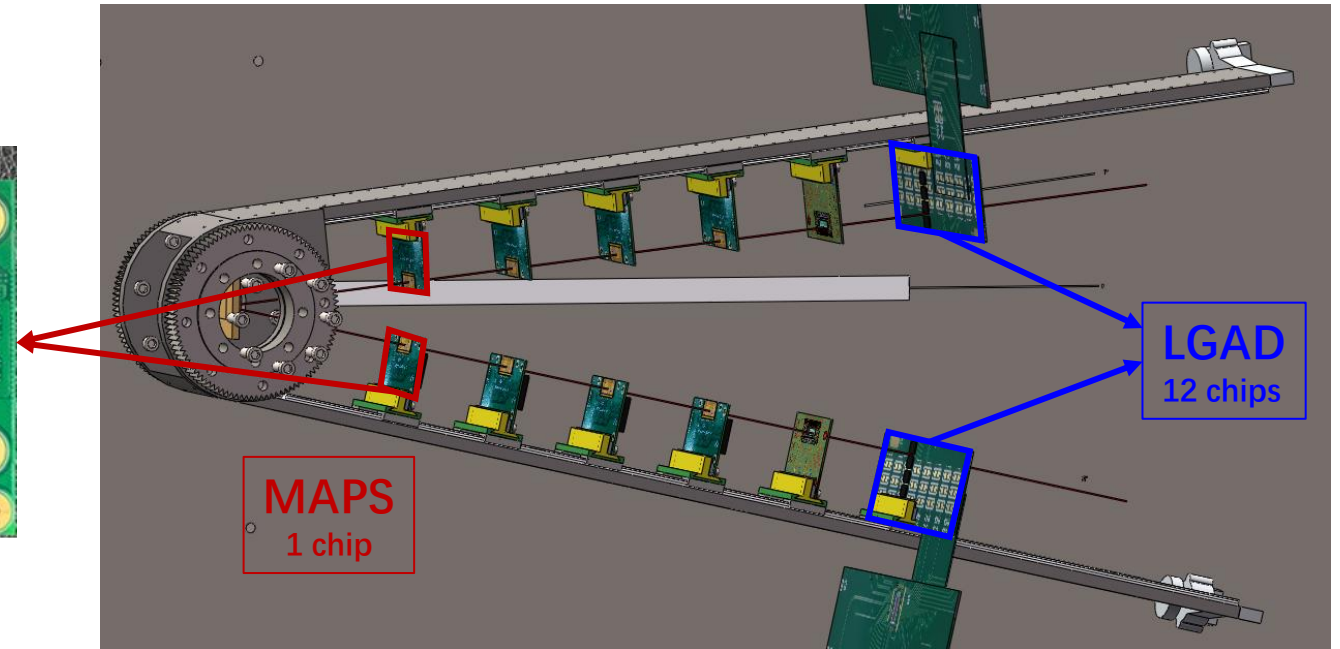


H-NS Prototype (H-NS0)

- To verify the technical feasibility of key detectors in the H-NS tracking system, including MAPS tracking detectors, the prototype H-NS0 was designed
- H-NS0 has a two-arm configuration. Each arm contains 5 MAPS layers and 1 LGAD layer. The opening angle between the two arms is adjustable



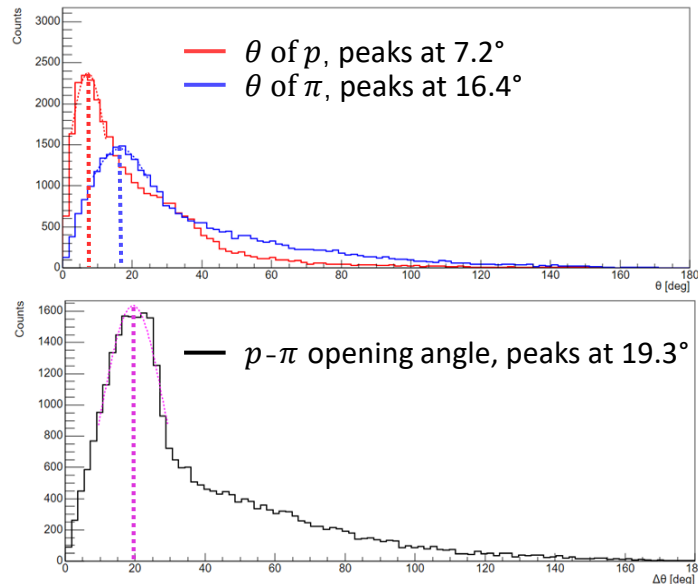
A MAPS Layer: MIC6 chip & Electronics board



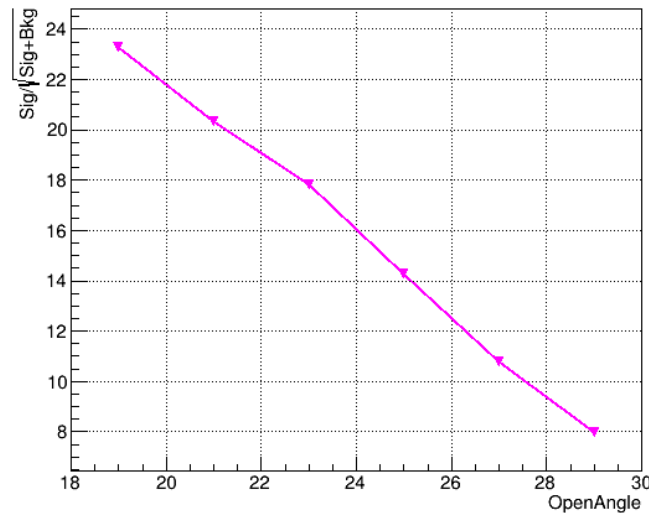
H-NS0 Design

H-NS Prototype (H-NS0)

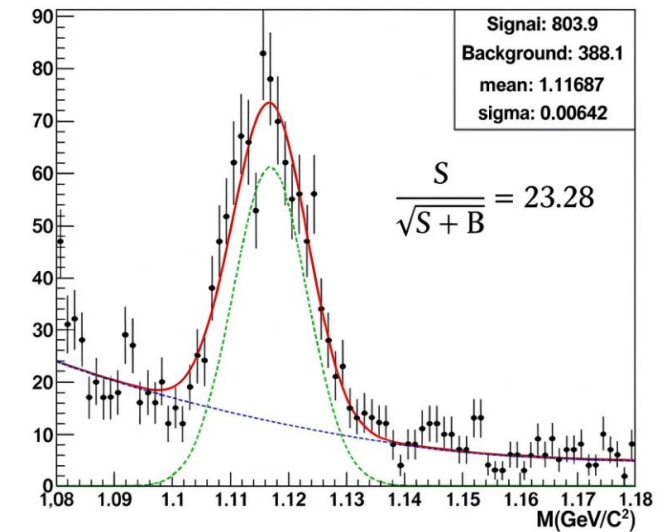
- Simulated the performance of H-NS0 in Λ reconstruction from O+C collision at a beam energy of 2.6 GeV
 - **JAM2** generator for 1B O+C events
 - H-NS0 can reconstruct Λ , Efficiency $\sim 10^{-6}$
 - Consider different arm open angle set, the significance is highest when the two arms make angles of 7° and 12° with the beam line
- A beam test for H-NS0 is planned for later this year



Angular distribution of $p\pi$ from Λ decay @2.6 GeV O+C collisions



Λ significance as a function of detector open angle



The $\Lambda \rightarrow p\pi^-$ Invariant mass distribution from O+C with open angle $7^\circ+12^\circ$

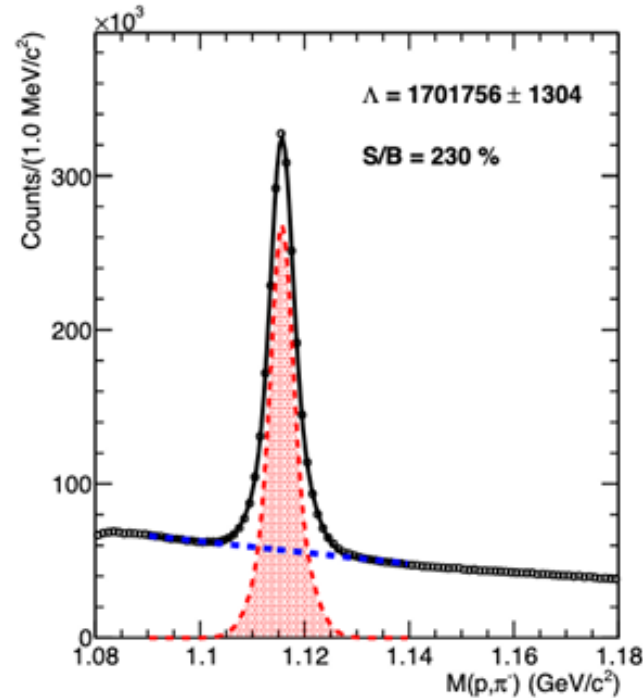
- **H-NS** is a fixed-target spectrometer at HIAF, dedicated to the study of Λ hyperon, proton and light hyper-nucleus polarization in pp, pA and AA collisions
- The H-NS tracker is designed based on MAPS technology, consisting of a 5 layers barrel and 5 layers endcaps, the material budget per layer is less than $0.8\% X/X_0$.
- Geant4 simulation shows that the momentum resolution reaches $2\% @ 1 \text{ GeV } (\eta < 2)$, and the DCA resolution is better than $100 \mu\text{m} @ 1 \text{ GeV } (\eta < 0.5)$ with the current design. The simulation also shows that H-NS can measure Λ polarization with high precision in various processes
- H-NS0 has been designed and initially constructed. The beam test is expected this year

Thank you for your attention !

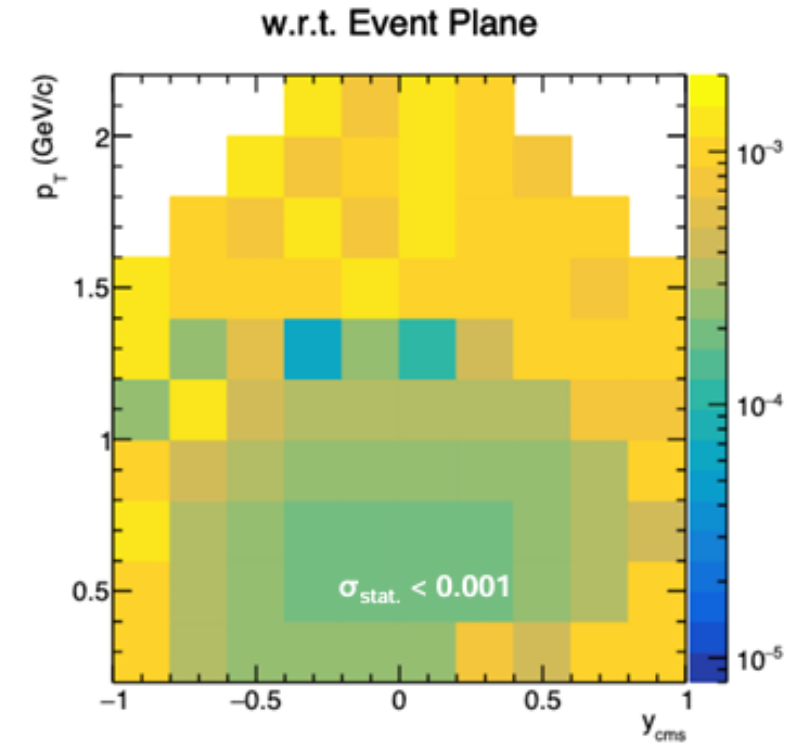
Backup

Physics projection simulation — Λ global polarization in AA

- Simulated the measurement precision of Λ global polarization in Au + Au collision at a beam energy of 2.8 GeV/u
 - **JAM2** generator for Au + Au events
 - Scale 20M events to 10^{11} events
 - uncertainty of the Λ polarization measurement can reach the level of 0.1%
 - Data from H-NS will take a few weeks



The Invariant mass spectrum from Au+Au

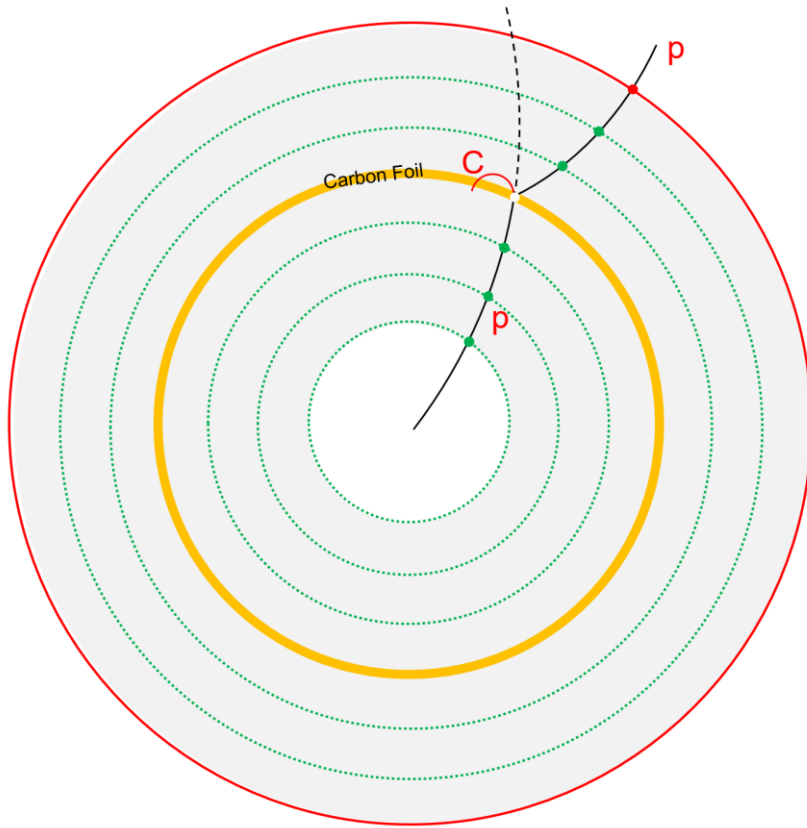


Λ polarization uncertainty w.r.t. eventplane

How to detect proton polarization

Determining proton polarization via elastic scattering

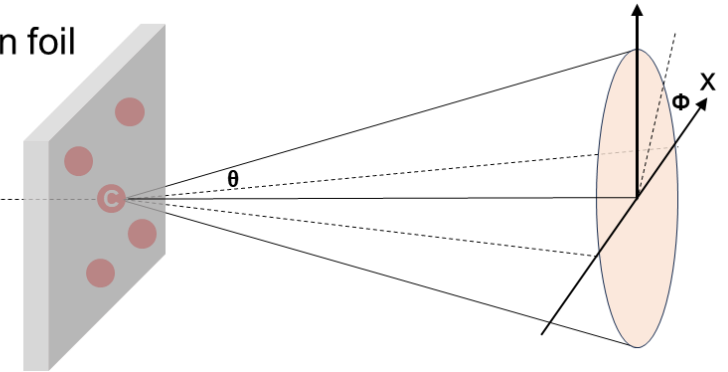
$$\frac{d\sigma}{d\phi d\cos\theta} = \frac{1}{2\pi} \frac{d\sigma_0}{d\cos\theta} [1 + \underline{P_y A_N(\theta)} \cos\phi]$$



Transversely
polarized protons



Carbon foil



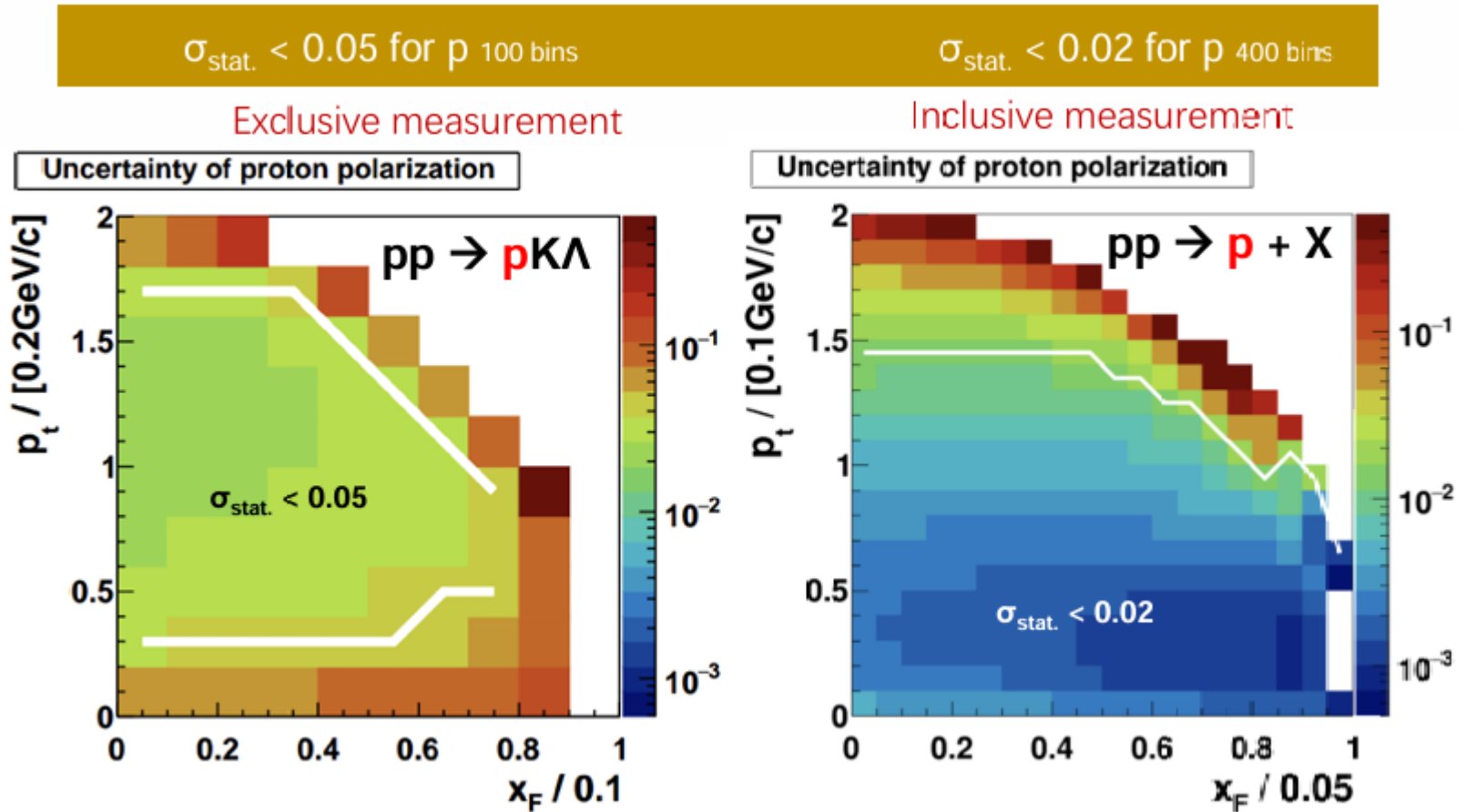
- The carbon film is located between the 3rd and 4th MAPS layers
- The first 3 MAPS layers determine the proton track before scattering
- The last 2 MAPS layers together with the LGAD determine the proton track after scattering

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

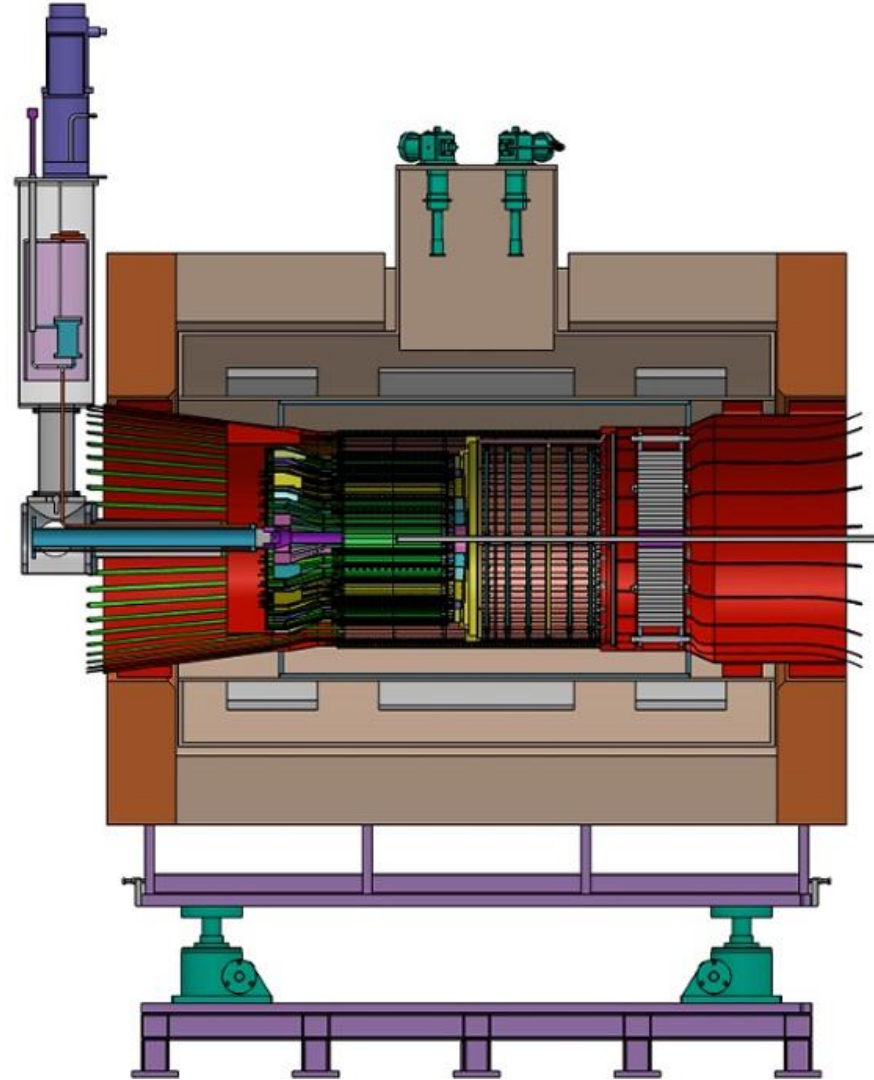
Physics projection simulation - proton polarization in pp

- Simulated the measurement precision of proton polarization in inclusive and exclusive processes at a beam energy of 9.3 GeV

- **Pluto** generator for $pp \rightarrow pK\Lambda$ events, **JAM2** generator for $pp \rightarrow pX$ events
- Scale 20M events to $10^{10}/10^{13}$ events
- Uncertainty of the Λ polarization measurement can reach the level of 2%/5%
- Data from H-NS will take 3 months

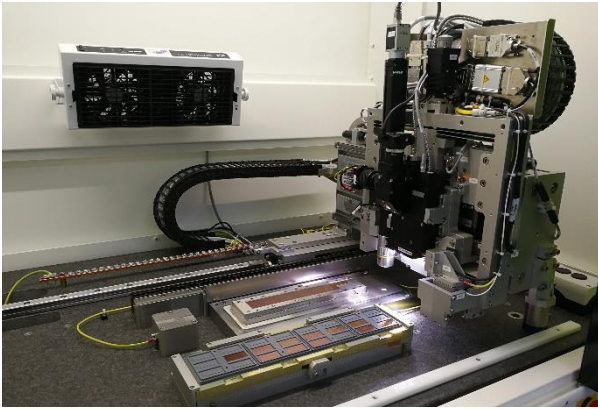


Mechanical Structure for H-NS

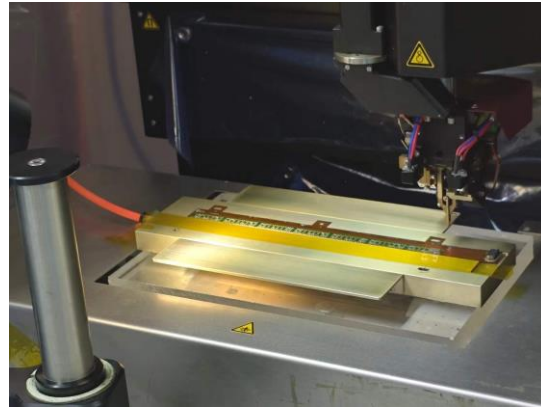


Detector assembly and testing system

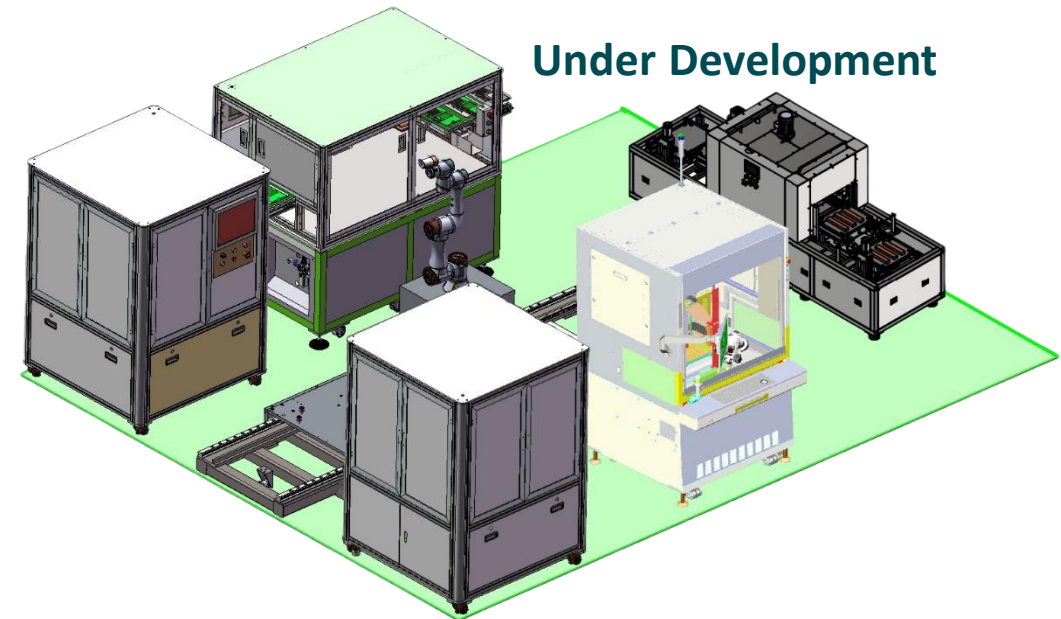
- Assembly and testing of chip modules: achieving chip integration precision within 5 μm for silicon pixel detectors
- Realizing high-precision ultrasonic bonding, with the pull strength of the bond wires meeting the requirements for operation in strong magnetic fields
- Used for ALICE/ITS2, NICA, etc.
- Based on the existing system, a new-generation automated assembly and testing system is under development. It will enable fully automated assembly and testing for chips/modules of different sizes, greatly improving mass-production efficiency



ALICIA at CCNU



Bonding machine



Under Development

Automated assembly & testing system