Review of exclusive J/ψ production

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LIVERPOOL THEORETICAL PHYSICS

- Introduction: basics, GPDs, k_T factorisation
- Ultraperipheral J/ψ production in pp
- Gluon fits using HERA and LHC data; predictions
- Use in global fits? NLO in collinear factorisation
- Outlook

Jones, Martin, Ryskin, T: JHEP 1311(2013)085, JPhysG41(2014)055009

Basics of Exclusive production of Vector Mesons

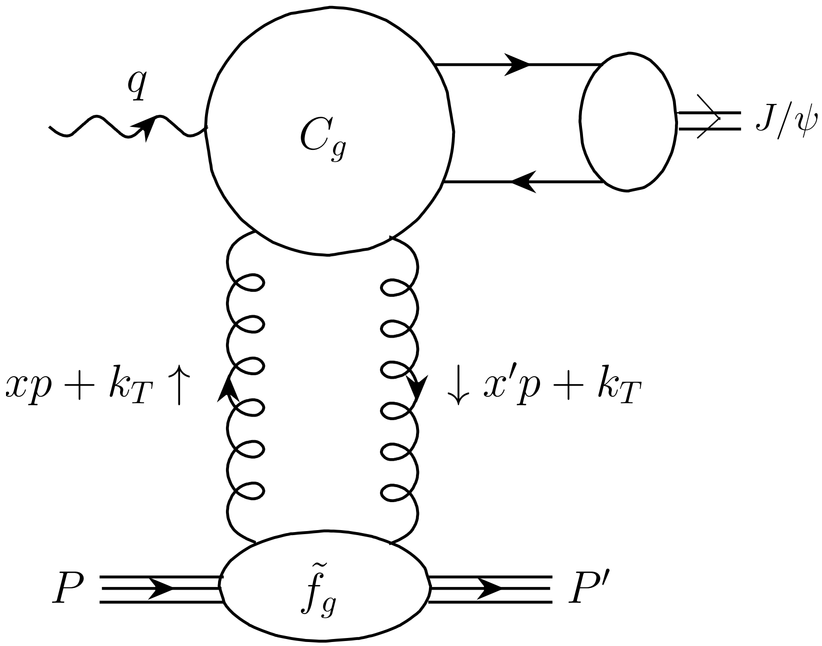
- need colour singlet exchange
  (modelled by 2g, Ryskin 1993)

- factorisation of basic γp amplitude:

$$\phi^{\gamma}_{c\bar{c}} \otimes T_{c\bar{c}+p} \otimes \phi^{J/\psi}_{c\bar{c}}$$

- cross section ~ $g(x,\mu^2)^2$

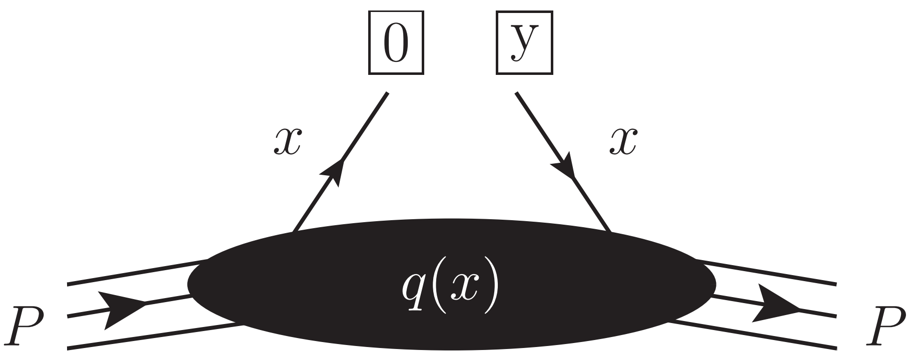
- perturbative QCD description if scale>>Λ_{QCD} (electroproduction, heavy quarks, or large p_T)



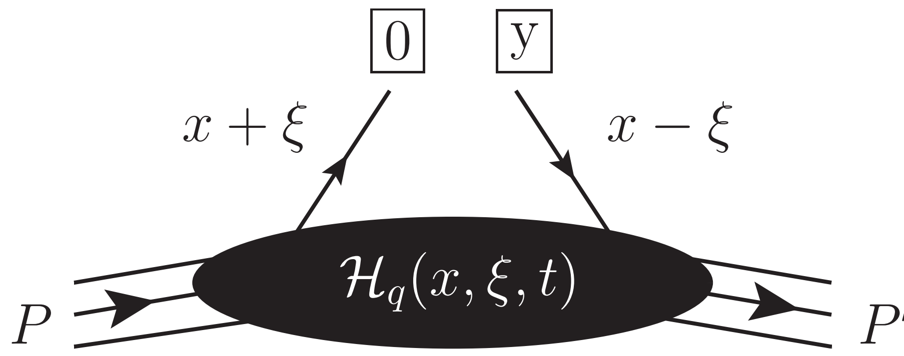
- heavy VMs described in non-relativistic approximation

Basics: GPDs

\`normal’, forward PDF



\`skewed’, generalised GPD: P≠P’



- forward limit: $\xi = 0$

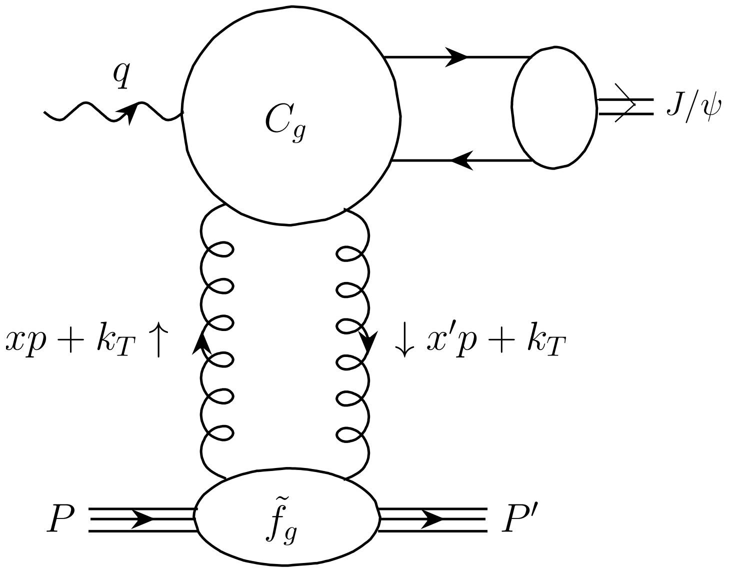
$H_q(x,0,0) = q(x)$ $\quad x > 0$
$H_q(x,0,0) = -\text{qbar}(-x)$ $\quad x < 0$
$H_g(x,0,0) = xg(x)$

- not well known, models
- studied in DVCS

- can be related, for small x, ξ, to forward PDFs by Shuvaev transform

Basics: k_T factorisation

- in standard collinear factorisation, k_T is only generated from higher orders
- can be bad approximation especially at high energy scattering with large logs, e.g. $\ln(s/m^2)$
- can include k_T by using unintegrated PDFs (Collins et al. 1991)
- general k_T factorisation formula with off-shell ME sigma-hat:



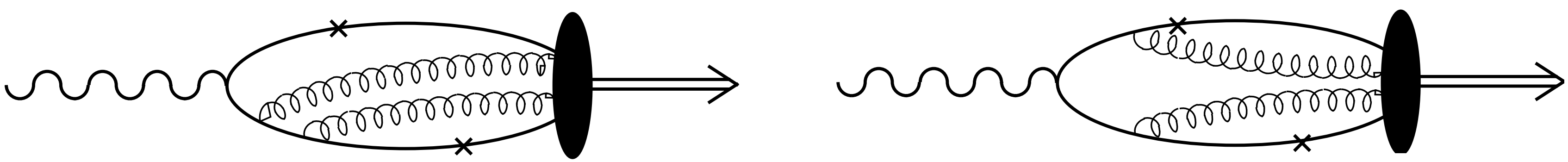
- perform loop integral over k_T numerically with uPDFs, captures leading contributions beyond LO

$$\sigma_{pp\to ppX}(s,m) = \sum_{i=q,g} \int dx_1 dx_2 dk_{1,T}^2 dk_{2,T}^2 f_i(x_1, k_{1,T}^2, \mu_F^2) \times f_i(x_2, k_{2,T}^2, \mu_F^2) \hat{\sigma}_i(x_1 x_2 s, k_{1,T}^2, k_{2,T}^2, m, \mu_F^2)$$

NRQCD approximation

- lowest order non-relativistic approximation sets $m_c = M_{J/\psi}/2$ and neglects all binding and higher order in v (and α_s) effects

- large suppression effects from Fermi motion were obtained by some authors using potential models for the J/ψ wave function



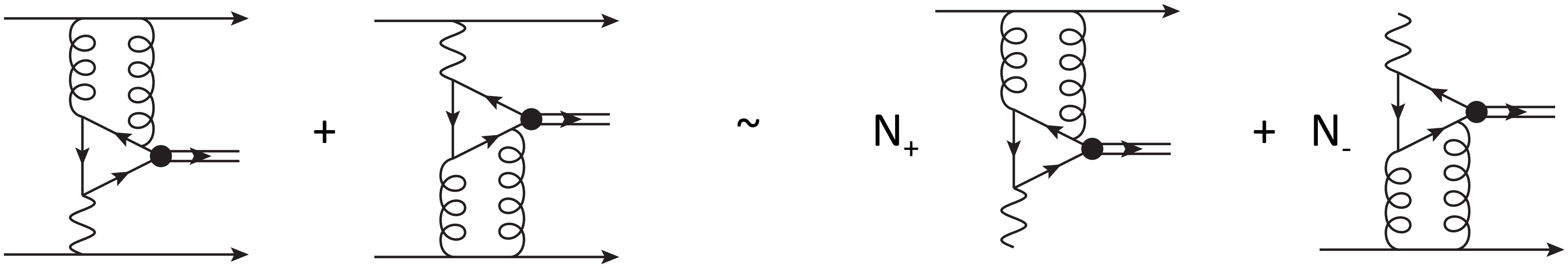
- Hoodbhoy has calculated leading relativistic corrections including higher (qqbar+g) Fock states required for gauge invariance and found only a 6% reduction for the x-section

- for results below experimentally measured Γ_{ee}^{exp} of J/ψ used

Ultraperipheral J/ψ production: TH description

- use of Equivalent Photon Approximation to relate pp to γp cross-section

- ultraperipheral cross-section at given rapidity y has contributions from two γp c.m. energies: $W_{\pm}^2 = M_{J/\psi}\sqrt{s}\,\exp(\pm|y|)$

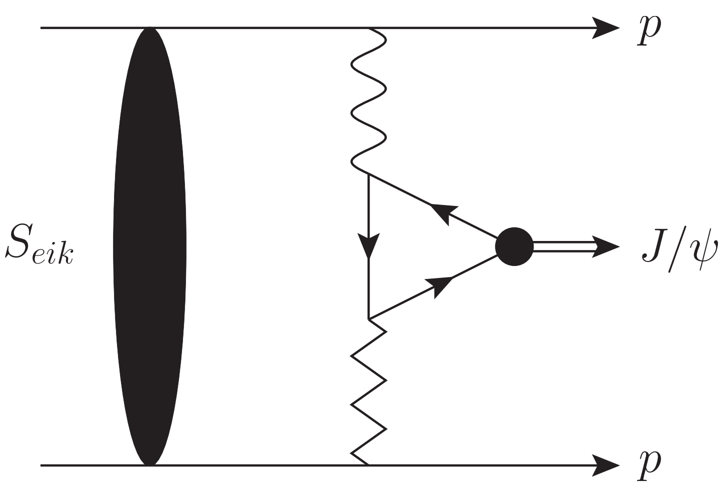


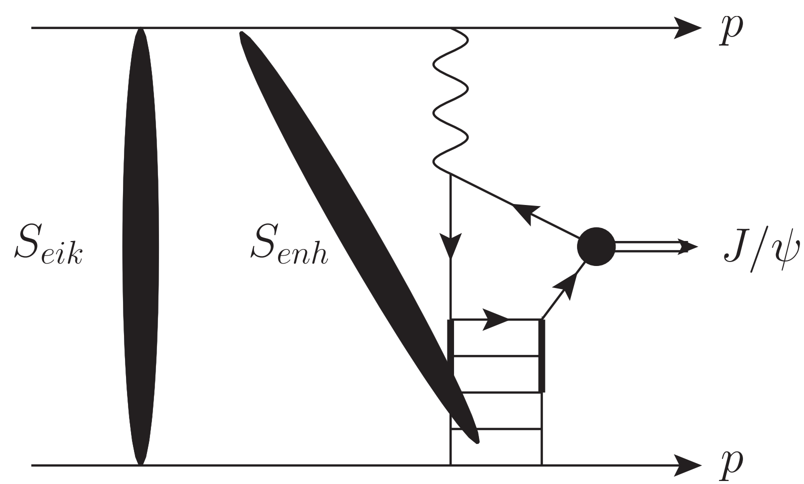
- $$\frac{d\sigma(pp)}{dy} \sim S_+^2 N_+ \sigma_+(\gamma p) + S_-^2 N_- \sigma_-(\gamma p)$$

  with photon fluxes $N_{\pm}$ (from EPA) and gap survival factors $S_{\pm}$ (from KMR model)

- same/similar description applicable for ultraperipheral pA collisions

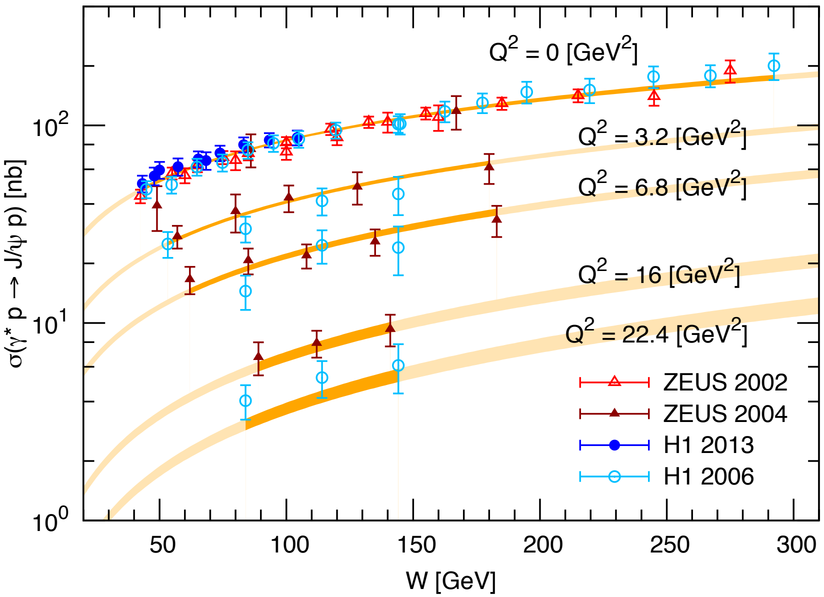
Ultraperipheral production: gap survival factors

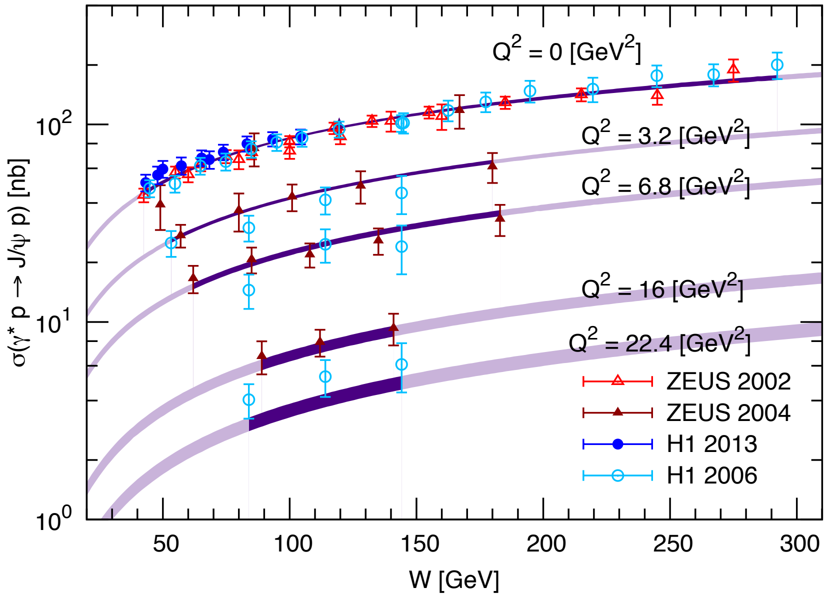




- soft QCD interactions with spectators can destroy the rapidity gaps/exclusivity
- have to account for gap survival factors S
- studied in detail for excl. H and other processes (Durham model, Khoze et al.)
- here use of KMR model: convolution (in impact parameter space) of process dependent matrix elements times exponential suppression with universal proton opacities
- model uses many pp and ppbar x-section data in fit procedure based on eikonal model and effective pomeron exchanges
- small corrections from `enhanced' rescattering; uncertainty from $S_{\pm}^2$: ~5%

Cross section and gluon fits

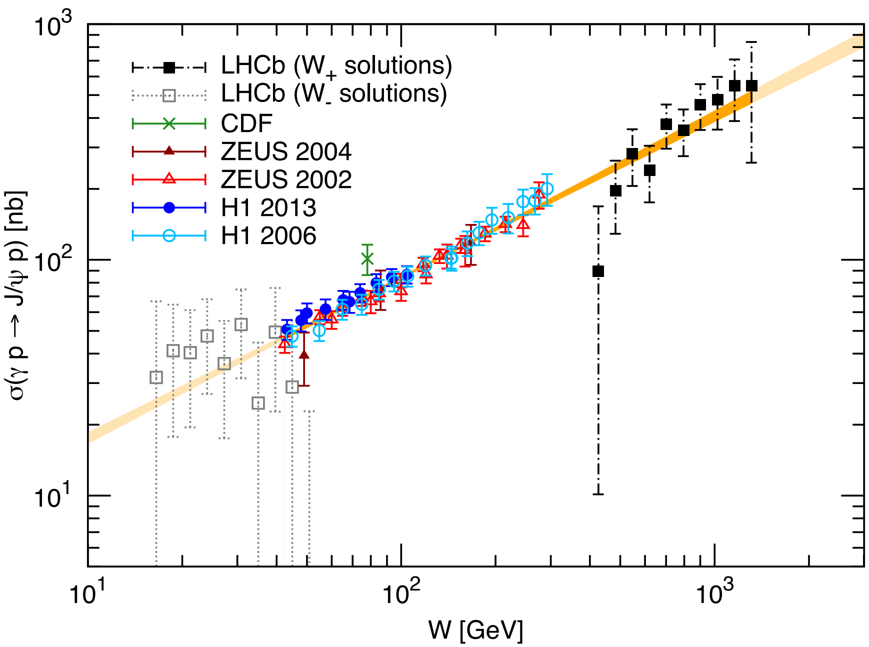


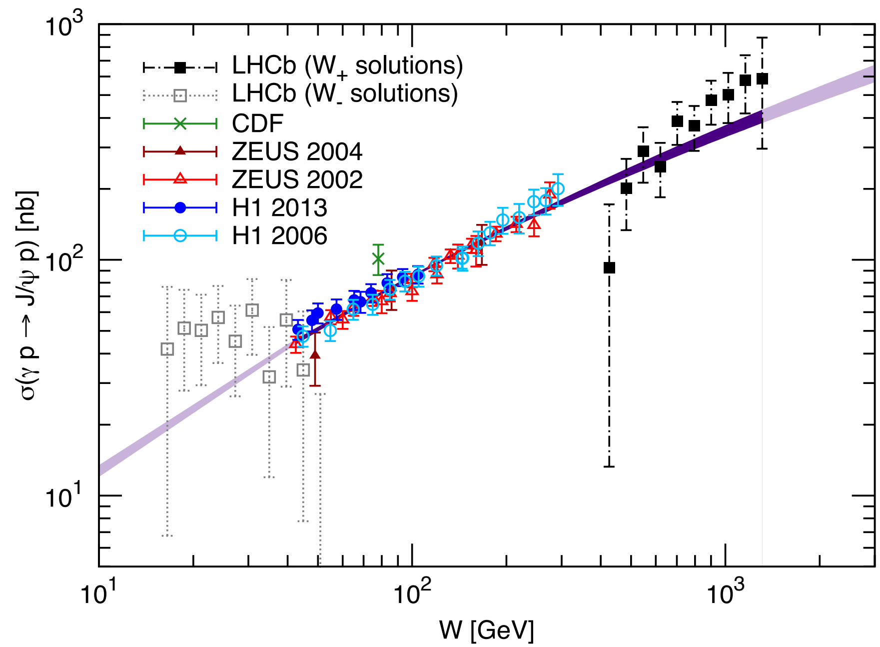


- HERA data fitted with LLA (LO, model 1) and unintegrated (`NLO', model 2) gluon forms, via non-linear χ^2 minimisation; x in range 10^{-4} … 10^{-2}, μ^2= 2.4 … 8 GeV^2
- LLA: power law $xg(x,\mu^2) = Nx^{-\lambda}$ with $\lambda = a + b\ln(\mu^2/0.45\text{GeV}^2)$
- NLO: effective evolution and leading double log resummation, IR parameter Q_0^2

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

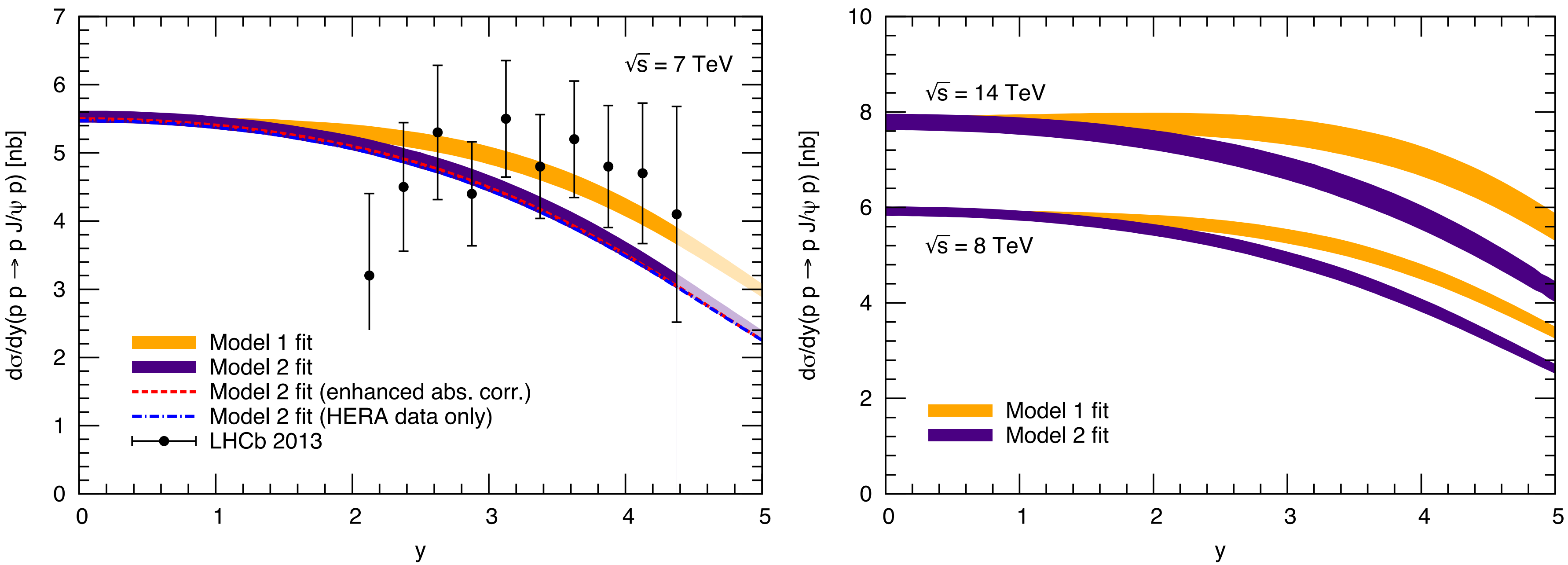
Cross section and gluon fits: including LHCb data





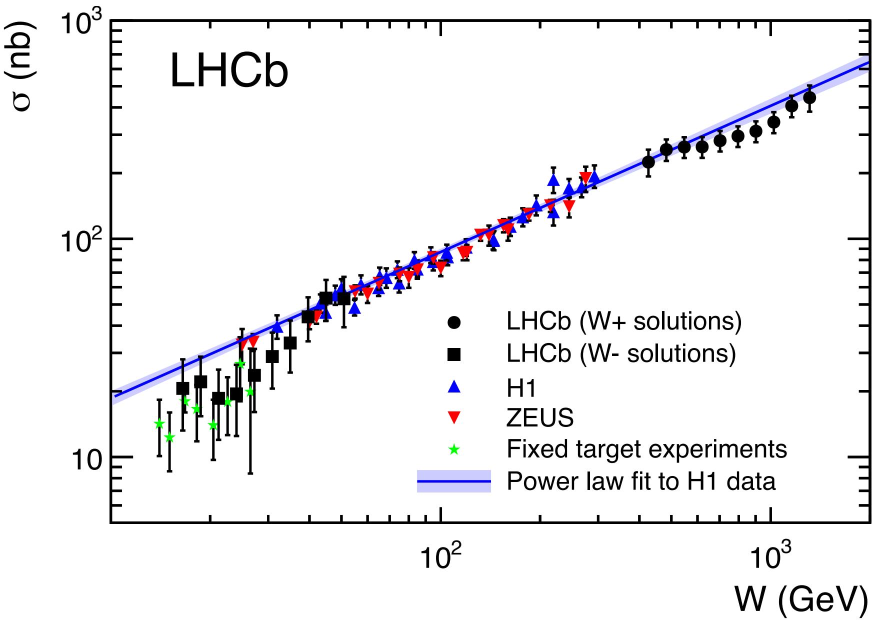
- LHCb data extend range down to $x \sim 10^{-6}$, but HERA data (still) dominant
- both underlying cross sections $\sigma_{\gamma p}(W_\pm)$ calculated with $S_\pm^2$ and $N_\pm$ factors
- both fits with good χ^2_{min}/d.o.f. < 1 (for details see publications)

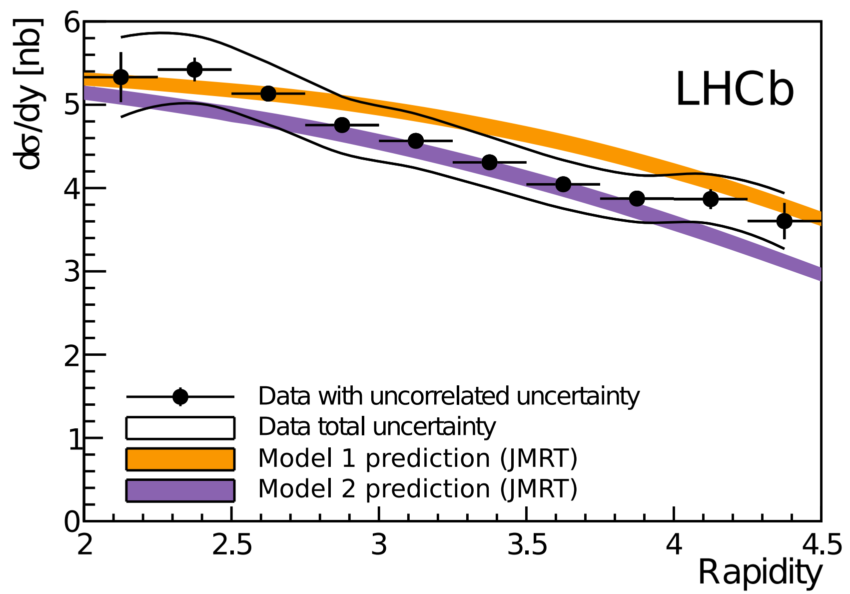
Gluon fits and predictions

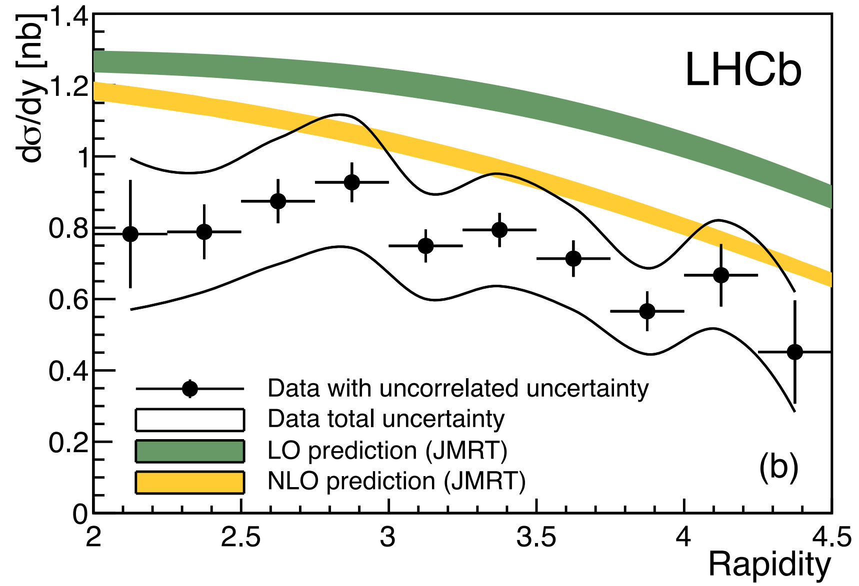


- can use fitted gluon (from HERA & LHCb 2013 data) for dσ(pp)/dy predictions at higher pp energies; LO and `NLO' similar/consistent at 7 TeV
- W_- component accounts for O(30-40%) of dσ(pp)/dy; better use other data (fixed target) there to minimise TH uncertainties?
- so far everything consistent; more fit constraints expected with future data

Gluon fits: LHCb 2014 data

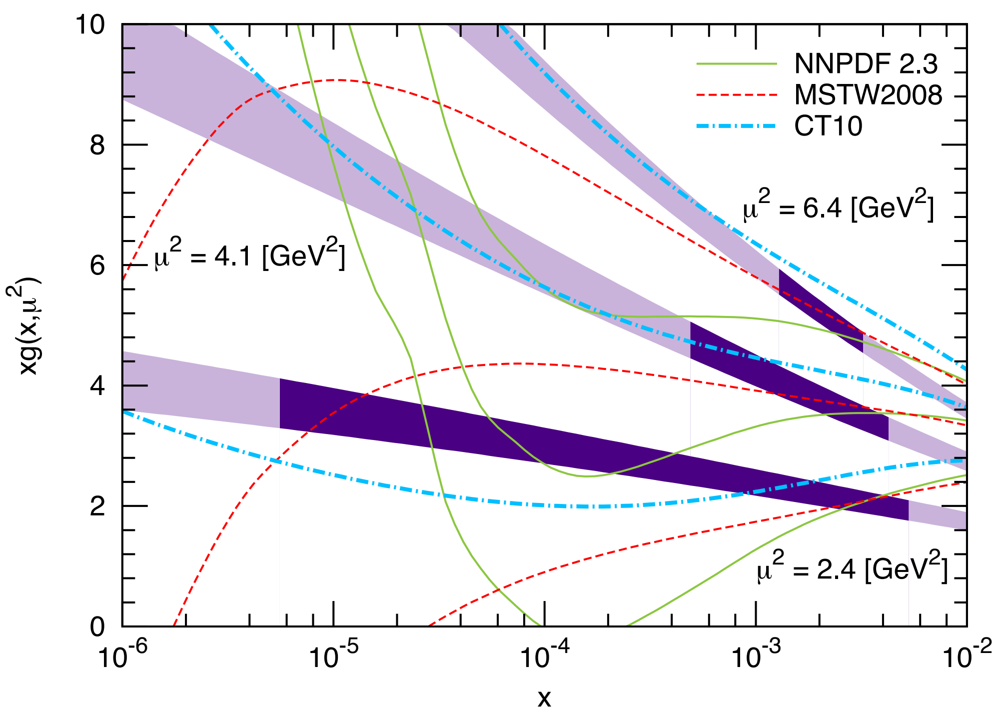






- LHCb 2014 data (at 7 TeV), not included in fit, have ~ half the error
- consistent with HERA power law and both our LO and `NLO' fits
- fits also used for exclusive ψ(2S) ➔ and ϒ predictions (no pp ϒ data yet, HERA data described, not fitted)

NLO gluon fit compared to global fits



- global fits (w/out J/ψ data) nearly unconstrained at low x and rel. low scales
- in our fit:
  - scale dependence (evol.) from electroproduction data and from k_T^2 integral
  - stable behaviour as expected from ansatz
  - errors displayed from data only; need to further scrutinise TH uncertainties

Exclusive (J/ψ) data and global fits, NLO in coll. fact.

- global fits (so far) don't use these exclusive data;
  - (unintegrated) GPDs not on the same footing; is this a problem?
  - TH uncertainties not straightforward; also not in standard approach
  - obvious tension at low x

- with more data in the future need to overcome obstacles!

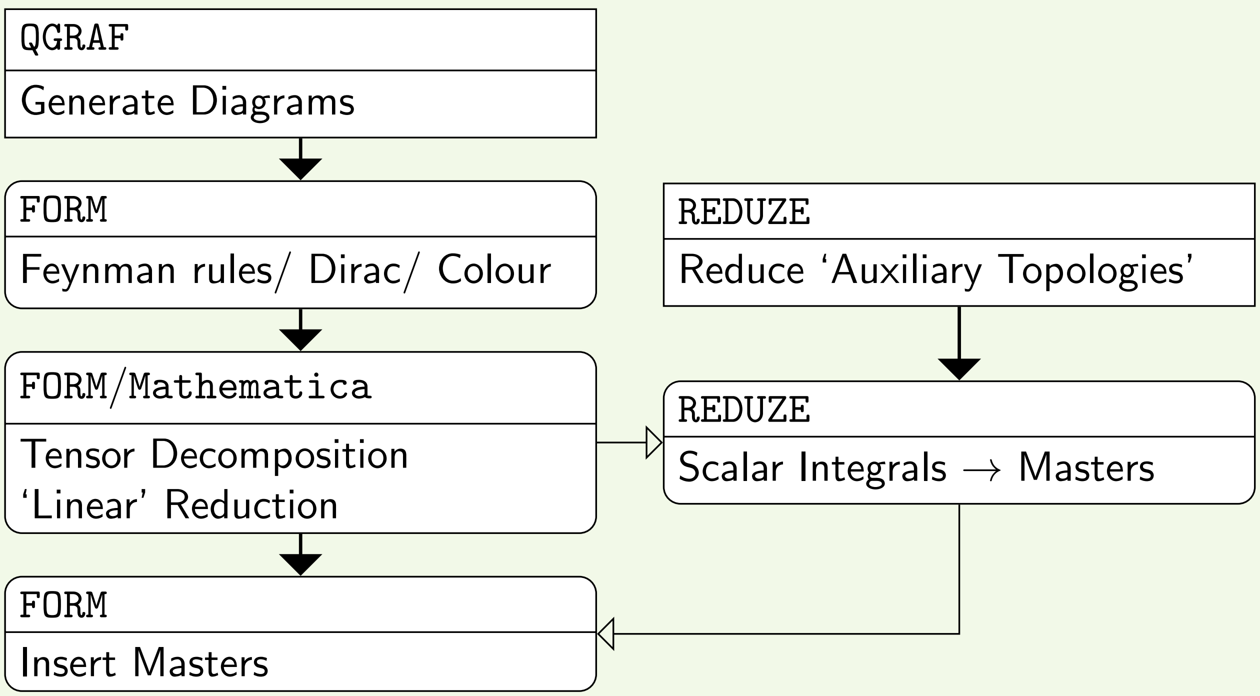
- other possible route: standard collinear factorisation at NLO:
  - results from Ivanov et al. in principle available since 2004,
  - but results show huge scale (renormalisation and factorisation) dependence when taken face value (need to sum large logs)

- independent calculation of Ivanov et al.'s results just finished (Stephen Jones);
  - use of standard loop-calculation tools (not based on cutting rules/dispersion relations)
  - semi-automated (so can be extended to similar processes) ➔
  - publication and phenomenological analysis in preparation

Full NLO in collinear factorisation: Stephen Jones

Calculation Overview

- Dimensional regularisation $d = 4 - 2\epsilon$



Outlook

- perturbative QCD framework with two gluon exchange is successfully describing many exclusive processes

- with improved experimental data for J/ψ in a wide x range the gluon can be constrained much better than is currently done in the global fits

- further developments and refinements are under way, including a complementary analysis based on a full NLO calculation within collinear factorisation

- more data in an even wider x range will add further crucial constraints on the form of the gluon

- data at higher scales (Υ photo- or J/ψ electroproduction data) would be extremely valuable to better scrutinise the PDF scale evolution in the fits

- ultimately a combined global fit should be performed.