Exclusive J/ψ and Υ production and the low x gluon

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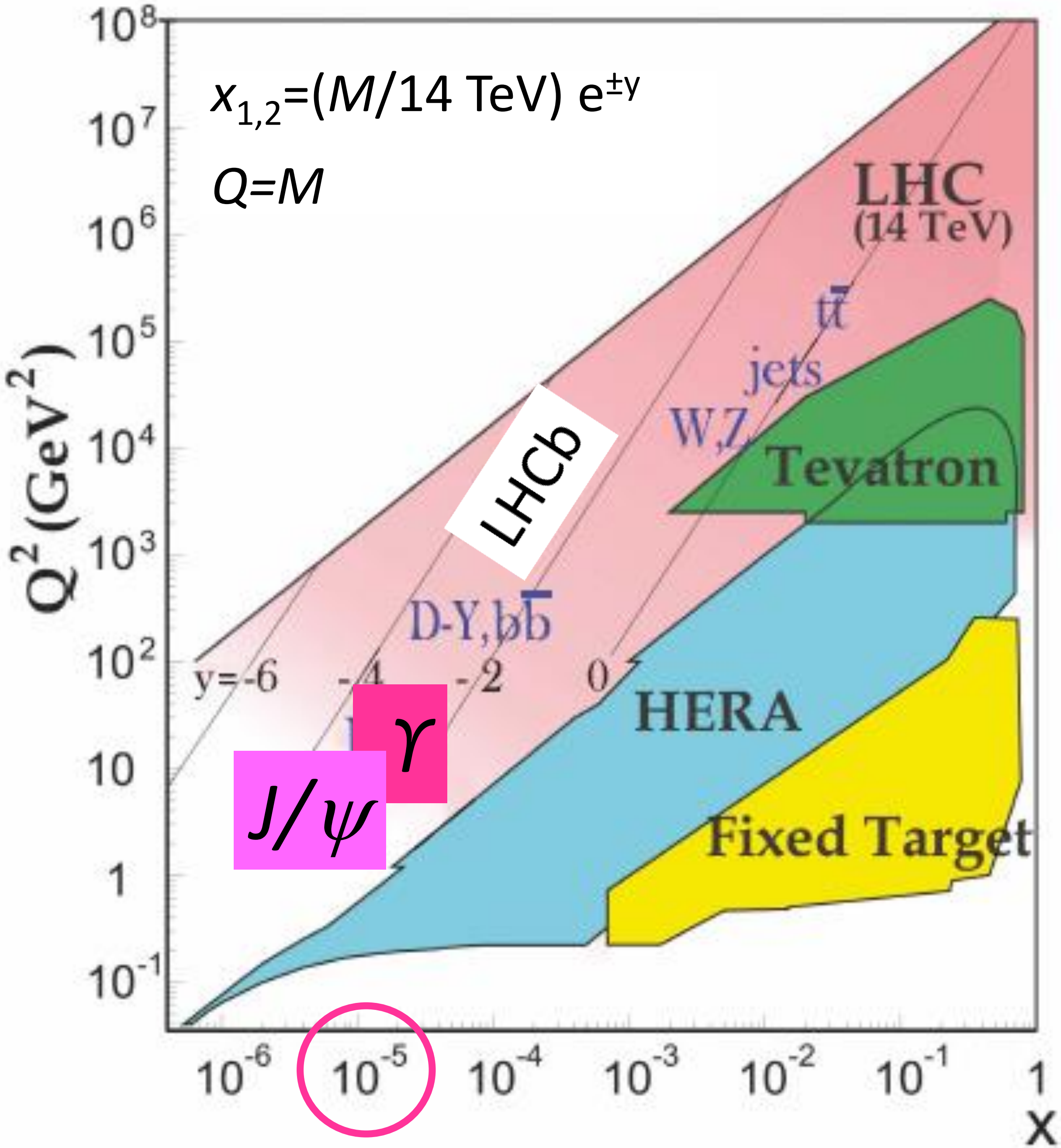
arXiv:1507.06942



Exclusive pp→pVp where V=J/ψ or Υ should probe gluon at x about 10^{-5}

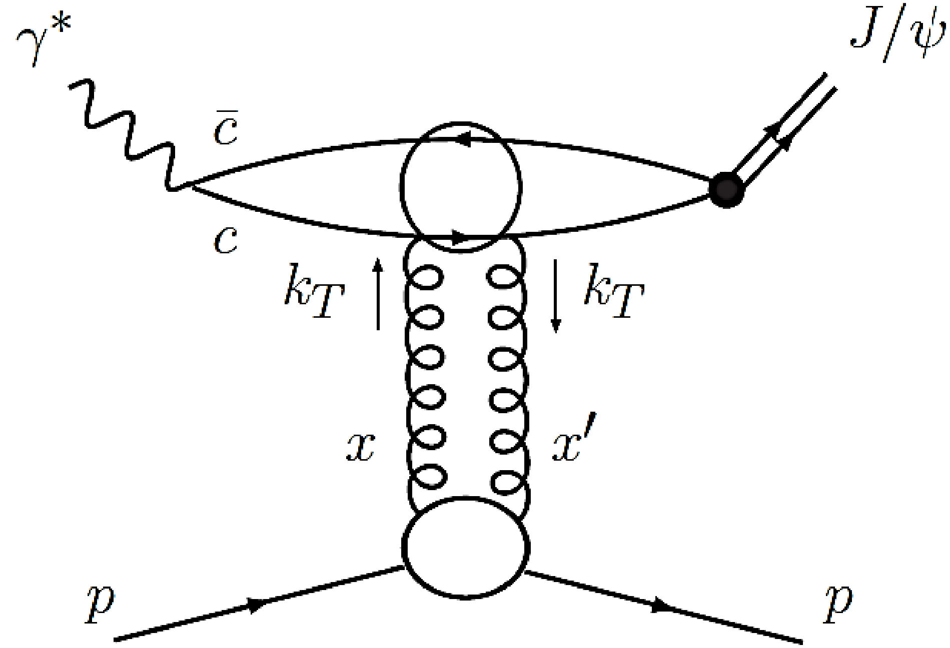
Why are these LHC data not used in global PDF fits ??

LO formula for $\gamma^* p \to J/\psi + p$ Ryskin(1993)

$$\frac{d\sigma}{dt}(\gamma^* p \to J/\psi\ p)\Big|_{t=0} = \frac{\Gamma_{ee} M_{J/\psi}^3 \pi^3}{48\alpha}\left[\frac{\alpha_s(\bar{Q}^2)}{\bar{Q}^4}\underline{xg(x,\bar{Q}^2)}\right]^2\left(1+\frac{Q^2}{M_{J/\psi}^2}\right)$$

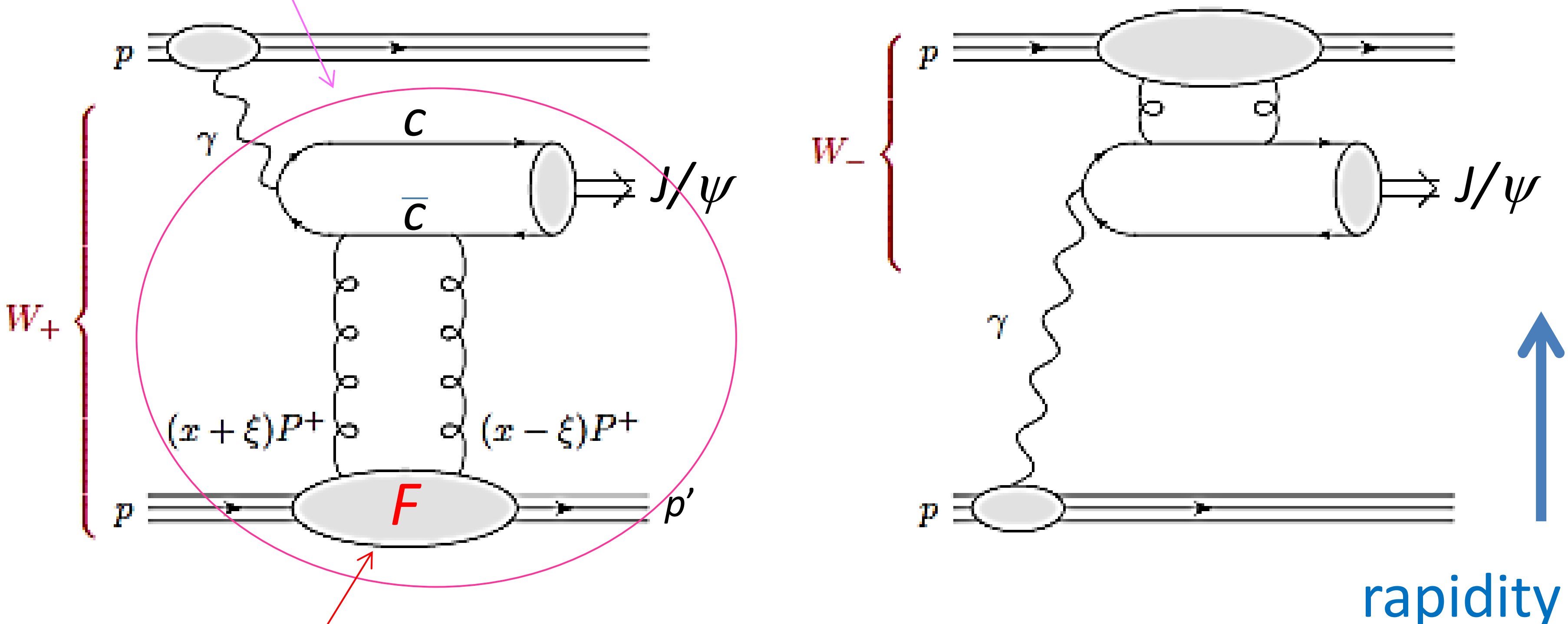
$$x = (Q^2 + M_{J/\psi}^2)/(W^2 + Q^2)$$

$$\bar{Q}^2 = (Q^2 + M_{J/\psi}^2)/4$$



So why are HERA (and LHC) exclusive J/ψ data not used in global analyses to fix low *x* gluon?

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



GPD: $F(x,\xi,\mu_f^2)$

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

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

(i) Described by GPD's

→ however can be related to PDFs at low ξ, via Shuvaev transform

(ii) Bad convergence of pert. series at low ξ & low scales

see also Ivanov, Pire, Szymanowski, Wagner

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

whereas NLO only allows emission of one gluon !

→ however knowledge of NLO allows us to resum ln(1/ξ) terms in LO contrib.
Is this sufficient?

(iii) Input gluons in PDF analyses valence-like at low scales!!

→ should not parametrize input gluon freely

Transfer part of NLO to LO term by $\mu_f \to \mu_F$ in LO term

we start with LO+NLO terms evaluated at μ_f

$$A^{(0)}(\mu_f) + A^{(1)}(\mu_f) \;=\; C^{(0)} \otimes F(\mu_f) + \alpha_s C^{(1)}(\mu_f) \otimes F(\mu_f)$$

we can evaluate LO term at another scale μ_F as long as we compensate by changes to NLO coeff. fn. $C^{(1)}$

$$A^{(0)}(\mu_F) \;=\; \left(C^{(0)} + \underbrace{\frac{\alpha_s}{2\pi} \ln\left(\frac{\mu_F^2}{\mu_f^2}\right) C^{(0)} \otimes V}_{\alpha_s\, c(\mu_F)} \right) \otimes F(\mu_f)$$

$$A^{(0)}(\mu_f) + A^{(1)}(\mu_f) \;=\; C^{(0)} \otimes F(\mu_F) + \underbrace{\alpha_s C^{(1)}_{\mathrm{rem}}(\mu_F)}_{\alpha_s(C^{(1)}-c(\mu_F))} \otimes F(\mu_f)$$

$$A^{(0)}(\mu_f) + A^{(1)}(\mu_f) \;=\; C^{(0)} \otimes F(\mu_F) + \alpha_s \underline{C^{(1)}_{\rm rem}(\mu_F) \otimes F(\mu_f)}$$

$$\underline{\int (dx/x)\, C^{(1)}_{\rm rem}(x/\xi, \mu_F) F(x, \xi, \mu_f)}$$

The aim is to choose μ_F to nullify this term

--- cannot do it completely, since it is a function of x/ξ

--- but can remove ln(1/ξ) contributions

which come from the limit $x \gg \xi$

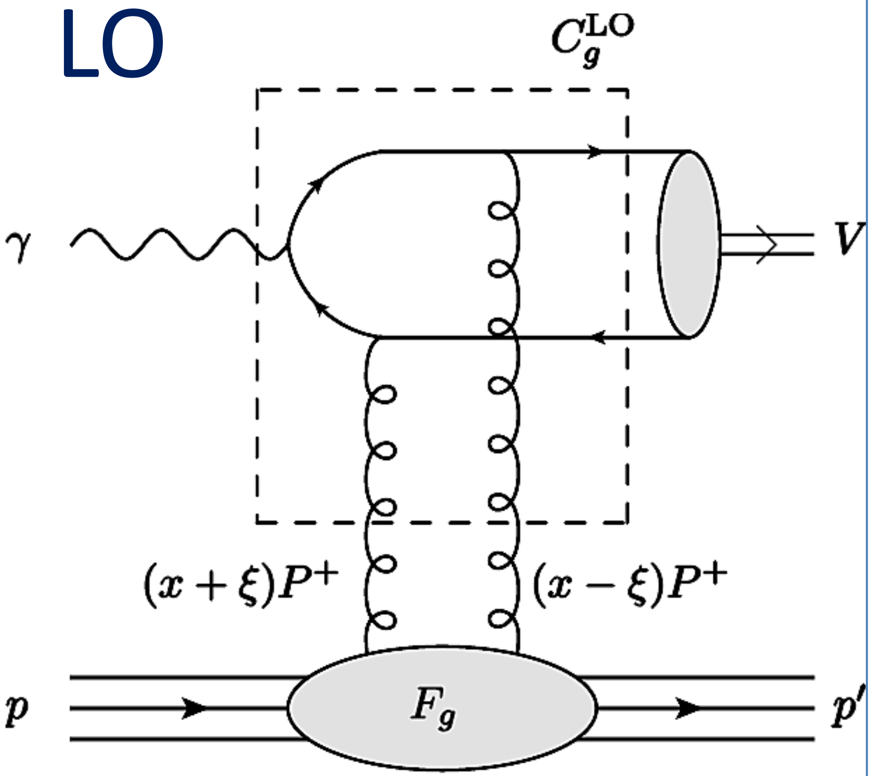
$$A^{(1)}(\xi, \mu_F) \;\approx\; -\mathrm{i}\pi\, C_g^{(0)} \left[\frac{\alpha_s(\mu_R) N_c}{\pi} \underline{\ln\left(\frac{m^2}{\mu_F^2}\right)} \int_\xi^1 \frac{\mathrm{d}x}{x} F_g(x, \xi, \mu_F) \right.$$

$$\left. + \; \frac{\alpha_s(\mu_R) C_F}{\pi} \underline{\ln\left(\frac{m^2}{\mu_F^2}\right)} \int_\xi^1 \mathrm{d}x \left(F_S(x, \xi, \mu_F) - F_S(-x, \xi, \mu_F)\right) \right]$$

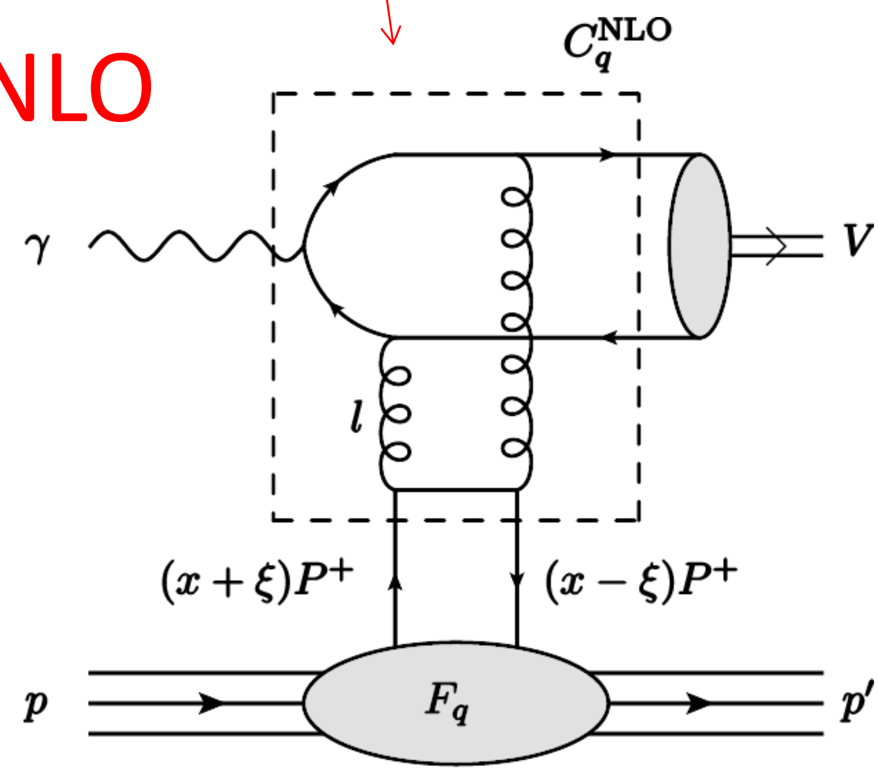
by making the choice $\mu_F = m = M_{J/\psi}/2$

$$A^{(1)}(\xi,\mu_F) \approx -i\pi\, C_g^{(0)} \left[\frac{\alpha_s(\mu_R) N_c}{\pi} \ln\left(\frac{m^2}{\mu_F^2}\right) \int_\xi^1 \frac{dx}{x} F_g(x,\xi,\mu_F) + \frac{\alpha_s(\mu_R) C_F}{\pi} \ln\left(\frac{m^2}{\mu_F^2}\right) \int_\xi^1 dx \left(F_S(x,\xi,\mu_F) - F_S(-x,\xi,\mu_F)\right) \right]$$

LO



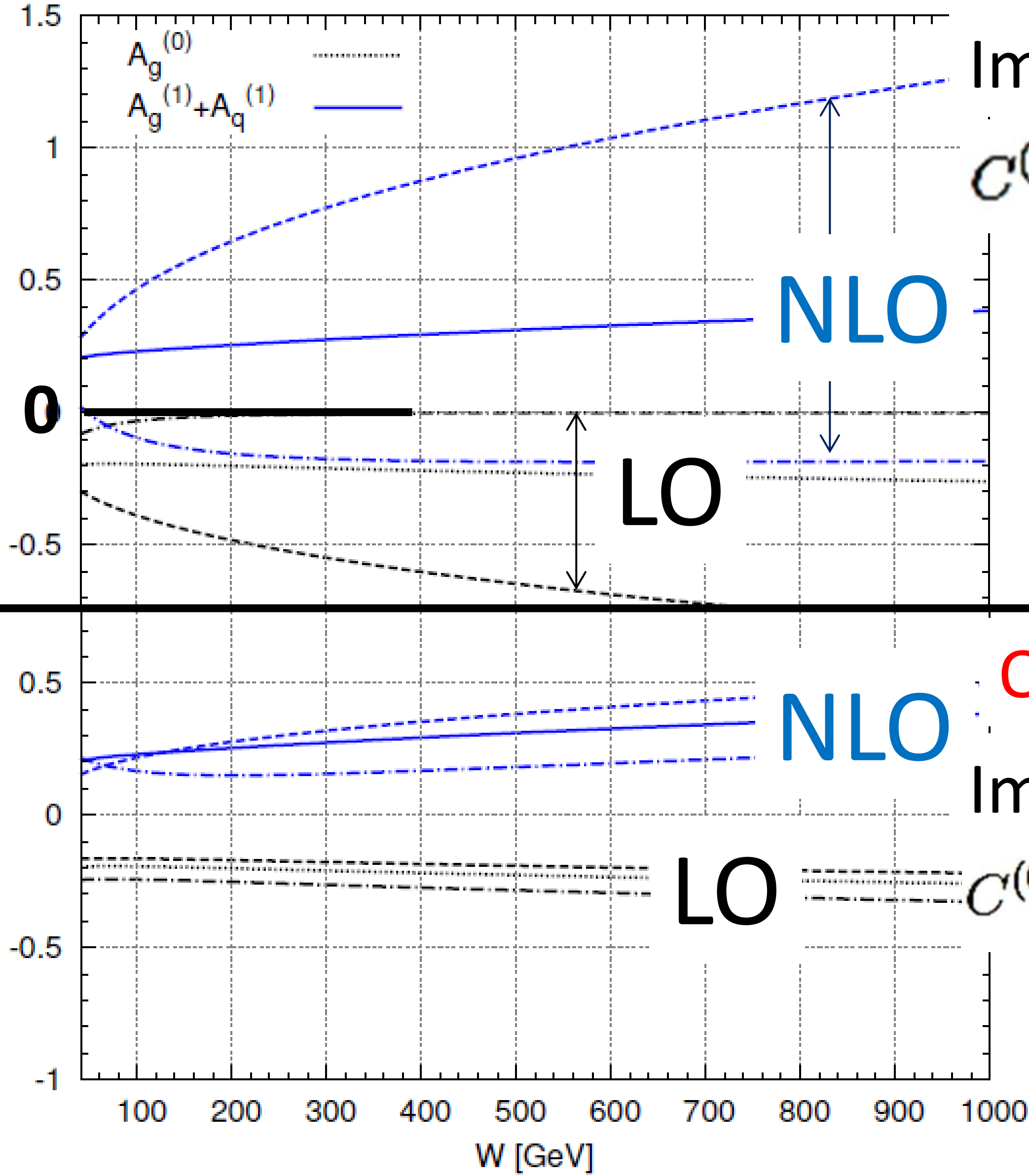
NLO



+ diag^{m} with q→g in lower part

Im $A\,/\,W^2$ versus W

$\gamma p \to J/\psi + p$



Im $A(\mu_f)$ =

$$C^{(0)} \otimes F(\mu_f) + \alpha_s C^{(1)}(\mu_f) \otimes F(\mu_f)$$

LO NLO

(i)large scale dependence

$\mu_f^2 = m^2/2,\ m^2,\ 2m^2$

(ii) large **opposite sign** NLO

Optimum scale $\mu_F = m = M_{J/\psi}/2$

Im $A(\mu_f)$ =

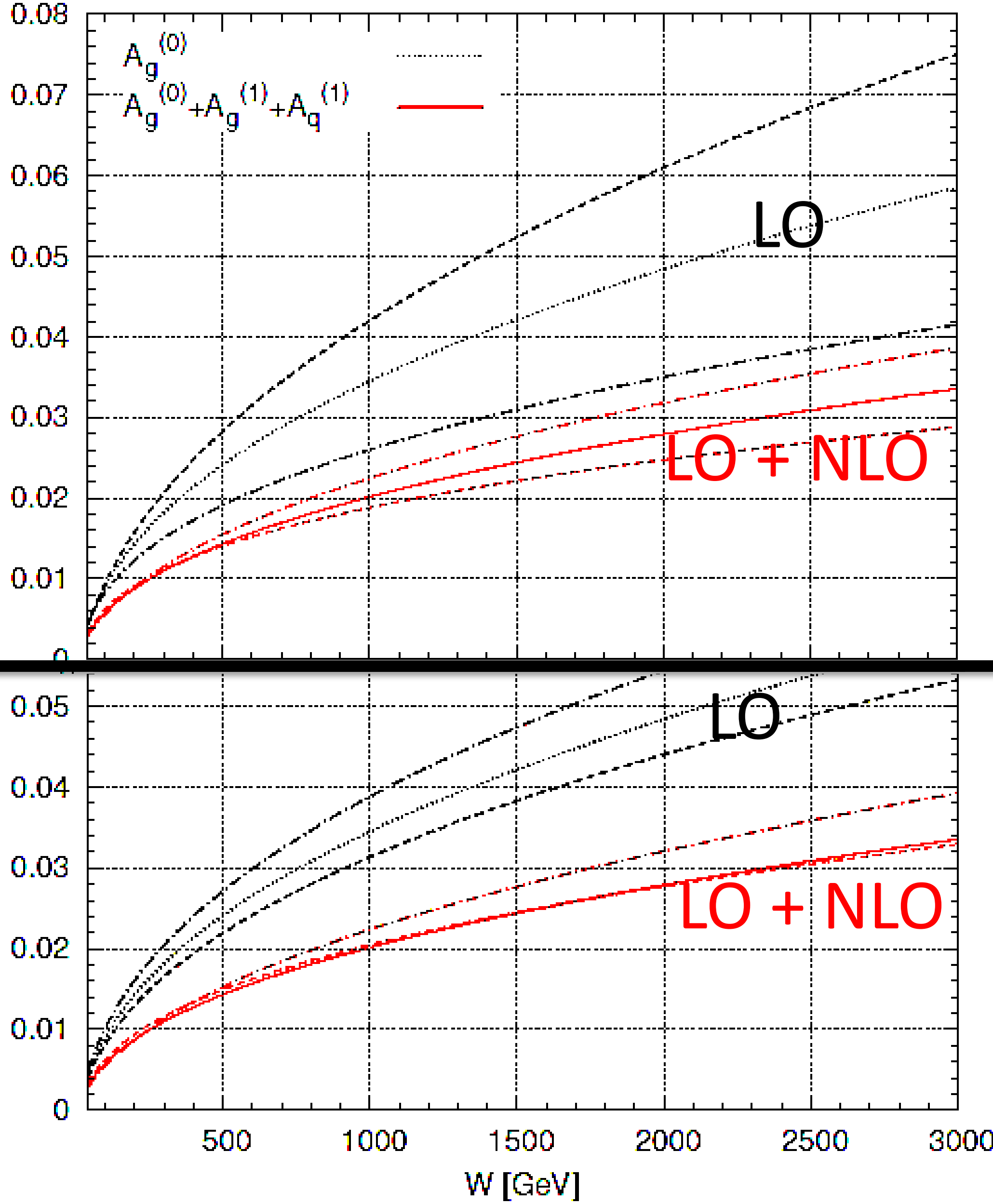
$$C^{(0)} \otimes F(\mu_F) + \alpha_s C^{(1)}_{\rm rem}(\mu_F) \otimes F(\mu_f)$$

LO NLO

(i)large scale dep. reduced

(ii)but no pert. convergence

Im A / W^2 versus W



$$\gamma p \to \Upsilon + p$$

Optimum scale $\mu_F = M_\Upsilon/2$

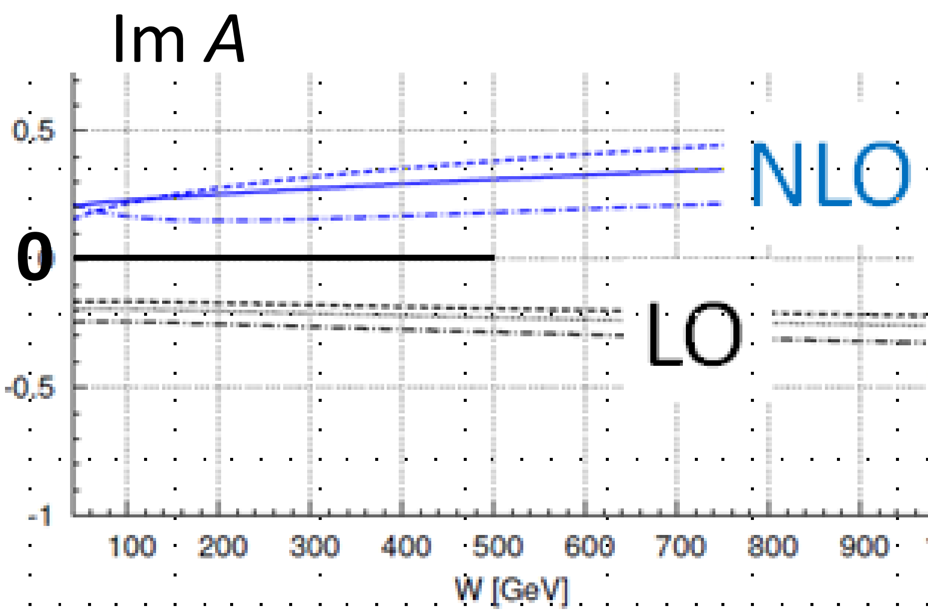
scale dep. and perturbative stability much better for Υ

so Υ data useful for global PDF fits

Comparison of HERA Υ exclusive data suggests a larger gluon PDF at low x (10^{-3} - 10^{-4}) by a factor of up to 2, than extrapolations of global PDFs

Alternative probe of small x gluon:
charm production in forward direction
1506.08025 Gauld, Rojo, Rottoli, Talbert
-- again large scale uncertainties
-- looking at their comparison with forward $D^0, D^{+/-}$ LHCb data, again it seems need larger small x gluon twice larger

Let us return to J/ψ and the large opposite sign NLO term



Optimum scale μ_F=m=$M_{J/\psi}/2$

Im $A(\mu_f)$ =

$$C^{(0)} \otimes F(\mu_F) + \alpha_s C^{(1)}_{\rm rem}(\mu_F) \otimes F(\mu_f)$$

LO NLO

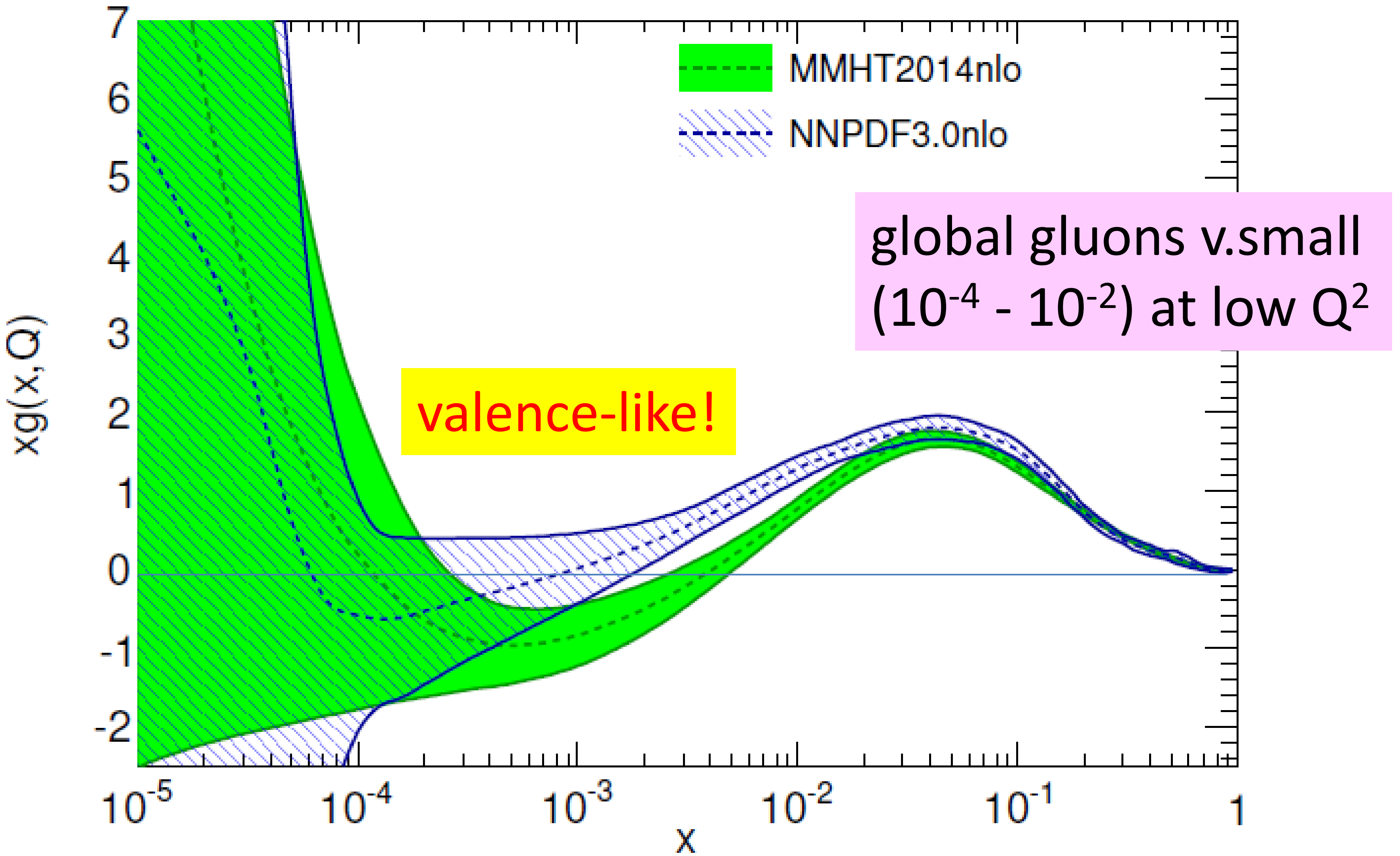
(i)large scale dep. reduced

(ii)but no pert. convergence

For a quasi-elastic process Im A cannot be negative!?

The explanation is interesting

The gluon at low x and Q^2=1.21 GeV^2



Suppose input g(x)=0, then only have NLO q term

But gluons cannot be smaller than density of gluons emitted before evol^{n} starts, so have opposite sign LO term

Input gluons cannot be freely parametrised in global fits, g(x) needs to be sufficiently positive

Pure global fits should take account of absorptive corrections which occur at low x, low Q^2.
Small/negative global input g(x) mimics this effect.

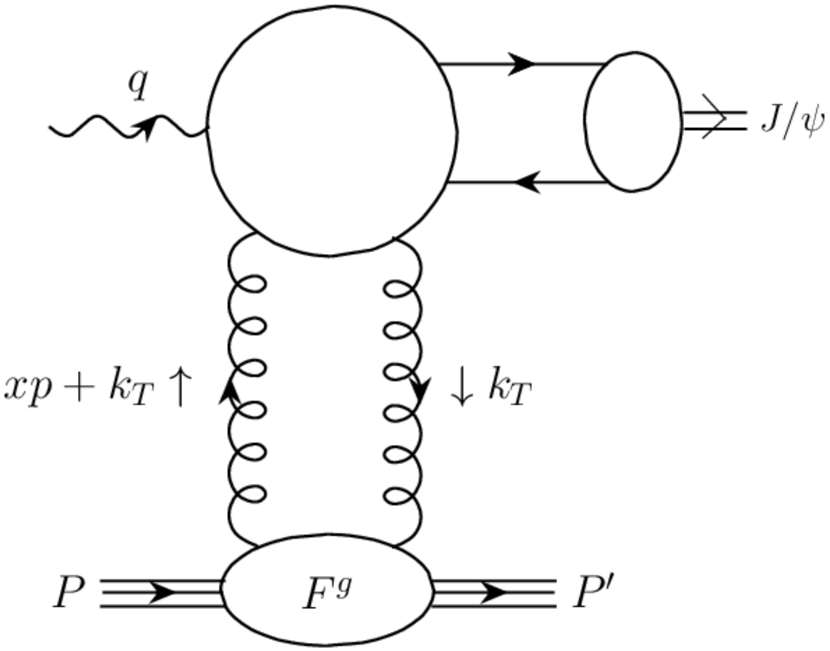
So much for conventional MS(bar) global PDFs at low x and low Q^2

Alternative k_t-factorization approach

The "NLO" prediction is obtained by taking the full integral over k_t in the loop; with an ansatz for the k_t-dependent gluon.

The convergence of the integral effectively gives the optimal fac. scale and sums up all the ln(1/ξ) terms.

(see JMRT: 1307.7099)

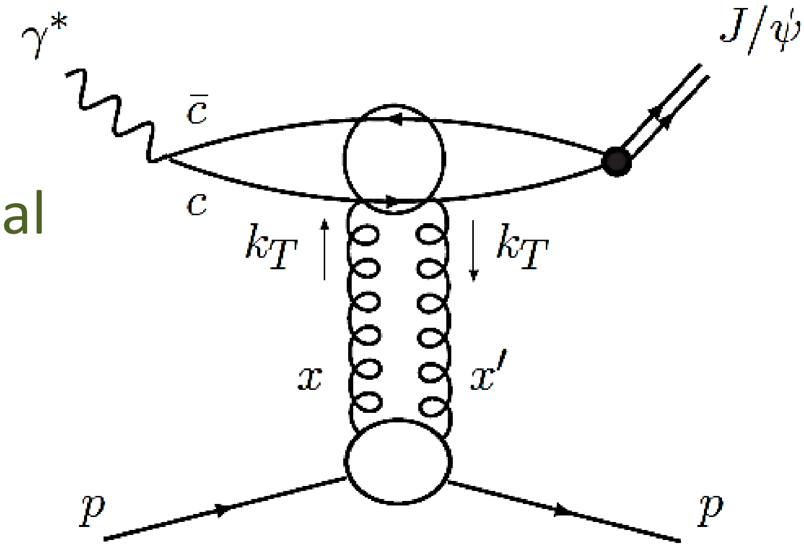


avoids small/negative low x, low Q^2 gluon

Formula for $\gamma^* p \rightarrow J/\psi + p$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}t}(\gamma^* p \to J/\psi\ p)\Big|_{t=0} = \frac{\Gamma_{ee} M^3_{J/\psi} \pi^3}{48\alpha} \left[\frac{\alpha_s(\bar{Q}^2)}{\bar{Q}^4} xg(x, \bar{Q}^2)\right]^2 \left(1 + \frac{Q^2}{M^2_{J/\psi}}\right)$$

$$x = (Q^2 + M^2_{J/\psi})/(W^2 + Q^2)$$
$$\bar{Q}^2 = (Q^2 + M^2_{J/\psi})/4$$



Allow for skewing (x≠x') a la Shuvaev et al
Allow for real part

Mimic NLO by including k_T^2 integration
in last step of evol^n (a la Kimber at al)

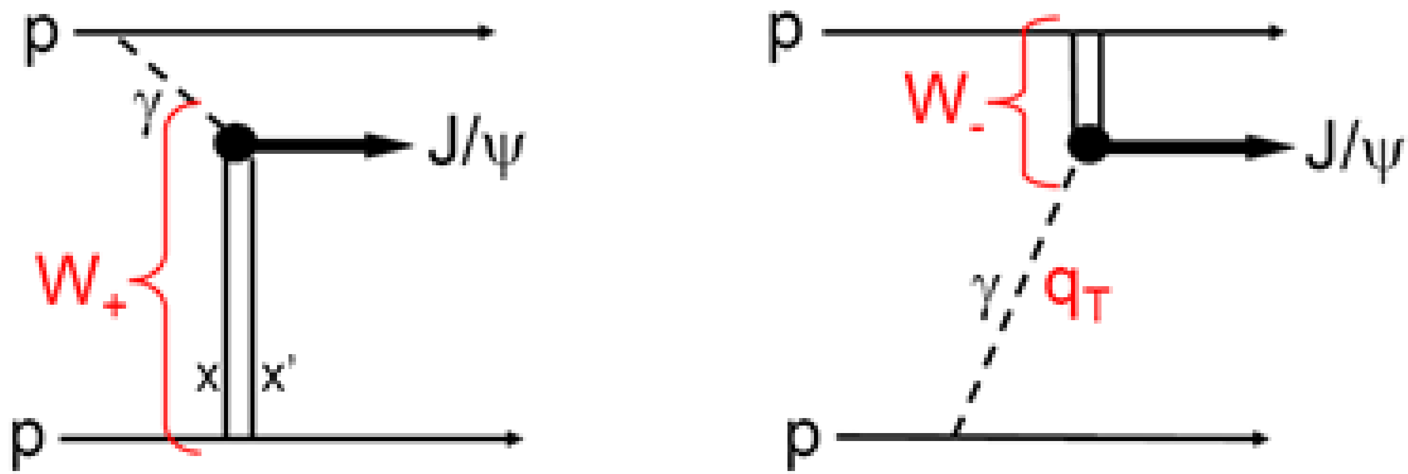
$$\left[\frac{\alpha_s(\bar{Q}^2)}{\bar{Q}^4} xg(x, \bar{Q}^2)\right] \longrightarrow \int_{Q_0^2}^{(W^2 - M^2_{J/\psi})/4} \frac{\mathrm{d}k_T^2\, \alpha_s(\mu^2)}{\bar{Q}^2(\bar{Q}^2 + k_T^2)} \frac{\partial\left[xg(x, k_T^2)\sqrt{T(k_T^2, \mu^2)}\right]}{\partial k_T^2}$$

+ Q_0 contribution

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

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

fit LHCb

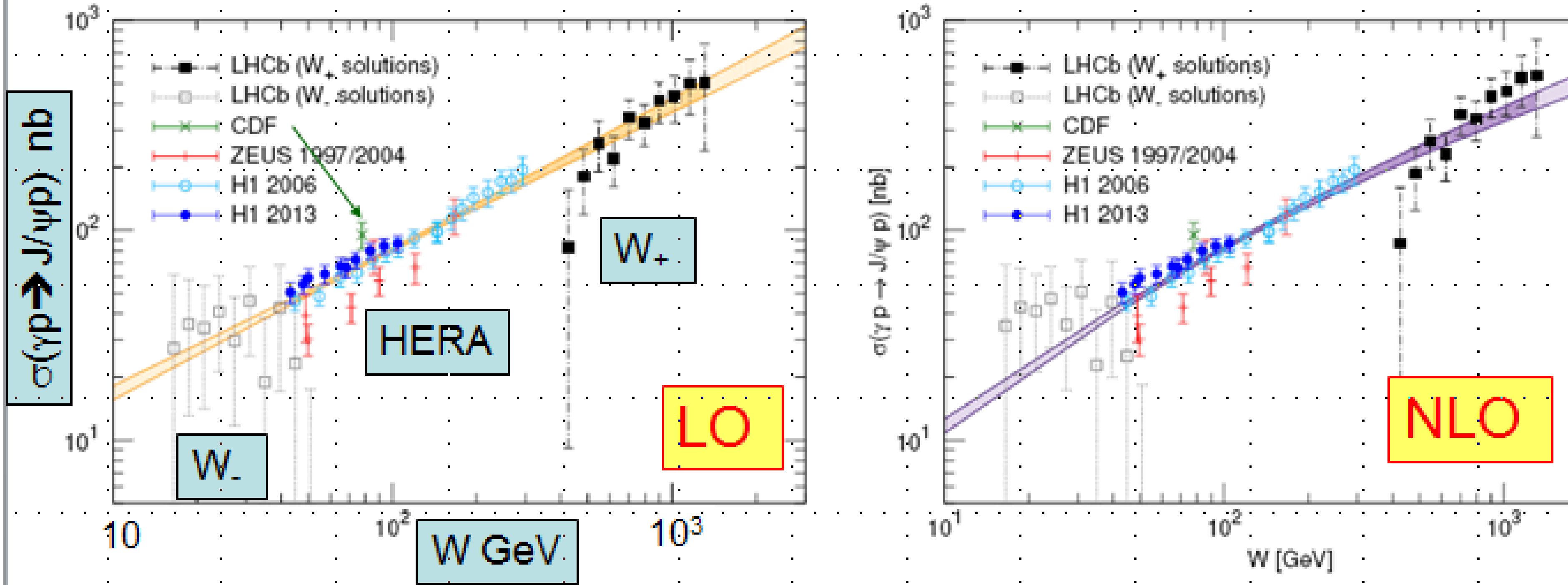
show   show

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

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

and S^2 are survival probabilities of LRG

Combined fit to HERA and LHC exclusive J/ψ data



survival factors for pp data at 7 TeV

y=2 $S^2(W_+)=0.87$ $S^2(W_-)=0.93$

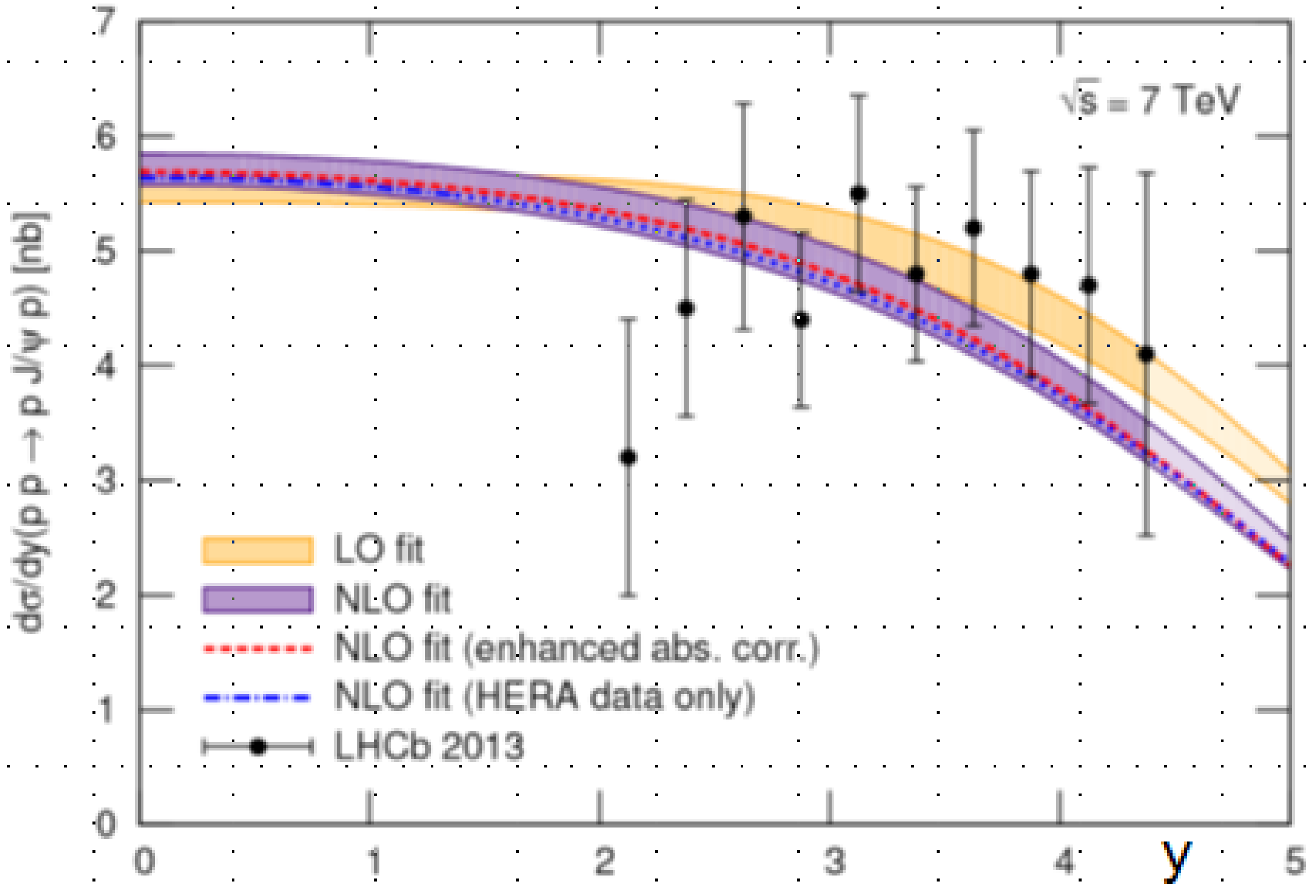
y=4 $S^2(W_+)=0.74$ $S^2(W_-)=0.95$

survival factor for HERA data $S^2 \sim 1$

JMRT

arXiv:1307.7099

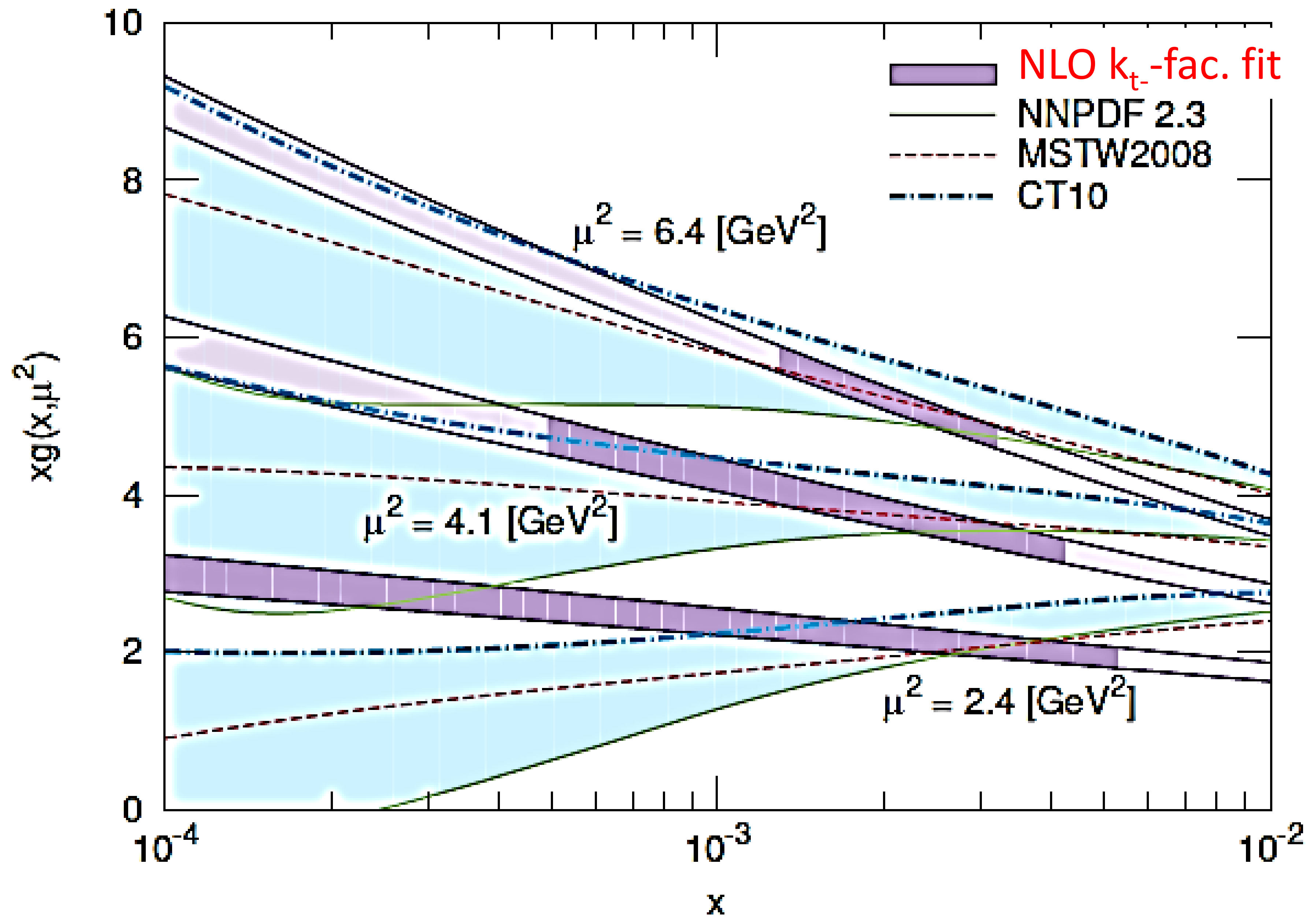
Actual description of LHCb data in combined fit



need parameterization of gluon from x ~10^{-5} to 0.1 to cover data

$$xg(x,\mu^2) \; = \; N x^{-a} (\mu^2)^b \exp\left[\sqrt{16 N_c/\beta_0 \ln(1/x) \ln(G)}\right] \qquad \text{with} \;\; G = \frac{\ln(\mu^2/\Lambda^2_{\rm QCD})}{\ln(Q_0^2/\Lambda^2_{\rm QCD})}$$

NLO



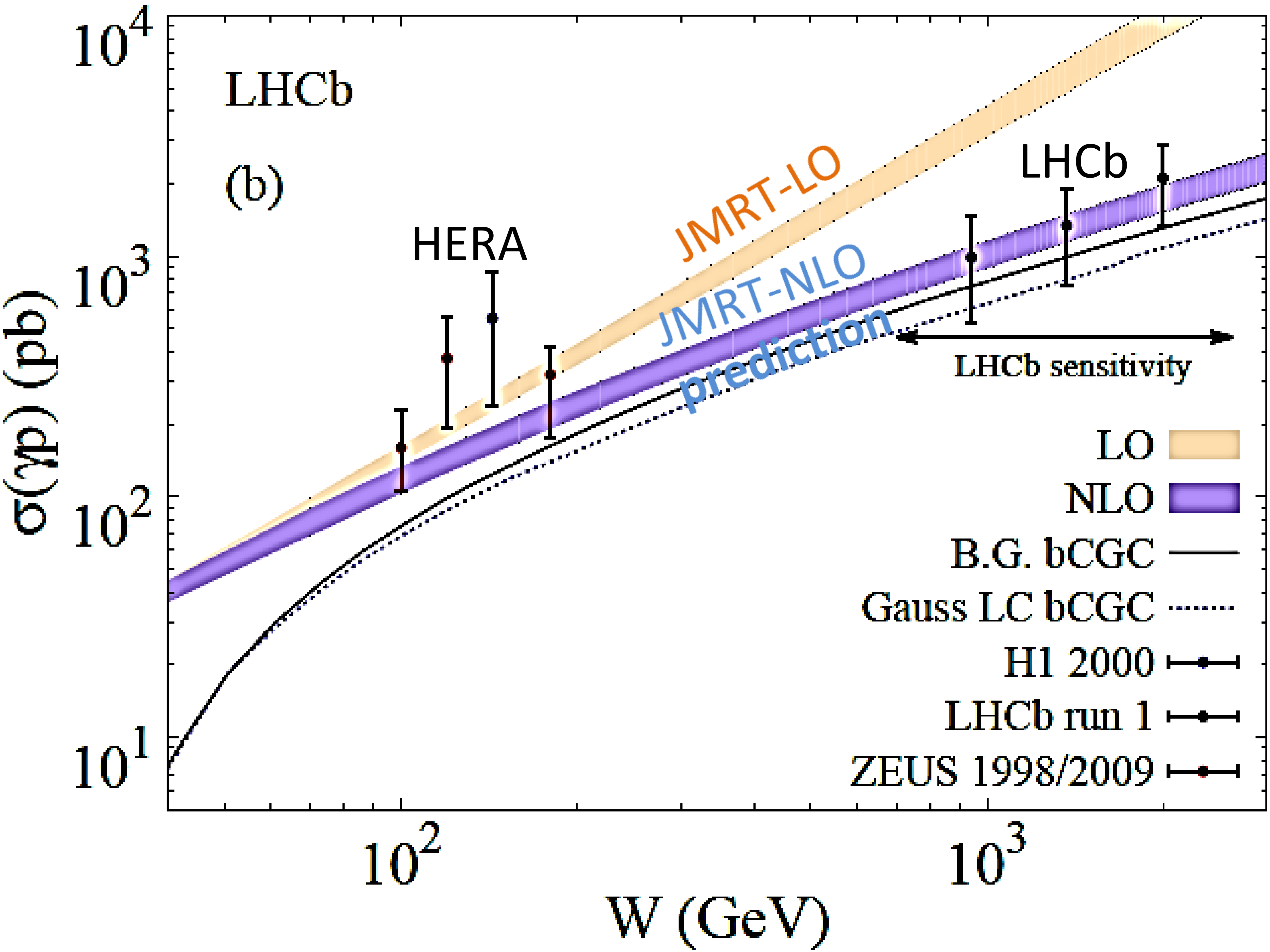
NLO k_{t}-fac. fit
NNPDF 2.3
MSTW2008
CT10
$\mu^2 = 6.4$ [GeV^2]
$\mu^2 = 4.1$ [GeV^2]
$\mu^2 = 2.4$ [GeV^2]
$xg(x,\mu^2)$
x
0
2
4
6
8
10
10^{-4}
10^{-3}
10^{-2}

Application of k_t-fac^n approach to Υ data

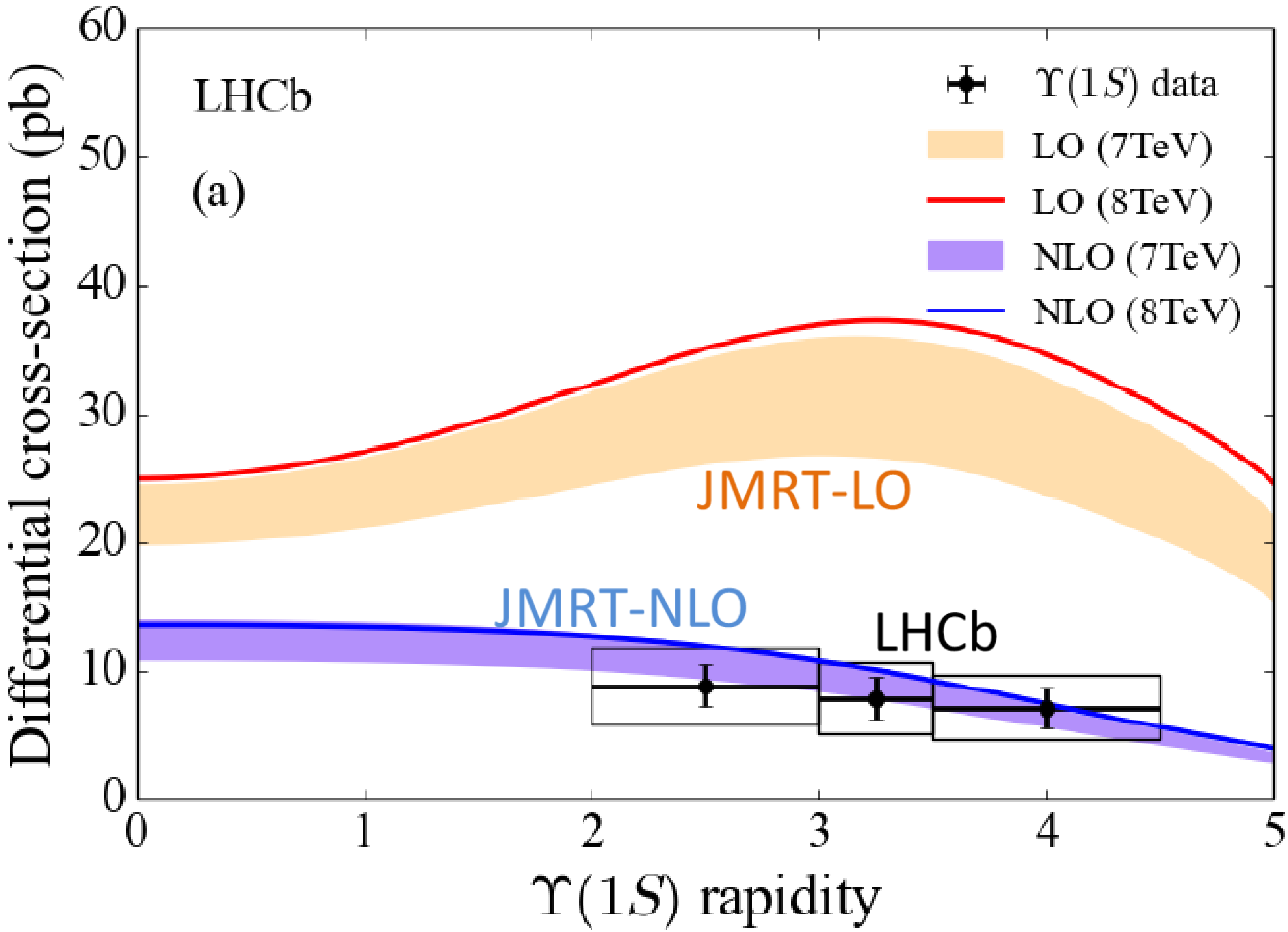
We use "NLO" gluon fitted to J/ψ HERA & LHC data

Proceed up to Υ production using this gluon
(We verified it reproduces NLO DGLAP evolution to good accuracy.)

Predictions agree well with HERA data and the very recent LHCb Υ data



LHCb
(b)
HERA
JMRT-LO
JMRT-NLO
prediction
LHCb
LHCb sensitivity
LO
NLO
B.G. bCGC
Gauss LC bCGC
H1 2000
LHCb run 1
ZEUS 1998/2009
10^4
10^3
10^2
10^1
$\sigma(\gamma p)$ (pb)
10^2
10^3
W (GeV)



(g_{NLO} less steep than $g_{LO} \sim x^{-\lambda}$ due to double log factor.)

Conclusions

For exclusive J/ψ main problem appeared to be very poor convergence of perturbation series in conventional collinear approach.
(Large NLO term opposite sign & comparable to LO term.)
However, we argued input g(x) too small at low x, low Q^2
-- should not be parametrized freely, but subject to some constraints.

Exclusive Υ the perturbative convergence is much better
-- scale dependence about +/-15%
-- data can be included in a global PDF fit to constrain gluon at low x --- suggests g(x) larger at low x, low Q^2.

k_t-fac^n approach gives hints of possible results.

Why is k_t-scheme (physical scheme) so much better than conventional MS(bar) scheme?

MS(bar) NLO evolution mixes partons of different types:

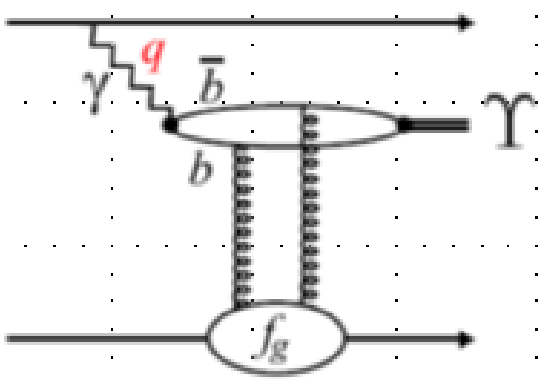
gluon acquires an admixture of singlet quarks

charm PDF acquires admixture of gluon PDF, etc.

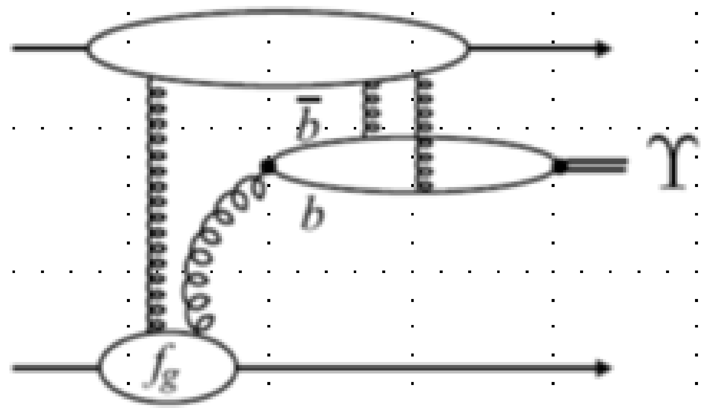
In physical scheme there is no admixture --- we work with Feynman diagrams and know exact quantum numbers of each line.

Exclusive Υ prod. → gen. uninteg gluon /odderon

(a) γ exch



(b) odderon exch



$$\left.\frac{d\sigma^{(a)}}{dy}\right|_{y=0} \simeq 70 \text{ pb}$$

x 0.025 (br for Υ→μμ)

Motyka, Watt: 0805.2113

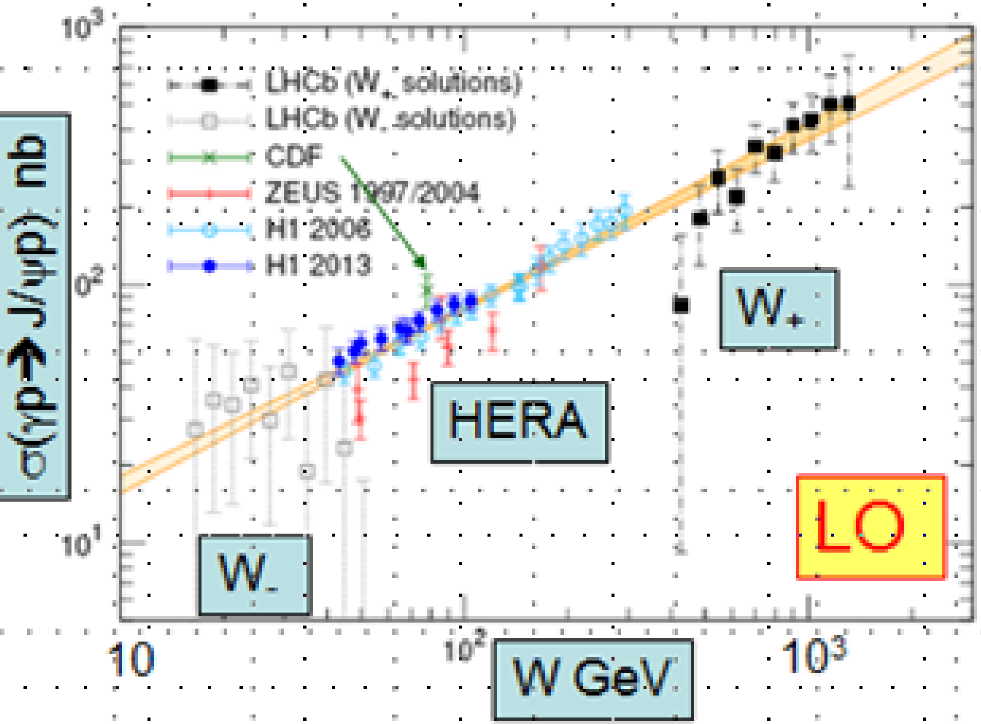
comparable ?

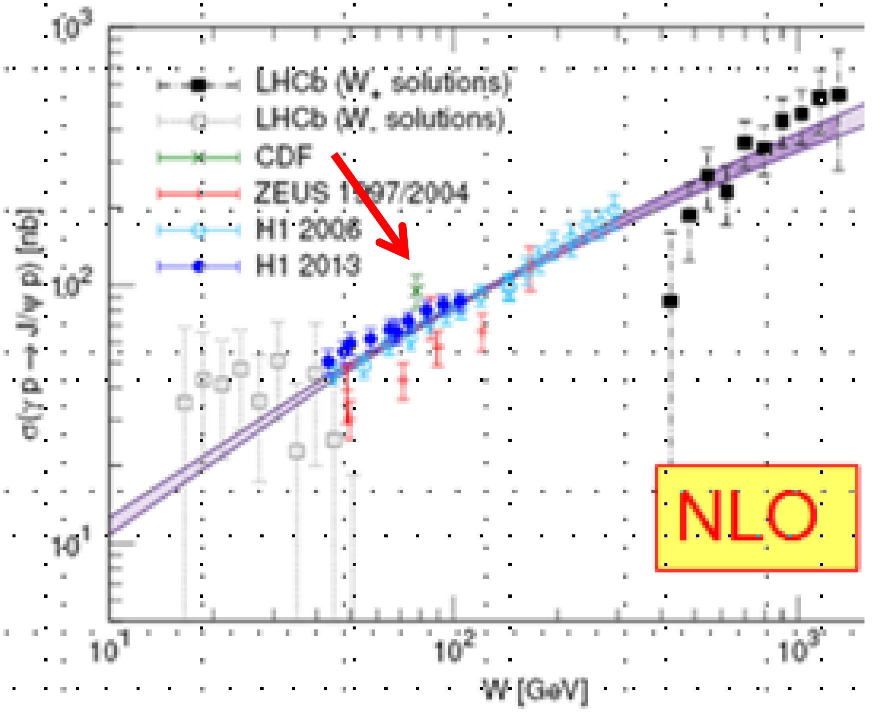
can separate by p_t if a tag of upper proton is done (odderon has larger p_t)

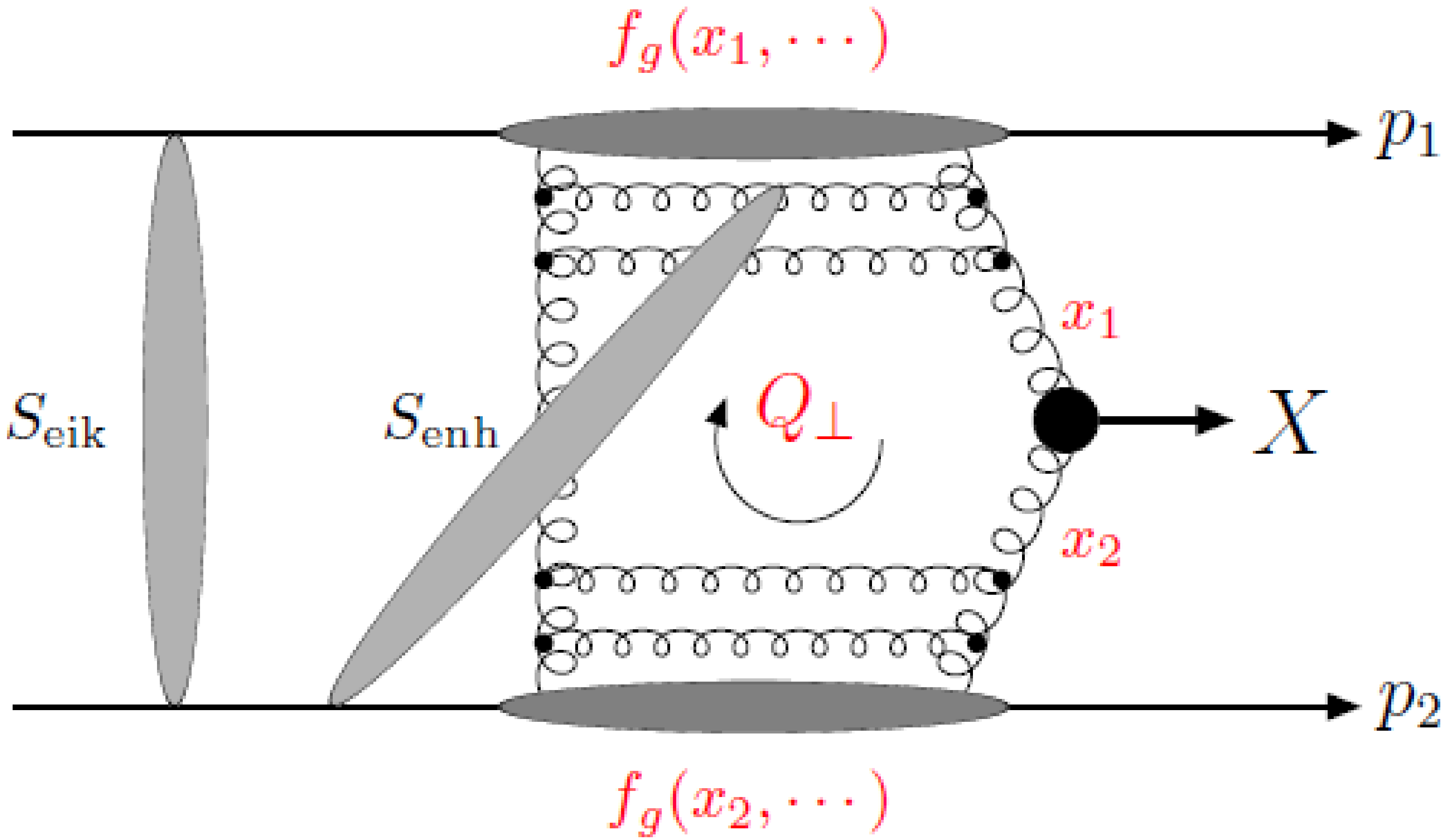
If $|y_\Upsilon| < 2.5$, then sample $f_g(x_1,x_2)$ with x_i in $(10^{-4}, 10^{-2})$

Need FSC. May use HERA $\gamma p \to J/\psi\, p$ and $J/\psi\, p^*$ to determine p^* fraction

Combined fit to HERA and LHC exclusive J/ψ data







$f_g(x_1, \cdots)$
p_1
S_{eik}
S_{enh}
$Q_\perp$
x_1
X
x_2
p_2
$f_g(x_2, \cdots)$