Highlights from the TOP2015 conference: Top production

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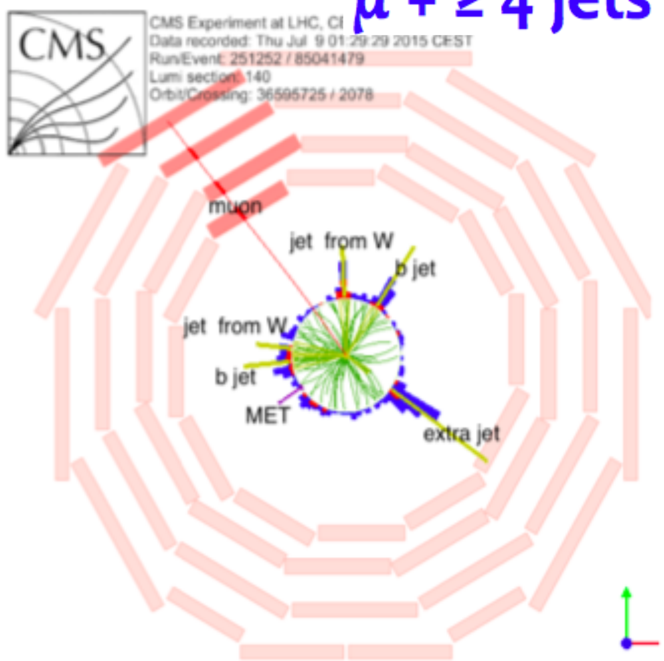
LHC Discussions, DESY, 02 November 2015

Top quark production

- **Top quarks: key to QCD, electroweak, and new physics**
  - Large mass → large coupling to Higgs (y ~ 1)
  - Decays before hadronizing: "bare" quark
  - New physics may preferentially couple/decay to top
  - Major source of background for many searches

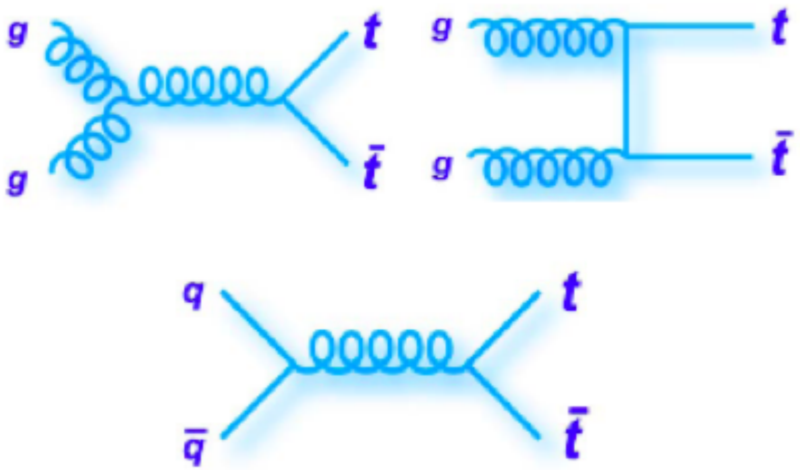
13 TeV
$\mu + \geq 4$ jets



- **Several million $t\bar{t}$ events produced in Run-I**
  - Great opportunity to study the details of top production mechanisms
    → Exploit kinematic distributions in different regions of the phase space
  - Production of $t\bar{t}$ in association with QCD jets or additional particles could reveal new physics
  - Theory predictions & models need to be tuned and tested with measurements

Top pair production and decay

- Top quarks produced mainly in pairs ($t\bar{t}$), and by gluon fusion at LHC (~90%)



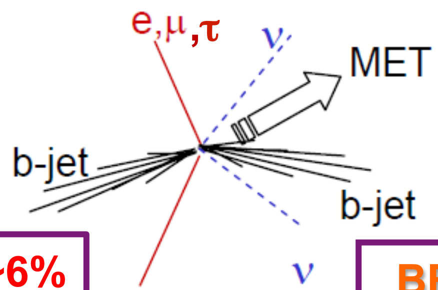
[Czakon, Fiedler, Mitov, arXiv:1303.6254]

$\sqrt{s}$ LHC	σ_{tt} (m_t = 172.5 GeV)[1]
7 TeV	$177.31^{+10.1}_{-10.8}$
8 TeV	$252.89^{+13.3}_{-14.5}$
13 TeV	$831.76^{+40.2}_{-45.6}$

x 3.3

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/TtbarNNLO

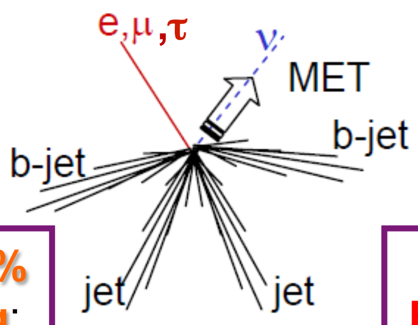
- In SM, t → W^+b (~100%) ➔ W decay modes define top final states



BR(μ,e)~6%
Low bg:
Z+jets

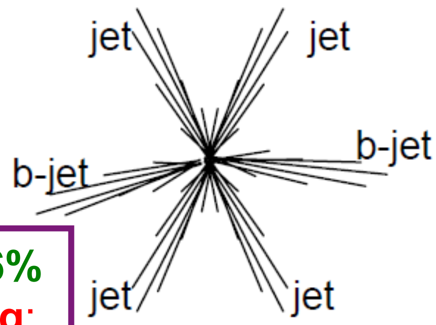
dileptons

BR(μ,e)~34%
Moderate bg:
W+jets



lepton + jets

BR~46%
Huge bg:
QCD

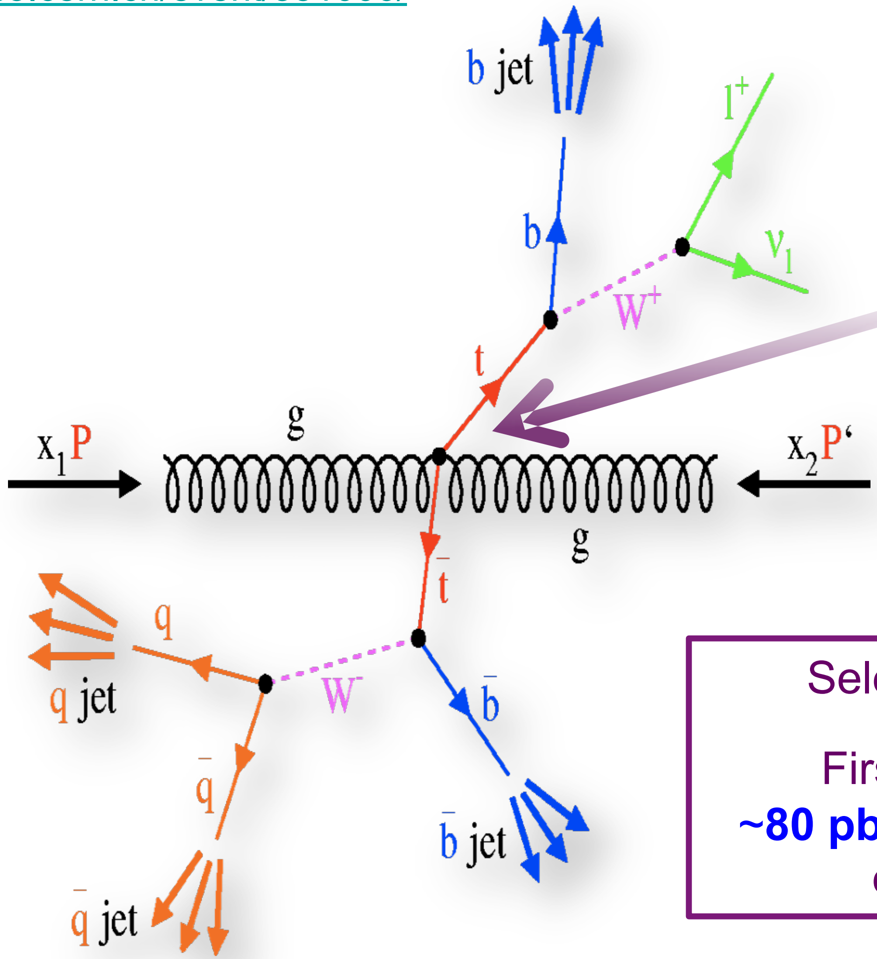


all hadronic

Menu for today

Many new measurements for TOP2015:

https://indico.cern.ch/event/351006/



$t\bar{t}$ production:

- **Inclusive xsec**
- **Differential xsec**
- **Boosted xsec**
- **$t\bar{t}$+jets, $t\bar{t}$+b(b)**
- **$t\bar{t}$+Z/W**

Selection of latest Run-I results

First 13 TeV results based on **~80 pb^{-1} (ATLAS)** and **42 pb^{-1} (CMS)** of the early 50ns dataset

$t\bar{t}$ cross section eμ "7+8" TeV – CMS

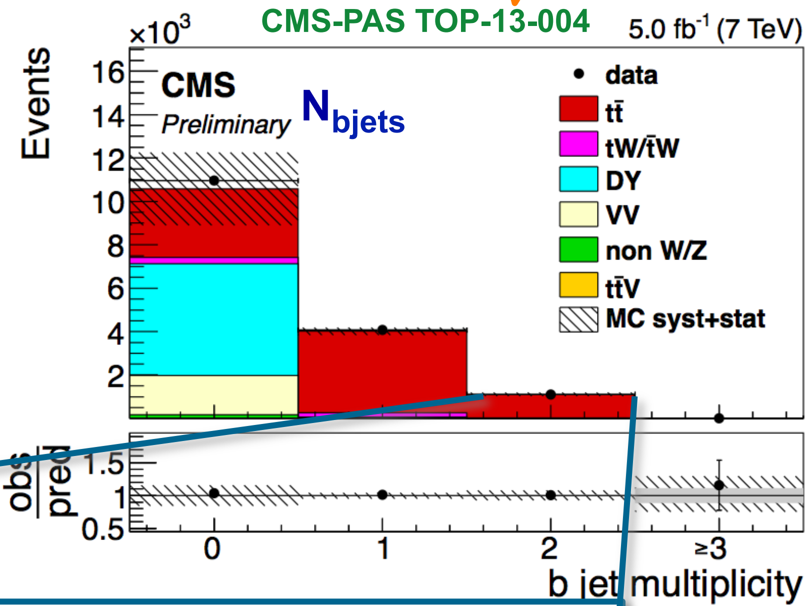
Sep'15

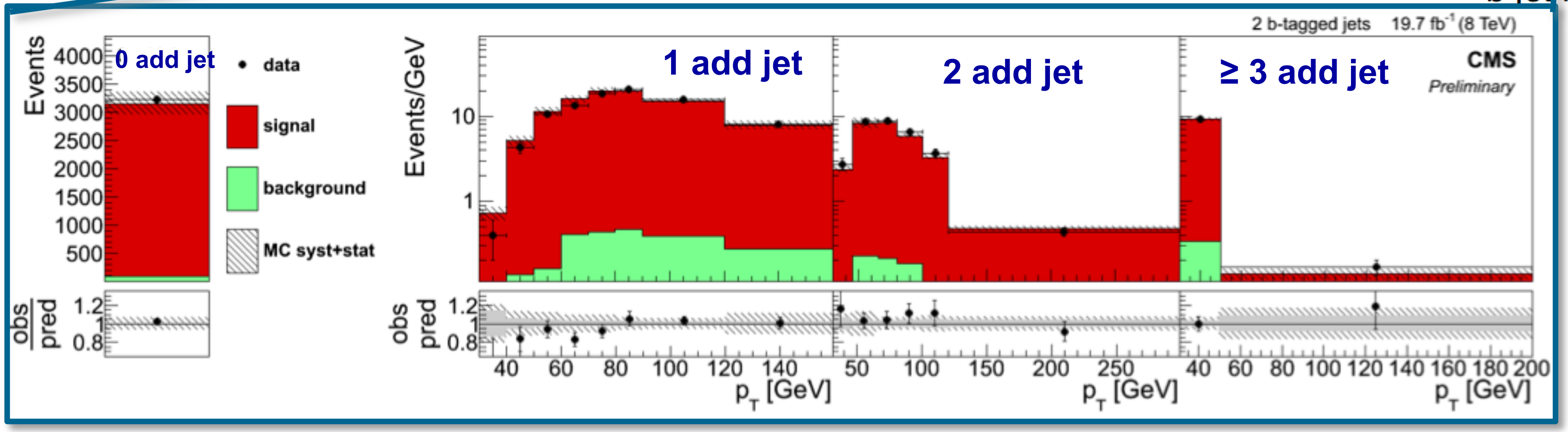
Last word from Run-I in dileptons at CMS

Selection: opp.-sign isolated eμ pair, jets, b-tags

- Simultaneous 7 & 8 TeV template fit with systematics as nuisance parameters:
  - N_{bjets} and additional non-btagged N_{jets} categories
  - fit to the softest additional non-btagged jet p_T distribution in each category

→ Large constraints on JES, extra radiation, b-tagging, etc





7 TeV: $\sigma_{t\bar{t}} = 174.5 \pm 2.1(\mathrm{stat}) \pm^{4.5}_{4.0} (\mathrm{syst}) \pm 3.8(\mathrm{lumi})$ pb (+3.6% - 3.4%)

8 TeV: $\sigma_{t\bar{t}} = 245.6 \pm 1.3(\mathrm{stat}) \pm^{6.6}_{5.5} (\mathrm{syst}) \pm 6.5(\mathrm{lumi})$ pb (+3.8% - 3.5%)

$t\bar{t}$ cross section in eμ at 13 TeV – ATLAS

Aug'15

ATLAS-CONF-2015-033

- Use eμ channel → very clean

  Selection: opposite-sign isolated eμ pair, 1 and 2 b-tagged jets

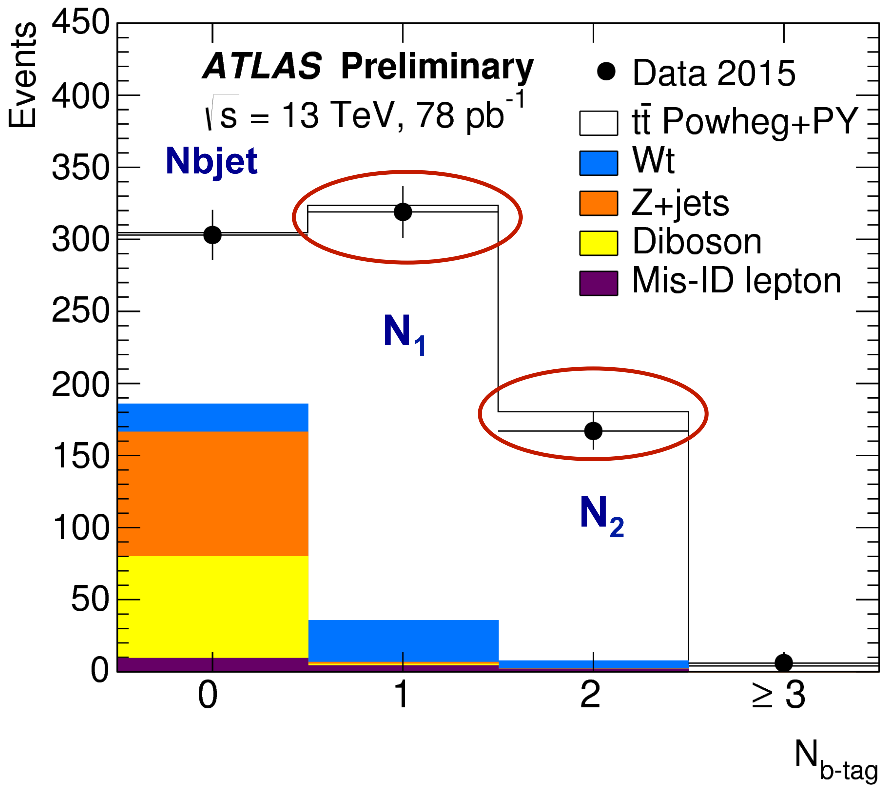
- Analysis strategy follows Run-I ATLAS best measurement

  - Simultaneous determination of σ_{tt} and b-tag efficiency in events with 1 and 2 b-tags

$$N_1 = \mathcal{L}\sigma_{t\bar{t}}\epsilon_{e\mu}2\epsilon_b(1 - C_b\epsilon_b) + N_1^{bkg}$$

$$N_2 = \mathcal{L}\sigma_{t\bar{t}}\epsilon_{e\mu}C_b\epsilon_b^2 + N_2^{bkg}$$

→ Minimize jet and b-tag systematics



$\boxed{\sigma_{tt} = 825 \pm 49\ (\text{stat}) \pm 60\ (\text{syst}) \pm 83\ (\text{lumi})\ \text{pb}}$ **(14%)**

- ε_b: product of b-tagging efficiency & jet kinematic acceptance for tt events
- $\varepsilon_{\mu e}$: leptonic acceptance
- C_b: tagging correlation

Dominant syst: luminosity, tt modelling, electron ID

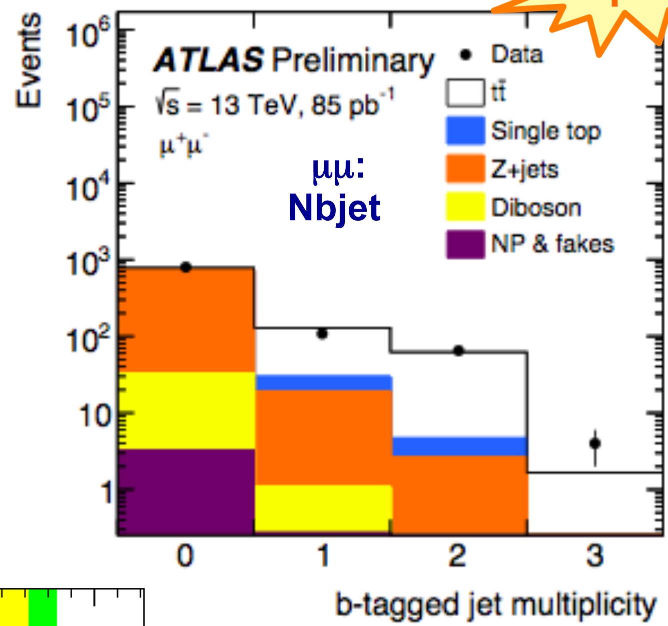
$t\bar{t}$ cross section in dileptons at 13 TeV – ATLAS

ATLAS-CONF-2015-049

Sep'15

- **ee**, **μμ** channels: same method as for **eμ**

  Selection: OS isolated ee/μμ pair, 1 and 2 b-tags
  + additional cuts to suppress DY and low m_{ll} resonances



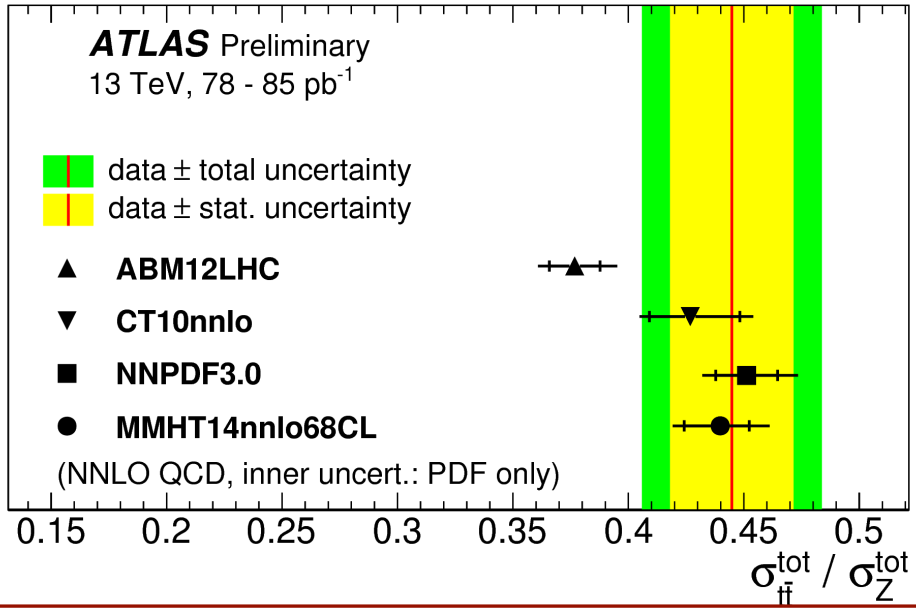
- Combined **ee** and **μμ**:

  σ_{tt} = 749 ± 57 (stat) ± 79 (syst) ± 74 (lumi) pb **(16%)**

  Dominant syst: luminosity, tt modelling

- $t\bar{t}$/Z ratio: interesting for PDF fits

Luminosity uncertainty cancels in the ratio



$t\bar{t}$ cross section in eμ at 13 TeV – CMS

Aug'15

arXiv:1510.05302, submitted to PRL

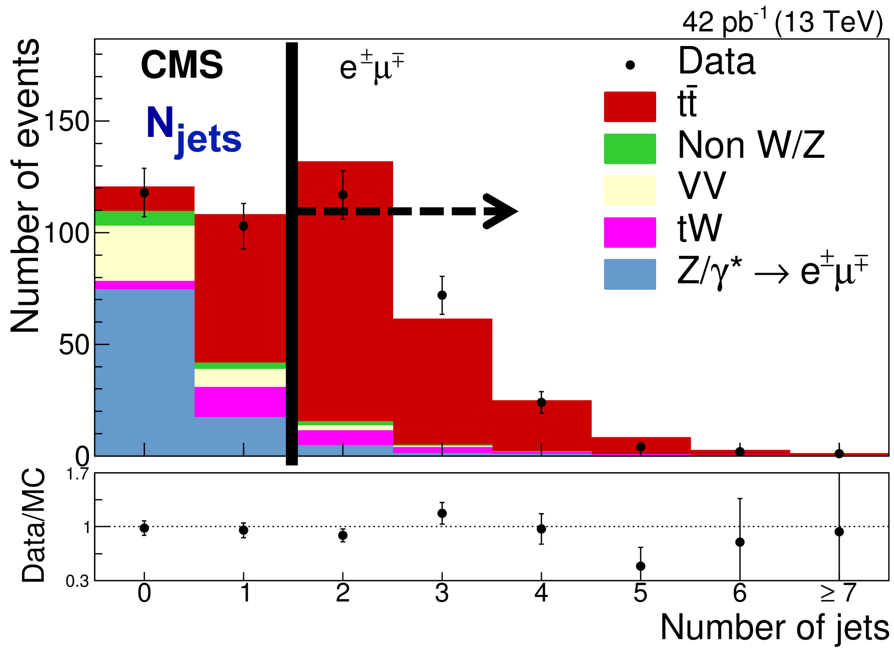
Is there a first glimpse of New Physics ?

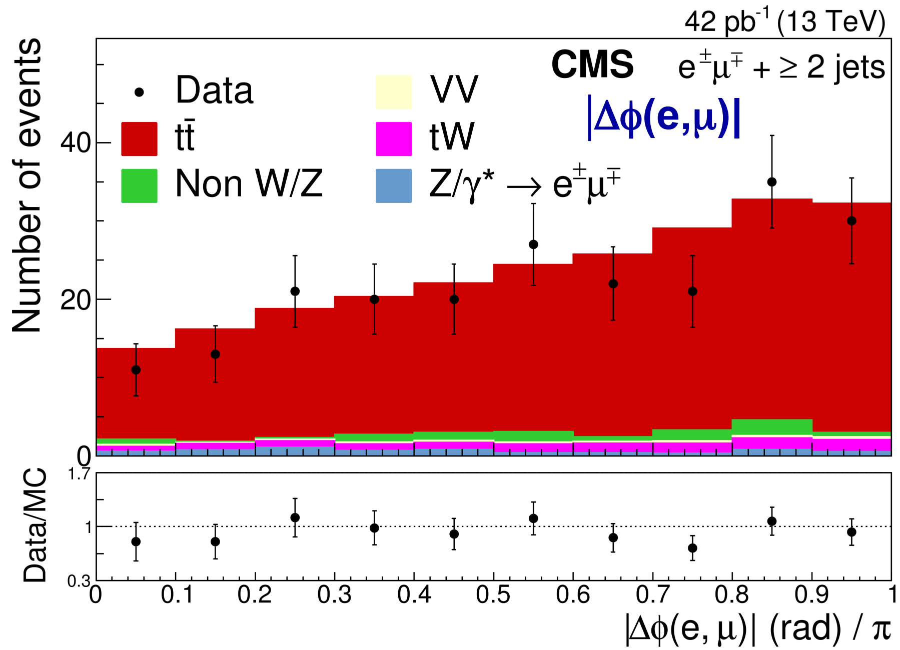
- Use eμ channel

  Selection: opposite-sign isolated eμ pair, ≥ 2 jets, **no b-tags**

$$\sigma = \frac{N_{data} - N_{bkg}}{\epsilon_{t\bar{t}} \int L dt}$$

- Cut & count approach (simple and robust)





$$\boxed{\sigma_{t\bar{t}} = 769 \pm 60\,(\text{stat}) \pm 55\,(\text{syst}) \pm 92\,(\text{lumi})\,\text{pb}}$$ **(16%)**

Dominant syst: luminosity, trigger & lepton efficiencies

$t\bar{t}$ cross section in l+jets at 13 TeV – ATLAS

ATLAS-CONF-2015-049

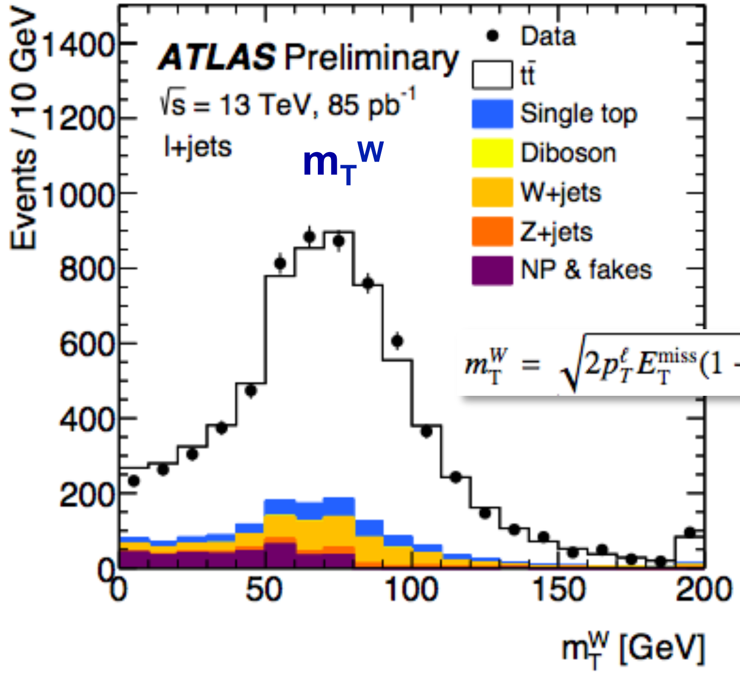
Sep'15

- e/μ+jets channel

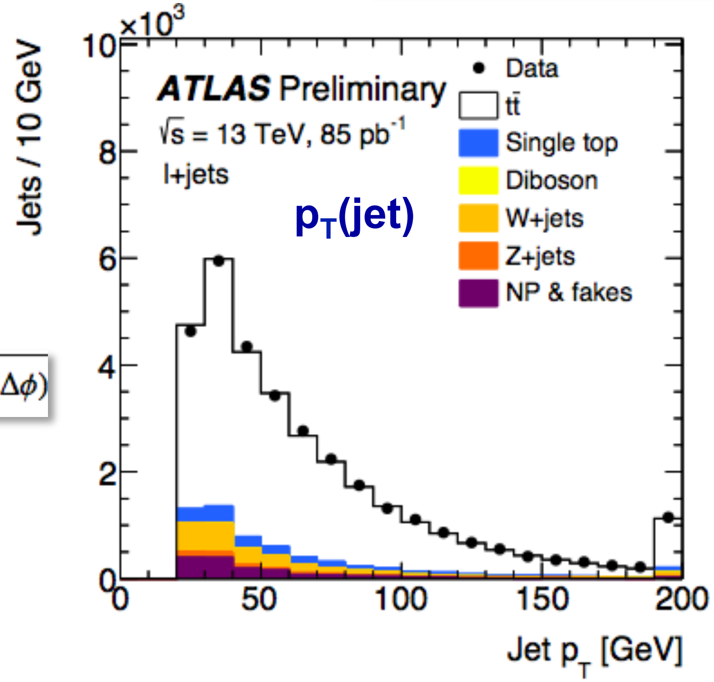
  Selection: e/μ, > 4 jets, > 1 b-tag
  + additional cuts to suppress W+jets and QCD background

- Cut & count approach

$$\sigma = \frac{N_{data} - N_{bkg}}{\epsilon_{t\bar{t}} \int L dt}$$



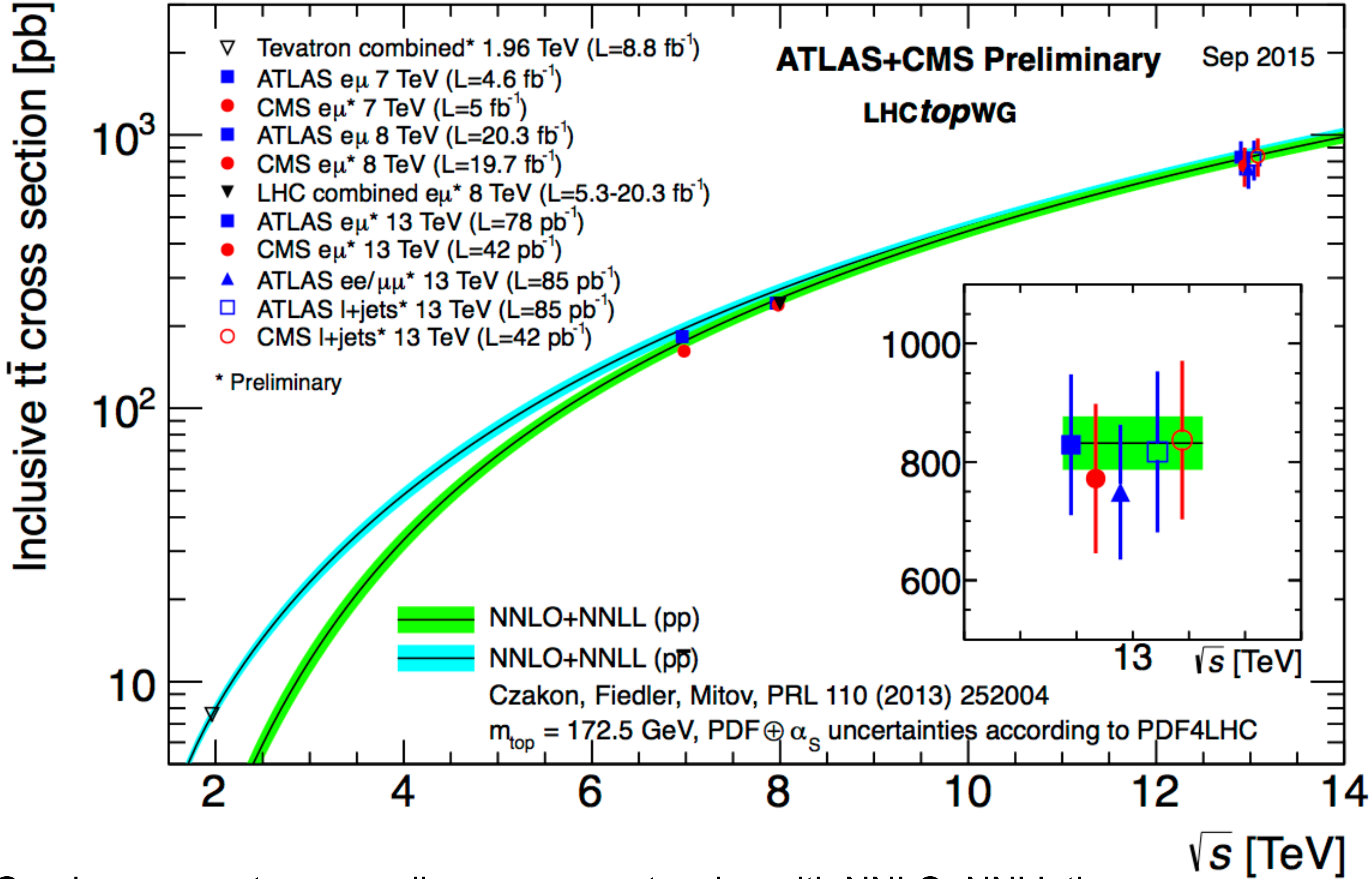
$$m_T^W = \sqrt{2 p_T^{\ell} E_T^{\mathrm{miss}} (1 - \cos \Delta\phi)}$$



σ_{tt} = 749 ± 57 (stat) ± 79 (syst) ± 74 (lumi) pb **(16%)**

Dominant syst: JES, luminosity

The full picture

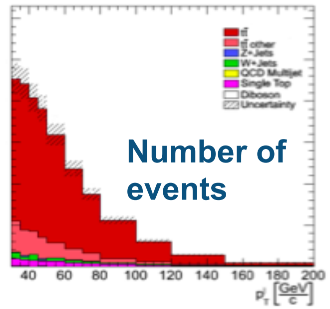


- Good agreement among all measurements, also with NNLO+NNLL theory
- 13 TeV results dominated by luminosity uncertainty: ~10% ATLAS, 12% CMS

Top pair differential cross sections

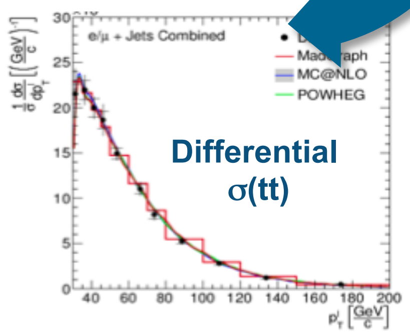
Scrutinize $t\bar{t}$ production in all channels as a function of many kinematic observables

- Main analysis ingredients
  - Tight event selection → pure $t\bar{t}$ sample
  - $t\bar{t}$ kinematic reconstruction
  - Bin-wise cross section measurement
  - Unfolding: correct for detector effects & acceptance
- Compare to theoretical predictions
  - Parton or particle level, in full or fiducial phase space
- Absolute or normalized to in-situ measured $\sigma(t\bar{t})$
  - Normalization: many systematics cancel, only shape uncertainties contribute



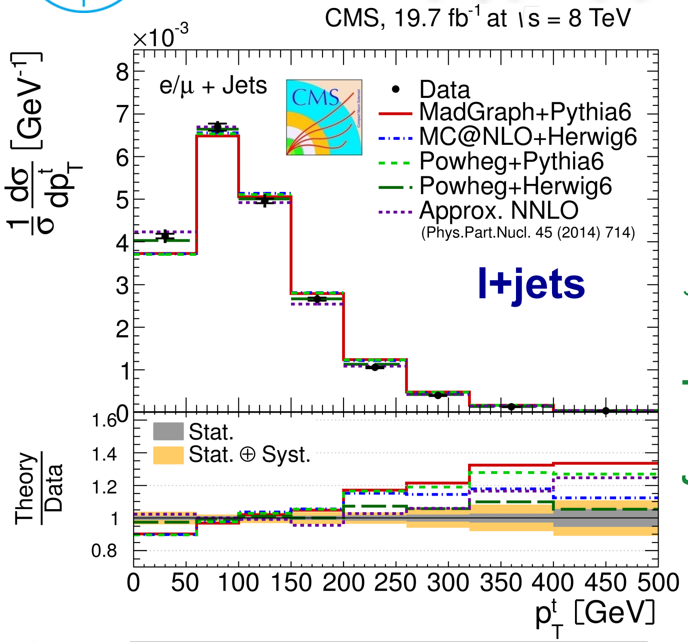
Δ^X_i = bin width for variable X

$$\boxed{\frac{d\sigma_i}{dX} = \frac{\mathrm{unfold}(s_i^X - b_i^X)}{\Delta_i^X \cdot \int \mathcal{L}dt}}$$

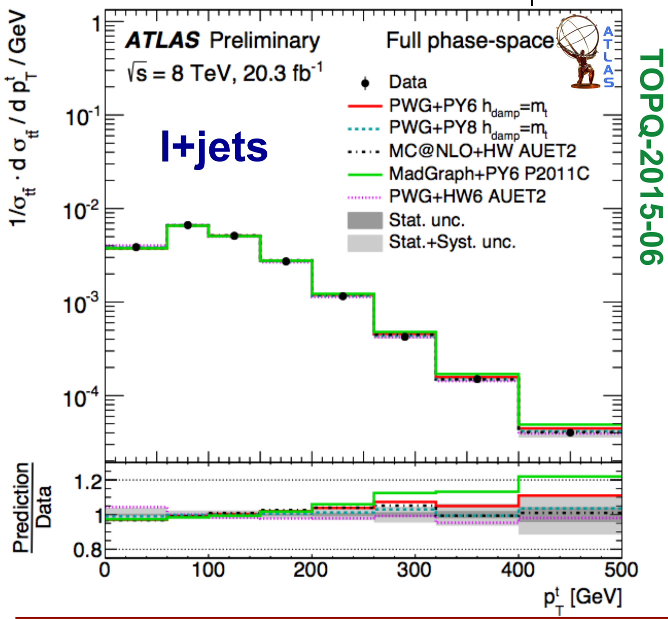


The p_T(top) distribution in Run-I

Sep'15



arXiv:1505.04480, accepted by EPJC



TOPQ-2015-06

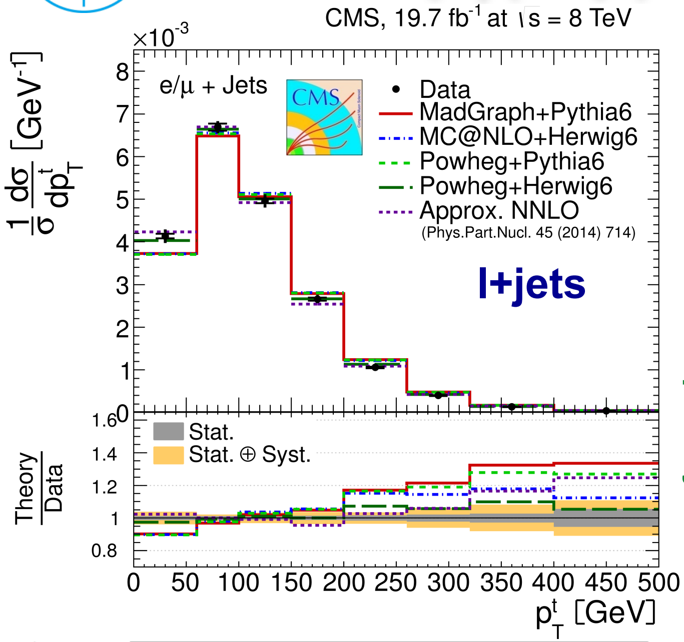
p_T spectrum softer in data, in particular at the tail
→ impact also on searches, $t\bar{t}$+H

CMS: Observed consistently in all channels, 7 & 8 TeV

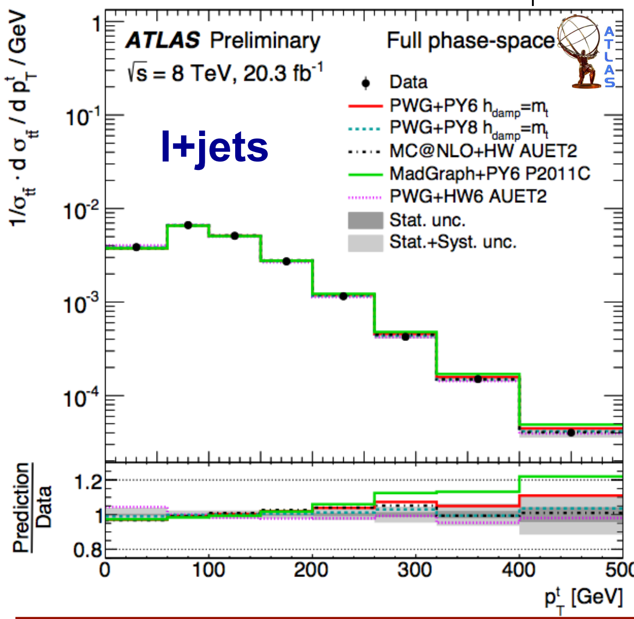
ATLAS and CMS data appear in good agreement at 8 TeV

The p_T(top) distribution in Run-I

Sep'15



arXiv:1505.04480, accepted by EPJC



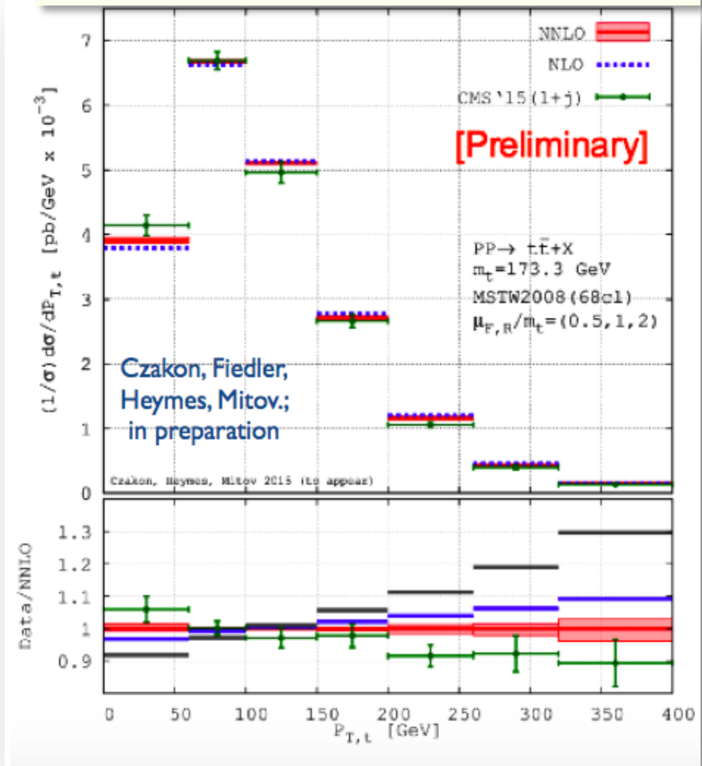
TOPQ-2015-06

p_T spectrum softer in data, in particular at the tail
→ impact also on searches, $t\bar{t}$+H

CMS: Observed consistently in all channels, 7 & 8 TeV

ATLAS and CMS data appear in good agreement at 8 TeV

Full NNLO calculation available !



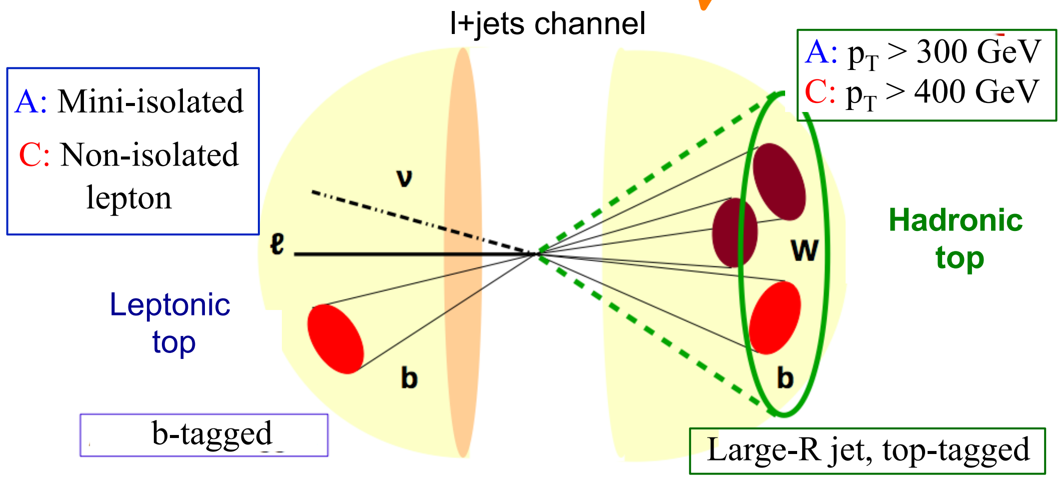
Full NNLO 'confirms' observed slope, in direction closer to data

High p_T tops: entering boosted regime

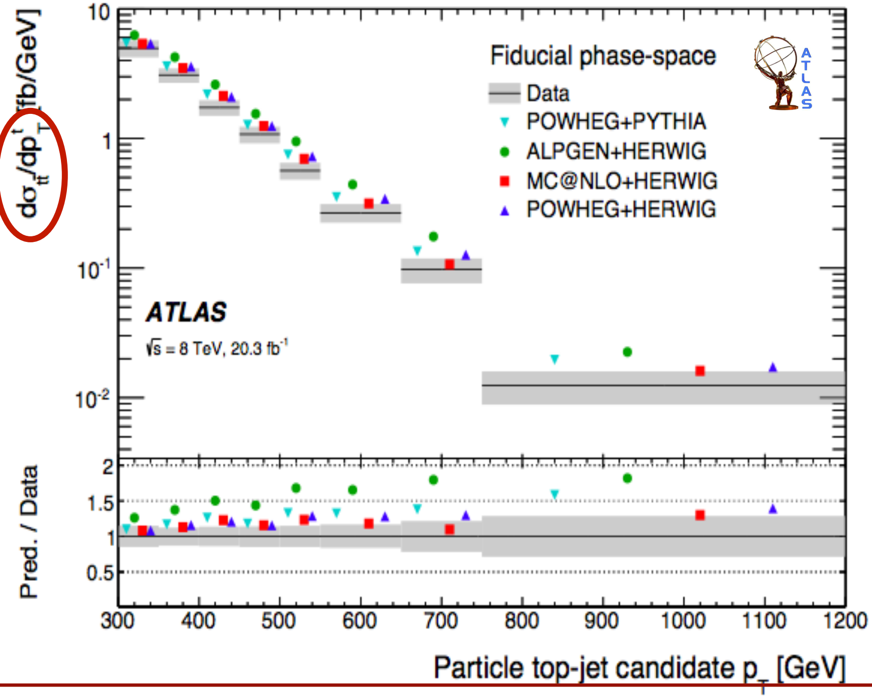
Sep'15

Measure top quarks at high p_T using optimized event selection & reconstruction up to TeV range !

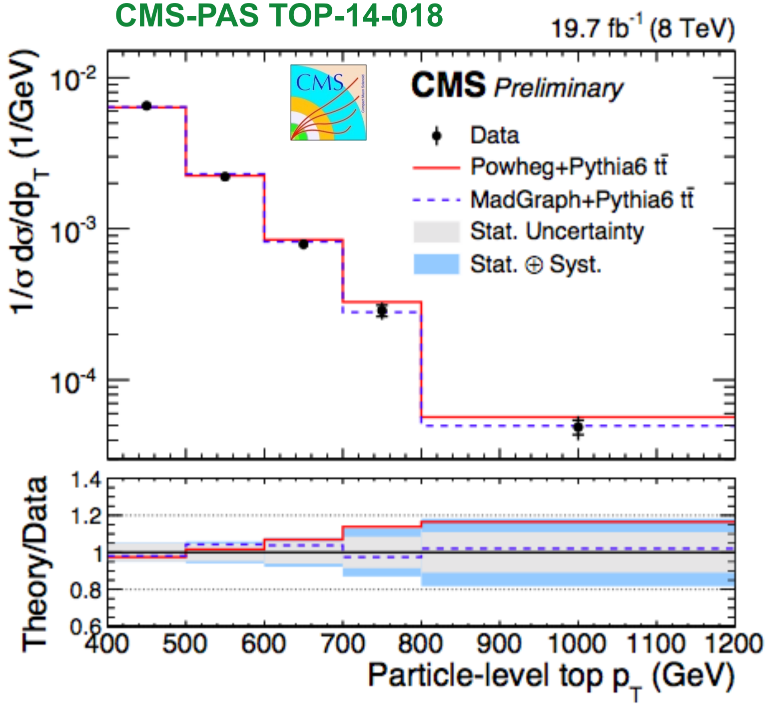
- Parton and particle level, full and fiducial phase space
- Slightly softer p_T spectrum in data for both ATLAS & CMS



arXiv:1510.03818, submitted to PRD



CMS-PAS TOP-14-018

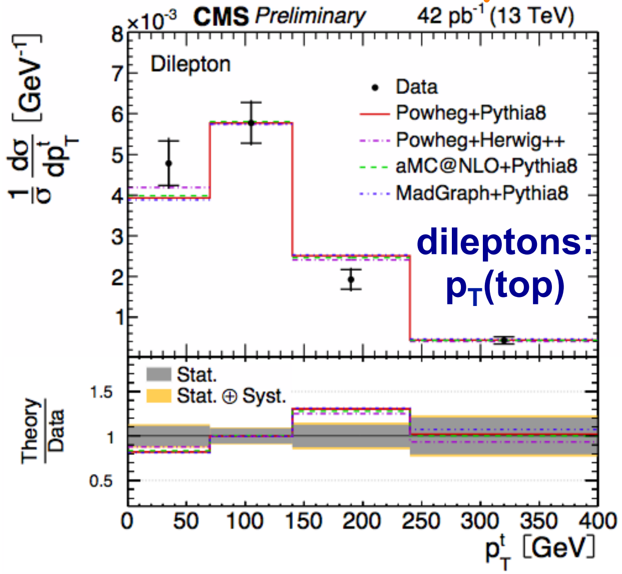


$t\bar{t}$ differential at 13 TeV – CMS

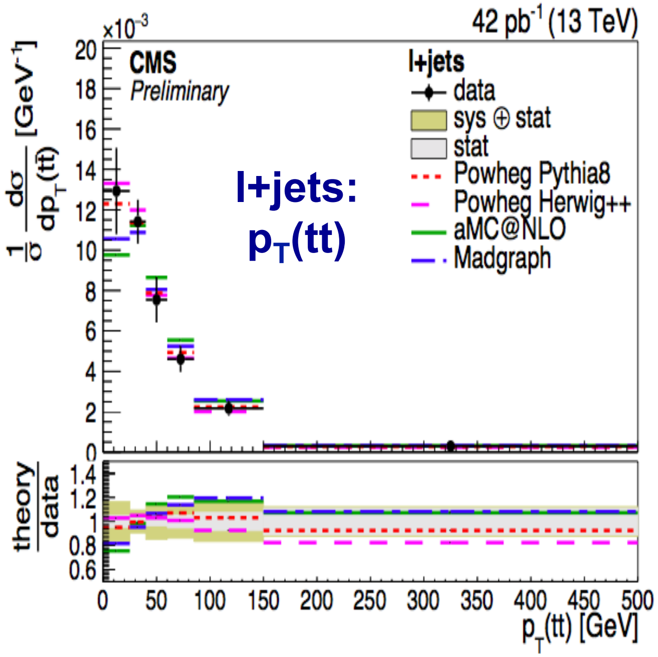
Aug'15

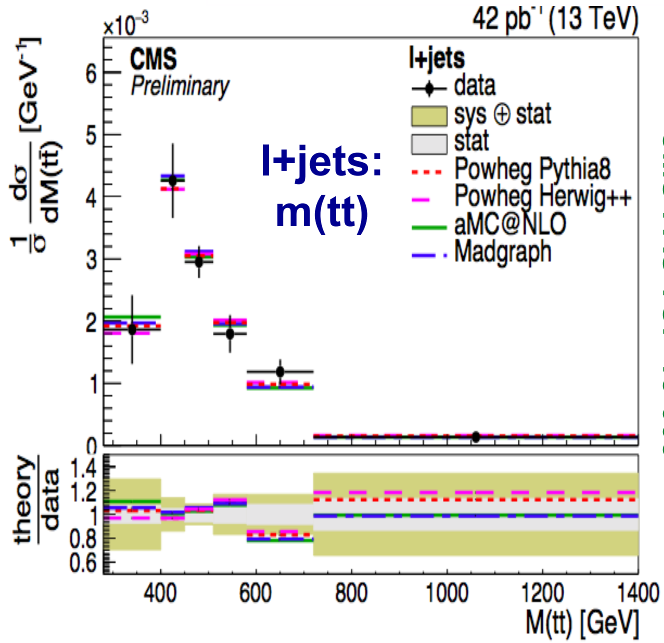
Important first test of QCD at 13 TeV

- Parton level, full phase space
- New generation of MCs available, with new tunes and configurations, are compared to data
- Good agreement between data and predictions



CMS-PAS TOP-15-010





CMS-PAS TOP-15-005

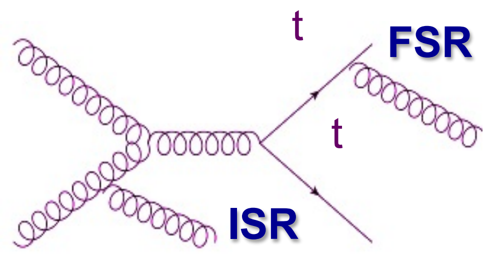
tt+"friends"

Jet multiplicity at 13 TeV – CMS

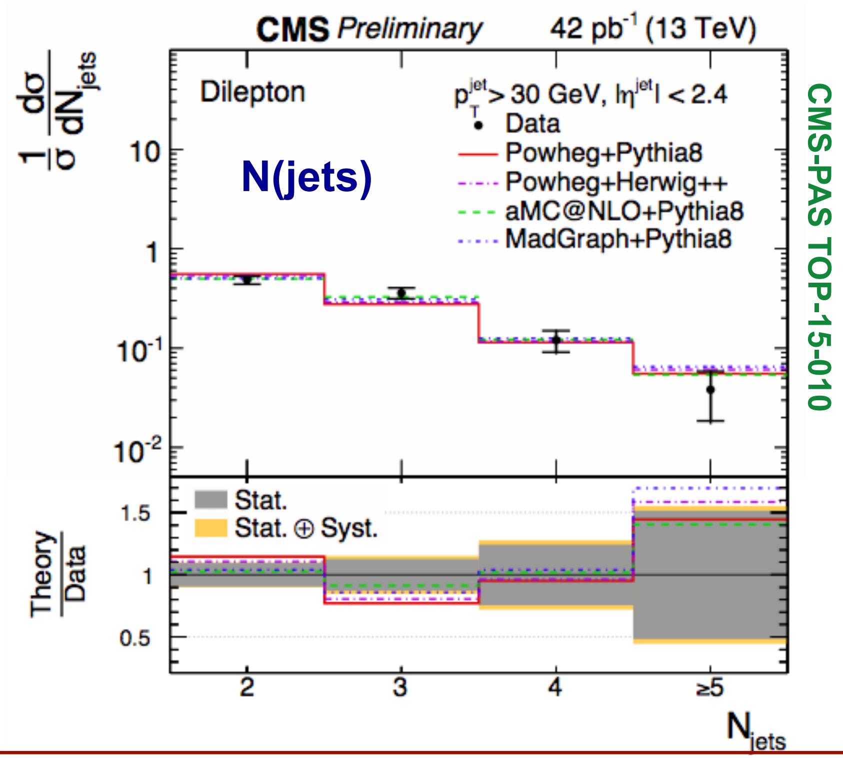
Aug'15

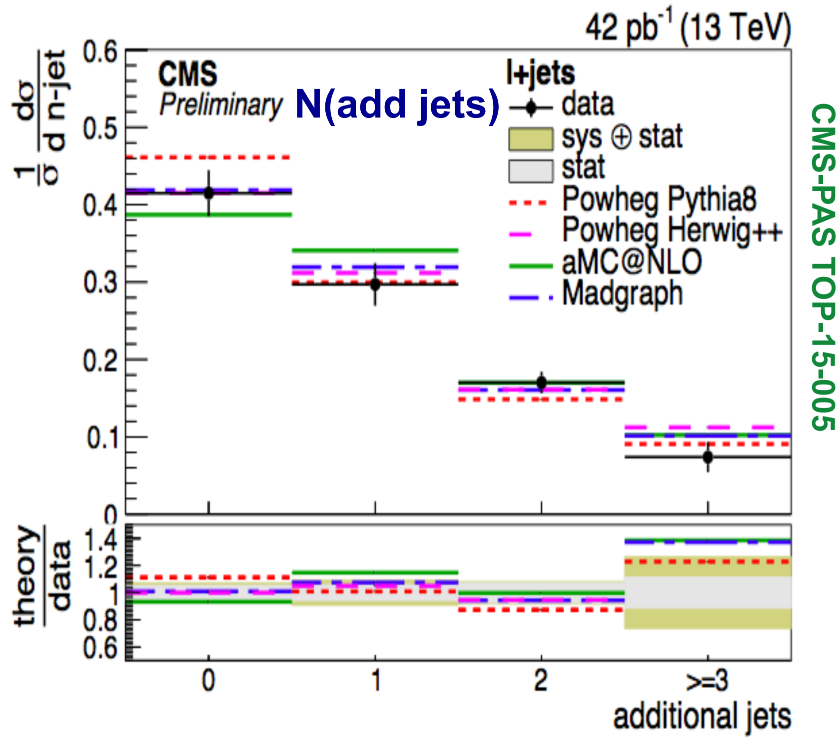
Large fraction of $t\bar{t}$ in Run-I have extra hard jets from initial or final state radiation

- Detailed study of pQCD at the highest scales
- Reveal presence of new physics in $t\bar{t}$+jets final states, bg for $t\bar{t}$+H



- First jet multiplicity results at 13 TeV
  - Measured at particle level in fiducial phase space



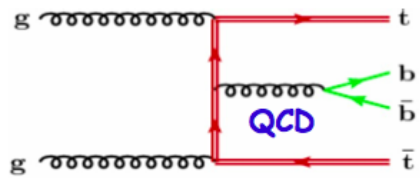


$t\bar{t}$+b(b) production at 8 TeV – ATLAS

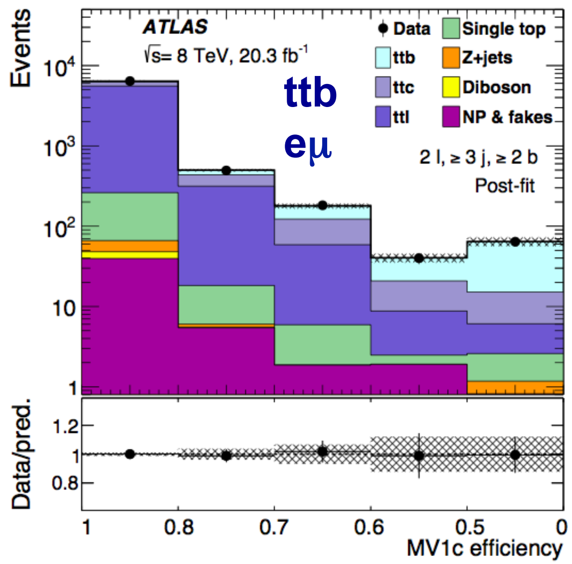
Aug'15

arXiv:1508.06868

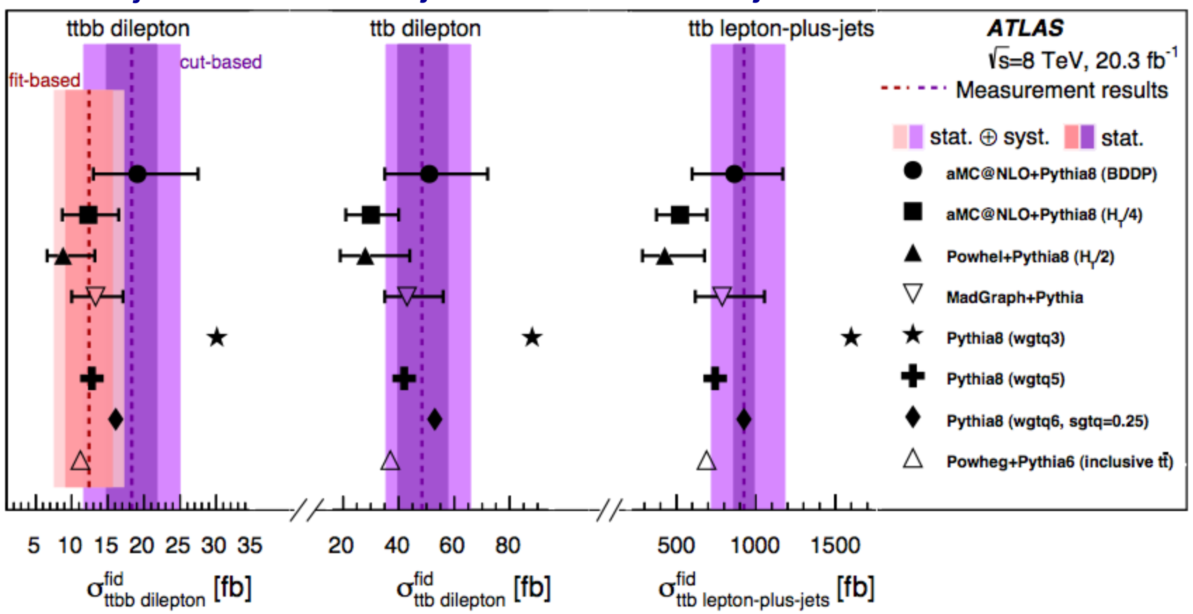
Irreducible, non-resonant background for $t\bar{t}$+H($b\bar{b}$)

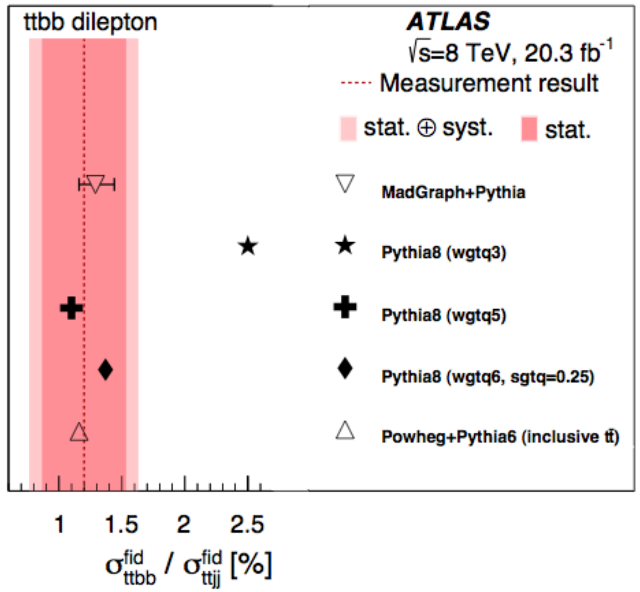


- tt+bb in dileptons (ee, μμ, eμ)
  tt+b in l+jets and in eμ channels
- Signal extraction by fit to MVA b-tag discriminator (tt+b, tt+bb) and cut-based (tt+bb)
- Compare to different g→bb splitting models



2l + 4j + 2b
2l + 3j + 2b
1l + 5j + 2b



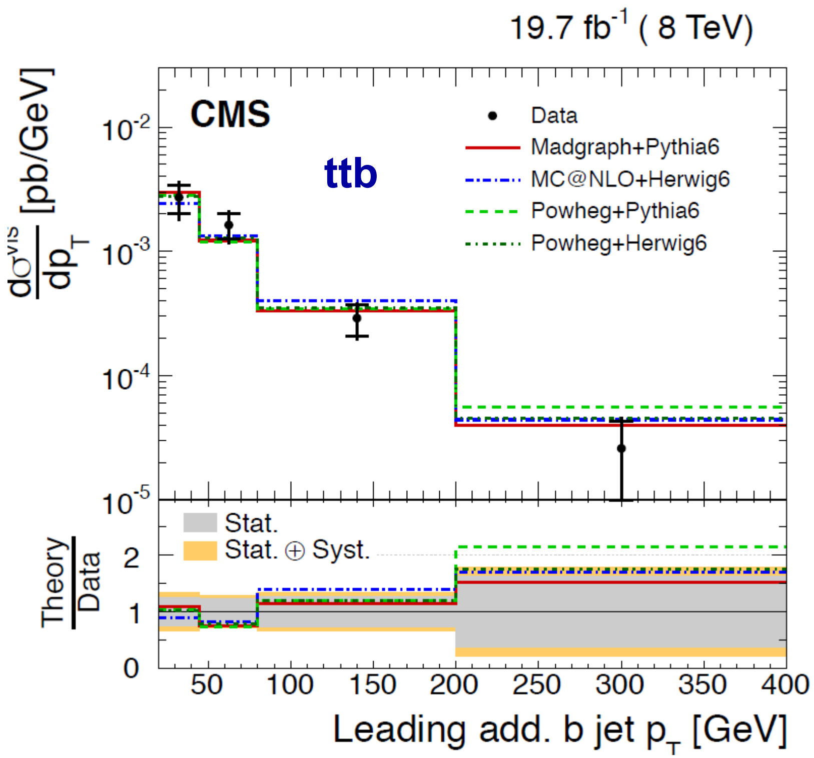


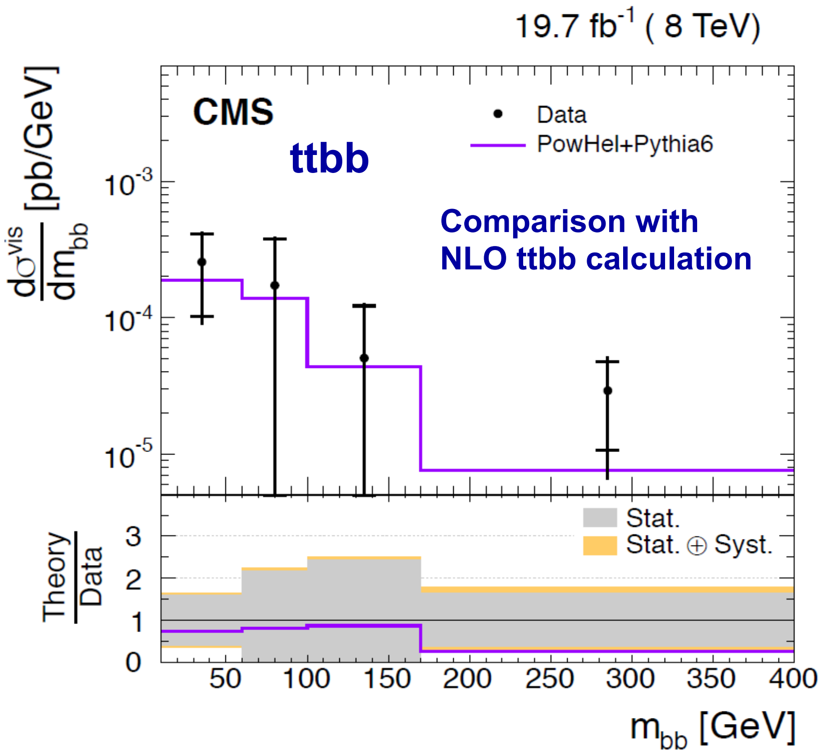
$t\bar{t}$+b(b) production at 8 TeV – CMS

Oct'15

arXiv:1510.03072, submitted to EPJC

- Dilepton channels:
  - Differentially as a function of the kinematic properties of the additional b jets



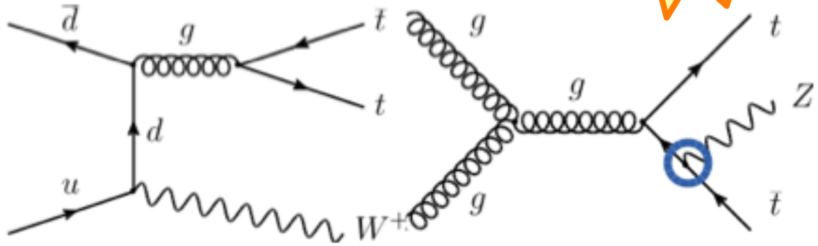


$t\bar{t}$+Z and $t\bar{t}$+W at 8 TeV – ATLAS

Sep'15

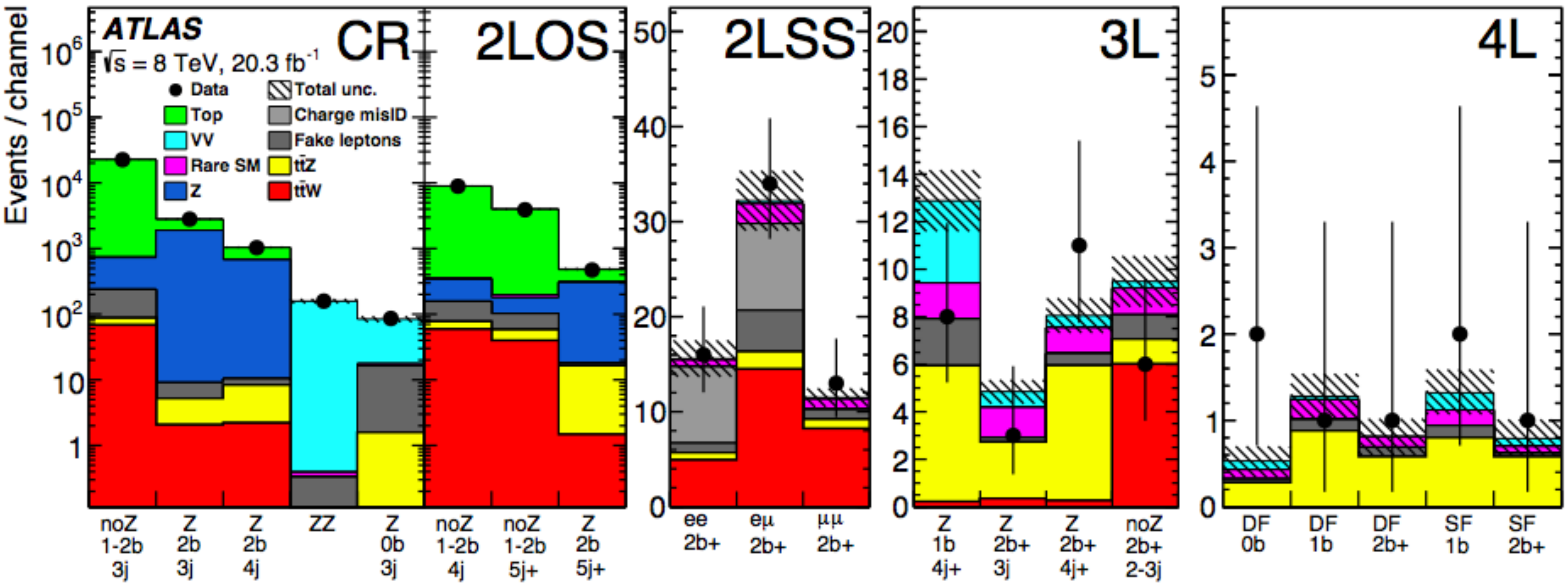
Very rare processes in SM

- Measure couplings to bosons
- Important background for BSM and $t\bar{t}$+H



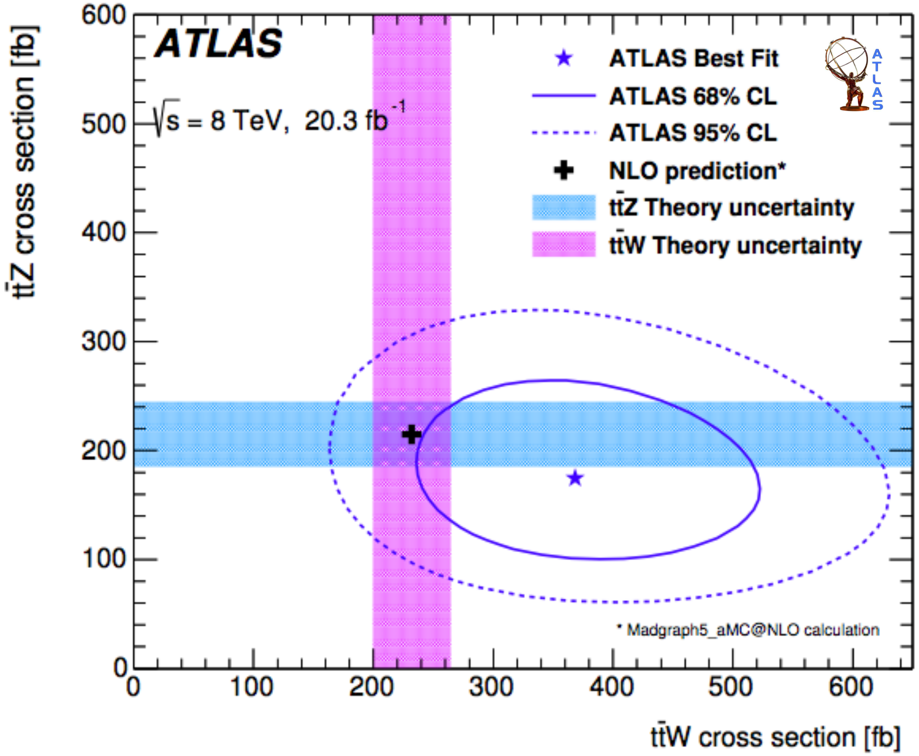
- 4 signal regions based on selected leptons: opposite sign (OS) 2l, same sign (SS) 2l, 3l, 4l
  - Extract $t\bar{t}$+Z, $t\bar{t}$+W simultaneously in a binned profile likelihood fit
  - Increase sensitivity: also split into jet and b-tagged jets categories, m_{ll} compatibility with Z

arXiv:1509.05276

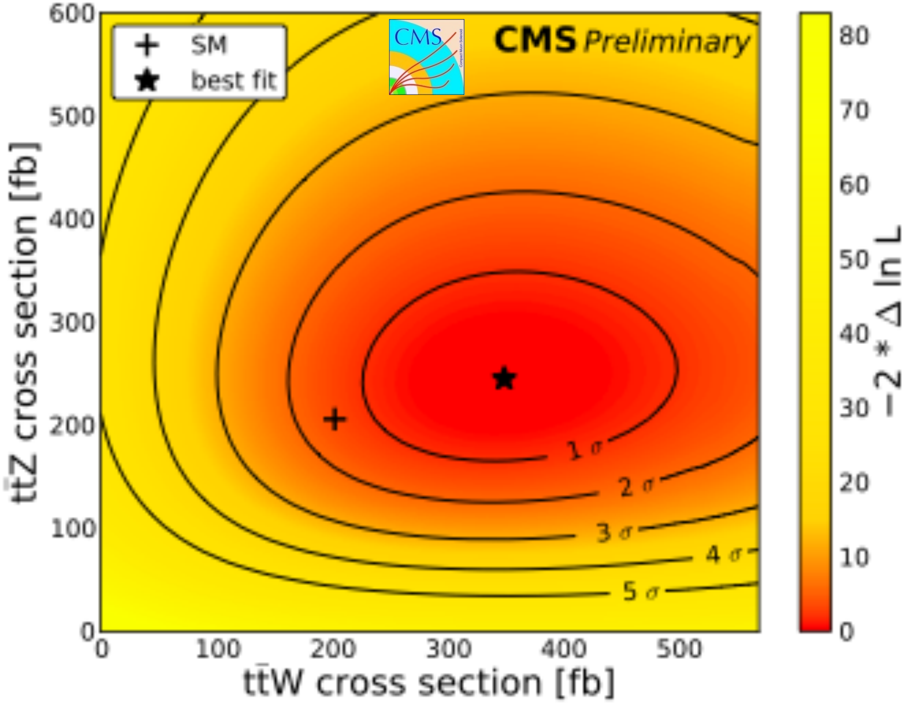


$t\bar{t}$+Z and $t\bar{t}$+W at 8 TeV

arXiv:1509.05276



CMS-PAS TOP-14-021



- $\sigma(ttW) = 369^{+100}_{-91}$ fb – 5.0σ obs. (3.2 exp)
- $\sigma(ttZ) = 176^{+58}_{-52}$ fb – 4.2σ obs. (4.5 exp)

- $\sigma(ttW) = 382^{+117}_{-102}$ fb – 4.8σ obs. (3.5 exp)
- $\sigma(ttZ) = 242^{+65}_{-55}$ fb – 6.0σ obs. (5.7 exp)

$t\bar{t}$+Z, $t\bar{t}$+W production established !

Summary

- Top quark physics: key to QCD, electroweak and New Physics
- Top quark production
  - tt inclusive cross sections measured with 4% accuracy
  - Differential: resolved vs boosted, parton vs particle level
  - $t\bar{t}$+heavy flavour production: irreducible, non-resonant background for $t\bar{t}H(bb)$
  - Observation of tt+Z/W/γ: potential to verify top couplings
- First 13 TeV cross section results are now available !
- So far, good agreement with SM predictions
- Run-II: expect 100 fb^{-1} by end of 2018:
  ~80M $t\bar{t}$, ~20M single top, ~80000 $t\bar{t}Z$ and tZ events
  - Trade off statistics for systematics
  - Access to new physics in the top environment

Exciting times ahead !
Stay tuned ! ☺

ATLAS: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults

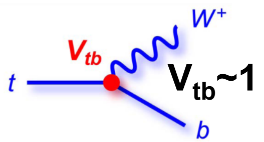
CMS: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

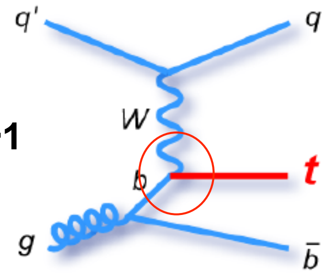
Additional information

Single top

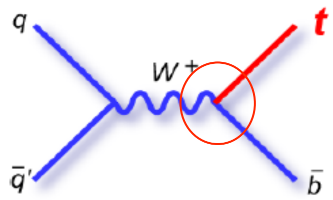
- Cross section proportional to $|V_{tb}|^2$, test unitarity of CKM

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

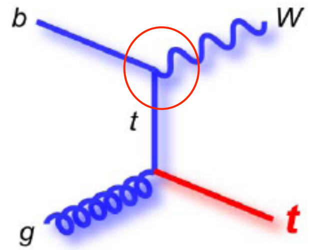




t-channel



s-channel



tW-channel

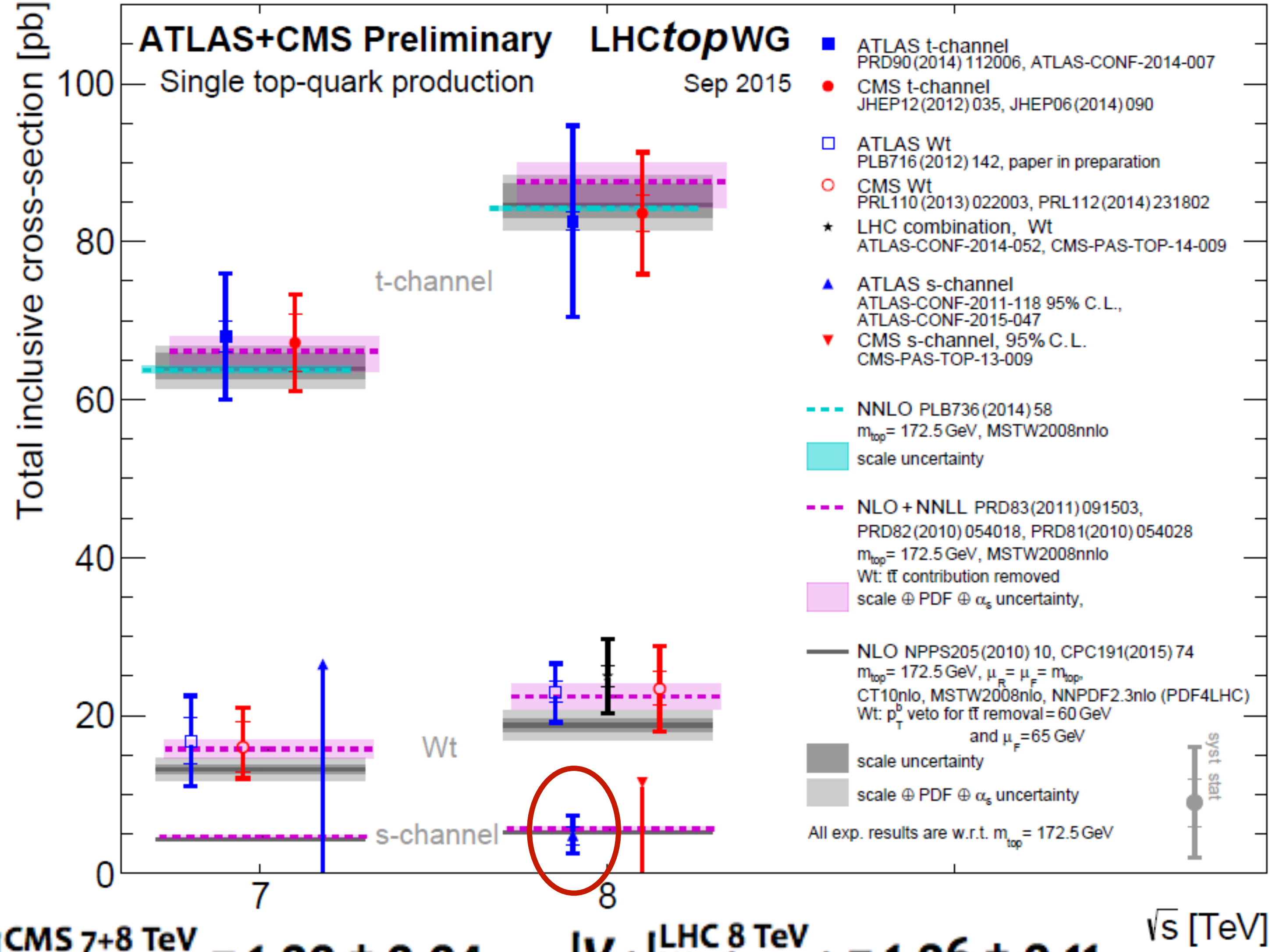
- Probe for new physics (4th gen., FCNC)
- Sensitivity to b-PDF and u/d-PDF
- Large backgrounds: $t\bar{t}$, W+jets, QCD
- Typically apply multivariate techniques (NN, BDT) using full event properties to maximize sensitivity

approx. NNLO, Phys. Part. Nucl. 45, **2014** arXiv:1506.04072, **2015**

	8 TeV (pb)	13 TeV (pb)	
t-chan	86.5 +3.4 –2.4	248 ± 5	(x 2.9)
tW-chan	22.0 ± 2.5	70.4 +3.7 –3.8	(x 3.2)
s-chan	5.65 ± 0.22	11.17 ± 0.42	(x 2)

- Single top well established at LHC:
  - **s-channel**: First evidence at LHC in Run-I from ATLAS ! **ATLAS-CONF-2015-047**
  - **t-channel**: First result at 13 TeV from CMS ! **CMS-PAS TOP-15-004**

Single top summary in Run-I



$$|V_{tb}|^{\text{CMS 7+8 TeV}}_{\text{t-channel}} = 1.00 \pm 0.04 \qquad |V_{tb}|^{\text{LHC 8 TeV}}_{\text{Wt-channel}} = 1.06 \pm 0.11$$

in good agreement with $|V_{tb}|_{\text{global SM fit}} = 0.99914 \pm 0.00005$ *Chin. Phys. C38 (2014)*

Single top t-channel

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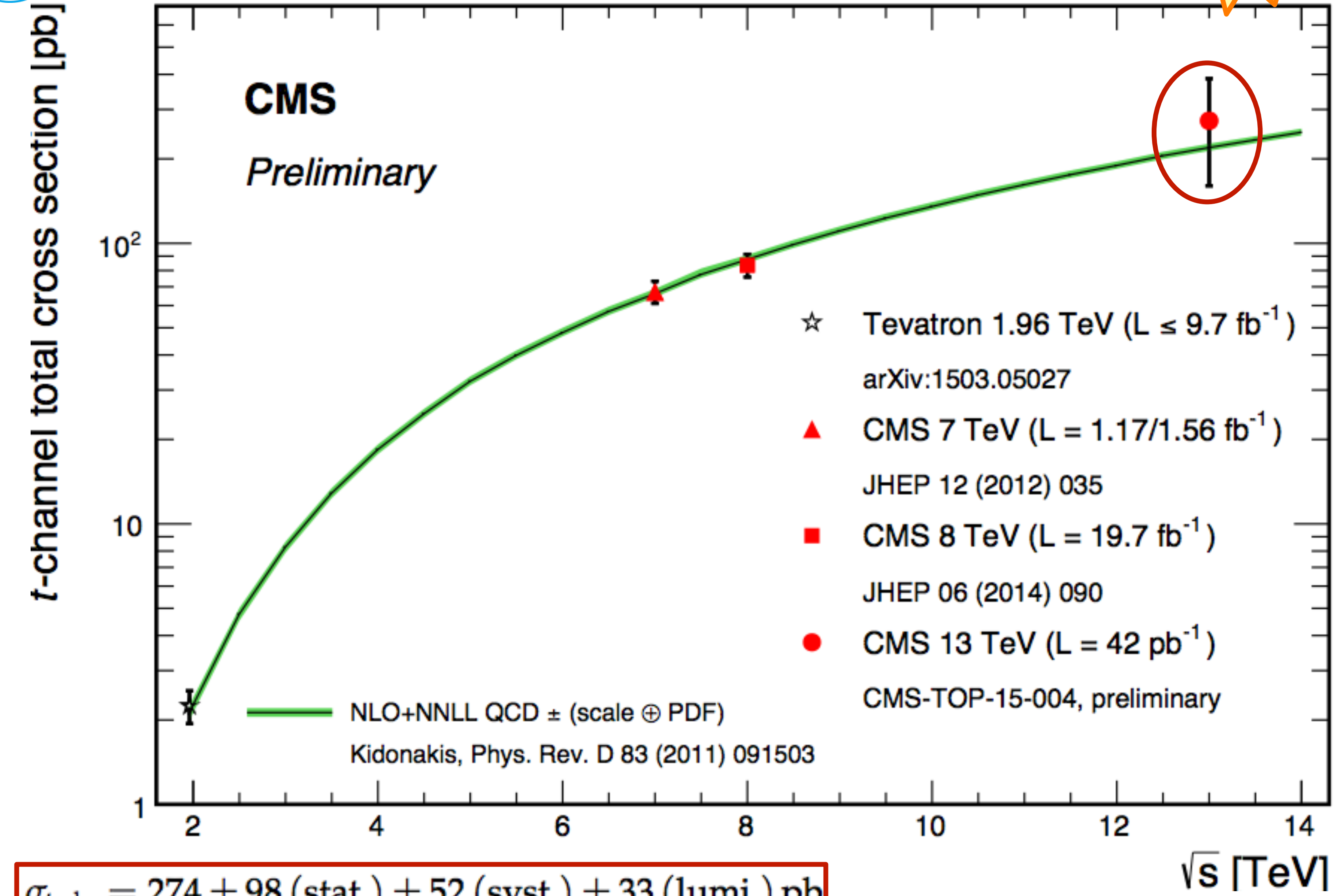
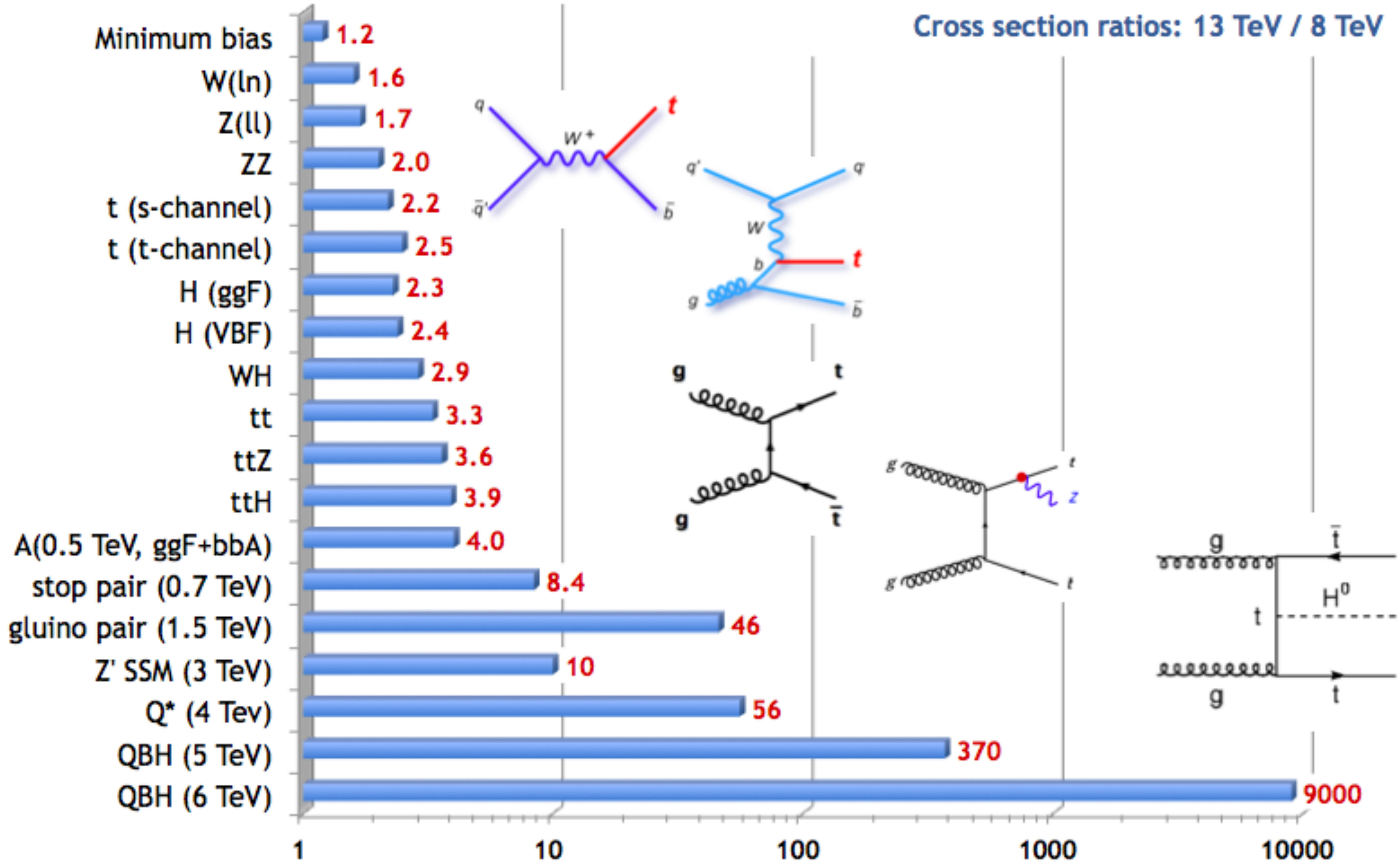


$$\sigma_{t\text{-ch.}} = 274 \pm 98\,(\text{stat.}) \pm 52\,(\text{syst.}) \pm 33\,(\text{lumi.})\ \text{pb}$$

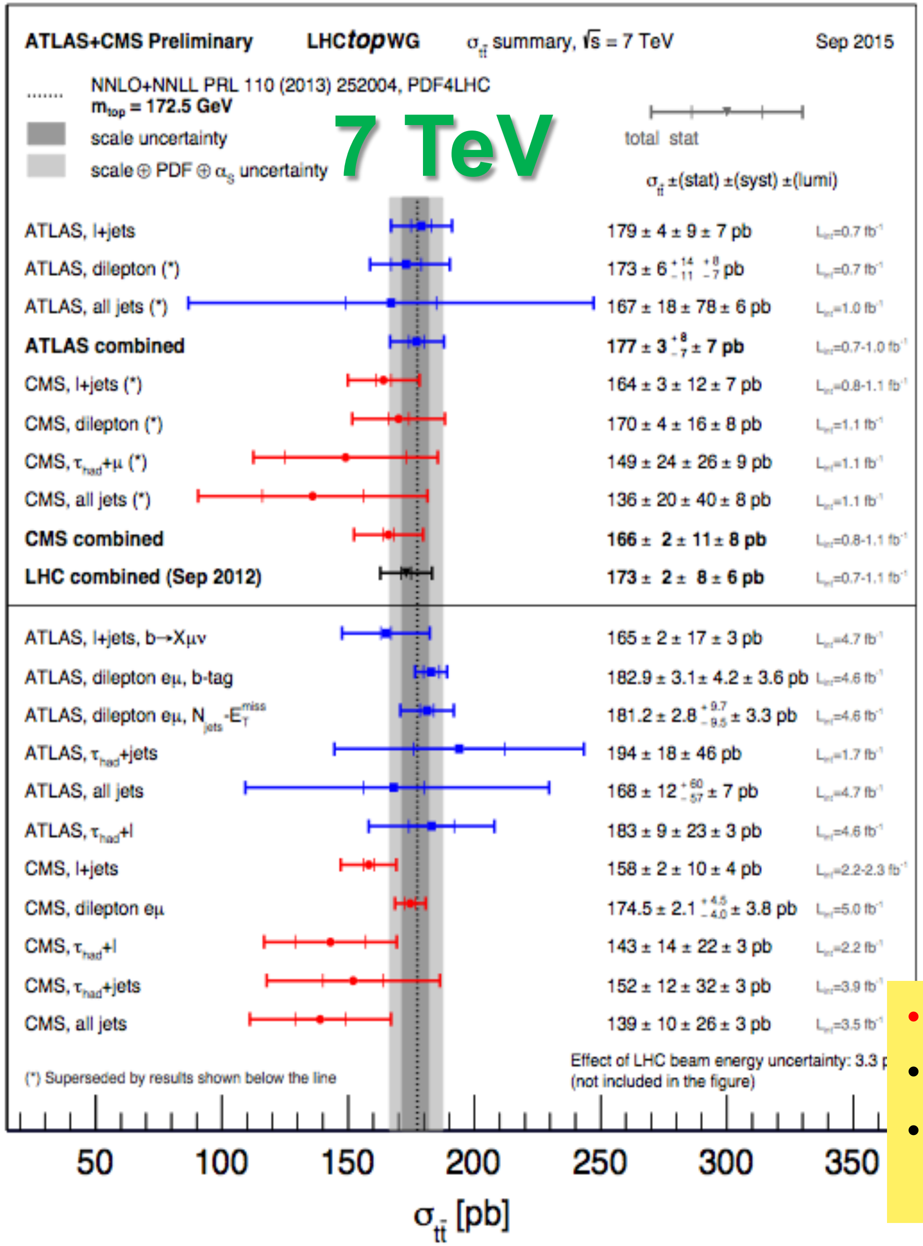
CMS-PAS TOP-15-004

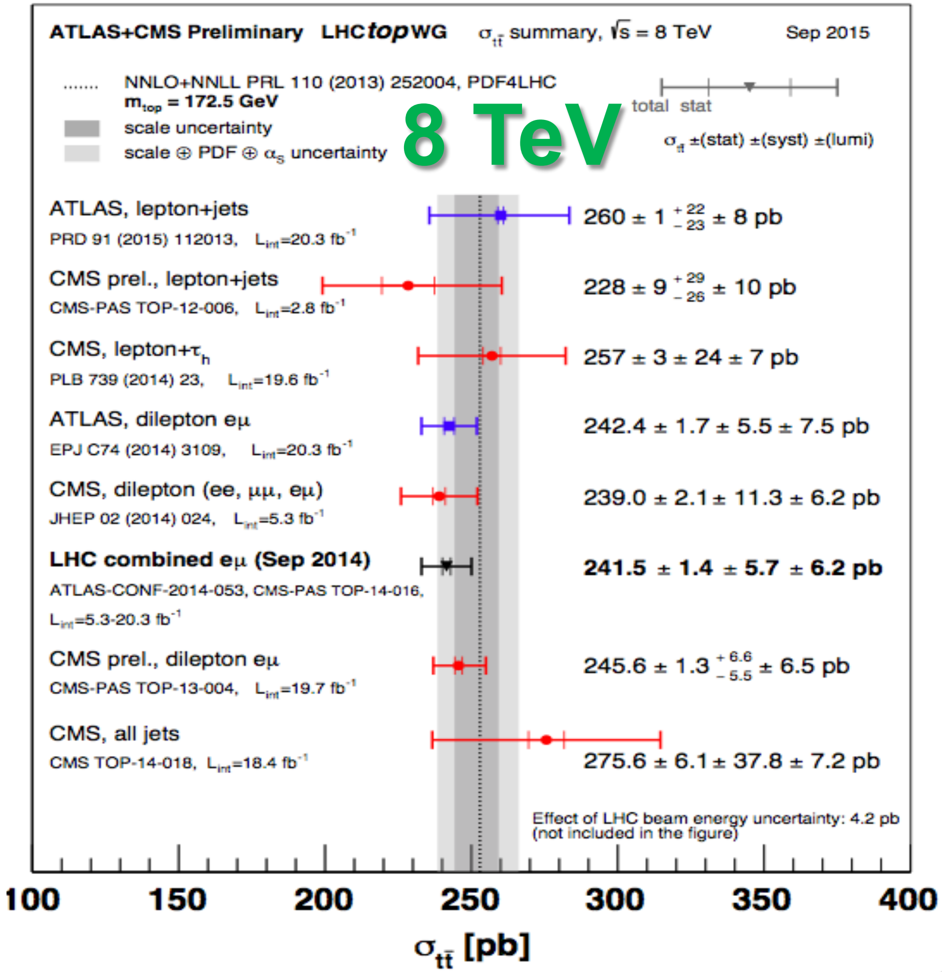
3.5σ Obs. (2.7σ Exp.)

Cross sections: 13 TeV / 8 TeV



Run-I inclusive $t\bar{t}$ cross section





- All channels measured to look for the unexpected
- Good agreement with NNLO+NNLL
- Precision of ~4% (dilepton channel), similar to theoretical prediction

Top pair cross section eμ “7+8” TeV

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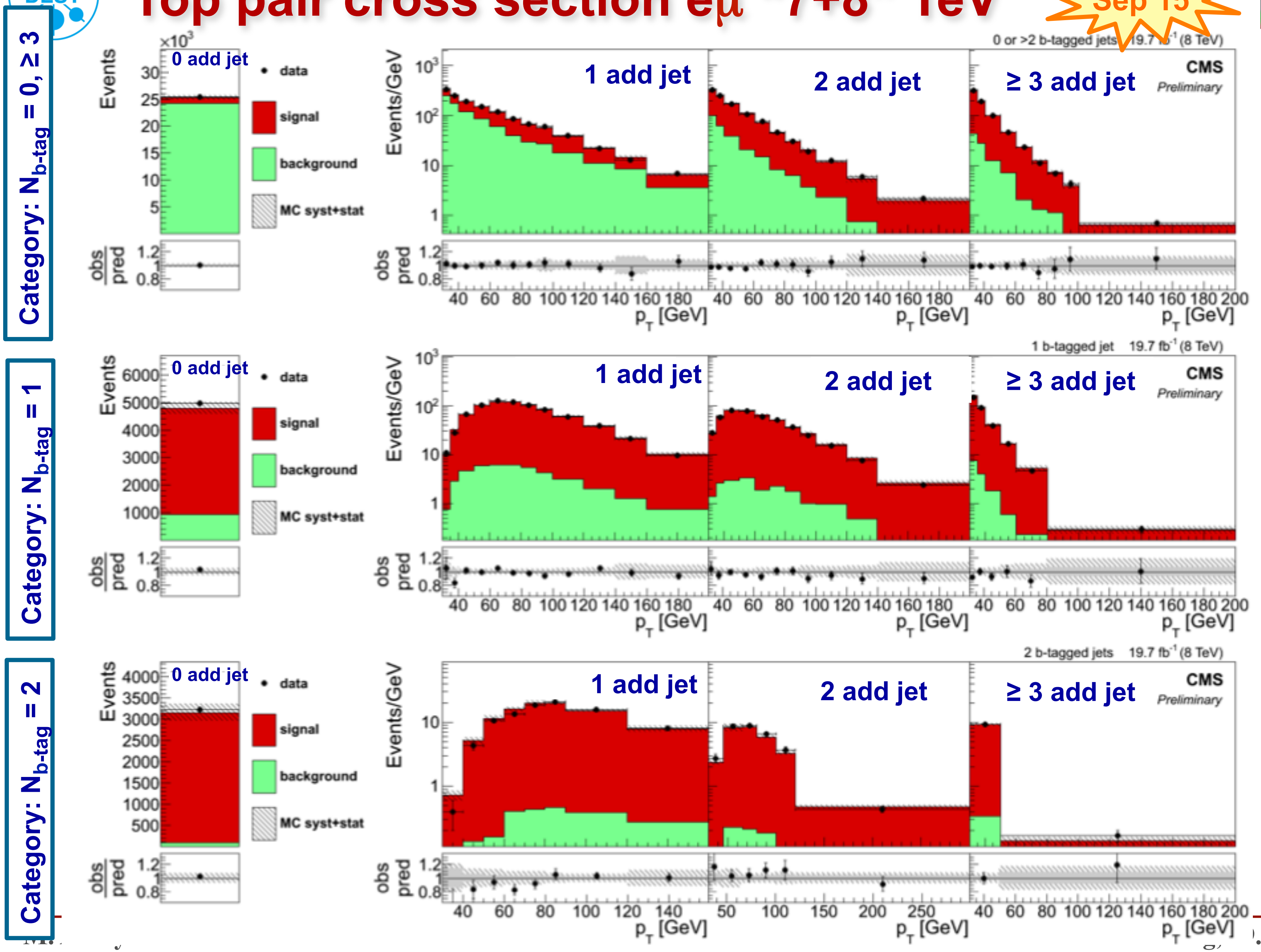
CMS-PAS TOP-13-004



Top pair cross section eμ "7+8" TeV

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CMS-PAS TOP-13-004

- Results:

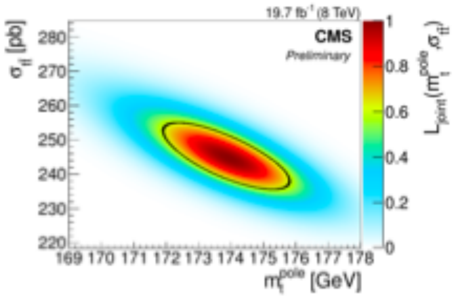
σ(7 TeV) = 174.5 ± 2.1(stat) $^{+4.5}_{-4.0}$(syst) ± 3.8(lumi) pb (+3.6% -3.4%)
σ(8 TeV) = 245.6 ± 1.3(stat) $^{+6.6}_{-5.5}$(syst) ± 6.5(lumi) pb (+3.8% -3.5%)

σ_{vis}(7 TeV) = 3.05 $^{+0.11}_{-0.10}$ pb (+3.5% -3.4%)
σ_{vis}(8 TeV) = 4.24 $^{+0.16}_{-0.14}$ pb (+3.7% -3.4%)

R (8/7 TeV) = 1.41 ± 0.06 (stat+syst)
R(7/8 TeV, NNLO) = 1.430

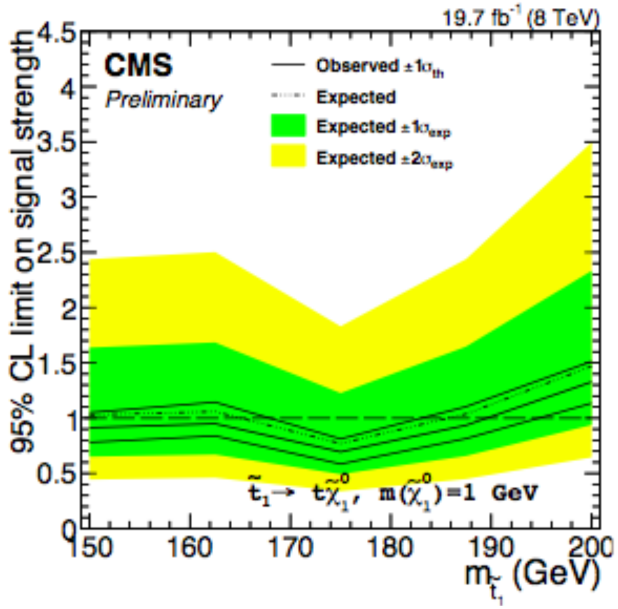
Top pole mass m_t = 173.6 $^{+1.7}_{-1.8}$ GeV

Source	Uncertainty [%] 7 TeV	Uncertainty [%] 8 TeV
Trigger	1.2	1.2
Lepton ID/isolation	1.4	1.5
Lepton energy scale	0.1	0.1
Jet energy scale	0.7	0.9
Jet energy resolution	0.1	0.1
Single top	0.9	0.6
DY	1.2	1.2
$t\bar{t}$ other	0.1	0.1
$t\bar{t}+V$	0.0	0.1
Diboson	0.2	0.6
W+jets	0.0	0.0
QCD	0.0	0.0
B-tag	0.5	0.5
Mistag	0.2	0.1
Pileup	0.3	0.3
Q^2 scale	0.3	0.3
ME/PS matching	0.2	0.1
MG+PY → PH+PY	0.2	0.4
Hadronization (JES)	0.6	0.8
Top p_T	0.3	0.3
Color reconnection	0.1	0.0
Underlying event	0.0	0.1
PDF	0.2	0.7
Luminosity	2.2	2.6
Statistical	1.2	0.6



SUSY Constraints from ttbar Cross Section: **Stop quarks with masses below 189 GeV are excluded (for light neutralinos)**

Similar level of exclusion by ATLAS



$t\bar{t}$ cross section in eμ at 13 TeV

ATLAS

Uncertainty	$\Delta\epsilon_{e\mu}/\epsilon_{e\mu}$ (%)	$\Delta C_b/C_b$ (%)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics			6.0
$t\bar{t}$ NLO modelling	1.9	-0.3	2.2
$t\bar{t}$ hadronisation	-4.0	0.5	4.5
Initial/final state radiation	-1.1	0.1	1.2
Parton distribution functions	1.3	-	1.4
Single-top generator*	-	-	0.5
Single-top/$t\bar{t}$ interference*	-	-	0.1
Single-top Wt cross-section	-	-	0.5
Diboson modelling*	-	-	0.1
Diboson cross-sections	-	-	0.0
Z+jets extrapolation	-	-	0.2
Electron energy scale/resolution	0.2	0.0	0.2
Electron identification	3.6	0.0	4.0
Electron isolation	1.0	-	1.1
Muon momentum scale/resolution	0.0	0.0	0.1
Muon identification	1.1	0.0	1.2
Muon isolation	1.0	-	1.1
Lepton trigger	1.3	0.0	1.3
Jet energy scale	-0.3	0.0	0.3
Jet energy resolution	-0.1	0.0	0.1
b-tagging	-	0.1	0.3
Misidentified leptons	-	-	1.3
Analysis systematics	6.4	0.6	7.3
Integrated luminosity	-	-	10.0
Total uncertainty	6.4	0.6	13.7

CMS

Source	$\Delta\sigma_{t\bar{t}}$ (pb)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Trigger efficiencies	34	4.4
Lepton efficiencies	26	3.4
Lepton energy scale	<1	$\leq$0.1
Jet energy scale	12	1.5
Jet energy resolution	<1	$\leq$0.1
Pileup	5.4	0.7
QCD scales	1.5	0.2
NLO generator of $t\bar{t}$ signal	15	1.9
Modeling of $t\bar{t}$ signal	14	1.8
PDF	18	2.4
Single top tW background	13	1.7
VV background	3.5	0.5
Drell-Yan background	4.2	0.5
Nonprompt leptons background	7.9	1.0
Total systematic (w/o luminosity)	55	7.2
Integrated luminosity	92	12
Statistical uncertainty	60	7.8
Total	123	16

$t\bar{t}$ cross section at 13 TeV - ATLAS

Dilepton

Uncertainty	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics	7.6
$t\bar{t}$ NLO modelling	2.6
$t\bar{t}$ hadronisation	7.9
Initial/final state radiation	1.5
PDF	3.7
Single-top Wt cross-section	0.6
Single-top interference	<0.05
Diboson cross-section	0.4
Z+jets $\rightarrow ee/\mu\mu$ modelling	1.5
Z+jets $\rightarrow \tau\tau$ modelling	0.1
Electron energy scale	0.3
Electron energy resolution	0.2
Electron identification	3.6
Electron trigger	0.2
Electron isolation	1.0
Muon momentum scale	0.1
Muon momentum resolution	1.1
Muon identification	0.8
Muon trigger	0.6
Muon isolation	1.0
Jet energy scale	1.2
Jet energy resolution	0.2
b-tagging efficiency	0.8
Missing transverse momentum	0.3
NP & fakes	1.5
Analysis systematics	11
Integrated luminosity	10
Total uncertainty	16

l+jets

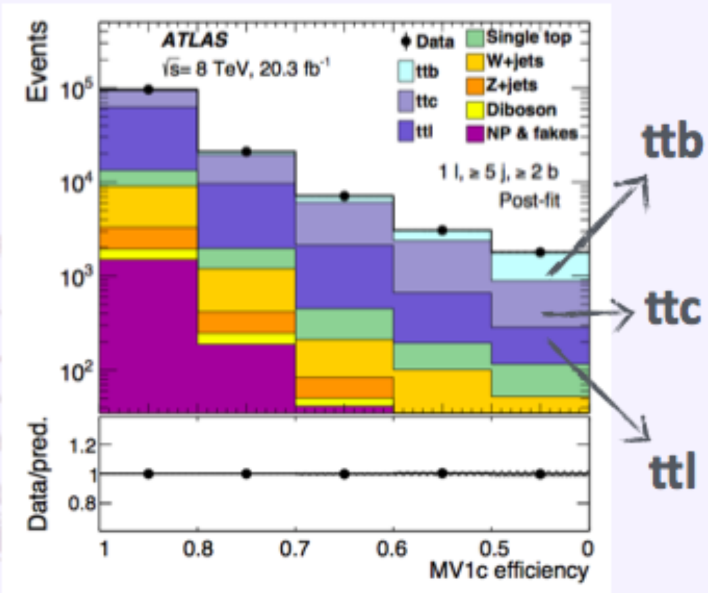
Uncertainty	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics	1.5
$t\bar{t}$ NLO modelling	0.6
$t\bar{t}$ hadronisation	4.1
Initial/final state radiation	1.9
PDF	0.7
Single top cross-section	0.3
Diboson cross-sections	0.2
Z+jets cross-section	1.0
W+jets method statistics	1.7
W+jets modelling	1.0
Electron energy scale/resolution	0.1
Electron identification	2.1
Electron isolation	0.4
Electron trigger	2.8
Muon momentum scale/resolution	0.1
Muon identification	0.2
Muon isolation	0.3
Muon trigger	1.2
$E_{\mathrm{T}}^{\mathrm{miss}}$ scale/resolution	0.4
Jet energy scale	$^{+10}_{-8}$
Jet energy resolution	0.6
b-tagging	4.1
NP & fakes	1.8
Analysis systematics	$^{+13}_{-11}$
Integrated luminosity	$^{+11}_{-9}$
Total uncertainty	$^{+17}_{-14}$

$t\bar{t}$+b(b) production at 8 TeV – ATLAS

Sep'15

Dilepton and l+jets ttb

- tt+jets selections:
  - Dilepton (≥3-jets)
  - L+jets (≥5-jets)
- Profile likelihood template fit to the b-tagging discriminator (MV1c) of 3rd highest jet ordered in MV1c
- 3 uncorrelated & unconstrained fit parameters

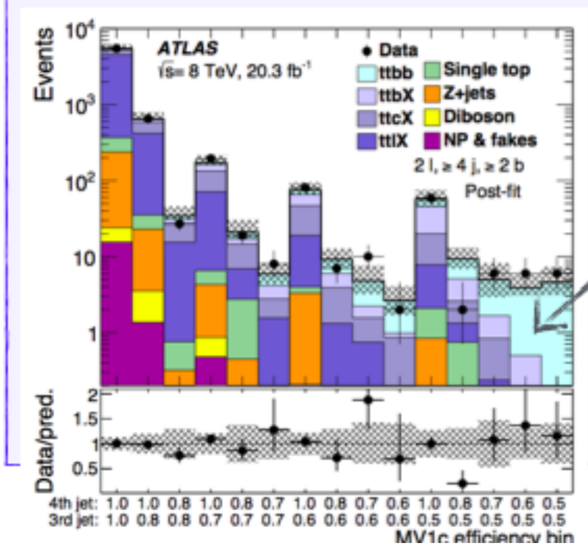


Dilepton ttbb (cut-based)

- High purity tt 4-b-jets selection (tighter b-tag criteria)
  - ttbb 68%, ttbX 16%, other 16%
- Event counting method to extract cross-section
- Correlated scale factor for ttbb and ttbX

Dilepton ttbb (fit-based)

- ≥ 4-jets selection
- Template fit with 3rd and 4th jet in MV1c



- 4 uncorrelated & unconstrained fit parameters
  - ttbb
  - ttbX
  - ttcX
  - ttlX

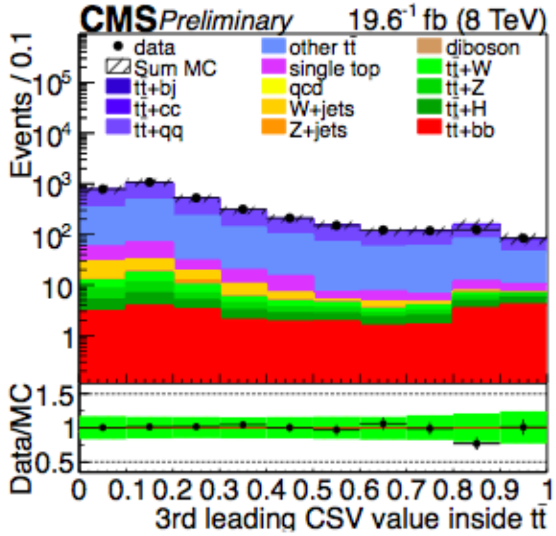
$t\bar{t}$+b(b) production at 8 TeV – CMS

Sep'15

- l+jets channel:
  - Signal extraction by fit to the measured b-tag discriminator in different N_{jets} and N_{btags} categories

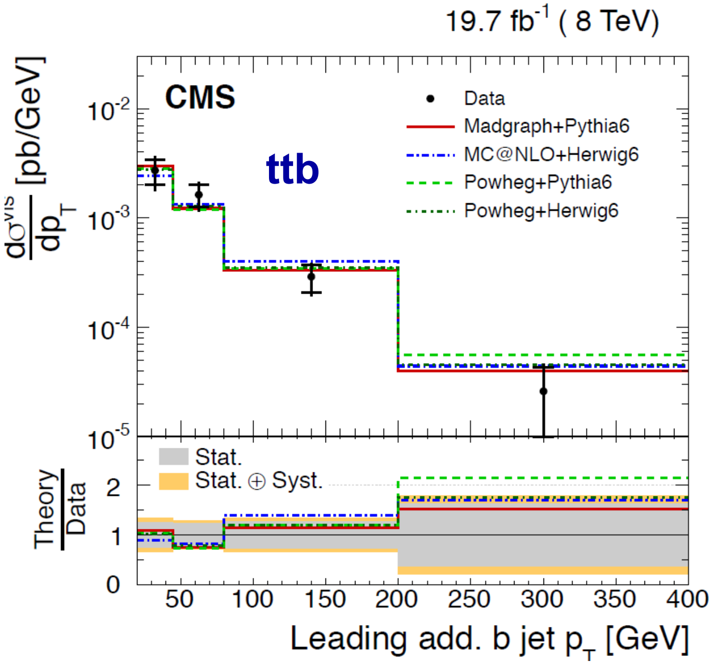
$$\frac{\sigma(t\bar{t}b\bar{b})}{\sigma(t\bar{t}jj)}^{hardB} = 0.0117 \pm 0.0040(\text{stat.}) \pm 0.0003(\text{syst.})$$

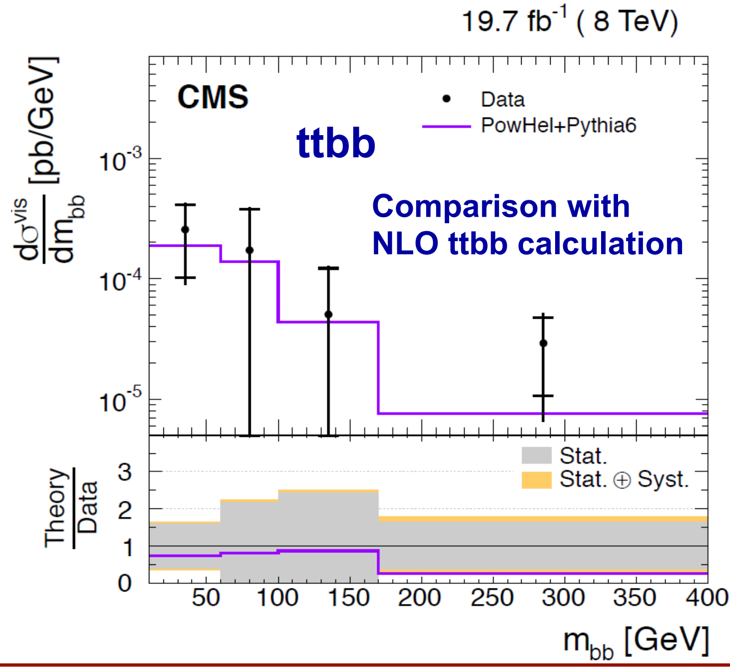
$$\frac{\sigma(t\bar{t}b\bar{b})}{\sigma(t\bar{t}jj)}^{hadronB} = 0.0151 \pm 0.0049(\text{stat.}) \pm 0.0004(\text{syst.})$$



CMS-PAS TOP-13-016

- Dilepton channels:
  - Differentially as a function of the additional b jets





arXiv:1510.03072, submitted to EPJC

Magnet cryogenics

- The CMS magnet has been operating intermittently due to persistent problems in the cryogenic system, consistent with the clogging effect of contaminants in the "Cold Box" that provides liquid helium.
- Last two Technical Stops: several complex and invasive interventions (change absorbers and filters) made in the cold box
  - to make system more tolerant to contamination.

- Still, maintenance procedures to clear contamination are having to be performed much more frequently than normal;
  - Some require stopping the cold-box; which means turning off the magnetic field
  - Trying to synchronize stops with accelerator to minimize impact on CMS data-taking.
- Response to the problem managed by joint CMS-CERN task force. Besides interventions already made:
  - Intensive diagnostic and analysis efforts to improve understanding and optimize interim strategy.
  - In parallel: organizing comprehensive program of component replacement or cleaning for forthcoming technical stops.

Many thanks to TE and EN departments for their exceptional effort