Overveiw of recent HERMES results

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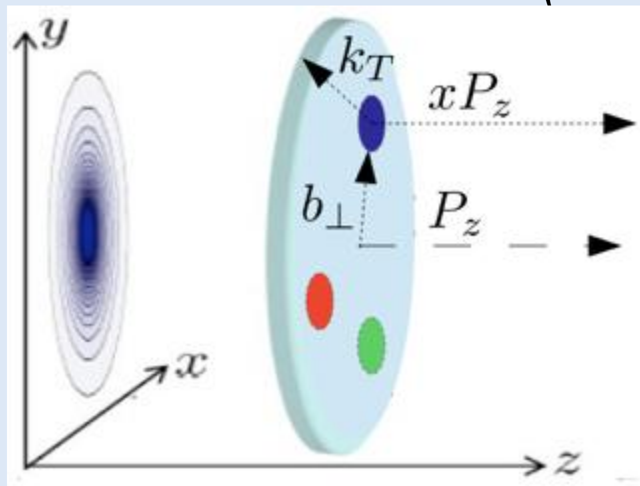
(on behalf of the HERMES Collaboration)

XVI WORKSHOP ON HIGH ENERGY SPIN PHYSICS
DSPIN – 15
Sept. 8 – 12, Dubna, Russia

- 3D picture of the nucleon
  - A_{UT} & A_{LT}, A_{LU} in semi-inclusive DIS
  - ω–meson production: SDMEs & A_{UT} from exclusive DIS
- Bose-Einstein correlations in DIS
- Λ polarization in quasi-real photoproduction
- Searching again for the pentaquark in quasi-real photoproduction

3D picture of the nucleon

Wigner distributions $W\left(x, \vec{k}_T, \vec{b}_\perp\right)$



$\int d^2\vec{b}_\perp$

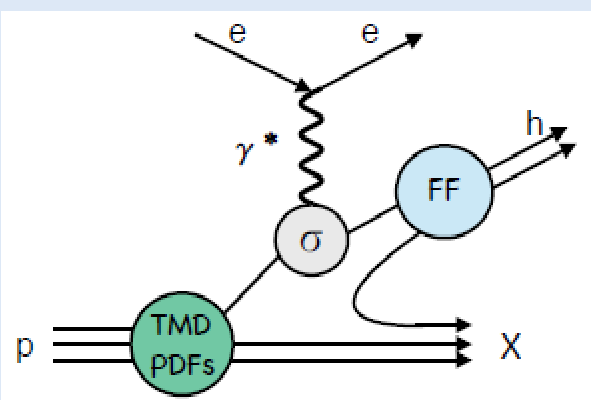
$\int d^2\vec{k}_T$

TMD PDFs: $f_p^q(x,k_T)$,...

GPDs: $H_p^q(x,\xi,t)$, ...

Semi-inclusive measurements
Direct info about momentum distribution

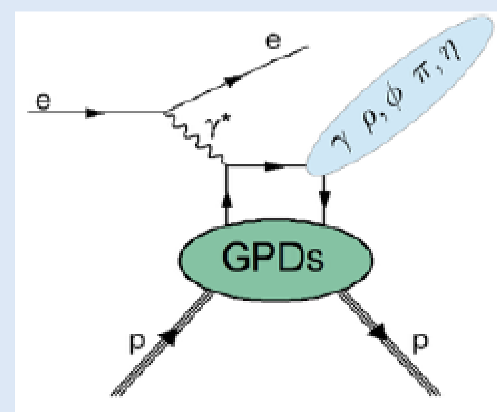
Exclusive Measurements
Direct info about spatial distribution



$\int d^2\vec{k}_T$

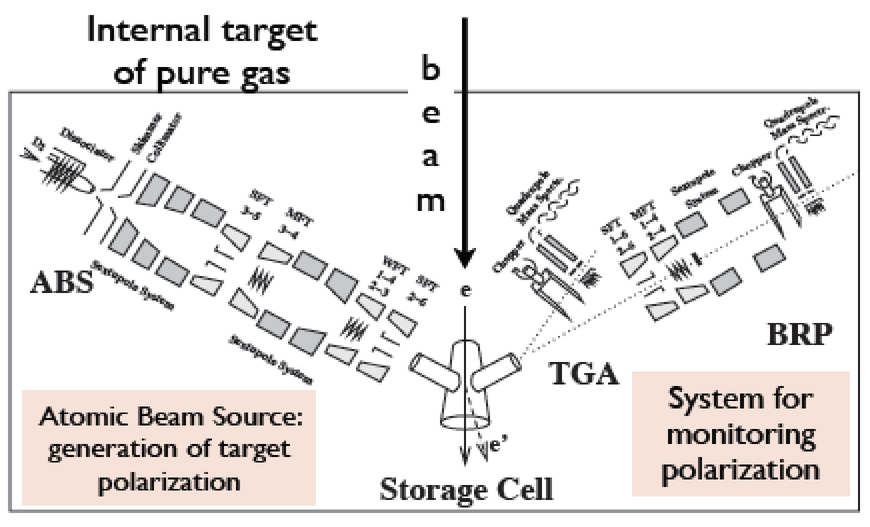
ξ=0, t=o

PDFs $f_p^q(x)$,...



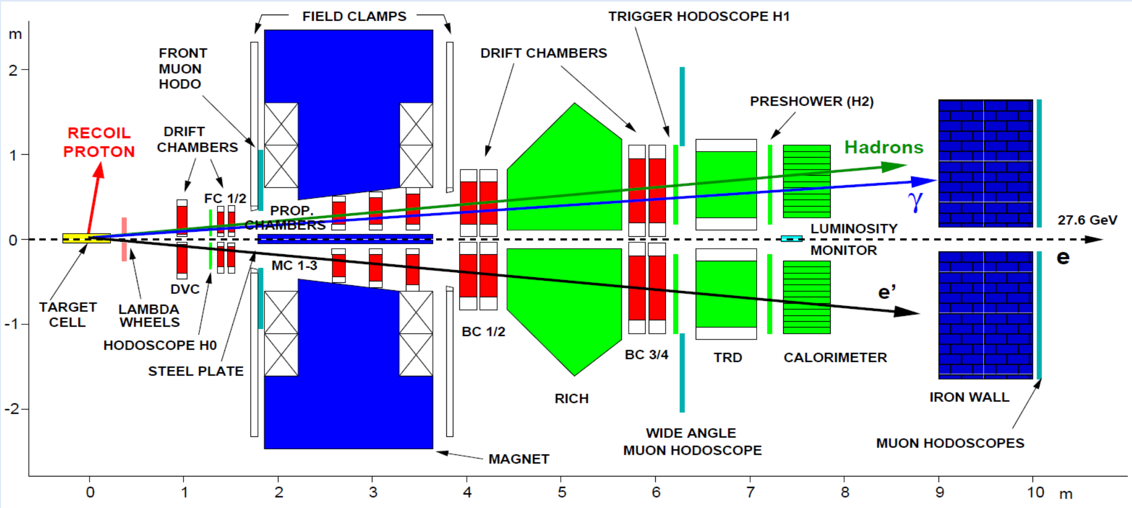
HERMES at DESY

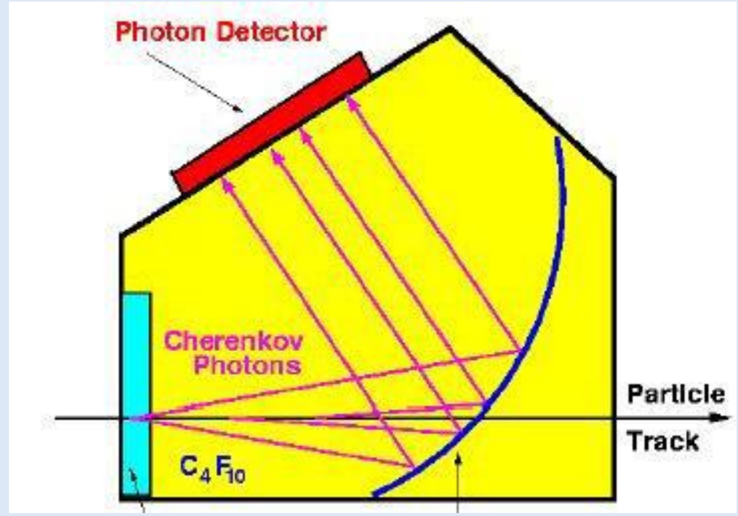
Self-polarized e^+ and e^- beams
27.6 GeV
Helicity switched every few months



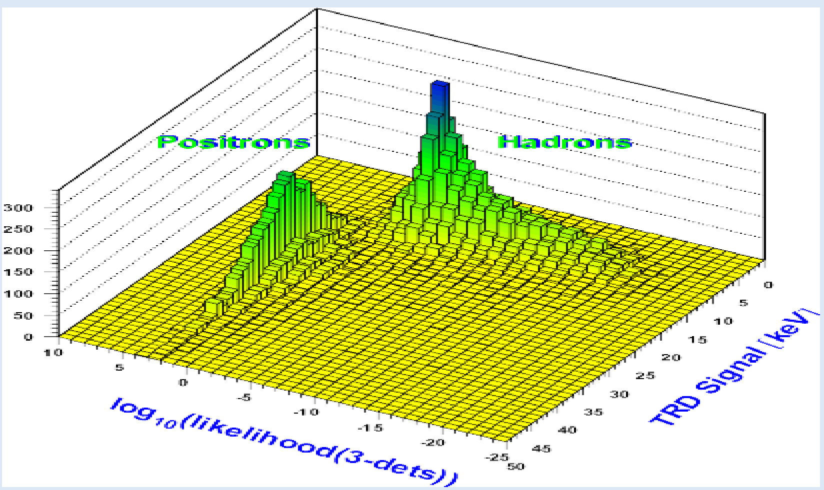
Polarized hydrogen (Long.,Trans.), deuterium (Long.)
Polarization flipped at 60-180 s time interval
Unpolarized *He,N,Ne,Kr,Xe*

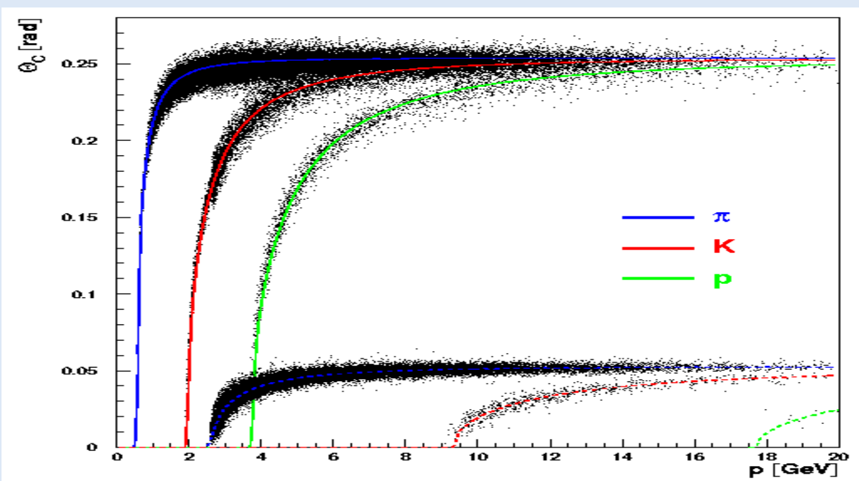
The HERMES Spectrometer





Aerogel Mirror



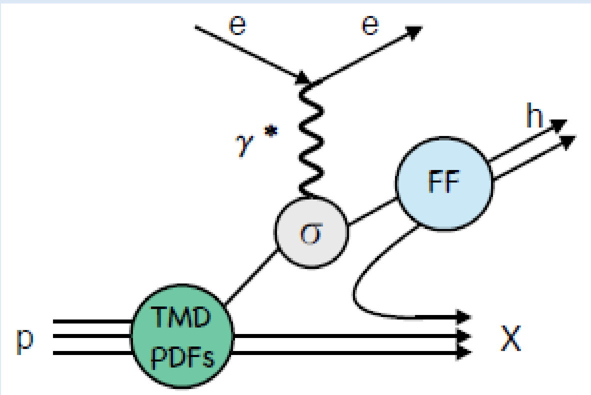


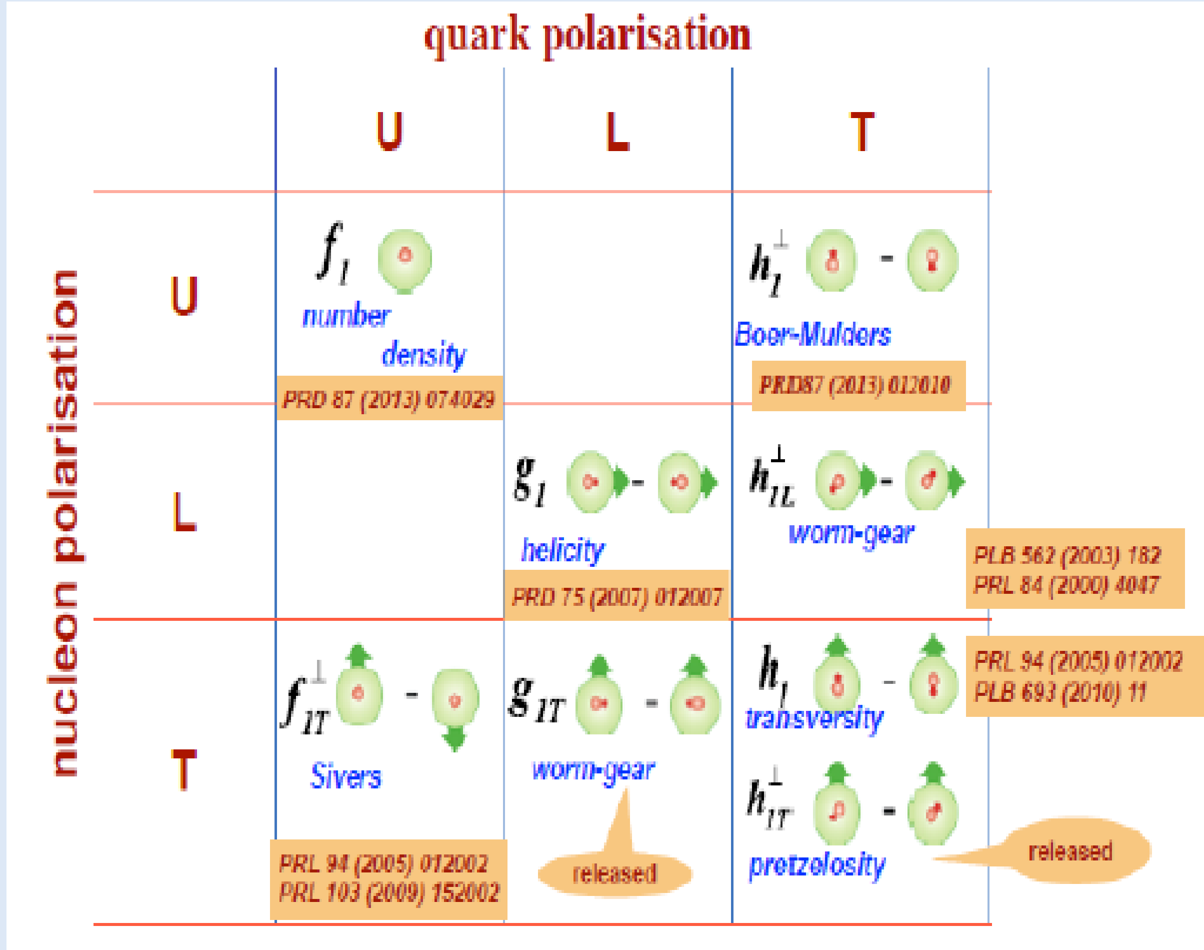
- PID: RICH, TRD, Preshower and Calorimeter; lepton-hadron > 98%
- Momentum resolution of charged particles: $\delta P/P \simeq 1.5\%$

A_{UT} & A_{LT}, A_{LU} in semi-inclusive DIS

- *Unpolarized* & longitudinally polarized e^+/e^- beam
- Transversely polarized H target
- *Unpolarized* H & D targets

Semi-inclusive DIS processes (SIDIS)



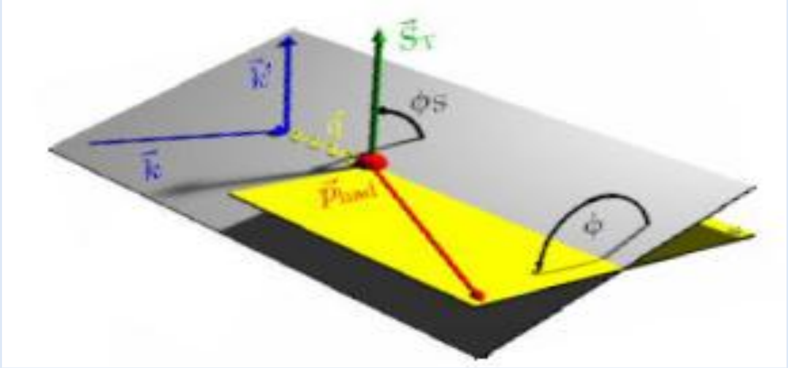


SIDIS processes:

- Describe spin-orbit correlation: correlations between the hadron transverse momentum and quark or nucleon spin
- Sensitive to quark orbital angular momentum

The SIDIS cross-section

$$
\begin{aligned}
\frac{d\sigma^h}{dx\,dy\,d\phi_S\,dz\,d\phi\,d\mathbf{P}^2_{h\perp}} = \quad & \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right) \\
\Big\{ \quad & \Big[F_{\mathrm{UU,T}} + \epsilon F_{\mathrm{UU,L}} \\
& + \sqrt{2\epsilon(1+\epsilon)}\cos(\phi) F_{\mathrm{UU}}^{\cos(\phi)} + \epsilon \cos(2\phi) F_{\mathrm{UU}}^{\cos(2\phi)}\Big] \\
+ \quad \lambda_l \; & \Big[\sqrt{2\epsilon(1-\epsilon)}\sin(\phi) F_{\mathrm{LU}}^{\sin(\phi)}\Big] \\
+ S_L \; & \Big[\sqrt{2\epsilon(1+\epsilon)}\sin(\phi) F_{\mathrm{UL}}^{\sin(\phi)} + \epsilon\sin(2\phi) F_{\mathrm{UL}}^{\sin(2\phi)}\Big] \\
+ S_L\,\lambda_l \; & \Big[\sqrt{1-\epsilon^2} F_{\mathrm{LL}} + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi) F_{\mathrm{LL}}^{\cos(\phi)}\Big] \\
+ S_T \; & \Big[\sin(\phi-\phi_S)\left(F_{\mathrm{UT,T}}^{\sin(\phi-\phi_S)} + \epsilon F_{\mathrm{UT,L}}^{\sin(\phi-\phi_S)}\right) \\
& + \epsilon\sin(\phi+\phi_S) F_{\mathrm{UT}}^{\sin(\phi+\phi_S)} + \epsilon\sin(3\phi-\phi_S) F_{\mathrm{UT}}^{\sin(3\phi-\phi_S)} \\
& + \sqrt{2\epsilon(1+\epsilon)}\sin(\phi_S) F_{\mathrm{UT}}^{\sin(\phi_S)} \\
& + \sqrt{2\epsilon(1+\epsilon)}\sin(2\phi-\phi_S) F_{\mathrm{UT}}^{\sin(2\phi-\phi_S)}\Big] \\
+ S_T\,\lambda_l \; & \Big[\sqrt{1-\epsilon^2}\cos(\phi-\phi_S) F_{\mathrm{LT}}^{\cos(\phi-\phi_S)} \\
& + \sqrt{2\epsilon(1-\epsilon)}\cos(\phi_S) F_{\mathrm{LT}}^{\cos(\phi_S)} \\
& + \sqrt{2\epsilon(1-\epsilon)}\cos(2\phi-\phi_S) F_{\mathrm{LT}}^{\cos(2\phi-\phi_S)}\Big]
\end{aligned}
$$



$F_{XY,Z} \propto \mathrm{PDF} \otimes \mathrm{FF}$

X=beam, Y=target,

Z=γ^*polarization

TMD PDFs

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

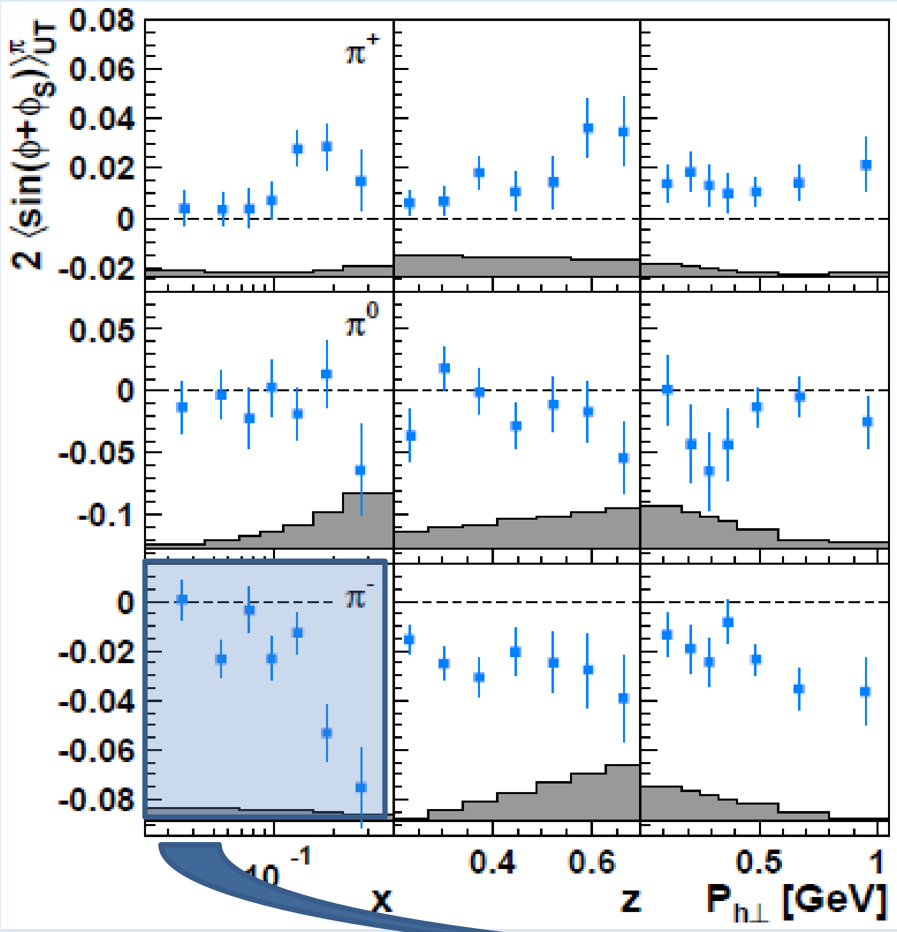
FFs

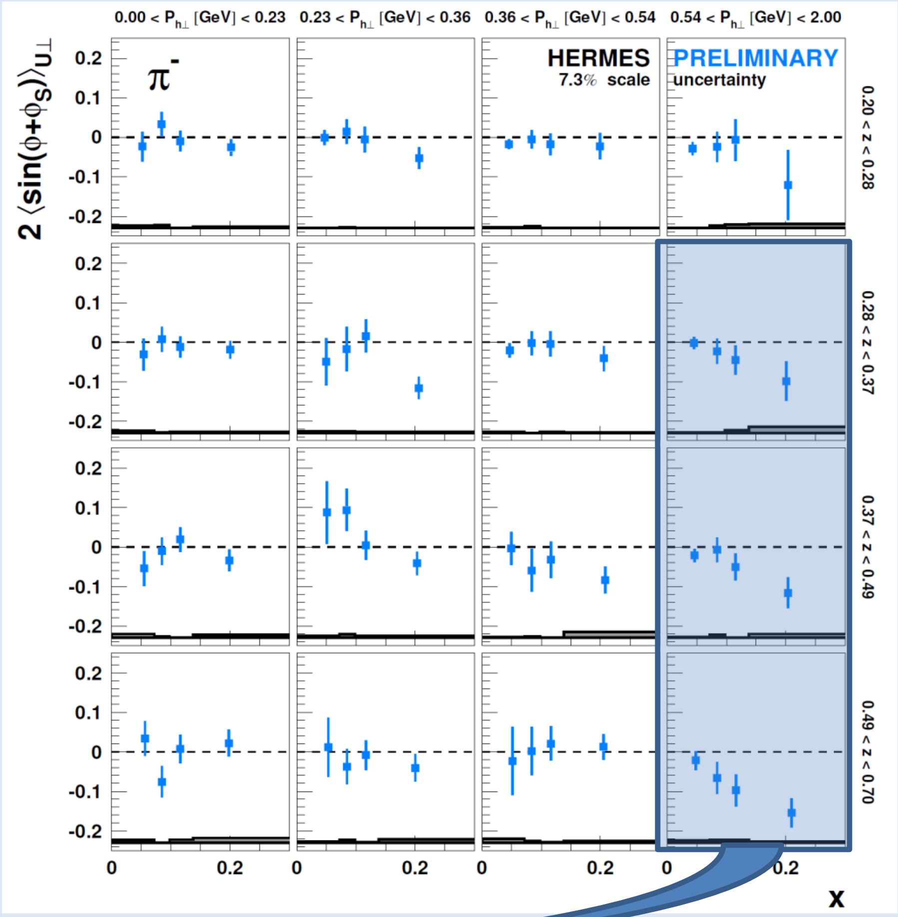
		quark U	quark L	quark T
h	U	D_1		$H_1^\perp$

Collins amplitudes

Phys. Lett. B 693 (2010) 11

$$F_{UT}^{\sin(\phi_h+\phi_S)} \propto h_1\left(x, p_T^2\right) \otimes H_1^{\perp}\left(z, k_T^2\right)$$

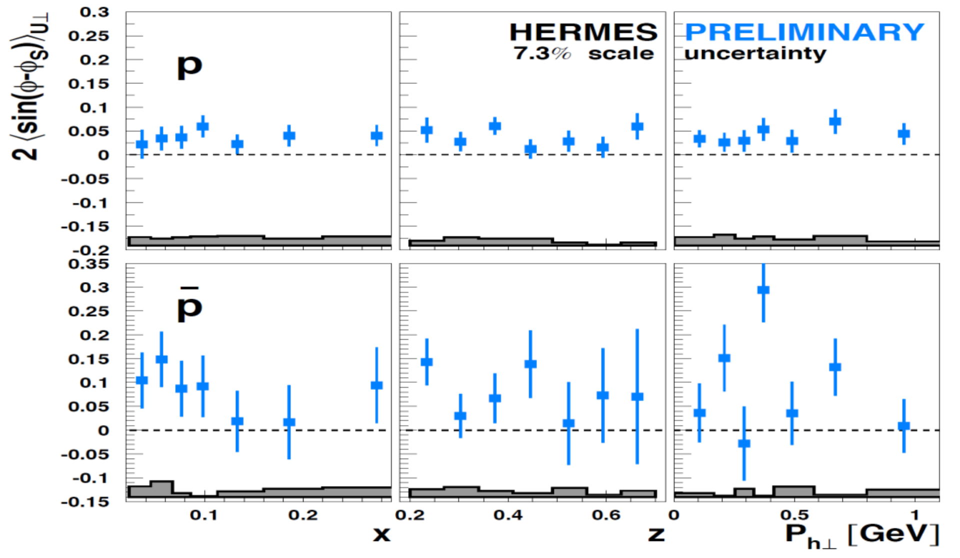


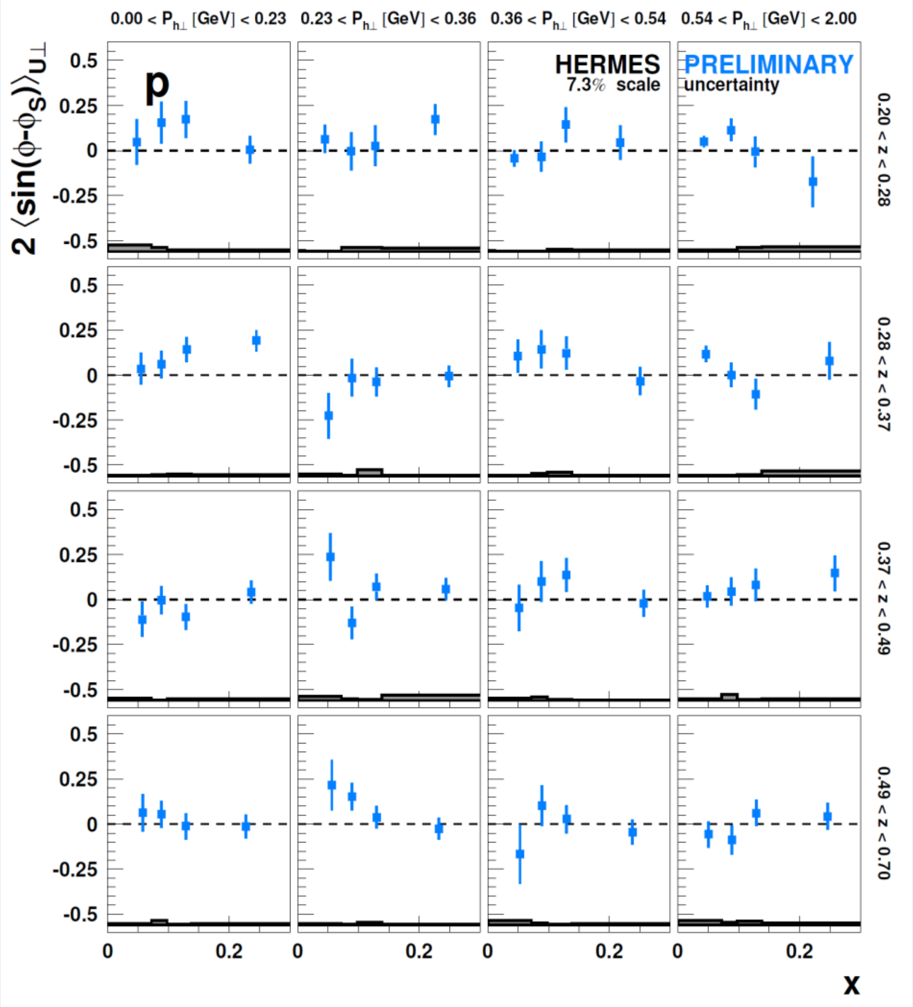


- 3D projections allow to constrain global fits in a more profound way
- π^- amplitudes increasing with x at large $P_{h\perp}$

Sivers amplitudes

$$F_{UT}^{\sin(\phi_h-\phi_S)} \propto f_{1T}^{\perp}\left(x,p_T^2\right)\otimes D_1\left(z,k_T^2\right)$$



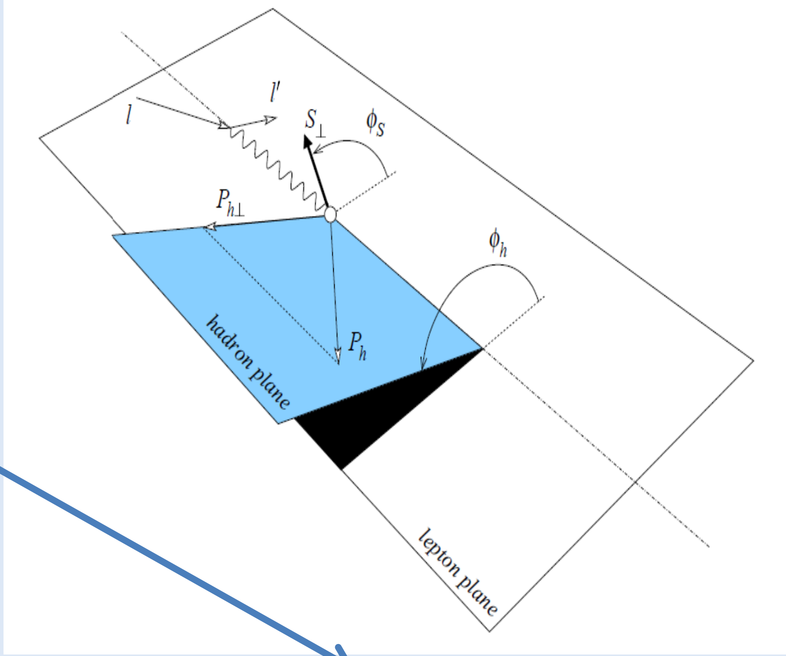


Talk Tue 17h20
by V. Korotkov

- Positive proton amplitudes

The SIDIS cross-section: A_{LU} amplitudes

$$
\begin{aligned}
&\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} = \\
&\frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Bigg\{F_{UU,T}+\varepsilon F_{UU,L}+\sqrt{2\varepsilon(1+\varepsilon)}\cos\phi_h\,F_{UU}^{\cos\phi_h} \\
&\quad+\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}+\lambda_e\sqrt{2\varepsilon(1-\varepsilon)}\sin\phi_h\,F_{LU}^{\sin\phi_h} \\
&\quad+S_\parallel\left[\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_h\,F_{UL}^{\sin\phi_h}+\varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right] \\
&\quad+S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL}+\sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_h\,F_{LL}^{\cos\phi_h}\right] \\
&\quad+|\boldsymbol{S}_\perp|\Bigg[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right) \\
&\qquad+\varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)} \\
&\qquad+\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\varepsilon(1+\varepsilon)}\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Bigg] \\
&\quad+|\boldsymbol{S}_\perp|\lambda_e\Bigg[\sqrt{1-\varepsilon^2}\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_S\,F_{LT}^{\cos\phi_S} \\
&\qquad+\sqrt{2\varepsilon(1-\varepsilon)}\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Bigg]\Bigg\},
\end{aligned}
$$



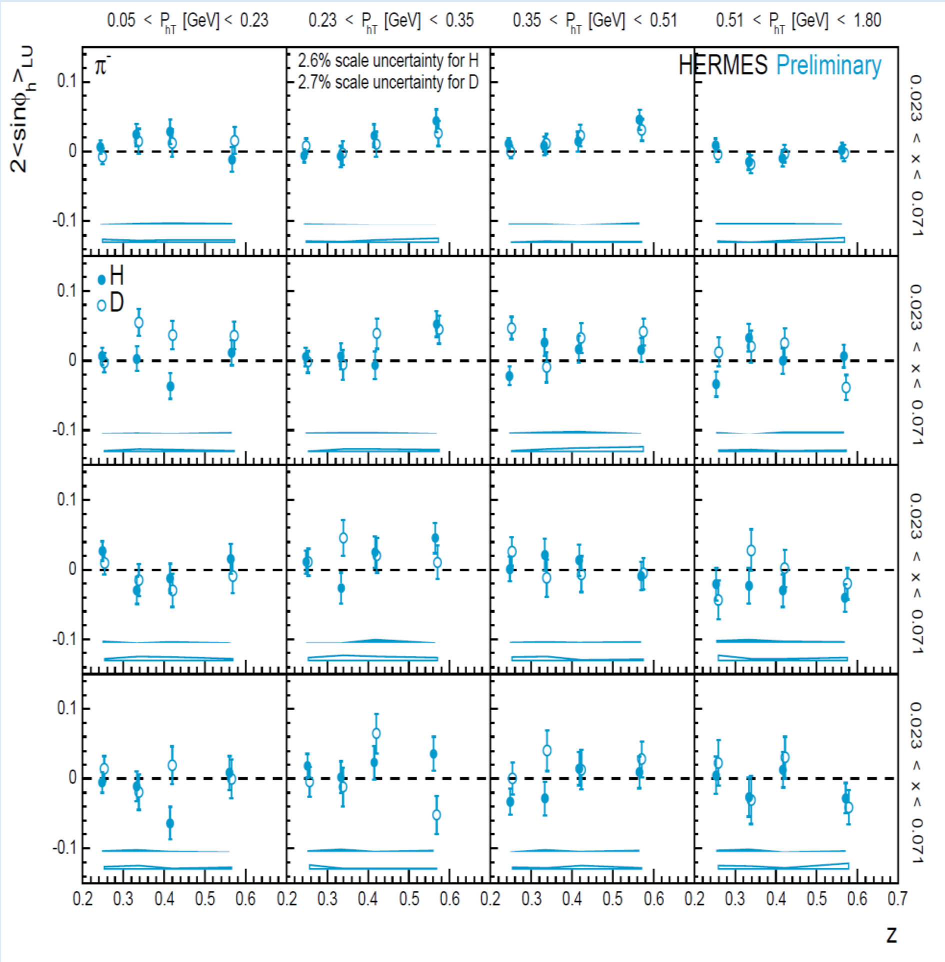
In case of longitudinal beam (L) and unpolarized target (U) only target spin-independent parts can contribute to the asymmetry. The structure function of interest :

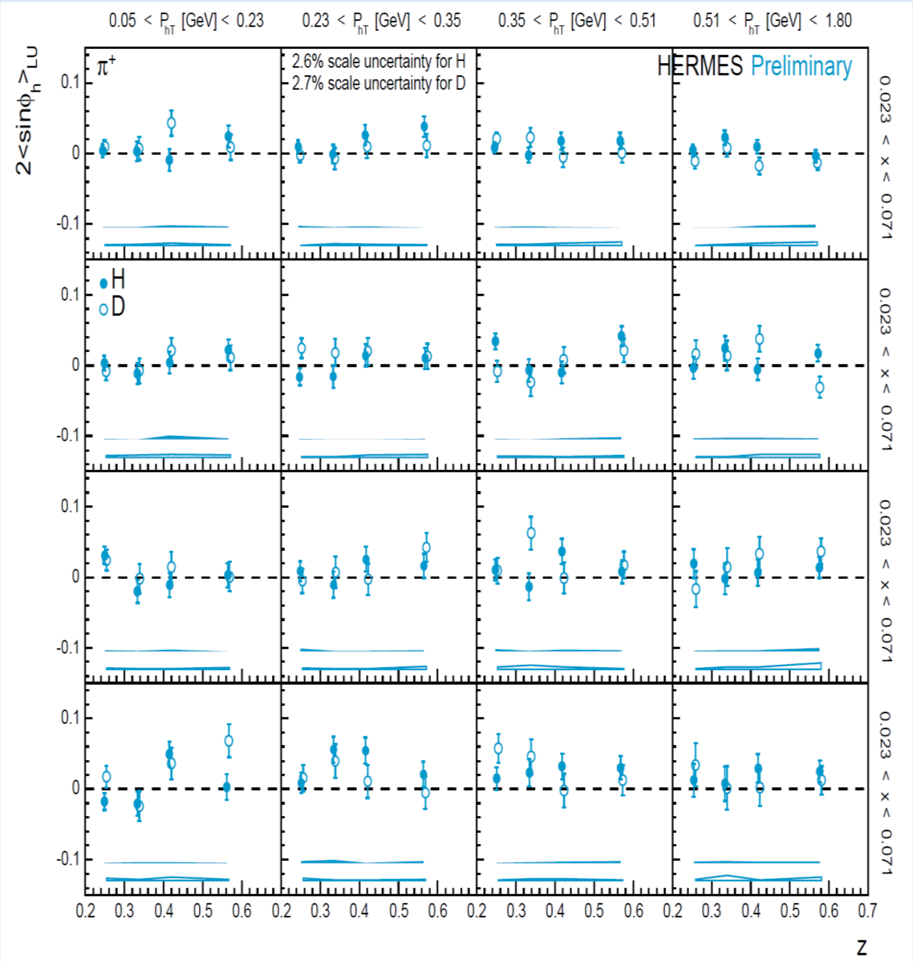
$$F_{LU}^{\sin\phi_h}$$

A_{LU} amplitudes: 3D extraction

$$d\sigma = d\sigma_{UU}^{0} + \cdots + P_l \frac{1}{Q} \sin(\phi)\, d\sigma_{LU}$$

→ Convolution of twist–2 & twist–3 functions





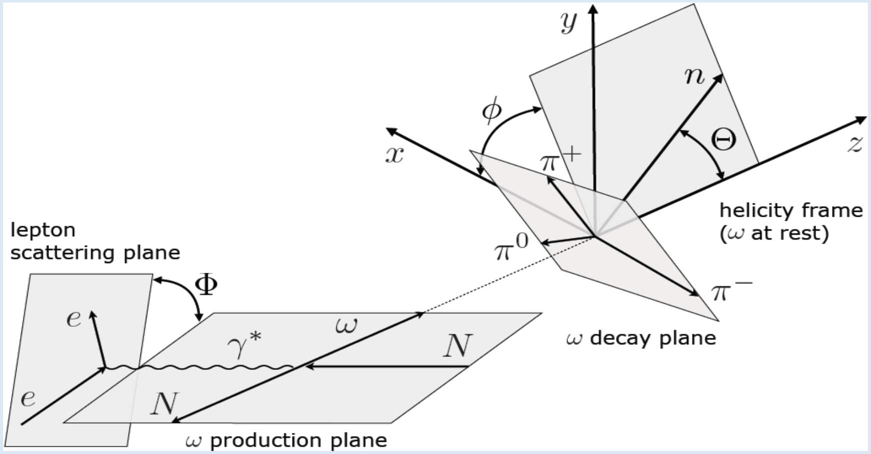
- The role of the twist-3 DF or FF is sizeable

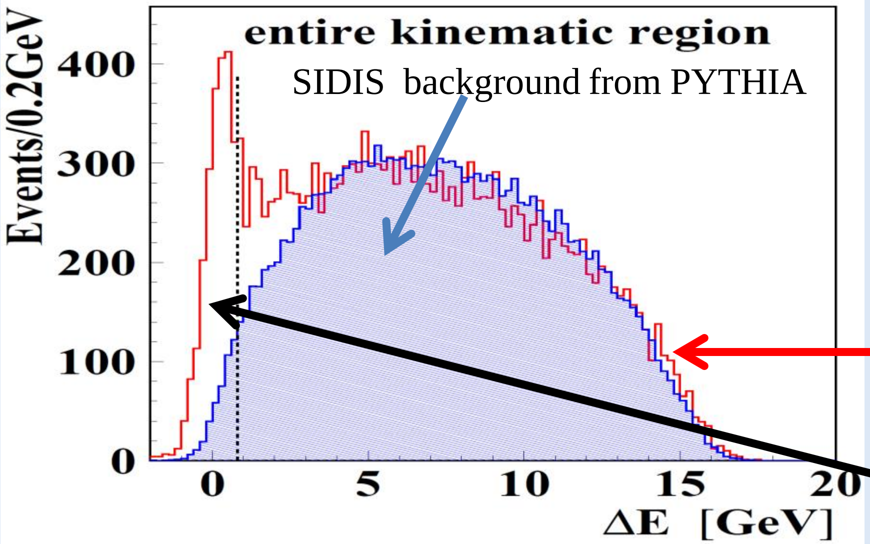
ω –meson production: SDMEs & A_{UT} from exclusive DIS

- *Unpolarized* & longitudinally polarized e^+/e^- beam
- Unpolarized H & D targets
- Transversely polarized H targets

Exclusive ω - meson production at HERMES

$$e(k) + N(p) \to e(k') + N(p') + \omega$$
$$\omega \to \pi^+ \pi^- \pi^0, \quad \pi^0 \to 2\gamma$$





Kinematic conditions:

$$1\ \mathrm{GeV}^2 < Q^2 < 10\ \mathrm{GeV}^2,$$
$$0.01 < x_B < 0.35,$$
$$3.0\ \mathrm{GeV} < W < 6.3\ \mathrm{GeV},$$
$$0 \le -t' = -(t - t_{min}) < 0.2\ \mathrm{GeV}^2$$

Two photon invariant mass:

$$0.11\ \mathrm{GeV} < M(\gamma\gamma) < 0.16\ \mathrm{GeV}$$

Three-pion invariant mass:

$$0.71\ \mathrm{GeV} < M(\pi^+\pi^-\pi^0) < 0.87\ \mathrm{GeV}$$

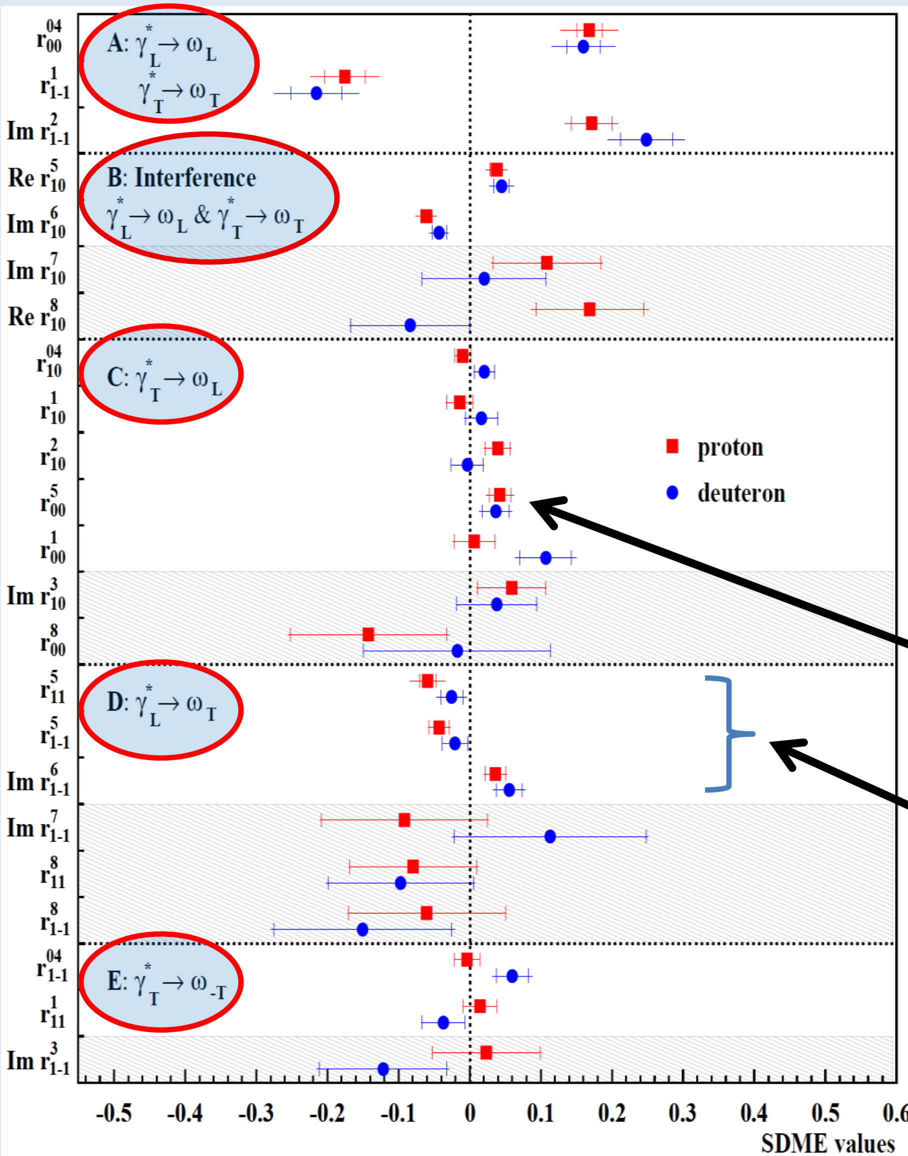
Missing energy:

$$\Delta E = \frac{M_X^2 - M_p^2}{2M_p}, \quad M_X^2 = (p + q - p_{\pi^+} - p_{\pi^-} - p_{\pi^0})^2$$

Exclusive region: $-1.0\ \mathrm{GeV} < \Delta E < 0.8\ \mathrm{GeV}$

SDMEs in exclusive ω production

Eur. Phys. J. C 74 (2014) 3110



- 5 classes of SDMEs
- Unpolarized and polarized SDMEs
- Similar magnitudes of SDMEs on proton & deuteron
- SCHC (S-Channel Helicity Conservation): holds for class – A & class – B SDMEs:

$$\begin{cases} r^1_{1-1} = -\mathrm{Im}\, r^2_{1-1} \\ \mathrm{Re}\, r^5_{10} = -\mathrm{Im}\, r^6_{10} \\ \mathrm{Im}\, r^7_{10} = \mathrm{Re}\, r^8_{10} \end{cases}$$

- SCHC: slightly violated for class – C

$r^5_{00} \neq 0$ by 3(2) σ for p(d)

- SCHC: slightly violated for class – D

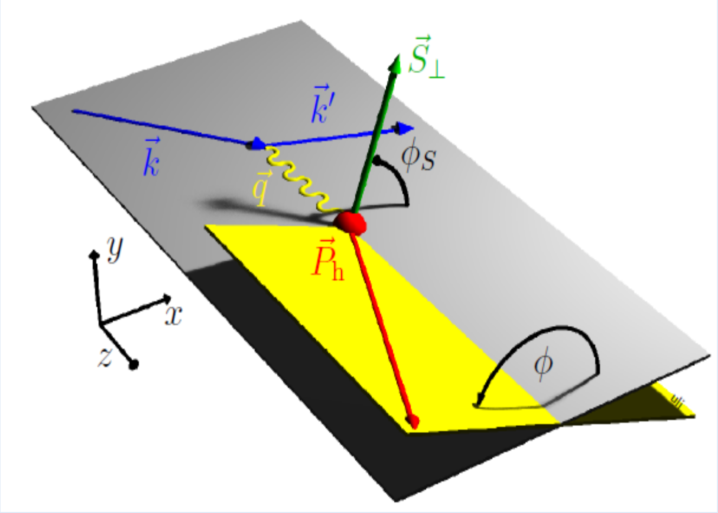
$r^5_{11} + r^5_{1-1} - \mathrm{Im}\, r^6_{1-1} \neq 0$ by 3(2.5) σ for p(d)

Talk Tue 17h50
by S. Manaenkov

Exclusive ω - meson production: A_{UT} asymmetry

$e(k) + N(p) \to e(k') + N(p') + \omega$

$\omega \to \pi^+ \pi^- \pi^0, \ \pi^0 \to 2\gamma$



Angular dependent part

$$w(\phi,\phi_S) = 1 + A_{UU}^{\cos(\phi)}\cos(\phi) + A_{UU}^{\cos(2\phi)}\cos(2\phi)$$

$$+S_\perp\Big[A_{UT}^{\sin(\phi+\phi_S)}\sin(\phi+\phi_S) + A_{UT}^{\sin(\phi-\phi_S)}\sin(\phi-\phi_S)$$

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

$$w(\phi,\phi_S,\theta) = \frac{3}{2}r_{00}^{04}\cos^2(\theta)\,w_L(\phi,\phi_S) + \frac{3}{4}\left(1-r_{00}^{04}\right)\sin^2(\theta)\,w_T(\phi,\phi_S)$$

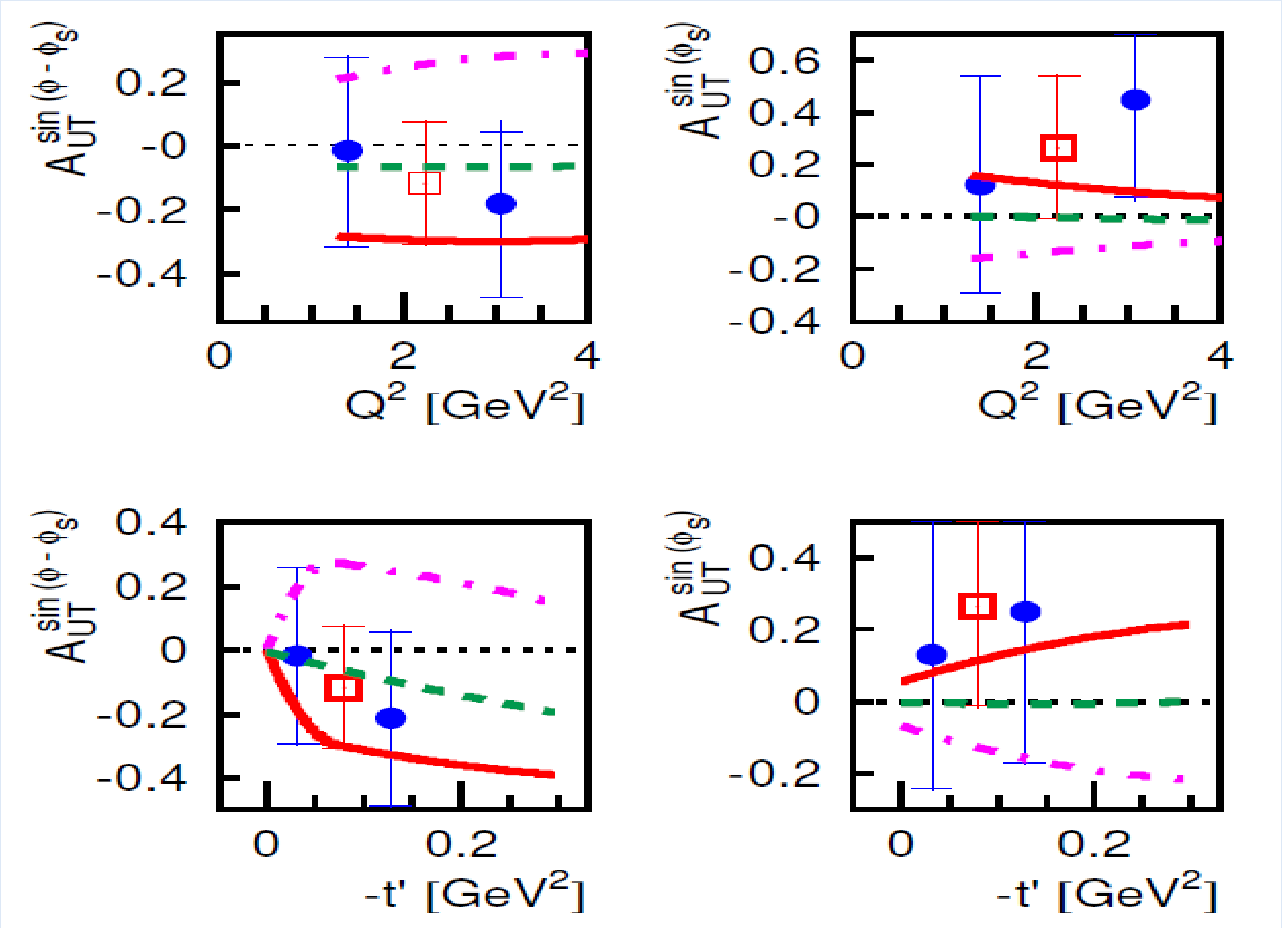
$$w_L(\phi,\phi_S) = 1 + A_{UU,L}(\phi) + S_\perp A_{UT,L}(\phi,\phi_S)$$

$$w_T(\phi,\phi_S) = 1 + A_{UU,T}(\phi) + S_\perp A_{UT,T}(\phi,\phi_S)$$

Fit angular distributions of ω–decay pions

Exclusive ω - meson production: amplitudes of A_{UT}

Submitted to EPJC: arXiv:1508.07612[hep-ex]



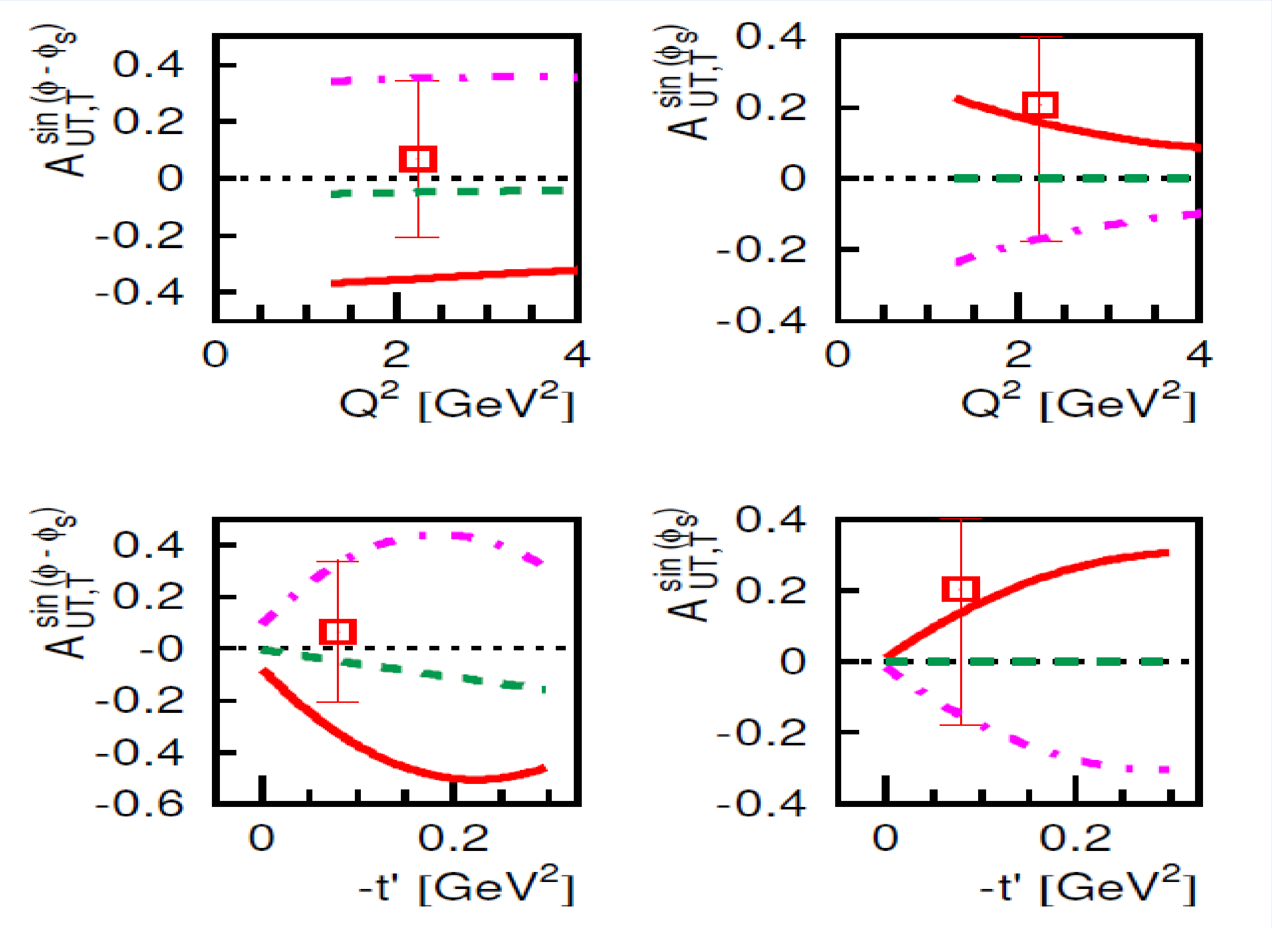
GK model
S. Goloskokov & P. Kroll,
Eur. Phys. J. A 50 (2014) 146
& Private communication

Talk Tue 17h50
by S. Manaenkov

- The solid (dash-dotted) lines show the calculation of the GK model for a positive (negative) $\pi\omega$ transition form factor
- Dashed lines are the model results without the pion pole.

Transversely polarized ω - meson: amplitudes of $A_{UT,T}$

Submitted to EPJC: arXiv:1508.07612[hep-ex]



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- The solid (dash-dotted) lines show the calculation of the GK model for a positive (negative) πω transition form factor
- Dashed lines are the model results without the pion pole.

Bose-Einstein correlations in DIS

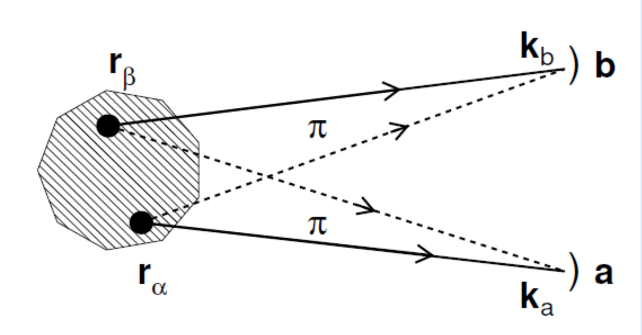
- *Unpolarized* e^+/e^- beam
- H, D, ^3He, ^4He, N, Ne, Kr, Xe target

Bose-Einstein correlations

- Incoherent source of identical bosons
- Symmetry of wave function under exchange of identical bosons

⇓

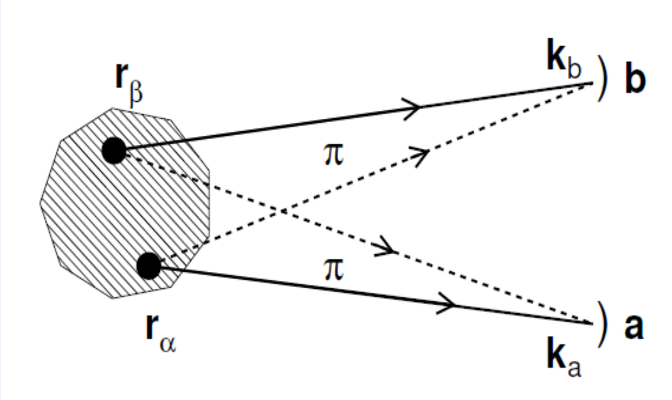
These correlations arise from interference between different parts of the symmetrized wave function



Measurement of source distribution

- Measurement of stellar radii (correlations of photons) by R. Hanbury Brown and R.Q. Twiss in 1956.
- First in particle physics: correlations of pions from proton-antiproton collisions: Goldhaber in1959.
- Widely used in heavy-ion collisions, study of “fireball” source distribution.
- Several studies in e^+e^- annihilation process: LEP experiments.
- Measurement from DIS lepton scattering experiments are far less abundant.

Bose-Einstein correlations function R



<u>Goldhaber parametrization</u> of continuous space-time distribution of sources

$$R(T) = 1 + \lambda \exp\left(-T^2 r_G^2\right)$$

- Gaussian shape of the particle source distribution
- r_G is the source distribution size
- $T^2=-(p_1-p_2)^2$, p_1 & p_2 are the particle four-momenta
- λ=0: for perfectly coherent sources; no correlation
  Λ=1: for completely incoherent sources

- Two-point sources:

$$R(k_\alpha, k_\beta) \propto 1 + \cos(\delta k, \delta r)$$

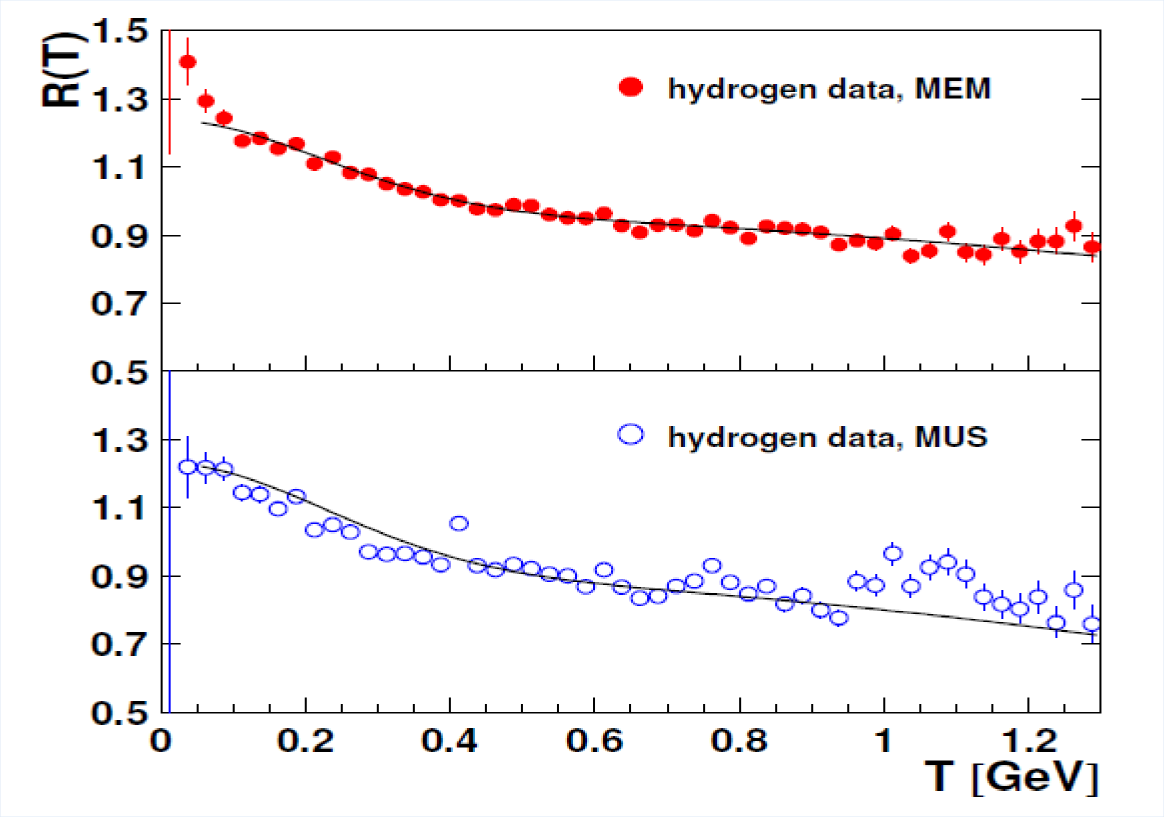
<u>Extraction of experimental correlation function: from data with like–sign unidentified hadrons</u>

$$R(p_1, p_2) = D(p_1, p_2) / D_r(p_1, p_2)$$

- Reference sample free from BEC, built from
  - Method of unlike–sign pairs (MUS)
  - Method of event mixing (MEM)

Results: double ratio correlations for hydrogen

Eur. Phys. J. C 75 (2015) 361



MEM

$$r_G = 0.64 \pm 0.03(\text{stat})^{+0.04}_{-0.04}(\text{sys})\text{fm}$$

$$\lambda = 0.28 \pm 0.01(\text{stat})^{+0.00}_{-0.05}(\text{sys})\text{fm}$$

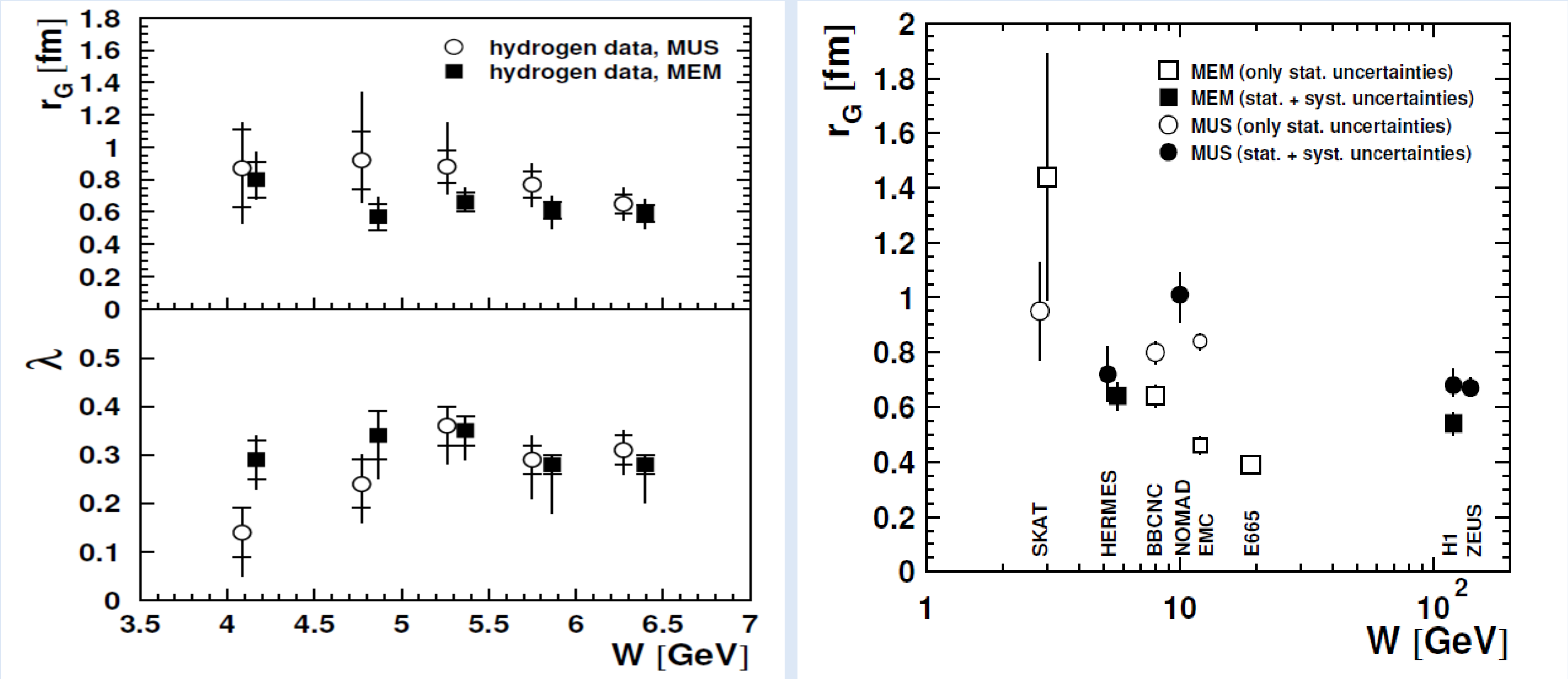
MUS

$$r_G = 0.72 \pm 0.04(\text{stat})^{+0.09}_{-0.09}(\text{sys})\text{fm}$$

$$\lambda = 0.28 \pm 0.02(\text{stat})^{+0.02}_{-0.04}(\text{sys})\text{fm}$$

Comparison to other experiments

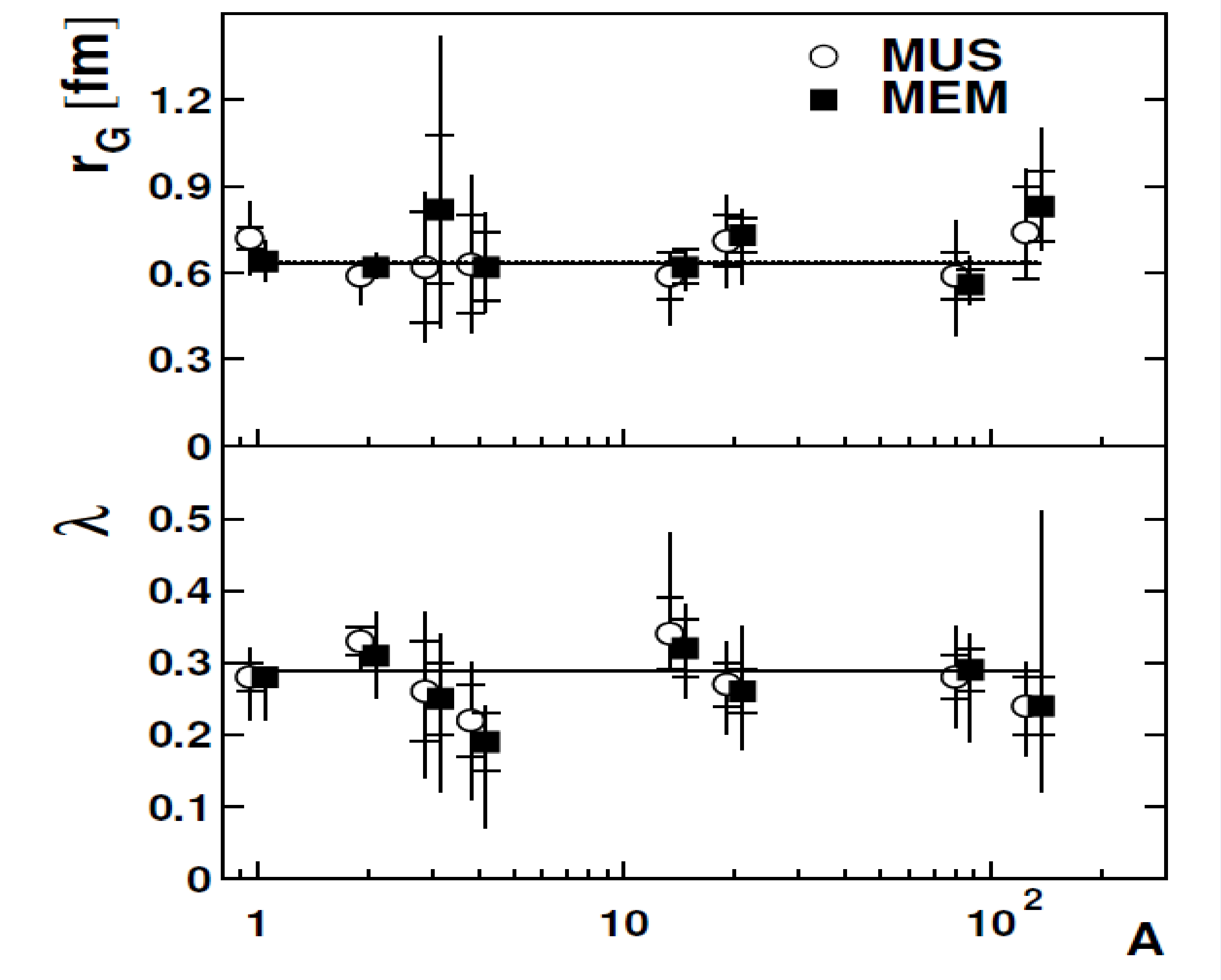
Eur. Phys. J. C 75 (2015) 361



- General agreement between experiments, with 0.4 fm < r_G < 1.0 fm
- Hermes & BBCNC agree well
- MUS values are higher than MEM

Nuclear-mass dependence

Eur. Phys. J. C 75 (2015) 361



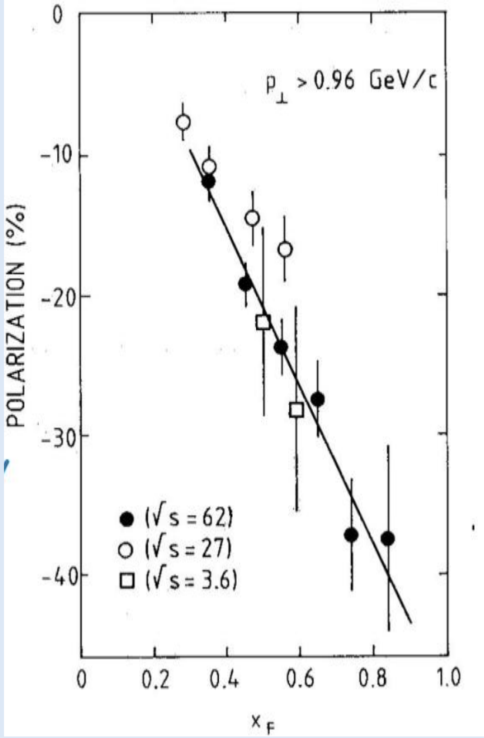
- no dependence on nuclear mass A observed

Λ polarization in quasi-real photoproduction

- *Unpolarized* e^+/e^- beam
- H, D, He, Ne, Kr, Xe target

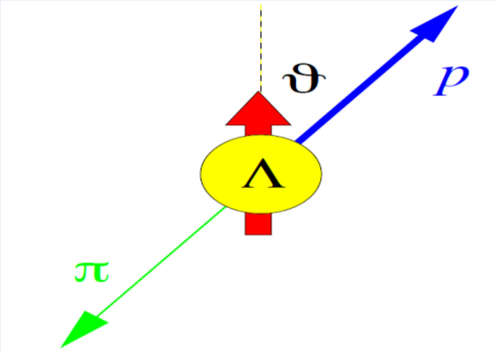
Λ polarization in quasi-real photoproduction

- Large transverse polarization of Λ P^{Λ} is observed in unpolarized hadron-nucleon/nucleus, nucleus-nucleus collisions: Bunce et al.
- Vast majority: negative polarization values are observed, except positive for $K^{-}p$ and $\Sigma^{-}N$
- Magnitude of the polarization increases with x_F and p_T, reaching plateau for p_T=1 GeV



A.D. Panagiotou. Int.J.Mod.Phys. A 5 (1990) 1197

- No generally accepted theoretical explanation!
  Recent developments based on twist-3 factorization of TMDs & FFs;
  SIDIS (high Q^2): $P^{\Lambda} \propto D_{1T}^{\perp}(z, k_T)$, polarising FF
- Current measurement: inclusive ($Q^2 \approx 0$)
- $e\, p \to \Lambda^{\uparrow} X \to p\, \pi^{-} X$

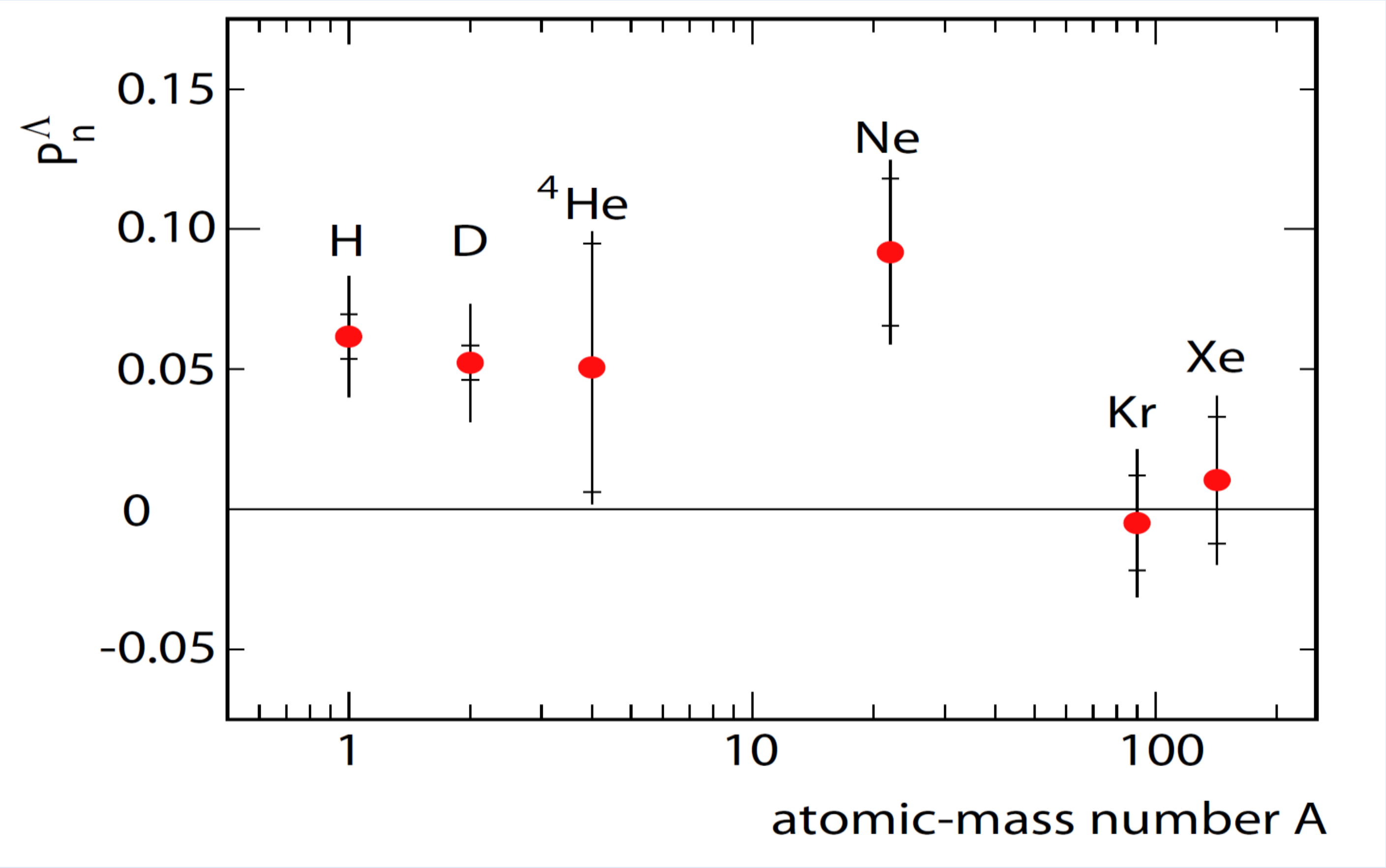


parity-violating weak decay of Λ: in Λ rest frame, proton preferably emitted along Λ spin direction

$$\frac{dN}{d\Omega_p} = \frac{dN_0}{d\Omega_p}\left(1 + \alpha P^{\Lambda} \cos\theta_p\right)$$

Atomic-mass dependence

Phys. Rev. D 90 (2014) 072007

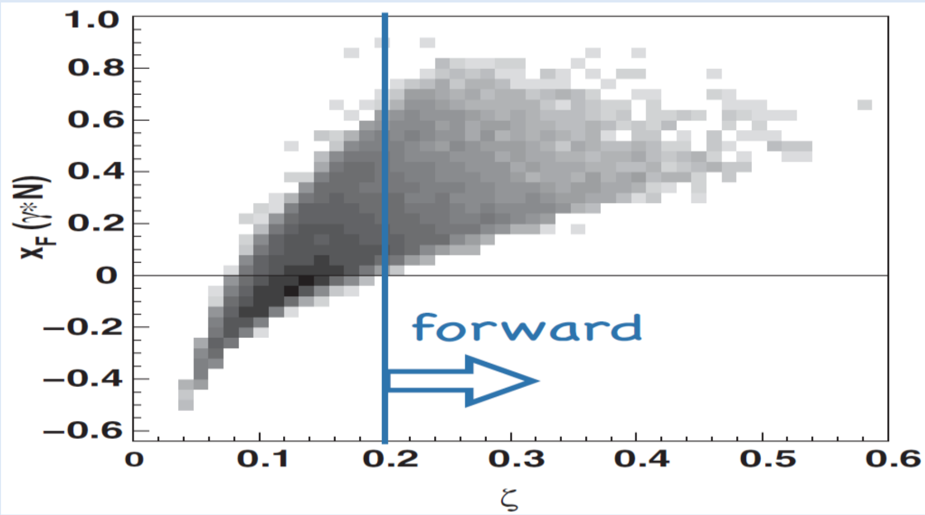


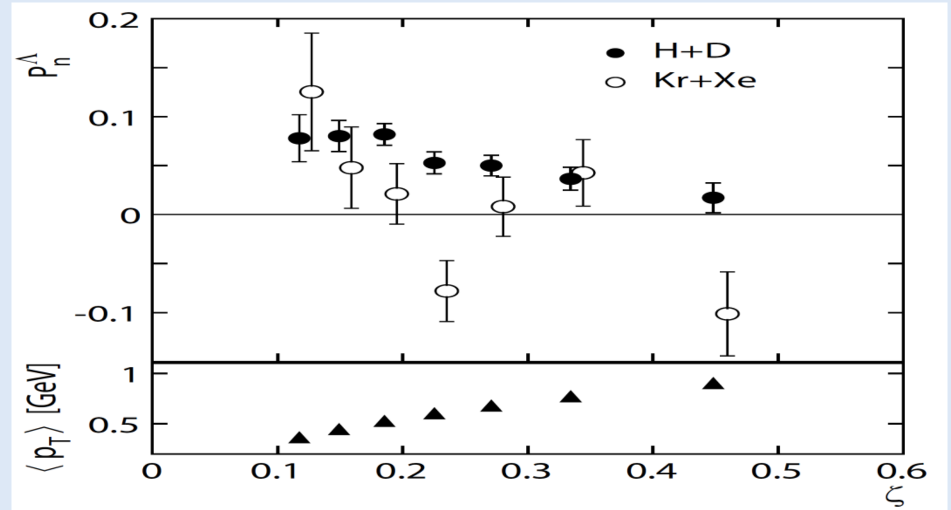
- Positive P_n^{Λ} for light nuclei
- P_n^{Λ} is consistent with zero for heavier nuclei

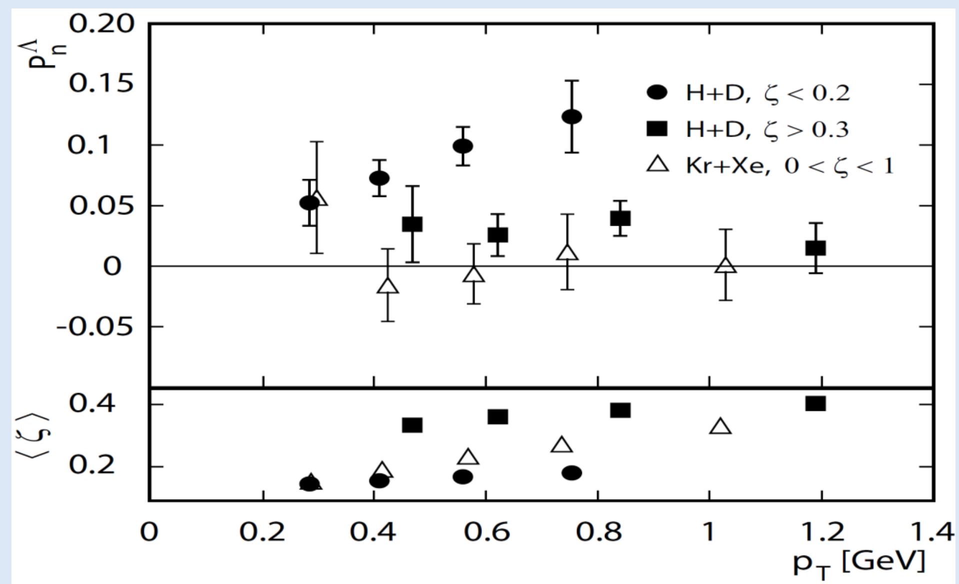
Kinematic dependencies

$$\zeta = \left(E_\Lambda + p_{z\Lambda}\right)/\left(E_e + p_e\right)$$

Phys. Rev. D 90 (2014) 072007







- H+D: P_n^Λ is larger in backward region of "light-cone momentum fraction" ζ: Possible influence of current & target fragmentation
- H+D: P_n^Λ increases with p_T in backward region, while constant in forward region

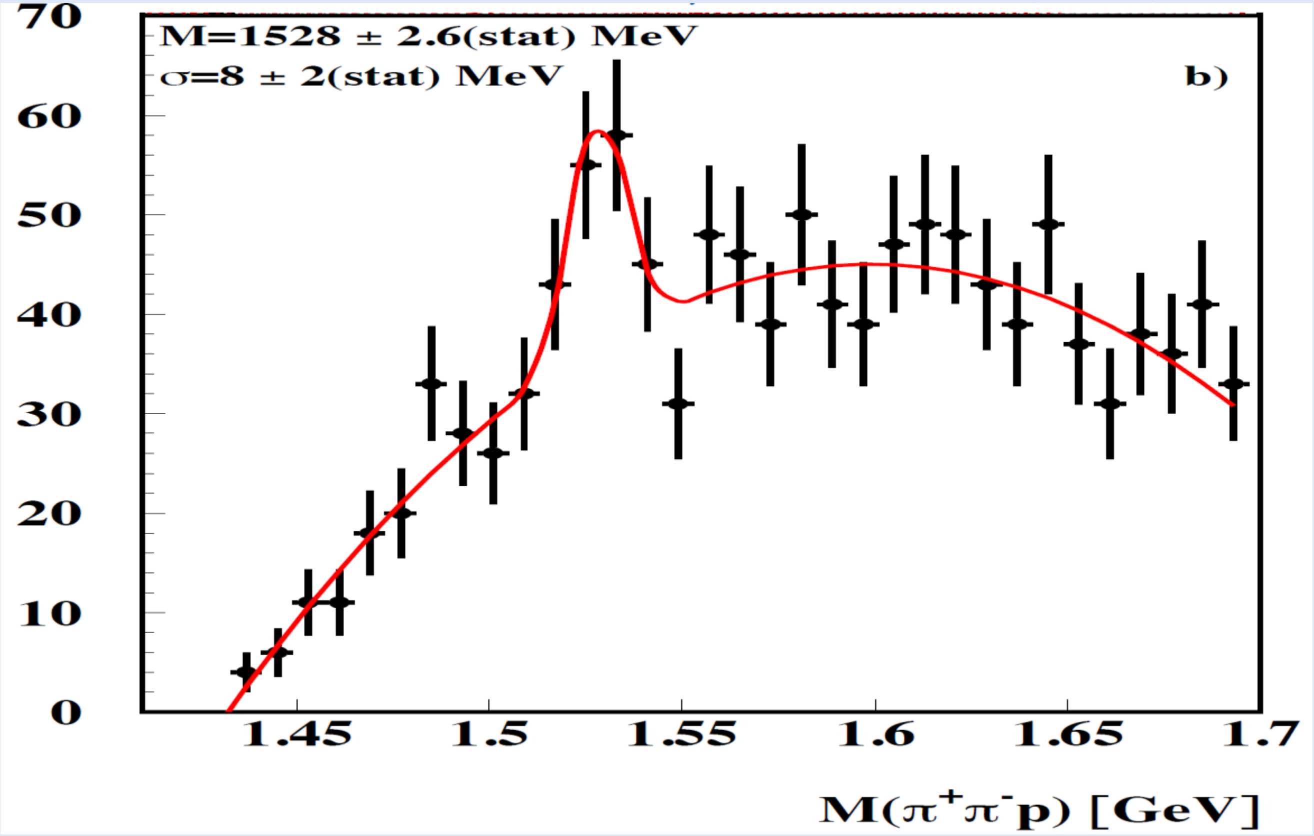
Searching for the pentaquark in quasi-real photoproduction

- *Unpolarized* e^+/e^- beam
- H, D target

Searching for the pentaquark at HERMES in 2004

$$e\,D \rightarrow \Theta^{+} X \rightarrow p\,K_S^{0} X \rightarrow p\,\pi^{+}\pi^{-} X$$

Phys. Lett. B 585 (2004) 213



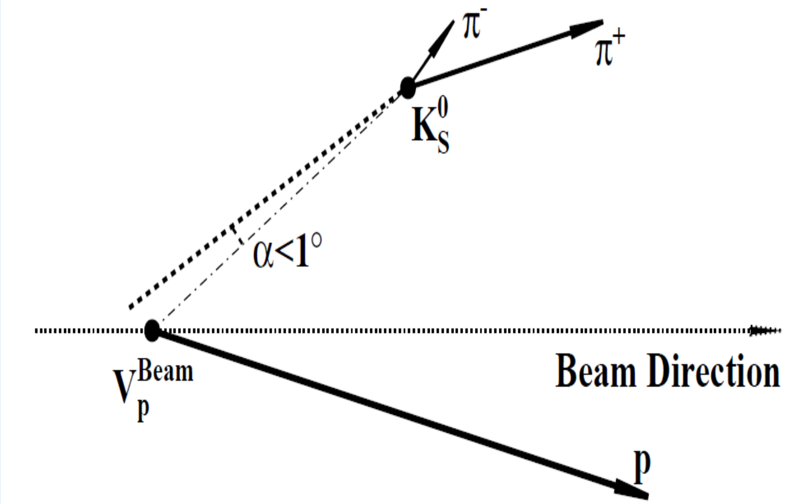
- Significance: 3.7 σ

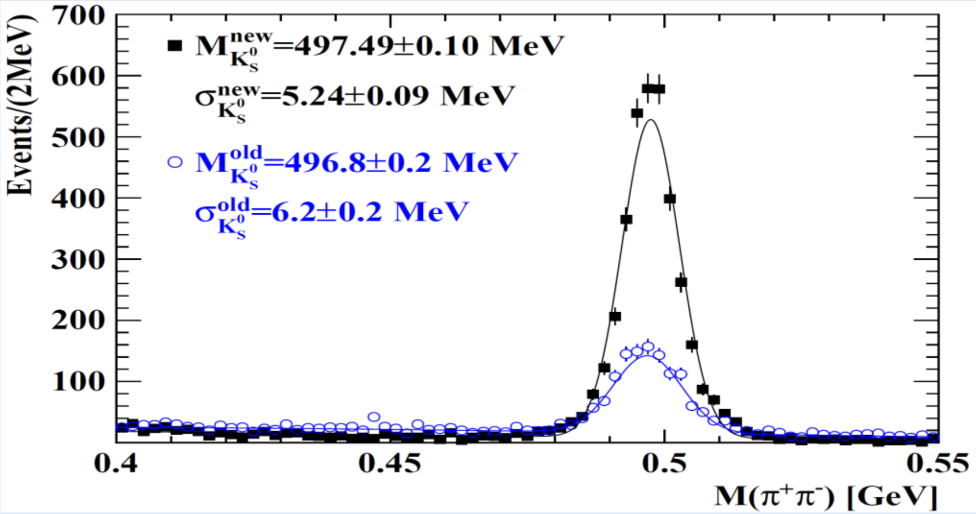
Searching for the pentaquark at HERMES in 2015

$$e\,N \rightarrow \Theta^{+} X \rightarrow p\,K_S^0 X \rightarrow p\,\pi^{+}\pi^{-} X$$

- The major modifications compared to previous analysis: Phys. Lett. B 585 (2004) 213
  - Increased statistics
  - Event-level algorithm for PID from RICH, compared to track-level algorithm
  - Improved event-level fitting track reconstruction, based on Kalman-filter algorithm
  - K_S^0 reconstruction based on track geometry, instead on PID

Phys. Rev. D 91 (2015) 057101

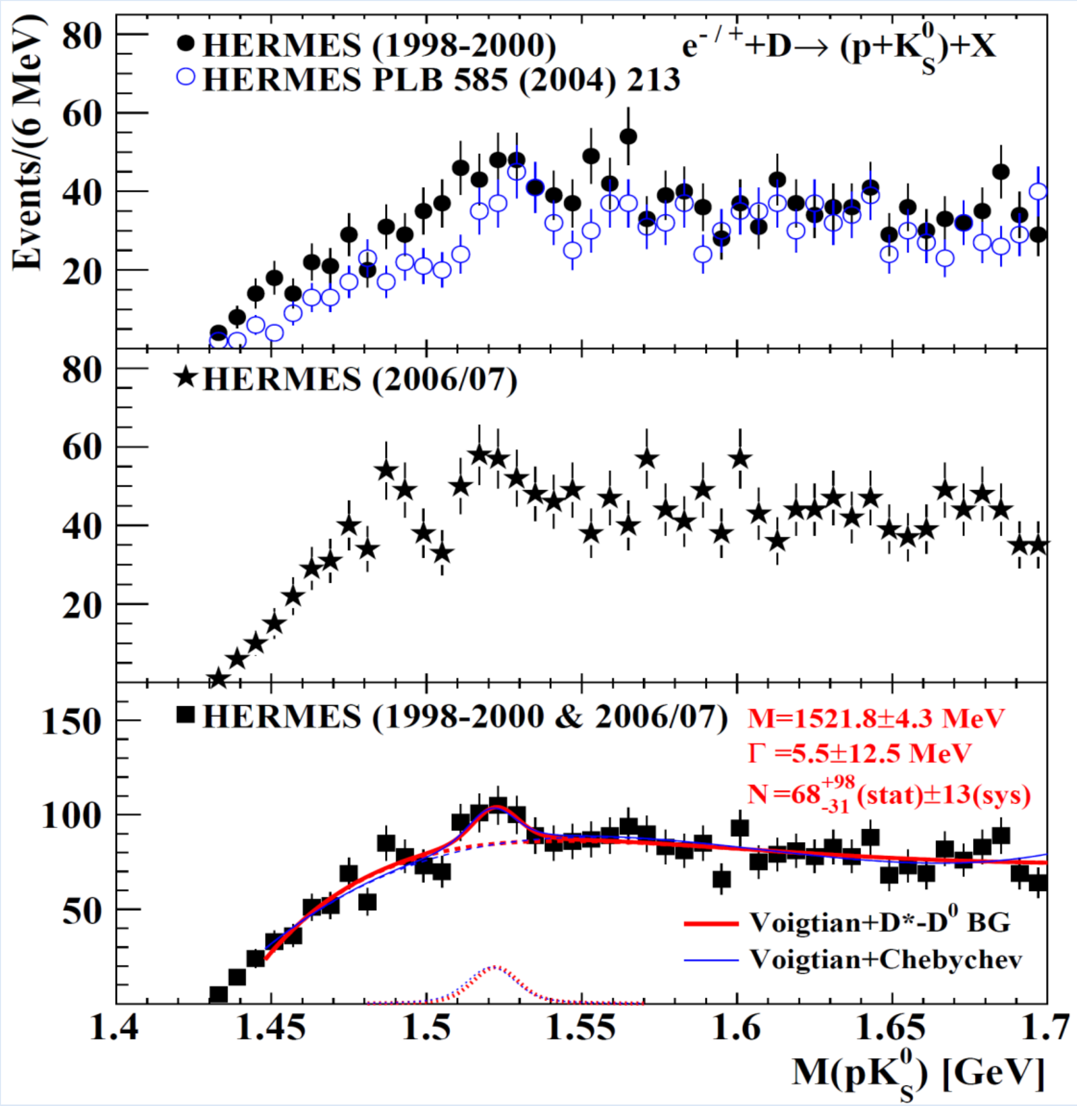




2004	2015
K_S^0: 963 ± 38	K_S^0: 3311 ± 60
Bg. events: 180 ± 15	Bg. events: 87 ± 11

Searching for the pentaquark at HERMES in 2015

Phys. Rev. D 91 (2015) 057101



- peak at 1521.8 ± 4.3 MeV
- Number of signal events:
  N=68 (stat.)± 13 (sys.)
- Significance: 2 σ
- No evidence for Θ^+ resonance on H

Summary

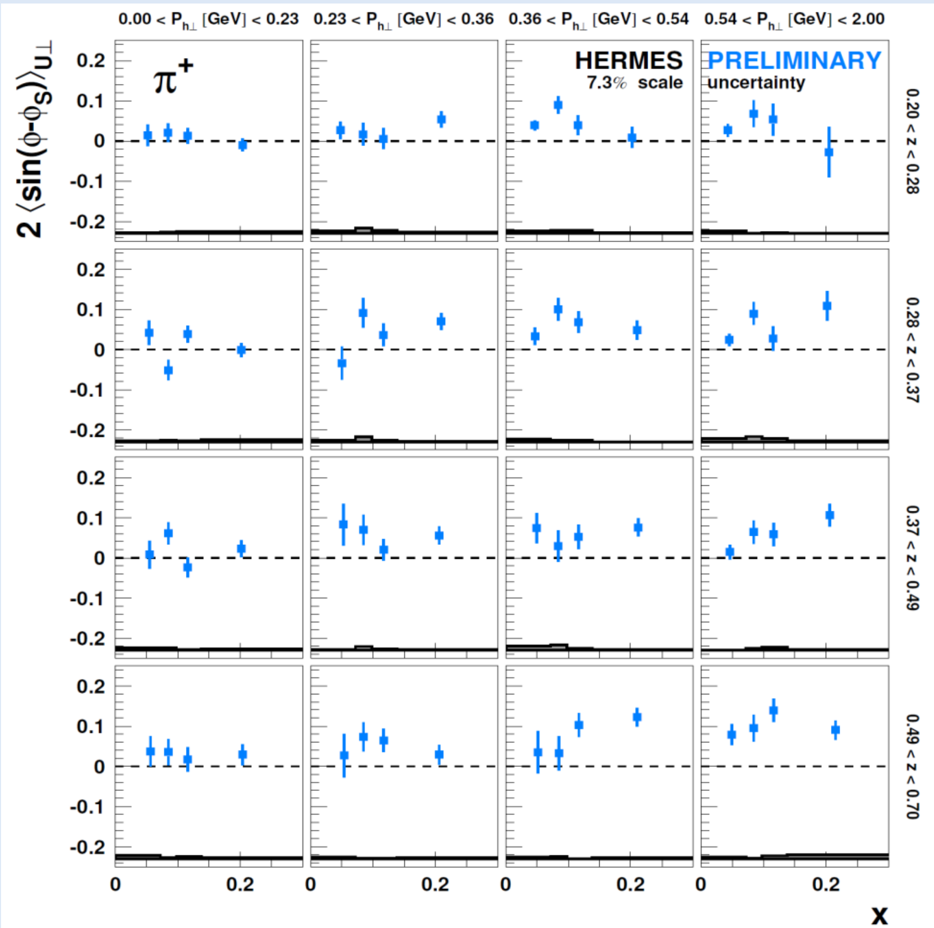
- 3D picture of the nucleon:
  - A_{UT} and A_{LT} in semi-inclusive DIS: 3D extraction, including protons: contribute to understanding of various TMD PDFs @ twist 2 and twist 3.
  - A_{LU} in semi-inclusive DIS: 3D extraction.
  - ω SDMEs & A_{UT} asymmetry amplitudes from exclusive DIS: good model description with inclusion of pion pole.
- Bose-Einstein correlations in DIS: clear signals are observed, no evidence for target-mass dependence.
- Λ polarization in quasi-real photoproduction: positive values for light nuclei; values compatible with zero for Kr and Xe.
- Searching again for the pentaquark in quasi-real photoproduction at HERMES: no evidence for Θ^+ resonance.

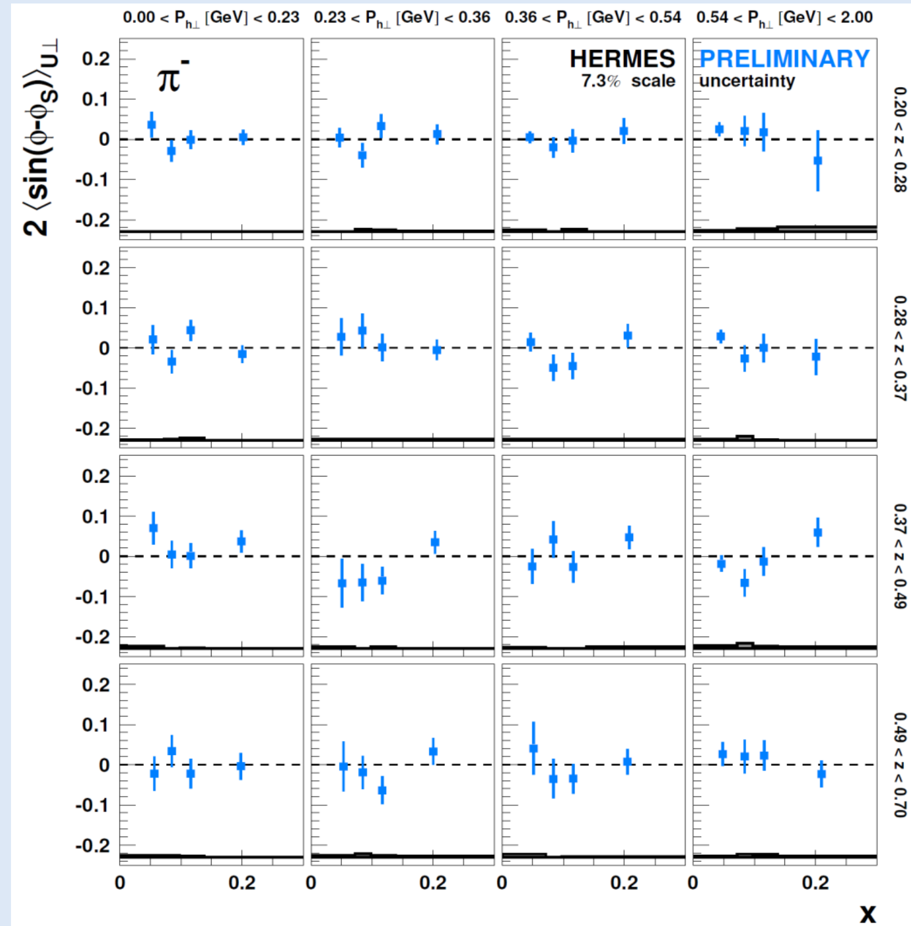
Thank You

Backup Slides

Sivers amplitudes

$$F_{UT}^{\sin(\phi_h-\phi_S)} \propto f_{1T}^{\perp}\left(x, p_T^2\right) \otimes D_1\left(z, k_T^2\right)$$

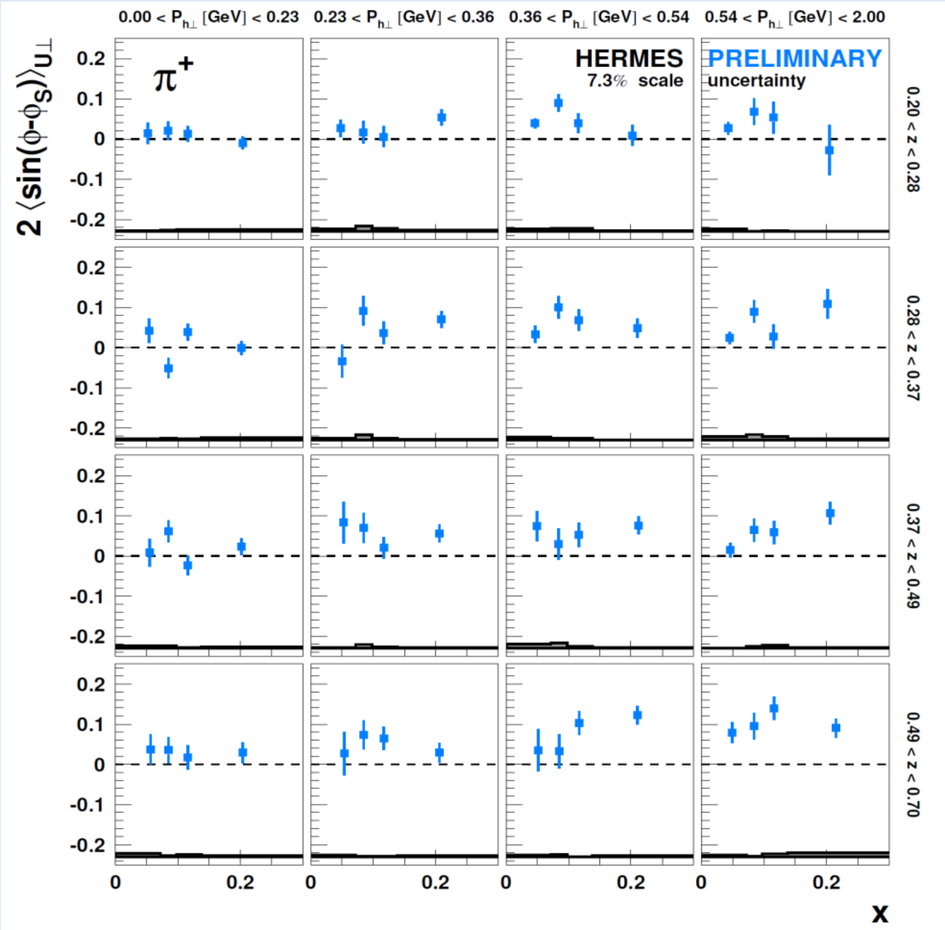


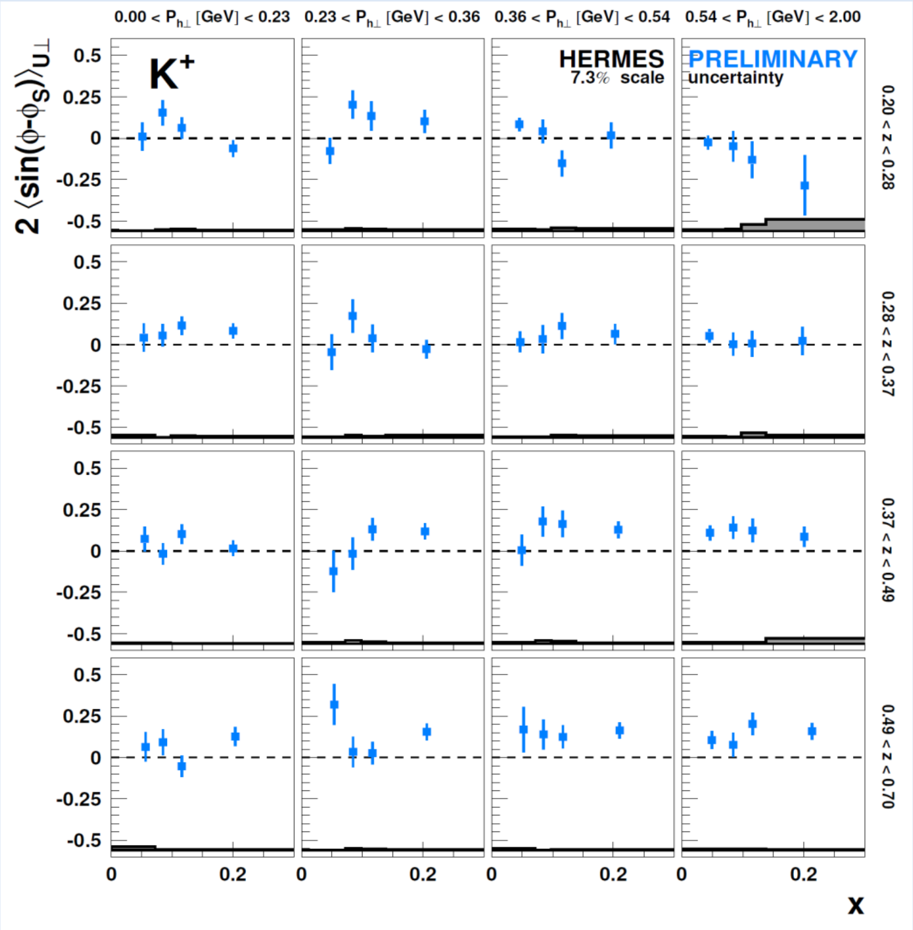


- π^+ amplitudes positive; π^- amplitudes ≈ 0
- π^+ amplitudes increasing with x at large $P_{h\perp}$

Sivers amplitudes

$$F_{UT}^{\sin(\phi_h-\phi_S)} \propto f_{1T}^{\perp}\left(x, p_T^2\right) \otimes D_1\left(z, k_T^2\right)$$



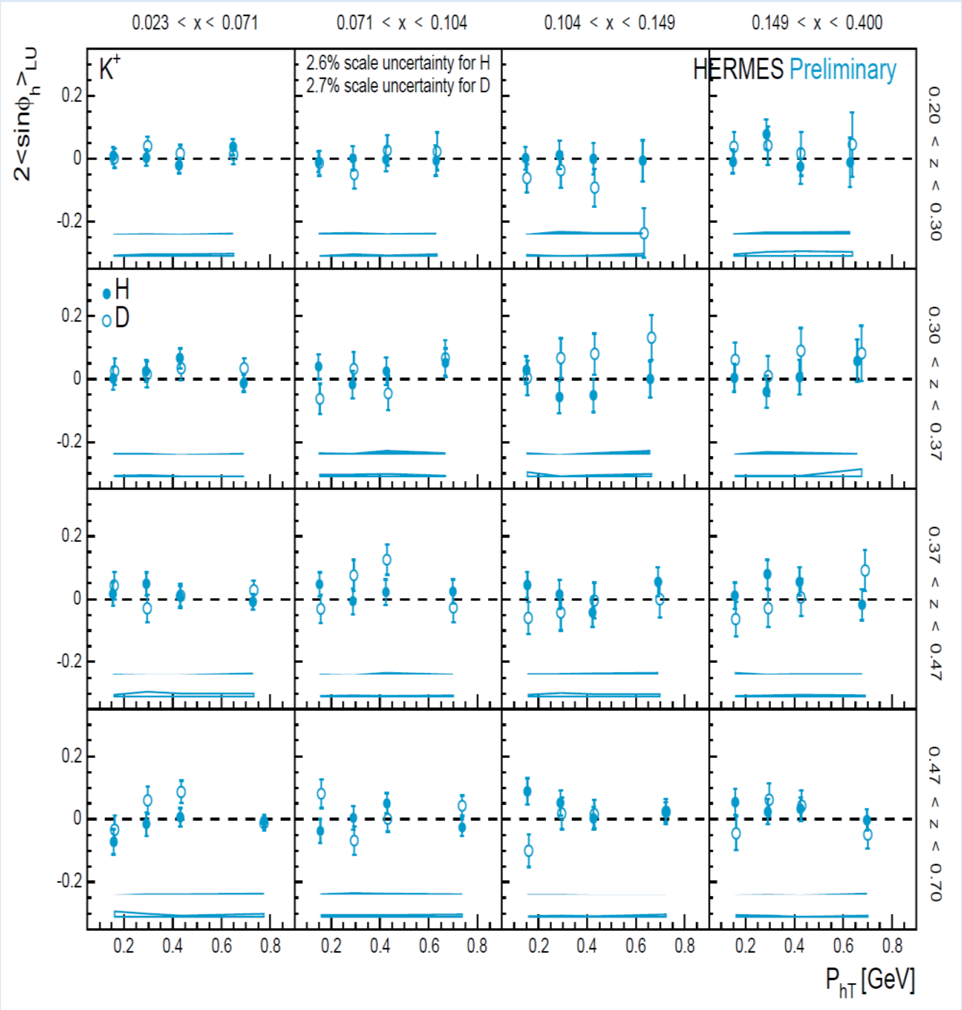


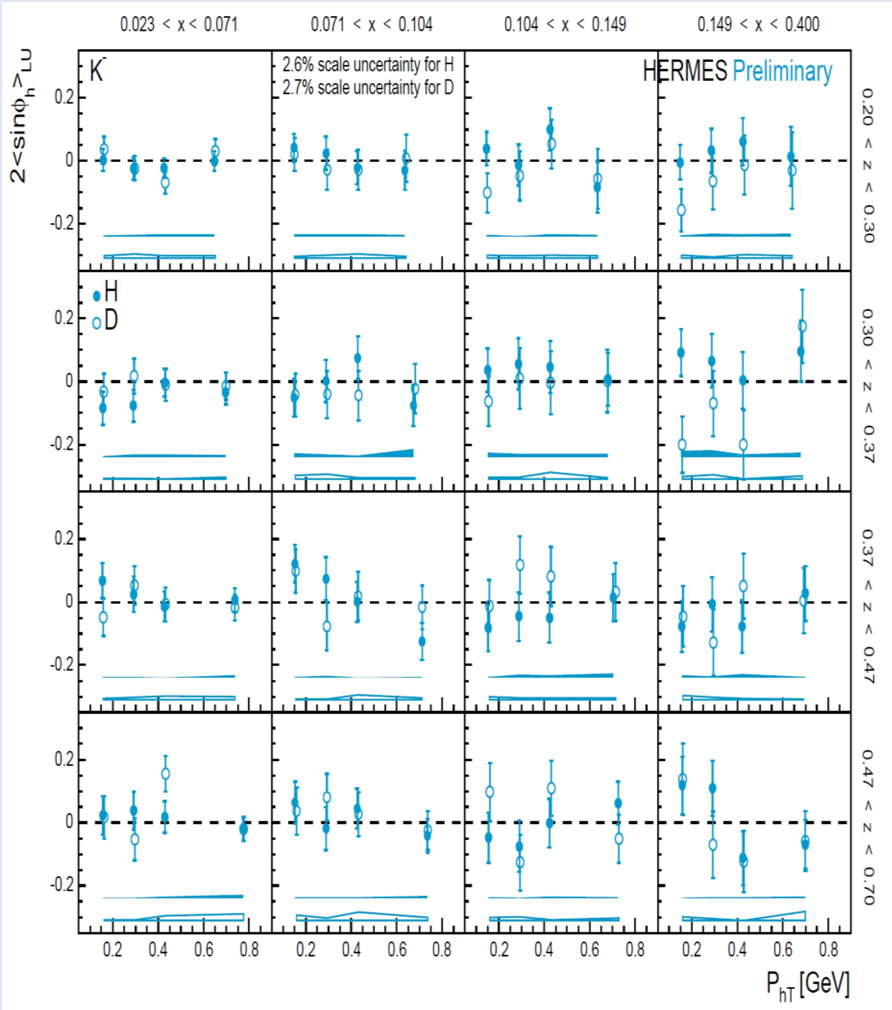
- K^+ amplitudes positive, larger than π^+
- Non-trivial role of sea quarks?

A_{LU} amplitudes: $K^{\pm}$

$$d\sigma = d\sigma^0_{UU} + \cdots + P_l \frac{1}{Q}\sin(\phi)\, d\sigma_{LU}$$

→ Convolution of twist–2 & twist–3 functions

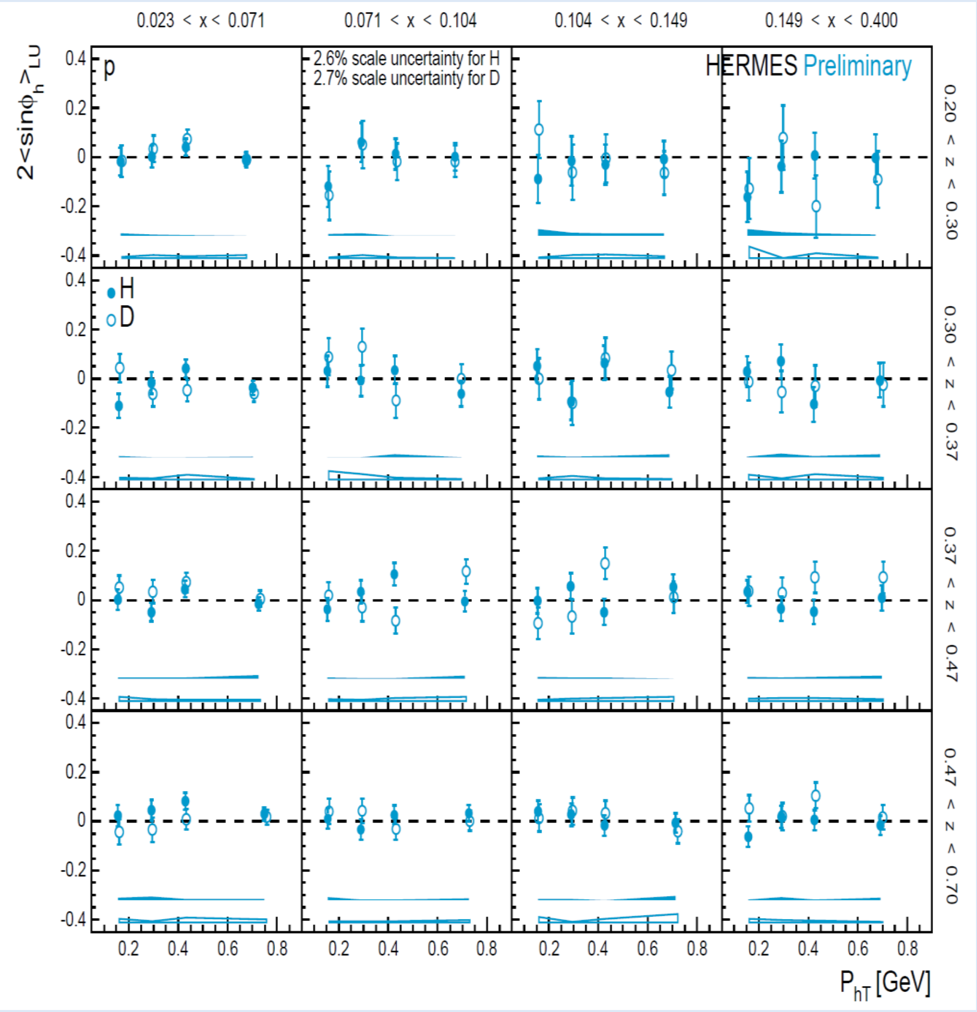


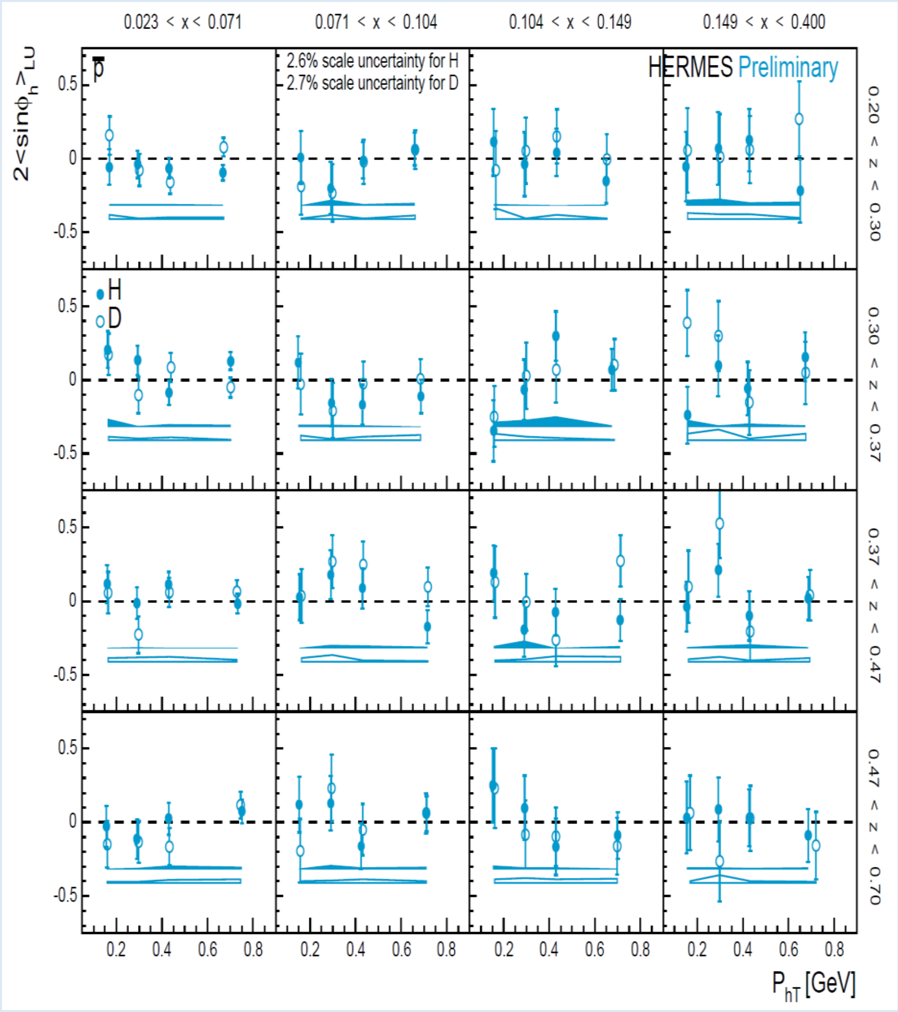


A_{LU} amplitudes: p & p^{bar}

$$d\sigma = d\sigma^{0}_{UU} + \cdots + P_l \frac{1}{Q}\sin(\phi)\, d\sigma_{LU}$$

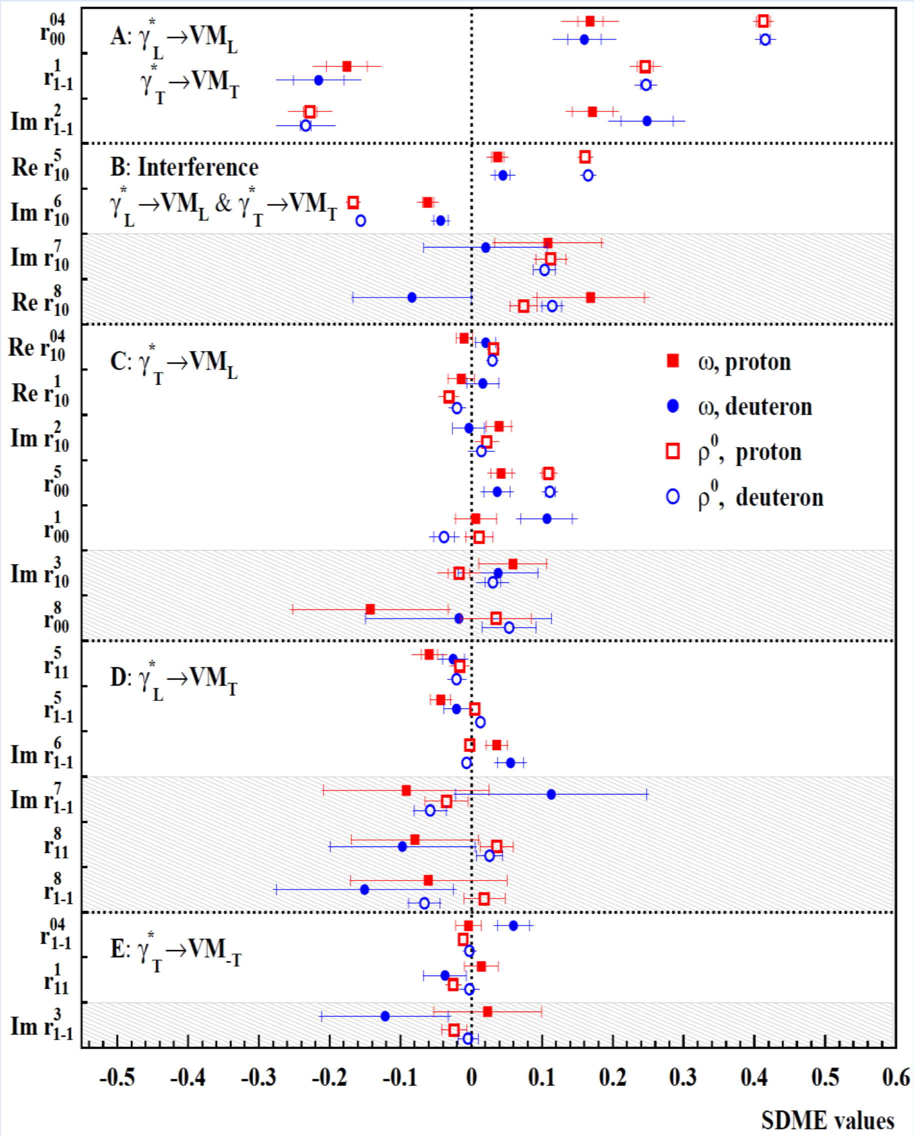
→ Convolution of twist–2 & twist–3 functions





Comparison of SDMEs in exclusive ω and ρ^0 productions

Eur. Phys. J. C 74 (2014) 3110



ρ^0 **SDMEs HERMES,** EPJ C 62 (2009) 659.

- The class – A SDMEs: r^1_{1-1} & Im r^2_{1-1} have opposite sign for ω and ρ^0.

- Large UPE contribution for ω:

$$r^1_{1-1} = \tilde{\sum}\left\{|T_{11}|^2 + |T_{1-1}|^2 - |U_{11}|^2 - |U_{1-1}|^2\right\}/2N,$$

$$\text{Im}\left\{r^2_{1-1}\right\} = \tilde{\sum}\left\{-|T_{11}|^2 + |T_{1-1}|^2 + |U_{11}|^2 - |U_{1-1}|^2\right\}/2N.$$

For ω meson

$$\text{Im}\left\{r^2_{1-1}\right\} - r^1_{1-1} = \tilde{\sum}\left\{-|T_{1-1}|^2 + |U_{11}|^2\right\}/N > 0$$

$$\tilde{\sum}|U_{11}|^2 > \tilde{\sum}|T_{1-1}|^2$$

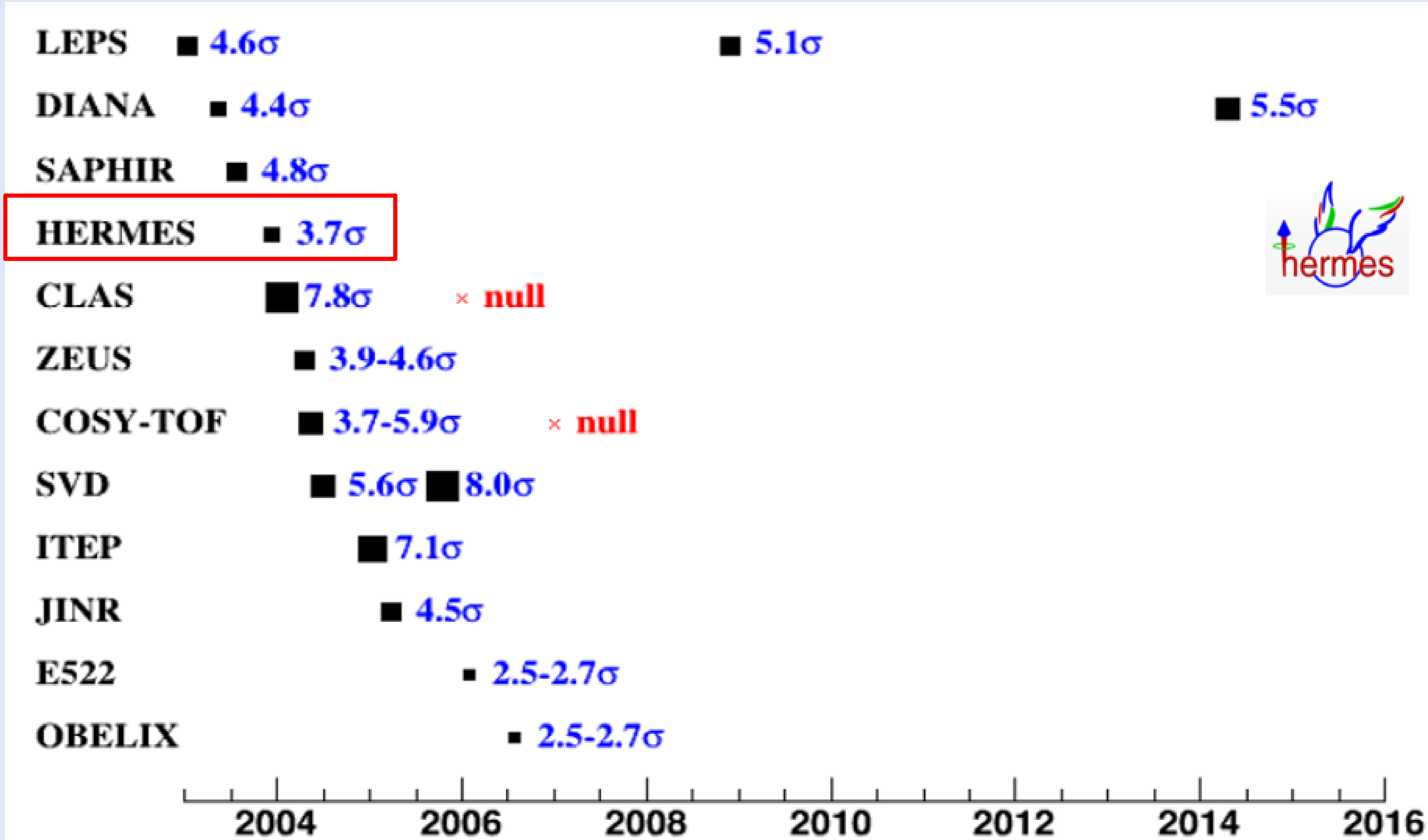
For ρ^0 meson

$$\text{Im}\left\{r^2_{1-1}\right\} - r^1_{1-1} = \tilde{\sum}\left\{-|T_{1-1}|^2 + |U_{11}|^2\right\}/N < 0$$

$$\tilde{\sum}|U_{11}|^2 < \tilde{\sum}|T_{1-1}|^2$$

Talk Tue 17h50
by S. Manaenkov

Significances of Θ^+(Groups ever announced positive results)



Slide is taken from: Siguang WANG *NSTAR2015, May 25-28, 2015 , Osaka , Japan*

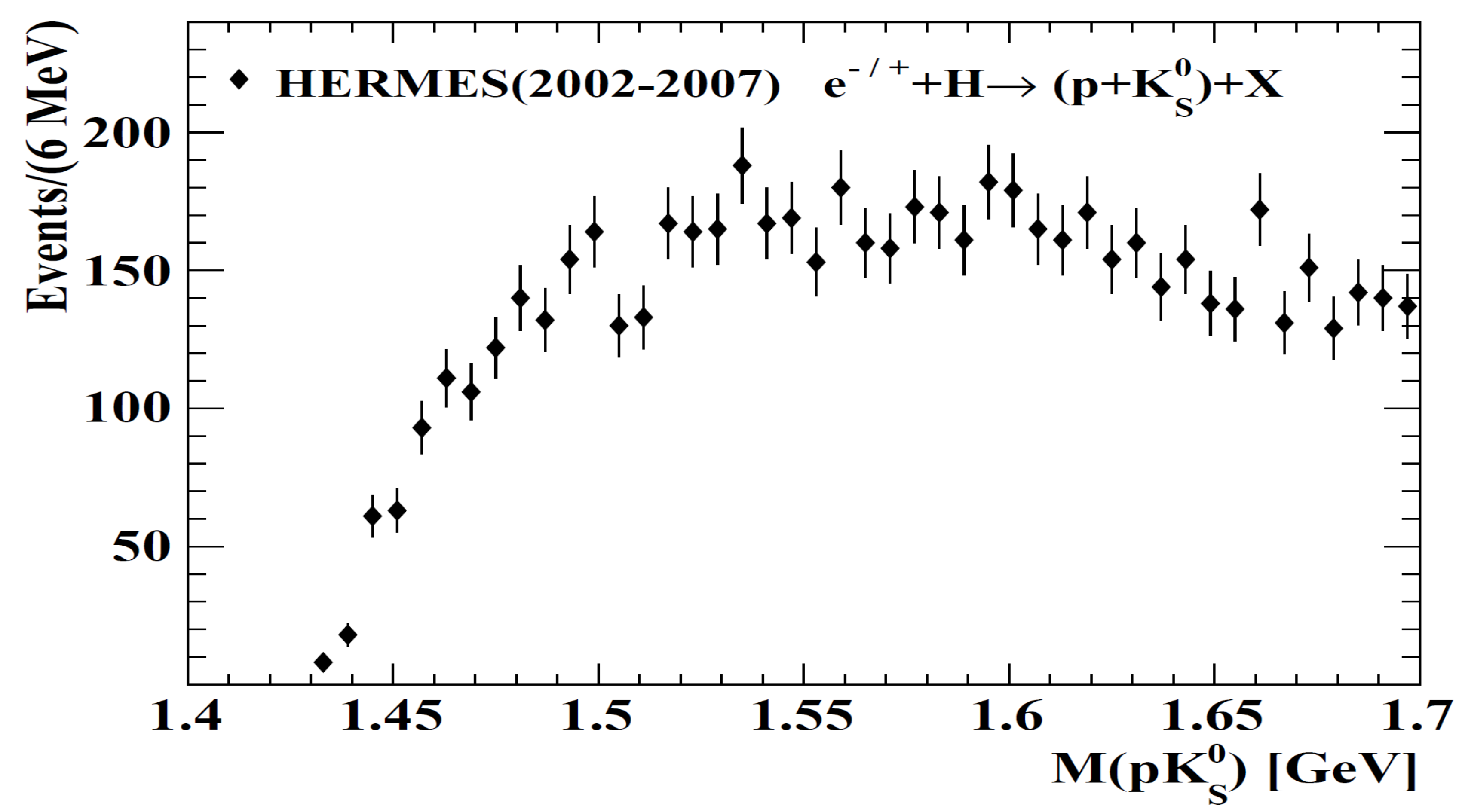
Groups with negative results (now)

Group	Reaction	Mode	Upper limit	Confidence
CLAS	$\gamma d \to pK^-K^+n$	K^+n	$\sigma < 0.3$ nb	95%
	$\gamma d \to \Lambda K^+n$	K^+n	$\sigma < 5$ nb	95%
	$\gamma p \to \overline{K}^0 K^+ n$	K^+n	$\sigma < 0.8$ nb	95%
			$N(\Theta^+)/N(\Lambda(1520)) < 0.22\%$	95%
	$\gamma p \to \overline{K}^0 K^0 p$	$K^0_S p$	$\sigma < 1.5$ nb	95%
COSY-TOF	$pp \to \Sigma^+ K^0 p$	$K^0_S p$	$\sigma < 0.15\ \mu$b	95%
FOCUS	$\gamma \mathrm{BeO} \to pK^0_S X$	$K^0_S p$	$\sigma(\Theta^+)\mathcal{B}(pK^0_S)/\sigma(K(892)^+) < 0.13\%$	95%
			$\sigma(\Theta^+)\mathcal{B}(pK^0_S)/\sigma(\Sigma(1385)^\pm) < 2.3\%$	95%
NOMAD	$\nu_\mu A \to K^0_S p X$	$K^0_S p$	$N(\Theta^+)/N_{\mathrm{events}} < 2.13 \times 10^{-3}$	90%
BES	$\psi(2S), J/\psi$ decays	K^+n, $K^0_S p$	see Eq.(2)	90%
BaBar	$e^+e^- \to \Upsilon(4S) \to pK^0_S X$	$K^0_S p$	$N(\Theta^+)/N_{\mathrm{events}} < 1.8 \times 10^{-4}$	95%
	$e^+e^- \to q\bar{q} \to pK^0_S X$	$K^0_S p$	$N(\Theta^+)/N_{\mathrm{events}} < 5.0 \times 10^{-5}$	95%
	$B^0 \to p\bar{p}K^0_S$	$K^0_S p$	$\mathcal{B}(\Theta^+) \cdot \mathcal{B}(pK^0_S) < 0.5 \times 10^{-7}$	95%
Belle	$B^0 \to p\bar{p}K^0_S$	$K^0_S p$	$\mathcal{B}(\Theta^+) \cdot \mathcal{B}(pK^0_S) < 2.3 \times 10^{-7}$	90%
	$KN \to pK^0_S X$	$K^0_S p$	$N(\Theta^+)/N(\Lambda(1520)) < 2.5\%$	90%
	$K^+n \to pK^0_S$	$K^0_S p$	$\Gamma < 0.64$ MeV	90%
ALEPH	$Z \to pK^0_S X$	$K^0_S p$	$N(\Theta^+)/N_{\mathrm{events}} < 2.5 \times 10^{-3}$	95%
DELPHI	$Z \to pK^0_S X$	$K^0_S p$	$N(\Theta^+)/N_{\mathrm{events}} < 2.0 \times 10^{-3}$	95%
L3	$\gamma\gamma \to p(\bar{p})K^0_S X$	$K^0_S p$	$N(\Theta^+)/N_{\mathrm{events}} < 4.7 \times 10^{-3}$	95%
H1	$ep \to ep(\bar{p})K^0_S$	$K^0_S p$	$\sigma < 120 - 360$ pb	95%
COSY-Jülich	$pp \to pK^0\pi^+\Lambda$	$K^0 p$	$\sigma < 58$ nb	95%
NA49	$pp \to pK^0_S X$	$K^0_S p$	not observed	–
CDF	$p\bar{p} \to pK^0_S X$	$K^0_S p$	$N(\Theta^+) < 89, 76$	90%
HERA-B	$p\mathrm{C} \to pK^0_S X$	$K^0_S p$	$N(\Theta^+)/N(\Lambda(1520)) < 2.7\%$	95%
SPHINX	$pN \to nK^+K^0_S N$	K^+n	$\sigma < 26$ nb	90%
	$pN \to pK^0_S K^0_L N$	$K^0_S p$	$\sigma < 42$ nb	90%
	$pN \to pK^0_L K^0_S N$	$K^0_L p$	$\sigma < 39$ nb	90%
	$pN \to pK^0_S K^0_S N$	$K^0_S p$	$\sigma < 52$ nb	90%
PHENIX	$d\mathrm{Au} \to K^-\bar{n}X$	$K^-\bar{n}$	not observed	–
HyperCP	$p(\pi^+,K^+)\mathrm{Cu} \to p(\bar{p})K^0_S X$	$K^0_S p$	$N(\Theta^+)/N_{\mathrm{events}} < 0.3\%$	90%
LASS	$K^+p \to K^+n\pi^+$	K^+n	no narrow resonance	–
WA89	$\Sigma^-\mathrm{C(Cu)} \to pK^0_S$	$K^0_S p$	$\sigma < 7.2\ \mu$b	99%
E559	$K^+p \to \pi^+X$	–	$d\sigma/d\Omega < 3.5\ \mu$b/sr	90%
J-PARC	$\pi^-p \to K^-X$	–	$d\sigma/d\Omega < 0.26\ \mu$b/sr	90%

Slide is taken from: Siguang WANG *NSTAR2015, May 25-28, 2015 , Osaka , Japan*

Searching for the pentaquark at HERMES in 2015

Phys. Rev. D 91 (2015) 057101



- No evidence for the resonance Θ^+ on H