Parton-hadron duality and PDF fits

Alberto Accardi
Hampton U. and Jefferson Lab

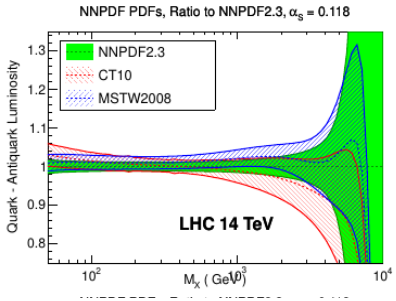
"Topical Meeting on Parton Hadron Duality"

University of Virginia, 13 March 2015

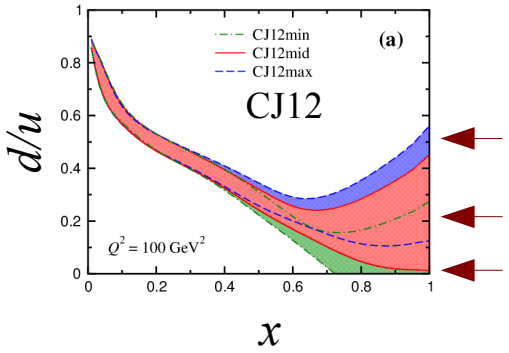
Why PDFs at large *x* ?

Accardi, Mod.Phys.Lett. A28(2013)35

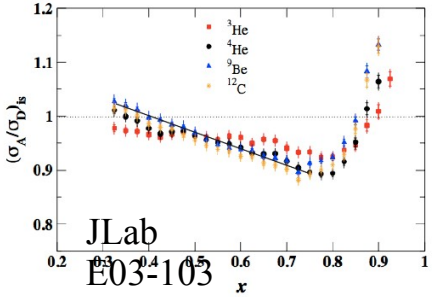
- **Reduce uncertainties**
  - Increase potential for LHC discoveries
  - Precision measurements of particle properties



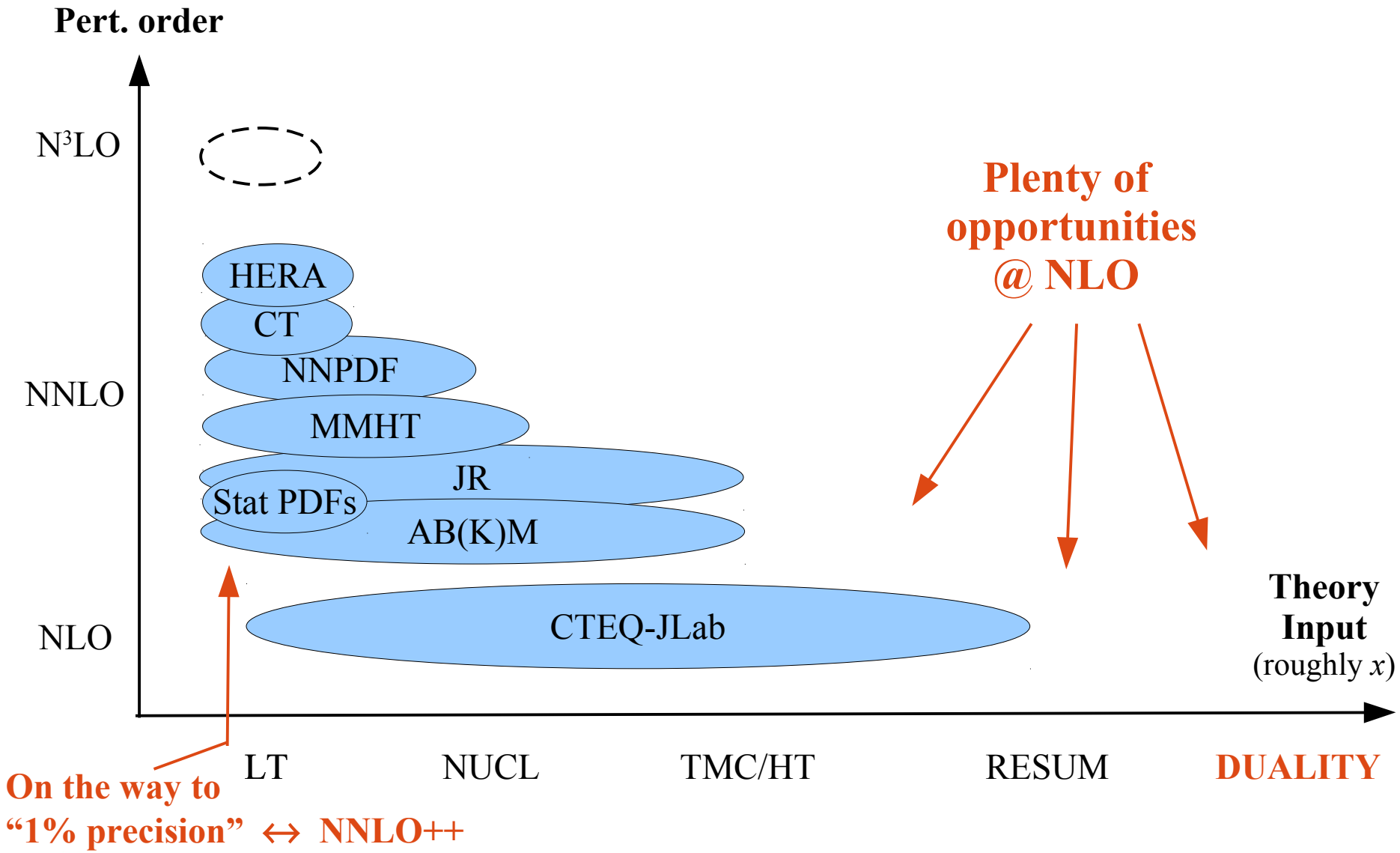
- **Non-perturbative structure of the proton**
  - Effects of confinement on valence quarks
  - q – qbar asymmetries; isospin symmetry violation
  - Strangeness, intrinsic charm
  - Comparison to (lattice) QCD, …



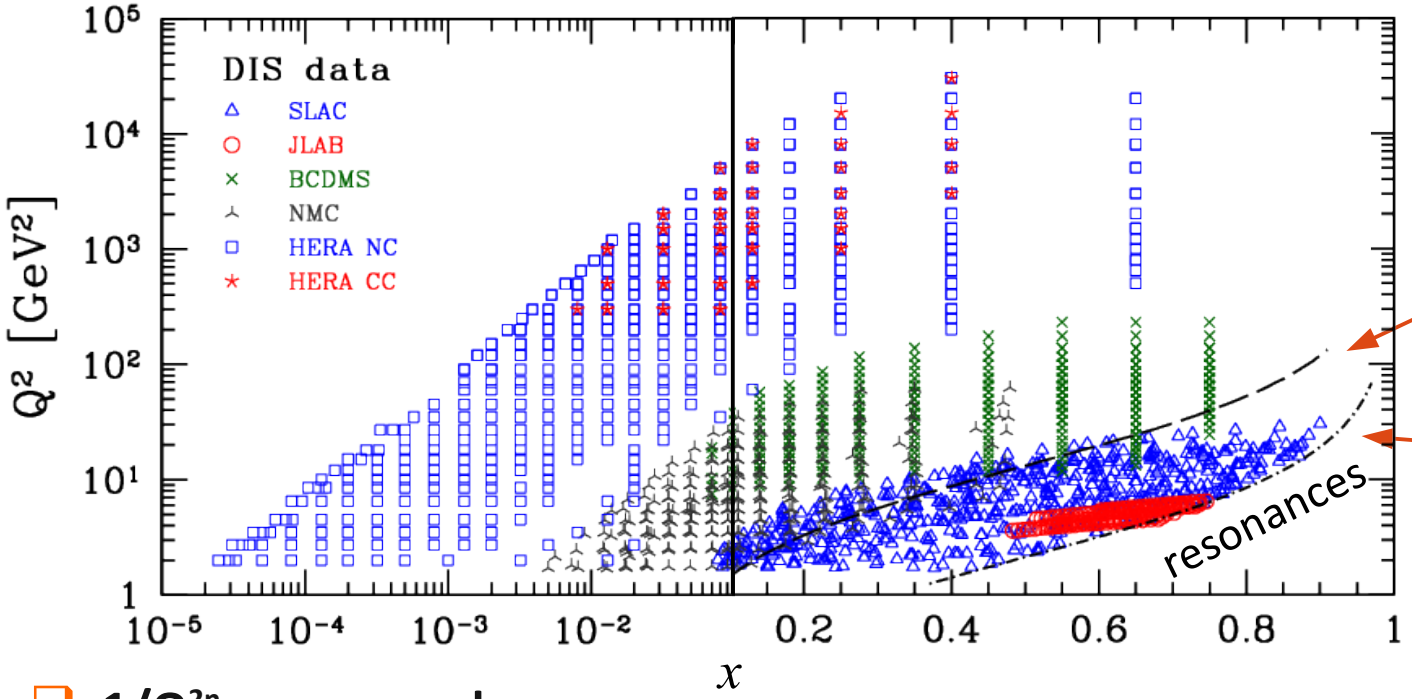
- **New handles on structure of the nucleus**
  - Nuclear targets for PDF fits (d-quark, neutrinos, ...)
  - Proton vs. nuclear targets
    → constraints on nuclear effects
  - A=1,2 anchor for nuclear PDFs / new light on EMC effect



A theory PDF landscape



Large-x, small-Q^2 corrections



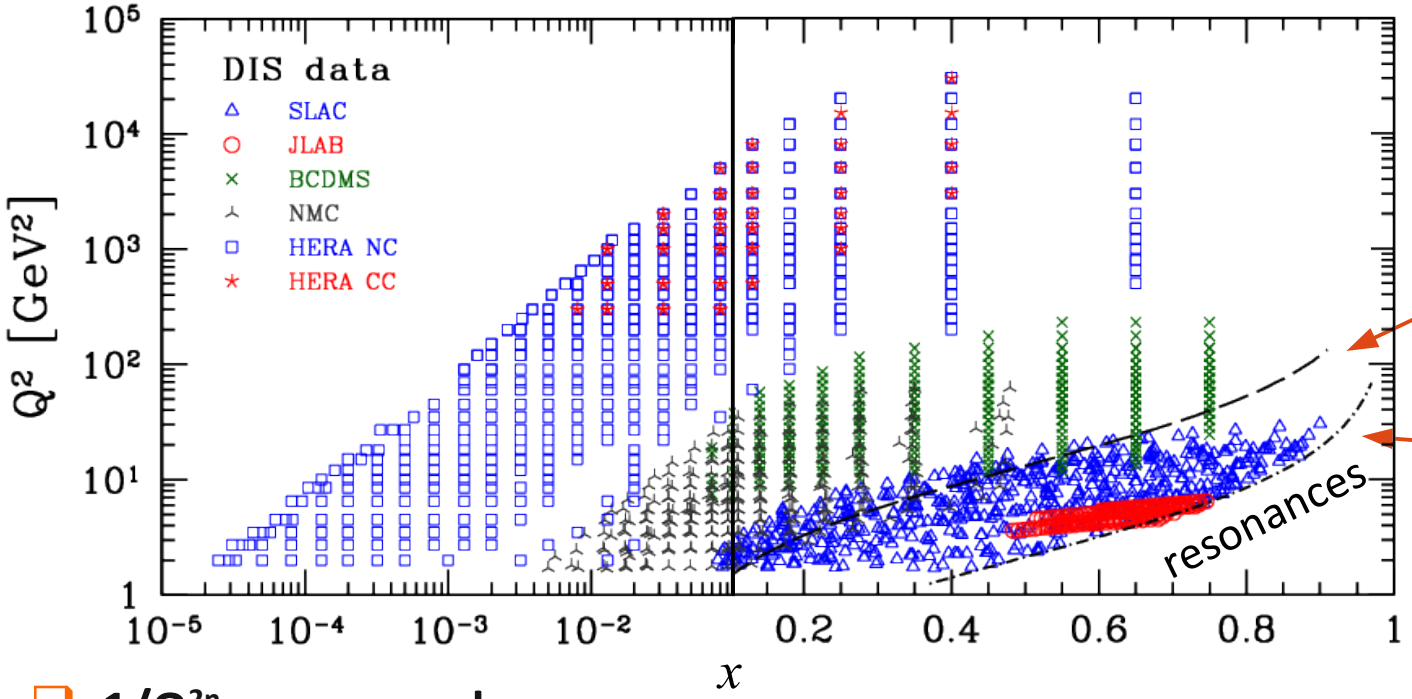
standard cut
$W^2 \gtrsim 14$ GeV^2

CJ12
$W^2 \gtrsim 3$ GeV^2

- **$1/Q^{2n}$ suppressed:**
  - Target mass corrections (TMC), higher-twists (HT)
  - Current jet mass, heavy quark masses
- **Non-suppressed**
  - Nuclear corrections, threshold resum., ...
- **New d-quark parametrization:** $d'(x) = d(x) + \alpha x^{\beta} u(x)$

Accardi et al.
*PRD **D81** (2010)*

Large-x, small-Q^2 corrections



standard cut
$W^2 \gtrsim 14$ GeV^2

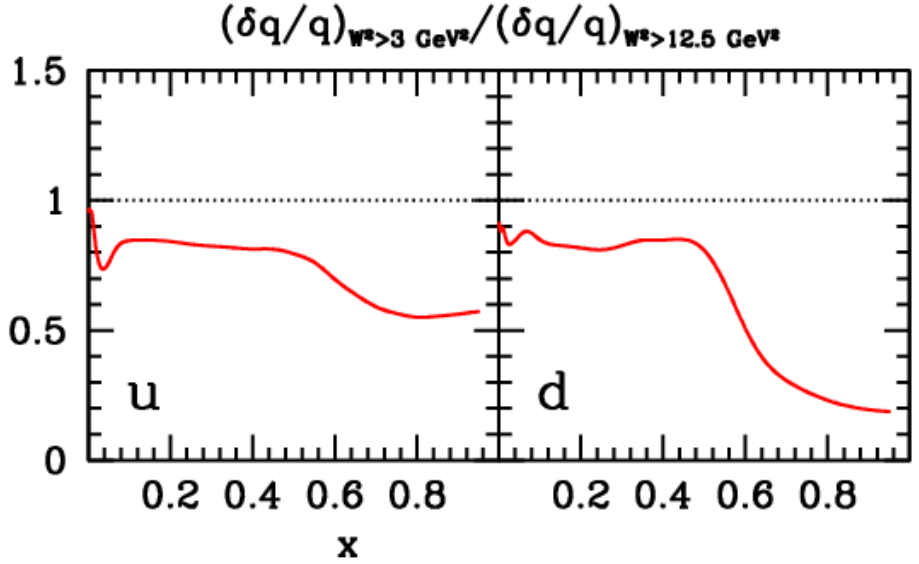
CJ12
$W^2 \gtrsim 3$ GeV^2

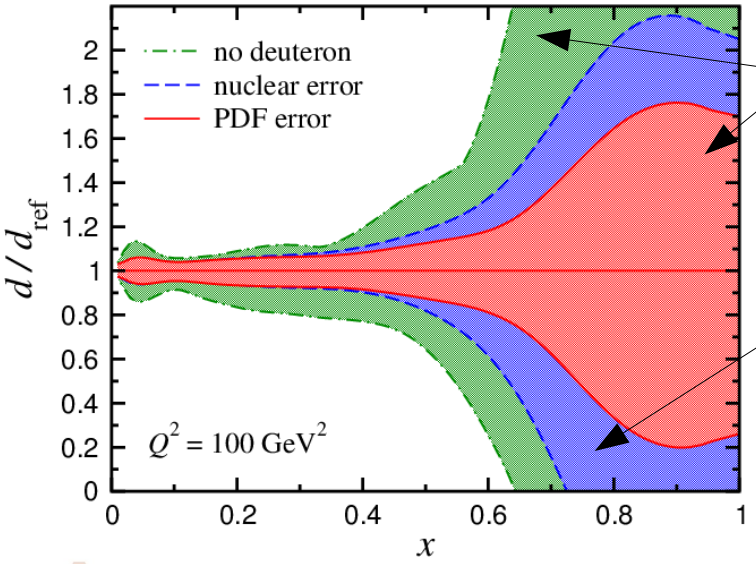
- **$1/Q^{2n}$ suppressed:**
  - Target mass corrections (TMC), higher-twists (HT)
  - Current jet mass, heavy quark masses
- **Non-suppressed**
  - Nuclear corrections, threshold resum., ...
- **New d-quark parametrization:** $d'(x) = d(x) + \alpha x^{\beta} u(x)$

Accardi et al.
PRD ***D81*** *(2010)*

included in CJ12 fits

CJ12 - statistical improvement



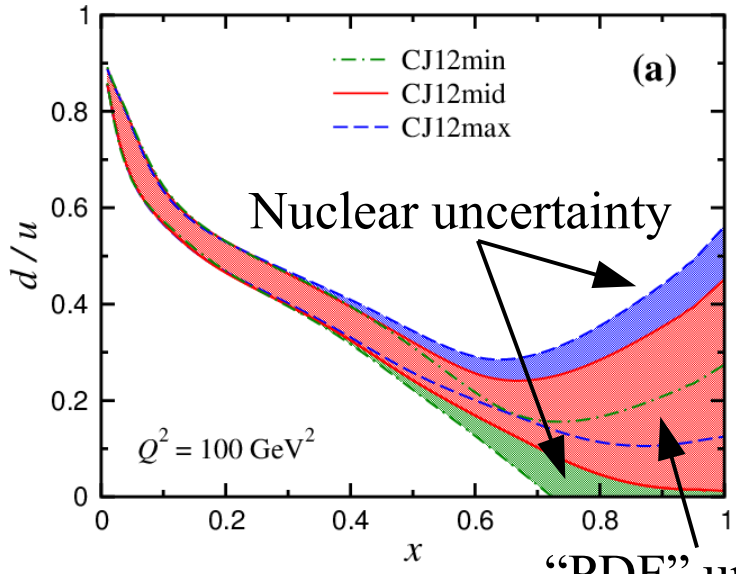


Largely reduced PDF errors
(increased statistics)

Nuclear uncertainties (systematic):
- choice of nuclear w.fn.
- size, type of off-shell correction

Large-x d/u quark ratio: state-of-the-art

Owens, Accardi, Melnitchouk, PRD87 (2013) 094012



Non-perturbative proton models

SU(6) spin-flavor

hard gluon exchange

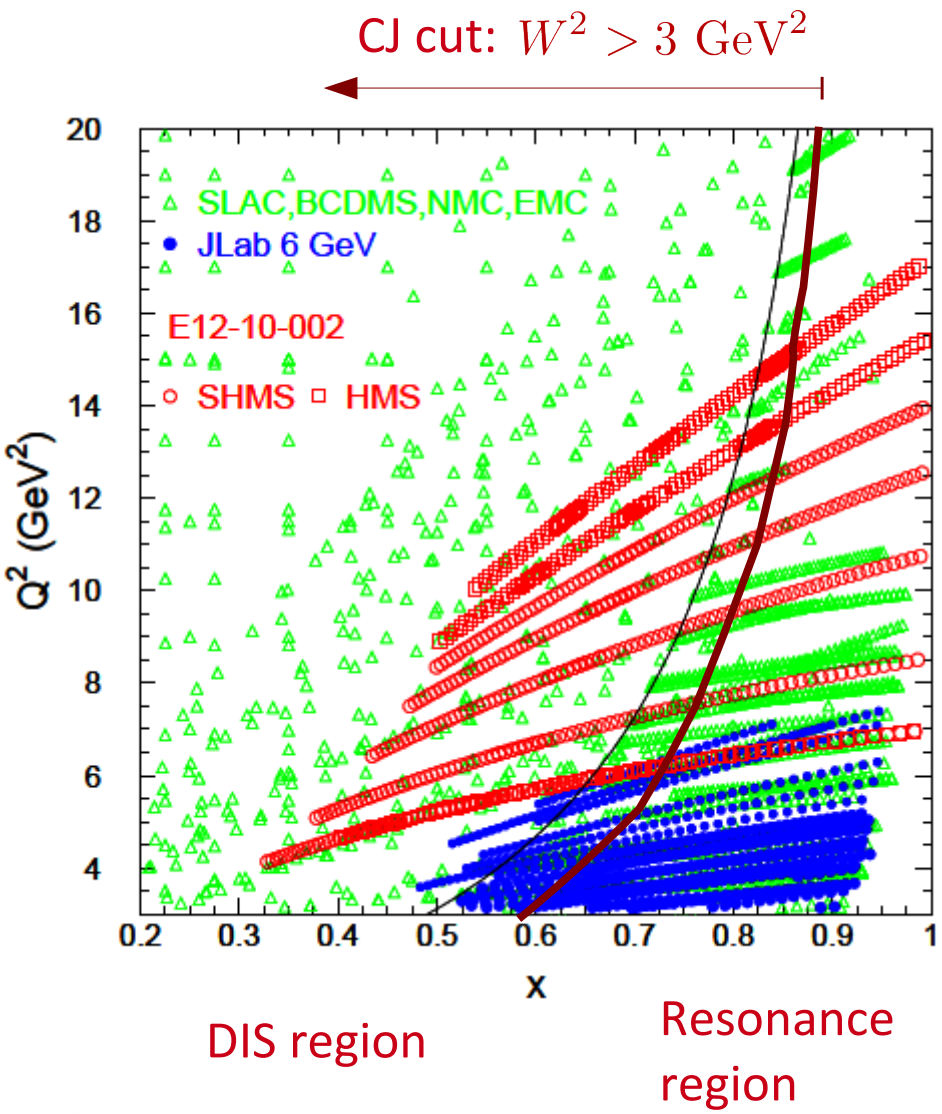
S=0 diquark dominance

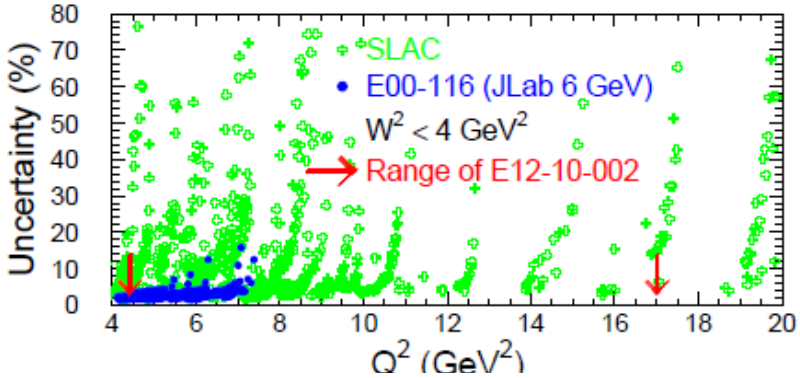
"PDF" uncertainty

- **Need to reduce uncertainties**
  - **Nuclear**: constraints from proton targets (*W* in p+p, PVDIS, ...)
    - weak interactions on *protons* (→ nuclear free *d*-quark) *vs.* DIS on *deuterons* (→ nuclear model dependent *d*-quark)
  - **Statistical:** more data!

Resonance region data

Jlab12 experiment E12-10-002





- **JLab 12 GeV**
  - More than double Q^2 range
  - Similar precision as JLab **6 GeV** (largely improve cf. **SLAC**)

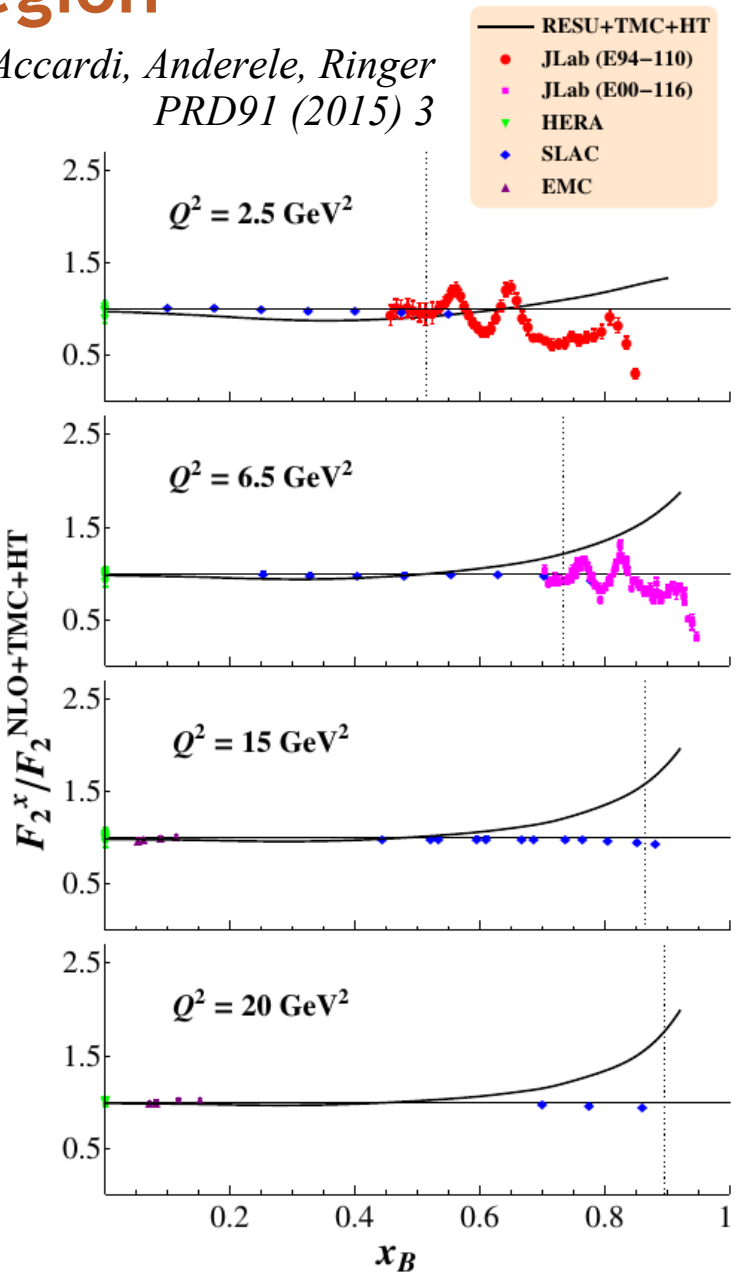
- **How to use these in PDF fits?**
  - Huge χ^2
  - Would drown rest of dataset

Confronting the resonance region

- **Data vs. CJ12 fits**
  - **Points**:
    bin-centered data / NLO theory
    - OK except Δ
  - **Lines**:
    NLO+resummation / NLO theory
    - Large effect also in DIS region

- **How to use these in PDF fits?**
  - Huge χ^2
  - Would drown rest of dataset

Accardi, Anderele, Ringer
PRD91 (2015) 3



Confronting the resonance region*

- **Truncated moments**

  (at fixed angle)

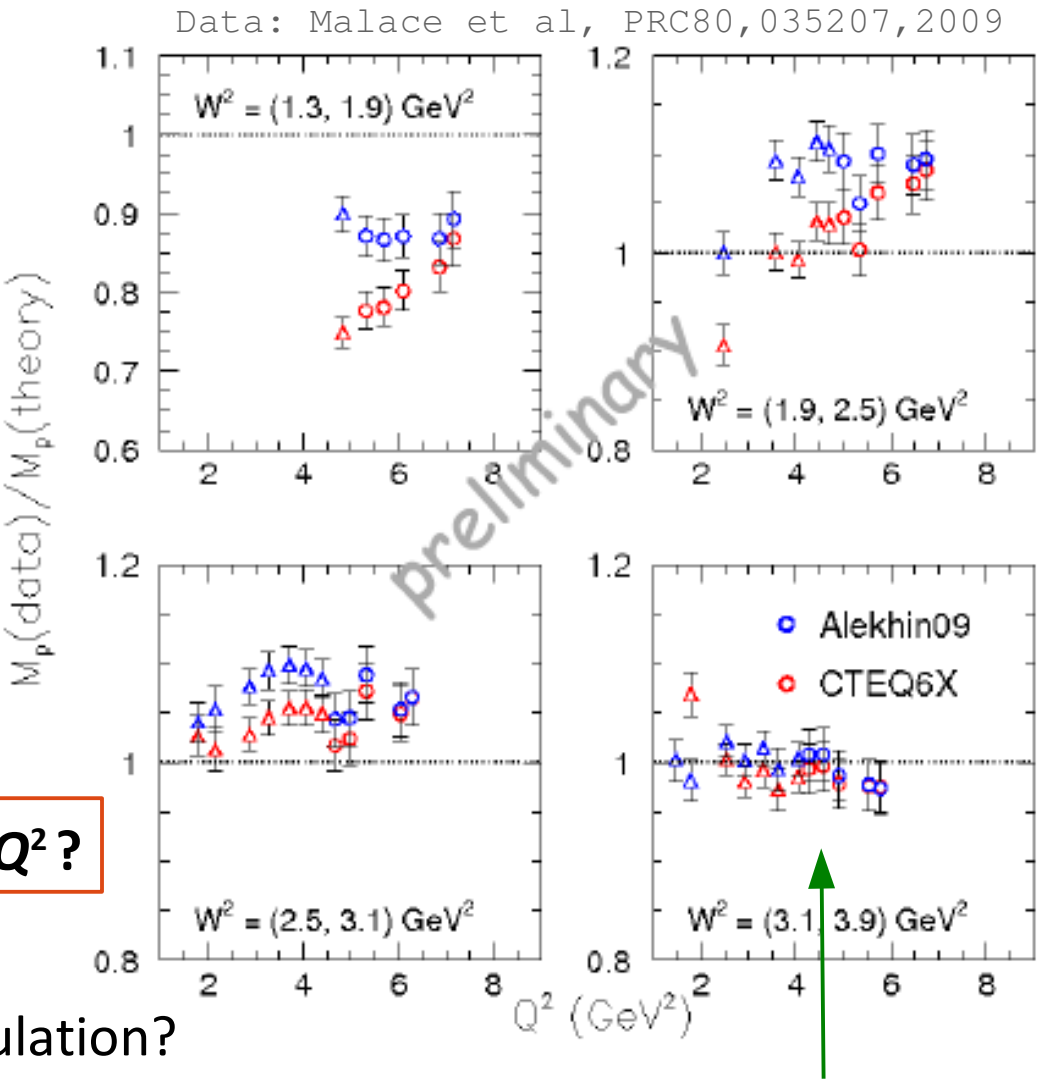
$$M = \int_{W=[W_m, W_M]} dx\, F_2(x, Q^2(x,\theta))$$

  - Within 5-10% of (extrapolated) DIS theory

- Question 1

Should moments be at fixed Q^2 ?

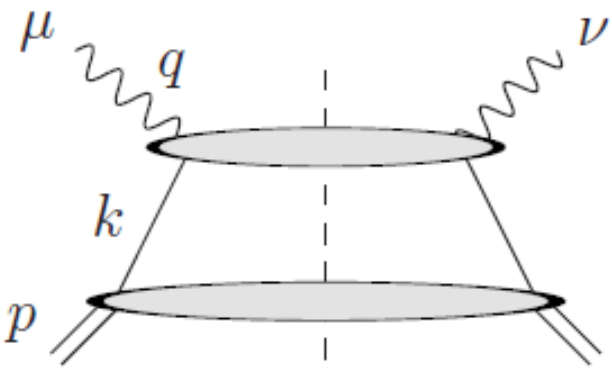
  - Or is it enough to match calculation to data manipulation?

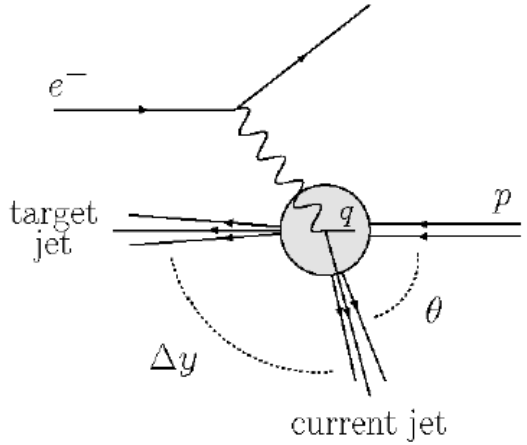


* *in collaboration with Simona Malace – see arXiv:1101.5148*

Confronting the resonance region*

- But: **where can we expect the handbag diagram to be valid ?**





- Current and jet separation in rapidity $y = \frac{1}{2} \ln p_h^+ / p_h^-$ with LO kinematics,

$$\Delta y \approx y_q - y_p = \log \frac{2\sqrt{2}\nu}{Q} \frac{1}{\sqrt{1 - Q^2/(2MxE)}}$$

- Berger criterion: $\Delta y > 2 \ (4)$ [Berger, ANL-HEP-CP-87-045, 1987; Mulders, hep-ph/0010199]

* *in collaboration with Simona Malace – see arXiv:1101.5148*

Confronting the resonance region*

- **Truncated moments**

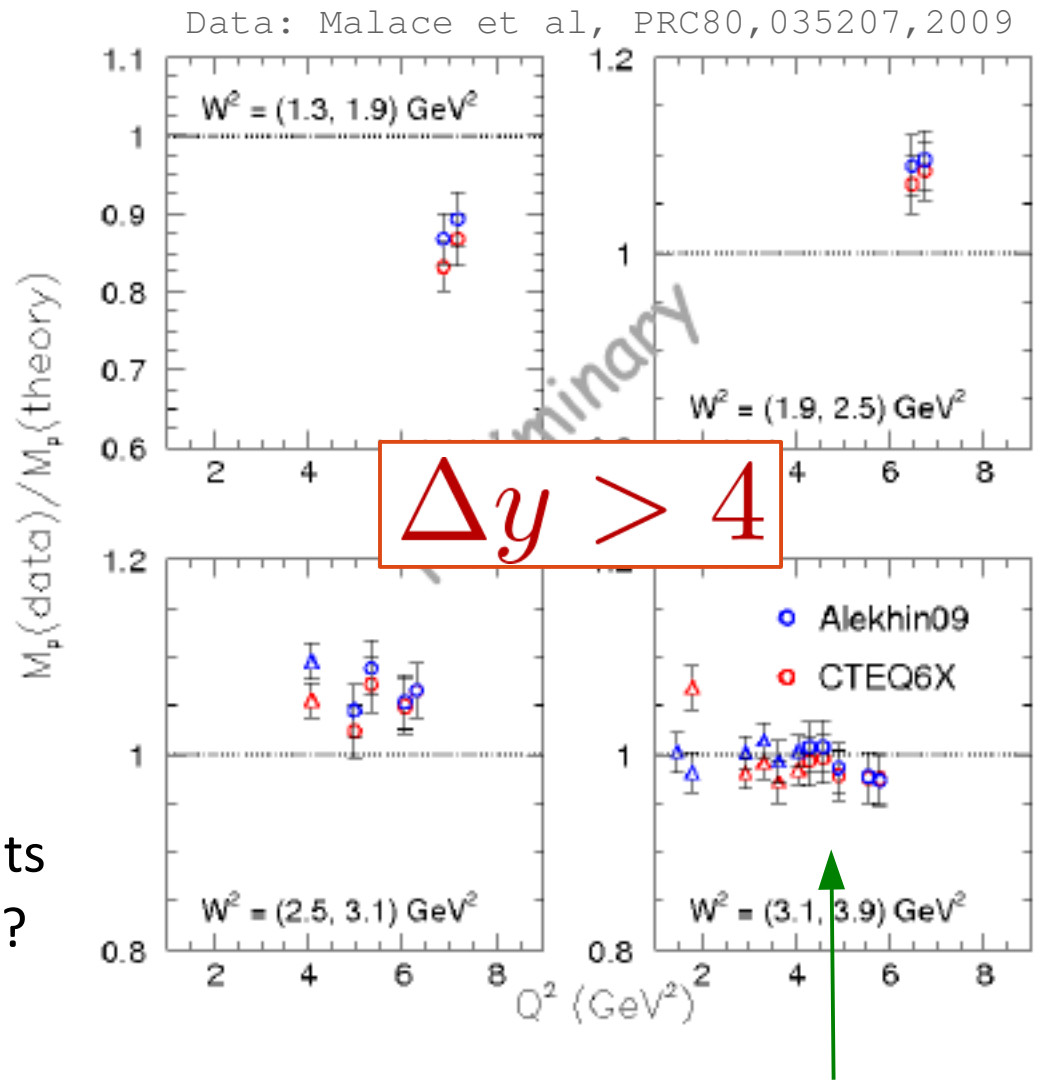
  (at fixed angle)

$$M = \int_{W=[W_m, W_M]} dx\, F_2(x, Q^2(x,\theta))$$

- Question 2:

How far can we go in the resonance region?

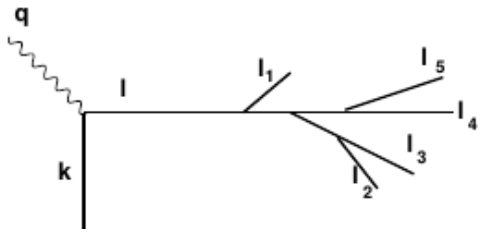
  - Can we trust the few points in the Δ resonance region?
  - Can we relax the Δy cut?



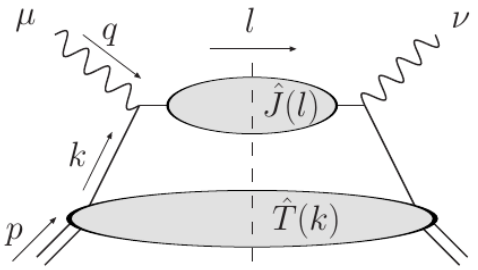
* *in collaboration with Simona Malace – see arXiv:1101.5148*

Let's go non-perturbative

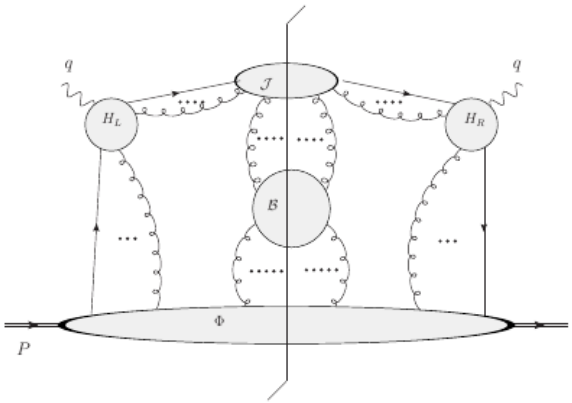
- **Soft-gluon resummation** *Catani et al., '90s*
  - pQCD treatment of large *log(1-x)*
  - *Pushes perturbative calculations*



- **Collinear Jet functions** *Accardi and Qiu, 2008*
  - *Can be seen as non-perturbative extension of soft-gluon emission*



- **Bridging the rapidity gap**
  - Need to account for soft interactions
  - Soft factors? *Collins, Rogers, Stasto, 2008*
    (TMD / fully unintegrated factorization)



Conclusions

Conclusions

- **Parton-hadron duality seems pervasive**
  - proton & neutron
  - Polarized & unpolarized
  - PVDIS, ...

- **How can we use it to constrain PDF at large *x* ?**
  - Need suitable “duality averaging procedures”
  - Truncated moments?
    - OK at fixed theta, or need fixed Q ?

- **How far can we push the handbag diagram?**
  - Berger criterion
  - Is soft gluon resummation enough?
  - Go nonperturbative: jet functions, soft factors?

Appendix:
HEP ↔ Nucl symbiosis

Impact on new physics searches

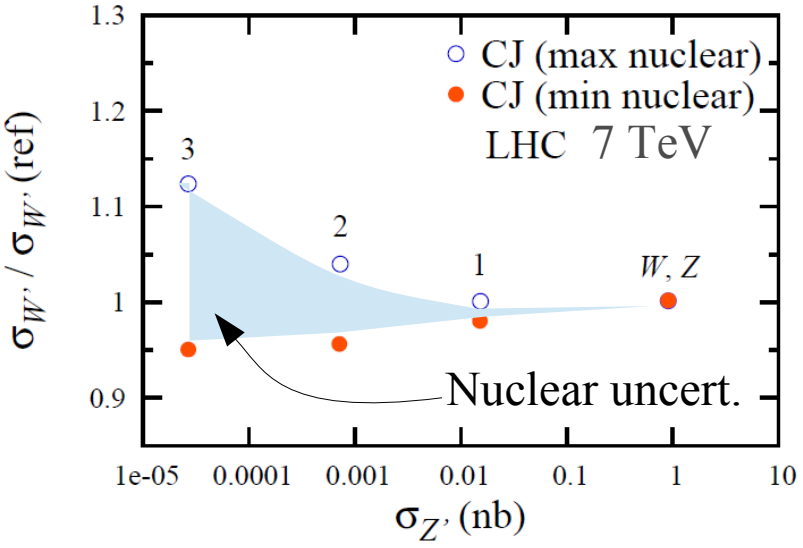
Accardi, Mod.Phys.Lett. A28(2013)35

Brady, A.A., Melnitchouk, Owens, JHEP 1206 (2012) 019

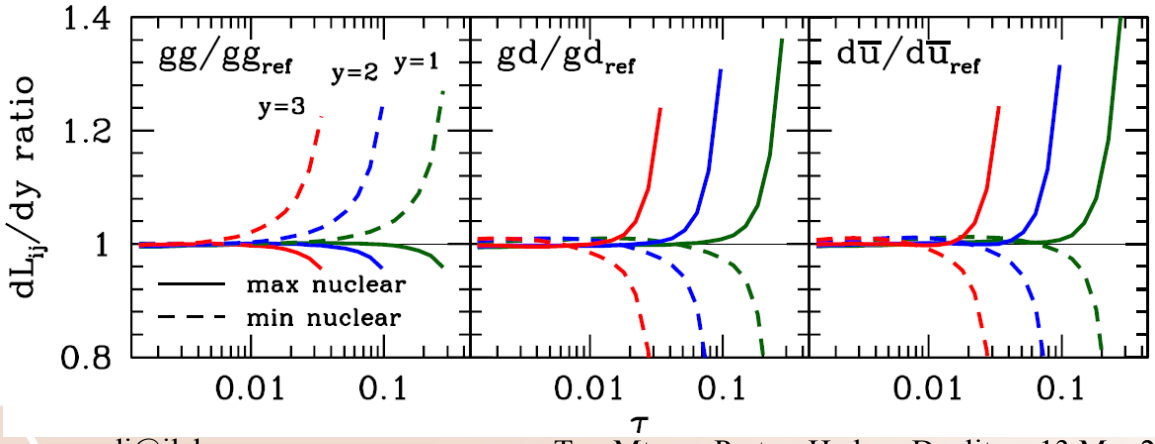
- **Large mass / forward physics**
  - Kaluza-Klein, $M > 1.5$ TeV, $M_n = n\, M_1$
  - Excited quarks, $M > 3.5$ TeV
  - Contact interactions, $M > 8$ TeV
  - Z+jets at large y
  - LHCb, ...

$$x = \frac{M}{\sqrt{s}} e^{y}$$

W' and Z' total cross sections



Differential parton luminosities



Need to constrain the nuclear corrections

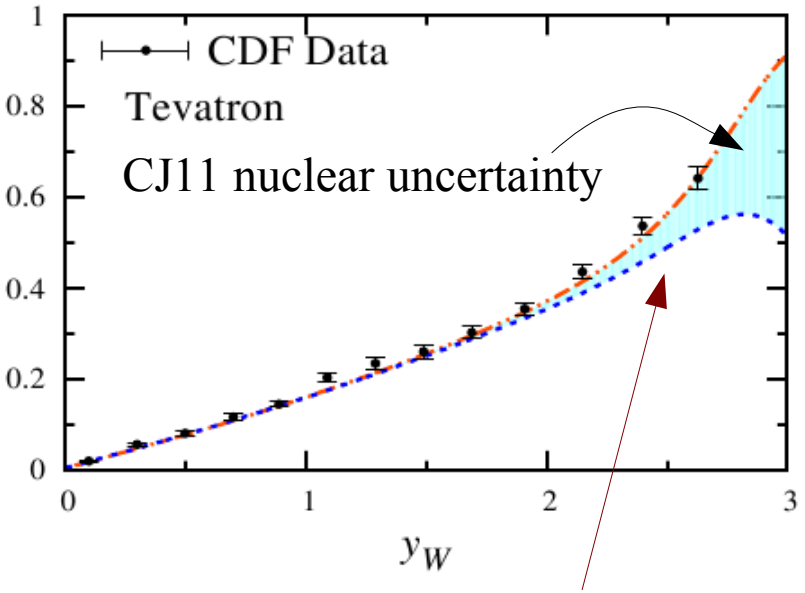
Use protons to study nuclei (!)

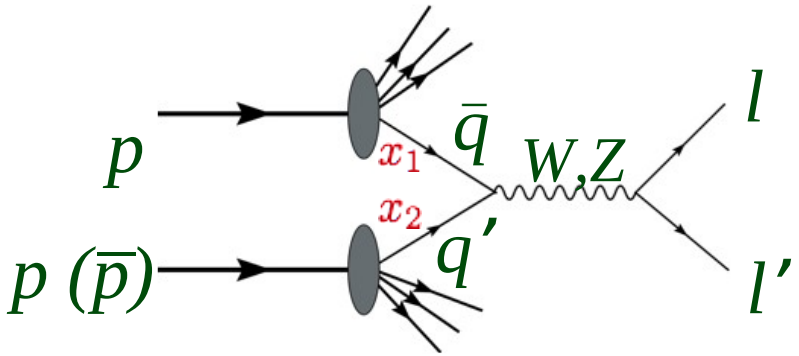
Accardi, Mod.Phys.Lett. A28(2013)35

Brady, A.A., Melnitchouk, Owens, JHEP 1206 (2012) 019

Directly reconstructed W:

- highest sensitivity to large *x*





$$A_W(y) = \frac{\sigma_(W^+) - \sigma_(W^-)}{\sigma_(W^+) + \sigma_(W^-)} \approx \frac{d/u(x_2) - d/u(x_1)}{d/u(x_2) + d/u(x_1)}$$

sensitive to *d* at high *x* → Can constrain Deuteron models!

- Preliminary indications of "small" to "medium" nuclear corrections

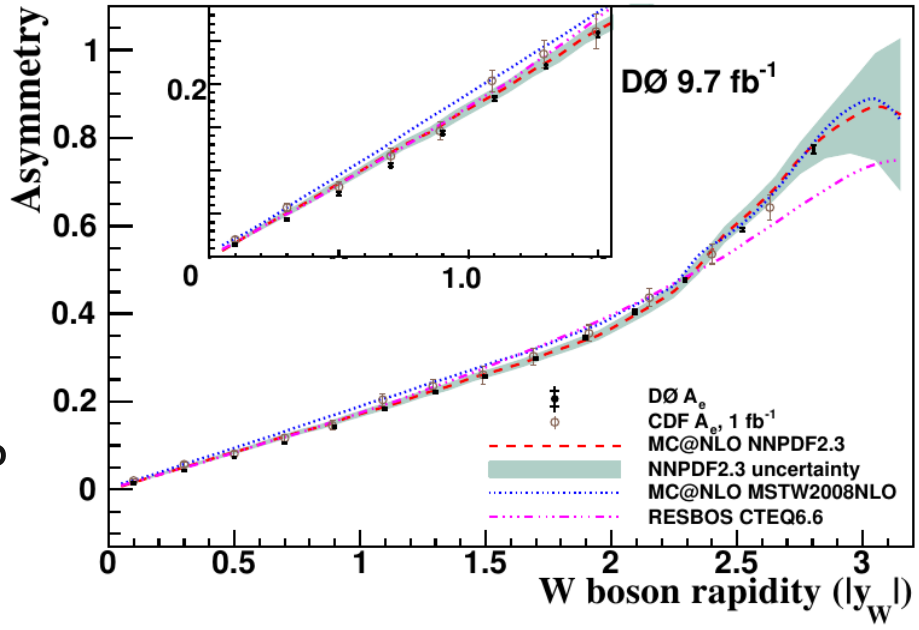
A.A., Owens, Menitchouk, PRD87 (2013); MMSTWW, EPJ C73 (2013)

Use protons to study nuclei (!)

Accardi, Mod.Phys.Lett. A28(2013)35

- New D0 data, 10 x statistics, large y_W coverage
  - Will likely fix:
    - size of nucl. Effects
    - Nuclear w.fn.
  - Let's be bold:
    - Shape??
    - Born approx / final st. int's?

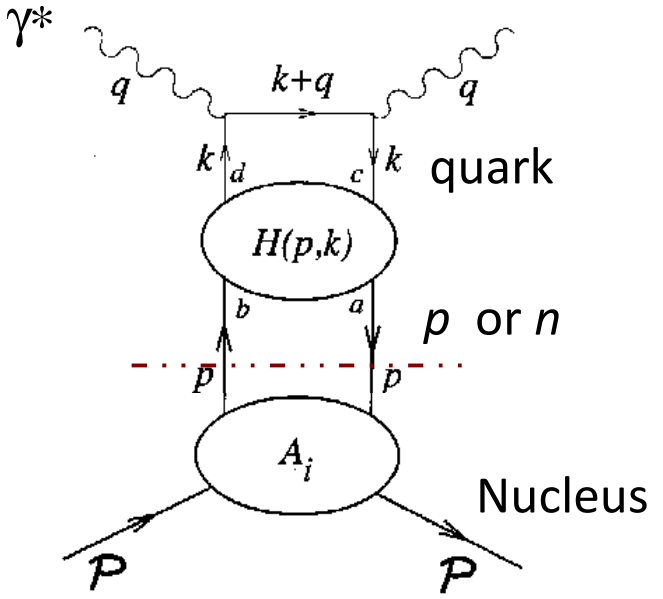
D0 coll. arXiv:1312.2895



- Needs to corroborate, consider PDF errors, extend method:
  - ***W, Z* at RHIC**, *Z* (*W*?) at LHC,
  - **BONUS**, MARATHON , PVDIS at JLab 6/12
  - CC @ EIC / LHeC

Two complementary strategies

- **CJ: Nuclear modeling**
  - ✔ Connects to underlying nuclear theory
  - ✔ Can reject models → verify assumptions
  - ✔ Extendible to other processes, e.g., DY(d)
  - ✘ How to explore the model space?
    - Continuous vs. discrete parameters
  - ✘ Limited to shapes provided by models

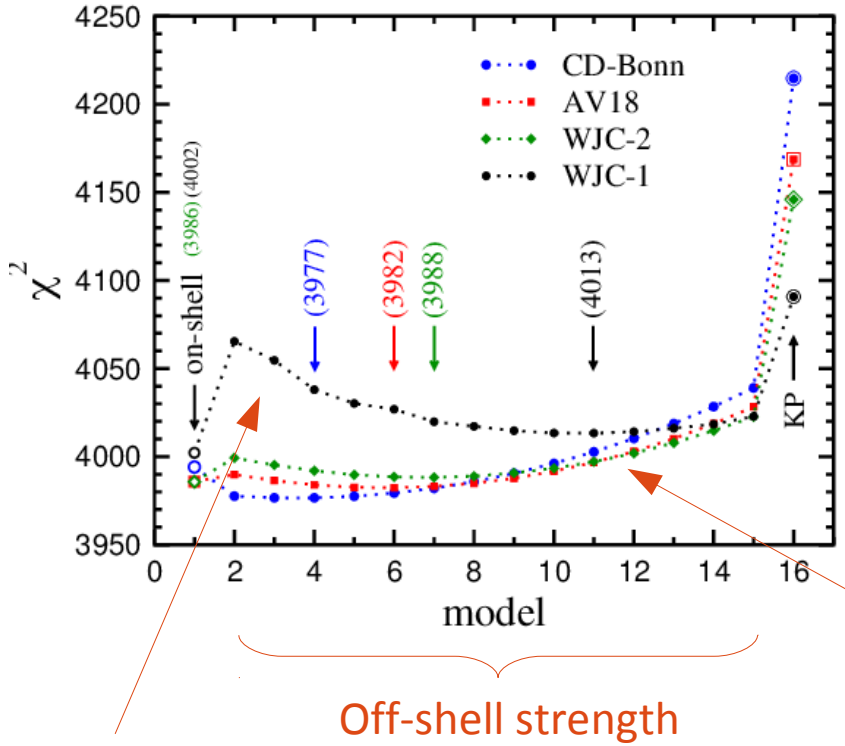


Low-energy factorization issues

- Renorm. of nucl. operators, gauge inv., FSI, ...

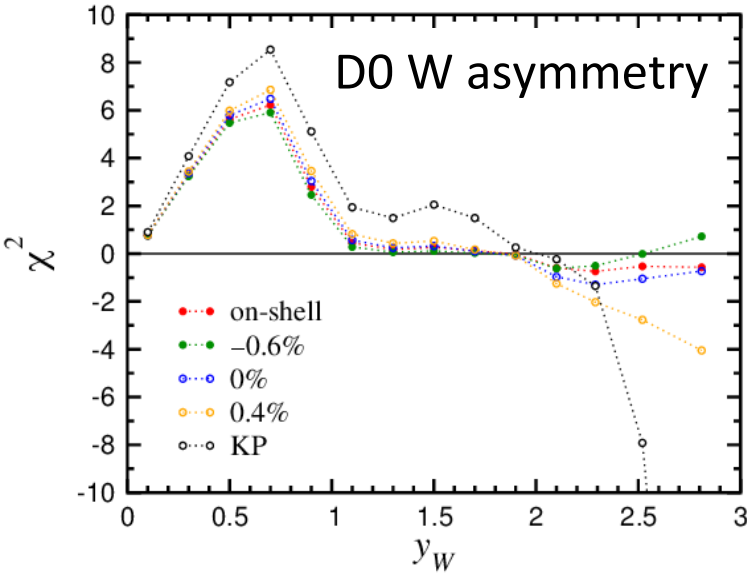
- **MMHT: parmetrize D/(p+n) ratio**
  - ✔ Nuclear uncertainty straightforward
  - ✔ No "model bias" (is parametrization flexible enough? Theory is Q^2 dependent)
  - ✘ Limited nuclear physics output
  - ✘ Cannot be extended to nDY, ...

Very preliminary analysis - χ^2

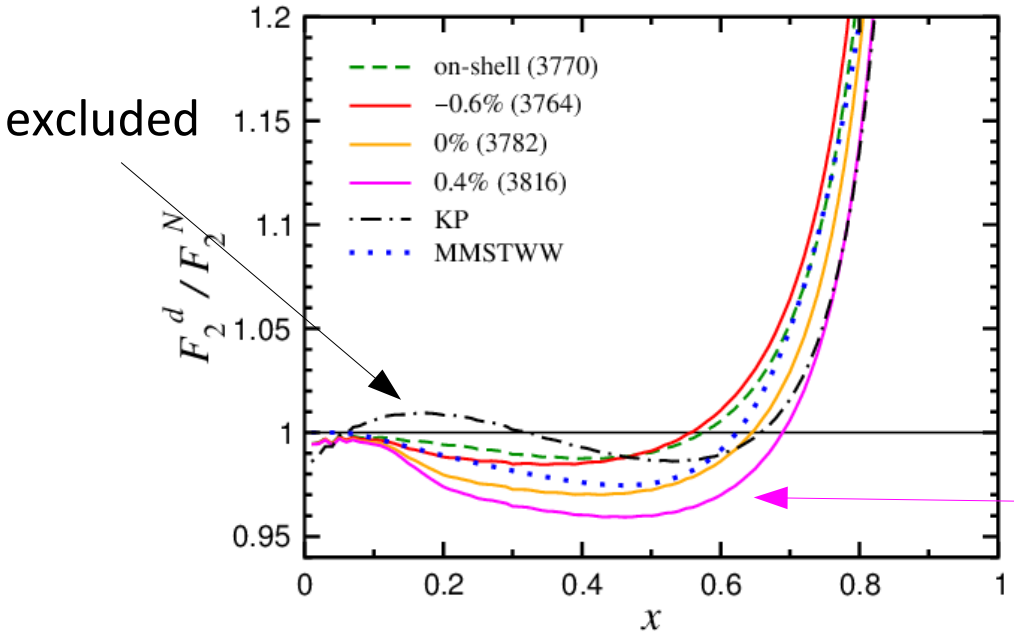


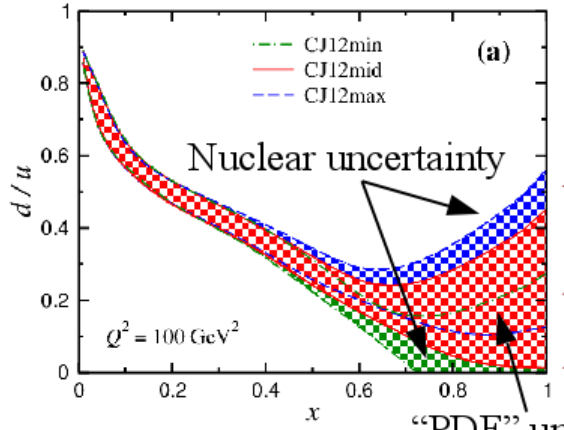
Off-shell strength

SLAC deuteron



Very preliminary analysis – nuclear corrections





Non-perturbative proton models

SU(6) spin-flavor

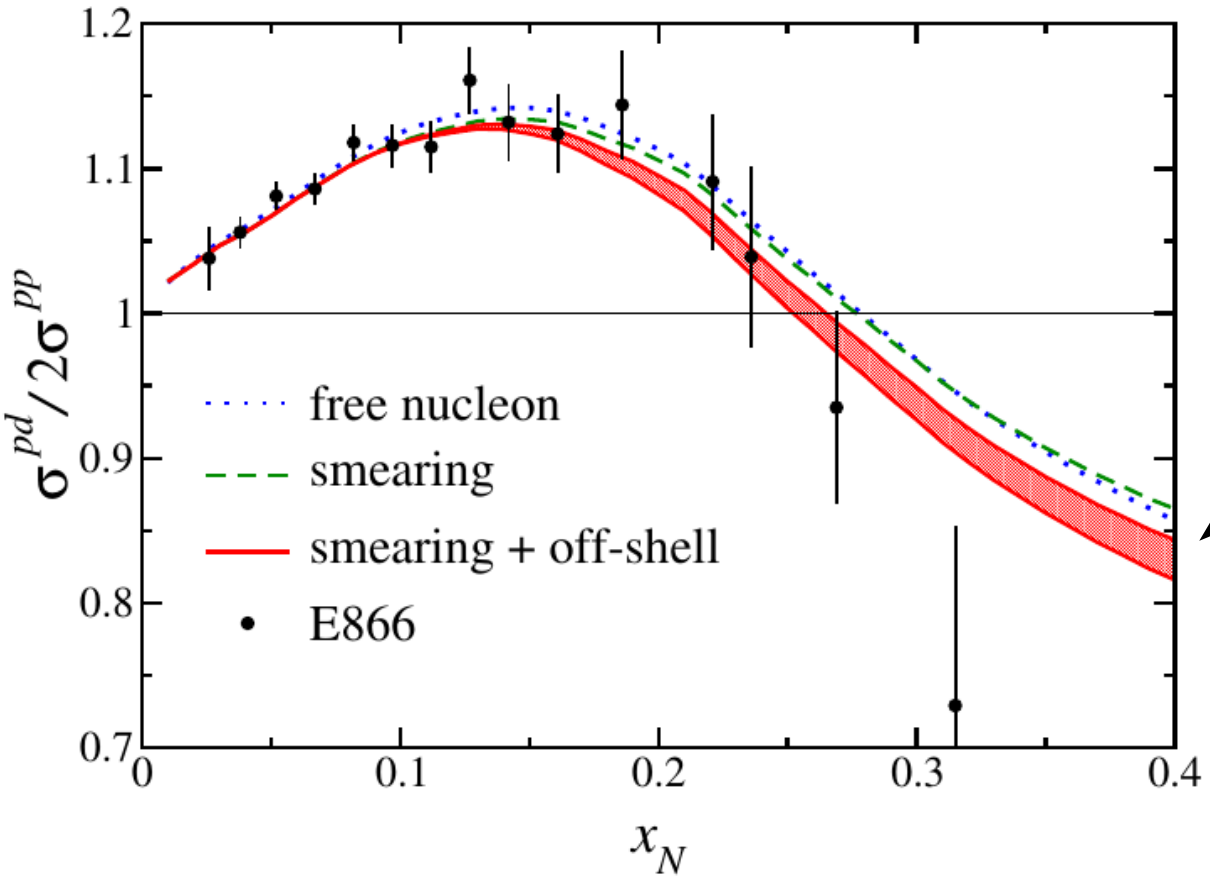
hard gluon exchange

S=0 diquark dominance

favored

Nuclear corrections…

Ehlers, AA, Brady, Melnitchouk, PRD90 (2014)

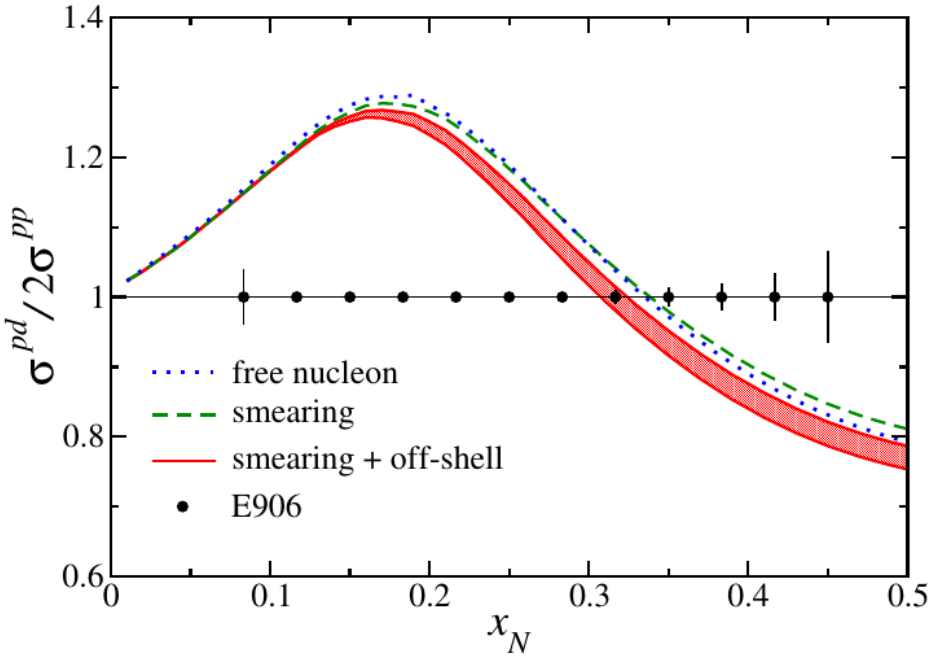


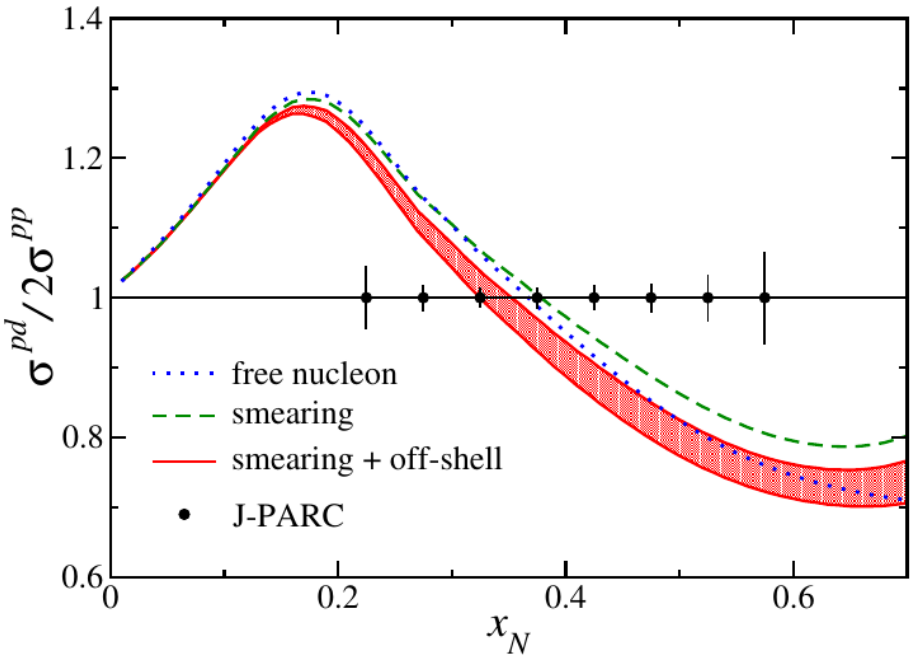
Red band:
combined wave fn. & off-shell model uncertainty

- **Off-shell corrections help makes dbar-ubar stay positive**

Future DY reaches into large-*x*

Ehlers, AA, Brady, Melnitchouk, PRD90 (2014)





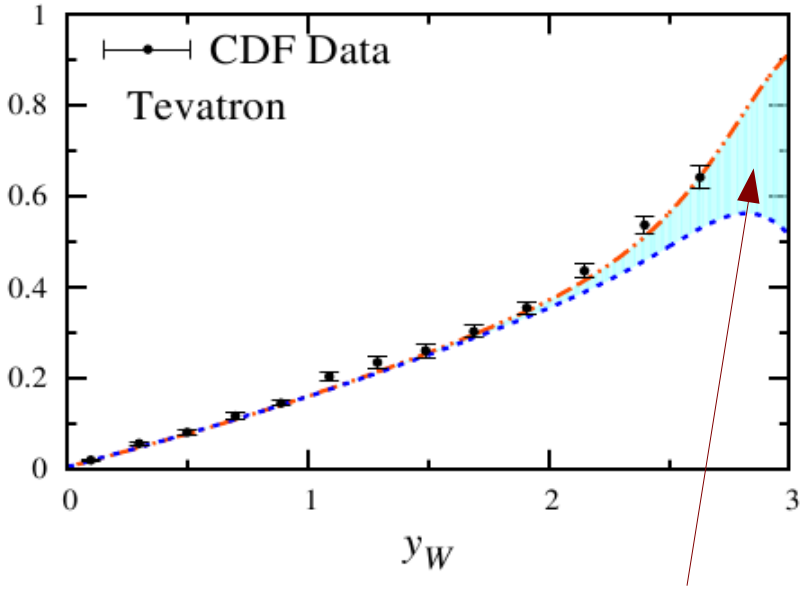
- **E906/Sea Quest:** off-shell effects even more important
- **J-PARC:** can cross-check nuclear smearing vs. DIS

W charge asymmetry at Tevatron

Brady, Accardi, Melnitchouk, Owens, JHEP 1206 (2012) 019

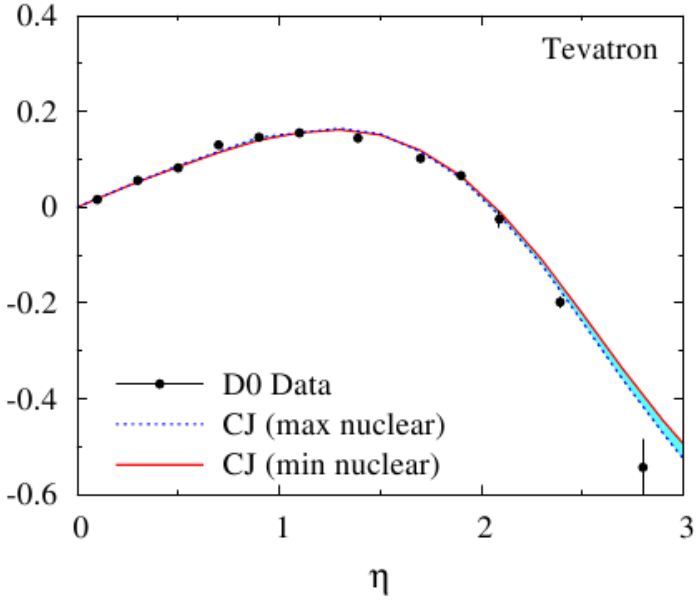
Directly reconstructed W:

- highest sensitivity to large *x*



From decay lepton W → l+ν:

- smearing in *x*



sensitive to *d* at high *x*

→ Can constrain Nuclear models!

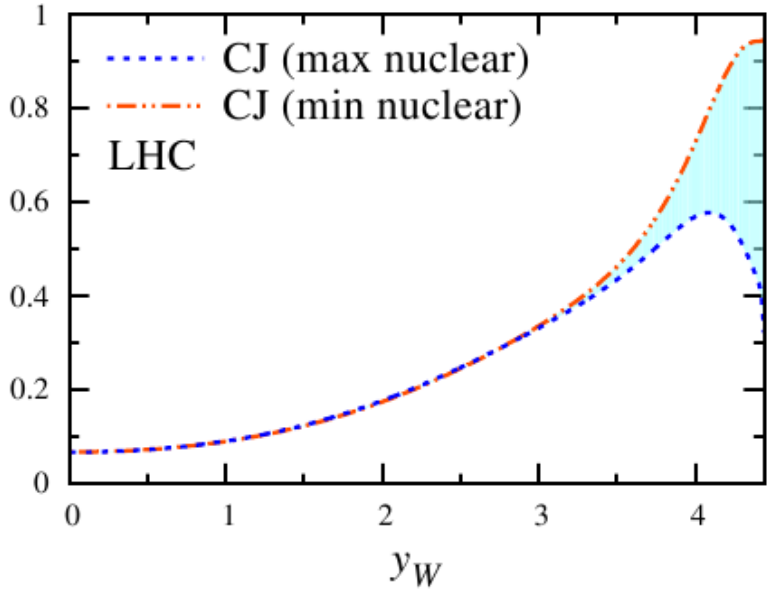
- Too little large-*x* sensitivity in lepton asymmetry:
  - **need reconstructed *W***

W charge asymmetry at LHC

Brady, Accardi, Melnitchouk, Owens, JHEP 1206 (2012) 019

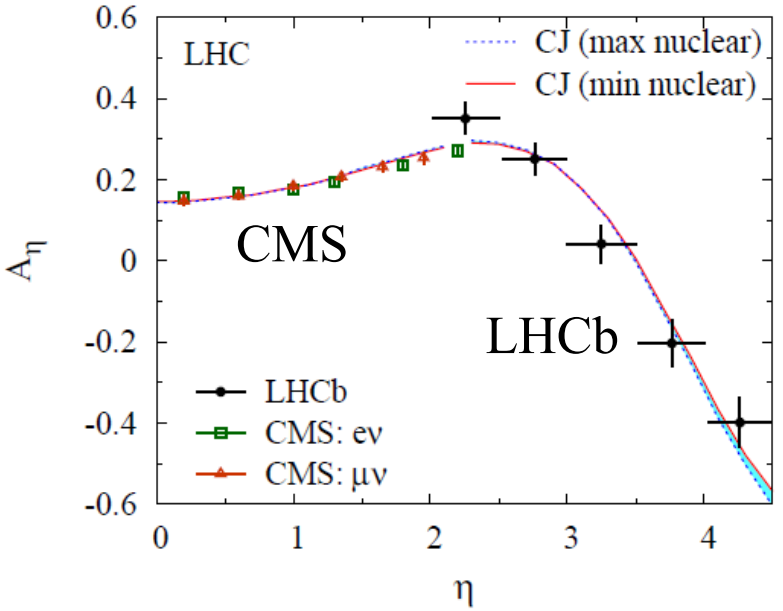
Directly reconstructed W:

- highest sensitivity to large *x*



From decay lepton W → l+ν:

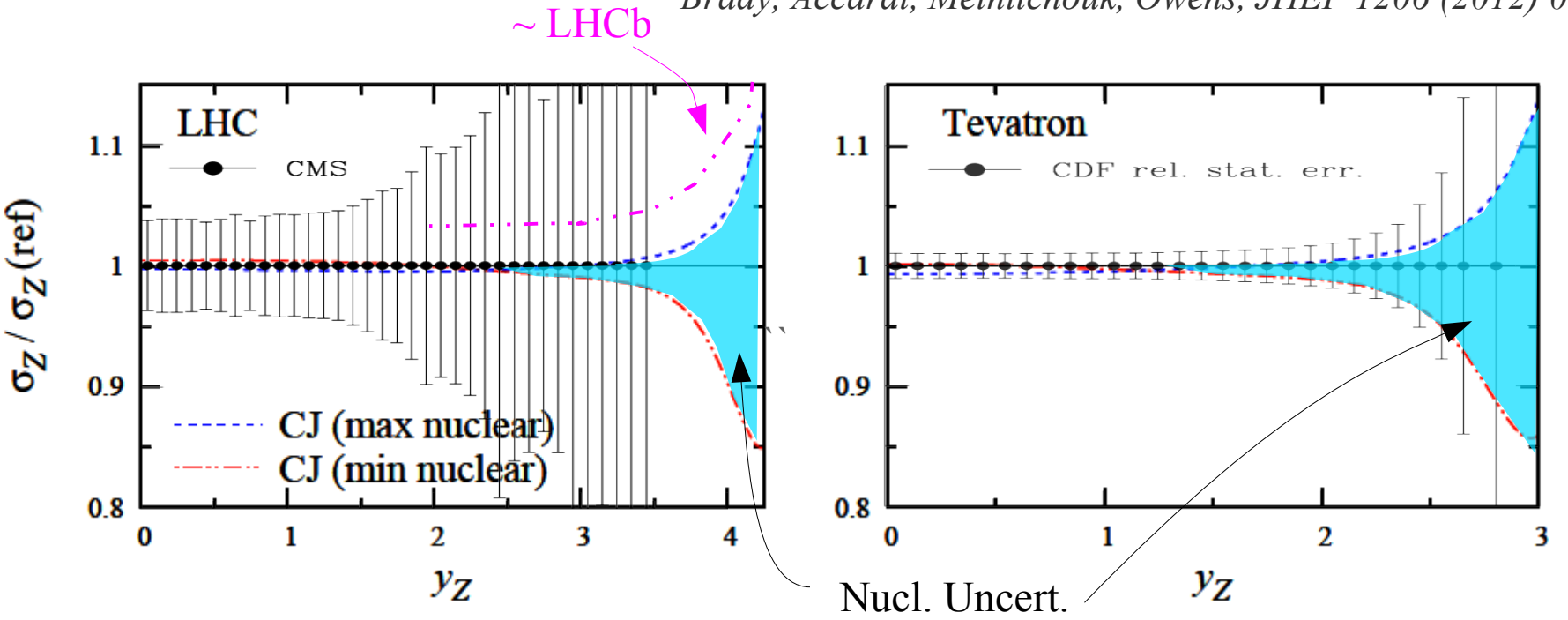
- smearing in *x*



- **Would be nice to reconstruct *W* at LHCb**
  - Definitely needs more statistics
  - Is it at all possible?? (too many holes in detector?)
  - Systematics in *W* reconstruction?
  - **What about RHIC, AFTER@LHC?**

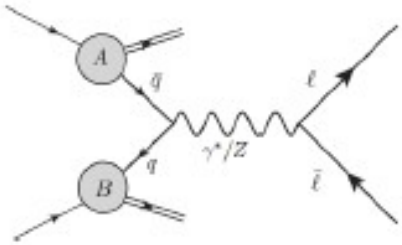
Z rapidity distribution

Brady, Accardi, Melnitchouk, Owens, JHEP 1206 (2012) 019

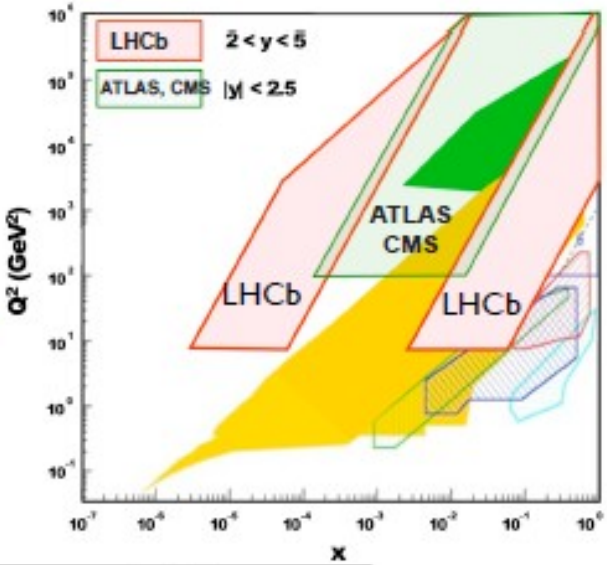


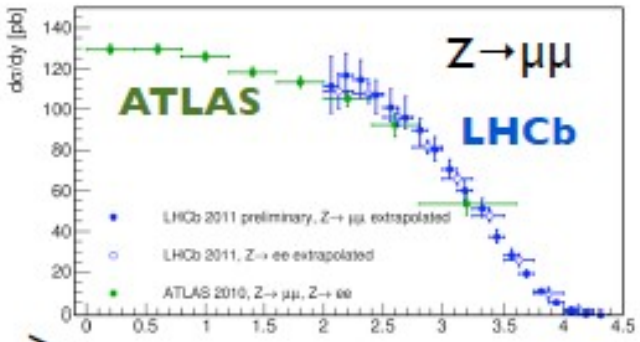
- Direct Z reconstruction is unambiguous in principle, but:
  - **Needs better than 5-10% precision at large rapidity**
  - Experimentally achievable?
    - At LHCb? RHIC? AFTER@LHC?
    - Was full data set used at Tevatron?

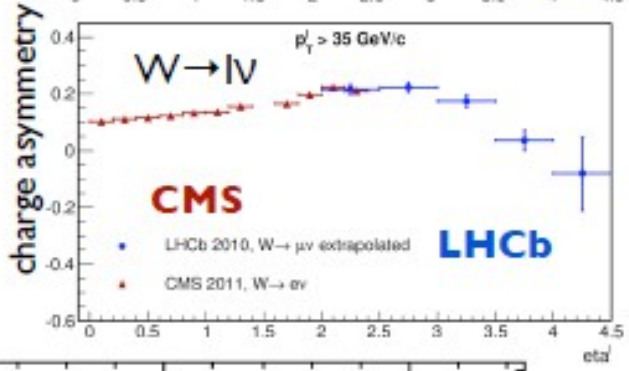
Constraints from the LHC: Electroweak Boson Production



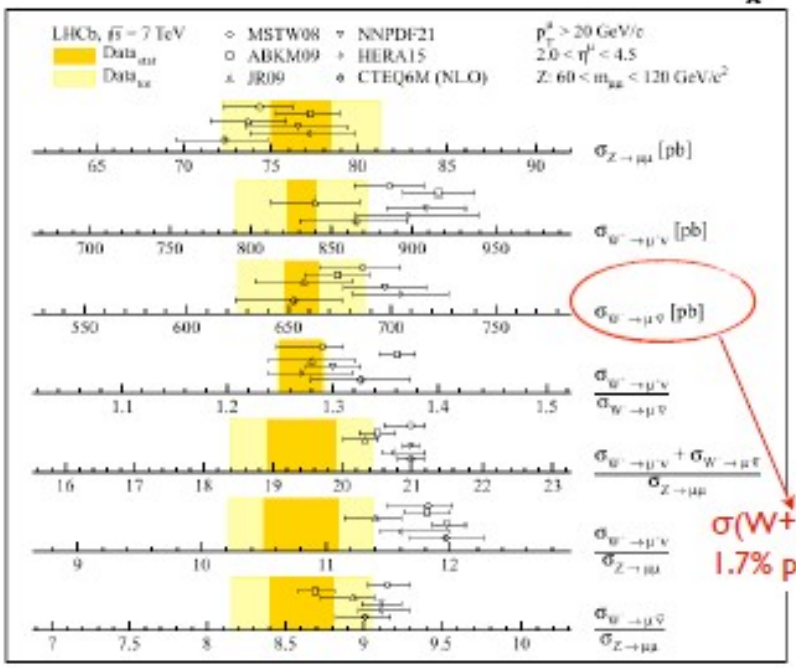
probe light quarks at low and high x



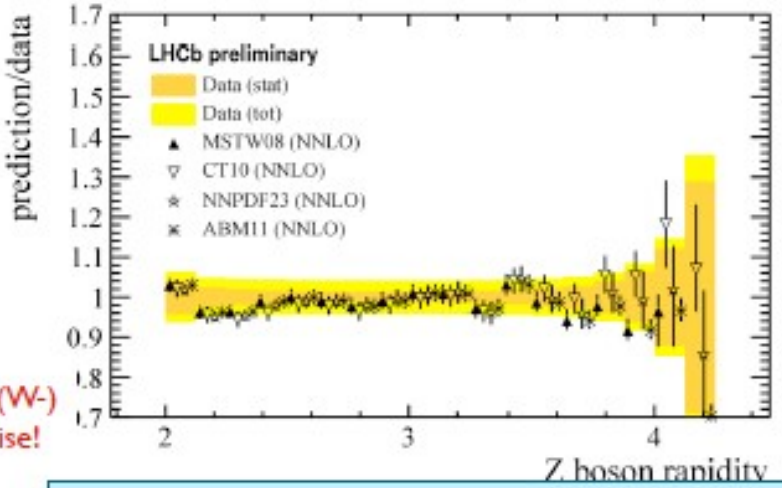




LHCb (S.Tourneur)



σ(W+)/σ(W-)
1.7% precise!



Systematic error comparable with PDF error
Benchmarking different PDF sets

K. Lipka, DIS'13 WG1 summary