Review of approximations: q_T resummation at NNLO+NNLL QCD with DYRes

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Milan University & INFN Milan

p_{T_Z} and p_{T_W} theory meeting – CERN – January 25 2018

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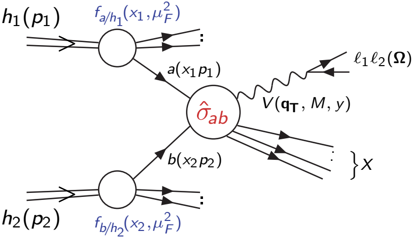
Drell–Yan $\mathbf{q_T}$ distribution



$$\mathbf{h_1(p_1) + h_2(p_2) \;\rightarrow\; V + X \;\rightarrow\; \ell_1 + \ell_2 + X}$$

where $\quad V = Z^0/\gamma^*, W^\pm$

QCD factorization formula:

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

Fixed-order perturbative expansion reliable only for $q_T \sim M$. When $q_T \ll M$:

$$\int_0^{q_T^2} d\bar{q}_T^2 \frac{d\hat{\sigma}_{q\bar{q}}}{d\bar{q}_T^2} \sim 1 + \alpha_S \left[c_{12} L_{q_T}^2 + c_{11} L_{q_T} + \cdots \right]$$

$$+ \alpha_S^2 \left[c_{24} L_{q_T}^4 + \cdots + c_{21} L_{q_T} + \cdots \right] + \mathcal{O}(\alpha_S^3)$$

with $\alpha_S^n L_{q_T}^m \equiv \alpha_S^n \log^m(M^2/q_T^2) \gg 1$.

Resummation of logarithmic corrections needed.

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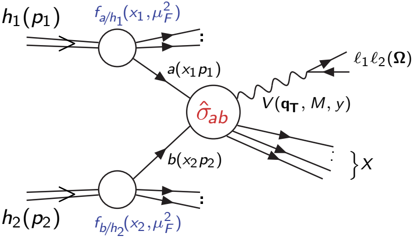

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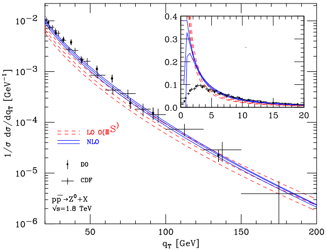

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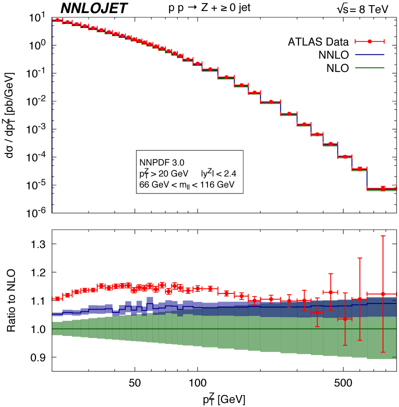

Z q_T spectrum ($q_T > 20$ GeV).

→ see A. Huss talk

- ATLAS data ($\sqrt{s} = 8$ TeV) [1512.02192] (2.8% luminosity uncertainty not shown).
- NNLO (i.e.$\mathcal{O}(\alpha_S^3)$) QCD predictions [G.-De Ridder, Gehrmann, Glover, Huss, Morgan('16)]. NNLO correction positive (∼6-8%) and reduce scale dependence (factor 2 around $\mu = \sqrt{M^2 + q_T^2}$).
- Agreement between data and theory improves by considering normalized distributions.

In the small q_T region effects of soft-gluon resummation are essential

At the LHC 90% of the $W^{\pm}$ and Z^0 are produced with $q_T \lesssim 20$ GeV

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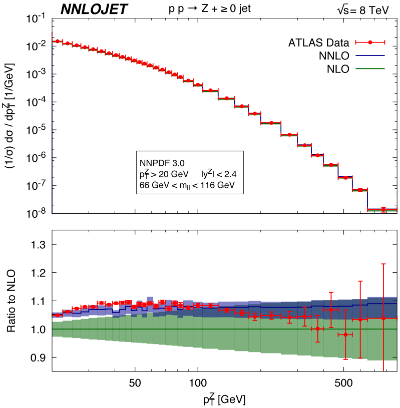

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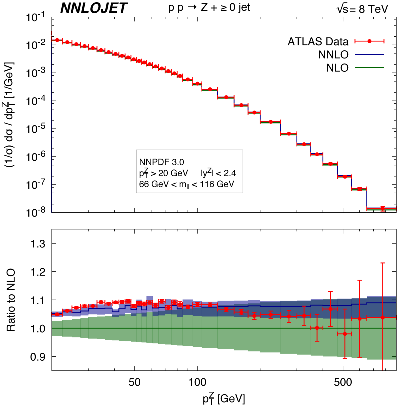

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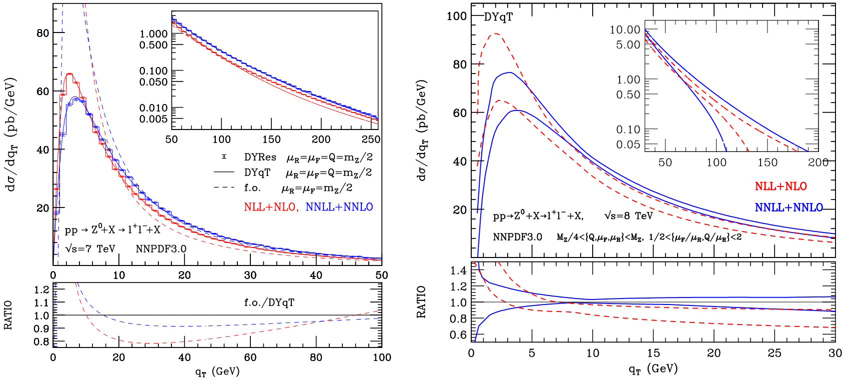
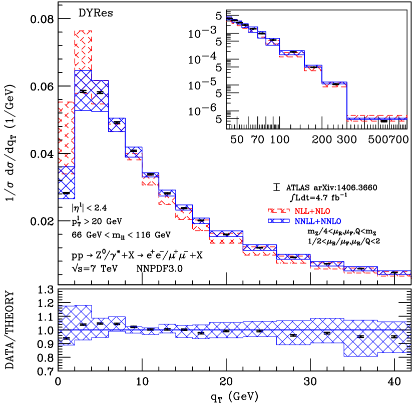
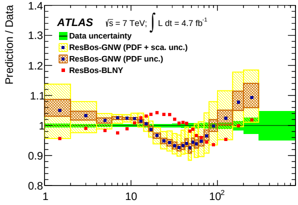
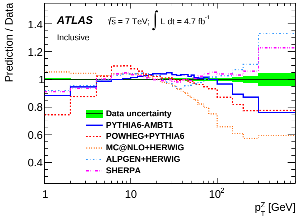


NLL+NLO and NNLL+NNLO Z q_T spectrum at the LHC at $\sqrt{s} = 7/8$ TeV.

q_T spectrum of Z boson: theory vs ATLAS data

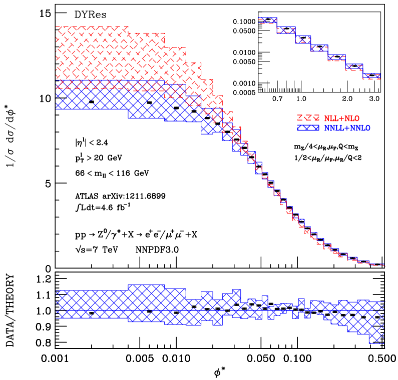




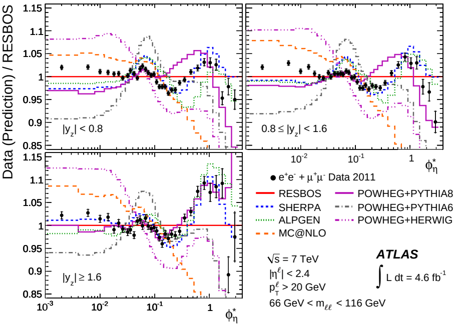


Left: NLL+NLO and NNLL+NNLO bands for Z/γ^* q_T spectrum compared with and ATLAS data (7 TeV).
Right Top: Ratios between ResBos predictions and ATLAS data.
Right Bottom: Ratios between various MC generators results and ATLAS data.

ϕ^* spectrum of Z boson: theory vs ATLAS data

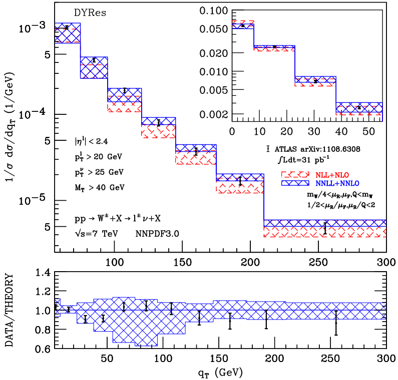


NLL+NNLO and NNLL+NNLO bands for Z/γ^* ϕ^* spectrum compared with ATLAS data.

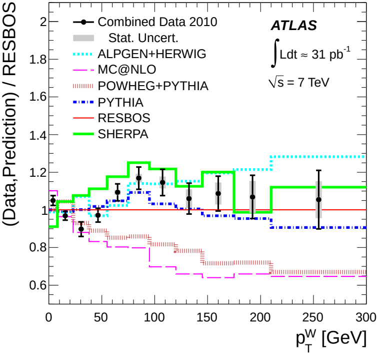


MC generators results and ATLAS data ratio to ResBos.

q_T spectrum of W: theory vs ATLAS data



NLL+NLO and NNLL+NNLO bands for $W^\pm$ q_T spectrum compared with ATLAS data.



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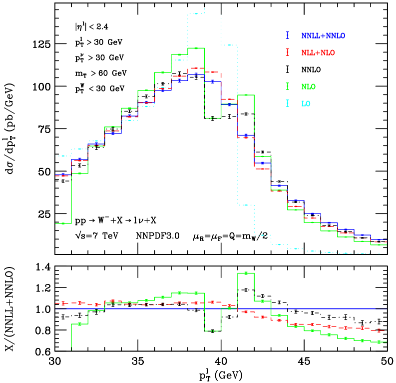
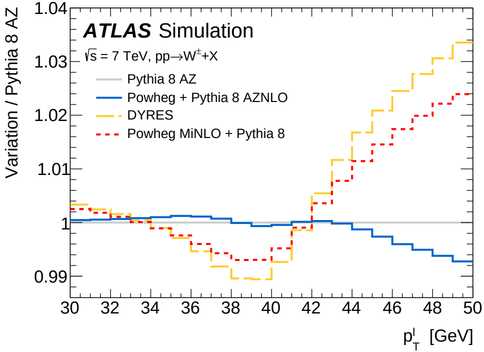
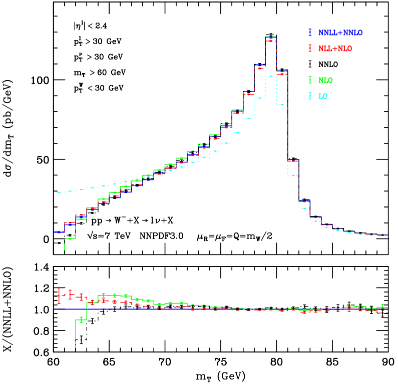
Lepton p_T distributions from W decay

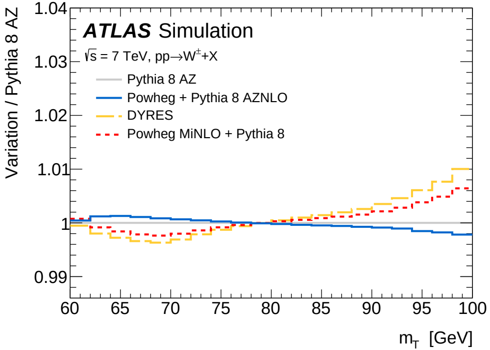




Ratios of the lepton p_T normalised distribution obtained using Powheg+Pythia 8 AZNLO, DYRES and Powheg MiNLO+Pythia 8 to the distribution obtained using PYTHIA 8 AZ.

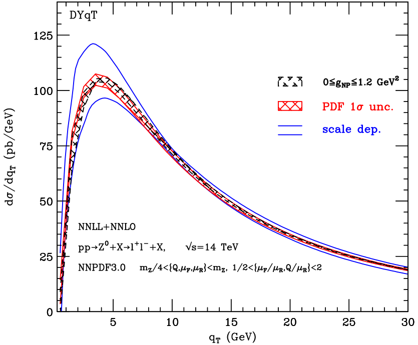
Transverse-mass distributions from W decay





Ratios of the m_T normalised distribution obtained using Powheg+Pythia 8 AZNLO, DYRES and Powheg MiNLO+Pythia 8 to the distribution obtained using PYTHIA 8 AZ.

PDF uncertainties and NP effects



NNLL+NNLO result for Z q_T spectrum at the LHC. Perturbative scale dependence, PDF uncertainties and impact of NP effects.

- PDF uncertainty is smaller than the scale uncertainty and it is approximately independent on q_T (around the 3% level).
- Non perturbative *intrinsic* k_T effects parametrized by a NP form factor $S_{NP} = \exp\{-g_{NP} b^2\}$ with $0 < g_{NP} < 1.2\, GeV^2$:

$$\exp\{\mathcal{G}_N(\alpha_S, \widetilde{L})\} \quad \rightarrow \quad \exp\{\mathcal{G}_N(\alpha_S, \widetilde{L})\}\, S_{NP}$$

- NP effects increase the hardness of the q_T spectrum at small values of q_T.
- NNLL+NNLO result with NP effects very close to perturbative result except for $q_T < 3 GeV$ (i.e. below the peak).

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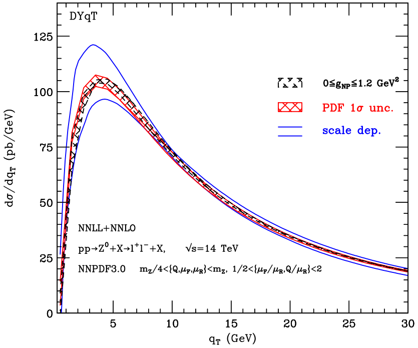

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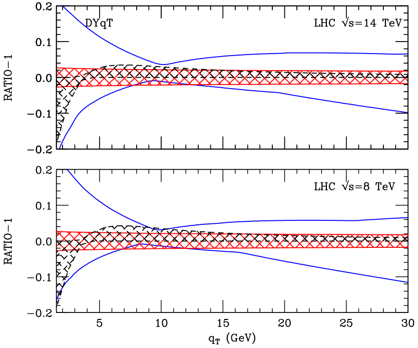

NNLL+NNLO result for Z q_T spectrum at the LHC. Perturbative scale dependence, PDF uncertainties and impact of NP effects normalized to central NNLL+NNLO prediction.

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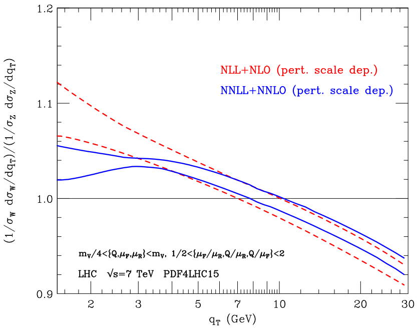
W/Z ratio: the q_T spectrum



Ratio of NNLL+NNLO and NLL+NLO results for W/Z q_T spectra at the LHC. Perturbative scale dependence.

- Ratio of W/Z observables substantially reduces both the experimental and theoretical systematic uncertainties [Giele,Keller('97)].
- *Correlated* ($\mu^W/M_W = \mu^Z/M_Z$) scale variations by factor 2 (avoiding ratios larger than 2) gives reasonable estimate of pert. uncertainty (nice overlap of scale variation bands for $q_T > 3\ GeV$).
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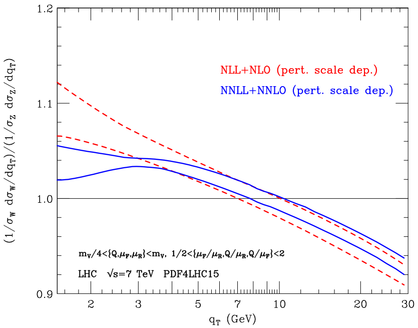

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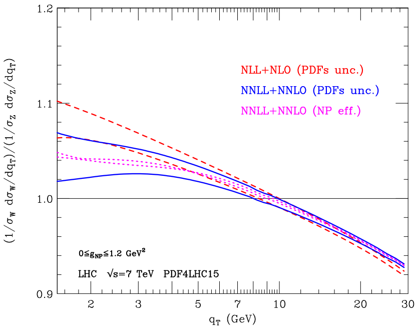

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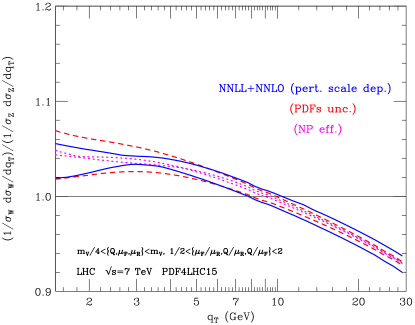

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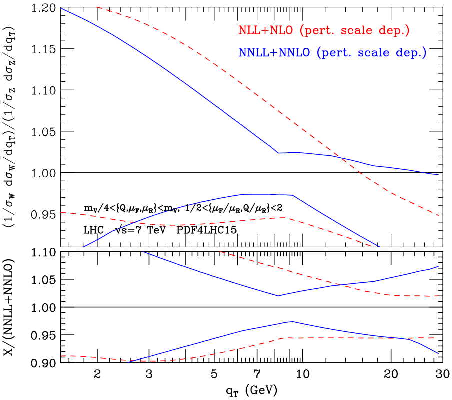
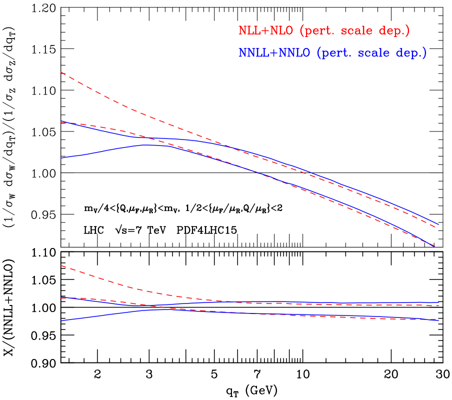
W/Z ratio q_T spectrum: perturbative scale uncertainty



DYqT resummed predictions for the ratio of W/Z normalized q_T spectra. Uncorrelated perturbative scale variation band.



DYqT resummed predictions for the ratio of W/Z normalized q_T spectra. Correlated perturbative scale variation band.