Detector concept with polarimetry function

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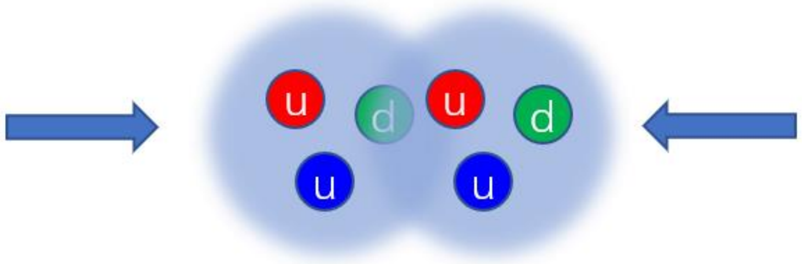
第一届Lambda超子自旋极化跨系统研讨会
USTC 2025.03.23

Based on arXiv: 2501.02439

Outline

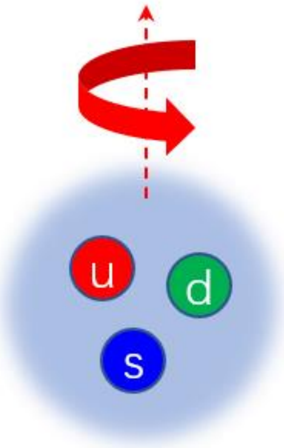
- **Introduction**
- **Principle of nucleon polarimetry**
- **Detector concept with polarimetry function**
- **How to validate the method**
- **Physics potentials with the new concept**
- **Summary**

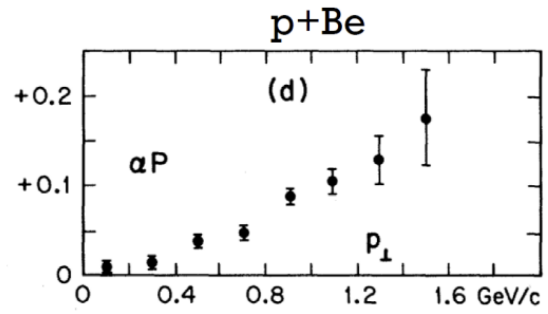
Motivation



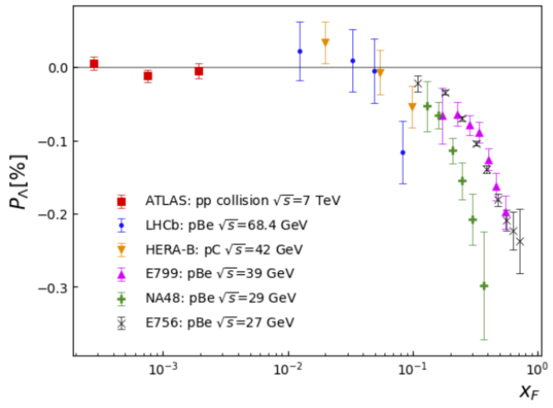
Λ polarization observed in various reactions.

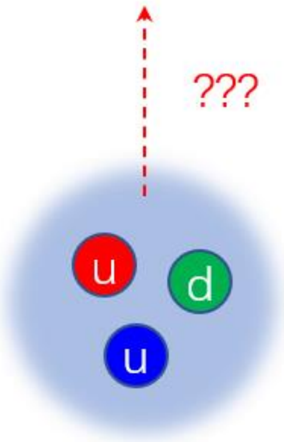
Source of hyperon polarization?





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





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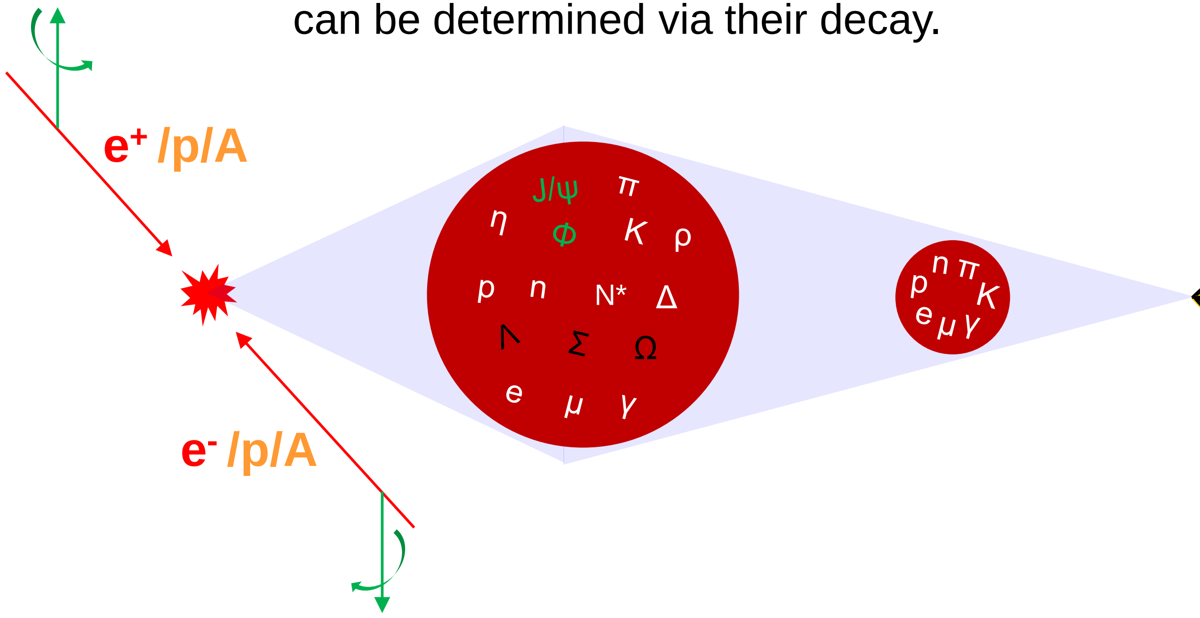
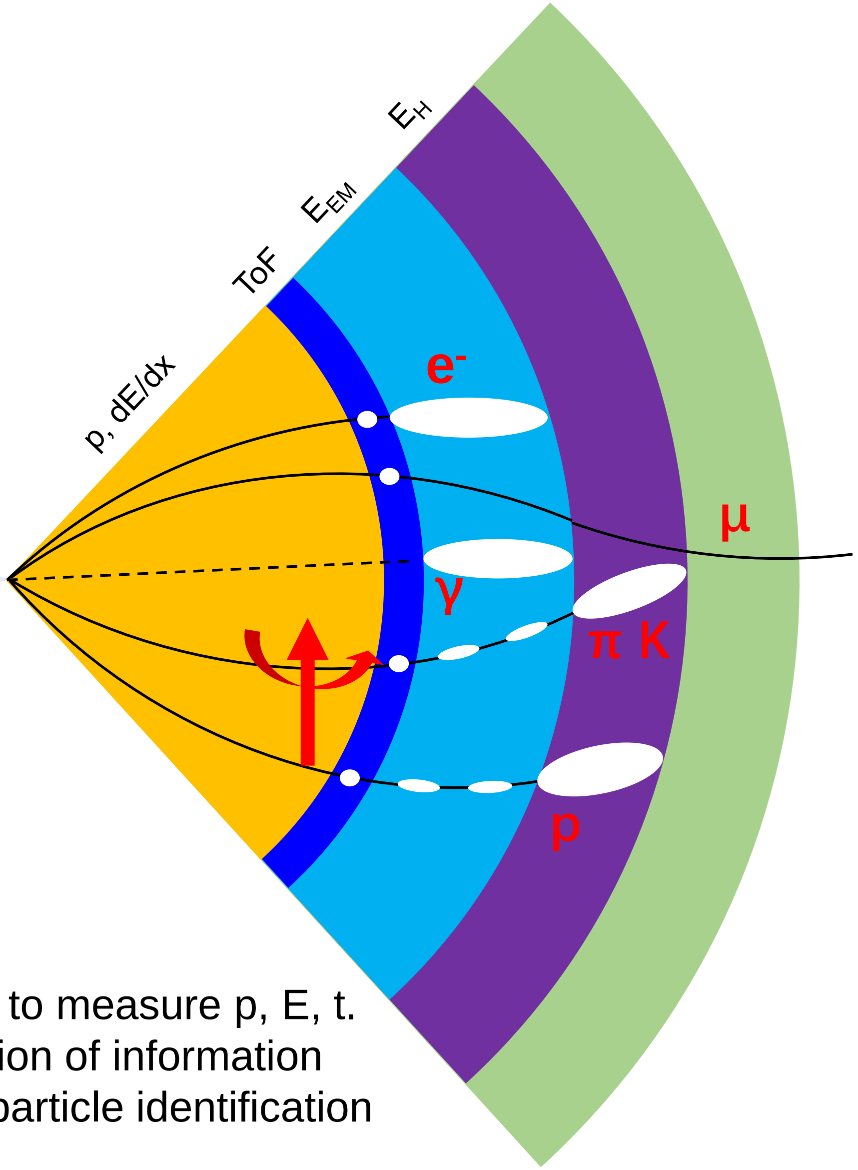
Observables in experiments

- **Complete initial state VS incomplete final state**

Polarization of some intermediate states can be determined via their decay.



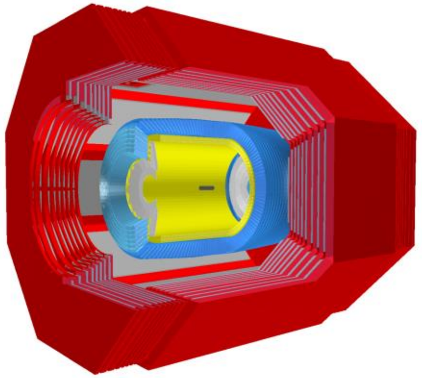


Complete and accurate initial state information: beam energy, beam polarization, etc.

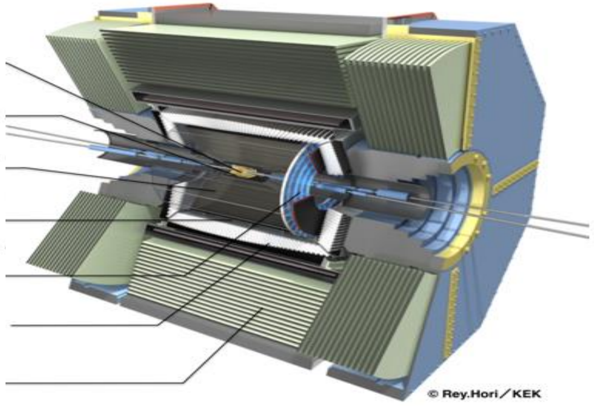
Detectors to measure p, E, t.
Combination of information provides particle identification

General-use detectors

BESIII



BELLE-II



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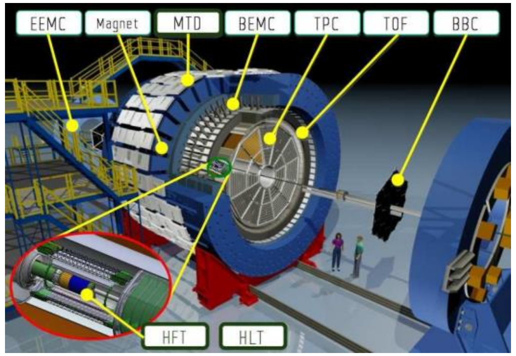
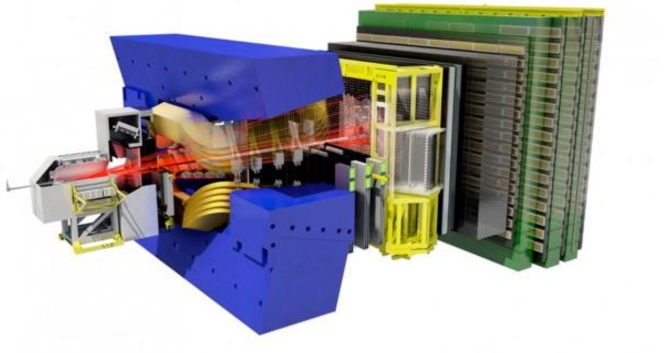
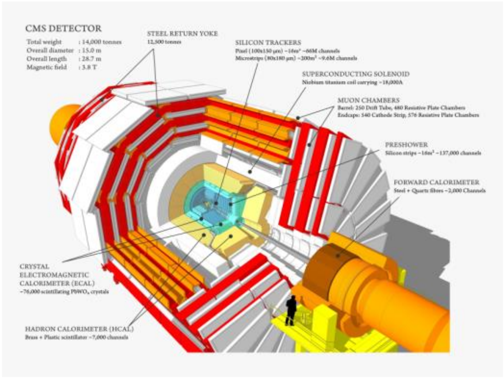


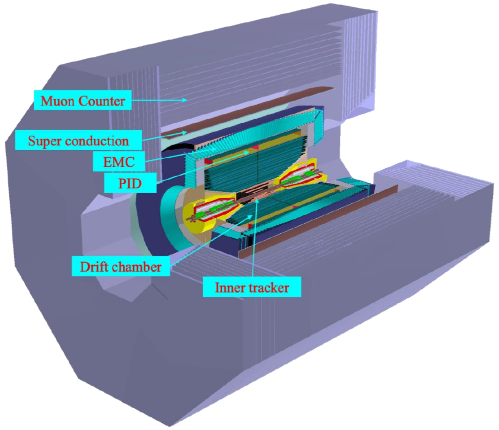
LHCb



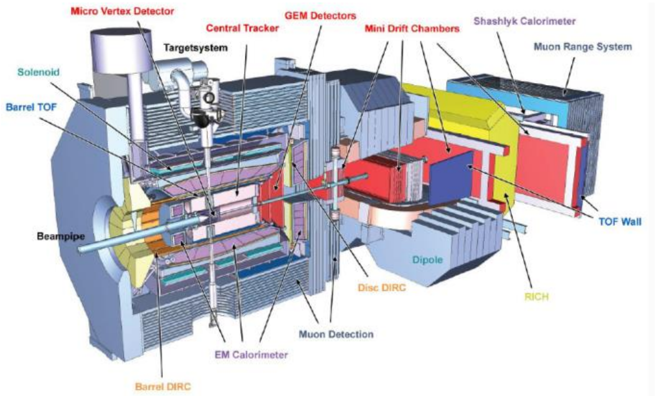
CMS



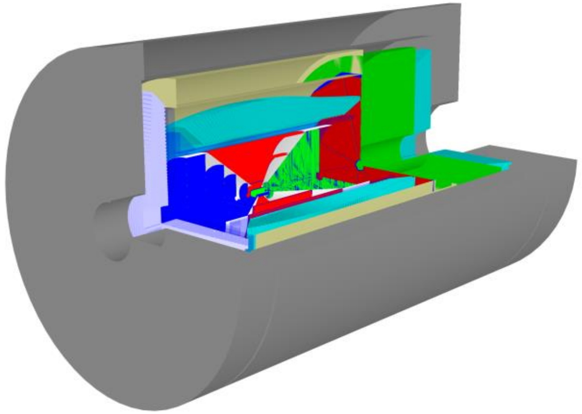
STCF



PANDA



EicC

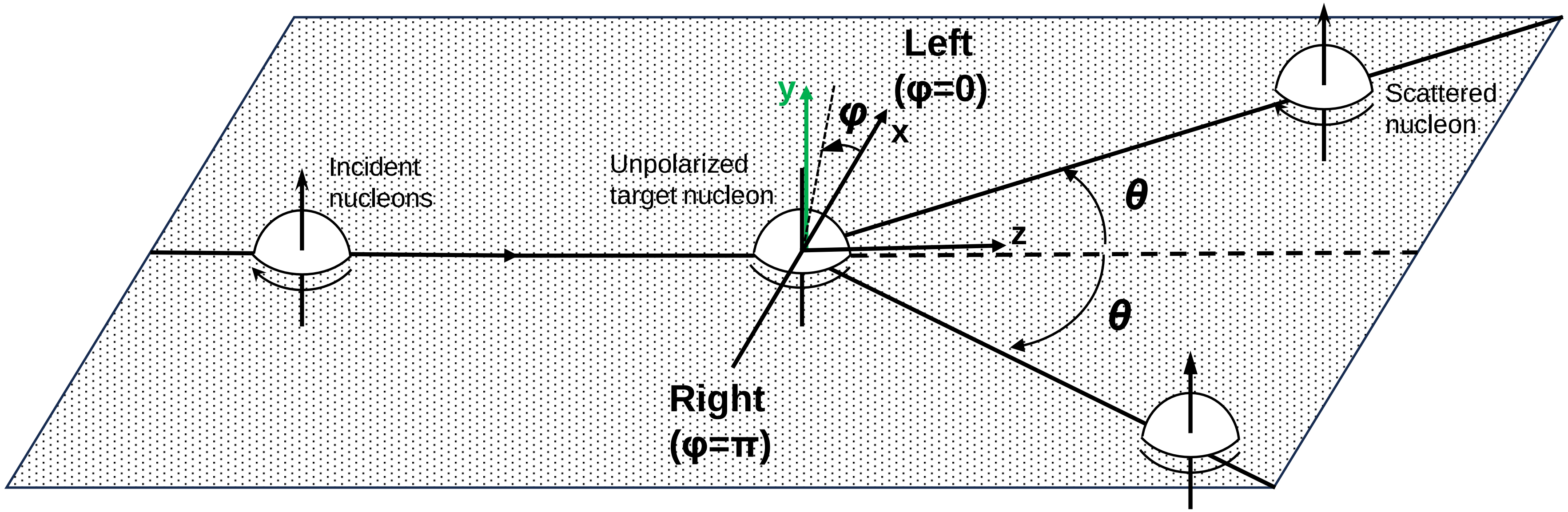


Principle of proton polarimetry

Principle of proton polarimeter

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

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

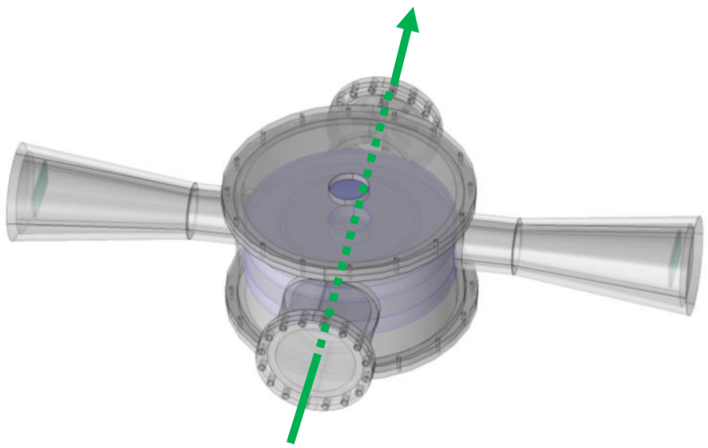


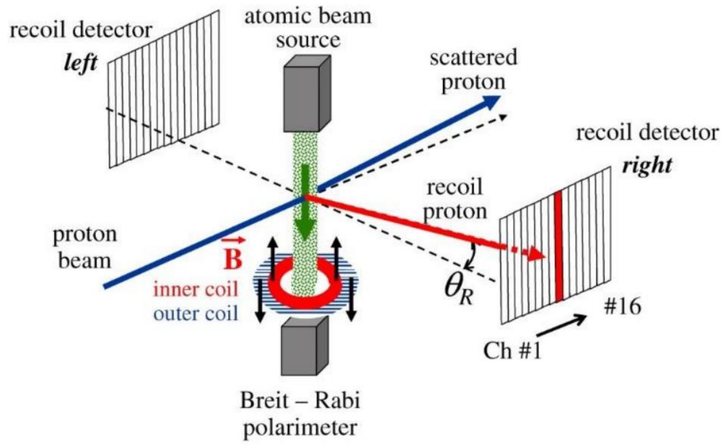
Widely used as polarimetric reaction at almost all proton accelerators (PSI, TRIMUF, LAMPF, COSY, SATURNE, ZGS, KEK-PS, AGS, RHIC …)

Principle of proton polarimeter

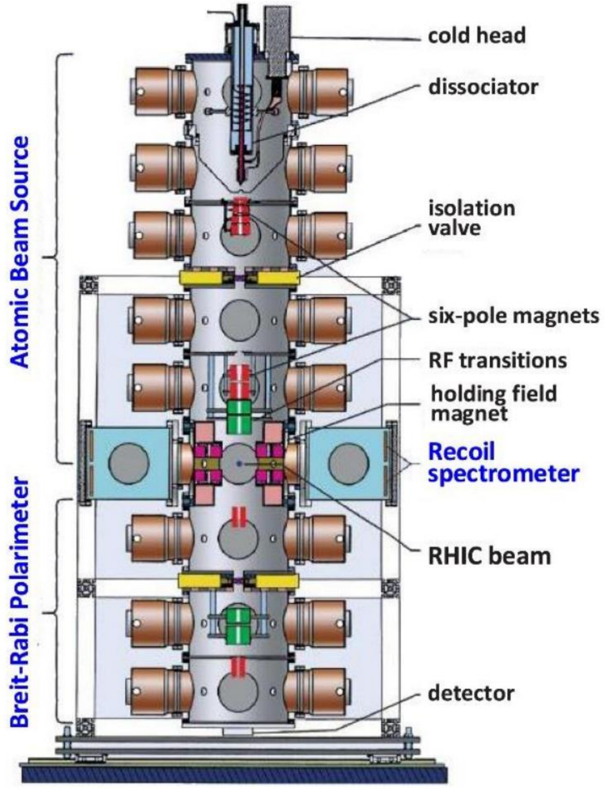
Relation between the **spin-dependent cross-section** of p + p/C scattering and the **asymmetries**

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





EicC p-polarimeter recoil detector



p-polarimeter at BNL

- Detectors, symmetrically placed in the **left** and **right** sides.

$$A_{LR} = \frac{N_L - N_R}{N_L + N_R} = P_y A_N$$

Dedicated proton polarimeter

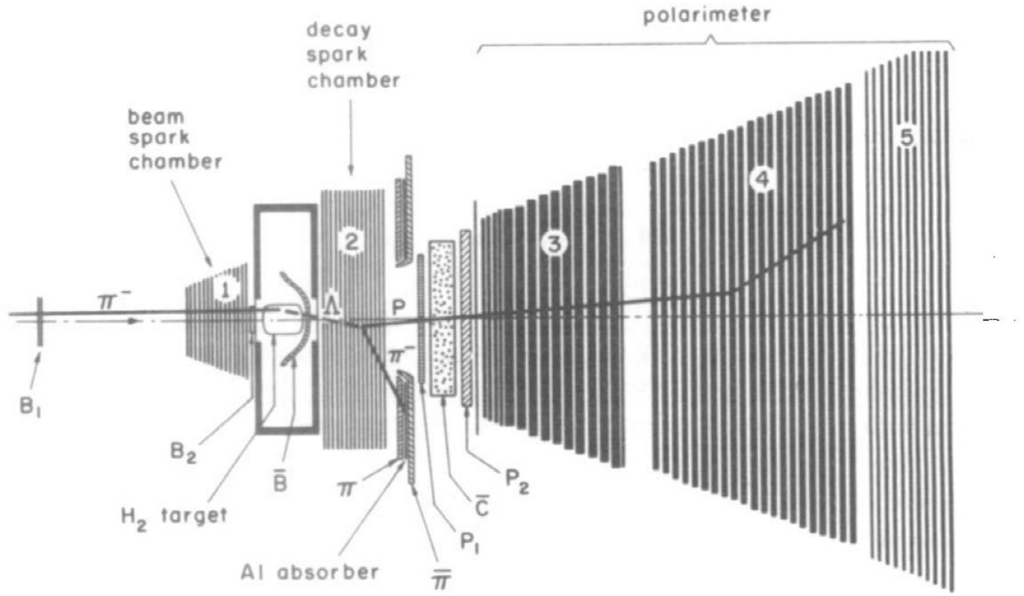


Fig. 3. Apparatus used to measure the polarization of protons from Λ^0 decay through proton-carbon scattering. The Λ^0 are produced in hydrogen. The counters π and $\bar{\pi}$ select low-energy decay pions, while P_1 P_2 $\bar{C}$ select decay protons. All counters are made of plastic scintillator except for $\bar{C}$, which is a water Čerenkov counter. The polarimeter consists of carbon plate spark chambers. The tracks are photographically recorded with 90° stereo.

[1] Nuclear Physics B40 (1972) 221-254.

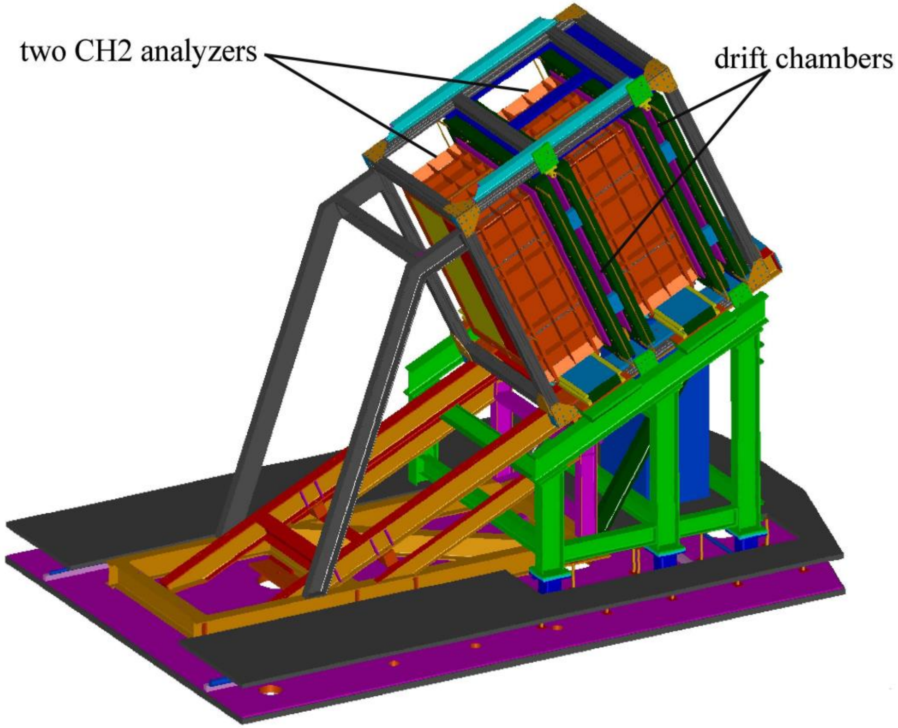
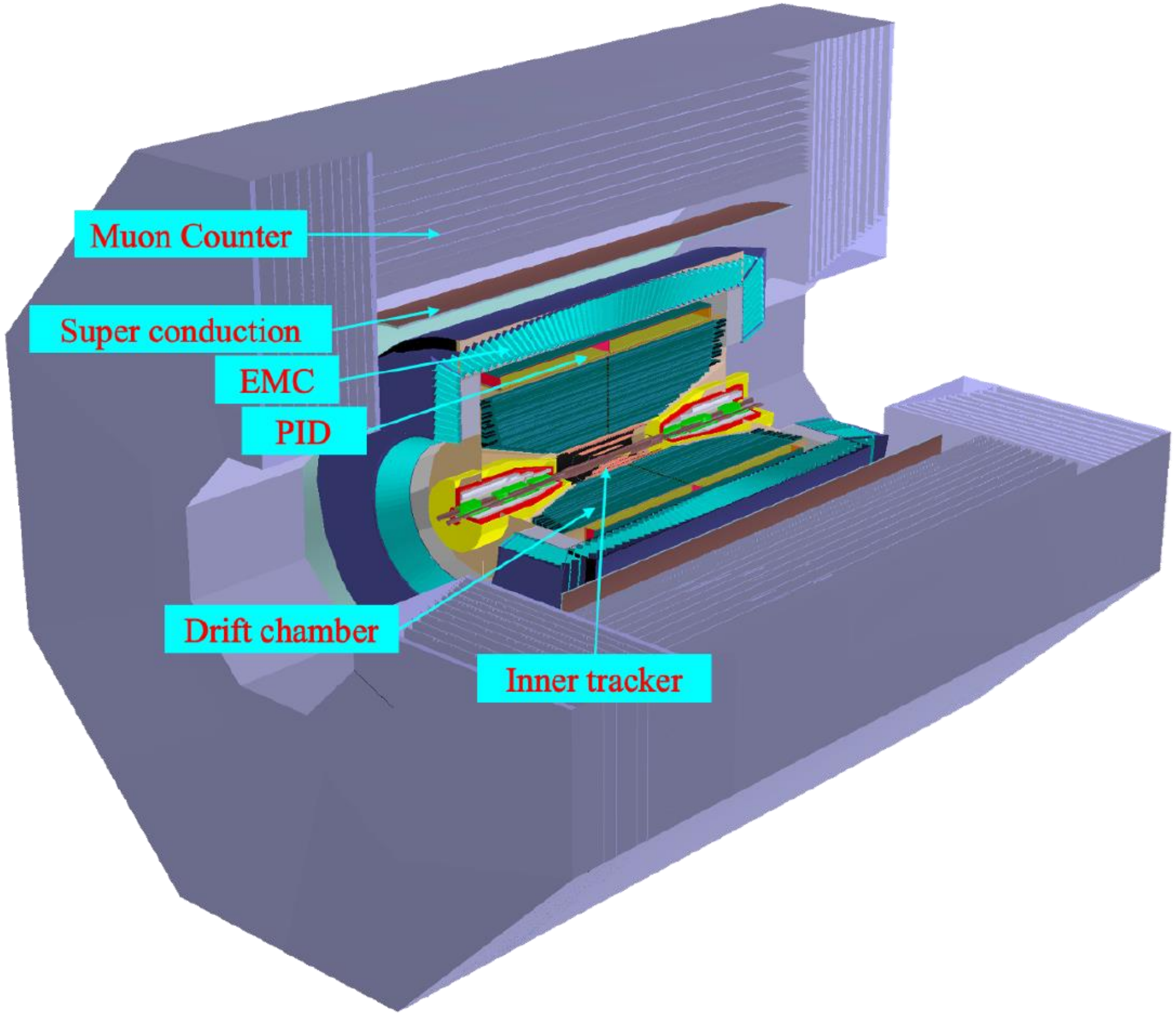


Figure 5: The FPP in the HMS in Hall C as currently designed.

[2] AIP Conf. Proc. 412, 342–348 (1997)

➢ **Difficult to integrate to the multi-purpose detector concept**

Add polarimeter function in general-use detector ?



General-use detector requirements:

1) Large acceptance
2) Good tracking efficiency
3) Good momentum resolution
4) Good energy resolution

Adding scattering layer affects the above performance.

?

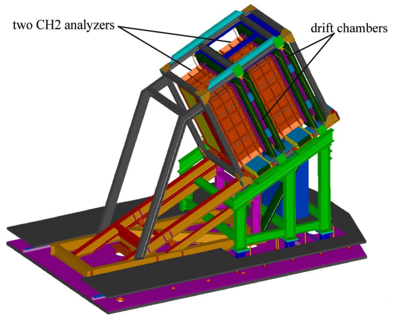
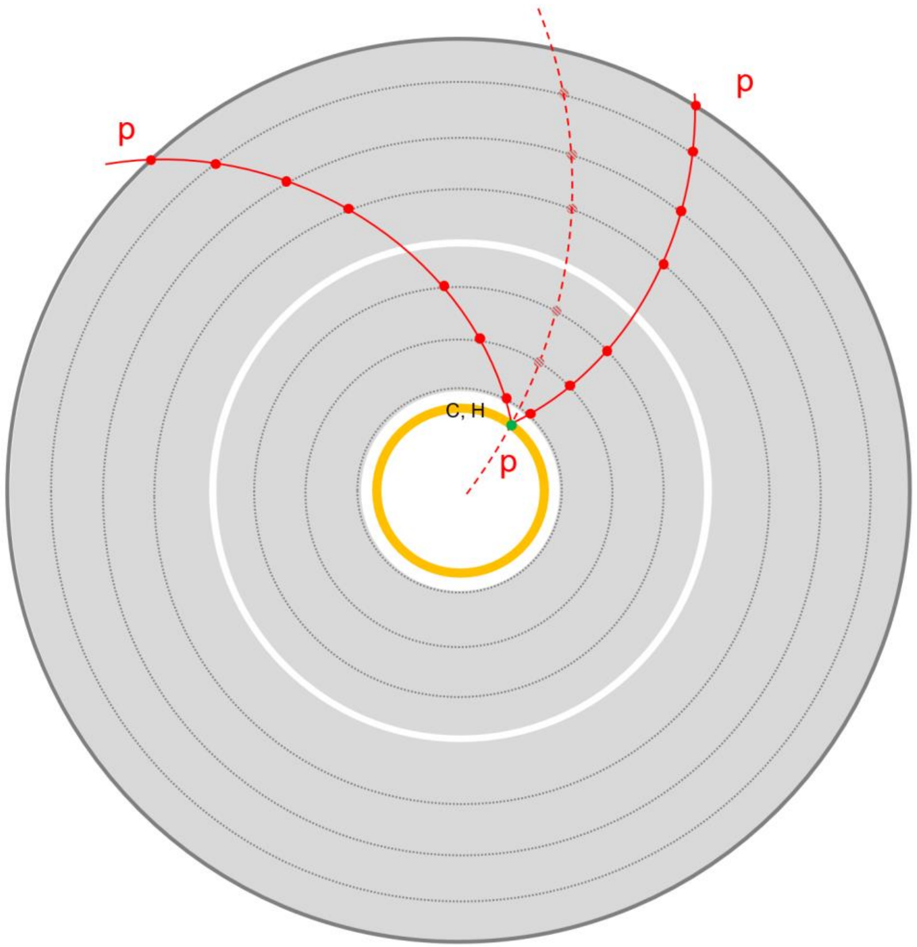
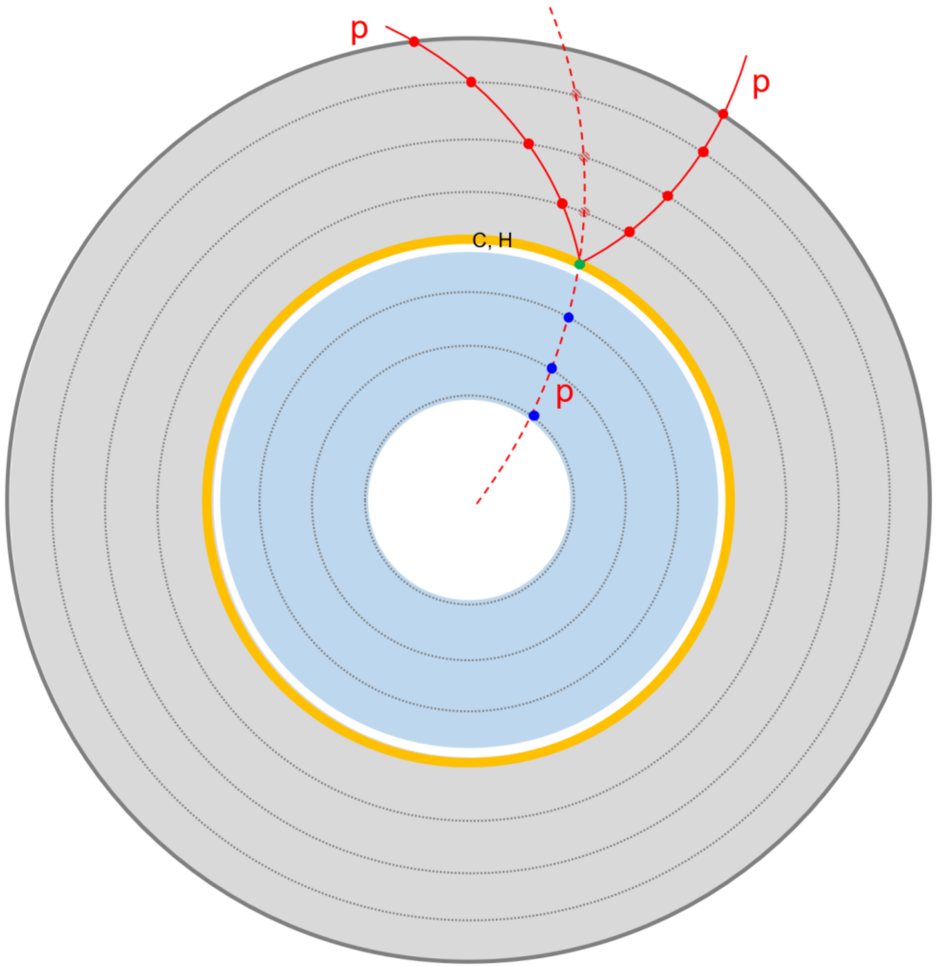


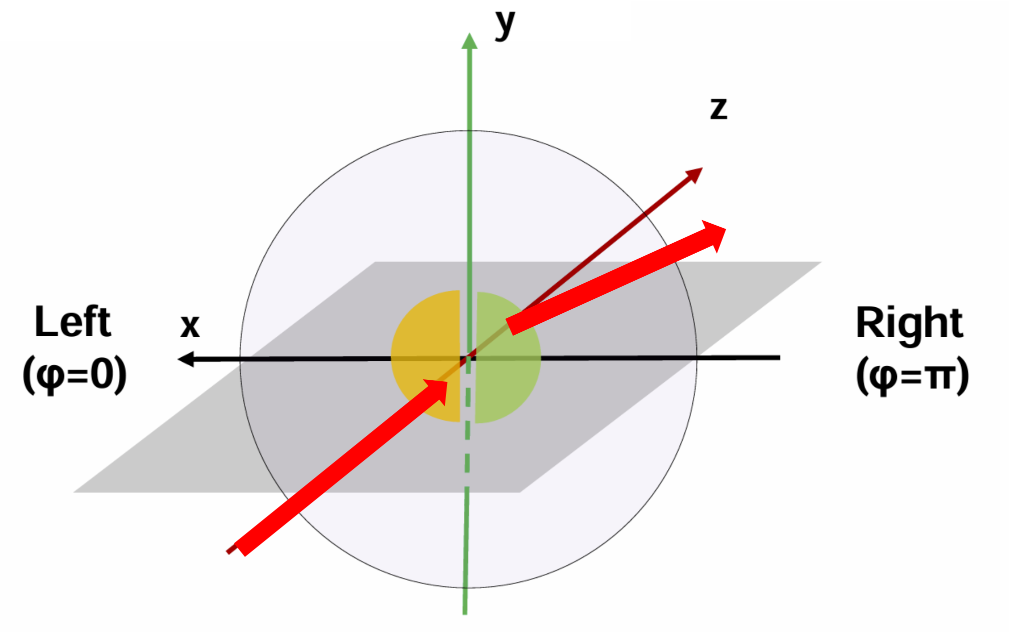
Figure 5: The FPP in the HMS in Hall C as currently designed.

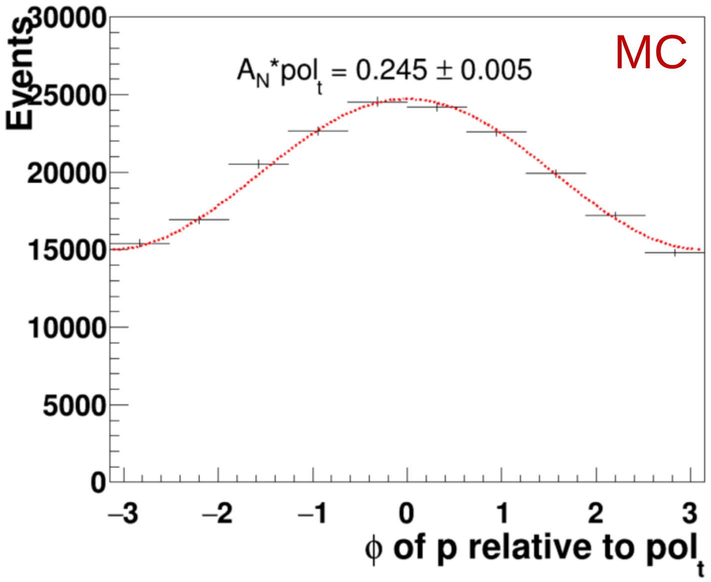
Possibility at high luminosity machine

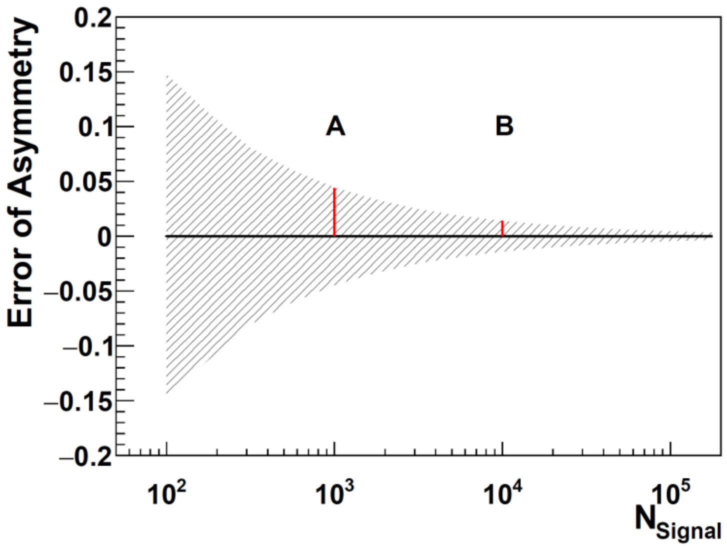




Possibility at high luminosity machine







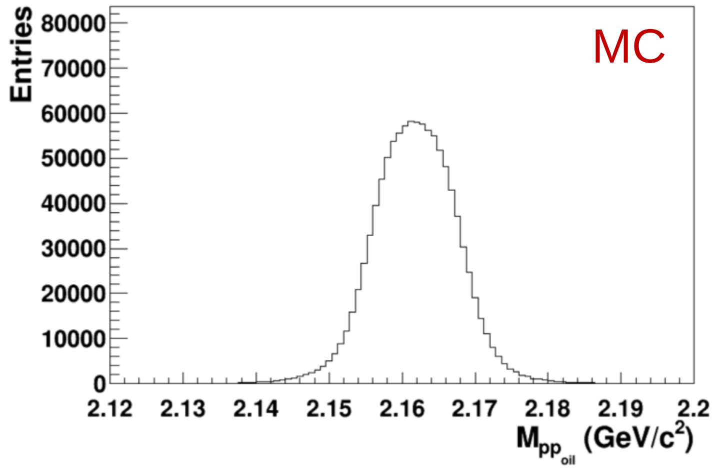
Mineral oil layer: 0.8 mm
Probability of pp scattering of 1GeV/c proton beam: 1E-4

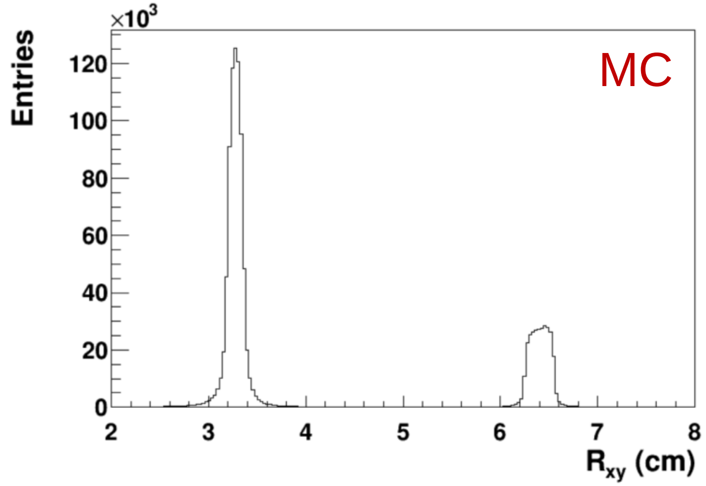
Take J/ψ→ $p\bar{p}$ as example:
1E10 * 2E-3 * 1E-4 * ε ~ 1E3 @ BESIII

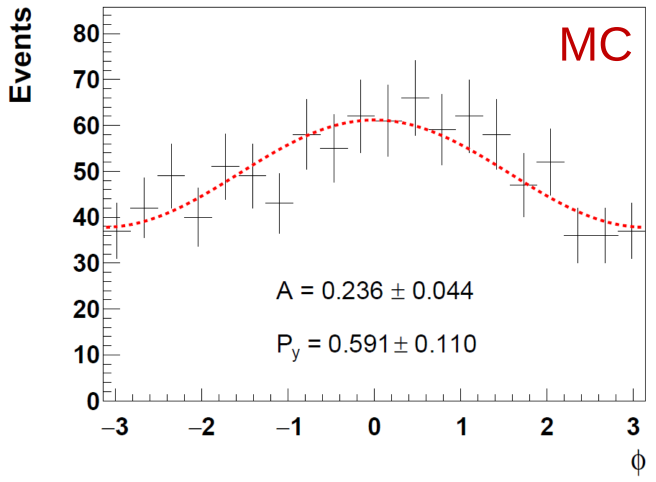
Uncertainty on A_{LR} < 0.005 at STCF!!!

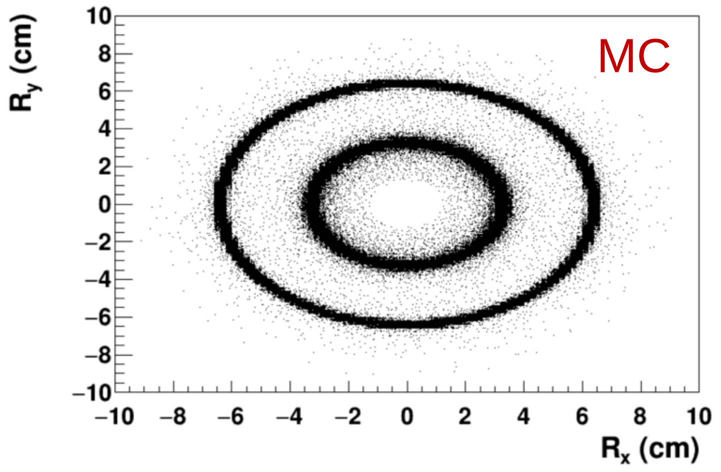
MC study at e^+e^- machine

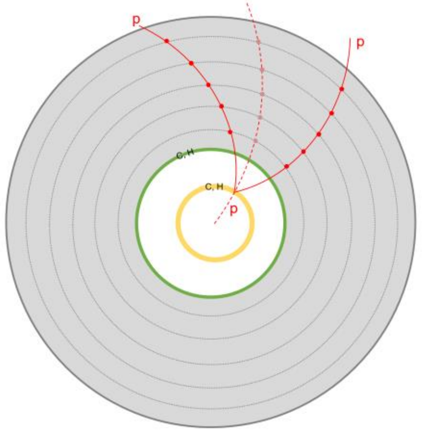
MC based on BESIII detector configuration











With good tracking and vertexing,

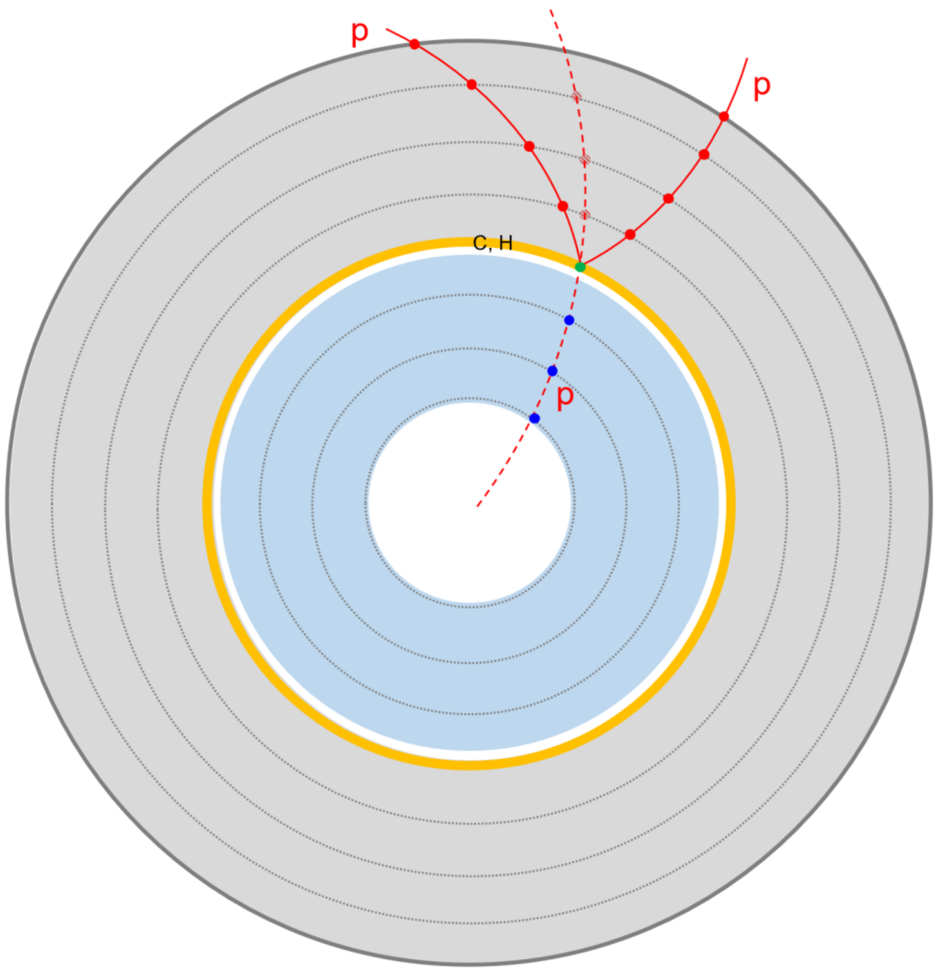
the general-use detector is ideal to:

1) find the pp scattering events.

2) measure the polarization precisely.

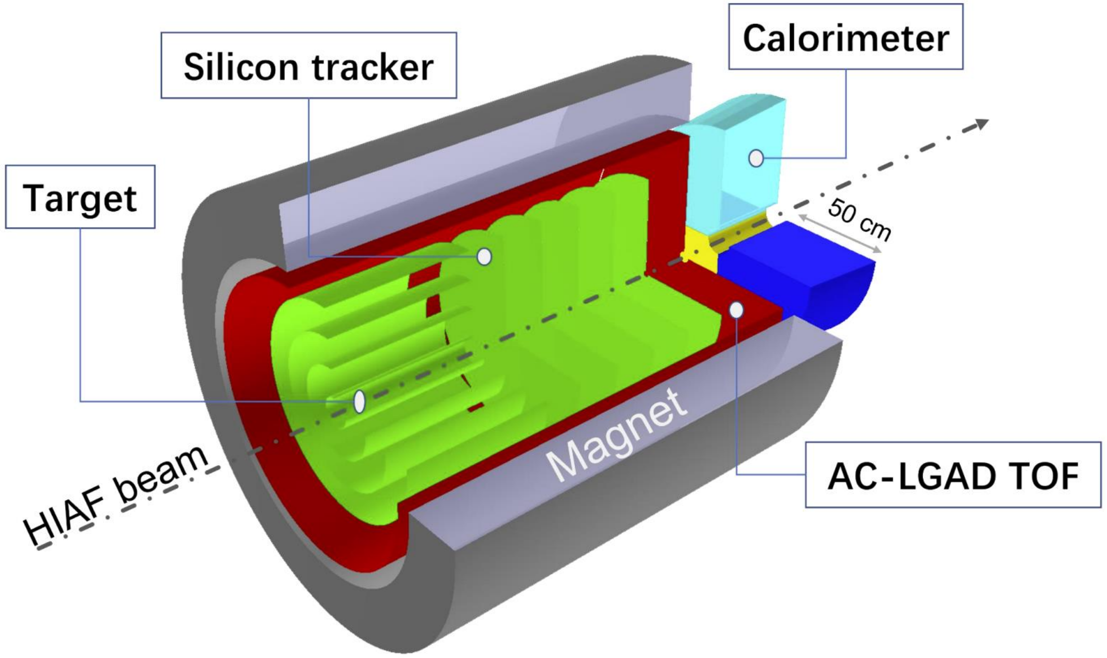
Detector concept with polarimetry function

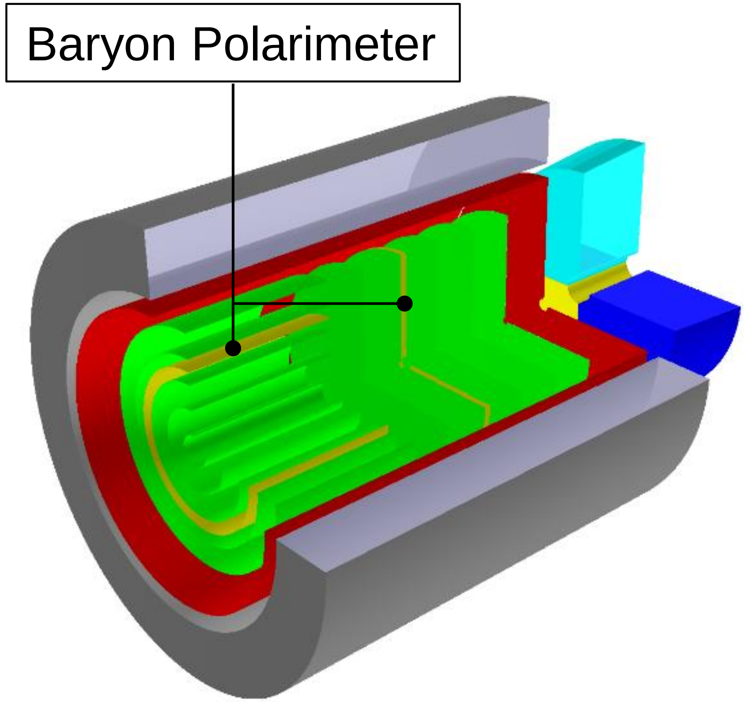
Recommendations on scattering layer



- **Position : in-between the tracking devices, such as the gap between inner and outer tracking detector**
  - **Appliable in all reactions: ee/ep/pp/pA/AA**
- **Material: H or C, single element**
  - **Detection of recoil proton is enough**
- **Carbon layer of 1-2 mm**
  - **Material budget: 1% X/X_0**
  - **Scattering probability: 1E-3**

Application at CHNS

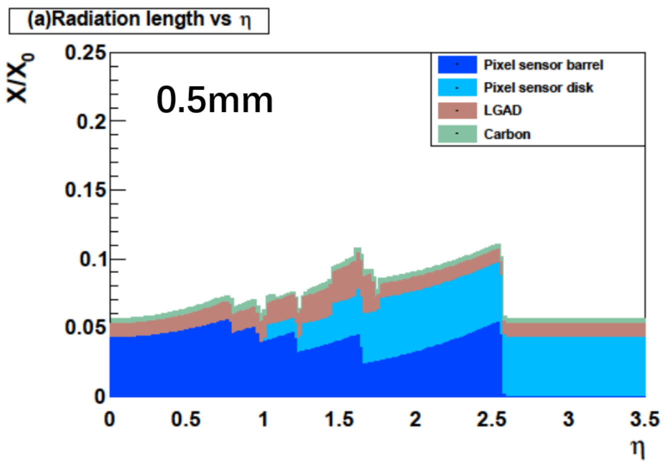


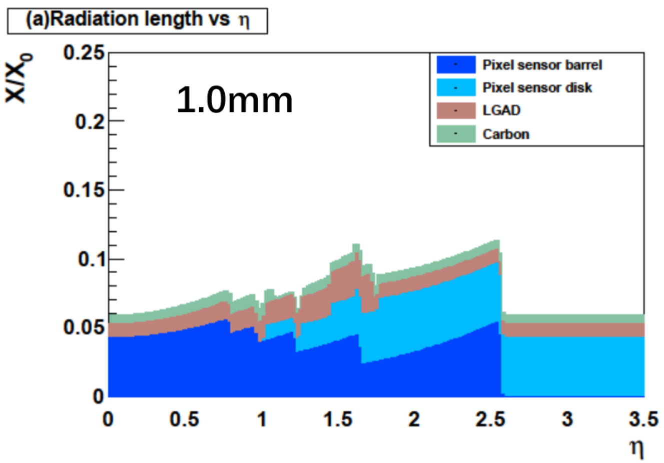


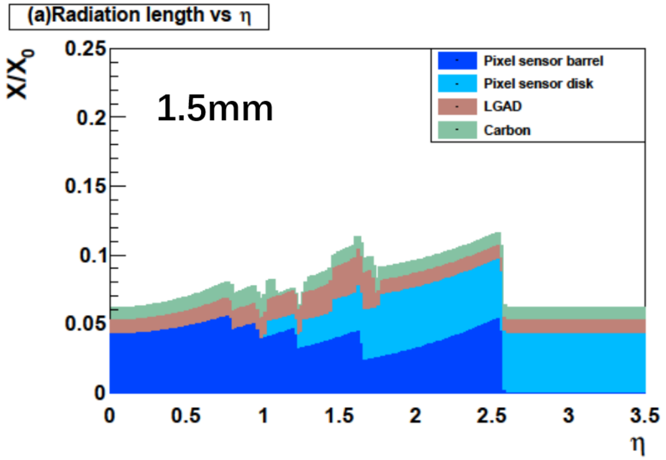
Measure the polarization of proton, when no strange quarks appear.

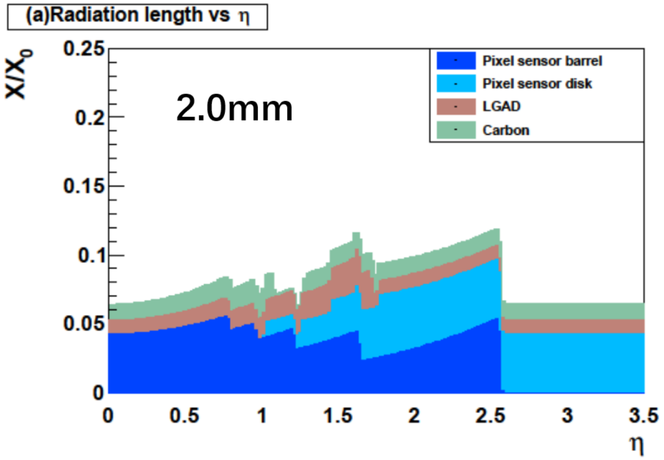
- If proton polarized same as hyperons: the strange quark in hyperon is not the key factor?
- If ……

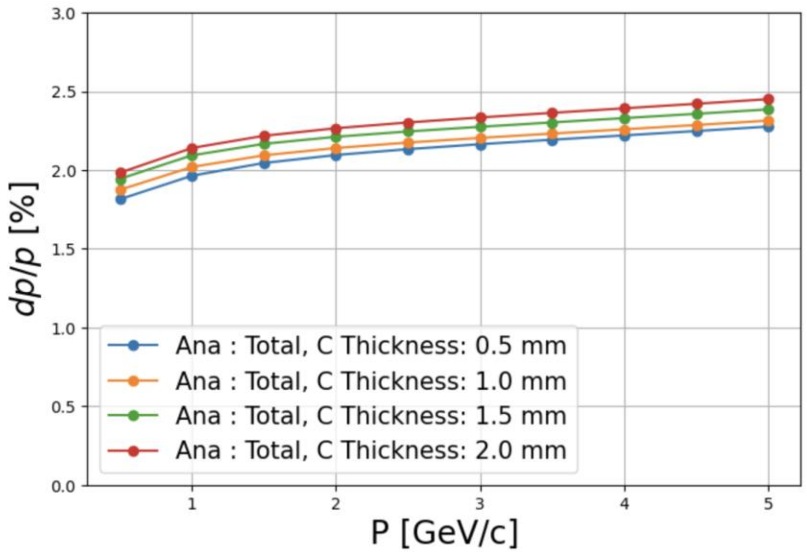
Material budget of carbon layer



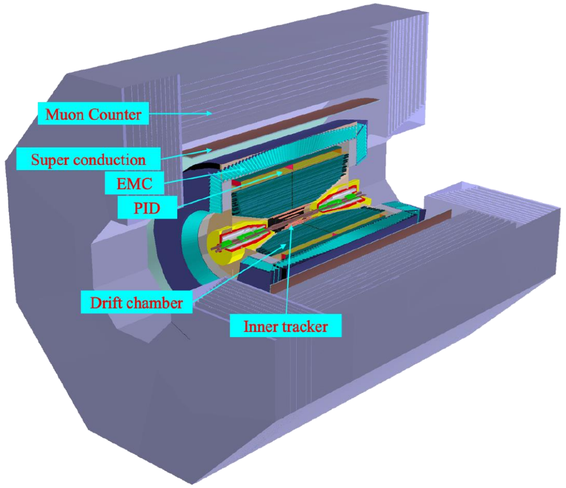


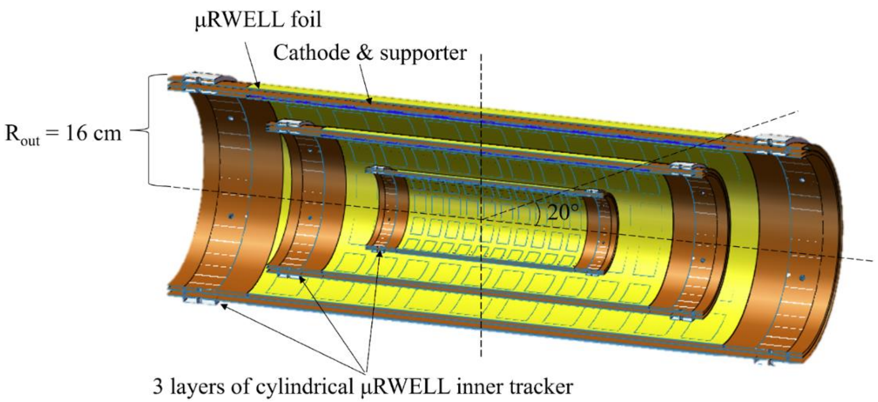


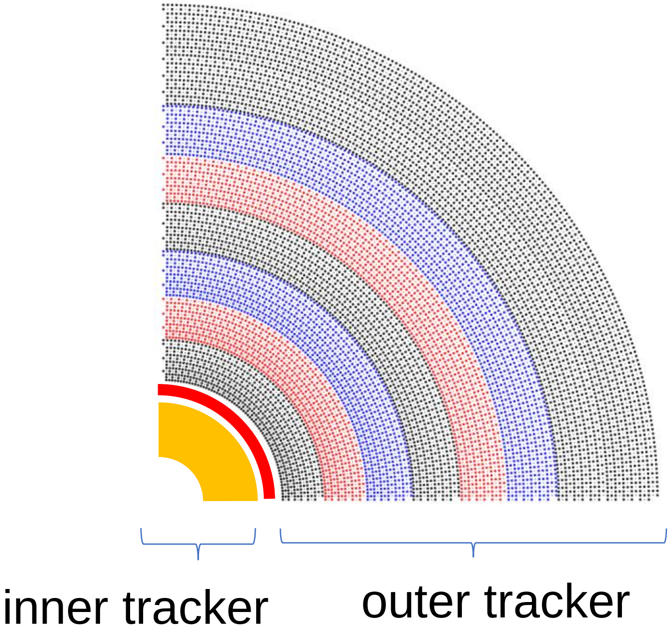


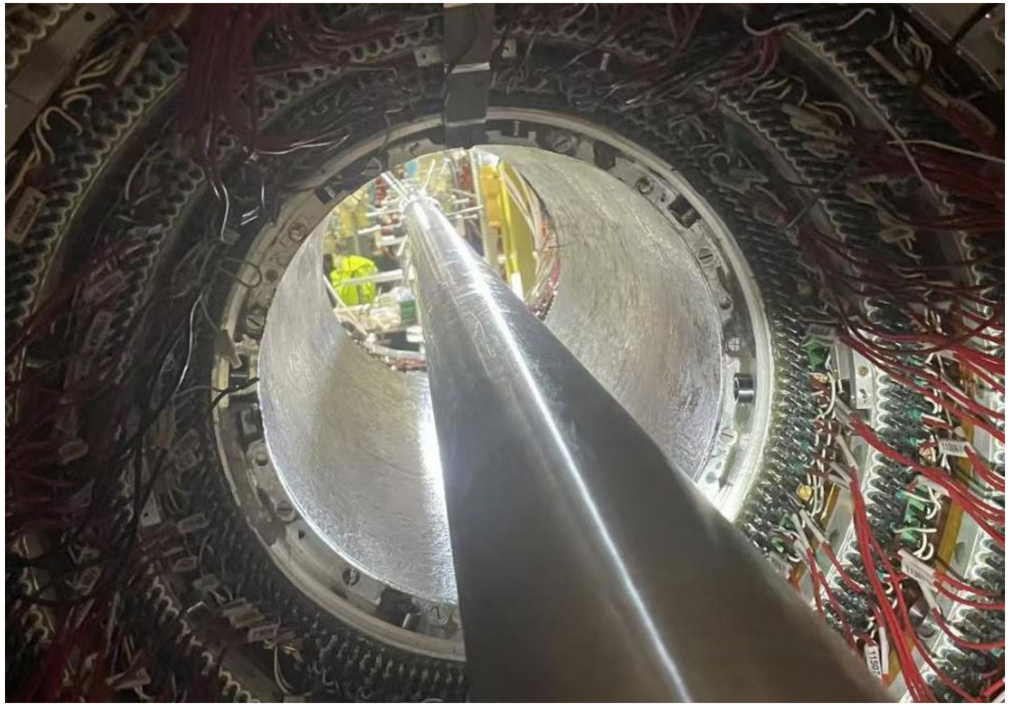


Application at STCF







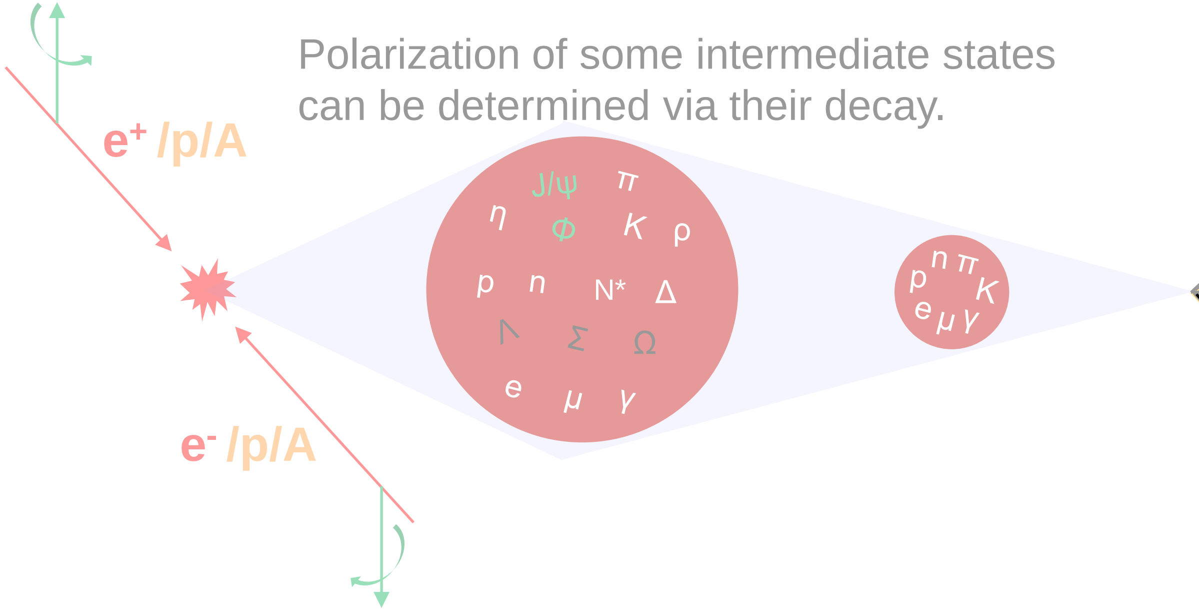


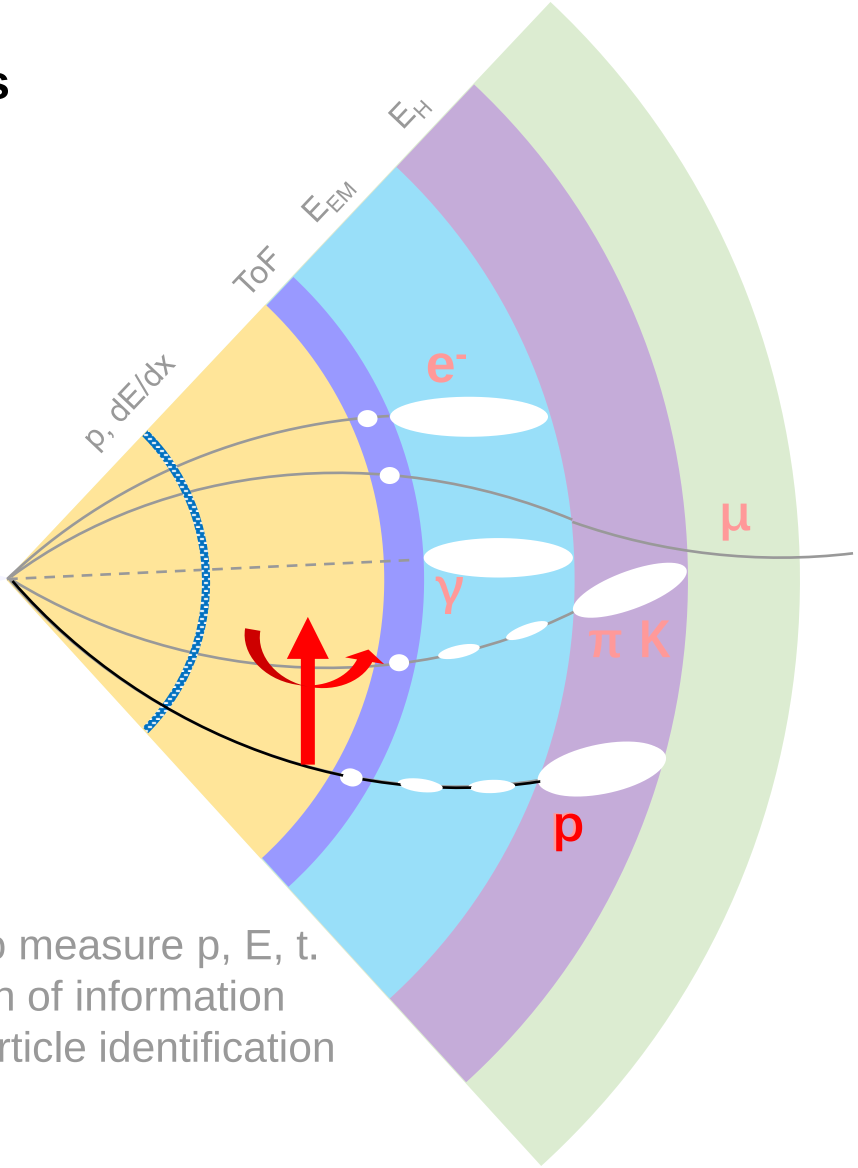
- A layer of carbon fiber, thickness of 1-2 mm
- The inner surface of MDC: cylindrical carbon fiber, thickness of 1 mm, radius of 19.6 cm
- Some effort on the tracking algorithm?

Detector concept

- **Almost no influence on the traditional detector functions**
- **Very tiny investment**
- **Appliable in various reactions, and in wide energy range**

Polarization of some intermediate states can be determined via their decay.





Complete and accurate initial state information:

Detectors to measure p, E, t.
Combination of information provides particle identification

➢ **Towards a more complete final state information**

How to validate the method

Polarized proton from Λ decay

The Fermilab Polarized Beam Facility*

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ANL-HEP-CP--90-103

DE91 006556

Abstract

A description[1] of the Fermilab 200-GeV/c polarized beam is presented, including the production, transport, and spin rotation of the polarized protons and antiprotons. The momentum and polarization of each beam particle is measured by a beam-tagging system. Verification of the beam polarization and of the beam-tagging method is given by two polarimeters. A brief summary of the E-704 experimental program using the polarized beam is also presented.

A. The Polarized Beam

The polarized proton beam is produced from the parity-nonconserving decay, $\Lambda^0 \rightarrow p + \pi^-$. As viewed in the Λ rest frame, the proton spin is aligned in the same direction as the proton's momentum. For unpolarized Λ particles, the polarization of the proton has been measured[2] to be ~~64~~%. This value comes from the interference of S and P-wave amplitudes.

75%

As shown in Fig. 1, an 800-GeV incident proton beam from the Tevatron hits a beryllium target and produces many particles in the collision, including both Λ and $\bar{\Lambda}$ hyperons. The unpolarized Λ particles then decay some distance downstream from the target. In the laboratory frame, the proton trajectory from this decay can be traced back to the plane of the target. The protons then appear to originate from a virtual source at the target. A correlation exists between the transverse distance from the target and the proton trajectory, which in turn is correlated to the proton spin direction. The correlation between the horizontal transverse distance from the target and the proton polarization is shown in Fig. 2. Protons with the same transverse spin component appear to originate

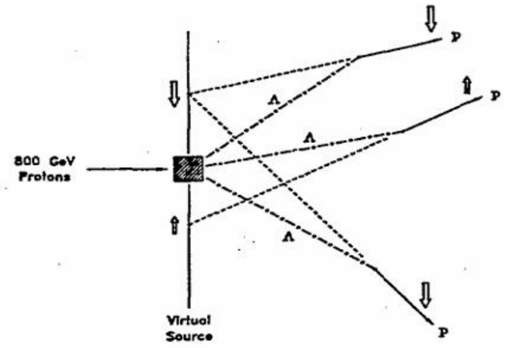


Figure 1: Diagram of the production target and Λ decays, showing the virtual source of polarized protons.

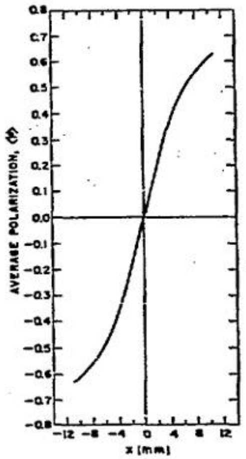


Figure 2: Correlation between the average particle polarization and the horizontal position.

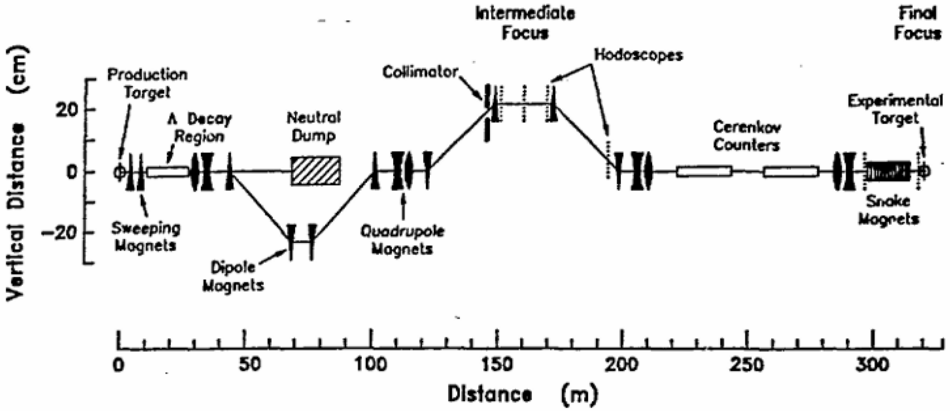
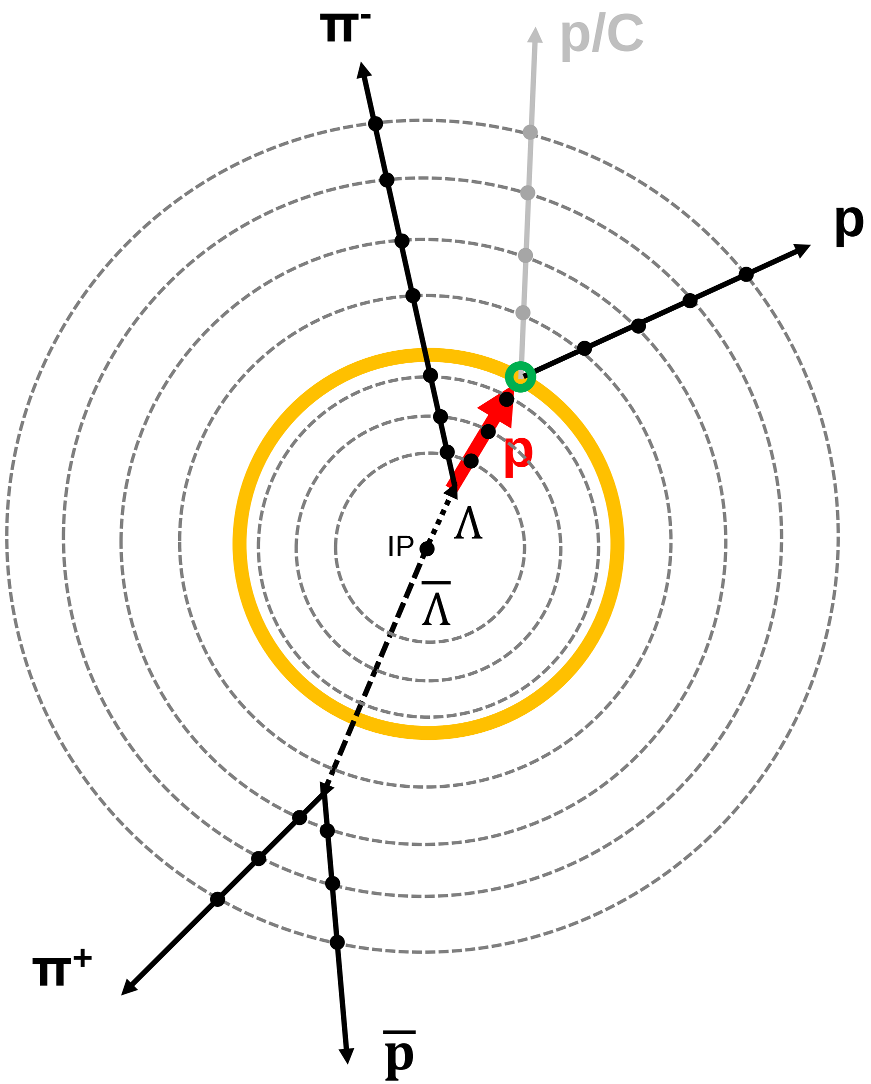


Figure 4: Side view of the Fermilab polarized beam line.

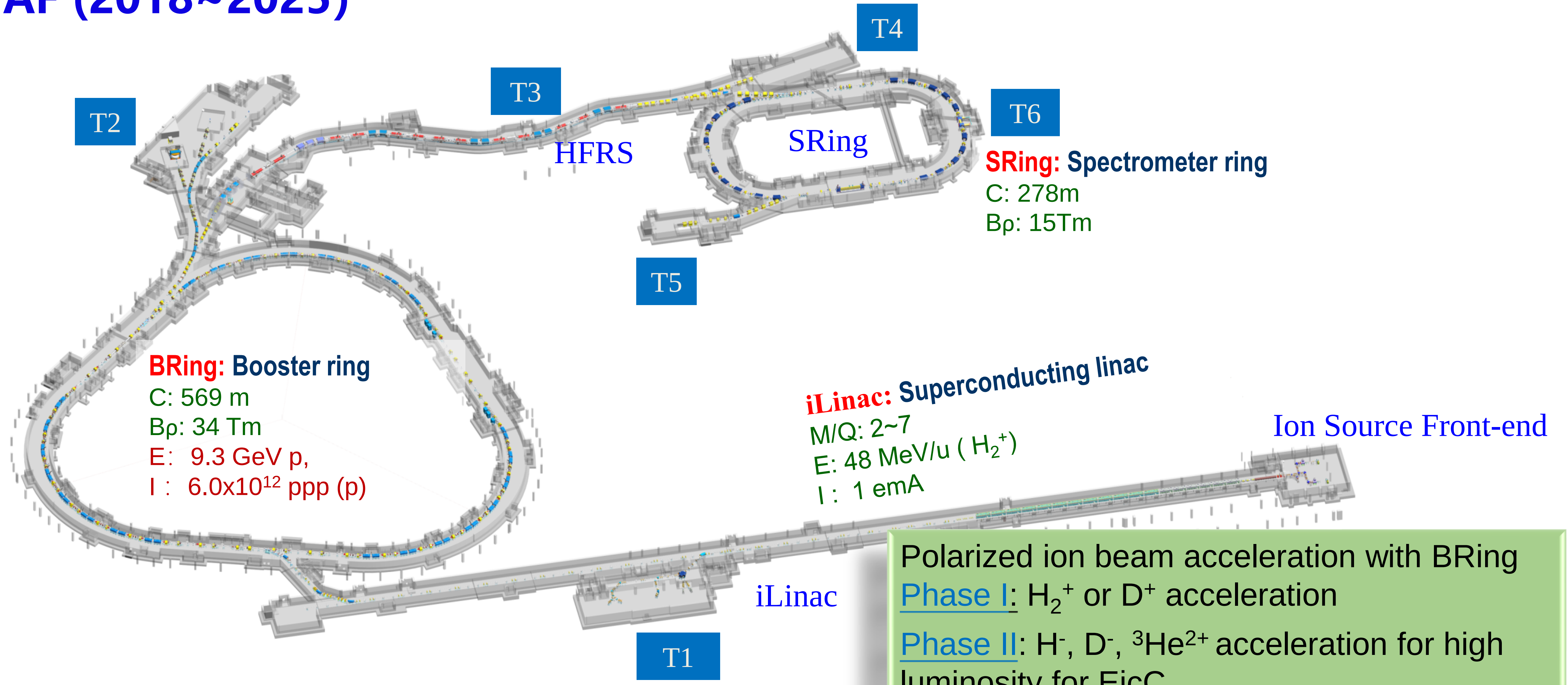
Beam test at e^+e^- machine



- Polarized proton from Λ decay:
  $J/\psi \rightarrow \Lambda\bar{\Lambda} \rightarrow \pi^- p \;\; \pi^+ \bar{p}$
- Polarized proton scattering off a proton:
  $pp \rightarrow pp$
- **Five final state particles: π^+ $\bar{p}$ π^- p p** are measured by the detector.
- Polarized proton, indicated by the red arrow, with transverse polarization of 59%, is measured before scattering.
- pp scattering vertex, indicated by green circle, is calculated by VertexFit.

Polarized proton at HIAF

HIAF (2018~2025)



Polarized ion beam acceleration with BRing

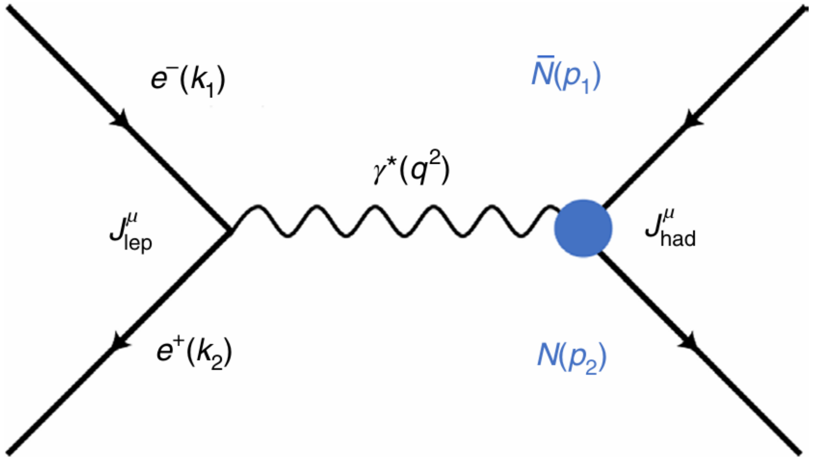
Phase I: H_2^+ or D^+ acceleration

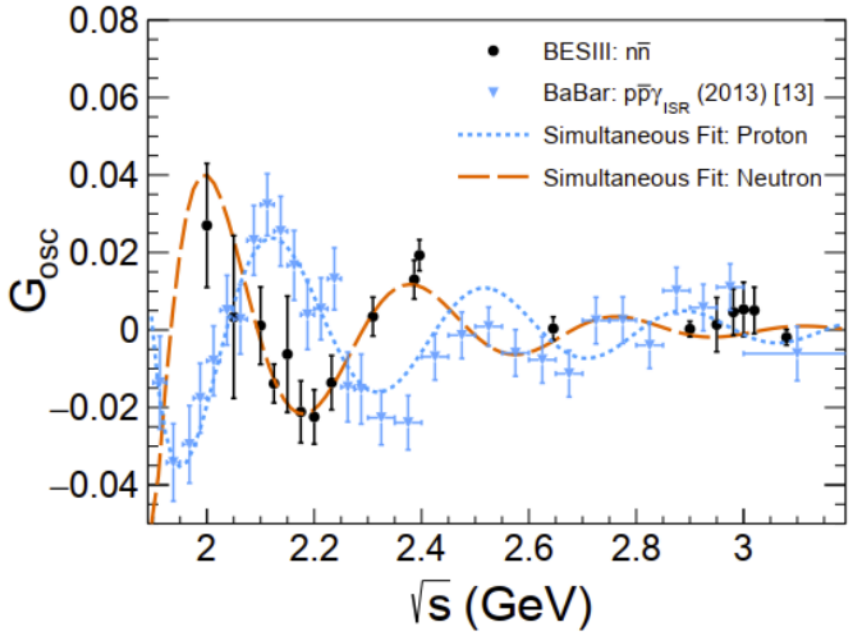
Phase II: H^-, D^-, $^3He^{2+}$ acceleration for high luminosity for EicC

Physics potentials with the new concept

Great potential at STCF

➢ **Helicity phase of proton G_E/G_M**





$$\frac{d\sigma_{p\bar{p}}(s)}{d\Omega} = \frac{\alpha^2\beta C}{4s}\left[|G_M(s)|^2(1+\cos^2\theta) + \frac{4m_p^2}{s}|G_E(s)|^2\sin^2\theta\right]$$

BESIII, Nature Physics, 17, 1200 (2021)

✓ **The helicity phase of proton time-like form factor: $\sigma_{\Delta\Phi = \Phi M - \Phi E}$ ~ 0.3 @ BESIII**

✓ **STCF could significantly reduce the uncertainty (<0.01)**

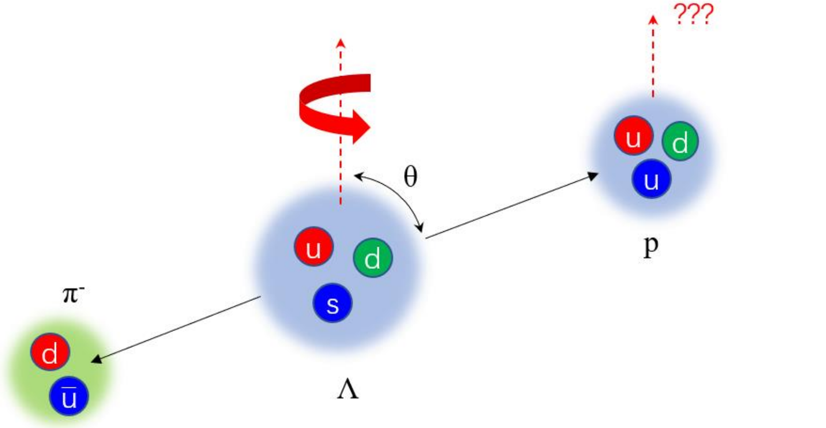
Decay parameters of hyperons

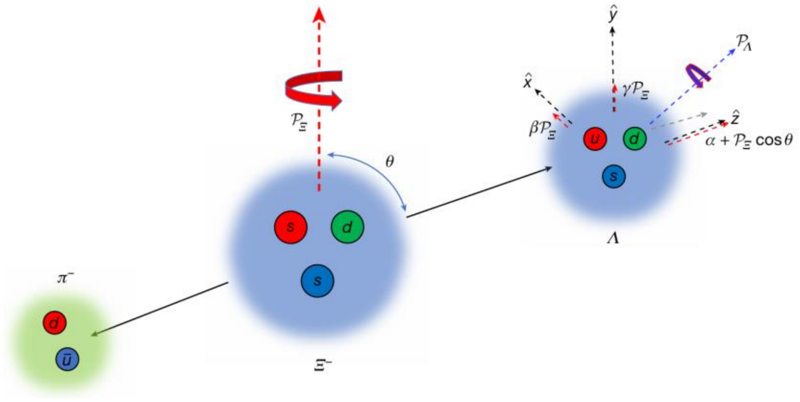
General Partial Wave Analysis of the Decay of a Hyperon of Spin ½

T. D. LEE* AND C. N. YANG

Institute for Advanced Study, Princeton, New Jersey

(Received October 22, 1957)





✓ **Decay parameters of hyperons**

- Spin-½ hyperons decays are quantified in terms of the decay parameters α , β and γ. $\alpha^2 + \beta^2 + \gamma^2 = 1$

$$dw(\theta) = \frac{1}{4\pi}(1 + \alpha P_\Lambda \cdot \hat{q})\, d\Omega$$

$$P_P = \frac{(\alpha + P_\Lambda \cdot \hat{q})\hat{q} + \beta(P_\Lambda \times \hat{q}) + \gamma(\hat{q} \times [P_\Lambda \times \hat{q}])}{1 + \alpha P_\Lambda \cdot \hat{q}}$$

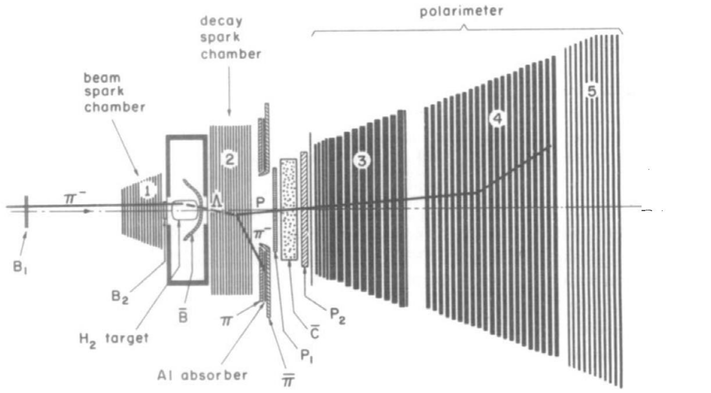
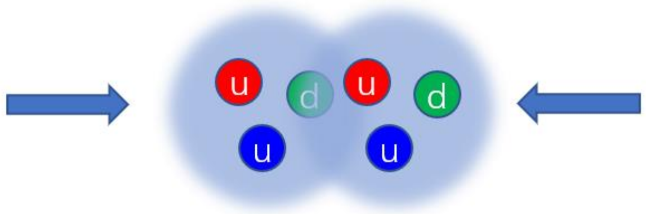
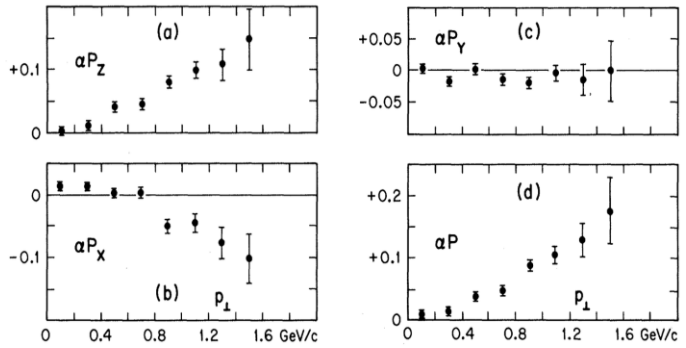


Fig. 3. Apparatus used to measure the polarization of protons from Λ^0 decay through proton-carbon scattering. The Λ^0 are produced in hydrogen. The counters π and $\bar{\pi}$ select low-energy decay pions, while $P_1 P_2 \bar{C}$ select decay protons. All counters are made of plastic scintillator except for $\bar{C}$, which is a water Čerenkov counter. The polarimeter consists of carbon plate spark chambers. The tracks are photographically recorded with 90° stereo.

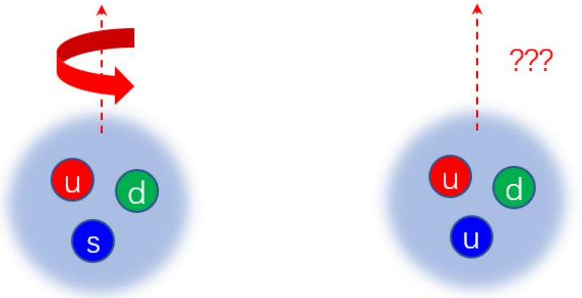
Nuclear Physics B40 (1972) 221-254.

Physics potential in hadron collision

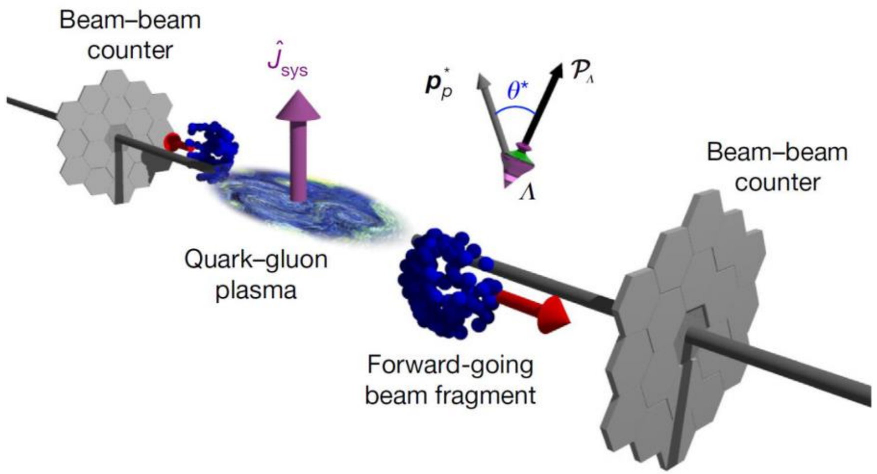


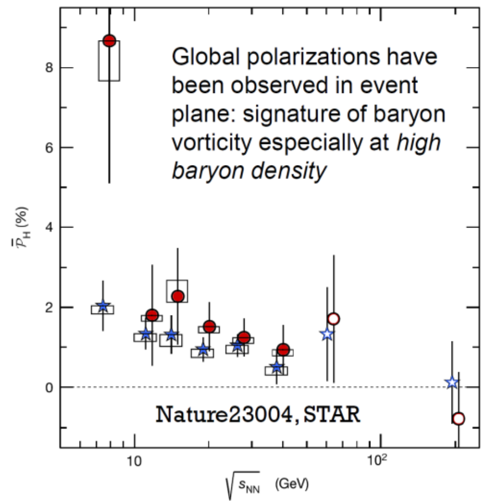


G. Bunce *et al.*, Phys. Rev. Lett. 36 (1976) 1113.



Source of hyperon polarization?





A new probe with proton polarization?

Summary

- ✓ Method to measure final state proton polarization at collider experiments proposed.
- ✓ Method of validation with polarized proton from hyperon decays proposed.
- ✓ Tested at the current running BESIII. Some physics can be performed for the first time.
- ✓ Applicable for existing and future experiments. Great potentials at STCF, CHNS, EicC.

Thank You