HERMES Experiment in 2012 (DESY)

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- Main Activities of HERMES in 2012
- Inclusive Vector-Meson Production in Deep-Inelastic Scattering
- Polarization of Lambda and Antilambda Hyperons in HERMES Experiment
- Azimuthal Dependence of Double-Spin Asymmetry in SIDIS
- Summary

Main Activities of HERMES in 2012

- $E_e = 27.6$ GeV, $S_e \approx \pm 0.5$, $S_T \approx \pm 0.9$, L=1505 pb^{-1}. End of data taking 2007.
- HERMES activities in data treatment:
  - publication results on inclusive structure functions,
  - study of quark and gluon helicity 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 (D.Veretennikov: ϕ-meson SDMEs, S.Manaenkov, D.Veretennikov: amplitude analysis of ρ production).

- Publication papers with information from recoil detector.

Inclusive 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):
  $\gamma^* + N \to V + N'$, $\gamma^* + N \to \gamma + N'$.
  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) $e \to e' + \gamma^*$, ii) $\gamma^* + N \to \rho^0 + N'$, 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.

- Spin-Density Matrix Elements (SDMEs) in Diehl's Formalism: $u,\ l,\ s,\ n$

  $$u^{\lambda_V\lambda'_V}_{\lambda_\gamma\lambda'_\gamma} = \frac{1}{N}\sum_{\lambda_2=\pm\frac{1}{2}}\Big[F_{\lambda_V\lambda_2\lambda_\gamma+\frac{1}{2}}(F_{\lambda'_V\lambda_2\lambda'_\gamma+\frac{1}{2}})^* + F_{\lambda_V\lambda_2\lambda_\gamma-\frac{1}{2}}(F_{\lambda'_V\lambda_2\lambda'_\gamma-\frac{1}{2}})^*\Big].$$

  $N = \sum_{\lambda_V,\lambda_1,\lambda_2}\Big[|F_{\lambda_V\lambda_2 1\lambda_1}|^2 + \epsilon|F_{\lambda_V\lambda_2 0\lambda_1}|^2\Big]$ is normalization factor.

  Symbolic $u = \frac{1}{N}\sum_{\lambda_2=\pm\frac{1}{2}}\Big[F_{+\frac{1}{2}}F^*_{+\frac{1}{2}} + F_{-\frac{1}{2}}F^*_{-\frac{1}{2}}\Big]$,

  $$l = \frac{1}{N}\sum_{\lambda_2=\pm\frac{1}{2}}\Big[F_{+\frac{1}{2}}F^*_{+\frac{1}{2}} - F_{-\frac{1}{2}}F^*_{-\frac{1}{2}}\Big],$$

  $$s = \frac{1}{N}\sum_{\lambda_2=\pm\frac{1}{2}}\Big[F_{\frac{1}{2}}F^*_{-\frac{1}{2}} + F_{-\frac{1}{2}}F^*_{+\frac{1}{2}}\Big],$$

  $$n = \frac{1}{N}\sum_{\lambda_2=\pm\frac{1}{2}}\Big[F_{+\frac{1}{2}}F^*_{-\frac{1}{2}} - F_{-\frac{1}{2}}F^*_{+\frac{1}{2}}\Big].$$

  Total number of SDMEs is equal to 71.

- Spin-Density Matrix Element Method

  SDMEs are Fourier coefficients in angular distribution of charged pions from decay $\rho^0 \to \pi^+ + \pi^-$.

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

- Amplitude Method
  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 can be expressed through amplitude ratios.
  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.

- Decomposition of helicity amplitudes
  $\mathsf{F}_{\lambda_V\lambda_2\lambda_\gamma\lambda_1} = T_{\lambda_V\lambda_2\lambda_\gamma\lambda_1} + U_{\lambda_V\lambda_2\lambda_\gamma\lambda_1}$. Symbolic: $F = T + U$.

  Natural Parity Exchange (NPE) amplitudes, T (10) are due to exchange of reggeons with $J^P = 0^+,\ 1^-,\ 2^+, \ldots$ (Pomeron, ω, ρ, f_2, ... reggeons)
  $T = T^{(1)}_{\lambda_2=\lambda_1} + T^{(2)}_{\lambda_2\neq\lambda_1},\ \ T^{(1)} \leftrightarrow T_{\frac{1}{2}\frac{1}{2}} = T_{-\frac{1}{2}-\frac{1}{2}},\ \ T^{(2)} \leftrightarrow T_{\frac{1}{2}-\frac{1}{2}} = -T_{-\frac{1}{2}\frac{1}{2}}.$
  Unnatural Parity Exchange (UPE) amplitudes, U (8) are due to exchange of reggeons with $J^P = 0^-,\ 1^+,\ 2^-, \ldots$ (π, a_1, ... reggeons)
  $U = U^{(1)}_{\lambda_2=\lambda_1} + U^{(2)}_{\lambda_2=-\lambda_1},\ \ U^{(1)} \leftrightarrow U_{\frac{1}{2}\frac{1}{2}} = -U_{-\frac{1}{2}-\frac{1}{2}},\ \ U^{(2)} \leftrightarrow U_{\frac{1}{2}-\frac{1}{2}} = U_{-\frac{1}{2}\frac{1}{2}}.$

- Amplitude Ratios $\eta_k \equiv T^{(1)}_{\lambda_V\lambda_\gamma}/T^{(1)}_{00}$, $T^{(2)}_{\lambda_V\lambda_\gamma}/T^{(1)}_{00}$, $U^{(1)}_{\lambda_V\lambda_\gamma}/T^{(1)}_{00}$, $U^{(2)}_{\lambda_V\lambda_\gamma}/T^{(1)}_{00}$

Sensitivity of Angular Distribution to Small Amplitudes

- Linear Contributions of Small Amplitudes

  Main contribution to angular distribution of π^+ and π^-: $u \approx T^{(1)}T^{*(1)}$.

  Extracted by HERMES, published in Eur. Phys. J. C71 (2011) 1609.

  Linear contribution of small $U^{(2)}$: $s \approx T^{(1)}U^{*(2)} + U^{(2)}T^{*(1)}$,

  Linear contribution of small $T^{(2)}$: $n \approx T^{(1)}T^{*(2)} - T^{(2)}T^{*(1)}$,

  Linear contribution of small $U^{(1)}$: $l \approx T^{(1)}U^{*(1)} + U^{(1)}T^{*(1)}$ cannot be studied

  with transversely polarized target.

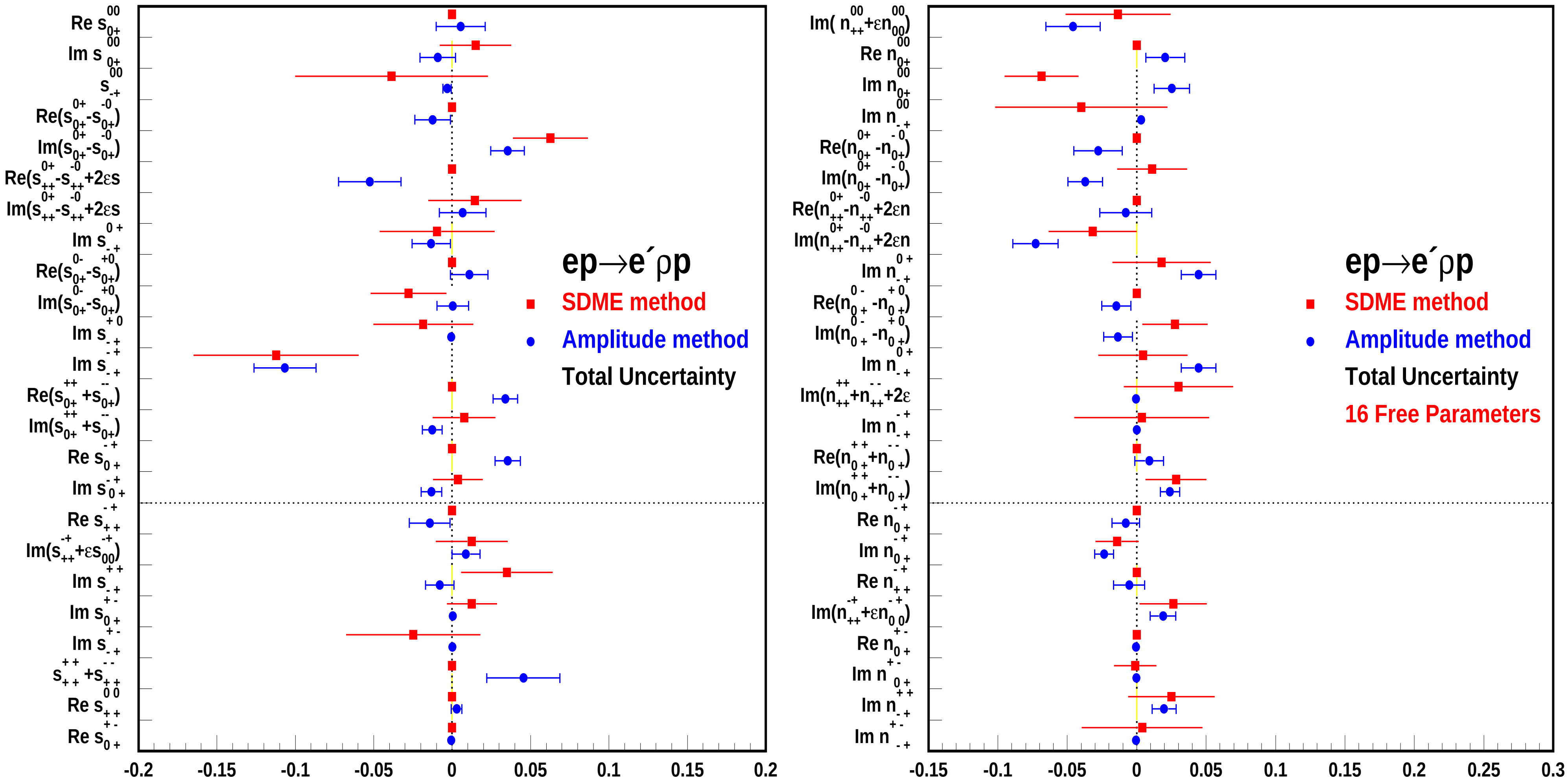
- Important NPE amplitudes:

  NPE amplitudes: $T_{00}^{(1)}$, $T_{11}^{(1)}$, $T_{10}^{(1)}$, $T_{1-1}^{(1)}$, $T_{01}^{(1)}$; $T_{10}^{(2)}$, $T_{1-1}^{(2)}$,$\mathrm{T}_{01}^{(2)}$

  UPE amplitudes: $U_{11}^{(2)}$, $U_{10}^{(2)}$, $U_{1-1}^{(2)}$, $U_{01}^{(2)}$;

  Additional amplitudes(?): $U_{11}^{(1)}$, $T_{11}^{(2)}$, $T_{00}^{(2)}$

Comparison of SDME and Amplitude Methods for $s^{\lambda\lambda'}_{\mu\mu'}$ and $n^{\lambda\lambda'}_{\mu\mu'}$



Polarization of Lambda and Antilambda Hyperons in HERMES Experiment

- "Spin Crisis" for Λ Hyperon
  $q(x,Q^2) = q(x,Q^2)\uparrow\Uparrow + q(x,Q^2)\downarrow\Uparrow$, $\Delta q(x,Q^2) = q(x,Q^2)\uparrow\Uparrow - q(x,Q^2)\downarrow\Uparrow$,
  $\Delta q \equiv \int_0^1 \Delta q(x,Q^2)dx$, $Q^2 = -(k-k')^2 \equiv -q^2$, $x = \frac{Q^2}{2(P_N\cdot q)}$.
  $\Sigma = \Delta u_P + \Delta d_P + \Delta s_P = 0.33 \pm 0.03$ for proton,
  $F = 0.464 \pm 0.008$ and $D = 0.806 \pm 0.008$ β-decay constants for baryon octet,
  $\Rightarrow \Delta u_\Lambda = \Delta d_\Lambda = -0.16 \pm 0.01,\ \ \Delta s_\Lambda = 0.57 \pm 0.01$ (R.L.Jaffe)
  Lattice-QCD $\Delta u_\Lambda = \Delta d_\Lambda = -0.02 \pm 0.04,\ \ \Delta s_\Lambda = 0.68 \pm 0.04$
- Fragmentation Function
  Massless particles $F_q^\Lambda(z,Q^2) = F_{q\uparrow}^{\Lambda\Uparrow}(z,Q^2) + F_{q\uparrow}^{\Lambda\Downarrow}(z,Q^2)$,
  $\Delta F_q^\Lambda(z,Q^2) = F_{q\uparrow}^{\Lambda\Uparrow}(z,Q^2) - F_{q\uparrow}^{\Lambda\Downarrow}(z,Q^2)$,
  $z = E_\Lambda/E_q$, $Q^2 = -q^2$ photon virtuality.
  $D_q^\Lambda(z,Q^2) = \frac{\Delta F_q^\Lambda(z,Q^2)}{F_q^\Lambda(z,Q^2)}$, $D_q^\Lambda(Q^2) = \frac{\int \Delta F_q^\Lambda(z,Q^2)dz}{\int F_q^\Lambda(z,Q^2)dz}$.
  Complementarity of DIS and e^+e^- annihilation
  DIS: u-dominance, ΔF_u^Λ; $e^+e^- \to Z^0 \to \Lambda\bar{\Lambda}$: ΔF_s^Λ $|S_s| \approx 0.98,\ |S_u| \approx 0.67$
- Relation between Parton Distributions and Fragmentation Functions
  Model estimates (Ashery, Lipkin) for first moments of valence quark distributions
  $D_q^\Lambda(Q^2) = \frac{\int \Delta F_q^\Lambda(z,Q^2)dz}{\int F_q^\Lambda(z,Q^2)dz} \approx \frac{\Delta q_\Lambda(Q^2)}{q_\Lambda(Q^2)}$.

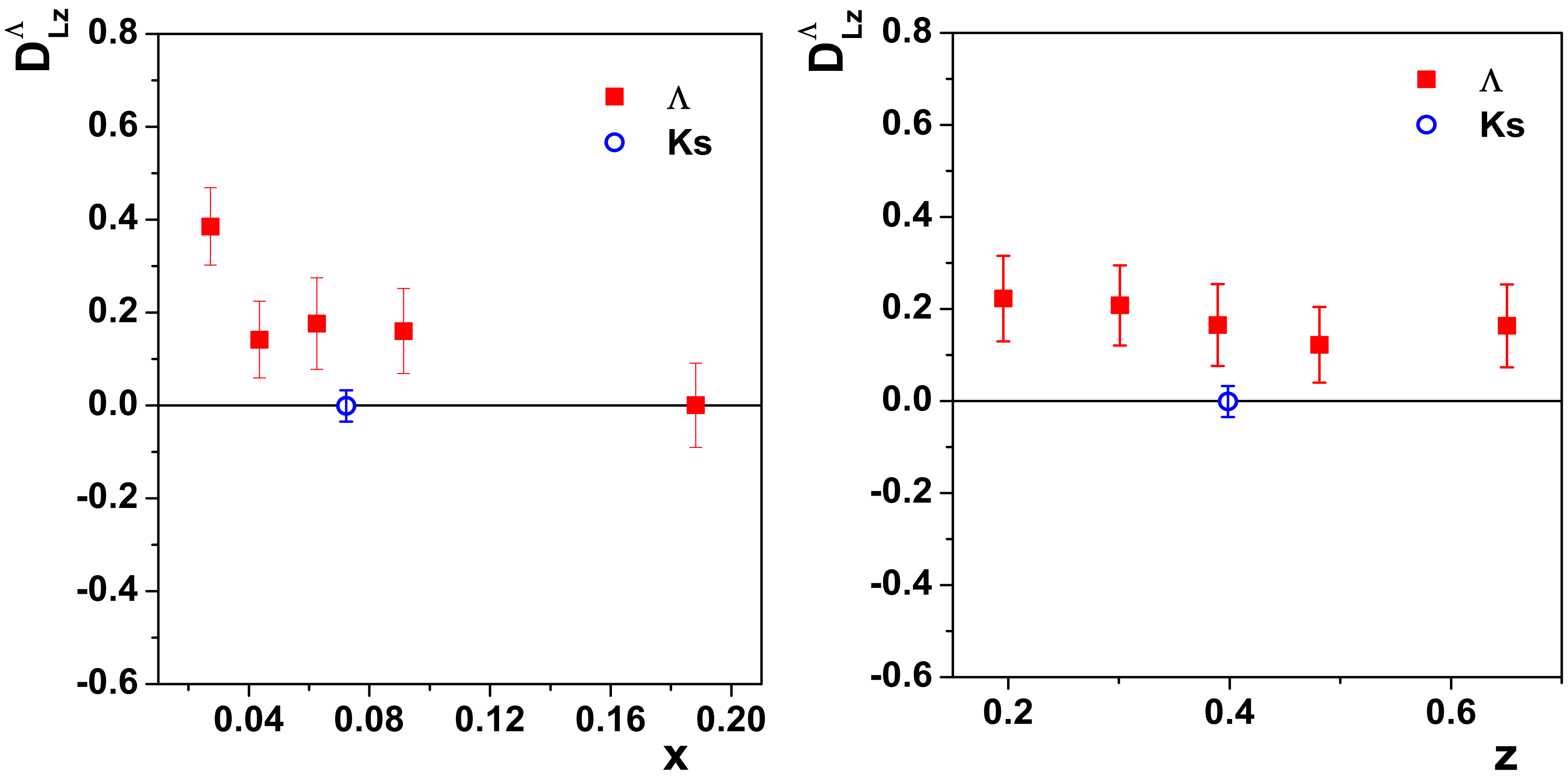
- Target and Current Fragmentation
  $x = \frac{1}{2}Q^2/(P_N \cdot q)$, $q = (\nu, 0, 0, \sqrt{\nu^2 + Q^2})$ in nucleon rest (lab.) system.
  Target fragmentation $x_F < 0$, $z < 0.2$. Current fragmentation $x_F > 0$, $z > 0.2$
  where $x_F = P_z^\Lambda / max(P_z^\Lambda)$ in CM system, $z = E^\Lambda/E_q = E^\Lambda/\nu$ in lab. system.

- Spin-Transfer Coefficients $D_{Lj}^\Lambda(z, Q^2)$ for Massive Particle
  All consideration in Cartesian right-handed Λ rest frame.
  Hyperon polarization vector, $\vec{S}^\Lambda$ can be found from $W = \frac{1}{4\pi}\left[1 + \alpha(\vec{S}^\Lambda \cdot \vec{P}_N)/|\vec{P}_N|\right]$,
  $\alpha = 0.642 \pm 0.013$ for $\Lambda \to p + \pi^-$ and -0.642 ± 0.013 for $\bar{\Lambda} \to \bar{p} + \pi^+$.
  $(\vec{S}^\Lambda)_j = D_{Lj}^\Lambda(x, z, Q^2) D(y) S_e$, $j = x,\ y,\ z$, $D(y) = \frac{1-(1-y)^2}{1+(1-y)^2}$, $y = \nu/E_e$.

$$D_{Lj}^\Lambda(x, z, Q^2) = \frac{\sum_q \left[D_{Lj}^{q\to\Lambda}(z,Q^2) F_q^\Lambda(z,Q^2) e_q^2 q(x,Q^2)\right]}{\sum_q \left[F_q^\Lambda(z,Q^2) e_q^2 q(x,Q^2)\right]}.$$

  First Lorentz system of frame:
  $j \equiv L' = x,\ y,\ z$. Z-axis is along virtual photon three-momentum, $\vec{q}$.
  Y-axis is parallel to $\vec{q} \times \vec{P}_\Lambda$ in lab. system. X-axis is orthogonal to Y and Z axes.
  Second Lorentz system of frame:
  $j \equiv L' = x',\ y',\ z'$. Z'-axis is along hyperon three-momentum $\vec{P}_\Lambda$ in lab. system.
  Y'-axis coincides with Y-axis. X'-axis is orthogonal to Y' and Z' axes.

Polarization of Lambda and Antilambda Hyperons in HERMES Experiment



$\frac{\Delta q(x=z)}{q(x=z)} \approx D^{\Lambda}_{Lz}(z)$ is positive.

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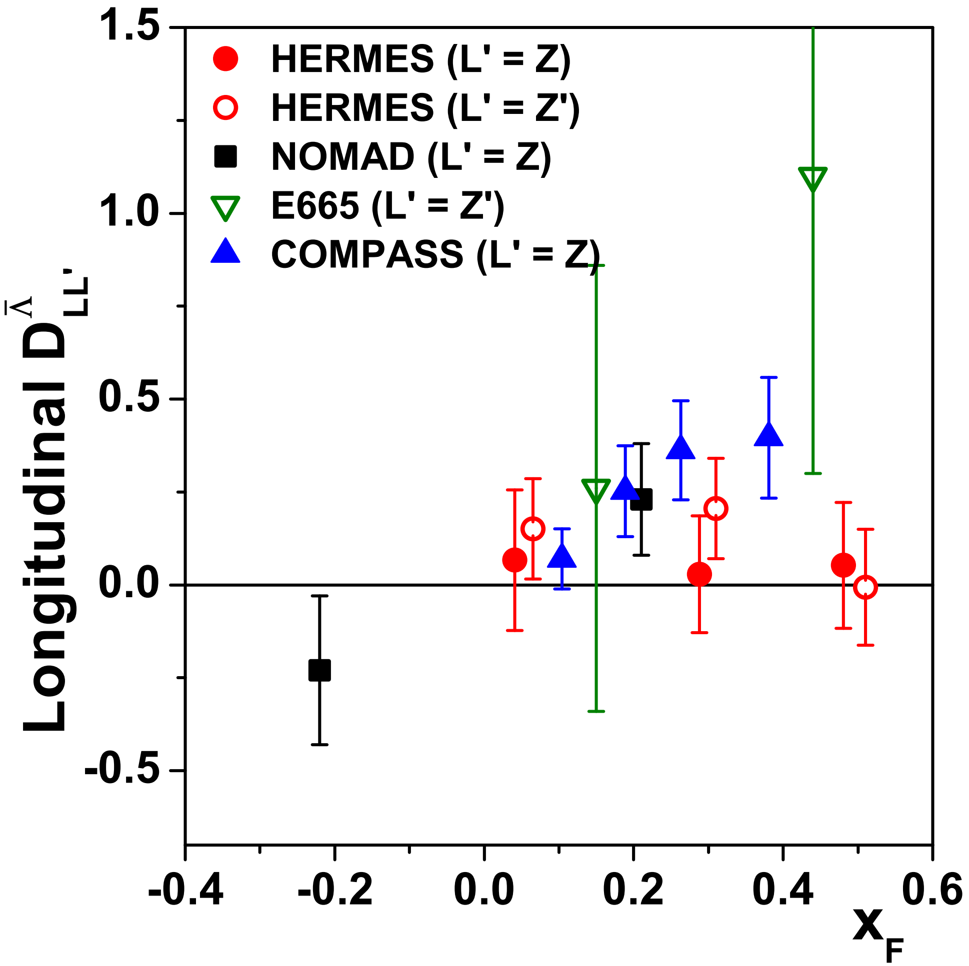
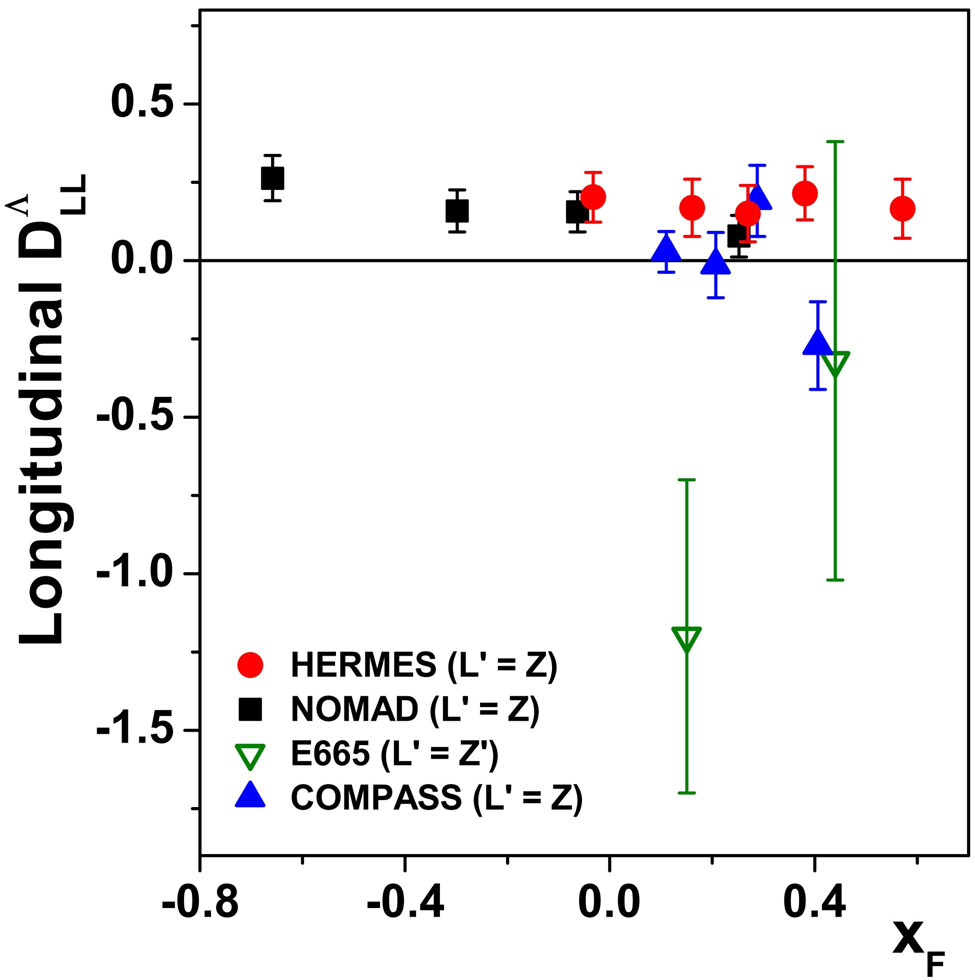
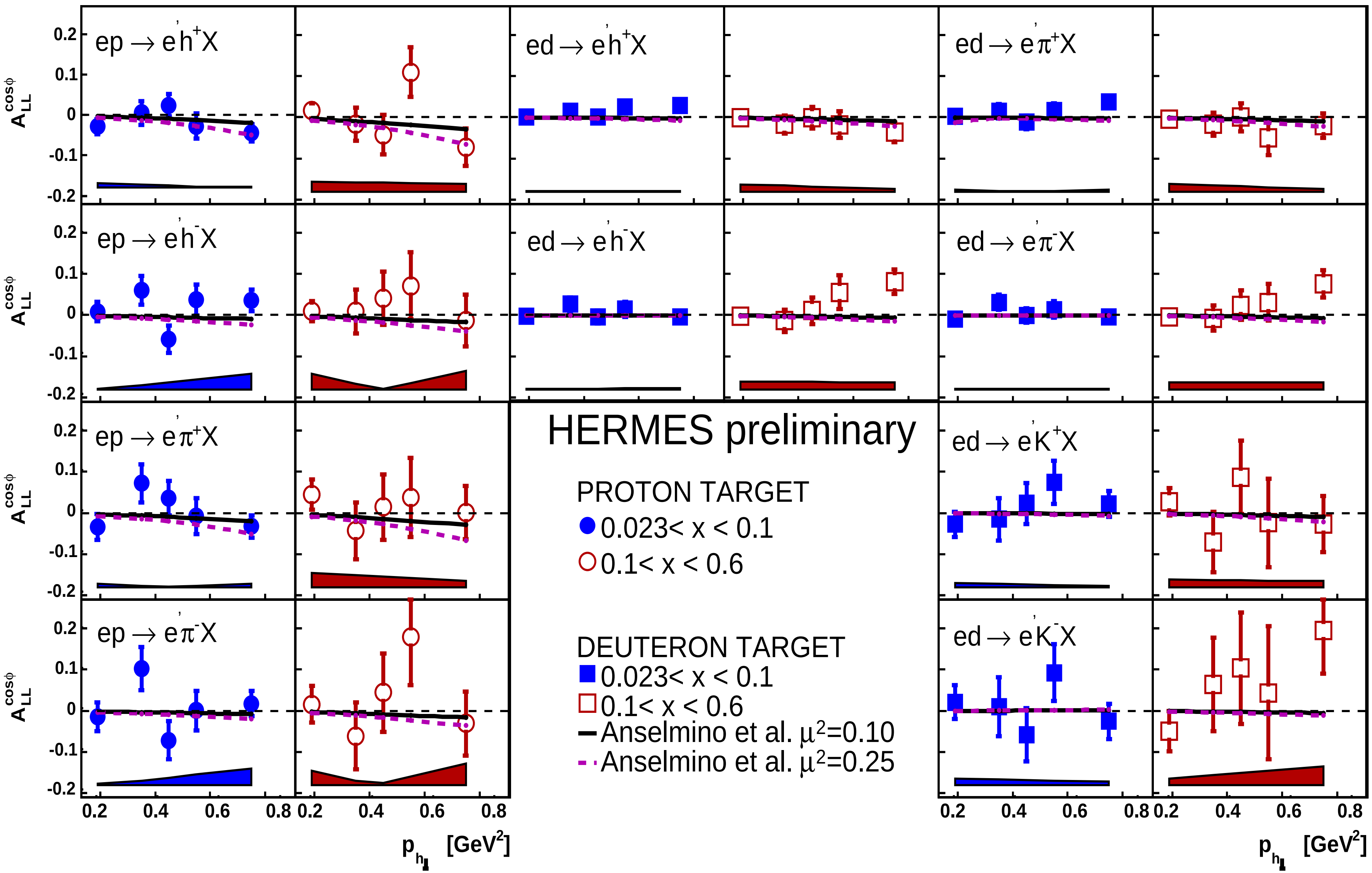




Azimuthal Dependence of Double-Spin Asymmetry in SIDIS



Summary

- End of HERMES data treatment is always in two years.
- 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 on azimuthal dependence of double-spin asymmetry in SIDIS is ready to first circulation.

Conferences and Publications

- S.Belostotski: talk at DSPIN-2012.
  P.Kravchenko: talk at DIS-2012.

- Paper preparation: DC-83, DC-88, DC-79.

- HERMES publications:
  A.Airapetian et. al., IHEP 07 (2012) 032.
  A.Airapetian et. al., IHEP 10 (2012) 042.
  A.Airapetian et. al., submitted to Phys. Rev. D.
  A.Airapetian et. al., Eur. Phys. J. C72 (2012) 1921.