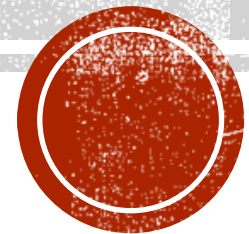# Λ hyperon pair spin-spin correlations at ePIC

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Λ POLARIZATION PUZZLE

- In the 70's, it was discovered that Λ hyperons are polarized in collisions of unpolarized p+Be collisions, which raised many questions   G.Bunce, *et al.*: Phys.Rev.Lett. 36, 1113-1116 (1976)

- Over nearly 50 years, Λ polarization has been seen in p+p, p+A, e+p, e^+e^- collisions up to collision energies about 40 GeV
  ATLAS: Phys. Rev. D 91, 032004 (2015)
  BELLE: Phys.Rev.Lett. 122, 042001 (2019)

- **What is the origin of the Λ polarization?**
  - Does polarization of Λ depend on spin of the target/projectile?
  - Is the observed Λ polarization an initial state effect or a final state effect?
  - Is there Λ hyperon spin correlation present in high energy collisions? Parton spin correlation and entanglement?   W. Gong, *et al.*: Phys.Rev.D 106 (2022) 3, L031501
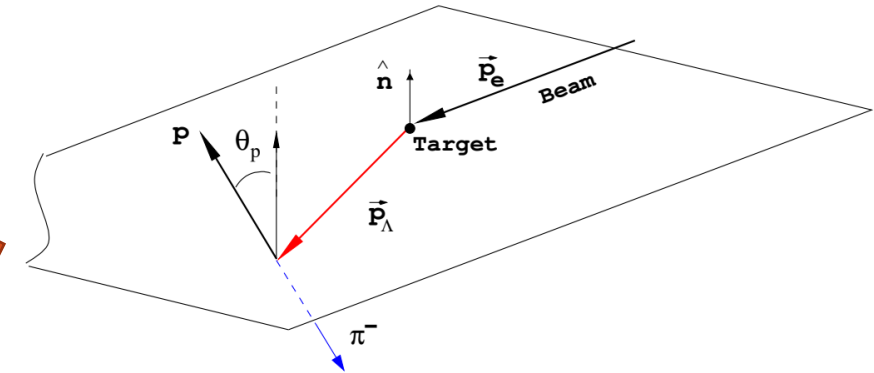
STANDARD EXPERIMENTAL METHOD

- Single Λ polarization is measured via $\Lambda^0 \to p\pi^+$ decay channel
  - In Λ rest frame, protons are emitted preferentially in direction of Λ spin

$$\hat{n} = \vec{p}_{beam} \times \vec{p}_\Lambda$$

- The distribution of protons in Λ's rest frame is then given by:

$$\frac{\mathrm{d}N}{\mathrm{d}\cos(\theta^*)} = 1 + \alpha P_\Lambda \cos(\theta^*)$$

HERMES: Phys.Rev.D76:092008,2007

  - P_Λ is the Λ polarization
  - $\Lambda^0 \colon \alpha_+ = 0.732 \pm 0.014, \ \overline{\Lambda^0} \colon \alpha_- = -0.758 \pm 0.012$
  - $\hat{n}$ is normal vector to the production plane
  - Angle (θ^*, or θ_p) is measured between $\hat{n}$ and momentum of proton ($\vec{p}_\Lambda$) in Λ's rest frame

FIRST MEASUREMENT OF Λ POLARIZATION

- First ever measurement of Λ polarization was performed in Fermilab in p+Be collisions with 300 GeV proton beam in 1976

- Surprising: Neither protons or Be were polarized, but the Λ hyperons were produced polarized

- How can the Λ hyperons be polarized when beam and target are not polarized?
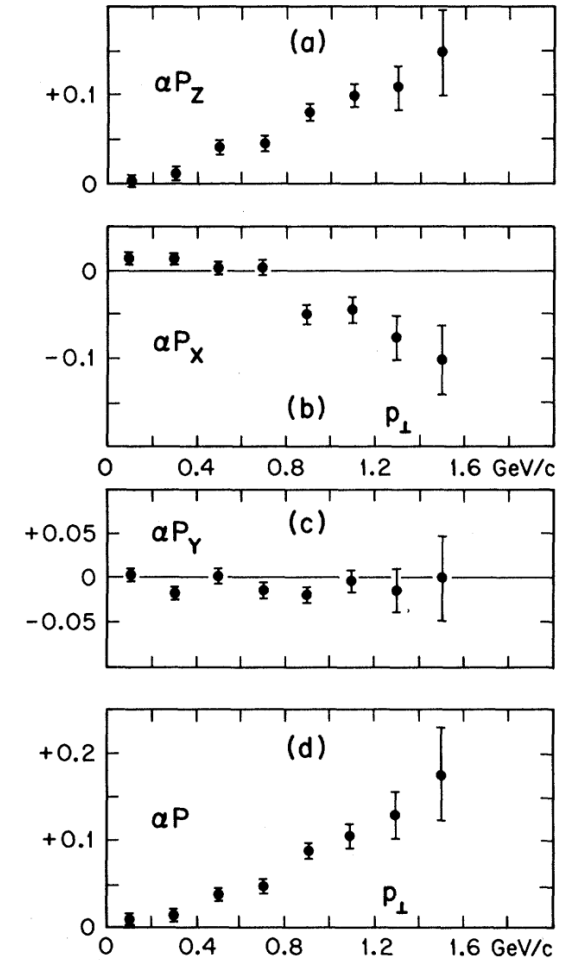
G.Bunce, *et al.*: Phys.Rev.Lett. 36, 1113-1116 (1976)

OVERVIEW OF Λ POLARIZATION MEASUREMENTS

- Many measurements of single Λ hyperon polarization over the last 50 years

- Figure: Comparison of Λ hyperon polarization measured in various collision systems and collision energies as a function of x_F
  - Larger polarization with larger $x_F = p_z^\Lambda / p_{beam}$
  - No significant dependence on the collision system or energy
  - ATLAS: p+p, HERA: e+p, E799 (Fermilab): p+Be, NA48 (SPS): p+Be, M2 (Fermilab): p+Be

- Single Λ hyperon polarization appears to depend mainly on x_F
  - Λ hyperon which are produced with large momentum along the beam axis are more polarized than those produced in transverse direction
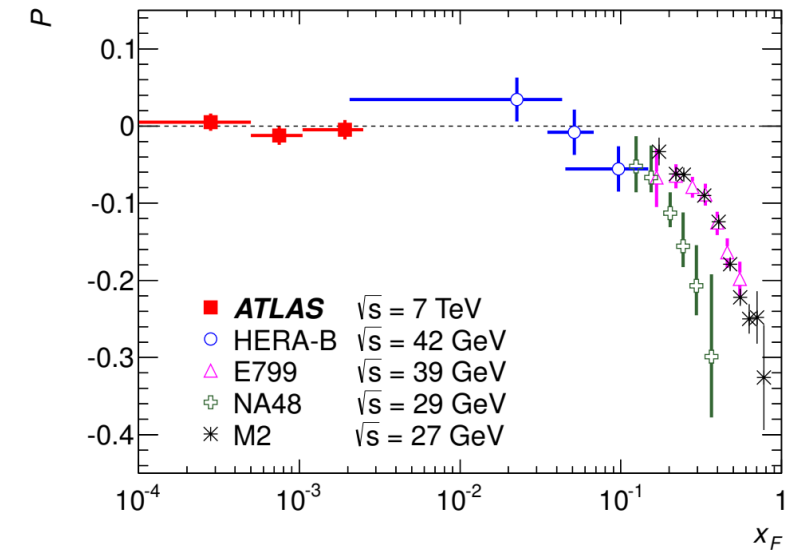
ATLAS: Phys. Rev. D 91, 032004 (2015)

Λ POLARIZATION IN e^+e^- COLLISIONS

- All previous results are from hadronic collisions

- BELLE observed Λ hyperon polarization also in e^+e^-
  - No quarks or gluons in the initial state

- Observed polarization depends on Λ hyperon p_T and z_Λ
  - $z_\Lambda = 2E_\Lambda/\sqrt{s}$

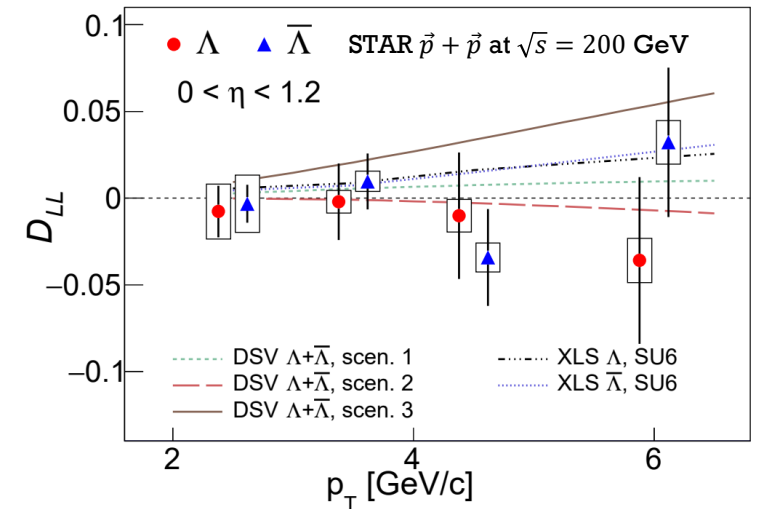- Gives access to study contribution of hadronization to the Λ hyperon polarization
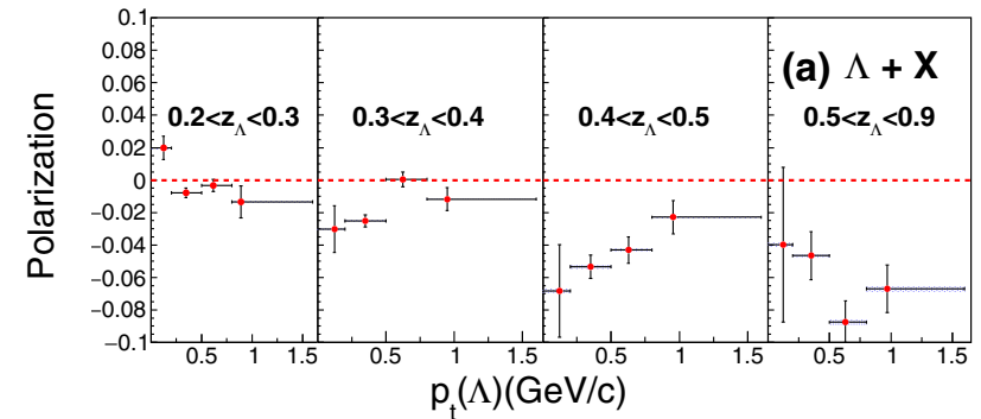
BELLE: Phys.Rev.Lett. 122, 042001 (2019)

Λ POLARIZATION WITH POLARIZED BEAMS

- Does polarization of Λ and $\overline{\Lambda}$ hyperons depend on the polarization of the particles in the beam?

- Measurement of longitudinal spin transfer D_{LL} to Λ and $\overline{\Lambda}$ hyperons in $\vec{p} + \vec{p}$ collisions at $\sqrt{s} = 200$ GeV measured by STAR

$$D_{LL} \overset{\mathrm{def}}{=} \frac{\sigma_{p^+ p \to \Lambda^+ X} - \sigma_{p^+ p \to \Lambda^- X}}{\sigma_{p^+ p \to \Lambda^+ X} + \sigma_{p^+ p \to \Lambda^- X}}$$

STAR: Phys. Rev. D 98, 112009 (2018)

- No significant spin transfer in high energy collisions of longitudinally polarized protons

MOTIVATION FOR Λ PAIR SPIN CORRELATIONS

- Single Λ polarization observed in collisions at low energies, but not at higher energies (e.g. RHIC) when measured with respect to production plane

- New, alternative approach is to measure spin correlations of $\Lambda\bar{\Lambda}$, $\Lambda\Lambda$, and $\bar{\Lambda}\bar{\Lambda}$ pairs
  - New choice of reference direction for polarization measurement – spin direction of a different Λ ($\bar{\Lambda}$) in the same event

- Similar approach as in measurement of the elliptic flow in heavy-ion collisions using particle correlations instead of reconstruction of the event plane

- **Where could correlation of spins of $\Lambda\bar{\Lambda}$, $\Lambda\Lambda$, or $\bar{\Lambda}\bar{\Lambda}$ pairs come from in high energy collisions?**
  - Initial parton spin correlations may result in final-state hadron spin correlation?
  - Can final-state effect, e.g., hadronization, generate spin correlation?
  - A Bell-type inequality test using Λ hyperon pair spin correlations in high energy collisions? W. Gong, *et al.*: Phys.Rev.D 106 (2022) 3, L031501

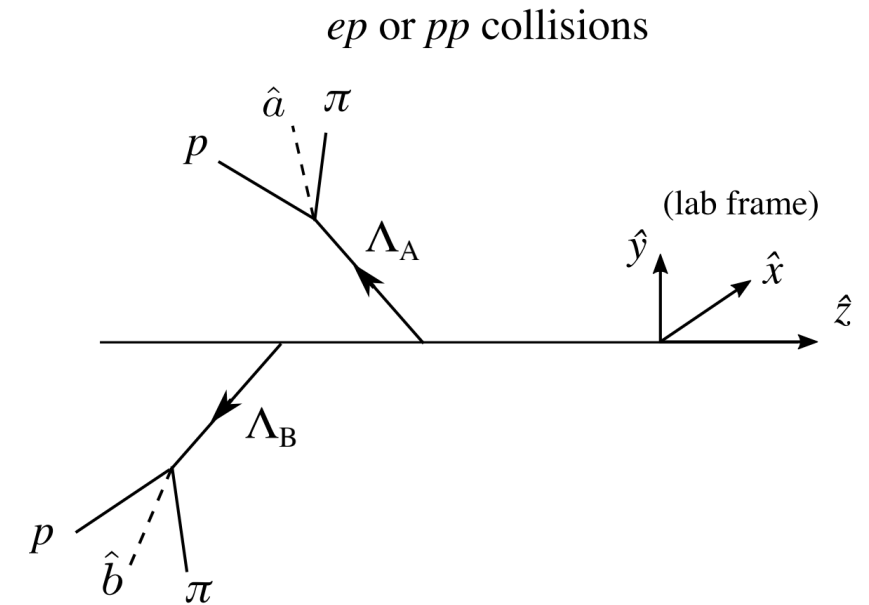
ep or *pp* collisions

(lab frame)
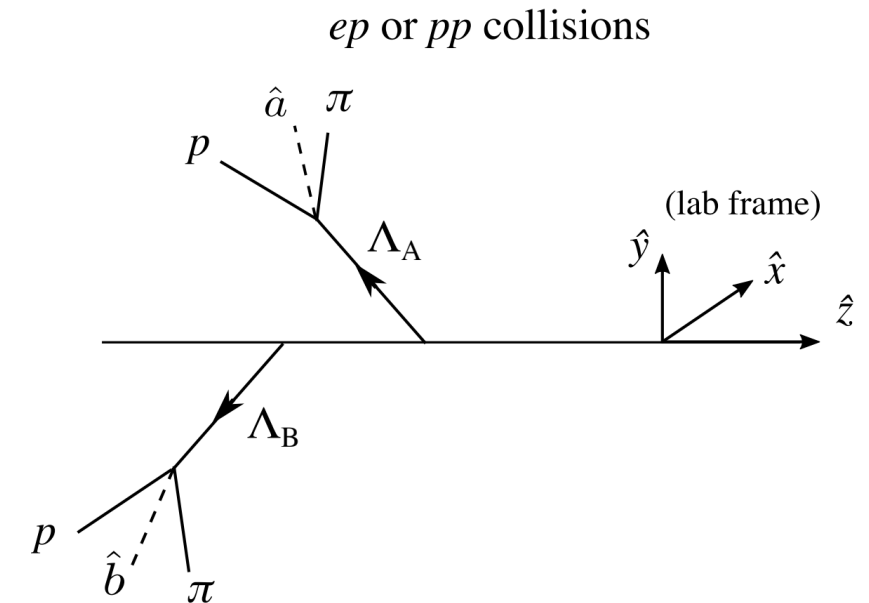
NEW EXPERIMENTAL METHOD

- Find $\Lambda\bar{\Lambda}$, $\Lambda\Lambda$, or $\bar{\Lambda}\bar{\Lambda}$ pair(s) in one event
  - Decay channel $\Lambda^0 \to p\pi^+$ and charge conjugate

- Boost (anti-)proton from decay of the corresponding Λ ($\bar{\Lambda}$) to **rest frame of its mother**
  - Proton momenta in mother rest frame: $\hat{a}, \hat{b}$

- Measure angle θ^* between the two **boosted protons**

- The distribution of pair angle is given by:

$$\frac{dN}{d\cos(\theta^*)} = 1 + \alpha_1\alpha_2 P_{\Lambda\Lambda}\cos(\theta^*)$$

- **A non-zero $P_{\Lambda\Lambda}$ would indicate spin correlation between the pair**

ep or *pp* collisions

(lab frame)

Λ HYPERON SPIN-SPIN CORRELATIONS AT ePIC

- Ongoing analysis of Λ hyperon spin-spin correlations in p+p collisions at $\sqrt{s} = 200$ and 510 GeV measured by the STAR experiment

- Goal is to perform the same analysis within the ePIC simulation framework

- Key steps:
  - Generate e+p sample using PYTHIA 8.3 and pass it through ePIC
  - Analyze produced MC sample using the same experimental method developed for the STAR analysis
  - Estimate e.g. reconstruction efficiency of $\Lambda\overline{\Lambda}$, $\Lambda\Lambda$, and $\overline{\Lambda}\overline{\Lambda}$ pairs and expected precision of $P_{\Lambda_1\Lambda_2}$

- Current status:
  - Have base for the PYTHIA simulation
  - Need to make some changes to produce output which can be used with ePIC simulation framework

THANK YOU FOR ATTENTION