# $p_{TZ}$ and $p_{TW}/p_{TZ}$ with analytical resummation

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$M_W$ topical meeting

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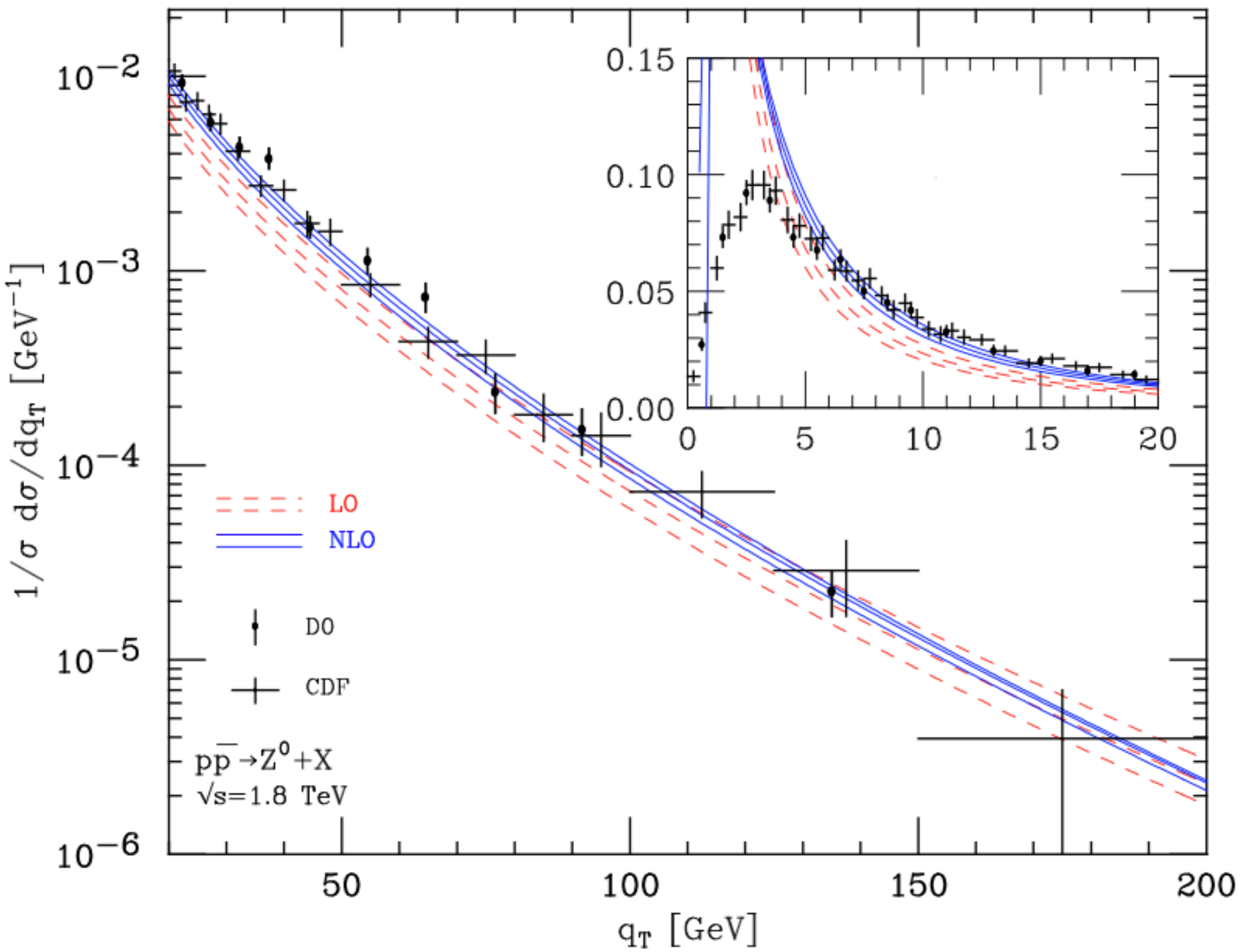
# Outline

- Introduction
- Analytical resummation
- The W/Z ratio
- Summary & Outlook

# Drell-Yan $q_T$ distribution

$$\frac{d\sigma}{d^2\mathbf{q_T}\, dM^2\, dy\, d\Omega} = \sum_{a,b} \int_0^1 dx_1 \int_0^1 dx_2\, f_{a/h_1}(x_1, \mu_F^2)\, f_{b/h_2}(x_2, \mu_F^2)\, \frac{d\hat{\sigma}_{ab}}{d^2\mathbf{q_T}\, dM^2\, d\hat{y}\, d\Omega}(\hat{s}; \alpha_S, \mu_R^2, \mu_F^2).$$




Fixed order perturbative calculation is OK when $q_T \sim m_V$

When $q_T \ll m_V$ large logarithmic terms appear that need be resummed to all orders

# Resummation

The resummation is "effectively" carried out by standard event generators but with limited (basically LL) accuracy

Analytical resummation works in impact parameter b-space, in order to factorise the kinematic constraint from transverse-momentum conservation

$$\delta^{(2)}(q_T - q_{T1} - q_{T2} \ldots - q_{Tn}) \to e^{ib\cdot q_T} \prod_i e^{-ib\cdot q_{Ti}}$$

The resummed and fixed order calculations can then be combined to achieve uniform theoretical accuracy over the entire range of $q_T$

$$\frac{d\hat{\sigma}}{dq_T} = \frac{d\hat{\sigma}^{(\text{res})}}{dq_T} + \frac{d\hat{\sigma}^{(\text{fin})}}{dq_T}$$

**contains all the logarithmically enhanced terms that are summed to all orders**

**standard fixed order result minus expansion of resummed formula at the *same* order**

# Resummation

S.Catani, D. de Florian, MG (2000)
G. Bozzi, S.Catani, D. de Florian, MG(2005)

Parton distributions factorized at $\mu_F \sim M$

**avoids PDF extrapolation to small scales**

$$\frac{d\hat{\sigma}_{ac}^{(\mathrm{res.})}}{dp_T^2} = \frac{1}{2}\int_0^\infty db\, b J_0(bp_T)\mathcal{W}_{ac}(b, M, \hat{s}; \alpha_S(\mu_R^2), \mu_R^2, \mu_F^2)$$

**process dependent**

$$\mathcal{W}_N^F(b, M; \alpha_S(\mu_R^2), \mu_R^2, \mu_F^2) = \mathcal{H}_N^F\left(M, \alpha_S(\mu_R^2); M^2/\mu_R^2, M^2/\mu_F^2, M^2/Q^2\right)$$
$$\times \exp\{\mathcal{G}_N(\alpha_S(\mu_R^2), L; M^2/\mu_R^2, M^2/Q^2)\}$$

**universal**

where the large logs are organized as:

$$\mathcal{G}_N(\alpha_S, L; M^2/\mu_R^2, M^2/Q^2) = L\, g^{(1)}(\alpha_S L)$$
$$+ g_N^{(2)}(\alpha_S L; M^2/\mu_R^2, M^2/Q^2) + \alpha_S\, g_N^{(3)}(\alpha_S L; M^2/\mu_R^2, M^2/Q^2) + \ldots$$

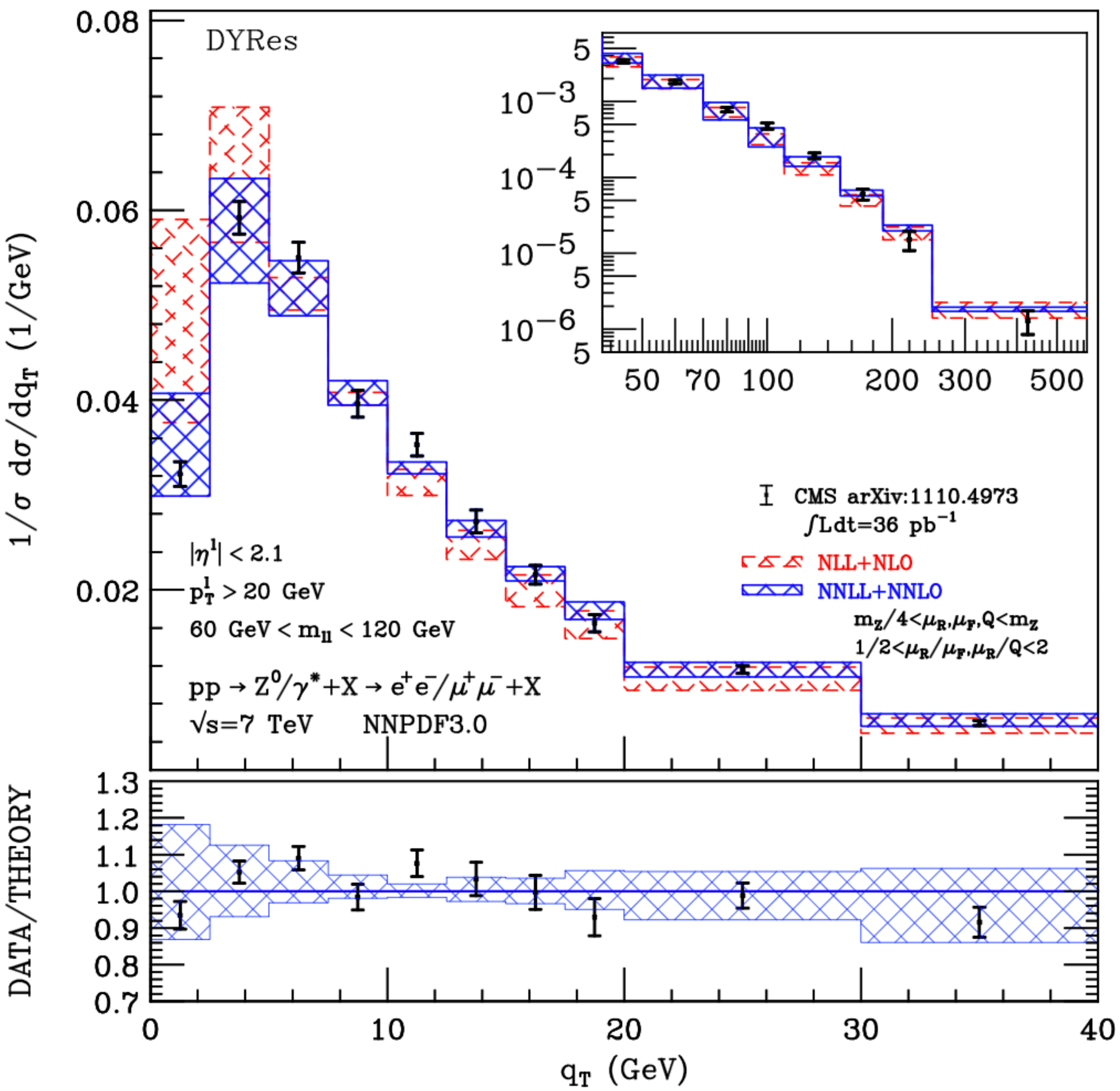
**includes parton evolution from M to 1/b at LO**

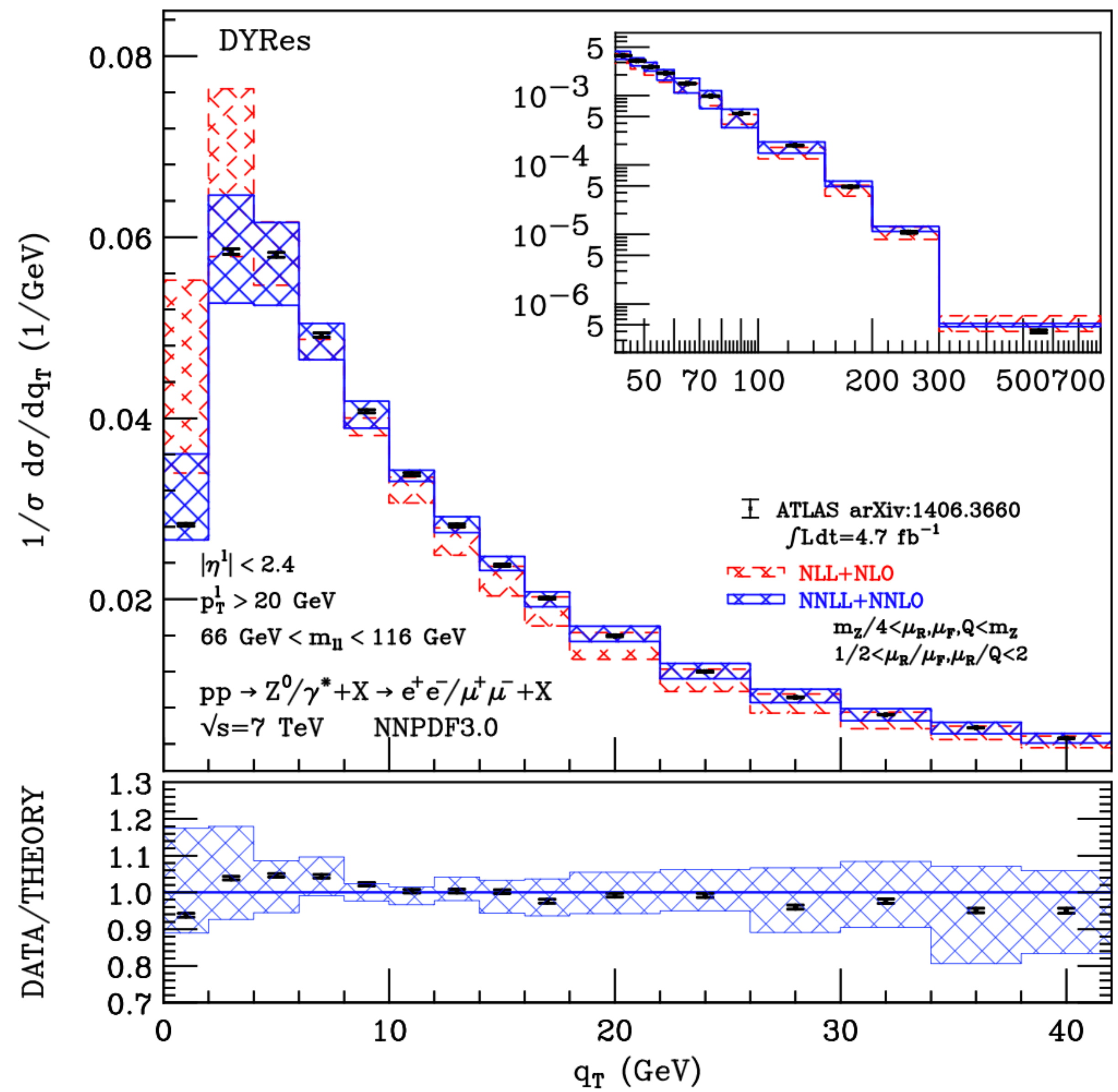
**includes parton evolution from M to 1/b at NLO**

- **Unitarity constraint enforces correct total cross section**
- **Allows a consistent study of perturbative uncertainties**

# NNLL+NNLO results

S.Catani, D. de Florian, G.Ferrera, MG (2015)



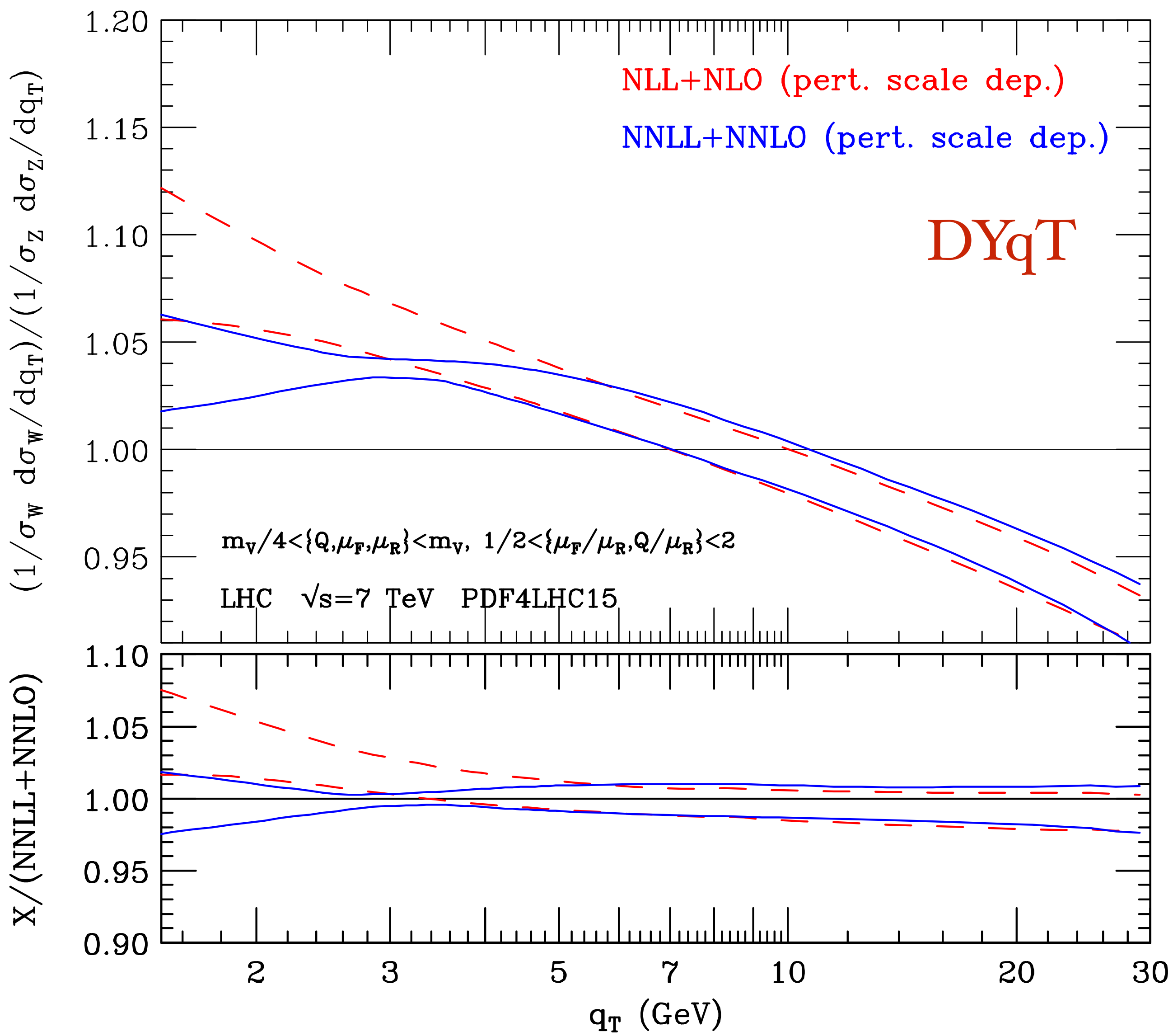

Nice description of ATLAS and CMS data within uncertainties

Theoretical uncertainties at NNLL+NNLO are still relatively large, despite the fact that we are considering normalised spectra

# The W/Z ratio

The theoretical uncertainties are expected to cancel, at least in part, in the W/Z ratio

How should we treat the scales in this ratio ?




First possibility: 100% correlation

uncertainty at the few % level but increases to ± O(5%) at very low $p_T$

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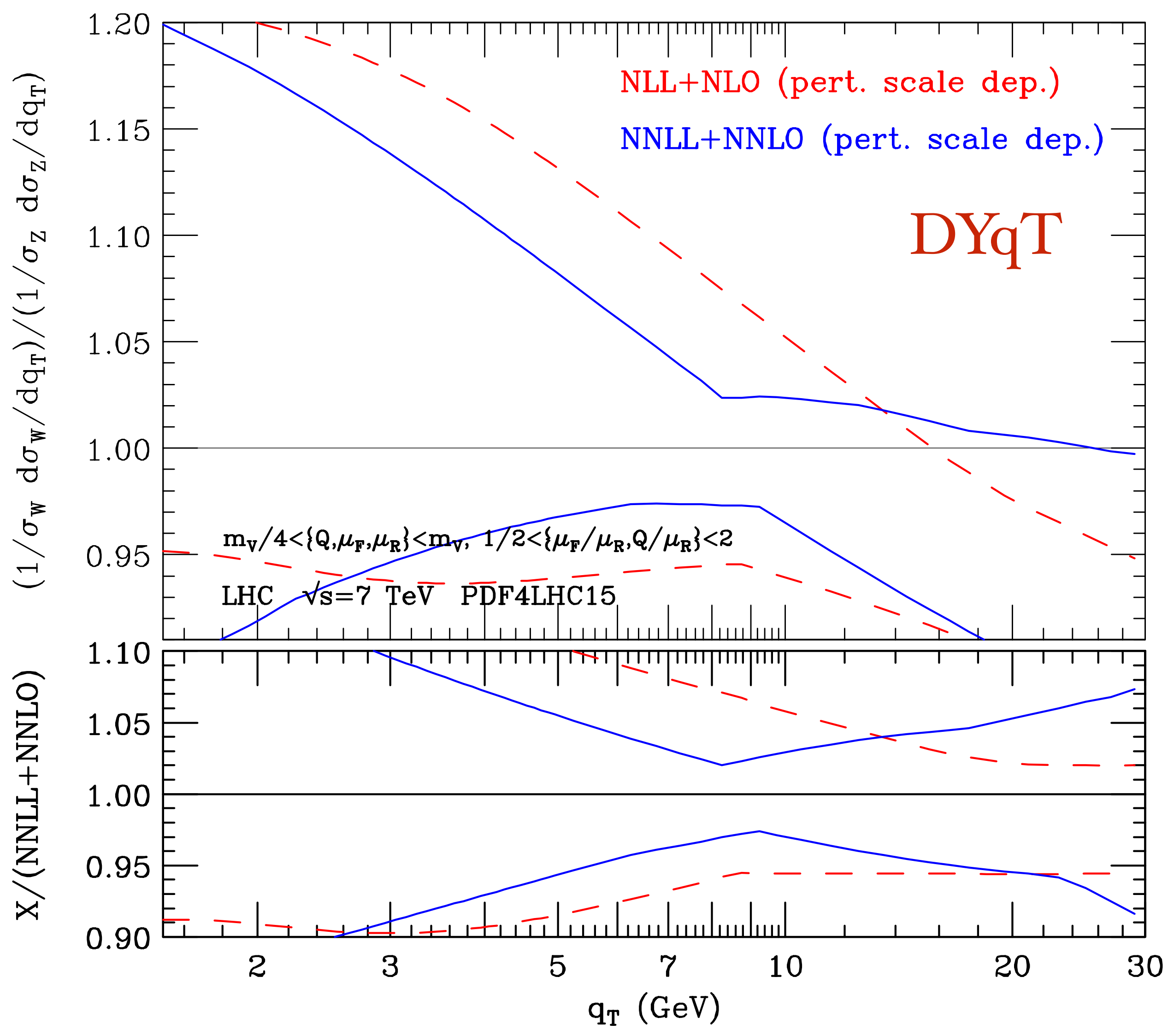



**Second possibility:** decorrelate $\mu_F$ in numerator and denominator but with the constraint

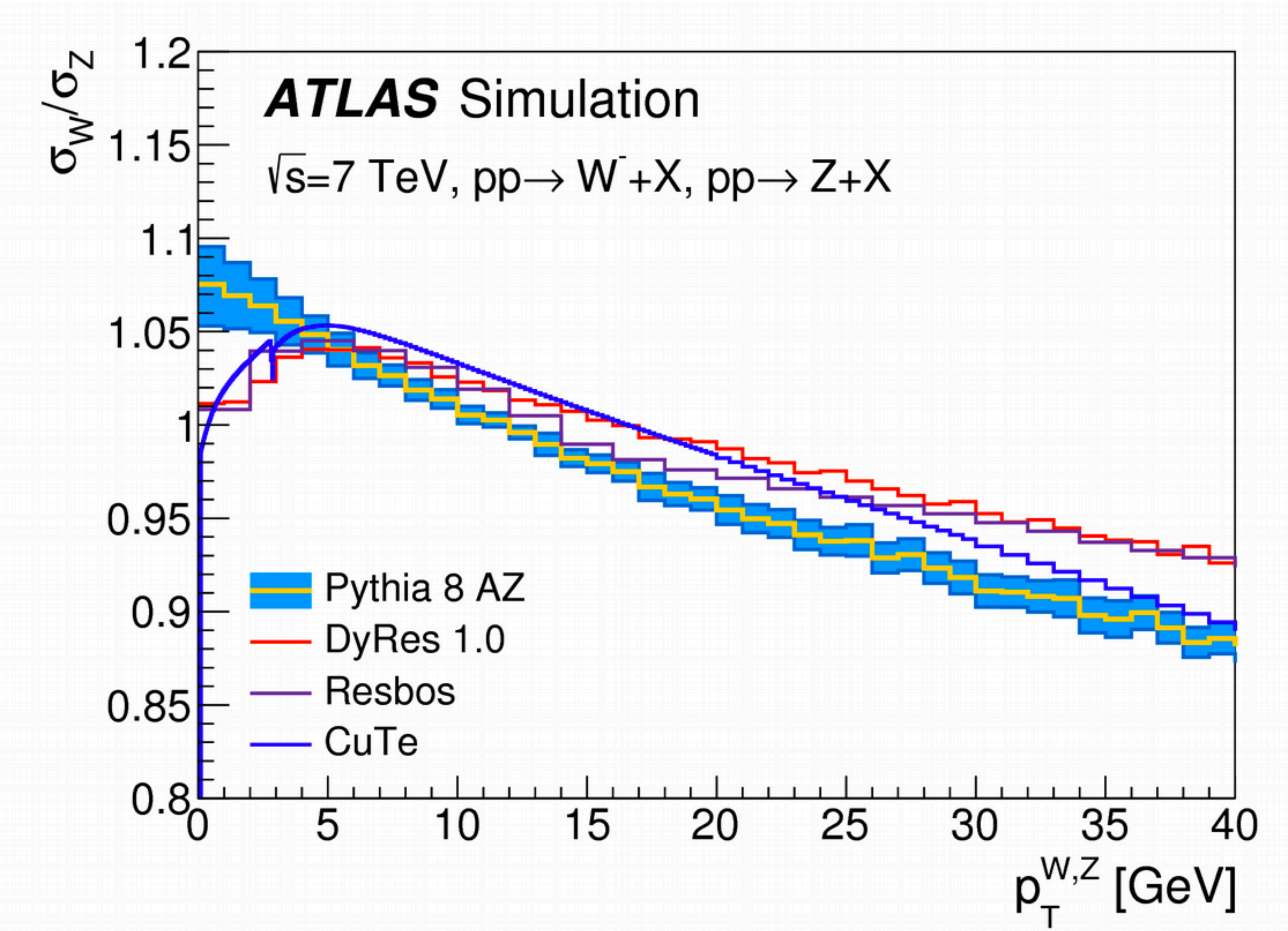
$$1/2 < (\mu_{FW}/m_W)/(\mu_{FZ}/m_Z) < 2$$

(W and Z probe different parton flavors)

➡ uncertainty increases considerably !

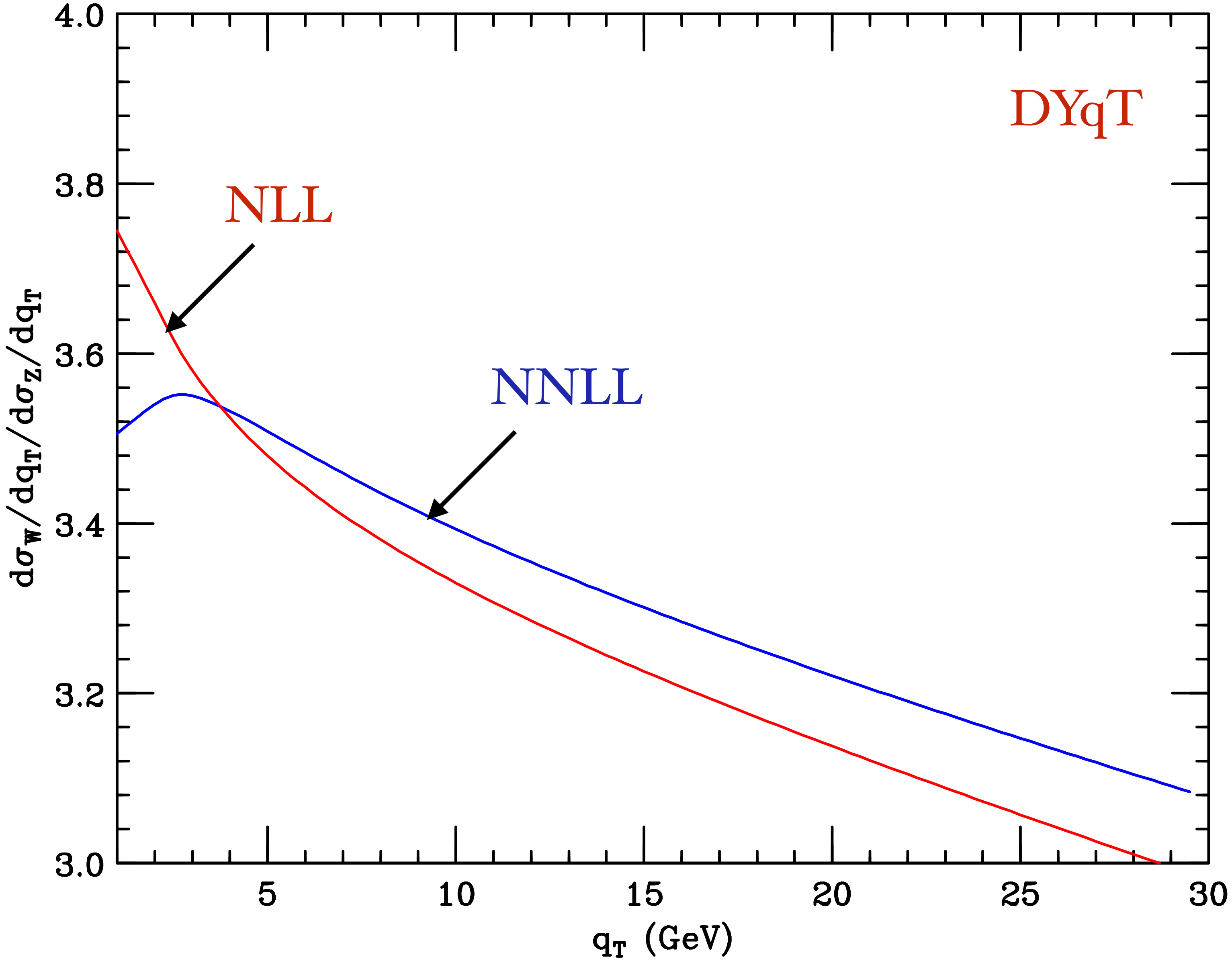
# The W/Z ratio

ATLAS claims that DYRes and other tools predicts this ratio too hard



# The W/Z ratio

It is interesting that this effect is very similar to what we observe when going from NLL to NNLL



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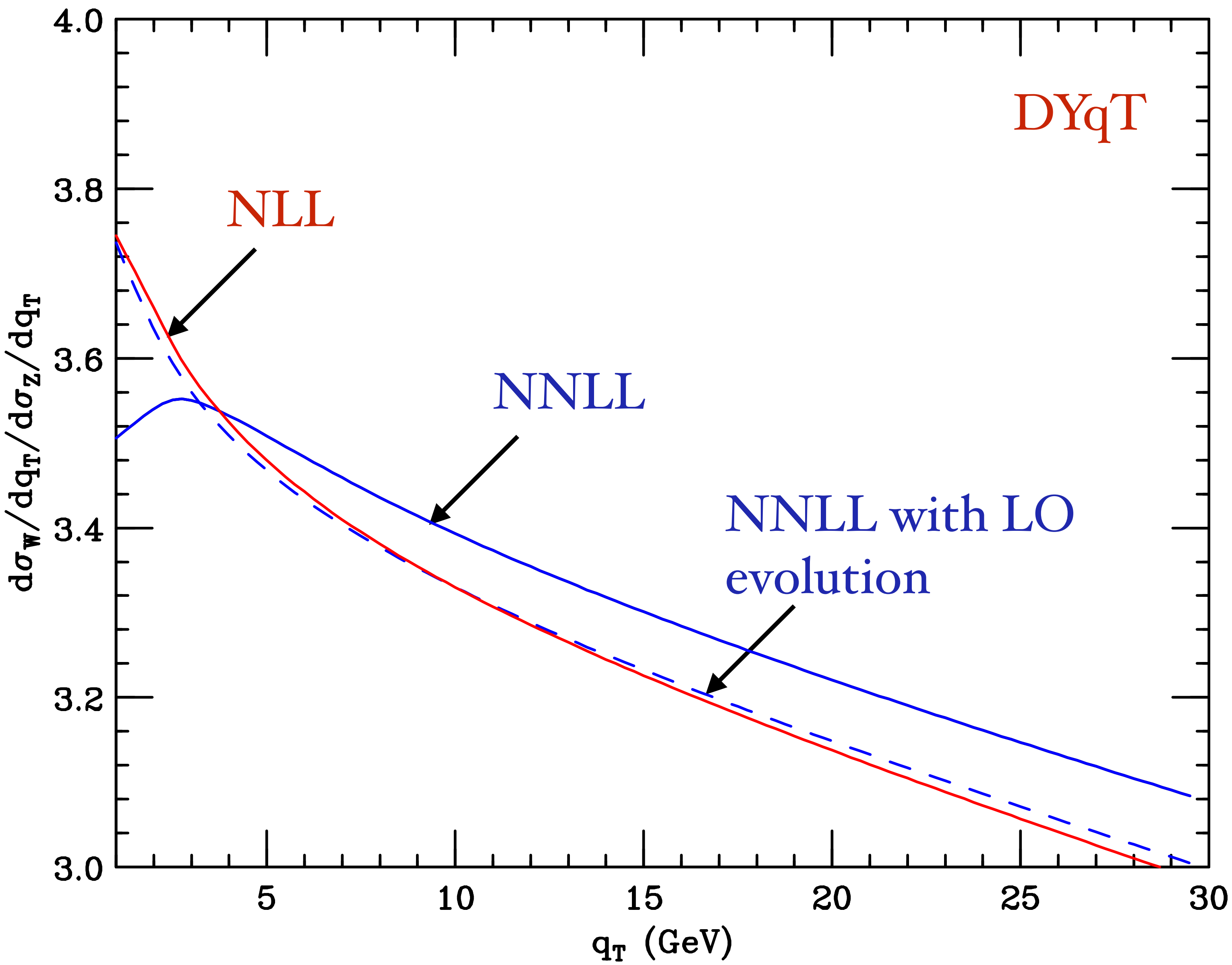
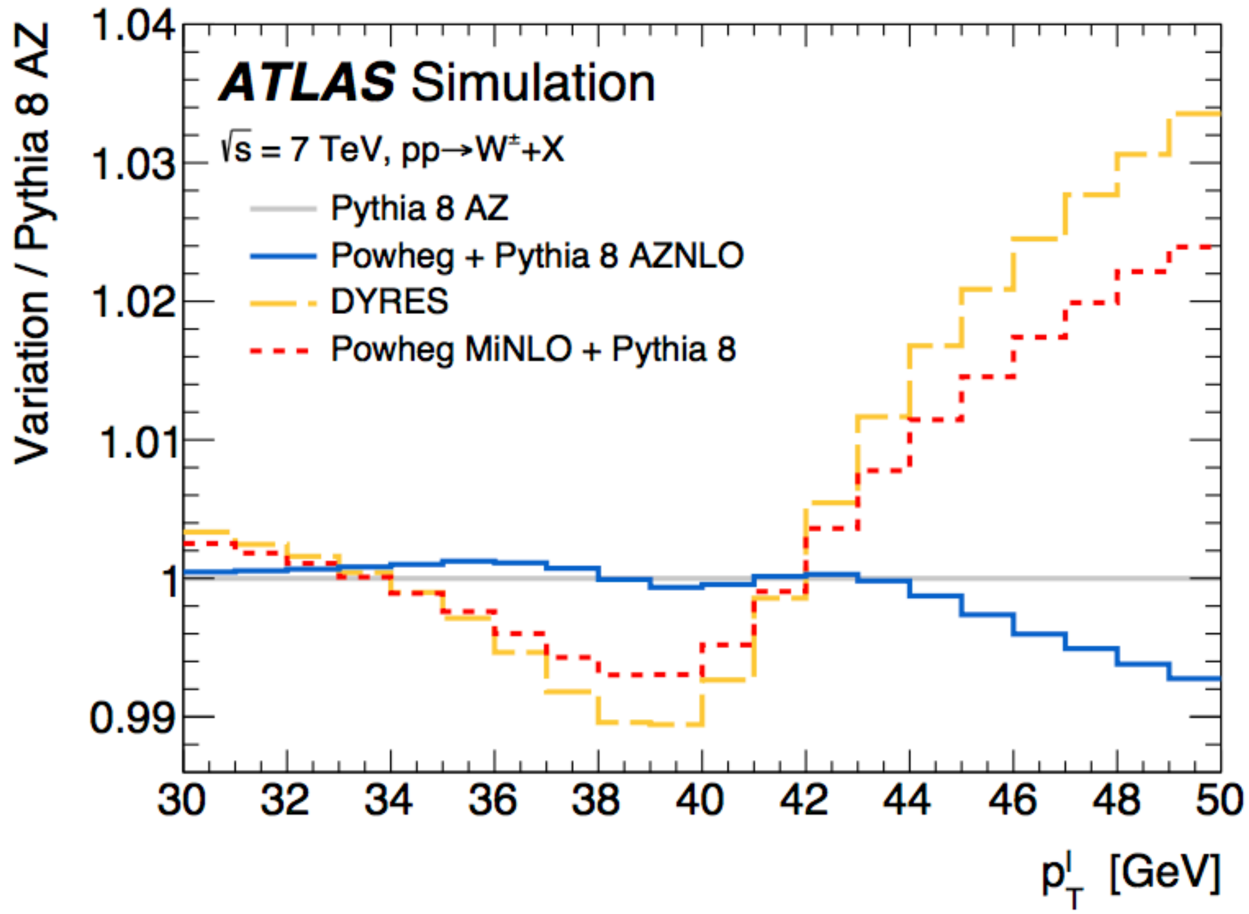
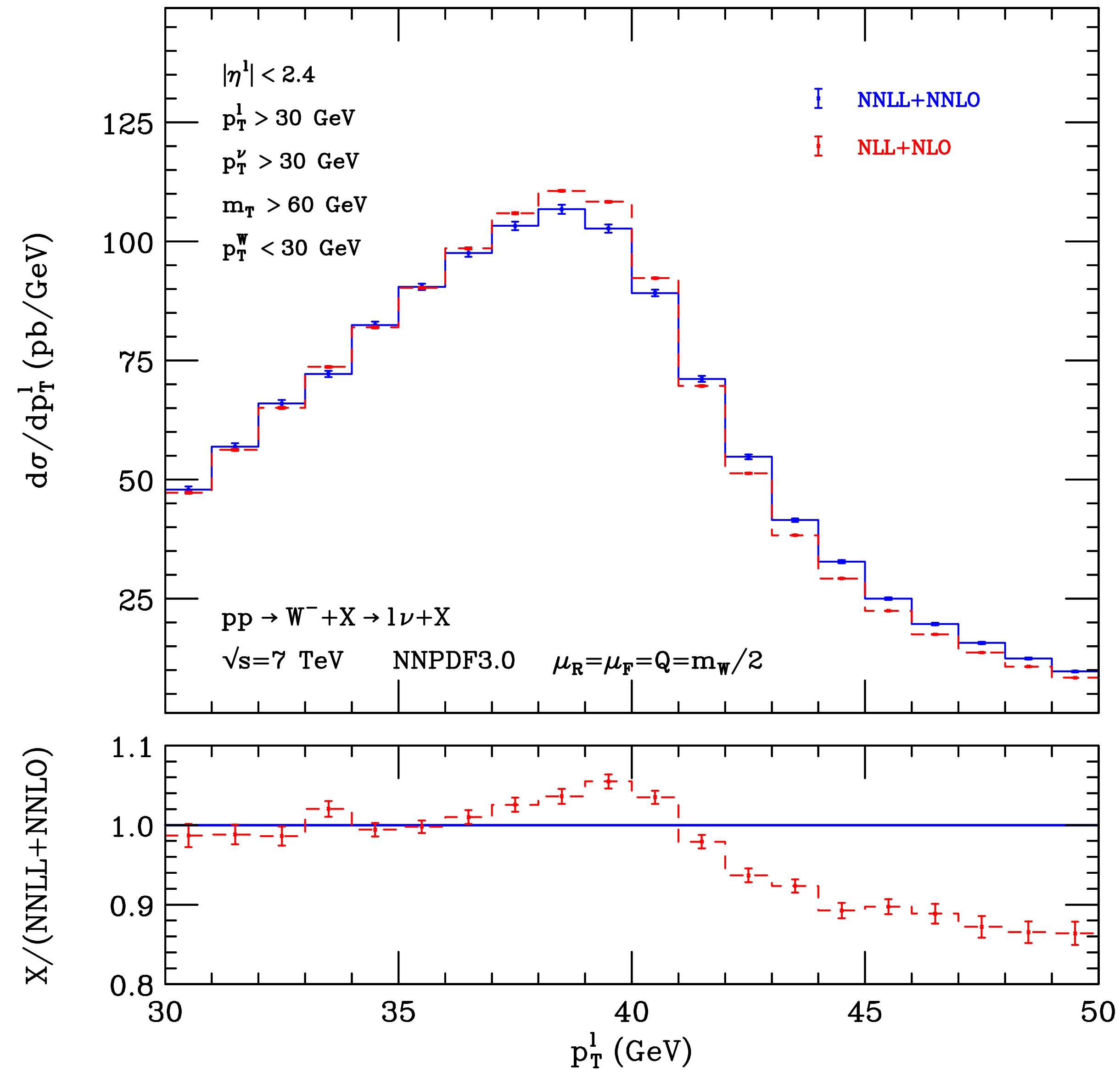



More precisely, we find that the bulk of the NNLL effect on the W/Z ratio comes from parton evolution

# The lepton $p_T$ distribution




The difference between NLL+NLO and NNLL+NNLO suggests that the theoretical uncertainties are at the few per cent level

# Summary & Outlook

- Perturbative computations based on analytic low-$q_T$ resummation matched to fixed order provide the most advanced theoretical description of the DY $q_T$ spectrum
- The predictions come with relatively large uncertainties that should be taken into account when comparing to data
- The hardness of the W/Z ratio appears to be due to NLO parton evolution
- The precision reached by the data calls for further theoretical improvements

  - going to N3LL
  - understand NP effects
  - include heavy quarks
  - ................