HERMES Experiment in 2013 (DESY)

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HEPD Academic Council

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- Main Activities of HERMES in 2013
- Publications in 2013
- Exclusive Vector-Meson Production in Deep-Inelastic Scattering

  Spin Density Matrix Elements

  Ratios of Helicity Amplitudes
- Study of Lambda and Anti-lambda Hyperon Polarization in HERMES Experiment

  Spin Transfer and Lambda Hyperon Structure

  A-Dependence of Transverse Lambda Polarization
- Summary

Main Activities of HERMES in 2013

- $E_e = 27.57$ GeV, $S_e \approx \pm 0.55$, (RUN I), $S_e \approx \pm 0.40$, (RUN II), $S_T \approx \pm 0.9$, L=1505 pb^{-1}.
  End of data taking 2007. End of HERMES July of 2014.
- HERMES activities in data treatment:
  - study of quark and gluon distributions,
  - asymmetries in deep-virtual Compton scattering,
  - transverse spin effects,
  - charged hadron ratios in quasi-real photoproduction,
  - systematic study of events for pentaquark θ^+ candidates,
  - azimuthal dependence of cross section of semi-inclusive hadron production (P.Kravchenko),
  - hyperon polarization in deep-inelastic scattering (DIS) and photoproduction (S.Belostotski, Yu.Naryshkin, D.Veretennikov),
  - exclusive vector-meson production in DIS (S.Manaenkov, D.Veretennikov).
  - Publication papers with information from recoil detector.

HERMES Publications in 2013

- Authors from PNPI: S. Belostotski, G. Gavrilov, A. Izotov, A. Kisselev, P. Kravchenko, S. Manaenkov, Y. Naryshkin, D. Veretennikov, V. Vikhrov

- Azimuthal distributions of charged hadrons, pions, and kaons produced in deep-inelastic scattering off unpolarized protons and deuterons, Phys. Rev. D67 (2013) 012010; arXiV: 1204.4161; Preprint DESY-12-060.

- Multiplicities of charged pions and kaons from semi-inclusive deep-inelastic scattering by the proton and the deuteron, Phys. Rev. D87 (2013) 074029; arXiV: 1212.5407; Preprint DESY-12-157.

- Transverse target single-spin asymmetry in inclusive electroproduction of charged pions and kaons, Phys. Lett. B728 (2014) 183-190; arXiV: 1310.5070; Preprint DESY-13-187.

- Beam-helicity asymmetry in associated electroproduction of real photons $ep \to e\gamma\pi N$ in the $\Delta-$resonance region, JHEP (in press); arXiV: 1310.5081; Preprint DESY-13-188.

Exclusive Vector-Meson Production in Deep-Inelastic Scattering

- Vector-Meson Production in DIS and Deep-Virtual Compton Scattering (DVCS) are two processes used to extract Generalized Parton Distributions (GPDs):
  $\gamma^* + N \to V + N', \quad \gamma^* + N \to \gamma + N'.$
  Ji's sum rule permits to establish angular momentum contribution to nucleon spin using GPDs.
- Three subprocesses in ρ^0-meson electroproduction in DIS
  i) $e \to e' + \gamma^*, \quad$ ii) $\gamma^* + N \to \rho^0 + N', \quad$ iii) $\rho^0 \to \pi^+ + \pi^-$
  i) Spin-density matrix of γ^* is known from QED.
  iii) Angular momentum conservation: $|\rho^0;\ 1M> \to |\pi^+\pi^-;\ 1M> \to Y_{1M}(\theta, \varphi)$.
  ii) Phenomenological helicity amplitudes, $F_{\lambda_V \lambda_2 \lambda_\gamma \lambda_1}$ of reaction $\gamma^* + N \to \rho^0 + N'$
  λ_1 and λ_2 are helicities of initial (N) and final (N') nucleon in CM system.
  λ_γ is virtual photon helicity, $\lambda_\gamma = 0$ scalar (longitudinal) polarization,
  $\lambda_\gamma = \pm 1$ transverse polarization.
  $\lambda_V = 0$ longitudinal polarization of vector meson, $\lambda_V = \pm 1$ transverse polarization.
  $F_{\lambda_V \lambda_2 \lambda_\gamma \lambda_1} = T_{\lambda_V \lambda_2 \lambda_\gamma \lambda_1} + U_{\lambda_V \lambda_2 \lambda_\gamma \lambda_1}$. Symbolic: $F = T + U$.
  Natural Parity Exchange (NPE) $T \leftrightarrow 0^+,\ 1^-, \ldots$. Pomeron, ρ, f_2, ω, ... reggeons.
  Unnatural Parity Exchange (UPE) $U \leftrightarrow 0^-,\ 1^+,\ 2^-, \ldots$. π, a_1, ... reggeons

Exclusive Vector-Meson Production in Deep-Inelastic Scattering

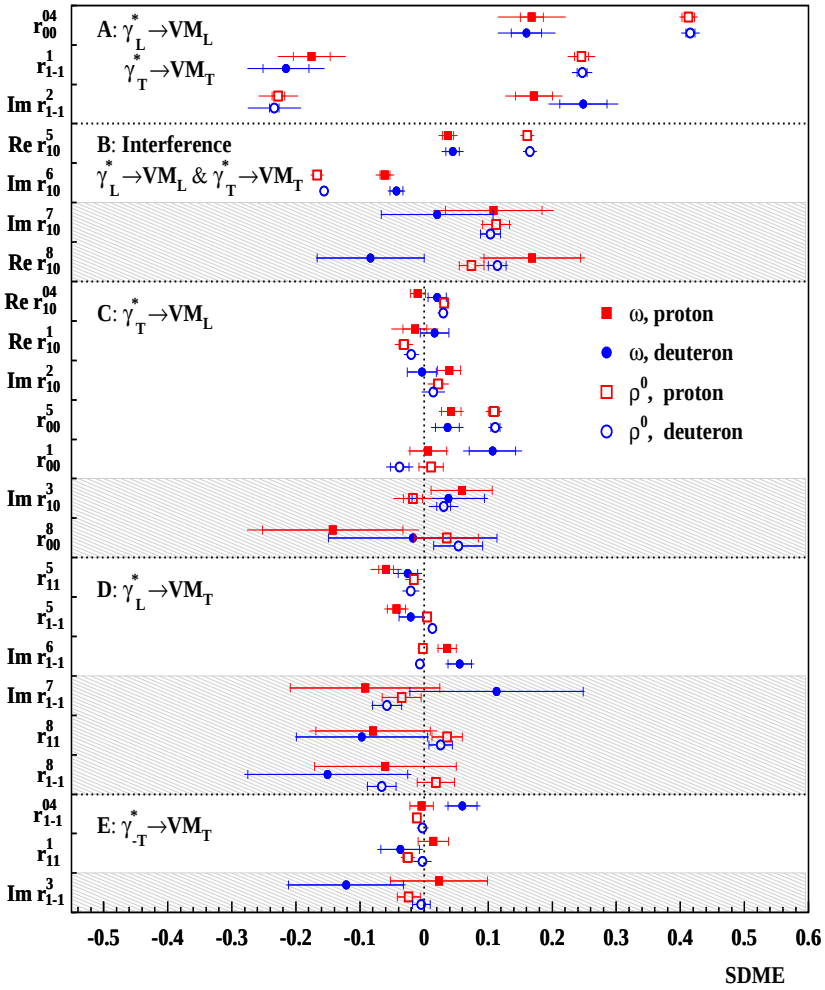
- Spin-Density Matrix Element Method
  SDMEs are Fourier coefficients in angular distribution of final lepton and hadrons from decay of vector mesons: $\rho^0 \to \pi^+ + \pi^-$; $\omega \to \pi^+ + \pi^- + \pi^0$; $\phi \to K^+ + K^-$.

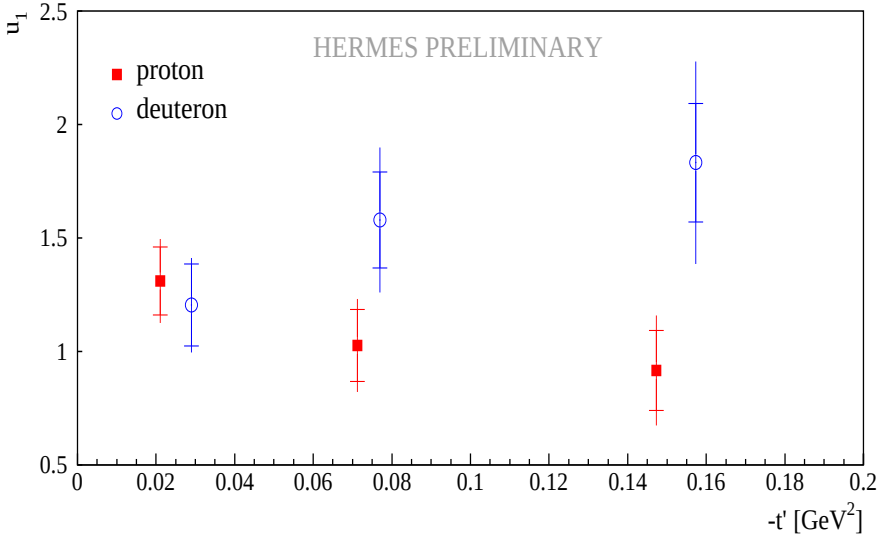
  SDMEs are considered as independent quantities and are free parameters in fit to the angular distribution.

  Total number of SDMEs is equal to 71.
  Unpolarized electron beam and unpolarized target: 15 SDMEs.
  Longitudinally polarized electron beam and unpolarized target: 23 SDMEs.

- Amplitude Method
  SDMEs are expressed through amplitude ratios.
  Ratios of helicity amplitudes are free parameters in fit to the angular distribution and extracted directly from experimental angular distribution of final pions.
  Number of independent complex ratios is 17 (34 real functions).
  SDMEs are not independent since $71 > 34$.
  Amplitude method takes into account correlations between SDMEs.
  Precision of Amplitude method is better than that of SDME method.

Spin Density Matrix Elements for ω Production in DIS

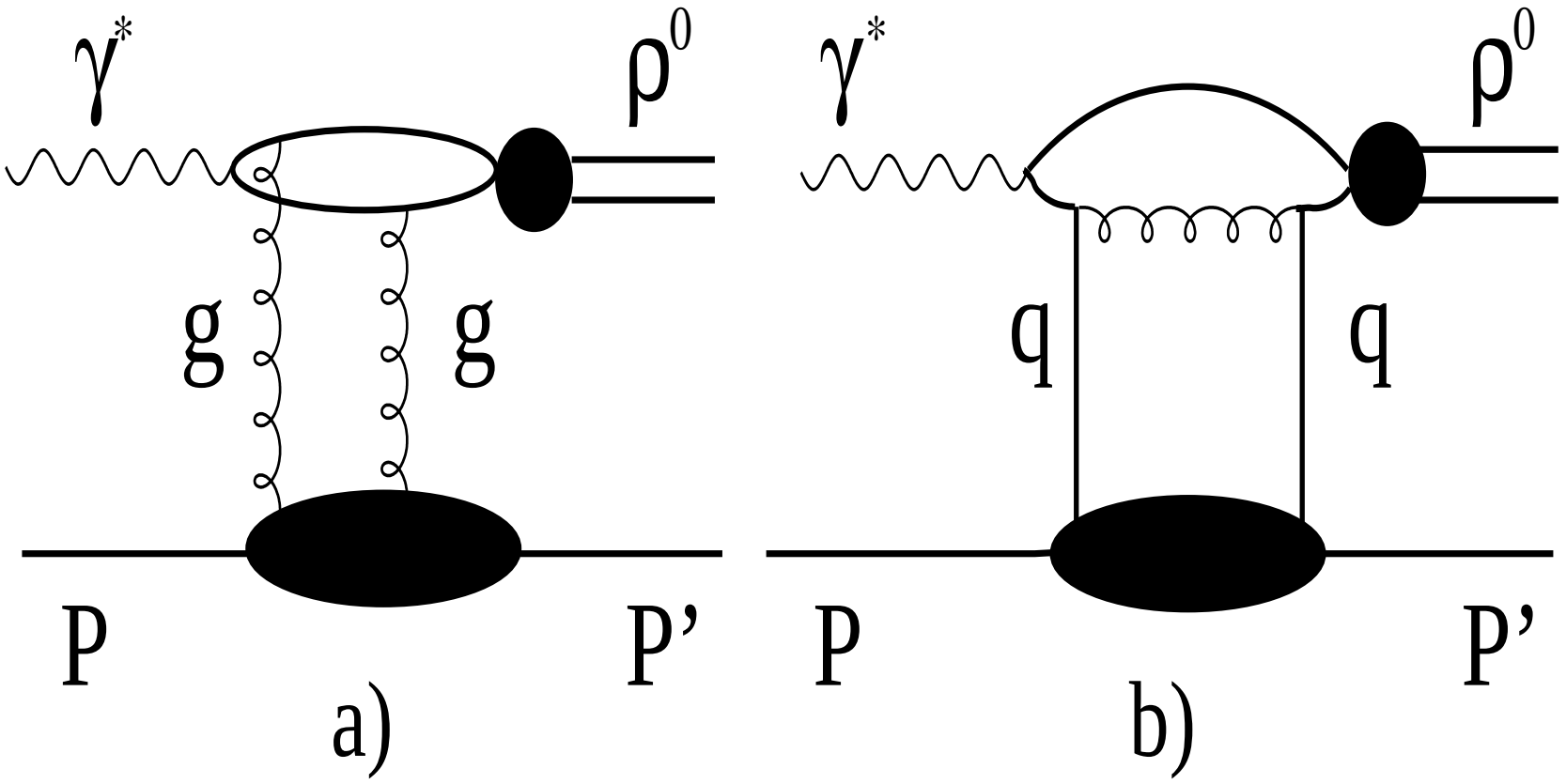




$\mathrm{Im}\{r^2_{1-1}\} - r^1_{1-1} = \sum[|U_{11}|^2 - |T_{11}|^2]/\mathcal{N}$. $u_1 = \sum[4\epsilon|U_{10}|^2 + 2|U_{11} + U_{1-1}|^2]/\mathcal{N}$.
$u_1 = 1 - r^{04}_{00} + 2r^{04}_{1-1} - 2r^1_{11} - 2r^1_{1-1}$

Unnatural-Parity Exchange (UPE) dominates for ω-meson production.

Spin Density Matrix Elements for ω Production in DIS



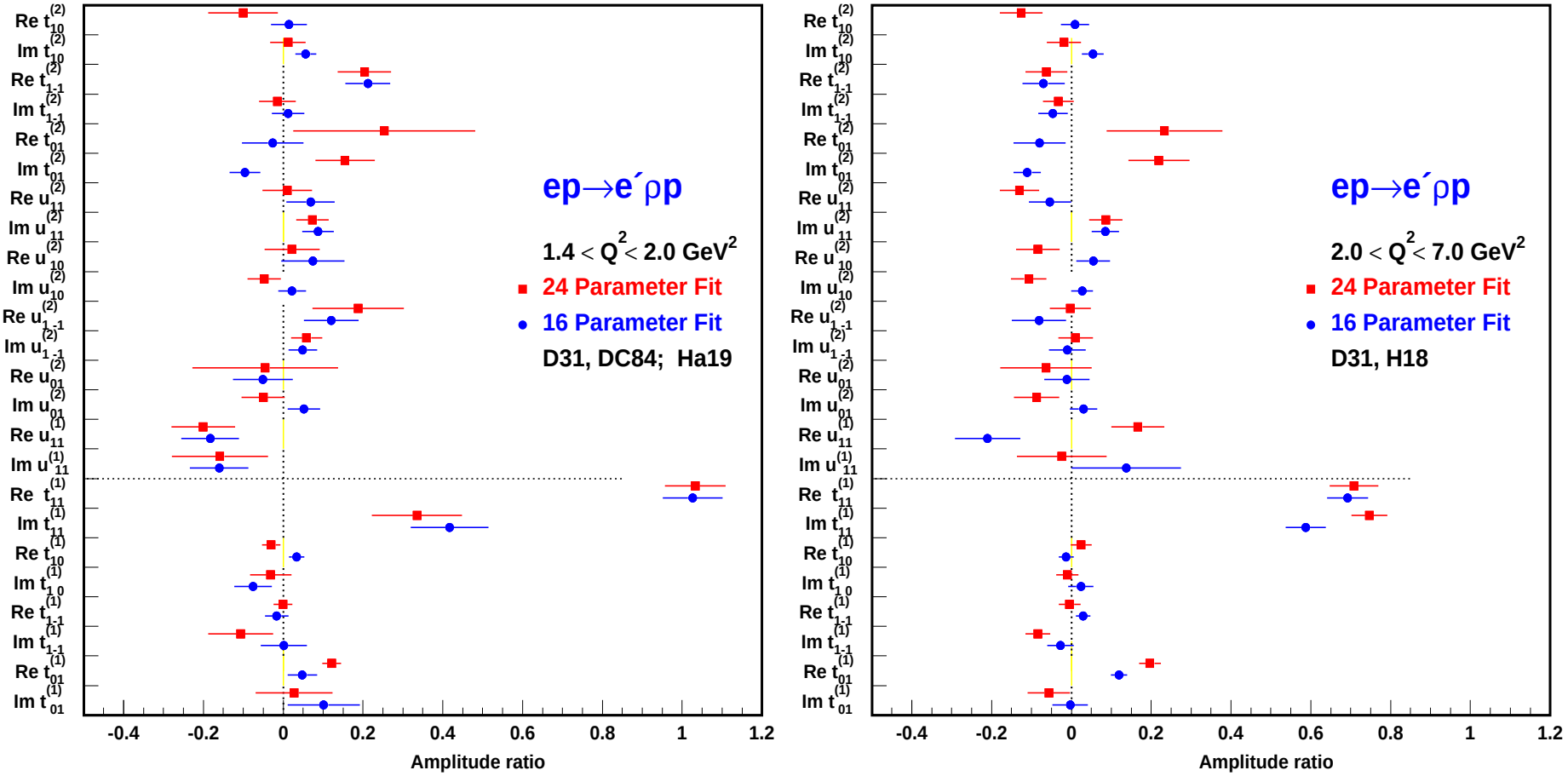
Final state interaction: π^0 exchange between ρ^0 and proton.

Vertex $\rho^0 \to \pi^0 + \omega$; Vertex $N + \pi^0 \to N$

Natural Parity: 0^+, 1^-, 2^+, ... Unnatural Parity: 0^-, 1^+, 2^-, ...

π reggeon exchange provides large UPE amplitude U_{11}.

Ratios of Helicity Amplitudes for ρ^0-Meson Production



Left panel $1.4 < Q^2 < 2.0$ GeV^2 (2641). Right panel $2.0 < Q^2 < 7.0$ GeV^2 (2799).

16 parameter fit of data. $t^{(n)}_{\lambda_V\lambda_\gamma} = T^{(n)}_{\lambda_V\lambda_\gamma}/T^{(1)}_{00}$, $u^{(n)}_{\lambda_V\lambda_\gamma} = U^{(n)}_{\lambda_V\lambda_\gamma}/T^{(1)}_{00}$, $n = 1,\ 2$.

$p_1 \div p_{16}$: $t^{(2)}_{10}$, $t^{(2)}_{1-1}$, $t^{(2)}_{01}$, $u^{(2)}_{11}$, $u^{(2)}_{10}$, $u^{(2)}_{1-1}$, $u^{(2)}_{01}$, $u^{(1)}_{11}$

Additional 8 parameters: $t^{(1)}_{11}$, $t^{(1)}_{10}$, $t^{(1)}_{1-1}$, $t^{(1)}_{01}$ from Eur. Phys. J. C71 (2011) 1609.

24 parameter fit of HERMES data

$p_1 \div p_{24}$: $t^{(2)}_{10}$, $t^{(2)}_{1-1}$, $t^{(2)}_{01}$, $u^{(2)}_{11}$, $u^{(2)}_{10}$, $u^{(2)}_{1-1}$, $u^{(2)}_{01}$, $u^{(1)}_{11}$ $t^{(1)}_{11}$, $t^{(1)}_{10}$, $t^{(1)}_{1-1}$, $t^{(1)}_{01}$

Polarization of Lambda and Anti-lambda Hyperons in HERMES Experiment

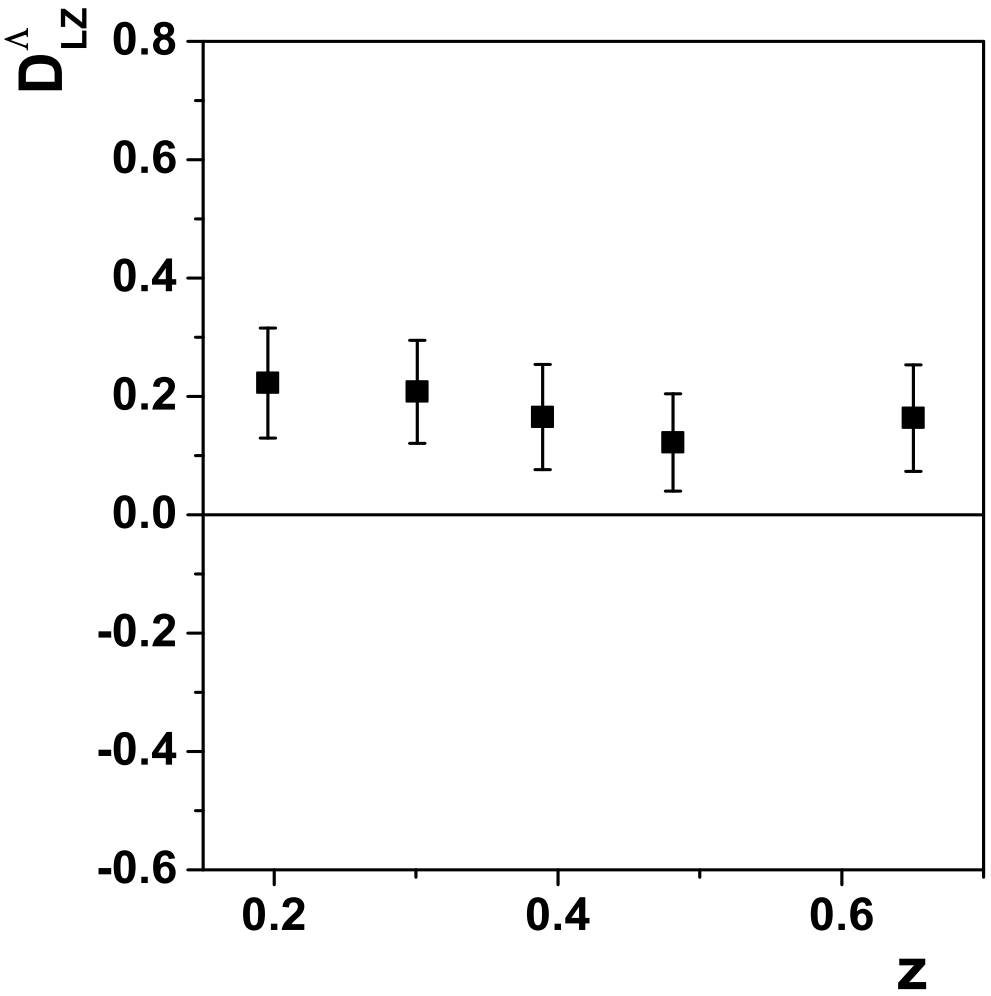
- "Spin Crisis" for Λ Hyperon
  $q(x,Q^2) = q(x,Q^2)\uparrow\Uparrow + q(x,Q^2)\downarrow\Uparrow$, $\Delta q(x,Q^2) = q(x,Q^2)\uparrow\Uparrow - q(x,Q^2)\downarrow\Uparrow$,
  $\Delta q \equiv \int_0^1 \Delta q(x,Q^2)dx$, $Q^2 = -(k-k')^2 \equiv -q^2$, $x = \frac{Q^2}{2(P_N\cdot q)}$.
  Naive quark model: $\Delta u_\Lambda = \Delta d_\Lambda = 0$, $\Delta s_\Lambda = 1$.
  $\Delta u_\Lambda = \Delta d_\Lambda = -0.16 \pm 0.01$, $\Delta s_\Lambda = 0.57 \pm 0.01$ (R.L.Jaffe, SU(3)).
  Lattice-QCD $\Delta u_\Lambda = \Delta d_\Lambda = -0.02 \pm 0.04$, $\Delta s_\Lambda = 0.68 \pm 0.04$.
- Fragmentation Functions
  Massless particles $F_q^\Lambda(z,Q^2) = F_{q\uparrow}^{\Lambda\Uparrow}(z,Q^2) + F_{q\uparrow}^{\Lambda\Downarrow}(z,Q^2)$,
  $\Delta F_q^\Lambda(z,Q^2) = F_{q\uparrow}^{\Lambda\Uparrow}(z,Q^2) - F_{q\uparrow}^{\Lambda\Downarrow}(z,Q^2)$, where $z = E_\Lambda/E_q$.
  $D_q^\Lambda(z,Q^2) = \frac{\Delta F_q^\Lambda(z,Q^2)}{F_q^\Lambda(z,Q^2)}$, $D_q^\Lambda(Q^2) = \frac{\int \Delta F_q^\Lambda(z,Q^2)dz}{\int F_q^\Lambda(z,Q^2)dz}$.
  Complementarity of DIS and e^+e^- annihilation
  DIS: u-dominance, $F_u^\Lambda(z,Q^2)$, $\Delta F_u^\Lambda(z,Q^2)$;
  $e^+e^- \to Z^0 \to q\bar{q} \to \Lambda\bar{\Lambda}$: $\Delta F_s^\Lambda(z,Q^2)$ $|S_s| \approx 0.98$, $|S_u| \approx 0.67$
- Relation between Parton Distributions and Fragmentation Functions
  Model estimates (Ashery, Lipkin) for first moments of valence quark distributions
  $D_q^\Lambda(Q^2) = \frac{\int \Delta F_q^\Lambda(z,Q^2)dz}{\int F_q^\Lambda(z,Q^2)dz} \approx \frac{\Delta q_\Lambda(Q^2)}{q_\Lambda(Q^2)}$.

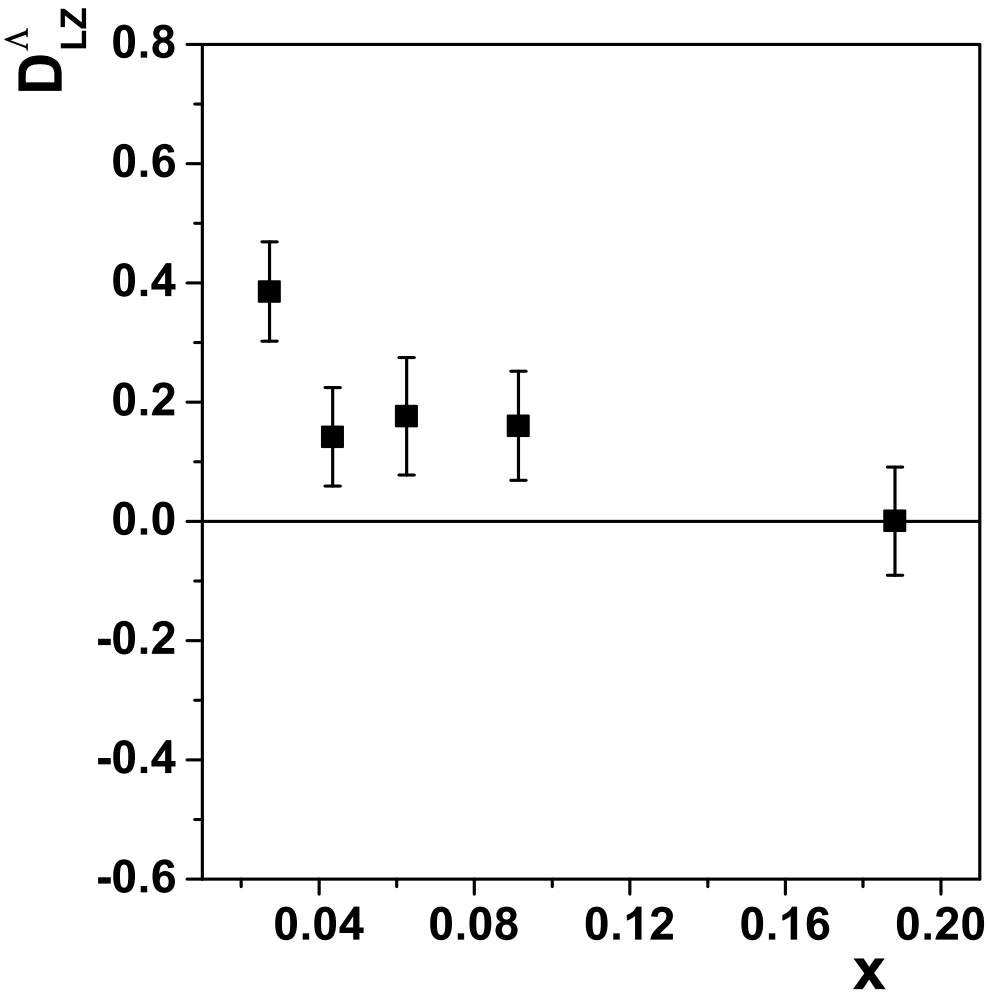
Polarization of Lambda and Anti-lambda Hyperons in HERMES Experiment

- Spin-Transfer Coefficients $D^{\Lambda}_{Lj}(z,Q^2)$ for Massive Particle
  All consideration in Cartesian right-handed Λ rest system of frame.
  Hyperon polarization vector, $\vec{S}^{\Lambda}$ can be found from $W = \frac{1}{4\pi}\Big[1+\alpha(\vec{S}^{\Lambda}\cdot\vec{P}_N)/|\vec{P}_N|\Big]$,
  $\alpha = 0.642 \pm 0.013$ for $\Lambda \to p + \pi^-$ and -0.642 ± 0.013 for $\bar{\Lambda} \to \bar{p} + \pi^+$.
  $(\vec{S}^{\Lambda})_j = D^{\Lambda}_{Lj}(x,z,Q^2)S_q$ $S_q = D(y)S_e$ $j = x,\ y,\ z.$ $D(y) = \frac{1-(1-y)^2}{1+(1-y)^2}$, $y = \frac{\nu}{E_e}$.
  $$D^{\Lambda}_{Lj}(x,z,Q^2) = \frac{\sum_q \Big[D^{q\to\Lambda}_{Lj}(z,Q^2)F^{\Lambda}_q(z,Q^2)e_q^2 q(x,Q^2)\Big]}{\sum_q \Big[F^{\Lambda}_q(z,Q^2)e_q^2 q(x,Q^2)\Big]}.$$
  Right-handed Λ rest system of frame:
  $j \equiv L' = x,\ y,\ z.$ Z-axis is along virtual photon three-momentum, $\vec{q}$.
  Y-axis is parallel to $\vec{P}_{\Lambda}\times\vec{q}$ in the laboratory system.

- Target and Current Fragmentation
  Target fragmentation $x_F < 0$, $z < 0.2$. Current fragmentation $x_F > 0$, $z > 0.2$
  where $x_F = P^{\Lambda}_z/max(P^{\Lambda}_z)$ in CM system, $z = E^{\Lambda}/E_q = E^{\Lambda}/\nu$ in lab. system.
- Direct and Indirect Λ Hyperons
  Direct 51%. Indirect: $\Sigma^0 \to \Lambda\gamma$ (22%); $\Sigma^{*+} \to \Lambda\pi^+$ (14%); $\Sigma^{*0} \to \Lambda\pi^0$ (8%).
  $C^{\Lambda}_{\Sigma^0} = -\frac{1}{3}$, $C^{\Lambda}_{\Sigma^*} = \frac{5}{9}$.

Spin Transfer and Lambda Hyperon Structure

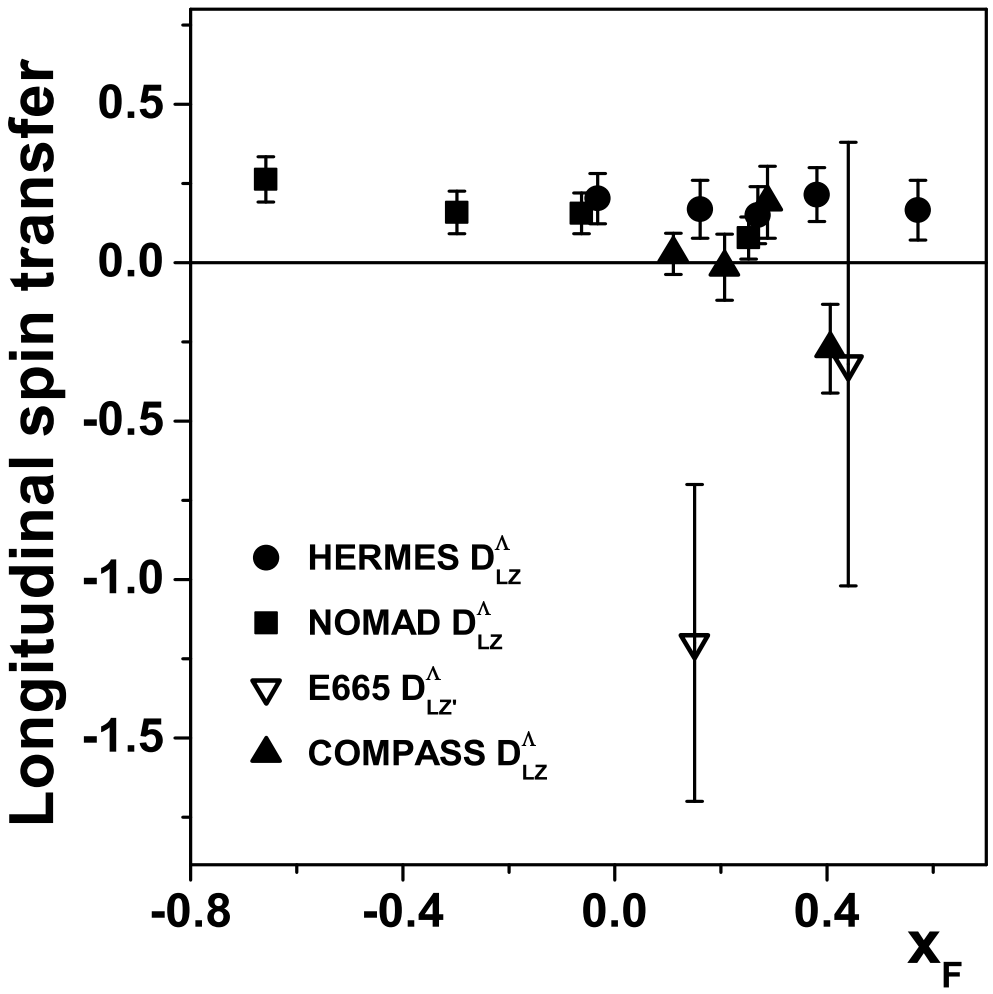


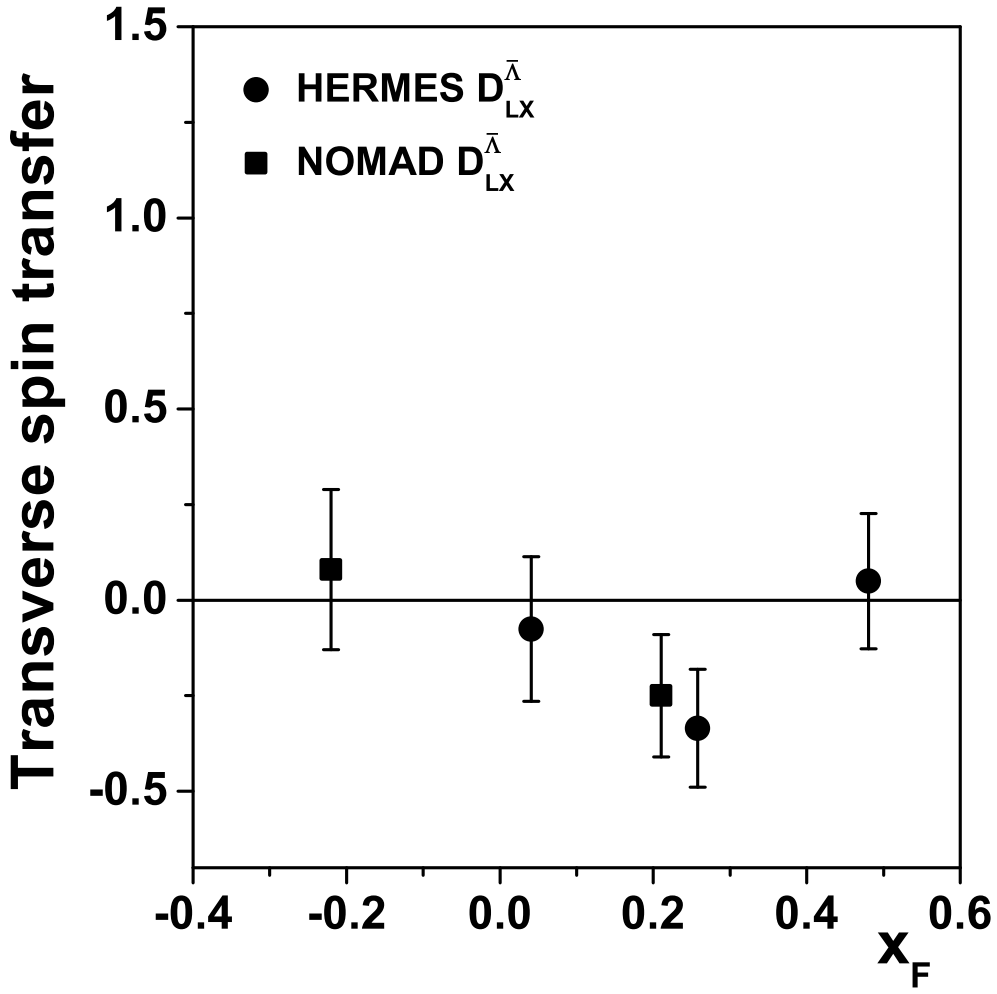


Dependencies of $D^{\Lambda}_{Lz}(x, z, Q^2)$ on z and x after averaging over complimentary kinematic variables.

$D^{\Lambda}_{Lz}(z)$ is positive! $D^{\Lambda}_{LL} = 0.15 \pm 0.03 \pm 0.02$

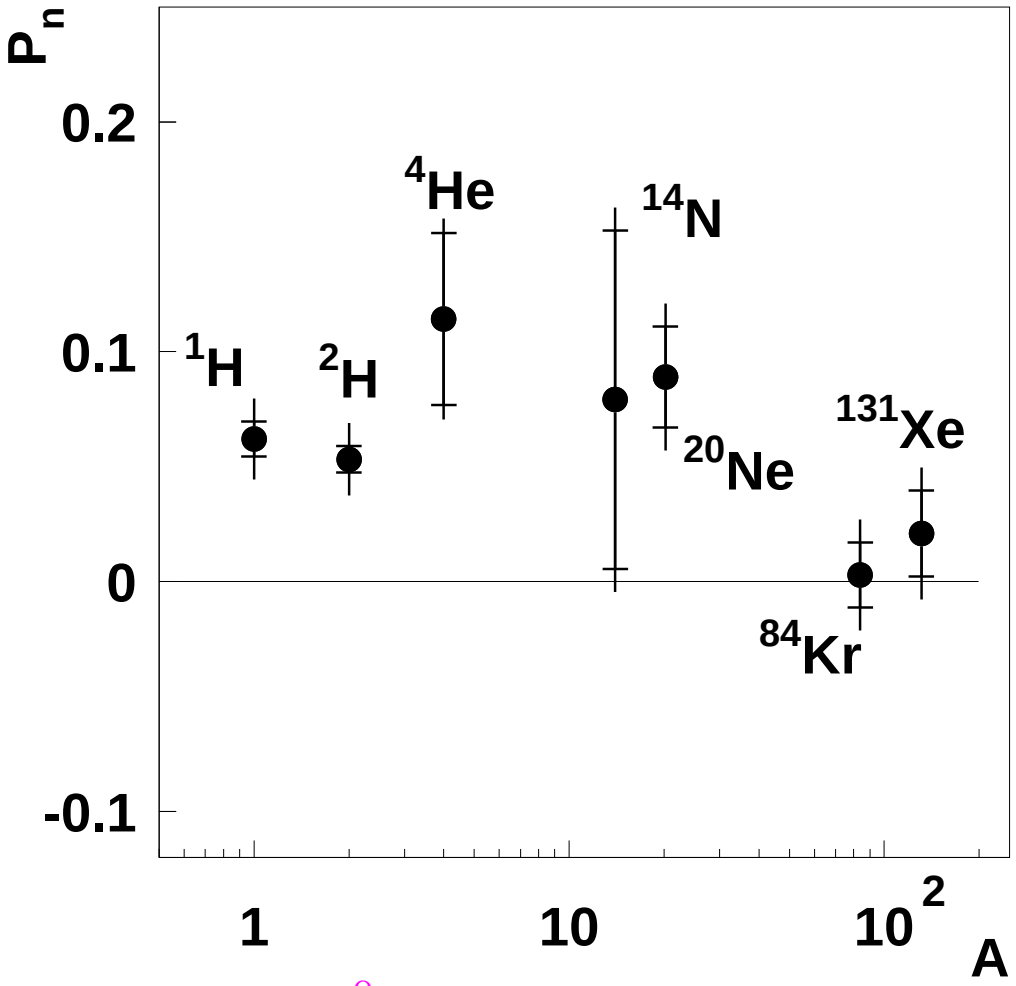
Spin Transfer and Lambda Hyperon Structure





Left Panel: Λ^0 hyperon $D^{\Lambda}_{Lz}(x, z, Q^2)$. Right Panel: $\bar{\Lambda}^0$ hyperon $D^{\bar{\Lambda}}_{Lx}(x, z, Q^2)$.

A-Dependence of Transverse Lambda Polarization



Polarizatin of Λ^0 hyperon normal to the production plane in photoproduction on unpolarized targets.

$P_n = (\vec{S}_\Lambda \vec{n}), \quad \vec{n} = (\vec{P}_\Lambda \times \vec{q})/|(\vec{P}_\Lambda \times \vec{q})|.$

Summary

- Official end of HERMES data treatment is July 2014.
- Study of SDMEs in ω-meson production is close to publication.
- Amplitude analysis of ρ^0-meson electroproduction can by finished next year.
- Study of Λ and $\bar{\Lambda}$ polarization in SIDIS is close to publication.
- Paper preparation: DC-83, DC-88, DC-79, DC-95.

HERMES data are stored
and
can be used by physical community.

Congratulations

Thank You.

A Happy New Year!