Drell-Yan at forward rapidities

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We analyze the Drell-Yan lepton pair production at forward rapidity at the Large Hadron Collider. Using the dipole framework for the computation of the cross section we find a a significant suppression in comparison to the collinear factorization formula due to saturation effects in the dipole cross section. We develop a twist expansion in powers of $Q_s(x_2)/M$ where Q_s is the saturation scale and M the invariant mass of the produced lepton pair. For the nominal LHC energy the leading twist description is sufficient down to masses of 6 GeV. Below that value the higher twist terms give a significant contribution. We perform the analysis for Tevatron and LHC energies.

In collaboration with K. Golec-Biernat and E.Lewandowska

Dipole model for Drell-Yan

Drell-Yan in the dipole model at small x

$$\frac{d^2\sigma^{DY}_{T,L}}{dM^2\,dx_F} = \frac{\alpha_{em}}{6\pi M^2}\frac{1}{x_1+x_2}\sum_f \int_{x_1}^{1}\frac{dz}{z}\,F_2^f\left(\frac{x_1}{z},M^2\right)\,\sigma^f_{T,L}(qp\to\gamma^* X)\,.$$

Structure function of the incoming projectile

z Fraction of the energy of the quark taken by the photon

Radiation of the photon from the fast quark

$$\sigma^f_{T,L}(qp\to\gamma^* X) = \int d^2r\,W^f_{T,L}(z,r,M^2,m_f)\,\sigma_{qq}(x_2,zr)\ ,$$

r Photon - quark transverse separation

$$W^f_T = \frac{\alpha_{em}}{\pi^2}\left\{[1+(1-z)^2]\,\eta^2 K_1^2(\eta r) + m_f^2\,z^4 K_0^2(\eta r)\right\}\ ,$$

$$W^f_L = \frac{2\alpha_{em}}{\pi^2}\,M^2(1-z)^2 K_0^2(\eta r)$$

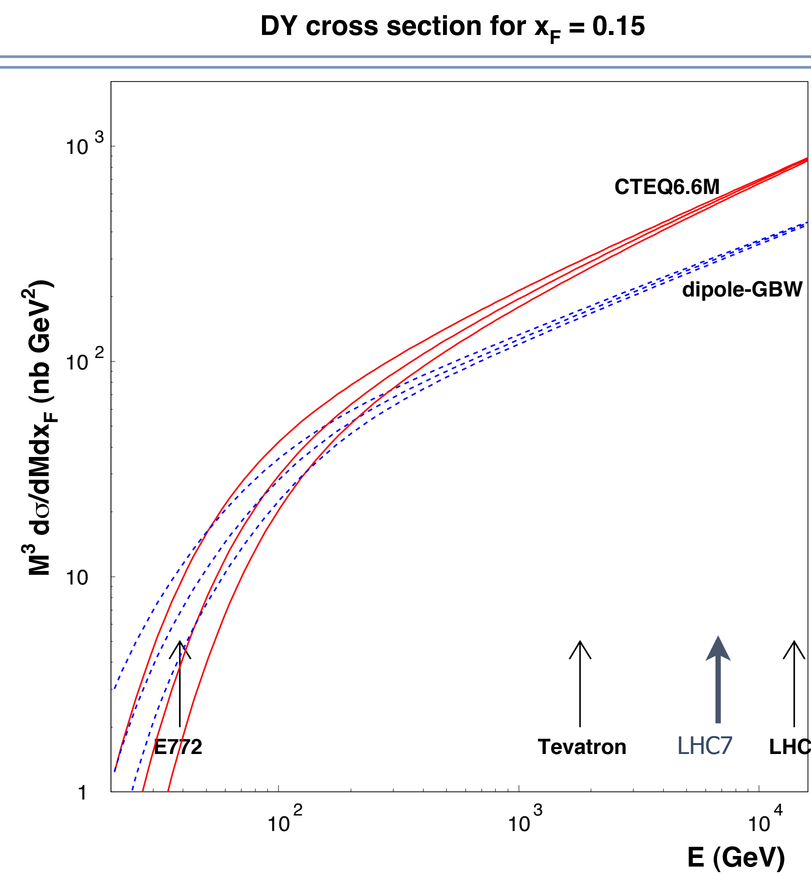
$$\eta^2 = (1-z)M^2 + z^2 m_f^2$$

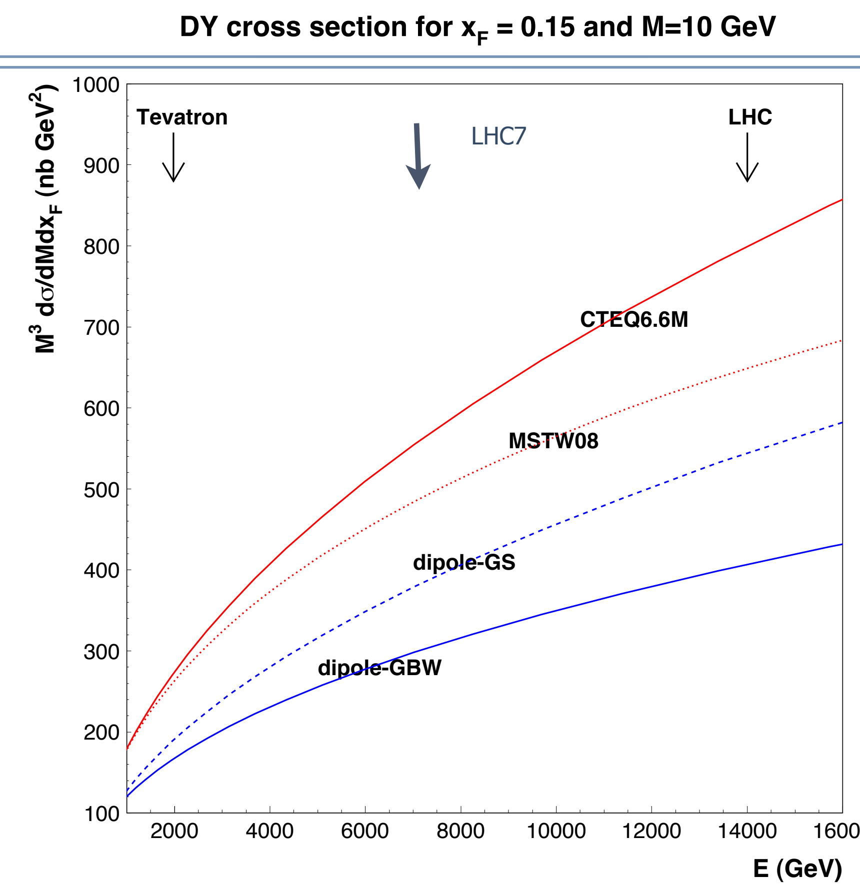
As an example use the Golec Biernat and Wusthoff formula

$$\sigma_{qq}(x,r) = \sigma_0\left\{1-\exp(-r^2 Q_s^2(x)/4)\right\}\ .$$

We will also use other models.

Predictions for LHC





Dilepton mass $M = 6, 8, 10$ GeV

dipole-GS (Golec-Sapeta)
DGLAP included

Large differences between collinear approaches

$x_2 \simeq 3 \cdot 10^{-6} - 10^{-5}$ typical values probed at energies 14-7 TeV

$y \sim 5 - 6$ range of rapidities

Dipole predictions systematically lower than the collinear calculations.

Twist expansion for Drell-Yan

It is more complicated than in DIS, because of the convolution with the structure function of the forward projectile.

$$\frac{d^2\sigma_T^{DY}}{dM^2\,dx_F} = \frac{\alpha_{em}^2\sigma_0}{6\pi^2 M^2}\frac{1}{x_1+x_2}\int_{c-i\infty}^{c+i\infty}\frac{d\gamma}{2\pi i}\,G(\gamma)\widetilde{H}_T(\gamma)\left(\frac{Q_s^2(x_2)}{4M^2}\right)^{\gamma}$$
$$\times\ \int_{x_1}^{1}\frac{dz}{z}\,F_2\!\left(\frac{x_1}{z},M^2\right)\left[1+(1-z)^2\right]\left(\frac{z^2}{1-z}\right)^{\gamma}$$

Cannot directly perform integral over z (fraction of the light-cone momentum of the initial quark carried away by the photon), since it is weighted by the structure function of the projectile.

Two methods: fully analytical in terms of expansion in (1-x1).
Semi-analytical with exact results for twist contributions

Twist expansion: explicit

Twist 2: contribution from $\gamma = 1$

$$\frac{d^2\sigma_T^{DY(\tau=2)}}{dM^2\,dx_F} = \Delta_{T,2}^{(0)} + \Delta_{T,2}^{(k>0)}$$

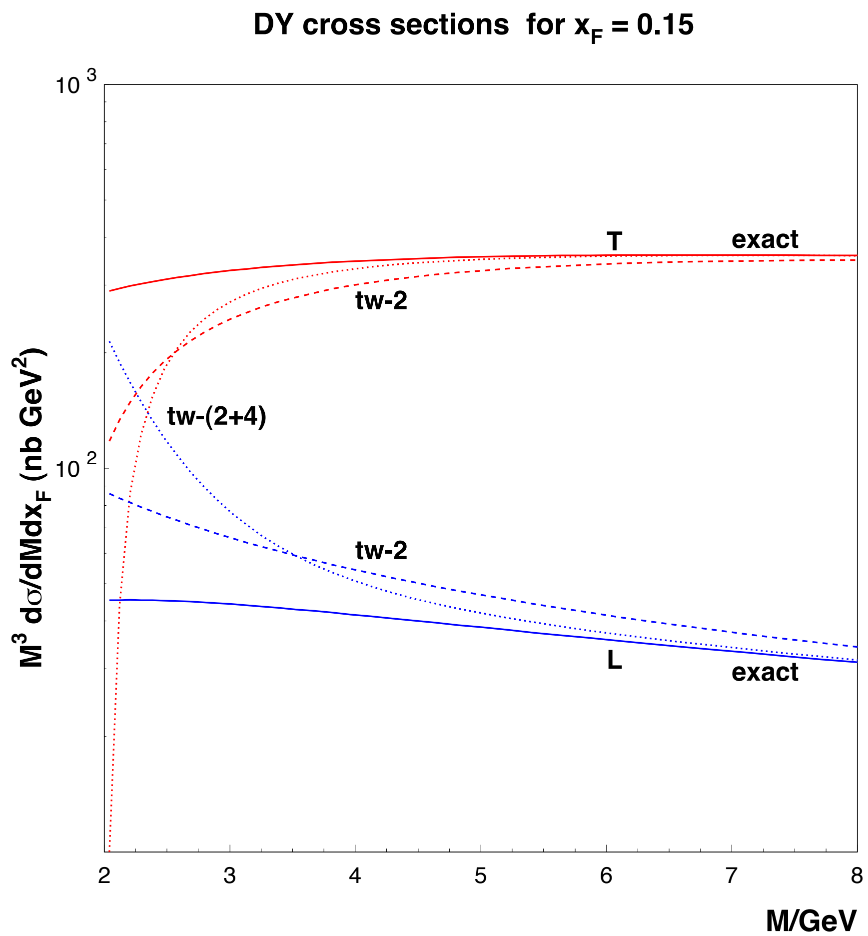
$$\Delta_{T,2}^{(0)} = \frac{\alpha_{em}^2\sigma_0}{6\pi^2 M^2}\frac{F_2(x_1,M^2)}{x_1+x_2} \times 2\frac{Q_s^2(x_2)}{4M^2}\left[\frac{4}{3}\gamma_E - 1 + \frac{2}{3}\psi(\frac{5}{2}) - \frac{2}{3}\ln\frac{Q_s^2(x_2)}{4M^2(1-x_1)}\right]$$

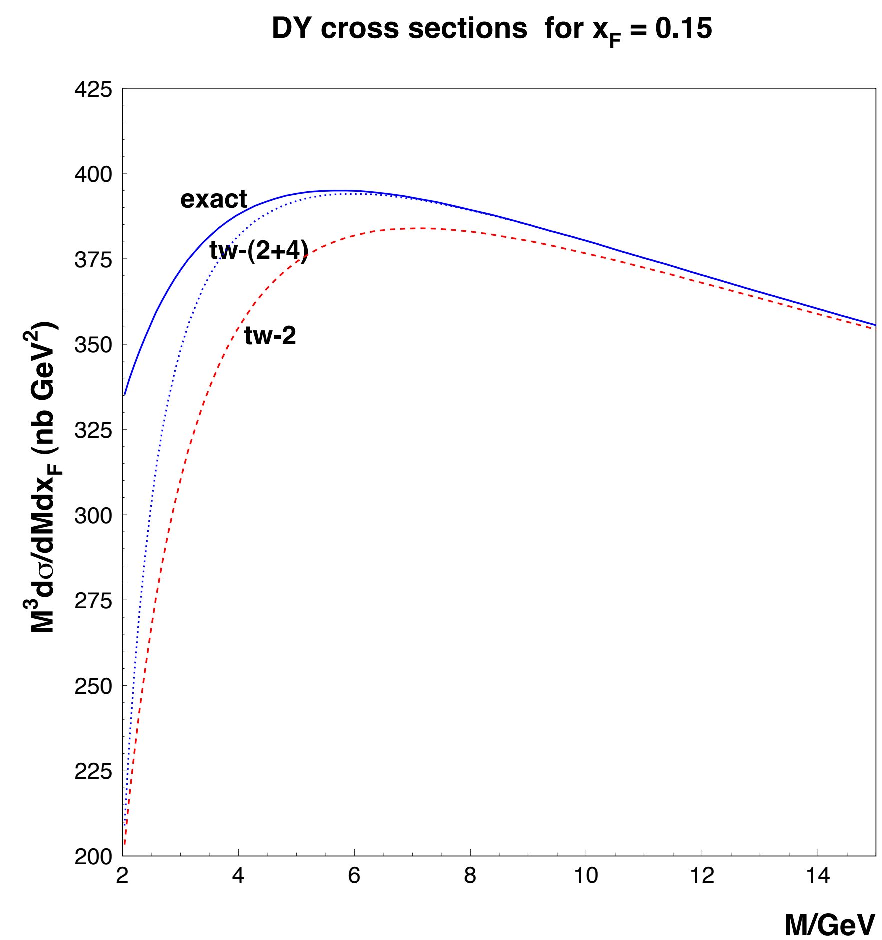
$$\Delta_{T,2}^{(k>0)} = \frac{\alpha_{em}^2\sigma_0}{6\pi^2 M^2}\frac{1}{x_1+x_2} \times \frac{4}{3}\left(\frac{Q_s^2(x_2)}{4M^2}\right)\int_{x_1}^1 dz\,\frac{zF_2(\frac{x_1}{z},M^2)(1+(1-z)^2) - F_2(x_1,M^2)}{1-z}$$

First term contains the contribution from the double pole in the Mellin space (hence the logarithm). The result is exact twist 2 contribution.

Note the integrals over z over the structure function of the projectile.

Twist expansion for DY: results





$\sqrt{s} = 14$ TeV

- Twist expansion divergent for M<4.
- For higher masses M>6 twist 2 sufficient.
- For longitudinal twist 2 overestimates, for transverse part underestimates the exact result.
- The sum is better approximated by twist expansion.