CMS measurement of multi-differential $t\bar{t}$ cross sections and simultaneous determination of α_s, m_t^{pole} and PDFs [TOP-18-004, arXiv:1904.05237]

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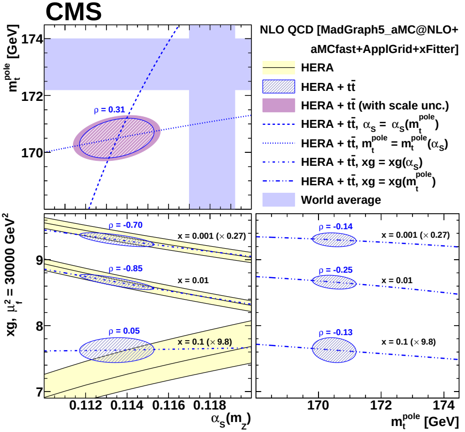
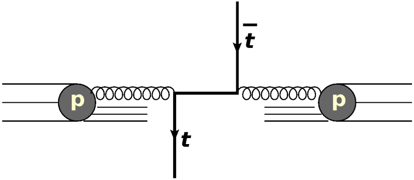
LHC discussion, DESY
03.06.2019

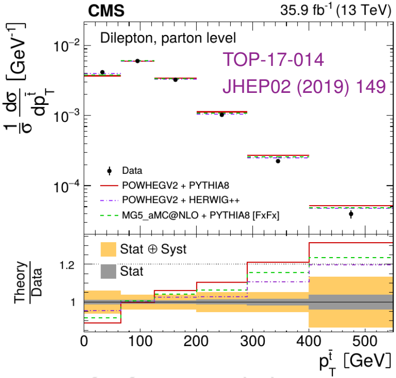


Introduction

Why measure $t\bar{t}$ production?



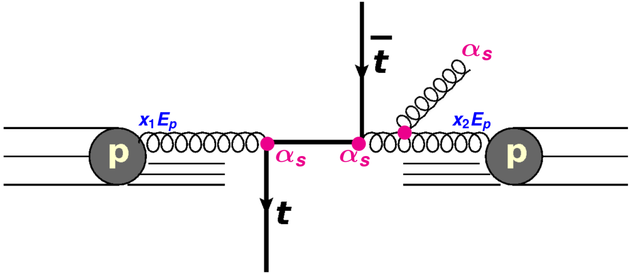
- m_t provides a hard scale
  ⇒ ultimate probe of pQCD
  (NLO, aNNLO, NNLO, ...)
- Produced mainly via *gg*
  ⇒ constrain gluon PDF at high x
- Production sensitive to α_s and m_t^{pole}
- May provide insight into possible new physics



Why measure 2D/3D?

- Previous 1D measurements: overall good agreement, but reveal some trends
- 2D [EPJ C77 (2017) 459, PRD97 (2018) 112003]: study production dynamics in more detail
- **3D: constrain α_s, m_t^{pole}, PDFs**

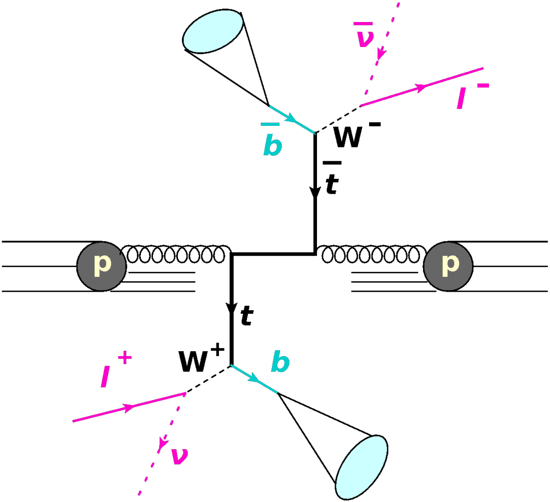
Idea of 3D $t\bar{t}$ measurement



Final state explored to get ultimate constraints on theory parameters:

- $x_1 x_2 = M(t\bar{t})^2/s$, $x_1/x_2 = e^{y(t\bar{t})}$
  $\rightarrow$ $M(t\bar{t})$ and $y(t\bar{t})$ constrain PDFs
- $\sigma(t\bar{t} + \text{jet})/\sigma(t\bar{t}) \propto \alpha_s$
  $\rightarrow$ N_{jet} constrains α_s
- $M(t\bar{t})^{\text{min}} = 2m_t^{pole}$
  $\rightarrow$ $M(t\bar{t})$ constrains m_t^{pole}
- g and α_s interplay via QCD evolution in PDF fits
  $\rightarrow$ constraining PDFs $\Leftrightarrow$ constraining α_s

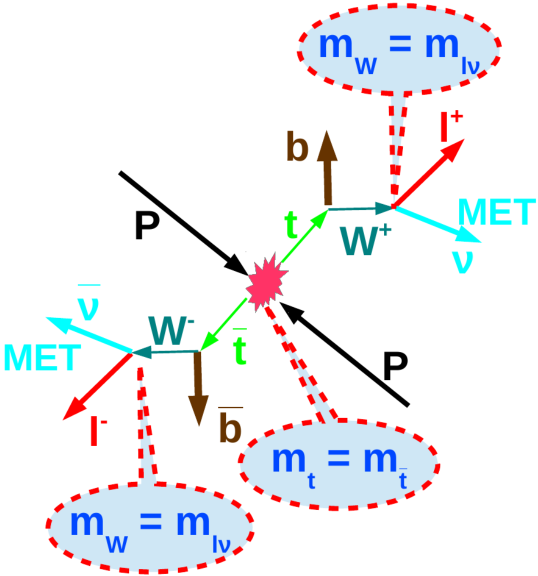
Event selection



Follows 1D measurement:
CMS-TOP-17-014 (JHEP02 (2019) 149)
2016 data (35.9 fb^{-1})

- **Leptons:**
  - 2 isolated $l^{\pm}l^{\mp}$
  - $p_T > 20(25)$ GeV
  - $|\eta| < 2.4$
- **Jets:**
  - at least 2 jets
  - $p_T > 30$ GeV
  - $|\eta| < 2.4$
  - at least 1 *b*-tagged

Kinematic reconstruction



- Measured input: leptons, jets, MET
- Unknowns: $\bar{p}_\nu$, $\bar{p}_{\bar{\nu}}$ (6)
- Constraints:
  - m_t, $m_{\bar{t}}$ (2)
  - m_{W^+}, m_{W^-} (2)
  - $(\bar{p}_\nu + \bar{p}_{\bar{\nu}})_T = \text{MET}$ (2)

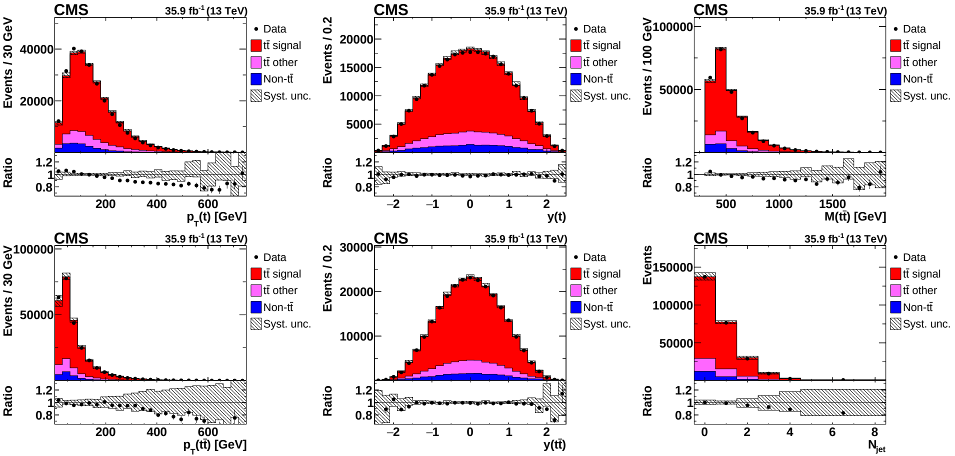
Two variants:

(1) Full reconstruction:
- recover t, $\bar{t}$
- use all constraints

(2) Loose reconstruction:
- recover $t\bar{t}$ only
- m_t constraints not used: $\sigma \neq \sigma(m_t^{\text{MC}})$ $\rightarrow$ reliable to extract m_t^{pole}

  crucial point for m_t^{pole} measurement! [BACKUP]

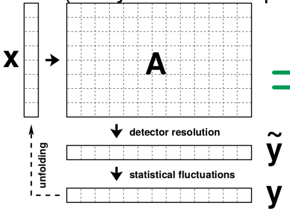
Kinematic distributions

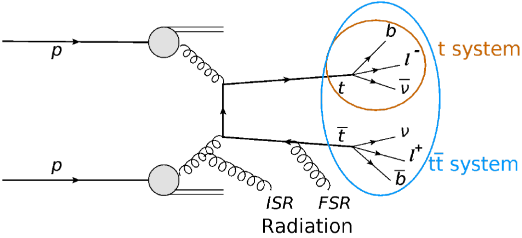


- $t\bar{t}$ signal MC: POWHEGV2 + PYTHIA8 (details in BACKUP)
- Overall good description of data within uncertainties
- Central MC predictions for $p_T(t)$, $p_T(t\bar{t})$, $M(t\bar{t})$, $N_{\rm jet}$ are softer than data

Overview of measured cross sections

TUnfold (no syst. nuisance par.)

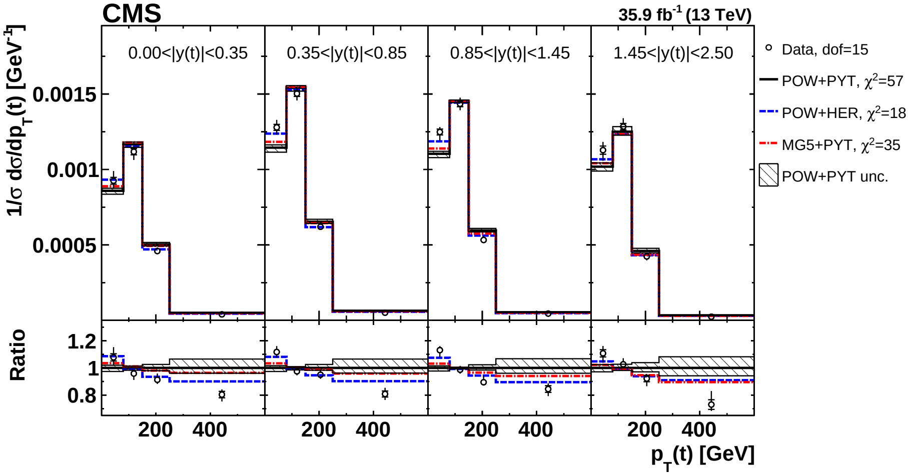




$$[X, Y, Z] = \frac{1}{\sigma}\frac{\mathrm{d}^3\sigma}{\mathrm{d}X\mathrm{d}Y\mathrm{d}Z}$$

- ***t* production:**
  - $[y(t), p_T(t)]$: most simple
- ***$t\bar{t}$* production:**
  - $[M(t\bar{t}), y(t\bar{t})]$: most sensitive to PDFs (at LO $x_{1,2} = \sqrt{\frac{M(t\bar{t})}{s}} e^{\pm y(t\bar{t})}$)
  - $[M(t\bar{t}), p_T(t\bar{t})]$: sensitive to radiation (at LO $p_T(t\bar{t}) \equiv 0$)
- ***t*, *$t\bar{t}$* mixed:**
  - $[M(t\bar{t}), y(t)]$: sensitive to PDFs (at LO $y(t\bar{t}) = (y(t) + y(\bar{t}))/2$)
  - $[M(t\bar{t}), \Delta\phi(t, \bar{t})]$: sensitive to radiation (at LO $\Delta\phi(t\bar{t}) \equiv \pi$)
  - $[M(t\bar{t}), \Delta\eta(t, \bar{t})]$: correlated with $p_T(t)$ and may shed light on $p_T(t)$ problem
  - $[M(t\bar{t}), p_T(t)]$: may shed further light on $p_T(t)$ problem
- **NEW *$t\bar{t}$* production with extra jets:**
  - $[N_{\mathrm{jet}}^{0,1+}, M(t\bar{t}), y(t\bar{t})]$: sensitive to α_s, m_t^{pole} and PDFs (nominal extraction)
  - $[N_{\mathrm{jet}}^{0,1,2+}, M(t\bar{t}), y(t\bar{t})]$: sensitive to α_s, m_t^{pole} and PDFs (cross check)

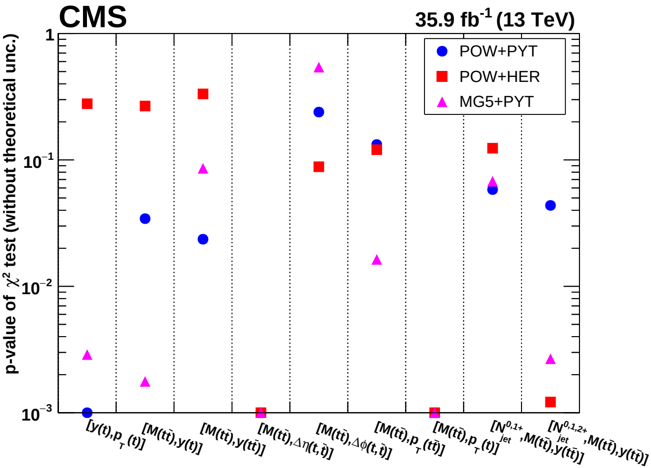
Results: 2D x-sections $[y(t), p_T(t)]$



- 'POW-PYT' and 'FXFX-PYT' predict softer $p_T(t)$ in entire $y(t)$ range
- better description by 'POW-HER'

... (other measured cross section in BACKUP)

Results: summary of comparison to MC models



- none of central MC predictions is able to describe all distributions, in particular $[M(t\bar{t}), \Delta\eta(t, \bar{t})]$, $[M(t\bar{t}), p_T(t)]$
- overall, best description is provided by 'POW-PYT' and 'POW-HER':
  - 'POW-HER' describes better distributions probing $p_T(t)$
  - 'POW-PYT' describes better distributions probing N_{jet} and radiation

Data interpretation consists of two parts:

(1) comparison theory vs data using external PDF sets:

- extracting α_s keeping m_t^{pole} fixed
- extracting m_t^{pole} keeping α_s fixed

$\rightarrow$ this presents α_s, m_t^{pole} extraction from $t\bar{t}$ data only

(2) simultaneous fit of PDFs, α_s and m_t^{pole} using $t\bar{t}$ and HERA DIS:

$\rightarrow$ this presents fully consistent extraction of α_s, m_t^{pole} and PDFs, but using also HERA data

$\rightarrow$ provides baseline for future global fits

NLO calculations:

[MadGraph5_aMC@NLO + aMCfast + ApplGrid + xFitter]

- For $[N_{\text{jet}}^{0,1+}, M(t\bar{t}), y(t\bar{t})]$, using NLO for $t\bar{t}$ of $O(\alpha_s^3)$ and NLO for $t\bar{t}+1\text{jet}$ of $O(\alpha_s^4)$:

  (1) $\sigma^{\text{NLO}}(N_{\text{jet}}=0) = \sigma^{\text{NLO}}(t\bar{t})[O(\alpha_s^3)] - \sigma^{\text{NLO}}(t\bar{t}+1\text{jet})[O(\alpha_s^4)]$
  (2) $\sigma^{\text{NLO}}(N_{\text{jet}}>0) = \sigma^{\text{NLO}}(t\bar{t}+1\text{jet})[O(\alpha_s^4)]$

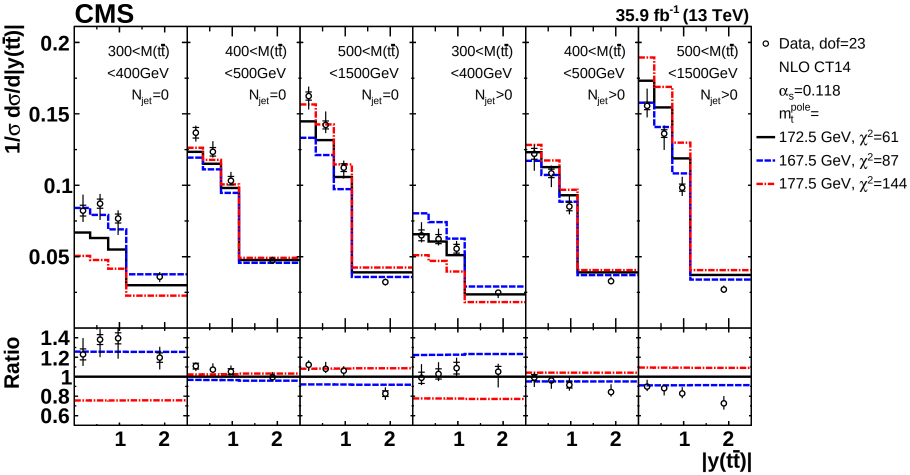
  - equivalent to comparing
    - ★ $\sigma^{\text{NLO}}(t\bar{t})[O(\alpha_s^3)]$ vs measured $\sigma(t\bar{t})$ (just summing two equations above)
    - ★ $\sigma^{\text{NLO}}(t\bar{t}+1\text{jet})[O(\alpha_s^4)]$ vs measured $\sigma(t\bar{t}+1\text{jet})$
    - ... (recall dijet and trijet measurements and $R_{3/2}$)
  - same for $[N_{\text{jet}}^{0,1,2+}, M(t\bar{t}), y(t\bar{t})]$: using $O(\alpha_s^3)$, $O(\alpha_s^4)$ and $O(\alpha_s^5)$ NLO calculations

- $\mu_r = \mu_f = H'/2$, $H' = \sum_i m_{T,i}$ where the sum runs over all final-state partons (t, $\bar{t}$ and up to three light partons in the $t\bar{t}+2$ jets calculations) and $m_T = \sqrt{m^2 + p_T^2}$. Uncertainties:
  - μ_r, μ_f are varied by factor 2 (6 variations in total) coherently in all bins
  - alternative functional form $\mu_r = \mu_f = H/2$, $H = m_{T,t} + m_{T,\bar{t}}$
    $\rightarrow$ mimics 'decorrelation' of scales, in particular for different bins of N_{jet}
  - treated as external uncertainties: no nuisance parameters, no constraints by data

- NLO calculations are multiplied with non-perturbative corrections ($< 5\%$) from parton to particle jet level (BACKUP)

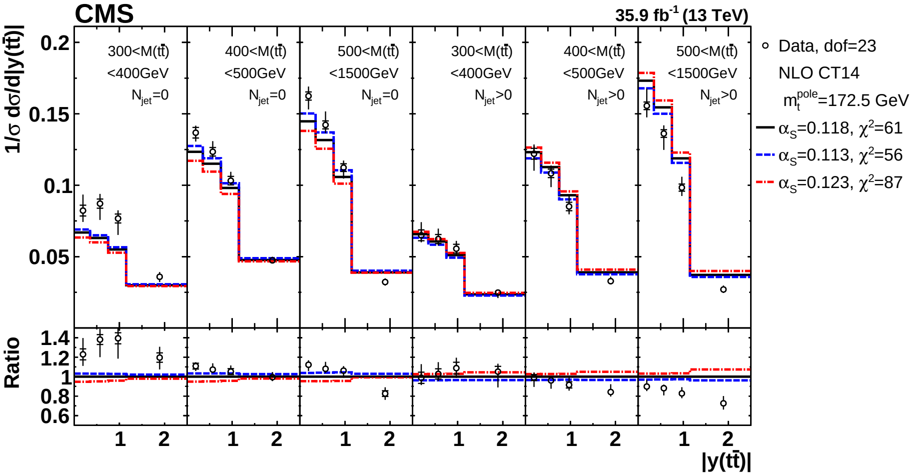
- NNLO corrections are not available for either of measured 2D or 3D distributions :-(

$[N_{\text{jet}}^{0,1+}, M(t\bar{t}), y(t\bar{t})]$ compared to NLO pred. with diff. m_t^{pole}



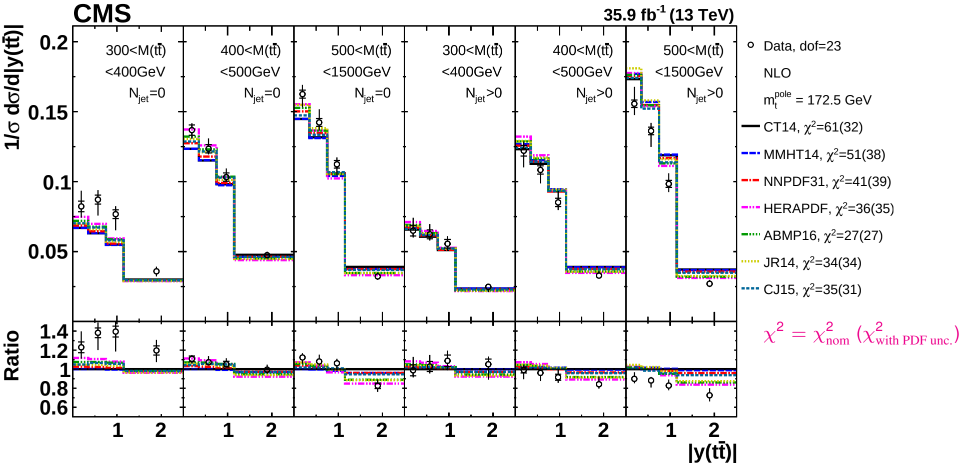
- m_t^{pole} sensitivity comes from $M(t\bar{t})$, mainly 1st bin
- this method differs from extracting m_t^{pole} from total $\sigma_{t\bar{t}}$, and is similar to extracting m_t^{pole} from $t\bar{t}j$ diff. x-section [EPJ C73 (2013) 2438, CMS-PAS-TOP-13-006, JHEP 1510 (2015) 121, 1905.02302]
- previous determination using this $M(t\bar{t})$: prelim. D0 results [FERMILAB-CONF-16-383-PPD]

$[N_{\mathbf{jet}}^{0,1+}, M(t\bar{t}), y(t\bar{t})]$ compared to NLO pred. with diff. α_s



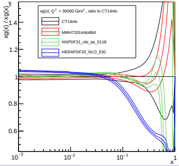
- α_s sensitivity comes from different N_{jet} bins
- also (indirect) sensitivity comes from $[M(t\bar{t}), y(t\bar{t})]$ via sensitivity to PDFs

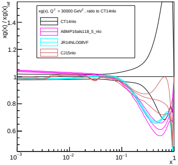
$[N_{\text{jet}}^{0,1+}, M(t\bar{t}), y(t\bar{t})]$ compared to NLO pred. with diff. PDFs



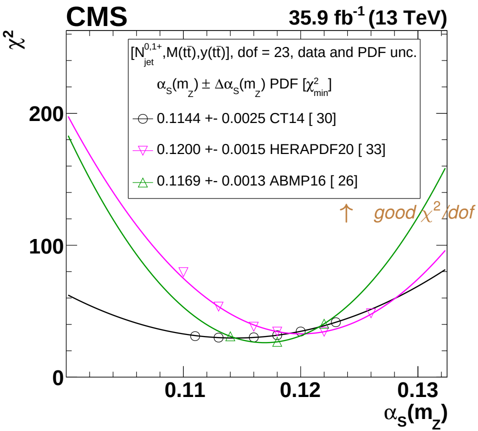
$\chi^2 = \chi^2_{\text{nom}}\ (\chi^2_{\text{with PDF unc.}})$

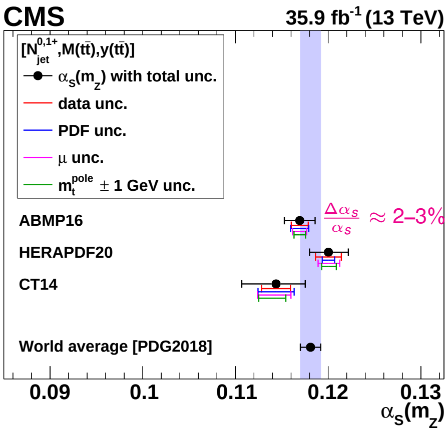
- All modern PDF sets considered:
  - MMHT2014, ABMP16: total $\sigma(t\bar{t})$ data
  - NNPDF3.1: total and dif. (Run-I) $\sigma(t\bar{t})$ data
  - other PDFs: no $t\bar{t}$ data





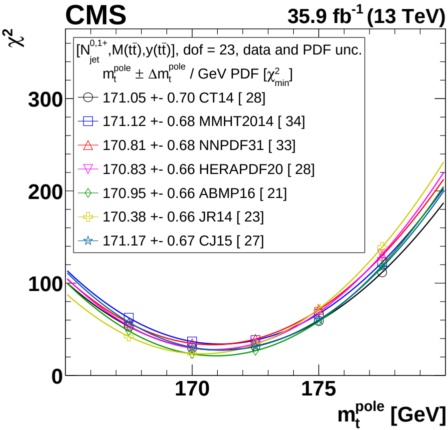
Extraction of α_s from $[N_{\text{jet}}^{0,1+}, M(t\bar{t}), y(t\bar{t})]$

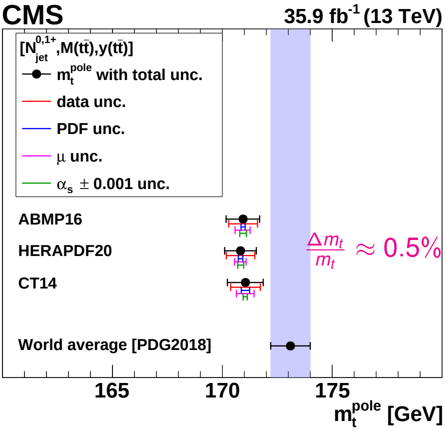




- used $m_t^{\text{pole}} = 172.5$ GeV in ME for all PDF sets (ABMP16 fitted $m_t^{\text{pole}} = 171.44$ GeV)
- precise determination of α_s is possible using these data
- significant dependence on PDF set observed (correlation between g and α_s)

Extraction of m_t^{pole} from $[N_{\text{jet}}^{0,1+}, M(t\bar{t}), y(t\bar{t})]$





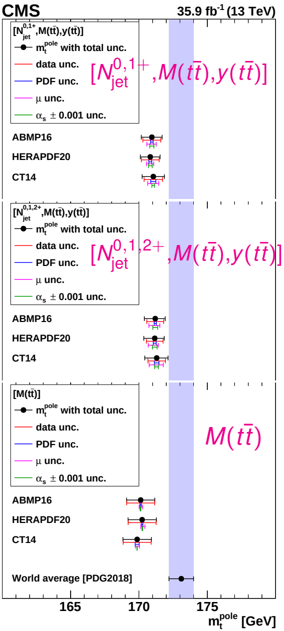
- used α_s from each PDF set ($\alpha_s = 0.118$ in CT and HERAPDF, $\alpha_s = 0.119$ in ABMP)
- precise determination of m_t^{pole} is possible using these data
- no significant dependence on PDF set
- these are our nominal observables, while several cross checks were done [next page]

Cross checks

- using $[N_{\text{jet}}^{0,1,2+}, M(t\bar{t}), y(t\bar{t})]$
- using single-differential N_{jet}, $M(t\bar{t})$ or $y(t\bar{t})$ cross sections
- using $[p_T(t\bar{t}), M(t\bar{t}), y(t\bar{t})]$ cross sections with 2 $p_T(t\bar{t})$ bins
- using unnormalised cross sections

→ consistent results obtained in all cross checks

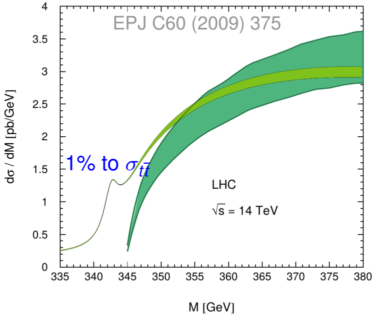
→ in this analysis, observables ($\frac{1}{\sigma}\frac{d\sigma}{d\ldots}$) have been chosen to have **maximum sensitivity to QCD paramaters and minimum experimental and scale uncertainties**

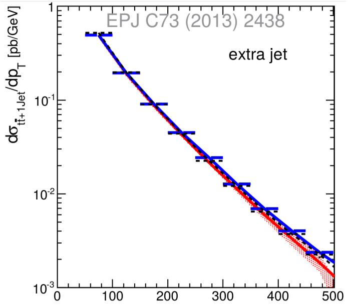


Remarks on limitations in NLO theory calculations

NLO is the only available theory publicly available today, but there are limitations:

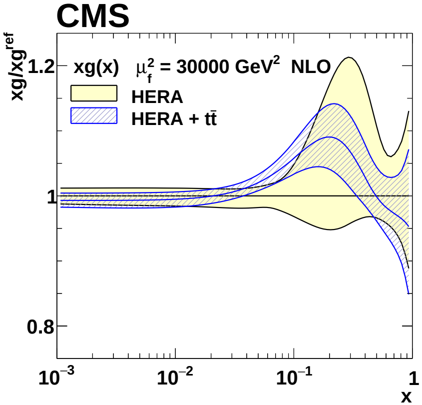
- impact of missing threshold resummation is $\Delta m_t \sim 0.7$ GeV [Eur.Phys.J. C60 (2009) 375]
- impact of missing FSR resummation is $\Delta m_t \sim 0.5$ GeV [Eur. Phys. J. C73 (2013) 2438]
  - in general, good agreement between NLO and NLO+PS [Fig. 1 in Eur. Phys. J. C73 (2013) 2438]
- EW corrections could be a few % near threshold [Phys. Rev. D91 (2015) 014020] [JHEP10 (2017) 186]
- **NNLO QCD corrections are needed** [NLO uncertainties are estimated by scale variations only: estimations of other numbers are too imprecise at the moment]

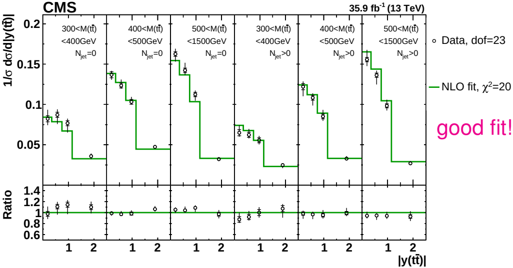




Simultaneous PDF + α_s + m_t^{pole} fit: results

- followed standard approach: using HERA DIS data only, or HERA + $t\bar{t}$ data to demonstrate added value from $t\bar{t}$ on PDF and α_s determination
- settings follow HERAPDF2.0 fit (very similar to TOP-14-013), use xFitter-2.0.0
- input data: combined HERA DIS [1506.06042] + $t\bar{t}$ (further details in BACKUP)

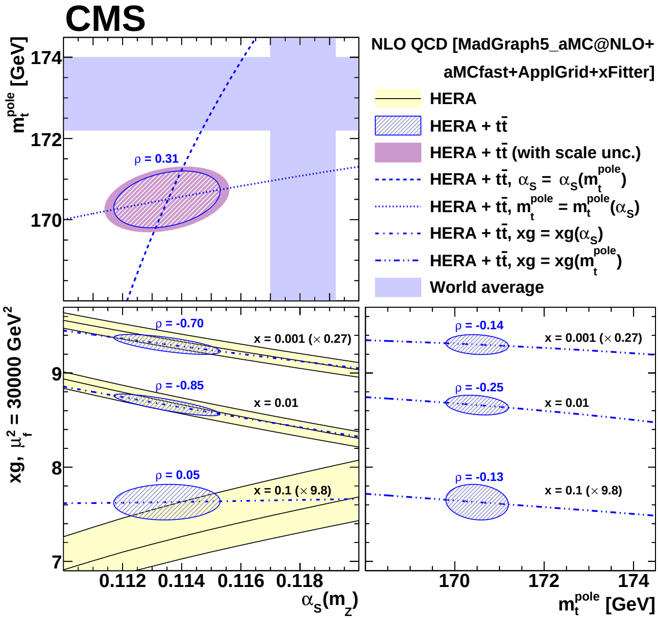




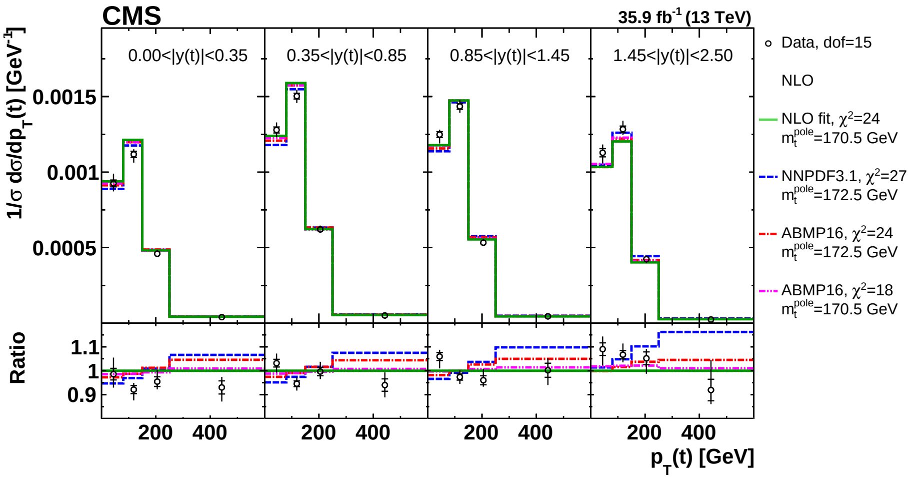
good fit!

$$\alpha_s(M_Z) = 0.1135 \pm 0.0016(\text{fit})^{+0.0002}_{-0.0004}(\text{mod})^{+0.0008}_{-0.0001}(\text{par})^{+0.0011}_{-0.0005}(\text{scale}) = 0.1135^{+0.0021}_{-0.0017}(\text{total})$$

$$m_t^{\text{pole}} = 170.5 \pm 0.7(\text{fit})^{+0.1}_{-0.1}(\text{mod})^{+0.0}_{-0.1}(\text{par})^{+0.3}_{-0.3}(\text{scale})\ \text{GeV} = 170.5 \pm 0.8(\text{total})\ \text{GeV}$$


CMS
NLO QCD [MadGraph5_aMC@NLO+ aMCfast+ApplGrid+xFitter]
HERA
HERA + tt̄
HERA + tt̄ (with scale unc.)
HERA + tt̄, αS = αS(mt pole)
HERA + tt̄, mt pole = mt pole(αS)
HERA + tt̄, xg = xg(αS)
HERA + tt̄, xg = xg(mt pole)
World average
ρ = 0.31
ρ = -0.70
ρ = -0.85
ρ = 0.05
ρ = -0.14
ρ = -0.25
ρ = -0.13
x = 0.001 (× 0.27)
x = 0.01
x = 0.1 (× 9.8)
mt pole [GeV]
xg, μf2 = 30000 GeV2
αS(mZ)
174
172
170
9
8
7
0.112
0.114
0.116
0.118
170
172
174

PDF + α_s + m_t^{pole} fit and "$p_T(t)$ problem"



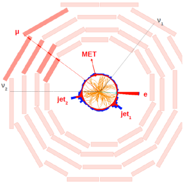
- $[p_T(t), y(t)]$ cross sections (whcih are not used in the fit) are are in satisfactory agreement with post-fit predictions

  $\rightarrow$ NLO predictions are able to describe $t\bar{t}$ data

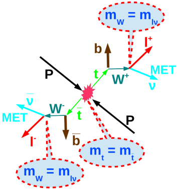
  $\rightarrow$ "$p_T(t)$ problem" is sensitive to PDFs and m_t^{pole}

Summary

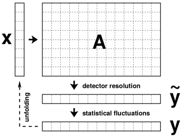
Event selection:
as in 1D



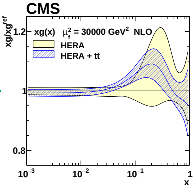
Kinematic reconstruction:
as in 1D + loose for m_t^{pole}

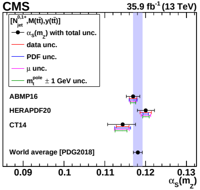


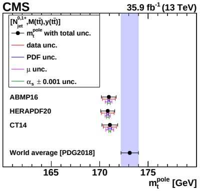
Unfolding: TUnfold,
no nuisance par. fit



Interpretation:
new approach



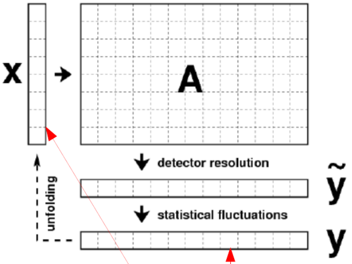




Measured 2D and 3D $t\bar{t}$ cross section in dilepton channel using 2016 data:

- Quantitative comparison to several MC predictions:
  - data distinguish between predictions and reveal trends
  - NNLO from theorists is not yet available
- Used measured 3D cross sections to constrain α_S, m_t^{pole}, PDFs at NLO
  - first extraction of such kind using differential $t\bar{t}$ cross sections
  - need 3D NNLO predictions to ultimately exploit LHC data

BACKUP



2d distributions are mapped to 1d arrays

`TUnfold` [JINST 7 (2012) T10003]

χ^2 minimisation with regularisation ($\approx$ 1%)

reco. data — unfolded distribution — regularization strength — regularization conditions (second derivative)

$$\chi^2 = (Y - AX)^T V_Y^{-1} (Y - AX) + \tau^2 (X - X_0)^T L^T L (X - X_0)$$

migration probability matrix — stat. errors of reco. — **gen.** distribution

$$Y = N_{measured} - N_{Background}$$

For each $\Delta\mathbf{a}^i$:

$$\left(\frac{1}{\sigma}\frac{d\sigma}{db}\right)^{ij} = \frac{1}{\sigma} \cdot \frac{X^{ij}}{BR \cdot L \cdot \Delta b^j}$$

Systematic uncertainties

Experimental uncertainties:

- JES (splitted in sources, also propagated to MET)
- JER
- b-tagging SFs
- lepton ID/ISO SFs
- triggers SFs
- pileup reweighting
- non-$t\bar{t}$ background normalisation varied by 30%
- lumi and branching ratios cancel for normalised cross section

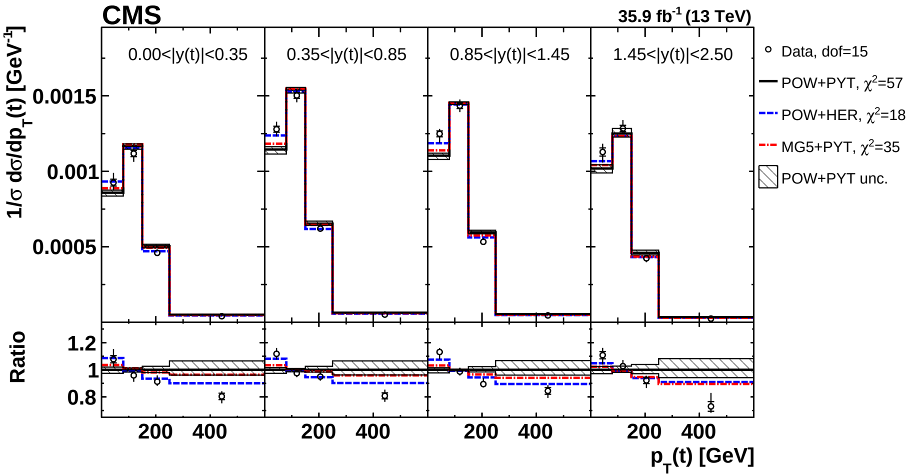
Model uncertainties:

- based on weights:
  - ME scales (envelope of 6 variations dominated by simultaneous μ_r,μ_f var.)
  - PDFs and α_s (CT14 eigenvectors)
  - b-quark fragmentation (envelope of varied Bowler-Lund and Peterson funct.)
  - b-hadron branching ratios
- based on independent samples:
  - $m_t \pm 1$ GeV (using samples with ± 3 GeV $\rightarrow$ rescaled by $1/3$)
  - $0.996 m_{\mathrm{t}} < h_{\mathrm{damp}} < 2.239 m_{\mathrm{t}}$
  - ISR μ, FSR μ variations (latter rescaled by $1/\sqrt{2}$)
  - color reconnection: envelope of 3 samples with different tunes
  - underlying event tune variation

MC predictions

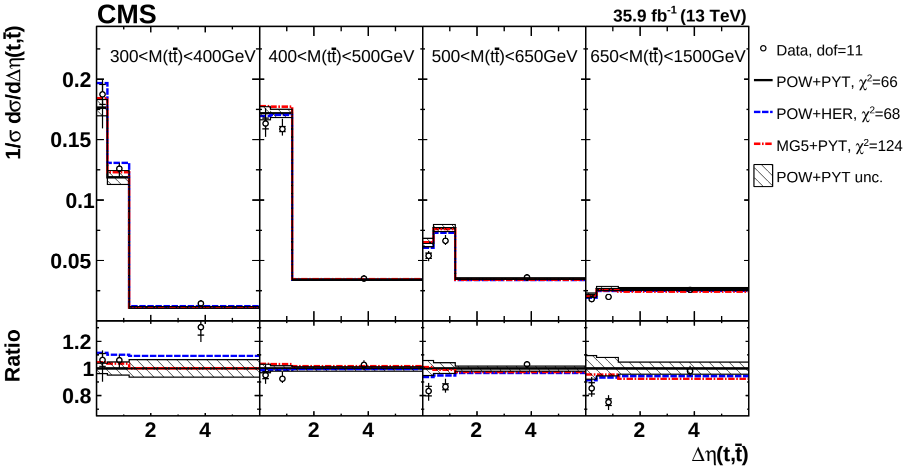
- POWHEGV2 + PYTHIA8
  - $h_{\mathrm{damp}} = 1.581 m_t$
  - $m_t = 172.5$ GeV
  - CUETP8M2T4 tune [CMS-PAS-TOP-16-021]
- POWHEGV2 + HERWIG++
  - $h_{\mathrm{damp}} = 1.581 m_t$
  - $m_t = 172.5$ GeV
  - EE5C tune [JHEP10 (2013) 113]
- MG5_aMC@NLO + PYTHIA8
  - FxFx prescription for $t\bar{t}$, $t\bar{t}$ +1 jet, $t\bar{t}$ +2 jets @ NLO [JHEP12 (2012) 061]
  - $m_t = 172.5$ GeV
  - CUETP8M2T4 tune [CMS-PAS-TOP-16-021]

2D x-sections $[y(t), p_T(t)]$



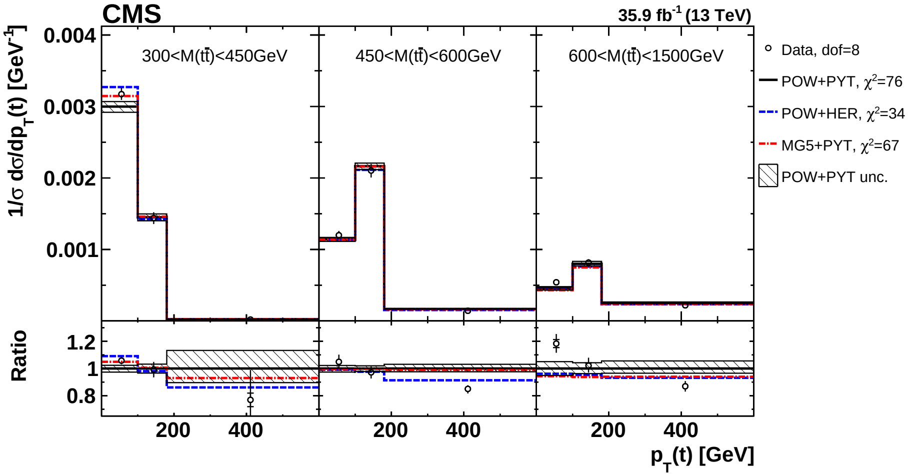
- ‘POW-PYT’ and ‘FXFX-PYT’ predict softer $p_T(t)$ in entire $y(t)$ range
- better description by ‘POW-HER’

2D cross sections $[M(t\bar{t}), \Delta\eta(t,\bar{t})]$



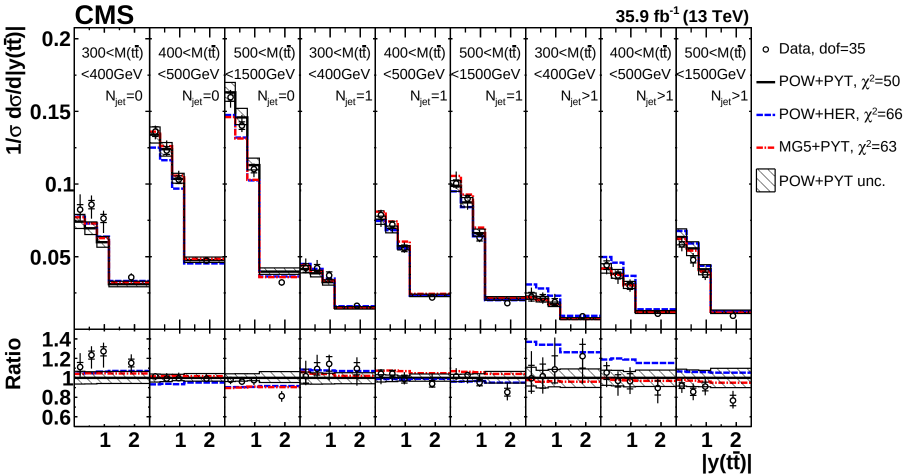
- predicted $\Delta\eta(t,\bar{t})$ are too low at medium and high $M(t\bar{t})$
- at large $M(t\bar{t})$, t and $\bar{t}$ have a larger η separation than in MC: correlated with a lower $p_T(t)$
- bad description by all MC central predictions, strongest disagreement for 'FXFX-PYT'

2D cross sections $[M(t\bar{t}), p_T(t)]$



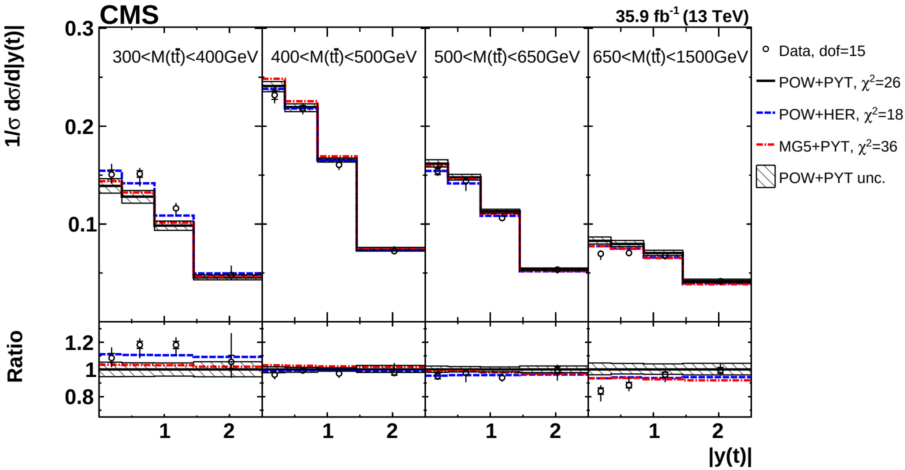
- bad description by all MC, strongest disagreement for 'POW-PYT'
- notice: 'POW-HER' describes $p_T(t)$ in entire $y(t)$ range well, but predicts too hard $p_T(t)$ at high $M(t\bar{t})$

3D cross sections $[N_{\text{jet}}^{0,1,2+}, M(t\bar{t}), y(t\bar{t})]$



- only ‘POW-PYT’ is in satisfactory agreement with data
- ‘POW-HER’ predicts too high cross section at $N_{\text{jet}} > 1$
- ‘FXFX-PYT’ describes worse $M(t\bar{t})$ at $N_{\text{jet}} = 1$
- . . . more plots in BACKUP

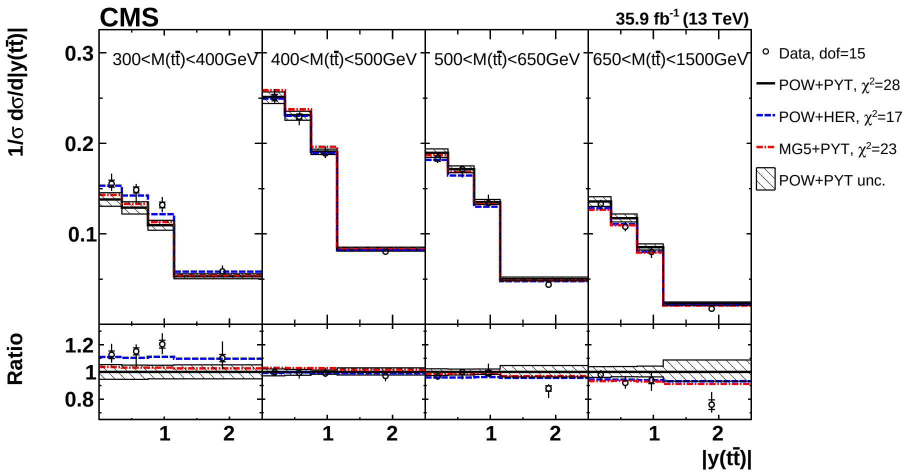
2D x-sections $[M(t\bar{t}), y(t)]$



→ MC is more central than data at largest $M(t\bar{t})$

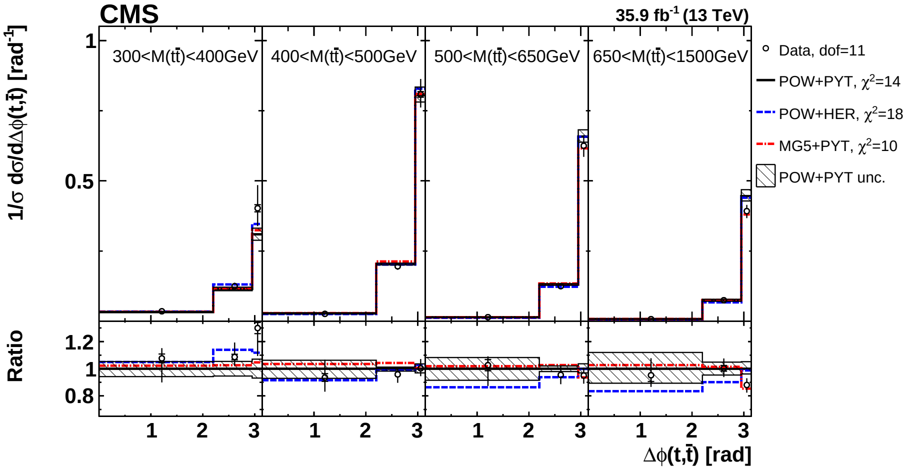
→ best description by 'POW-HER' (mainly $M(t\bar{t})$ slope)

2D cross sections $[M(t\bar{t}), y(t\bar{t})]$



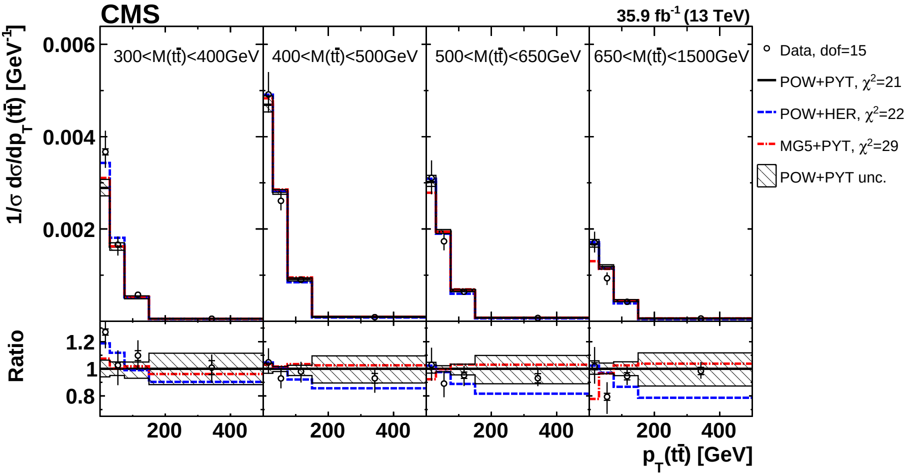
- MC is (somewhat) less central than data at largest $M(t\bar{t})$
- best description by 'POW-HER' (mainly $M(t\bar{t})$ slope)

2D x-sections $[M(t\bar{t}),\Delta\phi(t,\bar{t})]$



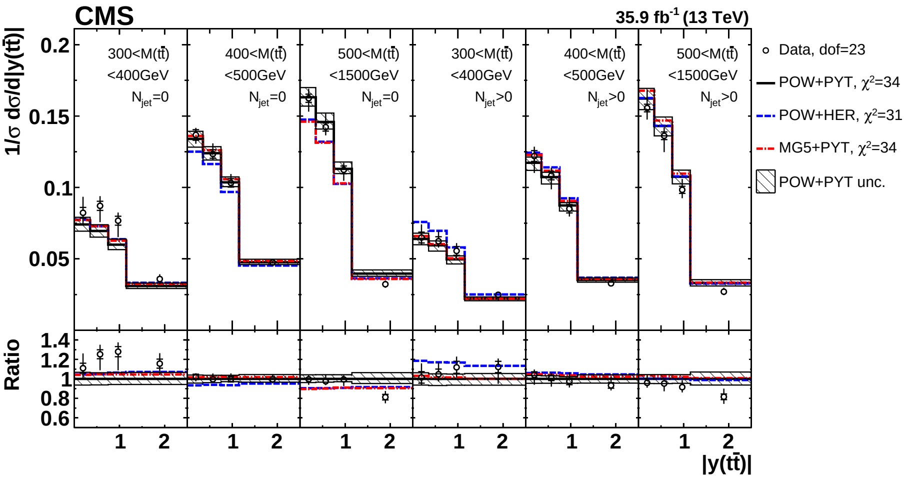
→ all MC describe data well

2D x-sections $[M(t\bar{t}), p_T(t\bar{t})]$



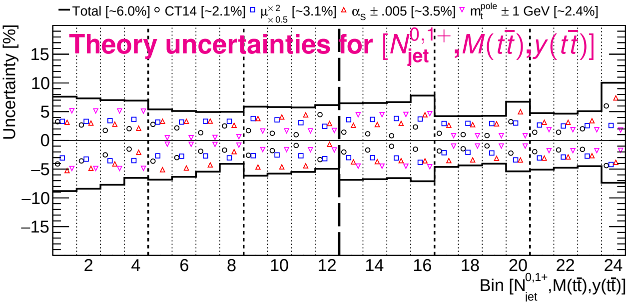
→ all MC describe data well, but 'FXFX-PYT' predicts too hard $p_T(t\bar{t})$ at highest $M(t\bar{t})$

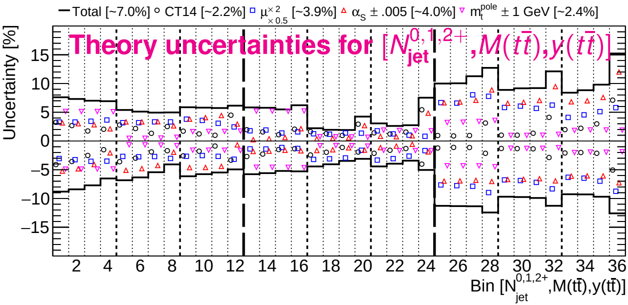
3D x-sections $[N_{\mathbf{jet}}^{0,1+}, M(t\bar{t}), y(t\bar{t})]$



→ all MC describe data well

Data and theory uncertainties $[N_{\mathbf{jet}}^{0,1+}, M(t\bar{t}), y(t\bar{t})]$





- Bins are grouped for $y(t\bar{t})$, $M(t\bar{t})$ and N_{jet} (separated by different vertical lines)
- NLO scale uncertainties are comparable to PDF, α_s and m_t uncertainties

  $\rightarrow$ data can constrain PDF, α_s and m_t
- Scale uncertainties are considerably smaller for $[N_{\text{jet}}^{0,1+}, M(t\bar{t}), y(t\bar{t})]$

  $\rightarrow [N_{\text{jet}}^{0,1,2+}, M(t\bar{t}), y(t\bar{t})]$ is used for cross check only

Definition of extra jets (not from top decay)

- NLO predictions for inclusive $t\bar{t}$, $t\bar{t}$ + 1 jet and $t\bar{t}$ + 2 jets computed and compared to data using MadGraph5_aMC@NLO + aMCfast + ApplGrid + xFitter
- particle-level jet definition used in measurement, further corrected to parton level using separate MC POWHEGV2 + PYTHIA8 simulations
  - $p_T(j) > 30$ GeV, $|\eta(j)| < 2.4$
  - 'Particle level': particle jets (no ν) required to be isolated within $\Delta R > 0.4$ from l and b from $t\bar{t}$
  - Parton level: standalone POWHEGV2 + PYTHIA8 generated without
    - **(1)** top decays: $C_{\mathrm{def}} = \sigma_{\text{no l,b from } t\bar{t}} \,/\, \sigma_{\text{no } t\bar{t}}$
    - **(2)** hadronisation: $C_{\mathrm{had}} = \sigma_{\text{with had.}} \,/\, \sigma_{\text{no had.}}$
    - **(3)** MPI: $C_{\mathrm{MPI}} = \sigma_{\text{with MPI}} \,/\, \sigma_{\text{no MPI}}$
- $C_{\mathrm{NP}} = \sigma_{\text{no l,b from } t\bar{t}} / \sigma_{\text{no } t\bar{t}\text{,had.,MPI}}$ $[C_{\mathrm{NP}} \approx C_{\mathrm{def}} \times C_{\mathrm{had}} \times C_{\mathrm{MPI}}]$
- theoretical predictions = $\mathrm{NLO} \times \mathrm{C_{NP}}$
- similar procedure used in jet measurements (although without excluding decay products)

Simultaneous PDF$+\alpha_s + m_t^{\text{pole}}$ fit: settings

- followed standard approach: using HERA DIS data only, or HERA + $t\bar{t}$ data to demonstrate added value from $t\bar{t}$ on PDF and α_s determination
- settings follow HERAPDF2.0 fit (very similar to TOP-14-013), use xFitter-2.0.0
- input data: combined HERA DIS [1506.06042] + $t\bar{t}$
- RTOPT, $M_c = 1.47$ GeV, $M_b = 4.5$ GeV, $Q^2_{\text{min}} = 3.5^{+1.5}_{-1.0}$ GeV^2
- predictions fot $t\bar{t}$ data via MadGraph5_aMC@NLO + aMCfast + ApplGrid, $\mu_r = \mu_f = H_t/4$, $H_t = \sqrt{m_t^2 + (p_T(t))^2} + \sqrt{m_t^2 + (p_T(\bar{t}))^2}$ varied by factor 2
  - dependence on α_s and scales written in ApplGrid tables
  - dependence on m_t^{pole} derived by linear interpolation between tables generated with different values of m_t^{pole} (new feature for xFitter)
  - kinematic range probed by $t\bar{t}$: $x = (M(t\bar{t})/\sqrt{s}) \exp[\pm y(t\bar{t})] \Rightarrow 0.01 \lesssim x \lesssim 0.1$
- 15-parameter form (backup) determined using parametrisation scan (one extra g parameter required by $t\bar{t}$ data) at $Q_0^2 = 1.9$ GeV^2, $f_s = 0.4 \pm 0.1$
- DGLAP NLO PDF evolution via QCDNUM-17.01.14
- PDF uncertainties: fit ($\Delta\chi^2 = 1$ via HESSE, cross checked with MC replica method), model and parametrisation; in addition for α_s and m_t^{pole} scale uncertainties for $t\bar{t}$ are considered

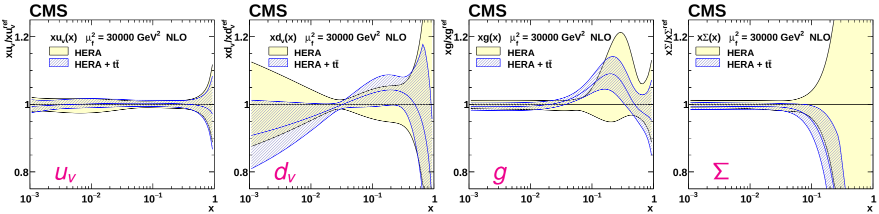
Simultaneous PDF, α_s and m_t^{pole} fit: PDF parametrisation

Determined using parametrisation scan:

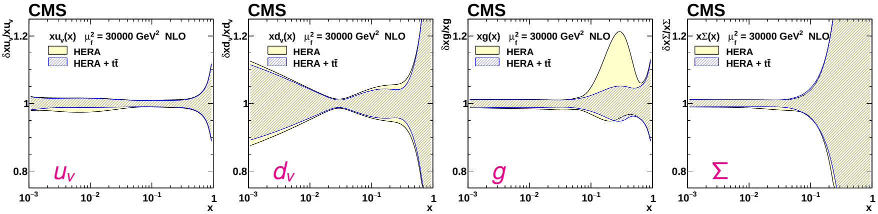
$$\begin{aligned}
xg(x) &= A_g x^{B_g} (1-x)^{C_g} (1 + E_g x^2) - A'_g x^{B'_g} (1-x)^{C'_g}, \\
xu_v(x) &= A_{u_v} x^{B_{u_v}} (1-x)^{C_{u_v}} (1 + D_{u_v} x), \\
xd_v(x) &= A_{d_v} x^{B_{d_v}} (1-x)^{C_{d_v}}, \\
x\overline{U}(x) &= A_{\overline{U}} x^{B_{\overline{U}}} (1-x)^{C_{\overline{U}}} (1 + D_{\overline{U}} x), \\
x\overline{D}(x) &= A_{\overline{D}} x^{B_{\overline{D}}} (1-x)^{C_{\overline{D}}},
\end{aligned}$$

- additional gluon parameyter (E_g) required by new $t\bar{t}$ data
- PDF parametrisation uncertainties given by $A'_g = 0$ (13p) and $E_g = 0$ (14p), and $Q_0^2 = 1.9 \pm 0.3$ GeV^2 variation

PDFs (α_s in HERA-only fit set to $\alpha_s = 0.1135 \pm 0.0016$)



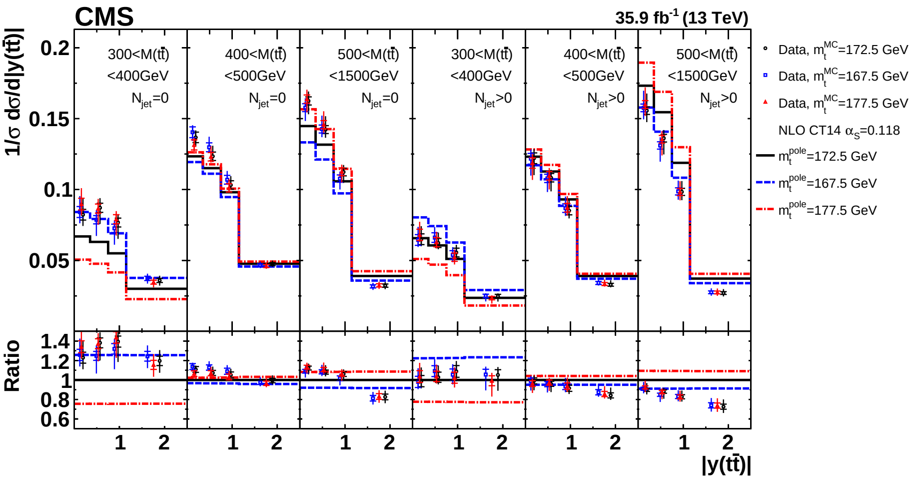
Relative PDF uncertainties



$\rightarrow$ reduced g uncertainty at high x

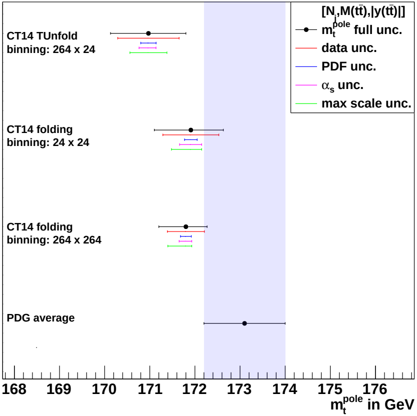
$\rightarrow$ smaller impact on other distributions via correlations in the fit

Dependence of measured cross sections on m_t^{MC}



Extraction of m_t^{pole} using CMS detector-level data

L. Materne, bachelor thesis “Differential Top-Pair Production Cross Section with the CMS Detector - Optimization of Measurement Information”, Karlsruher Institut für Technologie (KIT), Bachelorarbeit, 2018 [ETP-Bachelor-KA/2018-11]
`https://ekp-invenio.physik.uni-karlsruhe.de/record/49082`



- ‘CT14 TUnfold’ is TOP-18-004
- ‘CT14 folding’ is obtained using data at detector level theoretical predictions which are folded with the response matrix

TOP-18-004: discussion of a few comments received recently

- The analysis uses exclusive N_{jet} bins, while jet veto introduces logarithmic corrections not accounted by fixed order predictions

  $\rightarrow$ No exclusive bins are used, but only inclusive $\sigma(t\bar{t})$, $\sigma(t\bar{t}+1\mathrm{jet})$, $\sigma(t\bar{t}+2\mathrm{jets})$ (page 13). We will try to make a better description in the revised paper.

- Coherent scale variations in the predictions with different jet multiplicities may underestimate missing higher order effects

  $\rightarrow$ When estimating scale uncertainties, we adopt the alternative scale definition which specifically probes hard jets (page 13) and mimics incoherent scale variations.

- Was anything else done besides standard scale variation in order to estimate the errors?

  $\rightarrow$ Several consistency checks were done using different observables (page 16) and described in the paper. Consistent results were obtained.

  $\rightarrow$ Several effects were estimated (page 17) and discussed in the paper, though the estimations are too imprecise to be assigned as uncertainties (they are consistent with scale unc.).

- To estimate NNLO effects, one has to extract the mass using the POWHEG output at the shower level before hadronization, applied to data unfolded at the particle level

  $\rightarrow$ The full PDF+α_s +m_t^{pole} fit with PS is not possible using existing tools. If done for m_t^{pole} only:
  - would not it be a MC mass with different uncertainties, given that one could tune PS to obtain a different result?
  - we use bins with different jet multiplicities, while POWHEG inclusive $t\bar{t}$ does not have NLO accuracy for $t\bar{t}$ +jets. Some multijet merging algorithm has to be used [$\rightarrow$ extra unc.]?
  - somehow ‘before hadronization’ and ‘particle level’ sounds as contradiction