Selected results from the HERMES experiment

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(for the HERMES Collaboration)

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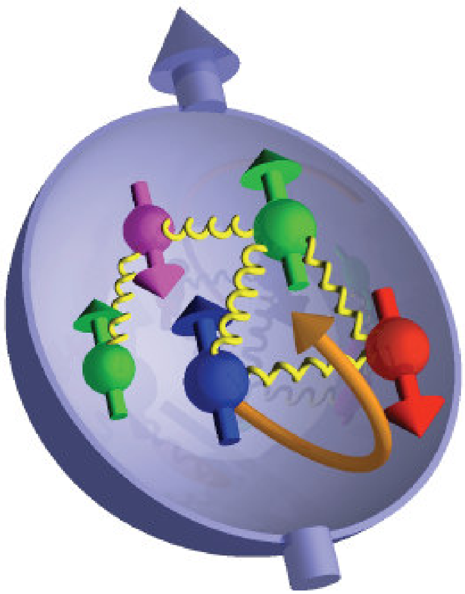
The nucleon spin structure



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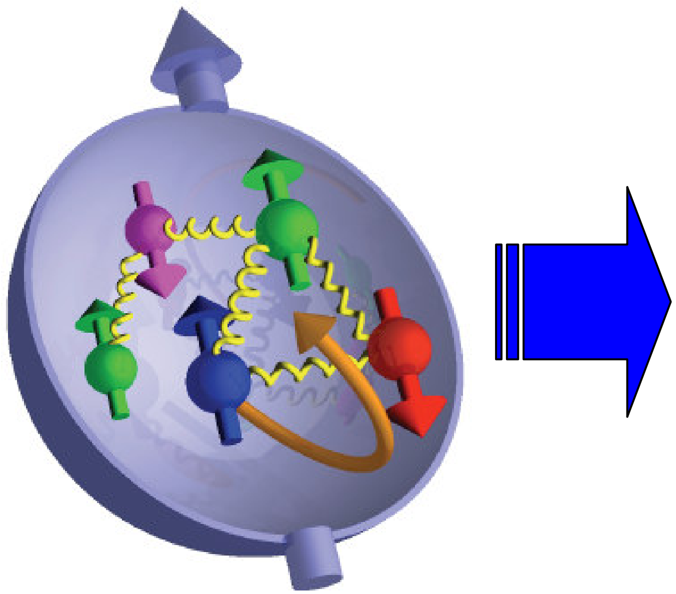
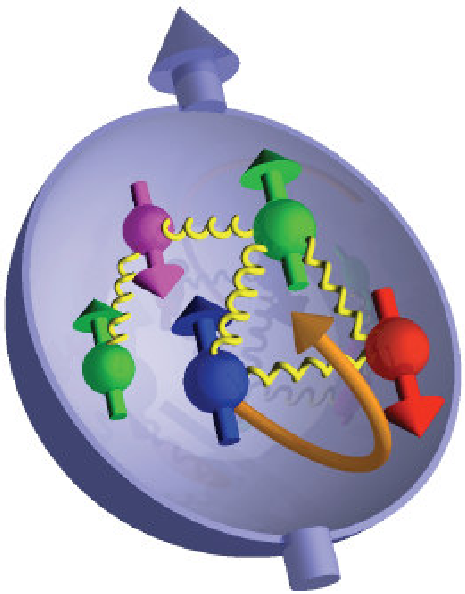


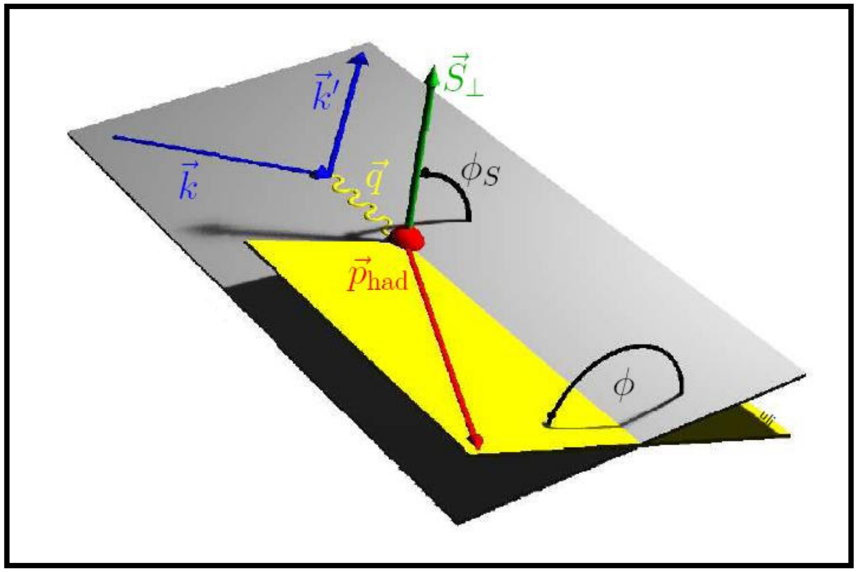
		quark		
		U	**L**	**T**
nucleon	**U**	f_1		
	L		g_1 -	
	T			h_1 -

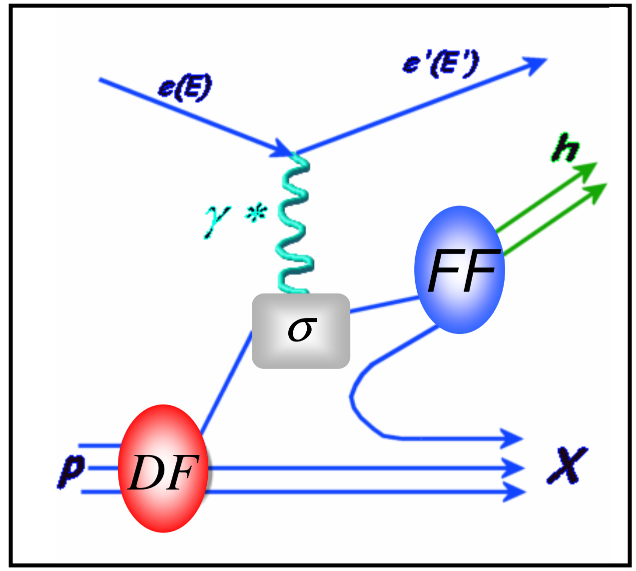
The nucleon spin structure



		quark		
		U	L	T
nucleon	U	f_1		$h_1^{\perp}$ -
	L		g_1 -	$h_{1L}^{\perp}$ -
	T	$f_{1T}^{\perp}$ -	$g_{1T}^{\perp}$ -	h_1 - $h_{1T}^{\perp}$ -

Can be studied by measuring azimuthal asymmetries in SIDIS

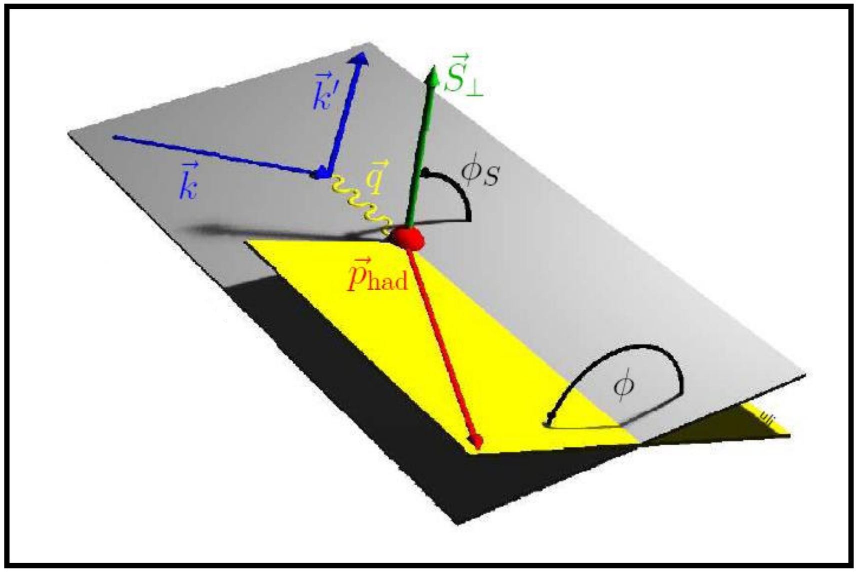


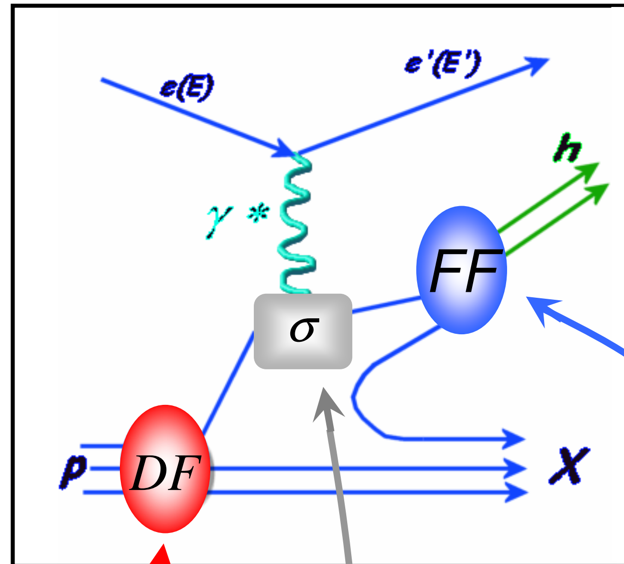


$$\sigma^{ep\to ehX}$$

↓

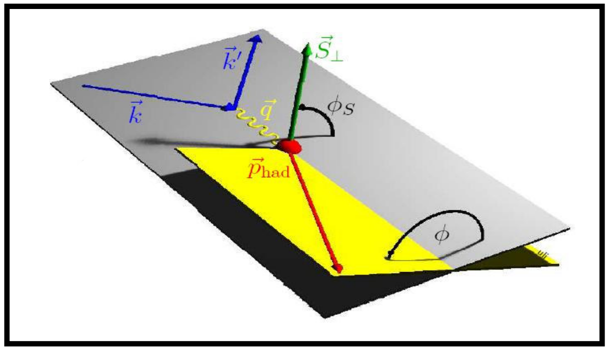
exhibits asymmetries in the azimuthal angles ϕ and ϕ_S

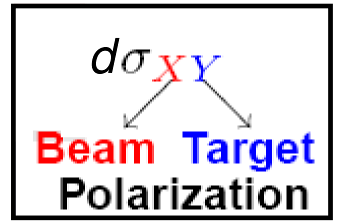




Factorization theorem: $\sigma^{ep\to ehX} = \sum_q DF \otimes \sigma^{eq\to eq} \otimes FF$

exhibits asymmetries in the azimuthal angles ϕ and ϕ_S





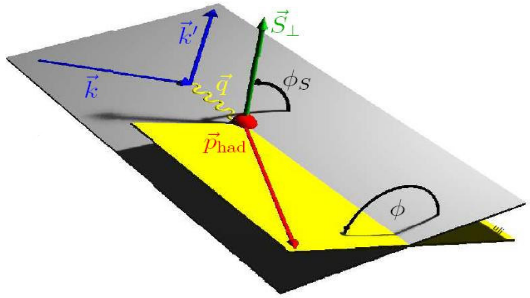
$$d\sigma = d\sigma^0_{UU} + \cos 2\phi \, d\sigma^1_{UU} + \frac{1}{Q}\cos\phi \, d\sigma^2_{UU} + \lambda_e \frac{1}{Q}\sin\phi \, d\sigma^3_{LU}$$

$$+ S_L \left\{ \sin 2\phi \, d\sigma^4_{UL} + \frac{1}{Q}\sin\phi \, d\sigma^5_{UL} + \lambda_e \left[d\sigma^6_{LL} + \frac{1}{Q}\cos\phi \, d\sigma^7_{LL} \right] \right\}$$

$$+ S_T \Big\{ \sin(\phi - \phi_S) \; d\sigma^8_{UT} + \sin(\phi + \phi_S) \; d\sigma^9_{UT} + \sin(3\phi - \phi_S) \; d\sigma^{10}_{UT}$$

$$+ \frac{1}{Q}\sin(2\phi - \phi_S) \; d\sigma^{11}_{UT} + \frac{1}{Q}\sin\phi_S d\sigma^{12}_{UT}$$

$$+ \lambda_e \left[\cos(\phi - \phi_S) \; d\sigma^{13}_{LT} + \frac{1}{Q}\cos\phi_S d\sigma^{14}_{LT} + \frac{1}{Q}\cos(2\phi - \phi_S) d\sigma^{15}_{LT} \right] \Big\}$$



8 leading-twist terms

$d\sigma_{XY}$

Beam Target

Polarization

$$d\sigma = d\sigma^0_{UU} + \cos 2\phi\, d\sigma^1_{UU} + \frac{1}{Q}\cos\phi\, d\sigma^2_{UU} + \lambda_e \frac{1}{Q}\sin\phi\, d\sigma^3_{LU}$$

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$$+ S_T\left\{\sin(\phi-\phi_S)\ d\sigma^8_{UT} + \sin(\phi+\phi_S)\ d\sigma^9_{UT} + \sin(3\phi-\phi_S)\ d\sigma^{10}_{UT}\right.$$

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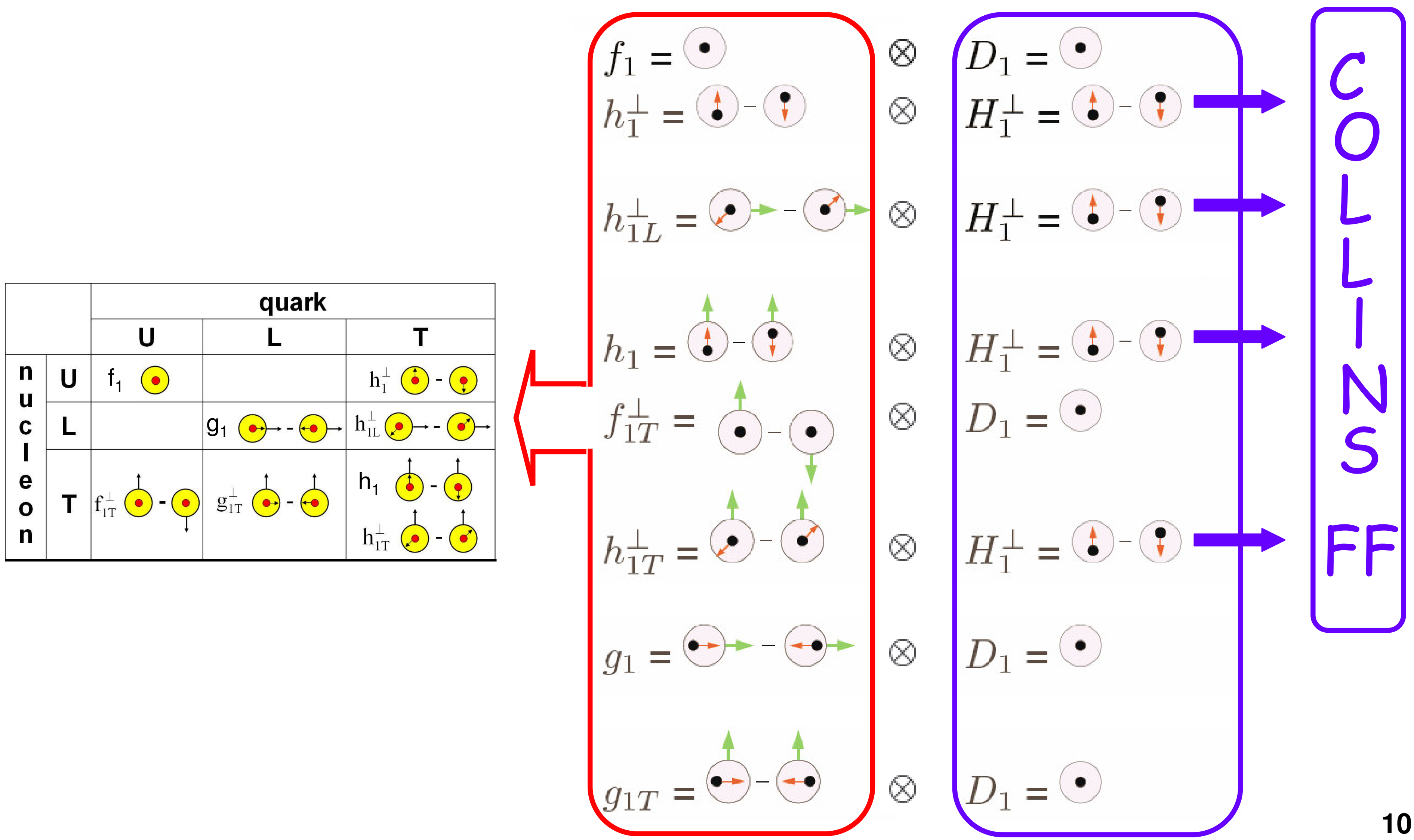
$$\left.+ \lambda_e\left[\cos(\phi-\phi_S)\ d\sigma^{13}_{LT} + \frac{1}{Q}\cos\phi_S d\sigma^{14}_{LT} + \frac{1}{Q}\cos(2\phi-\phi_S) d\sigma^{15}_{LT}\right]\right\}$$

$$\sigma^{ep\to ehX}_{BT} = \sum_q DF \otimes \sigma^{eq\to eq} \otimes FF$$

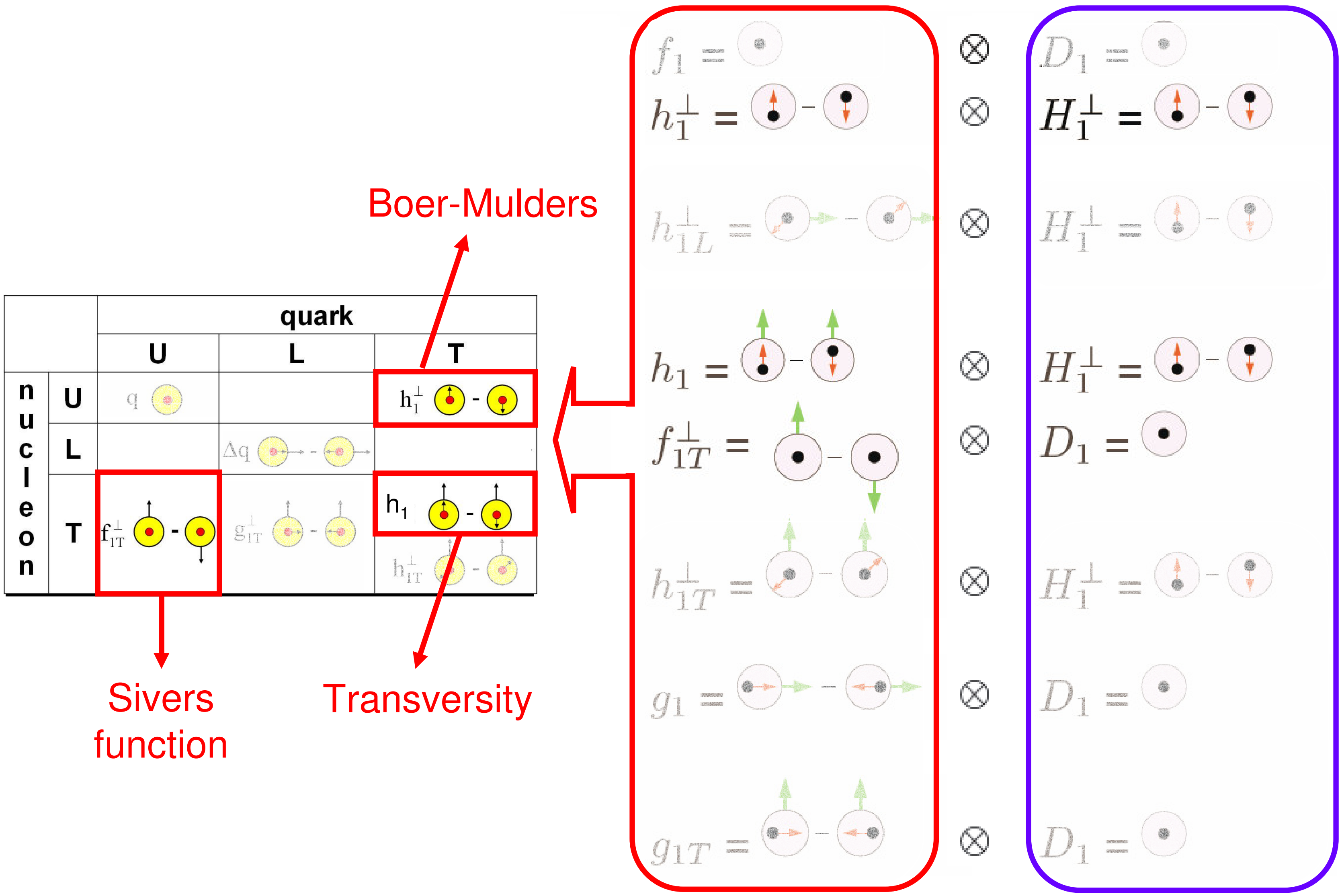
Beam pol. **Target pol.**

			DF		FF
1	UU	1	$f_1 =$	$\otimes$	$D_1 =$
2		$\cos(2\phi_h^l)$	$h_1^\perp =$	$\otimes$	$H_1^\perp =$
3	UL	$\sin(2\phi_h^l)$	$h_{1L}^\perp =$	$\otimes$	$H_1^\perp =$
4	UT	$\sin(\phi_h^l + \phi_S^l)$	$h_1 =$	$\otimes$	$H_1^\perp =$
5		$\sin(\phi_h^l - \phi_S^l)$	$f_{1T}^\perp =$	$\otimes$	$D_1 =$
6		$\sin(3\phi_h^l - \phi_S^l)$	$h_{1T}^\perp =$	$\otimes$	$H_1^\perp =$
7	LL	1	$g_1 =$	$\otimes$	$D_1 =$
8	LT	$\cos(\phi_h^l - \phi_S^l)$	$g_{1T} =$	$\otimes$	$D_1 =$

$$\sigma^{ep\to ehX}_{\mathbf{BT}} = \sum_q DF \otimes \sigma^{eq\to eq} \otimes FF$$

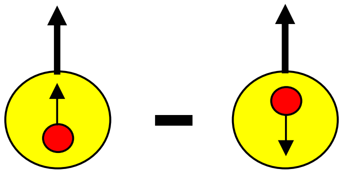


$$\sigma^{ep\to ehX}_{\mathbf{BT}} = \sum_q DF \otimes \sigma^{eq\to eq} \otimes FF$$



Transversity

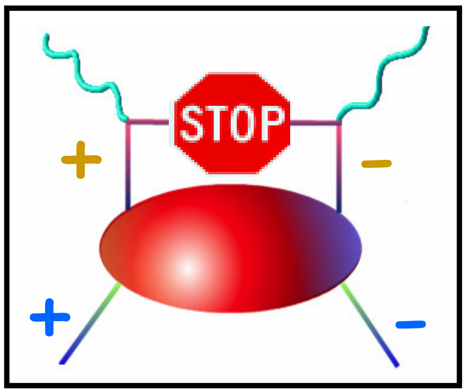
$$\delta q(x, Q^2) = q^{\uparrow} - q^{\downarrow}$$



Difference of probabilities to find quarks with spin aligned or anti-aligned to the nucleon transverse spin

Chiral-odd

requires spin flip of the quark



Not measurable in inclusive DIS

Unmeasured for long time!

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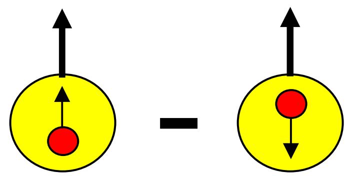

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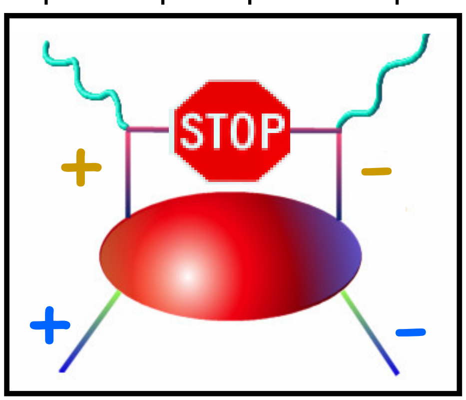

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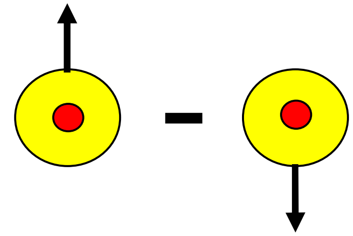
Sivers function

$f_{1T}^{\perp q}(x, p_T^2)$



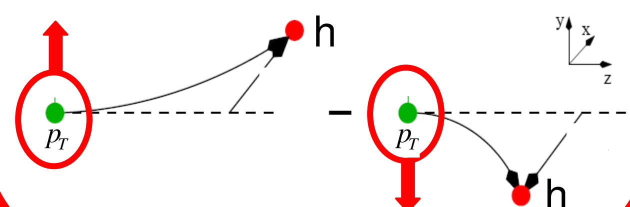
Chiral-even T- odd

Probability to find unpolarized quarks with transverse momentum p_T in a transversely pol. nucleon.

describes spin-orbit correlation in the nucleon

Requires **non-zero orbital angular momentum!**

azimuthal asymmetries in the direction of the outgoing hadrons.



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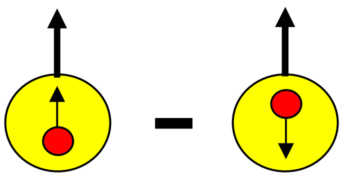
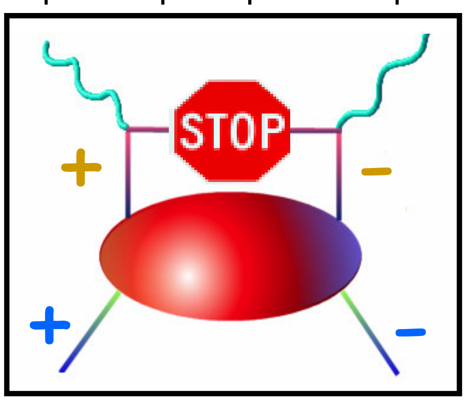


Difference of probabilities to find quarks with spin aligned or anti-aligned to the nucleon transverse spin

Chiral-odd

requires spin flip of the quark



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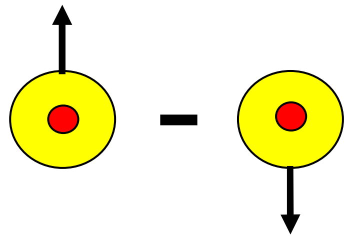

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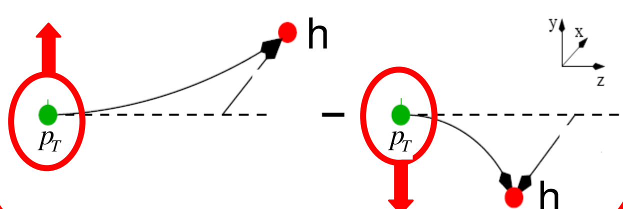


Collins function

$H_1^{\perp}(z, k_T^2)$

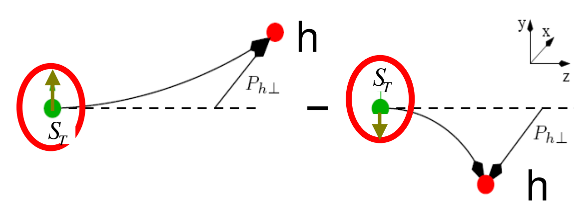
Chiral-odd T- odd

Correlation between transverse spin of the fragmenting quark and transverse momentum of the produced hadron

describes spin-orbit correlation in fragmentation

Analyzer of fragmenting quark's transv. polarization

azimuthal asymmetries in the direction of the outgoing hadrons.



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$$d\sigma^{Sivers}_{UT} \propto |S_T| \; \sin(\phi - \phi_S) \cdot \sum_q e_q^2 I\left[\frac{\vec{p}_T \cdot \hat{P}_{h\perp}}{M_h} f_{1T}^{\perp q}(x, p_T^2) \otimes D_1^q(z, k_T^2) \right]$$

$$d\sigma^{Collins}_{UT} \propto |S_T| \; \sin(\phi + \phi_S) \cdot \sum_q e_q^2 I\left[\frac{\vec{k}_T \cdot \hat{P}_{h\perp}}{M_h} h_1(x, p_T^2) \otimes H_1^{\perp q}(z, k_T^2) \right]$$

$I[...]$ =convolution integral over intrinsic ($\vec{p}_T$) and fragmentation ($\vec{k}_T$) transverse momenta

$$d\sigma = d\sigma_{UU}^{0} + \cos 2\phi\, d\sigma_{UU}^{1} + \frac{1}{Q}\cos\phi\, d\sigma_{UU}^{2} + \lambda_e \frac{1}{Q}\sin\phi\, d\sigma_{LU}^{3}$$

$$+ S_L \left\{ \sin 2\phi\, d\sigma_{UL}^{4} + \frac{1}{Q}\sin\phi\, d\sigma_{UL}^{5} + \lambda_e \left[d\sigma_{LL}^{6} + \frac{1}{Q}\cos\phi\, d\sigma_{LL}^{7} \right] \right\}$$

$$+ S_T \left\{ \boxed{\sin(\phi-\phi_S)\; d\sigma_{UT}^{8}} + \boxed{\sin(\phi+\phi_S)\; d\sigma_{UT}^{9}} + \sin(3\phi-\phi_S)\; d\sigma_{UT}^{10} \right.$$

$$+ \frac{1}{Q}\sin(2\phi-\phi_S)\; d\sigma_{UT}^{11} + \frac{1}{Q}\sin\phi_S\, d\sigma_{UT}^{12}$$

$$\left. + \lambda_e \left[\cos(\phi-\phi_S)\; d\sigma_{LT}^{13} + \frac{1}{Q}\cos\phi_S\, d\sigma_{LT}^{14} + \frac{1}{Q}\cos(2\phi-\phi_S)\, d\sigma_{LT}^{15} \right] \right\}$$

$$d\sigma_{UT}^{Sivers} \propto |S_T| \sin(\phi-\phi_S) \cdot \sum_q e_q^2 I\left[\frac{\vec{p}_T \cdot \hat{P}_{h\perp}}{M_h} f_{1T}^{\perp q}(x, p_T^2) \otimes D_1^q(z, k_T^2) \right]$$

Two distinctive signatures if $\phi_S \neq 0$ (transversely polarized target)

$$d\sigma_{UT}^{Collins} \propto |S_T| \sin(\phi+\phi_S) \cdot \sum_q e_q^2 I\left[\frac{\vec{k}_T \cdot \hat{P}_{h\perp}}{M_h} h_1(x, p_T^2) \otimes H_1^{\perp q}(z, k_T^2) \right]$$

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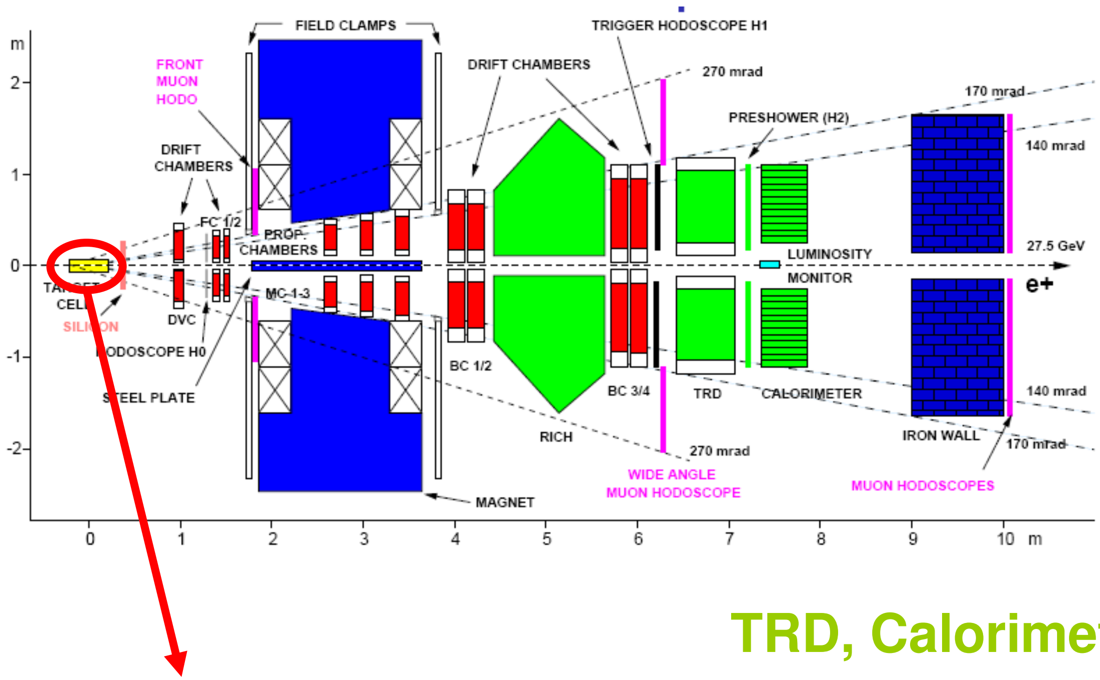
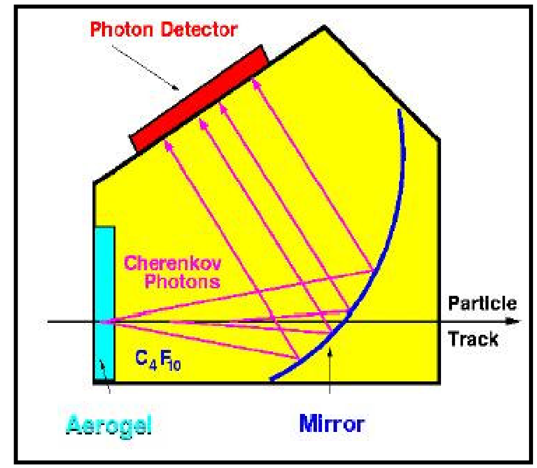
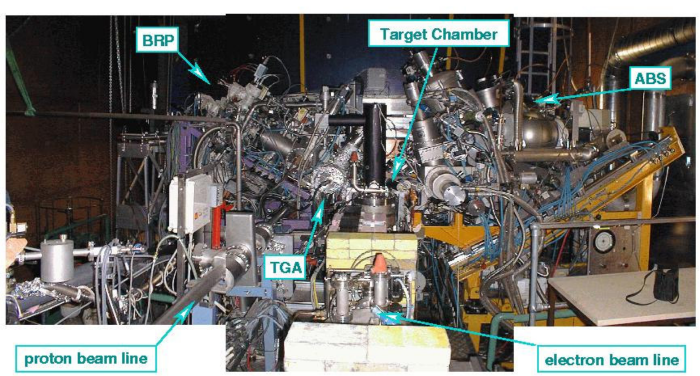
hermes

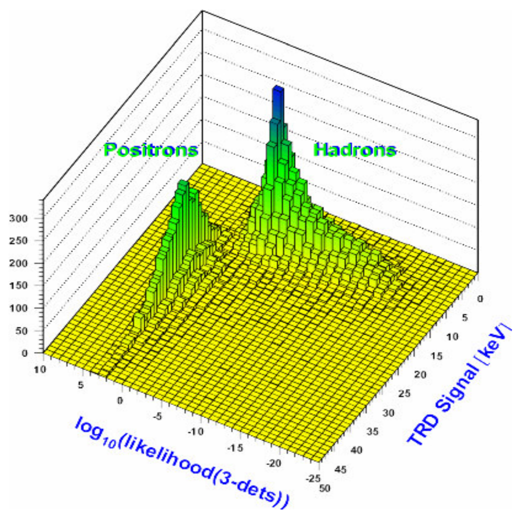




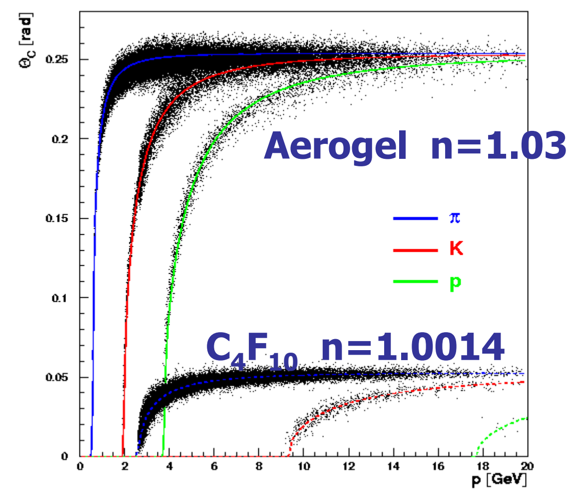


TRD, Calorimeter, preshower, RICH:

lepton-hadron > 98%



hadron separation



π ~ 98%, K ~ 88% , P ~ 85%

Full HERMES transverse data set (2002-2005)

(transversely polarized hydrogen target: $\langle P \rangle \approx 73\,\%$)

	inclusive DIS	semi-inclusive DIS
Four momentum transfer	$Q^2 > 1\,\mathrm{GeV}^2$	$Q^2 > 1\,\mathrm{GeV}^2$
Squared mass of final hadronic state	$W^2 > 4\,\mathrm{GeV}^2$	$W^2 > 10\,\mathrm{GeV}^2$
Fractional energy transfer	$0.1 < y < 0.95$	$y < 0.95$
Bjorken scaling variable	$0.023 < x < 0.4$	$0.023 < x < 0.4$
Virtual_photon – hadron angle		$\theta_{\gamma^* h} > 0.02\,\mathrm{rad}$
Hadron momentum		$2\,\mathrm{GeV} < P_h < 15\,\mathrm{GeV}$
Energy fraction		$0.2 < z < 0.7$

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The selected SIDIS events are used to extract the Collins and Sivers amplitudes through a Maximum Likelihood fit using the PDF:

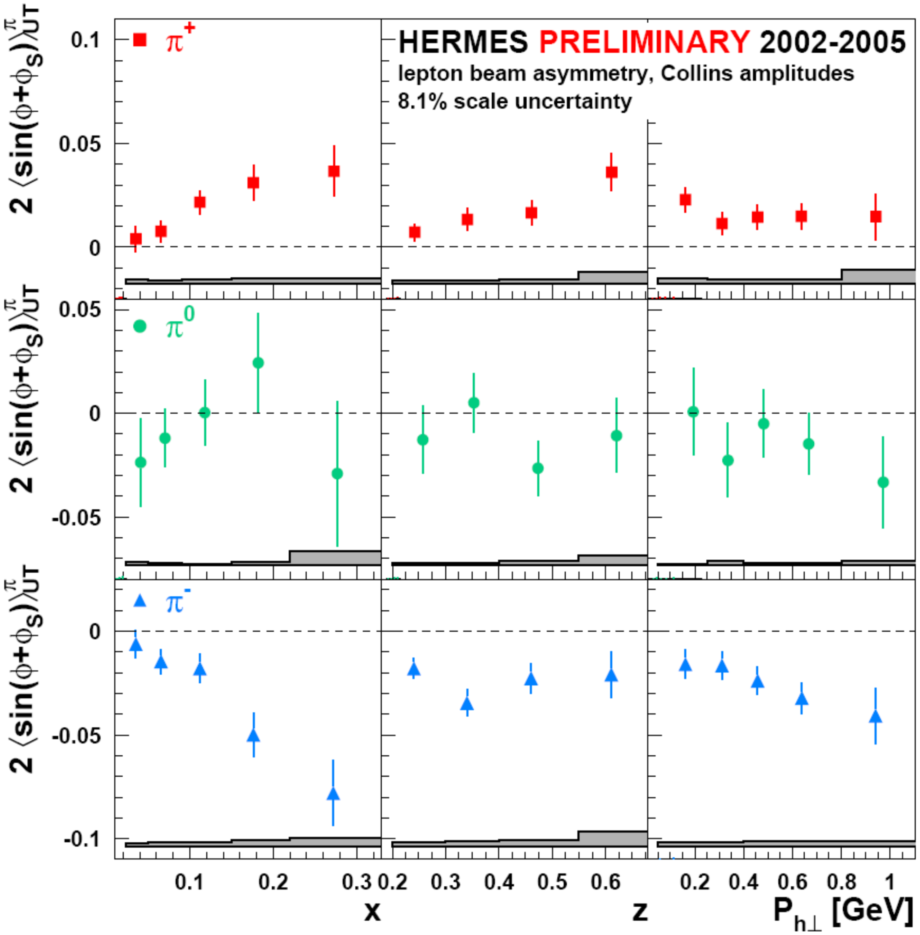
$$L = \prod_i (F_i)^{w_i}$$

$$F_i\left(\langle\sin(\phi\pm\phi_S)\rangle_{UT}^h, P_t, \phi, \phi_S\right) \propto 1 + P_t\Big[2\langle\sin(\phi+\phi_S)\rangle_{UT}^h \sin(\phi+\phi_S) + 2\langle\sin(\phi-\phi_S)\rangle_{UT}^h \sin(\phi-\phi_S)$$

$$+ 2\langle\sin(\phi_S)\rangle_{UT}^h \sin(\phi_S) + 2\langle\sin(3\phi-\phi_S)\rangle_{UT}^h \sin(3\phi-\phi_S) + 2\langle\sin(2\phi-\phi_S)\rangle_{UT}^h \sin(2\phi-\phi_S)\Big]$$

Results and interpretation

Collins moments for pions (2002-2005)



- positive amplitude for π^+
- ~ 0 amplitude for π^0
- negative amplitude for π^-

$$\begin{cases} u \Rightarrow \pi^+ \; ; \; d \Rightarrow \pi^- \; (fav) \\ u \Rightarrow \pi^- \; ; \; d \Rightarrow \pi^+ \; (unfav) \end{cases}$$

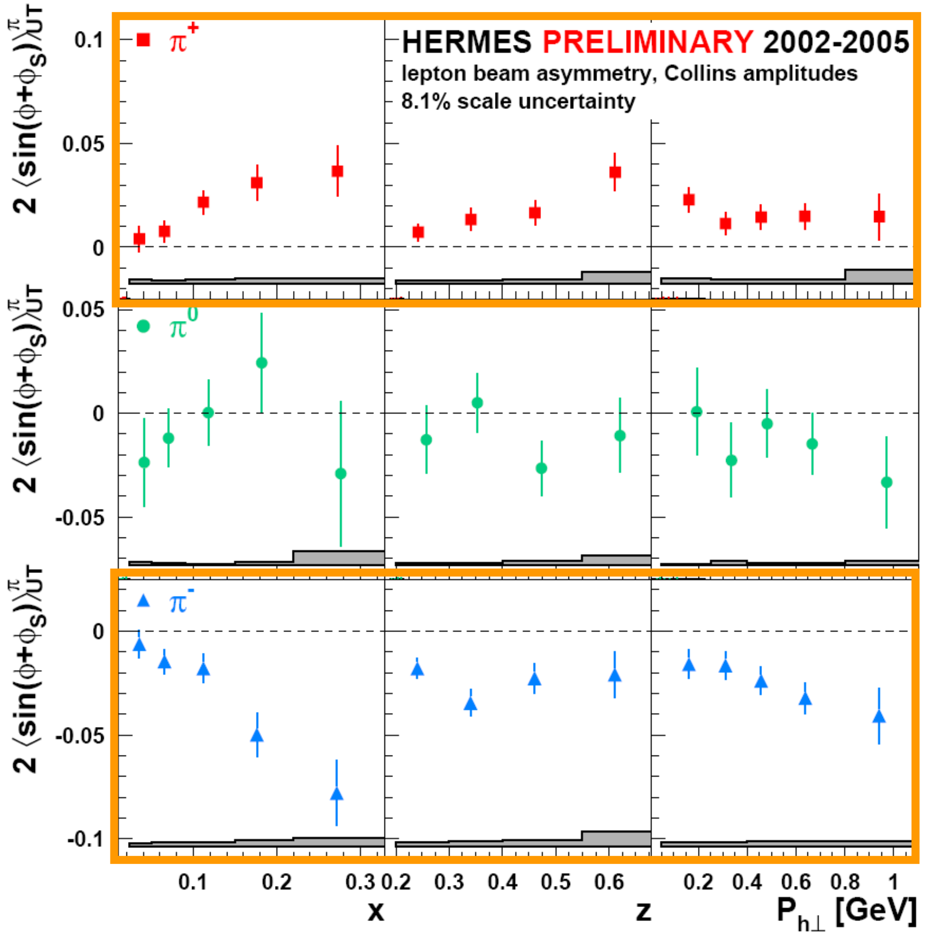
the large negative π^- amplitude suggests disfavored Collins function with opposite sign:

$$H_1^{\perp,\text{unfav}}(z) \approx -H_1^{\perp,\text{fav}}(z)$$

→ measurement at e^+e^- collider machines

$$\propto I[\,h_1(x) H_1^{\perp q}(z)]$$

Collins moments for pions (2002-2005)



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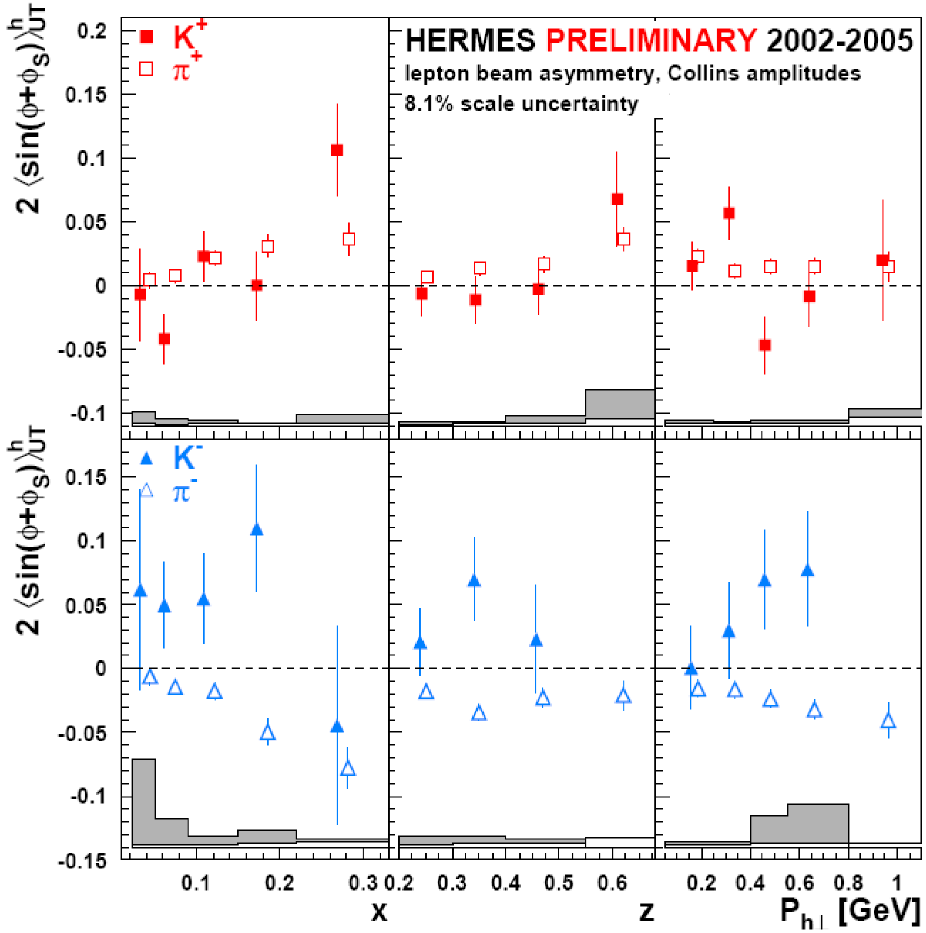
→ measurement at e^+e^- collider machines

$$\propto I[h_1(x) H_1^{\perp q}(z)] \neq 0$$

Transversity & Collins FF ≠ 0

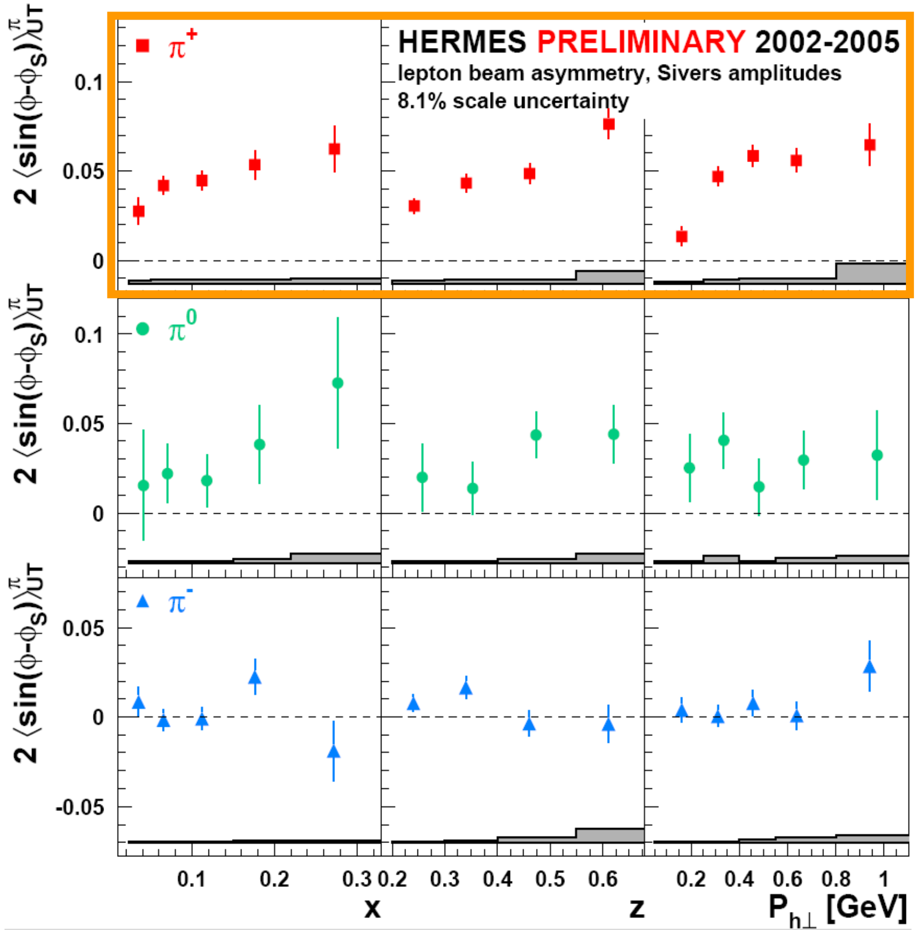
Collins moments: Pion-kaon comparison



- K^+ and π^+ amplitudes consistent (u-quark dominance)

- K^- and π^- amplitudes with opposite sign
(but $K^-(\bar{u}s)$ originates from fragmentation of sea quarks)

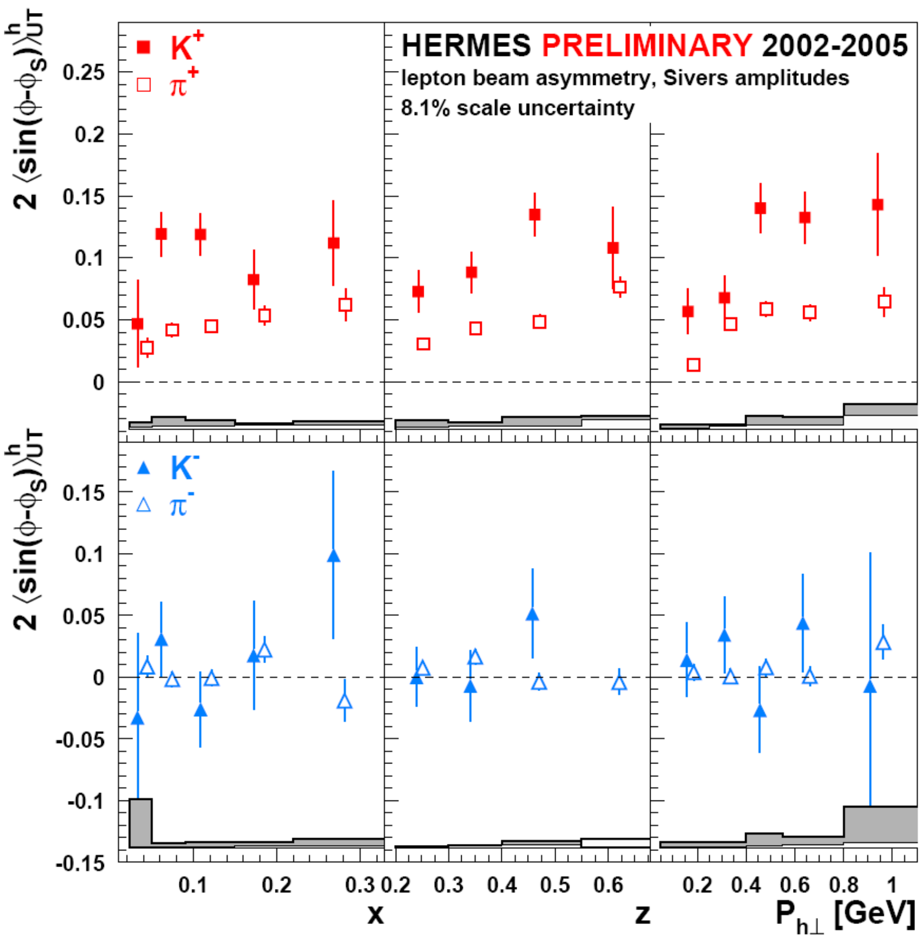
Sivers moments for pions (2002-2005)



- positive amplitude for π^+
- positive amplitude for π^0
- amplitude ~ 0 for π^-

$\propto I[f_{1T}^{\perp q}(x) D_1^q(z)] \neq 0$ ⇒ **Sivers function ≠ 0** ⇒ $L_q \neq 0$

Sivers moments: Pion-kaon comparison



- **K+ amplitude is larger than for π+** conflicts with usual expectations based on u-quark dominance

$$\pi^+ \equiv (u, \bar{d}) \qquad K^+ \equiv (u, \bar{s})$$

suggests substantial magnitudes of the Sivers function for the sea quarks

- Both K^- and π^- amplitudes are consistent with zero

The extraction of the Distribution Functions

$$\langle \sin(\phi+\phi_S) \rangle_{UT}^{h} = \frac{\int d\phi_S d^2\vec{P}_{h\perp} \sin(\phi+\phi_S)\; d\sigma_{UT}}{\int d\phi_S d^2\vec{P}_{h\perp} d\sigma_{UU}} \propto \mathbf{I}\left[\frac{\vec{k}_T\cdot\hat{P}_{h\perp}}{M_h} h_1(x,p_T^2) H_1^{\perp q}(z,k_T^2)\right]$$

Convolution integral on transverse momenta p_T and k_T

Experiment: Extraction of h_1 requires a full integration over $P_{h\perp}$ (from 0 to ∞)

Due to the partial experimental coverage in $P_{h\perp}$ acceptance effects need to be well under control.

Theory: difficult to solve ⟹ Gaussian ansatz

$$h_1(x,p_T^2) \approx \frac{h_1(x)}{\pi\langle p_T^2(x)\rangle} e^{-\frac{p_T^2}{\langle p_T^2(x)\rangle}} \qquad H_1^{\perp q}(z,k_T^2) \approx \frac{H_1^{\perp q}(z)}{\pi\langle k_T^2(z)\rangle} e^{-\frac{k_T^2}{\langle k_T^2(z)\rangle}}$$

(extraction assumption-dependent)

Extraction of transversity and Sivers function form global analyses

$$A_{UT}^{\sin(\phi+\phi_S)} \propto h_1(x) \otimes H_1^{\perp q}(z)$$

hermes: $lp \to l' hX$

COMPASS: $ld \to l' hX$

BELLE: $e^+e^- \to h_1 h_2 X$

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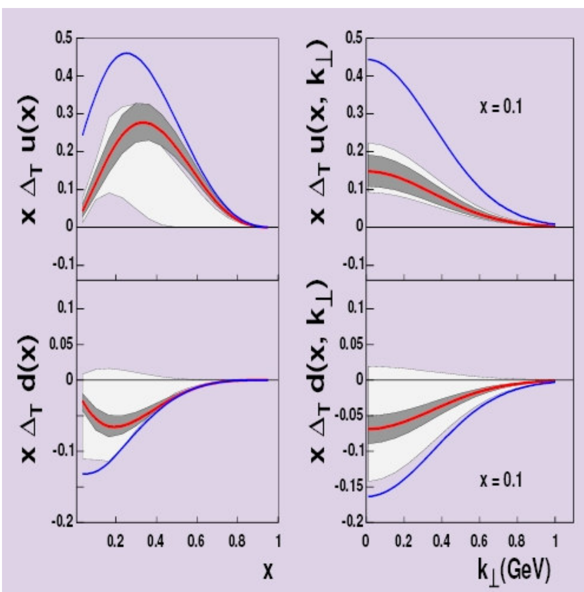
First extraction of Transversity!



Anselmino et al. Phys. Rev. D 75 (2007)

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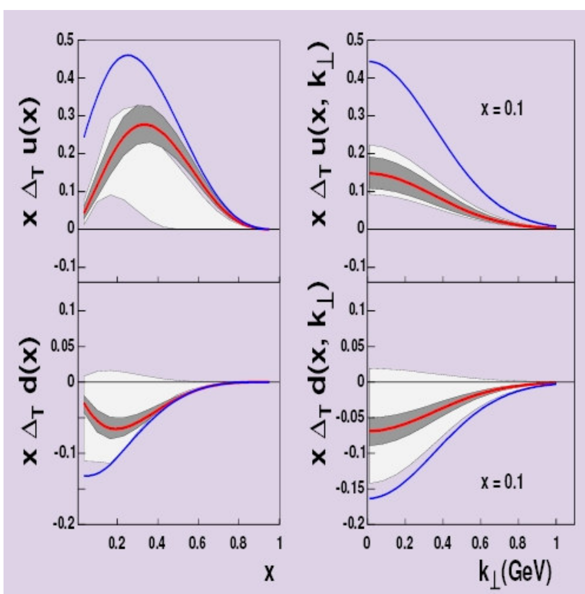

Anselmino et al. Phys. Rev. D 75 (2007)

$$A_{UT}^{\sin(\phi-\phi_S)} \propto f_{1,T}^{\perp}(x) \otimes D_1^q(z)$$

Known

hermes $lp \to l'hX$

COMPASS $ld \to l'hX$

Extraction of transversity and Sivers function form global analyses

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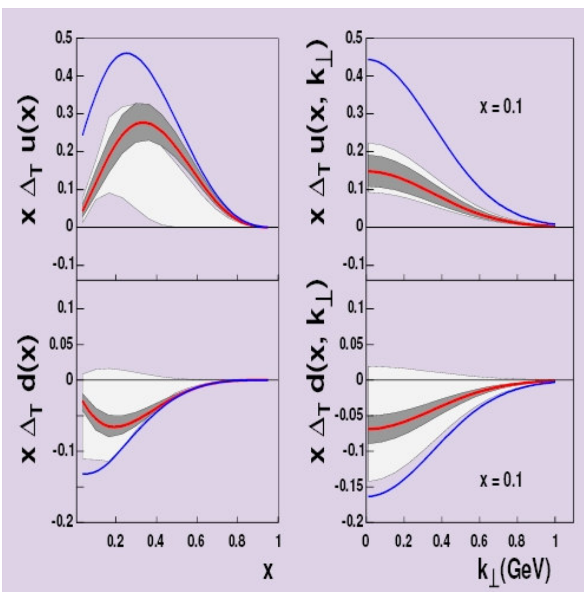

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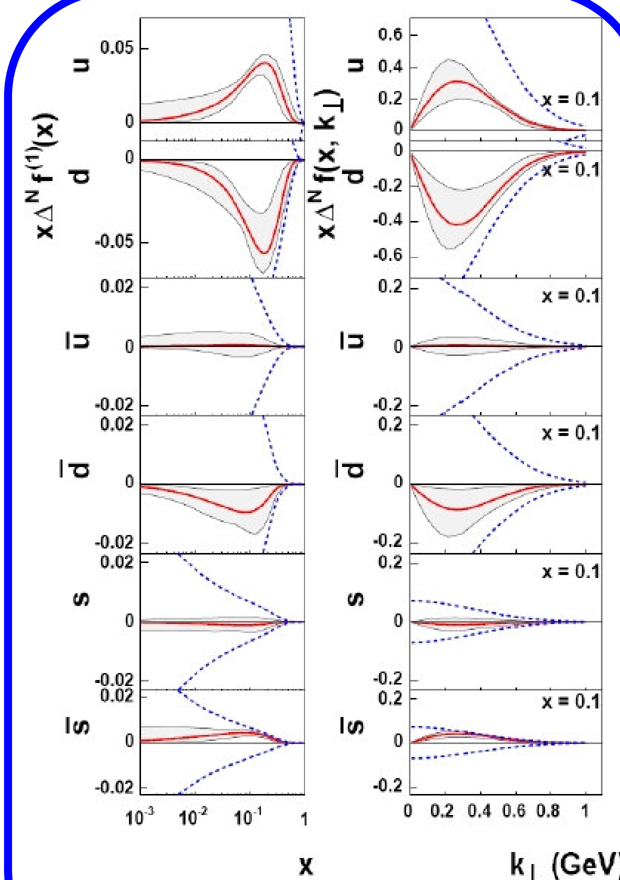
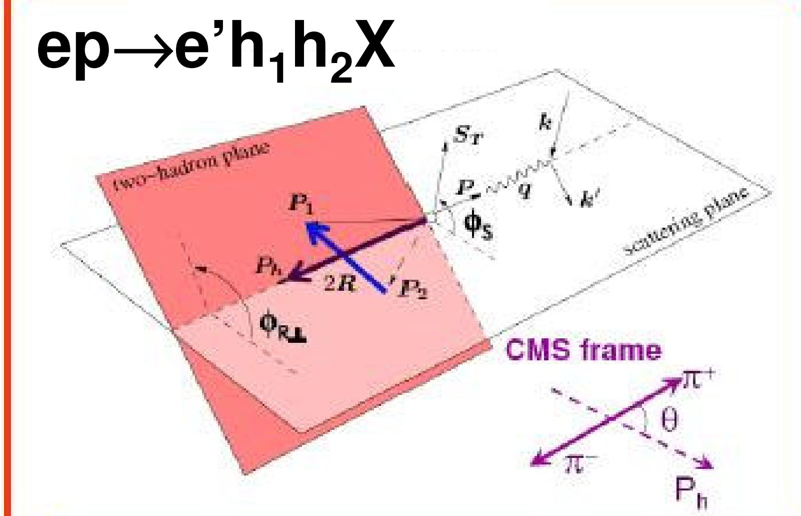


Anselmino et al. Eur.Phys.J.A39 (2009)

An alternative channel to access transversity



$$\sigma_{UT} \propto S_T \sin\theta \sin(\phi_{R\perp} + \phi_S) \sum_q e_q^2 h_1 H_{1,q}^{\triangleleft}$$

Interference FF

(does not depend on quark transv. momentum)

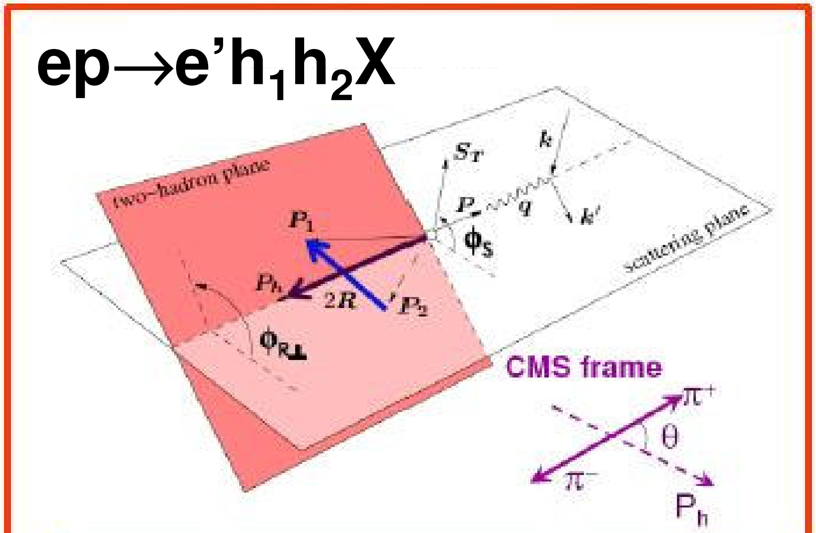
Chiral-odd T- odd

Correlation between transverse spin of the fragmenting quark and the relative orbital angular momentum of the hadron pair.

Describes Spin-orbit correlation in fragmentation

azimuthal asymmetries in the direction of the outgoing hadron pairs.

An alternative channel to access transversity



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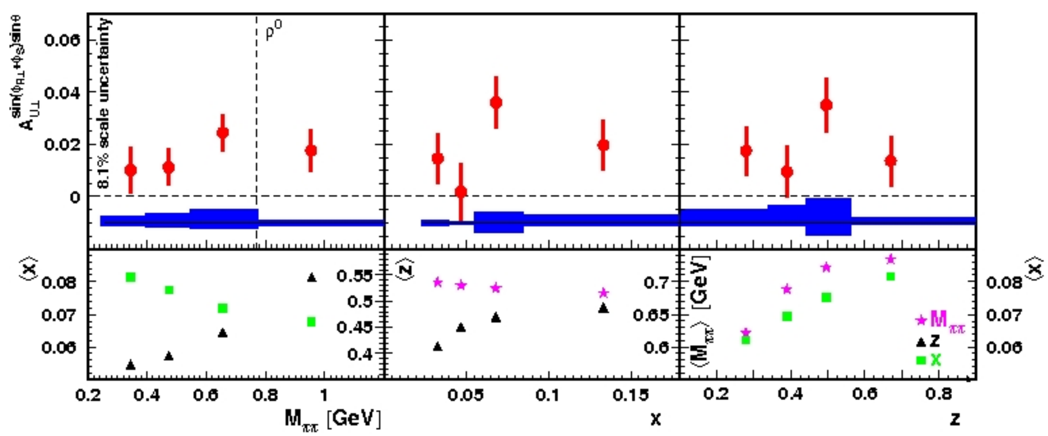
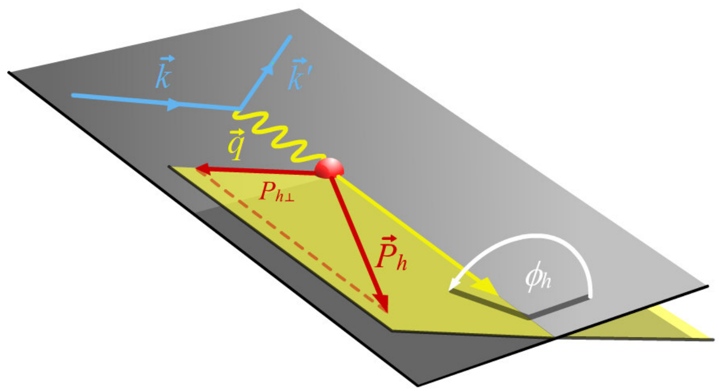


- Independent way to access transversity
- No complications due to convolution integral → interpretation more transparent
- ...but limited statistical power (v.r.t. single-hadron SSAs)
- published on JHEP 06 (2008) 017

The unpolarized cross section

$$d\sigma = d\sigma_{UU}^{0} + \cos 2\phi \, d\sigma_{UU}^{\cos 2\phi} + \frac{1}{Q}\cos\phi \, d\sigma_{UU}^{\cos\phi} + \text{ [polarized part]}$$



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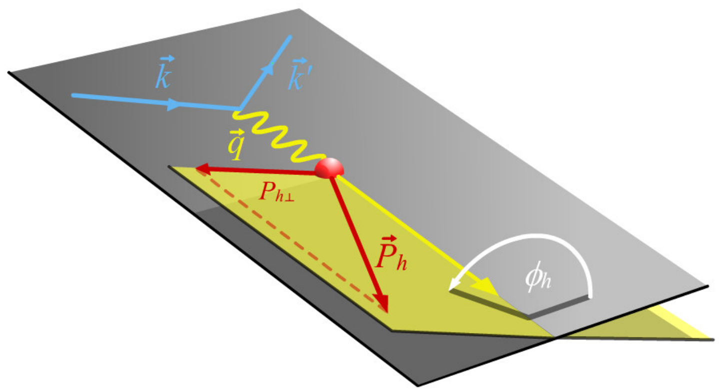

Twist-2: $d\sigma_{UU}^{Cos2\phi} \propto \cos 2\phi \cdot \sum_q e_q^2 I\left[\frac{2(\hat{P}_{h\perp}\cdot\vec{k}_T)(\hat{P}_{h\perp}\cdot\vec{p}_T) - \vec{k}_T\cdot\vec{p}_T}{MM_h} h_1^{\perp}\otimes H_1^{\perp}\right]$

Boer-Mulders effect

$I[\ldots]$ =convolution integral over intrinsic $(\vec{p}_T)$ and fragmentation $(\vec{k}_T)$ transverse momenta

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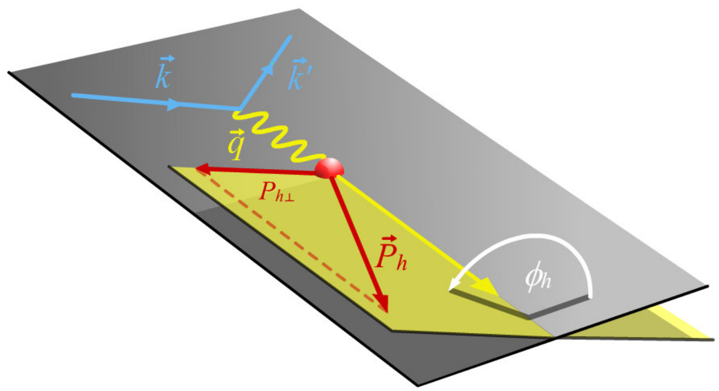

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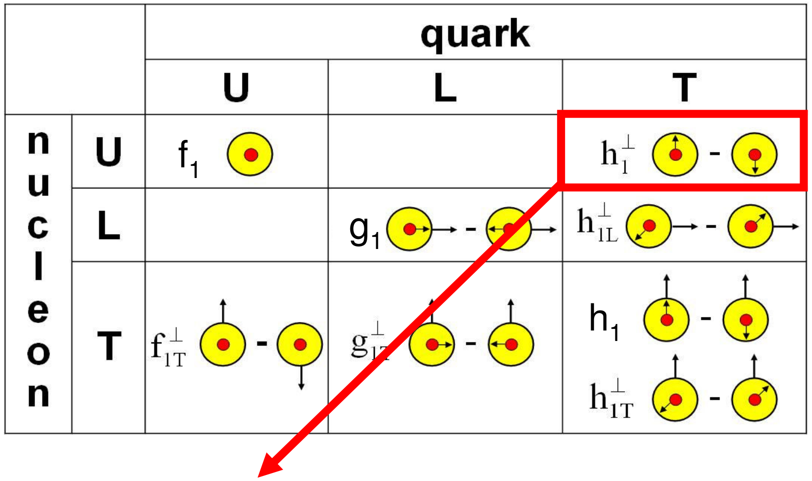
Boer-Mulders effect

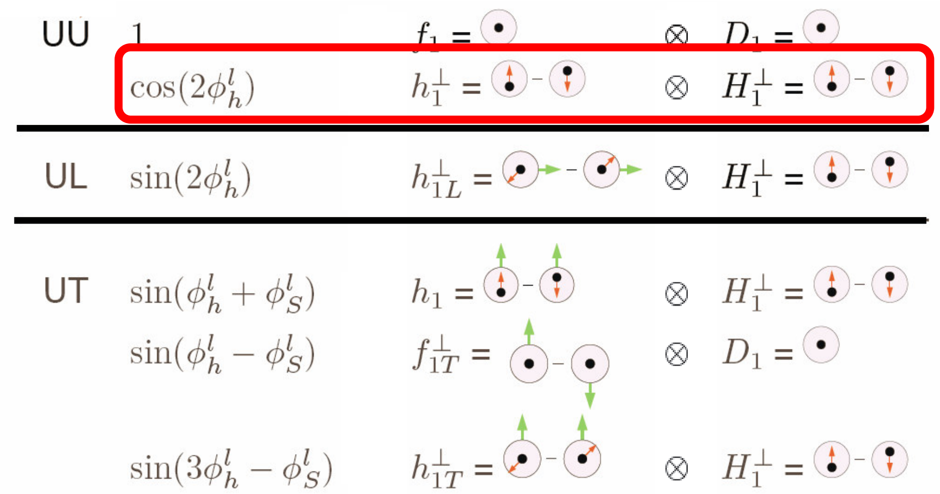
Cahn effect

Twist-3: $$d\sigma_{UU}^{Cos\phi} \propto \cos\phi \cdot \sum_q e_q^2 \frac{2M}{Q} I\left[-\frac{(\hat{P}_{h\perp}\cdot\vec{p}_T)}{M_h} x h_1^{\perp}\otimes H_1^{\perp q} - \frac{(\hat{P}_{h\perp}\cdot\vec{k}_T)}{M} x f_1\otimes D_1 + \ldots\right]$$

$I[\ldots]$ =convolution integral over intrinsic $(\vec{p}_T)$ and fragmentation $(\vec{k}_T)$ transverse momenta

Boer-Mulders function (unpolarized cross section)





Boer-Mulders function: correlation between transverse momentum and transverse spin of the quark in an unpolarized nucleon

Boer-Mulders function (unpolarized cross section)

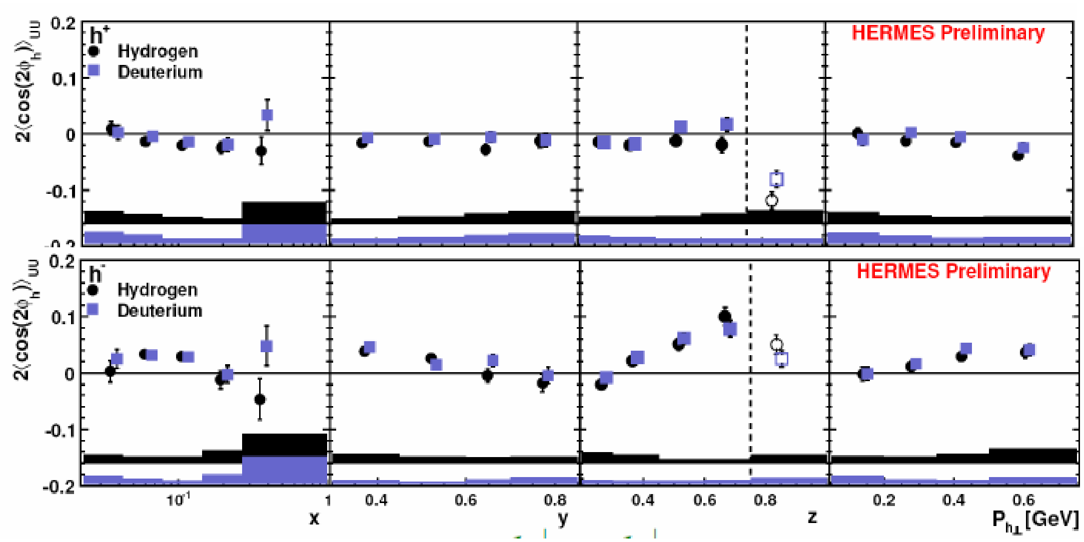
nucleon \ quark	U	L	T
U	f_1		$h_1^{\perp}$
L		g_1	$h_{1L}^{\perp}$
T	$f_{1T}^{\perp}$	$g_{1T}^{\perp}$	h_1, $h_{1T}^{\perp}$

UU	1	f_1	$\otimes$	D_1
	$\cos(2\phi_h^l)$	$h_1^{\perp}$	$\otimes$	$H_1^{\perp}$
UL	$\sin(2\phi_h^l)$	$h_{1L}^{\perp}$	$\otimes$	$H_1^{\perp}$
UT	$\sin(\phi_h^l + \phi_S^l)$	h_1	$\otimes$	$H_1^{\perp}$
	$\sin(\phi_h^l - \phi_S^l)$	$f_{1T}^{\perp}$	$\otimes$	D_1
	$\sin(3\phi_h^l - \phi_S^l)$	$h_{1T}^{\perp}$	$\otimes$	$H_1^{\perp}$

Boer-Mulders function: correlation between transverse momentum and transverse spin of the quark in an unpolarized nucleon

Accessible through azimuthal asymmetries in SIDIS with unpolarized hydrogen and deuterium targets

$\cos(2\phi)$ amplitudes



Boer-Mulders function (unpolarized cross section)

		quark U	quark L	quark T
nucleon	U	f_1		$h_1^\perp$
	L		g_1	$h_{1L}^\perp$
	T	$f_{1T}^\perp$	$g_{1T}^\perp$	h_1, $h_{1T}^\perp$

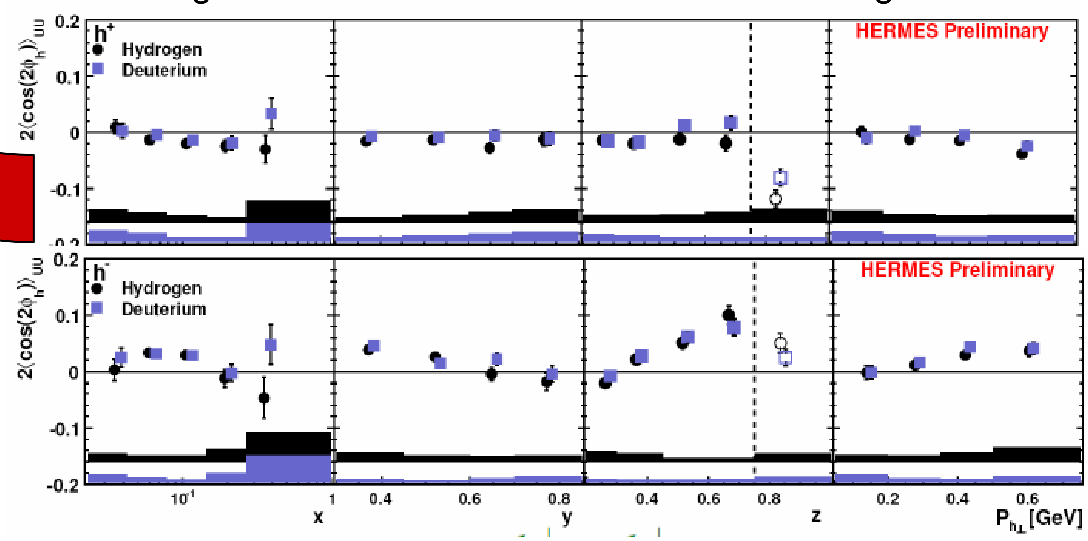
UU	1	$f_1 =$	$\otimes$	$D_1 =$
	$\cos(2\phi_h^l)$	$h_1^\perp =$	$\otimes$	$H_1^\perp =$
UL	$\sin(2\phi_h^l)$	$h_{1L}^\perp =$	$\otimes$	$H_1^\perp =$
UT	$\sin(\phi_h^l + \phi_S^l)$	$h_1 =$	$\otimes$	$H_1^\perp =$
	$\sin(\phi_h^l - \phi_S^l)$	$f_{1T}^\perp =$	$\otimes$	$D_1 =$
	$\sin(3\phi_h^l - \phi_S^l)$	$h_{1T}^\perp =$	$\otimes$	$H_1^\perp =$

Boer-Mulders function: correlation between transverse momentum and transverse spin of the quark in an unpolarized nucleon

Accessible through azimuthal asymmetries in SIDIS with unpolarized hydrogen and deuterium targets

cos(2ϕ) amplitudes

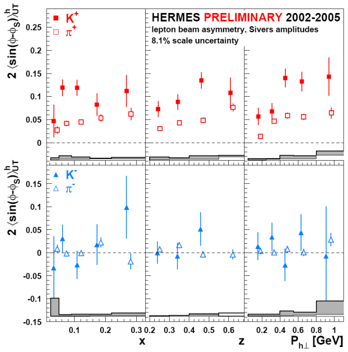
- analysis based on a multidimensional unfolding of data to correct for acceptance, smearing and QED effects
- amplitudes ≠ 0 → Boer-Mulders function non-zero!
- amplitudes of opposite sign for hadrons of opposite sign
- no significant differences between H and D targets

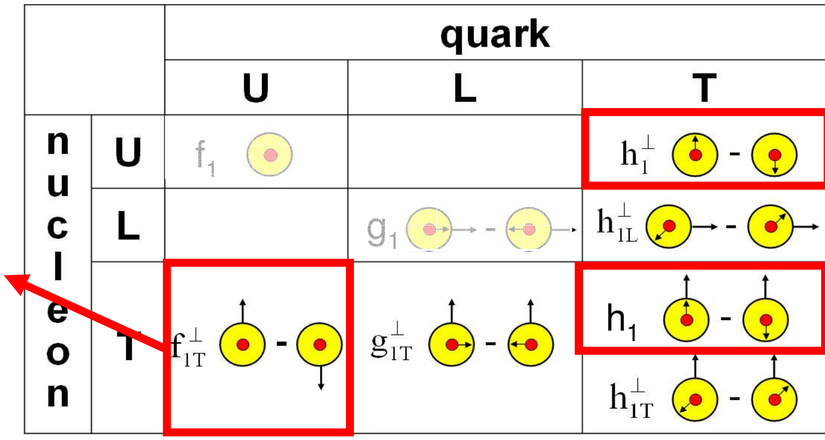


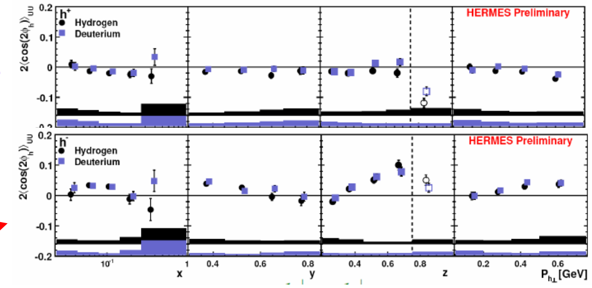
The transverse structure of the nucleon

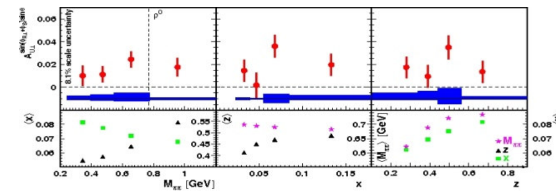
		quark		
		U	L	T
nucleon	U	f_1		$h_1^{\perp}$ -
	L		g_1 -	$h_{1L}^{\perp}$ -
	T	$f_{1T}^{\perp}$ -	$g_{1T}^{\perp}$ -	h_1 - $h_{1T}^{\perp}$ -

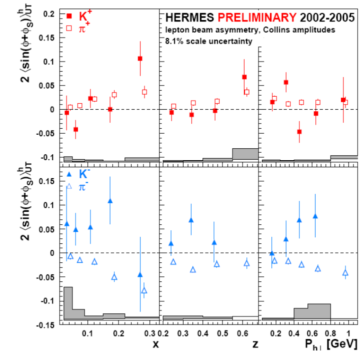
The transverse structure of the nucleon



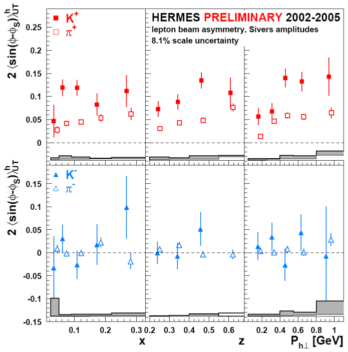


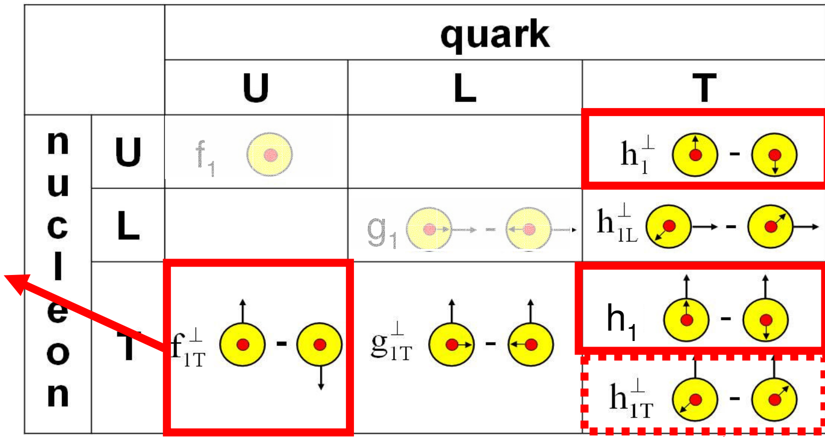


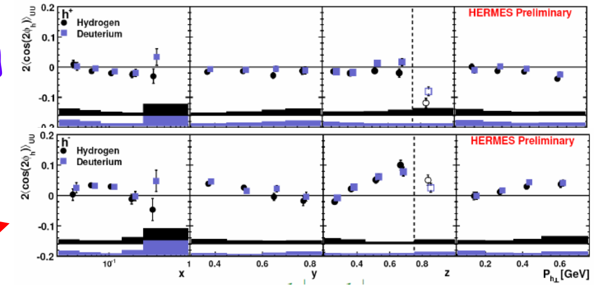


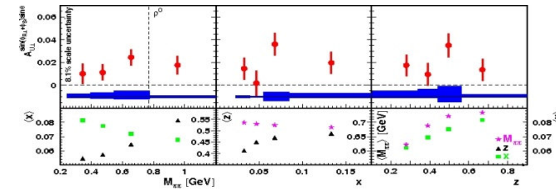


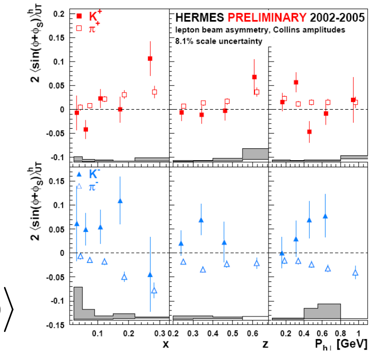
The transverse structure of the nucleon











Pretzelosity
(details in talk of Efremov)

Future plans:

- extraction of additional azimuthal modulations: $\langle \sin(3\phi - \phi_S) \rangle$, $\langle \sin(\phi_S) \rangle$, $\langle \sin(2\phi - \phi_S) \rangle$
- extraction of "$P_{h\perp}$**-weighted**" Collins and Sivers amplitudes
  - model-independent interpretation in terms of DF and FF
    - Extraction of the Sivers function with method of *purities*
- extraction of $\langle \cos(\phi) \rangle$, $\langle \cos(2\phi) \rangle$ for identified hadrons
  - full statistics (+ 5 Million SIDIS events for H e D targets)
  - new binning

Conclusions

- **significant Collins amplitudes observed for π-mesons**

$\rightarrow$ enabled first extraction of transversity

- **significant Sivers amplitudes observed for π^+ and K^+**

$\rightarrow$ clear evidence of non-zero Sivers function
$\rightarrow$ (indirect) evidence for non-zero quark orbital angular momentum

- Current extractions of transversity and Sivers function based on unweighted moments (need Gaussian ansatz)
- Assumpion-free extractions can be achieved in the future from $P_{h\perp}$-weighted moments.

- **significant di-hadron amplitudes observed**

$\rightarrow$ clear evidence of non-zero Interference Fragmentation Function
$\rightarrow$ more transparent interpretation in terms of DF and FF (no convol. integral)

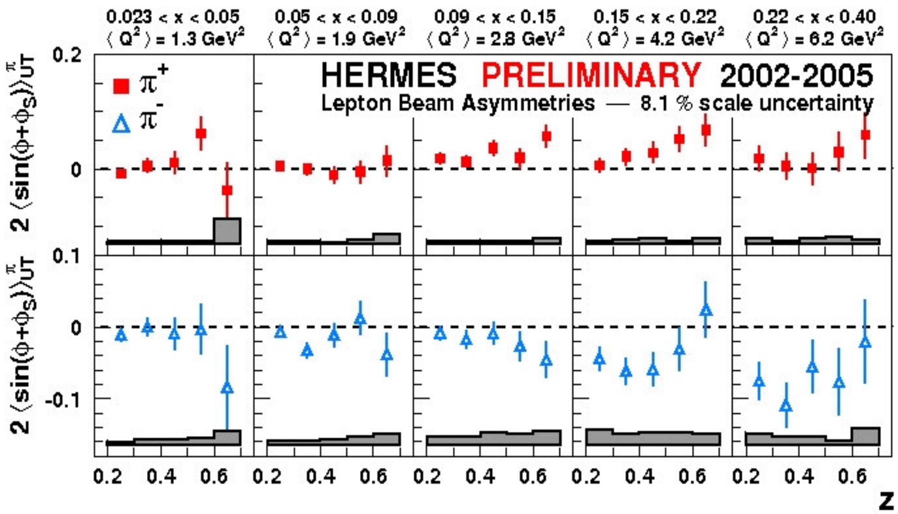
- **Non-zero Boer-Mulders effect observed for h^+ and h^-**

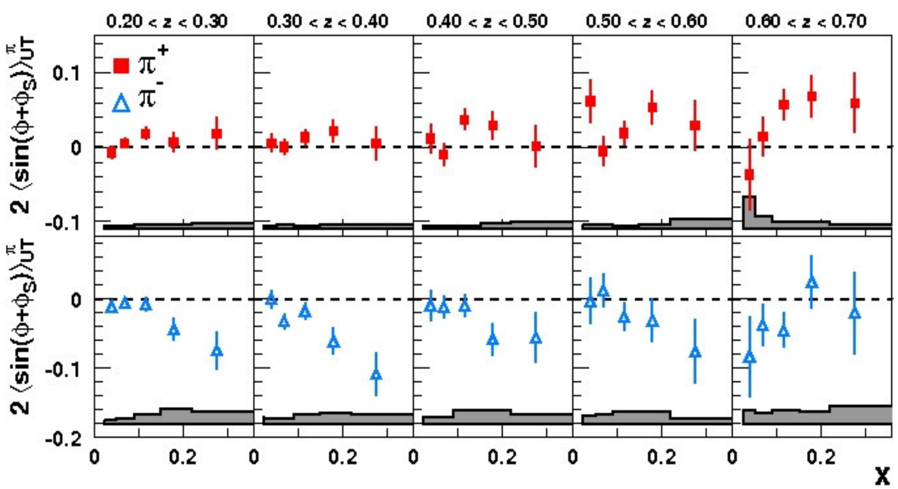
$\rightarrow$ clear evidence of non-zero Boer-Mulders function

Back-up slides

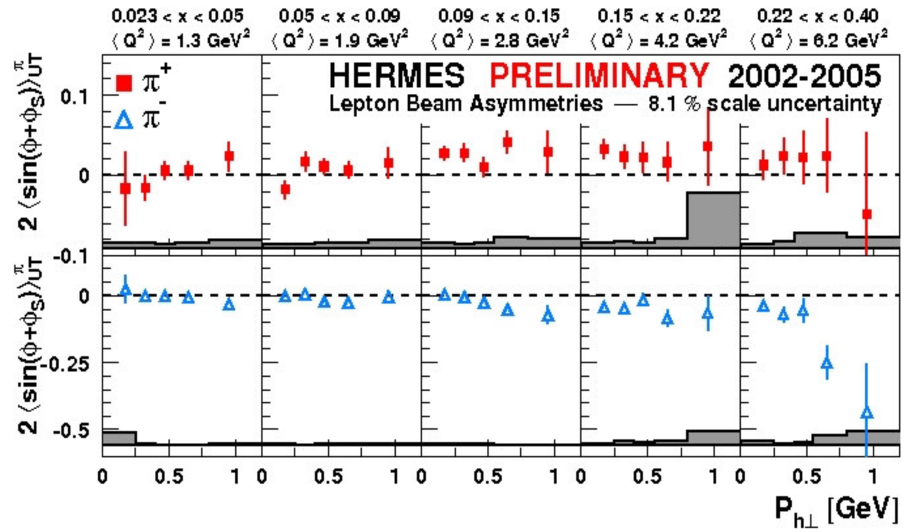
2-D Collins moments for $\pi^{\pm}$

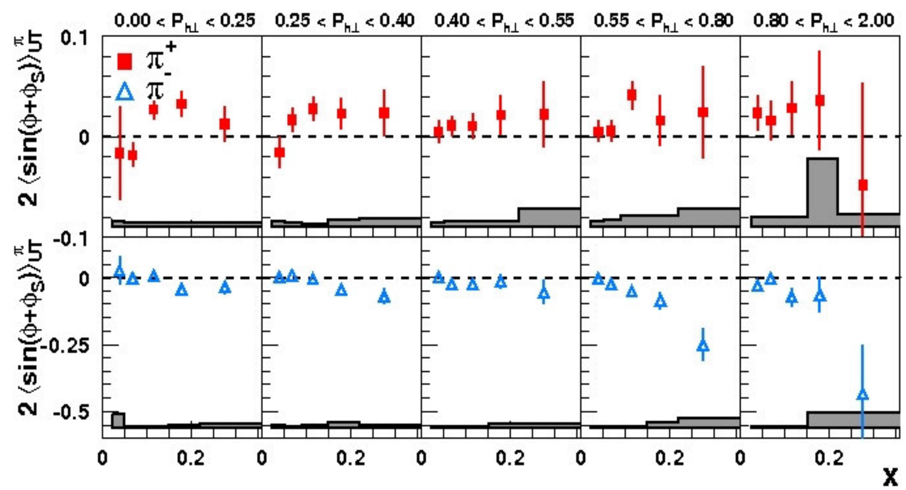
X vs. Z





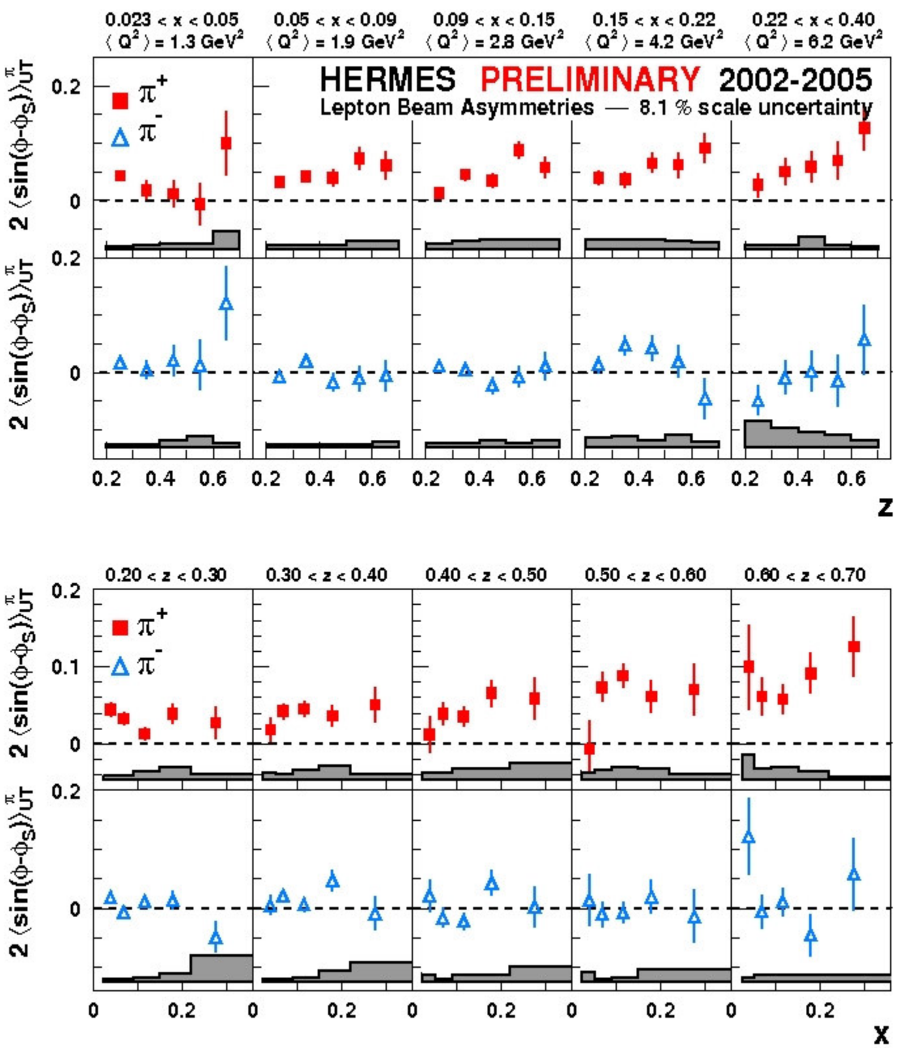
X vs. $P_{h\perp}$



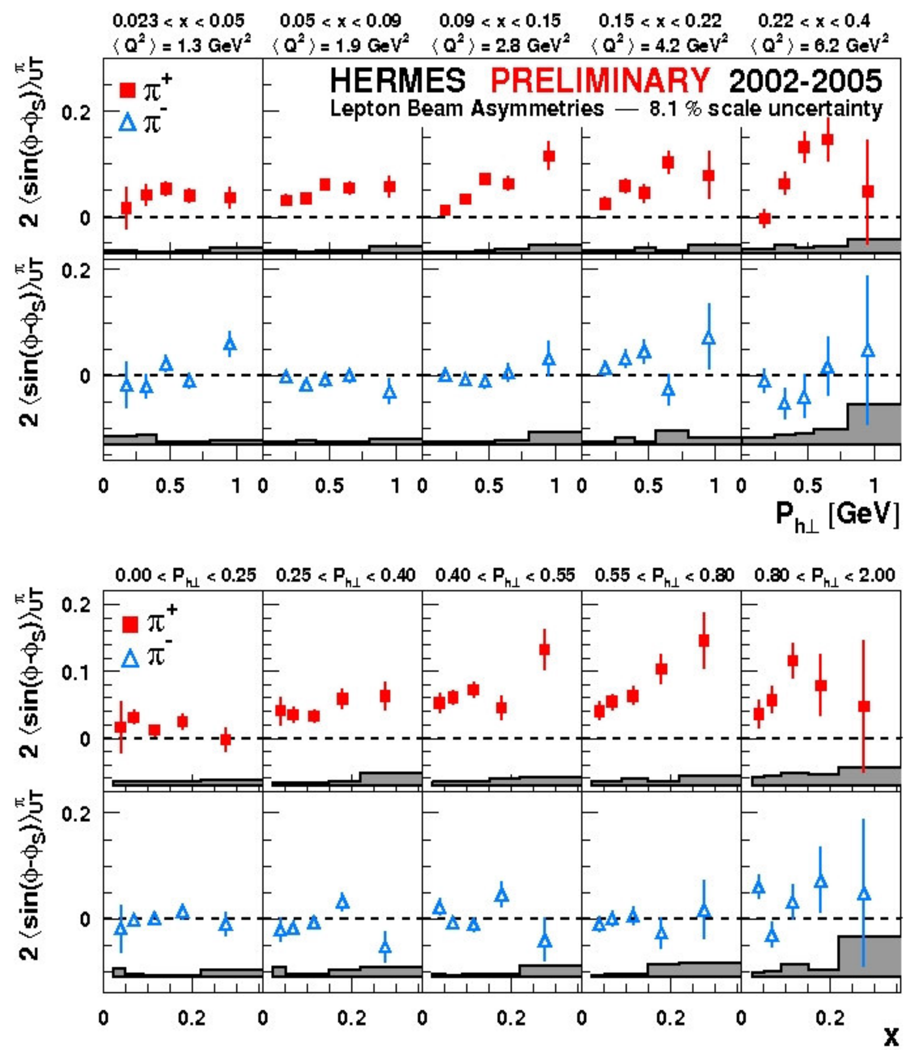


2-D Sivers moments for $\pi^{\pm}$

X vs. Z

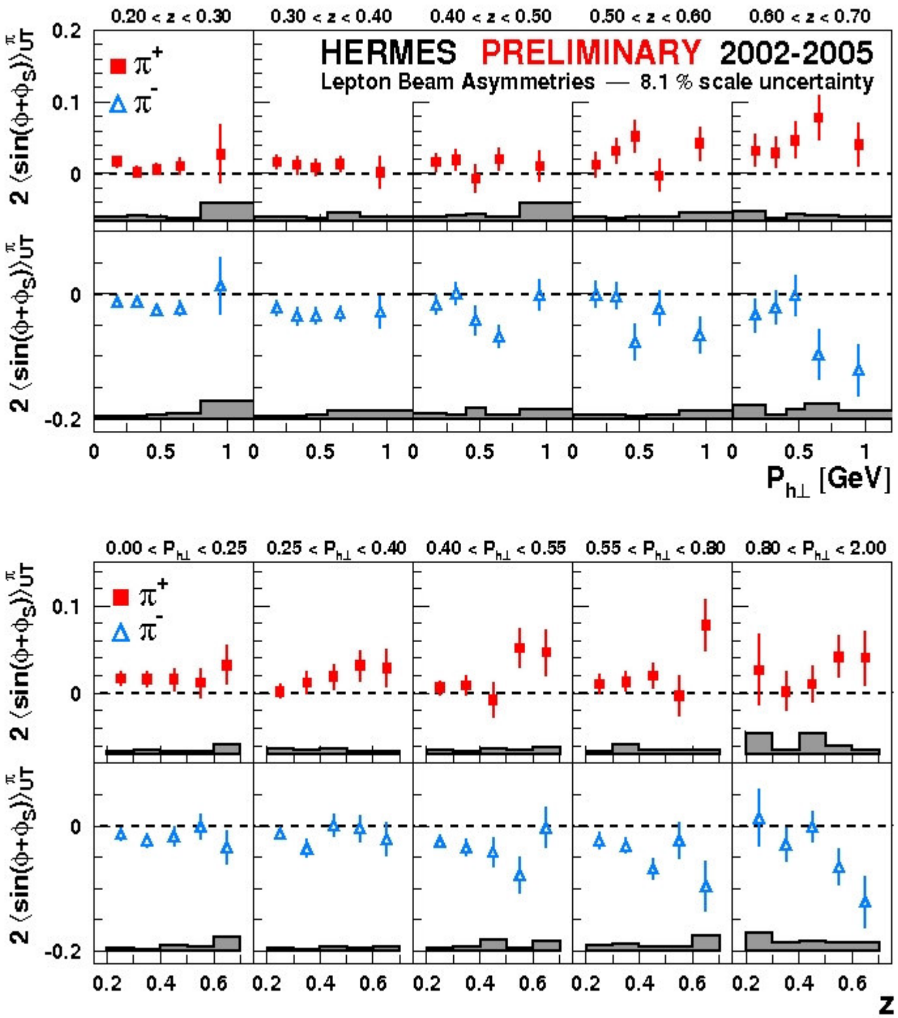


X vs. $P_{h\perp}$

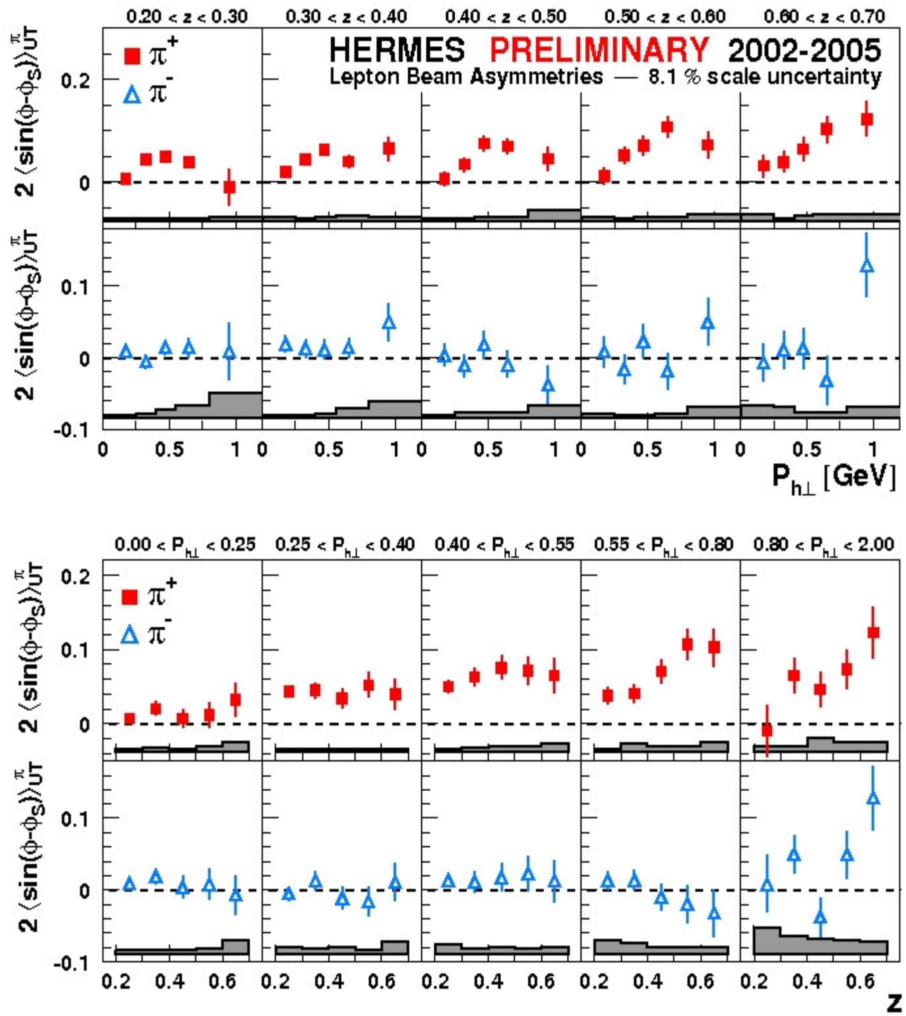


2-D moments for $\pi^{\pm}$: z vs. $P_{h\perp}$

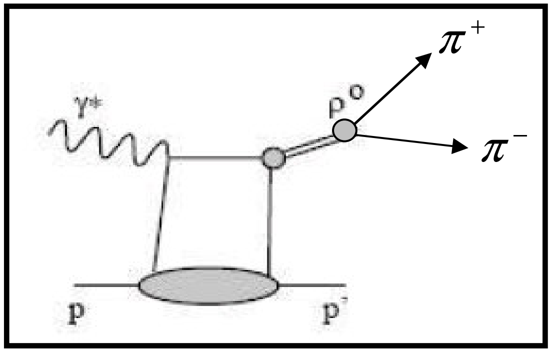
Collins



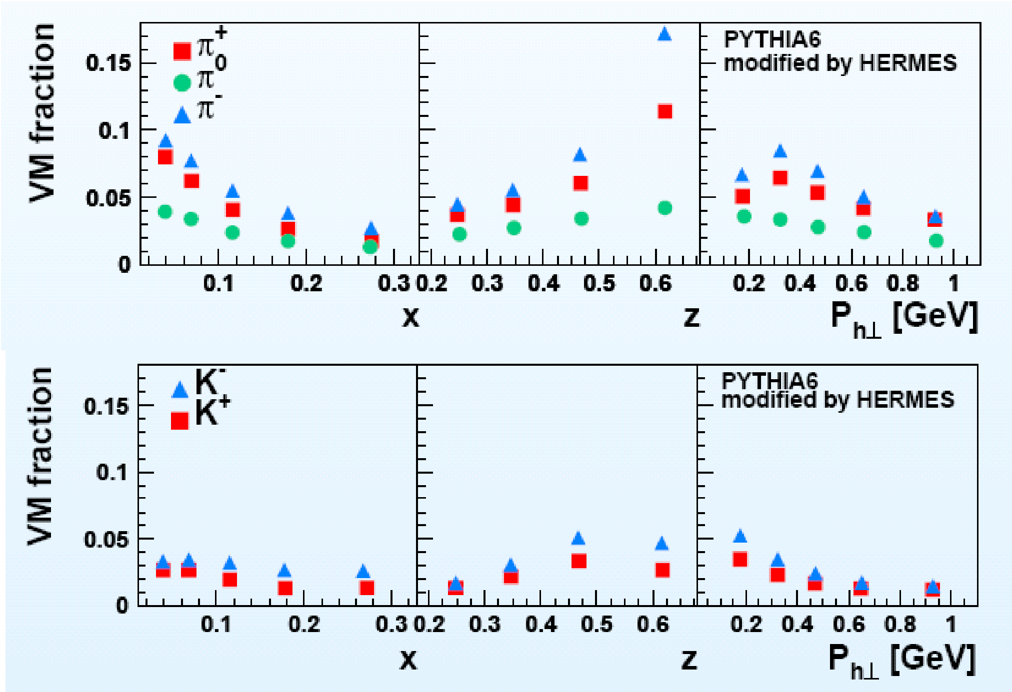
Sivers



Exclusive Vector Meson contribution



Contribution by decay of exclusively produced vector mesons is not negligible



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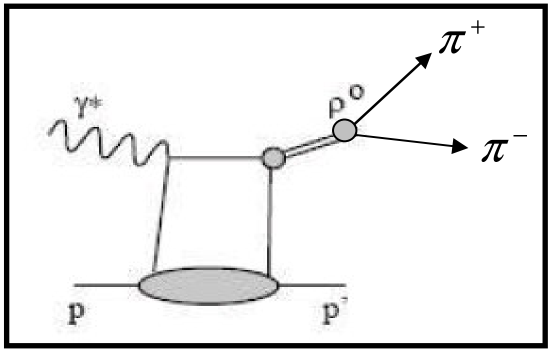

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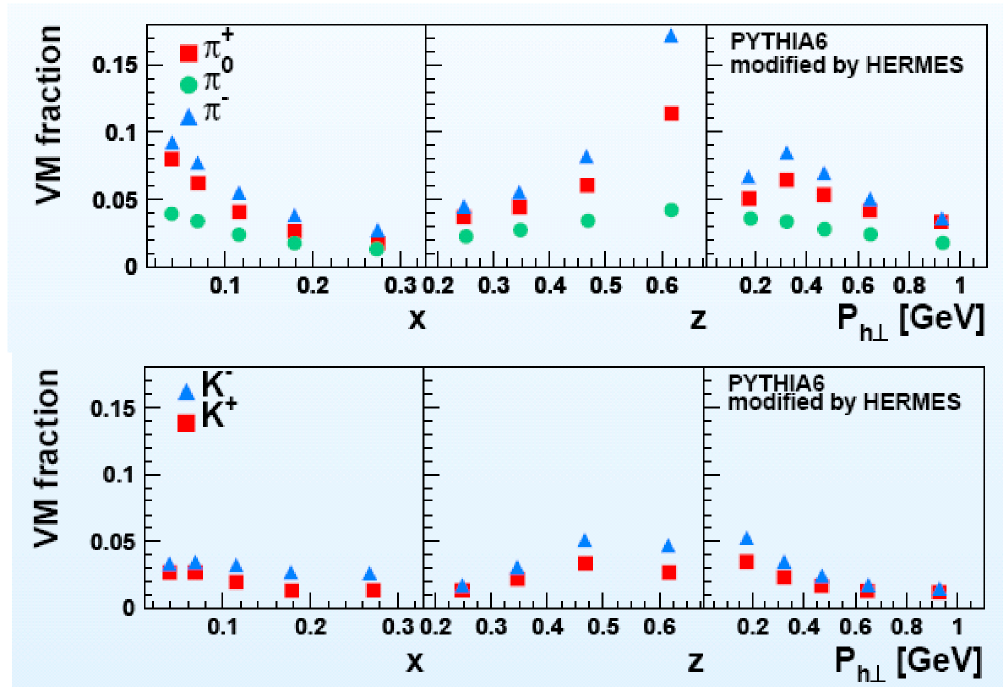

To evaluate the impact of this contribution on the extracted azimuthal moments, a new observable was regarded which does not experience contributions from the ρ^0: the **pion-difference target-spin asymmetry**

$$A_{UT}^{\pi^+-\pi^-}(\phi,\phi_S) \equiv \frac{1}{S_T}\frac{(\sigma_{U\uparrow}^{\pi^+}-\sigma_{U\uparrow}^{\pi^-})-(\sigma_{U\downarrow}^{\pi^+}-\sigma_{U\downarrow}^{\pi^-})}{(\sigma_{U\uparrow}^{\pi^+}-\sigma_{U\uparrow}^{\pi^-})+(\sigma_{U\downarrow}^{\pi^+}-\sigma_{U\downarrow}^{\pi^-})}$$

Pion-difference asymmetry

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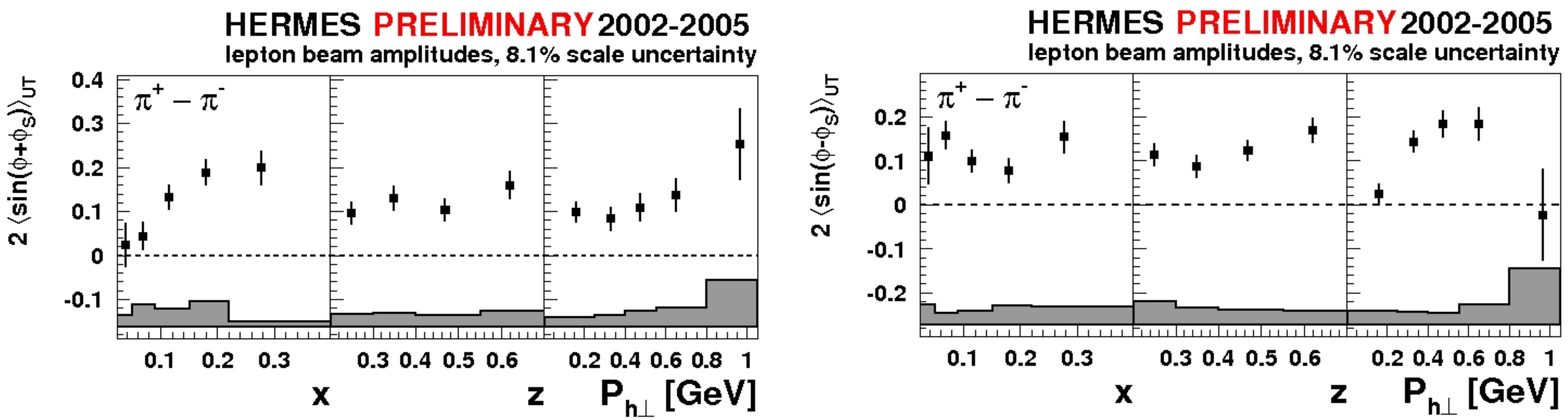
Contribution from exclusive ρ^0 largely cancels out



Significantly positive amplitudes are obtained as a function of $x, z, P_{h\perp}$.

the underlying (Collins and Sivers) asymmetry amplitudes are not generated by vector meson contribution.

Pion-difference asymmetry

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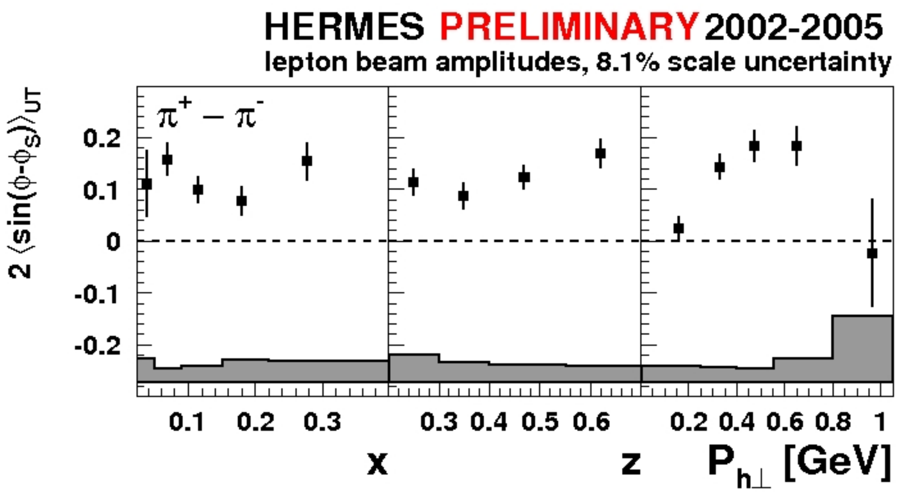
Contribution from exclusive ρ^0 largely cancels out

$$A_{UT}^{\pi^+-\pi^-} = -\frac{4f_{1T}^{\perp,u_v}-f_{1T}^{\perp,d_v}}{4f_1^{u_v}-f_1^{d_v}}$$

(assuming charge-conjugation and isospin symmetry amongst the pion fragmentation functions)



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The extraction of the Distribution Functions

$$\left\langle \sin(\phi+\phi_S)\right\rangle_{UT}^{h} = \frac{\int d\phi_S d^2\vec{P}_{h\perp} \sin(\phi+\phi_S)\ d\sigma_{UT}}{\int d\phi_S d^2\vec{P}_{h\perp} d\sigma_{UU}} \propto \mathbf{I}\left[\frac{\vec{k}_T\cdot\hat{P}_{h\perp}}{M_h} h_1(x,p_T^2) H_1^{\perp q}(z,k_T^2)\right]$$

Convolution integral on transverse momenta p_T and k_T

$$\left\langle \sin(\phi-\phi_S)\right\rangle_{UT}^{h} = \frac{\int d\phi_S d^2\vec{P}_{h\perp} \sin(\phi-\phi_S)\ d\sigma_{UT}}{\int d\phi_S d^2\vec{P}_{h\perp} d\sigma_{UU}} \propto \mathbf{I}\left[\frac{\vec{p}_T\cdot\hat{P}_{h\perp}}{M} f_{1T}^{\perp q}(x,p_T^2) D_1^q(z,k_T^2)\right]$$

Experiment: only partial coverage of the full $P_{h\perp}$ range (acceptance effects)

Theory: difficult to solve ⟹ Gaussian ansatz

$$h_1(x,p_T^2) \approx \frac{h_1(x)}{\pi\left\langle p_T^2(x)\right\rangle} e^{-\frac{p_T^2}{\left\langle p_T^2(x)\right\rangle}} \qquad H_1^{\perp q}(z,k_T^2) \approx \frac{H_1^{\perp q}(z)}{\pi\left\langle k_T^2(z)\right\rangle} e^{-\frac{k_T^2}{\left\langle k_T^2(z)\right\rangle}}$$

(extraction assumption-dependent)

Alternatively one can use the so-called $P_{h\perp}$ -weighted moments (don't require any assumption on transverse momenta distributions)

$$\left\langle \frac{P_{h\perp}}{zM}\sin(\phi-\phi_S)\right\rangle_{UT}^{h} \equiv \frac{\int d\phi_S d^2\vec{P}_{h\perp}\sin(\phi-\phi_S)\frac{P_{h\perp}}{zM}d^6\sigma_{UT}}{\int d\phi_S d^2\vec{P}_{h\perp}d^6\sigma_{UU}}$$

P_{hT}-weighted Sivers moments (measured)

$$\propto -\left|\vec{S}_T\right|\sum_{q\bar{q}}\mathbf{P}_q^h(x,z)\, f_{1T}^{\perp(1)q}(x)$$

→ **Sivers function**

$$\mathbf{P}_q^h(x,z) \equiv \frac{e_q^2 q(x) D_1^{q\to h}(z)}{\sum_{q'\bar{q}'} e_{q'}^2 q'(x) D_1^{q'\to h}(z)}$$

purities

(based on known quantities)

Extraction above requires, in principle, a full integration over $P_{h\perp}$ (from 0 to ∞)

Due to the partial experimental coverage in $P_{h\perp}$ the evaluation of acceptance effects is of crucial importance.