Experimental Overview on Polarised Quark Distributions

GPD2010:
Hard Photon and
Meson Production
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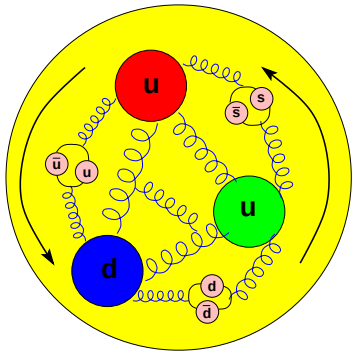
(supported by the BMBF)

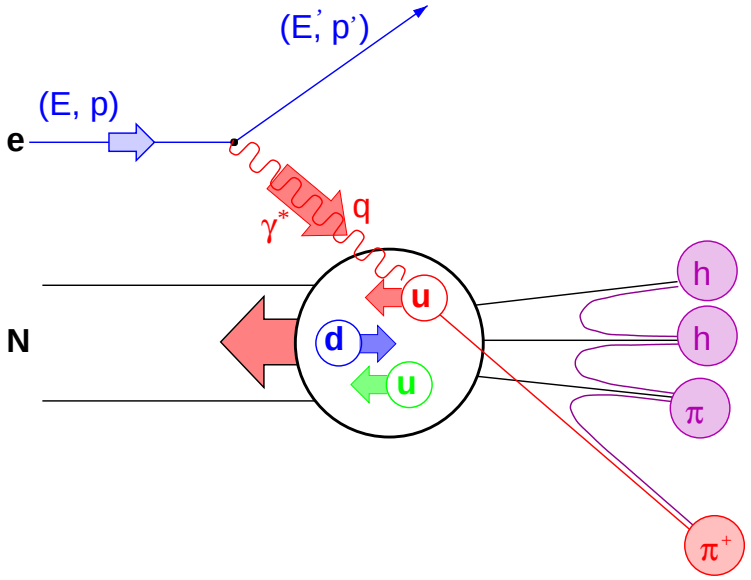
The spin of the nucleon



$$S_N = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

Main sources:	$\Delta\Sigma$, Δs	inclusive DIS
	ΔG	PGF in DIS, qg in pp
	Δu,Δd,Δs	Flavourseparation in SIDIS $W^{\pm}$ in pp
	L_q	DVCS

Deep inelastic scattering



$$Q^2 = -q^2 \qquad z = E_\mathrm{h}/\nu$$

$$\nu = E - E' \qquad p_\mathrm{T}^\mathrm{h} : \text{transverse}$$

$$x = Q^2/2M\nu \qquad \text{momentum}$$

$$q(x) = q(x)^+ + q(x)^- \quad + \text{quark} \uparrow\uparrow \text{nucleon}$$

$$\Delta q(x) = q(x)^+ - q(x)^- \quad - \text{quark} \downarrow\uparrow \text{nucleon}$$

- **photon nucleon asymmetry**

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \approx \frac{\Sigma_q\ e_q^2\ (q(x)^+ - q(x)^-)}{\Sigma_q\ e_q^2\ (q(x)^+ + q(x)^-)} = \frac{g_1(x)}{F_1(x)}$$

- **spin structure function**

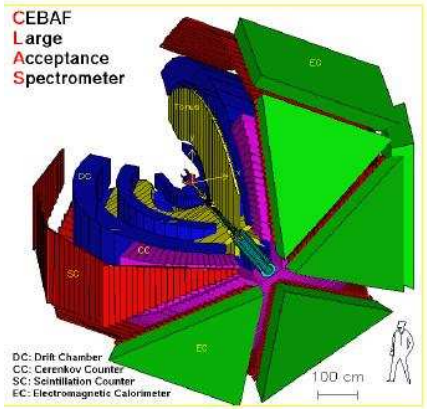
$$g_1 = \frac{1}{2}\Sigma_q\ e_q^2\ \Delta q(x) = A_1 \cdot \frac{F_2}{2x(1+R)} \approx \frac{A_\parallel}{D} \cdot \frac{F_2}{2x(1+R)}$$

Experiments

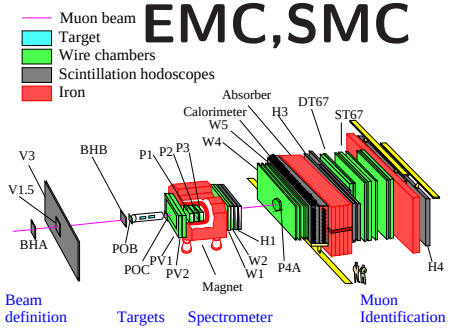
Experiments

SLAC: Endstation A

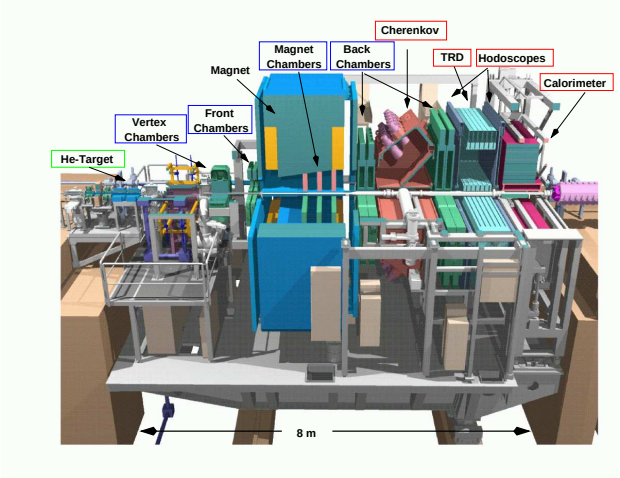
JLAB: CLAS



CERN: EMC,SMC

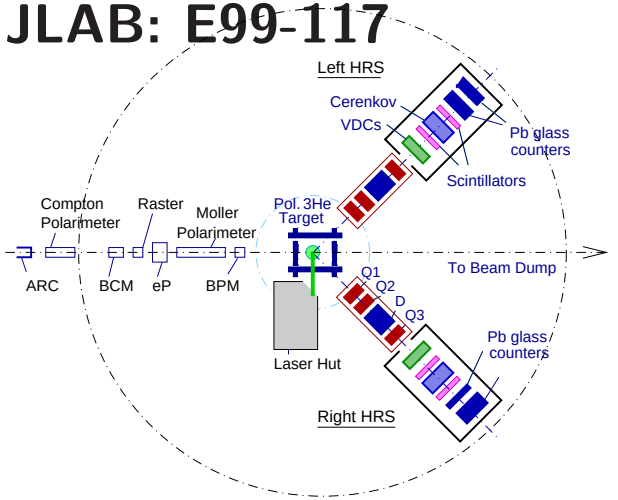


E80, E130	$\vec{e}\,\vec{p}$	≤ 20 GeV
EMC	$\vec{\mu}\,\vec{p}$	100–200 GeV
E142, 143	$\vec{e}\,\vec{p},\vec{n},\vec{d}$	≤ 28 GeV
SMC	$\vec{\mu}\,\vec{p},\vec{d}$	100, 190 GeV
E154, 155	$\vec{e}\,\vec{p},\vec{n},\vec{d}$	≤ 50 GeV
HERMES	$\vec{e}\,\vec{p},\vec{n},\vec{d}$	27.5 GeV
COMPASS	$\vec{\mu}\,\vec{p},\vec{d}$	160 GeV
HALL A	$\vec{e}\,\vec{n}$	6 GeV
CLAS	$\vec{e}\,\vec{p},\vec{d}$	6 GeV

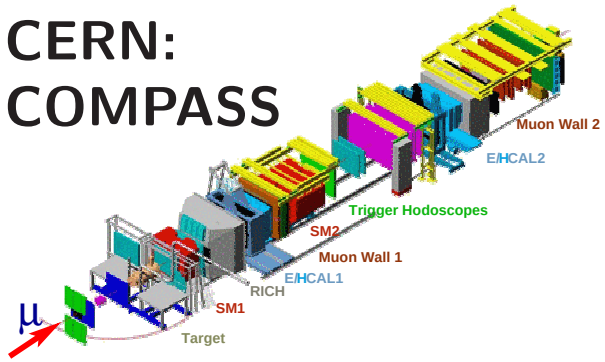


DESY: HERMES

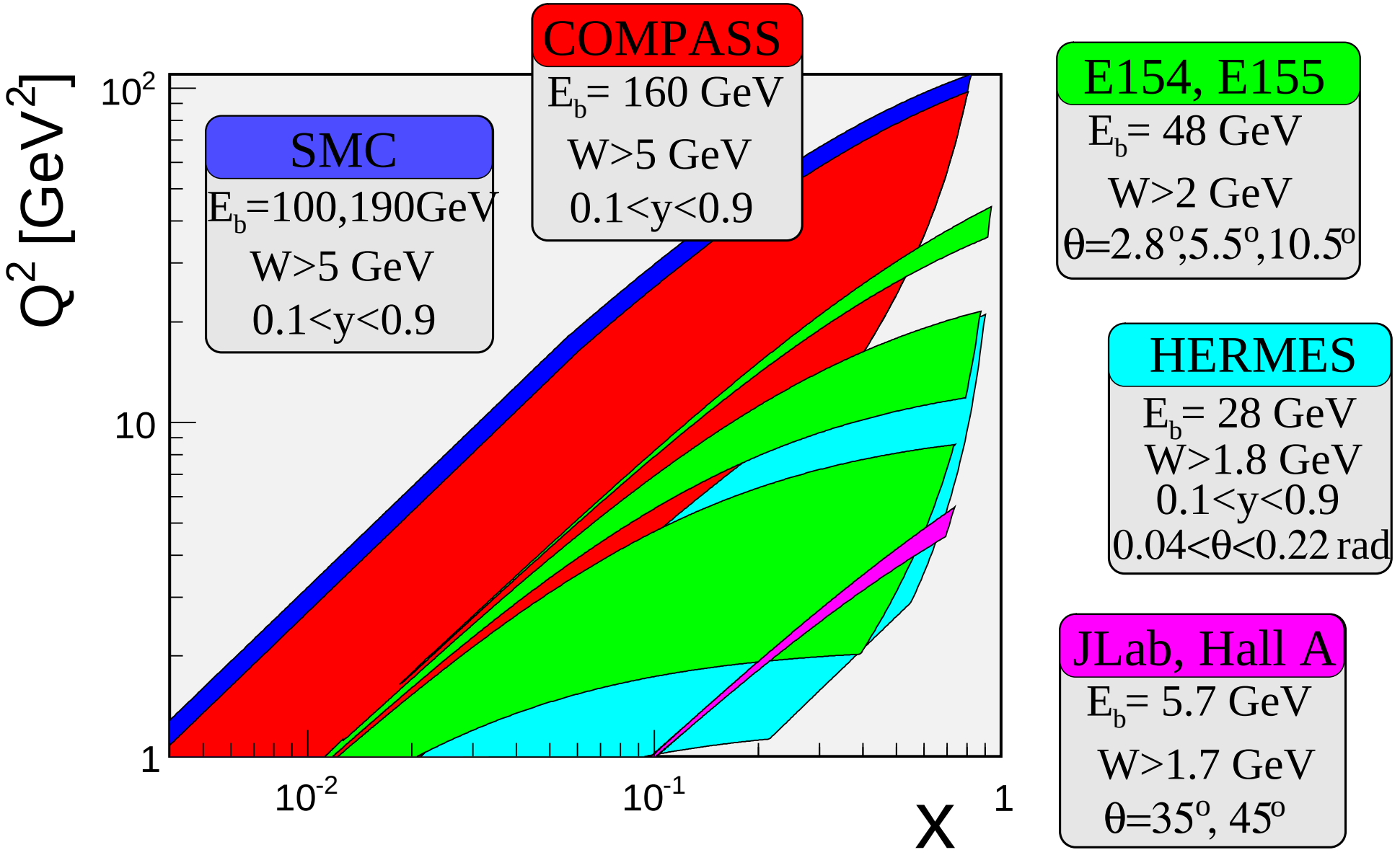
JLAB: E99-117



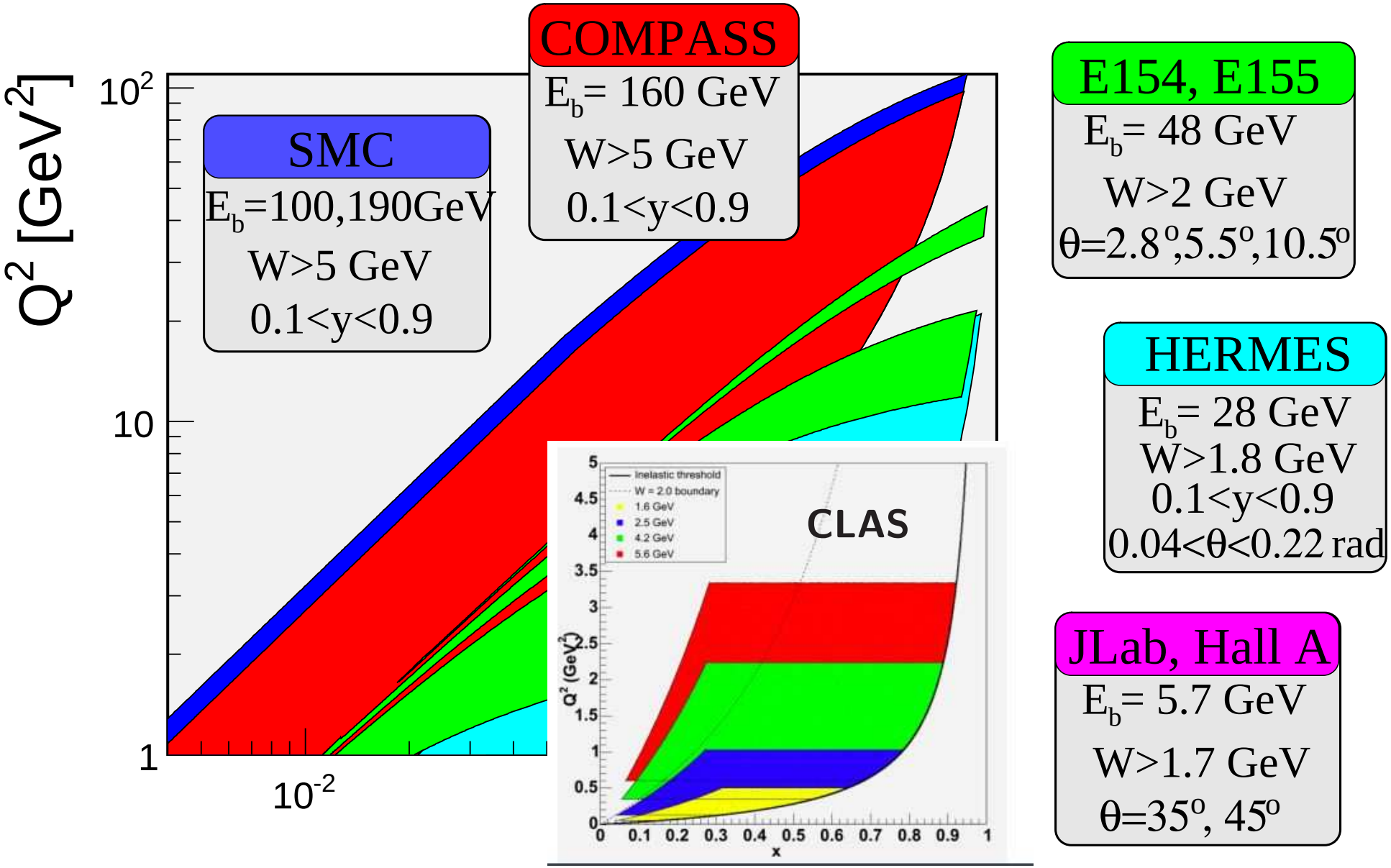
CERN: COMPASS



Kinematic domain of pDIS experiments



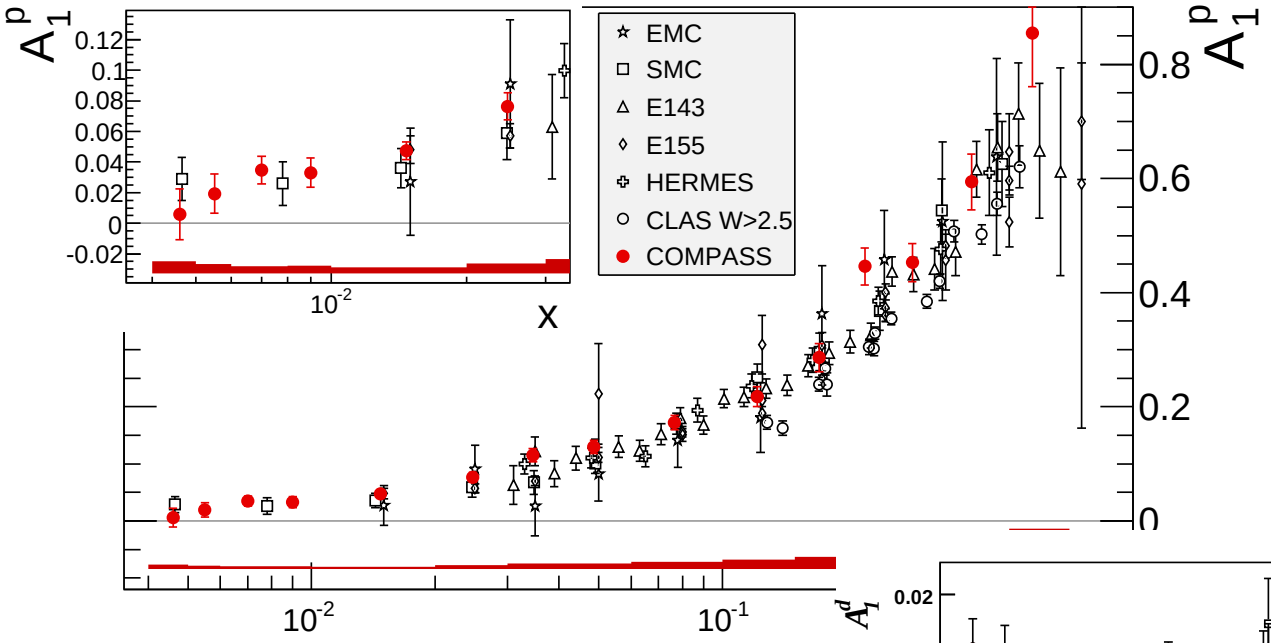
Kinematic domain of pDIS experiments



Inclusive asymmetries

World data for $A_1^{p,d}$ $(Q^2 > 1\ (\mathrm{GeV}/c)^2)$

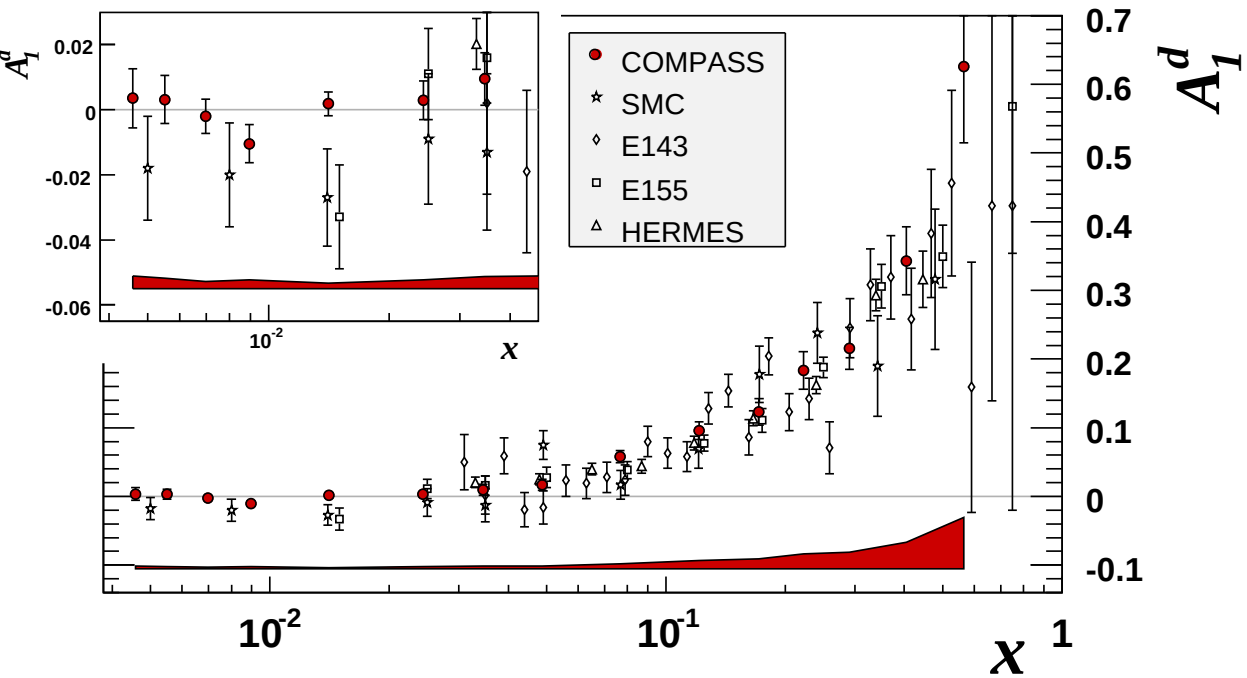
PLB 690 (2010) 466



final HERMES data
(PRD 75 (2007) 012007)

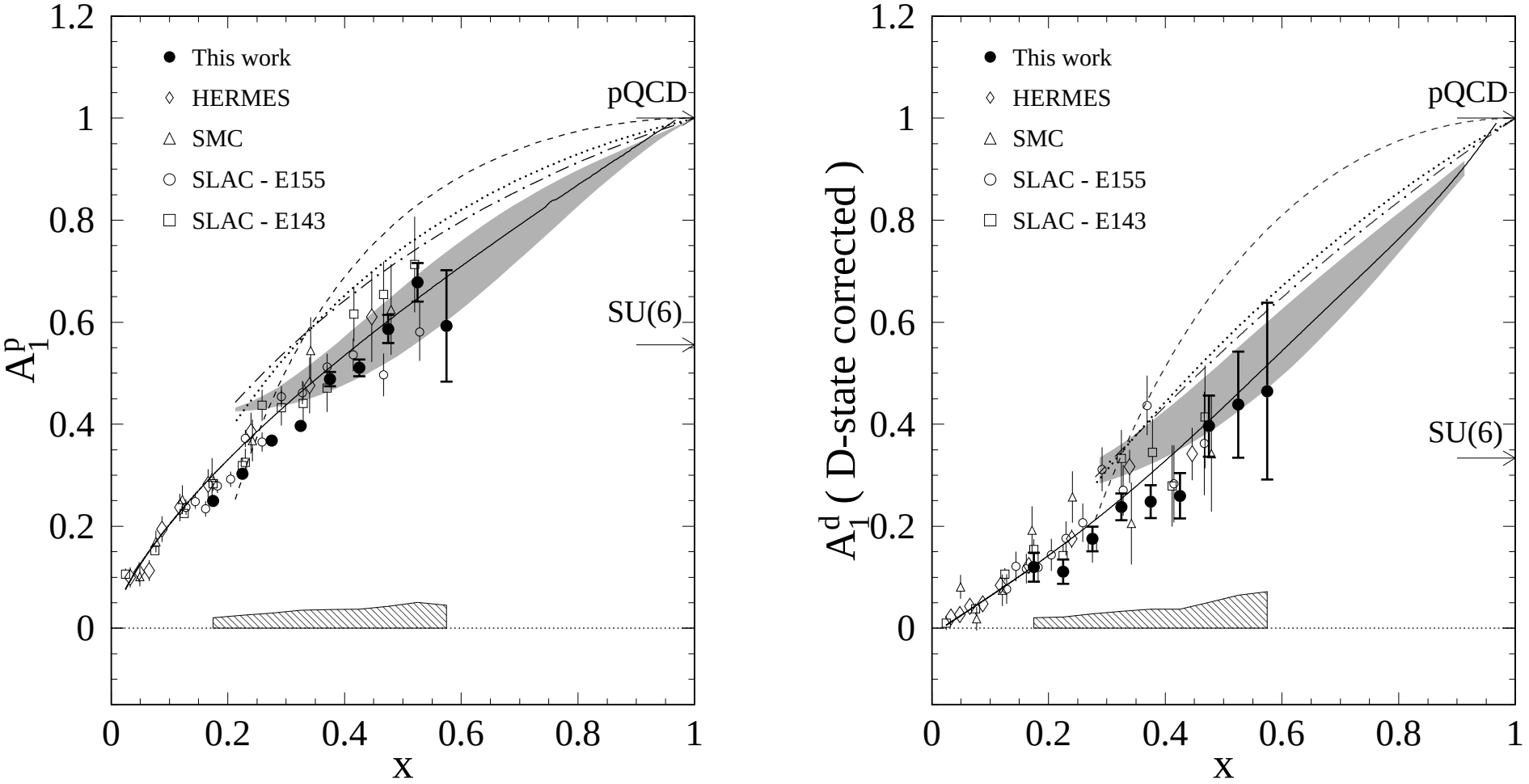
COMPASS d and p data

PLB 647 (2007) 8



- compatible with 0 for $x < 0.01$
- good agreement between all exp.
  $\longrightarrow$ weak Q^2 dependence of A_1
- no negative trend for d

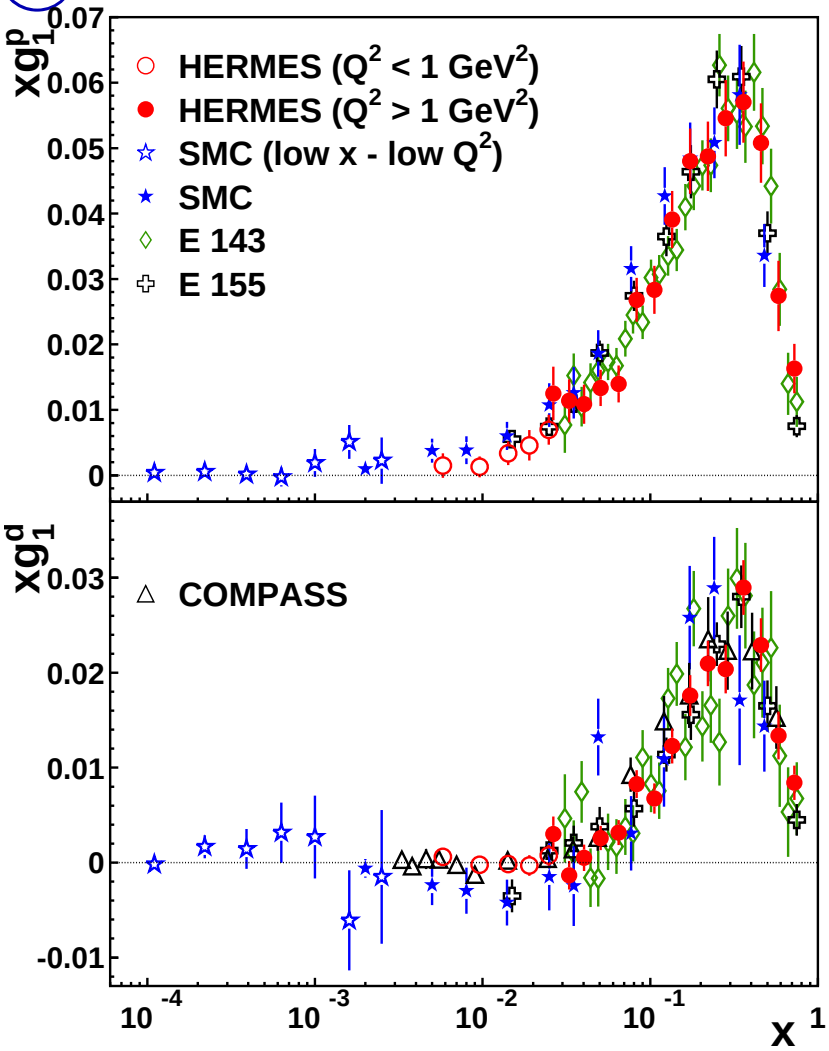
$A_1^{p,d}$ at large x

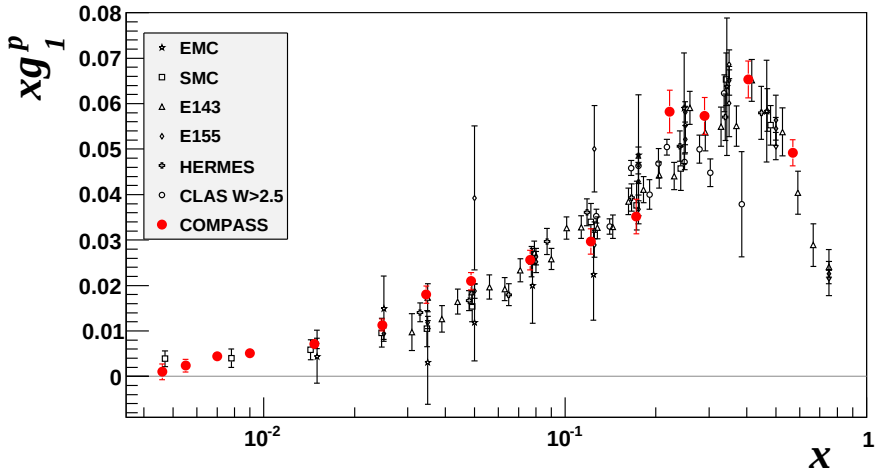


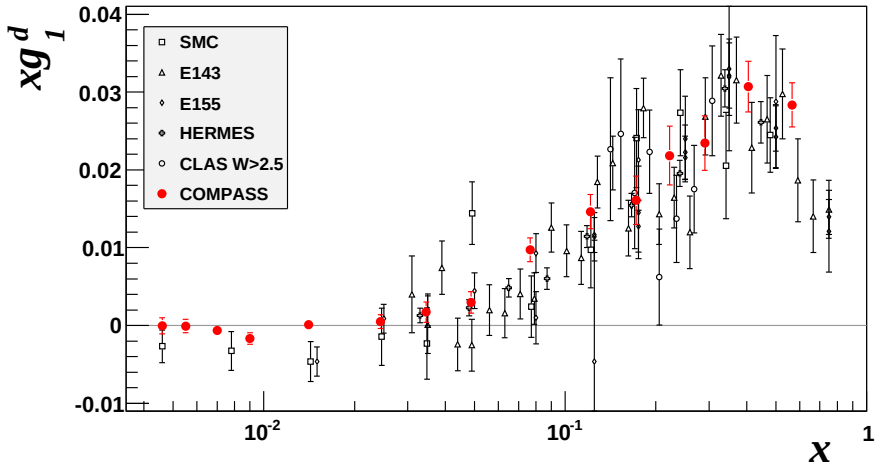
- CLAS data ((PLB 641 (2006)11) slightly below the other experiments
- in reasonable agreement with HFP(hyperfine perturbed) quark modell (shaded area)
- can be used directly to extract $\Delta u/u$ and $\Delta d/d$

Spin structure functions

World data on $g_1^{p,d}$ in DIS)

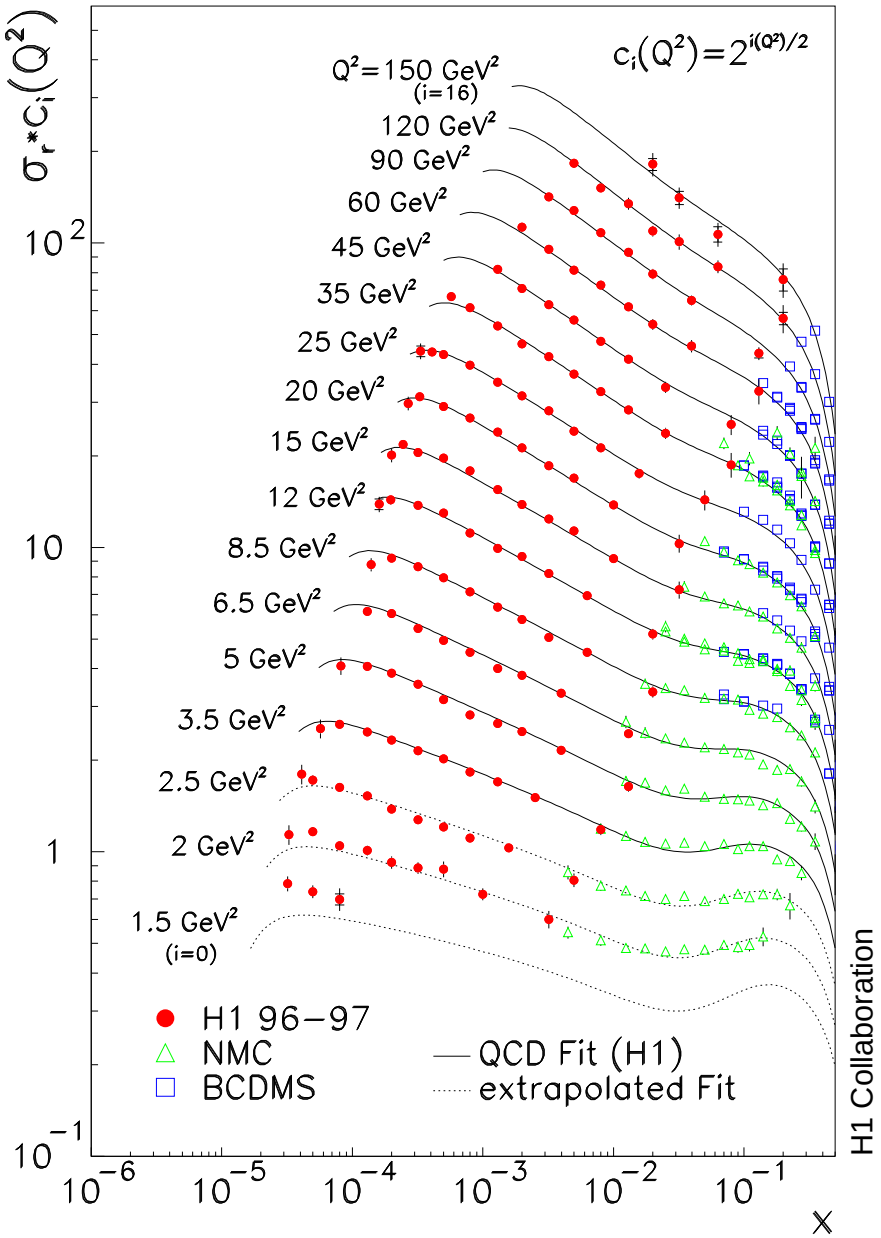


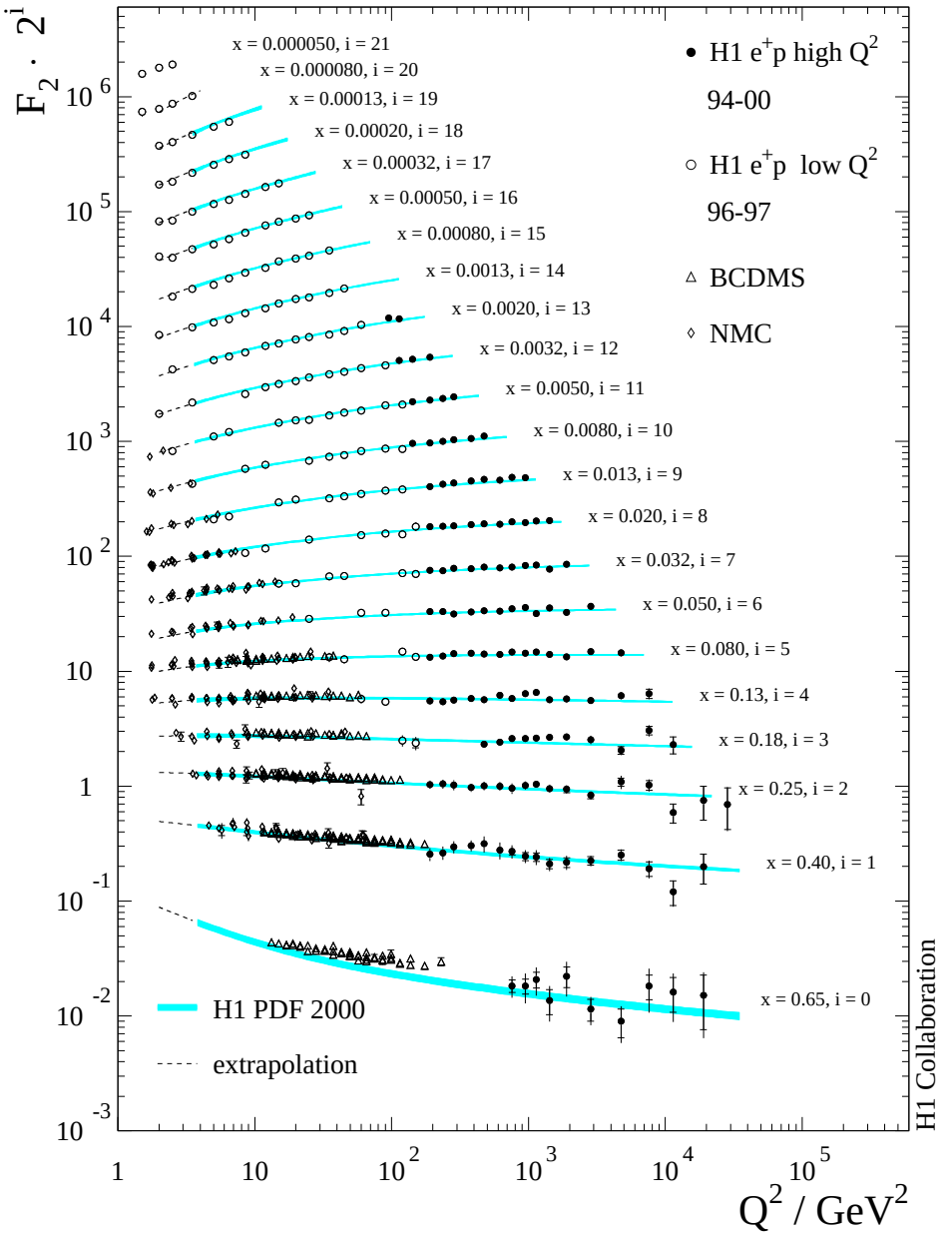




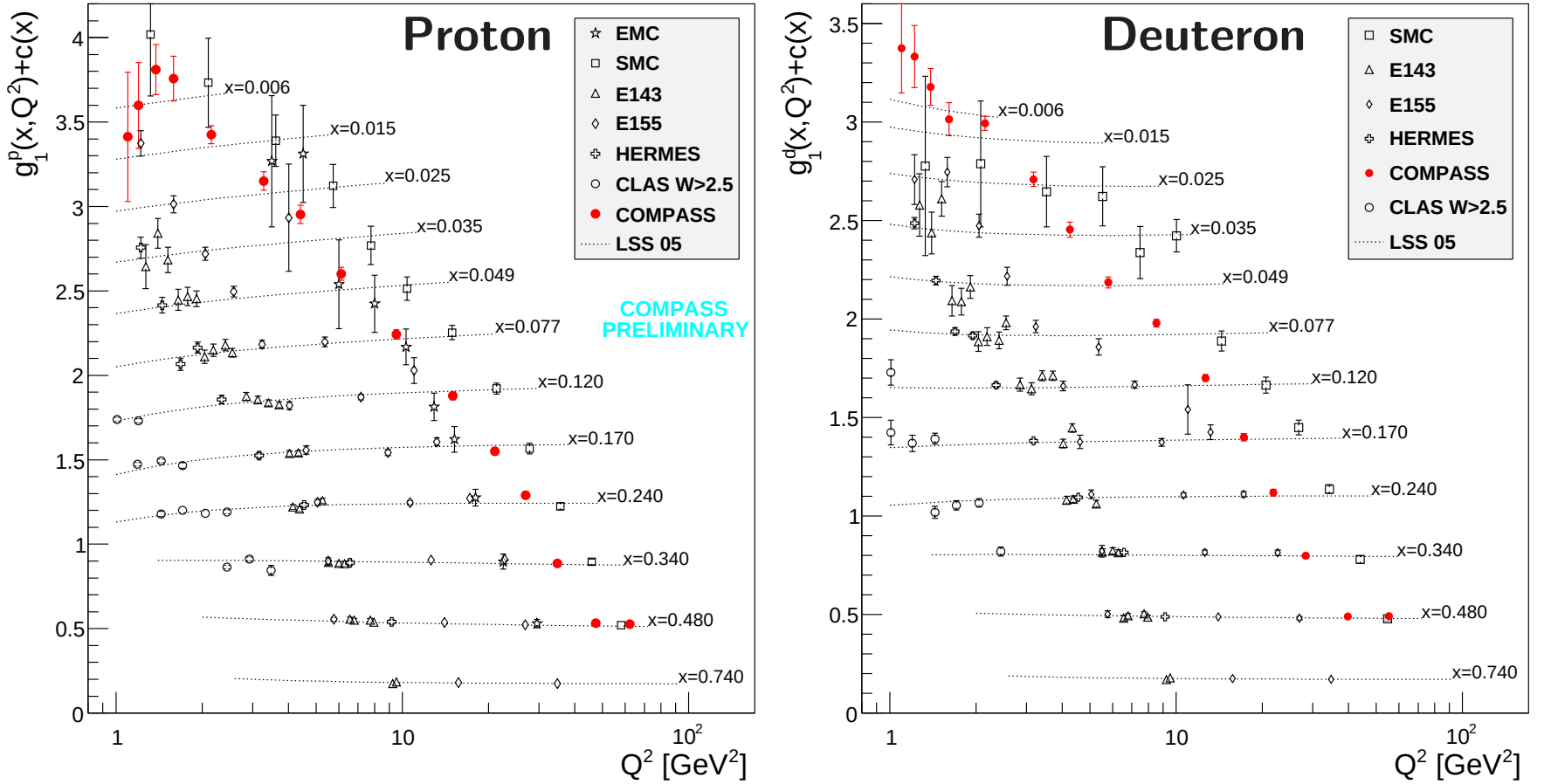
- high statistics $g_1 = A_1 \frac{F_2}{2x(1+R)}$ from proton and deuteron data
- Final HERMES data: New method for smearing corr. (rad. corr. and resolution)
- more data to come from COMPASS, in addition g_1^n from ^{3}He

What you really would like to have:





World data on $g_1(x, Q^2)$



It's getting better $\longrightarrow$ QCD analysis, but collider data clearly missing!

- $\Delta u + \Delta\bar{u}$ and $\Delta d + \Delta\bar{d}$ well constrained by data (LSS PRD 80 (2009) 054026)
- Δs and Δg need other data in addition to inclusive data
- Δs comes out negative (except for DSSV) and ΔG small (< 0.5)

Can one learn something without these fits?

First moments of g_1^{d}

- **COMPASS and HERMES**: $\Gamma_1^{\mathrm{N}} = \int_0^1 g_1^{\mathrm{N}} \mathrm{d}x$ from deuteron data
  - data used in measured range, QCD fit used for extrapolation
  - contribution of unmeasured region few %

- **using**: $a_0^{\overline{\mathrm{MS}}} = \Delta\Sigma$ and $\Gamma_1^{\mathrm{N}} = \frac{1}{9}(a_0 \Delta C_{\mathrm{S}}^{\overline{\mathrm{MS}}} + \frac{1}{4} a_8 \Delta C_{\mathrm{NS}}^{\overline{\mathrm{MS}}})$

$a_0(Q^2 = 3(\mathrm{GeV/c})^2) = 0.35 \pm 0.03(\mathrm{stat}) \pm 0.05(\mathrm{syst})$ **COMPASS**

$a_0(Q^2 = 5(\mathrm{GeV/c})^2) = 0.33 \pm 0.025(\mathrm{exp}) \pm 0.028(\mathrm{evol}) \pm 0.011(\mathrm{theo})$ **HERMES**

- **assuming SU(3) symmetry**: $(\Delta s + \Delta \bar{s}) = \frac{1}{3}(\hat{a}_0 + a_8)$

$(\Delta s + \Delta \bar{s}) = -0.08 \pm 0.01(\mathrm{stat}) \pm 0.02(\mathrm{syst})$ **COMPASS**

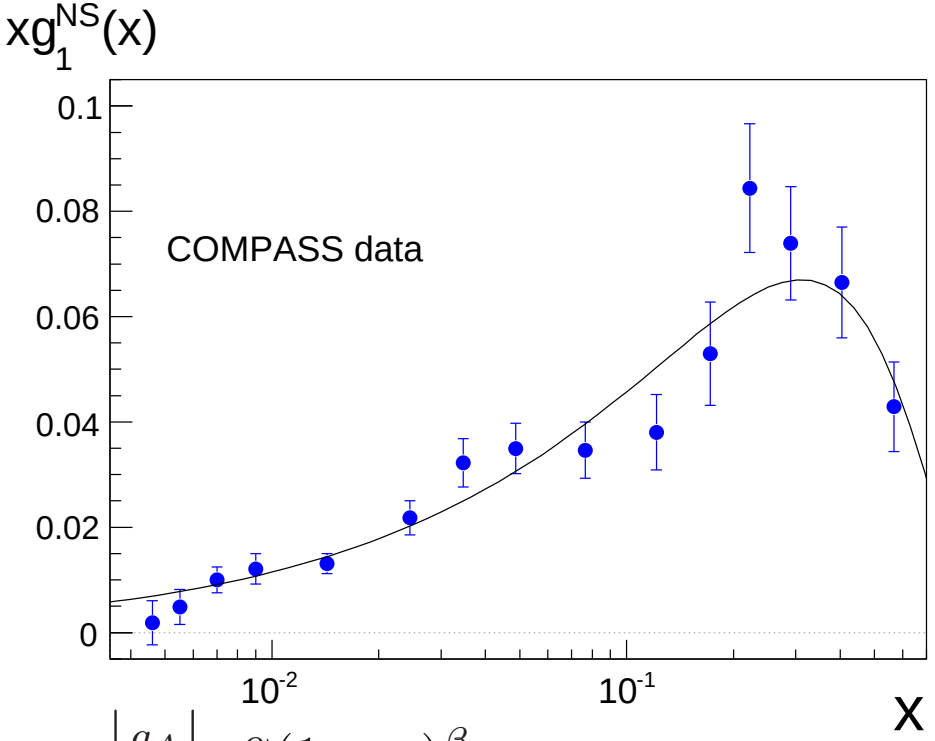
$(\Delta s + \Delta \bar{s}) = -0.085 \pm 0.008(\mathrm{exp}) \pm 0.009(\mathrm{evol}) \pm 0.013(\mathrm{theo})$ **HERMES**

- **negative strange sea polarisation**

Non-singlet structure function

- **non-singlet structure function**

$$g_1^{\mathrm{NS}} = g_1^{\mathrm{p}} - g_1^{\mathrm{n}}$$
$$= 2\left[g_1^{\mathrm{p}} - \frac{g_1^{\mathrm{d}}}{1 - 1.5\omega_{\mathrm{D}}}\right]$$



- **Bjorken sum rule**

$$\int_0^1 g_1^{\mathrm{NS}} \mathrm{d}x = \left|\frac{g_A}{g_V}\right| C^{\mathrm{NS}}$$

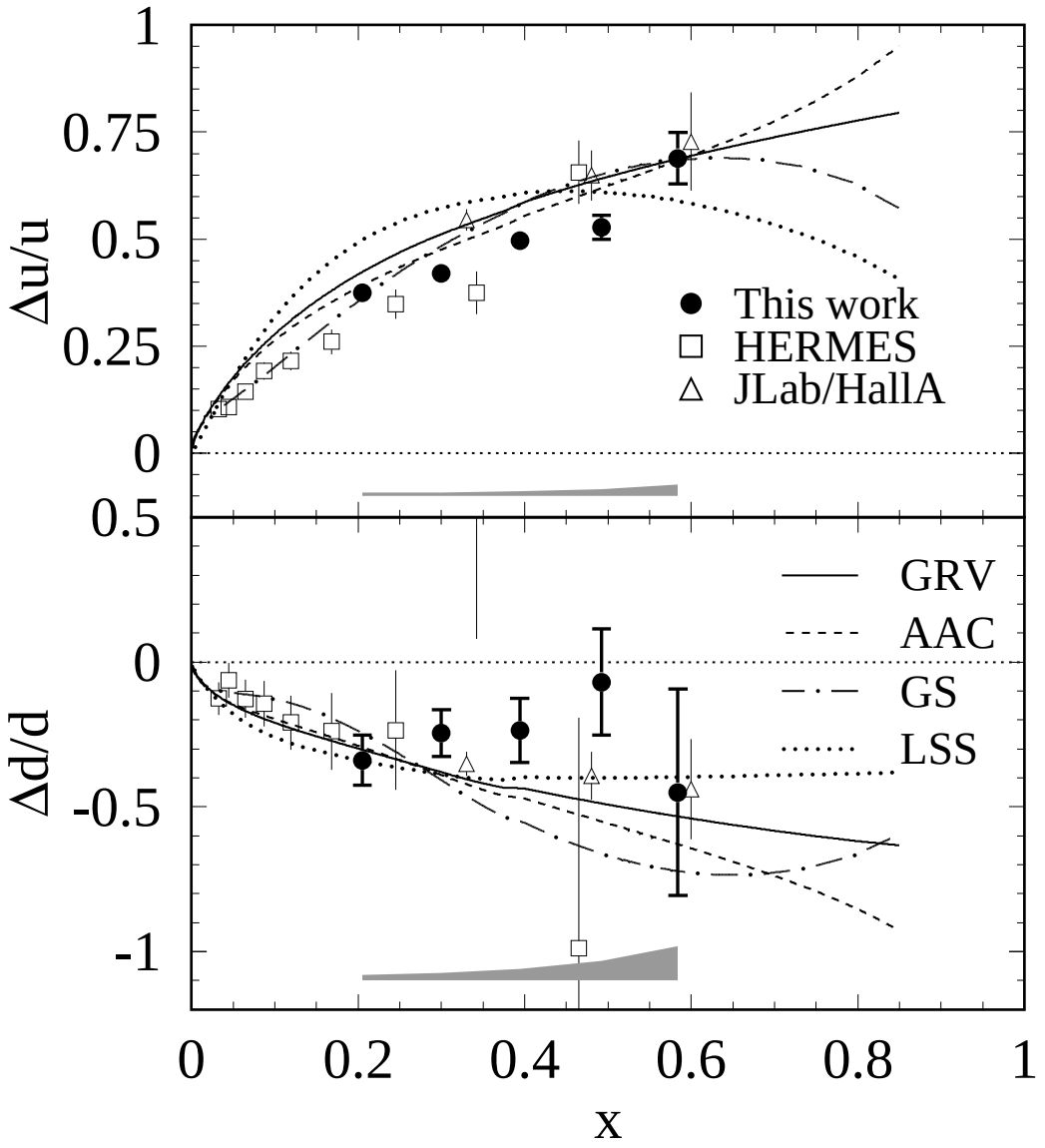
- QCD fit of COMPASS data alone: $\Delta q_{\mathrm{NS}} = \left|\frac{g_A}{g_V}\right| x^{\alpha}(1-x)^{\beta}$

$$\boldsymbol{g_A/g_V = 1.28 \pm 0.07(\mathrm{stat}) \pm 0.10(\mathrm{syst})}$$

- dominant systematic errors: beam and target polarisation
- PDG value: $g_A/g_V = 1.269 \pm 0.003$

Quark polarisation in the valence region

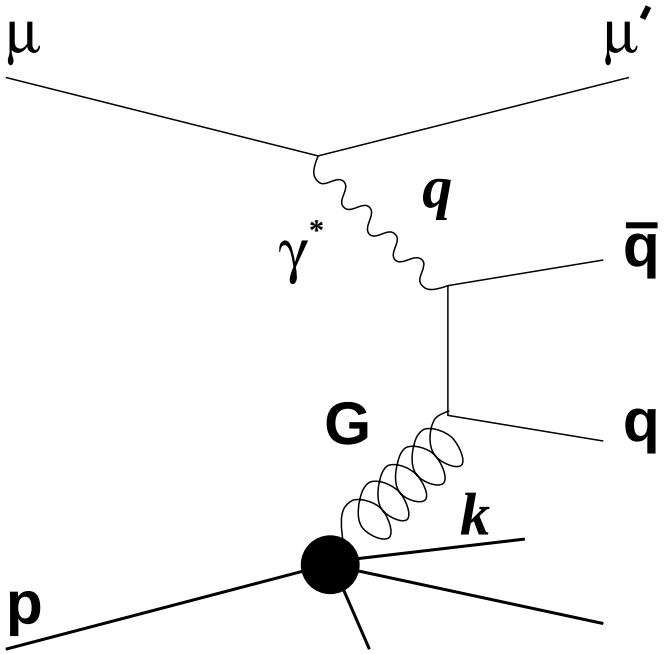
- CLAS EG1 result for $A_1^{\mathrm{p,d}}$
- assuming negligible sea contribution
- $\Delta u/u > 0$
- $\Delta u/u \to 1$ for $x \to 1$
  consistent with QM, pQCD, disagrees with SU(6)
- $\Delta d/d < 0$
  up to highest $x \sim 0.6$
- disagrees with pQCD without orbital angular momentum
  but agrees e.g. with HFP quark modell



Gluon polarisation

$\Delta G/G$ measurements in DIS

Photon gluon fusion



$$A_{\gamma N}^{PGF} = \frac{\int d\hat{s}\, \Delta\sigma^{PGF} \Delta G(x_g, \hat{s})}{\int d\hat{s}\, \sigma^{PGF} G(x_g, \hat{s})}$$

$$\approx \langle a_{LL}^{PGF} \rangle \frac{\Delta G}{G}$$

$\langle a_{LL}^{PGF} \rangle$ analysing power

Direct methods

- **Open charm production**

  $\gamma g \rightarrow c\bar{c}$

  $\rightarrow D^0, D^*$

  hard scale: M_c^2
  theoretically clean channel,
  low staticstics

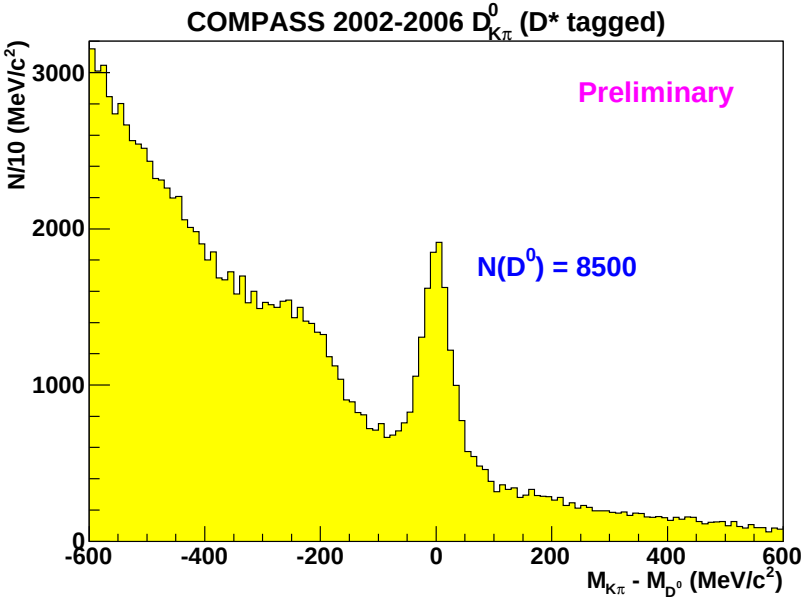
- **High p_T hadron pairs**

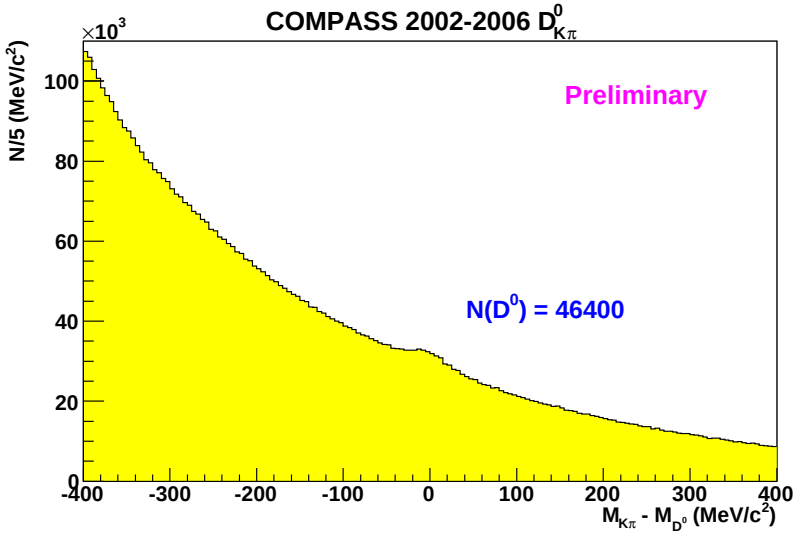
  $\gamma g \rightarrow q\bar{q}$

  $\rightarrow$ 2 jets or H^+H^-

  hard scale: Q^2 or Σp_T^2
  high statistics
  contributions from background processes

Open charm production





- **channels investigated**

$$D^* \rightarrow D^0\pi_{\rm slow} \rightarrow K\pi\pi_{\rm slow}$$
$$D^* \rightarrow D^0\pi_{\rm slow} \rightarrow K\pi\pi^0\pi_{\rm slow}$$
$$D^0 \rightarrow K\pi$$

- all deuteron data (PLB 676 (2009) 31)
- all Q^2, $a_{\rm LL}$ in LO
- scale $\mu^2 \approx 13\ ({\rm GeV}/c)^2$
- improved analysis method
- update with proton data (2007) and channels (**preliminary**)

$$D^* \rightarrow D^0\pi_{\rm slow} \rightarrow K\pi\pi\pi_{\rm slow}$$

$$\Delta g/g = -0.08 \pm 0.21({\rm stat}) \pm 0.11({\rm syst})$$

at $x_{\rm g} = 0.11$

High p_{T} hadron pairs

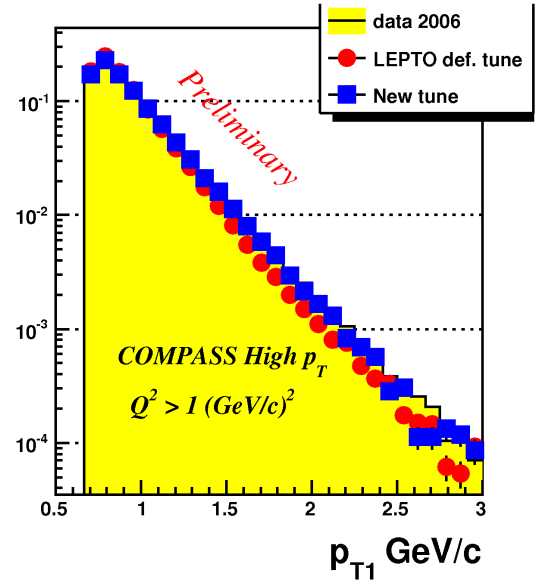
$$\Delta g/g(x_{\mathrm{g}}) = (A_{\mathrm{LL}}^{2h} + A^{\mathrm{corr}})/\beta$$

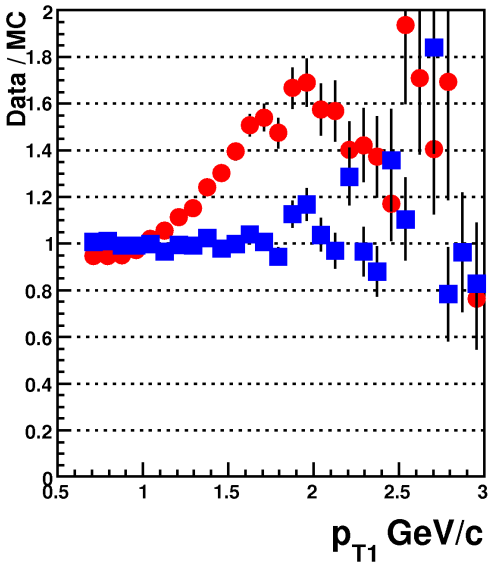
- **selection**
  $Q^2 > 1$ (GeV/c)^2, $p_{\mathrm{T}}^{h_1(h_2)} > 0.7(0.4)$ GeV/c
- **background processes**

  QCD-Compton, leading order
  (plus resolved photons for small Q^2)
- improved MC (Lepto) and NN method,
  new JETSET tuning
- **new preliminary result** from all deuteron data (2002–2006), three bins in x_g

$$\Delta g/g = 0.125 \pm 0.06(\mathrm{stat}) \pm 0.064(\mathrm{syst})$$

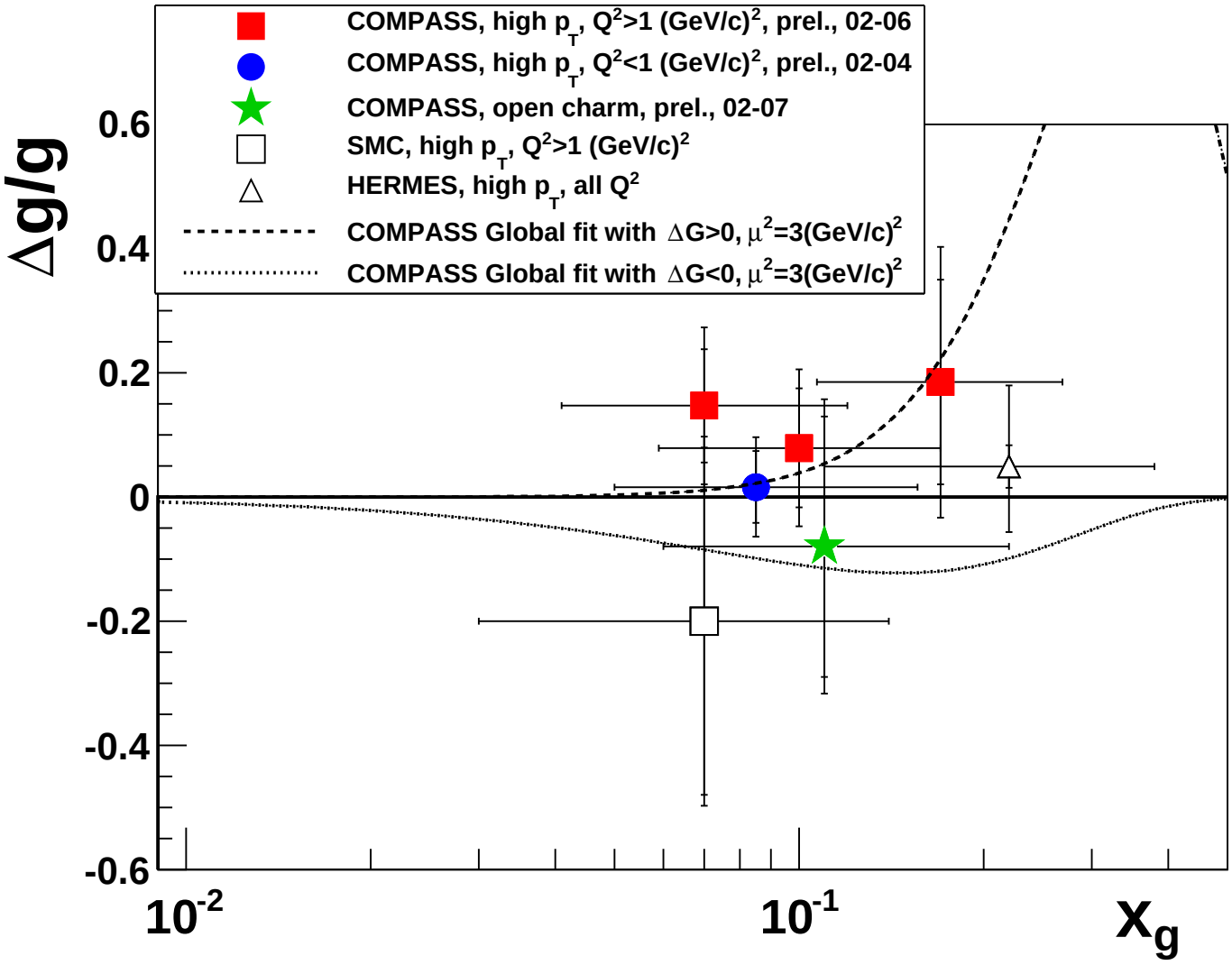
- at $x_{\mathrm{g}} = 0.09$ and scale $\mu^2 \approx 3.4$ (GeV/c)^2





similar for other variables

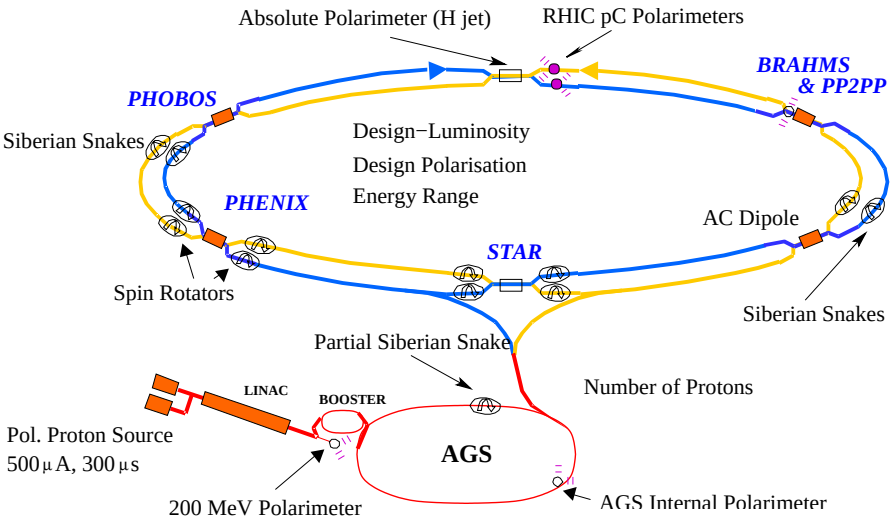
Results for $\Delta G/G$



- $\Delta G/G$ is small or has a node around $x_{\mathrm{g}} \approx 0.1$
- supported by recent PHENIX and STAR results from pp-collisions

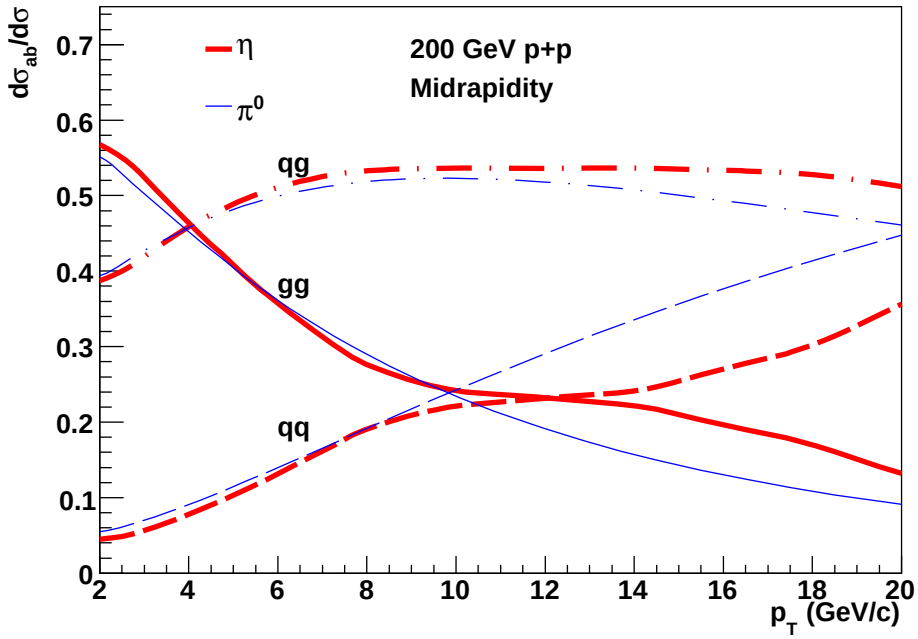
$\Delta G/G$ from pp collider

RHIC: $\vec{p}\vec{p}$ at 200 GeV



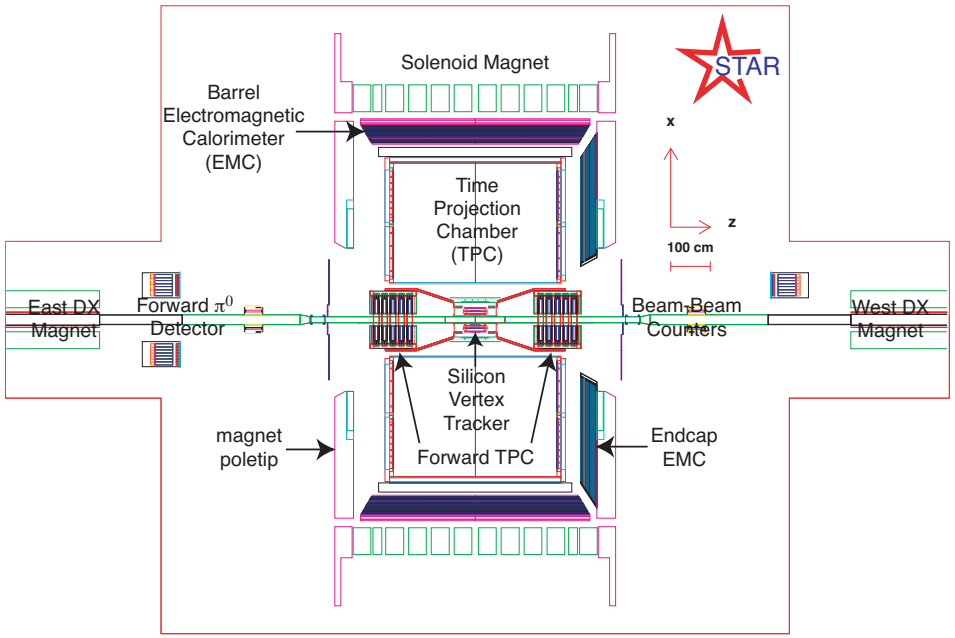
Methods

- cleanest channel
  prompt photons: $qg \longrightarrow q\gamma$
- needs high luminosity
- up to now: $qg \longrightarrow qg$
- pionproduction, jets



Experiments

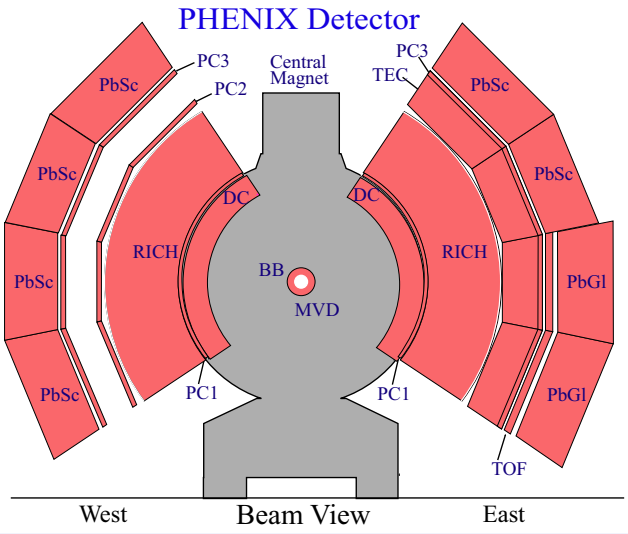
STAR

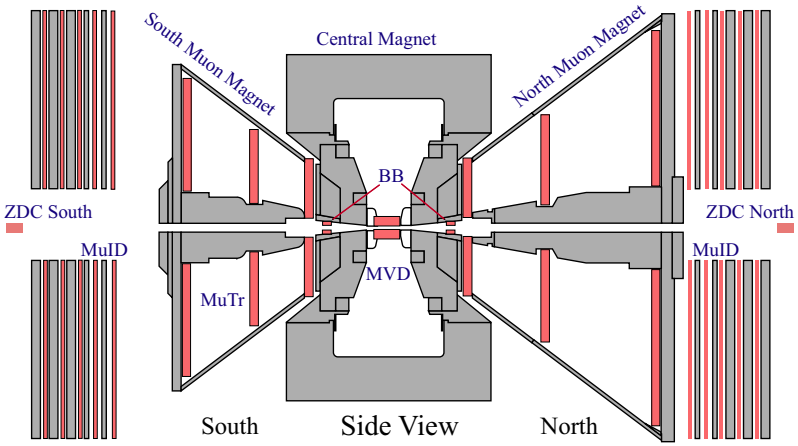


- analysis of jet events at midrapidity
- also: dijet, π^0, $\pi^{\pm}$
- first results from $W^{\pm}$ production

PHENIX

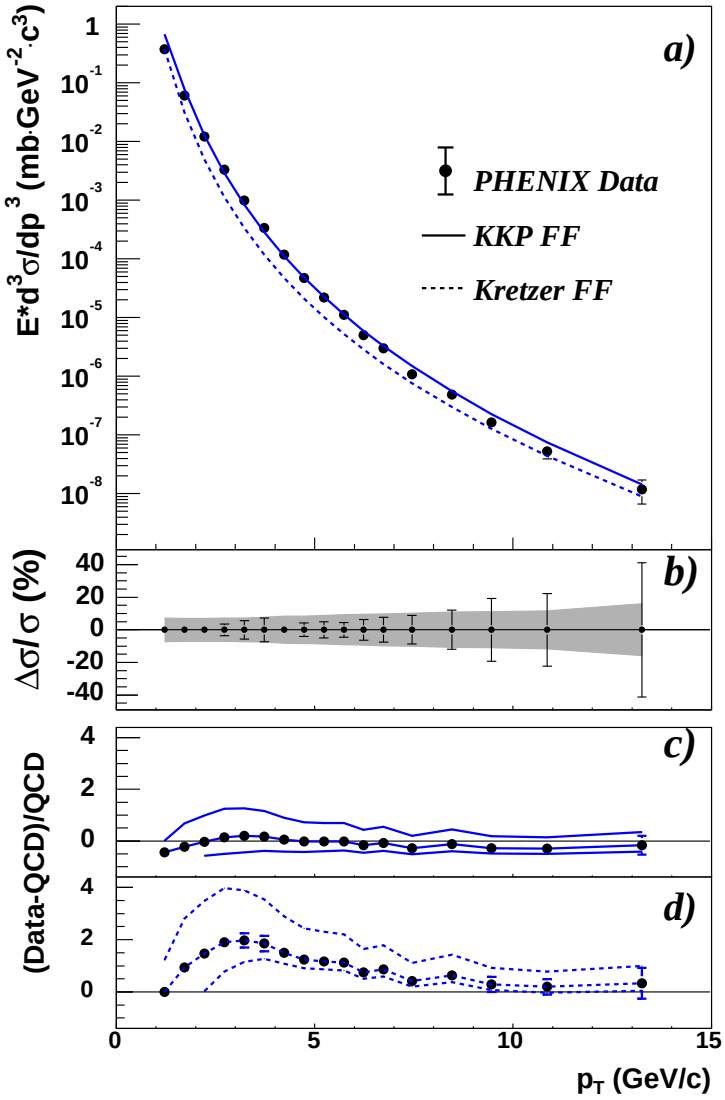
- analysis of π^0,η, $\pi^{\pm}$, γ production
- first results from $W^{\pm}$ production



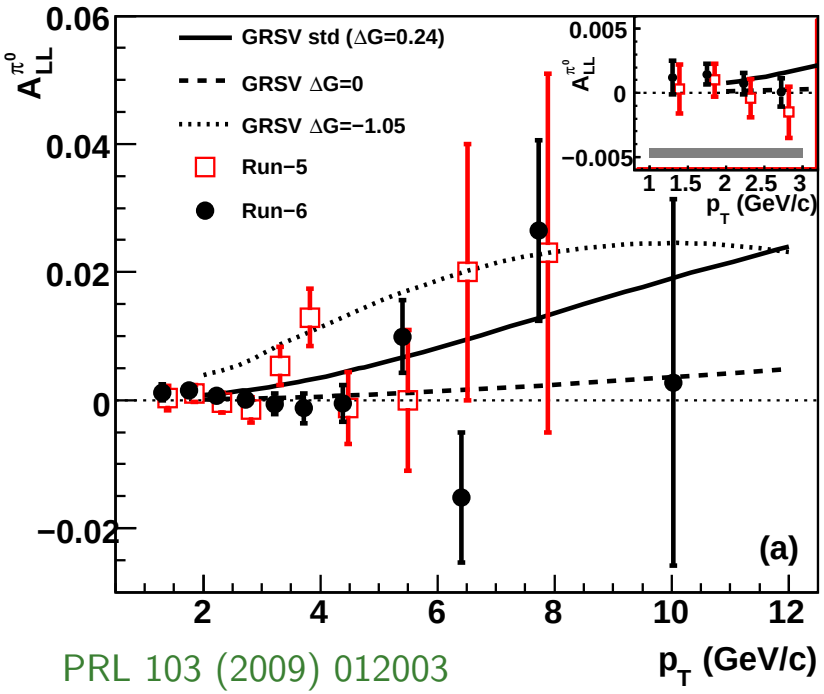


PHENIX results

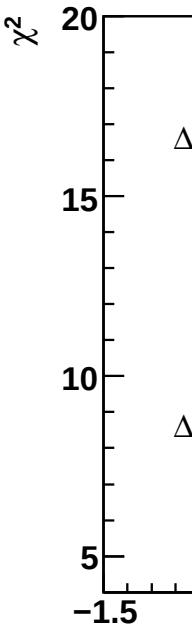
π^0 production



π^0 asymmetries



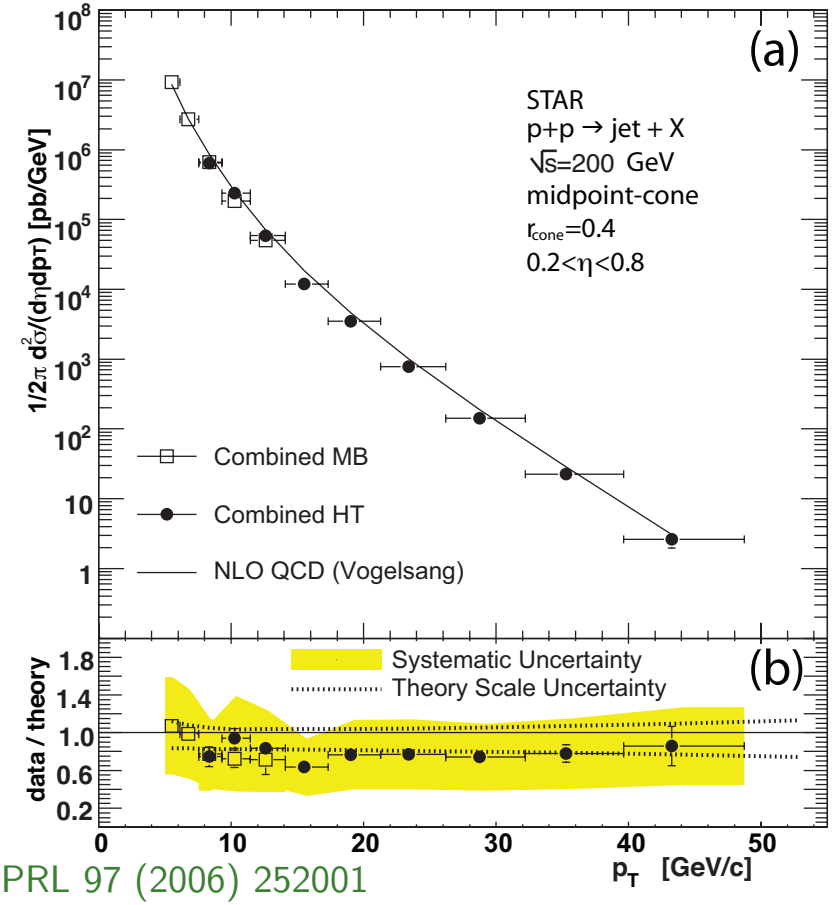
PRL 103 (2009) 012003



- good description of cross section with NLO QCD
- small asymmetries observed
- favours standard GRSV or smaller gluon distribution

STAR results

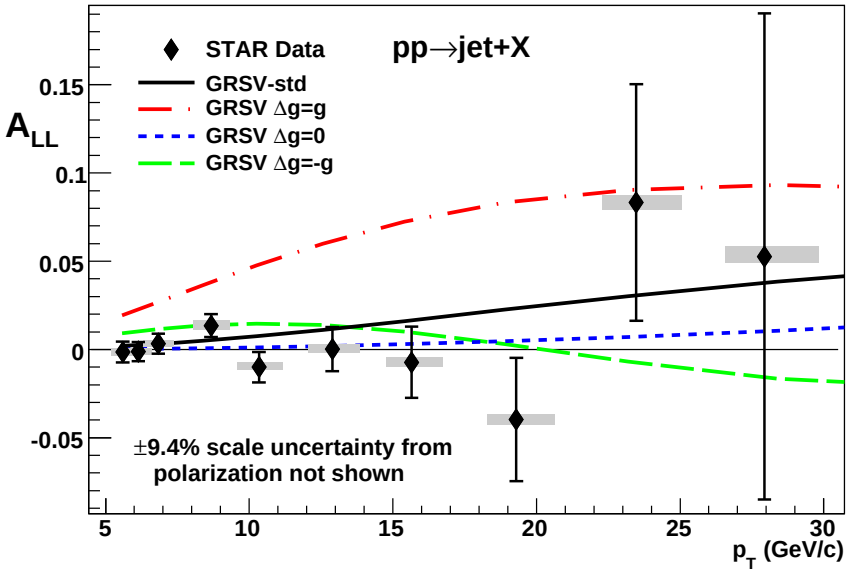
jet production

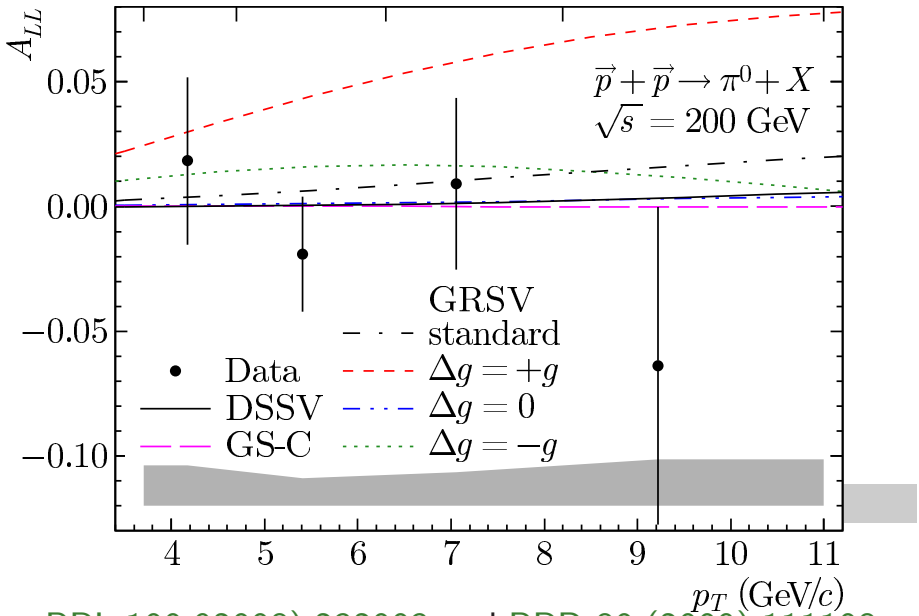


PRL 97 (2006) 252001

- good description of cross section with NLO QCD
- all RHIC A_{LL} favour small gluon distribution at x around 0.1

jet asymmetries

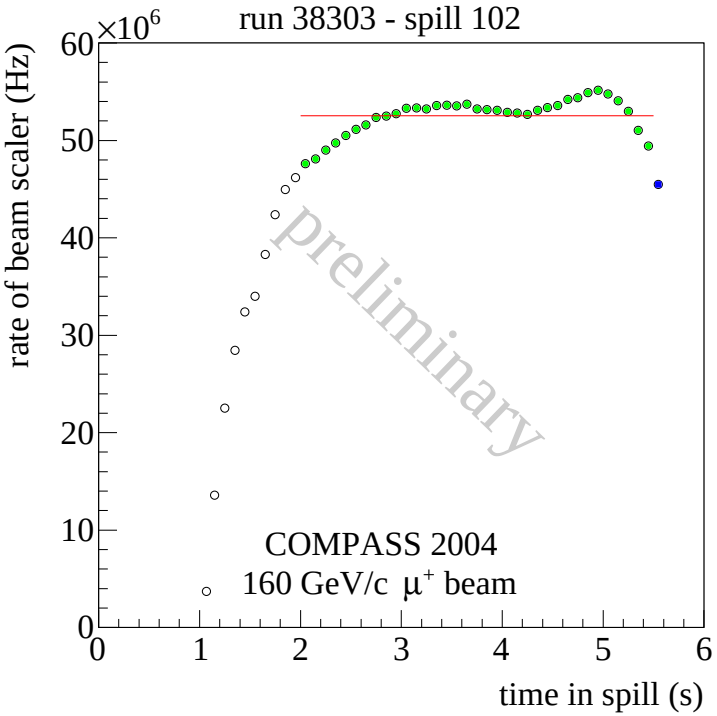


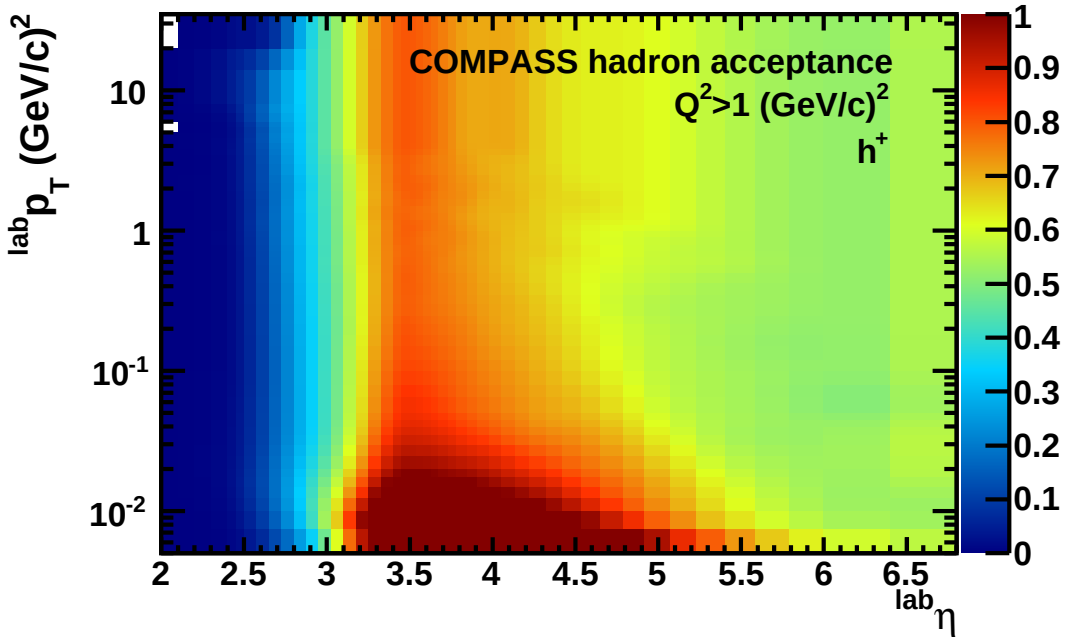


PRL 100 92008) 232003 and PRD 80 (2009) 111108

What about cross sections from COMPASS?

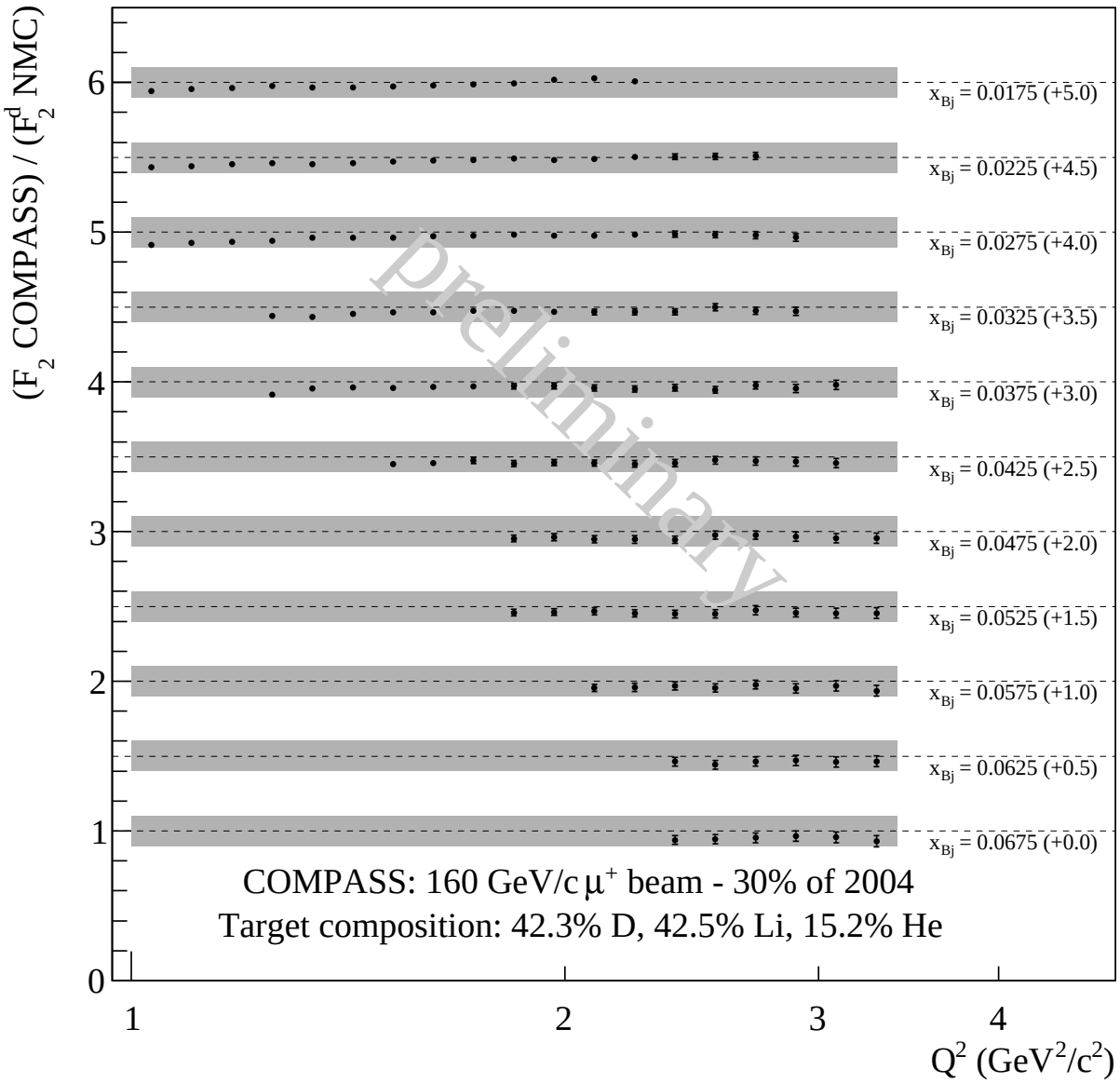
- **first step: luminosity determination for part of 2004 data**
  spill structure, effective beam flux (target dimensions),target density, DAQ and veto deadtimes taken into account, $\delta L = 10\%$





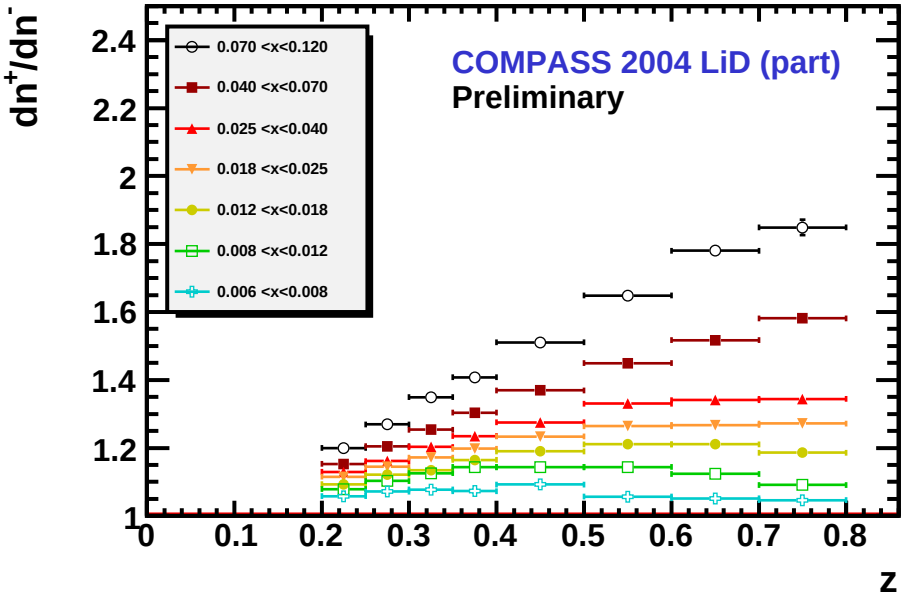
- **second step : acceptance determination for 2004**
  muon acceptance relative flat, between 60 and 80%
  hadron acceptance very similar for h^+ and h^-

Unpolarised structure function

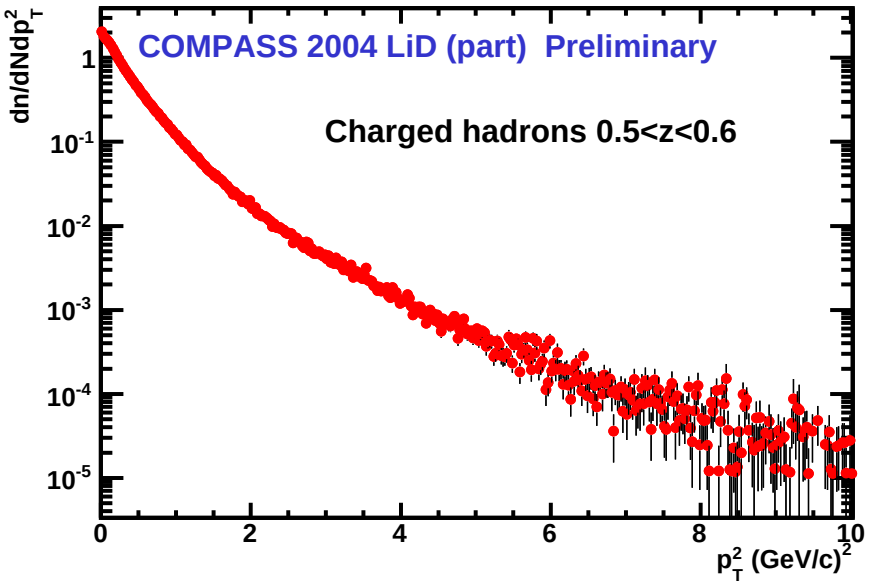


- determination of $F_2(x, Q^2)$
- part of 2004 LiD data
- one subtrigger
- Q^2 from 1 to 3 $(\mathrm{GeV}/c)^2$, $0.015 < x < 0.07$
- rather flat acceptance
- low rad. corr. $(y < 0.5)$
- shaded areas correpond to 10% luminosity error
- comparison to **NMC F_2 parametrisation**

SIDIS analysis



- ratio of h^+ and h^- vs z
  luminosity cancels
  nearly indep. of acceptance corr.



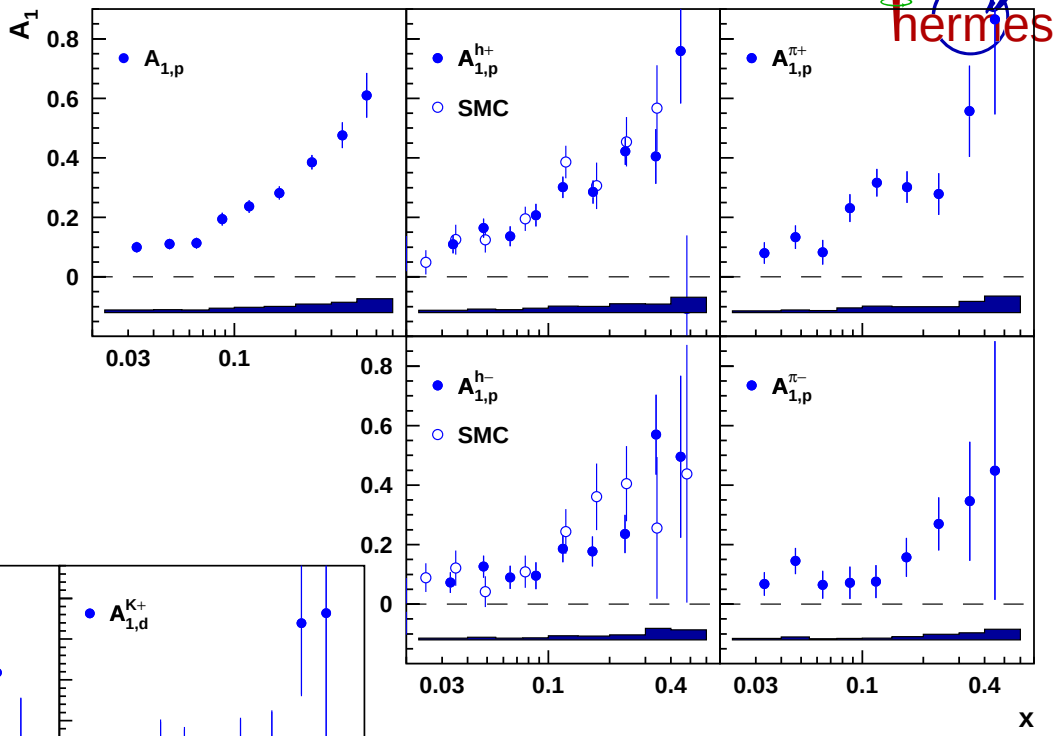
- hadron distribution vs p_{T}
  acceptance correcterd
  arbitrary normalisation

Semi-inclusive asymmetries

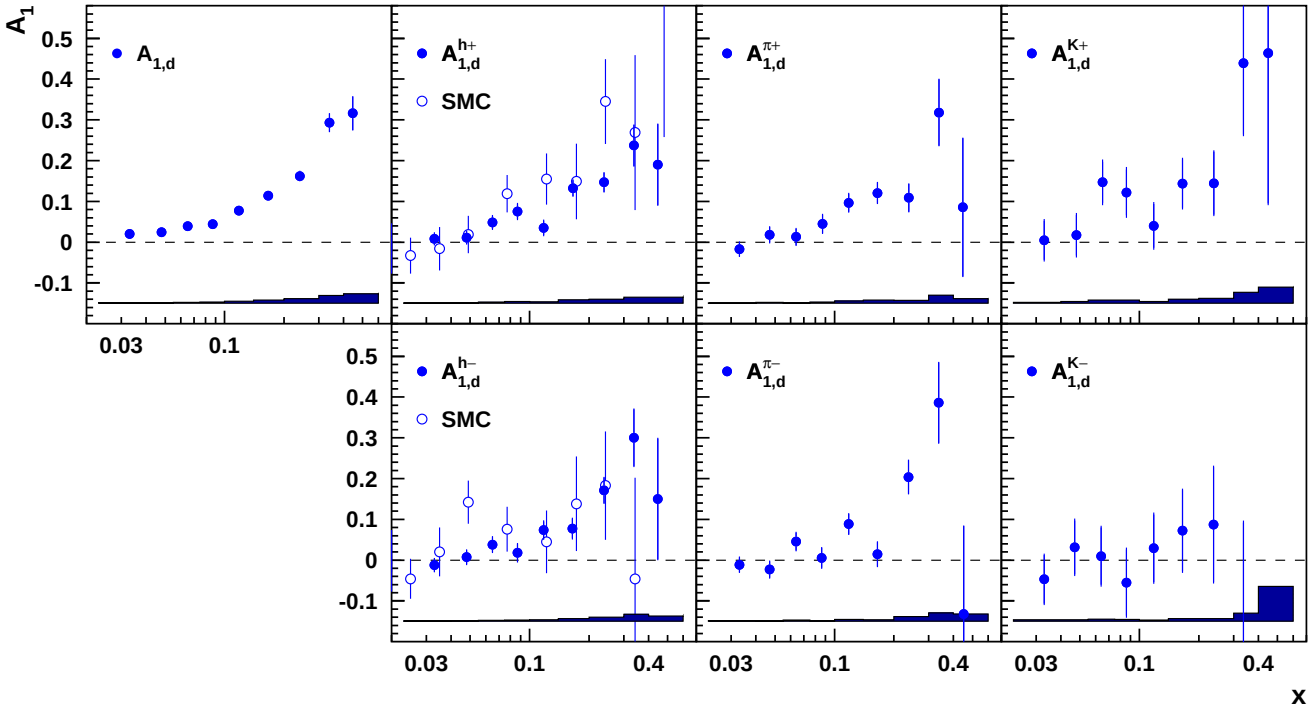
The data: HERMES

- **Kinematic domain:**

$$Q^2 > 1\ (\mathrm{GeV}/c)^2$$
$$W^2 > 10\ \mathrm{GeV}/c^2$$
$$y < 0.85$$
$$0.2 < z < 0.8$$
$$0.023 < x < 0.6$$



PRD 71 (2005) 012003

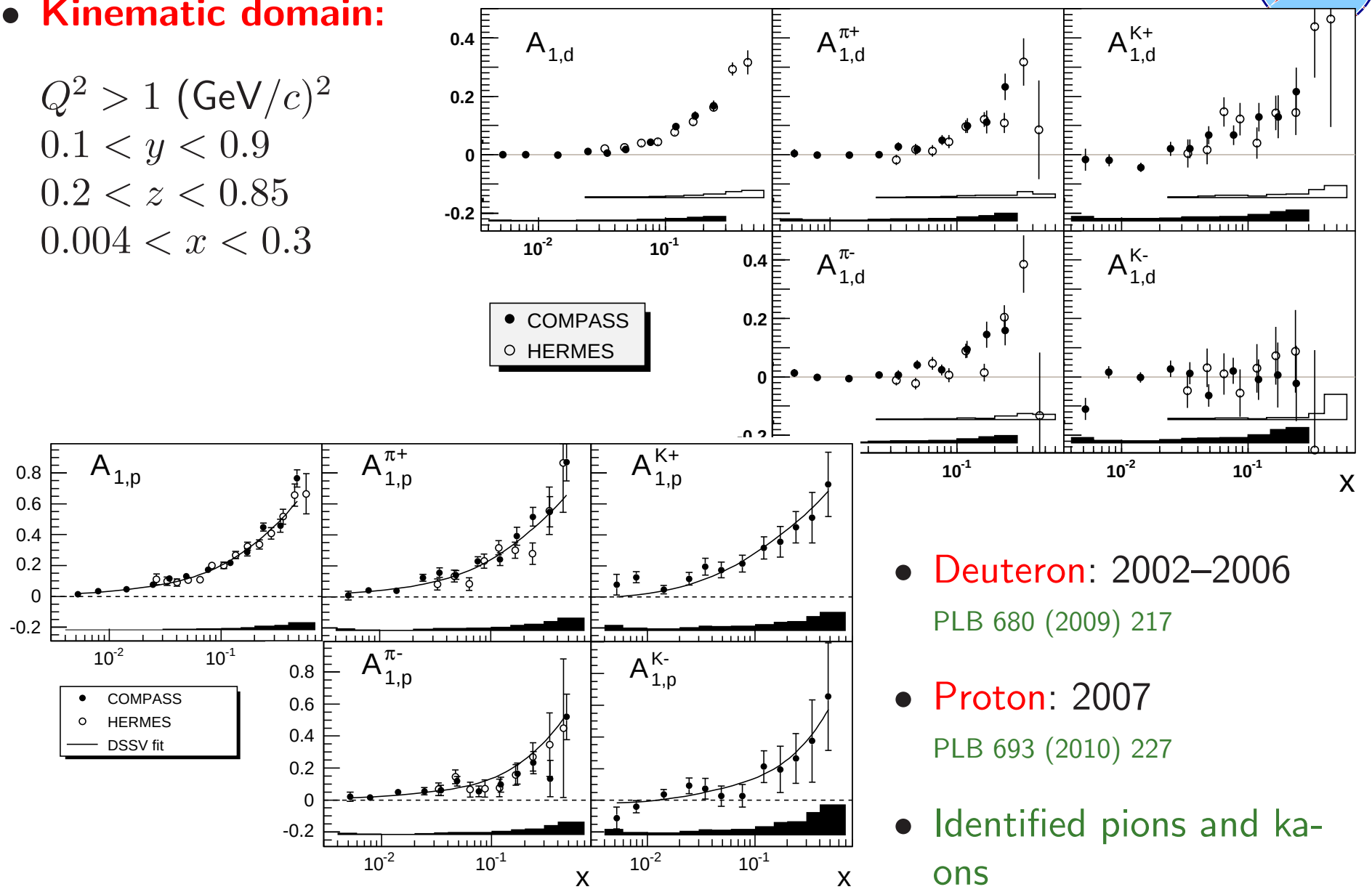


- deuteron, proton
- identified kaons and pions
- h^+ and h^- from SMC

The data: COMPASS

- **Kinematic domain:**

$$Q^2 > 1\ (\mathrm{GeV}/c)^2$$
$$0.1 < y < 0.9$$
$$0.2 < z < 0.85$$
$$0.004 < x < 0.3$$



- Deuteron: 2002–2006
  PLB 680 (2009) 217
- Proton: 2007
  PLB 693 (2010) 227
- Identified pions and kaons

Flavour separation

- **SIDIS** $A_1^h(x) = \Sigma_q P_q^h \frac{\Delta q(x)}{q(x)}$

  and

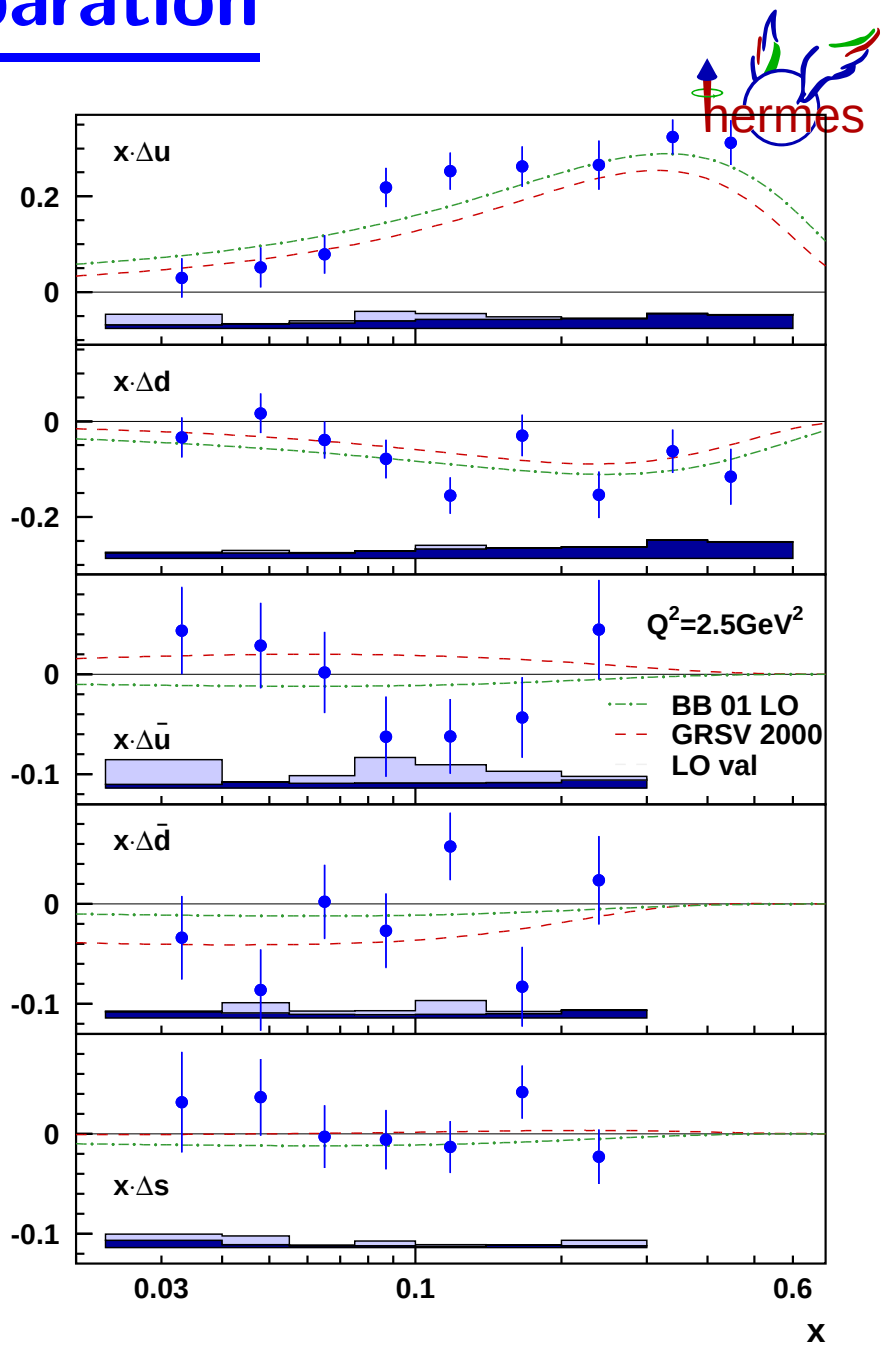
  $$P_q^h(x) = \frac{e_q^2 q(x) \int_{0.2}^{0.8} D_q^h(z)\mathrm{d}z}{\Sigma_{q'} e_{q'}^2 q'(x) \int_{0.2}^{0.8} D_{q'}^h(z)\mathrm{d}z}$$

- $D_q^h \neq D_{\bar{q}}^h$
  yields quark and antiquark separation

- **measured**:
  A_1^{d}, $A_{1\mathrm{d}}^{h\pm}$, $A_{1\mathrm{d}}^{K^\pm}$, $A_{1\mathrm{d}}^{\pi^\pm}$, A_1^{p}, $A_{1\mathrm{p}}^{h^\pm}$, $A_{1\mathrm{p}}^{\pi^\pm}$

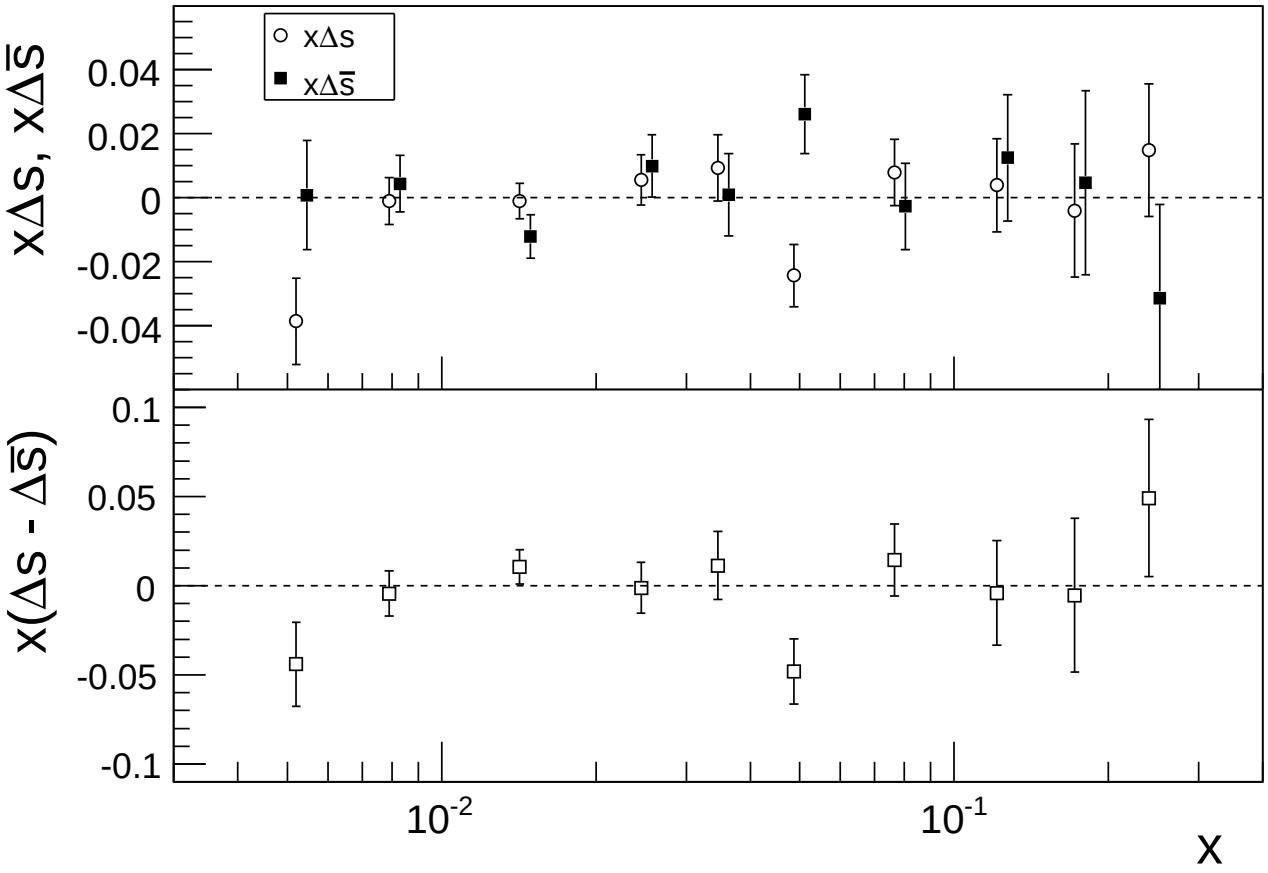
- **determined**: Δu, $\Delta \bar{u}$, Δd, $\Delta \bar{d}$, Δs
  assuming $\Delta \bar{s} = 0$
  all sea distrib. compatible with 0

- **inputs**:CTEQ5L unpolarised PDFs,
  FFs from LUND/JETSET tuned to HERMES multiplicities

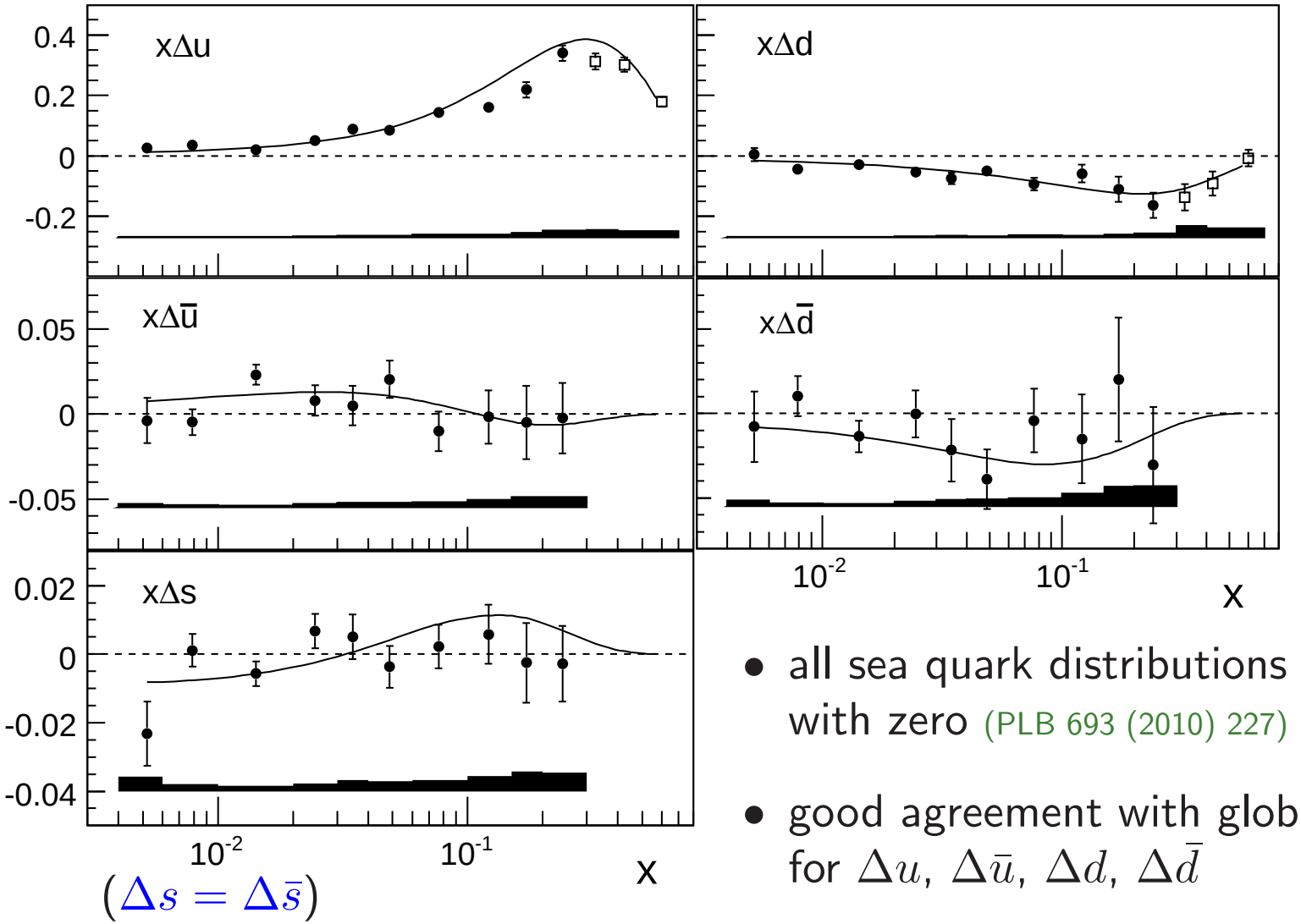


Strange sea asymmetry

- **SIDIS** $A_1^h = \dfrac{\Sigma_q e_q^2 (\Delta q(x) \int D_q^h(z) \mathrm{d}z}{\Sigma_q e_q^2 q(x) \int D_q^h(z) \mathrm{d}z}$
- **measured**: A_1^{d}, $A_{1\mathrm{d}}^{K^\pm}$, $A_{1\mathrm{d}}^{\pi^\pm}$, A_1^{p}, $A_{1\mathrm{p}}^{K^\pm}$, $A_{1\mathrm{p}}^{\pi^\pm}$
- **inputs**: MRST04 unpolarised LO PDFs, DSS parametr. of FFs
- **determined**: Δu, $\Delta \bar{u}$, Δd, $\Delta \bar{d}$, $\Delta s, \Delta \bar{s}$



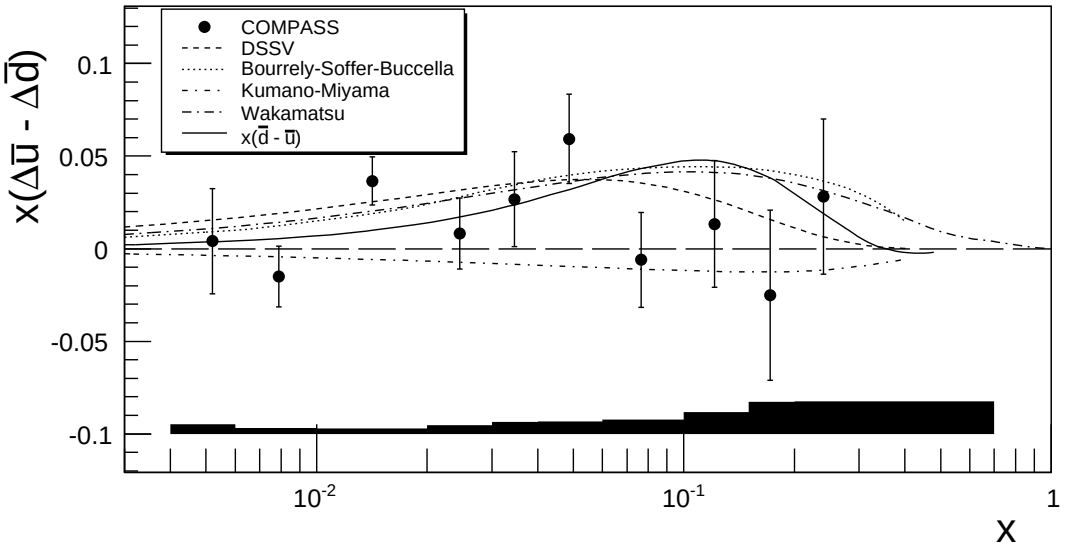
Flavour separation at $Q^2 = 3\ (\mathrm{GeV}/c)^2$

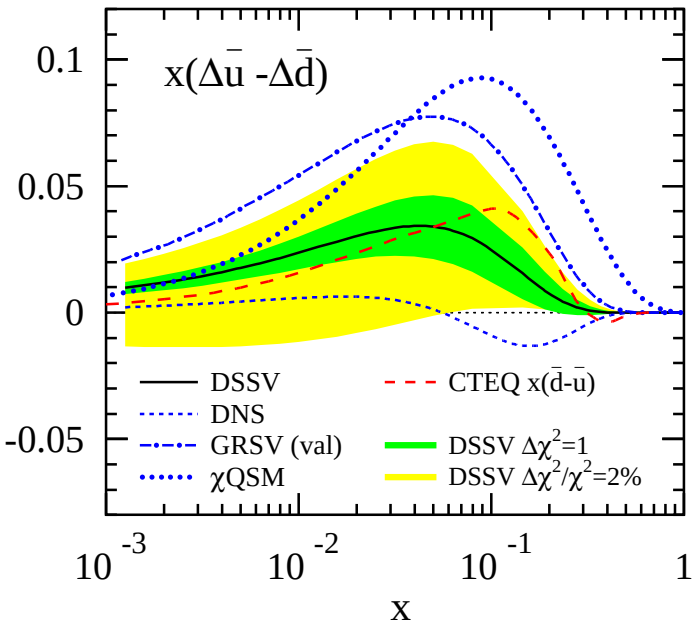


$(\Delta s = \Delta \bar{s})$

- all sea quark distributions compatible with zero (PLB 693 (2010) 227)
- good agreement with global fit for Δu, $\Delta \bar{u}$, Δd, $\Delta \bar{d}$
- significant discrepancy with Δs obtained from QCDfits to g_1

Flavour symmetry breaking





- presently only accessible via SIDIS
- uncertainty from FFs not included
- result at $Q^2 = 3$ (GeV/c)^2:

$$\int_{0.004}^{0.3}(\Delta\bar{u} - \Delta\bar{d})\mathrm{d}x = 0.06 \pm 0.04(\mathrm{stat}) \pm 0.02(\mathrm{syst})$$

- compatible with HERMES result:

$$\int_{0.023}^{0.6}(\Delta\bar{u} - \Delta\bar{d})\mathrm{d}x = 0.048 \pm 0.057(\mathrm{stat}) \pm 0.028(\mathrm{syst})$$

- comparable with effect in unpolarised PDFs ($\int(\bar{u} - \bar{d})\mathrm{d}x = -0.118 \pm 0.012$)

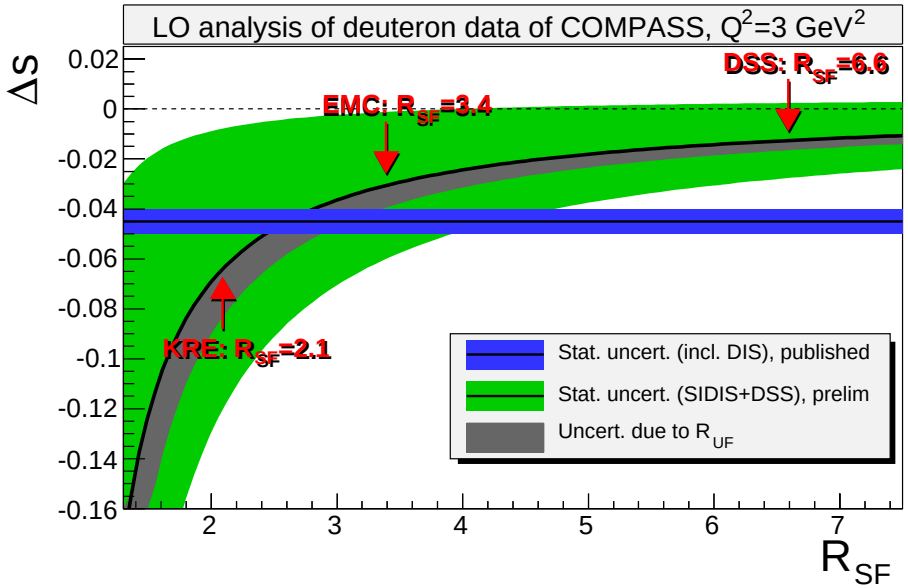
Dependence on FFs

- $K^{\pm}$ asymmetries from deuteron data

$$\frac{\Delta s}{s} = A_1^{\mathrm{d}} + \left(A_1^{K^+ + K^-} - A_1^{\mathrm{d}}\right) \frac{Q/s + \alpha}{\alpha - 0.8}$$

- $Q = u + \bar{u} + d + \bar{d},\ \alpha = \frac{2R_{UF} + 2R_{SF}}{3R_{UF} + 2}$

- $R_{UF} = \frac{\int D_d^{K^+}(z)\mathrm{d}z}{\int D_u^{K^+}(z)\mathrm{d}z},\ R_{SF} = \frac{\int D_{\bar{s}}^{K^+}(z)\mathrm{d}z}{\int D_u^{K^+}(z)\mathrm{d}z}$



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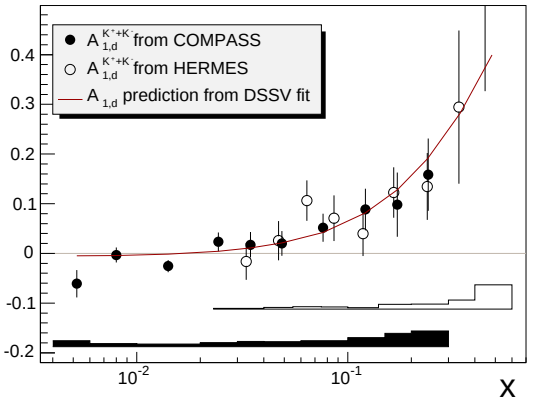
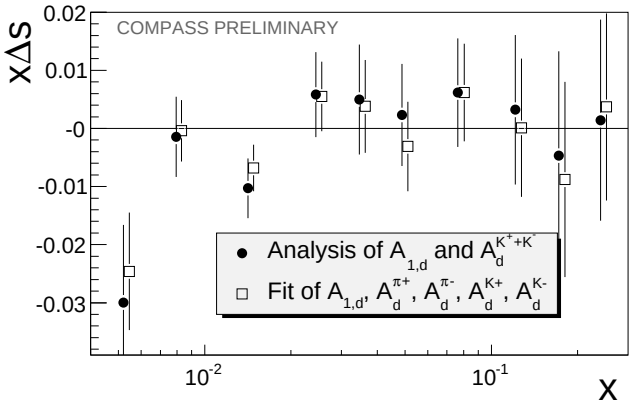




- large dependence on R_{SF}, slight dependence on R_{UF} for Δs

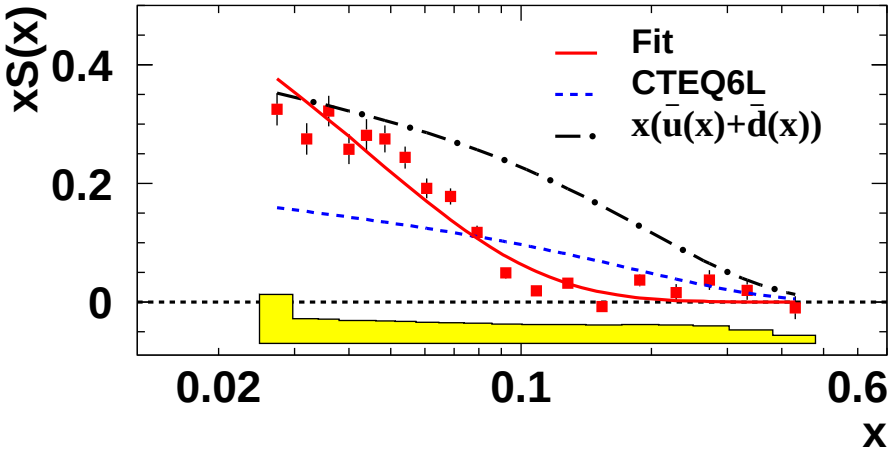
- determination of R_{SF} from data (hadron multiplicities) on the way

Strange quark distributions

for a deuteron target

$$s(x)\int D_s^K(z)\mathrm{d}z \approx Q(x)[5\frac{\mathrm{d}^2N^K(x)}{\mathrm{d}^2N^{\mathrm{DIS}}(x)} - \int D_Q^K(z)\mathrm{d}z]$$

- $\int D^k_{s,Q}(z)$ from DSS
- shape of $s(x)$ is incompatible with recent LO parametrisations



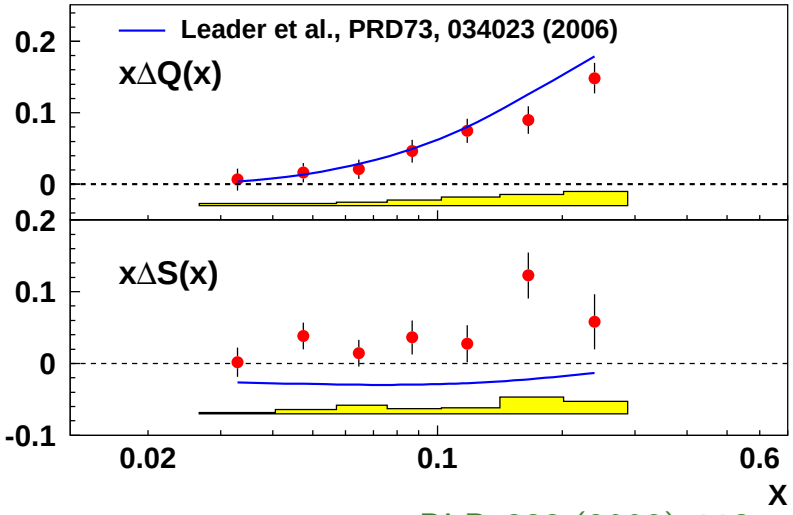
similar approach for

$$A_{\parallel,\mathrm{d}}(x)\frac{\mathrm{d}^2N^{\mathrm{DIS}}(x)}{\mathrm{d}x\mathrm{d}Q^2}$$

and

$$A^K_{\parallel,\mathrm{d}}(x)\frac{\mathrm{d}^2N^K(x)}{\mathrm{d}x\mathrm{d}Q^2}$$

- allow to determine $\Delta Q(x)$ and $\Delta s(x)$
- ΔQ is compatible with the g_1 data
- Δs is compatible with the result from the other measurements



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Summary of results

- in the last 25 years a lot of effort to measure polarised PDFs at SLAC, CERN, DESY, JLAB and RHIC
- precise results for $A_1^{\mathrm{p,d,n}}$ available, although in a limited kinematic range allow for the determination of $\Delta\Sigma$
- precise determination of Δu and Δd in NLO QCD analyses
- gluon polarisation ΔG measured in SIDIS and pp compatible with 0 for $x_g \sim 0.1$
- SIDIS results from identified hadrons from COMPASS and HERMES full flavour separation of polarised PDFs study of $\Delta\bar{u} - \Delta\bar{d}$ and $\Delta s - \Delta\bar{s}$
- still limited knowledge on strangeness and gluon polarisation

To come

- hadron multiplicities from COMPASS will shed more light on strange quark distribution and fragmentation
- COMPASS 2011: data taking with longitudinally polarised NH_3
  g_1^p at small x, balance p and d statistics for flavour separation
- more data from JLAB, especially in the valence region
- very promising prospects for $\Delta\bar{u}$, $\Delta\bar{d}$ from W production at RHIC
  larger range in x_g with higher energy, direct photons
- COMPASS II:
  measurement of unpolarised DIS off hydrogen
  detailed study of quark distributions and fragmentation