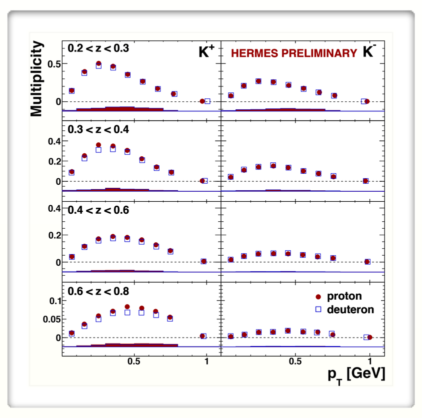
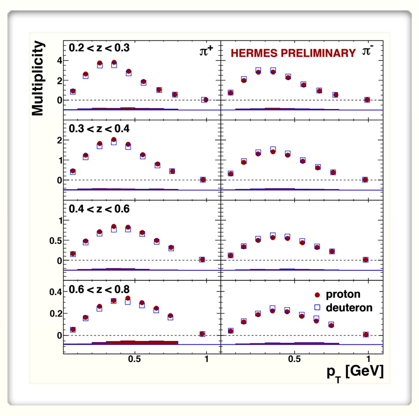
Multiplicities of charged pions and kaons from semi-inclusive deep-inelastic scattering on the proton and the deuteron

Multiplicities instead of cross section: no luminosity uncertainty

$$M^h(Q^2,x,z,p_T) \equiv \frac{dxdQ^2}{d^2N^{DIS}(Q^2,x)}\frac{d^4N^h(Q^2,x,z,p_T)}{dxdQ^2dzdp_T}$$





Assumptions: QPM, LO, leading twist factorized collinear QCD

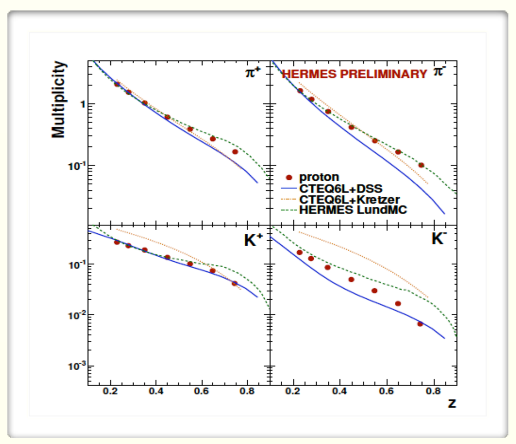
$$\frac{dM^h(Q^2,x,z)}{dz} \approx \frac{\sum_q e_q^2 f_1^q(Q^2,x) D_q^h(Q^2,z)}{\sum_q e_q^2 f_1^q(Q^2,x)}$$

Opens access to
- Fragmentation functions
  Disentangle q and anti-q contributions
- Parton distribution functions

Additionally, through the $p_\perp$ dependence
- Fragmentation $k_\perp$
- Intrinsic quark $p_\perp$

$$\frac{d^5\sigma^h}{dxdQ^2dzdp_T^2} \propto \sum_q e_q^2 \int d^2k_\perp d^2\vec{p}_\perp \delta^2(\vec{p}_T - \vec{p}_\perp - z\vec{k}_\perp) f_1^q(Q^2,x,k_\perp) D_q^h(Q^2,z,p_\perp)$$

High statistics
3D analysis (in x, z, p_T and Q^2)
For identified and charge-separated
High statistics data require sophisticated analysis:
Corrections for trigger inefficiencies
Charge-symmetric background correction
RICH unfolding
Multidimensional unfolding for radiative effects,
limited acceptance and detector smearing



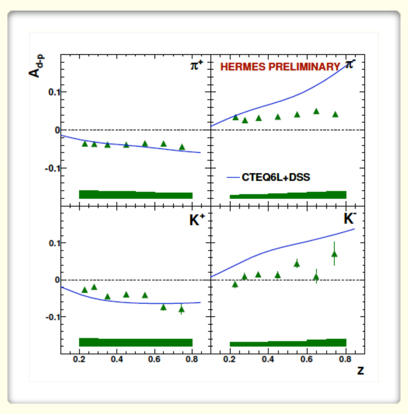
LO Interpretation
Good agreement with CTEQ6+DSS for π^+ and K^+

CTEQ6+Kretzer performs well for pions

Proton-deuteron multiplicity asymmetry

$$A^h_{d-p} \equiv \frac{M_d^h - M_p^h}{M_d^h + M_p^h}$$

Reflects different valence quark content
Improved precision by cancellations
in the systematic uncertainty



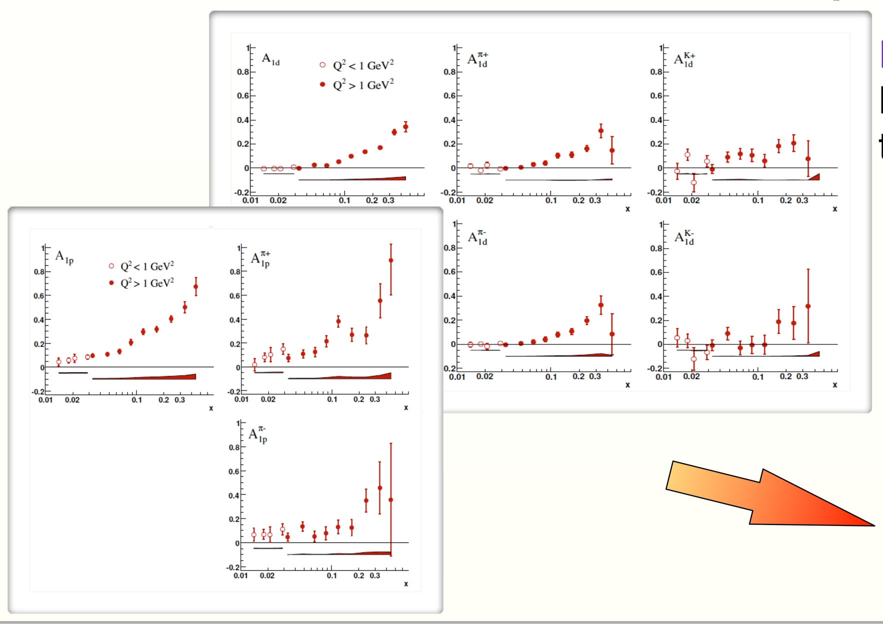
LO Interpretation:
Good agreement with LO model calculations for positive hadrons
Bigger discrepancy for negative hadrons

Quark Helicity Distributions in the Nucleon for up, down, and strange Quarks from Semi-inclusive Deep-inelastic Scattering

3D analysis (in x, z, p_T)
Charge-symmetric background correction
RICH unfolding
Multidimensional unfolding
for radiative effects, limited
acceptance and detector smearing
cosφ azimuthal corrections

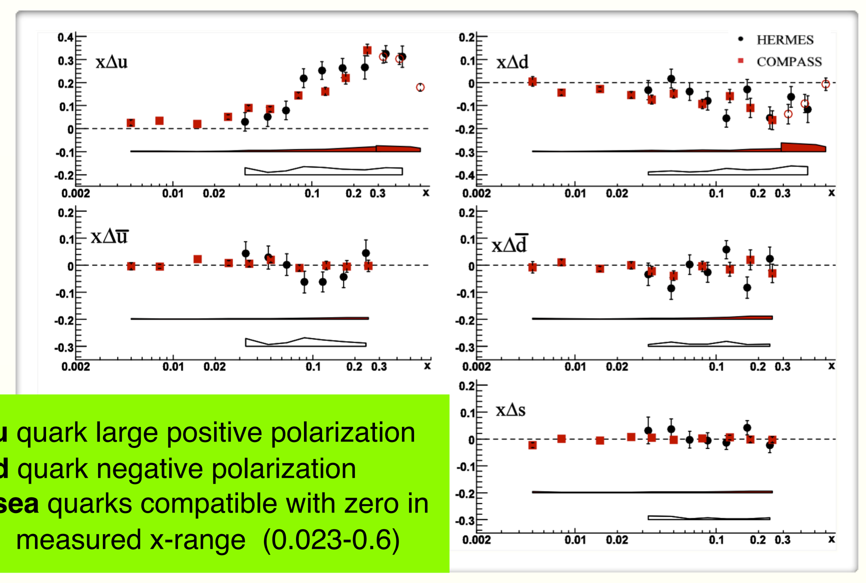
Helicity conservation in polarized DIS: select specific quark spin orientation
Hadron tagging: select specific quark flavor

$$A_1^h(x,Q^2) \overset{LO}{\approx} \frac{\sum_q e_q^2 \Delta q(x,Q^2)\int dz D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)\int dz D_q^h(z,Q^2)} \sim \sum_q \frac{e_q^2 q(x)\int dz D_q^h(z)}{\sum_{q'} e_{q'}^2 q' \int dz D_{q'}^h(z)}\frac{\Delta q(x)}{q(x)} \sim P_q^h \frac{\Delta q}{q}$$



Purity formalism:
Matrix inversion brings back from hadron asymmetries
to quark spin flavor distributions.

$$(A_{1p}^{\pi^+}, A_{1p}^{\pi^-}, \ldots A_{1d}^{K^-}) \vec{A} = P \cdot \vec{Q} \left(\frac{\Delta u}{u}(x), \frac{\Delta d}{d}(x), \ldots \frac{\Delta s}{s}(x)\right)$$



u quark large positive polarization
d quark negative polarization
sea quarks compatible with zero in measured x-range (0.023-0.6)

Charge difference asymmetries

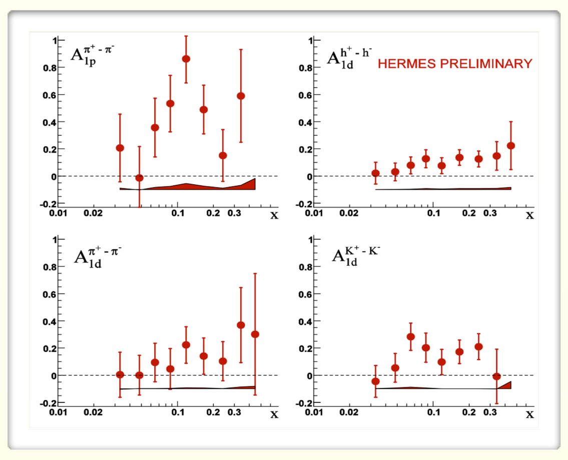
$$A_1^{h^+-h^-} = \frac{(d\sigma_{h^+}^{\overset{\rightarrow}{\Leftarrow}} - d\sigma_{h^-}^{\overset{\rightarrow}{\Leftarrow}}) - (d\sigma_{h^+}^{\overset{\rightarrow}{\Rightarrow}} - d\sigma_{h^-}^{\overset{\rightarrow}{\Rightarrow}})}{(d\sigma_{h^+}^{\overset{\rightarrow}{\Leftarrow}} - d\sigma_{h^-}^{\overset{\rightarrow}{\Leftarrow}}) + (d\sigma_{h^+}^{\overset{\rightarrow}{\Rightarrow}} - d\sigma_{h^-}^{\overset{\rightarrow}{\Rightarrow}})}$$

Assumptions
- Charge conjugation symmetry of fragmentation functions:
- Under leading order, leading twist, current fragmentation assumptions:

$$D_q^{h^+} = D_{\bar{q}}^{h^-}$$

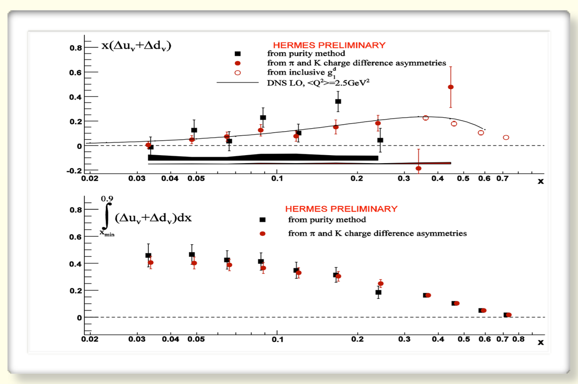
$$A_{1p}^{h^+-h^-} = \frac{4\Delta u_v - \Delta d_v}{4u_v - d_v}$$

$$A_{1d}^{h^+-h^-} = \frac{\Delta u_v + \Delta d_v}{u_v + d_v}$$



Evolved to Q^2=2.5GeV^2
For $u_v(x)+d_v(x)$ CTEQ6 LO used
Using LO DNS parameterization

Sea very small at large x:
with inclusive asymmetry determined
much better

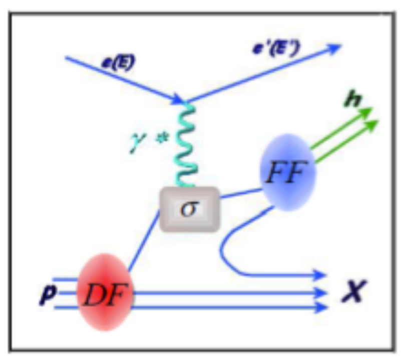


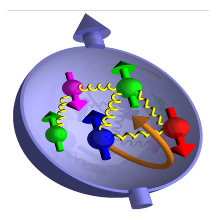
Integral over sum of valence distributions compatible with ΔΣ
Sea contribution to nucleon spin small

HERMES highlights on the longitudinal-momentum structure of the nucleon

$$S_z = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z^q + L_z^g$$

☑quark spin
☑gluon spin



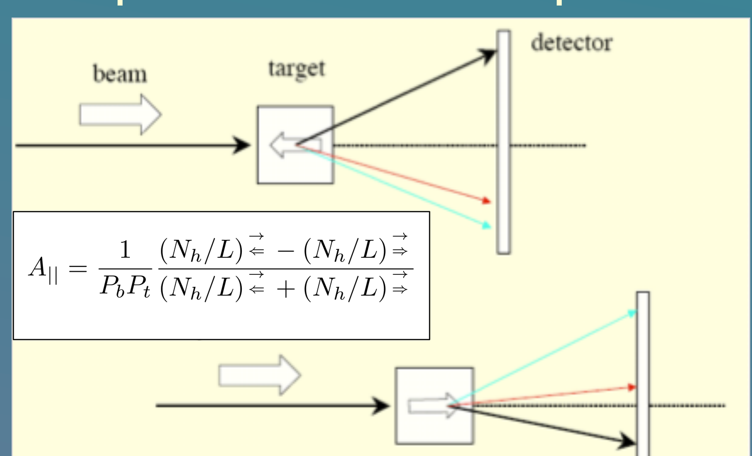


SEMI-INCLUSIVE DEEP-INELASTIC SCATTERING

Cross section contains Distribution Functions and Fragmentation Functions:

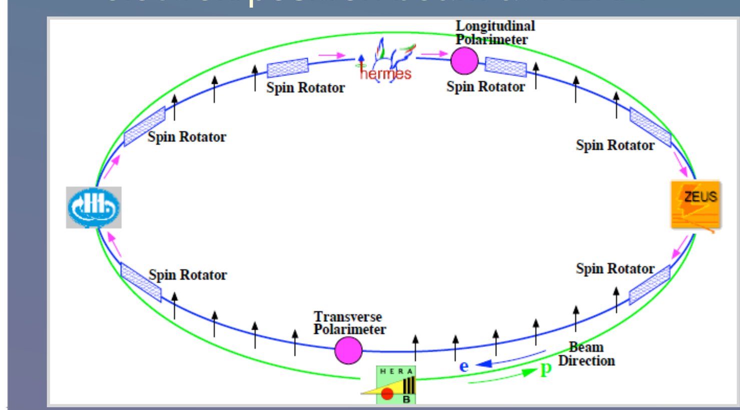
$$\sigma^{eN\rightarrow ehX} = \sum_q DF^{N\rightarrow q}(x) \otimes \sigma^{eq\rightarrow eq} \otimes FF^{q\rightarrow h}(z)$$

Experimental Prerequisits



N_h - number of SIDIS events
Pb, Pt - beam and target polarizations

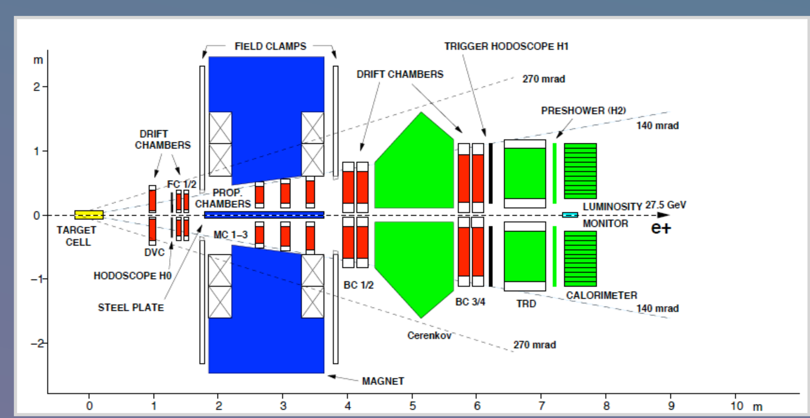
Longitudinally polarized 27.6 GeV electron/positron beam at HERA



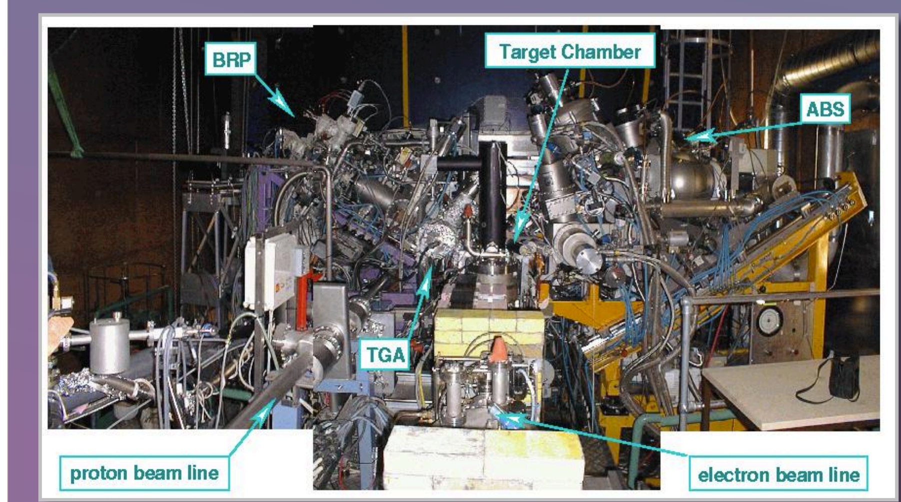
I_e<50mA, P_b=0.55
lifetime=12-14h
transversely polarized e± in storage ring
polarization build-up by emission
of synchrotron radiation (Sokolov-Ternov effect)
Spin rotators around HERMES IP

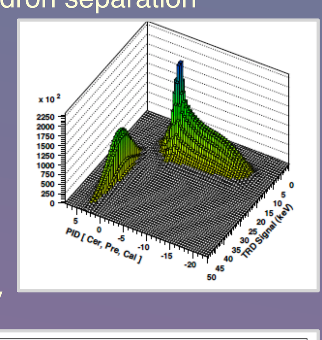
Forward spectrometer

Tracking: Drift Vertex Chambers, Front Chambers, Magnet Chambers, Back Chambers
Particle Identification: Čerenkov (RICH) Detector, Transition Radiation Detector, Preshower, Calorimeter
Luminosity Monitor (Bhabha/Møller scattering)

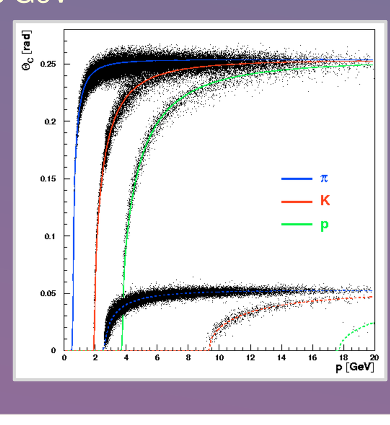


Measurement with high accuracy
Very clean lepton-hadron separation





RICH detector enables very good pion-kaon separation between 2-15 GeV

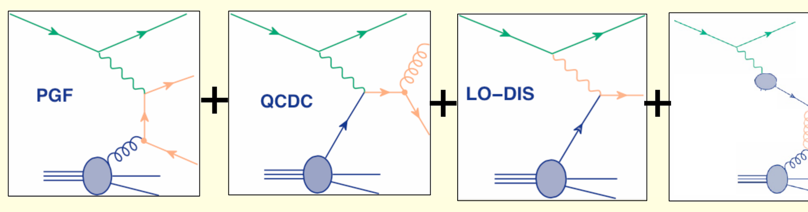


Longitudinally polarized pure H and D internal gas targets

P_T~ 0.85; polarized H↑→, D↑→
dilution factor=1
Thickness =10^{14}-10^{15} nucl/cm^2
Temperature=100K
internal to the HERA storage ring

Measurement of the Spin Asymmetry in the Photoproduction of Pairs of High-pT Hadrons at HERMES

Large p_T hadron pairs come from photon gluon fusion processes:
they carry information of the gluon spin

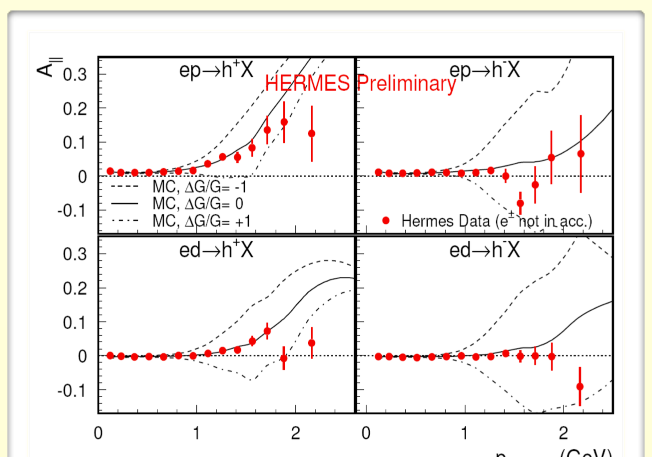


Measured asymmetry is an incoherent superposition of different hard and soft subprocess asymmetries:

$$A_{\|}^{meas}(p_T) = \sum_i f_i A_{\|}^i = f_{sig} A_{\|}^{sig} + f_{bg} A_{\|}^{bg} \quad f_i = \frac{\sigma_i}{\sigma_{tot}}$$

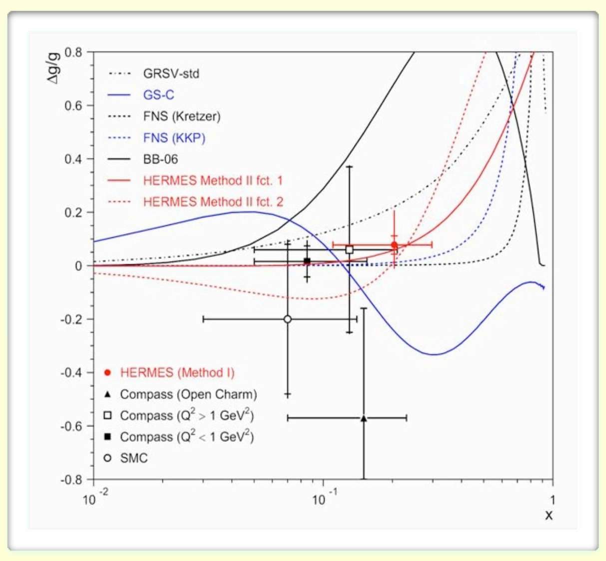
Background: all other sub-processes ➞ MC

High pt event selection.
Main contribution from PGF process.
Extraction of asymmetries from events with different topology for consistency of results.
CSB correction for positrons.
Trigger inefficiency estimation.
Dominative beam-target polarization systematic uncertainty.



- Intensive MC estimation of process-fractions contributing to ΔG such as PGF, VMD, pQCD processes.
- Using in MC CTEQ5L PDFs gaussian distribution for intrinsic and fragmentation transverse momenta.

- Method I:
  - Factorize $A_{\|}^{sig} \approx \langle \hat{a} \rangle (p_T) \frac{\Delta g}{g}(p_T)$
  - Assumes
    - No sign change in â(x)
  - No direct information on <x>
  - Gives average Δg/g over covered x range (0.07<x<0.7)
- Method II:
  - Fit: find a Δg/g(x) such that $A_{\|}^{MC} = A_{\|}^{meas}$
  - Assumes functional form for Δg/g(x)
  - Only small range in p_T
  - Gives Δg/g(x) and <x>



$$\frac{\Delta G}{G} = 0.071 \pm 0.034(stat) \pm 0.010(sys-exp) \,{}^{+0.127}_{-0.105}\,(sys-model)$$

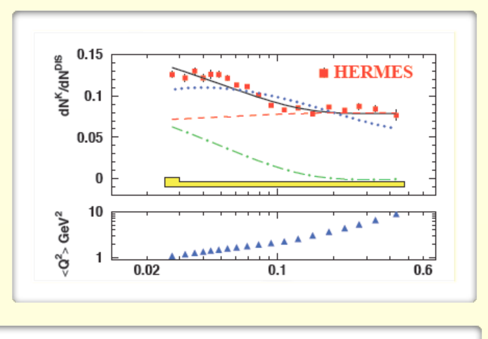
Measurement of Parton Distributions of Strange Quarks in the Nucleon from Charged-Kaon Production in Deep-Inelastic Scattering on the Deuteron

- Strange quarks carry no isospin, thus the same in proton and neutron
- Use isoscalar probe and target to extract strange-quark distributions

$$\Delta S = \Delta s + \Delta\bar{s}$$

- Only need inclusive asymmetries and K⁺+K⁻ asymmetries, as well as K⁺+K⁻ multiplicities on D
- Strange-quark fragmentation function either directly from data or from parameterizations

$$(A_{1d}, A_{1d}^{K^++K^-}) \vec{A} = P \cdot \vec{Q} \left(\frac{\Delta Q}{Q}(x), \frac{\Delta S}{S}(x)\right)$$

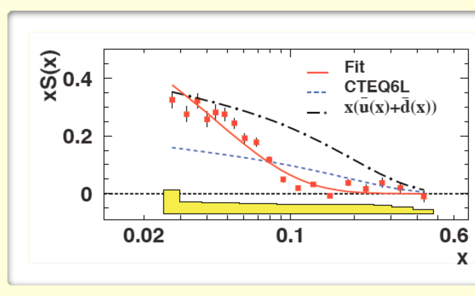


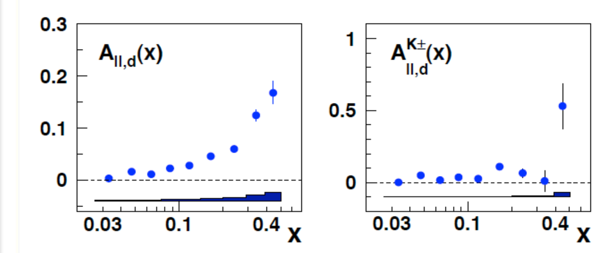
RICH unfolding
Multidimensional unfolding for radiative effects, limited acceptance and detector smearing
Beam-target systematic uncertainty estimation

Charged kaon multiplicities in LO:

$$\frac{dN^K(x)}{dN^{DIS}(x)} = \frac{Q(x)\int D_Q^K(z)dz + S(x)\int D_S^K(z)dz}{5Q(x) + 2S(x)}$$

Use of world data CTEQ6 PDFs in fit

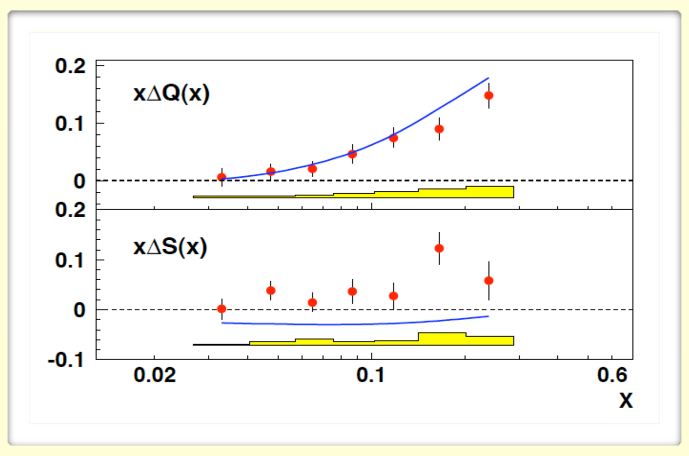




From S(x) extraction

$$A_{\|d}^K(x)\frac{d^2N^K(x)}{dxdQ^2} = K_{LL}(x,Q^2)[\Delta Q(x)\int D_Q^K(z)dz + \Delta S(x)\int D_S^K(z)dz]$$

$$A_{\|d}(x)\frac{d^2N^{DIS}(x)}{dxdQ^2} = K_{LL}(x,Q^2)[5\Delta Q(x) + 2\Delta S(x)]$$



$$\Delta S = 0.037 \pm 0.019 \pm 0.027$$