TMD Measurements at Hermes

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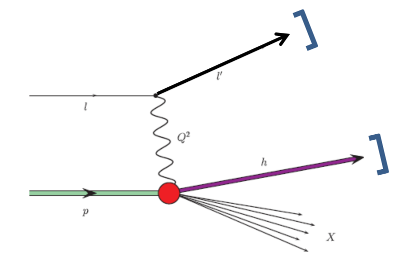
Outline

- Inclusive hadron electroproduction in DIS
- Single hadron production in TMD Semi-inclusive DIS
- Dihadron production in TMD Semi-inclusive DIS

Inclusive hadron electroproduction in DIS

Semi-Inclusive vs. Inclusive DIS

Semi-Inclusive

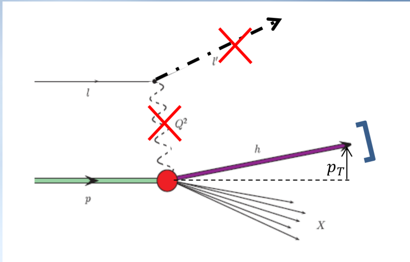


- Hadron detected in coincidence with lepton
- DIS regime $Q^2 > 1$ GeV^2
- Hard scales: Q^2, $P_{h\perp}$ (w.r.t. γ^*)
- Factorization valid for $P_{h\perp} \ll Q^2$

Hadron yields for UT data

	π^+	π^-	K^+	K^-
SIDIS	7.3 M	5.4 M	131 K	54 K
Incl. h	60 M	50 M	5.1 M	2.8 M

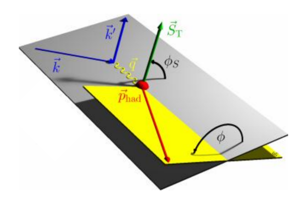
Inclusive



- No Q^2 information
- Data dominated by $Q^2 \approx 0$
- Hard scale: P_T (w.r.t. incident l)
- Main variables $x_F = 2\frac{P_L}{\sqrt{s}}$, P_T
- Events selected with at least one $\pi^\pm$ or $K^\pm$, regardless of any detected leptons.

Angles Semi-Inclusive vs. Inclusive DIS

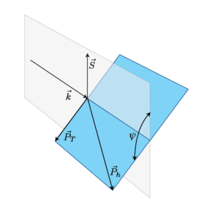
Semi-Inclusive



- Cross Section

$$d\sigma \propto F_{UU,T} + \epsilon F_{UU,L} +$$
$$\sqrt{2\epsilon(1+\epsilon)}\cos\phi_h F_{UU}^{\cos\phi_h} + \epsilon\cos 2\phi_h F_{UU}^{\cos\phi_h} +$$
$$S_T\Big[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\right) +$$
$$\epsilon\sin(\phi_h+\phi_S)F_{UT}^{\sin(\phi_h+\phi_S)} +$$
$$\epsilon\sin(3\phi_h-\phi_S)F_{UT}^{\sin(3\phi_h-\phi_S)} +$$
$$\sqrt{2\epsilon(1+\epsilon)}\sin(\phi_S)F_{UT}^{\sin(\phi_S)} +$$
$$\sqrt{2\epsilon(1+\epsilon)}\sin(2\phi_h-\phi_S)F_{UT}^{\sin(2\phi_h-\phi_S)}\Big] + \ldots$$

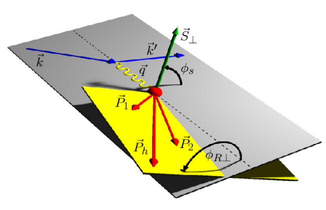
Inclusive



- Cross section
$$d\sigma = d\sigma_{UU}\left[1 + S_\perp A_{UT}^{\sin\psi}\sin\psi\right].$$
- $A_{UT}^{\sin\psi}$ includes contributions from Sivers, Collins, & higher twist
- HERMES kinematics implies $\sin\psi \approx \phi_h - \phi_S$

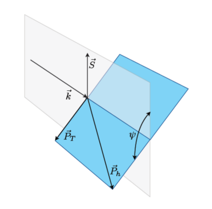
Angles Semi-Inclusive vs. Inclusive DIS

Semi-Inclusive



- Cross Section
  - Same general form, but polarization in the final state

Inclusive



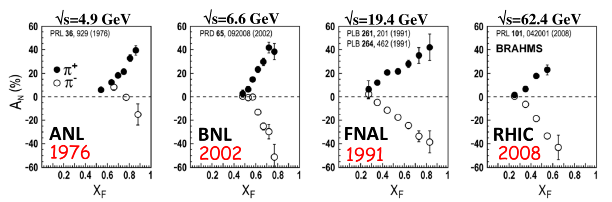
- Cross section
  $d\sigma = d\sigma_{UU}\left[1 + S_\perp A_{UT}^{\sin\psi}\sin\psi\right].$
- $A_{UT}^{\sin\psi}$ includes contributions from Sivers, Collins, & higher twist
- HERMES kinematics implies $\sin\psi \approx \phi_h - \phi_S$

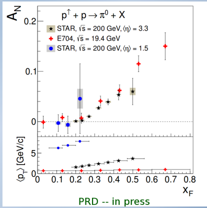
Inclusive Hadronic Lepto-production vs. $pp^{\uparrow}$

- For an ideal detector with full 2π coverage in ψ:

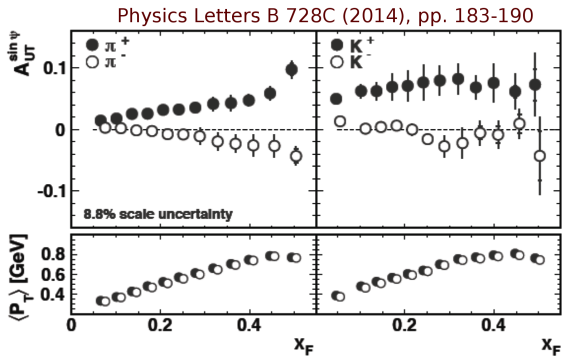
$$A_{UT}^{\sin\psi} = -\frac{\pi}{2}\frac{\int_0^{\pi} d\psi\ \sin\psi d\sigma_{UT}}{\int_0^{\pi} d\psi d\sigma_{UT}} = -\frac{\pi}{2}A_N$$

- pp A_N results mirror symmetric for $\pi^{\pm}$ vs x_F
- Reproduced by various experiments over 35 years over wide energy range ($\sqrt{s}$ from 5 to 200 GeV)
- Cannot be interpreted using standard leading-twist framework based on collinear factorization.



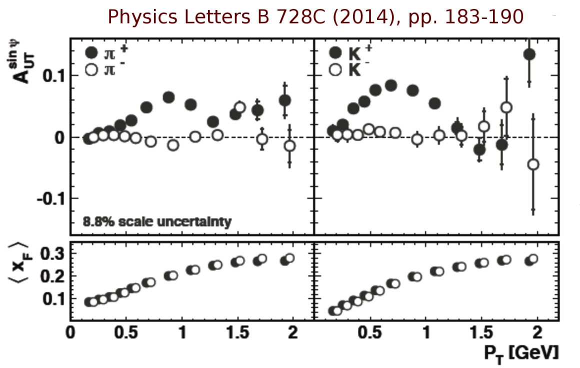


HERMES Results vs. x_F



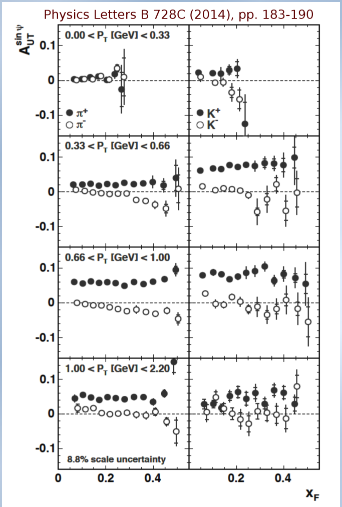
- π^+ amplitude rises fairly linearly with x_F up to a magnitude of 10%
- π^- amplitude is negative, also fairly linearly, but smaller magnitude
  - Pion results vs x_F have comparable features as A_N in pp scattering
- K^+ amplitude is quite constant, around 7%
- K^- amplitude is also quite constant, but consistent with zero.
  - Significant flavor dependence

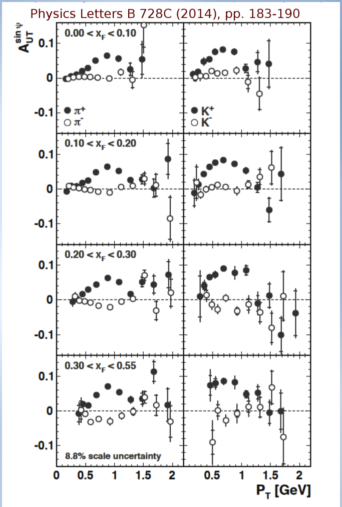
HERMES Results vs. p_T



- No $pp^\uparrow$ scattering data with sufficient coverage in p_T with high enough $|x_F|$
  - Expectation is linear rise from zero at small P_T and $1/P_T$ scaling at large P_T with minimal constraints on behavior at intermediate P_T
- π^+ and K^+ rise linearly from zero, as might be expected from A_N in pp.
  - Clear node in π^+ results, suggested node in K^+ results
  - Node in both cases around $P_T \approx 1.3$ GeV
- Negative mesons have much smaller amplitude, except one π^- point

Inclusive HERMES Results, 2D binning

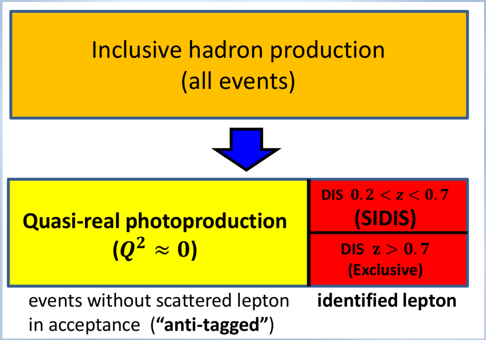




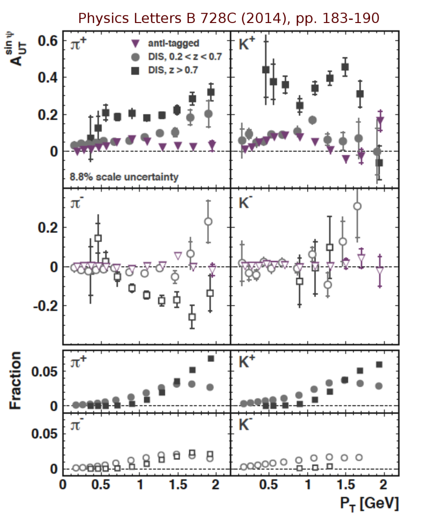
- Results generally quite flat with x_F
- Shape versus p_T persists even in limited x_F bins

Inclusive HERMES Results, Interpretation

- Results include mixtures of various contributions with different kinematic dependencies
  - Makes interpretation of the underlying physics quite difficult
- More insight can be gained through separating different contributing processes
- Overall, anti-tagged events constitute 98% of the statistics



Inclusive HERMES Results per Region



- Anti-tagged events look much like overall results, as they dominate the statistics
- Exclusive-like events: very large asymmetries!
  - Pions have contributions from exclusive ρ decays
  - Large π^- could be from d-quark Sivers and favored D_1 distribution function.
- SIDIS-like events: $\pi^\pm$ are larger and the magnitudes increase fairly linearly with P_T
  - In this regime, $Q^2 > P_T^2$ and TMDs can contribute without P_T-suppression

Single Hadron SIDIS

The Boer-Mulders Moment

$$\frac{d\sigma^h}{dx\,dy\,d\phi_S\,dz\,d\phi\,d\mathbf{P}^2_{h\perp}} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)$$

$$\Big\{ \Big[F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)}\cos(\phi) F_{UU}^{\cos(\phi)} + \epsilon\cos(2\phi) F_{UU}^{\cos(2\phi)}\Big]$$

$$+ \lambda_l \Big[\sqrt{2\epsilon(1-\epsilon)}\sin(\phi) F_{LU}^{\sin(\phi)}\Big]$$

$$+ S_L \Big[\sqrt{2\epsilon(1+\epsilon)}\sin(\phi) F_{UL}^{\sin(\phi)} + \epsilon\sin(2\phi) F_{UL}^{\sin(2\phi)}\Big]$$

$$+ S_L \lambda_l \Big[\sqrt{1-\epsilon^2} F_{LL} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi) F_{LL}^{\cos(\phi)}\Big]$$

$$+ S_T \Big[\sin(\phi-\phi_S)\left(F_{UT,T}^{\sin(\phi-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi-\phi_S)}\right) + \epsilon\sin(\phi+\phi_S) F_{UT}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S) F_{UT}^{\sin(3\phi-\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(\phi_S) F_{UT}^{\sin(\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi-\phi_S) F_{UT}^{\sin(2\phi-\phi_S)}\Big]$$

$$+ S_T \lambda_l \Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S) F_{LT}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi_S) F_{LT}^{\cos(\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S) F_{LT}^{\cos(2\phi-\phi_S)}\Big]\Big\}$$

Naive-T-odd & Chiral-odd
Describes correlation between quark transverse momentum and transverse spin in unpolarized nucleon

$F_{UU}^{\cos(2\phi)}$: $\propto h_1^\perp \otimes H_1^\perp + \frac{1}{Q^2}[f_1 \otimes D_1 + \cdots]$

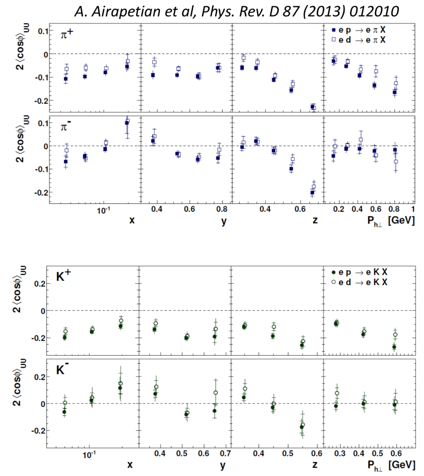
$F_{UU}^{\cos(\phi)}$: $\propto + \frac{1}{Q}[h_1^\perp \otimes H_1^\perp + f_1 \otimes D_1 \ldots]$

B-M effect [PRD 57 (1998)]

Cahn effect [PLB 78 (1978)]

Interaction dependent terms

Boer-Mulders Moment Results



- Pion Results:
  - Similar results for H and D indicate $h_1^{\perp,u} \approx h_1^{\perp,d}$.
  - Opposite sign for $\pi^{\pm}$ consistent w/ opposite signs of fav./unfav. Collins function.
- Kaon Results:
  - Kaon results are larger magnitude than pions and have different kinematic dependencies
  - K^+ generally positive, K^- generally consistent with zero
  - Suggests significant flavor dependence in Collin's fragmentation
- Preform your own projections of the 5D results
  `http://www-hermes.desy.de/cosnphi/`

The Collins Moment

$$\frac{d\sigma^h}{dx\,dy\,d\phi_S\,dz\,d\phi\,d\mathbf{P}^2_{h\perp}} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)$$

$$\Big\{ \Big[F_{\rm UU,T} + \epsilon F_{\rm UU,L} + \sqrt{2\epsilon(1+\epsilon)}\cos(\phi)F^{\cos(\phi)}_{\rm UU} + \epsilon\cos(2\phi)F^{\cos(2\phi)}_{\rm UU}\Big]$$

$$+ \lambda_l \Big[\sqrt{2\epsilon(1-\epsilon)}\sin(\phi)F^{\sin(\phi)}_{\rm LU}\Big]$$

$$+ S_L \Big[\sqrt{2\epsilon(1+\epsilon)}\sin(\phi)F^{\sin(\phi)}_{\rm UL} + \epsilon\sin(2\phi)F^{\sin(2\phi)}_{\rm UL}\Big]$$

$$+ S_L\,\lambda_l \Big[\sqrt{1-\epsilon^2}F_{\rm LL} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi)F^{\cos(\phi)}_{\rm LL}\Big]$$

$$+ S_T \Big[\sin(\phi-\phi_S)\Big(F^{\sin(\phi-\phi_S)}_{\rm UT,T} + \epsilon F^{\sin(\phi-\phi_S)}_{\rm UT,L}\Big) + \epsilon\sin(\phi+\phi_S)F^{\sin(\phi+\phi_S)}_{\rm UT} + \epsilon\sin(3\phi-\phi_S)F^{\sin(3\phi-\phi_S)}_{\rm UT} + \sqrt{2\epsilon(1+\epsilon)}\sin(\phi_S)F^{\sin(\phi_S)}_{\rm UT} + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi-\phi_S)F^{\sin(2\phi-\phi_S)}_{\rm UT}\Big]$$

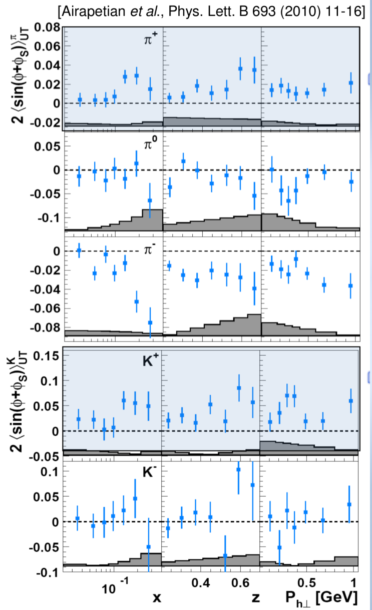
$$+ S_T\,\lambda_l \Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S)F^{\cos(\phi-\phi_S)}_{\rm LT} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi_S)F^{\cos(\phi_S)}_{\rm LT} + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S)F^{\cos(2\phi-\phi_S)}_{\rm LT}\Big]\Big\}$$

$\propto h_1 \otimes H_1^{\perp}$

Collins effect

[Nucl. Phys. B 396 (1993)]

The Collins Moment Results



- Results high magnitude and opposite sign for $\pi^{\pm}$
- Results consistent with zero for π^0
- *u*-quark dominance suggests opposite signs of fav./unfav. Collins function.
- K^+ results positive with higher magnitude than π^+
- K^- results consistent with zero.
- Exist TMD transversity extraction using these results, along with Compass and Belle
  M. Anselmino, *et al.*, Phys. Rev. D 75 (2007)

The Sivers Moment

$$\frac{d\sigma^h}{dx\,dy\,d\phi_S\,dz\,d\phi\,d\mathbf{P}_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)$$

$$\Big\{ \Big[F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)}\cos(\phi)F_{UU}^{\cos(\phi)} + \epsilon\cos(2\phi)F_{UU}^{\cos(2\phi)}\Big]$$

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$$+ S_L \Big[\sqrt{2\epsilon(1+\epsilon)}\sin(\phi)F_{UL}^{\sin(\phi)} + \epsilon\sin(2\phi)F_{UL}^{\sin(2\phi)}\Big]$$

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$$+ S_T \Big[\sin(\phi-\phi_S)\left(F_{UT,T}^{\sin(\phi-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi-\phi_S)}\right) + \epsilon\sin(\phi+\phi_S)F_{UT}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S)F_{UT}^{\sin(3\phi-\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(\phi_S)F_{UT}^{\sin(\phi_S)} + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi-\phi_S)F_{UT}^{\sin(2\phi-\phi_S)}\Big]$$

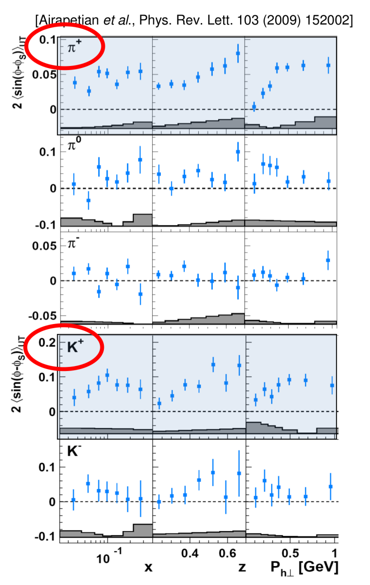
$$+ S_T\,\lambda_l \Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S)F_{LT}^{\cos(\phi-\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi_S)F_{LT}^{\cos(\phi_S)} + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S)F_{LT}^{\cos(2\phi-\phi_S)}\Big]\Big\}$$

$\propto f_{1T}^{\perp} \otimes D_1$

Sivers effect

[PRD 41 (1990)]

The Sivers Moment Results



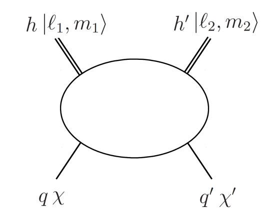
- Results significantly positive for π^+
- Results consistent with zero for π^-
- π^0 results appear as average of π^+, π^-
- K^+ results positive with higher magnitude than π^+
- K^- results slightly positive
- Further studies hints that K^+, π^+ difference may be due to higher twist effects for kaons

Dihadron SIDIS

Why SIDIS TMD Dihadrons?

- Dihadron cross section similar to single hadron cross section
  - Involves identical distribution functions but different factorization functions.
  - Dihadrons also access different flavor combinations.
    - Dihadrons give a wealth of flavor-dependent information
  - Different distribution functions also occur in the collinear cross section.
    - Collinear access to transversity
- Lund/Artru string fragmentation model predicts sign change in the Collins function between single hadron and the corresponding transversely polarized vector meson.
- Siver's function in ϕ-meson production may be related to gluon orbital angular momentum.

Fragmentation Functions and Spin/Polarization



- Leading twist Fragmentation functions are related to number densities
  - Amplitudes squared rather than amplitudes
- Difficult to relate Artru/Lund prediction with published notation and cross section.
- Propose new convention for fragmentation functions
  - Functions entirely identified by the polarization states of the quarks, χ and χ'
  - Any final-state polarization, i.e. $|\ell_1, m_1\rangle|\ell_2, m_2\rangle$, contained within partial wave expansion of fragmentation functions
- Exists exactly two fragmentation functions
  - D_1, the unpolarized fragmentation function ($\chi = \chi'$)
  - $H_1^\perp$, the polarized (Collins) fragmentation function ($\chi \neq \chi'$)
- New partial waves analysis proposed, using direct sum basis $|\ell, m\rangle$ rather than the direct product basis $|\ell_1, m_1\rangle|\ell_2, m_2\rangle$.

$$H_1^\perp = \sum_{\ell=1}^{\infty} \sum_{m=-\ell}^{\ell} P_{\ell,m}(\cos\vartheta) e^{im(\phi_R - \phi_k)} H_1^{\perp|\ell,m\rangle}(z, M_h, |\boldsymbol{k}_T|),$$

Dihadron Twist-2 and Twist-3 Cross Section

$$
\begin{aligned}
d\sigma_{UU} &= \frac{\alpha^2 M_h P_{h\perp}}{2\pi x y Q^2}\left(1+\frac{\gamma^2}{2x}\right) \\
&\times \sum_{\ell=0}^{2}\left\{A(x,y)\sum_{m=0}^{\ell}\left[P_{\ell,m}\cos(m(\phi_h-\phi_R))\left(F_{UU,T}^{P_{\ell,m}\cos(m(\phi_h-\phi_R))}+\epsilon F_{UU,L}^{P_{\ell,m}\cos(m(\phi_h-\phi_R))}\right)\right]\right. \\
&\quad + B(x,y)\sum_{m=-\ell}^{\ell}P_{\ell,m}\cos((2-m)\phi_h+m\phi_R)F_{UU}^{P_{\ell,m}\cos((2-m)\phi_h+m\phi_R)} \\
&\quad \left. + V(x,y)\sum_{m=-\ell}^{\ell}P_{\ell,m}\cos((1-m)\phi_h+m\phi_R)F_{UU}^{P_{\ell,m}\cos((1-m)\phi_h+m\phi_R)}\right\}, \\
d\sigma_{UT} &= \frac{\alpha^2 M_h P_{h\perp}}{2\pi x y Q^2}\left(1+\frac{\gamma^2}{2x}\right)|\boldsymbol{S}_\perp|\sum_{\ell=0}^{2}\sum_{m=-\ell}^{\ell}\left\{A(x,y)\left[P_{\ell,m}\sin((m+1)\phi_h-m\phi_R-\phi_S))\right.\right. \\
&\quad \left.\times\left(F_{UT,T}^{P_{\ell,m}\sin((m+1)\phi_h-m\phi_R-\phi_S)}+\epsilon F_{UT,L}^{P_{\ell,m}\sin((m+1)\phi_h-m\phi_R-\phi_S)}\right)\right] \\
&\quad + B(x,y)\left[P_{\ell,m}\sin((1-m)\phi_h+m\phi_R+\phi_S)F_{UT}^{P_{\ell,m}\sin((1-m)\phi_h+m\phi_R+\phi_S)}\right. \\
&\quad\quad \left. + P_{\ell,m}\sin((3-m)\phi_h+m\phi_R-\phi_S)F_{UT}^{P_{\ell,m}\sin((3-m)\phi_h+m\phi_R-\phi_S)}\right] \\
&\quad + V(x,y)\left[P_{\ell,m}\sin(-m\phi_h+m\phi_R+\phi_S)F_{UT}^{P_{\ell,m}\sin(-m\phi_h+m\phi_R+\phi_S)}\right. \\
&\quad\quad \left.\left. + P_{\ell,m}\sin((2-m)\phi_h+m\phi_R-\phi_S)F_{UT}^{P_{\ell,m}\sin((2-m)\phi_h+m\phi_R-\phi_S)}\right]\right\}.
\end{aligned}
$$

Twist-2 Structure Functions, Transverse Target

$$F_{UT,L}^{P_{\ell,m}\sin((m+1)\phi_h - m\phi_R - \phi_S)} = 0$$

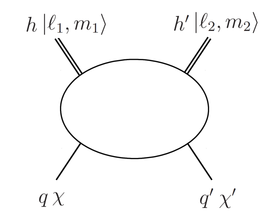
$$F_{UT,T}^{P_{\ell,m}\sin((m+1)\phi_h - m\phi_R - \phi_S)} = -\mathcal{I}\left[\frac{|\boldsymbol{p}_T|}{M}\cos\left((m+1)\phi_h - \phi_p - m\phi_k\right) \times \left(f_{1T}^{\perp}\left(D_1^{|\ell,m\rangle} + D_1^{|\ell,-m\rangle}\right) + \chi(m) g_{1T}\left(D_1^{|\ell,m\rangle} - D_1^{|\ell,-m\rangle}\right)\right)\right],$$

$$F_{UT}^{P_{\ell,m}\sin((1-m)\phi_h + m\phi_R + \phi_S)} = -\mathcal{I}\left[\frac{|\boldsymbol{k}_T|}{M_h}\cos\left((m-1)\phi_h - \phi_p - m\phi_k\right) h_1 H_1^{\perp|\ell,m\rangle}\right],$$

$$F_{UT}^{P_{\ell,m}\sin((3-m)\phi_h + m\phi_R - \phi_S)} = \mathcal{I}\left[\frac{|\boldsymbol{p}_T|^2|\boldsymbol{k}_T|}{M^2 M_h}\cos\left((m-3)\phi_h + 2\phi_p - (m-1)\phi_k\right) h_{1T}^{\perp} H_1^{\perp|\ell,m\rangle}\right].$$

- Can test Lund/Artru model with $F_{UT}^{\sin^2\vartheta\,\sin(-\phi_h + 2\phi_R + \phi_S)}$ and $F_{UT}^{\sin^2\vartheta\,\sin(3\phi_h - 2\phi_R + \phi_S)}$ via transversity
- In theory, could also test Lund/Artru and gluon radiation models with $F_{UT}^{\sin^2\vartheta\,\sin(\phi_h + 2\phi_R - \phi_S)}$ and $F_{UT}^{\sin^2\vartheta\,\sin(5\phi_h - 2\phi_R - \phi_S)}$ via pretzelocity
- Data from SIDIS pseudo-scalar production indicate pretzelocity very small or possibly zero

Where is “the Collins function?”



- Consider direct sum vs. direct product basis

$$\begin{aligned}\frac{1}{2}\otimes\frac{1}{2}\otimes\frac{1}{2}\otimes\frac{1}{2} &= \left(\frac{1}{2}\otimes\frac{1}{2}\right)\otimes\left(\frac{1}{2}\otimes\frac{1}{2}\right),\\ &= (1\oplus 0)\otimes(1\oplus 0)\,,\\ &= 2\oplus 1\oplus 1\oplus 1\oplus 0\oplus 0.\end{aligned}$$

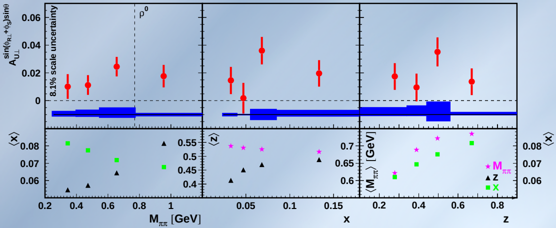
- The three $\ell = 1$ cannot be separated experimentally
  - Note: the usual IFF, related to $H_1^{\perp|1,1\rangle}$ is not pure *sp*, but also includes *pp* interference.
- Longitudinal vector meson state $|1,0\rangle|1,0\rangle$ is a mixture of $|2,0\rangle$ and $|0,0\rangle$
  - $|2,0\rangle$ partial waves affected very strongly by $\cos\vartheta$ acceptance
- Transverse vector meson states $|1,\pm1\rangle|1,\pm1\rangle$ are exactly $|2,\pm2\rangle$
  - Models predict dihadron $H_1^{\perp|2,\pm2\rangle}$ has opposite sign as pseudo-scalar $H_1^{\perp}$.
  - Cross section has direct access to $H_1^{\perp|2,\pm2\rangle}$
- Using symmetry, can calculate cross section for any polarized final state from the scalar final state cross section

Analysis Considerations

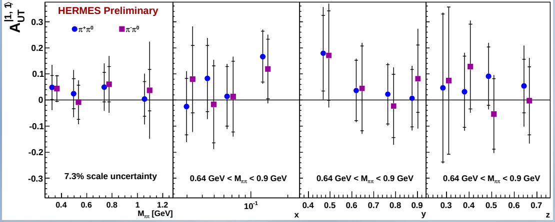
- Dihadrons considered in this talk: $\pi^{\pm}\pi^{0}$ ($\rho^{\pm}$), $\pi^{+}\pi^{-}$ (ρ^{0}), $K^{+}K^{-}$ (ϕ)
- $K^{+}K^{-}$ near the ϕ-peak ($M_{KK} < 1.05$ GeV^{2}) analyzed separately than non-resonant region (1.05 GeV $^{2} < M_{KK} < 2.5$ GeV^{2})
- Both TMDGen and Pythia were used as Monte Carlo generators for systematic studies
  - TMDGen was also used in the acceptance correction
- TMDGen uses a new TMD spectator model for the unpolarized dihadron fragmentation function $D_1^{|0,0\rangle}$
  - Different tunes of the model are used for each dihadron type and region.
- Acceptance effects are corrected by inverting the smearing matrix in the parameter space.
- As no p-wave signal was found in the non-resonant $K^{+}K^{-}$ region, only the $\ell = 0$ sector is used in the fitting functions.

$|1,1\rangle$ Moment for $\pi\pi$ Dihadrons

Published $\pi^+\pi^-$ Results

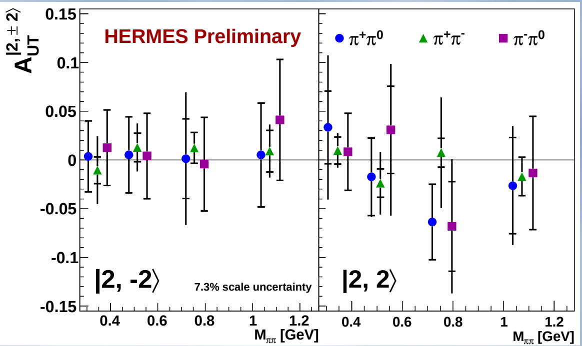


New $\pi^\pm\pi^0$ Results



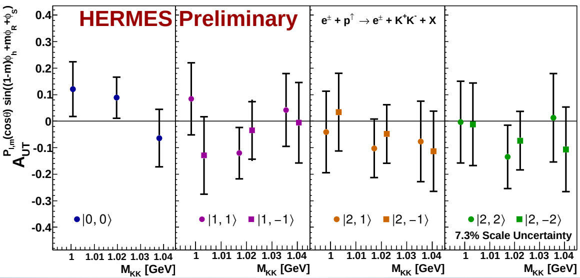
- Signs of moments are consistent for all $\pi\pi$ dihadron species.
- Statistics are much more limited for $\pi^\pm\pi^0$ dihadrons.
- Despite uncertainties, may still help constrain global fits.

$|2, \pm 2\rangle$ Moments for $\pi\pi$ Dihadrons



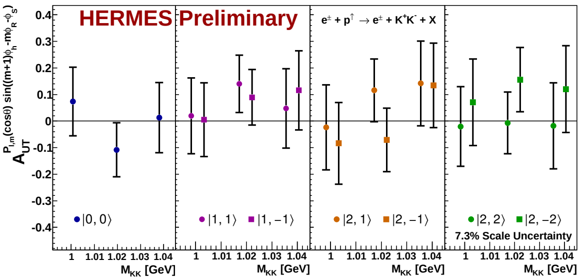
- $|2, -2\rangle$ moment very consistent with zero for all flavors
- Results for $|2, 2\rangle$ are consistent with expectations
  - No indication of any signal outside the ρ-mass bin
  - Suggests negative moments for $\rho^{\pm}$, very small ρ^0 moments
  - Results are sufficiently suggestive to merit measurements at current experiments.

K^+K^-, Res. Region, Collins Moments



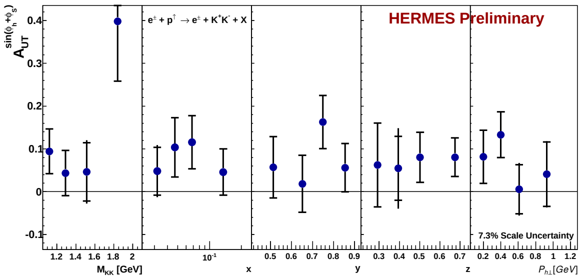
- Exists rotation in $SU(3)$ space, so no direct testing of Lund/Artru
- No obvious change within ϕ-meson peak (middle bin) vs. sidebands within available statistics for any partial waves.
- Collinear access to transversity: s-flavor of either transversity or Collins is small

K^+K^-, Res. Region, Sivers Moments



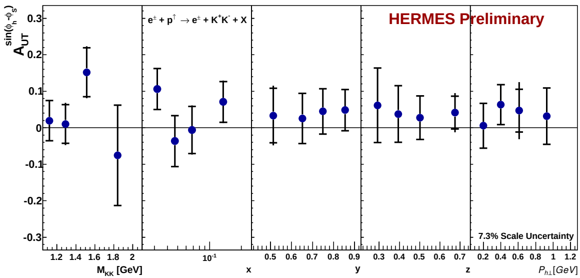
- Again, no obvious change within ϕ-meson peak vs. sidebands within available statistics
- The $|0, 0\rangle$ partial wave may suggest difference between strange and other sea flavors of Sivers function

K^+K^-, Non-Res. Region, Collins Moment



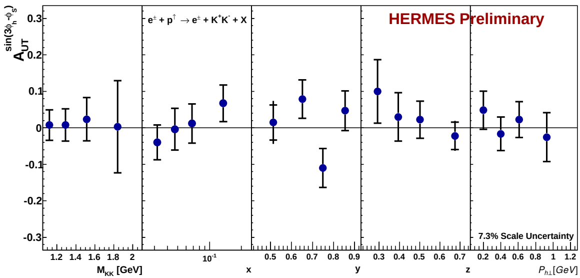
- Results consistent with small positive value
- Note: single hadron K^+ results positive and K^- are consistent with zero

K^+K^-, Non-Res. Region, Sivers Moment



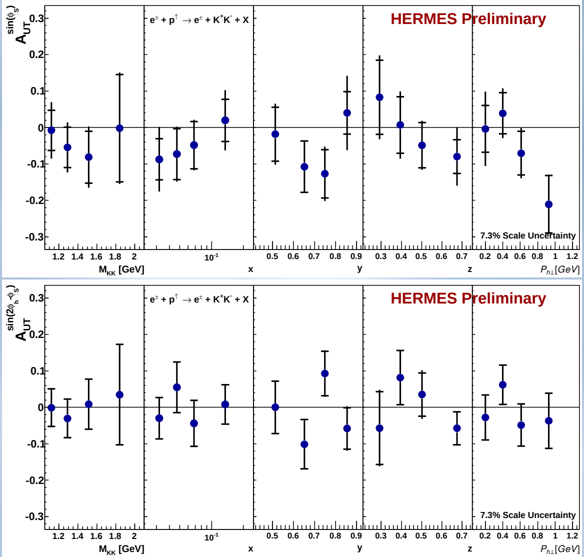
- Results consistent with small positive value
- Note: single hadron K^+ results also large and positive and K^- results small and slightly positive

K^+K^-, Non-Res. Region, Pretzelocity Moment



- Consistent with zero, as expected

K^+K^-, Non-Res. Region, Higher Twist Moments



- Higher twist moments also mostly consistent with zero

Conclusions

- HERMES inclusive hadron electroproduction reveal interesting features, common with A_N in $pp^{\uparrow}$ and the Sivers effect in SIDIS
- SIDIS single and dihadron results provide rich details regarding flavor separation for many distribution functions and both fragmentation functions.
  - DFs: $h_1^{\perp}$, h_1, $f_{1T}^{\perp}$, $h_{1T}^{\perp}$, ...
  - FFs: Single and dihadron $D_1^{|\ell,m\rangle}$, $H_1^{\perp|\ell,m\rangle}$
- The HERMES experiment has played a pioneering role in TMD studies, and there is still more to come...