International Symposium on Spin Physics

The Deep Exclusive Meson Production as a probe of the Λ^0 polarization at the EIC

Kong Tu, BNL Sep 26, 2023

This talk is based on a recently submitted manuscript arXiv:2308.09127

A big question and a longtime puzzle

- Discovered in the mid 1970s, Ahyperon polarization was observed in unpolarized proton-Beryllium collisions.
- ~ A 50-year problem that still not fully understood.
- Despite the mystery, Λ-hyperon's self-analyzing weak decay became an excellent experimental probe of spin observables.



FIG. 3. Three components and magnitude of the $\Lambda^0 \rightarrow p + \pi^-$ asymmetry as a function of Λ^0 transverse momentum.

This was the beginning of the `spin physics` in high energy scatterings. (see *measurements on A polarization* from different experiments in this conference)

Λ^0 polarization `puzzle`

Production plane



collisions.

* only in heavy-ion AA collisions, people think it's of different origin.

Λ^0 polarization `puzzle`

Production plane

Example: HERMES experiment of ep deep inelastic scattering (DIS).



 Λ^0 -polarization has been observed in p+p, NC/CC DIS, e+e, p+A, and AA* collisions.

* only in heavy-ion AA collisions, people think it's of different origin.

Parton spin direction

Example: COMPASS experiment of mu+p deep inelastic scattering (DIS)



In Λ rest frame:

 $rac{dN}{d\Omega} = rac{N_{tot}}{4\pi} \left(1 + lpha \vec{P} \vec{k}
ight)$ $lpha = +(-)0.642 \pm 0.013 - \Lambda (\bar{\Lambda}) ext{ decay}$

parameter, \vec{P} – polarization vector, \vec{k} – unit vector along the proton momentum, x-axis align with the virtual photon direction.

 Λ^0 polarization is to measure the longitudinal spin transfer from lepton/photon or nucleon to quark.

No signal has been observed.

Λ^0 polarization `puzzle`

Production plane

- TMD polarizing FFs seem to explain the e+e- data (Gamberg et al 2021).
- Thomas presession mechanism (Degrand and Miettinen 1981): valance quarks and k_T of the strange quark via recombination.
- Other models, including single-pion exchange (*Tornqvist and Sofer 1991*), resonance model with interference (*Jeseph and Sofer 1980*), etc.

Final-state effects: polarization generated by hadronisation

Parton spin direction

Measurement ~ helicity \otimes partonic scattering cross section \otimes pFFs

 $d\Delta\sigma^{\Lambda} = \sum \int dx_a dx_b dz \Delta f_a(x_a) f_b(x_b) \otimes \Delta\sigma(ab \to cd) \otimes \Delta D^{\Lambda}(z)$ helicity distribution pQCD calculable polarized FF

 Some argued: polarized FF is too small, so no signal is observed.
 Similar for transversity.

▶ ...

Some argued: Feed-down dilution.

Final-state effects: polarization NOT seen due to hadronisation

Deep Exclusive Meson Production (DEMP)

An exclusive reaction channel to study the meson structure and GPDs.

- Sensitive to the QCD confinement.
- Complementary to the Form Factor measurements.
- Three-dimensional structures, e.g., orbital angular momentum, of the Pion and Kaon.

See [T. Horn 2017] and [G. Huber's talk]



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This talk, I focus on:

 $e+p \rightarrow e' + K^+ + \Lambda^0$

with polarization observables.





Why DEMP?



This measurement tests an extreme case:

- 1. x_F ~ 1.0
- 2. Exclusive final-states, spin can be counted.
- 3. ~ No FFs involved.

Which direction Λ^0 would be polarized? \vec{s}_1 or \vec{S}_{beam} ? we force $\vec{s}_1 \cdot \vec{S}_{\text{beam}} = 0$ (perpendicular)

Expectation 1 – large P_{Λ} w.r.t production plane



*Sign of polarization depends on definition of plane. For all fixed target, it is `beam X lambda` and it matters if it is proton or photon projectile.



Expectation 2: What to expect for P_{Λ} w.r.t \vec{S}_{beam} ?



STAR data on proton target; similar for transverse spin transfer

Despite expectation of a positive P_{Λ} signal, it has never been observed.

- We don't know how much s quark (could) carries the spin of Λ. (some say 100%, some 60%, and some 0%)
- 2. In DIS or pp, **feed-down** from heavier particles could dilute signal, if there's any.
- **3. Fragmentation** seems to be playing an important role.

Measurement ~ helicity \otimes partonic scattering cross section \otimes pFFs



Eur.Phys.J.C64:171–179,2009

ect for P_{Λ} w.r.t \vec{S}_{beam} ?

Similarly found by COMPASS, but to make things cworse c signal for antilambda showed upbeen observed.

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Expectation 2: large P_{Λ} w.r.t \vec{S}_{beam}

TABLE VIII: First and second moments of various helicity distributions in the measured range at a scale of $Q_0^2 = 2.5 \text{ GeV}^2$.

	Moments in measured range
Δu	$0.601 \pm 0.039 \pm 0.049$
$\Delta ar{u}$	$-0.002\pm0.036\pm0.023$
Δd	$-0.226 \pm 0.039 \pm 0.050$
$\Delta ar{d}$	$-0.054\pm0.033\pm0.011$
Δs	$0.028 \pm 0.033 \pm 0.009$
$\Delta u + \Delta \bar{u}$	$0.599 \pm 0.022 \pm 0.065$
$\Delta d + \Delta ar{d}$	$-0.280 \pm 0.026 \pm 0.057$
$\Delta u_{\rm v}$	$0.603 \pm 0.071 \pm 0.040$
$\Delta d_{\rm v}$	$-0.172\pm0.068\pm0.045$
$\Delta \bar{u} - \Delta \bar{d}$	$0.048 \pm 0.057 \pm 0.028$
$\Delta\Sigma$	$0.347 \pm 0.024 \pm 0.066$
Δq_3	$0.880 \pm 0.045 \pm 0.107$
Δq_8	$0.262 \pm 0.078 \pm 0.045$

HERMES data (Phys.Rev.D71:012003,2005)

- Up quarks in proton accounts for 60% of the total spin. (down quark accounts negatively, so total 30% $\Delta\Sigma$)
- Knocking out one up quark is naively expected to be half of it. So 30% of the total spin.
- If the proton is longitudinally polarized ~ 70%, then the remaining polarization (the Λ⁰) is expected to be 70%*70% ~ 50% w.r.t the beam polarization direction.



ePIC detector at the EIC



(A. Jentsch, BNL)

An interesting channel that we need to detect exactly a Pion, Kaon, and Proton in the forward region, where momentum and position resolution needs to be good for proton – this is not easy

- Lowest energy (41 GeV/c) seems possible
- Highest energy (275 GeV/c) seems very difficult.
- Can second detector at the EIC focus more on forward direction with higher energy Λ⁰ ?
- Resolution of proton daughter reconstruction, beam effects, etc. are important.

Summary

- The DEMP has been proposed to be a probe to study the spin transfer at the EIC and might shine new lights on the 50 years of Λ^0 polarization puzzle.
 - Expectation 1: large Λ^0 polarization w.r.t production plane;
 - Expectation 2: large Λ^0 polarization w.r.t beam (parton) polarization;

• Feasibility studies will be followed up at the EIC and **CLAS12.**

