# Review of longitudinal spin physics

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COMPASS

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# Contents

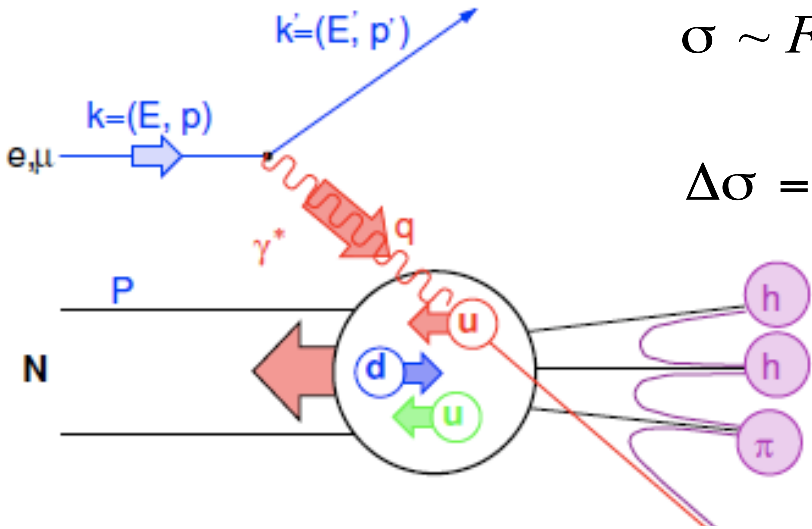
- Introduction: Nucleon spin structure
- Inclusive longitudinal spin asymmetries and $g_1$ structure function
- Semi inclusive asymetries and flavour separations
- Strange quark sea polarisation
- Gluon polarisation
- Summary

## Spin degree of freedom

- Spin is a fundamental degree of freedom originated from space-time symmetry quantum and relativistic object - survives high-energy limit
- Spin plays a critical role in determining the basic structure of fundamental interactions
- Spin provides a unique opportunity to probe the inner structure of a composite system such as the nucleon

After many years still the driving question for QCD spin physics is where the nucleon spin comes from?

# Nucleon spin structure in DIS/SIDIS




$$\sigma \sim F_1(x) = \tfrac{1}{2}\sum_i e_q^2 q_i(x) \qquad F_2(x) \approx 2xF_1$$

$$\Delta\sigma = \overset{\leftrightarrows}{\sigma} - \overset{\rightrightarrows}{\sigma} \sim g_1(x) = \tfrac{1}{2}\sum_i e_q^2 \Delta q_i(x) \qquad g_2$$

$$\Delta q(x) = q(x)^+ - q(x)^-$$

$$q(x) = q(x)^+ + q(x)^-$$

$+$ **quark ↑↑ nucleon**

$-$ **quark ↑↓ nucleon**

$$A_{meas} = \frac{1}{fP_T P_B}\left(\frac{N^{\leftrightarrows} - N^{\leftleftarrows}}{N^{\leftrightarrows} + N^{\leftleftarrows}}\right) \approx DA_1$$

$$A_1(x,Q^2) = \frac{\sigma_{\uparrow\downarrow} - \sigma_{\uparrow\uparrow}}{\sigma_{\uparrow\downarrow} + \sigma_{\uparrow\uparrow}} \approx \frac{\sum_q e_q^2 \Delta q(x,Q^2)}{\sum_q e_q^2 q(x,Q^2)} = \frac{g_1(x,Q^2)}{F_1(x,Q^2)}$$

First moment of $g_1$ structure functions

## Sum rules

first moment $\Gamma_1 = \int g_1(x)dx$

Bjorken s.r. $\Gamma_1^p - \Gamma_1^n = \frac{g_A}{6g_V} C_1^{NS}$

Ellis-Jaffe s.r. $\Gamma_1^{p,n} = \left(\pm a_3 + \frac{a_8}{3}\right)\frac{C_1^{NS}}{12} + a_0 \frac{C_1^S}{9}$

$a_3, a_8, g_{A,V}$ measuered in weak β decays (+Su(3)$_f$)

$C_1^{S,NS}$ calculable in pQCD

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$$a_0 = \Delta\Sigma = \Delta u + \Delta d + \Delta s$$

Quark contribution to nucleon helicity

# First moment of $g_1$ structure functions

Compass only    Phys. Lett. B 647 (2007) 8

$$\Gamma_1^N\left(Q^2\right)=\frac{1}{9}\left(1-\frac{\alpha_s(Q^2)}{\pi}+O(\alpha_s^2)\right)\left(a_0(Q^2)+\frac{1}{4}a_8\right)$$

from Y. Goto *et al.*, PRD62 (2000) 034017:
(SU(3)$_f$ assumed for weak decays)
$a_8 = 0.585 \pm 0.025$

$$a_{0|Q_0^2=3(GeV/c)^2} = 0.35 \pm 0.03(stat) \pm 0.05(syst)$$

QCD NLO

$$\Gamma_1^N\left(Q^2\right)=\frac{1}{9}C_1^S(Q^2)\hat{a}_0+\frac{1}{36}C_1^{NS}(Q^2)a_8$$

beyond NLO

$C_1$ calculated behind 3 loops app.
S.A.Larin *et al.*,Phys.Lett.B404(1997)153

$$\hat{a}_{0|Q^2\to\infty} = 0.33 \pm 0.03(stat) \pm 0.05(syst)$$

quark contribution to the proton spin: ~ 1/3

$$(\Delta s+\Delta\bar{s})=\frac{1}{3}(\hat{a}_0-a_8)=-0.08\pm 0.01(stat)\pm 0.02(syst)$$

comment: $a_8$ (under SU(3) symmetry) maybe reduced (model)

# Anomaly and the role of gluons

"Switching on" spin leads us to two complications:

$$q^{-} \sim \psi \tfrac{1}{2}(1-\gamma_5)\gamma_\mu \psi \qquad q^{+} \sim \psi \tfrac{1}{2}(1+\gamma_5)\gamma_\mu \psi$$

$$\Delta q = u^{+} - u^{-} \sim \psi \tfrac{1}{2}\gamma_\mu \gamma_5 \psi$$

- axial current is not conserved due to Adler-Bell-Jackiw triangle anomaly
- there is no local, gauge invariant dimension-3 axial operator for gluons

$\overline{\text{MS}}$ scheme - $a_0$ depends on the scale
AB scheme - $a_0$ does not depend on the scale but now

$$a_0 = \Delta\Sigma - \tfrac{3}{2}\frac{\alpha_S}{\pi}\Delta G$$

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$$a_0 = \Delta\Sigma - \tfrac{3}{2}\frac{\alpha_S}{\pi}\Delta G$$

anomaly gives a possible interpretation of the measured value of $a_0$
- if gluon polarization is large enough then E-J sum rule can be restored and quark contribution to the nucleon spin is significant as expected in simple QPM

# Longitudinal spin asymmetry

## Semi-inclusive asymmetry

Inclusive asymmetry: $$A_1(x,Q^2) = \frac{\sigma_{\uparrow\downarrow} - \sigma_{\uparrow\uparrow}}{\sigma_{\uparrow\downarrow} + \sigma_{\uparrow\uparrow}} \approx \frac{\sum_q e_q^2\, \Delta q(x,Q^2)}{\sum_q e_q^2\, q(x,Q^2)} = \frac{g_1(x,Q^2)}{F_1(x,Q^2)}$$

Semi-inclusive asymmetry: $$A_1^h(x,z,Q^2) = \frac{\sigma_{\uparrow\downarrow}^h - \sigma_{\uparrow\uparrow}^h}{\sigma_{\uparrow\downarrow}^h + \sigma_{\uparrow\uparrow}^h} \approx \frac{\sum_q e_q^2\, \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2\, q(x,Q^2) D_q^h(z,Q^2)}$$

inclusive and semi-inclusive asymmetry measured on proton and neutron or deuteron allows to full flavour separation

2002-2006 deuteron data taking in COMPASS (160 GeV): Phys. Lett. B 647 (2007) 8

2007: proton data; DIS events - $Q^2$ >1 $(\text{GeV}/c)^2$ (160 GeV): Phys. Lett. B 690 (2010) 466–472

New: 2011 proton data 200 GeV

# Difference asymmetry

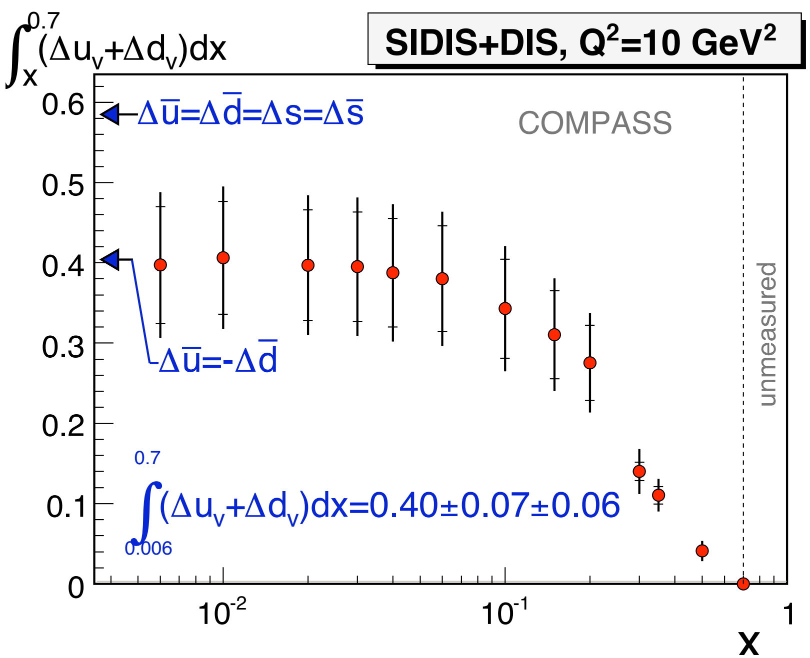
Idea: Phys.Lett.B230(1989)141,
SMC:Phys.Lett.B369(1996)93,
COMPASS: Phys.Lett.B660(2008)458

$$A^{+-} = \frac{(\sigma^{h^+}_{\uparrow\downarrow} - \sigma^{h^-}_{\uparrow\downarrow}) - (\sigma^{h^+}_{\uparrow\uparrow} - \sigma^{h^-}_{\uparrow\uparrow})}{(\sigma^{h^+}_{\uparrow\downarrow} - \sigma^{h^-}_{\uparrow\downarrow}) + (\sigma^{h^+}_{\uparrow\uparrow} - \sigma^{h^-}_{\uparrow\uparrow})}$$

$$A_d^{\pi^+-\pi^-}(x) = A_d^{K^+-K^-}(x) = \frac{\Delta u_v(x) + \Delta d_v(x)}{u_v(x) + d_v(x)}$$

Only valence quarks!

Fragmentation functions cancell out in LO and under the assuption of independent fragmentation.




$$\Delta\bar{u} = \Delta\bar{d} = \Delta s = \Delta\bar{s}$$ symmetric

$$\Delta\bar{u} = -\Delta\bar{d}$$ asymmetric

scenario

$$\Gamma_v = \int_0^1 (\Delta u_v(x) + \Delta d_v(x))dx$$

$$\Delta\bar{u} + \Delta\bar{d} = 3\Gamma_1^N - \tfrac{1}{2}\Gamma_v + \tfrac{1}{12}a_8 = (\Delta s + \Delta\bar{s}) + \tfrac{1}{2}(a_8 - \Gamma_v)$$

## polarised experiments

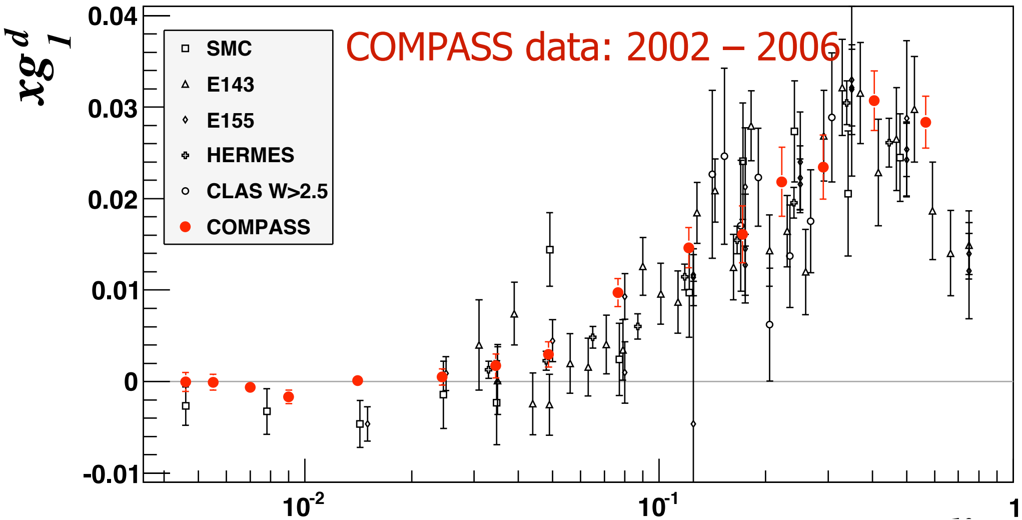
Experiments:

- Inclusive spin-dependent DIS
  EMC, SMC, COMPASS & COMPASS II (CERN),
  E142,E143,E154,E156,
  HERMES (DESY) ,JLAB-Hall,A,B(CLAS)
- Semi-inclusive DIS: SMC, COMPASS,HERMES
- Polarized pp collision RHIC-PHENIX & STAR, BRAHMS (Brookhaven)
- ee: BELLE (KEK) (Fragmentation functions)

JLAB-12, EIC, eLHC

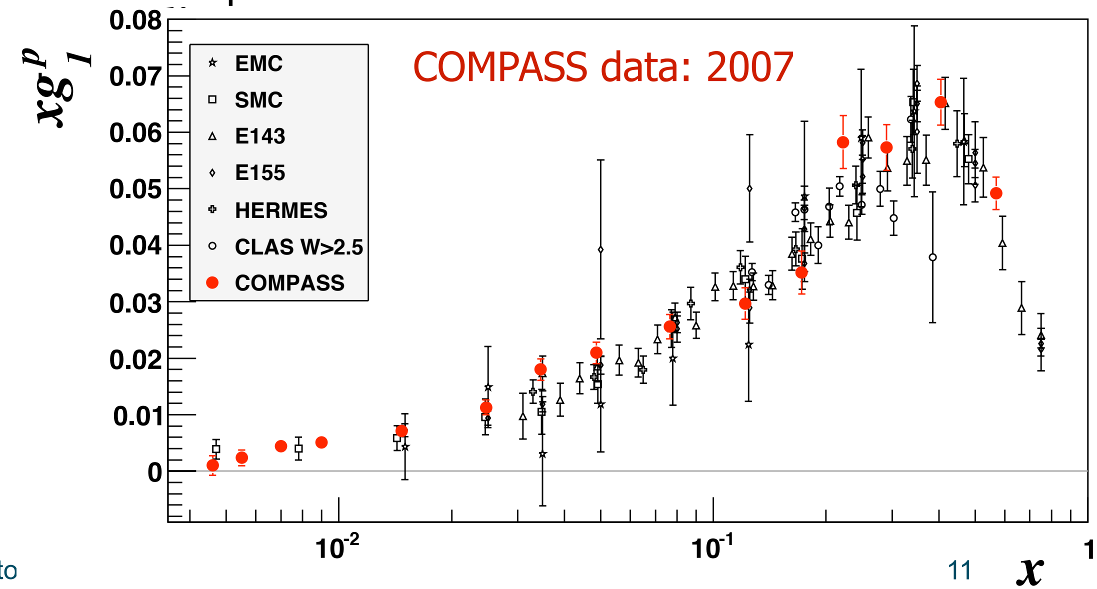
# Deuteron and proton $g_1$ structure function

## COMPASS data




Phys. Lett. B 647 (2007) 8

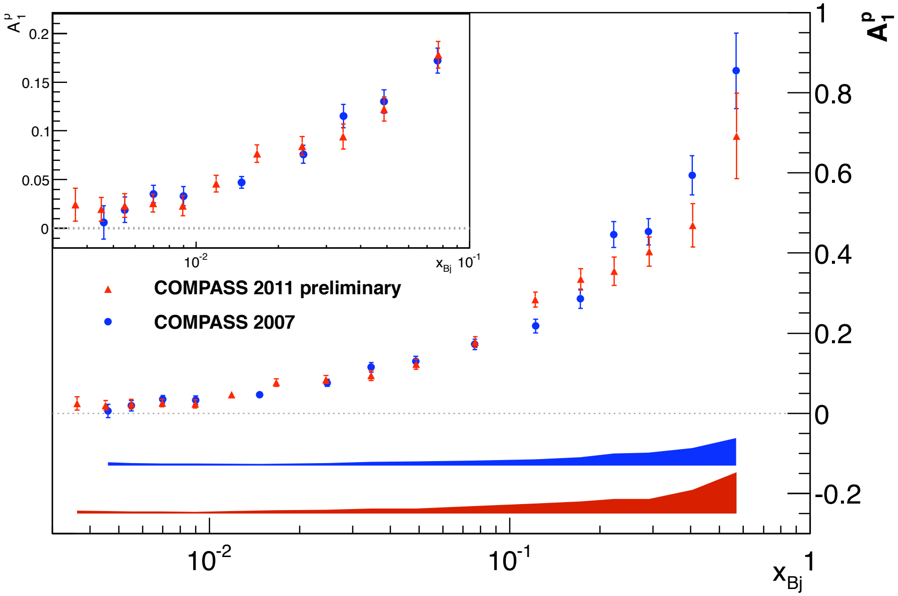
Phys. Lett. B 690 (2010) 466–472

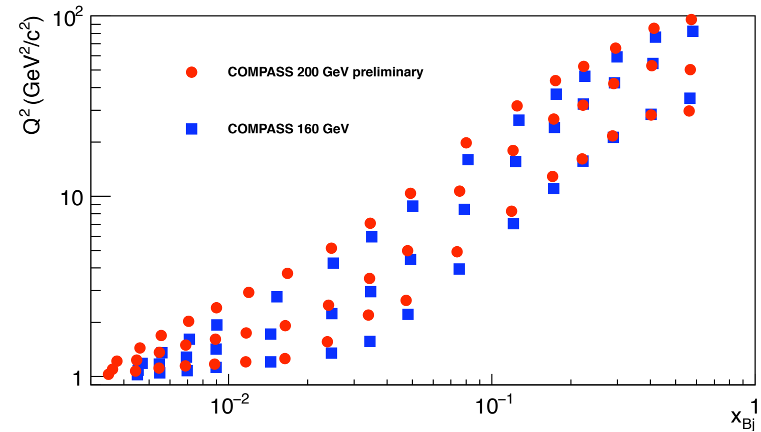



Very good agreement between experiments. Points evolved to $Q^2 = 3\ (\mathrm{GeV}/c)^2$

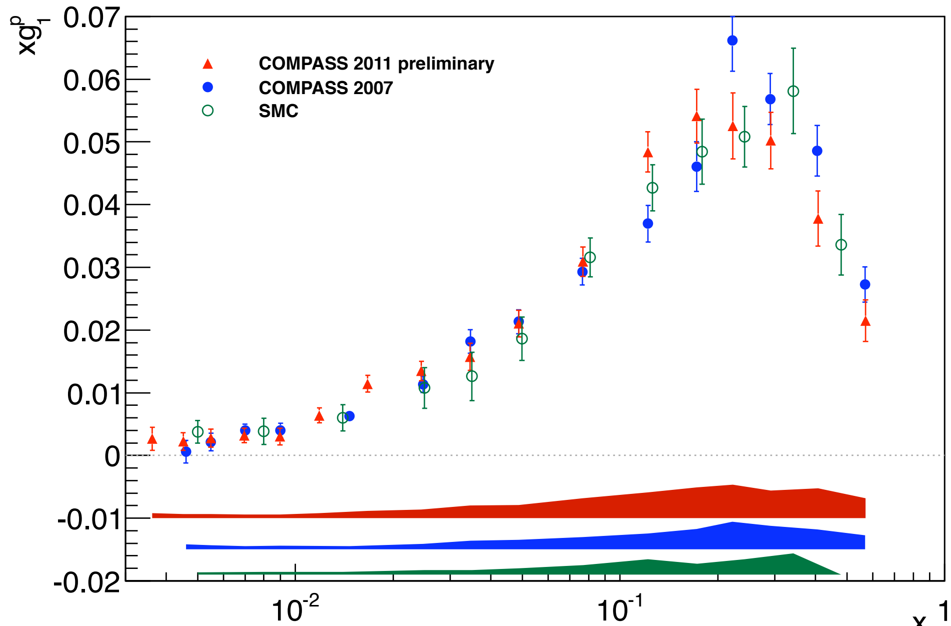
# Proton $g_1$ structure function

## COMPASS data 2011, 200 GeV




SMC parameterization of $F_2$ -
Phys.Rev.D 55 (1998) 112001
R - Phys. Lett. B 647 (2007) 330

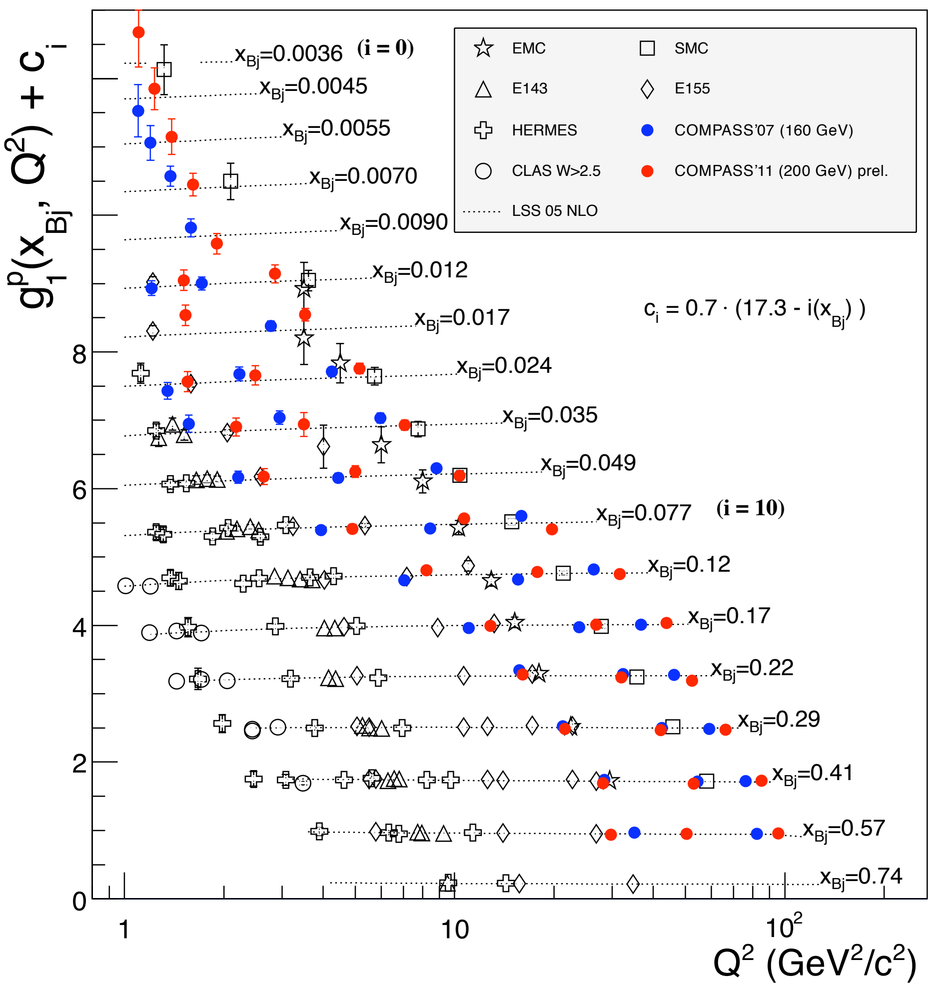


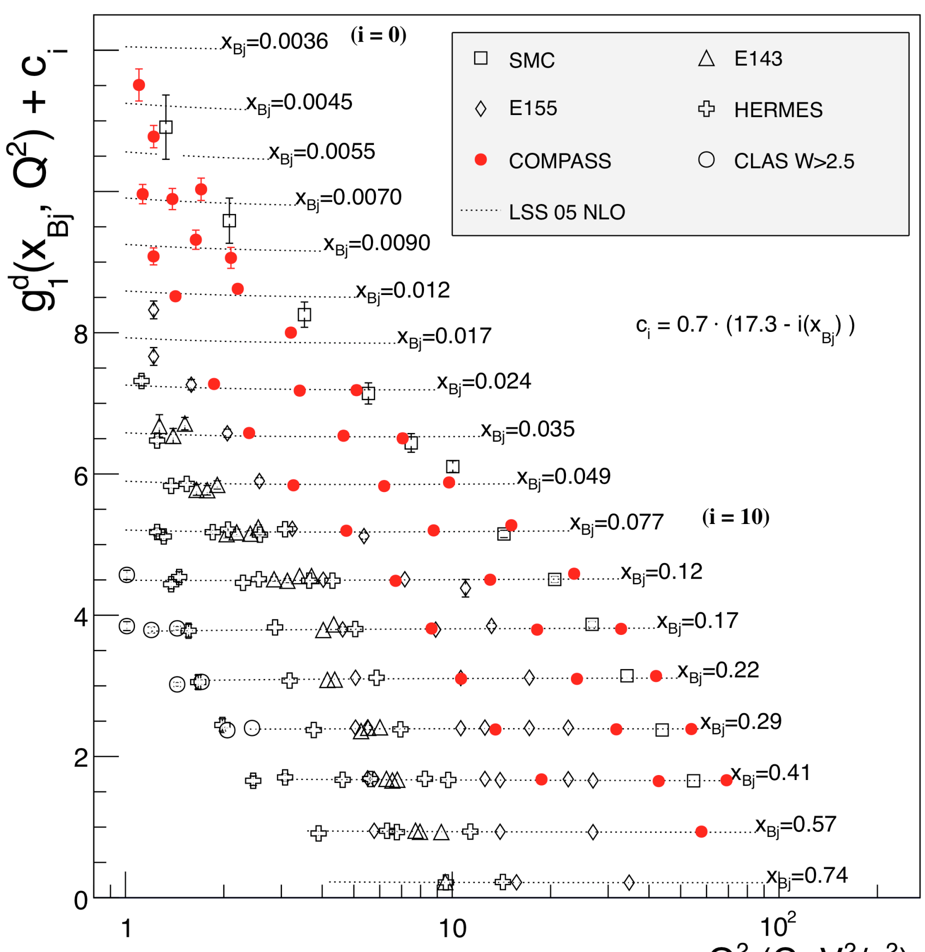

Lower $x_B$

data taken to balance the amount of deuteron data:
to increase precision of the Bjorken s.r.determination,
to better constrain the strange quark polarisation

# World data for proton and deuteron $g_1$ structure function

## COMPASS proton data 2011@200 GeV included

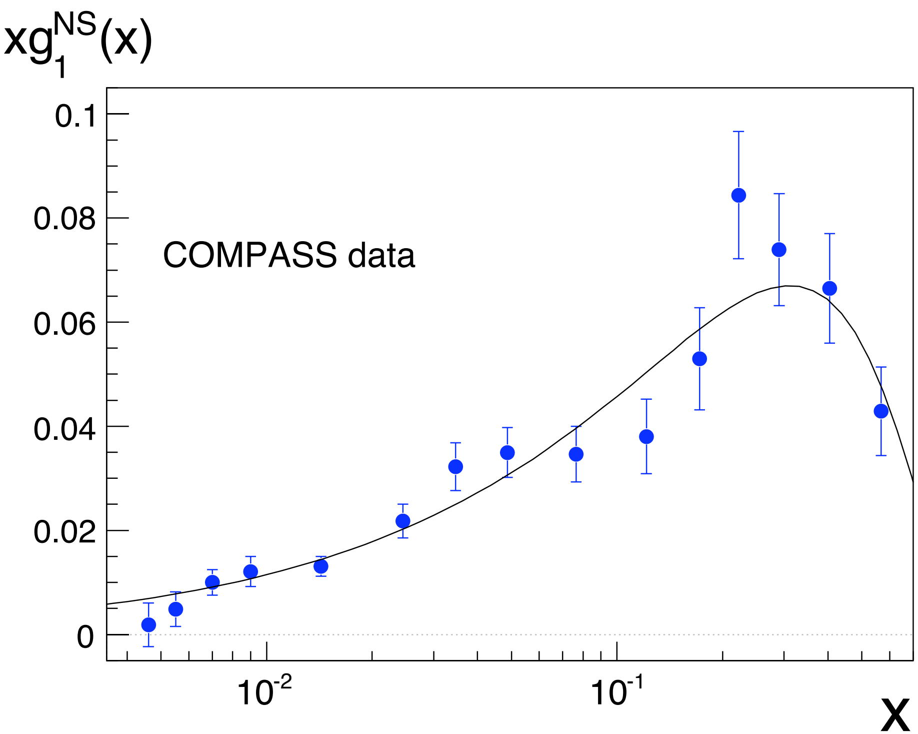


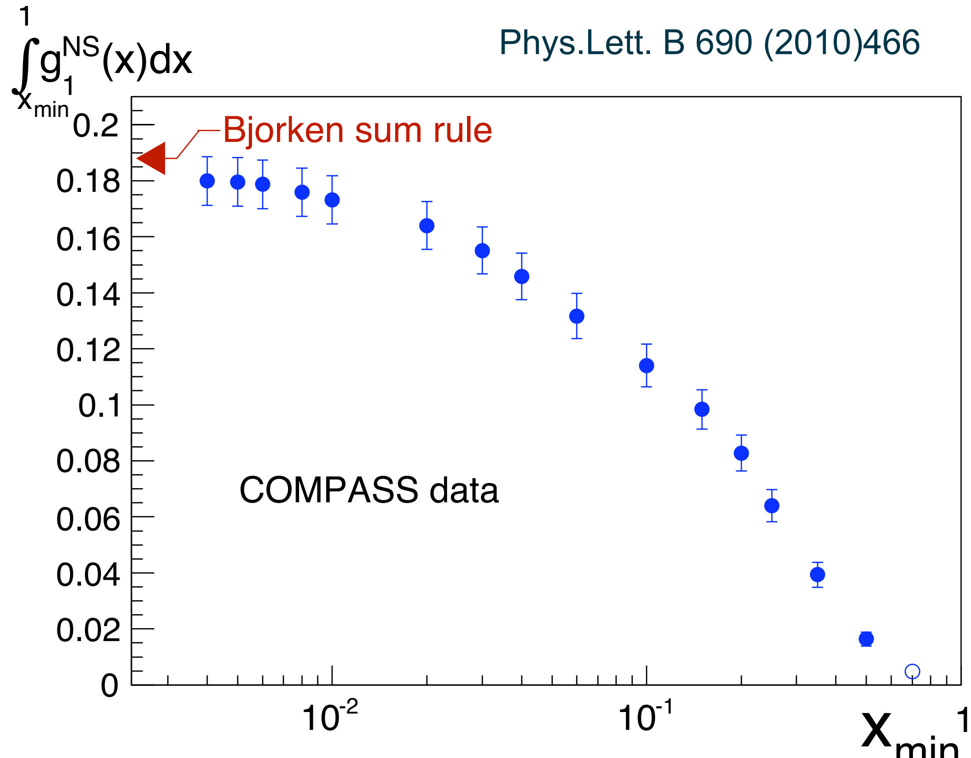




new input for global QCD fits

# Bjorken sum rule

## COMPASS data, SMC, HERMES




| $x$ range | $\Gamma_1^{NS}$ |
|---|---|
| 0 – 0.004 | 0.0098 |
| 0.004 – 0.7 | $0.175 \pm \boxed{0.009 \pm 0.015}$ |
| 0.7 – 1.0 | 0.0048 |
| 0 – 1 | $0.190 \pm 0.009 \pm 0.015$ |

in good agreement with SMC:
$0.198 \pm 0.023$ ($Q^2 = 10$).

truncated moment from x=0.021:
$0.1583 \pm 0.0085 \pm 0.014$
in good agreement with HERMES:
$0.1484 \pm 0.0055 \pm 0.016$

# Bjorken sum rule

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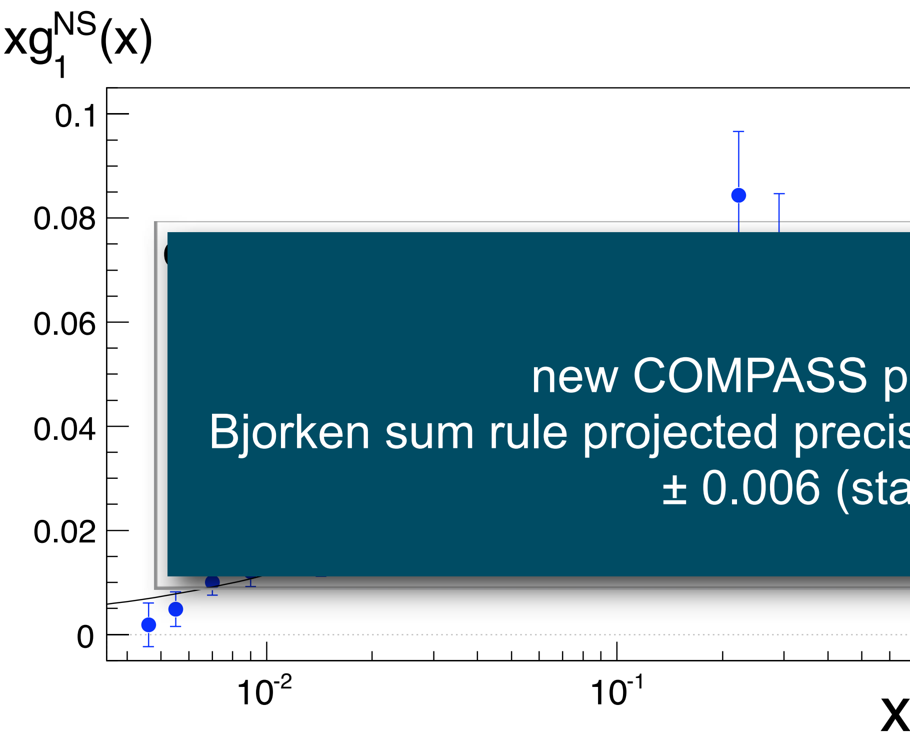


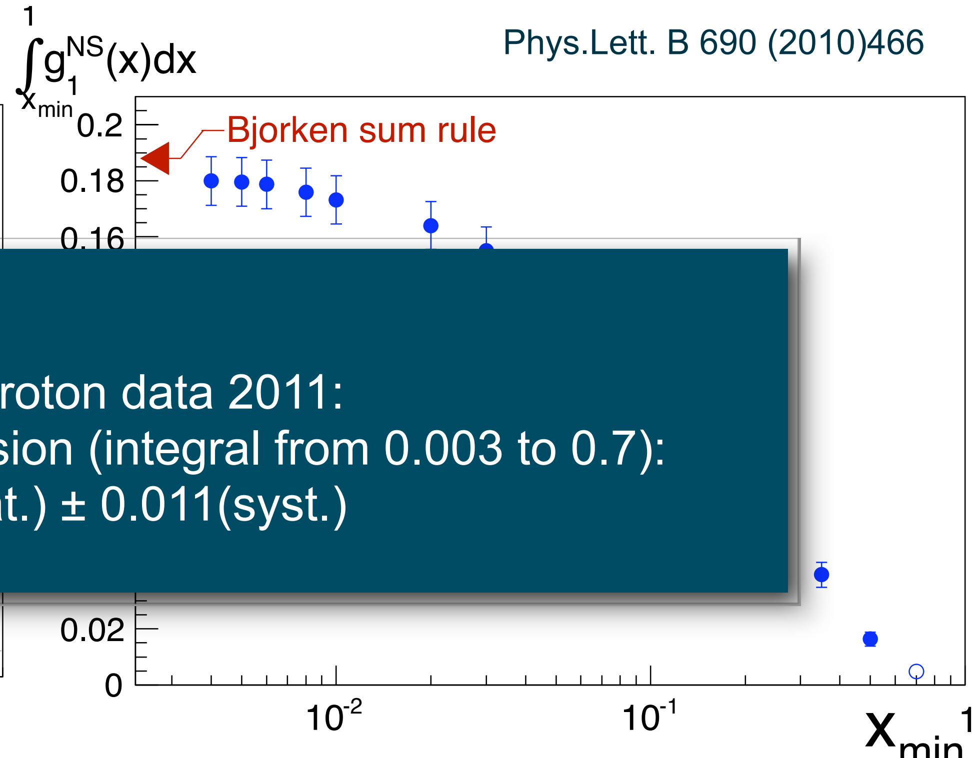


new COMPASS proton data 2011:
Bjorken sum rule projected precision (integral from 0.003 to 0.7):
± 0.006 (stat.) ± 0.011(syst.)

| $x$ range | $\Gamma_1^{NS}$ |
|---|---|
| $0 - 0.004$ | $0.0098$ |
| $0.004 - 0.7$ | $0.175 \pm \boxed{0.009 \pm 0.015}$ |
| $0.7 - 1.0$ | $0.0048$ |
| $0 - 1$ | $0.190 \pm 0.009 \pm 0.015$ |

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0.1583 ± 0.0085 ± 0.014
in good agreement with HERMES:
0.1484 ± 0.0055 ± 0.016

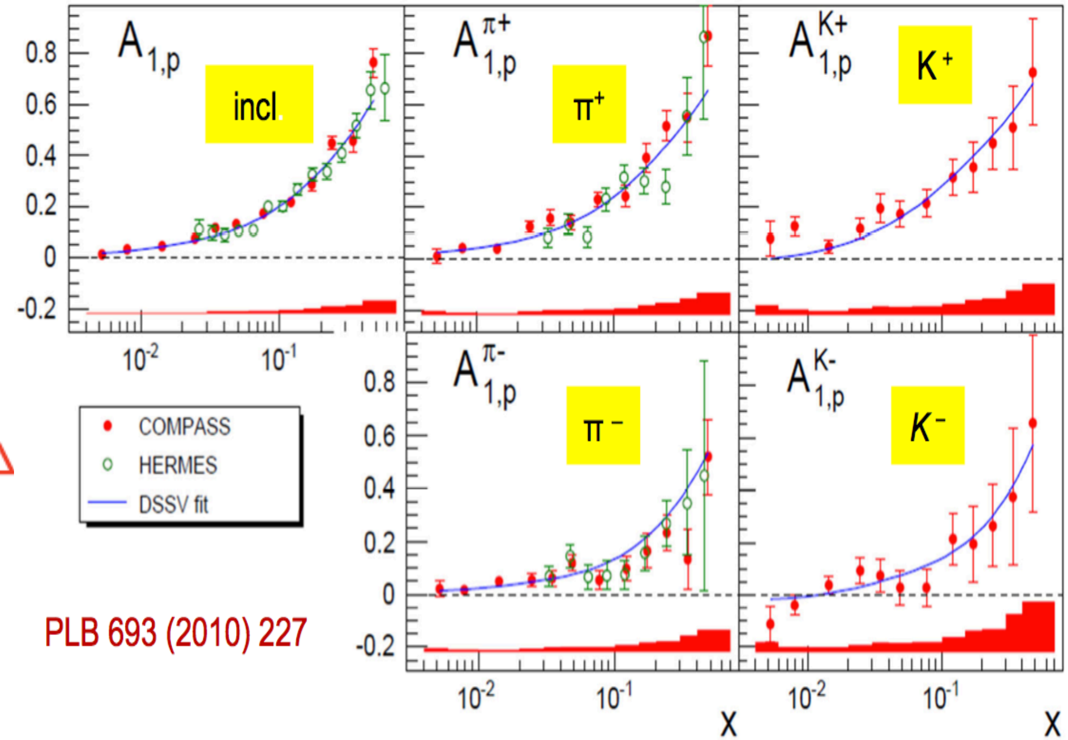
# Flavour separation analysis
# Asymmetries

## COMPASS & HERMES data

- **SIDIS**

$$A_1^h = \frac{\sum e_q^2 [\Delta q(x) \int D_q^h(z)dz + \Delta\bar{q}(x) \int D_{\bar{q}}^h(z)dz]}{\sum e_q^2 [q(x) \int D_q^h(z)dz + \bar{q}(x) \int D_{\bar{q}}^h(z)dz]}$$

- $D_q^h \neq D_{\bar{q}}^h$
  yields quark and antiquark separation
- **measured:**
  $A_1^d, A_{1d}^{K\pm}, A_{1d}^{\pi\pm}, A_1^p, A_{1p}^{K\pm}, A_{1p}^{\pi\pm}$
- **determined:** $\Delta u, \Delta\bar{u}, \Delta d, \Delta\bar{d}, \Delta s \equiv \Delta$
- system of linear equations in LO
- **input:** MRST04 unpolarised PDFs,
  DSS parametrisation of FFs
  ($e^+e^-$, DIS, hadron-hadron)

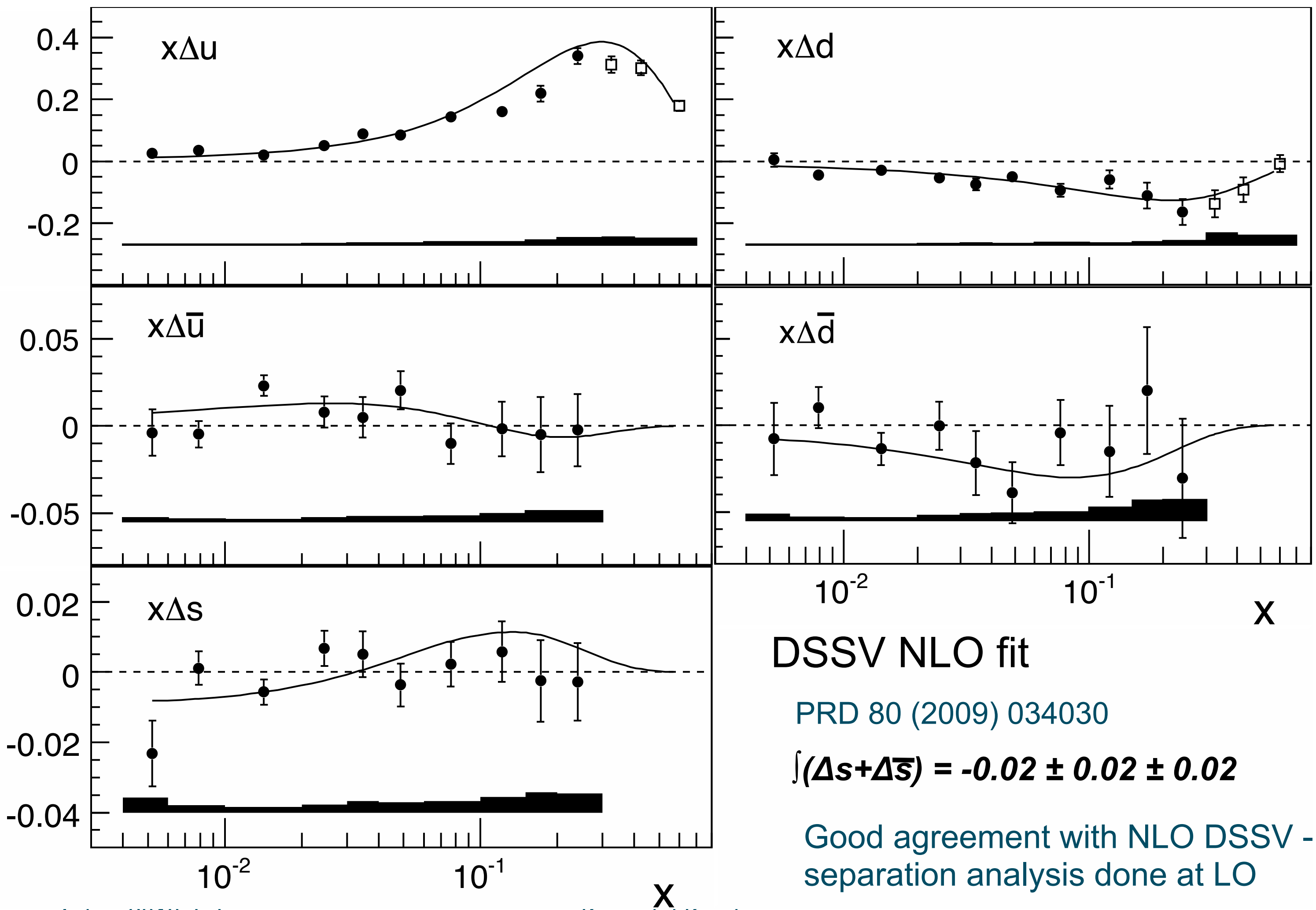



PLB 693 (2010) 227

PRL 101 (2008) 072001; PRD 80 (2009) 034030

# Flavour separation analysis
# Global QCD analysis: M. Stratmann)

## COMPASS data




DSSV NLO fit

PRD 80 (2009) 034030

$\int(\Delta s+\Delta\bar{s}) = -0.02 \pm 0.02 \pm 0.02$

Good agreement with NLO DSSV - qualitative, separation analysis done at LO

# Sea flavour helicity asymmetry $\Delta\bar{u} - \Delta\bar{d}$

## COMPASS data Phys.Lett.B 693 (2010) 227

$\Delta\bar{u} \geq \Delta\bar{d}$ ?

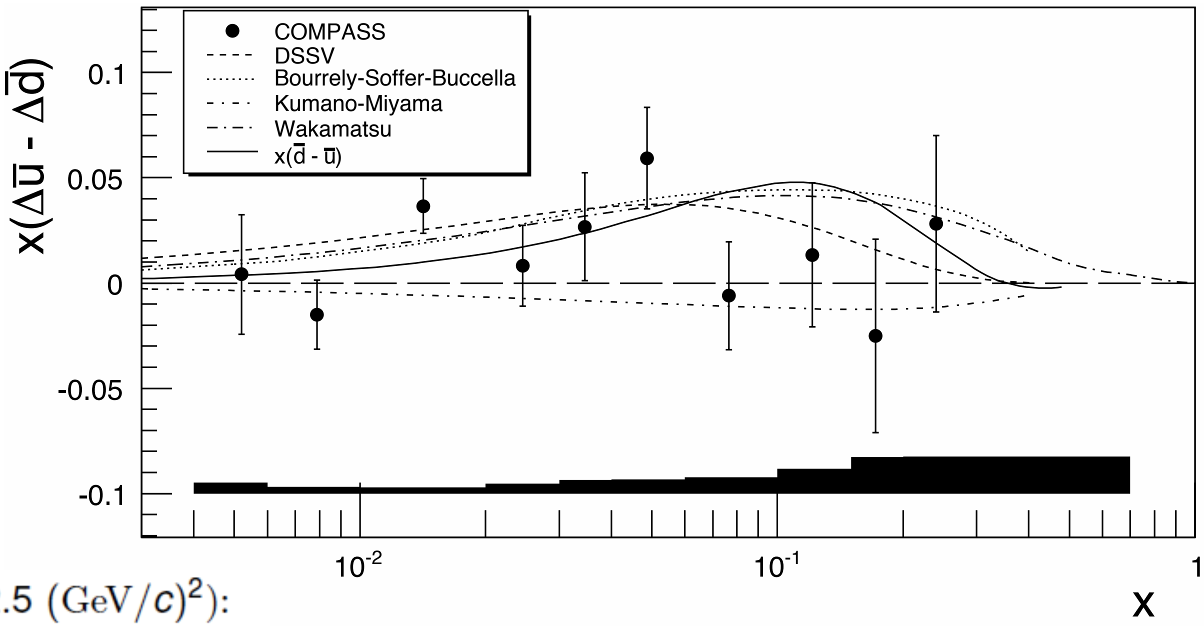
Phys. Rev. Lett. 18, (1967) 1174

Pauli exclusion principle, Δ resonance etc.

NMC,E866

unpolarized asymmetry:

$$\int_0^1 (\bar{d} - \bar{u})dx = 0.118 \pm 0.012$$




HERMES $(Q^2 = 2.5\ (\mathrm{GeV}/c)^2)$:

$$\int_{0.023}^{0.3} (\Delta\bar{u} - \Delta\bar{d})dx = 0.048 \pm 0.057(\mathrm{stat.}) \pm 0.028(\mathrm{syst.})$$

COMPASS $(Q^2 = 3\ (\mathrm{GeV}/c)^2)$:

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

The data disfavour models predicting $\Delta\bar{u} - \Delta\bar{d} \gg \bar{d} - \bar{u}$

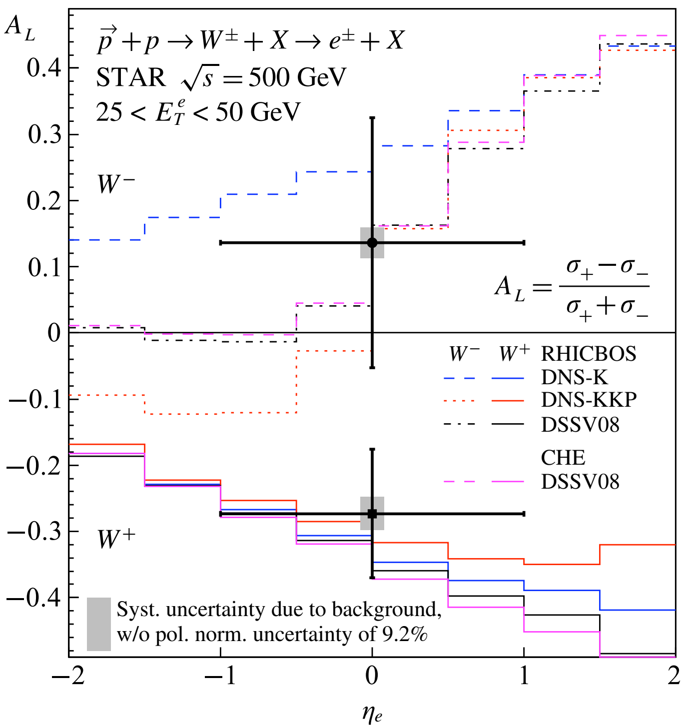
## Flavour separation analysis
## Global QCD analysis: M. Stratmann

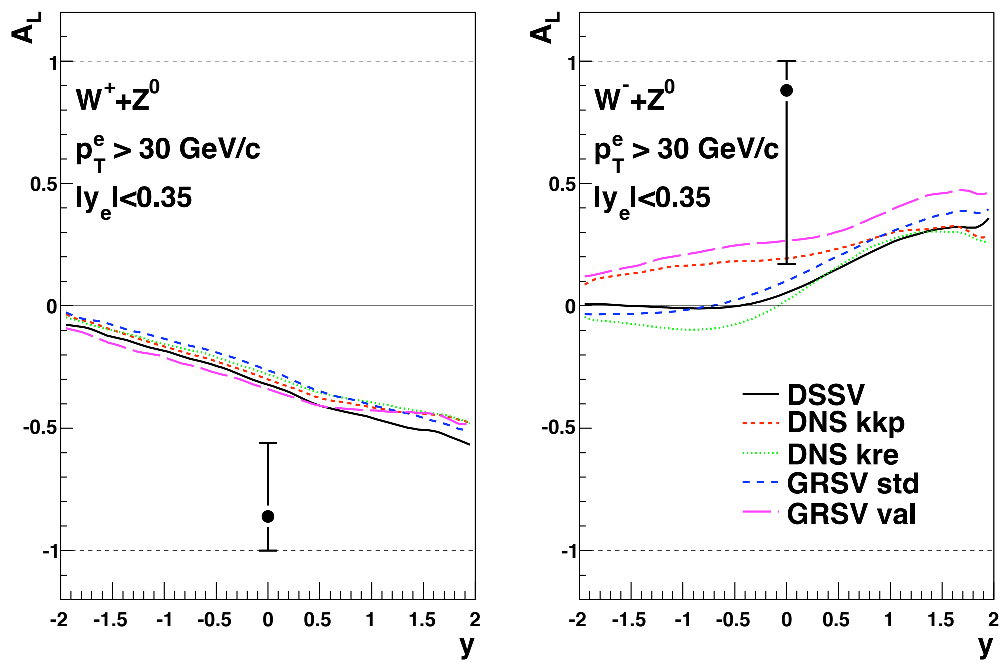
# RHIC W data

$$A_L^{W^+} = \frac{\Delta u(x_1)\overline{d}(x_2) - \Delta\overline{d}(x_1)u(x_2)}{u(x_1)\overline{d}(x_2) + \overline{d}(x_1)u(x_2)},$$

$$A_L^{W^+} \to \Delta u/u$$

$$A_L^{W^-} \to \Delta\overline{d}/\overline{d}$$



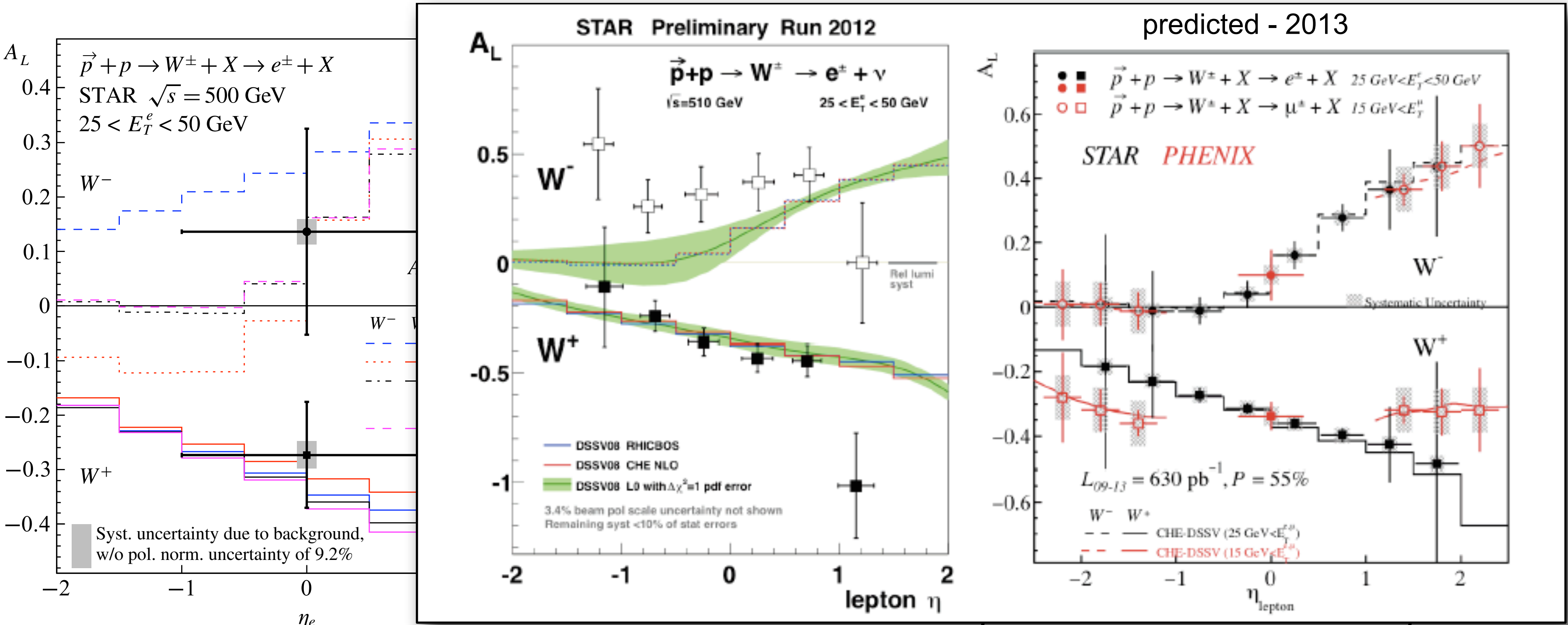



# RHIC W data

$$A_L^{W^+} = \frac{\Delta u(x_1)\bar{d}(x_2) - \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)},$$

$$A_L^{W^+} \to \Delta u/u$$

$$A_L^{W^-} \to \Delta\bar{d}/\bar{d}$$



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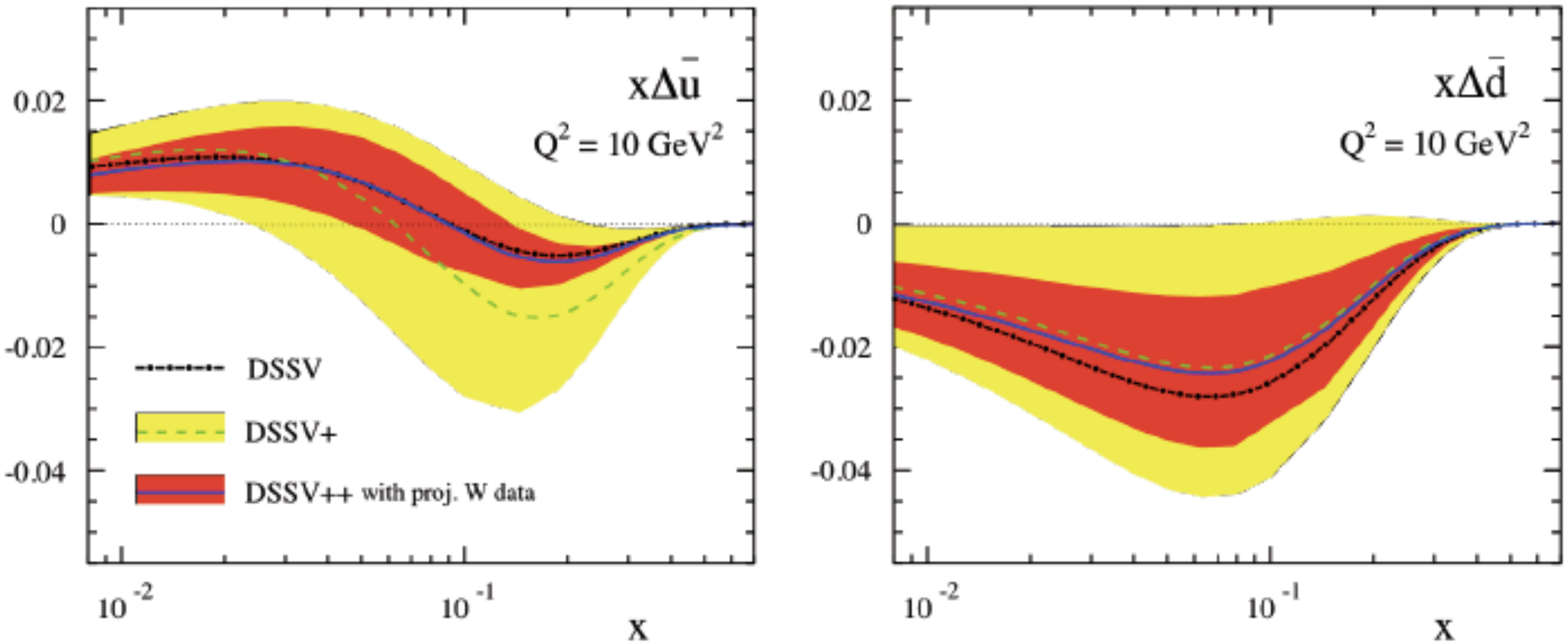
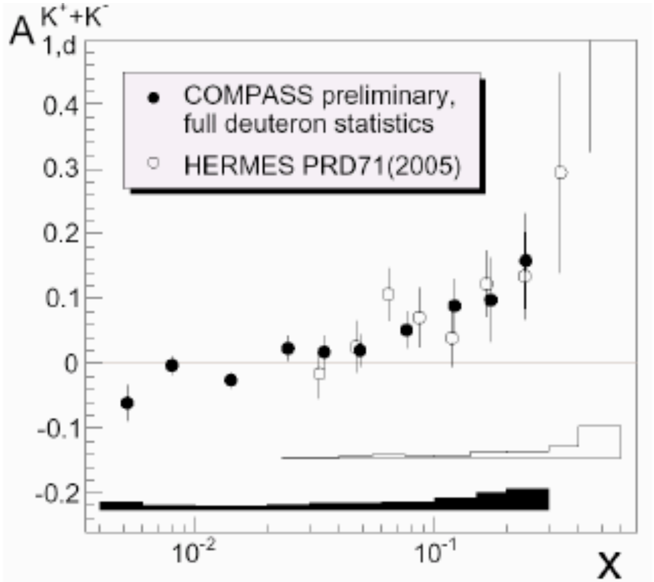
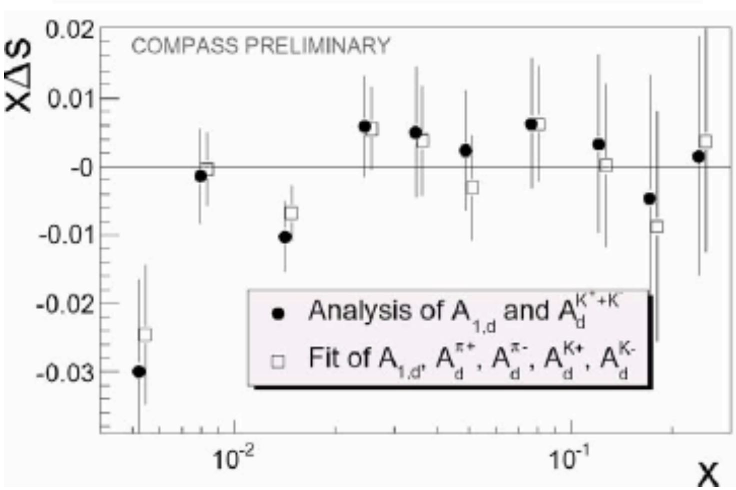


# Δs from charged Kaon's asymmetry

## COMPASS data




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

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

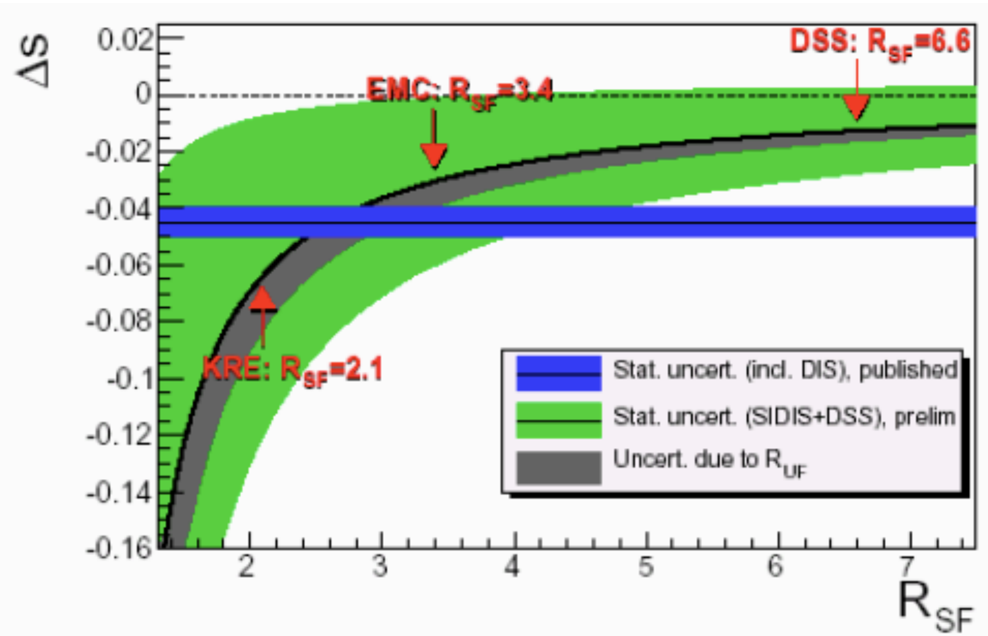
$$R_{UF} = \frac{\int D_d^{K^+}(z)dz}{\int D_u^{K^+}(z)dz} \qquad R_{SF} = \frac{\int D_{\bar{s}}^{K^+}(z)dz}{\int D_u^{K^+}(z)dz}$$

if $A_1^d = A^{K^+ + K^-} \Rightarrow \Delta s \geq 0$, insensitive to FFs

if $A^{K^+ + K^-} < 0$ (at low x) $\Rightarrow \Delta s < 0$

# $\Delta s$ from charged Kaon's asymmetry

## COMPASS data




Phys.Lett. B 680 (2009)217-114

$$R_{SF} = \frac{\int D_{\bar{s}}^{K^+}(z)dz}{\int D_{u}^{K^+}(z)dz}$$

$$R_{UF} = \frac{\int D_{d}^{K^+}(z)dz}{\int D_{u}^{K^+}(z)dz}$$

- $R_{UF}$ fixed at 0.14 from the DSS fragmentation functions
- Large statistical uncertainty due to $R_{SF}$, slight dependence on $R_{UF}$
- If $R_{SF}$>5 $\Delta s$(SIDIS)>$\Delta s$(DIS) and $\Delta s$ <0 for x<0.004
- If $R_{SF}$<4: $A^K$ becomes insensitive to $\Delta s$

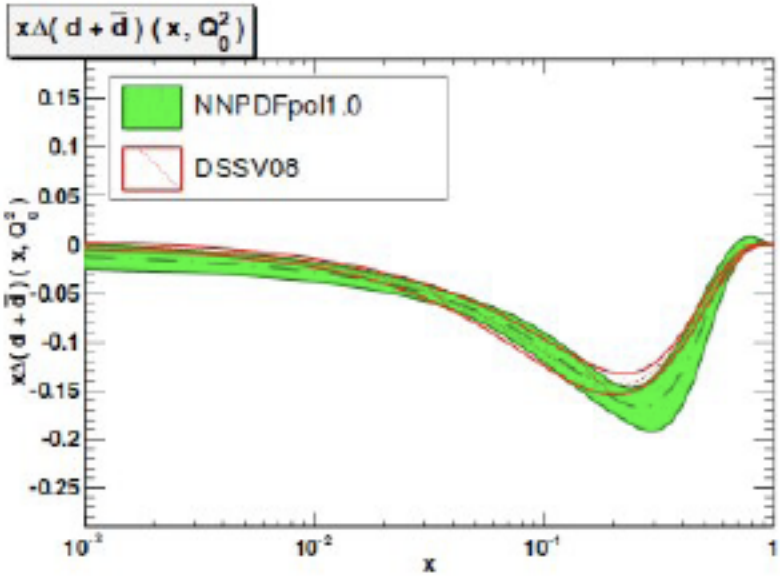
$\Delta s$ (inclusive) = –0.045 ± 0.005 ± 0.010

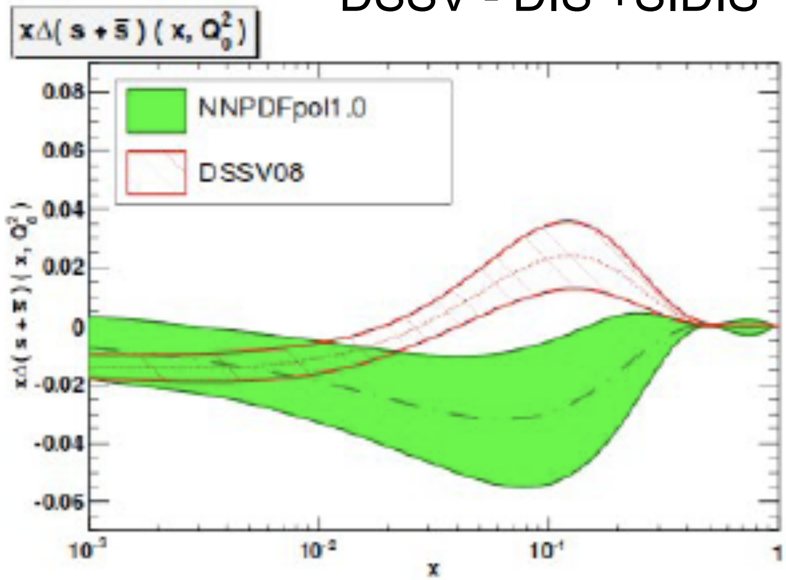
$\Delta s$ (SIDIS) = –0.01 ± 0.01 ± 0.01

in LO pQCD

# Δs puzzle

NNPDF - only DIS
DSSV - DIS +SIDIS



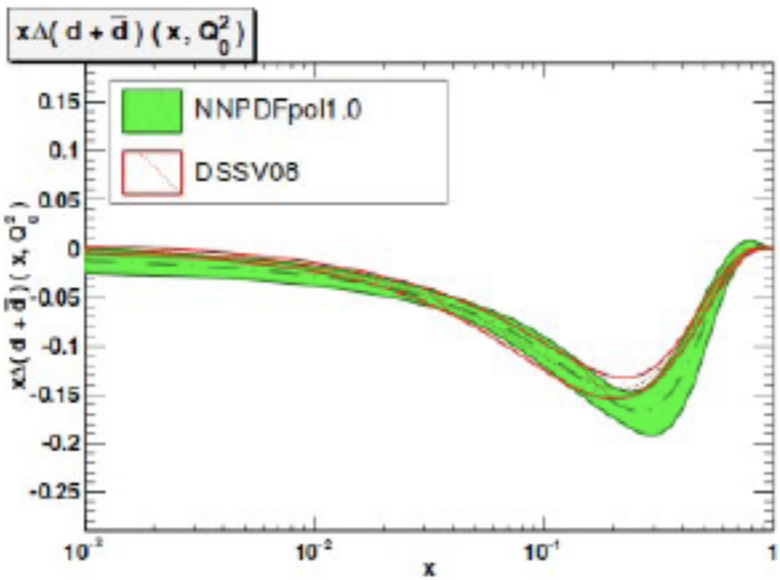




NNPDF, R.D.Ball et al. arXiv: 1303.7236

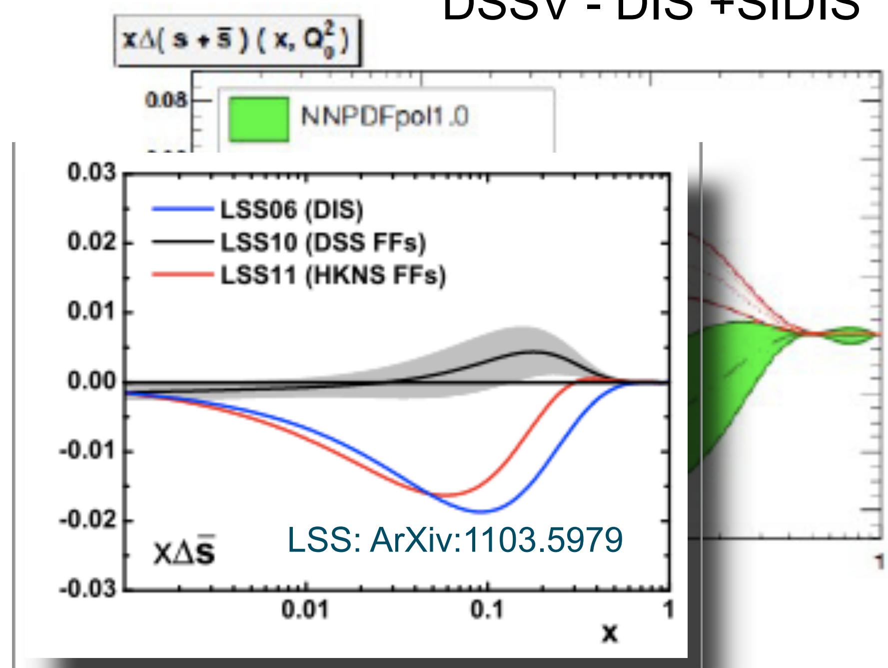
# $\Delta s$ puzzle

The lesson:
Important piece of information:
precise measurement of FFs

NNPDF - only DIS
DSSV - DIS +SIDIS

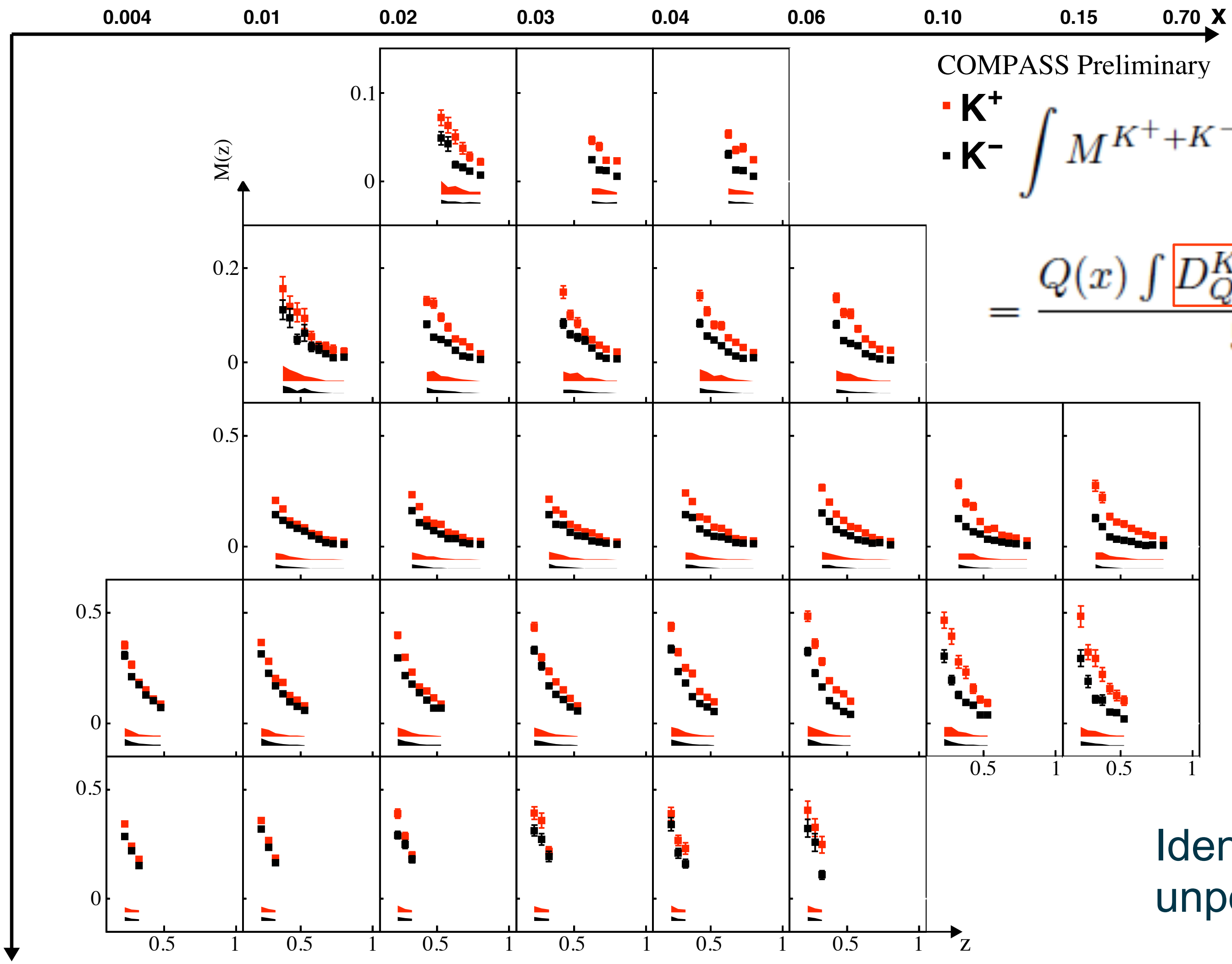



NNPDF, R.D.Ball et al. arXiv: 1303.7236



## Hadron multiplicities

### z dependence in x & y bins



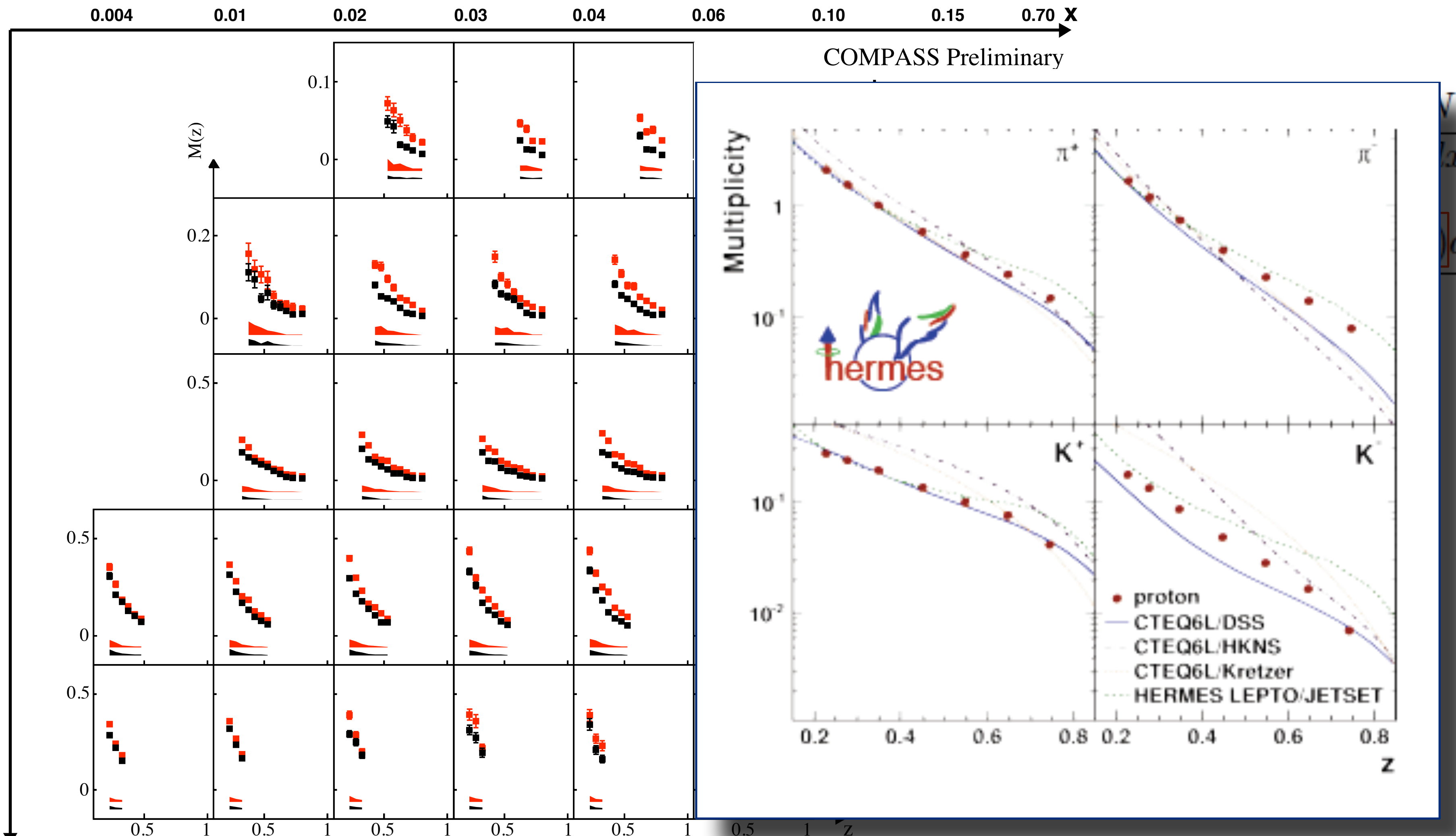

$$\int M^{K^+ + K^-}(z)dz = \frac{1}{dN^{DIS}/dx}\frac{dN^K}{dx} =$$

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

Identified K's and Pi's;
unpolarised - well known

# Hadron multiplicities

## z dependence in x & y bins

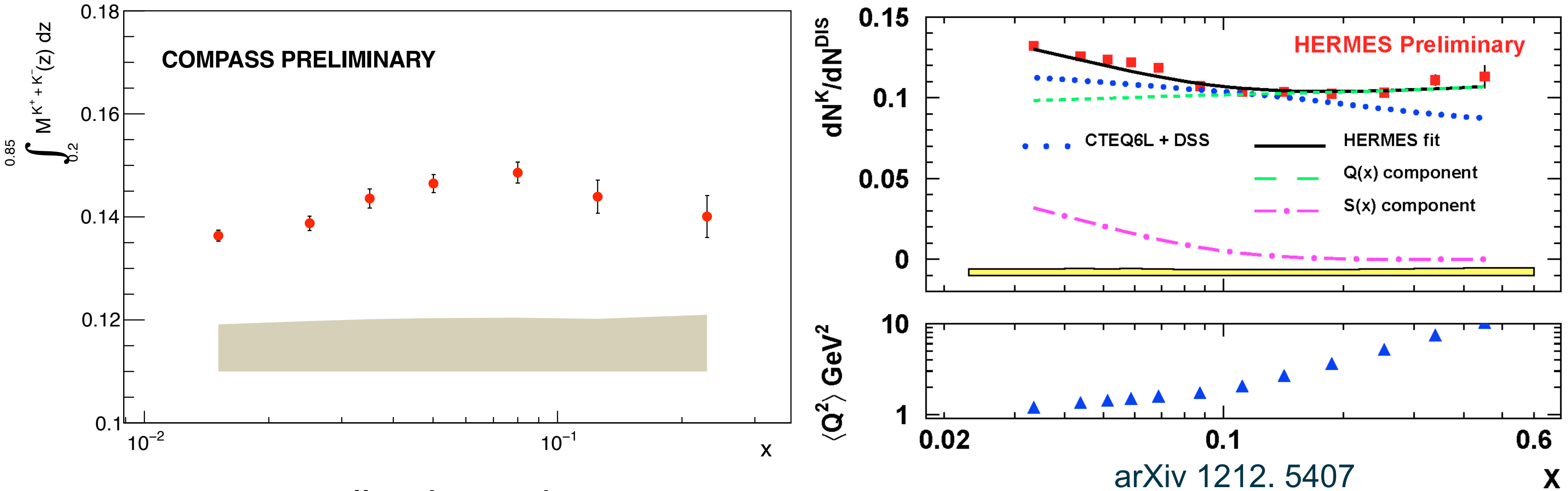


# Hadron multiplicities

**2S(x)<<5Q(x)**

$$\int_{0.2}^{0.85} M^{K^{+}+K^{-}}(x,z)dz = \frac{1}{5}\left(\int D_Q^K(z)dz + \frac{S(x)}{Q(x)}\int D_S^K(z)dz\right)$$

Directly related to strange PDF and FF of strange quark into K, should help in understanding strange see




small x dependence

arXiv 1212. 5407

## QCD evolution

- QCD fits - Idea:

$$g_1(x,Q^2)=\tfrac{1}{2}\langle e^2\rangle\left[C_q^s\otimes\Delta\Sigma+C_q^{NS}\otimes\Delta q^{NS}+2n_f C_G\otimes\Delta G\right]$$

DGLAP eqs

$$\frac{d}{dt}\Delta q^{NS}=\frac{\alpha_S(t)}{2\pi}P_{qq}^{NS}\otimes\Delta q^{NS}\qquad t=\log\left(\frac{Q^2}{\Lambda^2}\right)$$

$$\frac{d}{dt}\begin{pmatrix}\Delta\Sigma\\ \Delta G\end{pmatrix}=\frac{\alpha_S(t)}{2\pi}\begin{pmatrix}P_{qq}^S & 2n_f P_{qG}^S\\ P_{Gq}^S & P_{GG}^S\end{pmatrix}\otimes\begin{pmatrix}\Delta\Sigma\\ \Delta G\end{pmatrix}$$

Initial parameterization in x at fixed Q²

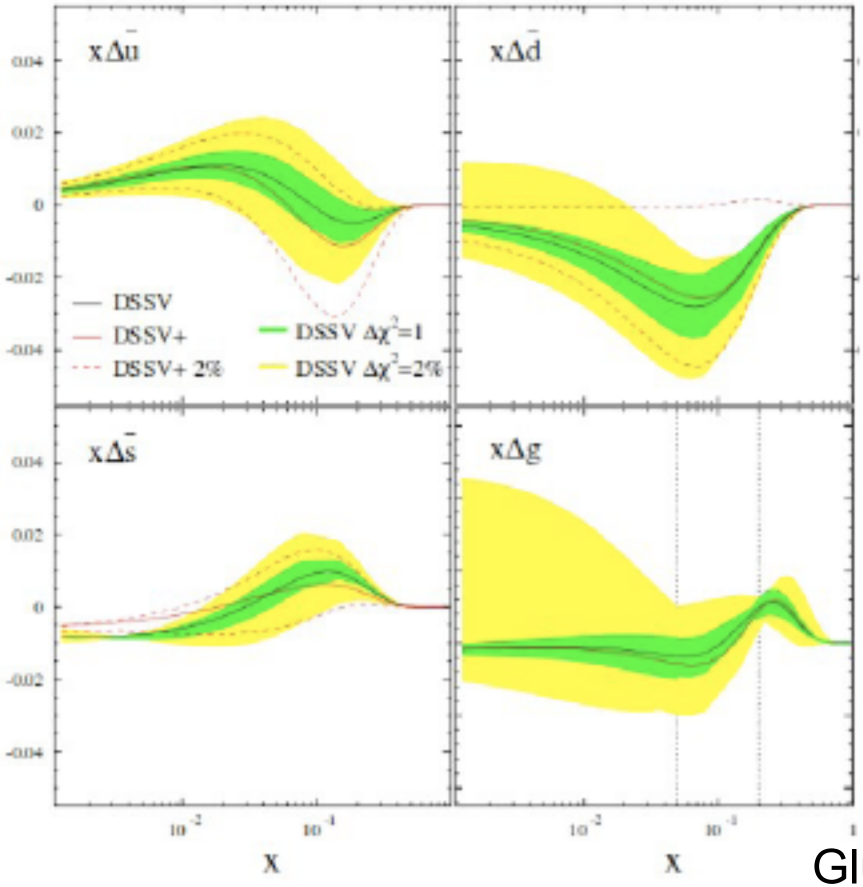
$$(\Delta\Sigma,\Delta q_s,\Delta q_8,\Delta G)=\eta\frac{x^\alpha(1-x)^\beta(1+\gamma x)}{\int_0^1 x^\alpha(1-x)^\beta(1+\gamma x)dx}$$

Minimalization procedure

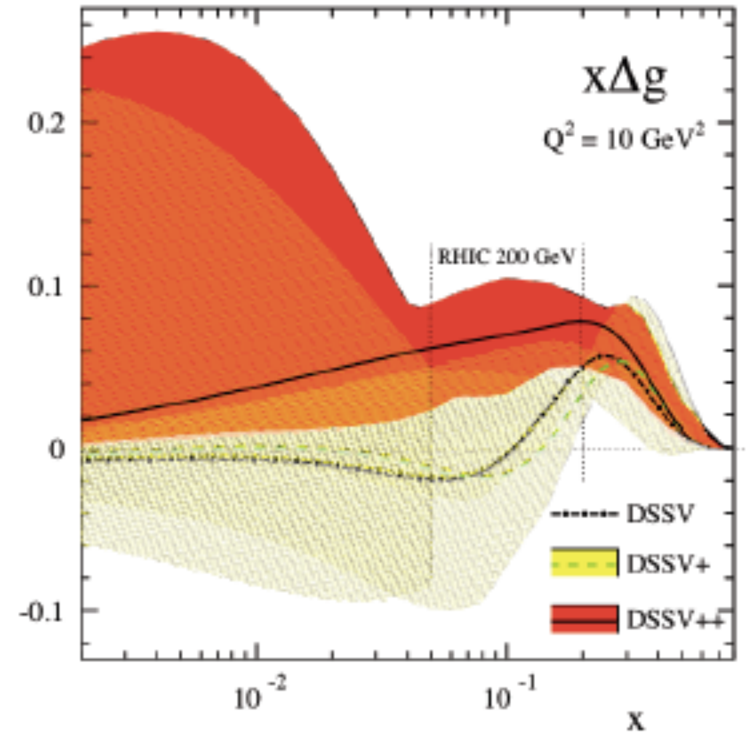
$$\chi^2=\sum_{i=1}^{N}\frac{\left[g_1^{calc}(x,Q^2)-g_1^{\exp}(x,Q^2)\right]^2}{\left[\sigma_{stat}^{\exp}(x,Q^2)\right]^2}$$

## QCD fits - DSSV

Global fits (DSSV/DSSV+/DSSV++) include: spin-dependent DIS data, SIDIS data with identified $\pi$ and K, and proton-proton data




arXiv: 1108.1713

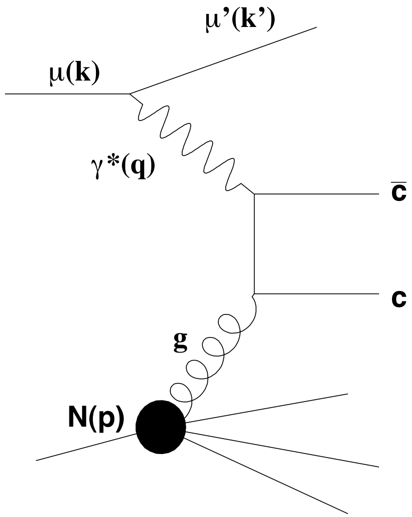



Latest PHENIX and STAR data included in DSSV++

Gluons are not constrained by inclusive DIS data

arXiv: 1304.0079

# Direct gluon polarisation detremination via tagging PGF events




To select PGF process two methods are used:

- Open-charm D meson production:
  charm quark pairs produced in PGF, "clean" channel however with huge combinatorial background, low statistics but analysis less MC dependent

- High transverse momentum hadron pairs production:
  light quark pairs produced, high statistics but physical background; strongly model and MC dependent analysis, requires a very good agreement between data and MC

$$\sigma^{PGF} = G \otimes \hat{\sigma}^{PGF} \otimes H$$

$$\Delta\sigma^{PGF} = \Delta G \otimes \Delta\hat{\sigma}^{PGF} \otimes H$$

from MC

$$A \approx \boxed{\frac{\Delta G}{G}(\bar{x}_G)} < \hat{a}_{LL}^{PGF} >_G$$

signal asymmetry from data

# High transverse momentum hadron pairs

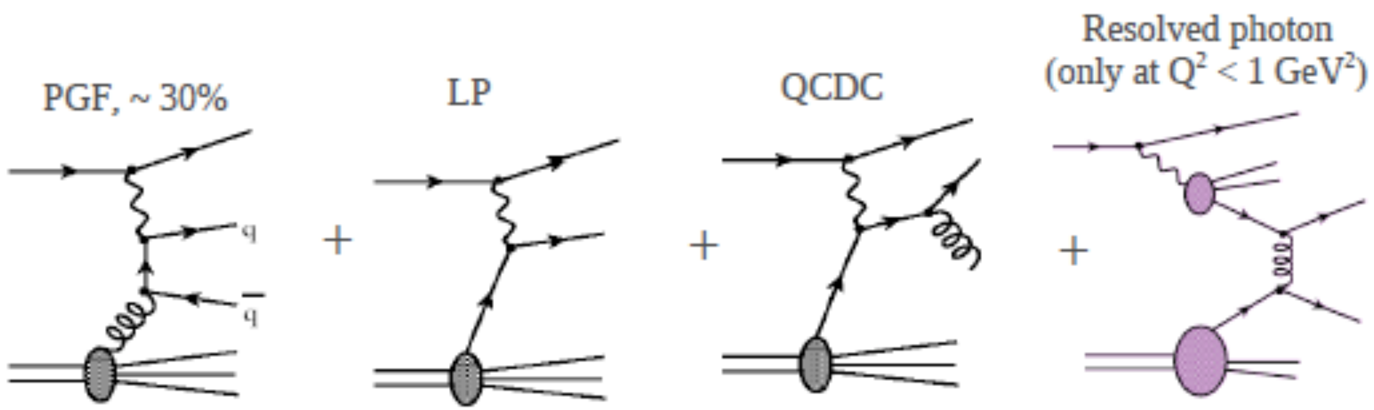
COMPASS@Low $Q^2$ - Phys. Lett. B 633 (2006) 25-32 COMPASS@high $Q^2$ - Phys. Lett. B 718 (2013) 922

R.D.Carlitz, J.C.Collins and A.H.Mueller, Phys.Lett.B 214, 229 (1988)
Revisited by A.Bravar,D.von Harrach and A.Kotzinian, Phys.Lett.B 421, 349 (1998)
Applied by SMC, HERMES and COMPASS

Two kinematical regions: low and large $Q^2$ :

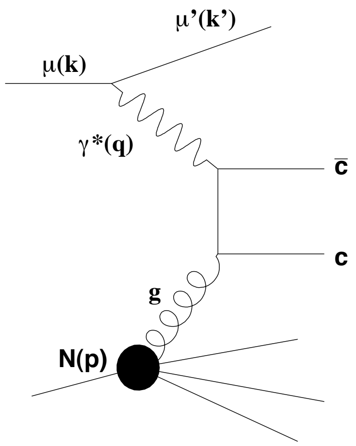
- low $Q^2$ - $Q^2<1$ (GeV/c)$^2$ - here $p_T$ is a perturbative scale, also resolved photon contribution important (~50%) - COMPASS 2002-2003 data published

- large $Q^2$ - $Q^2>1$ (GeV/c)$^2$ - scale $Q^2$ - 2002-2006 COMPASS data, method based on Neural Network approach used



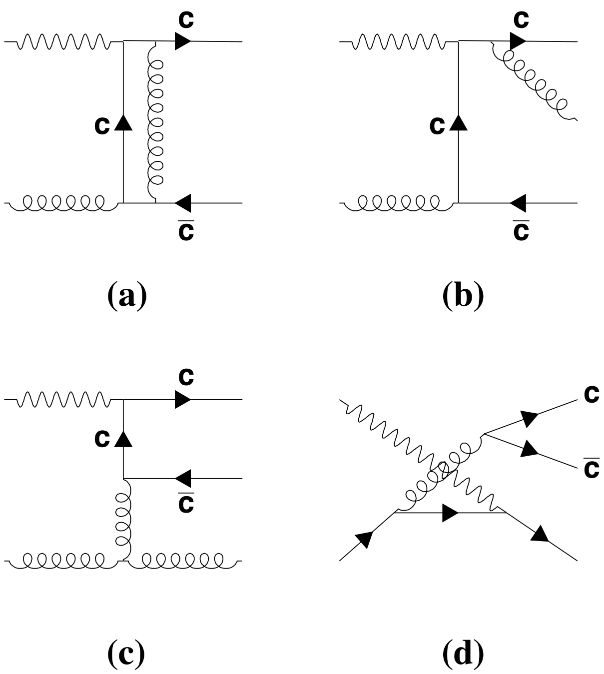
# gluon polarisation from charm meson production

COMPASS: Phys. Rev. D(2013) 052018




LO

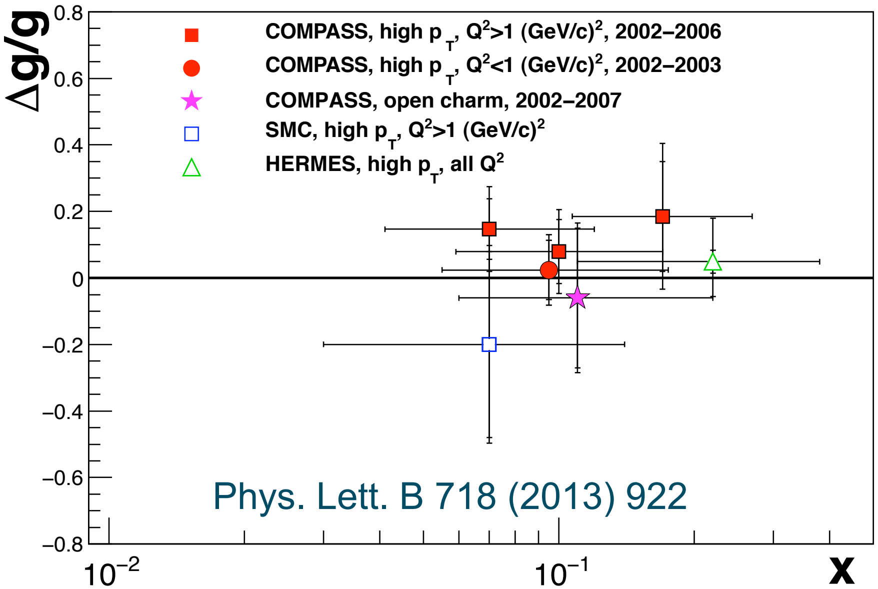
ex. of NLO

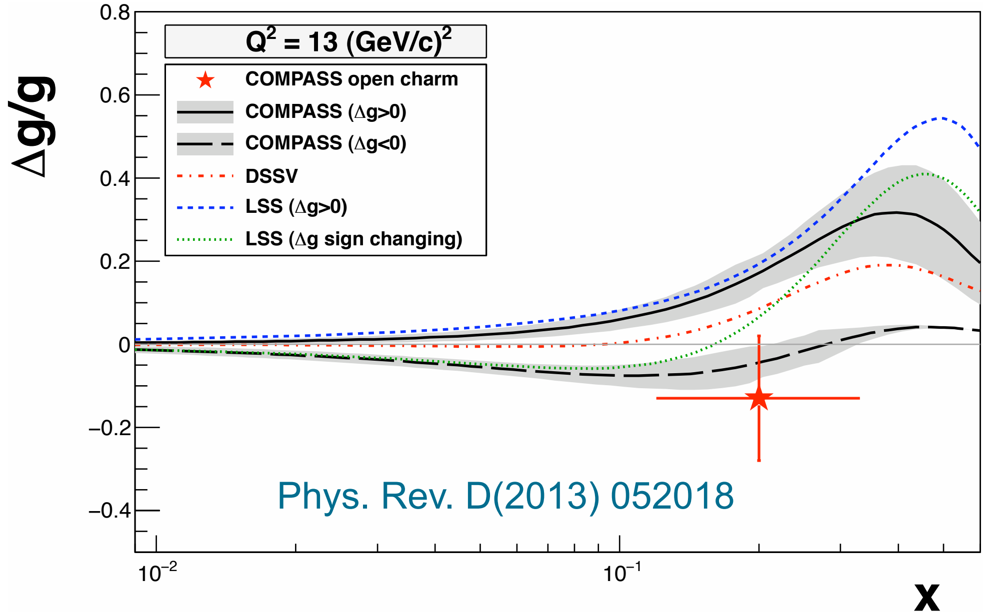



$$A^{\gamma N} = \frac{a_{LL}}{D}\frac{\Delta g}{g} + A_{corr}$$

Aroma MC generator used for simulating Phase Space (kinematics) (NLO - Parton Shower) calculations
NLO Calculations from I. Bojak and M. Stratmann: Phys. Lett. B 433 (1998) 411; Nucl. Phys. B 540 (1999) 345

# gluon polarisation from charm meson production



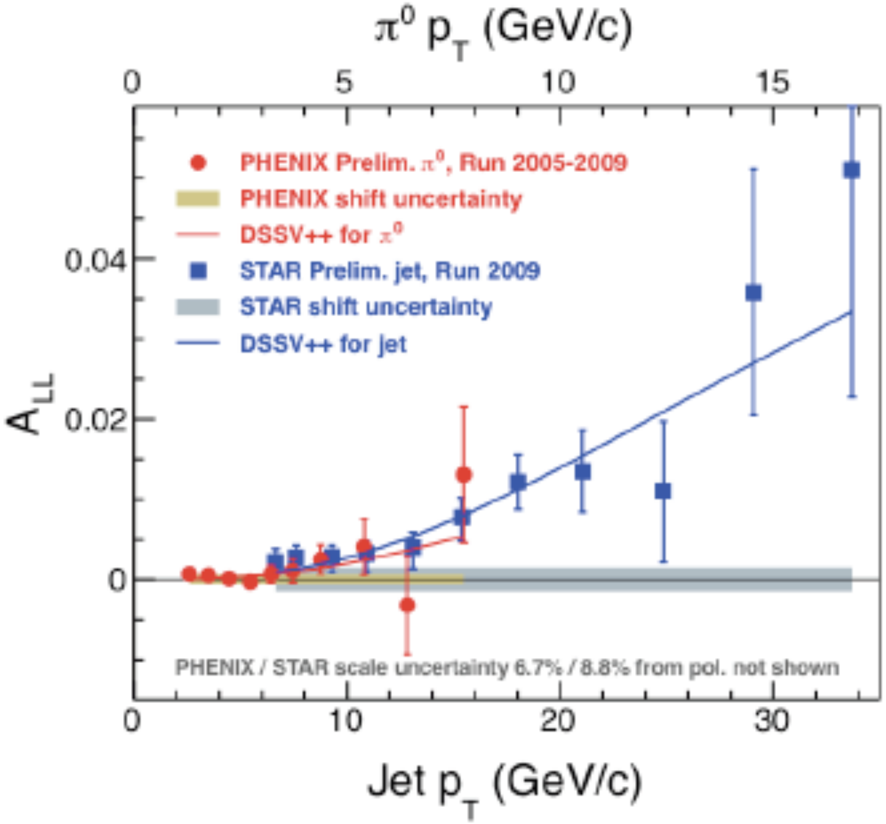



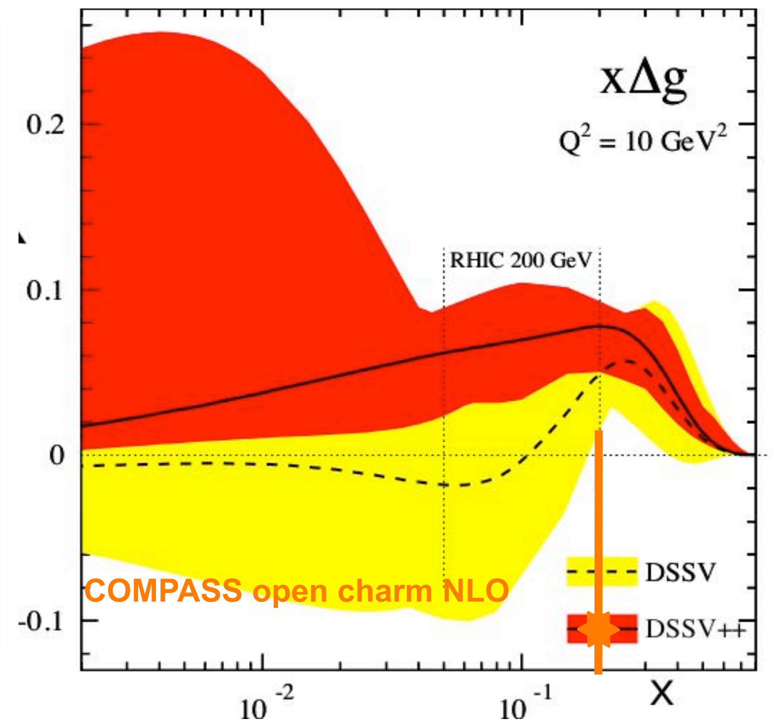

LO: all data consistent and point toward small gluon polarisation

NLO QCD result of COMPASS, at $\langle x \rangle \approx 0.20$, influences a $\Delta g(x) > 0$ fit, reducing $\Delta G = 0.39 \pm 0.07$ (stat.) to $0.24 \pm 0.09$ (stat.) at $Q^2 = 3$ $(\mathrm{GeV}/c)^2$.

$$\left\langle \frac{\Delta g}{g} \right\rangle^{\mathrm{NLO}} = -0.13 \pm 0.15\ (\mathrm{stat.}) \pm 0.15\ (\mathrm{syst.}).$$

# RHIC results.
# Gluon polarisation summary

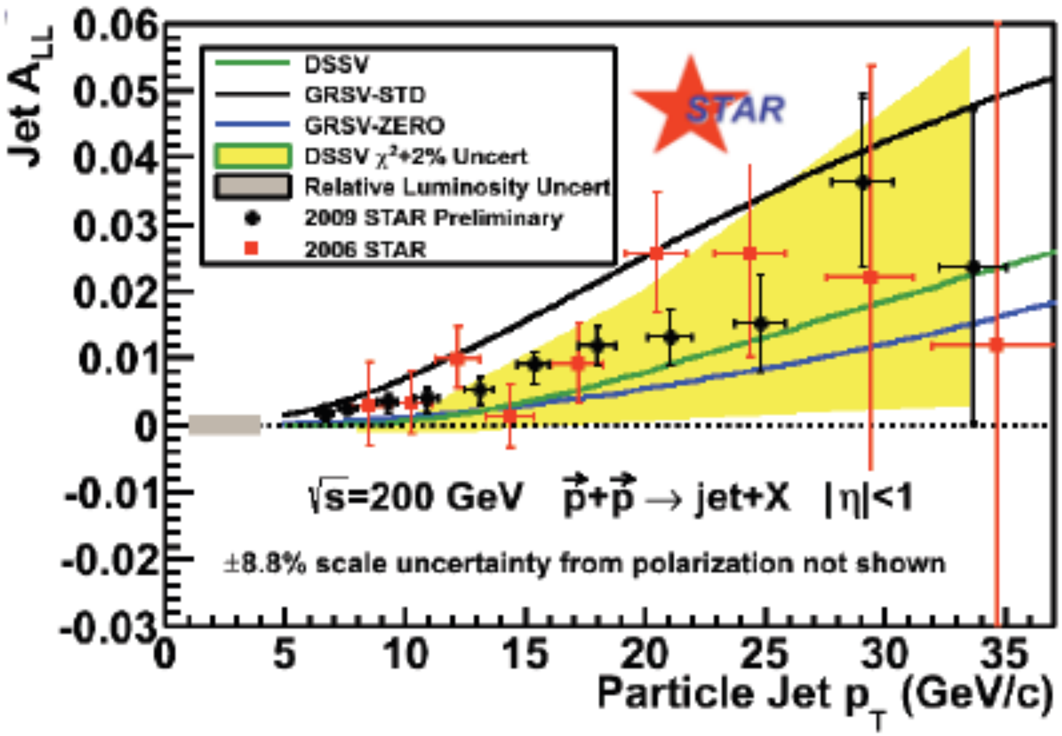


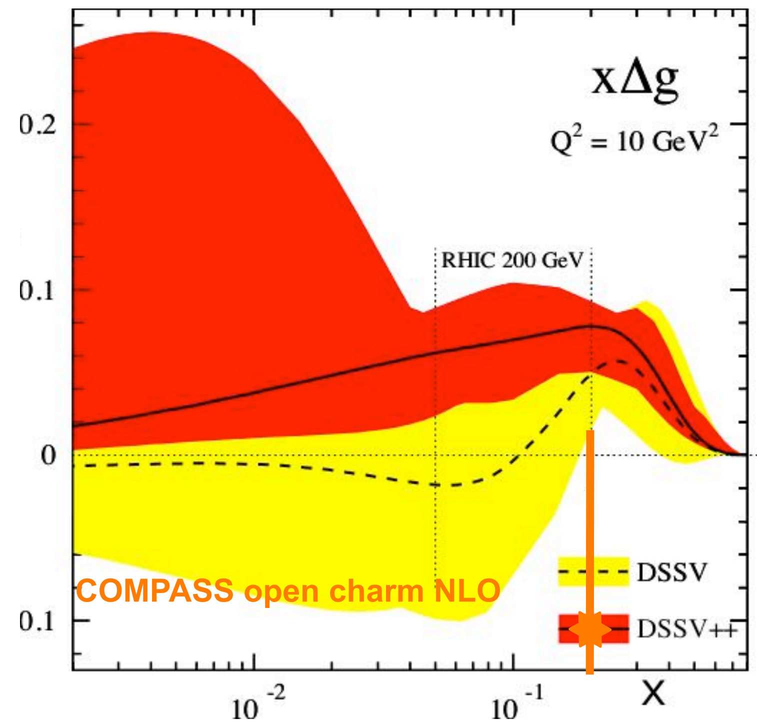




$$At\ Q^2 = 10\ GeV^2,\ DSSV: \int_{0.05}^{0.2} \Delta g(x)dx = 0.005^{+0.129}_{-0.164}\ ;\ \boxed{DSSV++: \int_{0.05}^{0.2} \Delta g(x)dx = 0.10^{+0.06}_{-0.07}}$$

$$But\ \ DSSV: \int_0^1 \Delta g(x)dx = 0.013^{+0.702}_{-0.314}\ ;\ DSSV++: \int_0^1 \Delta g(x)dx = ?$$

# RHIC results.
# Gluon polarisation summary



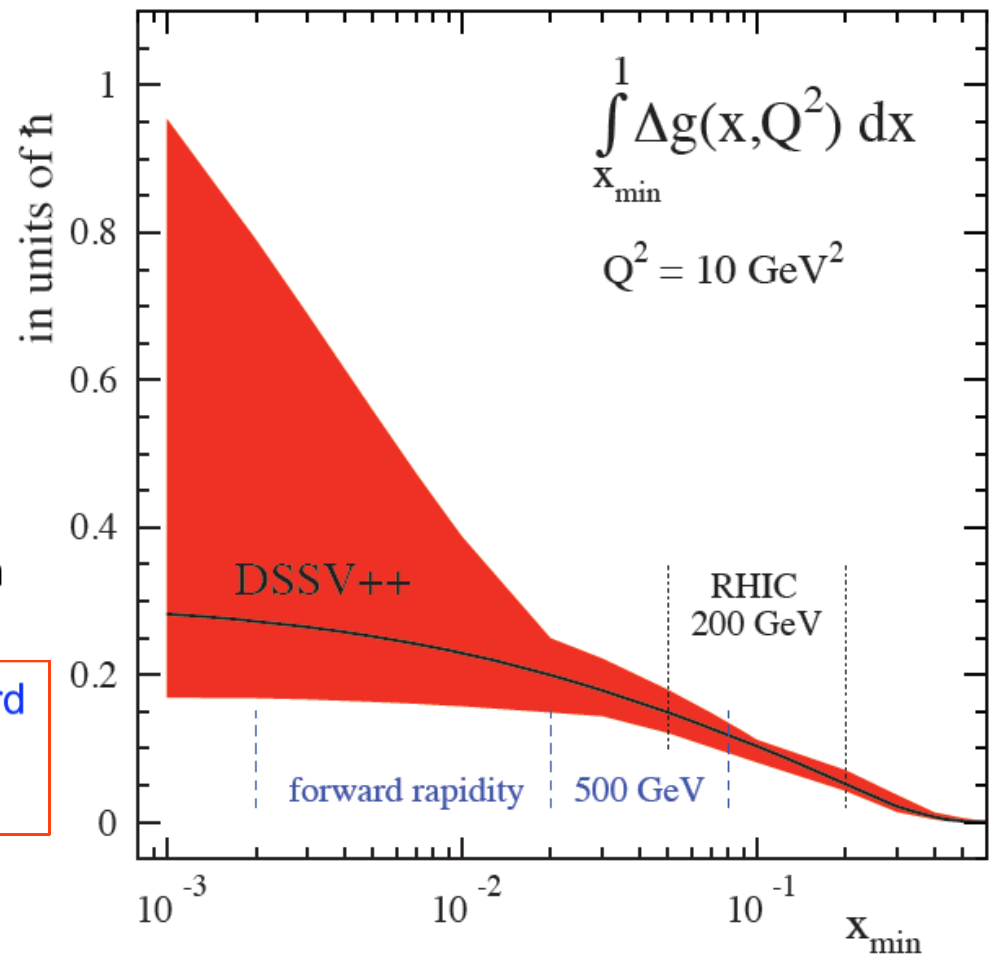




$$At\ Q^2 = 10\ \ GeV^2,\ DSSV: \int_{0.05}^{0.2} \Delta g(x)dx = 0.005^{+0.129}_{-0.164}\ ;\ \boxed{DSSV++: \int_{0.05}^{0.2} \Delta g(x)dx = 0.10^{+0.06}_{-0.07}}$$

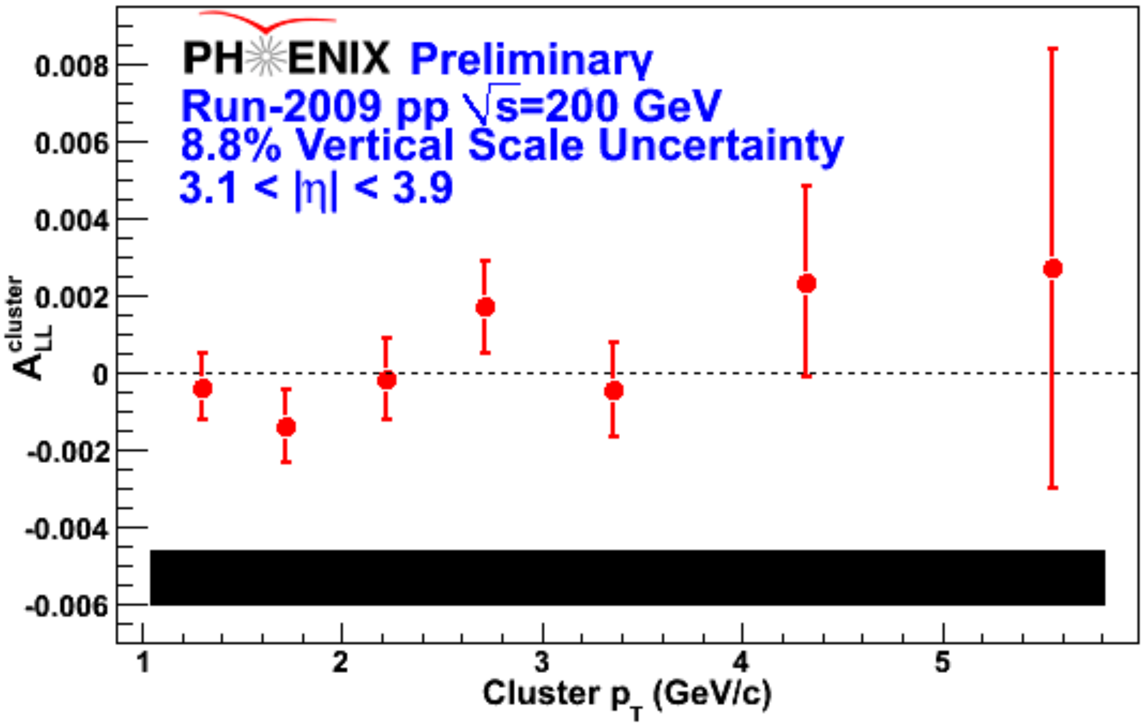
$$But\ \ DSSV: \int_0^1 \Delta g(x)dx = 0.013^{+0.702}_{-0.314}\ ;\ DSSV++:\ \int_0^1 \Delta g(x)dx = ?$$

# RHIC results.Current uncertainty on gluon polarisation at RHIC

- **Large uncertainty still remains in both the shape of Δg(x) and its integral, particularly for small x region not yet accessed by current RHIC data**
- **RHIC will continue to improve constraints through the following:**
  - Reduced statistical and systematic uncertainties for all $A_{LL}$ channels
  - Better handle on measured x through correlation measurements
  - Access lower x region through forward measurements and $\sqrt{s} = 500\ GeV$



# First forward measurement of $A_{LL}$




- High $p_T$ EM Cluster Asymmetry, forward pseudo-rapidity $3.1<|\eta|<3.9$
  - >80% Merged $\pi^0$

- 510 GeV Datasets: Run09, Run11, Run12, Run13
  - Run12 and Run13 use new MPC electronics with ~4x higher purity

# Summary

- New precise data have been presented - new input to global QCD analysis
- New multiplicities for K and Pi can constrain FFs, especially $D_s^K$.It can explain the difference between DIS and SIDIS strange quark sea polarisation
- New RHIC W boson data can significantly improves precision on $\Delta\bar{u}$ and $\Delta\bar{d}$ (DSSV++ prediction)
- New RHIC data increase the value of the gluon polarisation in global QCD analysis (DSSV++). Still open question what the value of integral is - large uncertainties for small x region. New measurements for small x needed to constrains $\Delta G$
- After more than 30 years - still the spin structure of the nucleon is understood only qualitatively. What we learnt is that even fast moving nucleon is a 3-dimensional complicated object with probably non-negligible orbital momentum contribution to it's spin.

# Thank you