Left-right asymmetry for pion and kaon production in SIDIS process

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1. Introduction
2. Theoretical description
3. Numerical calculation
4. Summary

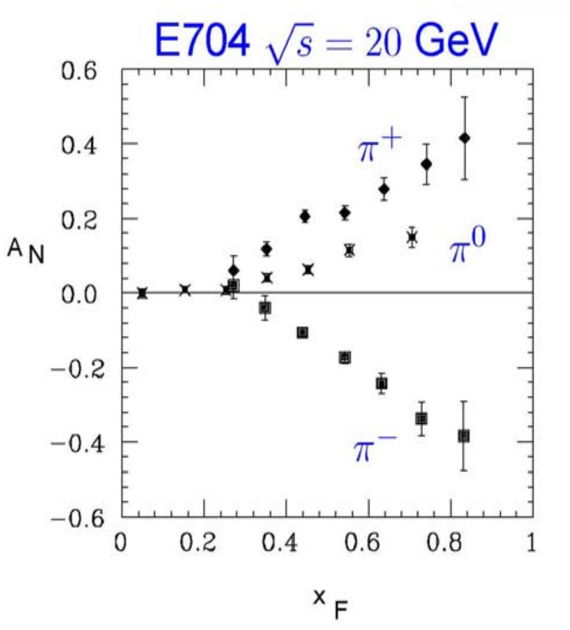
Left-right asymmetry

- several experiments have been carried to measure the "single spin asymmetry A_N", large asymmetry have been observed, whereas the theoretical prediction lead to $A_N = 0$.
- Left-right asymmetry reported by E704 experiment:

$$p^{\uparrow} p \to \pi X$$

$$A = -\frac{1}{P\cos\phi}\frac{N_{\uparrow} - N_{\downarrow}}{N_{\uparrow} + N_{\downarrow}}$$

Adama D, et al. Phys. Lett. B, 1991, 264: 462-466.



Theoretical understanding

- To describe the left-right asymmetry, two mechanism are available.

  Sivers effect: originated from quark intrinsic transverse momentum.

  Sivers, Phys. Rev. D 43, 261 (1991).

  Collins effect: generate the asymmetry in hadronization processes.

  Collins, Nucl. Phys. B 396, 191 (1993).

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3. Numerical calculation
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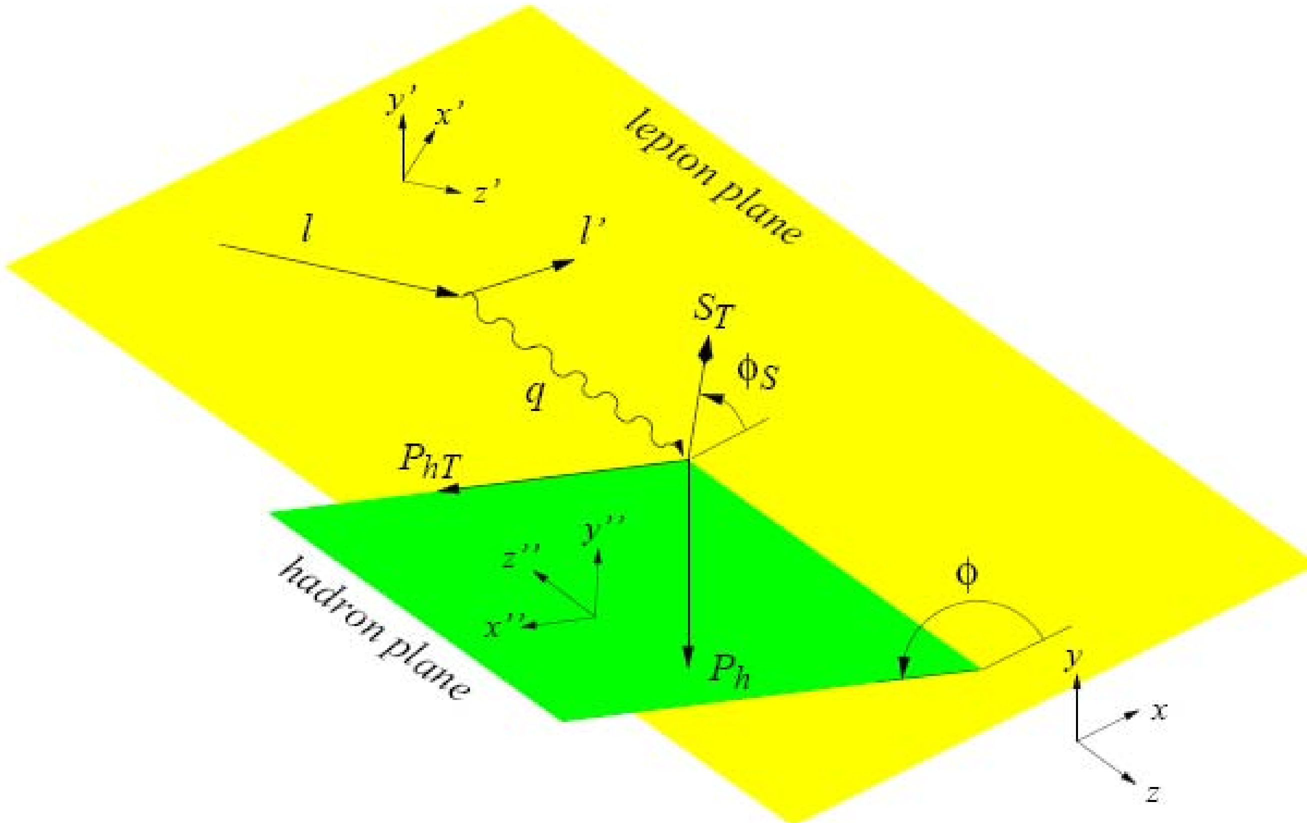
Coordinate system

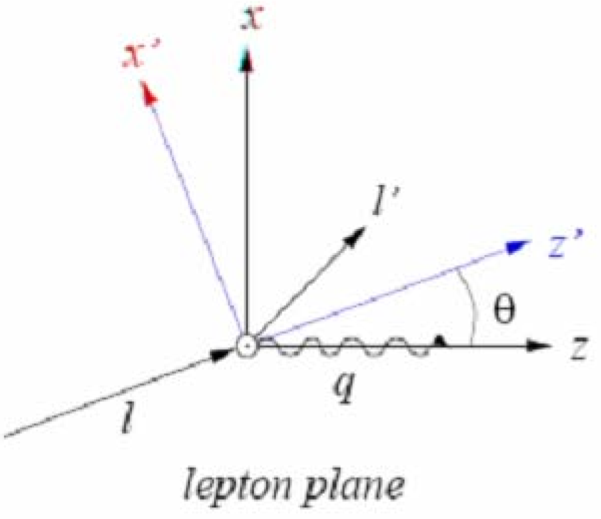


ℓp and $\gamma^* p$ frame

Transform from $\gamma^* p$ fram to lp fram

$$A_{UT}^{\ell} = \frac{\cos\theta A_{UT}^{\gamma^*} + \sin\theta\cos\phi_S A_{UL}^{\gamma^*}}{\sqrt{1-\sin^2\theta\sin^2\phi_S^{\ell}}}$$

$$\sin\theta = \gamma\sqrt{\frac{1-y-\frac{1}{4}y^2\gamma^2}{1+\gamma^2}}, \qquad \gamma = \frac{2xM_p}{Q}$$



•An estimation of θ :

HERMES: $\langle x\rangle = 0.09$, $\langle y\rangle = 0.54$, $\langle Q^2\rangle = 2.41\mathrm{GeV}^2$, $\langle\sin\theta\rangle = 0.073$

JLab(6GeV): $\langle x\rangle = 0.23$, $\langle y\rangle = 0.6$, $\langle Q^2\rangle = 1.8\mathrm{GeV}^2$, $\langle\sin\theta\rangle = 0.19$

JLab(12GeV): $\langle x\rangle = 0.23$, $\langle y\rangle = 0.57$, $\langle Q^2\rangle = 2.5\mathrm{GeV}^2$, $\langle\sin\theta\rangle = 0.17$

Indeed small

Cross section

Diehl and Sapcta, Eur. Phys. J. C 41, 515 (2005).

Bacchetta, et al., JHEP 0702:093 (2007).

$$\frac{d\sigma}{dx\,dy\,d\phi^{\ell}\,dz\,d\phi_h\,dP_{h\perp}^2} = \frac{\alpha^2}{2sx(1-\varepsilon)}\frac{\cos\theta}{1-\sin^2\theta\sin^2\phi_s^{\ell}} \times \Big\{ F[f_1 D_1]$$

$$-\frac{S_T\cos\theta}{\sqrt{1-\sin^2\theta\sin^2\phi_s^{\ell}}}\sin(\phi_h^{\ell}-\phi_s^{\ell})F\left[\frac{\vec{h}\cdot\vec{p}_\perp}{M_p}f_{1T}^{\perp}D_1\right]$$

$$-\frac{S_T\cos\theta}{\sqrt{1-\sin^2\theta\sin^2\phi_s^{\ell}}}\sin(\phi_h^{\ell}+\phi_s^{\ell})F\left[\frac{\vec{h}\cdot\vec{k}_\perp}{M_h}h_1 H_1^{\perp}\right]\Big\}$$

$$= d\sigma_{UU} + d\sigma_{Siv} + d\sigma_{Col}$$

$$F[\omega f D] = \sum_a e_a^2 \int d^2\vec{p}_\perp d^2\vec{k}_\perp \delta^2(\vec{p}_\perp - \vec{k}_\perp - \frac{\vec{P}_{h\perp}}{z})\omega(\vec{p}_\perp, \vec{k}_\perp) f_a(x, \vec{p}_\perp^{\,2}) D_a(z, z^2\vec{k}_\perp^{\,2})$$

Conventional treatment

- Deconvolution

$$\mathcal{W} = \begin{cases} \frac{|P_{h\perp}|}{M_N} & : \text{Sivers} \\ \frac{|P_{h\perp}|}{M_h} & : \text{Collins} \end{cases}$$

$$\int d^2 P_{h\perp} \left(\left[\frac{|P_{h\perp}|}{M_h} \right] \cdot d\sigma_C \right) = -\frac{2\alpha^2}{sxy^2} A(y) \sum_q e_q^2 z h_1^q(x) H_1^{\perp(1)q}(z)$$

A factorized expression in x and z obtained

- Projection

$$\int d\phi \cdot \sin(\phi \pm \phi_s) \cdots = 0$$

$$\langle w \cdot \sin(\phi - \phi_s) \rangle_{UT} \propto d\sigma_{siv} \frac{1}{2} (2\pi)^2$$

$$\langle w \cdot \sin(\phi + \phi_s) \rangle_{UT} \propto d\sigma_{Col} \frac{1}{2} (2\pi)^2$$

- Why do we choose sin(Φ-Φs) as weighting function for Sivers effect, and sin(Φ+Φs) as weighting function for Collins effect.
- The choice of the weighting functions show a bias on a certain theory.

An universal way

J. She, Y. Mao, B.-Q. Ma, Phys. Lett. B 666, 355 (2008).

- The weighting functions are not put into use.
- Only the hadrons produced within a range, rather than the whole space are selected.

e.g., $-\frac{\pi}{4} \leq \phi_h \leq \frac{\pi}{4}$, left; $\frac{3\pi}{4} \leq \phi_h \leq \frac{5\pi}{4}$, right.

$$A_{LR} = \frac{1}{S_T} \frac{\int d\phi^\ell d\phi_h dP_{h\perp}^2 (d\sigma(\phi_S) - d\sigma(\phi_S + \pi))}{\int d\phi^\ell d\phi_h dP_{h\perp}^2 (d\sigma(\phi_S) + d\sigma(\phi_S + \pi))}$$

$$= \frac{1}{S_T} \frac{\int d\phi^\ell d\phi_h dP_{h\perp}^2 (d\sigma(\phi_h) - d\sigma(\phi_h + \pi))}{\int d\phi^\ell d\phi_h dP_{h\perp}^2 (d\sigma(\phi_h) + d\sigma(\phi_h + \pi))}$$

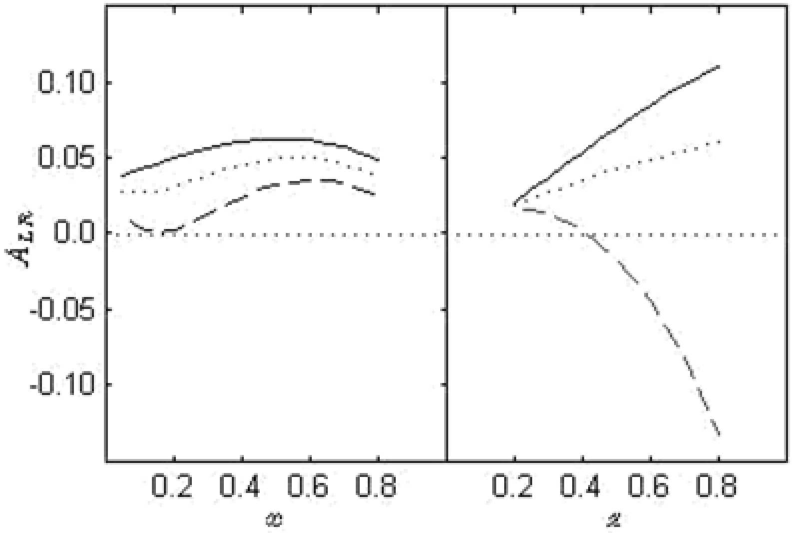
- Integral over Φ^1,

$$\frac{1}{2\pi}\int_0^{2\pi} d\phi^\ell \frac{\sin(\phi_h^\ell - \phi_s^\ell)}{(1-\sin^2\theta\sin^2\phi_s^\ell)^{3/2}} = \sin(\phi_h - \phi_s)(1+\frac{3}{4}\sin^2\theta + o(\sin^4\theta))$$

$$\frac{1}{2\pi}\int_0^{2\pi} d\phi^\ell \frac{\sin(\phi_h^\ell + \phi_s^\ell)}{(1-\sin^2\theta\sin^2\phi_s^\ell)^{3/2}} = -\sin(\phi_h - \phi_s)(\frac{3}{8}\sin^2\theta + o(\sin^4\theta))$$

Sivers effect is *o*(1), but other terms such as the Collins effect are *o*($\sin^2\theta$) So Sivers effect is dominant and other effects are suppressed.

- Unweighted Asymmetry



- only u and d quark are considered here

- We reanalyze the pions production extend our calculation on the kaons production using the latest parameterization which contain information of both valance and sea quarks.
- Collins effect is not known so clearly yet and is not considered in our analysis as it is strongly suppressed

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Sivers function

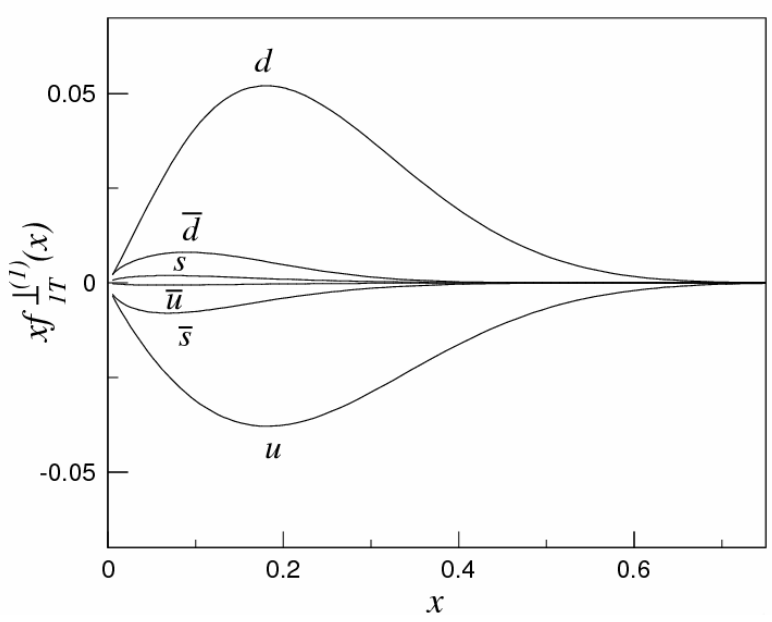
- Parameterization for Sivers function:

$$f_{1T}^{\perp q}(x, p_\perp^2) = -\frac{M_p}{p_\perp}\mathcal{N}_q(x) f_q(x) g(p_\perp^2) h(p_\perp^2),$$

$$\mathcal{N}_q(x) = N_q x_q^\alpha (1-x)_q^\beta \frac{(\alpha_q + \beta_q)^{(\alpha_q+\beta_q)}}{\alpha_q^{\alpha_q}\beta_q^{\beta_q}},$$

$$g(p_\perp^2) = \frac{e^{-p_\perp^2/\langle p_\perp^2\rangle}}{\pi\langle p_\perp^2\rangle}, \quad h(p_\perp^2) = \sqrt{2e}\frac{p_\perp}{M'}e^{-p_\perp^2/\langle M'^2\rangle}.$$

$N_u = 0.35^{+0.08}_{-0.08}$	$N_d = -0.90^{+0.43}_{-0.10}$	$N_s = -0.24^{+0.62}_{-0.50}$
$N_{\bar{u}} = 0.04^{+0.22}_{-0.24}$	$N_{\bar{d}} = -0.40^{+0.33}_{-0.44}$	$N_{\bar{s}} = 1^{+0}_{-0.0001}$
$\alpha_u = 0.73^{+0.72}_{-0.58}$	$\alpha_d = 1.08^{+0.82}_{-0.65}$	$\alpha_{sea} = 0.79^{+0.56}_{-0.47}$
$\beta = 3.46^{+4.87}_{-2.90}$	$M_1^2 = 0.34^{+0.30}_{-0.16}(GeV/c)^2$	

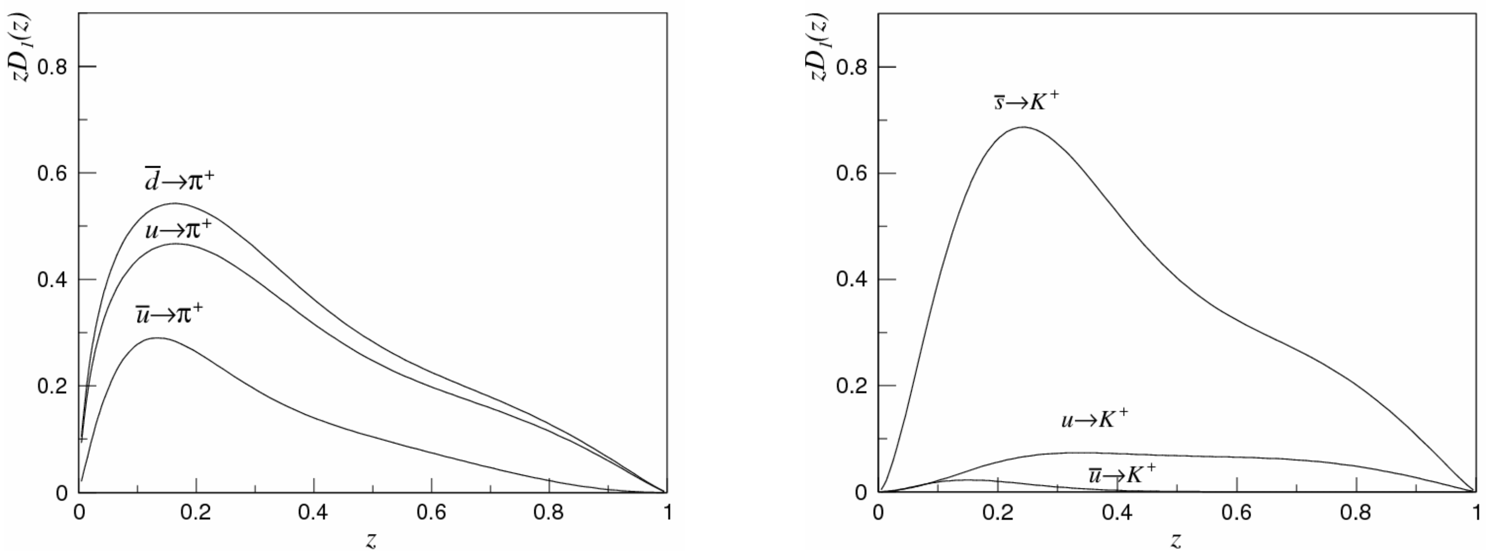


M. Anselmino et al., Eur. Phys. J. A 39 89 (2009).

Fragmentation function

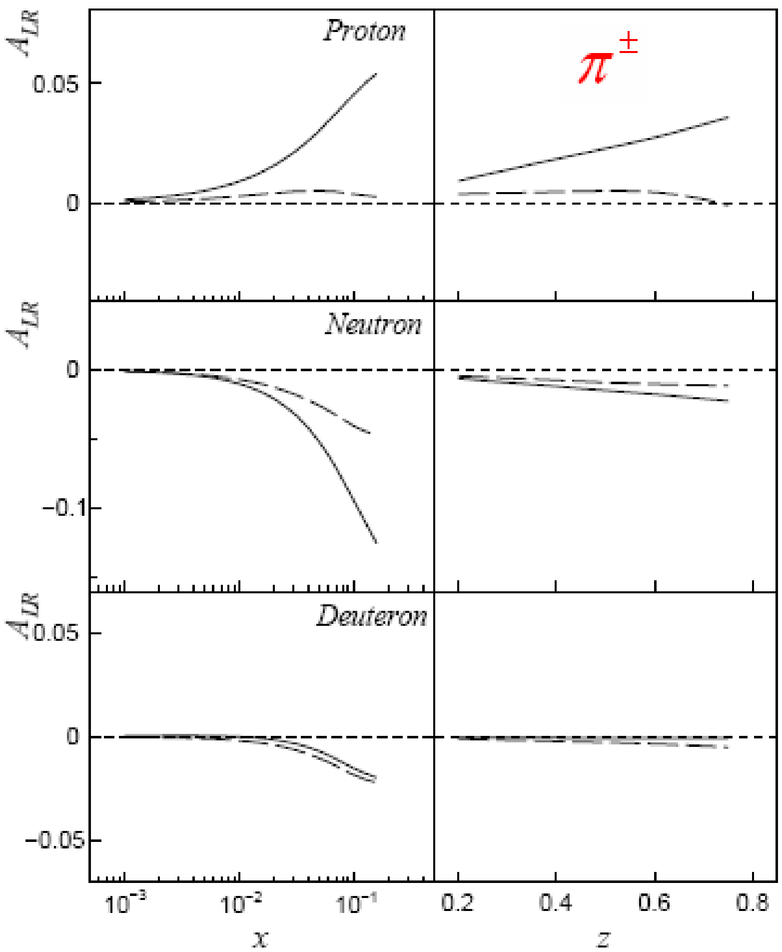
- Parameterization for fragmentation function:

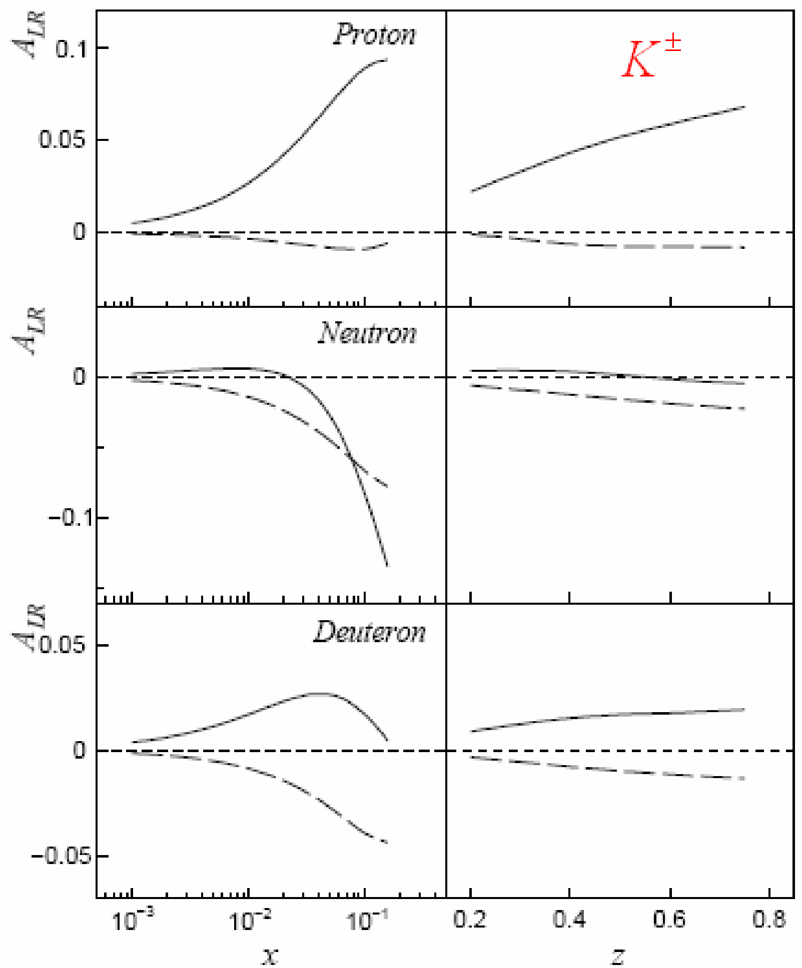
$$D_i^H(z,\mu_0) = \frac{N_i z^{\alpha_i}(1-z)^{\beta_i}[1+\gamma_i(1-z)^{\delta_i}]}{B[2+\alpha_i,\beta_i+1]+\gamma_i B[2+\alpha_i,\beta_i+\delta_i+1]},$$



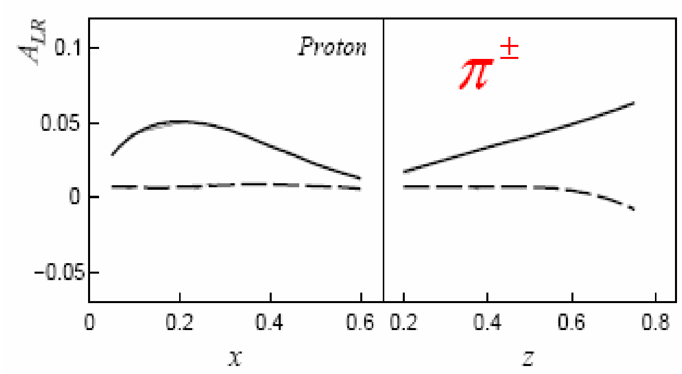
D. de Florian, R. Sassot, Phys. Rev. D 75, 114010 (2007).

Results on COMPASS kinematics

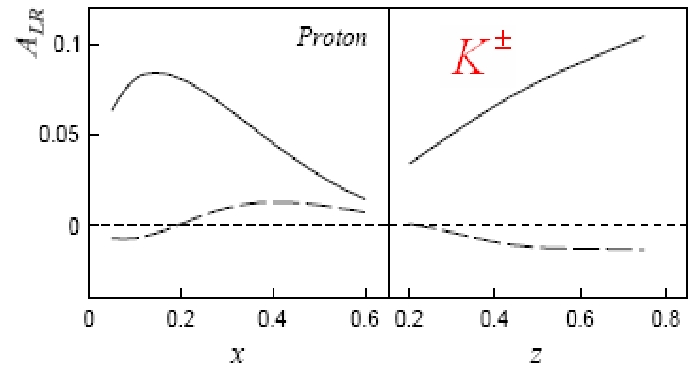




HERMES

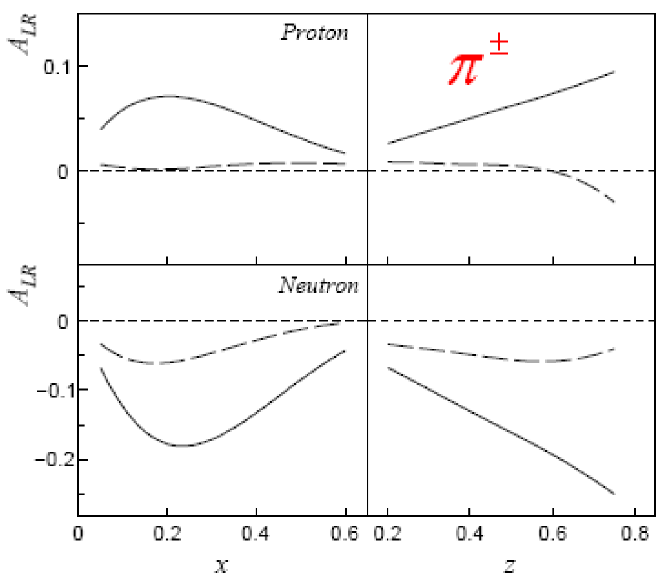


A_LR
Proton
π±
0.1
0.05
0
−0.05
0
0.2
0.4
0.6
0.2
0.4
0.6
0.8
x
z

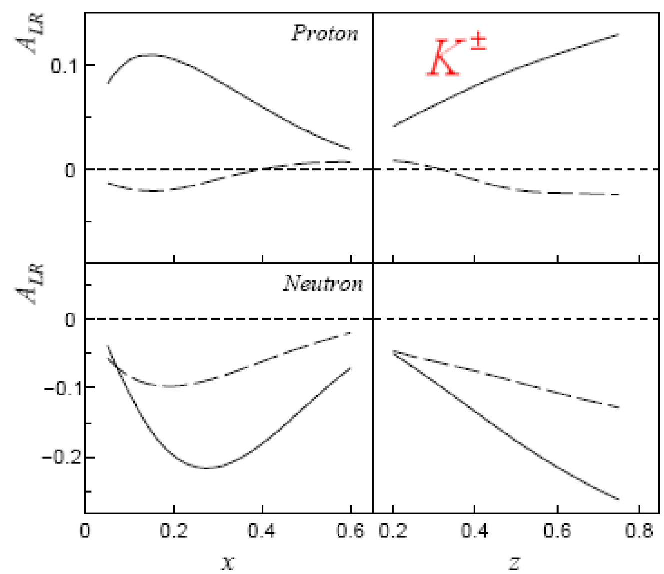


A_LR
Proton
K±
0.1
0.05
0
0
0.2
0.4
0.6
0.2
0.4
0.6
0.8
x
z

JLab



A_LR
Proton
π±
0.1
0
A_LR
Neutron
0
−0.1
−0.2
0
0.2
0.4
0.6
0.2
0.4
0.6
0.8
x
z



A_LR
Proton
K±
0.1
0
A_LR
Neutron
0
−0.1
−0.2
0
0.2
0.4
0.6
0.2
0.4
0.6
0.8
x
z

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Summary

- E704 method can be used in SIDIS process. Asymmetry can be obtained in this way.
- We provide the prediction for pions and kaons production on HERMES, JLab and COMPASS kinematics on different targets. Be caution that results for K^- production may not accurate enough.
- With the current understanding, Sivers effect dominant here, Collins effect is suppressed.

We suggest relevant collaboration apply data analysis under this way to provide more information for theoretical studies.