Brookhaven Forum: Great Expectations, a New Chapter

Brookhaven – October 7, 2015

CMS top quark results at 13 TeV

- Introduction and dataset (42 pb^{-1} at 13 TeV)
- Dilepton channel
  - eμ inclusive cross section
  - Differential cross section (ee, eμ, μμ)
- Lepton plus jets channel
  - Differential and inclusive cross section
  - Comparison with ATLAS and theory
- Single top t-channel cross section
- Conclusions

UNIVERSITY of ROCHESTER

Arán García-Bellido

On behalf of the CMS Collaboration

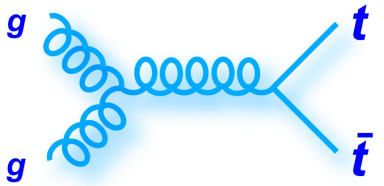
Introduction to top quarks at CMS

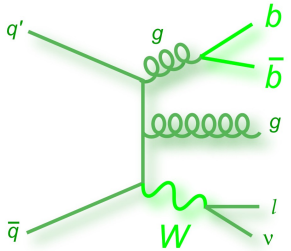
- Measuring top quark cross sections is important at 13 TeV:
  - Precision tests of QCD calculations
  - $t\bar{t}$ is a background in almost all other analyses (SUSY, ttH, etc...)
  - Can use to measure m_t, α_s, calibrate b-tagging
  - Sensitive to BSM physics
- All analyses shown here use 42 pb^{-1} good quality data (July 2015)
- $t\bar{t}$ MC (NLO): Powheg(v2)+Pythia8, NNPDF3.0, m_t=172.5 GeV
  - Alternative with MG5_aMC@NLO, Madgraph5, Powheg+Herwig

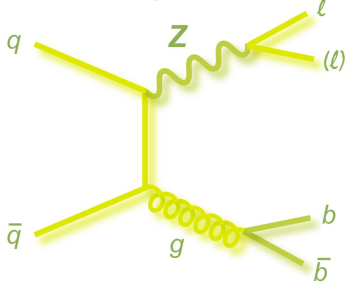
$$\sigma_{t\bar{t}} = 832^{+20}_{-29}(\text{scale}) \pm 35(\text{PDF} + \alpha_s)\ \text{pb}$$

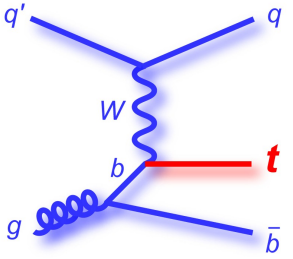
NNLO+NNLL, m_t=172.5 GeV, Czakon and Mitov

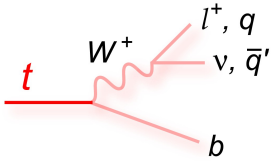
- Singletop tW (71pb), t-channel (217pb): Powheg, aMC@NLO+Pythia
- Main backgrounds:
  - W+jets, Z+jets: MG5_aMC@NLO + Pythia
  - QCD multijet, Diboson: Pythia8 (and from data)







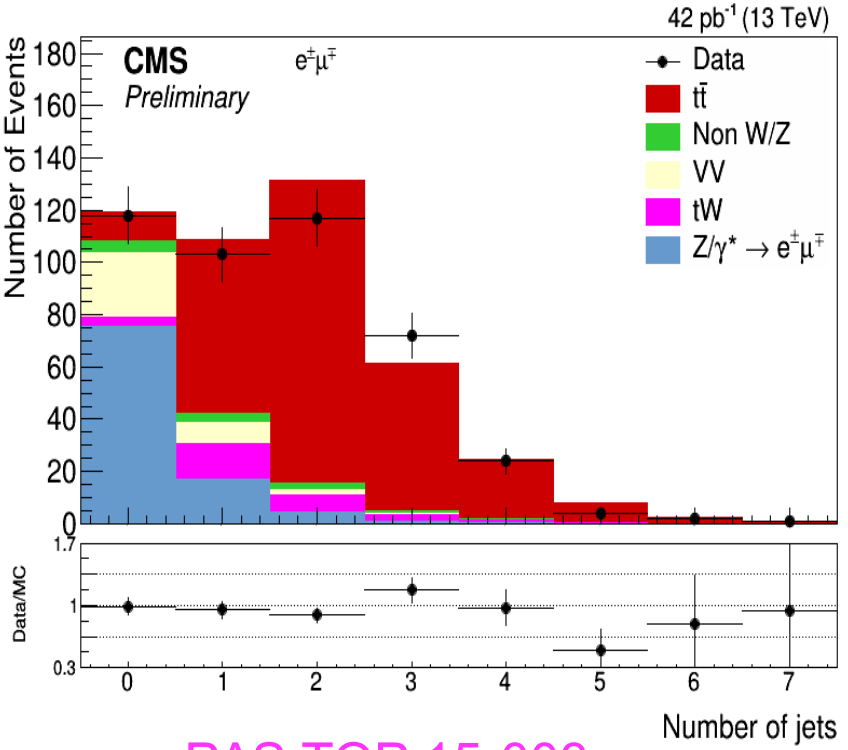




Inclusive eμ cross section

- Trigger: dilepton (eμ) trigger
- Event selection:
  - Isolated OS eμ pair, p_T>20 GeV, |η|<2.4
  - ≥2 jets, p_T>30 GeV, |η|<2.4
  - No b-tagging
  - $m_{\ell\ell}$ > 20 GeV
- Background estimation:
  - DY normalized to MC prediction by a data/MC SF from Z peak in data
  - Non-W/Z from SS control region
  - Single top, diboson from MC
- Cut and Count

$$\sigma_{t\bar{t}} = \frac{N_{\text{data}} - N_{\text{bkg}}}{\varepsilon A \mathcal{L}}$$

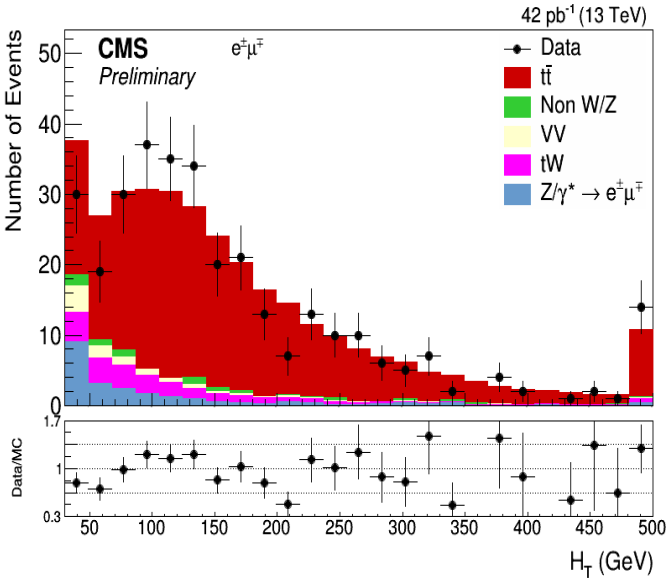


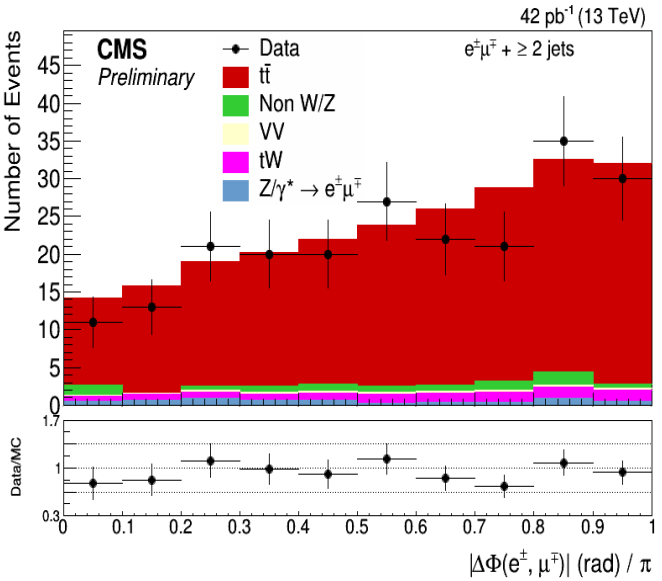
PAS TOP 15-003

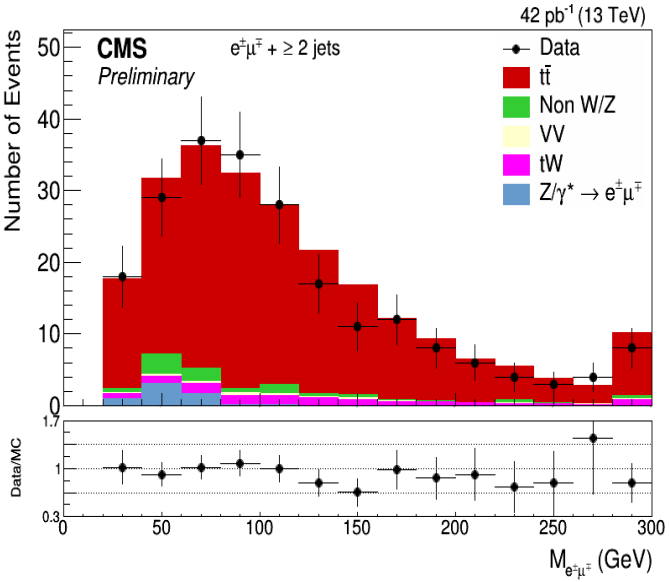
Source	Number of events $e^{\pm}\mu^{\mp}$
Drell–Yan	6.4 ± 1.2
Non-W/Z leptons	8.5 ± 4.3
Single top quark	10.6 ± 3.4
VV (V = W or Z)	2.6 ± 0.9
Total background	28.1 ± 5.7
$t\bar{t}$ dilepton signal	207 ± 16
Data	220

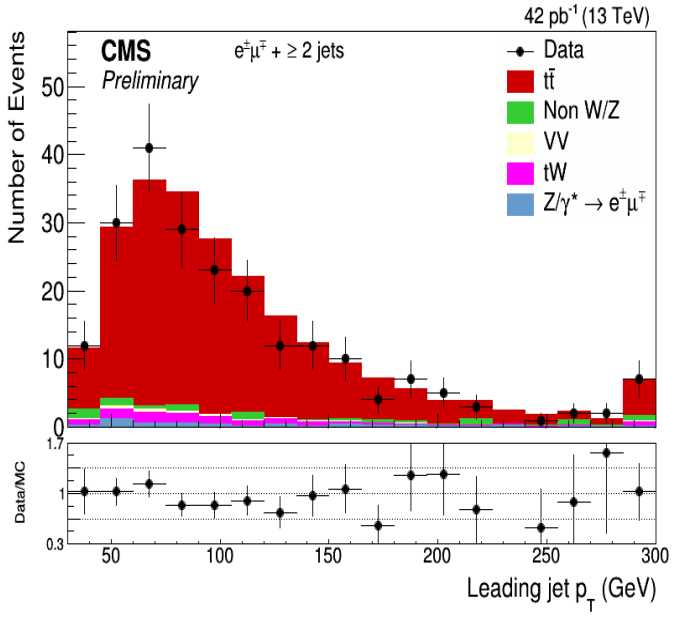
Kinematic distributions

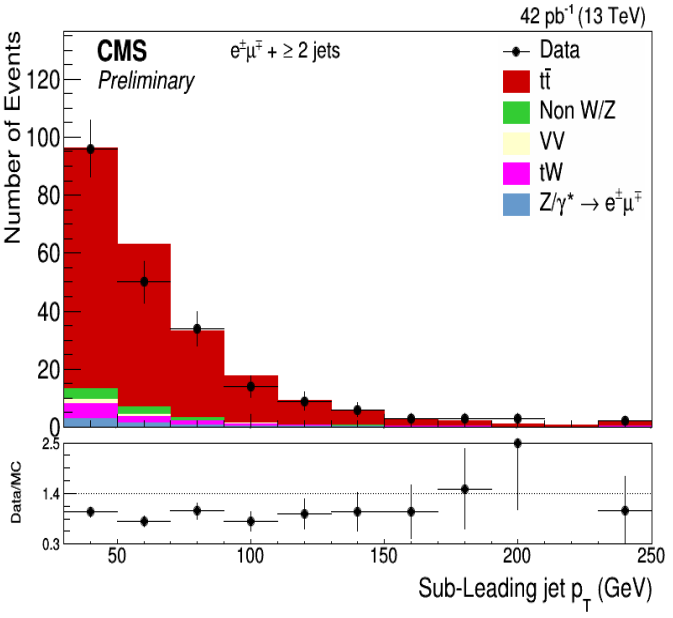
- $t\bar{t}$ normalized to NNLO+NNLL

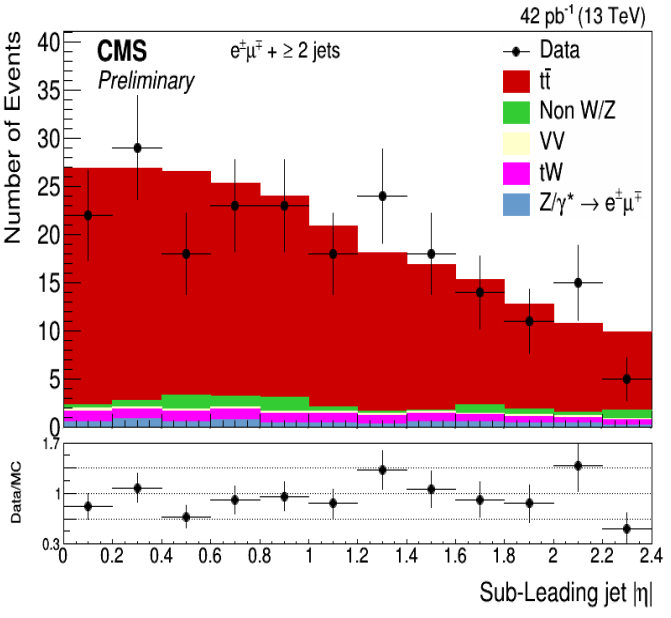












eμ inclusive cross section results

- Luminosity uncertainty dominates
- Main effects will be reduced with more data and further studies

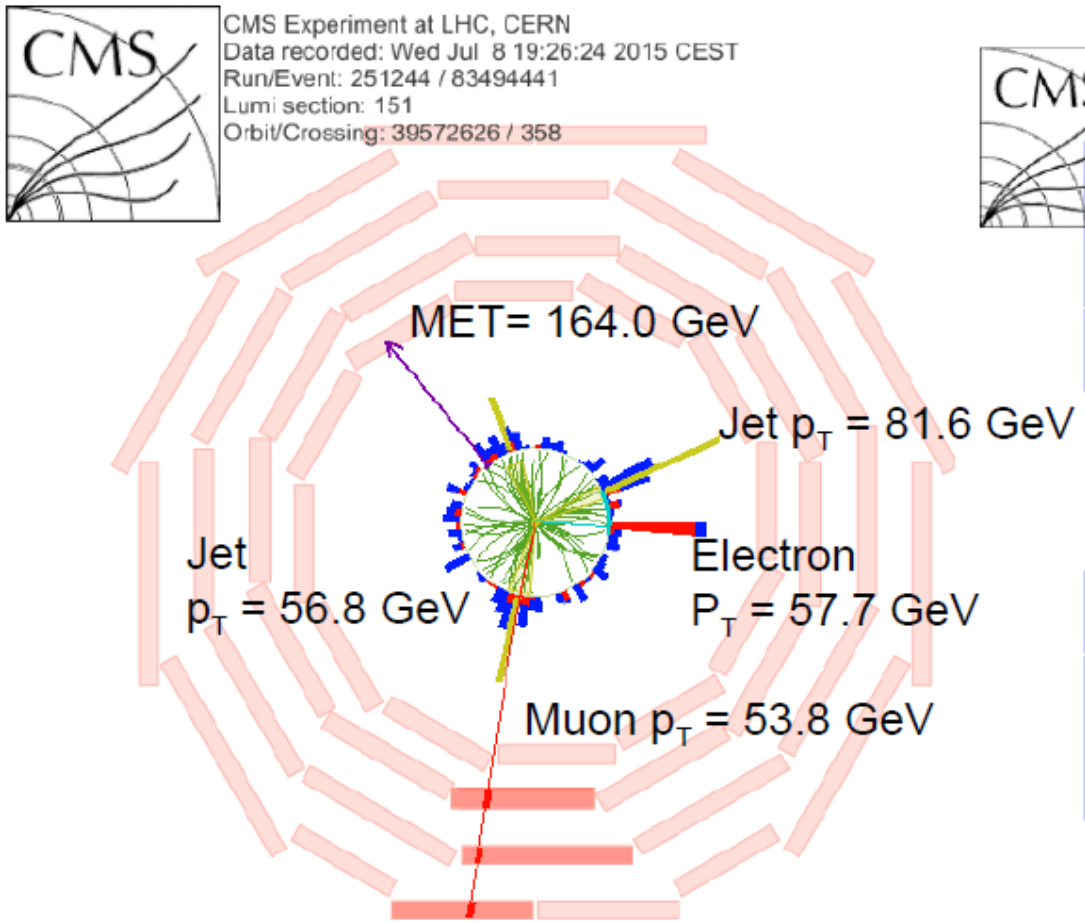
Source	$\Delta\sigma_{t\bar{t}}$ (pb)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics	60	7.7
Trigger efficiencies	39	5.0
Lepton efficiencies	33	4.3
Lepton energy scale	< 1	≤ 0.1
Jet energy scale	20	2.6
Jet energy resolution	< 1	≤ 0.1
Pileup	2.8	0.4
Scale (μ_F and μ_R)	1.5	0.2
$t\bar{t}$ NLO generator	15	1.9
$t\bar{t}$ hadronization	14	1.8
PDF	12	1.5
Single top quark	14	1.8
VV (V = W or Z)	3.5	0.5
Drell–Yan	3.9	0.5
Non-W/Z leptons	8	1.0
Total systematic (no integrated luminosity)	62	8.0
Integrated luminosity	93	12
Total	126	16.4

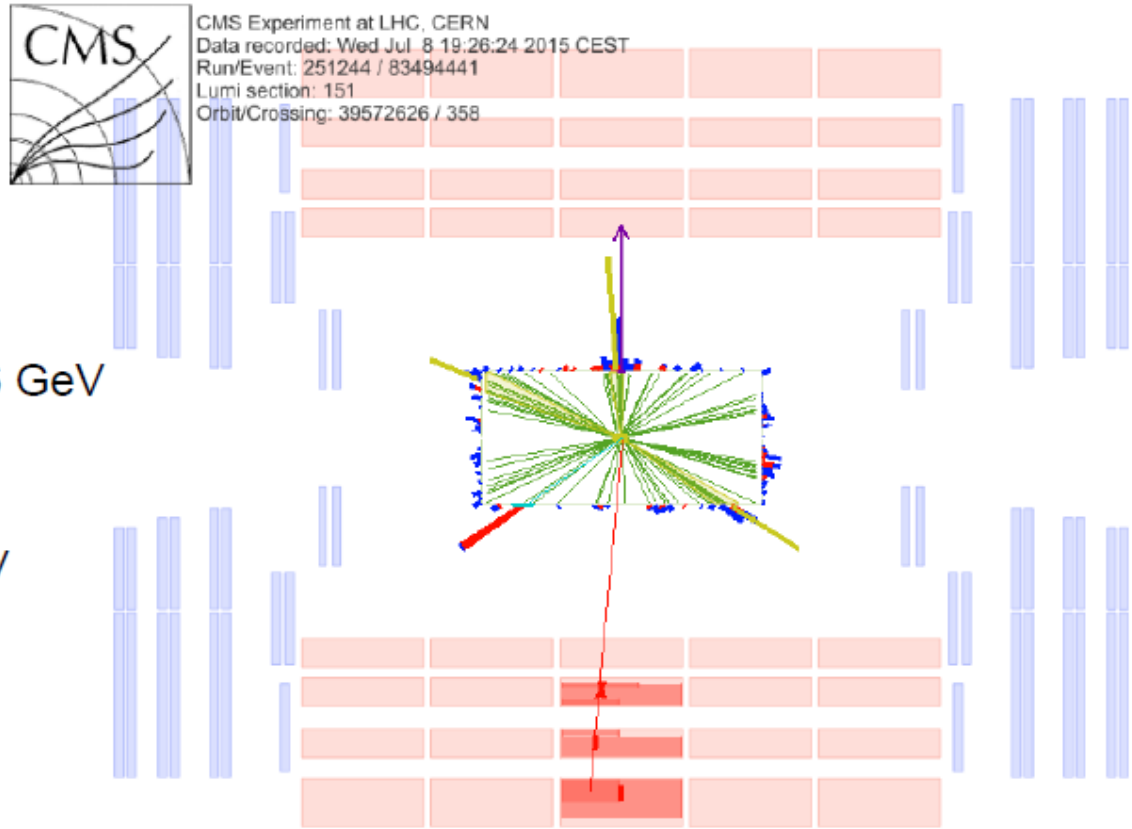
$\sigma_{t\bar{t}}$ = 12.9 ± 1.0(stat) ± 1.1(syst) ± 1.5(lumi) pb [fiducial eμ]

$\sigma_{t\bar{t}}$ = 772 ± 60 (stat) ± 62 (syst) ± 93 (lumi) pb [total]

Values for m_t=172.5 GeV. For m_t=173.34 GeV $\sigma_{t\bar{t}}$ decreases by ~0.7%.

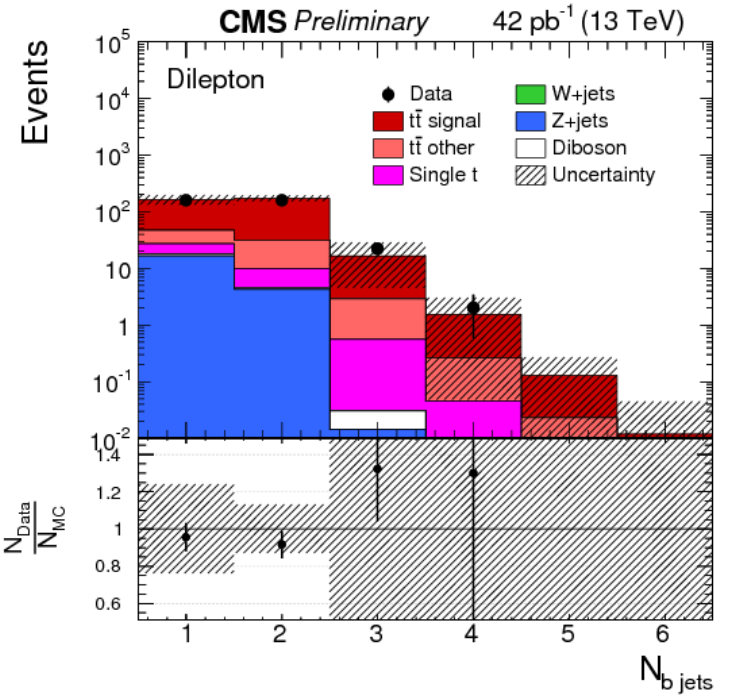
$t\bar{t} \rightarrow e\nu_e b \mu\nu_\mu b$ candidate event

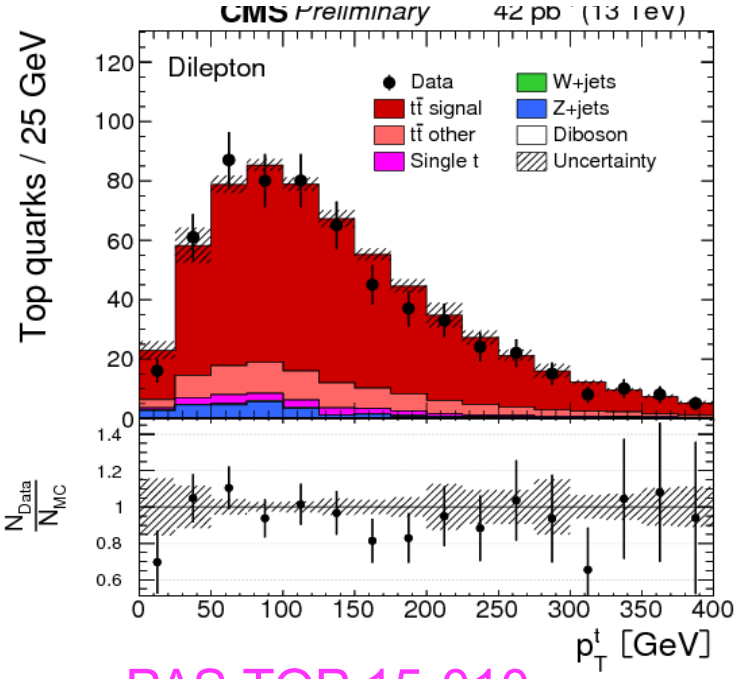




Dilepton differential cross section

- Trigger on isolated dileptons and $\ell\ell$+jets topologies
- Event selection (ee, eμ, μμ)
  - Isolated OS leptons: p_T>20 GeV, |η|<2.4
  - ≥2 jets: p_T>30 GeV, |η|<2.4
    - ≥1 b-tag jet (CSV): $\varepsilon_b \approx 80\%$; $\varepsilon_{qg} \approx 10\%$
  - $m_{\ell\ell}$>20 GeV
  - ee, μμ: MET>40GeV and $|91-m_{\ell\ell}|$>15GeV
- Same background estimations as inclusive σ
- Kinematic reconstruction (94% efficient)
  - Constraints: m_t=172.5 GeV (x2), m_W=80.4 GeV (x2), $(p_\nu+p_{\bar{\nu}})_T$=MET
  - Reconstruct each event 100 times, smearing inputs by their resolution
  - Consider weighted average
  - Derive scale factor $\varepsilon_{DATA}/\varepsilon_{MC}$



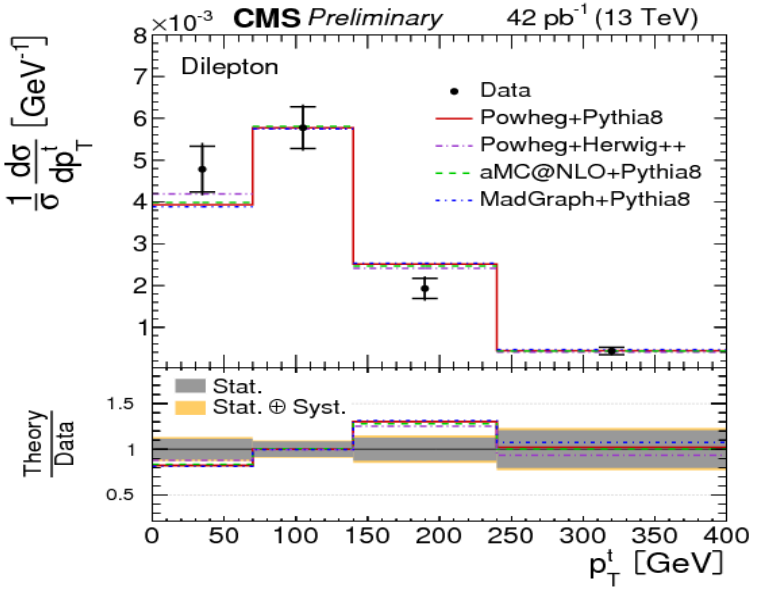


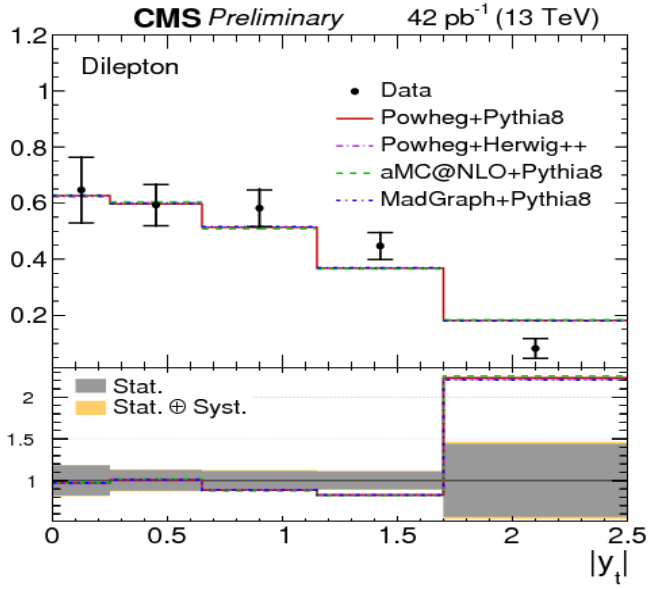
PAS TOP 15-010

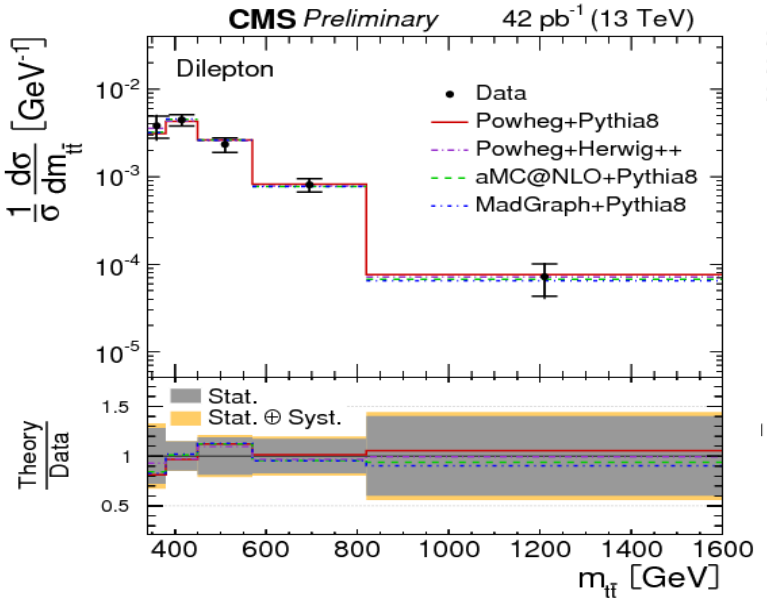
Dilepton differential results

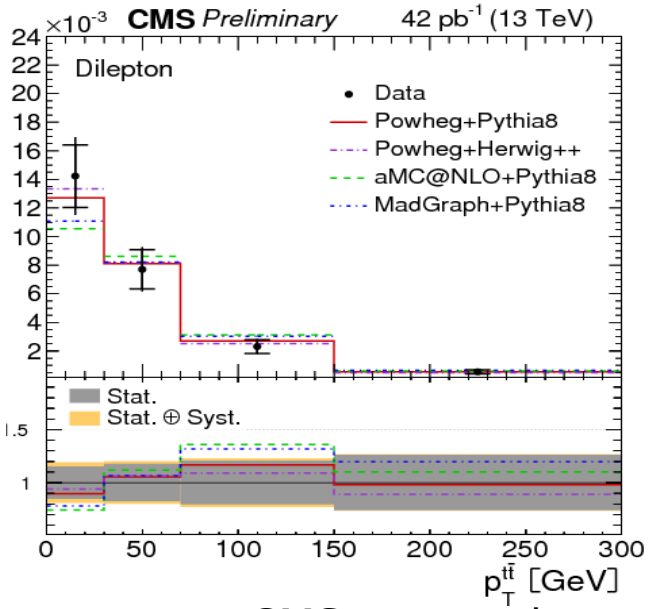
- Calculate normalized differential cross sections to reduce systematics
- Perform regularized unfolding to parton level
- Good agreement overall: still dominated by statistical uncertainty

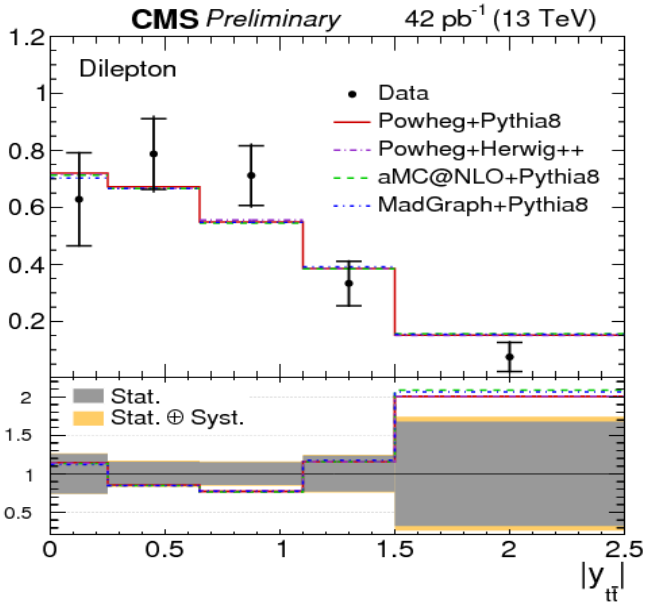
Process	Events
DATA	306
$t\bar{t}$ signal	80%
$t\bar{t}$ other	13%
Single top (tW)	4%
Z+jets	3%
VV, W+jets, QCD neglible	





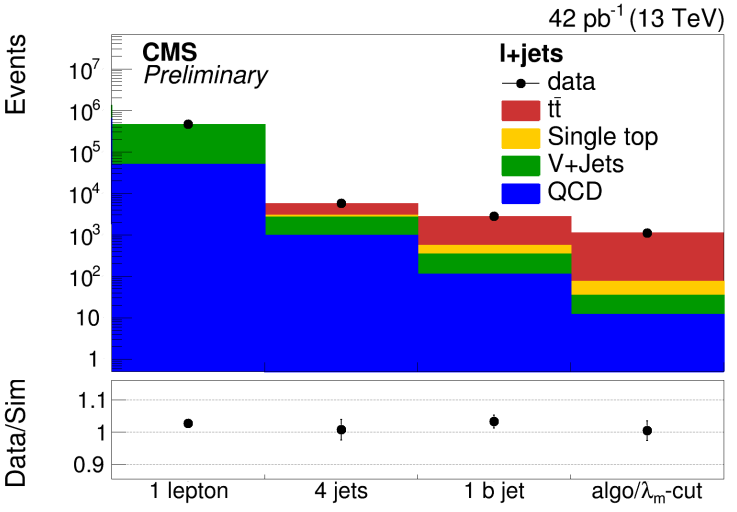


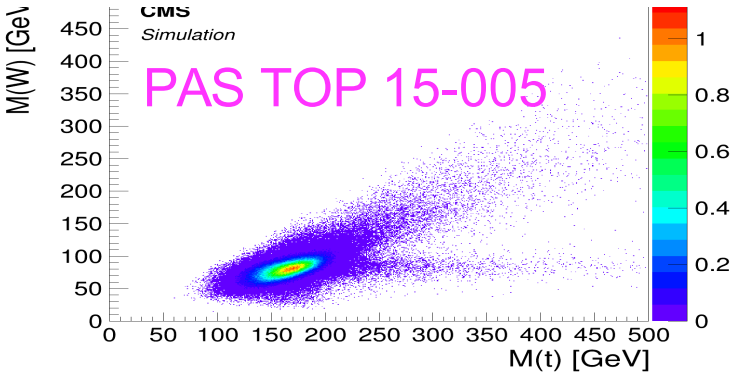


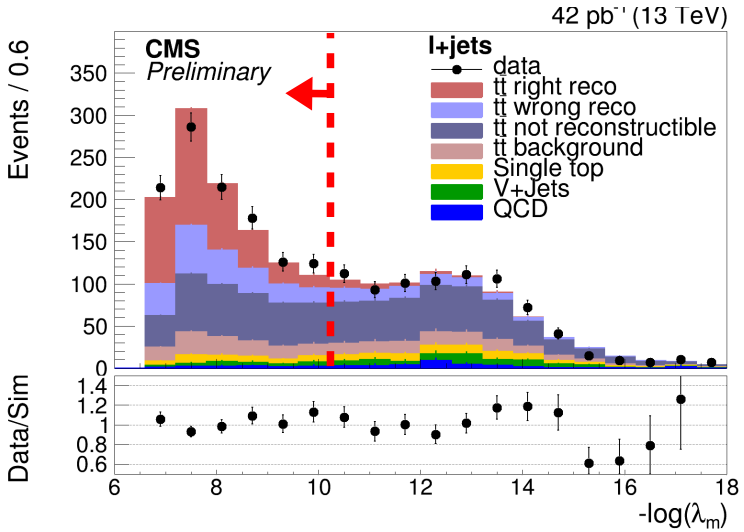


Differential ℓ+jets cross section

- Triggers based on single isolated lepton
- Event selection:
  - 1 isolated lepton with p_T>30 GeV, |η|<2.1
  - ≥4 jets with p_T>25 GeV, |η|<2.4
    - ≥1 b-tagged ($\varepsilon_b \approx 65\%$; $\varepsilon_{qg} \approx 3\%$)
    - b-tag jet and leading non-b jet: p_T>35 GeV
- Kinematic reconstruction
  - Use mass constraints of m_t, m_W on leptonic side to obtain neutrino momentum (NIM 736, 169 [2014]) and correct b-jet on leptonic side
  - Calculate probability λ_m according to 2D mass distributions of m_t, m_W on hadronic side to obtain best permutation of jets
  - Correct jets to top match combination: 85% for 4jet, ~40% for 7jet events
  - Cut -log(λ_m)<10
- 1100 events, with 83% signal

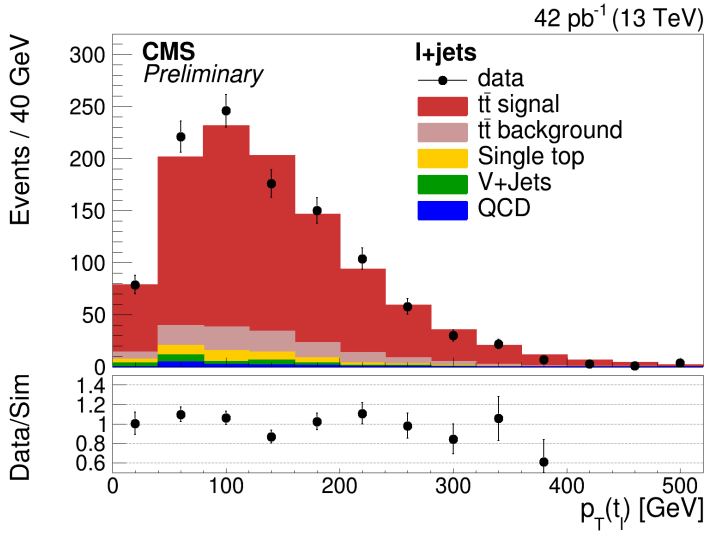


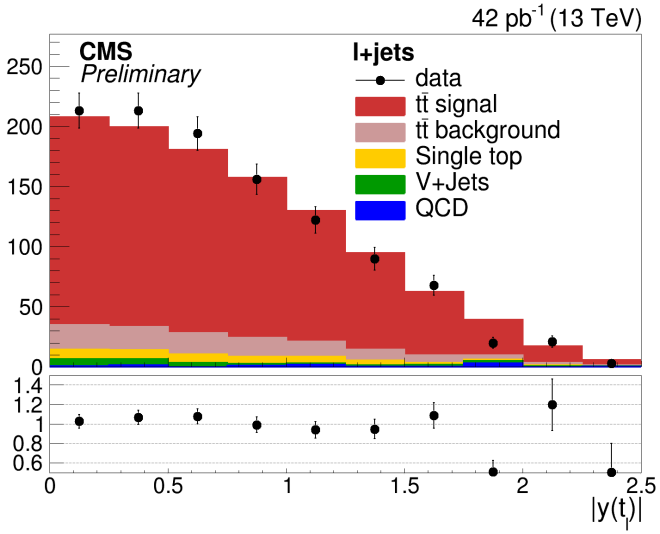


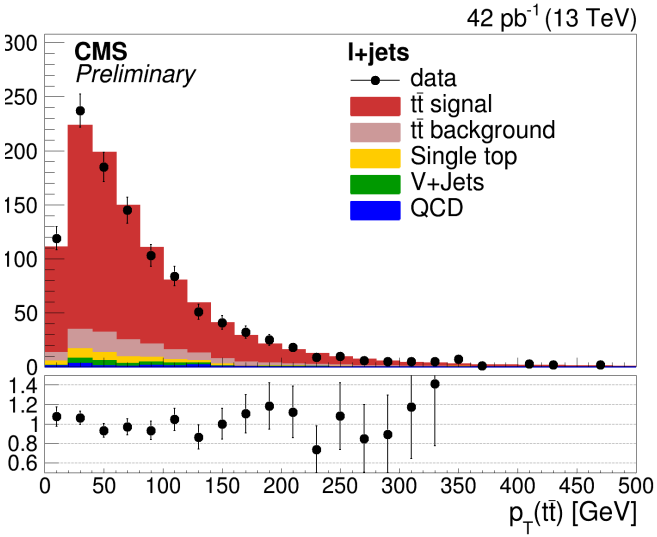


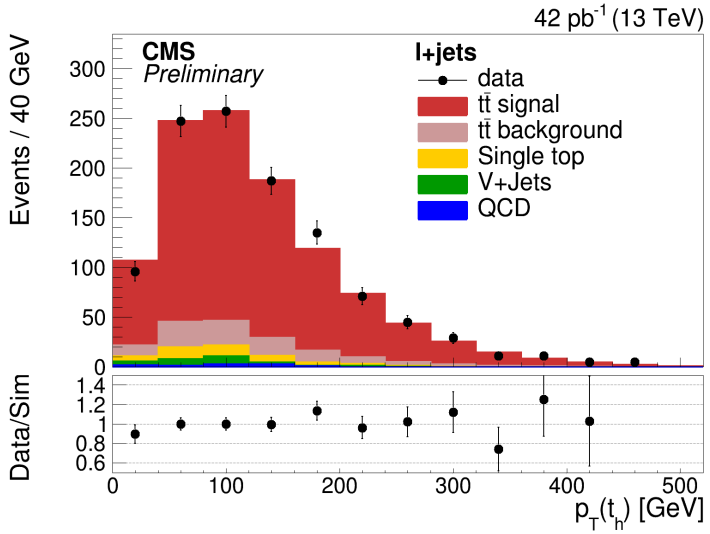
Kinematic distributions

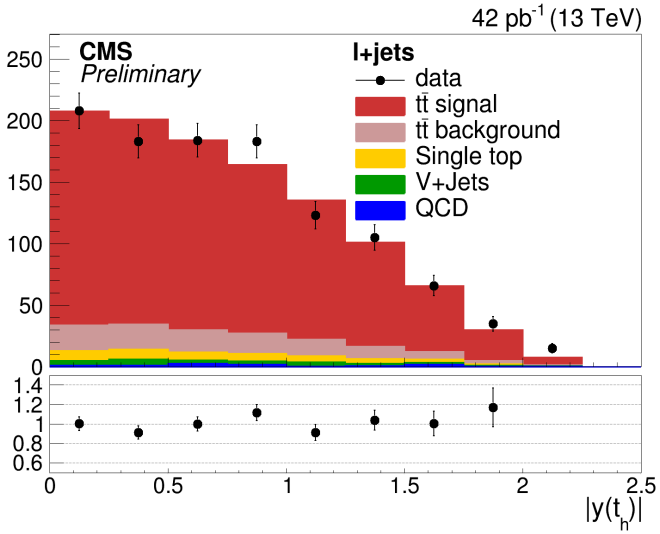
- $t\bar{t}$ normalized to NNLO+NNLL cross section
- Backgrounds from MC simulations (50% syst. on their normalization)

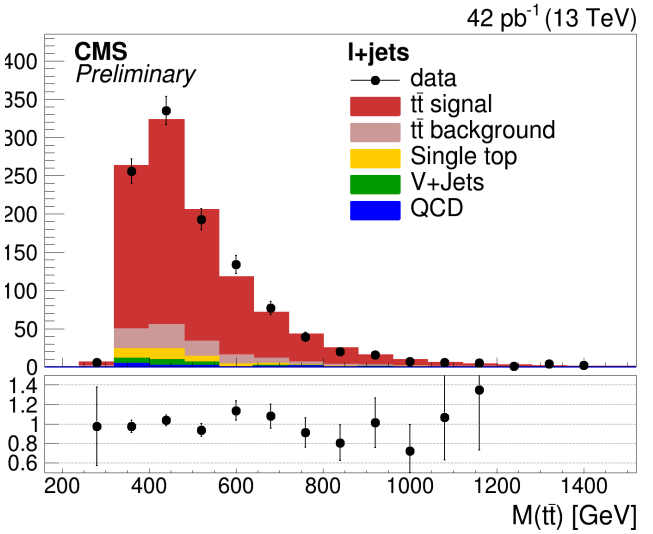






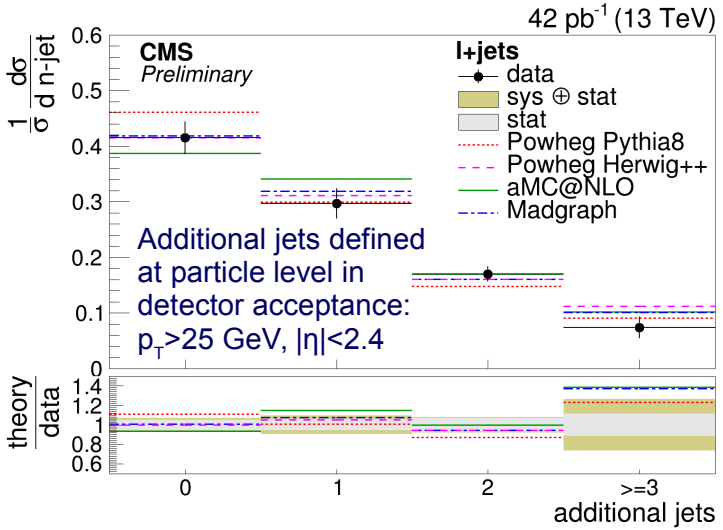


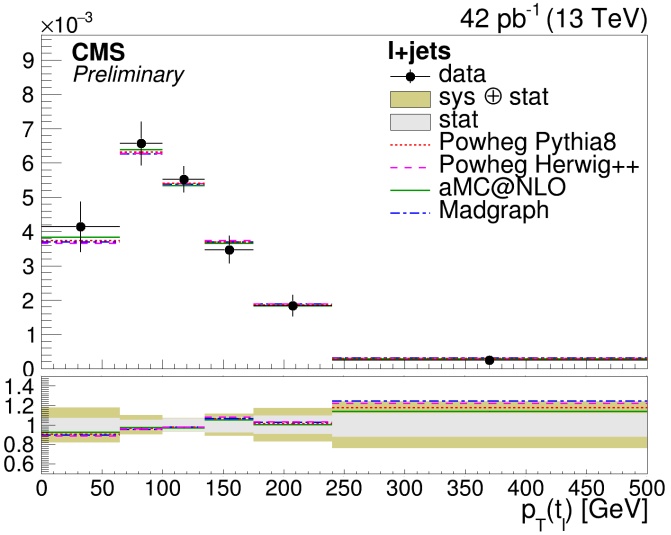


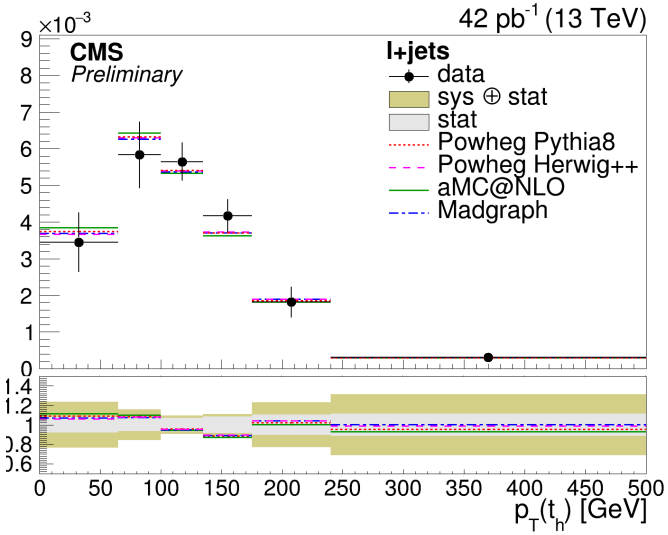


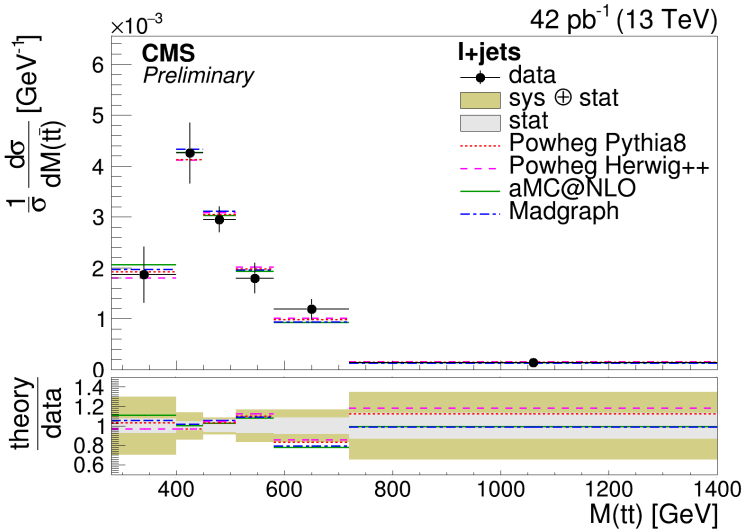
Parton level distributions ℓ+jets

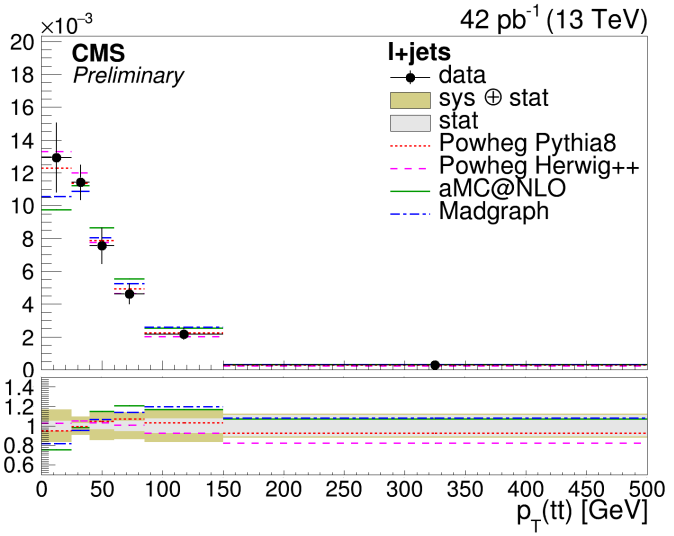
- Unfolded and extrapolated to full phase space
- Binning optimized to have similar number of events per bin
- Good description of $p_T(t)$: Powheg+Pythia6 was harder in previous 8 TeV results
- $p_T(t\bar{t})$ better described by Powheg than MG5_aMC@NLO or Madgraph (+≤3 jets)

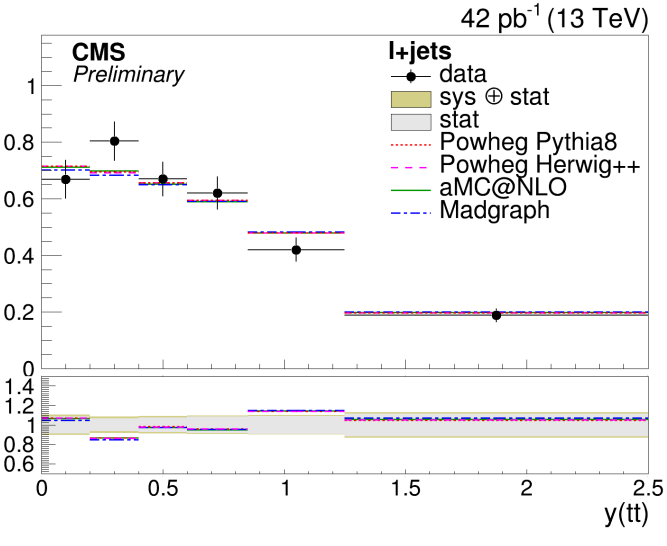












Inclusive ℓ+jets cross section

- Use differential analysis in 1 bin to obtain inclusive cross section
- Unfolding is just ε·A correction of 9.9%
- Uncertainty dominated by luminosity, b-tagging and PS/hadronization unc.

source	inclusive cross section [%]
statistical uncertainty	3.2
b tagging	5.1
jet energy scale	3.5
jet energy resolution	3.4
lepton selection	3.0
E_T^{miss}(non jet)	< 0.1
pileup	1.2
background	1.6
PDF	4.7
factorization scale	< 0.1
renormalization scale	< 0.1
NLO generator	2.0
POWHEG+ PYTHIA8vs. HERWIG++	3.4
total systematic uncertainty (no luminosity)	10.0
luminosity	12
total uncertainty	15.6

$\sigma_{t\bar{t}}$ = 244 ± 8 (stat) ± 24 (sys) ± 29 (lumi) pb [ℓ+jets]

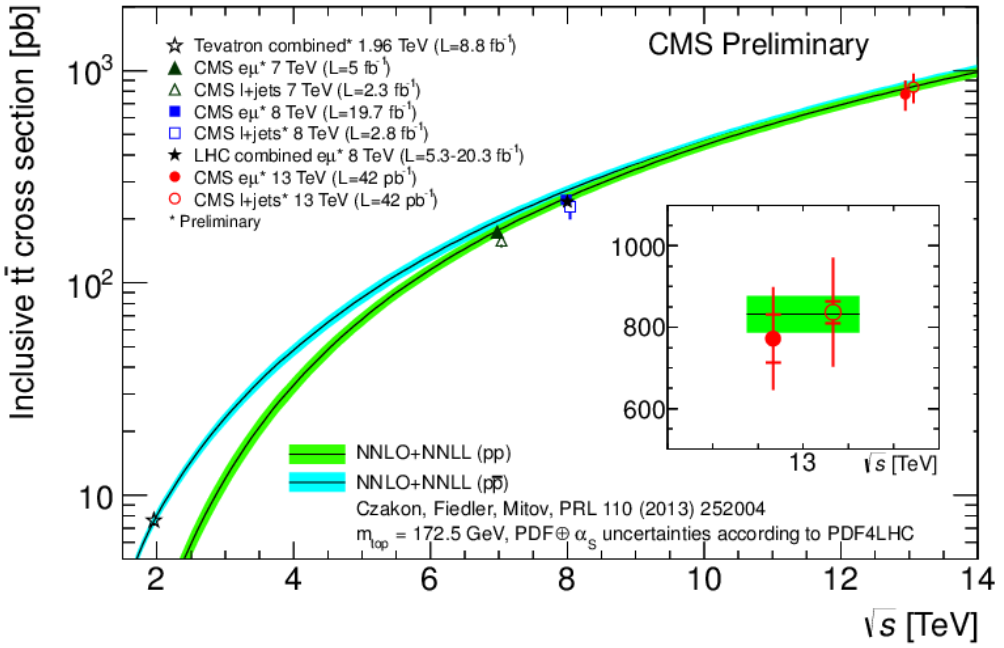
$\sigma_{t\bar{t}}$ = 836 ± 27 (stat) ± 84 (sys) ± 100 (lumi) pb [total]

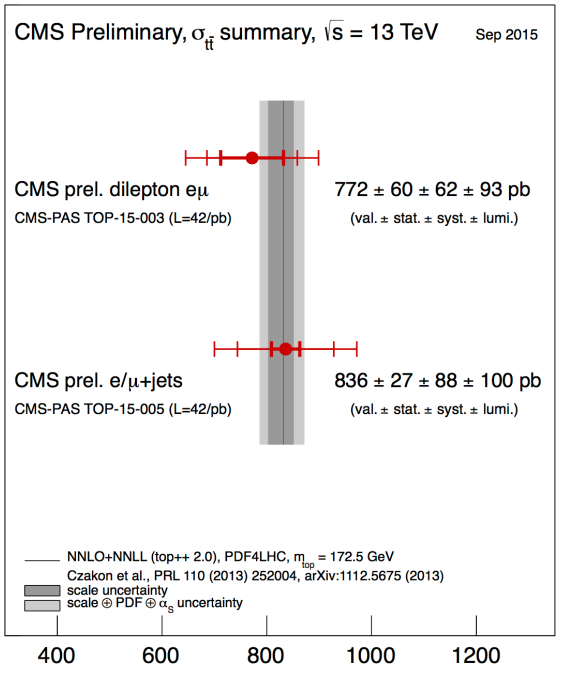
Values for m_t=172.5 GeV. Slope: -6.3 pb/GeV

$\sigma_{t\bar{t}}$ comparison with ATLAS and theory

- New measurements at 13 TeV are in agreement between each other and the NNLO+NLL prediction
- Now working on reducing systematic uncertainties
  - Better luminosity scans, understanding of JES, trigger, b-tagging

Channel	Theory [pb]	Experiment	Meas. σ [pb]	Stat. (%)	Sys. (%)	Lumi. (%)
eμ	832	CMS PAS 15-005, 42 pb^{-1}	772	7.7	8.0	12
		ATLAS CONF 15-033, 78 pb^{-1}	825	5.9	7.3	10
ℓ+jets	832	CMS PAS 15-003, 42 pb^{-1}	836	3.3	10.3	12
		ATLAS CONF 15-049, 85 pb^{-1}	817	1.6	12.6	11



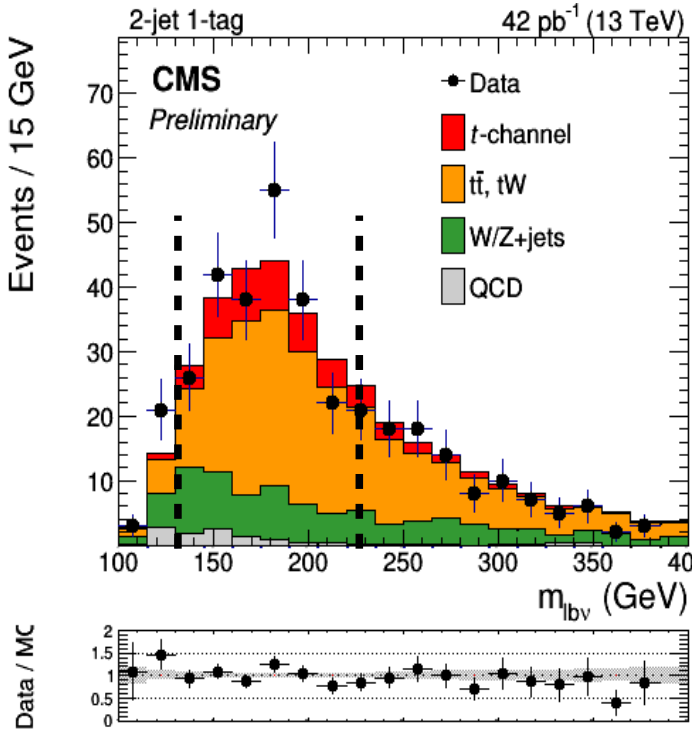


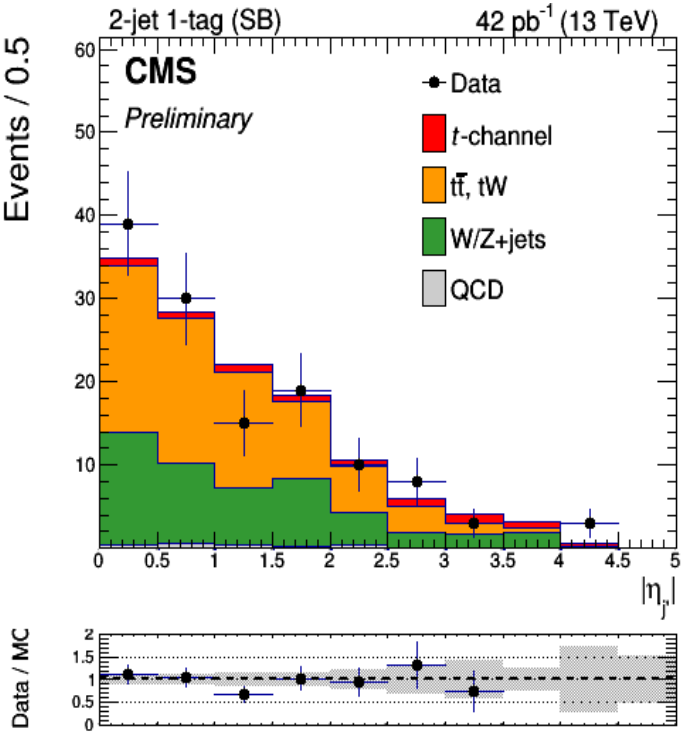
Single top t-channel cross section

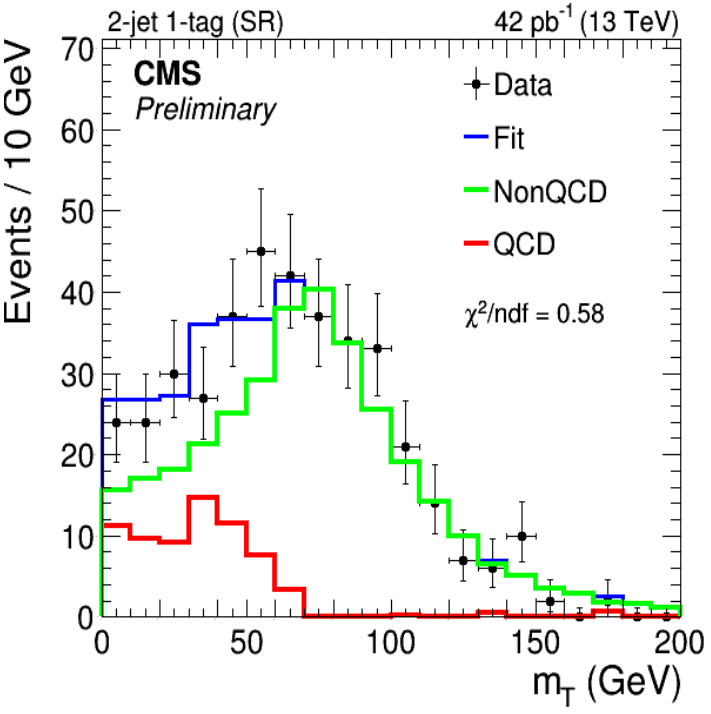
- Event selection
  - 1 isolated μ, pT>22 GeV, |η|<2.1
  - 2 jets, pT>40 GeV, |η|<4.7
  - 1 b-tag (MVA)
- W+jets from simulation, validated outside top mass window: $130<m_{\ell\nu b}<225$ GeV
- QCD shape from data, normalization from fit of $m_T(W)$ in SB and cut: $m_T(W)>50$ GeV

Process	SR	SB
$t\bar{t}$ & tW	157 ± 1	71.7 ± 0.4
W/Z+jets	40 ± 4	47 ± 4
QCD	10 ± 5	2 ± 1
t-channel	33 ± 1	7.2 ± 0.3
Total expected	240 ± 6	128 ± 4
Data	252	127

PAS TOP 15-004

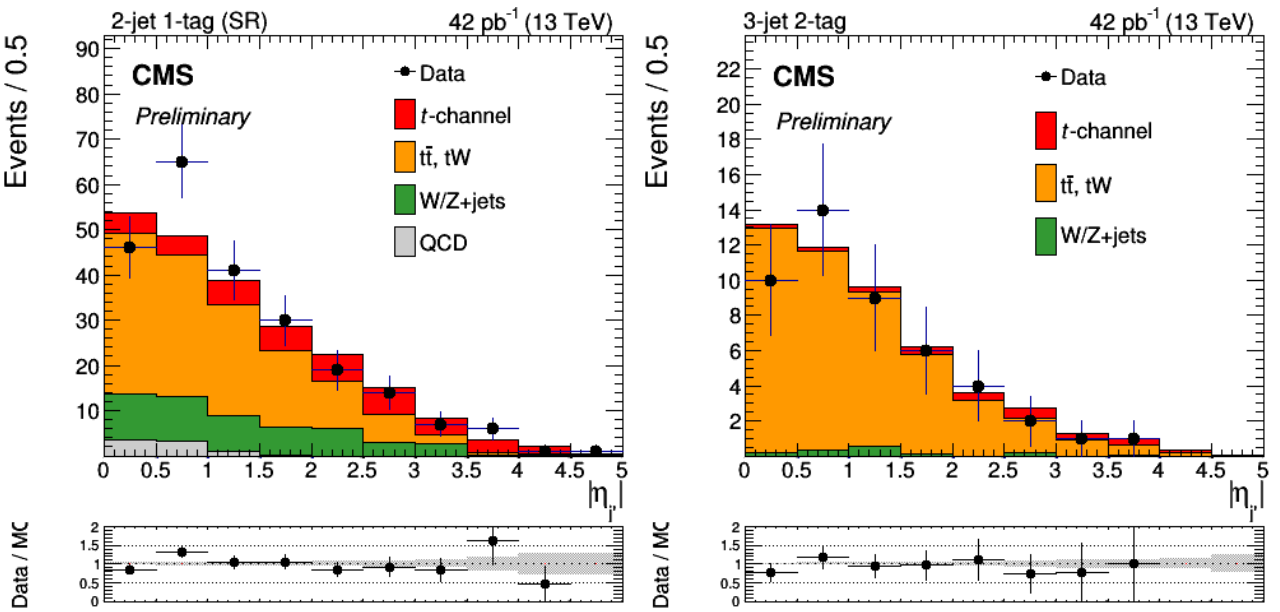






t-channel results

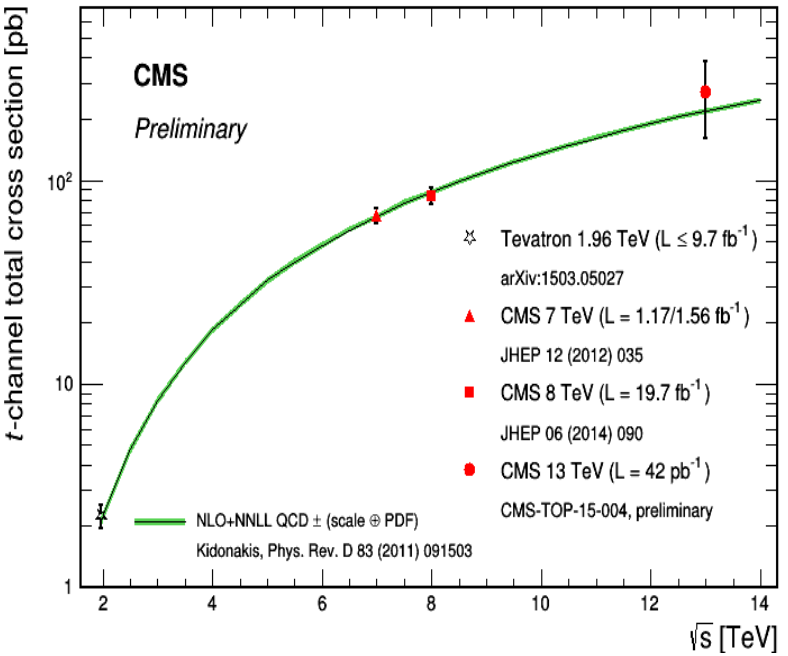
- Binned likelihood fit to $|\eta_{j'}|$ in 2 jets (1 b-tag) and 3 jets (2 b-tags)
  - 3j2t dominated by $t\bar{t}$
  - Bkg norm. constrained
  - Sig norm. unconstrained
- Statistics dominated
- 42% overall unc.
- Significance:
  - Observed=3.5σ
  - Expected=2.7σ



$\sigma_t = 274 \pm 98\ (stat) \pm 52\ (sys) \pm 33\ (lumi)$ pb

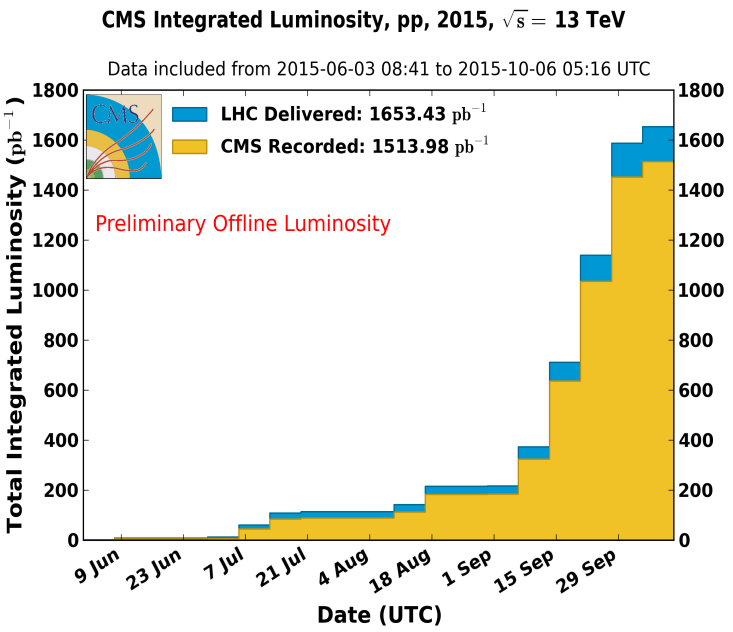
$\sigma_t = 217.0 \pm 6.6(scale) \pm 6.2(PDF)$ pb [NLO]

NNLO available: 214.5 ± 0.6 [PLB 736, 58 (2014)]



Conclusions

- New $t\bar{t}$ and t-channel production cross section measurements
- Robust measurements with early Run II data
- Slow start, but plenty more data coming in!
- Will focus now on precision
  - Luminosity uncertainty (12%) will be reduced soon
  - Better understanding of JES, trigger, and b-tagging
- Results in agreement with theory and ATLAS
  - No signature of new physics yet!



- Rich program of properties and searches in top quark sector
- Recently ($\sqrt{s}$ = 7, 8 TeV data):
  - Mass combination: 172.44±0.13(stat)±0.47(syst) GeV
  - Observation of ttV, charge asymmetry, all-jets σ, differential σ
  - Cross section ratio σ(ttbb)/σ(ttjj), W boson helicity
- More papers coming with new tools: boosted top tagging, pile-up cleaning algorithms
- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP