Transversity experiment (E06-010) at JLab

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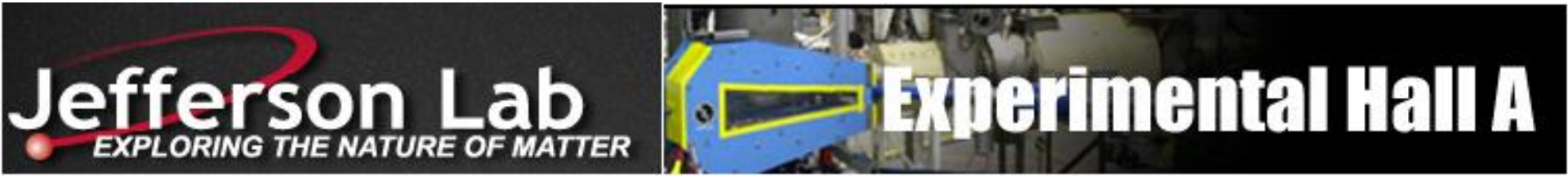
Spokesperson of E06-010: Jian-ping Chen(JLab), Xiaodong Jiang(LANL), Haiyan Gao(Duke)
Evaristo Cisbani(INFN, Rome), Jen-Chieh Peng(UIUC)

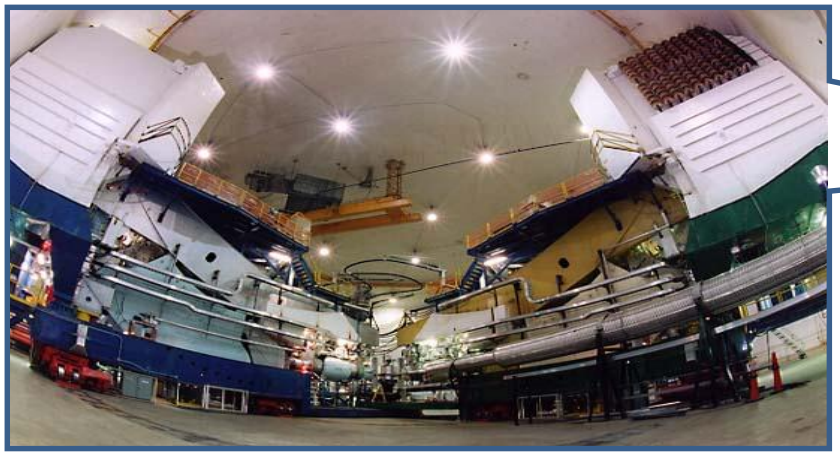


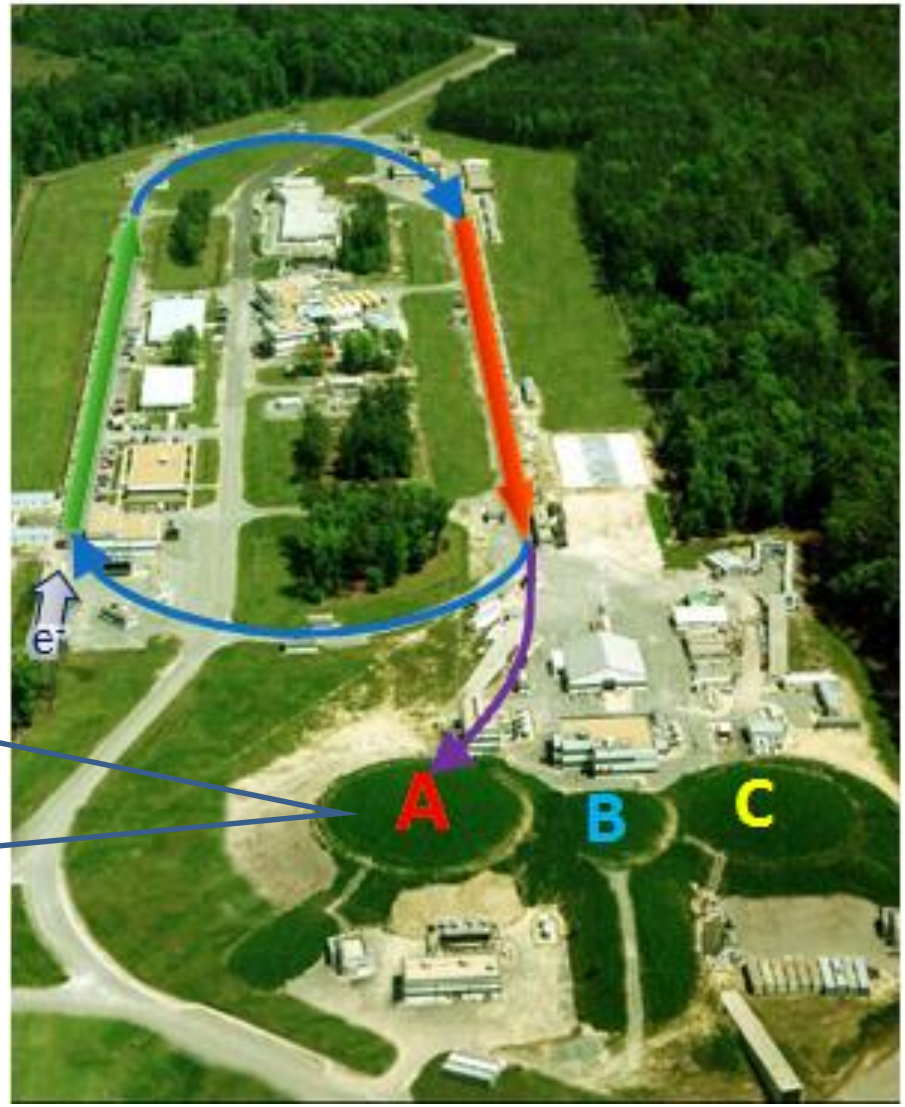
Outline

- **Overview of Jefferson Lab – 6GeV**
- **Introduction of Transversity (E06-010) experiment at Jefferson Lab Hall A**
  - ✓ Physics motivation
  - ✓ Setup of the experiment
- **Published/submitted and preliminary results**
- **Summary**

Thomas Jefferson National Accelerator Facility ---6 GeV

- Located in Newport News, Virginia, USA
- 2 linear accelerator provides continuous polarized electron beam
  - ✓ E_{beam}=6 GeV
  - ✓ P_{beam}=85%
- 3 experimental halls

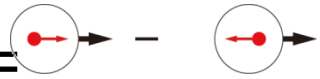
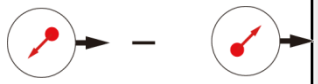


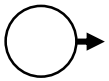


Introduction of Transversity(E06-010) experiment at Jefferson Lab Hall A

- Physics motivation
- Setup of the experiment

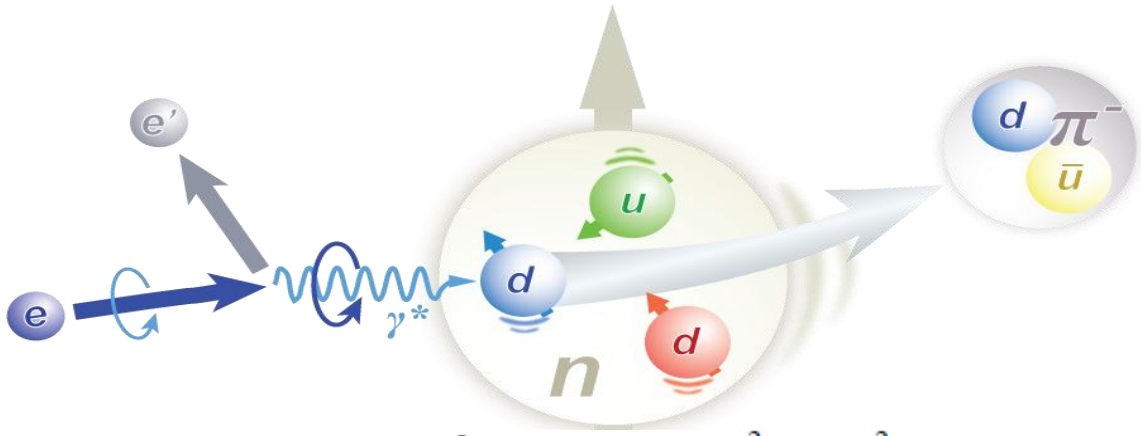
Leading-Twist TMD PDFs(TMDs)

Nucleon Polarization	Quark polarization: Unpolarized (U)	Quark polarization: Longitudinally Polarized (L)	Quark polarization: Transversely Polarized (T)
U	f_1 = 		$h_1^{\perp}$ =  Boer-Mulders
L		g_1 =  Helicity	$h_{1L}^{\perp}$ =  Worm Gear
T	$f_{1T}^{\perp}$ =  Sivers	g_{1T} =  Worm Gear	h_1 =  Transversity $h_{1T}^{\perp}$ =  Pretzelosity



: Probed with transversely polarized target
HERMES, COMPASS, JLab E06-010

TMDs in SIDIS Cross Section



$$\frac{d\sigma}{dx dy d\phi_S dz d\phi_h dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\cdot$$

	f_1 =		$\{F_{UU,T} + \ldots$	Unpolarized
Boer-Mulder	$h_1^\perp$ =	–	$+ \varepsilon\cos(2\phi_h)\cdot F_{UU}^{\cos(2\phi_h)} + \ldots$	
	$h_{1L}^\perp$ =	–	$+ S_L[\varepsilon\sin(2\phi_h)\cdot F_{UL}^{\sin(2\phi_h)} + \ldots]$	Polarized Target
Transversity	h_{1T} =	–	$+ S_T[\varepsilon\sin(\phi_h+\phi_S)\cdot F_{UT}^{\sin(\phi_h+\phi_S)}$	
Sivers	$f_{1T}^\perp$ =	–	$+ \sin(\phi_h-\phi_S)\cdot(F_{UL}^{\sin(\phi_h-\phi_S)} + \ldots)$	
Pretzelosity	$h_{1T}^\perp$ =	–	$+ \varepsilon\sin(3\phi_h-\phi_S)\cdot F_{UT}^{\sin(3\phi_h-\phi_S)} + \ldots]$	
	g_1 =	–	$+ S_L\lambda_e[\sqrt{1-\varepsilon^2}\cdot F_{LL} + \ldots]$	Polarized Beam and Target
	$g_{1T}^\perp$ =	–	$+ S_T\lambda_e[\sqrt{1-\varepsilon^2}\cos(\phi_h-\phi_S)\cdot F_{LT}^{\cos(\phi_h-\phi_S)} + \ldots]\}$	

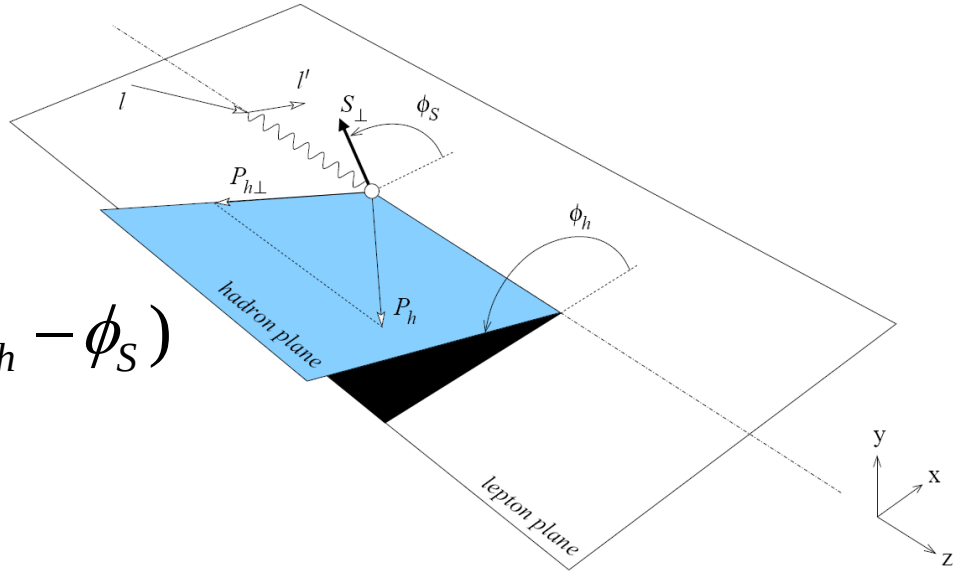
S_L, S_T: Target Polarization; λ_e: Beam Polarization

Separation of Collins, Sivers and pretzelosity effects through azimuthal angular dependence

$$A_{UT}(\varphi_h^l, \varphi_S^l) = \frac{1}{P}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

$$= A_{UT}^{Collins} \sin(\phi_h + \phi_S) + A_{UT}^{Sivers} \sin(\phi_h - \phi_S)$$

$$+ A_{UT}^{Pretzelosity} \sin(3\phi_h - \phi_S)$$



UT: **U**npolarized beam + **T**ransversely polarized target

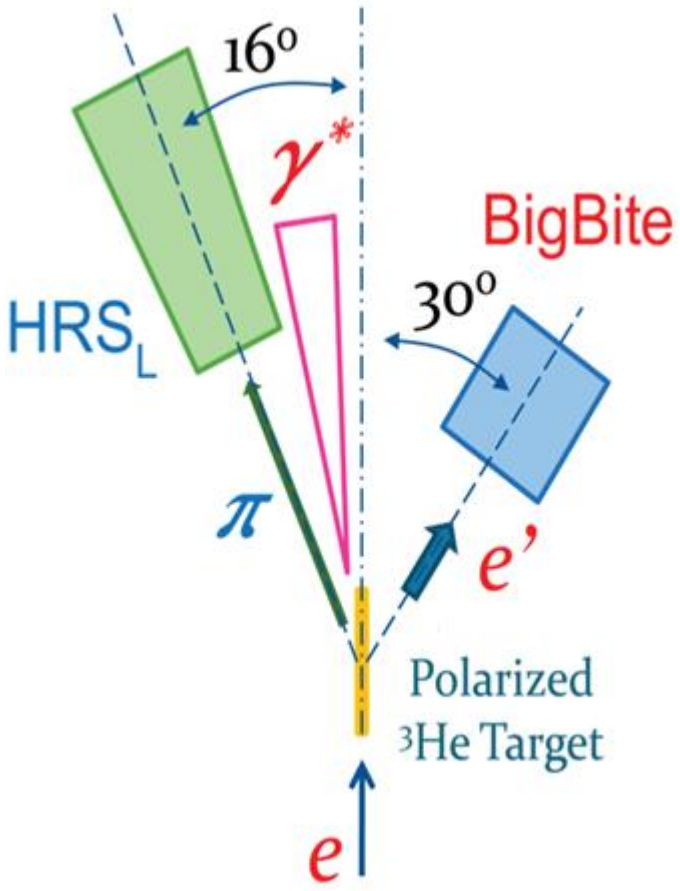
$$A_{UT}^{Collins} \propto \langle \sin(\phi_h + \phi_S) \rangle_{UT} \propto h_1 \otimes H_1^{\perp}$$ →TMD: Transversity

$$A_{UT}^{Sivers} \propto \langle \sin(\phi_h - \phi_S) \rangle_{UT} \propto f_{1T}^{\perp} \otimes D_1$$ →TMD: Sivers

$$A_{UT}^{Pretzelosity} \propto \langle \sin(3\phi_h - \phi_S) \rangle_{UT} \propto h_{1T}^{\perp} \otimes H_1^{\perp}$$ →TMD: Prezelosity

Introduction of E06-010 experiment

- Beam energy: 5.89 GeV (30Hz)
- Target: (World record!!!)
  - ✓ ^{3}He : transversely and vertically polarized
  - ✓ In beam Polarization: ~60%
  - ✓ Spin flips: 20 minutes
- BigBite:
  - ✓ 3 Drift chambers, pre-shower, scin. ,shower
  - ✓ Momentum: 0.6 ---2.5 GeV
- LHRS:
  - ✓ VDC, S1, S2m(CTOF),
    A1, CO_2 gas Cer., RICH, pion rejector
  - ✓ Momentum: 2.35 GeV
  - ✓ PID: pion, kaon, proton separation



- **Trigger: Singles on HRS or BigBite**
  Coincidence trigger
- **Polarized target and Beam**

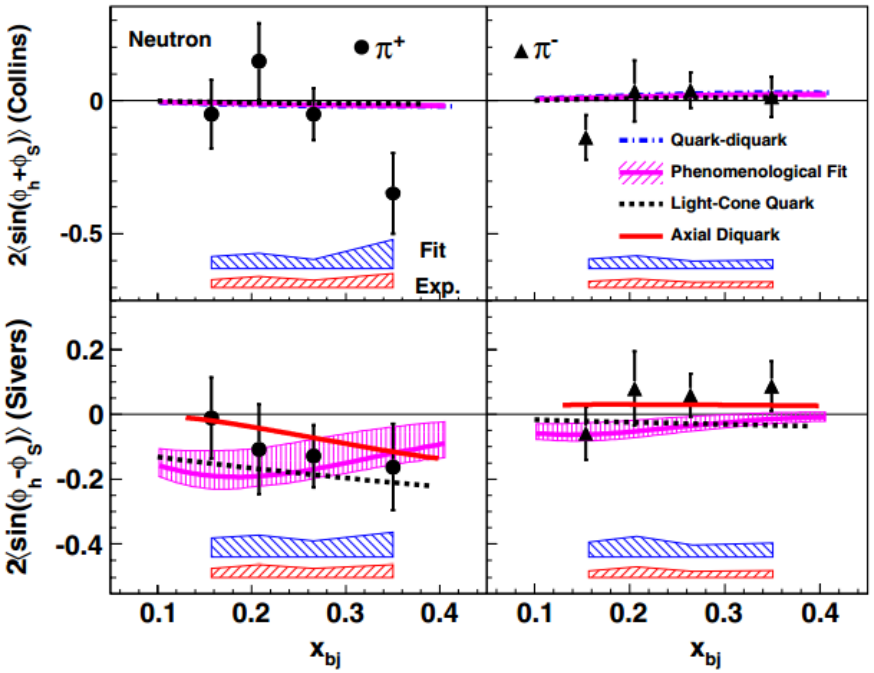
- **SIDIS or Inclusive**
- **SSA or DSA**

Published/submitted and preliminary results

- SIDIS results
- Inclusive hadron SSA/DSA

PRL 107, 072003 (2011) PHYSICAL REVIEW LETTERS week ending 12 AUGUST 2011

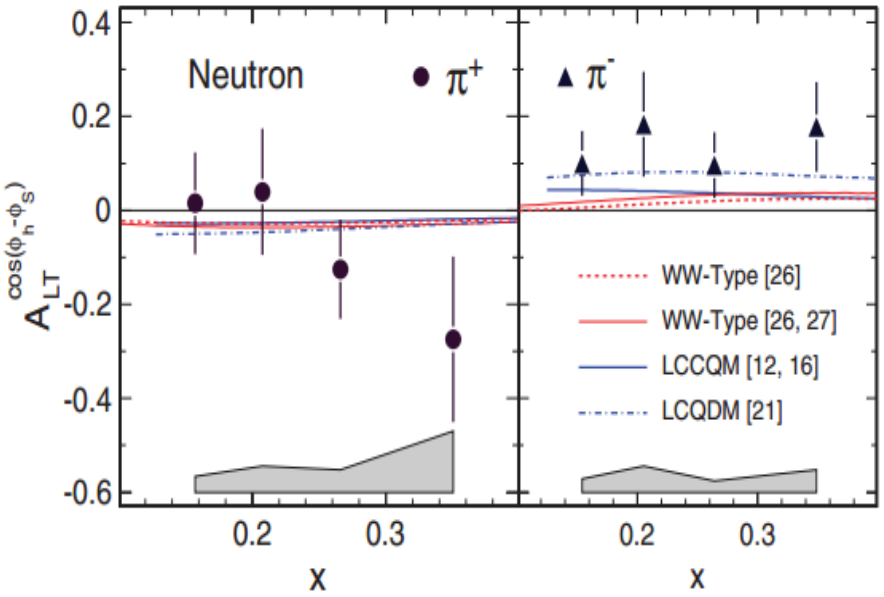
Single Spin Asymmetries in Charged Pion Production from Semi-Inclusive Deep Inelastic Scattering on a Transversely Polarized ^{3}He Target at $Q^2 = 1.4$–2.7 GeV^2



X. Qian et al. (Hall A Collaboration)

PRL 108, 052001 (2012) PHYSICAL REVIEW LETTERS week ending 3 FEBRUARY 2012

Beam-Target Double-Spin Asymmetry A_{LT} in Charged Pion Production from Deep Inelastic Scattering on a Transversely Polarized ^{3}He Target at $1.4 < Q^2 < 2.7$ GeV^2



J. Huang et al. (Hall A Collaboration)

Kaon SIDIS SSA
---why kaon is interesting

- Collins effect
  - ✓ Hermes: $\pi^- > \pi^+$ and kaon > pion
  - ✓ Unfavored Collins fragmentation function plays a more important role???
  - ✓ Importance of favored or unfavored Collins fragmentation function

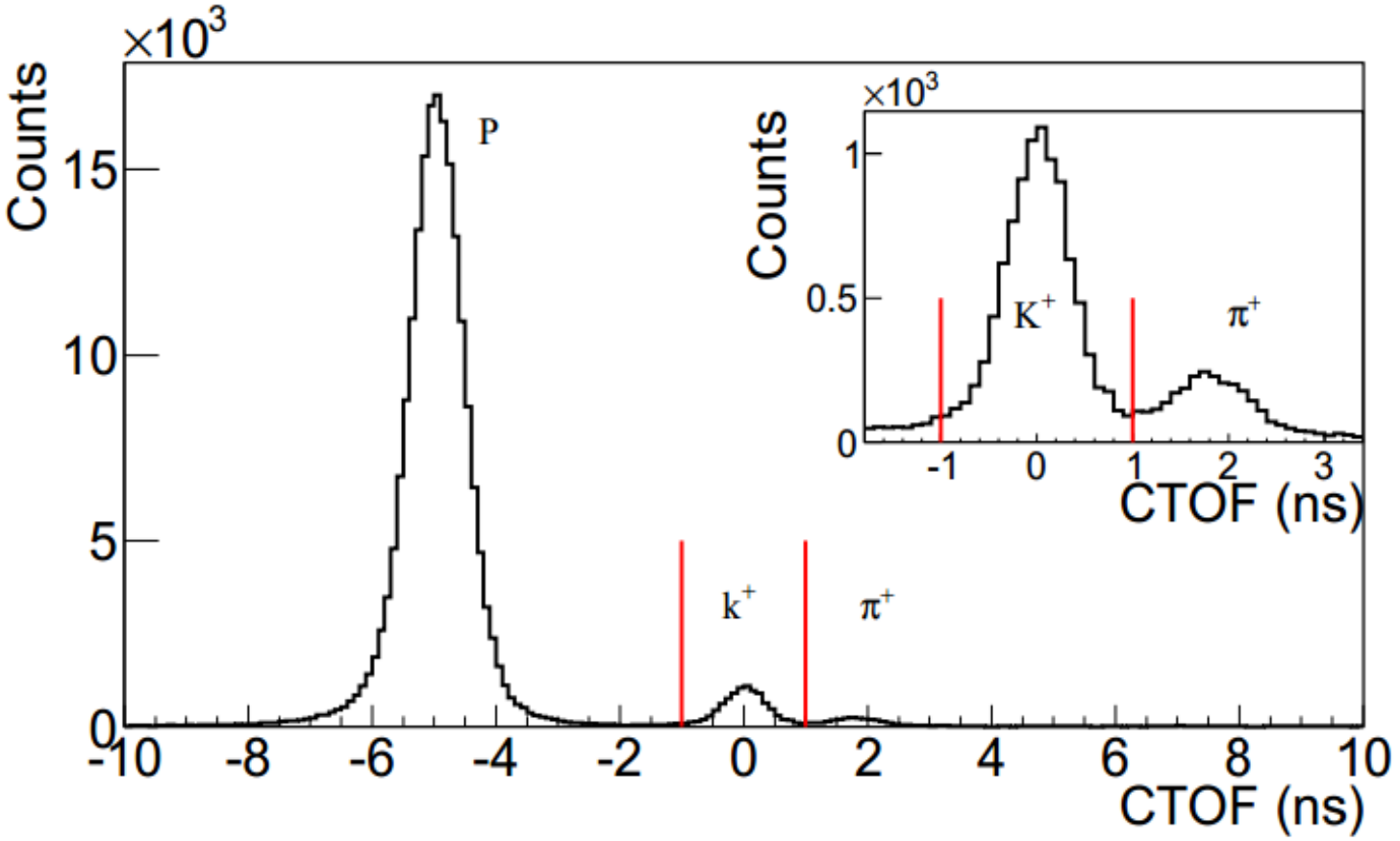
- Sivers effect
  - ✓ Difference between π^+ and K^+: d-bar $\Longleftrightarrow$ s-bar
    - " Sea quark effect "
    - " Fragmentation effect "

      → difference is small through calculation, quark mass difference cancels in ratio

- Important inputs to the global kaon data from He-3 target

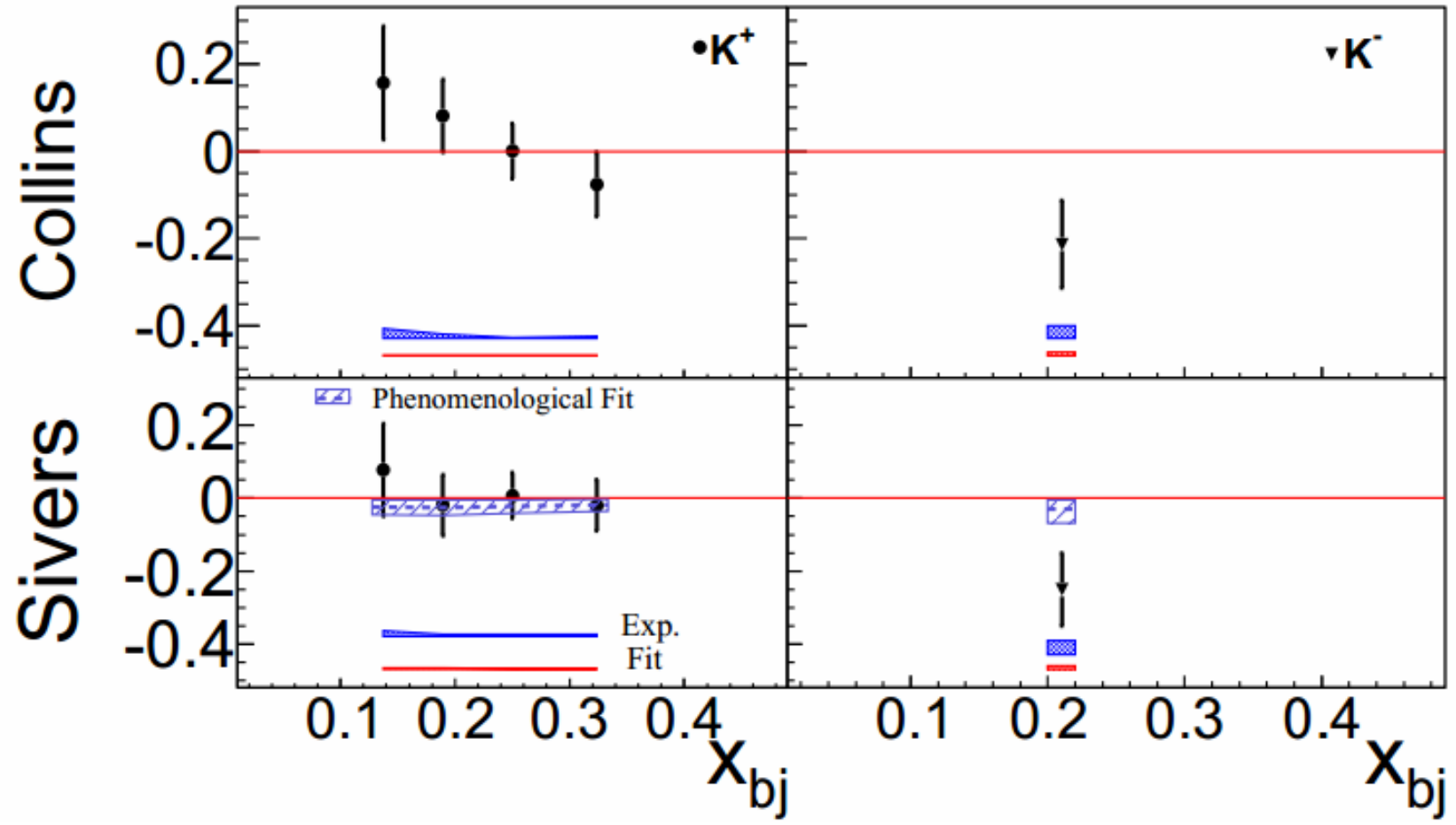
- Current theoretical understanding or phenomenological fits could be tested or improved

Kaon PID



- Contamination of pion in kaon sample is well controlled:
  - π+ in k+: <2%
  - π- in k-: <5%

Kaon Collins and Sivers asymmetries on He-3 target

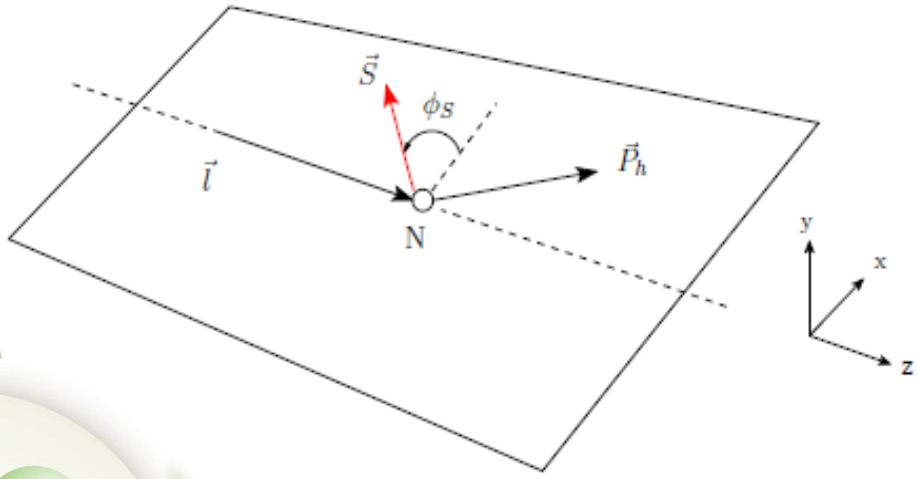


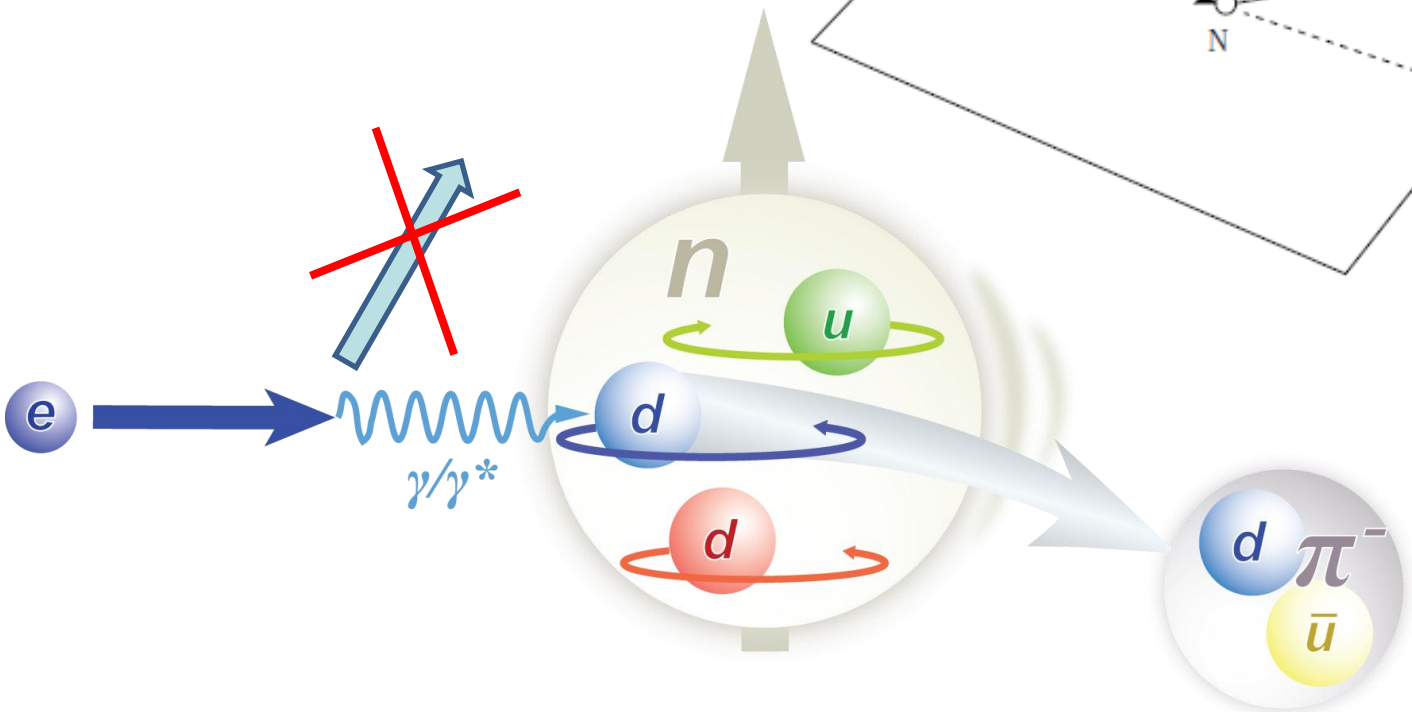
Y. X. Zhao, Y. Wang et al. (Hall A Collaboration)

Accepted by PRC, in Production **arXiv: 1404.7204**

Inclusive hadron SSA

$$A_{UT}(x_F, p_T) = \frac{1}{P}\frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} \sin\phi_S = A_N \sin\phi_S$$

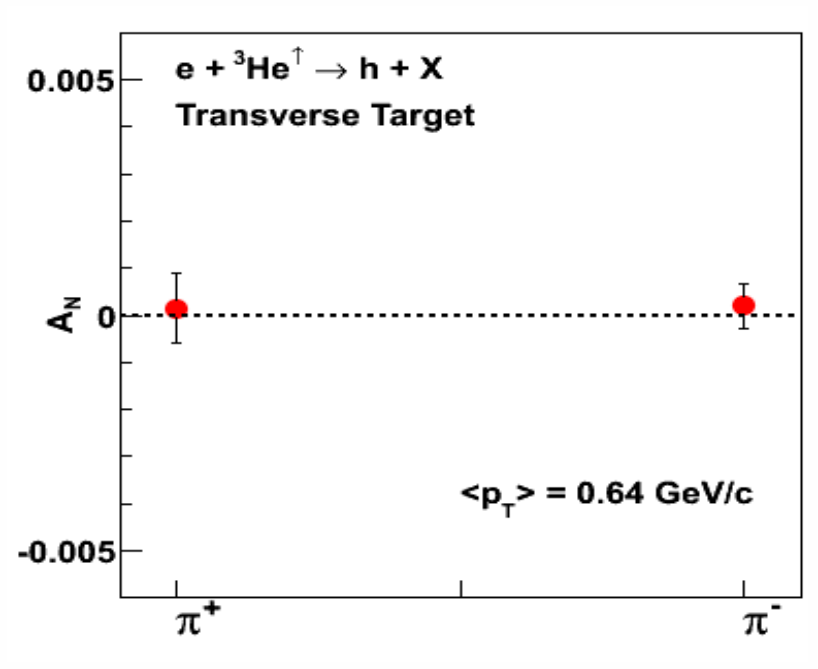




- **Assuming TMD factorization valid in inclusive hadron production:**
  - ✓ **Sivers contribution dominates SSA**
  - ✓ **Collins contribution is negligible**

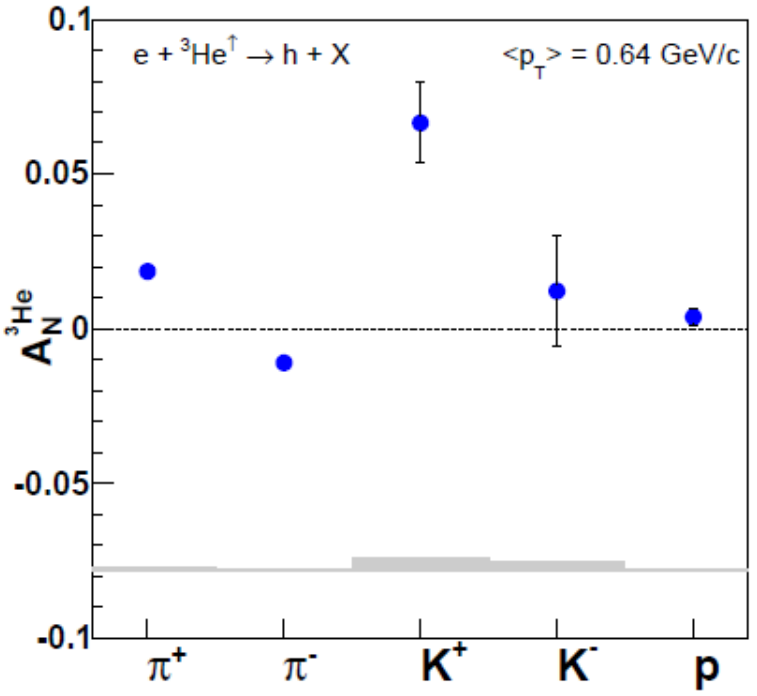
14

Inclusive hadron SSA



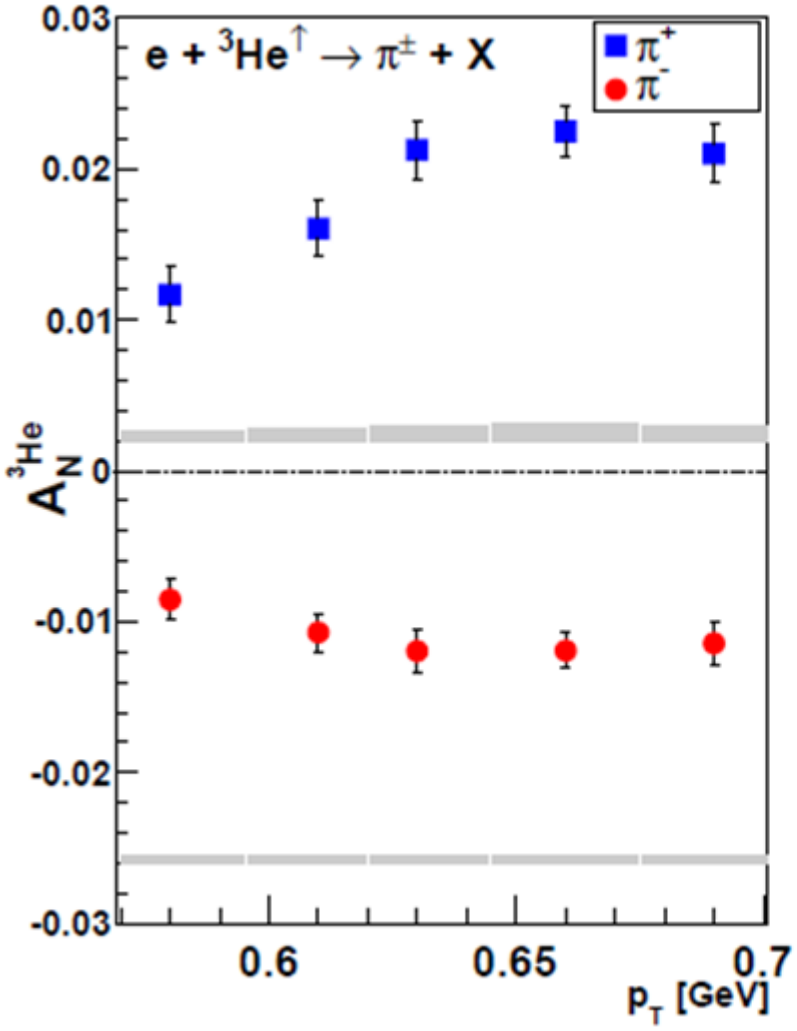
- **Indication of our false asymmetry: <0.1%**

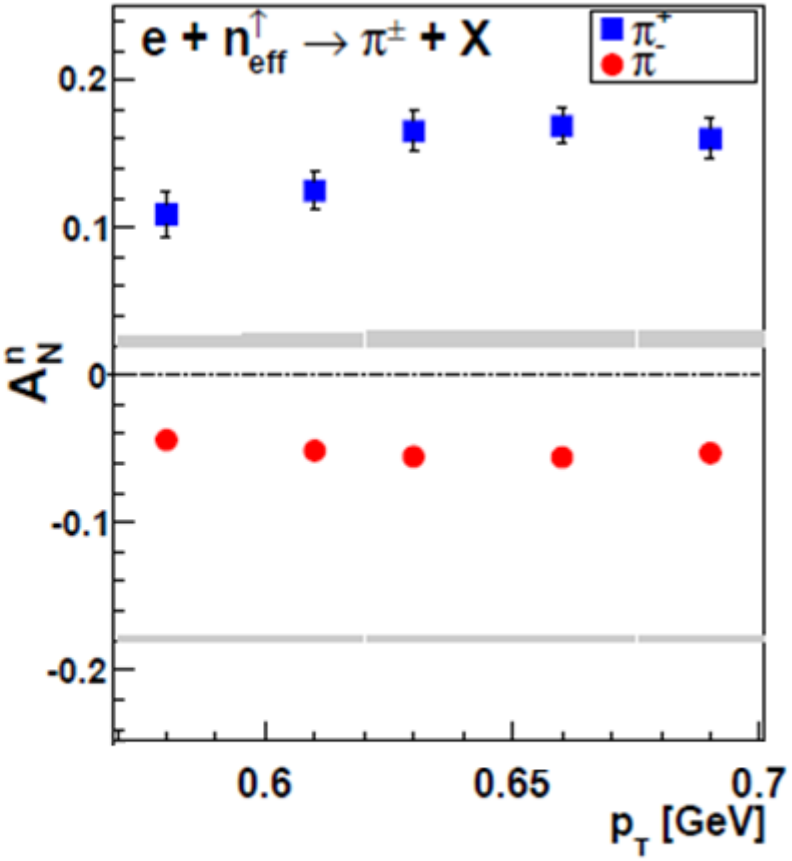
$$A_{UT}(x_F, p_T) = \frac{1}{P}\frac{d\sigma^\uparrow - d\sigma^\downarrow}{d\sigma^\uparrow + d\sigma^\downarrow}\sin\phi_S = A_N \sin\phi_S$$



- $\phi_s = 90^o$
- **Clear non-zero asymmetries are observed for π^+ and π^- and K^+**
- **π^+ and π^- asymmetries have opposite sign**

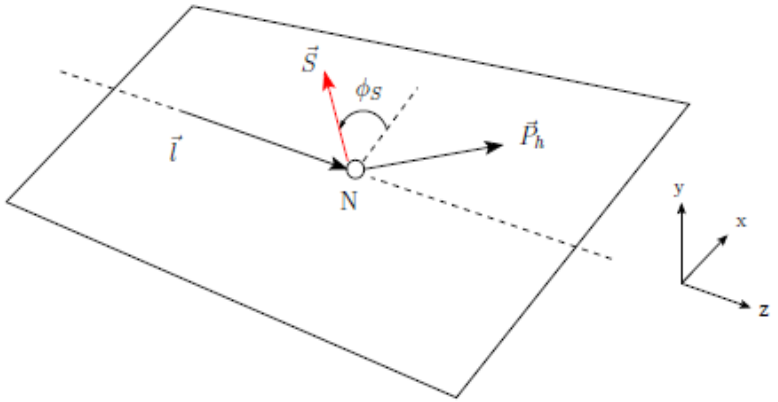
Inclusive hadron SSA



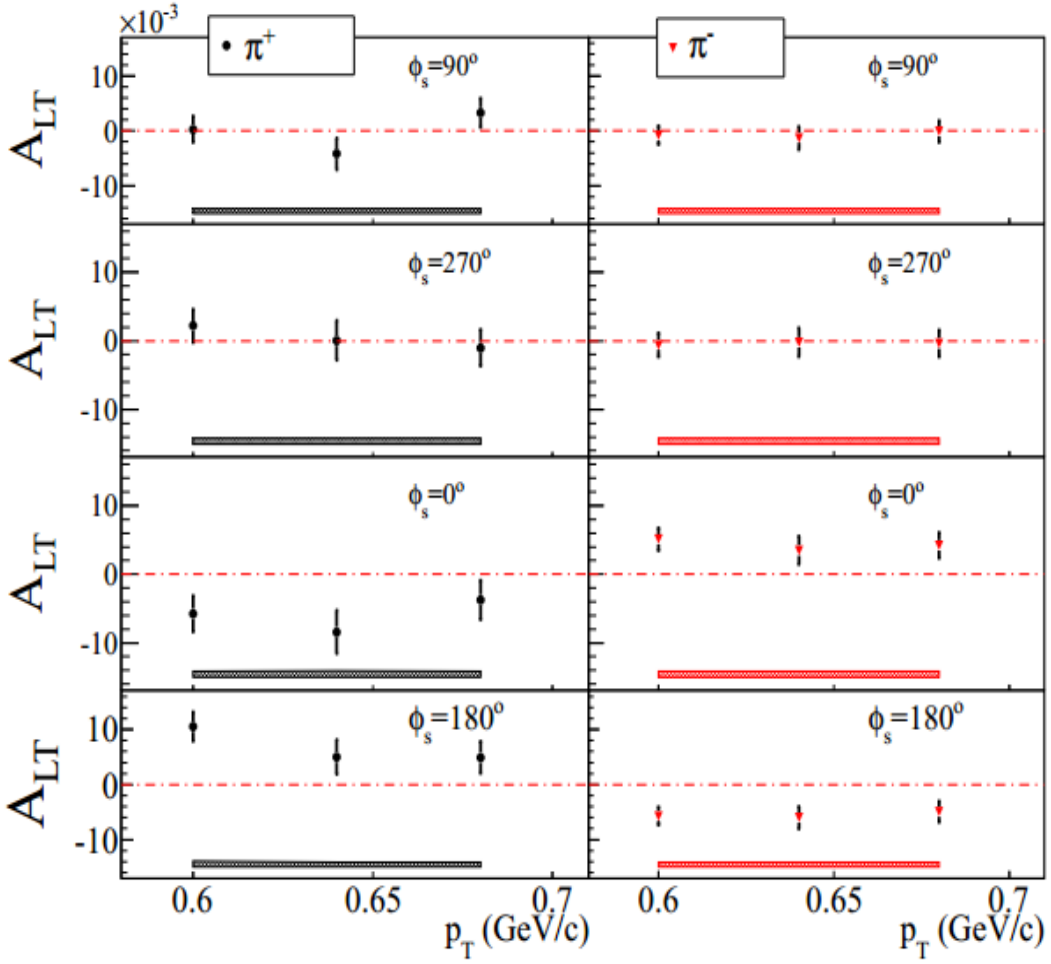


K. Allada, Y. X. Zhao et al.
(Hall A Collaboration)
Phys. Rev. C 89, 042201(R)

Inclusive hadron DSA



$$A_{LT} = \frac{1}{|P_B P_{target}|} \frac{d\sigma^{\uparrow\rightarrow} - d\sigma^{\downarrow\rightarrow}}{d\sigma^{\uparrow\rightarrow} + d\sigma^{\downarrow\rightarrow}}$$



- Andrei & Carl Carlson:
  - ✓ Fragmentation process
  - ✓ Direct photoproduction
  - ✓ Resolved photon process
- Collinear twist-3 framework:
  - ✓ g_{1T}

Preliminary

Summary

- Transversity experiment (E06-010) is introduced
- Several results are presented
- It's just the beginning...
  - ✓More 12 GeV experiments at Jlab
  - ✓Kalyan Allada's talk on Friday, S3 session
    - ◆"Key Future Measurements of TMDs at Jlab and Other Facilities"
  - ✓Jian-ping Chen's talk on Friday, S11 session
    - ◆"TMD Studies and More with SoLID at Jlab"

E06010(6-GeV Transversity) collaboration

Institutions (38)

Univ. Kentucky, W&M, Duke Univ., CalTech, UIUC, Lanzhou Univ, California State Univ, Univ. Glasgow, MIT, CMU, JLab, ODU, UVa, Hampton Univ, INFN, Mississippi State Univ, Rutgers, Kharkov Inst. of Phys. and Tech., Los Alamos National Lab, Longwood Univ, Cairo Univ, Kyungpook National Univ, China Inst. of Atomic Energy, Kent State Univ, Univ. of Sci. & Tech. of China, Florida International Univ., Univ. Massachusettes, Temple Univ, Univ. Blaise Pascal, Univ. of New Hampshire, Syracuse Univ., Yerevan Physics Inst., Univ. Ljubljana, Seoul National Univ.

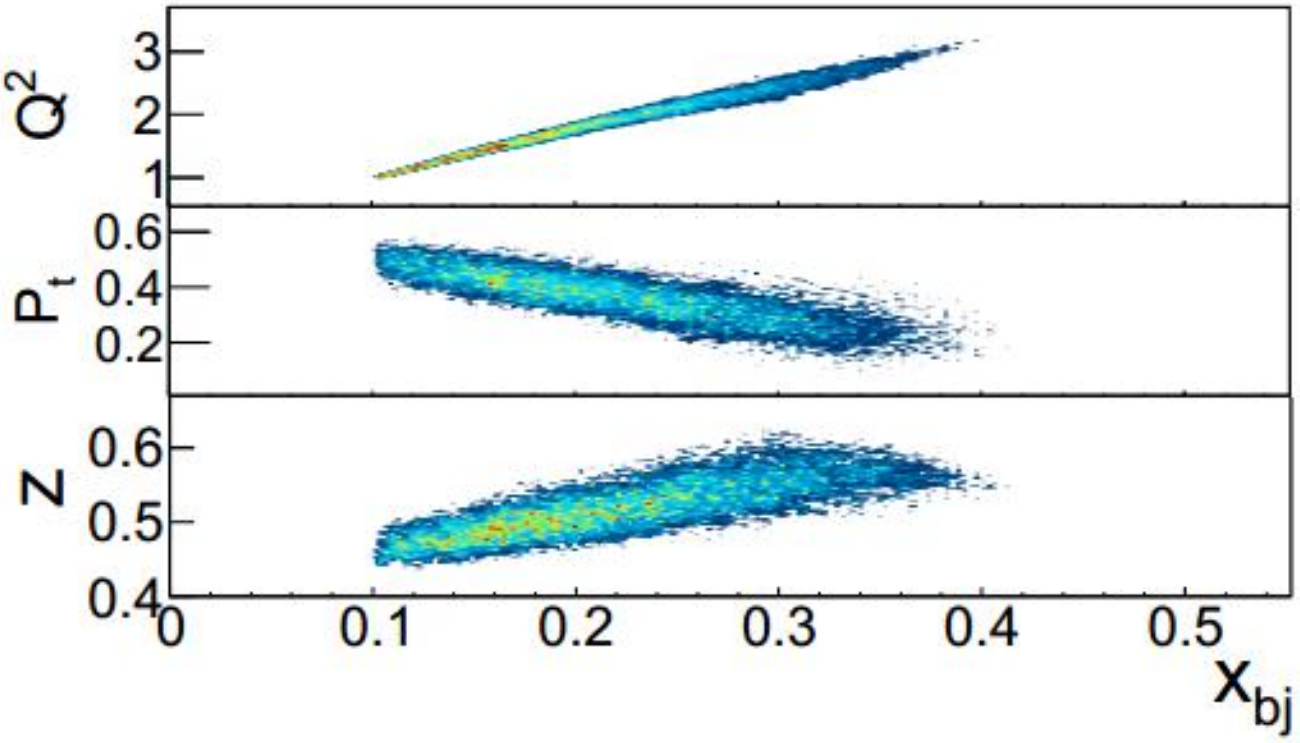
Collaboration members (115)

K. Allada, K. Aniol, J. R. M. Annand, T. Averett, F. Benmokhtar, W. Bertozzi, P. C. Bradshaw, P. Bosted, A. Camsonne, M. Canan, G. D. Cates, C. Chen, J.-P. Chen, W. Chen, K. Chirapatpimol, E. Chudakov, E. Cisbani, J. C. Cornejo, F. Cusanno, M. M. Dalton, W. Deconinck, C.W. de Jager, R. De Leo, X. Deng, A. Deur, H. Ding, P. A. M. Dolph, C. Dutta, D. Dutta, L. El Fassi, S. Frullani , J. Huang, H. Gao, F. Garibaldi, D. Gaskell, S. Gilad, R. Gilman, O. Glamazdin, S. Golge, L. Guo, D. Hamilton, O. Hansen, D.W. Higinbotham, T. Holmstrom, M. Huang, H. F. Ibrahim, M. Iodice, X. Jiang, G. Jin, M. K. Jones , J. Katich, A. Kelleher, W. Kim, A. Kolarkar, W. Korsch, J. J. LeRose, X. Li, Y. Li, R. Lindgren, N. Liyanage, E. Long, H.-J. Lu, D. J. Margaziotis, P. Markowitz, S. Marrone, D. McNulty, Z.-E. Meziani, R. Michaels, B. Moffit, C. Munoz Camacho, S. Nanda, A. Narayan, V. Nelyubin, B. Norum, Y. Oh, M. Osipenko, D. Parno, J. C. Peng, S. K. Phillips, M. Posik, A. J. R. Puckett , X. Qian, Y. Qiang, A. Rakhman, R. D. Ransome, S. Riordan, A. Saha, B. Sawatzky, E. Schulte, A. Shahinyan, M. H. Shabestari, S. Sirca, S. Stepanyan, R. Subedi, V. Sulkosky, L.-G. Tang, A. Tobias, G. M. Urciuoli, I. Vilardi, K.Wang, Y. Wang, B.Wojtsekhowski, X. Yan, X.F. Yan, H. Yao, Y. Ye, Z. Ye, L. Yuan, X. Zhan, Y. Zhang, Y.-W. Zhang, B. Zhao, Y. X. Zhao, X. Zheng, L. Zhu, X. Zhu, and X. Zong

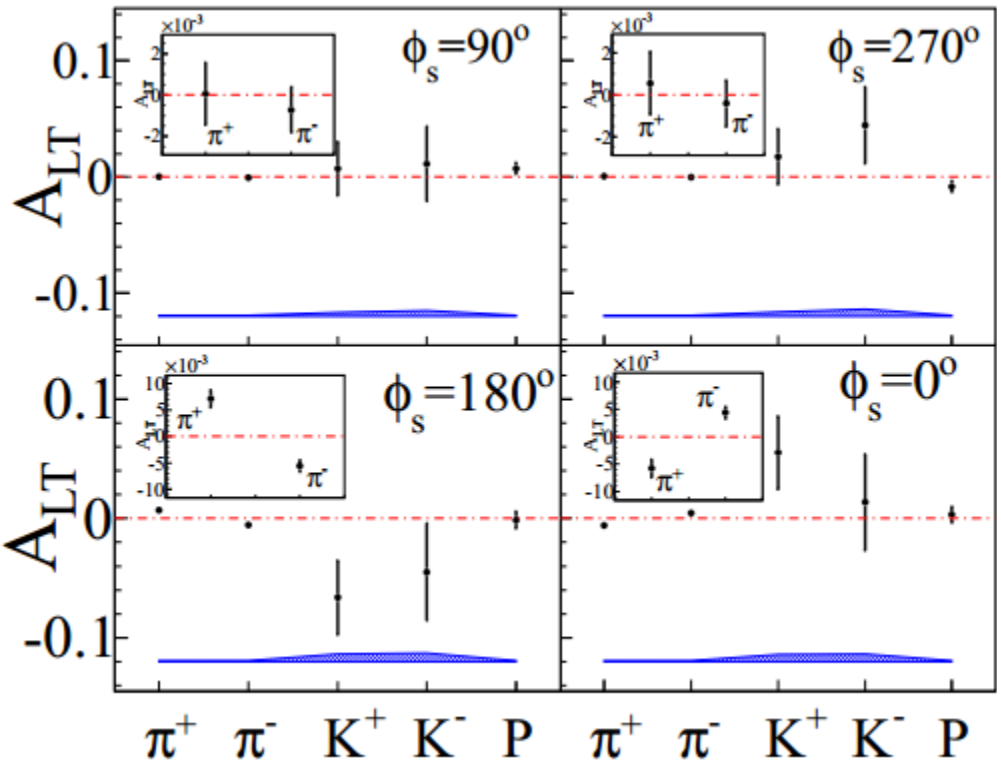
Co-spokesperson , Graduate student, Leading Postdoc

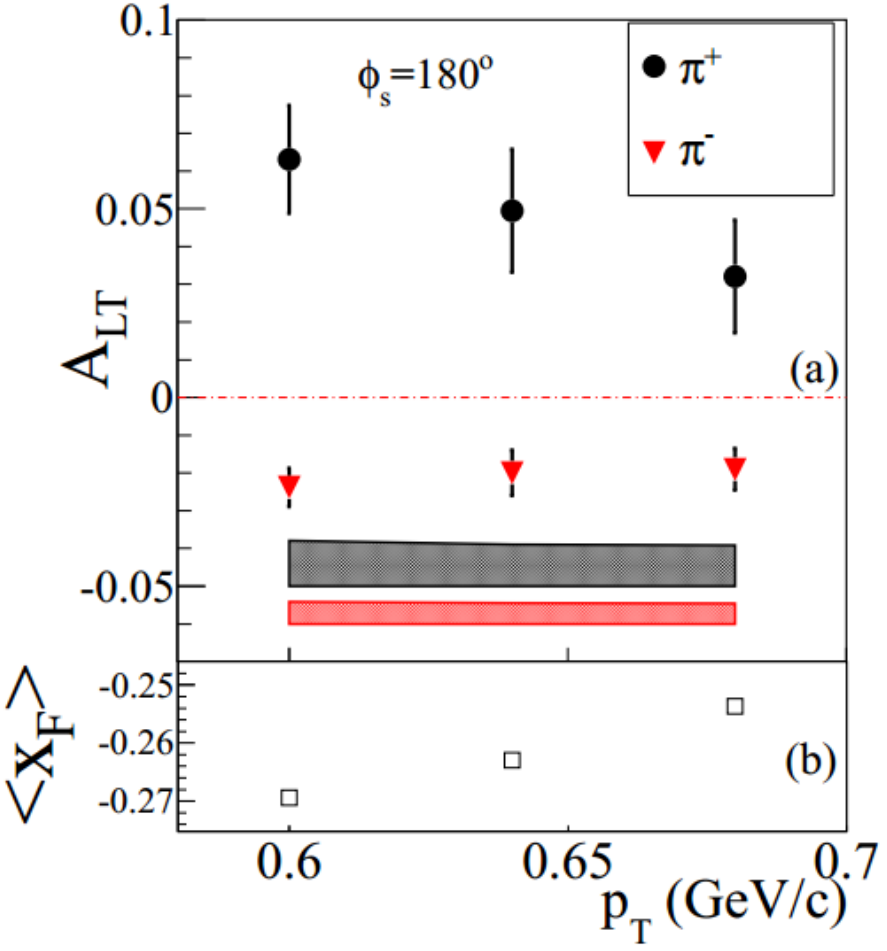
Backup

Kaon SIDIS

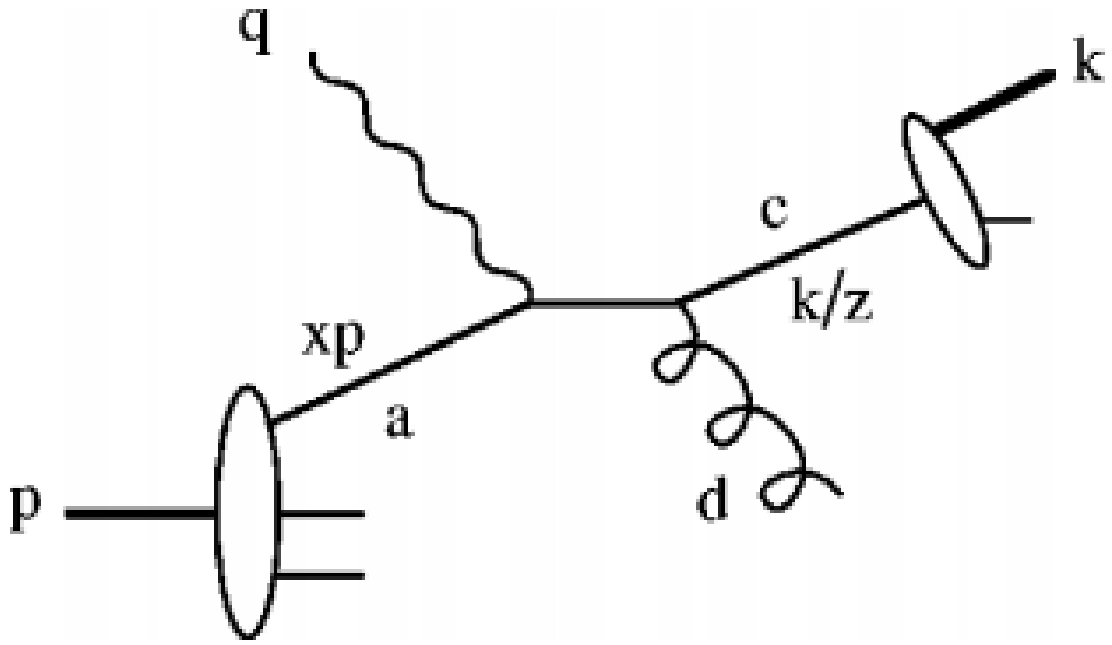


DSA ---**Preliminary**

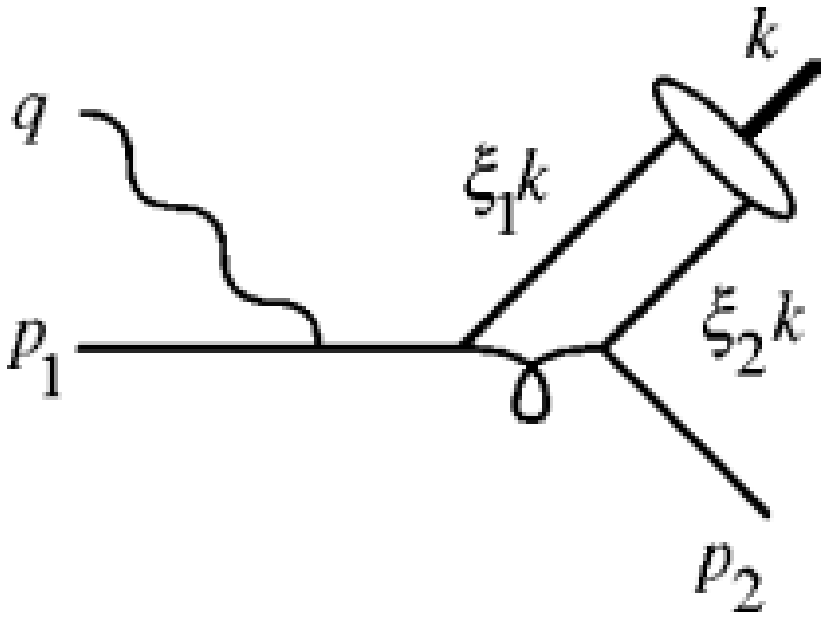




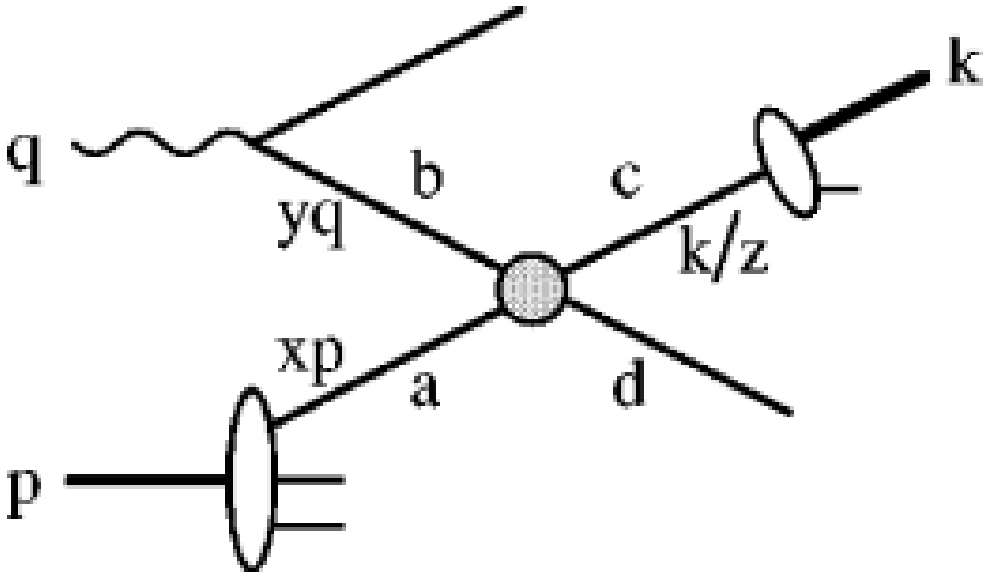
DSA---fragmentation process



DSA---direct photoproduction



DSA---resolved photon process



Target-Beam Double spin asymmetry ---Vertically polarized target

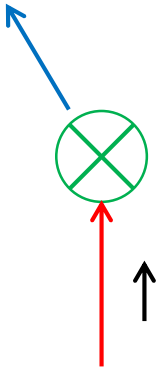
Hadron momentum direction

Electron momentum direction

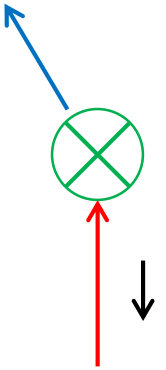
Electron spin direction

Target spin direction, view from top

$$A_{LT} = \frac{1}{|S_T P_B|} \frac{d\sigma^{\rightarrow\uparrow} - d\sigma^{\leftarrow\uparrow}}{d\sigma^{\rightarrow\uparrow} + d\sigma^{\leftarrow\uparrow}}$$



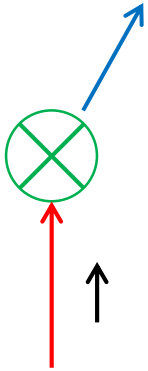
Naiive P transformation :



P conservation

No A_{LT}

Naiive T transformation :



No constrains On A_{LT}

Target-Beam Double spin asymmetry ---Transversely polarized target

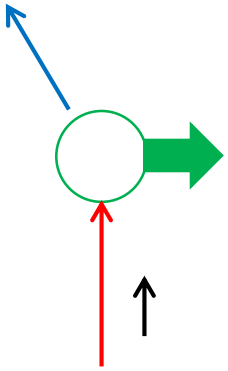
Hadron momentum direction

Electron momentum direction

Electron spin direction

Target spin direction, Transverse

$$A_{LT} = \frac{1}{|S_T P_B|} \frac{d\sigma^{\rightarrow\uparrow} - d\sigma^{\leftarrow\uparrow}}{d\sigma^{\rightarrow\uparrow} + d\sigma^{\leftarrow\uparrow}}$$



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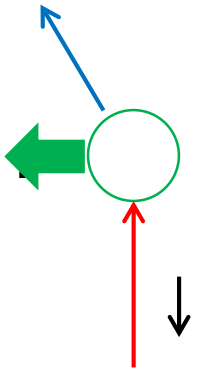
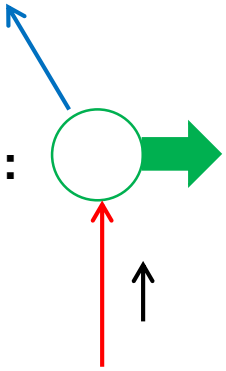


No Constrain On A_{LT}

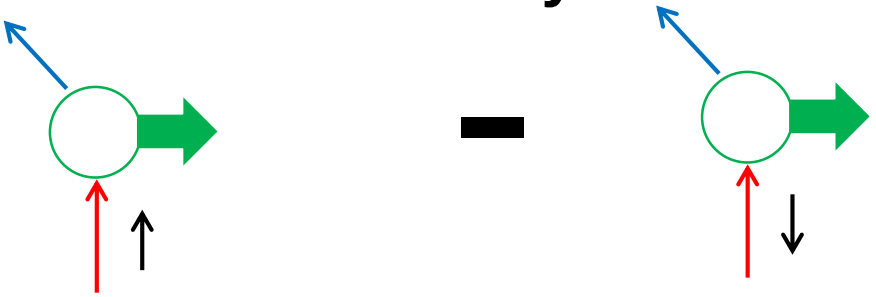


Naiive T transformation :

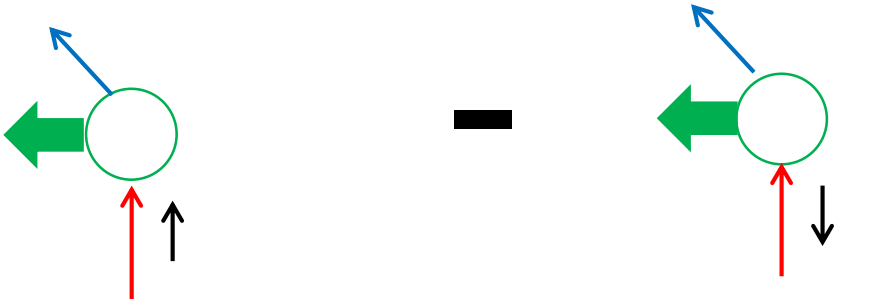
No Constrain On A_{LT}

Asymmetry sign change by reversing target spin transversely

Asy_1 =



Asy_2 =



Naiive P Transfer.

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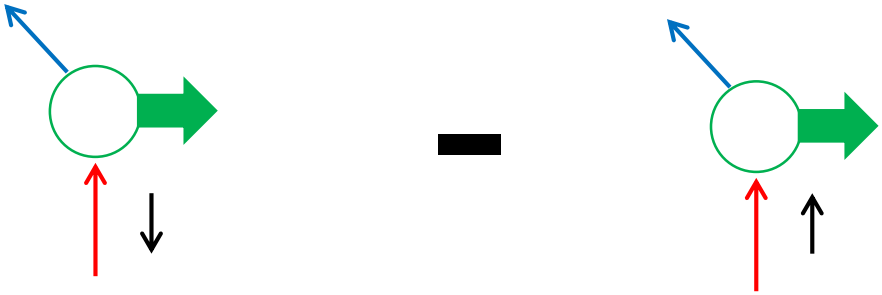

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