

Hyperon-Nucleon Spectrometer at HIAF

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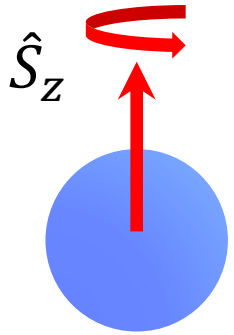
第六届中国格点QCD研讨会-深圳

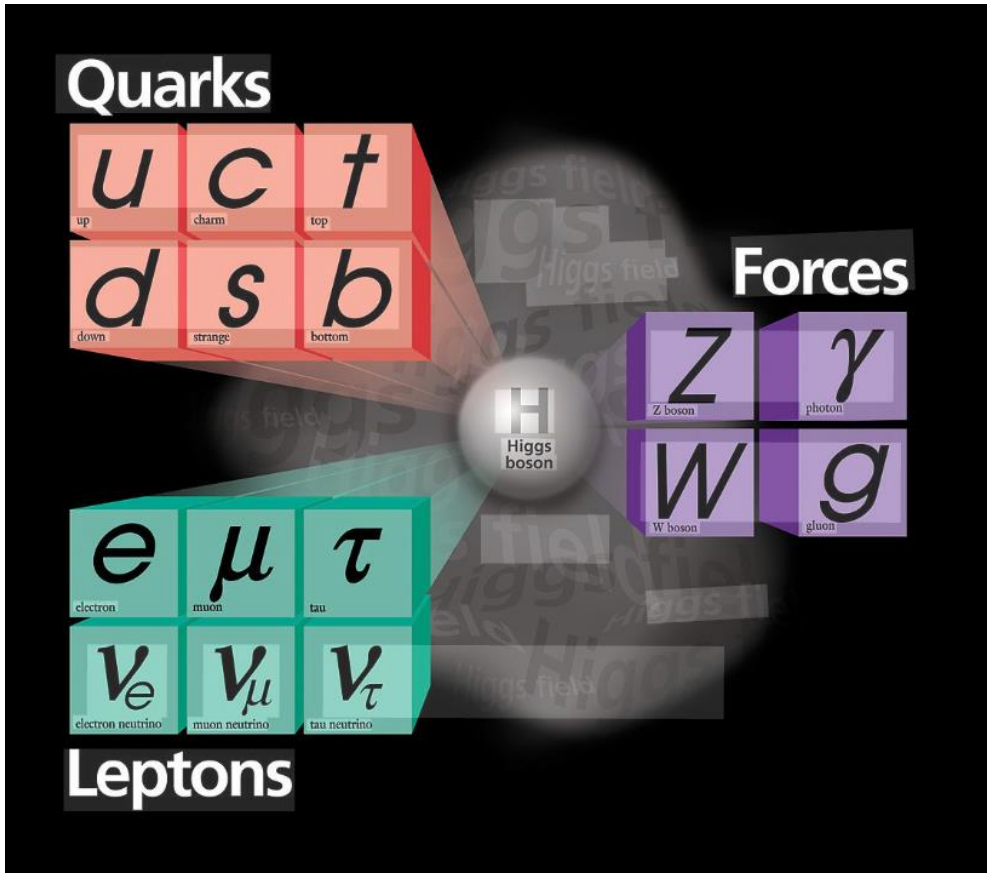
Outline

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

Spin and its polarization

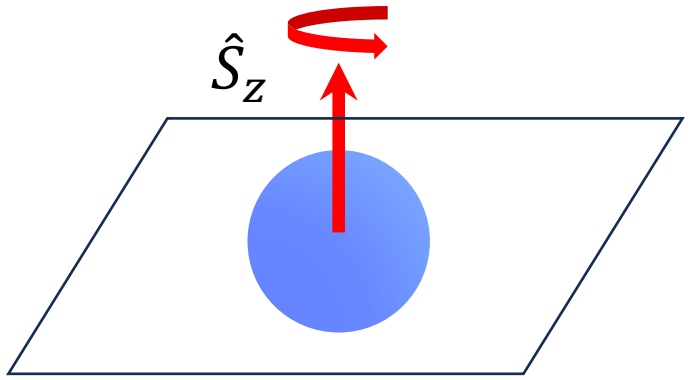
Spin: fundamental degree of freedom for element particles, an intrinsic property of all quantum particles





Spin and its polarization

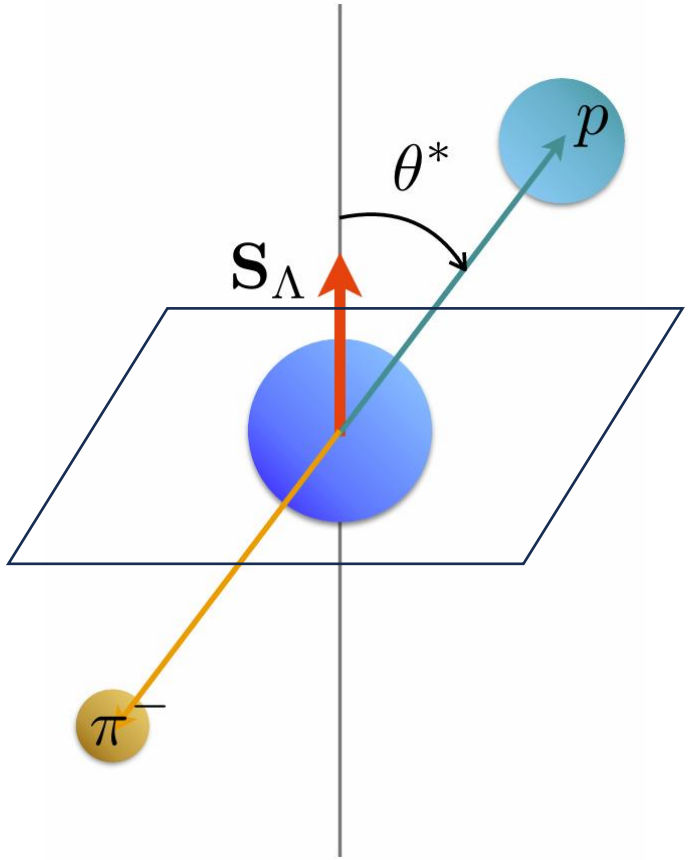
Polarization: spin of particles in a system is aligned in a preferred direction.



Reference plane

Measurement of polarization

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



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

branch ratio: $64.1 \pm 0.5\%$

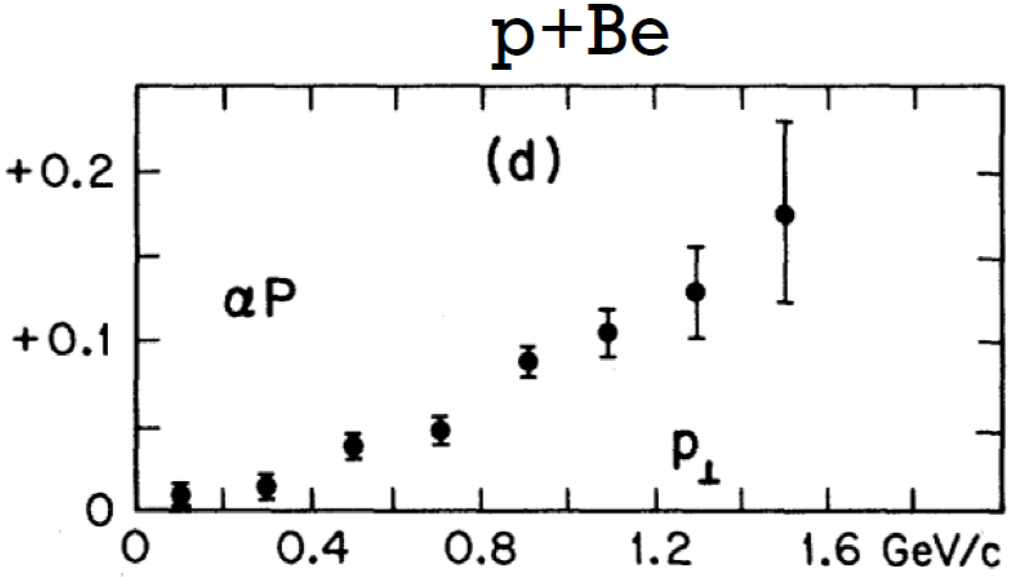
parity violating weak decay

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

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

[Current PDG value]

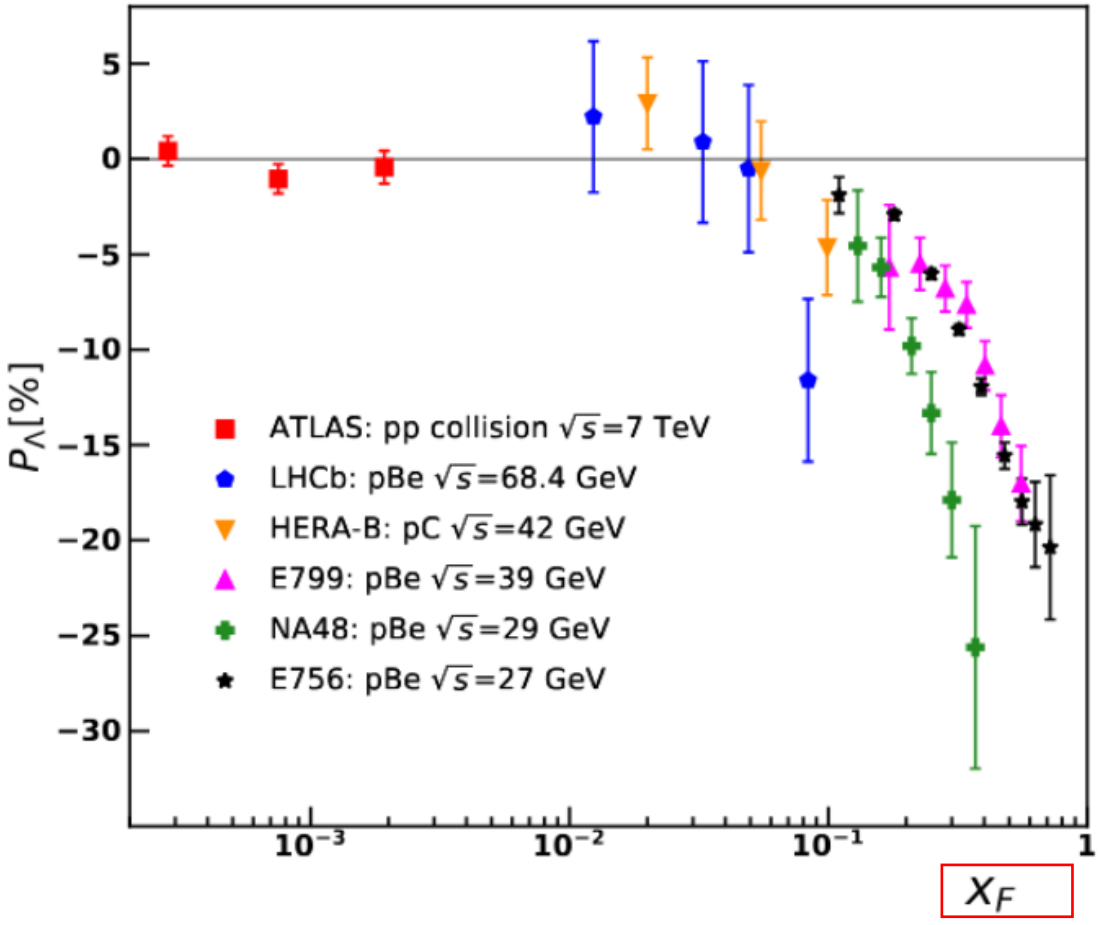
First observation of Λ^0 polarization in the 1970's

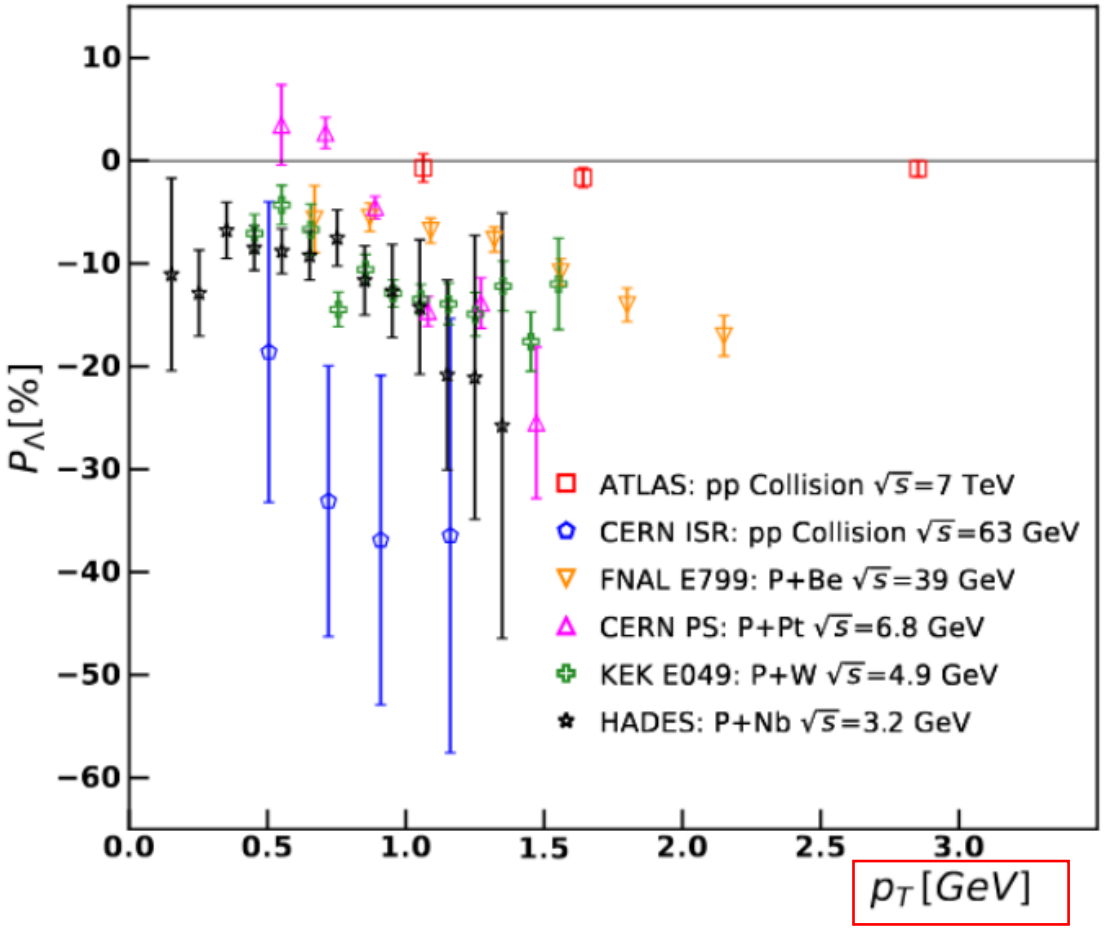


G.Bunce, *et al.*: Phys.Rev.Lett. 36, 1113-1116 (1976)

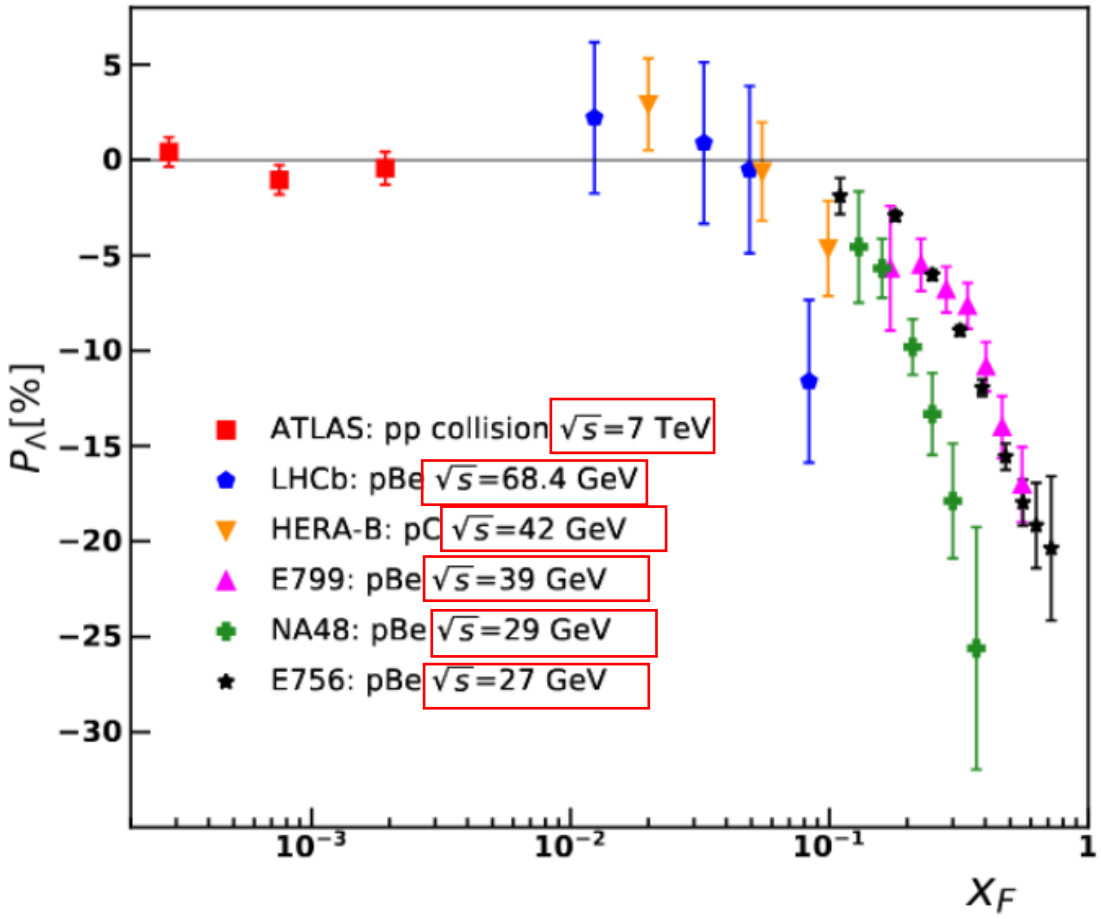
- Hyperons can be produced polarized in collisions of **unpolarized particles**
- Discovered at Fermilab in the 1970's in p + Be collisions: 300 GeV protons on Beryllium

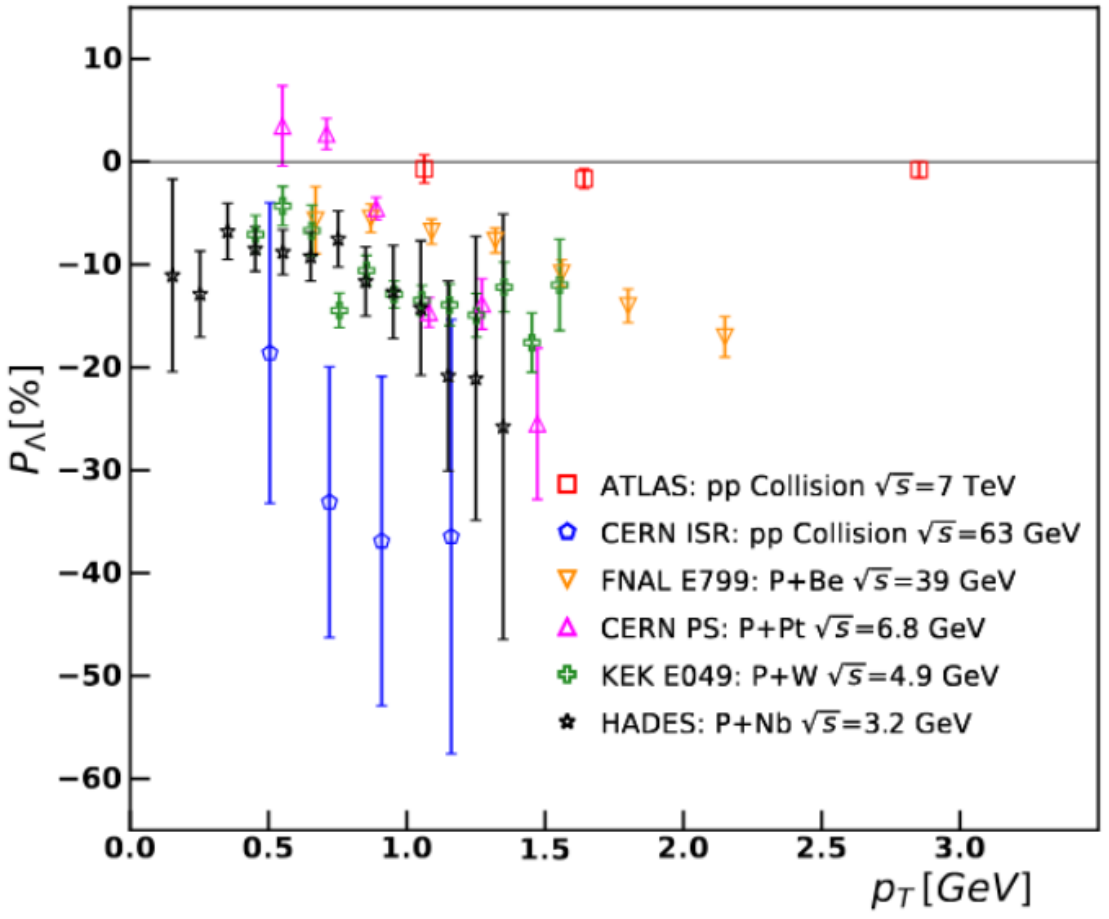
Λ^0 polarization measurements



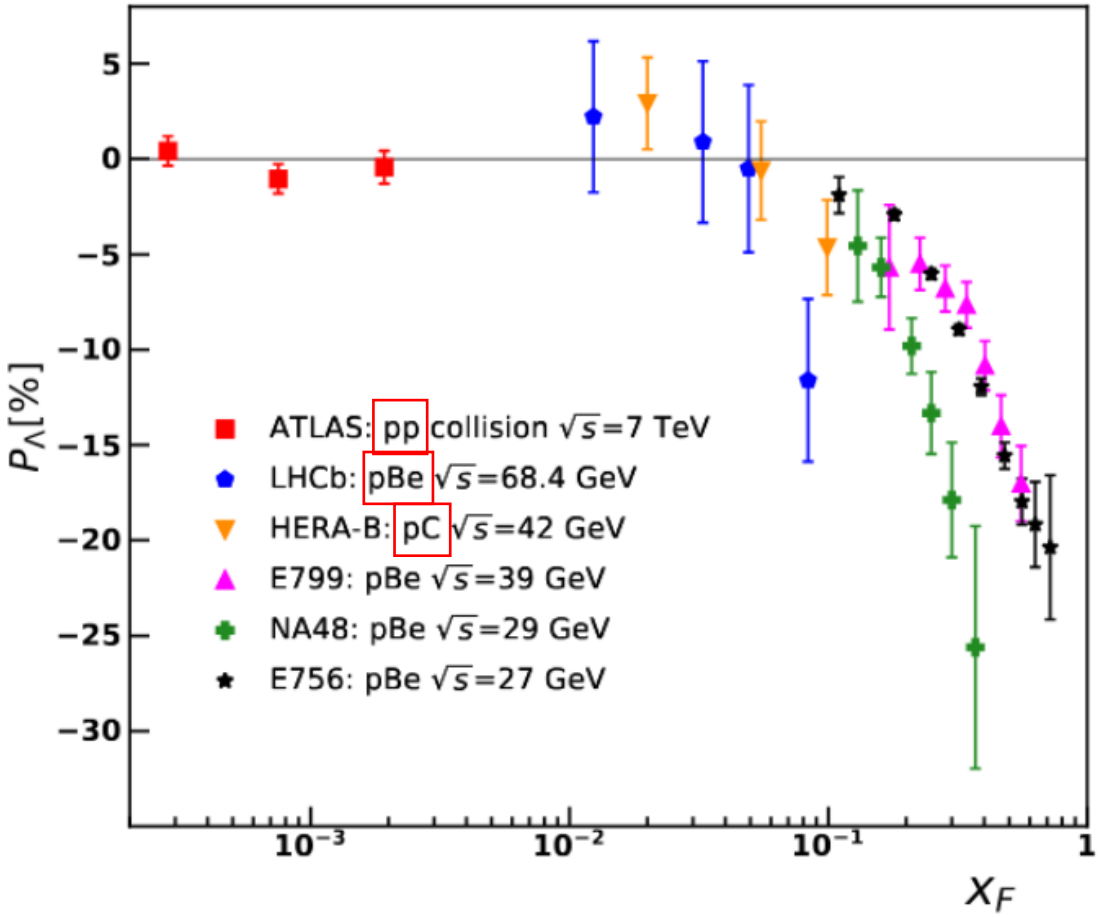


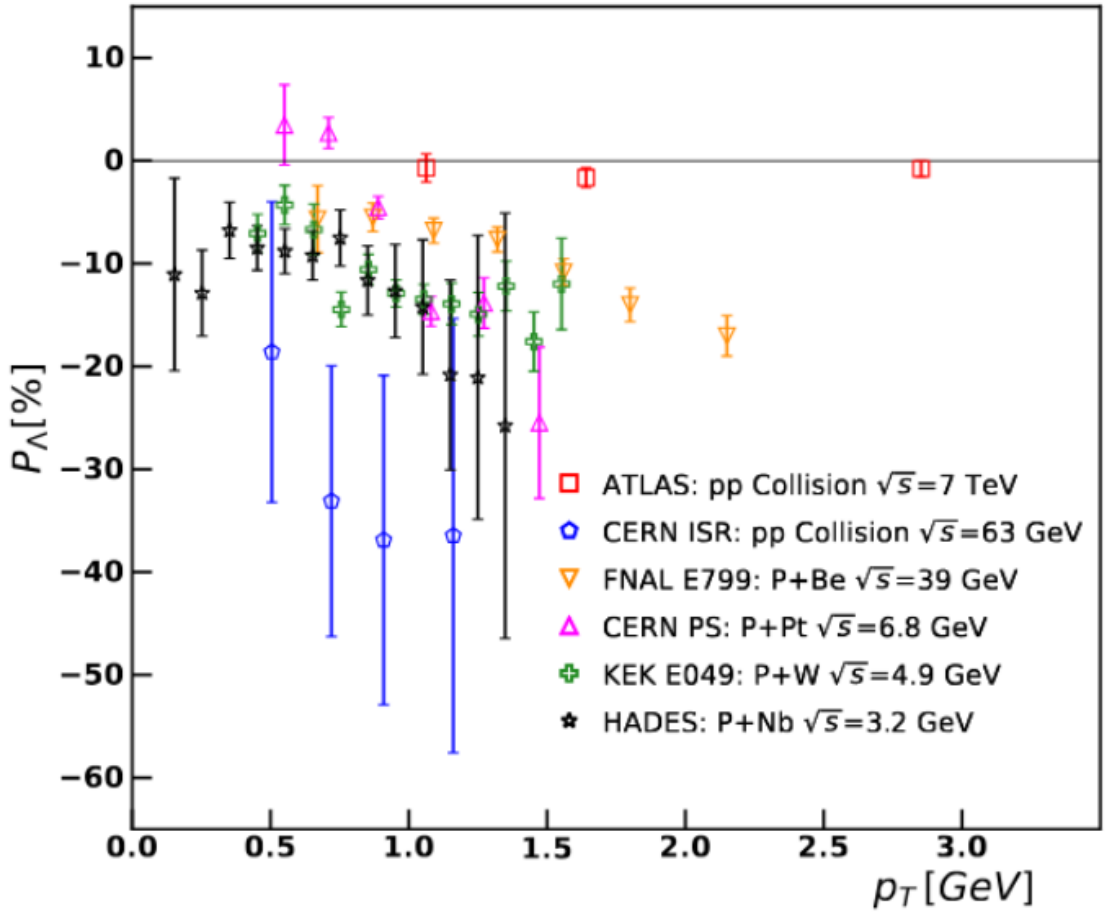
Λ^0 polarization measurements



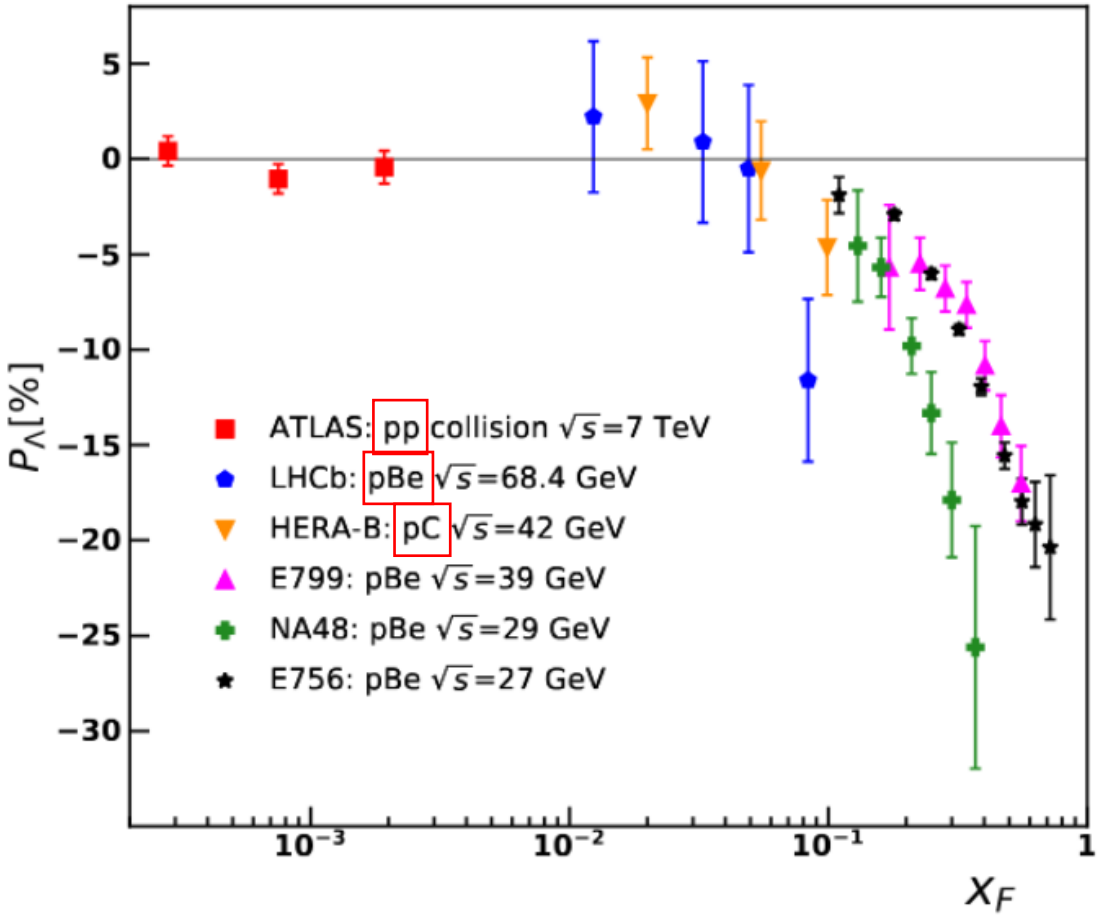


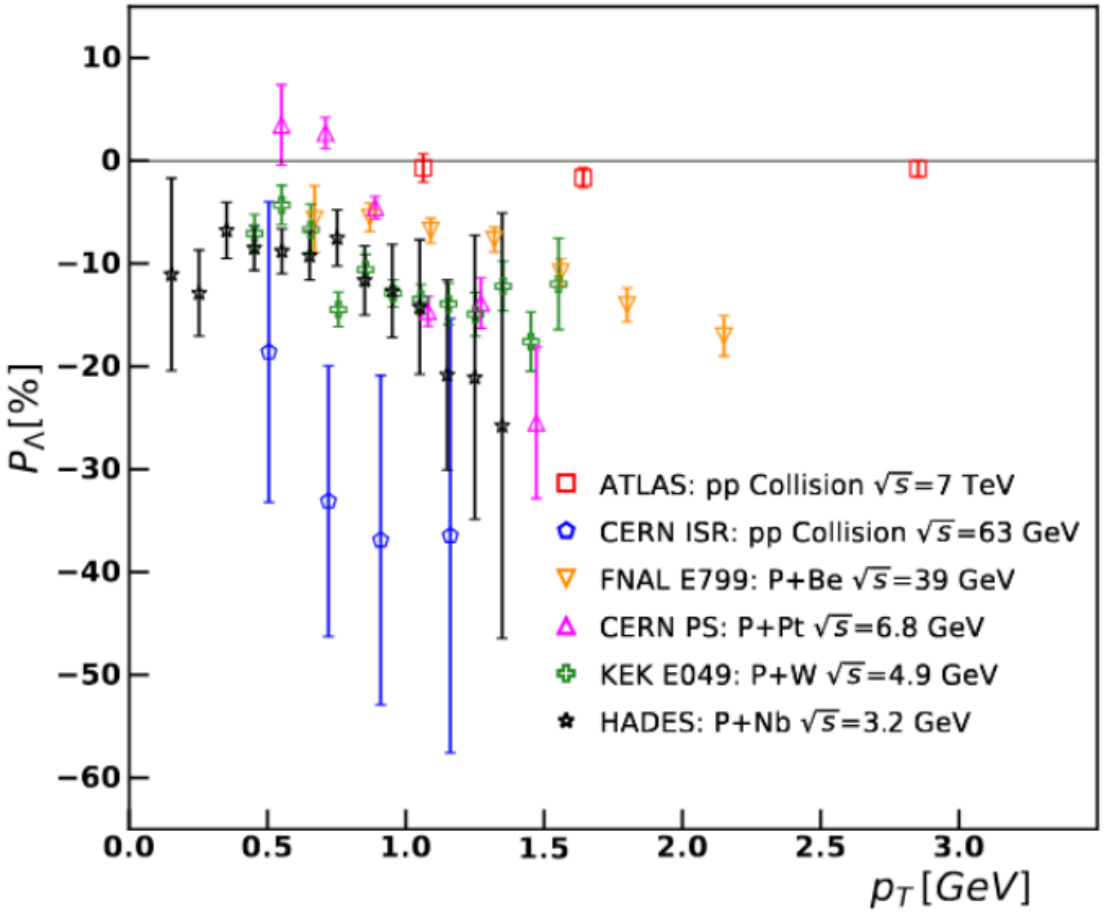
Λ^0 polarization measurements





Λ^0 polarization measurements

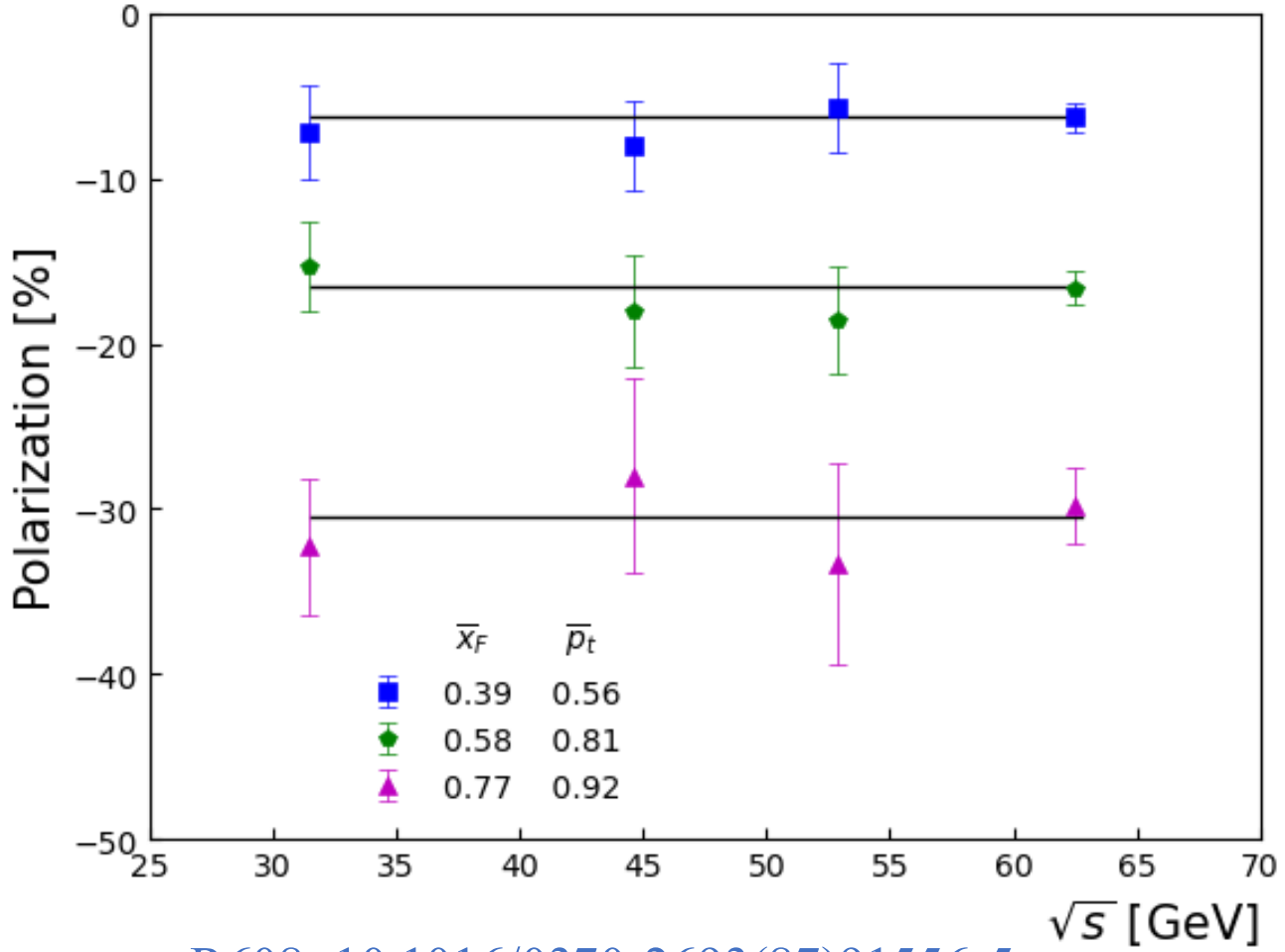




In standard collinear pQCD, the single quark polarization *P* from hard scattering follows the scaling relation: $P \propto \alpha_s \frac{m_q}{Q}$

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

“Scaling” of Λ^0 polarization ?



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

Theories:

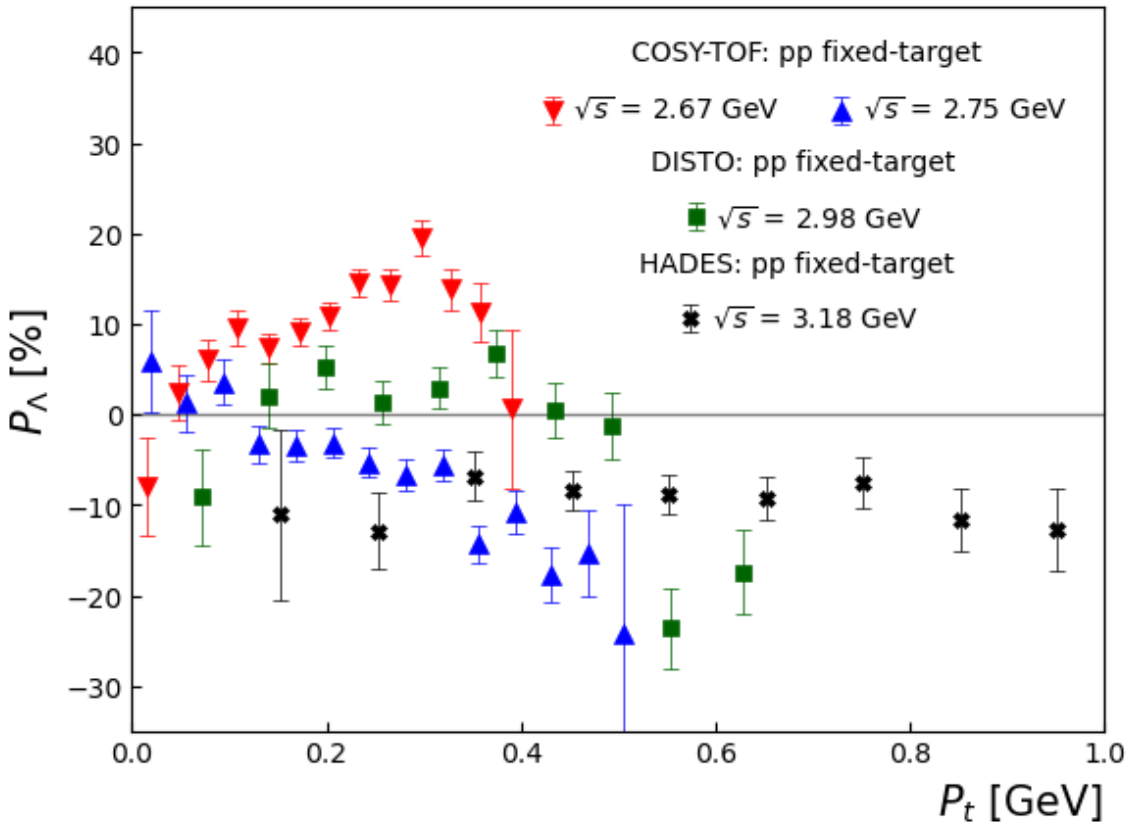
Polarizing Fragmentation Functions (TMD FFs) *Phys. Rev. D 63 (2001) 054029*

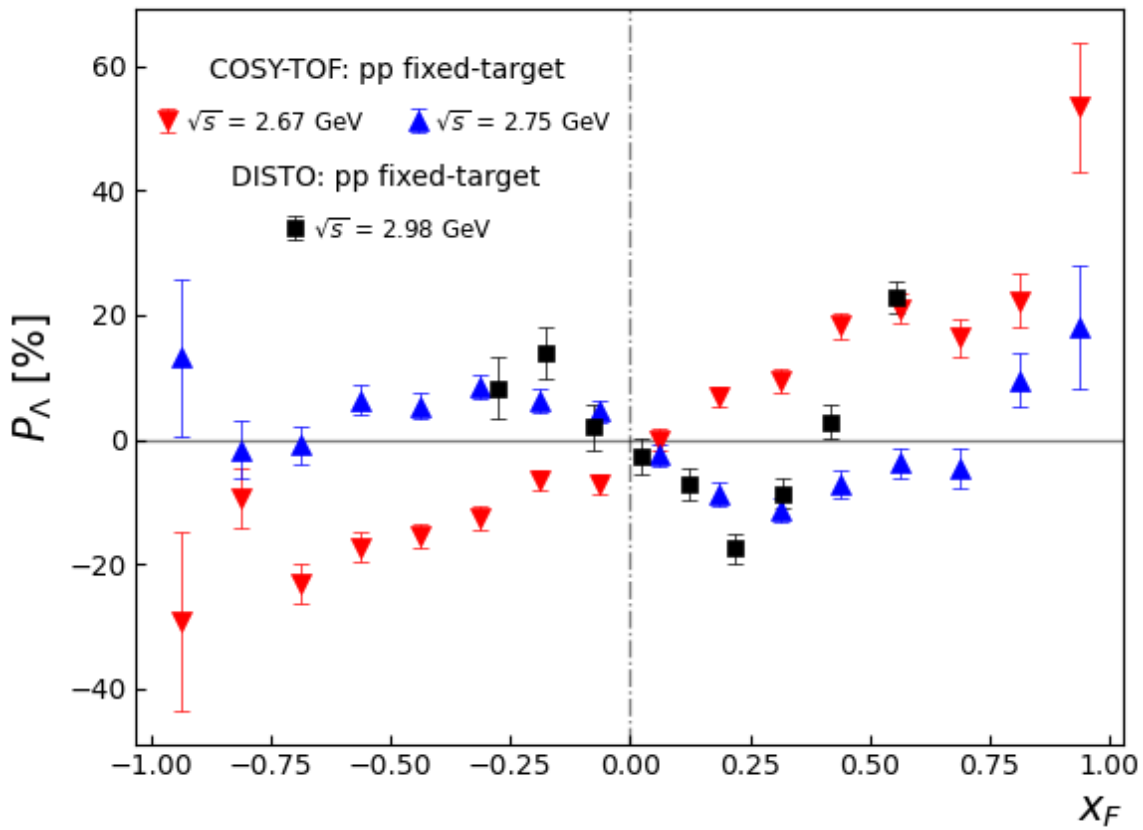
Twist-3 Factorization (Soft Gluon Poles)

Phys. Rev. Lett. 67 (1991) 2264

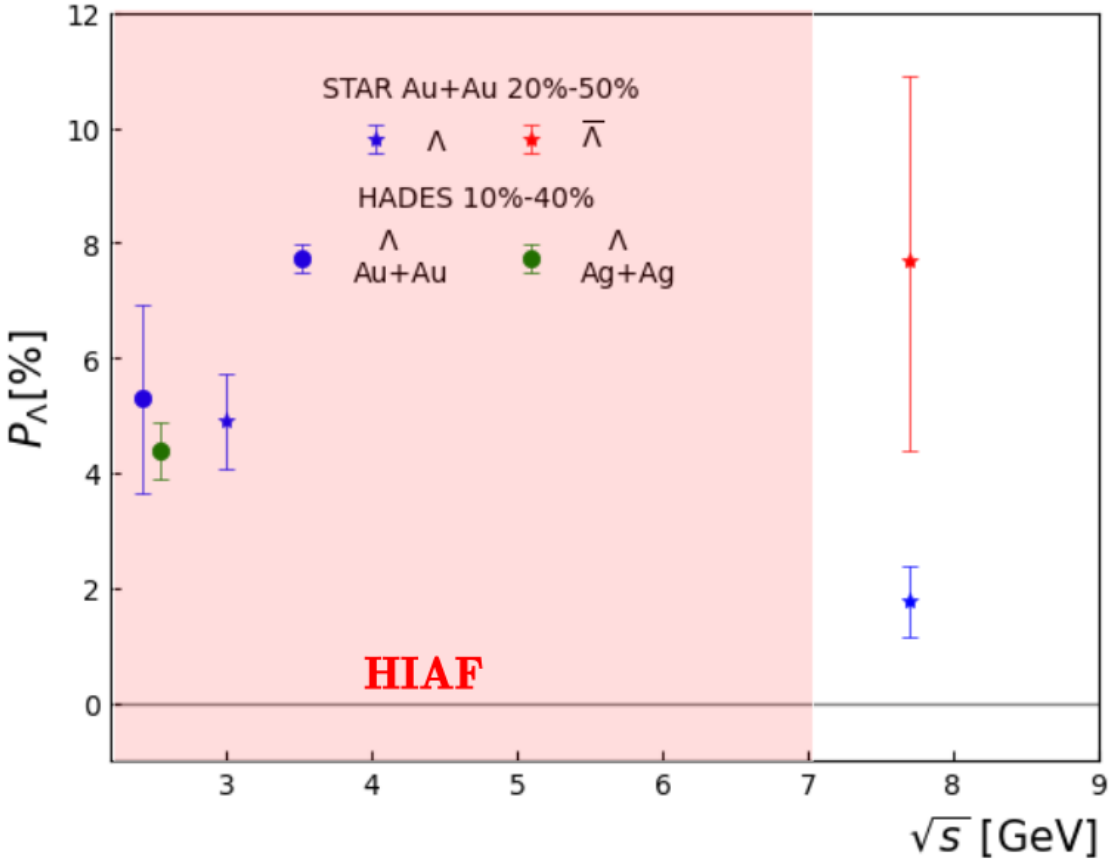
pQCD predicts that the polarization will be decreasing as energy increases

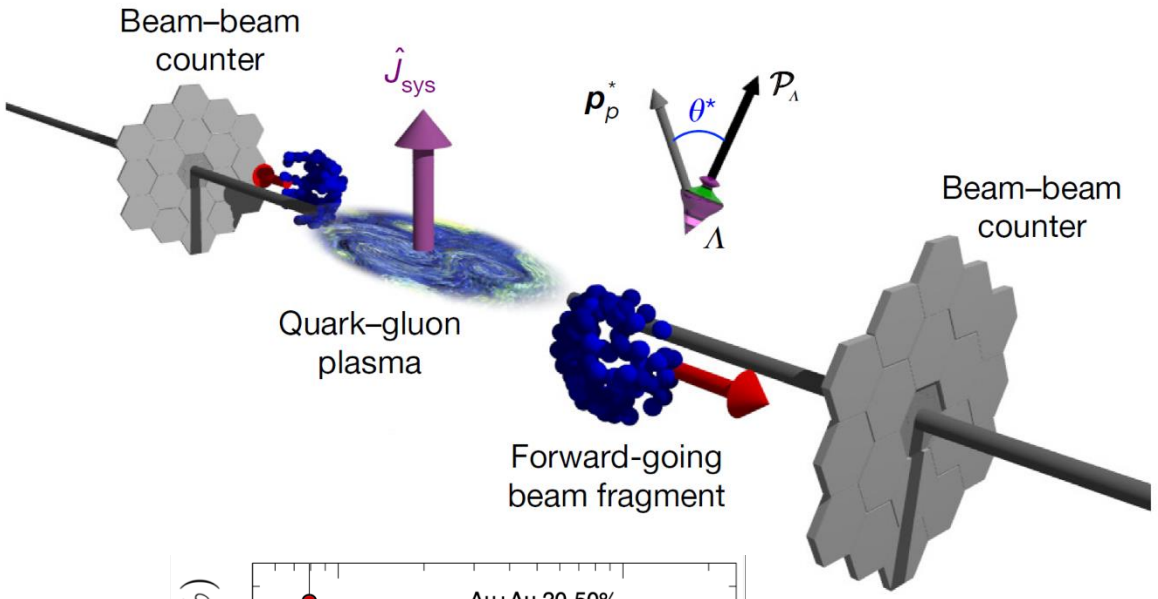
Puzzle in low energy collisions



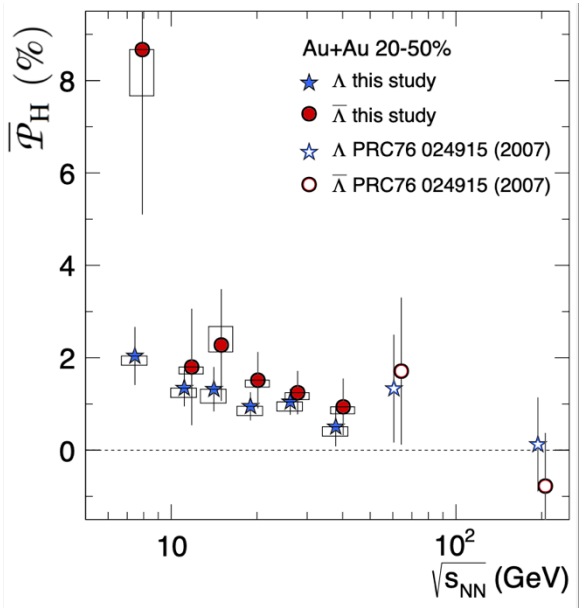


What's more? with A-A



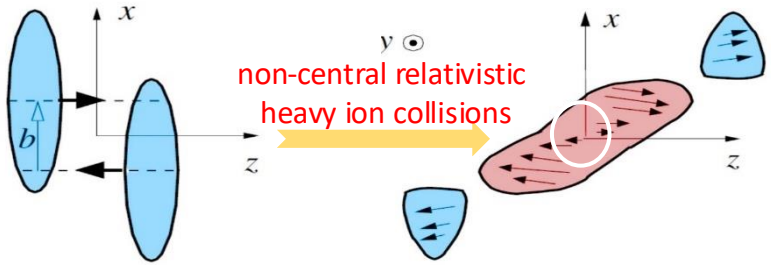


STAR实验证实Λ超子整体极化[Nature 548 (2017) 62]



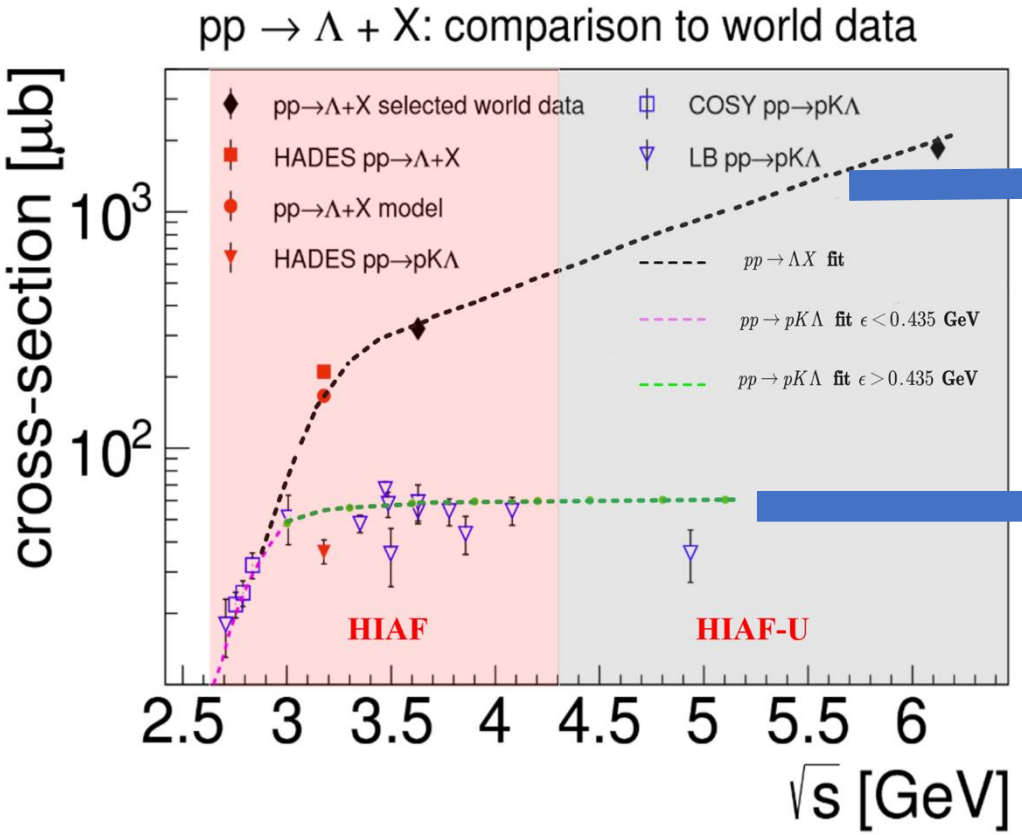
Study the hyperon polarization in different production mechanism

- 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**

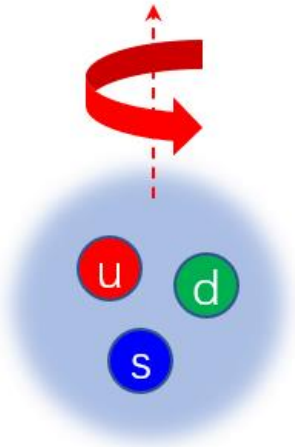
Zuo-tang Liang, and C. Boros, Phys. Rev. Lett. 79, 3608 (1997); PRD 61, 117503 (2000).
H. Dong and Zuo-tang Liang, PRD 70, 014019 (2004); PRD 72, 033006 (2005).

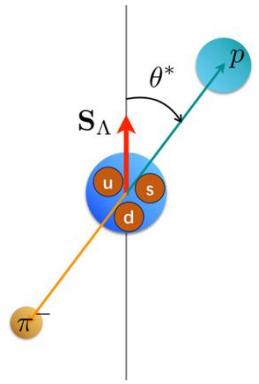
③ $pp \to pK\,\Lambda$ **Λ polarization in exclusive processes**

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

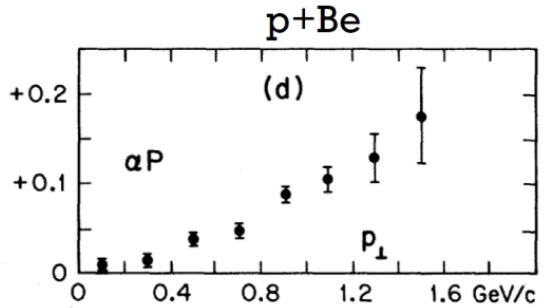
An interesting question: Is proton polarized as well?

pp → p K Λ





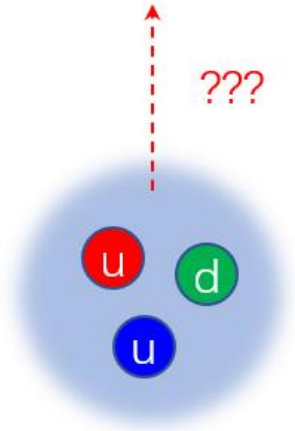
超子弱衰变角分布测量超子极化

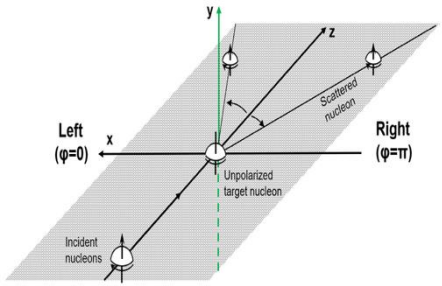


G.Bunce, *et al.*: Phys.Rev.Lett. 36, 1113-1116 (1976)

15

pp → p + X

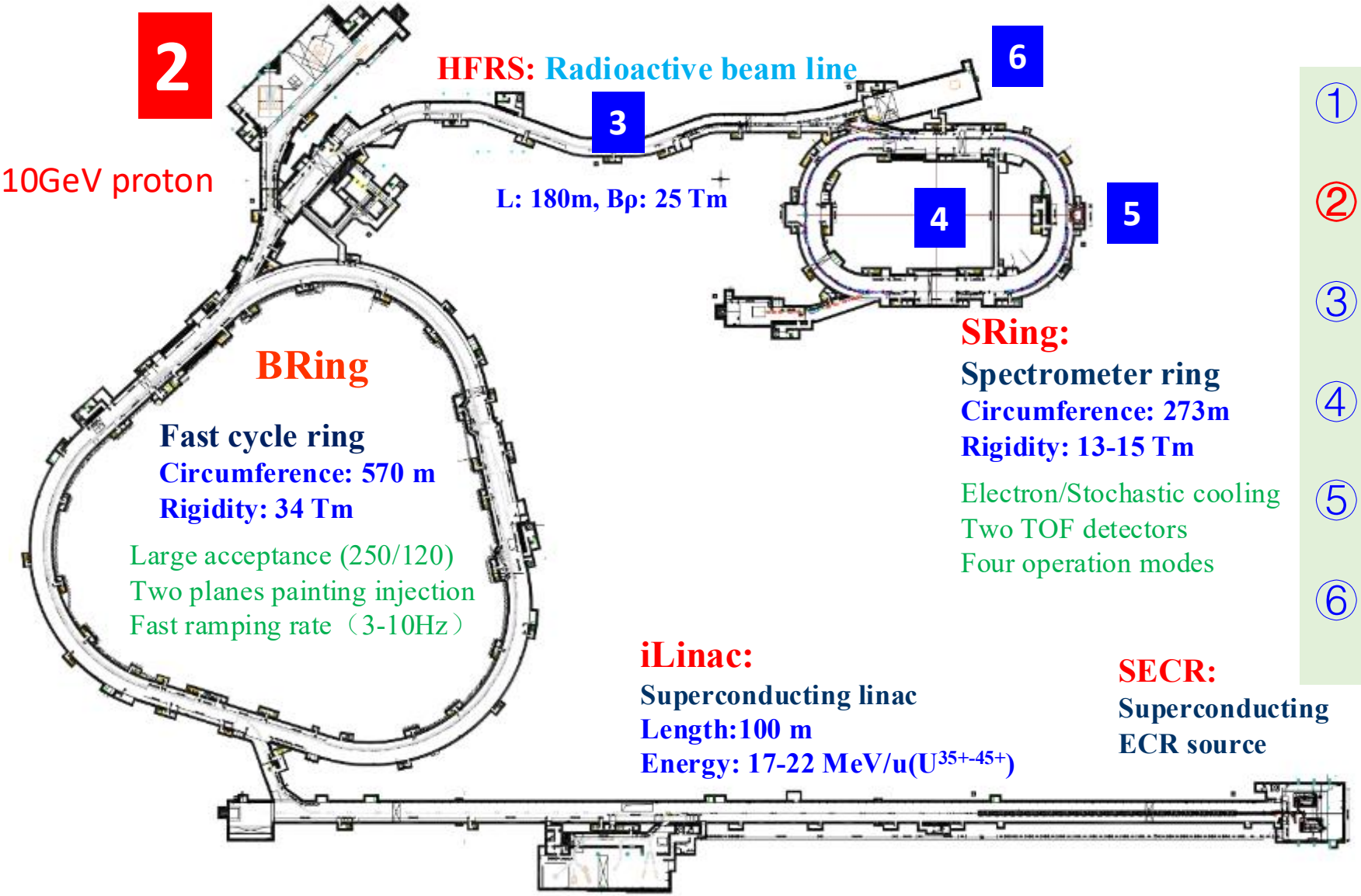




核核弹性散射测量核子极化

???

High Intensity heavy-ion Accelerator Facility (HIAF)



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.

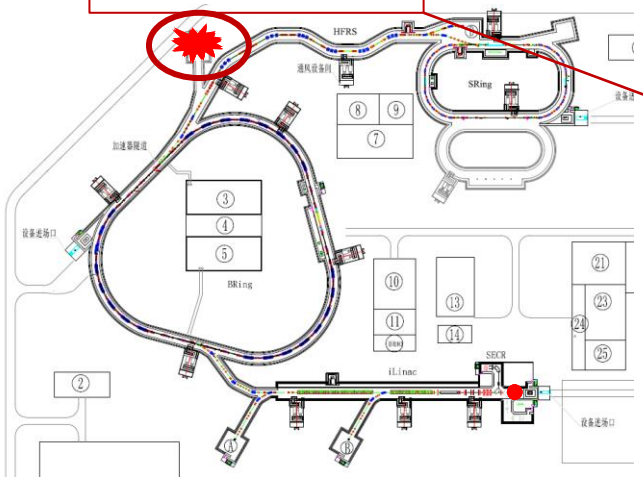


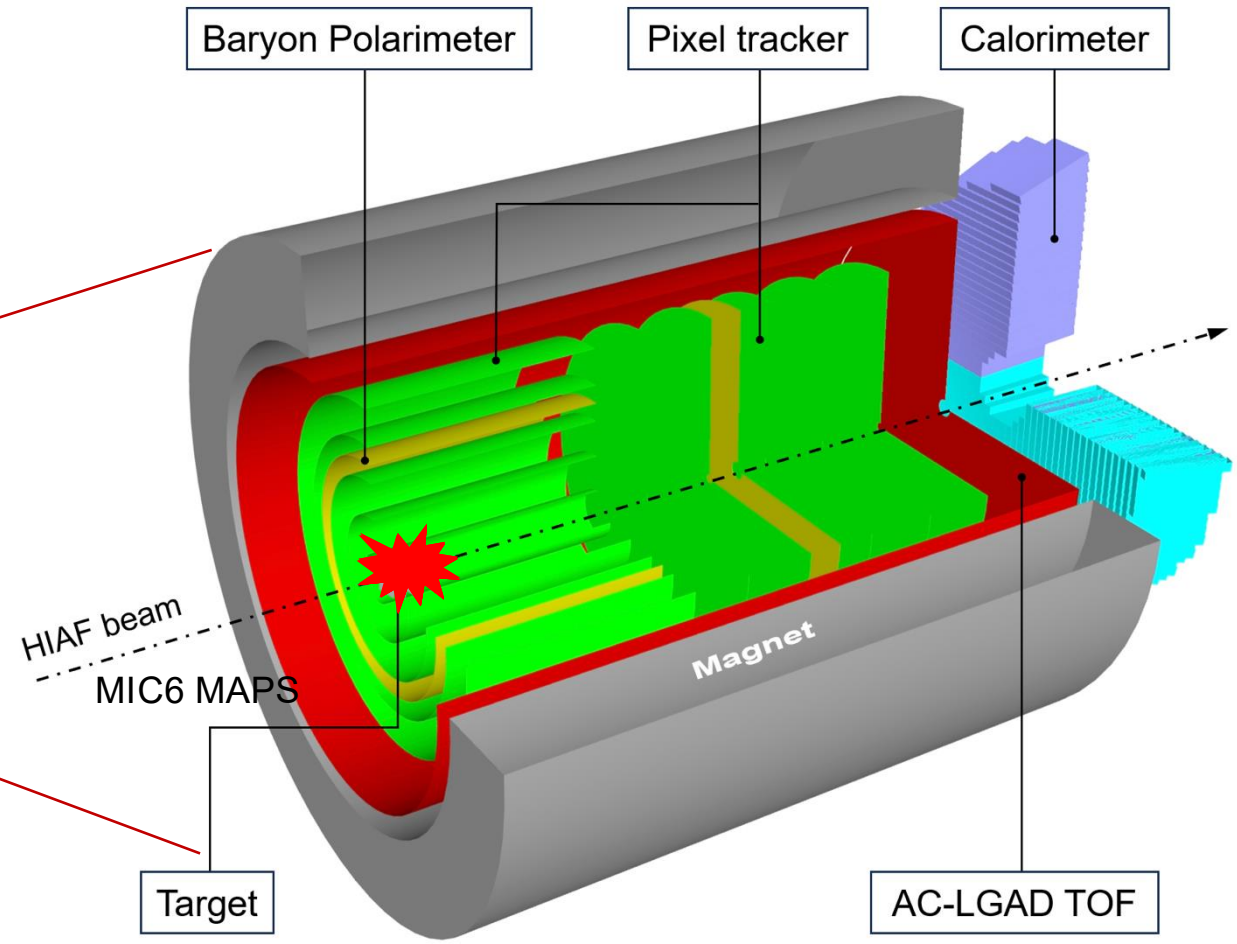
Hyperon Nucleon Spectrometer (H-NS)

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





HIAF beam parameters

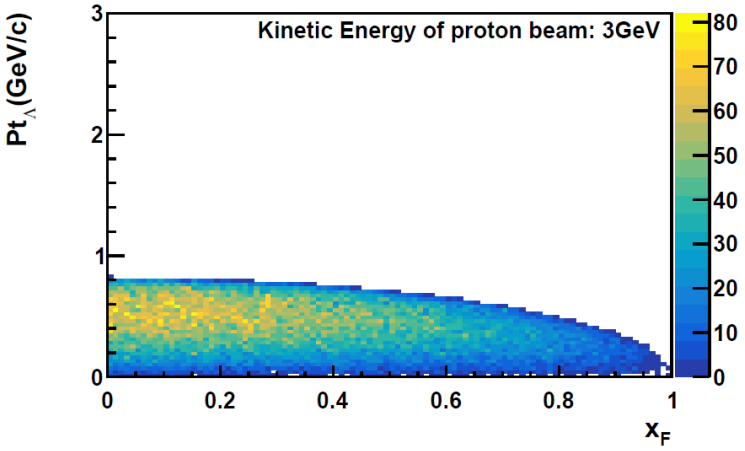
Ion	Intensity (ppp)	Kine_Energy (GeV/u)
$^{238}U^{35+}$	2.0×10^{11}	0.84
$^{238}U^{76+}$	5.0×10^{10}	2.5
$^{129}Xe^{27+}$	3.6×10^{11}	1.4
$^{78}Kr^{19+}$	5.0×10^{11}	1.7
$^{40}Ar^{12+}$	7.0×10^{11}	2.3
$^{18}O^{6+}$	8.0×10^{11}	2.6
p	5.0×10^{12}	9.3

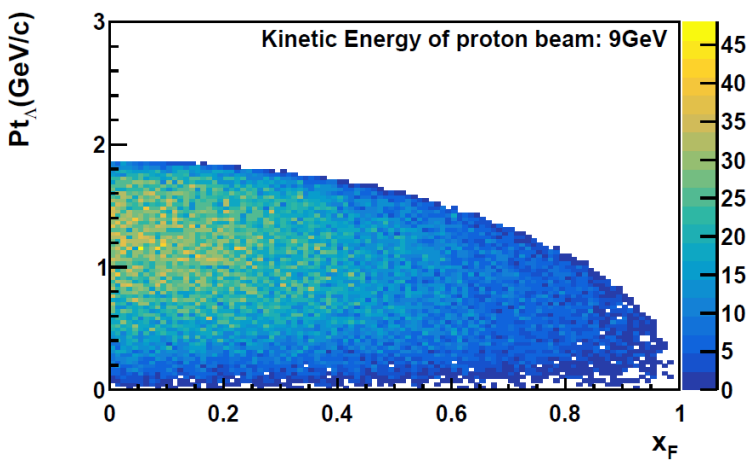
HIAF beam parameters

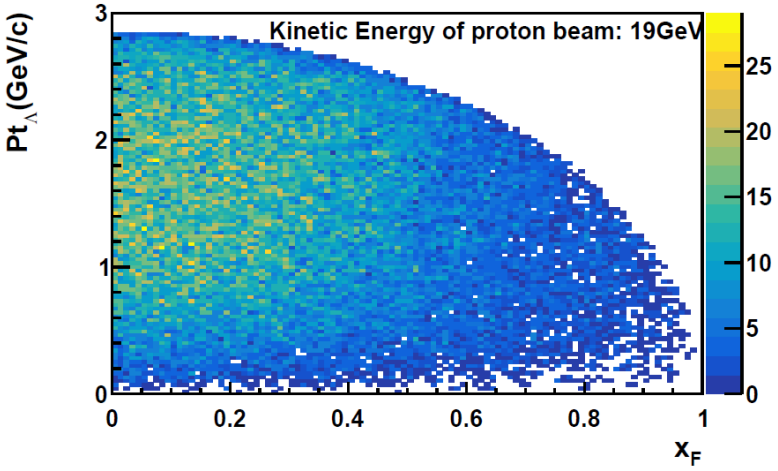
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p	5.0×10^{12}	9.3

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







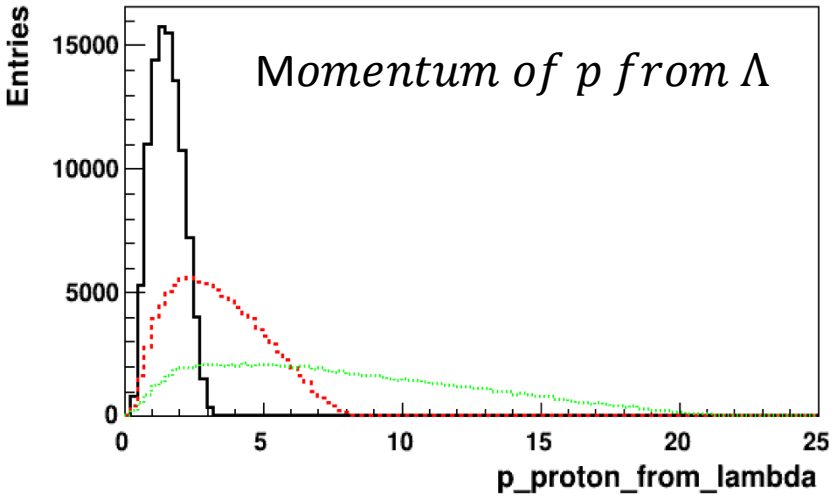
3 GeV → 9 GeV → 20 GeV

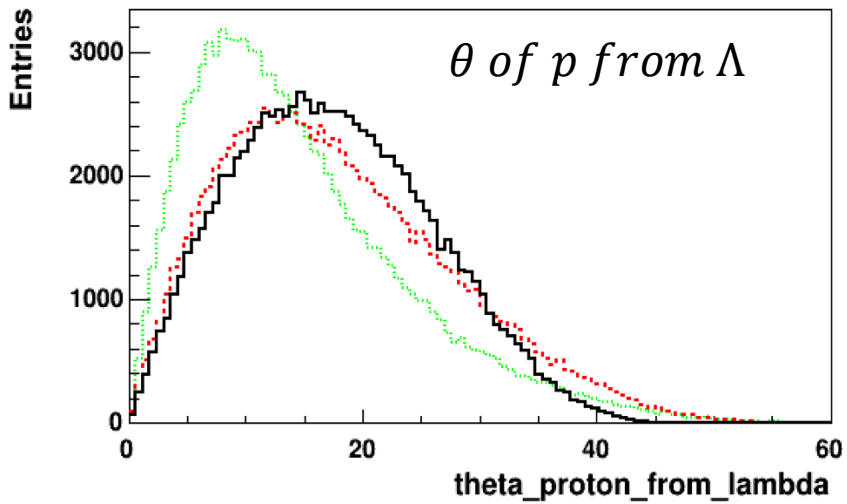
Allow for a multi-dimensional mapping of the Λ^0 polarization and production

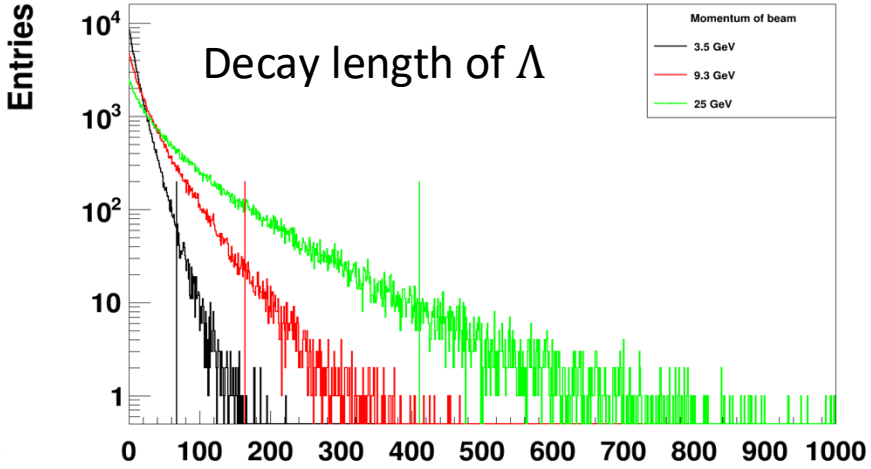
- Beam energy scan
- p→p, p→A, A→A data taking

The challenge

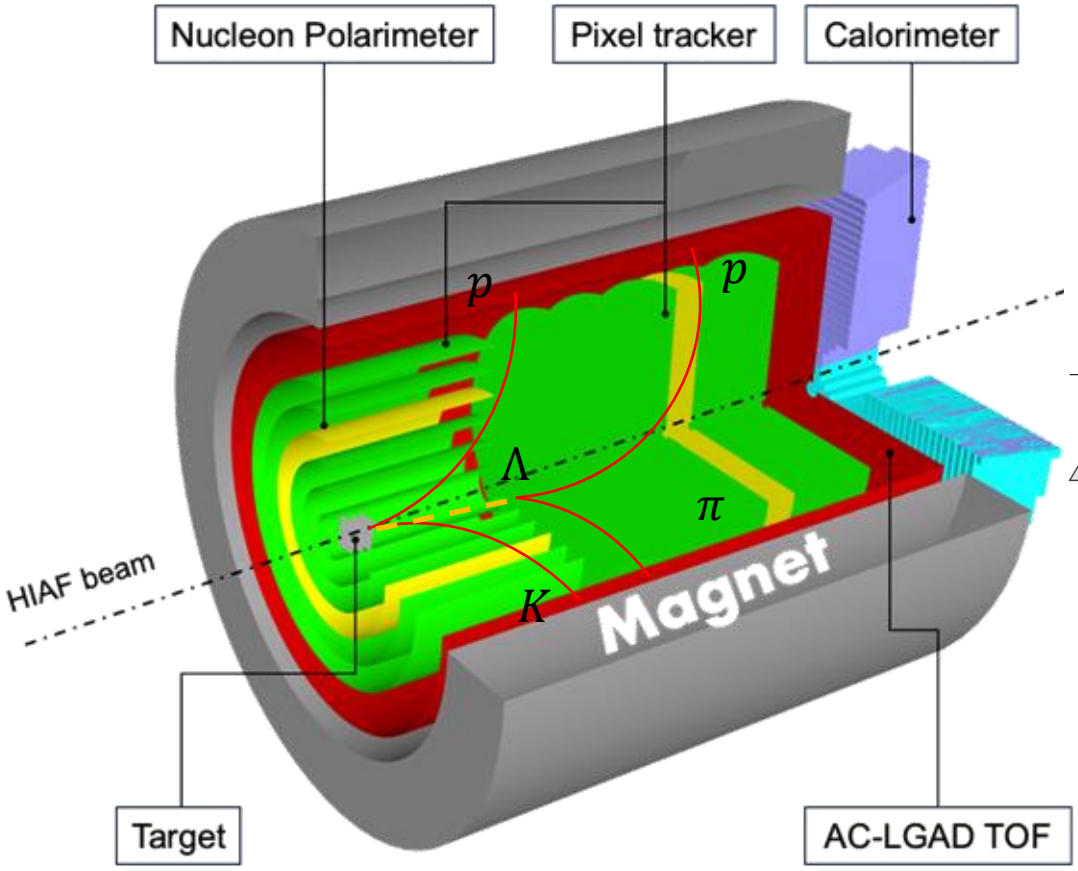
All the momentum, angular distributions and the Λ decay length are beam energy-dependent







H-NS Physics Requirements & Technical Challenges



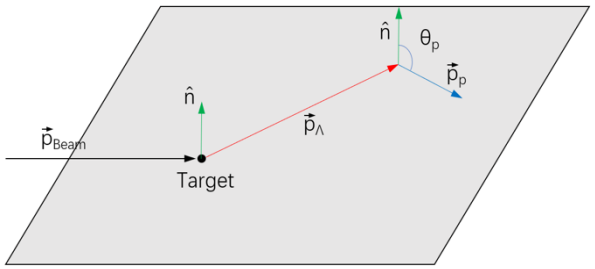
Technical challenges:

- Fast response: rate ~MHz level
- High momentum resolution, high position resolution, low material budget
- K, π, pparticle identification
- Radiation hard

Hyperon polarization

pp → p K^+ Λ;

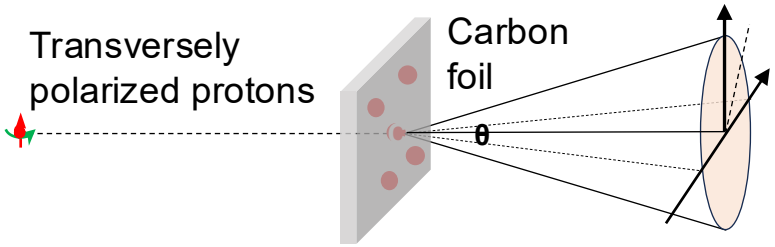
Λ → pπ



$$\frac{dN}{d\Omega} = N_0(1 + \alpha \mathcal{P} cos\theta),$$

Proton polarization

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



Compact design: R<1m

Large acceptance:

- 5 to 100 degree

High event rate

- 100kHz - 1MHz (pp, pA)

Baryon polarization measurement

- Determine the final-state proton polarization

P resolution：~2%@1GeV (η<2.5)

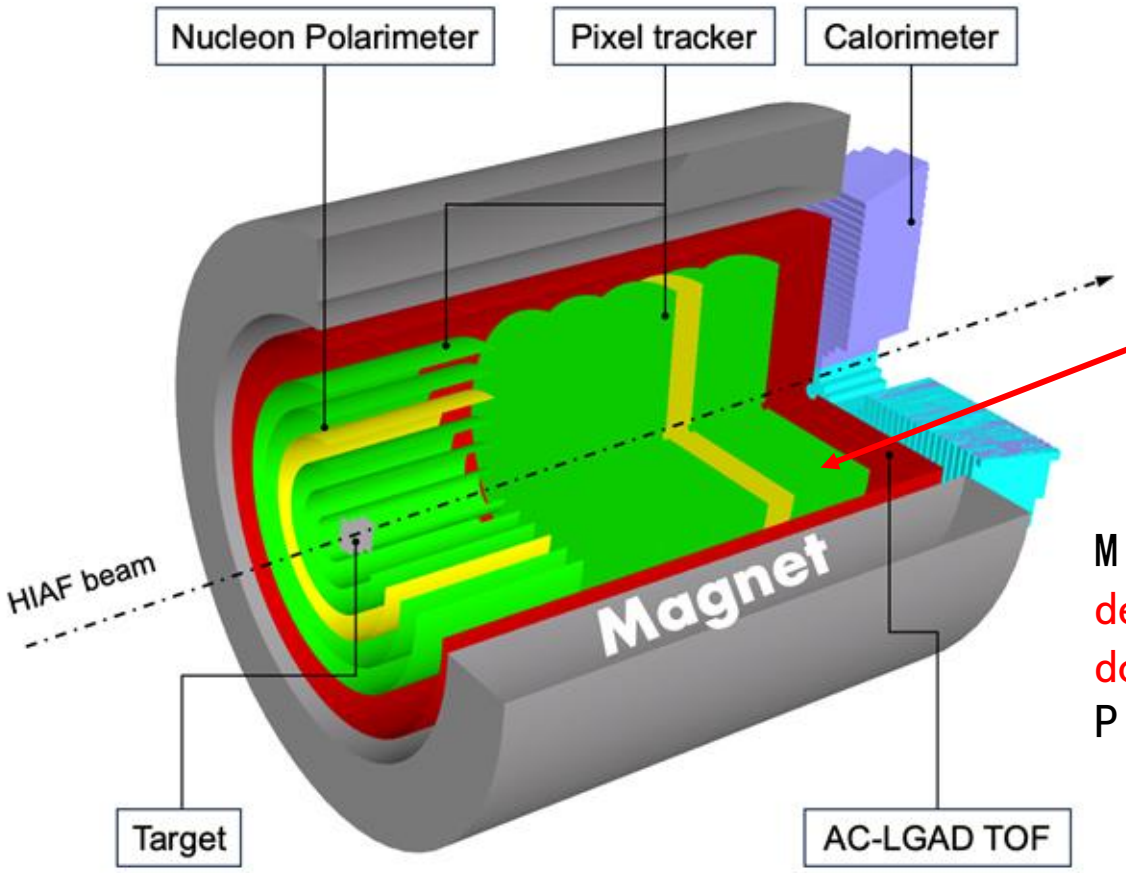
PID:

- K, π seperation (~3σ) up to 2 GeV/c
- K, p seperation (~3σ) up to 5 GeV/c

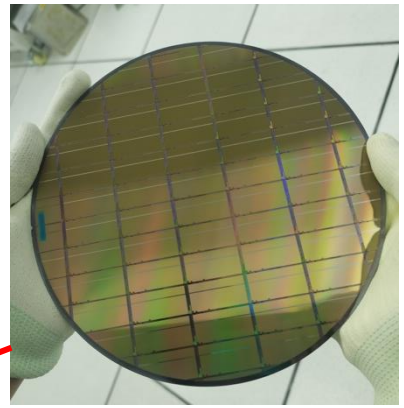
Vertex resolution:

- Excellent resolution(<500micron)
- Low material bugdet(<10% X/X_0)

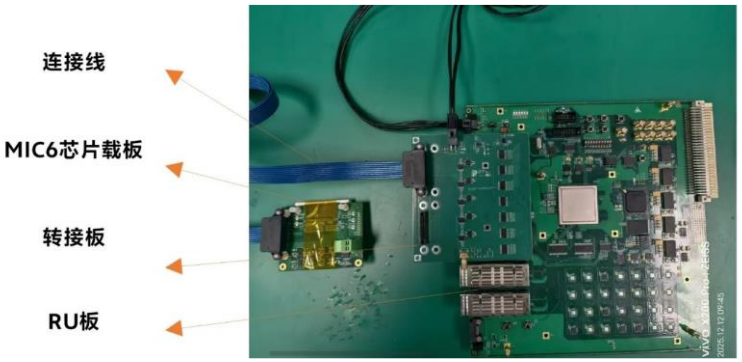
H-NS Tracking Detector System



MIC6 V3 wafer



MIC6 V3 test system

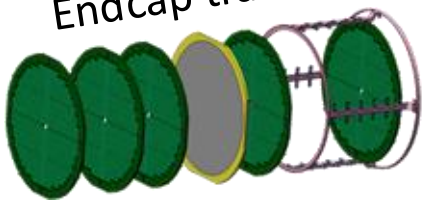


MIC6 MAPS pixel chip:
developed and fabricated with domestic technology
Pixel size: 30 μm
- material: 0.8% X/X_0
- Integration time : 5-10 μs

Barrel tracking detector

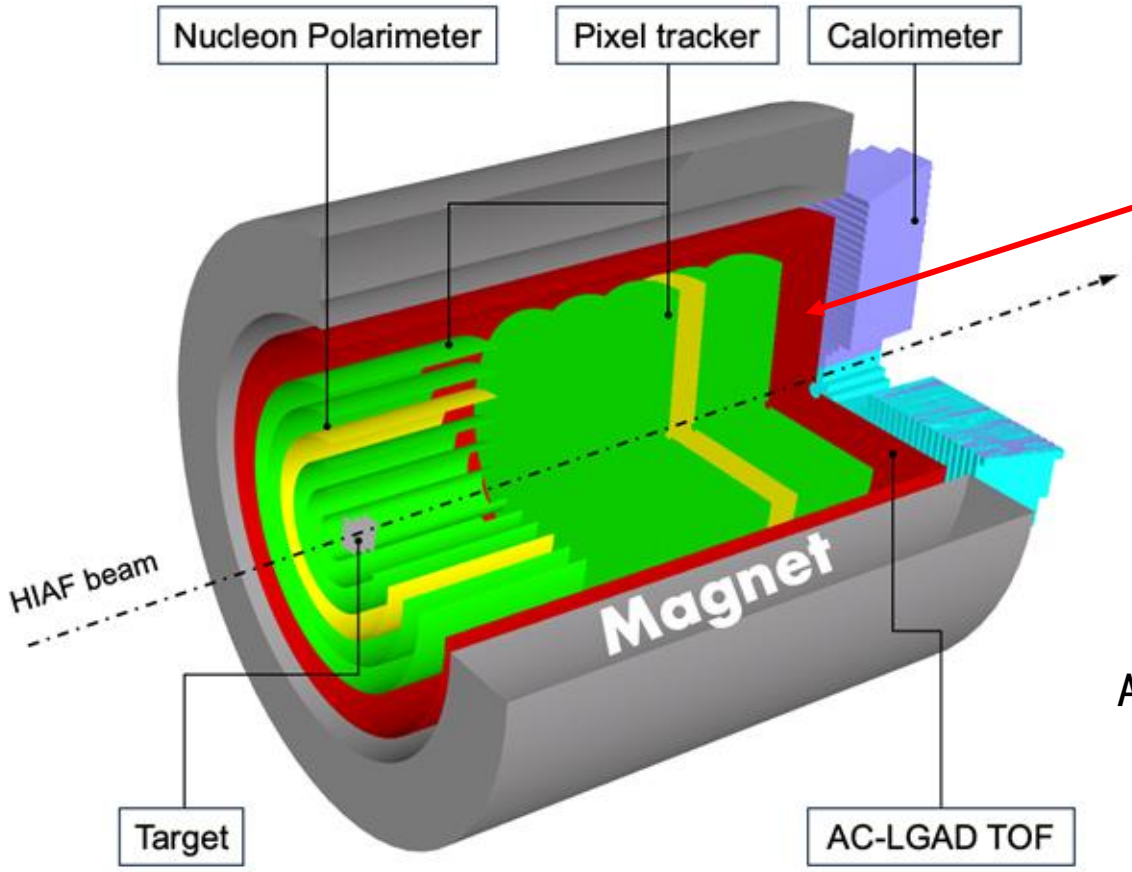


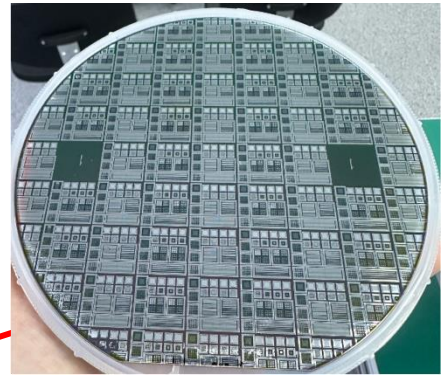
Endcap tracking detector

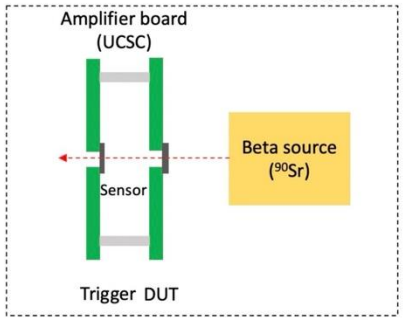


CCNU + USTC + IMP + NPU

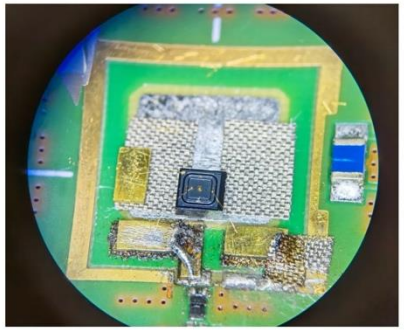
H-NS Particle Identification System



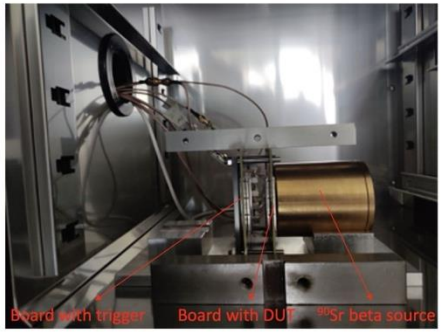




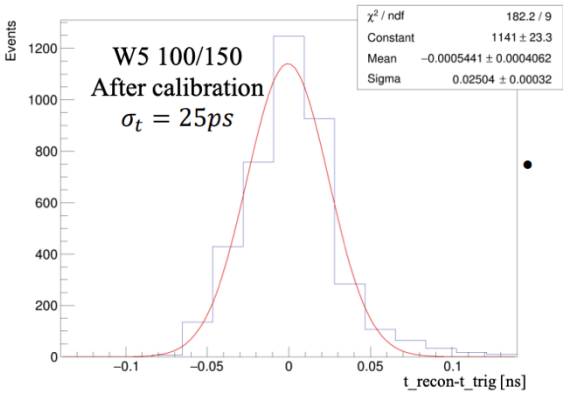
(a)



(b)

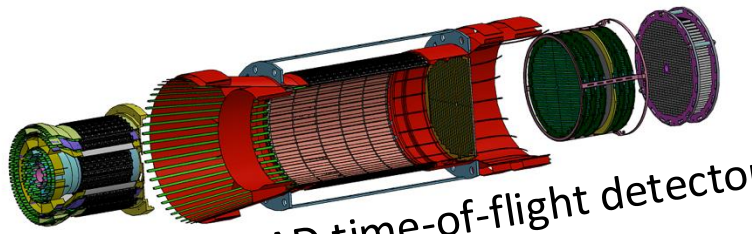


(c)



AC-LGAD

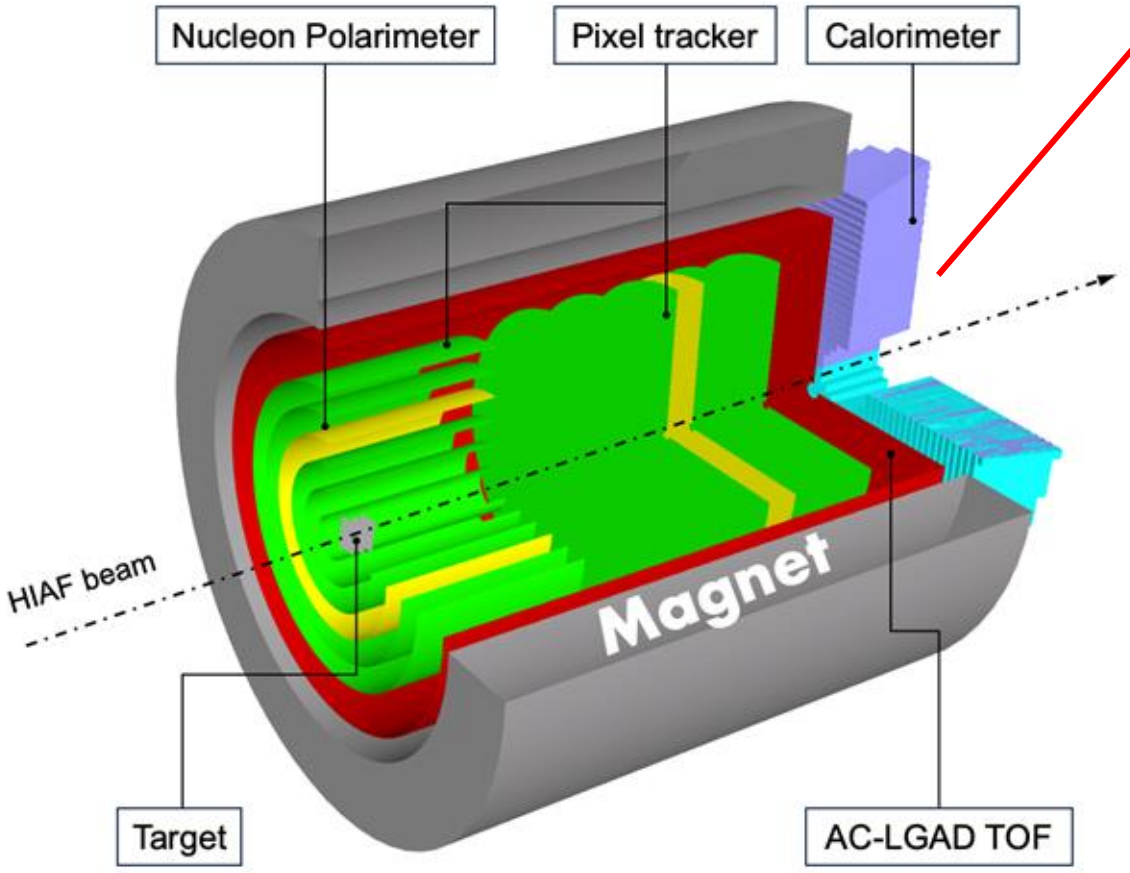
- Compact structure
- Time resolution : ~30 ps
- Spatial resolution : ~100



AC-LGAD time-of-flight detecto

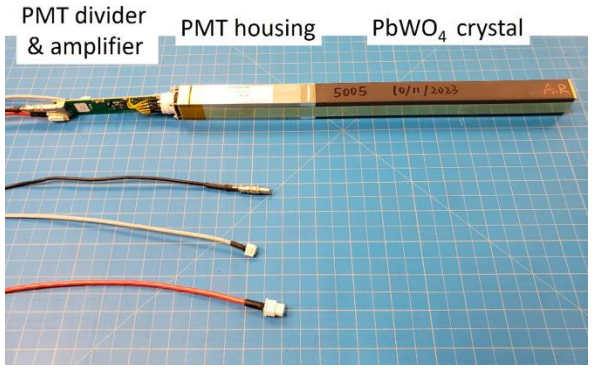
USTC + SDU + IMP + Tsinghua

H-NS Calorimeter System



Dual functions of the calorimeter system：

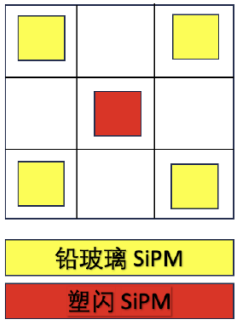
1. Reconstruct neutral particles etc., serving physics research γ, π^0, for physics research
2. High-performance calorimeter R&D platform supporting future experiments



PbWO4 crystal: compact volume, good energy resolution

- Energy resolution： $3\%/\sqrt{E}$
- Position resolution： ～3mm

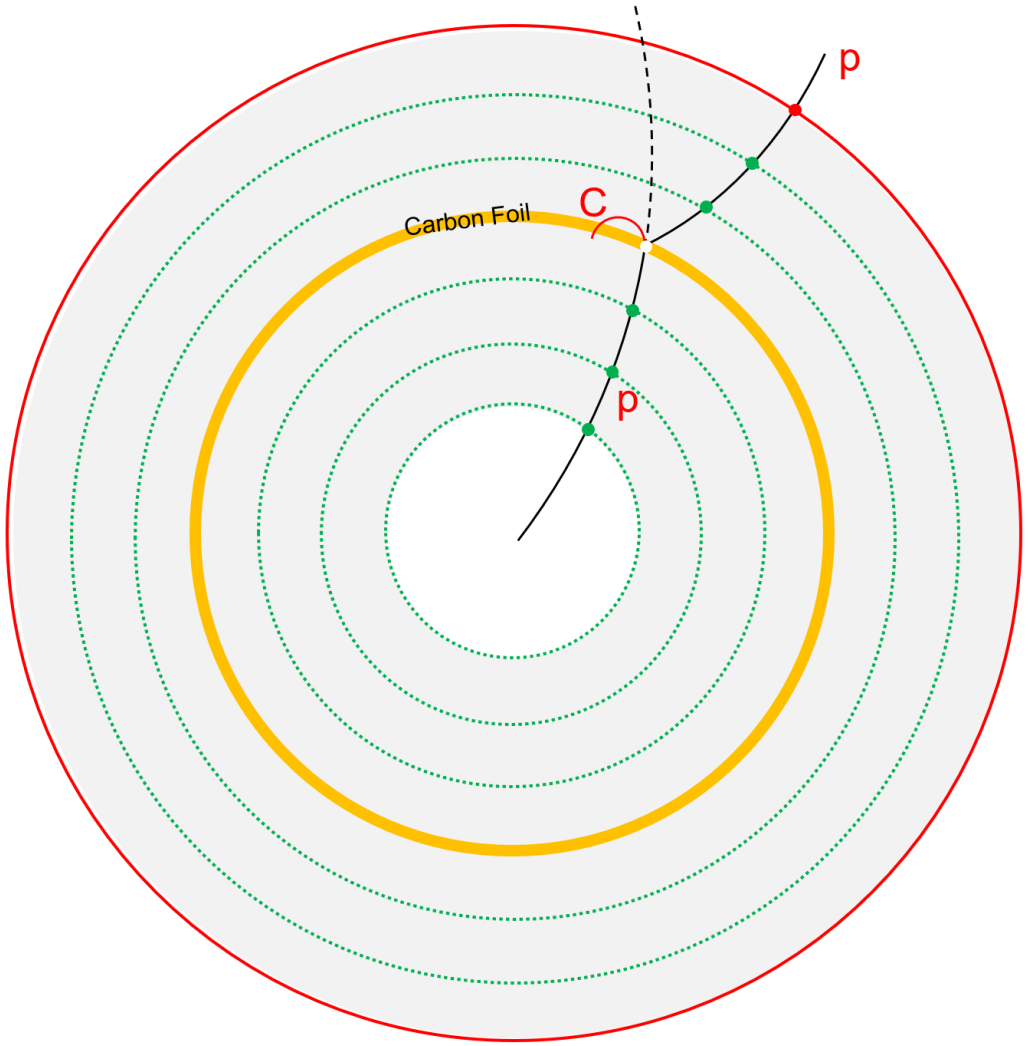




R&D of a dual-readout calorimeter with Cherenkov and scintillation light

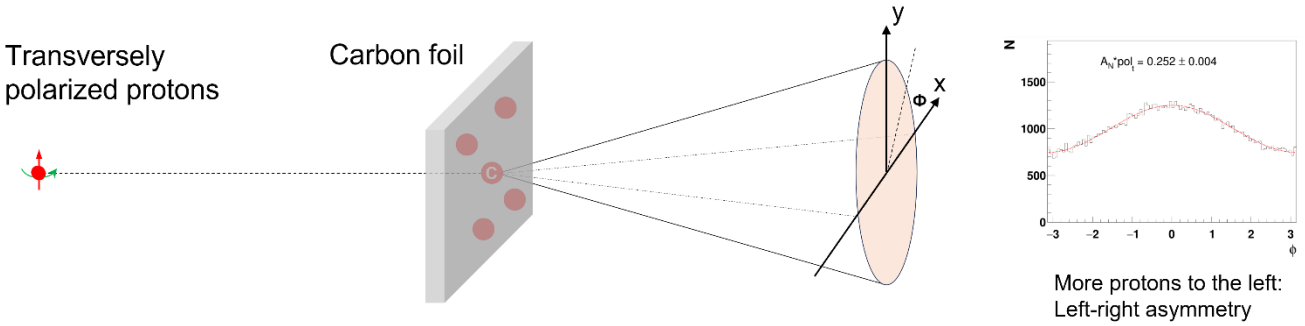
Tsinghua + Fudan + IMP

H-NS Baryon Polarimeter



Determine proton polarization via elastic scattering

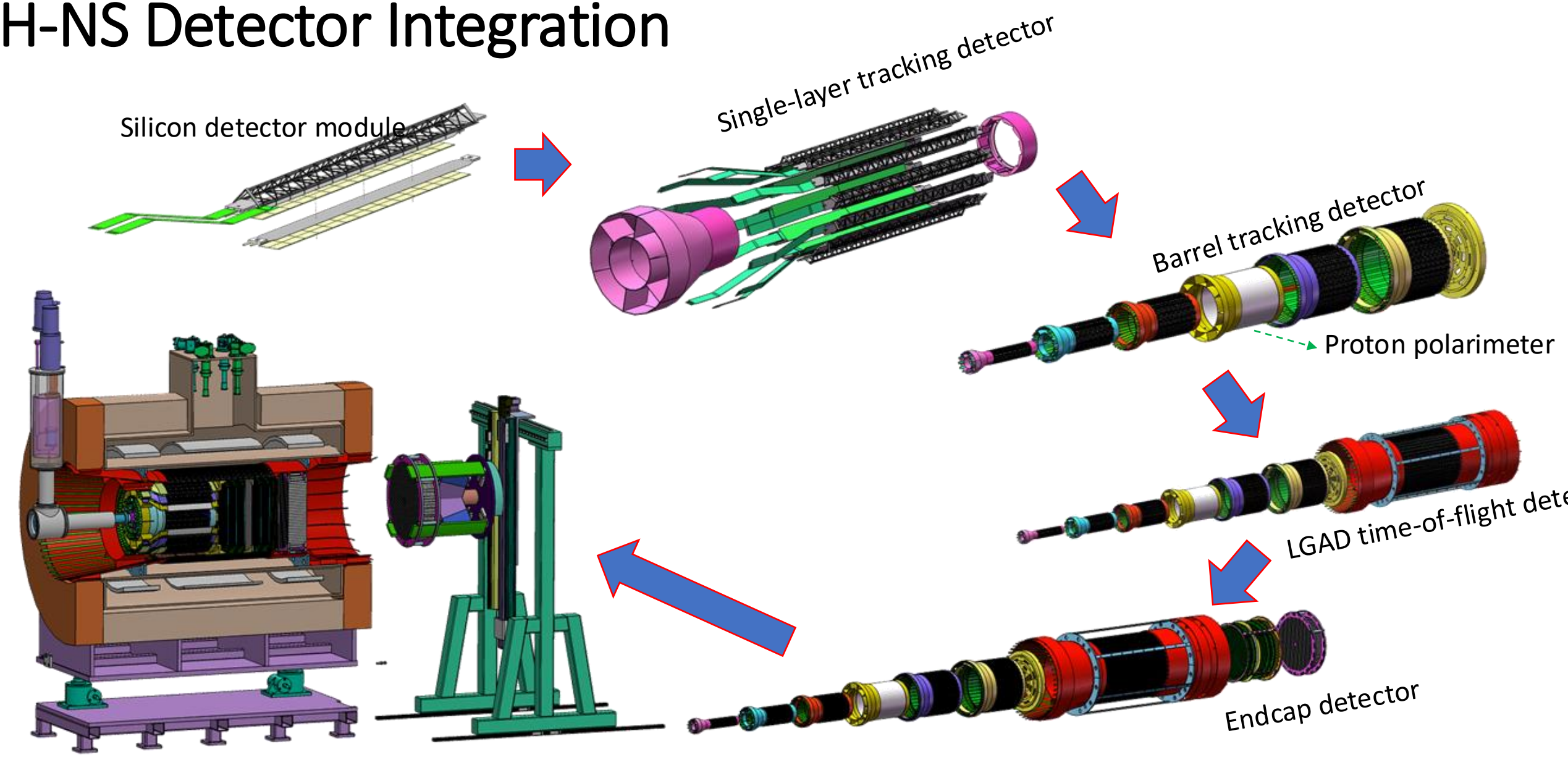
$$\frac{d\sigma}{d\phi d\cos\theta} = \frac{1}{2\pi}\frac{d\sigma_0}{d\cos\theta}\left[1 + P_y A_N(\theta)\cos\phi\right]$$



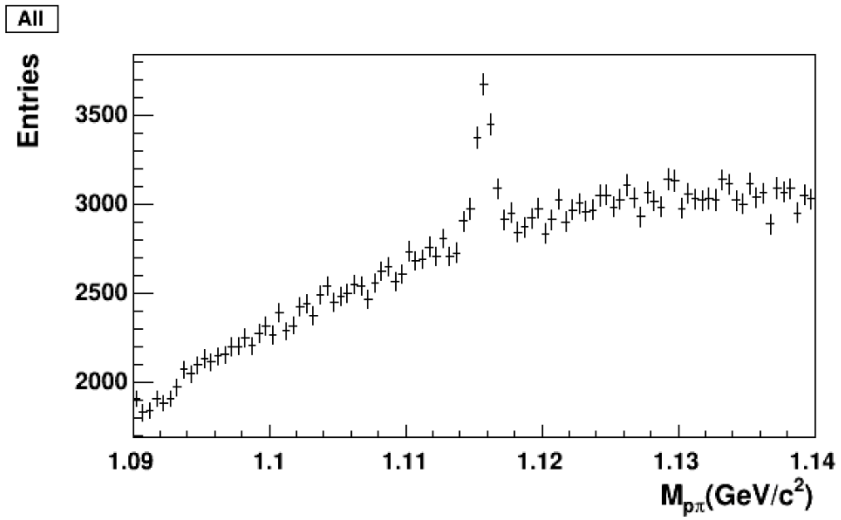
- **Carbon target layer**
  - **~1 mm thickness**
  - **Material budget: <1% X/X0**
  - **Reaction probability: pC (1E-3)**
- **Position: in the middle of the tracker**

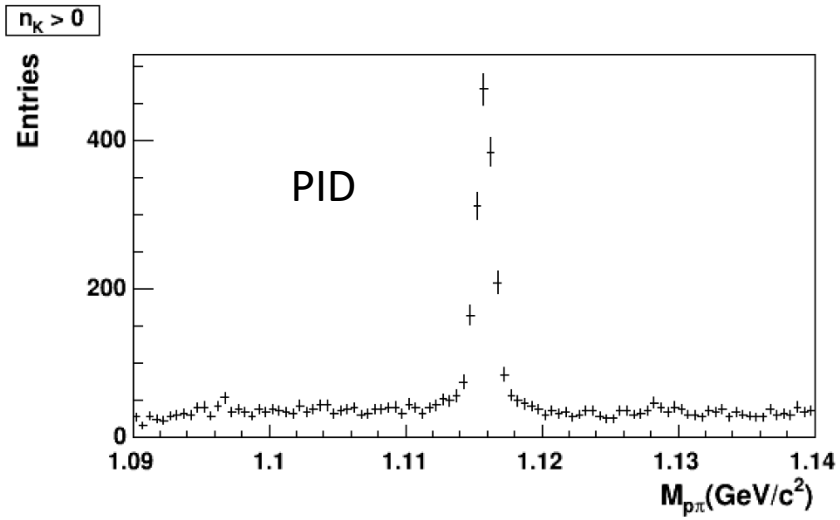
Y. T. Liang et. al. Phys. Rev. D 112, L031502 (2025)

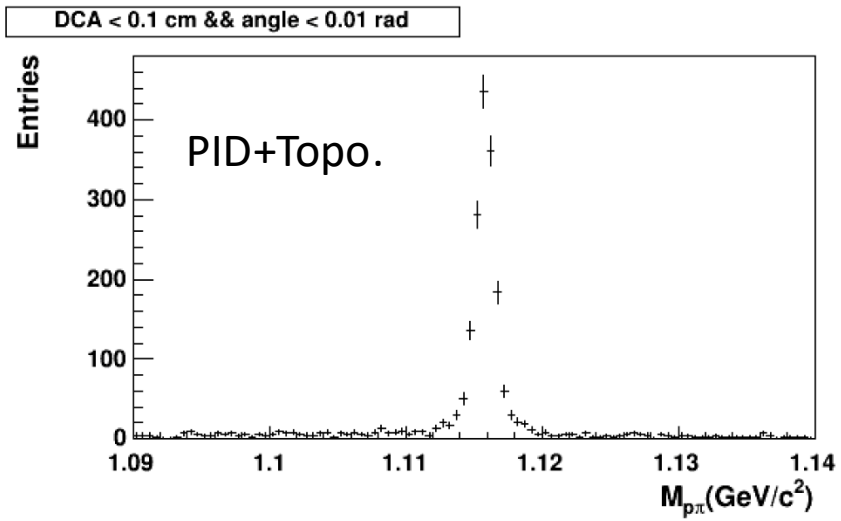
H-NS Detector Integration

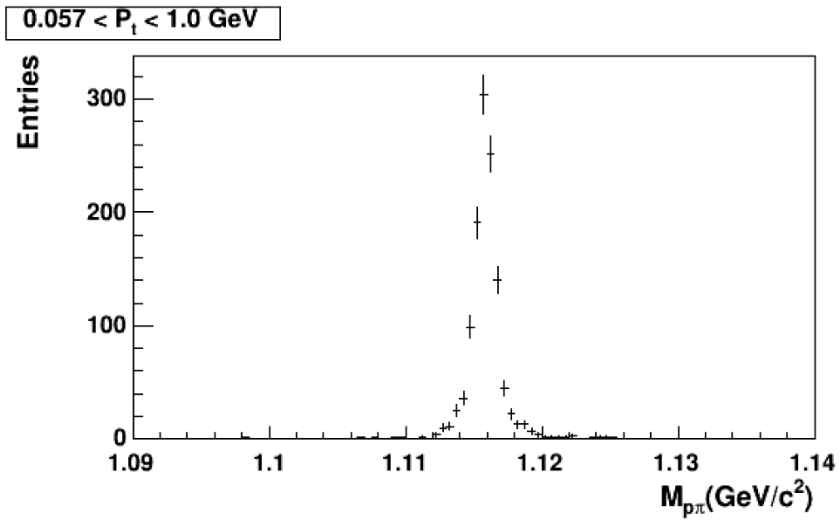


Λ^0 reconstruction in H-NS









Uncertainty projection of the polarization measurement

pp → pKΛ

pp →Λ+X

H-NS

Reaction: p+p

Event rate:1MHz

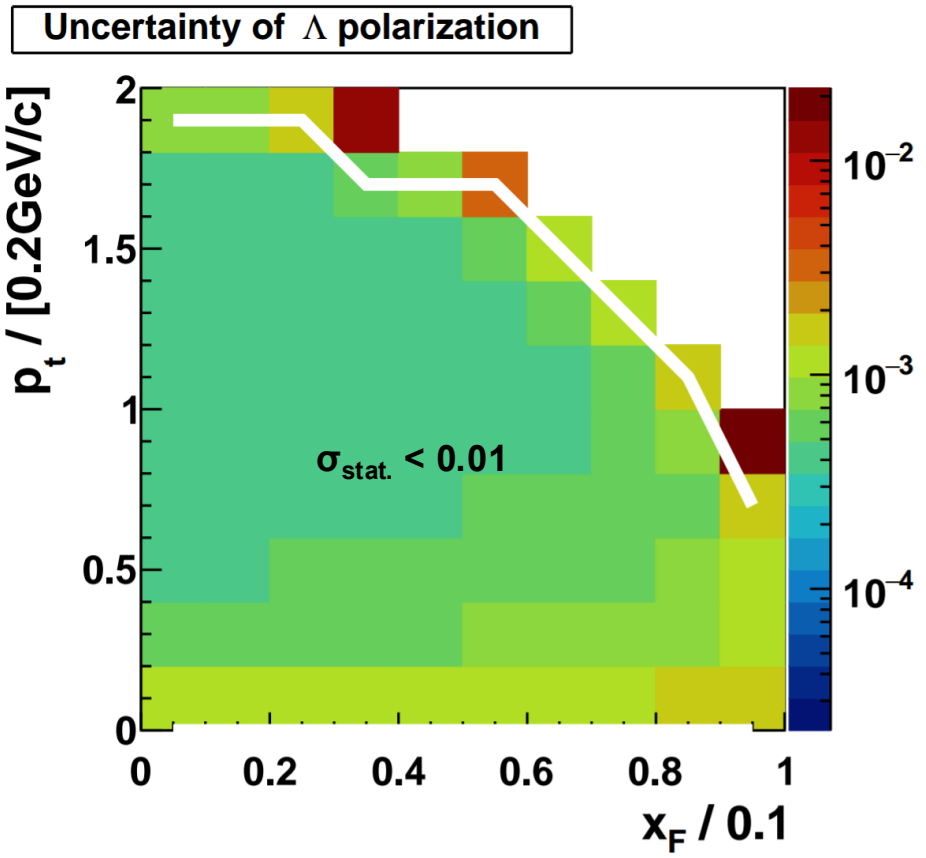
Time: 3 months

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

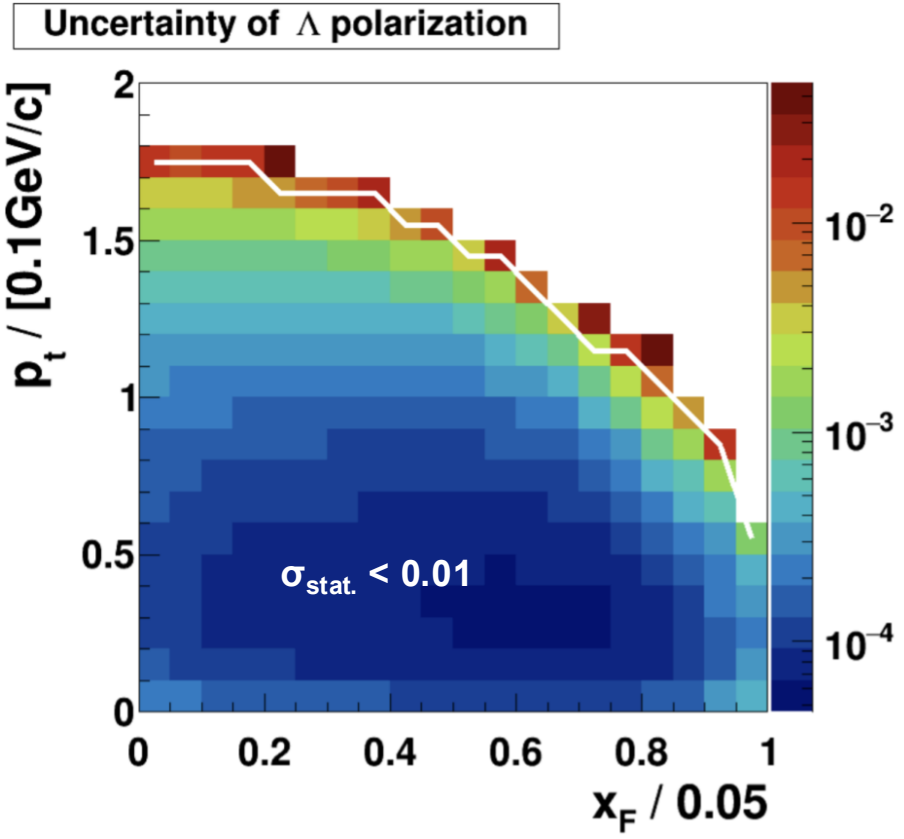
$\sigma_{stat.}$ < 0.01 for Λ 100 bins

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

Exclusive measurement



Inclusive measurement



Uncertainty projection of the polarization measurement

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}

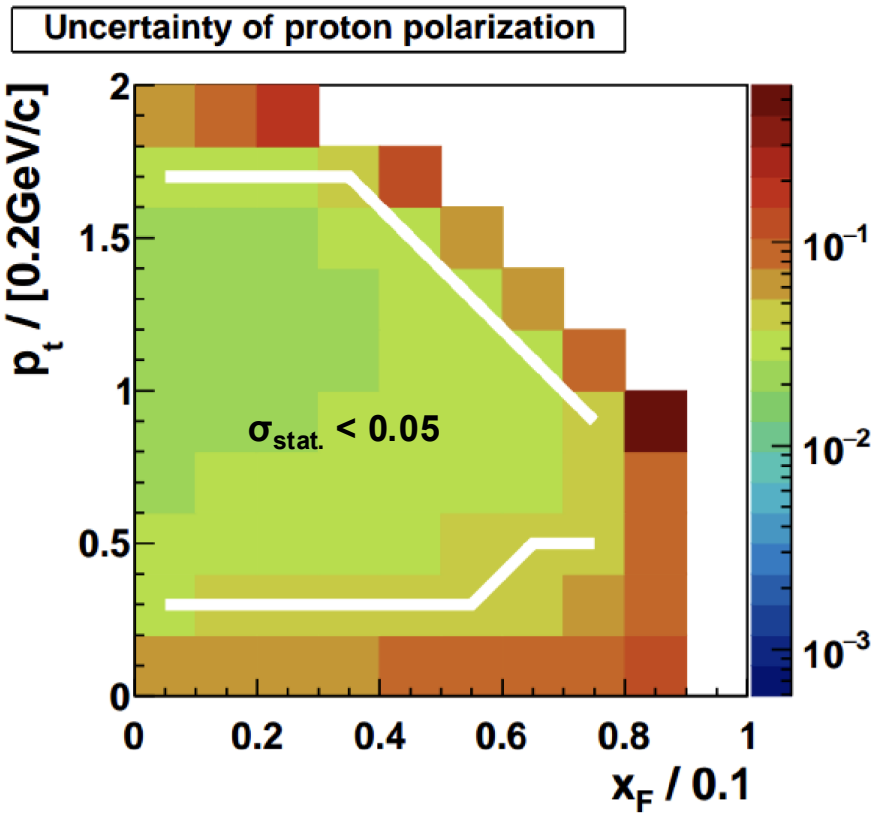
pp → pKΛ

pp → p + X

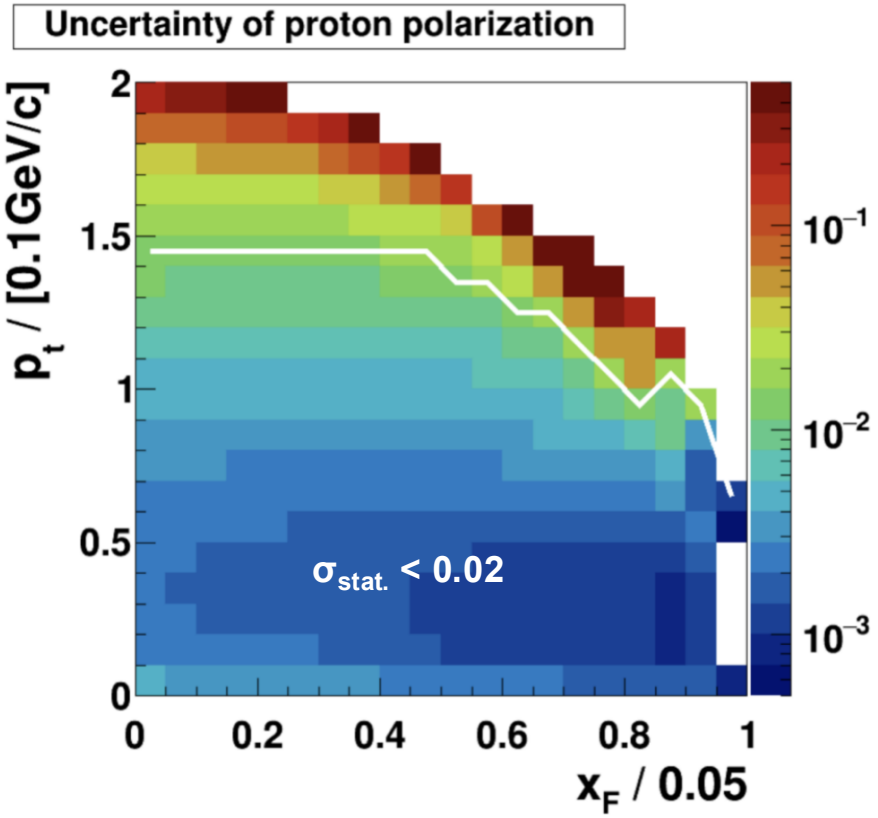
$\sigma_{stat.}$ < 0.05 for p 100 bins

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

Exclusive measurement

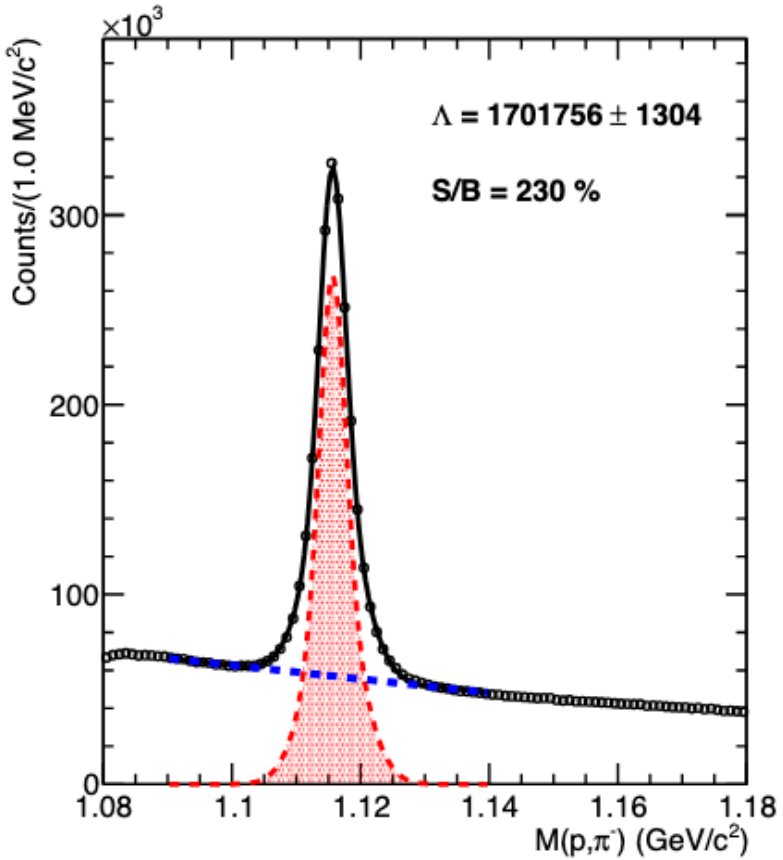


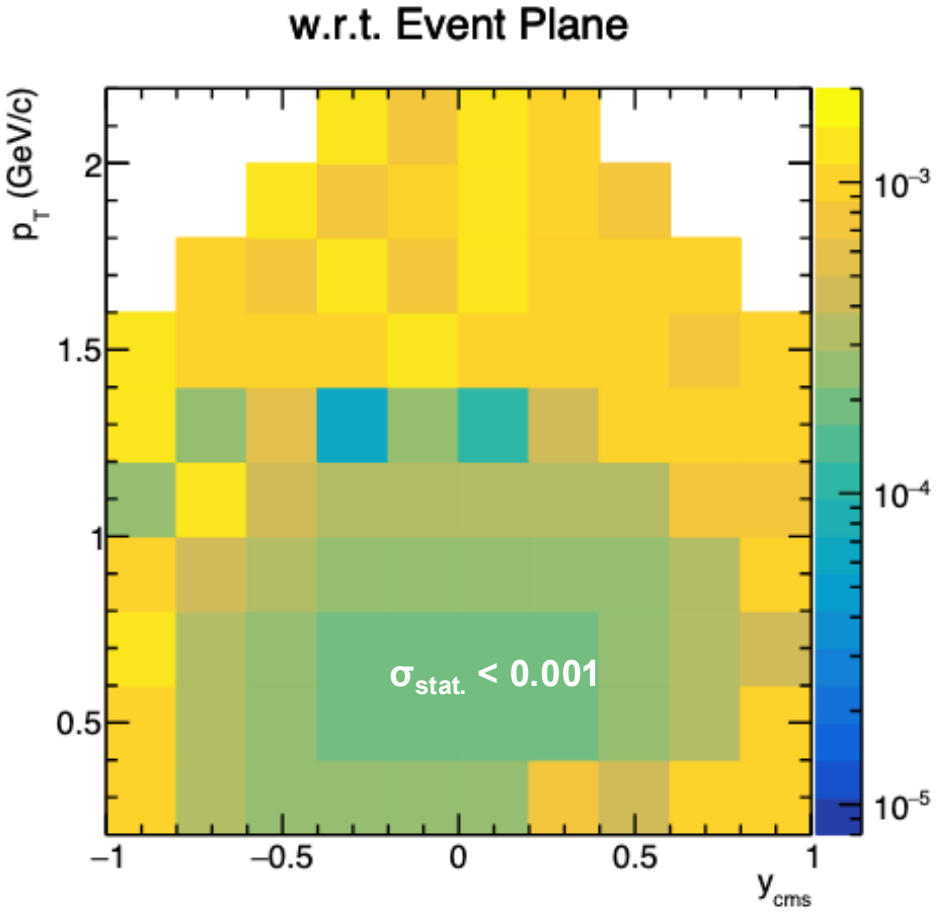
Inclusive measurement



Uncertainty projection of the Global polarization in A-A

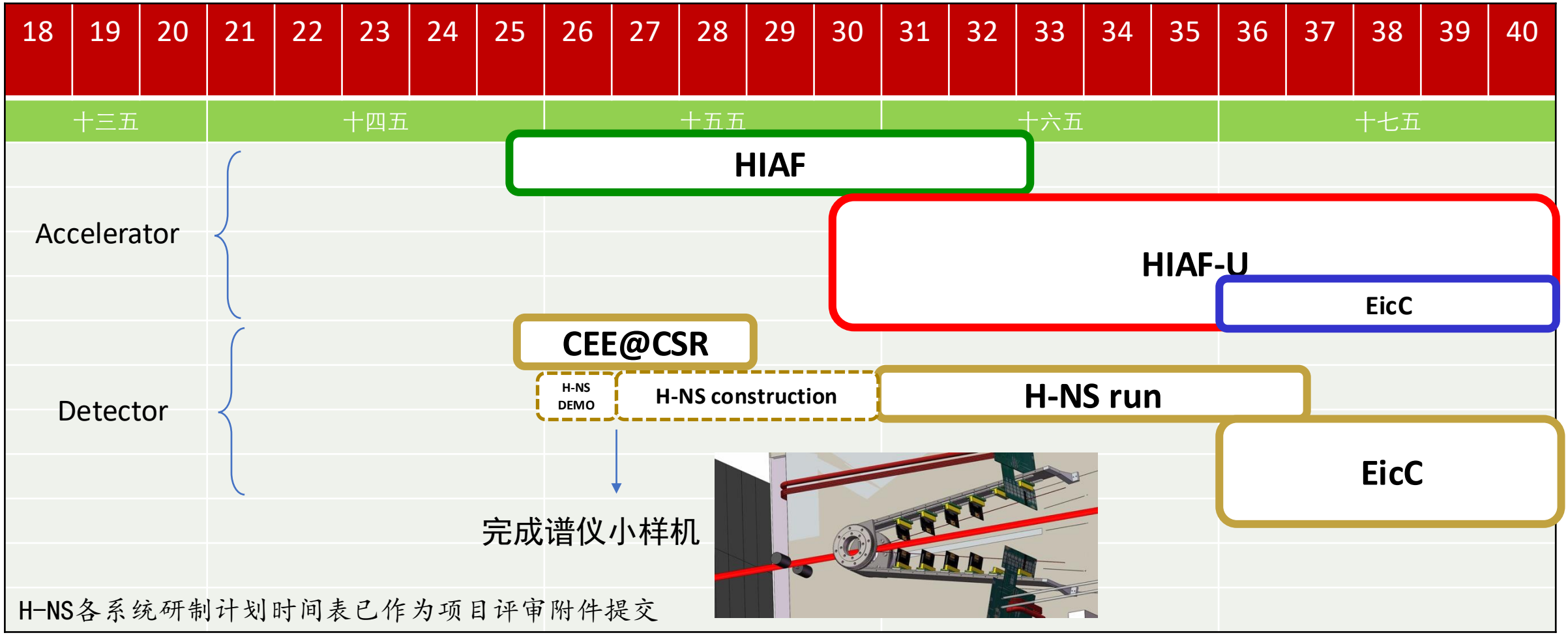
Au+Au events at beam kinetic energy of 2.8 GeV/u





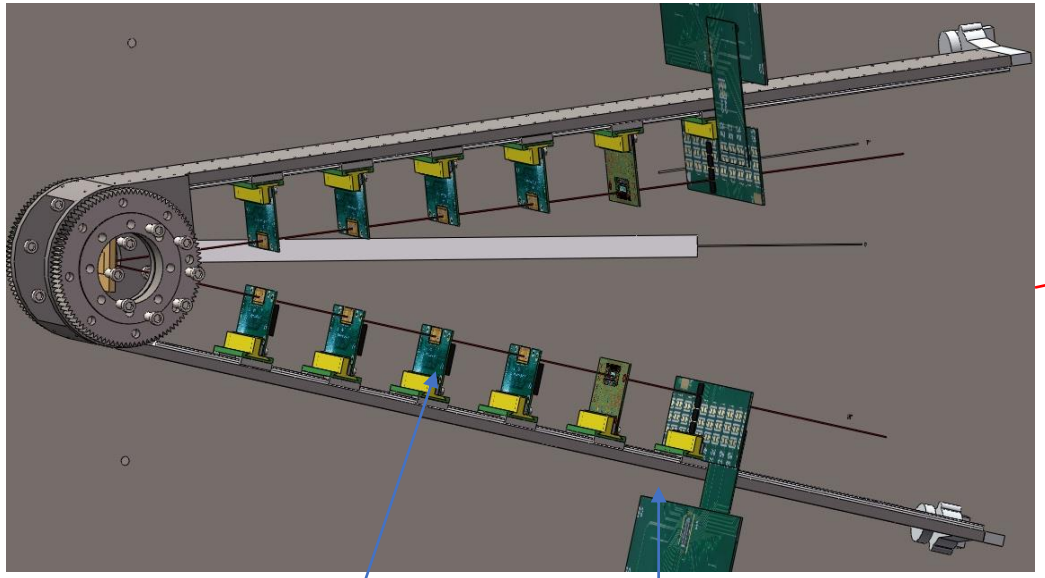
2D uncertainty of Λ polarization using 10^{11} Au+Au events, few weeks data taking

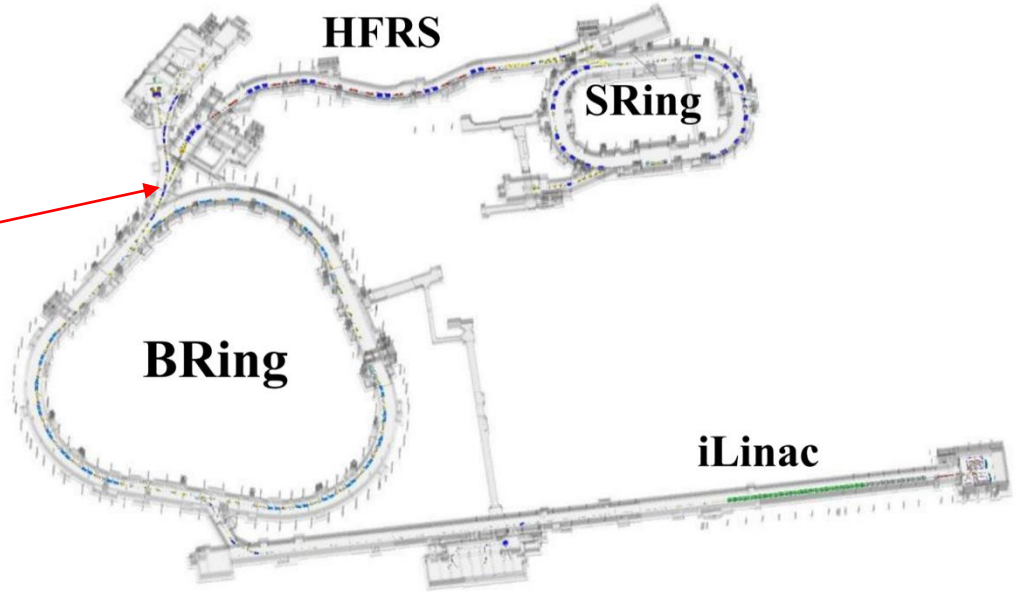
Hyperon-Nucleon Spectrometer → EicC

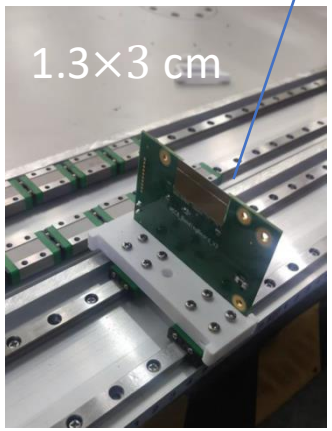


持续推动基于HIAF大科学装置上开展强相互作用物理世界一流研究

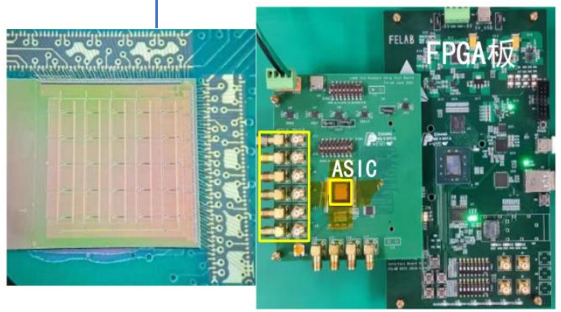
H-NS0 Design and R&D







MAPS

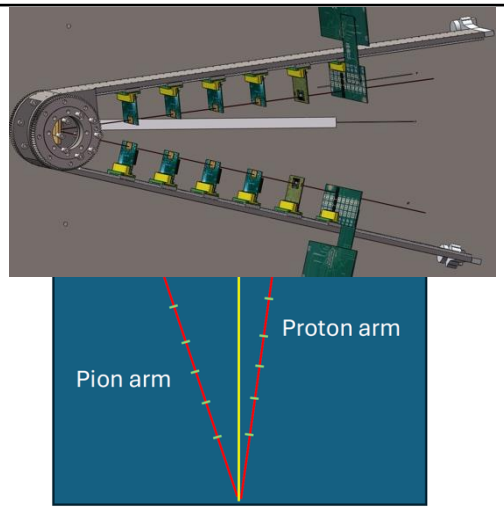


LGAD

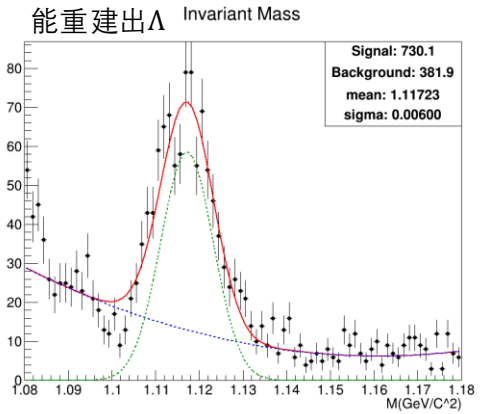
Currently under integration in Huizhou, to be completed in 2026!

H-NS0: DEMO for key technology validation
detector + electronics + DAQ + control system

Three-step strategy to realize H-NS

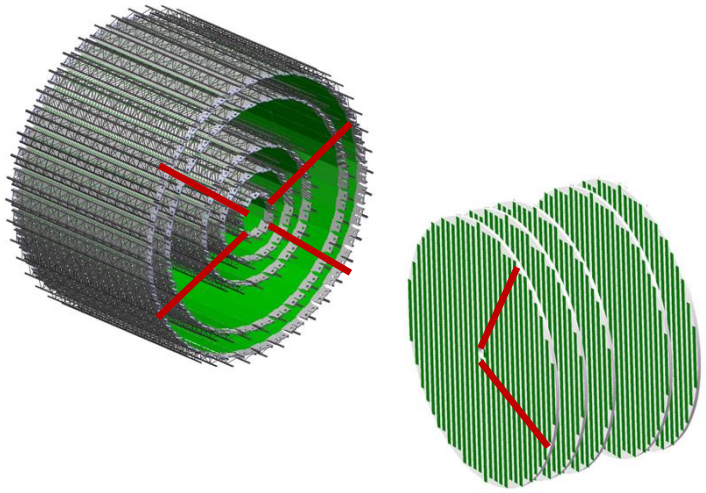


H-NS0: 探测器+电子学+DAQ 核心技术验证

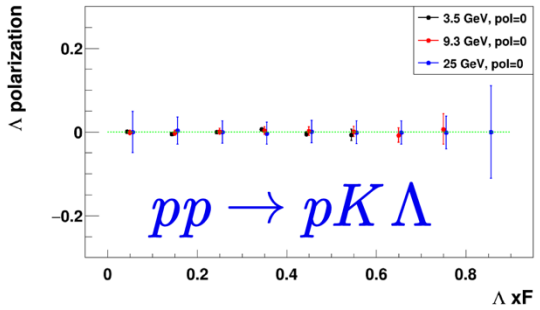


MIC6/LGAD chip validation

2026



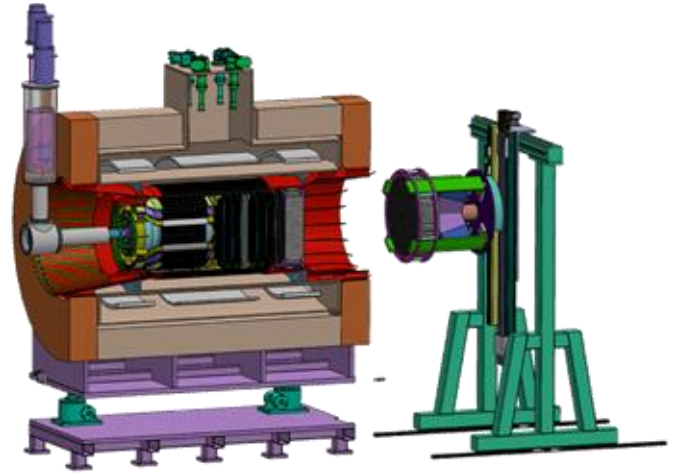
部分探测器，可扩展性



Full-size magnet + detector with partial solid-angle coverage: operational for physics output

Partial funding support

2026-2029



全尺寸探测器

Rich physics program:

- High-precision, multi-dimensional hyperon/proton polarization measurements
- Light-hadron physics, exotic hadronic states
- Nuclear medium effects
- Hypernuclear physics
- Phase structure of nuclear matter

Full funding support

2029-

超子 - 核子谱仪 (H-NS) 合作组

Spokesperson Office

赵　雷　(USTC)
赵宇翔　(IMP)

Advisory Committee

高原宁、季向东、梁作堂、马余刚、
孙志宇、赵红卫、赵政国、邹冰松...

PHYSICS WORKING GROUP

PWG1 Simulation

郭爱强　(IMP)
梁羽铁　(IMP)
孙叶磊　(BHU)
张金龙　(SDU)

PWG3 A-A

罗晓峰　(CCNU)
孙旭　(IMP)
谢冠男　(UCAS)

PWG2 p-p

梁羽铁　(IMP)
徐庆华　(SDU)
赵宇翔　(IMP)

。 。 。 。 。 。

support

DETECTOR WORKING GROUP

Detector Control System

李敏　(IMP)
郭艳蓉　(HFUT)
魏晓娟　(XBMU)

Baryon Polarimeter

梁羽铁　(IMP)
熊伟志　(SDU)

Pixel Tracker

王亚平　(CCNU)
孙向明　(CCNU)
王博群　(IMP)
徐来林　(USTC)

LGAD

刘衍文　(USTC)
刘佩莲　(SDU)
王贤刚　(THU)

EMCal

张卫斌　(IMP)
何万兵　(FDU)
叶志鸿　(THU)

Target

刘红娜　(BNU)
李夏卿　(SDU)
Norihito　(IMP)
勾伯兴　(IMP)

Integration

康新才　(IMP)
余玉洪　(IMP)

Magnet

陈玉泉(IMP)
朱自安　(USTC)
张展　(HMFL)

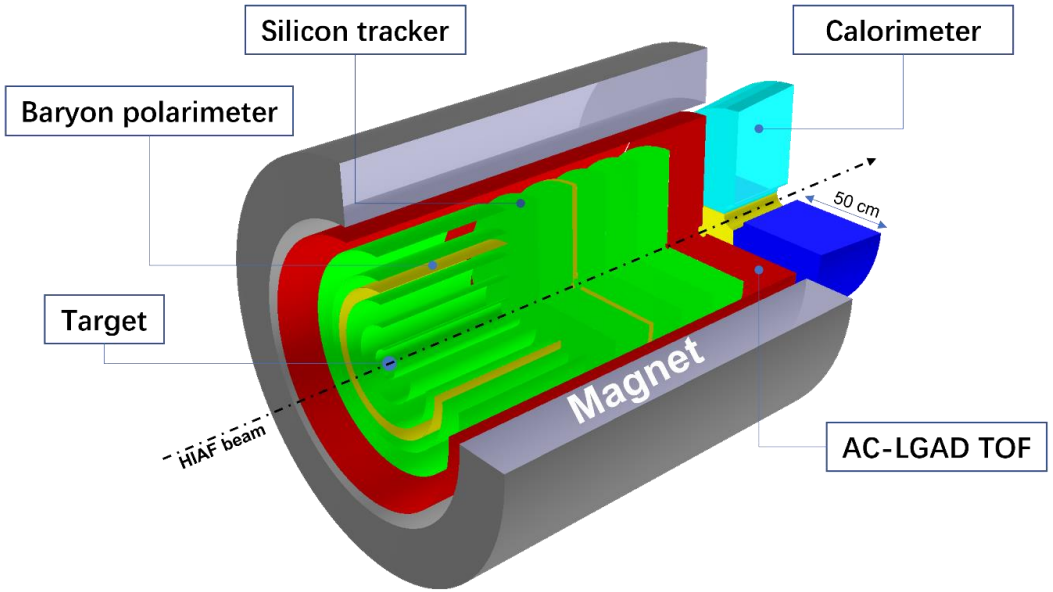
DAQ

陈凯　(CCNU)
杨俊峰　(USTC)
李敏　(IMP)

Electronics

秦家军　(USTC)
千奕　(IMP)
张亮　(SDU)
胡坤　(SDU)
郑然　(NWPU)

Summary



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

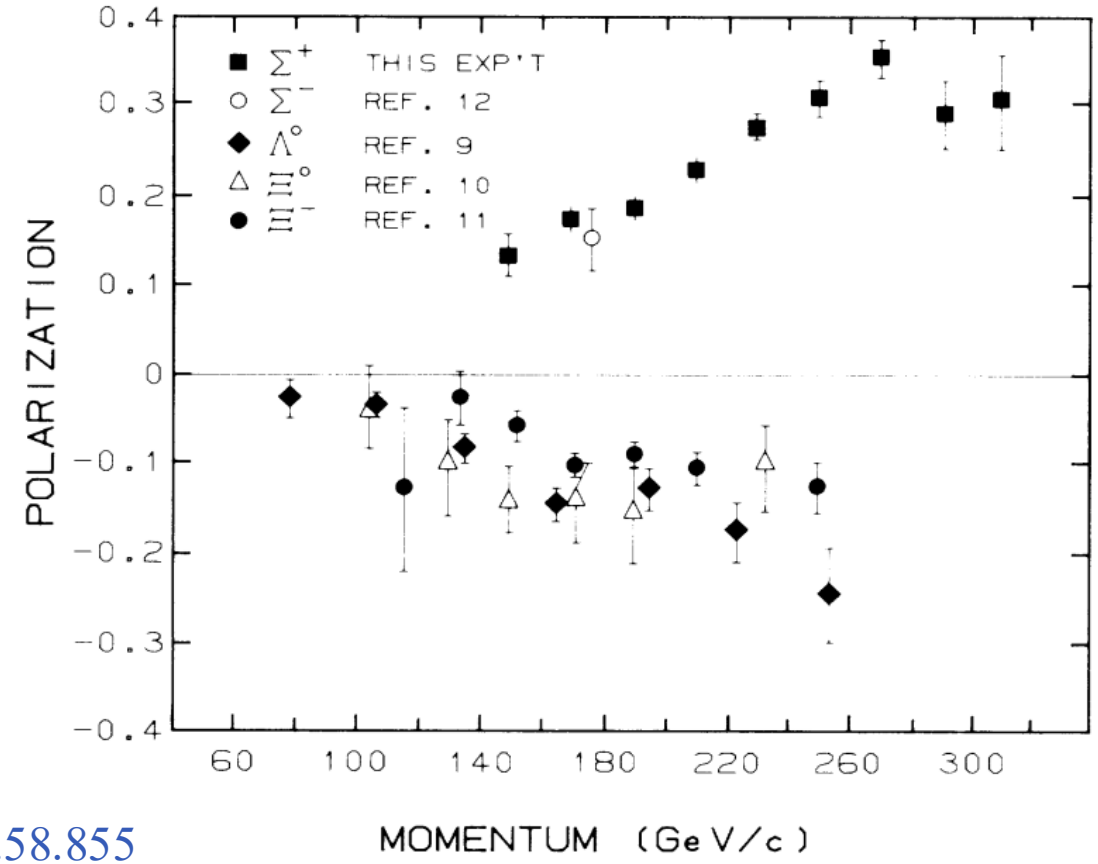
Thank you !



backups

Polarization of other hyperons

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



PhysRevLett.58.855

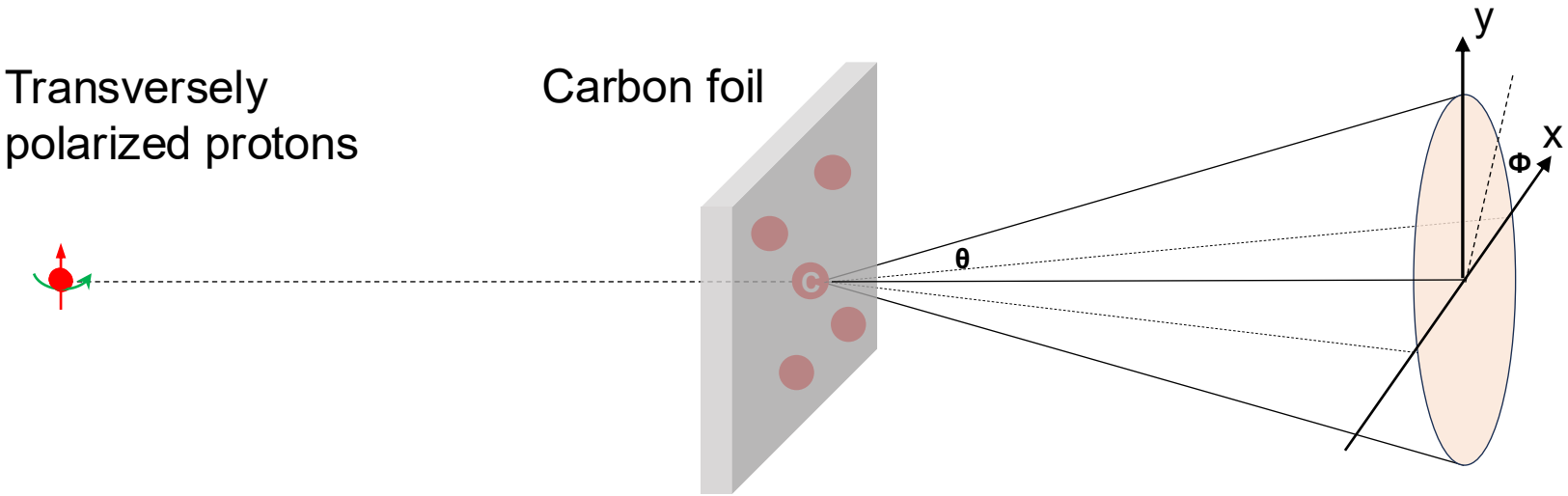
Principle of proton polarimeter

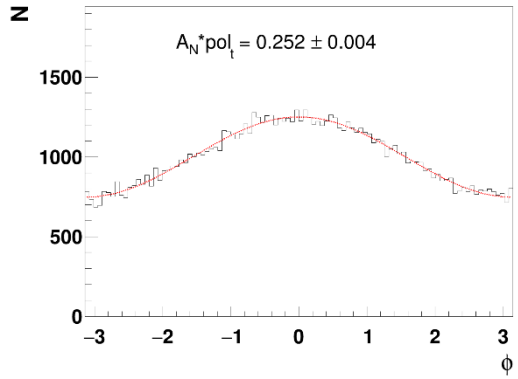
Relation between the **spin-dependent cross-section** of p + p/C scattering and the **asymmetries**

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

Transversely polarized protons

Carbon foil



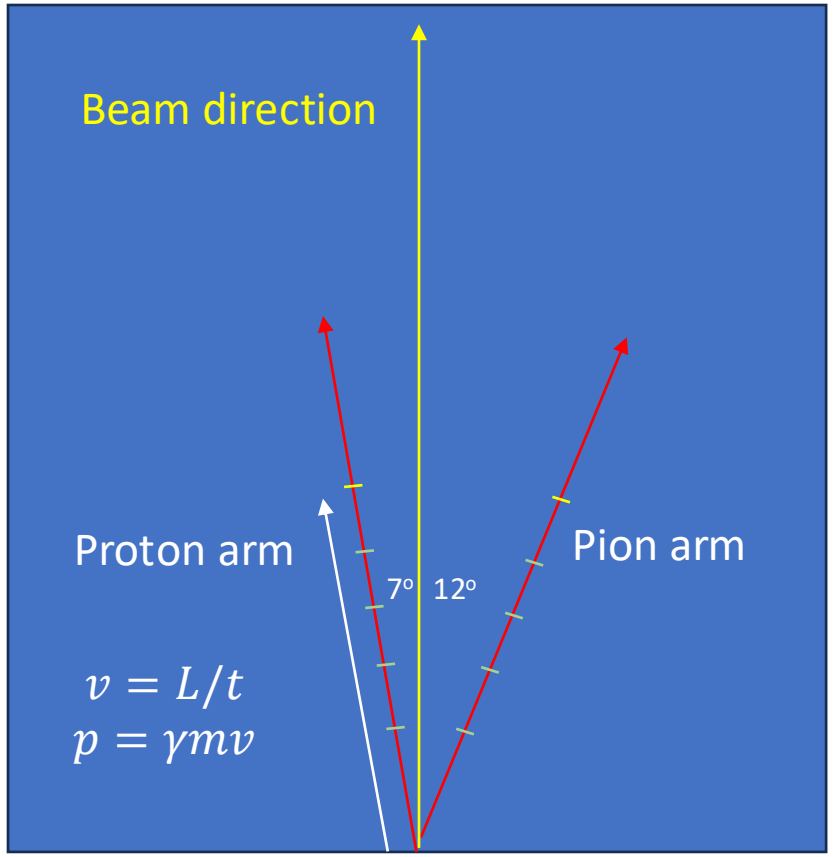


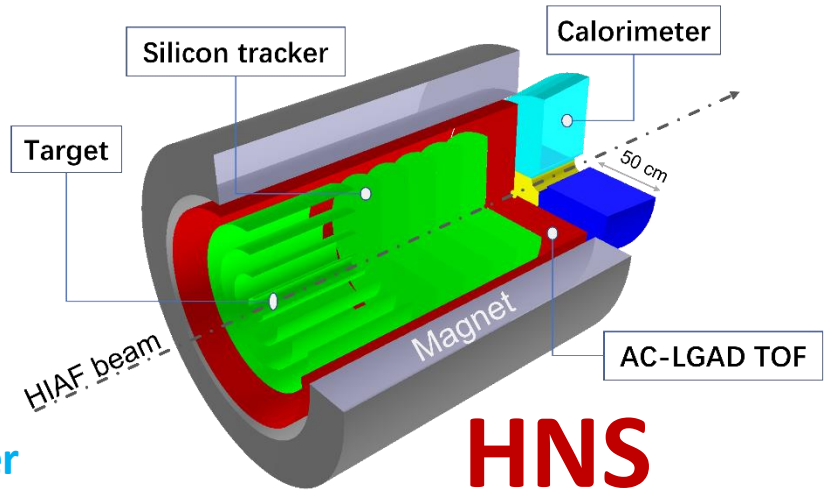
More protons to the left:
Left-right asymmetry

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

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

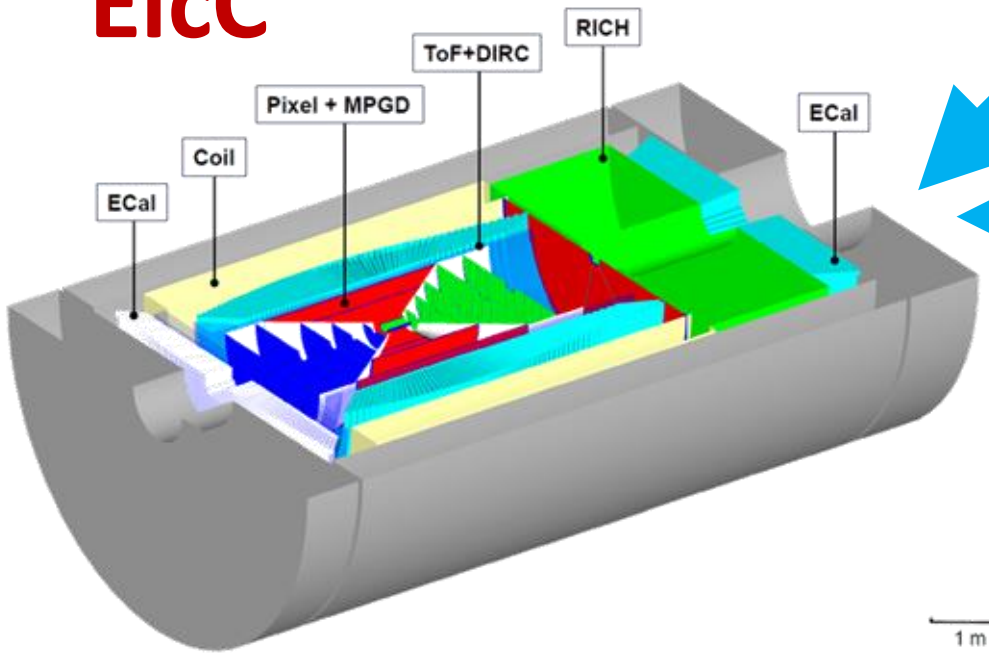




HNS

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

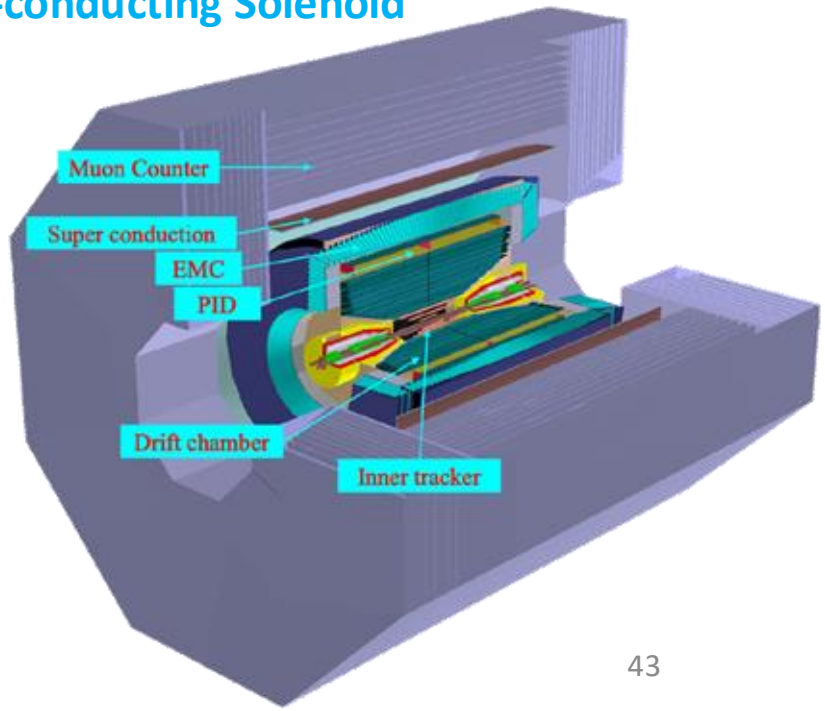
EicC



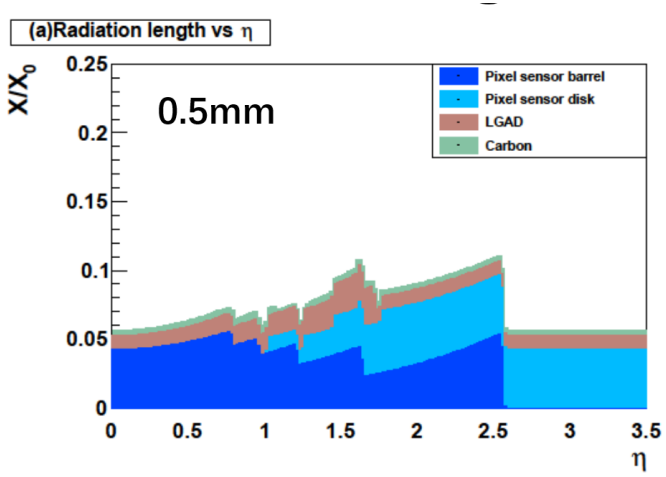
Silicon tracker
MPGD tracker
DIRC (PID)
RICH (PID)
Ecal
Super-conducting Solenoid

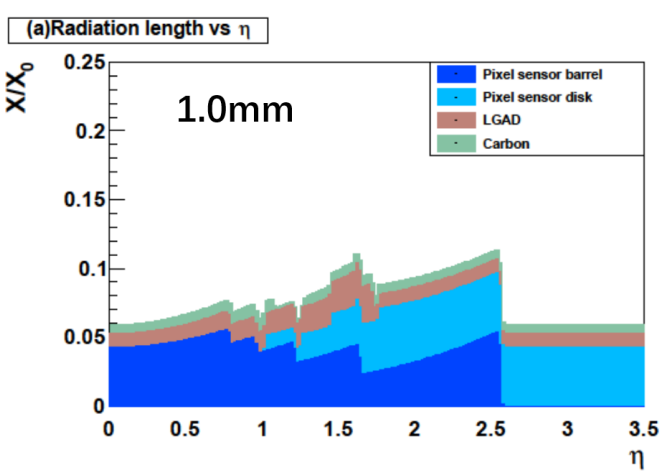
Silicon tracker
Ecal.
Super-conducting Solenoid

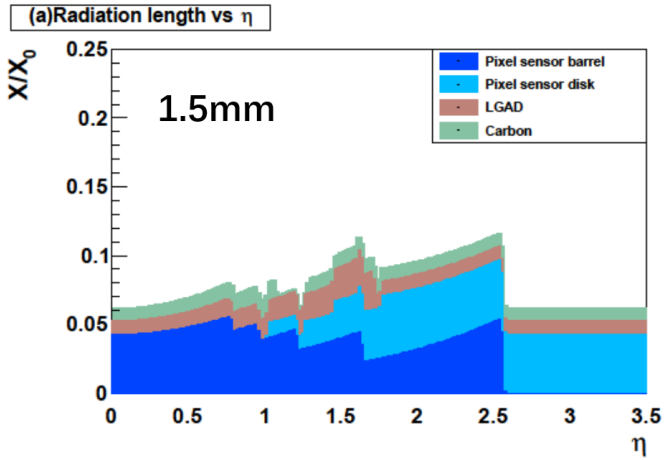
STCF

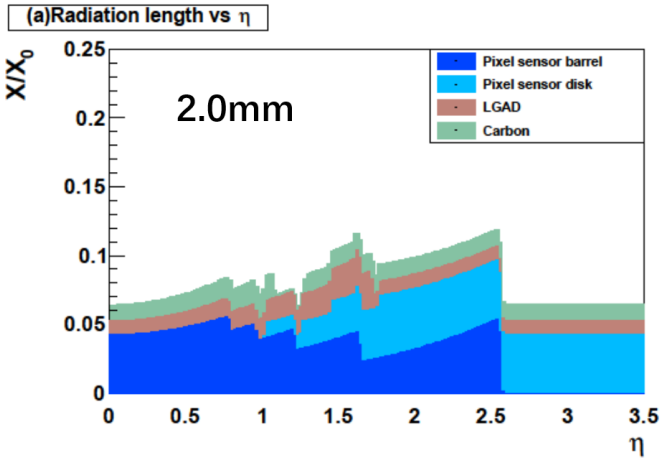


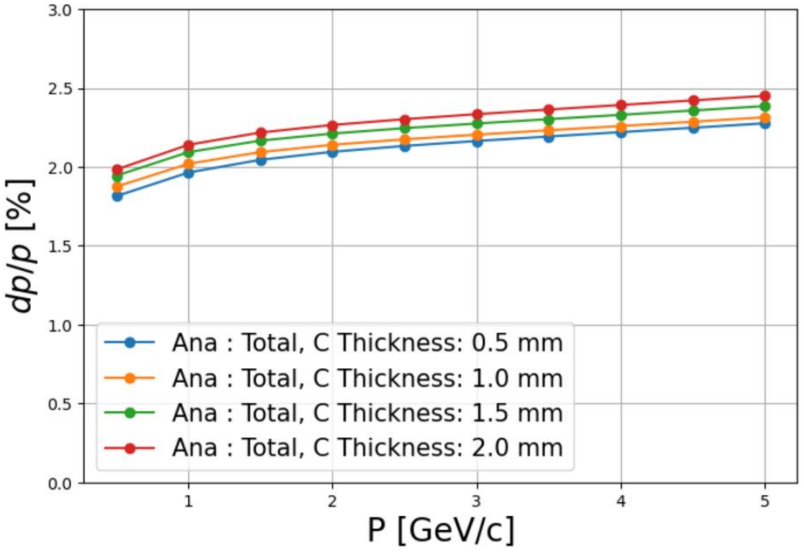
Material budget of carbon layer











- Tiny influence on the conventional performance