How to measure transverse polarization on a symmetric collider

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1. Motivations

Polarization of baryons: important application

Parity violation

Eisler et al., PRD108(1957)1353

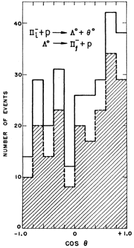
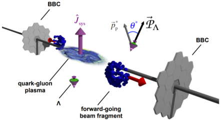


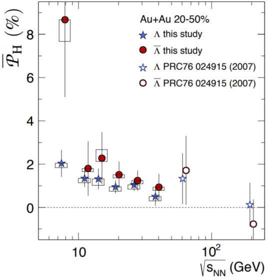
Fig. 1. Distribution in cosθ for process (1). The shaded area represents events for production angles in the center-of-mass range 30°–150°.

$$Dis = 1 + P_\omega \alpha \cos\theta$$

QGP verticity

STAR, Nature548(2017),62





top and New Physics

- charged lepton asymmetry
- top polarization
- $t\bar{t}$ spin correlation

polarization measurements of Λ_b

Transverse polarization of Λ_b (through $\Lambda_b \to J/\psi\Lambda$)

$$P_{\Lambda_b}^{\text{LHCb}} = 0.06 \pm 0.07 \pm 0.02 \qquad \text{PLB724(2013),27}$$

$$P_{\Lambda_b}^{\text{CMS}} = 0.00 \pm 0.06 \pm 0.06 \qquad \text{PRD97(2018),072010}$$

world average

$$P_{\Lambda_b}^{\text{HFLAV}} = 0.03 \pm 0.06$$

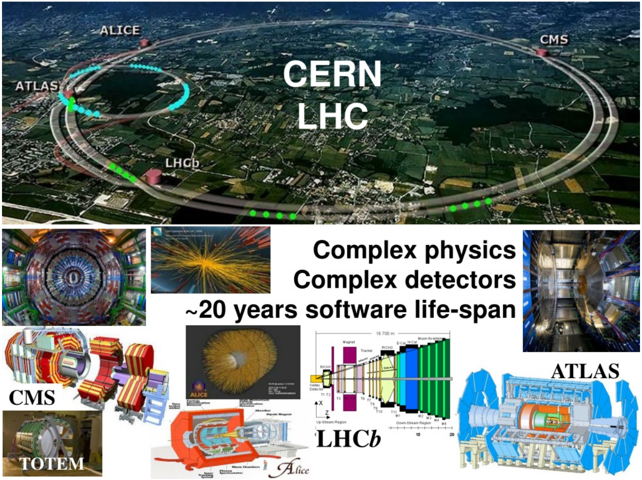
theoretical prediction

at the 10% level

$P_{\Lambda_b}^{\mathrm{LHCb}}$ and $P_{\Lambda_b}^{\mathrm{CMS}}$ are two different things.

2 Transverse Polarization of Λ_b

detectors on LHC



symmetric detector (CMS ATLAS)

- Parity $\mathbb{P}$
- rotation of π: $\mathbb{R}_z(\pi)$

asymmetric detector (LHCb)

$\mathbb{R}_z(\pi)\mathbb{P}$

Pseudorapidity-dependence of P_{Λ_b}

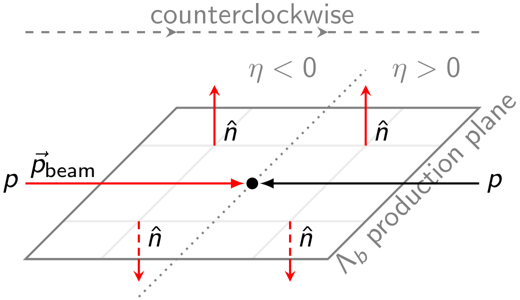


Figure: definition of $\hat{n}$: $\hat{n} = \frac{\vec{p}_{\rm beam} \times \vec{p}_{\Lambda_b}}{|\vec{p}_{\rm beam} \times \vec{p}_{\Lambda_b}|}$.

$P_{\hat{n}}(\eta, p_T) = \vec{P}_{\Lambda_b} \cdot \hat{n}$ can be nonzero, and odd on pseudorapidity η

$$P_{\hat{n}}(\eta, p_T) = -P_{\hat{n}}(-\eta, p_T) \quad (1)$$

Proof of eq. (1)

Up to an irrelevant overall factor, the transverse polarization of Λ_b for a given pseudorapidity η is defined as

$$P_{\hat{n}}(\eta, p_T) \equiv \sum_{\lambda, X} \lambda \left| \langle \Lambda_b(\vec{p}_{\Lambda_b}, \lambda) X | \mathcal{T} | p(\vec{p}_{\text{beam}}) p(-\vec{p}_{\text{beam}}) \rangle \right|^2$$

$$P_{\hat{n}}(-\eta, p_T) \equiv \sum_{\lambda, X} \lambda \left| \langle \Lambda_b(-\vec{p}_{\Lambda_b}, \lambda) X | \mathcal{T} | p(\vec{p}_{\text{beam}}) p(-\vec{p}_{\text{beam}}) \rangle \right|^2$$

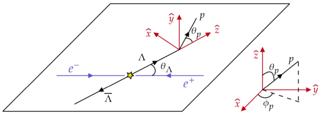
Proof of eq. (1)

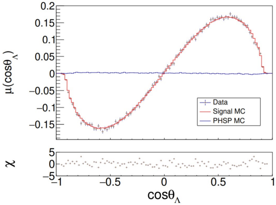
$$
\begin{aligned}
& P_{\hat{n}}(-\eta, p_T) \\
= & \sum_{\lambda, X} \lambda \left| \left\langle \Lambda_b(-\vec{p}_{\Lambda_b}, \lambda) X \middle| \mathbb{R}_z^\dagger(\pi) \mathbb{R}_z(\pi) \mathcal{T} \middle| p(\vec{p}_{\text{beam}}) p(-\vec{p}_{\text{beam}}) \right\rangle \right|^2 \\
= & \sum_{\lambda, X} \lambda \left| \left\langle \Lambda_b(\vec{p}_{\Lambda_b}, -\lambda) X^{\mathbb{R}} \middle| \mathbb{R}_z(\pi) \mathcal{T} \middle| p(\vec{p}_{\text{beam}}) p(-\vec{p}_{\text{beam}}) \right\rangle \right|^2 \\
= & \sum_{\lambda} \lambda \sum_{X} \left| \left\langle \Lambda_b(\vec{p}_{\Lambda_b}, -\lambda) X^{\mathbb{R}_z(\pi)} \middle| \mathcal{T} \mathbb{R}_z(\pi) \middle| p(\vec{p}_{\text{beam}}) p(-\vec{p}_{\text{beam}}) \right\rangle \right|^2 \\
= & \sum_{\lambda, X} \lambda \left| \langle \Lambda_b(\vec{p}_{\Lambda_b}, -\lambda) X | \mathcal{T} | p(-\vec{p}_{\text{beam}}) p(\vec{p}_{\text{beam}}) \rangle \right|^2 \\
= & -\sum_{\lambda, X} \lambda \left| \langle \Lambda_b(\vec{p}_{\Lambda_b}, \lambda) X | \mathcal{T} | p(\vec{p}_{\text{beam}}) p(-\vec{p}_{\text{beam}}) \rangle \right|^2 \\
= & -P_{\hat{n}}(\eta, p_T)
\end{aligned}
$$

Comparison of symmetric and asymmetric colliders

BESIII, PRL129(2022),131801

- symmetric colliders:
  Eq. (1) always holds, regardless that Λ_b is produced though strong or weak interactions.
- asymmetric colliders:
  Eq. (1) holds, if the hadrons are produced through strong interactions (Parity symmetry).





$$\mu[\cos(\theta_\Lambda)] = (m/N)\sum_{i=1}^{N_k}(n_{1,y}^{(i)} - n_{2,y}^{(i)})$$

$$\mu(\cos\theta_\Lambda) = \frac{\alpha_- - \alpha_+}{2}\frac{1+\alpha_{J/\psi}\cos^2\theta_\Lambda}{3+\alpha_{J/\psi}}P_y(\theta_\Lambda)$$

Comparison of $P_{\Lambda_b}^{\mathrm{CMS}}$ and $P_{\Lambda_b}^{\mathrm{LHCb}}$

$$P_{\Lambda_b}^{\mathrm{LHCb}} = P_{\Lambda_b}^{\mathrm{forward}} = \frac{\int_0^{+\infty} P_{\hat{n}}(\eta) N(\eta) d\eta}{\int_0^{+\infty} N(\eta) d\eta} \neq 0$$

$$P_{\Lambda_b}^{\mathrm{CMS}} = \langle P_{\hat{n}} \rangle^{\eta \in (-\infty, +\infty)} \equiv \frac{\int_{-\infty}^{+\infty} P_{\hat{n}}(\eta) N(\eta) d\eta}{\int_{-\infty}^{+\infty} N(\eta) d\eta} = 0$$

What if $P_{\Lambda_b}^{\mathrm{CMS}}$ nozero?

$$P_{\Lambda_b}^{\mathrm{CMS}} = 0.00 \pm 0.06 \pm 0.06$$

Measuring $P_{\Lambda_b}^{\text{forward}}$ on CMS and ATLAS

$$P_{\Lambda_b}^{\text{forward}} = \frac{\int_0^{+\infty} P_{\hat{n}}(\eta) N(\eta) d\eta}{\int_0^{+\infty} N(\eta) d\eta}$$

Measuring $P_{\Lambda_b}^{\text{forward}}$ on CMS and ATLAS

$$P_{\Lambda_b}^{\text{forward}} = \frac{\int_{-\infty}^{+\infty} \text{sign}(\eta) P_{\hat{n}}(\eta) N(\eta) d\eta}{\int_{-\infty}^{+\infty} N(\eta) d\eta}$$

Measuring $P_{\Lambda_b}^{\text{forward}}$ on CMS and ATLAS

$$P_{\hat{n}'}(\eta) = P_{\hat{n}'}(-\eta)$$

$$P_{\Lambda_b}^{\text{forward}} = \frac{\int_{-\infty}^{+\infty} P_{\hat{n}'}(\eta) N(\eta) d\eta}{\int_{-\infty}^{+\infty} N(\eta) d\eta}$$

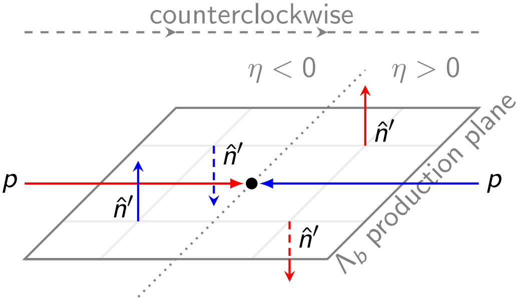


Figure: Definition of $\hat{n}'$: $\vec{n}' \equiv \frac{\vec{p}_{\text{beam}}\,' \times \vec{p}_{\Lambda_b}}{|\vec{p}_{\text{beam}}\,' \times \vec{p}_{\Lambda_b}|}$

3. Summary and outlook

- the measurement of the Λ_b polarization by CMS collaboration should be exactly equal to zero.
- The updated LHCb Λ_b transverse polarization measurement is undergo.
- strongly suggest CMS and ATLAS to perform the measurement of the Λ_b transverse polarization in the forward region of the pseudorapidity.

Thanks for your attention!