How to include LHCb exclusive J/ψ data in global PDF analyses

arXiv 1908.08398

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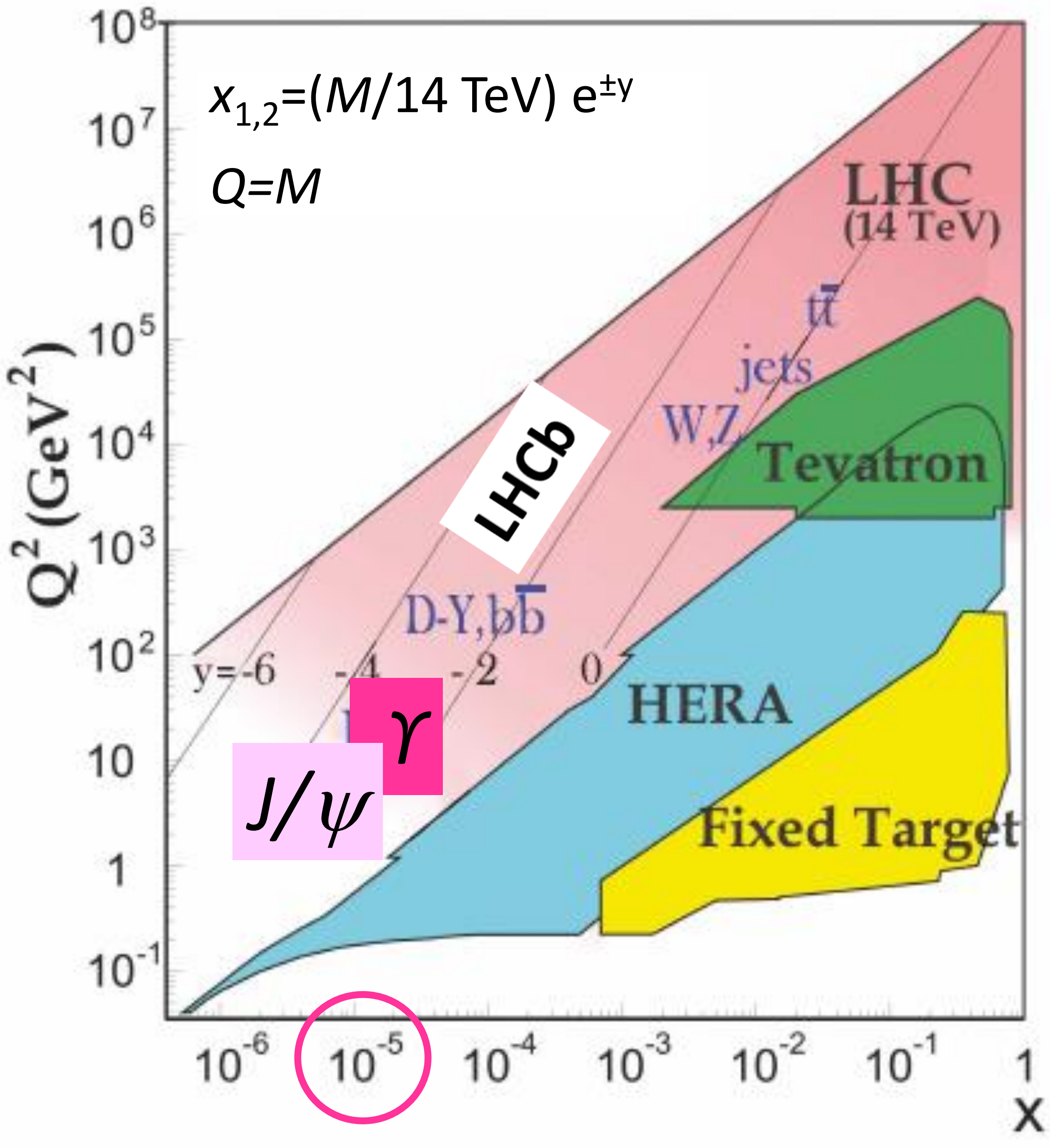
$pp \rightarrow p + J/\psi + p$

PDF4LHC meeting
IPPP, Durham
September, 2019



$pp \rightarrow p + J/\psi + p$

LHCb with $2 < y < 4.5$ can probe gluon down to $x \sim 3 \times 10^{-6}$

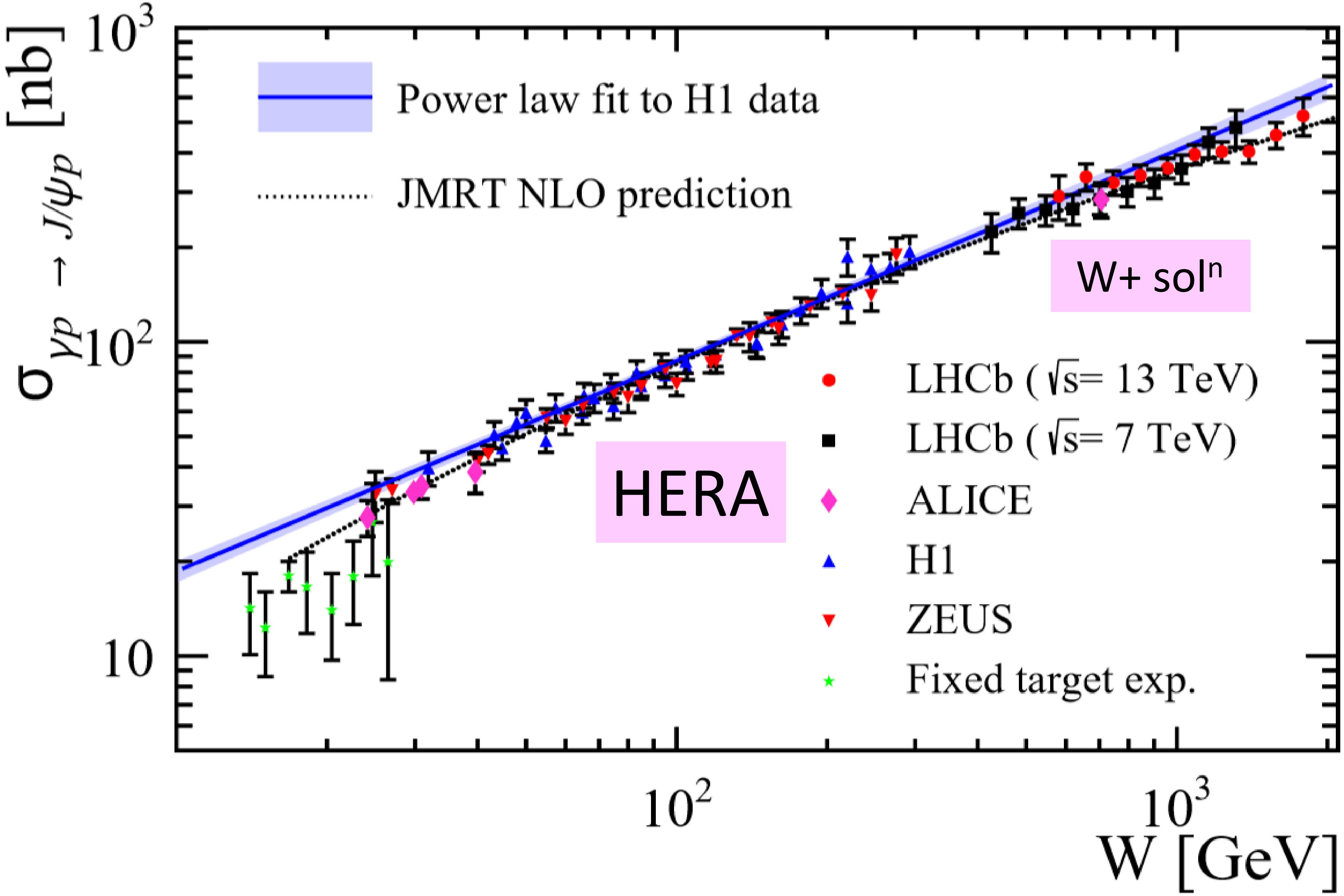
exclusive J/ψ, Υ
[$Q=M_V/2$ (scale)]

Why are these LHCb data not used in global PDF fits ??

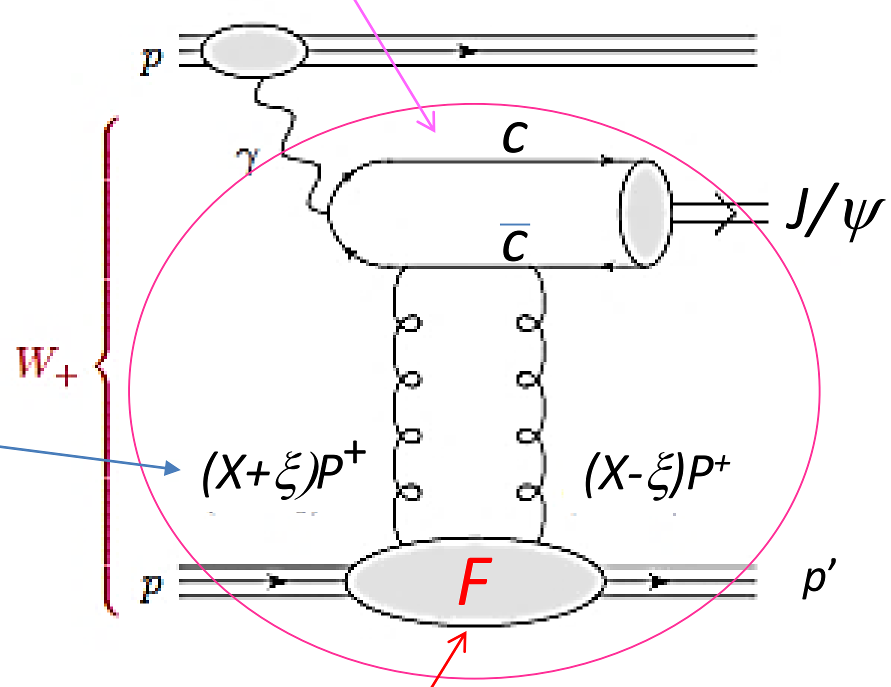
$\gamma p \rightarrow J/\psi\, p$

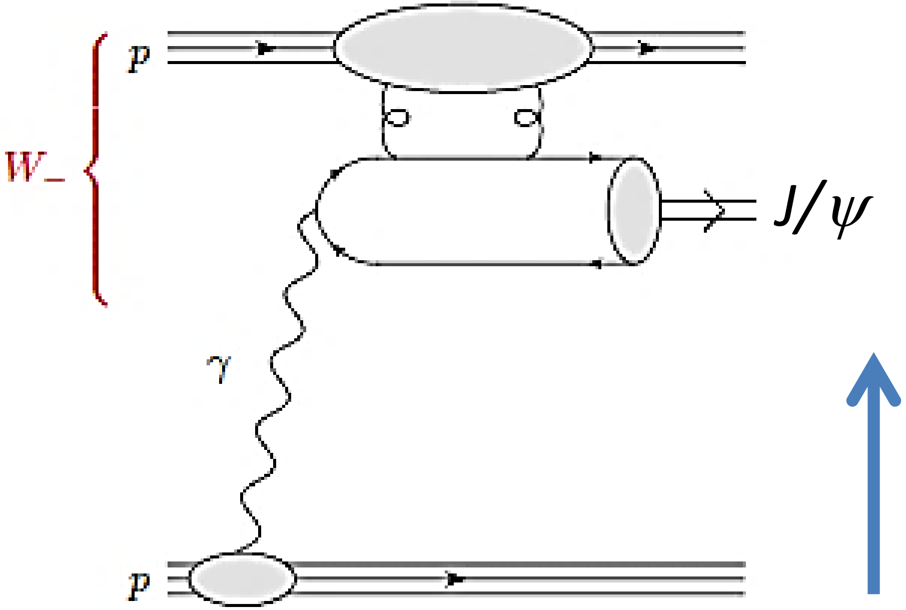
LHCb “data”

1806.04079



$\gamma^* p \rightarrow J/\psi + p$ is the quasi-elastic process which drives the LHC data for $pp \rightarrow p + J/\psi + p$





rapidity

$x = X + \xi$

$x' = X - \xi$

$x >> x'$

$x \sim 2\xi$

GPD: $F(X, \xi, \mu_F^2)$

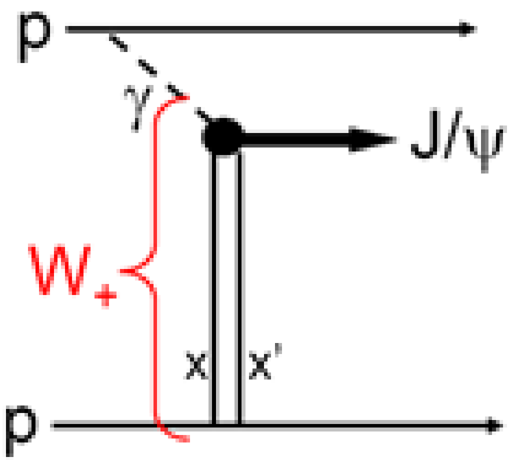
$(p' - p = \xi(p + p'))$

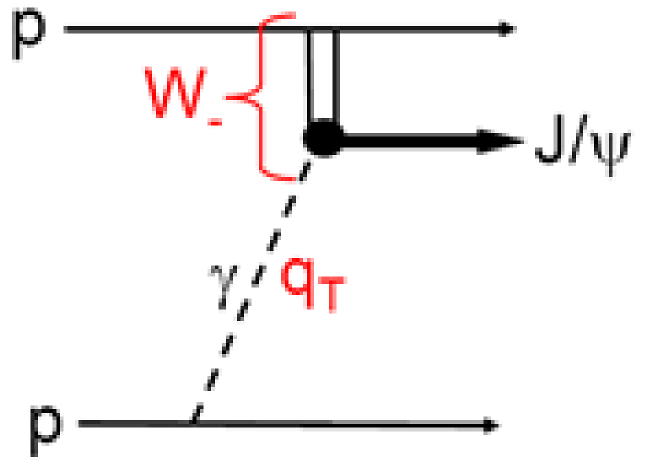
but 2 diagrams

pp → p + J/ψ + p at the LHC

$$W_{\pm}^2 = M_{J/\psi}\sqrt{s}\ e^{\pm|y|}$$

γp, pγ ambiguity





|y|=4

$x \sim M_{J/\psi}\exp(-|y|)\ /\sqrt{s} \sim 10^{-5}$

$x \sim M_{J/\psi}\exp(|y|)\ /\sqrt{s} \sim 0.02$

Data LHCb

Show W+

HERA gives W-

$$\frac{d\sigma^{th}(pp)}{dy} = S^2(W_+)\left(k_+\frac{dn}{dk_+}\right)\sigma_+^{th}(\gamma p) + S^2(W_-)\left(k_-\frac{dn}{dk_-}\right)\sigma_-^{th}(\gamma p)$$

where (...) is photon flux for photon energy $k_{\pm}$

and S^2 are survival probabilities of LRG

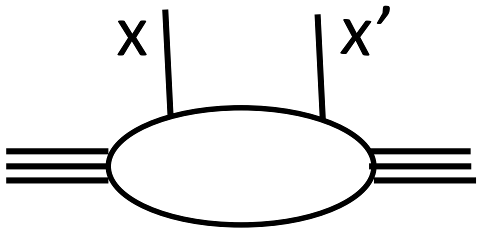
interference between diagrams is negligible

Problems of using exclusive J/ψ data in global PDF fits?

1. Process described by GPD's

→ however not a problem for 1 >> x >> x' ~ 0

GPD(X,ξ) = PDF(x) ⊗ Shuvaev(ξ,x,x') to O($x \sim 2\xi$)



hep-ph/9902410

2. Bad convergence of LO, NLO,... pert. series

additional gluons = $\langle n\rangle \simeq \frac{\alpha_s N_C}{\pi} \ln(1/\xi)\, \Delta \ln \mu_F^2$ ~ 5

whereas **NLO** allows the addition of only 1 gluon !

Prob. to emit g in some $\Delta\mu_F$ enhanced by large longit. phase space ln(1/ξ) at low x

So why is the JMRT "NLO" prediction so reasonable?

1307.7099

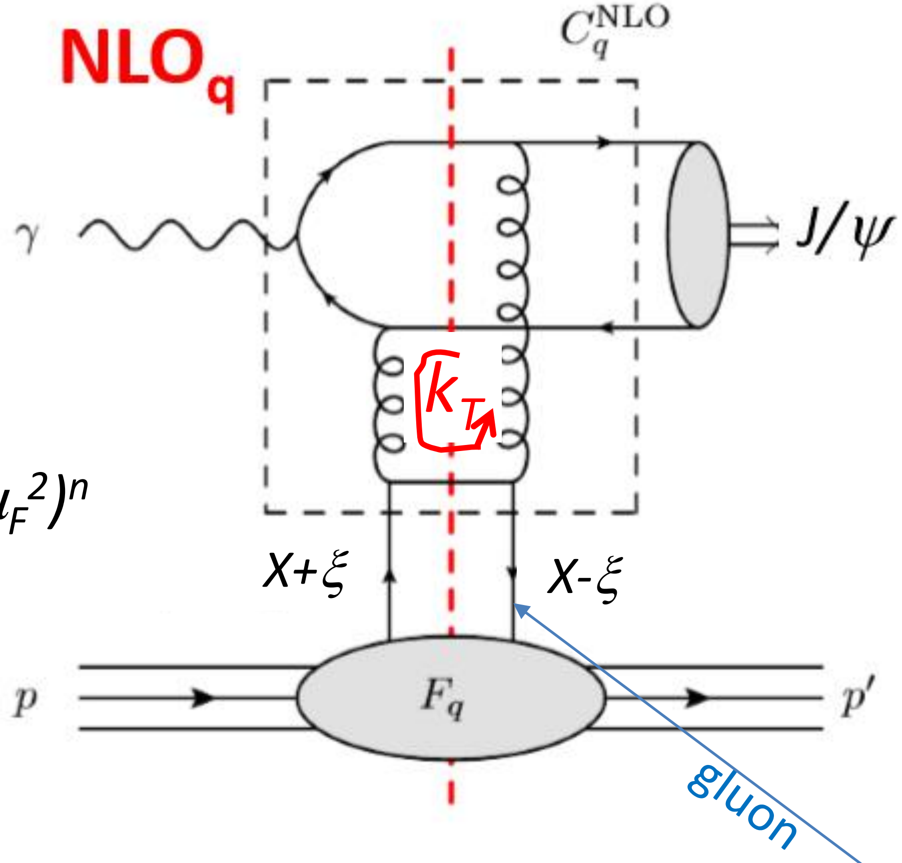
It uses **k_T fact^n** scheme which resums the ln(1/ξ) diagrams

An aside to explain:

k_T fact^n procedure

Obtain approx NLO corr^{ns} to coeff. fns by performing explicit k_T integration in the last step of evolution, and using an input PDF with resummed $(\alpha_s \ln(1/\xi) \ln \mu_F^2)^n$ terms arising from ladder diag^s.

Not the complete NLO, but includes most important diagrams at low x and low μ_F^2



also NLO$_g$ coeff. fn.

Need gluon PDF unintegrated over k_T

$$f(x,k_T^2) = \partial \left[xg(x,k_T^2) T(k_T^2,\mu^2) \right] / \partial \ln k_T^2$$

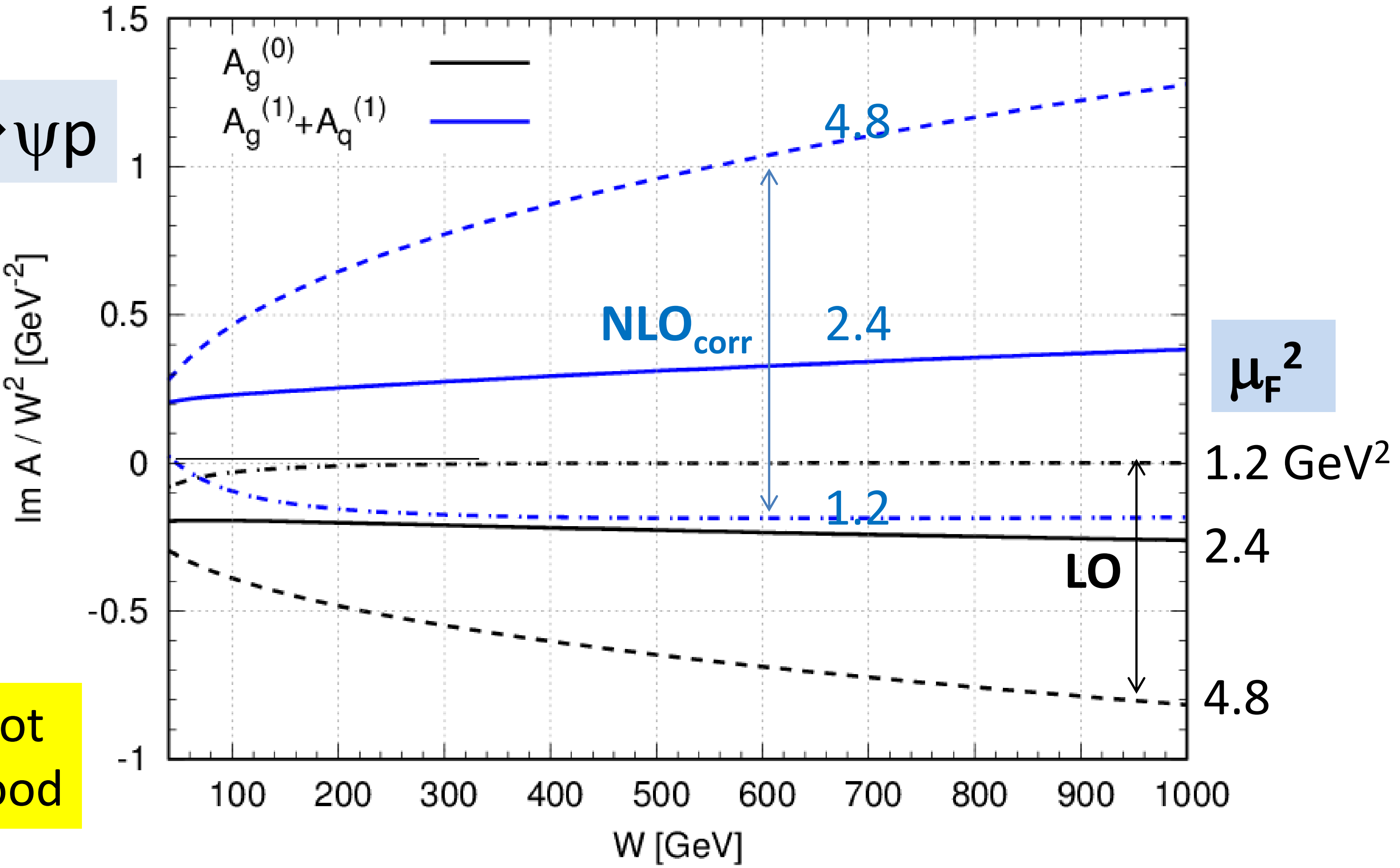
known Sudakov factor T so no additional gluons > k_T emitted

NLO known in MS(bar) scheme, but problems:

D. Ivanov, B.Pire, L.Szymanowski, J.Wagner, 1411.3750
S.P.Jones, A.D.Martin, M.Ryskin, T.Teubner, 1507.06942

A. Bad perturbative convergence $|NLO_{correctn.}| > |LO|$ and opp. sign
B. Strong dependence on scale μ_F

$\gamma p \rightarrow \psi p$



Does not look good

We saw why it is a problem at low ξ

gluons emitted = $\langle n \rangle \simeq \frac{\alpha_s N_C}{\pi} \ln(1/\xi)\, \Delta \ln \mu_F^2$ ~ 5

for ξ << 1 and reasonable variation of μ_F

whereas NLO only allows emission of one gluon !

however can resum $(\alpha_s \ln(1/\xi) \ln\mu_F^2)^n$ terms and move into LO contrib. by choosing $\mu_F = m_c$ (see JMRT, 1507.06942)

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

Use explicit NLO to calculate small remainder C_{rem}.
Residual dependence on scale μ_f is small

Aside: choice of renormalization scale

Choose $\mu_R = \mu_F$.   Two reasons:

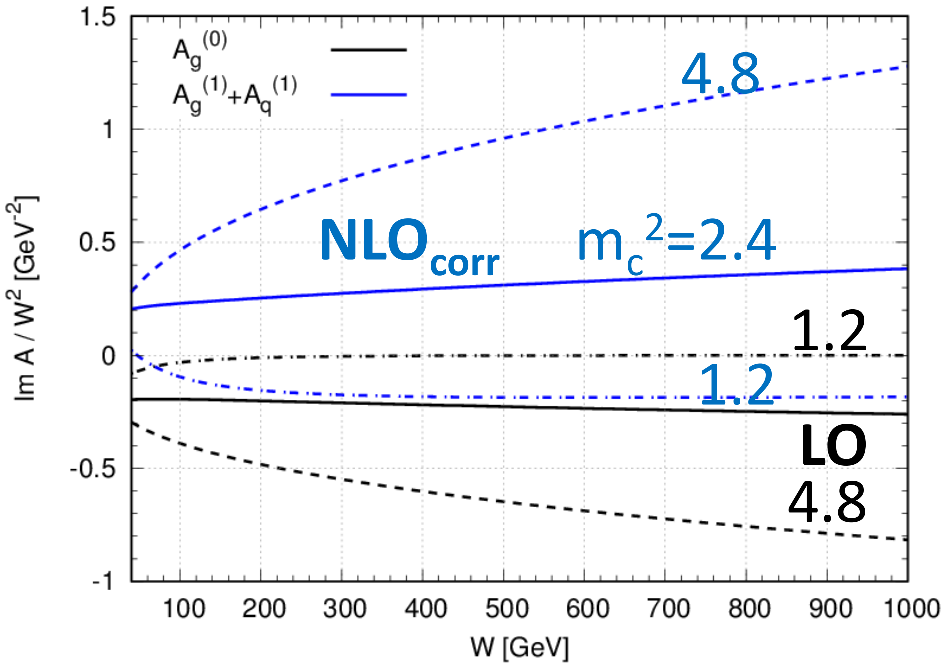
1. Corresponds to BLM prescription --- eliminates NLO $\beta_0 \ln(\mu_R/\mu_F)$ term
2. New q loop in g propagator appears twice:
   (a) part for scales $\mu<\mu_F$ by virtual comp^t of LO splitting in DGLAP evolution.
   (b) part for scales $\mu>\mu_R$ from running α_S behaviour after regular^n of UV divergence.

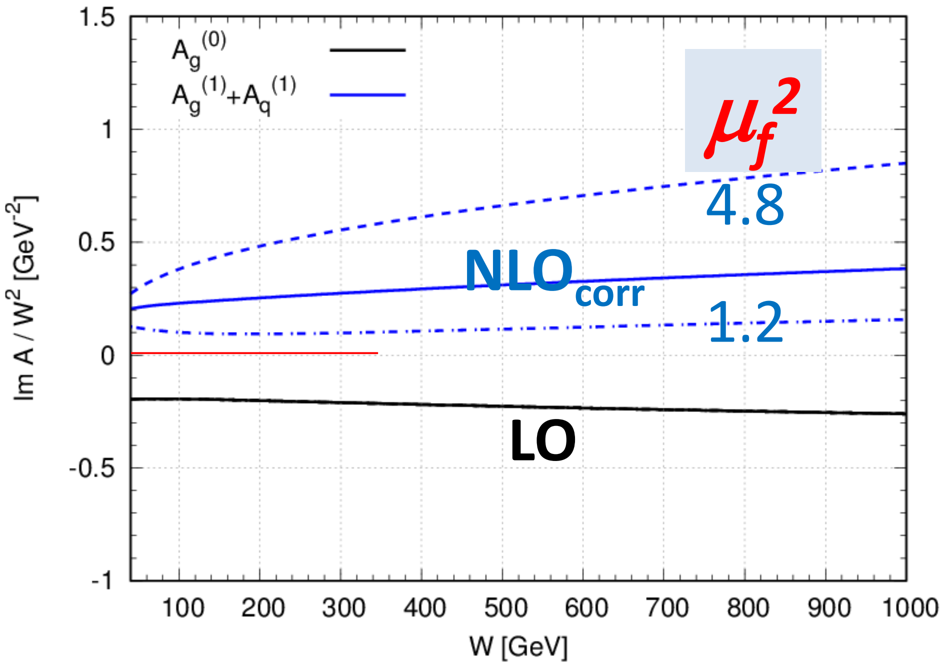
Not to miss part and/or to avoid double counting take

$$\mu_R = \mu_F$$

$$A(\mu_f) \;=\; C^{LO} \otimes GPD(\mu_F) + C^{NLO}_{rem}(\mu_F) \otimes GPD(\mu_f)$$

Before $\mu_F = \mu_c$





scale dependence now weaker

A. But still have very bad perturbative convergence

$NLO_{correction}$ ~ LO and opposite sign

Have we missed something? **YES**. Effect of important Q_0 cut

Q_0^2/μ_F^2 power corr^{ns}.

Start DGLAP evol. at Q_0

At LO everything below Q_0 is included in input PDF(Q_0)

At NLO the contrib^n from $|q^2| < Q_0^2$ is double counting

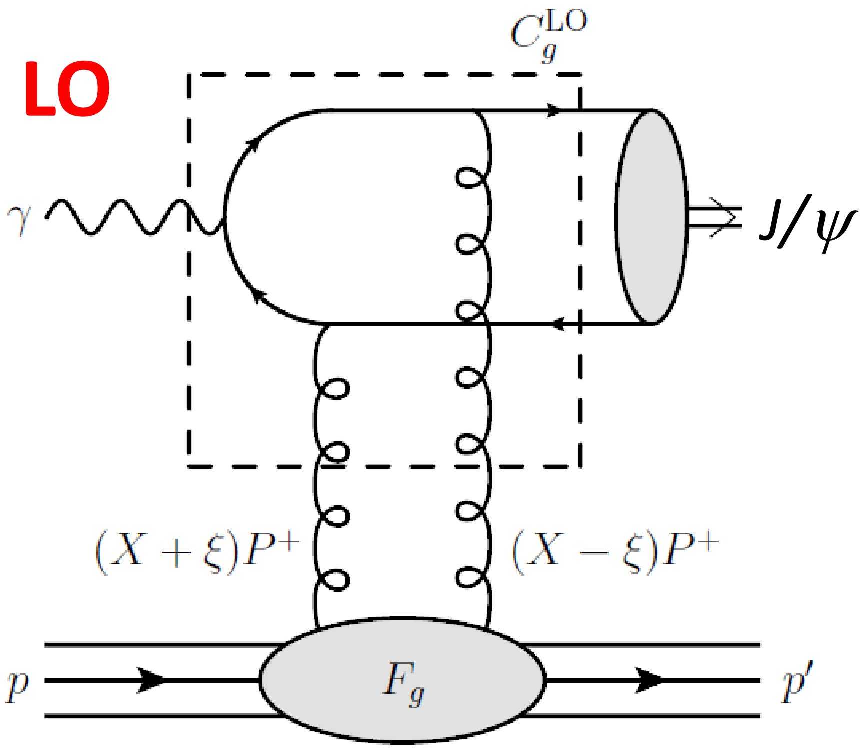
Need to subtract NLO($|q^2|<Q_0^2$) contrib^n for both *q* & *g*

See appendix of 1610.02272

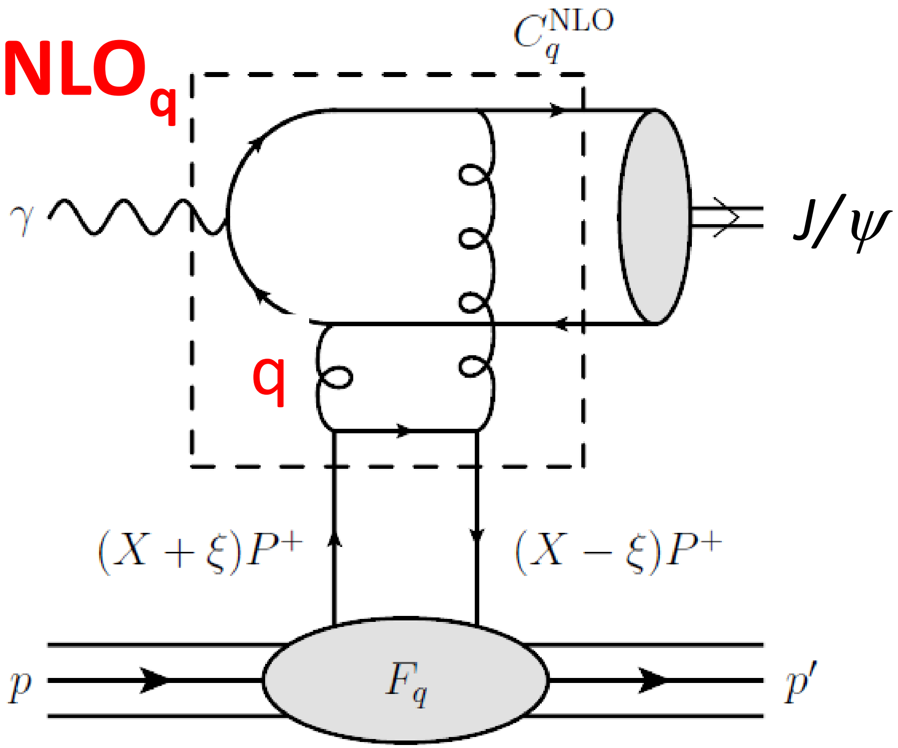
$x = X + \xi$
$x' = X - \xi$

$x >> x'$
$x \sim 2\xi$

LO

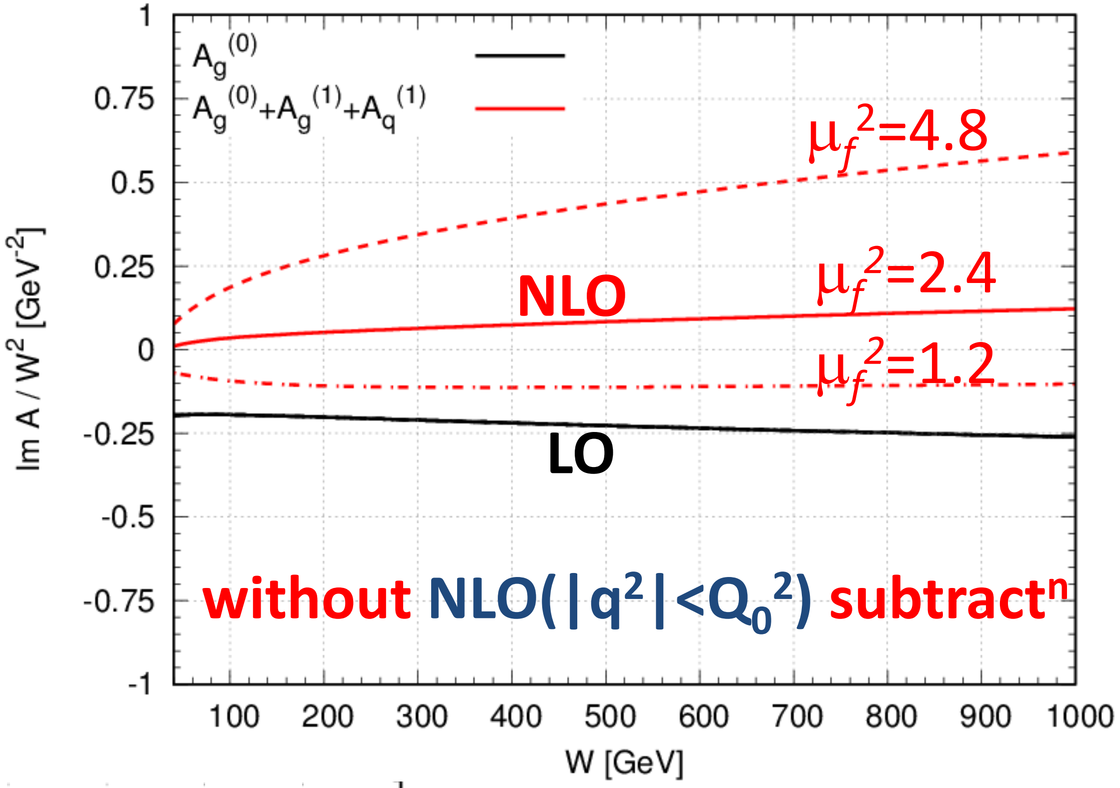


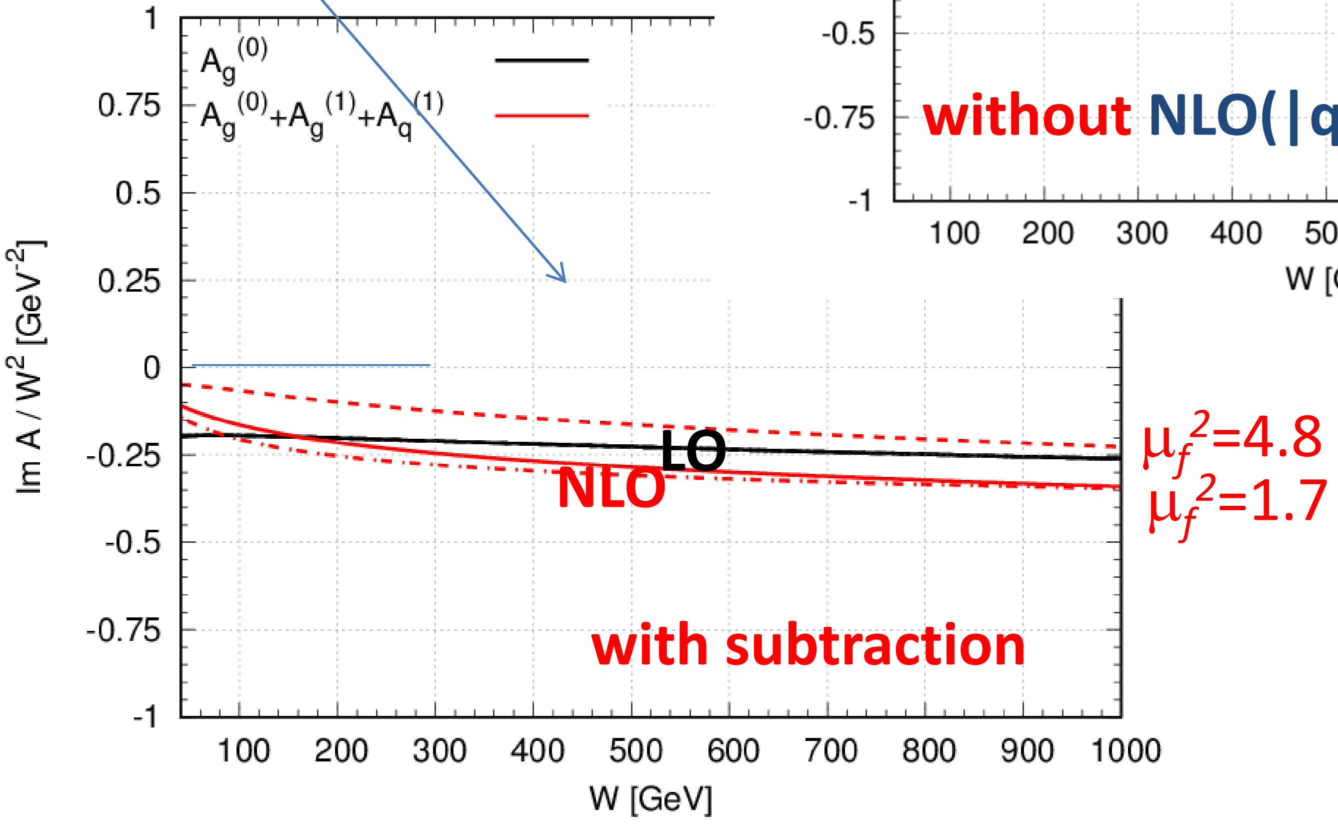
NLO$_q$



also need NLO$_g$ coeff. fn

NLO_{corr} is (i) now **small**
and (ii) much less
dependent on choice of
(residual) fact^{n} scale μ_f



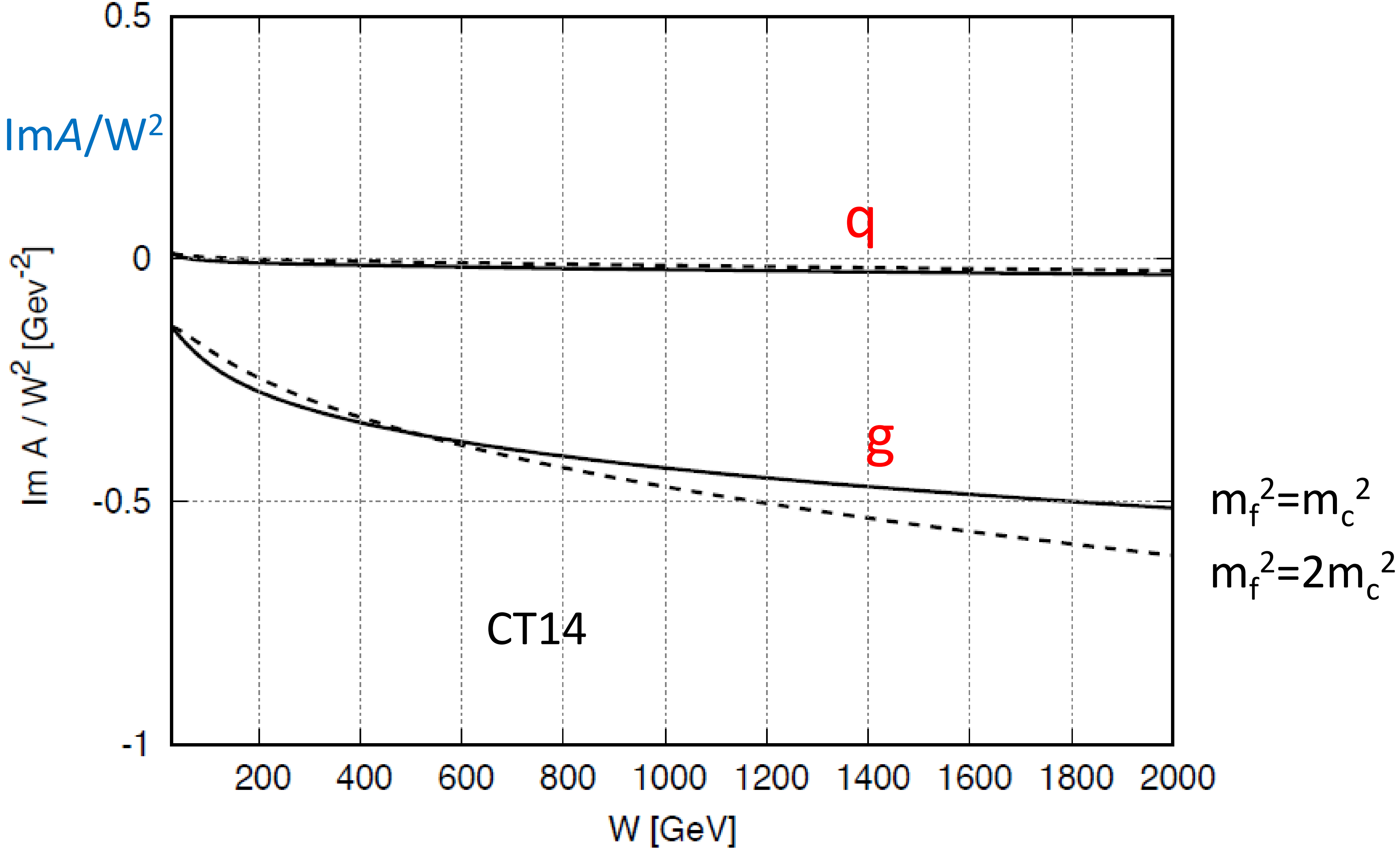


Subtract^n of NLO($|q^2|<Q_0^2$) plus choice $\mu_F=M_\psi/2$

(no double counting) (resum of double logs)

provides reasonable framework to include the exculsive LHCb J/ψ data in the NLO global PDF analyses to explore the gluon PDF in the low x regime for the first time.

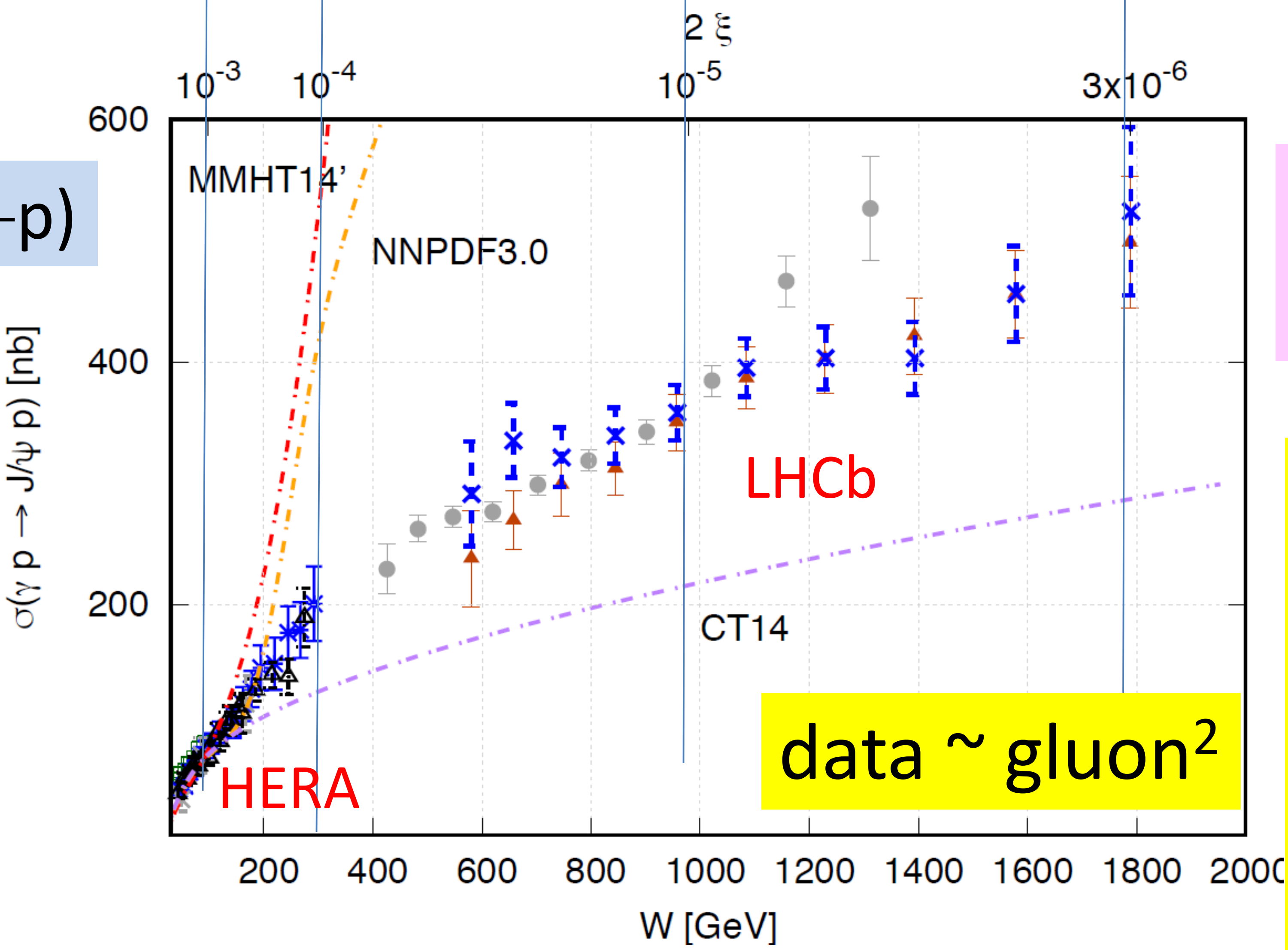
We compare predictions of 3 global PDF sets with LHCb data:
NNPDF3.0, MMHT14, CT14
The contribution from q PDFs is negligible compared to that of g



0.5
0
-0.5
-1
200
400
600
800
1000
1200
1400
1600
1800
2000
W [GeV]
Im A / W^2 [Gev^-2]
ImA/W^2
q
g
$m_f^2=m_c^2$
$m_f^2=2m_c^2$
CT14

$x \gtrsim 2\xi \;=\; 10^{-3} \; 10^{-4} \qquad 10^{-5} \qquad 3\times10^{-6}$

$\sigma(\gamma p \rightarrow J/\psi + p)$

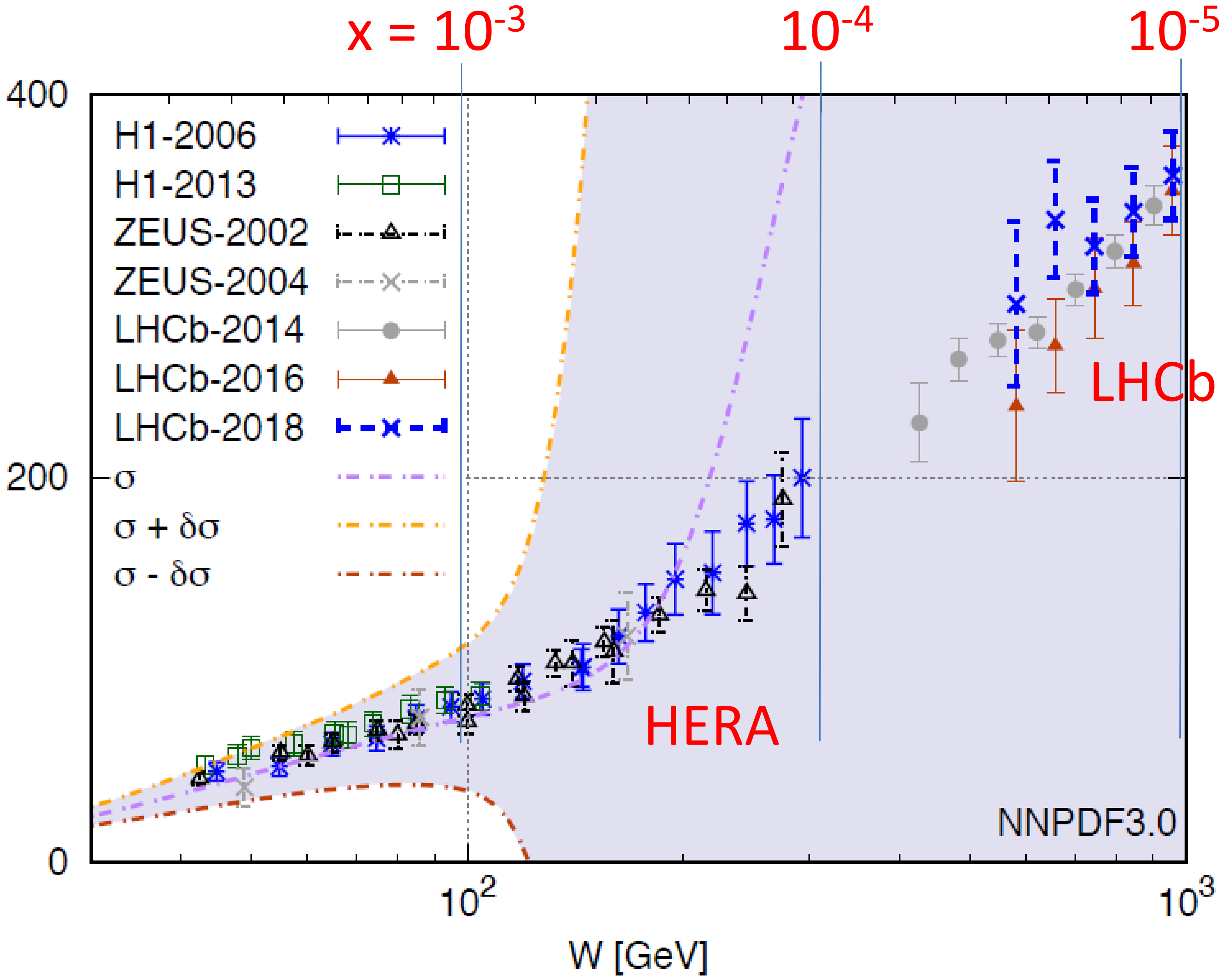


$Q^2 \sim m_c^2 = 2.4\ \text{GeV}^2$

data ~ gluon^2

gluon will be greatly constrained by LHCb data for low x

$\sigma(\gamma p \rightarrow J/\psi + p)$ nb



uncert. PDFs >> data uncert.

NLO gluon at Q^2=2.4 GeV^2

fixed by LHCb J/ψ data down to x = 3 x 10^{-6}

fixed by HERA J/ψ data for $10^{-4} < x < 10^{-3}$

LHCb exclusive J/ψ (and Υ) data remove the huge uncertainties in the gluon PDF at very low $x \sim 10^{-5}$ and $Q^2 = m_c^2$ (m_b^2)

Will improve precision of gluon up to $Q^2 \sim$ 10 (or 100) GeV^2, however should not effect the global parton sets predictions for heavy objects at the LHC

Recall distribution of gluons as $x \to 0$ governs high energy asymptotics of scattering amplitude. That is, important for BFKL programme in the low x domain --- important for understanding confinement and saturation