Hyperon-Nucleon Spectrometer at HIAF

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Acknowledgement: Inputs from Aiqiang Guo, Yutie Liang, Nu Xu and Zhe Zhang

Outline

- Introduction of physics
- H-NS at HIAF
- Summary and Outlook

Spin, Chirality, helicity

“Experiments with spin have killed more theories in physics, than any other single physical variable”

Elliot Leader

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

Zeitschrift für Physik C Particles and Fields

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

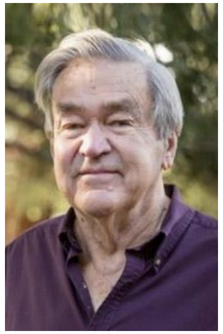
E. Leader[1] and M. Anselmino[2]

Birkbeck College, University of London, London, UK

Dipartimento di Fisica Teorica, Università di Torino, I-10125 Torino, Italy

Received 18 March 1988

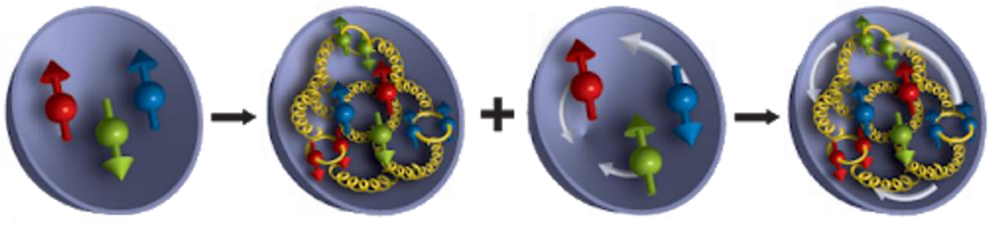
“If theorists had their way, they would ban all experiments involving spin”



James D. Bjorken

About nucleon spin structure

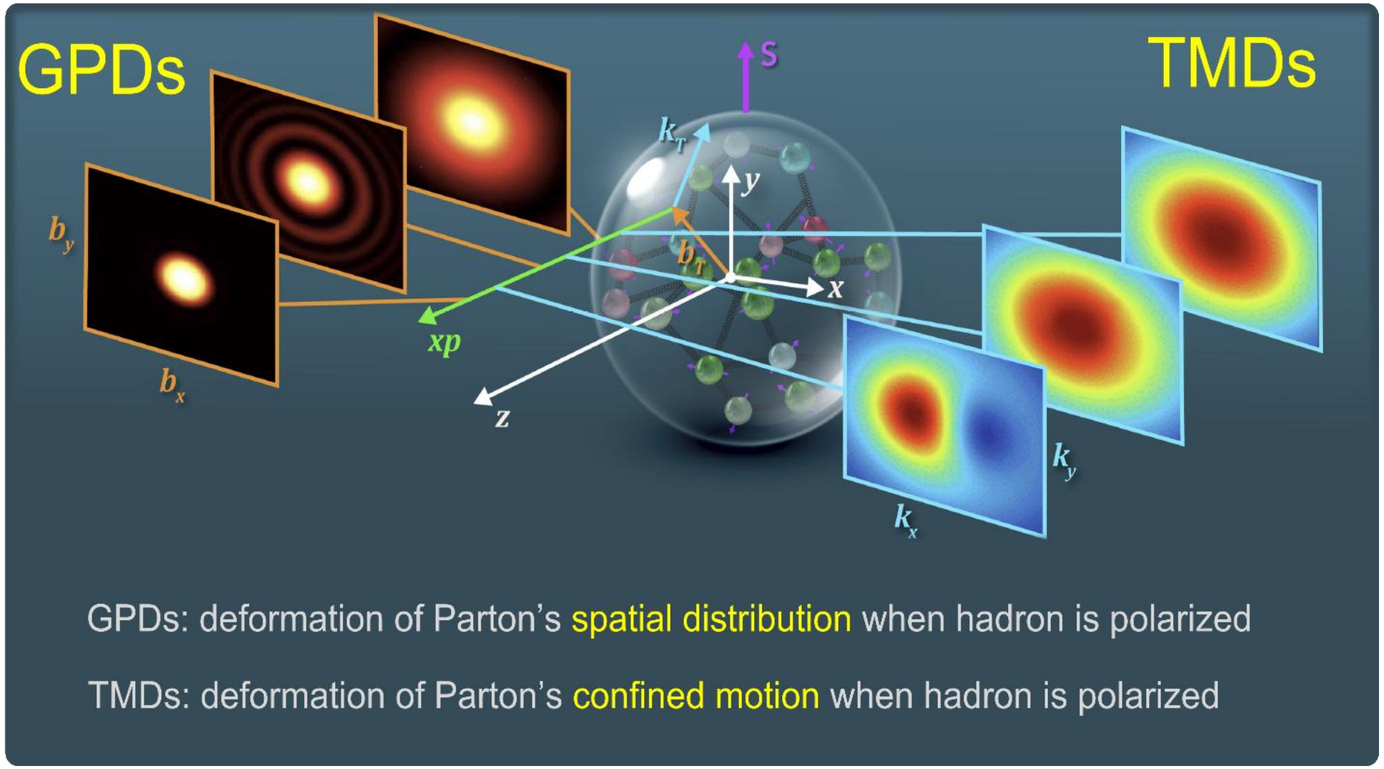
1988 EMC experiment → "Spin crisis"



1970s 1980s/2000s Now

Spin decomposition:

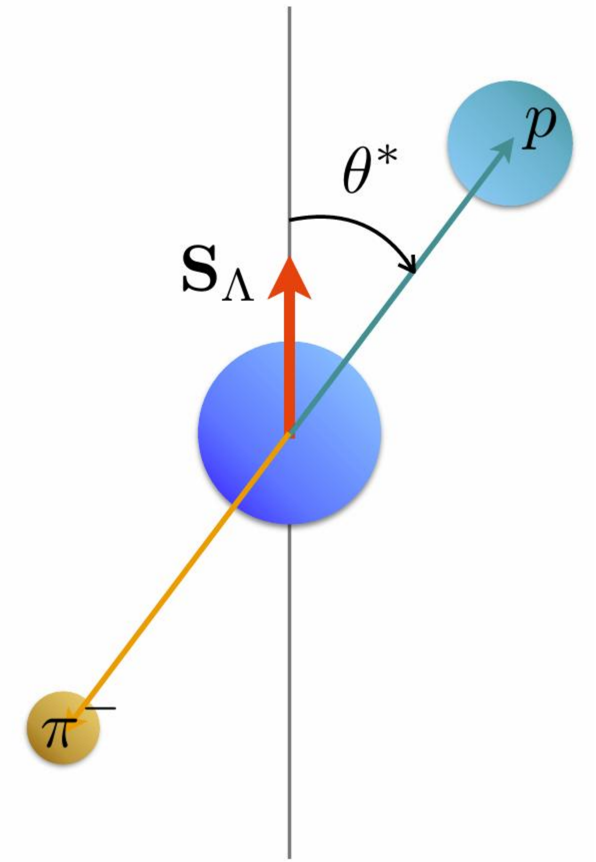
$$S_{tot} = \frac{1}{2} = \underbrace{\frac{1}{2}\Delta\boldsymbol{\Sigma}}_{\text{Quark spin}} + \underbrace{\Delta\boldsymbol{G}}_{\text{Gluon Spin}} + \underbrace{\boldsymbol{\mathcal{L}}_{q}}_{\text{Quark OAM}} + \underbrace{\boldsymbol{\mathcal{L}}_{g}}_{\text{Gluon OAM}}$$



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

A new domain: from nucleon to hyperon

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

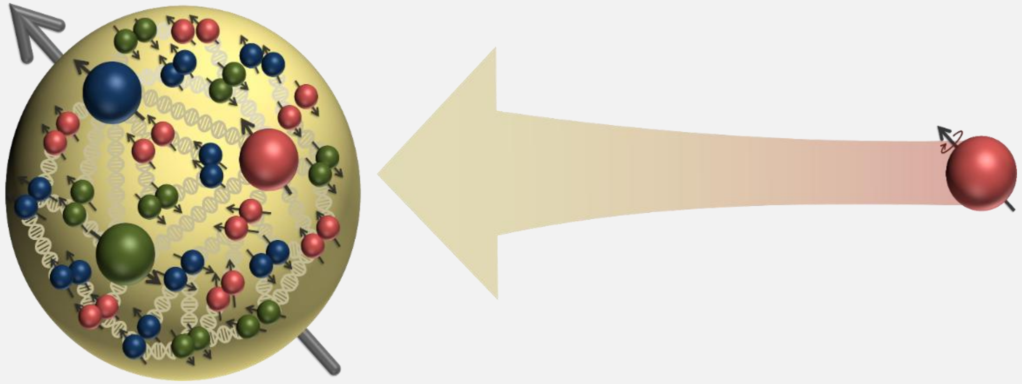
$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} \propto \mathcal{A}\left(1 + \alpha_\Lambda P_\Lambda \cos\theta^*\right)$$

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

[Current PDG value]

-What is the origin of Λ polarization?
-What is the link between Λ spin structure and polarization?

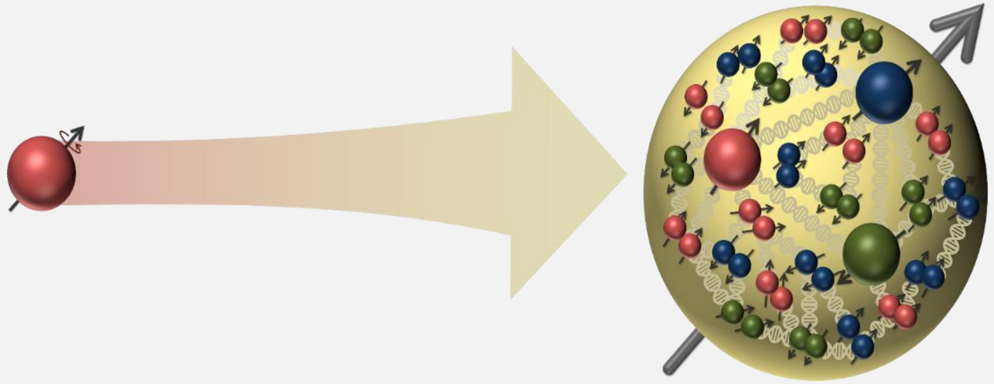
EIC: **Initial state** is polarized
-How do partons form up a polarized nucleon?



Initial state

Polarized by device

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

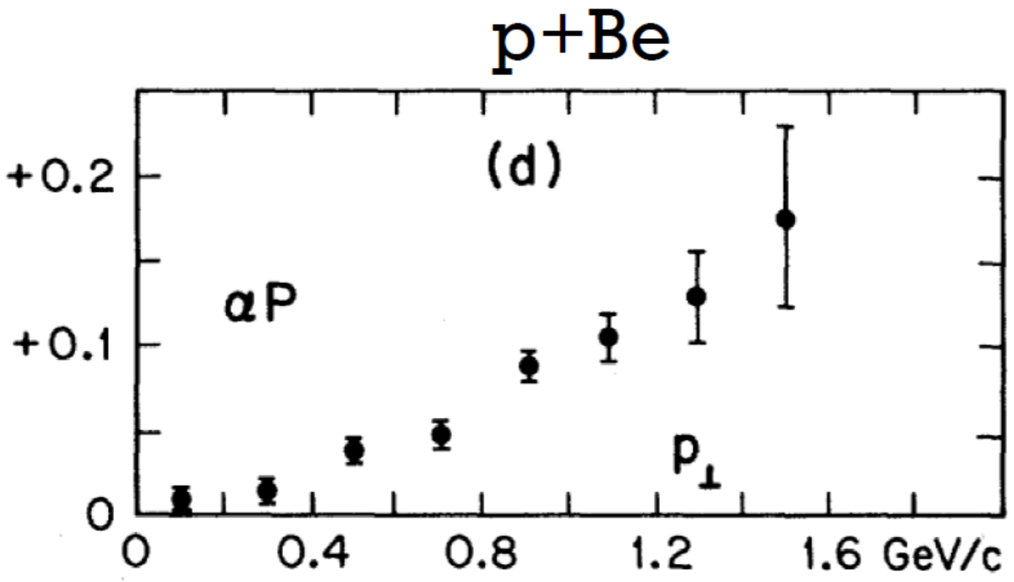


Final state

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

origin of nucleon spin VS origin of Λ polarization

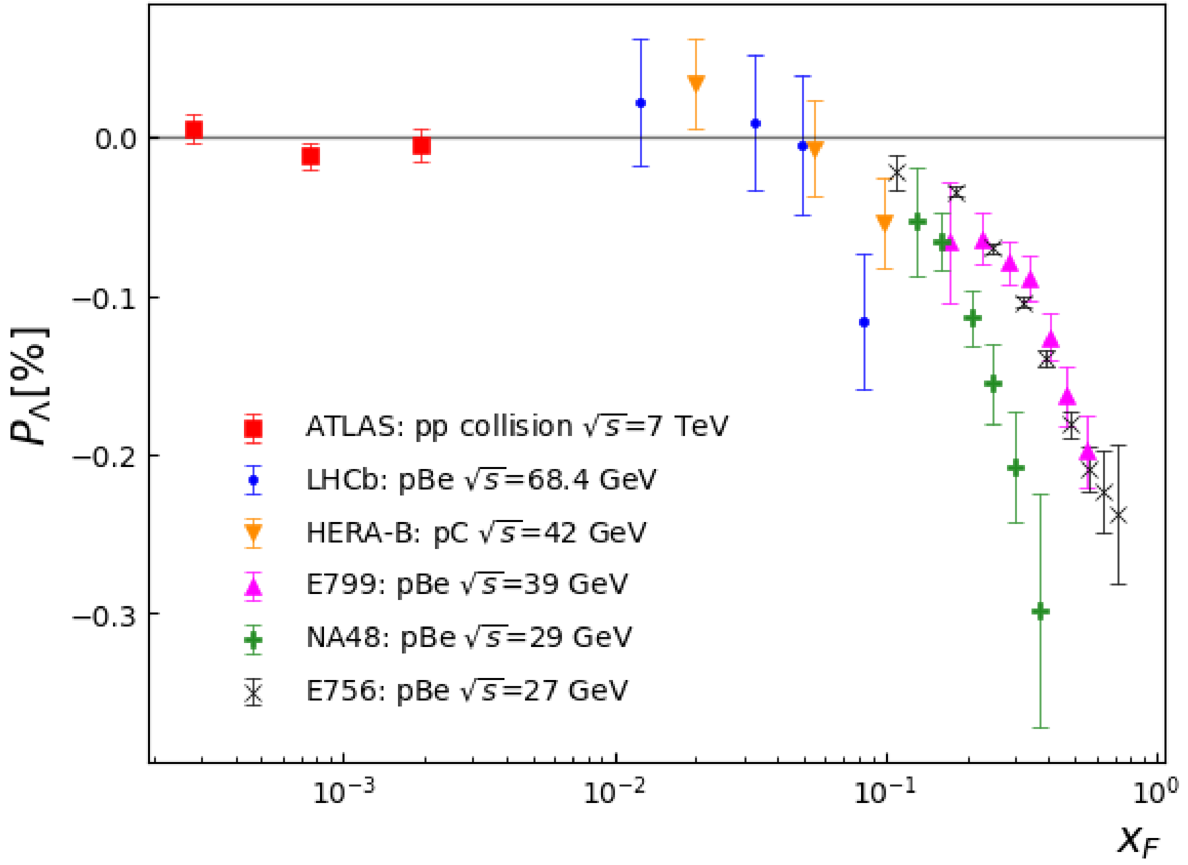
First observation of Λ^0 polarization in the 1970's

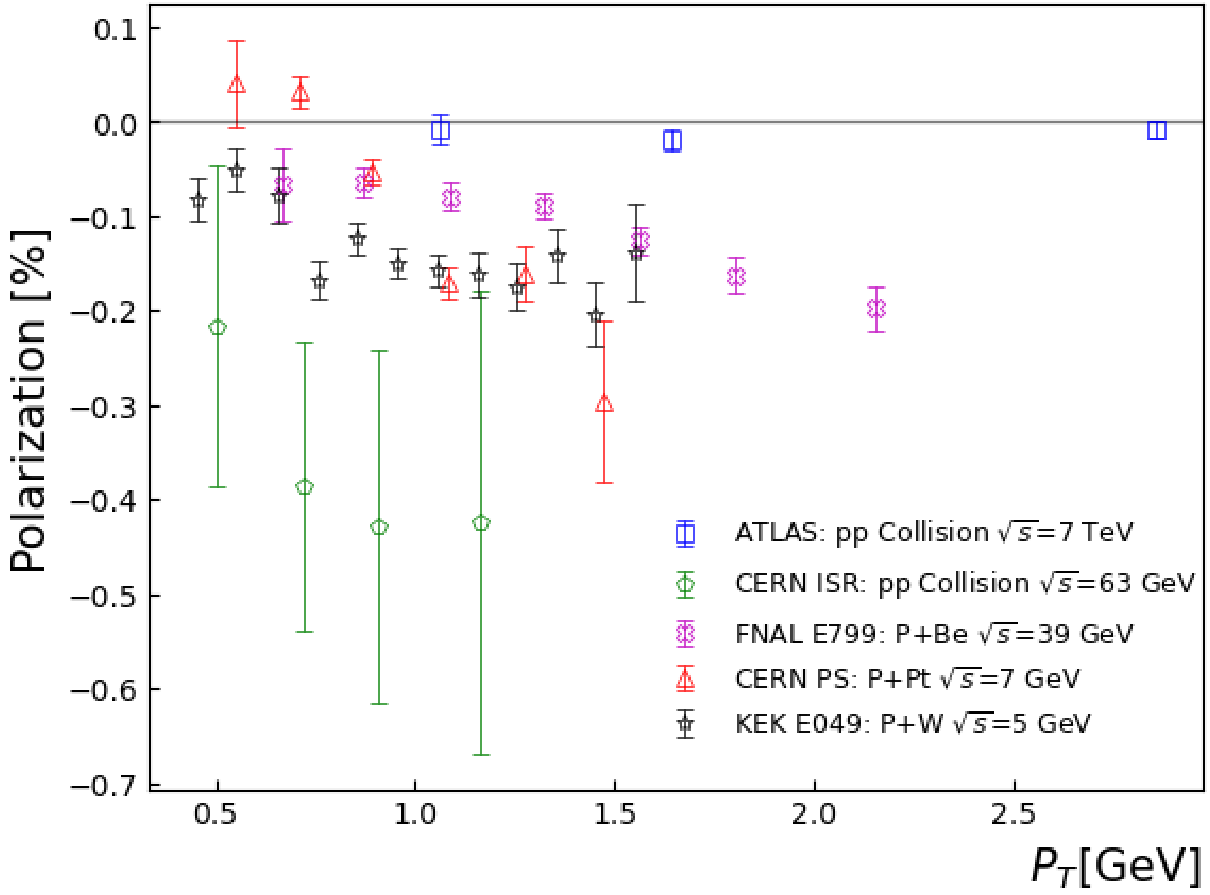


G.Bunce, *et al*.: Phys.Rev.Lett. 36, 1113-1116 (1976)

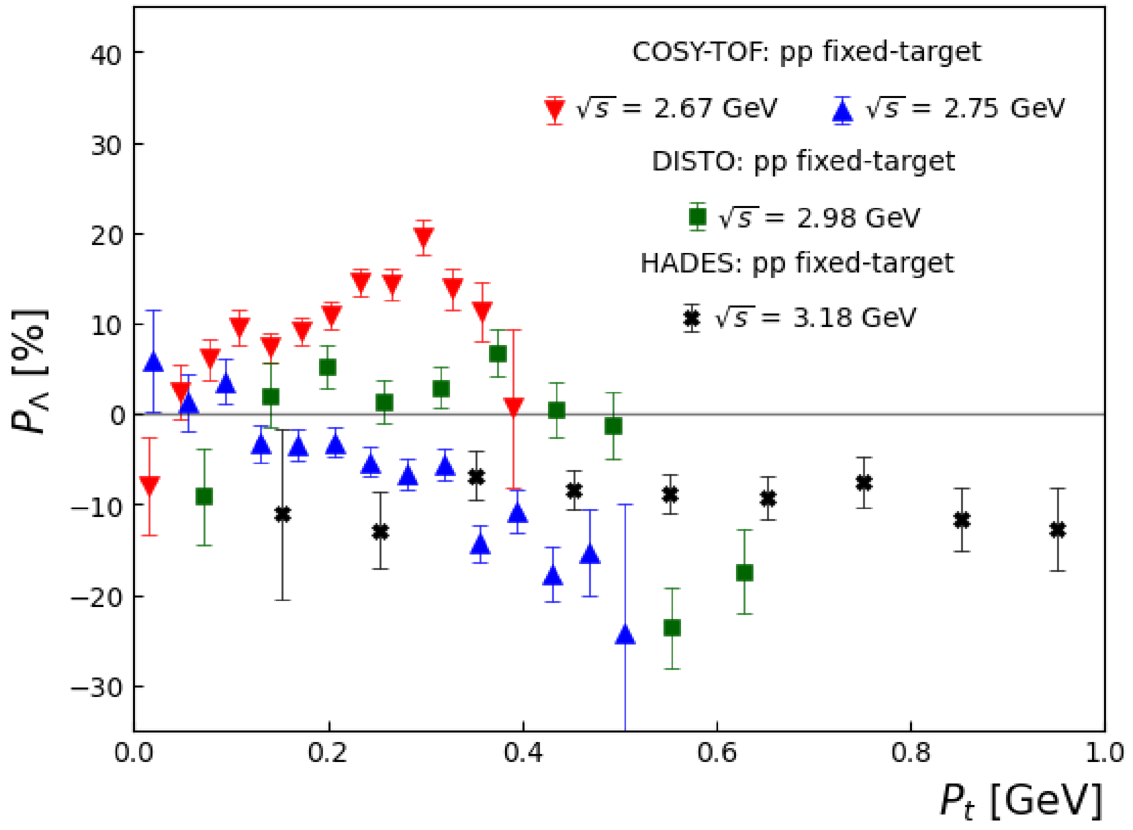
- Hyperons can be produced polarized in collisions of elementary particles
- Discovered at Fermilab in the 1970's in p + Be collisions: 300 GeV protons on Beryllium

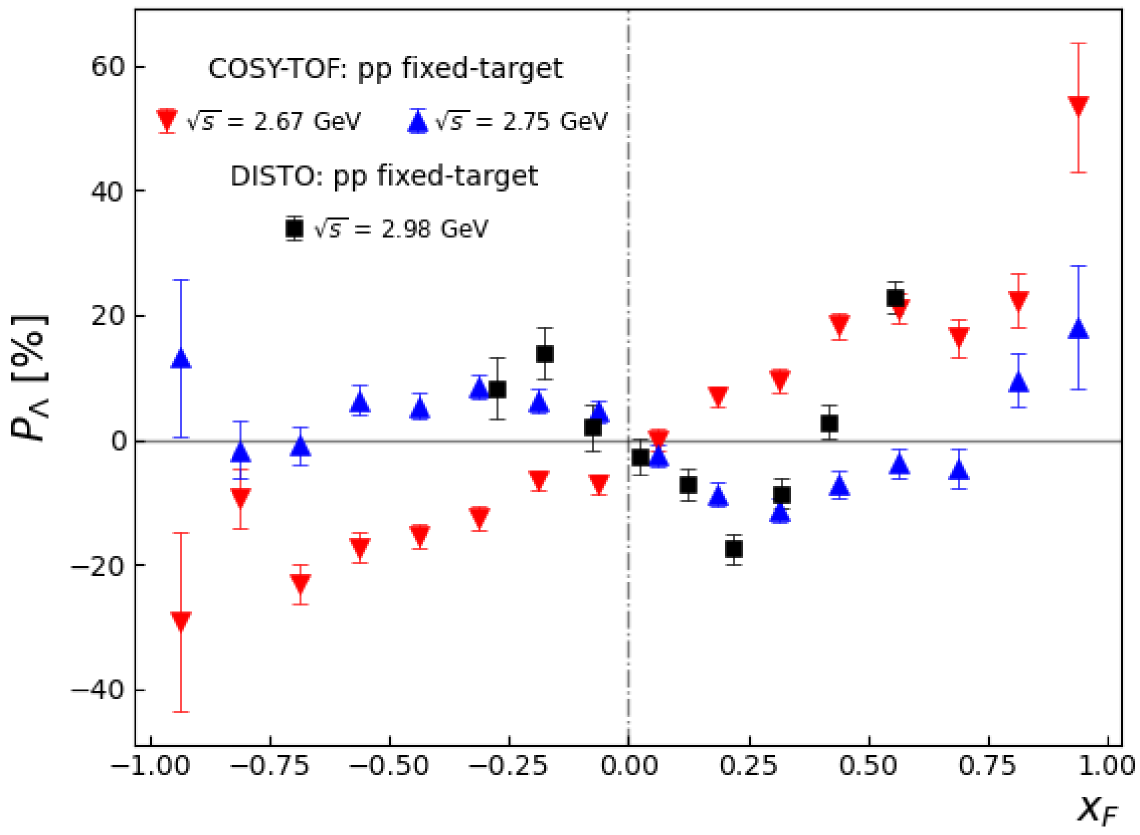
Λ^0 polarization measurements



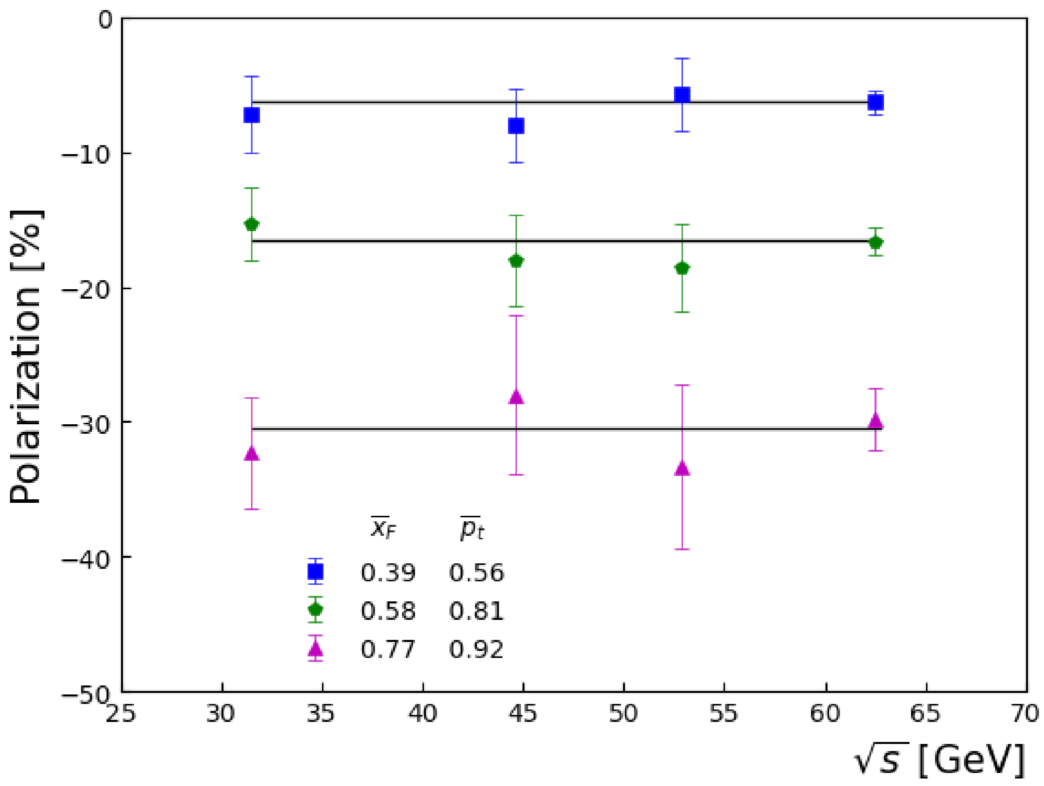


Puzzle in low energy collisions

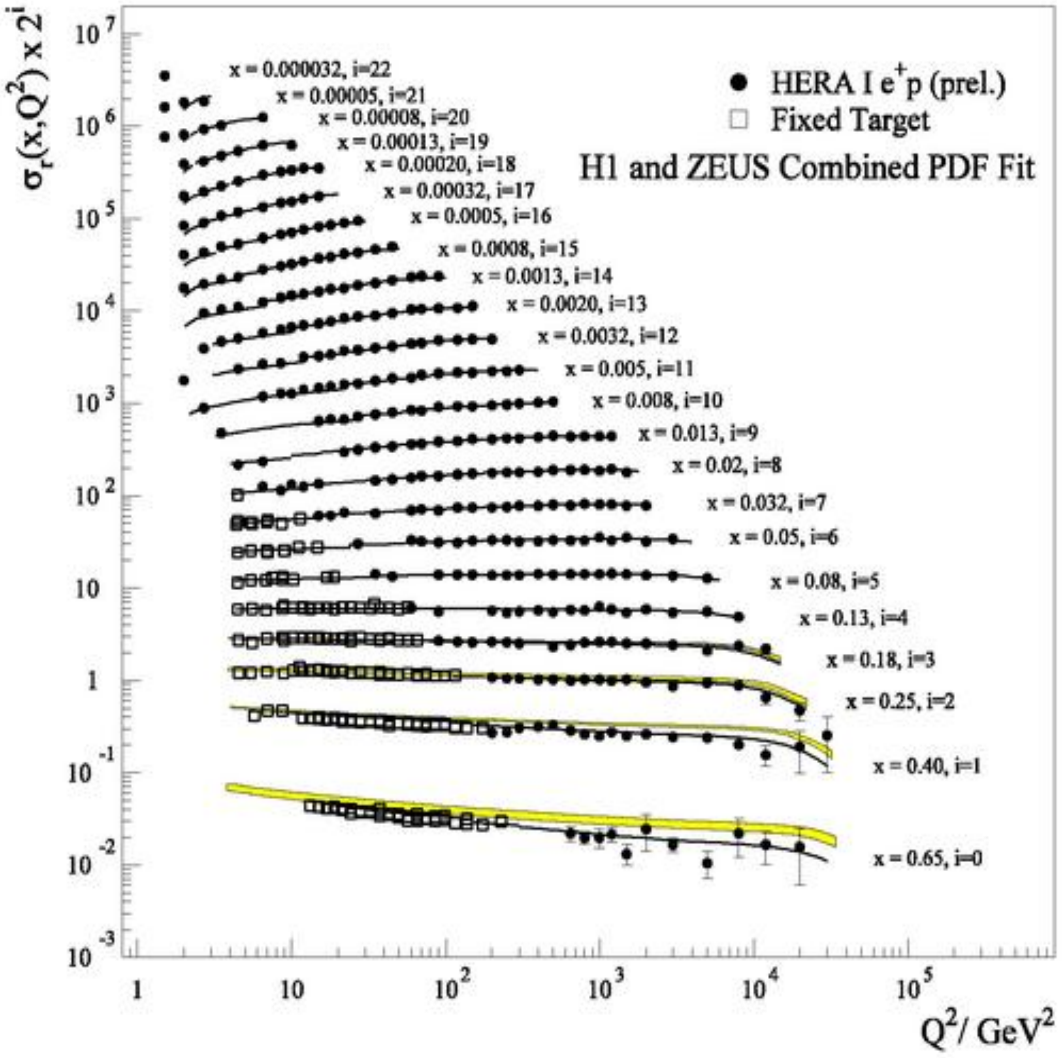




"Scaling" of Λ^0 polarization ?

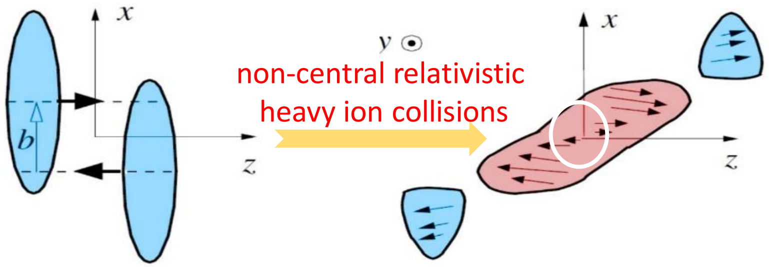


R608: 10.1016/0370-2693(87)91556-5



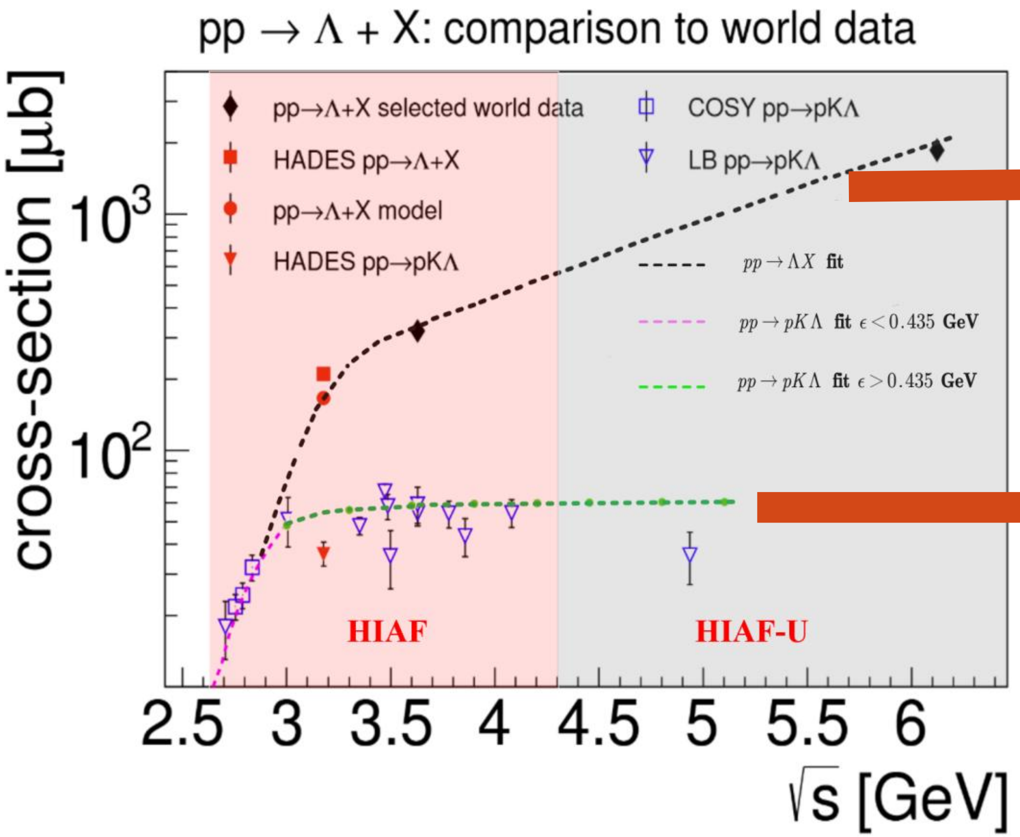
One has to take into account the production mechanism

- across energy region and collision system



① $AA \to \Lambda X$ **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).



② $pp\,(A) \to \Lambda X$ **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).

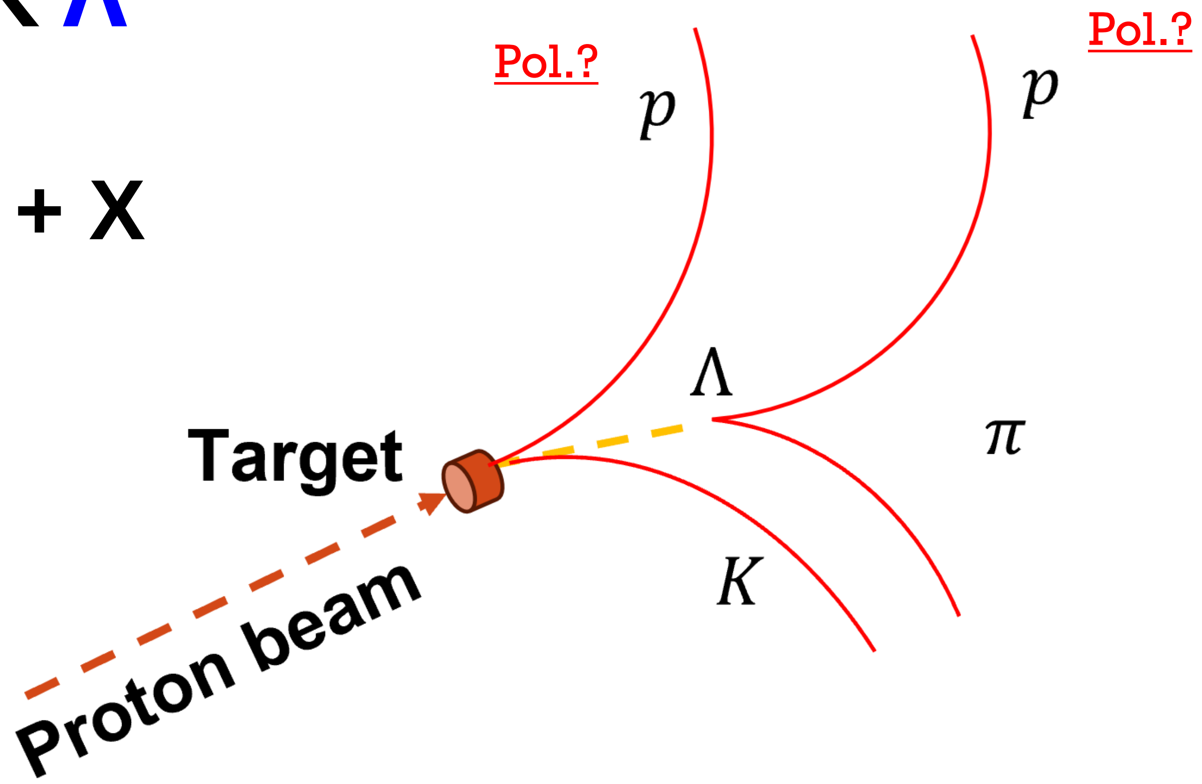
③ $pp \to pK\Lambda$ **Λ polarization in exclusive processes**

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?

pp → p K Λ

pp → p/Λ + X



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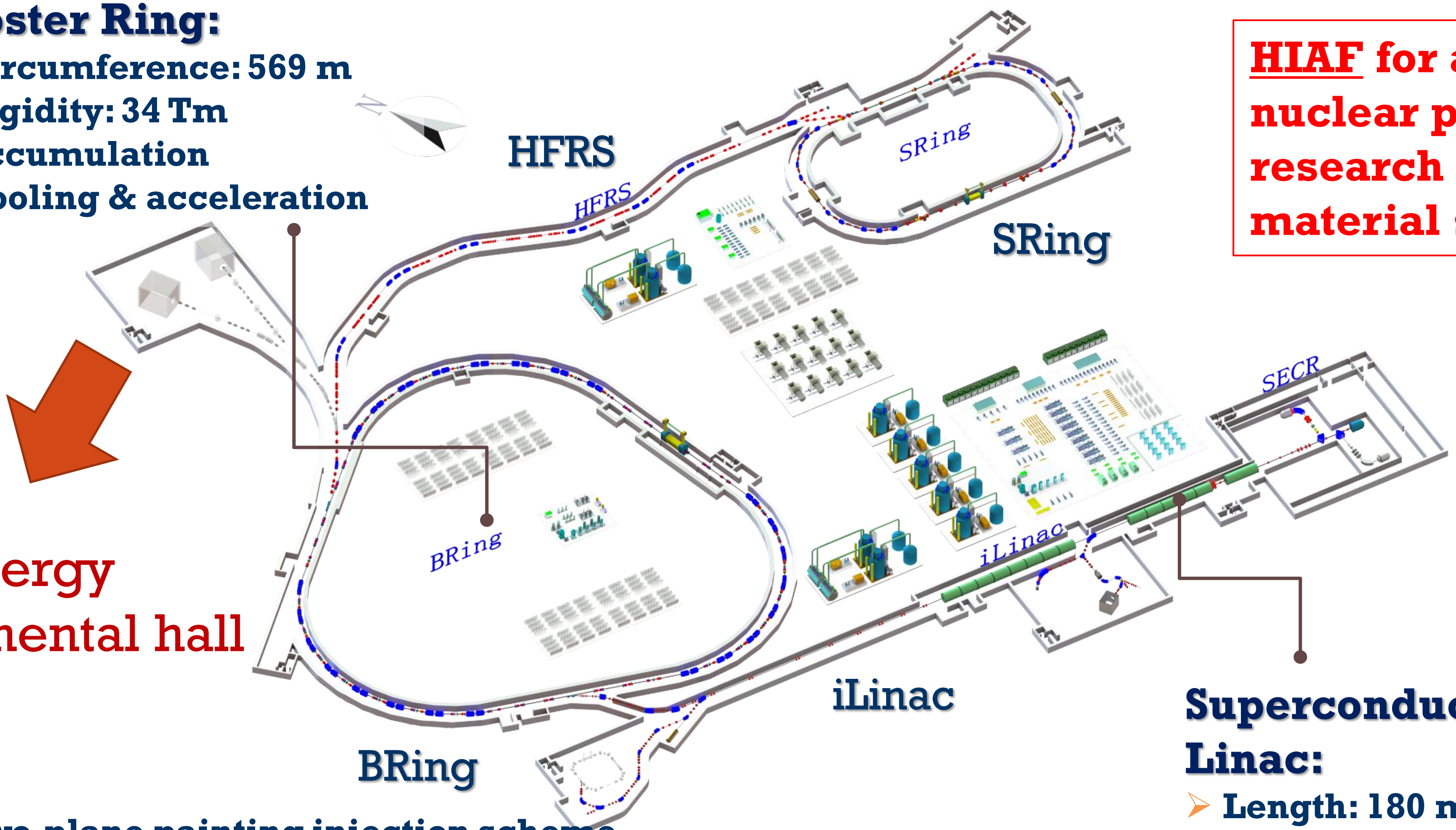
High Intensity heavy-ion Accelerator Facility (HIAF)

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

HIAF for atomic physics, nuclear physics, applied research in biology and material science etc.



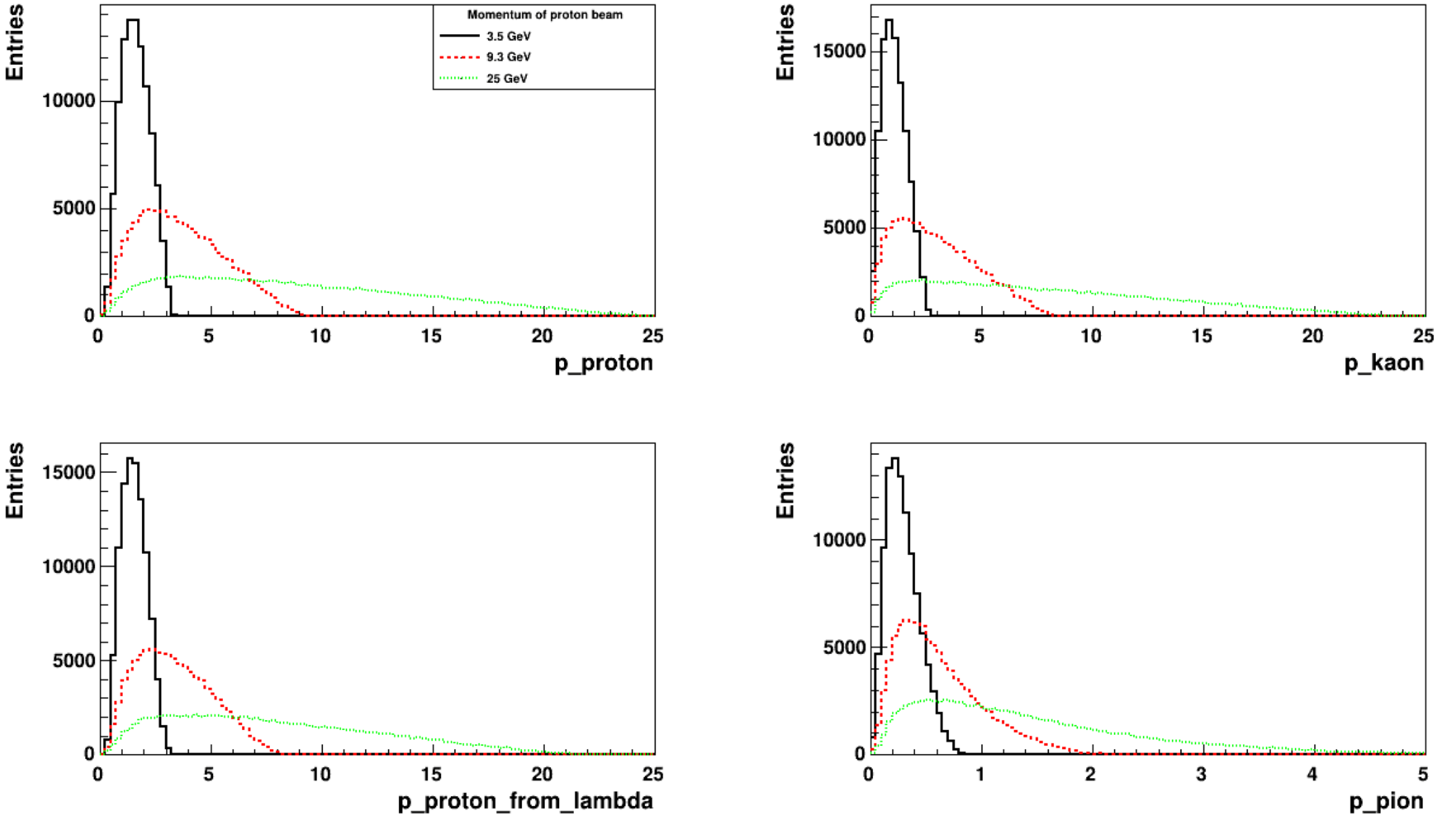
- Two-plane painting injection scheme
- Fast ramping rate operation

Superconducting Ion Linac:
- Length: 180 m
- Energy: 17 MeV/u (U^{34+})
- CW and pulse modes

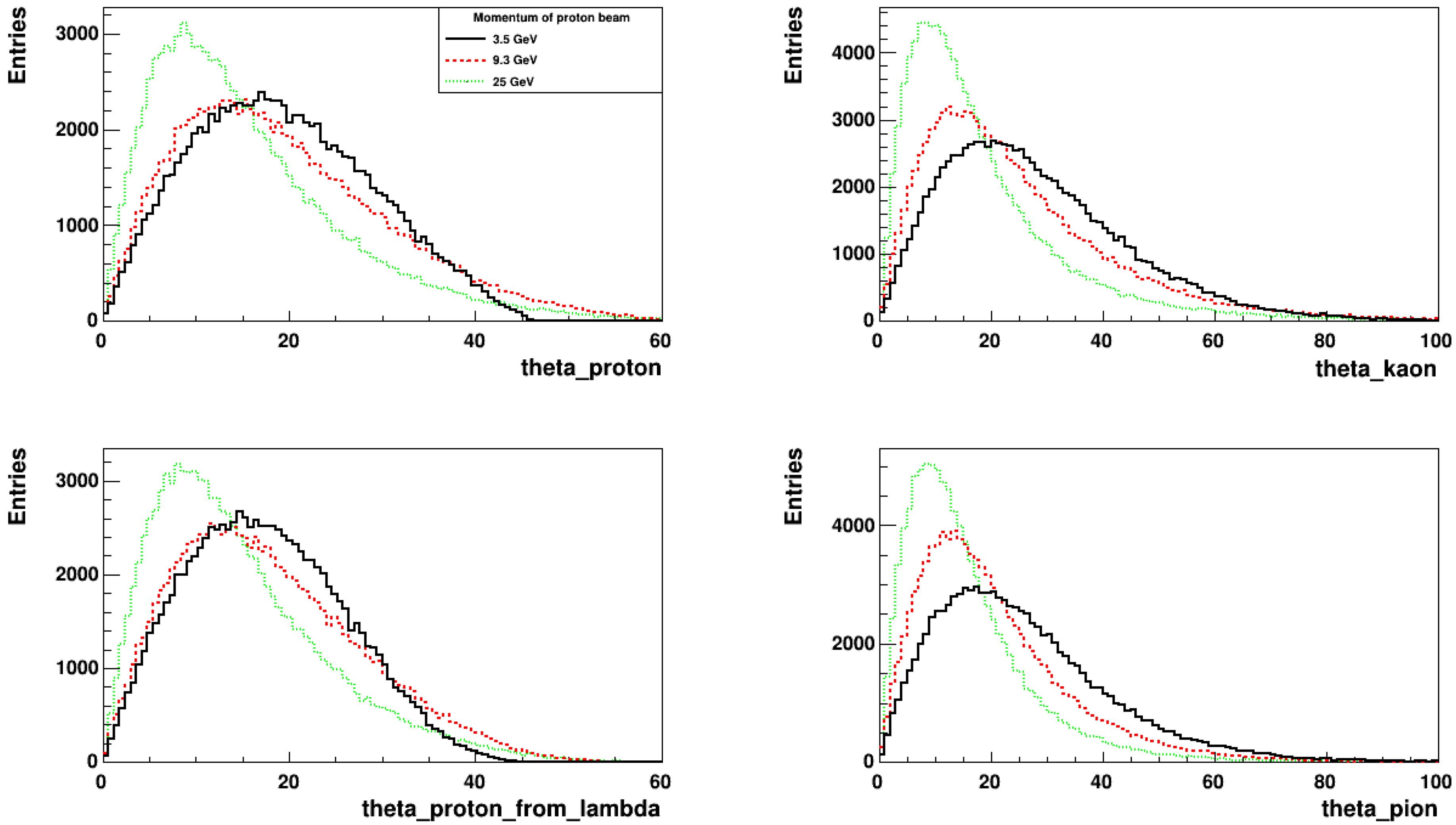
HIAF beam parameters

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

Distributions of momentum of final states

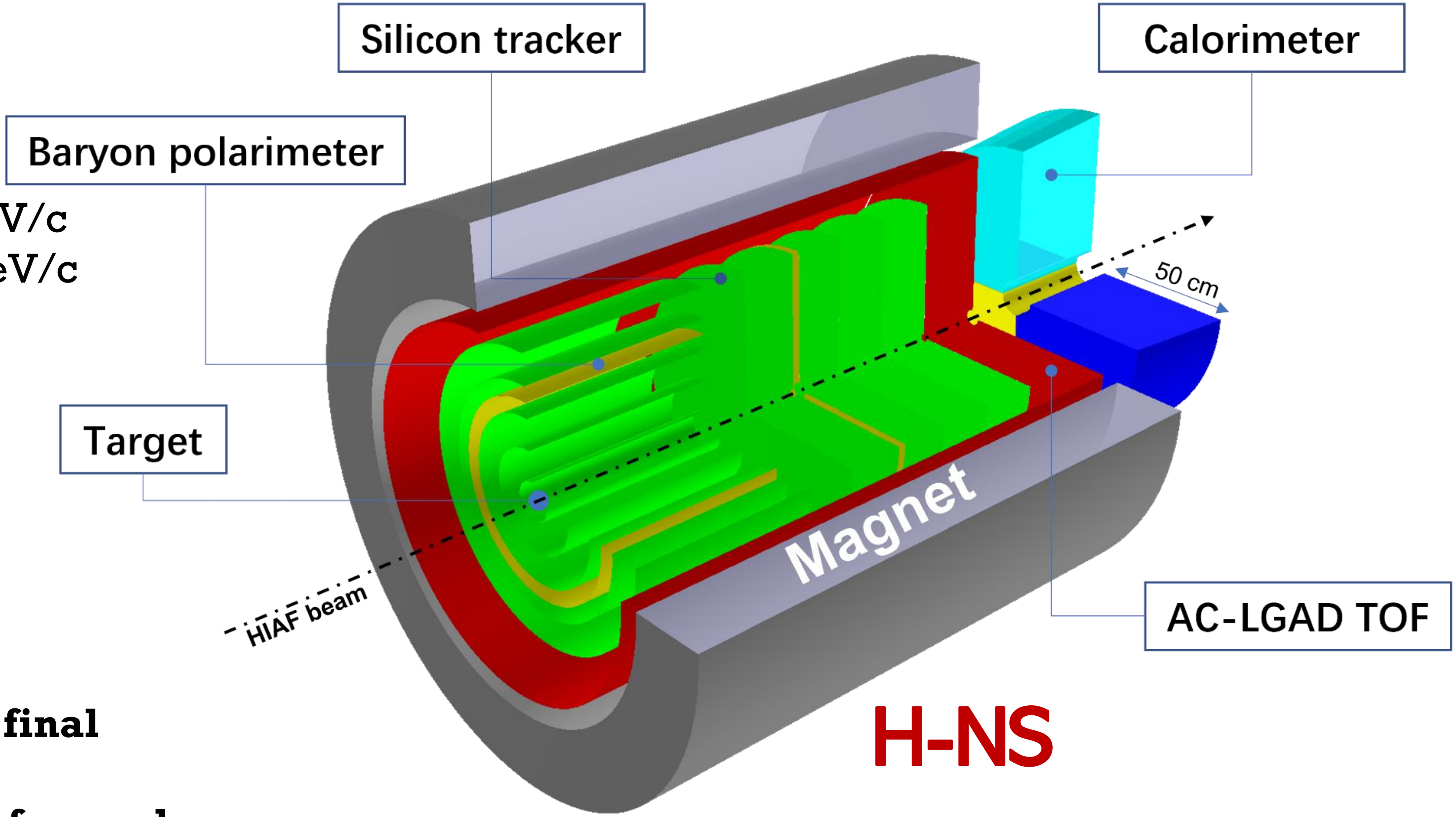


Angular distributions of final states

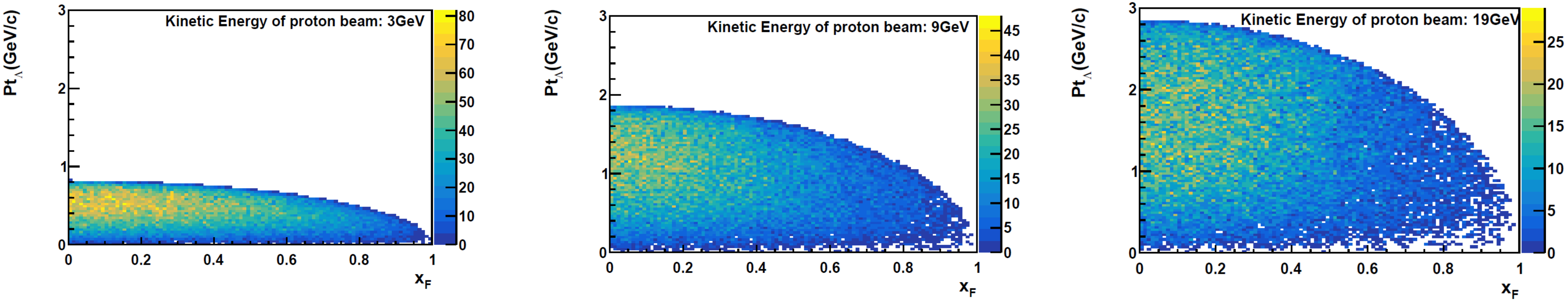


Hyperon-Nucleon Spectrometer

- **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**
- **Provide detector R&D platform in forward region**



H-NS kinematics coverage

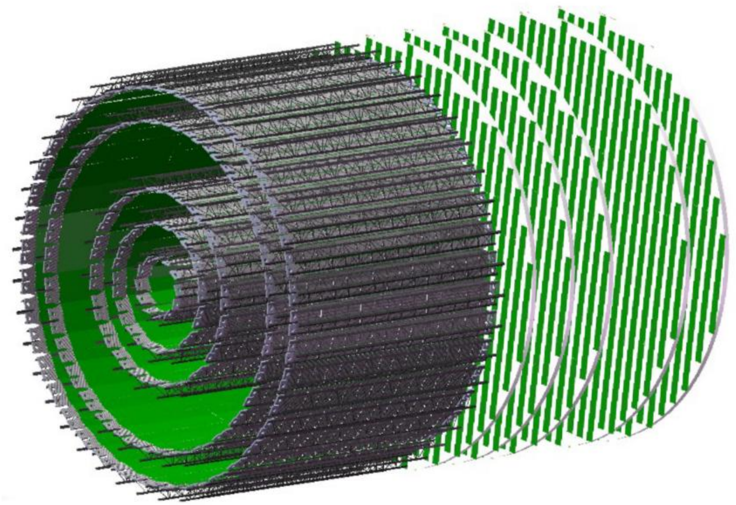


3 GeV → 9 GeV → 20 GeV

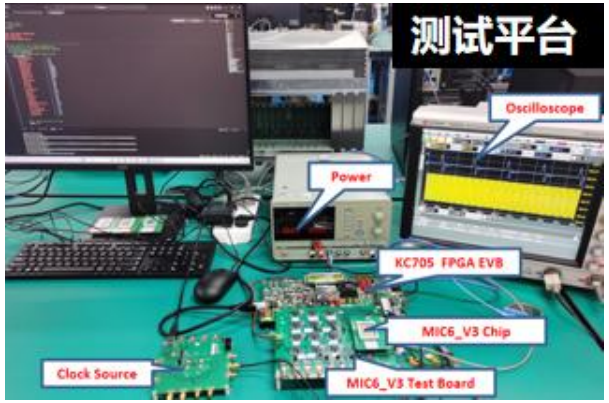
Allow for a multi-dimensional mapping of the Λ^0 polarization and production

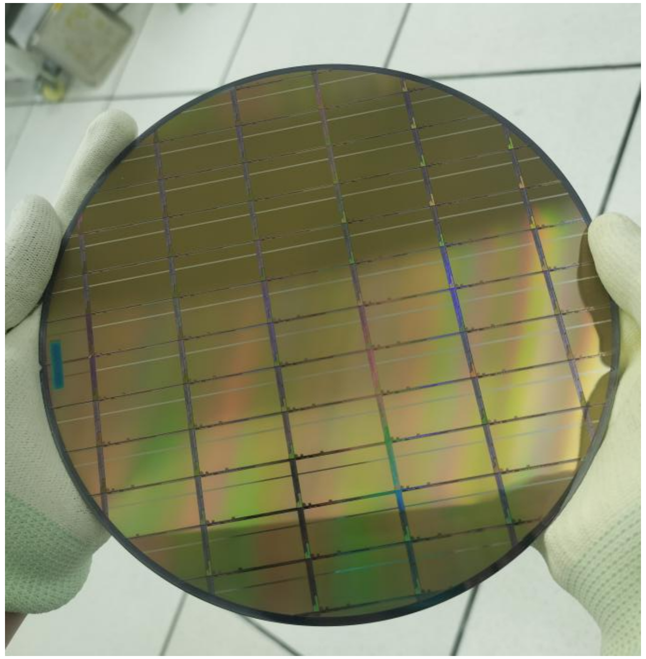
- Beam energy scan
- p→p, p→A, A→A data taking

Silicon tracker at H-NS



MIC6 development at CCNU



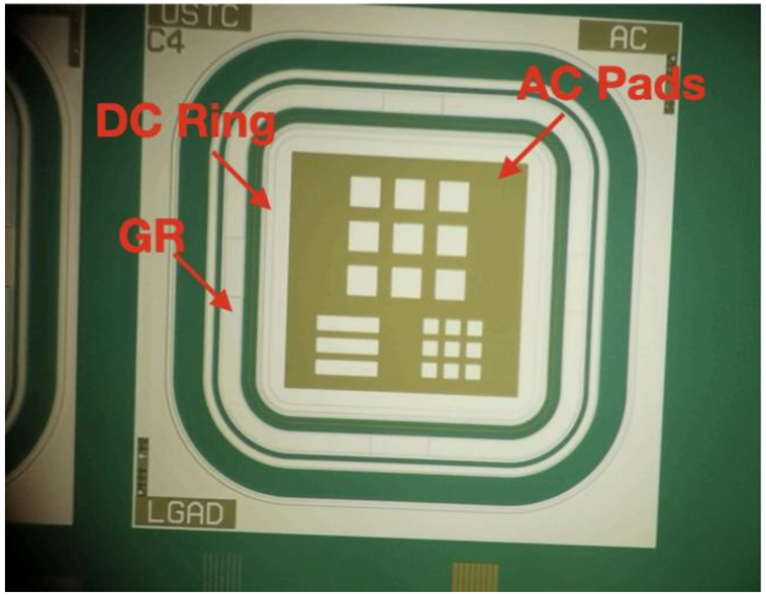


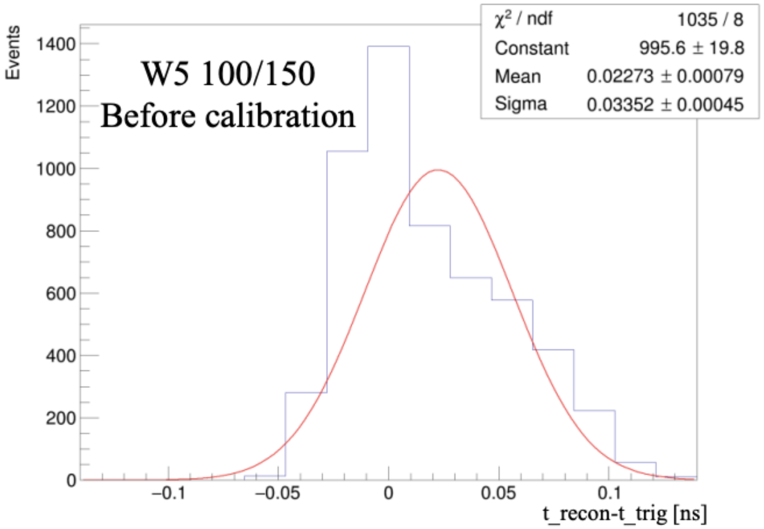
- **MIC6 MAPS pixel chip:** development and manufacture with the domestic process
- **Readout electronics** (ITS2 based design) **and DAQ** (ALICE CRU/FELIX protocol, GBTx, …)
- **Detector assembly and integration:**
  - **Vertex detector:** Stave module design (spatial resolution: ~ 5 μm with pixel 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)

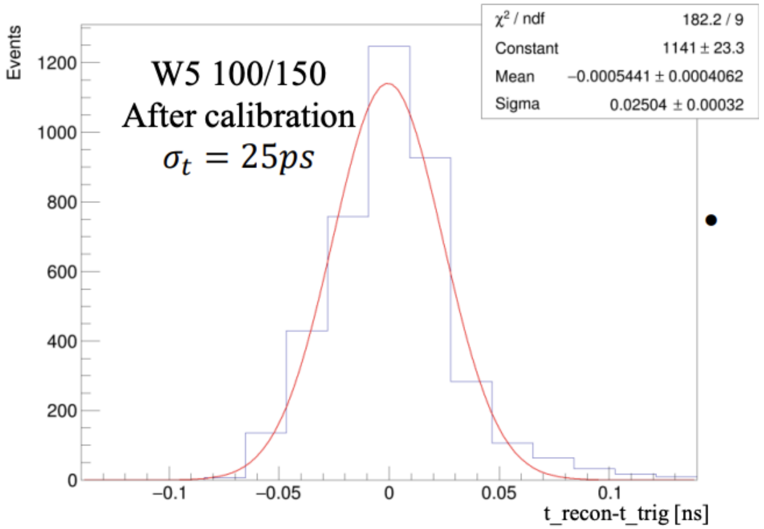
AC-LGAD at H-NS

Recent development at USTC:

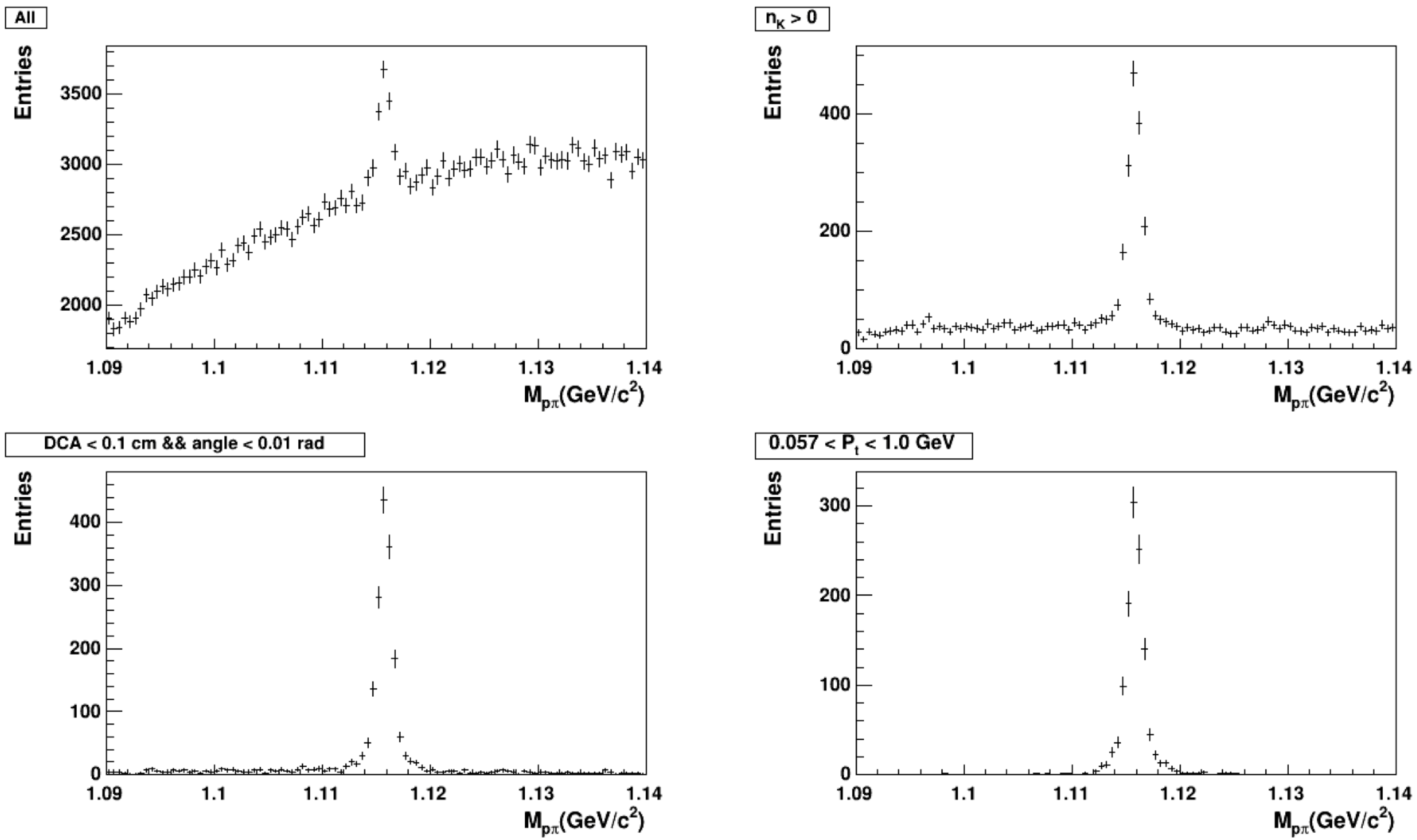
- Two wafers with different n$^+$ dose: W5 high n$^+$ dose and W6 low n$^+$ dose.
- Sensor size : 1300×1300×50 μm.
- Sensor with different pad-pitch size: Large pad size/pitch: 100/150 μm, Small pad (Strip) size/pitch: 50/75 μm.



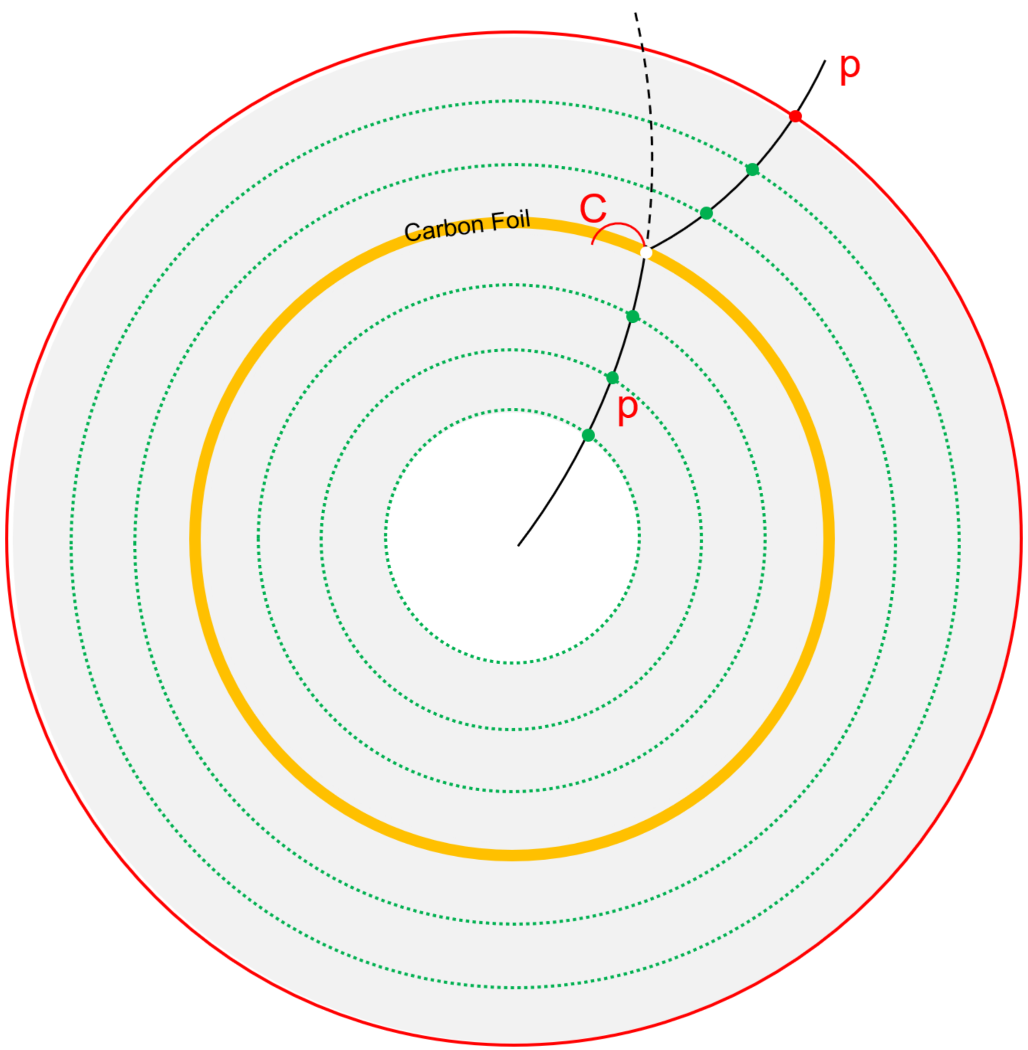




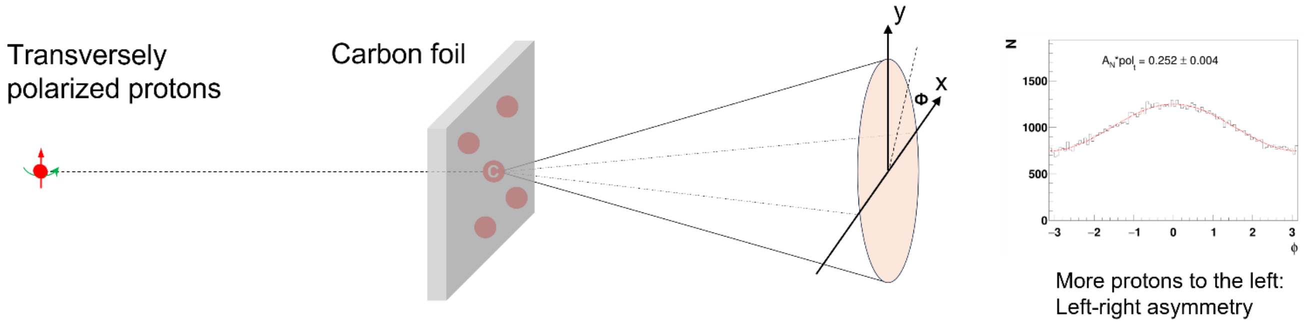
Almost background free reconstruction (Beam energy 3.5 GeV)



Baryon polarimeter: determining proton polarization via elastic scattering



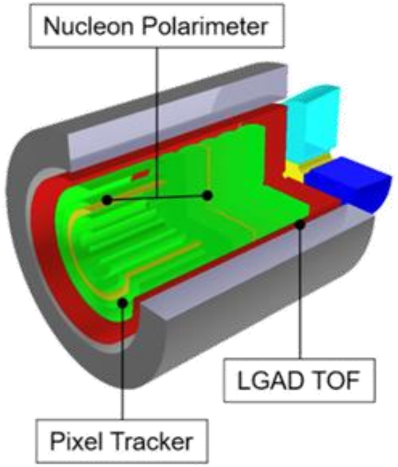
$$\frac{d\sigma}{d\phi d\cos\theta} = \frac{1}{2\pi}\frac{d\sigma_0}{d\cos\theta}\left[1 + \underline{P_y A_N(\theta)}\cos\phi\right]$$



- **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)

Projection of Λ and proton polarization (beam energy: 9.3 GeV)



H-NS

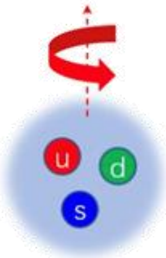
Reaction: p+p

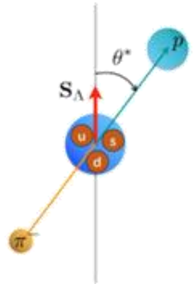
Event rate:1MHz

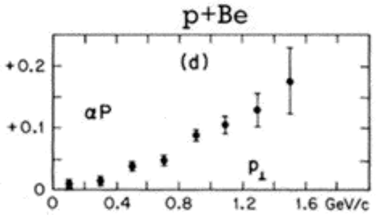
Time: 3 months

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

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

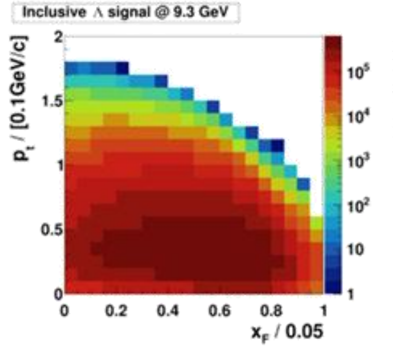


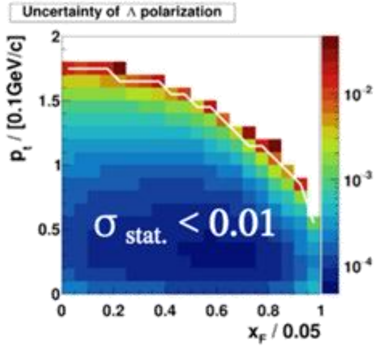




G.Bunce, *et al.*: Phys.Rev.Lett. 36, 1113-1116 (1976)

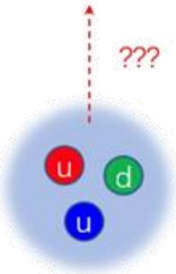
Λ polarization

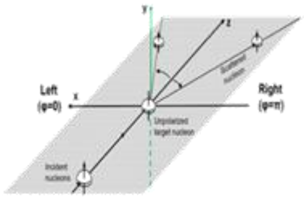


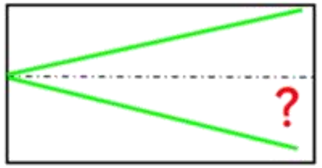


p p → p + X $\sigma_{\text{stat.}} < 0.02$ 2D:400 bins

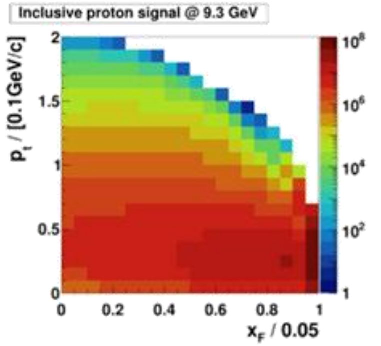
pC scattering ~ 10^{13} * $4*10^{-4}$ = $4*10^{9}$

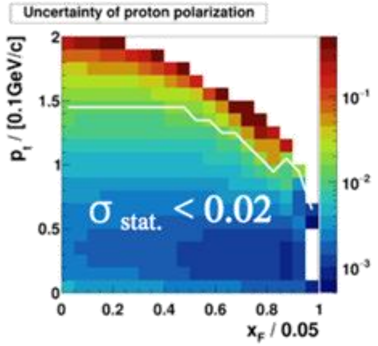




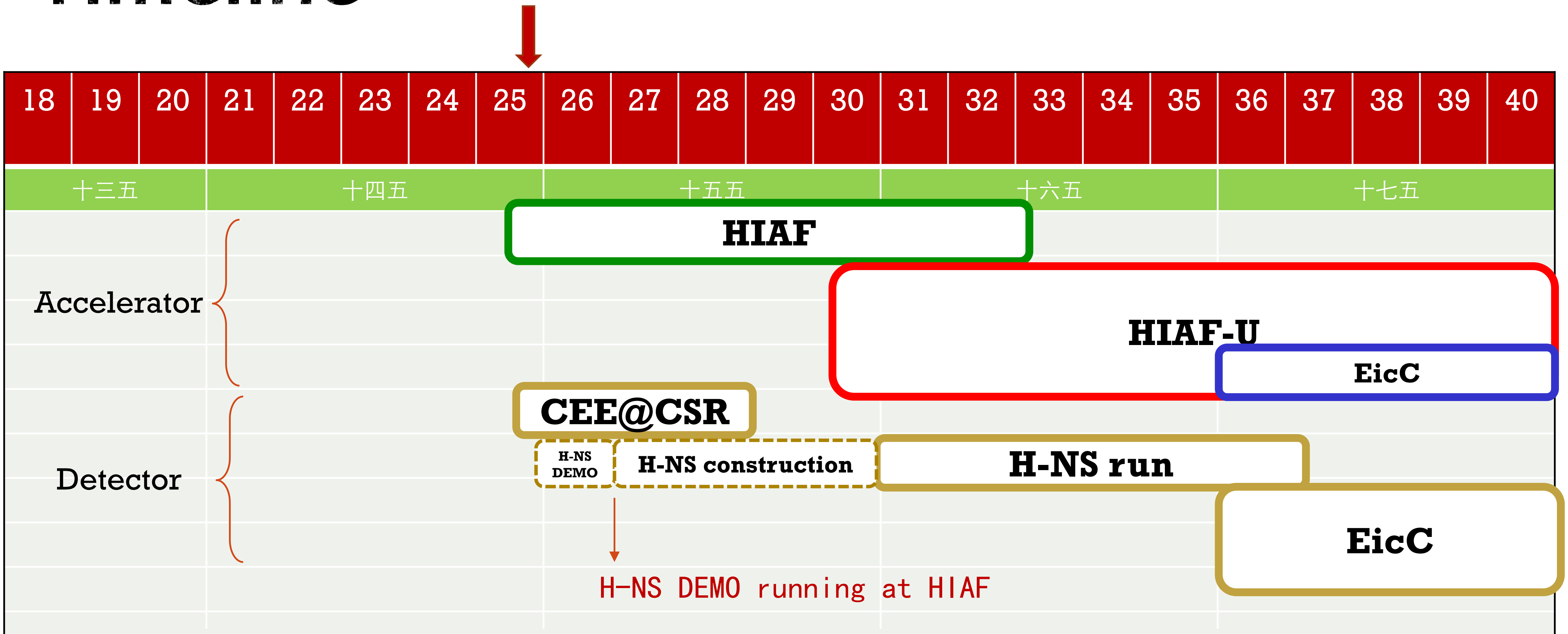


proton polarization



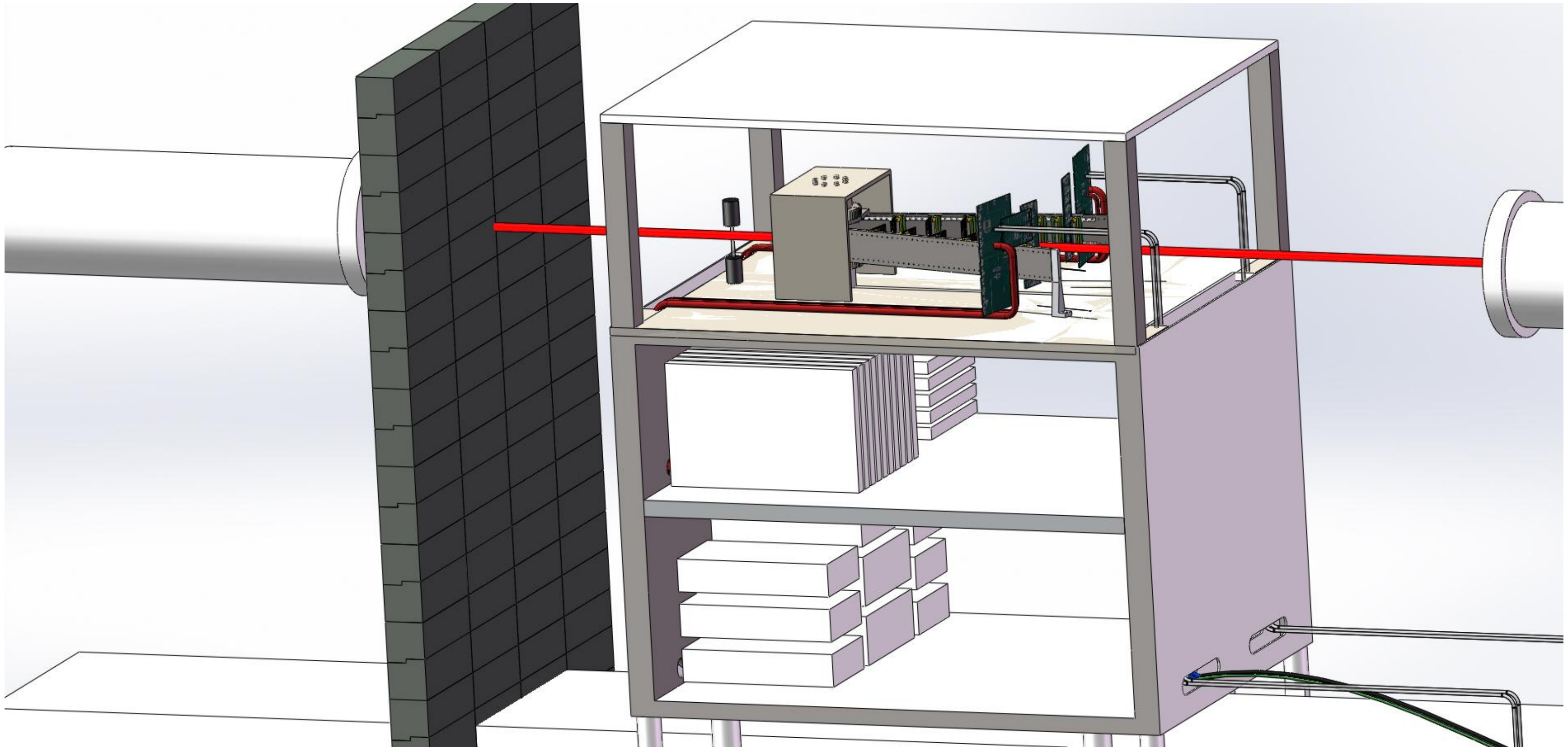


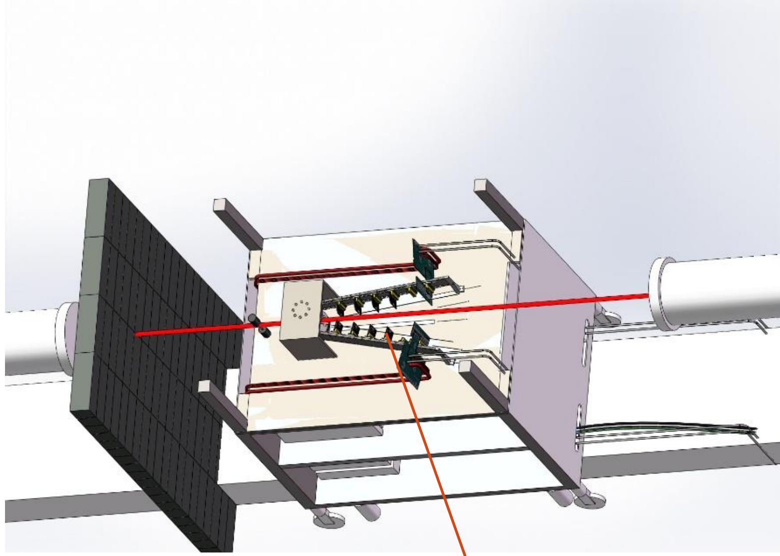
Timeline

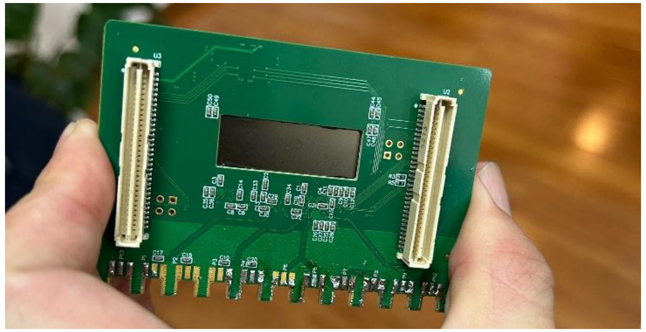


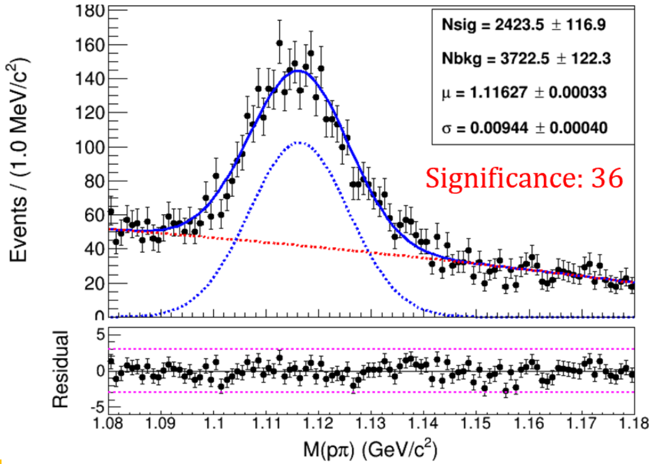
A smooth transition from H-NS to EicC, in terms of both physics and hardware

H-NS demo: H-NS0









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

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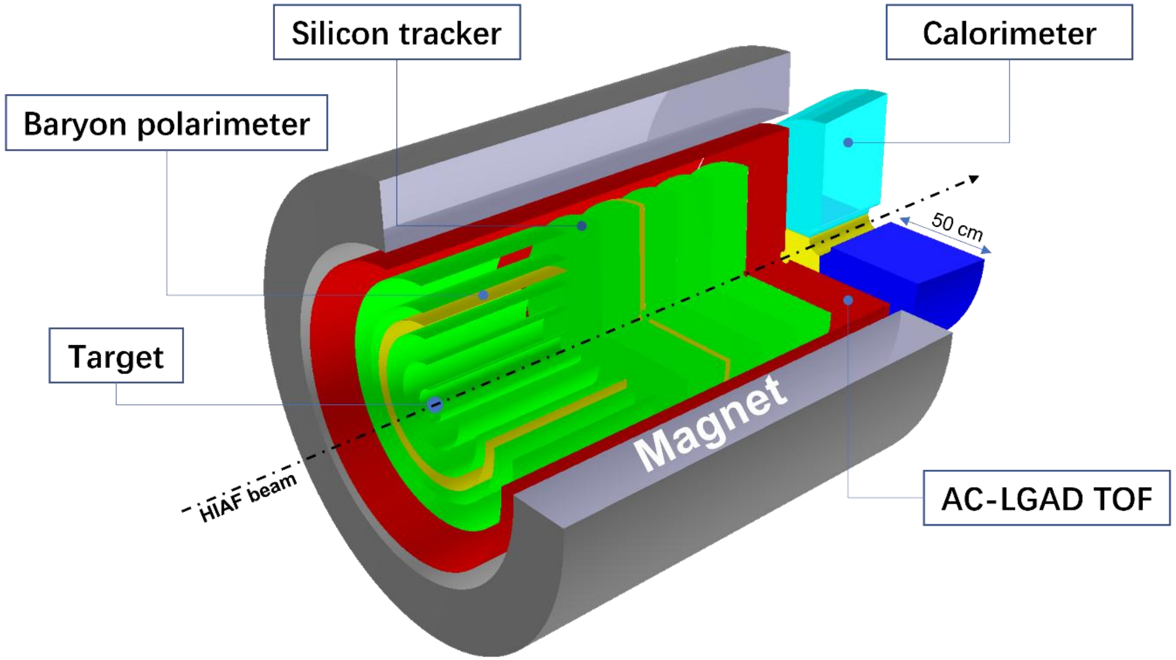
Hyperon-Nucleon Spectrometer (H-NS)



Institutes in China：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、近代物理研究所、清华大学、山东大学、香港中文大学（深圳）、中科大

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 interests are expected: Japan

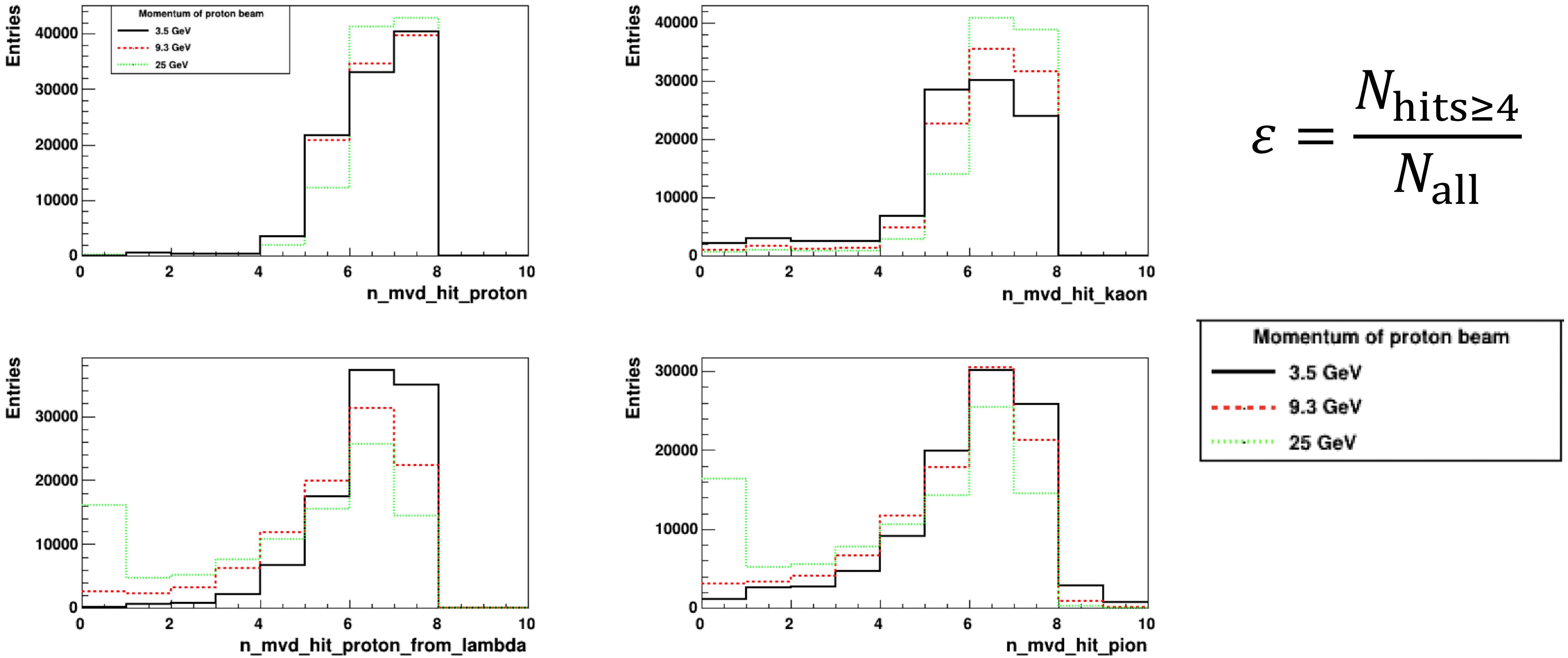
III. Detector R&D

- 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

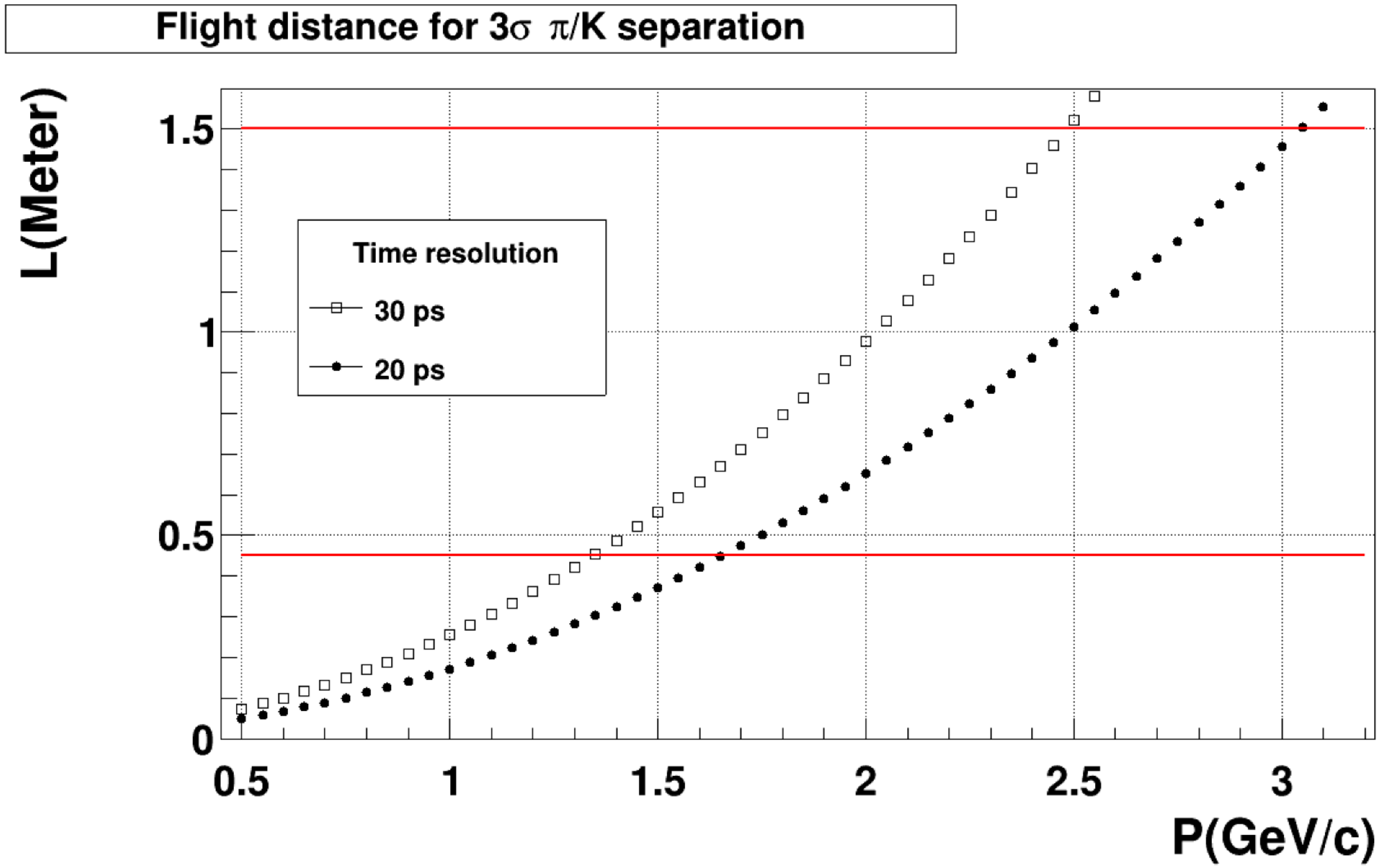
Efficiency due to tracking

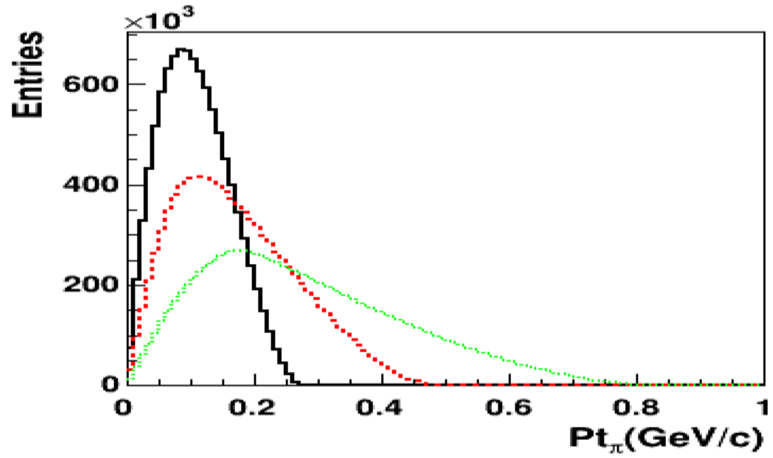


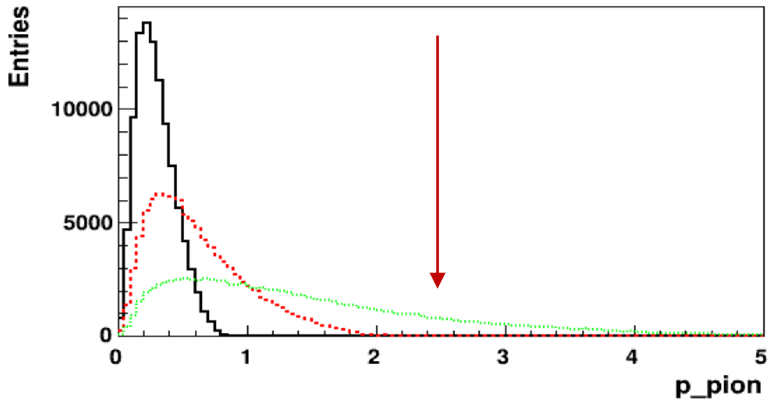
$$\varepsilon = \frac{N_{\mathrm{hits}\geq 4}}{N_{\mathrm{all}}}$$

E beam	$\varepsilon(p)$	$\varepsilon(\mathrm{K})$	$\varepsilon(\pi)$ (Λ)	$\varepsilon(p)$ (Λ)	$\varepsilon(Event)$
3.5GeV	98%	89%	88%	96%	76%
9.3GeV	98%	95%	82%	86%	74%
25GeV	98%	96%	65%	66%	60%

PID performance: pion/kaon

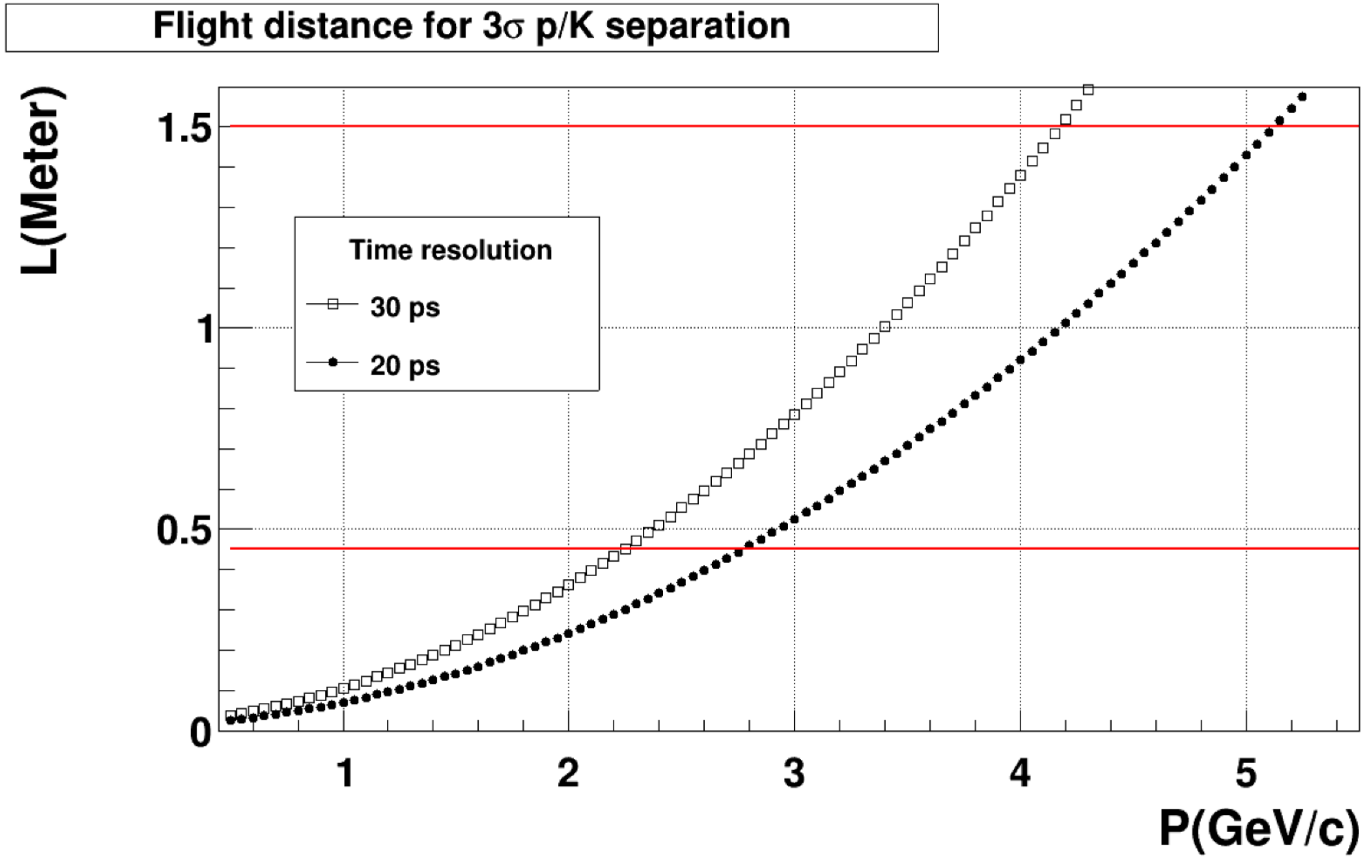


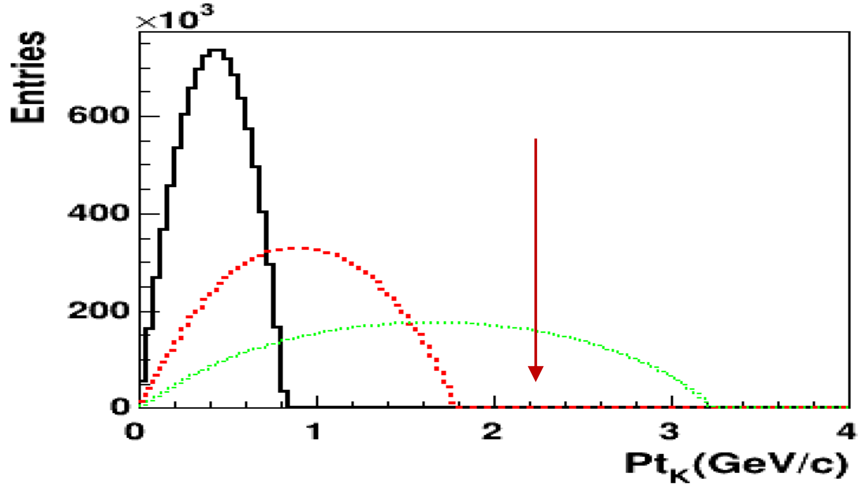


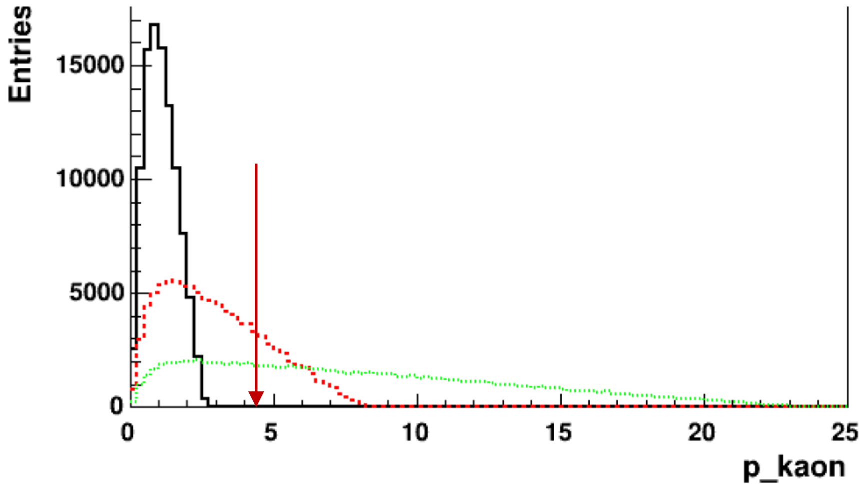


Assume a resolution of 30 ps:
LGAD barrel (R=45cm), can cover a Pt up to 1.35 GeV/c
LGAD endcap (Z=150) can up to 2.5 GeV/c

PID performance: proton/kaon

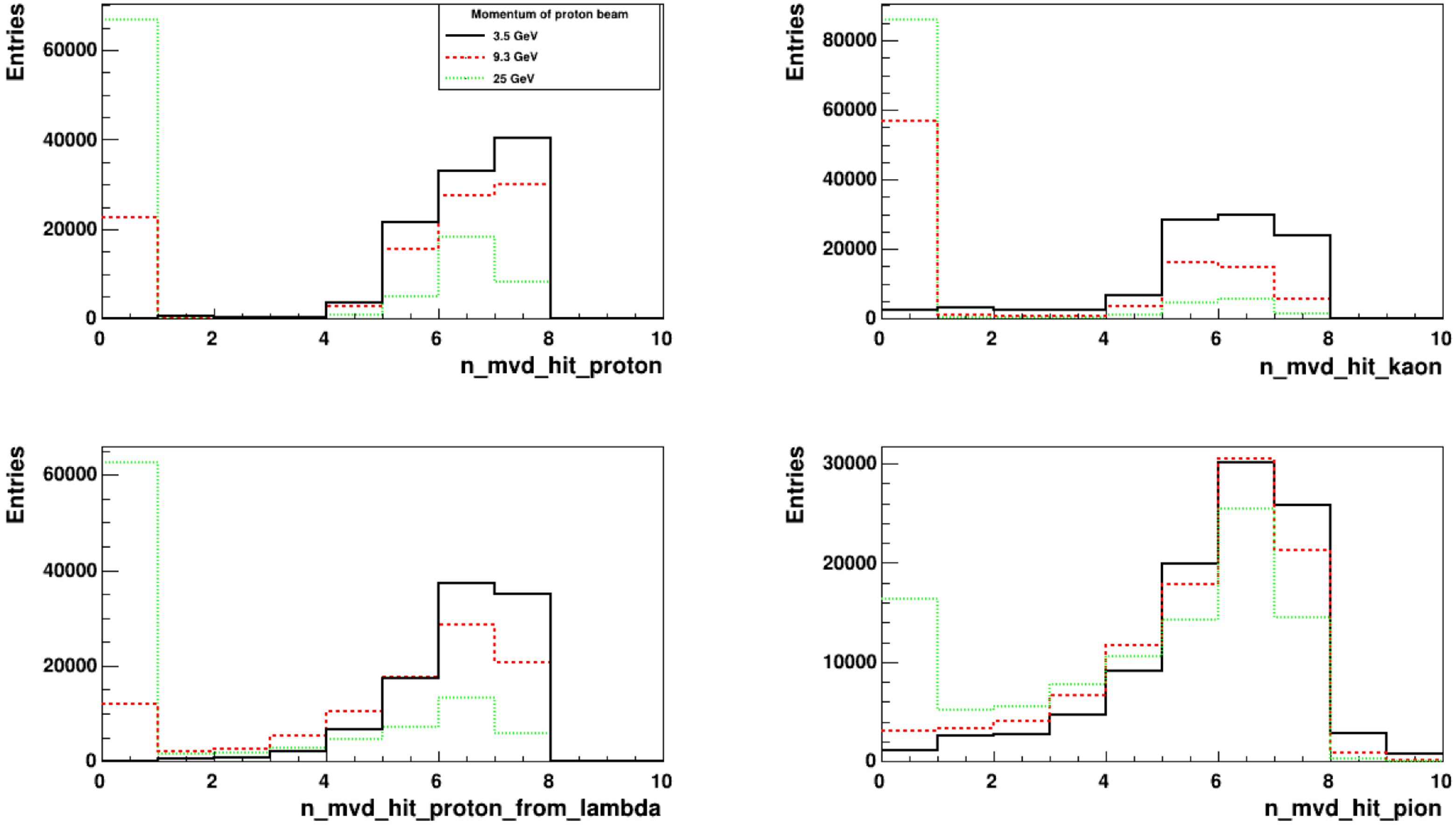






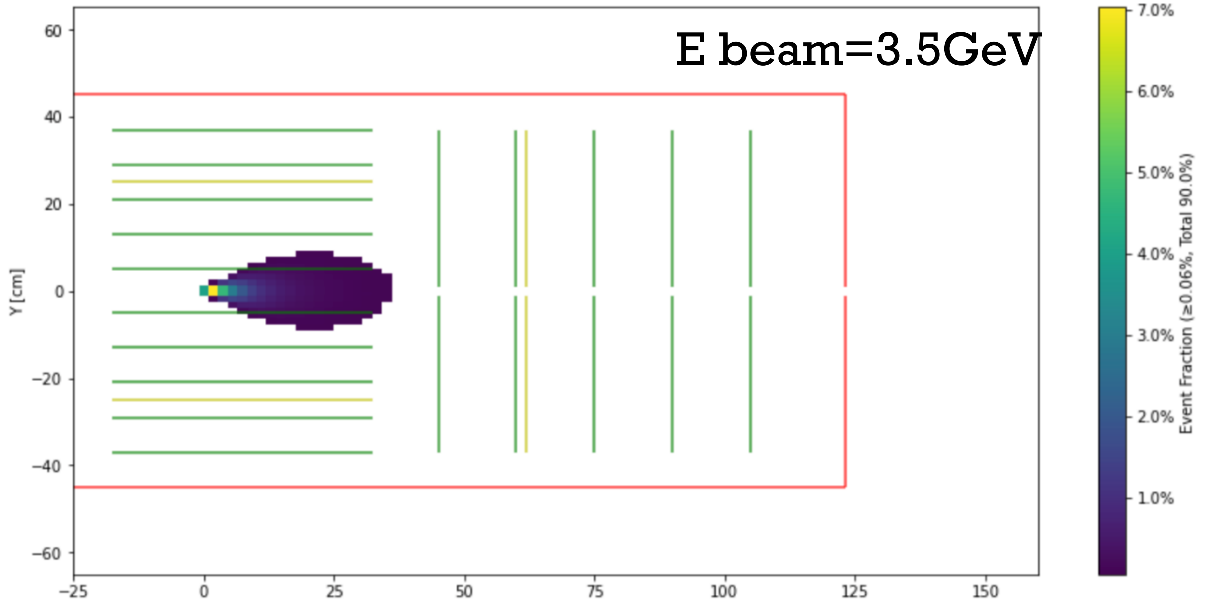
Assume a resolution of 30 ps:
LGAD barrel, (R=45cm), can cover a Pt up to 2.25 GeV/c
LGAD endcap, (Z=150) can up to 4.2 GeV/c

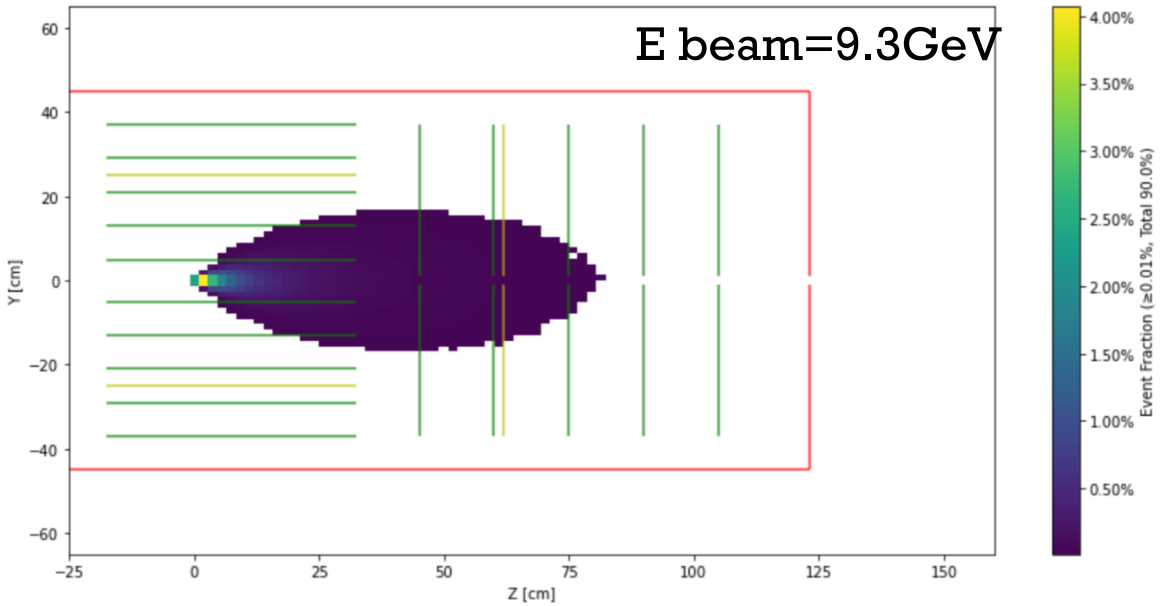
Efficiency due to PID+tracking

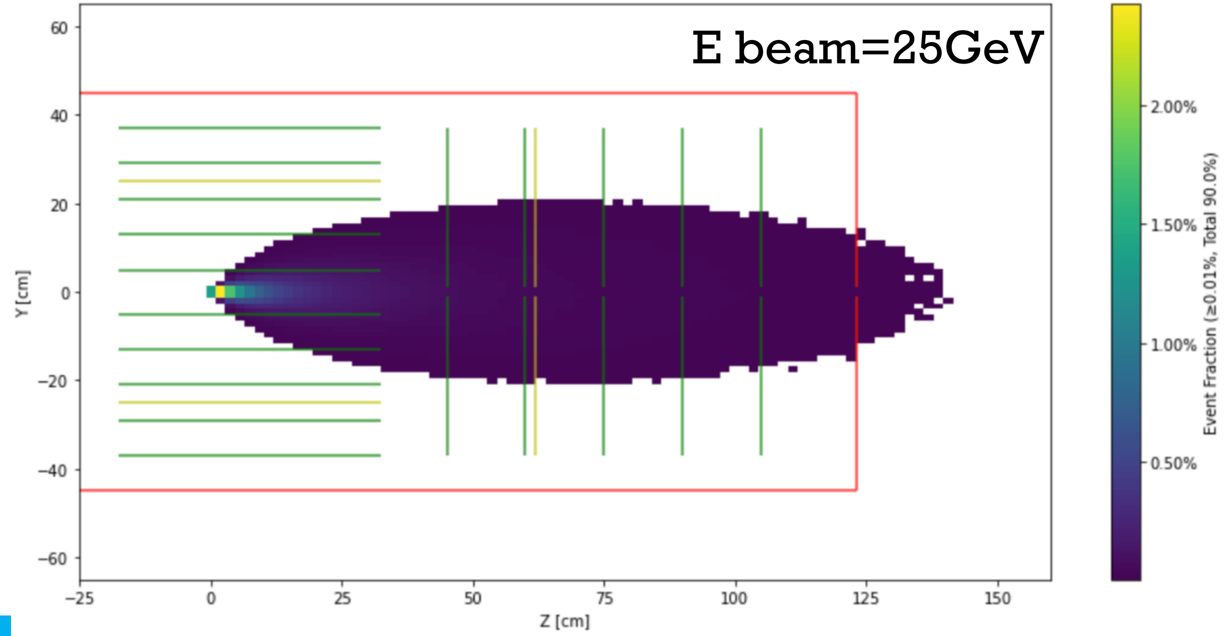


E beam	$\varepsilon(p)$	$\varepsilon(\mathbf{K})$	$\varepsilon(\pi)$ (Λ)	$\varepsilon(p)$ (Λ)	$\varepsilon(Event)$
3.5GeV	98%→98%	89%→89%	88%→88%	96%→96%	76%→76%
9.3GeV	98%→76%	95%→40%	82%→82%	86%→77%	74%→20%
25GeV	98%→32%	96%→13%	65%→65%	66%→31%	60%→1.5%

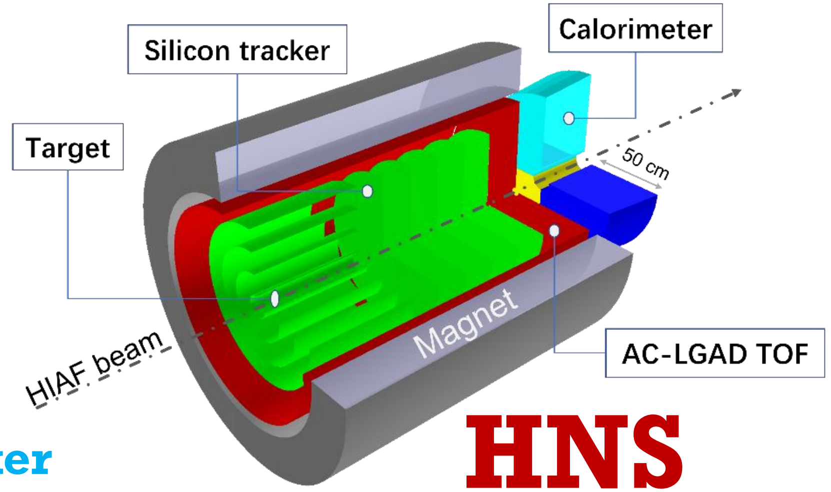
Efficiency due to tracking







- Λ decay vertex distribution
- 90% of all event
- Normalized to total event



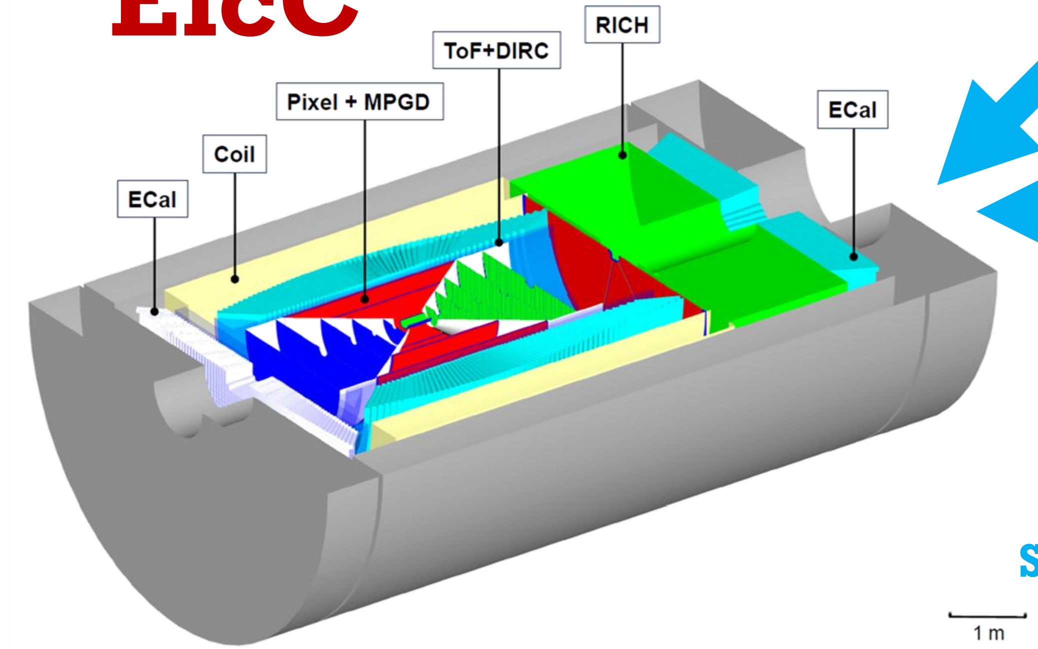
HNS

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

Silicon tracker
Ecal.
Super-conducting Solenoid

STCF

EicC



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