The resummation of the low-ϕ^* domain of Z production

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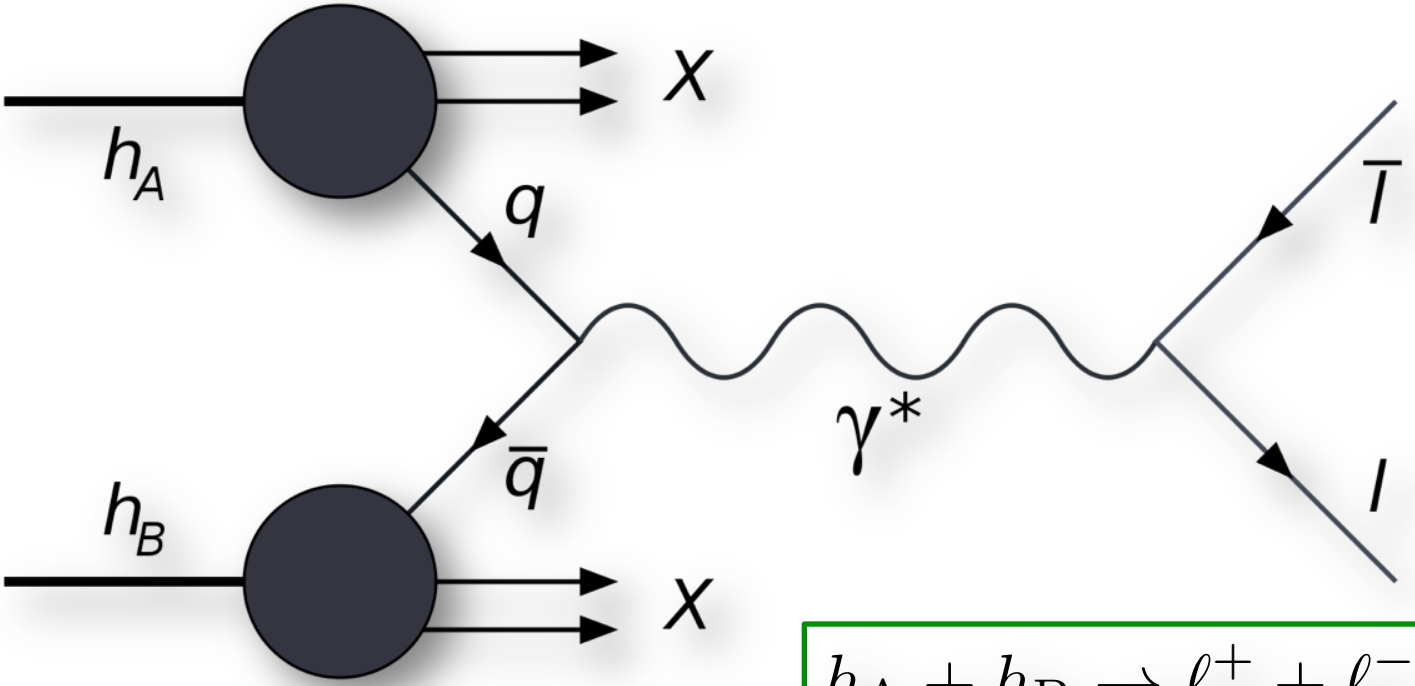
The Drell-Yan process

The Born approximation



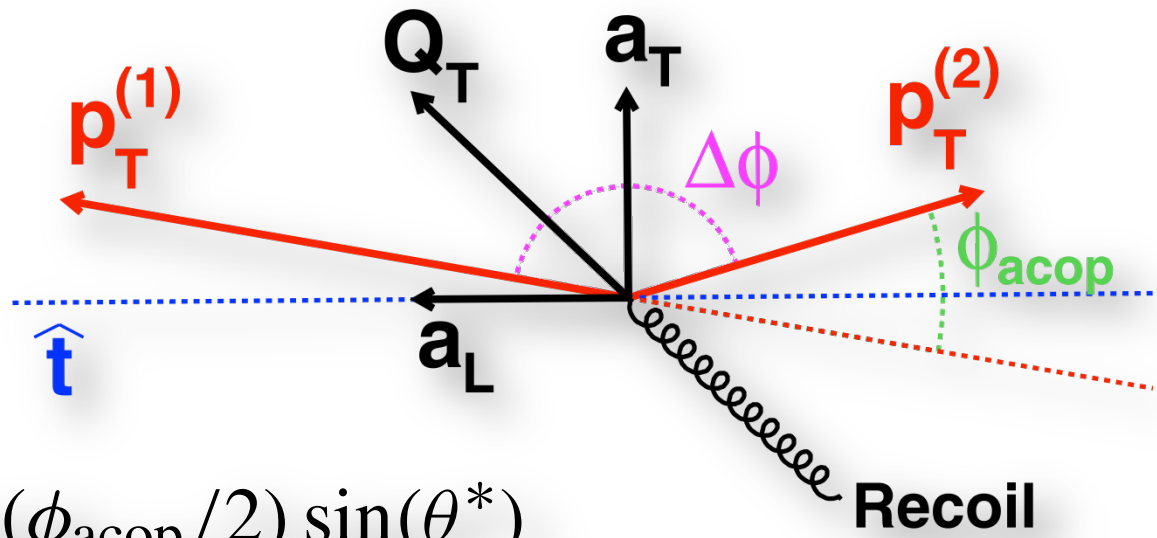
$$h_{\mathrm{A}} + h_{\mathrm{B}} \to \ell^+ + \ell^- + X$$

S. Drell and T.-M. Yan, Massive Lepton Pair Production in Hadron-Hadron Collisions at High-Energies, Phys. Rev. Lett. 25 (1970) 316 [Erratum ibid. 25 (1970) 902]

The ϕ^* observable

Optimisation of variables for studying dilepton transverse momentum distributions at hadron colliders, A. Ban, S. Redford, M. Vesterinen, P. Waller and T. R. Wyatt, EPJ C, Volume 71, Number 3 (2011), 1600

…is experimentally better-determined than Q_T, making this an important observable for study.



$$\phi^* \equiv \tan(\phi_{\rm acop}/2)\sin(\theta^*)$$

* Indicates the frame in which the leptons are (longitudinally) back-to-back. θ^* is the angle the leptons make with respect to the z axis in this frame.

Multiple emission

- ϕ^* observable is sensitive to multiple soft-collinear gluon emission
- Order-by-order, perturbative expansion is enhanced by large logs
- Logs are large in some regions of phase space because of the disparity between relevant physical scales in the process
- Cannot truncate: must sum entire classes of logs to all orders → *resummation*

Scale régimes

There exist three important and distinct scale régimes:

- Fixed-order is formally valid: $Q_{\mathrm{T}} \sim M \sim M_{\mathrm{Z}}$
- All-orders required: $\boxed{\Lambda_{\mathrm{QCD}} \ll Q_{\mathrm{T}} \ll M}$
- Non-perturbative régime: $Q_{\mathrm{T}} \sim \Lambda_{\mathrm{QCD}}$

where M is the invariant mass of the lepton pair.

The formalism

The distribution is computed as follows:

$$\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\phi^*}\right)_{\text{matched}} = \left(\frac{\mathrm{d}\sigma}{\mathrm{d}\phi^*}\right)_{\text{resummed}} + \left(\frac{\mathrm{d}\sigma}{\mathrm{d}\phi^*}\right)_{\text{NLO}} - \left(\frac{\mathrm{d}\sigma}{\mathrm{d}\phi^*}\right)_{\text{expanded}}$$

The resummed distribution has the following form:

$$\begin{aligned}\frac{\mathrm{d}\sigma}{\mathrm{d}\phi^*_{\text{resummed}}}(\phi^*, M, \cos\theta^*, y) &= \frac{\pi\alpha^2}{sN_c}\int_0^\infty dbM\cos(bM\phi^*)\, e^{-R(b,M,\mu_Q,\mu_R)} \\ &\times \Sigma(x_1, x_2, \cos\theta^*, b, M, \mu_Q, \mu_R, \mu_F)\,,\end{aligned}$$

R same for Q_T, but with Bessel in place of cosine.

where $x_{1,2} = \frac{M}{\sqrt{s}}e^{\pm y}$ and $b = \frac{be^{\gamma_E}}{2}$.

$R(\bar{b}M) = Lg^{(1)}(\alpha_s L) + g^{(2)}(\alpha_s L) + \frac{\alpha_s}{\pi}g^{(3)}(\alpha_s L)$: encodes logs we wish to resum

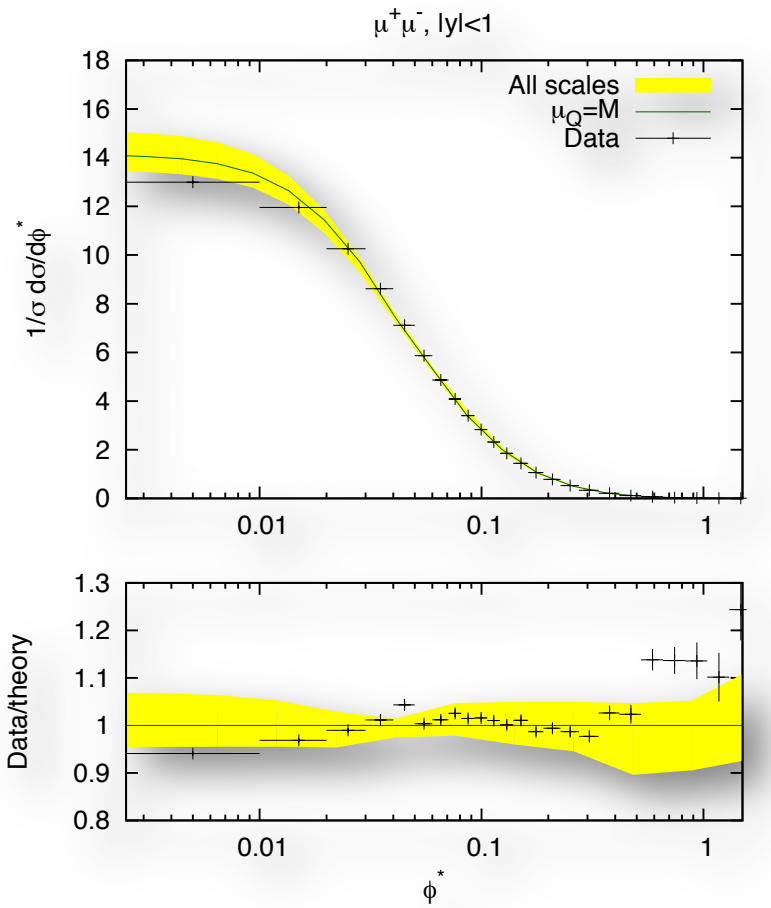
Features of the calculation

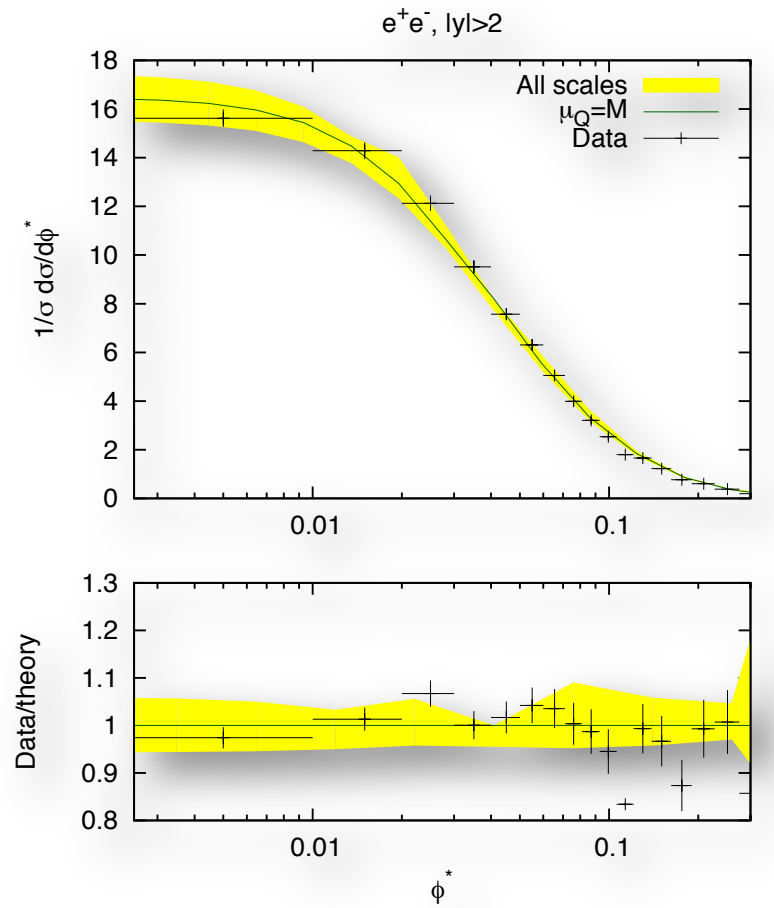
- Captures next-to-next-to-leading logs (NNLL)
- Matched with next-to-leading order (NLO) calculation
- Independent variation of all perturbative scales to obtain uncertainty
- Purely perturbative calculation: not reliant on the intrinsic k_t
- Better understanding of vector boson low Q_T
  - What NP corrections need to be applied and how do they depend on kinematics x, M^2?
- Of benefit when it comes to studying the equivalent Higgs spectrum

Relevant papers:

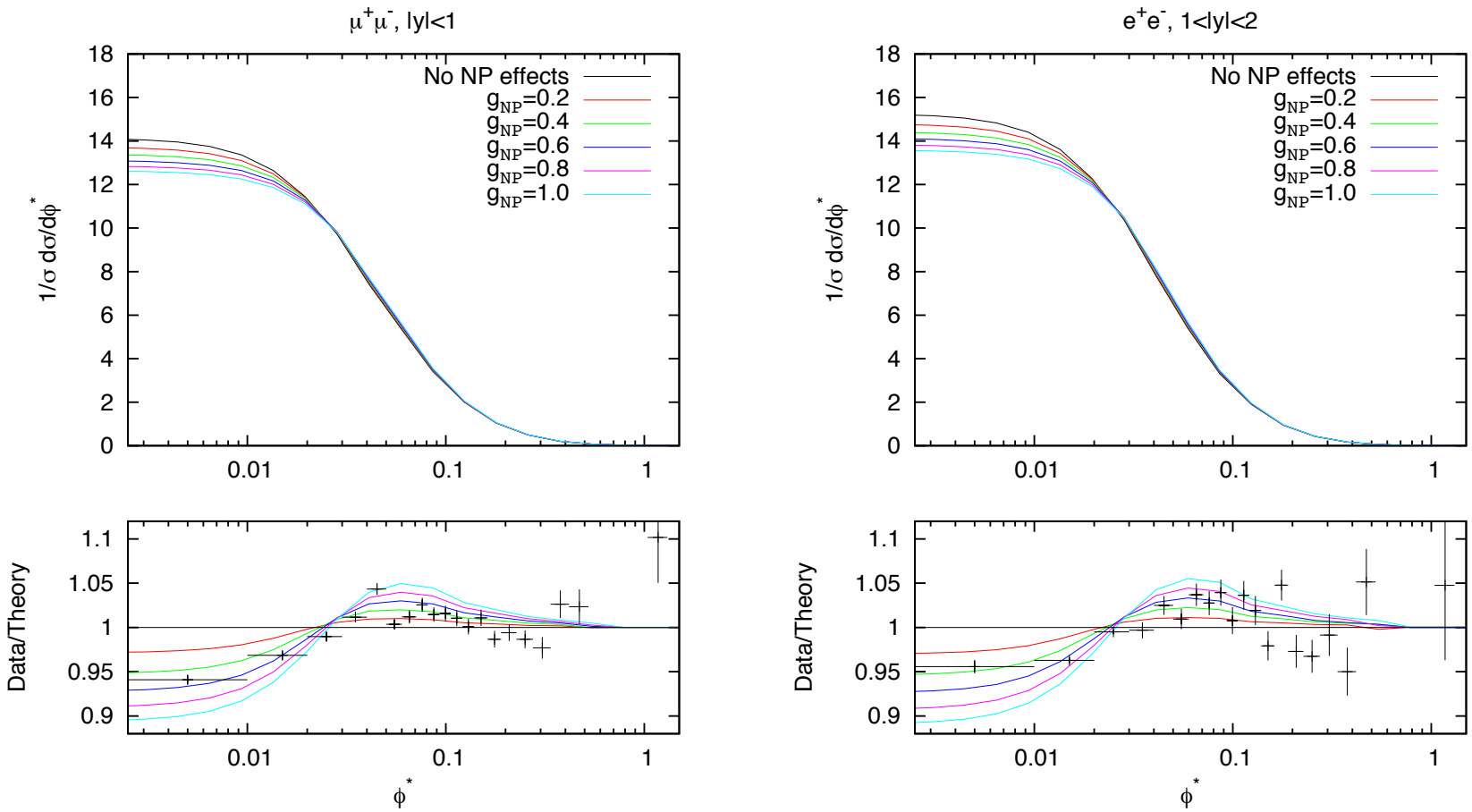
The a_T distribution of the Z boson at hadron colliders, JHEP 0912:022, 2009
QCD predictions for new variables to study dilepton transverse momenta at hadron colliders, Phys. Lett. B 701:75-81, 2011
Probing the low transverse momentum domain of Z production with novel variables, JHEP 01 (2012) 044
Predictions for Drell-Yan ϕ^* and Q_T observables at the LHC, Phys. Lett. B 715:152-156, 2012

Comparisons to DØ data

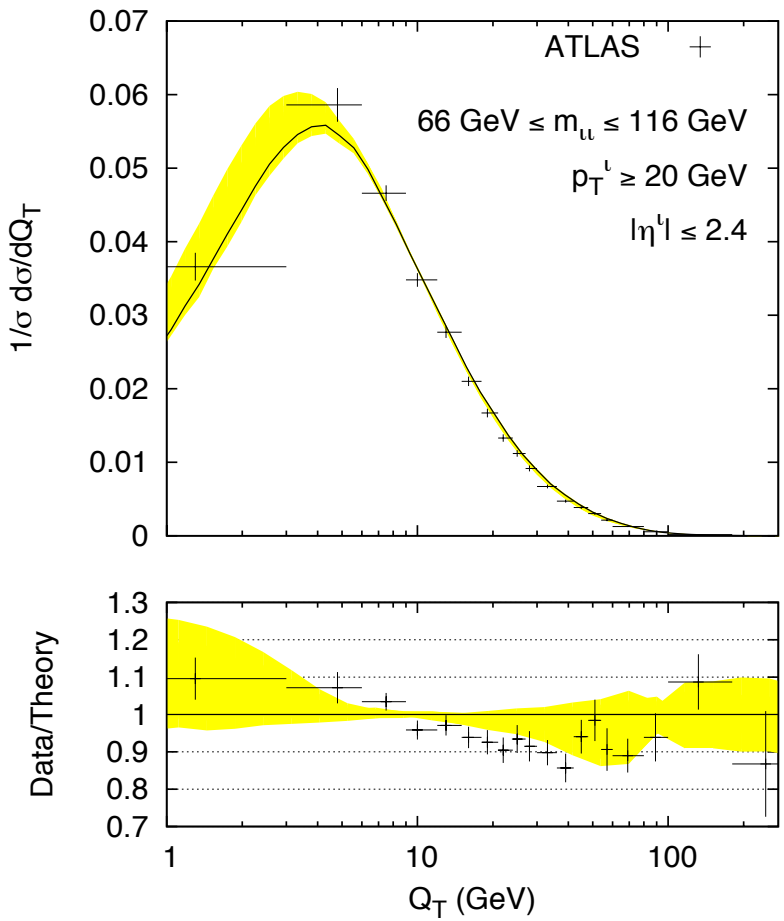


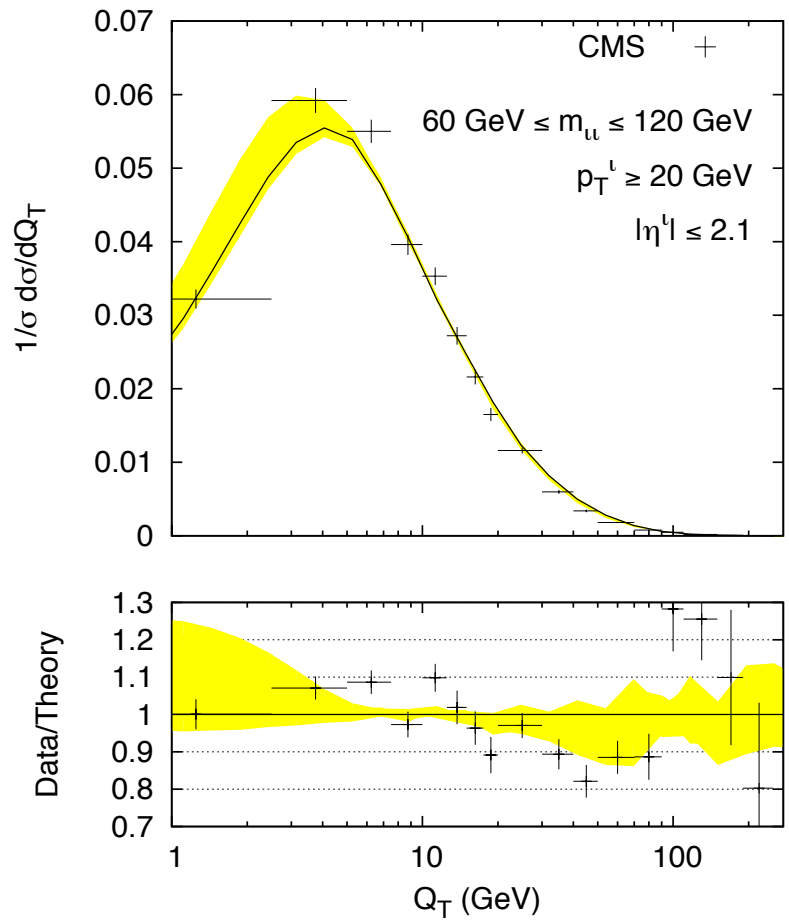


Non-perturbative effects

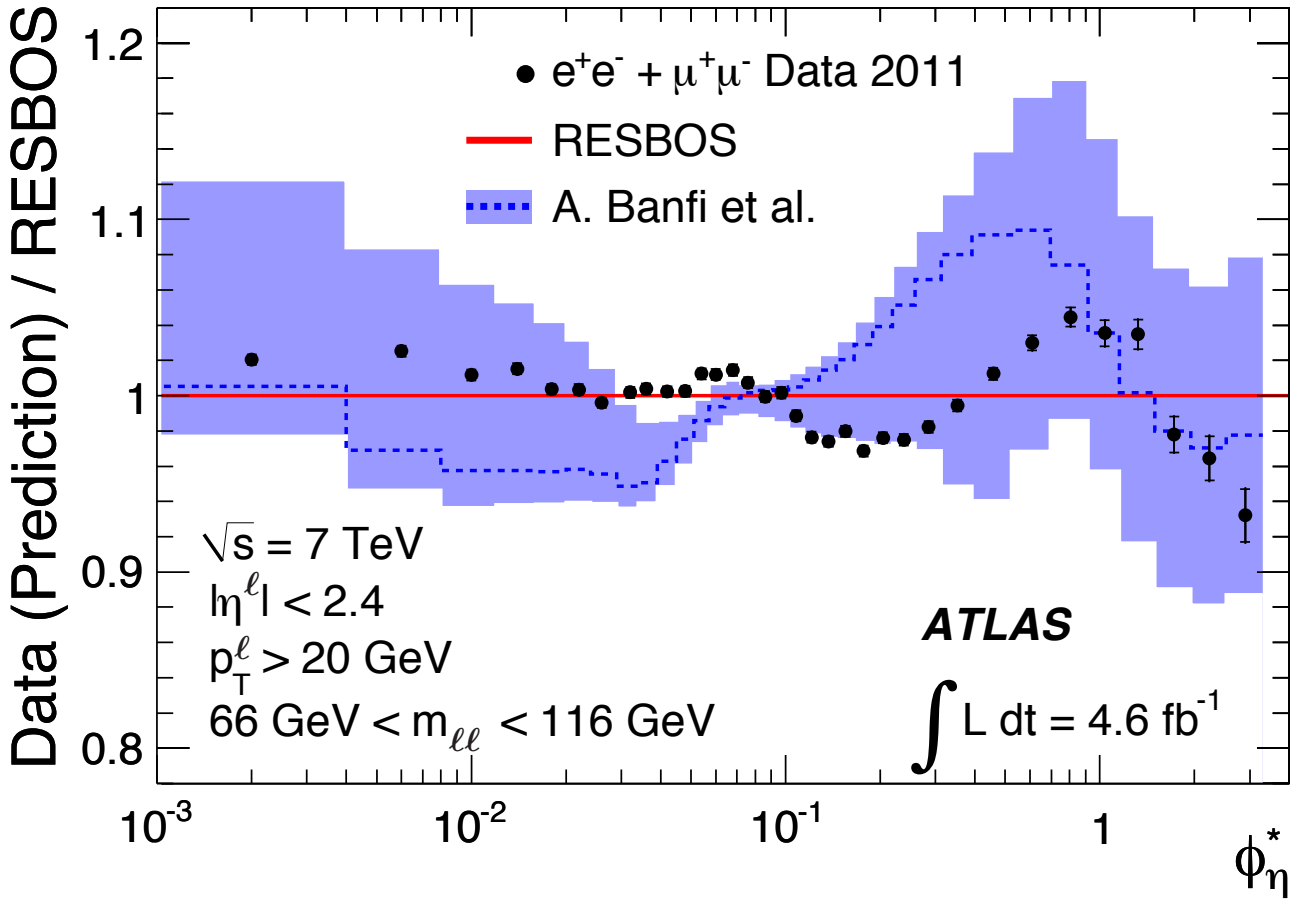


ATLAS and CMS Q_T spectra

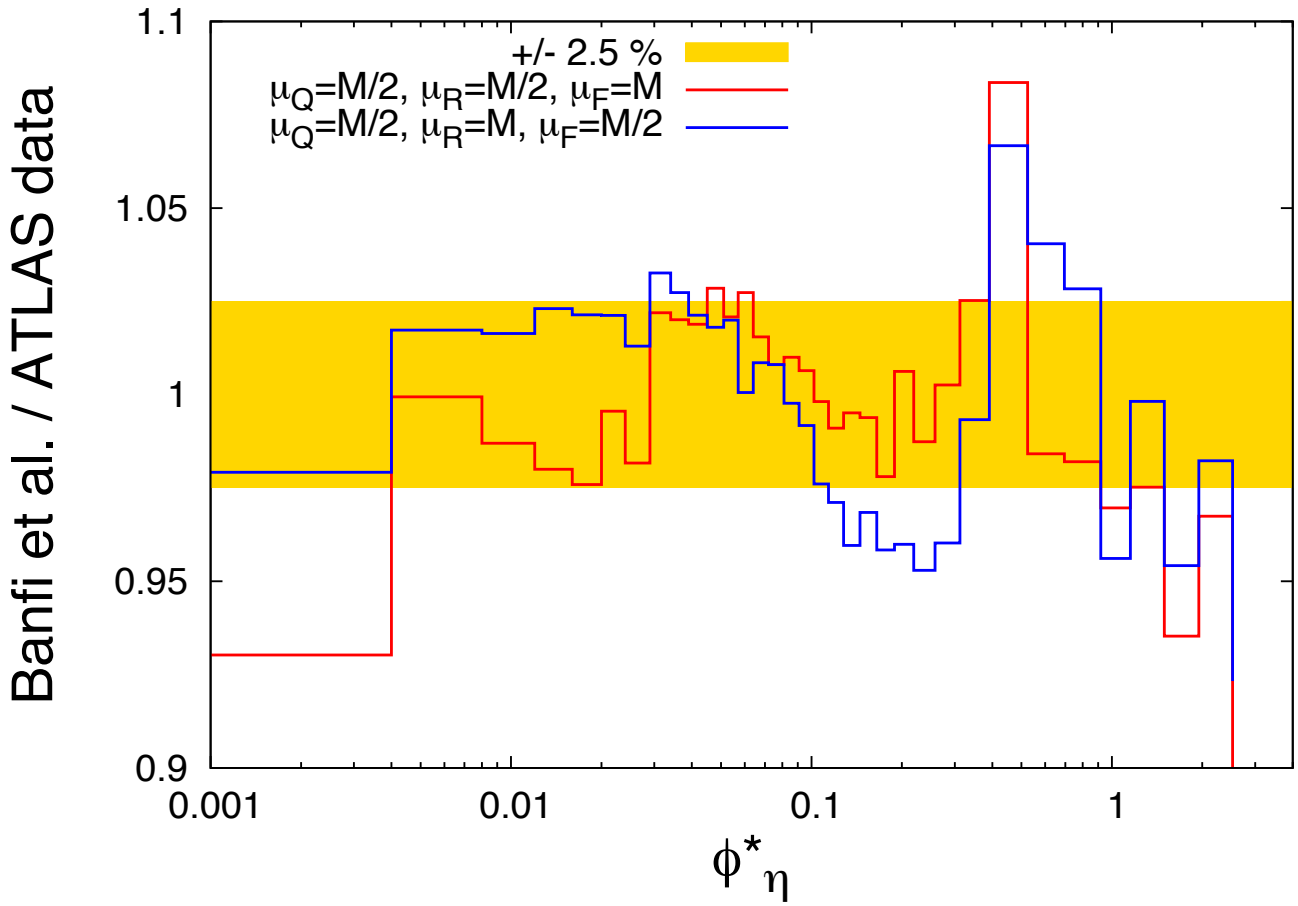




ATLAS prediction



ATLAS prediction: a detailed look



Concluding remarks

- Public code is available at:
  http://www.hep.manchester.ac.uk/u/tomlinson/code/ptresum_alpha.tar.gz

- Future considerations:
  - It would be interesting to see more extreme kinematic régimes explored (LHCb) which may challenge standard Q_T resummation
  - Is there a need for TMDs?
  - Can we reduce the theoretical uncertainty?