Heavy flavors *(s,c,b)*

in LHC processes

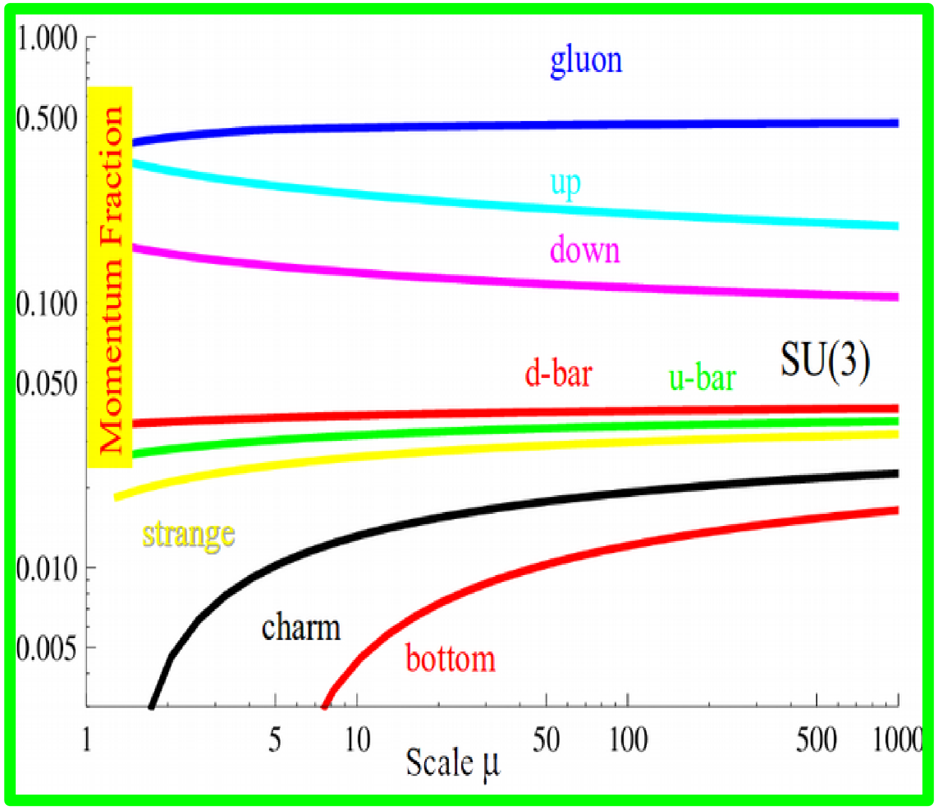
Fred Olness

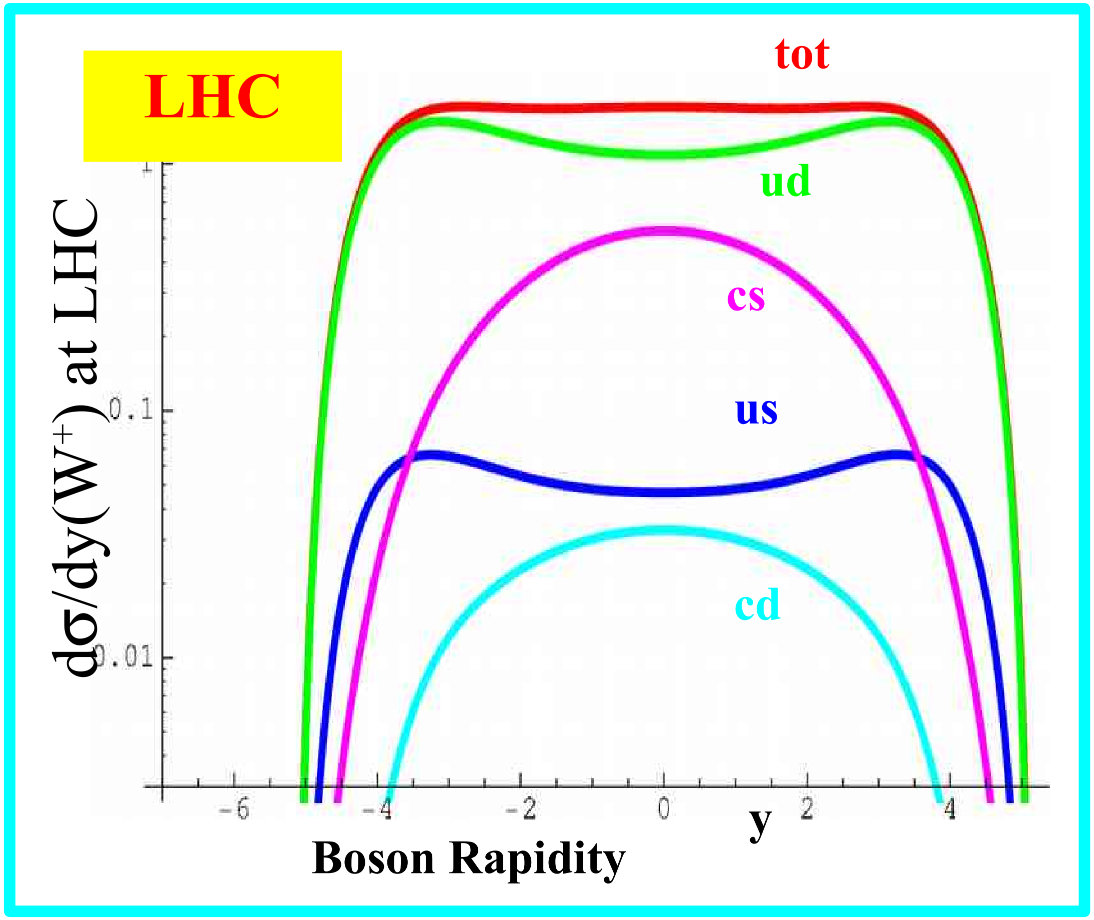
SMU

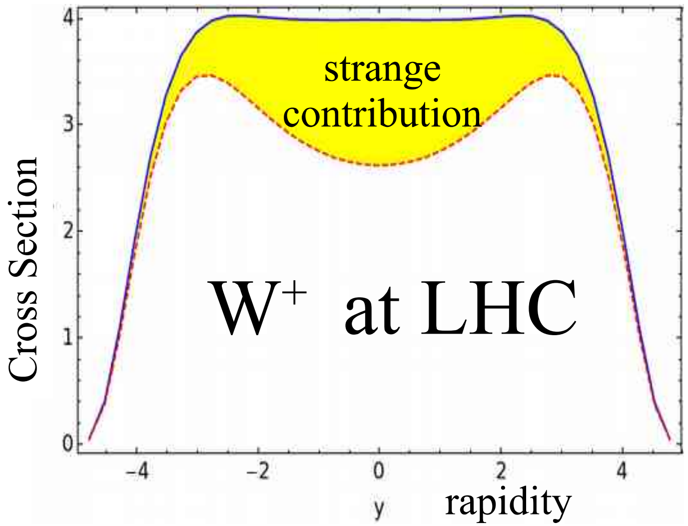
Thanks to:
A. Kusina, F. Lyonnet, B. Clark, E. Godat, I. Schienbein, K. Kovarik, J.Y. Yu,
T. Jezo, J.G. Morfin, J.F. Owens, P. Nadolsky, M. Guzzi, V. Radescu, C. Keppel

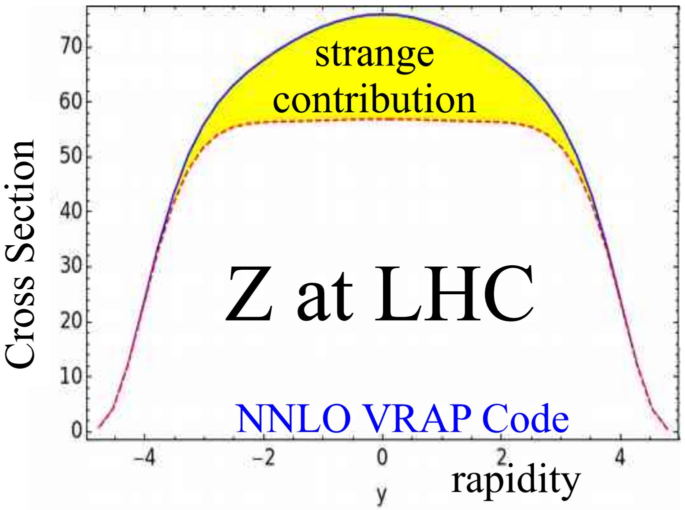
DIS2016
12 April 2106

Heavy Flavors play an increasingly important role at the LHC







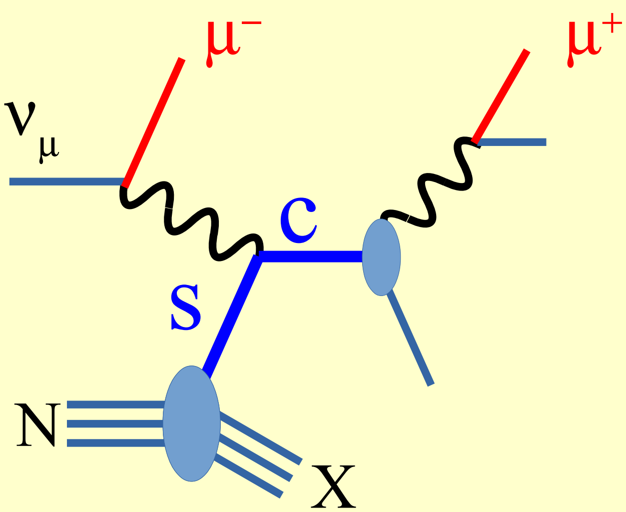


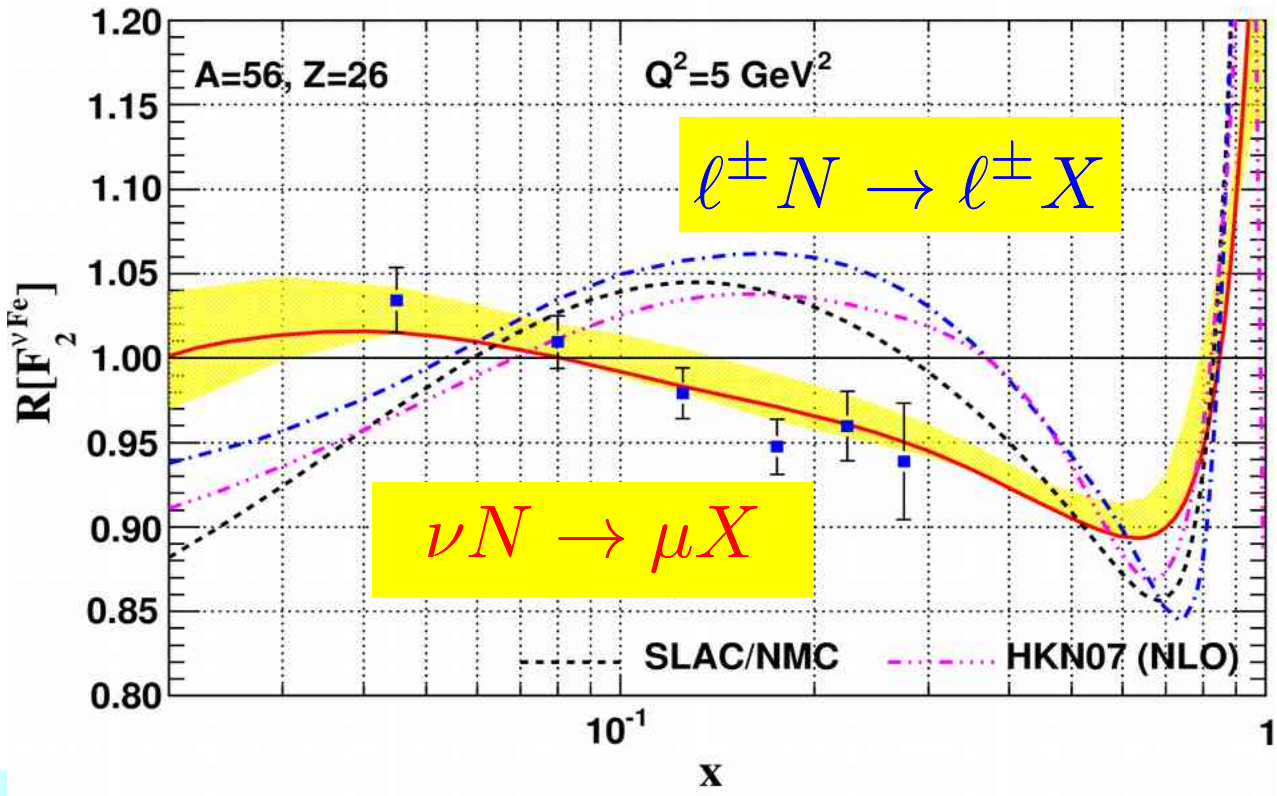
NNLO VRAP Code
Anastasiou, Dixon, Melnikov, Petriello,
Phys.Rev.D69:094008,2004.

Kusina, Stavreva, Berge, Olness,
Schienbein, Kovarik, Jezo, Yu, Park
Phys.Rev. D85 (2012) 094028

Where does the s(x) information come from???

$$\nu N \to \mu^+ \mu^- X$$





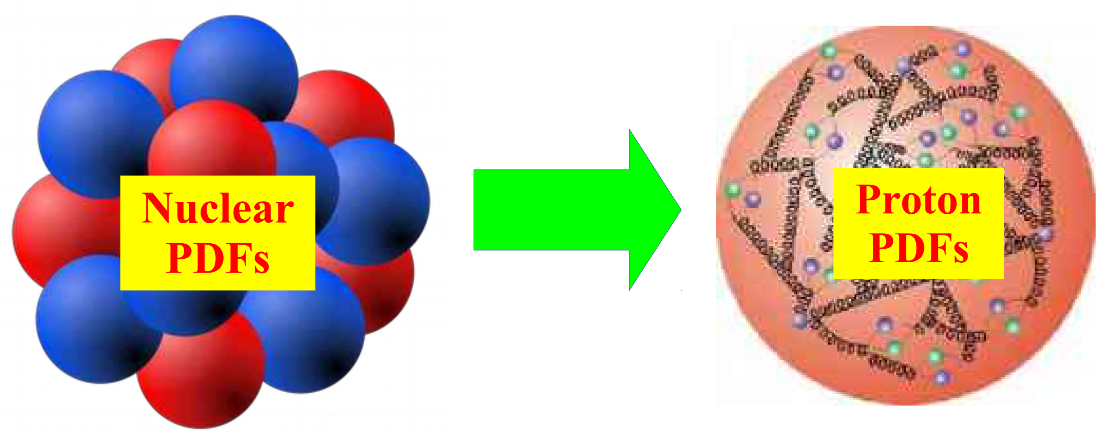
$$F_2^{\nu} \sim [d + s + \bar{u} + \bar{c}]$$

$$F_2^{\bar{\nu}} \sim [\bar{d} + \bar{s} + u + c]$$

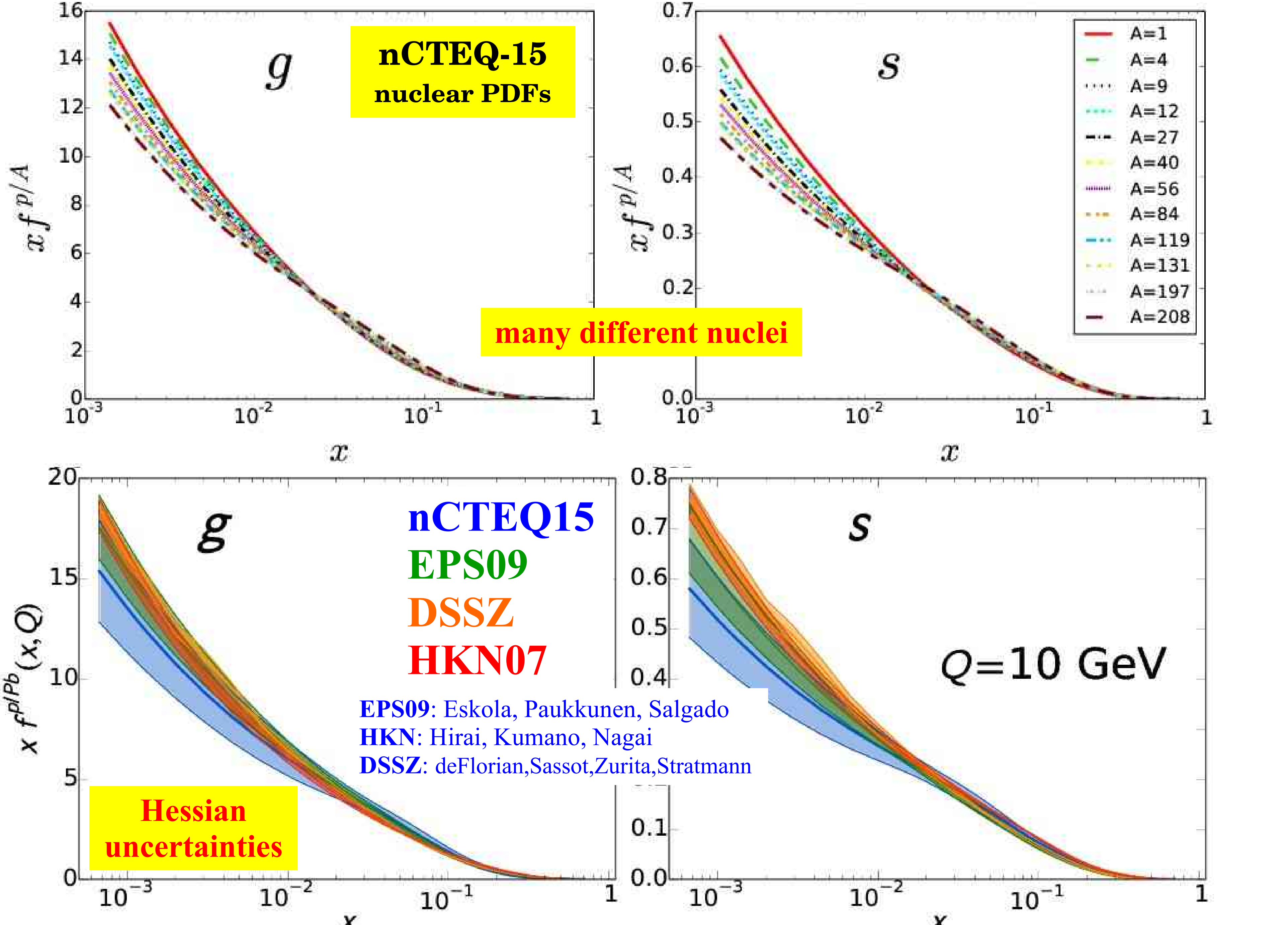
$$F_3^{\nu} = 2\,[d + s - \bar{u} - \bar{c}]$$

$$F_3^{\bar{\nu}} = 2\,[u + c - \bar{d} - \bar{s}]$$

Depends on nuclear corrections



nCTEQ15 PDFs … *from A to Z … with Uncertainties*

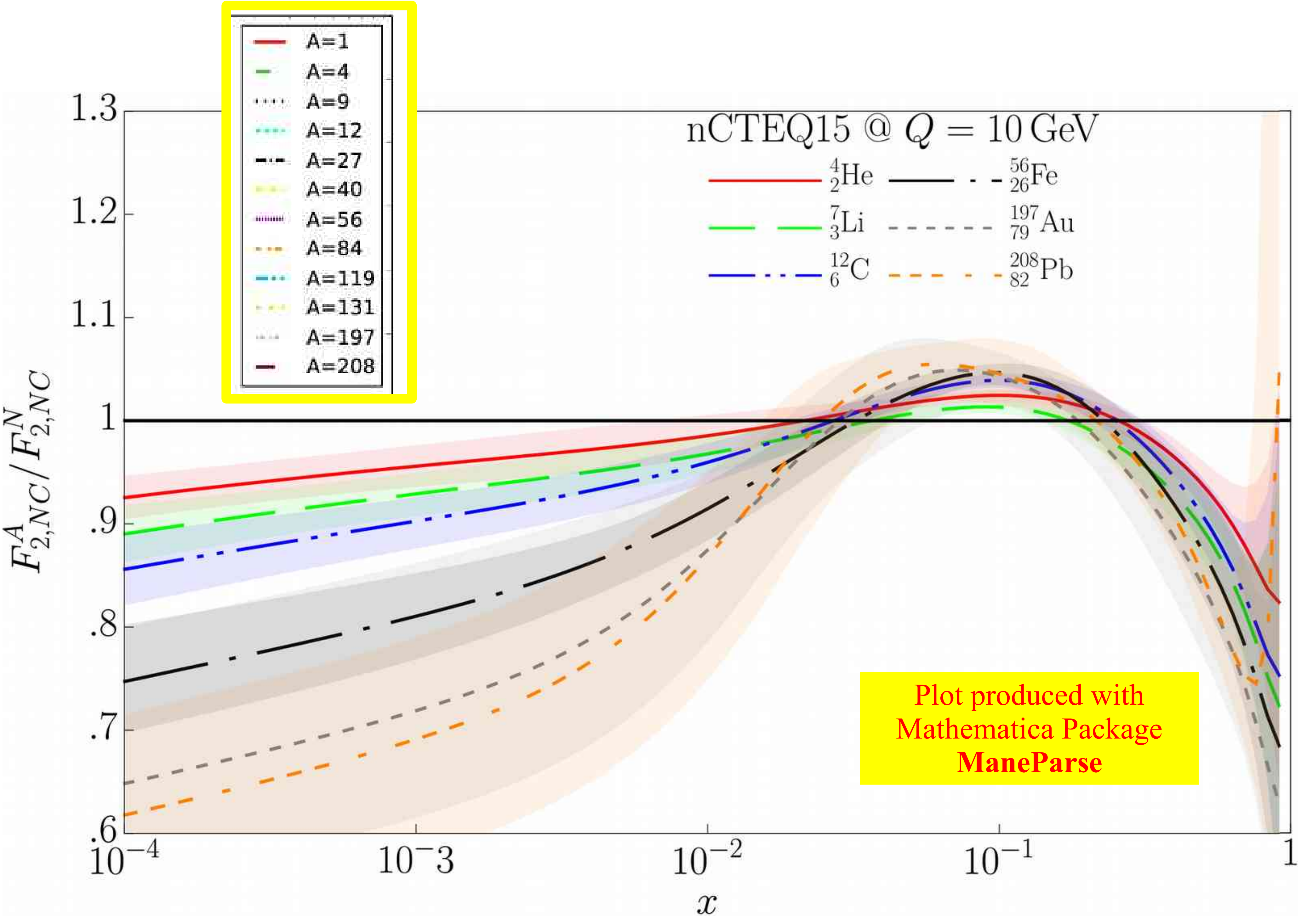


… see talk by Aleksander Kusina tomorrow

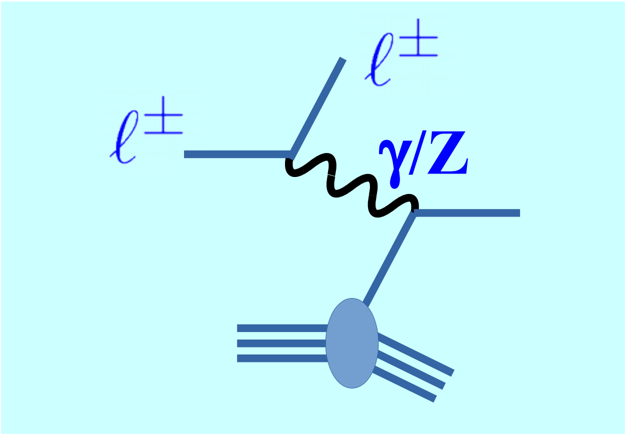
files on HepForge

arXiv:1509.00792

An Example: Nuclear Correction Factor vs. Nuclear-*A*



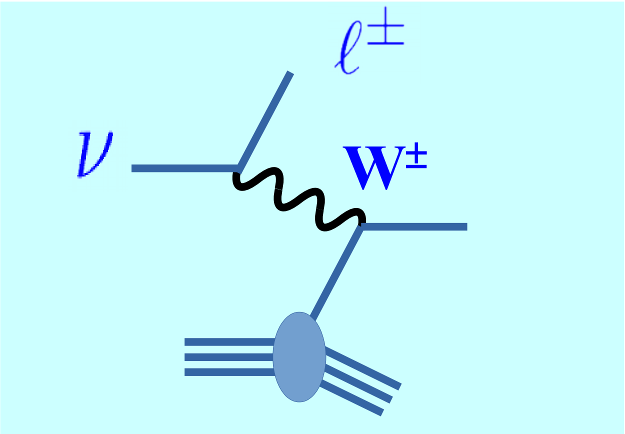
Charged Lepton DIS



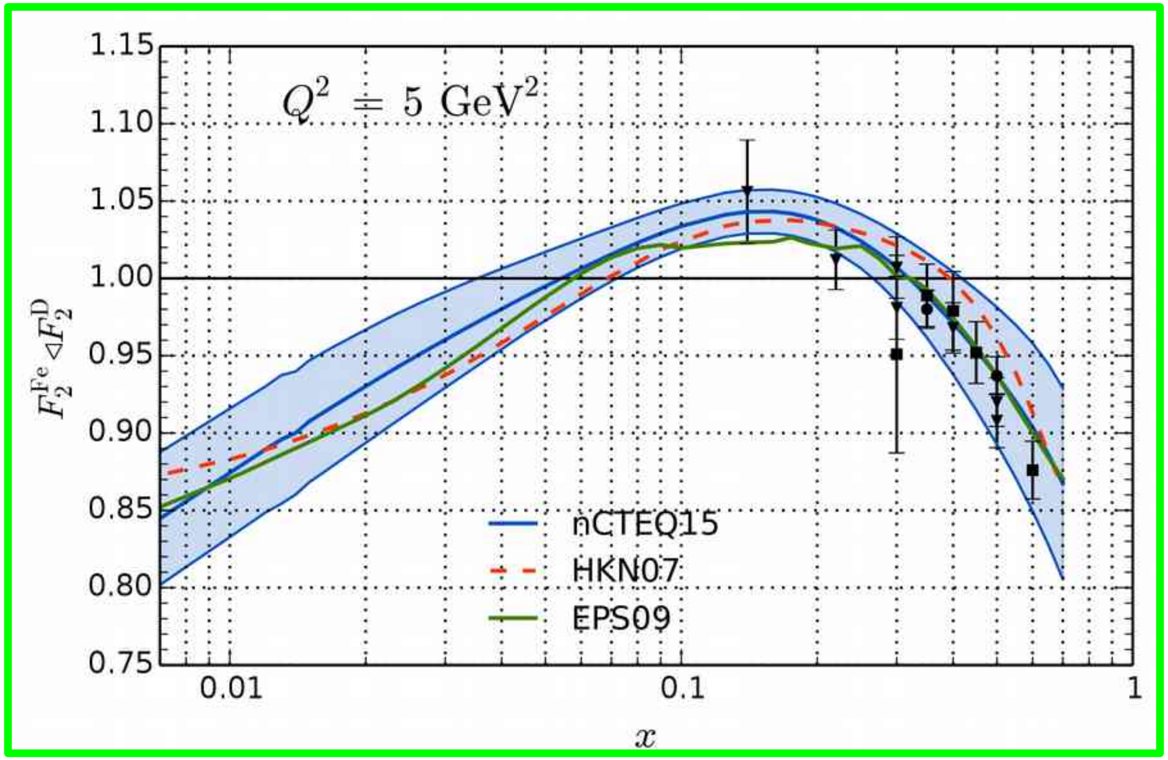
$$\ell^\pm N \to \ell^\pm X$$

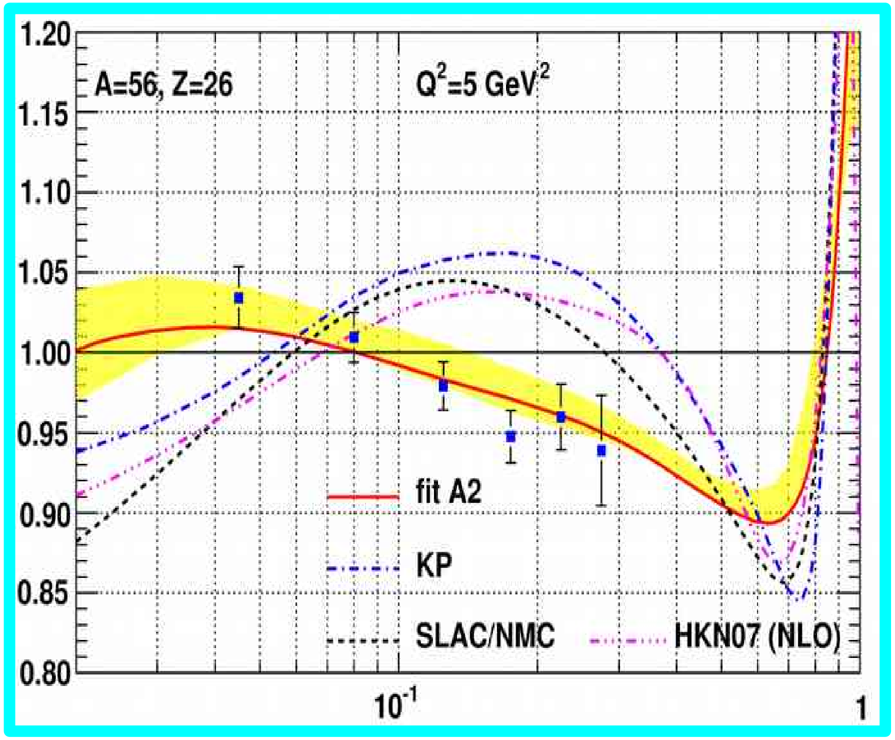
Very different nuclear corrections

Neutrino DIS



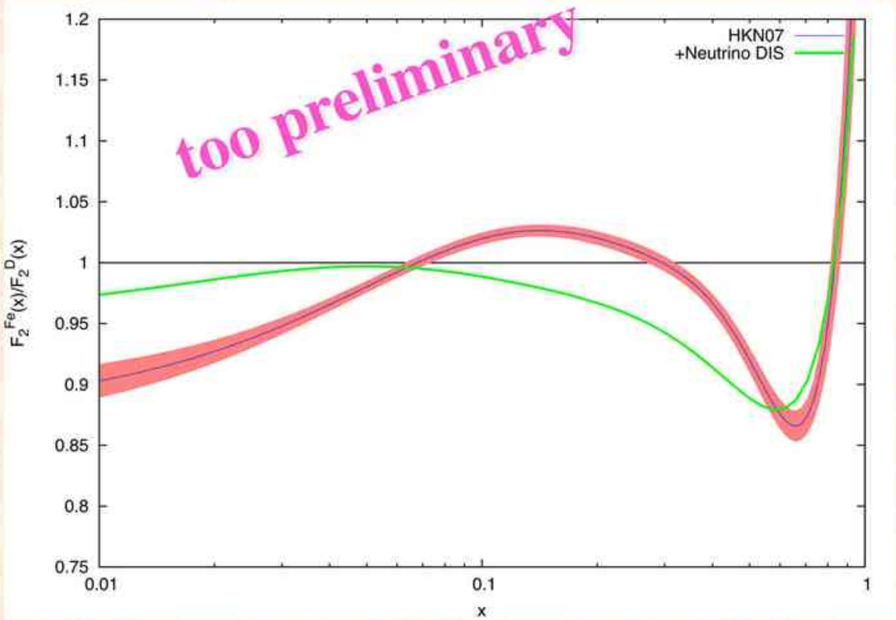
$$\nu N \to \ell^\pm X$$

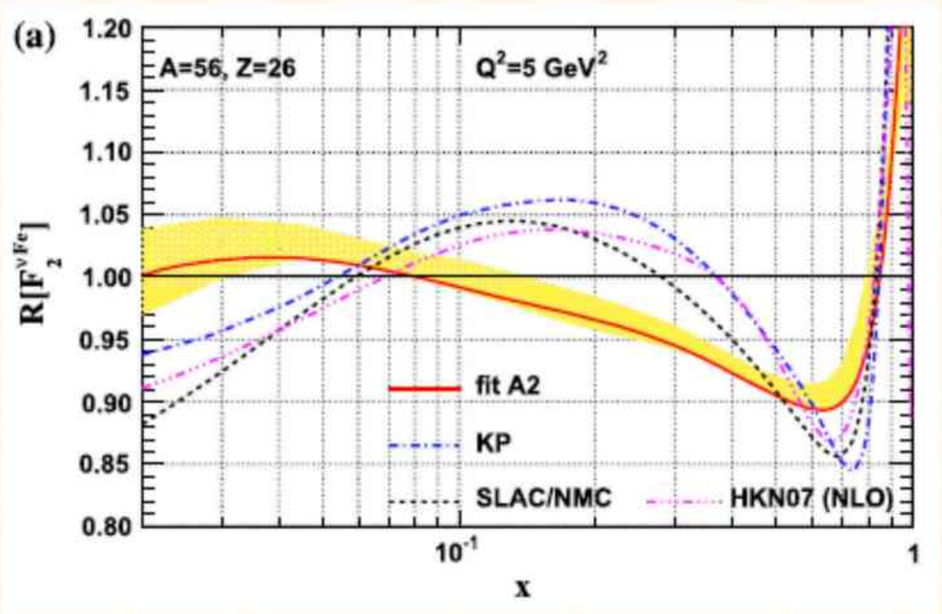




HKN sees similar effects

Our research in progress (M. Hirai, SK, K. Saito)



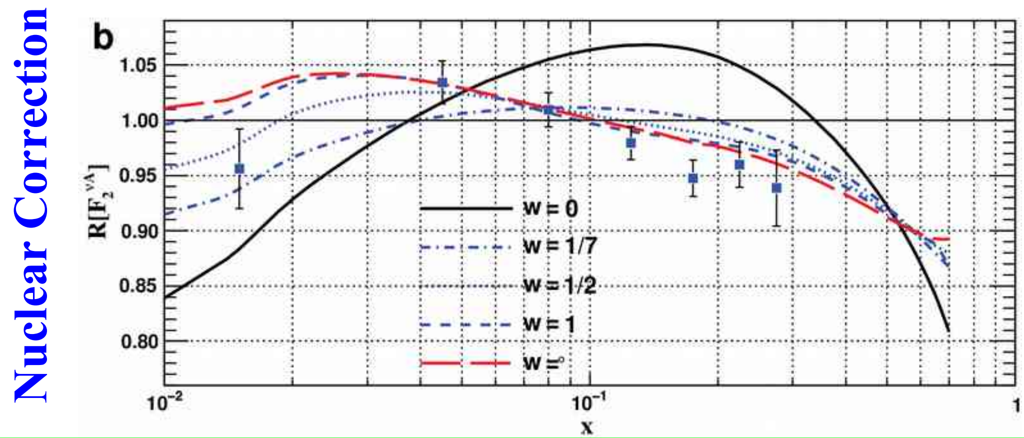


We are getting a similar modification to the nCTEQ one.

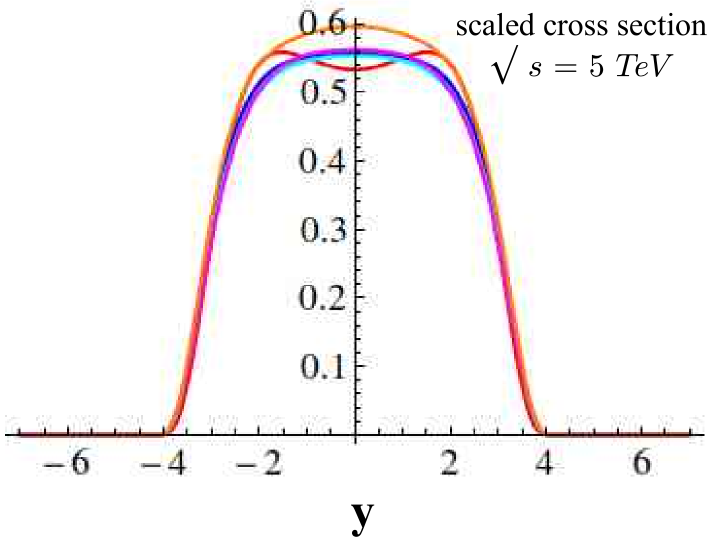
Shunzo Kumano
KEK/J-PARC
Fermi Theory Seminar
9 March 2016

Uncertainty in s(x) feeds into other processes

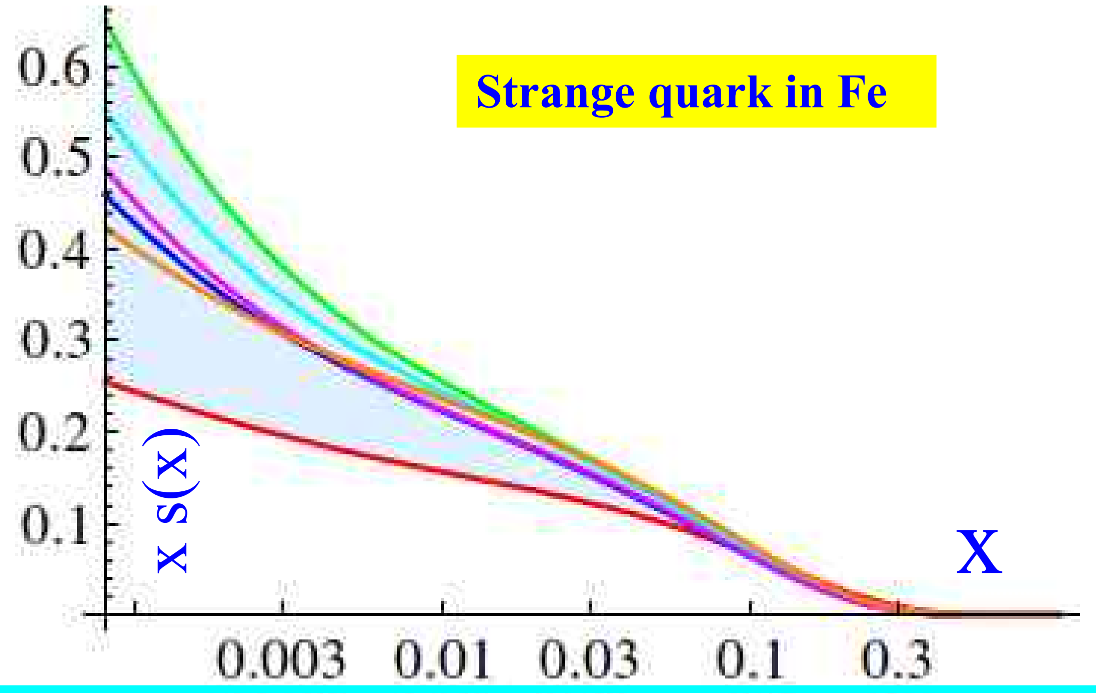
Interpolate between νN and $\ell^{\pm} N$



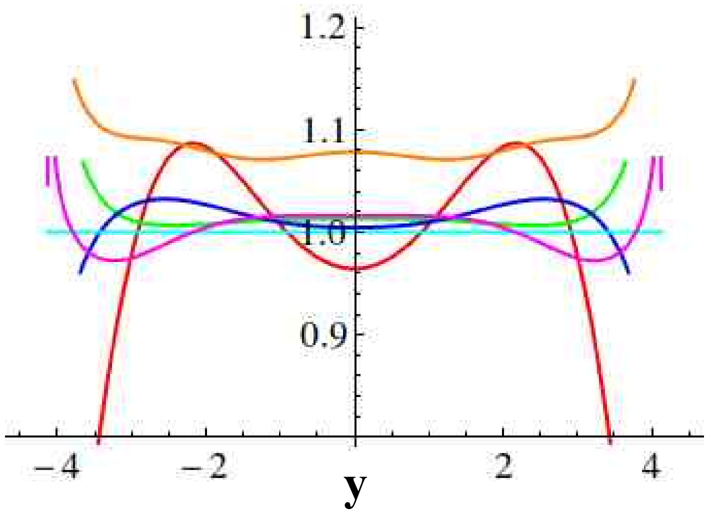
W+ Production: $d\sigma/dy$



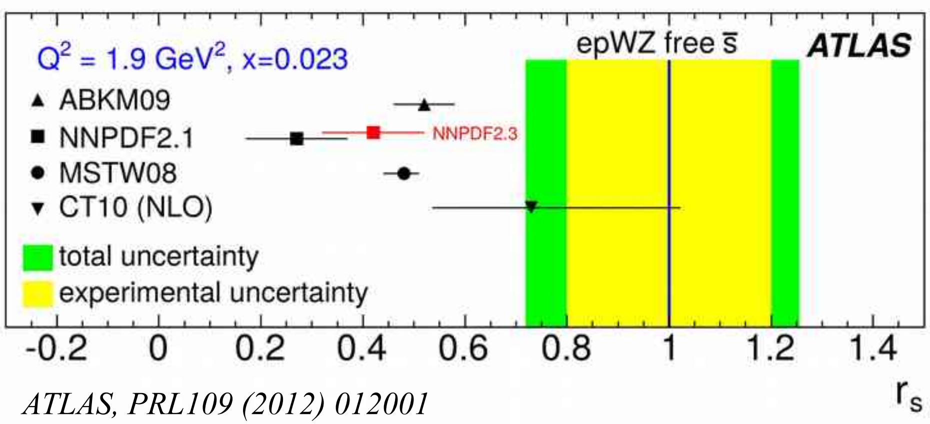
Strange quark in Fe



W+ Production: ratio

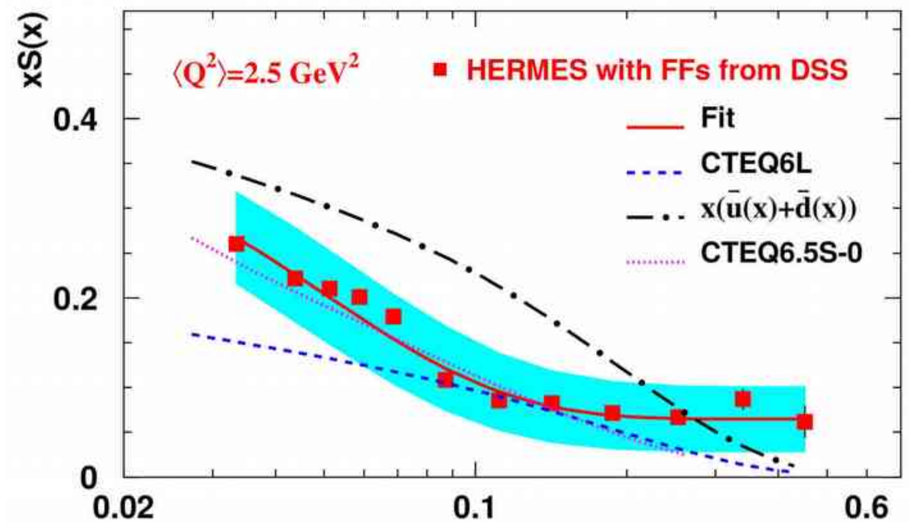


so … what do we know about s(x)



ATLAS, PRL109 (2012) 012001

$$r_s = 0.5\frac{s+\bar{s}}{\bar{d}}$$



PhysRevD.89.097101

$$\kappa_s = \frac{\int_0^1 x(s+\bar{s})dx}{\int_0^1 x(\bar{u}+\bar{d})dx}$$

CMS: $\kappa_S = 0.52$

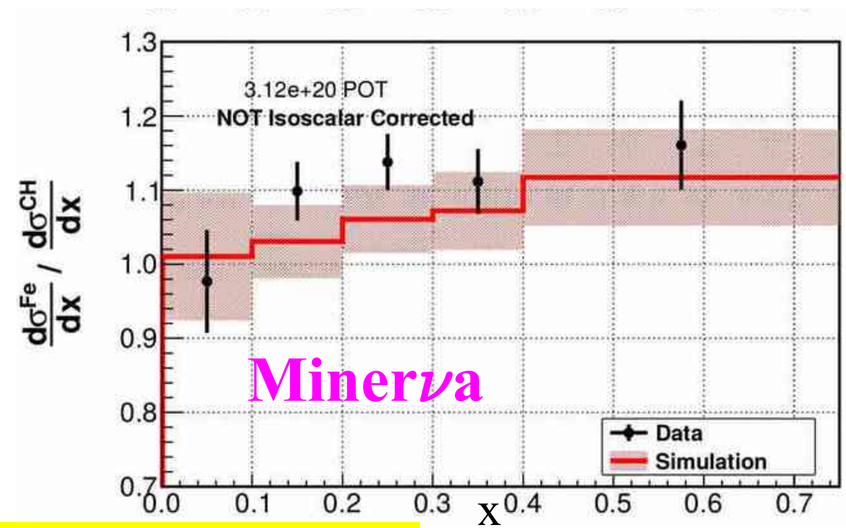
PRD 90, 032004 (2014)

NOMAD: $\kappa_S = 0.591$

NPB876, 339 (2013).

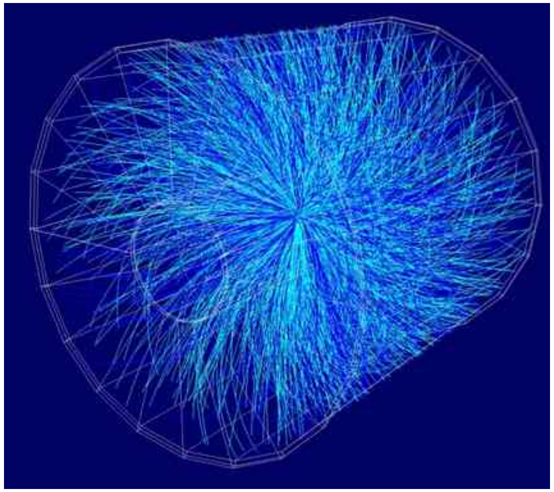
NuTeV: $\kappa_S = 0.58$

PRL99 (2007) 192001

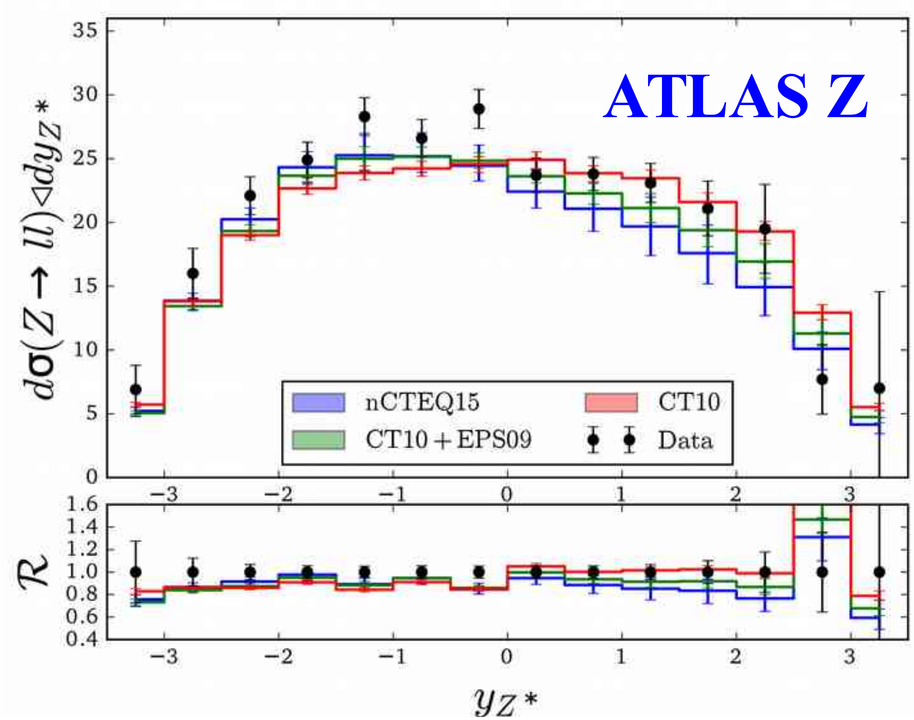


more data coming

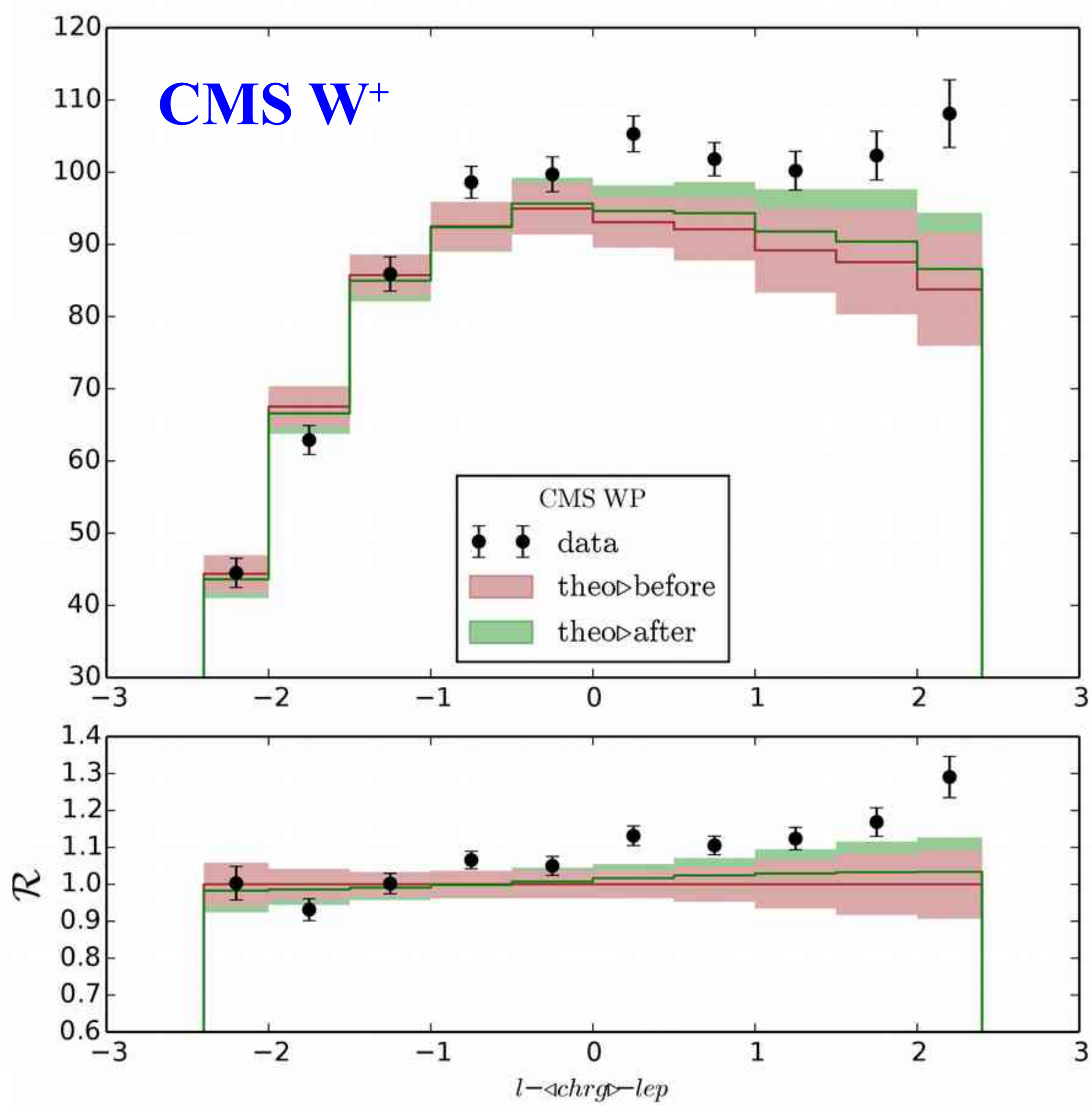
arXiv:1601.06313



Compare with rapidity distribution

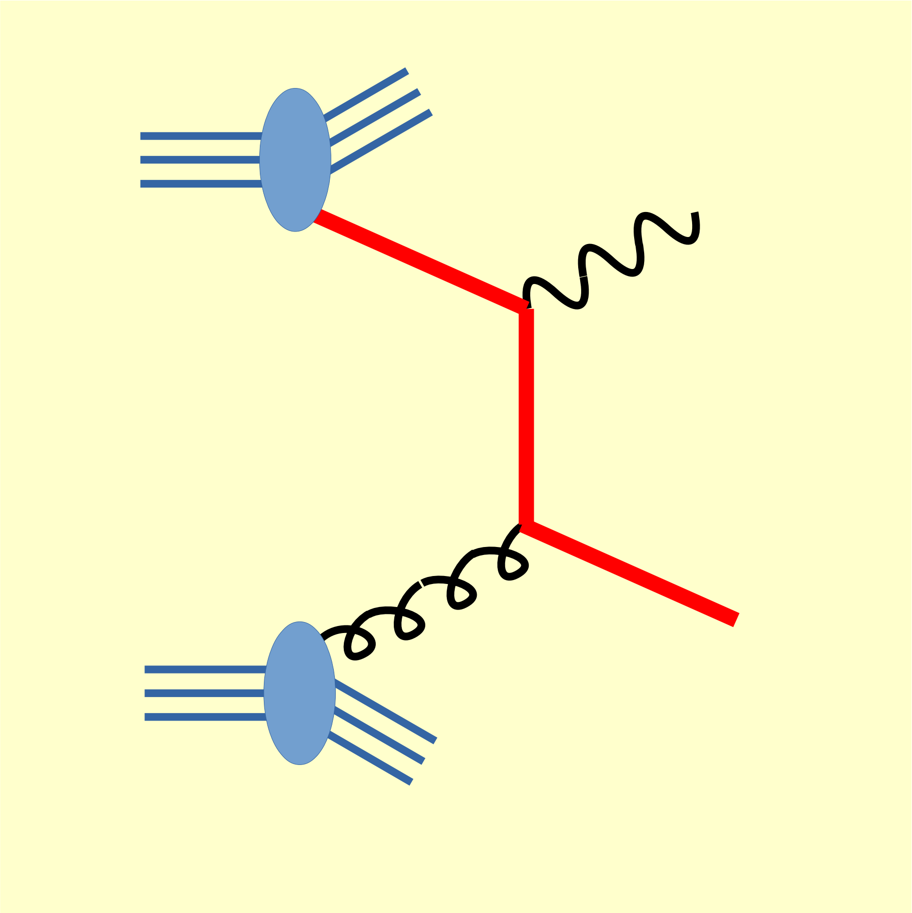


PDF re-weighting with CMS data



LHC: Boson + Heavy Flavor

$$p + p \to V + Q$$



Charged Current

s g→ c W

c g→ b W

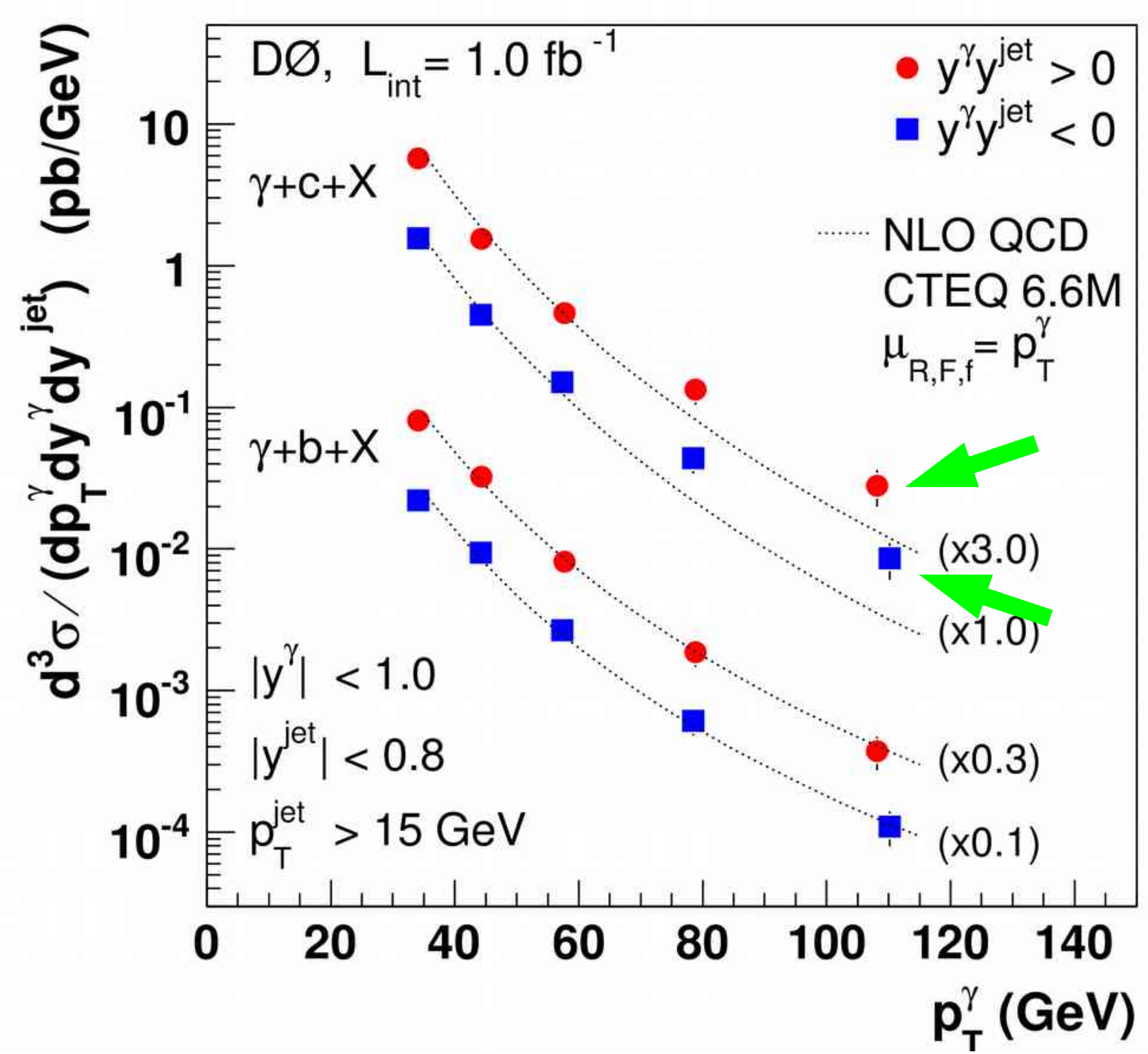
Neutral Current

c g→ c γ/Z

b g→ b γ/Z

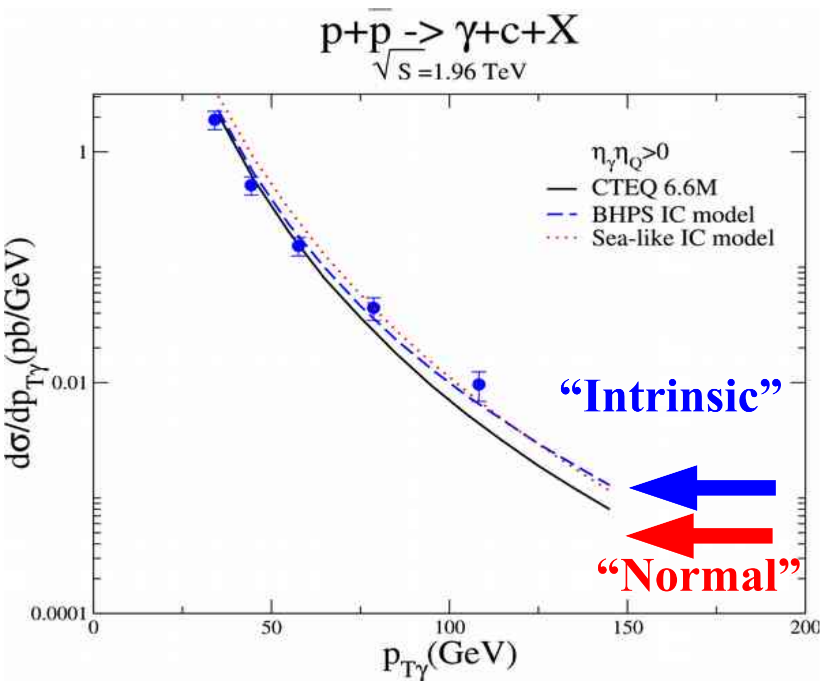
good place to find both extrinsic & intrinsic PDFs

Heavy Quarks at the Tevatron: … "intrinsic" charm???



Excess in Charm, NOT Bottom

only at high PT



D. Duggan (D0) arXiv:0906.0136

T. Stavreva, I. Schienbein, F. Arleo, K. Kovarik, F. Olness, J.Y. Yu, J.F. Owens, JHEP 1101 (2011) 152

Short Cut: how to add "intrinsic" charm to any PDF

DGLAP Evolution equations …
including **ordinary Q_0** and **intrinsic Q_1** heavy quark

$$\dot{g} = P_{gg} \otimes g + P_{gq} \otimes q + P_{gQ} \otimes Q_0 + \cancel{P_{gQ} \otimes Q_1},$$
$$\dot{q} = P_{qg} \otimes g + P_{qq} \otimes q + P_{qQ} \otimes Q_0 + \cancel{P_{qQ} \otimes Q_1},$$
$$\dot{Q}_0 + \dot{Q}_1 = P_{Qg} \otimes g + P_{Qq} \otimes q + P_{QQ} \otimes Q_0 + P_{QQ} \otimes Q_1 .$$

neglect

Equations decouple:
- Intrinsic component evolves independently
- Scale set by m_Q
- Adjust normalization by simple rescaling

$$\dot{Q}_1 = P_{QQ} \otimes Q_1 .$$

$$c_1(x) = \bar{c}_1(x) \propto x^2[6x(1+x)\ln x + (1-x)(1+10x+x^2)]$$

JHEP 1507 (2015) 141: On the intrinsic bottom content of the nucleon and its impact on heavy new physics at the LHC
F. Lyonnet, A. Kusina, T. Ježo, K. Kovařík, F. Olness, I. Schienbein, J.Y. Yu

LHCb future constraints on intrinsic charm

BHPS Model: Brodsky, Hoyer, Peterson, Sakai

Phys.Lett. B93 (1980) 451-455

$$c_1(x) = \bar{c}_1(x) \propto x^2[6x(1+x)\ln x + (1-x)(1+10x+x^2)]$$

BHPS1: 0.6%
BHPS2: 2%

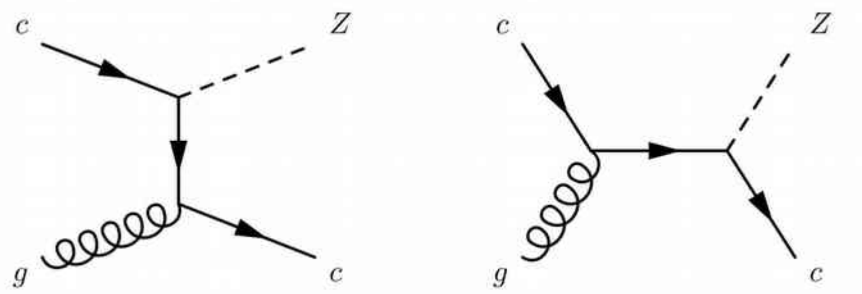
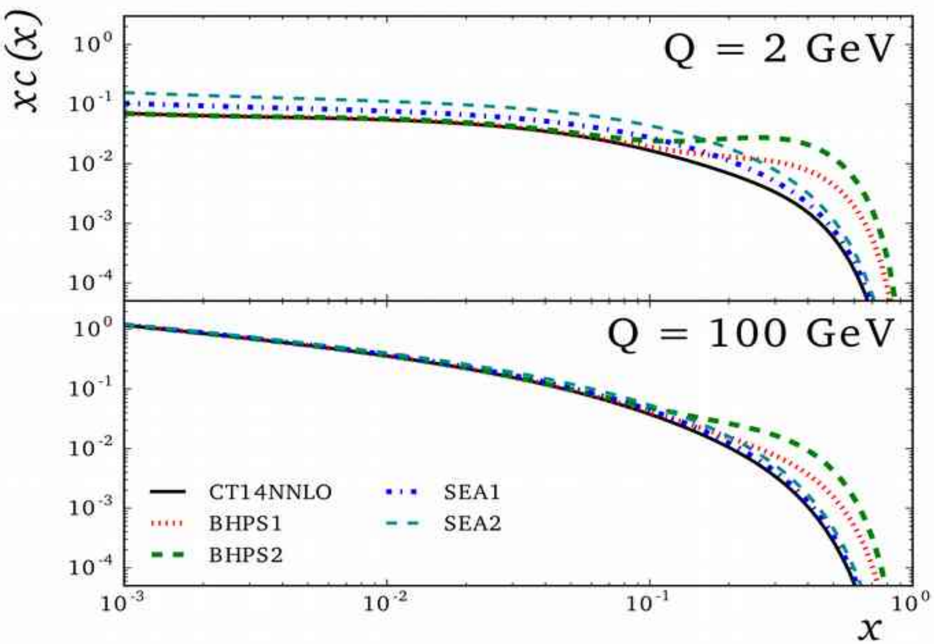
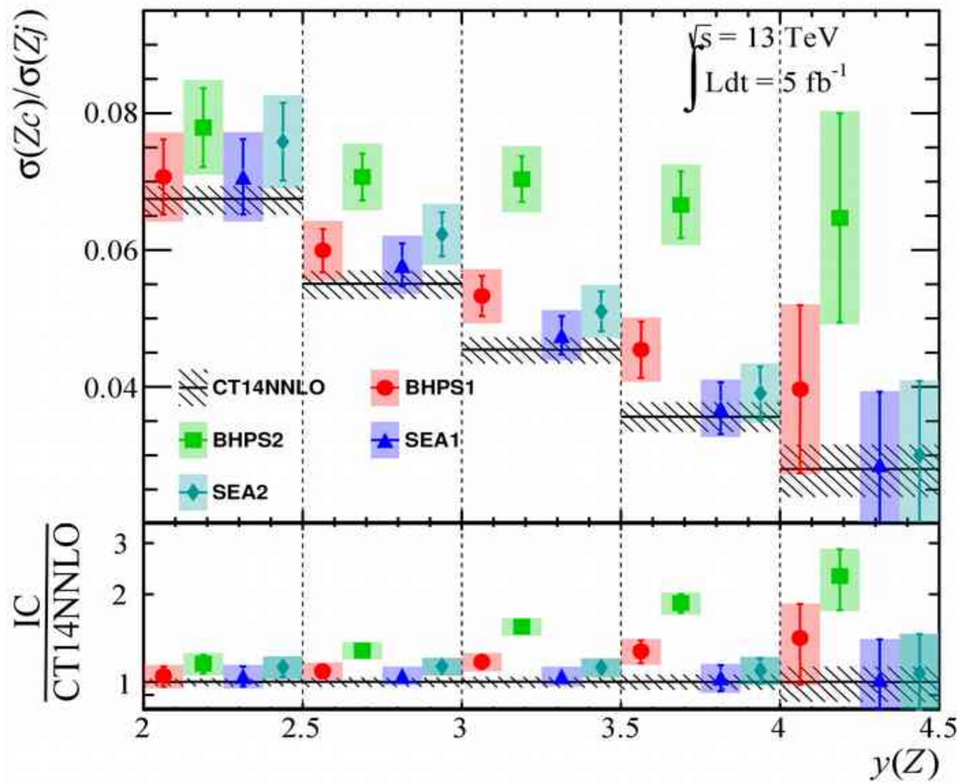


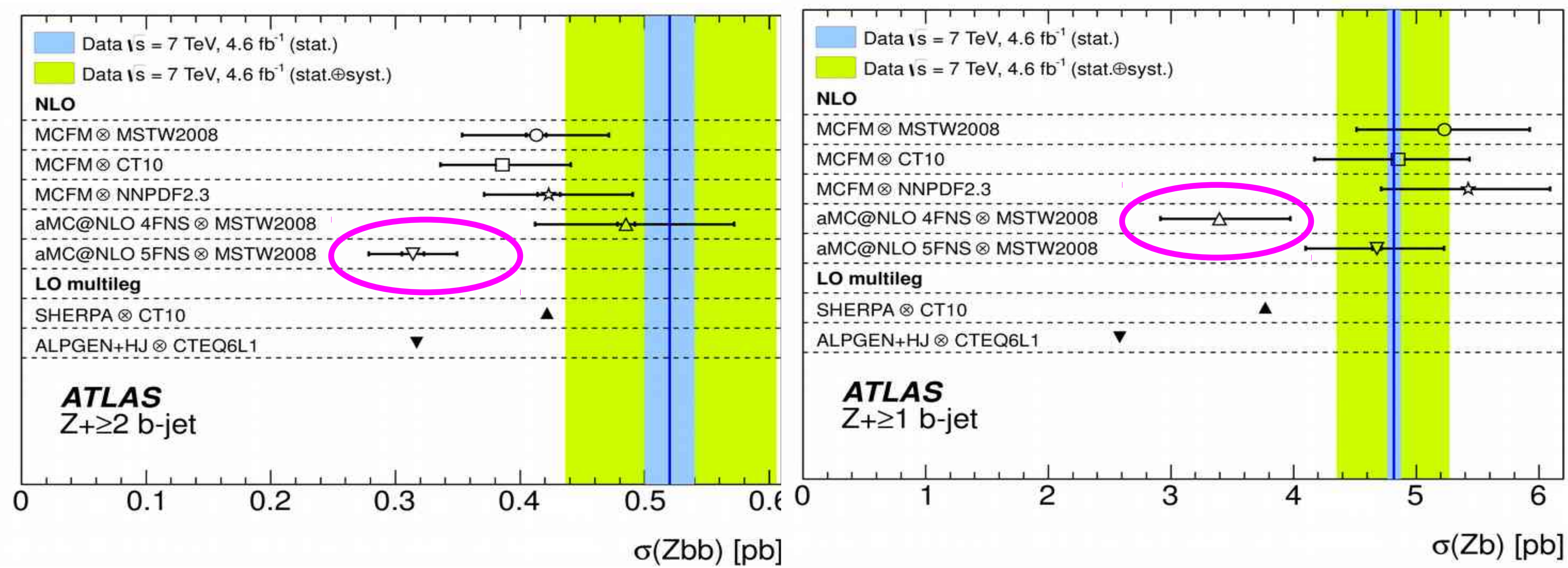
FIG. 1. Leading-order Feynman diagrams for $gc \to Zc$.





A direct probe of the intrinsic charm content of the proton
Tom Boettcher, Philip Ilten, Mike Williams. arXiv:1512.06666

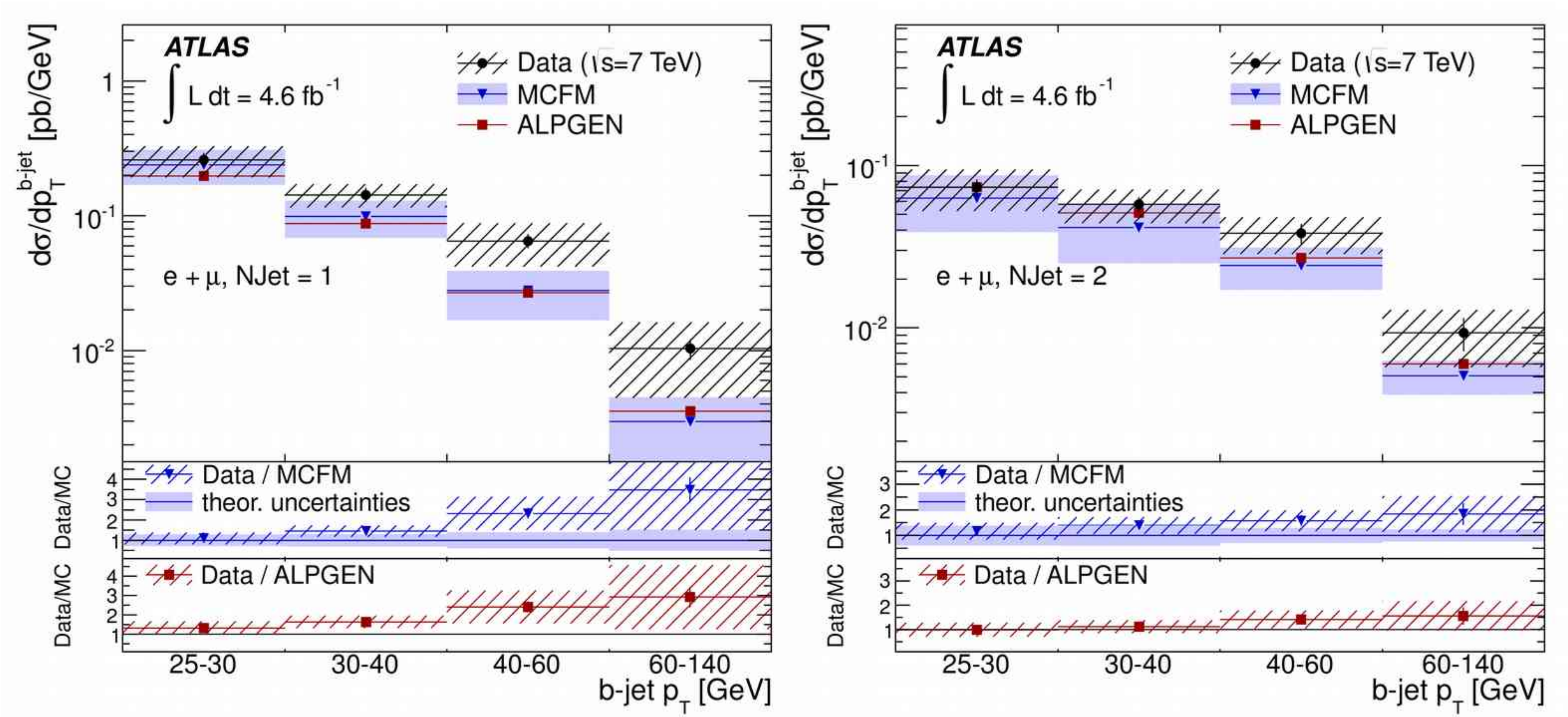
ATLAS Z+b and Z+bb



Measurement of differential production cross-sections for a Z boson in association with b-jets in 7 TeV proton-proton collisions with the ATLAS detector. JHEP10(2014)141

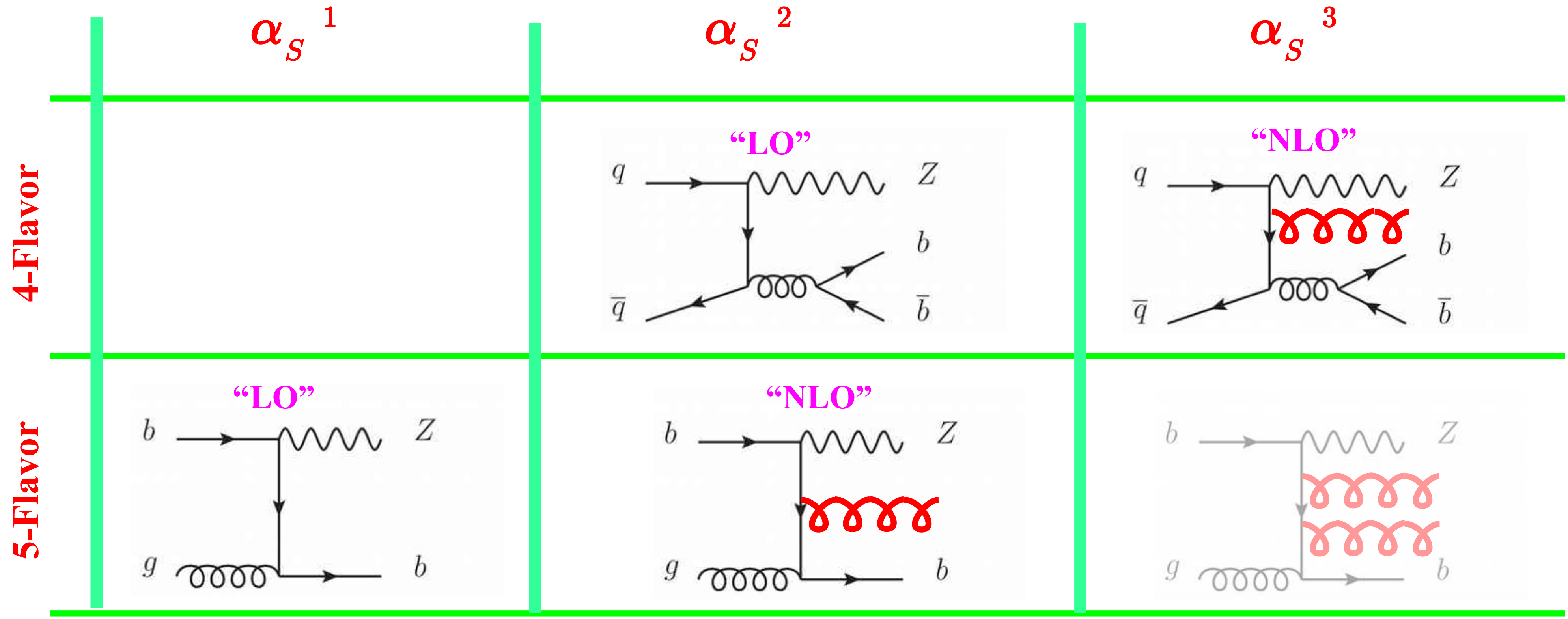
The agreement of the amc@nlo cross-section prediction with data differs in the Z+ ≥ 1 b-jet and Z+ ≥ 2 b-jets cases, with the former better described by the 5FNS prediction and the latter better described by the 4FNS prediction. Even at NLO, scale uncertainties dominate and currently limit any sensitivity to different PDF sets. Descriptions of the shapes of the differential cross-sections are generally good within uncertainties for both LO and NLO predictions. For angular distributions in the Z+ ≥ 1 b-jet selection, where the fixed-order NLO prediction is observed to break down, the differential shapes in data are well modelled by LO multi-legged predictions.

ATLAS W+b and W+bb



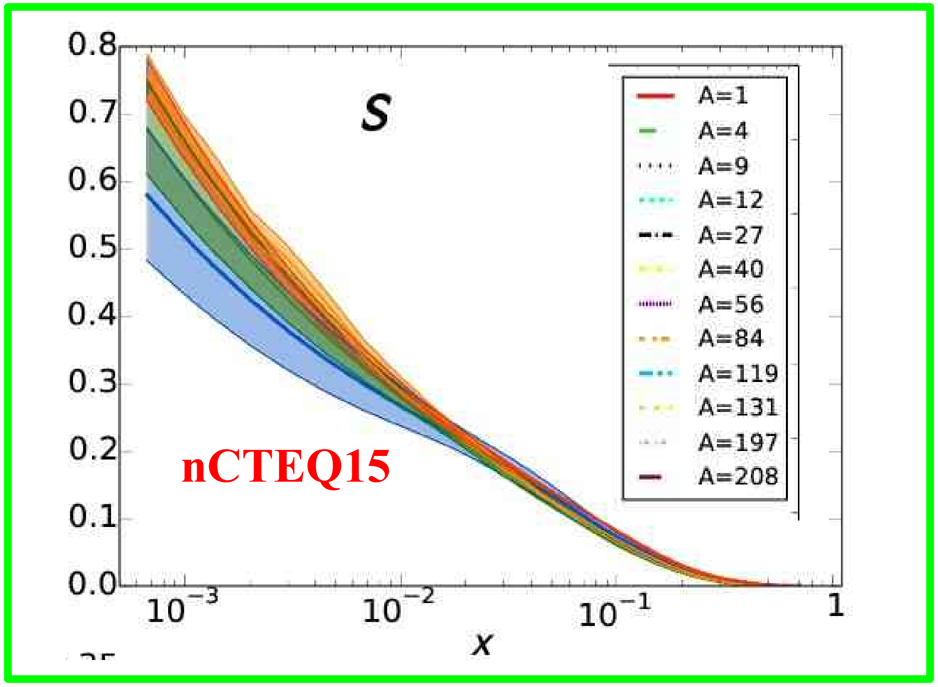
Measurement of the cross-section for W boson production in association with b-jets in pp collisions at sqrt(s) = 7 TeV with the ATLAS detector. JHEP 06 (2013) 084

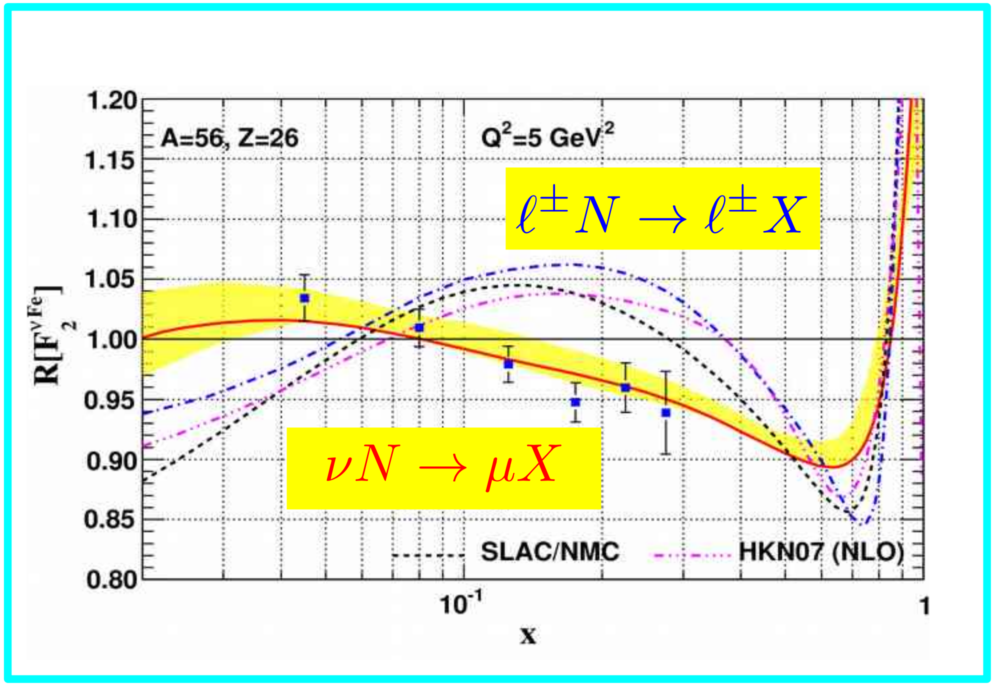
4 & 5 Flavor Comparison: *…. Order Mis-Match*

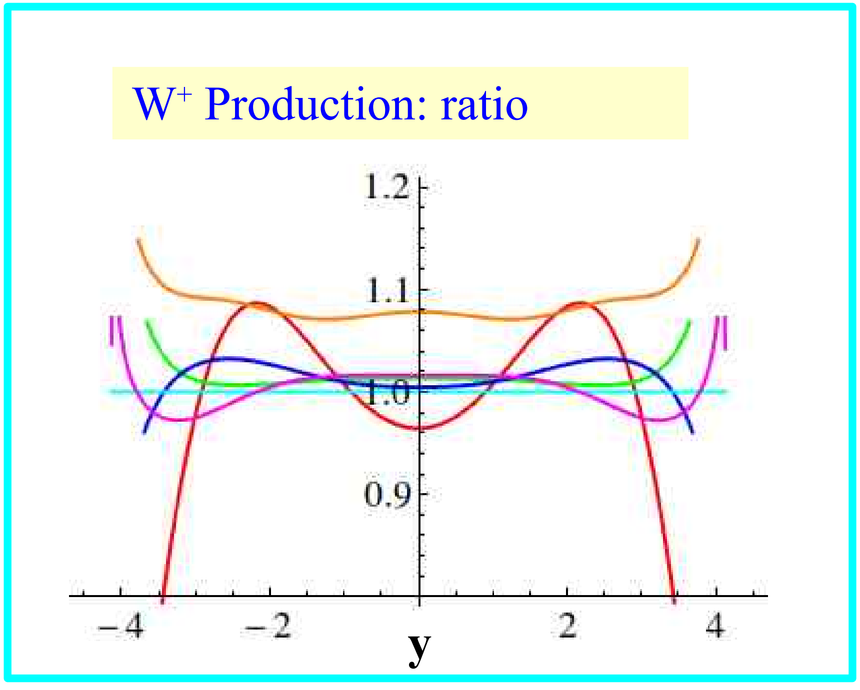


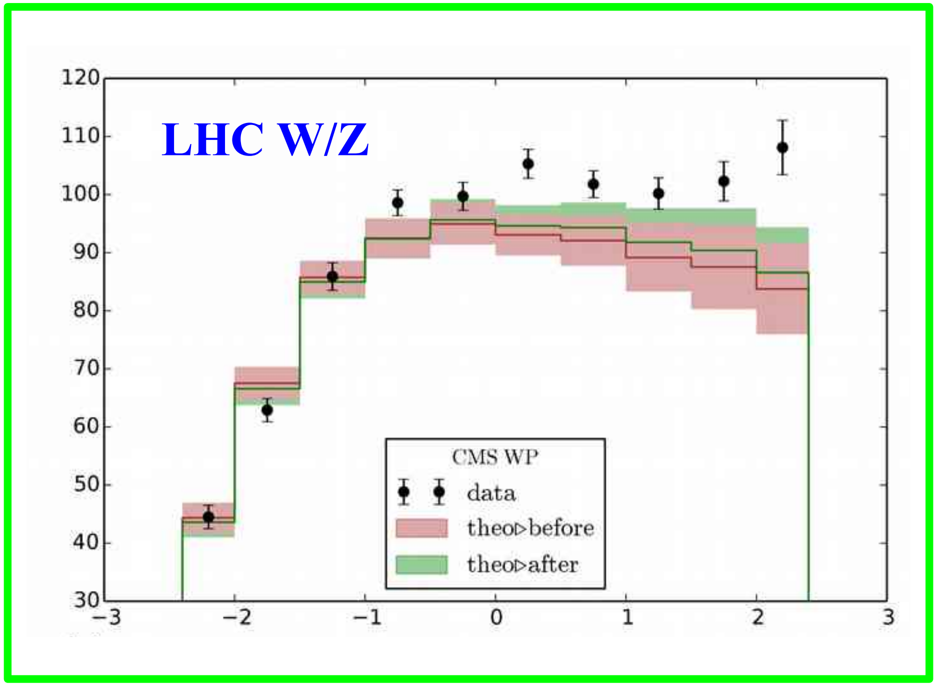
The agreement of the amc@nlo cross-section prediction with data differs in the Z+ ≥ 1 b-jet and Z+ ≥ 2 b-jets cases, with the former better described by the 5FNS prediction and the latter better described by the 4FNS prediction. Even at NLO, scale uncertainties dominate and currently limit any sensitivity to different PDF sets. Descriptions of the shapes of the differential cross-sections are generally good within uncertainties for both LO and NLO predictions. For angular distributions in the Z+ ≥ 1 b-jet selection, where the fixed-order NLO prediction is observed to break down, the differential shapes in data are well modeled by LO multi-legged predictions.

Conclusions



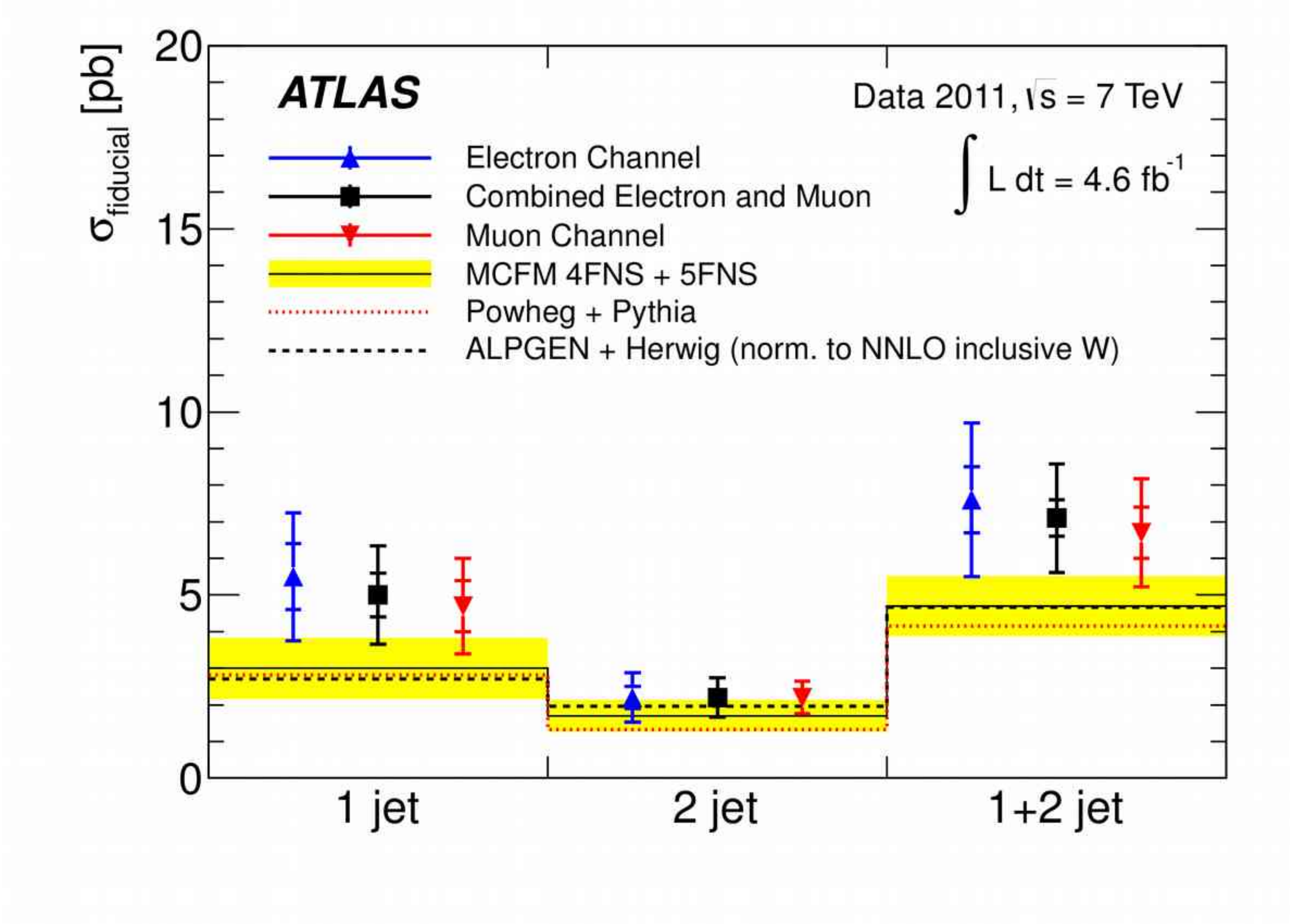






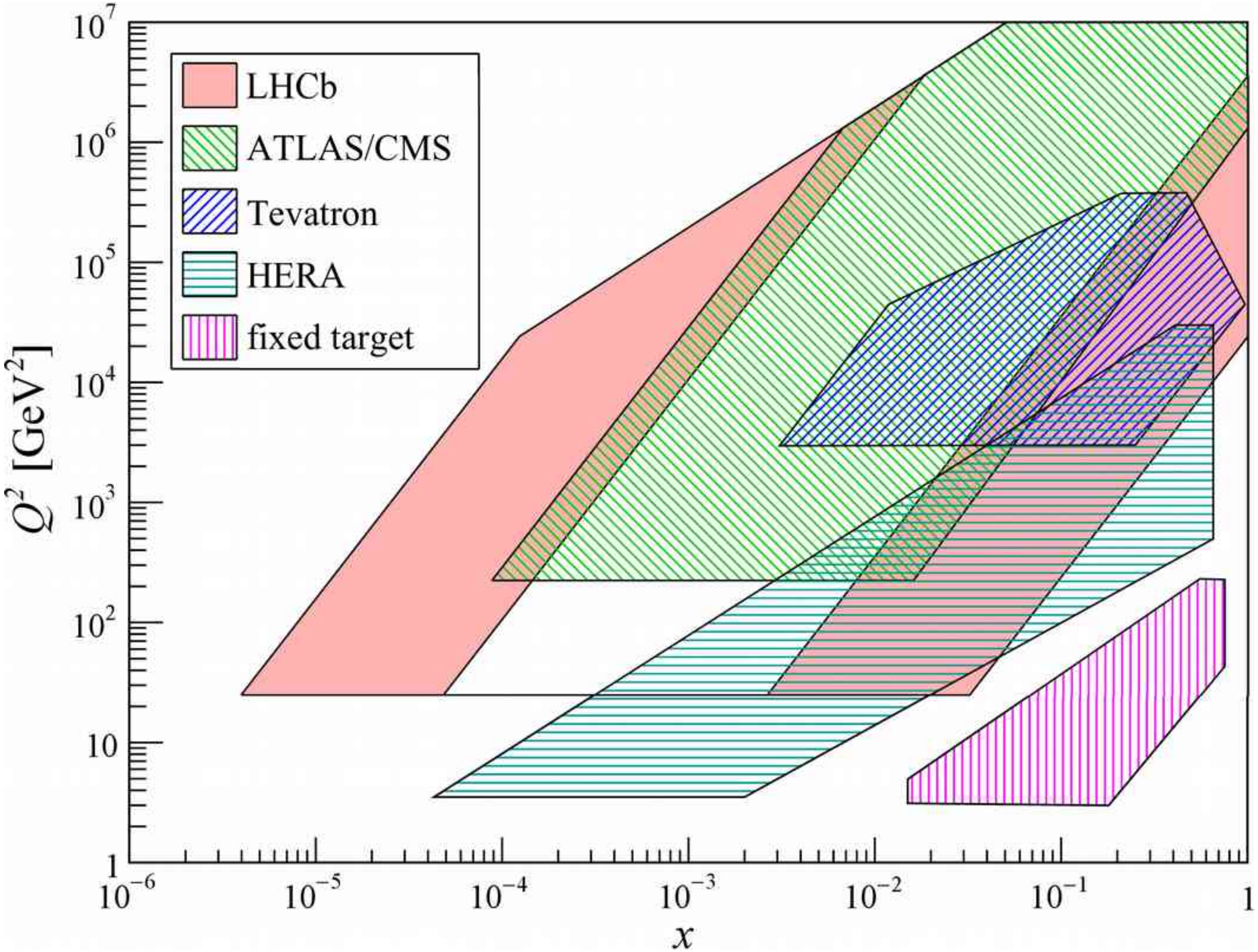
Conclusions

ATLAS W Production



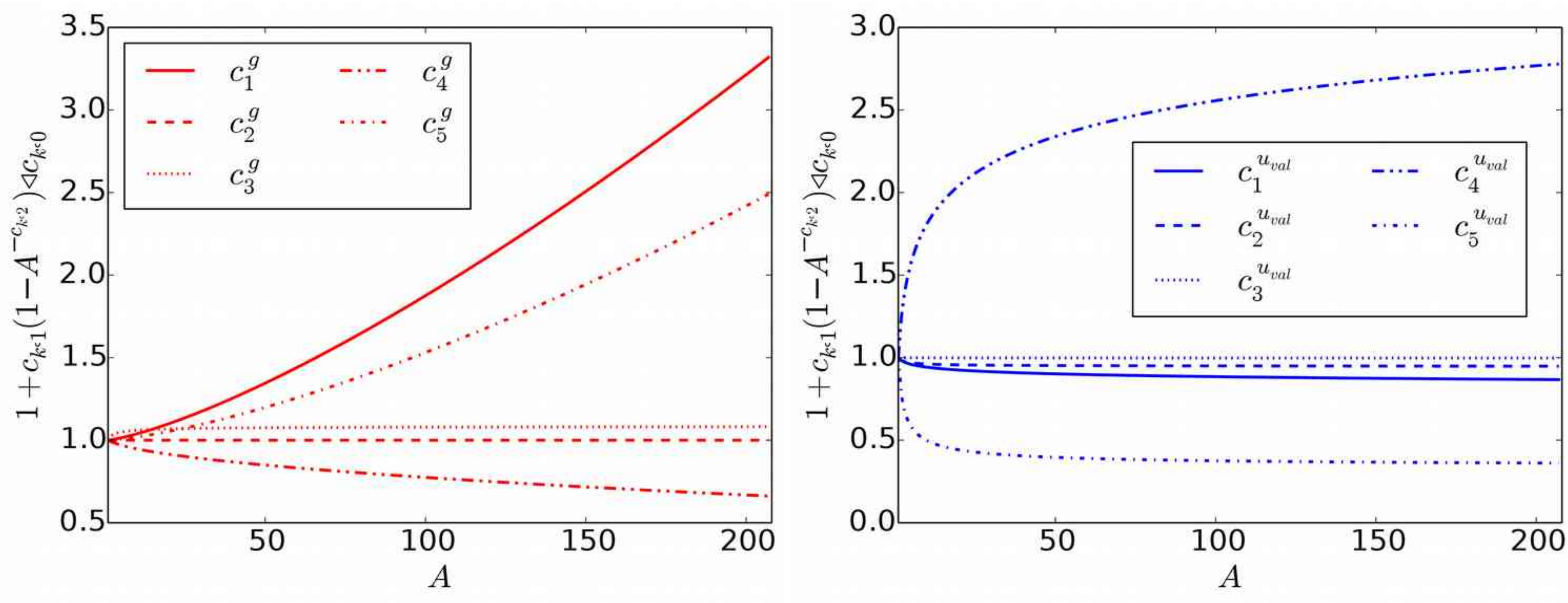
Measurement of the cross-section for W boson production in association with b-jets in pp collisions at sqrt(s) = 7 TeV with the ATLAS detector. JHEP 06 (2013) 084

LHCb Kinematics

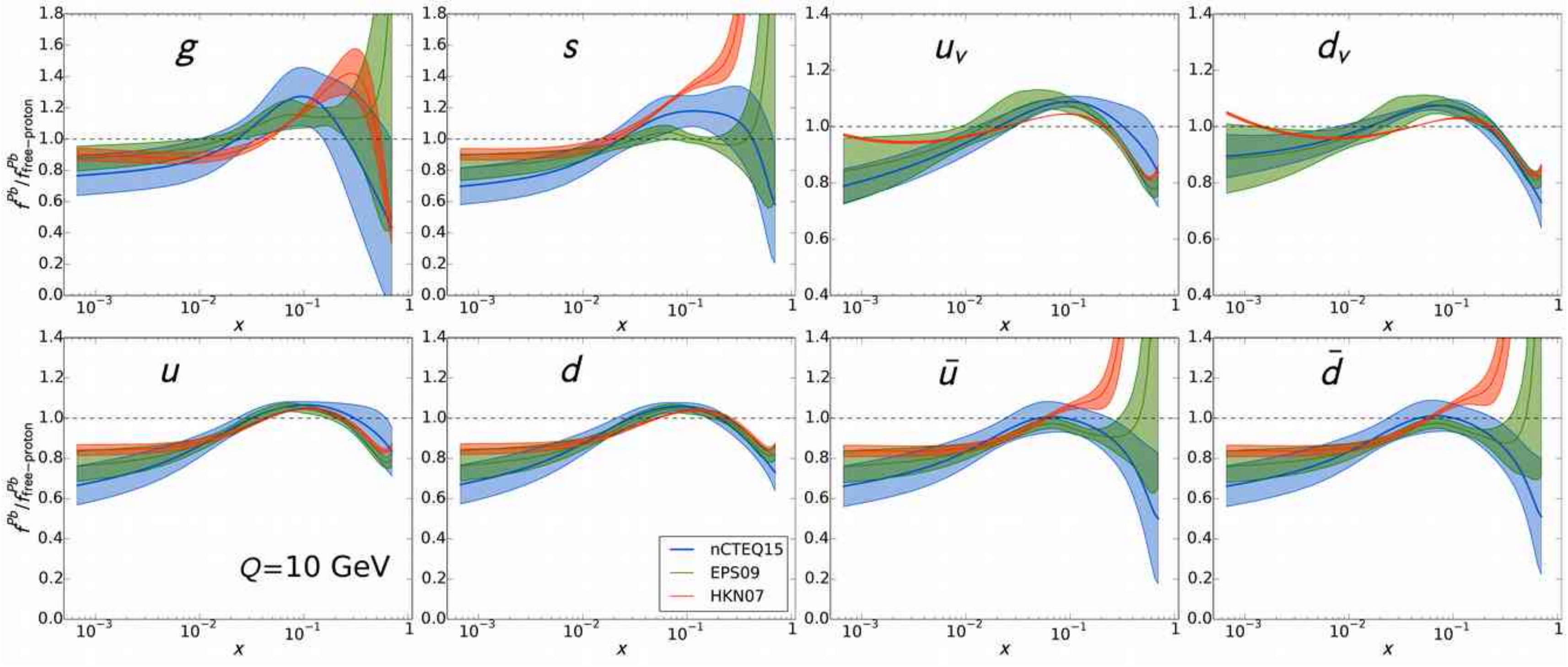


A direct probe of the intrinsic charm content of the proton
Tom Boettcher, Philip Ilten, Mike Williams.
arXiv:1512.06666

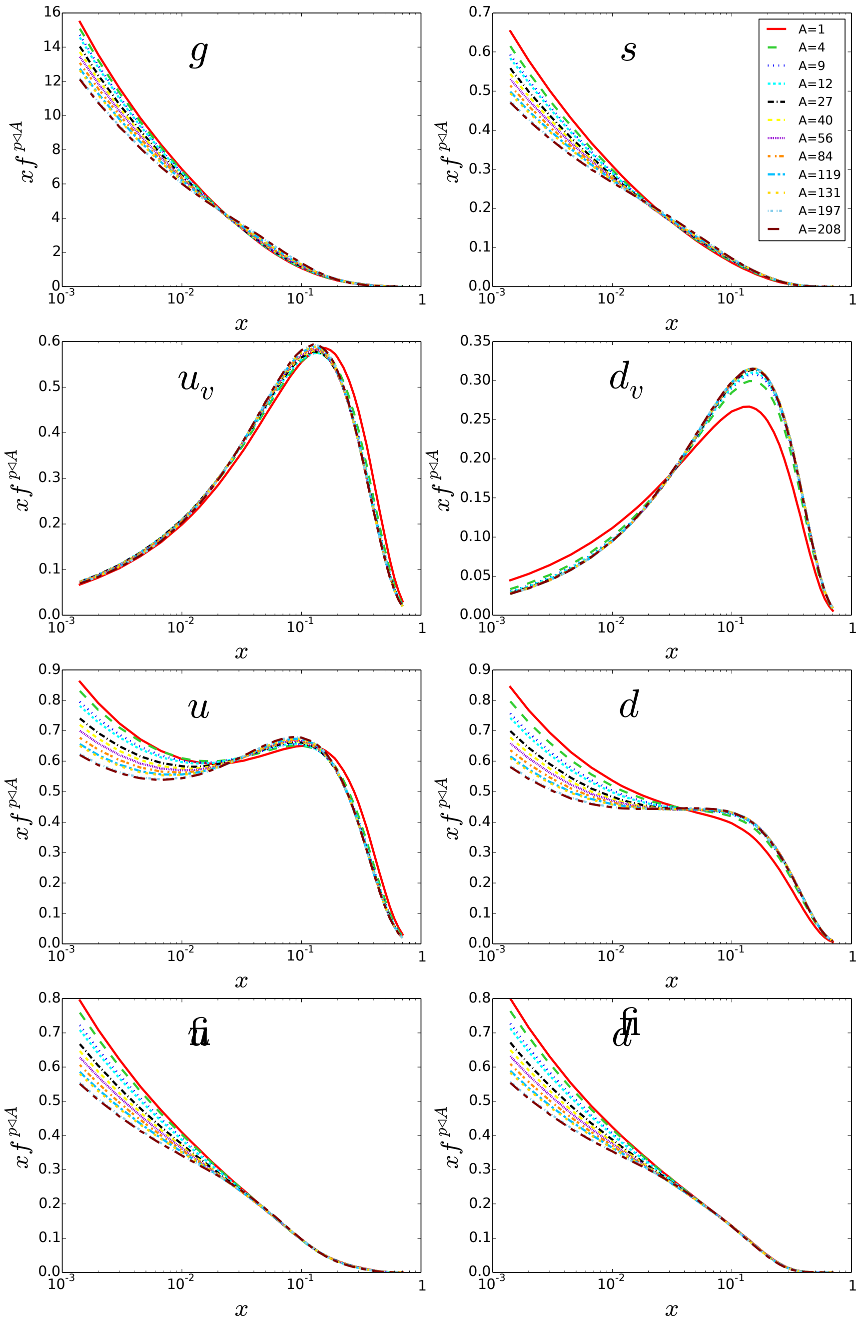
nCTEQ15 A-Dependence

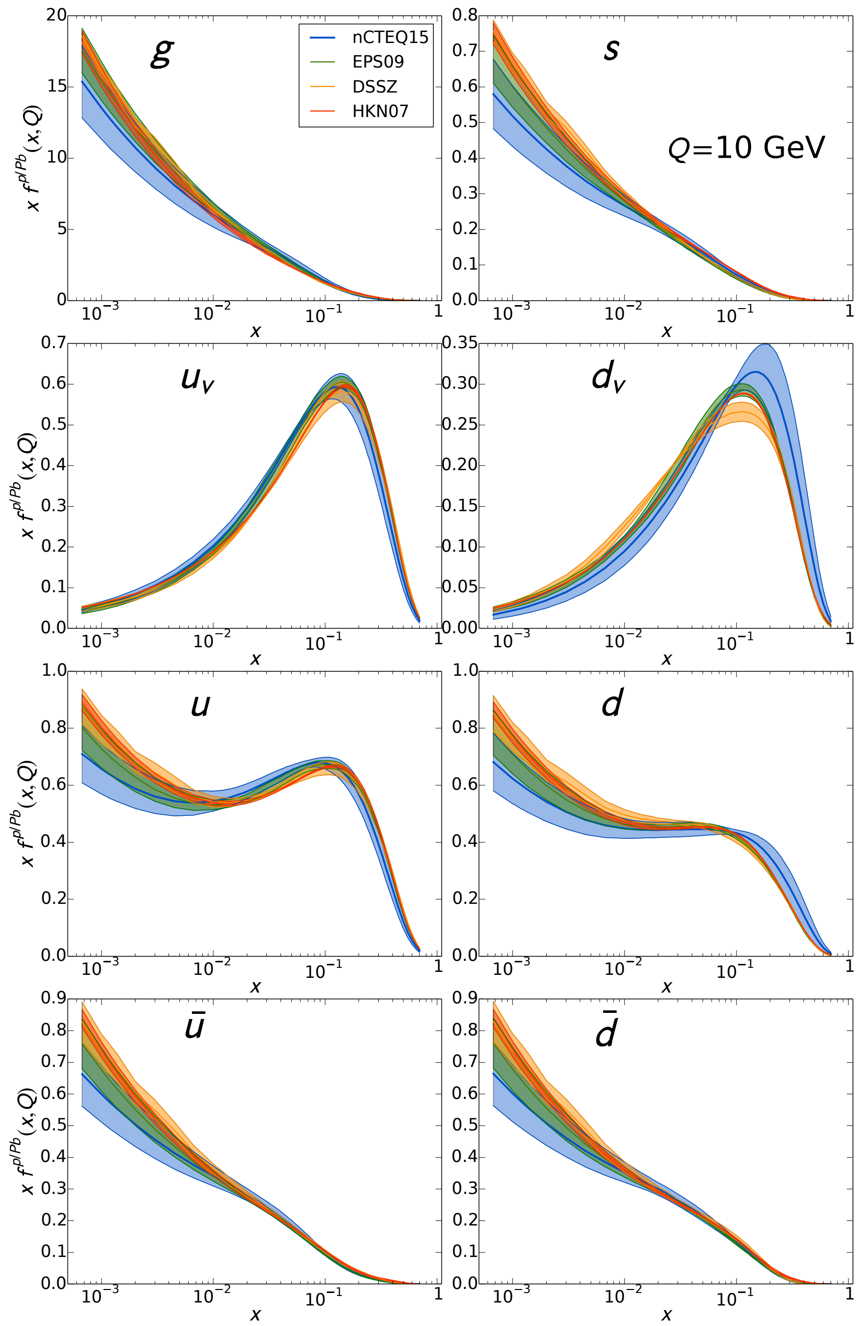


Lead to Proton nPDFs

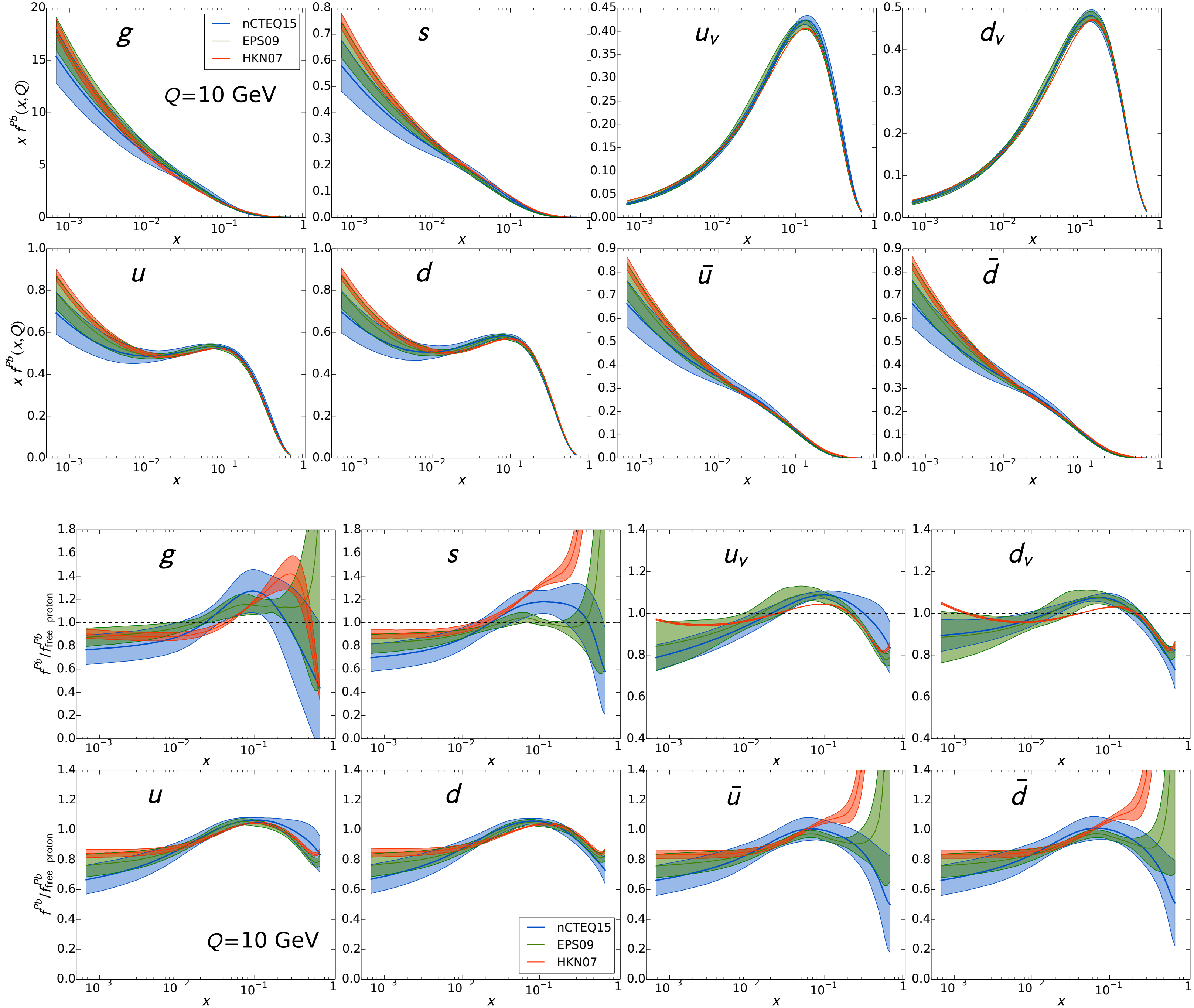


nCTEQ15 PDFs





Lead PDFs



g
s
u_v
d_v
nCTEQ15
EPS09
HKN07
Q=10 GeV
$x\,f^{Pb}(x,Q)$
x
u
d
$\bar{u}$
$\bar{d}$
$f^{Pb}/f^{Pb}_{\text{free-proton}}$