Improving our knowledge on antiquark polarized distributions studying

Theory Own ~~Over~~view : W Physics at RHIC

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RHIC SPIN : Next Decade
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One (big) Purpose of spin program: obtain a full set of polarized pdfs

information about nucleon polarization

Requires measurement and analysis of several processes

sensitive to different combinations

PDFs obtained as a result of a global fit

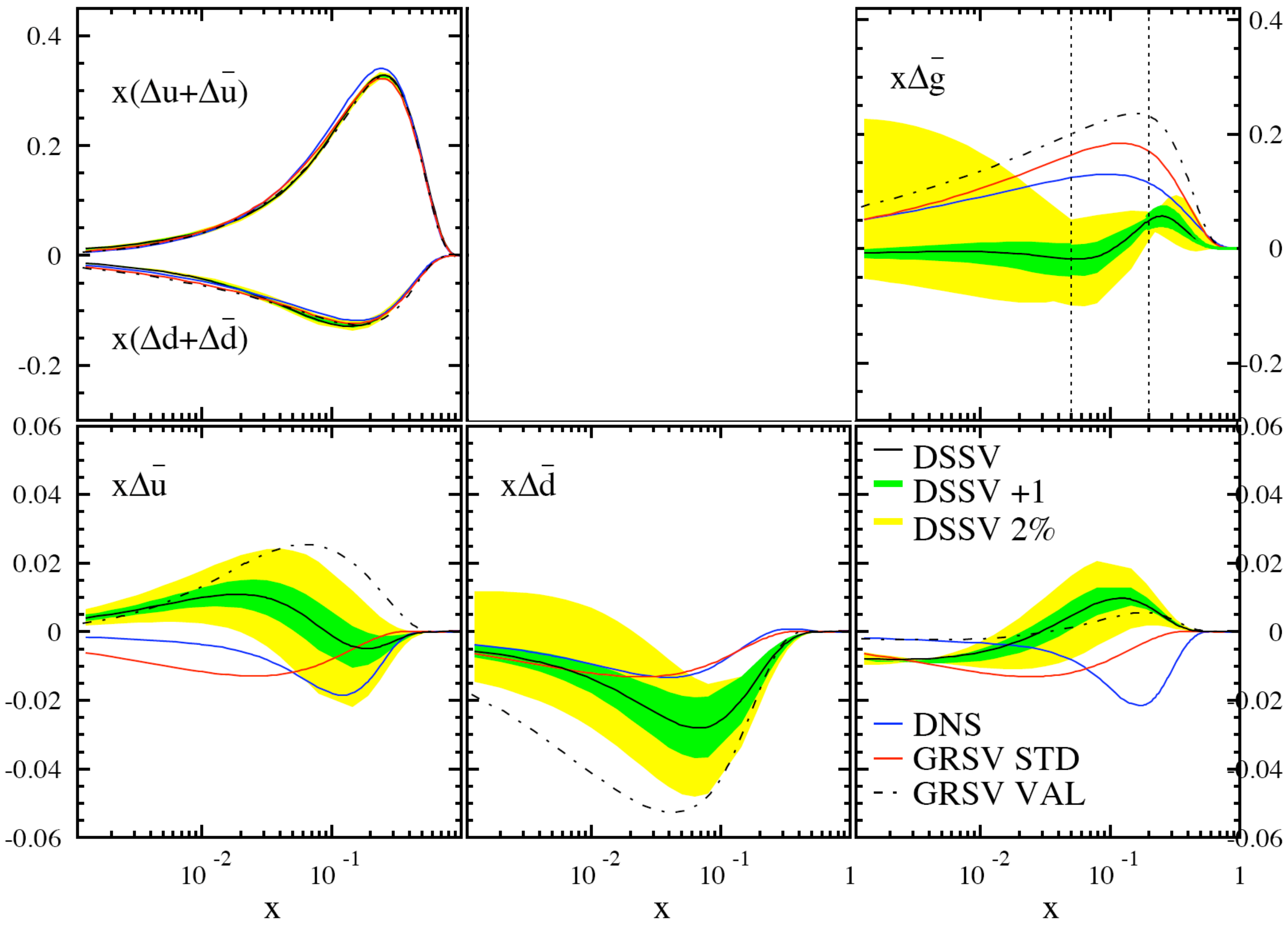
learn from unpolarized

pd/pp DY experiments designed for $\frac{\bar{u}}{\bar{d}}$ measurement

DSSV analysis

de F. , Sassot, Stratmann, Vogelsang

Still not negligible uncertainty on antiquark polarized densities



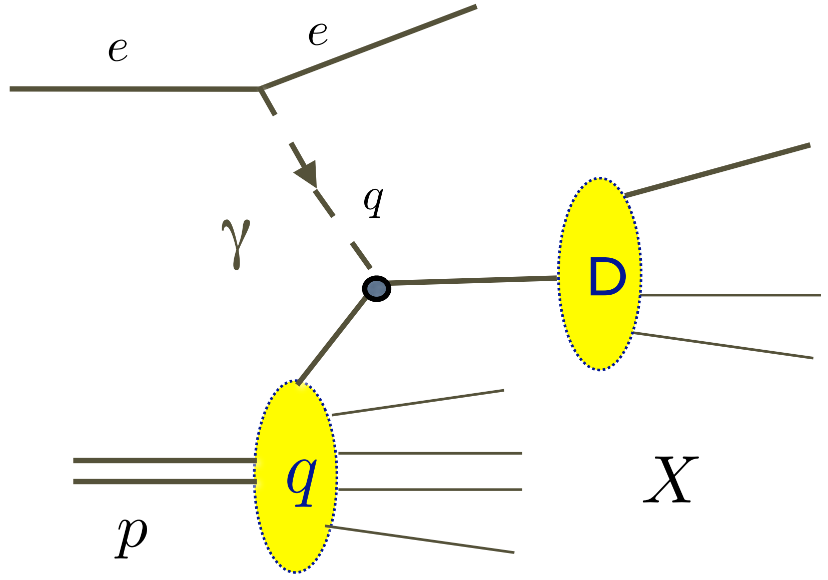
$Q^2 = 10\ \mathrm{GeV}^2$

Uncertainties using Lagrangian method :
truncated moment [0.001 - 1]

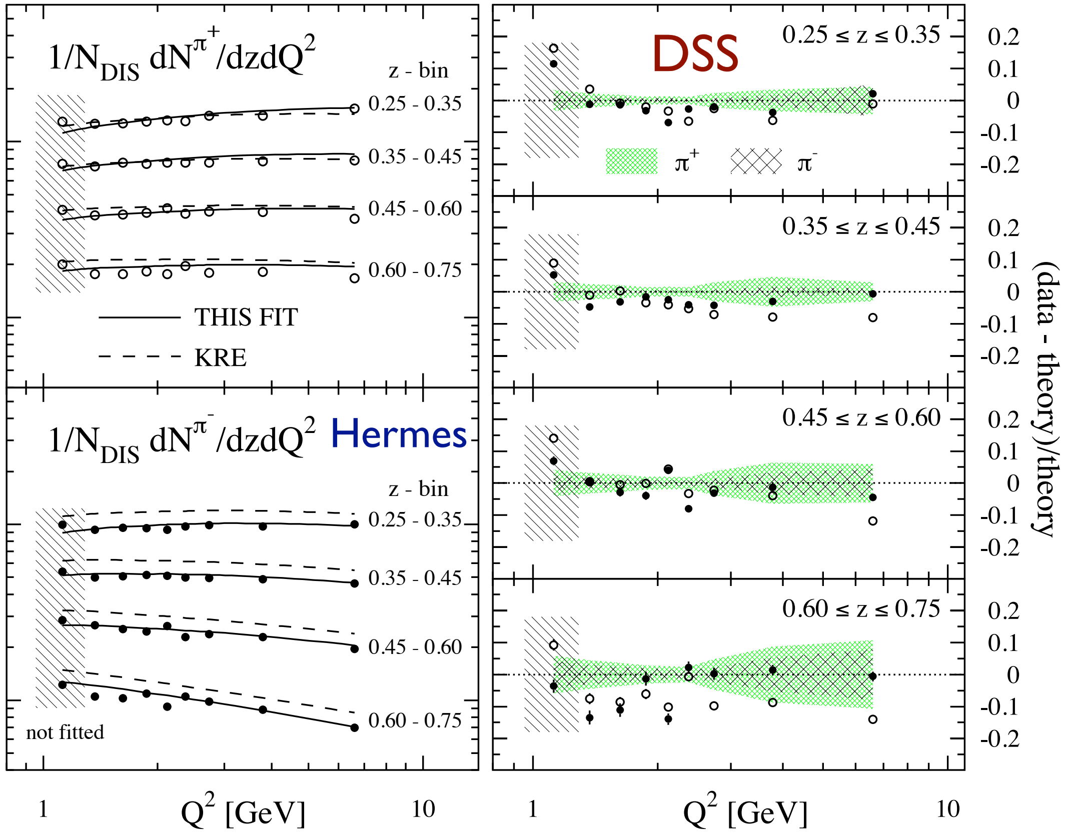
(almost) All information comes from SIDIS ...

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

SIDIS



q/qbar separation (fully) depends on fragmentation functions DSS



DdF., R.Sassot, M.Stratmann

Separation of FFs (fully) depends on SIDIS (Hermes multiplicities)!

Hermes data preliminary

Effects beyond factorization?

Relies on knowledge of unpolarized PDFs

Any modification in unpolarized PDFs affects FFs extraction

$$s(x) \rightarrow D_s^K(z) \rightarrow \Delta s(x)$$

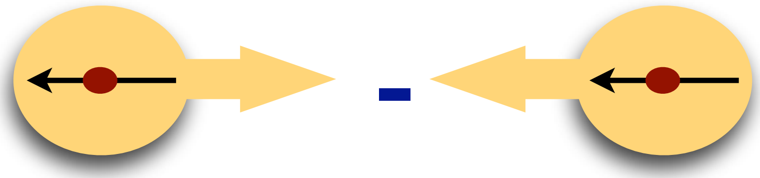
Difficult to quantify those “uncertainties”

Need a cleaner observable for antiquark density measurement

W single-spin asymmetries

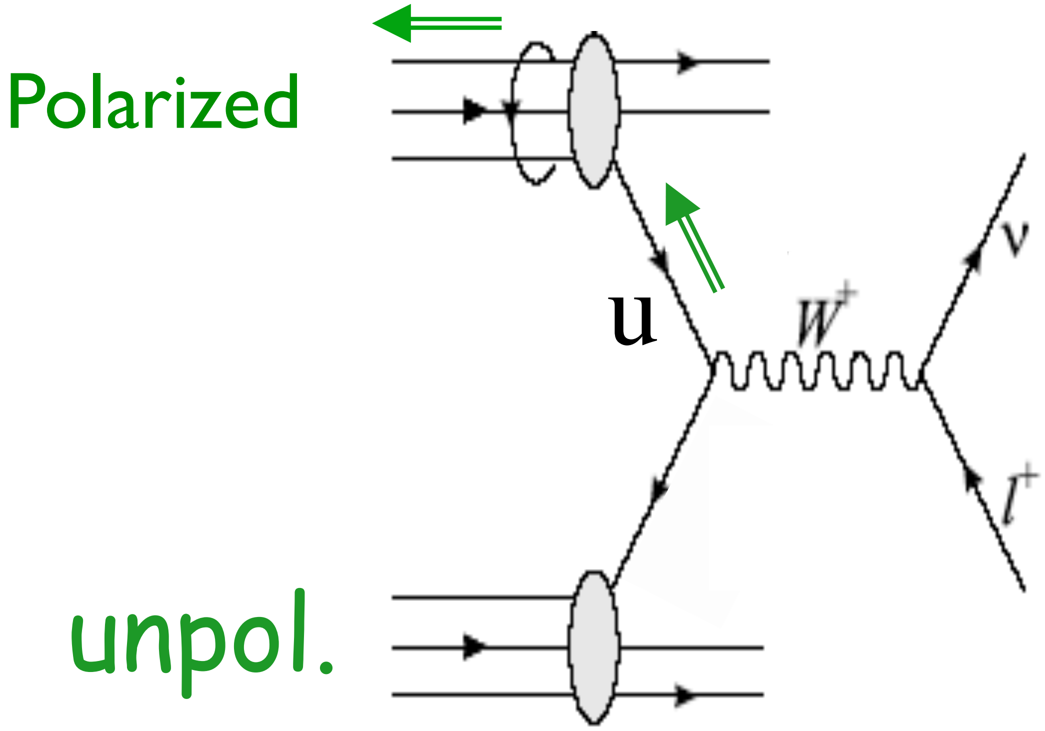
If parity violated can have $A_L = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} \neq 0$

- W couples only to one helicity type: max. parity violation
- Large asymmetries possible



- W mass provides hard scale: pQCD

Only one polarized beam $A_L = \frac{\sigma^{++} + \sigma^{+-} - \sigma^{-+} - \sigma^{--}}{\sigma^{++} + \sigma^{+-} + \sigma^{-+} + \sigma^{--}}$



$$\frac{\Delta q_i(x_1)\, q_j(x_2)}{q_i(x_1)\, q_j(x_2)}$$

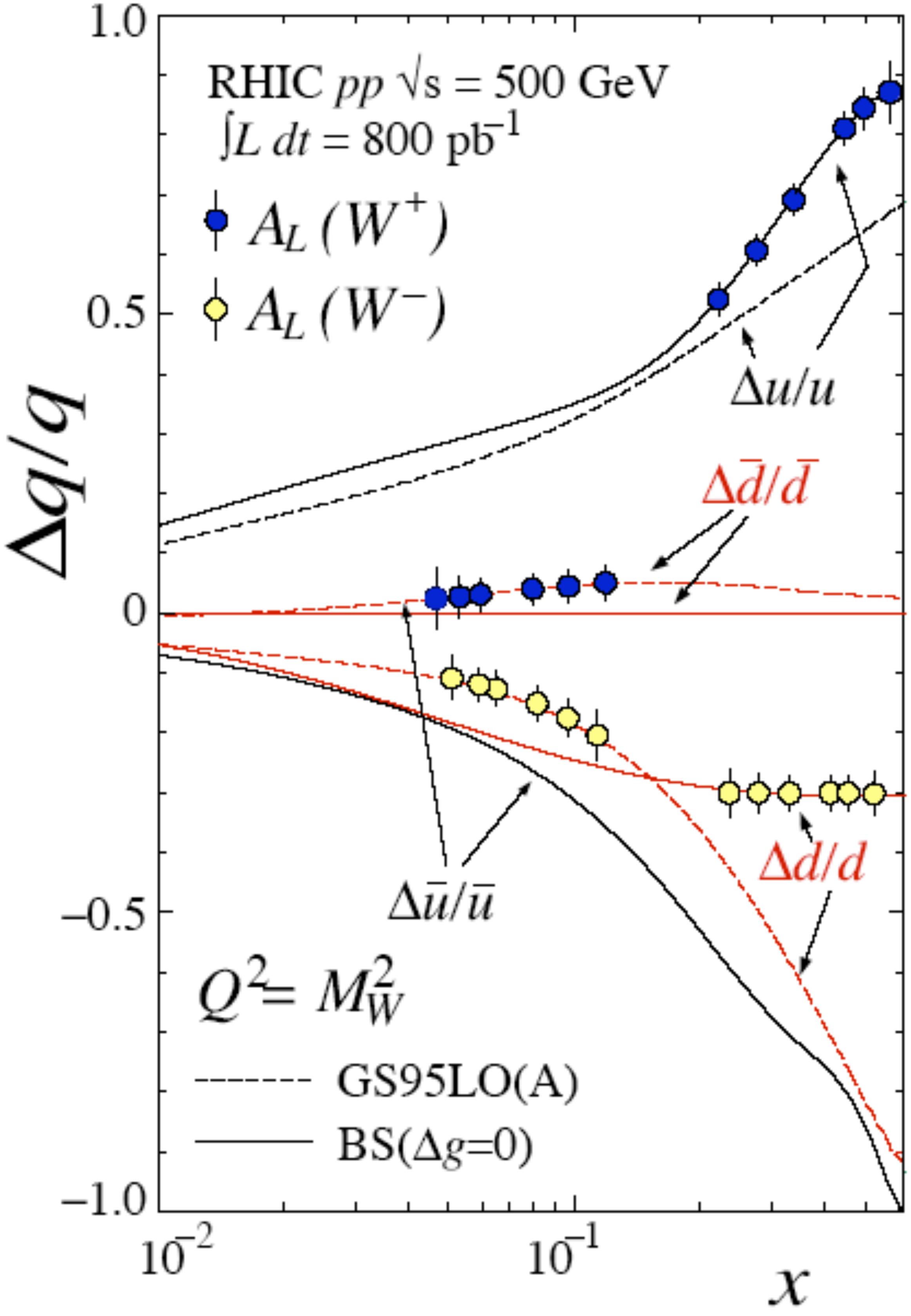
W single-spin asymmetries

Should have strong sensitivity
on flavor structure

Bourrely, Soffer

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

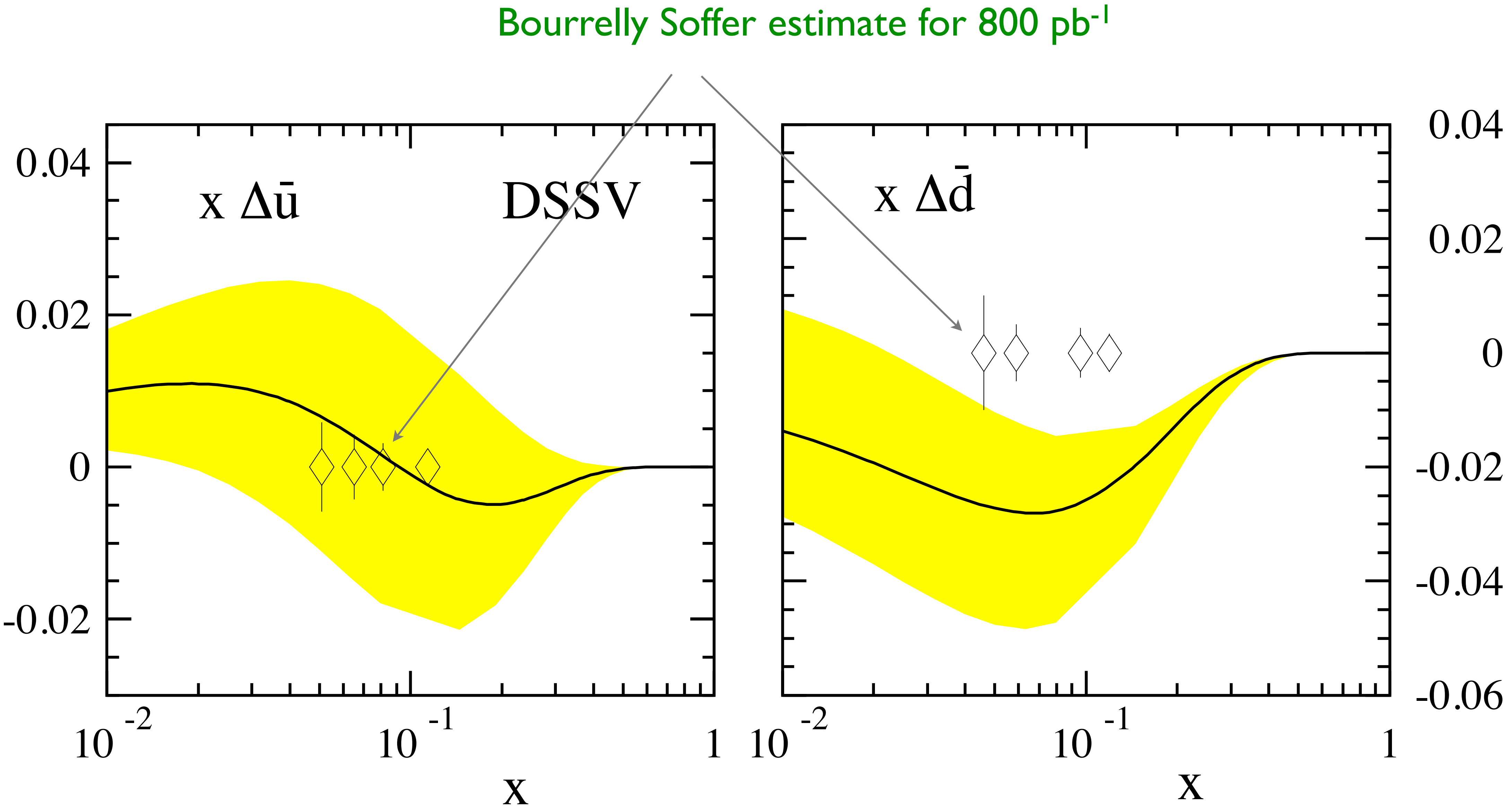
$$x_{1,2} = \frac{M_W}{\sqrt{S}} e^{\pm y_w}$$



Naive* analysis anticipates good prospect

* Relies on measuring W kinematics
Lepton affects both kinematics and dynamics

Will need reasonably high statistics to 'compete' with SIDIS



realistic exp. conditions result in higher 'x'

Move to next step Include 'lepton' W asymmetries in global analysis

NLO needed for quantitative studies in pp collisions ~ 30% effect for W production

Important : No “full” NLO calculation available yet
RhicBos has several NLO ingredients plus some extra terms
(qt-resummation) not needed/not convenient for RHIC

★ Makes technically difficult to include the observable in global fit

Need to count with a new calculation $\sigma(pp \to e\bar{\nu}X)$

- Exclusive to implement experimental cuts
- “Ready/Available” for Mellin implementation
- Full NLO in line with other observables already in fit

We have just finished the computation and implemented it in a MonteCarlo-like code (in the same line as dijets and h+jet codes)

de F. , Vogelsang

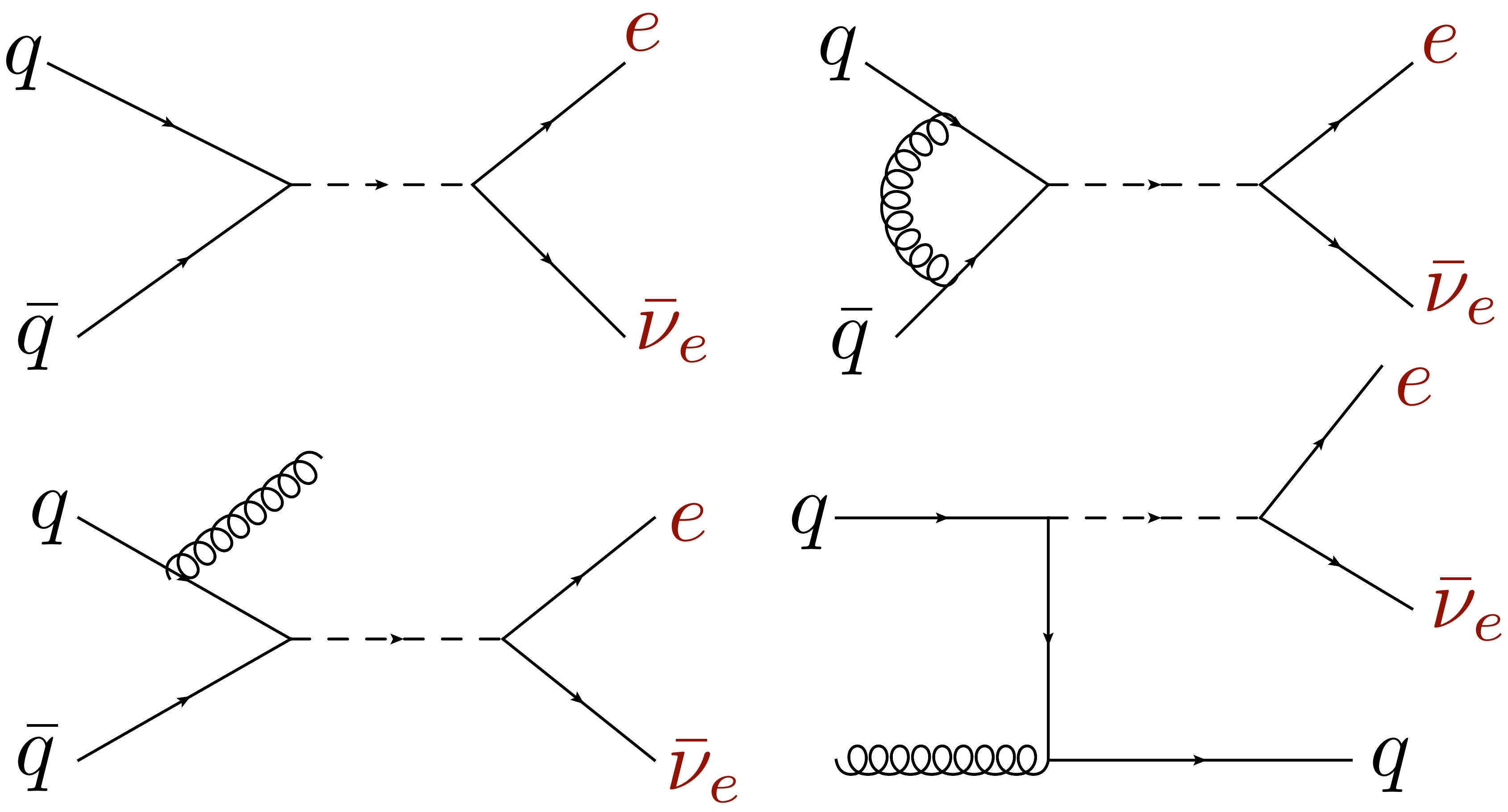
Full access to final and initial state kinematics :
compute any infrared-safe observable

New channels at NLO

W-

$$\begin{array}{lcl}
\Delta\bar{q}\; q & \longrightarrow & e\,\bar{\nu}_e \\
\Delta q\; \bar{q} & \longrightarrow & e\,\bar{\nu}_e \\
\Delta\bar{q}\; g & \longrightarrow & e\,\bar{\nu}_e\,\bar{q} \\
\Delta g\; \bar{q} & \longrightarrow & e\,\bar{\nu}_e\,\bar{q} \\
\Delta q\; g & \longrightarrow & e\,\bar{\nu}_e\,g \\
\Delta g\; q & \longrightarrow & e\,\bar{\nu}_e\,g
\end{array}$$

Some diagrams ..



Rather simple to use

```
'test'                 ! prefix for files
 500.d0 1.d0           ! energy,  fact/renorm. scalefactor
  0                    ! polarization   0(unpol)  1(single pol)  2(double pol)
 -1                    ! Charge of the final state W
  1   1                ! Hadron beams  p=1 pbar=-1
  46                   ! set of pdfs beam 1
  46                   ! set of pdfs beam 2 =1 if Ipol=0 or 2
  -60    -60           ! Number of iterations for vegas (LO, NLO)
  2   2                ! Vegas parameters: 0 to exclude, 1 for new run, 2 to restart
  250000  1500000      ! Number of calls for vegas
```

Can use different pdfs, scales, etc

Define observable (bin cross-section) in “user file” : output in topdrawer file

```
      subroutine outfun(www)
c  This is the user analysis routine. It is called for each generated event with the parameter www: weight of the event
c The kinematic of each particle is given by
c      xkt(i)=modulus of the transverse momentum of particle # i  in GeV
c      xeta(i)=pseudorapidity of particle # i
c     xphi(i)=azimuthal angle of particle # i
c     xkt(i),xeta(i),xphi(i) correspond to
c                                              i=1 jet
c                                              i=2 lepton
c                                              i=3 neutrino
c                                            (i=4 W boson as e+nu)
c
c The rapidity is POSITIVE in the direction of beam 1
c
c    To fill the histograms, use
c     topfill(hn,x,weight)
c where:
c     hn = histogram number
c     x = x value
c    weight = weight of the event
```

Available soon ... (manual & paper in preparation)

One more thing

Experiments measure lepton : other processes contribute to the cross section

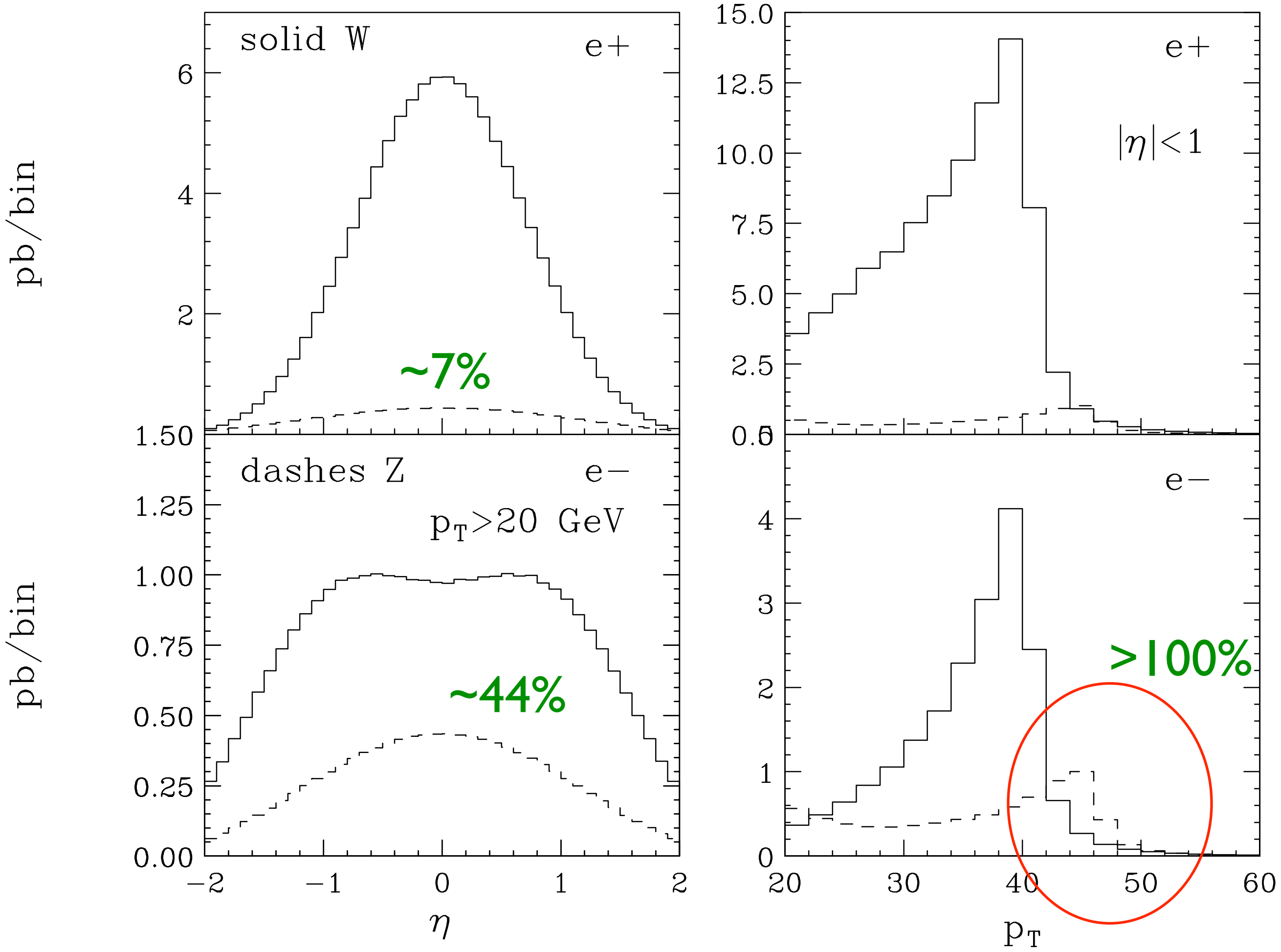
$pp \xrightarrow[Z/\gamma]{} e^- e^+$ to both W^- , W^+

Z/γ increases the unpolarized cross section

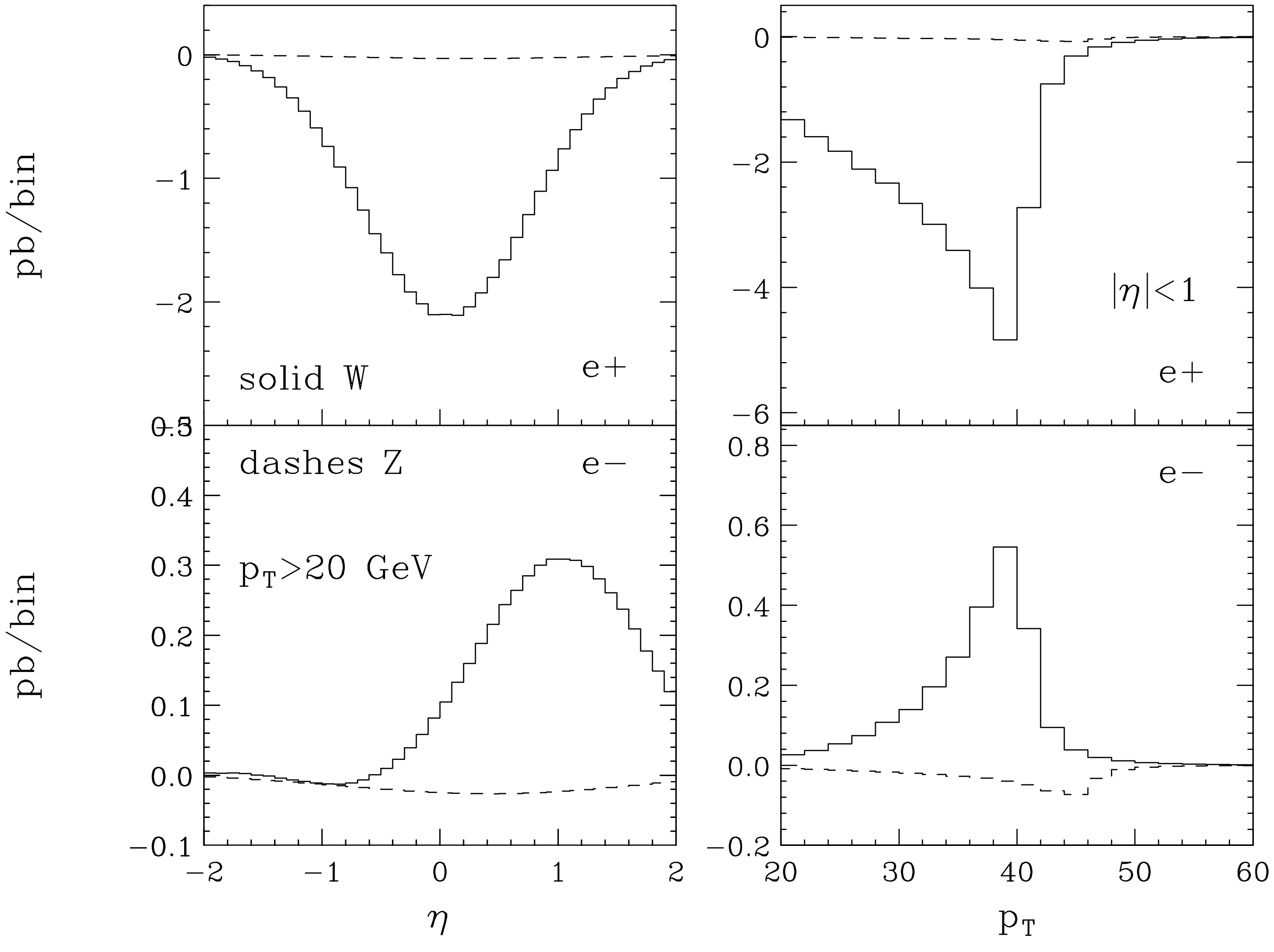
New Code de F. ,Vogelsang

Z (PV component) contributes to single-spin cross section

Unpolarized sizable



Polarized rather small



Electron/positron Asymmetries

- NLO
- Include Z/Gamma contribution
- MRST for unpolarized
- Various polarized pdfs (some already ruled out)

$$\sqrt{S} = 500\,\mathrm{GeV}$$

$$\mu_F^2 = \mu_R^2 = \frac{M_W^2 + p_T^2}{2}$$

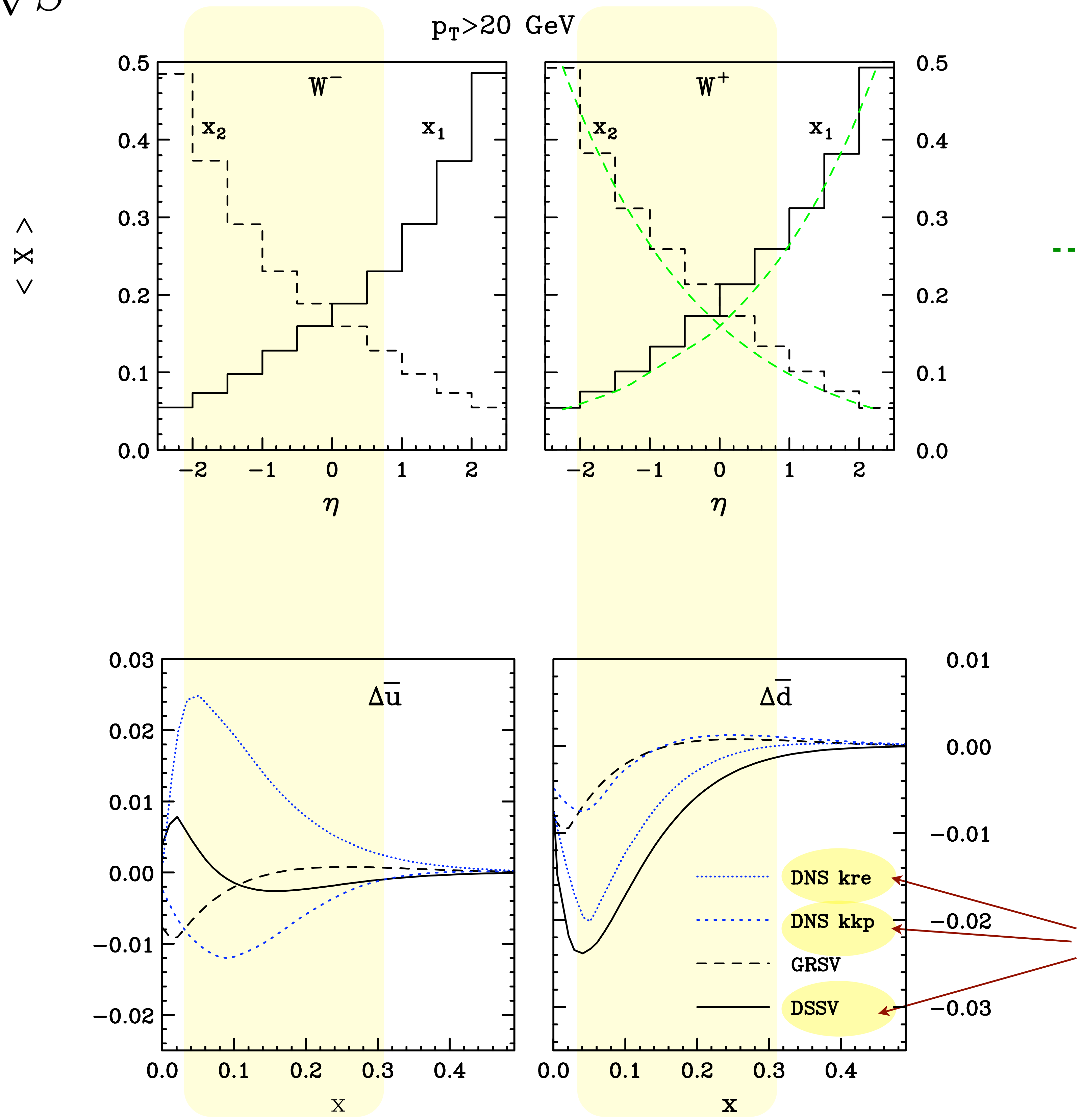
$$M_W = 80.398\,\mathrm{GeV}$$

$$M_Z = 91.876\,\mathrm{GeV}$$

couplings from PDG

Lepton rapidity inherits relation to x

$$x_{1,2} = \frac{M_W}{\sqrt{S}} e^{\pm y_w}$$

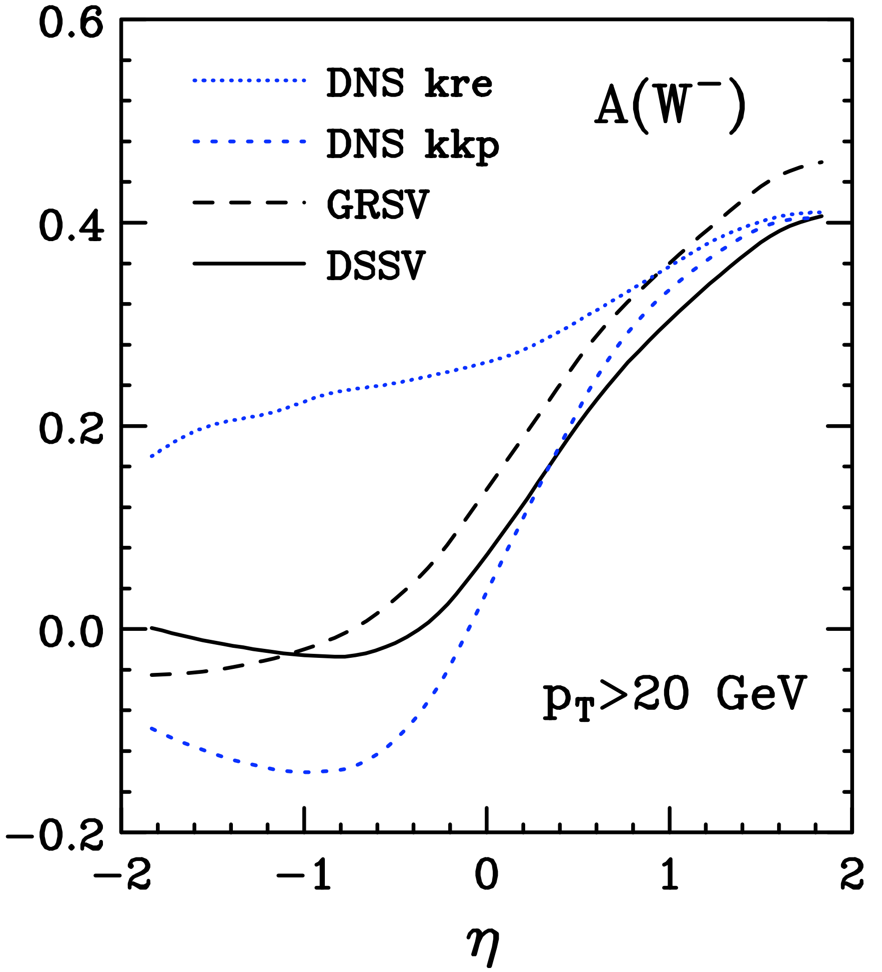


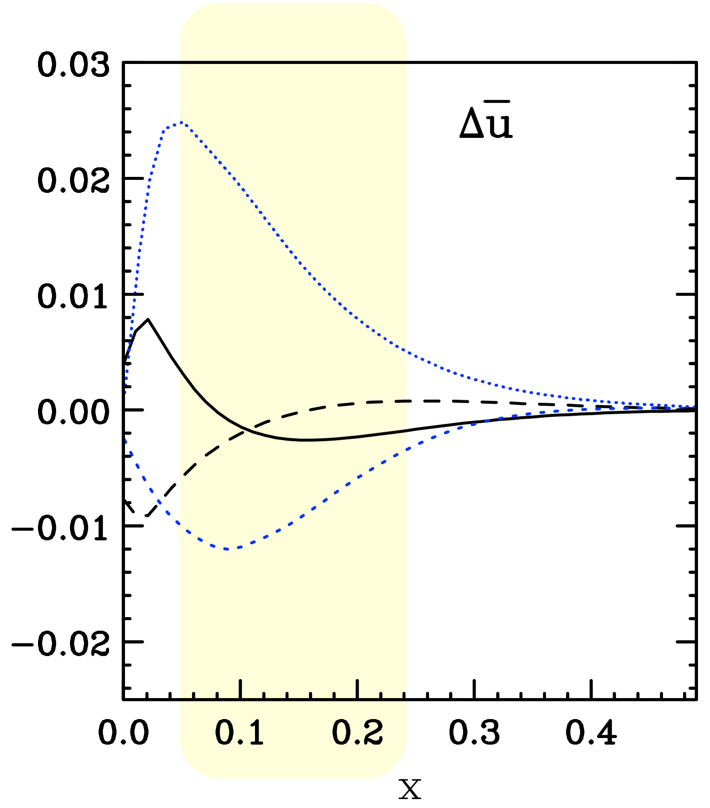
-------- $< X_{1,2} > \simeq \frac{M_W}{\sqrt{S}} e^{[\mp\eta/2]}$

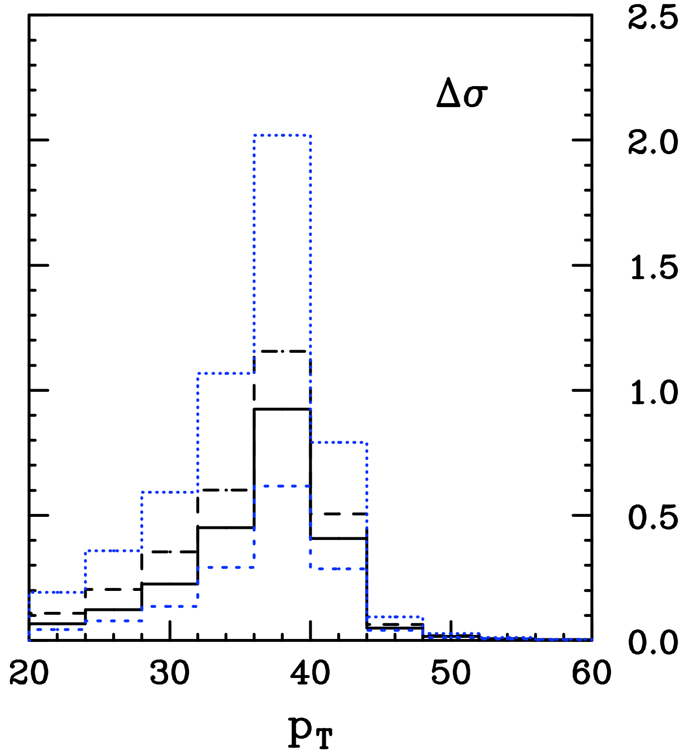
include SIDIS
with different
FFs

‘Better’ observable than transverse momentum
p_T integration get rid off problem at $M_W/2$

W- (electron rapidity)



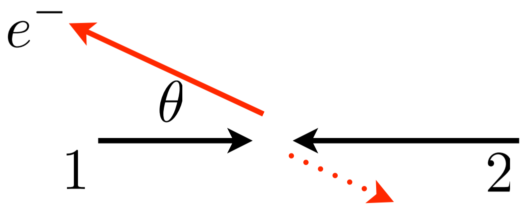




t large ⟷ u large

$\Delta\bar{q}_1\, q_2$ $\Delta q_1\, \bar{q}_2$

p_T misses main features (sign!)



$$\boxed{\Delta\bar{u}(x_1)d(x_2)(\hat{t}^2)} + \Delta d(x_1)\bar{u}(x_2)(-\hat{u}^2)$$

$$\hat{t}^2 \sim (1+\cos\theta)^2$$
$$\hat{u}^2 \sim (1-\cos\theta)^2$$

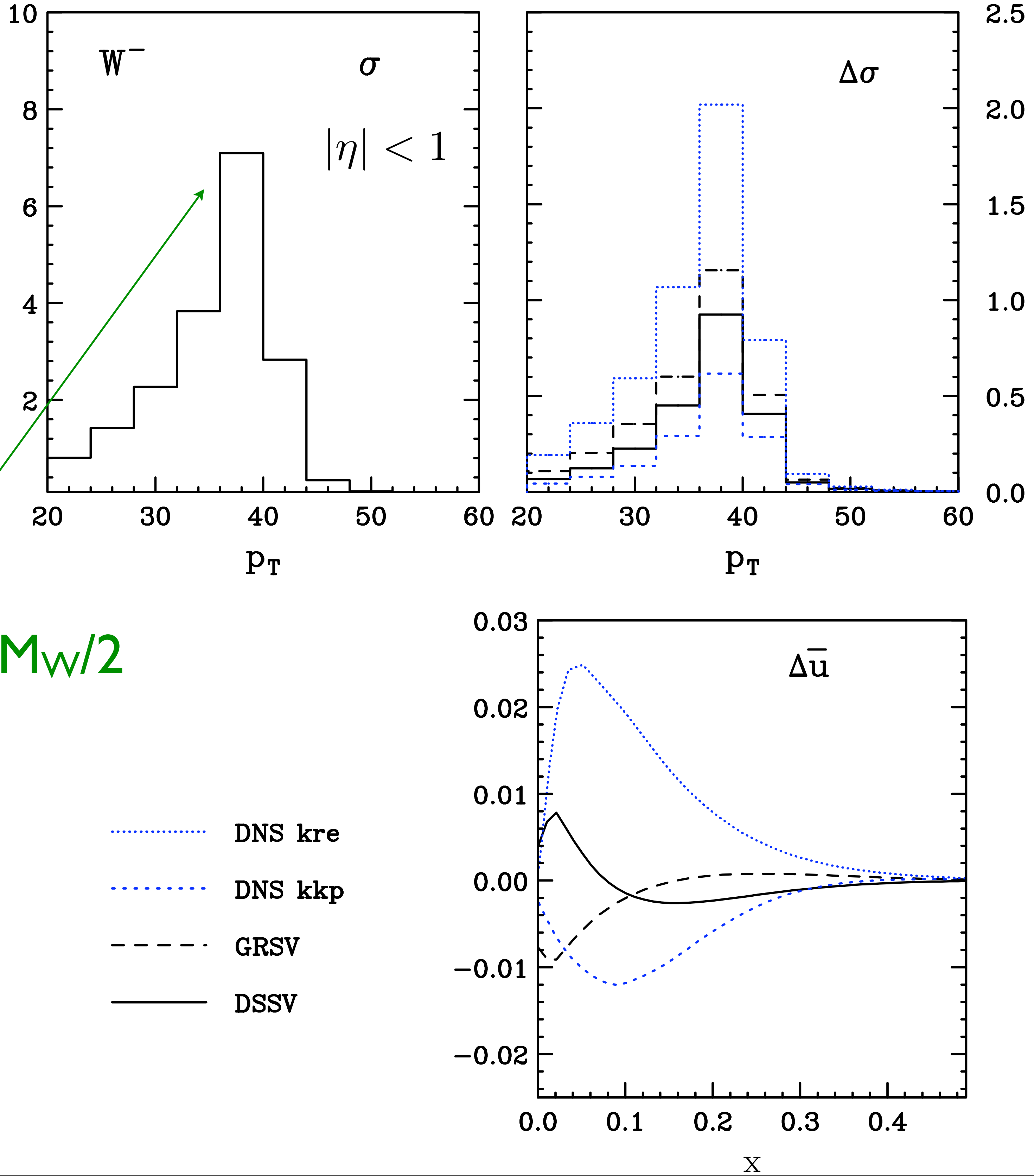
angular momentum conservation

Best scenario: polarized antiquark contribution dominant at central/negative rapidity (small x)

Strong sensitivity on $\Delta\bar{u}$

Transverse momentum distribution picks up the “normalization”: integral over covered range of x

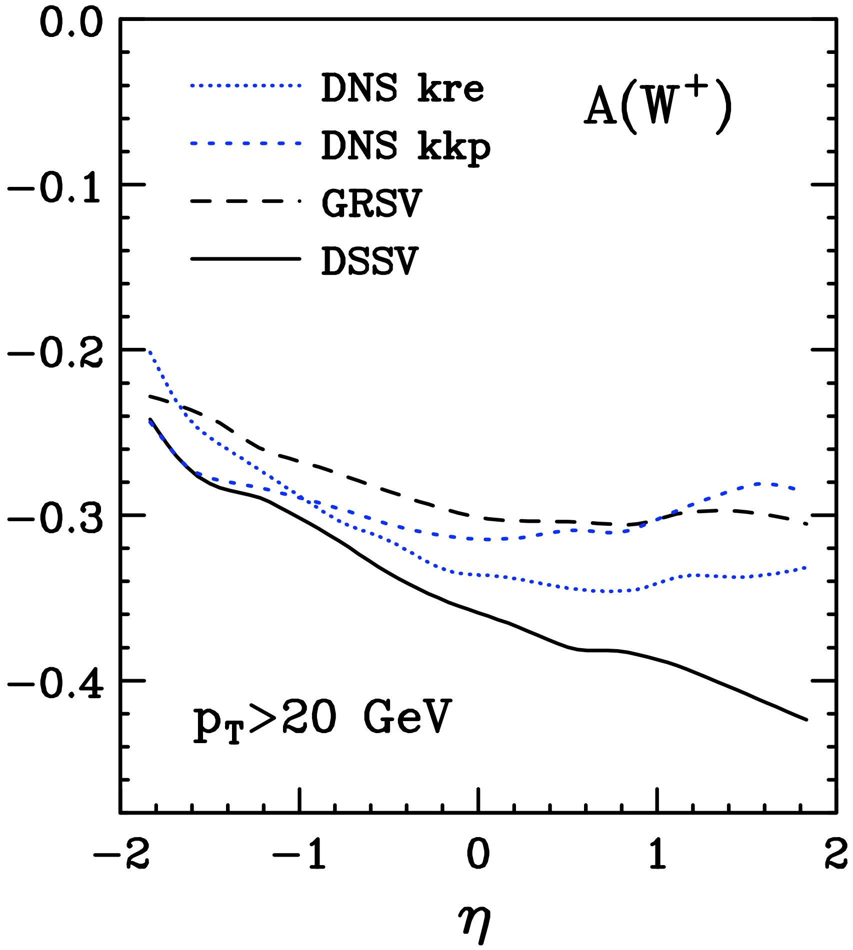
Shape not much determined by pdfs

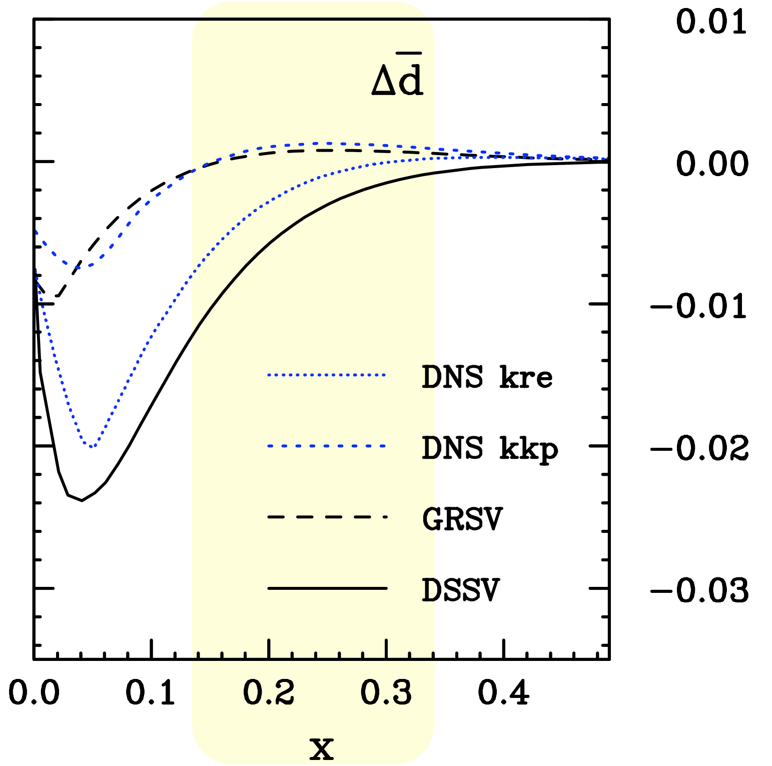


peak around $M_W/2$

can hide features that show up only at certain rapidity range

W+ (positron rapidity)

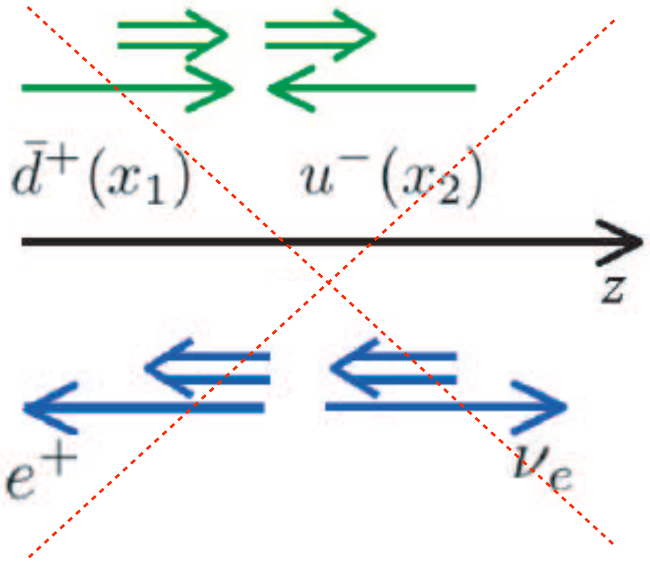




t large ⟷ u large

$\Delta q_1\,\bar{q}_2$ $\Delta\bar{q}_1\,q_2$

polarized antiquark contribution dominant at central/positive rapidity (larger x)



$$\boxed{\Delta\bar{d}(x_1)u(x_2)(\hat{u}^2)} + \Delta u(x_1)\bar{d}(x_2)(-\hat{t}^2)$$

Not that much sensitivity on $\Delta\bar{d}$ need to look at forward rapidities

Include some “data” in global fit and check impact on distributions

Global fit best in Mellin space : very fast solution of evolution equations and cross-sections (DIS,SIDIS)

$$f^n = \int dz\; z^{n-1}\, f(z)$$

$$d\Delta\sigma(pp \to l) = \frac{1}{2\pi i}\sum_{ab} \int_{\mathcal{C}_n} dn \;\; \Delta f_a^n \;\; \int dx_a \int dx_b\, x_a^{-n}\, f_b(x_b)\, d\Delta\sigma_{ab}$$

Standard Mellin Inverse

Contains all dependence on polarized pdfs

Completely independent on polarized pdfs : can be “pre-calculated” prior to fit

$$(d\Delta\sigma_{ab})_n = \int dx_a \int dx_b\, x_a^{-n}\, f_b(x_b) \boxed{d\Delta\sigma_{ab}}$$

still PS integrals
First time with a MC code!

‘Grids’ produced for rapidity bins of size 0.33 (added to match exp. conditions)

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

0 for sea/gluon

node allowed

Data Simulation

pseudodata generated according to DSSV with gaussian dispersion with $\epsilon = \frac{1}{P\sqrt{\mathcal{L}\,\sigma}}$ $P = 60\%$

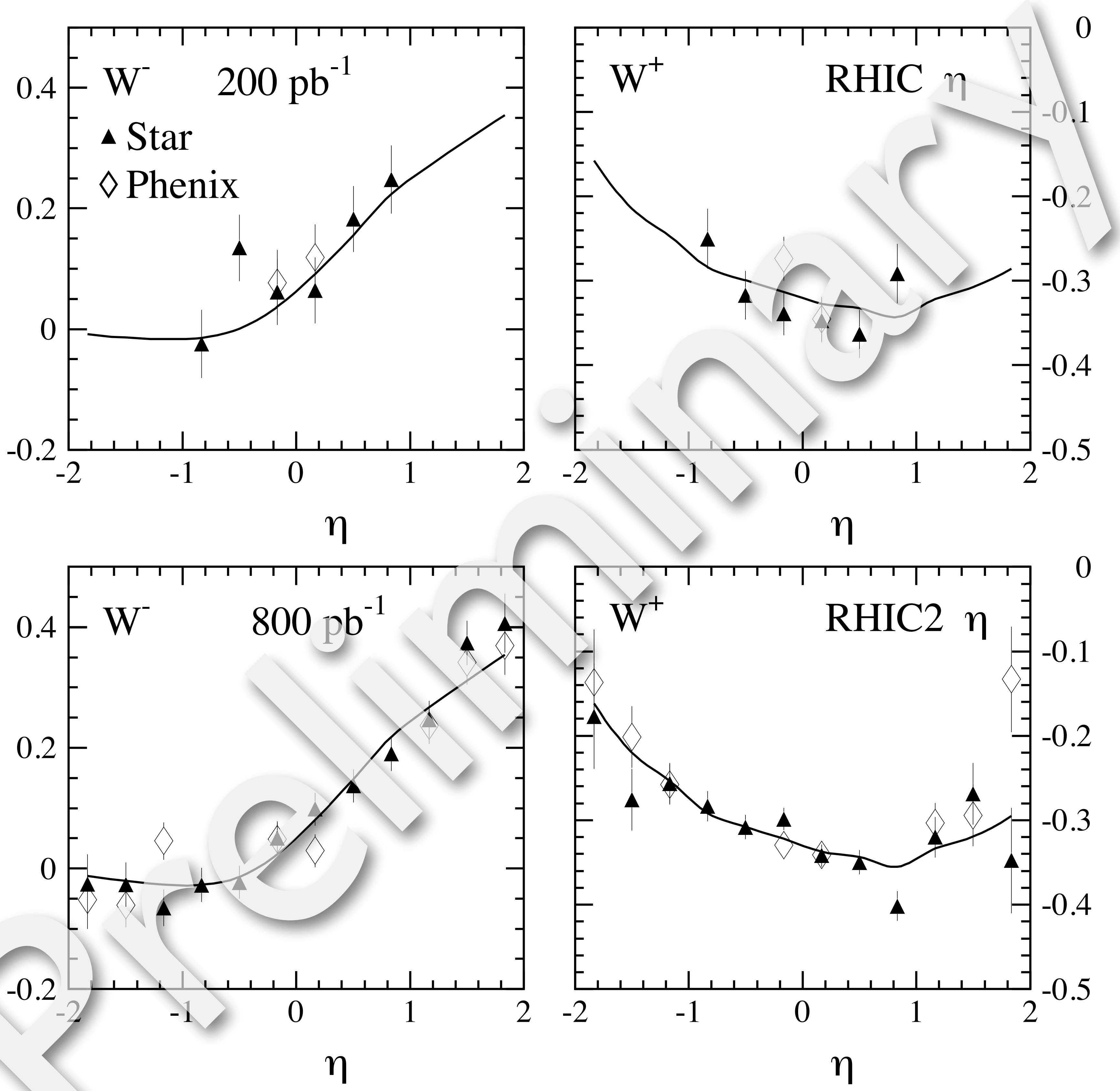
Different scenarios

Rapidity	STAR	'Phenix'
RHIC	$\|\eta\| < 1$	$\|\eta\| < 0.35$
RHIC '2'	$\|\eta\| < 2$	$1 < \|\eta\| < 2$ and $\|\eta\| < 0.35$

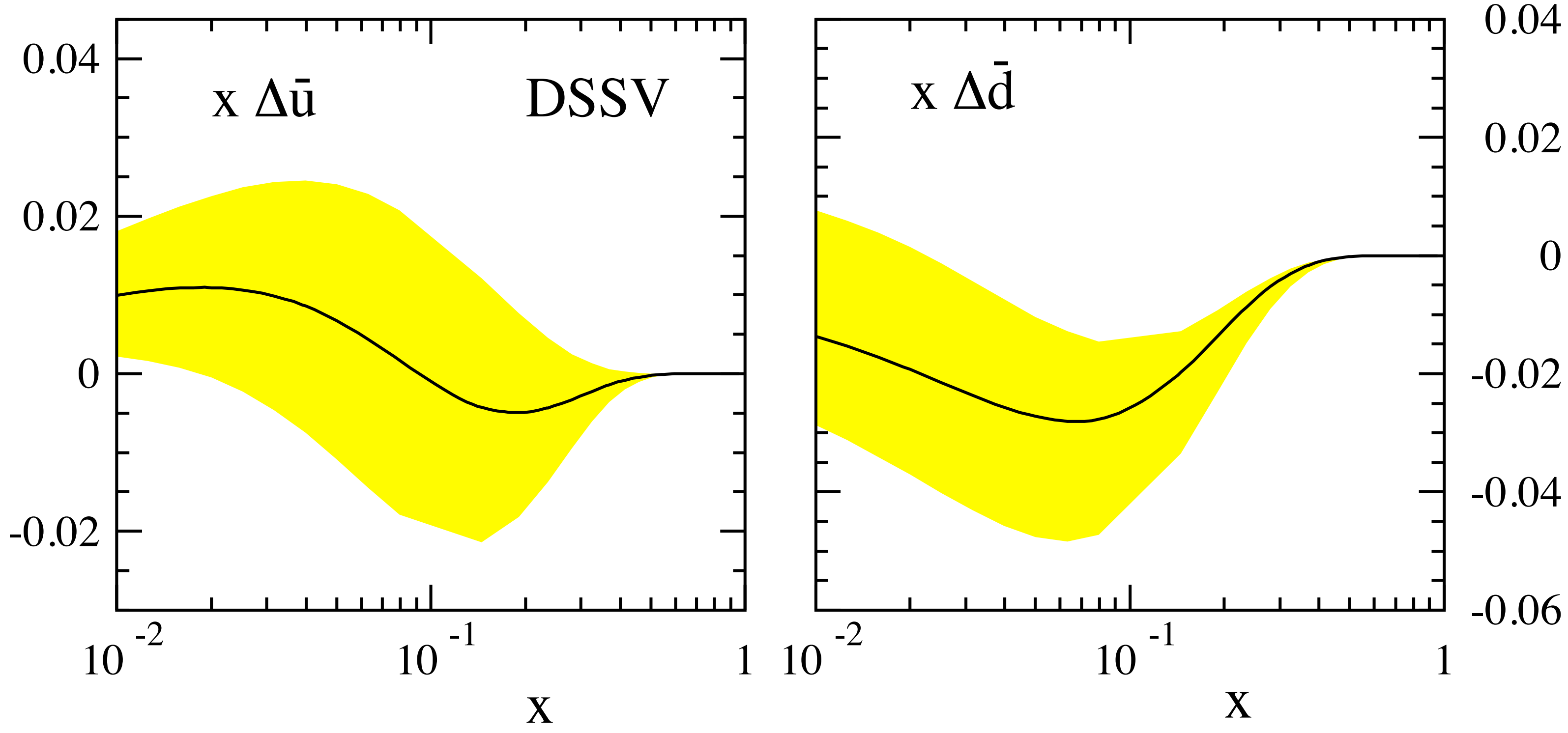
Luminosity

$\mathcal{L} = 200\,\mathrm{pb}^{-1}$
$\mathcal{L} = 800\,\mathrm{pb}^{-1}$

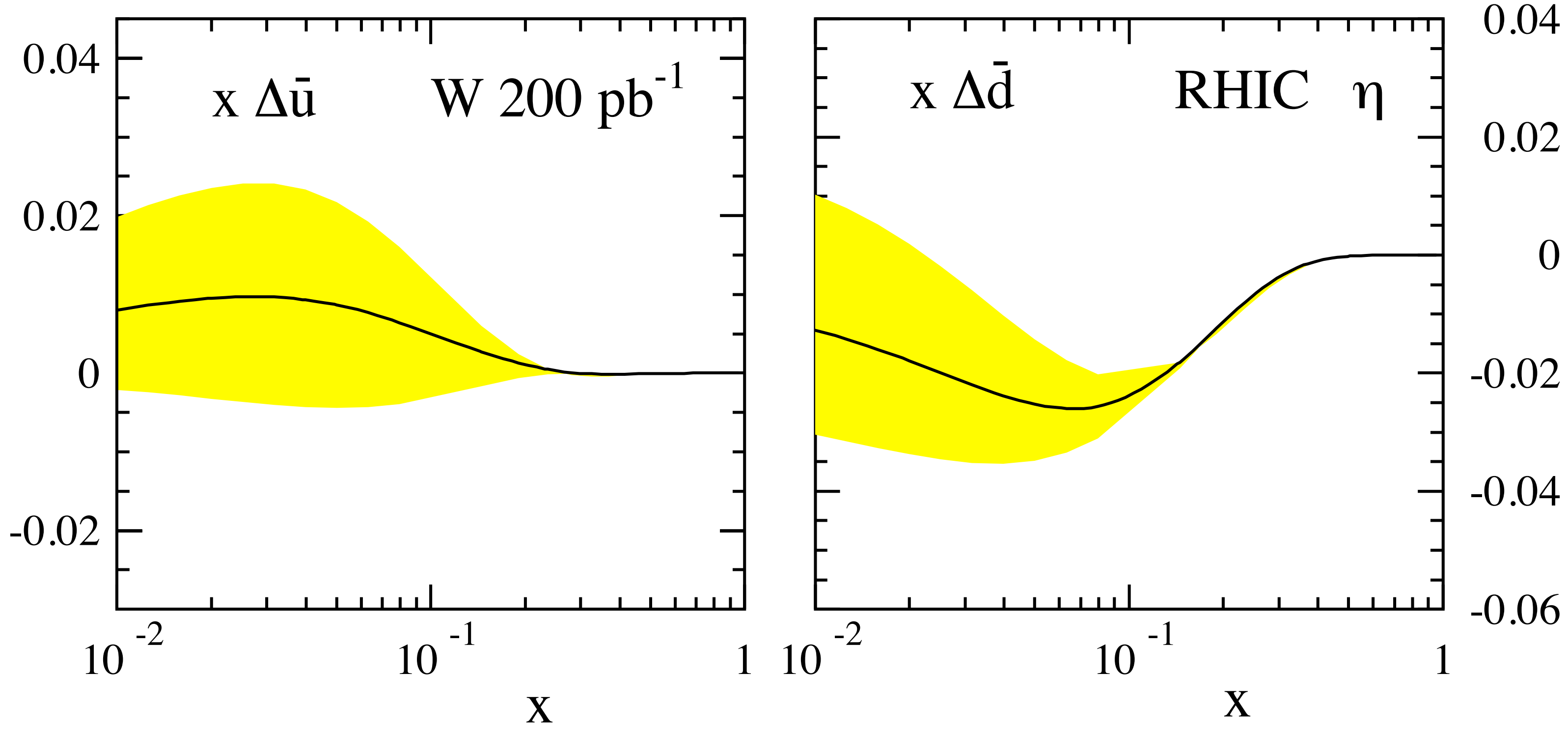
$$\Delta\chi^2 = 2\%\,\chi^2$$


W⁻ 200 pb⁻¹
Star
Phenix
W⁺ RHIC η
W⁻ 800 pb⁻¹
W⁺ RHIC2 η
0.4
0.2
0
-0.2
0
-0.1
-0.2
-0.3
-0.4
-0.5
-2
-1
0
1
2
η

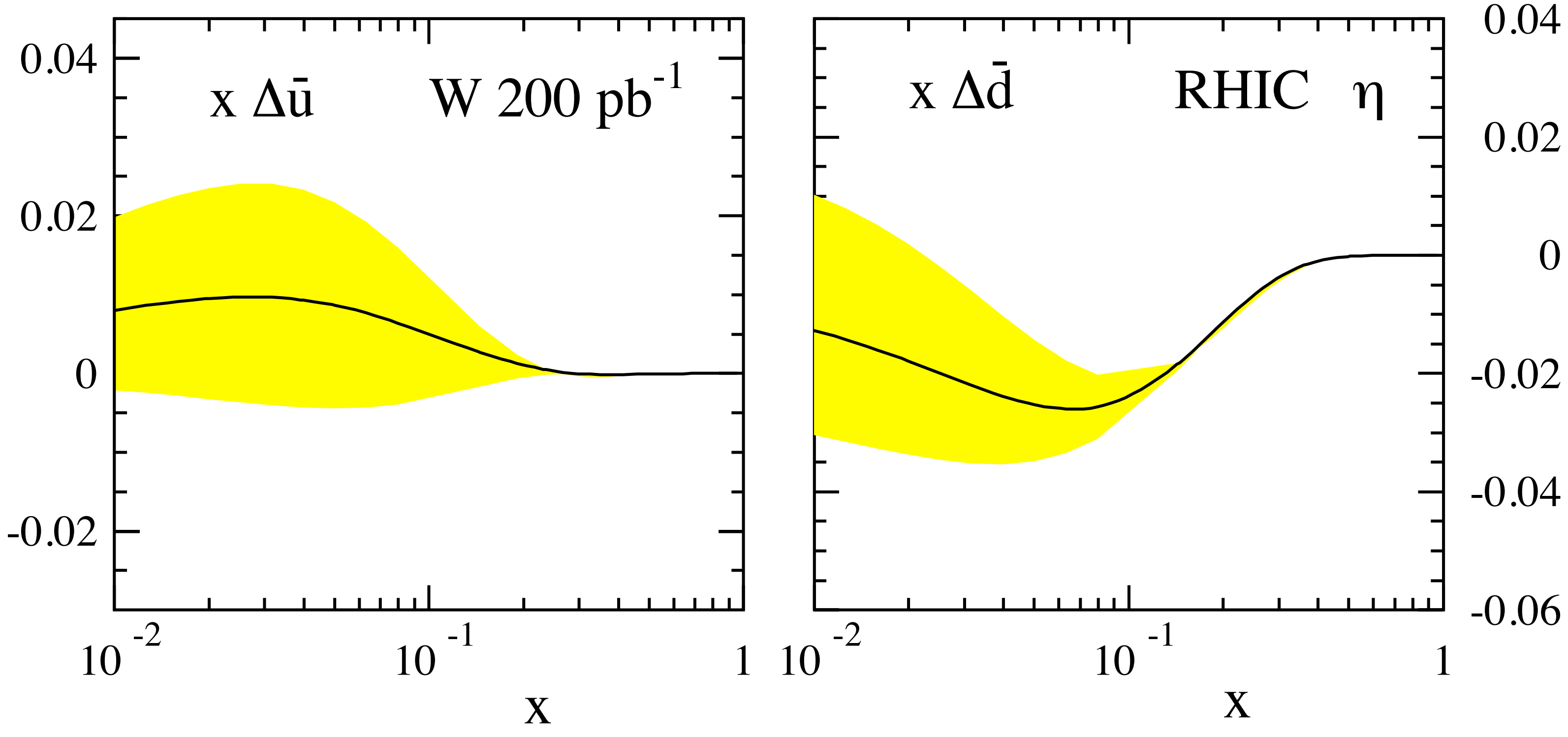
DSSV result



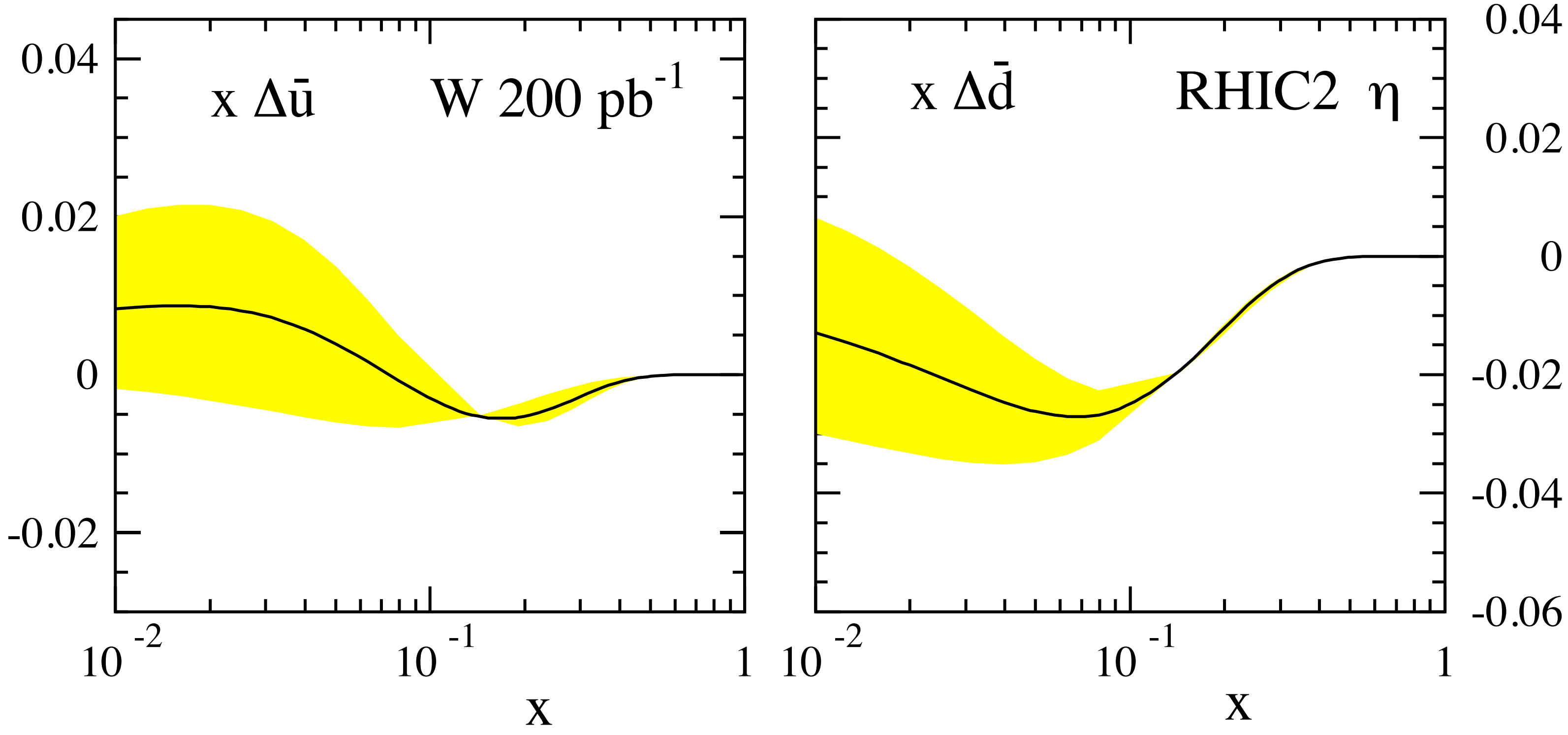
Include W data (present rapidity coverage)

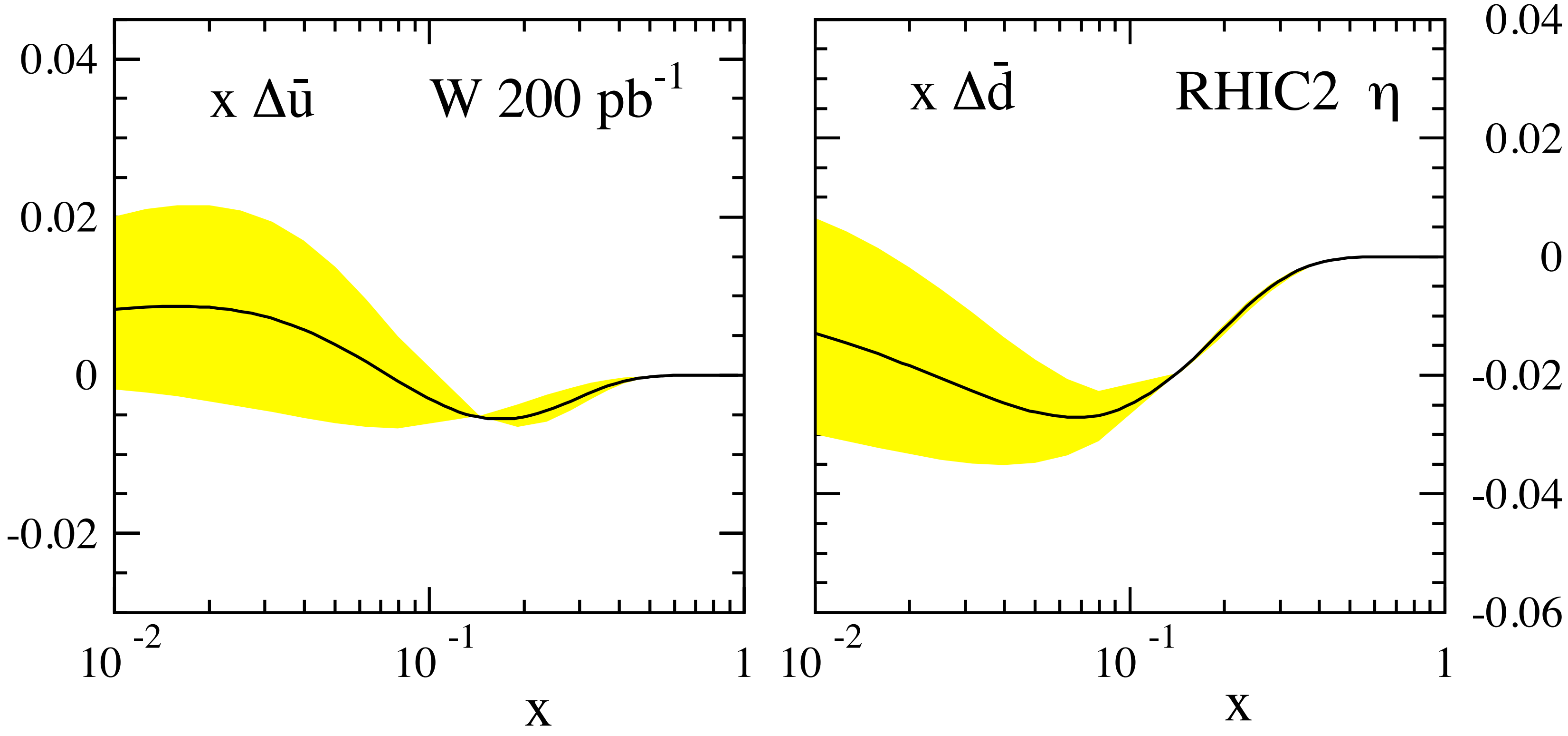


Strong reduction in uncertainty band at $x > 0.05$

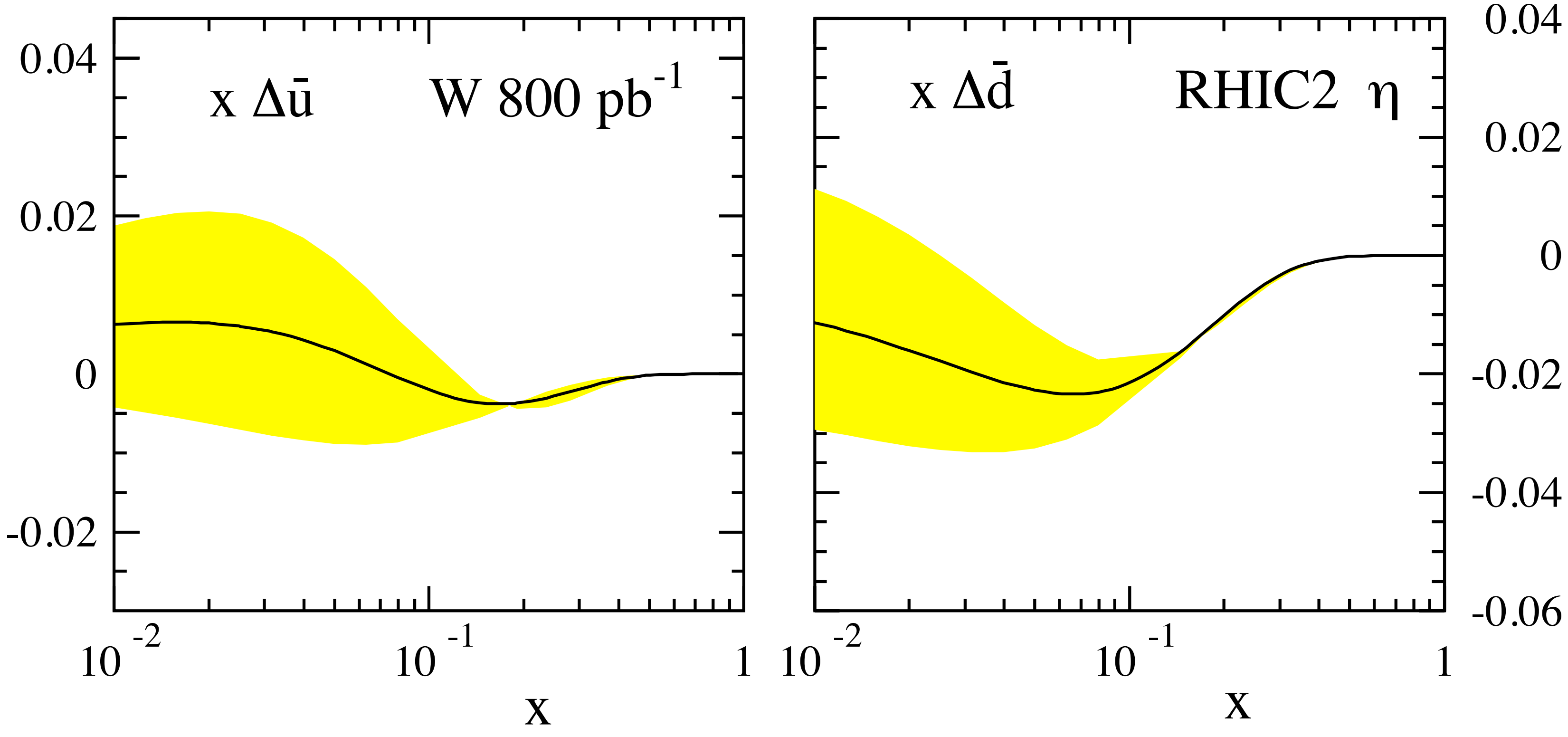


Effect at smaller x with larger rapidity coverage (ubar)





Larger luminosity : moderate effect

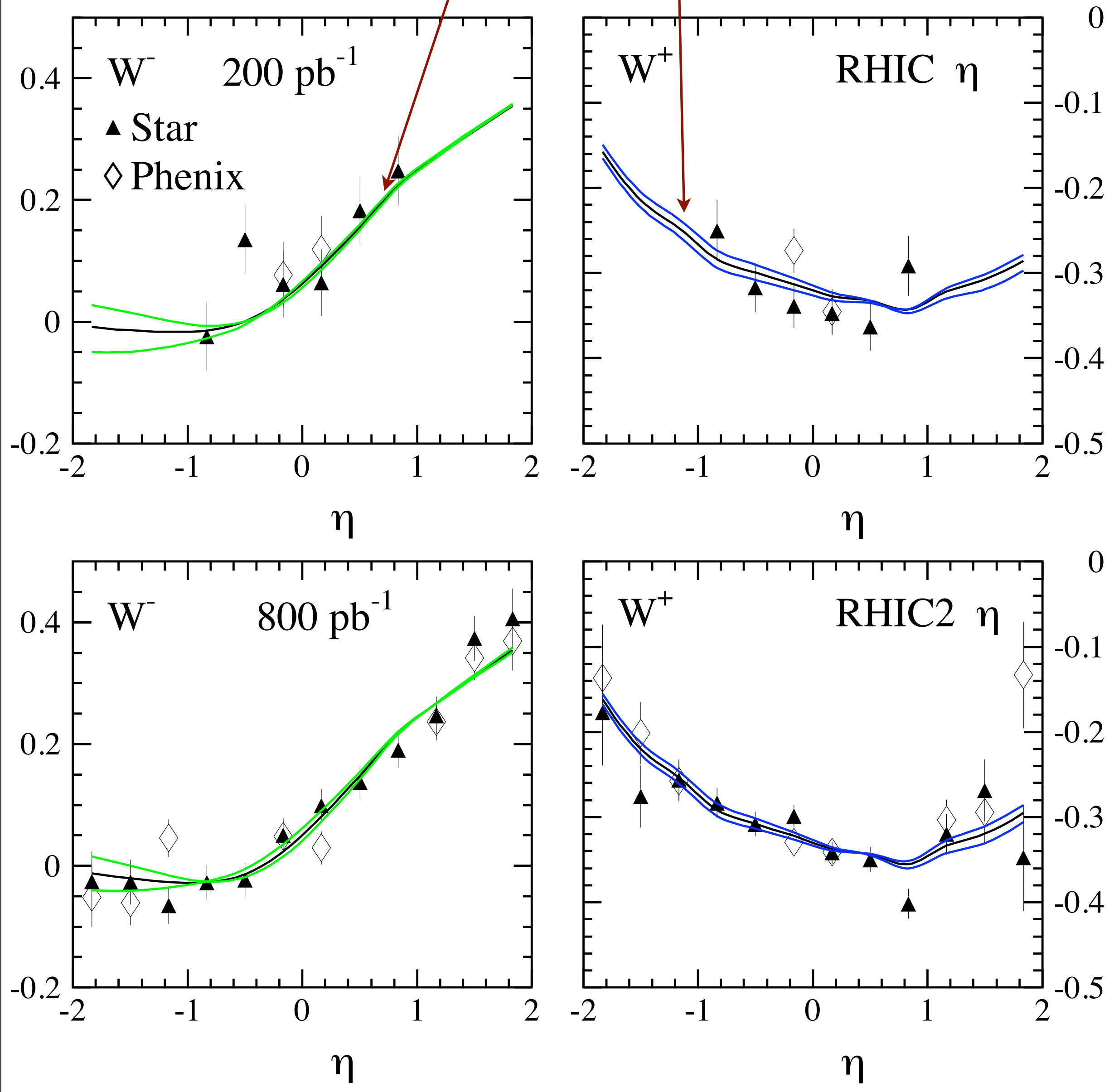


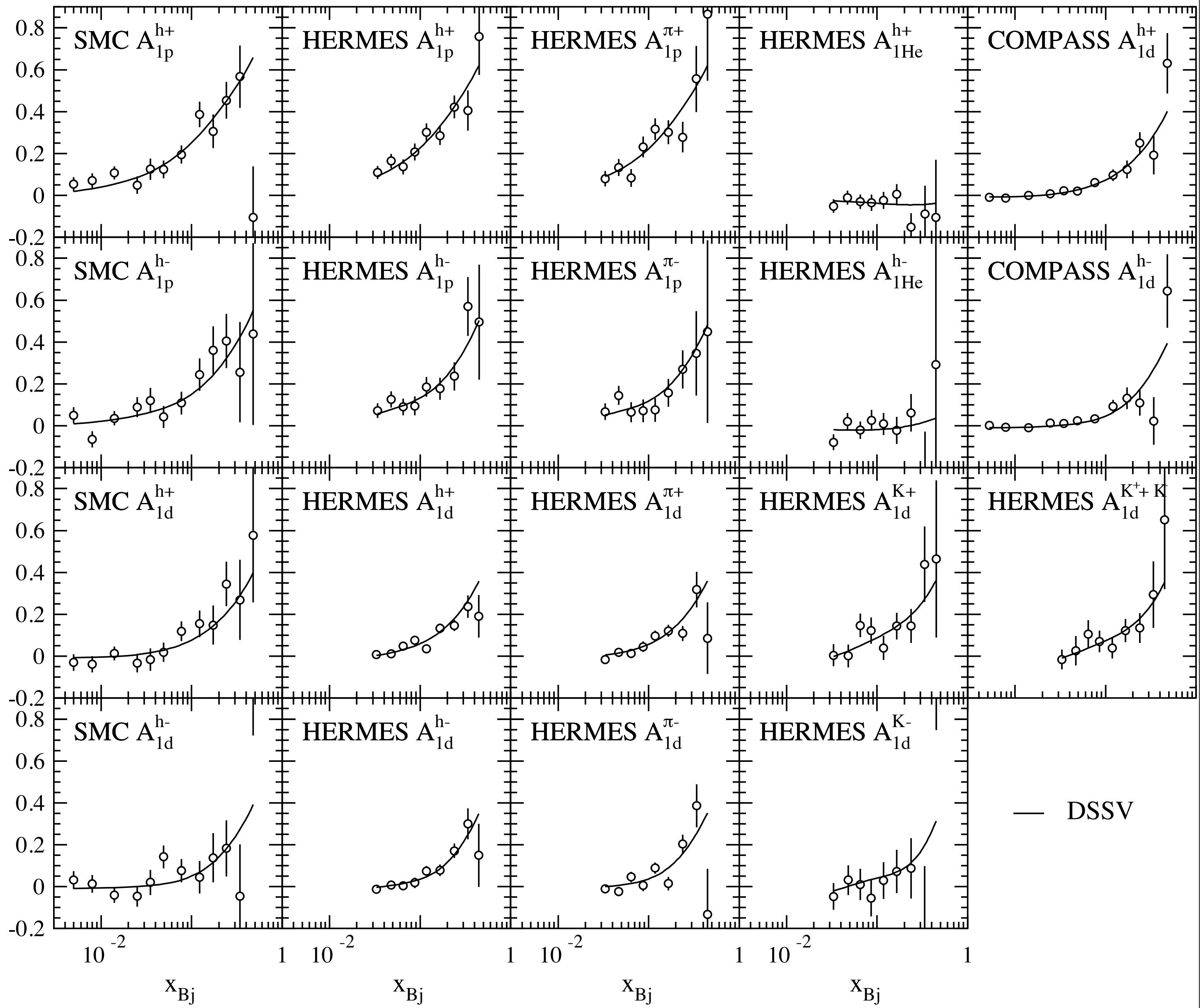
simulated data: rapidity more relevant than luminosity? Not likely with real data!

Effect of uncertainties on antiquark distributions over asymmetries

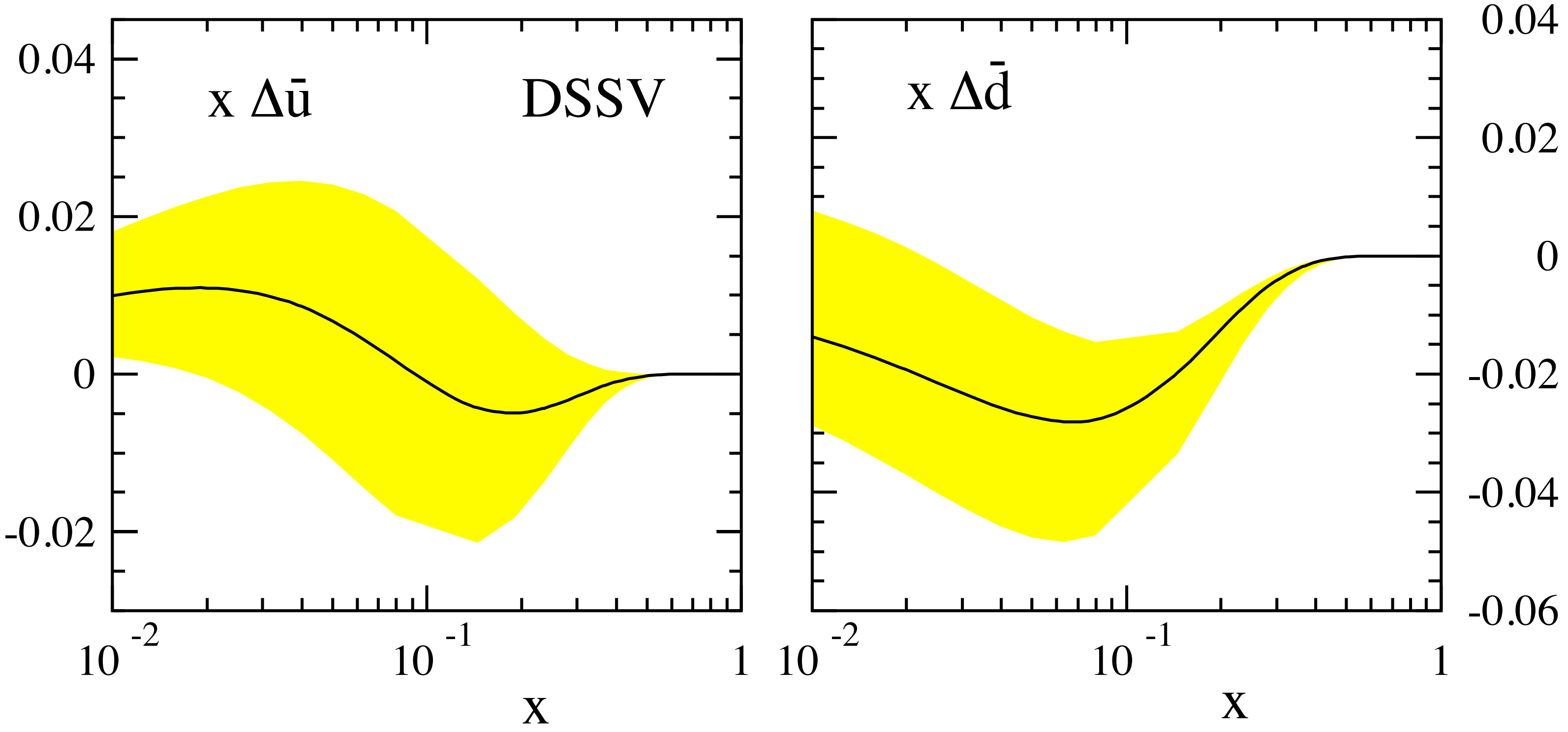
already pretty tight bands!   (partly from SIDIS)

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

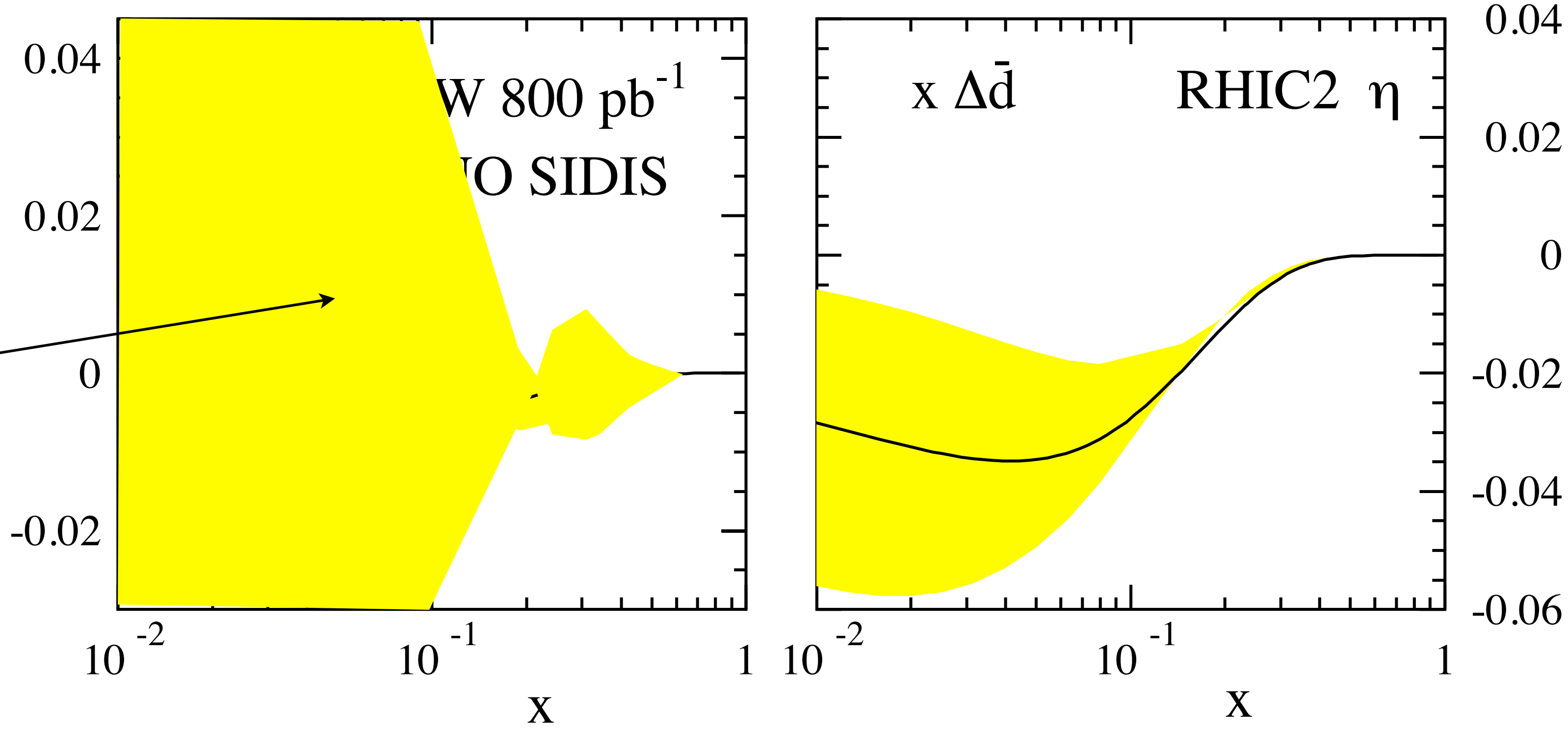




DSSV result
(no W)



Now without SIDIS: all from W's



RHIC with
200 pb^{-1}

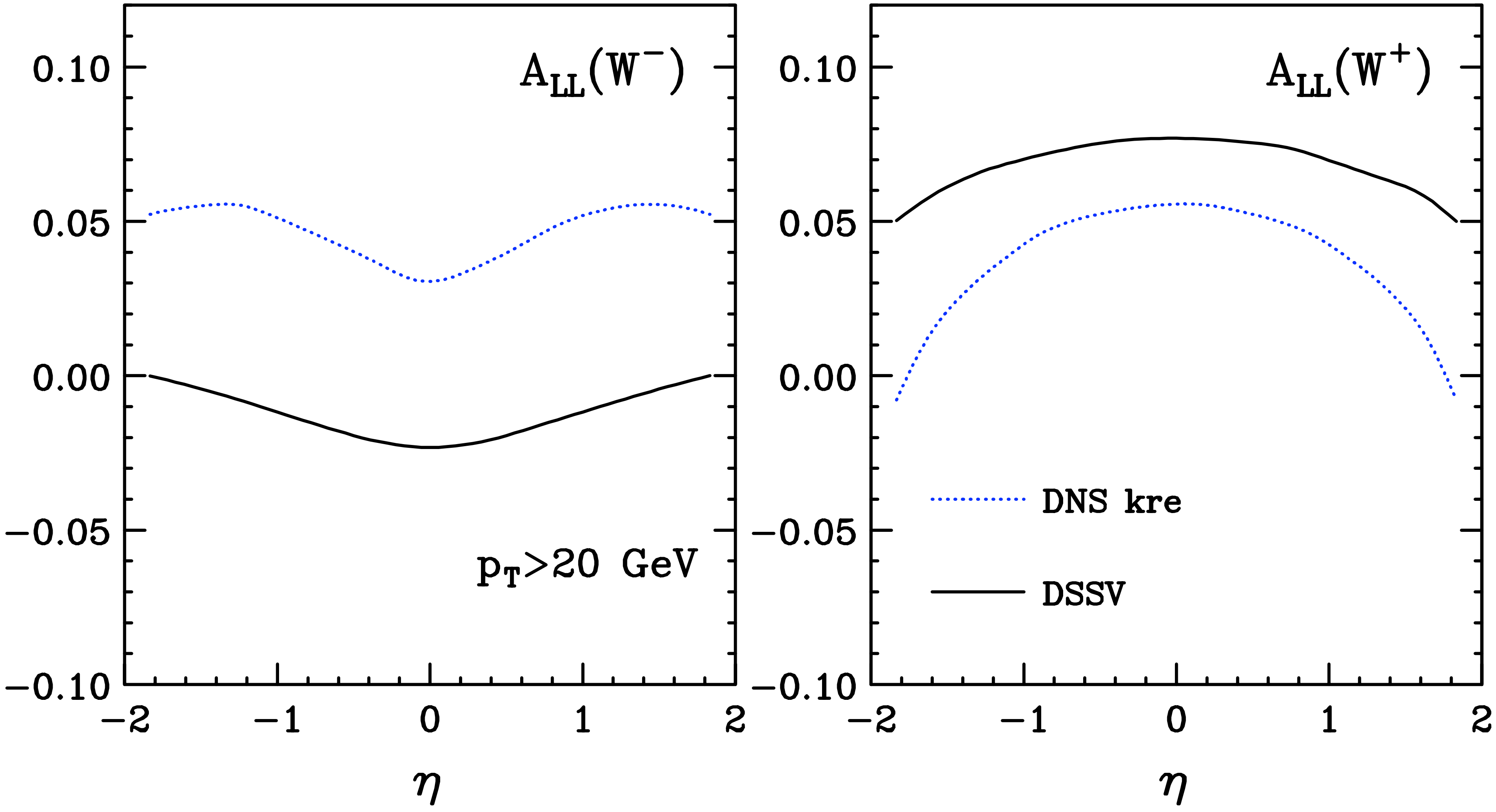
pretty good at x>0.07 but lack of resolution at smaller x

What about double spin asymmetries ?

$$A_{LL} = \frac{\sigma^{++} + \sigma^{--} - \sigma^{-+} - \sigma^{+-}}{\sigma^{++} + \sigma^{--} + \sigma^{-+} + \sigma^{+-}}$$

$$\frac{\Delta q_i}{q_i} \, \frac{\Delta \bar{q}_j}{\bar{q}_j}$$

smaller but different combination

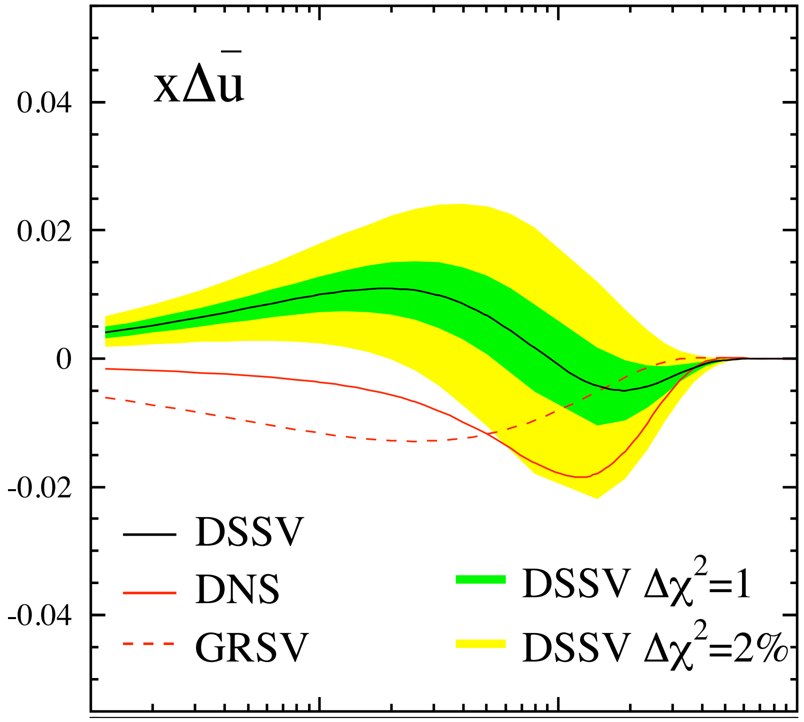


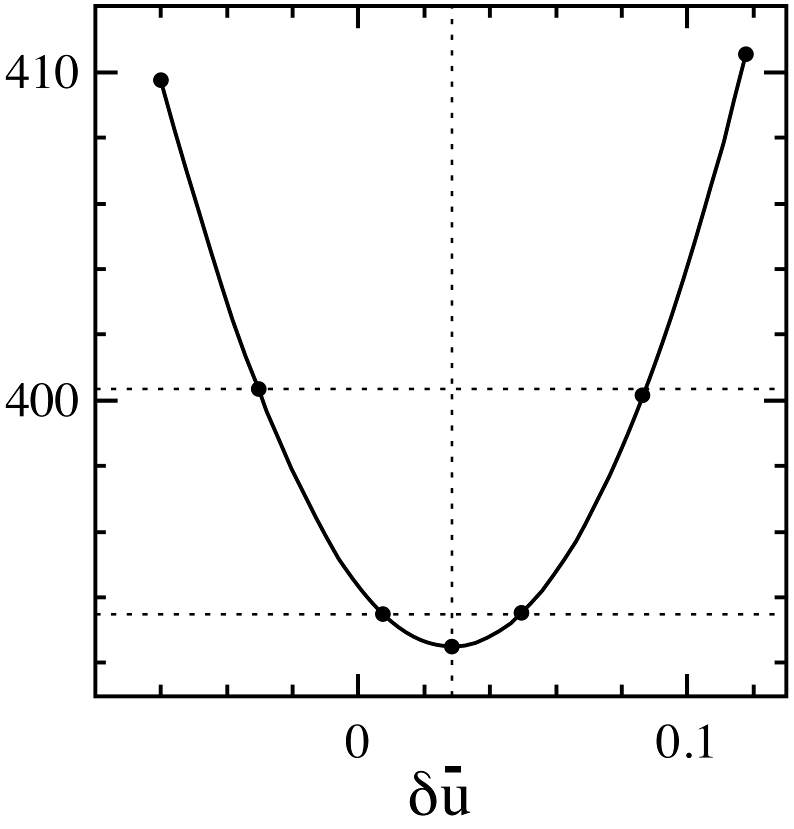
Summary (good news)

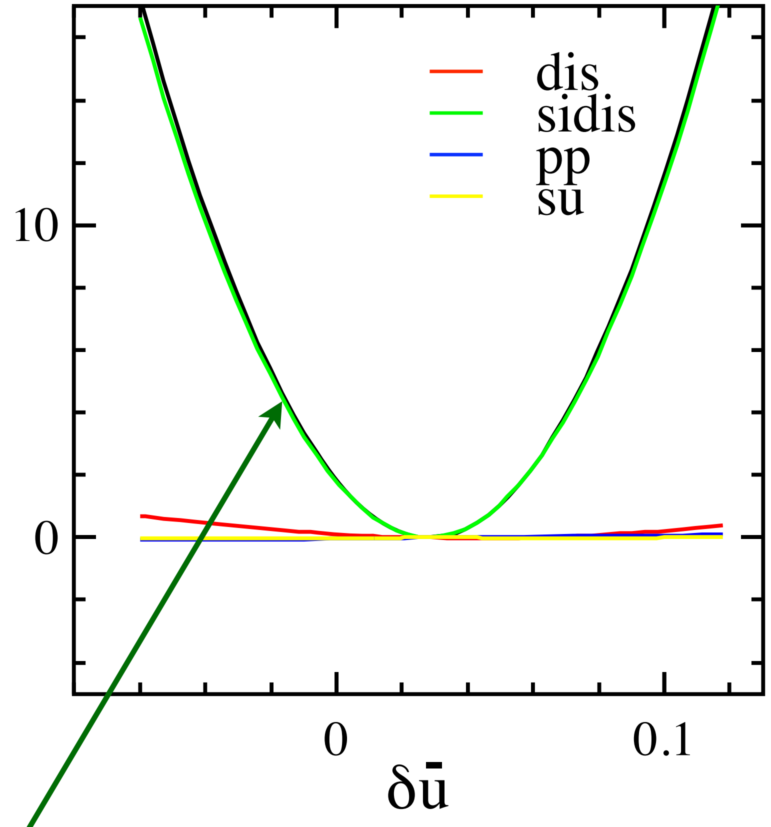
- ✓ Full NLO calculation for W asymmetries
- ✓ Includes Z/Gamma contribution
- ✓ Can be included in Global Fit (Mellin grids)
- ✓ First (realistic) analysis with 'simulated' data
- ✓ W asymmetries clearly help to constrain $\Delta\bar{u}$, $\Delta\bar{d}$

$x \gtrsim 0.05$

During next decade : Confront/Compete/Check/Replace
SIDIS ! (in some kinematical range)







sidis clearly dominates

charged hadrons dominance

pions agree