Newport News, April 13th, 2010

XIX International Workshop on Deep-Inelastic Scattering and Related Subjects

Global Analysis of Helicity PDFs

past – present - future

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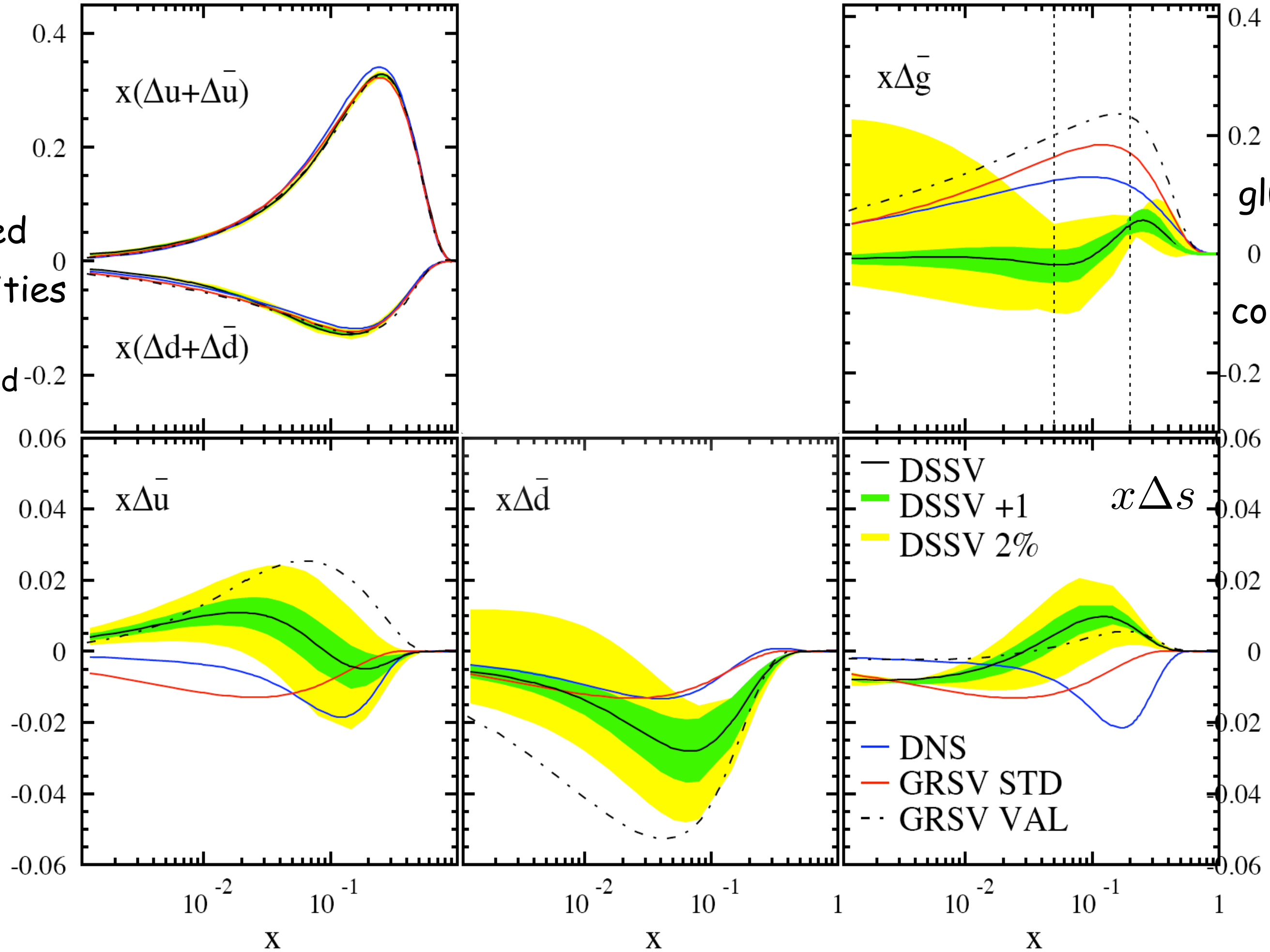
work done in collaboration with D. de Florian, R. Sassot, W. Vogelsang

emerging picture from DSSV analysis in 2008/09

DSSV: de Florian, Sassot, MS, Vogelsang; PRL101 (2008) 072001; PRD80 (2009) 034030

well constrained
total quark densities

x -> 1 behavior
to be determined



gluon small (node?)
in x-region
constrained by data

indications for non-trivial sea quark polarizations $\Delta\bar{u} > 0$ $\Delta\bar{d} < 0$

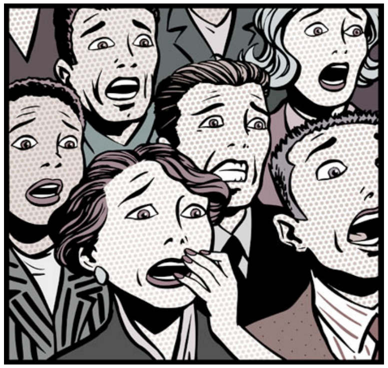
surprising strangeness polarization

sizable SU(3) breaking?

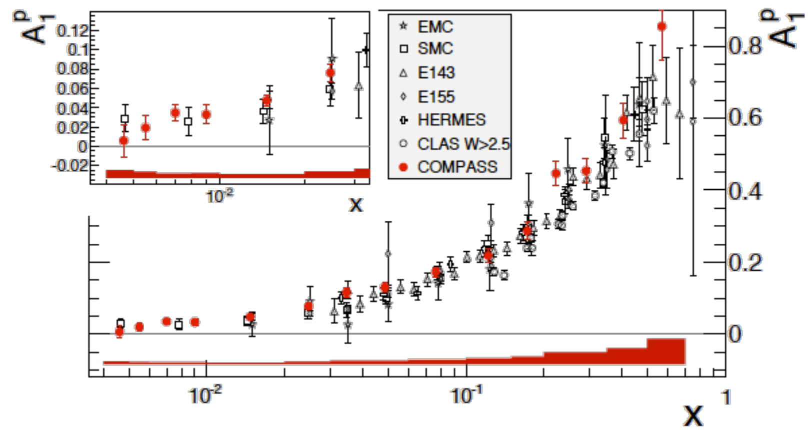
requires reliable kaon fragmentation fcts.

lattice: Bali et al., 0811.0807; 0911.2407; 1011.2194

meanwhile, new data became available …



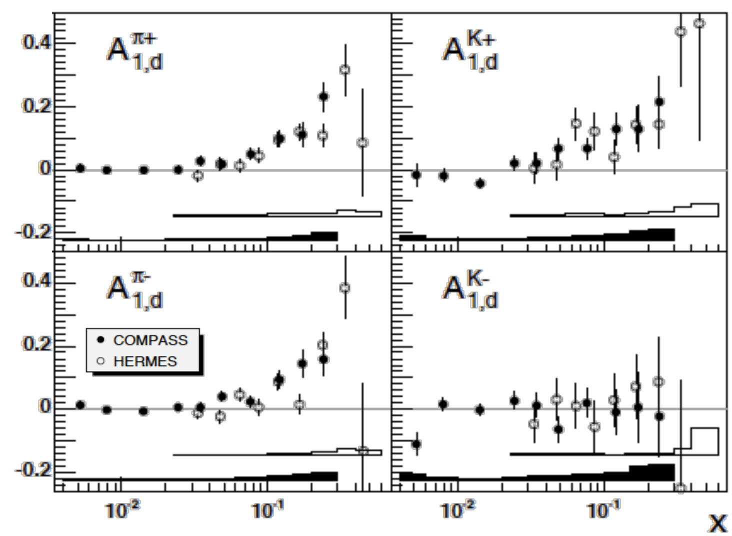
- how well are we doing ?
- refit/new analysis necessary ?
- impact on uncertainties ?



- **DIS:** A_1^p from COMPASS
  arXiv:1001.4654

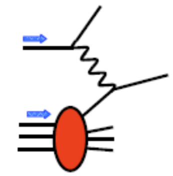
- **SIDIS:** $A_{1,d}^{\pi,K}$ from COMPASS
  arXiv:0905.2828

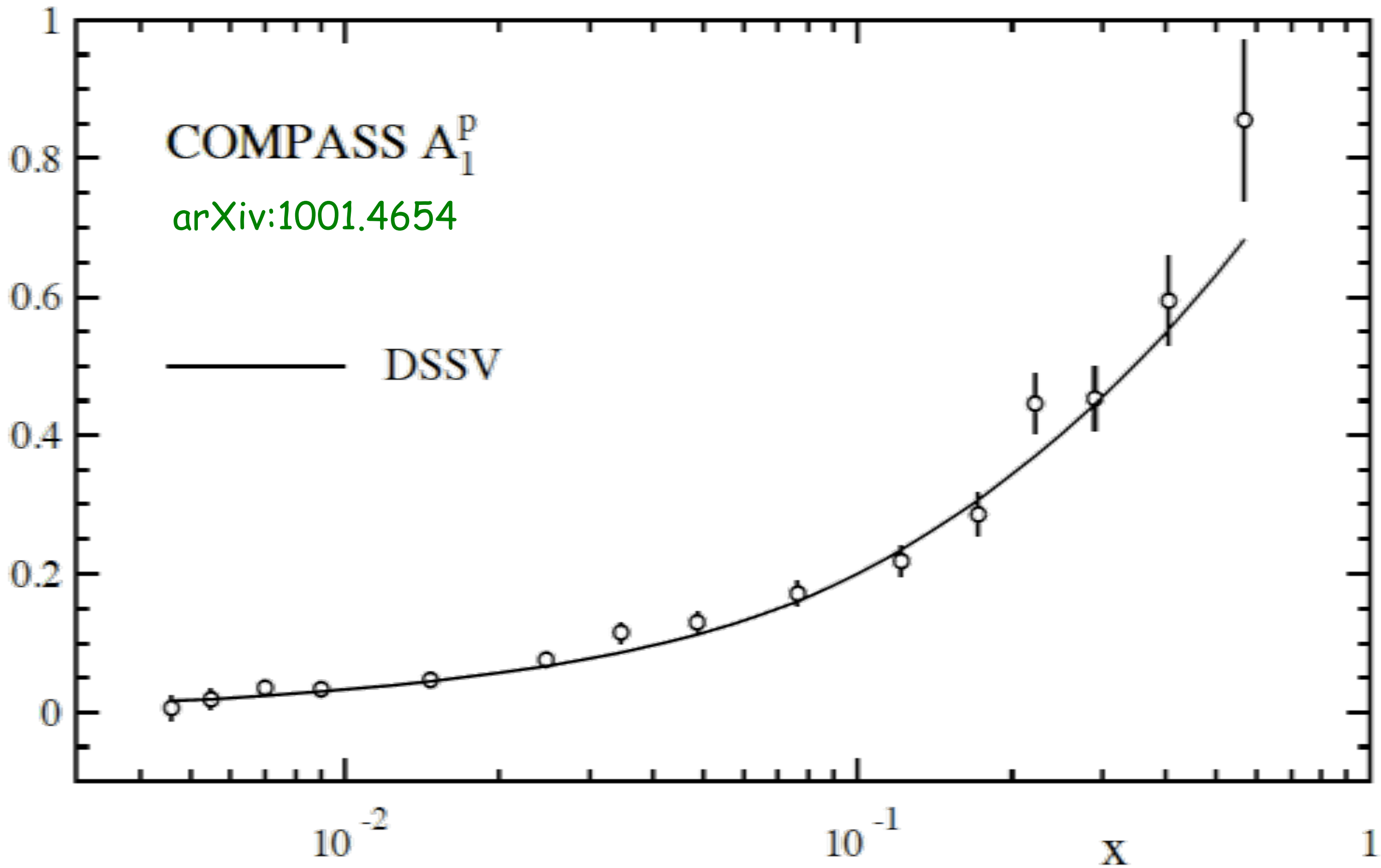
- **SIDIS:** $A_{1,p}^{\pi,K}$ from COMPASS
  arXiv:1007.4061



extended x coverage w.r.t. HERMES

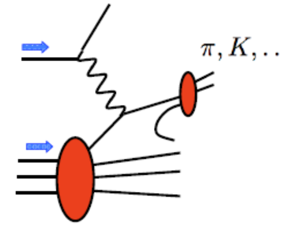
coping with new data: DIS A_1^p

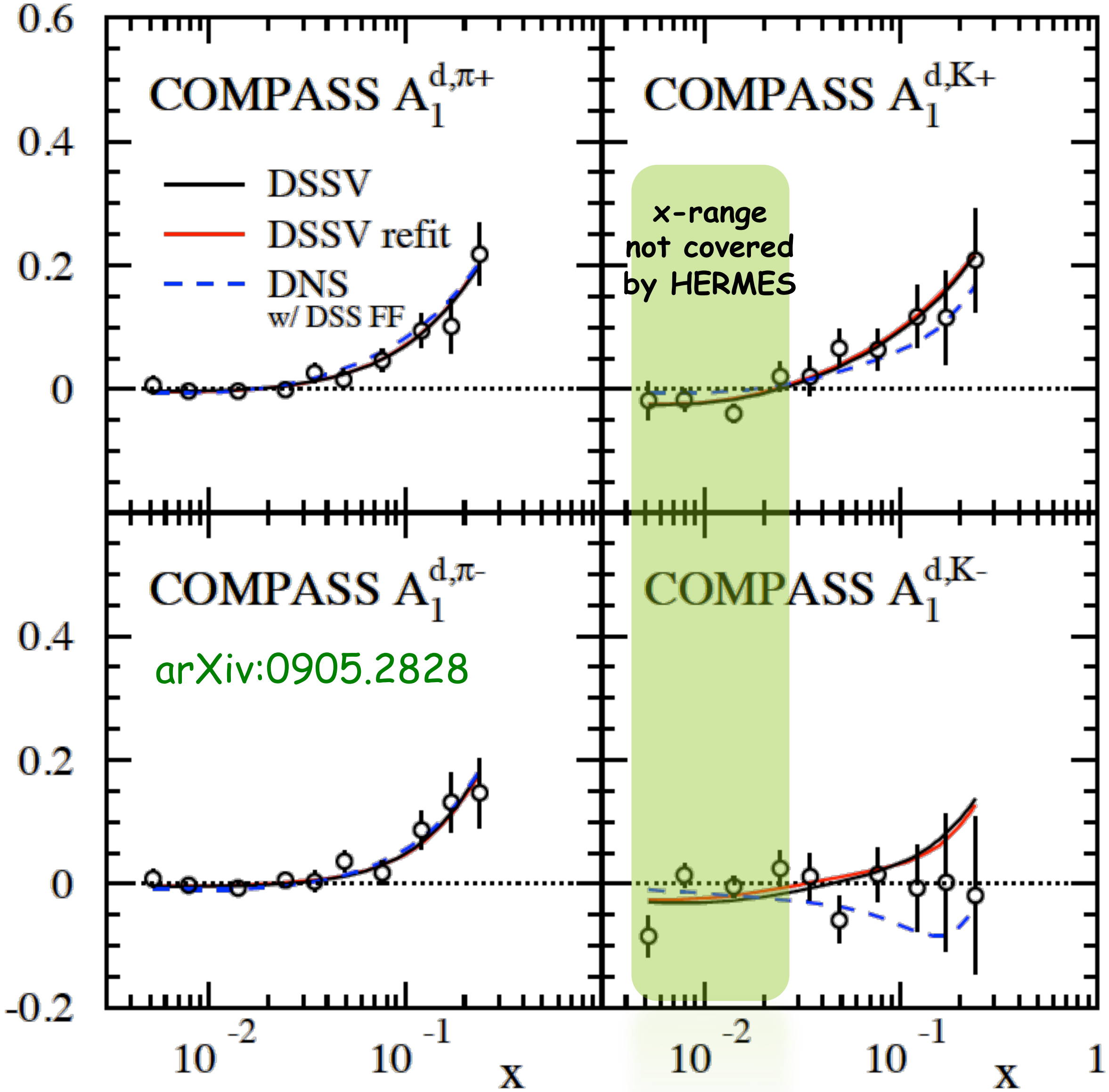




✓ DSSV does a very good job: 15 points, χ^2 = **14.2**

coping with new data: SIDIS $A_1^{d,\pi,K}$





✓ DSSV works well:

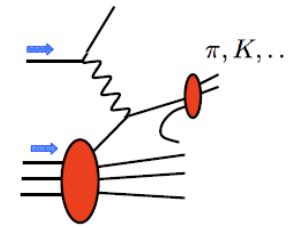
no surprises at small x

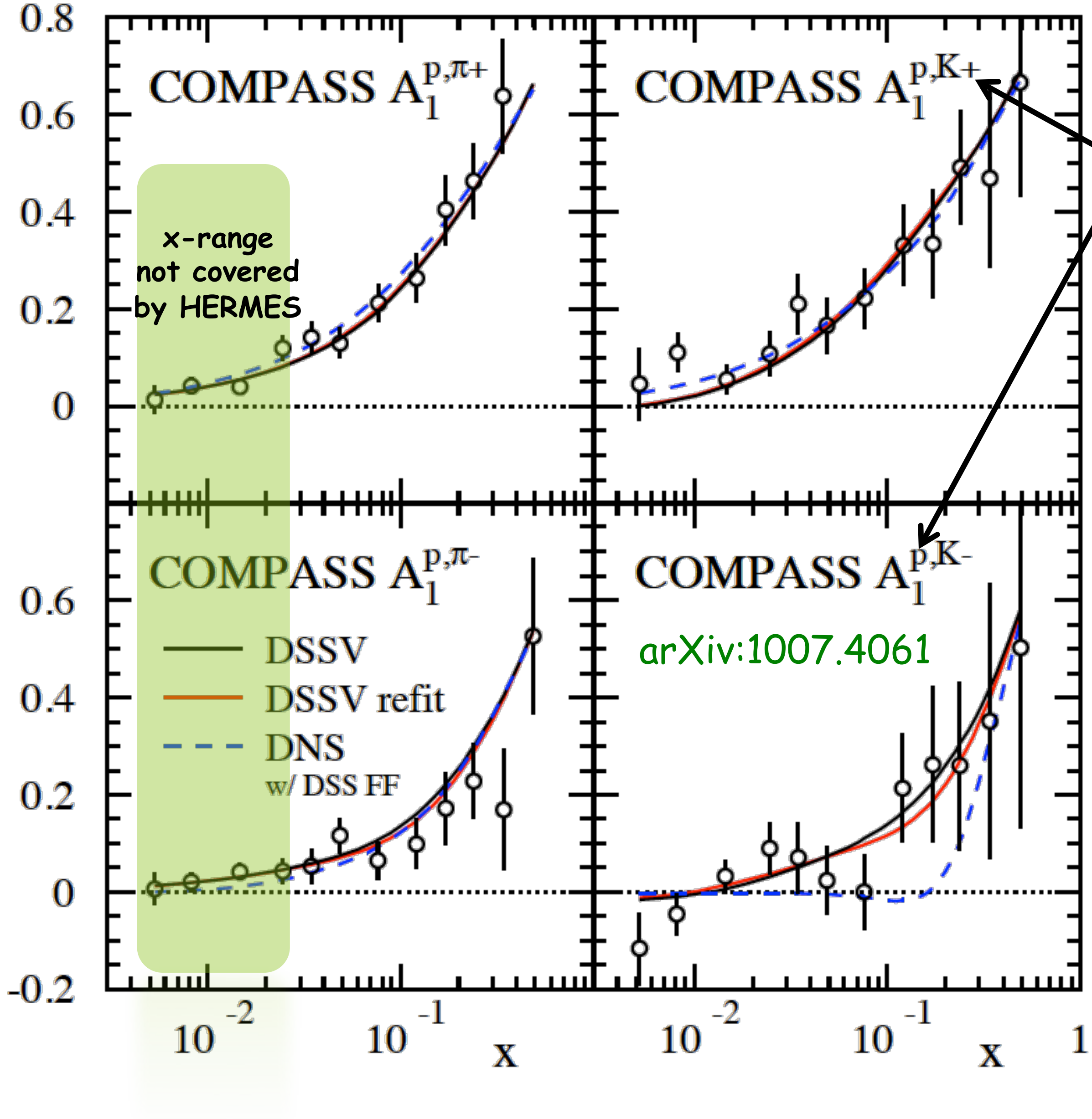
χ^2 numerology♮:

	DSSV 08 data sets	with $A_1^{d,\pi,K}$
DSSV 08	392.5	420.8
DSSV+		418.9

♮ the branch of knowledge that deals with the occult significance of numbers

coping with new data: SIDIS $A_1^{p,\pi,K}$





1st kaon data on p-target
(not available from HERMES)

χ^2 numerology:

	DSSV 08 data sets	with $A_1^{p\&d,\pi,K}$
DSSV 08	392.5	456.4
DSSV+		453.0

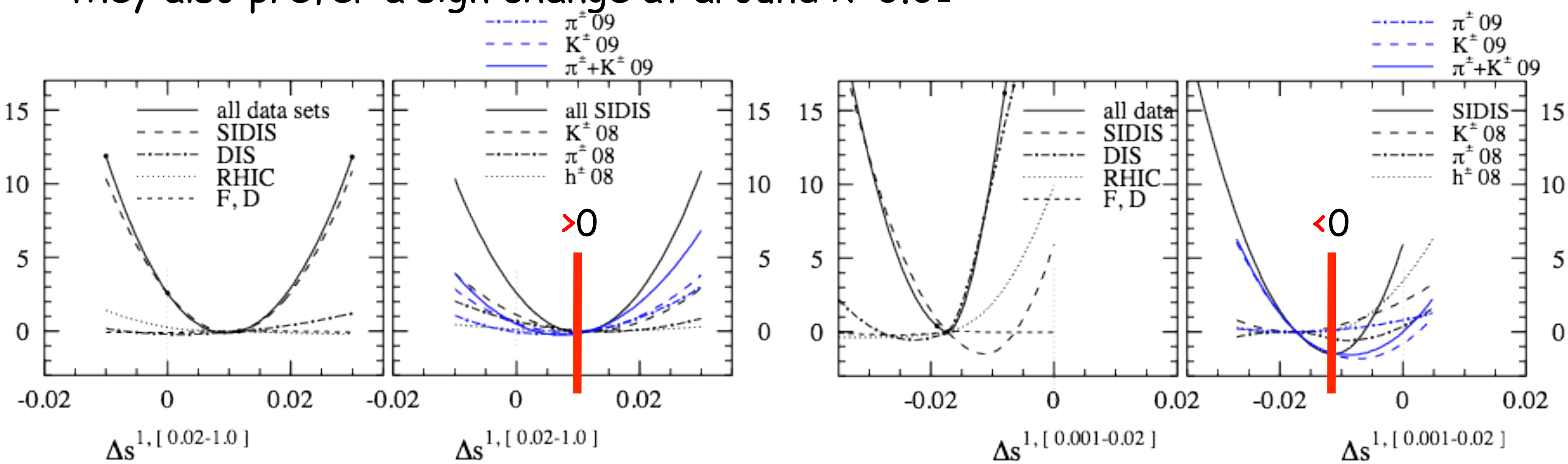
✓ **no refit required**
($\Delta\chi^2=1$ does not reflect faithful PDF uncertainties)

- trend for somewhat less polarization of sea quarks; $\Delta\bar{u} - \Delta\bar{d} \neq 0$ less significant

Δs revisited: impact of COMPASS data

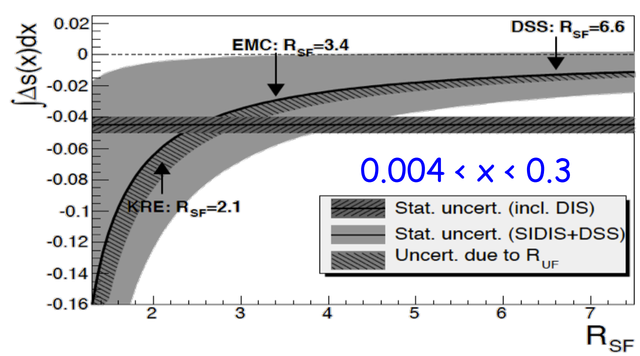
current value for ΔΣ strongly depends on assumptions on low-x behavior of Δs

- new COMPASS data support small/positive Δs(x) at x > 0.01
- they also prefer a sign change at around x=0.01



- but large negative 1st moment entirely driven by assumptions on SU(3)
- caveat: dependence on FFs

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



COMPASS

Δs: can we blame it on the fragmentation fcts ?

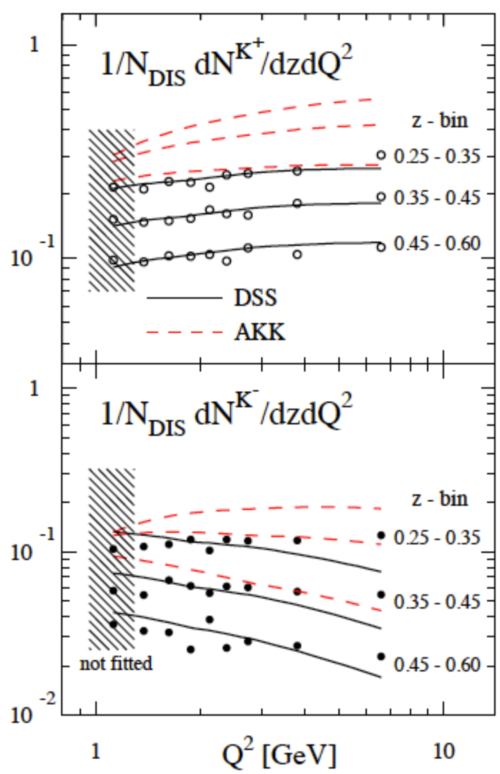
recently proposed as a "solution" to the "strange quark puzzle": Leader, Sidorov, Stamenov arXiv:1103.5979

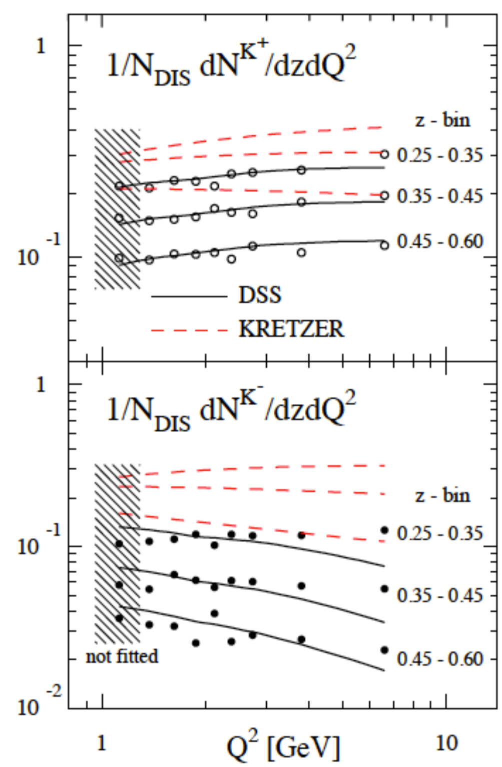
indeed, flavor decomposition strongly depends on fragmentation functions

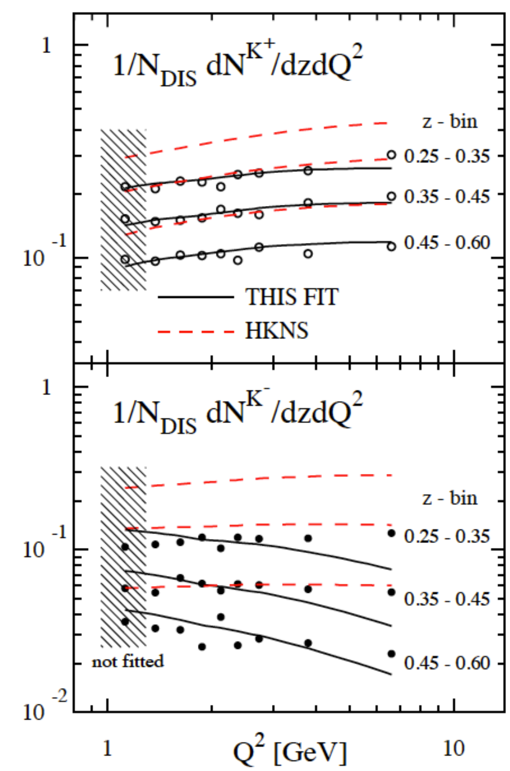
different FFs → different results   but wrong FFs → misleading results

find: only DSS FFs describe underlying unpol. cross sections in the relevant kinematics

of course, this does not guarantee that we extracted the right Δs: more data are needed



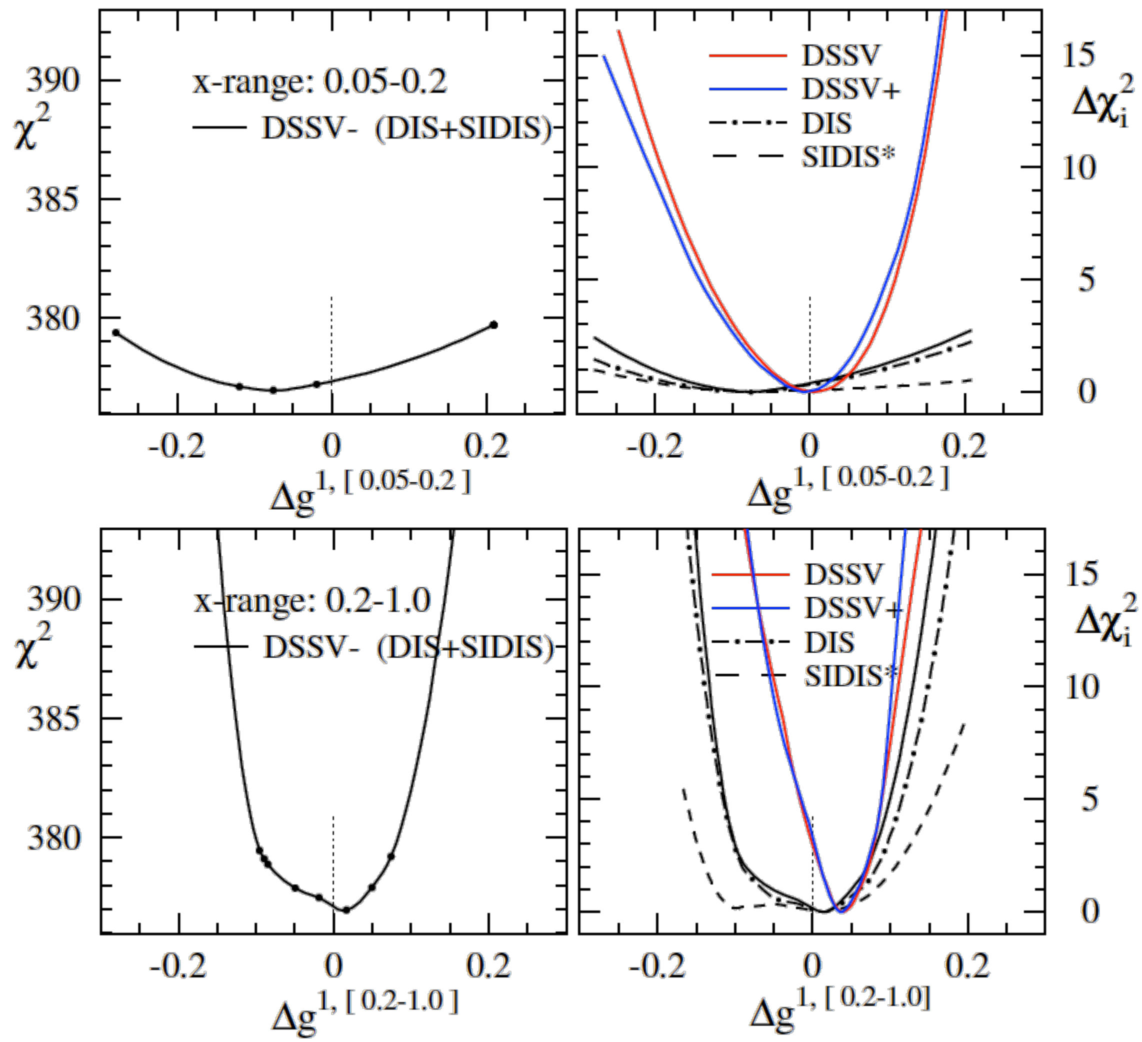




Δg and the relevance of RHIC data

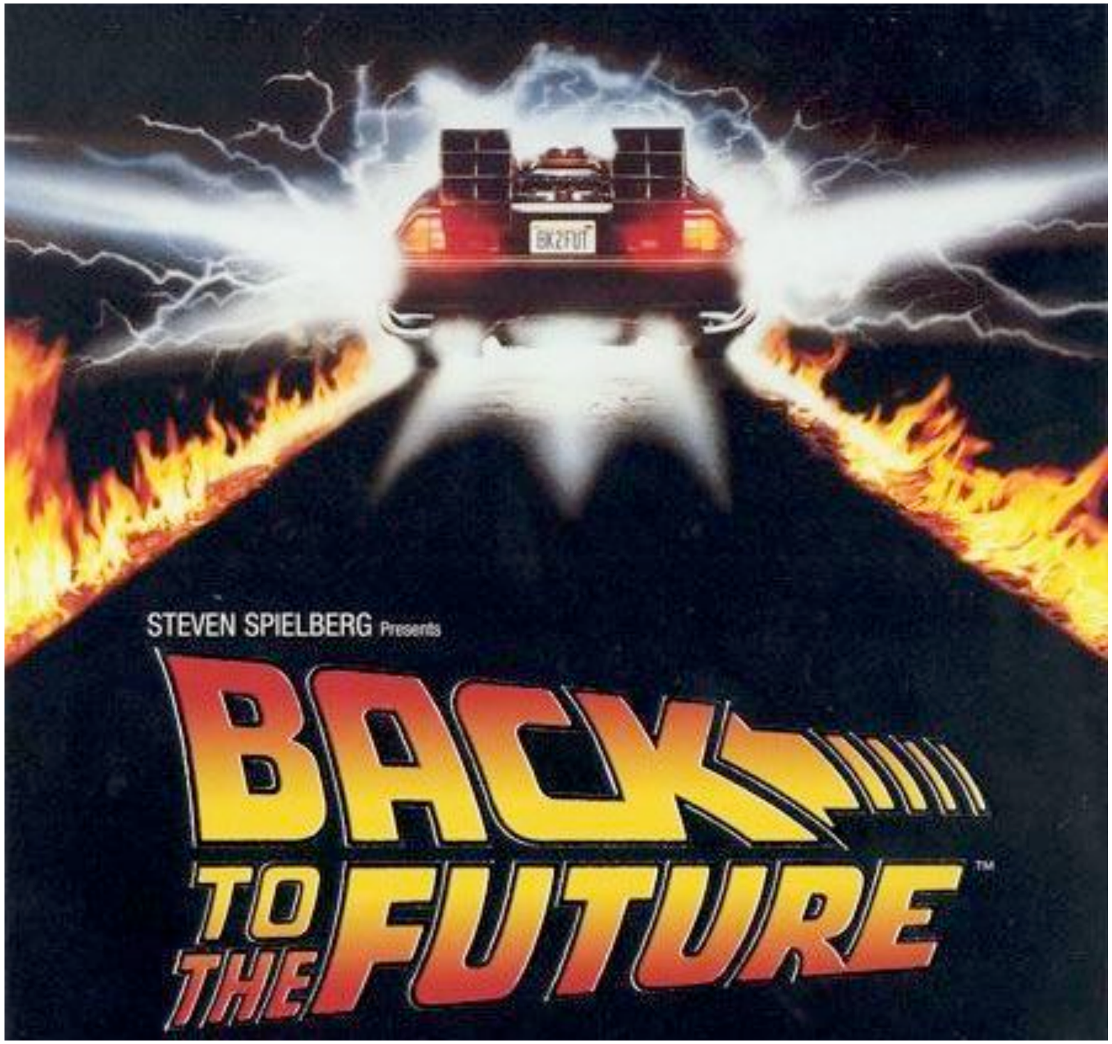
truncated moment
("RHIC pp region")

truncated moment
("high x")



bottom line

- RHIC pp data clearly needed (current DIS+SIDIS data alone do not constrain Δg)
- new (SI)DIS data do not change much for Δg
- trend for positive Δg at large x (as before)



Future Avenues

RHIC & Beyond

DSSV – readiness for new observables

- **general policy:** NLO must be known for an observable to be included in fit
- use of **improved Mellin technique** allows us to included *any* observable consistently at NLO accuracy without the usual cheating ("K-factors", etc)

most promising future avenues at RHIC to further our knowledge of pol. PDFs

focus on

- particle correlations, like di-jets — Δg

  better control on probed x-range; expect data soon

- rare probes (prompt photons, heavy flavors) — Δg

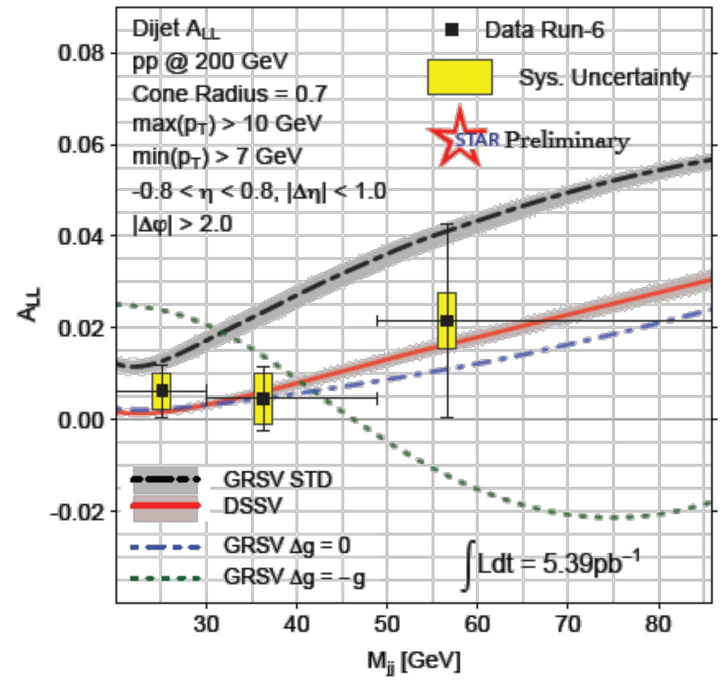
  probe different aspects of hard scattering dynamics (test of factorization)

- W boson parity-violating single spin asymmetries A_L — $\Delta\bar{u}, \Delta\bar{d}$; $\Delta u, \Delta d$

  neat handle on flavor separation; large asymmetries

Δg from jet-jet correlations

as presented at DNP'10



- particle correlations allow for a more precise mapping of x dependence

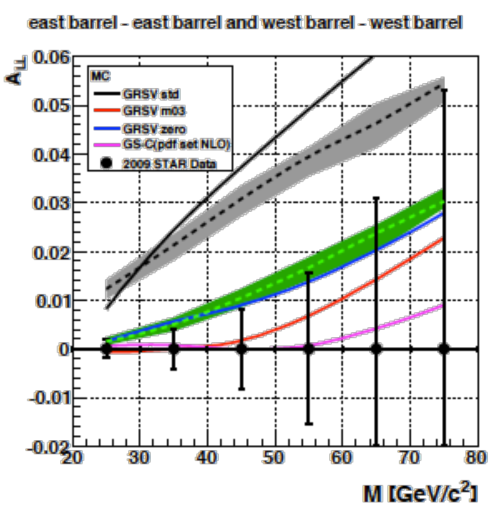
$$x_{1,2} = \frac{p_T}{\sqrt{S}}(e^{\pm\eta_3} + e^{\pm\eta_4})$$

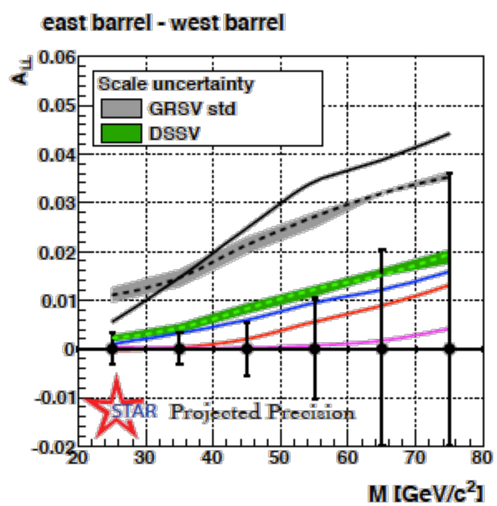
$$M^2/S = x_1 x_2$$

- NLO corrections available for dijets

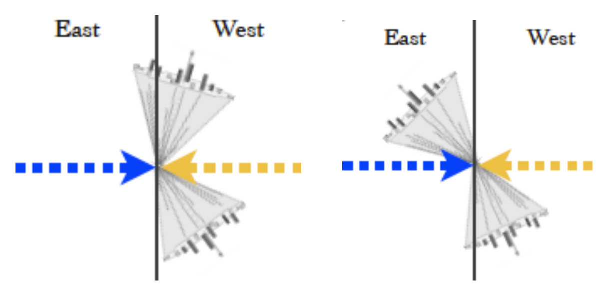
  de Florian, Frixione, Signer, Vogelsang

- Mellin technique in place to include upcoming data in DSSV analysis



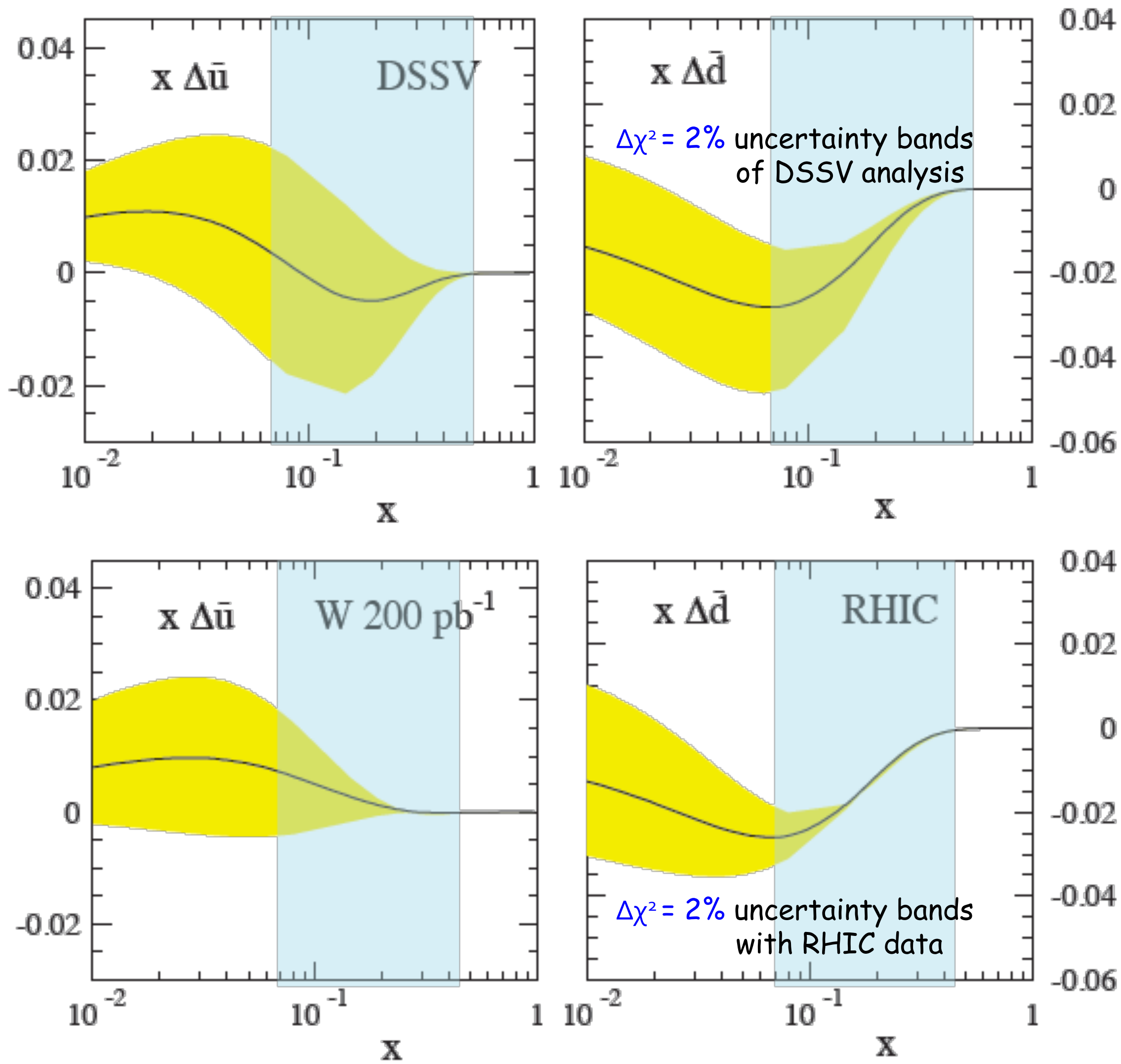


- projections for run 9



W program @ RHIC: what can we learn?

key measurement at RHIC: parity violating single spin asymmetry



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

new versatile NLO MC code

de Florian, Vogelsang, arXiv:1003.4533

simulated impact of RHIC W boson data on global fit

- ✓ reduction of uncertainties for 0.07 < x < 0.4
- ✓ can test consistency of low Q^2 SIDIS data in that x regime
- ✓ 1st PHENIX & STAR data no impact on fit yet "proof of principle"

opportunities for spin physics studies at an EIC

so far, our knowledge on polarized (SI)DIS is based on fixed target experiments

many "weak spots" & room for new "spin surprises":

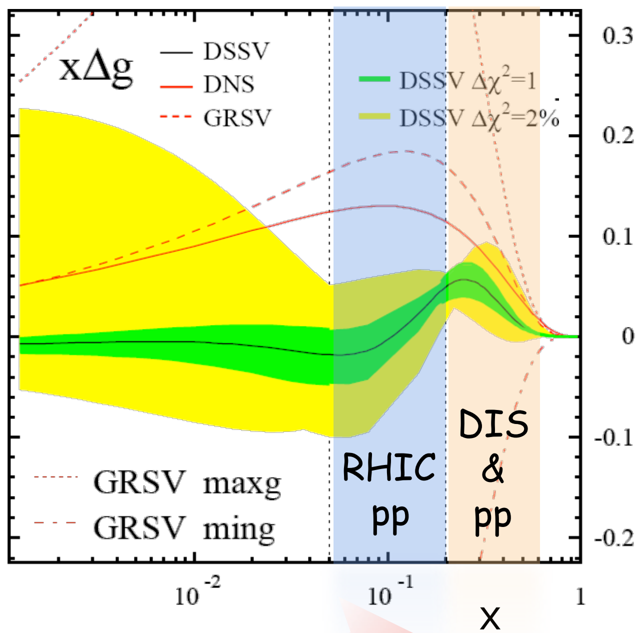
- small x region: crucial for all sum rules ("proton spin", "Bjorken", …) **unknown**
- flavor separation: SU(2), SU(3) breaking, strangeness **largely unknown**
- electroweak effects/structure fcts. **never measured**
- full understanding of transverse spin phenomena **still in early stages**
- issues with factorization for Sivers fct. **intriguing**
- role of orbital angular momentum **largely unknown**
- plus: spin phenomena in diffraction, photoproduction, hadronization, …

see also all the EIC talks tomorrow in the "Future of DIS" session

repeat full HERA program in polarized high energy ep scattering with good particle ID & ability to measure exclusive processes

teaser I: what can be achieved for Δg?

current status:

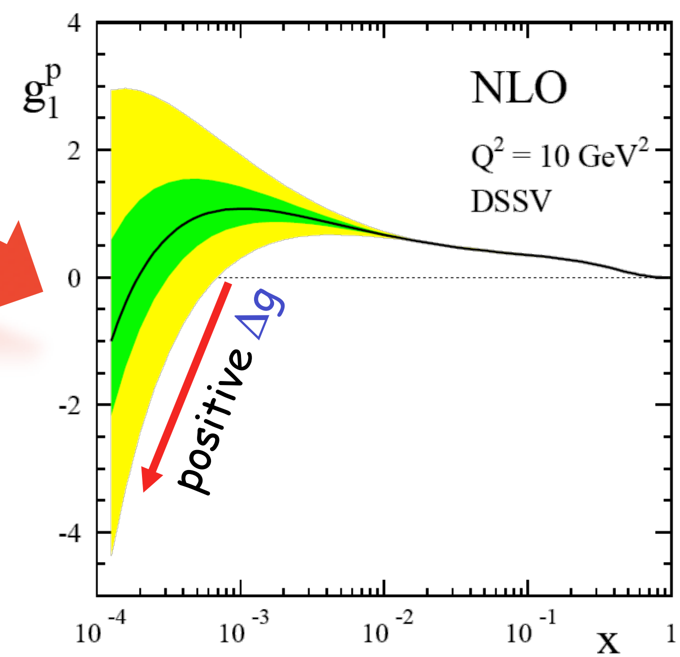


DSSV global fit
de Florian, Sassot, MS, Vogelsang

- low x behavior unconstrained
  significant polarization still possible
- no reliable error estimate for 1st moment $\int_0^1 dx\,\Delta g(x,Q^2)$ (entering spin sum rule)
- find $\int_{0.05}^{0.2} dx\,\Delta g(x,Q^2) \approx 0$

pQCD scaling violations

$$\frac{dg_1}{d\log(Q^2)} \propto -\Delta g(x,Q^2)$$

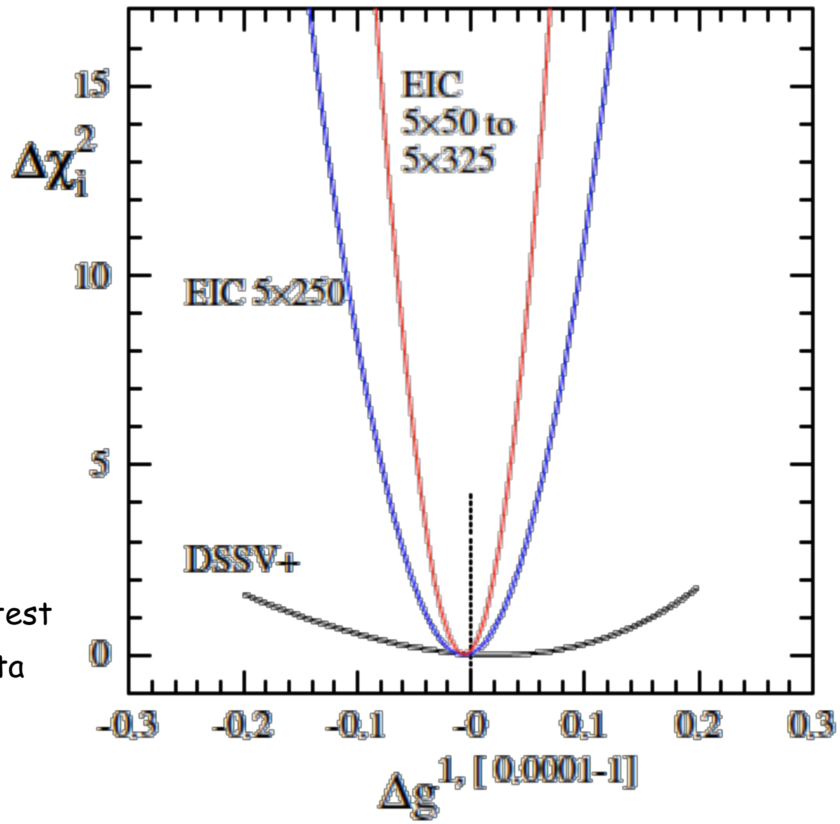


what can be achieved for Δg? – cont'd

how effective are scaling violations at the EIC

(studies based on simulated data for stage-1 of eRHIC [5x50, 5x100, 5x250, 5x325])

5x325 corresponds to $x_{min} \approx 1.6 \times 10^{-4}$



DSSV+ includes also latest COMPASS (SI)DIS data (no impact on DSSV Δg)

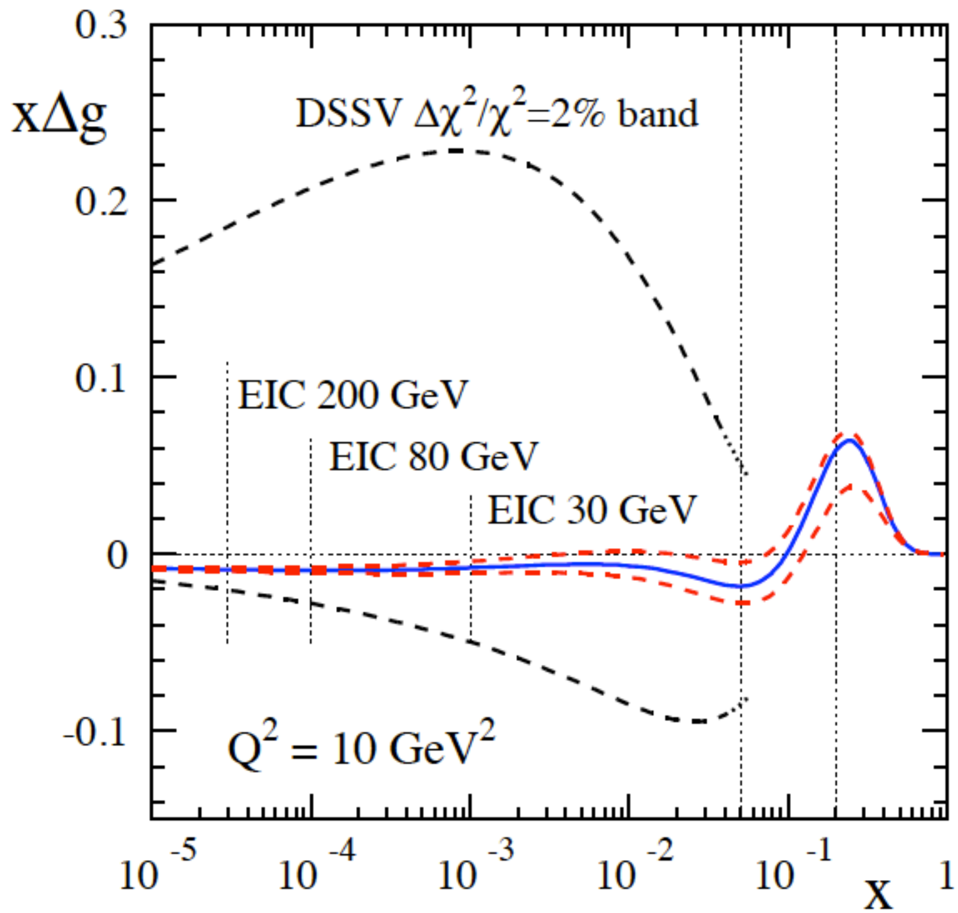
χ^2 profile slims down significantly already for EIC stage-1 (one month of running)

"issues":

- DIS meas. will be limited by systematics: polarimetry, detector performance, rel. lumi, …
- QED rad. corrections known to be large but need to reconstruct true x,Q^2 very well

what can be achieved for Δg? – cont'd

what about the uncertainties on the x-shape …

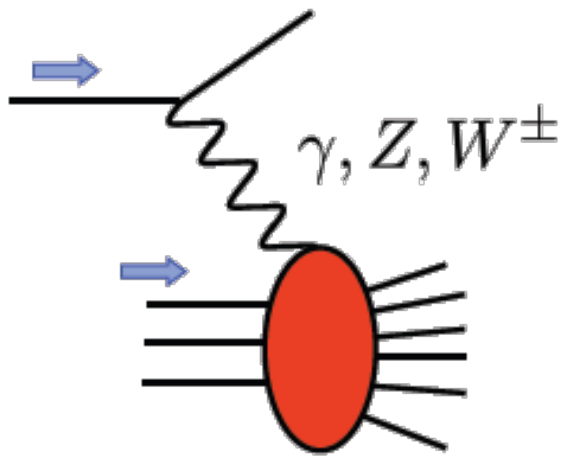


similar improvements can be expected for all quark flavors by studying SIDIS (work in progress)

- expect to determine $\int_0^1 dx\, \Delta g(x, Q^2)$ at about 10% level (or better – more studies needed)

kinematic reach down to $x = 10^{-4}$ essential to determine integral

teaser II: electroweak probes



studies by Deshpande, Kumar, Ringer, Riordan, Taneja, Vogelsang

at high enough Q^2 electroweak probes become relevant

- **neutral currents** (γ, Z exchange, γZ interference)
- **charged currents** (W exchange)

parameterized by new structure functions which probe combinations of PDFs different from photon exchange
--> **flavor decomposition without SIDIS, e-w couplings**

hadron-spin averaged case: studied to some extent at HERA (limited statistics)

hadron-spin difference:

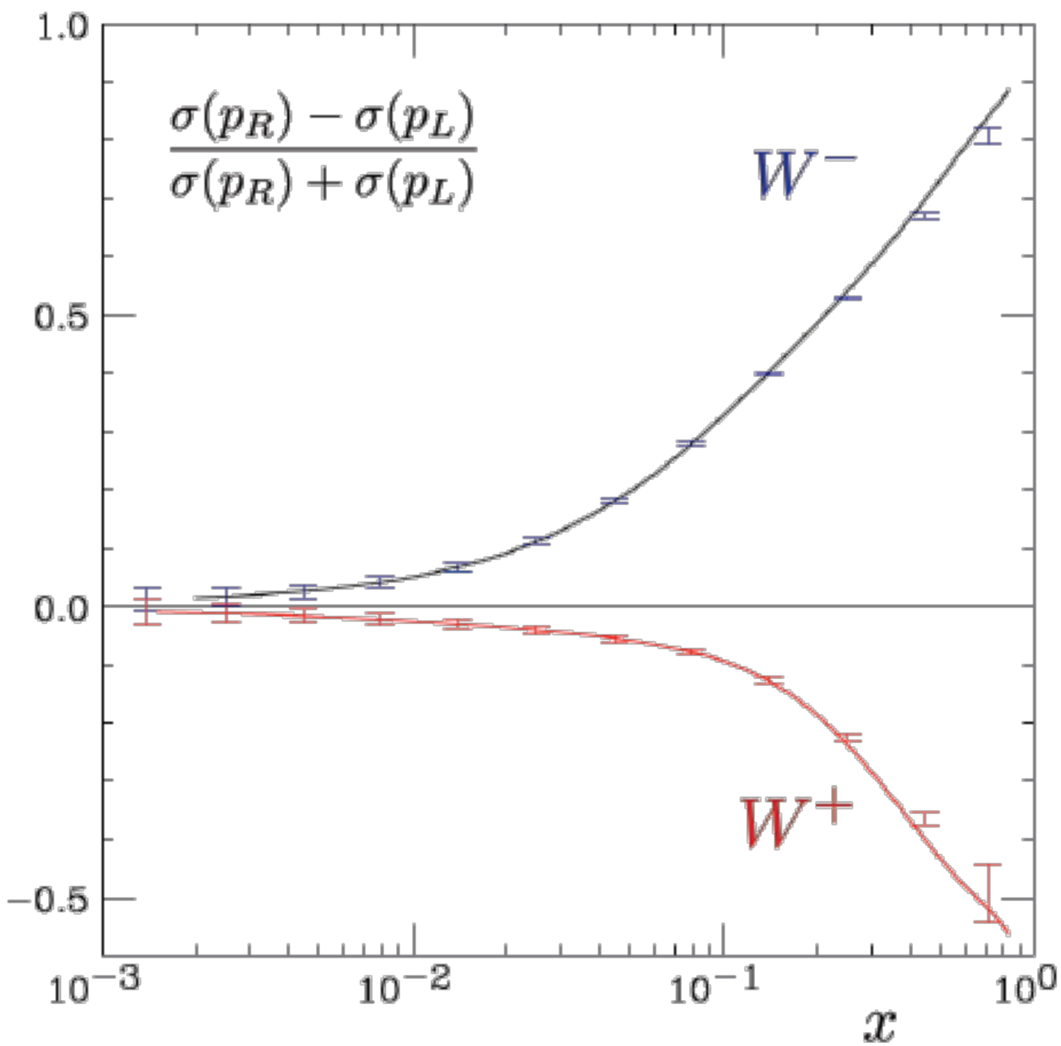
Wray; Derman; Weber, MS, Vogelsang; Anselmino, Gambino, Kalinowski; Blumlein, Kochelev; Forte, Mangano, Ridolfi; ...

contains e-w propagators and couplings

$$\frac{d\Delta\sigma^{e^{\mp},i}}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2}\left[\pm y(2-y)x\hat{g}_1^i - (1-y)\hat{g}_4^i - y^2 x\hat{g}_5^i\right] \quad \mathrm{i} = \mathrm{NC}, \mathrm{CC}$$

unexplored so far – unique opportunity for the EIC

most promising: CC DIS



20 × 250 GeV

$Q^2 > 1$ GeV^2

$0.1 < y < 0.9$

10 fb^{-1}

DSSV PDFs

need to be able to reconstruct x, Q^2 from hadronic final-state

separate up-type and down-type PDF combinations by varying y

$$A^{W^-} = \frac{(\Delta u + \Delta c) - (1-y)^2(\Delta\bar{d} + \Delta\bar{s})}{(u+c) + (1-y)^2(\bar{d}+\bar{s})} \qquad A^{W^+} = \frac{(1-y)^2(\Delta d + \Delta s) - (\Delta\bar{u} + \Delta\bar{c})}{(1-y)^2(d+s) + (\bar{u}+\bar{c})}$$

Cabibbo suppressed contributions neglected

other opportunities in polarized DIS at the EIC

- watch out for "surprises" at small-x = deviations from DGLAP Bartels, Ermolaev, Ryskin; Ermolaev, Greco, Troyan
  (might set in earlier than in unpol. DIS: $[\alpha_s \ln^2(1/x)]^k$; showing up as tension in global fits (?))

- tag on g_1^{charm} - irrelevant so far (<< 1%), driven by Δg at small x, NLO in progress Kang, MS

- extract (anti-)strangeness from CC charm production $W^+ s' \to c$ NLO Kretzer, MS

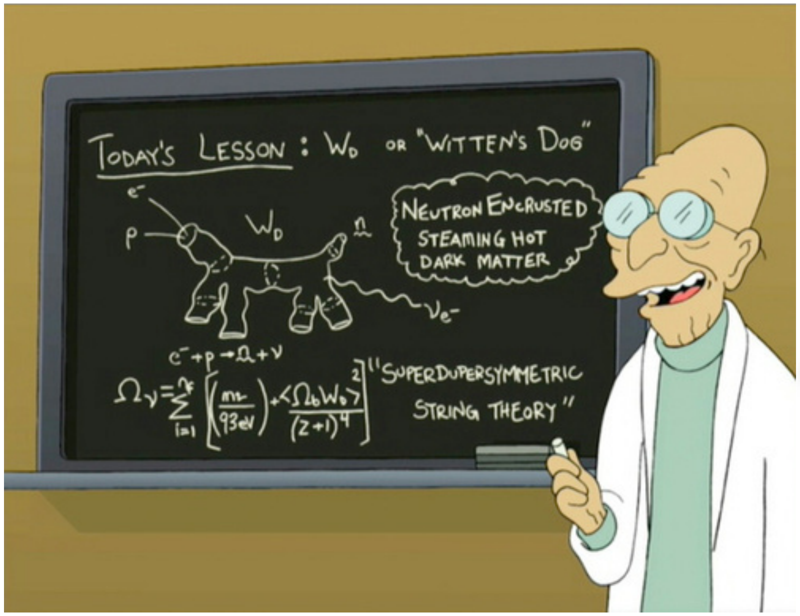
- Bjorken sum rule: $\int_0^1 dx\, [g_1^p(x,Q^2) - g_1^n(x,Q^2)] = \frac{1}{6} C_{\text{Bj}}\, [\alpha_s(Q^2)]\; g_A$

  - C_{Bj} known to $O(\alpha_s^4)$ Kodaira; Gorishny, Larin; Larin, Vermaseren; Baikov, Chetyrkin, Kühn, ...
  - but not a tool to determine α_s (1% change in α_s translates in 0.08% change of Bj sum)
  - experimental challenge: effective neutron beam (^{3}He), very precise polarimetry, ...
  - theor. motivation for precision measurement: **Crewther relation**

non-trivial relation of two seemingly unrelated quantities

Adler function $D(Q^2)$ in e^+e^- $\xleftrightarrow{\sim 1 + \frac{\beta(\alpha_s)}{\alpha_s} K(\alpha_s)}$ Bj sum $C_{Bj}(Q^2)$ in DIS

deviation from exact conformal symmetry



summary & outlook

- DSSV analysis of 2008 still in good shape
  - no official update forthcoming
  - COMPASS SIDIS data nicely described
  - may look into uncertainty bands
- ready to include di-jet, W boson data, … at NLO as they become available
- for the time being, flavor separation depends largely on SIDIS data
  - important to further improve fragmentation functions; DSS global analysis efforts ongoing
- to address outstanding questions access to small x is required
  - **having an EIC in the future is essential** (the sooner the better)
  - its c.m.s energy must be sufficiently large to reach $x \approx 10^{-4}$
  - we will need to control systematic uncertainties with unprecedented accuracy