Hyperon-Nucleon Spectrometer
超核谱仪

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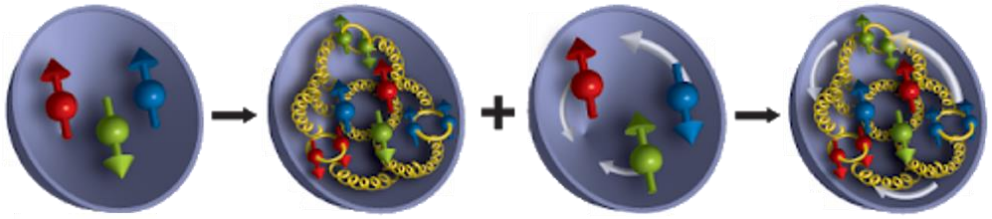
Outline

- Introduction
- HNS at HIAF
- Summary and Outlook

About nucleon spin structure

1988 EMC experiment → "Spin crisis"

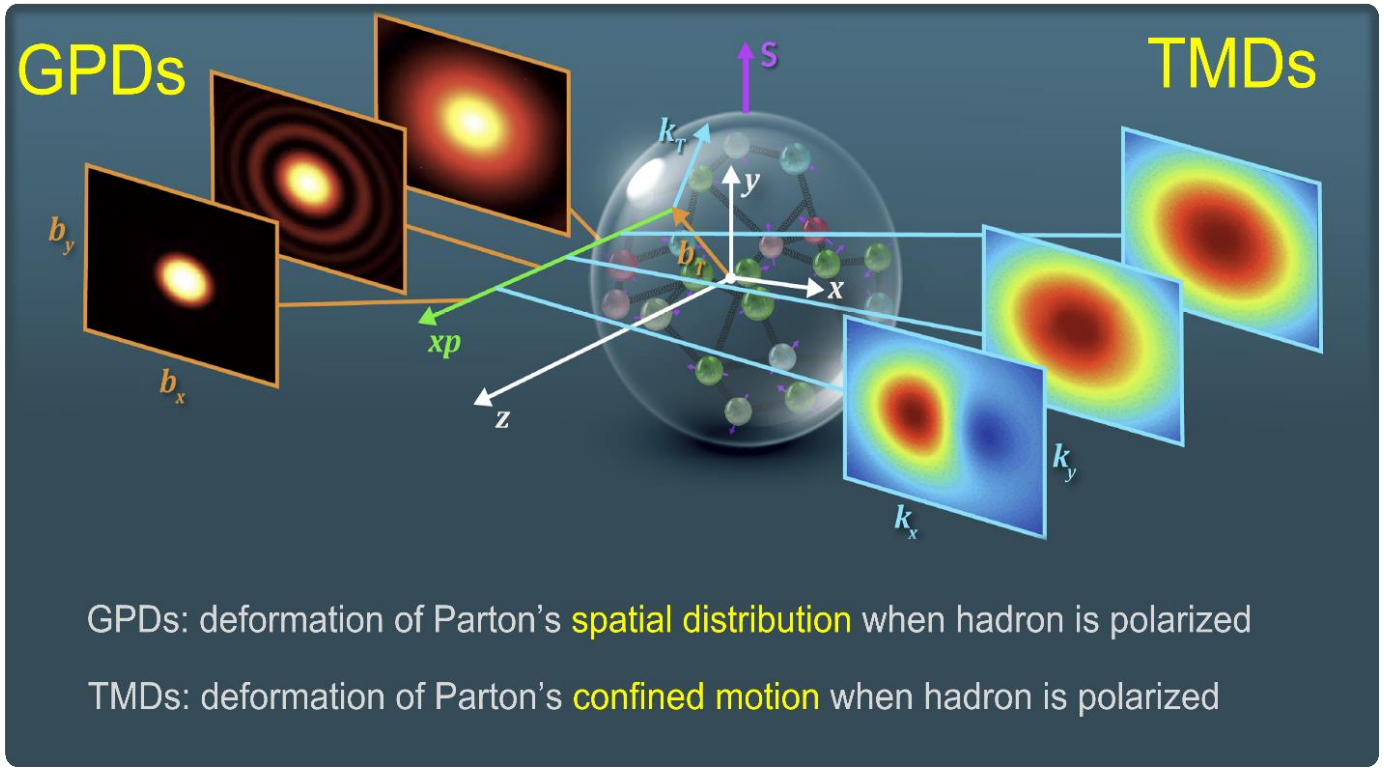


1970s 1980s/2000s Now

Spin decomposition:

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

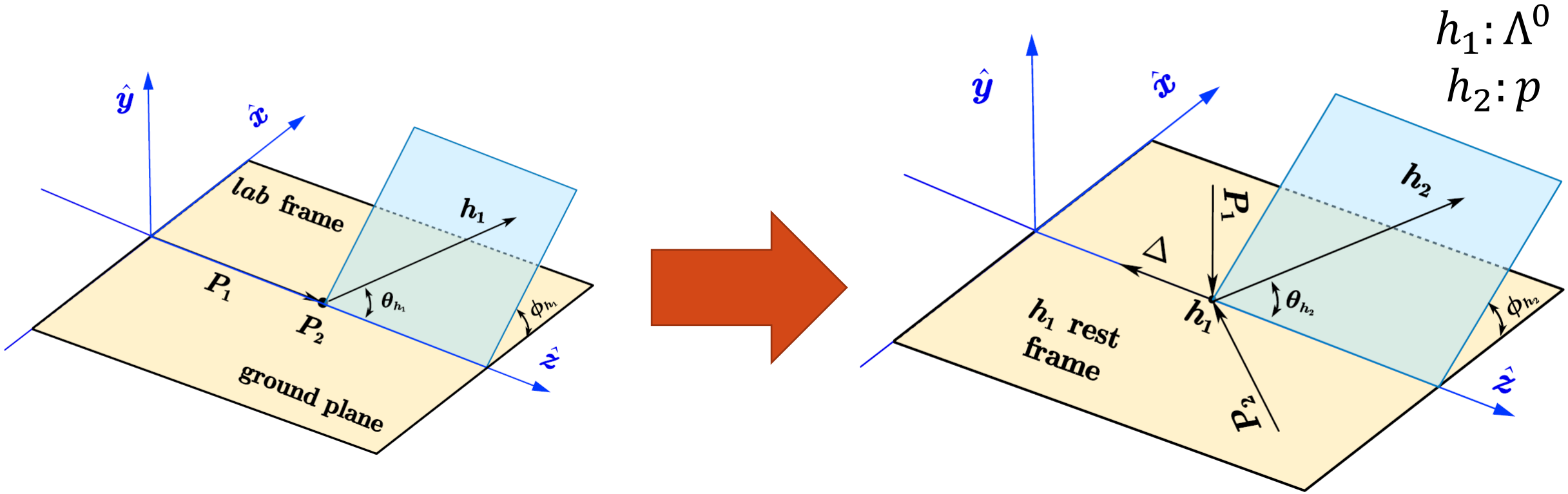
Quark spin | **Gluon Spin** | **Quark OAM** | **Gluon OAM**



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

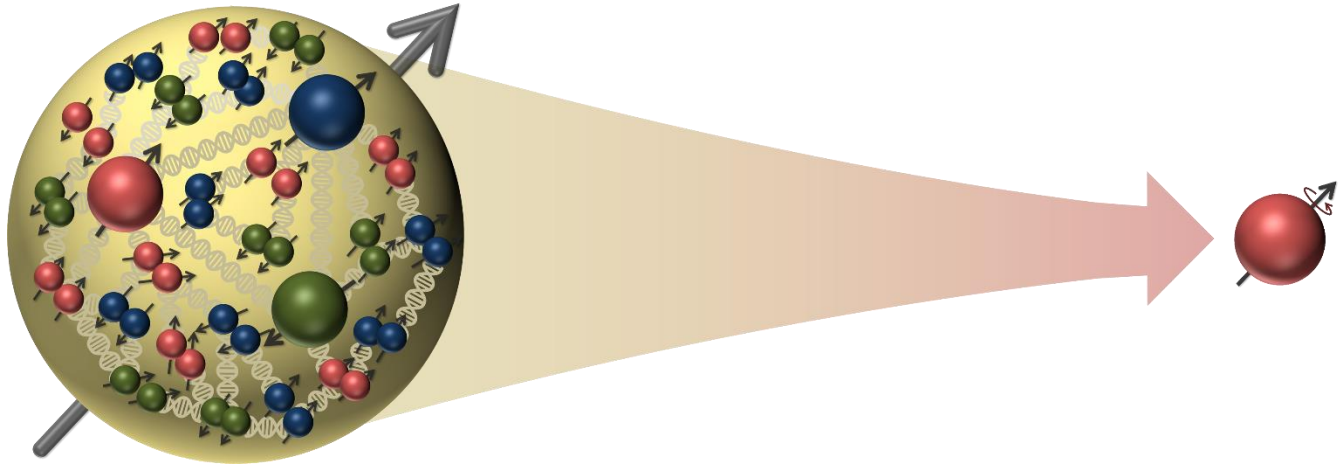
A new domain: from nucleon to hyperon

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

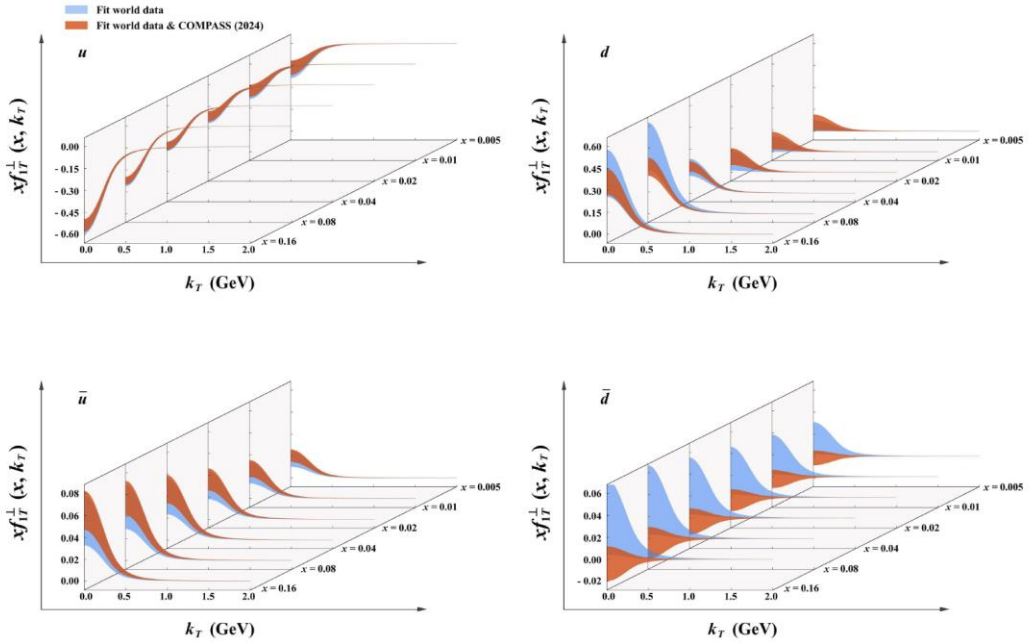


$$\text{yield} \sim (1 + \alpha P cos\theta_{h_2})/4\pi$$

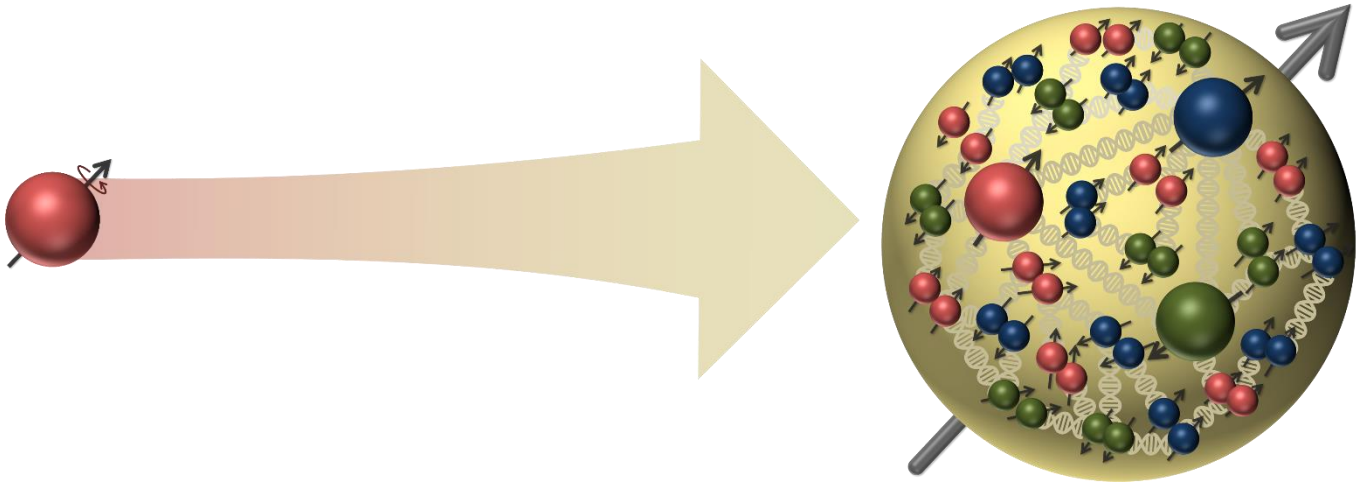
Initial state

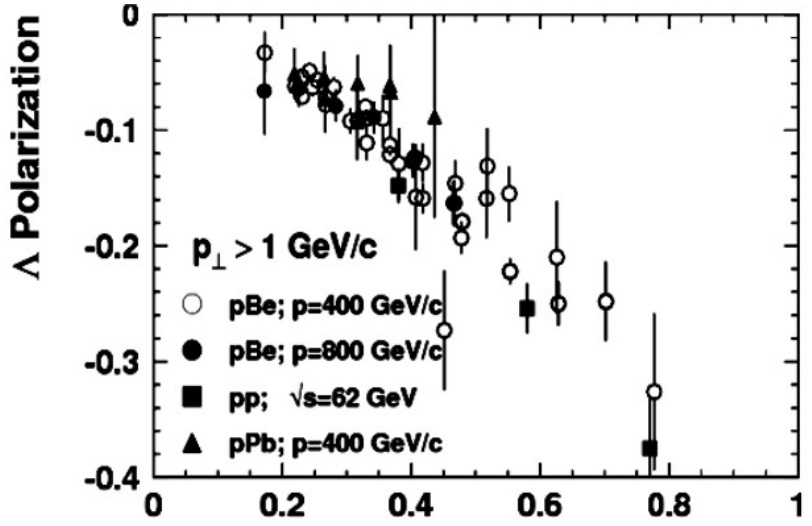


Nucleon



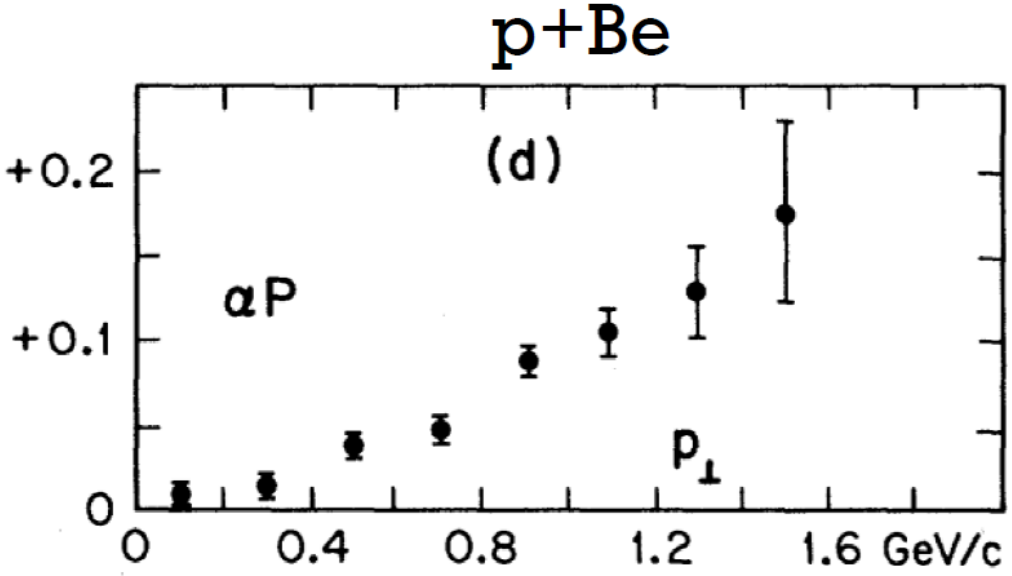
Hyperon





Final state

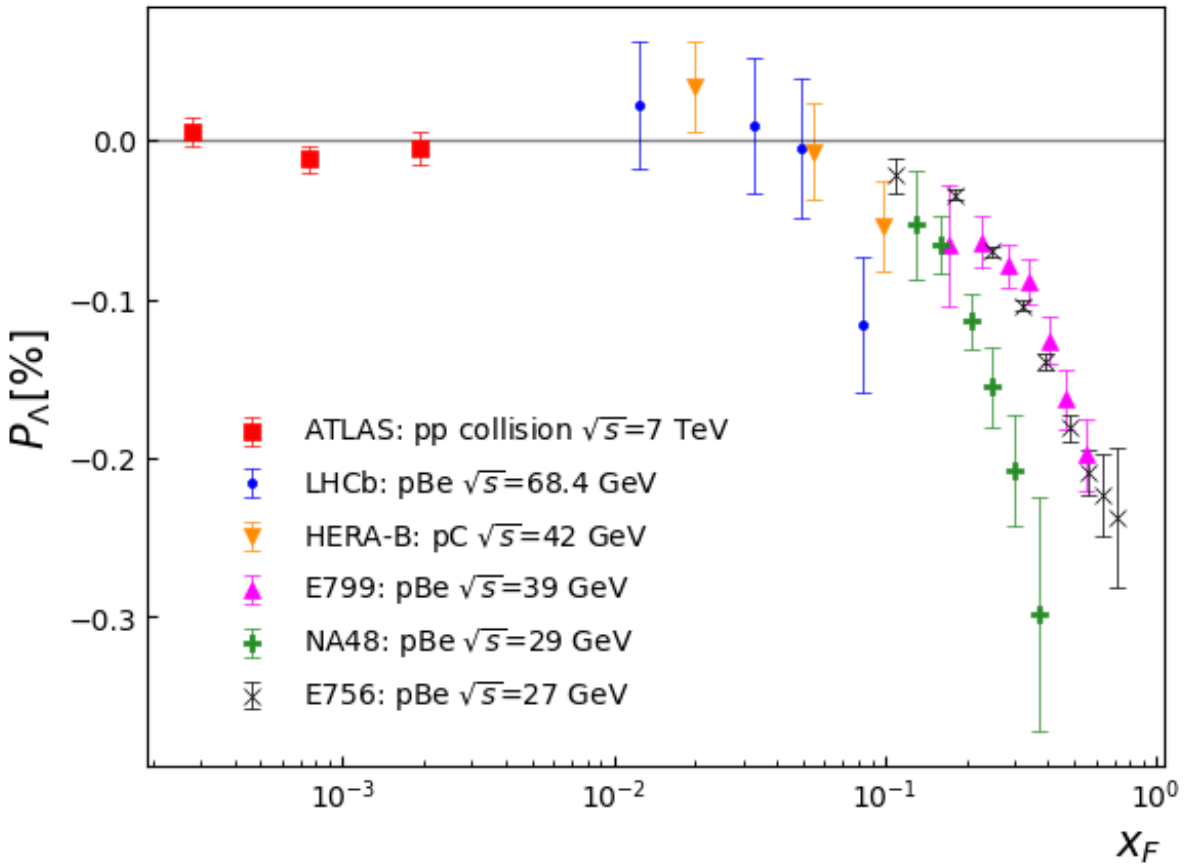
First observation of Λ^0 polarization in the 1970's

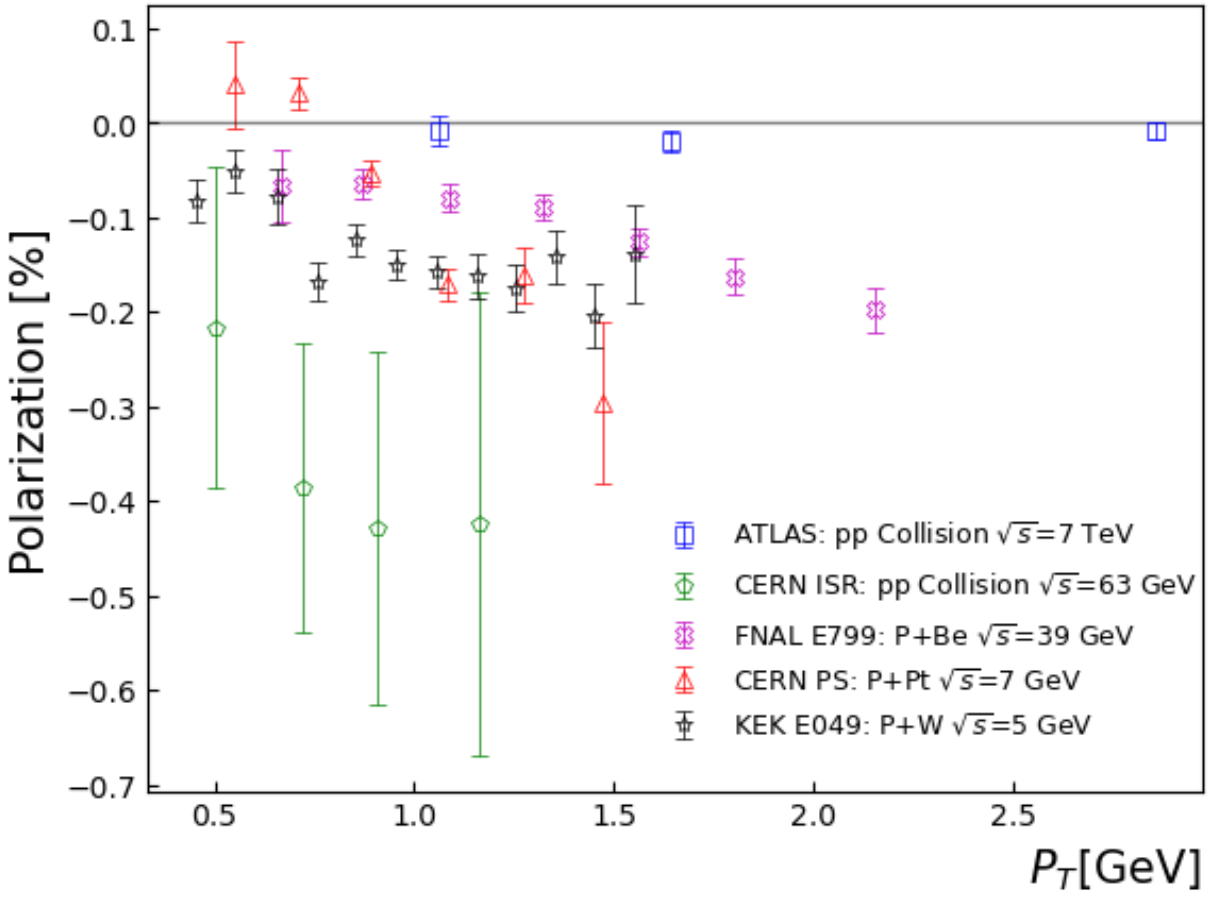


G.Bunce, *et al.*: Phys.Rev.Lett. 36, 1113-1116 (1976)

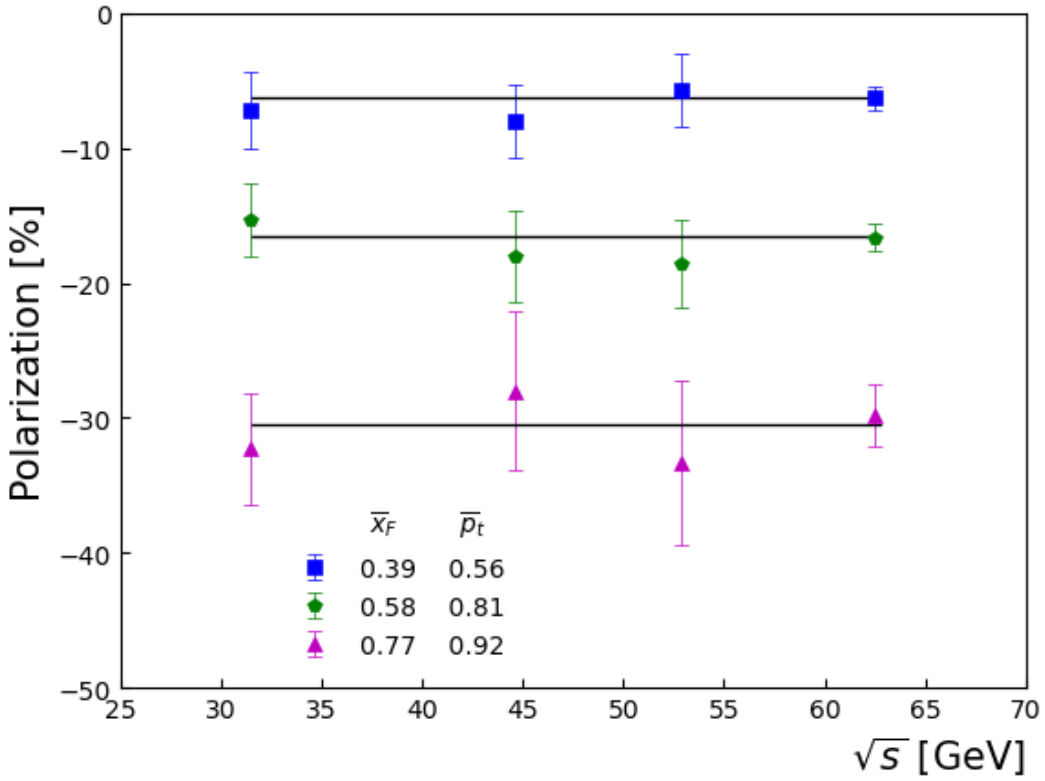
- Hyperons can be produced polarized in collisions of elementary particles
- Discovered at Fermilab in the 1970's in p + Be collisions: 300 GeV protons on Beryllium

Λ^0 polarization measurements

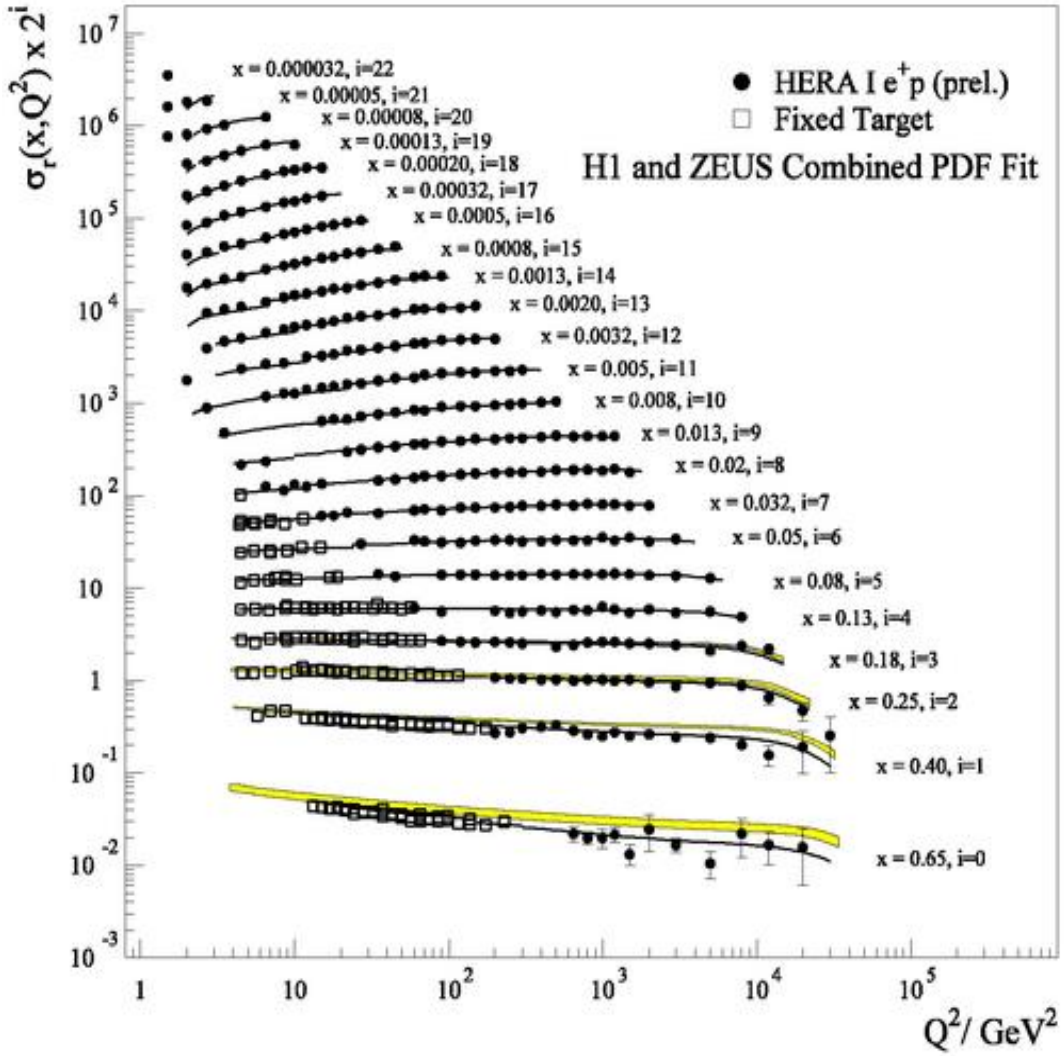




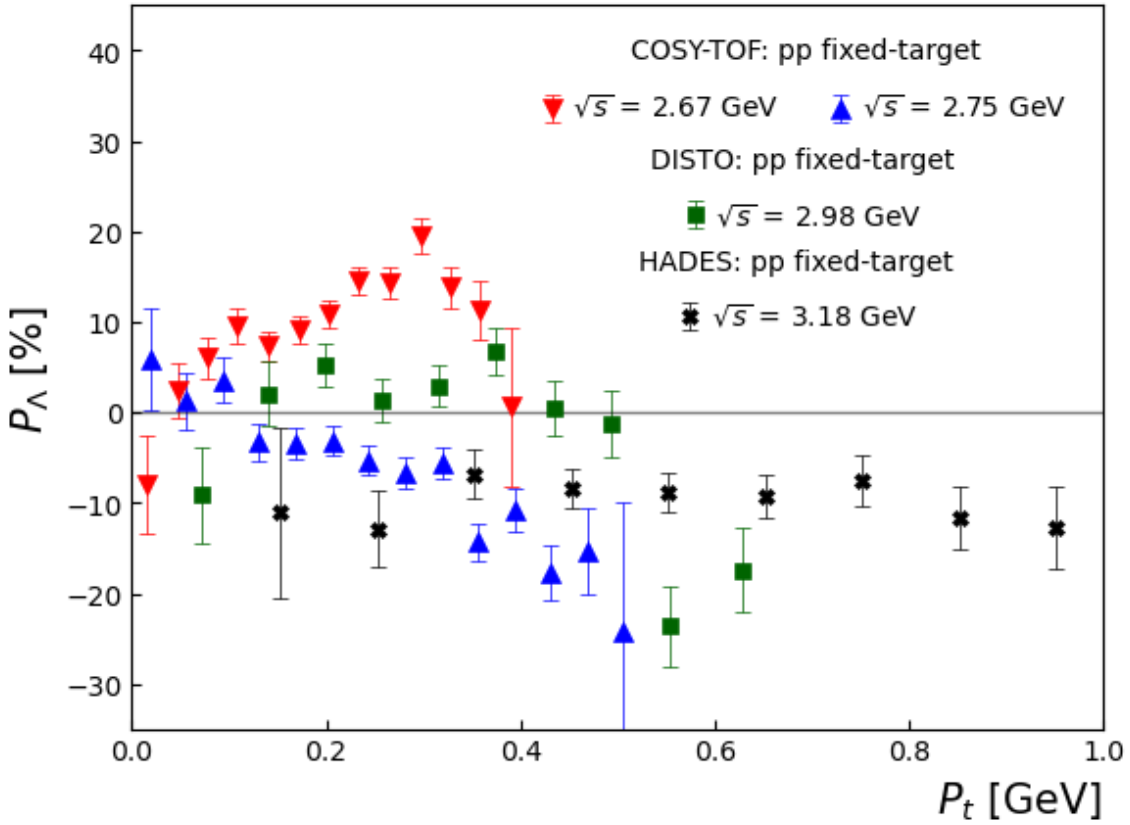
“Scaling” of Λ^0 polarization ?

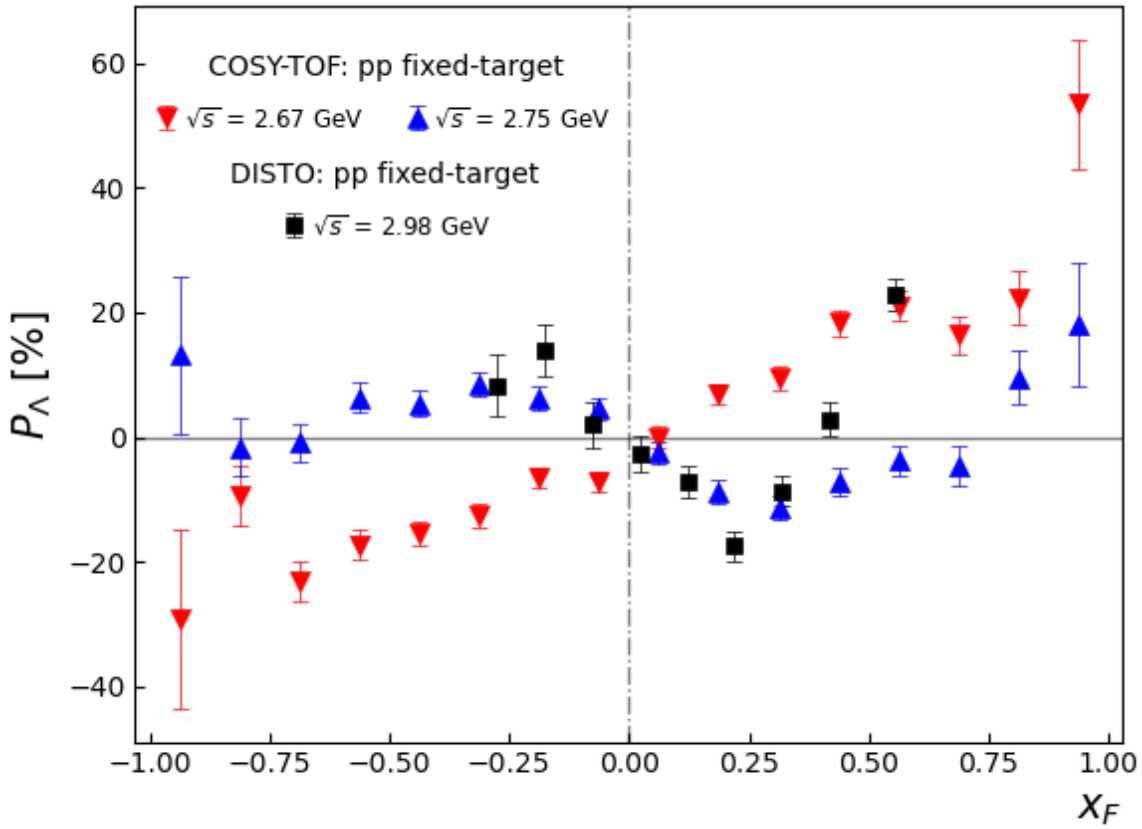


R608: 10.1016/0370-2693(87)91556-5

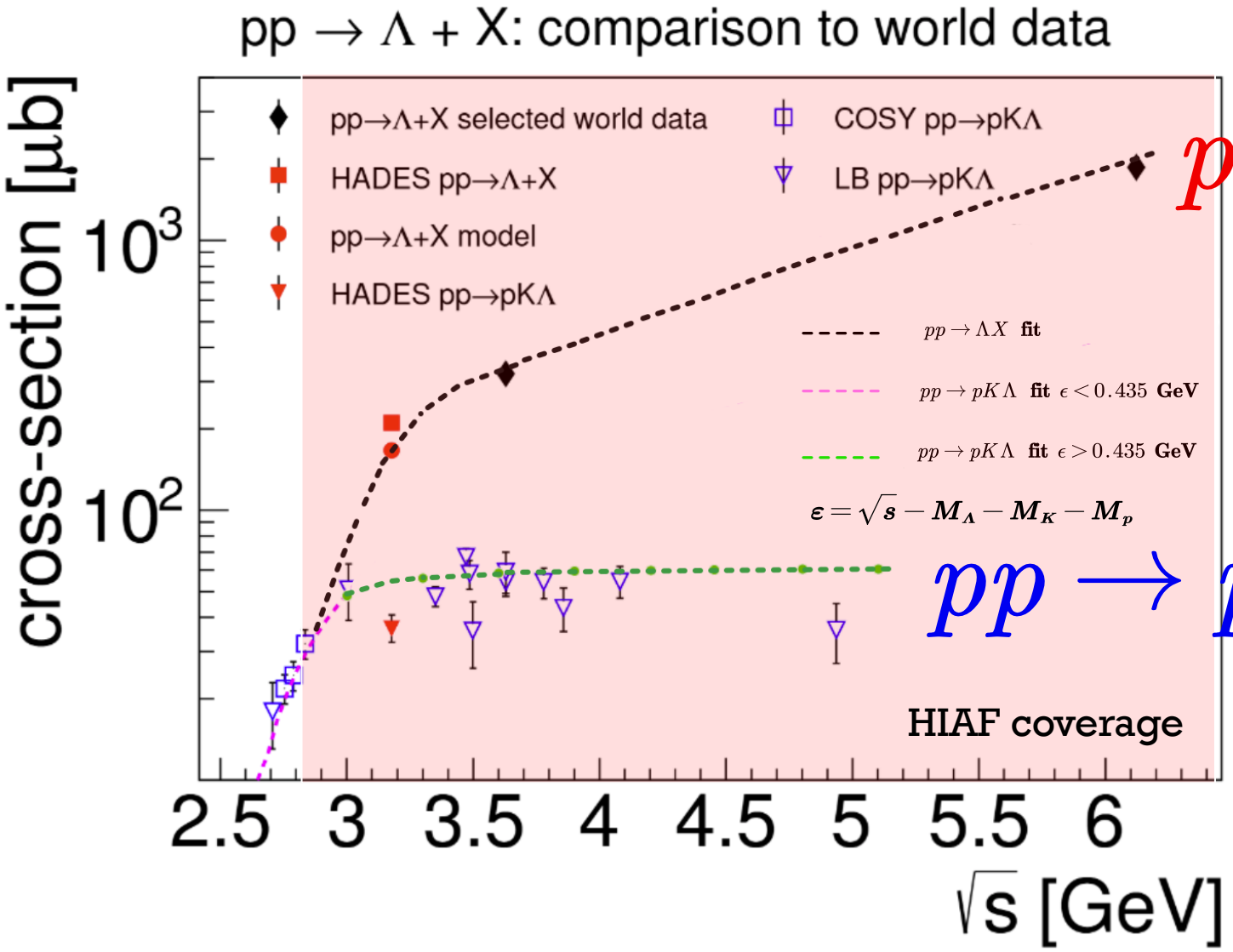


Puzzle in low energy collisions





Not only polarization but also production

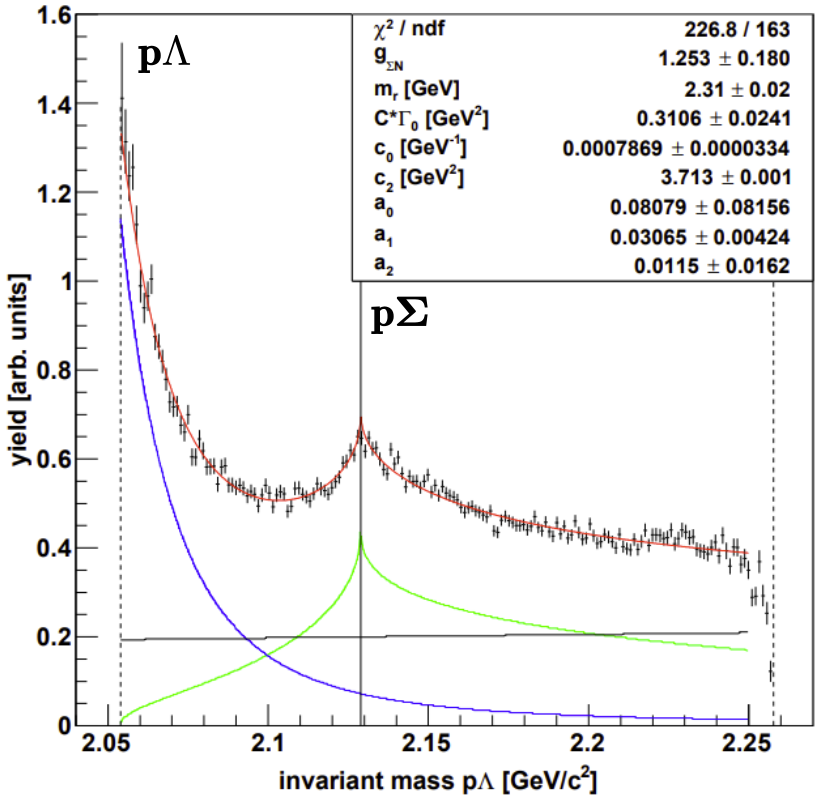


$pp \to \Lambda X$

$pp \to pK\Lambda$

Not only polarization but also production

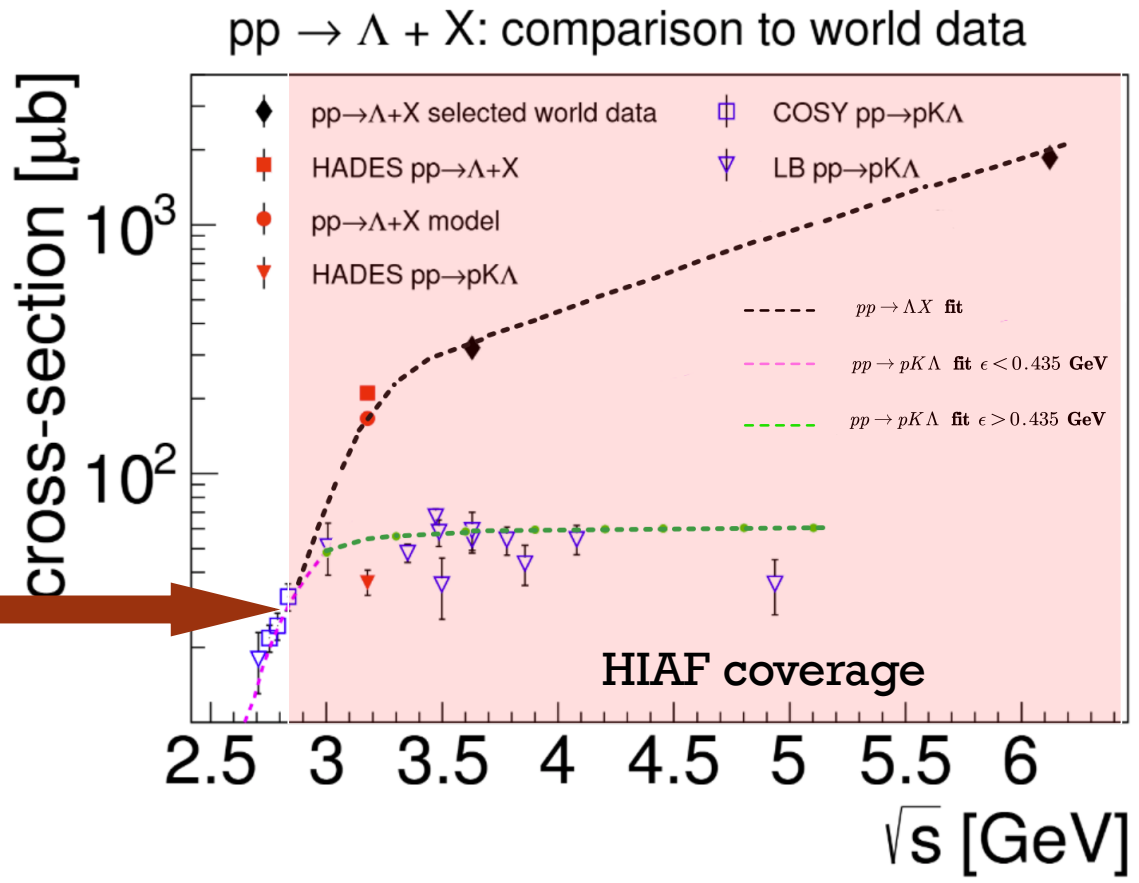
$p(2.95\ \mathrm{GeV}) + p \rightarrow pK\Lambda$



$$\frac{d\sigma^{meas}}{dm_{p\Lambda}} / \frac{d\sigma^{MC}}{dm_{p\Lambda}} = FSI(m_{p\Lambda}) + TH(m_{p\Lambda}) + RF(m_{p\Lambda})$$

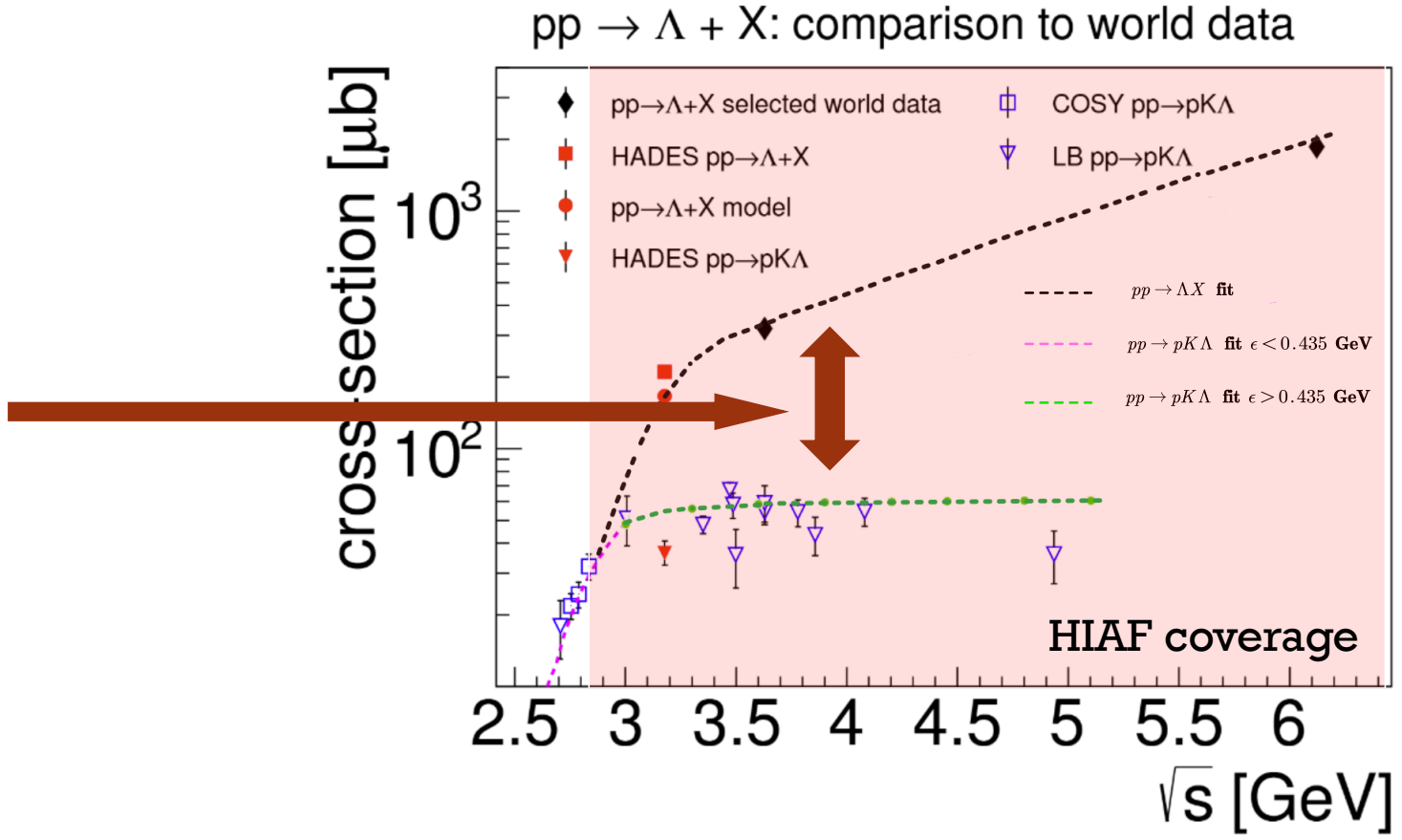
hyperon-nucleon ($p\Lambda$) interaction — **coupled channel effect of $N\Lambda \leftrightarrow N\Sigma$** — **reflections of the N* resonances**

COSY-TOF Collaboration, Eur. Phys. J. A 52 1, 7 (2016).

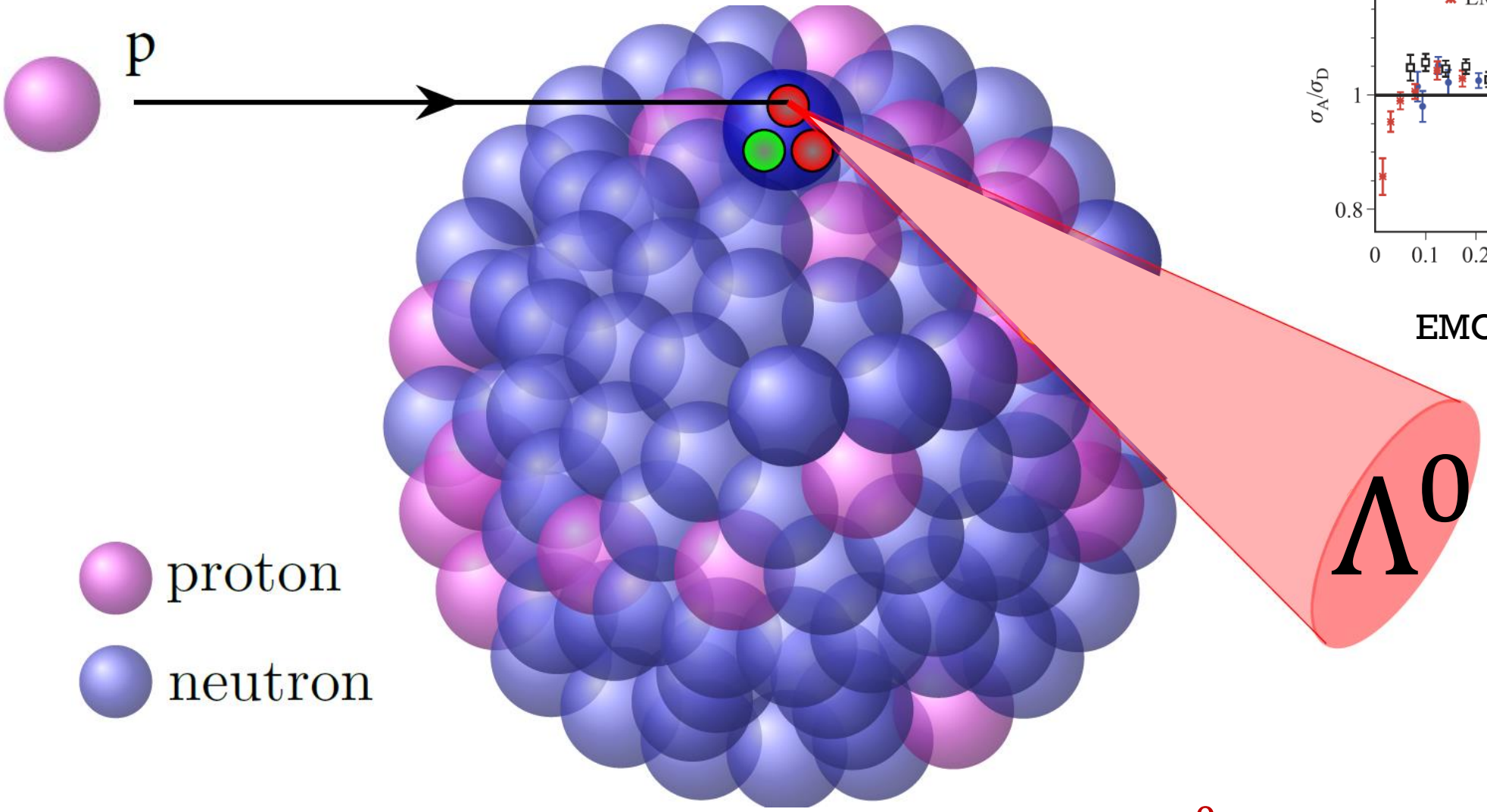


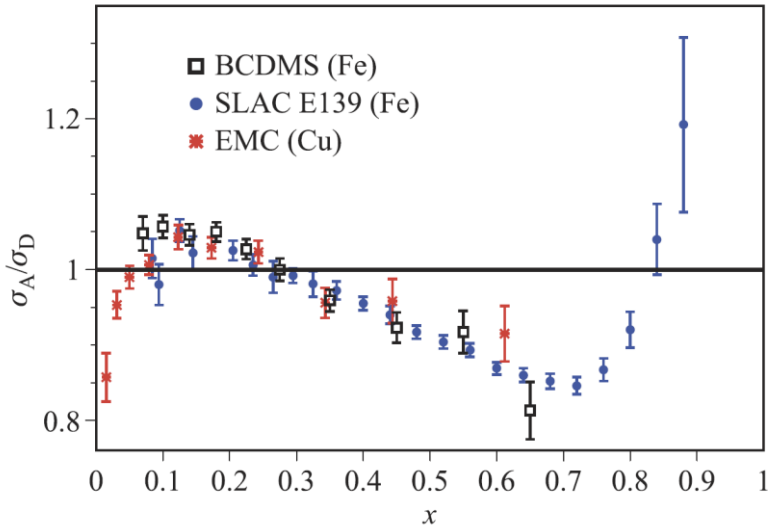
Not only polarization but also production

Resonance and fragmentation



What's more? with p-A

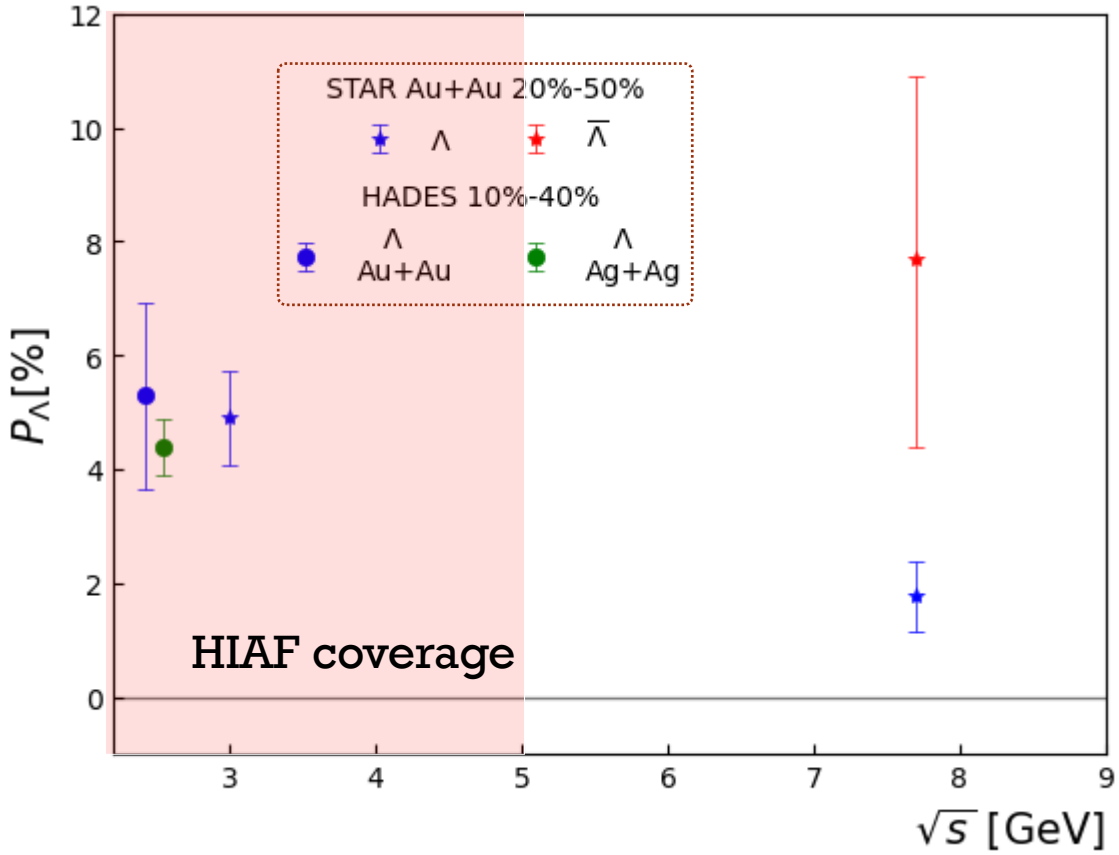


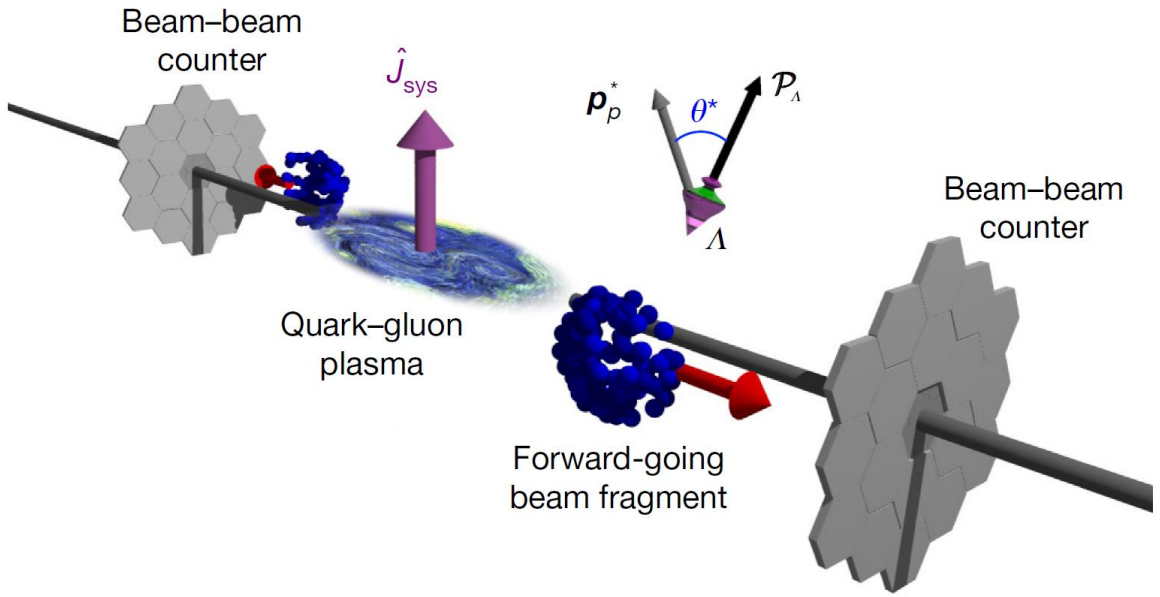


EMC effect is there for PDFs

Cold nuclear medium effect for Λ^0 polarization

What's more? with A-A





Hot nuclear medium effect

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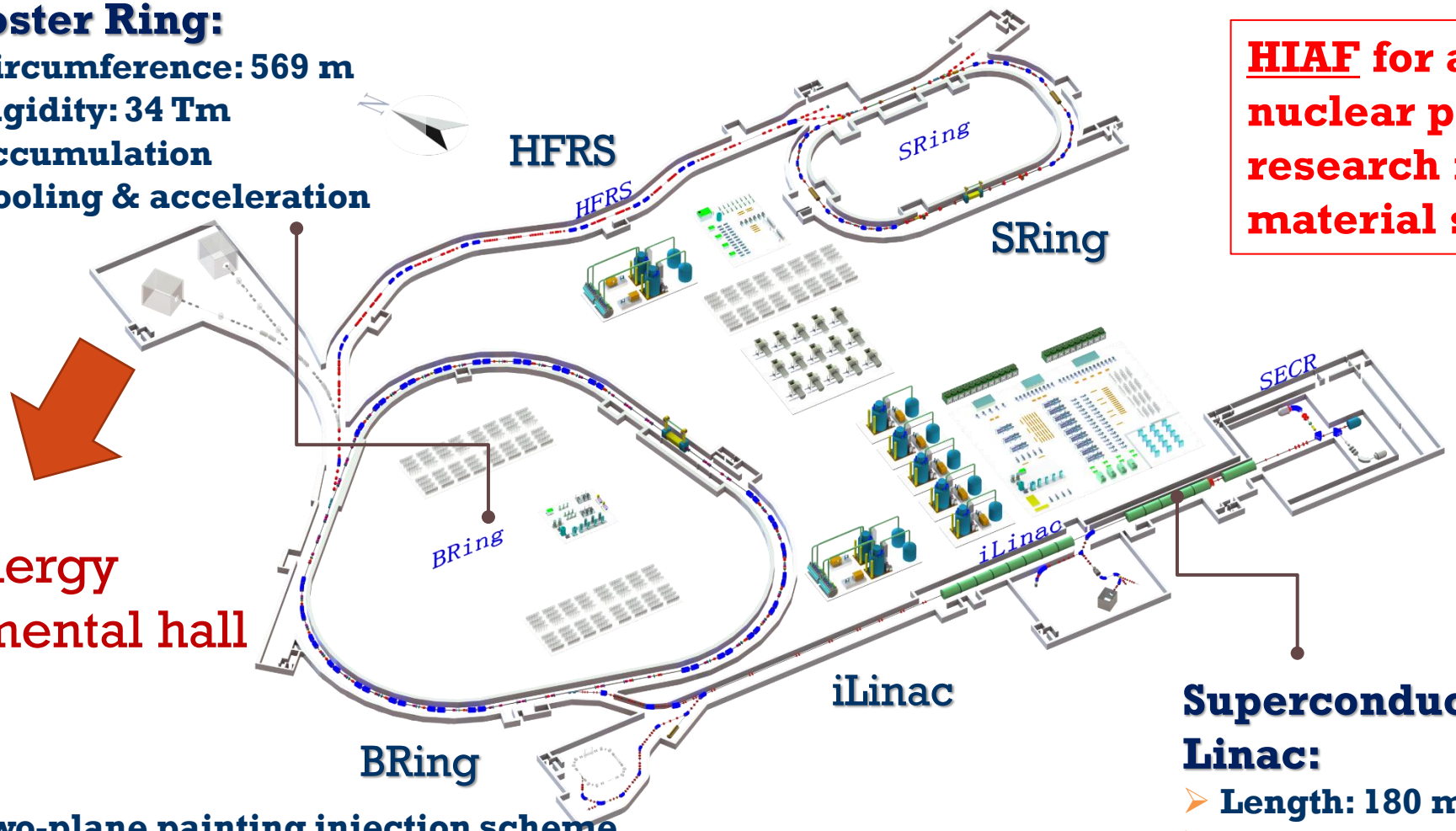
High Intensity heavy-ion Accelerator Facility (HIAF)

Booster Ring:

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



High energy experimental hall

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

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

Superconducting Ion Linac:

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

High Intensity heavy-ion Accelerator Facility (HIAF)

Booster Ring:

- **Circumference: 569 m**
- **Rigidity: 34 Tm**
- **Accumulation**
- **Cooling & accele**

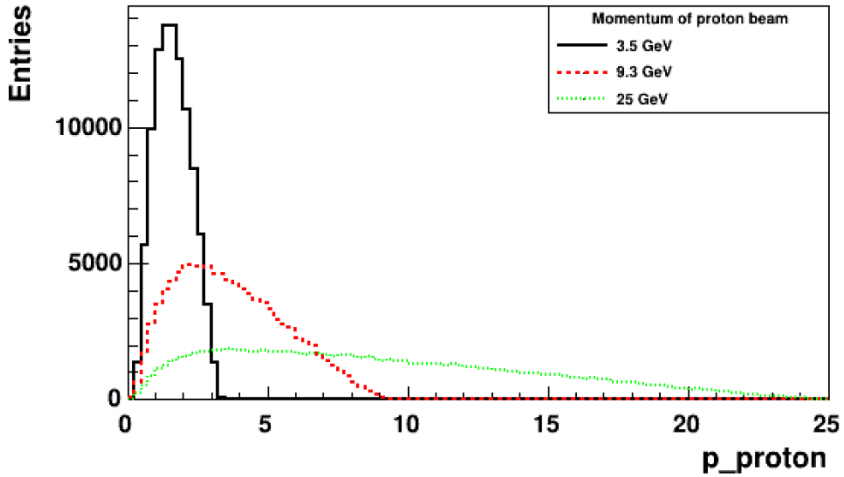
High energy experimental hall

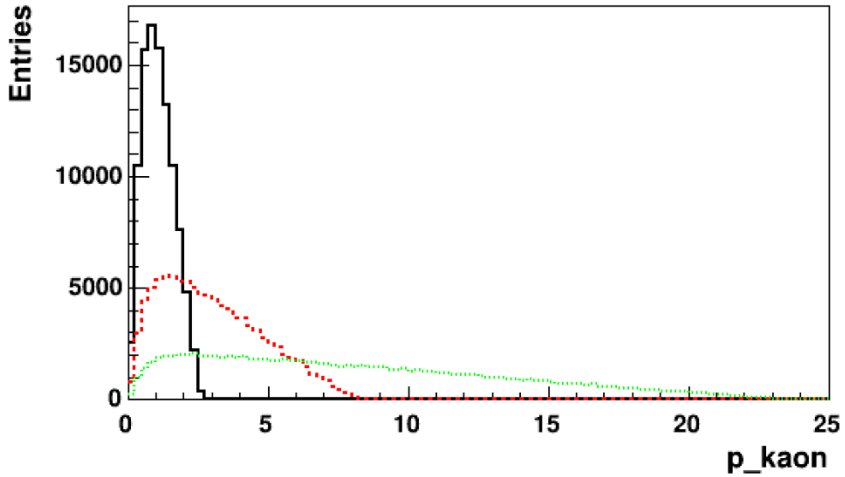
- **Two-plane painting injection scheme**
- **Fast ramping rate operation**

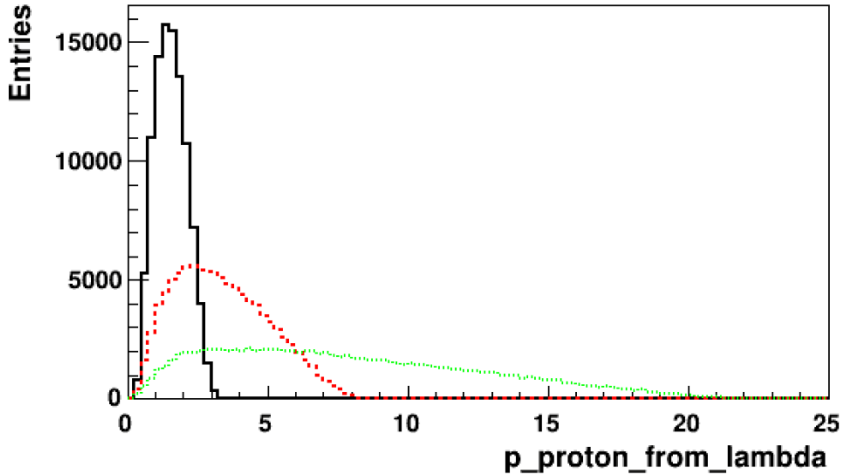
HIAF beam parameters

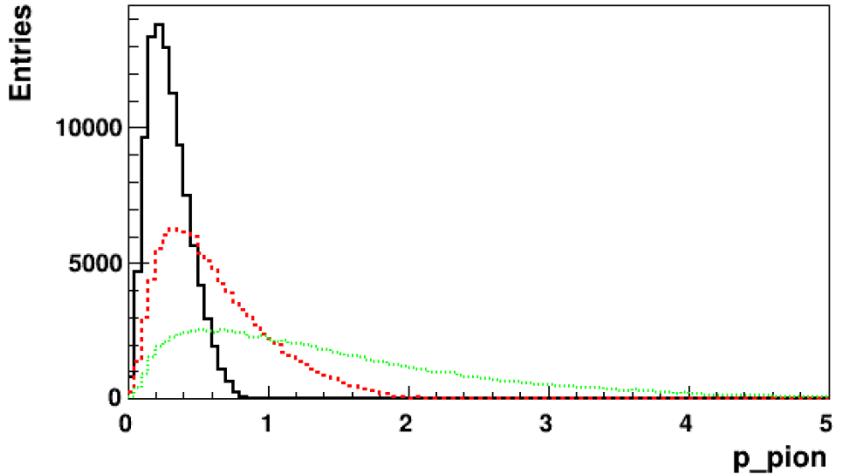
Ion	Intensity (ppp)	Kine_Energy (GeV/u)
$^{238}U^{35+}$	2.0×10^{11}	0.84
$^{238}U^{76+}$	5.0×10^{10}	2.5
$^{129}Xe^{27+}$	3.6×10^{11}	1.4
$^{78}Kr^{19+}$	5.0×10^{11}	1.7
$^{40}Ar^{12+}$	7.0×10^{11}	2.3
$^{18}O^{6+}$	8.0×10^{11}	2.6
p	5.0×10^{12}	9.3

Distributions of momentum of final states

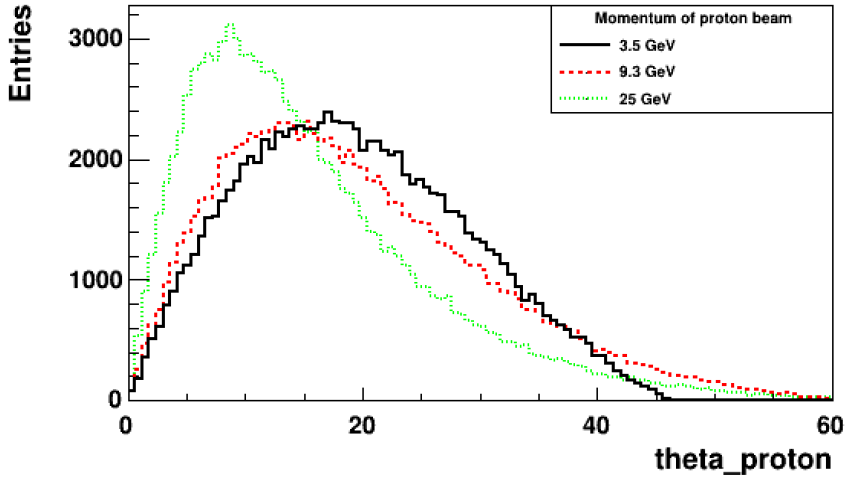


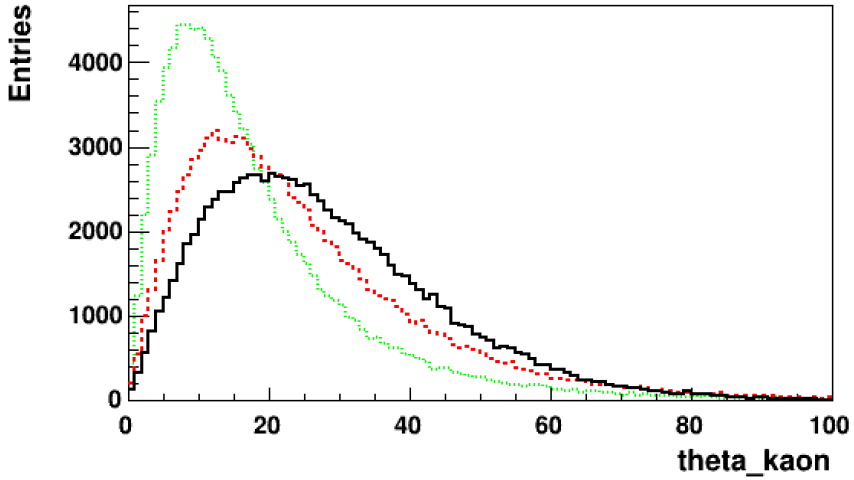


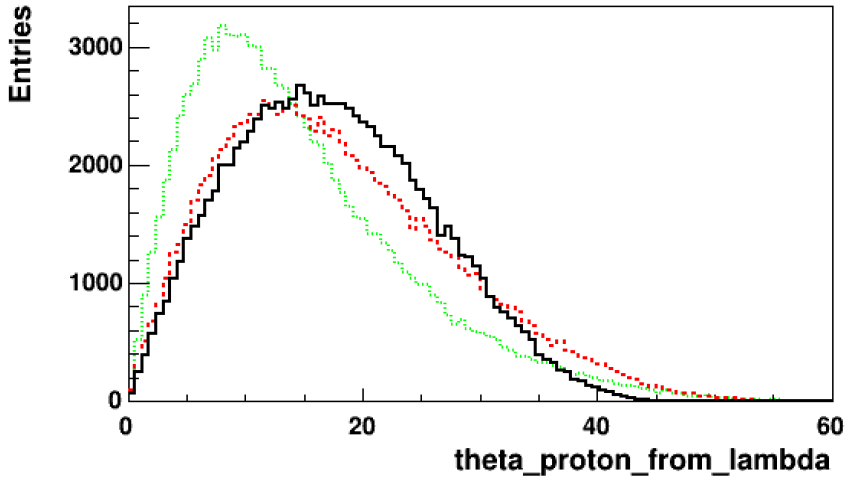


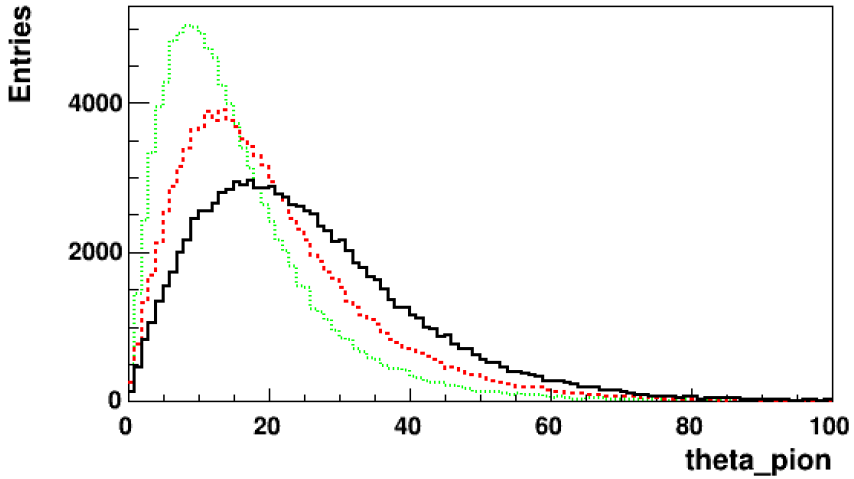


Angular distributions of final states



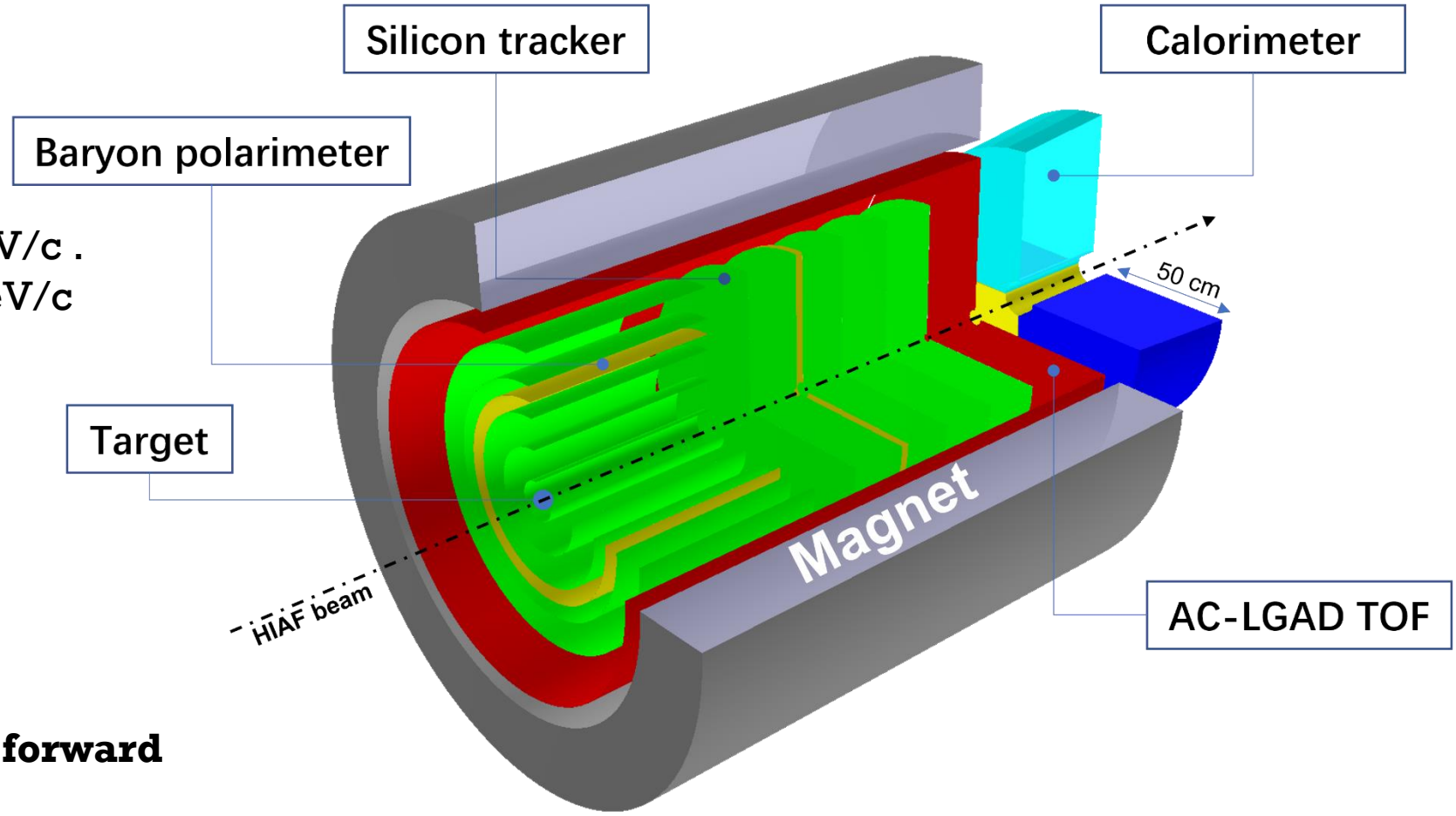




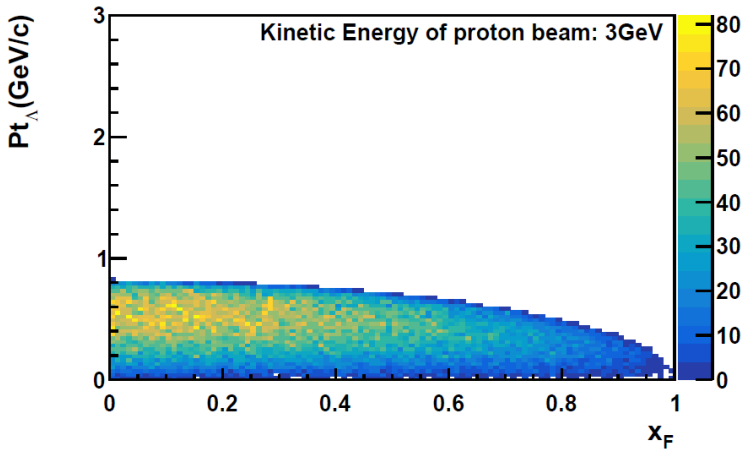


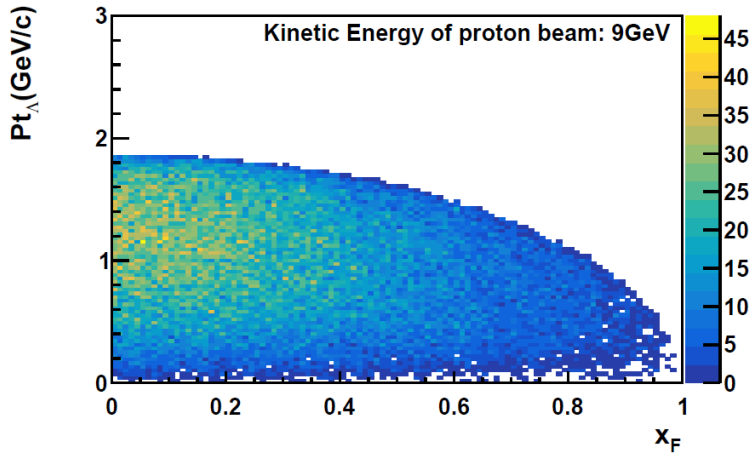
Hyperon-Nucleon Spectrometer

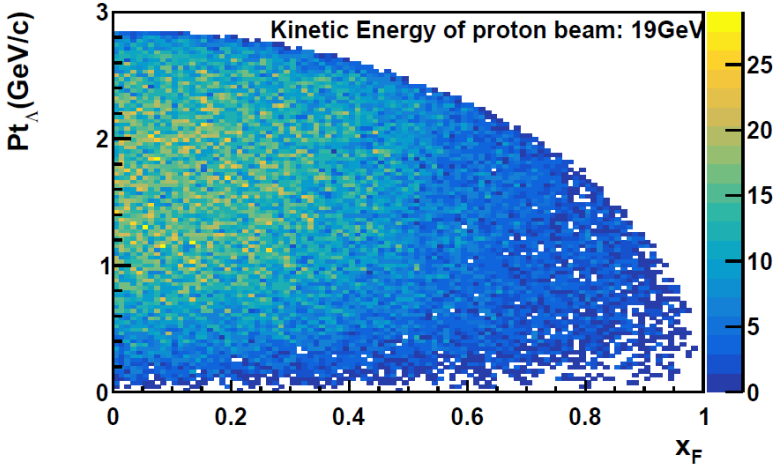
- **Momentum resolution:**
  - ~2%@1GeV when η<2.5
- **PID:**
  - K, π separation (~3σ) up to 2 GeV/c .
  - K, p separation (~3σ) up to 5 GeV/c
- **Vertex resolution:**
  - Excellent vertex resolution for background suppression
  - Material budget (<10%)
- **Acceptance:**
  - 5 to 100 degree
- **High event rate**
  - 100MHz
- **Provide detector R&D platform in forward region**



HNS kinematics coverage





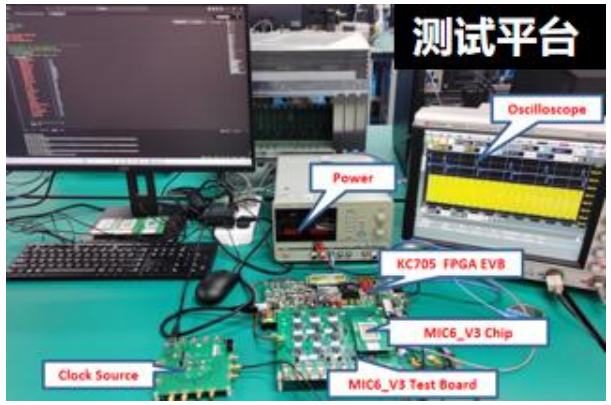


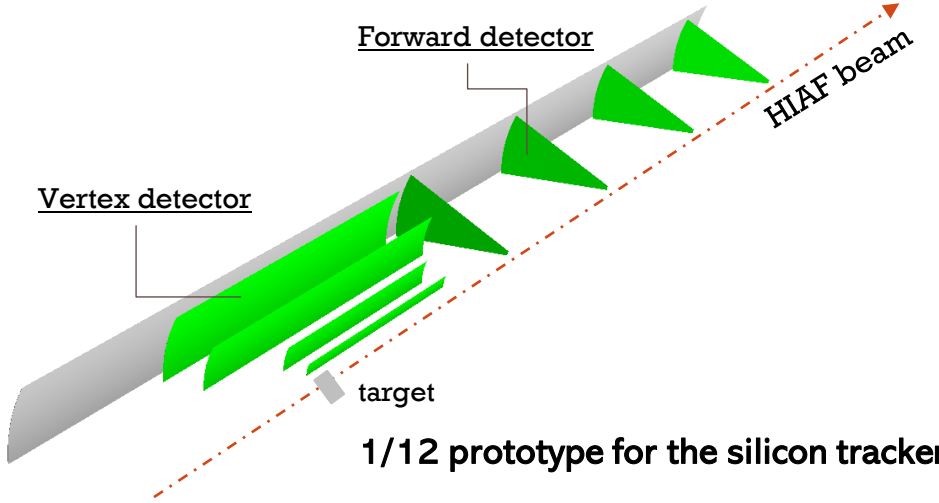
3 GeV → 9 GeV → 20 GeV

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

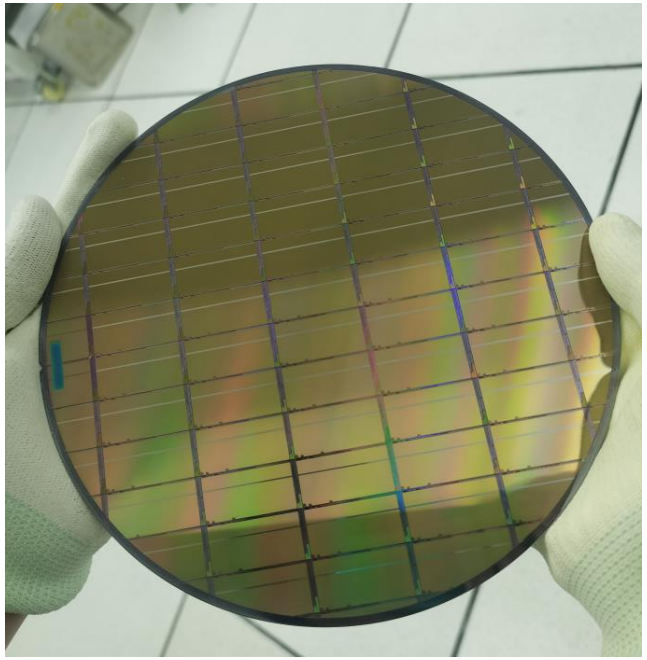
Silicon tracker at HNS

MIC6 development at CCNU



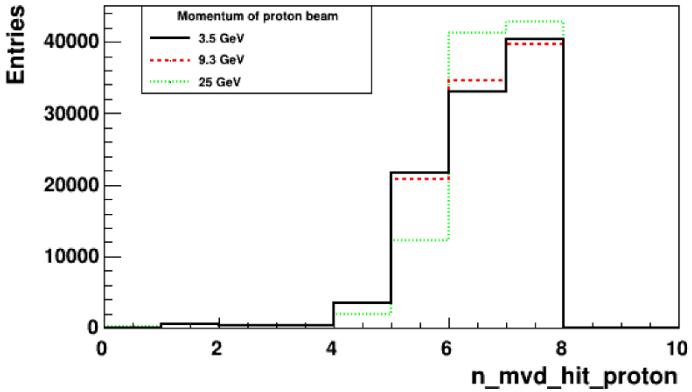


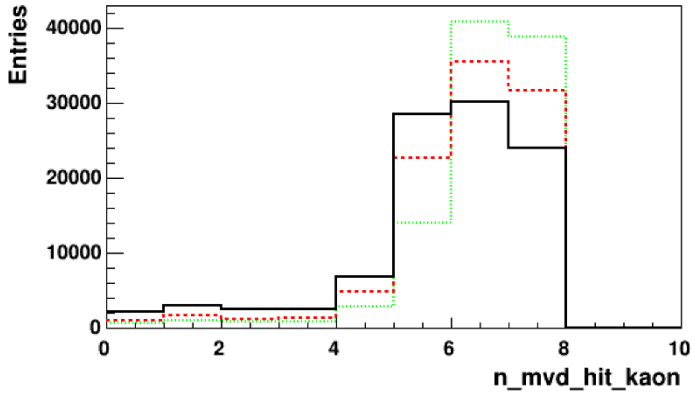
1/12 prototype for the silicon tracker

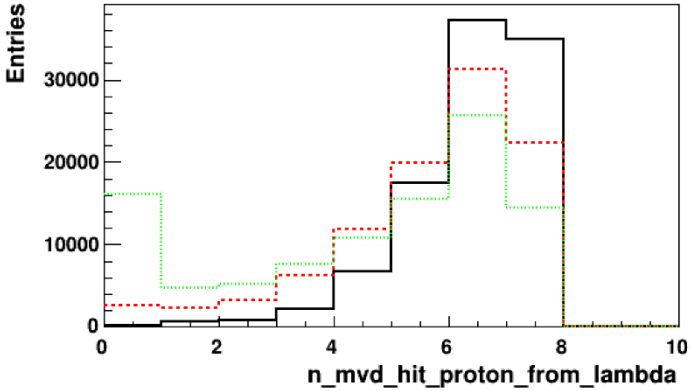


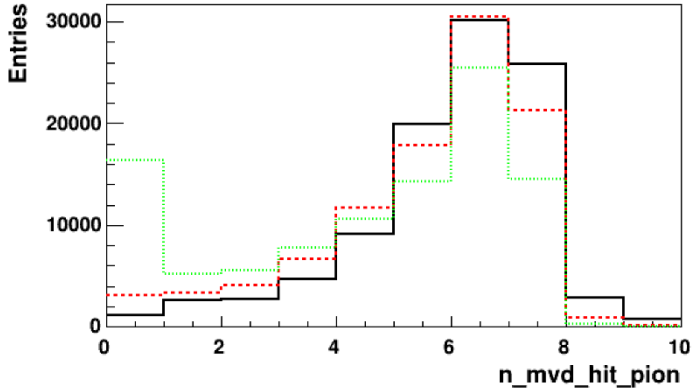
- **MIC6 MAPS pixel chip:** development and manufacture with the domestic process
- **Readout electronics** (ITS2 based design) **and DAQ** (ALICE CRU/FELIX protocol, GBTx, …)
- **Detector assembly and integration:**
  - **Vertex detector:** Stave module design (spatial resolution: ~ 5 μm with pixel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

Efficiency due to tracking

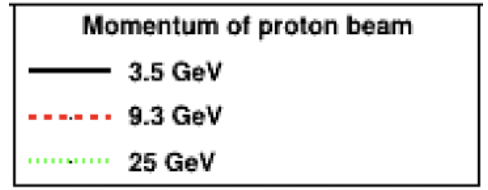








$$\varepsilon = \frac{N_{\text{hits}\geq 4}}{N_{\text{all}}}$$

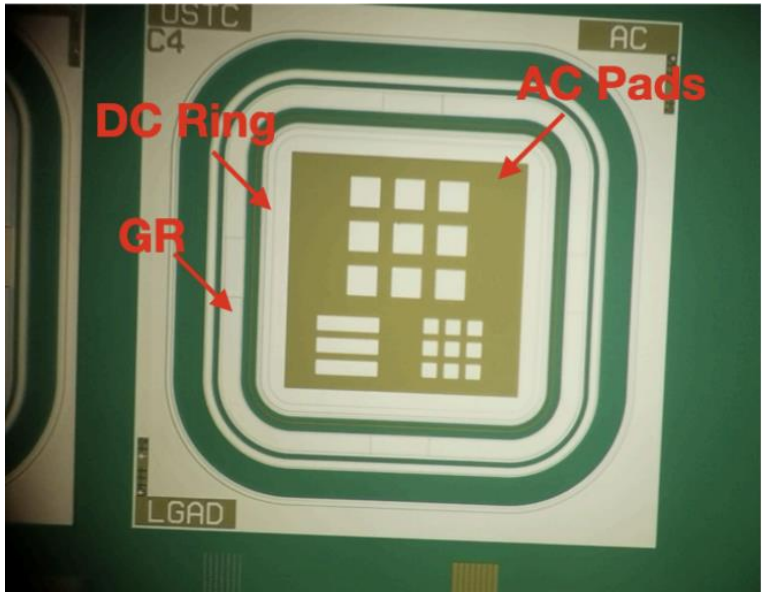


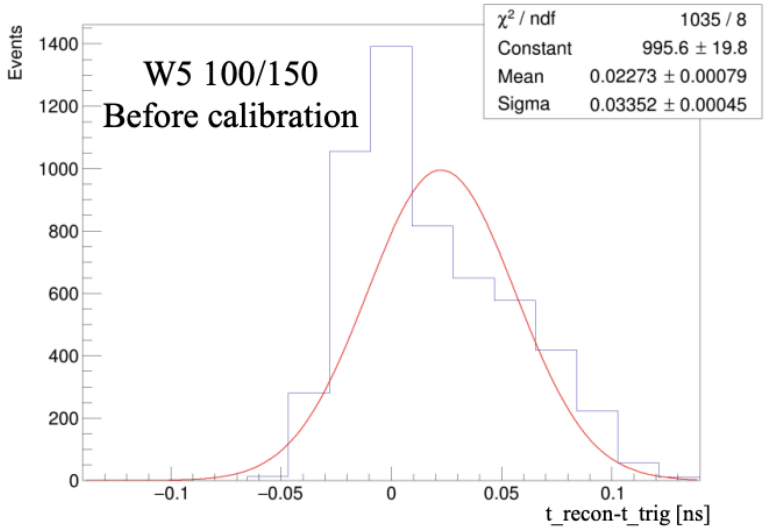
E beam	$\varepsilon(p)$	ε(K)	$\varepsilon(\pi)$ (Λ)	$\varepsilon(p)$ (Λ)	$\varepsilon(Event)$
3.5GeV	98%	89%	88%	96%	76%
9.3GeV	98%	95%	82%	86%	74%
25GeV	98%	96%	65%	66%	60%

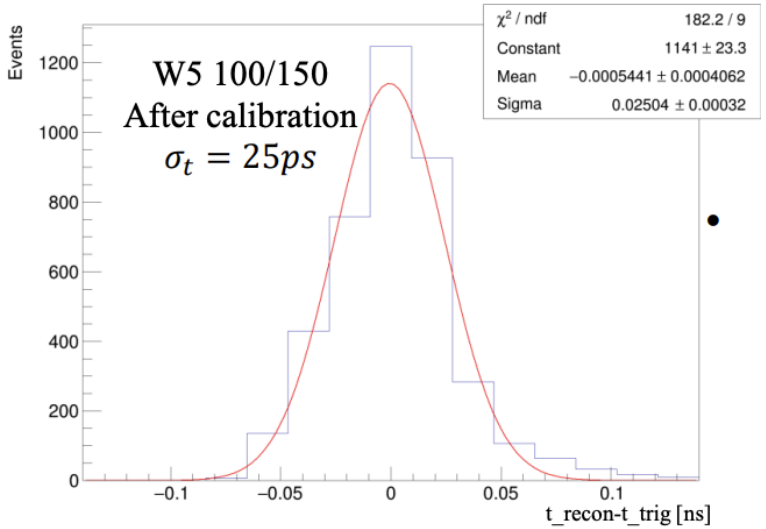
AC-LGAD at HNS

Recent development at USTC:

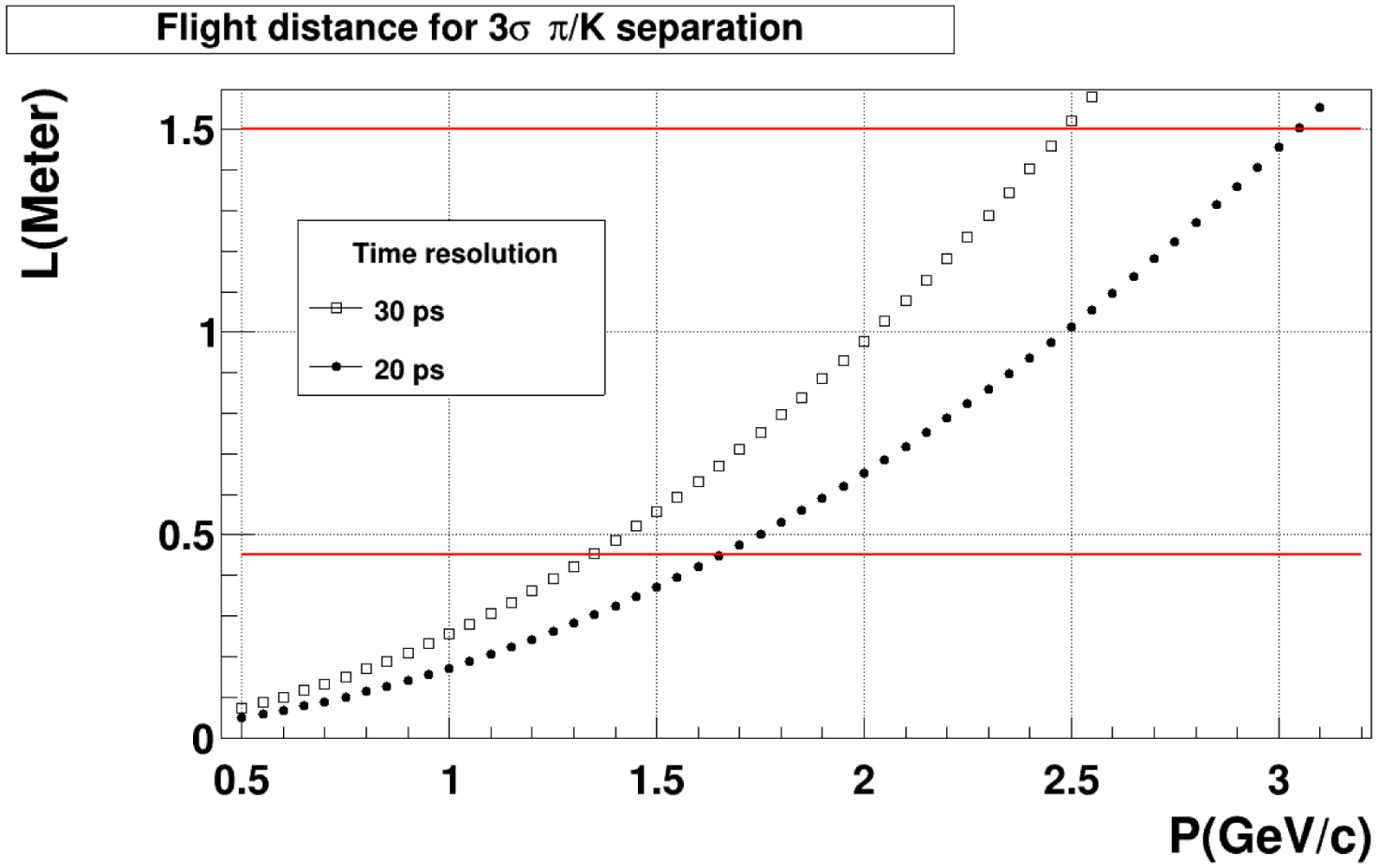
- Two wafers with different n^+ dose: W5 high n^+ dose and W6 low n^+ dose.
- Sensor size : 1300×1300×50 μm.
- Sensor with different pad-pitch size: Large pad size/pitch: 100/150 μm, Small pad (Strip) size/pitch: 50/75 μm.

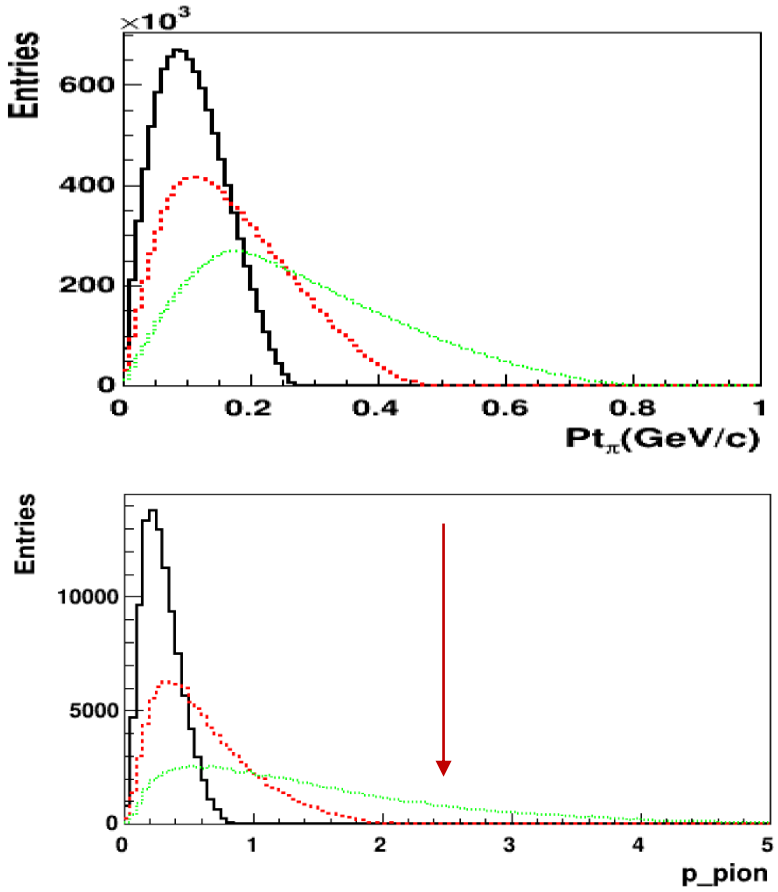






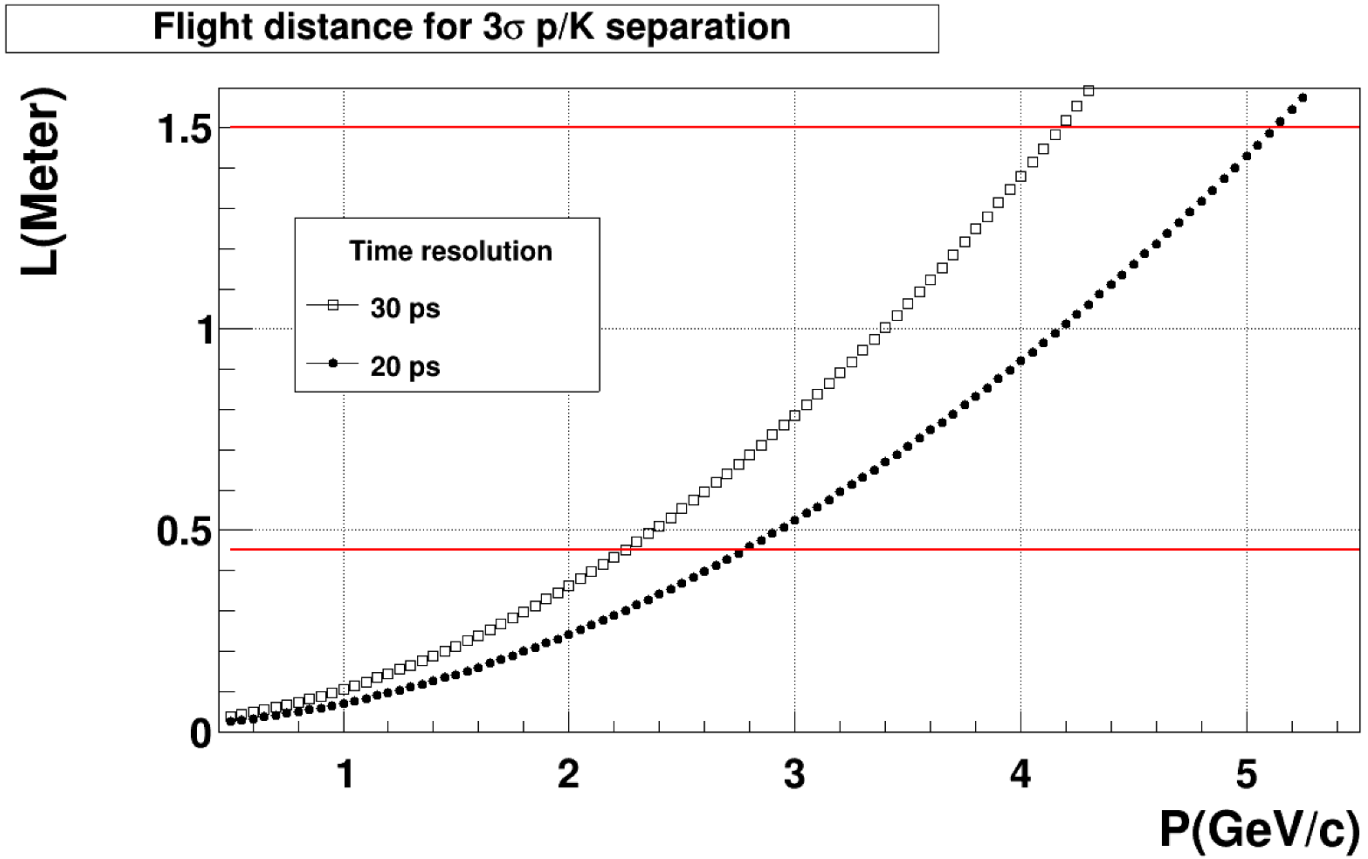
PID performance: pion/kaon

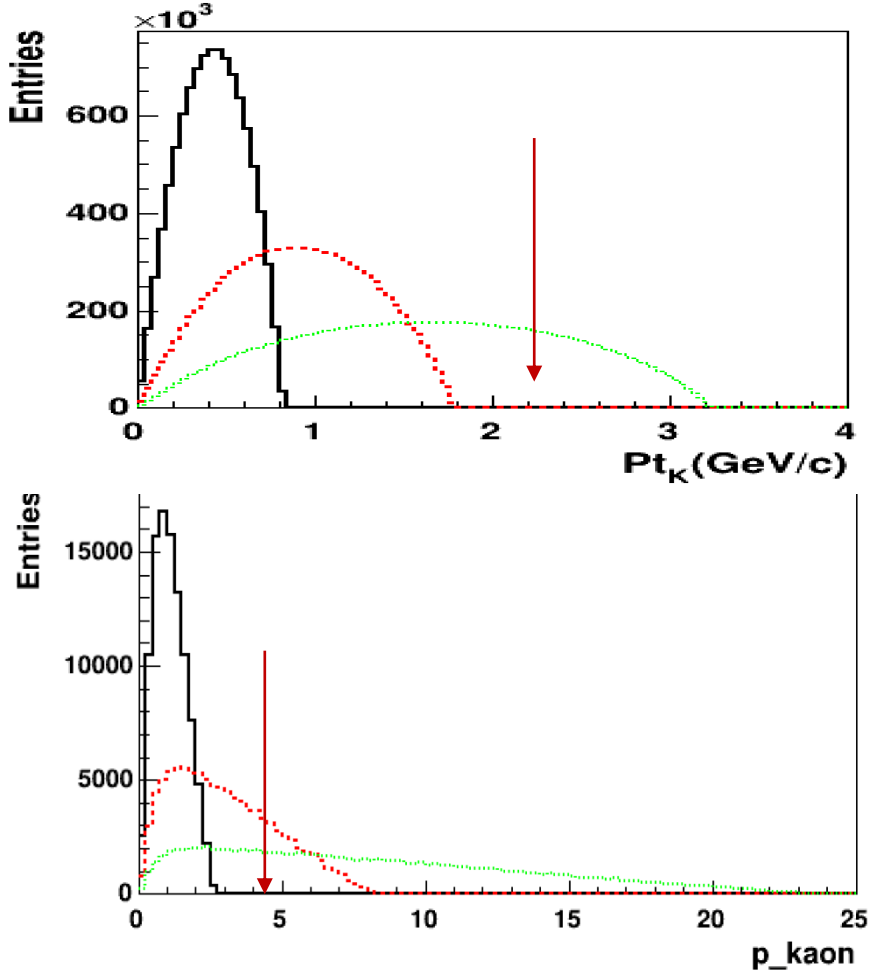




Assume a resolution of 30 ps:
LGAD barrel (R=45cm), can cover a Pt up to 1.35 GeV/c
LGAD endcap (Z=150) can up to 2.5 GeV/c

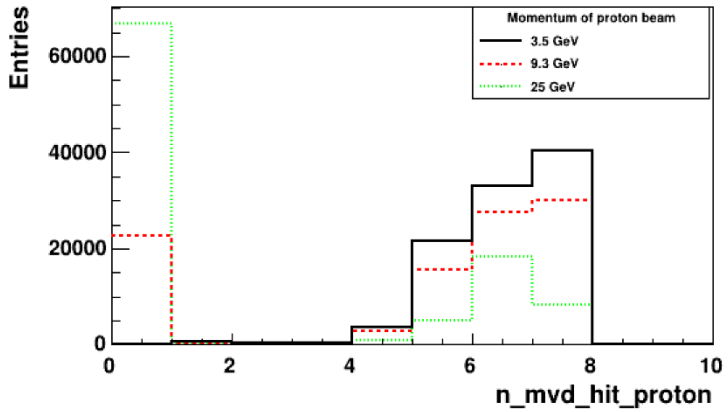
PID performance: proton/kaon

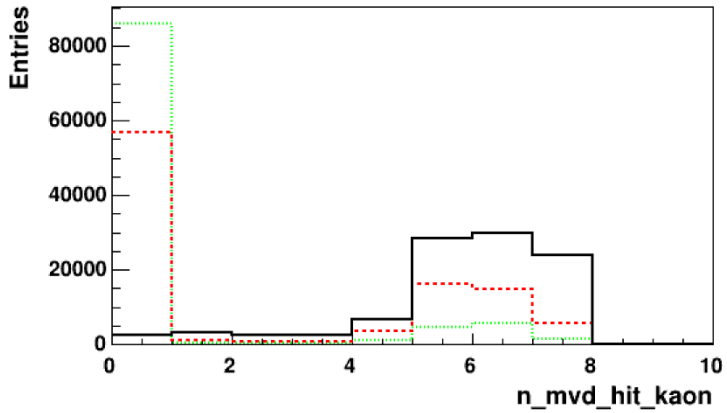


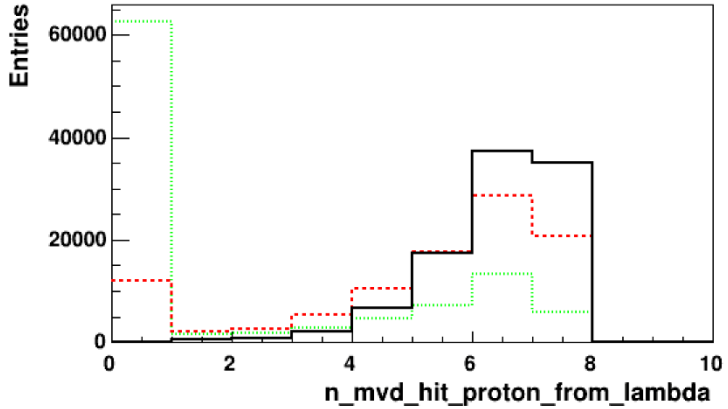


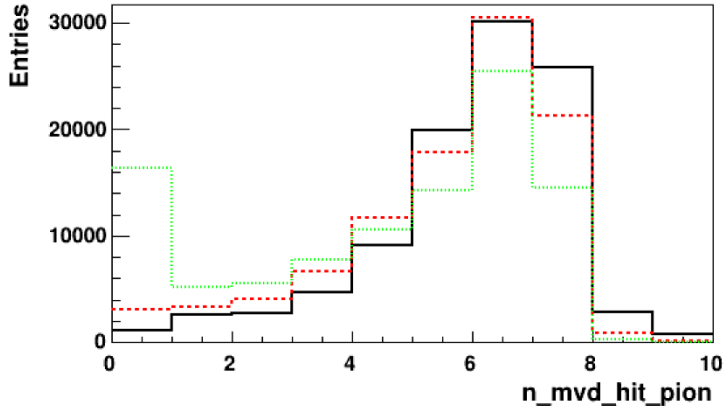
Assume a resolution of 30 ps:
LGAD barrel, (R=45cm), can cover a Pt up to 2.25 GeV/c
LGAD endcap, (Z=150) can up to 4.2 GeV/c

Efficiency due to PID+tracking



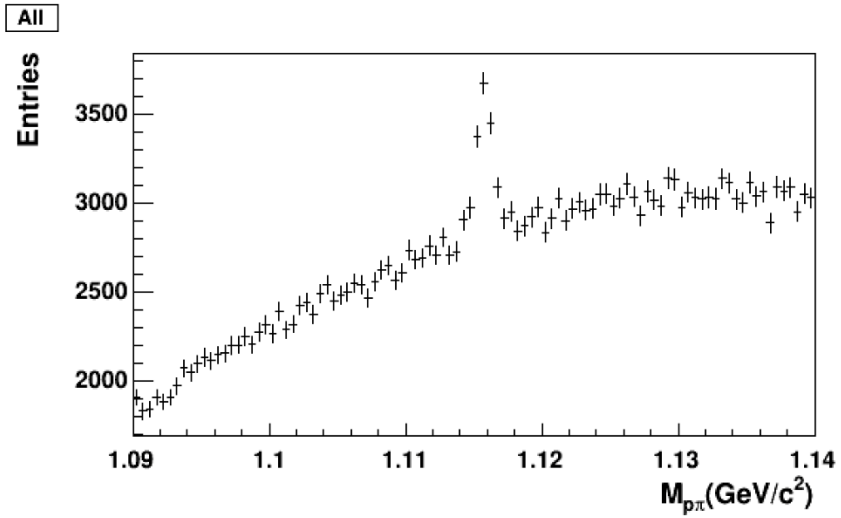


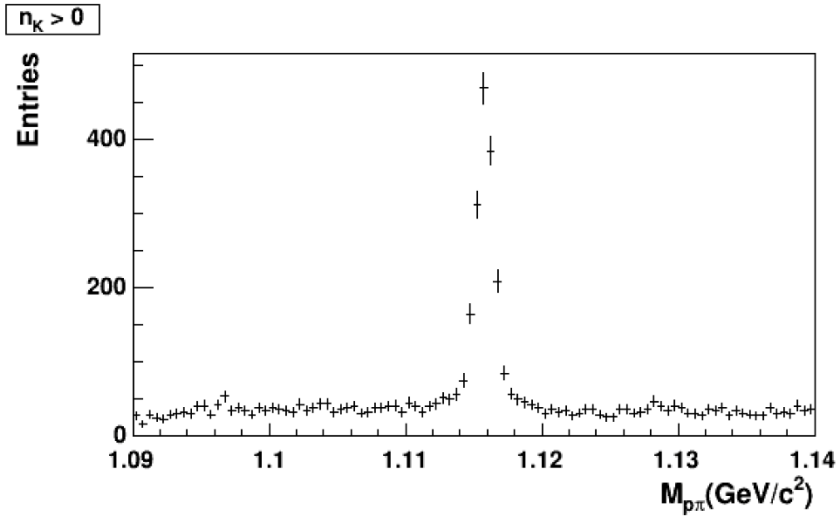


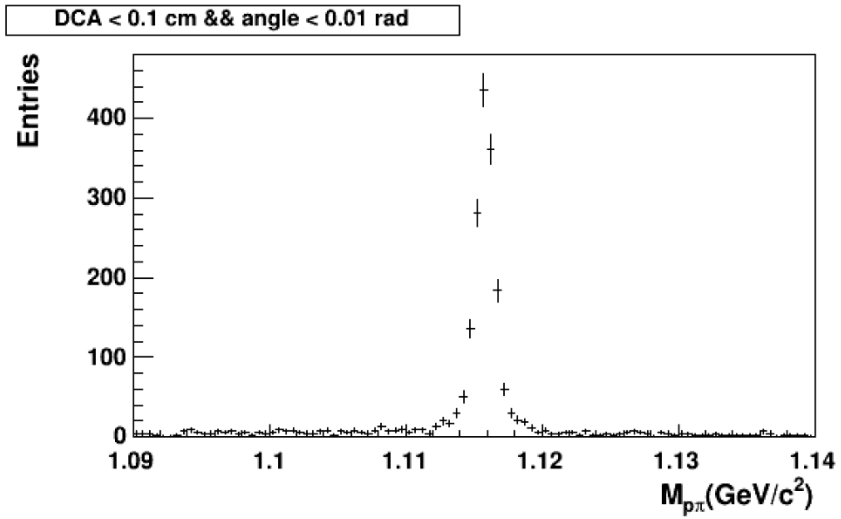


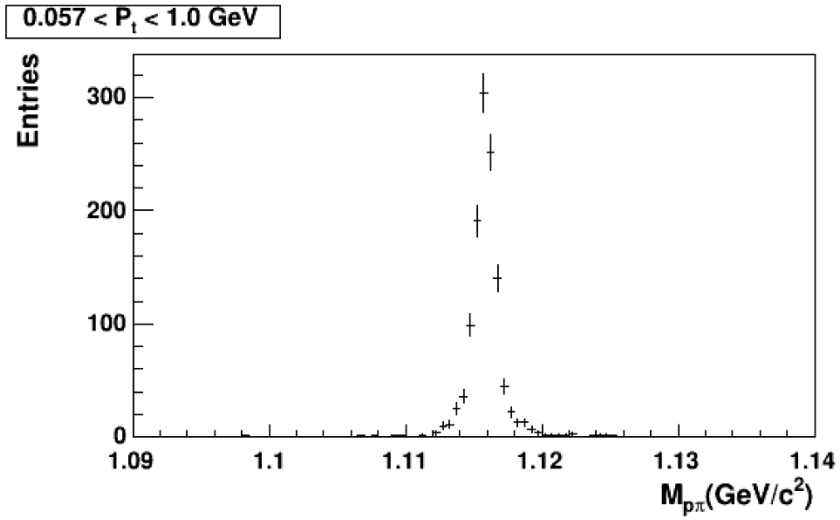
E beam	$\varepsilon(p)$	ε(K)	$\varepsilon(\pi)$ (Λ)	$\varepsilon(p)$ (Λ)	$\varepsilon(Event)$
3.5GeV	98%→98%	89%→89%	88%→88%	96%→96%	76%→76%
9.3GeV	98%→76%	95%→40%	82%→82%	86%→77%	74%→20%
25GeV	98%→32%	96%→13%	65%→65%	66%→31%	60%→1.5%

Almost background free reconstruction (Beam energy 3.5 GeV)

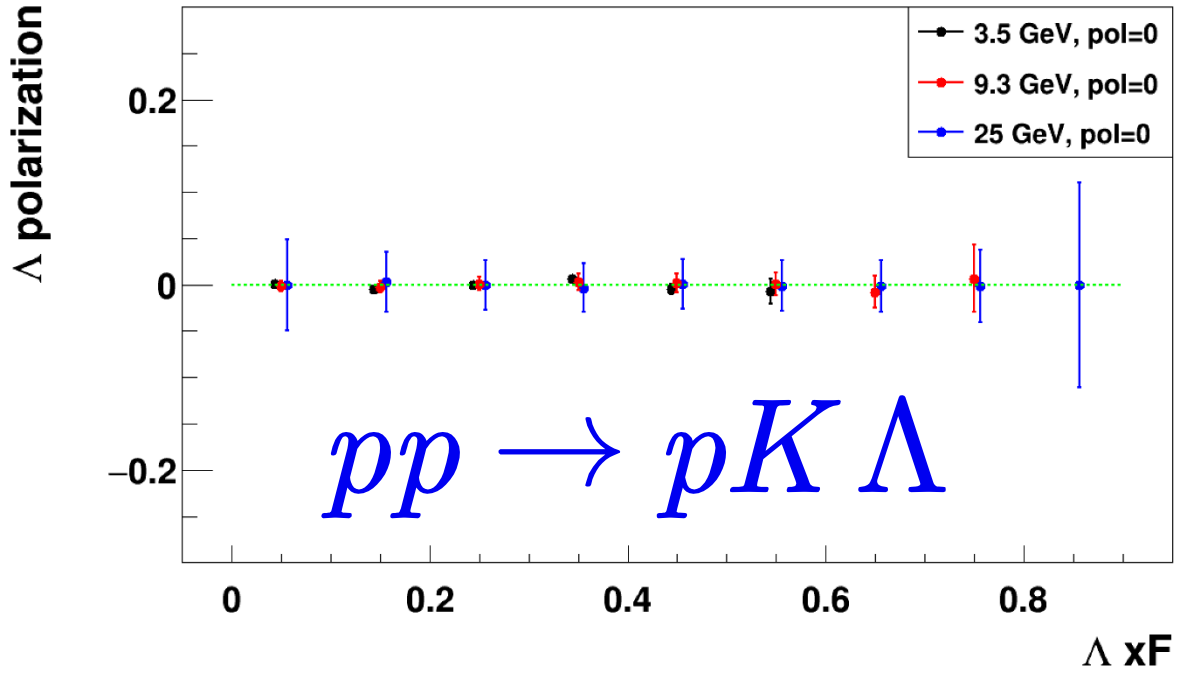


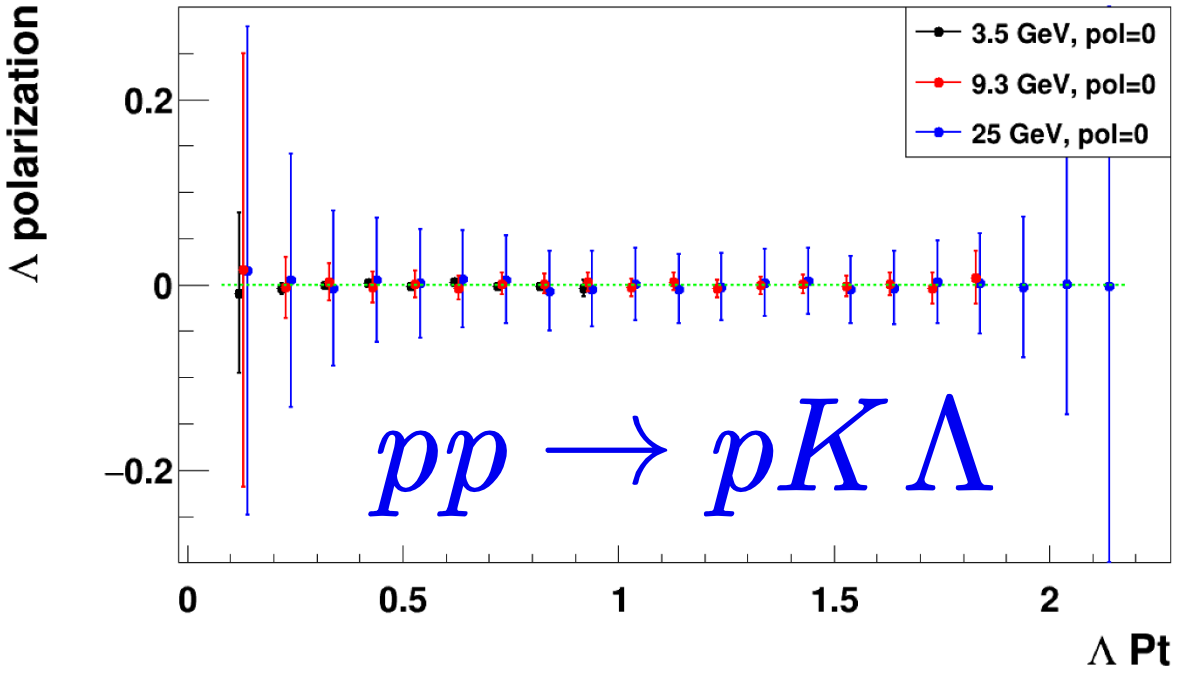






Projection of Λ polarization with 10M pp events





Only take ~10 minutes assuming 100MHz event rate

Collaboration	events
COSY pp->P K Λ $\sqrt{s} = 2.75$ GeV	$2* 10^5$
DISTO pp->P K Λ $\sqrt{s} = 2.98$ GeV	$1.7* 10^5$
HADES pp-> ΛX $\sqrt{s} = 3.176$ GeV	$1.2* 10^9$
BESIII $e^+e^- \rightarrow \Lambda\bar{\Lambda}$ $\sqrt{s} = 3.096$ GeV	$3.2* 10^6$

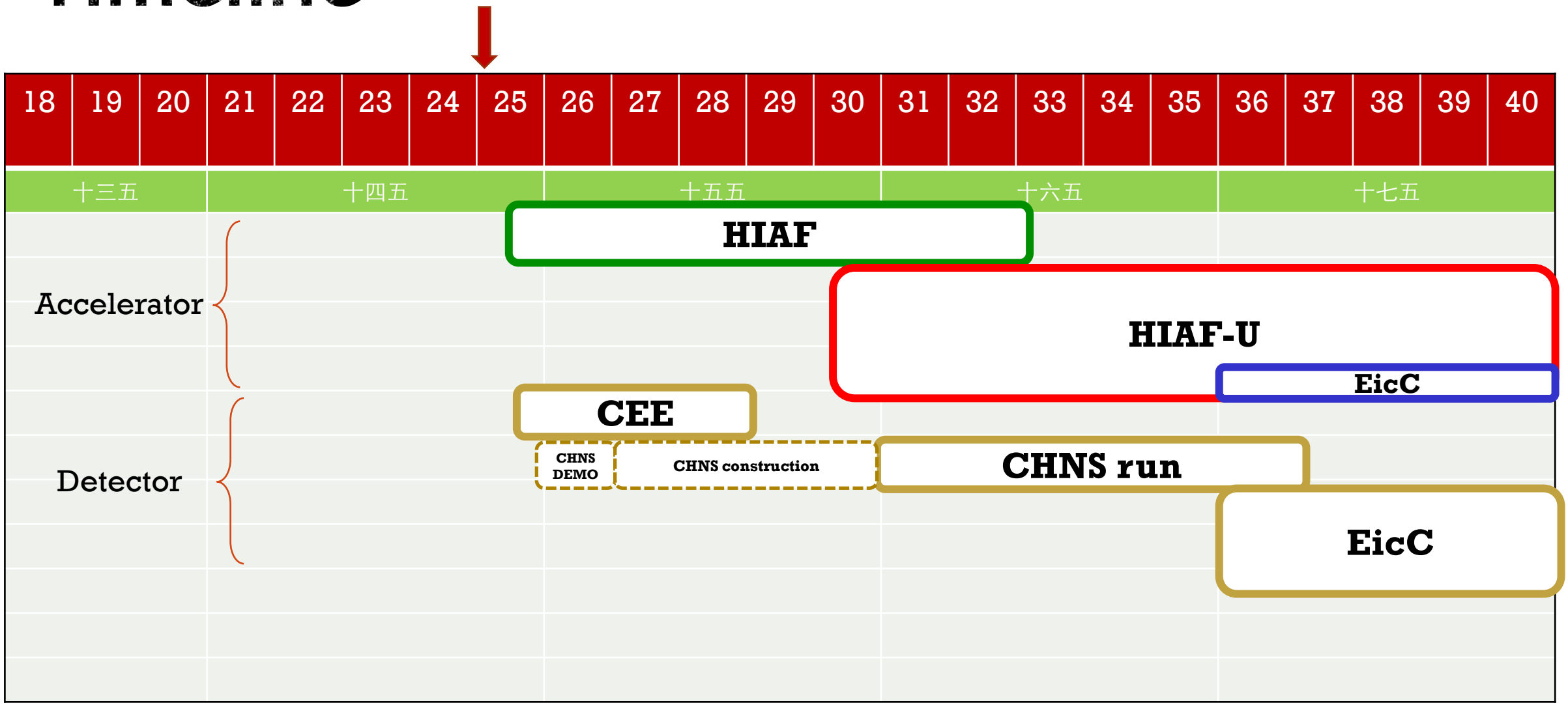
White paper （2025）

Physics Conveners: 刘天博(SDU)、浦实(USTC)、肖博文(CHKU)、张哲(IMP)

Detector Conveners: 刘建北（USTC）、徐庆华（SDU）

- Tracking 郭爱强(IMP)、王亚平(CCNU)、王博群(IMP)、孙向明(CCNU)、赵承心(IMP)
- PID 刘衍文(USTC)、李昕(IMP)
- Calorimetry 林德旭(IMP)、何万兵(FDU)
- Magnet 磁铁室(IMP)
- Target 李夏卿(SDU)、勾伯兴（IMP）
- DAQ 陈凯(CCNU)

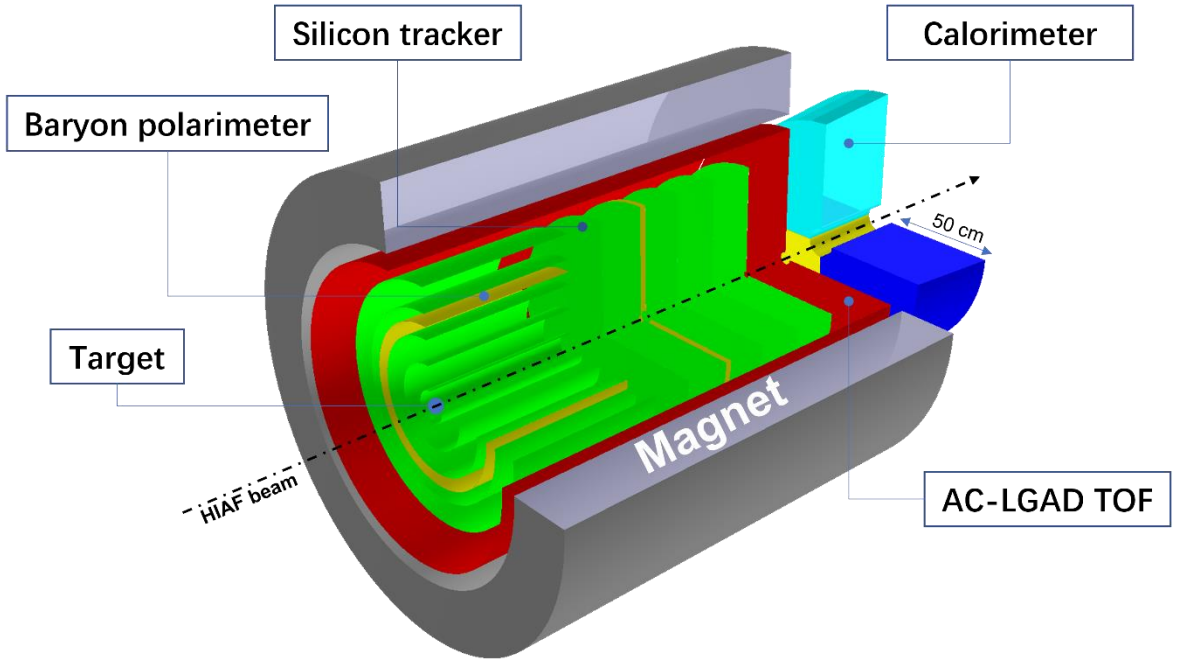
Timeline


18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
十三五
十四五
十五五
十六五
十七五
Accelerator
Detector
HIAF
HIAF-U
EicC
CEE
CHNS DEMO
CHNS construction
CHNS run
EicC

Outline

- Introduction
- HNS at HIAF
- Summary and Outlook

Hyperon-Nucleon Spectrometer (HNS)



目前参加单位：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

子系统研发：Silicon tracker, AC-LGAD, Target, Baryon polarimeter, Calorimeter, Electronics, DAQ, Magnet, Beamline, Mechanics + Engineering

I. Physics:

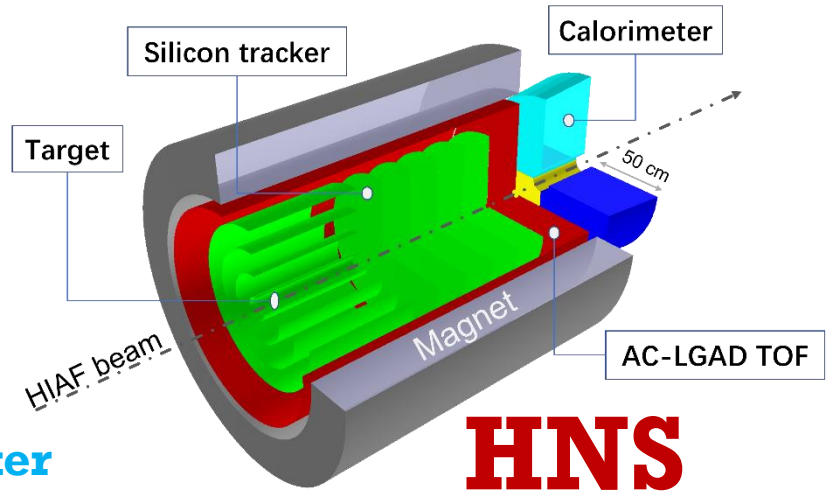
- Λ production and polarization (*p+p*)
  - Medium effect (*p+A*)
  - Global polarization of Λ hyperon (*A+A*)
- Hadron physics via *p+p*

II. Community:

- Supports both communities of hadron structure and heavy-ion physics
- International interests are expected: Japan

III. Detector R&D

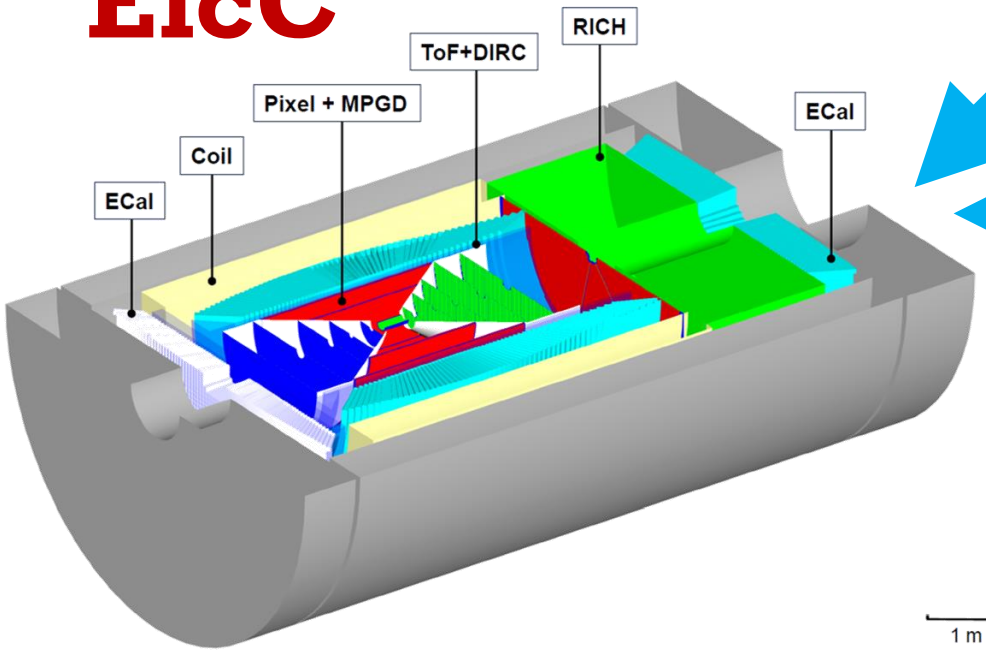
- Many parts are similar for CEPC, HNS, EicC, and STCF. Save resources.
- HNS: a detector R&D platform for EicC, ½ EicC



HNS

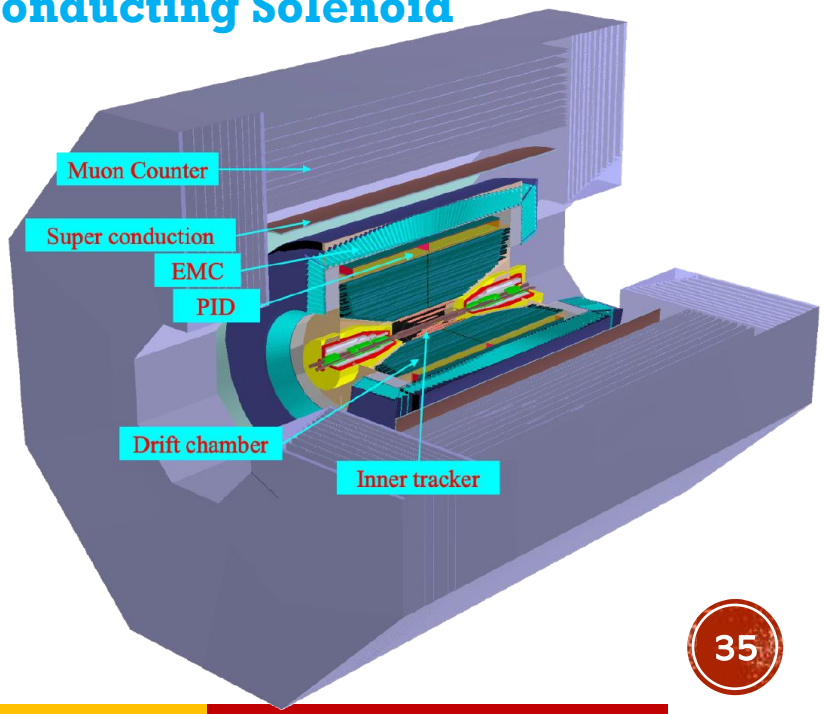
Silicon tracker
AC-LGAD (PID)
Ecal.
Super-conducting Solenoid

EicC



Silicon tracker
Ecal.
Super-conducting Solenoid

STCF

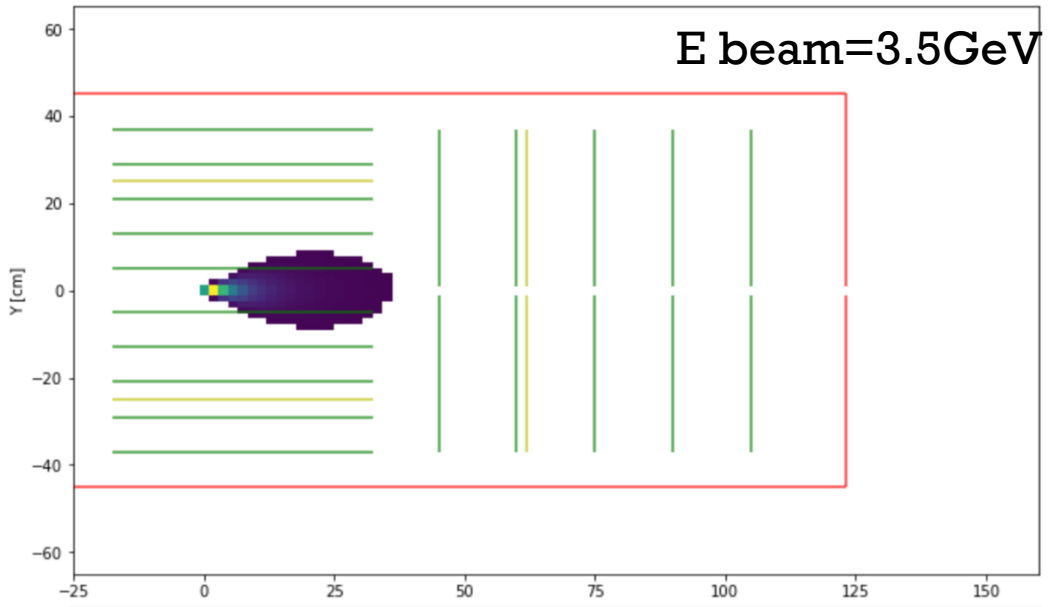


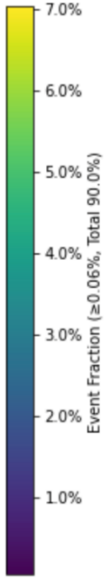
Silicon tracker
MPGD tracker
DIRC (PID)
RICH (PID)
Ecal
Super-conducting Solenoid

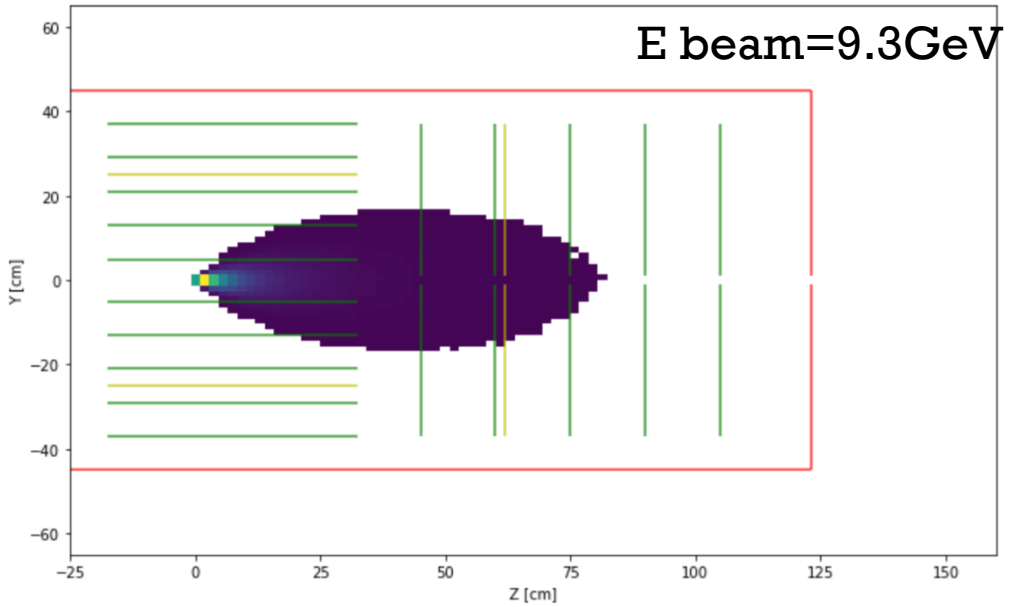
Thank you !

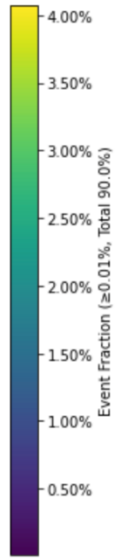
backups

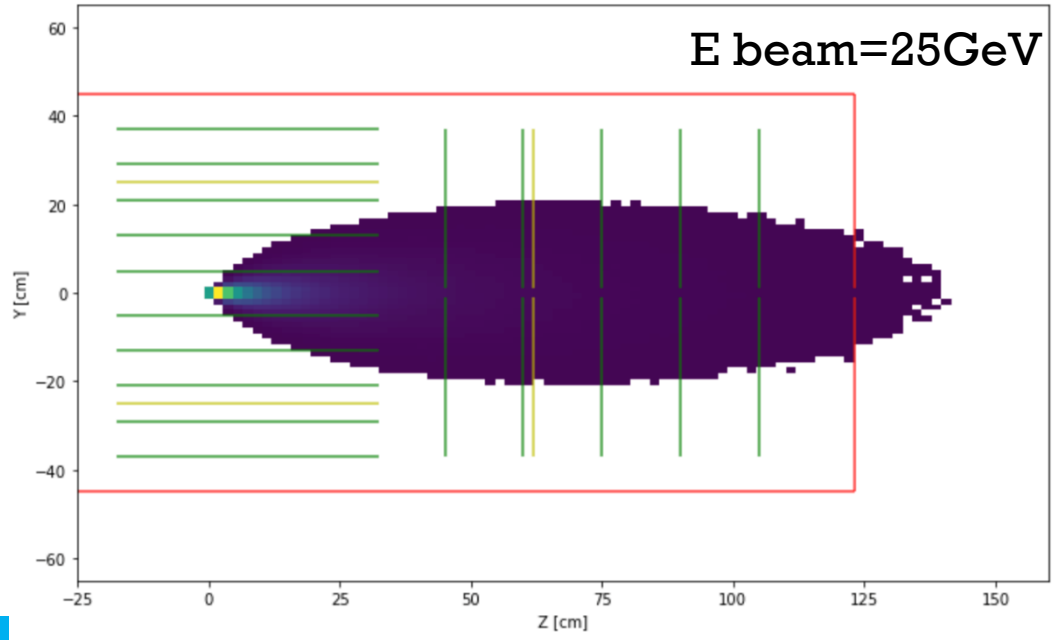
Efficiency due to tracking

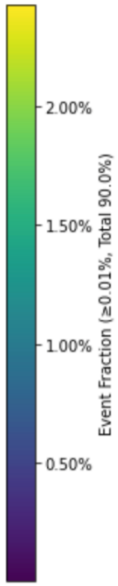












- Λ decay vertex distribution
- 90% of all event
- Normalized to total event