tt cross section

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On behalf of:

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Total cross-section

If space permits we may add some basic facts for the total cross-section

✓ At a 27 TeV HE-LHC the top-pair production cross-section is very large:

σ_{tot} = $3727^{+119(3.2\%)}_{-180(4.8\%)}$ (scales)$^{+31(0.8\%)}_{-31(0.8\%)}$ (pdf) [pb] (in NNLO QCD)
σ_{tot} = $3794^{+88\ (2.3\%)}_{-142(3.7\%)}$ (scales) [pb] (in NNLO+NNLL QCD)

✓ This is 4x larger than at LHC 14 TeV

σ_{tot} = $962.285^{+23.4(2.4\%)}_{-34.8(3.6\%)}$ (scales) [pb] (NNLO+NNLL QCD)

(the above numbers are for: m_{top}=173.3GeV, NNPDF3.1NNLO)

✓ Composition of the initial state at 27 TeV:

✓ gg = 92% , qqbar = 6% , qg = 2%

✓ Approximately the same composition of the initial state as at 14 TeV:

✓ gg = 90% , qqbar = 9% , qg = 1%

HL LHC

Differential cross-section: CMS

✓ Possible studies:

- 2-dim and 3-dim distributions accessible. However today systematics already dominates in most measurements
- Understand the effect of high pileup

✓ Novel features at HL LHC:

- Significantly increased acceptance (will ensure good overlap with LHCb)

CMS today:
leptons $|\eta| < 2.4$, $p_{\mathrm{T}} > 30\,\mathrm{GeV}$
jets (with b-tagging) $\eta < 2.4$, $p_{\mathrm{T}} > 30\,\mathrm{GeV}$

CMS upgrade:
leptons $|\eta| < 3$, $p_{\mathrm{T}} > 30\,\mathrm{GeV}$
jets (with b-tagging) $|\eta| < 3.8?$, $p_{\mathrm{T}} > 30\,\mathrm{GeV}$

- Expected improvements (w/r to today)
  - **Jet energy scale:** today highest uncertainty is 2–3% (for $|\eta| < 2.4$) $\rightarrow$preliminary recommendations for upgrade 1% for all jets $|\eta| < 3.8$.
  - **Final and initial scale shower:** preliminary recommendations suggests reduction by factor 1/2, same for all theoretical uncertainties including PDFs.
  - **Luminosity** reduction from 2.7% to about 1%.

Differential cross-section: CMS

✓ Proposed studies:

- update selections for upgraded detector
- tests of pileup mitigation (PUPPI jets)
- use projections of systematics

- Parton and particle level analysis similar to recent 13 TeV study CMS-PAS-TOP-17-002
  - Main top 1dim distributions
  - Some 2 dim distributions
- NOTE: way too many distributions are studied there. We don't have the space for all. Need to focus on the kinematic reach for selected distributions and emphasize kinematic reach and expected precision.
- NOTE 2: perhaps it will be useful to compare with LHC 13 and show what is different and what is the same…

Differential cross-section: ATLAS

- ✓ Have not received any specific input from ATLAS. Should we expect one or should we progress based on CMS and LHCb?

Differential cross-section: LHCb

✓ Top measurements from LHCb exist and already public

✓ Main features:

- High rapidity coverage. Useful for constraining PDF
- Overlap in rapidity: opportunity for side-by-side comparisons with ATLAS/CMS

✓ Plans for the YR:

- plan to focus on two final states
  - ℓb - highest statistics, lowest purity (lepton pt > 20 GeV, 2.0 < eta < 4.5, b jet pt > 60 GeV, 2.2 < eta(j) < 4.2)
  - $\mu e b$ - highest purity, lowest statistics (lepton pt > 20 GeV, 2.0 < eta < 4.5, b jet pt > 20 GeV, 2.2 < eta(j) < 4.2)
- also possible that some other final states could contribute, e.g. ℓbb
- currently, a particle level study is foreseen, with reasonable estimates of the detector performance regarding efficiencies, resolution etc...
- will use this to establish the statistical precision with which we can determine the cross-section and asymmetry in the different final states
- the generation of background processes will also be important, particularly to make a precise measurement of the top asymmetry

Differential cross-section: theory

- ✓ No dedicated numbers have so far been run for 14 TeV.
- ✓ Can use extensive existing 13 TeV studies as a proxy.
- ✓ If need be, 14 TeV numbers can be rerun at NLO and then rescaled to NNLO based on 13 TeV. Feedback needed from experiments

- ✓ What can theory do in time for the YR (all numbers for 13 TeV):

  - ✓ Top level:

    - 1-dim distributions with extended kinematics public (NNLO + EW)
    - 2-dim distributions for different values of m_{top} (8 TeV already computed – not yet public) in NNLO

    - EW corrections can be included as needed

  - ✓ Leptons and jets:

    - A factor of 2 improvement in precision for MC generators is reasonable to assume in time for HL-LHC.

- ✓ Top mass has not been investigated as systematics so far, but it is only relevant at small Mtt and PT. Should not be an issue for the boosted regime.

- ✓ α_S is more important in the boosted regime

Differential cross-section: theory

✓ What to present:

- Expected error in selected kinematic distributions (1d and 2d). Distributions and bins should be agreed with experiments.

- No new results at particle level expected in time for the YR. Presumably simply assume factor of x2 for MC generators?

HE LHC

HE LHC: experiment

- ✓ Have not received any specific input from experiments. As far as I know no specific studies are planned. Please let me know if this is not the case.

HE LHC: theory

✓ Various studies (at NLO in QCD and NLO in EW) can be performed in time.

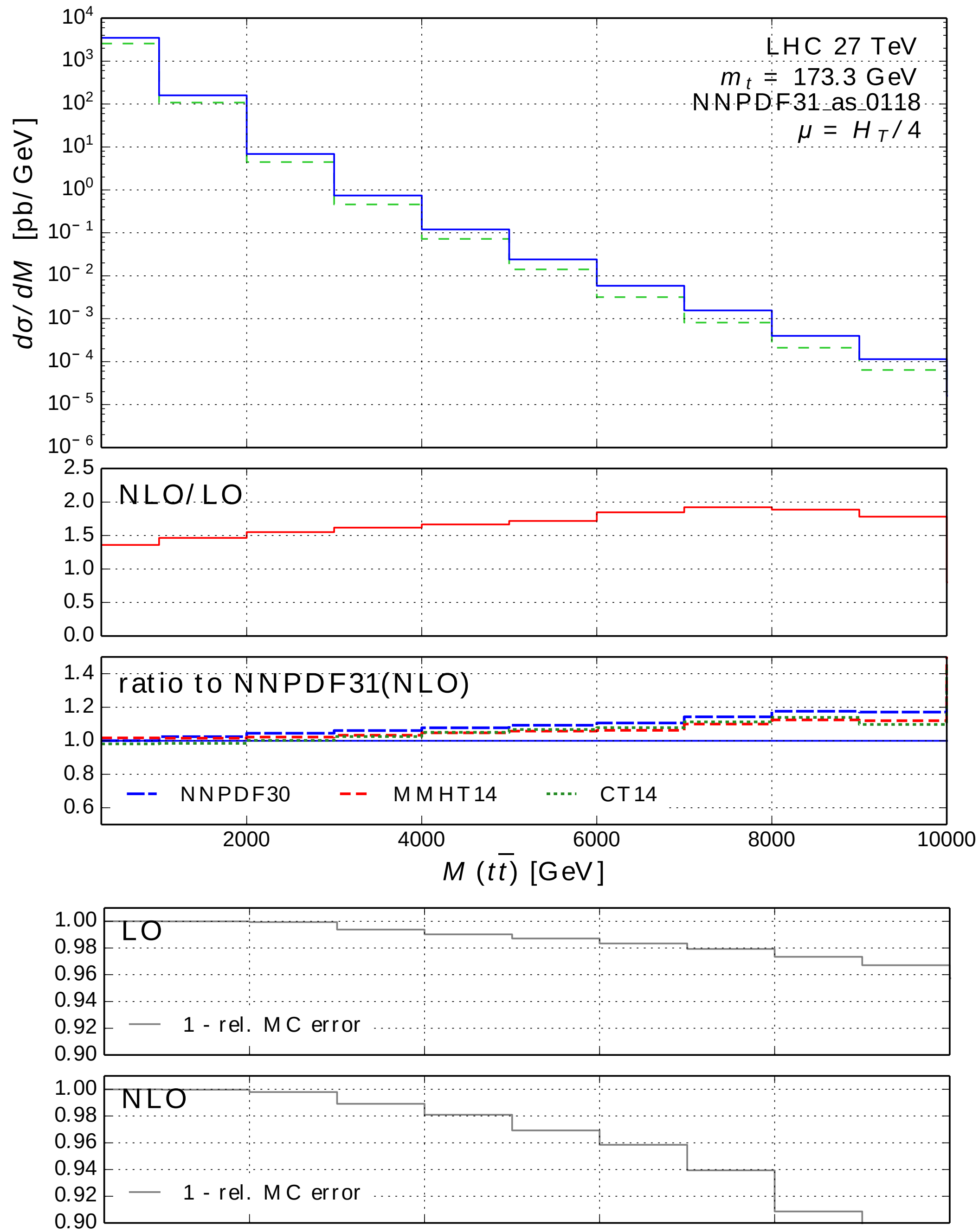
- One can explain what is computable nowadays and speculate what should be possible then.

- Various novel issues, not yet appearing at 13 TeV, can be mentioned.

- Examples of the above are given in the following slides

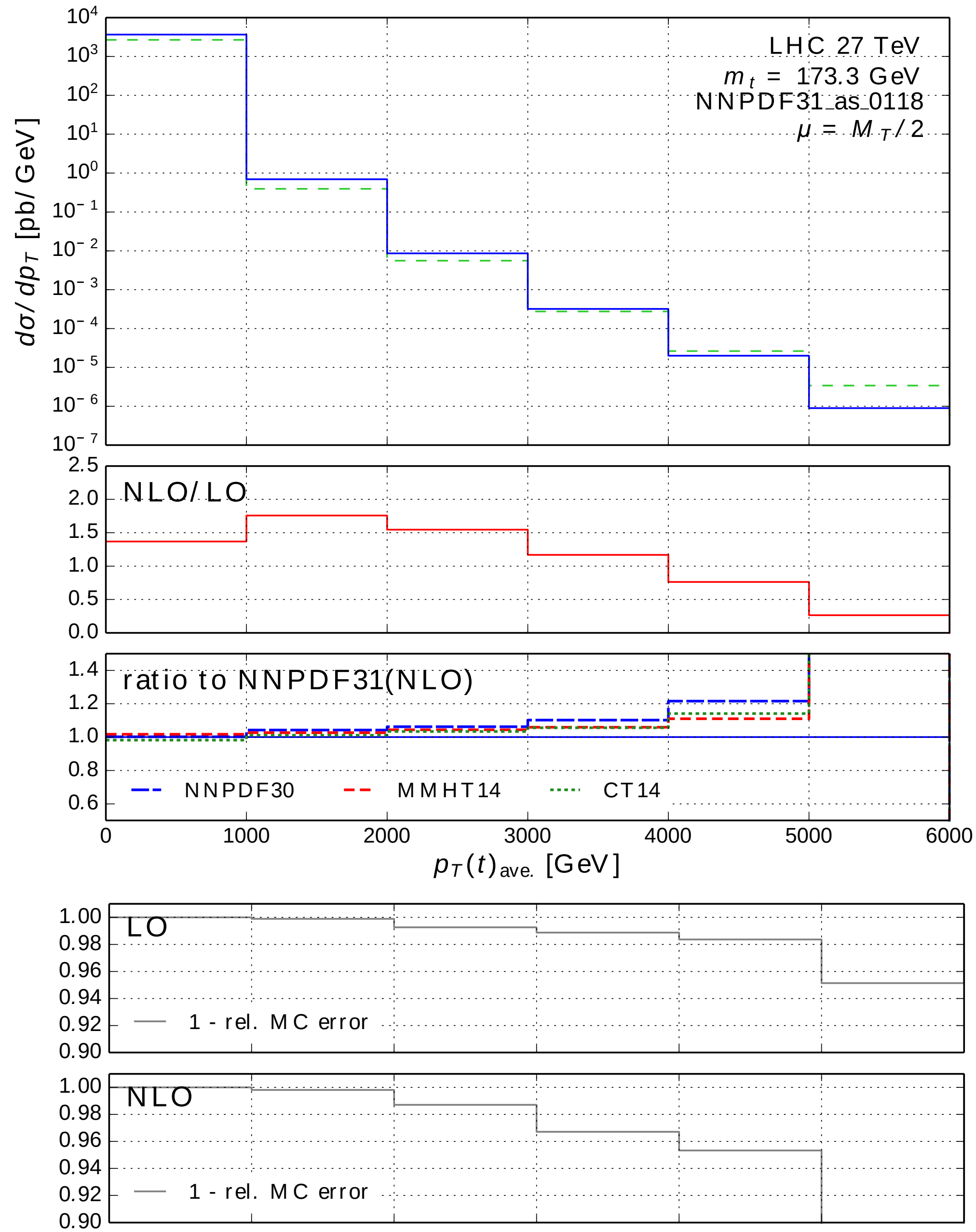
Differential reach in M_{tt}

- ✓ At LHC at 27 TeV very large M_{tt} can be reached
- ✓ Estimates at LO and NLO:
  - ✓ 10% effect in the tails from NNPDF3.1 w/r to older sets
  - ✓ MC error can be handled up to M_{tt}~10TeV
  - ✓ The dynamic scales behave OK (at least) up to 10 TeV
  - ✓ Very modest growth of scale error



Differential reach in P_T

- ✓ At LHC at 27 TeV very large P_T can be reached: up to 6 TeV
- ✓ Estimates at LO and NLO:
  - ✓ Significant difference in the tails from NNPDF3.1 w/r to older sets
  - ✓ MC error can be handled to M_{tt}~6TeV
  - ✓ The dynamic scales behave OK up to (at least) 6 TeV
  - ✓ Scale error is OK



Some novel issues in top production at 27 TeV

Is top massive if P_T is above 3 TeV?

- ✓ 5FS versus 6FS for top production?
- ✓ A new study on heavy flavors and pdfs shows that for factorization scales above 10x the mass a massless scheme is appropriate

  Bertone, Glazov, Mitov, Papanastasiou, Ubiali' 17

- ✓ If we take the factorization scale used here: $\mu_F = m_T/2$, we can conclude that above P_T=3 TeV the top is massless.

  Czakon, Heymes, Mitov '16

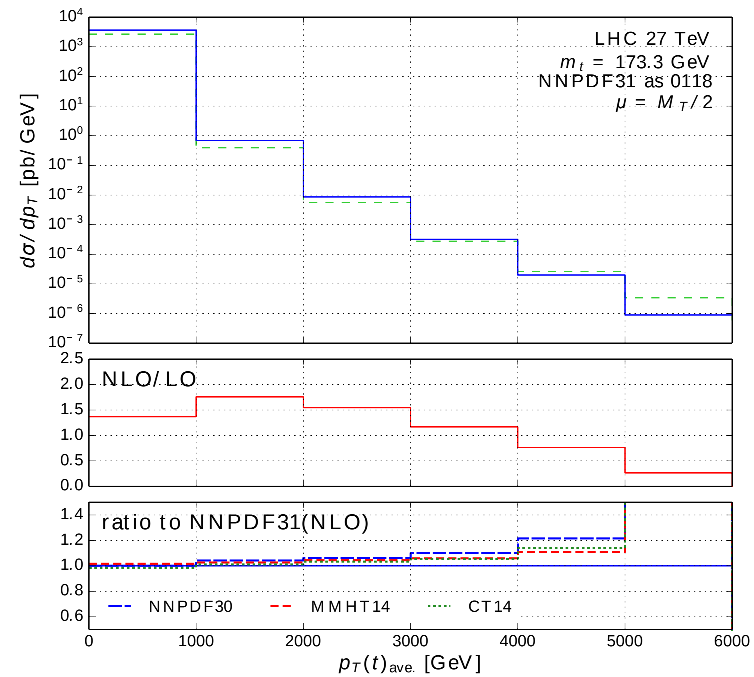
- ✓ To cover P_T as high as 6 TeV one will need:
  - ✓ Top pdf (not a problem – it is purely perturbative)
  - ✓ Well identified tops as studied now are unlikely to be the correct objects to study
    - ✓ Use top jets: can be computed at NNLO with either massive or massless tops. Will be useful in the context of current boosted top analyses.
    - ✓ Calculate with massless identified tops (perturbative fragmentation function). This will be available at NNLO in few years; also needed for b-production.

Are pdf's under control at such a large P_T?

✓ Plot to the right indicates new generation of pdfs have different behavior at large PT

✓ Recall: new LHC data included in NNPDF3.1, in particular top production at 8 TeV

✓ Chances are that by the time HE-LHC starts operations pdfs will be much better than today. Lattice input at large x may also be available then.

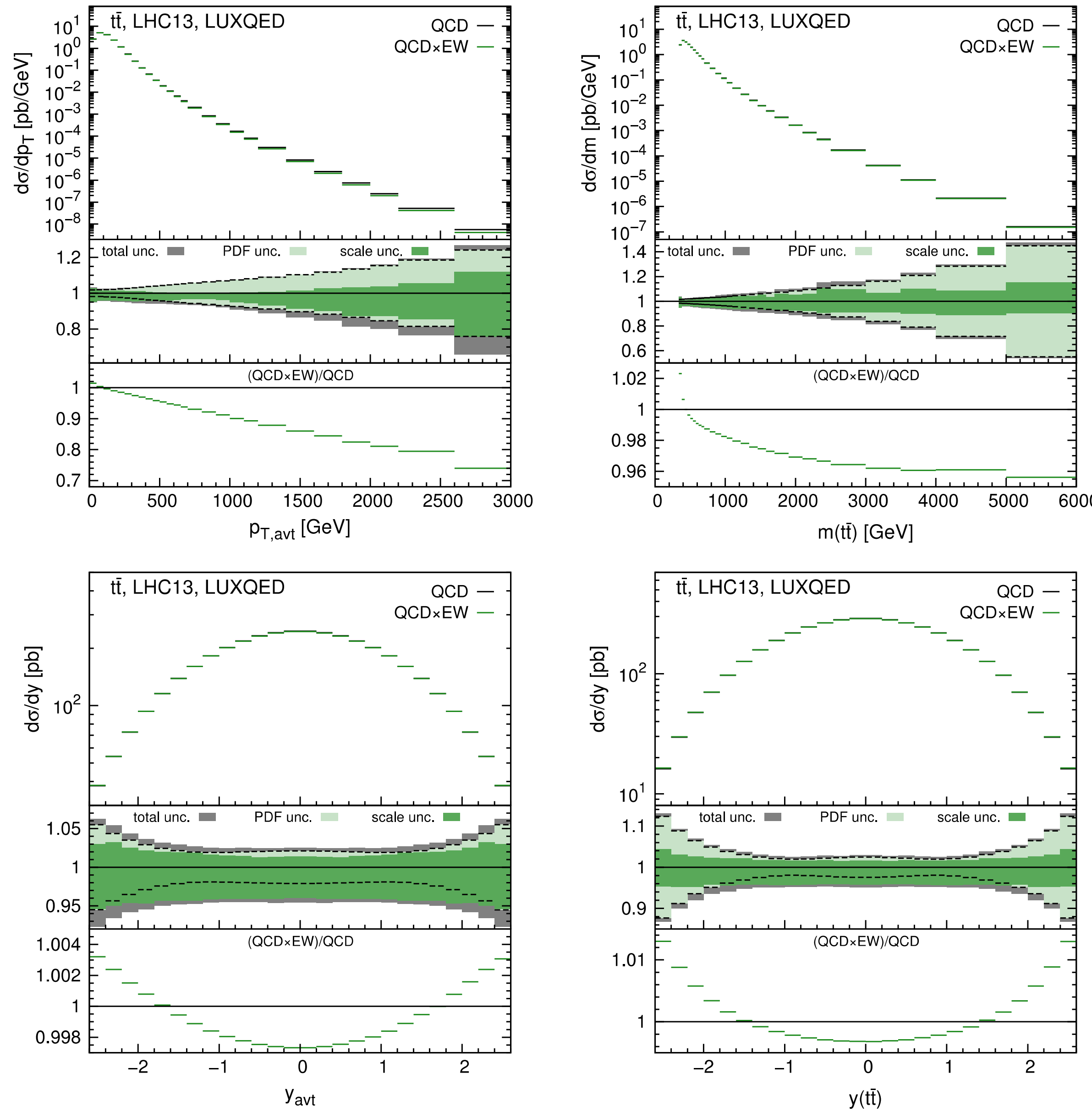


EW corrections

✓ At 27 TeV they will be even more important that at 13 TeV.

✓ From 13 TeV studies one can see that EW corrections in the multi-TeV range are very important

✓ They can be computed and their inclusion should not be a challenge



Czakon, Heymes, Mitov, Pagani, Tsinikos, Zaro 2017

Soft-gluon/small mass resummation

- ✓ An important question will be: how reliable our scale choices are for very large P_T?
- ✓ This question will be addressed in time with data, but one would like to have better theoretical arguments beforehand
- ✓ Using resummation is one way to probe the dynamics at such scales.

Czakon, Ferroglia, Heymes, Mitov, Pecjak, Scott, Wang, Yang ‘18

- ✓ We find that for the dynamic scale choices used today the resummation adds very little on top of the NNLO QCD. Therefore, reliable predictions for Mtt.
- ✓ Improvement from resummation on PT distribution, especially at large PT, is small.
- ✓ It will be good to have FONLL predictions for 27 TeV. Working with the authors; if numbers become available in time for the YR they will be included.