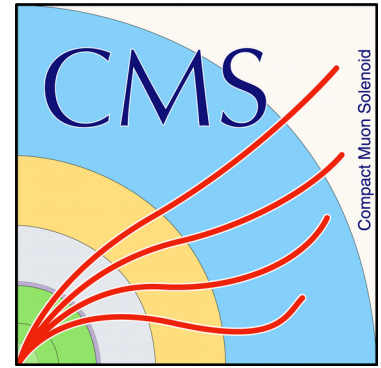


UNIVERSIDAD DE OVIEDO



# Top quark pair production and modeling via QCD in CMS

Juan R. González Fernández (**Universidad de Oviedo**)

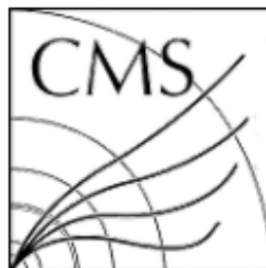
On behalf of the **CMS Collaboration**

4/4/17

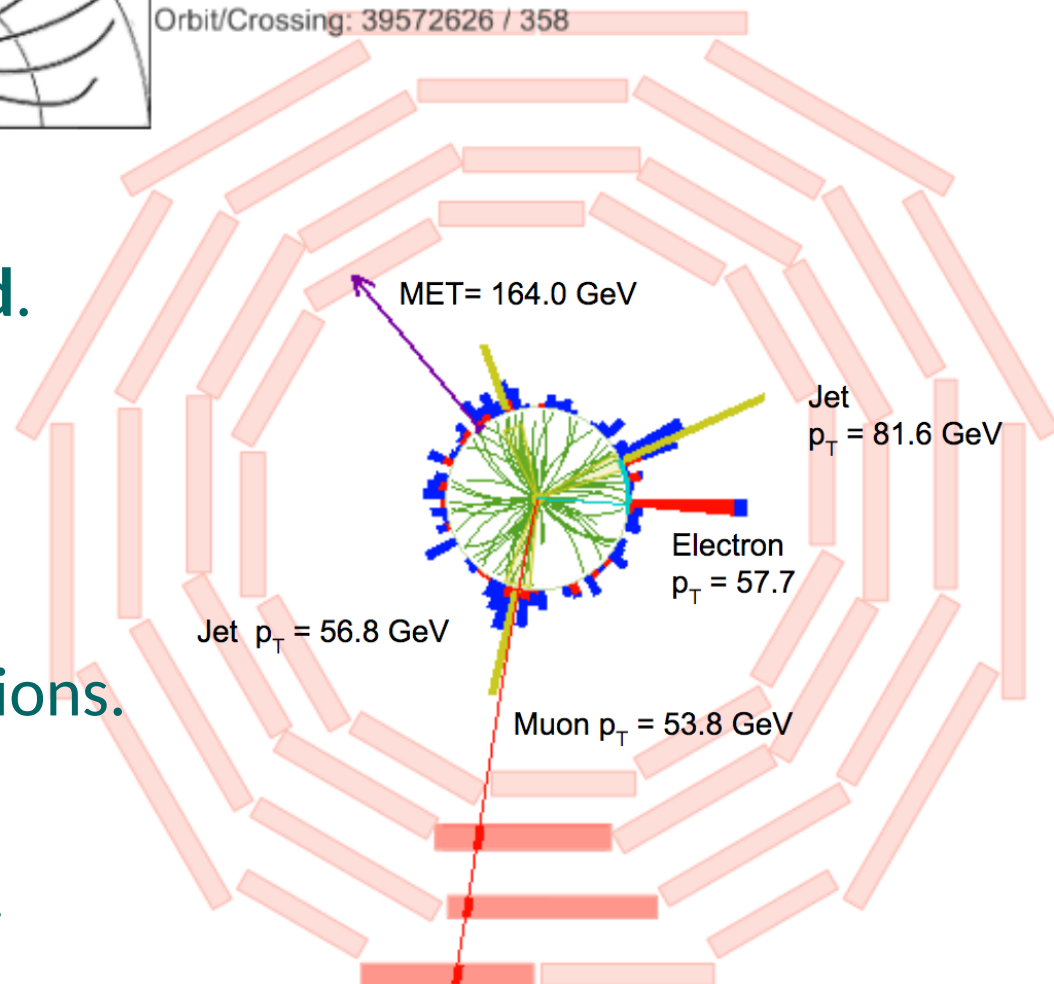
**25th International Workshop on Deep Inelastic  
Scattering and Related Topics, Birmingham**

# Outline

- Introduction
  - **Why is top important?**
- **Inclusive** cross sections:
  - **New result at 5.02 TeV!!**
  - 13 TeV: All hadronic + **boosted**.
  - Dilepton, lepton + jets.
- **Differential** cross sections:
  - Recent **results at 13 TeV**.
  - **Double-differential** cross sections.
- **Modeling of  $t\bar{t}$  production**
  - New **Powheg+Pythia8** tuning.
- **$t\bar{t}+b\bar{b}$  and  $t\bar{t}t\bar{t}$  cross sections.**

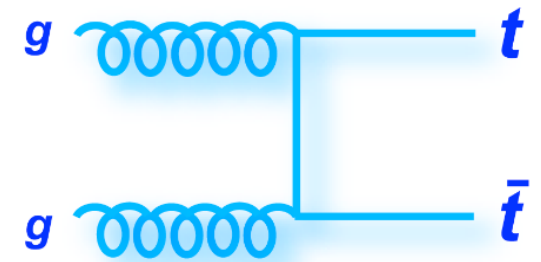
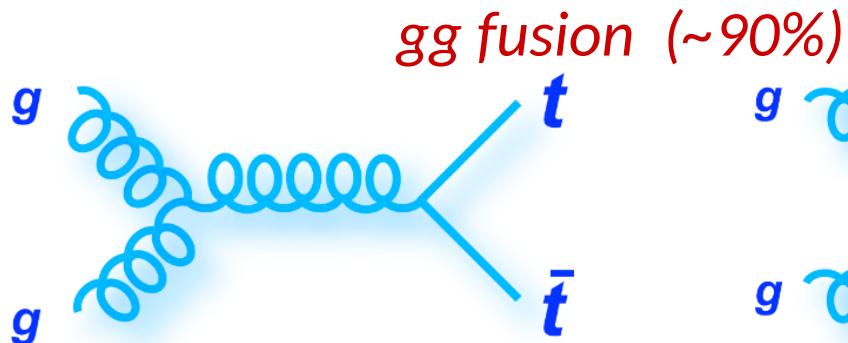
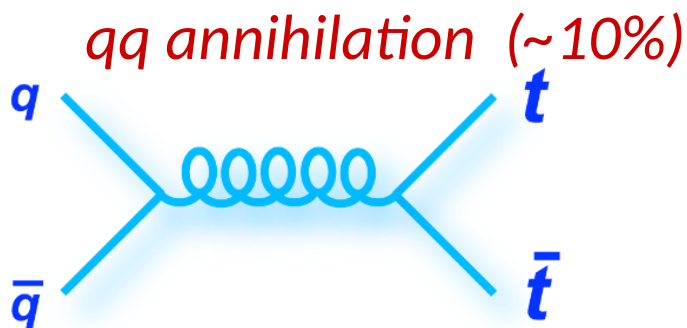
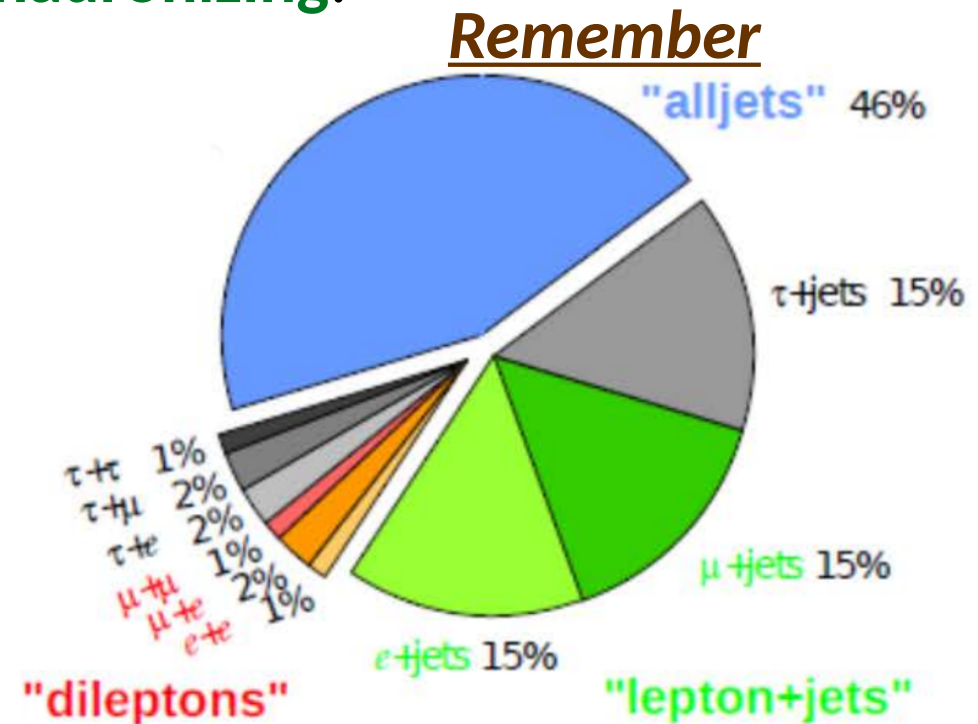


CMS Experiment at LHC, CERN  
Data recorded: Wed Jul 8 19:26:24 2015 CEST  
Run/Event: 251244 / 83494441  
Lumi section: 151  
Orbit/Crossing: 39572626 / 358



# Why top quark is SO important

- Heaviest particle in the SM:  $M_t = 172.33 \pm 0.49 \text{ GeV}$  [arXiv: 1509.04044]
- The only quark that **decays before hadronizing**.
- Essential for probing the SM:
  - ✓ pQCD precision tests.
  - ✓ Consistency of  $M_H$ ,  $M_W$ ,  $M_t$ .
  - ✓ Strongest Yukawa coupling.
- Constrains **proton PDFs** and **new physics** scenarios.
- **Main background** in plenty of BSM searches.



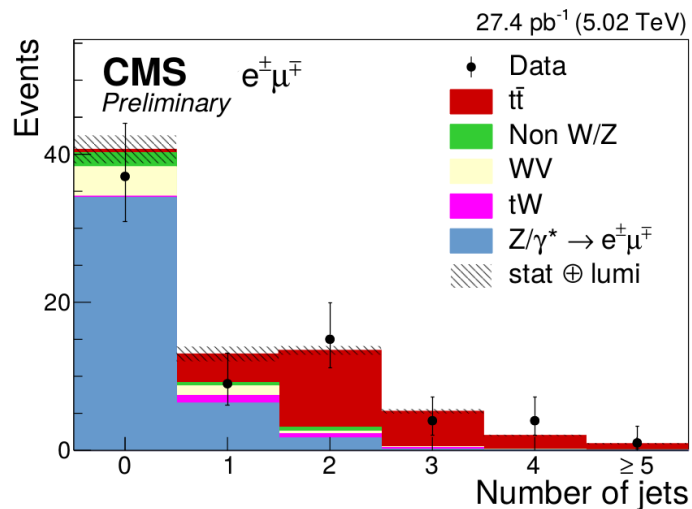
# Inclusive cross section: new measurement

## New result at 5.02 TeV

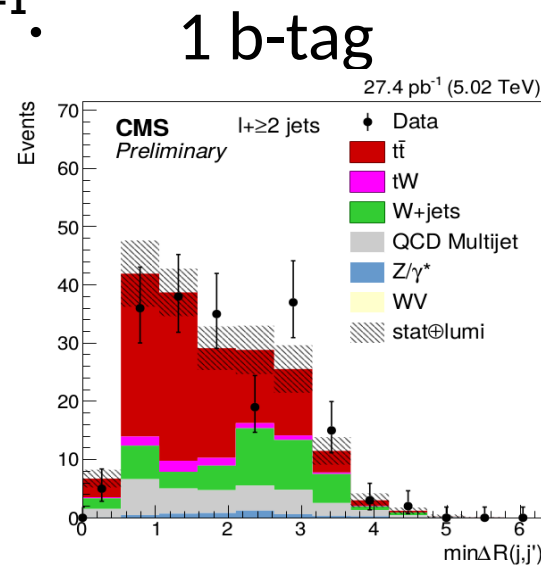
Prediction:

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

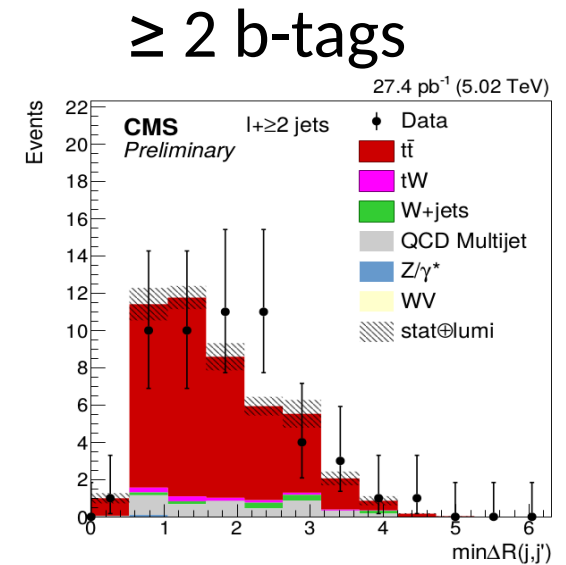
**TOP-PAS-16-023** Combination measurement in lepton+jets,  $e\mu$  and  $\mu\mu$  final states, with  $27.4 \text{ pb}^{-1}$ .



Dilepton, counting experiment.



Lepton+jets, PLR fit.



This measurement probes **high  $\langle x \rangle$  gluon PDFs**  $\rightarrow$  [See talk from Katerina Lipka](#)

Combined result (12% total uncertainty):

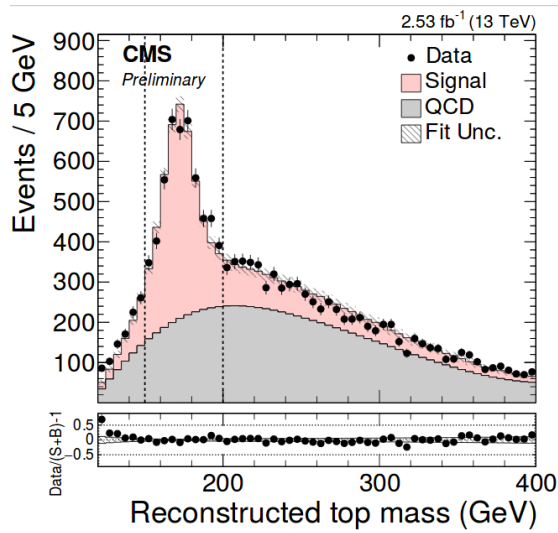
$$\sigma(pp \rightarrow t\bar{t}) = 69.5 \pm 6.1 (\text{stat}) \pm 5.6 (\text{syst}) \pm 1.6 (\text{lumi}) \text{ pb}$$



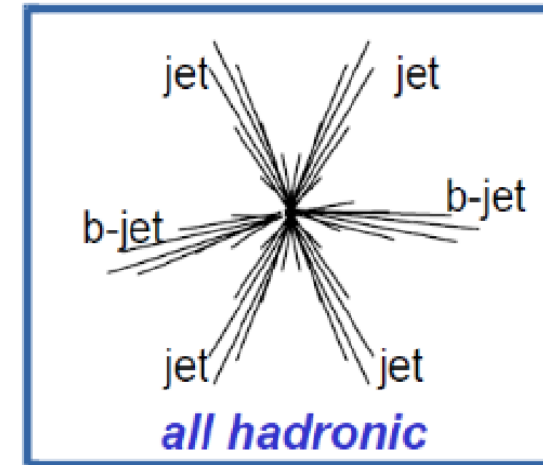
# Inclusive cross section: 13 TeV

Latest results at 13 TeV with **2.3 or 2.5 fb<sup>-1</sup>**

TOP-PAS-16-013



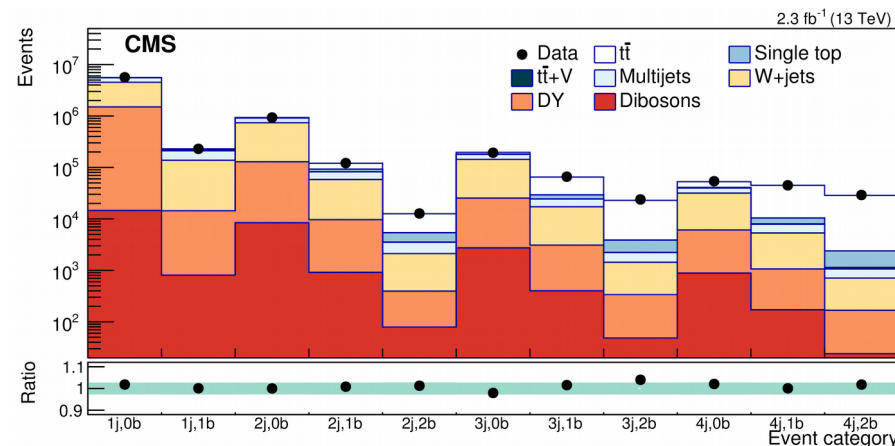
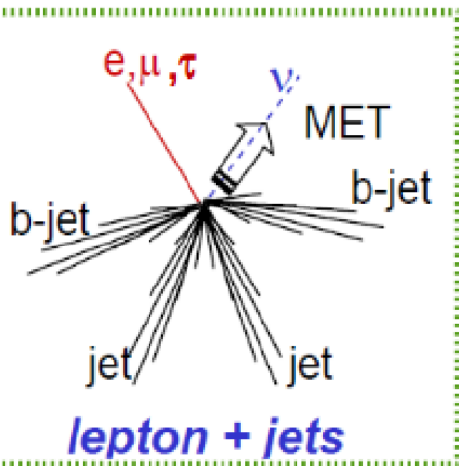
- Large BR but huge **QCD background**.
- Unbinned likelihood maximum fit to **mt** and extract signal and background **normalization**.
- Dominant uncertainties: **JES, b-tagging**.
- Includes study in boosted regime.



arXiv:1701.06228  
[submitted to JHEP]

Simultaneous binned likelihood fit with systematics as nuisance parameters.  
**Categories of jets and b-tags.**

- **QCD** and **W+Jets** estimated from data.
- **Experimental systematics constrained.**
- Main uncertainties: **W+Jets, modeling, luminosity**.

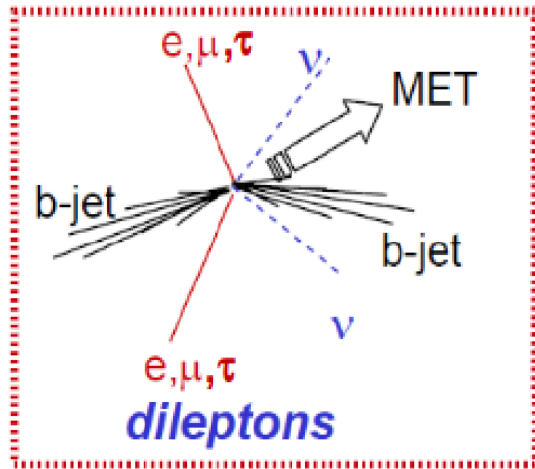


# Inclusive cross section: 13 TeV

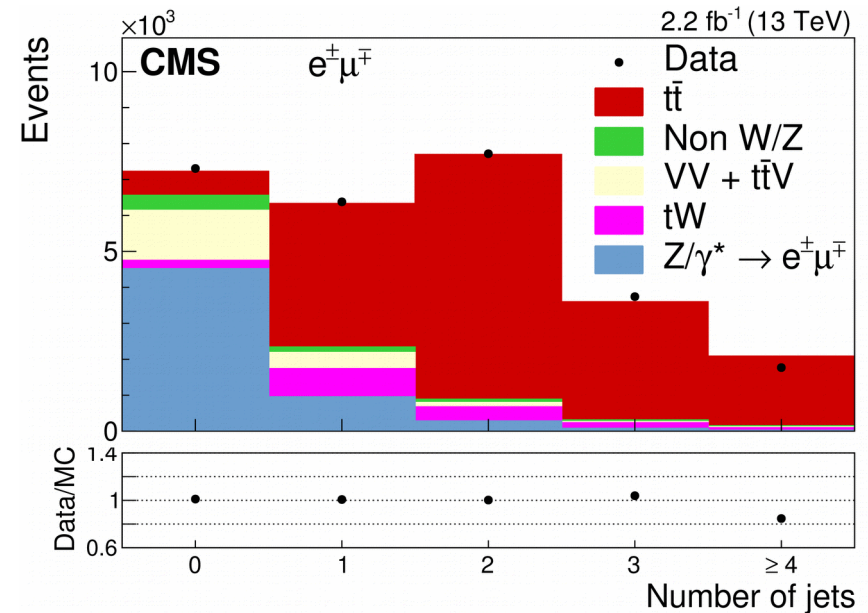
Latest results at **13 TeV** with **2.2 fb<sup>-1</sup>**

**TOP-16-005**

[EPJC 77 (2017) 172]



- **eμ** channel used.
- **DY** and **NonW/Z** estimated from data.
- Robust counting method to extract the cross section.
- Main uncertainties: **JES and modeling** (hadronization, NLO generator).

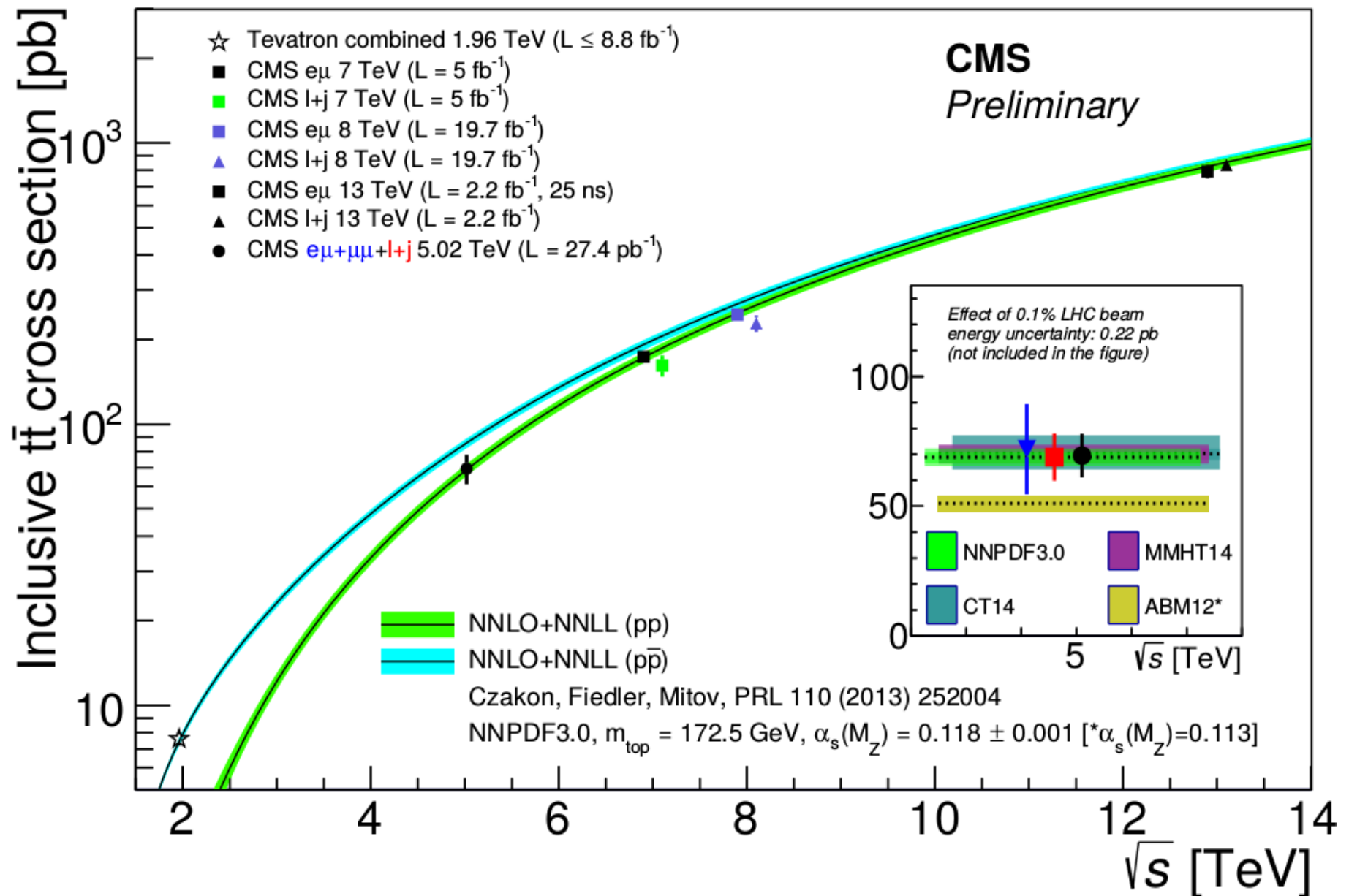


## Results

Channel	Central value	Stat	Syst	Lumi	Total uncertainty
All hadronic	834	25	+118, -104	23	116 (14%)
Lepton + Jets	834.6	2.5	22.8	22.5	32.1 (3.85%)
Dilepton eμ	815	9	38	19	43 (5.3%)

Prediction	Central value	Scales	PDF+α <sub>s</sub>	Total uncertainty
arXiv:1112.6254	832	+20, -29	35	43 (5.3%)

# Inclusive cross section with $\sqrt{s}$

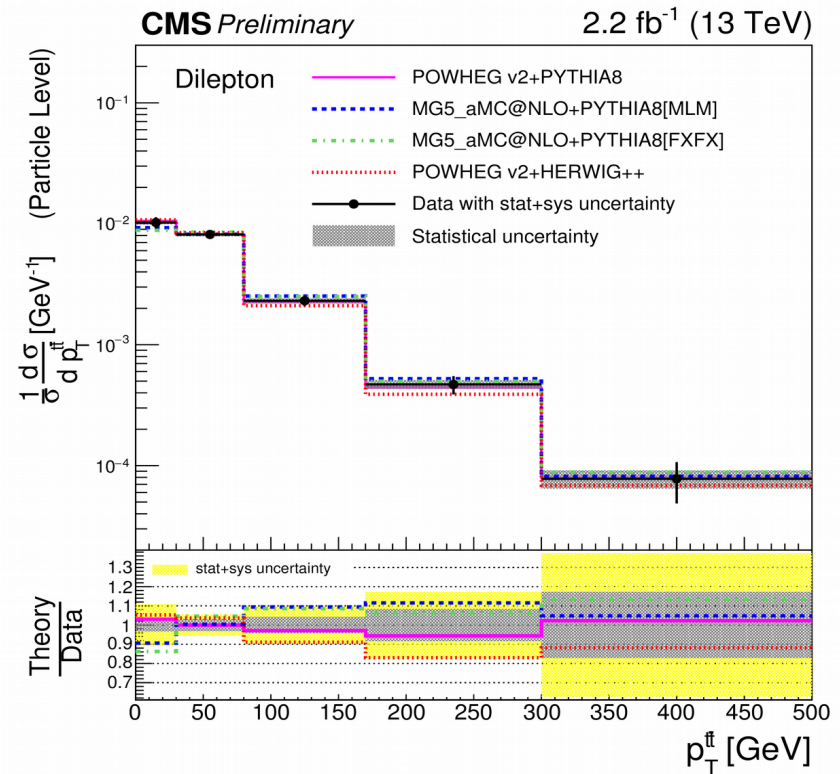
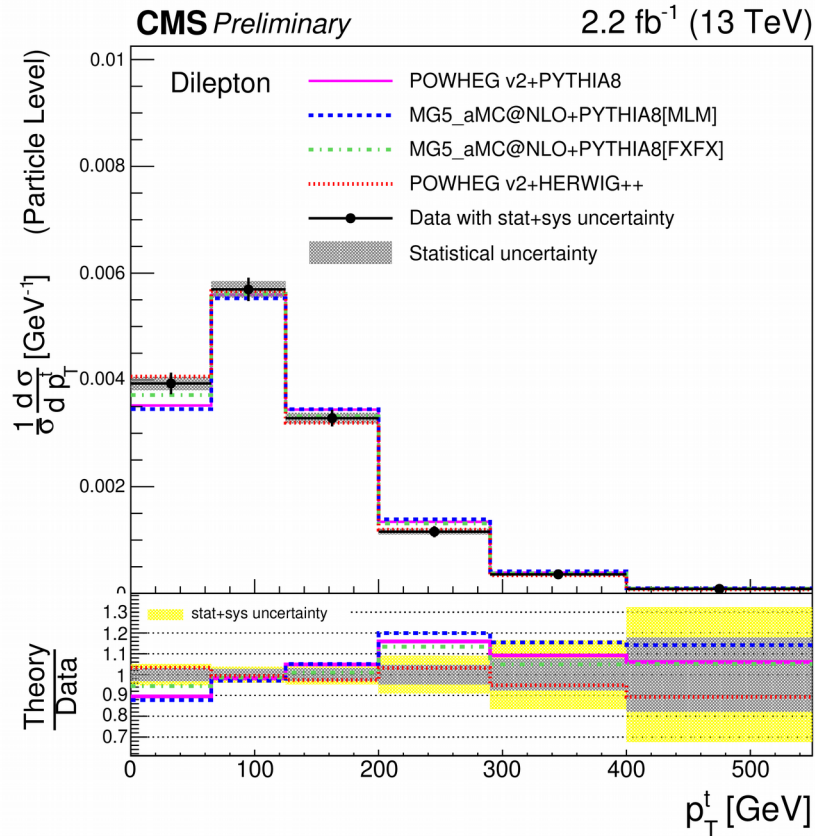


Inclusive cross section is well understood for all energies.

# Differential cross section

CMS-PAS-TOP-16-007

- Results at 13 TeV at **particle level** in the **dilepton** channel.
- Improvement in systematics w.r.t. parton level (CMS-PAS-TOP-16-011).

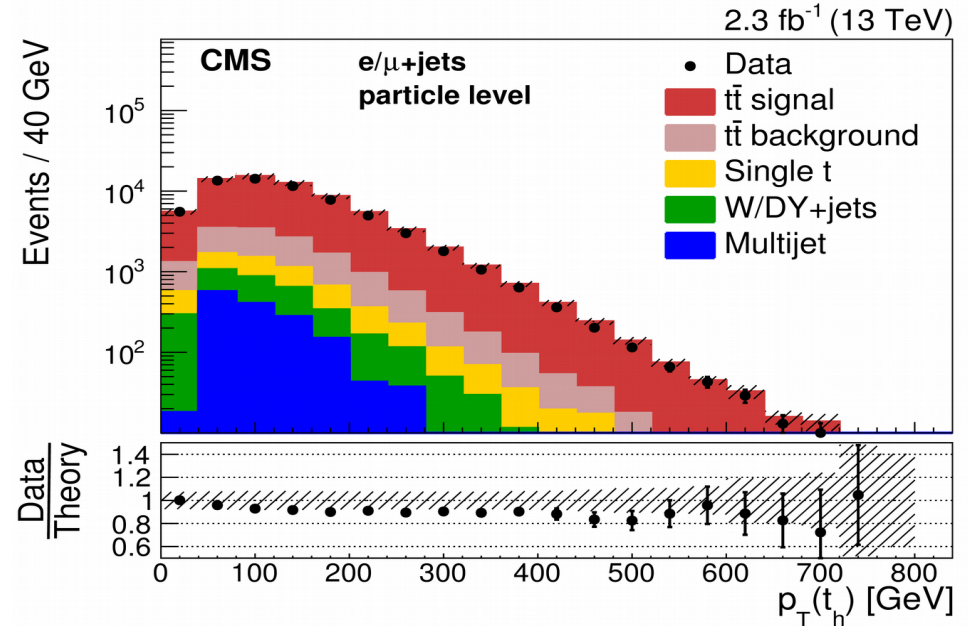
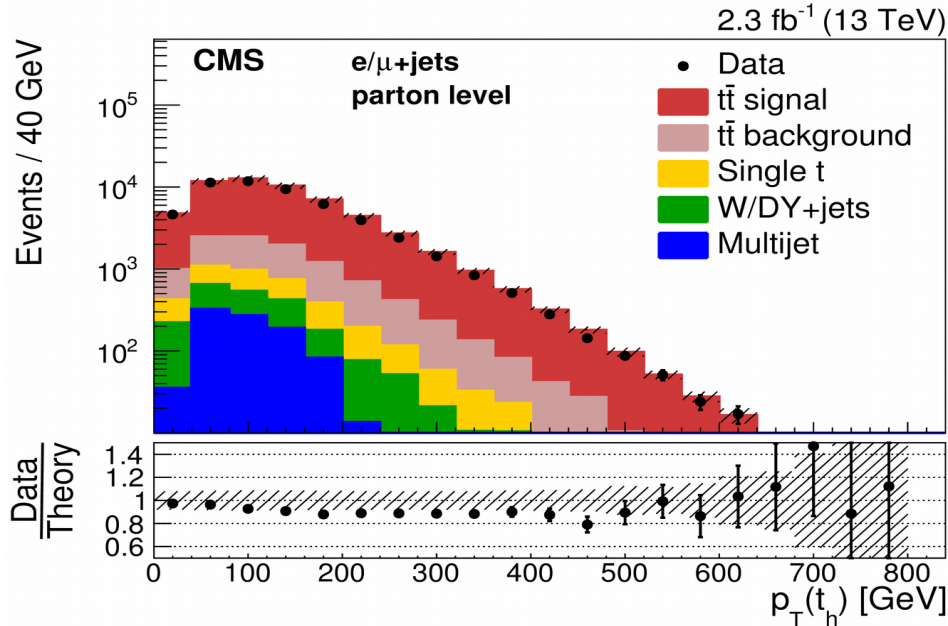


- Main sources from systematics: hadronization, MC modeling.

# Double differential cross section: 13 TeV

Particle level, within experimental acceptance, parton level in the full phase space. Lepton + jets,  $2.3 \text{ fb}^{-1}$ .

arXiv:1610.04191  
[accepted by PRD]



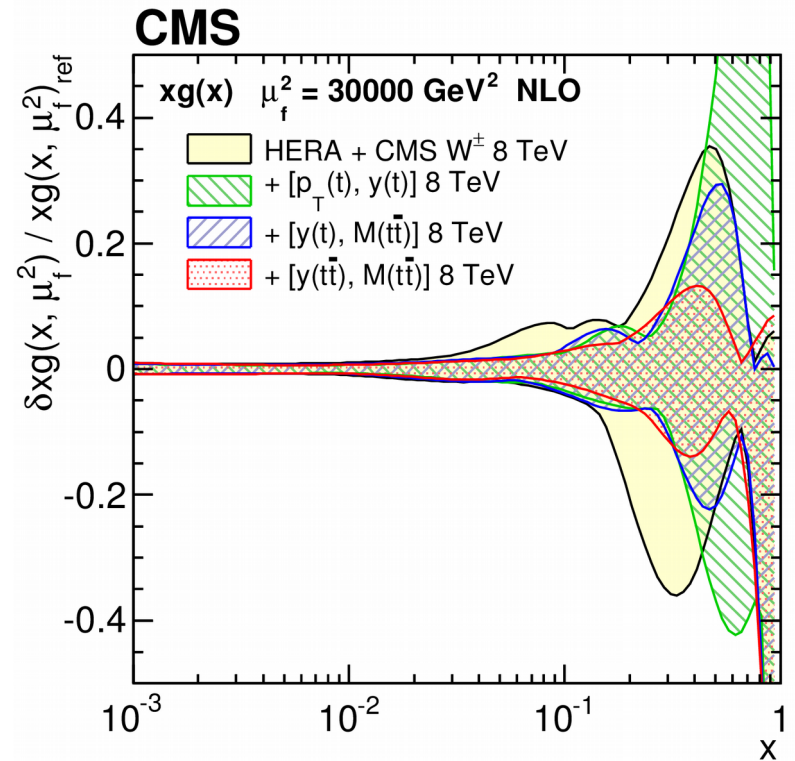
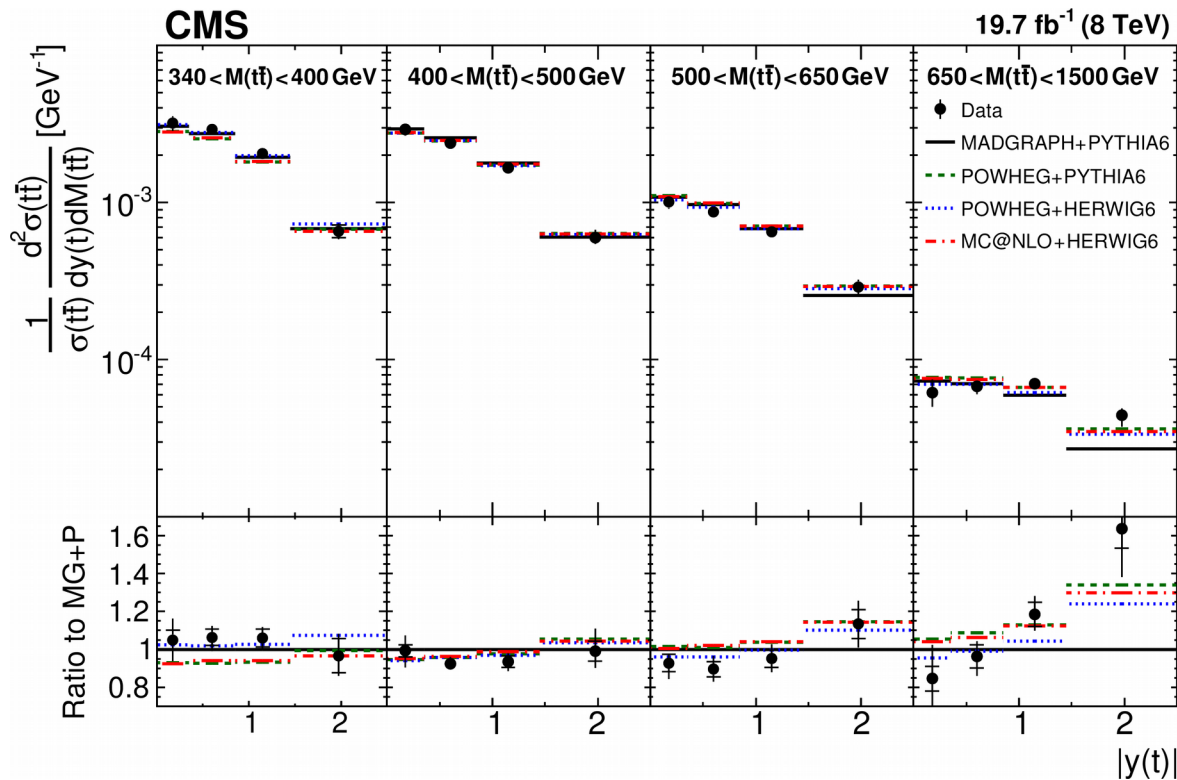
- **Top quark** and  **$t\bar{t}$  system** are reconstructed and several distributions compared with **predictions**.
- Sensitive to various phenomena: **PDFs**, **top mass** or **new physics**...
- Measurement at parton level dominated by uncertainty in **parton shower** and modeling of **hadronization**. **JES** and **b-tagging** for particle level.
- Observed **top  $p_T$**  slightly softer than prediction. Expected **number of additional jets** is lower than observed.



# Double differential cross section: 8 TeV

- Normalized double-differential cross section,  $e\mu$  channel,  $19.7 \text{ fb}^{-1}$ .
- Distributions of  $\mathbf{P}_T^{\text{top}}$ ,  $\mathbf{y}^{\text{top}}$ ,  $M^{\text{tt}}$ ,  $\mathbf{y}^{\text{tt}}$ .

arXiv: 1703.01630  
[submitted to EPJC]



- Sensitive to fundamental parameters.  
Constrains **PDFs**.

See talk from  
Katerina Lipka

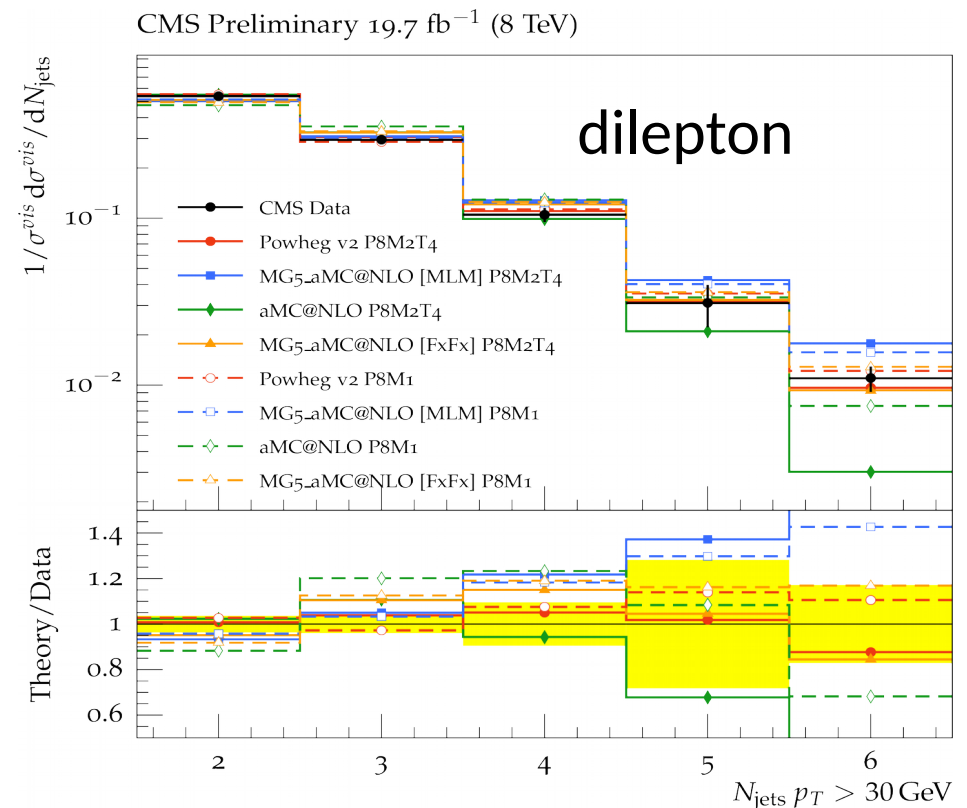
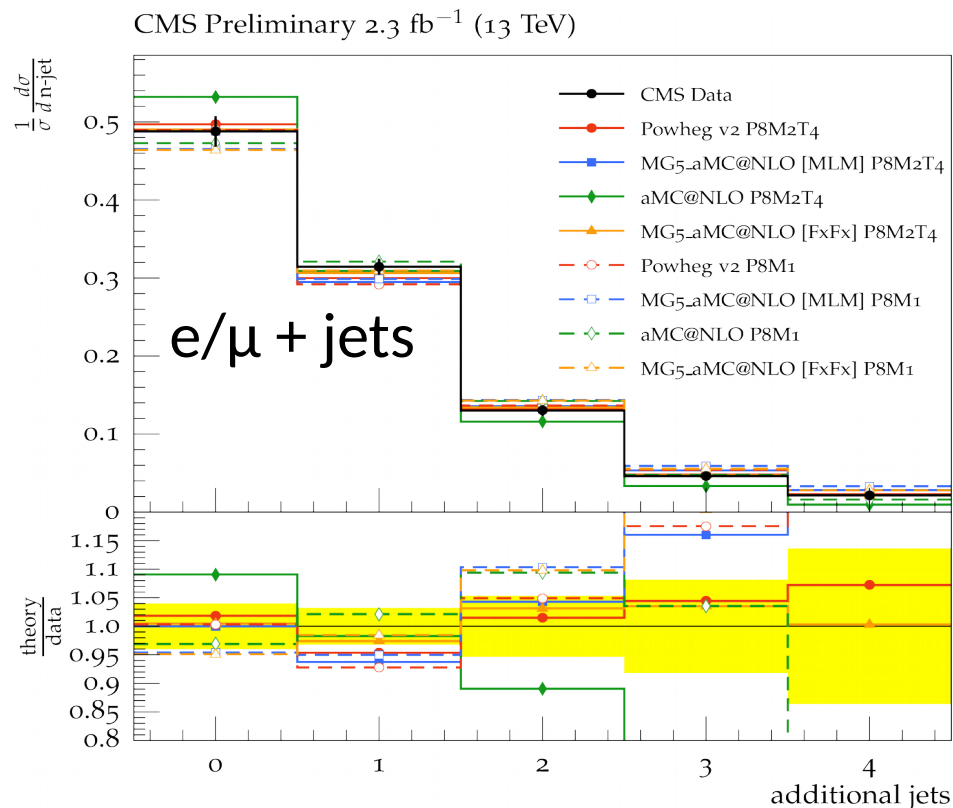


# Modeling of top pair production

- Study of **tt modeling** at  $\sqrt{s} = 8$  and 13 TeV. **CMS-PAS-TOP-16-021**
- Study of several modeling parameters and variations: **matrix element** and **parton shower scale, initial-state** and **final-state radiation**.
- Comparison between generators: **tuning of Powheg + pythia8** sample.

**Tuned parameters:**

•  **$hdamp$**  •  **$\alpha_s^{ISR}$**

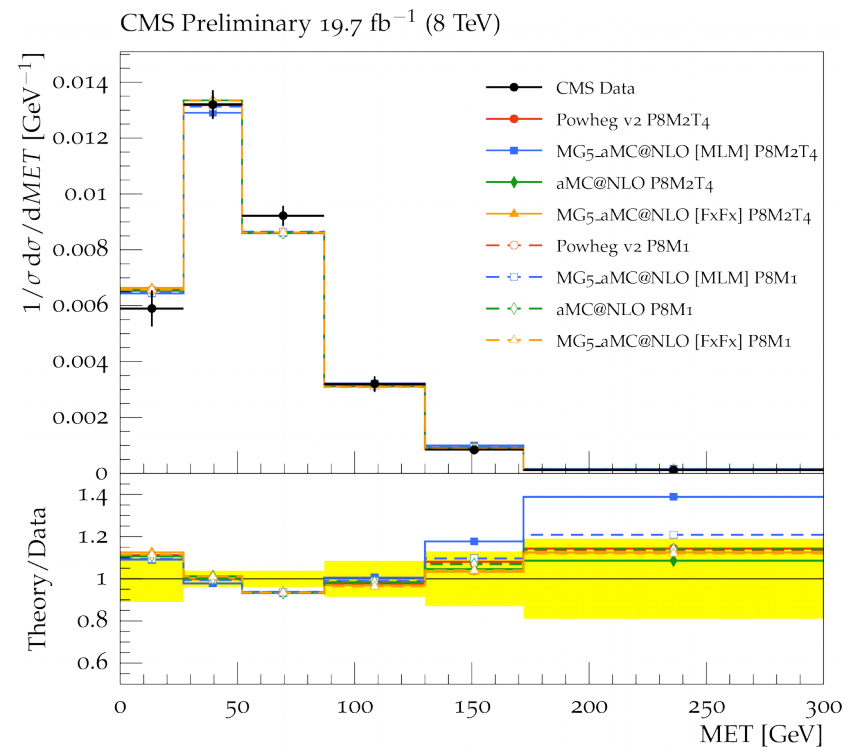


# Modeling of top pair production

CMS-PAS-TOP-16-021

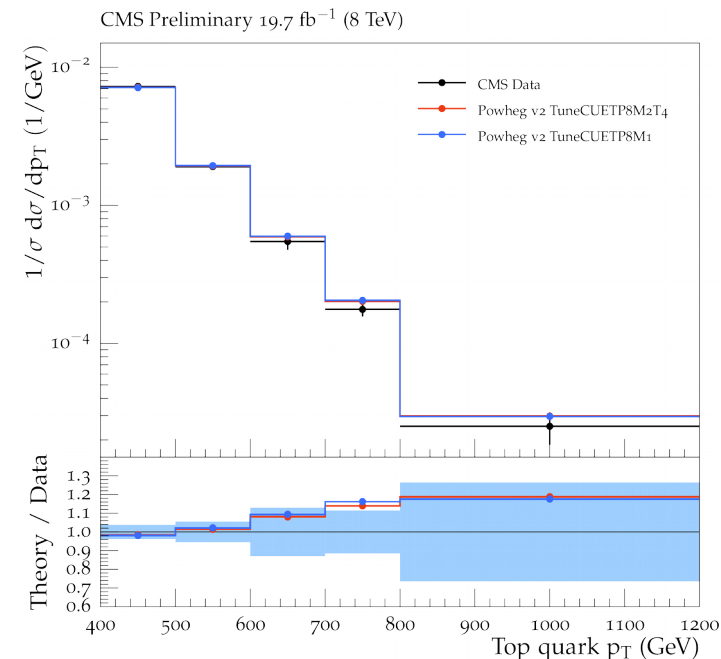
With the *new tuning*:

- **Jet multiplicity** is now well described by **Powheg + Pythia8**.
- **Most distribution of global variables remains unchanged**.
- Main exception:  **$p_T(t\bar{t} \text{ system})$** , sensitive to **extra jets** in the event.



MET distribution for different generators and parameters

Distributions of transverse momentum of top quark for old and new powheg tuning at parton level



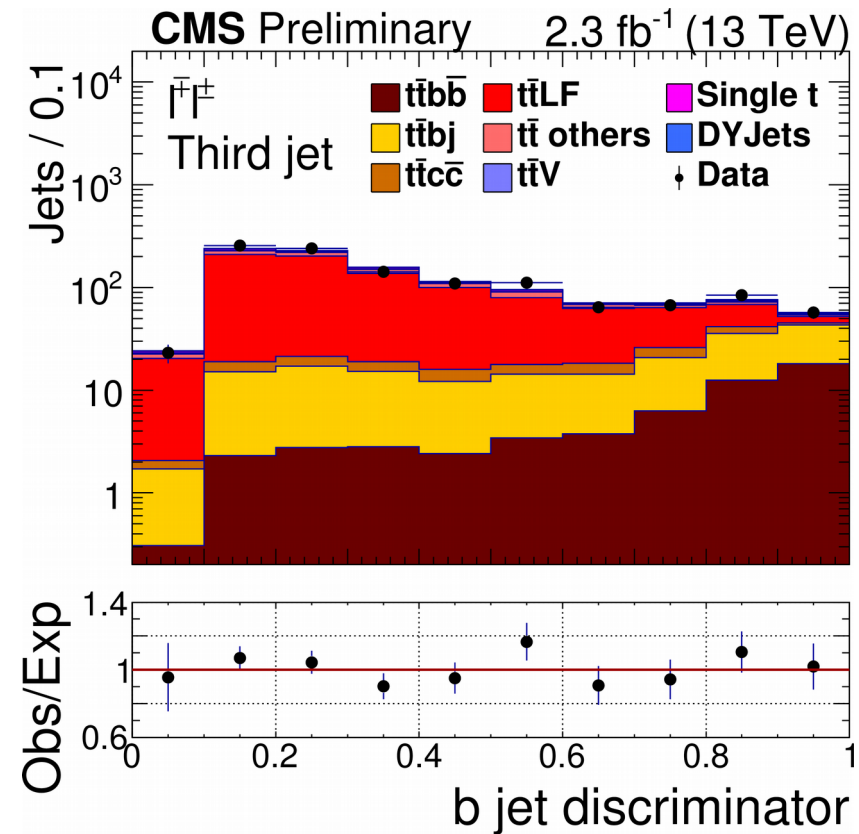
# Top pair production in association with b-quark pairs

## $t\bar{t}b\bar{b}$ production

CMS-PAS-TOP-16-010

- Important background in  $t\bar{t}t\bar{t}$  searches and  $t\bar{t}H$  ( $H \rightarrow b\bar{b}$ ).
- Main background:  $t\bar{t}$  + jets.
- OS dileptons,  $\geq 4$  jets,  $\geq 2$  b-jets.
- Likelihood fit to **b-tag discriminator** for 3<sup>rd</sup> and 4<sup>th</sup> jets.
- Dominant uncertainty: **b-tagging**.

## Results



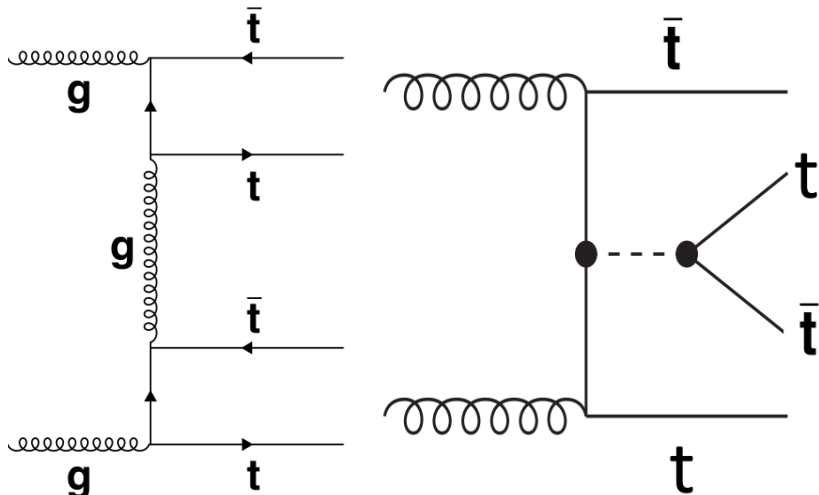
Large cancellation  
of uncertainties in  
the ratio:  
 $t\bar{t}b\bar{b}/t\bar{t}j\bar{j}$

Phase Space	$\sigma_{t\bar{t}b\bar{b}}$ [pb]	$\sigma_{t\bar{t}j\bar{j}}$ [pb]	$\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}j\bar{j}}$
Measurement			
Visible	$0.085 \pm 0.012 \pm 0.029$	$3.5 \pm 0.1 \pm 0.7$	$0.024 \pm 0.003 \pm 0.007$
Full	$3.9 \pm 0.6 \pm 1.3$	$176 \pm 5 \pm 33$	$0.022 \pm 0.003 \pm 0.006$
Simulation (POWHEG)			
Visible	$0.070 \pm 0.009$	$5.1 \pm 0.5$	$0.014 \pm 0.001$
Full	$3.2 \pm 0.4$	$257 \pm 26$	$0.012 \pm 0.001$

# Cross section of the production of four top quarks

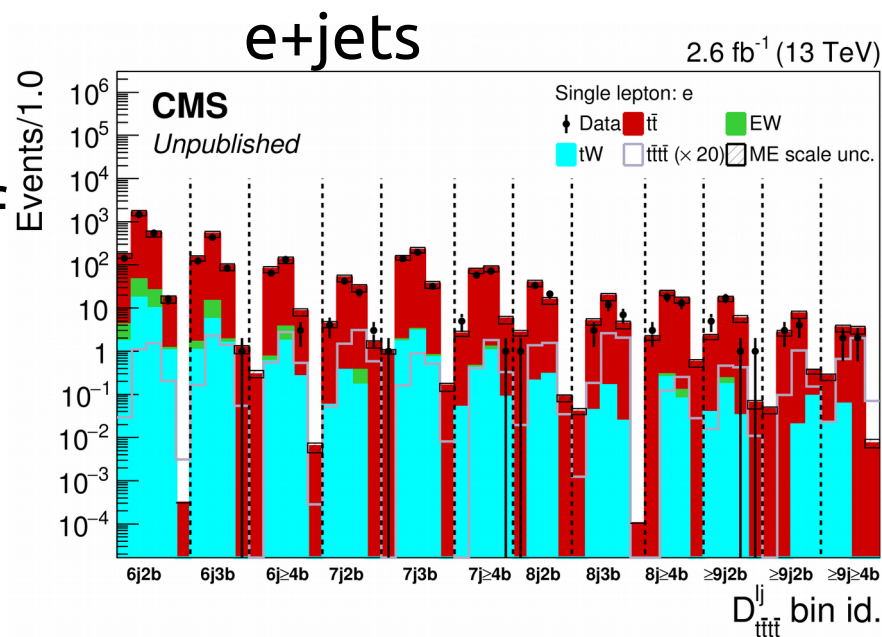
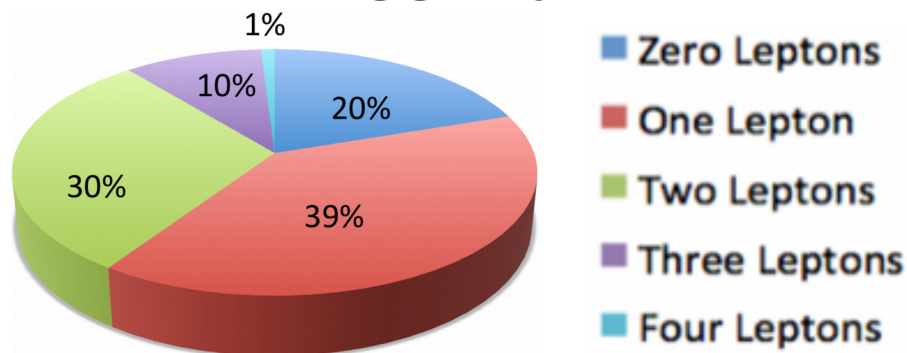
**tttt** production, **13 TeV**, **2.6 fb<sup>-1</sup>**

arxiv: 1702.06164  
[submitted to PLB]



- Sensitive to **new physics**.
- Probes **Yukawa** couplings.
- Rare process in the SM. Expected cross section of  **$\sigma^{\text{SM}} = 9.2 \text{ fb}$** .

- Combination of **OS + SS + single lepton**.
- Discriminant variables: number of jets and b-tagged jets. **Two BDTs**.

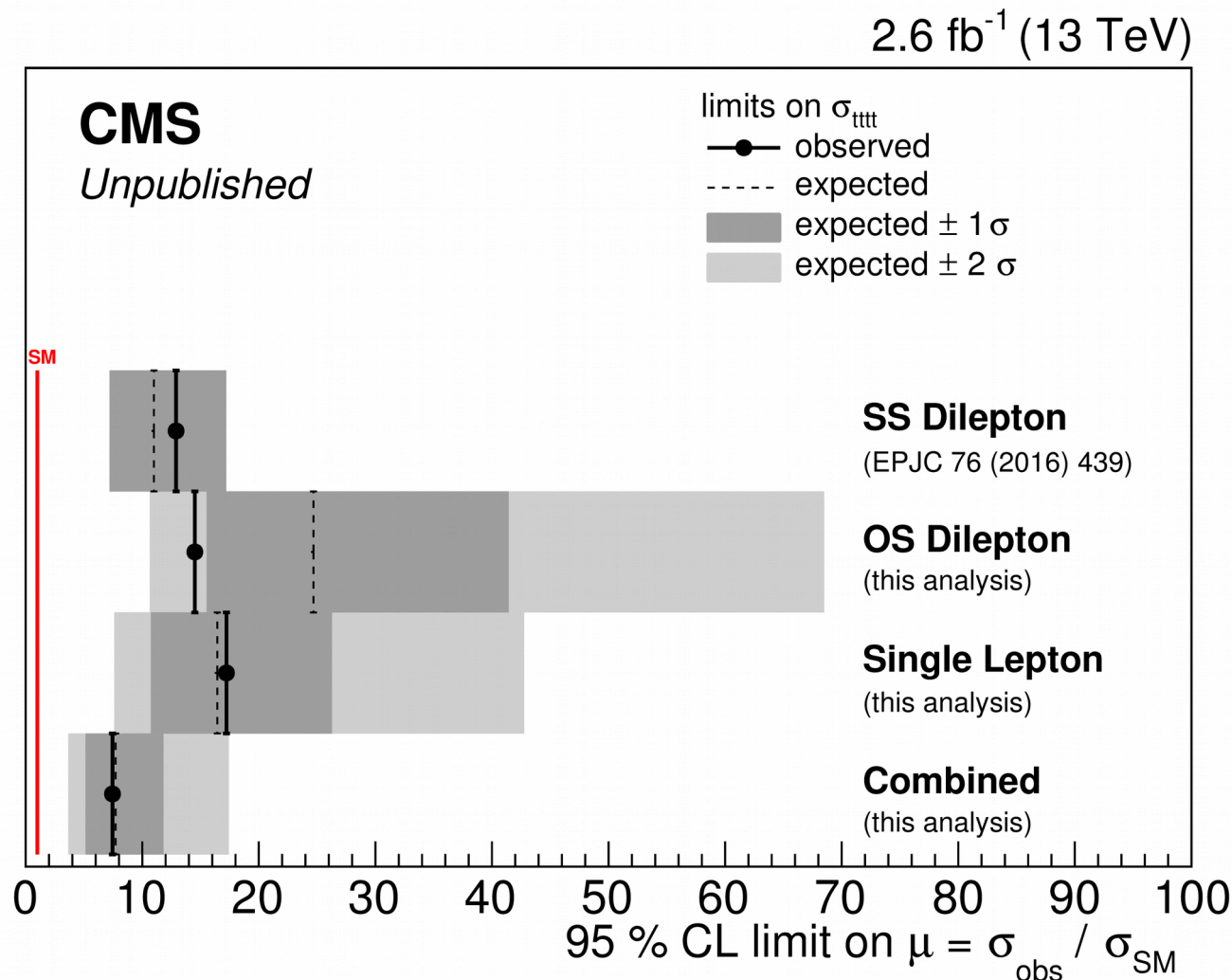


# Cross section of the production of four top quarks

PLR fit to extract upper limits on the cross section.

arxiv: 1702.06164

[submitted to PLB]



Recent search for  
**SUSY** with **same-sign**  
**leptons:**

[CMS-PAS-SUS-16-035]

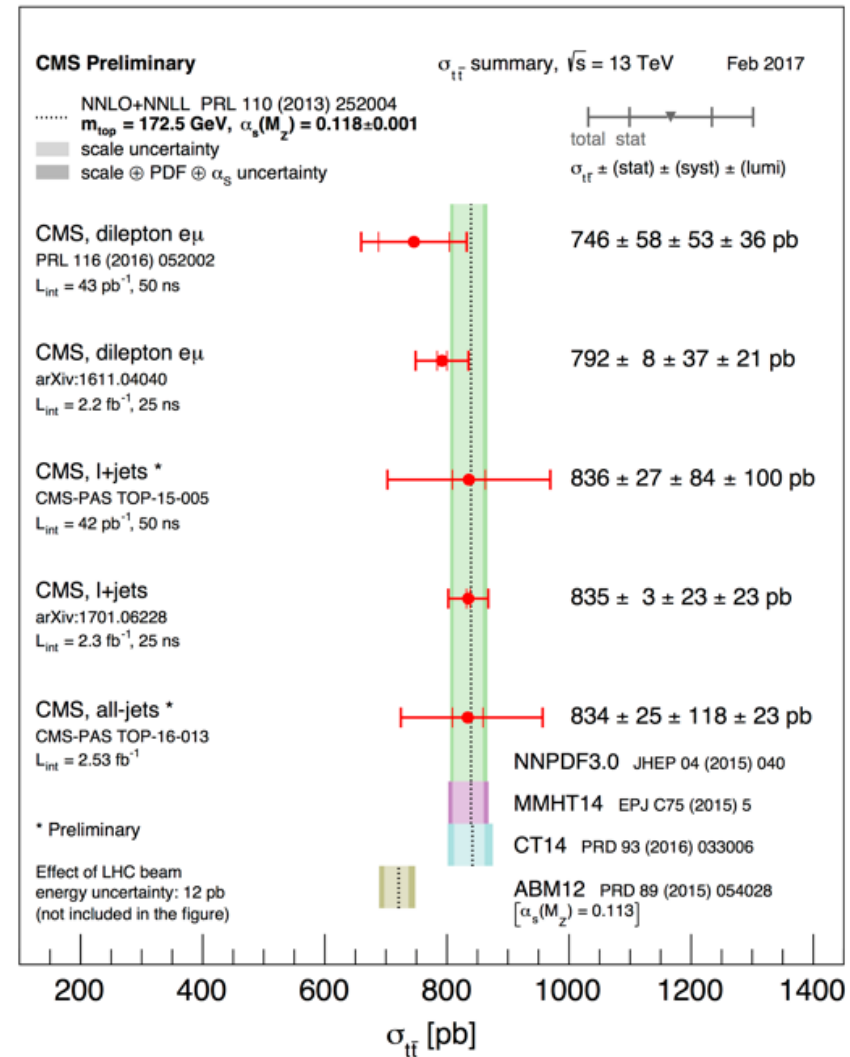
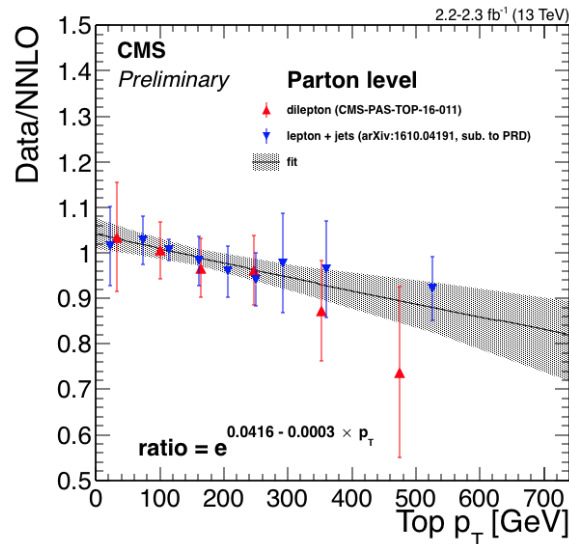
95% CL upper limit  
of four top quarks  
production:

$$\sim 4.3 \times \sigma^{\text{SM}}$$



# Summary


- Top pair production cross section measurements have been presented, all consistent with the SM prediction.
- New result at 5.02 TeV.
- Double differential cross sections are being used to constrain PDFs and new physics. Also to study the modeling of several generators.



More results at:

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP>





Back up