

DRELL YAN AT LOW INVARIANT MASS



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PDF4LHC, CERN
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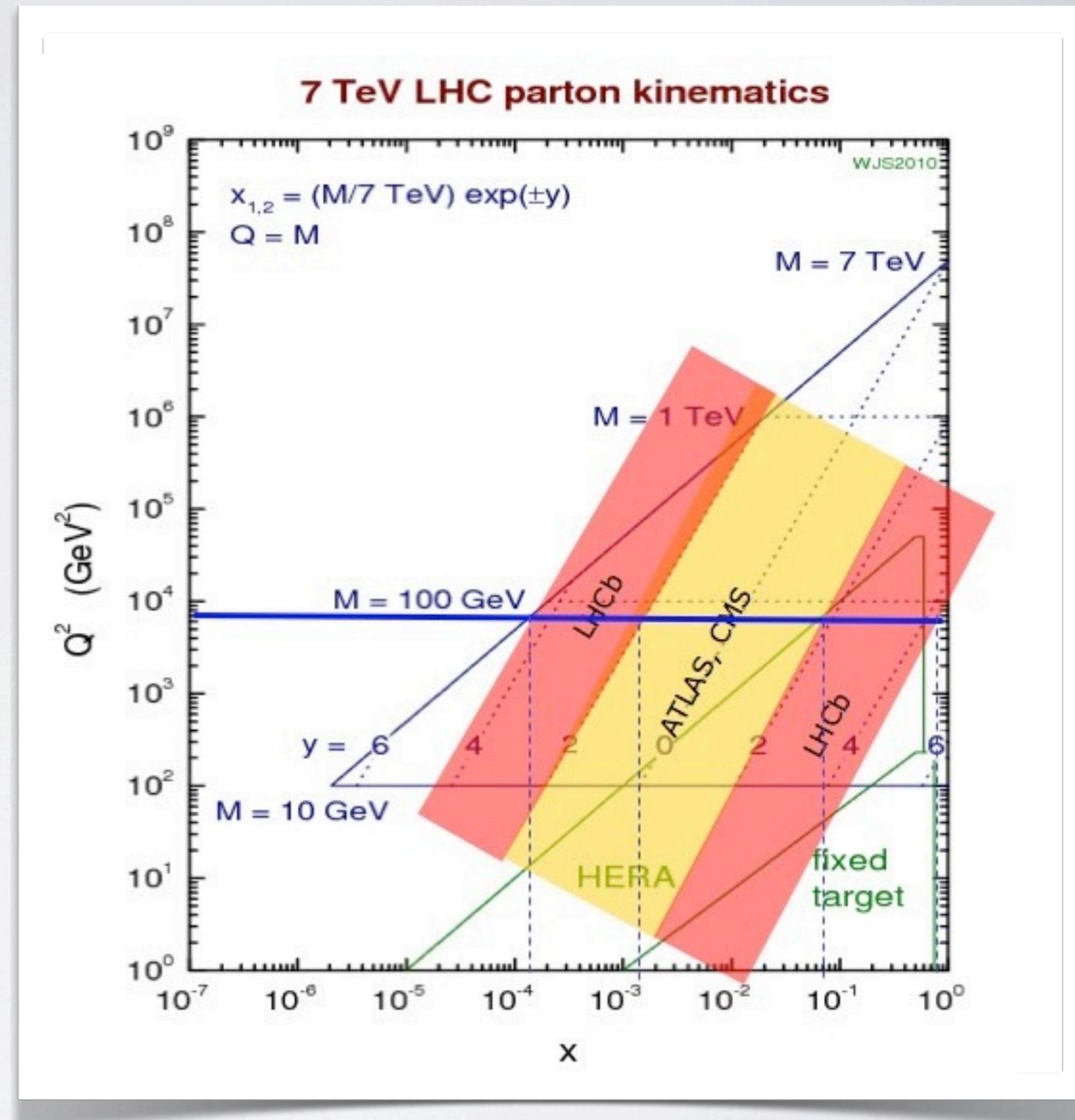
LHC kinematics

LHC is mainly about

- discovery of the Higgs
- study of its properties
- search for new physics

But also:

- strong force at unprecedently high energies
- Precise EW / QCD physics
- Unexplored regions of (x, Q^2) plane
- Better determination of the partonic structure of the proton (PDFs)



Rojo

arXiv:1106.1997

Low- x partons

$$x_{1,2} = \frac{M}{\sqrt{s}} e^{\pm Y}$$

Central Z ($M=m_Z, Y=0$):

$$x_1 = x_2 = 0.011$$

Forward Z ($M=m_Z, Y=4$):

$$x_1 = 0.62, x_2 = 0.21 \cdot 10^{-3}$$

Central low mass ($M=6 \text{ GeV}, Y=0$):

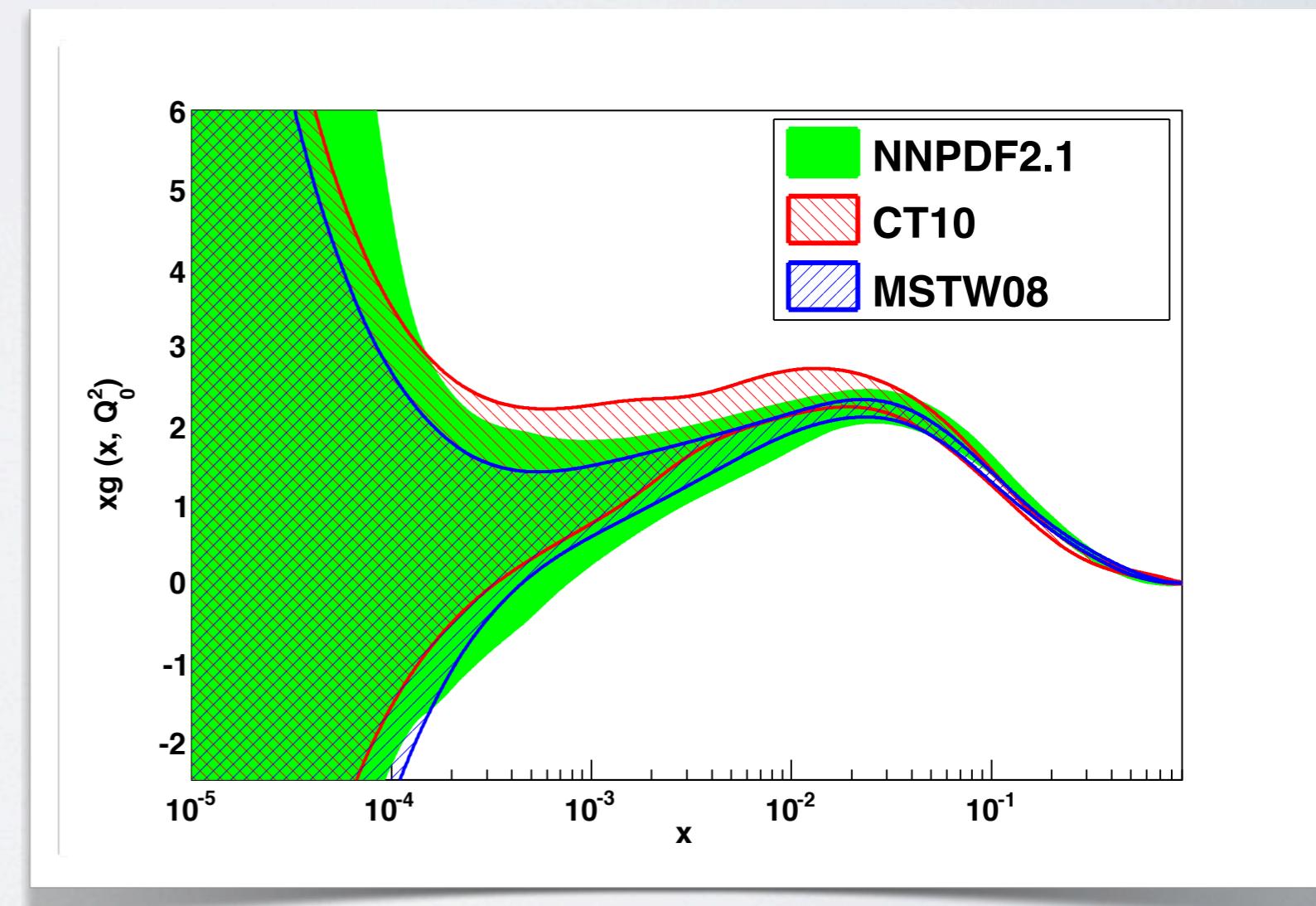
$$x_1 = x_2 = 0.75 \cdot 10^{-3}$$

Forward low mass ($M=6 \text{ GeV}, Y=4$):

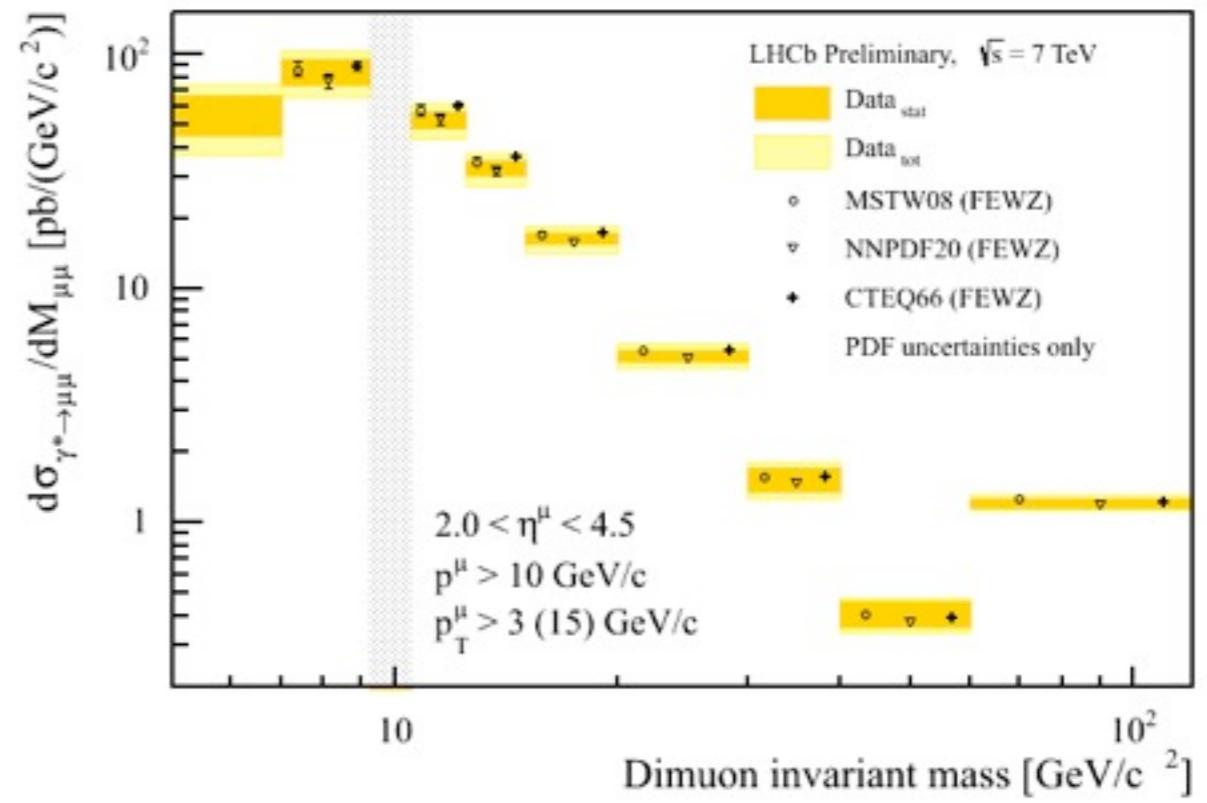
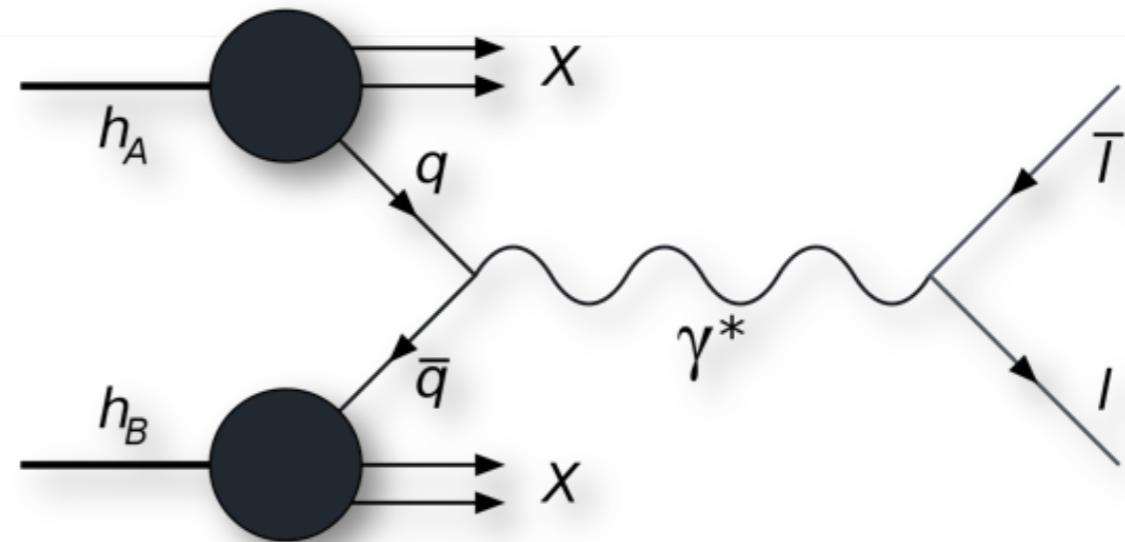
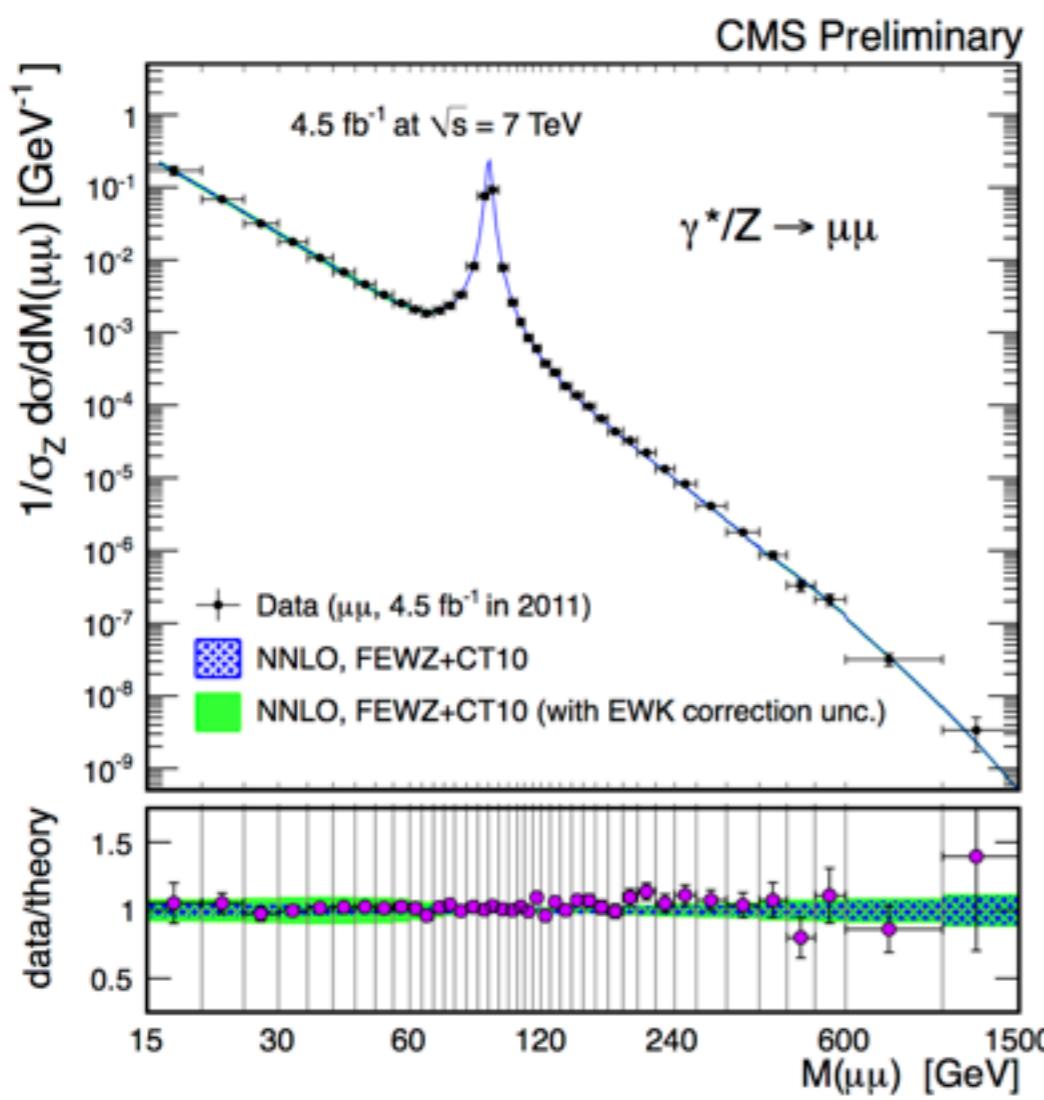
$$x_1 = 0.041, x_2 = 0.14 \cdot 10^{-4}$$

for $s = (8 \text{ TeV})^2$

- Small-mass / forward Drell Yan produced by low- x partons
- They are generated by the evolution, which is driven by the gluon
- Thus, low-mass and forward DY is a probe of the gluon at low x

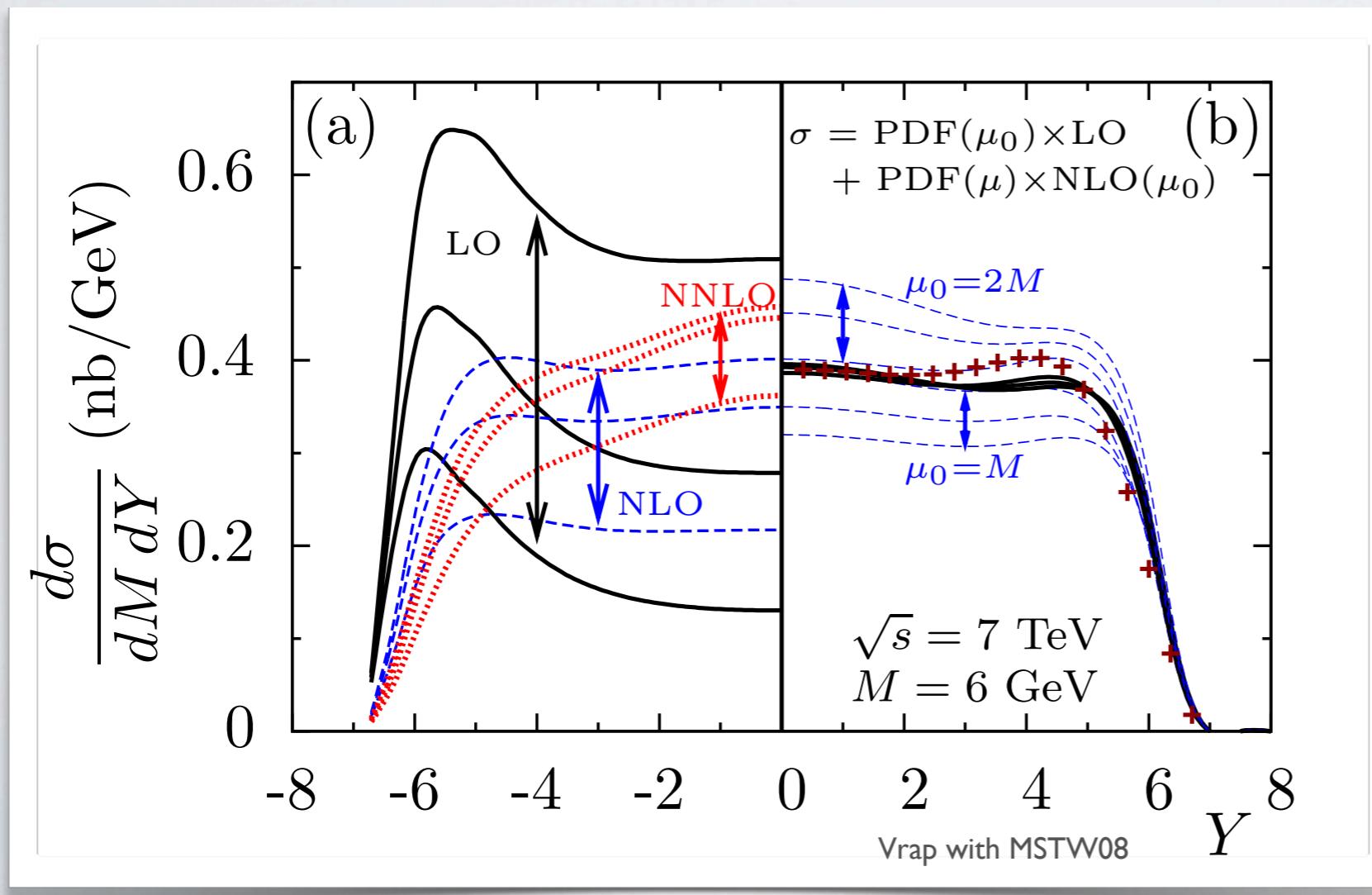


Small mass Drell Yan



Importance of higher orders

- Large scale dependence: importance of higher orders
- μ_F variation generates $\sim \alpha_s \ln x \ln \mu_F$
- Choose $\mu_F = \mu_0$ in the LO part to minimise these contributions
- Studying the dominant NLO contribution (ladder-type qg)
 $\mu_0 = 1.4 M$ is found



Oliveira, Martin, Ryskin
arXiv:1205.6108

Can we resum
small- x logs more
systematically ?

Small- x resummation

- High-energy logs present in PDF evolution and coefficient functions
- For consistency, we need to resum both

$$\sigma = (C^{\text{FO}} + C^{\text{LL}x} - C^{\text{LL}x,\text{exp}}) \otimes f_1 f_2$$

- Resummed coefficient functions at the leading (non trivial) logarithmic accuracy Catani, Ciafaloni, Hautmann
- Resummed PDF evolution at NLL x Altarelli, Ball, Forte
Ciafaloni, Colferai, Salam, Stasto
Thorne, White

QCD evolution equations

DGLAP: Q^2 evolution for N moments of the parton density

$$\frac{d}{d \ln(Q^2/\mu^2)} G(N, Q^2) = \gamma(N, \alpha_s) G(N, Q^2)$$

BFKL: small- x evolution for M moments of the parton density

$$\frac{d}{d \ln(1/x)} G(x, M) = \chi(M, \alpha_s) G(x, M)$$

In Mellin space logs are mapped into poles

$$\ln^k \frac{Q^2}{\mu^2} \leftrightarrow \frac{1}{M^{k+1}}$$
$$\ln^k \frac{1}{x} \leftrightarrow \frac{1}{N^{k+1}}$$

Can we write an anomalous dimension that resums both collinear and high-energy logs ?

Resummed evolution

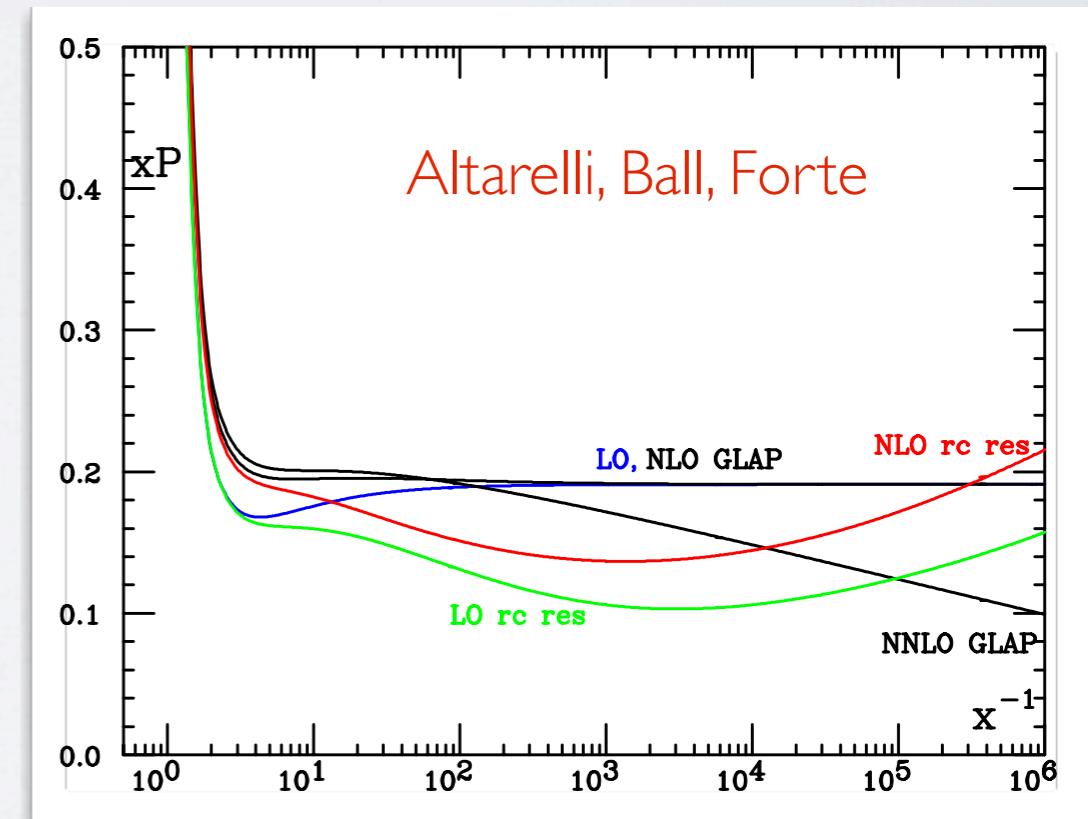
- Problem studied by different groups in late '90s /early '00s
- The main interest was DIS at low x

for a comparative review see *HERA-LHC Proc. arXiv:0903.3861*

- Key ingredients:
 - stable solution of the running coupling BFKL equation
 - match to standard DGLAP at large $N(x)$
 - important subleading effects

Are resummed-evolution
tools available ?

Consistent procedure: re-fit
PDFs

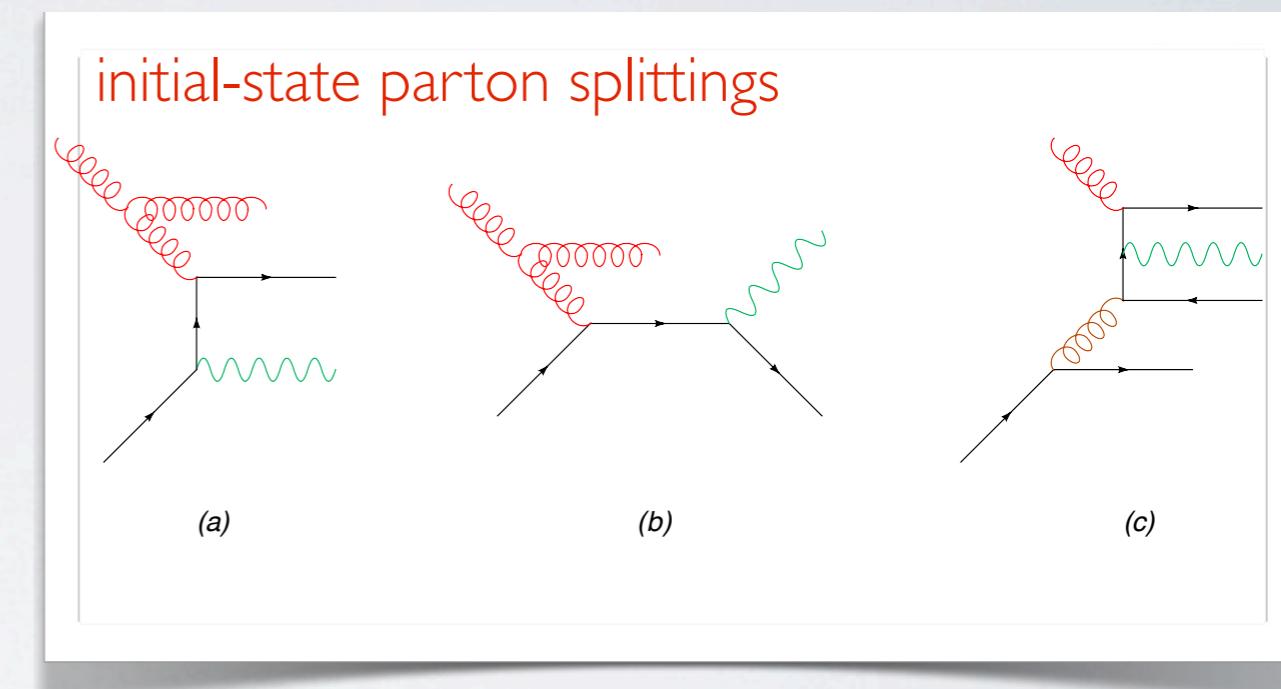
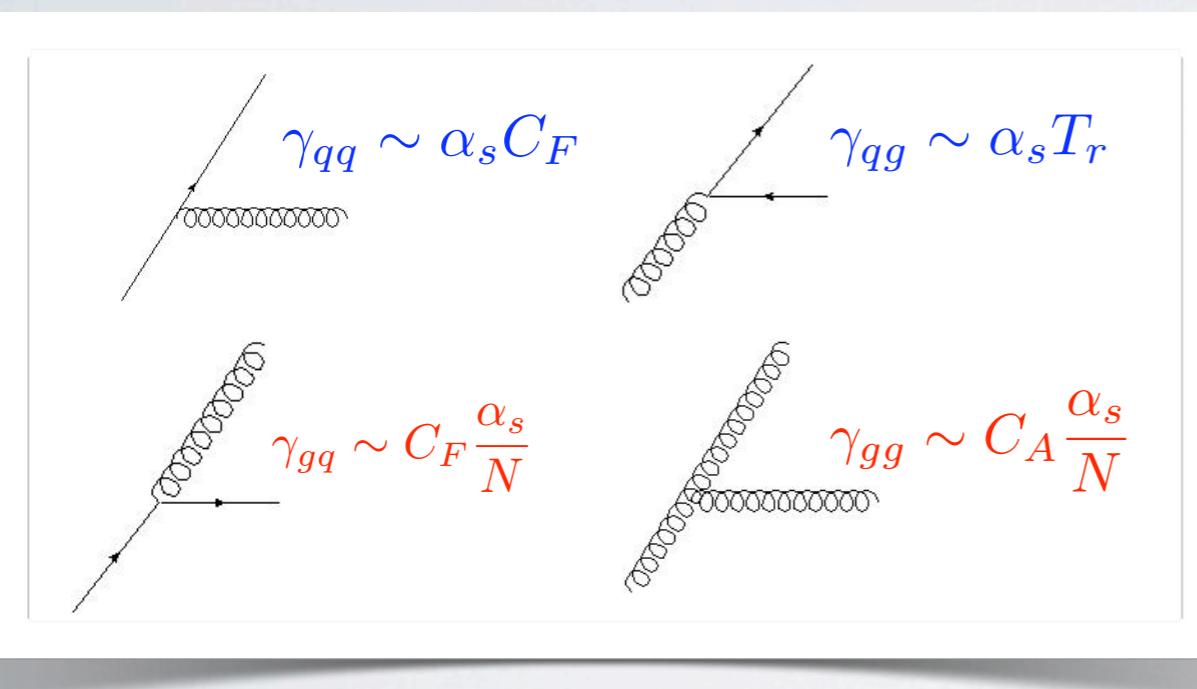


Resummed coefficient function

- All-order (leading) small- x behaviour for inclusive cross-section with high-energy factorisation
Catani, Ciafaloni, Hautmann
NPB366 (1991) 135-188
- Factorisation-scheme dependence known as well
Catani, Hautmann
hep-ph/9405388
- Subleading (running coupling) terms play a crucial role in stabilising the result
R. D. Ball
arXiv:0708.1277
- Consistent resummation of rapidity distribution using high-energy factorisation is also possible
Caola, Forte, SM
arXiv:1010.2743

What can we use for Drell Yan?

- We can use high-energy factorisation to compute all-order small- x contributions to DY
- Which are the dominant contributions ?



- We calculate the high energy singularities in the qg channel using high-energy factorisation
 - We then compute qq channel via colour-charge relations
 - All other channels are subleading (although gg is numerically relevant)

Invariant mass distribution

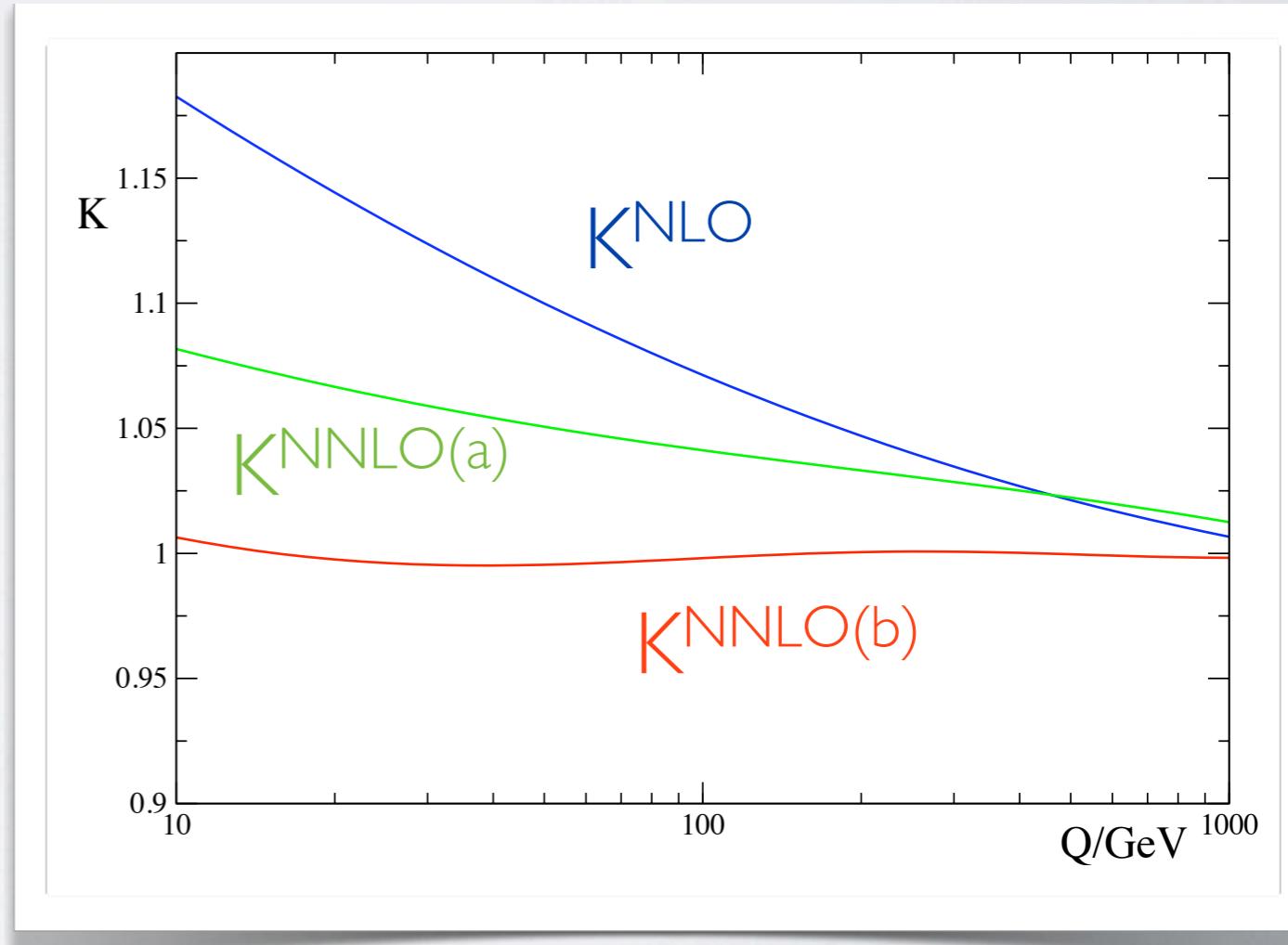
- The “inclusive” calculation is enough for the invariant mass distribution of the lepton pair
- All-order resummation performed

$$D_{qg}(N, \alpha_s) = \frac{\alpha_s}{18\pi} T_R \left[1 + \left(\frac{29}{6} + 2\pi^2 \right) \frac{C_A}{\pi} \frac{\alpha_s}{N} + \left(\frac{1069}{108} + \frac{11}{3}\pi^2 + 4\zeta_3 \right) \left(\frac{C_A}{\pi} \frac{\alpha_s}{N} \right)^2 + \left(\frac{9031}{648} + \frac{85}{18}\pi^2 + \frac{7}{20}\pi^4 + \frac{73}{3}\zeta_3 \right) \left(\frac{C_A}{\pi} \frac{\alpha_s}{N} \right)^3 + \dots \right]$$

Ball, SM arXiv:0812.3602

Phenomenology yet to be performed

Sizeable correction wrt NLO
Smaller wrt NNLO, but
strongly dependent of PDF
treatment
(NLOres (a) or NNLO (b))

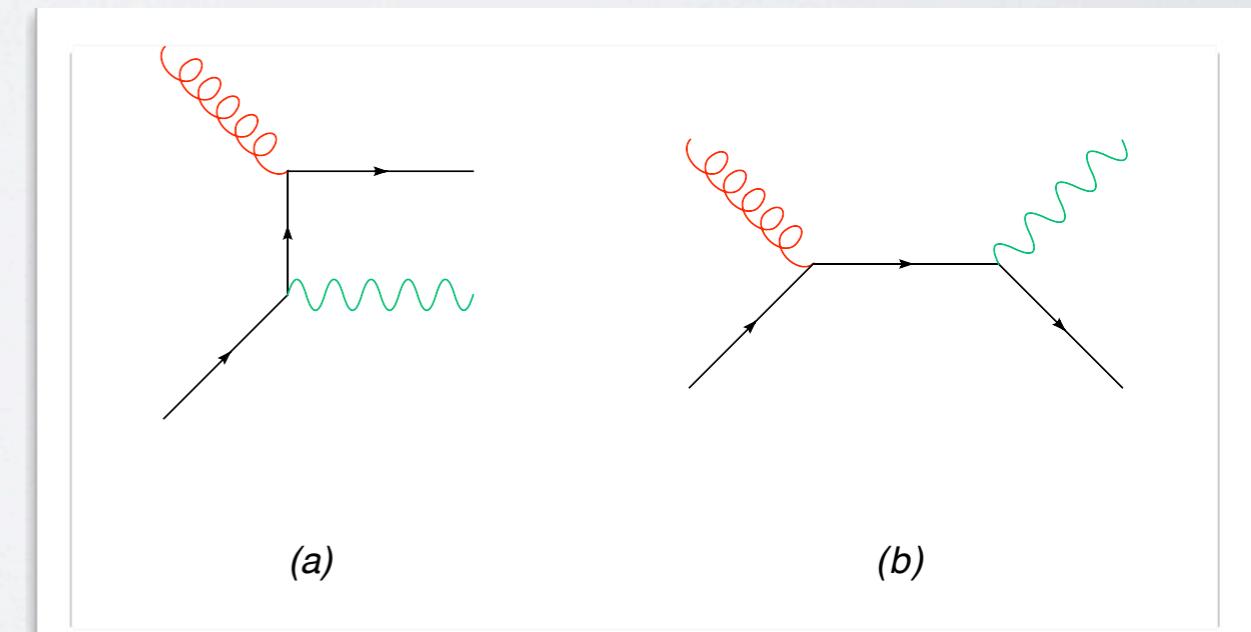


Rapidity distribution

- The formalism to compute small- x resummed rapidity distribution has been worked out
- Mellin - Fourier generalisation of the inclusive method
- Applied to Higgs production in gg fusion
- Drell-Yan calculation can be done (especially if needed !)

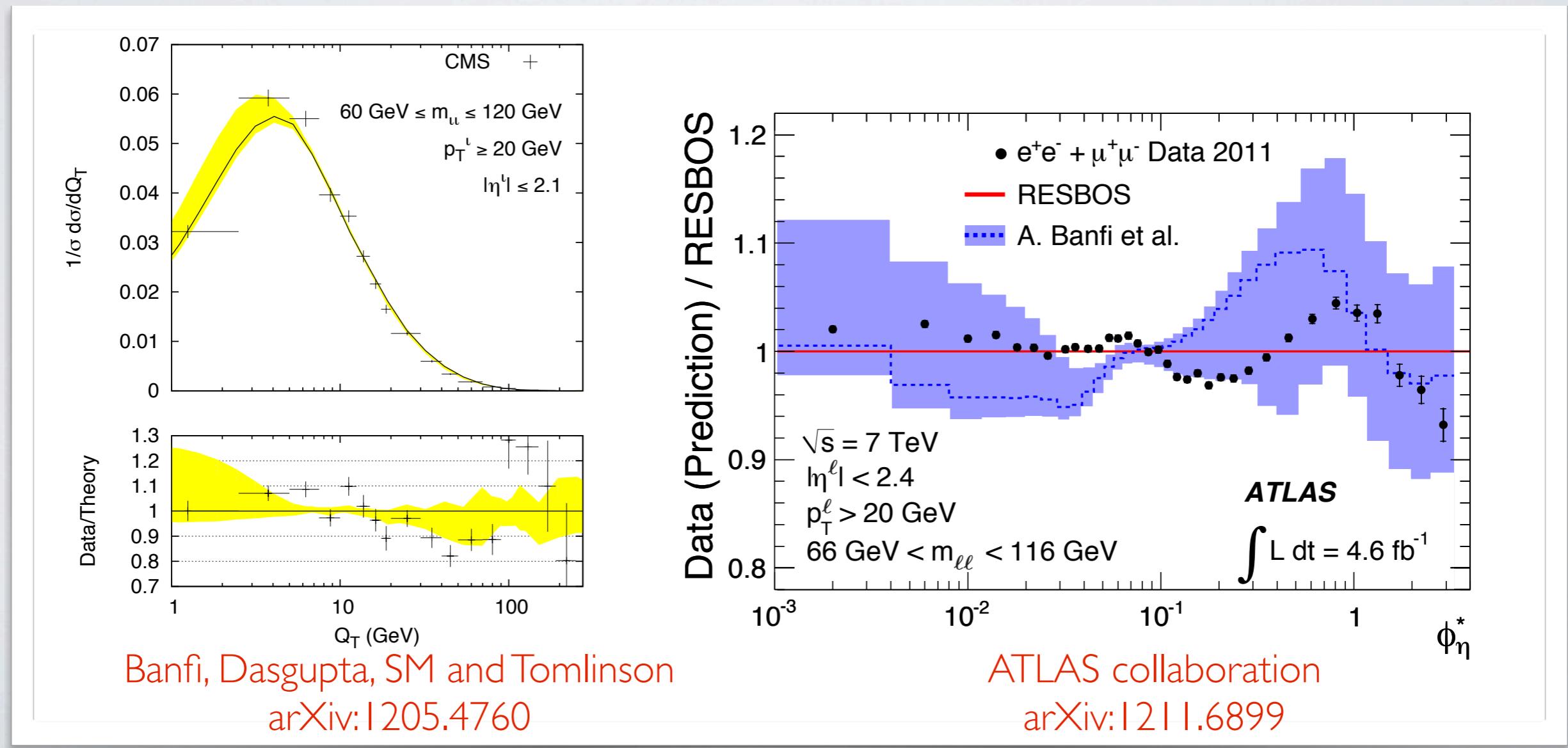
Caola, Forte, SM
arXiv:1010.2743

Kinematic complication: rapidity dependence of the leading contribution



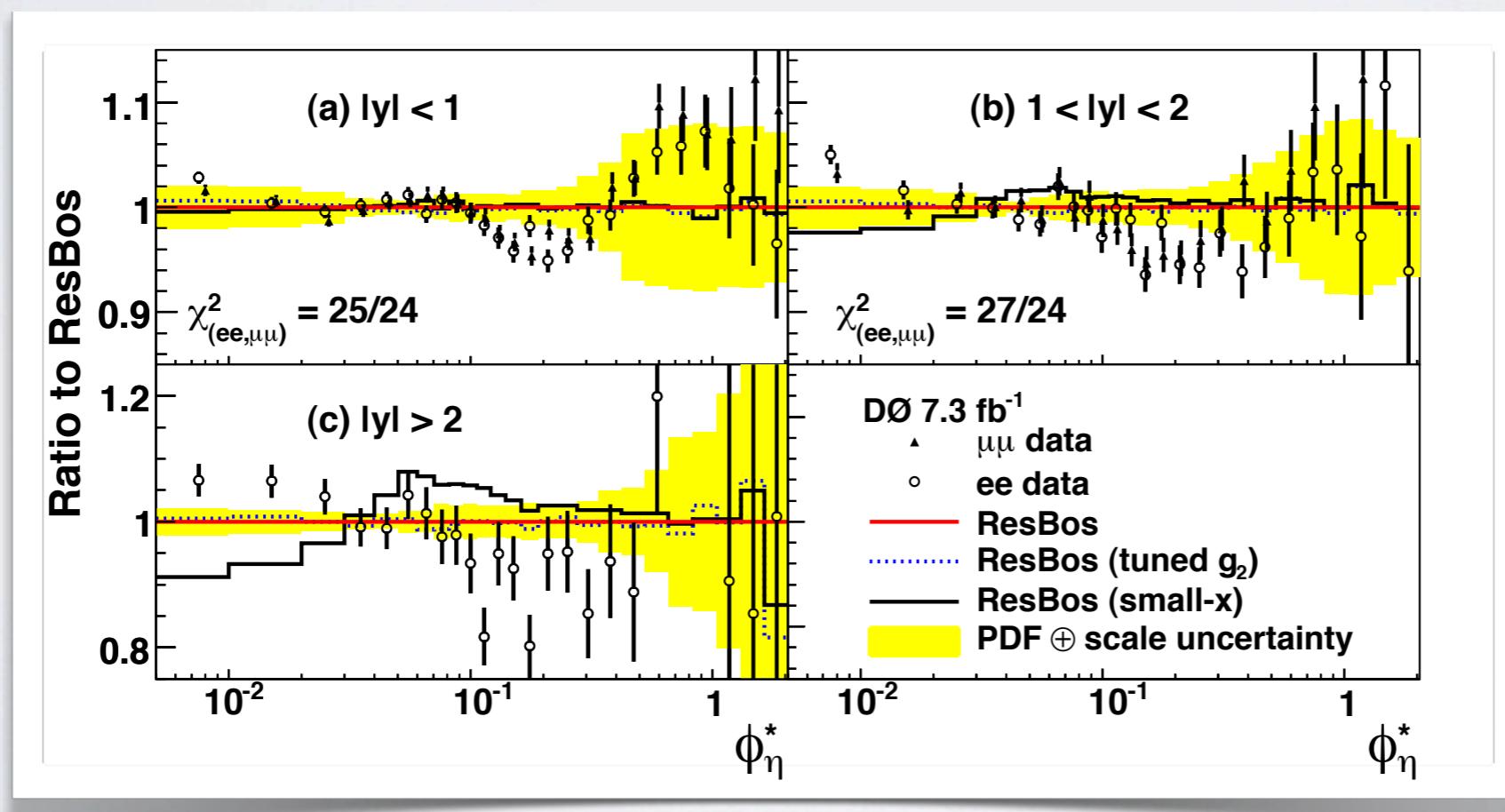
Transverse momentum spectra

- Together with invariant mass and rapidity, Q_T spectra often studied
- Angular variable ϕ^* probes similar physics but with much lower experimental uncertainties
- Good agreement between LHC data and NNLL+NLO in the central region (obtained with new program [PTRESUM](#))



Q_T / ϕ^* in the forward region

- LHCb is measuring these variables in the forward region
- DØ has performed off-peak measurements (not public yet)
- Maybe we should start worrying about low Q_T and low x
- Be careful: precise ϕ^* data tell us that models sometimes don't work (e.g. small- x broadening from semi-inclusive DIS)



DØ collaboration
arXiv:1010.0262

Accounting for Sudakov effects

- We want to probe low x and low scale
- Cut on lepton pairs $Q_T < k_0$
- We need to account for logs of k_0 / M
- OMR: leading-log Sudakov form factor + running coupling
- This modifies optimal scale: $k_0 = M/4$ one gets $\mu_0 = 0.42 M$

Oliveira, Martin, Ryskin
arXiv:1212.3135

- In my opinion the remarkable accuracy of Q_T and ϕ^* experimental data requires precise theoretical calculations
- Is a joint small- x /small- Q_T resummation possible / needed ?
(large- x /small- Q_T done by Laenen (Kulesza), Sterman and Vogelsang)
- Recent work in the context of pA collisions

Mueller, Xiao Yuan
arXiv:1210.5792

Conclusions

- Low mass / forward Drell Yan probes partons at small x
- Theoretical predictions need to go beyond fixed order
- Particular choices of factorisation scale seem to cure instabilities
- Small x resummation possible for DY distributions
 - invariant mass, rapidity, transverse momentum (?)
(work in progress on rapidity distribution)
- Not so much phenomenology has been done so far