

News from DSSV and DSS

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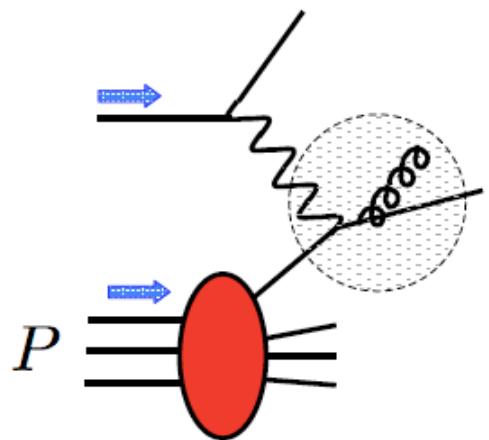
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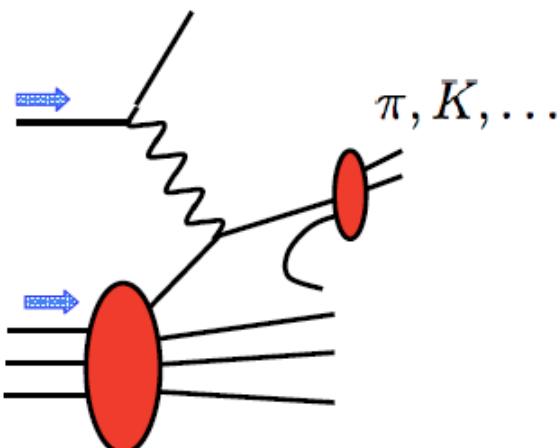
some DSSV basics

DSSV: a truly *global* NLO analysis

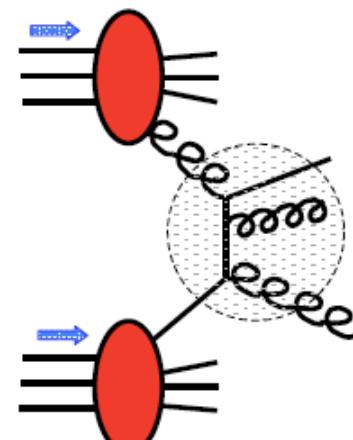
$$\Delta f(x) = f_{\rightarrow}(x) - f_{\leftarrow}(x)$$



DIS



SIDIS



pp

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

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

Δg charm, 2-hadrons

not yet
NLO complicated

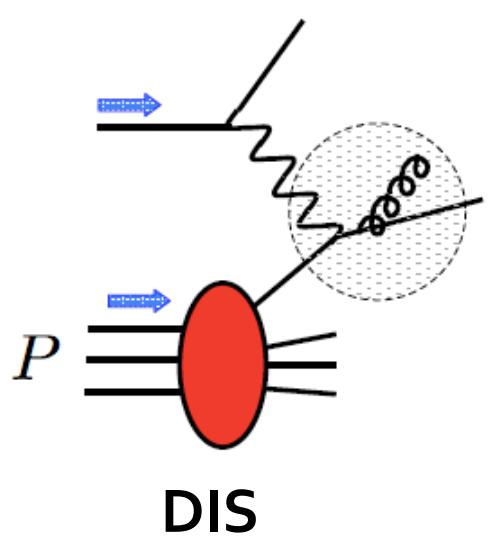
Δg 1-jet, 1-hadron

$\Delta q, \Delta \bar{q}$ $W^{+/-}$ bosons

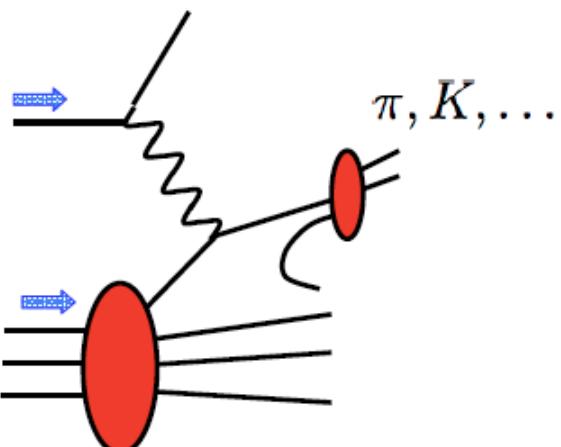
PRELIMINARY

DSSV: a truly **global** NLO analysis

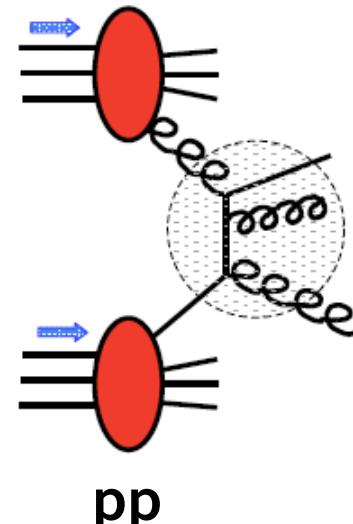
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PRELIMINARY

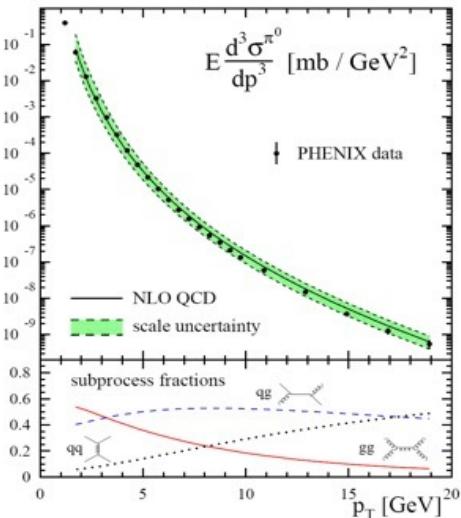
guiding principle: **factorization**

$$\text{e.g. DIS} \quad d\Delta\sigma = \sum_{f=q,\bar{q},g} \int dx \Delta f(x, Q^2) d\Delta\hat{\sigma}_{\gamma^* f}(xP, \alpha_s(Q^2))$$

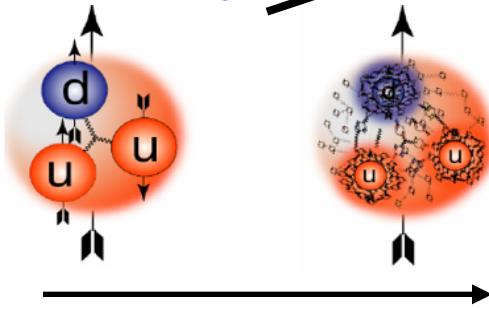
$$\text{essential: QCD corrections} \quad d\Delta\hat{\sigma} = d\Delta\hat{\sigma}^{\text{LO}} + \alpha_s d\Delta\hat{\sigma}^{\text{NLO}} + \dots$$

need DIS + SIDIS + pp to constrain **all** aspects of PDFs (also a way to test universality)

anatomy of DSSV global QCD analysis



Jager, MS, Vogelsang; de Florian;
Bojak, MS; Riedl, Schafer, MS;
Gordon, Vogelsang; Signer et al.;
Hendlmeier, Schafer, MS;
Contogouris et al.;

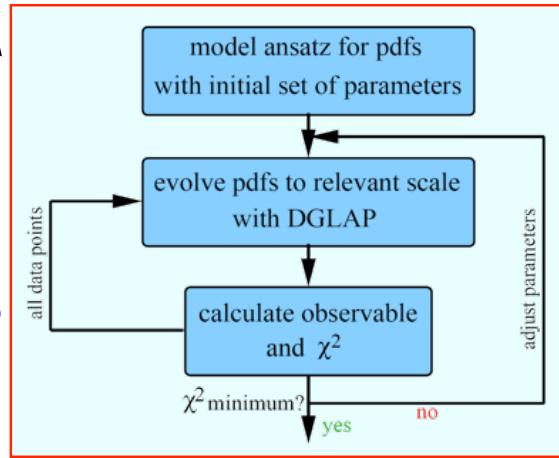


NLO: Mertig, van Neerven; Vogelsang; ... ;
NNLO: Moch, Vermaseren, Vogt 1409.5131

cross sections at NLO

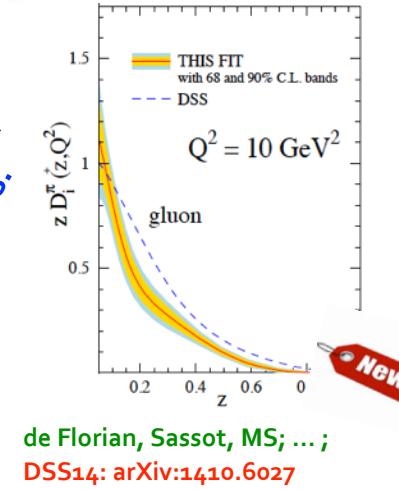
evolution kernels at NLO

obtain helicity PDFs
through global χ^2 optimization



set of optimum parameters
for assumed functional form

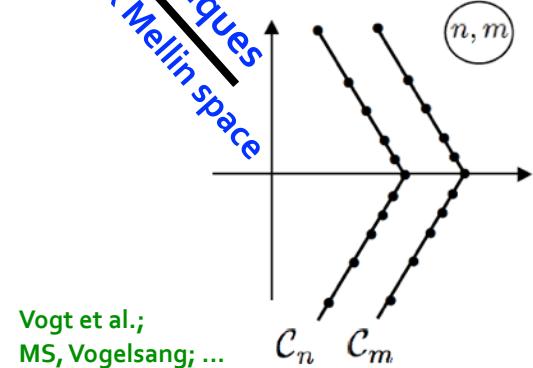
plus a prescription to
estimate & propagate
uncertainties



de Florian, Sassot, MS; ... ;
DSS14: arXiv:1410.6027

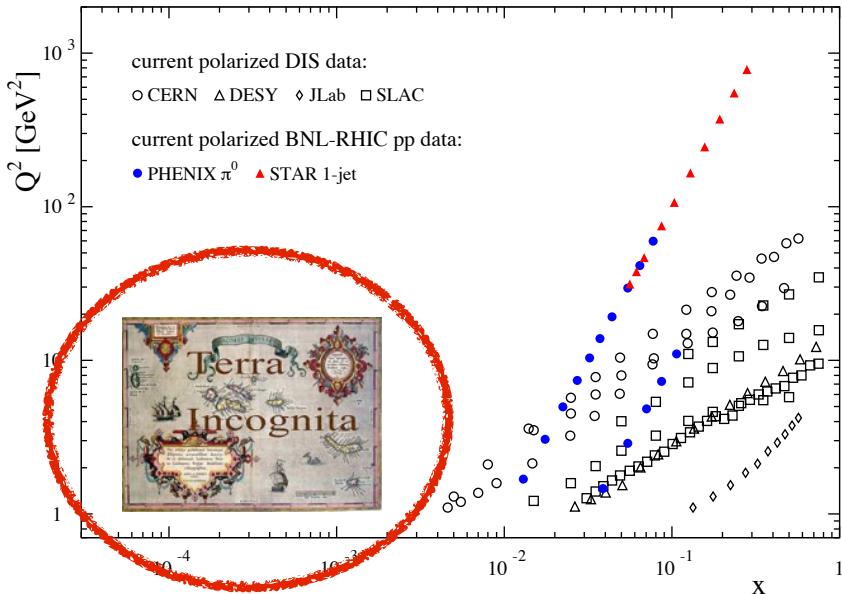
non-pert. inputs
e.g. frag. fcts.

novel techniques
e.g. in complex Mellin space



Vogt et al.;
MS, Vogelsang; ...

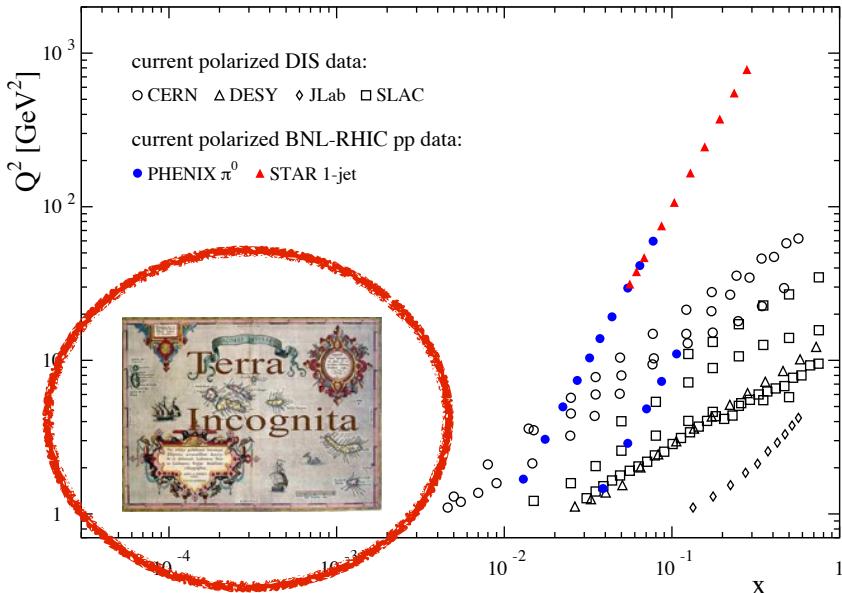
challenges compared to unpolarized PDF fits



□ rather limited x-Q² coverage

- difficult to get Δg from scaling violations
 - ▶ need to rely on “direct probes” for Δg
- need to use data down to $Q^2 = 1 \text{ GeV}^2$
 - ▶ applicability of pQCD ? higher twist ?

challenges compared to unpolarized PDF fits

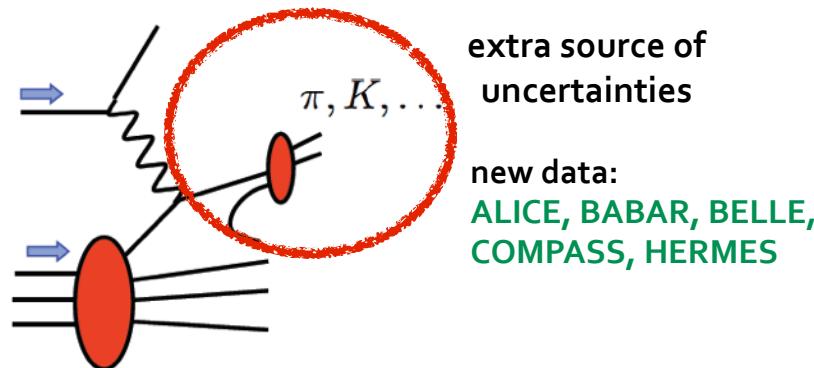


□ no neutrino DIS data

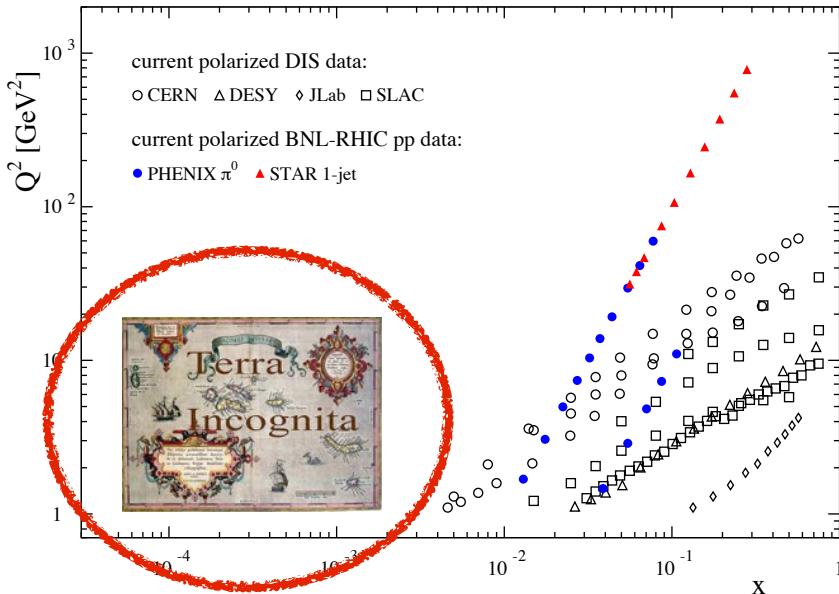
- no quark/anti-quark separation from DIS
 - ▶ largely rely on SIDIS for flavor separation
 - ▶ need fragmentation functions to analyze data

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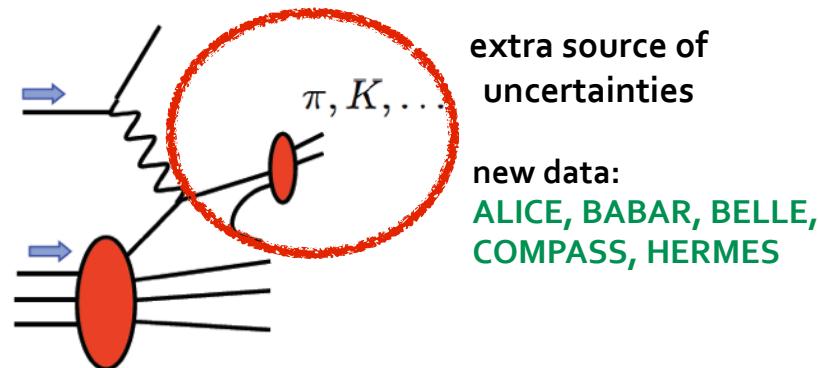
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□ sum rules on shaky (?) grounds

- 1st moments of non-singlet combinations <-> hyperon decays
 - ▶ constraint on unmeasured small-x behavior of Δs and $\Delta \Sigma$
 - ▶ doubts, however, on applicability of SU(3) relation
- Savage, Walden; ... ; Bali et al. 1112.3354 (lattice)**

□ rather limited x-Q² coverage

- difficult to get Δg from scaling violations
 - ▶ need to rely on “direct probes” for Δg
- need to use data down to $Q^2 = 1 \text{ GeV}^2$
 - ▶ applicability of pQCD ? higher twist ?



$$\begin{aligned} F + D &= 1.2701 \pm 0.0025 \\ 3F - D &= 0.585 \pm 0.025 \end{aligned}$$

$\Delta s(x) ??$

2



DSSV through the years

evolution of DSSV

DSSV '08

PRL 101, 072001 (2008)

PHYSICAL REVIEW LETTERS

week ending
15 AUGUST 2008

Global Analysis of Helicity Parton Densities and their Uncertainties

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Werner Vogelsang

Physics Department, Brookhaven National Laboratory, Upton, New York 11973, USA

(Received 3 April 2008; published 14 August 2008)

We present a new analysis of the helicity parton distributions of the nucleon. The analysis takes into account the available data from inclusive and semi-inclusive polarized deep inelastic scattering, as well as from polarized proton-proton ($p-p$) scattering at RHIC. For the first time, all theoretical calculations are performed fully at next-to-leading order (NLO) of perturbative QCD, using a method that allows incorporation of the NLO corrections in a very fast and efficient way in the analysis. We find evidence for a rather small gluon polarization in the nucleon, over a limited region of momentum fraction, and for interesting flavor patterns in the polarized sea.

DOI: 10.1103/PhysRevLett.101.072001

PACS numbers: 13.88.+e, 12.38.Bx, 13.60.Hb, 13.85.Ni

DSSV ++

various impact studies for RHIC,
e.g., STAR W boson data

1st evidence for non-zero Δg from RHIC

68 and 90% CL uncertainties with
dynamical tolerances [a la MSTW]

extraction of Δg from 1st RHIC data

“ $\Delta\chi^2 = 2\%$ ” error estimates based on L.M.

DSSV +

adds new COMPASS DIS & SIDIS data
impact on u, d sea quarks

DSSV '14

PRL 113, 012001 (2014)

PHYSICAL REVIEW LETTERS

week ending
4 JULY 2014

Evidence for Polarization of Gluons in the Proton

Daniel de Florian^{*} and Rodolfo Sassot[†]

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Ciudad Universitaria, Pabellón 1 (1428) Buenos Aires, Argentina

Marco Stratmann[‡]

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and Physics Department, Brookhaven National Laboratory, Upton, New York 11973, USA

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(Received 17 April 2014; published 2 July 2014)

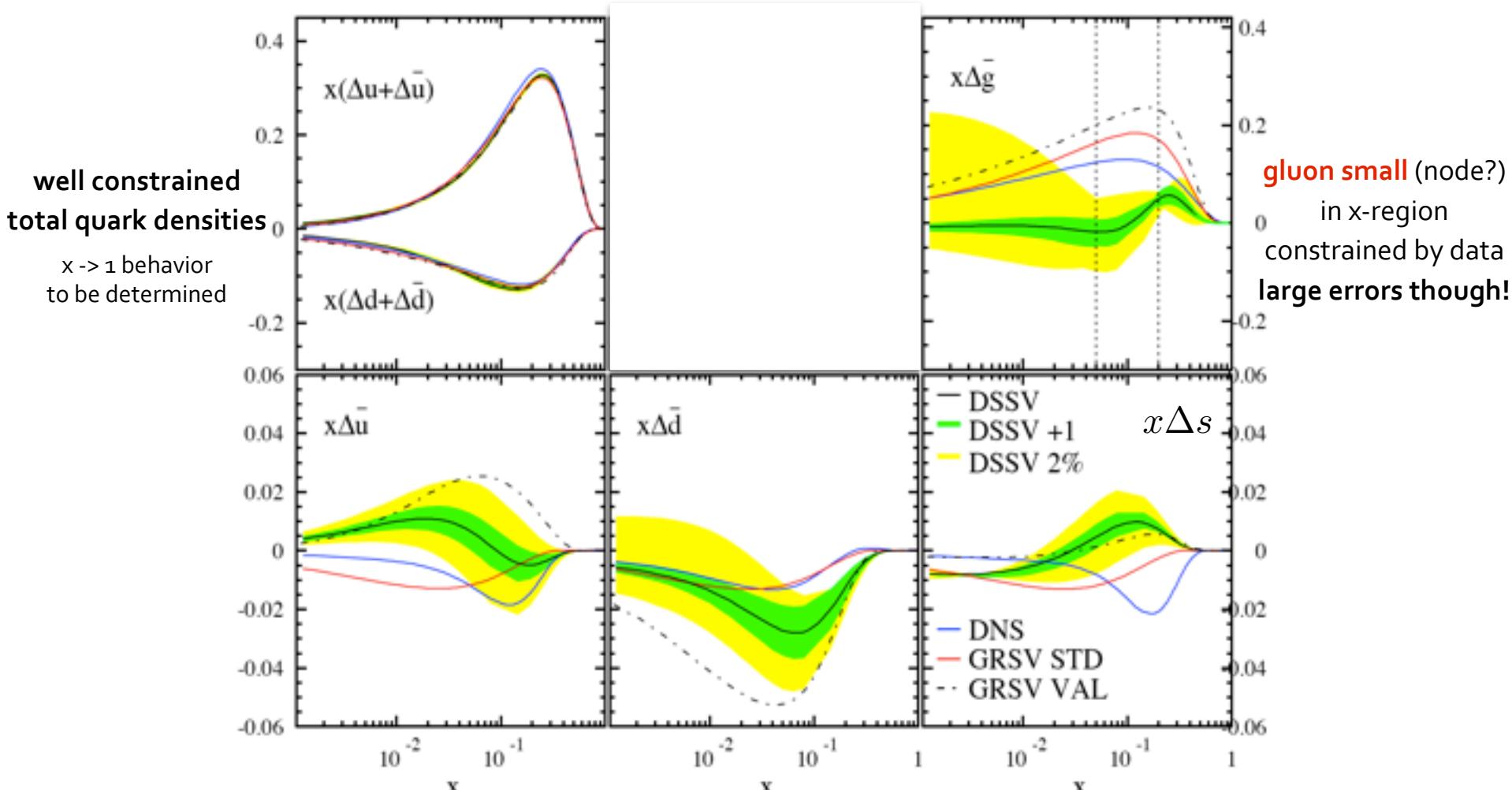
We discuss the impact of recent high-statistics Relativistic Heavy Ion Collider data on the determination of the gluon polarization in the proton in the context of a global QCD analysis of polarized parton distributions. We find evidence for a nonvanishing polarization of gluons in the region of momentum fraction and at the scales mostly probed by the data. Although information from low momentum fractions is presently lacking, this finding is suggestive of a significant contribution of gluon spin to the proton spin, thereby limiting the amount of orbital angular momentum required to balance the proton spin budget.

DOI: 10.1103/PhysRevLett.113.012001

PACS numbers: 13.88.+e, 12.38.Bx, 13.60.Hb, 13.85.Ni

emerging picture from original DSSV '08 analysis

de Florian, Sassot, MS, Vogelsang; PRL 101 (2008) 072001; PR D80 (2009) 034030



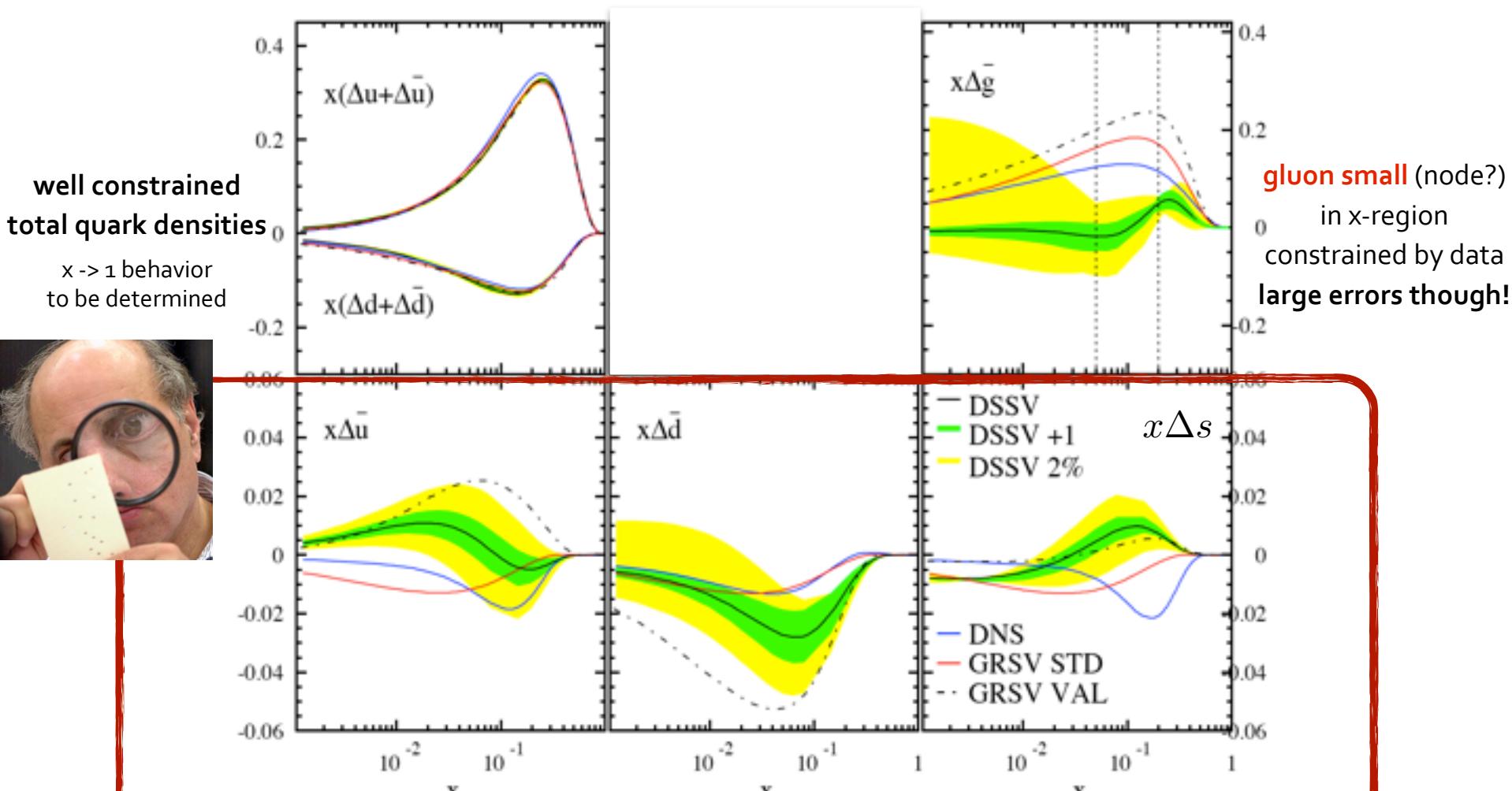
indications for non-trivial $\Delta\bar{u} > 0$
sea quark polarizations $\Delta\bar{d} < 0$

surprising strangeness polarization
sizable SU(3) breaking?

requires reliable kaon fragmentation fcts.
lattice: Bali et al., 0811.0807; 0911.2407; 1011.2194

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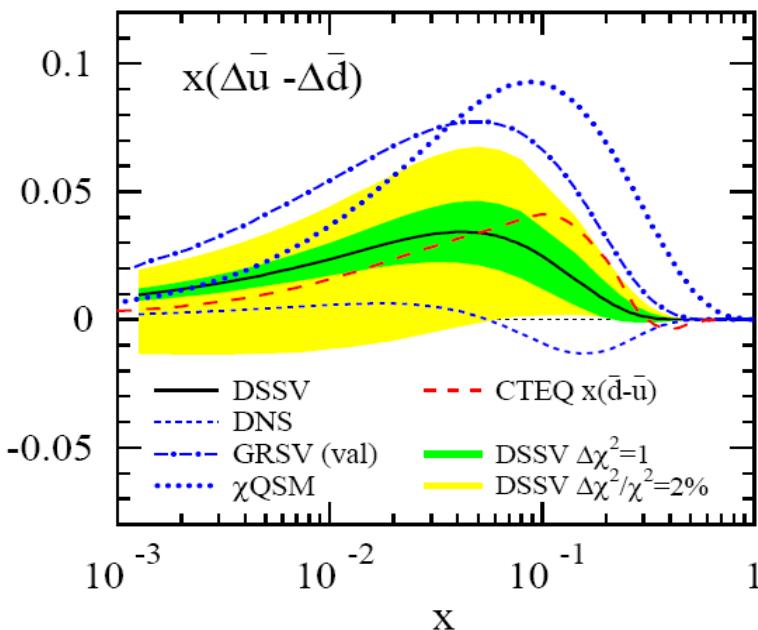
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gluon small (node?)
in x-region
constrained by data
large errors though!

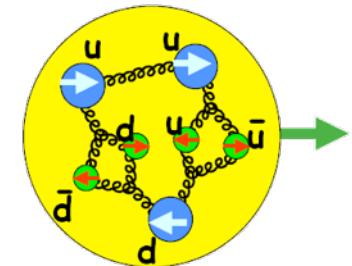
some hints at non-trivial sea polarizations



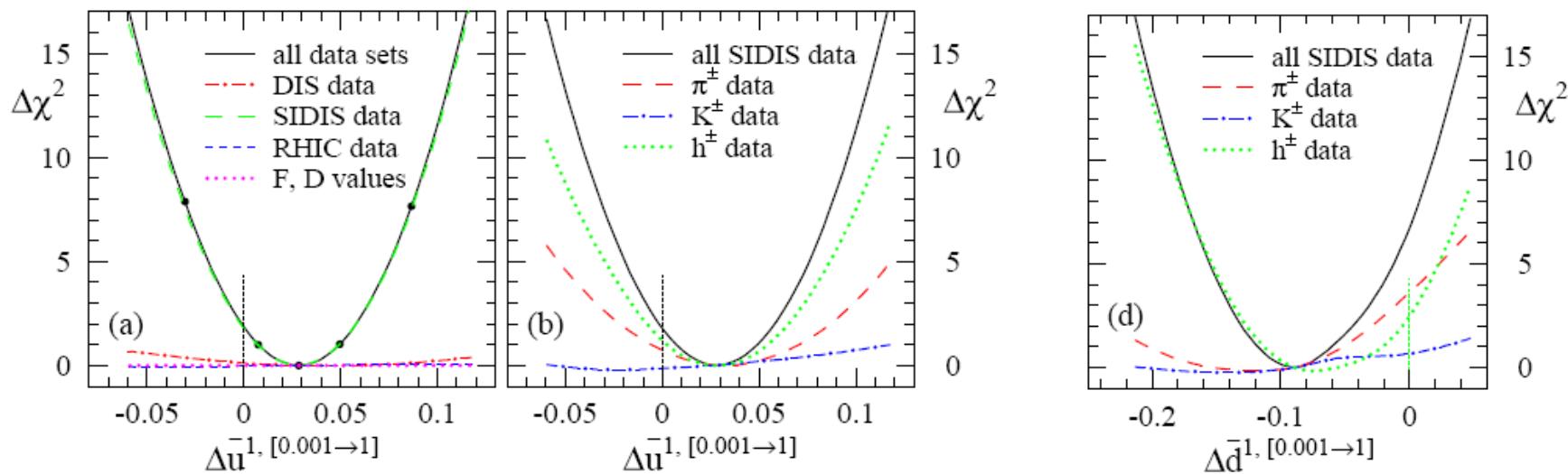
$$\Delta\bar{u} > 0 \quad \Delta\bar{d} < 0$$

- similar size but opposite sign than in unp. fits
- uncertainties still large
- driven by SIDIS data on π^+ and π^-
- connection to model calculations

Thomas, Signal, Cao; Holtmann, Speth, Fassler;
Diakonov, Polyakov, Weiss; Schafer, Fries;
Kumano; Wakamatsu; Gluck, Reya; Bourrely, Soffer, ...



relevant χ^2 profiles from L.M. analysis:



strangeness conundrum

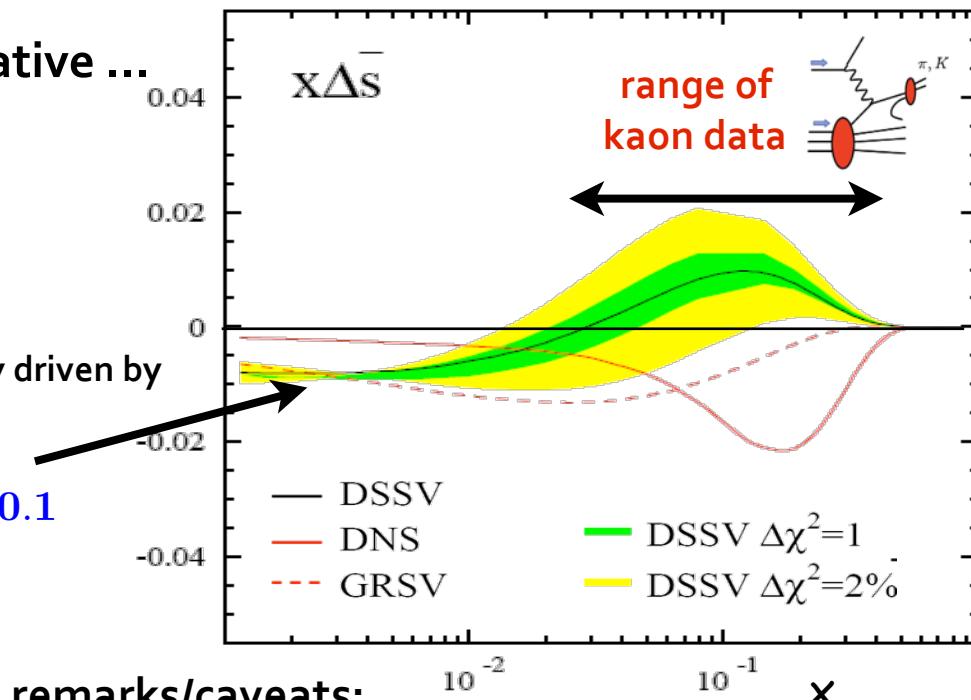
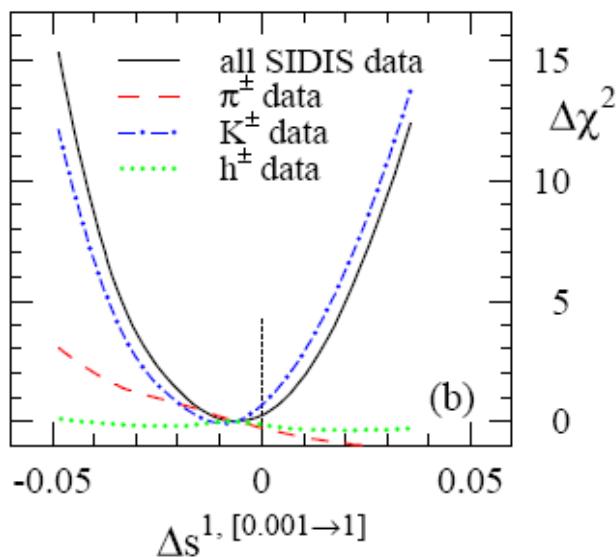
- Δs always assumed to be negative ...

sign change & small uncertainties entirely driven by

$$3F - D = 0.585 \pm 0.025$$

leads to $\int_0^1 dx [\Delta s + \Delta \bar{s}](x) \simeq -0.1$

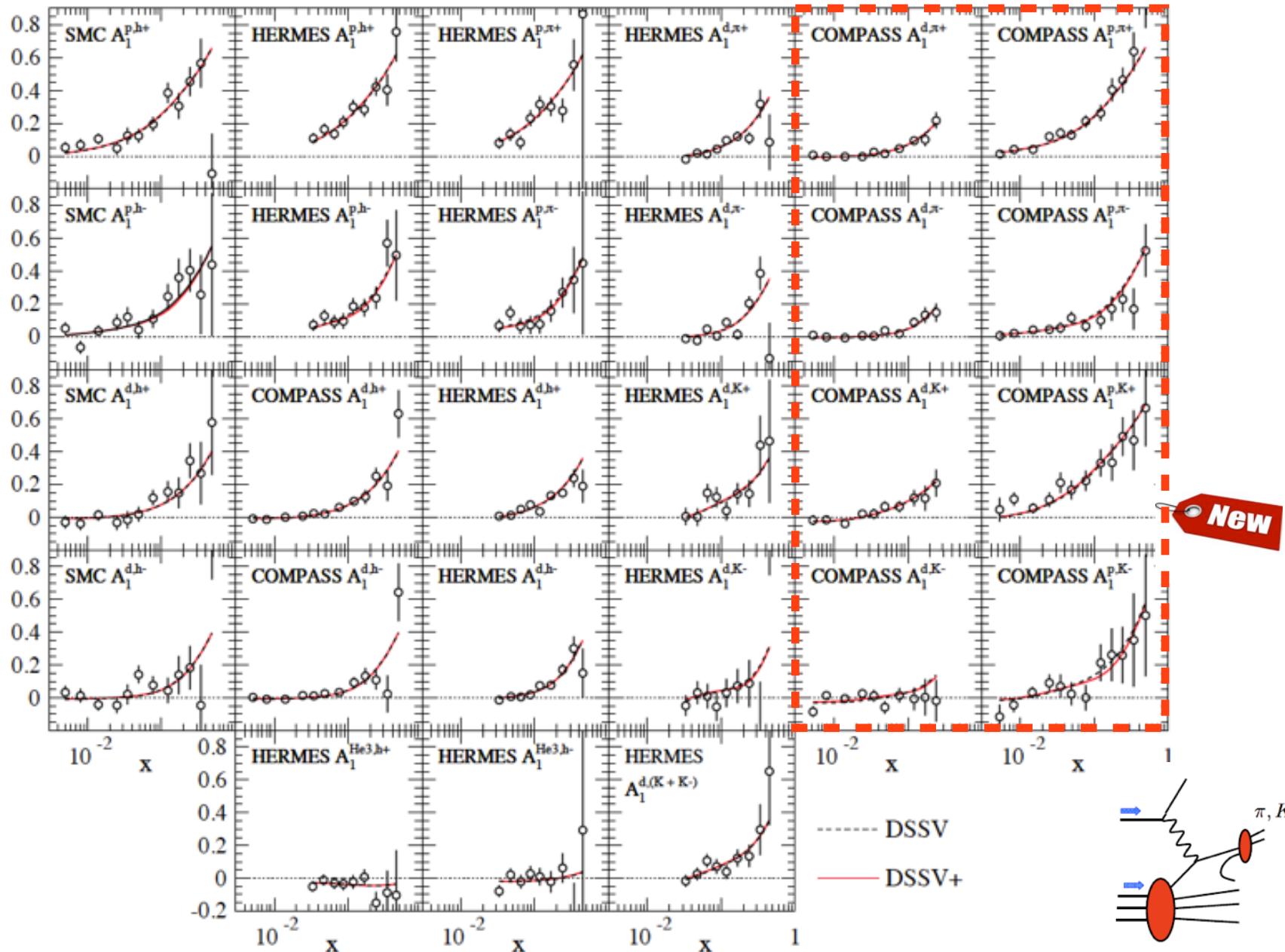
relevant χ^2 profile:



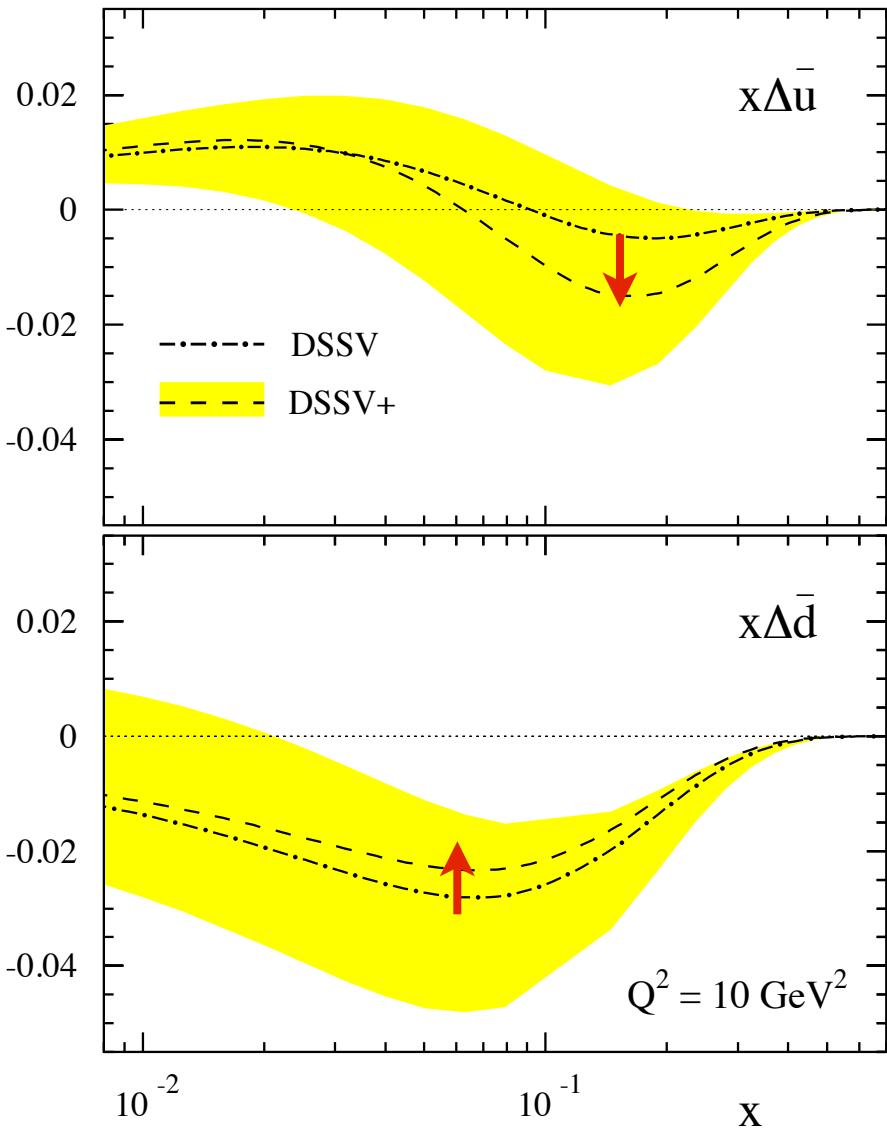
remarks/caveats:

- knowledge of parton-to-kaon FFs
- only HERMES data were available for DSSV fit
- can we trust $3F-D$ constraint ?
Lipkin; Zhu, Puglia, Ramsey-Musolf; Savage, Walden; ...
- lattice finds smallish strangeness
 $\int_0^1 dx [\Delta s + \Delta \bar{s}](x) \simeq -0.020(10)(1)$ Bali et al. 1112.3354
<-> large breaking of $3F-D$ relation
- recall old GRSV “valence scenario” with $\Delta s = 0$!

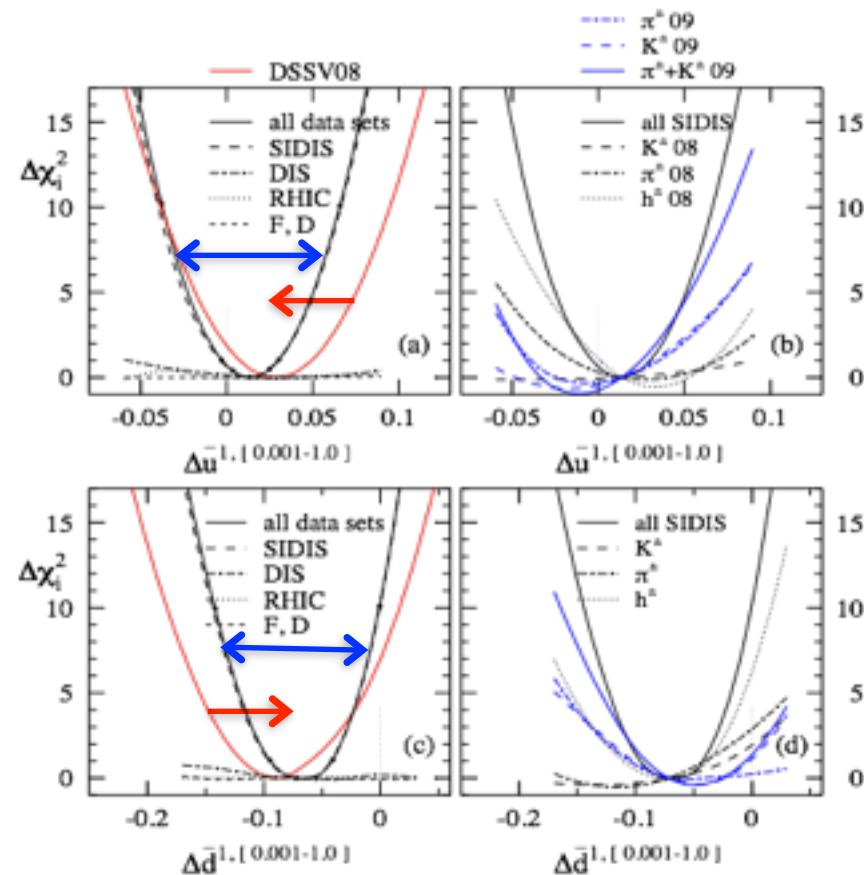
set of SIDIS data in DSSV+ analysis



DSSV vs DSSV+: what has changed?



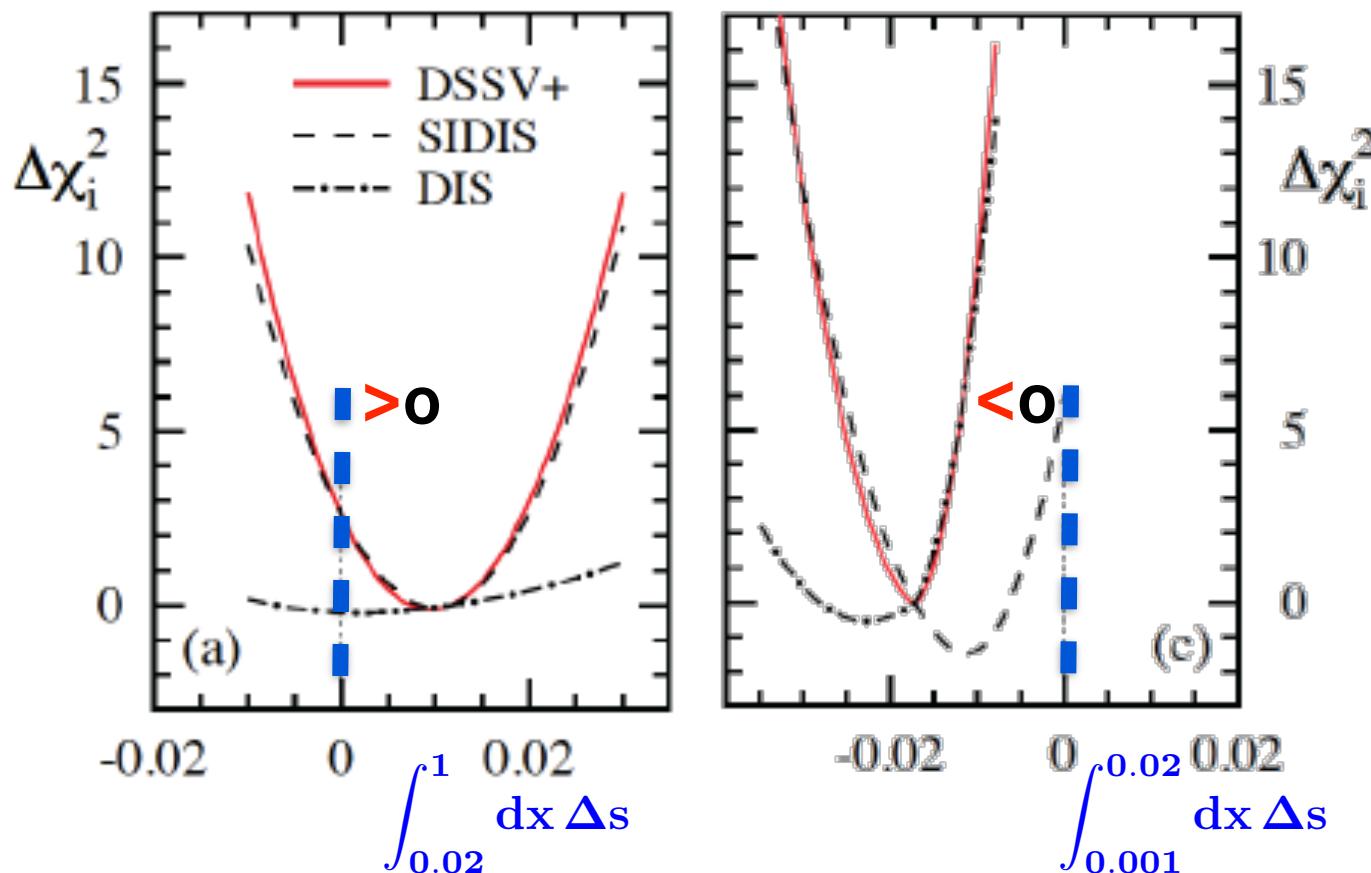
- less net polarization of sea quarks
- leads to smaller $\Delta\bar{u}(x) - \Delta\bar{d}(x)$
- Δs unchanged; HERMES & COMPASS compatible
- somewhat smaller uncertainties



Δs revisited: impact of COMPASS data

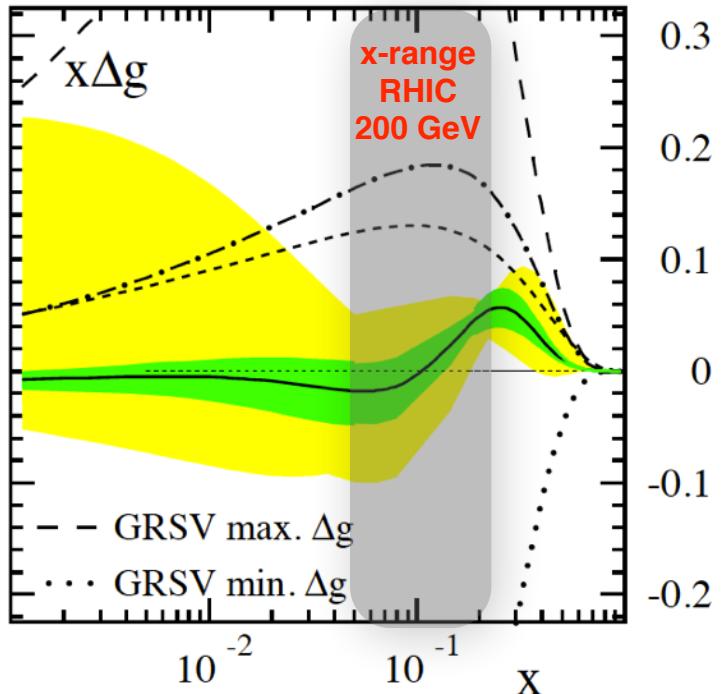
split up analysis of χ^2 profiles into

- x-region covered by HERMES and
- new information at smaller x from COMPASS



- agrees with Δs from HERMES data
- no tension with DIS data
- mild preference for sign change at around 0.01

extraction of Δg from RHIC

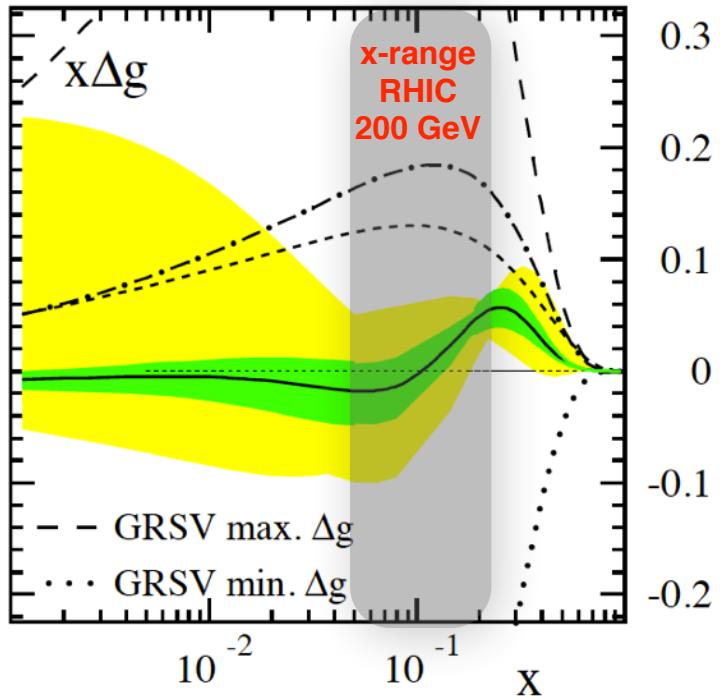


- 200 GeV data mainly probe gluon in $x=0.05-0.2$
- found to be small, but uncertainties still large

$$\int_{0.05}^{0.2} dx \Delta g(x, Q^2 = 10 \text{ GeV}^2) = 0.005^{+0.129}_{-0.164}$$

from DSSV '08 analysis

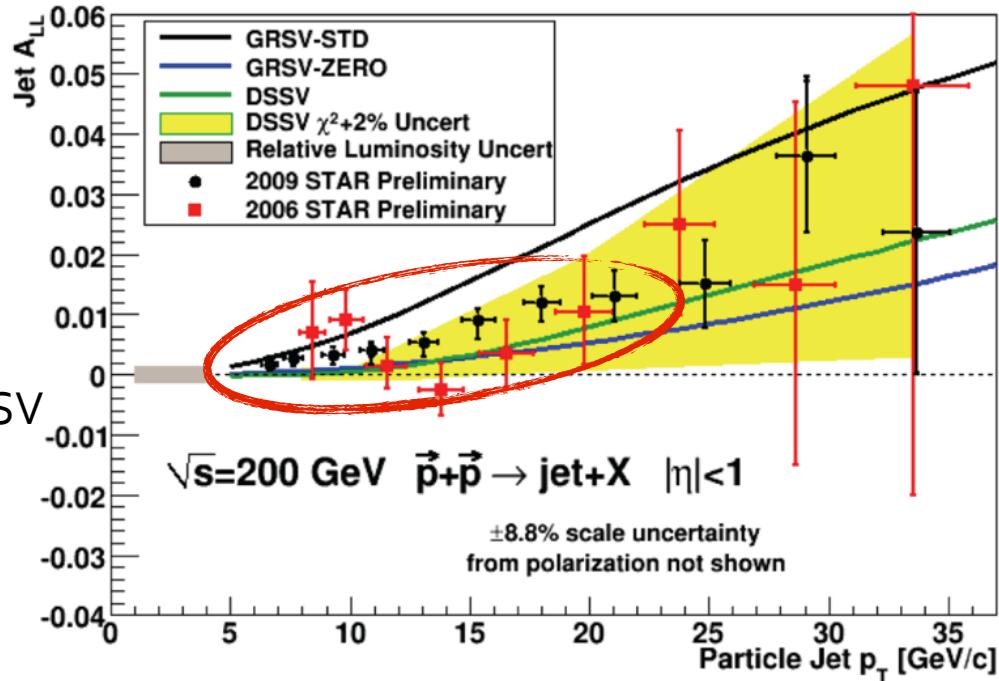
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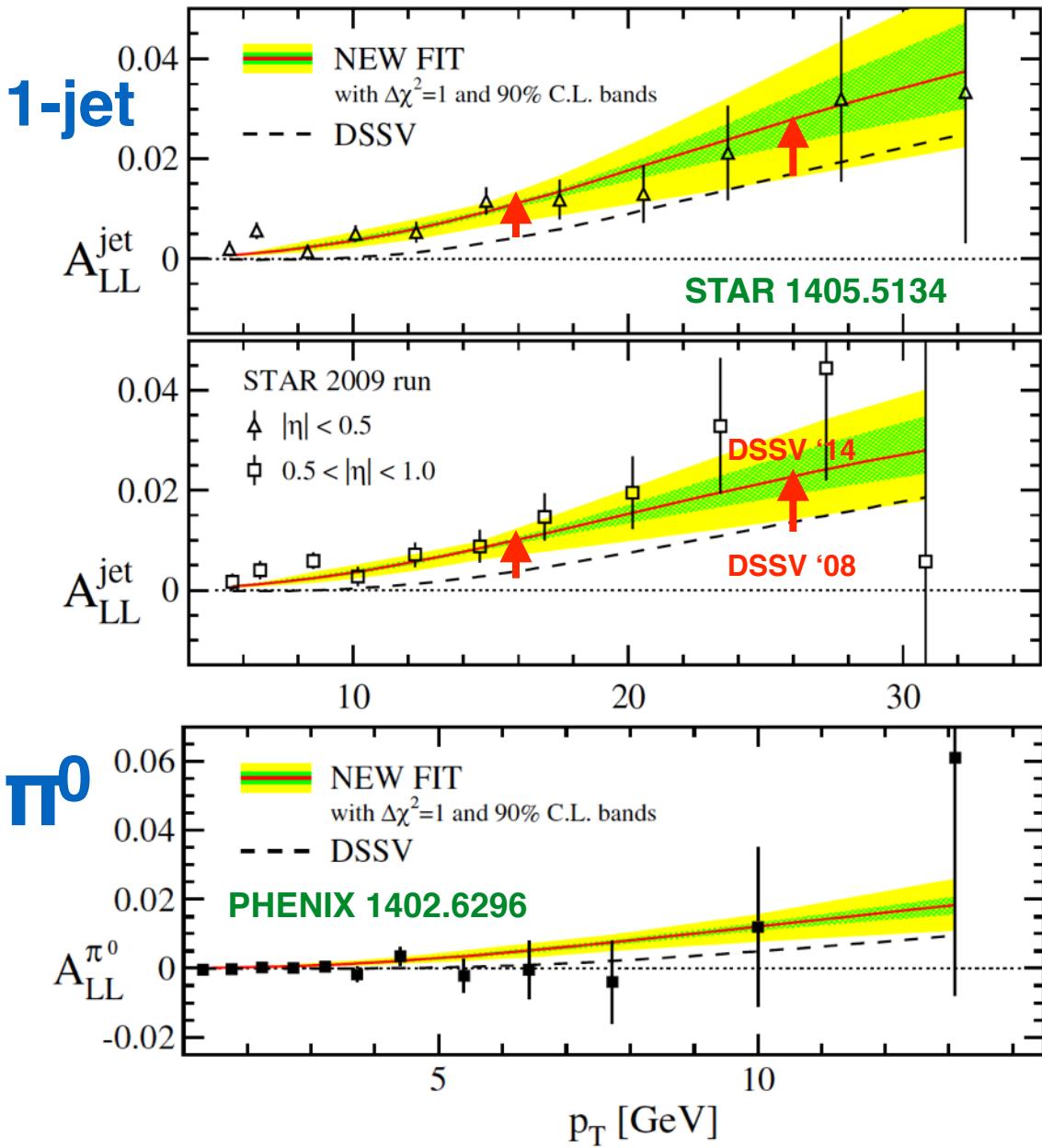
- new jet data consistently above DSSV
- considerably smaller errors

what's the impact?

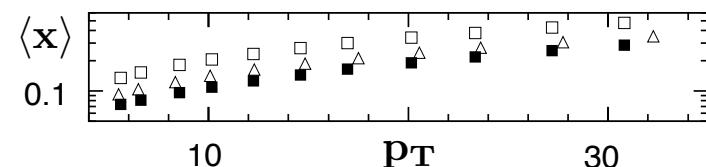


DSSV '14 adds run9 jet and π^0 data

de Florian, Sassot, MS, Vogelsang; PRL 113 (2014) 012001

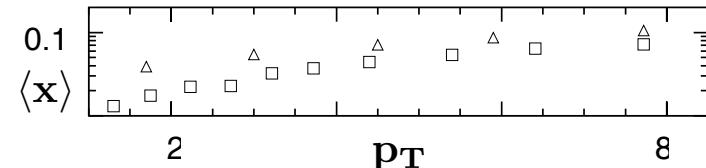


- jet data pull on Δg
- relevant x-range:

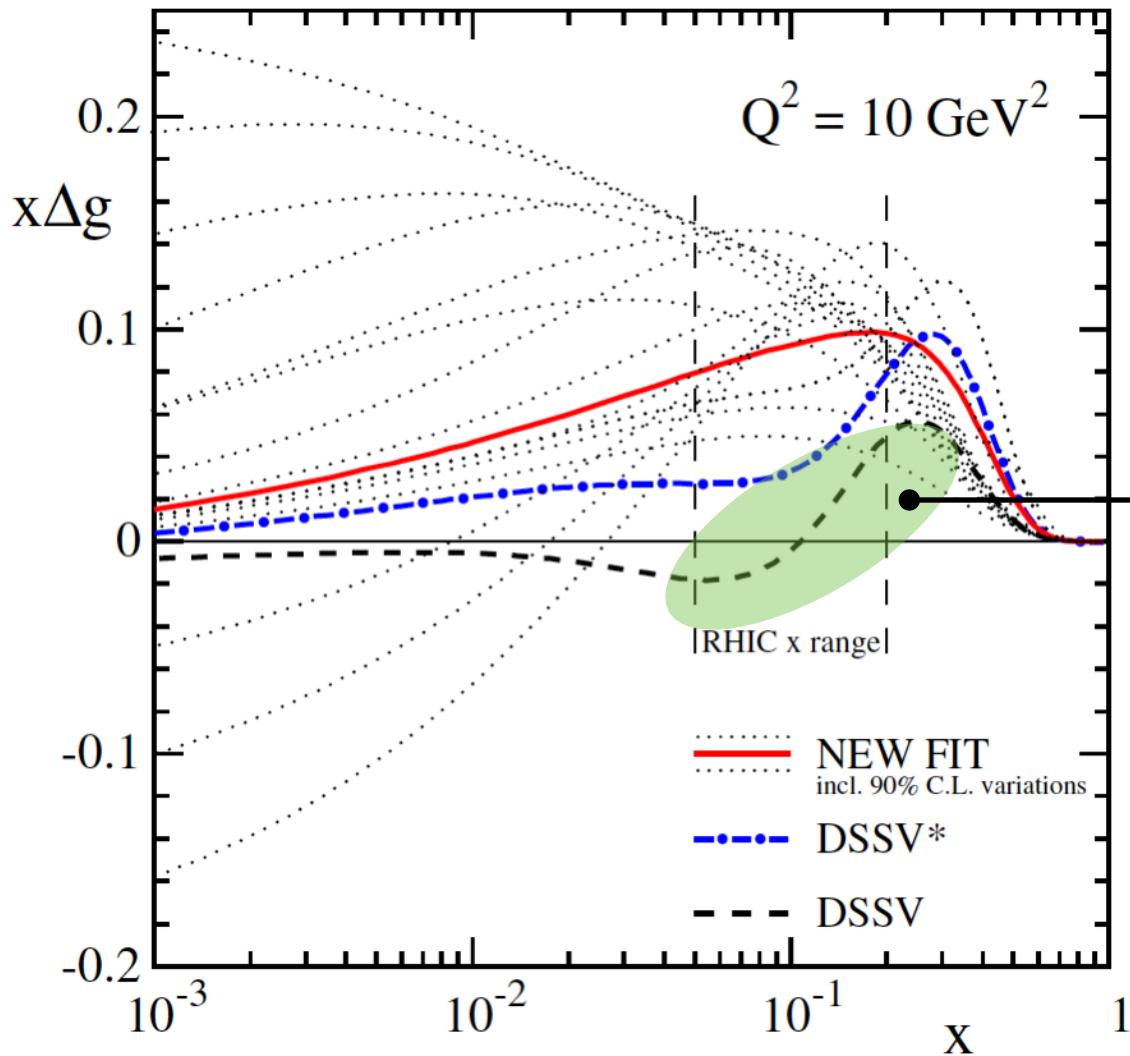


good combined fit
of STAR & PHENIX data
complementarity!

- π^0 's well described by DSSV '08
- probe lower x values:



resulting DSSV '14 gluon



functional form in DSSV:

$$x\Delta g(x, \mu_0^2) = N_g x^{\alpha_g} (1-x)^{\beta_g} (1 + \eta_g x^{\kappa_g})$$

“famous” node in DSSV’08

η_g essential for good fit

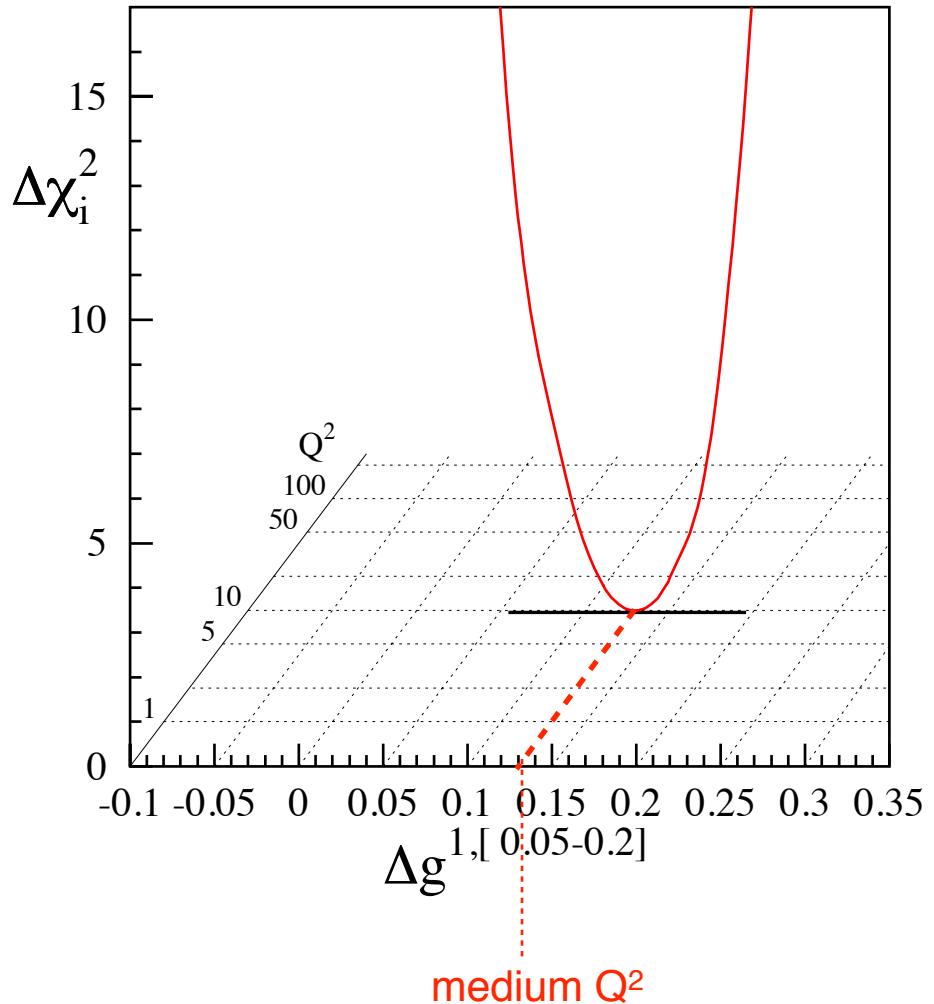
DSSV ’14 Δg much larger and positive

η_g only to produce small x variations

its Q^2 dependence

truncated moment in RHIC x-region

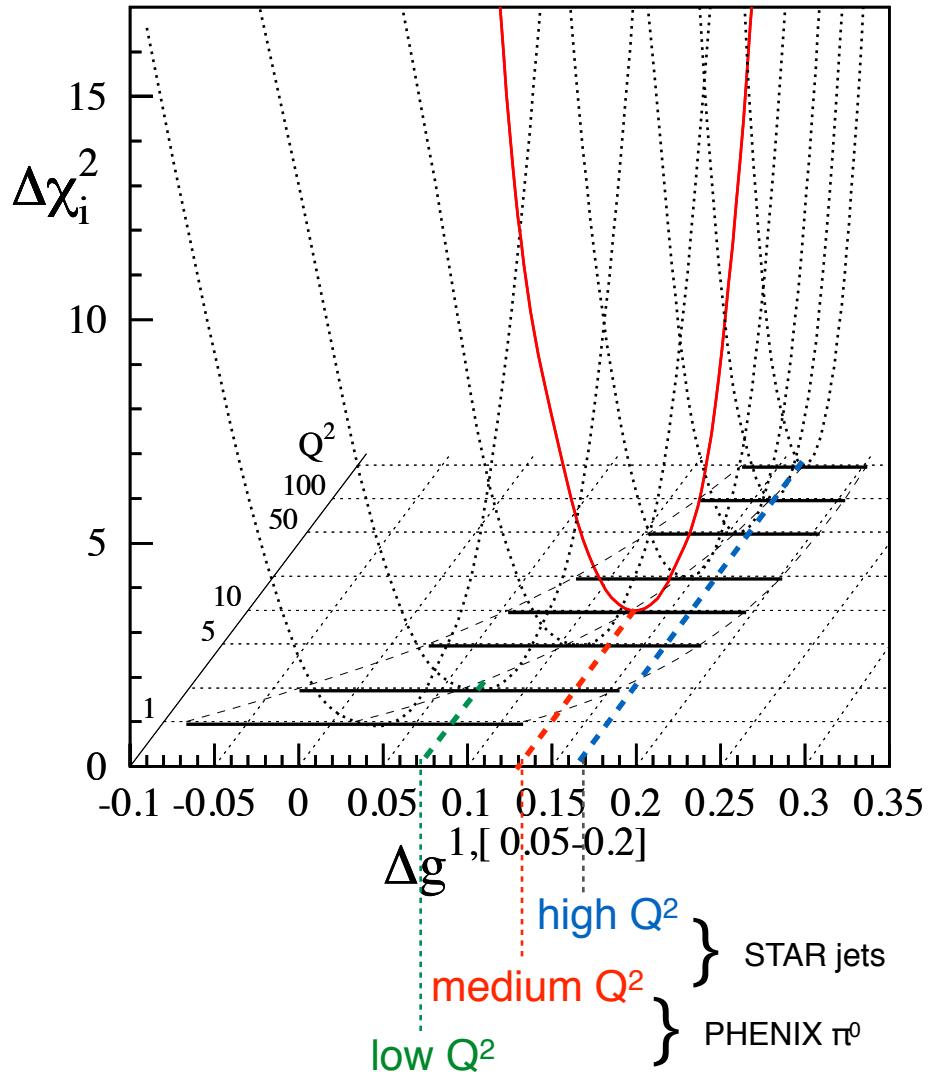
$$\Delta g^{1,[0.05-0.2]}(Q^2) \equiv \int_{0.05}^{0.2} \Delta g(x, Q^2) dx$$



its Q^2 dependence

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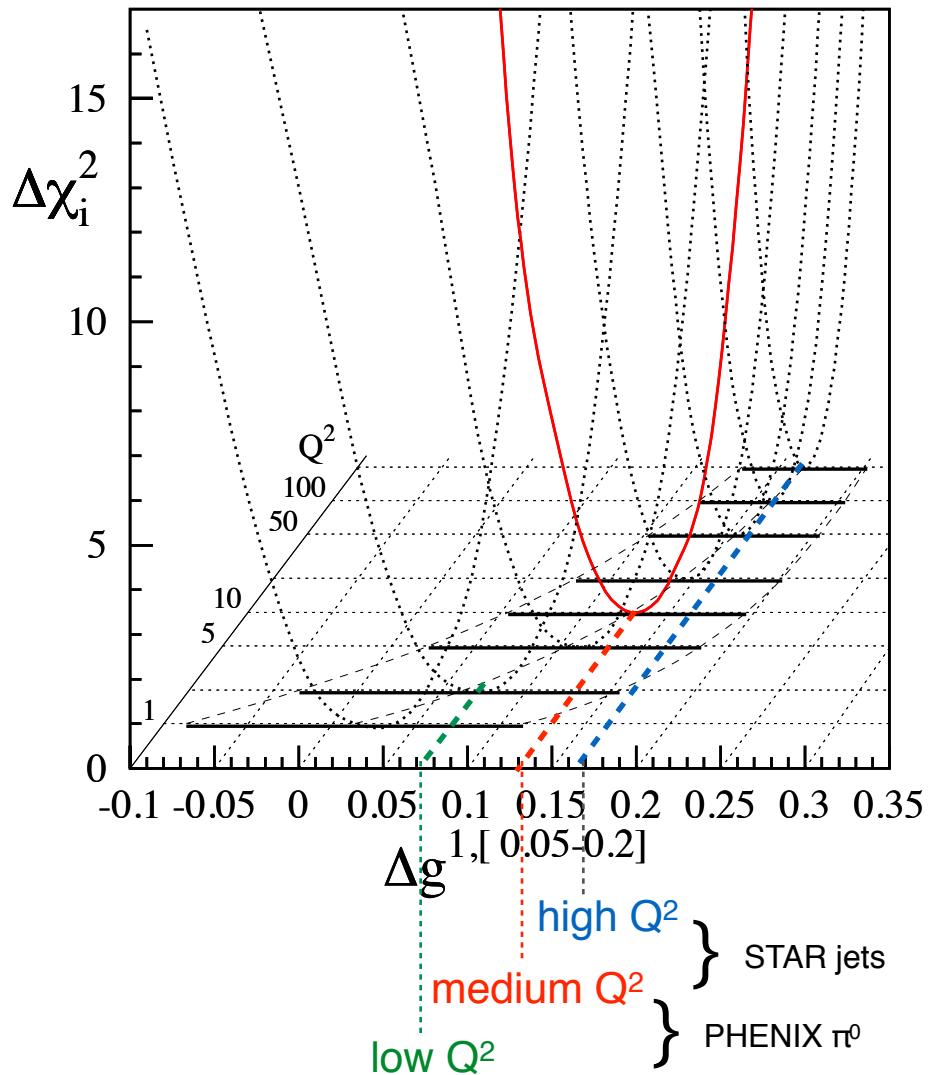
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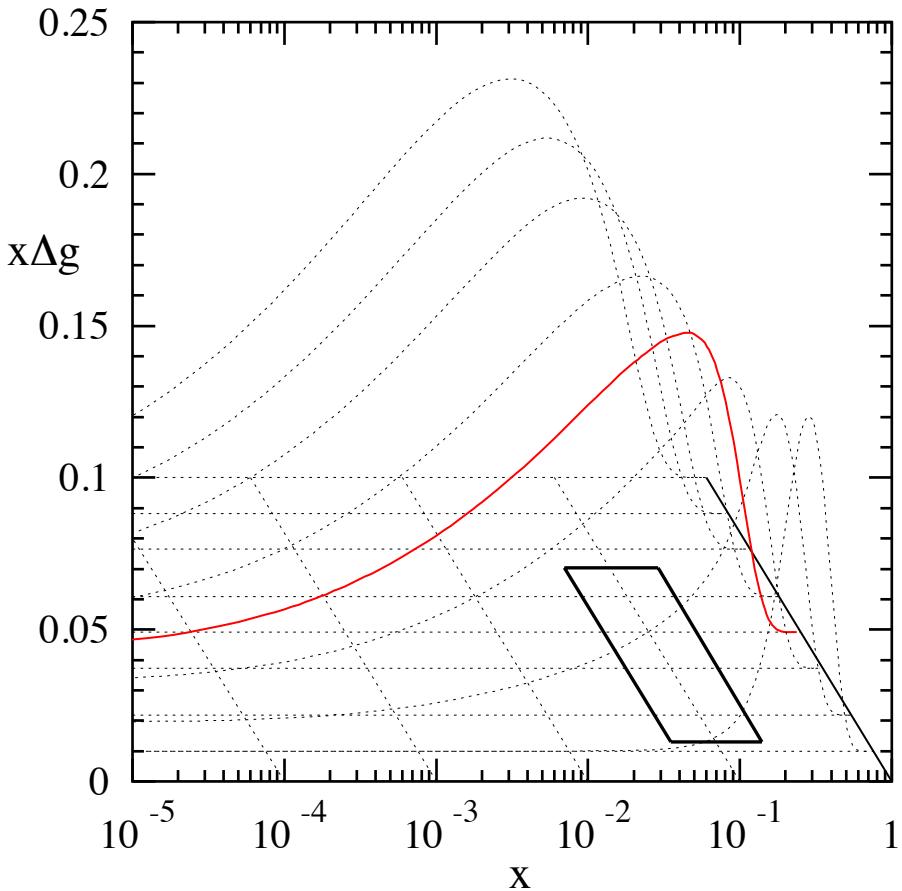
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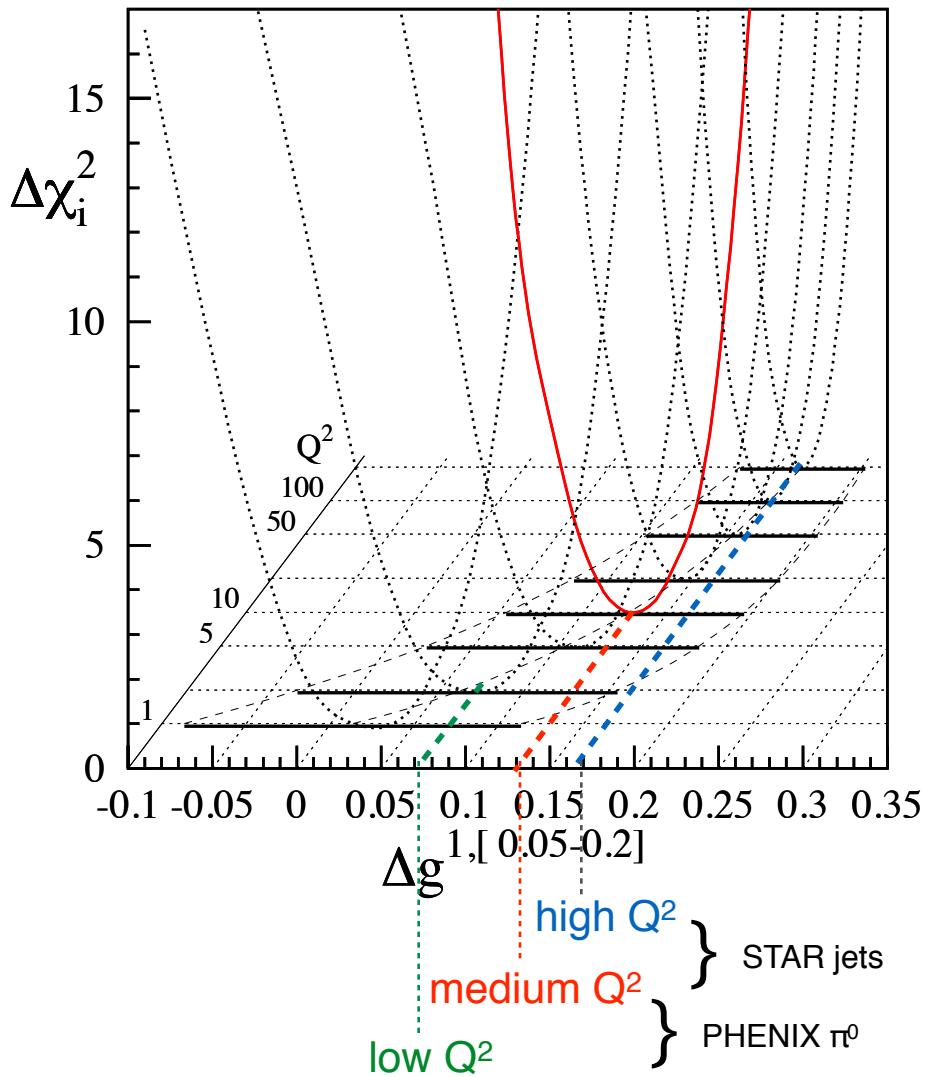
fast evolution in RHIC x-region
helps to describe jets and π^0 's simultaneously



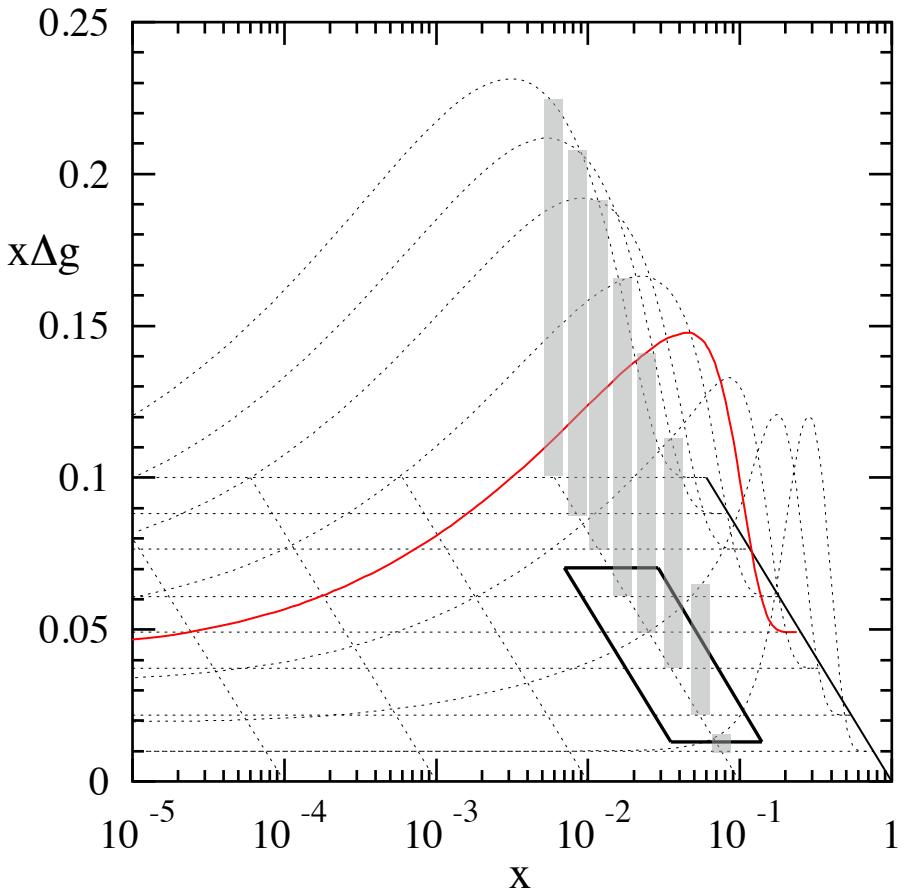
its Q^2 dependence

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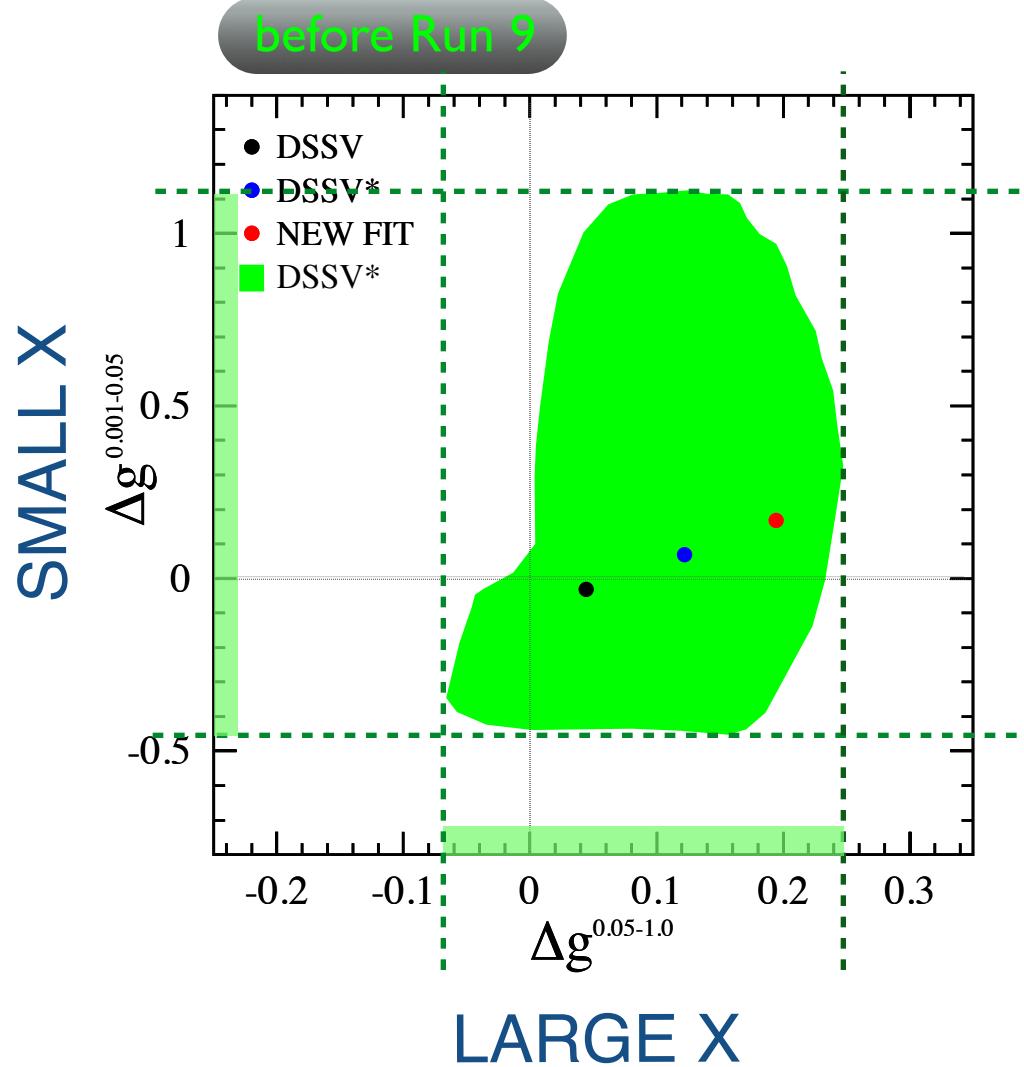
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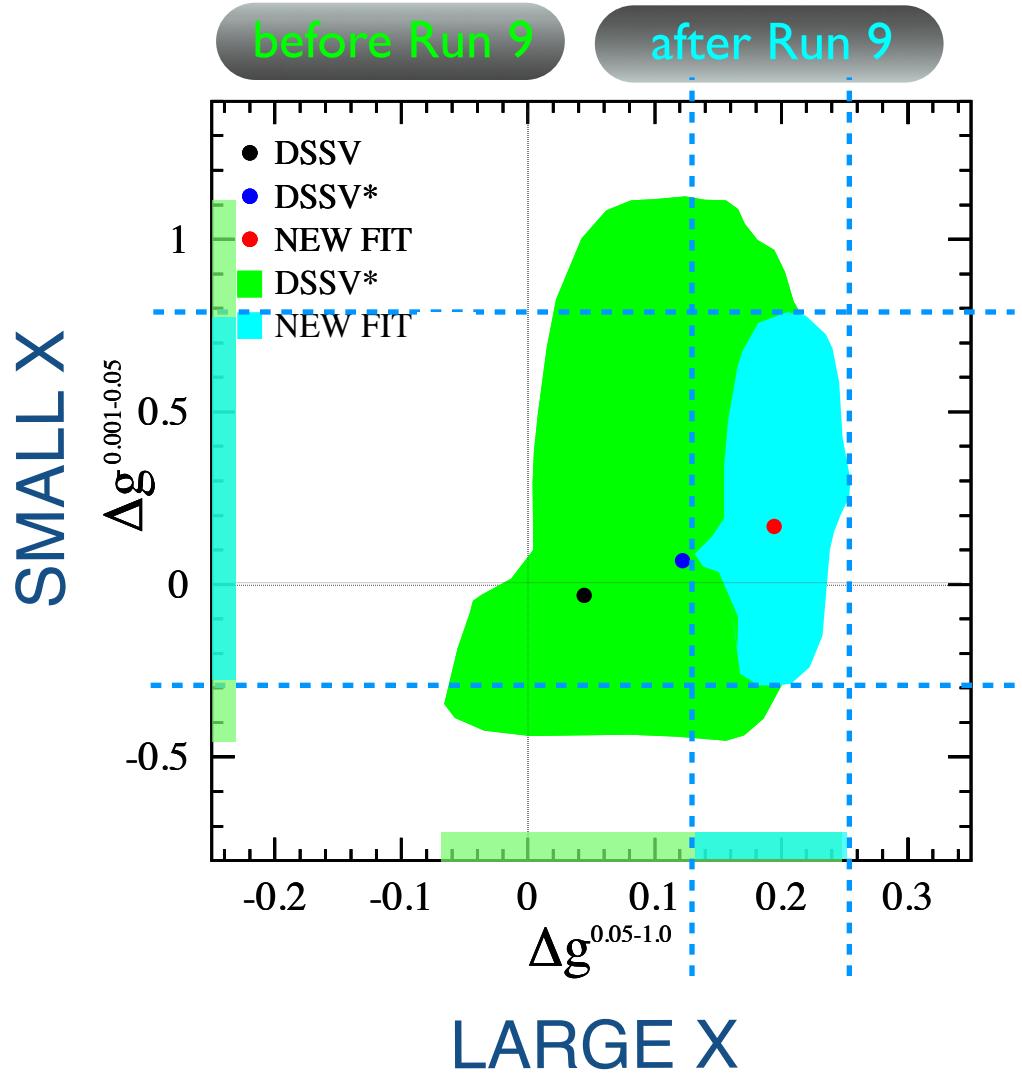
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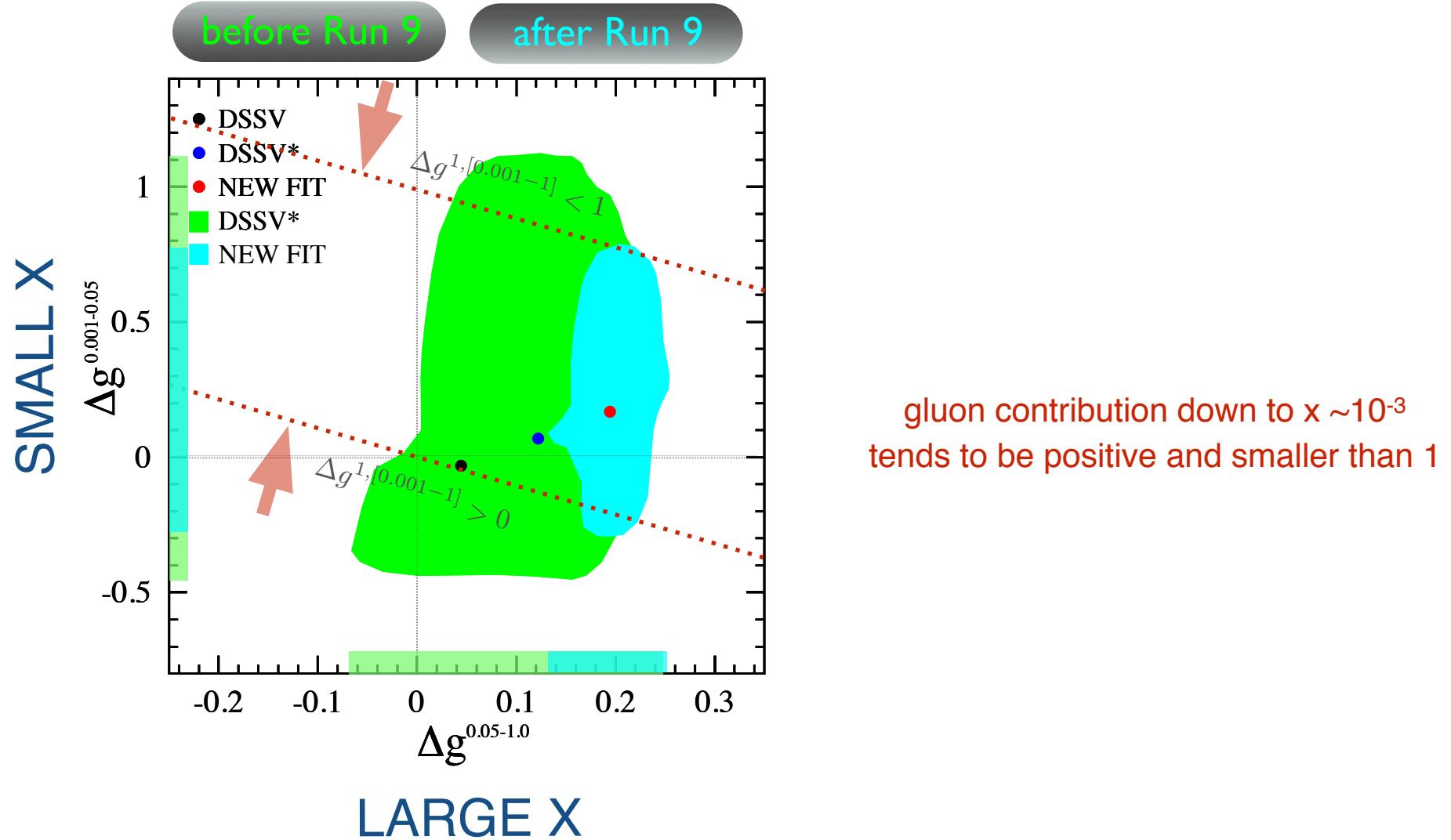
towards the first moment of Δg



towards the first moment of Δg



towards the first moment of Δg



comparison to NNPDFpol1.1

see talk by Nocera

PRL 113, 012001 (2014)

PHYSICAL REVIEW LETTERS

week ending
4 JULY 2014

Evidence for Polarization of Gluons in the Proton

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Werner Vogelsang^d

Institute for Theoretical Physics, Tübingen University, Auf der Morgenstelle 14, 72076 Tübingen, Germany

(Received 17 April 2014; published 2 July 2014)

We discuss the impact of recent high-statistics Relativistic Heavy Ion Collider data on the determination of the gluon polarization in the proton in the context of a global QCD analysis of polarized parton distributions. We find evidence for a nonvanishing polarization of gluons in the region of momentum fraction and at the scales mostly probed by the data. Although information from low momentum fractions is presently lacking, this finding is suggestive of a significant contribution of gluon spin to the proton spin, thereby limiting the amount of orbital angular momentum required to balance the proton spin budget.

DOI: 10.1103/PhysRevLett.113.012001

PACS numbers: 13.88.+e, 12.38.Bx, 13.60.Hb, 13.85.Ni

Introduction.—The gluon helicity distribution function $\Delta g(x)$ of the proton has long been recognized as a fundamental quantity characterizing the inner structure of the nucleon. In particular, its integral $\Delta G \equiv \int_0^1 dx \Delta g(x)$ over all gluon momentum fractions x may in $A^+ = 0$ light-cone gauge be interpreted as the gluon spin contribution to the proton spin [1]. As such, ΔG is a key ingredient to the proton helicity sum rule

$$\frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + L_q + L_g. \quad (1)$$

where $\Delta \Sigma$ denotes the combined quark and antiquark spin contribution and $L_{q,g}$ are the quark and gluon orbital angular momentum contributions. For simplicity, we have omitted the renormalization scale Q and scheme dependence of all quantities.

It is well known that the quark and gluon helicity distributions can be probed in high-energy scattering processes with polarized nucleons, allowing access to $\Delta \Sigma$ and ΔG . Experiments on polarized deep-inelastic lepton-nucleon scattering (DIS) performed since the late eighties [2] have shown that relatively little of the proton spin is carried by the quark and antiquark spins, with a typical value $\Delta \Sigma \sim 0.25$ [2–4]. The inclusive DIS measurements have, however, very little sensitivity to gluons. Instead, the best probes of Δg are offered by polarized proton-proton collisions available at the BNL Relativistic Heavy Ion Collider (RHIC) [5]. Several processes in $p\bar{p}$ collisions, in particular jet or hadron production at high transverse momentum p_T , receive substantial contributions

from gluon-induced hard scattering, hence, opening a window on Δg when polarized proton beams are used.

The first round of results produced by RHIC until 2008 [5] were combined with data from inclusive and semi-inclusive DIS in a next-to-leading order (NLO) global QCD analysis [3], hereafter referred to as “DSSV analysis”. One of the main results of that analysis was that the RHIC data—with their uncertainties at the time—did not show any evidence of a polarization of gluons inside the proton. In fact, the integral of Δg over the region $0.05 \leq x \leq 0.2$ of momentum fraction, primarily accessed by the RHIC experiments was found to be very close to zero. Other recent analyses of nucleon spin structure [4] did not fully include RHIC data; as a result Δg was left largely unconstrained.

Since the analysis [3], the data from RHIC have vastly improved. New results from the 2009 run [6,7] at center-of-mass energy $\sqrt{s} = 200$ GeV have significantly smaller errors across the range of measured p_T . This will naturally put tighter constraints on $\Delta g(x)$ and may extend the range of x over which meaningful constraints can be obtained. A striking feature is that the STAR jet data [6] now exhibit a double-spin asymmetry A_{LL} that is clearly nonvanishing over the whole range $5 \lesssim p_T \lesssim 30$ GeV, in contrast to the previous results. Keeping in mind that, in this regime, jets are primarily produced by gluon-gluon and quark-gluon scattering, this immediately suggests that gluons inside the proton might be polarized. At the same time, new PHENIX data for π^0 production [7] still do not show any significant asymmetry, and it is of course important to reveal whether the two data sets provide compatible information. In this Letter, we assess the impact of the 2009 RHIC data sets on

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A first unbiased global determination of polarized PDFs and their uncertainties

NNPDF Collaboration

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Abstract

We present a first global determination of spin-dependent parton distribution functions (PDFs) and their uncertainties using the NNPDF methodology: NNPDFpol1.1. Longitudinally polarized deep-inelastic scattering data, already used for the previous NNPDFpol1.0 PDF set, are supplemented with the most recent polarized hadron collider data for inclusive jet and W boson production from the STAR and PHENIX experiments at RHIC, and with open-charm production data from the COMPASS experiment, thereby allowing for a separate determination of the polarized quark and antiquark PDFs, and an improved determination of the medium- and large- x polarized gluon PDF. We study the phenomenological implications of the NNPDFpol1.1 set, and we provide predictions for the longitudinal double-spin asymmetry for semi-inclusive pion production at RHIC.

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DSSV '14 1404.9293

~ gluon update of DSSV '08 0804.0422

NNPDFpol1.1 1406.5539

~ sea quark & gluon upgrade of 1.0 1303.7236

comparison to NNPDFpol1.1

see talk by Nocera

DSSV '08

+

DIS (+COMPASS)

SIDIS (+COMPASS)

All jets (+RUN9,RUN5-6*)

All pions (+RUN9,RUN5-6*)

-

-

NNPDFpol 1.0

+

DIS

-

All jets

-

All charm (COMPASS)

AL W \pm (STAR)

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DSSV '08

+

DIS (+COMPASS)

SIDIS (+COMPASS)

All jets (+RUN9,RUN5-6*)

All pions (+RUN9,RUN5-6*)

-

-

GLOBAL FIT

proven technique

input parameterization

flexibility & bias ?

Lagrange Multipliers errors

+ dynamical tolerances à la MSTW

NNPDFpol 1.0

+

DIS

-

All jets

-

All charm (COMPASS)

A_L W[±] (STAR)

DIS FIT & reweighting

under development

neural networks

largely bias-free

Monte Carlo replicas

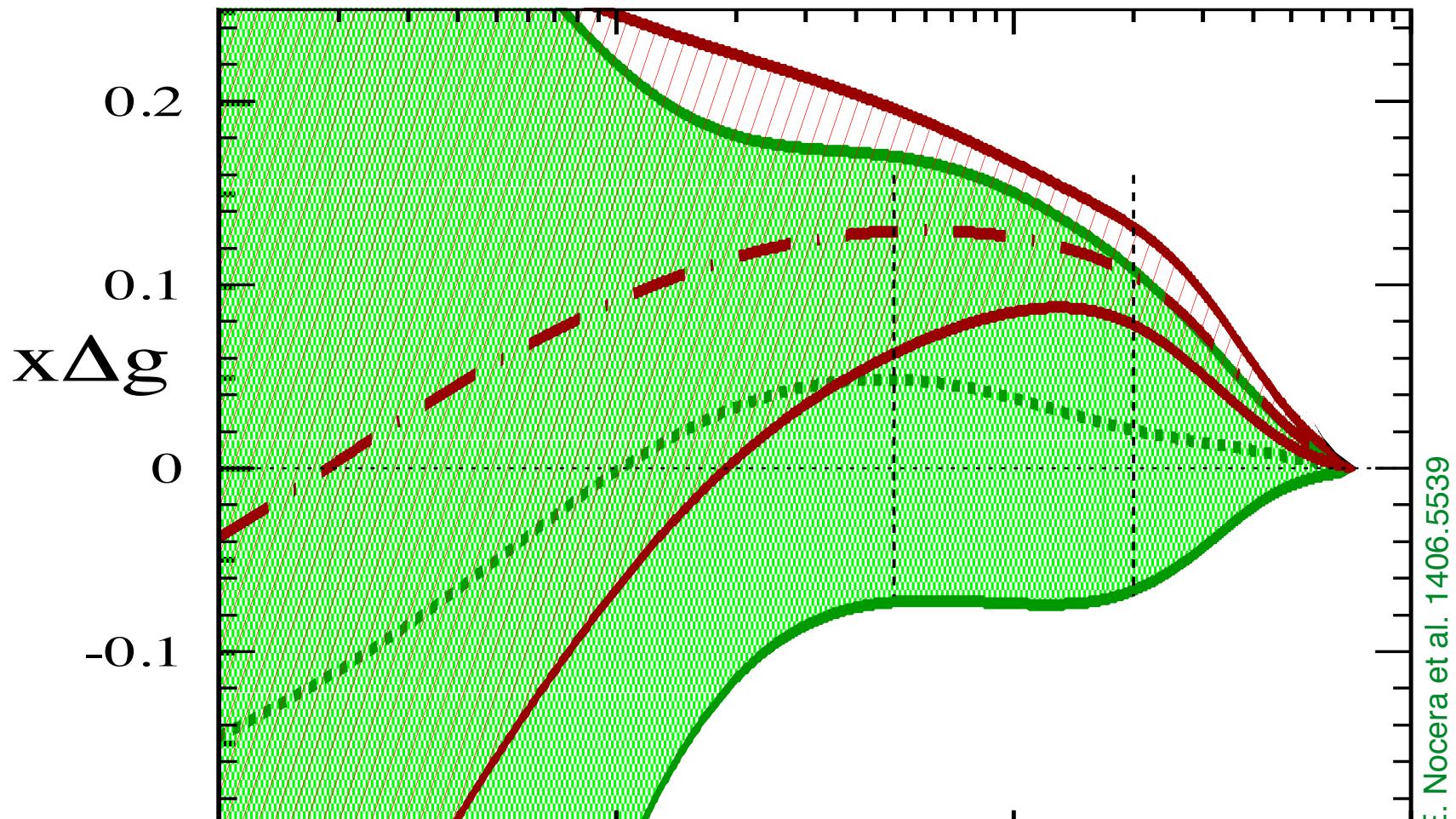
à la NNPDF

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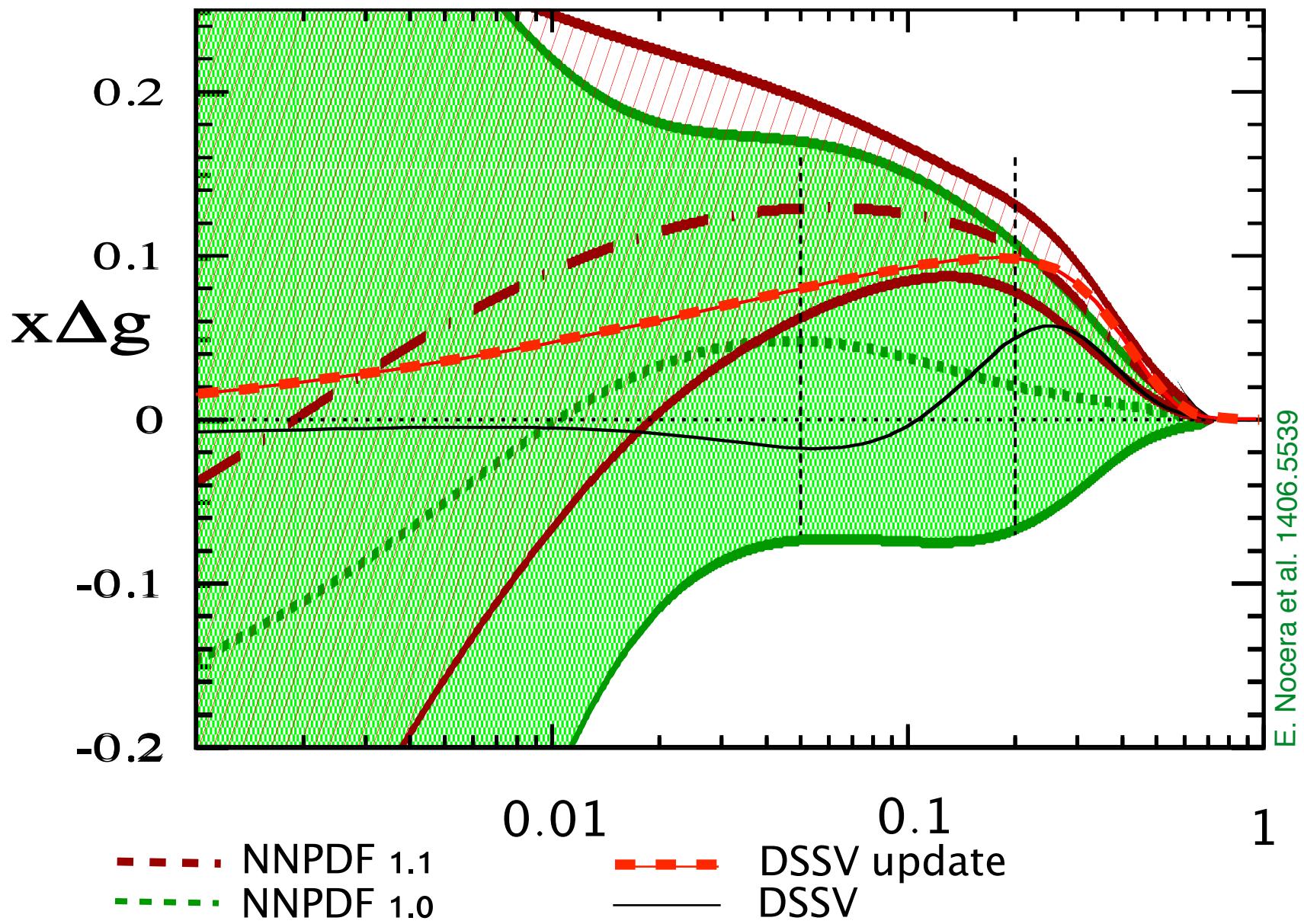
NNPDFpol1.1 1406.5539

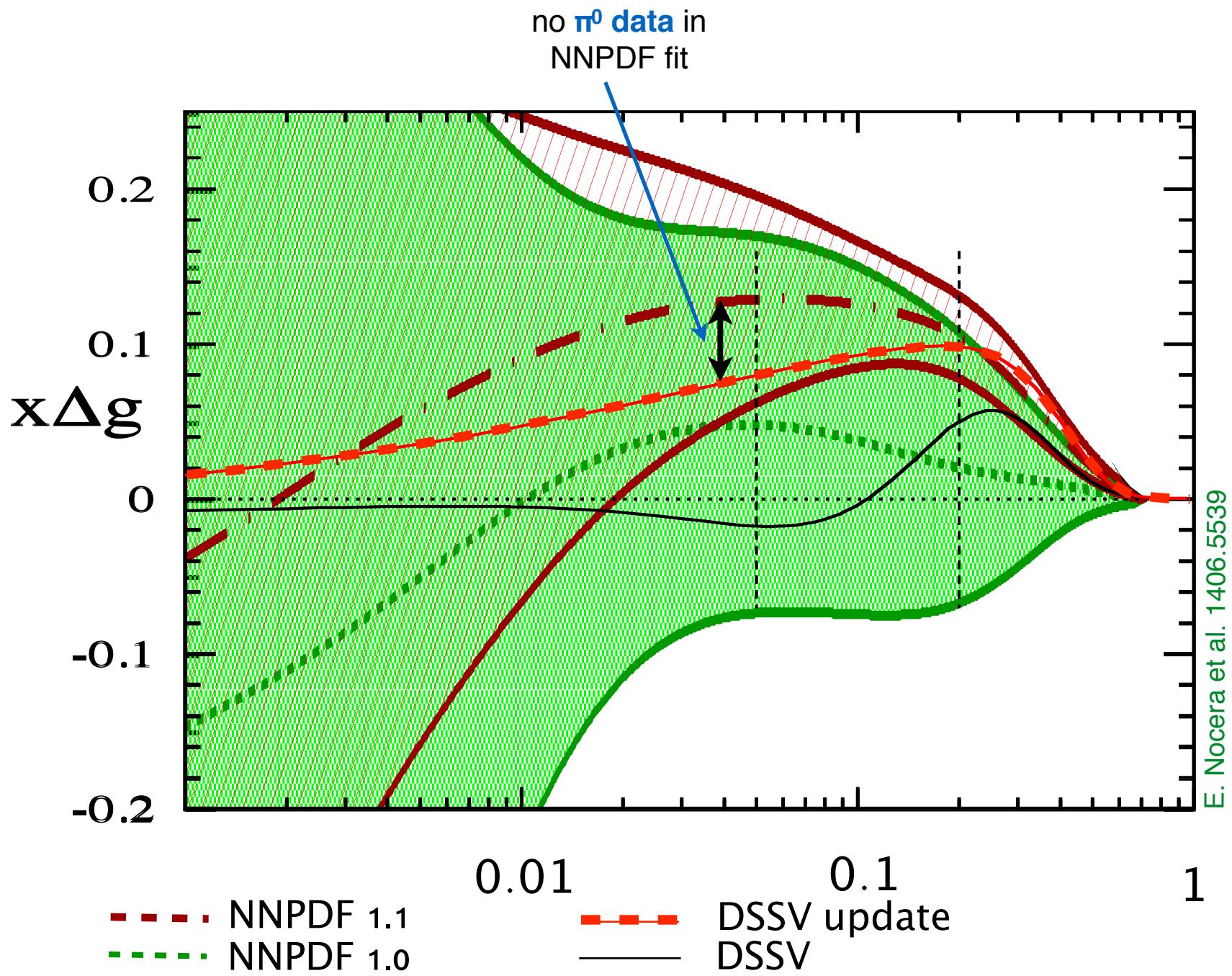
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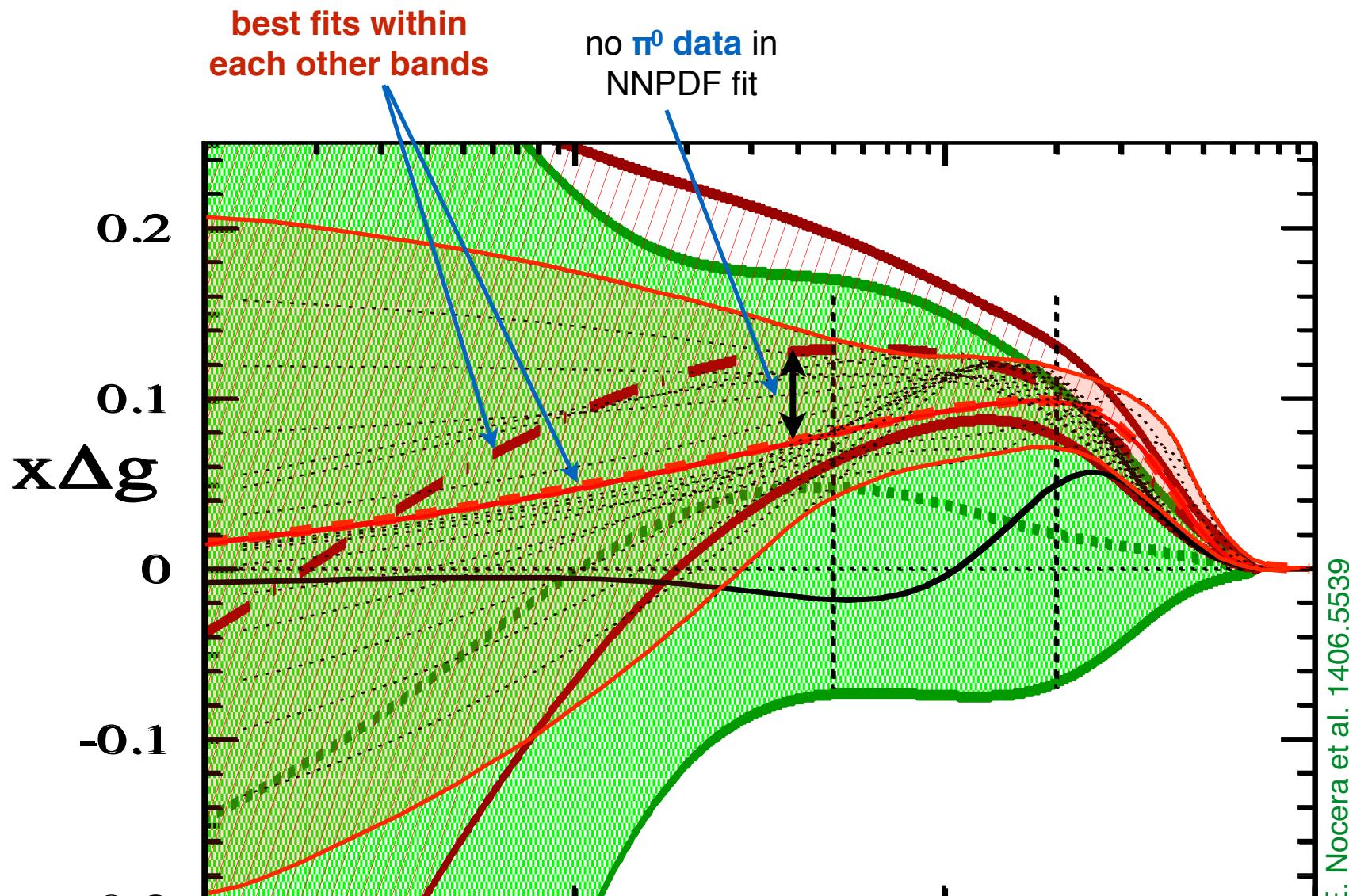


— NNPDF 1.1
- - - NNPDF 1.0

E. Nocera et al. 1406.5539



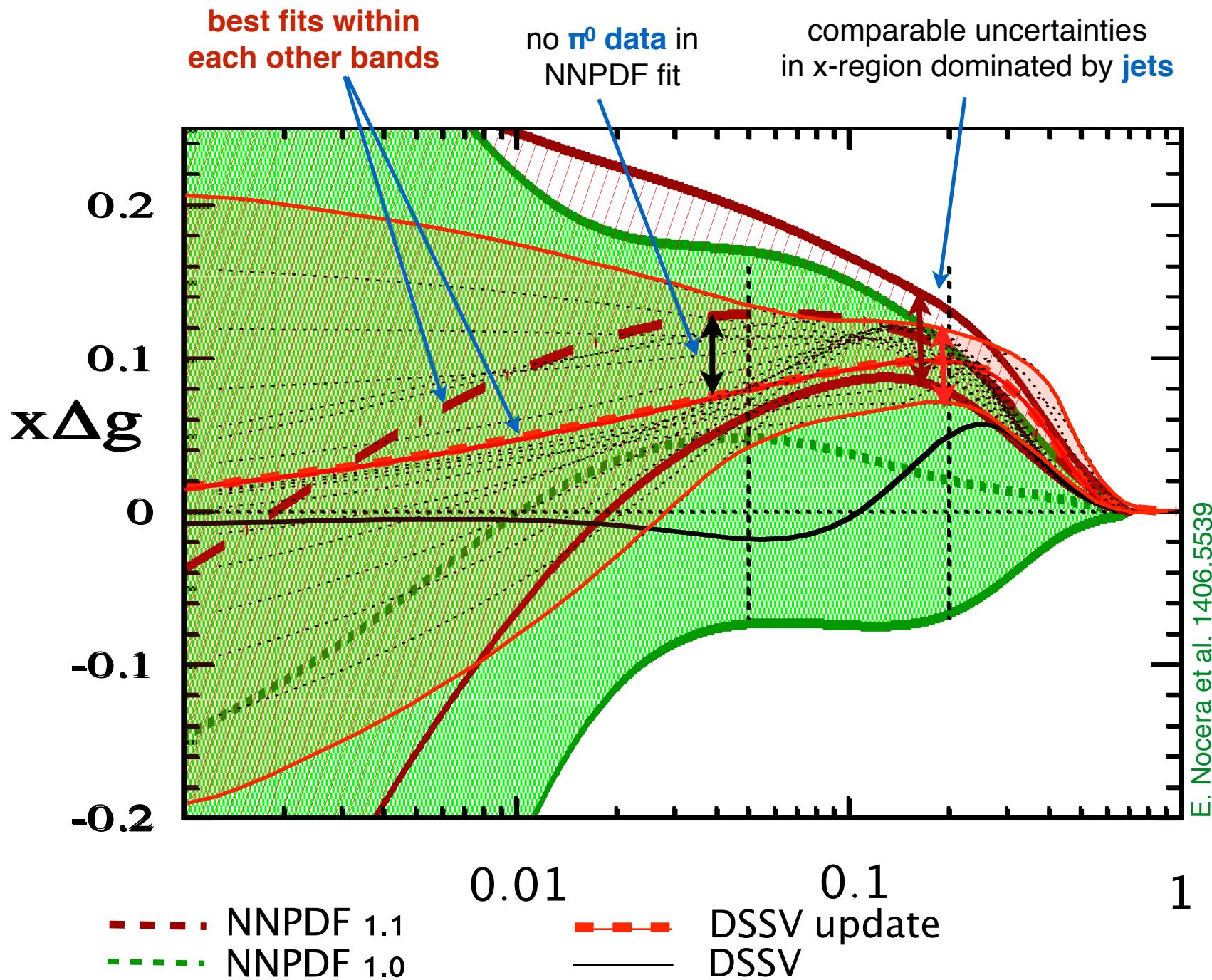




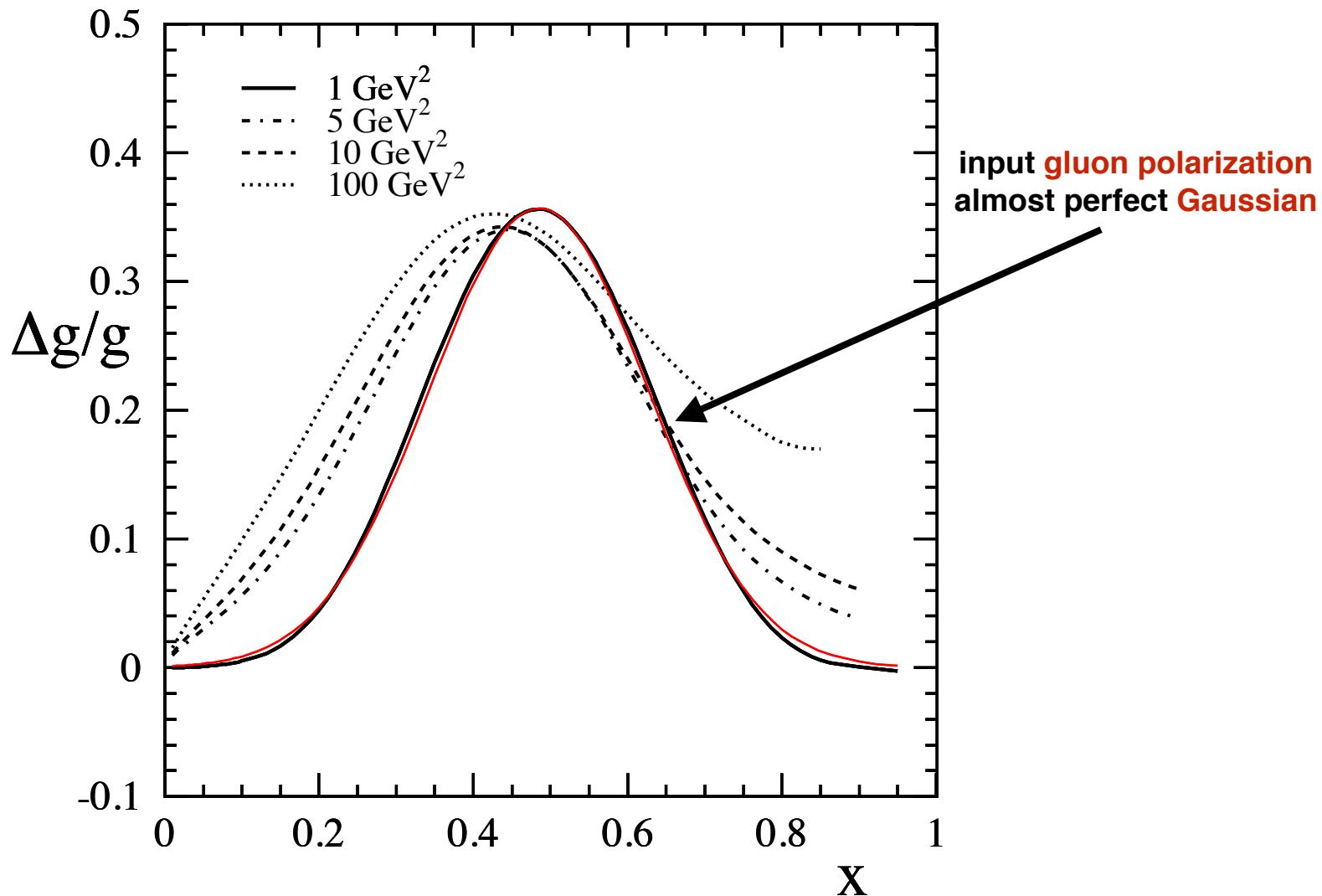
— NNPDF 1.1

- - NNPDF 1.0

— DSSV update
— DSSV



peculiar feature of $\Delta g/g$ in DSSV '14

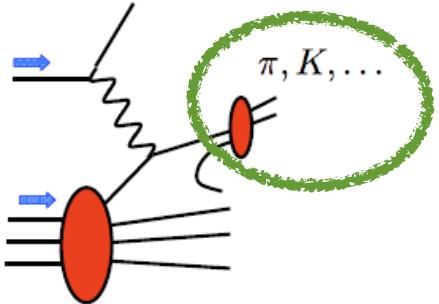


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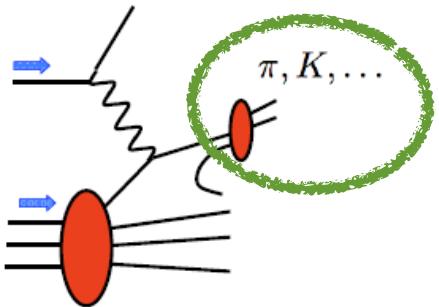
DSS pion fragmentation functions reloaded

need for precise fragmentation functions



- fragmentation functions provide “*analyzing power*” for different quark flavors in **SIDIS** and **hadron production in pp**
 - determine parton → hadron FFs & uncertainties from **global fit** to π^+ , π^- , K^+ , K^- yields in e^+e^- , DIS multiplicities, and pp
- DSSV uses DSS '07 FFs for SIDIS and RHIC π^0 data

need for precise fragmentation functions

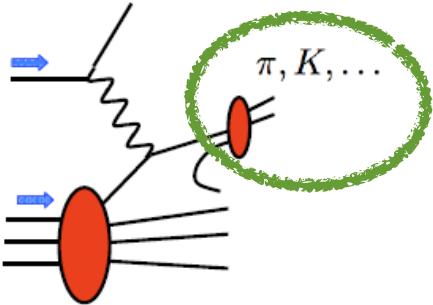


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DSS'07 in a nutshell: D. de Florian, R. Sassot, MS, PRD 75 (2007) 114010; 76 (2007) 074033

- good global description of all data sets
- only set of FFs which describes DIS multiplicities
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lots of new data *after* DSS'07 analysis:

e⁺e⁻: BaBar, Belle DIS: COMPASS, HERMES; pp: ALICE, STAR, PHENIX

→ DSS'14 update for pion FFs

kaon FF analysis awaits more data

arXiv:1410.6024

ENIX Parton-to-Pion Fragmentation Reloaded

Daniel de Florian*, and R. Sassot
Departamento de Física and IFIBA, Facultad de Ciencias Exactas y Naturales,
Universidad de Buenos Aires, Ciudad Universitaria, Pabellón 1 (1428) Buenos Aires, Argentina

Instituto de Física La Plata, CONICET - UNLP,
Departamento de Física La Plata, C.C. 69, La Plata, Argentina

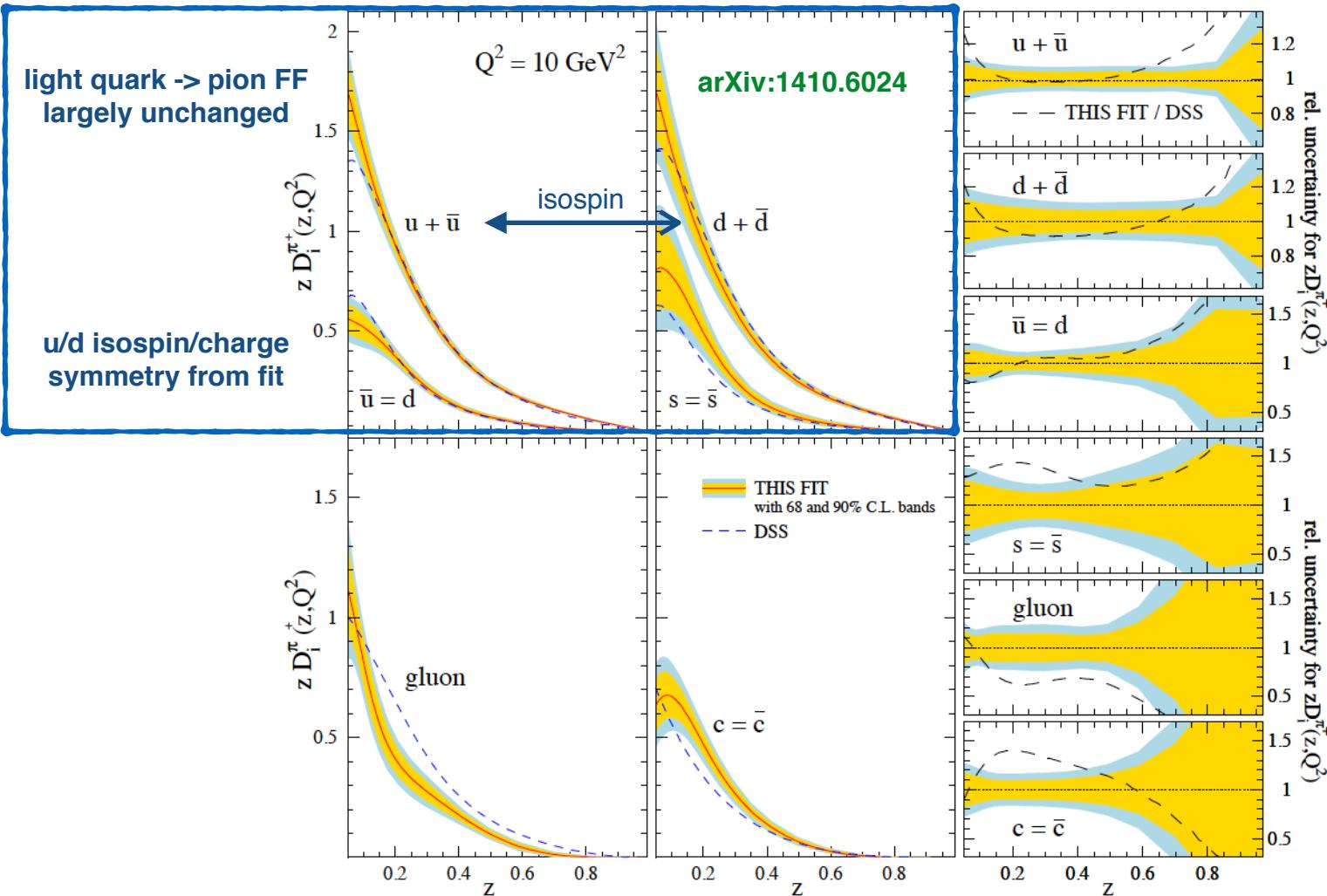
Roger J. Hernández-Pinto[§]
Departamento de Física Corpuscular, Universidad de Valencia, Pabellón 1 (46188) Valencia-Consejo Superior de Investigaciones Científicas, Spain

Marco Stratmann[¶]
Institute for Theoretical Physics, University of Tübingen,
Auf der Morgenstelle 14, 72076 Tübingen, Germany

A comprehensive global analysis of parton-to-pion fragmentation functions in QCD. The obtained results are based on the latest experimental data in electron-positron annihilation, lepton-nucleus and nucleon-nucleon collisions. An excellent description of all data is obtained by the parton-to-pion fragmentation function. Comparisons to the results from our previous global fits are presented.

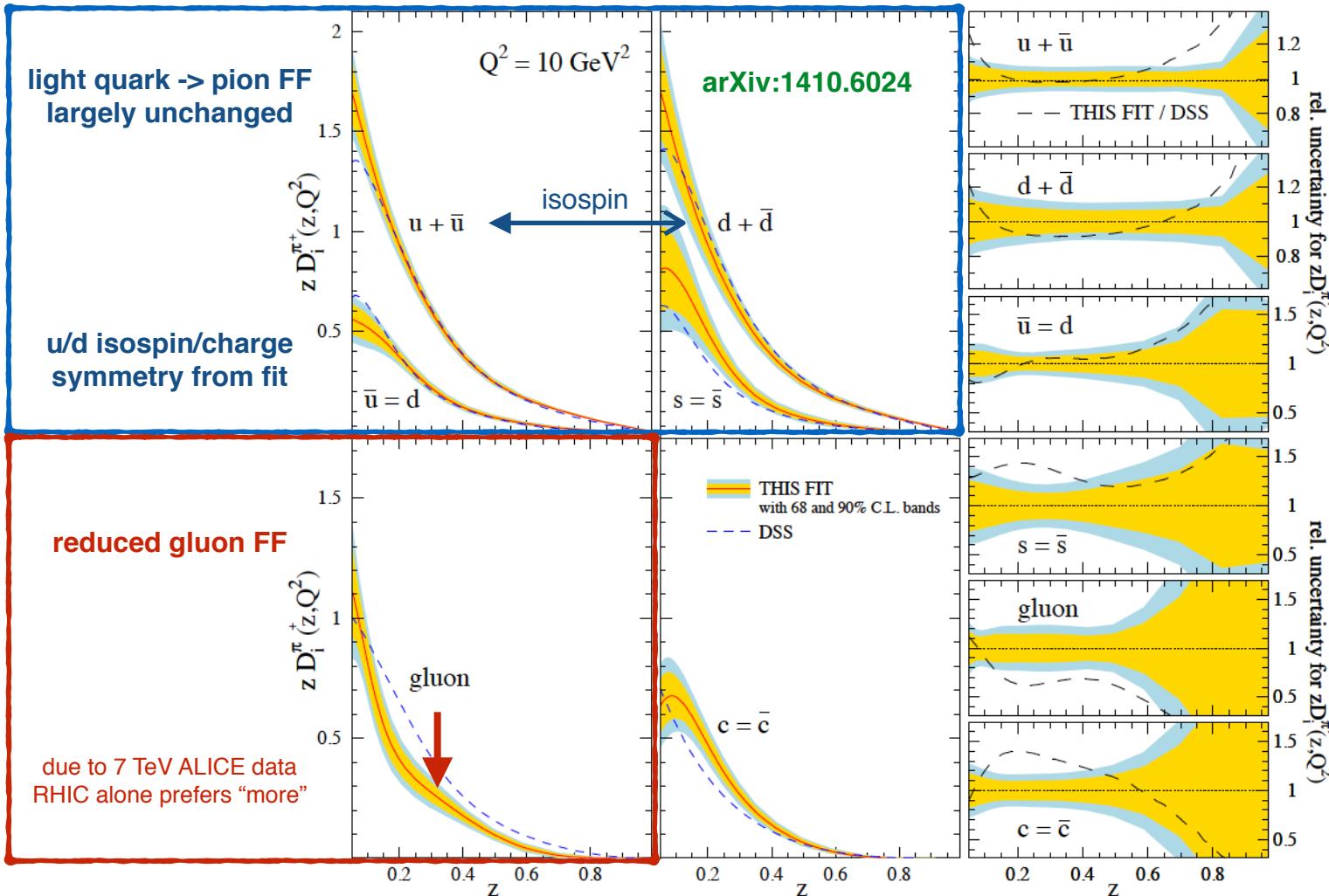
DSS '07 -> DSS '14: what's new?

- main features:
- new data allow for first reliable uncertainty estimate of FFs (with Hessian method)
 - excellent global description of all sets [biggest “tension” among RHIC & LHC pp data]



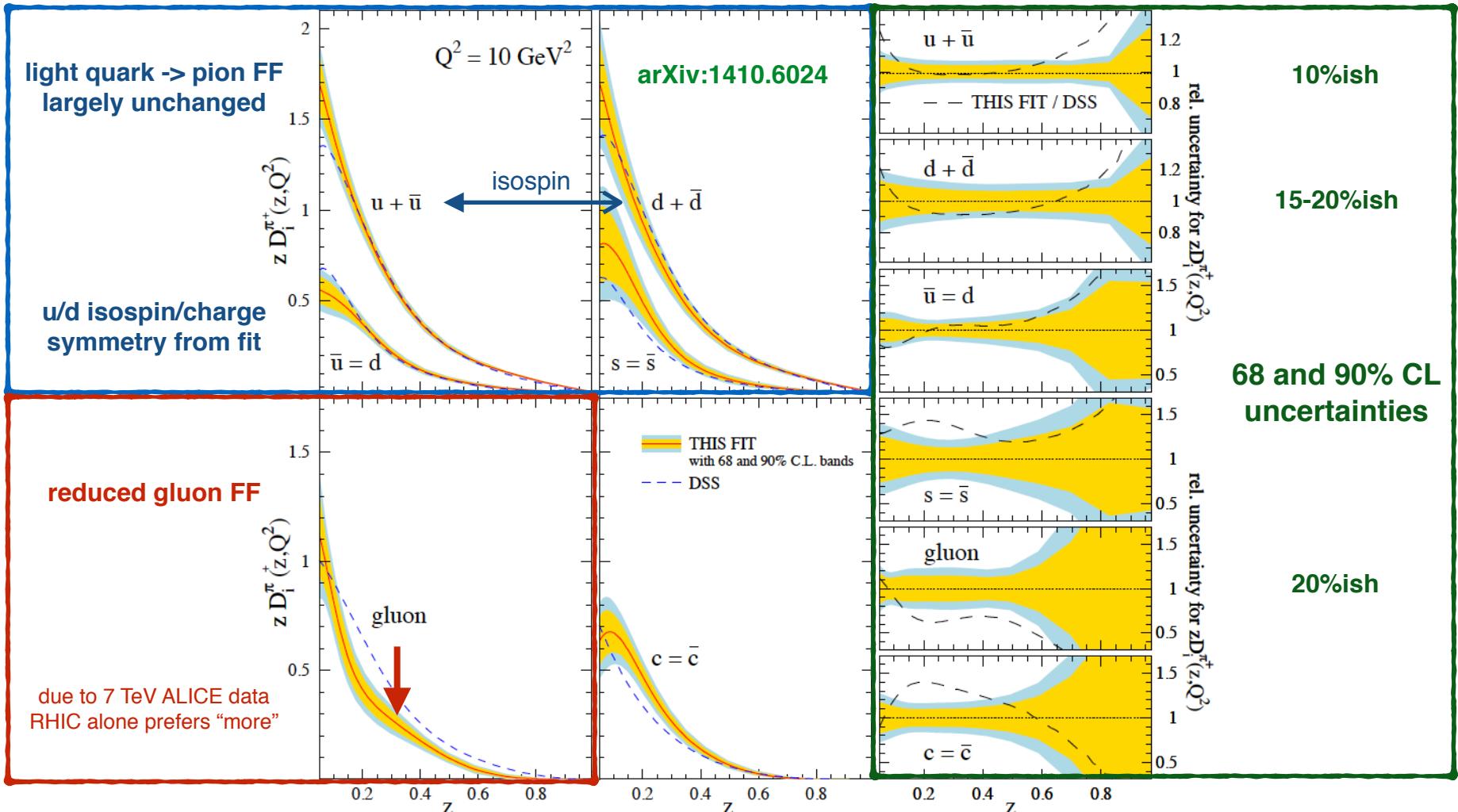
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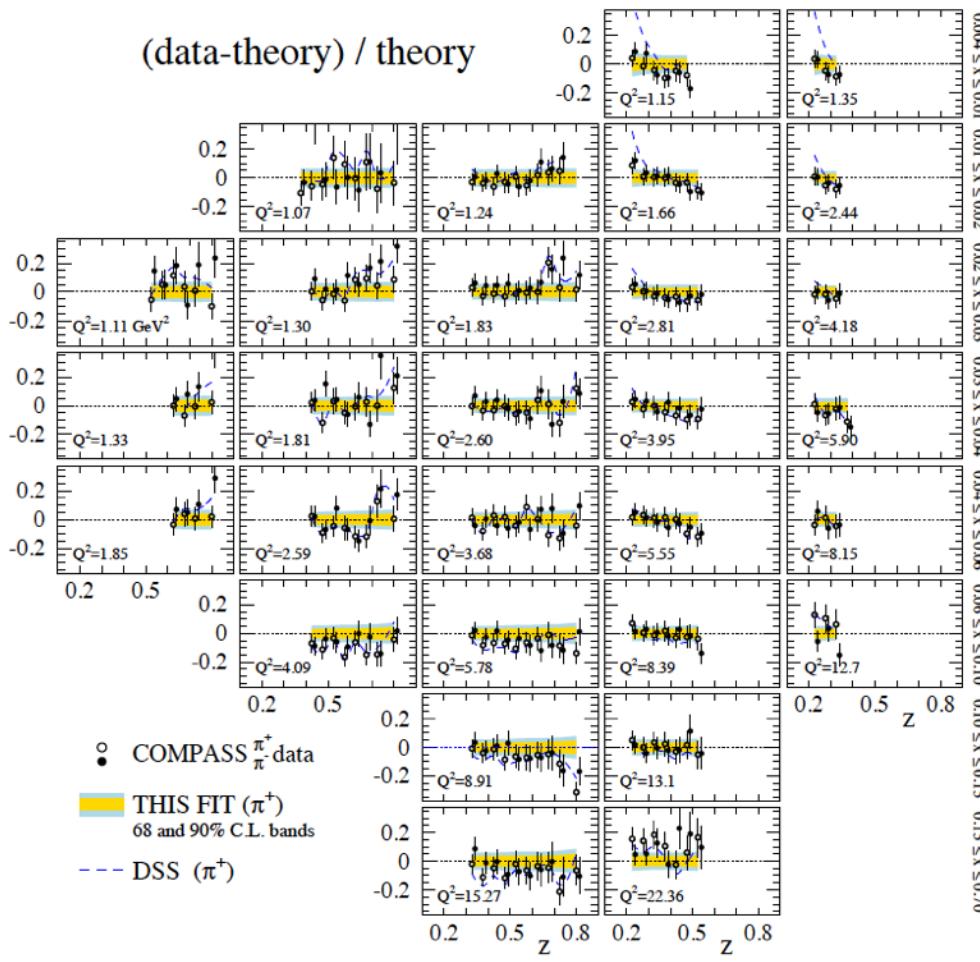
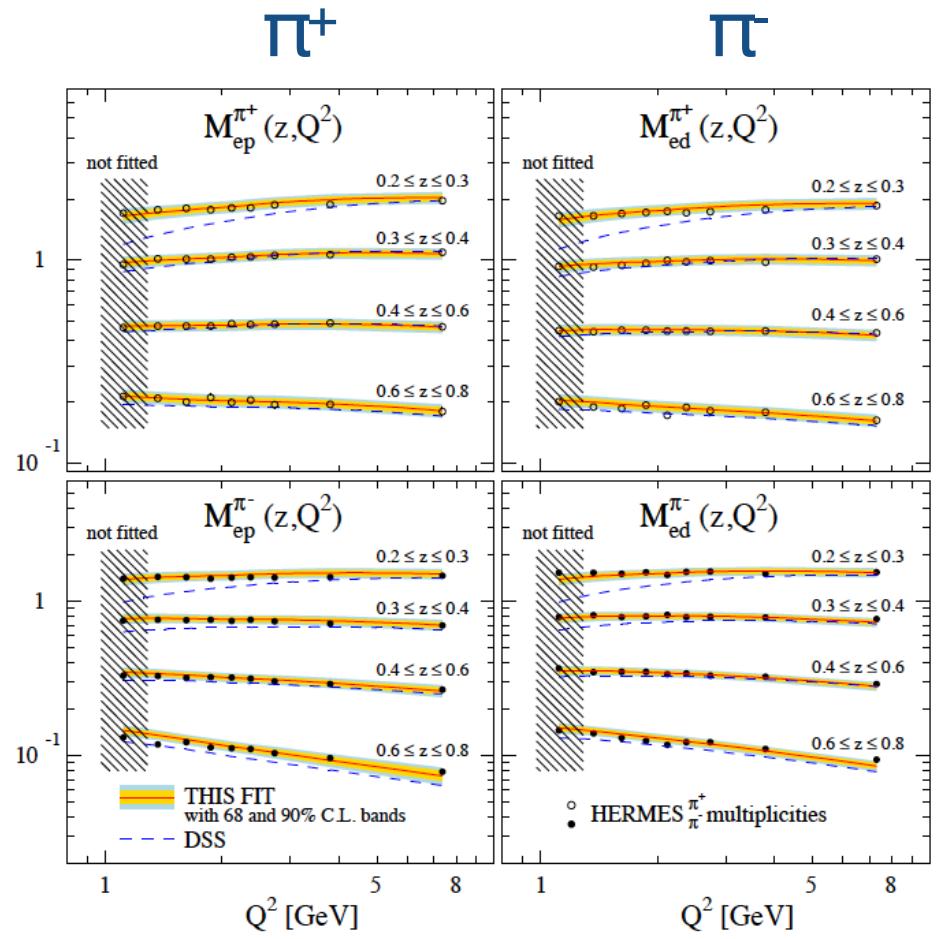
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DSS '14 example: DIS multiplicities

HERMES

COMPASS (prel.)



very consistent z-dependence for pion multiplicities

remains to be checked for kaons (relevant for Δs extraction !)

4

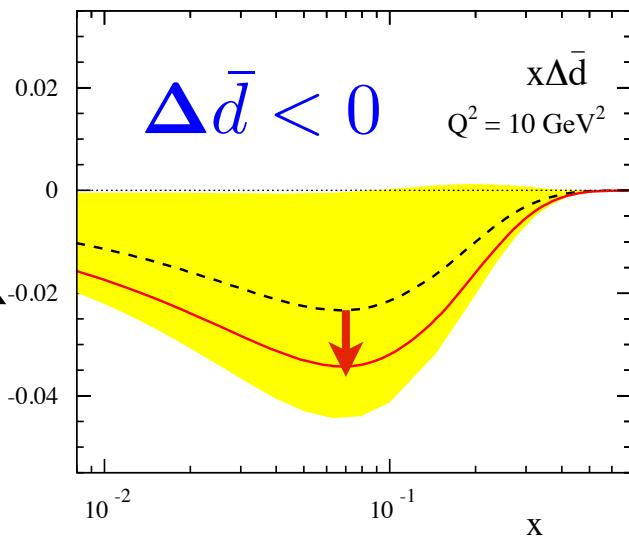
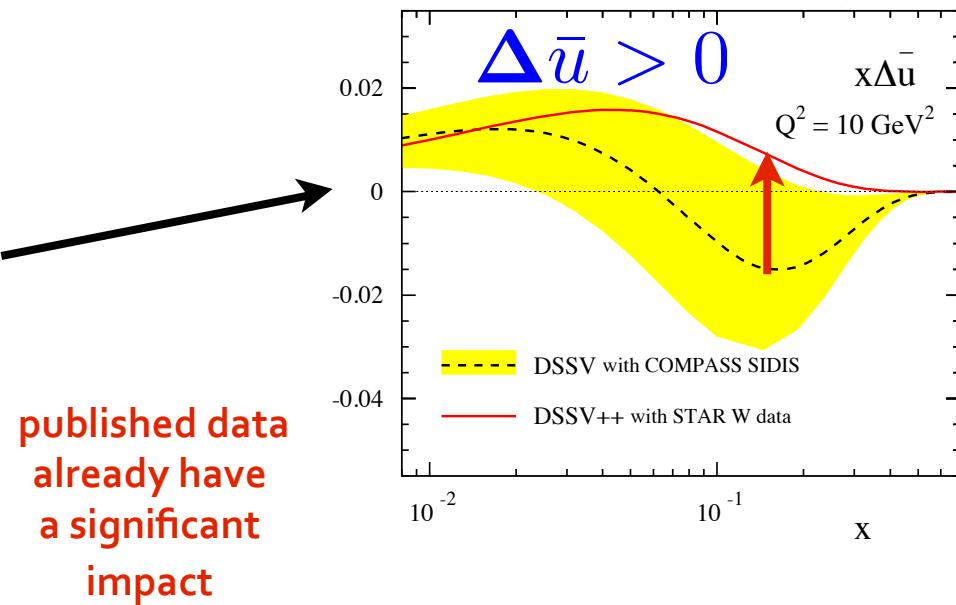
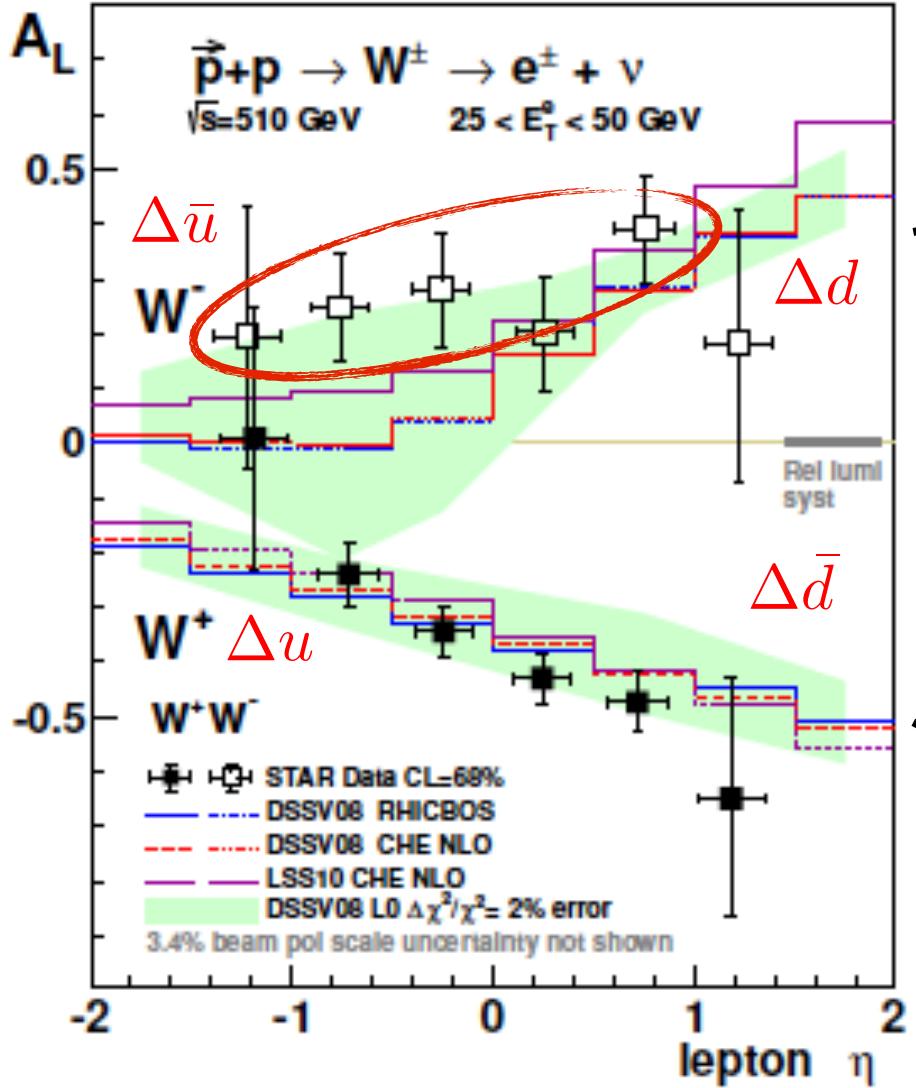


future avenues
RHIC spin & eRHIC

2011/12 STAR W data & impact on DSSV fit

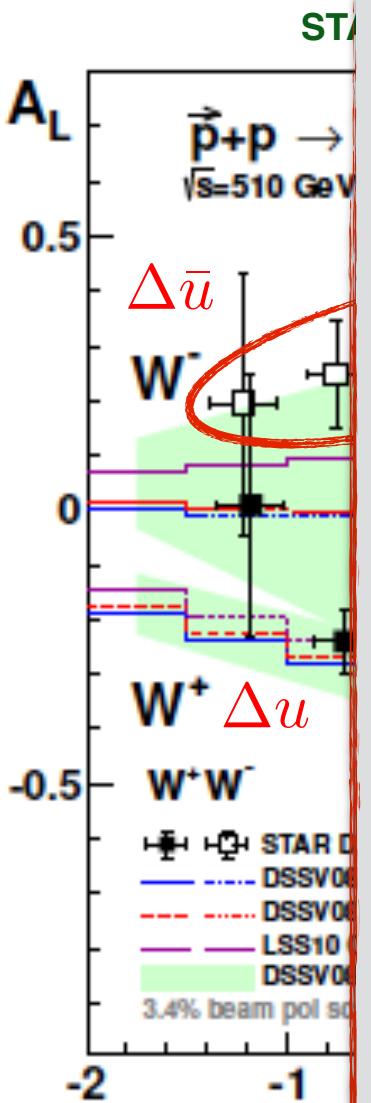
PRELIMINARY

STAR arXiv:1404.6880

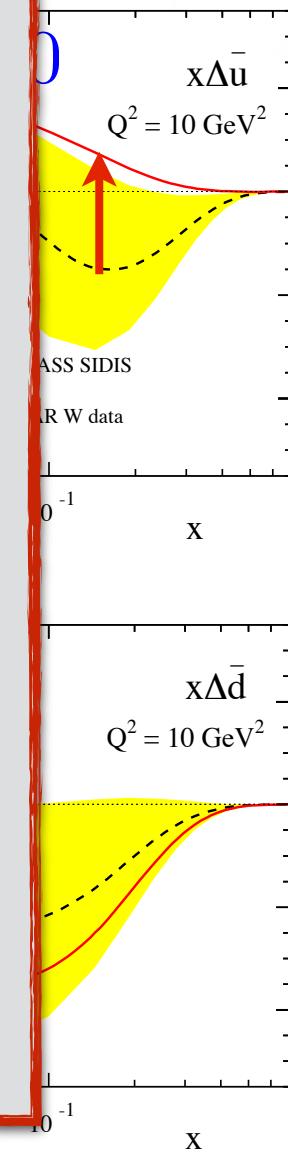
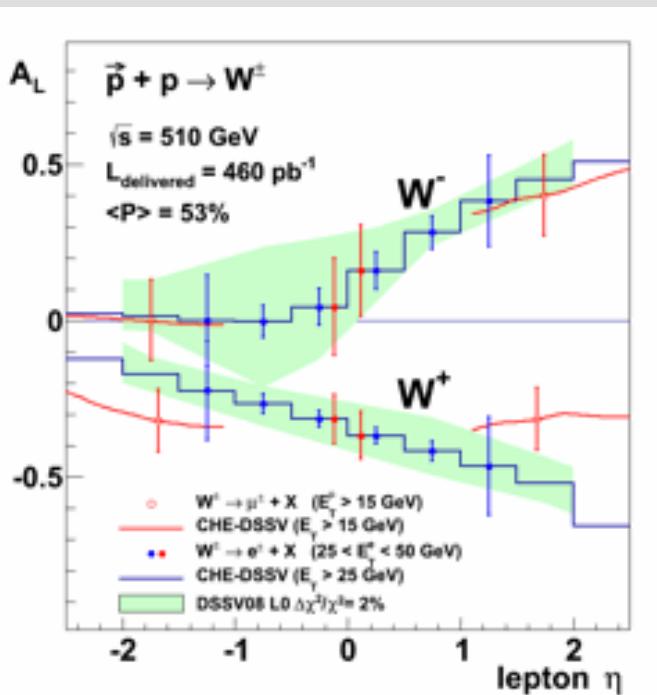


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PRELIMINARY



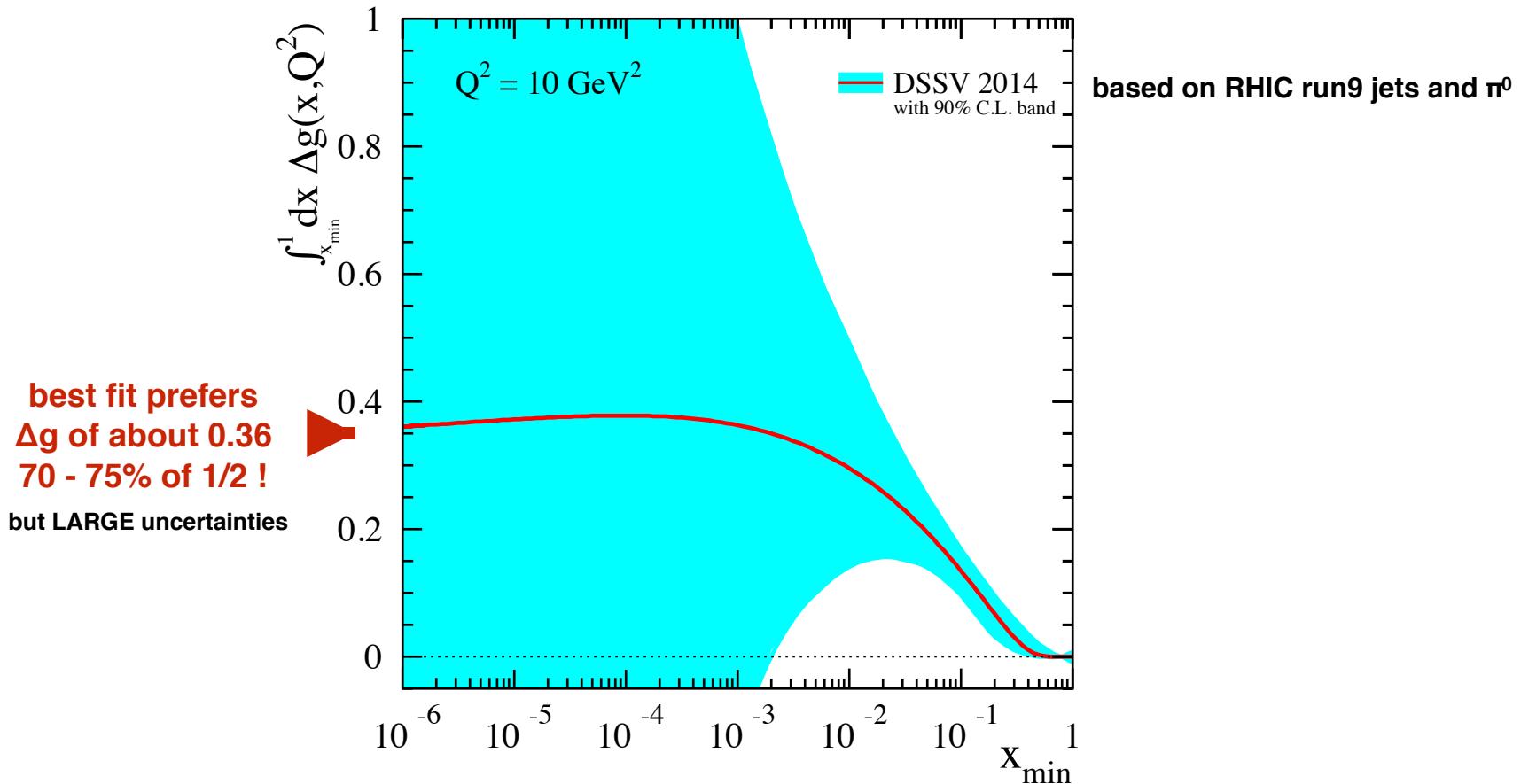
- points towards rather sizable positive $\Delta\bar{u}(x) - \Delta\bar{d}(x)$
- same trend seen by NNPDF (talk by Nocera)
- starts to test what we know from SIDIS
- 2013 RHIC data: further reduce uncertainties by 2



status & expectations for Δg

Aschenauer, Sassot, MS

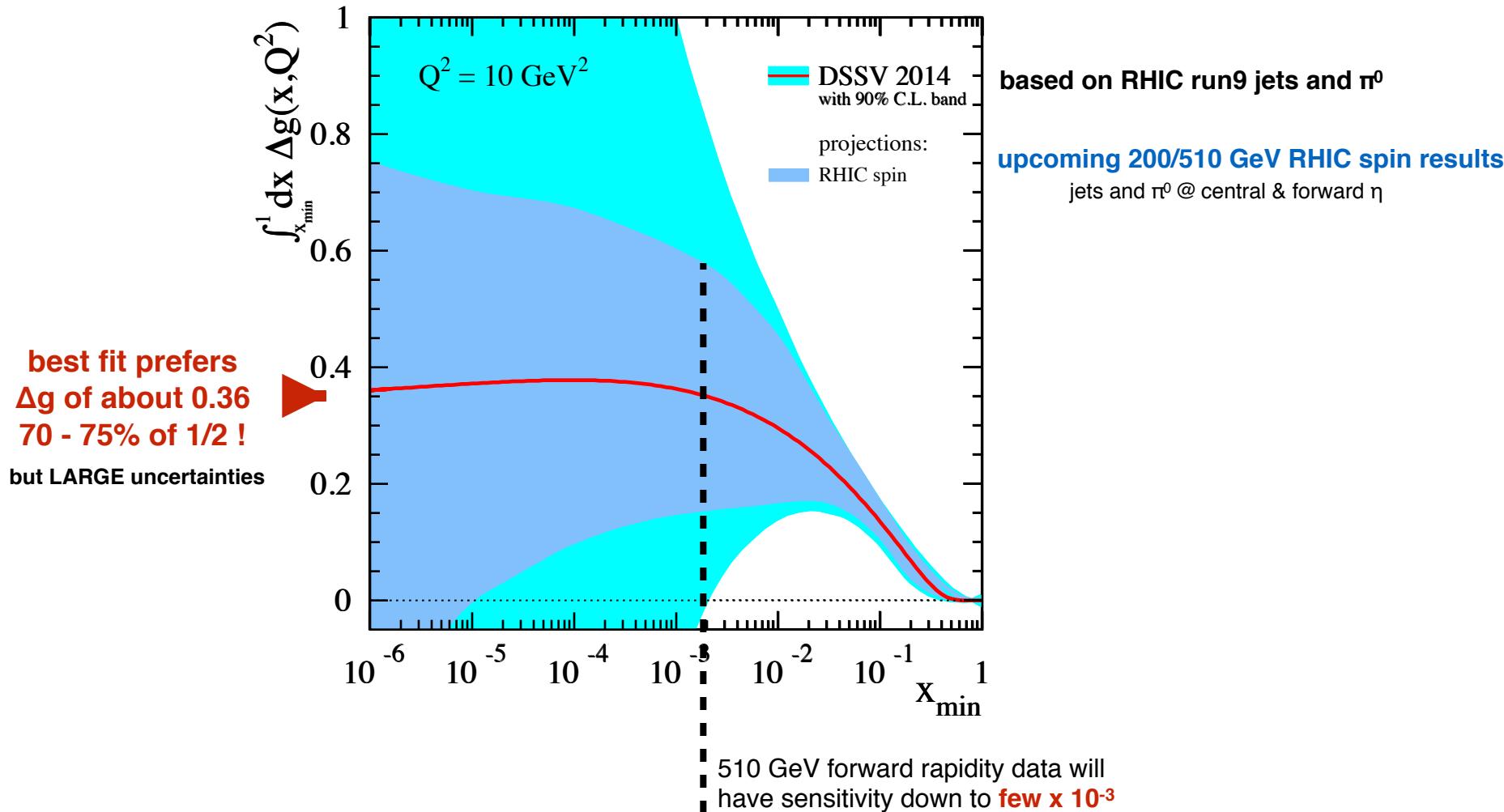
status for “running integral” of Δg (\rightarrow spin sum rule) :



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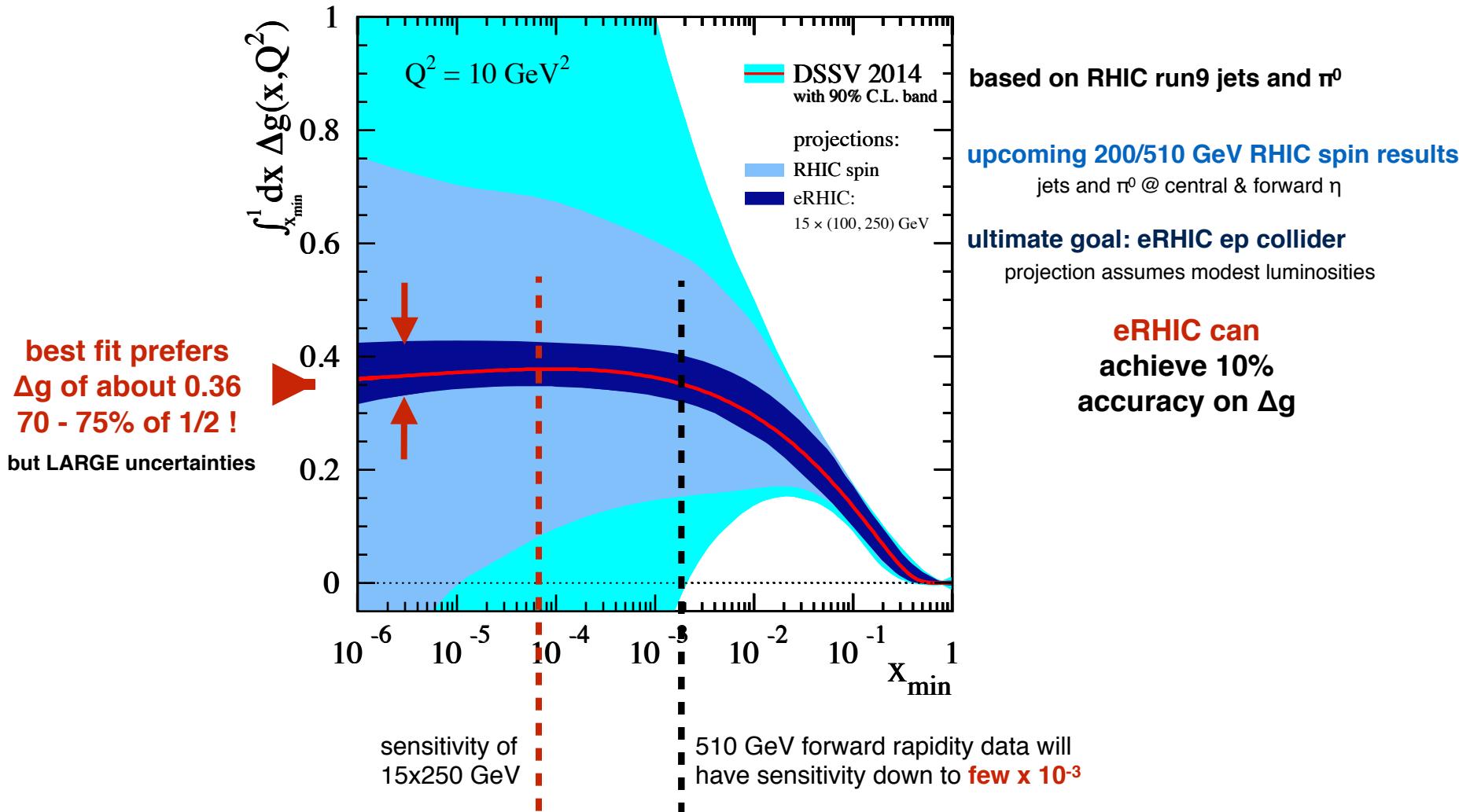
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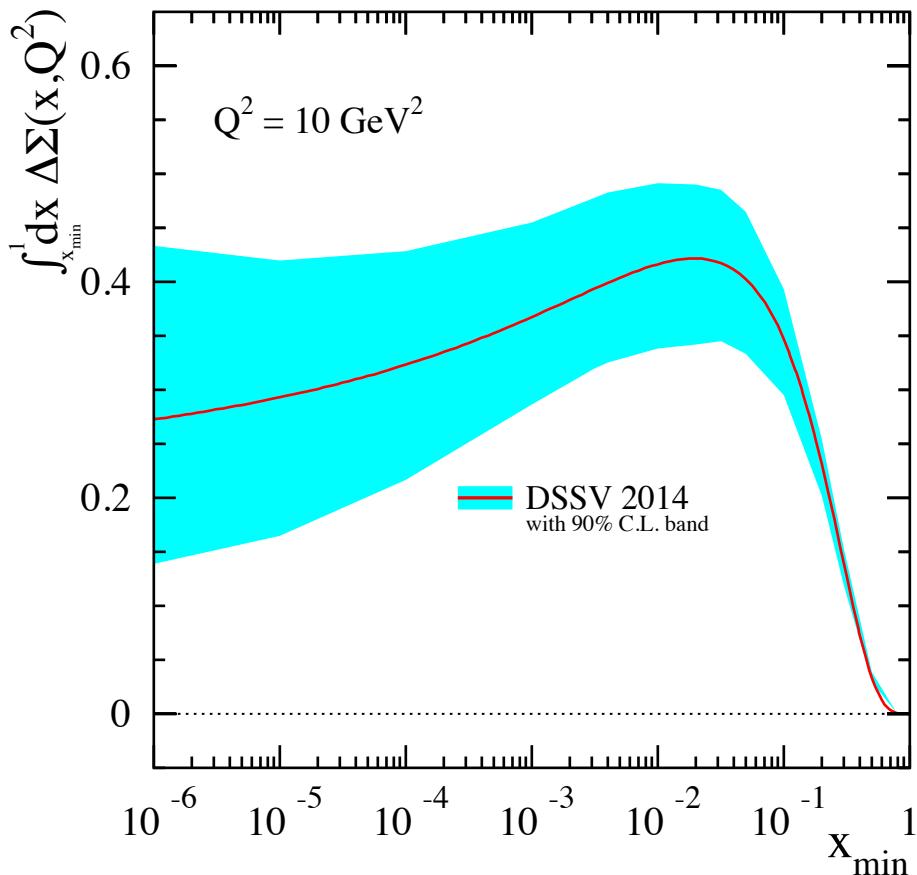
Aschenauer, Sassot, MS

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what about $\Delta\Sigma$ and OAM ?

running integral for $\Delta\Sigma$



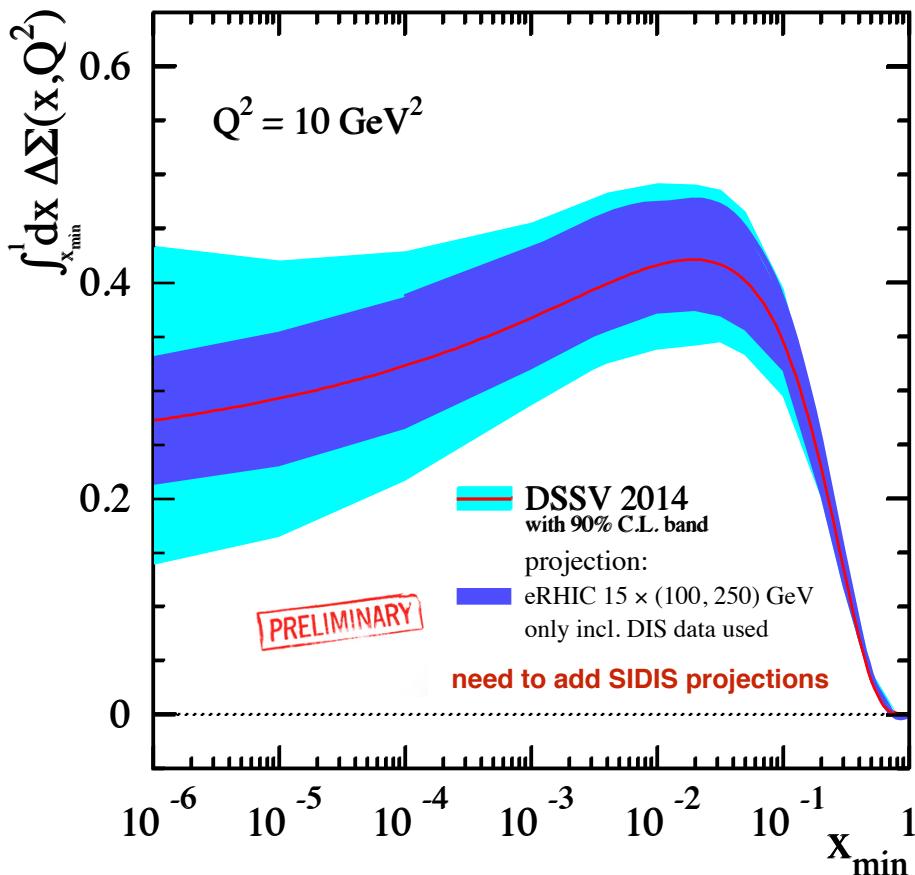
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likewise for the Bj sum rule !

- main culprit: small x behavior of Δs
need to scrutinize 3F-D constraint

what about $\Delta\Sigma$ and OAM ?

running integral for $\Delta\Sigma$



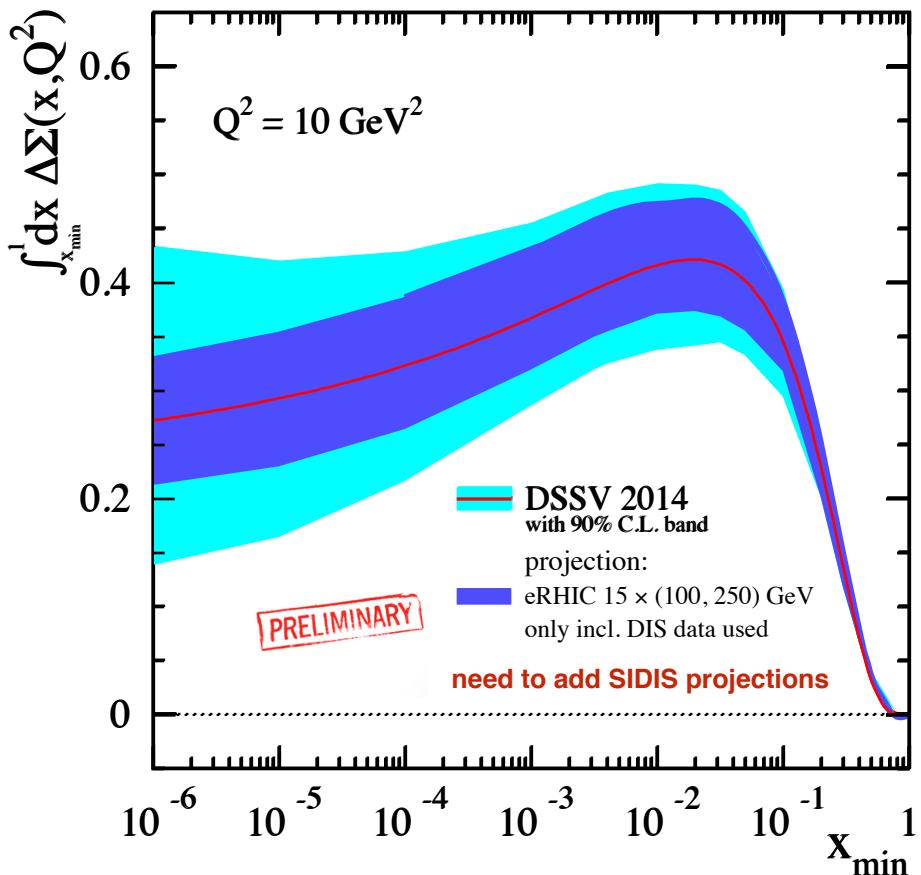
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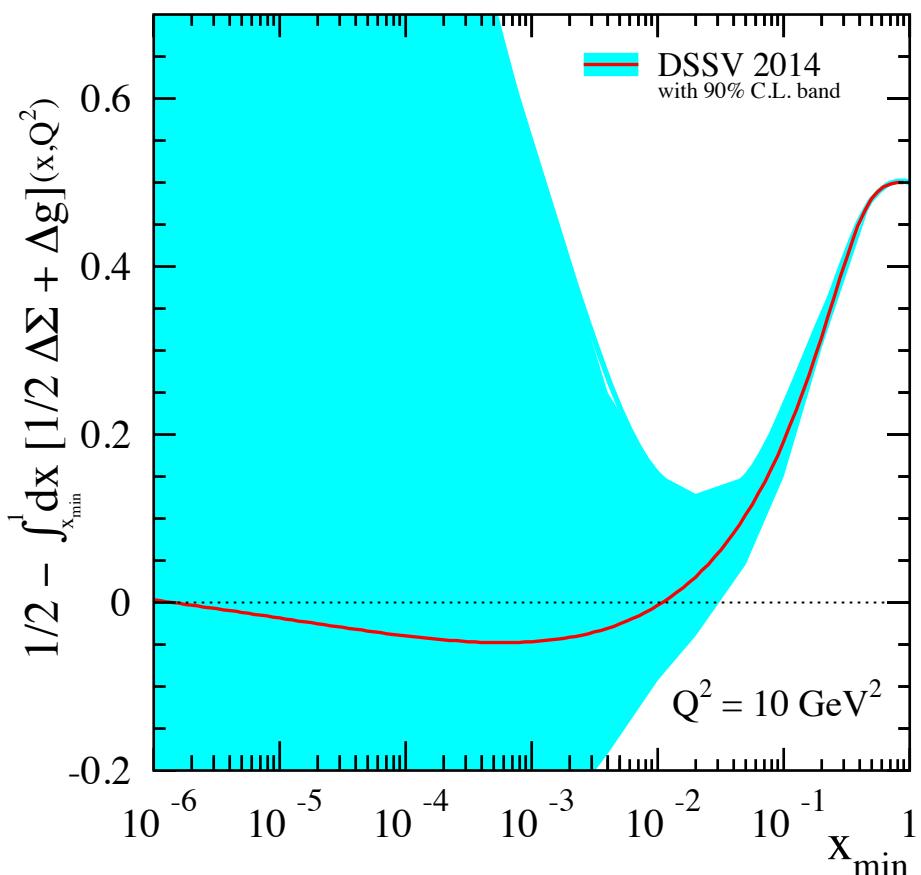


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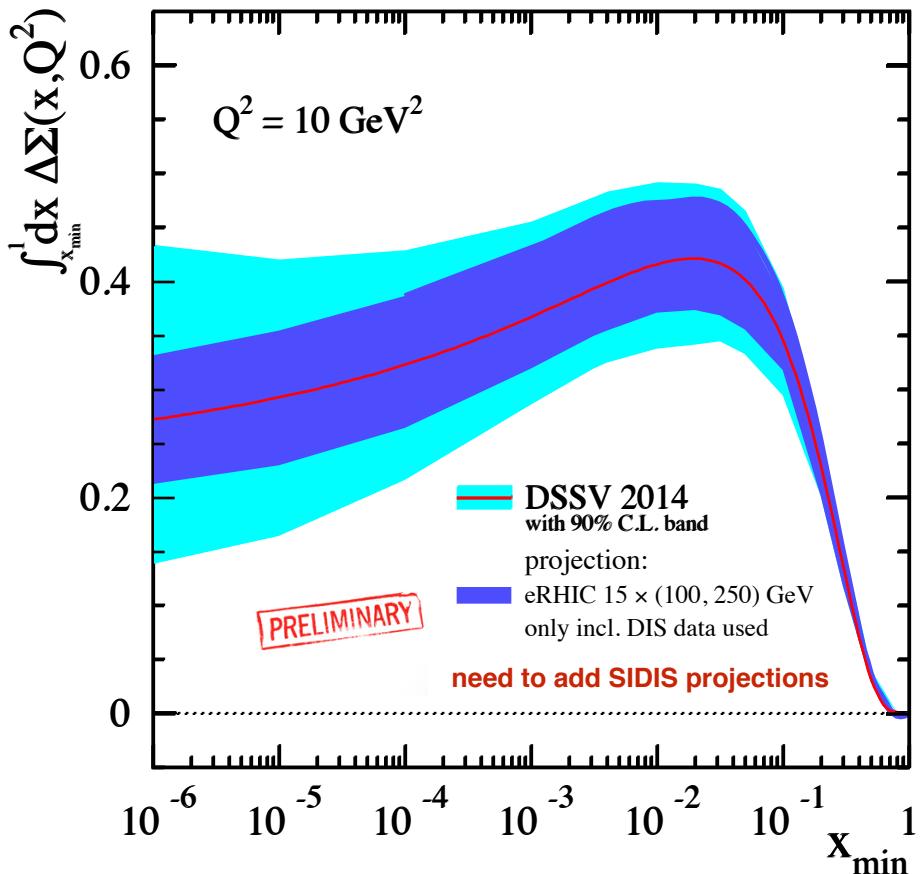
a little subtraction game



- best fit has no OAM at 10 GeV²

what about $\Delta\Sigma$ and OAM ?

running integral for $\Delta\Sigma$

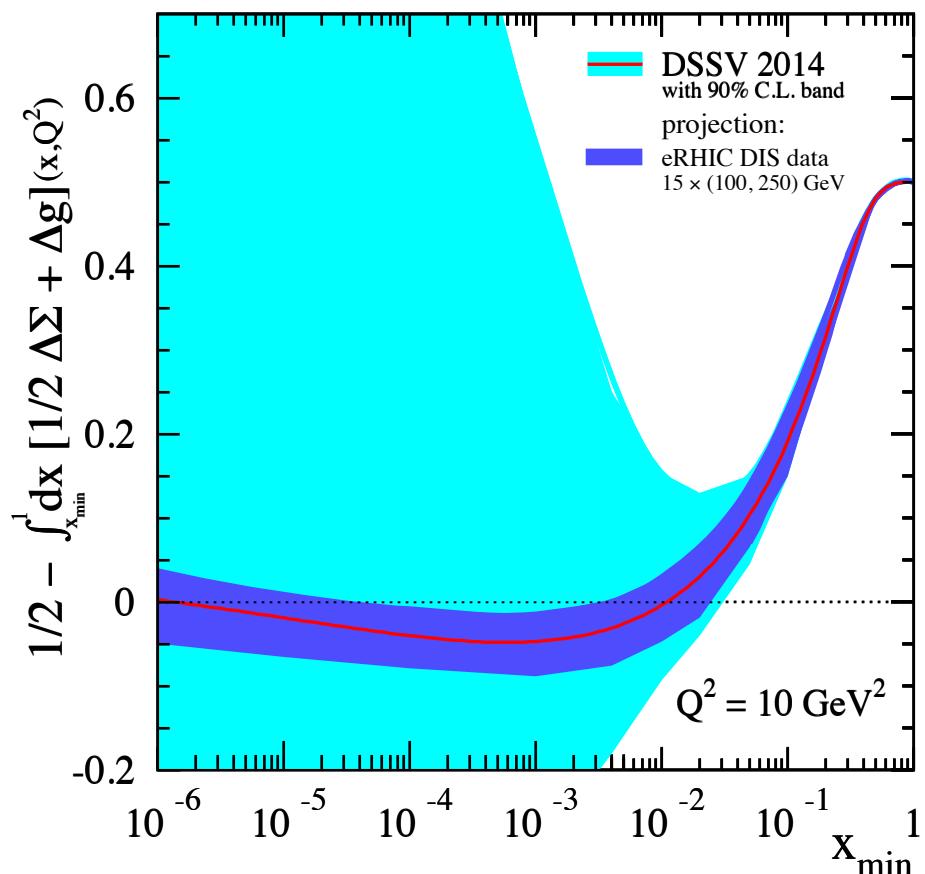


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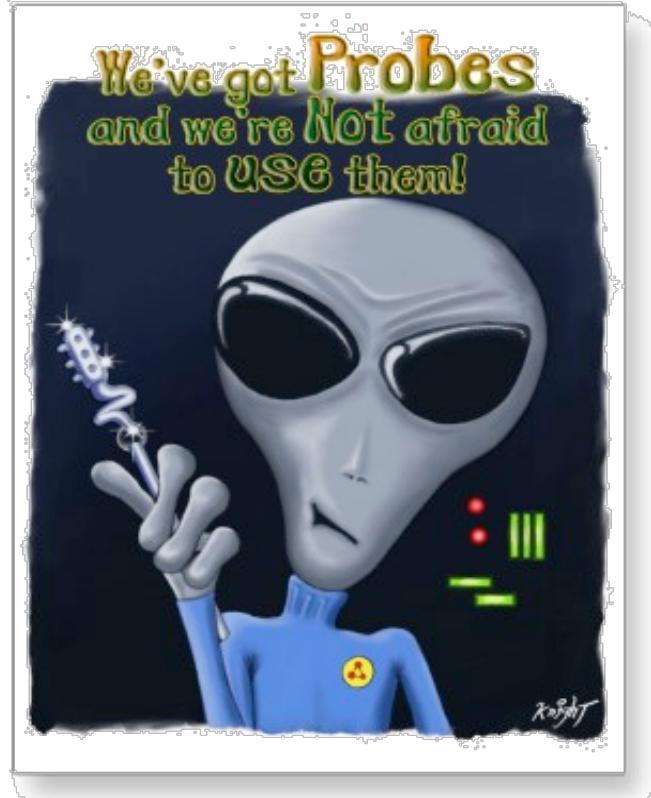
a little subtraction game



- best fit has no OAM at 10 GeV²

- eRHIC can make definitive statement
presumably most precise (indirect) handle on OAM

take away message



**spin experiments continue to produce
high impact results**

theory efforts & global QCD fits try to keep up
 Δg has gained quite some weight in proton spin sum
RHIC spin has many more results to come

**to close the chapter on the proton spin
an EIC is the only option**

