Differential $t\bar{t}$ cross sections in the $\ell$+jets channels at CMS and the HL-LHC

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HL-LHC projection for differential $t\bar{t}$ cross sections measurements with resolved $e/\mu$+jets events.

- HL-LHC will produce 240M $t\bar{t} \rightarrow e/\mu$+jets events per 1 ab$^{-1}$.
  - Almost unlimited statistics in the bulk of kinematic distributions allow for double- or even triple-differential measurements, finer binning, and measurements in low populated corners of the phase-space.
- Already today most of the measurements are dominated by systematic uncertainties.
- Several low populated phase-space regions (high $p_T(t)$ and $M(t\bar{t})$) not accessible in resolved analyses.

Plans:

- Provide projections for measurements of standard 1D distributions $p_T(t)$, $y(t)$, $M(t\bar{t})$ ...
- 2D distributions $M(t\bar{t})$ vs. $y(t\bar{t})$ and make projection for PDF constraints (Oleksandr Zenaiev)

Assuming at least one 1D example and PDF constraints can go into the YR (two pages?).
Selection Phase II (today):

- exactly 1 e/µ: |η| < 2.8 (|η| < 2.4), \( p_T > 30 \text{ GeV} \), veto with \( p_T > 15 \text{ GeV} \)
- 4 jets, with 2 b tagged: \( \eta < 3.0 \) (|η| < 2.4), \( p_T > 30 \text{ GeV} \)

→ Improved acceptance in important forward region (e.g., for PDFs).
→ Reduces uncertainties in theory based extrapolation into full phase-space.
Analysis based on CMS-TOP-17-002 (arXiv:1803.08856)

- Successfully ran the analysis on HL-LHC full simulation MC with pileup of 200 (3M events):
  - switched to PUPPI jets and $p_T^{\text{miss}}$. (Run2 charged hadron subtracted jets not working, about 100 jets per event)
  - reconstruction algorithm successfully working. However, resolution of reconstructed top quarks slightly worse than in Run2.

- Successfully ran the analysis on HL-LHC Delphes simulation with pileup of 200 (50M events):
  - spent some time to convert Delphes output into analysis framework format.
  - resolutions of top quarks kinematics in reasonable agreement between full simulation and Delphes.
  - unfolding is working (tested with skewed spectra). Use CMS-TOP-17-002 binning with extended $\eta$/rapidity ranges.

*MC production and conversion from Delphes were hopefully the biggest obstacles – CMS internal document in preparation.*
Experimental improvements (preliminary!):

- **Jet energy scale**: today dominant uncertainty 2–3% (for $|\eta| < 2.4$), PhaseII 1% for all jets $|\eta| < 3.0$.
- **b-tagging**: ?
- **Luminosity** reduction from about 2.5% to 1%.
Theory improvements:

- parton shower modeling (shower scales, tune ... ). Has direct impact on unfolding.
  - better experimental constraints (from orthogonal measurements).
  - improved PS models.
- precision of PDFs and hard process affects mostly extrapolations. Matching with PS and full event needed for unfolding.
  - improved PDF constraints.
  - NNLO QCD+NLO EW, NNLO+NNLL’ (JHEP05(2018)149) in QCD available, but no in event generation.

*Suggested was an assumed improvement by a factor 2.*

Proposal:

- Experimental: reweight/scale MC according to PhaseII uncertainties and unfold central MC to obtain cross sections uncertainties.
- Theory: take uncertainties evaluated in CMS-TOP-17-002 scaled by 1(0.5) and plot two error-bands conservative(optimistic).
LHCb offers unique opportunity to measure top quark production in the forward region
- Higher contribution from quark-initiated production
- Access to larger values of Bjorken-x

Lack of missing energy measurement means measurements are performed at lepton/jet level only

Low acceptance makes partial reconstruction of final state attractive
- Require from two to four final state particles in acceptance

Three measurements performed in Runs 1-II, in mub, lbb, and mueb final states
- All measurements currently statistically limited

Extra statistics available at HL-LHC will allow precision top physics measurements at LHCb
Four final states considered
- $l^b$ - lepton and a b-jet (measured in Run 1)
- $lbb$ - lepton plus two b-jets (measured in Run 1)
- $mueb$ - muon, electron and b-jet (measured in Run II)
- $muebb$ - muon, electron and two b-jets

Fiducial Region:
- Leptons: $p_T > 20$ GeV, $2.0 < \eta < 4.5$
- B-jets: $p_T > 20$ (60) GeV, $2.2 < \eta < 4.2$
EVENT YIELD

- Expected yield extrapolated from existed measurements and NLO predictions
  - Improvements in selection and tagging efficiency assumed
- Sub-percent statistical precision in lepton+jets channel, percent level in di-lepton channels
  - Can make two-dimensional cross-section measurements to test predictions in new region and constrain gluon PDF at high-x
PLANS FOR YELLOW REPORT

- Develop optimized binning for cross-section measurements
  - Exploit overlap with ATLAS/CMS as they extend coverage forward
- Estimate systematic uncertainties achievable with upgraded LHCb detector