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Constraining PDFs through exclusive processes at the LHCb

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Implications of LHCb measurements '19

*Speaker

Work presented appears in

'*Towards a determination of the low x gluon via exclusive J/psi production*'

CAF, S.P.Jones, A.D.Martin, M.G.Ryskin, T.Teubner, 1907.06471

'*How to include exclusive J/psi production data in global PDF analyses*'

CAF, S.P.Jones, A.D.Martin, M.G.Ryskin, T.Teubner, 1908.08398
Submitted to EPJC

Earlier works

'*Exclusive J/psi and Y production and the low x gluon*'

S.P.Jones, A.D.Martin, M.G.Ryskin, T.Teubner, 1507.06942

'*The exclusive J/psi process at the LHC tamed to probe the low x gluon*'

S.P.Jones, A.D.Martin, M.G.Ryskin, T.Teubner, 1610.02272

Introduction

- Inclusive processes do not well constrain small x/Regge limit domain of PDFs
- Exclusive processes offer sensitive probe of this domain but as of yet not included in global analyses PDF determination - why?
    1. Off forward kinematics imply susceptibility to *GPD* over conventional PDFs
    2. Reliability and stability of theoretical predictions

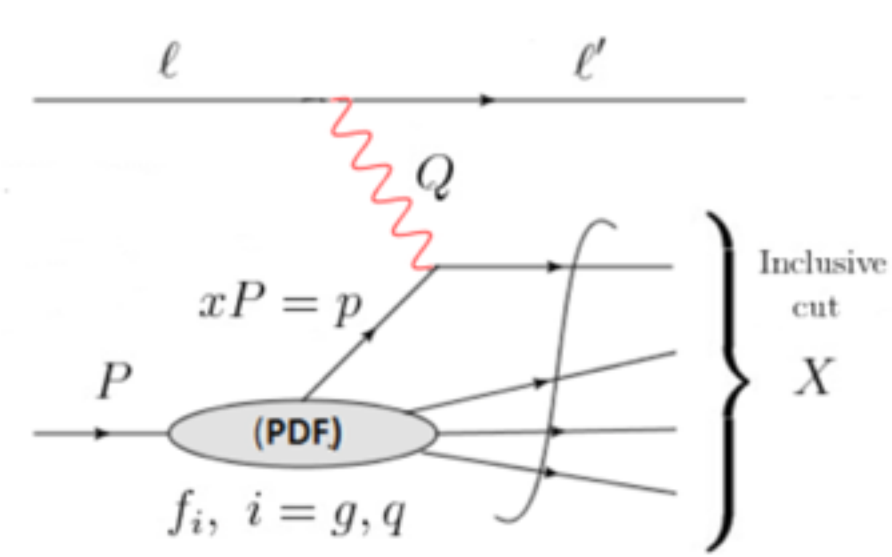
- As higher CM energies are realised at LHC, pushed towards small x domain, W ~ 1/x

$$\frac{\mathrm{d}\sigma}{\mathrm{d}t}(\gamma^* p)\bigg|_{t=0} = \frac{\Gamma_{ee}^{J/\psi} M_{J/\psi}^3 \pi^3}{48\alpha_{\mathrm{em}}} \left[\frac{\alpha_s(\bar{Q}^2)}{\bar{Q}^4} R_g x g(x,\bar{Q}^2)\right]^2 \left(1+\frac{Q^2}{M_{J/\psi}^2}\right)$$

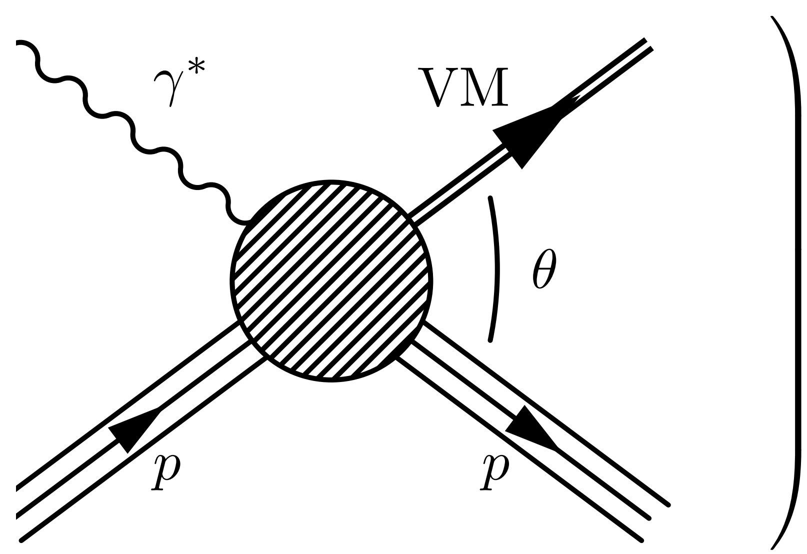
Ryskin 1993

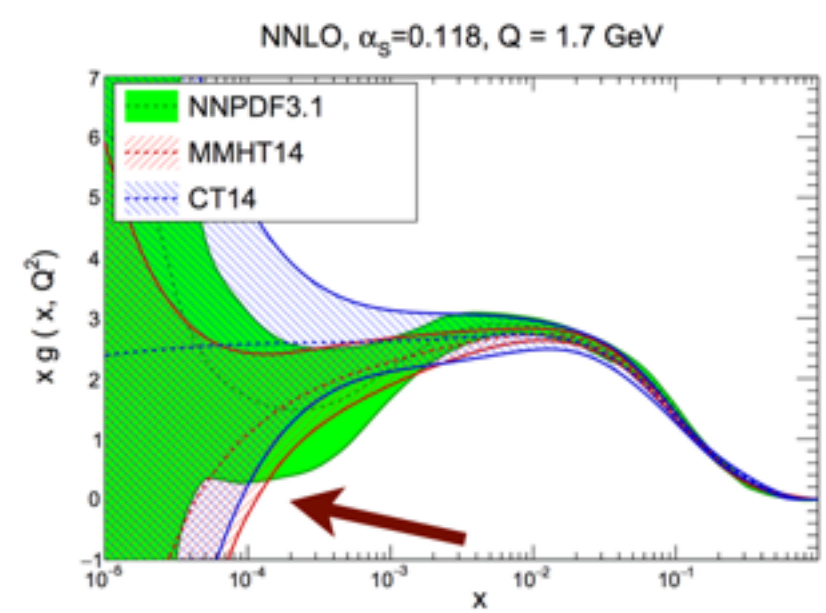
Inclusive - included in global parton analyses

Exclusive - can we use the data?



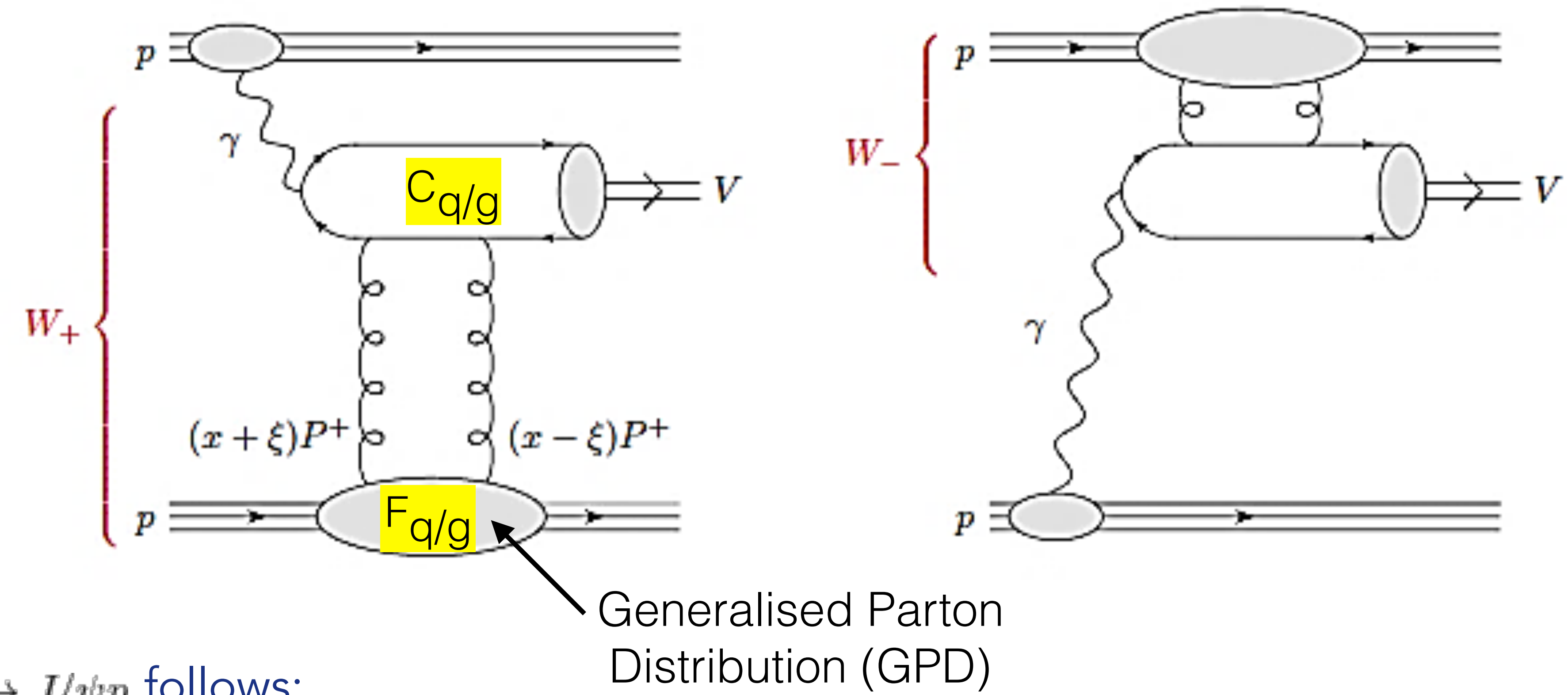
e.g DIS





nnpdf.mi.infn.it

General Set up and assumptions



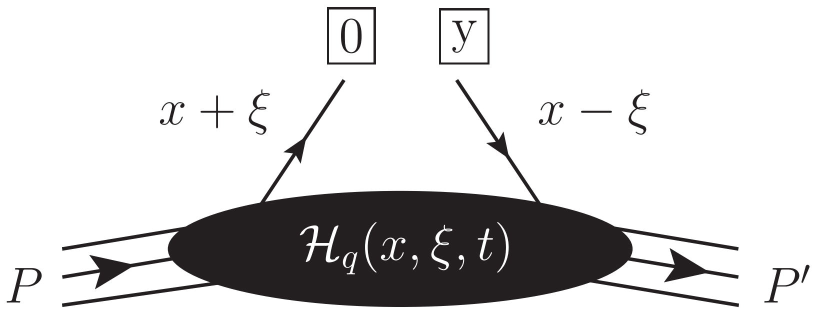
Setup for $\gamma p \to J/\psi p$ follows:
Ivanov, Schäfer, Szymanowski, Krasnikov, 04

- Assume a factorisation $F_{q/g} \otimes C_{q/g} \otimes \phi^V_{Q\bar{Q}}$
- Leading zeroth order term in rel. velocity (NRQCD)
- Colour singlet exchange between hard and soft sectors

$$A \propto \int_{-1}^{1} \mathrm{d}x \left[C_g(x,\xi) F_g(x,\xi) + \sum_{q=u,d,s} C_q(x,\xi) F_q(x,\xi) \right]$$

GPDs and the Shuvaev transform

GPDs generalise PDFs: outgoing/incoming partons carry different momentum fractions Müller 94; Radyushkin 97; Ji 97



$\langle P'|\overline{\psi}_q(y)\mathcal{P}\{\}\psi_q(0)\,|P\rangle$

Shuvaev: Relates GPDs to PDFs at small x under physically motivated assumptions c.f analyticity

Shuvaev 99 Martin et al. 09

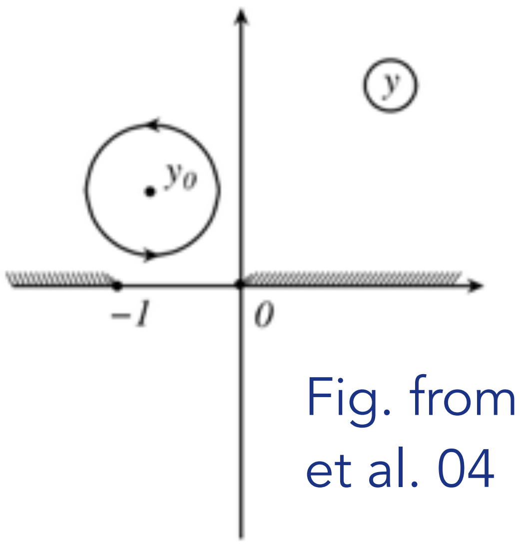


Fig. from Ivanov et al. 04

Idea: Conformal moments of GPDs = Mellin moments of PDFs
(up to corrections of order xi^2)

- Construct GPD grids in multidimensional parameter space x,xi/x,qsq with forward PDFs from LHAPDF
- Costly computationally due to slowly converging double integral transform
- Regge theory considerations => Shuvaev transform valid in space like (DGLAP) region only. In time like (ERBL) region imaginary part of coefficient is zero

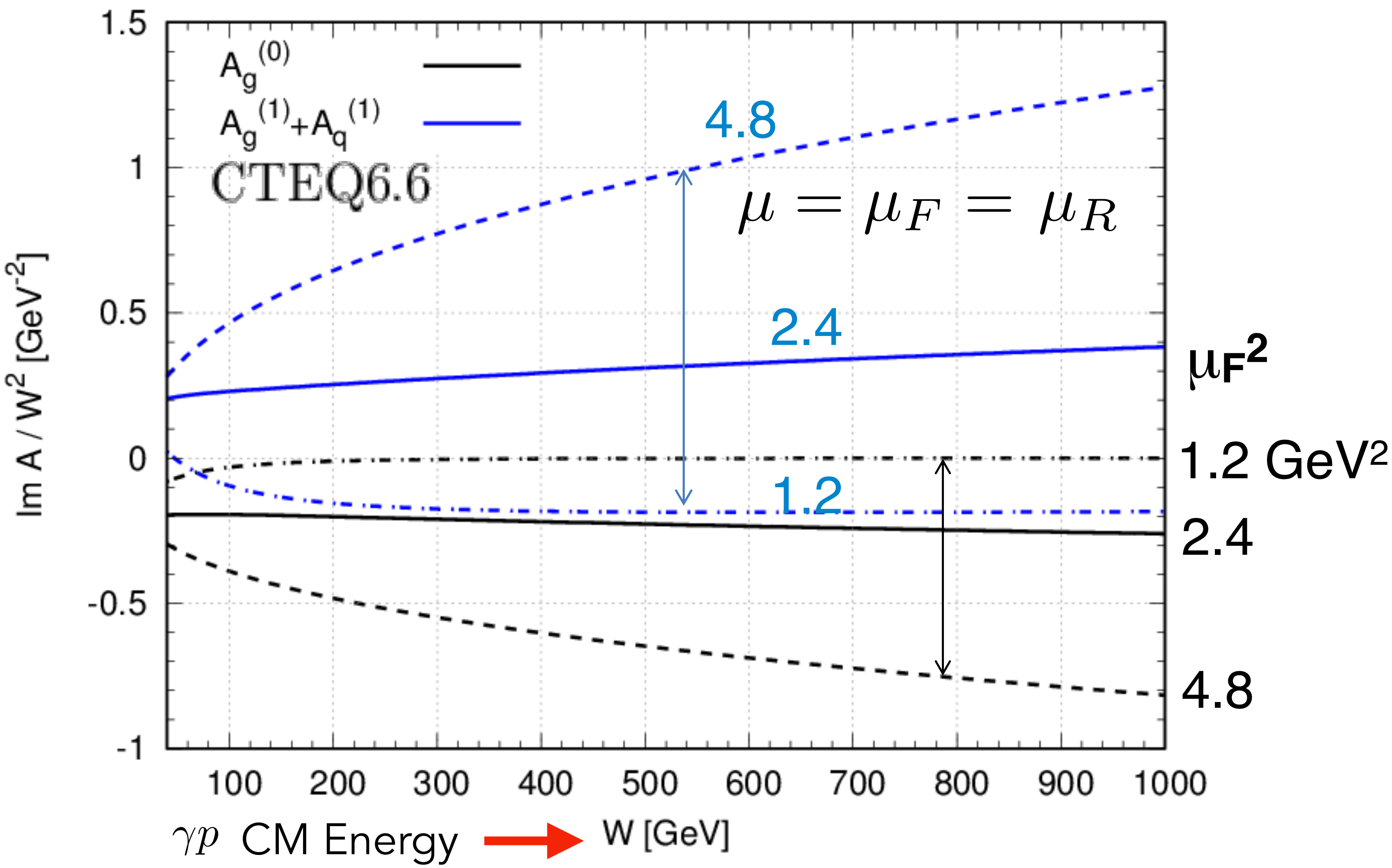
Stability of prediction I

NLO in MSbar scheme

D. Ivanov, B.Pire, L.Szymanowski, J.Wagner, 1411.3750
S.P.Jones, PhD thesis, Liverpool (2014)

A. Bad perturbative convergence **$|NLO_{correctn.}| > |LO|$ and opp. sign**

B. Strong dependence on scale μ_F



Disclaimer: Plots generated using existing global partons. Here, CTEQ6.6

Can do better…

Stability of prediction II

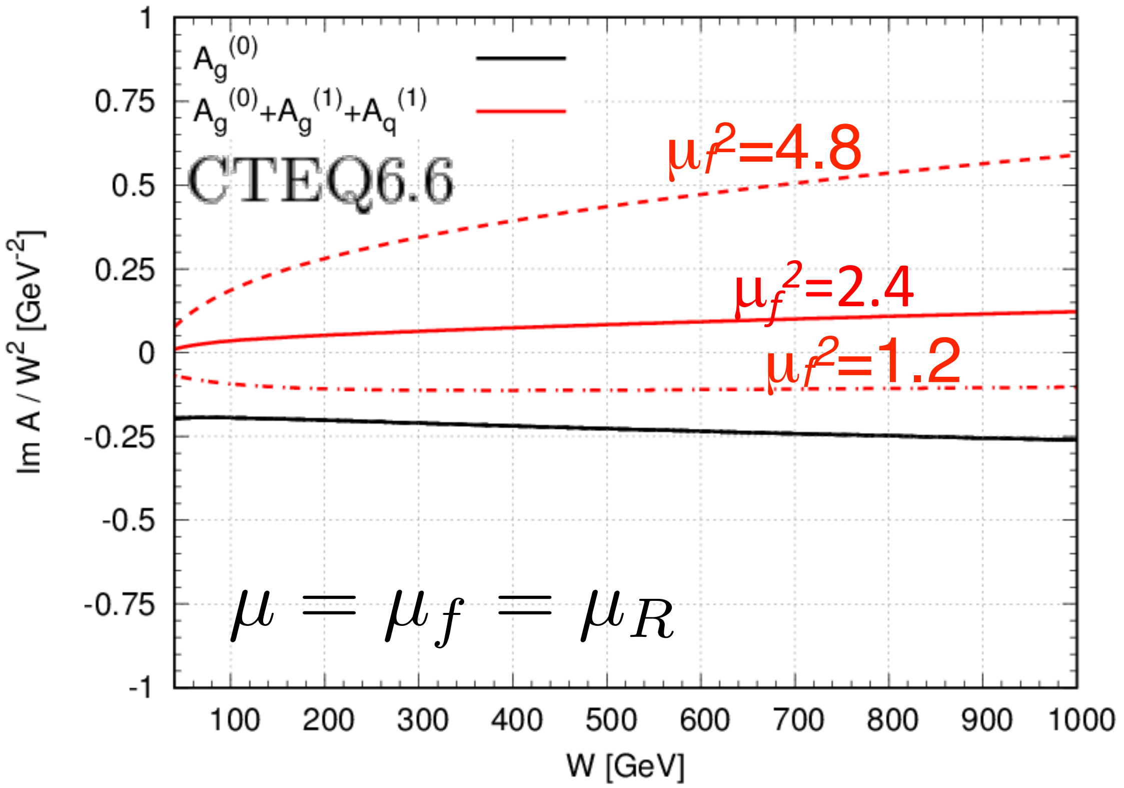
'Scale Fixing'

`Optimal' factorisation scale $\mu_F = m$ eliminates large logs at NLO

S.P.Jones, A.D.Martin, M.G.Ryskin, T.Teubner, 1507.06942

Resummation of $(\alpha_S \ln(1/\xi)\ \ln(\mu_F/m))^n$ terms into LO PDF, leaving remnant NLO coefficient and residual, μ_f, scale dependence

Fix: $\mu_F^2 = 2.4\ \mathrm{GeV}^2$

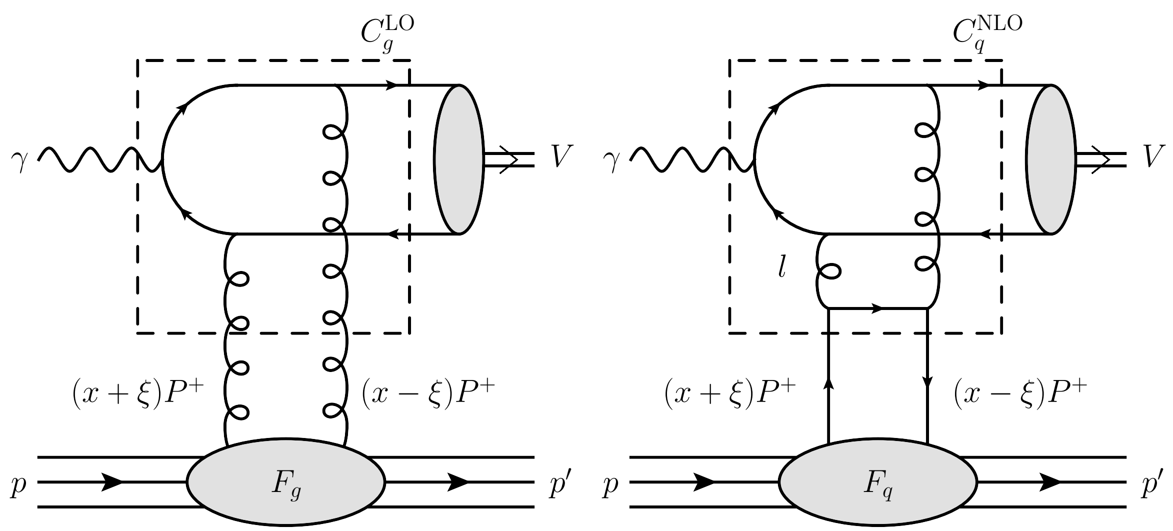


$$A(\mu_f) = C^{LO} \times GPD(\mu_F) + C^{NLO}(\mu_F) \times GPD(\mu_f)$$

Look for another sizeable correction that can reduce variations further -> implementation of a **`Q0'** cut

Stability of prediction III

`Q0' cut   S.P.Jones, A.D.Martin, M.G.Ryskin, T.Teubner, 1610.02272



Subtract DGLAP contribution

NLO ($|q^2|<Q_0^2$)

from known NLO MSbar coefficient function to avoid a double count with input GPD at Q0.

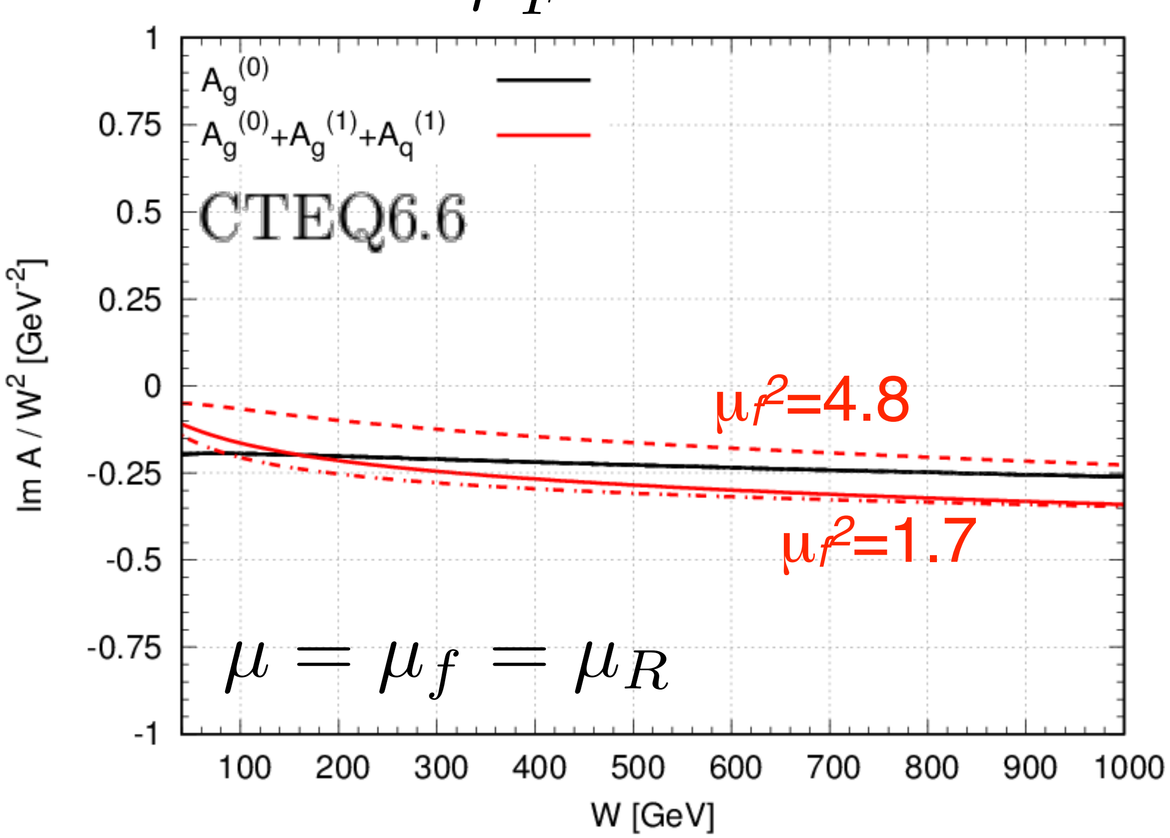
Typically power suppressed, but sizeable here

$$\mathcal{O}(Q_0^2/M_{J/\psi}^2)$$

→

How do these predictions map onto the data at HERA and LHCb?

Fix: $\mu_F^2 = 2.4\ \mathrm{GeV}^2$



Philosophy

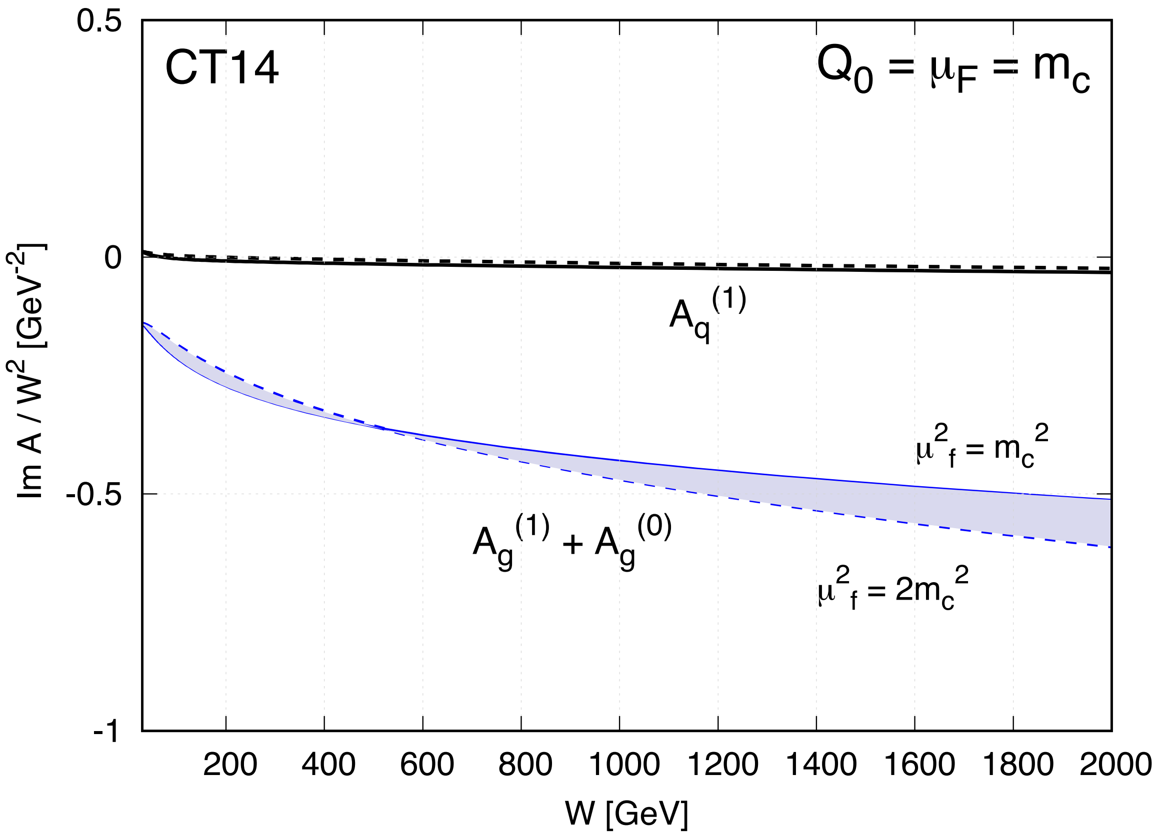
CAF, S.P.Jones, A.D.Martin, M.G.Ryskin, T.Teubner, 1907.06471 & 1908.08398

Philosophy:

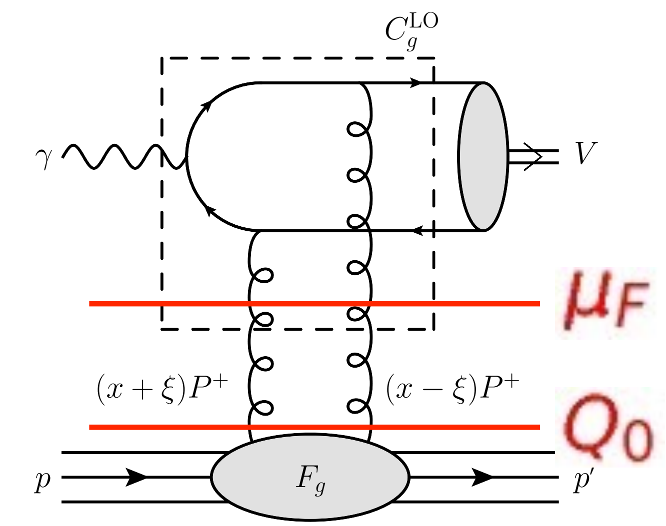
- I) Achieve cross section stability in small parameter space
- II) Any deficiency in LHCb regime attributed to small x global fitter behaviour

Choices:

- Q_0^2 IR transition parameter
- $\mu_F = m_c$ to resum large logarithm at high energy
- $\mu_f = \mu_R$ in accordance with BLM prescription

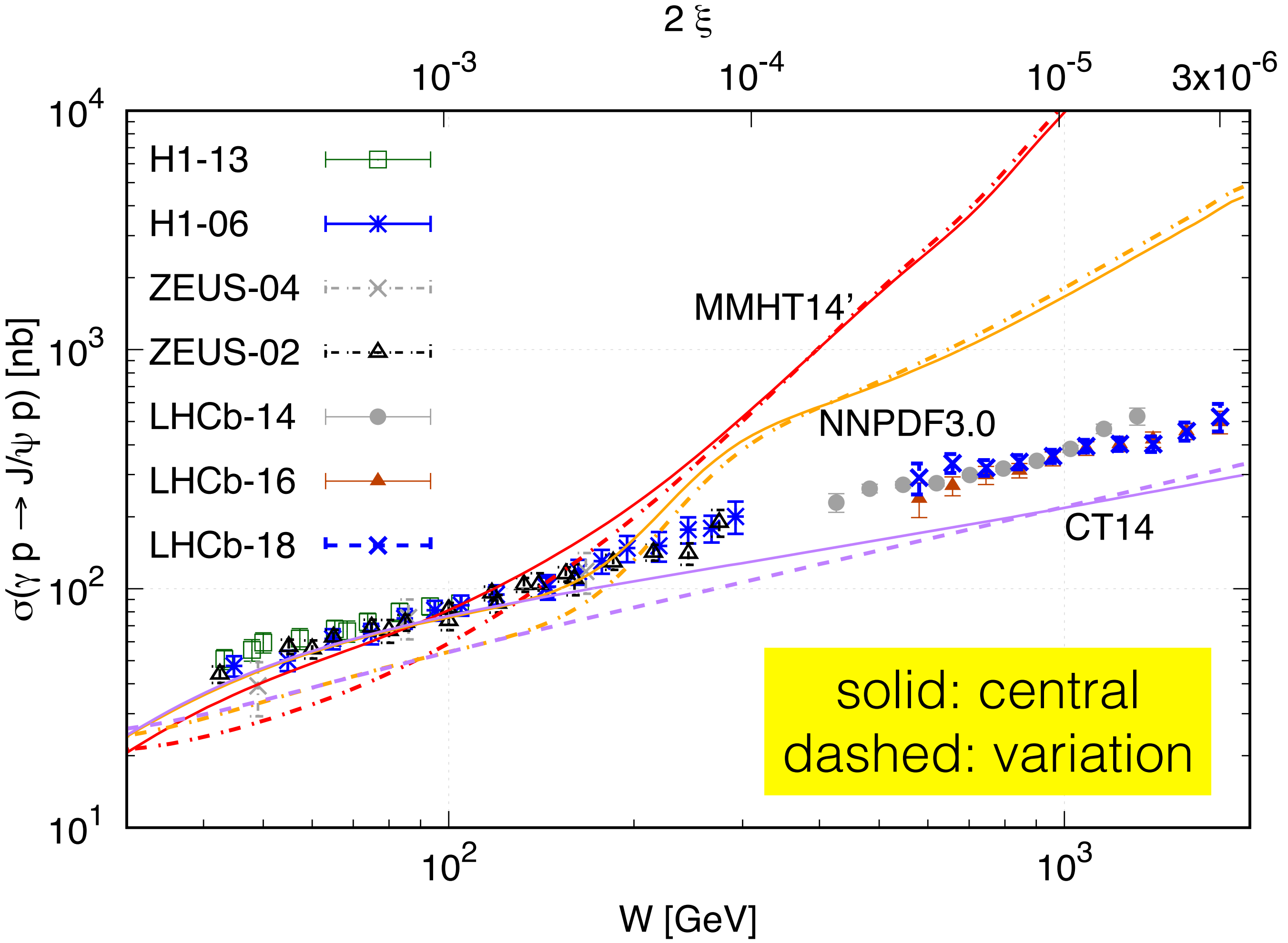


- Exclusive J/psi probe of gluon density, quark contribution effectively absorbed by Q0 subtraction



Cross section stability

- Regge based arguments => imaginary part of amplitude dominant
- Nonetheless, may restore real part through dispersion relation - numerically evaluate perturbation $\frac{\mathrm{Re}\mathcal{M}}{\mathrm{Im}\mathcal{M}} \sim \frac{\pi}{2}\lambda = \frac{\pi}{2}\frac{\partial \ln \mathrm{Im}\mathcal{M}/W^2}{\partial \ln W^2}$ with $\mathcal{M} \sim x^{-\lambda}$
- Achieved good cross section stability at $Q_0 = \mu_F = m_c$ and with variations w.r.t $\mu_f^2, \mu_R^2 \in [m_c^2, 2m_c^2]$



Repeat Disclaimer: Convoluting with existing global partons. Here, MMHT14, NNPDF3.0 & CT14

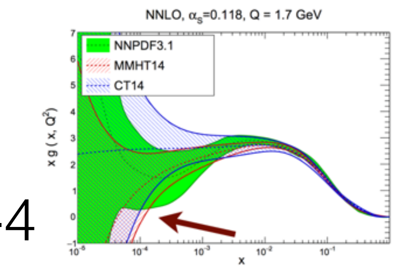
Plot demonstrates good scale stability of our NLO predictions in LHCb regime

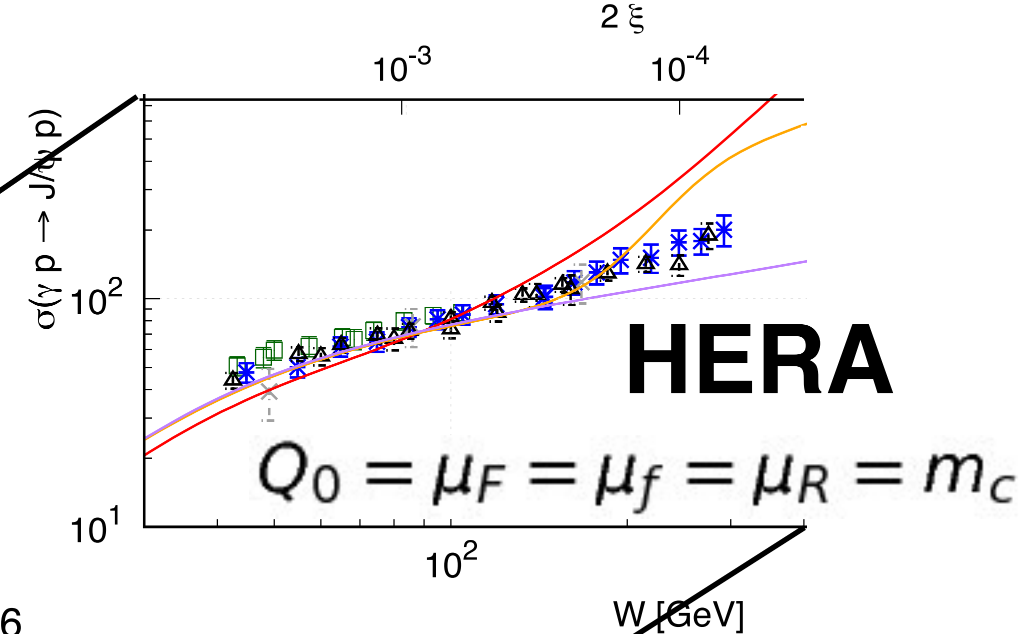
Predictions at optimal scale (solid) agree better with HERA data

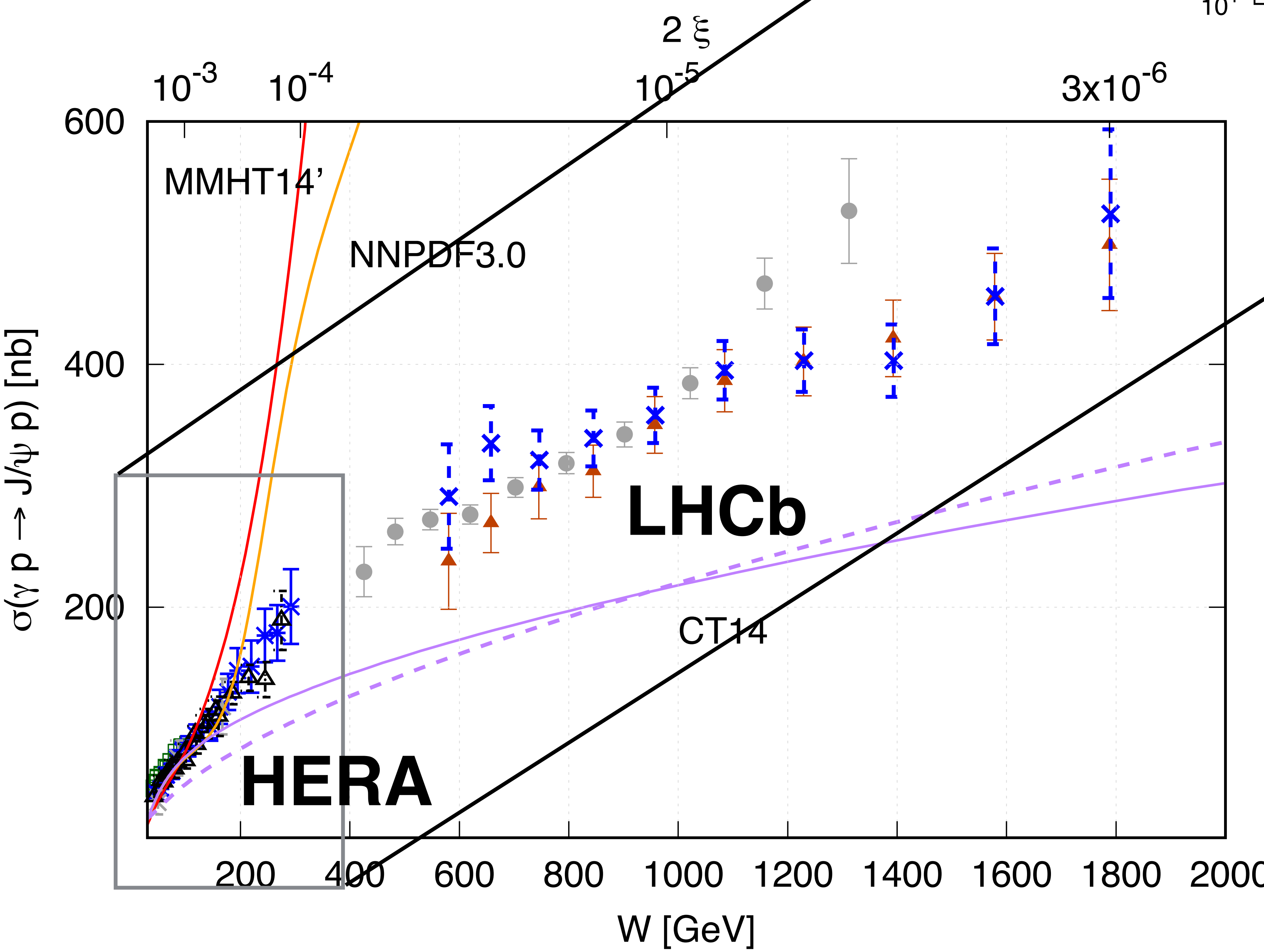
CAF, S.P.Jones, A.D.Martin, M.G.Ryskin, T.Teubner, 1907.06471 & 1908.08398

Towards the bigger picture

- NNPDF3.0 and MMHT central values overshoot HERA data towards x ~10^{-4}, but is covered by 1sigma error band (see next)







- But wildly different behaviours in LHCb regime! Important message….

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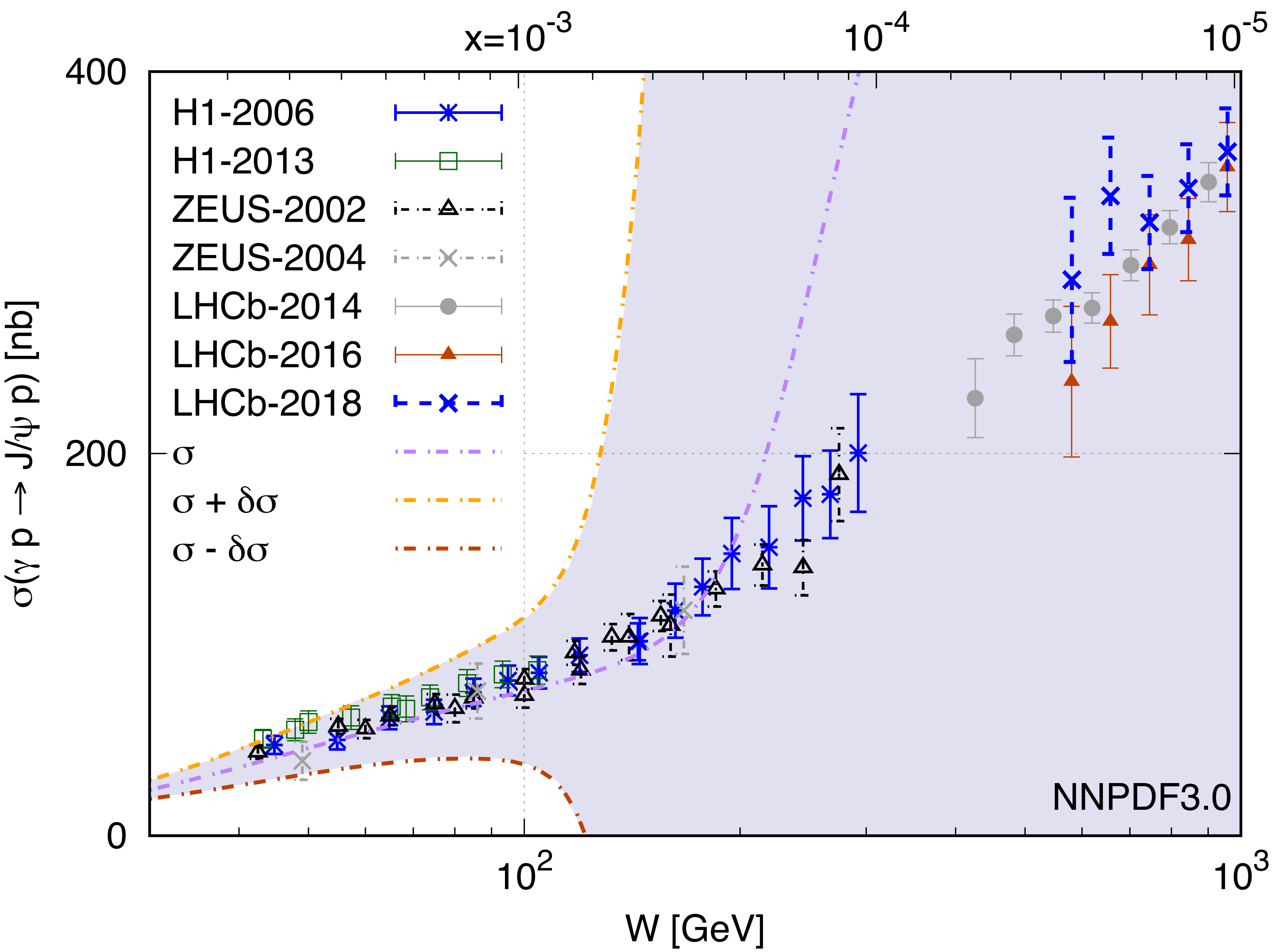
Error budgets: errors due to parameter variations in global fits >> experimental uncertainty and scale variations in the theoretical result

…… exclusive data now in a position to readily improve global analyses



Exclusive LHCb data will constrain small x growth whilst *exclusive* HERA data will improve determination of partons in regime with data constraints already from diffractive DIS HERA data

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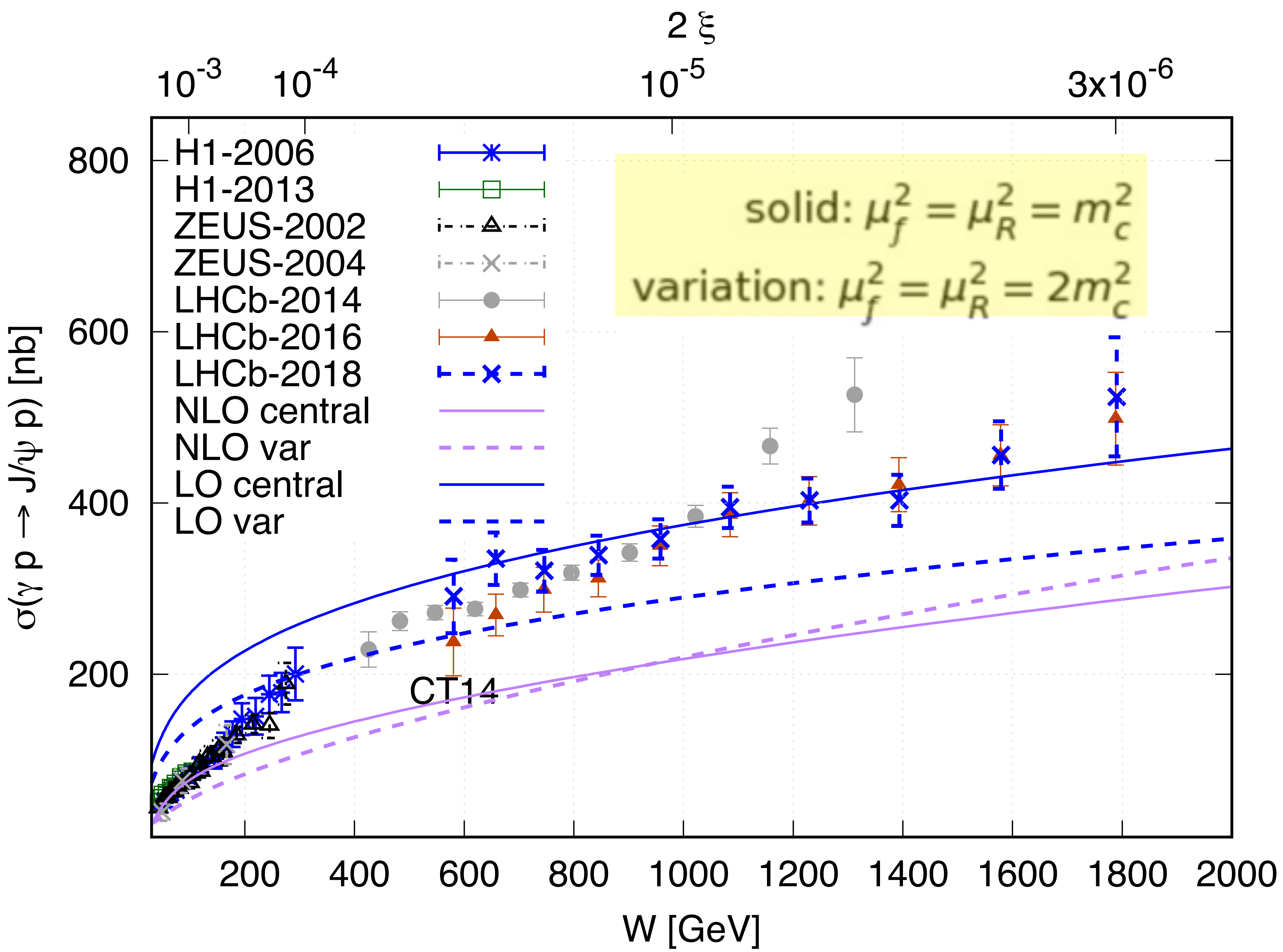
Summary

- Naive MSbar NLO coll. fact. result unreliable and unstable
- Systematic taming via ‘Q0’ cut and resummation of large logarithmic contributions collectively reduce wild scale variations
- Mapped predictions to cross section level with good stability observed and central values in agreement of data within 1sigma error bands
- MMHT14’ and NNPDF3.0 largely overshooting data in LHCb regime
- Upshot: Exclusive data constrains the growth of these partons, certain small x behaviours must be rejected to permit reconciliation with our data constraint.
- In a position to finally use this exclusive data in a global fitter framework

Thank you

Backups



Achieve better stability in going from LO -> NLO

NLO correction in better agreement with HERA

Reasonable description of LHCb regime at LO interpreted as coincidental: indeed curve is flatter with wrong W growth

Shuvaev Transform

Full Transform:

$$\mathcal{H}_q(x,\xi) = \int_{-1}^{1} \mathrm{d}x' \left[\frac{2}{\pi}\mathrm{Im}\int_0^1 \frac{\mathrm{d}s}{y(s)\sqrt{1-y(s)x'}}\right] \frac{\mathrm{d}}{\mathrm{d}x'}\left(\frac{q(x')}{|x'|}\right),$$

$$\mathcal{H}_g(x,\xi) = \int_{-1}^{1} \mathrm{d}x' \left[\frac{2}{\pi}\mathrm{Im}\int_0^1 \frac{\mathrm{d}s(x+\xi(1-2s))}{y(s)\sqrt{1-y(s)x'}}\right] \frac{\mathrm{d}}{\mathrm{d}x'}\left(\frac{g(x')}{|x'|}\right),$$

$$y(s) = \frac{4s(1-s)}{x+\xi(1-2s)}.$$