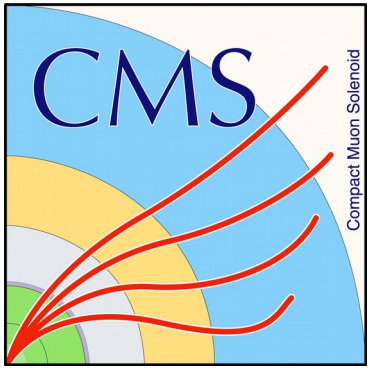


Top pair production cross sections in CMS

Juan R. González Fernández (Universidad de Oviedo)

On behalf of the **CMS Colaboration**

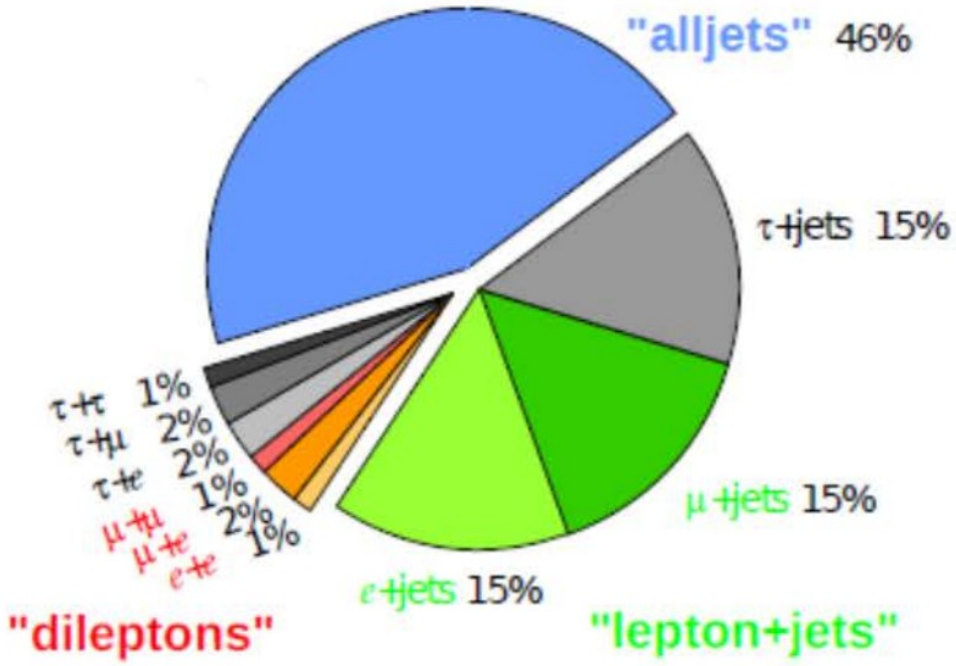
07 June 2018

LHCP 2018**, Bologna.**

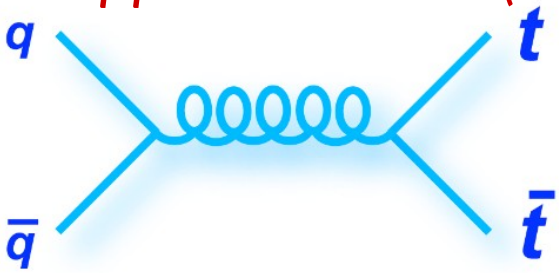
Outlook of $t\bar{t}$ production process

- Essential for probing SM through **pQCD** precision tests.
- Constrains **proton PDFs** and **new physics** scenarios.
- **Main background** in plenty of BSM searches.

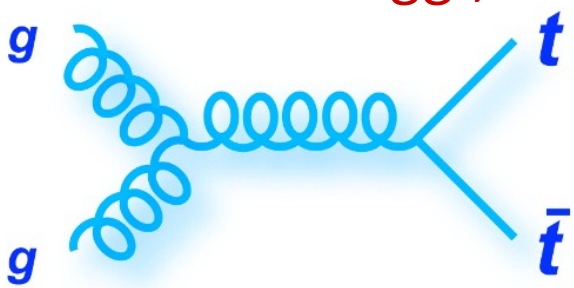
Remember

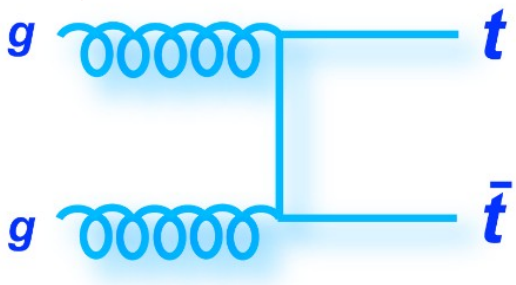


qq annihilation (~10%)

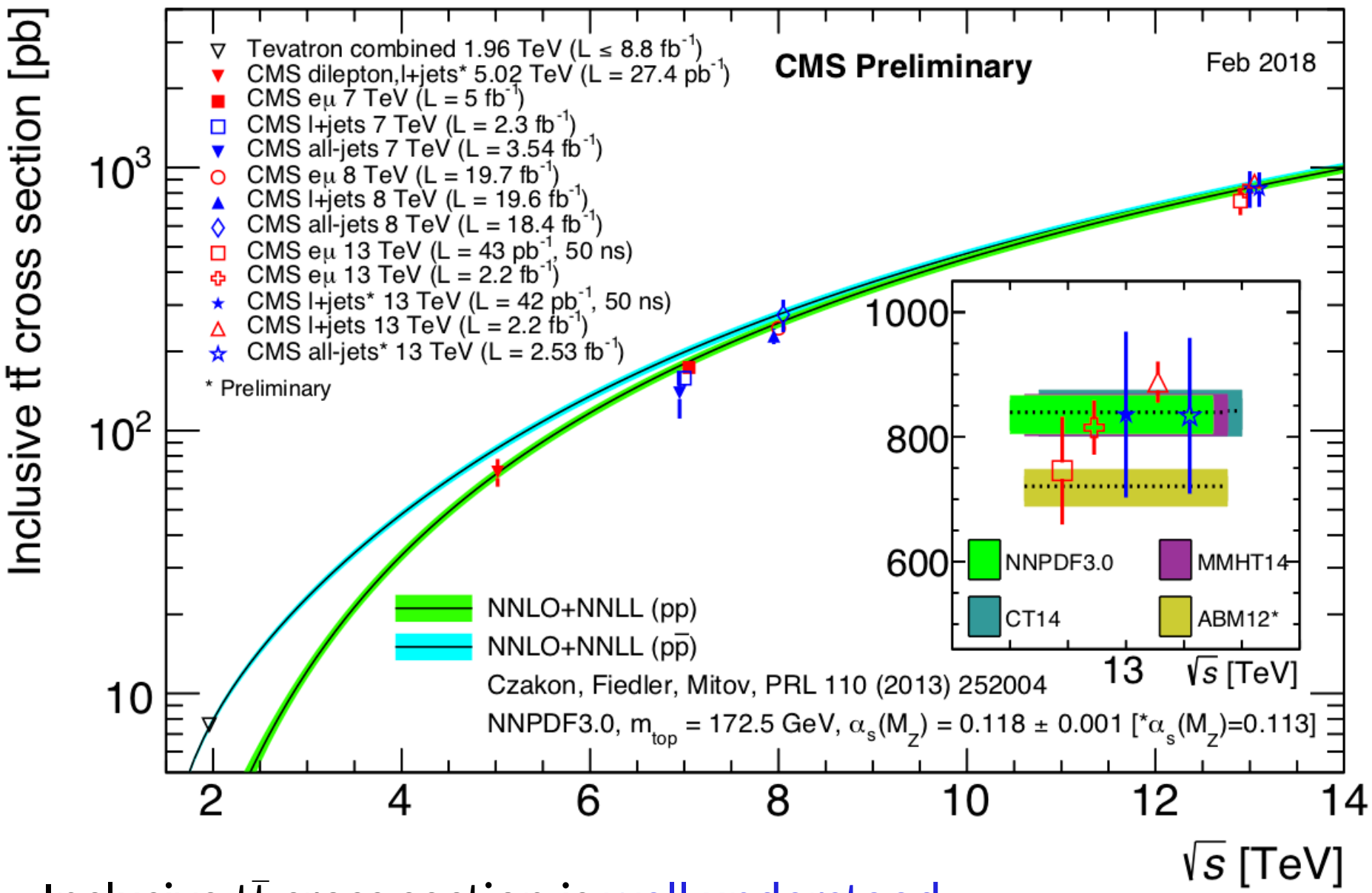


gg fusion (~90%)





$t\bar{t}$ cross section overview



Inclusive $t\bar{t}$ cross section is well understood in a wide range of centre-of-mass energies.

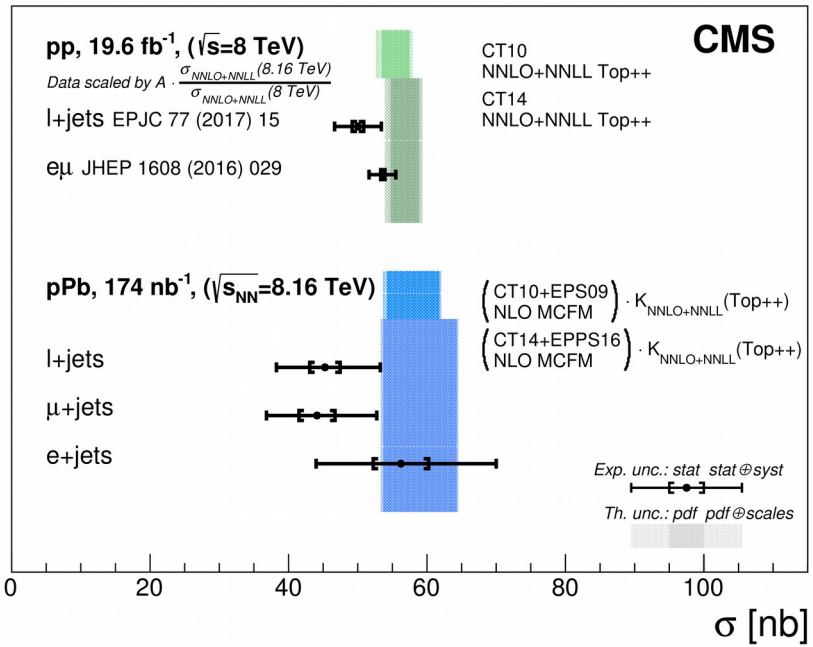
$t\bar{t}$ observation in pPb collisions at 8.16 TeV

Phys. Rev. Lett. 119, 242001 (2017)

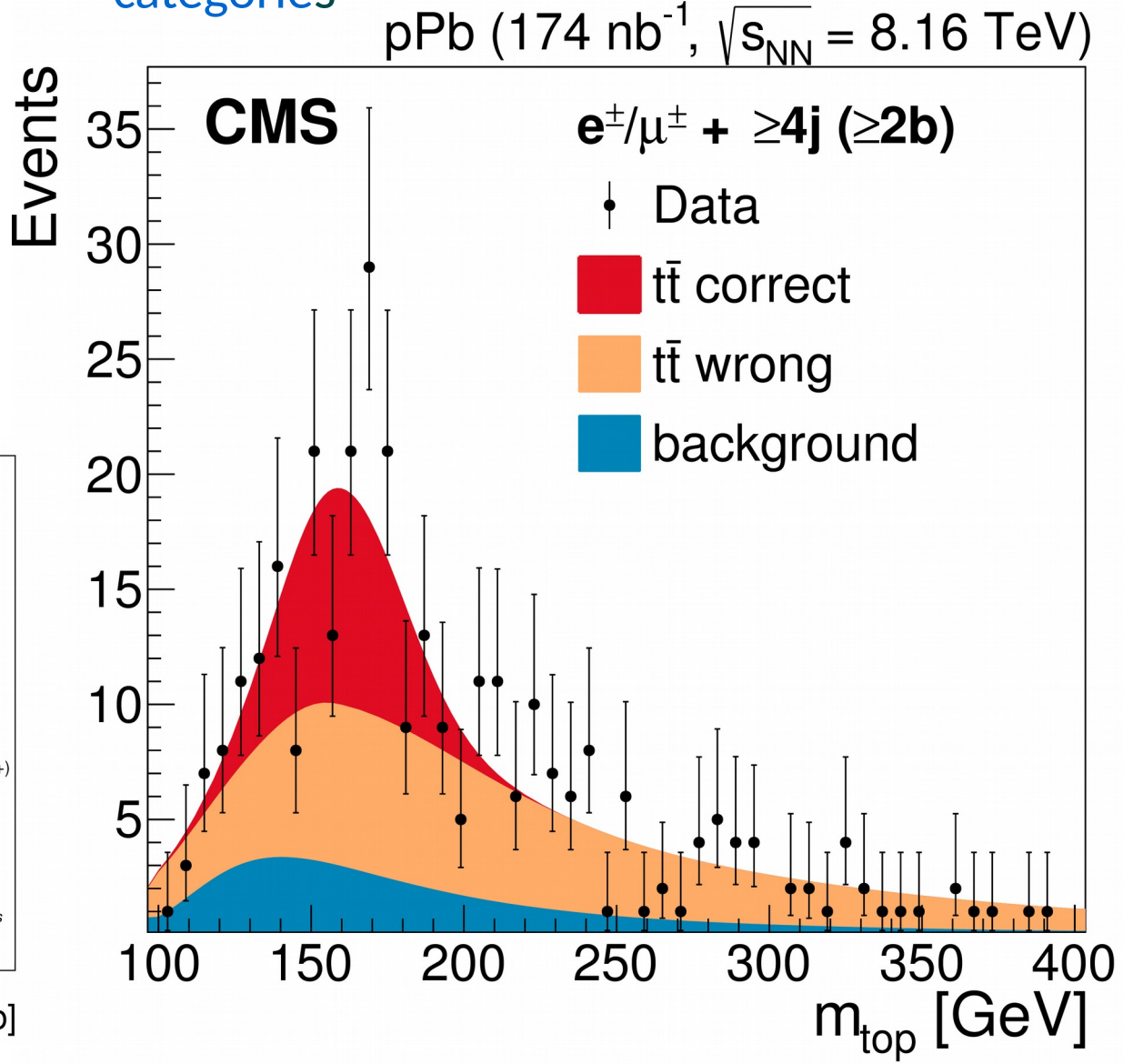
- $\sqrt{s[NN]}$ = 8.16 TeV
- Lumi: 174 nb^{-1}
- Measured cross section:

  45 ± 8 nb

- Main uncertainties: b tagging efficiency, bkg prediction.
- Result in agreement with NNLO+NNLL pQCD with NLO proton/nuclear PDFs.

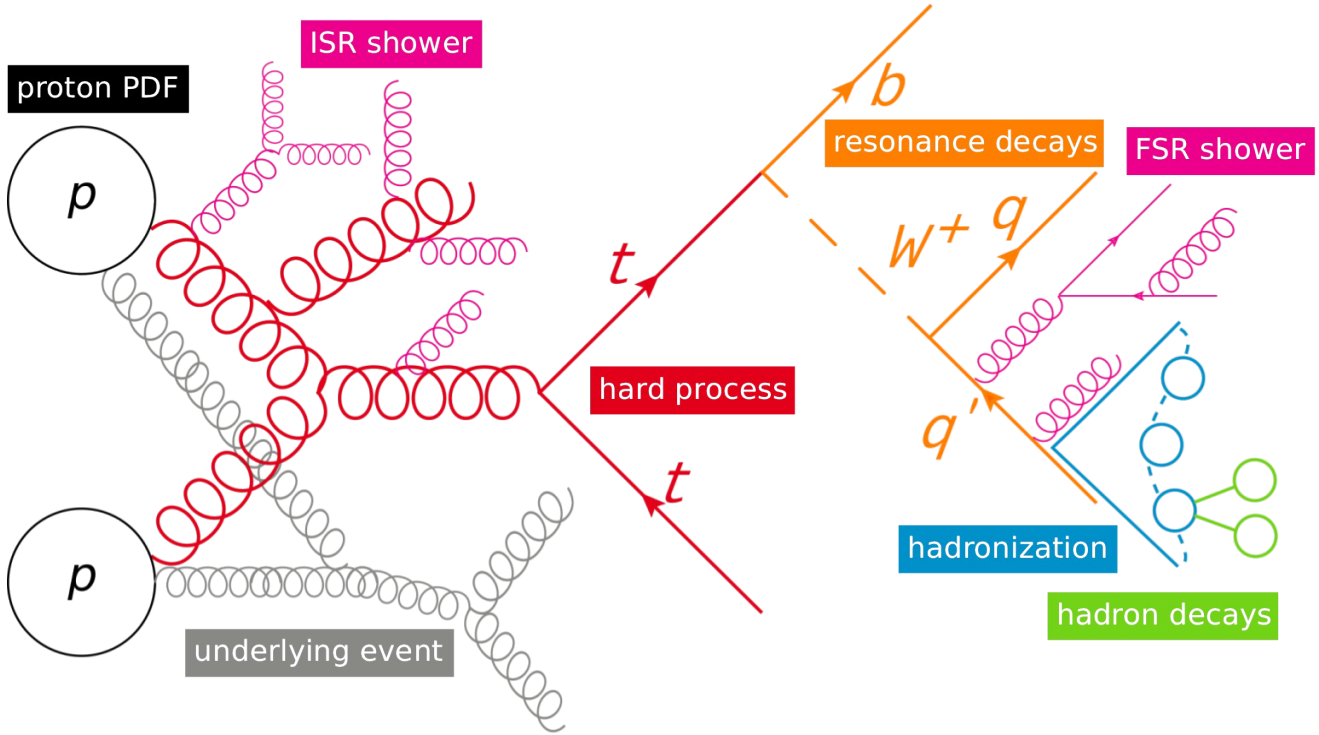


- Signal extraction based on fits of the W→jj' mass in different b-jet and lepton flavor categories



Outlook of $t\bar{t}$ differential cross sections

- Differential cross sections provide:
  - ➔ Comparison between MC generators and setups and data for LO and NLO predictions.
  - ➔ Studies of the modeling in different regions of the phase space: tune of parameters.



Unfolded data: distributions directly comparable with predictions.

- Particle level: final state objects with safe and unambiguous definition. Fiducial phase space (avoid extrapolation uncertainties).
- Parton level: extrapolation to the full phase space, based on NLO ME and simulation of PS.

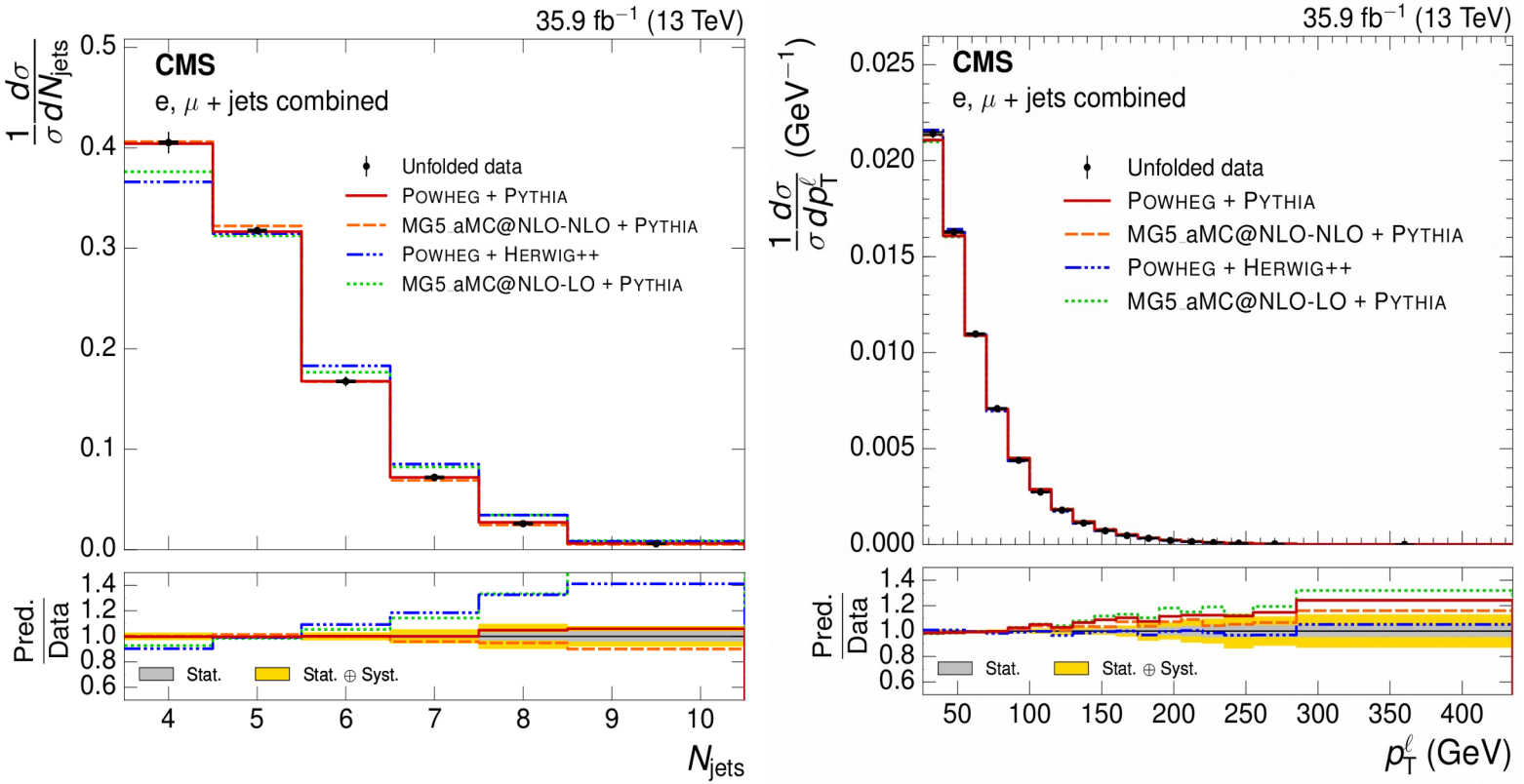
Kinematic event variables

CMS-TOP-16-014 (accepted by JHEP, arxiv:1803.03991)

- Differential $t\bar{t}$ production cross section, 13 TeV, 35.9 fb^{-1}. Single lepton (e/μ) + jets channel, particle level.
- Kinematic event variables that not require the reconstruction of the $t\bar{t}$ system: N_{Jets}, H_T (scalar sum of Jet p_T), S_T (scalar sum of all particles), p_T^{miss}, p_T^W, lepton p_T and η.

Tuned Powheg+Pythia sample good N_{jet} distribution.

Lepton p_T show same trends as top p_T.

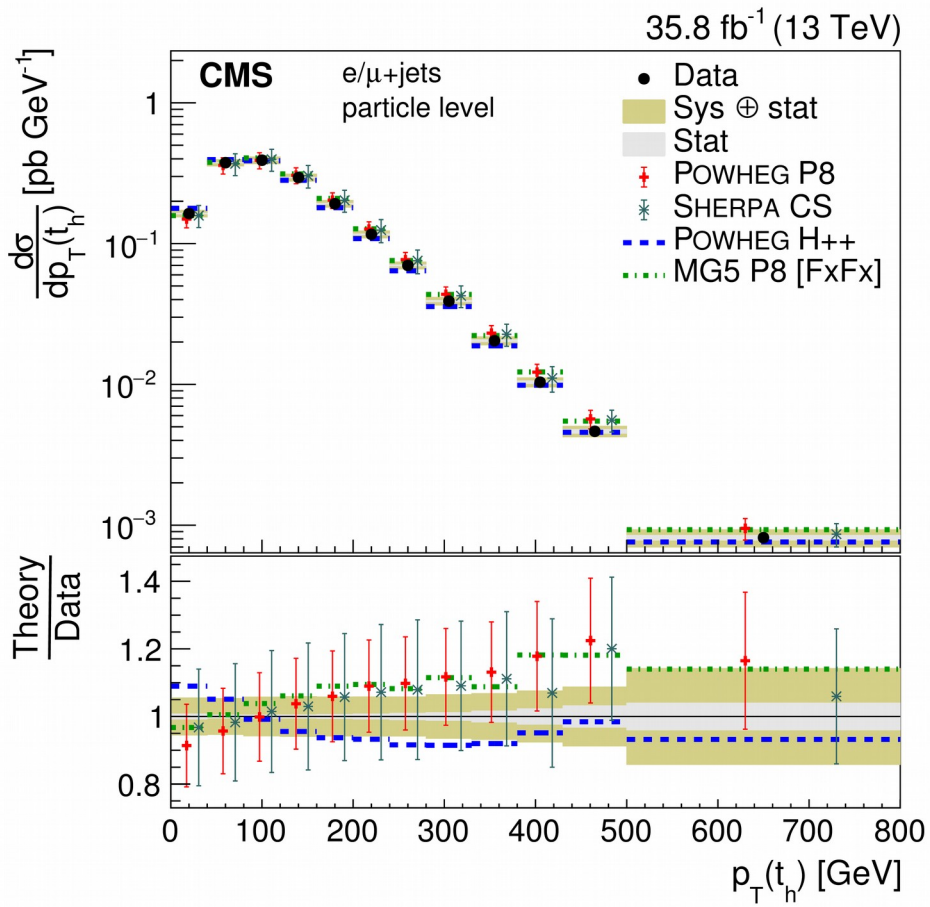


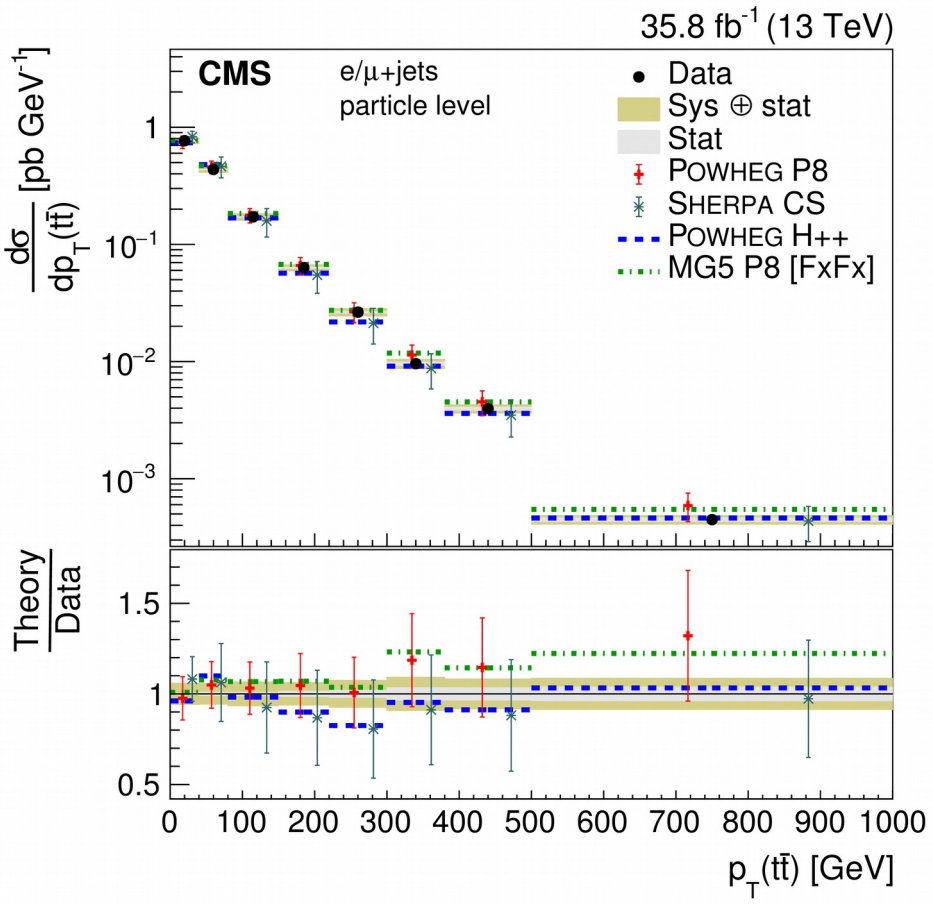
Main uncertainties: Jet energy scale and modeling.

Top quark and $t\bar{t}$ system

CMS-TOP-17-002 (accepted by PRD, arxiv:1803.08856)

- 13 TeV, 35.8 fb^{-1}, e/μ+ jets channel, parton and particle level.
- Kinematic variables of top quark and $t\bar{t}$ system.
- **Double differential** cross sections.
  - ➔ Top p_T,rapidity; $t\bar{t}$ p_T, mass, rapidity; Jet p_T, η...

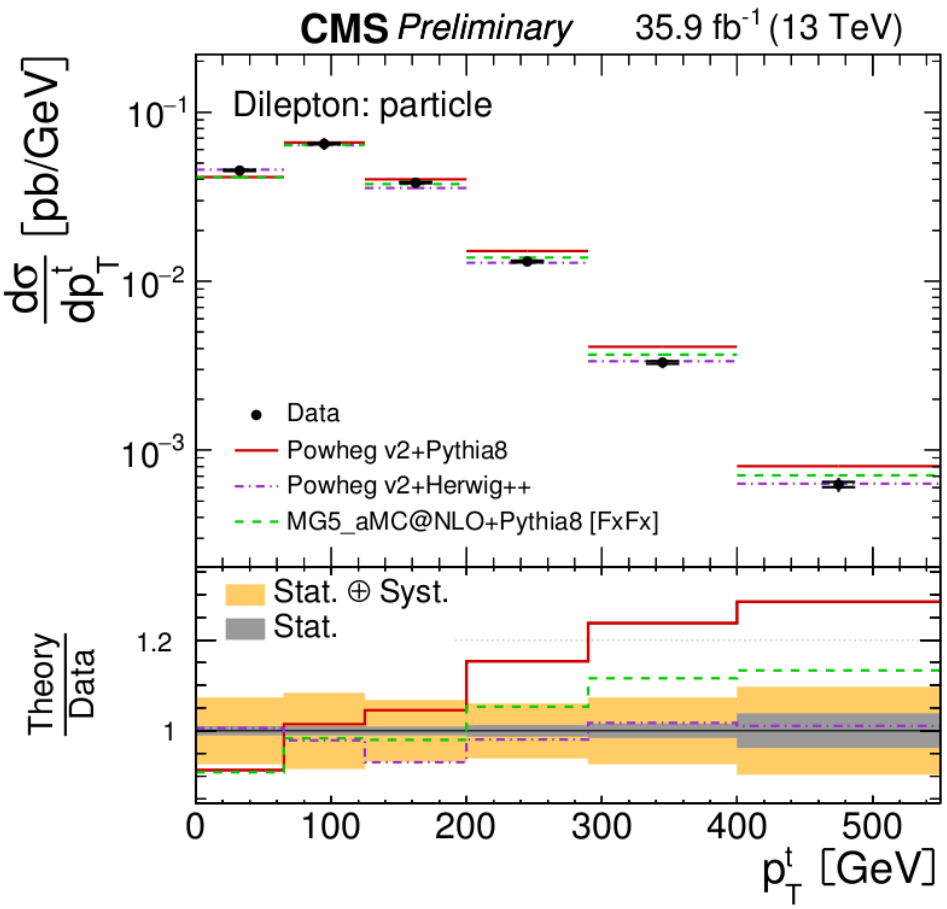


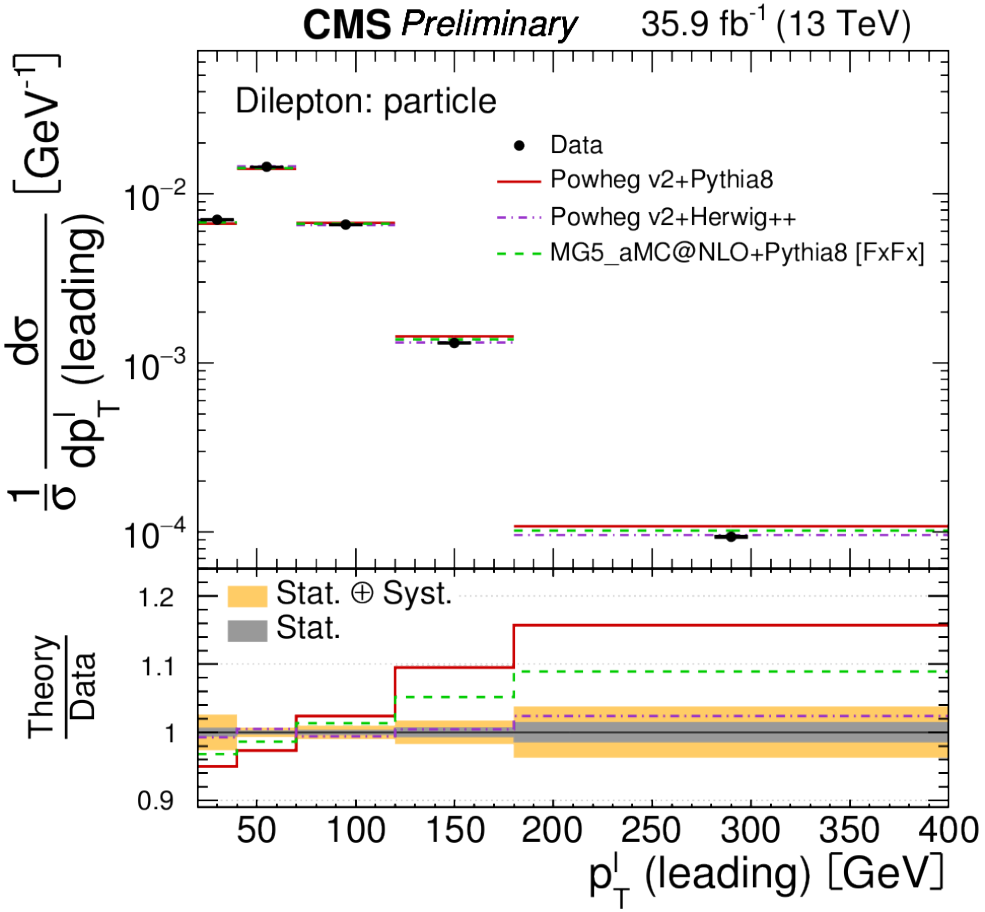


Differential cross sections in dilepton final state

CMS-PAS-TOP-17-014

- 13 TeV, 35.9 fb^{-1}, dilepton channel, parton and particle level.
- Kinematic variables of top quark and $t\bar{t}$ system and their decay products.





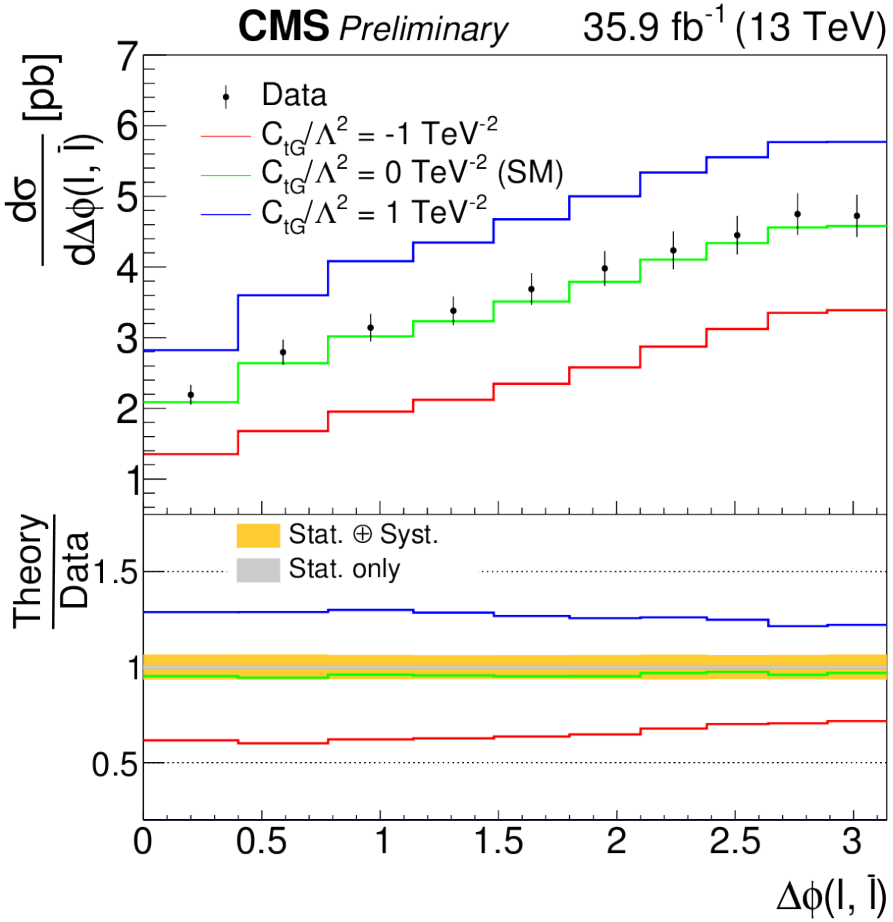
- Top quark p_T not well modeled by Powheg+Pythia8.

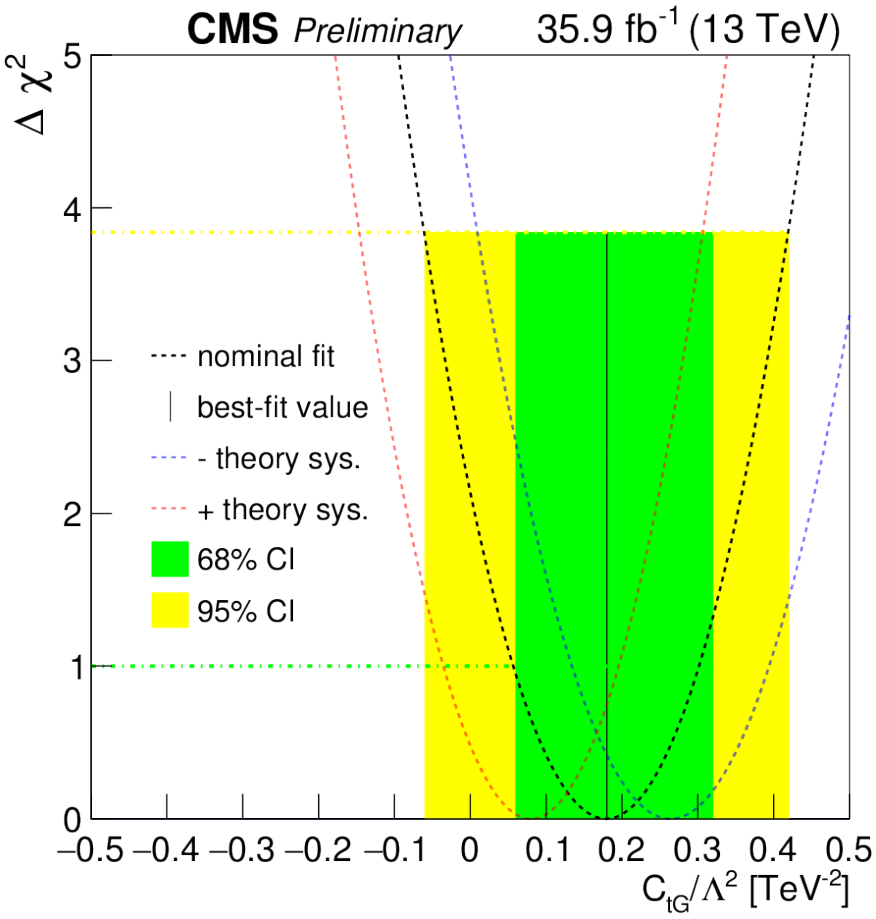
Differential cross sections in dilepton final state (2)

- The top quark **chromomagnetic dipole moment** (CMDM) is constrained from the differential $t\bar{t}$ cross section as a function of $\Delta\phi(l,\bar{l})$.

CMS-PAS-TOP-17-014

- Predictions at NLO in an EFT framework [Phys.Rev.D 91(2015)114010], sensitivity to CMDM parameterized with C_{tG}/Λ^2 (C_{tG}: dimensionless Wilson coef.).

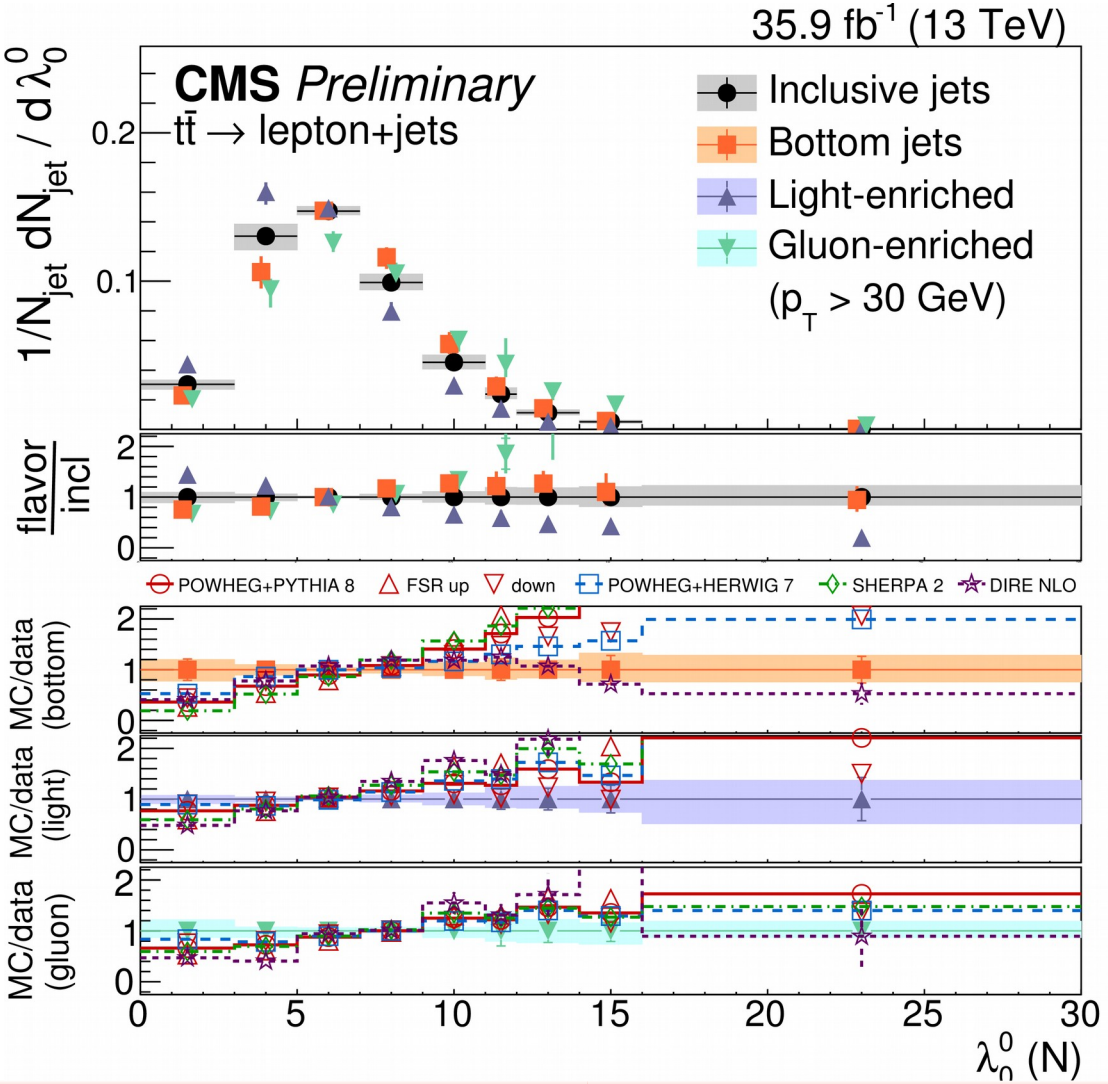




Jet substructure in $t\bar{t}$

CMS-PAS-TOP-17-013

- 13 TeV, 35.9 fb^{-1}, e/μ+ jets, unfolded data to particle level.
- Multiple jet substructure variables: particle multiplicity, eccentricity, p_T dispersion, N-subjettiness ratios, energy correlations, etc.
- Samples enriched in jets coming from b quarks, light quarks and gluons.

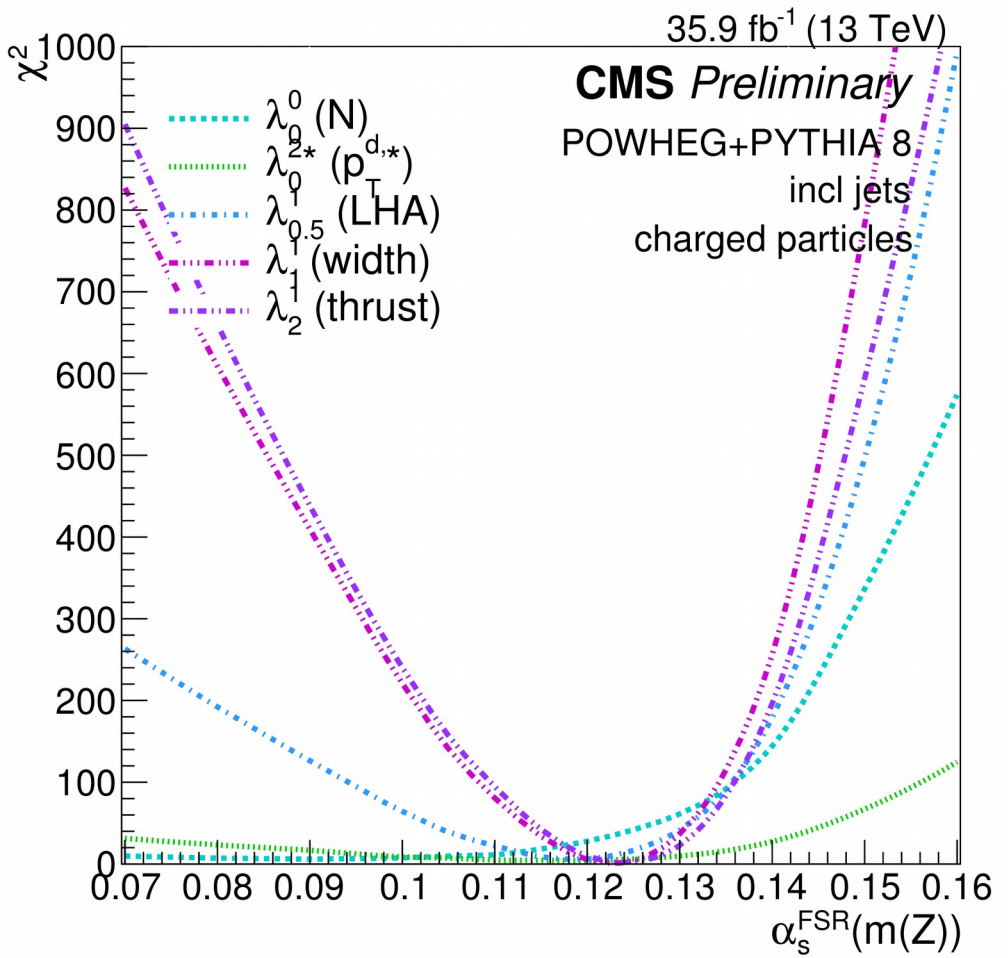


- None of the probed generator has a good overall agreement with data. Further tuning based on this analysis is derived.
- A better agreement is achieved by lowering the default value of the effective strong coupling for FSR.
- Main uncertainties: FSR modeling, tracking.

Jet substructure in $t\bar{t}$ (2)

CMS-PAS-TOP-17-013

- Fit to $\alpha_s^{FSR}(m_Z)$ (Pythia8) using different families of jet substructure observables.



- Fit to different shape-related jet observables.
- Great precision from the fit to jet width (λ_1).

Best value of $\alpha_s^{FSR}(m_Z) = 0.1227 \pm 0.0013$.

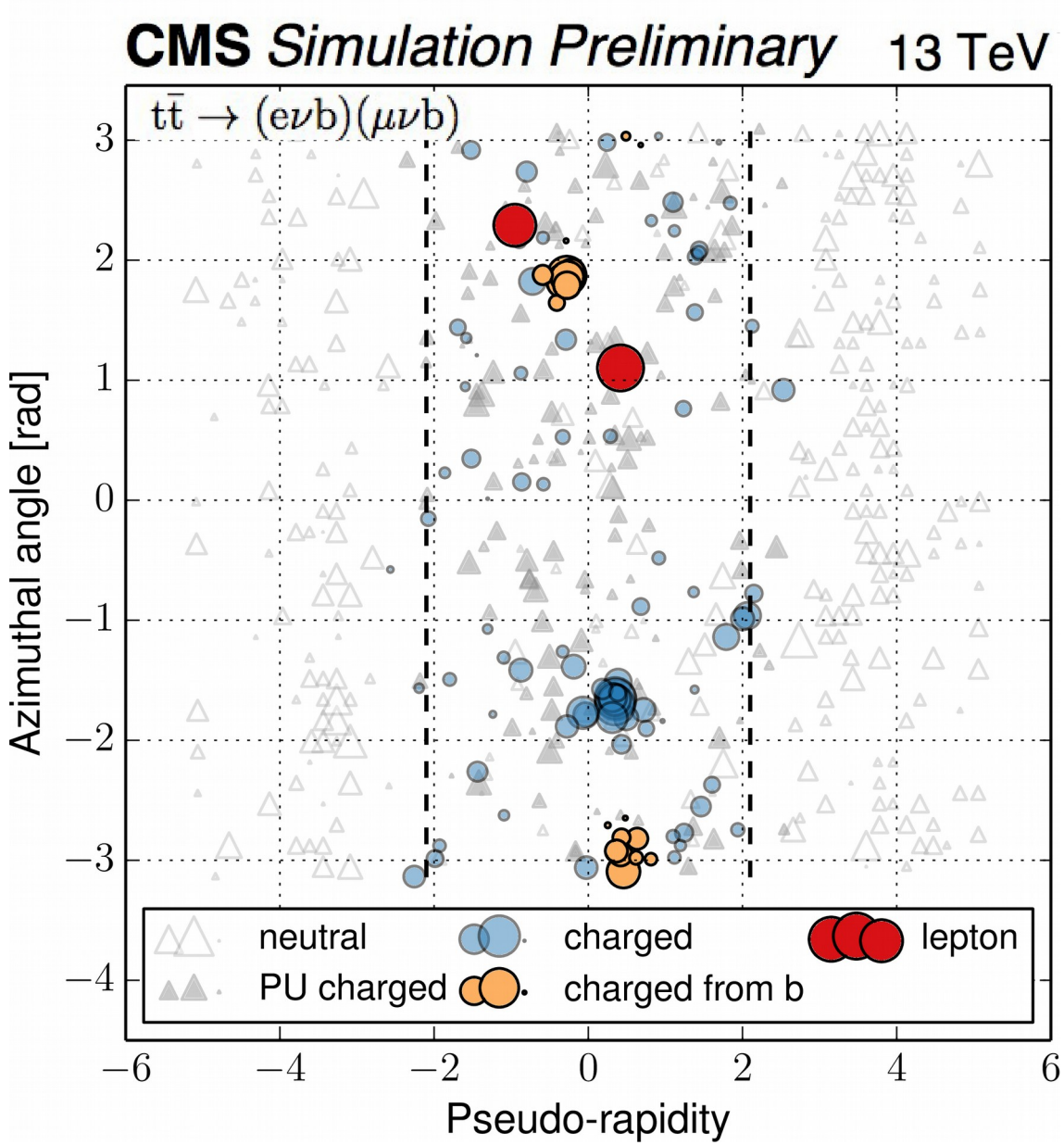
Underlying event in $t\bar{t}$ events

CMS-PAS-TOP-17-015

First measurement of UE in $t\bar{t}$ events.

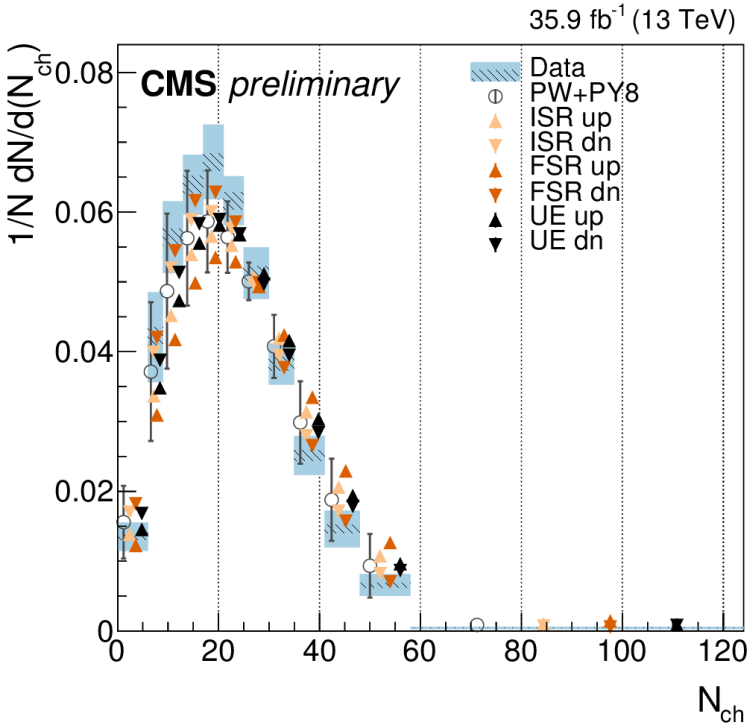
- <u>UE candidates:</u>
  All particles in the event not coming from PU interactions nor coming from $t\bar{t} \rightarrow e\mu bb$ decay.

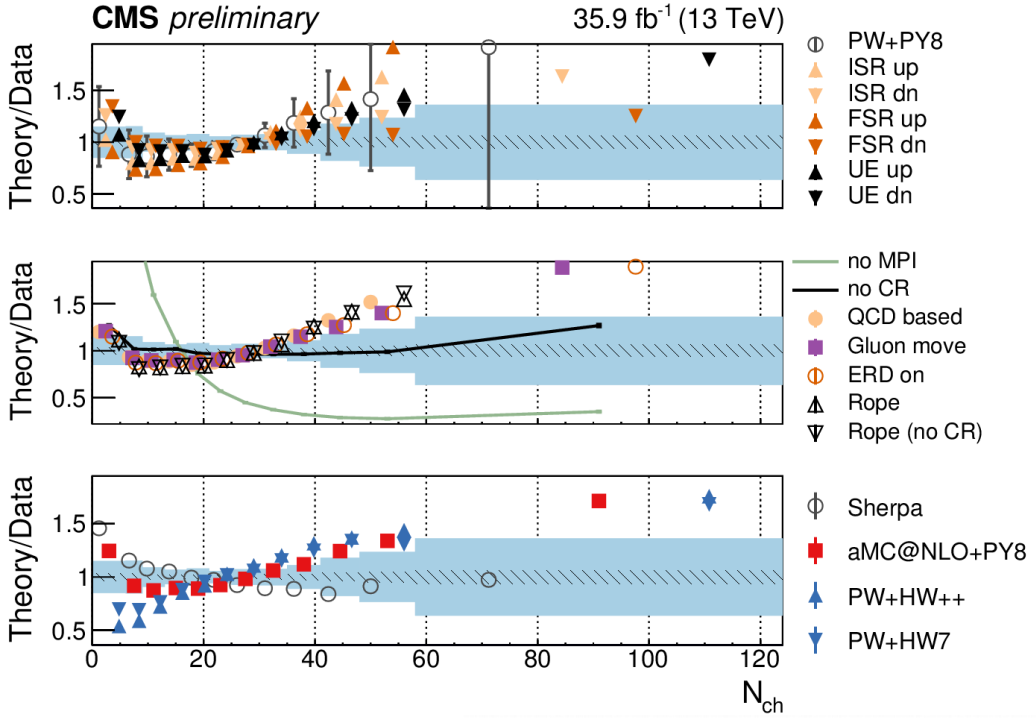
- <u>This analysis:</u>
  Study of different observables: charged particle multiplicity, charged particle recoil, average particle p_T, etc.



Underlying event in $t\bar{t}$ events (2)

- Different observables are compared with predictions.

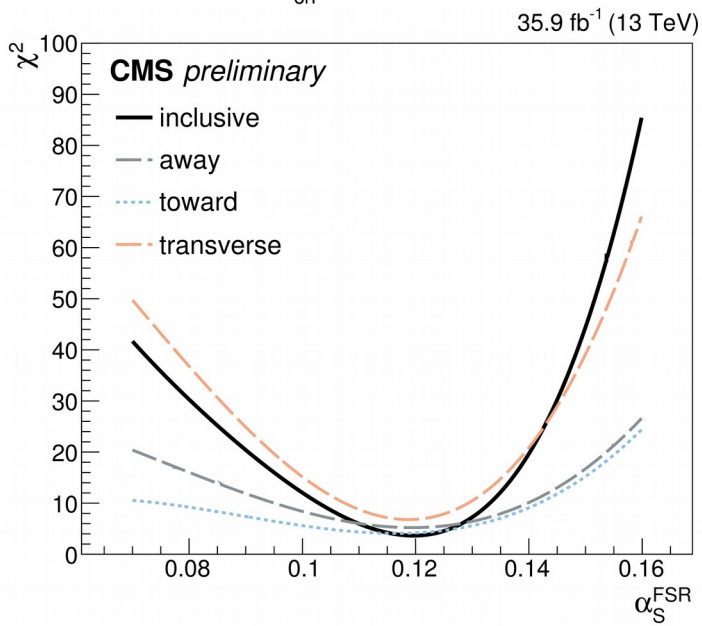




- Large sensitivity to FSR.

Main uncertainties: tracking efficiency, top quark p_T modeling.

- Extraction of $\alpha_S^{FSR}(m_Z)$.



$\lvert\vec{p}_T(\ell\ell)\rvert$ region	Inclusive	Away	Toward	Transverse
Best fit α_S^{FSR}	0.120	0.119	0.116	0.119
68% CI	[-0.006,+0.006]	[-0.011,+0.010]	[-0.013,+0.011]	[-0.006,+0.006]
95.45% CI	[-0.013,+0.011]	[-0.022,+0.019]	[-0.030,+0.021]	[-0.013,+0.012]

Conclusions

$t\bar{t}$ cross section measurements give us an excellent tool to study QCD and probe the SM predictions.

Inclusive cross section:

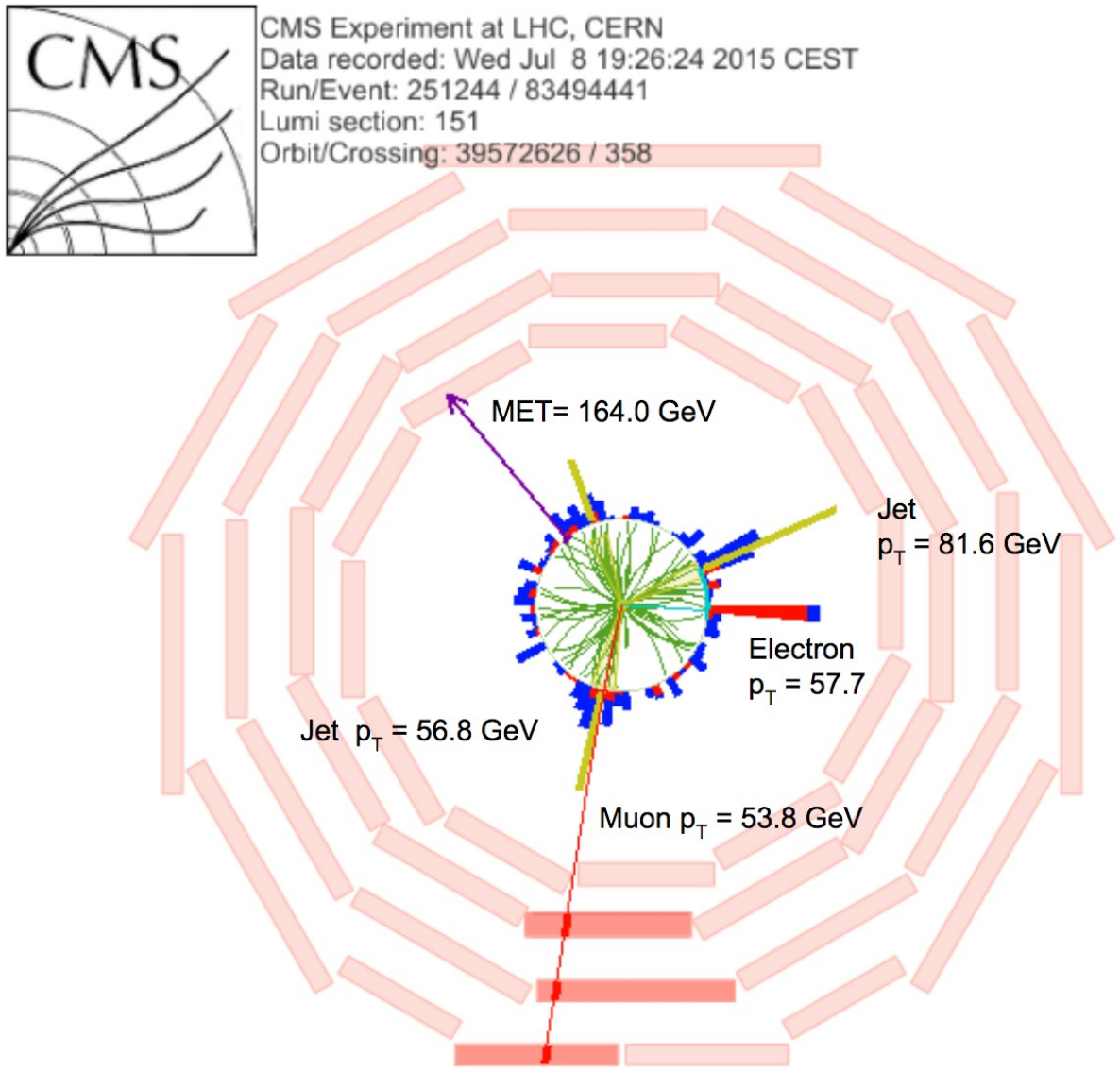
- Good agreement with theory over a large range of centre-of-mass energies (5.02 TeV to 13 TeV) and collision systems (pp, pN).

Differential cross section:

- Several new results by CMS.
- First UE measurement on $t\bar{t}$ events.
- Several channels, also double differential.
- A deep look into jet substructure.
- Great impact on the determination of α_s and $t\bar{t}$ modeling.

BACK UP SLIDES

$t\bar{t}$ production

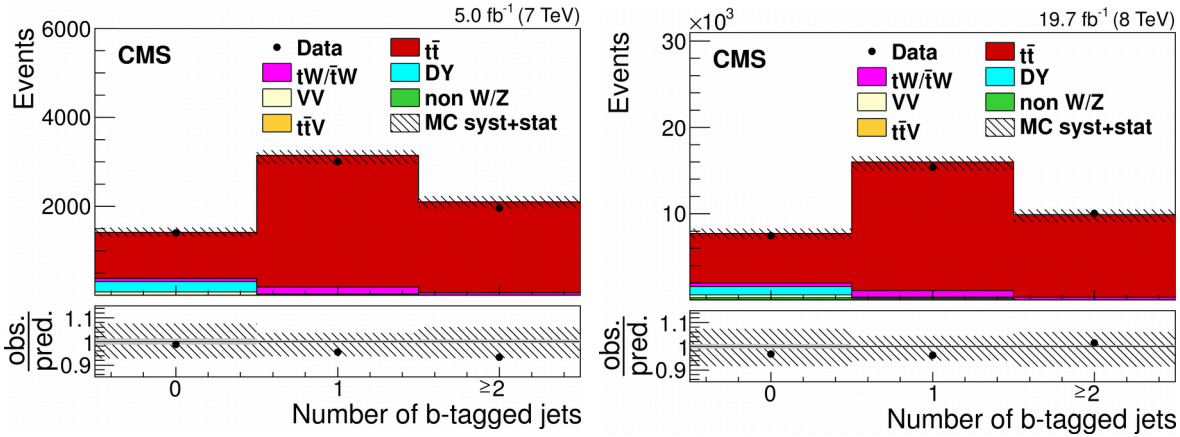


Legacy inclusive cross sections at 7 and 8 TeV

Precision measurement with 5.0 fb^{-1} at 7 TeV, 19.7 fb^{-1} at 8 TeV, eμ.

JHEP. 08 (2016) 029

Binned likelihood fit to multi-differential distributions, jet and b-jet multiplicity.

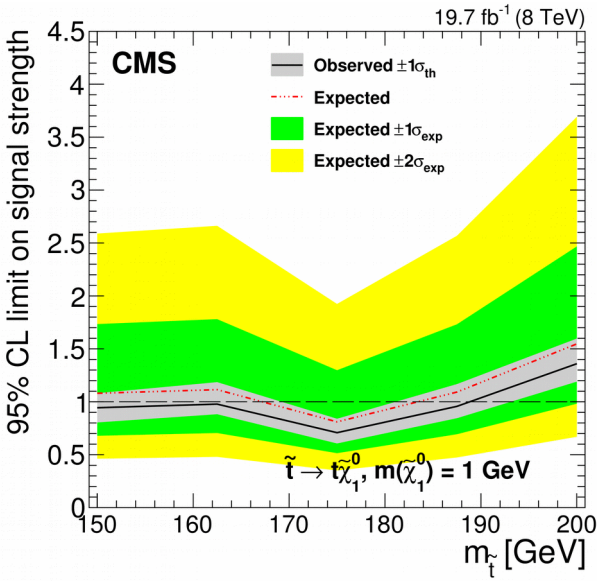


Precision higher than theory predictions:

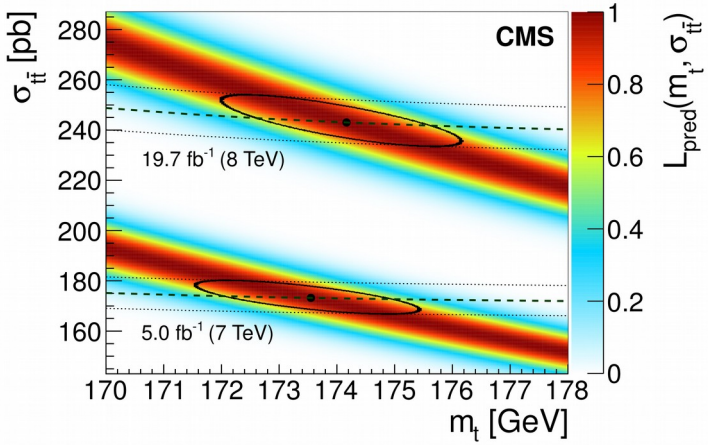
√s	Value	Stat	Syst	Lumi	Total
7 TeV	173.6	2.1	+4.5, -4.0	3.8	6.2 (3.6%)
8 TeV	244.9	1.4	+6.3, -5.5	6.4	9.1 (3.7%)

√s	Theory	Scales	PDF+α_s	Total
7 TeV	173.3	+4.7, -6.0	9.0	10.8 (6.1%)
8 TeV	252.9	+6.4, -8.6	11.7	14.5 (5.7%)

Constrains to SUSY models

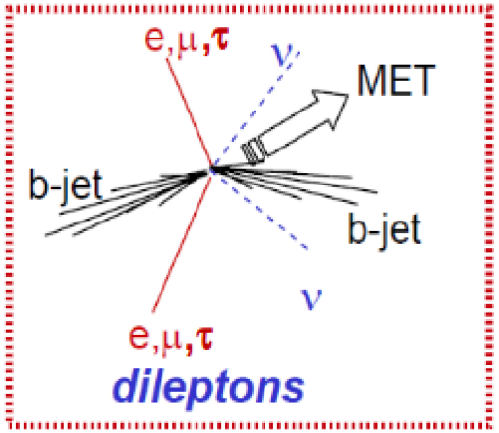


Pole-mass measurement



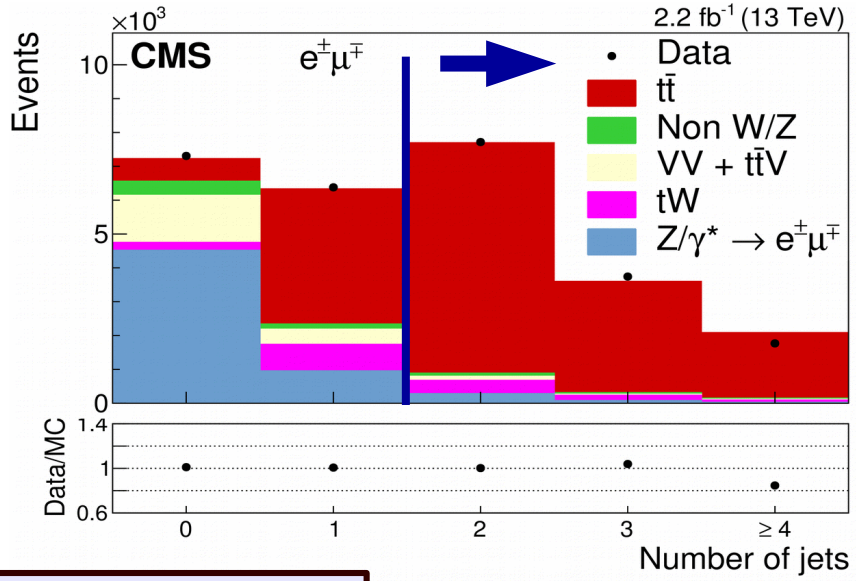
Latest inclusive $t\bar{t}$ cross sections at 13 TeV (2.3 fb^{-1})

EPJC 77 (2017) 172

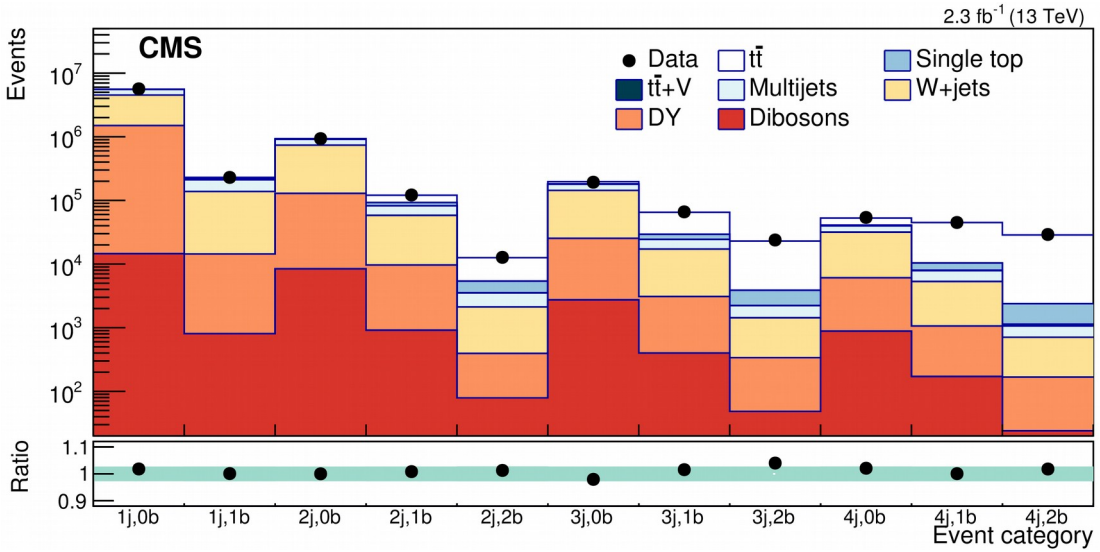


- **Very pure final state (> 95%).**
- Counting method to extract the cross section.
- Main uncertainties: **JES and modeling** (hadronization, NLO generator).

$$\sigma_{t\bar{t}} = \frac{N - N_B}{\mathcal{BR} \cdot \varepsilon \cdot \mathcal{A} \cdot \mathcal{L}'}$$

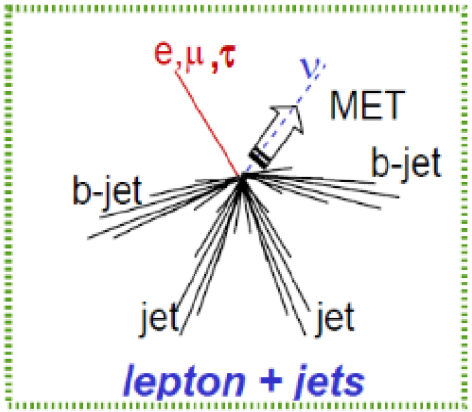


σ_{tt}(13 TeV) = 815 ± 9 (stat) ± 38 (syst) ± 18 (lumi) pb = 815 ± 43 (5.3%) pb



- **PLR fit to jet / b-tag categories.** Syst. unc. as nuisances.
- **QCD** and **W+Jets** estimated from data.
- Main uncertainties: W+Jets, modeling, luminosity.

JHEP 09 (2017) 051



σ_{tt}(13 TeV) = 888 ± 2 (stat) +28, -26 (syst) ± 20 (lumi) pb = 888 ± 34 (3.9%) pb

$t\bar{t}$ cross section measurement at 5.02 TeV

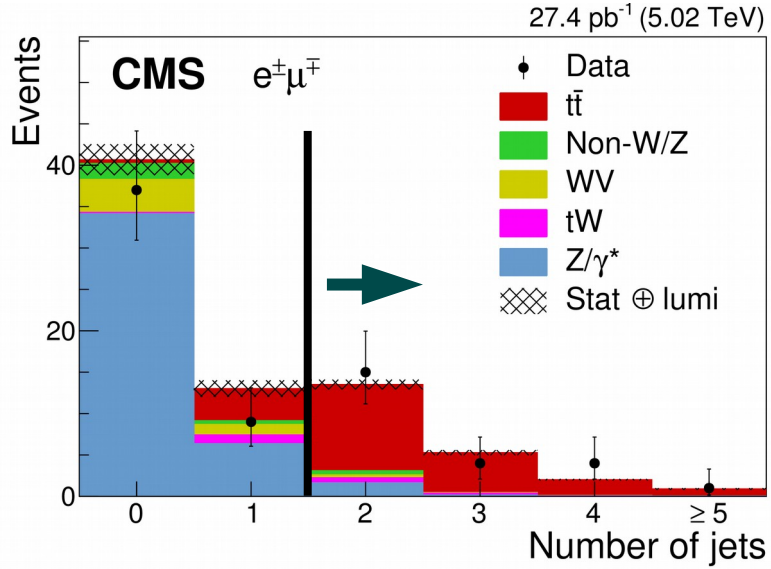
2015 dataset, 27.4 pb^{-1}.

Prediction:

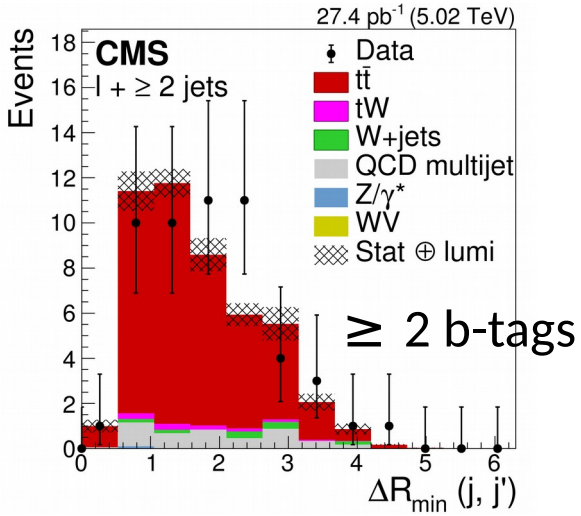
$$\sigma_{t\bar{t}}^{NNLO} = 68.9^{+1.9}_{-2.3}(\text{scale}) \pm 2.3(\text{PDF})^{+1.4}_{-1.0}(\alpha_S)\ \text{pb}$$

JHEP 03 (2018) 115

Combination measurement in lepton+jets,



Main uncertainties: Statistics, W+Jets estimate (in lepton +jets).

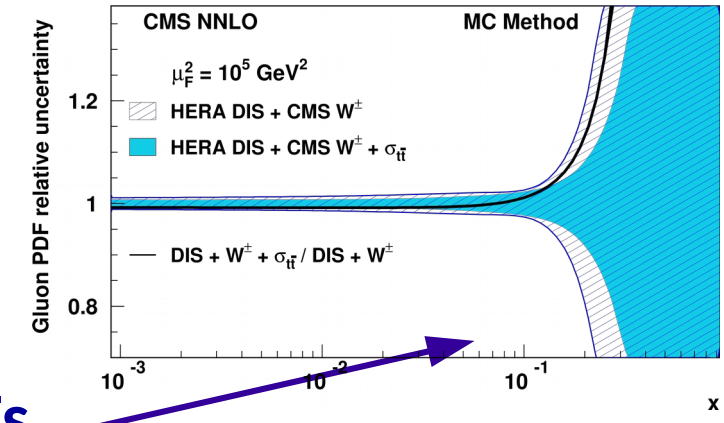


Dilepton, counting experiment.

Lepton+jets, PLR fit.

Combined result:

σ_{tt}(5.02 TeV) = 69.5 ± 6.1 (stat) ± 5.6 (syst) ± 1.6 (lumi) pb = 69.5 ± 8.4 (12%) pb

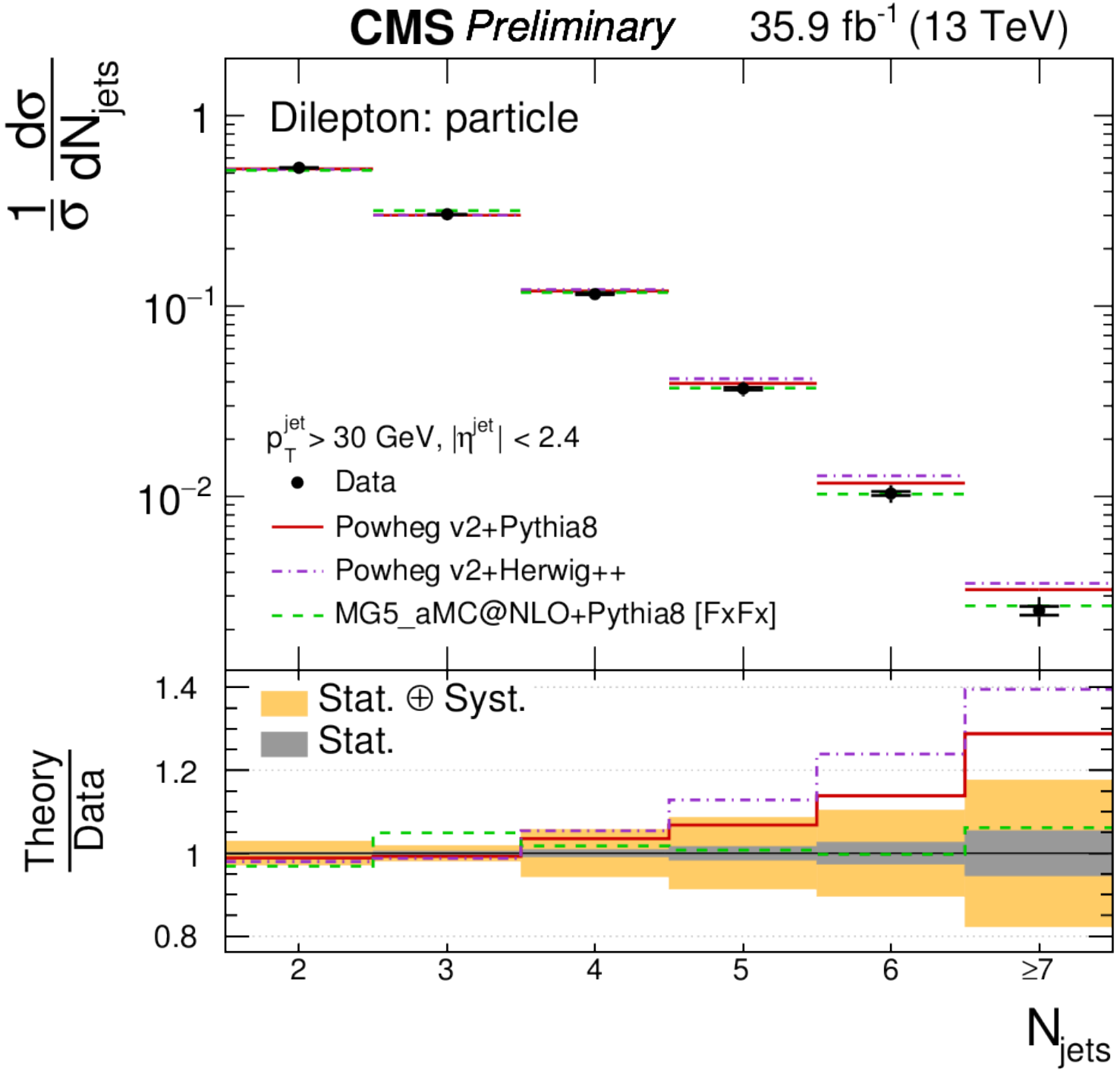


This measurement probes **high <x> gluon PDFs**

Differential cross sections in dilepton final state (2)

CMS-PAS-TOP-17-014

- Comparisons of different generators at particle level.
  - Powheg+P8
  - Powheg+H++
  - aMC@NLO+P8 [PxPx]



Double differential cross sections

CMS-TOP-17-002 (submited to PRD, arxiv:1803.08856)