Bloomington, Aug 20th, 2012

Precision Studies of the Proton's Helicity Structure at an EIC

Marco Stratmann

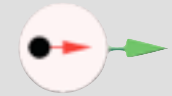
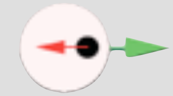
BROOKHAVEN NATIONAL LABORATORY

marco@bnl.gov

talk largely based on
E.C. Aschenauer, R. Sassot, MS: arXiv:1206.6041

open questions

significant experimental and theoretical progress in past 25+ years, yet many unknowns

recall:  

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DSSV global fit
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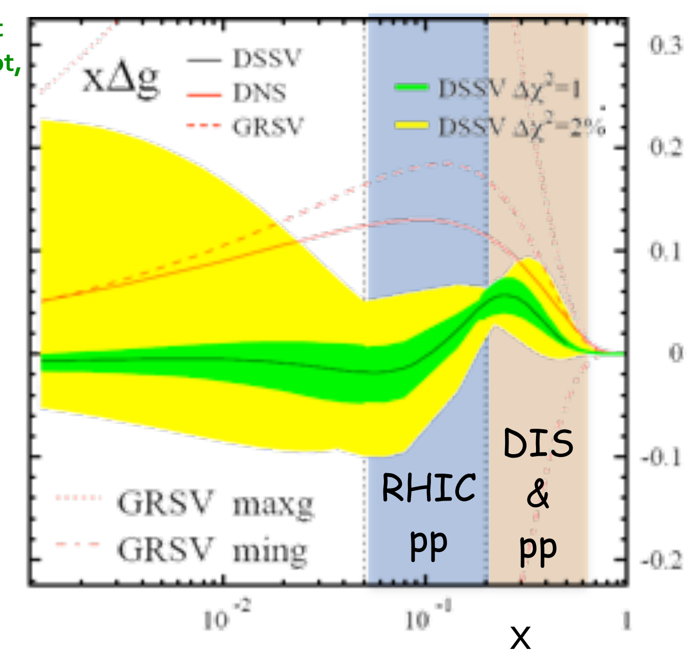

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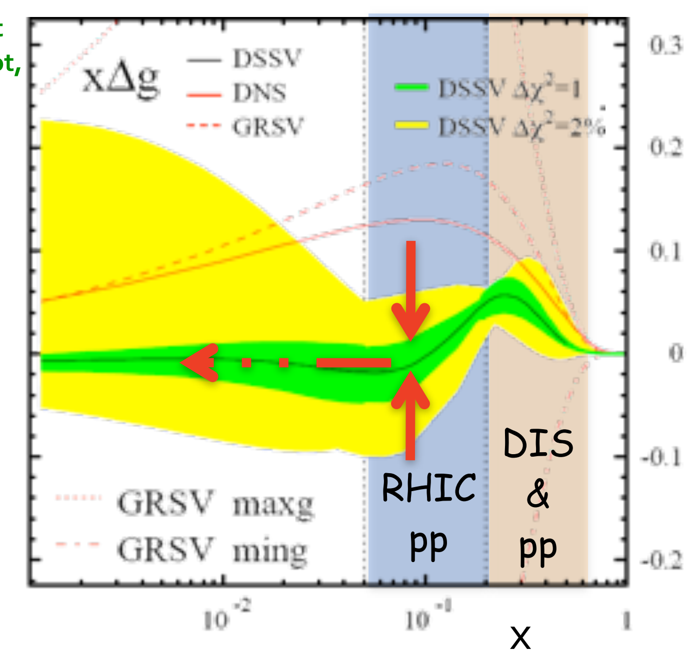

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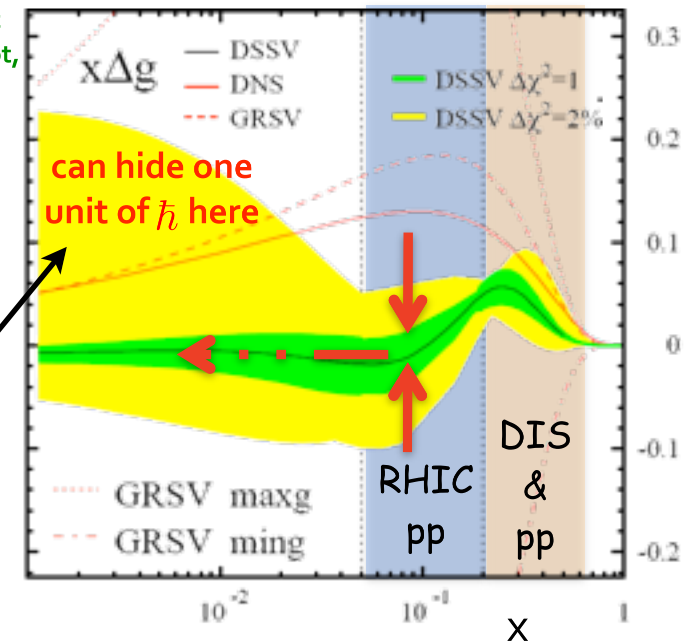

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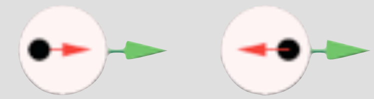
recall: 

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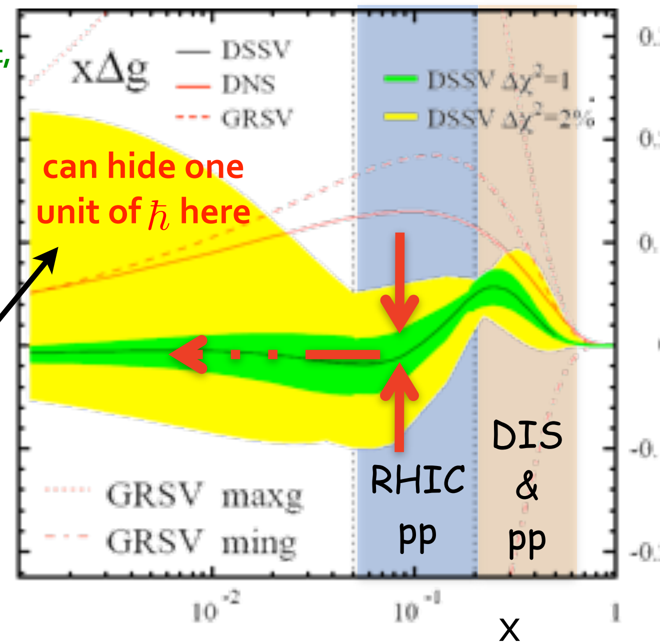

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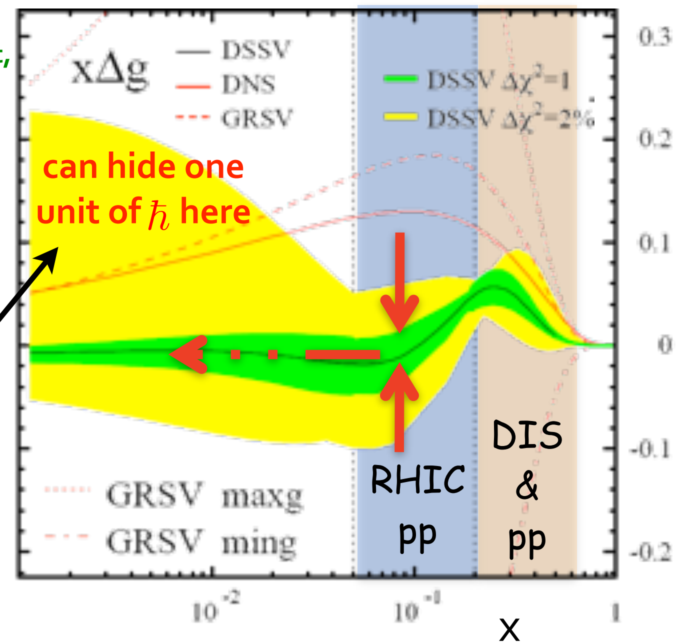
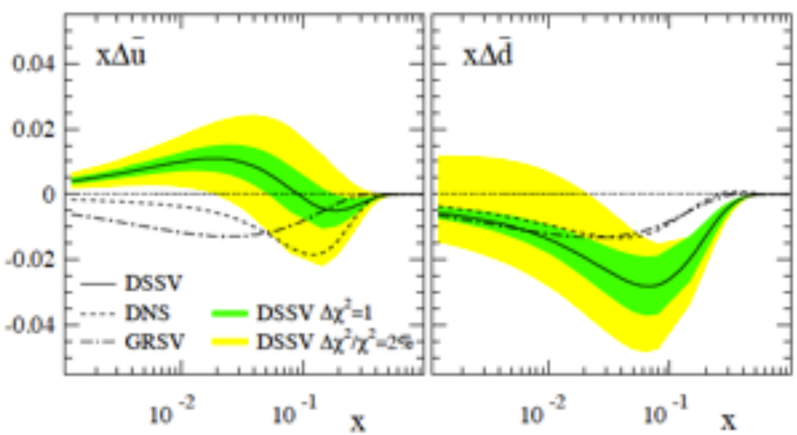


Δq's (x,Q^2)



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yet, large uncertainties in $\Delta\Sigma$ from unmeasured small x
$\Delta\Sigma \simeq 0.3$ assumes validity of SU(3) symmetry (F,D values)

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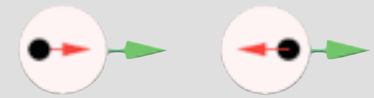

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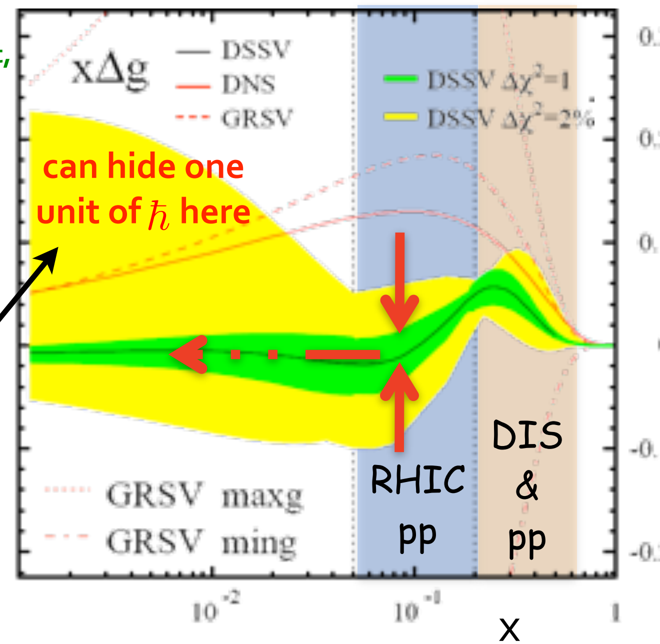

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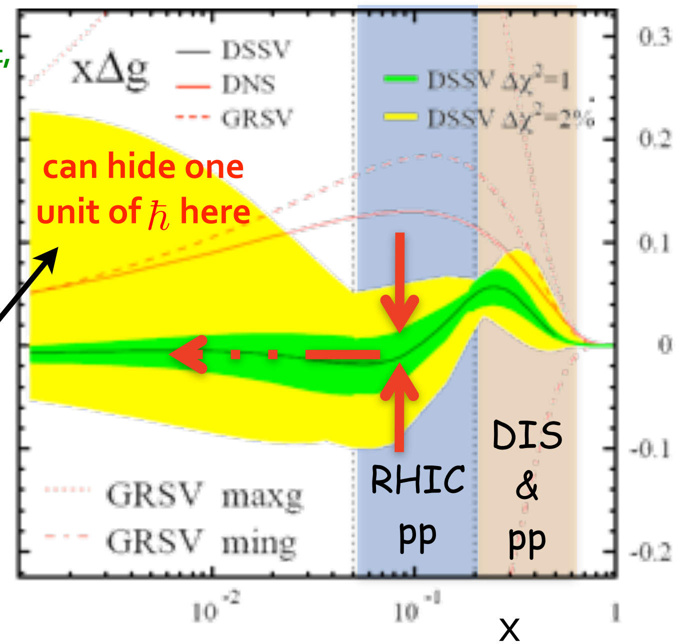

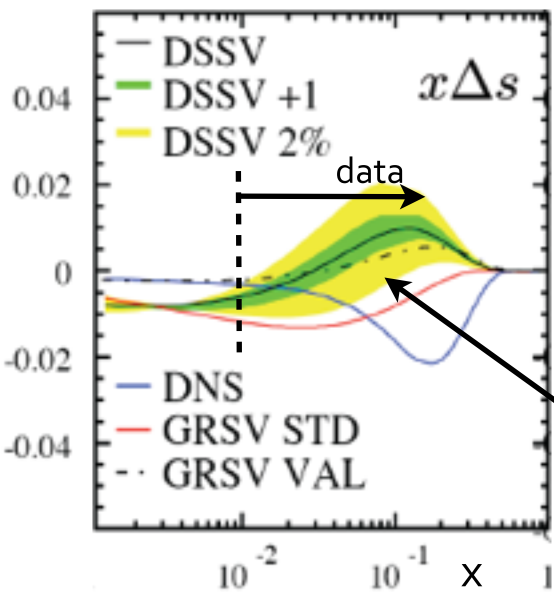

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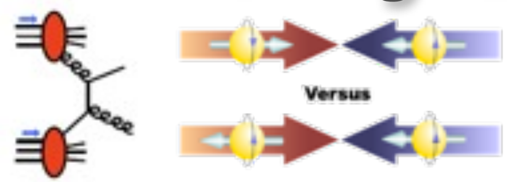
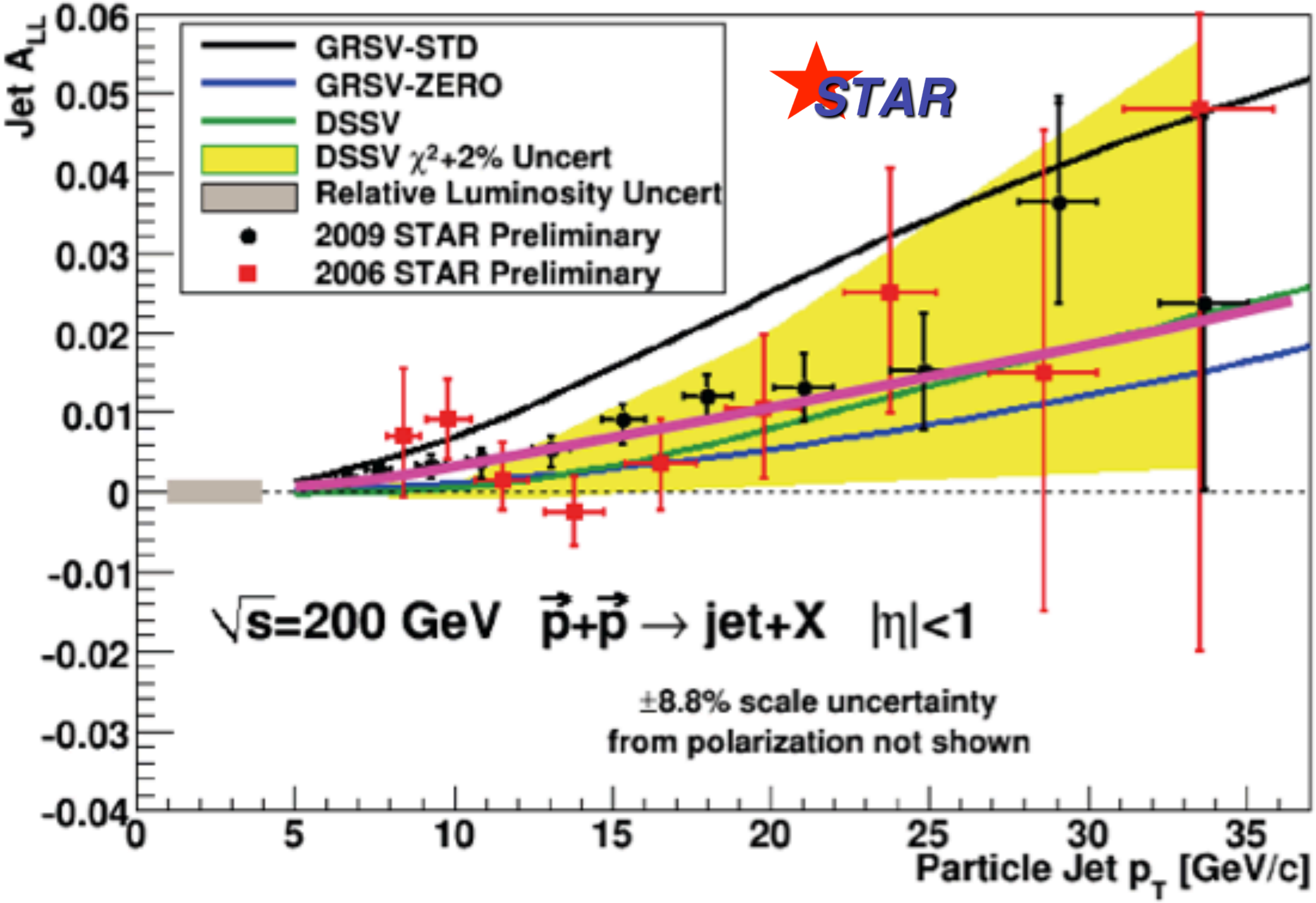
- some indications for non-trivial flavor structure of quark sea
- surprisingly small/positive Δs from SIDIS

does it comply with neg. integral expected from SU(3) arguments

what to expect from future RHIC running: Δg

tantalizing hints for non-zero Δg





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fits well

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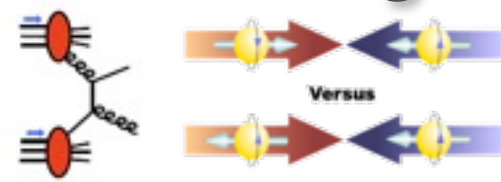

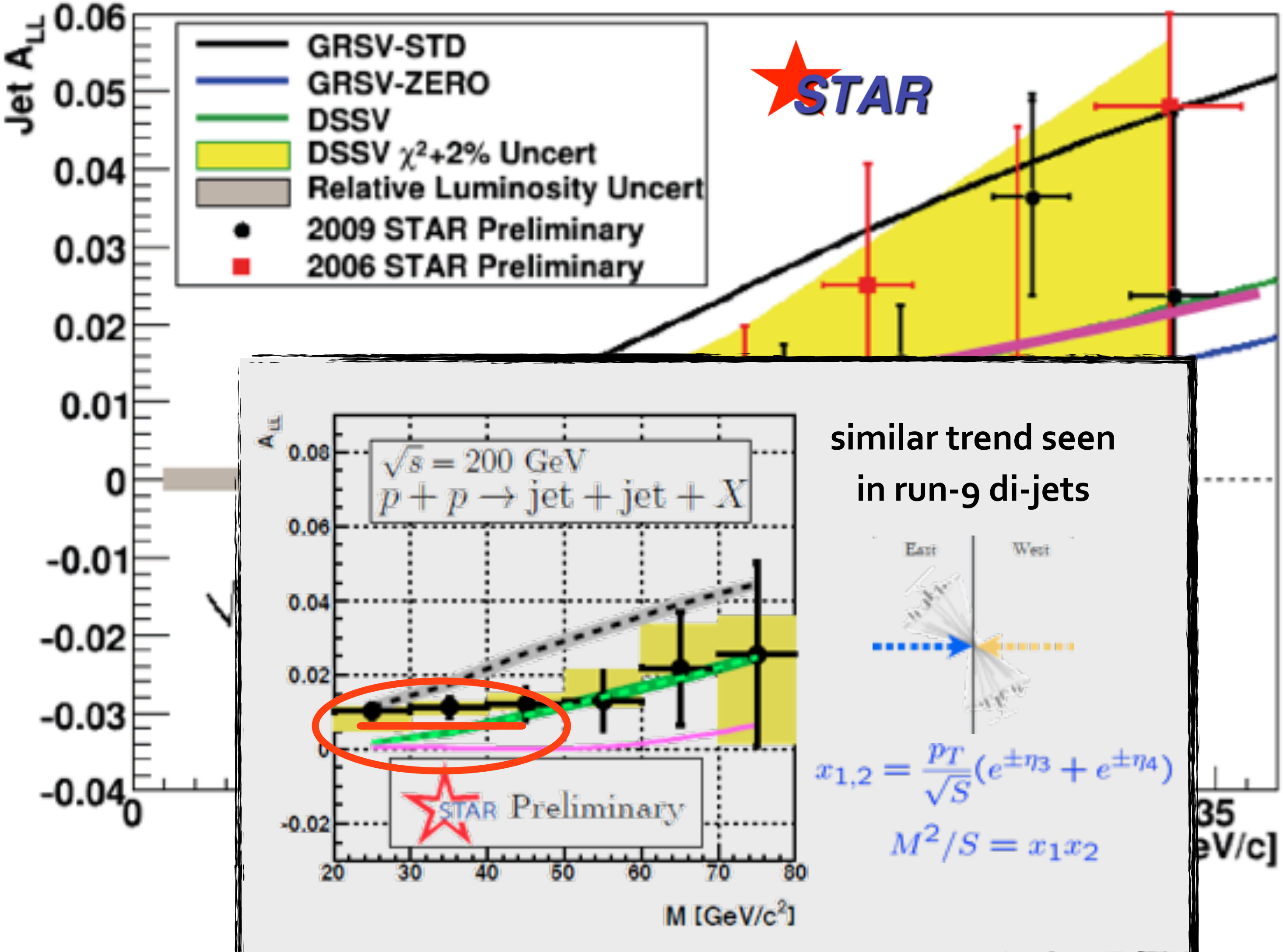

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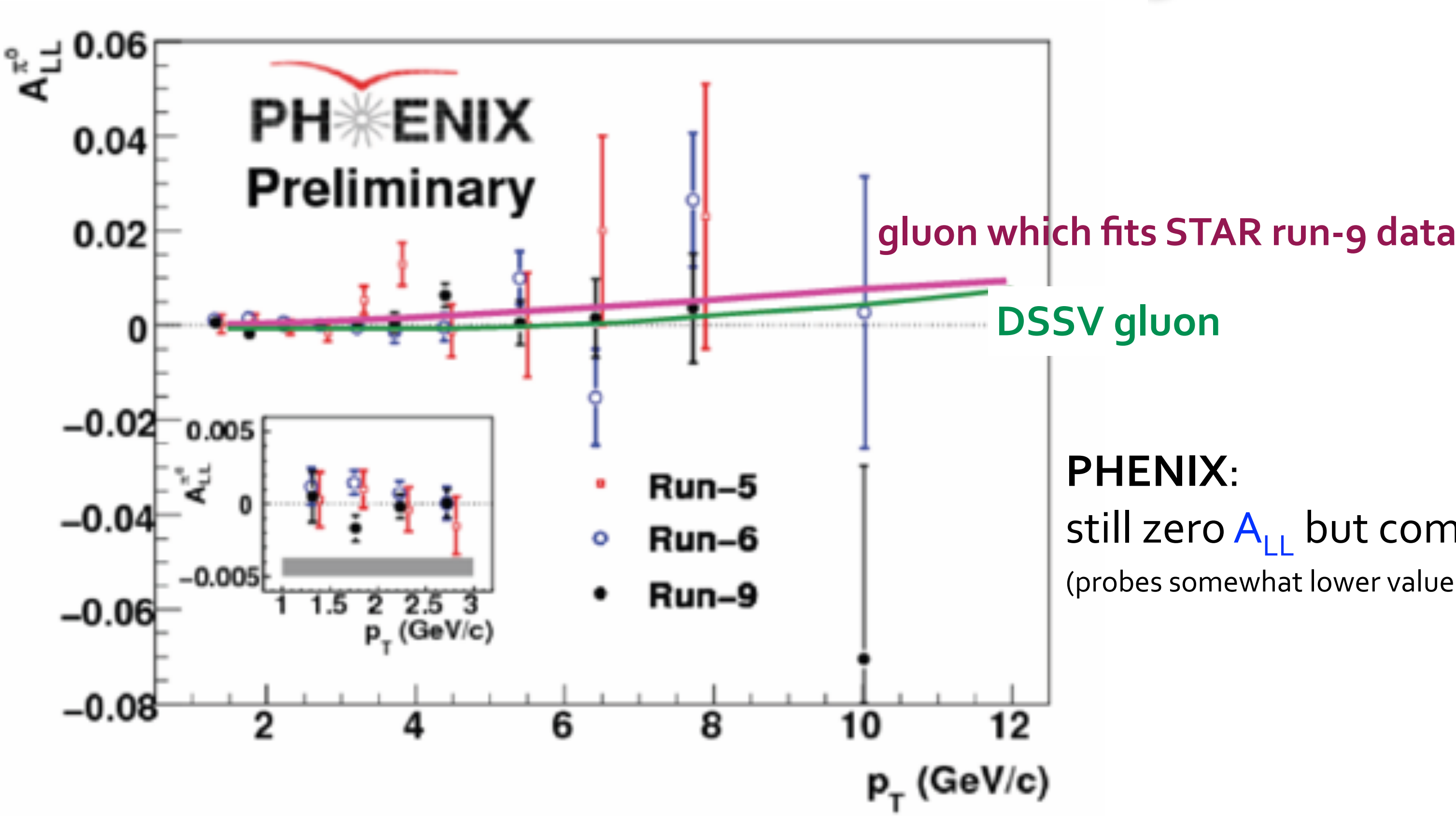

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still zero A_{LL} but compatible with STAR

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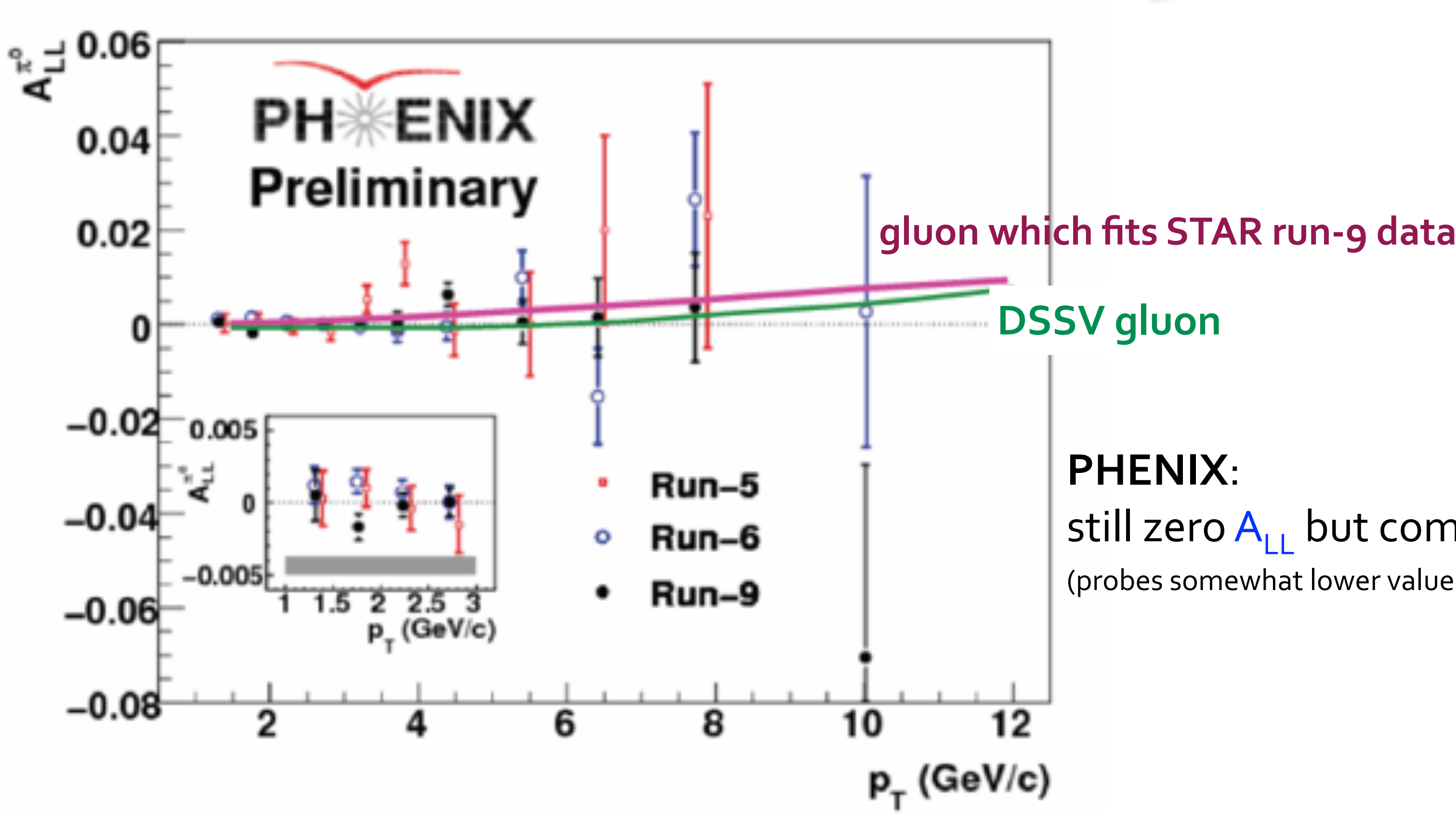

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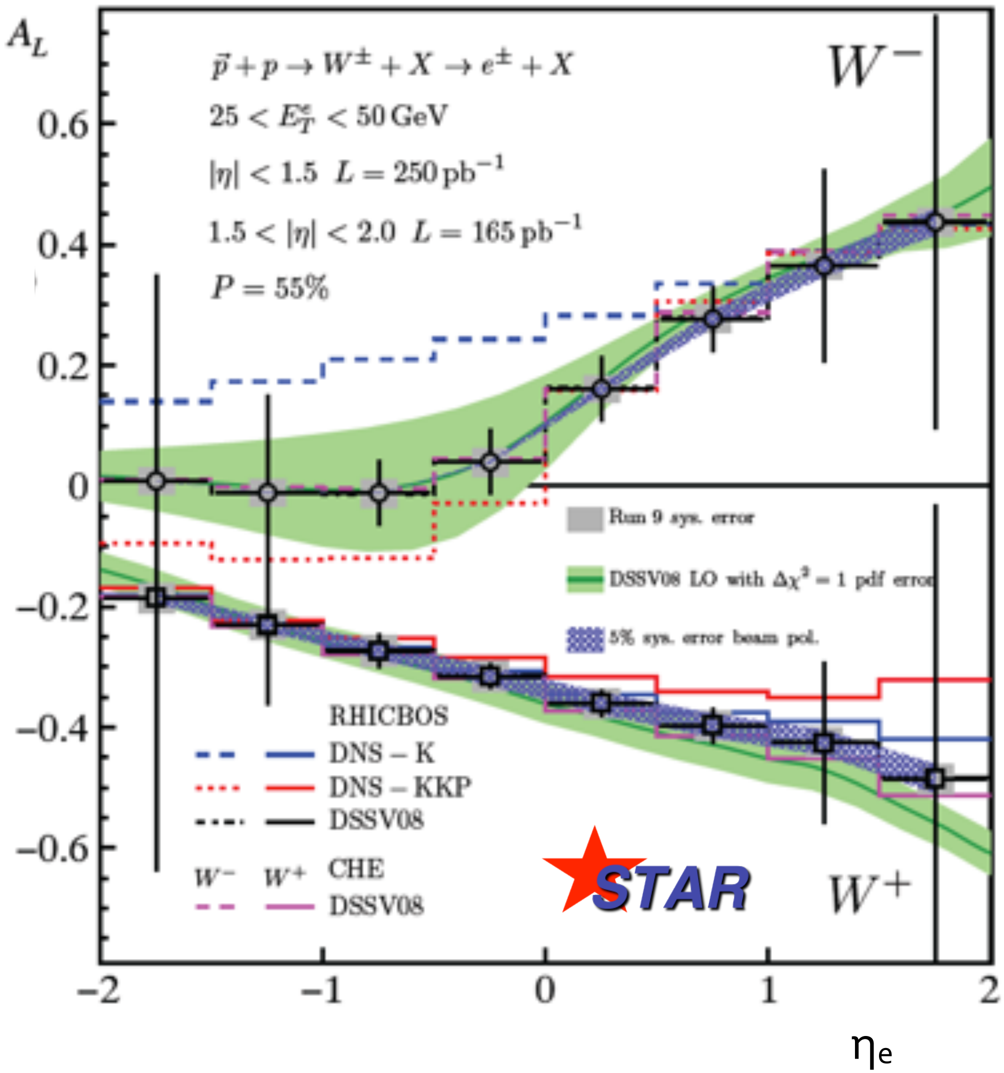
200 + 500 GeV jet, di-jet, pion data will continue to improve knowledge of Δg
expect: meaningful constraint down to about x =0.01
not sufficient to reliably determine its integral

future RHIC running: Δq - what do we expect to learn ?

projection for run-13



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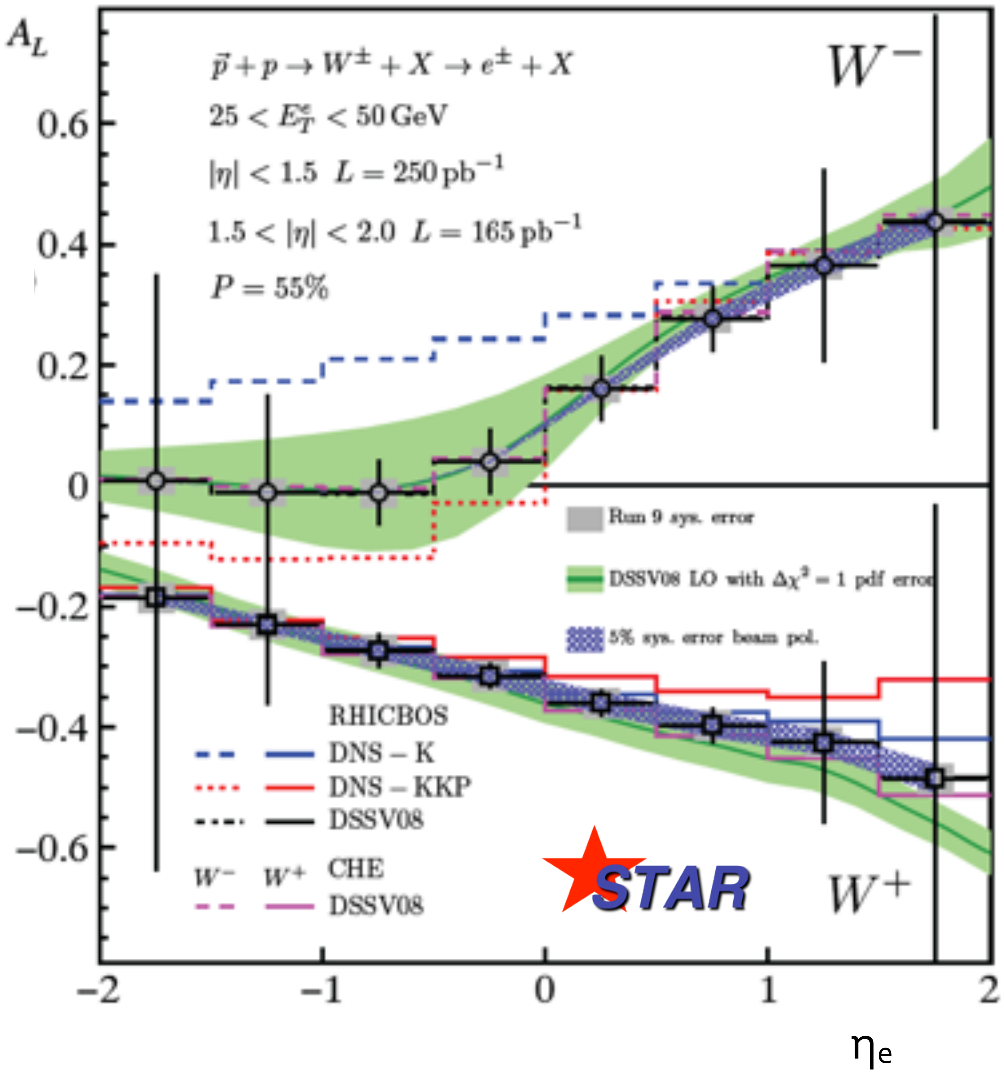

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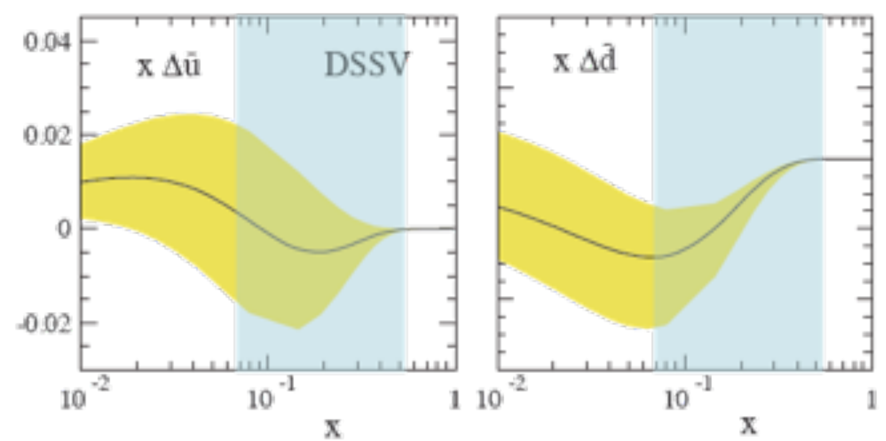
DSSV fit based on current SIDIS data



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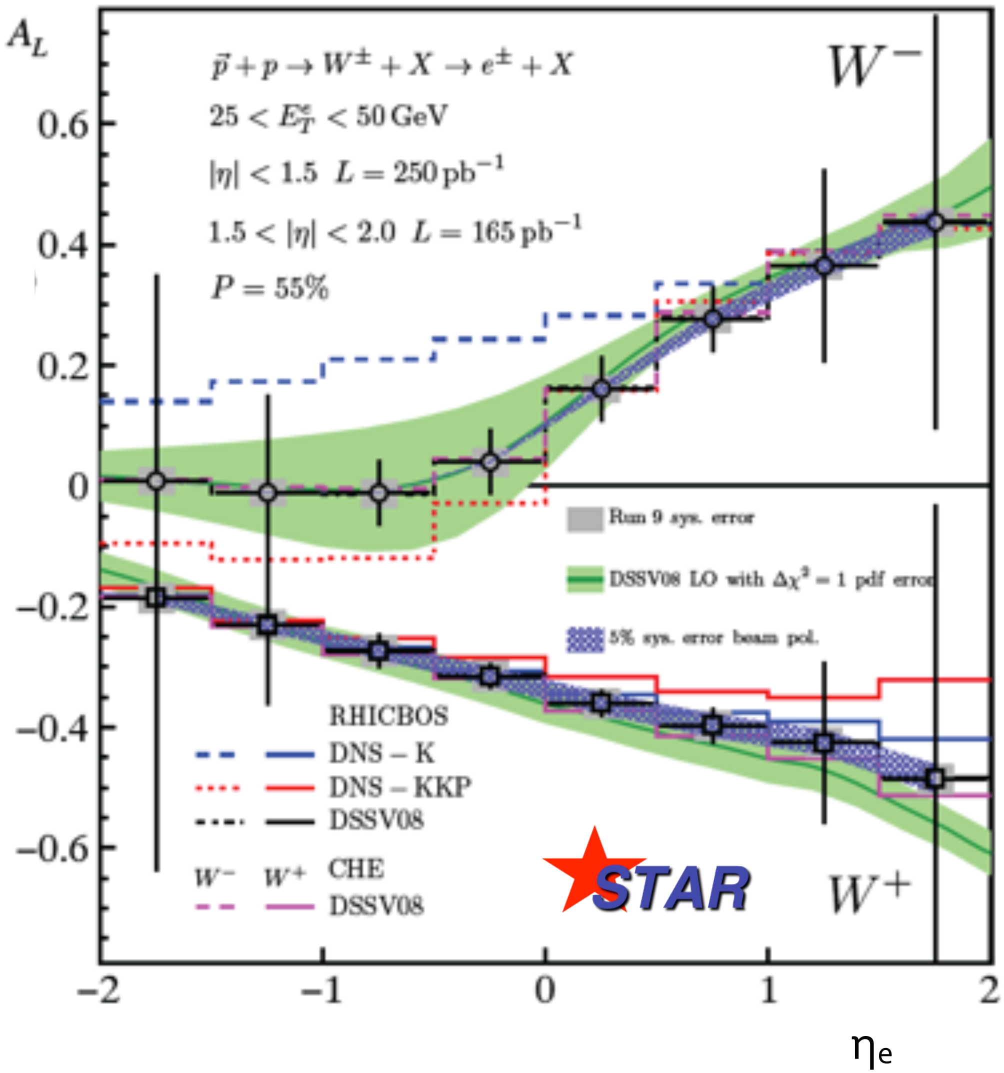

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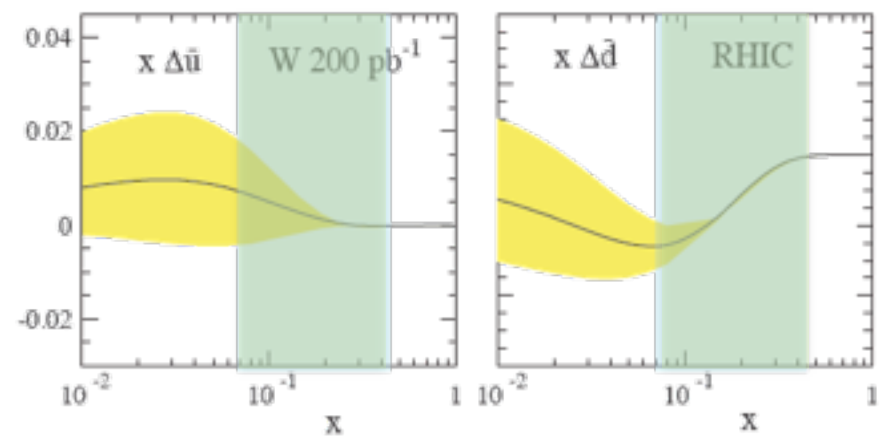
DSSV fit including projected RHIC data



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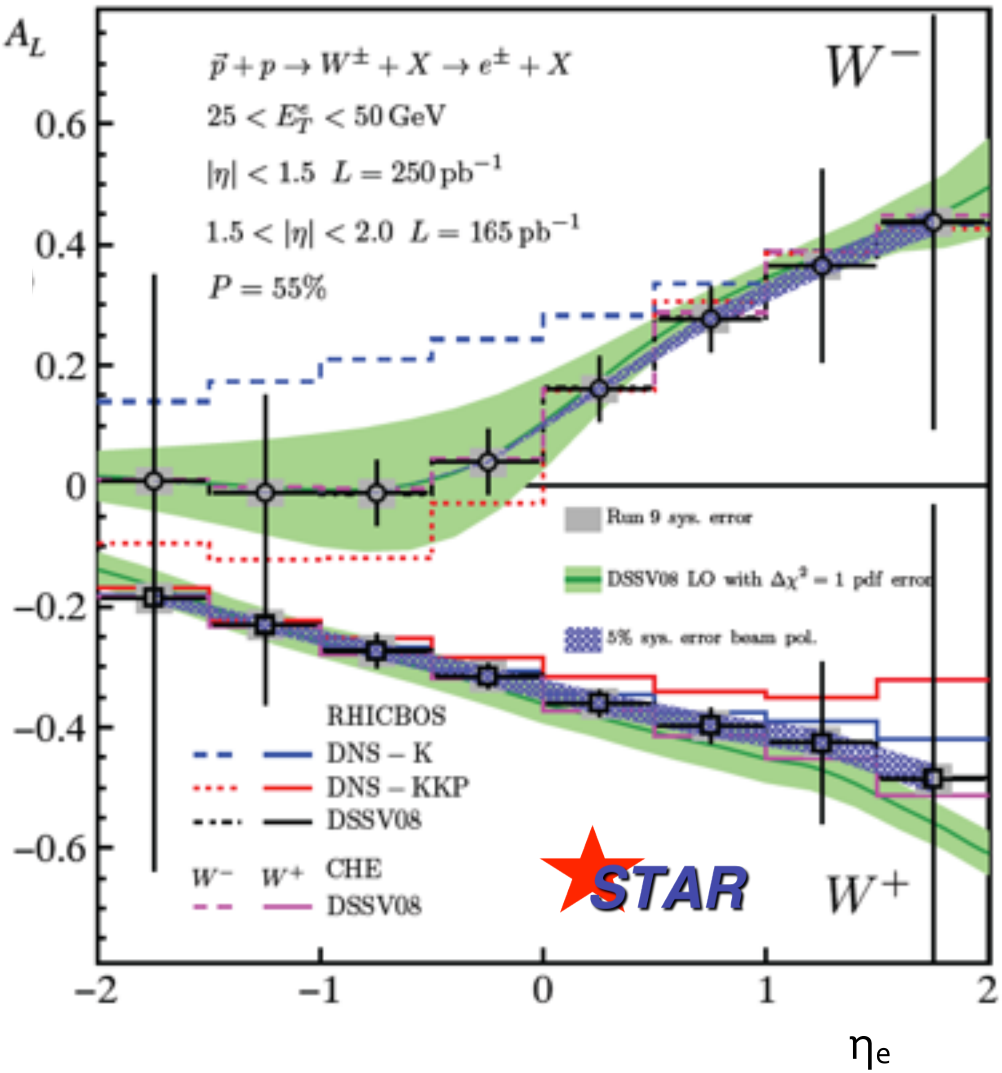

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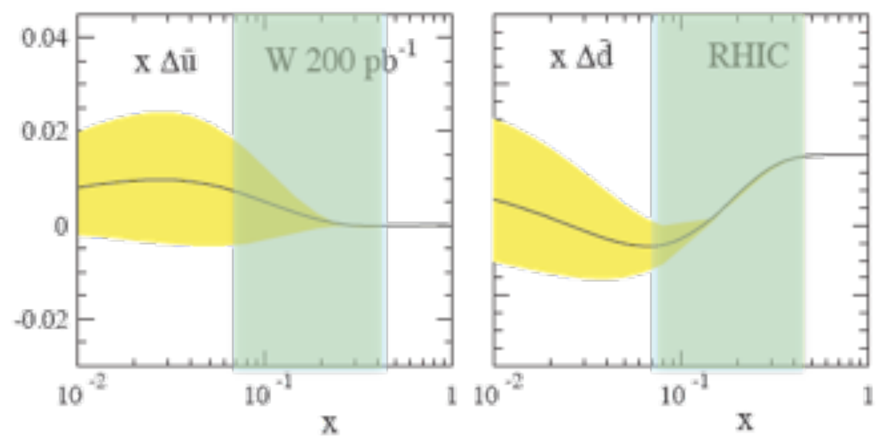

reduction of uncertainties for 0.07 < x < 0.4

- [x] tests consistency of low Q^2 SIDIS data in large x regime
- [ ] no access to small x
- [ ] no access to Δs

precision studies of the proton's helicity structure

key measurements & requirements

EIC mission: complete survey of nucleon's spin structure

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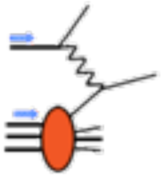

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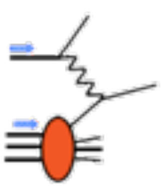

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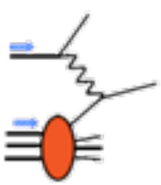

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prerequisites

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$$\sqrt{S} \gtrsim 40\,\mathrm{GeV}$$

to access $x < 10^{-3}$ where sea quarks and gluons dominate

modest luminosity requirements

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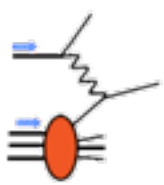

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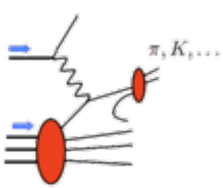

semi-inclusive DIS

scattered lepton

identified pions, kaons, …

deliverables: $\Delta u, \Delta \bar{u}$; $\Delta d, \Delta \bar{d}$; $\Delta s, \Delta \bar{s}$

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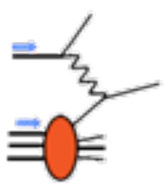

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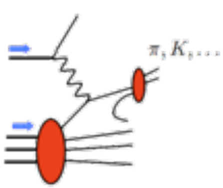

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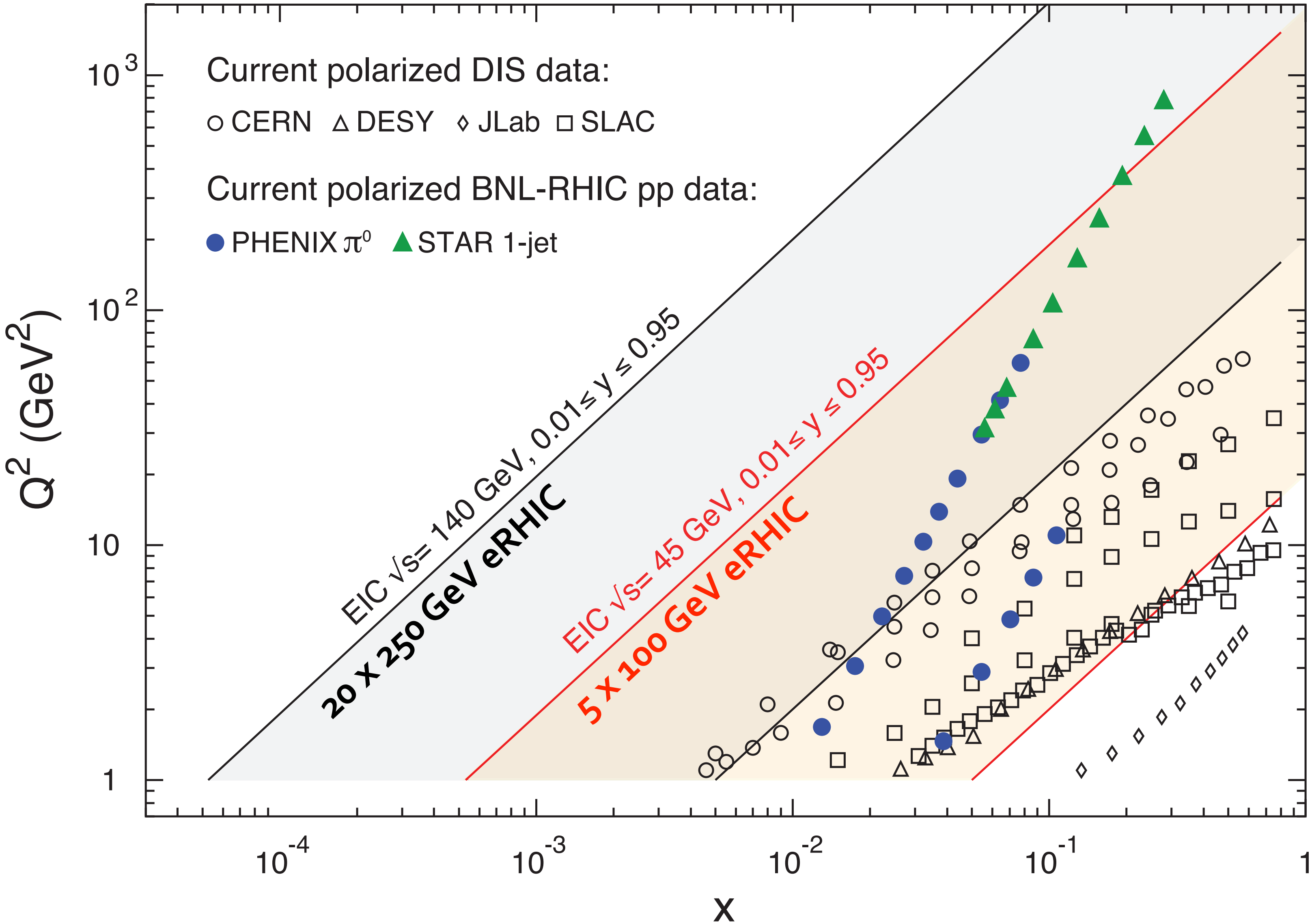
good control of

- systematic uncertainties
- particle ID for SIDIS
- "hadronic method" for e-w
- QED radiative corrections

key asset of an EIC: kinematic coverage

EIC likely to be realized in stages: e.g. **5 x 100 – 5 x 250 GeV** [stage-1 eRHIC] to **20 x 250 GeV** [full]



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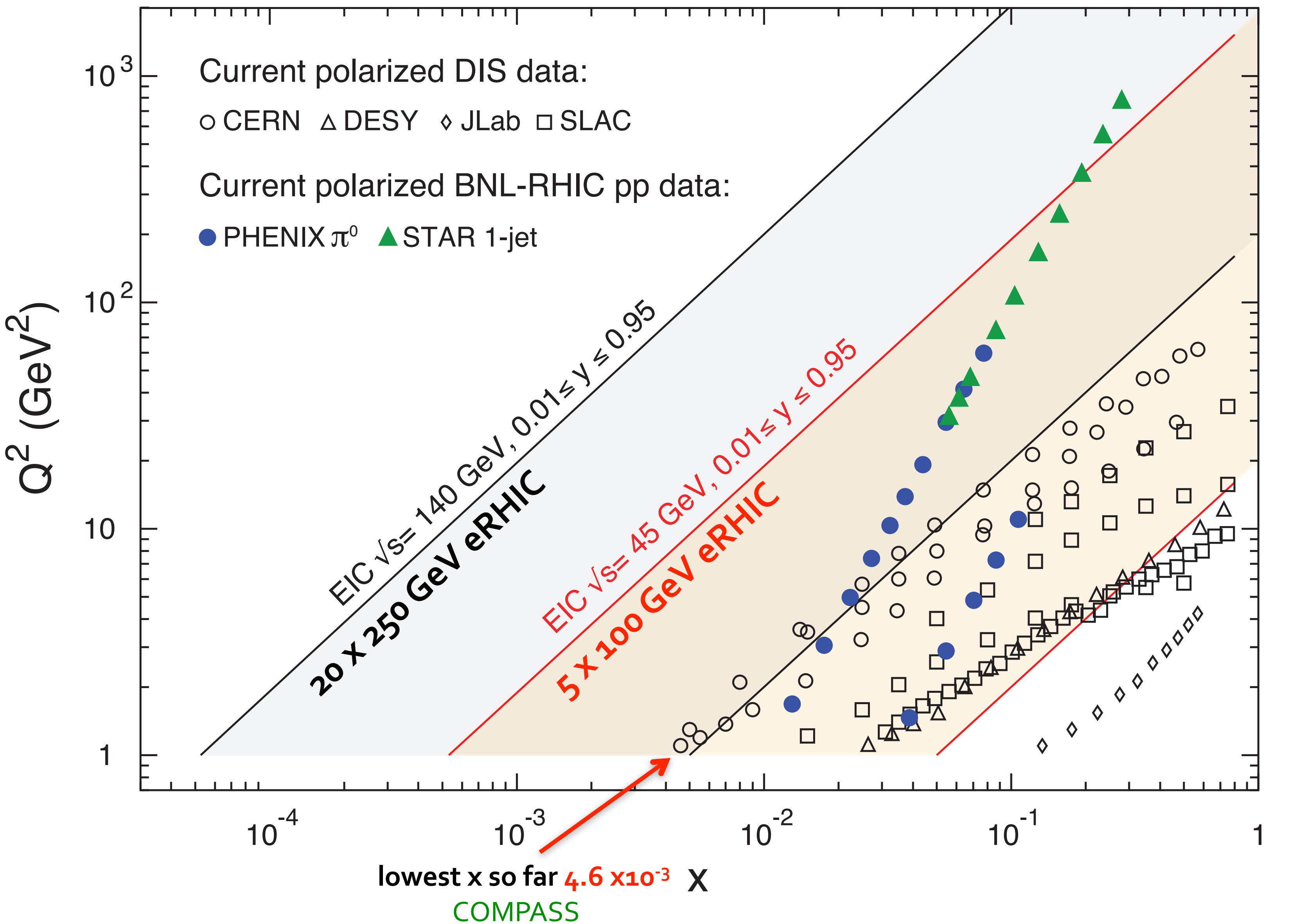

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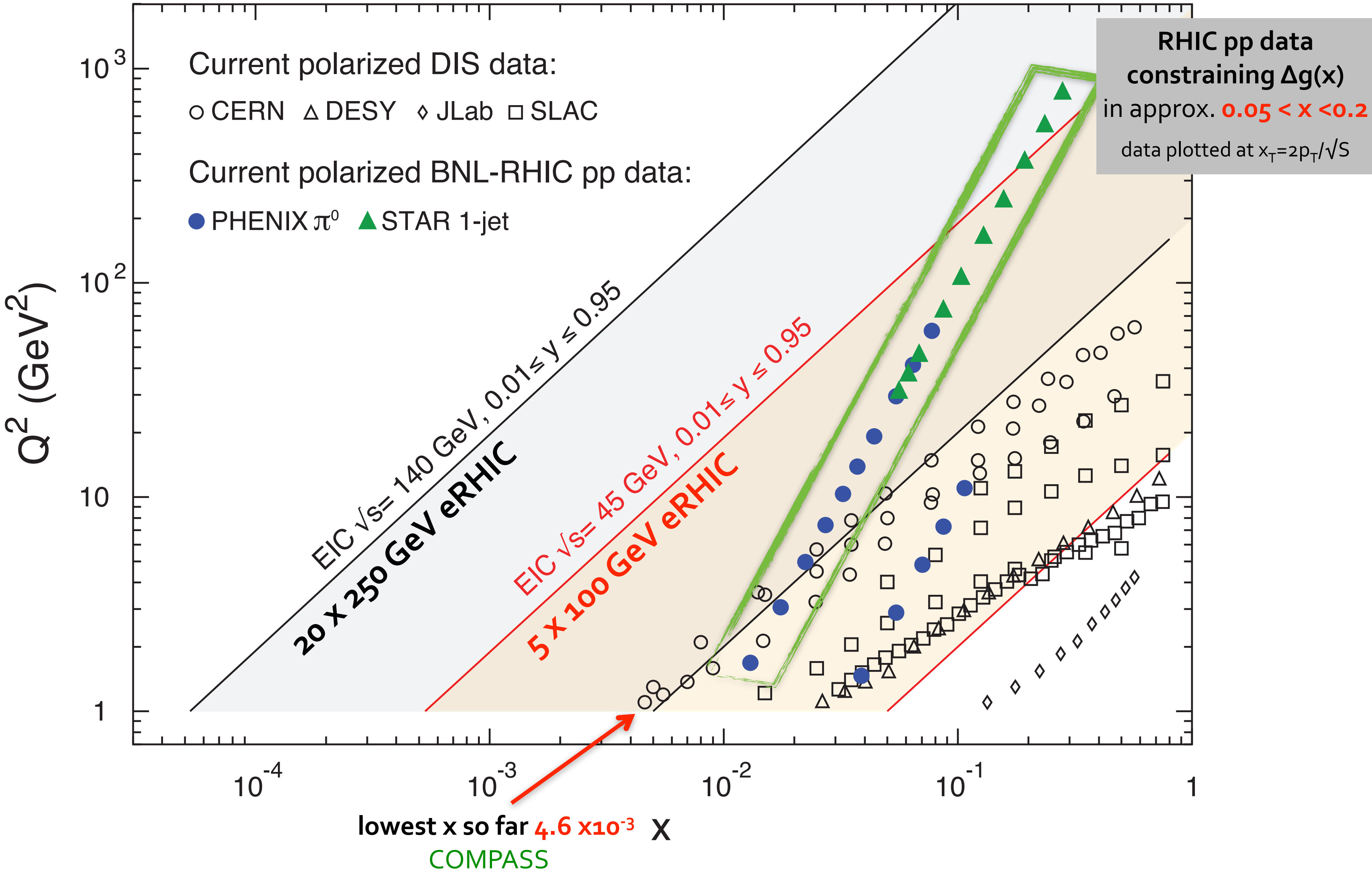

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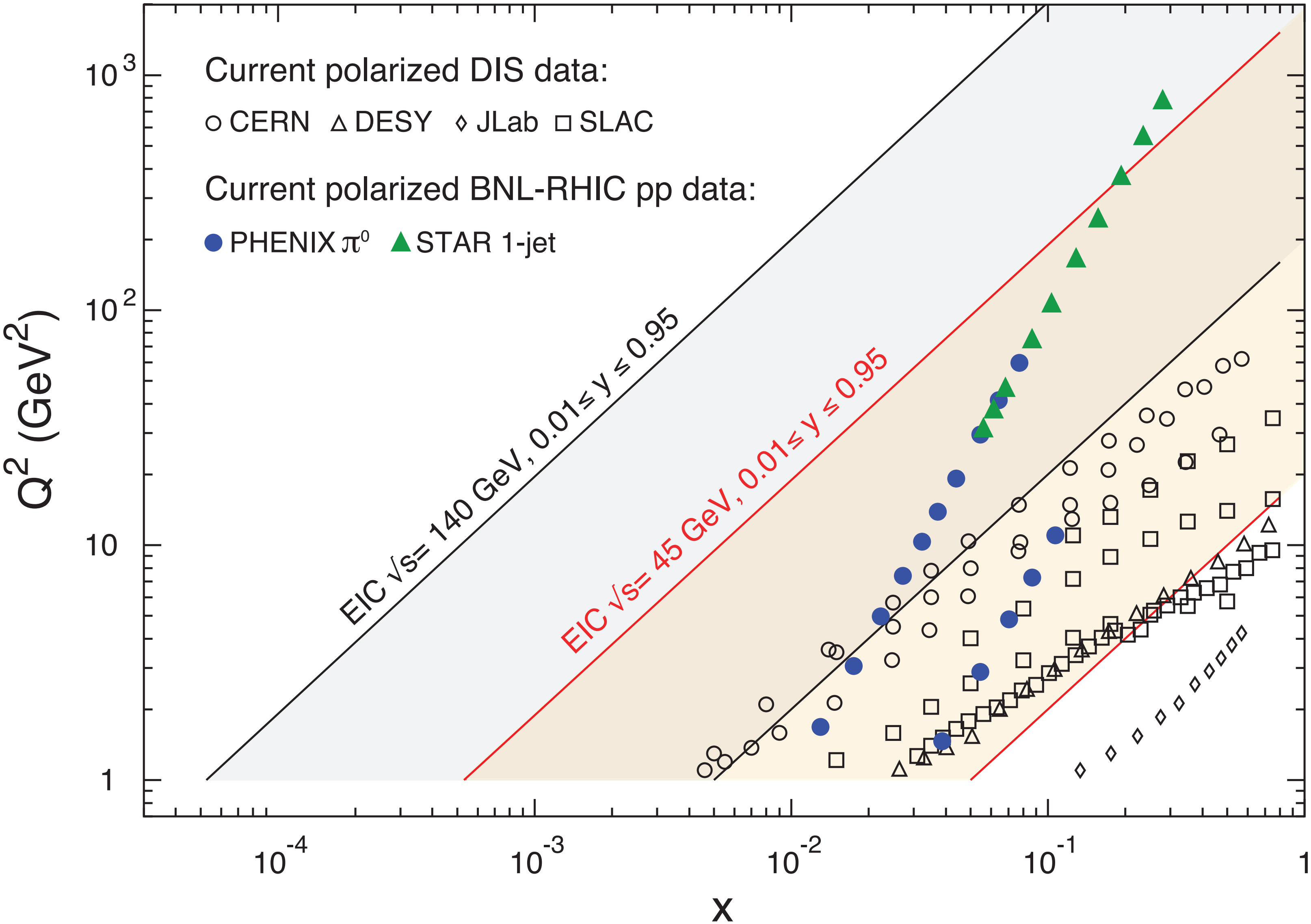

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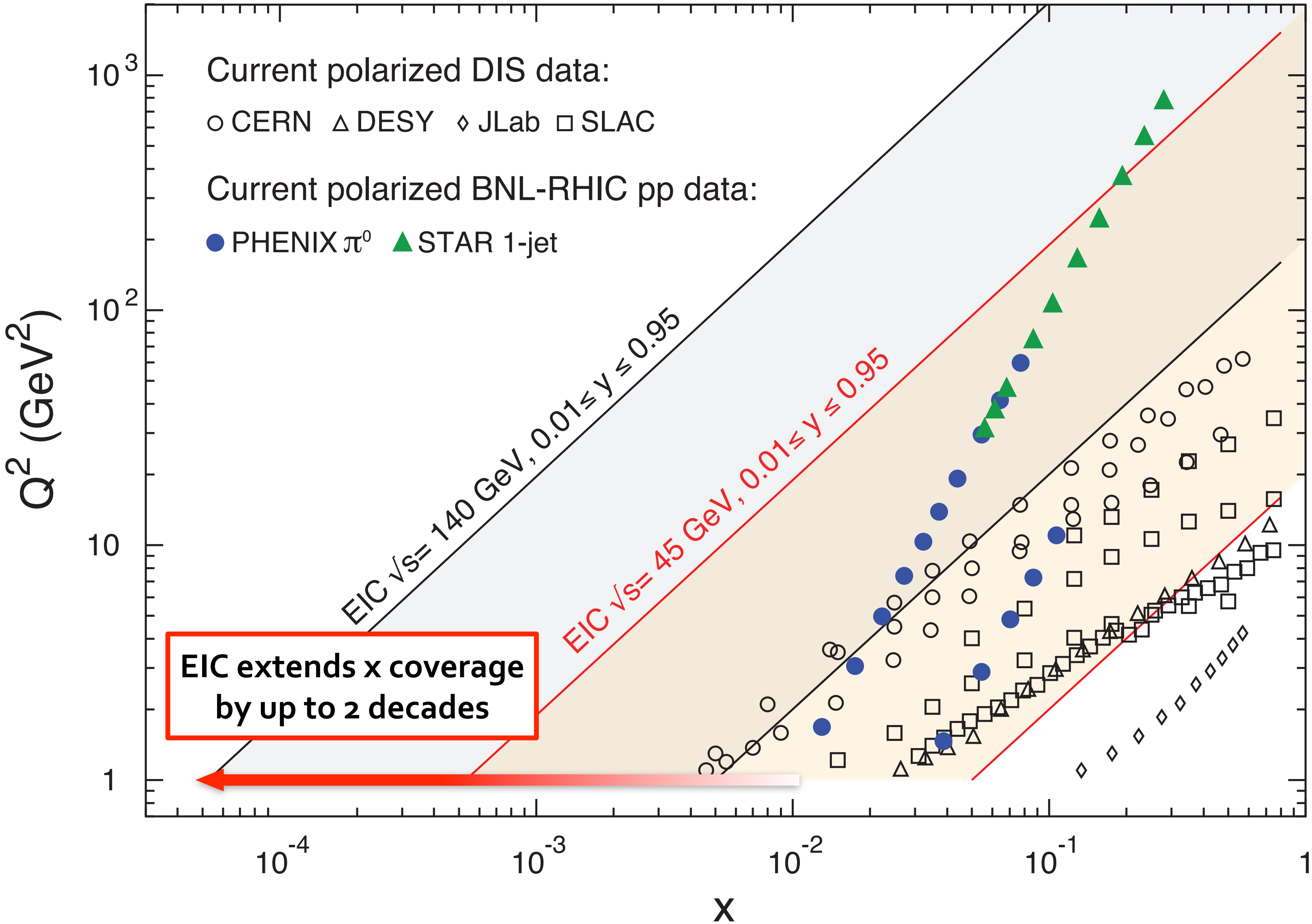

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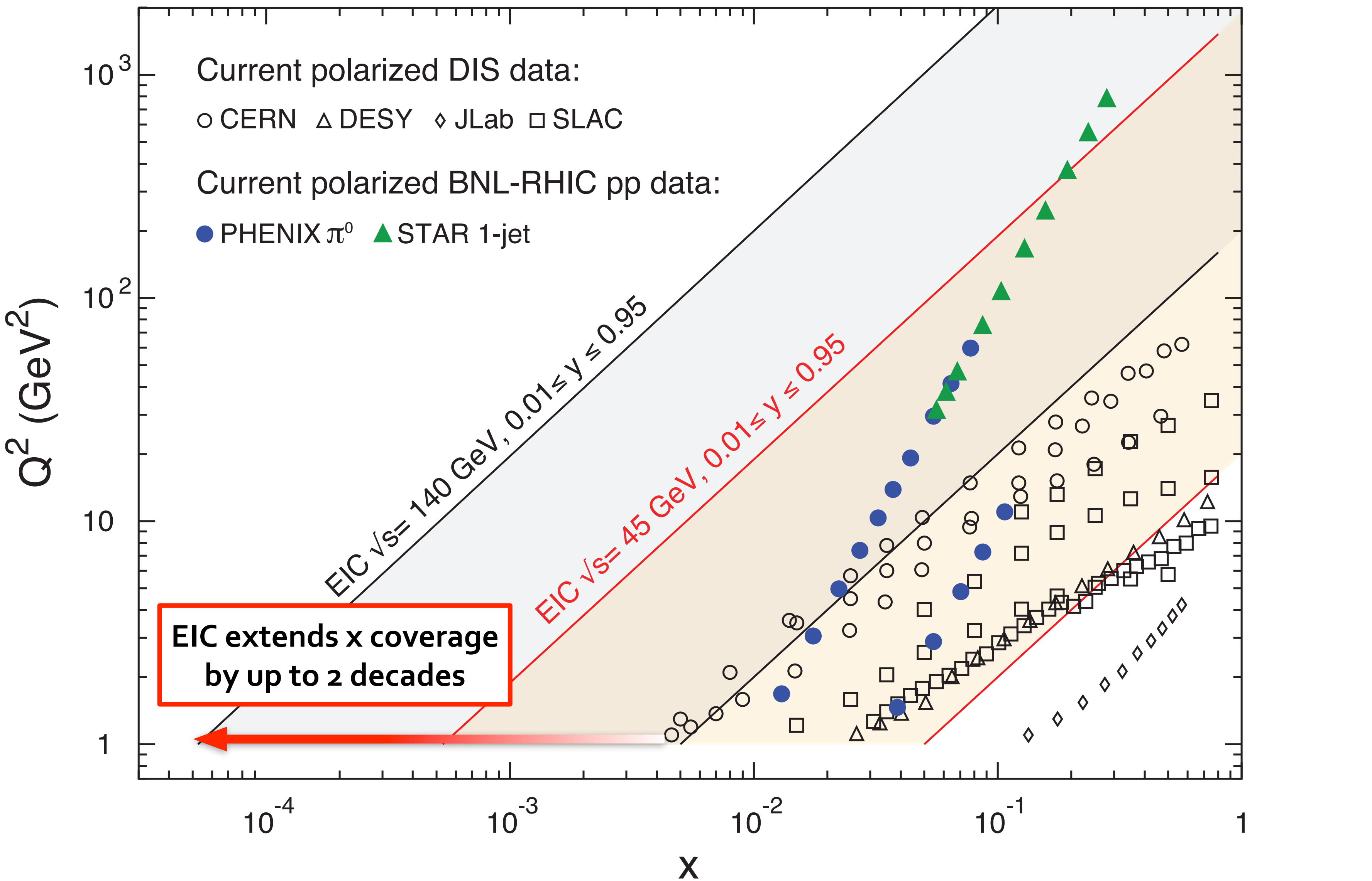

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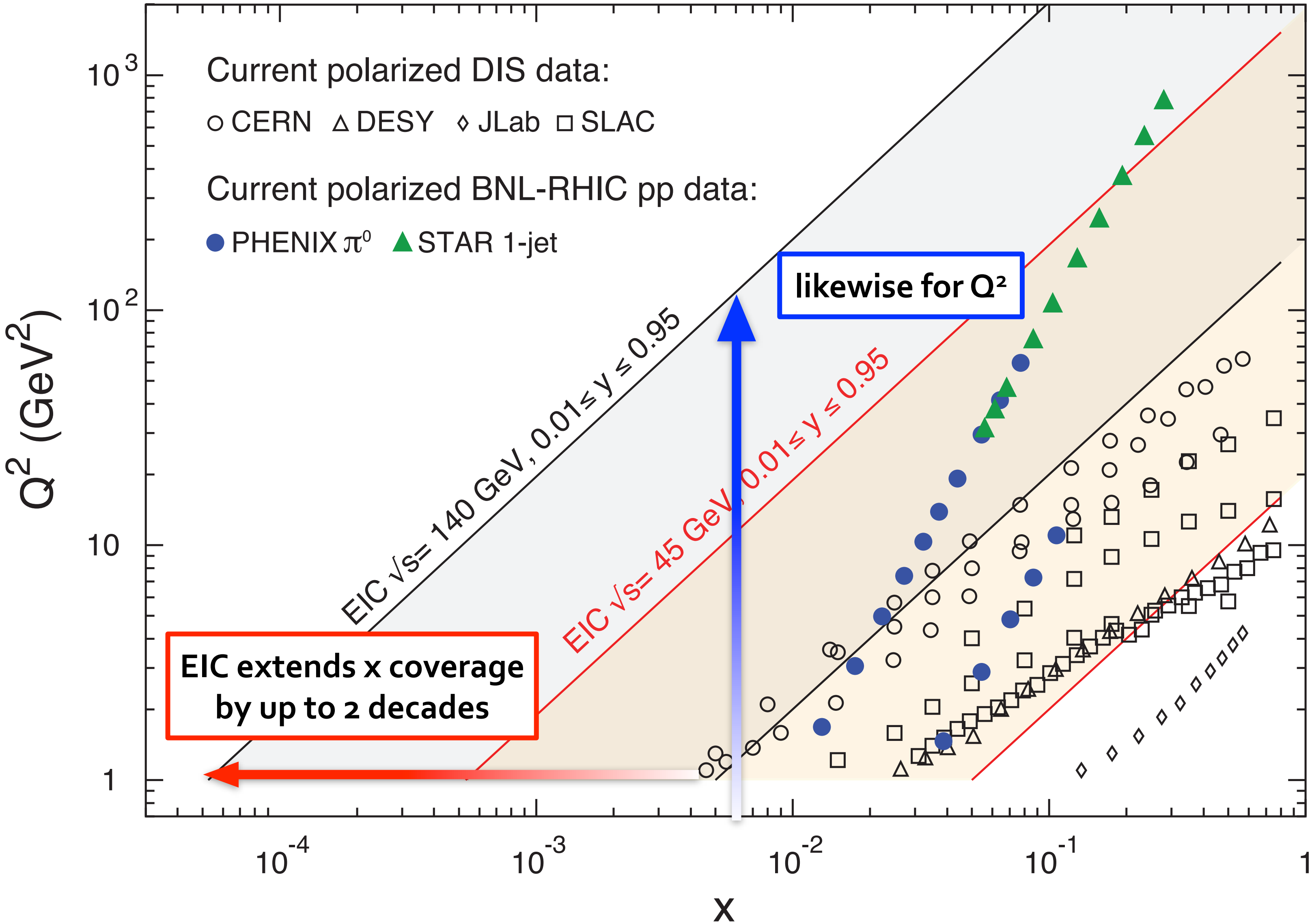

key asset of an EIC: kinematic coverage

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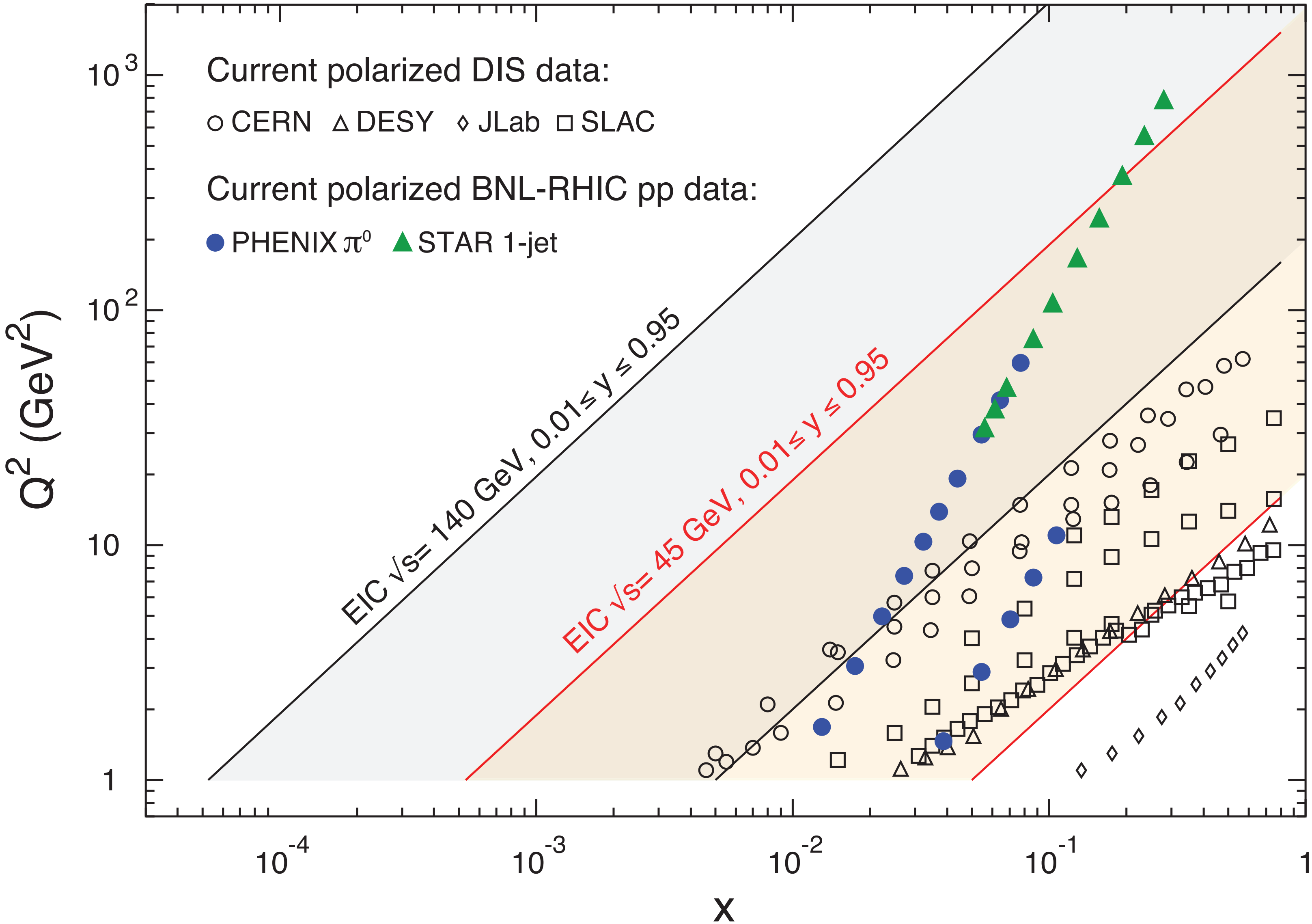

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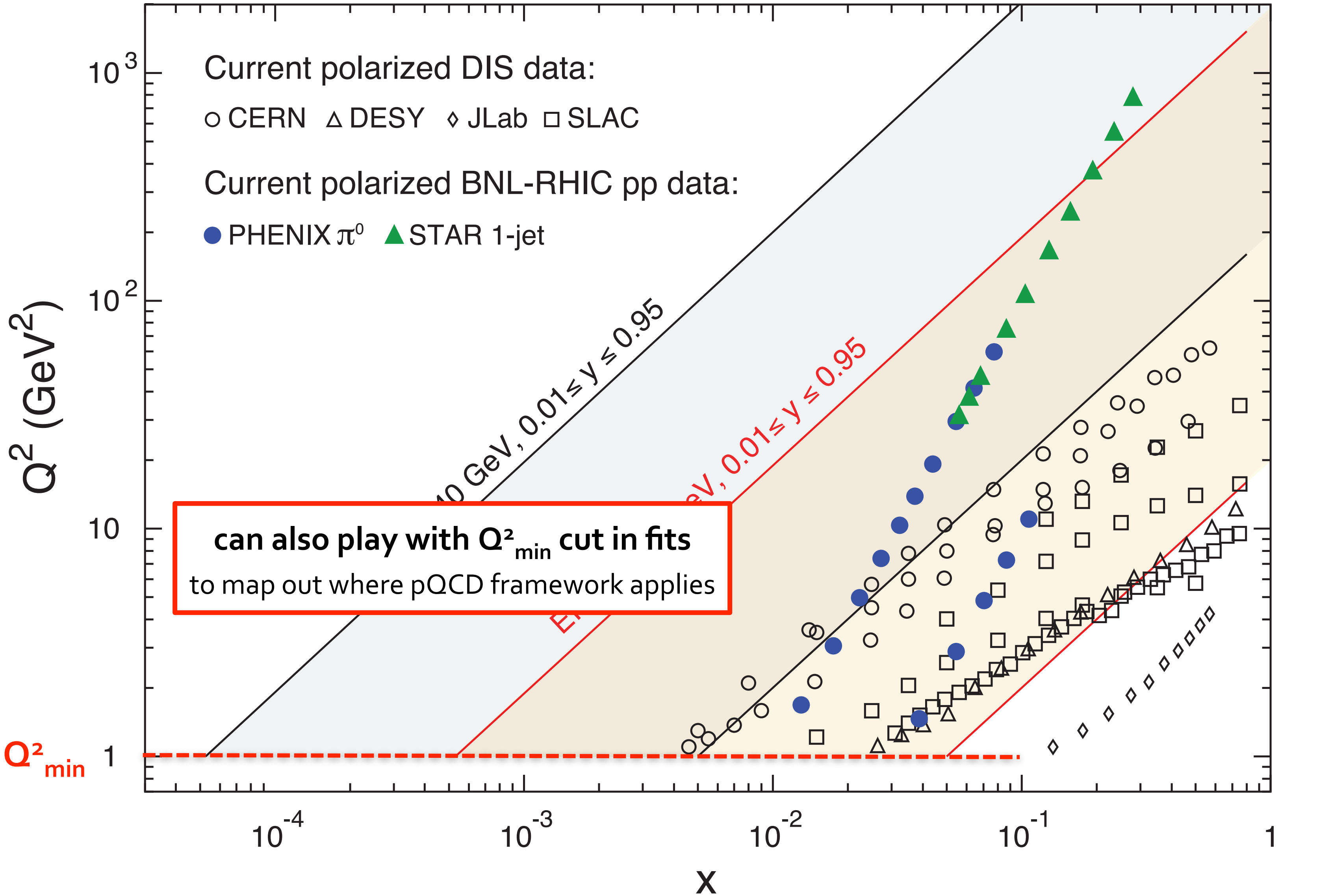

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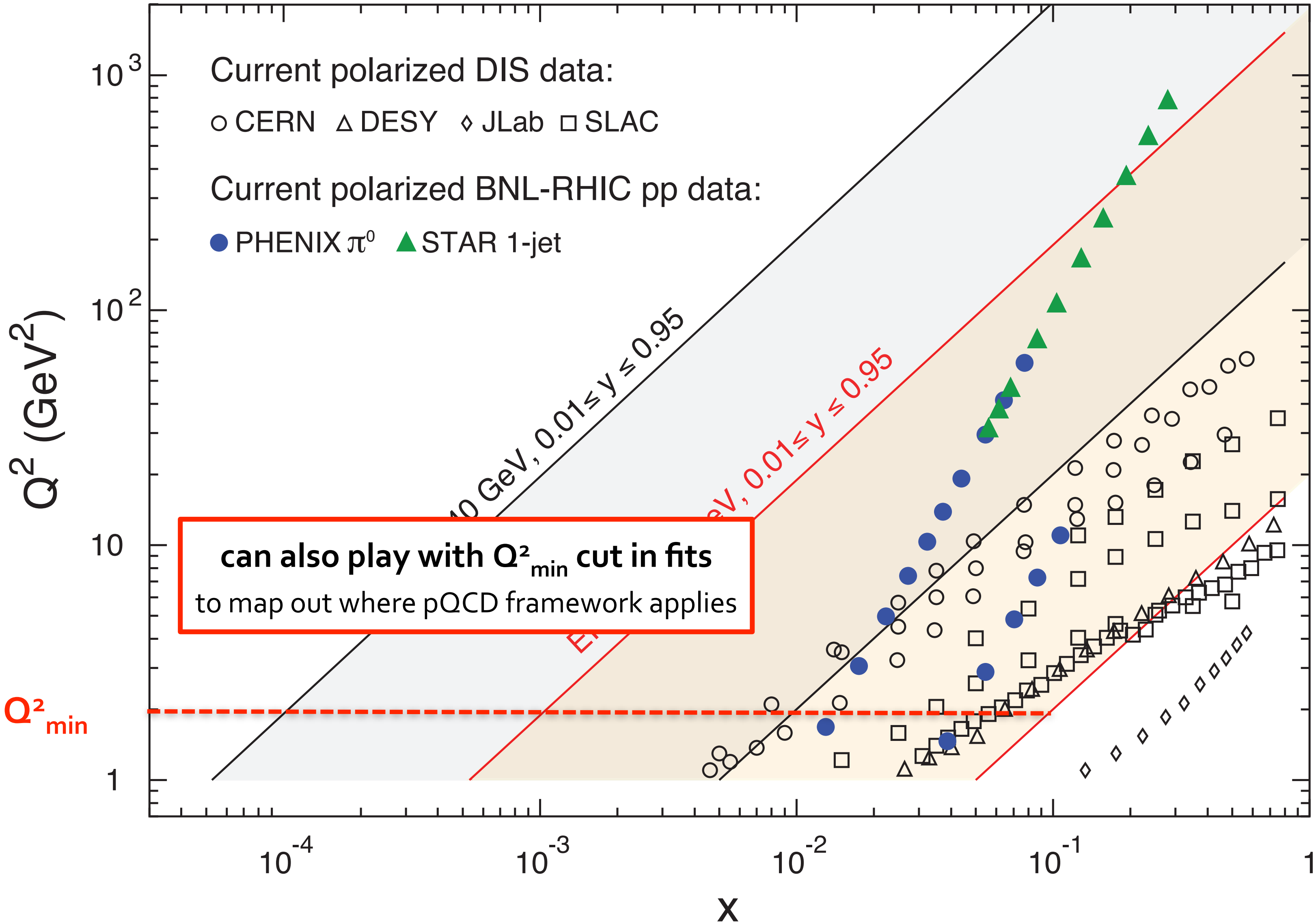

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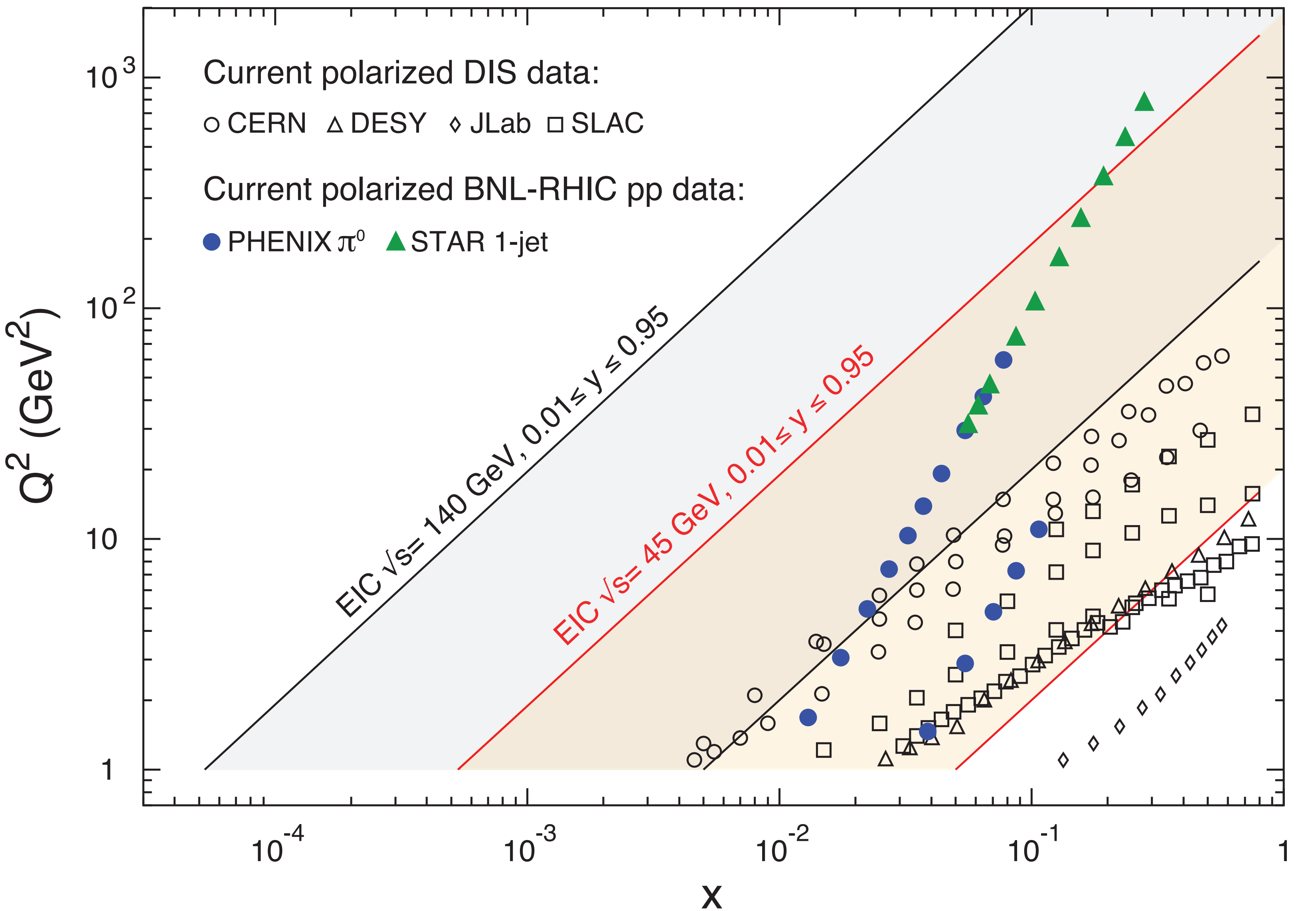

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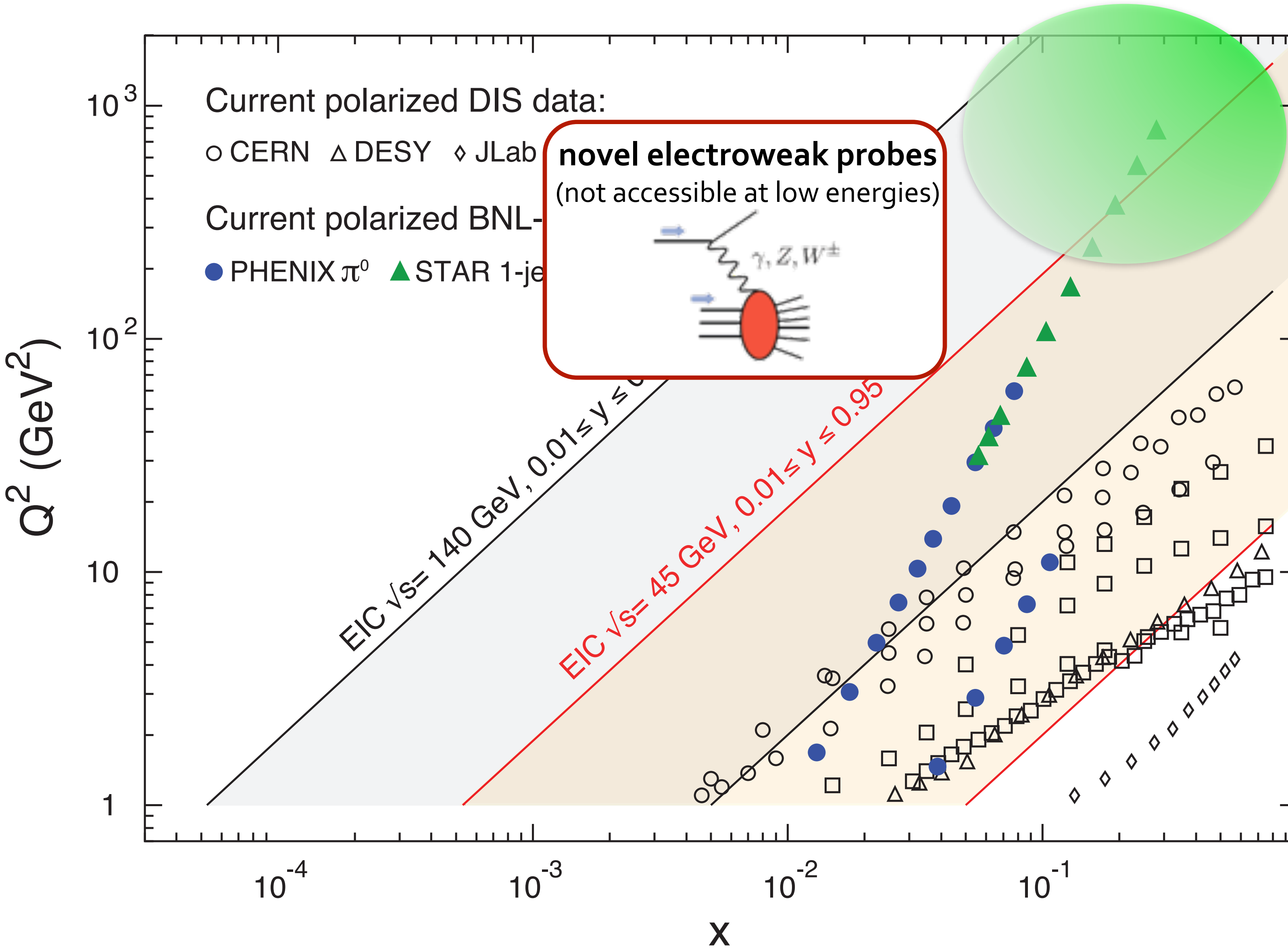

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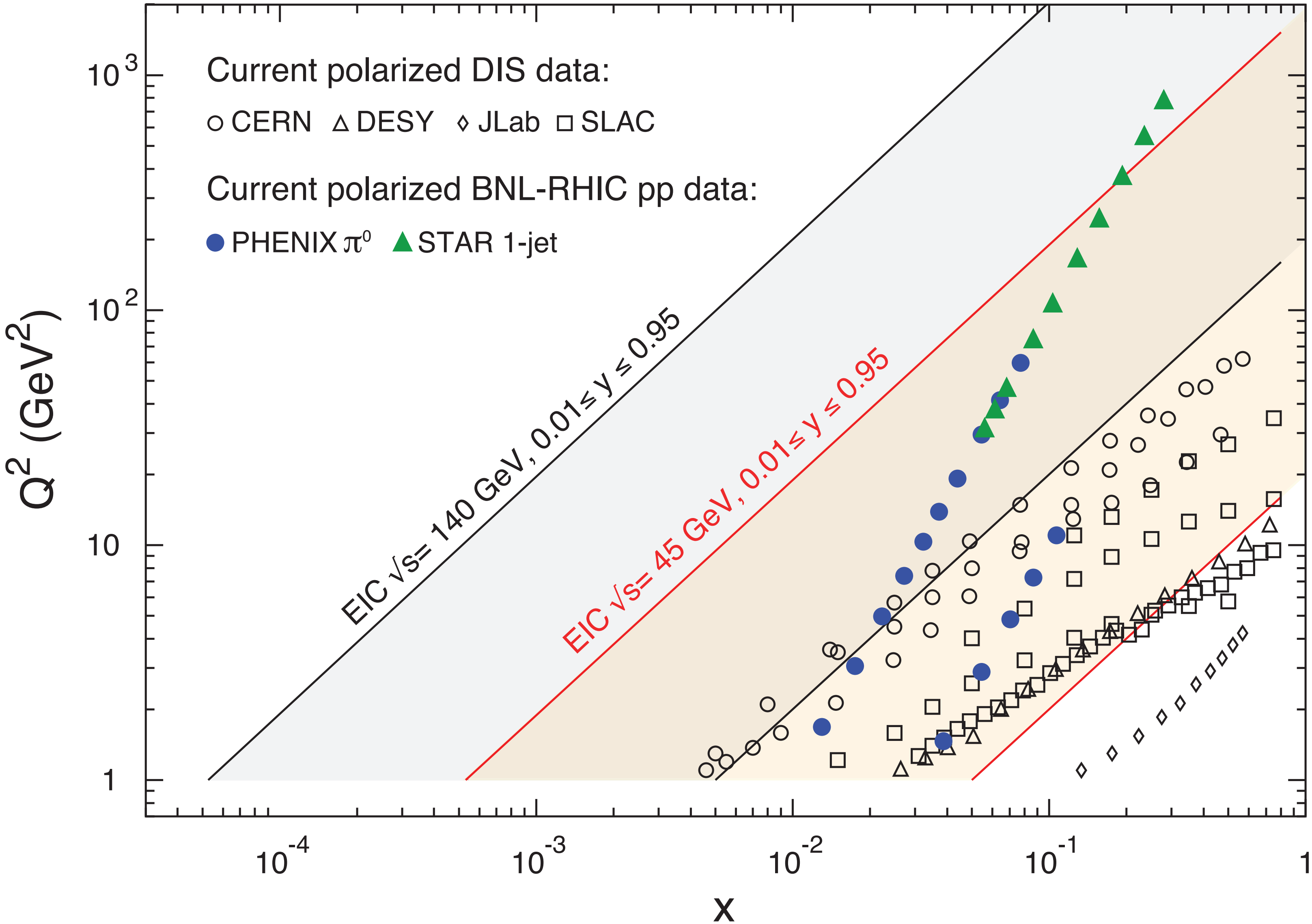

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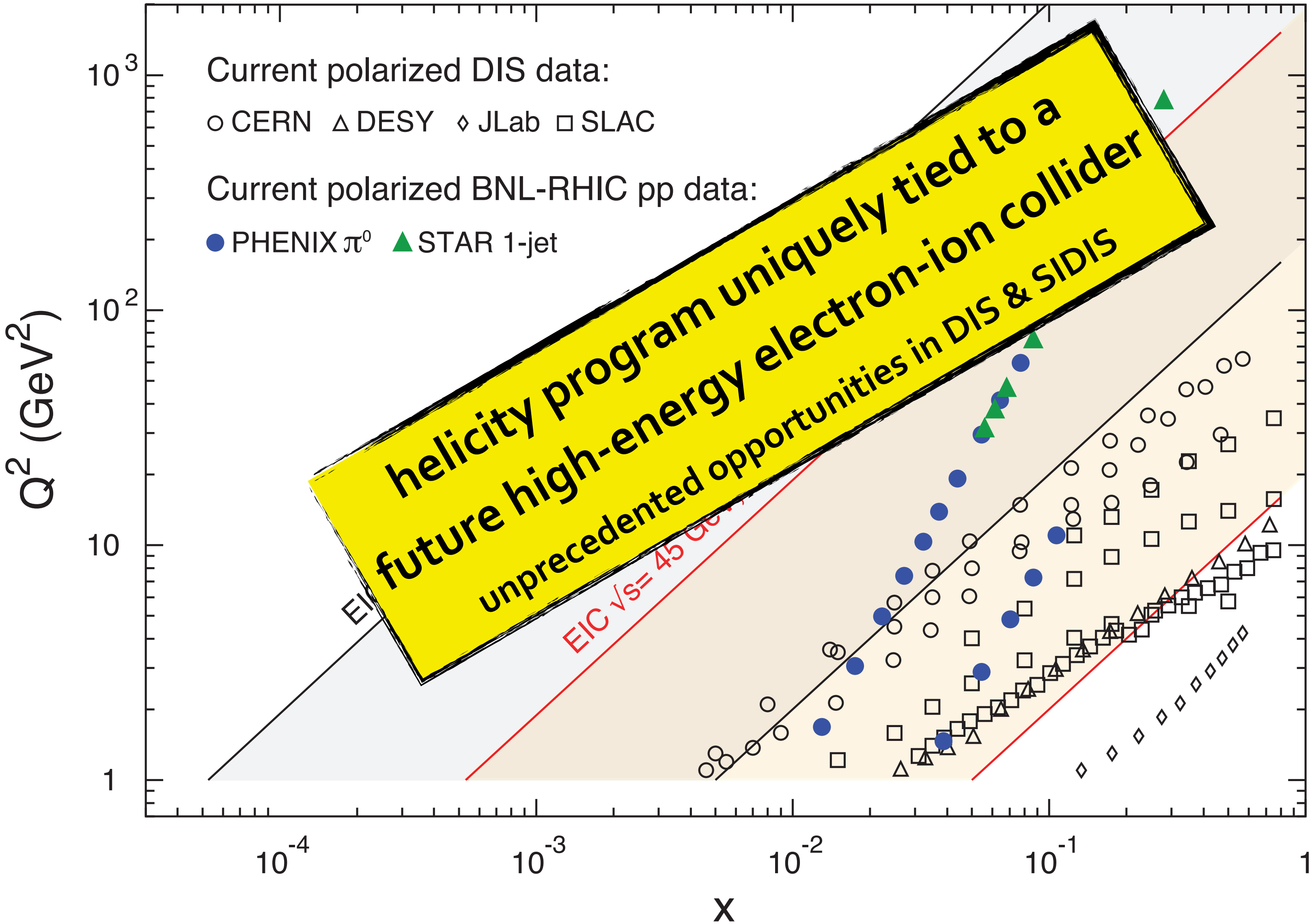
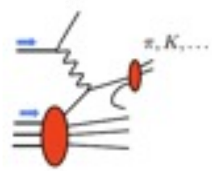


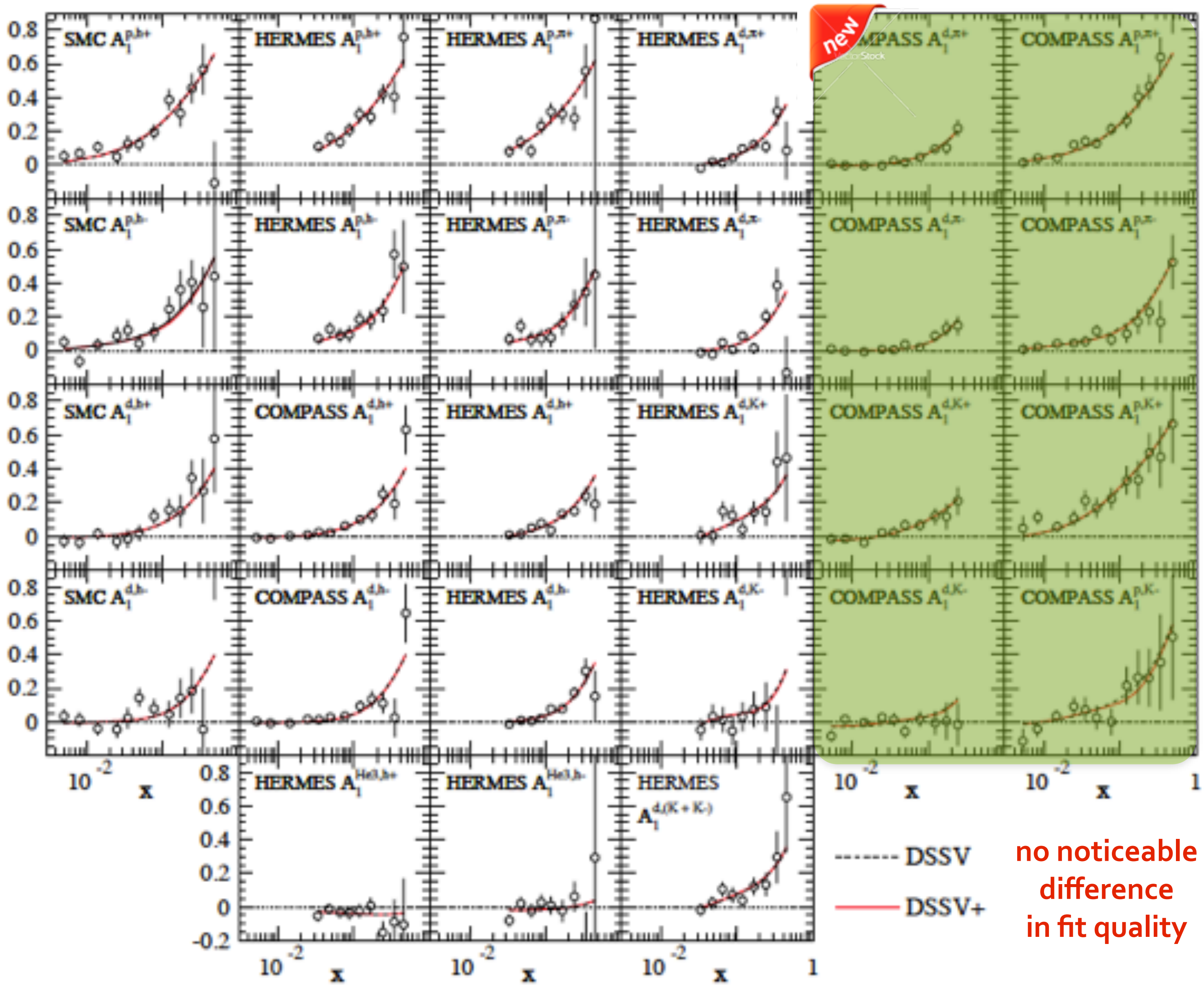
What can be achieved at an EIC ?

1^{st} step: up-to-date baseline fit

DSSV+ analysis: based on DSSV framework but updated with recent COMPASS data

SIDIS world data



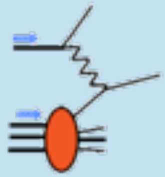


no noticeable difference in fit quality

preparation of DIS and SIDIS pseudo data

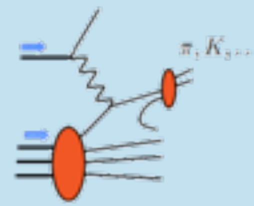
- **PEPSI MC** to generate σ^{++} and σ^{+-} with LO GRSV PDFs

DIS



inclusive final-state

SIDIS



identified charged pions and kaons

assume modest **10 fb^{-1}** for each energy, **70%** beam polarizations

$Q^2 > 1$ GeV^2, $0.01 < y < 0.95$, invariant mass $W^2 > 10$ GeV^2

depolarization factor of virtual photon $D(y,Q^2) > 0.1$ (cuts on small y)

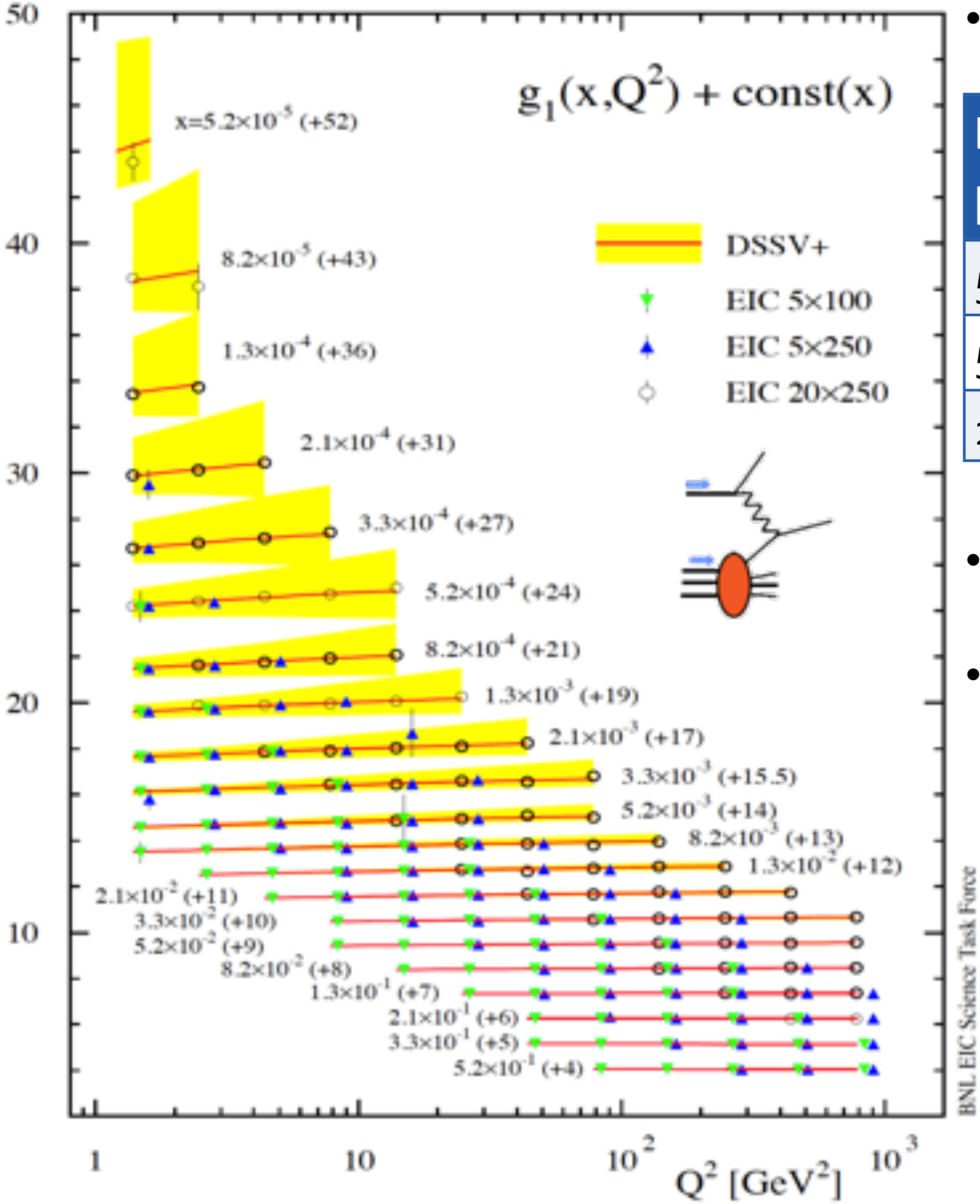
scattered lepton: $1^o < \theta_{elec} < 179^o$ and $p_{elec} > 0.5$ GeV

hadron: $p_{hadr} > 1$ GeV, $0.2 < z < 0.9$, $1^o < \theta_{hadr} < 179^o$

- use relative uncert. of data to generate pseudo data by **randomizing** around DSSV+ **by 1-σ**
- **SIDIS:** incl. typical **5% (10%) uncertainty for pion (kaon) frag. fcts** (from DSS analysis)

example: projected DIS data for g_1^p

Aschenauer, Sassot, MS: arXiv:1206.6041



- 3 sets of realistic energy settings studied:

$E_e \times E_p$ [GeV]	$\sqrt{s}$ [GeV]	x_{min} for y_{max} = 0.95 and Q^2 = 1 GeV²	**Q^2 = 2 GeV²**
5 x 100	44.7	5.3×10^{-4}	1.1×10^{-3}
5 x 250	70.7	2.1×10^{-4}	4.2×10^{-4}
20 x 250	141.4	5.3×10^{-5}	1.1×10^{-4}

- 4 [5] bins/decade in Q^2 [x] (spaced logarithmically)

- **bands reflect current uncertainties** on g_1^p
  DSSV+ estimate

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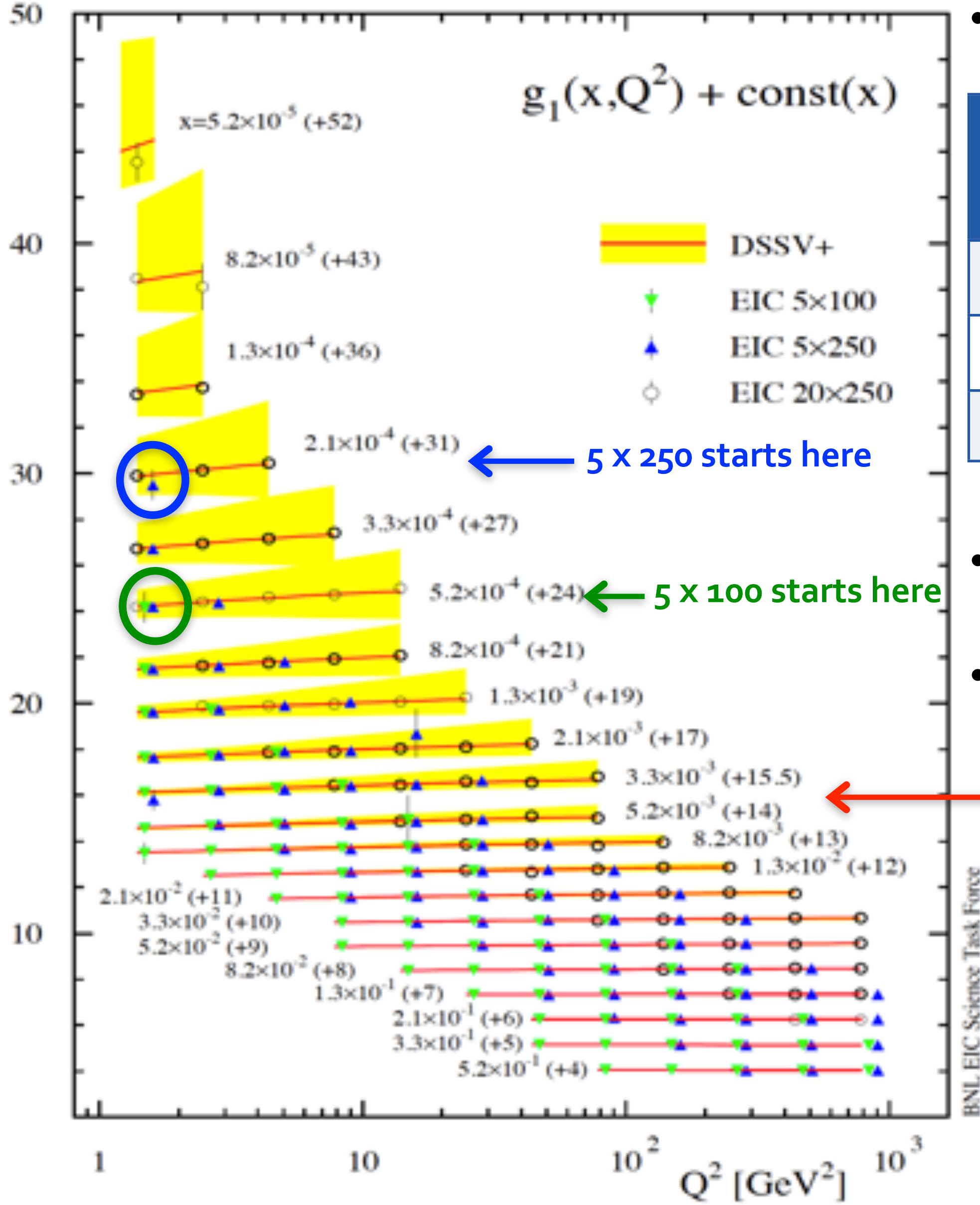

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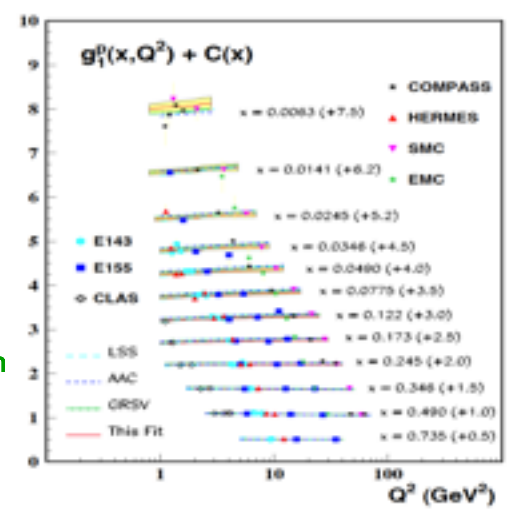
DSSV+ estimate

current data start here



taken from Blumlein, Bottcher

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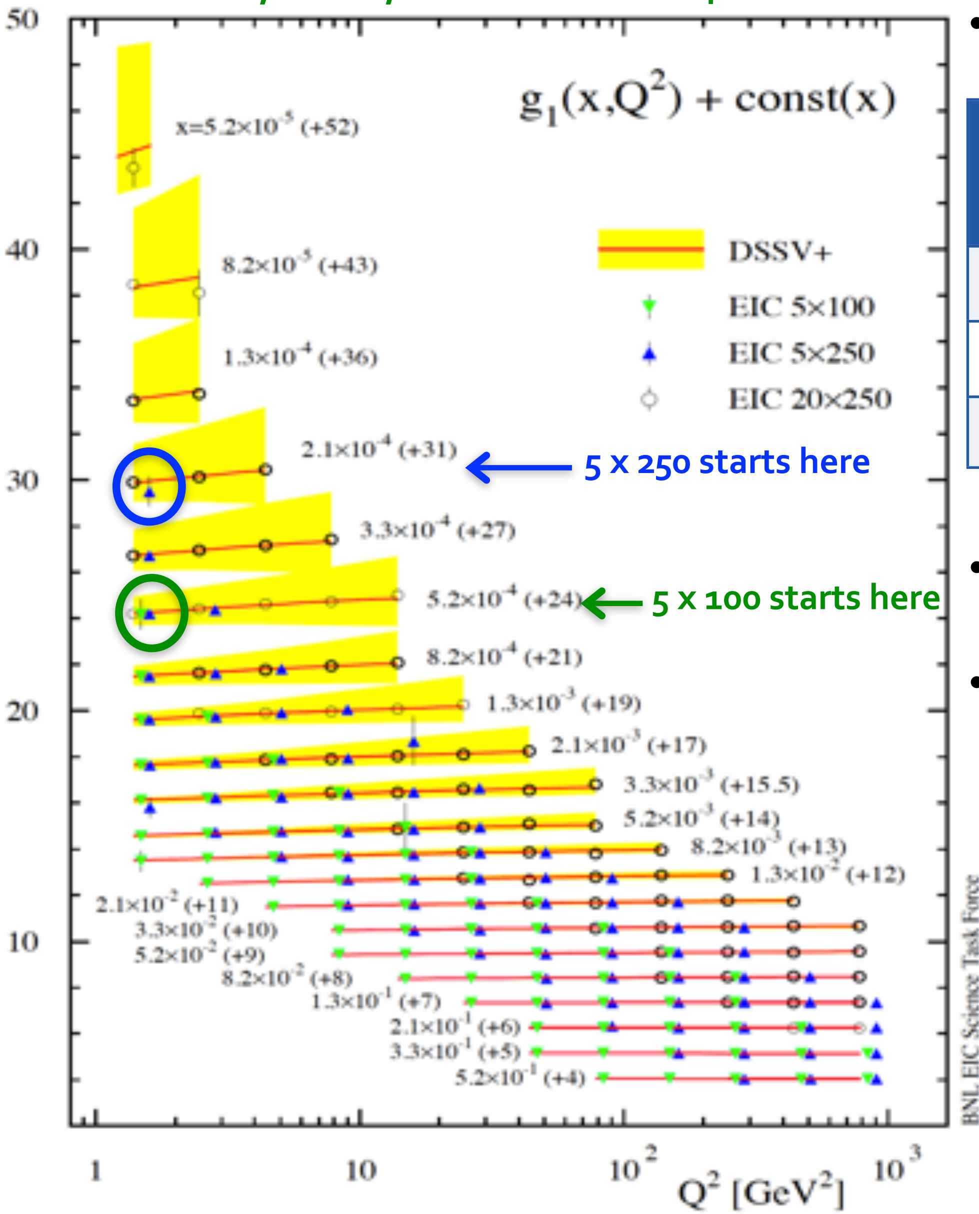

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  DSSV+ estimate

similar data sets generated for SIDIS with identified charged pions and kaons

powerful tool: scaling violations at small x

rough small-x approximation to Q^2-evolution:

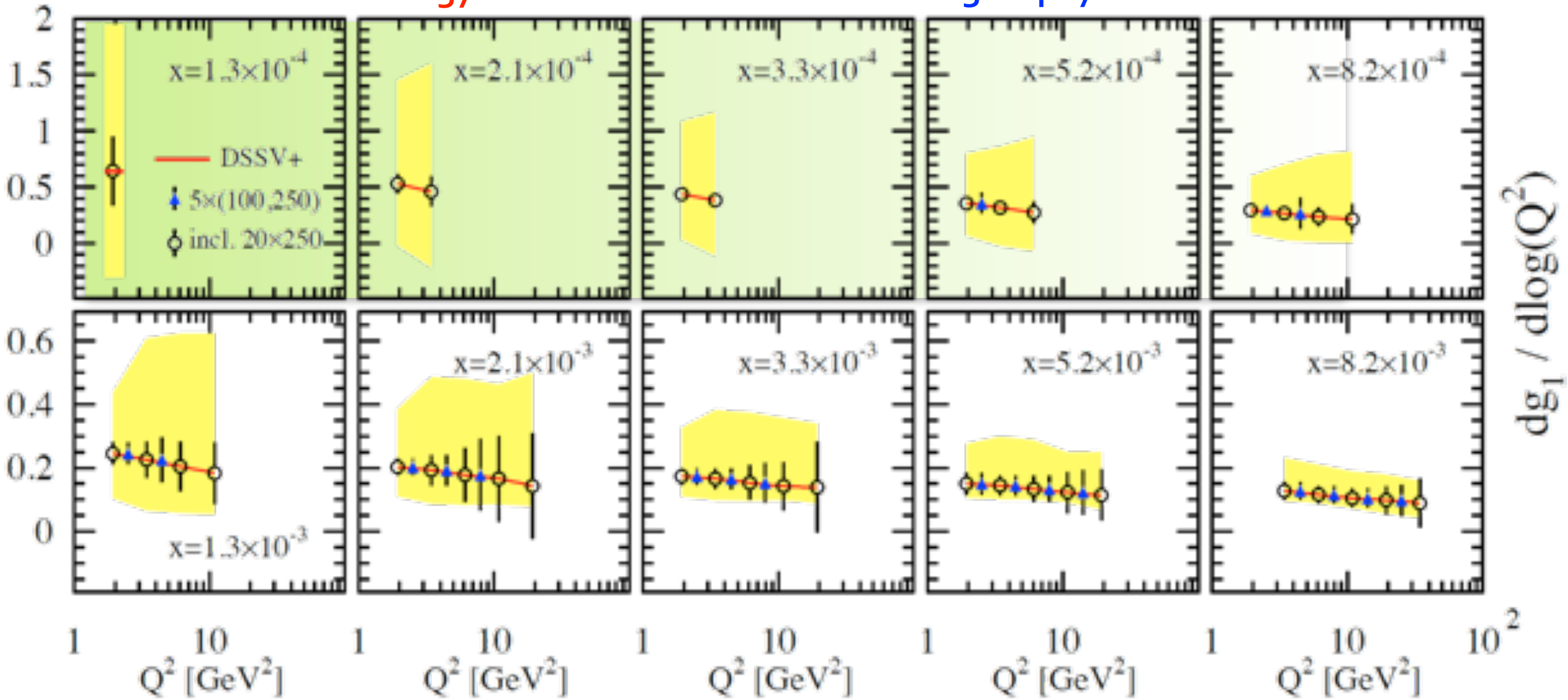
$$\frac{dg_1}{d\log(Q^2)} \propto -\Delta g(x,Q^2)$$

spread in $\Delta g(x,Q^2)$ translates into spread of scaling violations for $g_1(x,Q^2)$

• need x-bins with a least two Q^2 values to compute derivative (limits x reach somewhat)

need full energy EIC down here

stage-1 physics starts here

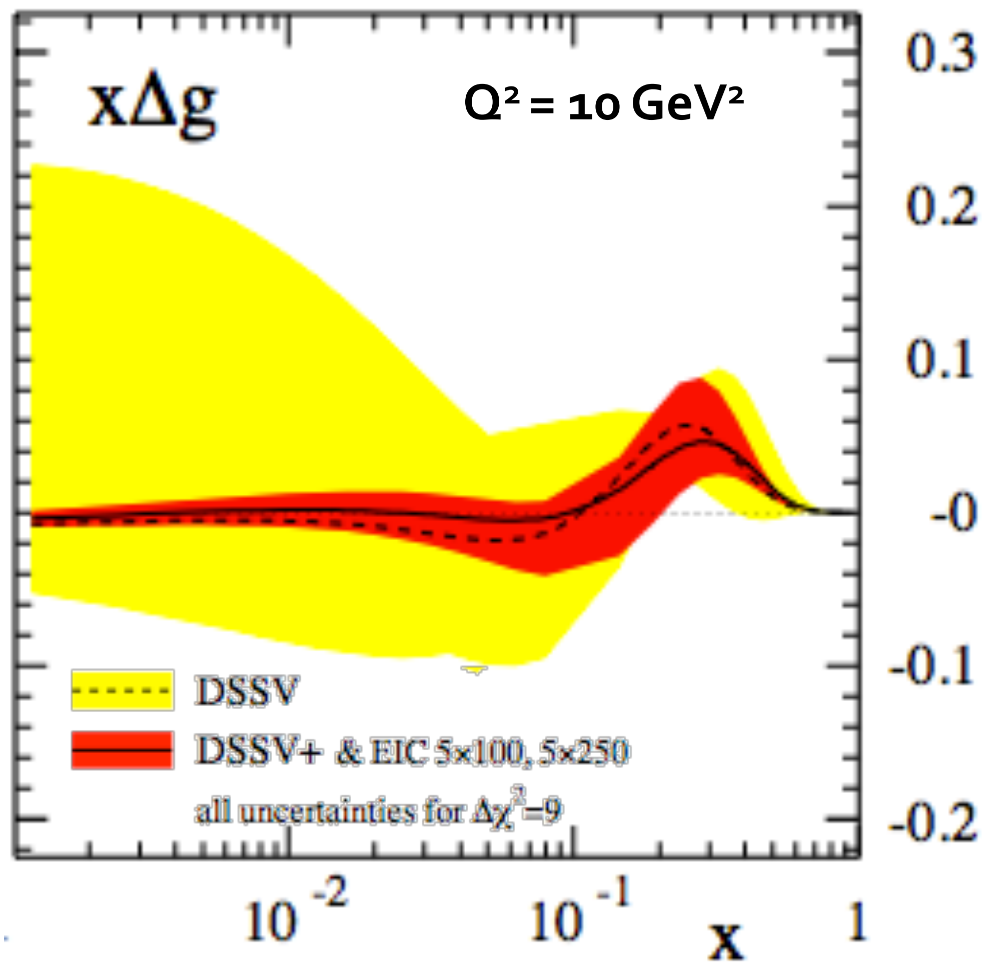


• error bars for moderate **10fb^{-1} per c.m.s. energy**; bands parameterize current DSSV+ uncertainties

impact of EIC data on helicity PDFs

DIS scaling violations mainly determine Δg at small x (SIDIS scaling violations add to this)

Aschenauer, Sassot, MS: arXiv:1206.6041



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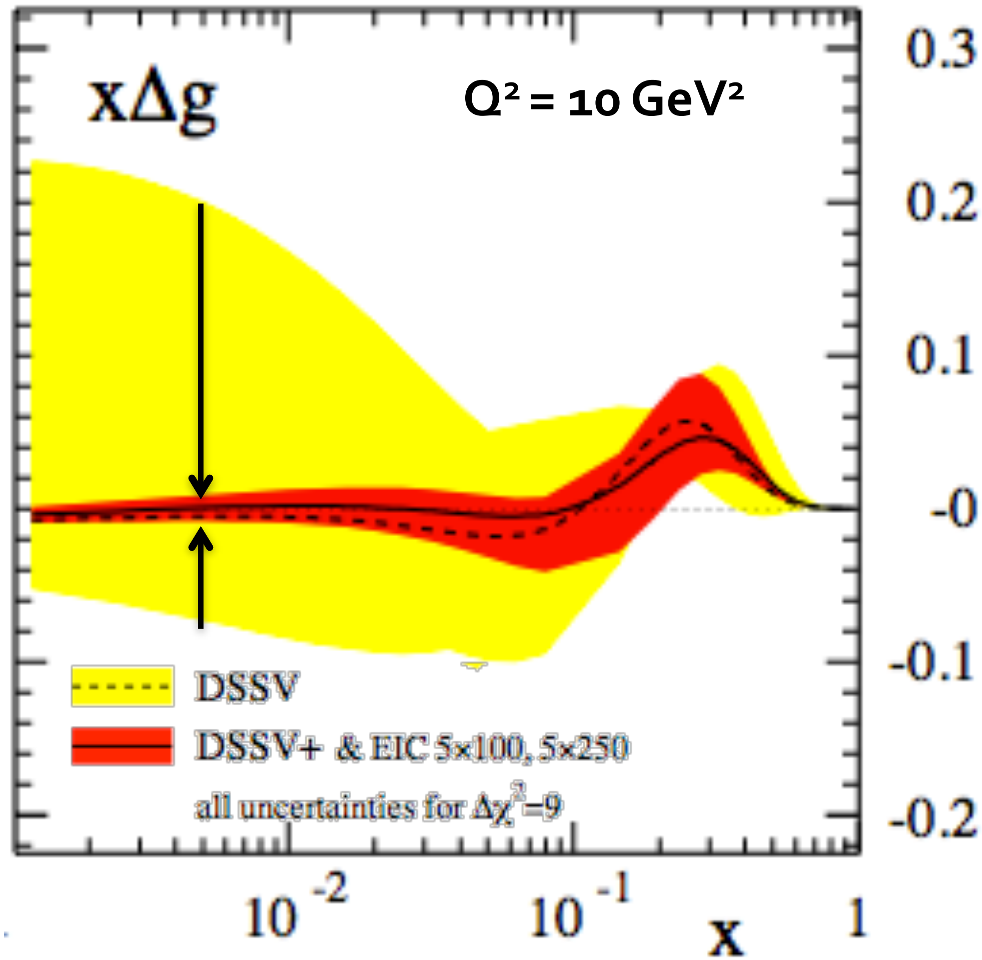
dramatic reduction of uncertainties:

"before"

"after"



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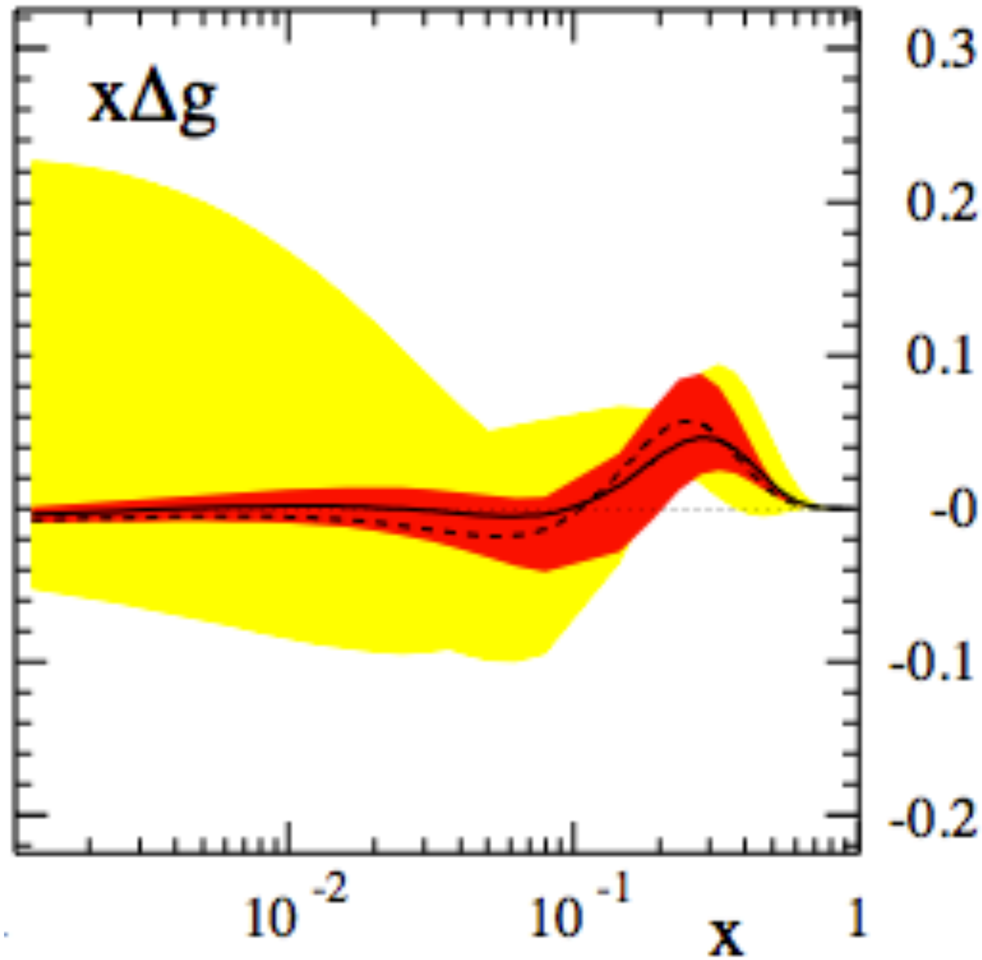

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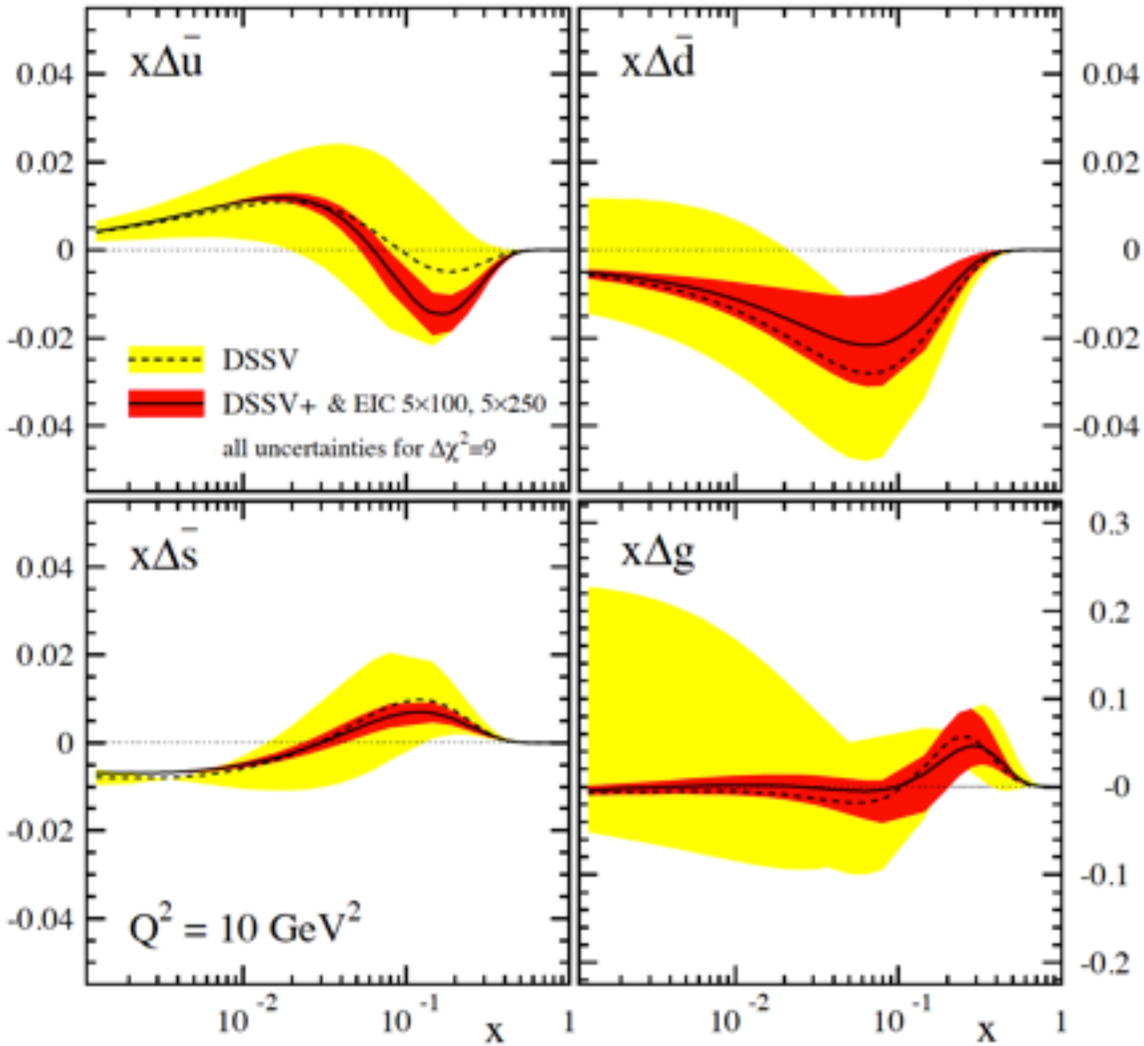

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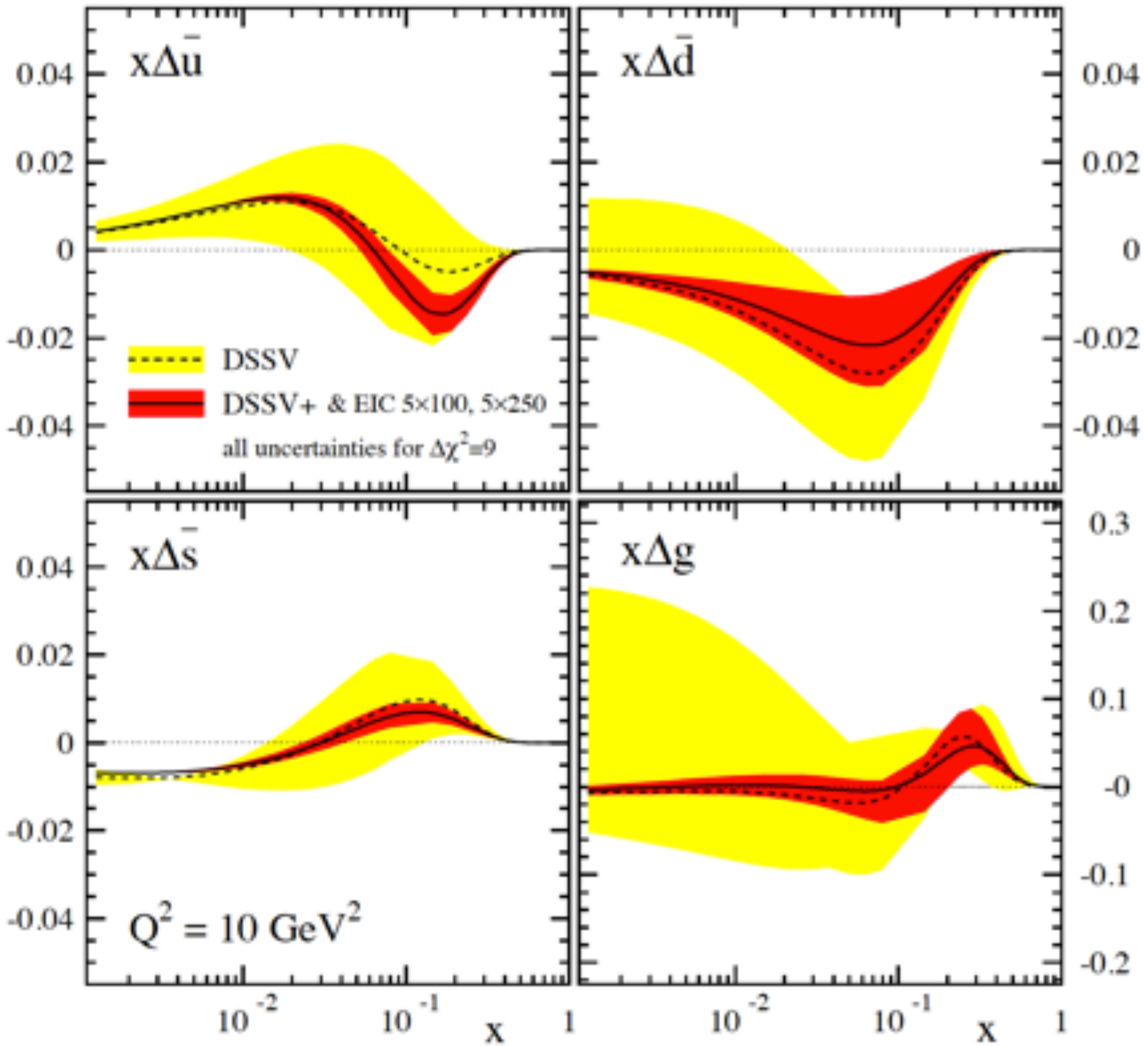


- **includes only "stage-1 data"**
  [even then Q^2_{min} can be 2-3 GeV²]
- can be pushed to $x=10^{-4}$ with 20 x 250 GeV data
  [still one can play with Q^2_{min}]

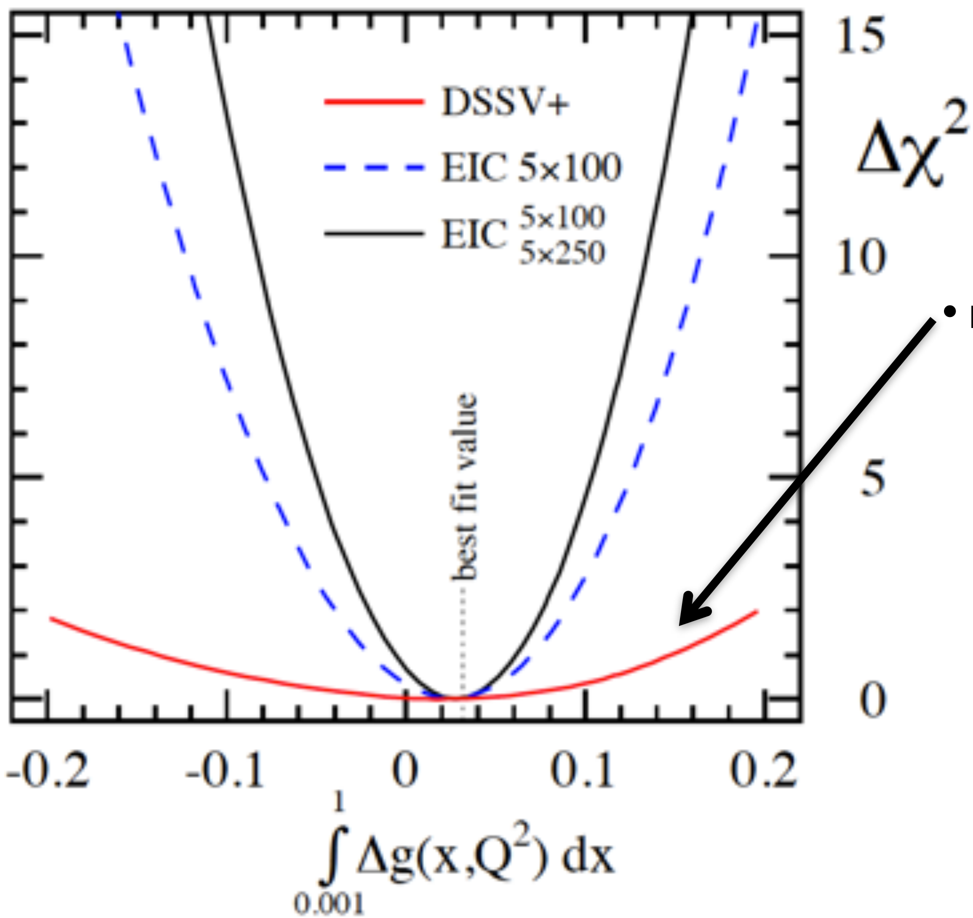
"issues":

- (SI)DIS @ EIC limited by **systematic uncertainties**
  need to control rel. lumi, polarimetry, detector performance, … very well
- **QED radiative corrections**
  need to "unfold" true x,Q²
  well known problem (HERA)
  BNL-LDRD project **to sharpen tools**

impact of EIC data in terms of χ^2 profiles

- dramatic improvements for [truncated] first moments $\int_{\mathbf{x}_{\min}}^{\mathbf{x}_{\max}} \mathbf{\Delta f(x, Q^2) dx}$
  best visualized by χ^2 profiles obtained with Lagrange multipliers

- **example**: **Δg** in x-range **0.001-1** without/with stage-1 EIC data



- not well constrained by current data
  profile not parabolic

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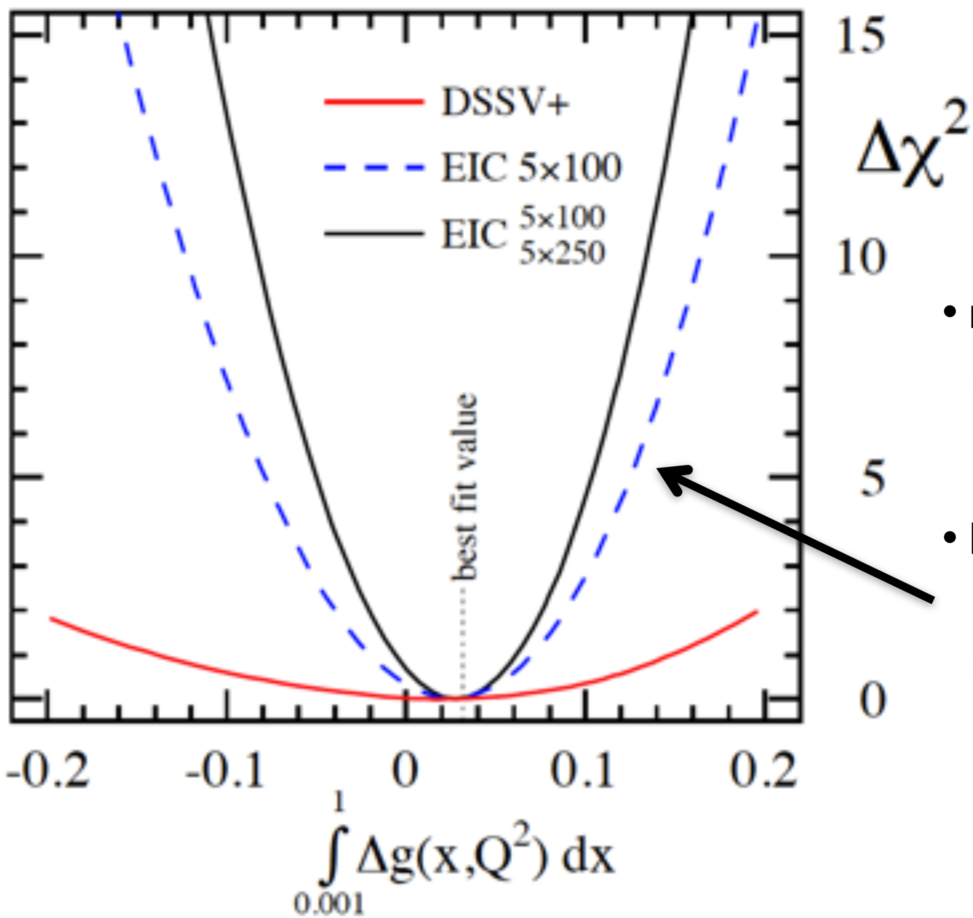

- not well constrained by current data

  profile not parabolic

- EIC [stage-1] DIS data

  lead to significant improvement

  profile parabolic; Hessian method also works

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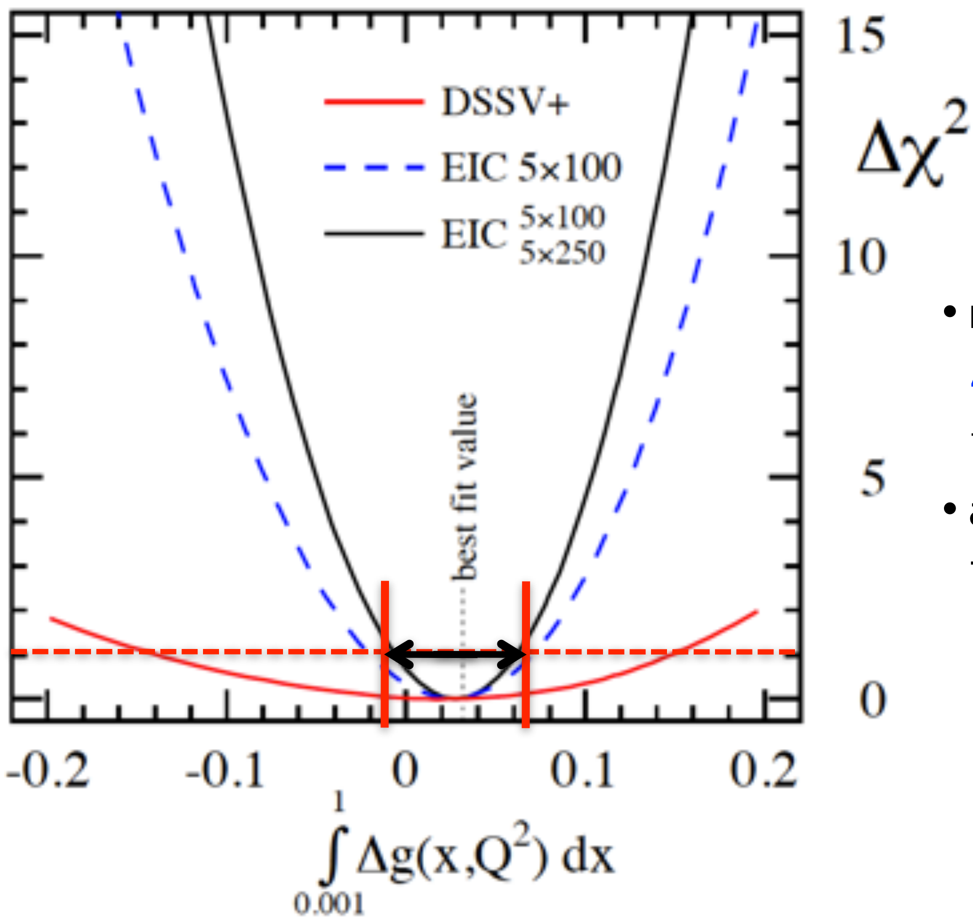

- read off uncertainties for given $\Delta\chi^2$

  $\Delta\chi^2$ =1 usually not leading to a faithful error

  take conservative **$\Delta\chi^2$ = 9** as in DSSV analysis

- appropriate tolerance $\Delta\chi^2$ can be further refined once data are available

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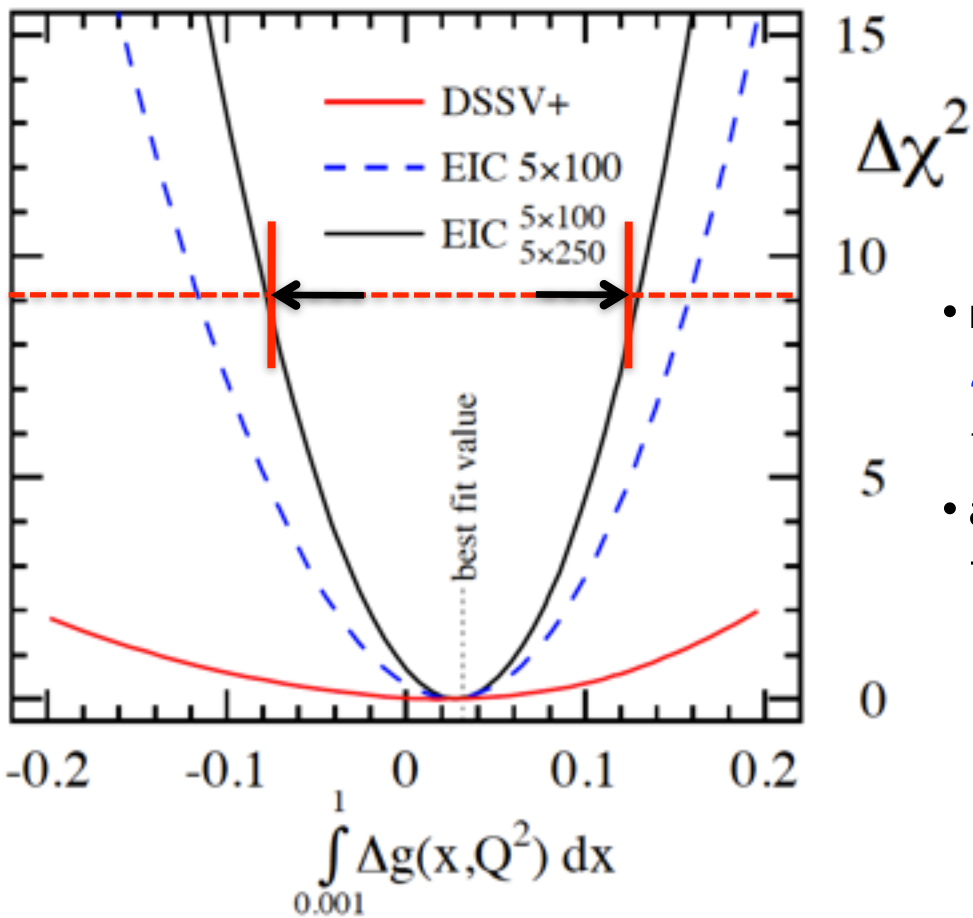

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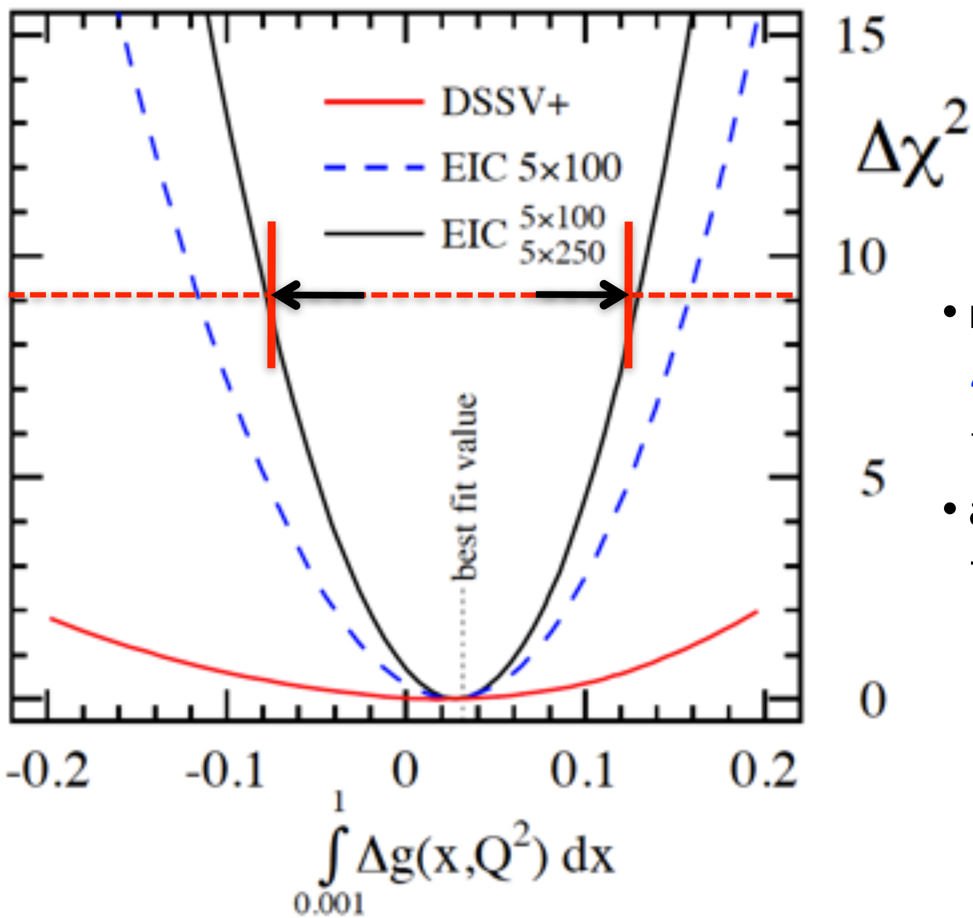

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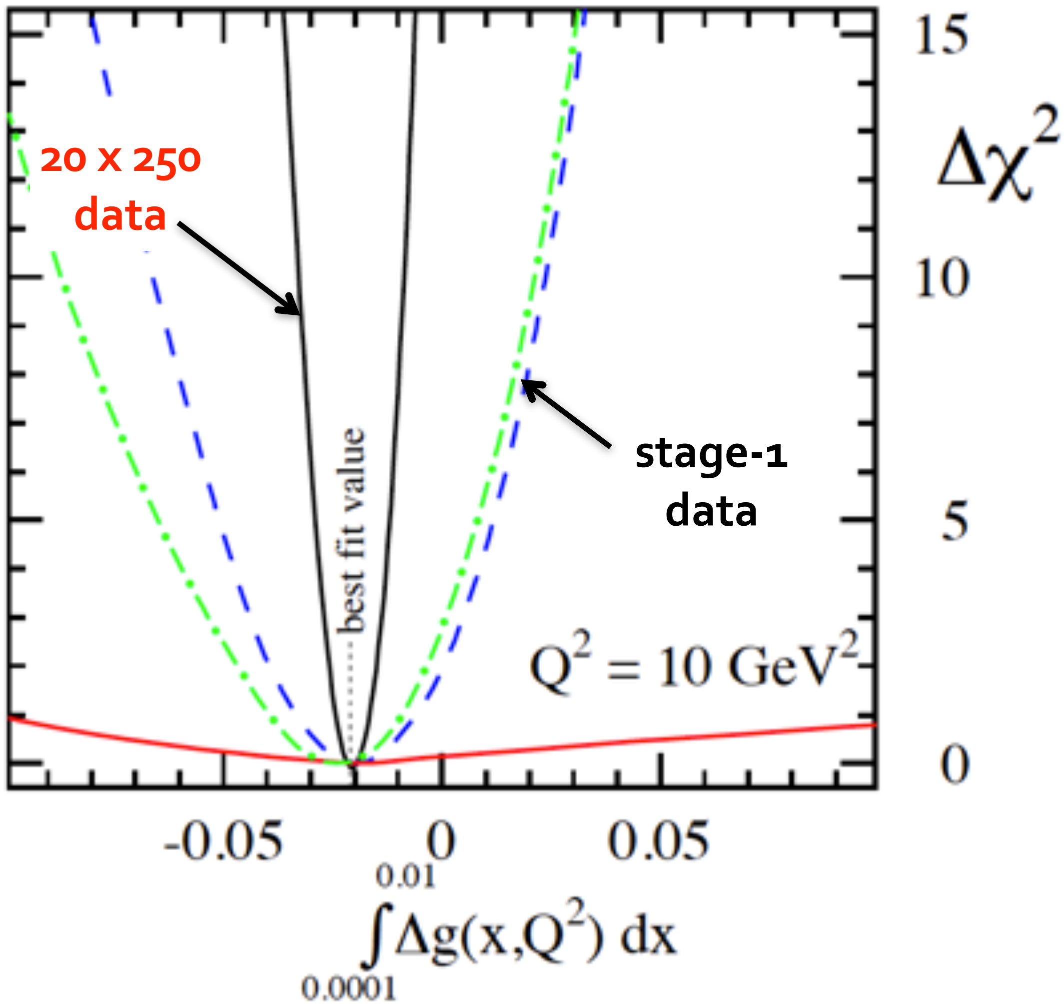
similar improvements for all quark flavors

impact of EIC data (cont'd)

- further improvements with 20 x 250 GeV data at smaller x
- **example**: Δg in x-range **0.0001-0.01** without/with EIC data



impact of EIC data (cont'd)

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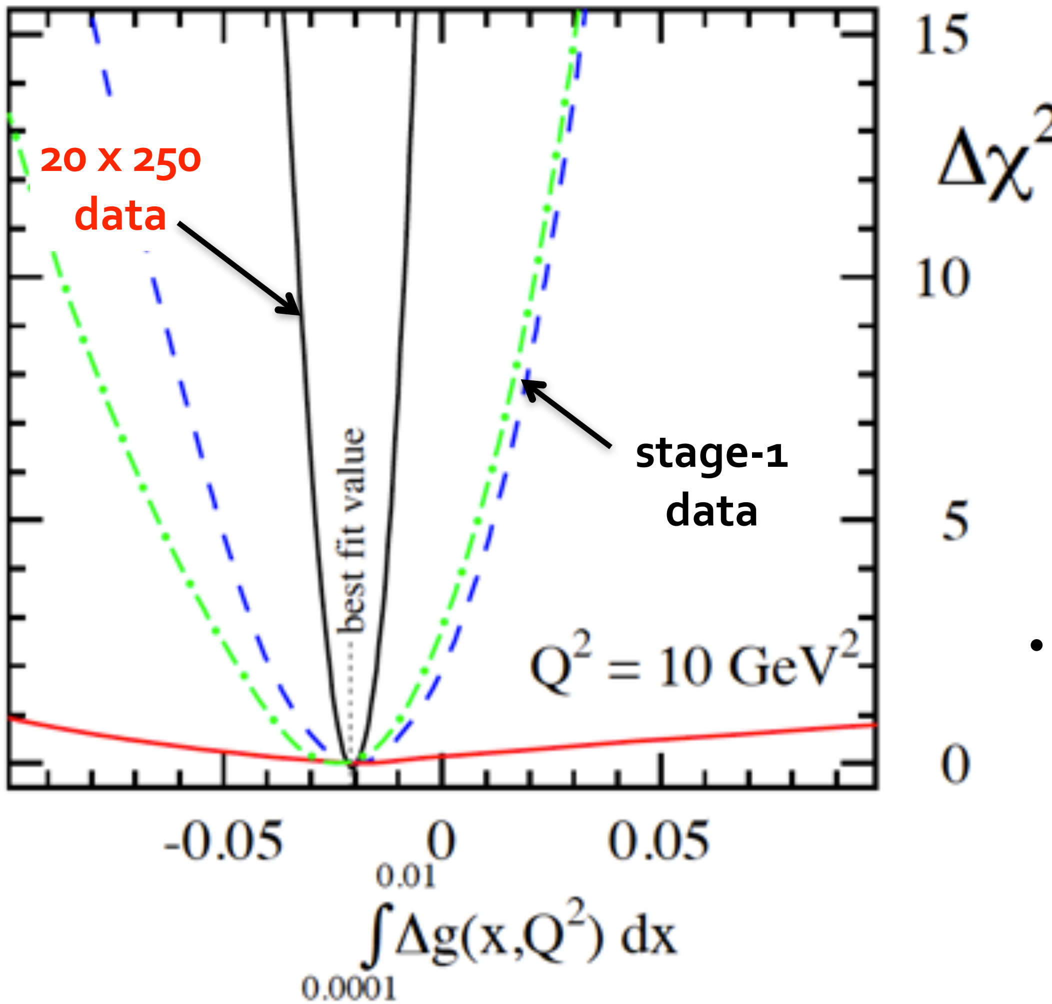
- **example**: **Δg** in x-range **0.0001-0.01** without/with EIC data



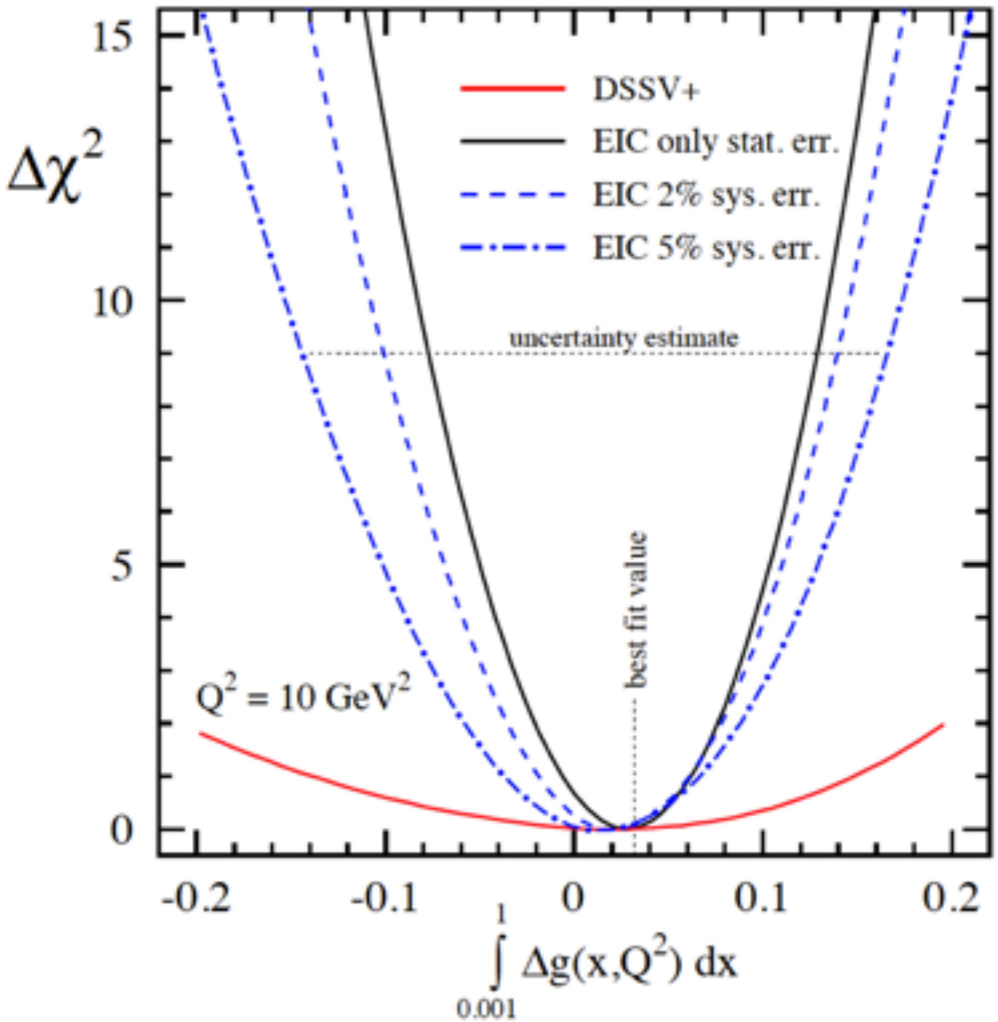
- somewhat less dramatic for **quark sea**

impact varies with quark flavor

impact of systematic uncertainties on Δg

(SI)DIS is systematics limited - how much of a systematic error is tolerable?

assume a 2 (5) % point-to-point systematic uncertainty in analysis of Δg



- 2% has little impact
  5% is certainly "borderline"
- recall that SIDIS analysis includes 5 (10)% error from fragmentation

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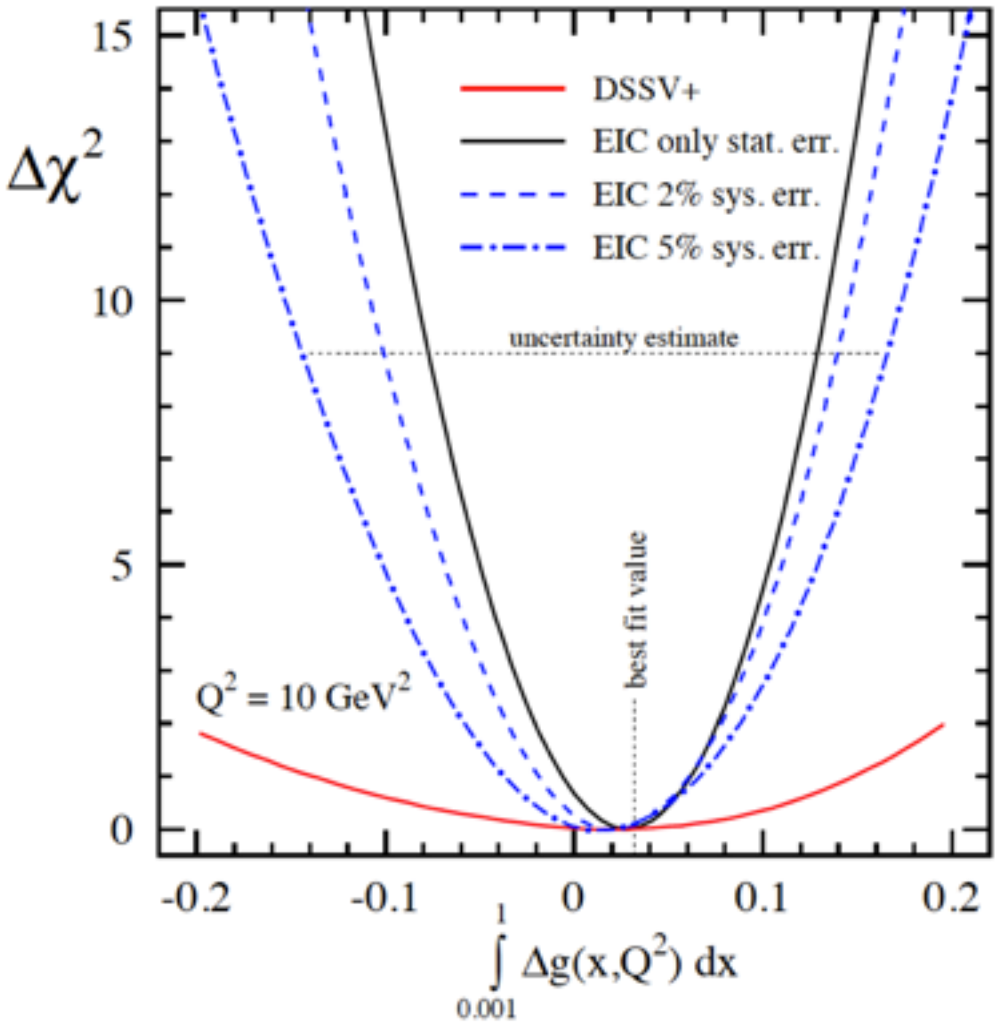

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- recall that SIDIS analysis includes 5 (10)% error from fragmentation

correlated systematic uncertainties

- lead to a shift
  [global fits account for relative normalizations between different experiments]

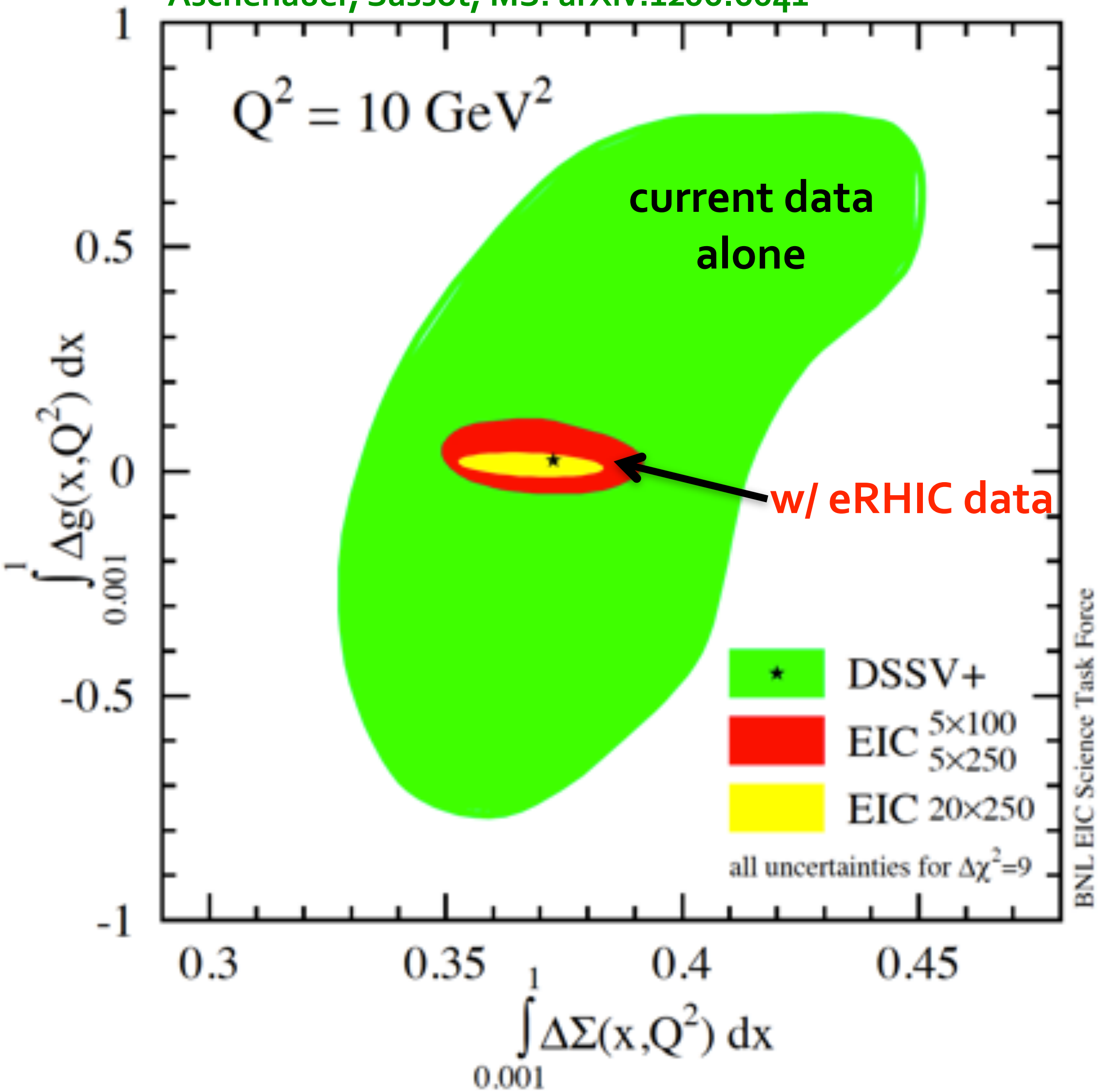
- polarization measurement is likely to be the dominant source

- relative luminosity error in A_{LL}
  [A_{LL} can be as small as a few times 10^{-4} at small x if Δg is small]

closing in on the spin sum rule

• combined correlated uncertainties for ΔΣ and Δg

Aschenauer, Sassot, MS: arXiv:1206.6041



• results obtained with two Lagrange multipliers

• similar improvement for 0.0001-1 moments

needs 20 x 250 GeV data

• can expect approx. 5-10% uncertainties on ΔΣ and Δg

but need to control systematics

probing a possible asymmetry in the polarized sea

- current SIDIS data not sensitive to $\Delta\bar{u}(x) - \Delta\bar{d}(x)$ (known to be sizable for unpol. PDFs)
- many models predict sizable asymmetry [large N_C, chiral quark soliton, meson cloud, Pauli blocking]

Thomas, Signal, Cao; Holtmann, Speth, Fassler;
Diakonov, Polyakov, Weiss; Schafer, Fries; Kumano;
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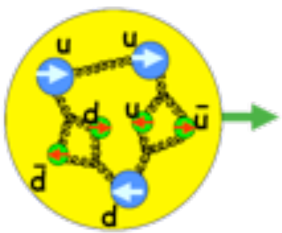
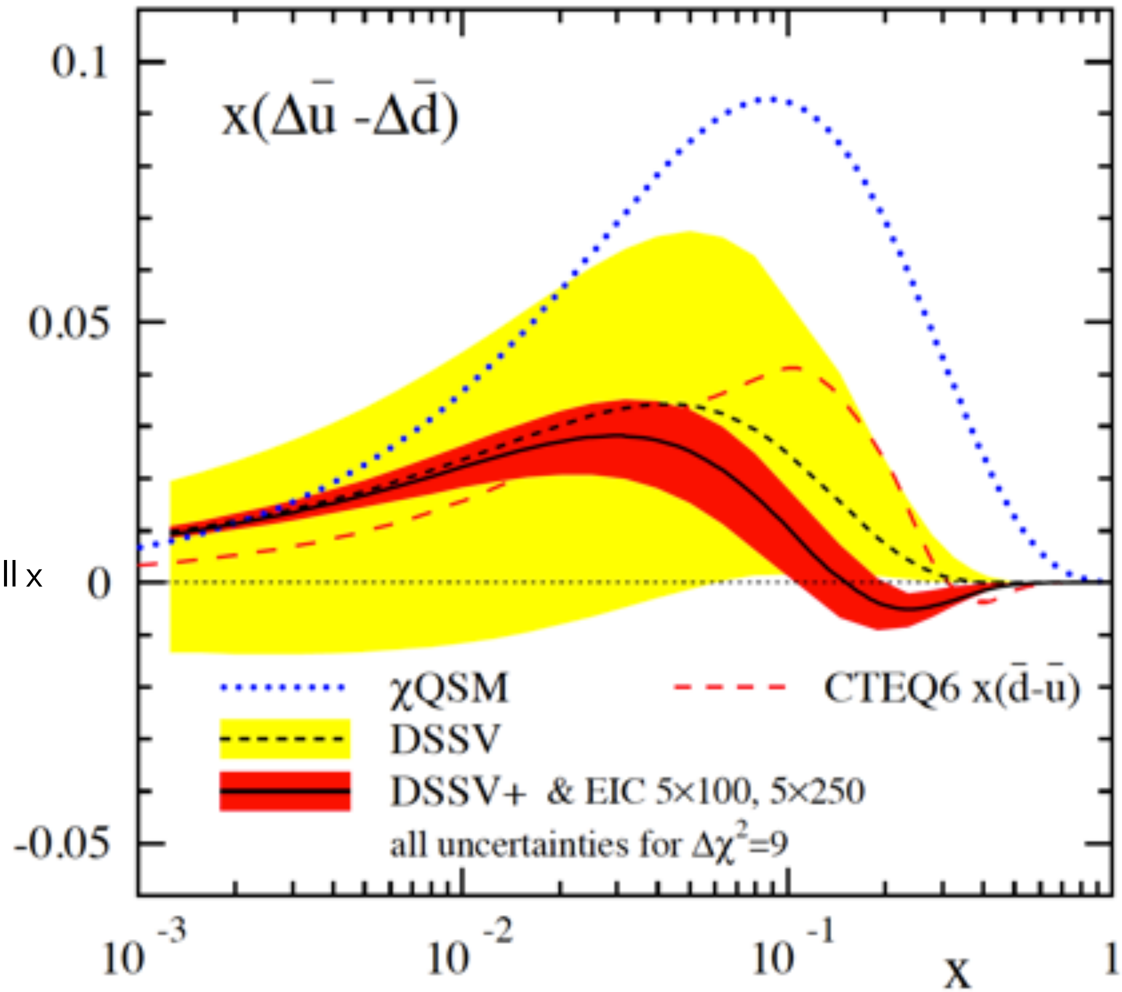


- **can be easily studied at an EIC with stage-1 data**

main effect expected to be at not too small x



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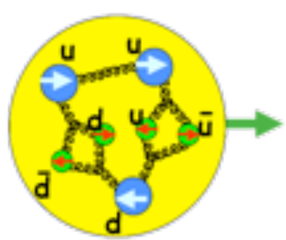

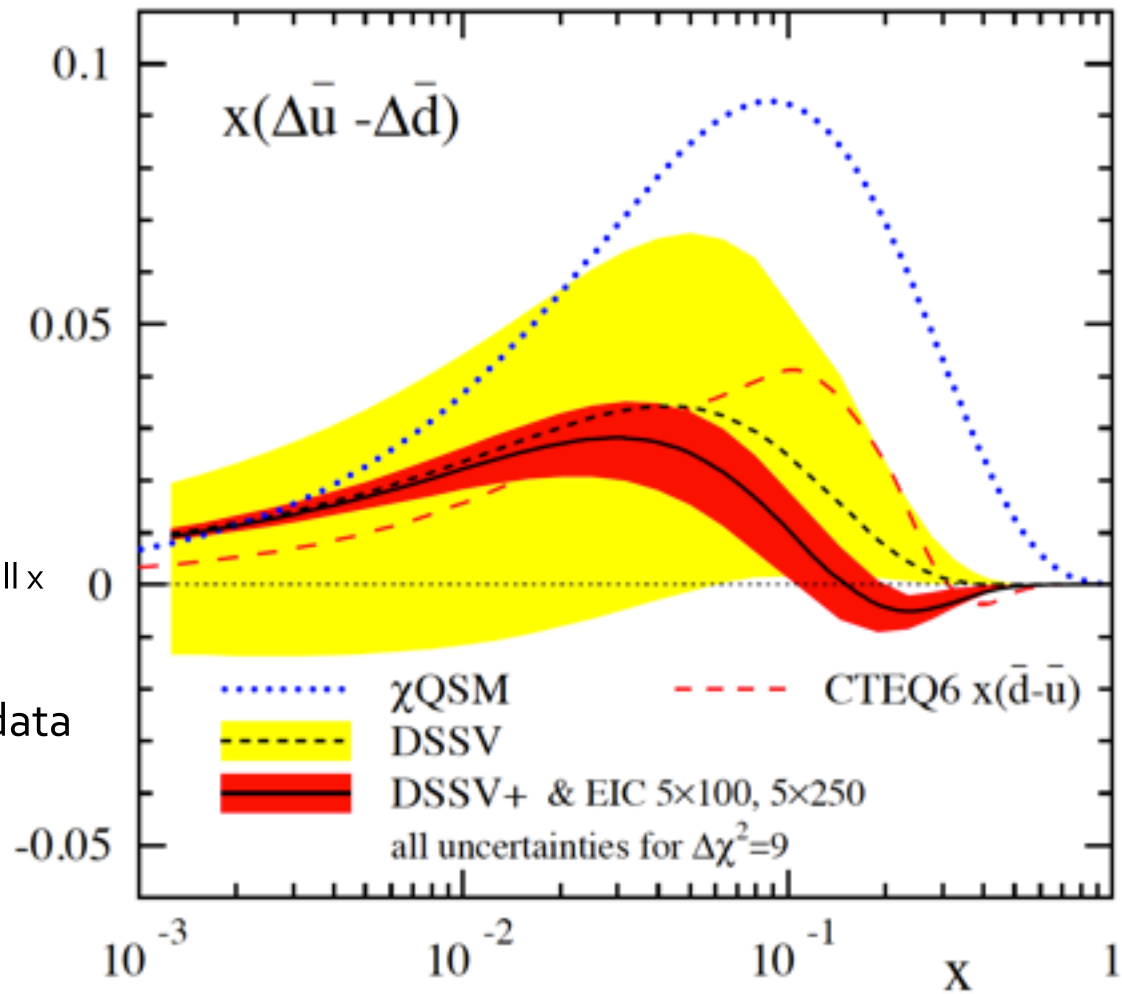

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main effect expected to be at not too small x

- can try to look into a possible $\Delta s(x) - \Delta\bar{s}(x)$ with $K^{+/-}$ SIDIS data

[kaon FFs expect to improve with upcoming BELLE, COMPASS, … data]

also: study multiplicities @ EIC to further constrain FFs

other/related opportunities

other opportunities in polarized (SI)DIS at an EIC

- aim for **high precision polarized experiments** [progress in polarimetry, detectors, …]

  -> should be able to measure **polarized cross sections** rather than spin asymmetries

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- studies presented here are based on lepton – *proton* collisions – **what about neutrons?**

  main objective would be fundamental **Bjorken sum rule**

$$\int_0^1 dx \left[g_1^p(x,Q^2) - g_1^n(x,Q^2)\right] = \frac{1}{6} C_{\mathrm{Bj}} \left[\alpha_s(Q^2)\right] \; g_A$$

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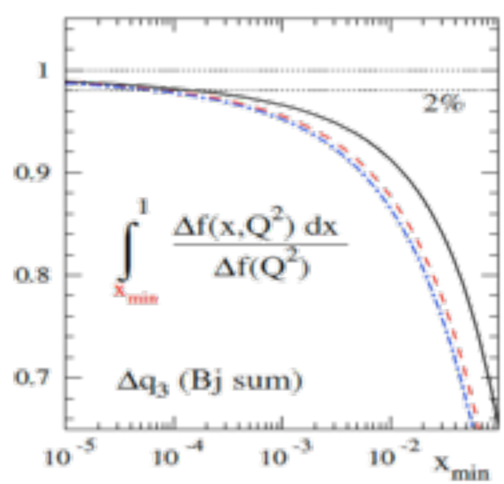
- **C_{Bj} known up to $O(\alpha_s^4)$** Kodaira; Gorishny, Larin; Larin, Vermaseren; Baikov, Chetyrkin, Kühn, ...
- theoretically interesting, non-trivial relation to Adler fct. in e^+e^- **"Crewther relation"**
- **experimental challenge:** effective neutron beam (^{3}He), very precise polarimetry, ...
- expect to **need data down to 10^{-4}** to determine relevant non-singlet combination Δq_3 to about 1-2 %



"running integral" for Bjorken sum

other opportunities at an EIC (cont'd)

- can watch out for **possible "surprises" at small x**

  some expectations that non-linear effects might set in earlier than in unpol. DIS

  method: onset of tensions in global fits by varying Q^2_{min}

Bartels, Ermolaev, Ryskin; Ermolaev, Greco, Troyan

other opportunities at an EIC (cont'd)

- can watch out for **possible "surprises" at small x**

  some expectations that non-linear effects might set in earlier than in unpol. DIS

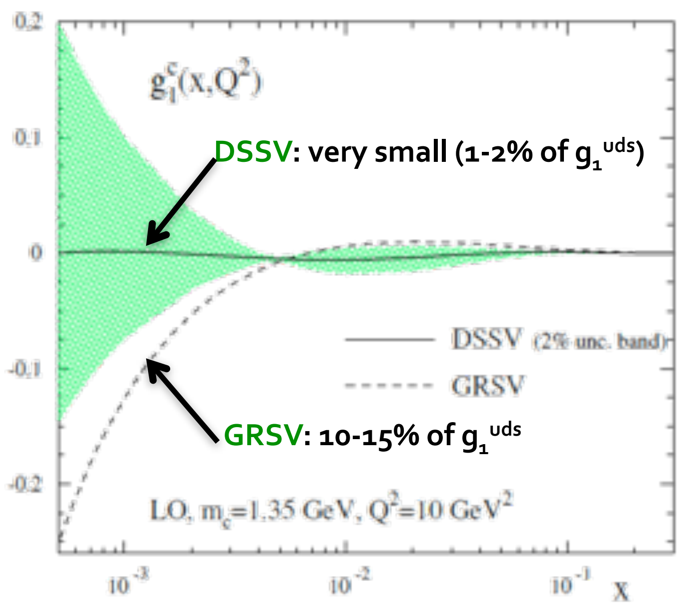
  Bartels, Ermolaev, Ryskin; Ermolaev, Greco, Troyan

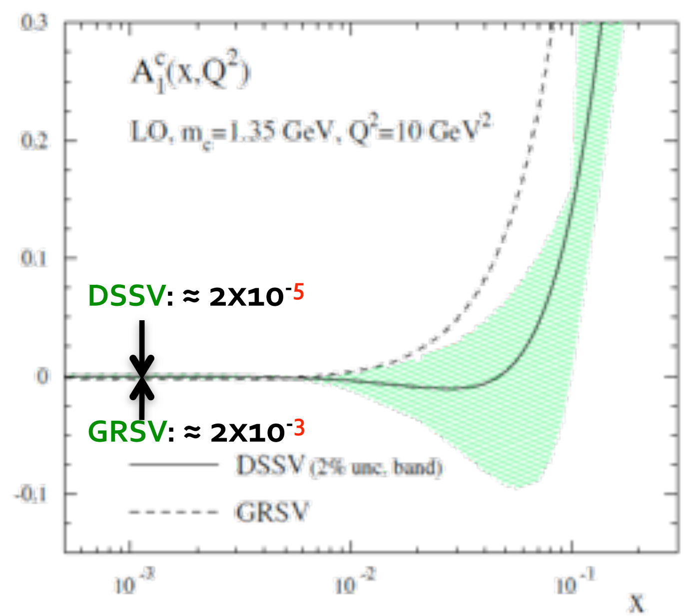
  method: onset of tensions in global fits by varying Q^2_{min}

- can systematically study **charm contribution to g_1**
  - irrelevant so far (<< 1%) in fixed target data
  - relevance at EIC strongly depends on size of Δg
  - charm not massless for EIC kinematics; need to compute relevant NLO corrections [in progress]

some expectations (LO estimates)

g_1^{charm}





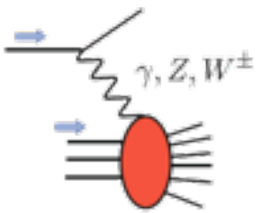
A_1^{charm}

other opportunities at an EIC (cont'd)

- **high Q²**: access to novel **electroweak structure functions** [thanks to 100-1000 x HERA lumi]
  probes combinations of PDFs different from photon exchange -> **flavor separation from DIS**

contains e-w propagators and couplings

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



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

most promising: CC structure fcts

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

$$g_1^{W^-} = (\Delta u + \Delta\bar{d} + \Delta\bar{s} + \Delta c)$$
$$g_1^{W^+} = (\Delta\bar{u} + \Delta d + \Delta s + \Delta\bar{c})$$

requires a **positron beam** not necessarily polarized

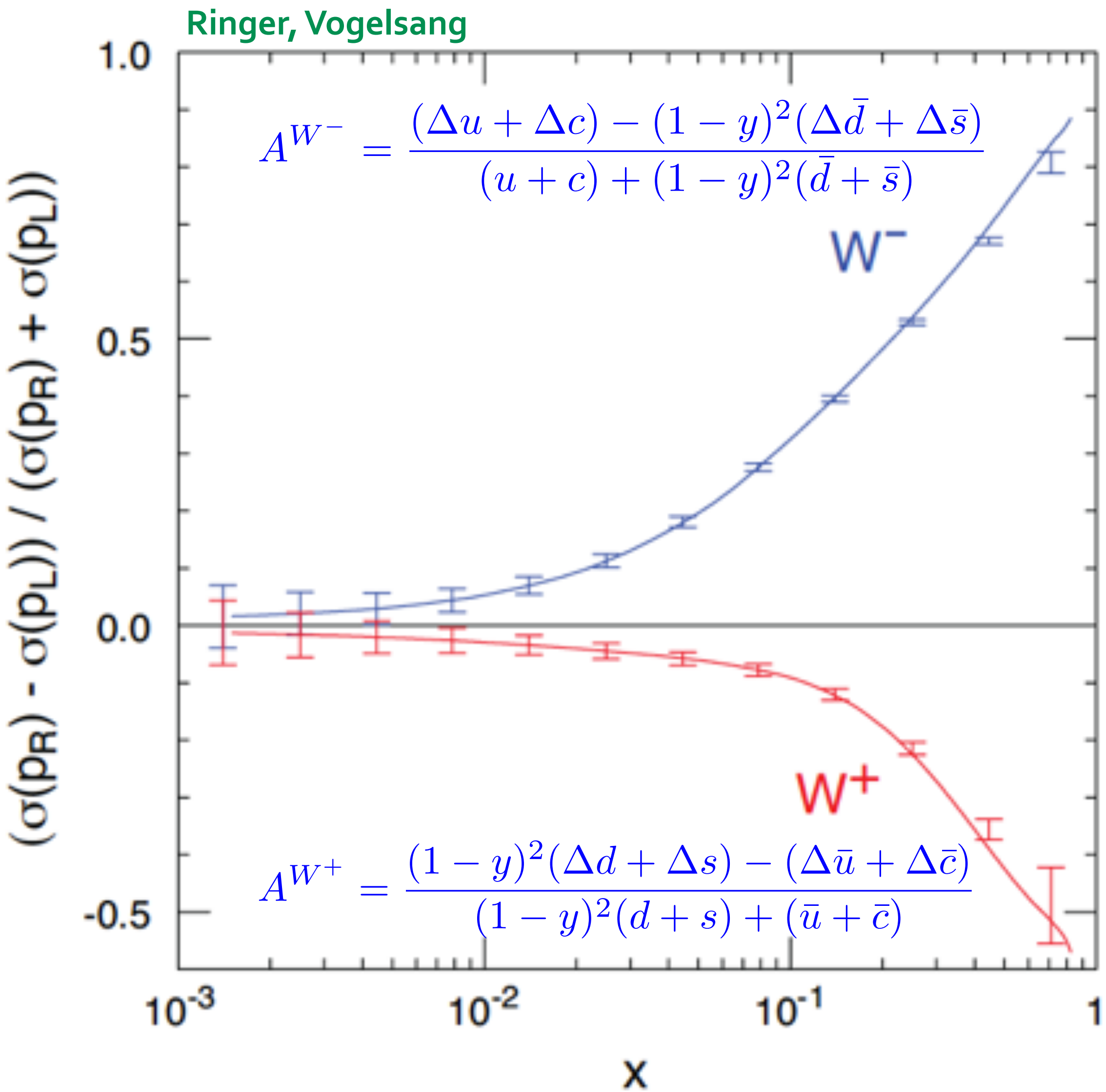
- NLO QCD corrections all available — de Florian, Sassot; MS, Vogelsang, Weber; van Neerven, Zijlstra; Moch, Vermaseren, Vogt
- can be easily put into global QCD analyses
- kinematically limited to medium-to-large x region
- novel Bj-type sum rules — MS, Vogelsang, Weber

  e.g. $$g_5^{W^-,p} - g_5^{W^+,n} = \left(1 - \frac{2\alpha_s}{3\pi}\right) g_A$$

- can extract (anti-)strangeness from CC charm production $W^+ s' \rightarrow c$ — **NLO:** Kretzer, MS

other opportunities at an EIC (cont'd)

example



20 x 250 GeV

$Q^2 > 1$ GeV^2

$0.1 < y < 0.9$

10 fb^{-1}

DSSV PDFs

to-do item / issue:
hadronic method to determine x, Q^2 problematic at large y

take away message

many unique opportunities to study helicity PDFs at a high-energy polarized lepton-nucleon collider

- access to small x to reliably determine Δg and $\Delta\Sigma$
- flavor separation in broad x, Q^2 range to study (a)symmetry of quark sea
- access to novel electroweak probes at high Q^2
- effective neutron beam: study of Bjorken sum rule