



Top quark results

XXIV International Workshop on Deep-Inelastic
Scattering and Related Subjects,
Hamburg (Germany), 11/04/2016

Alberto Orso Maria Iorio,
for the Atlas, CMS, and LHCb collaborations

Outline

- **Introduction on top quark:**

- production mechanisms
- detection channels

- **Top quark measurements:**

- strong production:
 - inclusive measurements and interpretation
 - differential measurements and properties
- electroweak single top production
- top quark mass

This talk contains measurements from Atlas, CMS, and LHCb from Run I and II of LHC

More results can be found here:

<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults>

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

<https://lhcb.web.cern.ch/lhcb/Physics-Results/LHCb-Physics-Results>

For more details follow also the talks in the Heavy Flavours session

top-quark production in the standard model @LHC

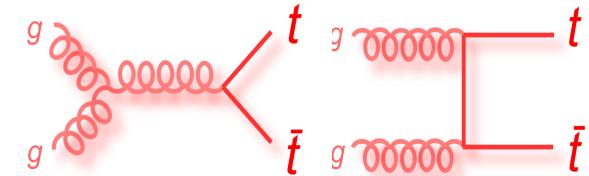
Production mechanism...

- **tt pairs** via strong interaction:
 - dominant at the LHC and Tevatron
 - depends on α_s
 - sensitive to pdf

...cross section...

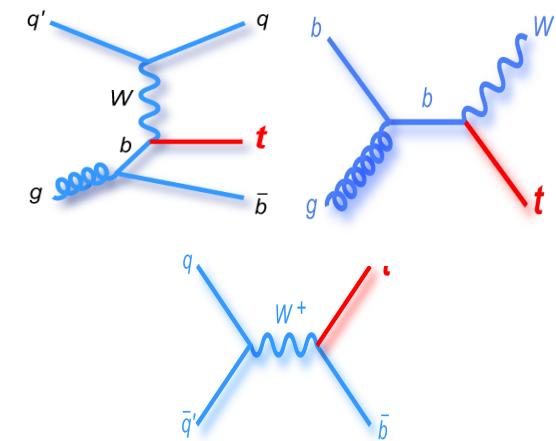
LO $\propto (\alpha_s/m_{\text{top}})^2$
 pp collisions @ 7/8/13 TeV:
 $\sim 172/246/830 \text{ pb}$

...LO diagrams

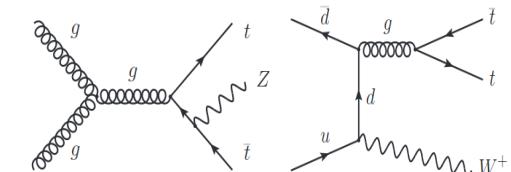


- **single-tops:**
 - weak charged current interactions
 - t -, s -channel and W -associated
 - tWb vertex in production
 - Sensitive to V_{tb}

LO $\propto (\alpha^* |V_{tb}|)^2$
 pp collisions @ 7/8/13 TeV:
 $\sim 66/85/217 \text{ pb } (t\text{-ch.})$
 $\sim 15/22/72 \text{ pb } (tW)$
 $\sim 4.4/5.5/11 \text{ pb } (s\text{-ch.})$

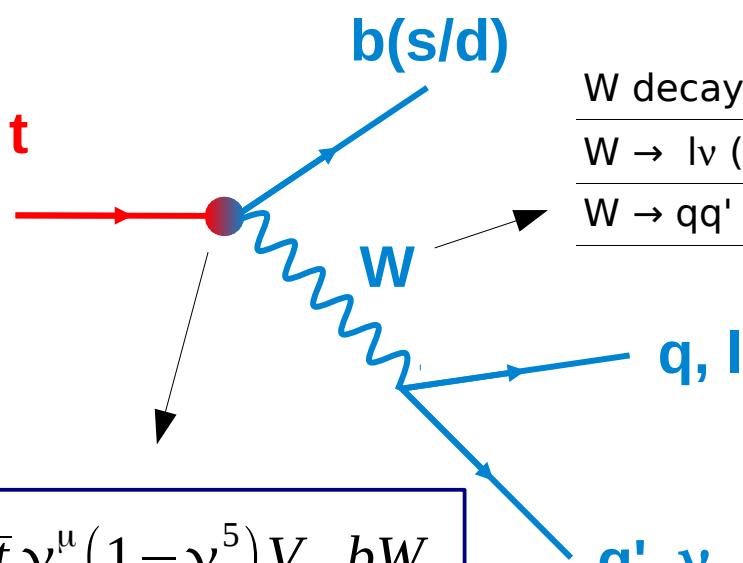


- **top + X :**
 - top pair and single top + W, Z, γ, \dots
 - way to probe neutral current vertices involving top quark

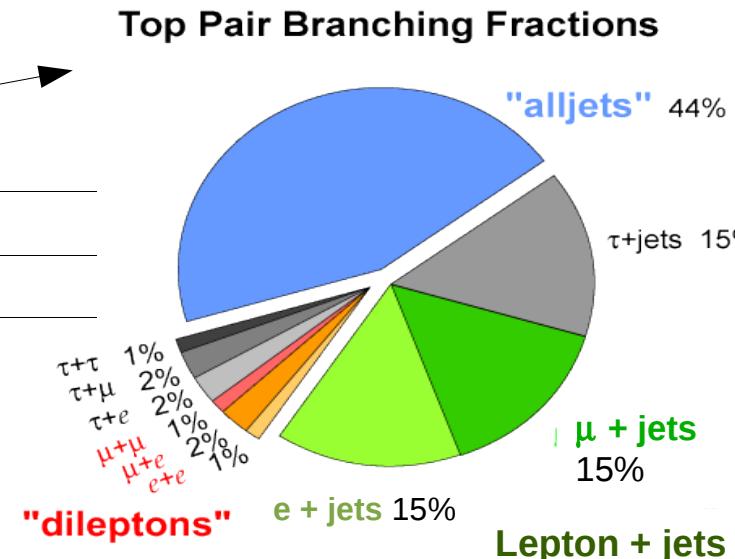


top-quark decays

- Main mechanism is electroweak: no hadronisation



W decay:	BR:
$W \rightarrow l\nu$ (any)	0.32
$W \rightarrow q\bar{q}'$ (any)	0.68



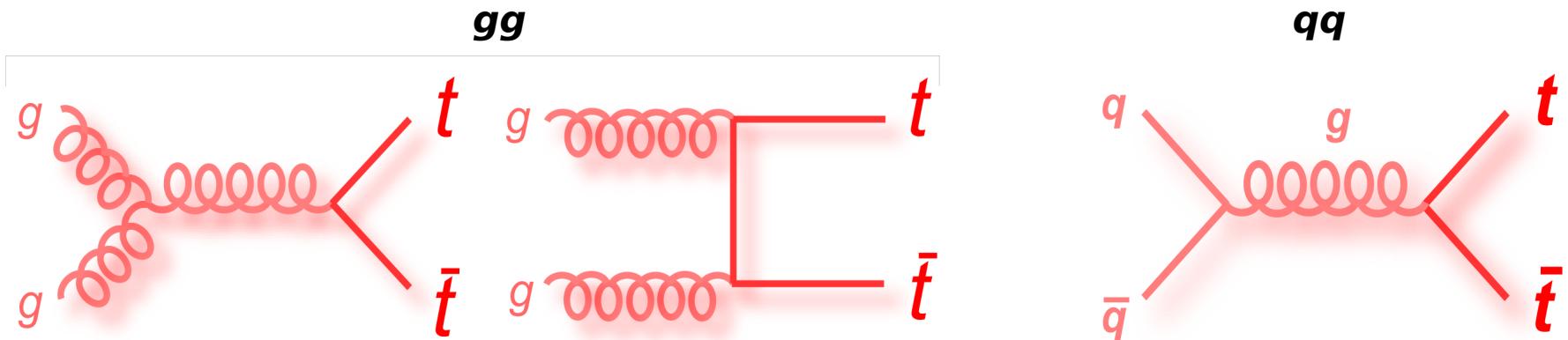
- Electroweak **tWb vertex**:

- V-A: **polarization** of the products and defined **W-helicity**
- CKM matrix element $|V_{tb}| \sim 1 \rightarrow \Gamma(t \rightarrow b) \gg \Gamma(t \rightarrow s, d)$

$1/m_{\text{top}}$ $<$ $1/\Gamma_t$ $<$ $1/\Lambda$ $<$ m_t/Λ^2
 production lifetime hadronization spin decorrelation

top pair production: inclusive cross section

The top pair production: a probe for strong interactions



- **Strong production means:**

- sensitive to α_s at the production vertex
- very sensitive to gluon pdf
- testing ground for QCD modeling!

- **Clean signature in the decays:**

- can measure the tWbdecay vertex properties
- can use as probe for associated production

$\sigma(t\bar{t})$ (*PhysRevLett.110.252004*)

@13 TeV

832 \pm 40 pb
(~90% gg / 10% qq)

@8 TeV

252 \pm 12 pb
(~85% gg / 15% qq)

@7 TeV

178 \pm 10 pb
(~85% gg / 15% qq)

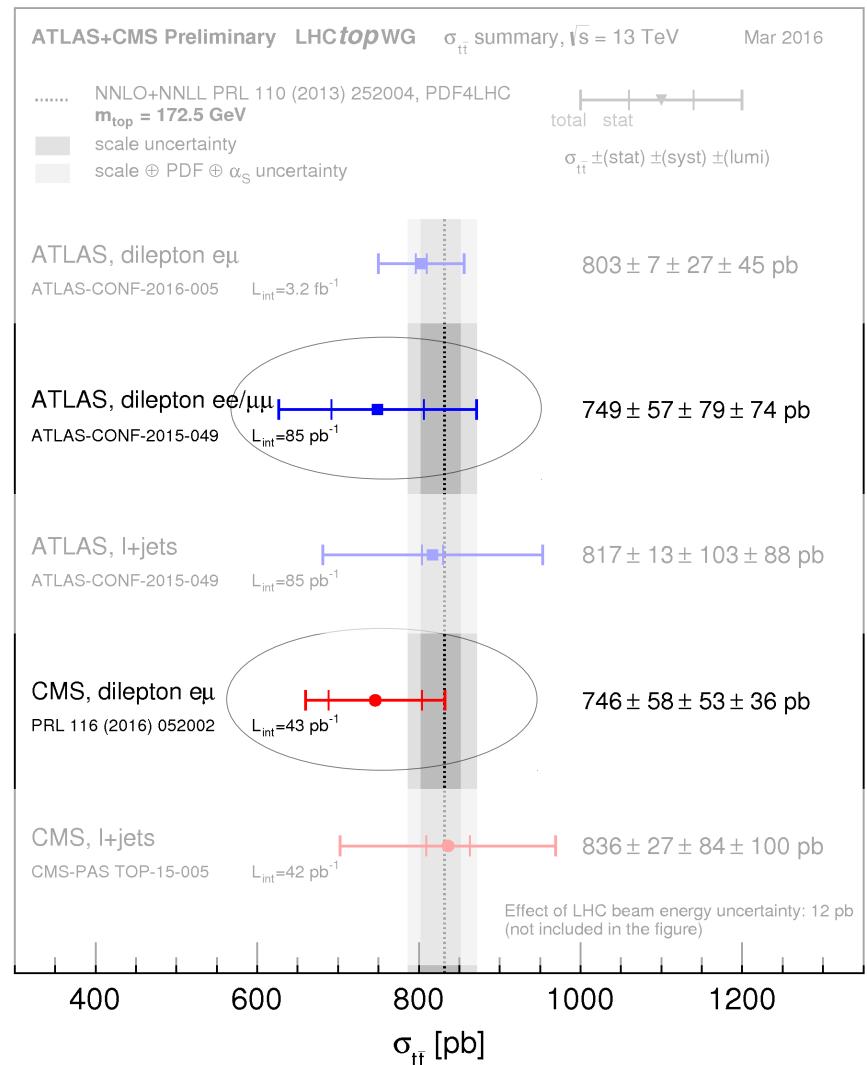
All with top mass = 172.5 GeV

The 13 TeV journey of top quark “re-discovery”

A bit of recent history:

- **First observation at 13 TeV:**

- di leptonic channels almost background-free



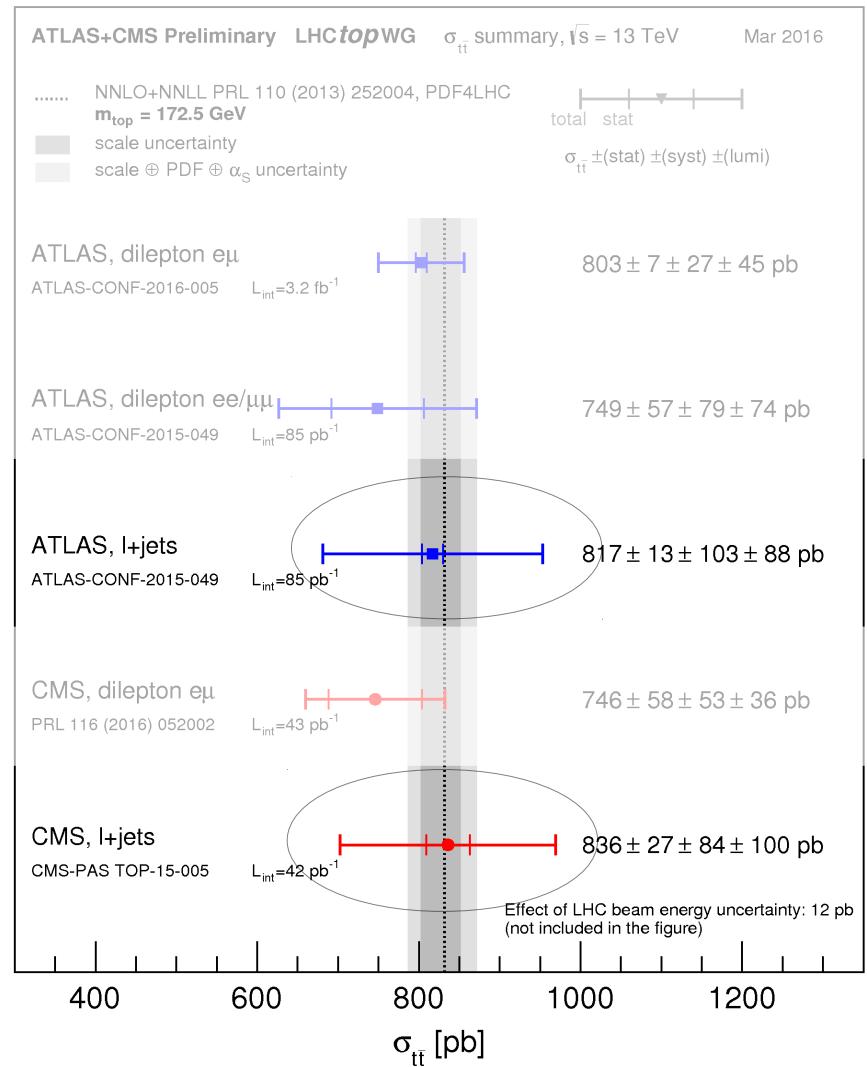
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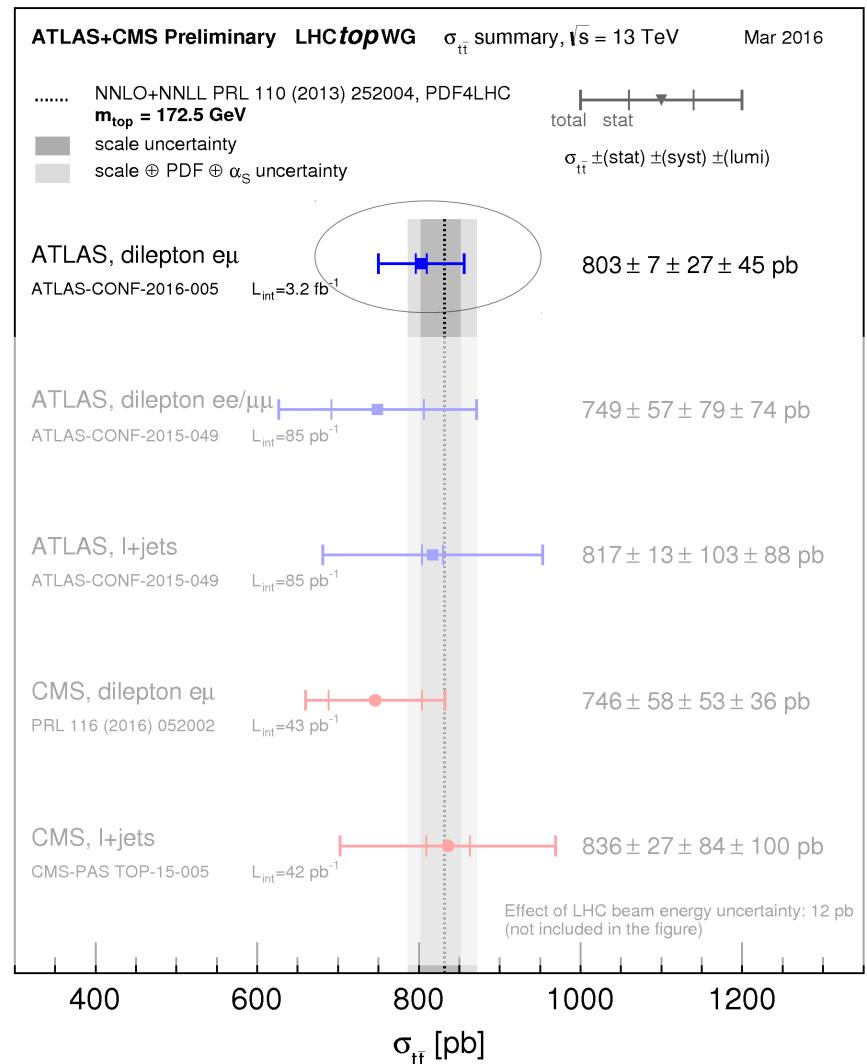
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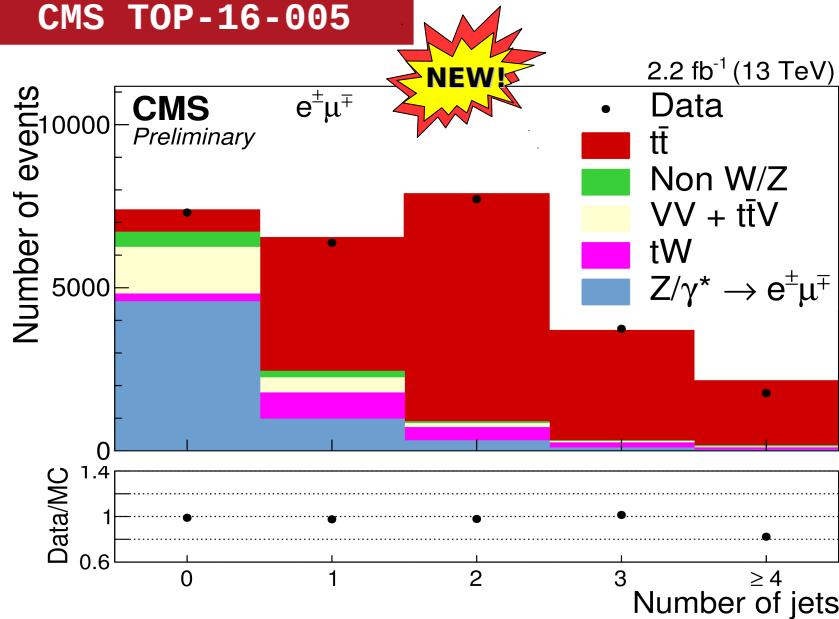
- **From discovery to precision: systematic regime already entered!**

Note: plot still needs to be updated with results shown in the next slides



tt 13 TeV: dilepton channels

CMS TOP-16-005



◦ Fit to different b-jet bins:

- in situ measurement of b-tag

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

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

$$\sigma_{t\bar{t}} = 803 \pm 7 \text{ (stat)} \pm 27 \text{ (syst)} \pm 45 \text{ (lumi)} \pm 12 \text{ (beam)} \text{ pb}$$

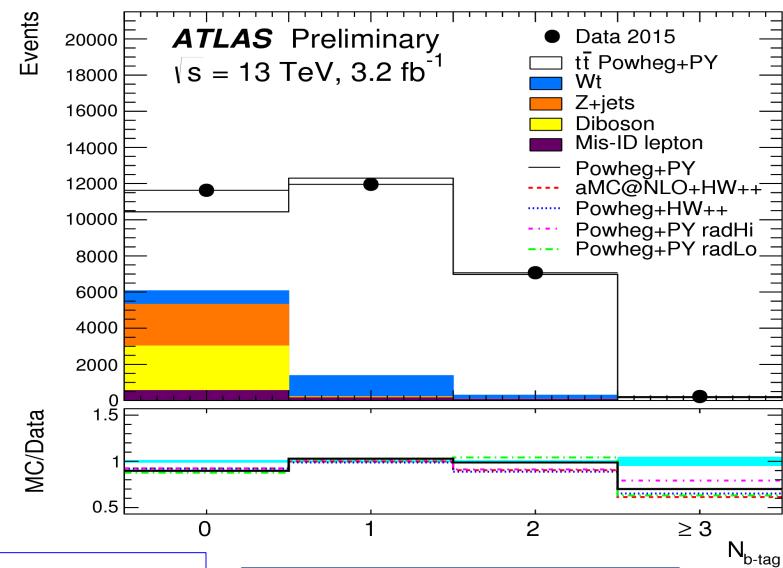
◦ Simple cut and count analysis:

- $e\mu$ pair: ($p_T > 20 \text{ GeV}$, $|\eta| < 2.5$)
- at least two jets: $p_T > 30 \text{ GeV}$, $|\eta| < 2.5$

◦ Main backgrounds:

- tW single-top, Drell-Yan, Fakes

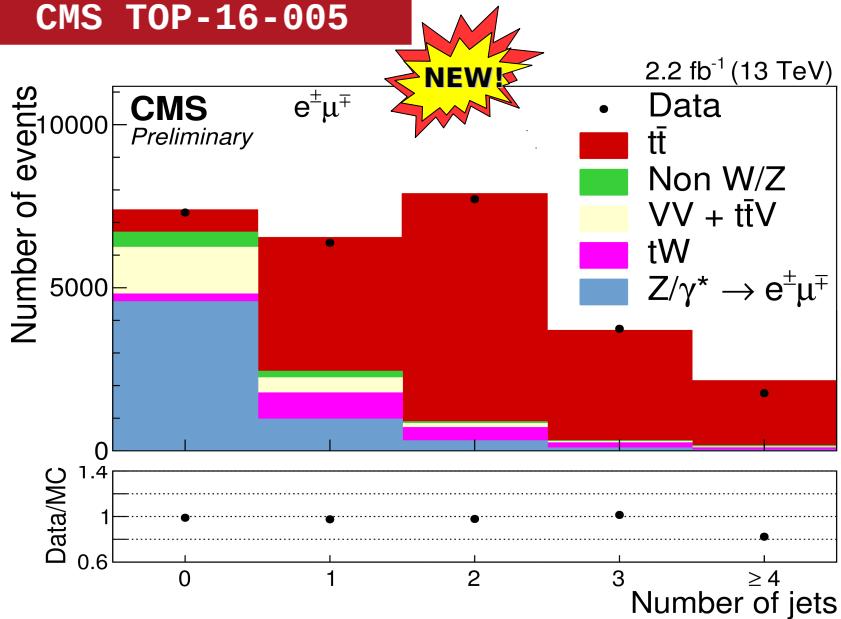
$$\sigma_{t\bar{t}} = 793 \pm 8 \text{ (stat)} \pm 38 \text{ (syst)} \pm 21 \text{ (lumi)} \text{ pb}$$



ATLAS CONF-2016-005

13 TeV dileptons: uncertainties

CMS TOP-16-005



Main uncertainties on σ_{tt} [%]

	Atlas	CMS
tt model	0.8	2.1
tt hadronisation	2.8	1.3
Jet energy scale	0.3	2.2

- Room for improvement:

- improve calibrations/
efficiency measurements
- if possible: measure in-situ the uncertainty
components together with the cross section

See also talks by [N. Bartosik](#) and [H. Ahmed](#)

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tt cross section as input for pdf calculation

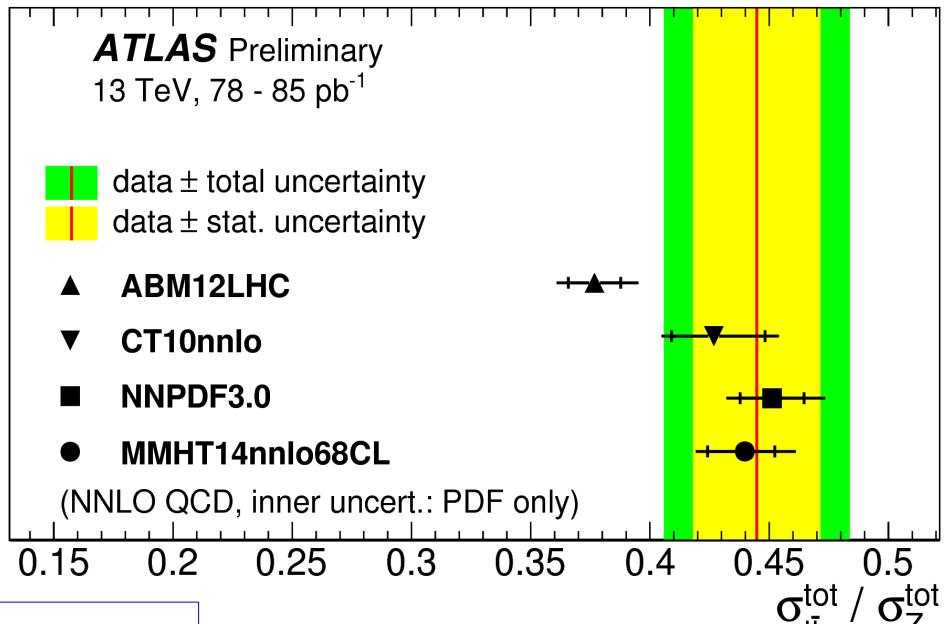
- **Ratio tt over drell-yan cross section:**

ATLAS CONF-2015-049

- reduces luminosity uncertainty
- sensitive to gg ratio over qq and qg

$$R_{t\bar{t}/Z} = \frac{\sigma_{t\bar{t}}}{0.5(\sigma_{Z \rightarrow ee} + \sigma_{Z \rightarrow \mu\mu})} =$$

$$= 0.445 \pm 0.027 \text{ (stat)} \pm 0.028 \text{ (syst)} = 0.445 \pm 0.039$$

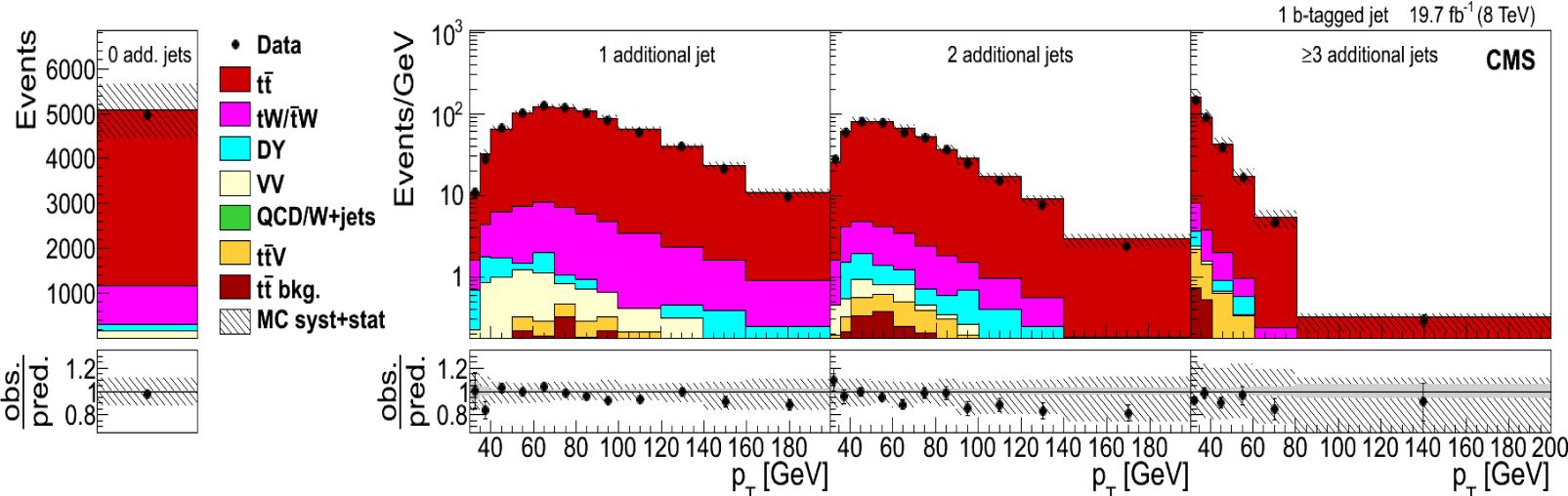


Note: tension with ABM12LHC is due to different gluon density of this set

Back to 7/8 TeV, and forward to high precision!

- Legacy measurement at 8 TeV

arXiv:1603.02303



- profile likelihood fit over several regions
- final state distributions sensitive to modeling uncertainties limiting precision
- measurement in a visible phase space to disentangle acceptance effects
- uncertainties treated as nuisance parameters

$$\begin{aligned}\sigma_{t\bar{t}} &= 173.6 \pm 2.1 \text{ (stat)} {}^{+4.5}_{-4.0} \text{ (syst)} \pm 3.8 \text{ (lumi)} \text{ pb} & 7 \text{ TeV} \\ \sigma_{t\bar{t}} &= 244.9 \pm 1.4 \text{ (stat)} {}^{+6.3}_{-5.5} \text{ (syst)} \pm 6.4 \text{ (lumi)} \text{ pb} & 8 \text{ TeV}\end{aligned}$$

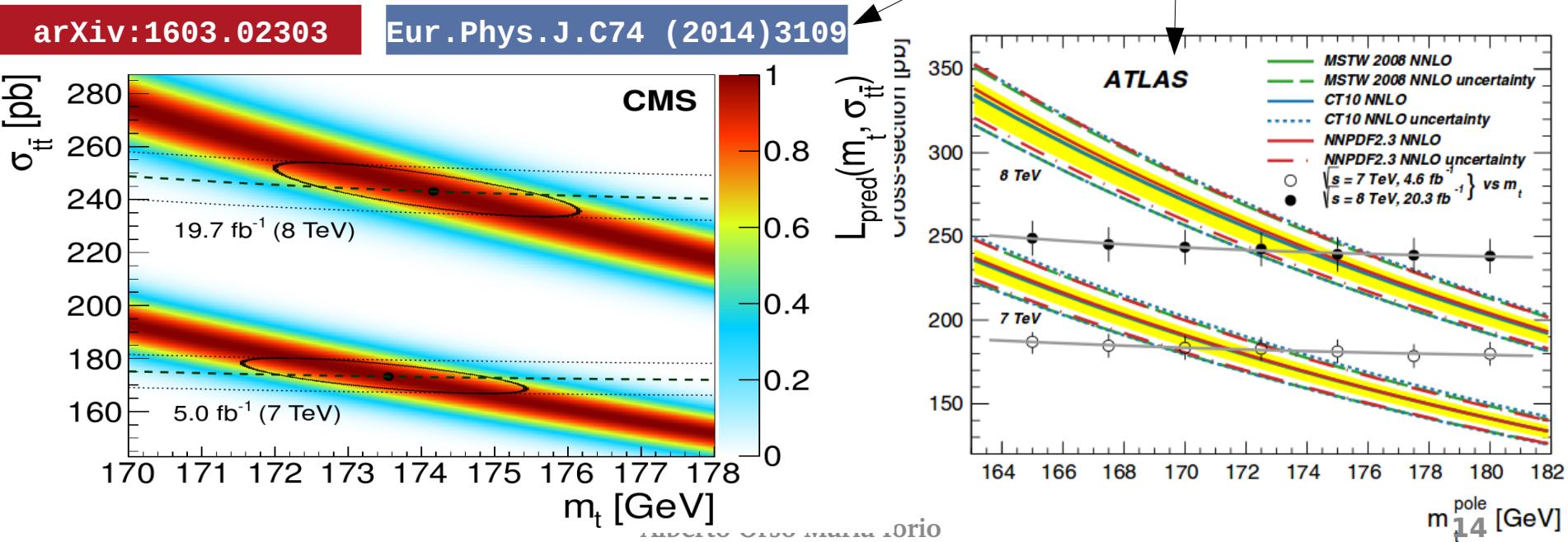
Measurements interpretation: top-quark pole mass

- **Re-interpretation of cross section measurements:**

- top mass m_{top} parameter in the MC :depends on the renormalisation scheme used
- can be taken from the cross section parametrisation
(example from cms)
- uncertainties from cross section measurement:
luminosity, background yield, lepton reconstruction

$$\sigma_{t\bar{t}}(7 \text{ TeV}, m_t^{\text{MC}}) = \exp \left[-0.1718 (m_t^{\text{MC}} / \text{GeV} - 178.5) \right] + 170.9 \text{ pb}$$

$$\sigma_{t\bar{t}}(8 \text{ TeV}, m_t^{\text{MC}}) = \exp \left[-0.1603 (m_t^{\text{MC}} / \text{GeV} - 185.4) \right] + 237.0 \text{ pb}$$



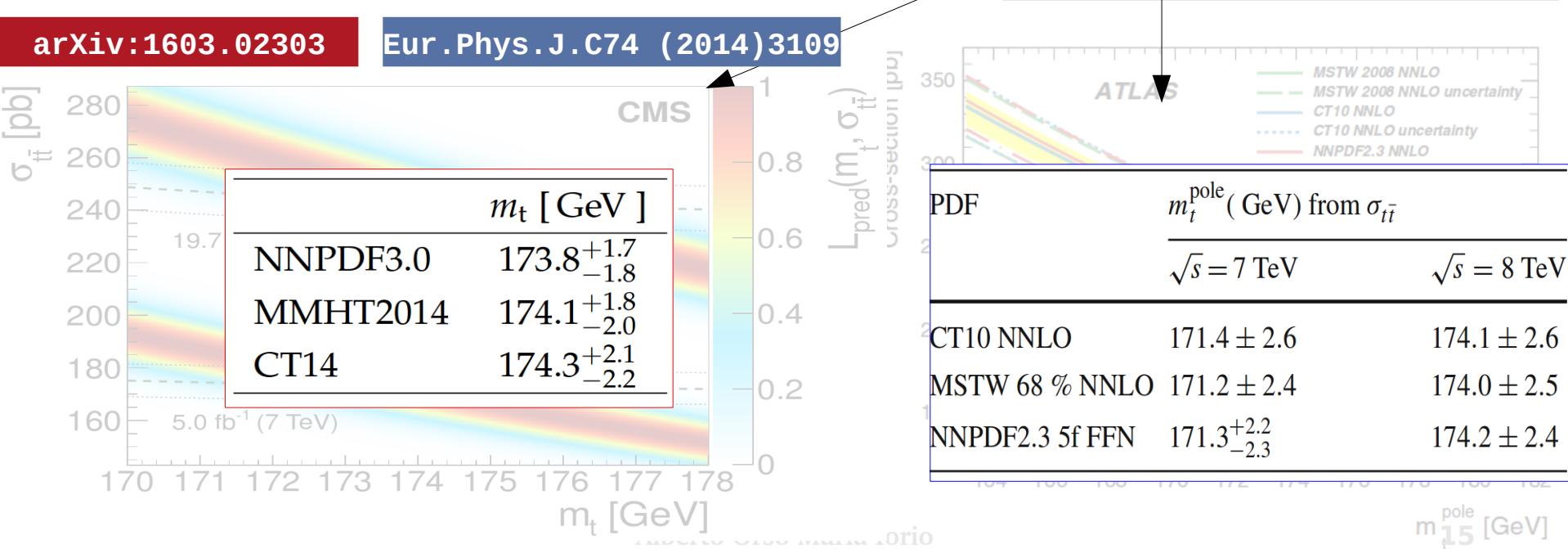
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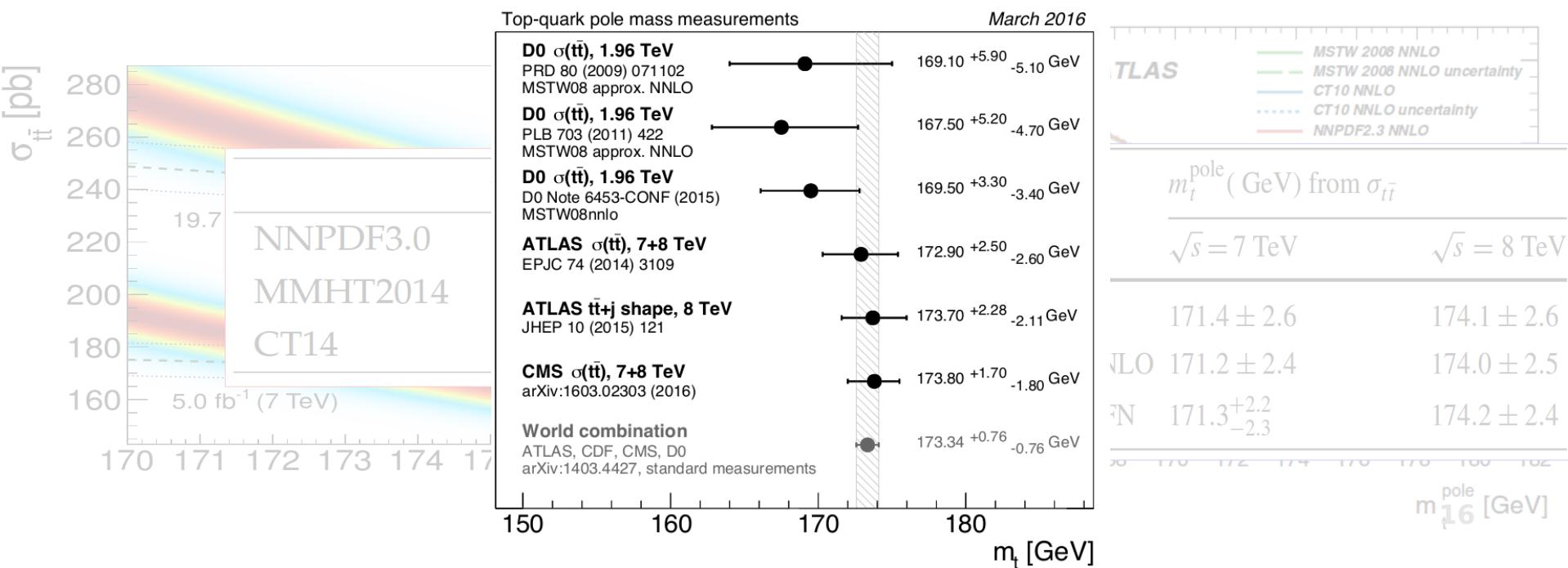
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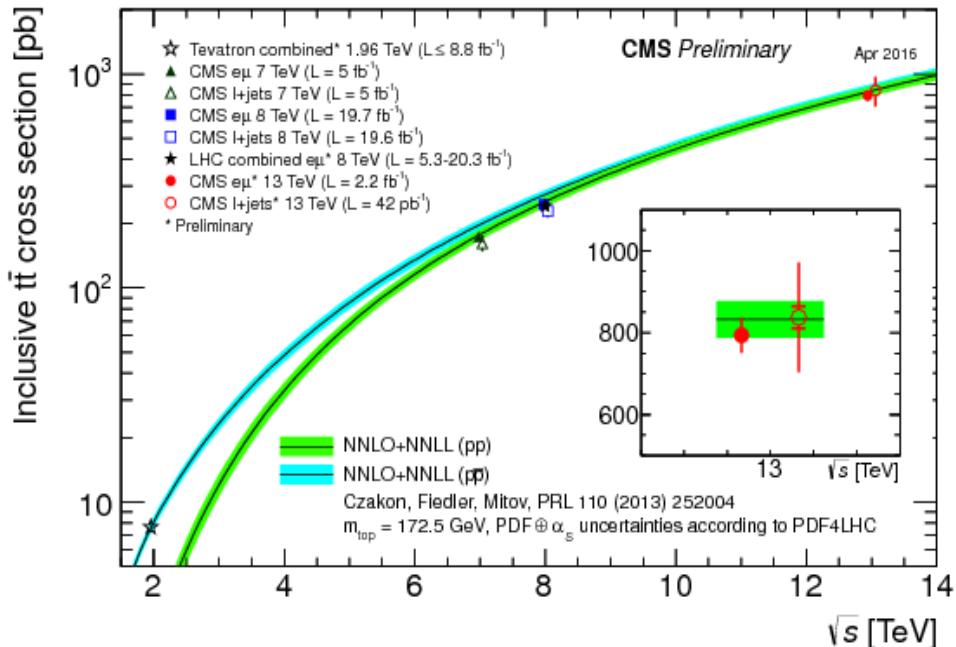
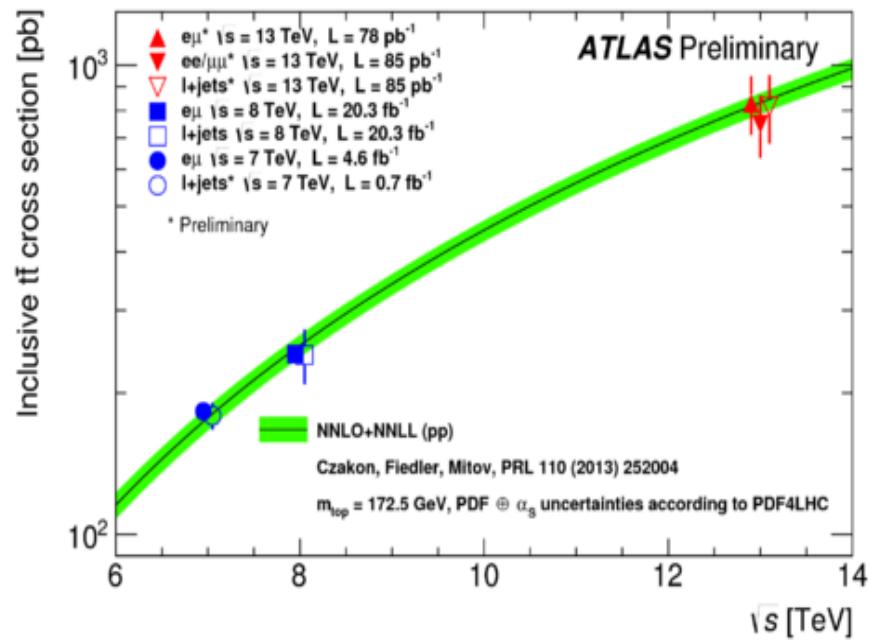
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Top pair as function of \sqrt{s}



Measurements at all energies:

- Systematics dominated also at 13 TeV - going towards systematics constrain from data!
- Handle on gluon pdf and α_s
- Measurement top quark pole mass

Top production at LHCb in forward events

- Measurement of top quarks at LHCb

Phys. Rev. Lett. 115 (2015) 112001

- first observation with Run-I data in asymmetric p-p collisions

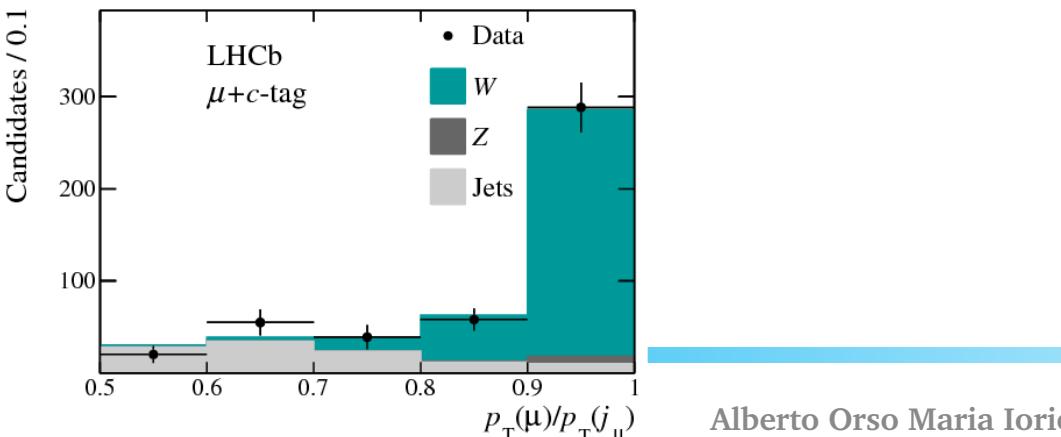
- 75% ttbar / 25% single-top t-channel

- selected events with 1 top \rightarrow Wb \rightarrow $\mu\nu b$

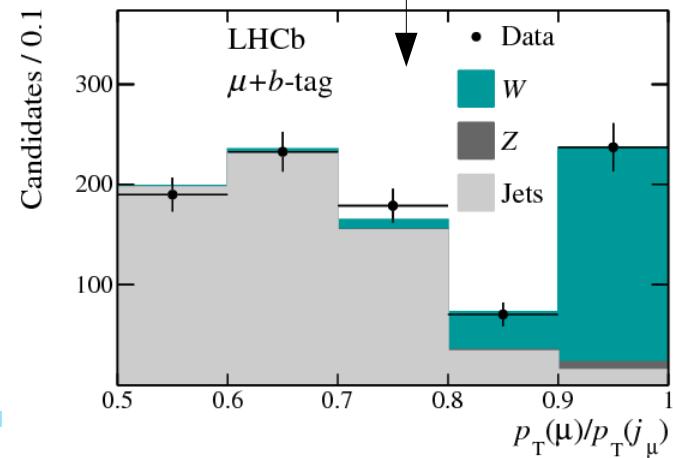
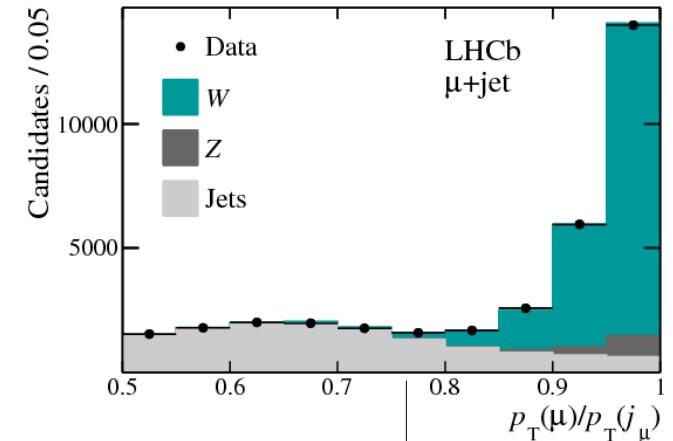
- 1 muon: $p_T > 25 \text{ GeV}$; $2.0 < \eta < 4.5$
- ≥ 1 jet $50 < p_T < 100 \text{ GeV}$; $2.2 < \eta < 4.2$
- jet must be b-tagged

- use of the pre-tag region to reduce uncertainties

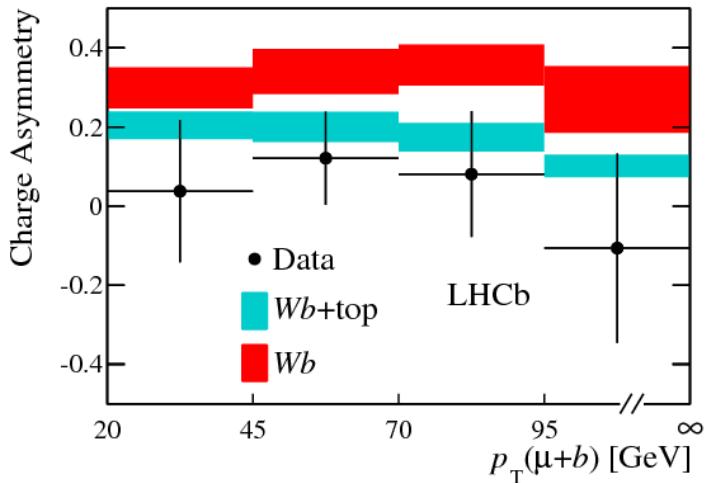
- cross-check region with c-jets



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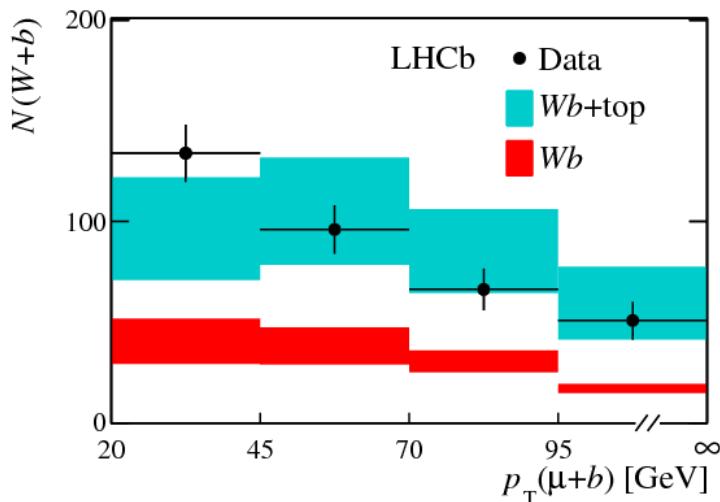


Top production at LHCb in forward events



- **Top content extraction:**

- 2D maximum likelihood fit to charge asymmetry and event yield
- consistent with SM prediction, significance of 5.4 standard deviations
- Main uncertainties: b-tagging, theory



$$\sigma(\text{top})[7 \text{ TeV}] = 239 \pm 53 \text{ (stat)} \pm 33 \text{ (syst)} \pm 24 \text{ (theory)} \text{ fb}$$

$$\sigma(\text{top})[8 \text{ TeV}] = 289 \pm 43 \text{ (stat)} \pm 40 \text{ (syst)} \pm 29 \text{ (theory)} \text{ fb}$$

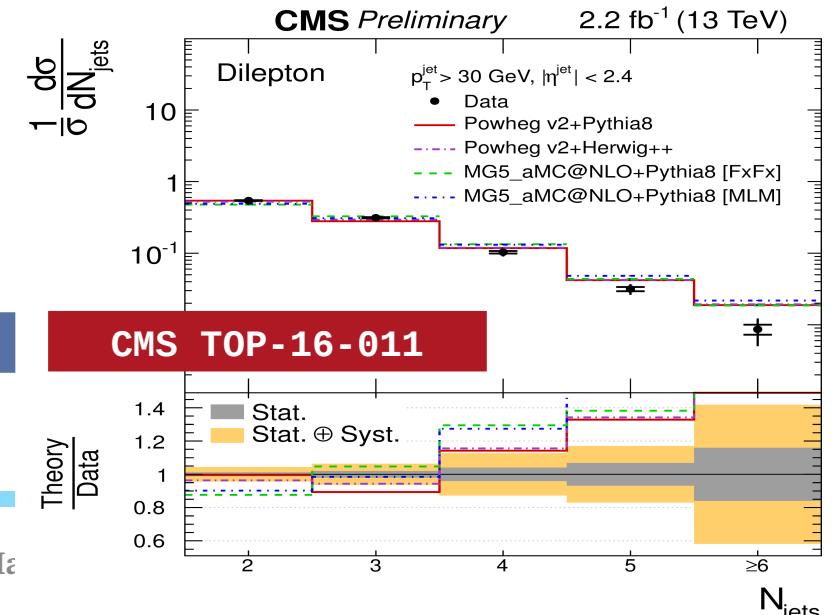
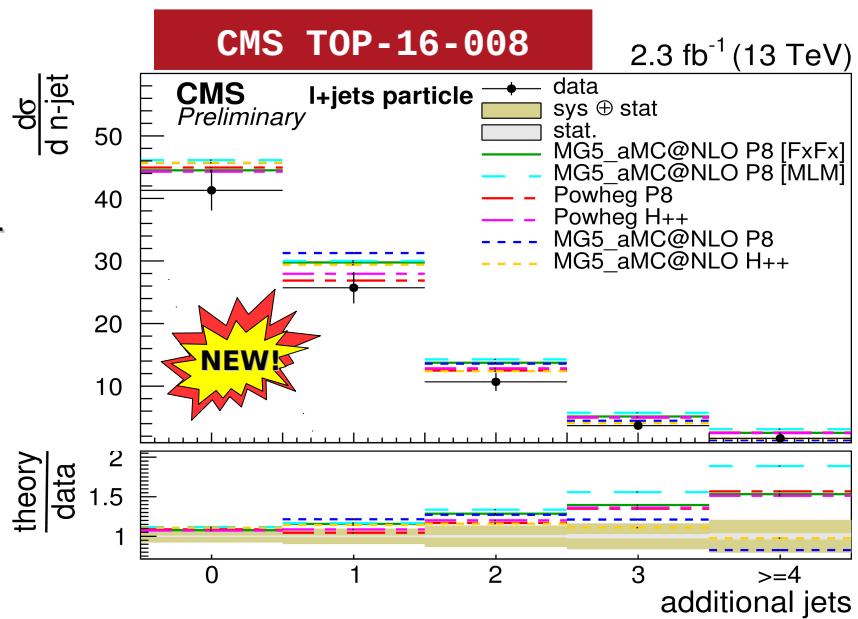
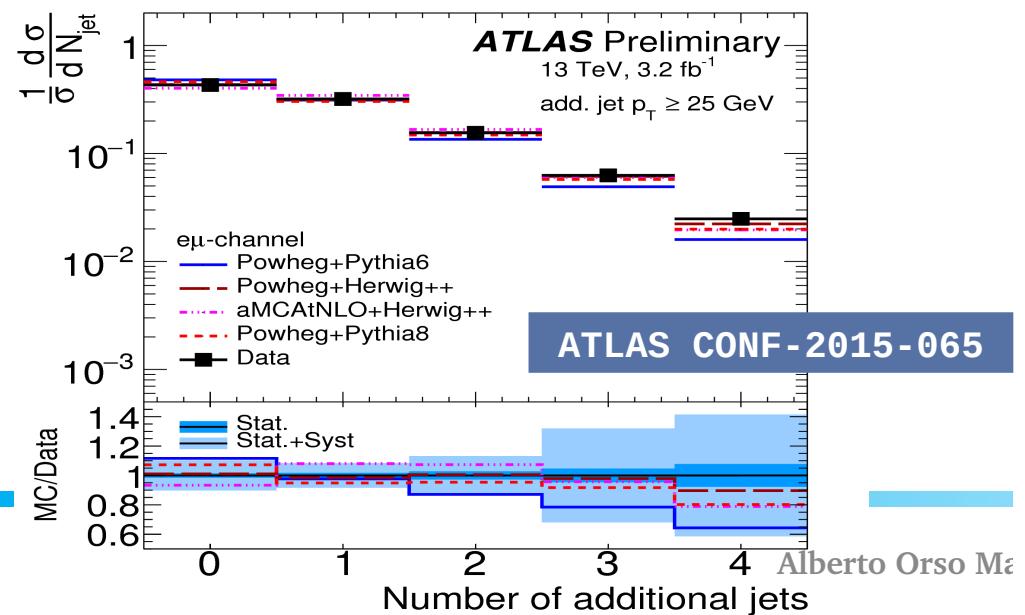
Phys. Rev. Lett. 115 (2015) 112001

top pair production: differential measurements and properties

tt + jets associated production

- **Study of Matrix element and PS jets:**

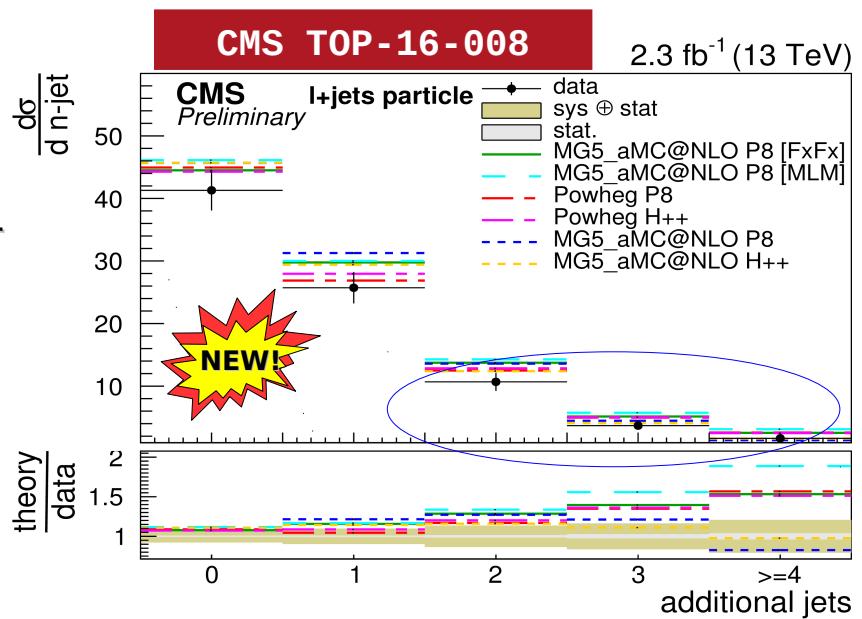
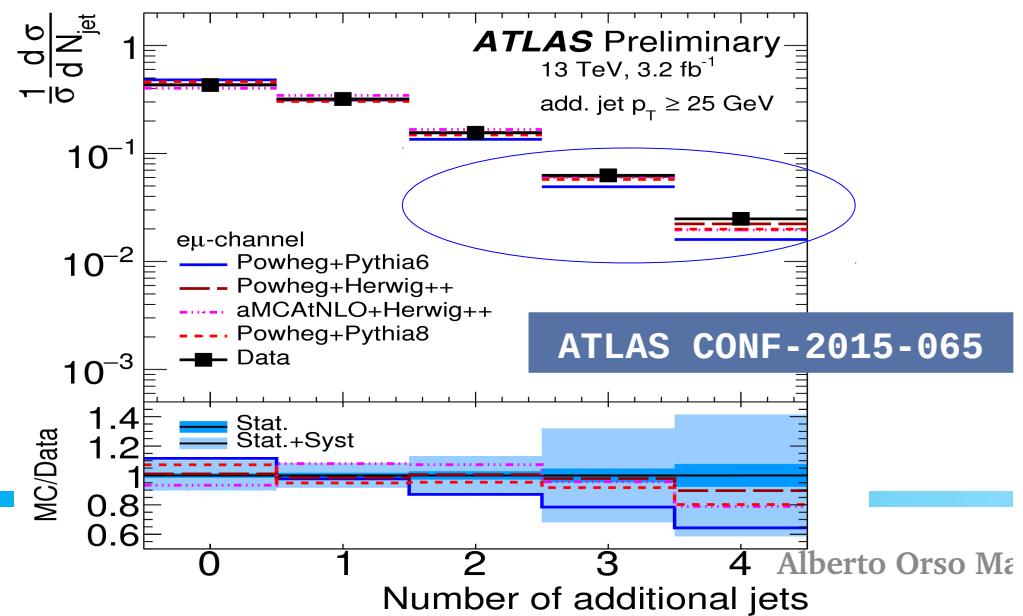
- # additional jets wrt the ones from top decay
- high jet multiplicity tt events : background for new physics
- Same selection as semileptonic or dileptonic analysis, selecting best ttbar hypothesis
- High end of the jet spectrum dominated by parton showering



tt + jets associated production

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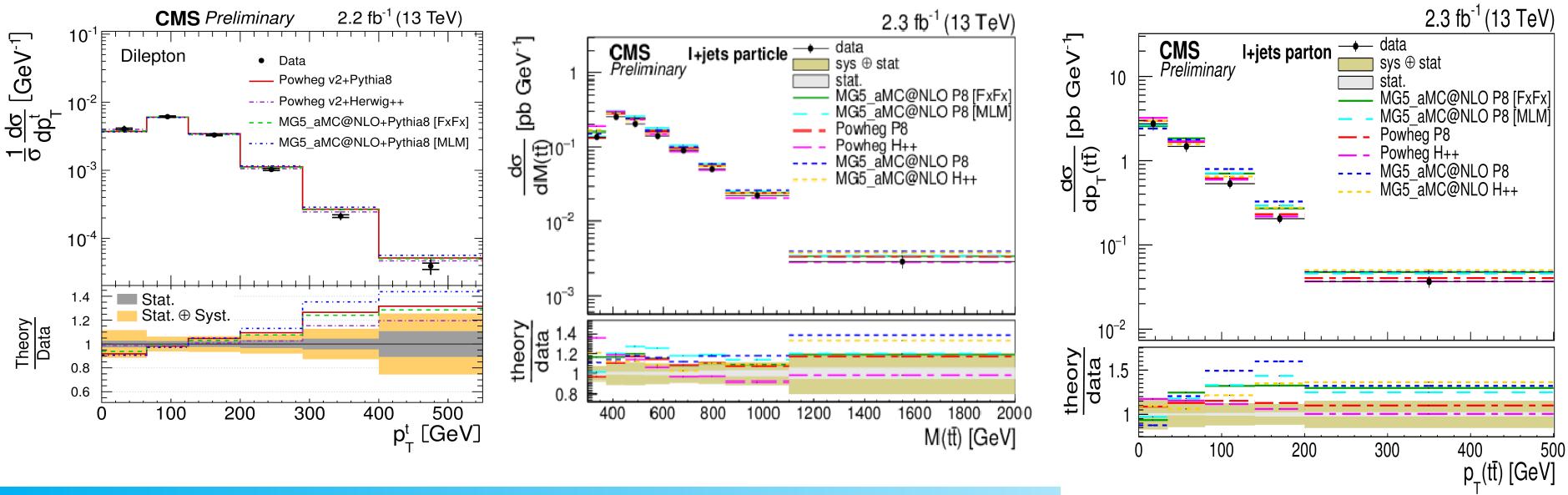
tt differential cross sections: top kinematic observables

- **Kinematic properties:**

- sensitive to higher QCD perturbative orders of the theory
- potential hints of new physics in the spectra
 - e.g. mass of the ttbar pair
- top transverse momentum : softer in data than in all NLO ME + PS combinations

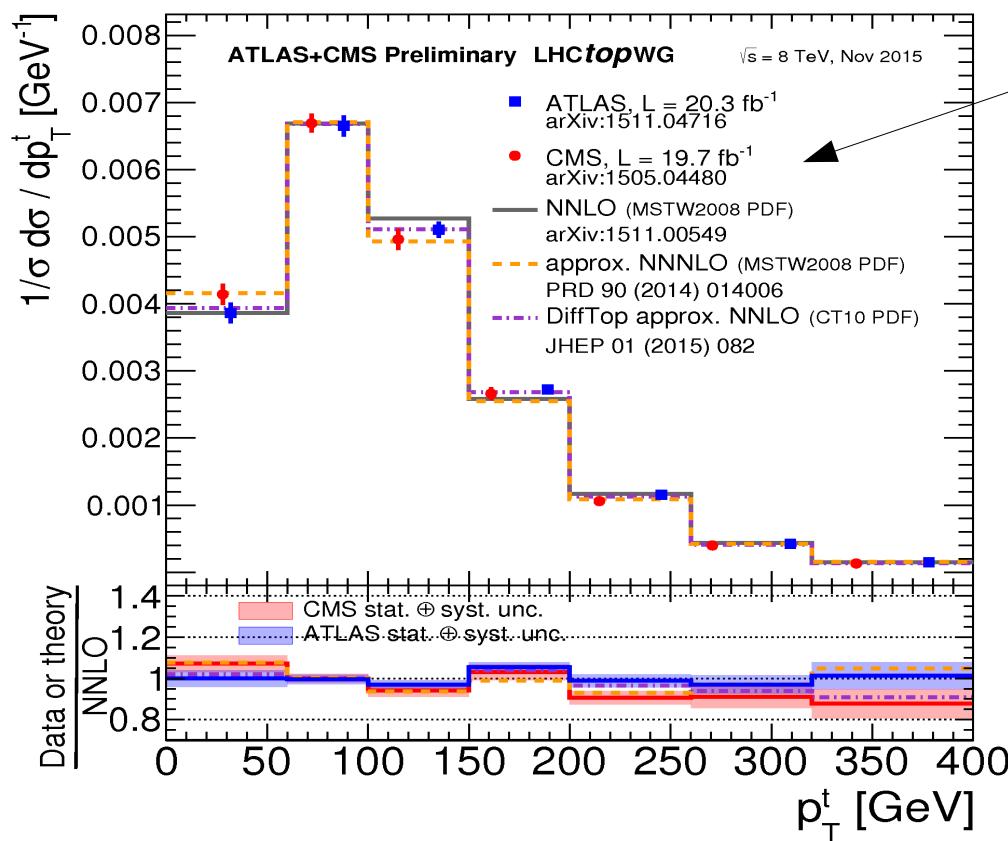
CMS TOP-16-008

CMS TOP-16-011



Measured vs NNLO cross section

- **Run-I** difference between measured top p_T spectrum and prediction from simulation with matrix element + parton showering

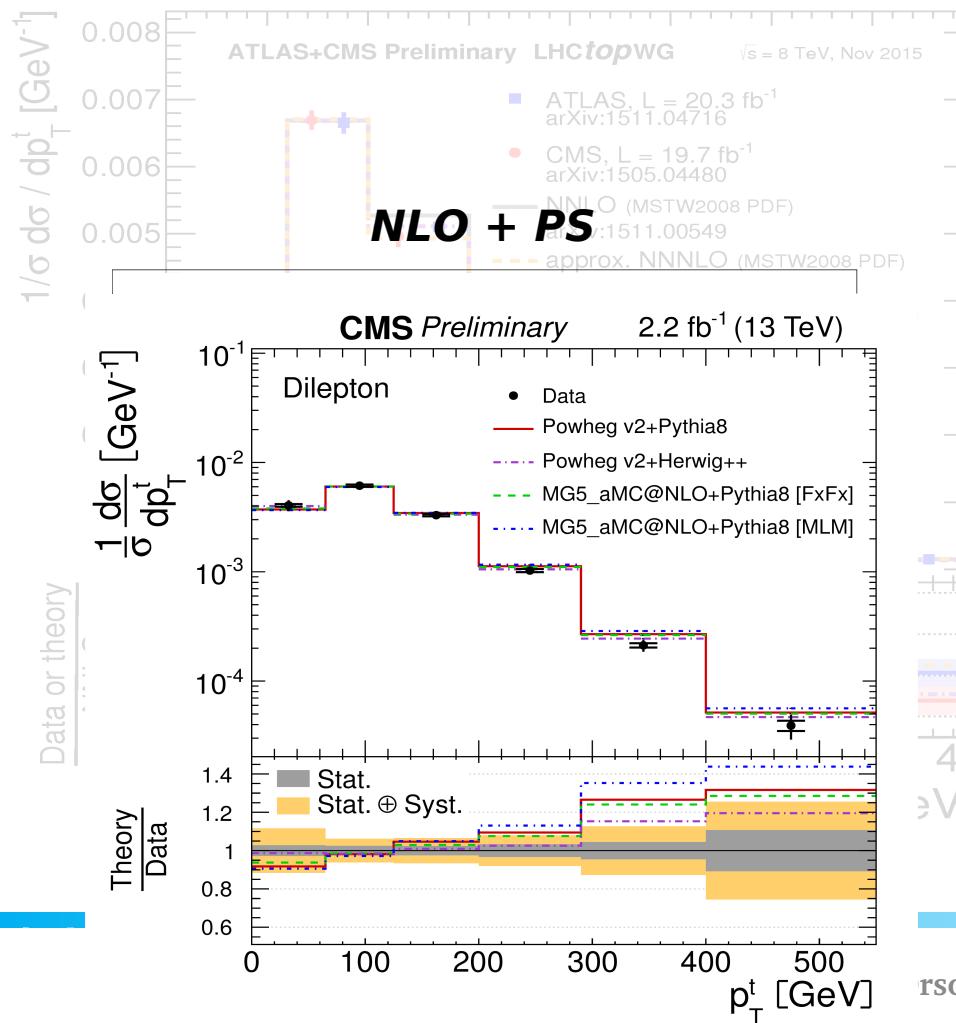


- Better agreement with the recent **differential NNLO QCD** calculations.

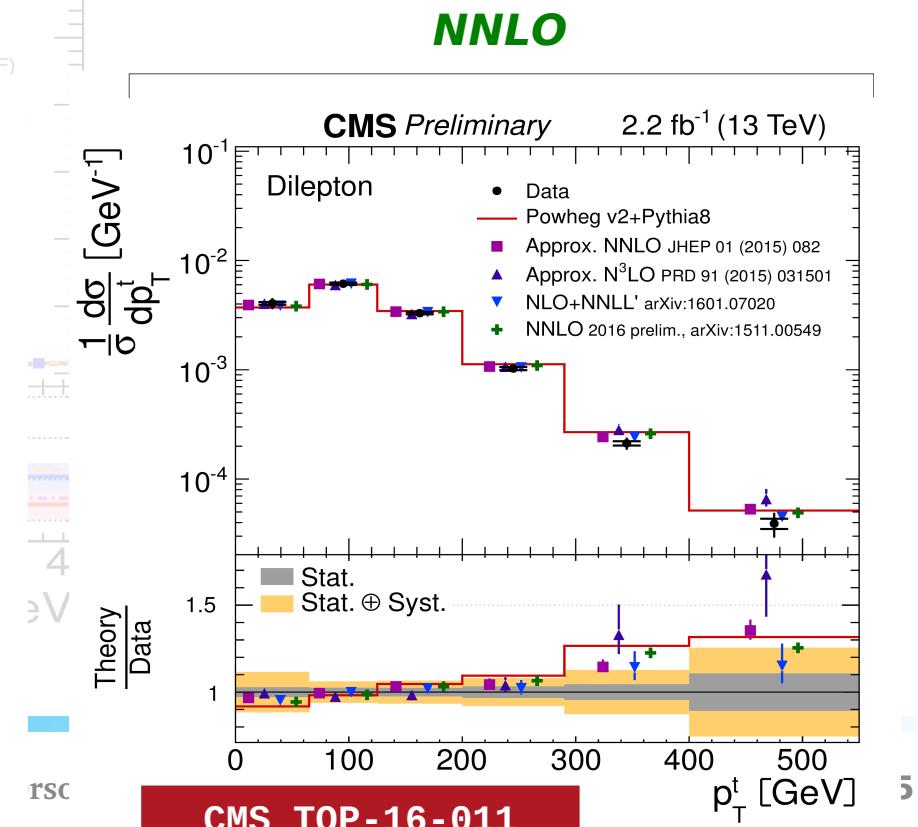
LHC Top WG summary plots

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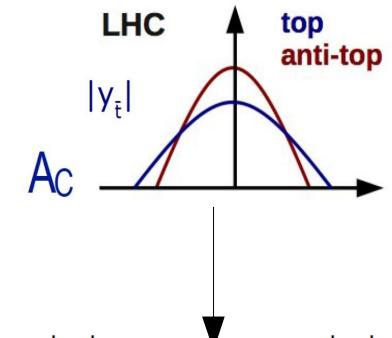
- Better agreement with the recent **differential NNLO QCD** calculations.
- Comparison also at **13 TeV**:



Charge asymmetry in top quark pairs

- **Asymmetry in top-antitop quark production:**

- at the LHC: a difference in the rapidity spectra
- top quark is more forward than anti-top



$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

$$\Delta|y| = |y_t| - |y_{\bar{t}}|$$

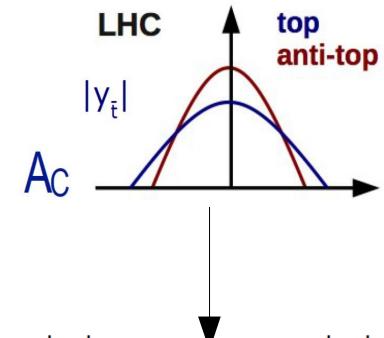
Charge asymmetry in top quark pairs

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- **Precision measurement, at 7/8 TeV:**

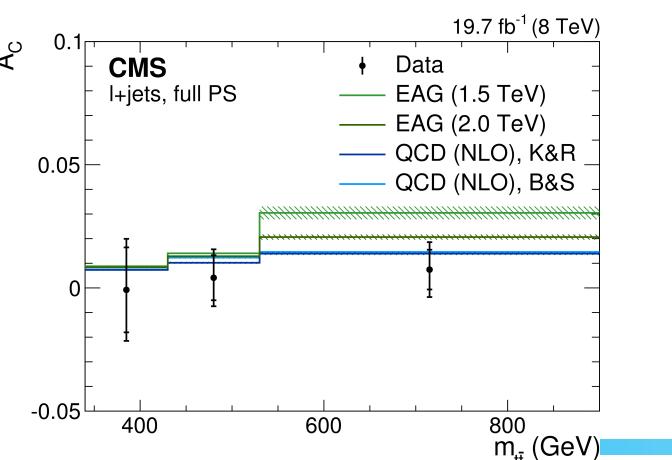
- several channels exploited, including top boosted regime



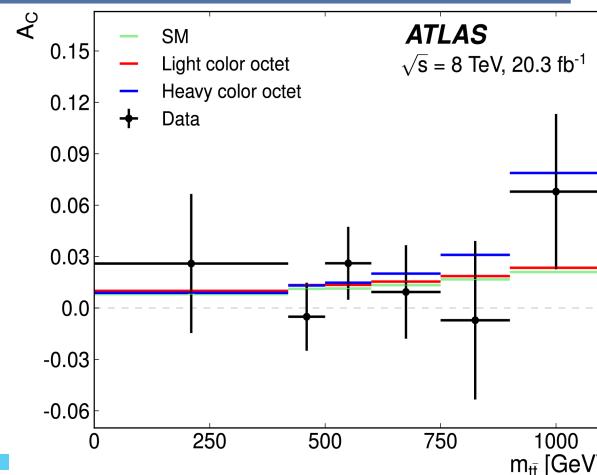
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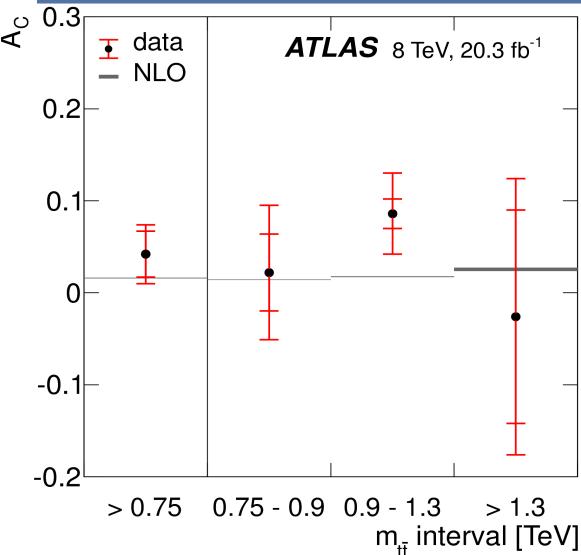
[arXiv:1507.03110](https://arxiv.org/abs/1507.03110)



Eur. Phys. J. C76(2016)87



Phys. Lett. B(2016)756, 52-71



See also talks by [D. Poyraz](#) and [M. Kareem](#)

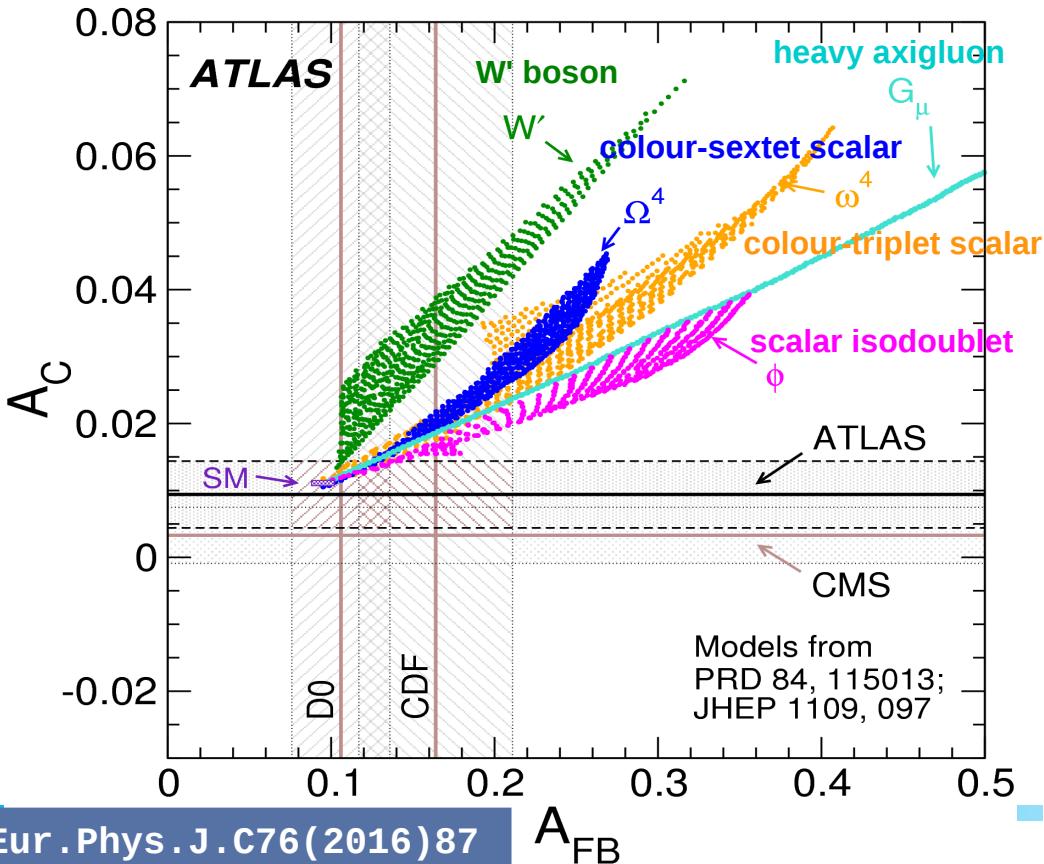
Alberto Orso Maria Iorio

Charge asymmetry in top quark pairs

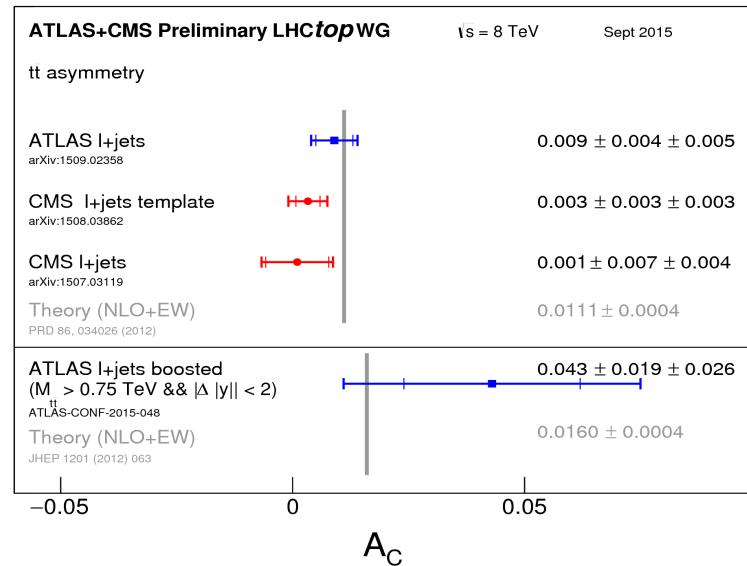
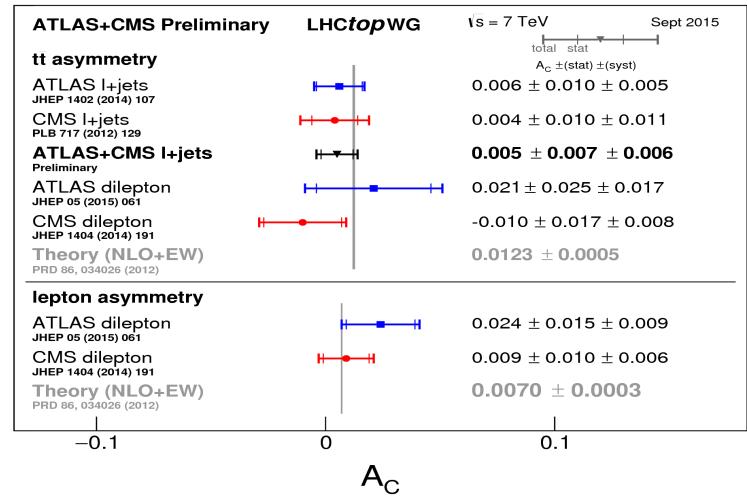
- No significant deviation from expectation

- Rich array of measurements from Atlas and CMS

- Several BSM models can be excluded



LHC Top WG summary plots



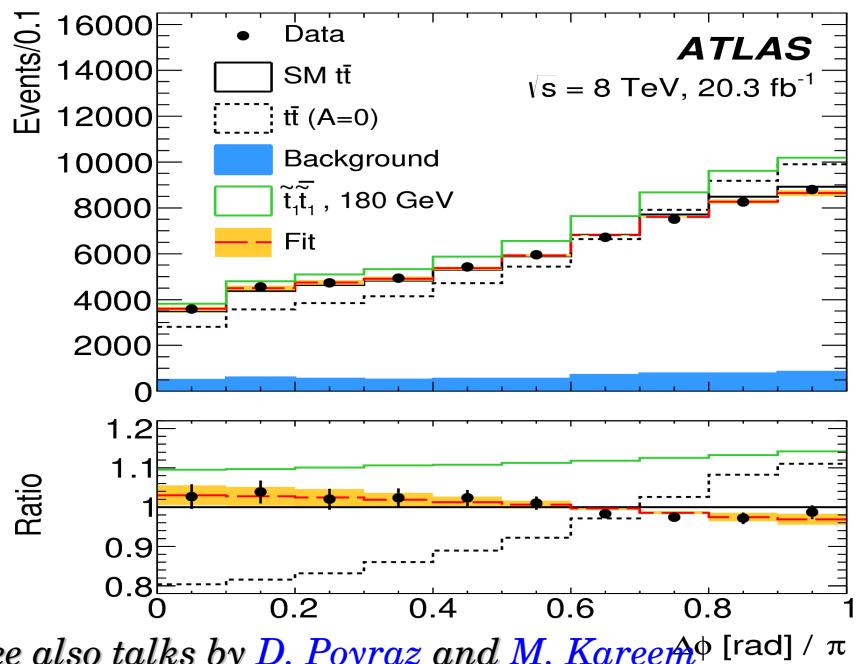
Spin correlation and top polarisation

- **Top quarks in strong production:**
 - produced unpolarised
 - angular correlations stem from gluon helicities

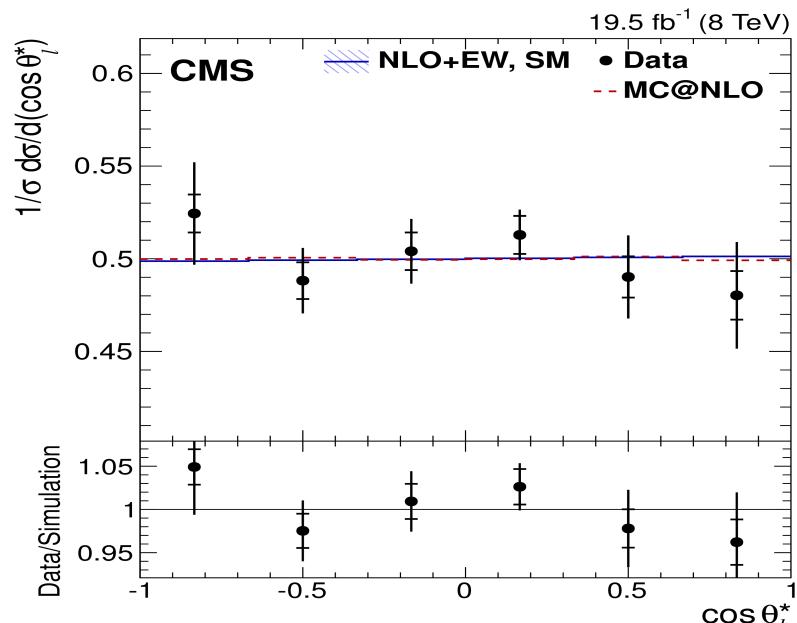
- **What we do measure:**

- fraction of spin-correlated events $f_{SM} = \frac{N_{SM}^{t\bar{t}}}{N_{SM}^{t\bar{t}} + N_{Uncor}^{t\bar{t}}}$
- Unfolding to angular distributions → measure asymmetries

Phys. Rev. Lett. 114, 142001(2015)

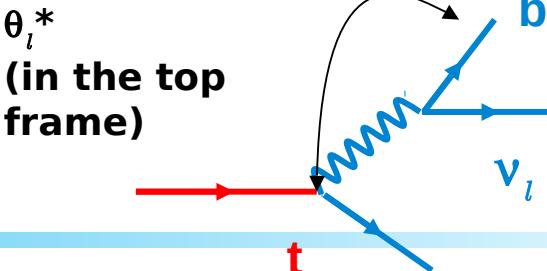


See also talks by D. Poyraz and M. Kareem



◦ **Sensitive observables:** arXiv:1601.01107

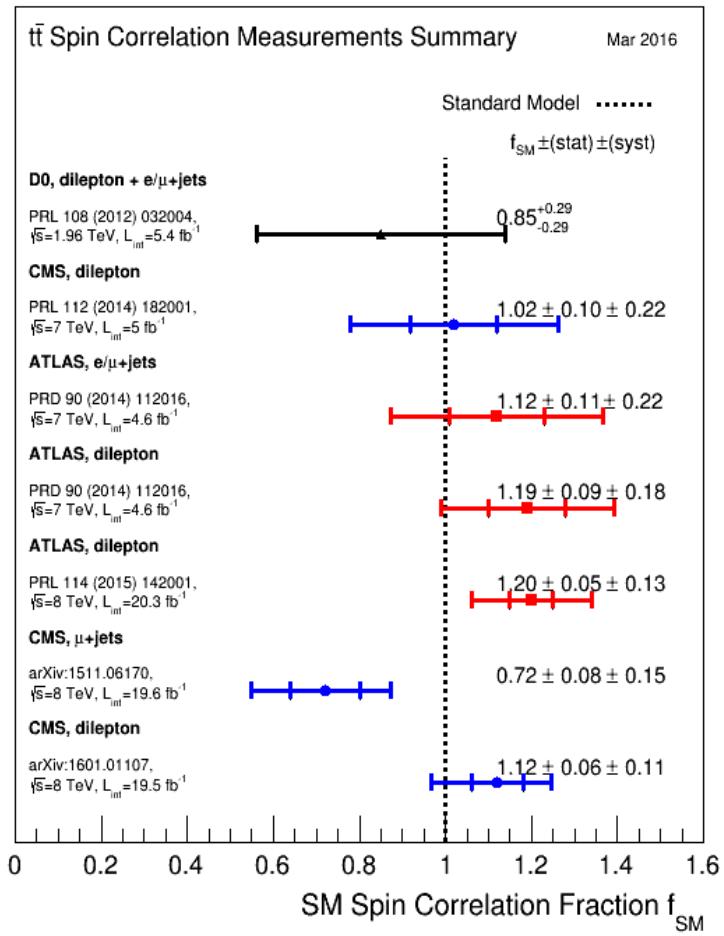
- angle θ^* for leptonically decaying tops
- angle ϕ between leptons in dileptonic top decays



Spin correlation and top polarisation

- **Several methods explored!**

- Both dileptonic and semileptonic channels studied
- Measurements of $\Delta\phi$, $\cos\theta^*$, etc.
- Matrix Element method
- good agreement with the standard model, two measurement show a slight tension, however less than $2\sigma_{f_{SM}}$



CP asymmetry in ttbar events

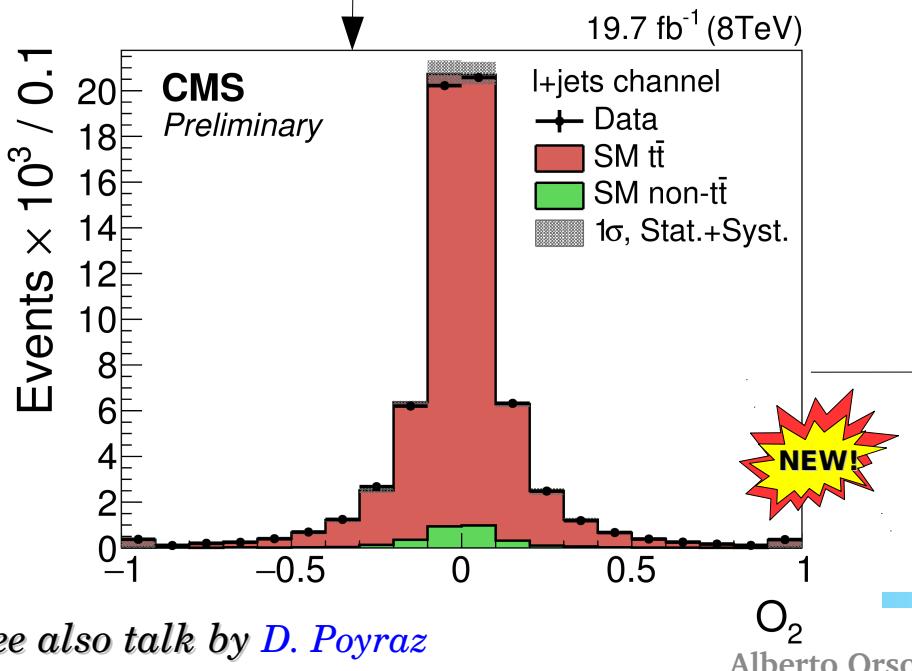
- **Probes of CP violation in tt production:**

- Decay channels with 1 lepton + jets

- Four **observables** are chosen with **asymmetry** in presence of CP violation

- Respective distributions are probed in 8 TeV data

CMS TOP-16-001



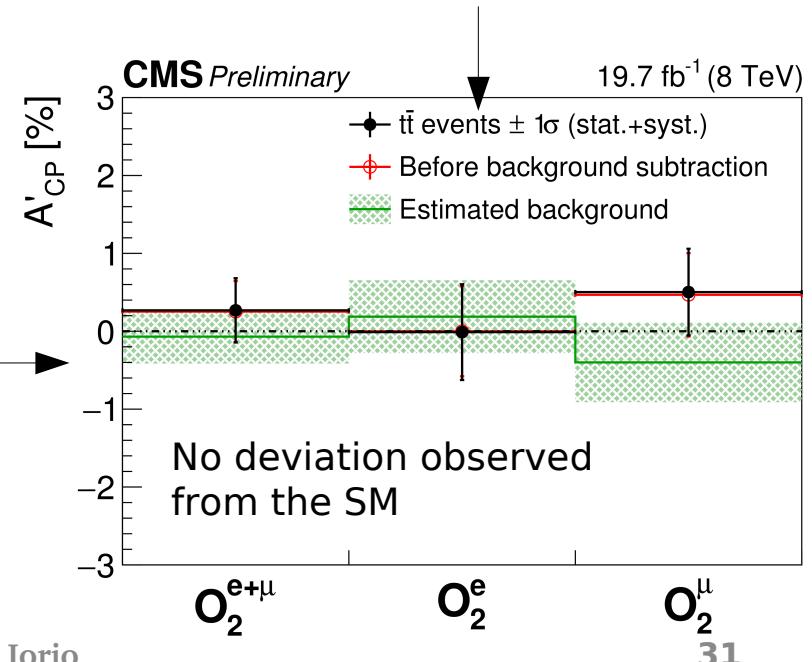
$$O_2 = \epsilon(P, p_b + p_{\bar{b}}, p_\ell, p_{j1}) \xrightarrow{\text{lab}} \propto (\vec{p}_b + \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j1})$$

$$O_3 = Q_\ell \epsilon(p_b, p_{\bar{b}}, p_\ell, p_{j1}) \xrightarrow{\text{bb CM}} \propto Q_\ell \vec{p}_b \cdot (\vec{p}_\ell \times \vec{p}_{j1})$$

$$O_4 = Q_\ell \epsilon(P, p_b - p_{\bar{b}}, p_\ell, p_{j1}) \xrightarrow{\text{lab}} \propto Q_\ell (\vec{p}_b - \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j1})$$

$$O_7 = q \cdot (p_b - p_{\bar{b}}) \epsilon(P, q, p_b, p_{\bar{b}}) \xrightarrow{\text{lab}} \propto (\vec{p}_b - \vec{p}_{\bar{b}})_z (\vec{p}_b \times \vec{p}_{\bar{b}})_z$$

$$A_{CP}(O_i) = \frac{N_{events}(O_i > 0) - N_{events}(O_i < 0)}{N_{events}(O_i > 0) + N_{events}(O_i < 0)}$$



See also talk by [D. Poyraz](#)

Single-top and vector bosons associated production

The single-top production: top in the electroweak sector

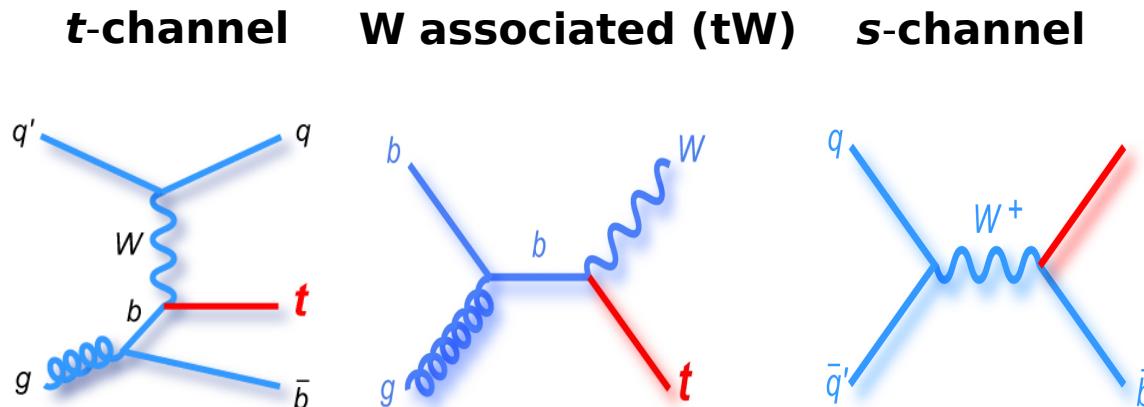
- **Single-top quark:**

- **tWb vertex in production**

- Top is produced polarised

- non SM couplings can appear in cross section and properties

- All channels cross sections: proportional to $|V_{tb}|^2$



LHC pp @ 7 TeV⁽¹⁾⁽²⁾

63.9±0.2.7 pb

15.7±1.2 pb

4.29±0.18 pb

LHC pp @ 8 TeV⁽¹⁾⁽²⁾

85.2±2.2 pb⁽³⁾

22.4±1.5 pb

5.24±0.21 pb

LHC pp @ 13 TeV⁽¹⁾⁽²⁾

217.0±8.4 pb

84.4±4.4 pb

10.32±0.38 pb

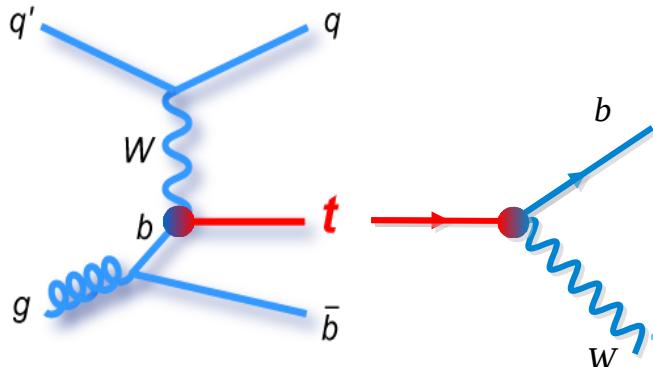
(1): LHCTopWG: calculations with HATOR, see also <https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SingleTopRefXsec>

(2): N. Kidonakis Phys. arXiv:1205.3453

(3): M. Burcherseifer, F.Caola, K. Melnikov: arXiv:1404.7116

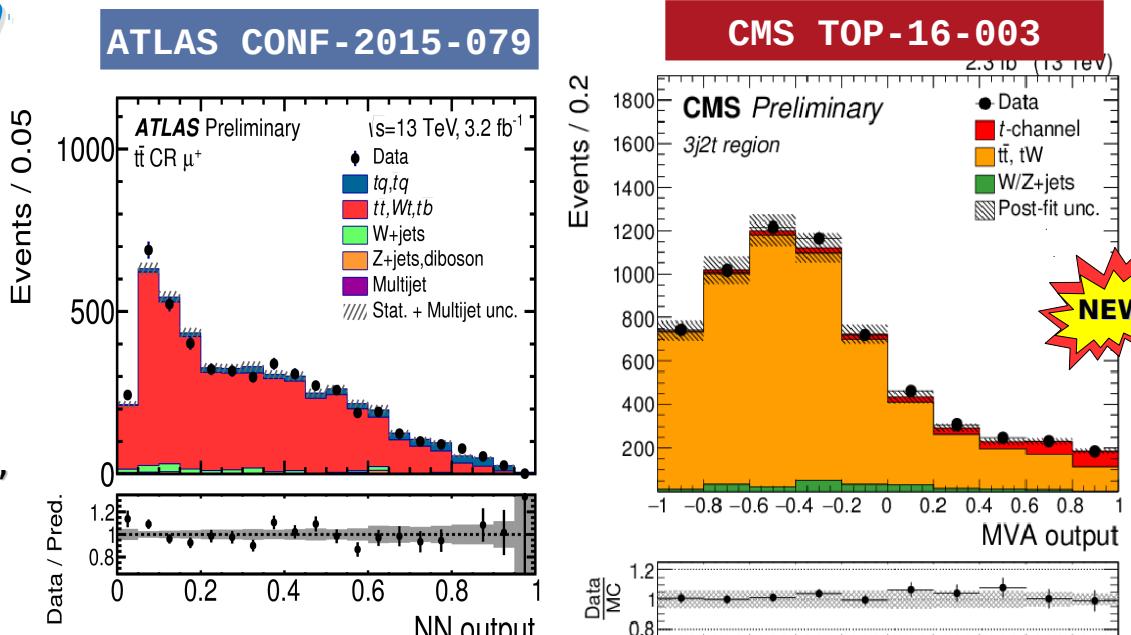
All with top mass = 172.5 GeV

t-channel Single top production:



- **Inclusive cross sections:**
 - leptonic only decay channels
 - MVAs to maximize background rejection
 - Selection:
 - 1 lepton (μ for CMS, μ/e for atlas),
 - 2 or 3 jets
 - 1 or 2 b-jets
 - Control regions for main backgrounds

- **Most abundant single-top ($\sigma \sim 1/3 \times \sigma(t\bar{t})$):**
 - measurement of V_{tb} in production!



t -channel single-top: cross sections and $|V_{tb}|$

- Cross sections:

$\sigma_{t\text{-channel}} [\text{pb}]$

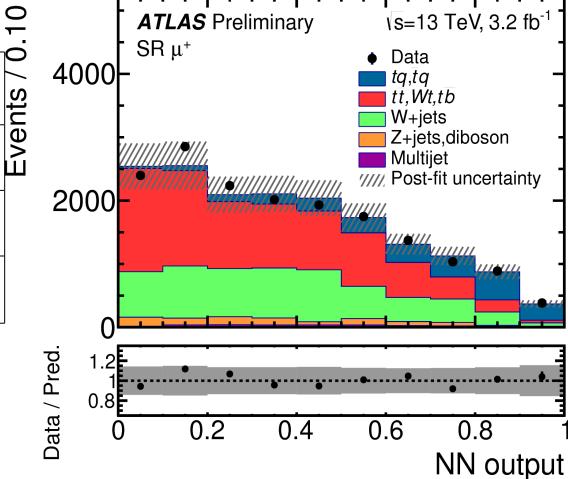
	Atlas	CMS
7 TeV	68 ± 8	67.2 ± 6.1
8 TeV	82.6 ± 12.1	83.6 ± 7.8
13 TeV	229 ± 48	227 ± 33

- $|V_{tb}|$: Assuming $|V_{td}|, |V_{ts}| \ll |V_{tb}|$

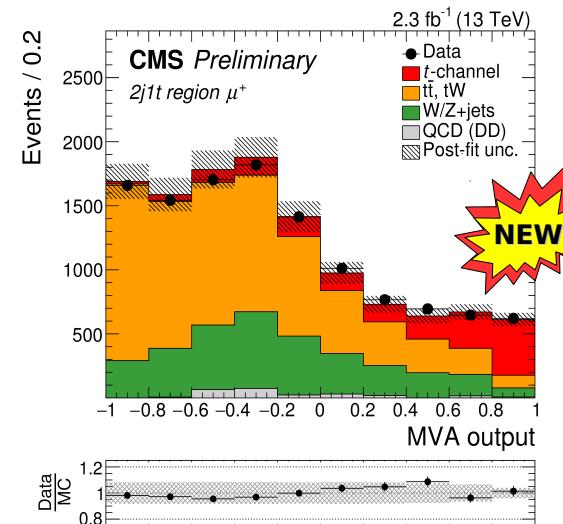


$$|V_{tb}| = \sqrt{(\sigma_{t\text{-ch.}}^{\text{obs.}} / \sigma_{t\text{-ch.}}^{\text{theo.}})}$$

	Atlas	CMS
7 TeV	1.02 ± 0.07	1.02 ± 0.05
8 TeV	0.97 ± 0.09	0.978 ± 0.04
13 TeV	1.03 ± 0.11	1.02 ± 0.07



ATLAS CONF-2015-079



CMS TOP-16-003

Main uncertainties on $\sigma_{t\text{-chan.}} (t, 13\text{TeV}) [\%]$

	Atlas	CMS
Signal scale	5.9	+5.1 -7.1
Signal model	11.0	10.1
Jet energy scale	5.5	5.7

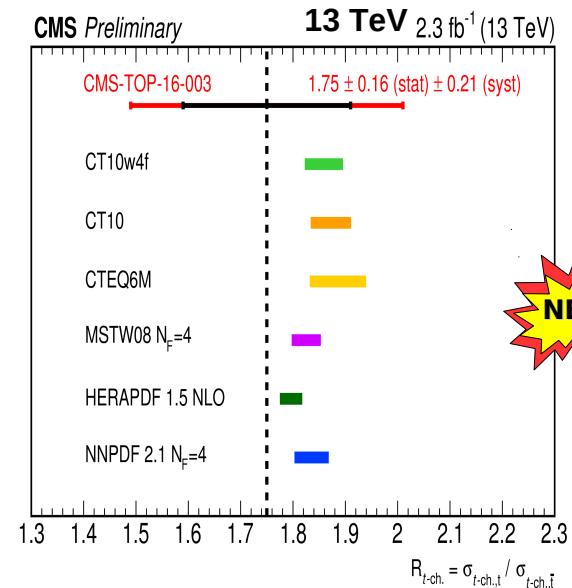
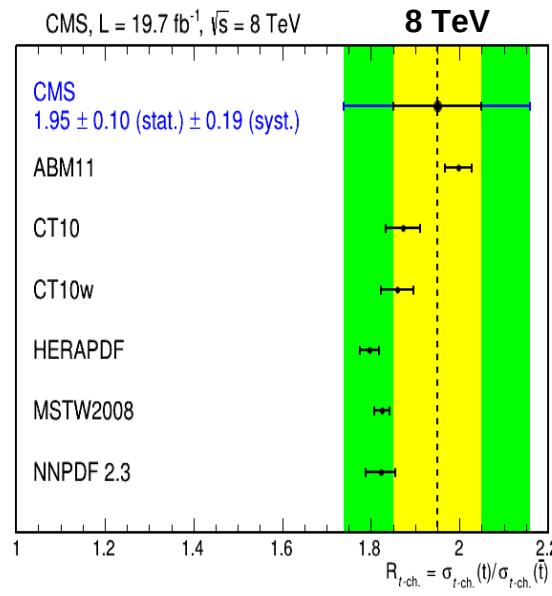
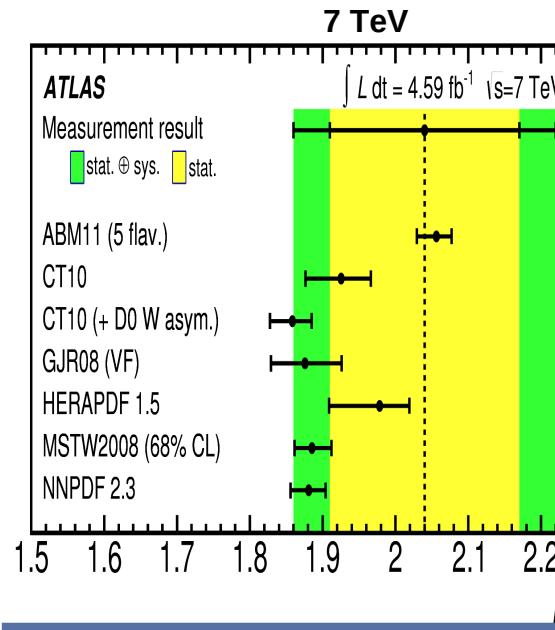
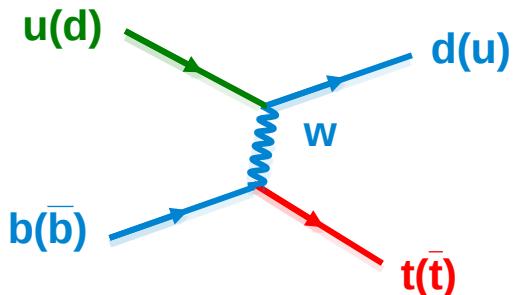
t -channel single-top: charge ratio measurement

- **Asymmetry in top production :**

- stems from valence quark composition:

$$\sigma(\text{top})/\sigma(\text{antitop}) \sim 2$$

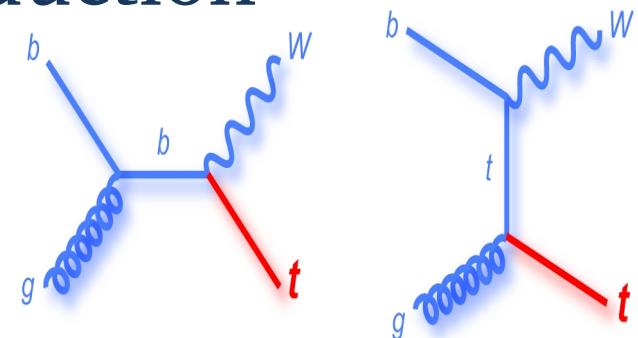
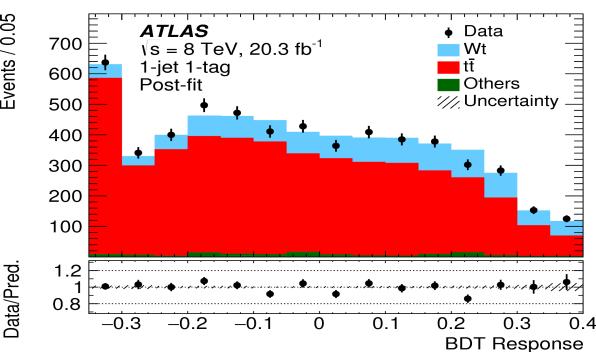
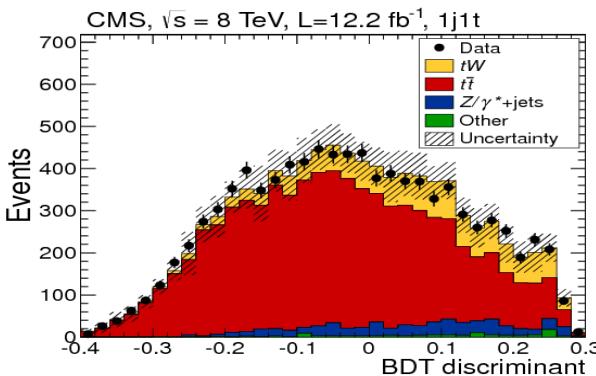
- can be inferred directly from lepton sign



The single-top quark W-associated production

- Entirely different production mechanism:

- complementary to t-channel route to measure tWb properties and Vtb



- Measurement at LHC with 8 TeV datasets:

- Measured in channels where both t and W decay leptonically: 2 opposite sign isolated leptons in the final state

$$\sigma(8 \text{ TeV}) [\text{pb}] = 23.0 \pm 3.6 \text{(Atlas)} / 23.4 \pm 5.4 \text{ (CMS)}$$

- Main uncertainty contributions:

Atlas: Background normalisation ($^{+10}_{-8.5}\%$), Jet Energy Scale ($^{+9.0}_{-9.9}\%$), ISR/FSR ($^{+8.2}_{-9.4}\%$);

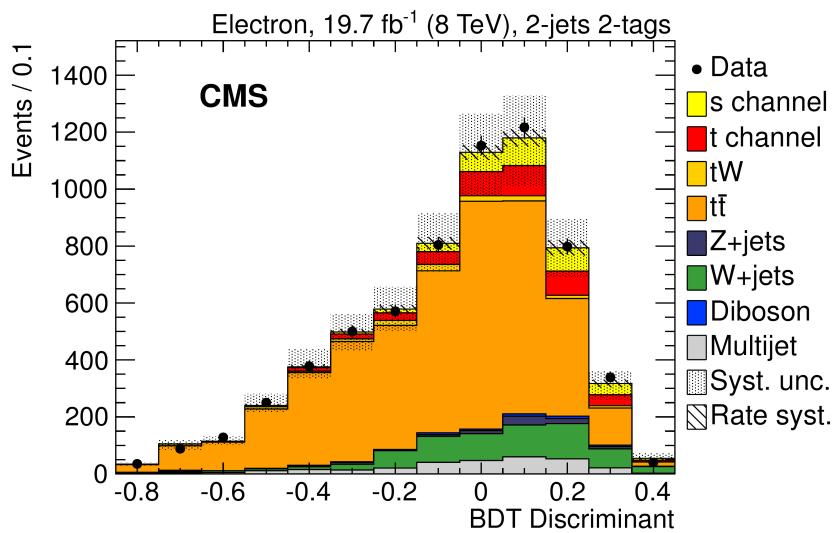
CMS: $t\bar{t}$ ME/PS matching (14%), fact/renormalisation scales (11%), top quark mass (11%);

Single-top in the s-channel

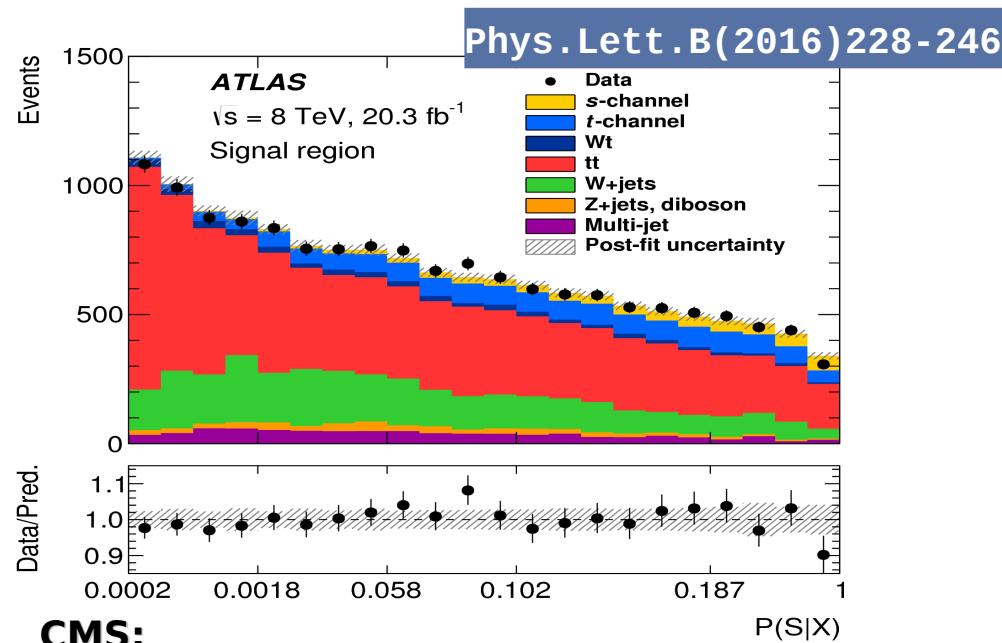
- First evidence of s-channel: →
- selection on 1 lepton and 2 b-tagged jets
- using matrix element method to maximize discrimination
- profile likelihood fit including systematics

$$\sigma_s = 4.8 \pm 0.8(\text{stat.})^{+1.6}_{-1.3}(\text{syst.}) \text{ pb}$$

Statistical significance (expected)/observed:
(3.9)3.2 standard deviations



arXiv:1603.02555



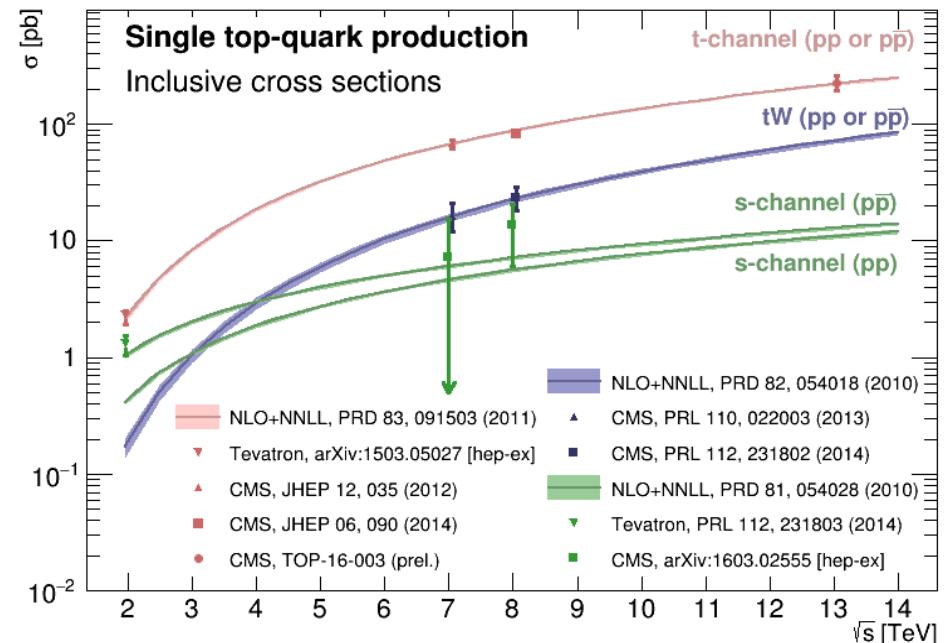
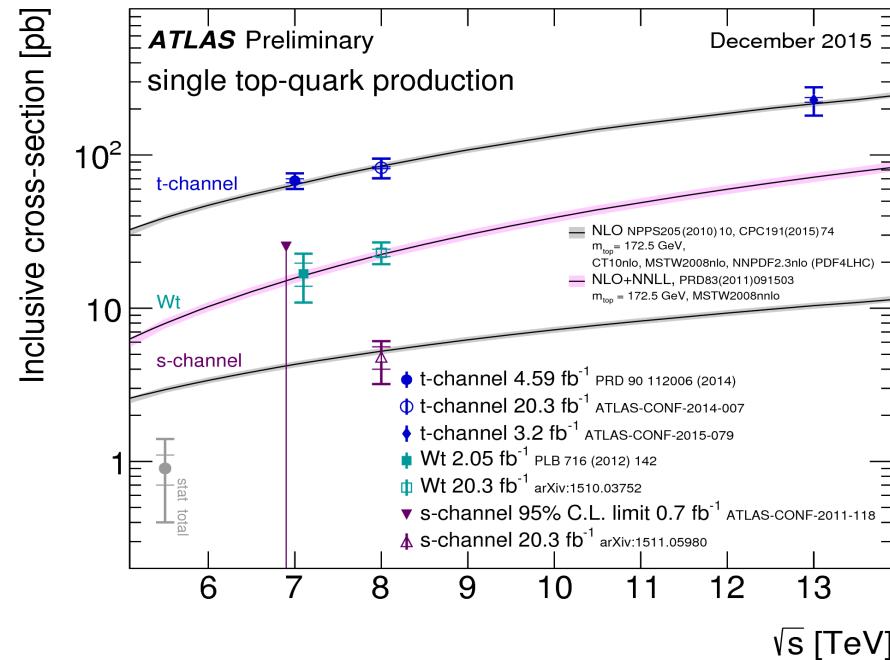
CMS:

- s-channel at 7 + 8 TeV:
 - uses MVA analysis to discriminate from backgrounds
 - signal strength correlated amongst two energies
 - No profiling of systematics
 - Main systematics: background modeling

$$\sigma_s = 7.1 \pm 8.1 \text{ (stat + syst) pb}, \quad 7 \text{ TeV};$$

$$\sigma_s = 13.4 \pm 7.3 \text{ (stat + syst) pb}, \quad 8 \text{ TeV}.$$

Single-top overview



- **All single top processes** have been studied in Run I
 - including differential cross sections and angular measurements
- **First t-channel measurements** at 13 TeV as by both experiments
- Ramping up towards a new era of high precision for the electroweak sector of top physics

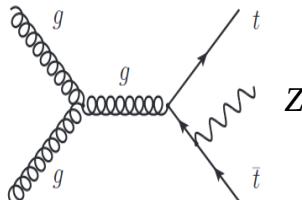
Top quark pairs + W/Z

Probe electroweak Neutral Currents: established at 8 TeV, now measured at **13 TeV as well!**

ATLAS CONF-2016-003

CMS TOP-16-009

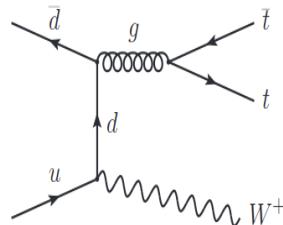
tt+Z



CMS and Atlas:
requiring 3-4 leptons and ≥ 2 jets in different categories

$$\sigma(t\bar{t} Z) = \mathbf{0.9 \pm 0.3 \text{ (Atlas)}} / \mathbf{1.1 \pm 0.4 \text{ (CMS)}} \text{ pb}$$

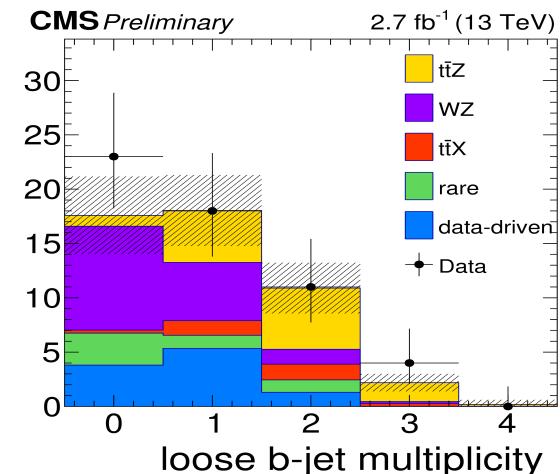
tt+W



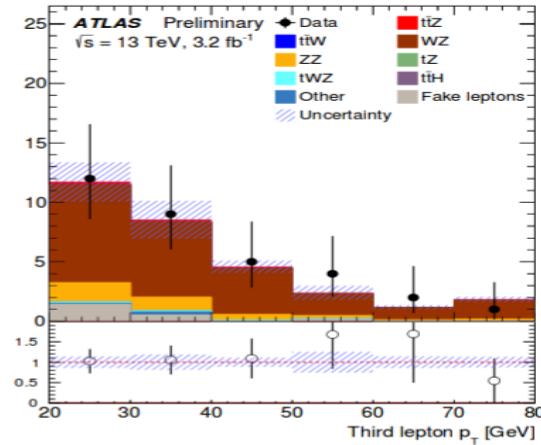
Atlas analysis with equiring 2-3 leptons and ≥ 2 jets,

$$\sigma(t\bar{t} W) = \mathbf{1.4 \pm 0.8 \text{ pb}}$$

Events



Events / 10 GeV
Data / Pred.



Top quark pairs + photon

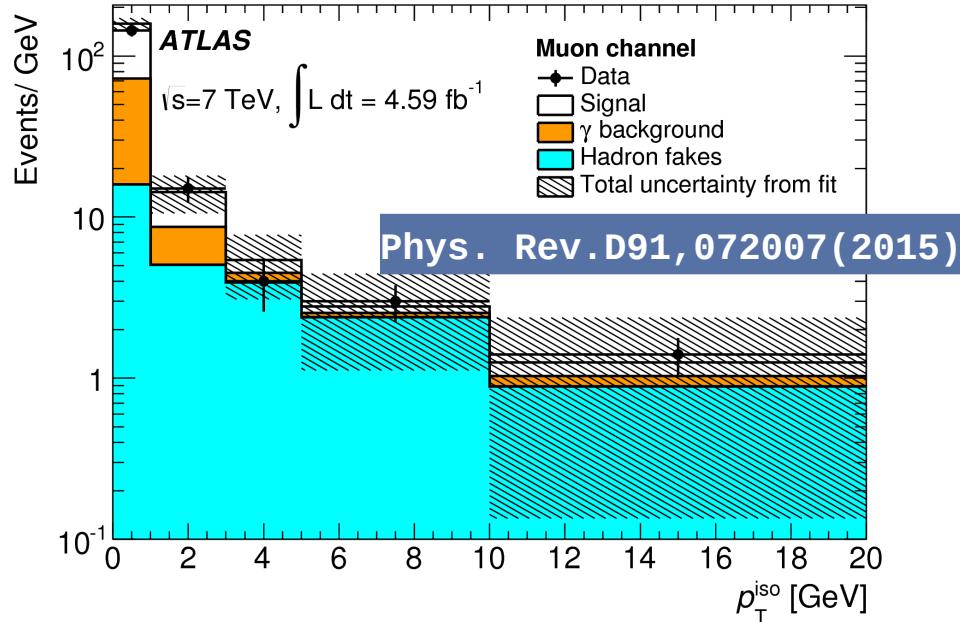
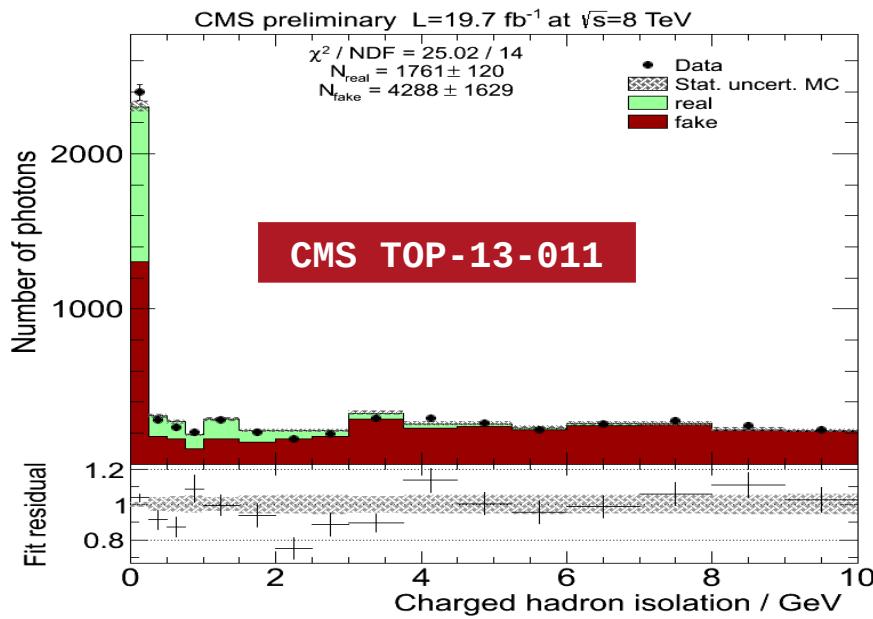
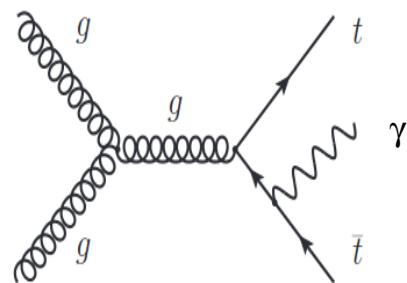
Completes the picture together with W/Z

Probes **top quark charge** via the coupling

Measurements at 7 (**Atlas**) and 8 (**CMS**) TeV :

$\sigma(t\bar{t}\gamma) = 68 \pm 17 \text{ fb}$ at 7 TeV (48 fb expected)

$\sigma(t\bar{t}\gamma) = 2.4 \pm 0.6 \text{ pb}$ at 8 TeV (1.8 pb expected)



top quark mass

High precision single measurements

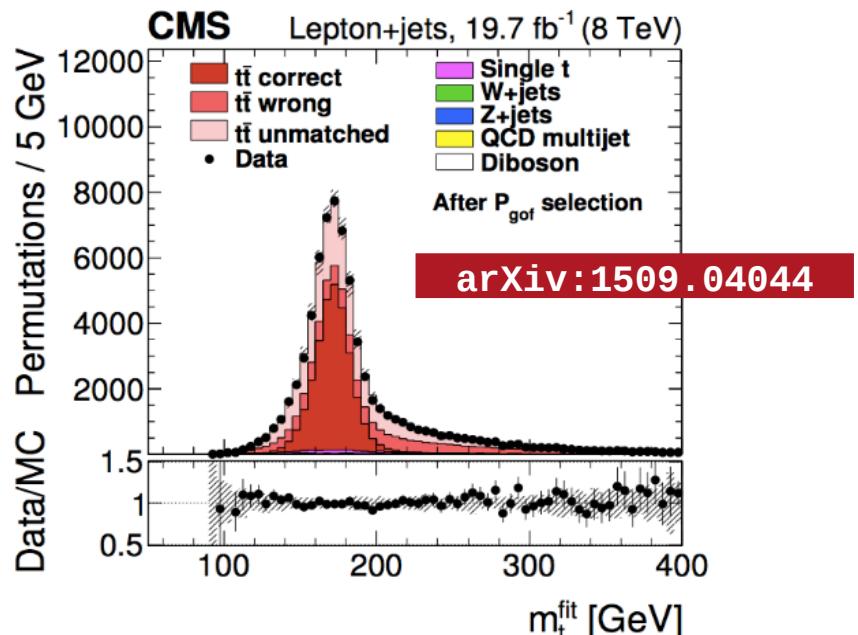
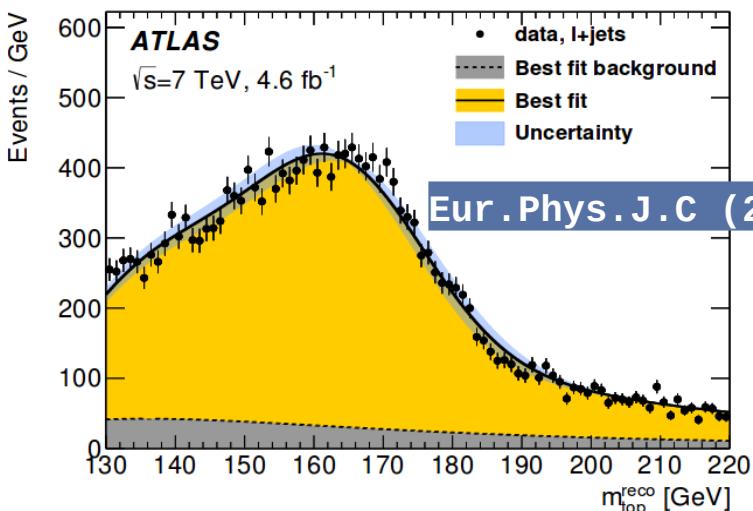
- **1 lepton + jets channel:**

- Choosing correct permutation of hadronic top with kinematic fit
- fit simultaneously the top quark mass and energy scale of jets

- **Main systematics:**

- b hadron jet energy corrections
- b hadron decay modeling

$$m_t^{\text{hyb}} = 172.35 \pm 0.16 \text{ (stat+JSF)} \pm 0.48 \text{ (syst) GeV}$$



- **1-2 lepton + jets channel:**

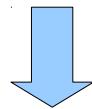
- Using likelihood fit to **several sensitive variables**

$$m_{\text{top}}^{\text{comb}} = 172.99 \pm 0.48 \text{ (stat)} \pm 0.78 \text{ (syst) GeV}$$

See also talks by [S. Spennagel](#) and [M. Bender](#)

Alternative approaches

Most precise measurements: sensitive to hadronisation uncertainties, color reconnection, etc...



Other ideas are explored by the experiments!

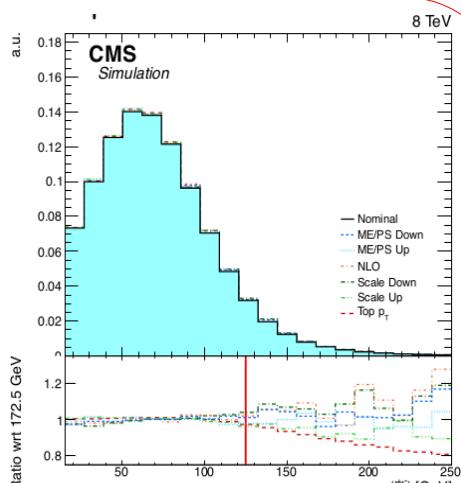
- From **different observables...**

Use observables
of lepton from top
decay

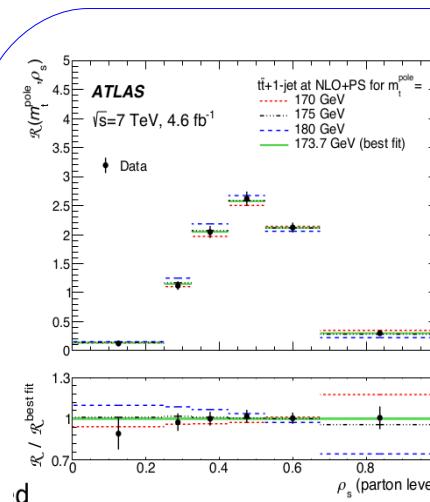
- less sensitive to
hadronisation

- suggested in
ArXiv:1407.2763

$m_t = 171.7 \pm 1.1 \text{ (stat)} \pm 2.9 \text{ (syst+theo)}$



CMS TOP-16-002



$$m_{top} = 173.7^{+2.3-2.1} \text{ GeV}$$

JHEP10(2015)121

Measure the
 $t\bar{t} + 1$ jet shapes

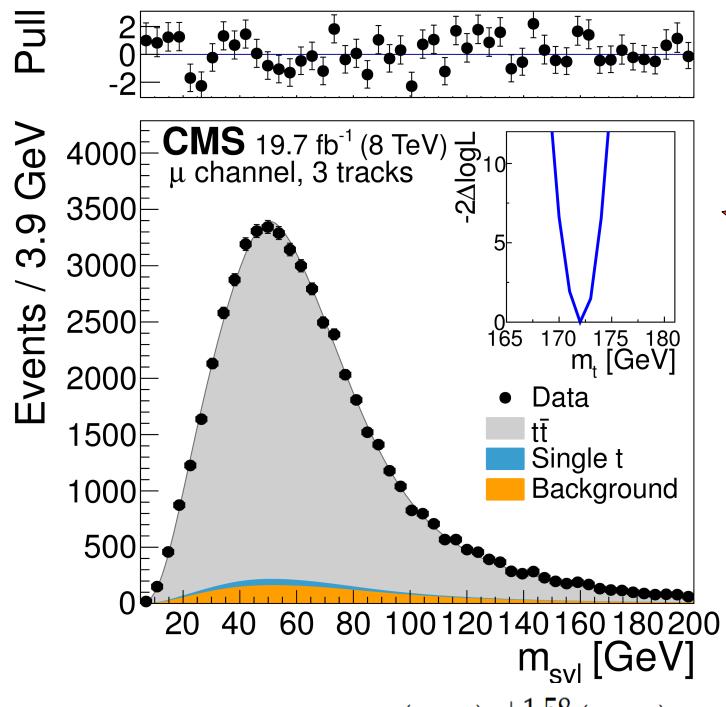
- Can be calculated
at NLO

- suggested in
ArXiv:1303.6415

Alternative approaches

... to different modes of decay or production!

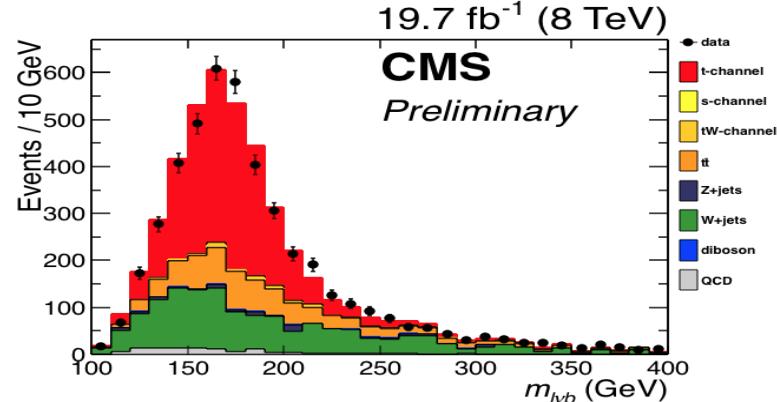
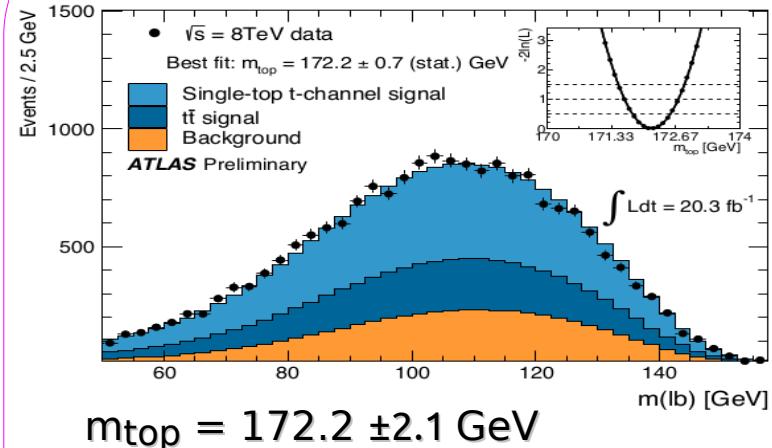
$t\bar{t}$ with charged particles from hadron decays and W lepton (see also: talk by Simon Spannagel)



arXiv:1603.06536

ALESSIO Orso Maria Iorio

Single-top topologies:

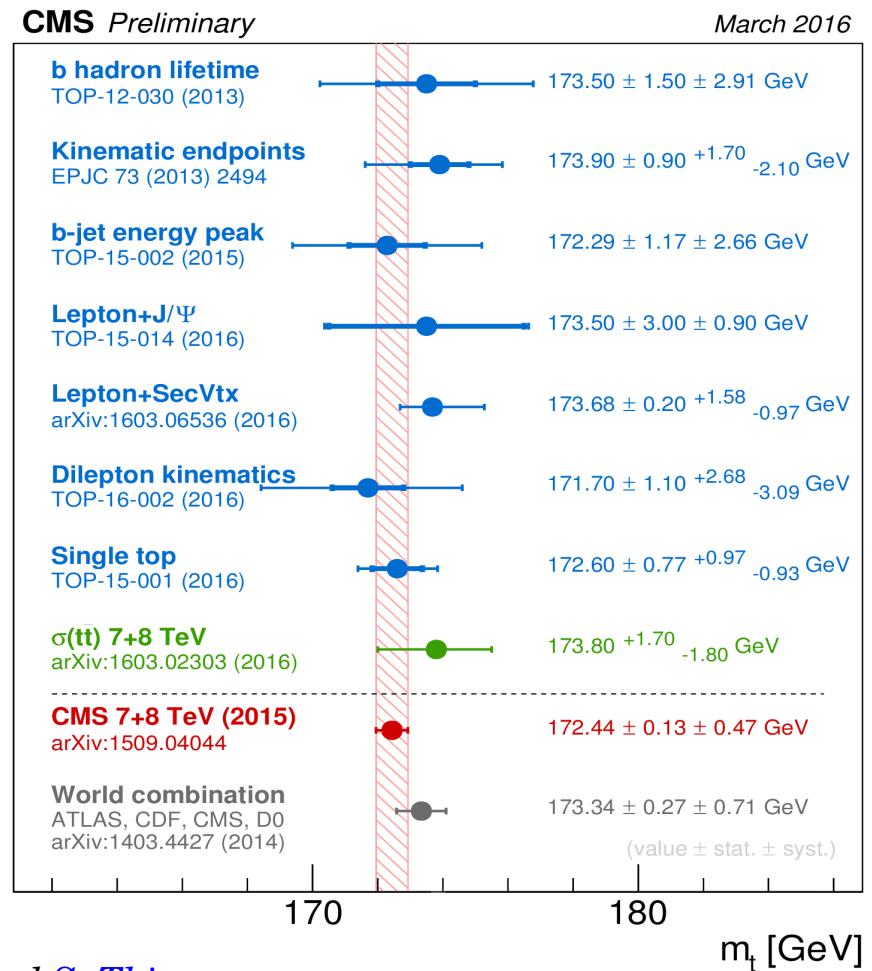
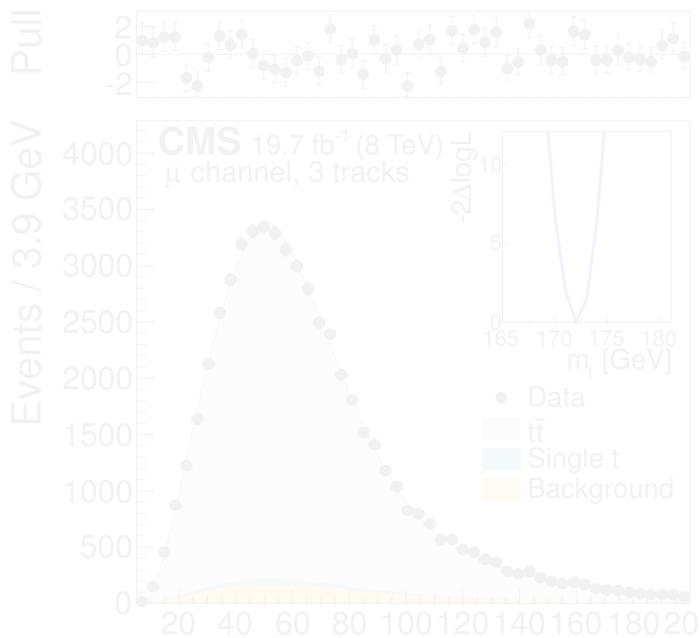


CMS TOP-15-001

Alternative approaches

... to different modes of decay or production!
... many more available!

$t\bar{t}$ with charged particles from hadron decay and W lepton (see also: talk by Simon Spannagel)

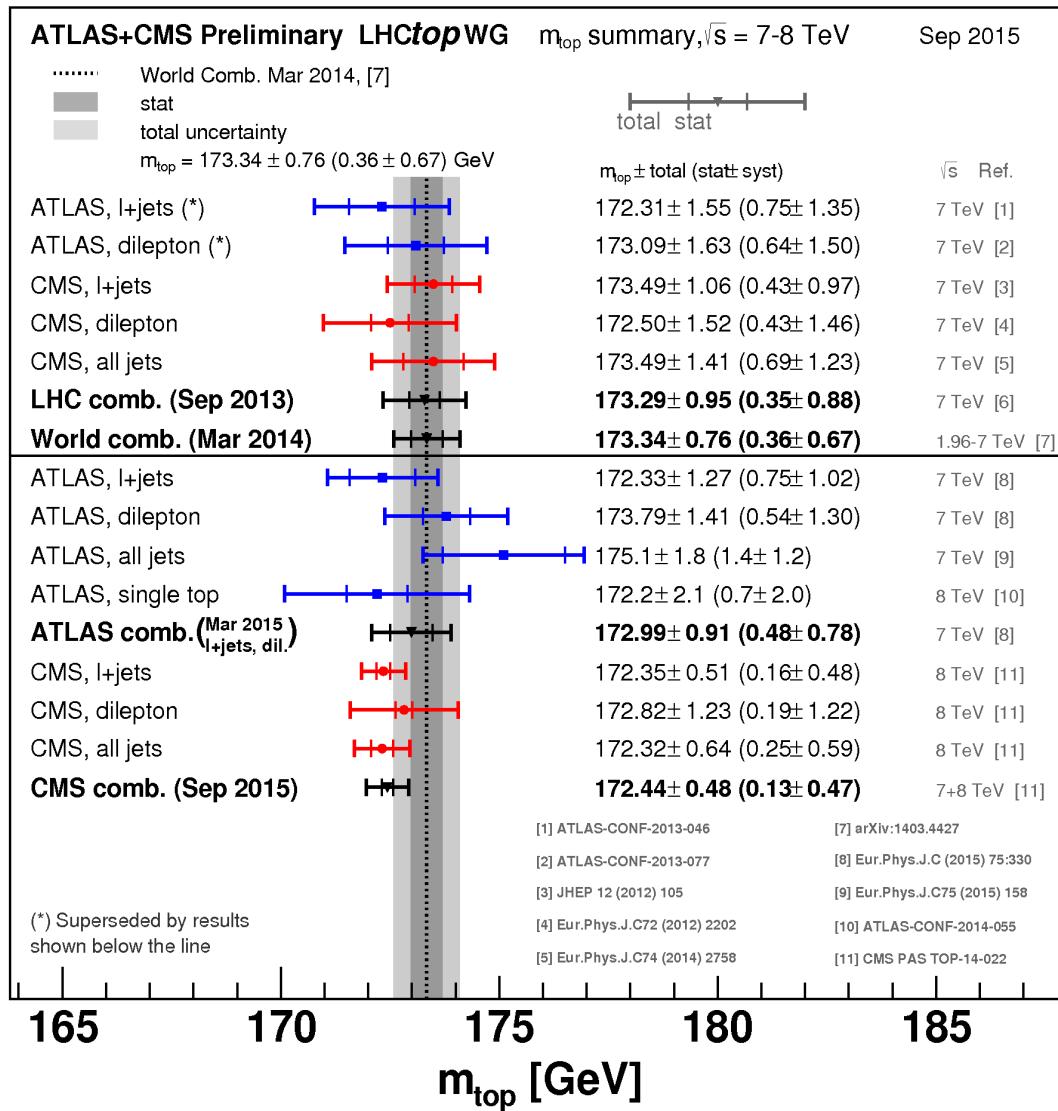


See also talks by **S. Spennagel, M. Bender, B. Bilin and S. Thier**

$$m_t = 173.68 \pm 0.20(\text{stat})^{+1.58}_{-0.97}(\text{syst}) \text{ GeV}$$

$$m_{\text{top}} = 172.6 \pm 1.2 \text{ GeV}$$

Overview of top mass measurements



Climbing the systematics wall!

Main enemy of current methods:
hadronisation modeling uncertainty

Continuous efforts to

- improve current techniques
- develop new methods
- combine the results... **also across energies and experiments!**

LHC Top WG summary plots

Summary and outlook

- **Standard model top quark production established at 13 TeV**

both **strong** and **electroweak** production modes

Inclusive and differential measurements performed

- **Solid ground to start a new era of top quark physics**

Mature studies based on the experience of LHC Run-I

New measurements to be made possible by higher luminosity and energy!

Looking forward to 2016 data!

Thanks!

Additional material

ttbar 13 TeV: early semileptonic channels

- **Cut and count analysis:**

- 1 e/ μ
- Atlas: $pT > 25 \text{ GeV}$, $|\eta| < 2.47$
- CMS: $pT > 30 \text{ GeV}$, $|\eta| < 2.1$
- at least 4 jets ($pT > 25 \text{ GeV}$, $|\eta| < 2.5$), 1 b-tag
- Atlas: cuts on ET_{miss} and w transverse mass

- **Main backgrounds:**

- single-top, W+jets, QCD

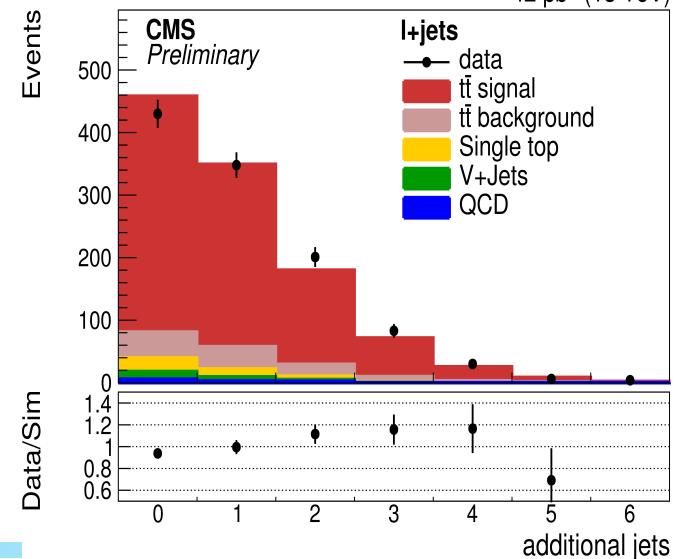
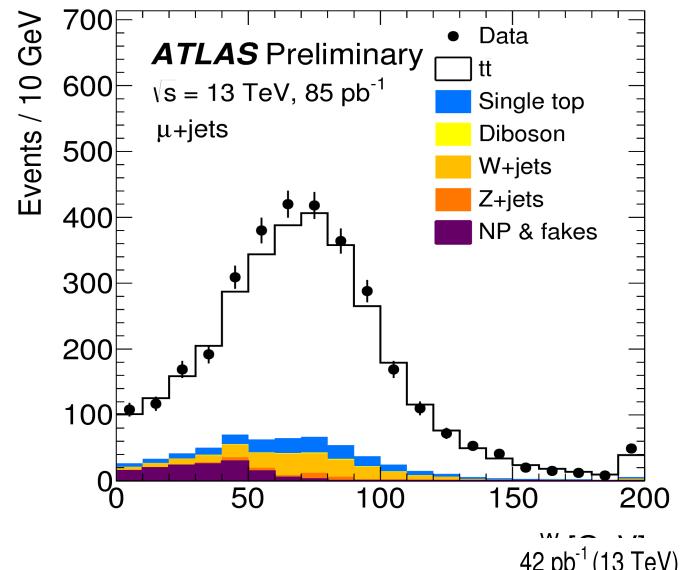
Results with $< 100 \text{ pb}$:

$$\sigma_{t\bar{t}} = 817 \pm 13 \text{ (stat)} \pm 103 \text{ (syst)} \pm 88 \text{ (lumi)} \text{ pb}$$

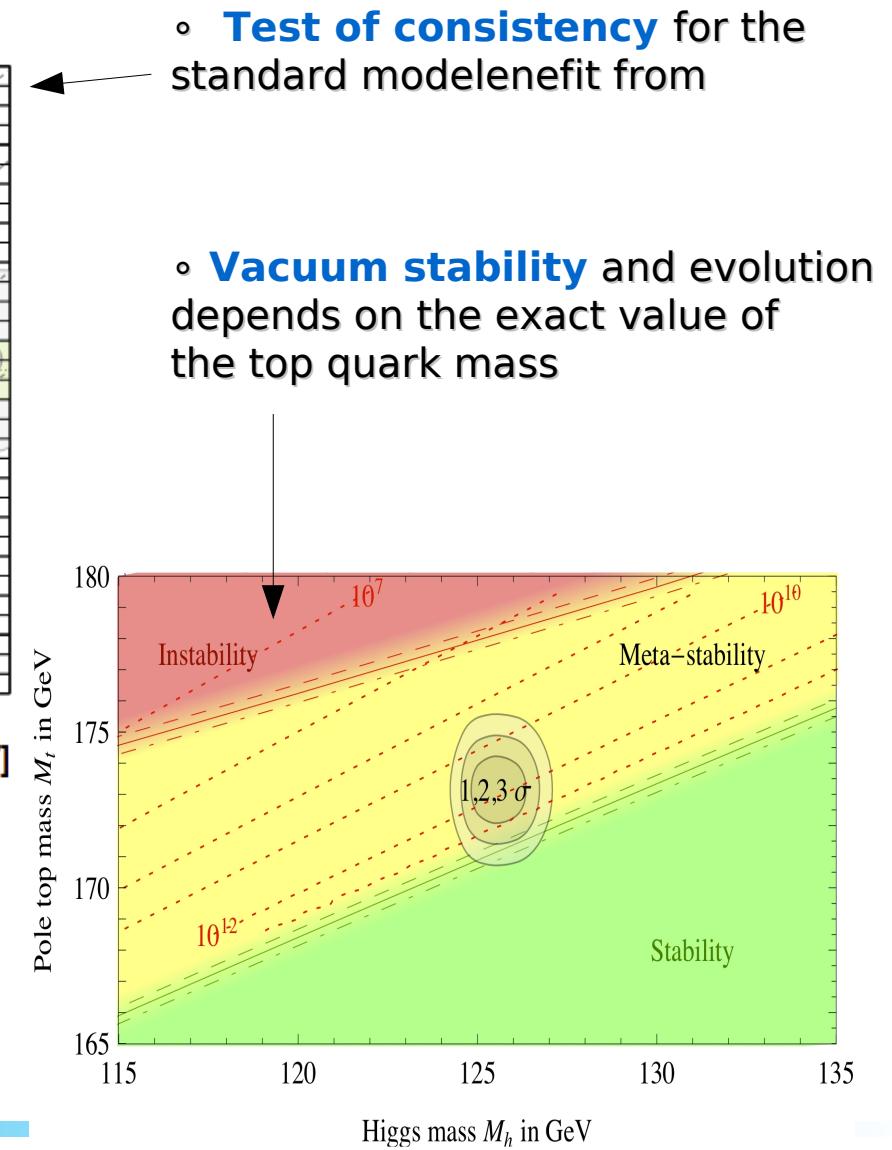
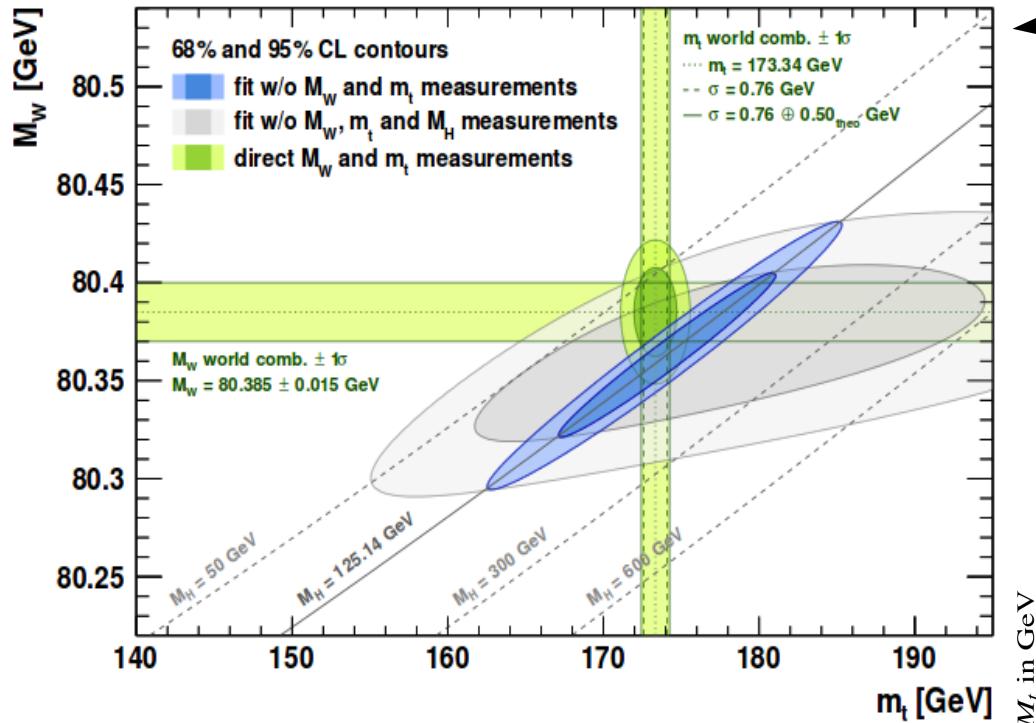
$$\sigma_{t\bar{t}} = 836 \pm 27 \text{ (stat)} \pm 88 \text{ (sys)} \pm 100 \text{ (lumi)} \text{ pb}$$

Main systematic uncertainties:

background normalisation, jet energy calibration,
luminosity



Top quark mass measurement



t -channel single-top: cross sections and $|V_{tb}|$

Source	$\Delta\sigma_{tq}/\sigma_{tq}$ [%]	$\Delta\sigma_{\bar{t}q}/\sigma_{\bar{t}q}$ [%]
Data statistics	± 4.6	± 5.0
MC statistics	± 6.3	± 6.5
Multijet normalisation	± 0.8	± 2.4
Other background normalisation	± 1.4	± 0.5
Muon uncertainties	± 1.6	± 1.6
JES	± 5.5	± 1.6
Jet energy resolution	± 4.3	± 3.1
E_T^{miss} modelling	± 4.2	± 4.5
b -tagging efficiency	± 7.1	± 7.5
c -tagging efficiency	< 0.5	< 0.5
Light-jet tagging efficiency	< 0.5	< 0.5
Pile-up reweighting	± 1.2	± 3.2
W +jets modelling	± 2.3	± 1.0
$t\bar{t}, Wt$ and s -channel shower generator	< 0.5	± 2.3
$t\bar{t}, Wt$ and s -channel NLO matching	± 2.7	± 7.0
$t\bar{t}, Wt$ and s -channel scale	± 2.6	± 0.9
t -channel scale	± 5.9	± 7.7
t -channel generator	± 11.0	± 15.0
PDF	< 0.5	± 1.0
Luminosity	± 5.0	± 5.0
Total systematic uncertainty	± 18.4	± 24.4
Total uncertainty	± 19.0	± 25.0

uncertainty source	$\Delta\sigma_{t\text{-ch}, t+\bar{t}}/\sigma_{t\text{-ch}, t+\bar{t}}^{\text{obs}}$	$\Delta\sigma_{t\text{-ch}, t}/\sigma_{t\text{-ch}, t}^{\text{obs}}$	$\Delta\sigma_{t\text{-ch}, \bar{t}}/\sigma_{t\text{-ch}, \bar{t}}^{\text{obs}}$
uncertainty of the fit (stat. + prof. unc.)	$\pm 6.8\%$	$\pm 7.4\%$	$\pm 11.9\%$
statistical uncertainty	$\pm 4.0\%$	$\pm 4.7\%$	$\pm 7.6\%$
profiled uncertainties	$\pm 5.5\%$	$\pm 5.7\%$	$\pm 9.2\%$
MC statistics	$\pm 2.8\%$	$\pm 3.4\%$	$\pm 4.0\%$
pileup	$-0.2/+0.1\%$	$-0.5/+0.4\%$	$-0.1/+0.7\%$
experimental uncertainty	$-6.2/+6.2\%$	$-6.7/+6.7\%$	$-10.0/+10.0\%$
Signal modeling	$\pm 7.9\%$	$\pm 10.1\%$	$\pm 8.2\%$
$t\bar{t}$ modeling	$\pm 4.3\%$	$\pm 3.9\%$	$\pm 4.6\%$
W +jets modeling	$-2.1/+1.7\%$	$-1.6/+1.1\%$	$-2.8/+2.3\%$
Q^2 scale t -channel	$-5.7/+7.0\%$	$-7.1/+5.1\%$	$-6.1/+6.9\%$
Q^2 scale $\bar{t}\bar{t}$	$-2.7/+4.1\%$	$-2.5/+4.0\%$	$-3.9/+3.4\%$
Q^2 scale tW	$-0.3/+0.5\%$	$-0.4/+0.3\%$	$-1.1/+0.4\%$
Q^2 scale W +jets	$-2.7/+3.0\%$	$-2.5/+4.2\%$	$-5/+2.4\%$
PDF uncertainty	$-3.0/+2.6\%$	$-3.1/+3.2\%$	$-3.7/+4.2\%$
top p_T modeling	$\pm 0.1\%$	$\pm 0.1\%$	$\pm 0.2\%$
total theory uncertainties	$-12.1/+12.6$	$-13.8/+13.6$	$-13.5/+13.4\%$
luminosity	$\pm 2.7\%$	$\pm 2.7\%$	$\pm 2.7\%$
total uncertainty	$-14.5/+14.8\%$	$-16.3/+16.1\%$	$-18.6/+18.6\%$

Measurements interpretation: top-quark pole mass

- **Re-interpretation of cross section measurements:**

- top mass used as parameter in the MC depends on the renormalisation scheme used
- top mass from the cross section parametrisation
- main uncertainties: from cross section measurement:
luminosity, background yield, lepton reconstruction

