Higher order QCD Corrections for the tT cross section

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What happened since the last episode

Off-shell effects at NLO in QCD
- tT+jet → ***talk by M. Worek***
- tT+Higgs

Off-shell effects at NLO in EW → ***talk by S. Pozzorini***

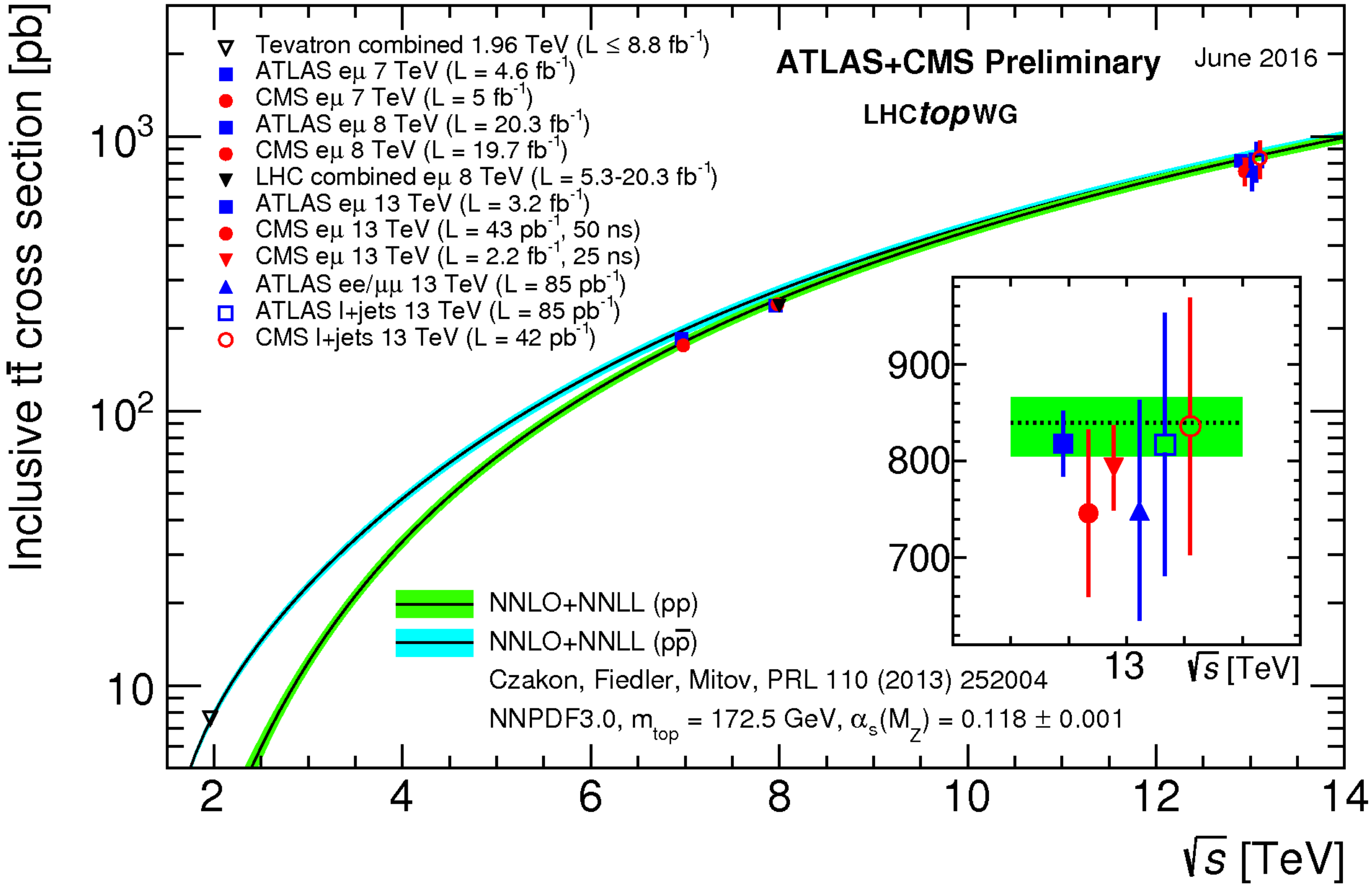
tT + 3 jets at NLO in QCD → ***talk by S. Pozzorini***

Parton shower matching with improved resonance treatment

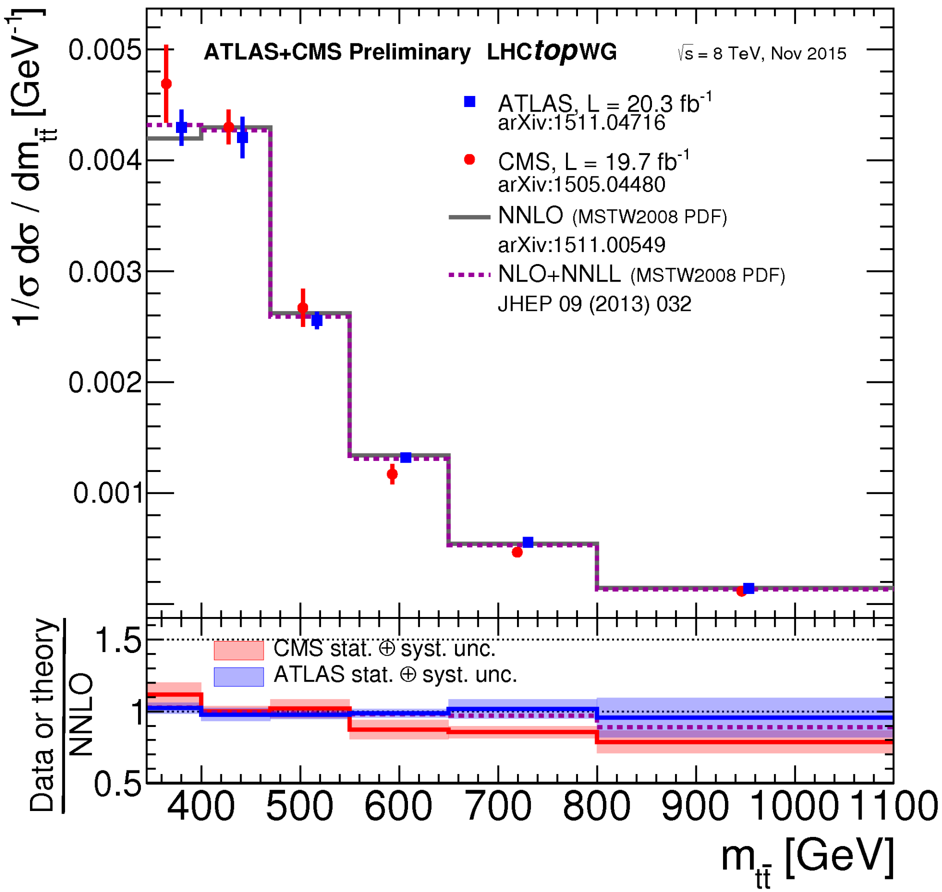
Single-top at NNLO in QCD in the NWA → ***talk by F. Tramontano***

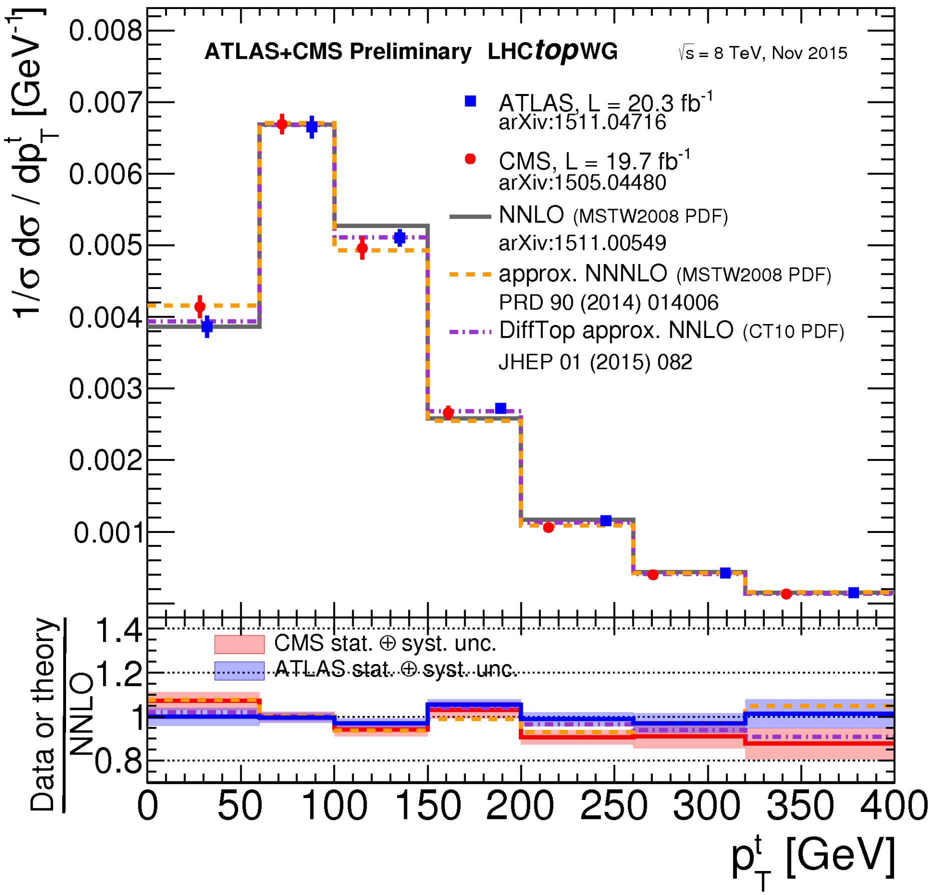
Four-loop relation between the MS and on-shell mass definitions
EW corrections at NLO with photon PDF contributions -> talk by I. Tsinikos
Boosted-top resummation
NNLO differential distributions with dynamical scales

Total Cross Sections

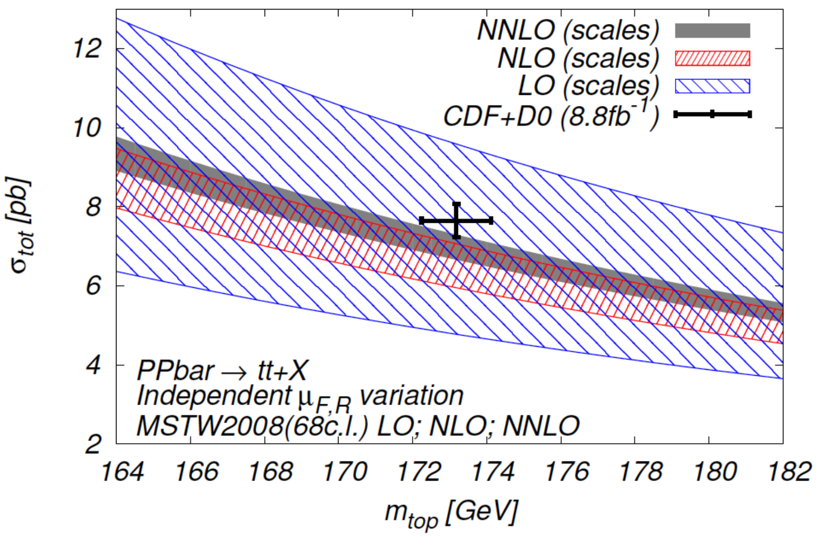


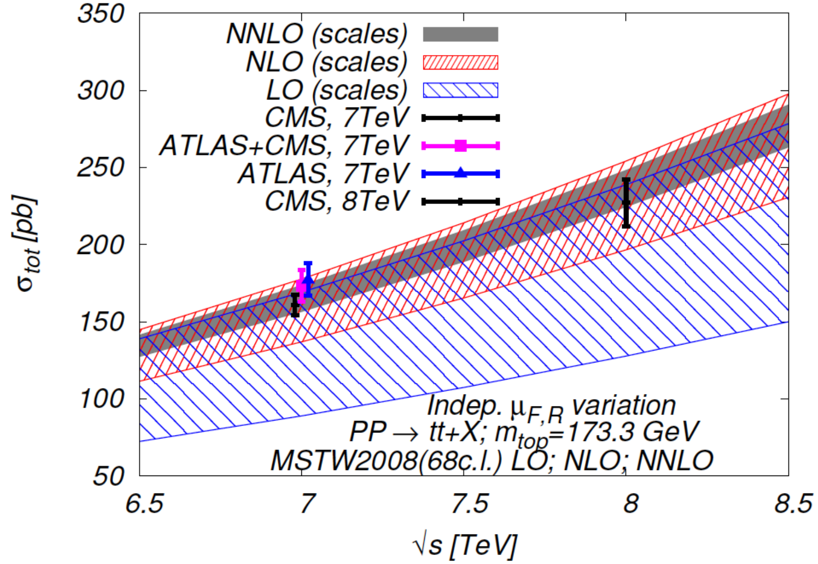
Differential Cross Sections

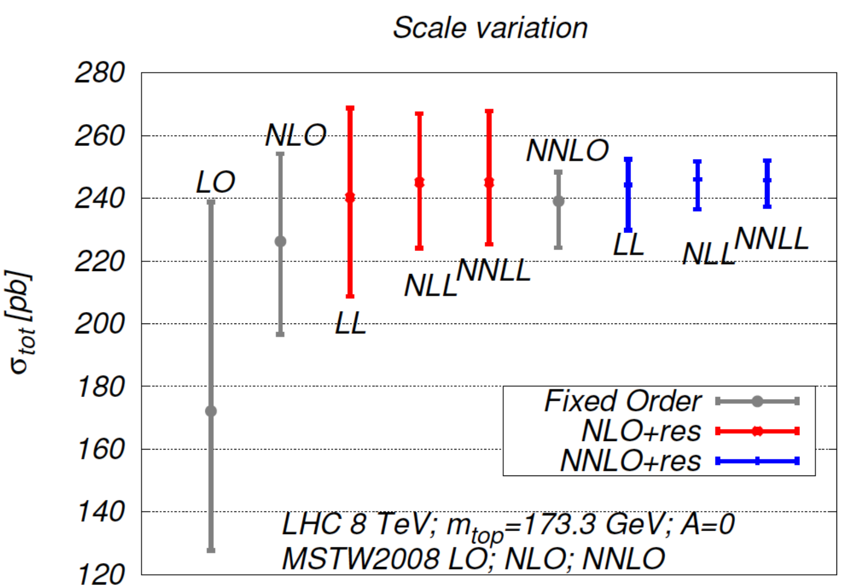




Perturbation Theory Convergence







Concurrent uncertainties:

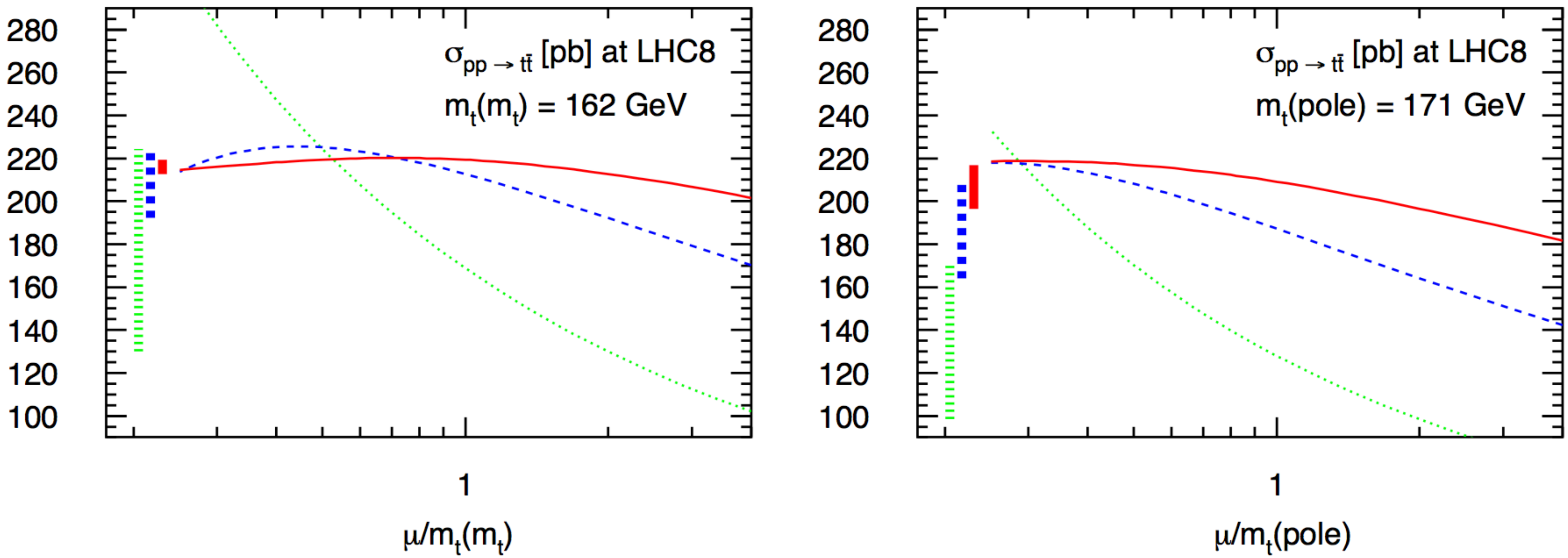
Scales	**~ 3%**
pdf (at 68%cl)	**~ 2-3%**
α_S (parametric)	**~ 1.5%**
m_{top} (parametric)	**~ 3%**

Soft gluon resummation makes a difference: **5% → 3%**

MC, Fiedler, Mitov `13

Perturbation Theory Convergence

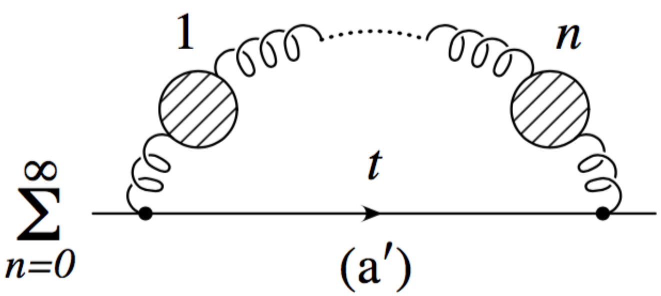
- It has been argued that it is better to use the MS mass to improve convergence
- Is there a better scale in the on-shell scheme?
- Relevant for differential Monte Carlo description



Alekhin, Blümlein, Moch `13

Ambiguity of the Pole Mass

- Pole mass defined by an asymptotic series



$$\Sigma^{(1)}(m_R, a) = \frac{16 m_R}{3\beta_0} \sum_{n=0}^{\infty} c_n a^{n+1}$$

$$c_n \overset{n\to\infty}{\longrightarrow} e^{-C/2} 2^n n!$$

$$a \equiv \frac{\beta_0 \alpha_s(m_R)}{4\pi}$$

- **Renormalon ambiguity: the series is not Borel summable**
- Ambiguity proportional to Λ_{QCD} , but with what coefficient ?
- Relation to MS mass up to 4-loops

$$m_P = 163.643 + 7.557 + 1.617 + 0.501 + (0.195 \pm 0.005)\,\text{GeV}$$

Marquard, Smirnov, Smirnov, Steinhauser `15

- Most recent estimate of the ambiguity

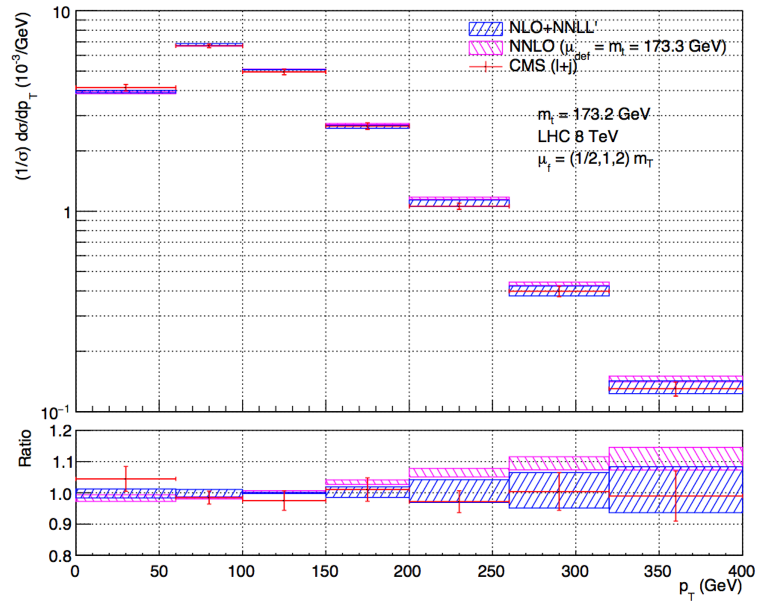
$$\delta^{(5+)} m_P = 0.250^{+0.015}_{-0.038}\,(N) \pm 0.001\,(c_4) \pm 0.010\,(\alpha_s) \pm 0.071\;(\text{ambiguity})\;\text{GeV}$$

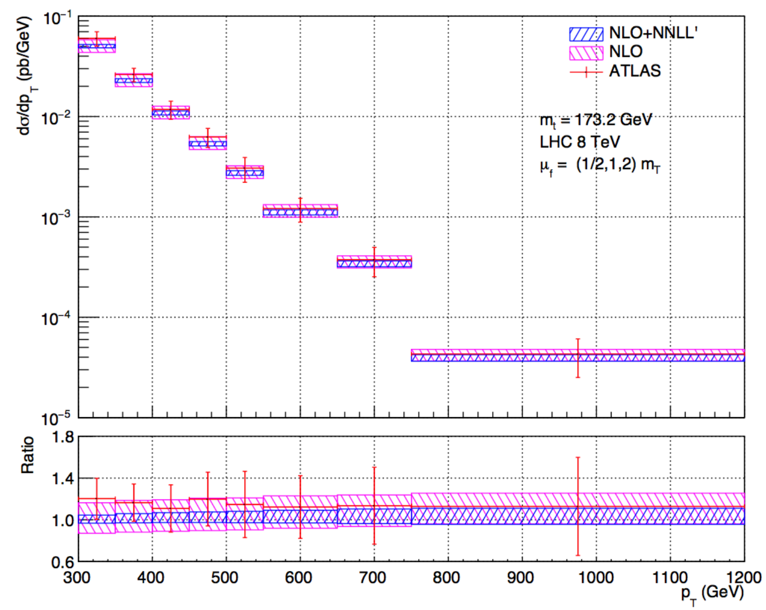
Beneke, Marquard, Nason, Steinhauser arXiv:1605.03609

Boosted Top Resummation

- Soft-gluon resummation on top of top-quark fragmentation
- Transverse momentum distribution modified by dynamical scales and resummation
- At low p_T better description of CMS data, slightly worse for ATLAS (not shown)
- Larger scale dependence?

Pecjak, Scott, Wang, Yang `15

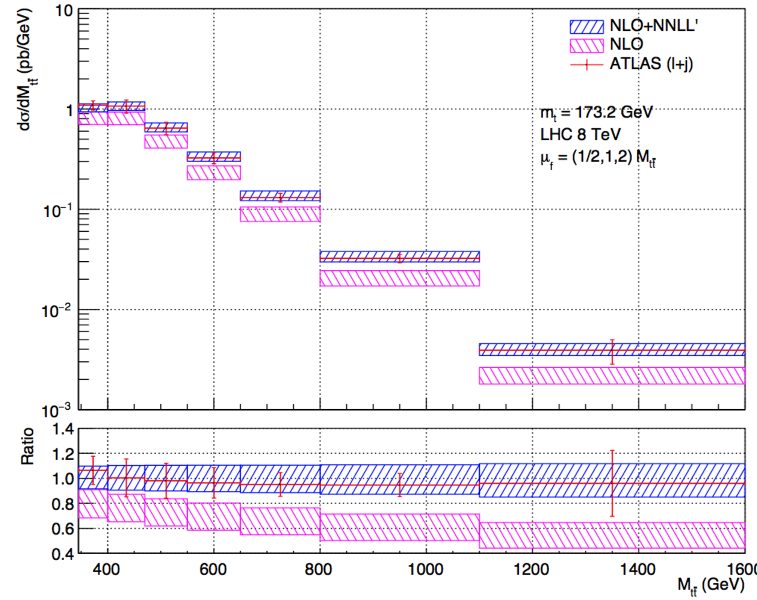


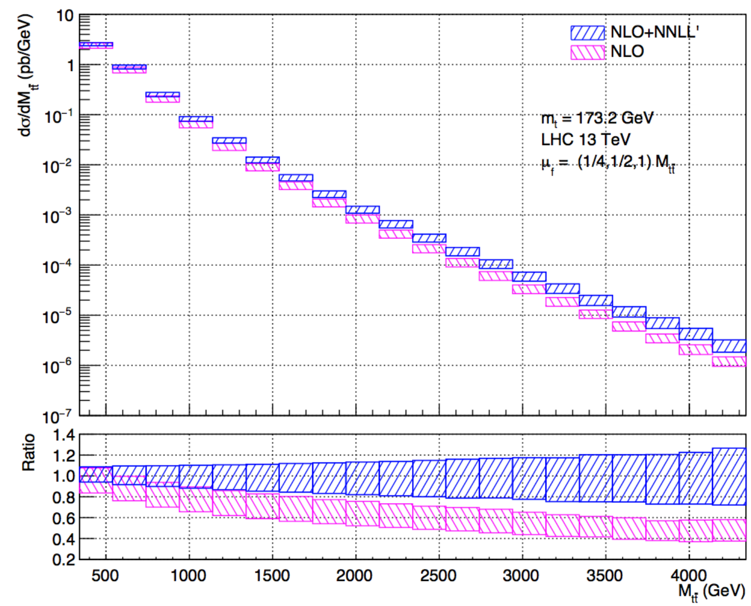


Boosted Top Resummation

- Observable dependent scale
- Results presented for 13 TeV as well
- At some point consistent matching to NNLO will become necessary
- When is true resummation needed?

Pecjak, Scott, Wang, Yang `15



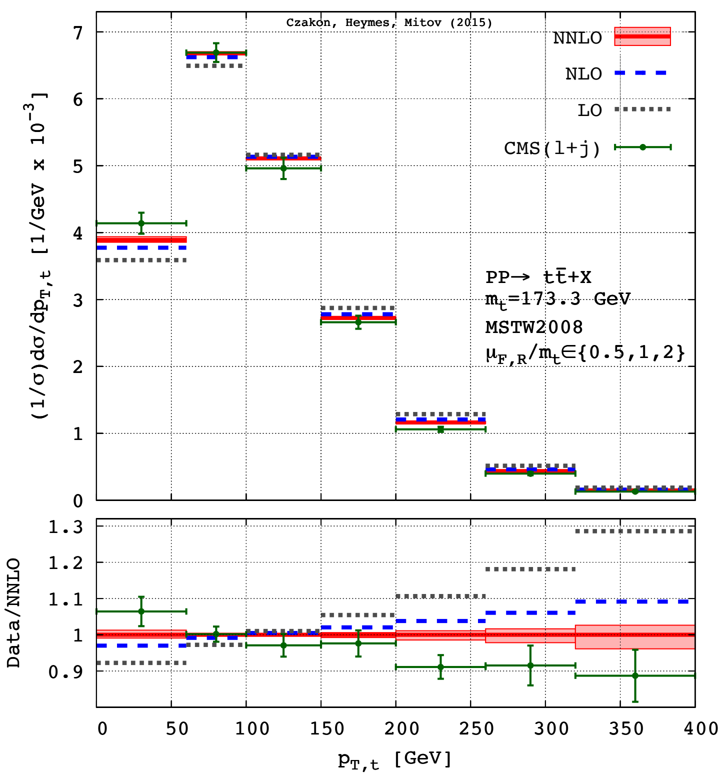


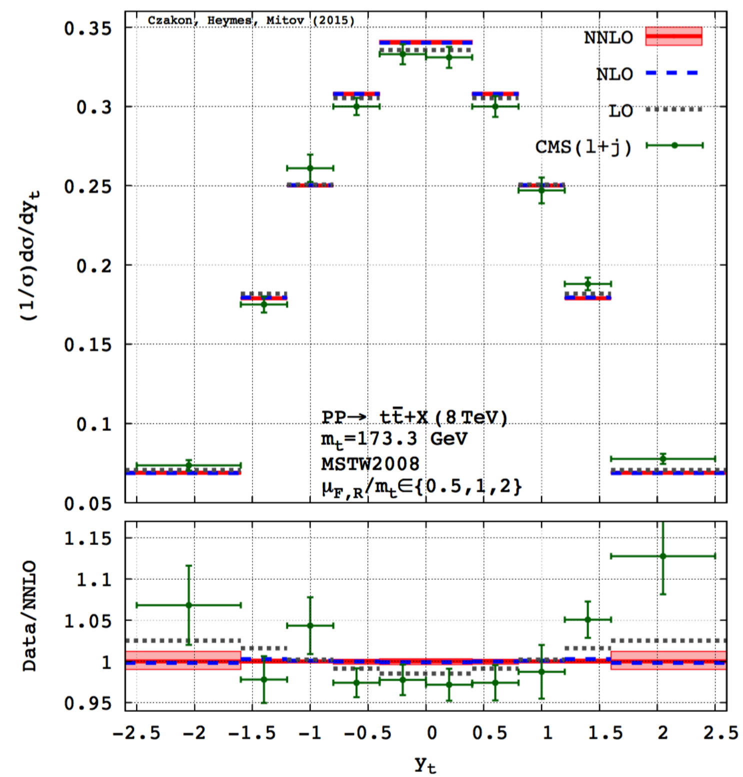
Differential Distributions

Typical differential distributions are:

1. transverse momentum of the top-quark and the top-quark pair
2. rapidity of the top-quark and the top-quark pair
3. invariant mass of the top-quark pair

Difference between normalized and absolute distributions





MC, Heymes, Mitov `15

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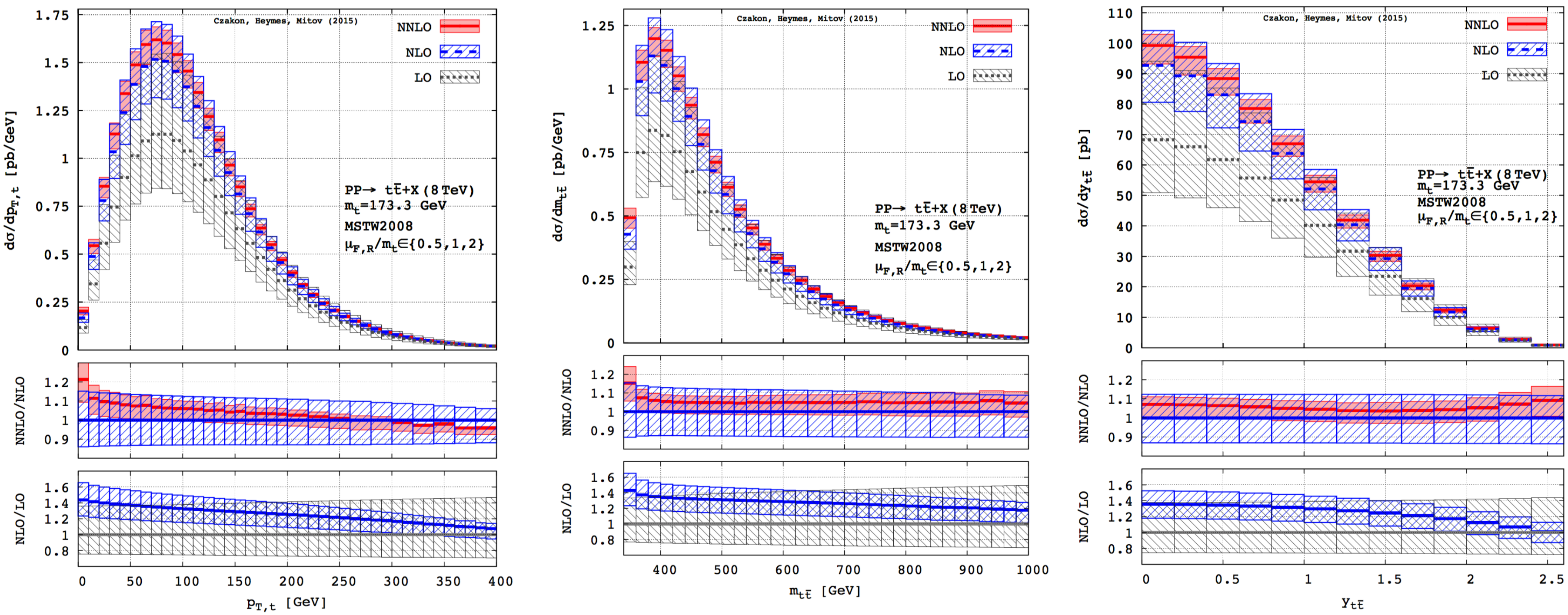


MC, Heymes, Mitov `15

Dynamical Scales

- Over extended kinematical ranges it is necessary to use dynamical scales
- Examples in the case of top-quark pair production:

Our recommendation for p_T (but ½)

Our recommendation for the others (but ¼)

$$\mu_0 \sim m_t \,,$$

$$\mu_0 \sim m_T = \sqrt{m_t^2 + p_T^2} \,,$$

$$\mu_0 \sim H_T = \sqrt{m_t^2 + p_{T,t}^2} + \sqrt{m_t^2 + p_{T,\bar{t}}^2} \,,$$

$$\mu_0 \sim H_T' = \sqrt{m_t^2 + p_{T,t}^2} + \sqrt{m_t^2 + p_{T,\bar{t}}^2} + \sum_i p_{T,i} \,,$$

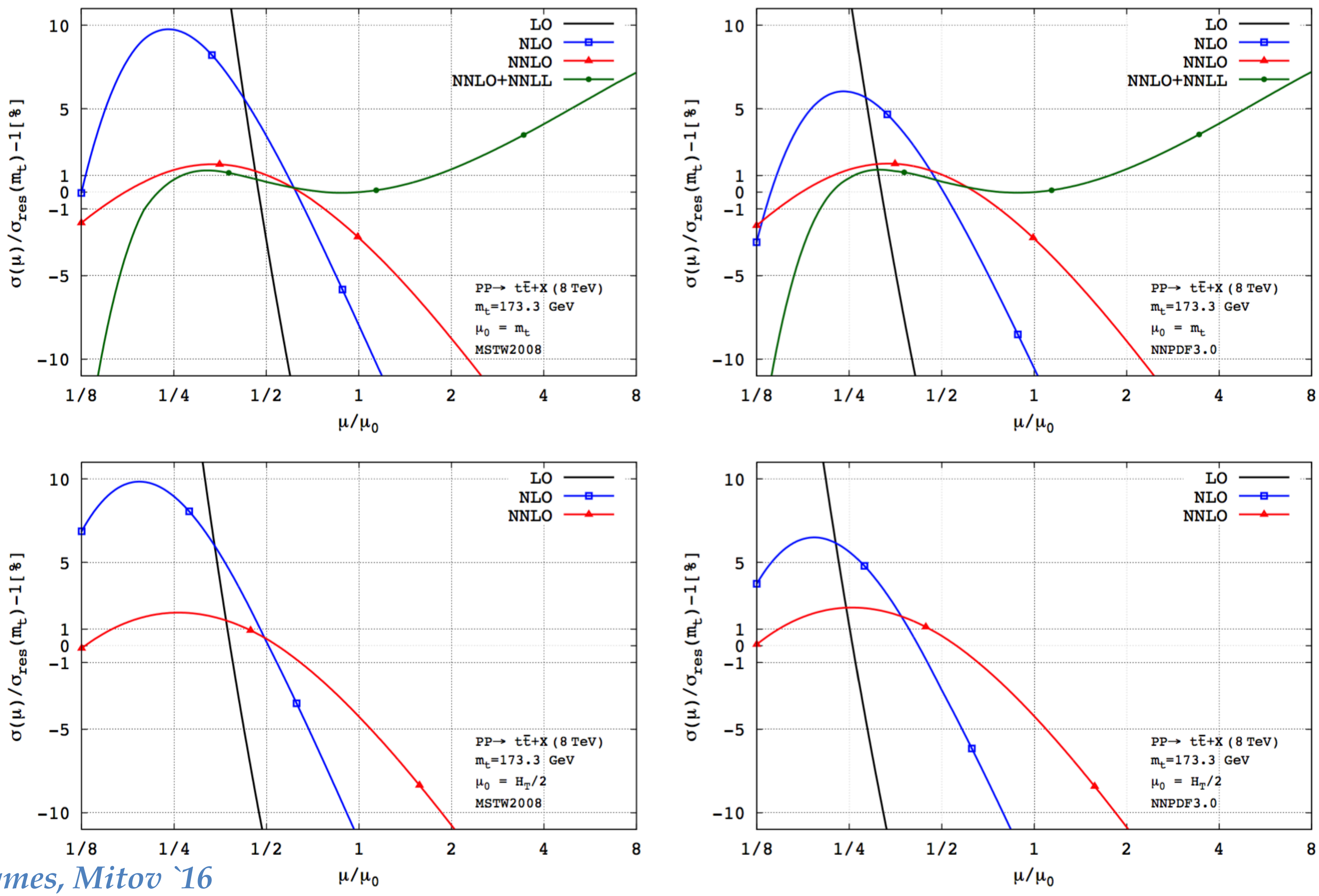
$$\mu_0 \sim E_T = \sqrt{\sqrt{m_t^2 + p_{T,t}^2}\sqrt{m_t^2 + p_{T,\bar{t}}^2}} \,,$$

$$\mu_0 \sim H_{T,\mathrm{int}} = \sqrt{(m_t/2)^2 + p_{T,t}^2} + \sqrt{(m_t/2)^2 + p_{T,\bar{t}}^2} \,,$$

$$\mu_0 \sim m_{t\bar{t}} \,,$$

Dynamical Scales

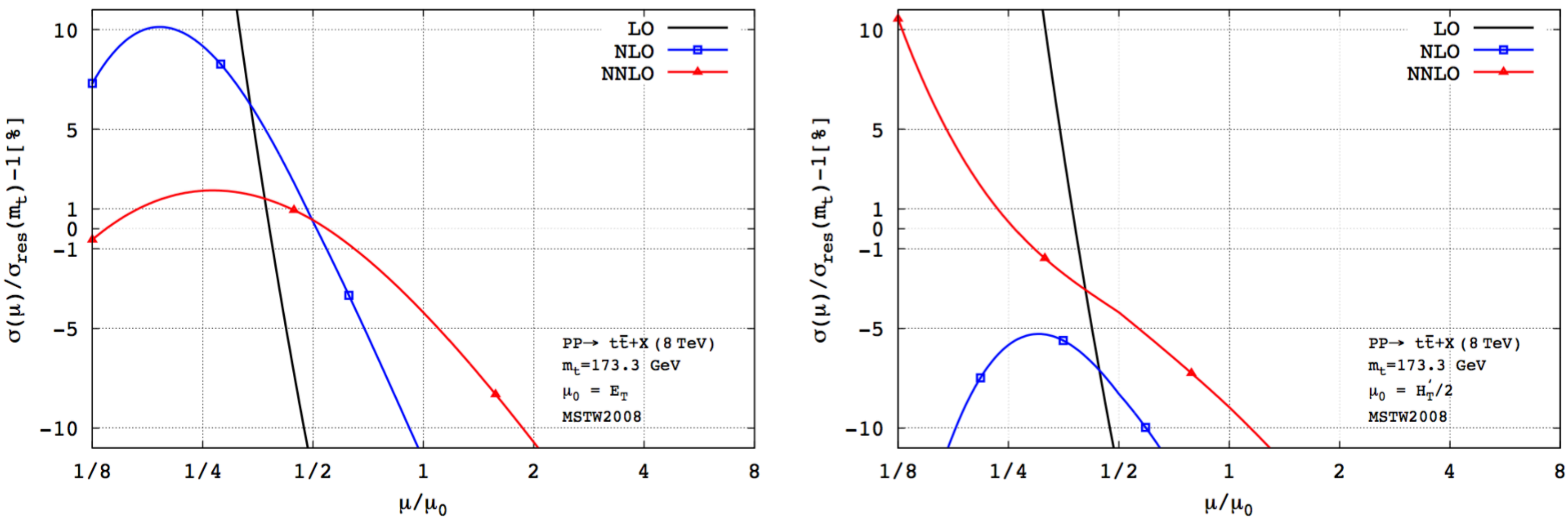
- Dynamical scales modify the total cross section
- Because of threshold enhancement close results from an "average" fixed scale



MC, Heymes, Mitov `16

Dynamical Scales

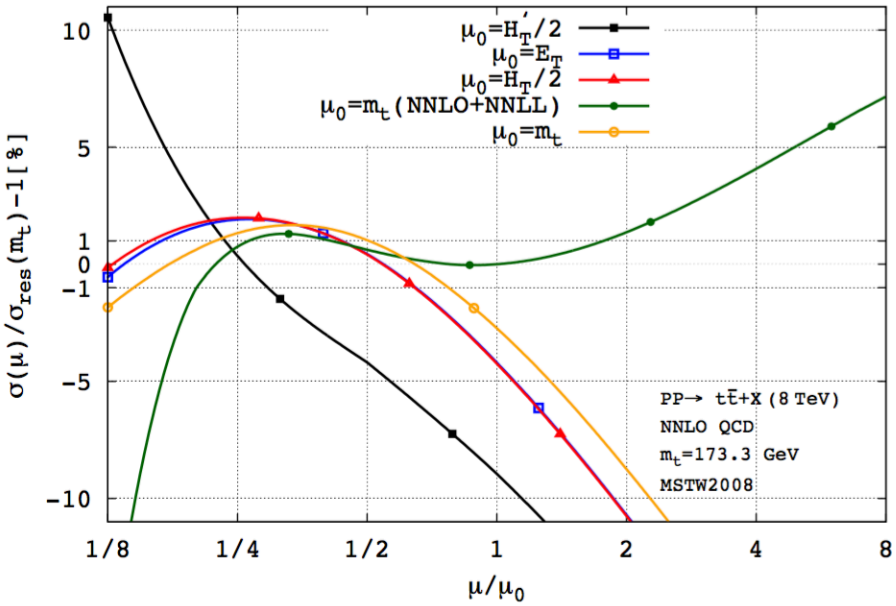
- Some scales behave suspiciously, while seeming perfectly reasonable

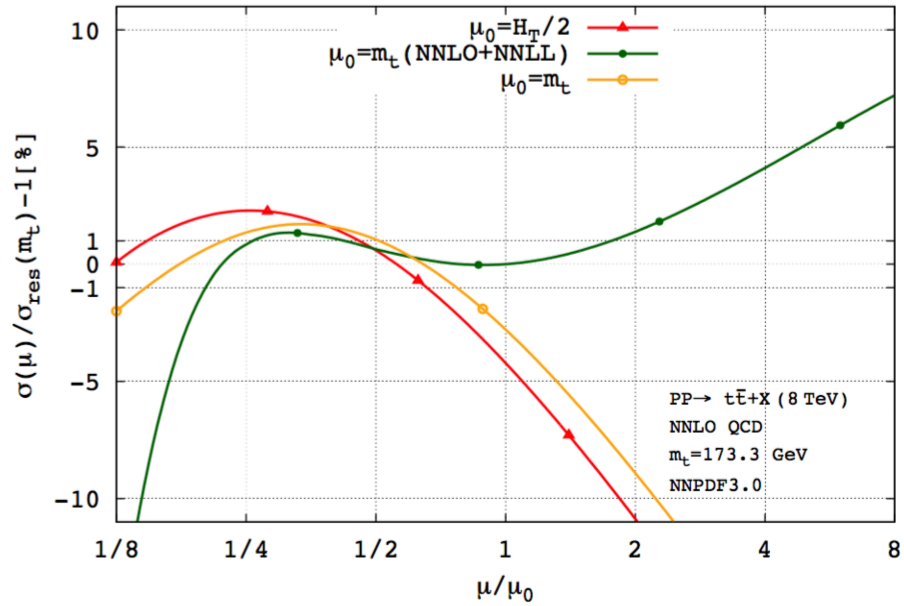


MC, Heymes, Mitov `16

Dynamical Scales

- A comparison of different scales at highest precision
- Different PDF sets

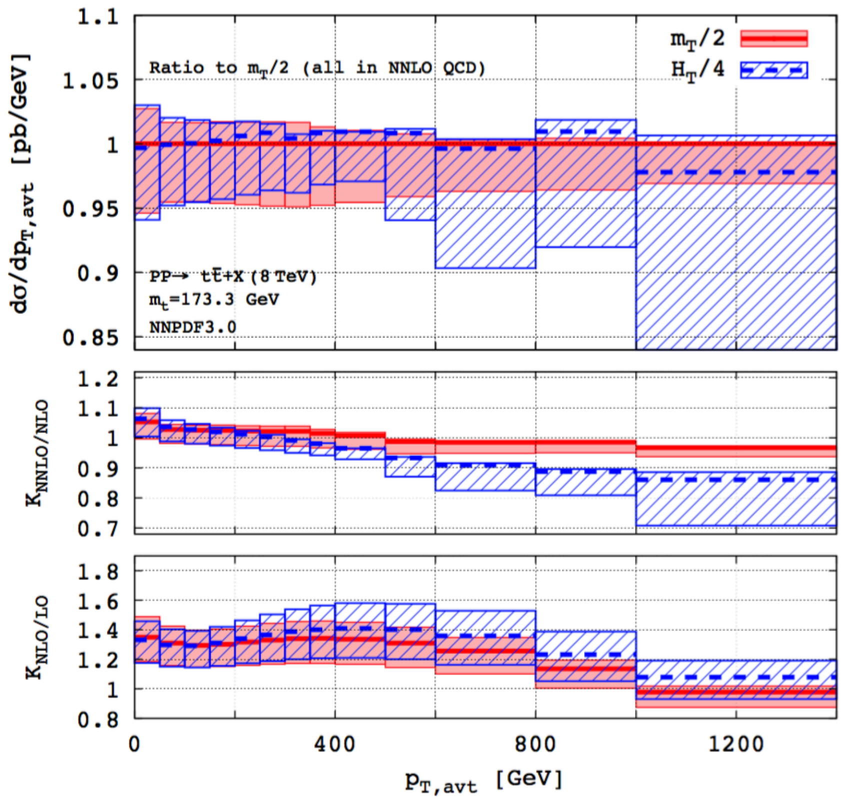


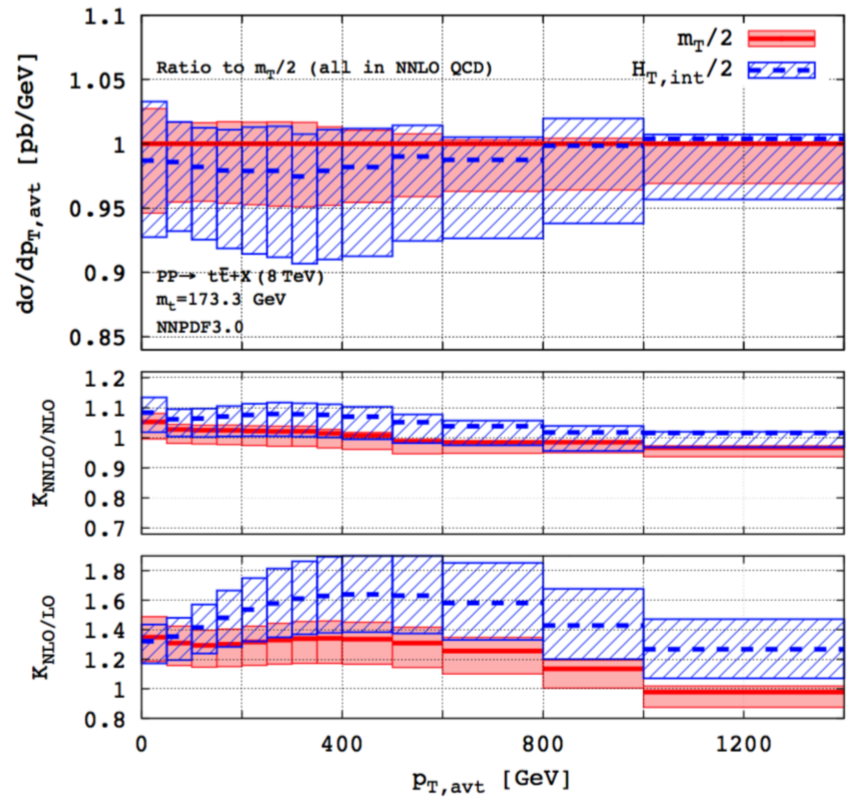


MC, Heymes, Mitov `16

Dynamical Scales

- Improvements of convergence with “reasonable” scales

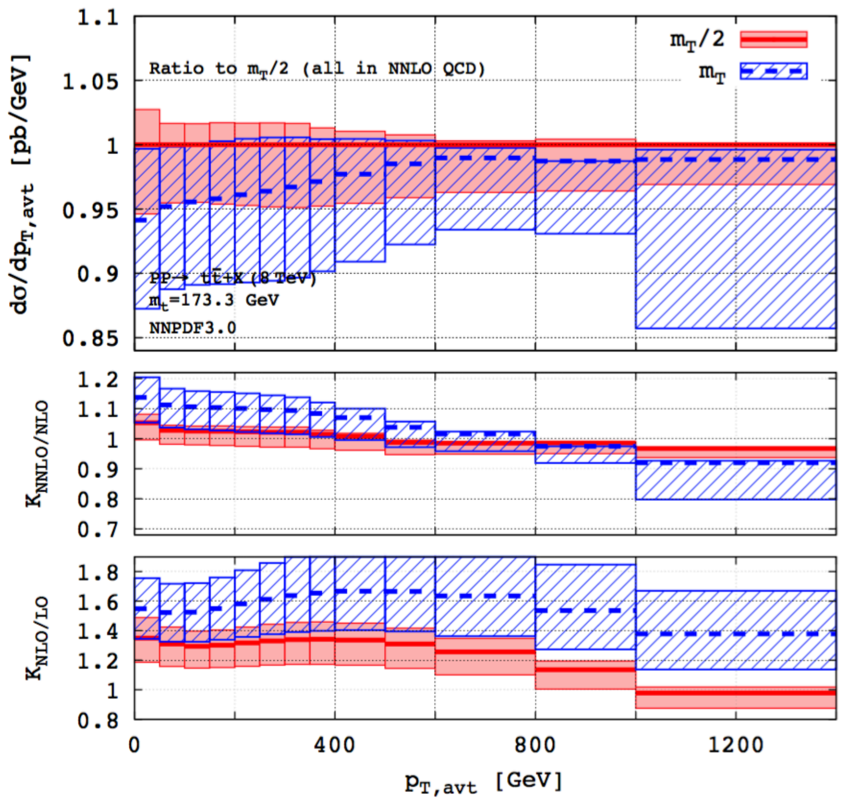


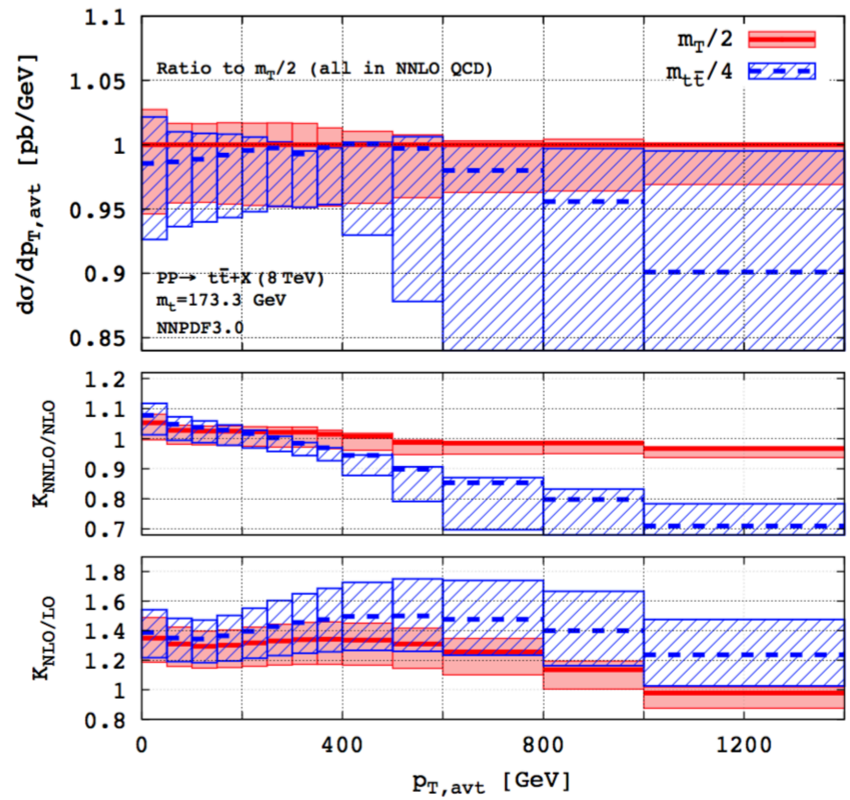


MC, Heymes, Mitov `16

Dynamical Scales

- Improvements of convergence with "reasonable" scales
- Problems in the case of "less reasonable" scales

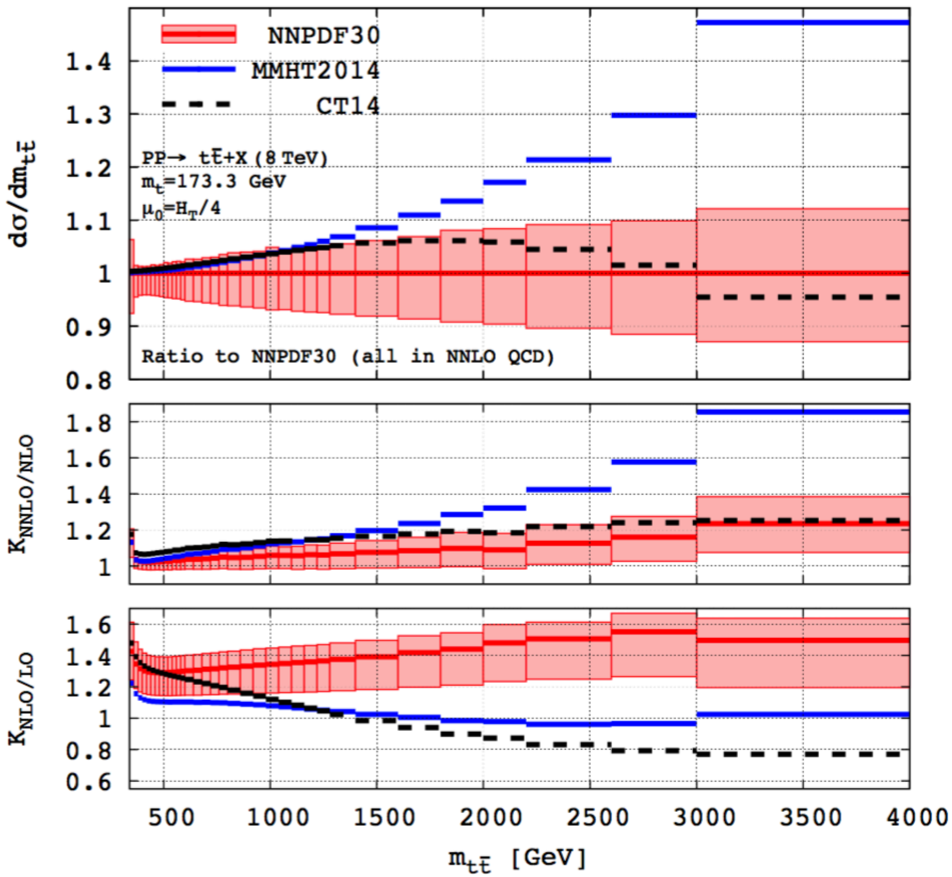




MC, Heymes, Mitov `16

Reliability of PDF Sets

- Above a certain invariant mass no more precise predictions
- Use the distributions to improve PDFs?



MC, Heymes, Mitov `16

Concluding Remarks

- High precision should be associated with fixed order perturbation theory:
  - Clear advantage: not many ambiguities
  - But: beware of range of applicability
  - Currently at next-to-next-to-leading order for on-shell production

    MC, Bärnreuther, Fiedler, Heymes, Mitov `12 - `16
  - Partial independent results by:

    Abelof, Gehrmann-De Ridder, Maierhofer, Pozzorini `14

    Catani, Grazzini, Torre `14 - `15
  - Currently substantial effort to include Narrow Width Approximation

- Advertisment
  - Combination with electroweak corrections

    see talk by I. Tsinikos on Tuesday evening

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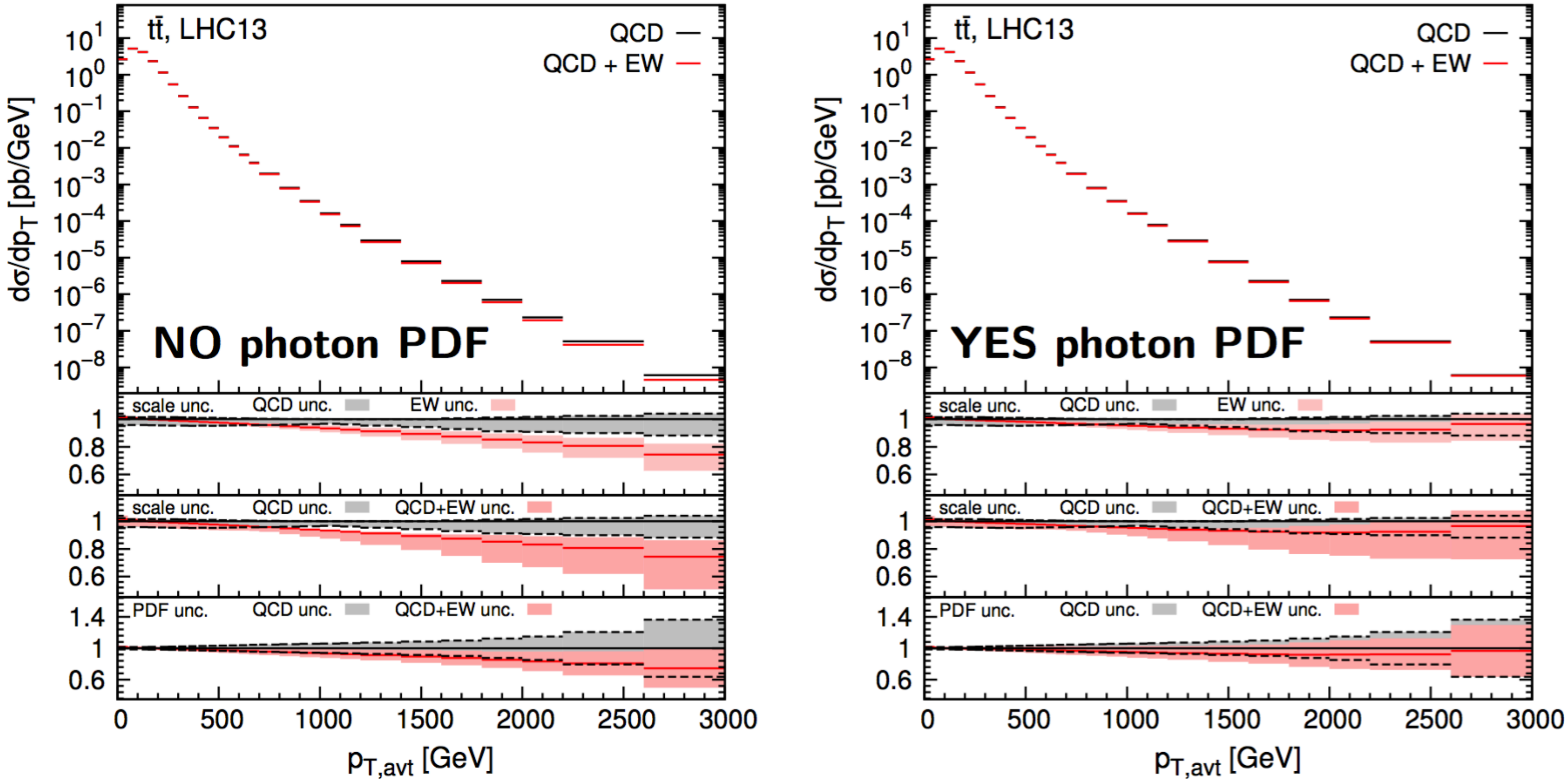

Preliminary: MC, D. Heymes, A. Mitov, D. Pagani, I. Tsinikos, M. Zaro

- Advertisment
  - Combination with electroweak corrections
    see talk by I. Tsinikos on Tuesday evening