MANCHESTER 1824
The University of Manchester

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

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In collaboration with A. Banfi (Uni. Sussex), M. Dasgupta (Uni. Manchester) and S. Marzani (IPPP Durham)

This talk

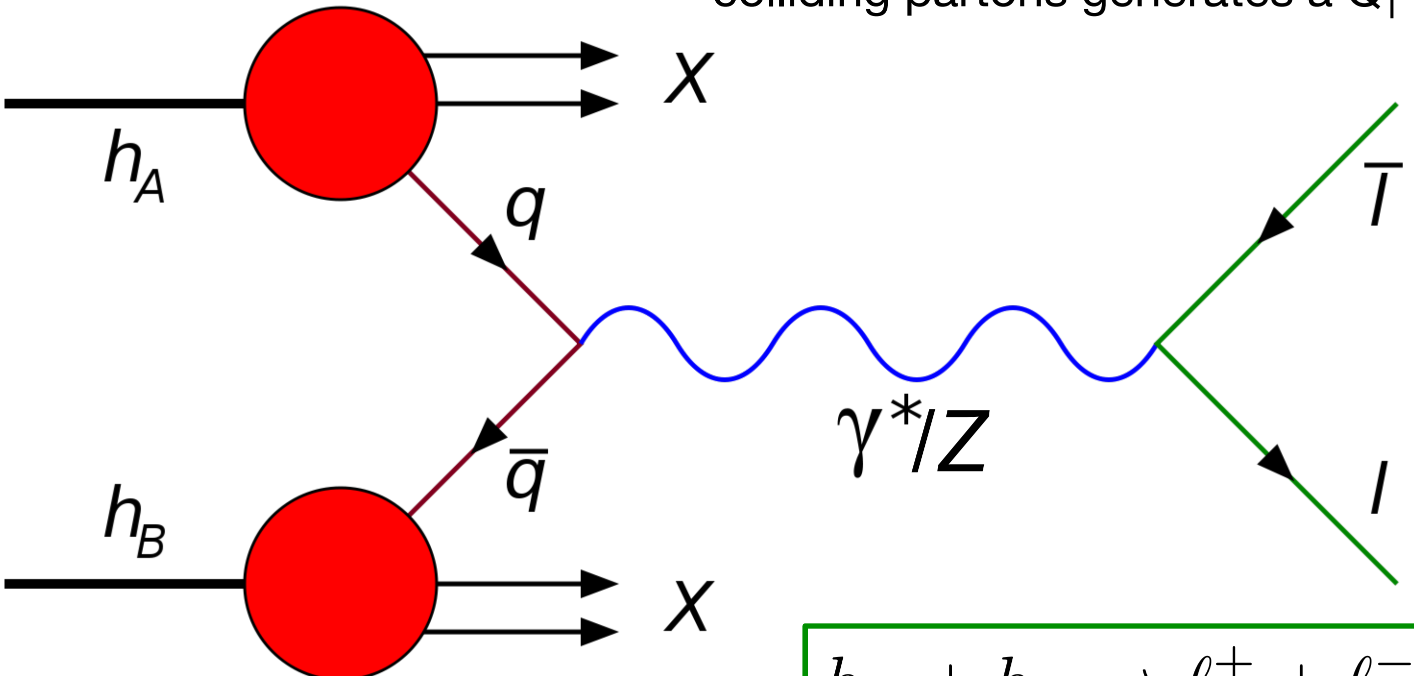
…is on phenomenological work I've done with Banfi, Dasgupta & Marzani involving the ϕ^* observable (and Q_T as a cross-check)

- Introduce ϕ^* in the context of Drell-Yan production (of massive lepton pairs)
- Discuss effects of gluon emission on observable(s)
- Present formal aspects of our NNLL *resummed* calculation
- Present comparisons to data and recent predictions
- Future considerations

The Drell-Yan process

(…in the Born approximation)

Recoil of the Z boson against emission(s) from colliding partons generates a Q_T spectrum



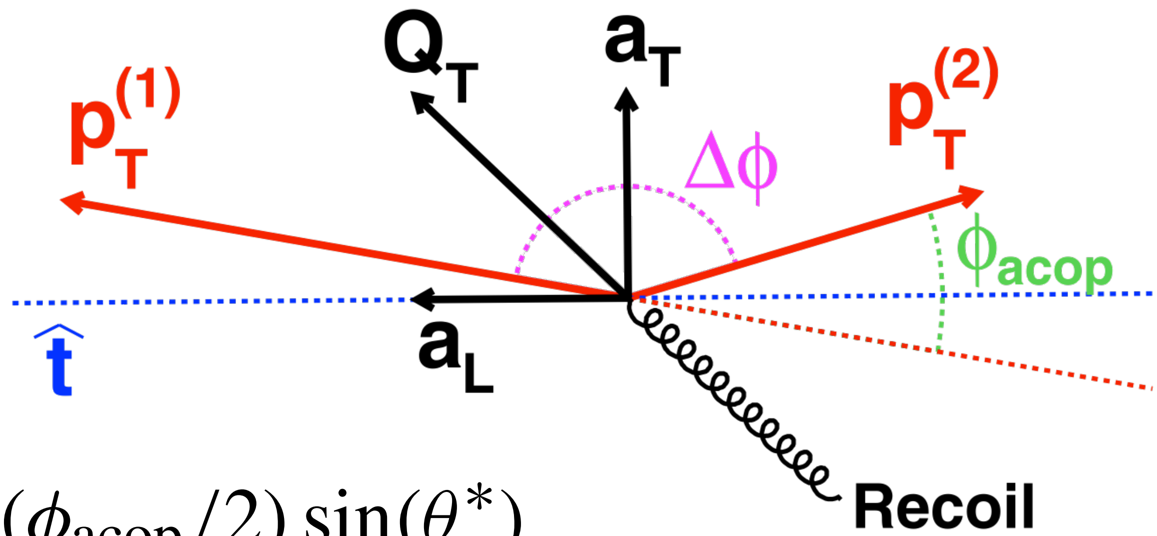
$$h_A + h_B \to \ell^+ + \ell^- + X$$

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. Banfi, S. Redford, M. Vesterinen, P. Waller and T. R. Wyatt, EPJ C, Volume 71, Number 3 (2011), 1600

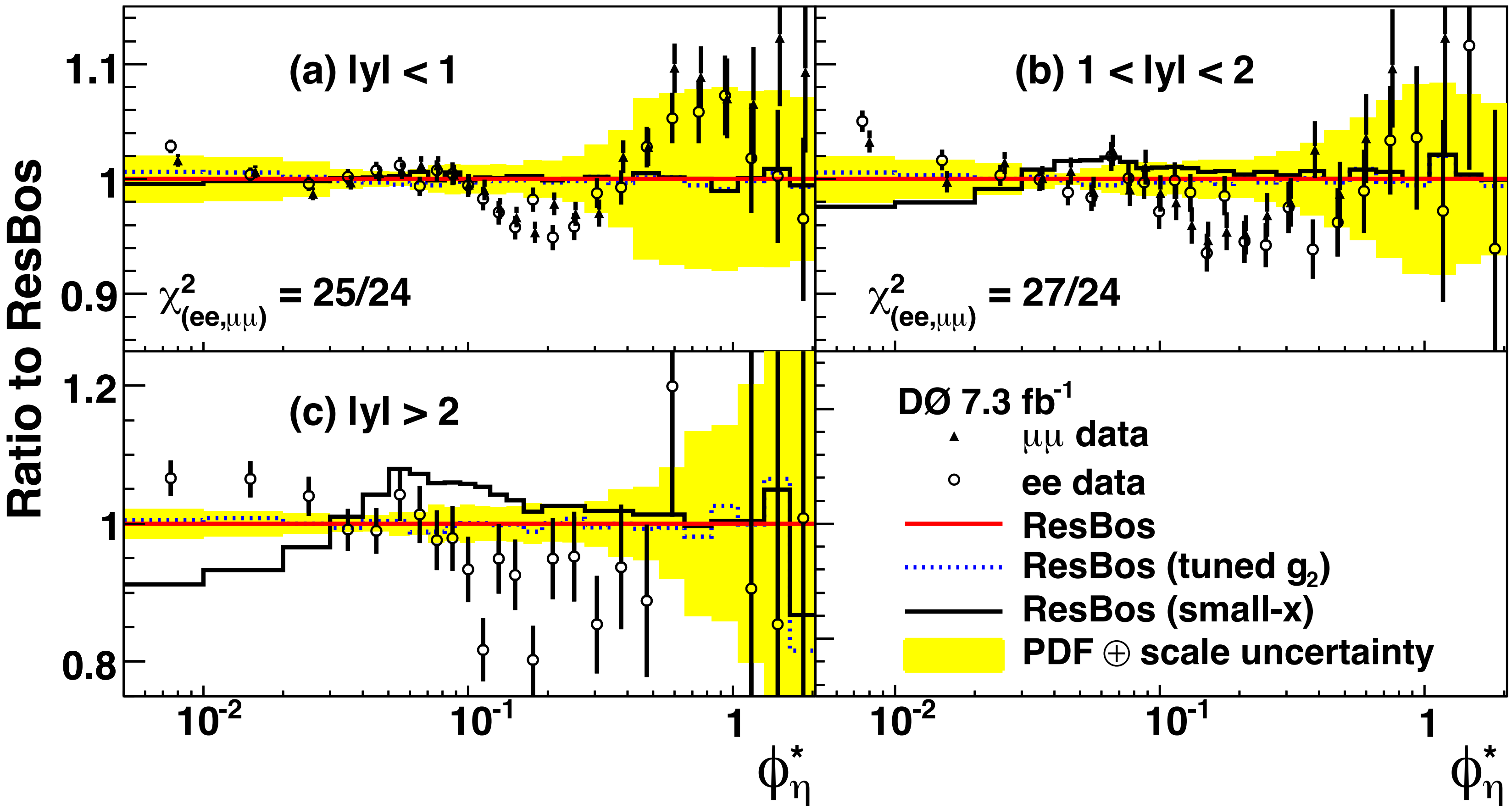
…is experimentally better-determined that Q_T, making this an important observable for study.



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

* 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.

(One) motivation for study



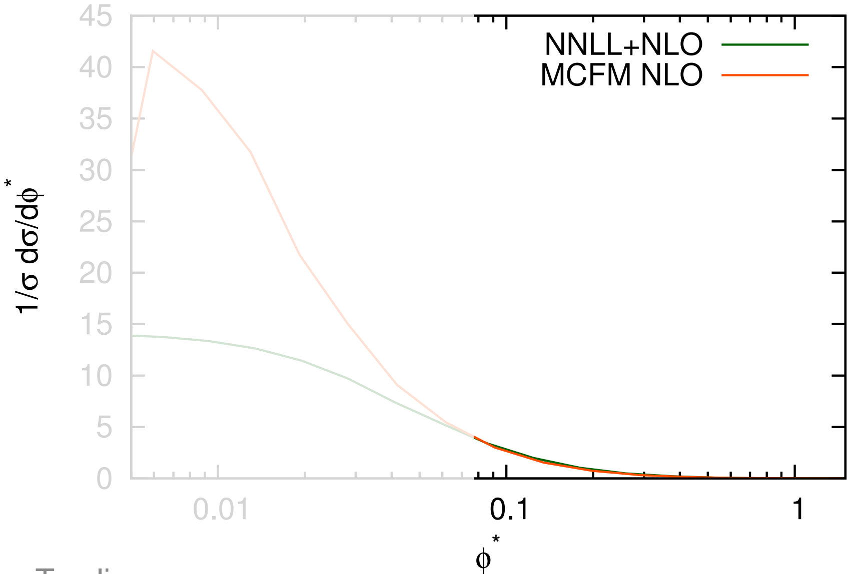
Precise study of the Z/γ∗ boson transverse momentum distribution in $p\bar{p}$ collisions using a novel technique, D0 Collaboration: V. M. Abazov, et al., Phys.Rev.Lett.106:122001, 2011

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: $\Lambda_\mathrm{QCD} \ll Q_\mathrm{T} \ll M$
- Non-perturbative régime: $Q_\mathrm{T} \sim \Lambda_\mathrm{QCD}$

where *M* is the invariant mass of the lepton pair.
Similar régimes exist for ϕ^*…



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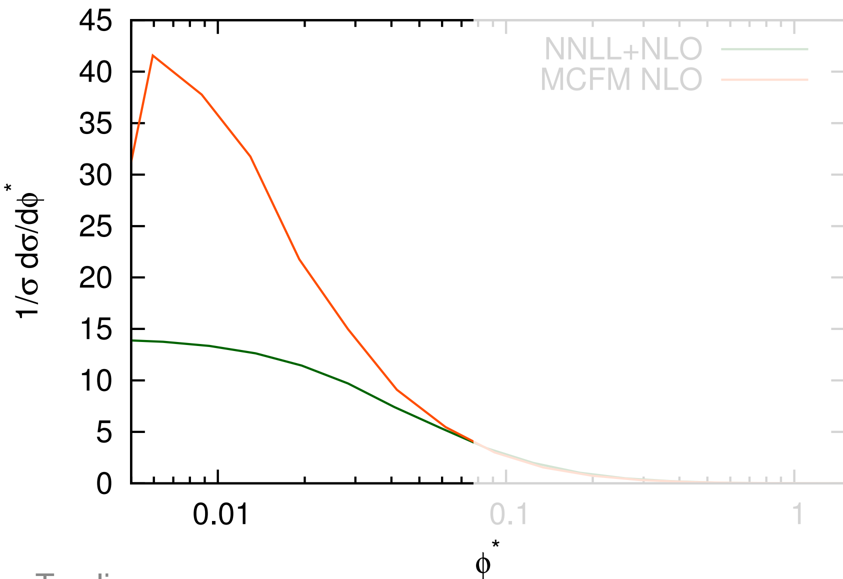

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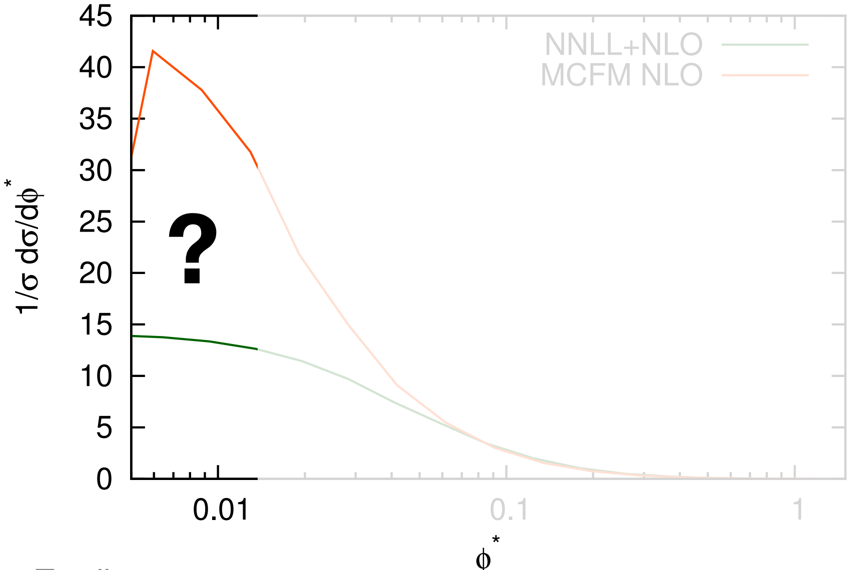

Multiple emission

- Fixed-order Q_T and ϕ^* differential cross-section distributions diverge at low values. This corresponds to soft/collinear emission from incoming partons.
- Order-by-order, perturbative expansion is enhanced by large logs – effective expansion parameter: e.g. $\alpha_s \rightarrow \alpha_s L^2$
- …in this region of phase space because of the disparity between relevant physical scales in the process.
- Cannot truncate series: must restructure the perturbation series and sum entire classes of logs to all orders → *resummation*
- In practice, relies heavily on concept of independent emission.

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:

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

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

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

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

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Reweighting of Born approximation into bins according to NNLL resummation

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Born calculation (and C_1)

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Fixed-order at NLO

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Expansion of resummation to NLO

The resummed distribution has the following form:

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Features of the calculation

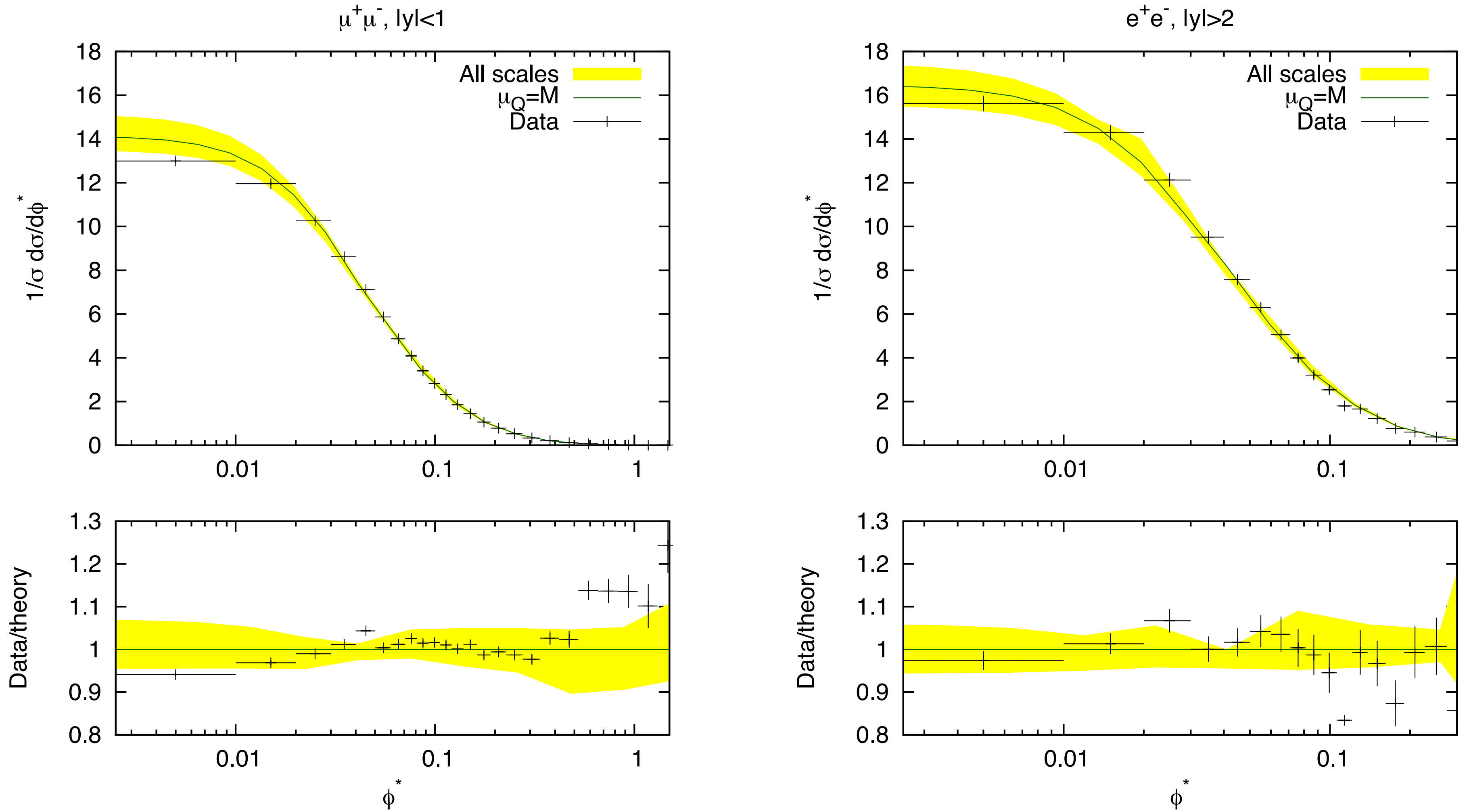
- Captures next-to-next-to-leading logs (NNLL)
- Matched with next-to-leading order (NLO) calculation*
- Independent variation of all perturbative scales to obtain uncertainty
- Purely perturbative calculation: not reliant on the intrinsic k_t
- Better understanding of vector boson low Q_T
  - What NP 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

* i.e. the *distribution* is NLO

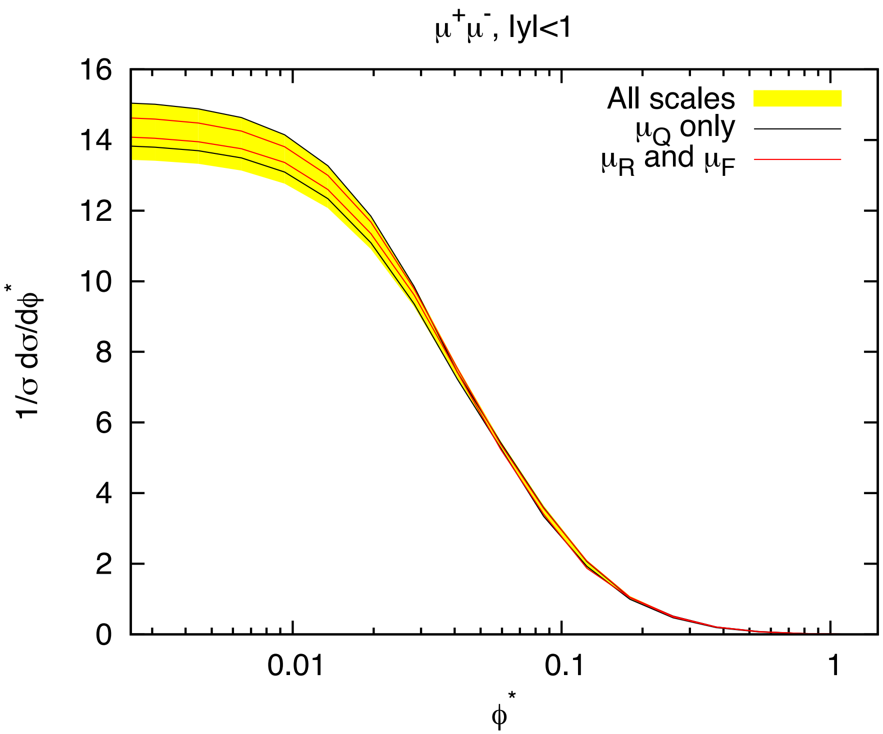
Relevant papers:

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

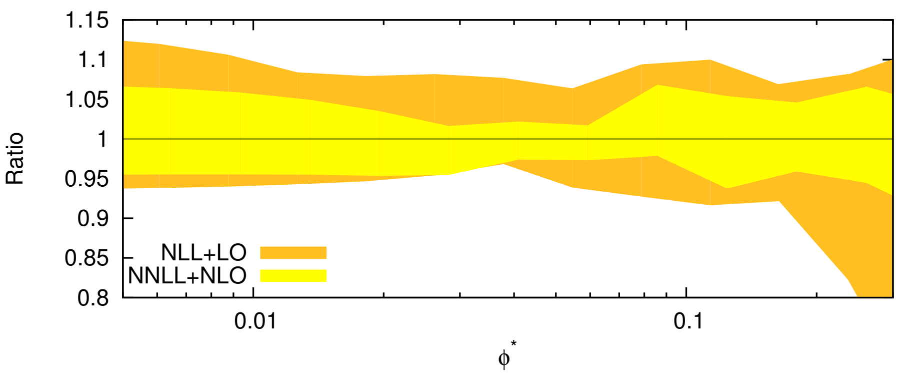
Comparisons to DØ data



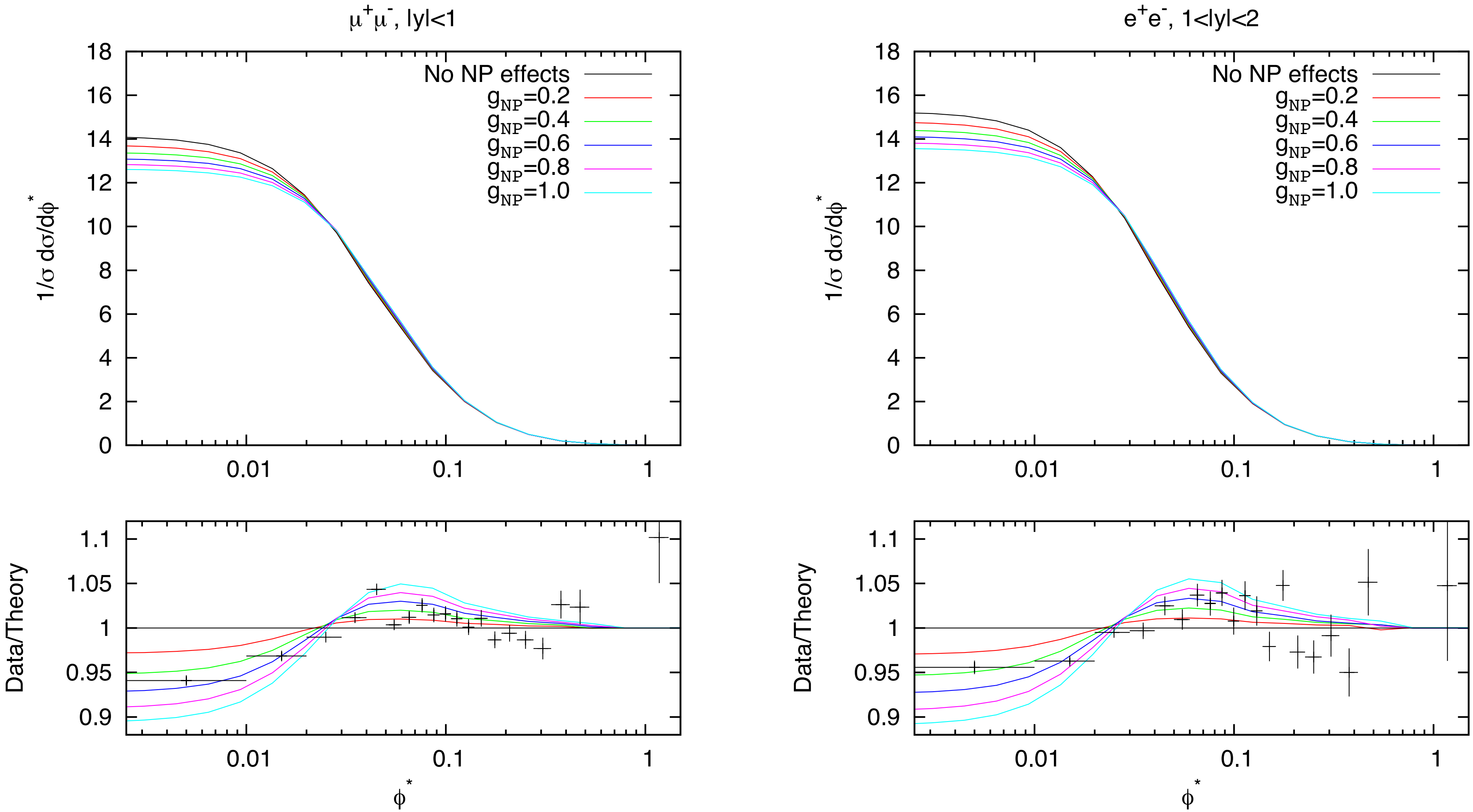
Scale variations



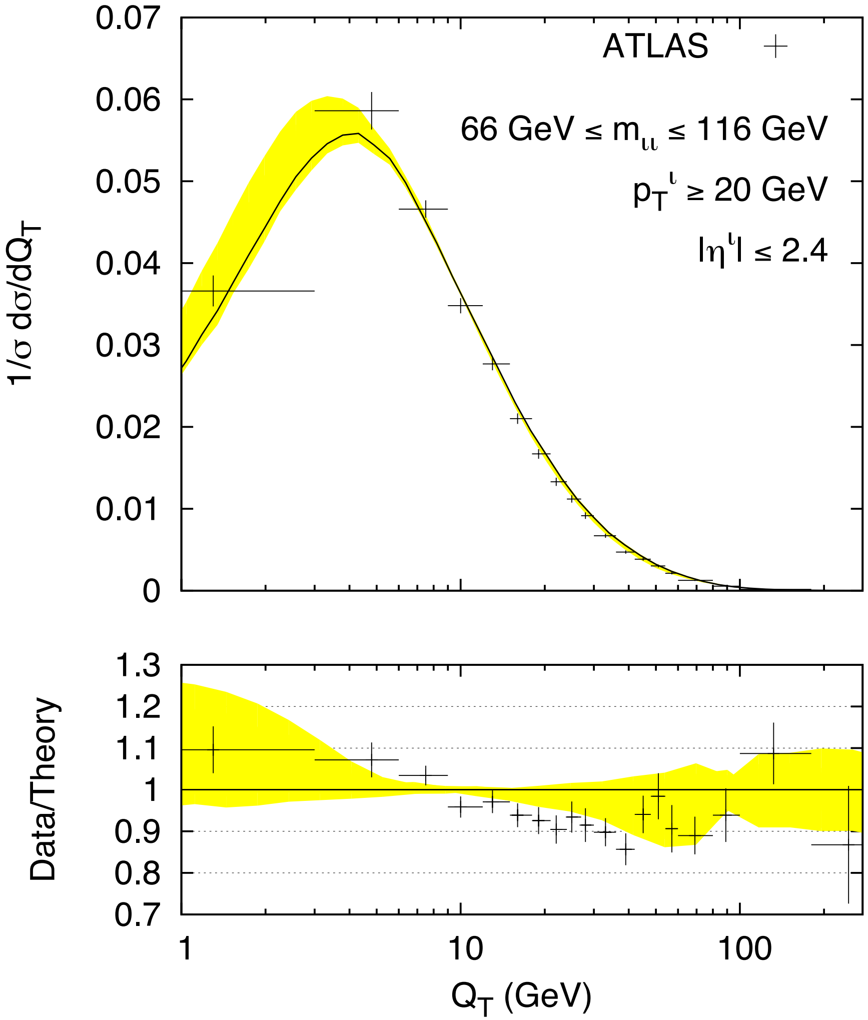
NLL vs. NNLL

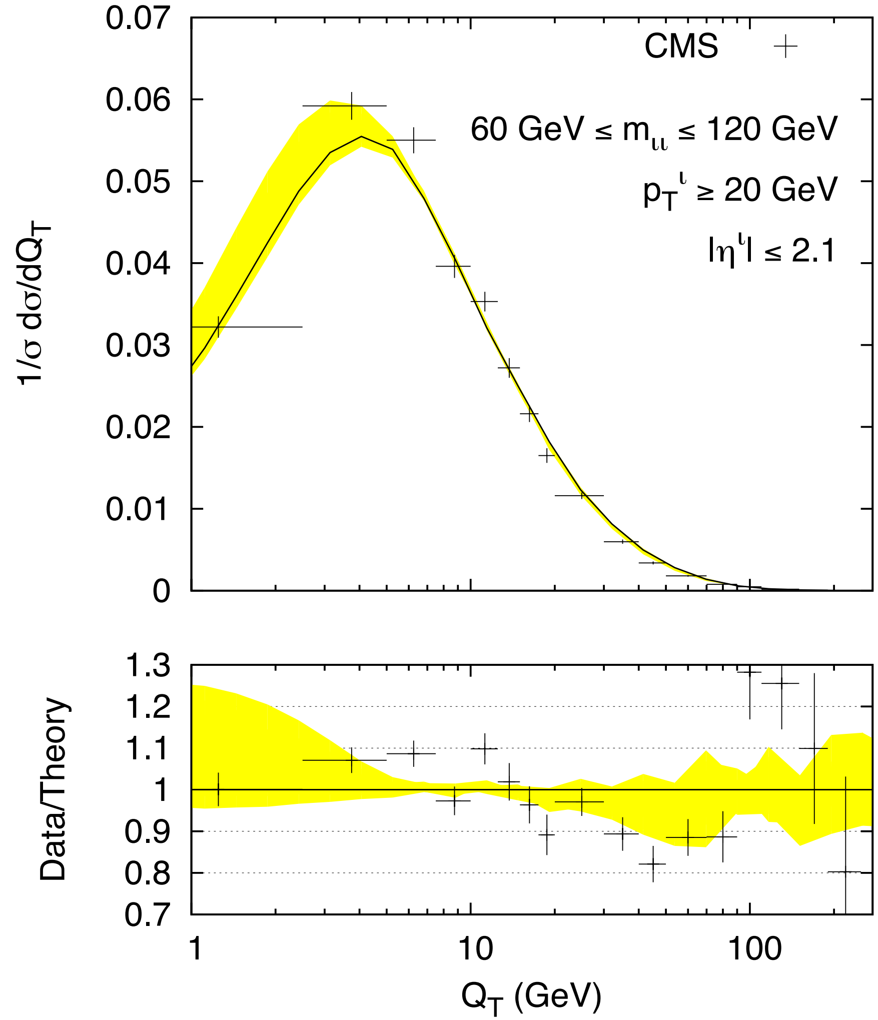


Non-perturbative effects

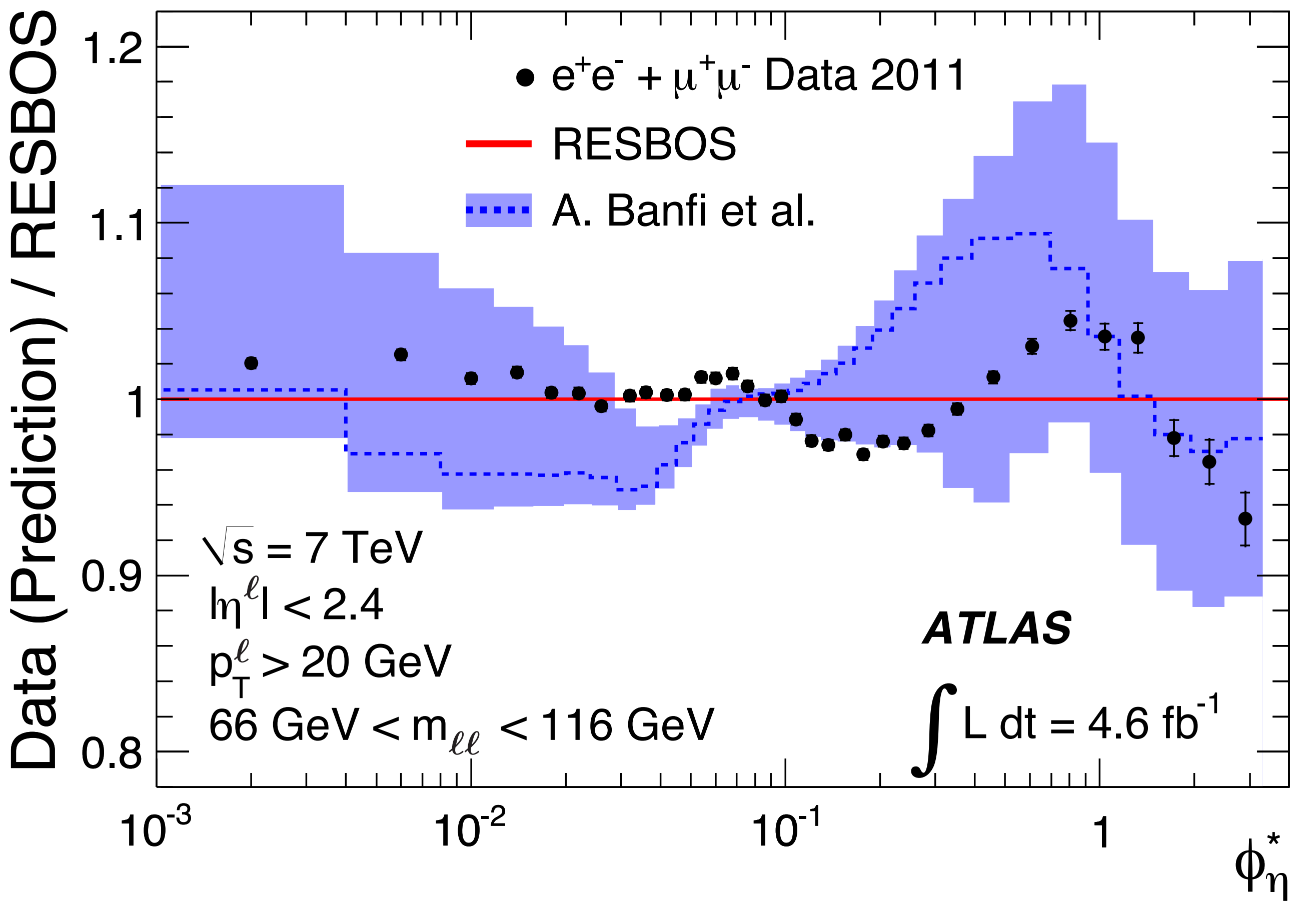


ATLAS and CMS Q_T spectra

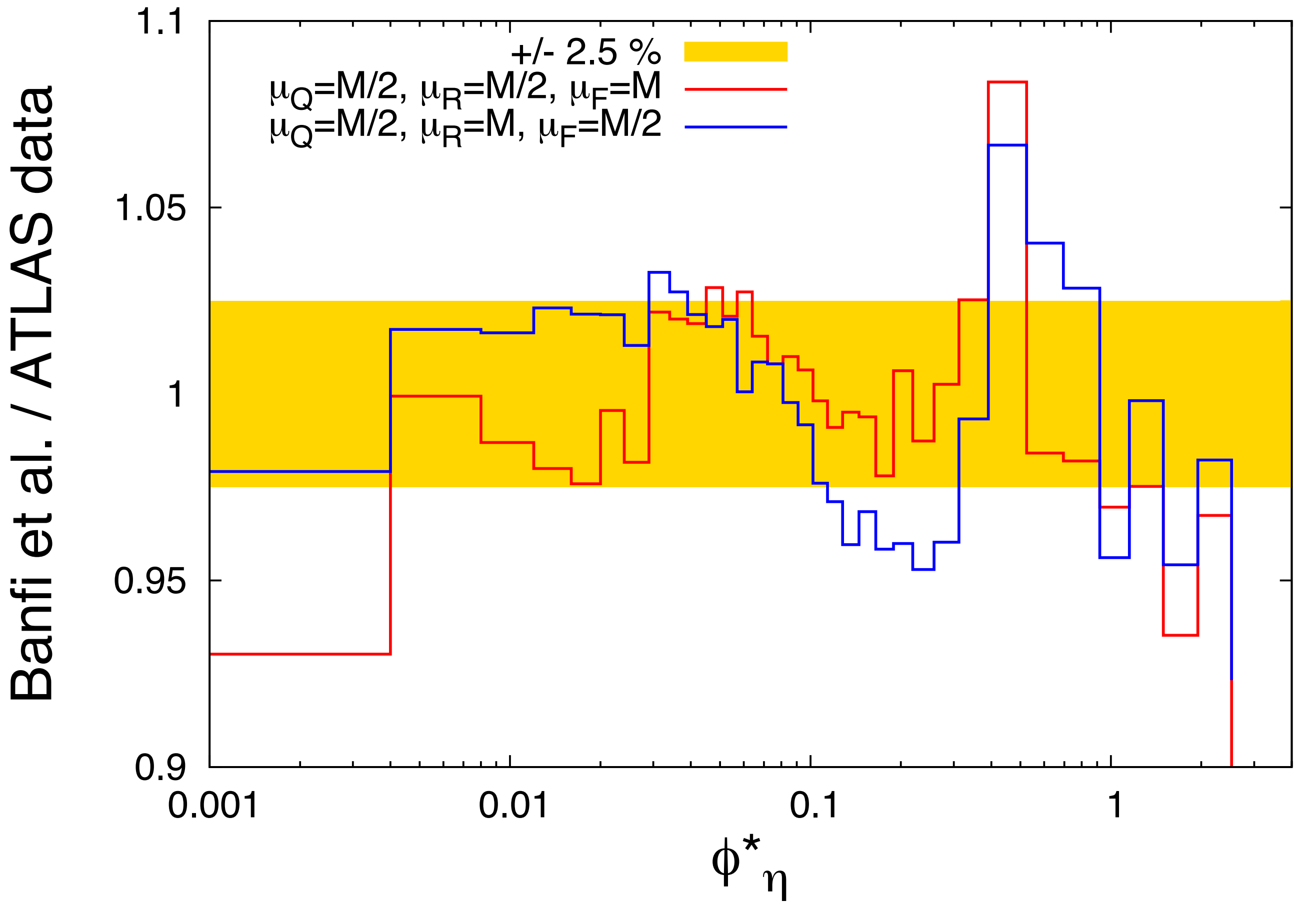




ATLAS φ* PREDICTION



ATLAS ϕ^* 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 (e.g. LHCb) which may challenge standard Q_T resummation
    - Explore *x*-dependent models in the radiator
  - Is there a need for TMDs?
  - Can we reduce the theoretical uncertainty?

Backup slides

Relation between a_T and ϕ^*:

$$\phi^* = \tan\left(\phi_{\mathrm{acop}}/2\right)\sin\theta^* = \left|\sum_i \frac{k_{Ti}}{M}\sin\phi_i\right| + \mathcal{O}\left(\frac{k_{Ti}^2}{M^2}\right)$$

$$a_T = \left|\sum_i k_{ti}\sin\phi_i\right|$$