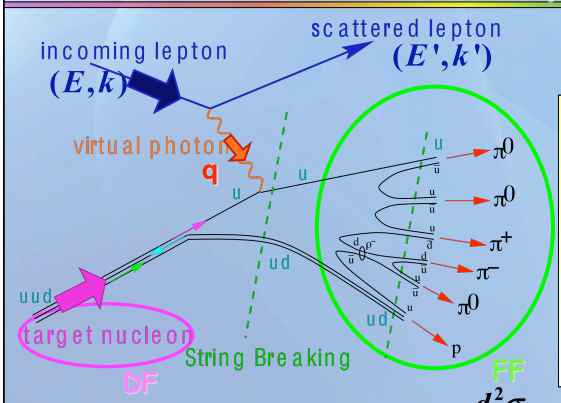
Abstract

Deep Inelastic Scattering
or
A clean way to access the partonic structure of nucleons

The question after the individual parton (quarks and gluons) contributions to the spin of the nucleon is even after 20 years of experimental efforts not yet solved. After several very precise measurements in polarized deep inelastic scattering it is clear, that the spin of the nucleon can not be explained by the contribution of the quarks alone. This is affirmed by the newest results from COMPASS, HERMES and JLAB on the inclusive spin structure function g1 and on the individual contributions from the different quark flavors from semi-inclusive deep inelastic scattering data.
Recently COMPASS and HERMES have started to measure the gluon polarization by isolating the photon gluon fusion process in semi-inclusive deep inelastic scattering; latest results on the contribution of the gluons to the nucleon spin from these measurements and RHIC will be discussed.
The clear experimental evidence of exclusive reactions, especially DVCS, allows in the formalism of generalised parton distributions the study of an other component of the nucleon spin the orbital angular momentum.
The most recent results (H1, Zeus, Hermes and JLab) on indications of the size of the orbital angular momentum of quarks will be presented.
The newest data from HERMES and COMPASS constraining the fast developing field of transverse momentum distributions, like transversity and the Sivers fct will be also presented.

Deep Inelastic Scattering



Important kinematic variables:

Collider:

Photon:

$$Q^2 = -q^2 = -(k-k')^2 = 2E_e E_e'(1+\cos\Theta_e)$$

$$\nu = E - E'$$

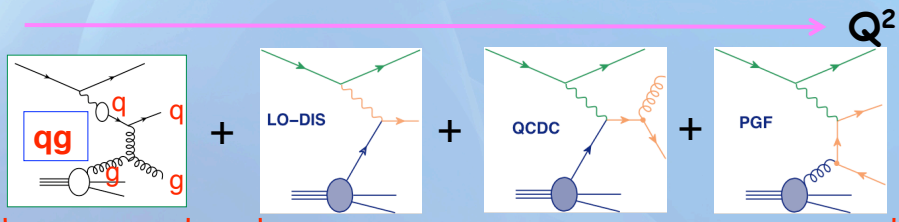
Quark: $x = \frac{Q^2}{sy}$

Hadron: $z = \frac{E_h}{\nu}$ $\quad p_t^2$

cross section: $\frac{d^2\sigma}{d\Omega dE'} \sim L_{\mu\nu} W^{\mu\nu}$

$$W^{\mu\nu} = \underbrace{-g^{\mu\nu}F_1 - \frac{p^\mu p^\nu}{\nu}F_2 + \frac{i}{\nu}\varepsilon^{\mu\nu\lambda\sigma}q^\lambda s^\sigma g_1 + \frac{i}{\nu^2}\varepsilon^{\mu\nu\lambda\sigma}q^\lambda(p\cdot qs^\sigma - s\cdot qp^\sigma)g_2}_{\text{Spin 1}}$$
$$\underbrace{-r_{\mu\nu}b_1 + \frac{1}{6}(s_{\mu\nu}+t_{\mu\nu}+u_{\mu\nu})b_2 + \frac{1}{2}(s_{\mu\nu}-u_{\mu\nu})b_3 + \frac{1}{2}(s_{\mu\nu}-t_{\mu\nu})b_4}_{\text{Spin 1}}$$

Main Underlying Processes



Splitting of $\gamma \rightarrow qq$

hard QCD 2→2

„Soft" & Hard VMD:

Elastic, diffractive, non-diffractive minimum bias

Scale: p_t or m_q

x of parton is not known

very much like pp

scattered lepton in detector

virtual photon know x of parton

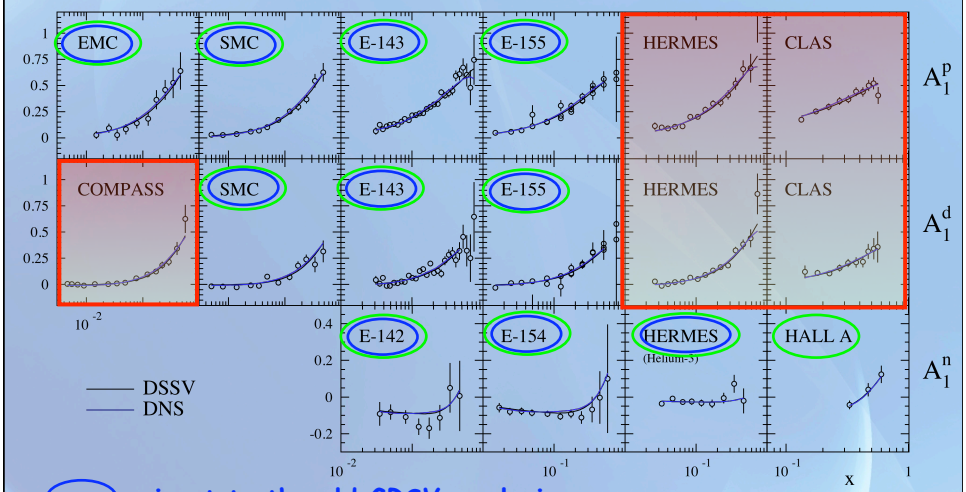
Scale: Q^2

p_t can be big

Inclusive World data

- Inclusive DIS-Data:

not in DNS



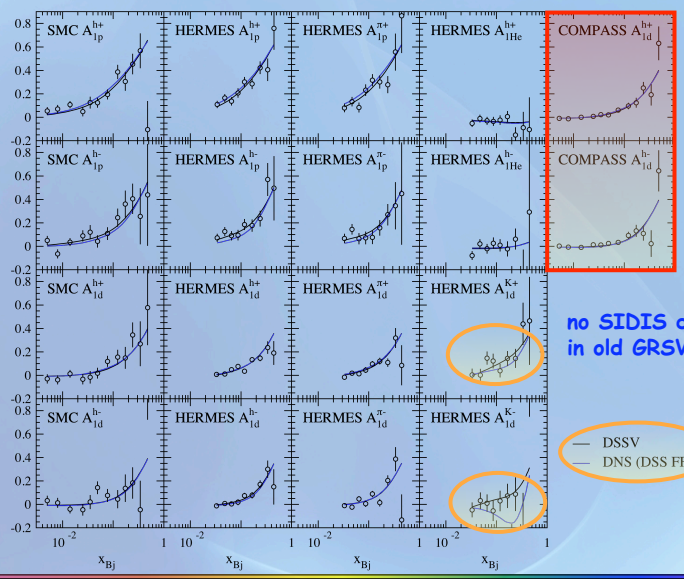
: input to the old GRSV-analysis

: input to the DIS & SIDIS – analysis by DNS

Semi-Inclusive World Data

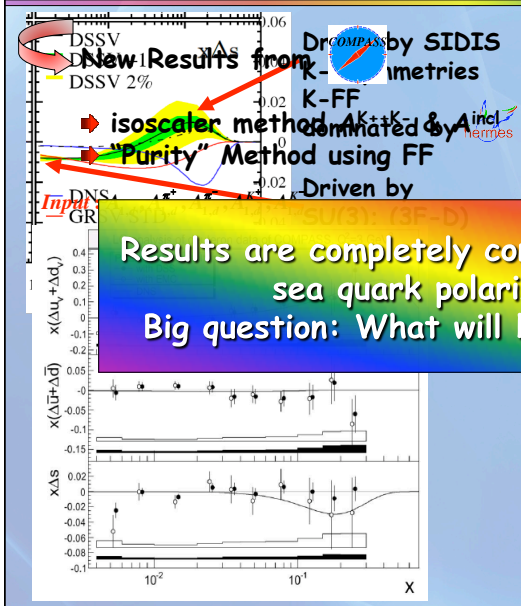
- Semi-inclusive DIS-Data:

not in DNS



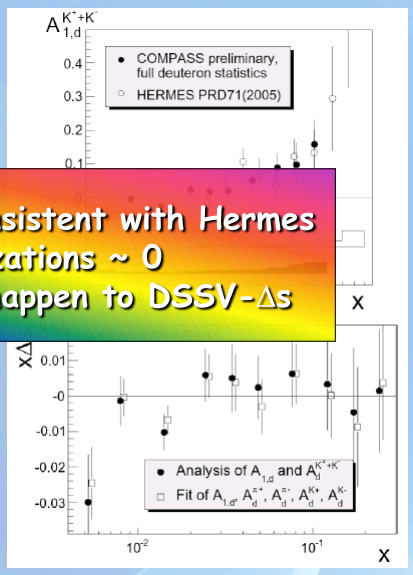
no SIDIS data included in old GRSV-analysis

Polarized Strangeness



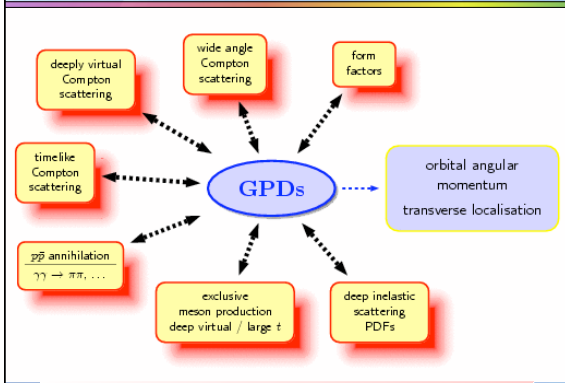
- New Results from
  - isoscaler method $A^{K^+ + K^-}$ & A^{incl}
  - "Purity" Method using FF

Dr by SIDIS
K- metries
K-FF
dominated by
Driven by
SU(3): (3F-D)



Results are completely consistent with Hermes sea quark polarizations ~ 0
Big question: What will happen to DSSV-Δs

How to access GPDs?



quantum number of final state selects different GPDs:

- theoretically very clean DVCS (γ): H, E, $\tilde{H}$, $\tilde{E}$
- VM (ρ, ω, ϕ): H E
- info on quark flavors PS mesons (π, η): $\tilde{H}$ $\tilde{E}$

π^0	$2\Delta u+\Delta d$
η	$2\Delta u-\Delta d$
ρ^0	$2u+d$, $9g/4$
ω	$2u-d$, $3g/4$
ϕ	s, g
ρ^+	$u-d$
J/ψ	g

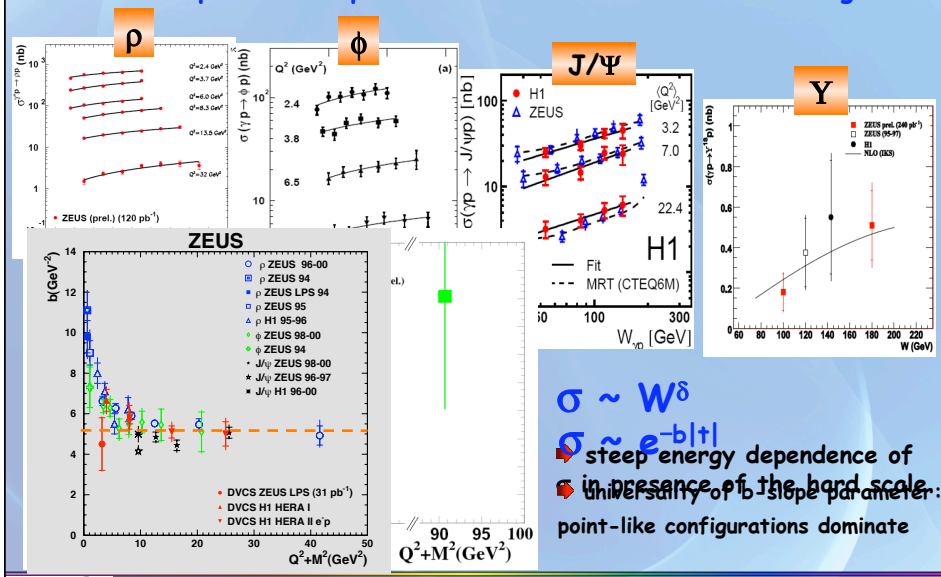
$$\frac{1}{2} = J_q^z + J_g^z = \frac{1}{2}\sum_q \Delta q + \sum_q \mathcal{L}_q^z + J_g^z$$

$$J_q^z = \frac{1}{2}\sum_q \Delta q + \sum_q \mathcal{L}_q^z$$

$$J_q^z = \frac{1}{2}\left(\int_{-1}^{1} x\,dx\left(H^q + E^q\right)\right)_{t\to 0}$$

VM production @ small x

W & t dependences: probe transition from soft → hard regime



$\sigma \sim W^{\delta}$

$\sigma \sim e^{-b|t|}$

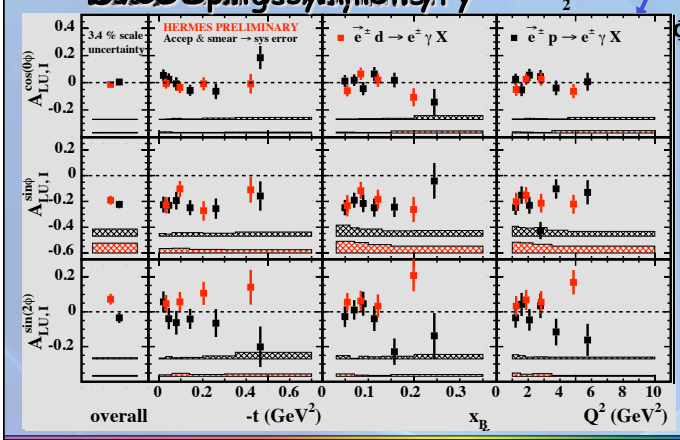
- steep energy dependence of σ in presence of the hard scale
- universality of b slope parameter: point-like configurations dominate

DVCS

HERMES: combined analysis of charge & polarization dependent data
→ separation of interference term + DVCS²

$$\sigma_{LU}(\Phi, P_l, e_l) = \sigma_{UU}(\Phi)\{1 + P_l A_{LU}^{DVCS}(\Phi) + e_l P_l A_{LU}^{I} + e_l A_C(\Phi)\}$$

DVCS Spin Asymmetry



$$\Phi) \sum_{n=0}^{3} c_n^I \cos(n\Phi)$$

$$\sim A_c(n=0)\cos\Phi$$

$$\sim \mathrm{Re}[F_1 H]$$

$$\sim \mathrm{Im}[F_1 H]$$

higher twist

higher twist

More insights to the proton - TMDs

Explore spin orbit correlations

Unpolarized distribution function q(x), G(x)

Transversity distribution function δq(x)
Correlation between $\vec{s}_\perp^{\,q}$ and $\vec{S}_\perp^{\,N}$

Helicity distribution function Δq(x), ΔG(x)

Boer-Mulders distribution function $h_1^\perp$
Correlation between $\vec{s}_\perp^{\,q}$ and $\vec{k}_\perp^{\,q}$

Sivers distribution function $f_{1T}^\perp$
Correlation between $\vec{S}_\perp^{\,N}$ and $\vec{k}_\perp^{\,q}$

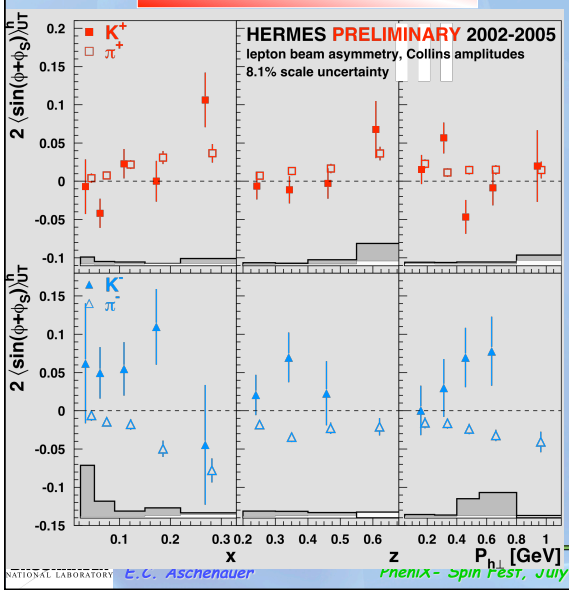
Single Spin Asymmetries

peculiarities of $f_{1T}^\perp$

chiral even naïve T-odd DF
related to parton orbital angular momentum
violates naïve universality of PDFs
QCD-prediction:
$f_{1T,DY}^\perp = -f_{1T,DIS}^\perp$
also valid for BM-fct $h_1^\perp$

HERMES-Proton: Collins moments

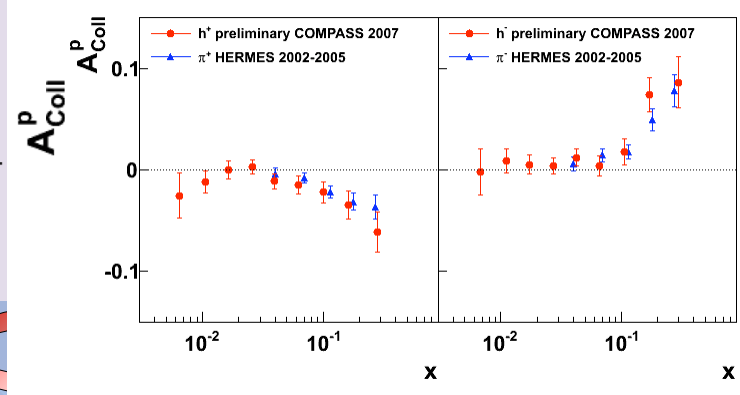
$$A_{coll} \propto h_1(x) H_1^{\perp}(z)$$



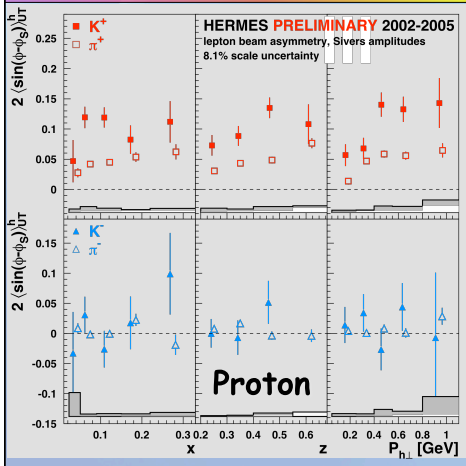
- Collins moment:
  $\pi^+ > 0 \quad \pi^- < 0 \quad \pi^0 \sim \pi^+ + \pi^-/2$
- π^- unexpected large
  ⟹ role of unfavoured FF
  $\hat{H}_{1\,fav}(z) = -\hat{H}_{1\,unf}(z)$
- $K^+ > 0 \qquad K^- > 0$
  K^+ in agreement with π^+

Results from theoretical fits

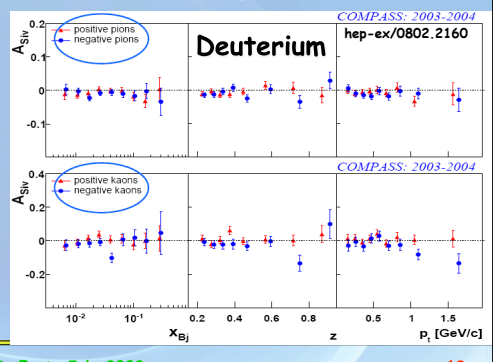
Hermes and Compass
transveristy p-data
perfect agreement !



HERMES & COMPASS Measurements

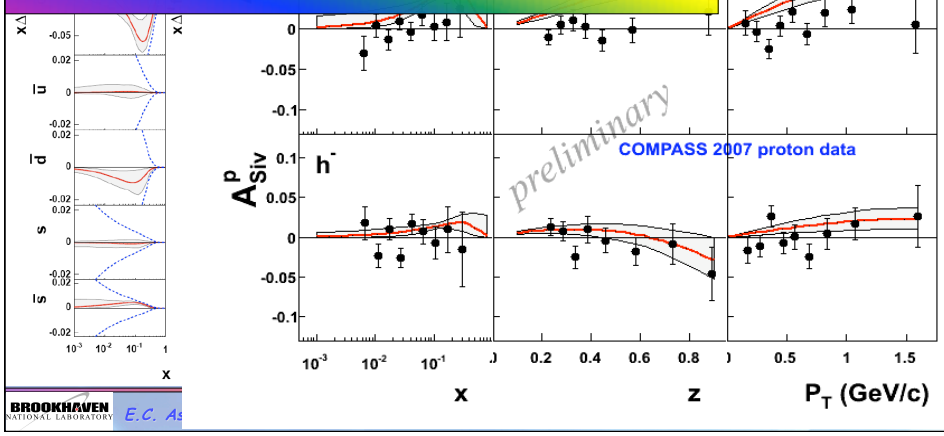


- Proton:
- Sivers moment:
  $\pi^+ > 0$ $\pi^- \sim 0$
- $K^+ > 0$ $K^- \sim 0$
  $K^+ > \pi^+$
  - importance of sea quarks?
- Deuterium ~ 0
  - u and d quark cancel



$$A_{Sivers} \propto f_{1T}^{\perp}(x) D_1(z)$$

COMPASS p-data

- M. Anselmino et al
  - combine Hermes and Compass Deuterium
  - extract

Bummer,
Hermes and Compass Sivers p-data disagree
Sivers-Q^2 evolution?
big higher Twist contribution?
→ more proton running @ COMPASS