

Top quark physics results

María Aldaya (DESY)

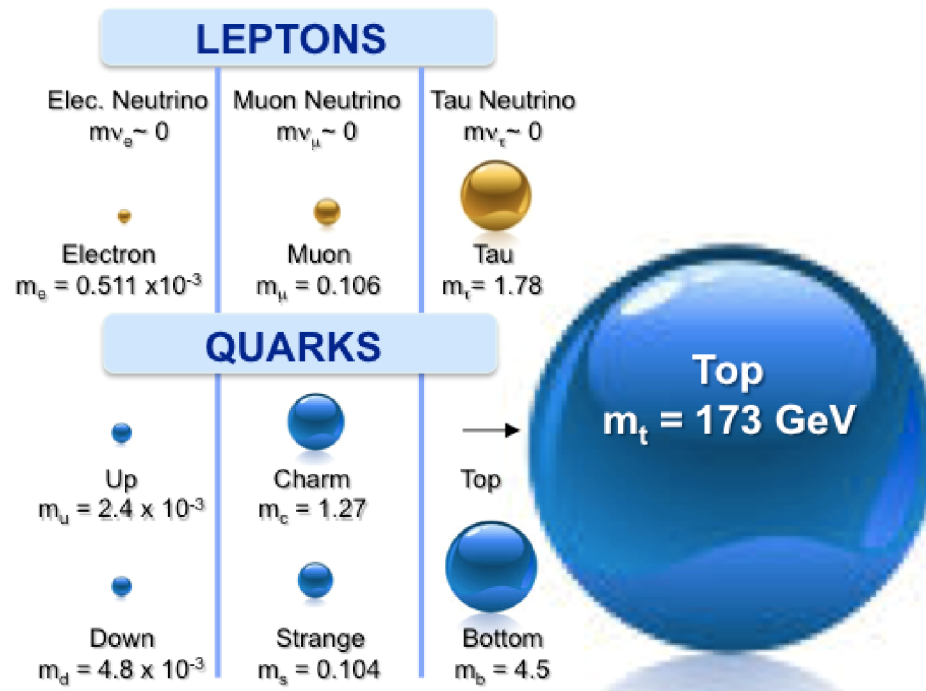
for the ATLAS, LHCb, and CMS collaborations



28th Rencontres de Blois on Particle Physics and Cosmology
29 May – 3 June 2016



Why is the top quark still interesting?



- Heaviest elementary particle known
 - top: largest Yukawa coupling to Higgs

- Several open questions:

- Is the top mass generated by the Higgs mechanism?
- Role in EW symmetry breaking?
- Role in beyond SM (BSM) physics?

- Only quark that decays before hadronizing:

$$\tau(\text{had}) \sim 1/\Lambda_{\text{QCD}} \sim 2 \times 10^{-24} \text{ s}$$

$$\tau(\text{top}) \sim 5 \times 10^{-25} \text{ s} \ll 1/\Lambda_{\text{QCD}}$$

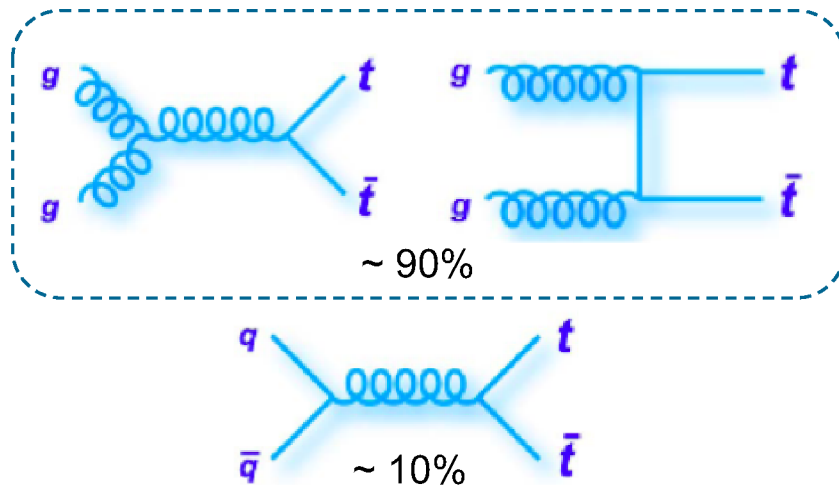
→ No bound states, spin information propagated to decay products

- Main background for Higgs and many searches for BSM physics

Precise understanding of top quark production and properties is crucial

Top quark pairs

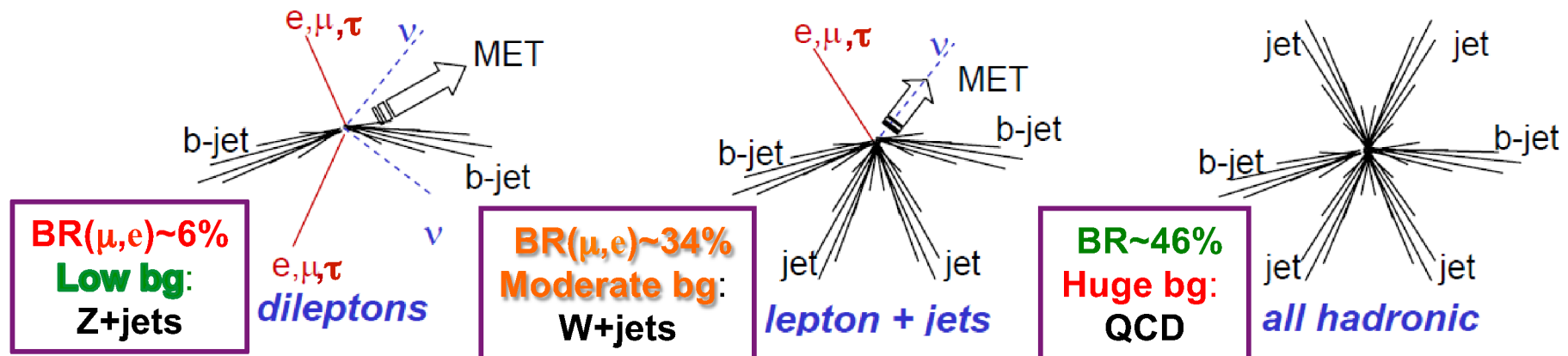
- Strong top pair ($t\bar{t}$) production: sensitive to α_s and gluon PDF



$\sigma(tt)$ (PhysRevLett. 110.252004)

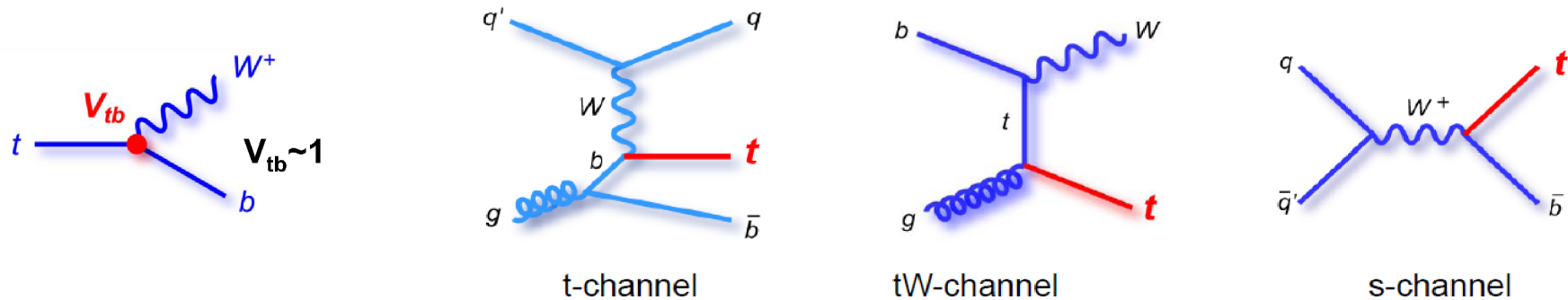
@13 TeV	832 +- 40 pb
@8 TeV	252 +- 12 pb
@7 TeV	178 +- 10 pb

- In SM, $t \rightarrow Wb$ ($\sim 100\%$) $\rightarrow$ W decay defines final states



Single top

- Electroweak single top production: tWb vertex in production, sensitive to V_{tb}



LHC pp @7 TeV⁽¹⁾⁽²⁾

LHC pp @8 TeV⁽¹⁾⁽²⁾

LHC pp @13 TeV⁽¹⁾⁽²⁾

63.9±2.7 pb

85.2±2.2 pb⁽³⁾

217.0±8.4 pb

15.7±1.2 pb

22.4±1.5 pb

71.7±3.8 pb

4.29±0.18 pb

5.24±0.21 pb

10.32±0.38 pb

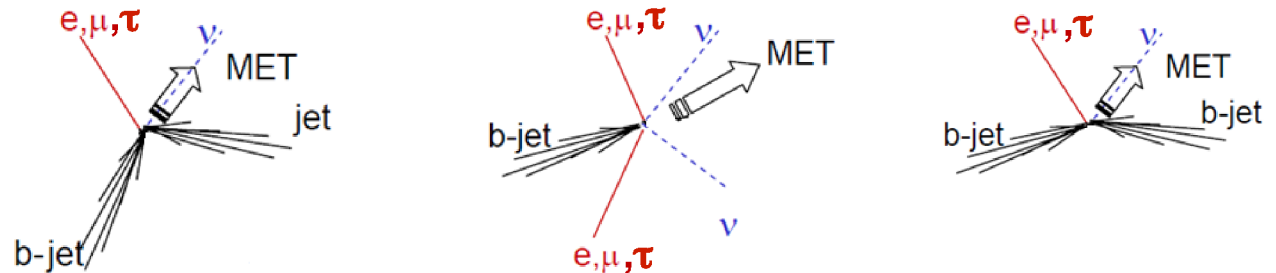
(1): LHCTopWG: calculations with HATOR, see also <https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SingleTopRefXsec>

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

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

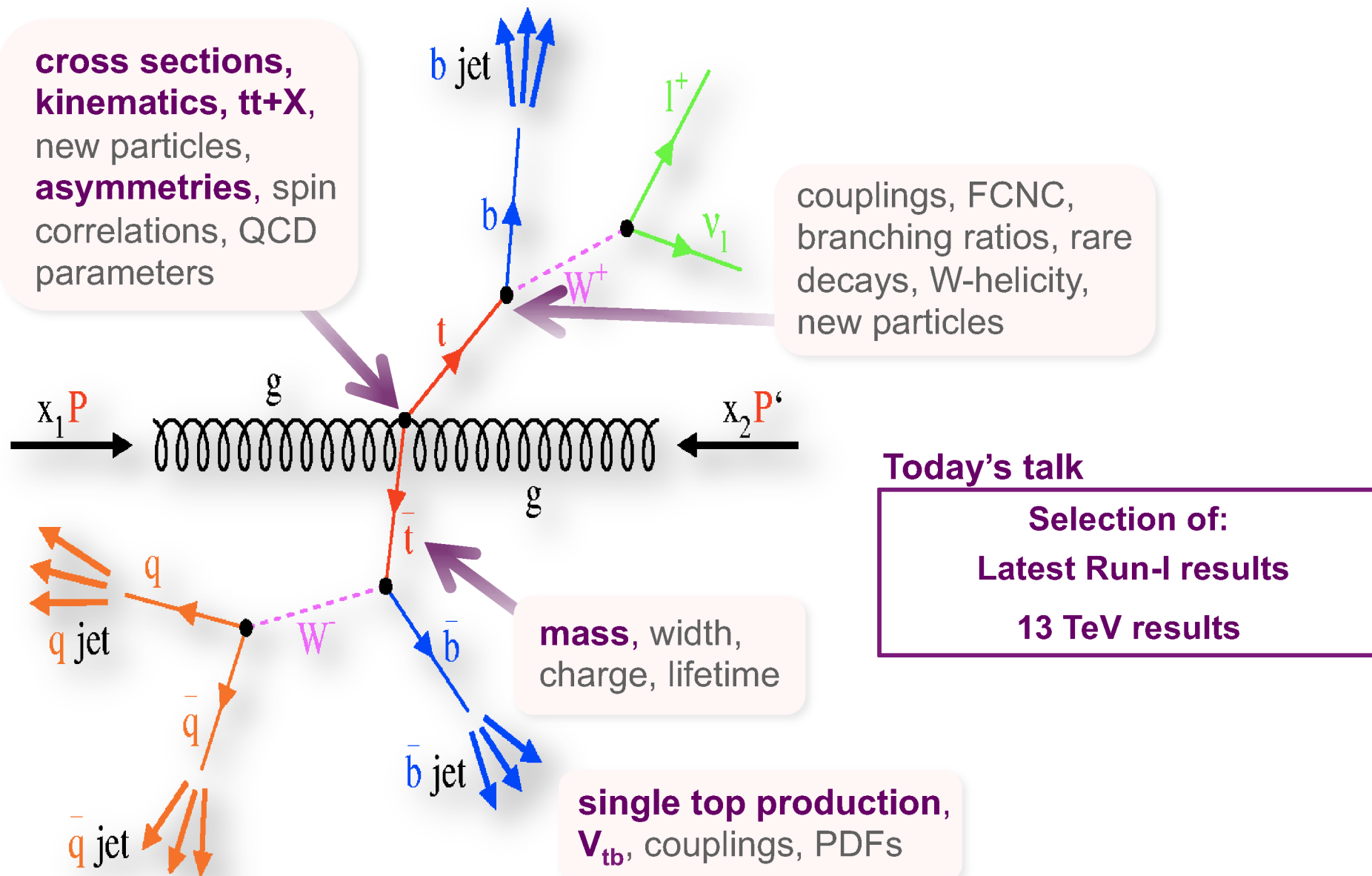
All with top mass = 172.5 GeV

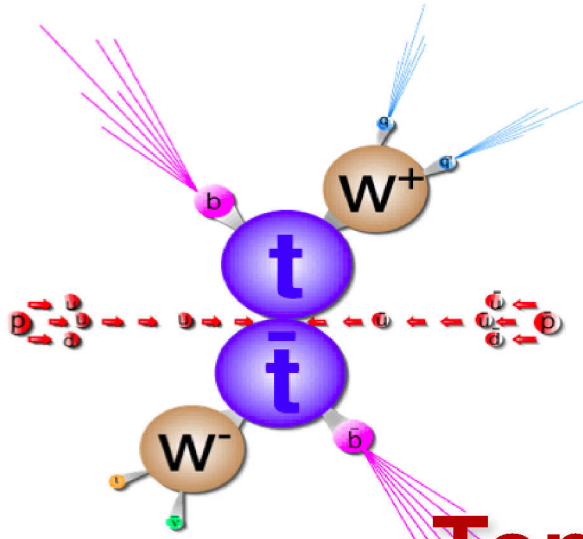
- Final states:



- Large backgrounds: W/Z +jets, $t\bar{t}$, QCD

Top quark properties in production and decay





Top quark production (differential) cross sections

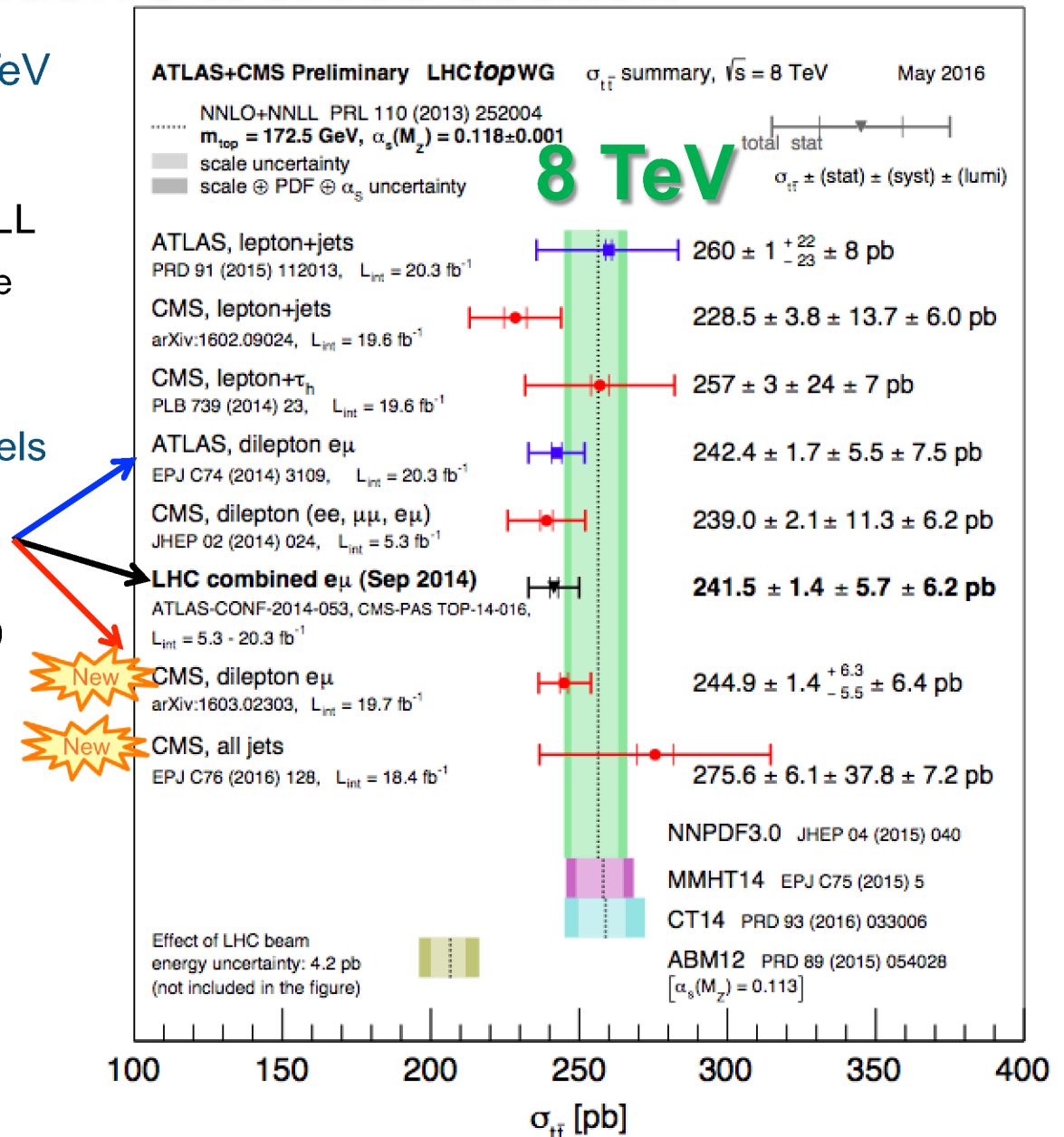
- First step in understanding top physics
- Test of theoretical calculations and search for new physics

→ More in talk by A. Sioda

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

All channels measured at 7 & 8 TeV
to look for the unexpected

- Good agreement with NNLO+NNLL
 - Some tension with ABM12 due to the different gluon density of this set
- Highest precision: dilepton channels
~4%, similar to theory prediction
 - High purity (~90%)
 - Large acceptance (loose selections)
 - Also used to set limits to stop quark production



$t\bar{t}$ cross section in $e\mu$ at 7 & 8 TeV

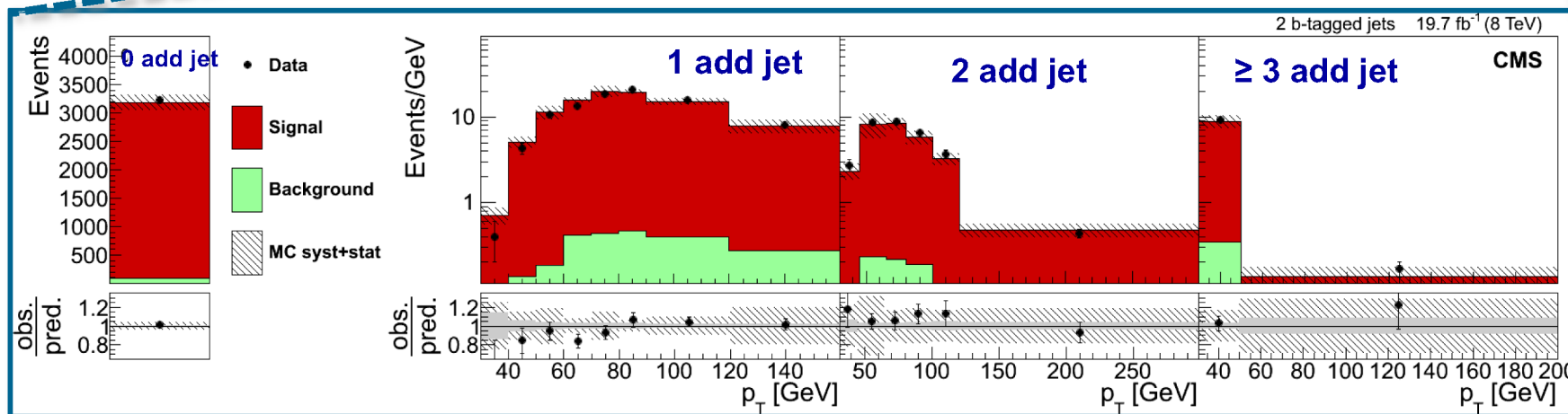
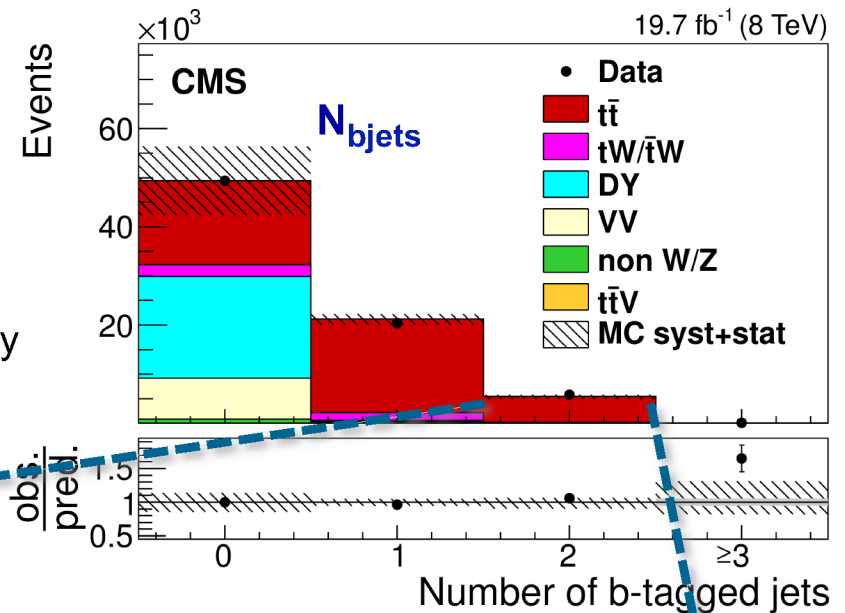
CMS, arXiv:1603.02303



Last word from Run-I in dileptons at CMS

Selection: opp.-sign isolated $e\mu$ pair, jets, b-tags

- Multiple (b-)jet distributions used in template fit with uncertainties treated as nuisance parameters
 - Signal/background discrimination, modelling sensitivity
 - Constraints on backgrounds and main systematic uncertainties (fiducial phase space)



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

(3.7%)

Main syst: luminosity, trigger, lepton selection

Top production in forward rapidities

LHCb, PRL 115 (2015) 112001

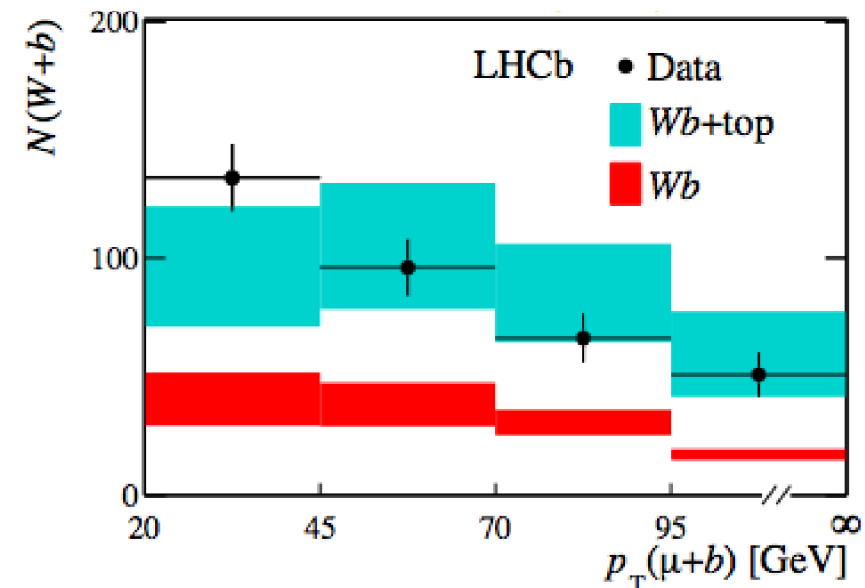
First observation of top quarks at LHCb !

- Forward region: enhanced sensitivity to BSM, can constrain gluon PDF at larger x
- Combined measurement of $t\bar{t}$ (75%) and single top (25%) in $\mu+b$ final state
 - 1 μ : $p_T > 25$ GeV, η in (2.0, 4.5)
 - ≥ 1 jet: p_T in (50, 100) GeV, η in (2.2, 4.2)
 - 1 b-tag
- Extract top content from likelihood fit to charge asymmetry $A(\mu+b)$ and event yields $N(\mu+b)$

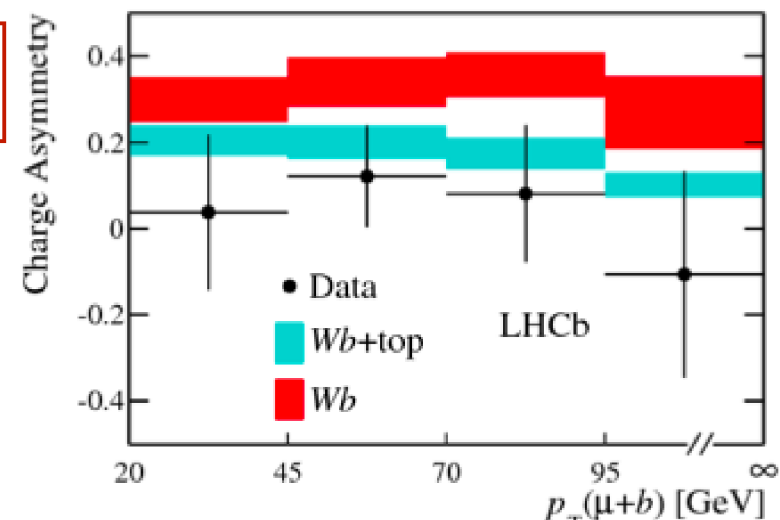
$$\begin{aligned}\sigma(\text{top})[7 \text{ TeV}] &= 239 \pm 53 (\text{stat}) \pm 33 (\text{syst}) \pm 24 (\text{theory}) \text{ fb} \\ \sigma(\text{top})[8 \text{ TeV}] &= 289 \pm 43 (\text{stat}) \pm 40 (\text{syst}) \pm 29 (\text{theory}) \text{ fb}\end{aligned}$$

- Wb-only hypothesis excluded at 5.4σ
- Consistent with SM prediction (MCFM NLO)

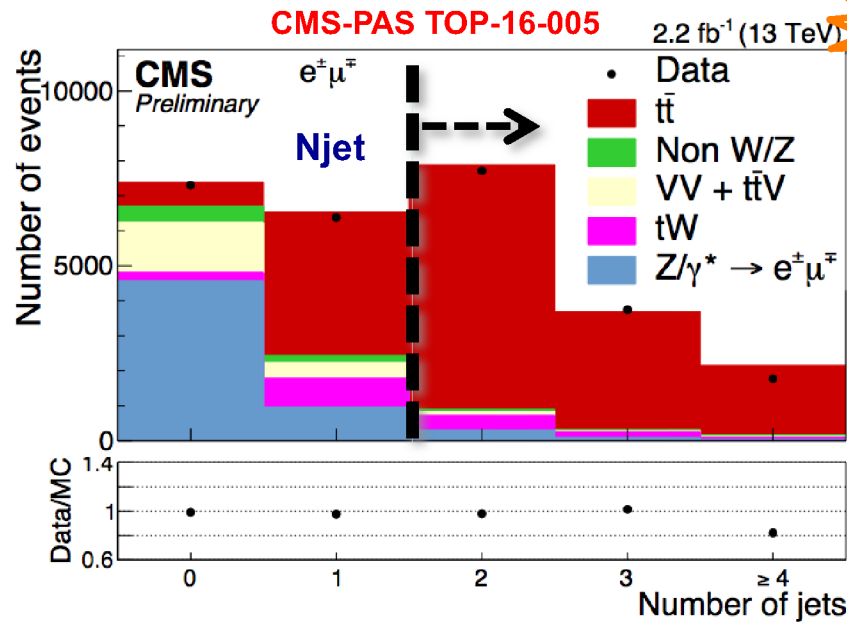
Main syst: b-tagging, theory



$$\mathcal{A}(Wq) = \frac{\sigma(W^+q) - \sigma(W^-q)}{\sigma(W^+q) + \sigma(W^-q)}$$



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



- **CMS**: focus on counting high-purity $e\mu$ events

Selection: $e\mu$ pair, ≥ 2 jets, ≥ 1 b-tag

(~6%)

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

Main syst: luminosity, trigger

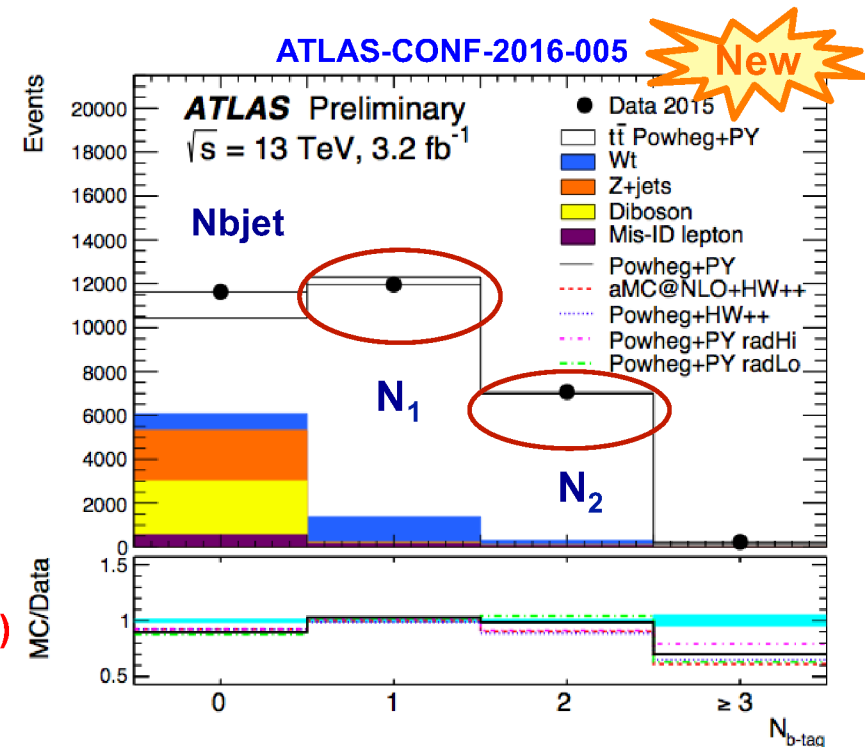
- **ATLAS**: already constraining some systematic uncertainties with data !
- Simultaneous fit to $\sigma_{t\bar{t}}$ & b-tag efficiency

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

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

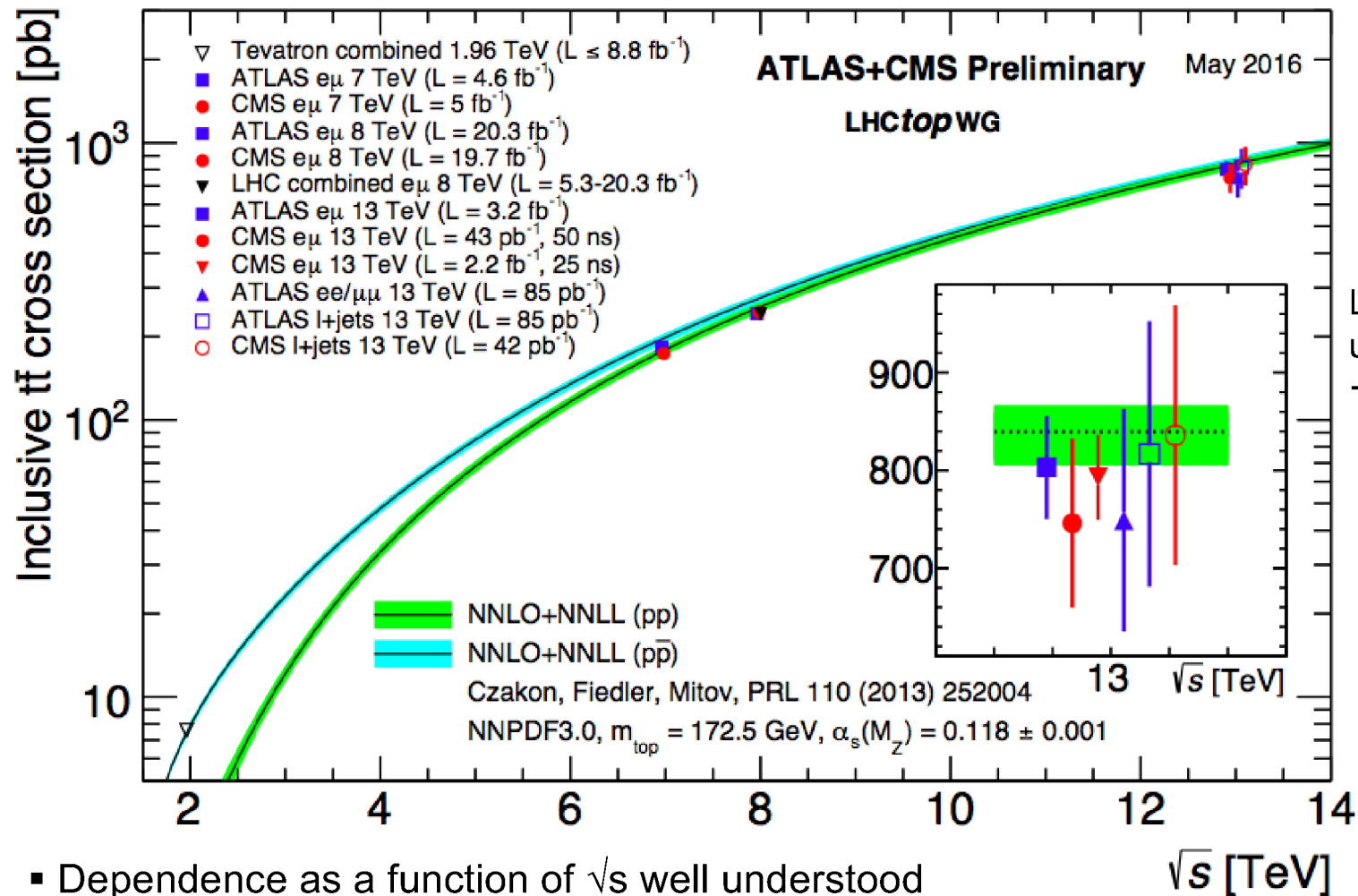
$$\sigma_{t\bar{t}} = 803 \pm 7 \text{ (stat)} \pm 27 \text{ (syst)} \pm 45 \text{ (lumi)} \text{ pb} \quad (\sim 7\%)$$

Main syst: luminosity, $t\bar{t}$ modelling



$t\bar{t}$ cross section measured at all energies

Re-established $t\bar{t}$ production at 13 TeV with very early data ($< 50 \text{ pb}^{-1}$)



Limited by systematic uncertainties
 $\rightarrow$ Starting to use data to constrain them

- Dependence as a function of $\sqrt{s}$ well understood
- ATLAS:** $t\bar{t}/Z$ ratio (13 TeV): $0.445 \pm 0.039 \rightarrow$ test gg/qq ratio, cancel some syst. (lumi)

ATLAS-CONF-2015-049

$t\bar{t}$ differential cross sections

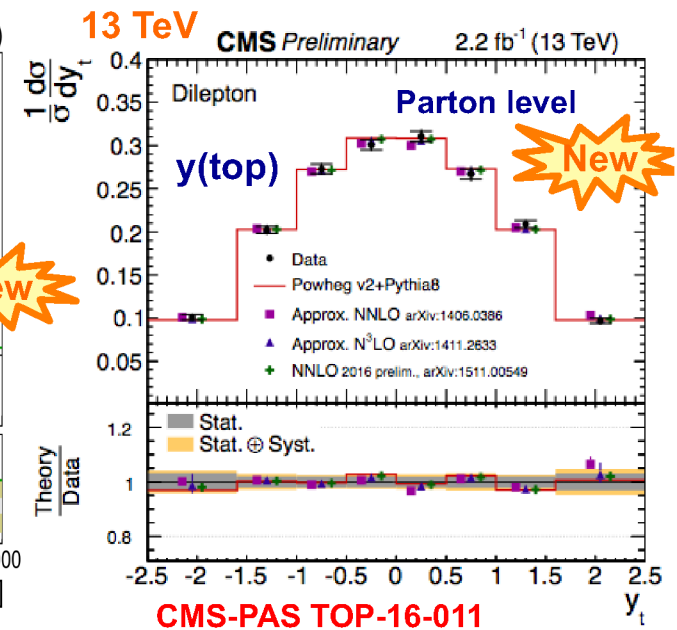
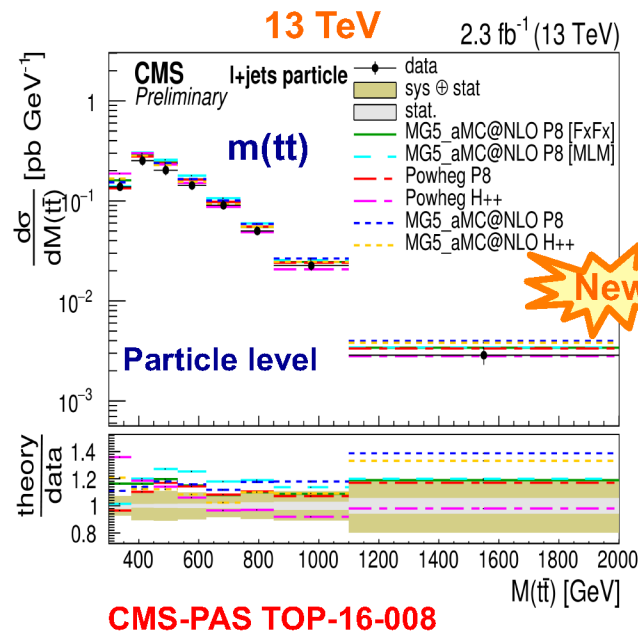
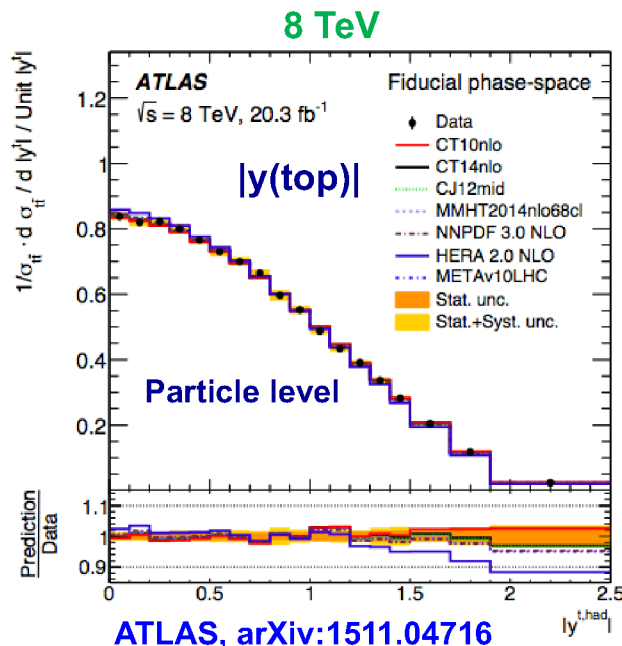
Scrutinize $t\bar{t}$ production in all channels as a function of many kinematic observables

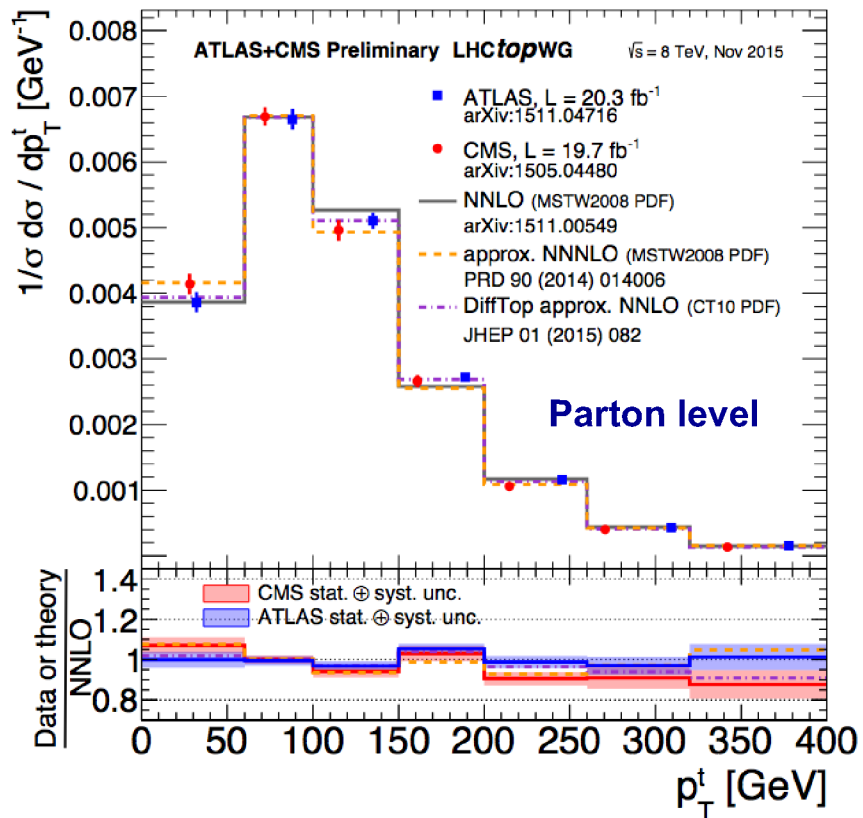
→ Precision tests of pQCD in different regions of phase space, window to BSM physics

- Use final-state products to reconstruct top quark candidates
- Correct for detector effects & acceptance → unfolding
 - to **parton level**: allows comparison with fixed-order calculations
 - to **particle level**: mimic detector-level selections and reconstruction algorithms (closer to what is measured in the detector)

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

Δ_i^X = bin width for variable X





The $p_T(\text{top})$ distribution

Run-I: p_T spectrum softer in data than in matrix element + parton shower simulations
(observed in all decay channels by CMS)

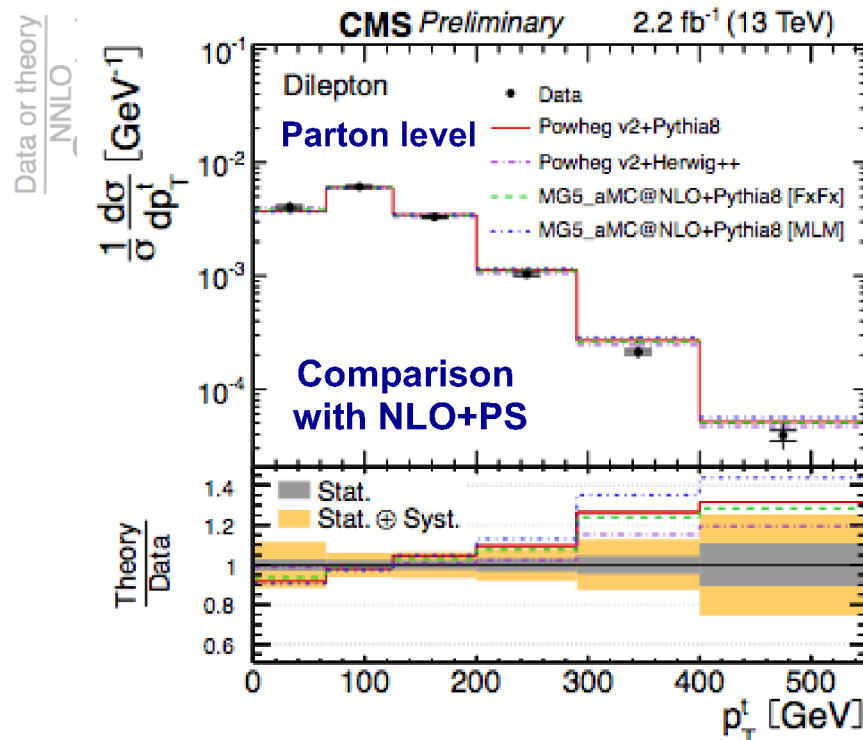
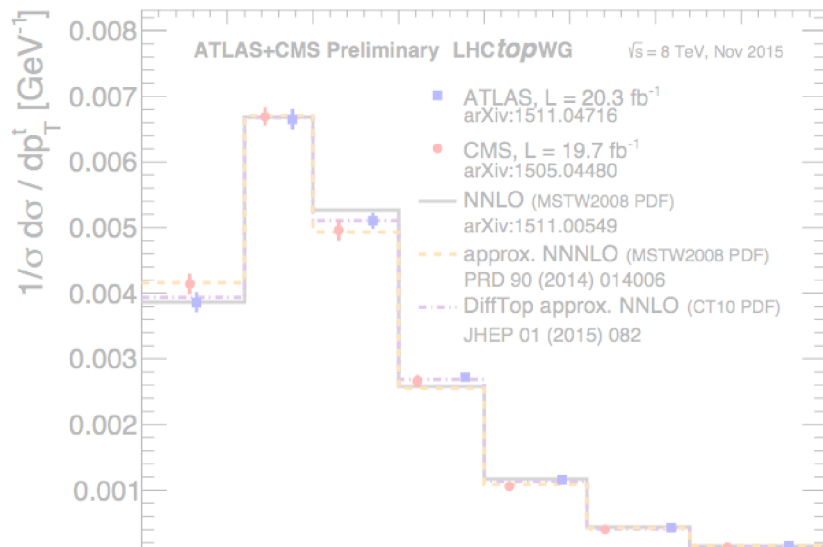
Fair agreement between **ATLAS** and **CMS** data at 8 TeV, better described by NNLO QCD calculations

The $p_T(\text{top})$ distribution

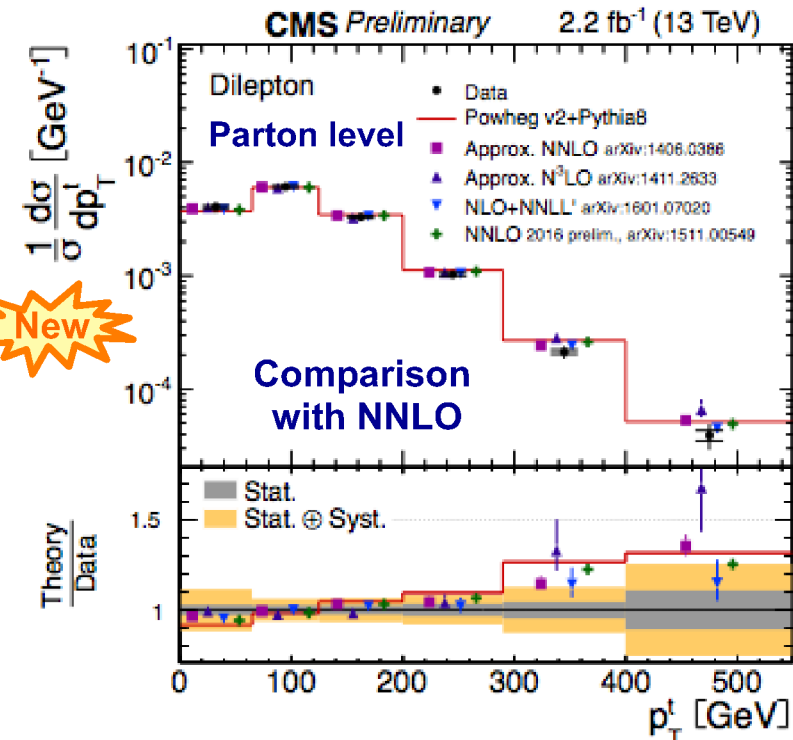
Run-I: p_T spectrum softer in data than in matrix element + parton shower simulations
(observed in all decay channels by CMS)

Fair agreement between **ATLAS** and **CMS** data at 8 TeV, better described by NNLO QCD calculations

First results at **13 TeV**



New

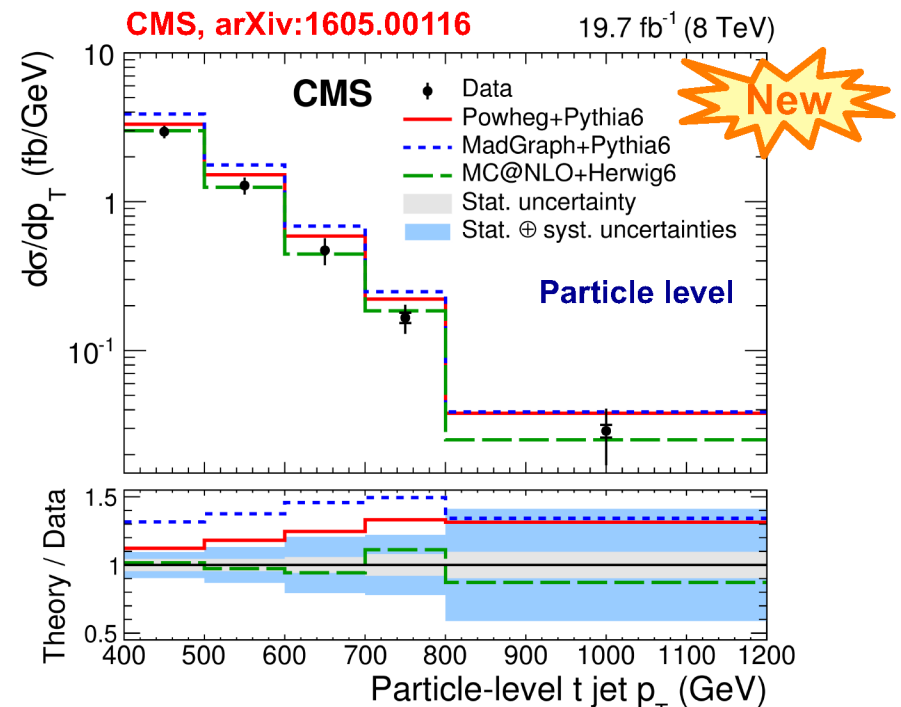
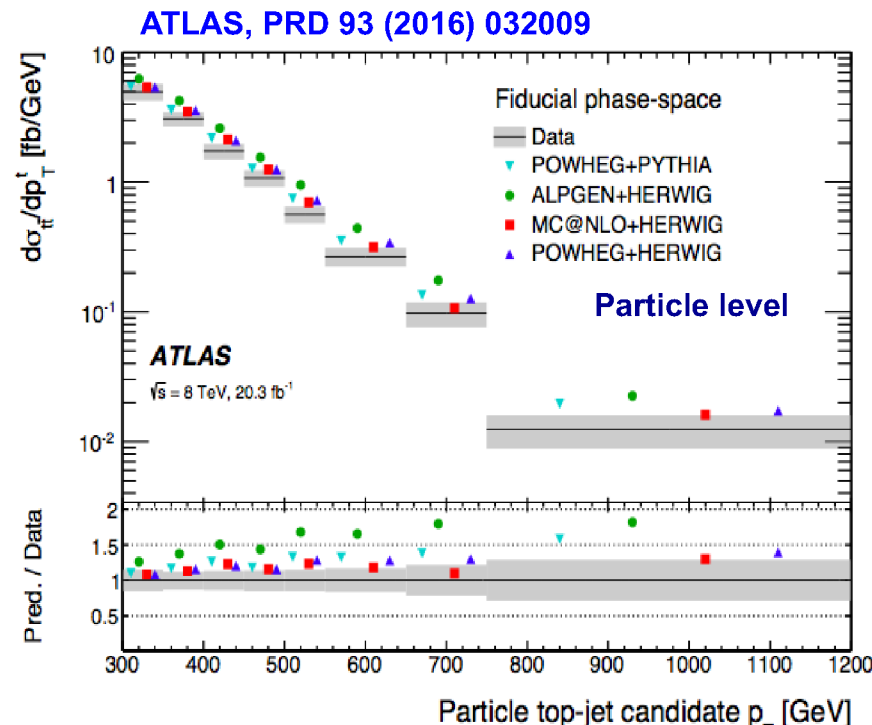
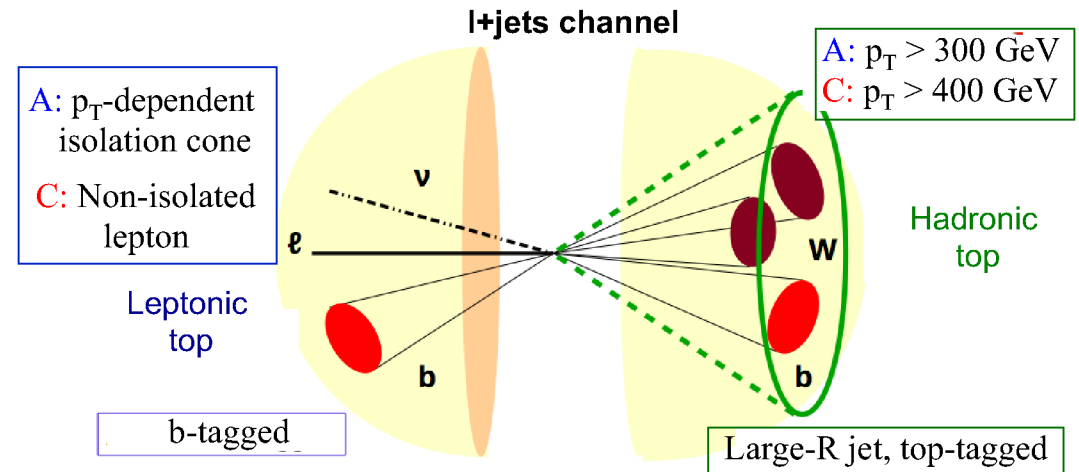


CMS-PAS TOP-16-011,
see also CMS-PAS TOP-16-008

High p_T tops: entering boosted regime in Run-I

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

- Parton and particle level
- Slightly softer p_T spectrum in data for both **ATLAS** & **CMS**

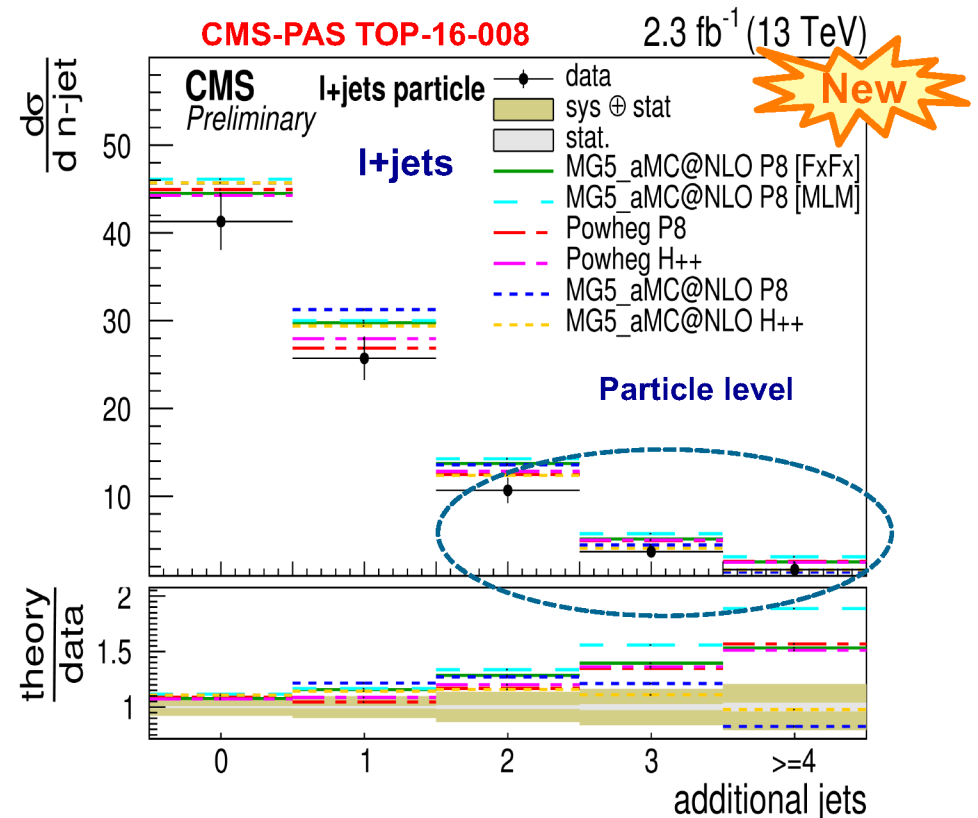
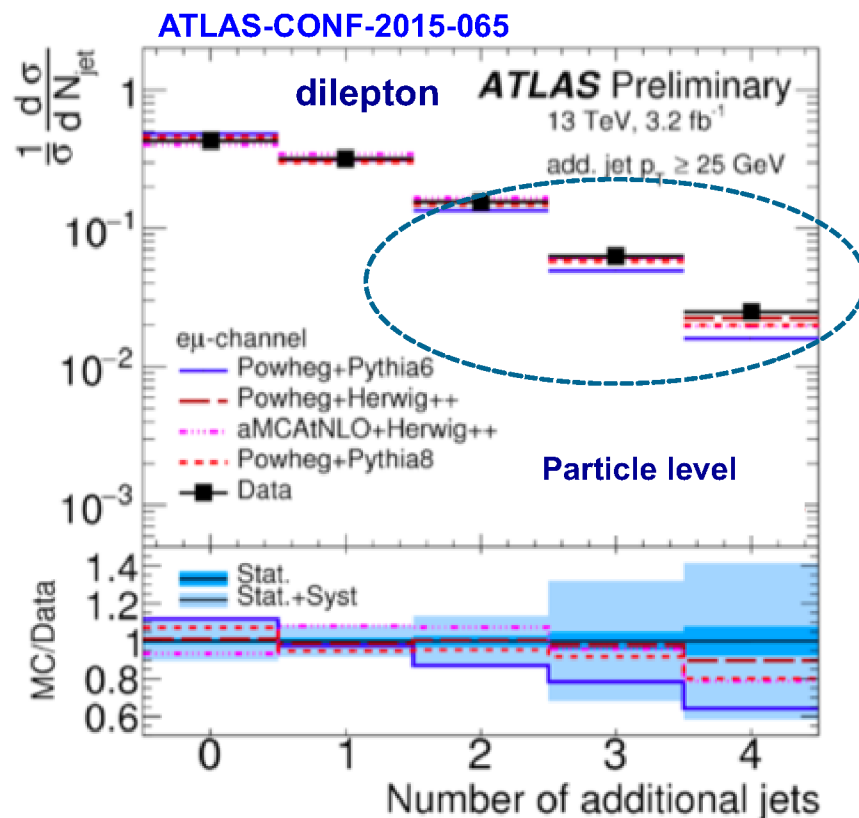


t̃t production + “friends”

Jet multiplicity at 13 TeV

Large fraction of $t\bar{t}$ events have extra hard jets from initial or final state radiation

- Sensitive to matching of matrix element to parton shower
- Reveal presence of new physics in $t\bar{t}$ +jets final states, bg for $t\bar{t}$ +H
- High jet multiplicity dominated by parton shower, further tuning needed to improve description of data (CMS)



$t\bar{t}+Z$ and $t\bar{t}+W$ at 13 TeV

ATLAS-CONF-2016-003

CMS-PAS TOP-16-009

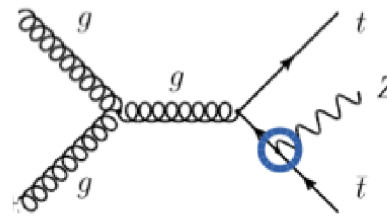
Very rare processes in SM

- Measure couplings to bosons, important background for BSM and $t\bar{t}+H$
- Established at 8 TeV (also $t\bar{t}+\gamma$), first results at 13 TeV !
- $t\bar{t}+Z$ (ATLAS & CMS):
3-4 leptons, > 2 jets in different (b) jet categories

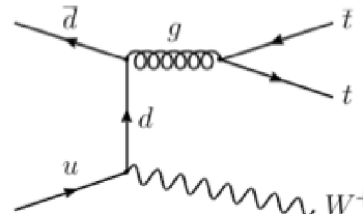
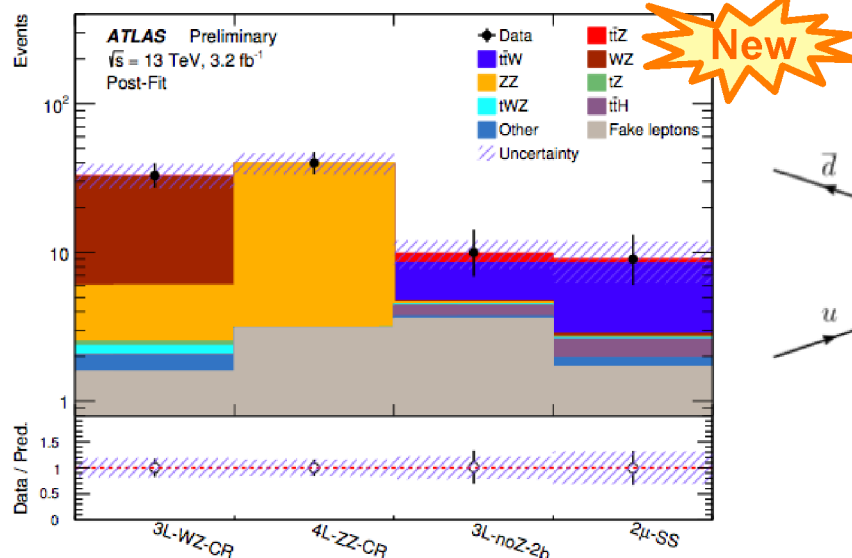
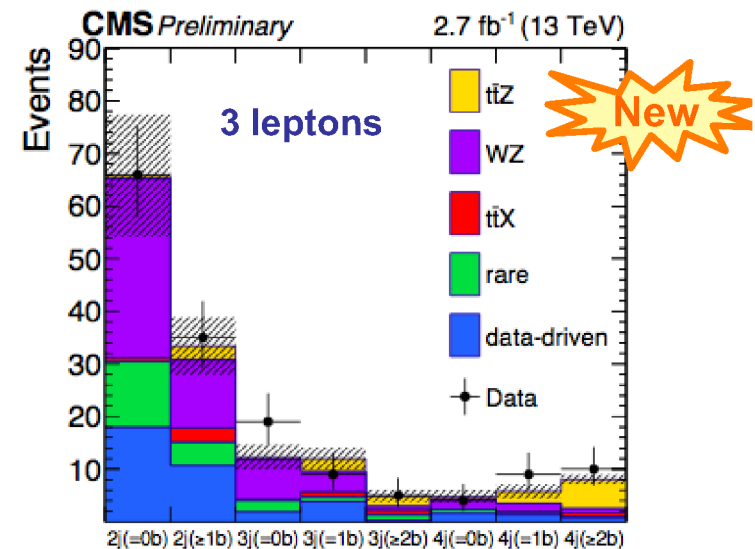
- Extract $t\bar{t}+Z$ from likelihood fit

ATLAS: $\sigma(t\bar{t}+Z) = 0.9 \pm 0.3$ pb

CMS: $\sigma(t\bar{t}+Z) = 1.1 \pm 0.4$ pb



Theory (aMC@NLO)
 $= 0.76 \pm 0.08$ pb



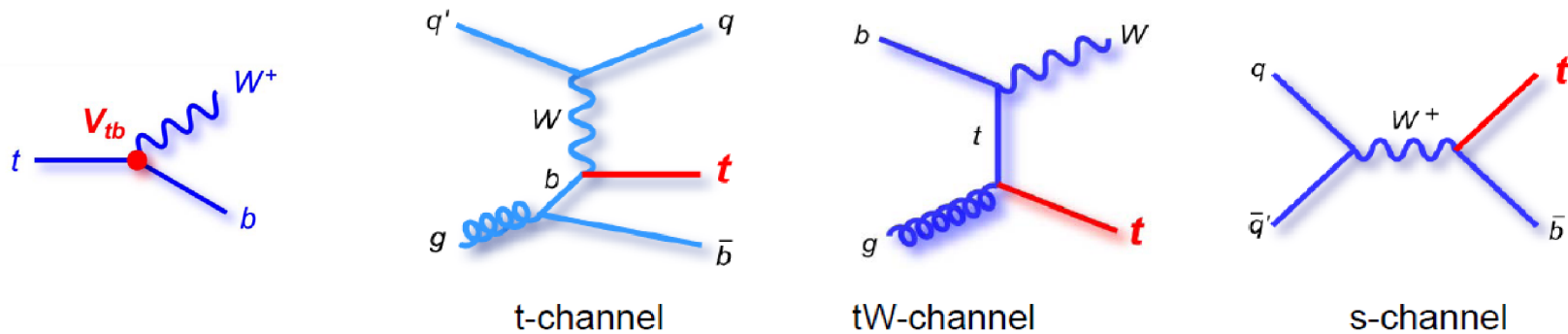
- $t\bar{t}+W$ (ATLAS):

2-3 leptons (one same-sign pair) and
> 2 jets in different categories

- Extract $t\bar{t}+W$ from likelihood fit

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

Theory (aMC@NLO) = 0.57 ± 0.06 pb

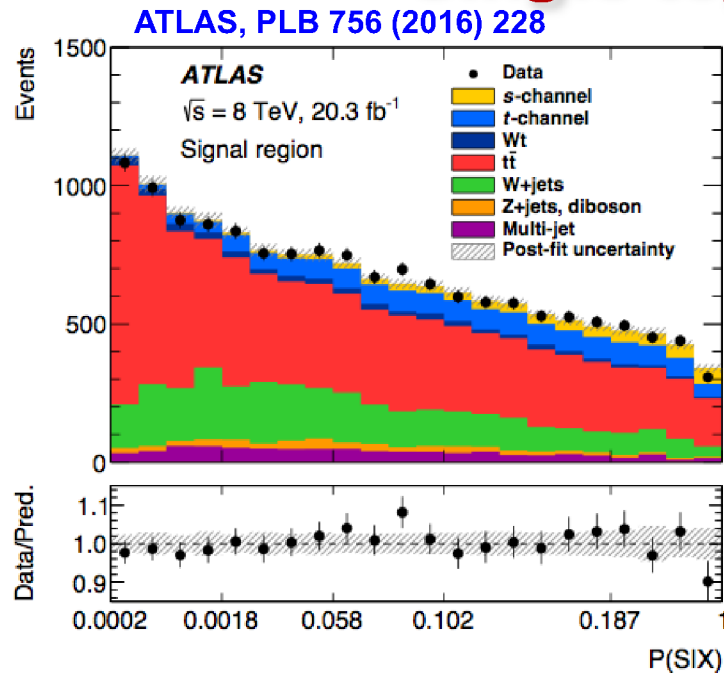


Single top quark

- Probe CKM matrix element V_{tb} , EWK coupling structure
- Probe alternative production mechanisms (e.g heavy bosons, FCNC)
- Sensitive to b-PDF and u/d-PDFs
- Need multivariate techniques using full event properties to maximize sensitivity

→ More in talk by J. Andrea

Single top s-channel at 8 TeV



- **ATLAS:** First evidence of s-channel at LHC !

Selection: 1 lepton and 2 b-tagged jets

- Use matrix element approach to discriminate signal
- Profile likelihood fit including systematics

$$\sigma_s = 4.8 \pm 0.8(\text{stat.})_{-1.3}^{+1.6}(\text{syst.}) \text{ pb} \quad (34\%)$$

3.2 σ obs (3.9 σ exp)

- **CMS:** s-channel at 7+8 TeV

Selection: 1 lepton, 2-3 jets, 1-2 b-tags

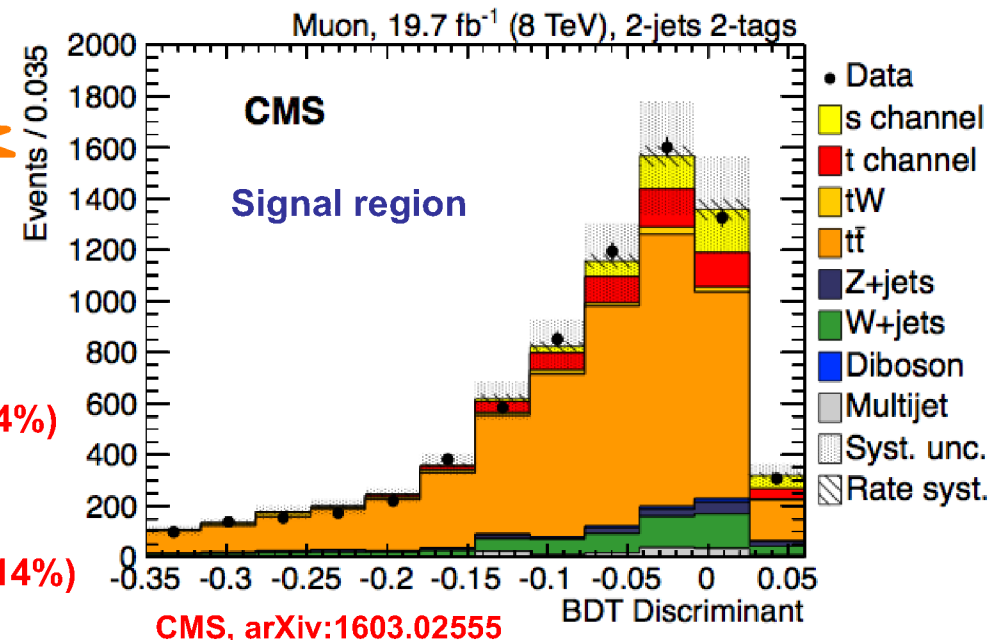
- Use MVA approach to discriminate signal
- No profiling of systematics

8 TeV: $\sigma_s = 13.4 \pm 7.3(\text{stat} + \text{syst}) \text{ pb} \quad (54\%)$

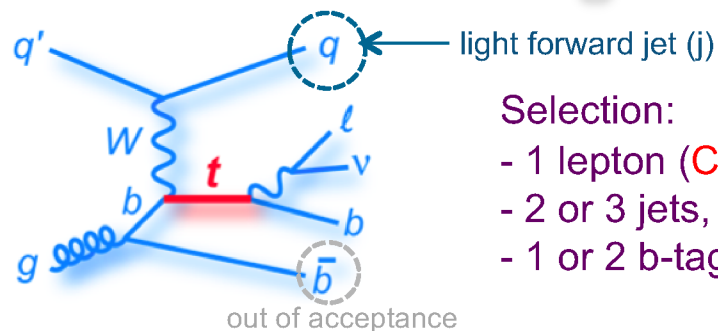
2.3 σ obs (0.8 σ exp)

7 TeV: $\sigma_s = 7.1 \pm 8.1(\text{stat} + \text{syst}) \text{ pb} \quad (114\%)$

0.9 σ obs (0.5 σ exp)



Single top t-channel at 13 TeV



- Control regions for main backgrounds
- Extract signal from fit to MVA discriminator optimized to maximize background rejection
 - Most relevant variables: $\eta(j)$, m_t , m_{lvb} , m_{jb} , $m_T(W)$

- Cross sections:

ATLAS: $\sigma(t\bar{t}) = 229 \pm 48 \text{ pb}$ (21%)

CMS: $\sigma(t\bar{t}) = 228 \pm 33 \text{ pb}$ (15%)

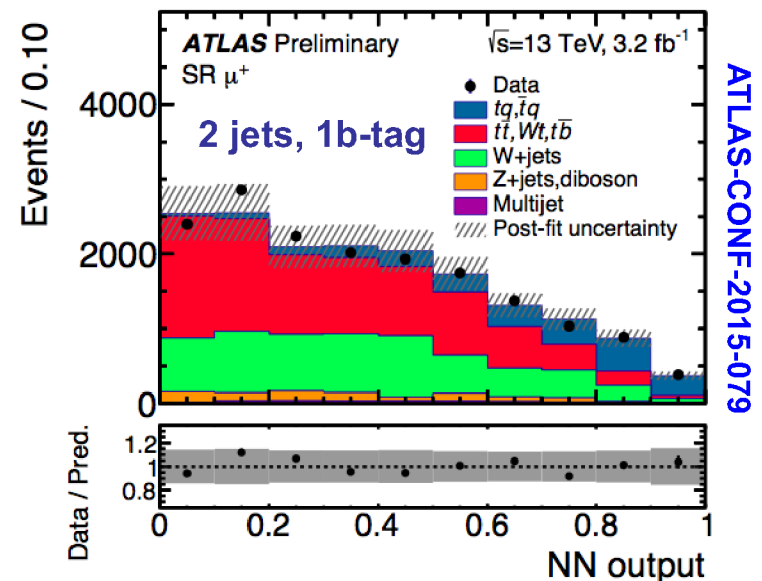
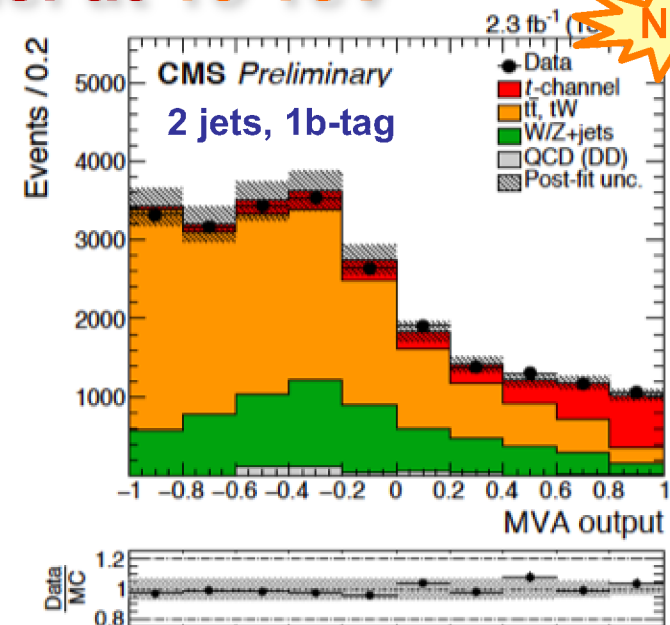
Main syst for both:
signal model, JES

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

ATLAS: $|V_{tb}| = 1.03 \pm 0.11$

CMS: $|V_{tb}| = 1.02 \pm 0.07$

(for $|V_{ts}|, |V_{td}| \ll |V_{tb}|$)



t-channel differential at 13 TeV

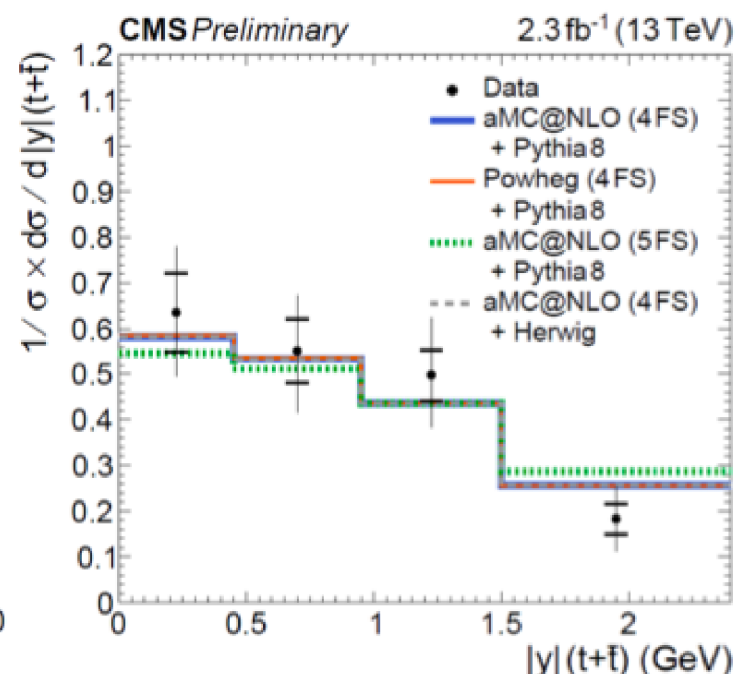
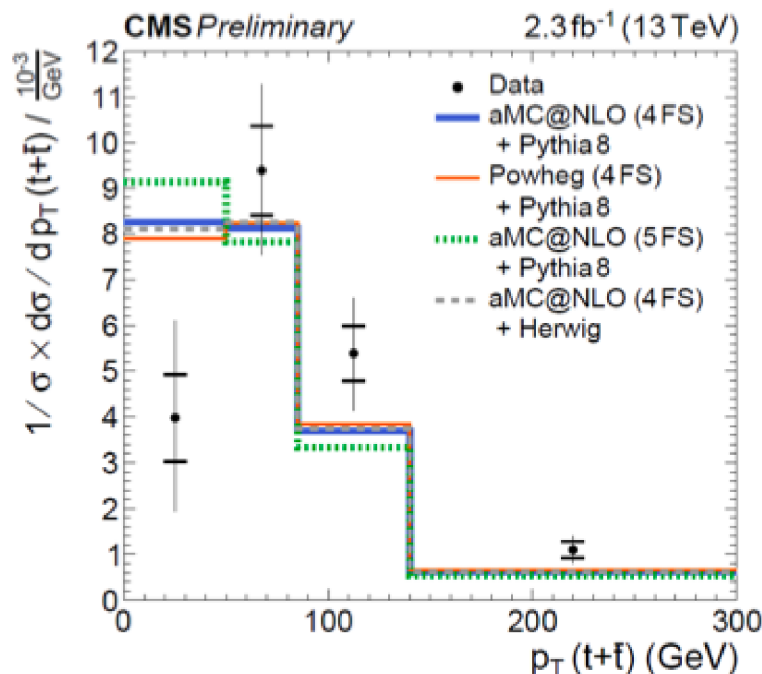
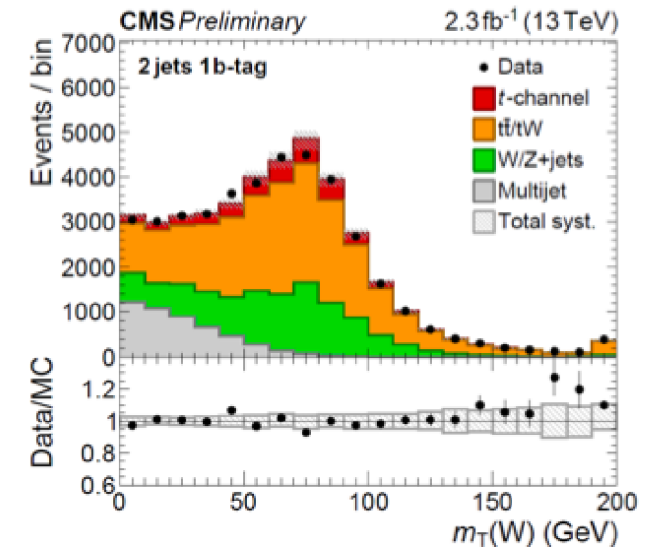
CMS-PAS TOP-16-004



First single top differential cross sections at 13 TeV !

1 isolated μ/e , 1 b-tag jet, 1 forward light jet, E_T^{miss}

- Maximum likelihood fit to $m_T(W)$ and BDT discriminant
 - BDT discriminant with variables like $\eta(\text{jet})$ or $m_T(W)$
- Data described by predictions within large uncertainties



Single top production: the big picture

All single top processes studied in Run-I

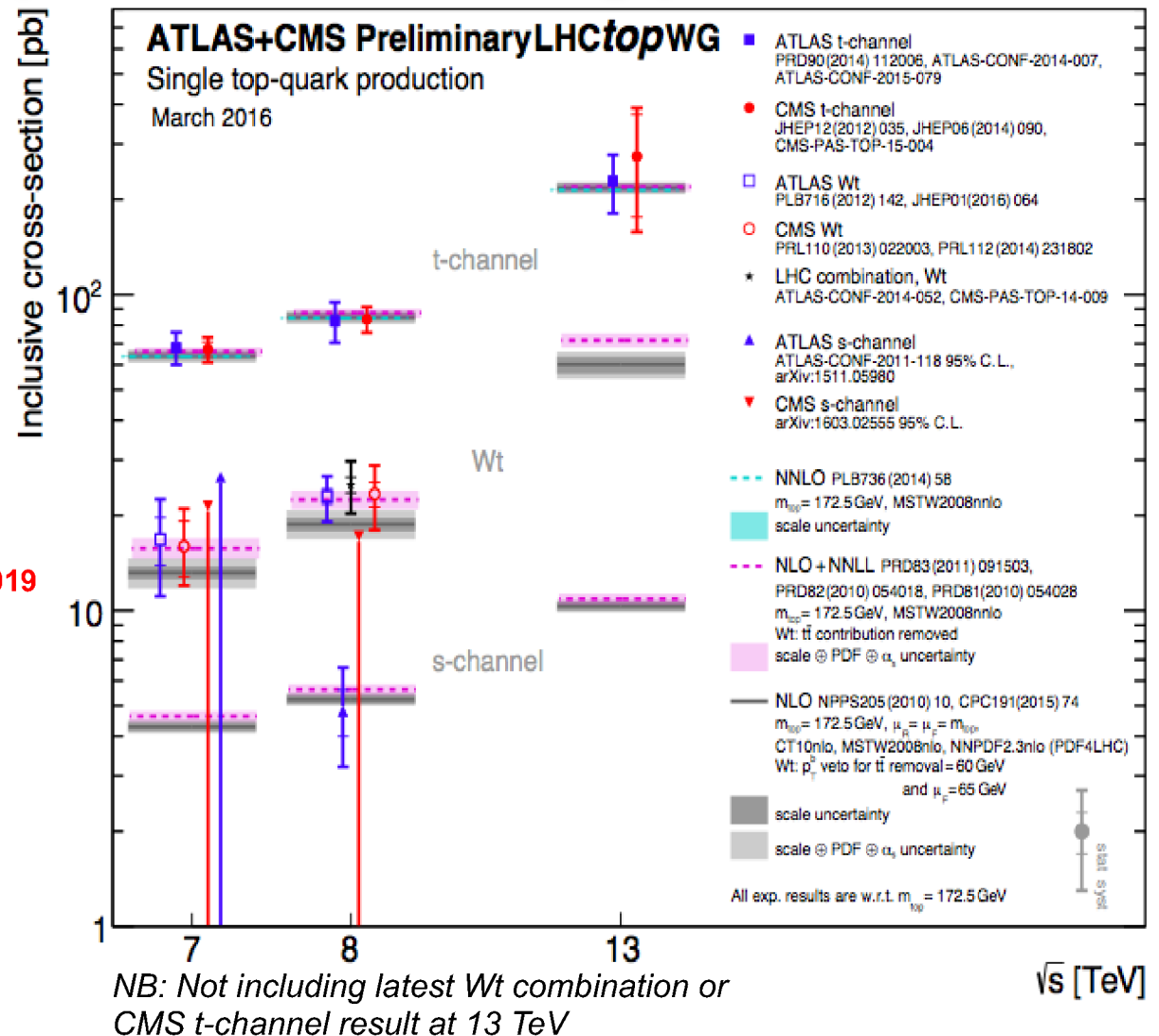
- Final **ATLAS** & **CMS**  combination of Wt at 8 TeV:

$$\sigma(Wt) = 23.1 \pm 1.1 \text{ (stat)} \pm 3.3 \text{ (syst)} \pm 0.8 \text{ (lumi)} \text{ pb}$$

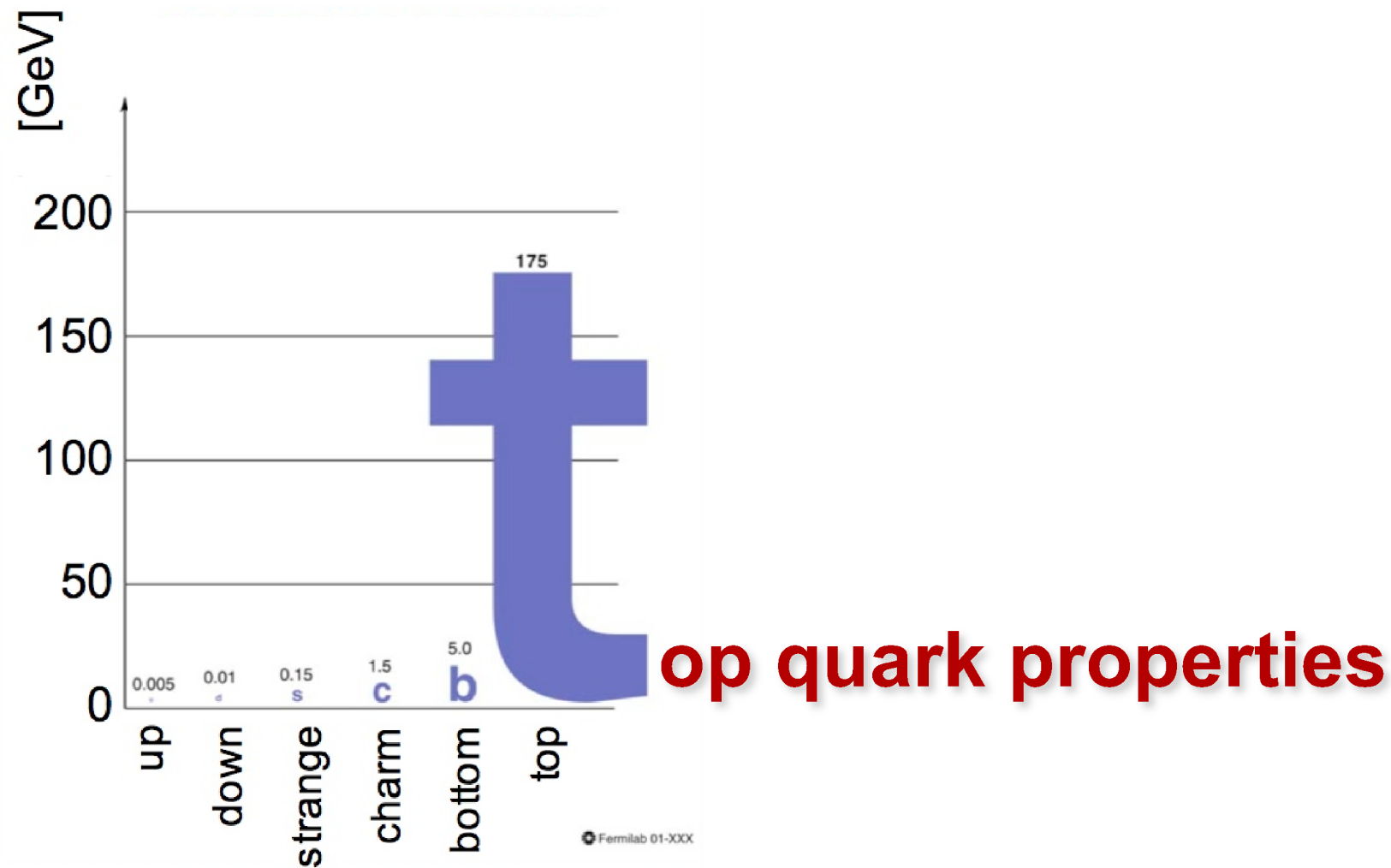
(15.6%)

ATLAS-CONF-2016-023 / **CMS-PAS TOP-15-019**

- First t-channel results at 13 TeV by ATLAS and CMS

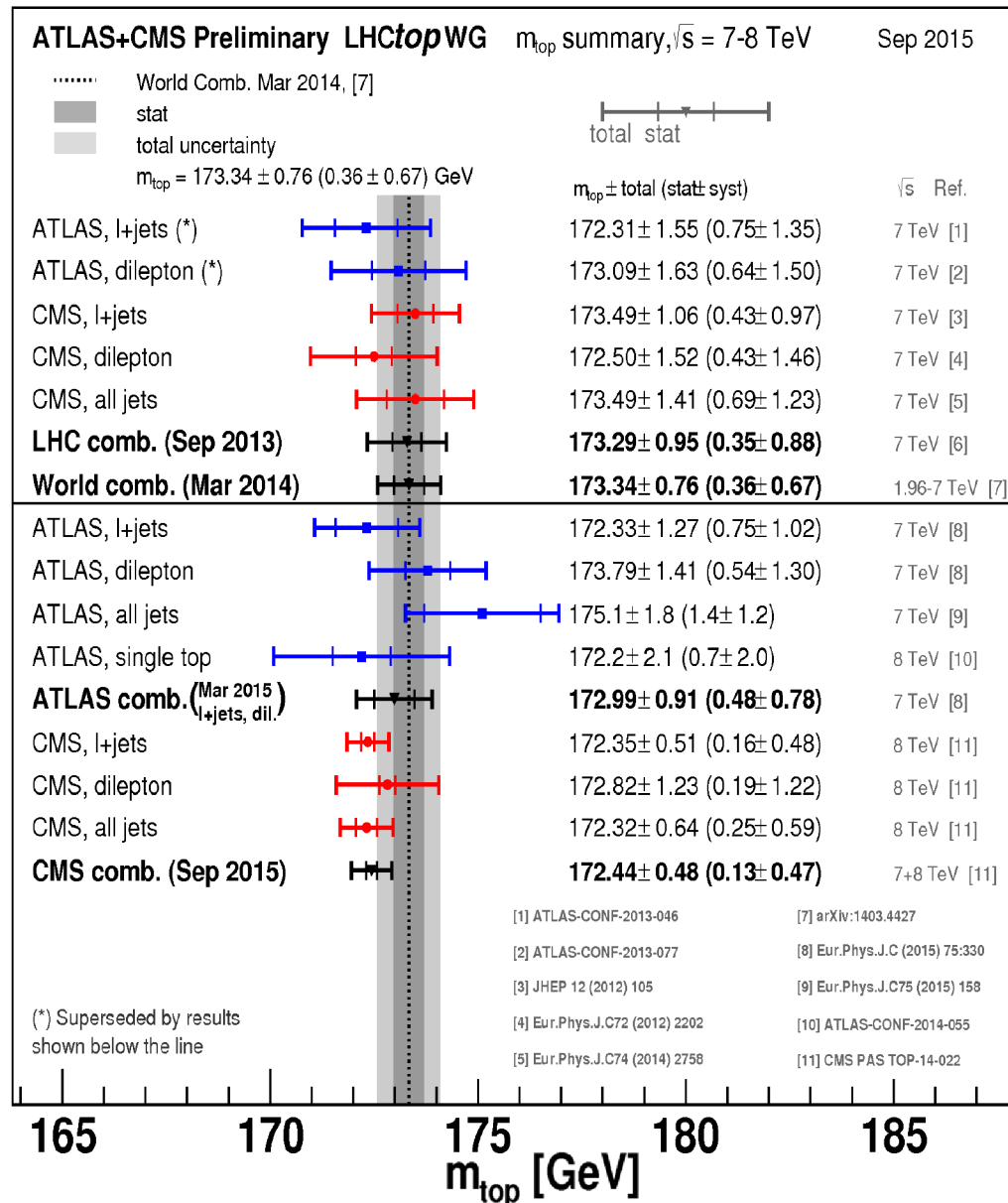


Ramping up towards new era of high-precision in single top



→ More in talks by J. Piedra, I. Brodsky

Top quark mass: overview



Fundamental parameter in SM, not an observable $\rightarrow$ scheme-dependent

- Pole mass, running mass, different from mass defined in MC

Top mass ($m_{\text{top}}(\text{MC})$) results using standard (i.e, most sensitive) methods are reaching a precision of **order 500 MeV** ($< 0.3\%$)

▪ Dominant uncertainties:

- Jet energy response calibration
- Hadronization modelling

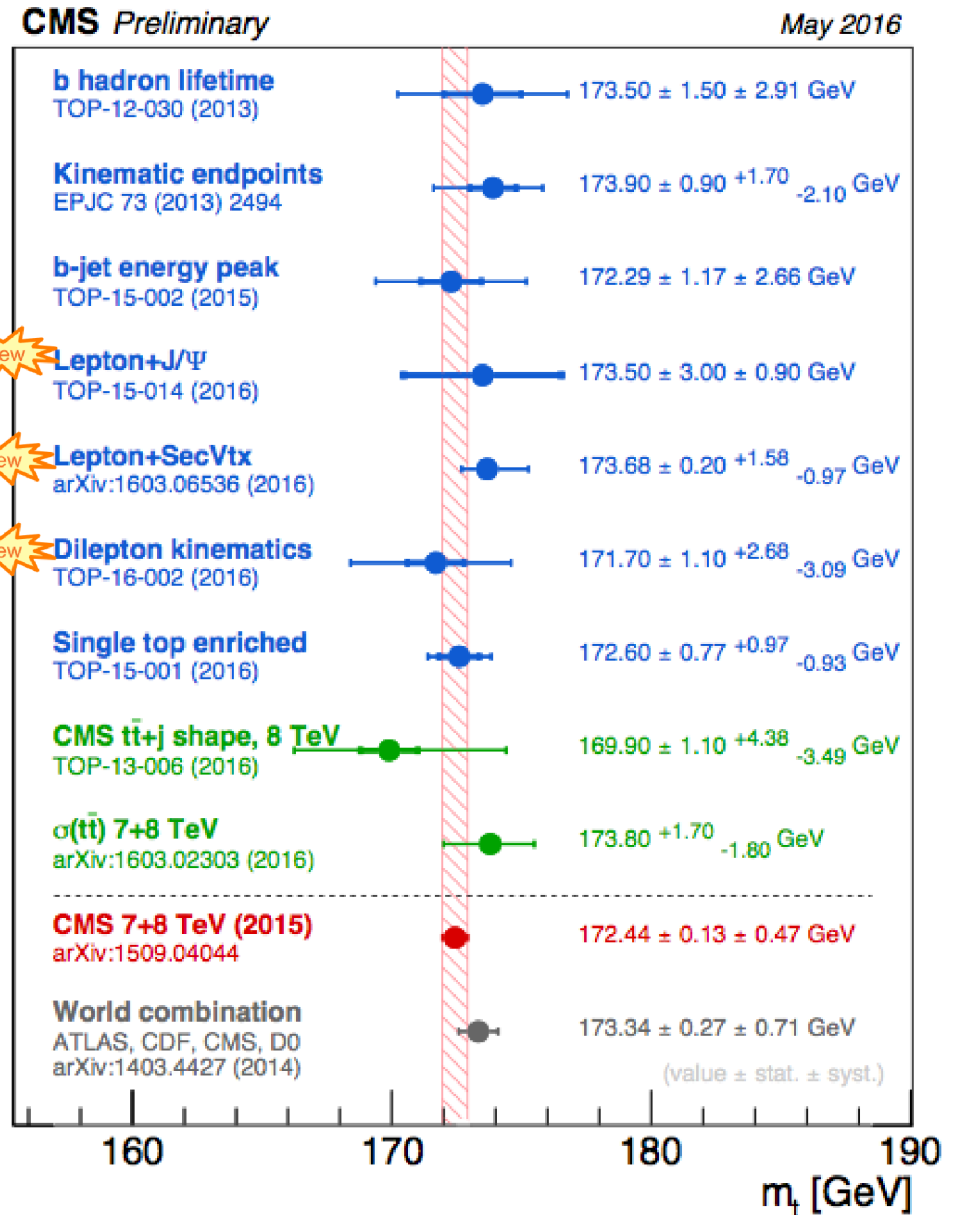
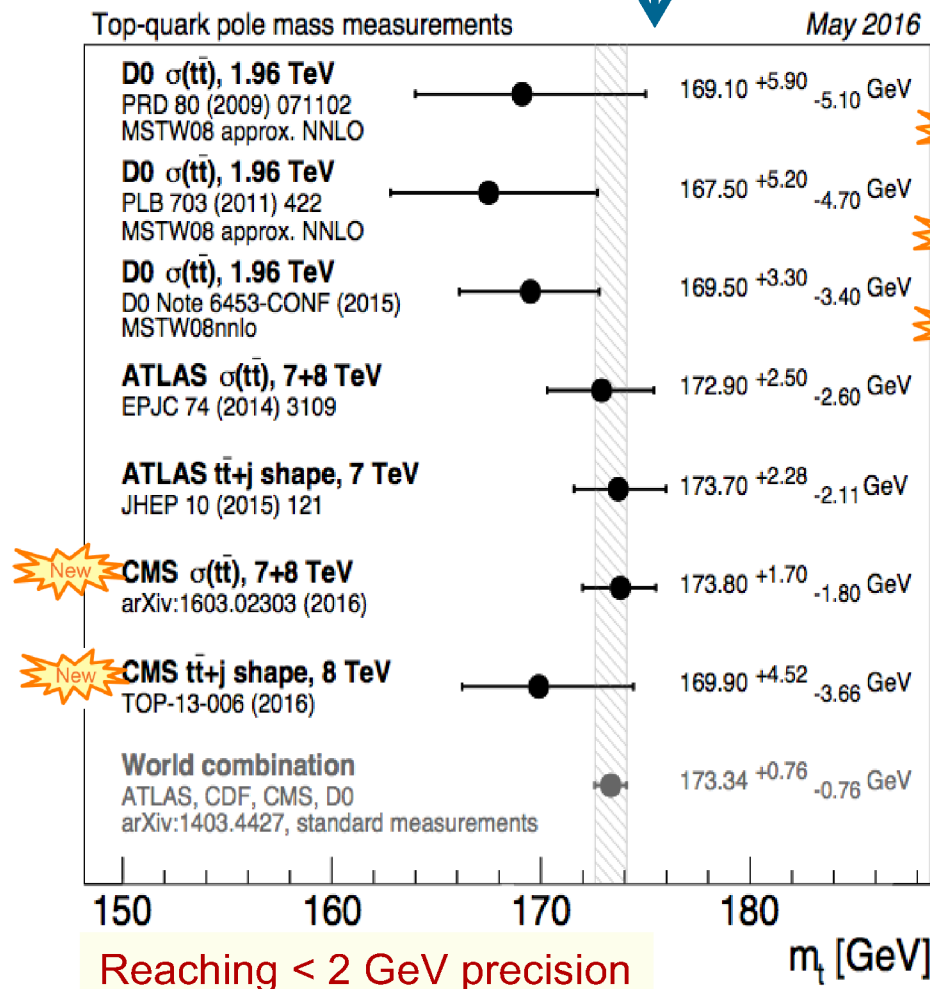
▪ Continuous efforts to:

- Improve current techniques
- Develop new methods
- Combine results

$\rightarrow$ More in talk by J. Piedra

Pole mass and other alternative methods

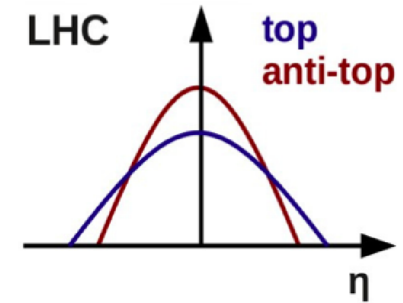
- Exploit other (“cleaner”) observables
- Extract pole mass from cross sections



$t\bar{t}$ charge asymmetry

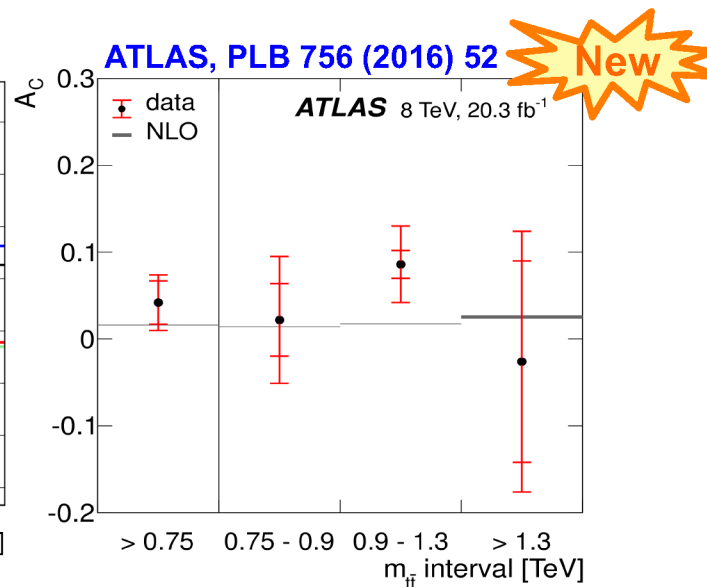
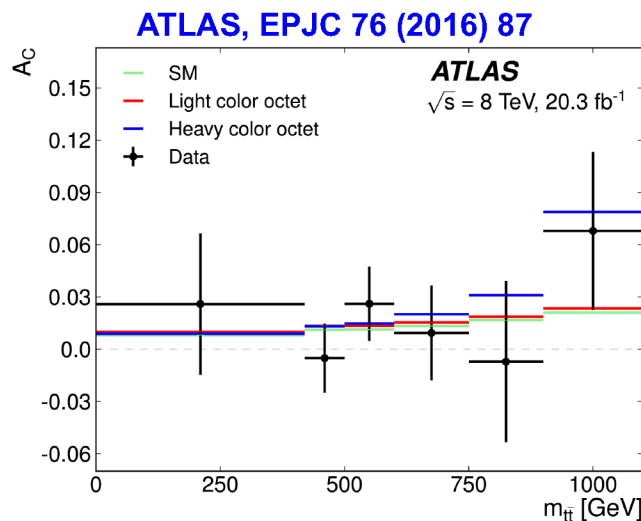
Top-pair angular production asymmetries may indicate BSM top production interfering with SM

- NLO effect originating from interference of $q\bar{q} \rightarrow t\bar{t}$ diagrams, can be enhanced by BSM physics (e.g, W' , axigluon)
- LHC: top is more forward than antitop
- Several channels exploited in Run-I, also boosted top regime
- Investigate regions of phase space where charge asymmetry can be enhanced (differentially in, e.g, $m(t\bar{t})$, $p_T(t\bar{t})$, $|y(t\bar{t})|$, $\beta_z(t\bar{t})$)



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

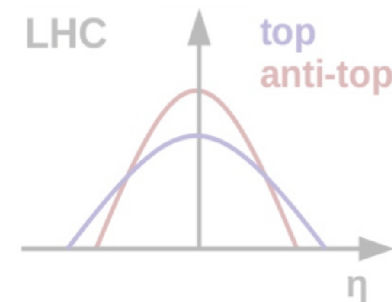
$$\Delta|y| = |y_{\text{top}}| - |y_{\text{antitop}}|$$



$t\bar{t}$ charge asymmetry

Top-pair angular production asymmetries may indicate BSM top production interfering with SM

- NLO effect originating from interference of $q\bar{q} \rightarrow t\bar{t}$ diagrams, can be enhanced by BSM physics (e.g, W' , axigluon)
- LHC: top is more forward than antitop
- Several channels exploited in Run-I, also boosted top regime
- Investigate regions of phase space where charge asymmetry can be enhanced (differentially in, e.g, $m(t\bar{t})$, $p_T(t\bar{t})$, $|y(t\bar{t})|$, $\beta_z(t\bar{t})$)

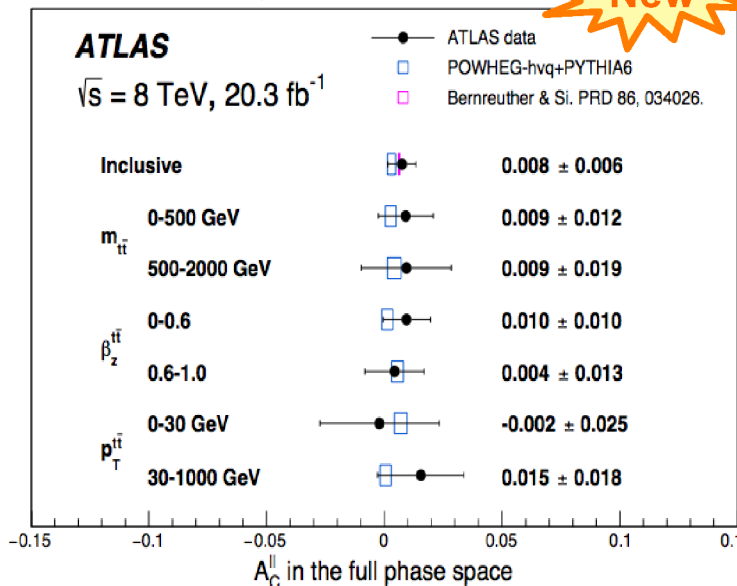


$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

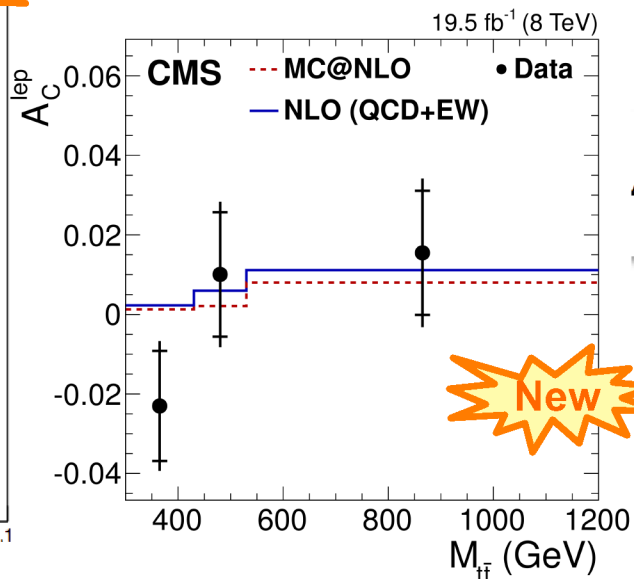
$$\Delta|y| = |y_{\text{top}}| - |y_{\text{antitop}}|$$

ATLAS, arXiv:1604.05538

New



CMS, arXiv:1603.06221



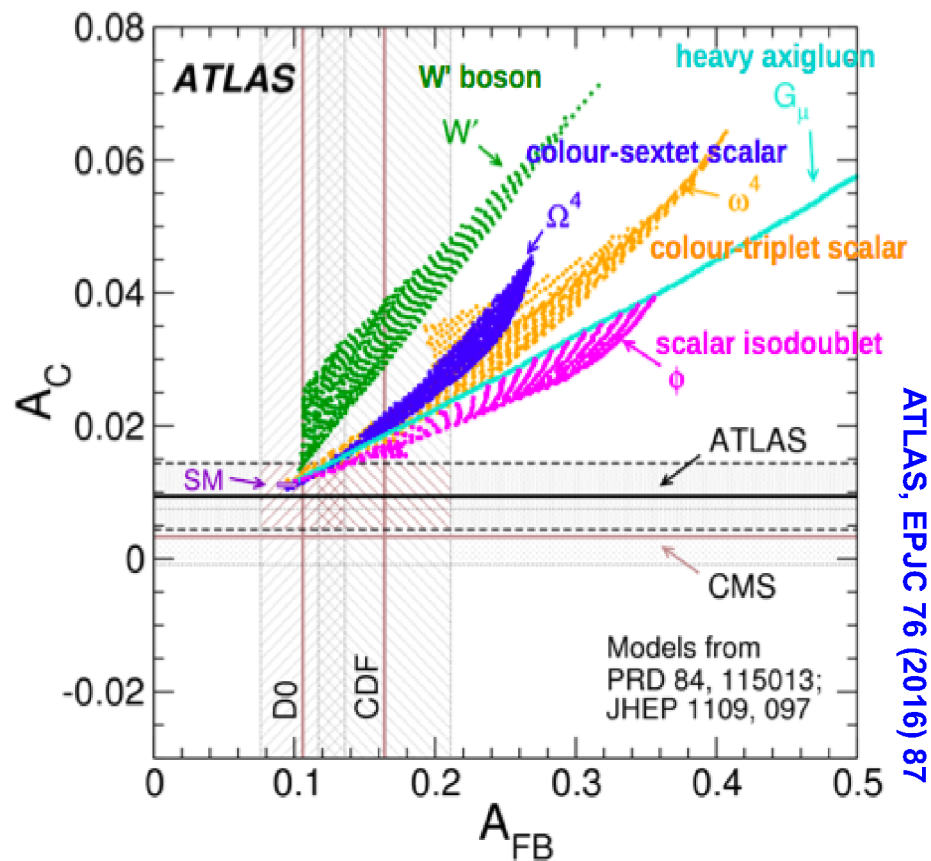
Also: lepton asymmetry

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

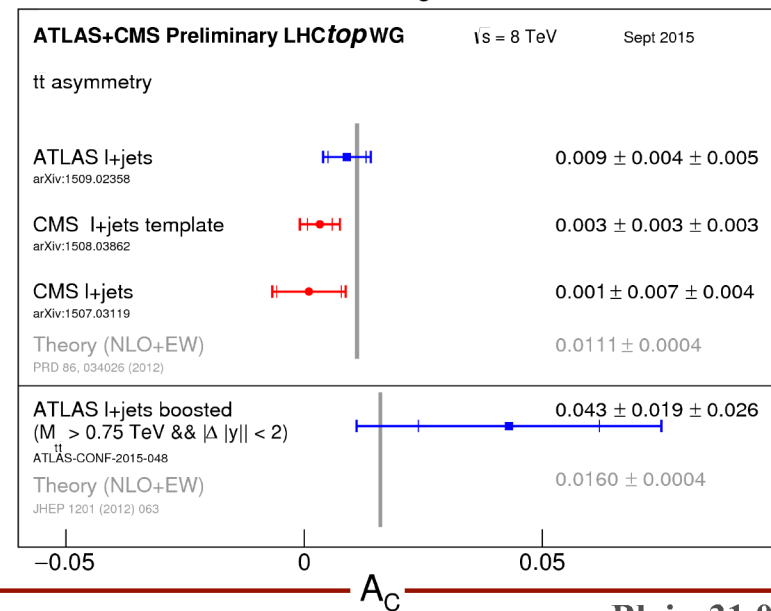
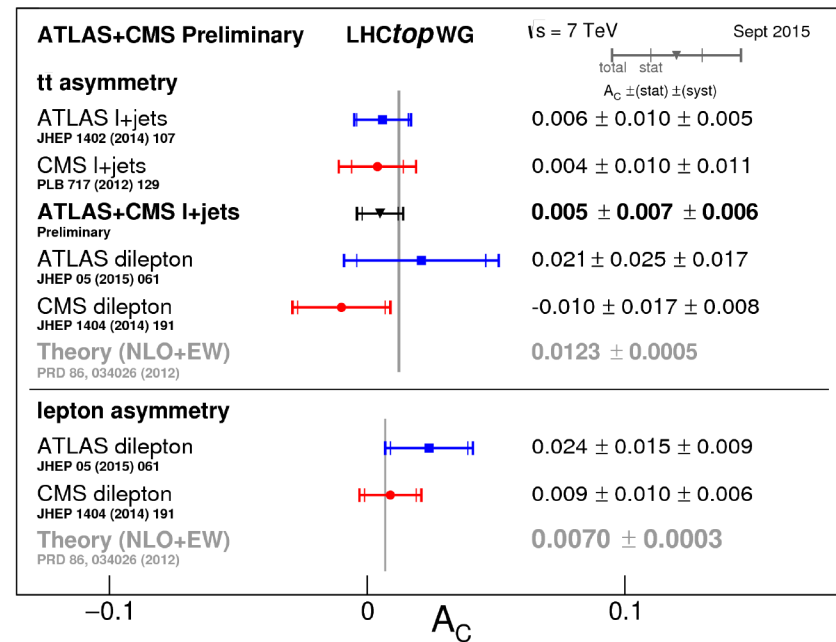
$$\Delta|\eta| = |\eta_{l+}| - |\eta_{l-}|$$

$t\bar{t}$ charge asymmetry: summary

- Plethora of results from **ATLAS** and **CMS**
- No significant deviation from SM
- Several BSM models can be excluded



→ More in talk by I. Brod



Not including latest lepton asym. results

CP asymmetry in $t\bar{t}$ events at 8 TeV

CMS-PAS TOP-16-001



Probing CP violation for the first time in $t\bar{t}$ production

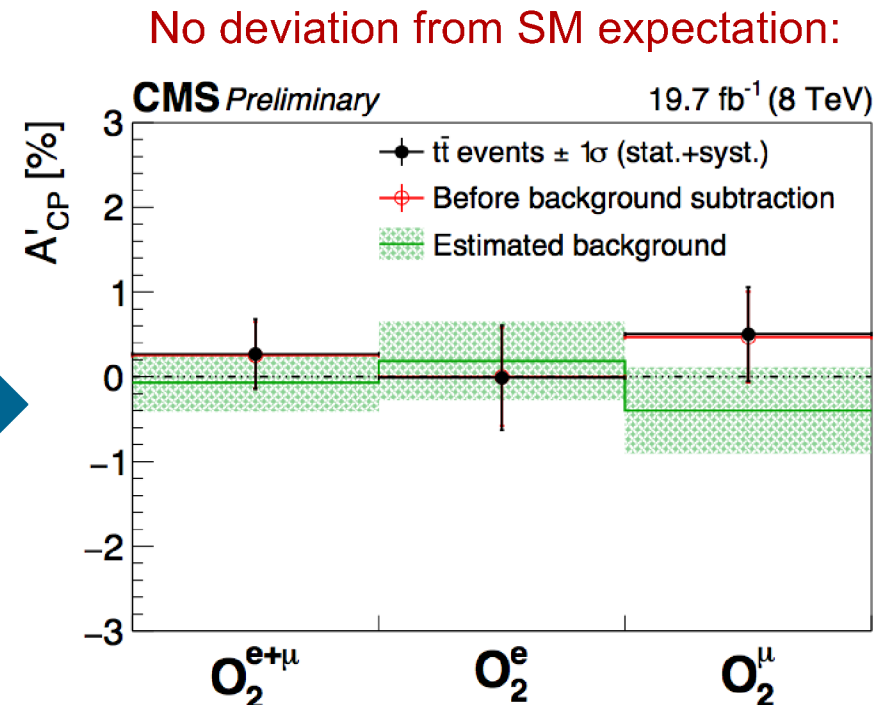
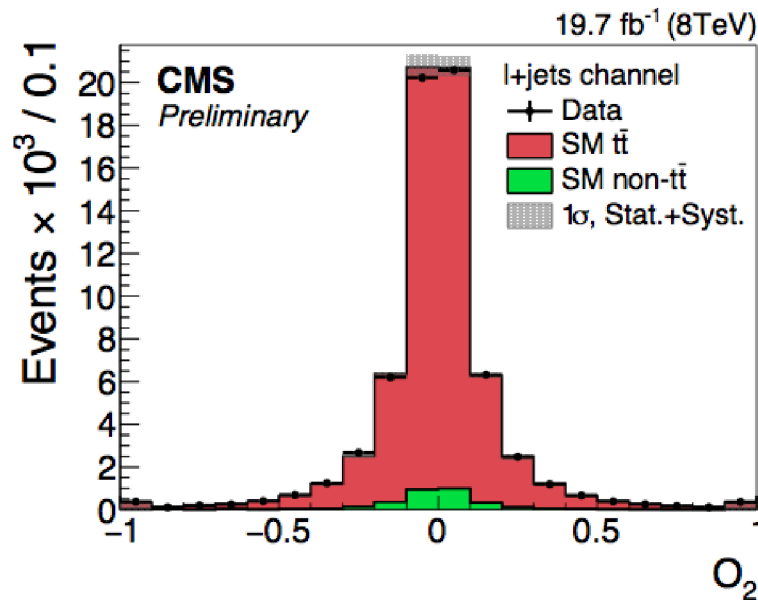
- Use observables that show asymmetry in presence of CP violation

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

$$\begin{aligned} O_2 &= \epsilon(P, p_b + p_{\bar{b}}, p_\ell, p_{j1}) \xrightarrow{lab} \propto (\vec{p}_b + \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j1}) \\ O_3 &= Q_\ell \epsilon(p_b, p_{\bar{b}}, p_\ell, p_{j1}) \xrightarrow{b\bar{b} CM} \propto Q_\ell \vec{p}_b \cdot (\vec{p}_\ell \times \vec{p}_{j1}) \\ O_4 &= Q_\ell \epsilon(P, p_b - p_{\bar{b}}, p_\ell, p_{j1}) \xrightarrow{lab} \propto Q_\ell (\vec{p}_b - \vec{p}_{\bar{b}}) \cdot (\vec{p}_\ell \times \vec{p}_{j1}) \\ O_7 &= q \cdot (p_b - p_{\bar{b}}) \epsilon(P, q, p_b, p_{\bar{b}}) \xrightarrow{lab} \propto (\vec{p}_b - \vec{p}_{\bar{b}})_z (\vec{p}_b \times \vec{p}_{\bar{b}})_z \end{aligned}$$

- Measurement in the $l+jets$ channel

Selection: 1 e/μ , ≥ 4 jets, 2 b-tags



W helicity in top decays in Run-I

CMS, arXiv:16xxxxx



Anomalous contributions to the tWb vertex change the probabilities of the W helicity states

- In SM: 3 possible W helicity states ($F_R + F_L + F_0 = 1$):

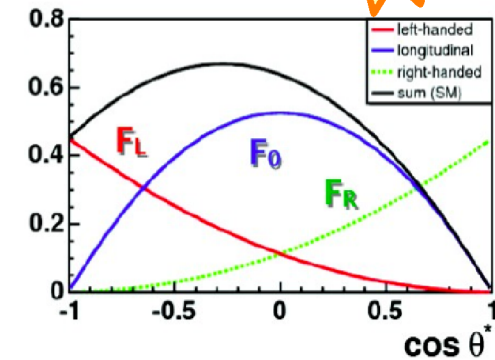
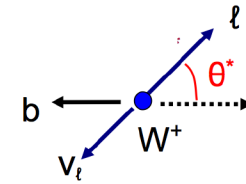
$$\frac{1}{\Gamma} \frac{d\Gamma}{d\cos\theta^*} = \frac{3}{8}(1 + \cos\theta^*)^2 F_R + \frac{3}{8}(1 - \cos\theta^*)^2 F_L + \frac{3}{4}\sin^2\theta^* F_0$$

SM:

~0%

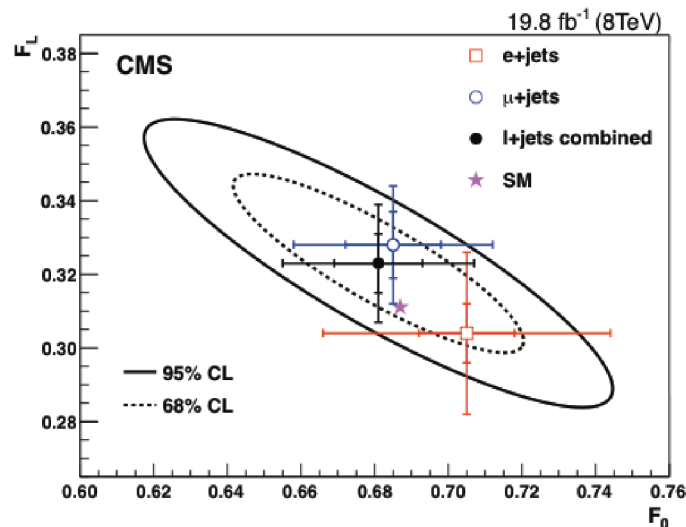
~30%

~70%



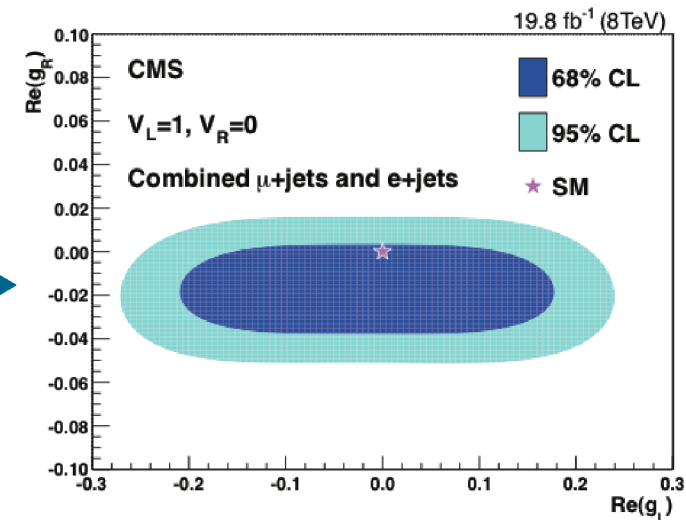
Sensitive variable: $\cos(\theta^*)$

- Helicity fractions extracted from maximum likelihood fit to F_0 and F_L :



Exclusion limits
on anomalous
 tWb couplings

Most precise F_0 and
 F_L results so far!
($< 5\%$)



$$\begin{aligned} F_0 &= 0.681 \pm 0.012 \text{ (stat)} \pm 0.023 \text{ (syst)} \\ F_L &= 0.323 \pm 0.008 \text{ (stat)} \pm 0.014 \text{ (syst)} \\ F_R &= -0.004 \pm 0.005 \text{ (stat)} \pm 0.014 \text{ (syst)} \end{aligned}$$

$$\mathcal{L}_{tWb} = \mathcal{L}_{tWb}^{\text{SM}} - \frac{g}{\sqrt{2}} \bar{b} \left[(V_L P_L + V_R P_R) \gamma^\mu + \frac{i\sigma^{\mu\nu} q_\nu}{m_W} (G_L P_L + G_R P_R) \right] t W_\mu$$

0 in the SM

Summary & outlook

- Top physics: key to QCD, electroweak and New Physics
- In Run-I, the LHC became a real “top factory”
 - Top quark production & properties measurements entered precision regime
 - First measurements of associated $t\bar{t}+X$ production
 - Started to challenge theory predictions in many respects
- First 13 TeV cross section results !
- 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
 - Improvements in MC models and theory calculations
 - Access to new physics in the top environment

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

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

Additional information

$t\bar{t}$ cross section ratios

ATLAS-CONF-2015-049

Sep'15

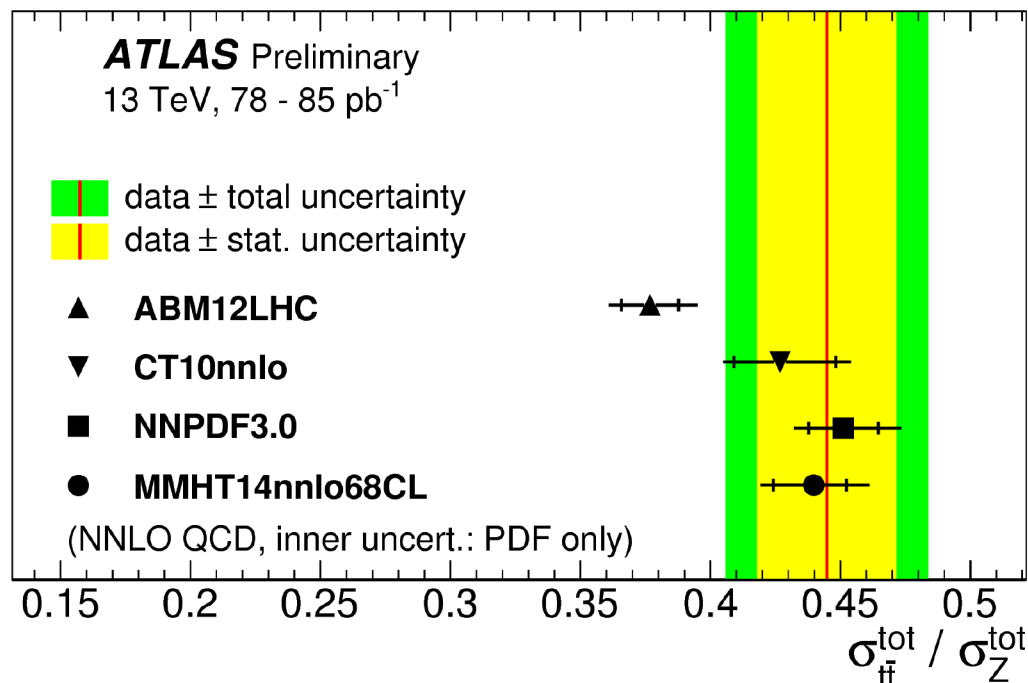
Ratios of cross sections are expected to cancel out some of the systematic uncertainties

→ Comparison to theory: potential to constrain PDFs, sensitive to BSM effects

- $t\bar{t}/Z$ ratio: testing the gg/qq ratio

- Reduces luminosity uncertainty (10% → 1%), electron ID (3.2% → 1.3%)

$$R_{t\bar{t}/Z} = 0.445 \pm 0.027 \text{ (stat)} \pm 0.028 \text{ (syst)} = 0.445 \pm 0.039$$



- General good agreement between data and different PDF

- ABM12LHC uses smaller gluon density

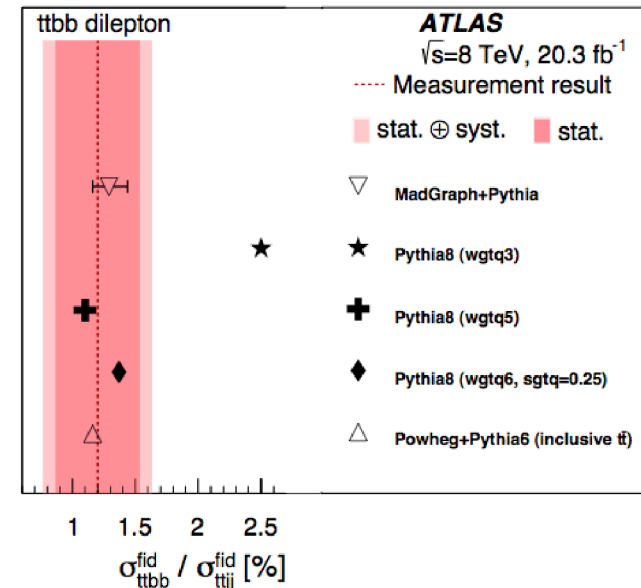
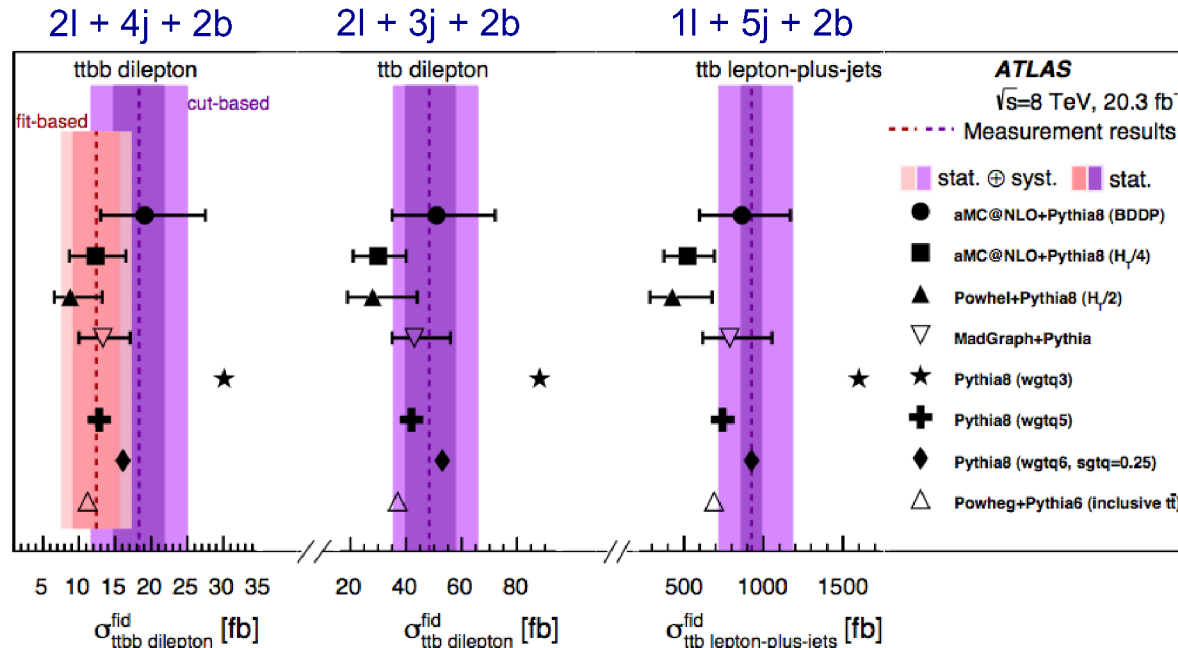
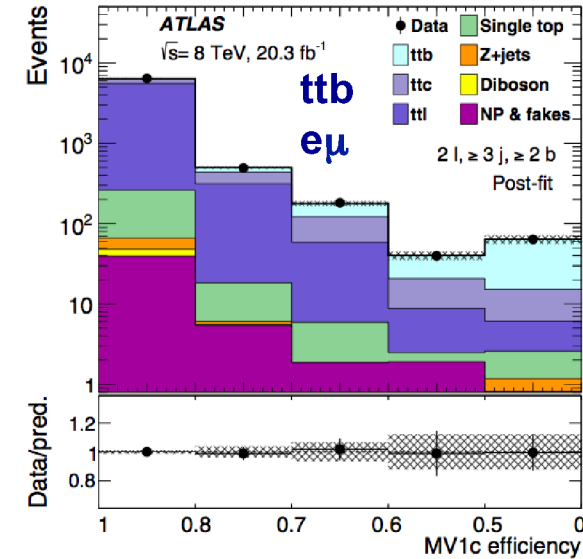
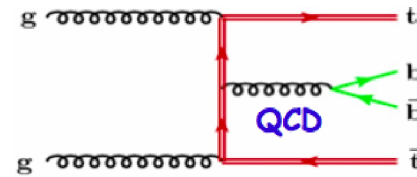
Run-II: potential to explore different ratios, also at different energies, to constrain further PDFs

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

ATLAS, arXiv:1508.06868

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

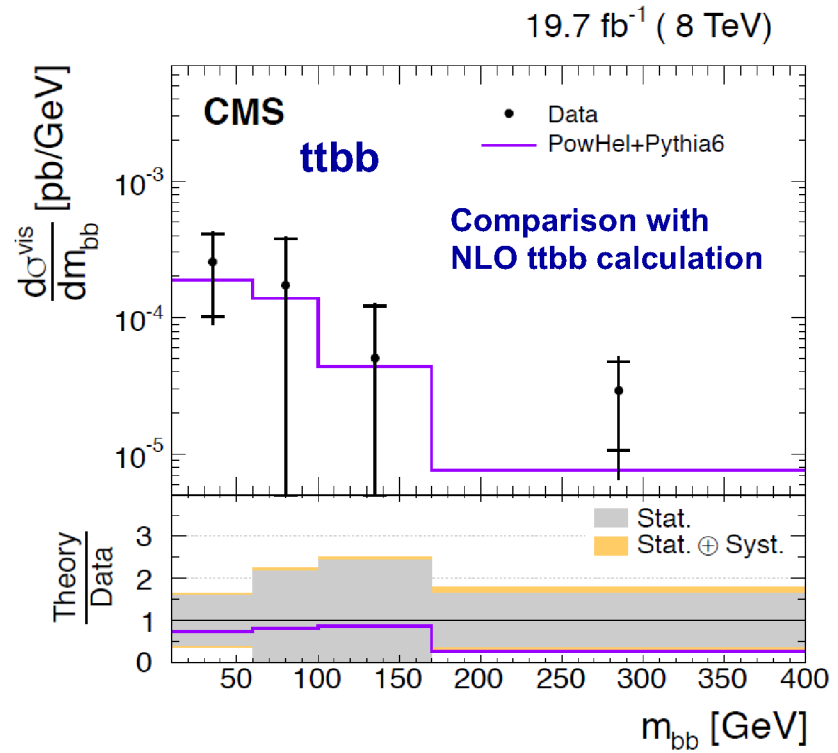
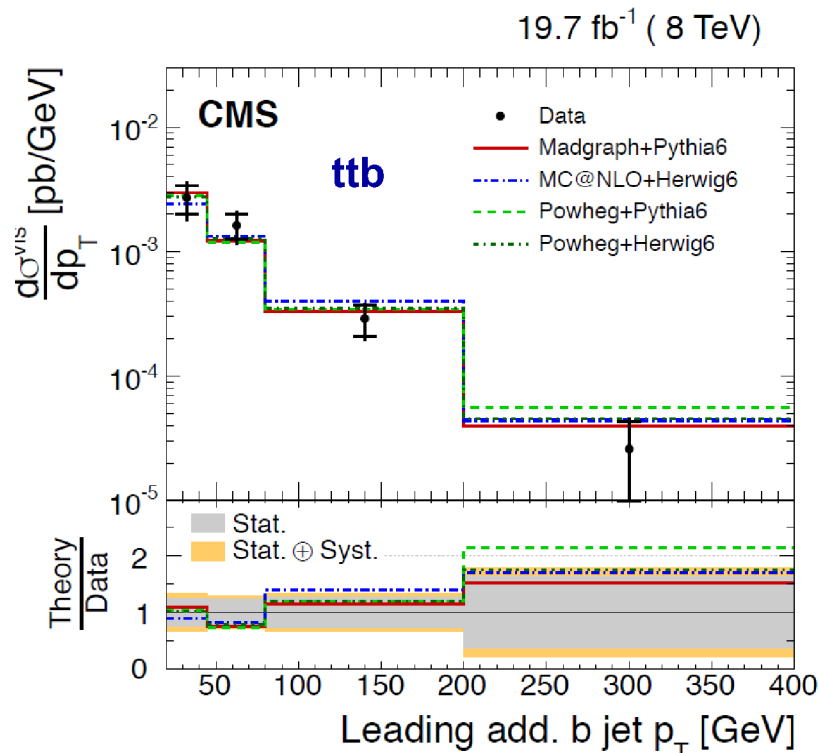
- $t\bar{t}+bb$ in dileptons ($ee, \mu\mu, e\mu$)
 $t\bar{t}+b$ in l +jets and in $e\mu$ channels
- Signal extraction by fit to MVA b-tag discriminator ($t\bar{t}+b, t\bar{t}+bb$) and cut-based ($t\bar{t}+bb$)
- Compare to different $g \rightarrow b\bar{b}$ splitting models



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

CMS, arXiv:1510.03072

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

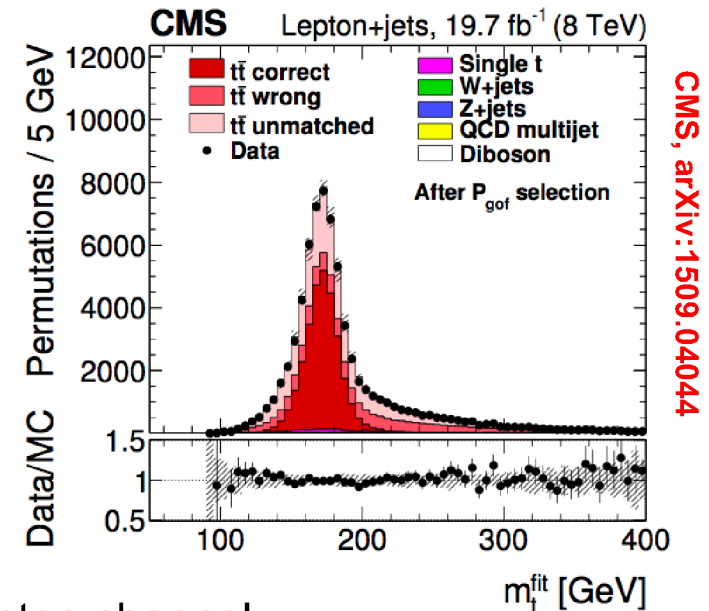
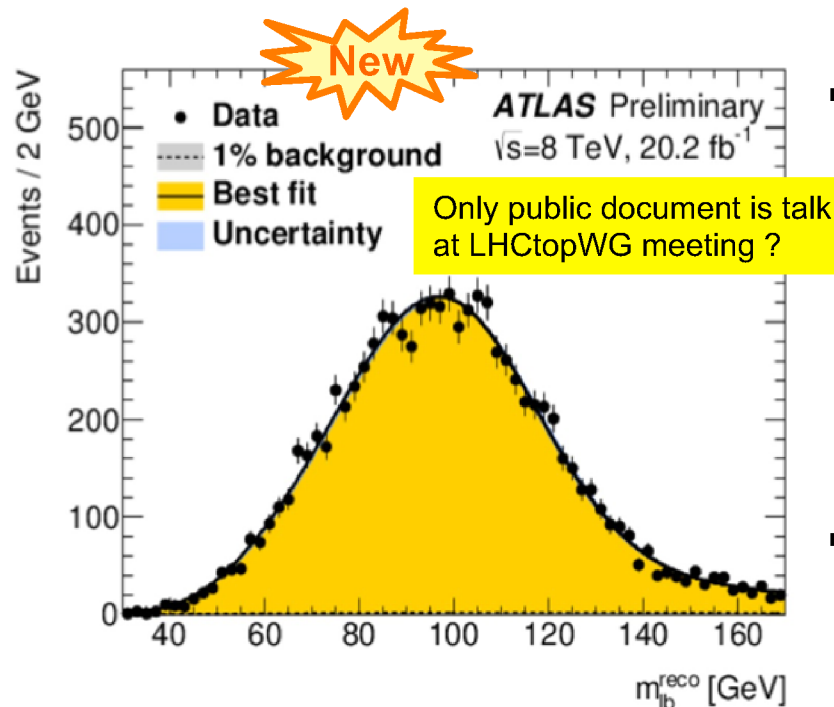


High precision top mass measurements

- **CMS:** l+jets channel: 1 μ/e , ≥ 4 jets, 2 b-tags
 - 2D likelihood fit to extract m_{top} and light-quark jet energy scale from W-mass constraint
 - All different jet permutations are taken into account

$$m_t^{\text{hyb}} = 172.35 \pm 0.16 (\text{stat+JSF}) \pm 0.48 (\text{syst}) \text{ GeV} \quad (0.29\%)$$

Main syst: bJES, b hadron decay modelling



CMS, arXiv:1509.04044

- **ATLAS:** dilepton channel
 - 2 leptons, ≥ 2 jets, b-tagged jets, cut on p_T of the lepton-b-jet systems (p_{Tlb})

- Likelihood fit to m_{lb} distribution

$$m_{\text{top}} = 172.99 \pm 0.41 (\text{stat.}) \pm 0.74 (\text{syst.}) \text{ GeV} \quad (0.49\%)$$

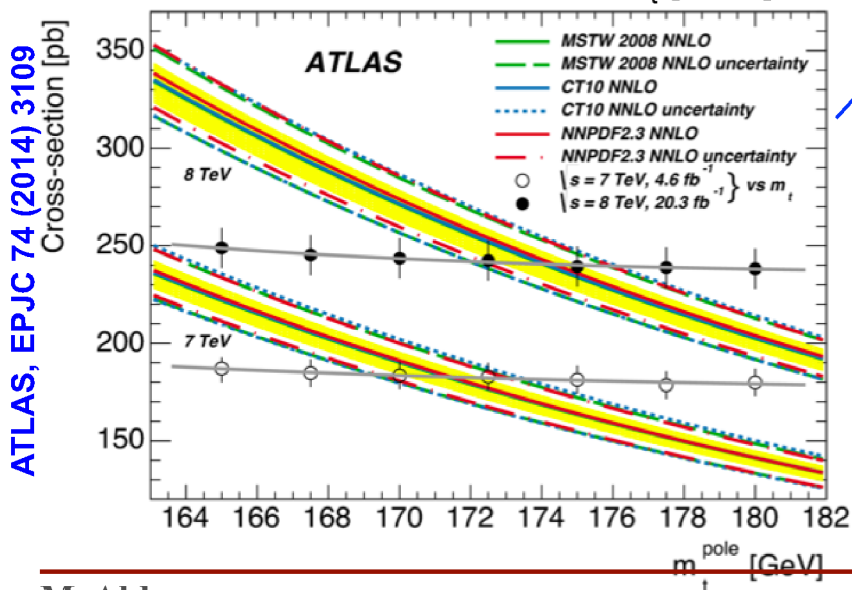
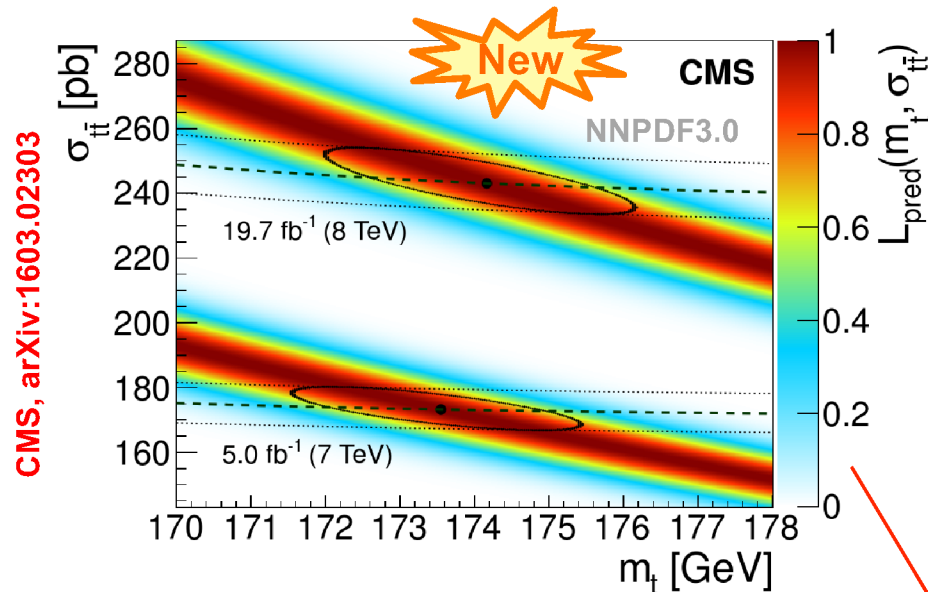
Main syst: (b)JES, hadronization, ISR/FSR

- Combine with 7 TeV result ([ATLAS, EPJC 75 \(2015\) 330](#)):

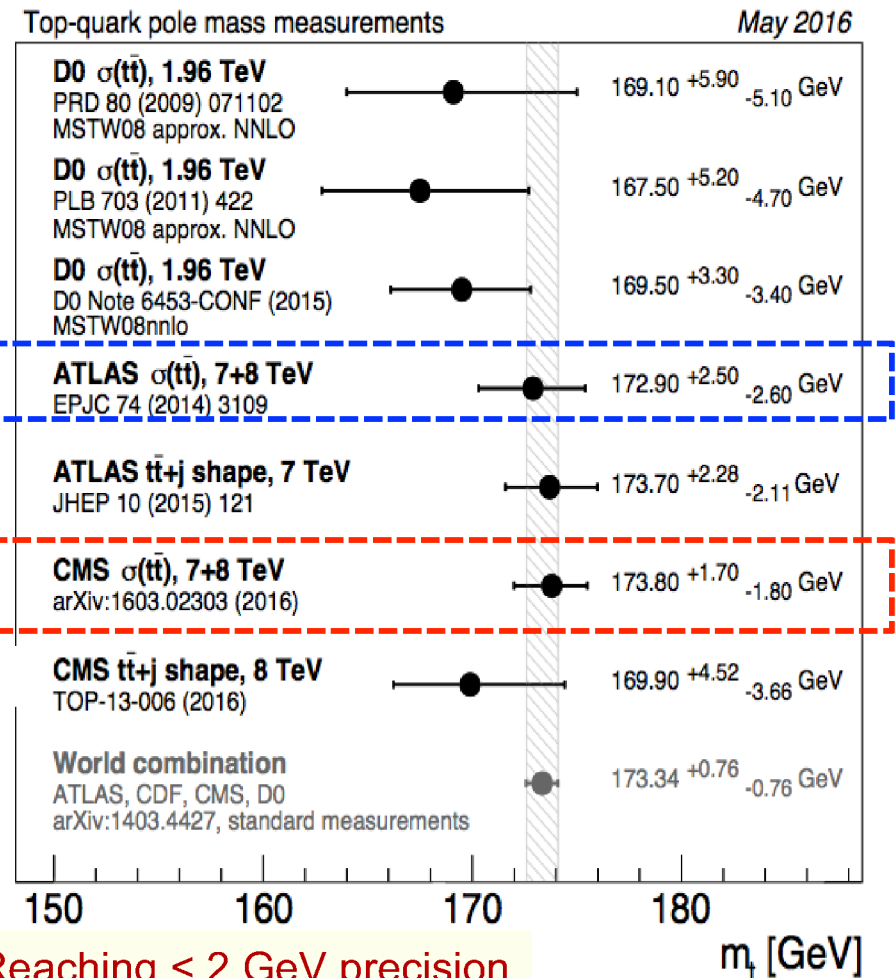
$$m_{\text{top}}^{\text{comb}} = 172.84 \pm 0.34 (\text{stat.}) \pm 0.61 (\text{syst.}) \text{ GeV} \quad (0.40\%)$$

Top pole mass from $\sigma(t\bar{t})$

Mass dependence of predicted cross section allows determining m_t from measured $\sigma(t\bar{t})$

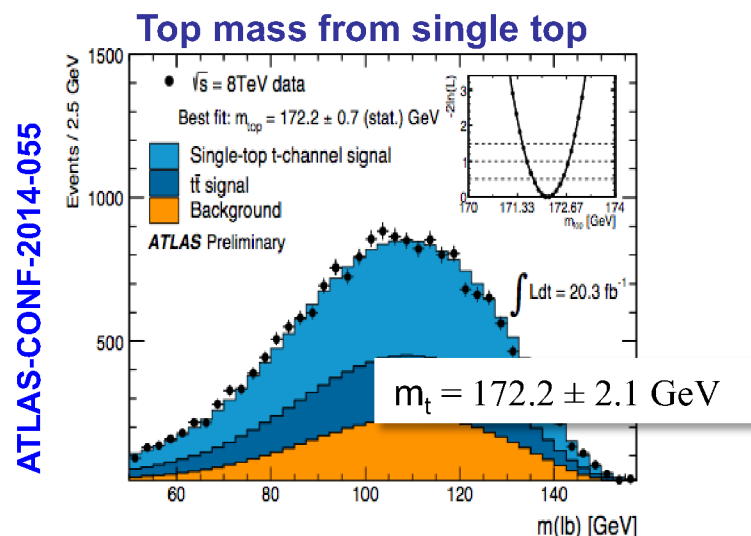


Use most precise theory (NNLO) and measurements to extract m_t (for fixed α_s and PDF)

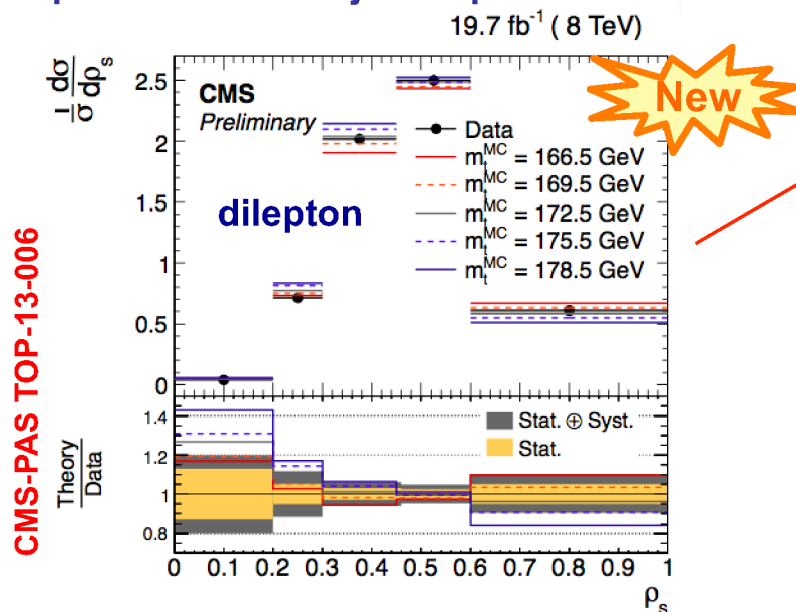


Reaching < 2 GeV precision

Other alternative methods

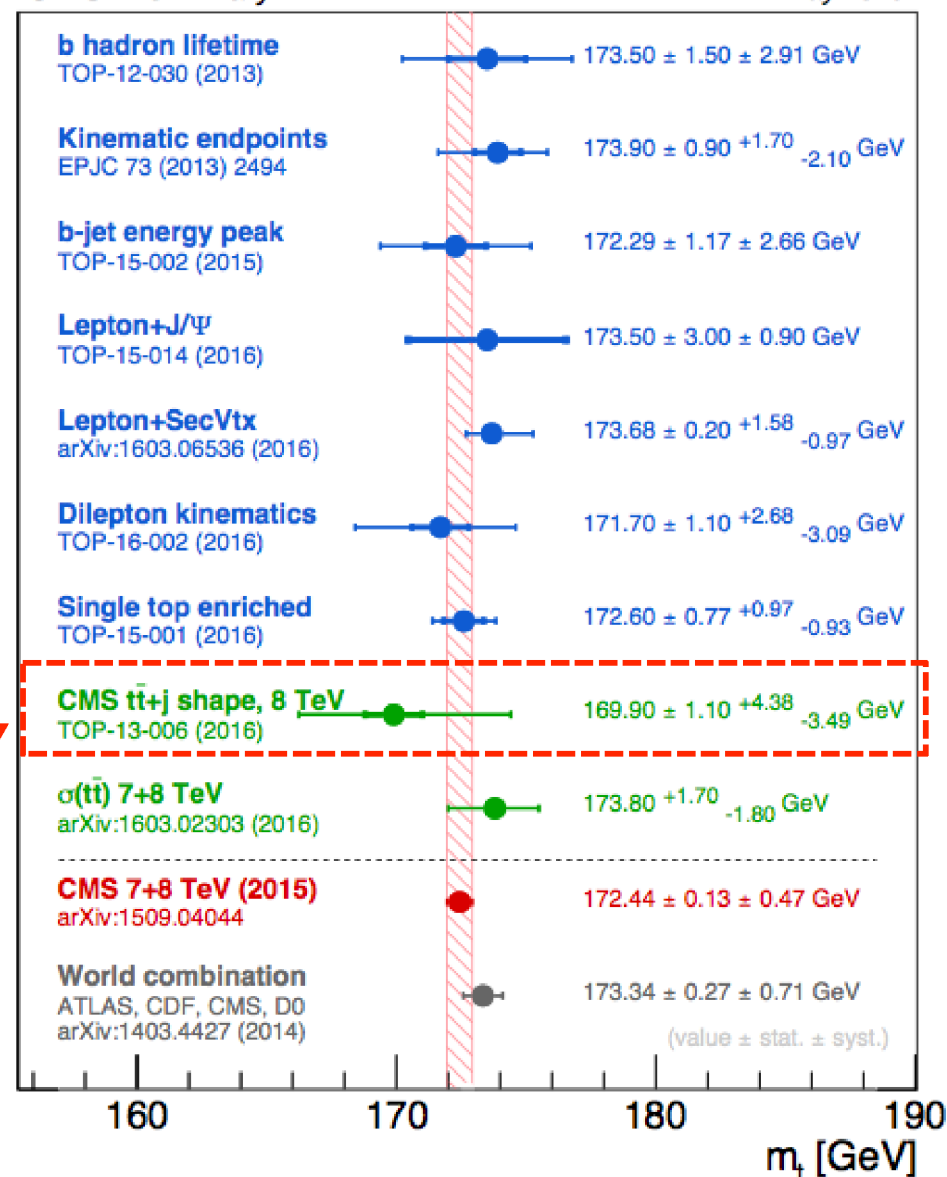


Top mass from $t\bar{t}+1\text{jet}$ shape



CMS Preliminary

May 2016



Asymmetry in dileptons at 8 TeV

ATLAS, arXiv:1604.05538



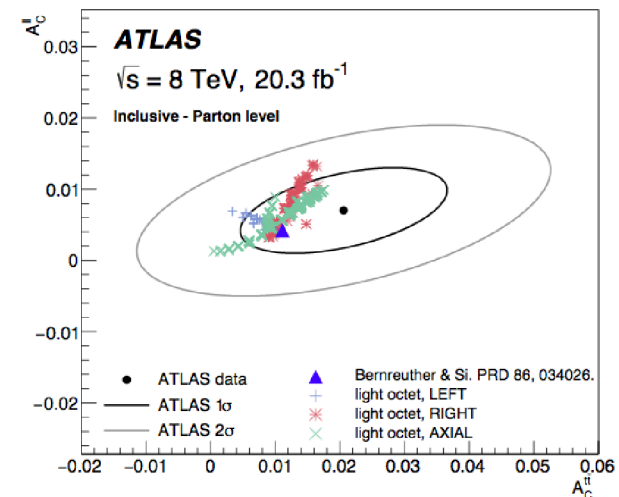
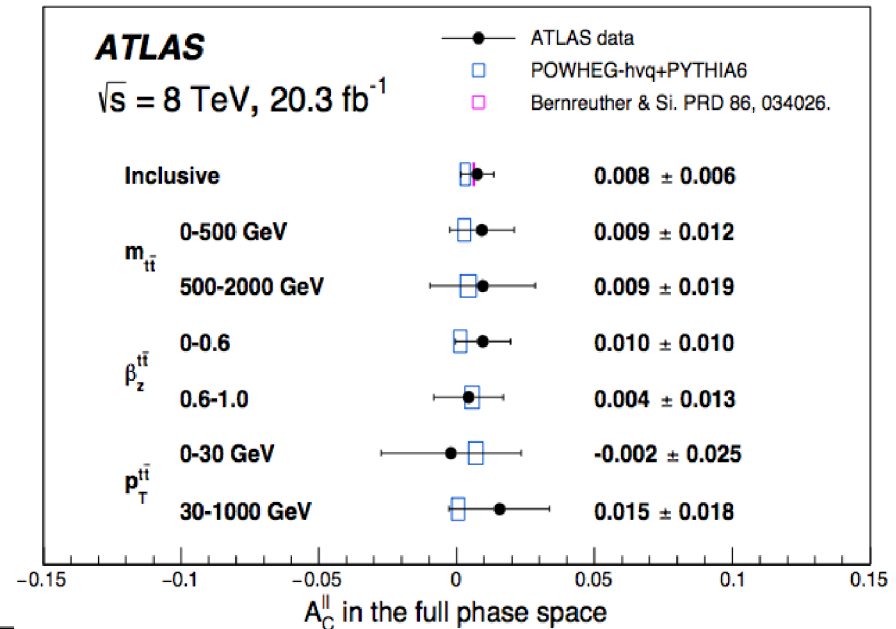
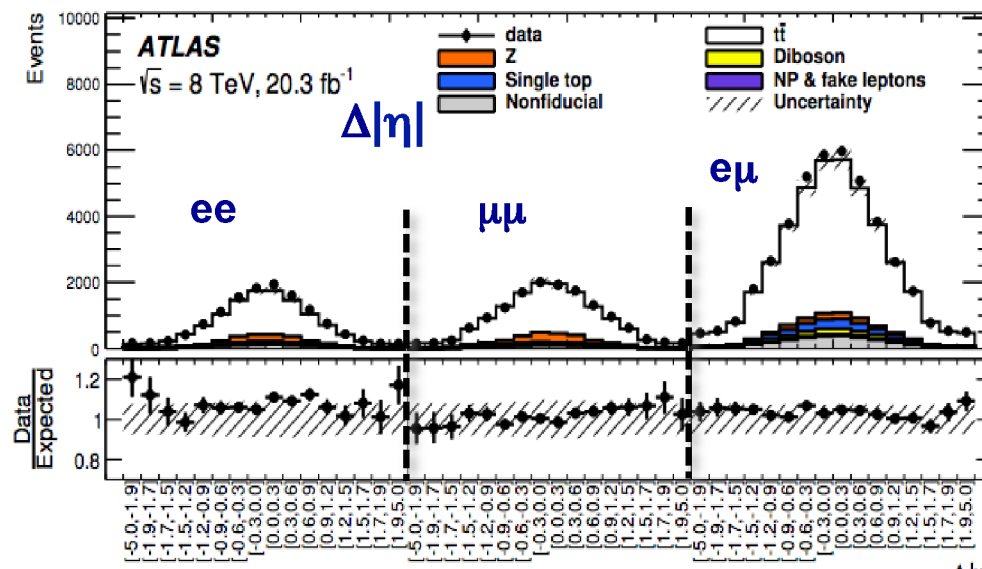
Alternative approach: lepton asymmetry

- Sensitive to top polarization, no tt kinematic reconstruction needed

$$A_c^{\parallel} = \frac{N(\Delta|\eta| > 0) - N(\Delta|\eta| < 0)}{N(\Delta|\eta| > 0) + N(\Delta|\eta| < 0)}$$

$$\Delta|\eta| = |\eta_{l+}| - |\eta_{l-}|$$

Selection: 2 leptons, ≥ 2 jets &
 ≥ 1 b-tag (ee, $\mu\mu$) or large H_T (e μ)



Consistent with SM, limited by stat. uncertainties