ATLAS EXPERIMENT

Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

Young Scientist Workshop @ Ringberg
July 18th 2014

Top quark mass measurements in the light of full NLO calculations

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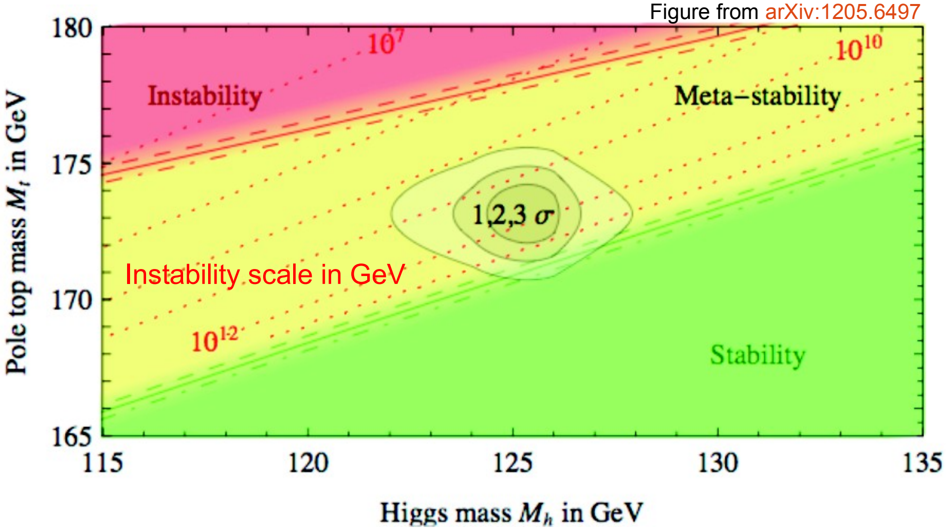
Introduction and overview

- This talk is based on
  - close collaboration between members of
    - the MPP phenomenology group (G. Heinrich, J. Schlenk, J. Winter)
    - the MPP ATLAS SCT group (G. Compostella, G. Cortiana, A. A. Maier, R. Nisius)
  - a top quark mass measurement: ATLAS-CONF-2013-077
  - a top quark production and decay calculation: arXiv:1312.6659v2 (accepted by JHEP)
- This talk's outline
  - Basics 1: The top quark mass and typical observables
  - Basics 2: Full NLO calculation of top quark observables
  - Synthesis: Impact on a top quark mass measurement
  - Summary and outlook

Motivation for top quark physics

- **Top quark mass**
  - relation to W boson mass as an indicator for SM or MSSM Higgs
  - determination of the Higgs quartic coupling and the vacuum stability
  - current world average*:
    $m_{top} = 173.34 \pm 0.27_{stat} \pm 0.71_{syst}\,\mathrm{GeV}$

Figure from arXiv:1205.6497



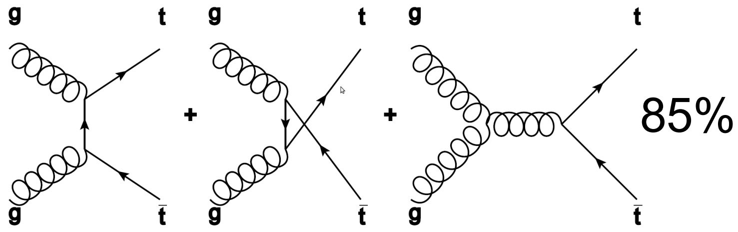
- **Top quark properties**
  - polarization, charge asymmetry, cross-section etc. as handle for physics beyond the SM (FCNC, MSSM etc.)

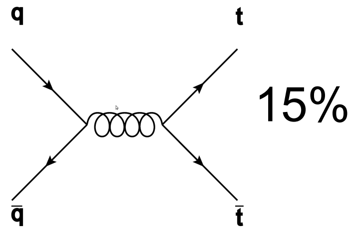
- **Top quark physics**
  - driver for developments in detector calibration and reconstruction performance
  - improvements in MC modeling
  - top quark events are an important background for many physics analyses

*First combination of Tevatron and LHC measurements of the top-quark mass: arXiv:1403.4427

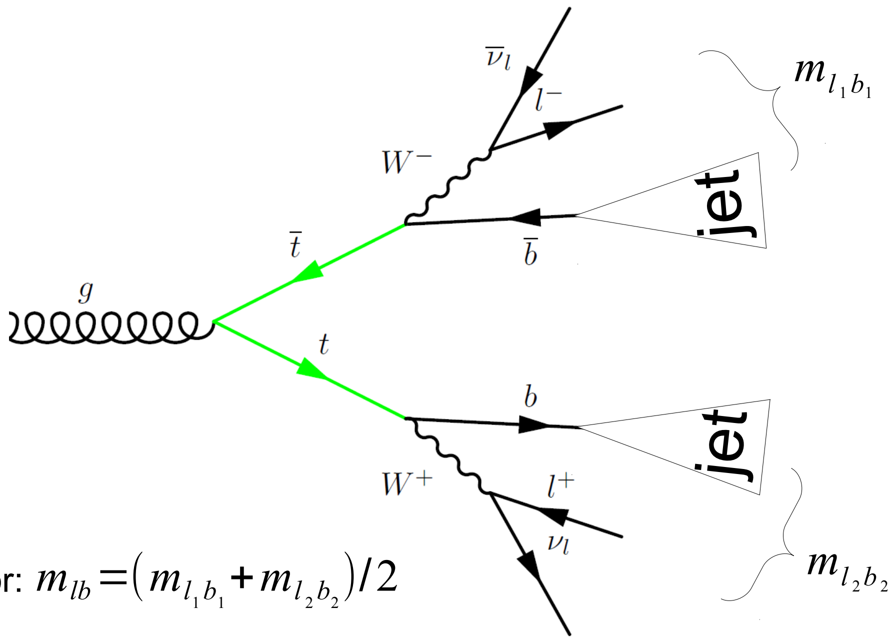
Top quark production and decay

- Focus on $t\,\bar{t}$ production at LHC: $\sigma_{t\bar{t}}(7\ \mathrm{TeV}) = 177\ ^{+10}_{-11}\ \mathrm{pb}$ (total)



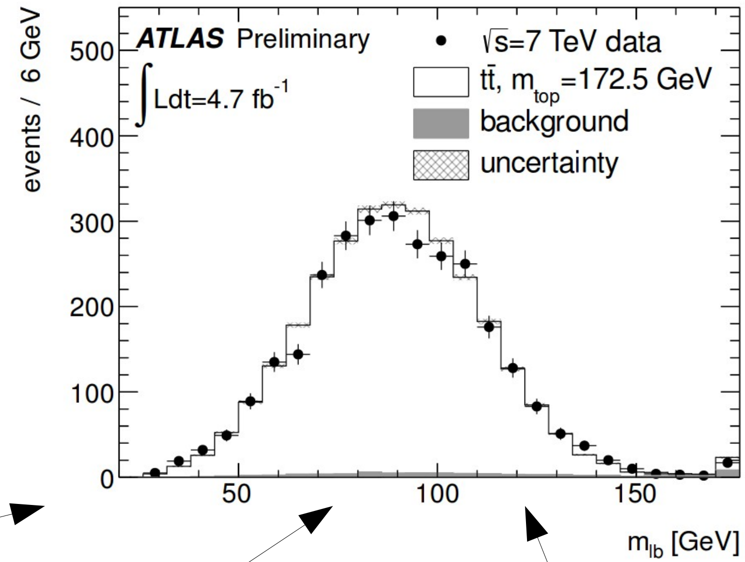


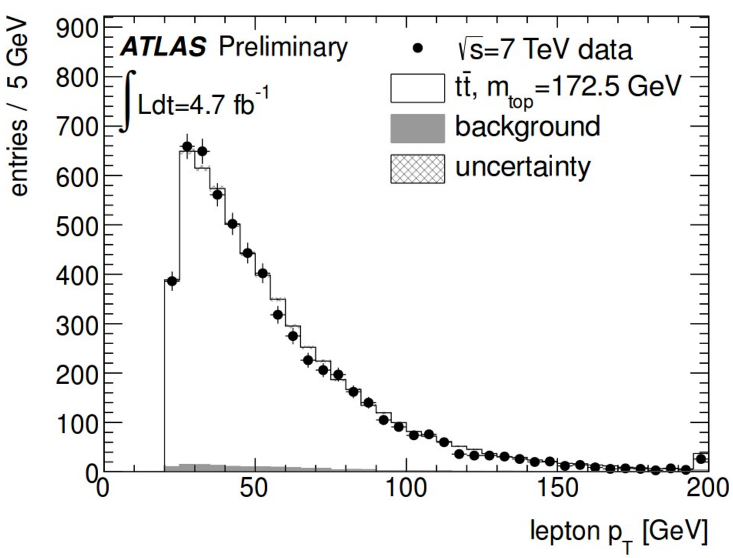
- Focus on the dileptonic decay mode
  - branching ratio of 9%
  - very clean signal
  - simple combinatorics
  - final states: leptons, jets, etc.

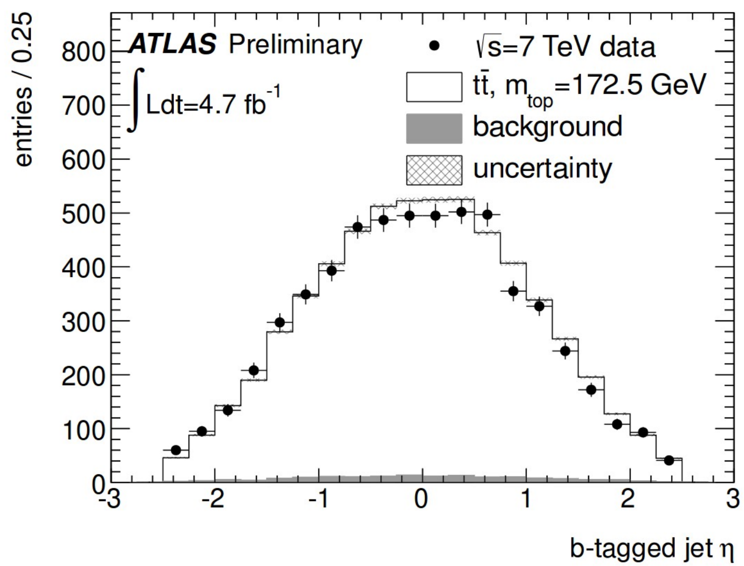


- Here: combine jets with corresponding lepton
  - mass: $m^2_{l_i b_i} = (p_{\text{b-jet i}} + p_{\text{lepton i}})^2$
  - take the average to get a single estimator: $m_{lb} = (m_{l_1 b_1} + m_{l_2 b_2})/2$

- The four-vectors of the particle final states are measured in the detector
- **Direct observables** are per event quantities of a particle like p_T or η*
- From these one can calculate **indirect observables** like masses, polarization etc.
- The figures show a comparison of data (dots) to the prediction (histogram), normalized to data







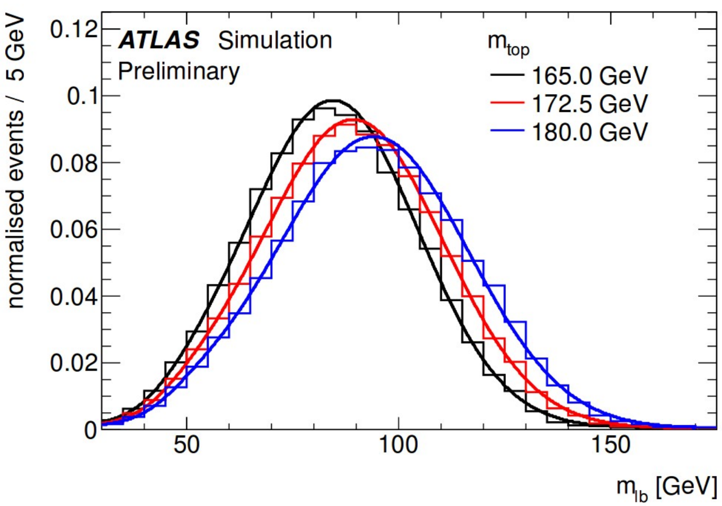
Φ, E etc ...

$^*\eta = -\log \tan \theta/2$

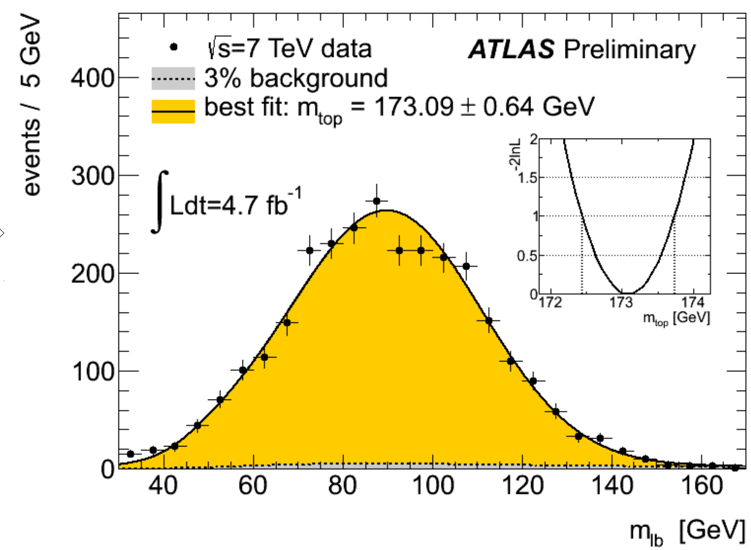
Estimators and the measurement

- In the analysis context, an observable sensitive to the physics parameter of interest is called **estimator**
  - here m_{lb} is used to measure m_{top}
- Estimator distributions (**templates**) can be produced for different assumption of m_{top}
- A fit to the templates determines the parameters of a fit function
- A fit to the data distribution yields the measured value of the top quark mass

Estimator distributions and fit function



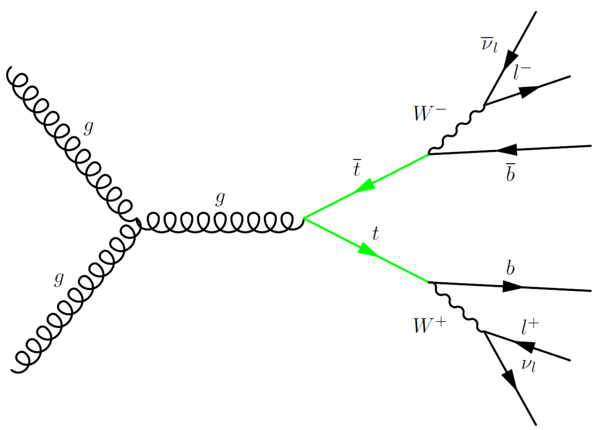
Fit to data



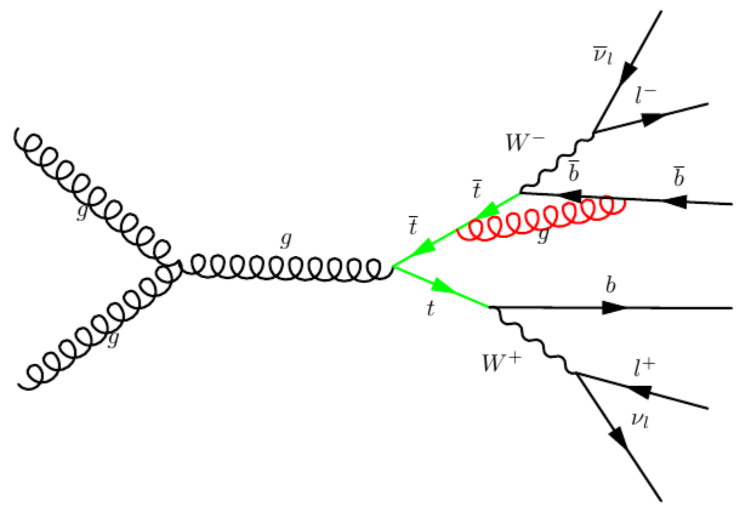
We need simulations

- Calculation of millions of events is necessary for different m_{top} assumptions
- This includes a full simulation of the parton shower and the detector interactions!
  - the following is a **parton level** study, so we neglect these effects today...
- The top quark pair production and decay can be calculated in perturbation theory
- But already the NLO top quark pair decay is so complex, that one has to simplify

Leading Order (LO)



Next to Leading Order (NLO)



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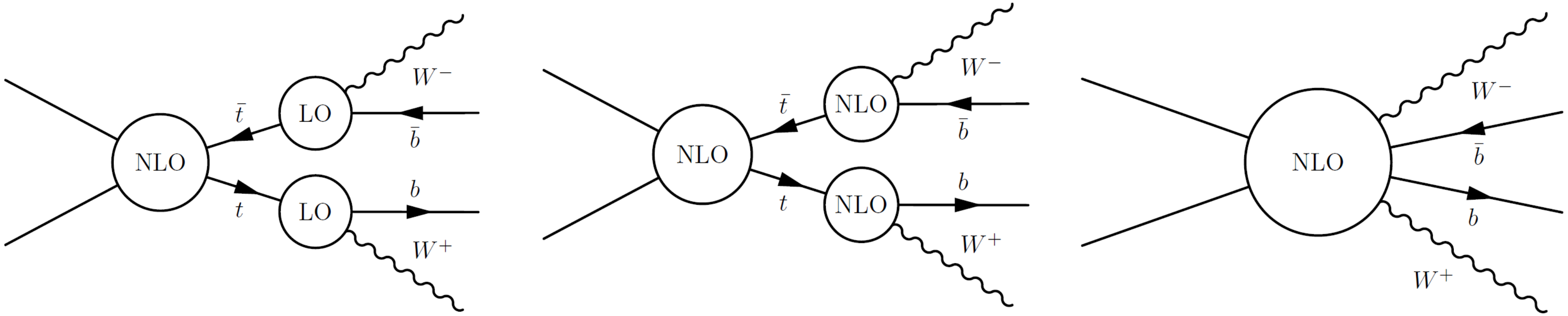


Factorized (tt):

- NLO tt production with LO decays attached
- Standard in MC@NLO, Powheg, MadGraph
- Used for **LHC physics**

Narrow width approximation:

- NLO tt production with NLO decays attached
- Treats top quarks as long lived

Full (WWbb):

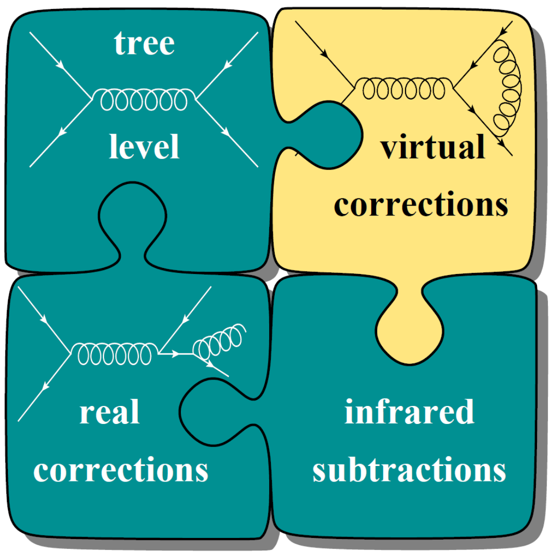
- Full NLO description of the WWbb final state
- This is **NEW***

*first calculated by Denner et al. and Bevilacqua et al.

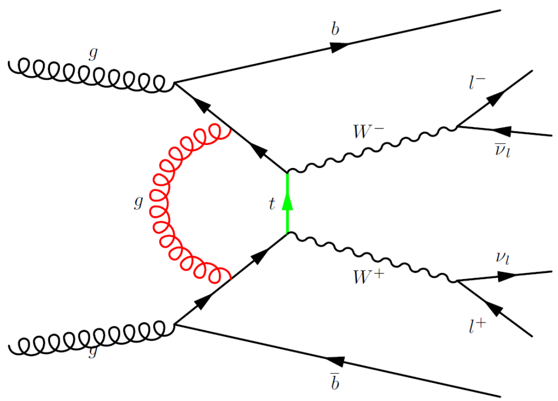
The full NLO WWbb calculation

- GOSAM 2.0: **virtual corrections**
- Sherpa 2.1: **the rest**
- b-quarks are treated as massless
- Includes NLO top quark decays and nonresonant contributions
- W decays at LO, including spin correlations

Parts of a NLO calculation

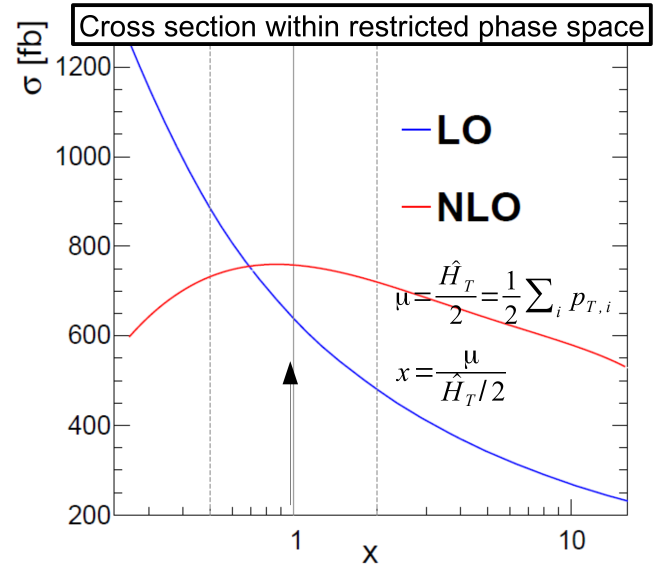


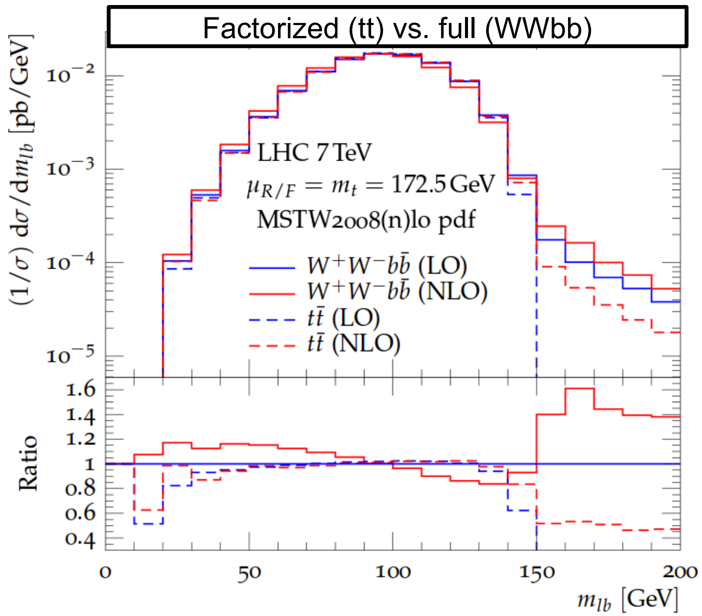
Example of a nonresonnant contribution

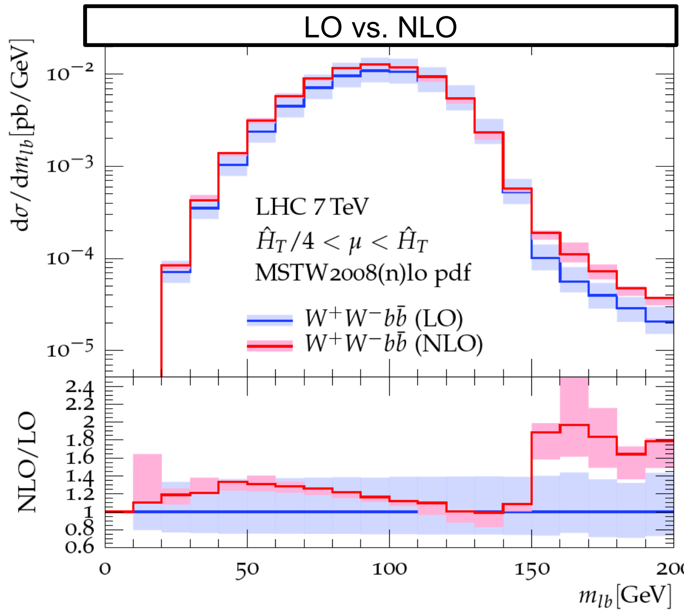


Does it matter anyway?

- Sizable differences in cross section (i.e. normalization)
  - higher orders tend to stabilize the results
  - does not affect this mass measurement
- Sizable shape changes of the estimator distribution
  - this is what the method is sensitive to
  - asymmetric uncertainty bands shift the mass

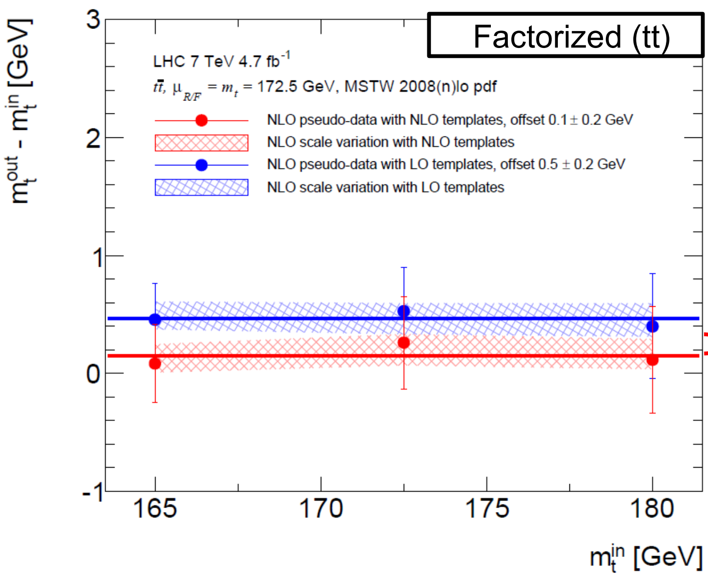




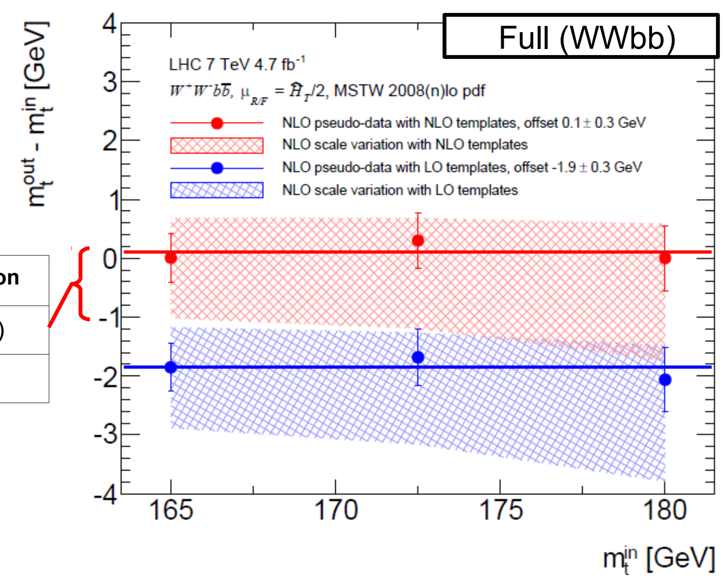


Quantitative implications for m_{top}

- Perform pseudo-experiments
  - calibrate the method to templates taken from NLO or LO simulation
  - measure NLO pseudo-data with or without scale variations for three different m_{top} values
  - do this for both, the factorized and the full approach
- Significant difference in sensitivity to scale variations (red band)
  - caveat: effect at parton level, but parton shower and the detector simulation may well dilute the effect



m_{top} differences due to scale variation	
Factorized (tt)	Full (WWbb)
~0.1 GeV	~1 GeV

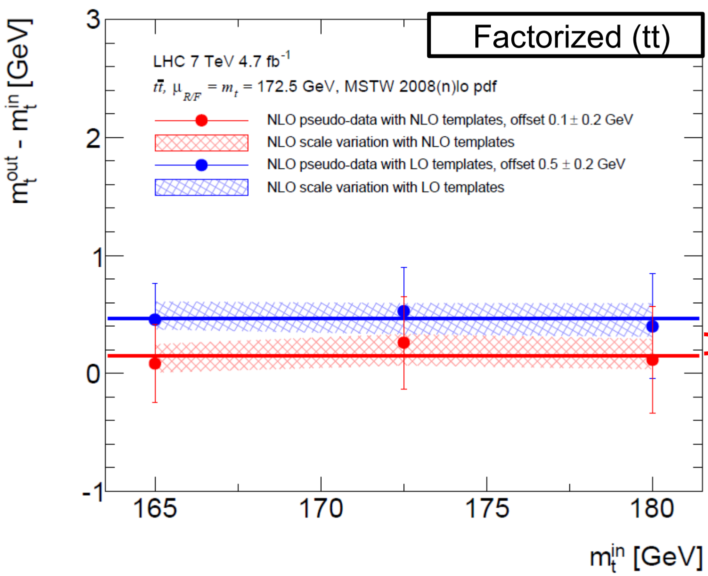


Quantitative implications for m_{top}

- The scale variation is among the many sources of top quark mass uncertainties
  - it has been evaluated with the factorized approach until now!
  - if it persists the parton shower and detector simulation, then the scale variation uncertainty has been significantly underestimated

- At least part of it will be covered by other theoretical uncertainties, e.g. ISR/FSR, CR*
  - they are treated as uncorrelated and may even double count some effects
  - a 1 GeV effect would nevertheless delay the efforts to precisely determine m_{top}

*Initial/Final State Radiation, Color Reconnection



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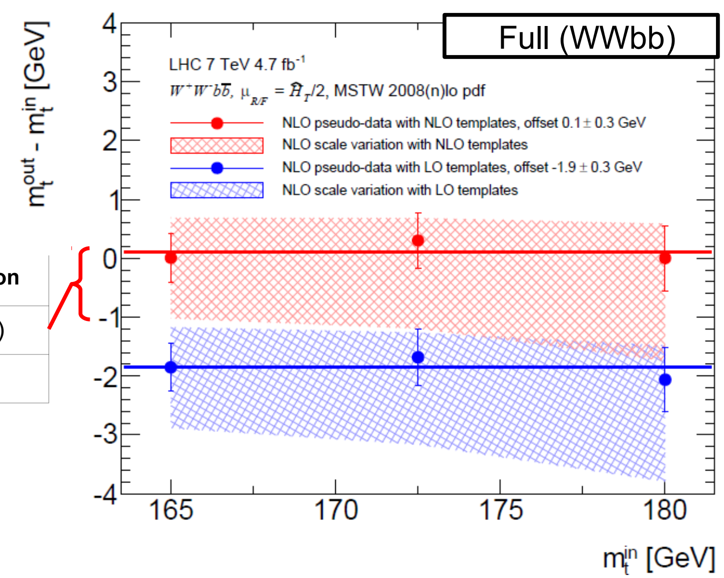

Summary and outlook

- The full NLO production and decay calculation reveals significant differences to previous calculations at parton level
- There are hints for an underestimation of the scale variation uncertainty
- A precision measurement of m_{top} remains a challenge, conceptually, numerically and experimentally

Thank you for your attention!