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Top-quark mass extraction from top pair differential distributions

David Heymes

dheymes@hep.phy.cam.ac.uk

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Cavendish Laboratory - HEP Group

Top-Quark mass measurements at Tevatron and LHC

- Direct techniques (extraction of m_{top}(generator))
  - Matrix-Element method
  - Template Method, etc.
  - Combined value

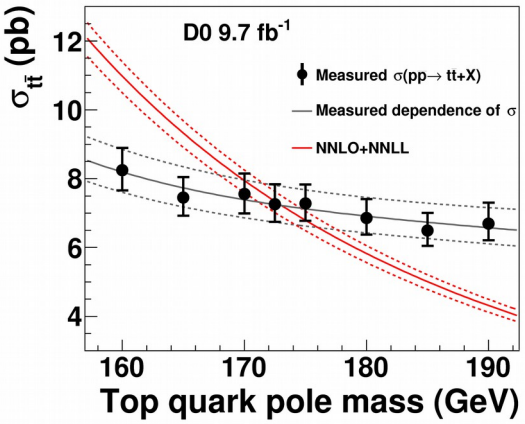
$$m_{\mathrm{top}} = 173.34 \pm 0.27 \pm 0.71 \ \mathrm{GeV}$$ ***D0, CDF, ATLAS,CMS (PDG)***

→ Difference of 1 GeV m_{top}(pole) and m_{top}(generator)

- Pole-mass extractions: $m_{top} = m_{top}$(pole) (indirect)
  - Total cross section extraction using NNLO+NNLL

$$m_{\mathrm{top}}^{\mathrm{pole}} = 174.2 \pm 1.4 \ \mathrm{GeV}$$

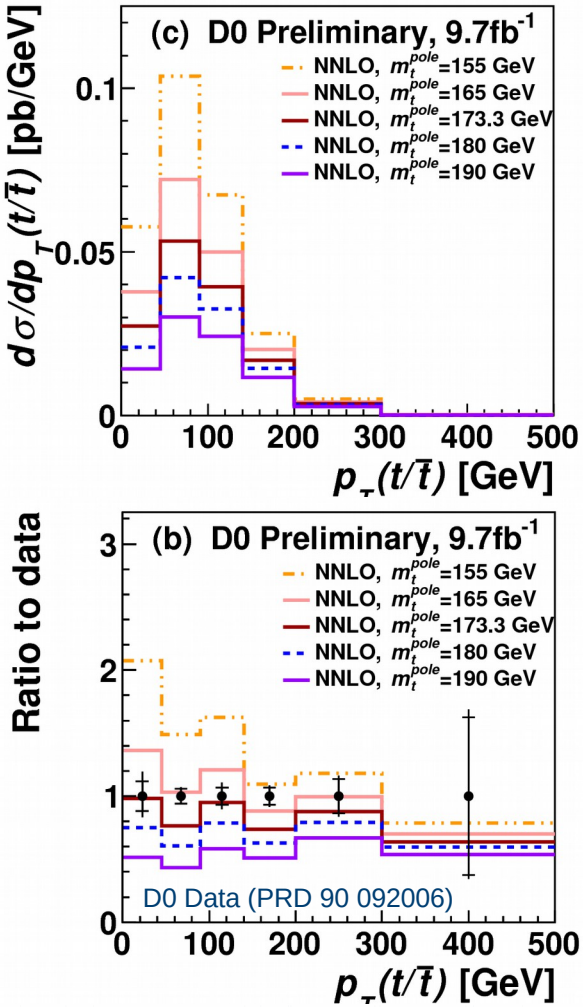
  - Here: Extraction from differential distributions



D0,Czakon, Fielder, Heymes, Mitov 2016
D0 Note 6473-CONF

Mass sensitivity of top-pair differential distributions

D0,Czakon, Fielder, Heymes, Mitov 2016



- Idea: Extract m_{top} from differential distribtutions (m_{tt}, p_T)
- NNLO Calculation based on *Czakon, Fielder, Heymes, Mitov 2016*
  - Fixed scales $\mu_F = \mu_R = m_{top}$
  - Theory (Scale) Uncertainty: Independent variation by 2

    < 5 % in the bulk of the distribution

    < 10 % in the tail bin
  - MSTW2008, CT10, NNPDF23, HERAPDF15

    pdf error small
- Calculation for 9 different values of m_{top}
- Highest sensitivity in the bulk of the distributions
- No/less sensitivity in the tails
- Data: D0 Run II *Phys. Rev. D 90 2014*

Mass sensitivity of top-pair differential distributions

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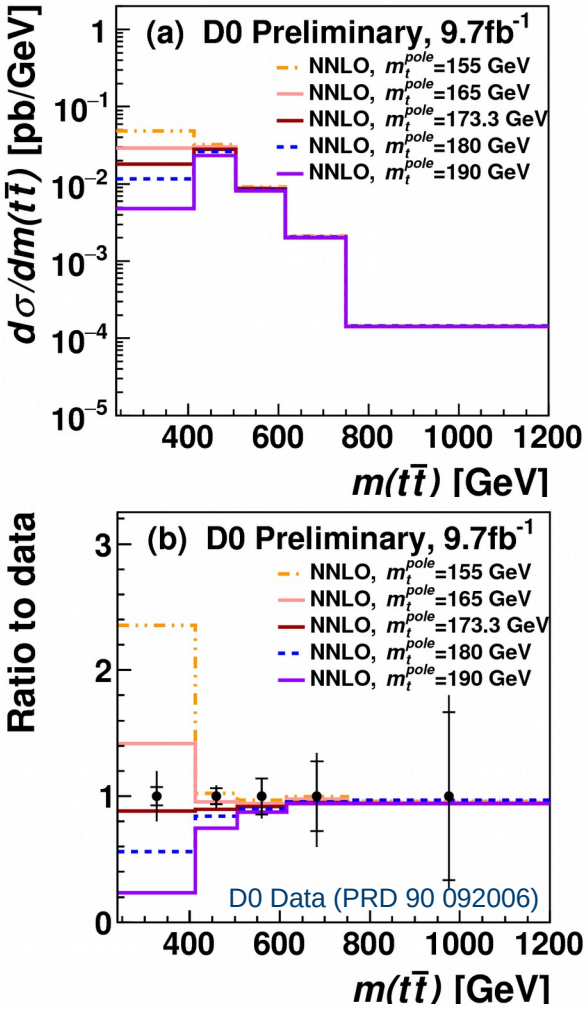

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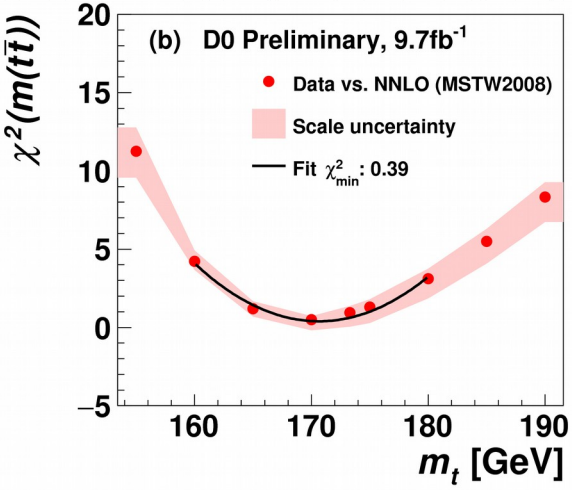
Top-mass extraction procedure

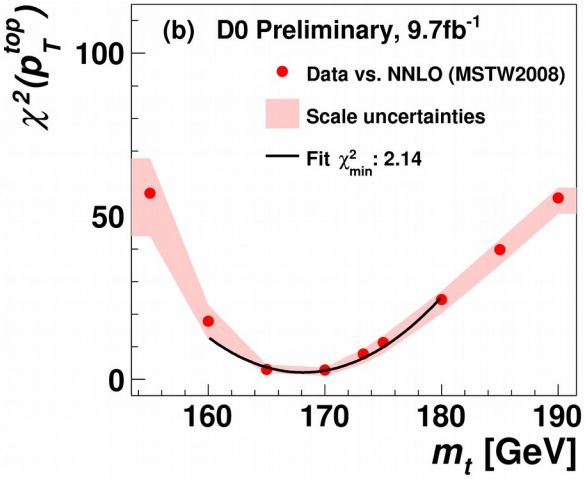
D0,Czakon, Fielder, Heymes, Mitov 2016

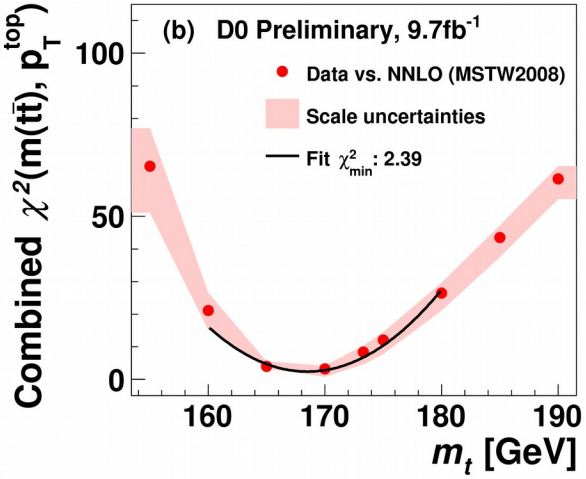
- Minimize distance between theoretical calculation and unfolded differential data in each bin i,j:

$$\chi^2(m_{\rm top}) = \sum_{i,j}(x_i^{\rm true} - x_i^{\rm theo})\boldsymbol{V_{i,j}^{-1}}(x_j^{\rm true} - x_j^{\rm theo})$$

- Statistical, systematic uncertainties and bin correlations in cov. matrix $\boldsymbol{V_{i,j}^{-1}}$
- Parabolic fit to find minimum, restricted to values around minimum
- For different scale choices → shaded area
- Total uncertainty obtained by $\Delta\chi^2 = 1$







Results

D0,Czakon, Fielder, Heymes, Mitov 2016

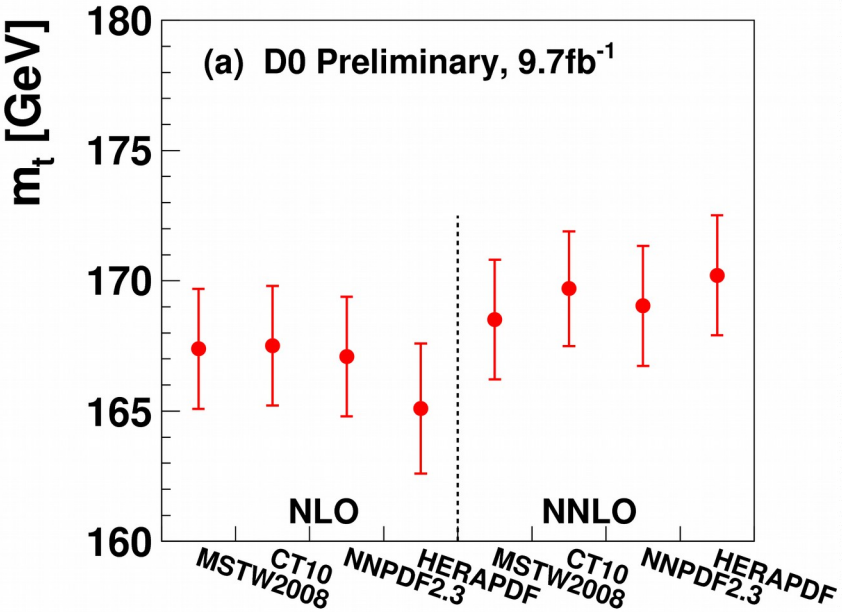
$$m_{\text{top}}^{\text{pole}} = 169.1 \pm 2.5(\text{tot.}) \left[\pm 2.2(\text{exp.}) \pm 0.8(\text{scale}) \pm 1.2(\text{PDF})\right] \text{GeV}$$

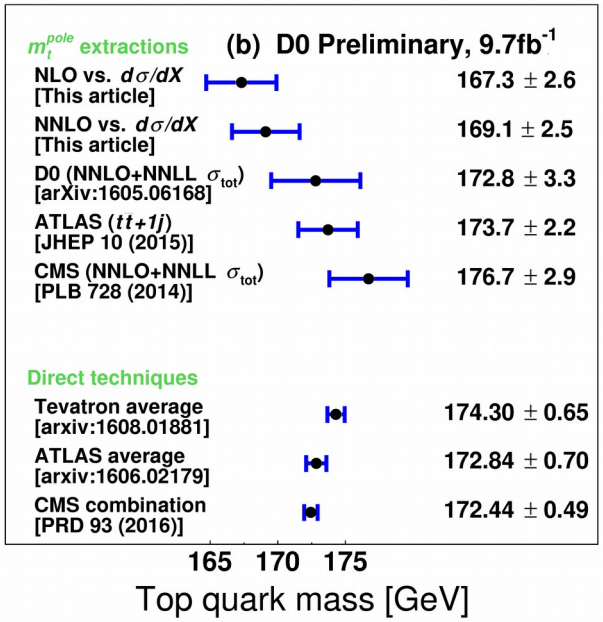
- Uncertainties:
  - Exp. : set theory uncertainty to 0 for the extraction
  - Scale.: set experimental uncertainty to zero for the extraction with different scale choices
  - Pdf. : Combine calculation for MSTW2008, CT10 and NNPDF23 and assign error
- P_T - distribution dominates the mass extraction
- Correlation between distribution is taken into account
- Normalized distributions have less systematic uncertainties, but sensitivity to the top mass is lower → larger uncertainties on the extraction

Results

D0,Czakon, Fielder, Heymes, Mitov 2016

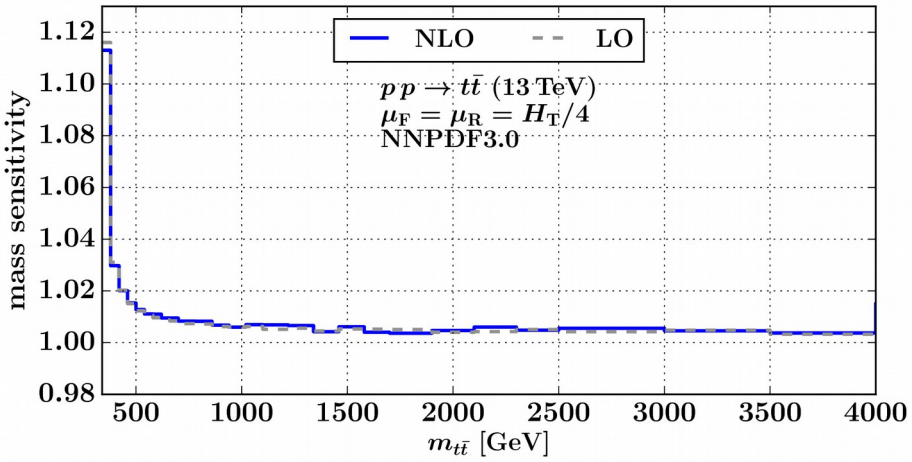
- NLO tends to gives smaller results, because of lower cross section
- m_{top} tends to be lower than in total-cross section extractions using NNLO+NNLL
  - Dynamic scales alleviate difference between NNLO and NNLO+NNLL

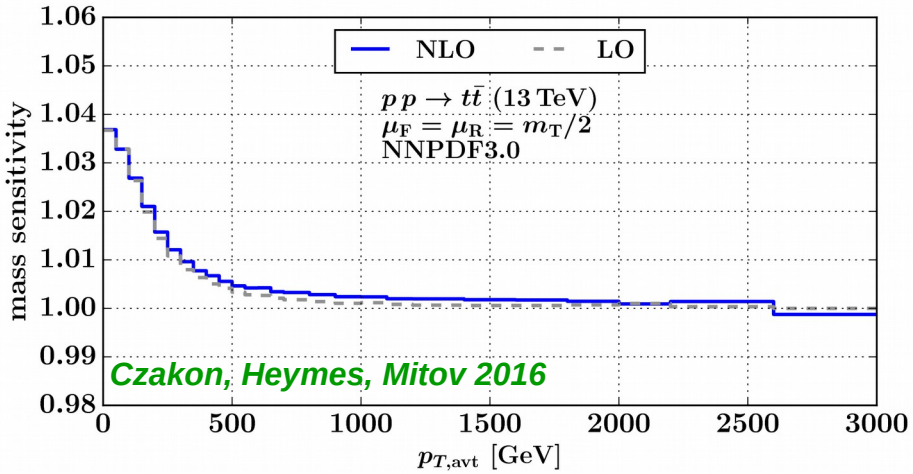




Mass sensitivity at the LHC

- Procedure can be directly extended to the LHC
  - What about other (theoretical) uncertainties (α_s, pdfs) ? → simultaneous extraction?
- Mass sensitivity of 1D distributions (What about 2D distributions?)
  - Dynamical scales → Difference between NNLO and NNLO+NNLL is numerically small





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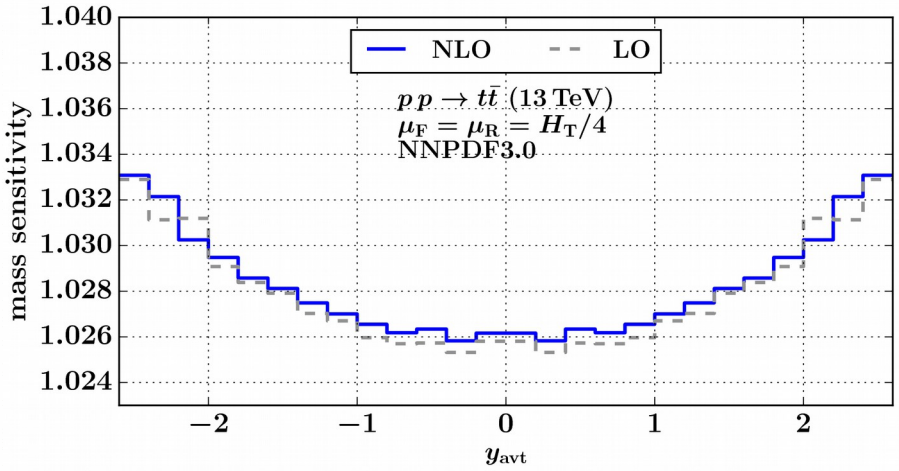

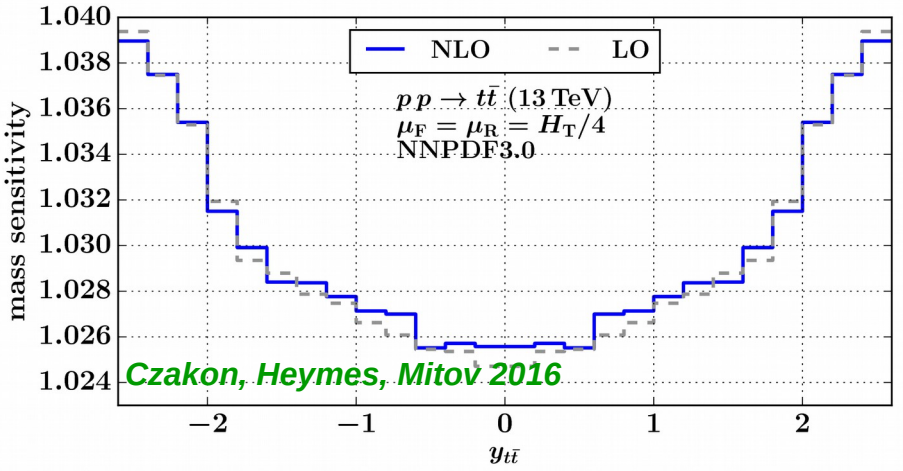

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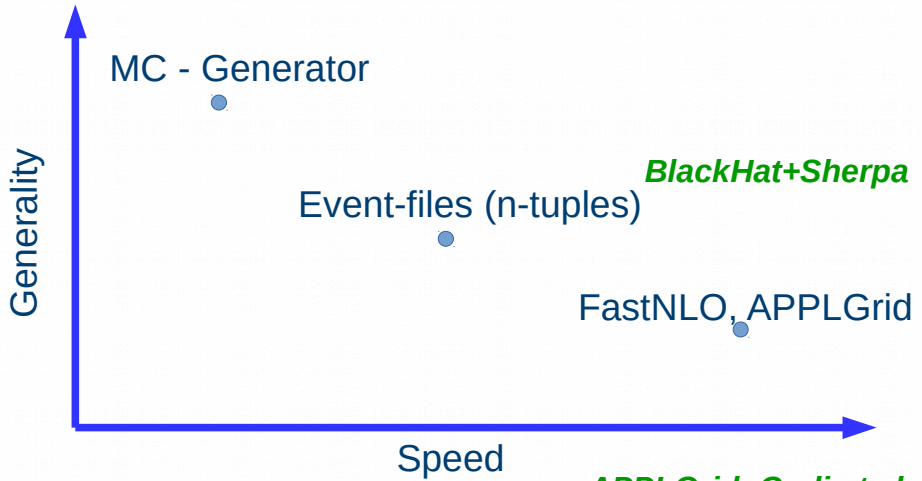
FastNLO tables for top-quark pairs at NNLO

How to store/distribute (N)NLO calculations?

- O(10000) CPU hours for single NNLO calculation
- Observables, scales, masses, E_{cms}, PDFs are fixed once calculation is done
  → More flexible storage format required



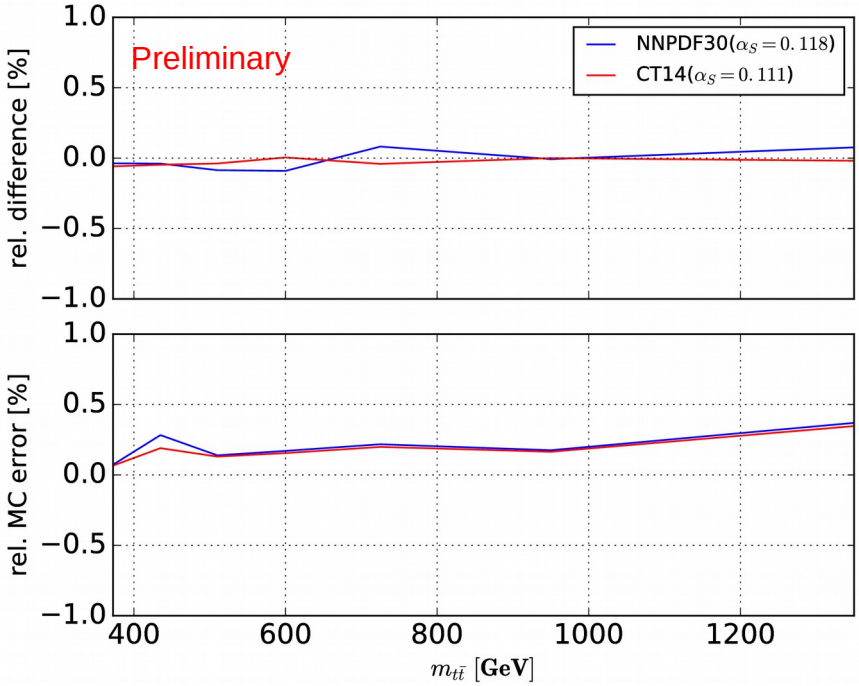
APPLGrid: Carli et al.

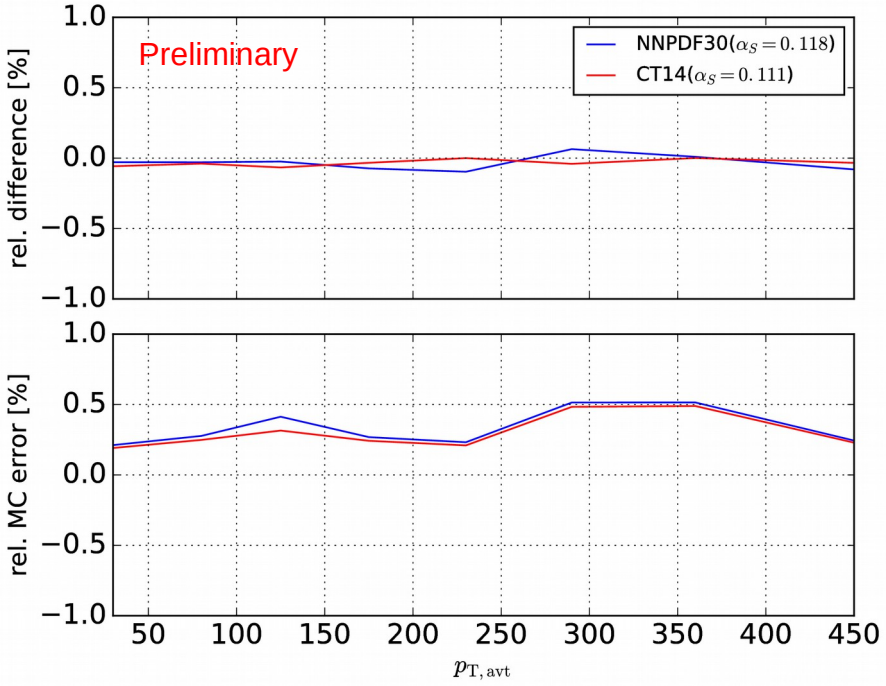
FastNLO: Britzger, Kluge, Rabbertz, Wobisch

- FastNLO interface to NNLO event generator STRIPPER
- PDF and α_s independent storage → fast recalculation of distributions
- Useful for pdf extractions, α_s variation, etc. ***Czakon, Hartland, Mitov, Nocera, Rojo 2016.***
- Example: NNLO predictions for LHC at 8TeV, differential measurement in the lepton+jets channel
  - Tables for the central (dynamical) scale choice and main distributions: m_{tt}, p_{Tavt}, y_{tt}, y_{avt}

FastNLO interface to Stripper at NNLO – Validation 1

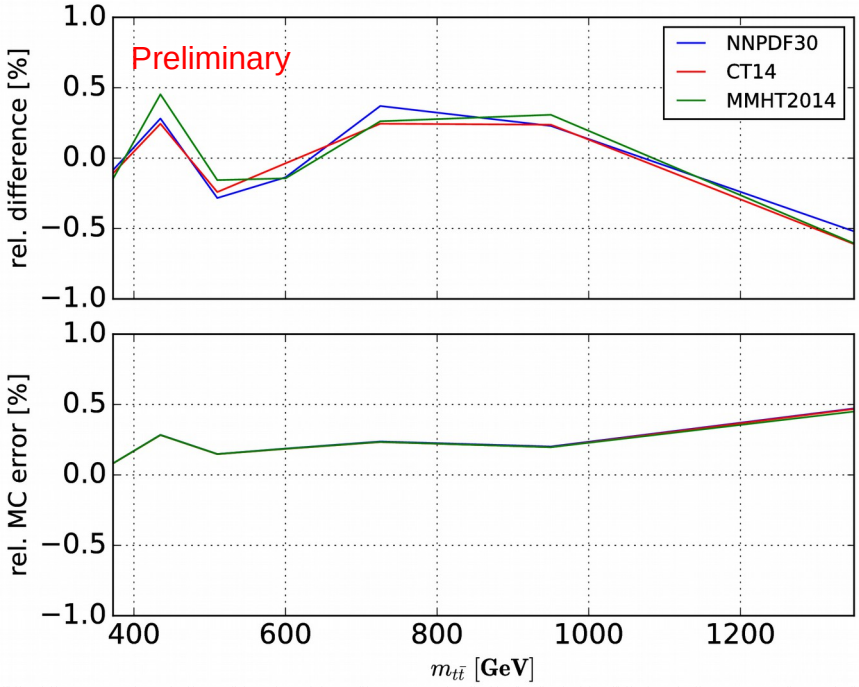
- Accuracy of the fastNLO Interpolation at NNLO
  - Same sample of MC points for direct calculation and filling of the table is used
  - Interpolation error < 0.1 %, much smaller than MC error of NNLO calculation < 0.5 %

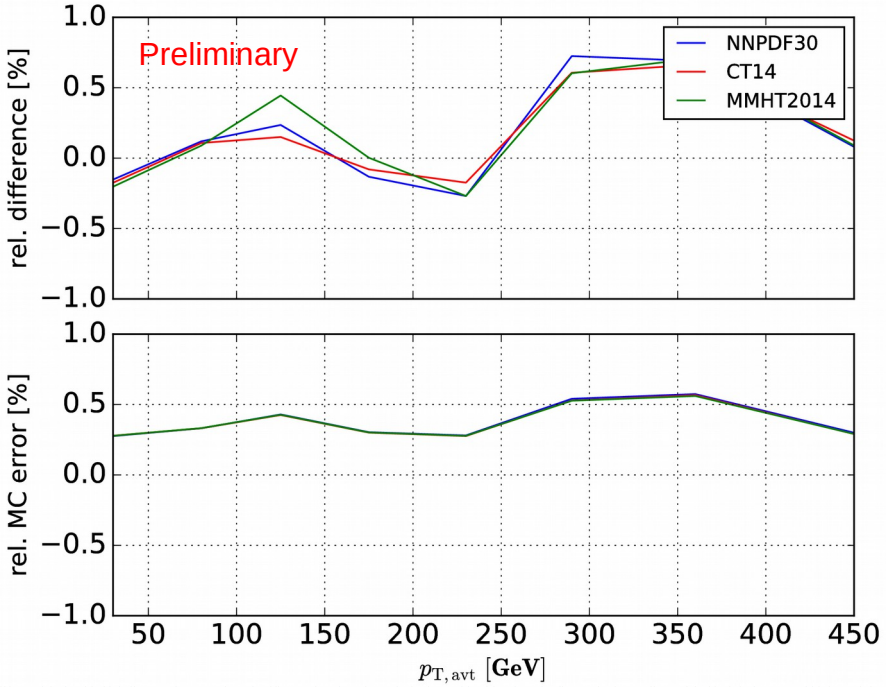




FastNLO interface to Stripper – Validation 2

- Numerical precision of the fastNLO table at NNLO
  - Comparison of an independent direct calculation and results obtained from fastNLO table
  - Statistical uncertainty of NNLO prediction < 0.5 %





Summary and Outlook

- Top pole mass extraction using differential distributions for top-quark pair production at the Tevatron

$$m_{\mathrm{top}}^{\mathrm{pole}} = 169.1 \pm 2.5(\mathrm{tot.})\,[\pm 2.2(\mathrm{exp.}) \pm 0.8(\mathrm{scale}) \pm 1.2(\mathrm{PDF})]\,\mathrm{GeV}$$

  - Uncertainties comparable to other indirect extraction methods (total cross section extraction)
  - Method can be applied at the LHC as well
  - However: Predictions are computational expensive

- FastNLO interfaced to NNLO event generator STRIPPER
  - Pdf independent way of storing NNLO results
  - FastNLO tables for LHC 8TeV top-pair measurements are available

    → pdf extractions, α_s variation, …

- Future: Event files for NNLO results (?), Mass extraction at the LHC