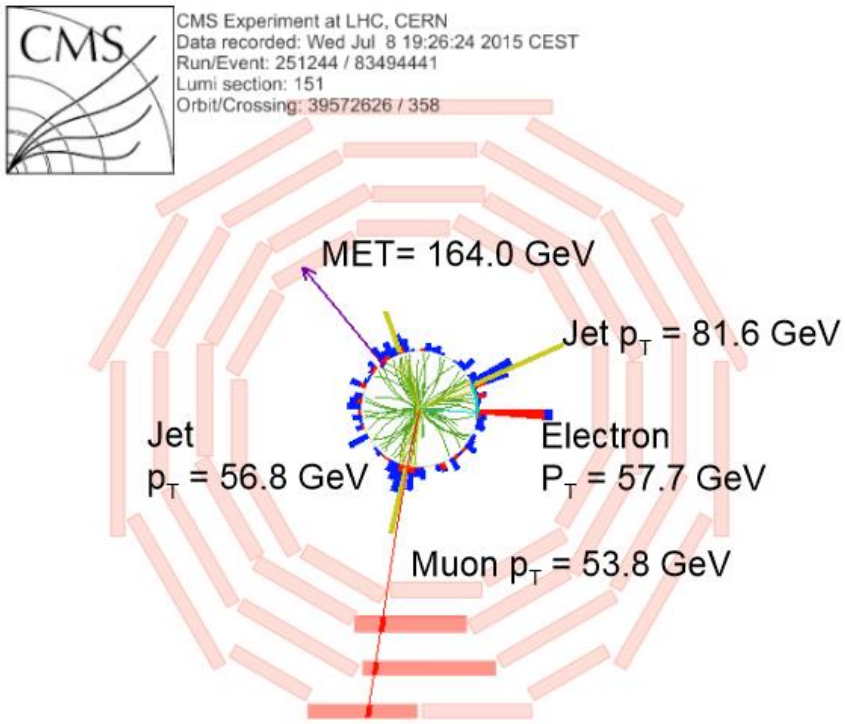
CMS measurements of top quark pair production



Till Arndt for the CMS Collaboration

EPS-HEP 2017

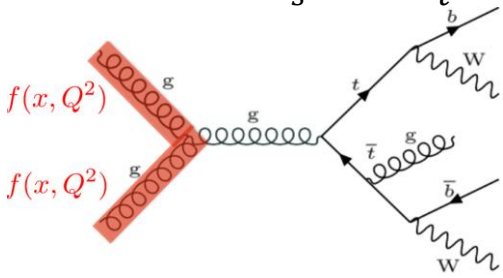
Venice, 07.07.2017

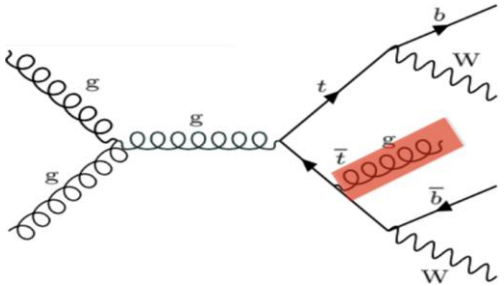
HELMHOLTZ ASSOCIATION

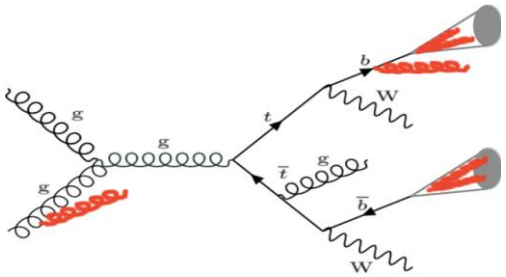
DESY

Introduction

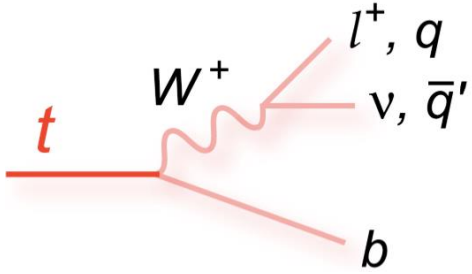
- Why is measuring top quark pair production important ?
  - Constrain gluon PDF (dominantly produced through gluon-gluon fusion)
  - Extract α_s and M_t
  - Probe QCD at higher order
  - Modelling of parton shower and hadronization





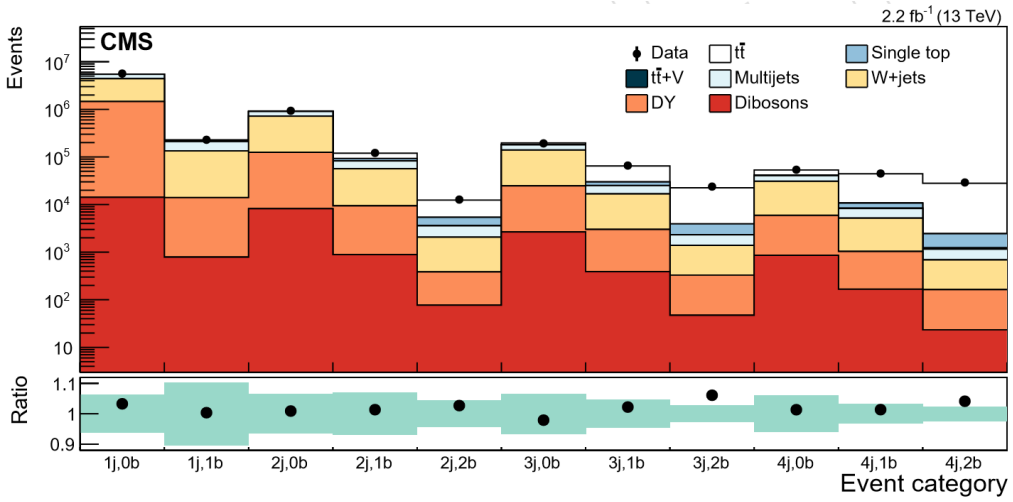


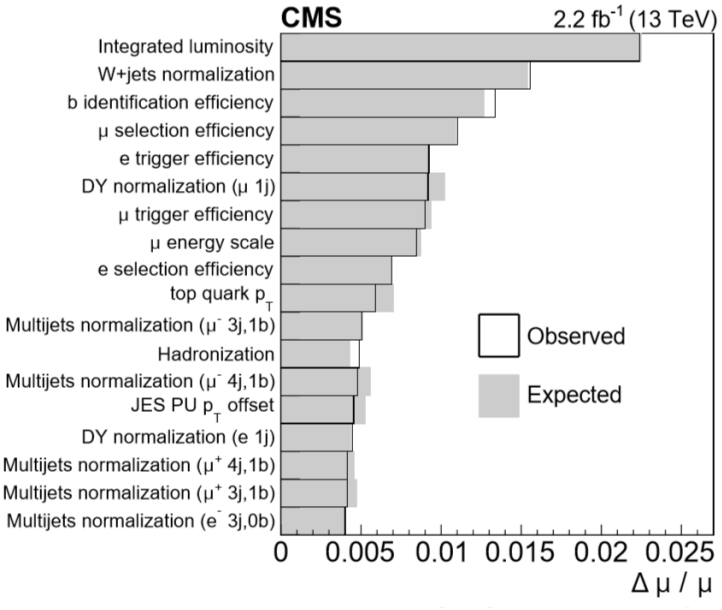
- Top quark decays separated by the w-boson decay
  - All jets: High branching ratio, low S/B
  - L+jets: moderate branching ratio, good S/B
  - Di-lepton: low branching ratio, best S/B



Inclusive $\sigma_{t\bar{t}}$ in the l+jets channel at 13 TeV

arxiv 1701.06228
Submitted to JHEP





- Cross section extraction with a profile likelihood fit
  - $M_{l,b}$ or $\min(M_{l,b})$ in 44 lepton flavors and charges, b-tagged jet and n-jets multiplicity
  - Dedicated nuisances for rate and shape effects
- Updated results with new central luminosity

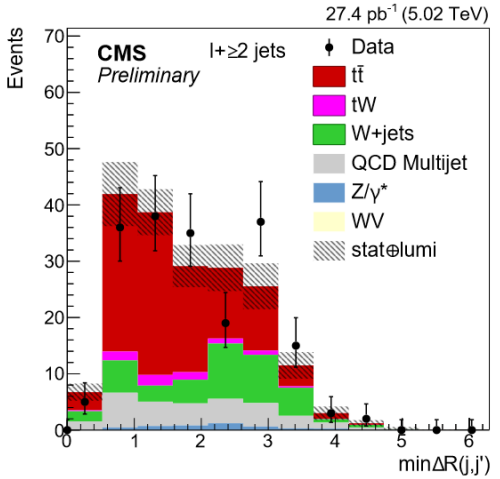
$\sigma_{NNLO} = 832^{+40}_{-46}$ pb (PRL 110 (2013), 252004)
$\sigma_{t\bar{t}} = 888 \pm 2(\text{stat.}) \pm 28(\text{syst.}) \pm 20\ (\text{lumi})$ pb

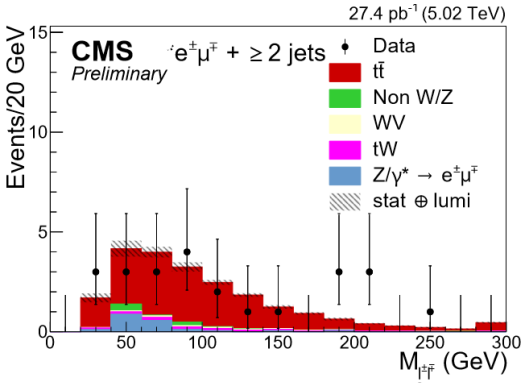
Inclusive $\sigma_{t\bar{t}}$ at 5.02 TeV

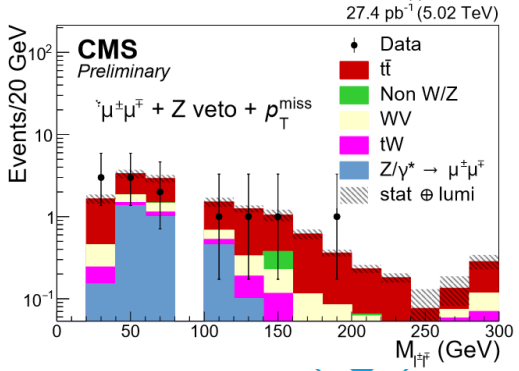
CMS-TOP-PAS-16-023

- Combination of l+jets and di-lepton channel with a luminosity of $27.4\ \mathrm{pb}^{-1}$
- l+jets: Cross section extraction with a profile likelihood fit
  - min $\Delta R(j, j')$ in 3 categories of b-tagged jets
  - Dominant systematics: Scale, W+jets background
- di-lepton channel: Cross section extraction through cut & count
- Uncertainties statistically dominated
- Modest impacts on PDFs due to high stat. uncert.

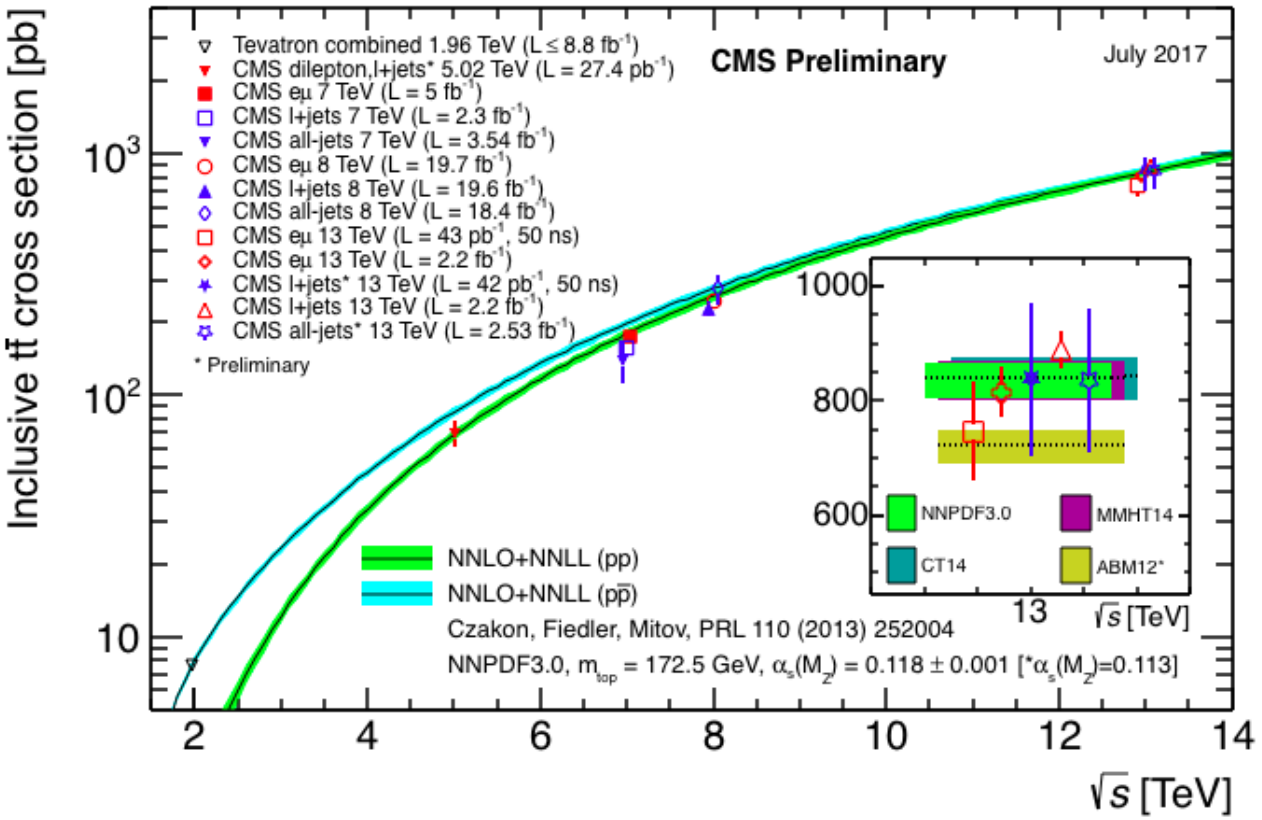
$\sigma_{\mathrm{NNLO}} = 68.9^{+3.3}_{-3.4}\ \mathrm{pb}$ (PRL 110 (2013), 252004)
$\sigma_{t\bar{t}}(\mathrm{comb}) = 69.5 \pm 6.1(\mathrm{stat}) \pm 5.6(\mathrm{syst}) \pm 1.6(\mathrm{lumi})\ \mathrm{pb}$







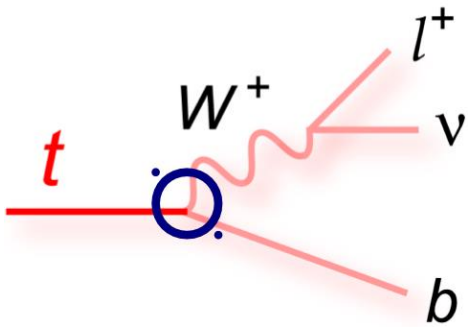
Summary of inclusive $\sigma_{t\bar{t}}$ measurements



> Agreement over a large range of center of mass energies

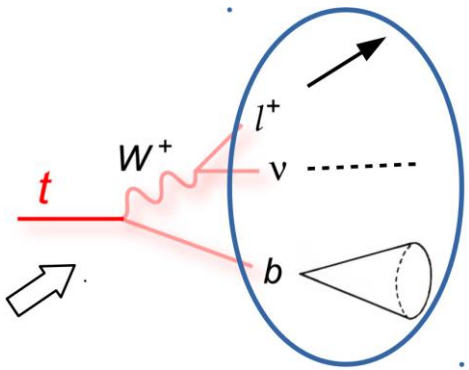
Differential measurements of $\sigma_{t\bar{t}}$

- $\sigma_{t\bar{t}}$ measured in bins
  - Unfolding algorithms correct for acceptance and efficiency
- Defined with respect to $t\bar{t}$ signal:
  Parton level (full phase space)
  - After QCD radiation and before decay
  - Mimics definitions of bare quark widely used in fixed order theory calculations
  - Used for extraction of SM parameters



Particle Level (fiducial phase space, CMS-NOTE-17-004)

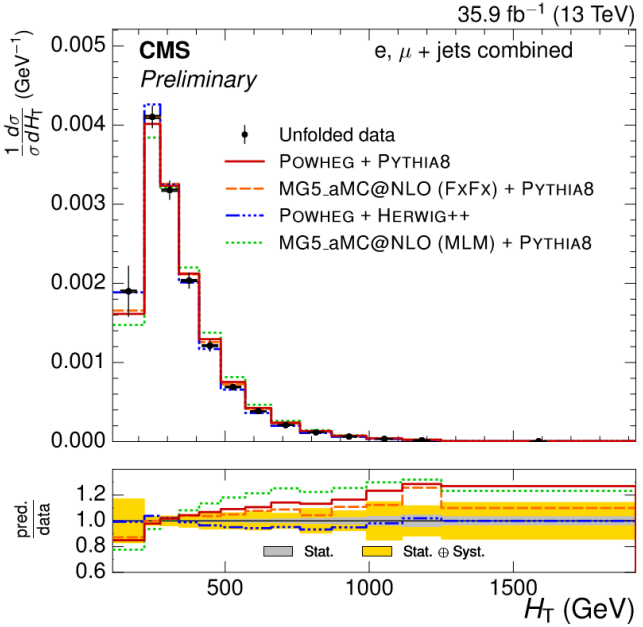
- Based on stable particle after hadronization
- Fiducial phase space defined according to detector level cuts
- Reduced effect from extrapolation
- Used for MC tuning and test of BSM models

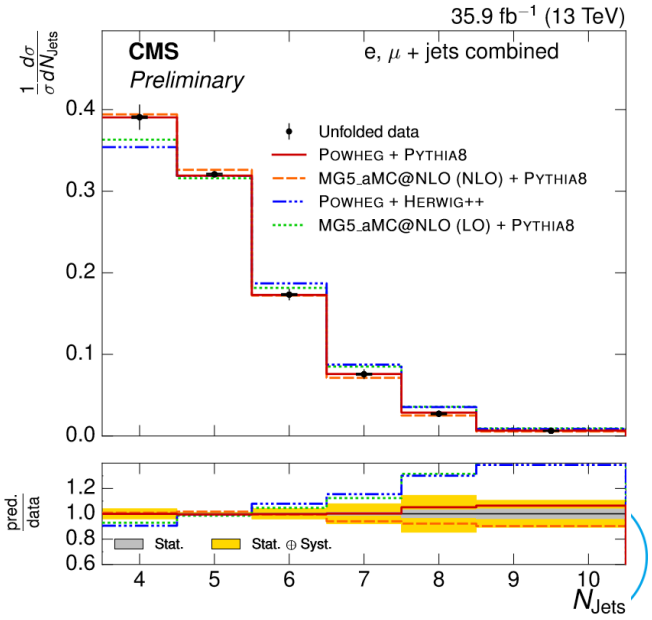


Differential $\sigma_{t\bar{t}}$ for global event variables in the single lepton channel with 2016 data

CMS-TOP-PAS-16-014

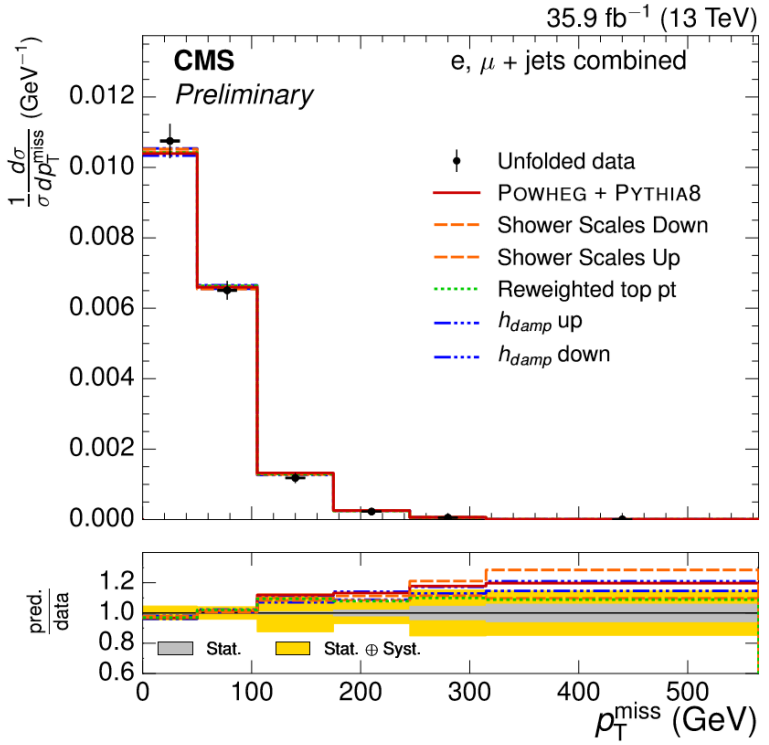
- New measurement using full 2016 data
  - Luminosity $35.9\ \mathrm{fb}^{-1}$
- Global event variables
  - No need to reconstruct $t\bar{t}$
  - Particle level
- Normalised differential $\sigma_{t\bar{t}}$
  - Compared to MC predictions
- Dominant uncerts:
  - $t\bar{t}$ modelling,Jet energy scale





Differential $\sigma_{t\bar{t}}$ for global event variables in the single lepton channel with 2016 data

- Compared to MC predictions for different parameters for matrix element and parton shower
  - Can be used to tune these parameters
- Overall good agreement between data and predictions

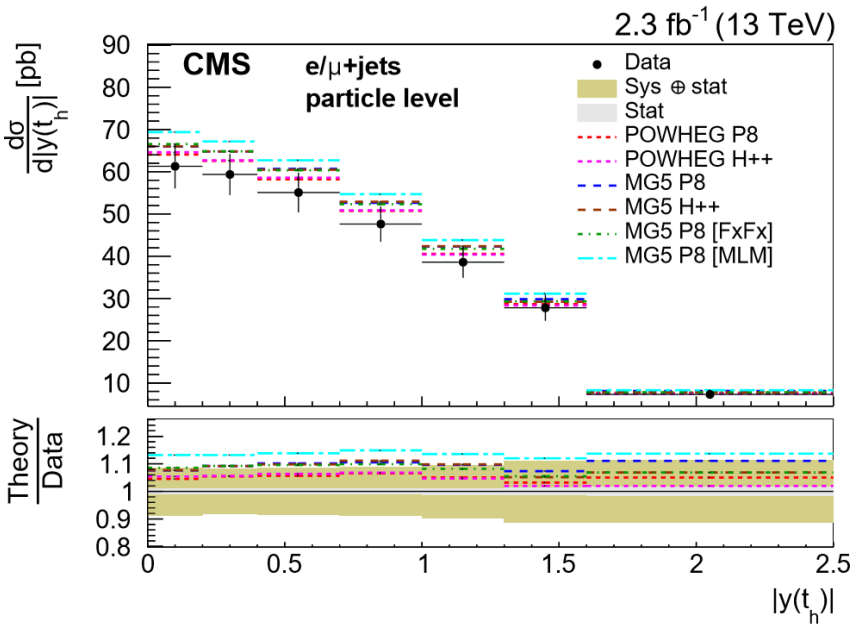


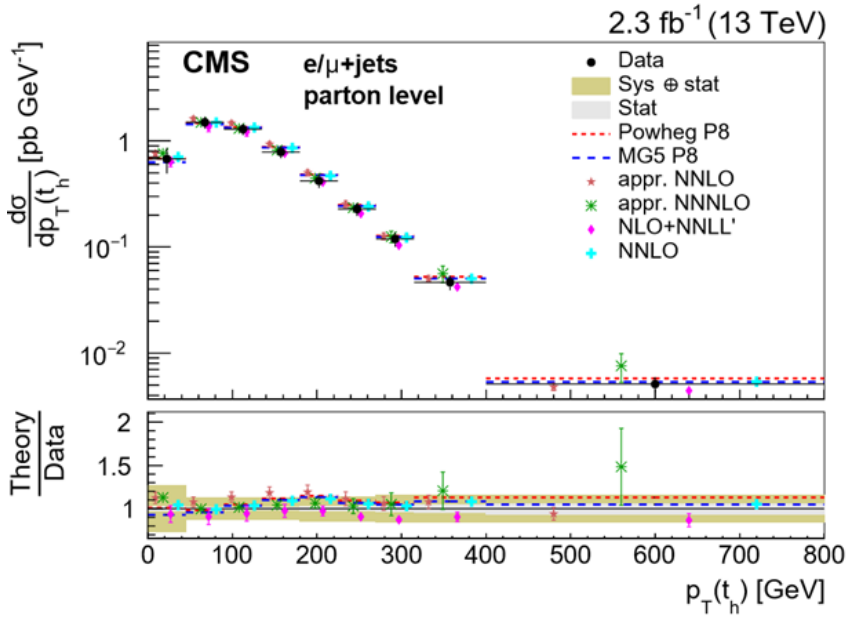
	POWHEG + PYTHIA8		POWHEG + PYTHIA8 including simulation theory uncertainties	
	χ^2 / ndf	p-value	χ^2 / ndf	p-value
N_{Jets}	2.5 / 6	0.87	2.4 / 6	0.88
p_T^W	10 / 7	0.19	6.6 / 7	0.48
p_T^l	36 / 17	< 0.01	16 / 17	0.49
H_T	35 / 13	< 0.01	8.2 / 13	0.83
S_T	26 / 13	0.015	10 / 13	0.7
p_T^{miss}	7.2 / 6	0.3	4.7 / 6	0.58
All	116.7 / 62	< 0.01	47.9 / 62	0.91

Differential $\sigma_{t\bar{t}}$ in the single-lepton channel

arxiv 1610.04191
PRD(DX11697)

- Absolute differential $\sigma_{t\bar{t}}$
  - Compared to both MC predictions and fixed order calculations
- Dominant uncerts:
  - Parton level:
    MC modelling, hadronization
  - Particle level:
    Jet energy scale, PS scale
- Generally compatible within uncertainties
  - Measured $p_T(t)$ softer than predictions

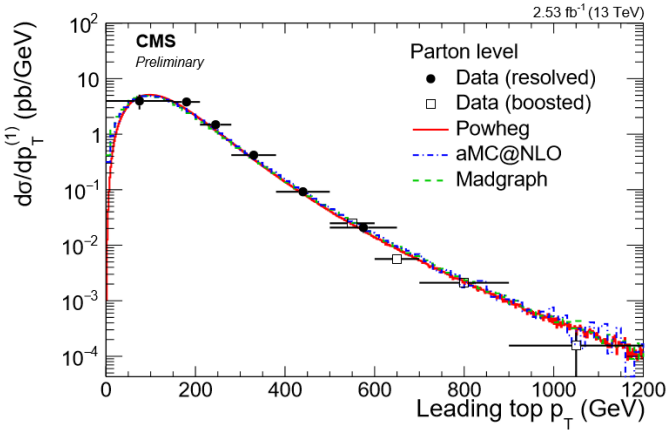


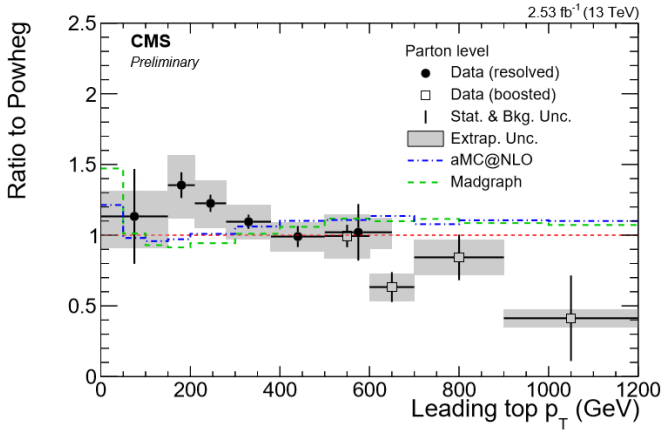


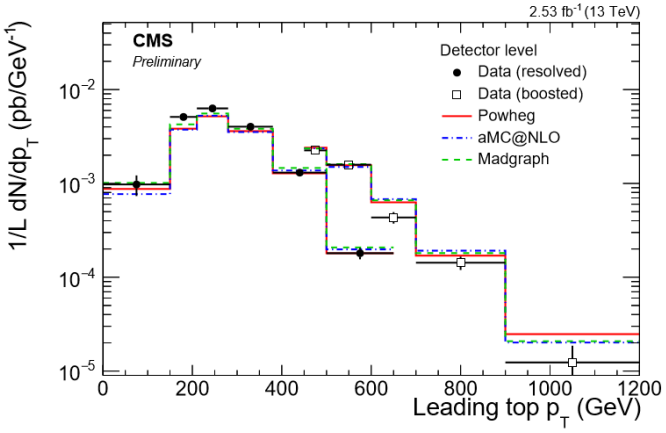
Differential $\sigma_{t\bar{t}}$ in the all jets channel

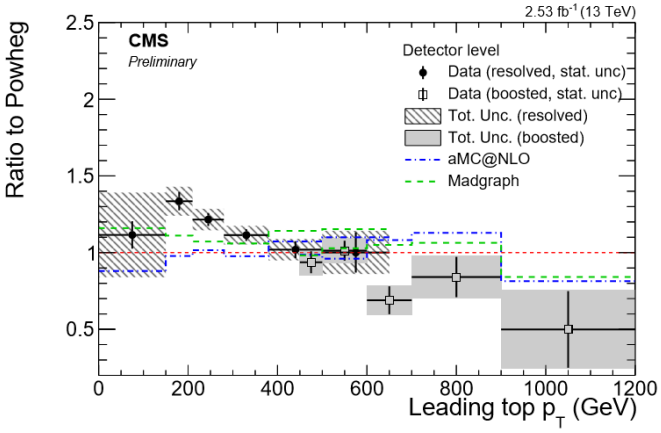
CMS-TOP-PAS-16-013

- Absolute diff. $\sigma_{t\bar{t}}$
- Boosted and resolved regime
- Dominant uncerts:
  - Resolved: Jet energy scale, b-tagging
  - Boosted: b-tagging, MC modelling
- Measured $p_T(t)$ spectrum softer than predictions



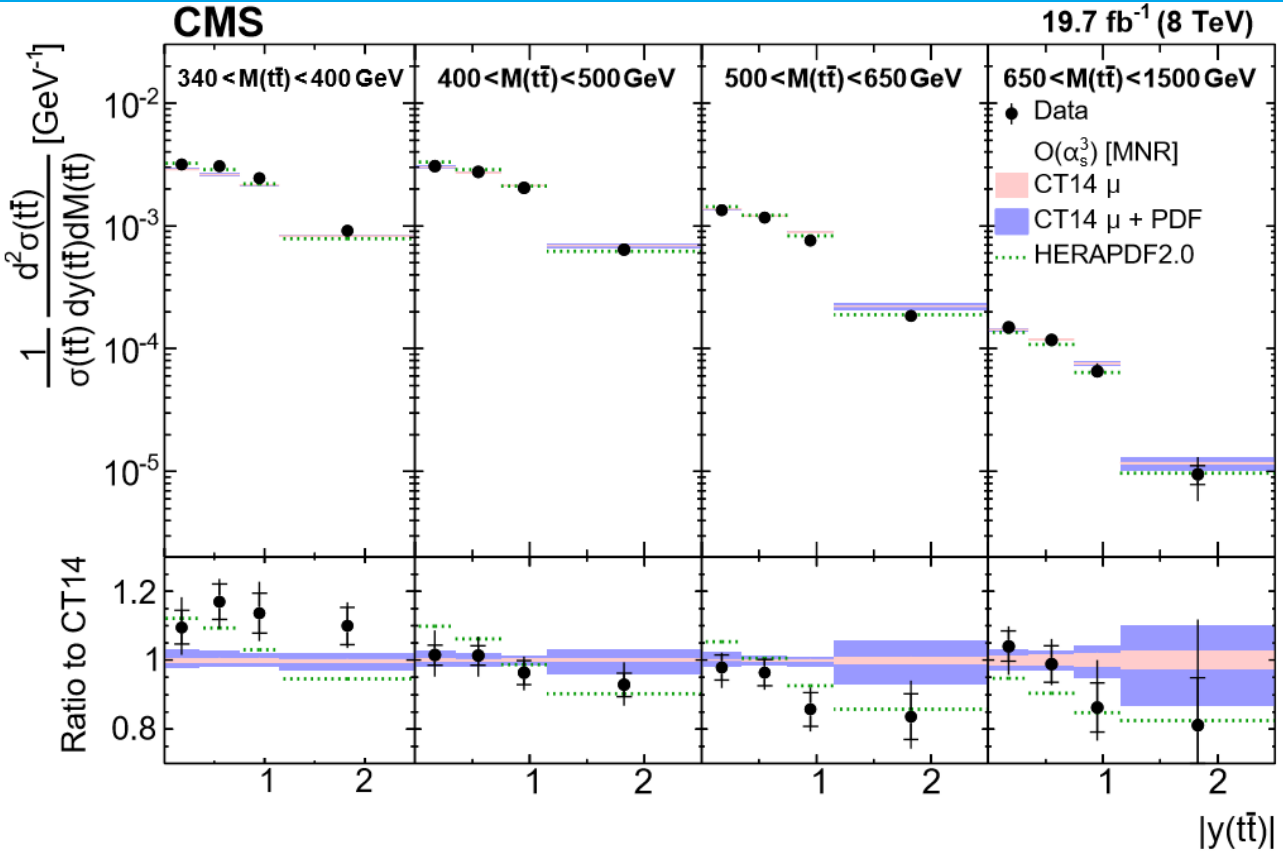






Double differential cross section at 8 TeV (di-lepton channel)

arxiv 1703.01630
submitted to EPJC



- First measurement of this type at LHC
  - Many distributions as functions of $t\bar{t}$ variables
- See dedicated talk on PDF extraction in the QCD session (17:15)

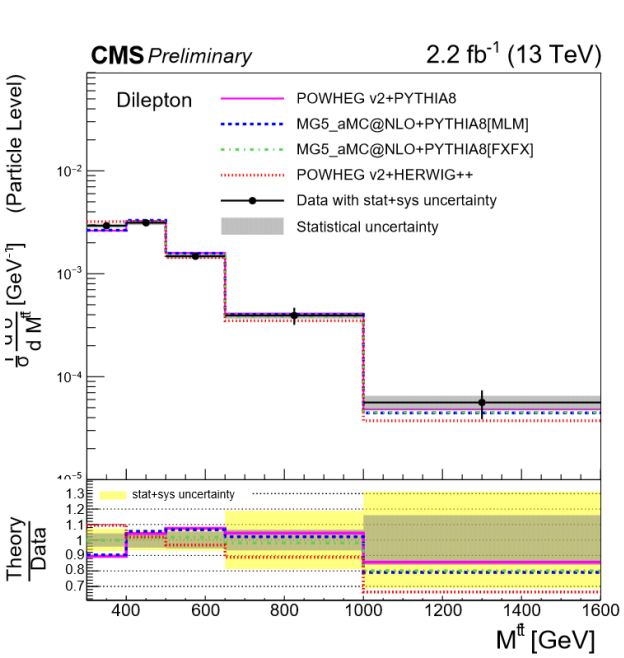
Conclusions

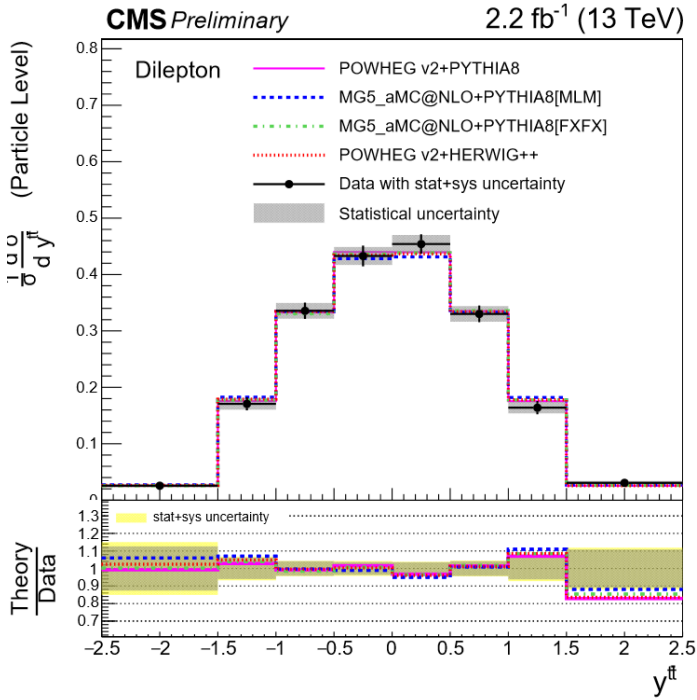
- Top cross sections are measured in a wide range of studies at CMS
  - Inclusive: Agreement with predictions over a broad spectrum of energies
  - Differential: Overall agreement between measurement and predictions
  - Double differential: Agreement between data and predictions, significant reduction in uncertainties when included in PDF fits
- Overall the measurements are in good agreement with SM NNLO+NNLL predictions
  - Most measurements are systematically dominated
  - Higher precision to further improve knowledge on SM
- Current results use $2.3\ \mathrm{fb}^{-1}$ of data from 2015, stay tuned for 2016 results with ~ $36\ \mathrm{fb}^{-1}$

BACKUP

Differential $\sigma_{t\bar{t}}$ in the di-lepton channel

- Normalized to inclusive $\sigma_{t\bar{t}}$
  - Compared to both MC predictions and fixed order calculations
- Particle level
- Dominant uncerts:
  - MC modelling, backgrounds

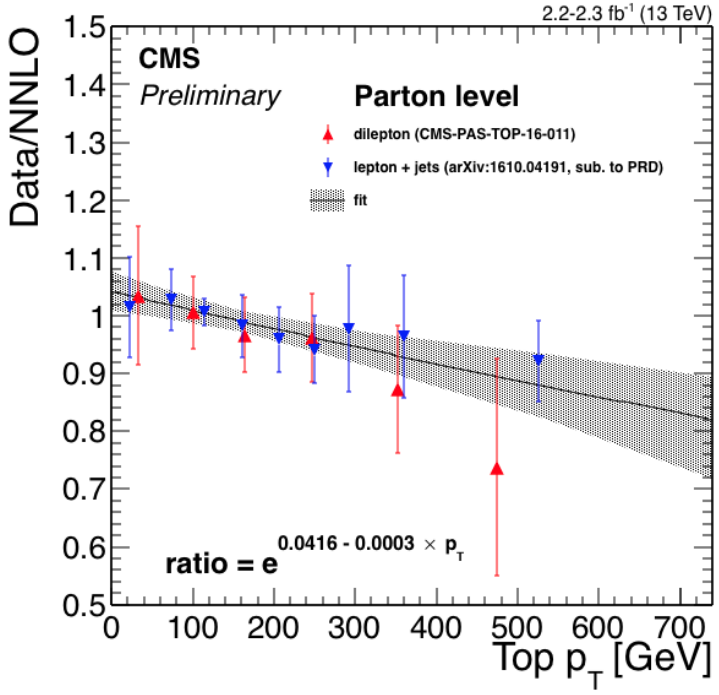


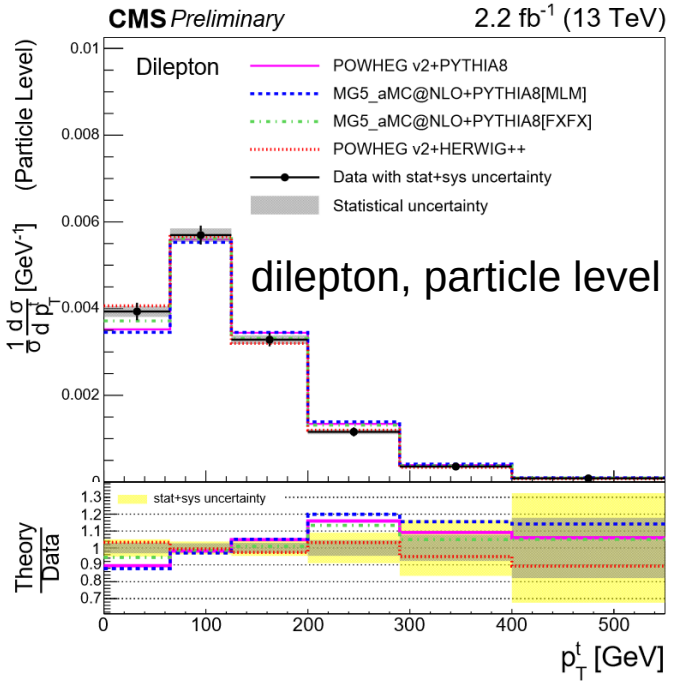


Fairly good agreement between data and prediction

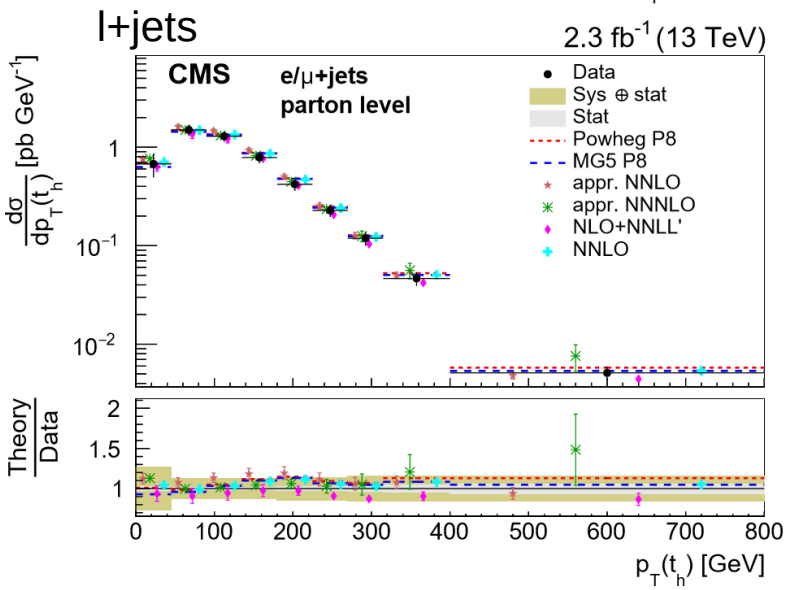
Differential measurements in $p_T(top)$

CMS-TOP-PAS-16-007
arxiv 1610.04191
PRD(DX11697)





- Measured $p_T(top)$ consistently softer than prediction in all channels
- Very sensitive to higher order corrections



Inclusive $\sigma_{t\bar{t}}$ in the l+jets channel at 13 TeV