Status of polarized pdf's and the role of the gluon

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Electromagnetic Interactions with Nucleons and Nuclei

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Outline

- Introduction: spin sum rule
- DSSV analysis
- The polarized Gluon
- Summary

Ουτλινε

- Ιντροδυχτιον : σπιν συμ ρυλε
- ΔΣΣς αναλψσισ
- Τηε πολαριζεδ Γλυον
- Συμμαρψ

(Longitudinal) Spin structure of the proton

Spin share between components

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

Jaffe-Manohar

Quark Spin — Gluon Spin — OAM

Naive expectation SU(6) : 70% corresponds to Quark Spin

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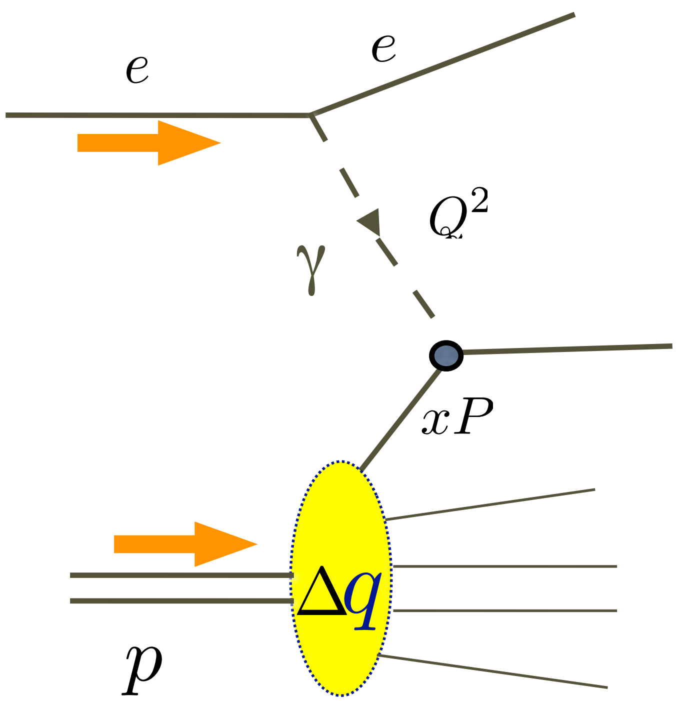
Measure at polarized DIS : structure function



$$g_1(x,Q^2) = \frac{1}{2}\sum_q e_q^2 \left[\Delta q(x,Q^2) + \Delta\bar{q}(x,Q^2)\right]$$

Polarized PDFs $\Delta f_i(x,Q^2) \equiv f_i^{\uparrow}(x,Q^2) - f_i^{\downarrow}(x,Q^2)$

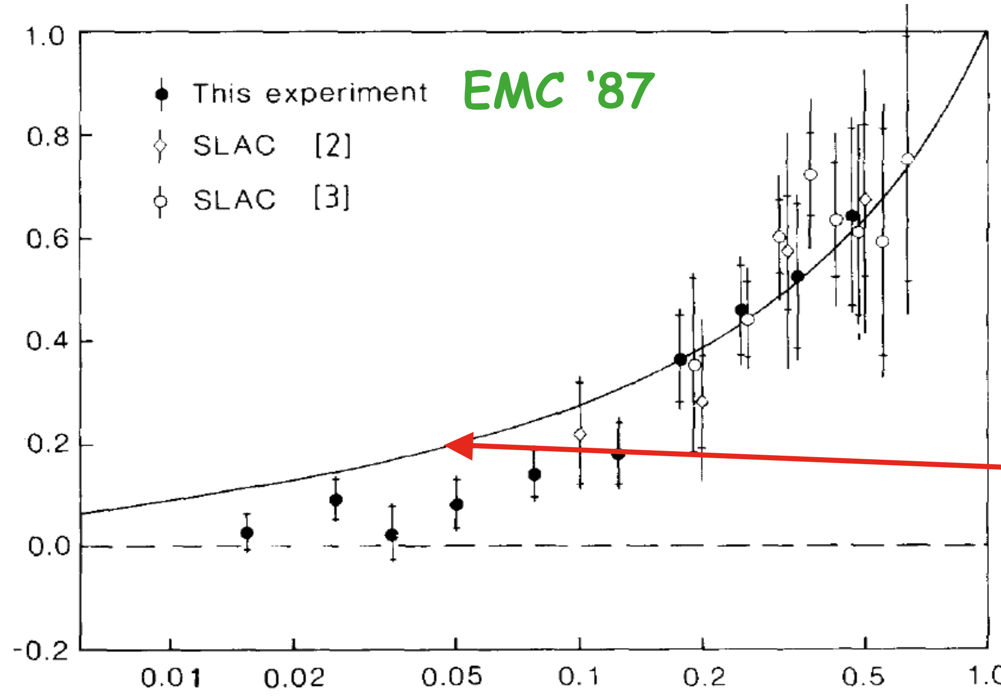
$$\frac{d}{d\ln Q^2}\begin{pmatrix}\Delta q\\ \Delta g\end{pmatrix}(x,Q^2) = \int_x^1 \frac{dz}{z}\begin{pmatrix}\Delta P_{qq}(\alpha_s(Q^2),z) & \Delta P_{qg}(\alpha_s(Q^2),z)\\ \Delta P_{gq}(\alpha_s(Q^2),z) & \Delta P_{gg}(\alpha_s(Q^2),z)\end{pmatrix}\begin{pmatrix}\Delta q\\ \Delta g\end{pmatrix}\left(\frac{x}{z},Q^2\right)$$

Quark and Gluon spin contributions

$$\Delta\Sigma = \sum_i \int_0^1 \Delta q_i(x,Q^2)\,dx \qquad \Delta G = \int_0^1 \Delta g(x,Q^2)\,dx$$

1987 : EMC

$$A_1(x) = \frac{g_1(x)}{F_1(x)}$$



naive expectation

$\Delta\Sigma \sim 0.0 \pm 0.24 \quad (Q^2 = 10\,\mathrm{GeV}^2)$ ‘spin ~~crisis~~ puzzle’

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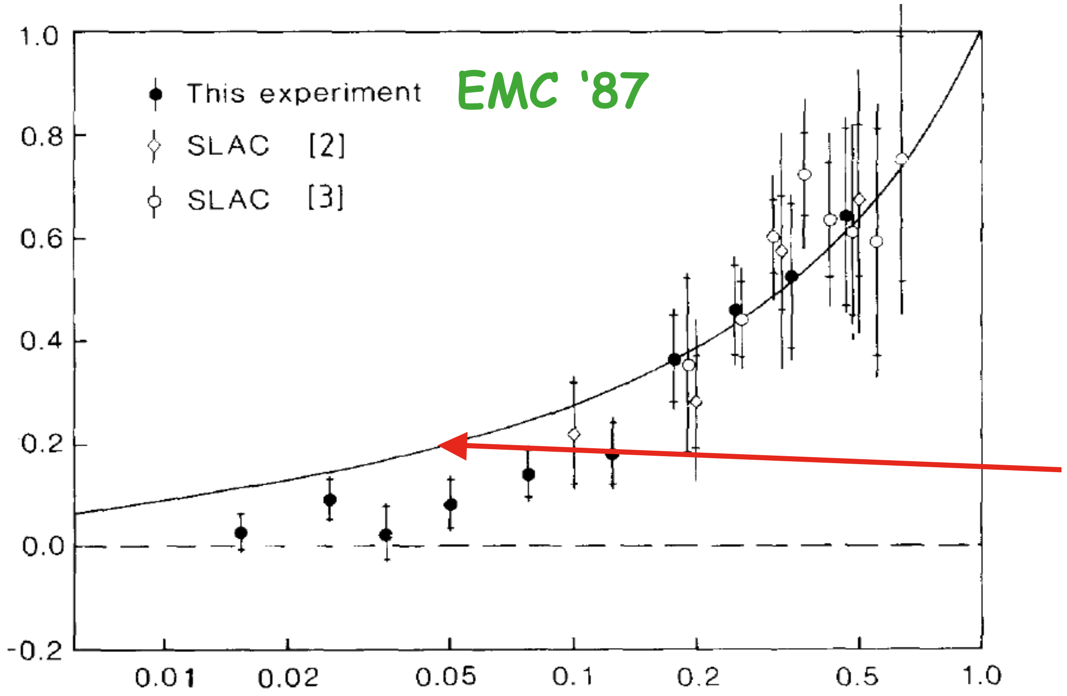

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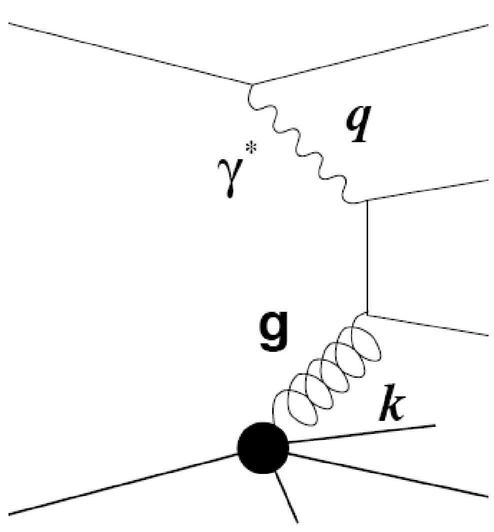
Any way to recover naive expectation?



Gluon contribution through Anomaly

Altarelli, Ross
Efremov, Teryaev

'gluon contamination'

$$\Delta\Sigma^{exp} = \Delta\Sigma - 3\frac{\alpha_s}{2\pi}\Delta G$$

~0 ~0.7 $\Delta G > 5$!! unnaturally large

Increased the interest on measuring the gluon contribution (full set of pdfs)

Polarized PDFs

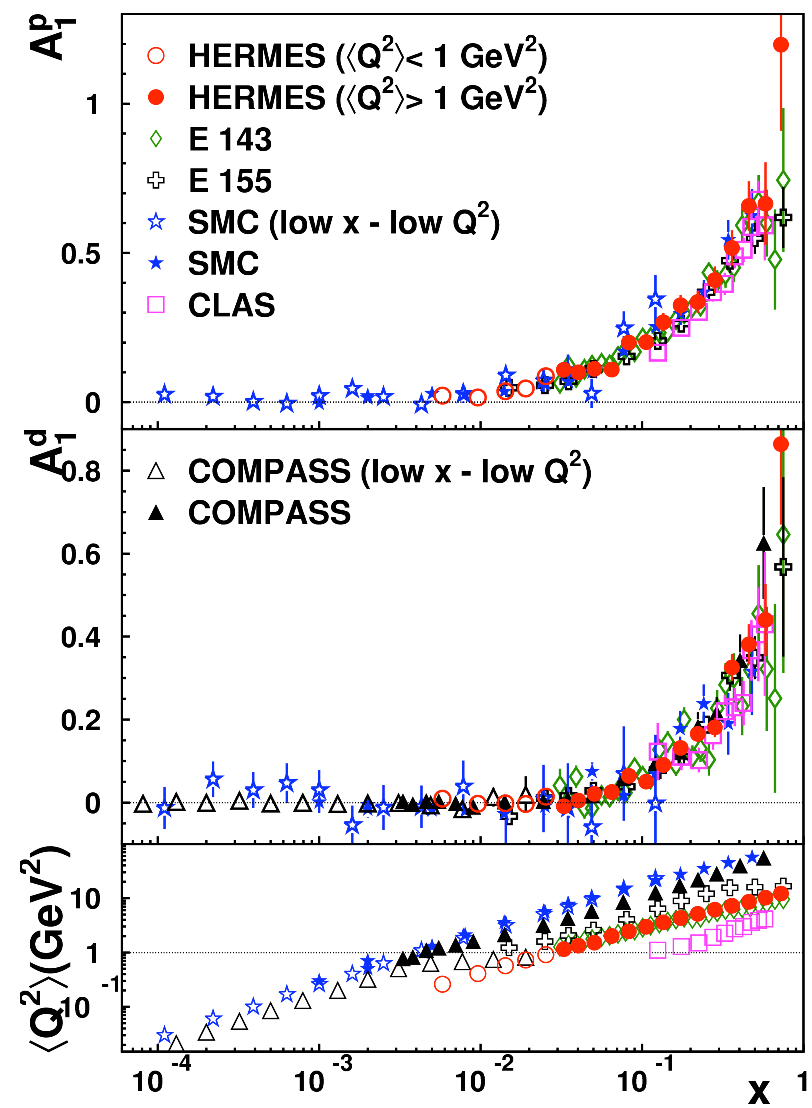
Several attempts to obtain polarized PDFs during the last decade

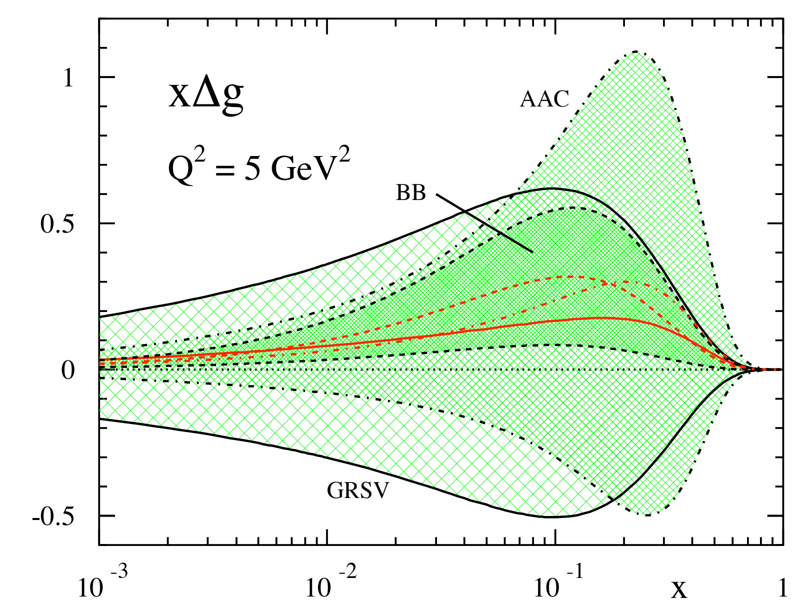
A few of them:

- E.Leader, A.V.Sidorov and D.B.Stamenov, LSS
- M. Glück, E. Reya, M. Stratmann and W. Vogelsang, GRSV
- T. Gehrmann and W.J. Stirling, GS
- J. Bluemlein and H. Boettcher, BB
- Asymmetry Analysis Collaboration, AAC
- DdF and R. Sassot, DS
- DdF, G.A. Navarro and R. Sassot, DNS
- C. Bourrely, F. Buccella and J. Soffer, BBS
- G. Altarelli, R. Ball, S. Forte, G.Ridolfi, ABFS
- SMC
- HERMES
- + several others

DIS fixed target

$$\Delta G(Q^2 = 10) \sim 1 - 2$$





Aidala et al

All fits include DIS data : agree on 'quark'
Differ on assumptions about the sea
Huge differences on gluon distribution

First GLOBAL analysis at NLO accuracy

DdF, R.Sassot, M.Stratmann, W.Vogelsang (DSSV)

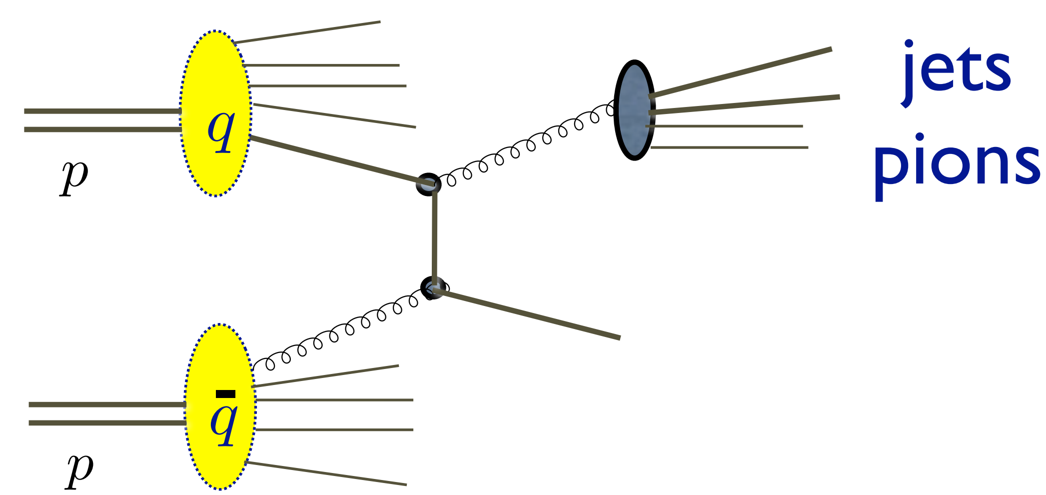
experiment	data type	data points fitted
EMC, SMC	DIS	34
COMPASS	DIS	15
E142, E143, E154, E155	DIS	123
HERMES	DIS	39
HALL-A	DIS	3
CLAS	DIS	20
SMC	SIDIS, $h^{\pm}$	48
HERMES	SIDIS, $h^{\pm}$	54
	SIDIS, $\pi^{\pm}$	36
	SIDIS, $K^{\pm}$	27
COMPASS	SIDIS, $h^{\pm}$	24
PHENIX (in part prel.)	200 GeV pp, π^0	20
PHENIX (prel.)	62 GeV pp, π^0	5
STAR (in part prel.)	200 GeV pp, jet	19
TOTAL:		467

$\Delta q + \Delta \bar{q}$

$\Delta q, \ \Delta \bar{q}$

Δg

PP @ RHIC



jet @ STAR $p_T \geq 5\,\mathrm{GeV}$

pions @ Phenix $p_T^{\pi} \geq 1\,\mathrm{GeV}$

DIS/SIDIS $Q \geq 1\,\mathrm{GeV}$

Gluons at LO !

x~ $0.05 - 0.2$

Data Selection

Important lesson from unpolarized physics : use "safe" observables

Parton Model Factorization

pdfs

$$d\Delta\sigma = \sum_{ab} \int dx_a \int dx_b \, \Delta f_a(x_a, Q^2) \Delta f_b(x_b, Q^2) \times d\Delta\hat{\sigma}_{ab}(x_a, x_b, p_T, \alpha_s(Q^2), p_T/Q)$$

partonic cross-section

Only Rule (not bias): Check that works on the unpolarized case!

Solid basis for the analysis

First develop new set of fragmentation functions to validate semi-inclusive processes

DSS fragmentation (DdeF, Sassot, Stratmann)

from e+e-, ep and pp collisions

SIDIS ✓ $pp \to \pi$ ✓

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SIDIS ✓ $pp \longrightarrow \pi$ ✓

Do not include: "high pT" hadrons from Compass and Hermes

No NLO description available (soon!)

Not clear pQCD works well : check unpolarized?

Global Fit

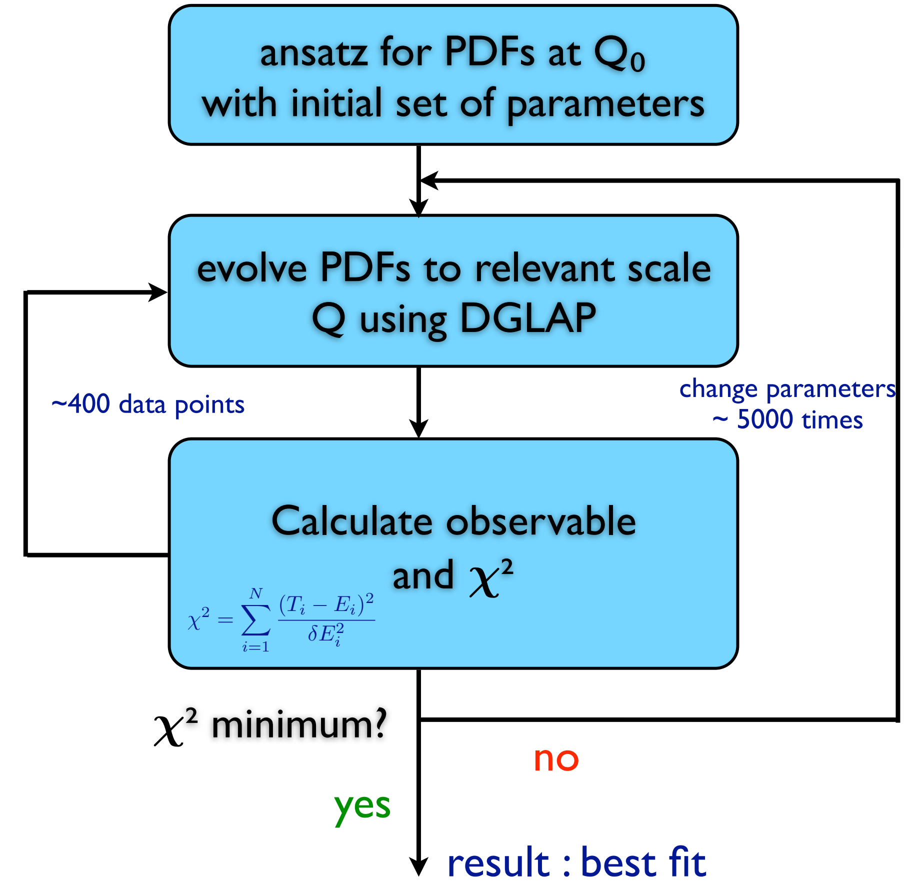
$$x\Delta f_j(x,Q_0^2) = N_j x^{\alpha_j}(1-x)^{\beta_j}(1+\gamma_j\sqrt{x}+\eta_j x)$$

0 for sea/gluon — node allowed

Some constraints from unpol./sym.

21 free parameters

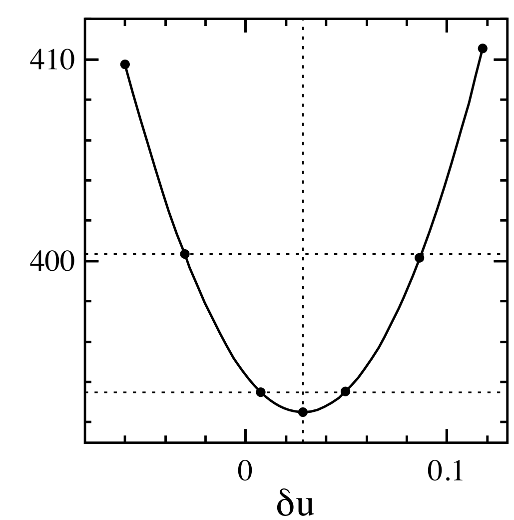
PDFs obtained by global fit : χ^2 minimization



- Use Lagrange Multipliers technique to estimate uncertainties (from exp. errors) on some observables

$$\Phi(\lambda_i,\{a_j\}) = \chi^2(\{a_j\}) + \sum_i \lambda_i \mathcal{O}_i(\{a_j\})$$

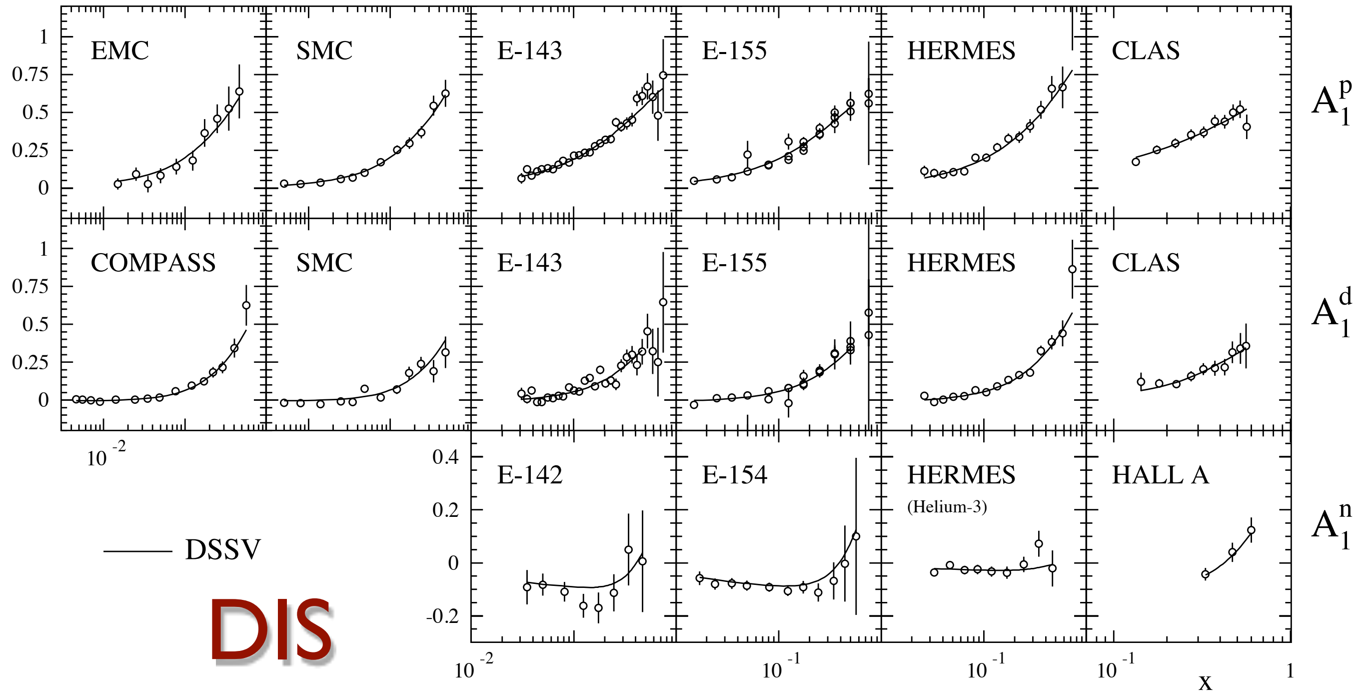
See how fit deteriorates when PDFs forced to give different prediction for $\mathcal{O}_i$

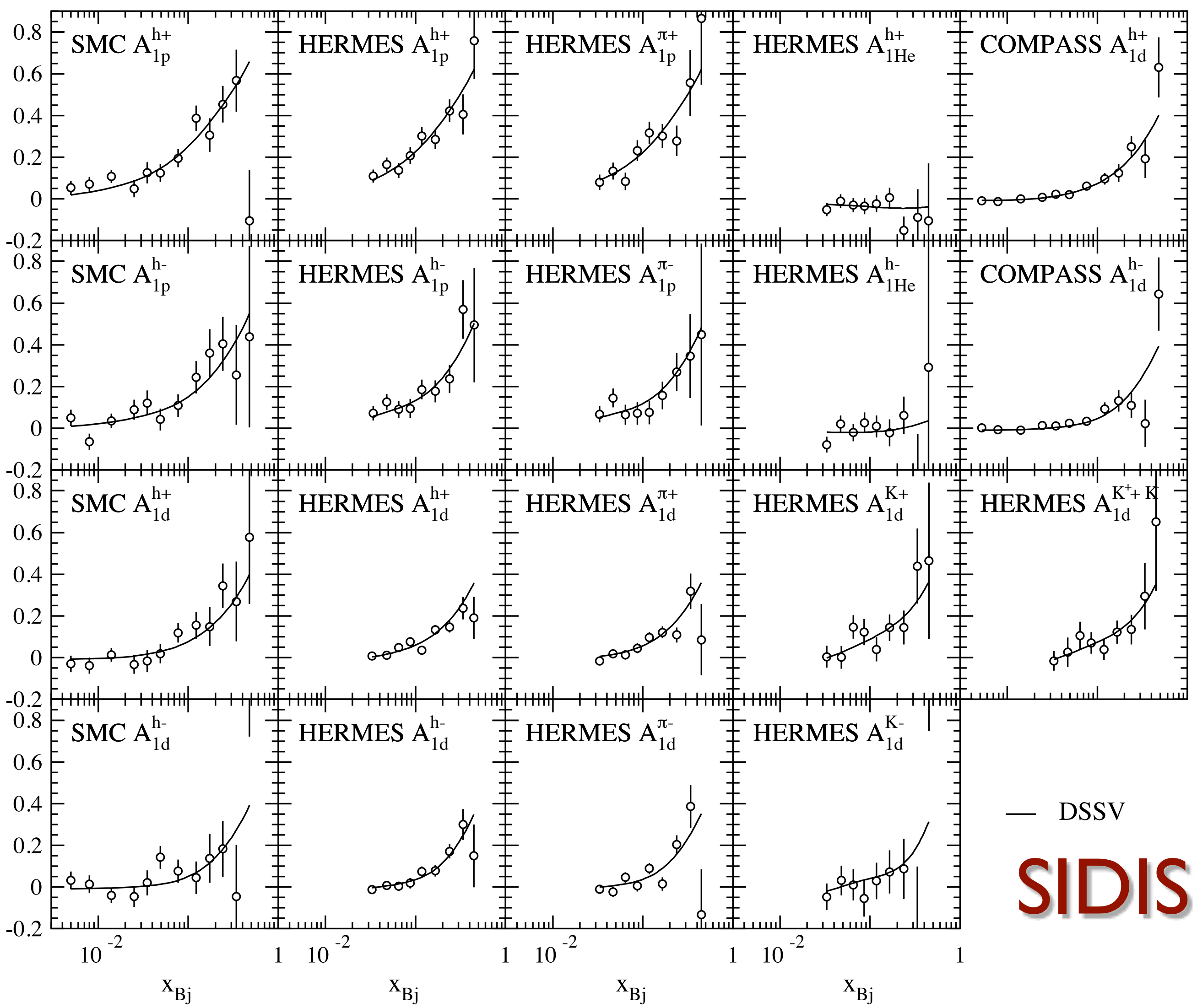


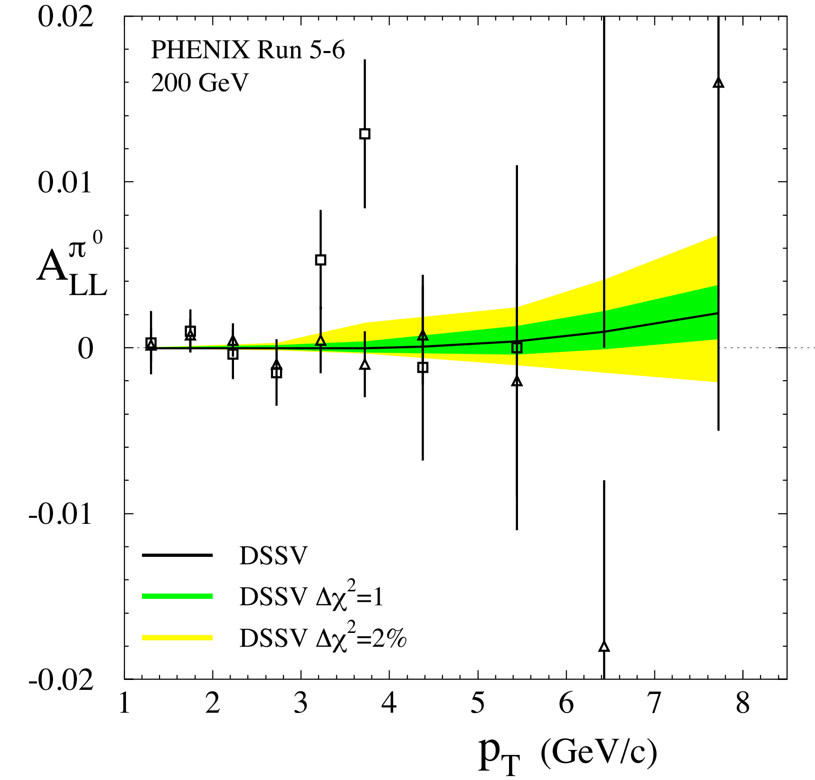
$\Delta\chi^2_n$ We take a pragmatic 2% to define uncertainty bands

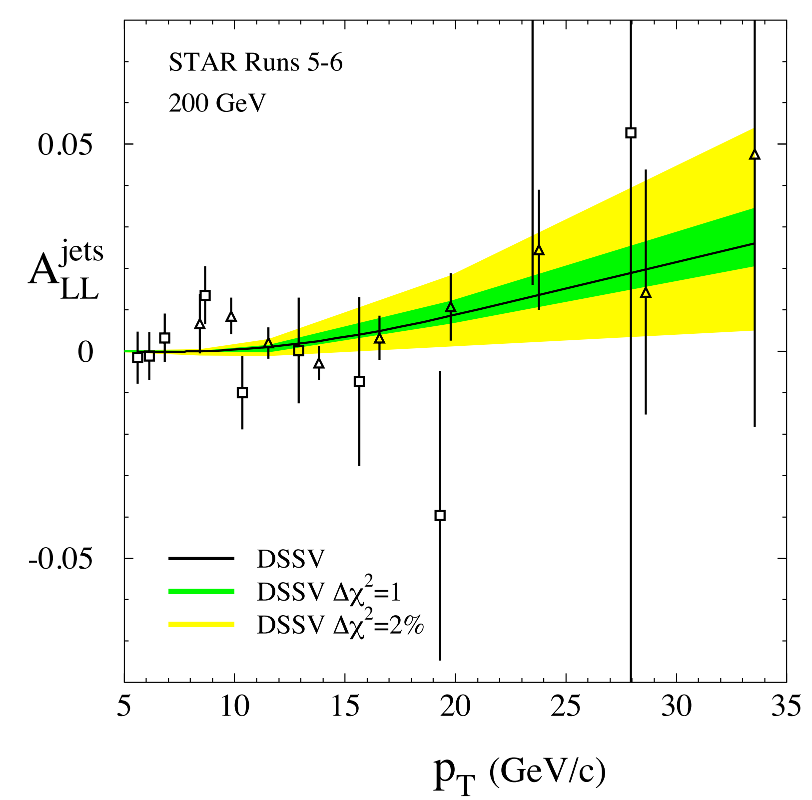
First moments as ‘observables’

RHIC observables







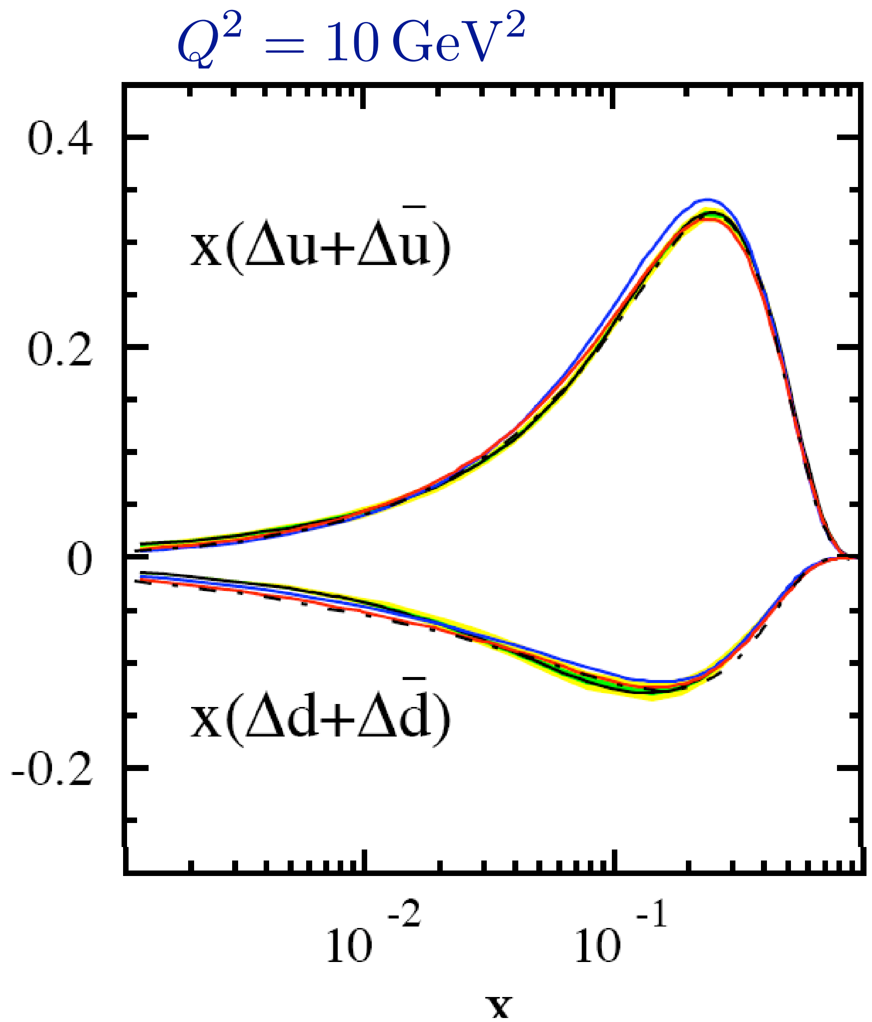


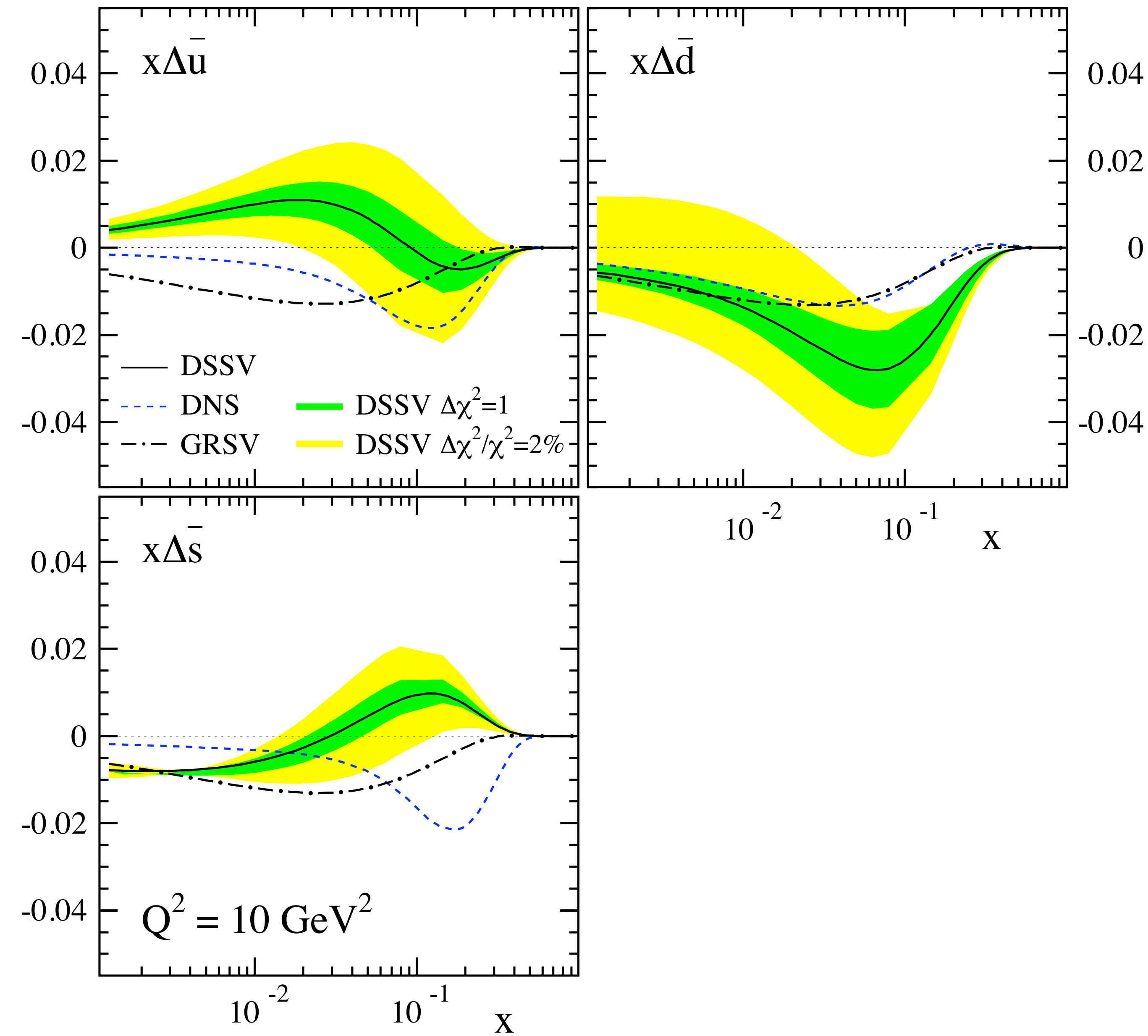
$\chi^2/\text{pdf} = 0.86$

Green bands corresponds to $\Delta\chi^2 = 1$

Yellow bands corresponds to $\Delta\chi^2/\chi^2 = 2\%$

PDFs and “uncertainties”





$\Delta\bar{u}$ ~ positive

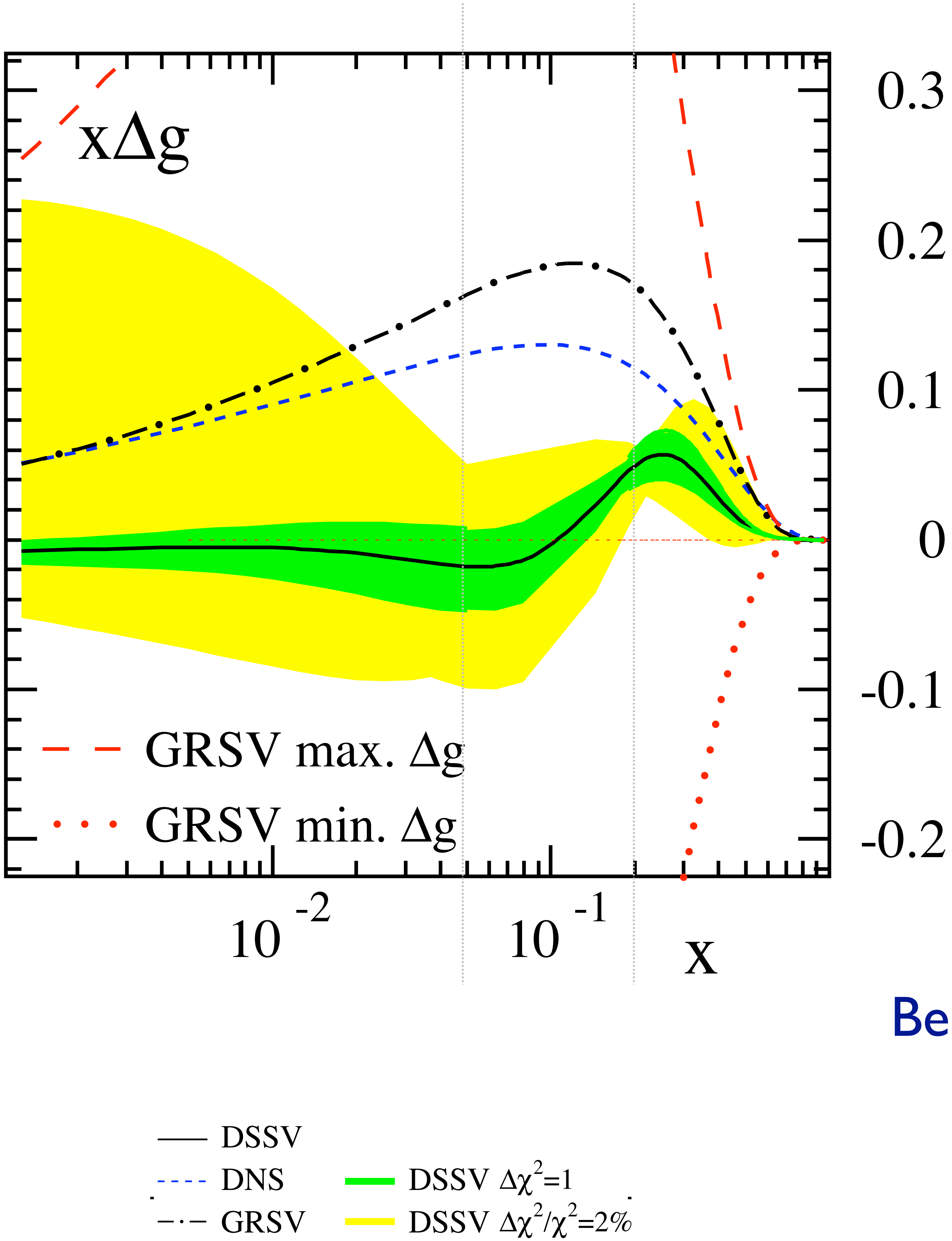
Robust pattern : ~~SU(3)~~ sea

$\Delta\bar{d}$: negative

$\Delta\bar{s}$: SIDIS requires positive (HERMES)
but first moment negative (DIS)

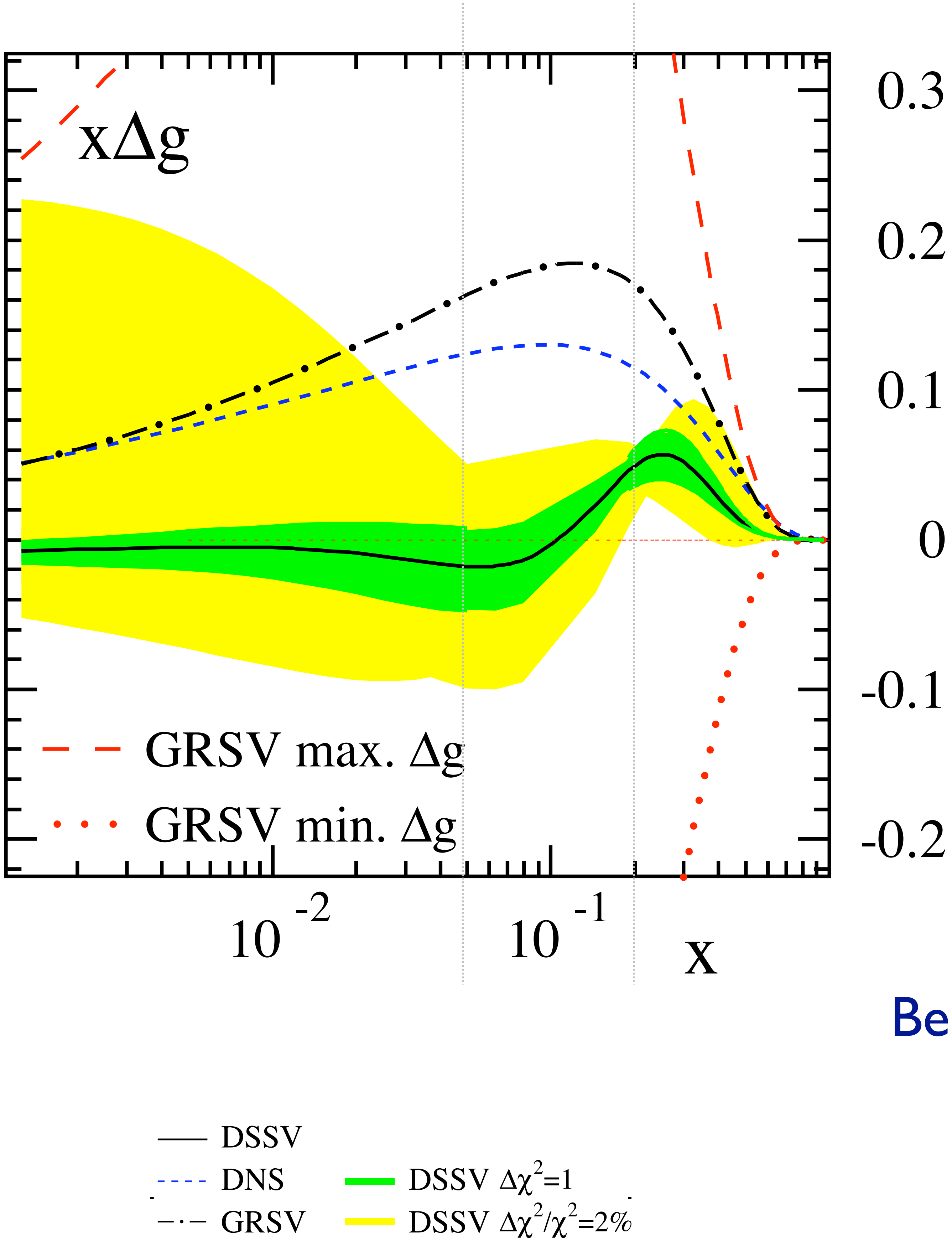
SIDIS relies on DSS frag. functions DdeF, Sassot, Stratmann (DSS)

Gluon



Best fit has a node, negative below x~0.1

Gluon



polarized gluon rather small
even moderate estimates
(from only DIS data)
ruled out

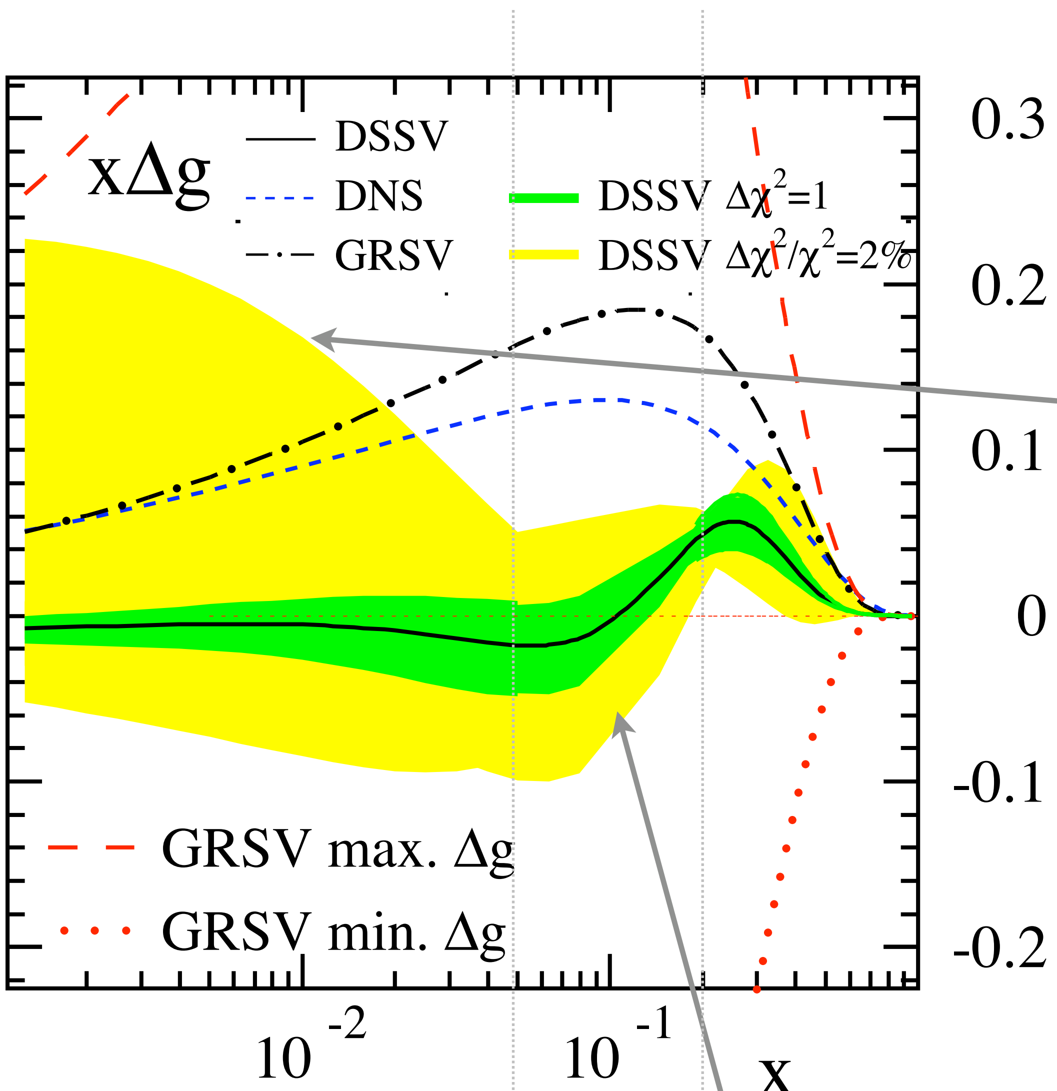
Best fit has a node, negative below x~0.1

Gluon

Moments $Q^2 = 10\,\mathrm{GeV}^2$

	$x_{\min} = 0$	$x_{\min} = 0.001$	
	best fit	$\Delta\chi^2 = 1$	$\Delta\chi^2/\chi^2 = 2\%$
Δg	-0.084	$0.013\,^{+0.106}_{-0.120}$	$0.013\,^{+0.702}_{-0.314}$

Best fit : small first moment ... but..



No clear statement possible for First moment : ~0 but huge uncertainty at small x

but great improvement at medium x

Sum Rule

$$\int_{x_{\min}}^{1} \Delta f(x, Q^2)\, dx$$

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	best fit	$\Delta\chi^2 = 1$	$\Delta\chi^2/\chi^2 = 2\%$
$\Delta u + \Delta\bar{u}$	0.813	$0.793\ ^{+0.011}_{-0.012}$	$0.793\ ^{+0.028}_{-0.034}$
$\Delta d + \Delta\bar{d}$	-0.458	$-0.416\ ^{+0.011}_{-0.009}$	$-0.416\ ^{+0.035}_{-0.025}$
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large (negative) contribution from small x extrapolation

unreliable for gluons

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...no proceedings...to encourage the presentation
of preliminary results, speculative ideas..

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Michel Garçon

What if ? $\Delta G \sim -\frac{1}{2}\Delta\Sigma$

AdS/CFT result in strong coupling limit (Gao, Xiao, Hatta, Ueda)

‘Static’ Scenario?

What if ? $\Delta G \sim -\frac{1}{2}\Delta\Sigma$ (at some Q^2)

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

(the terms $\frac{1}{2}\Delta\Sigma$ and ΔG are crossed out)

All spin by OAM

max. violation of naive expectation

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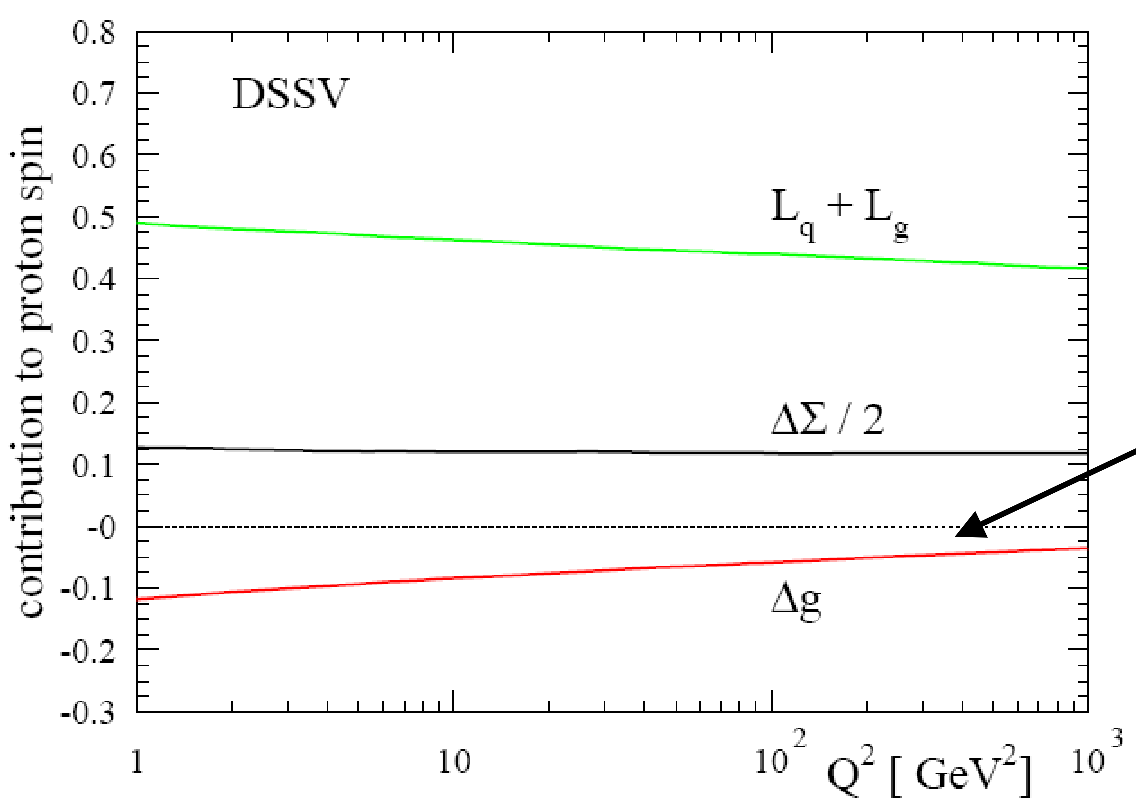
Evolution of first moment at LO

$$\frac{d}{d\ln(\mu^2)}\begin{pmatrix}\Delta\Sigma \\ \Delta g\end{pmatrix} = \frac{\alpha_s}{2\pi}\begin{pmatrix}0 & 0 \\ \frac{3}{2}C_F & \frac{1}{2}\beta_0\end{pmatrix}\begin{pmatrix}\Delta\Sigma \\ \Delta g\end{pmatrix}$$

2 ~ 4

← constant

← constant if $\Delta G \sim -\frac{1}{2}\Delta\Sigma$ (all Q^2)



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$2 \qquad \sim 4$

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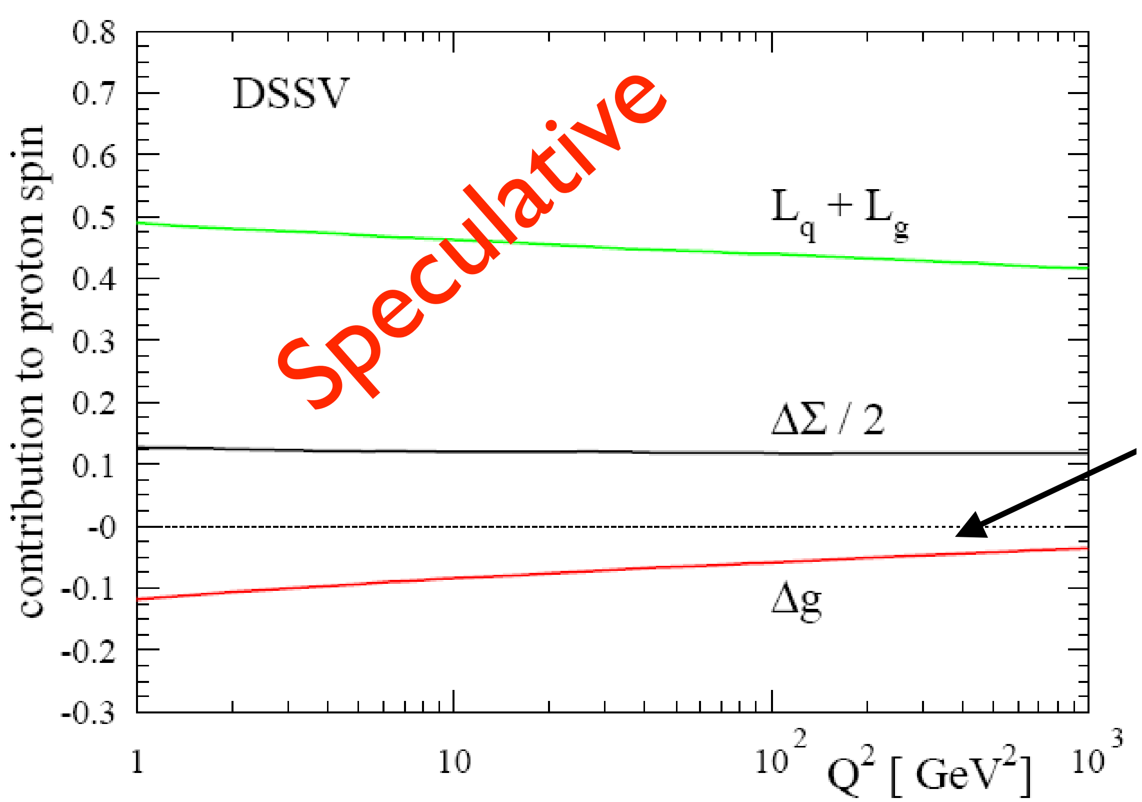

DSSV close to static

Any nucleon model supports this speculation?

Future of ΔG

- TH: Understand better COMPASS observables (and keep asking for cross-sections!)
- DIS: COMPASS and JLAB-12 data (evolution)
- RHIC: more precise and at 500 GeV (smaller x)
- Less inclusive observables

Dijets
Jet + pion
pion + photon

  - Less inclusive allows to perform a more detailed selection

Cuts to enhance sensitivity on some partonic channel
Slightly different scales

Summary

- Learnt a lot about polarized pdfs and proton spin contribution
- Reasonable knowledge on quark, more work needed for antiquarks
- Gluon polarization much smaller than expected at medium x

$Q^2 = 10$ $\Delta G \sim 5$ → $\Delta G \sim 1 - 2$ → $\Delta G \sim 0?$ $\Delta G \sim -\frac{1}{2}\Delta\Sigma?$

Anomaly → DIS → Global

- But still far from solving the spin sum rule puzzle: huge uncertainty

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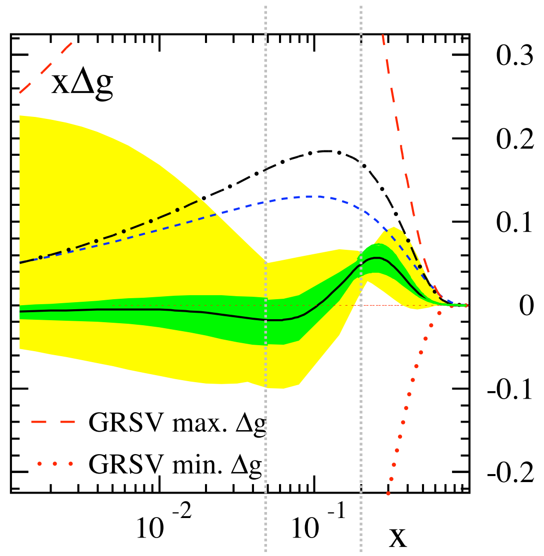

$$\int_0^1 \Delta g(x, Q^2)\, dx$$

Need gluon at small x

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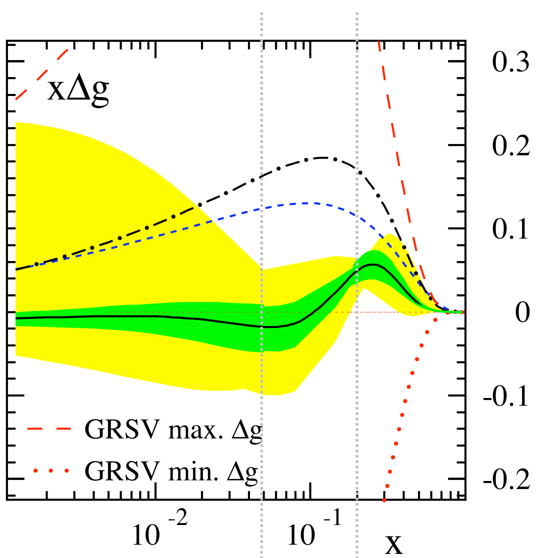

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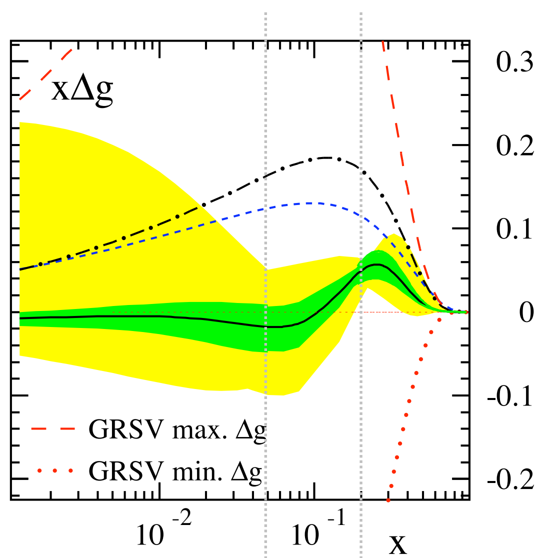

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Need gluon at small x

- Polarized ep collider needed to get first moment

Thanks

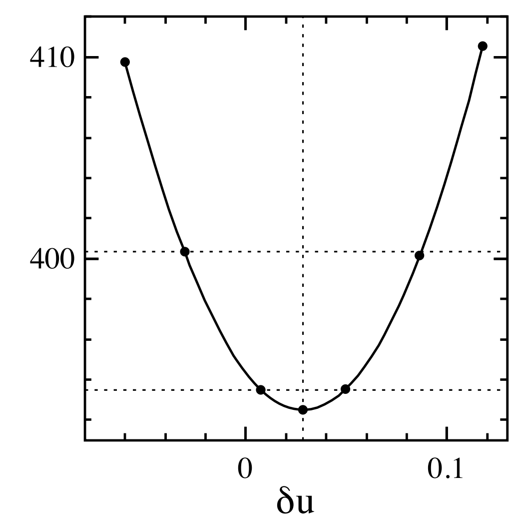
Uncertainties

- Use Lagrange Multipliers technique to estimate uncertainties (from exp. errors) on some observables

$$\Phi(\lambda_i, \{a_j\}) = \chi^2(\{a_j\}) + \sum_i \lambda_i \, \mathcal{O}_i(\{a_j\})$$

See how fit deteriorates when PDFs forced to give different prediction for $\mathcal{O}_i$

$\Delta\chi^2_n$ should be parabolic if data set can determine the observable (otherwise monotonic o flat)



$\Delta\chi^2_n$ We take a pragmatic 2% to define uncertainty bands

- Use Hessian Method to estimate uncertainties (from exp. errors) on pdfs

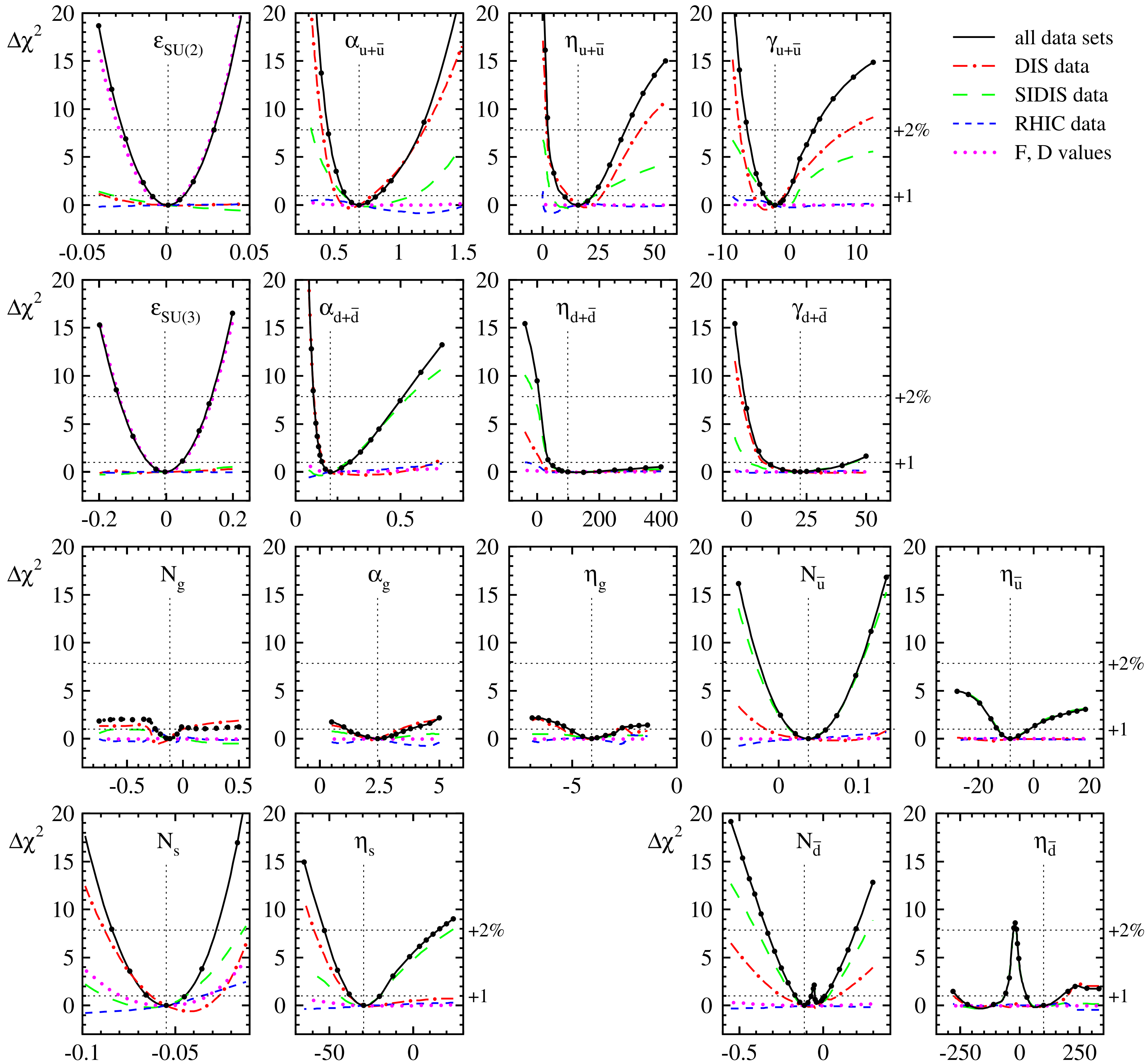
(J.Pumplin and CTEQ)

38 DSSV eigenvector sets to compute uncertainties on any observable

Unfortunately only for $\Delta\chi^2_n = 1$

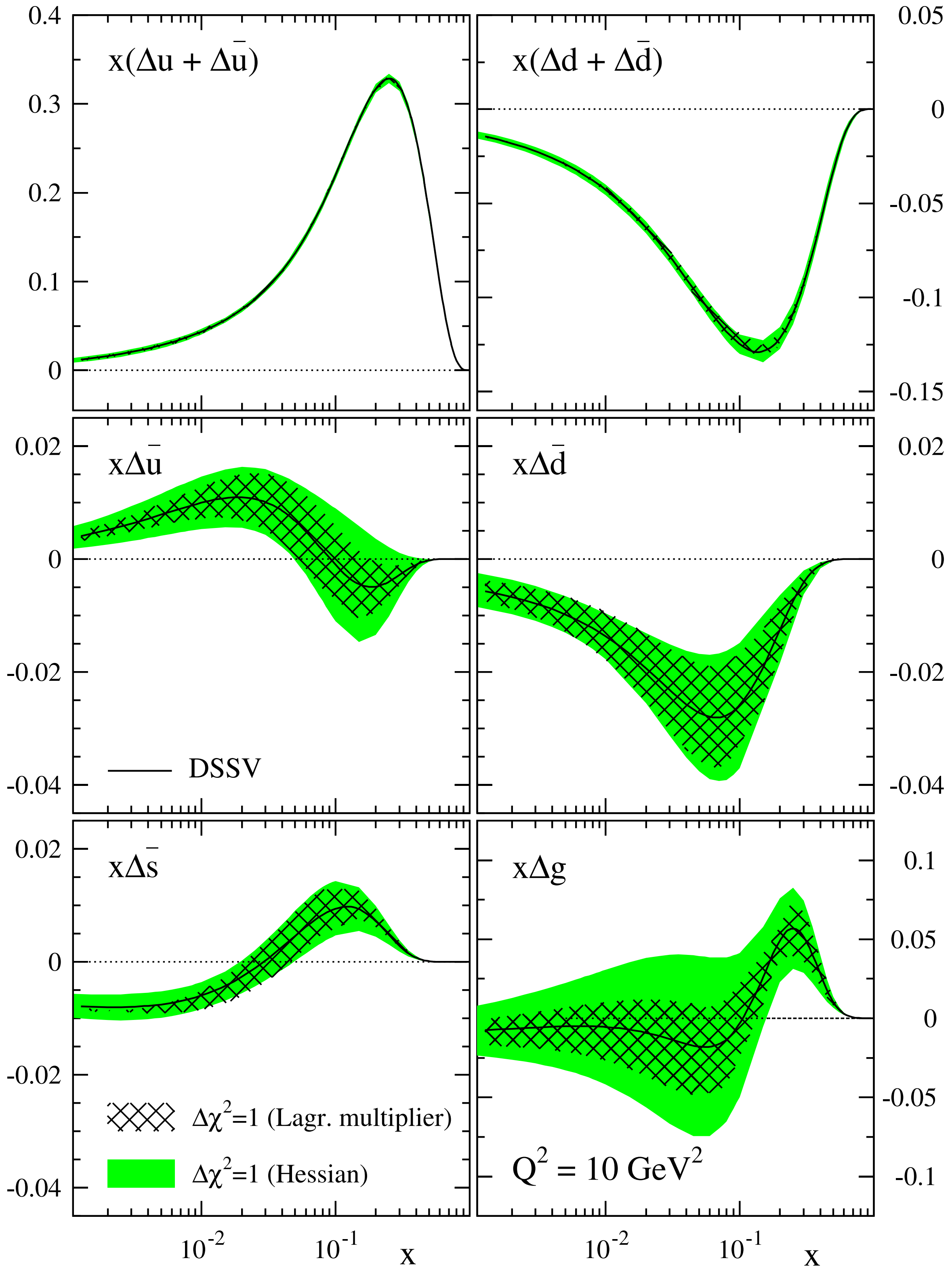
$$\Delta\mathcal{O}_i = \frac{1}{2}\left(\sum_{k=1}^{N_{\text{par}}} \left[\mathcal{O}_i(S_k^+) - \mathcal{O}_i(S_k^-)\right]^2\right)^{1/2}$$

Profiles



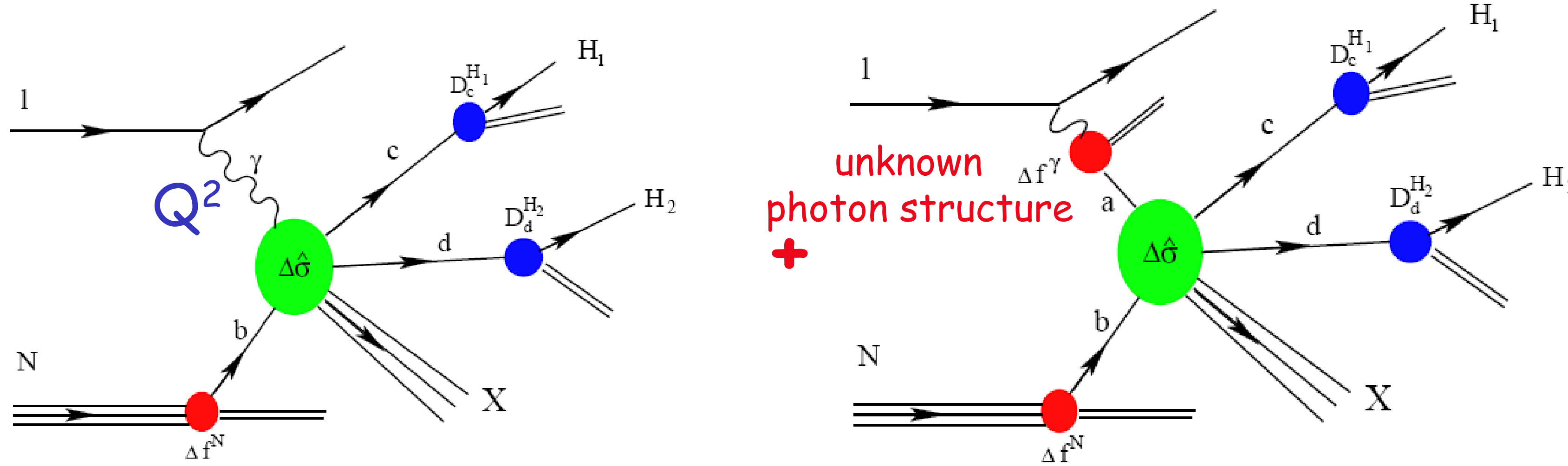
Δχ²
ε SU(2)
α u+ū
η u+ū
γ u+ū
ε SU(3)
α d+d̄
η d+d̄
γ d+d̄
N g
α g
η g
N ū
η ū
N s
η s
N d̄
η d̄
+2%
+1
all data sets
DIS data
SIDIS data
RHIC data
F, D values

Hessian vs Lagrange

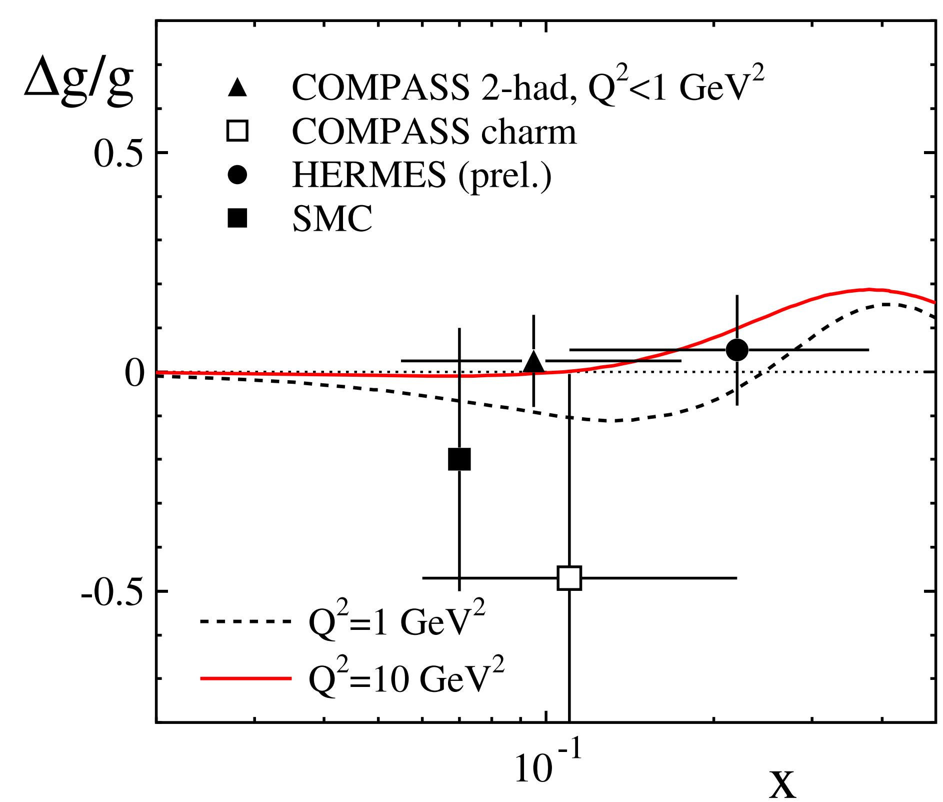


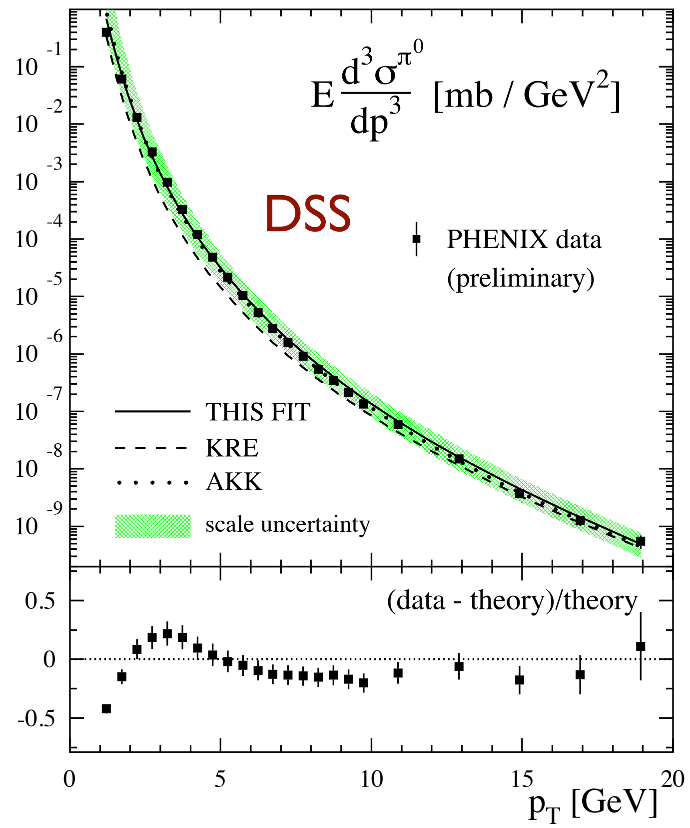
Compass/Hermes $\Delta G/G$

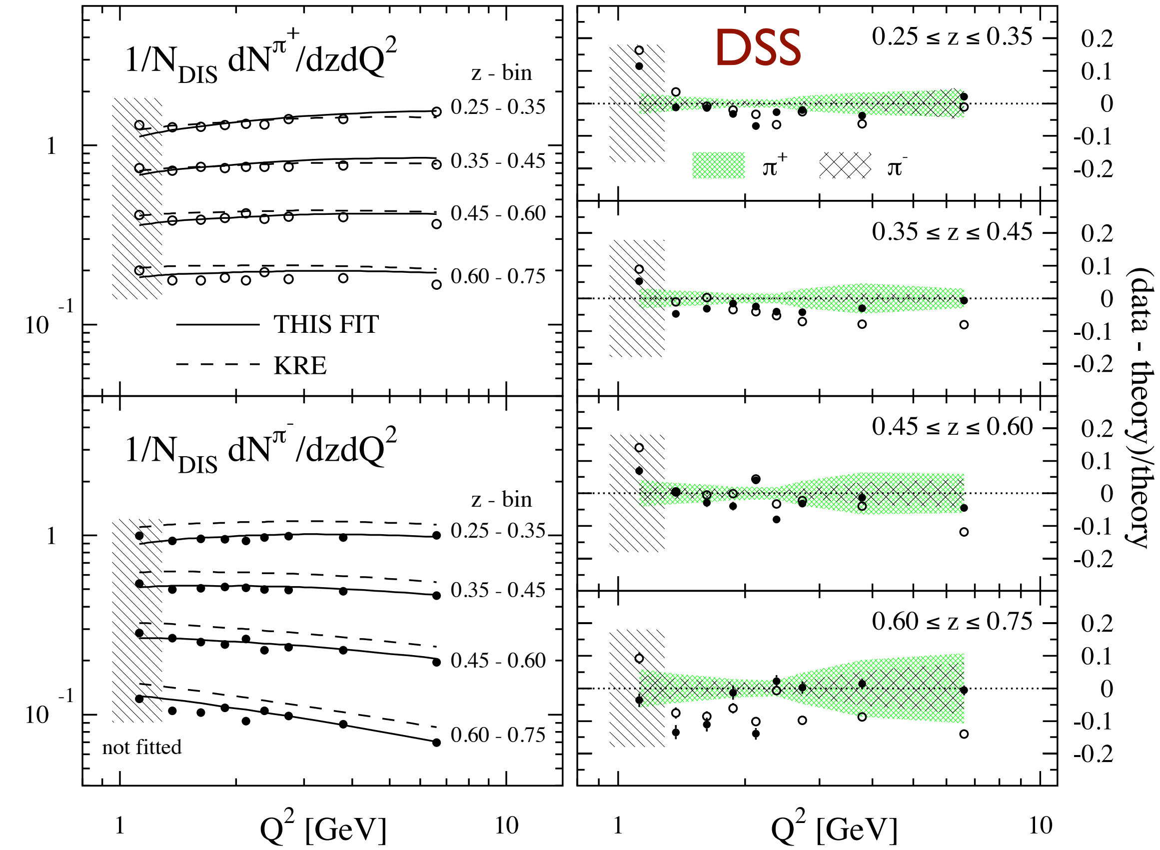
Two hadron production : gluon enters at Lowest order enhanced contribution



- Low transverse momentum/less inclusive → Factorization/pQCD at risk?
- Photoproduction : resolved polarized photon?
- only lowest order analysis : if factorization works, NLO corrections expected to be large







Hermes

✓ Pion production at RHIC OK

$p_T^{\pi} \geq 1\,\mathrm{GeV}$

✓ SIDIS OK with DSS fragmentation functions

DdF., R.Sassot, M.Stratmann

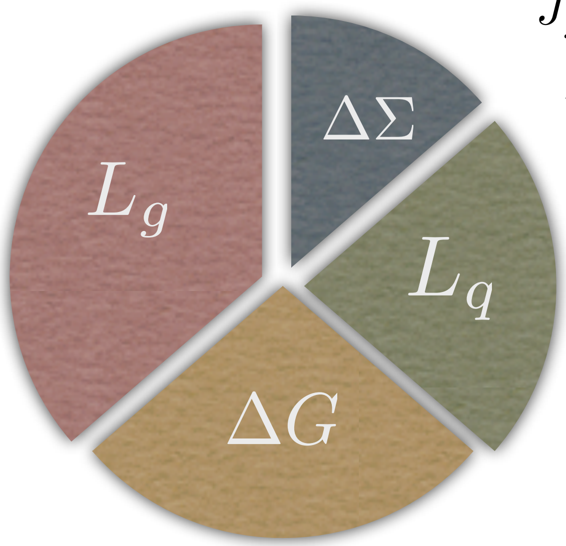
DSS fragmentation functions extracted from a global fit that includes RHIC and HERMES unpolarized data!

All other FF sets fail to reproduce Hermes data

SPIN SUM RULES

Adapted from M.Burkardt

Jaffe, Manohar



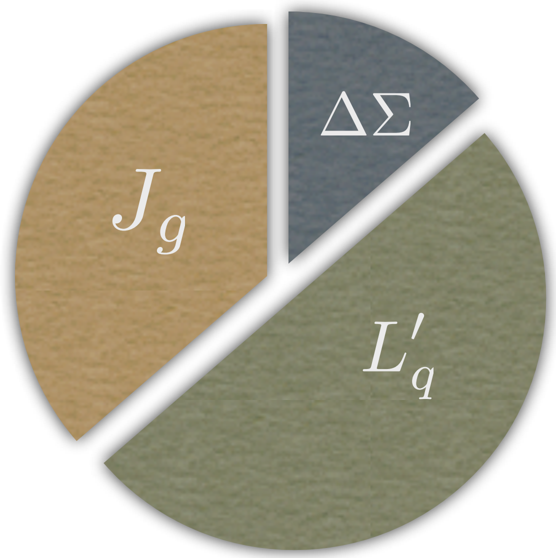
$J_g \neq L_g + \Delta G$

$L_q \neq L'_q$

Partonic interpretation
local operator only in
light cone gauge

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

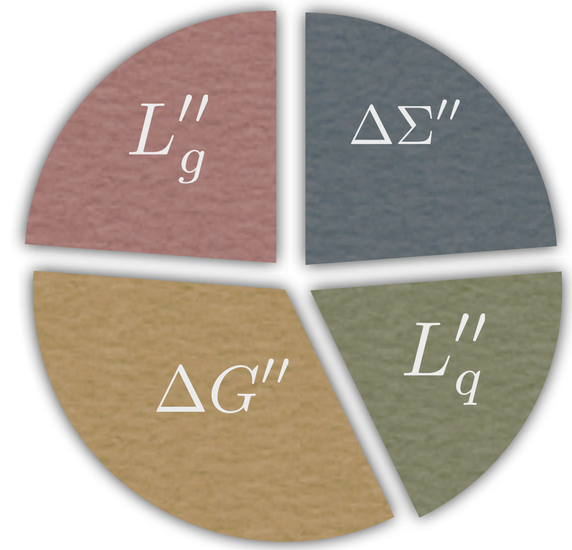
Ji



Gauge invariant
Lattice and GPDs
Contains interactions

$$\frac{1}{2}\Delta\Sigma + L'_q + J_g = \frac{1}{2}$$

Chen, Lu, Sun, Wang, Goldman



Gauge invariant
physical interpretation ?
related to new pdfs ?

$$\frac{1}{2}\Delta\Sigma'' + \Delta G'' + L''_q + L''_g = \frac{1}{2}$$

Technical Issues and Mellin

Technical Problem: several evaluations of evolved PDFS and observables

Evolution of PDFs and NLO corrections involve convolutions: time consuming

Mellin space : convolutions turn into products

$$\Delta f_j^n(Q^2) \equiv \int_0^1 dx\, x^{n-1}\, \Delta f_j(x, Q^2)$$

$$\int f \otimes g \rightarrow f^n \times g^n$$

Exact (analytic) solution for DGLAP equations and DIS and SIDIS coefficients

Efficient (fast) inversion possible

Rather more complicated for pp observables

$$d\Delta\sigma = -\frac{1}{4\pi^2} \sum_{ab} \int_{\mathcal{C}_n} dn \int_{\mathcal{C}_m} dm\, \Delta f_a^n(Q^2)\, \Delta f_b^m(Q^2)$$

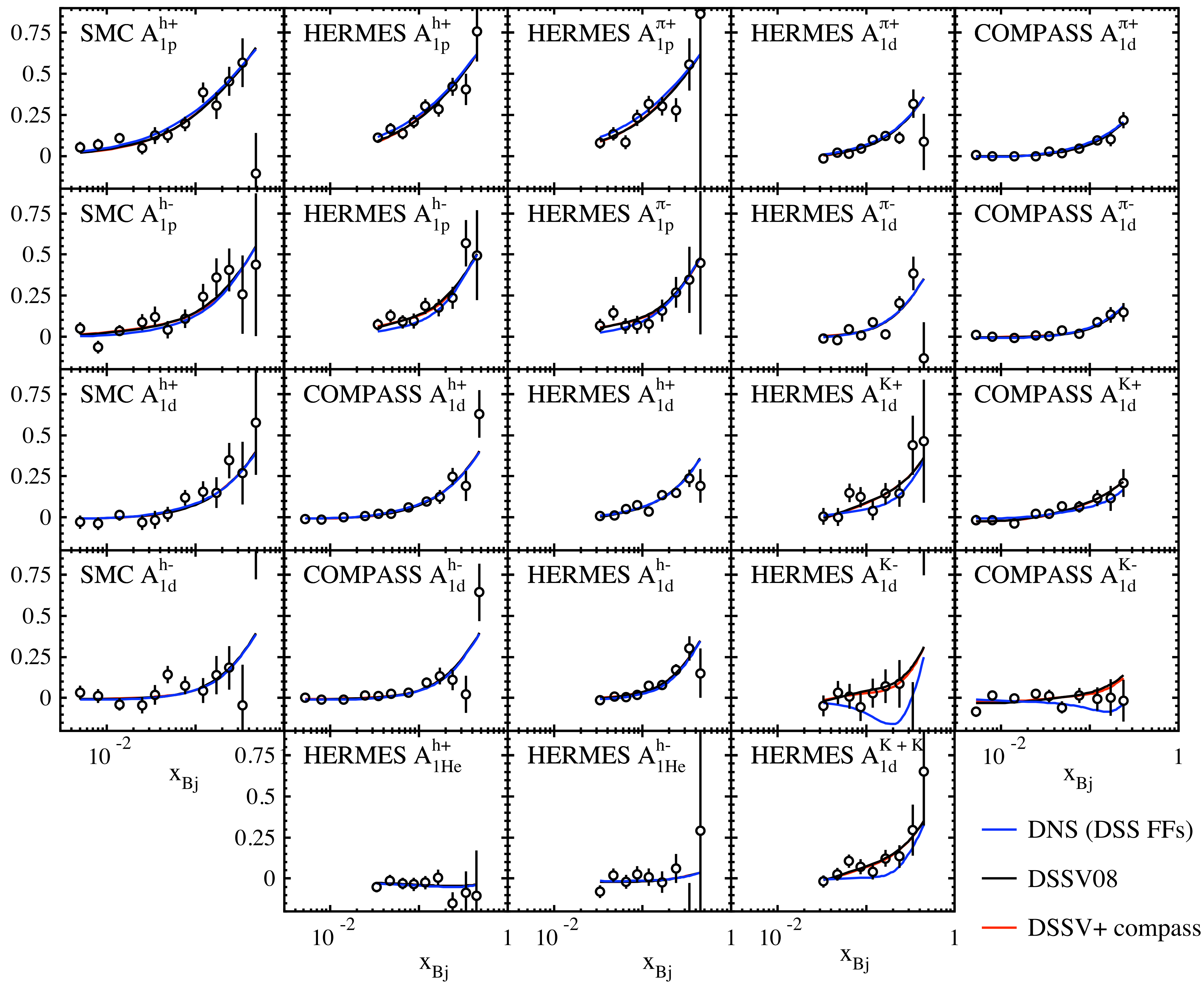
$$\times \quad \underbrace{\int dx_a \int dx_b\, x_a^{-n}\, x_b^{-m} d\Delta\hat{\sigma}_{ab}(x_a, x_b, \ldots)}_{\equiv \Delta\hat{\sigma}_{ab}^{n,m}}$$

pre- compute $n \times m$ grids in complex space

M.Stratmann, W.Vogelsang

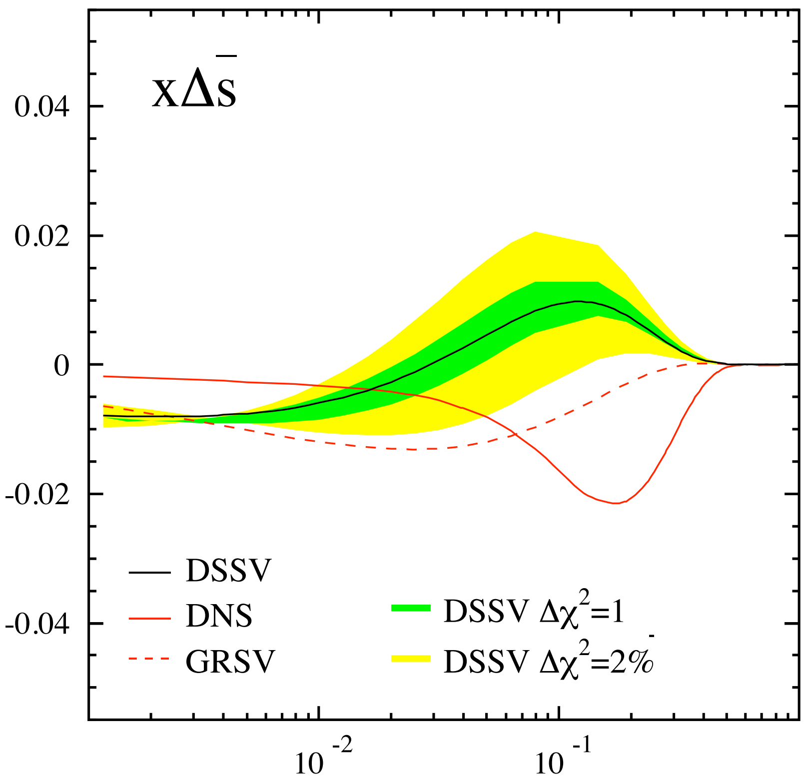
New: any observable possible using sampling techniques faster evaluation ~1 day-computer

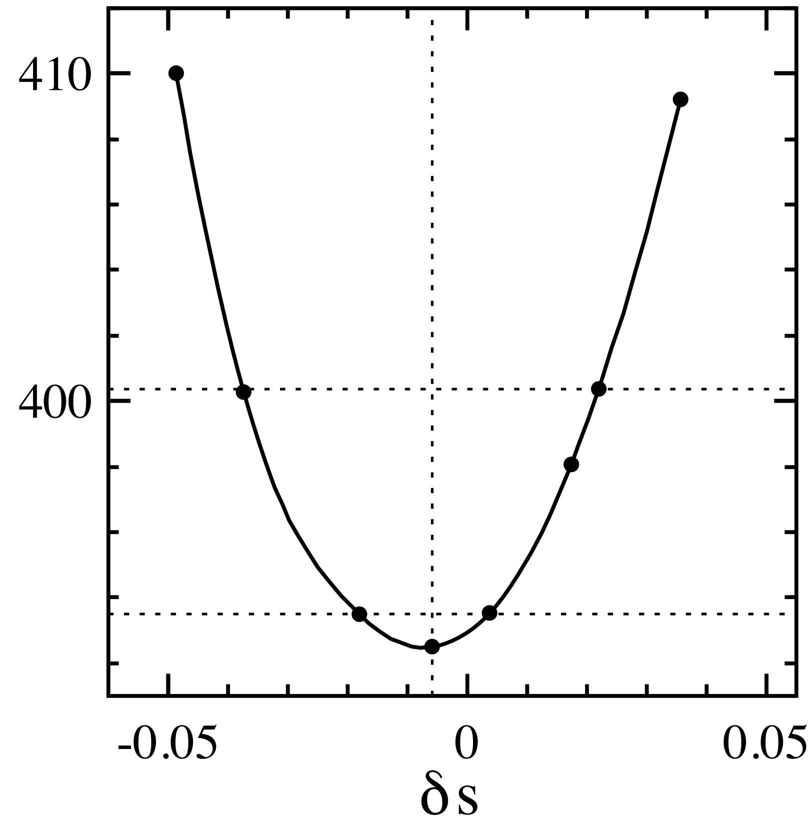
dijets with exp. cuts

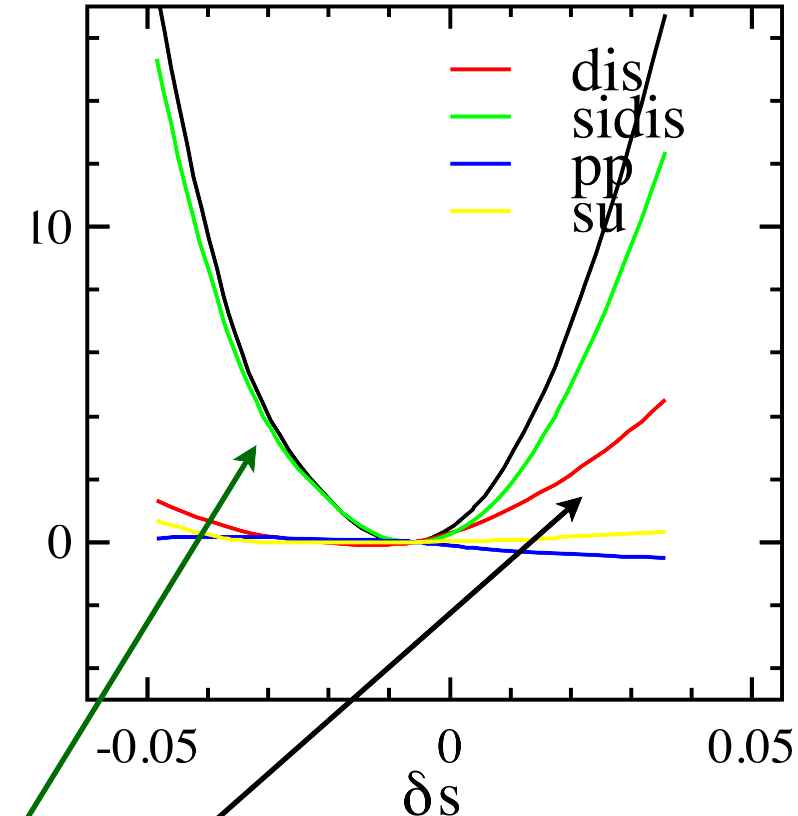


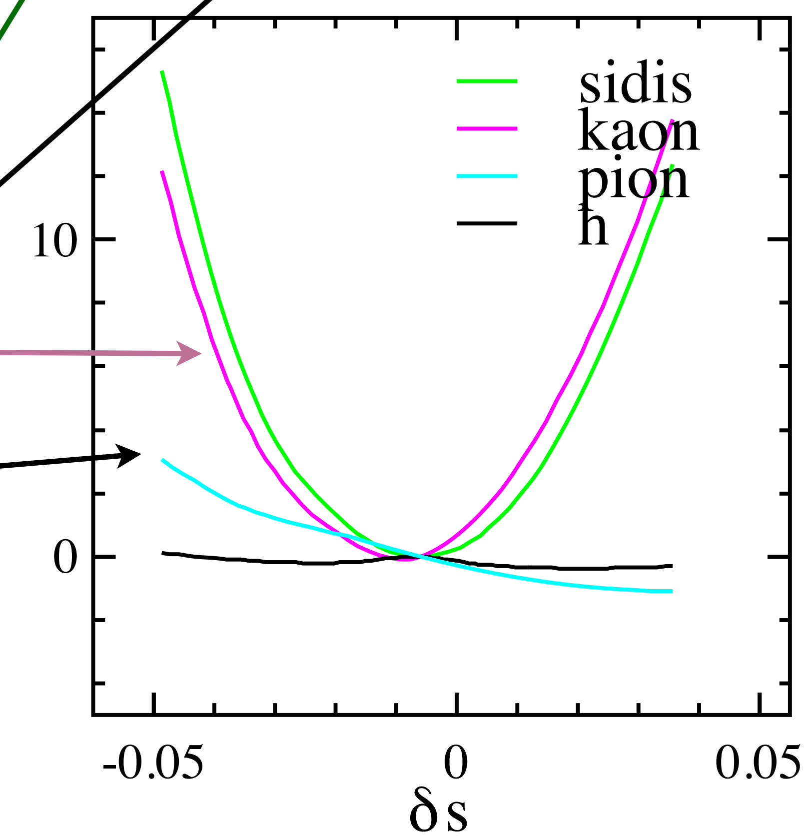
SMC A_{1p}^{h+}
HERMES A_{1p}^{h+}
HERMES $A_{1p}^{\pi+}$
HERMES $A_{1d}^{\pi+}$
COMPASS $A_{1d}^{\pi+}$
SMC A_{1p}^{h-}
HERMES A_{1p}^{h-}
HERMES $A_{1p}^{\pi-}$
HERMES $A_{1d}^{\pi-}$
COMPASS $A_{1d}^{\pi-}$
SMC A_{1d}^{h+}
COMPASS A_{1d}^{h+}
HERMES A_{1d}^{h+}
HERMES A_{1d}^{K+}
COMPASS A_{1d}^{K+}
SMC A_{1d}^{h-}
COMPASS A_{1d}^{h-}
HERMES A_{1d}^{h-}
HERMES A_{1d}^{K-}
COMPASS A_{1d}^{K-}
HERMES A_{1He}^{h+}
HERMES A_{1He}^{h-}
HERMES A_{1d}^{K+K}
0.75
0.5
0.25
0
10^{-2}
1
x_{Bj}
DNS (DSS FFs)
DSSV08
DSSV+ compass

Flavor separation still dependent of FF (unpol. Hermes multiplicities)







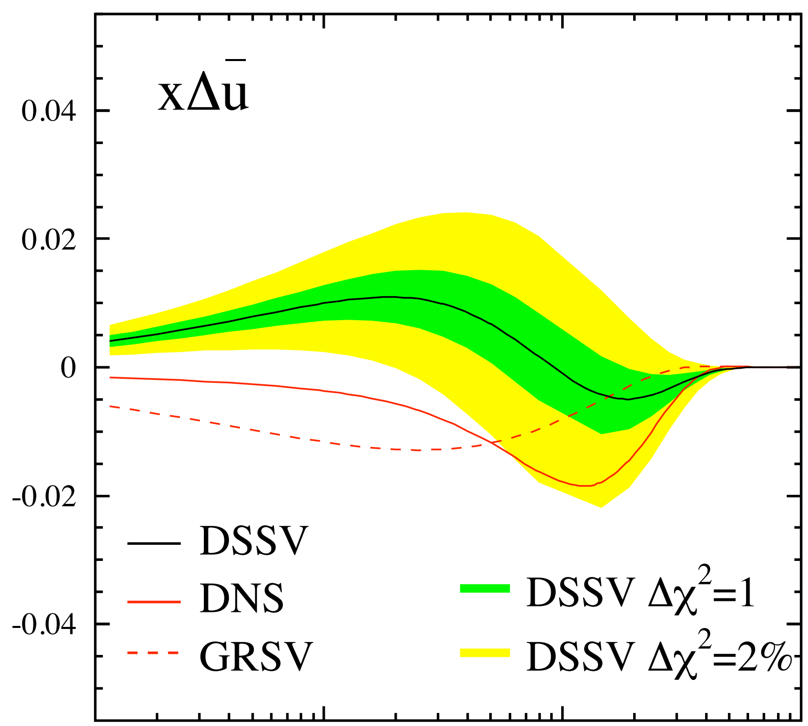


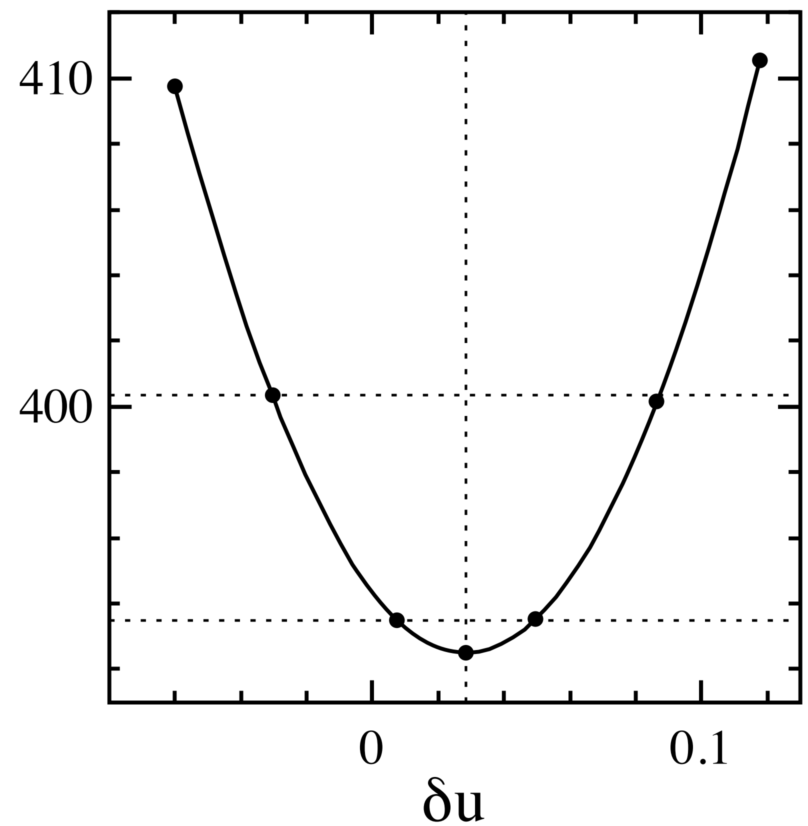
$$\delta\bar{s} \equiv \int_{0.001}^{1} \Delta\bar{s}\, dx$$

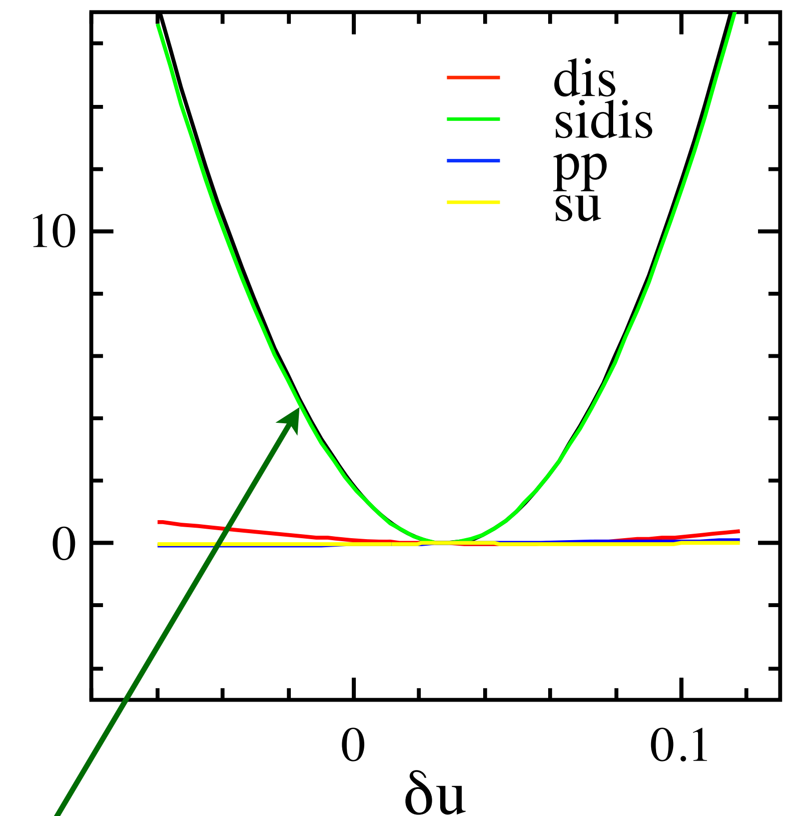
sidis clearly dominate

kaons dominate

pions + dis
confabulation







sidis clearly dominates

charged hadrons dominance

pions agree ...