# Top quark physics with the ATLAS detector: recent highlights

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on behalf of the ATLAS Collaboration

# The top quark

ATLAS EXPERIMENT

| Production time | | Decay time | | Hadronisation time | | Spin-Decorr. time |
|---|---|---|---|---|---|---|
| $\frac{1}{m_t}$ | $<$ | $\frac{1}{\Gamma_t}$ | $<$ | $\frac{1}{\Lambda_{QCD}}$ | $<$ | $\frac{m_t}{\Lambda}$ |
| **$\sim 10^{-27}$ s** | | **$\sim 10^{-25}$ s** | | **$\sim 10^{-23}$ s** | | **$\sim 10^{-22}$ s** |

Why top quarks?

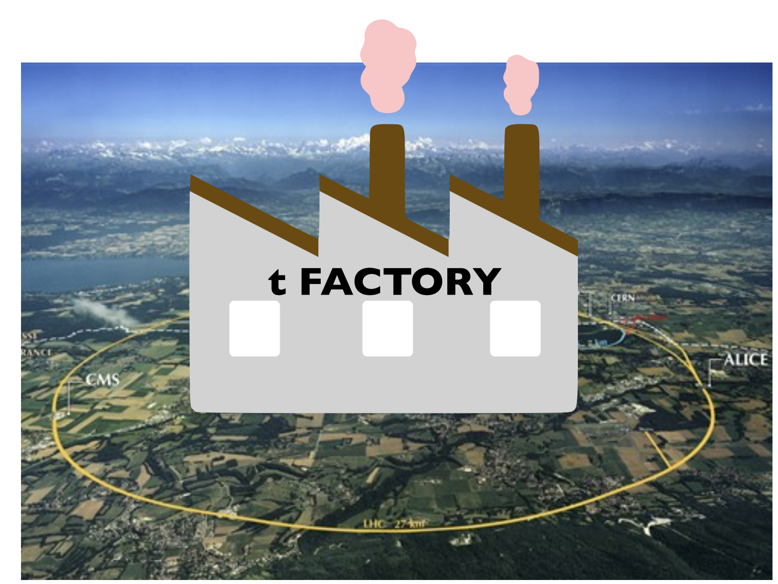
- heaviest known particle, only "bare" quark
- high statistics allows **precision measurements** and search for **new physics**

Copious production at the LHC (top-factory):

- ~150 fb$^{-1}$ @13TeV collected in Run 2 by ATLAS…

$$N = \mathscr{L} \cdot \sigma_{t\bar{t}},$$
$$\sigma_{t\bar{t}} \sim 830\,\text{pb}, \quad \Longrightarrow$$
$$\mathscr{L} \sim 15 \cdot 10^{33}\,\text{cm}^2\,\text{s}^{-1}$$

**~750 $t\bar{t}$ pairs produced/minute**
(125M @150fb$^{-1}$)



# Papers overview

x-section  Mass  Properties  top+W/Z/γ  Searches

ATLAS EXPERIMENT

| Short Title | Journal Reference | Date | √s (TeV) | L |
|---|---|---|---|---|
| Search for FCNC tqgamma in single top NEW | Submitted to Phys. Lett. B | 22-AUG-19 | 13 | 80 $fb^{-1}$ |
| Differential ttbar cross-sections in lepton+jets with 36 fb-1 NEW | Submitted to EPJC | 20-AUG-19 | 13 | 36 $fb^{-1}$ |
| K_S^0 and Lambda^0 production in ttbar events at 7 TeV NEW | Submitted to EPJC | 25-JUL-19 | 7 | 5 $fb^{-1}$ |
| Measurement of the top-quark mass using ttbar+1jet events at 8 TeV | Submitted to JHEP | 06-MAY-19 | 8 | 20.3 $fb^{-1}$ |
| Spin correlation measurement at 13 TeV | Submitted to EPJC | 18-MAR-19 | 13 | 36 $fb^{-1}$ |
| Measurement of the jet shapes at 13 TeV | JHEP 08 (2019) 033 | 07-MAR-19 | 13 | 36 $fb^{-1}$ |
| ATLAS+CMS combination of Run 1 single top measurements and extraction of Vtb | JHEP 05 (2019) 088 | 18-FEB-19 | 8 | 20 $fb^{-1}$ |
| Measurement of ttV in multilepton final states using 36.5fb-1 at 13 TeV | Phys. Rev. D 99 (2019) 072009 | 11-JAN-19 | 13 | 36 $fb^{-1}$ |
| Search for flavor-changing neutral current t to Hq with H->b-bbar and tautau at 13 TeV | JHEP 05 (2019) 123 | 30-DEC-18 | 13 | 36 $fb^{-1}$ |
| Measurement of the ttbar+gamma cross section at 13 TeV | Eur. Phys. J. C 79 (2019) 382 | 04-DEC-18 | 13 | 36 $fb^{-1}$ |
| Measurement of the ttbb cross section at 13 TeV | JHEP 04 (2019) 046 | 29-NOV-18 | 13 | 36 $fb^{-1}$ |
| 4 top quark search with 1 or 2 leptons | Phys. Rev. D 99 (2019) 052009 | 06-NOV-18 | 13 | 36 $fb^{-1}$ |
| Measurement of the top quark mass in the lepton+jets channel at 8 TeV | Eur. Phys. J. C79 (2019) 290 | 03-OCT-18 | 8 | 20.2 $fb^{-1}$ |
| Same-sign dilepton plus b-jet search | JHEP 12 (2018) 039 | 31-JUL-18 | 13 | 36.1 $fb^{-1}$ |
| Quantum Interference Between Single and Doubly Resonant Top Quark Production | Phys. Rev. Lett. 121 (2018) 152002 | 12-JUN-18 | 13 | 36 $fb^{-1}$ |

| | | | | |
|---|---|---|---|---|
| Inclusive and lepton differential cross-sections in dilepton ttbar with 36 fb-1 NEW | ATLAS-CONF-2019-041 | 04-AUG-19 | 13 | 36 $fb^{-1}$ |
| Top width measurement in dilepton ttbar NEW | ATLAS-CONF-2019-038 | 02-AUG-19 | 13 | 139 $fb^{-1}$ |
| Measurement of ttbar charge asymmetry at 13 TeV in l+jets | ATLAS-CONF-2019-026 | 09-JUL-19 | 13 | 139 $fb^{-1}$ |
| Search for charged lepton flavour violation in top quark decays | ATLAS-CONF-2018-044 | 13-SEP-18 | 13 | 80 $fb^{-1}$ |

# Outline

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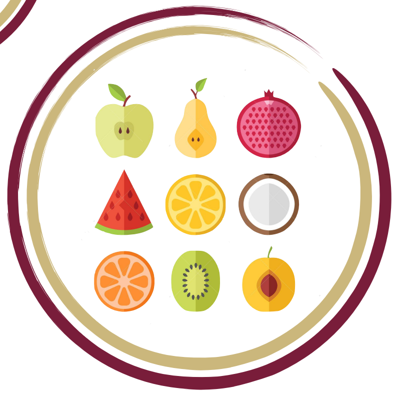
ATLAS EXPERIMENT

**$t\bar{t}$ x-section**

Talk: $t\bar{t}$ x-sec - Adam Bozson -

**29/08 h12:10**

# Outline

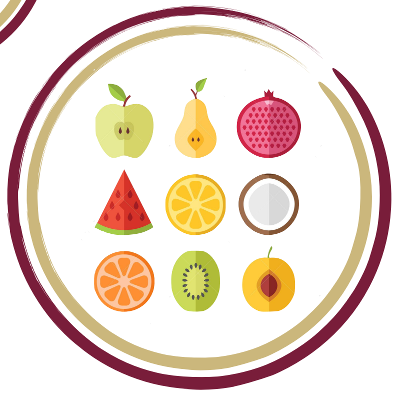


**$t\bar{t}$ x-section**

Talk: $t\bar{t}$ x-sec - Adam Bozson - **29/08 h12:10**

**Strange hadron production**

# Outline



**$t\bar{t}$ x-section**

Talk: $t\bar{t}$ x-sec - Adam Bozson -
**29/08 h12:10**

**Strange hadron production**

Talk: top mass - Jiri Hejbal -
**24/08 h11:50**

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ATLAS EXPERIMENT

Talk: top mass - Jiri Hejbal - **24/08 h11:50**

**Mass**

**$t\bar{t}$ x-section**

Talk: $t\bar{t}$ x-sec - Adam Bozson - **29/08 h12:10**

**Strange hadron production**

**Properties**

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## $t\bar{t}$ x-section

Talk: $t\bar{t}$ x-sec - Adam Bozson - **29/08 h12:10**

## Strange hadron production

Talk: top mass - Jiri Hejbal - **24/08 h11:50**



## top+W/Z/γ

Talk: ttV - Paul Glaysher - **28/08 h16:50**
Poster: 4 tops - Thibault Chevalerias - **26/08 h20:30**

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## $t\bar{t}$ x-section

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## Strange hadron production

## Mass

Talk: top mass - Jiri Hejbal - **24/08 h11:50**

## Properties

## Searches

## top+W/Z/γ

Talk: ttV - Paul Glaysher - **28/08 h16:50**

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$t\bar{t}$ **x-section**

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**Mass**

**Properties**

**Searches**

**top+W/Z/γ**

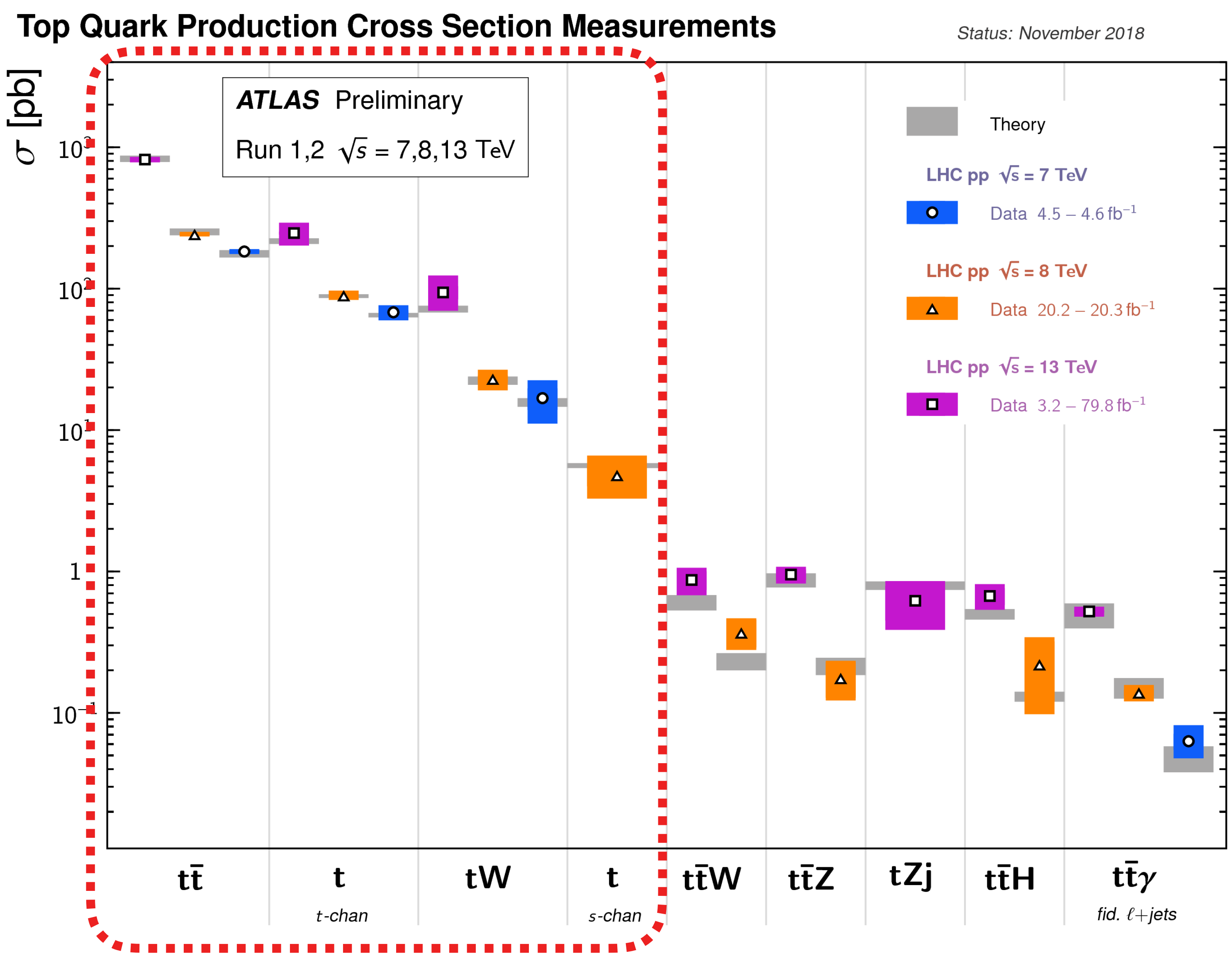
Talk: ttV - Paul Glaysher - **28/08 h16:50**

Poster: 4 tops - Thibault Chevalerias - **26/08 h20:30**

**Conclusions**

# Cross sections

Talk: "*Top-quark pair production cross-section measurements with the ATLAS detector*"
Adam Bozson
**29/08 h12:10**

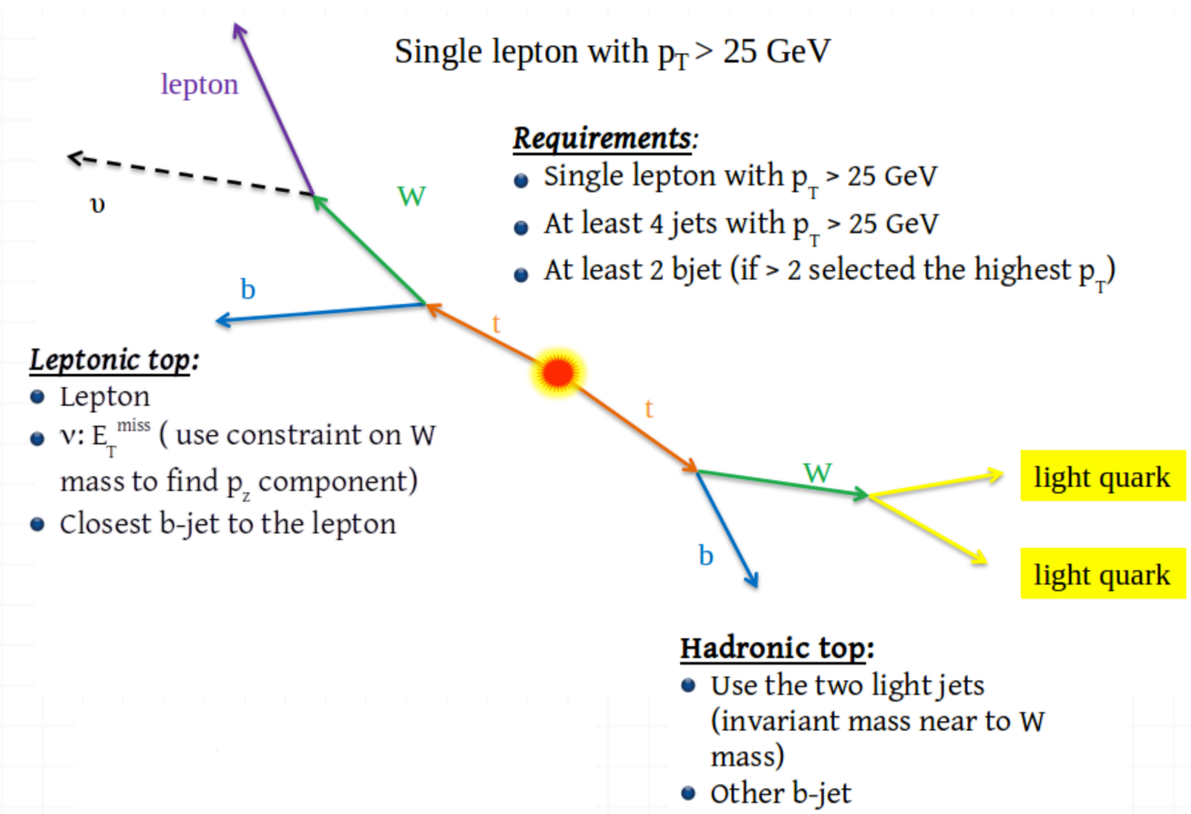


# $t\bar{t}$ x-sec in $\ell$+jets

Submitted to EPJC - **NEW!**

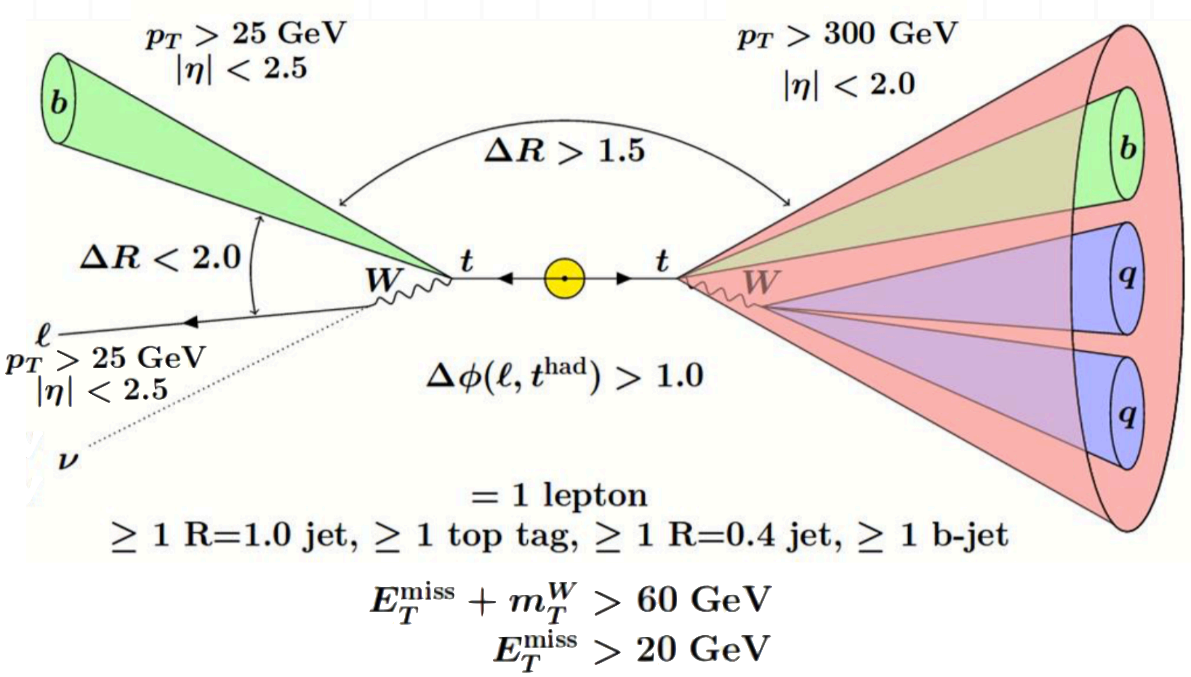
Differential and 2-differential in the $\ell$+jets channel, 36.1 fb$^{-1}$ @13TeV

## Resolved regime




Algorithms for event reconstruction employed (Pseudo-top and KLFitter)

## Boosted regime

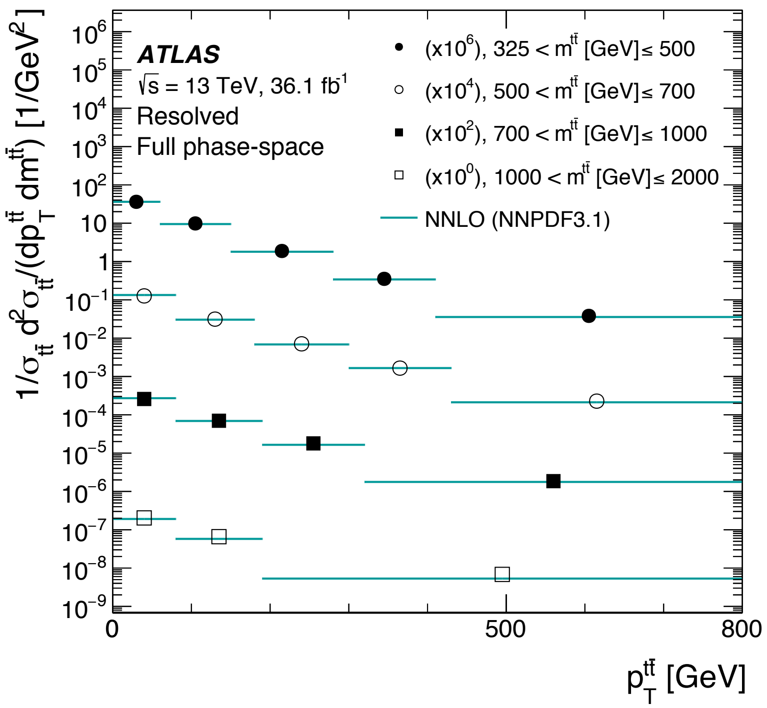



Overlap with resolved events removed

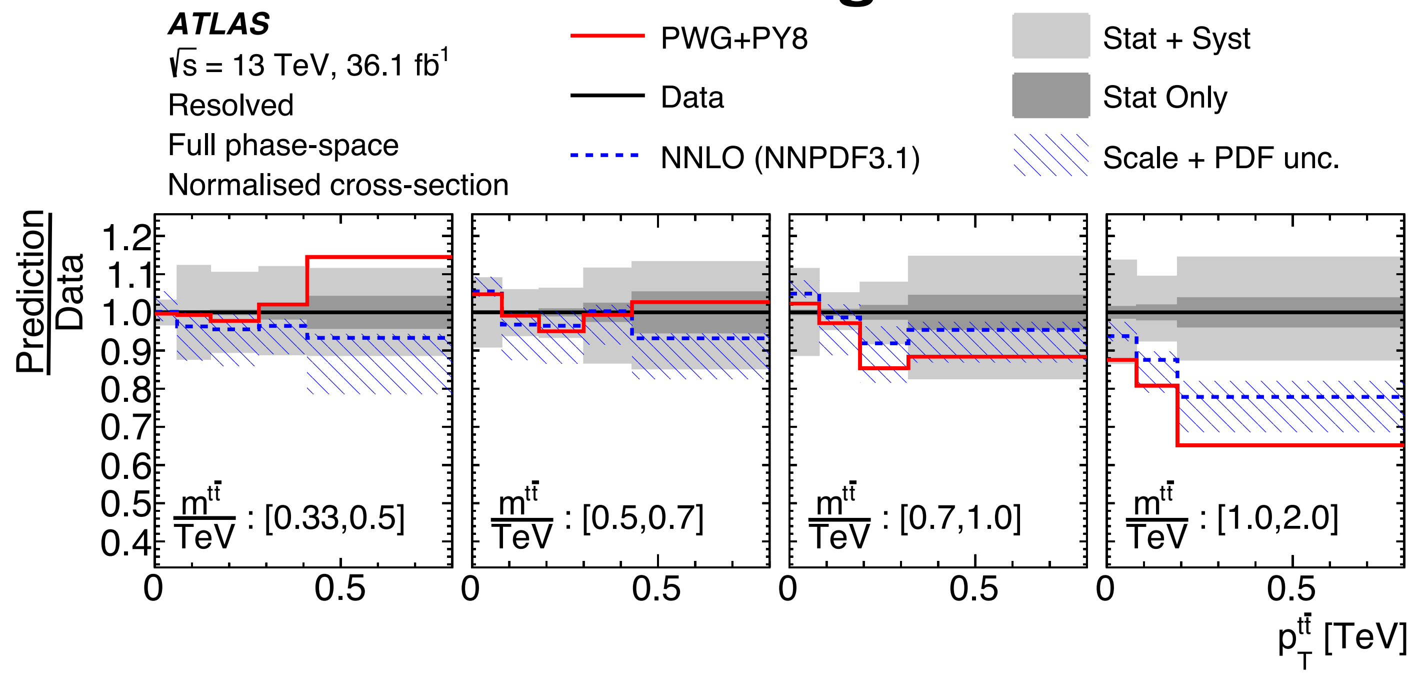
**Unfolded to parton and particle level with Iterative D'Agostini method**

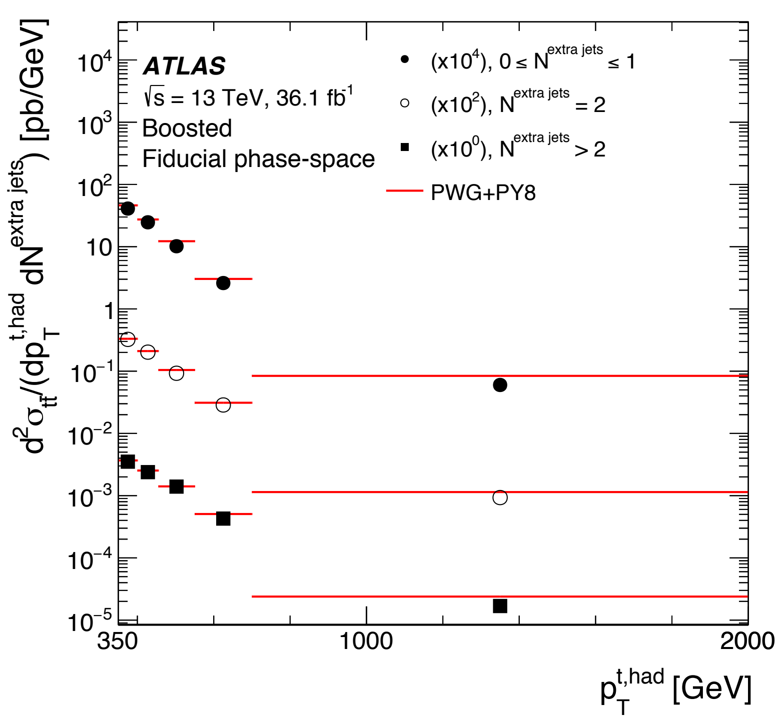
# $t\bar{t}$ x-sec in $\ell$+jets

Submitted to EPJC - **NEW!**

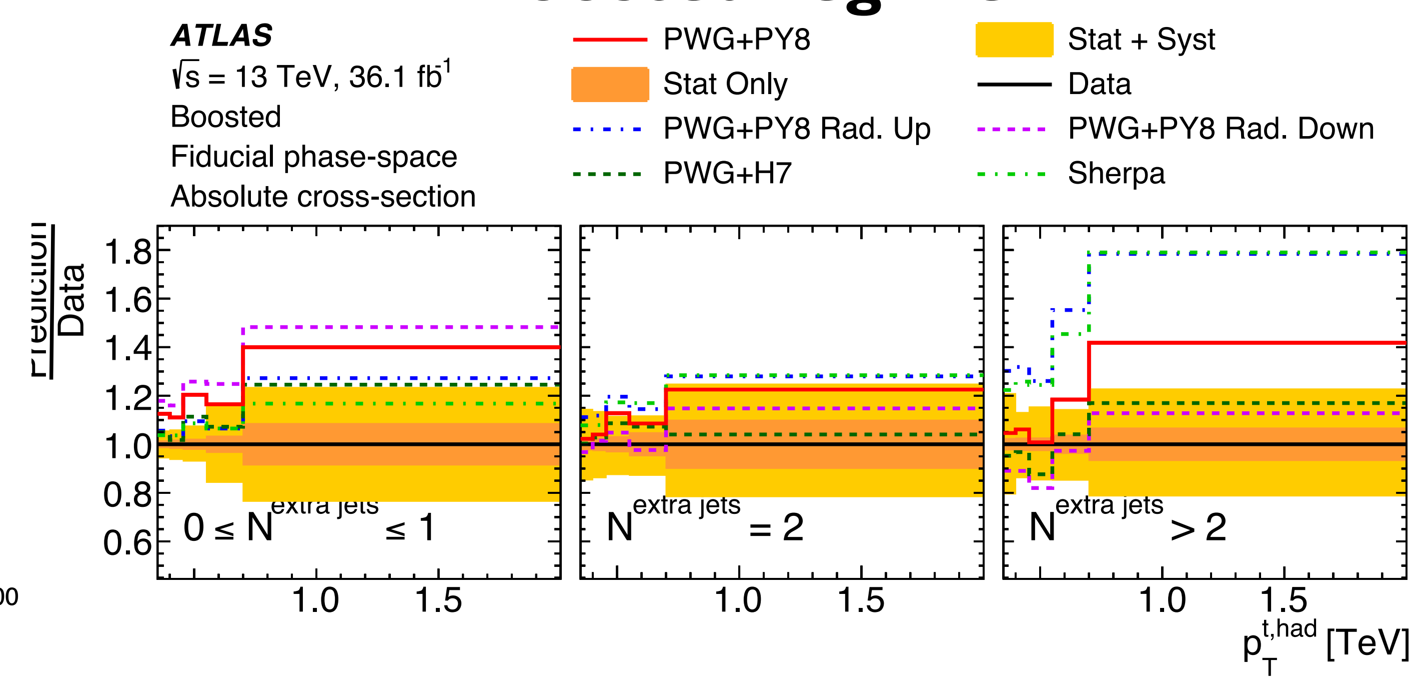



## Resolved regime



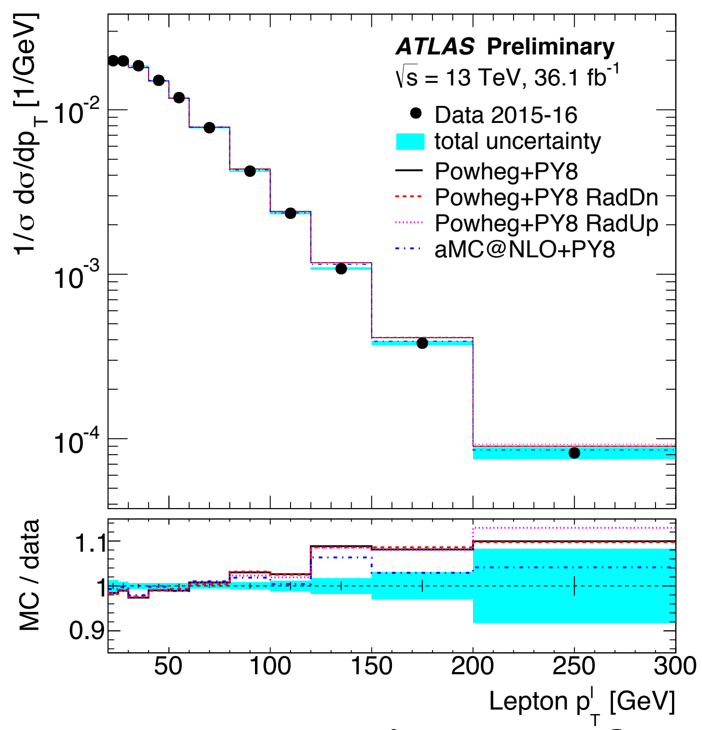

## Boosted regime



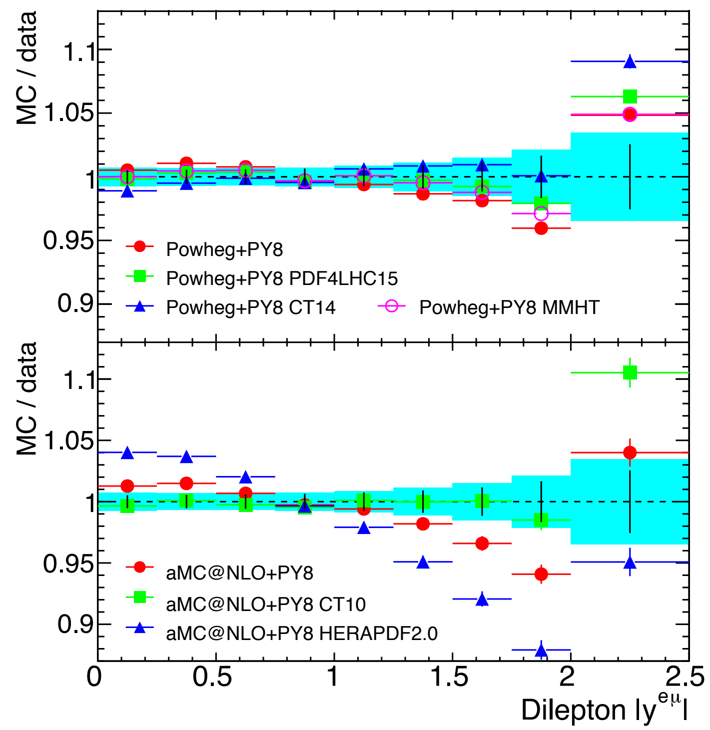

>60 spectra in total, compared with MC generators and NNLO predictions

# $t\bar{t}$ x-sec in dilepton

ATLAS-CONF-2019-041 - **NEW**




**overestimate of $p_T$ spectra**



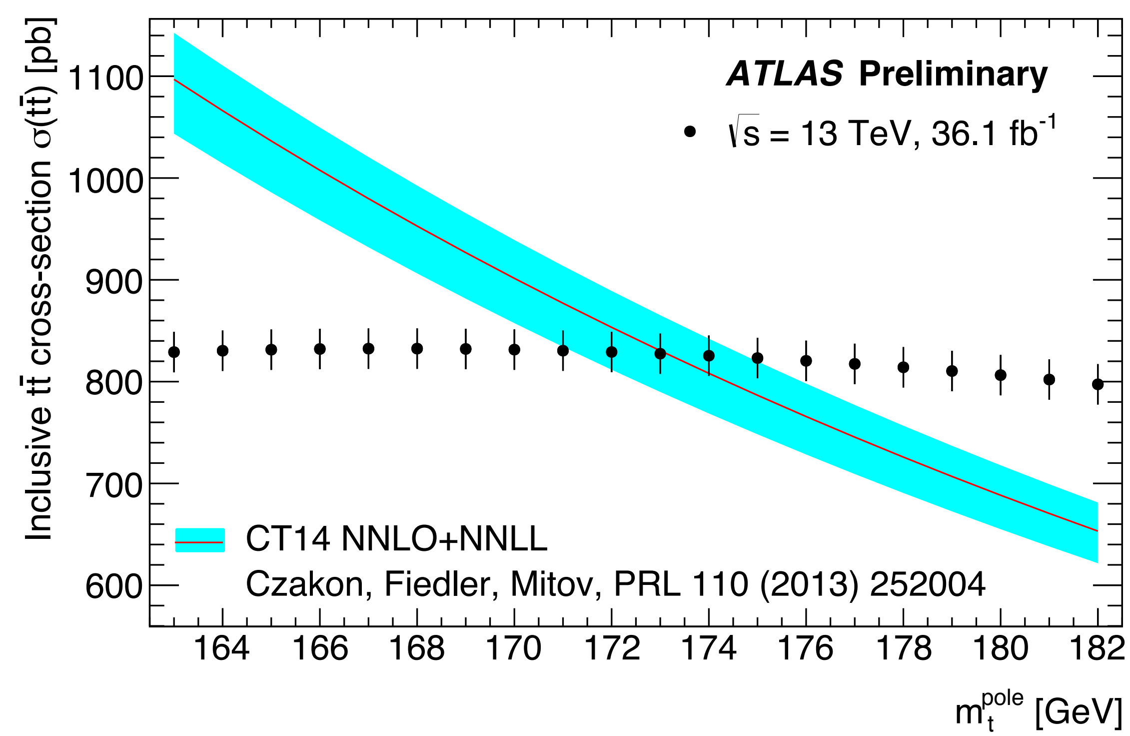

**sensitivity to PDF thanks to rapidity**

Inclusive & (2D-)differential in eμ channel, 36.1 fb-1 @13TeV

- **$\sigma_{t\bar{t}}$ = 826.4±19.9 pb**
  **→ highest precision, 2.4%**
- CMS measurements
  - 4.0% in dilepton 2015+16,
  - 3.8% in l+jets 2015

- extraction of $m_{top}^{pole}$ by unfolding

| PDF set | $m_t^{pole}$ [GeV] |
|---|---|
| CT14 | $173.1^{+2.0}_{-2.1}$ |
| CT10 | $172.1^{+2.0}_{-2.0}$ |
| MSTW | $172.3^{+2.0}_{-2.1}$ |
| NNPDF2.3 | $173.4^{+1.9}_{-1.9}$ |
| PDF4LHC | $172.1^{+3.1}_{-2.0}$ |



# $K_s^0$ & $\Lambda^0$ production

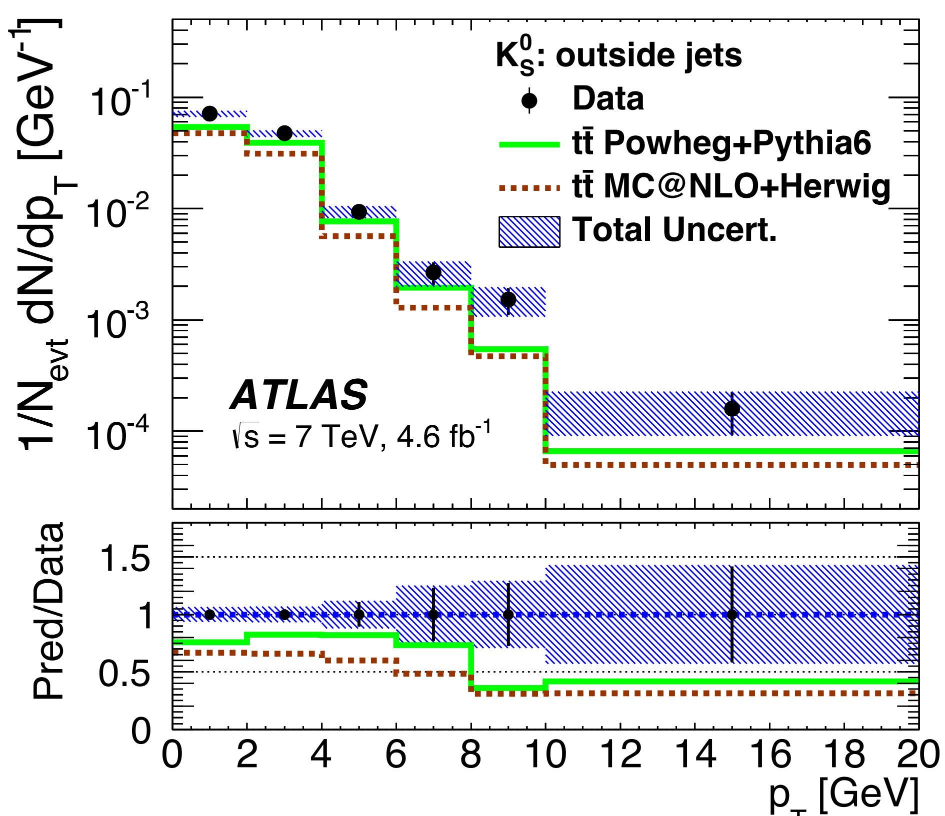
Submitted to EPJC - **NEW!**

Measurements of neutral strange particle production interesting

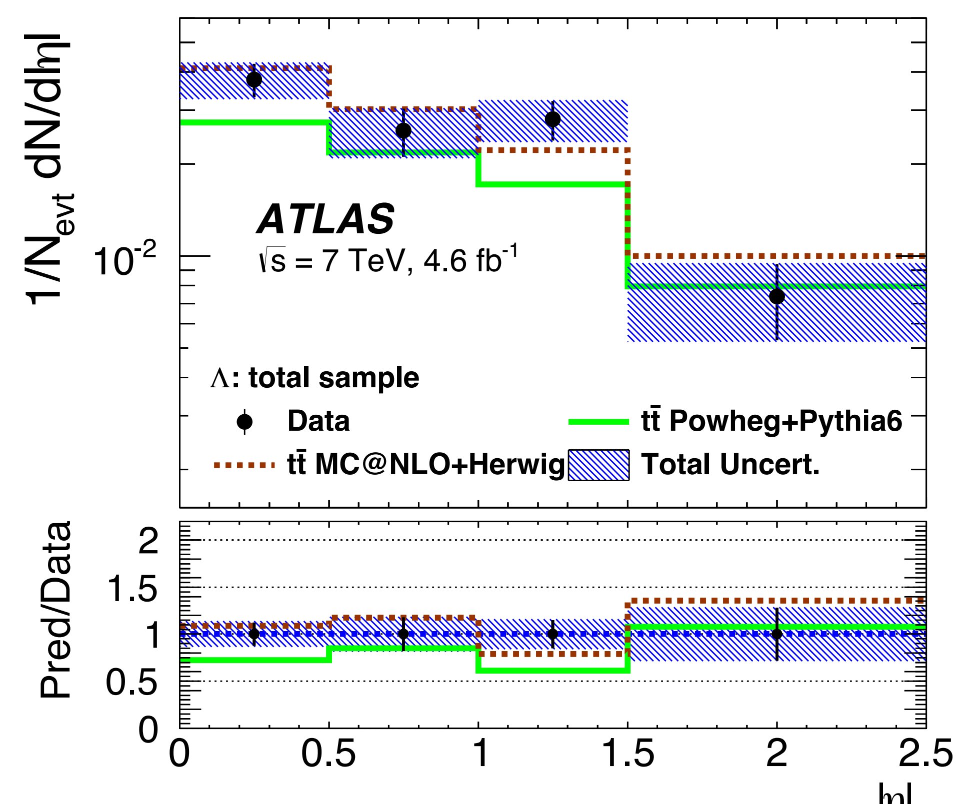
- to test theoretical jet fragmentation functions
- to constrain the underlying event (UE) effects
- → helpful to to tune strange particle content of MC models

Standard dilepton selection @7TeV data

- classification as inside bjet, inside non-b-jet and outside any jet
- unfolding to particle level



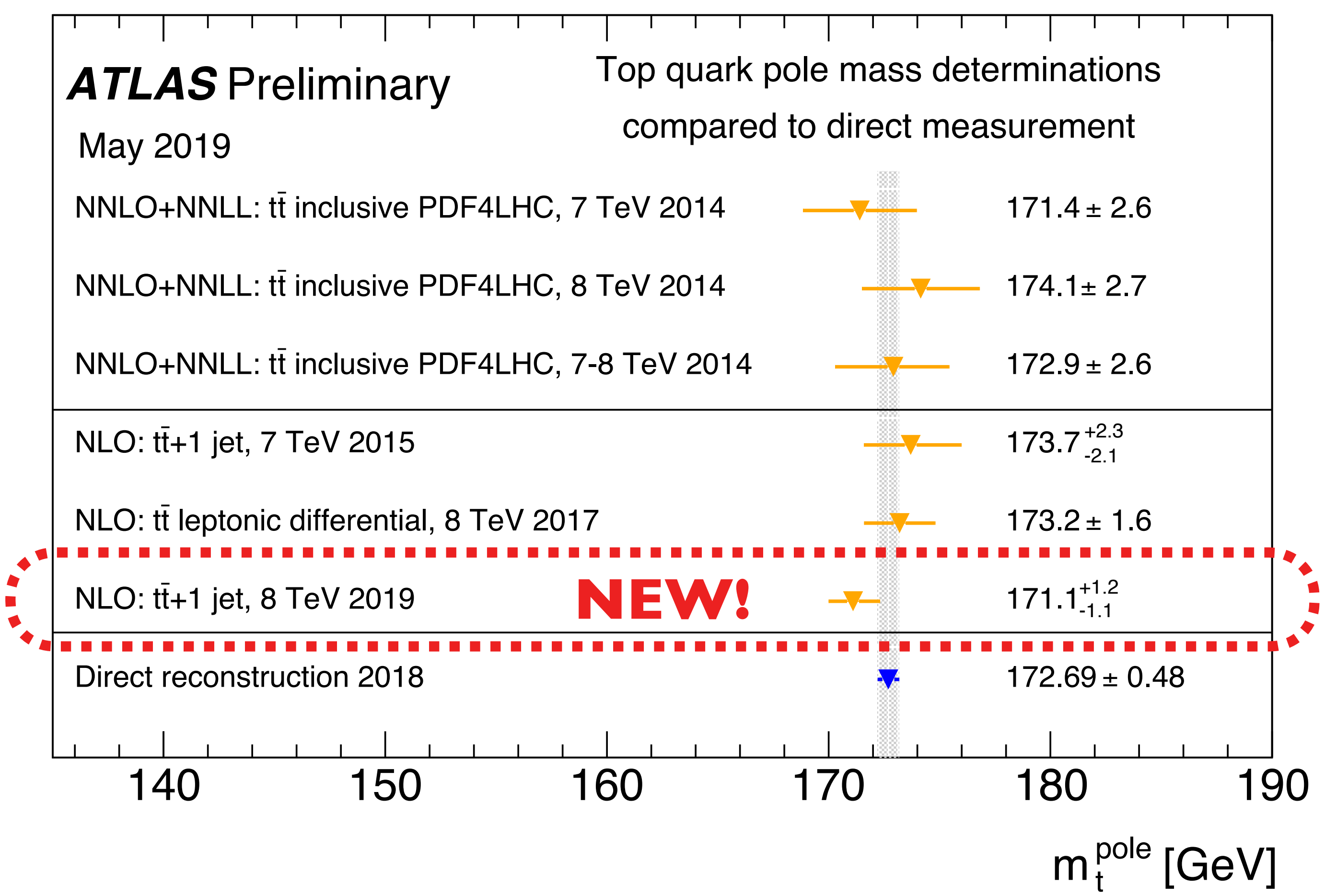

**some mismodelling for $K_s^0$ outside jets**

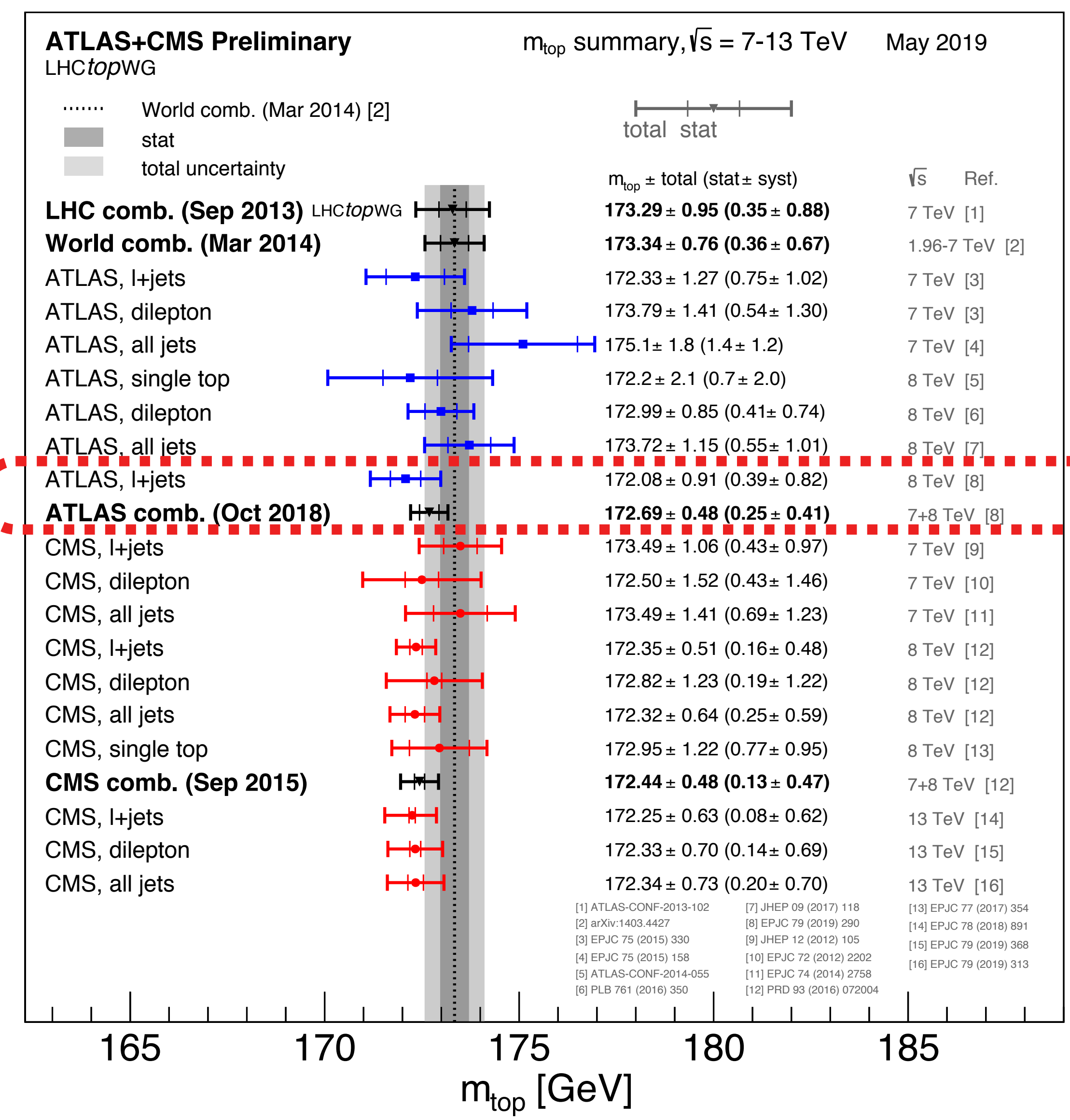



**$K_s^0$ and $\Lambda^0$ well described**

# Mass

Talk: *"Measurements of the top quark mass using the ATLAS detector at the LHC"*
Jiri Hejbal
**24/08 h11:50**



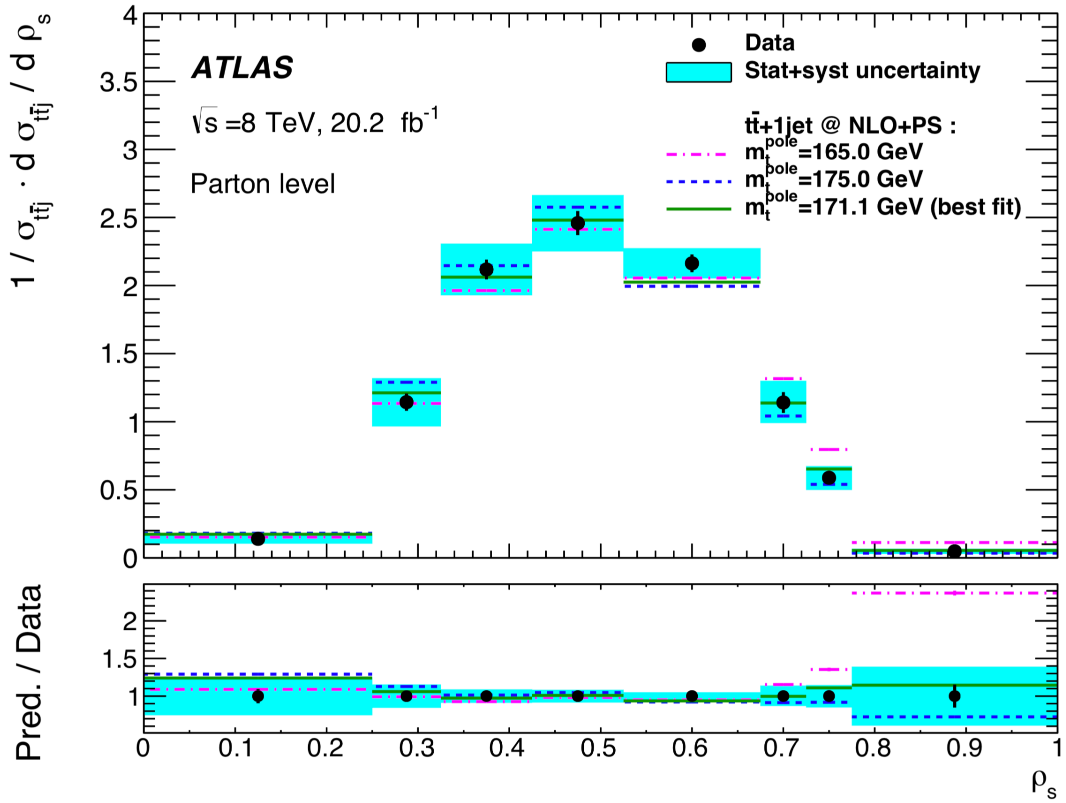



# Mass with $t\bar{t}$+1 jet

Submitted to JHEP - **NEW!**

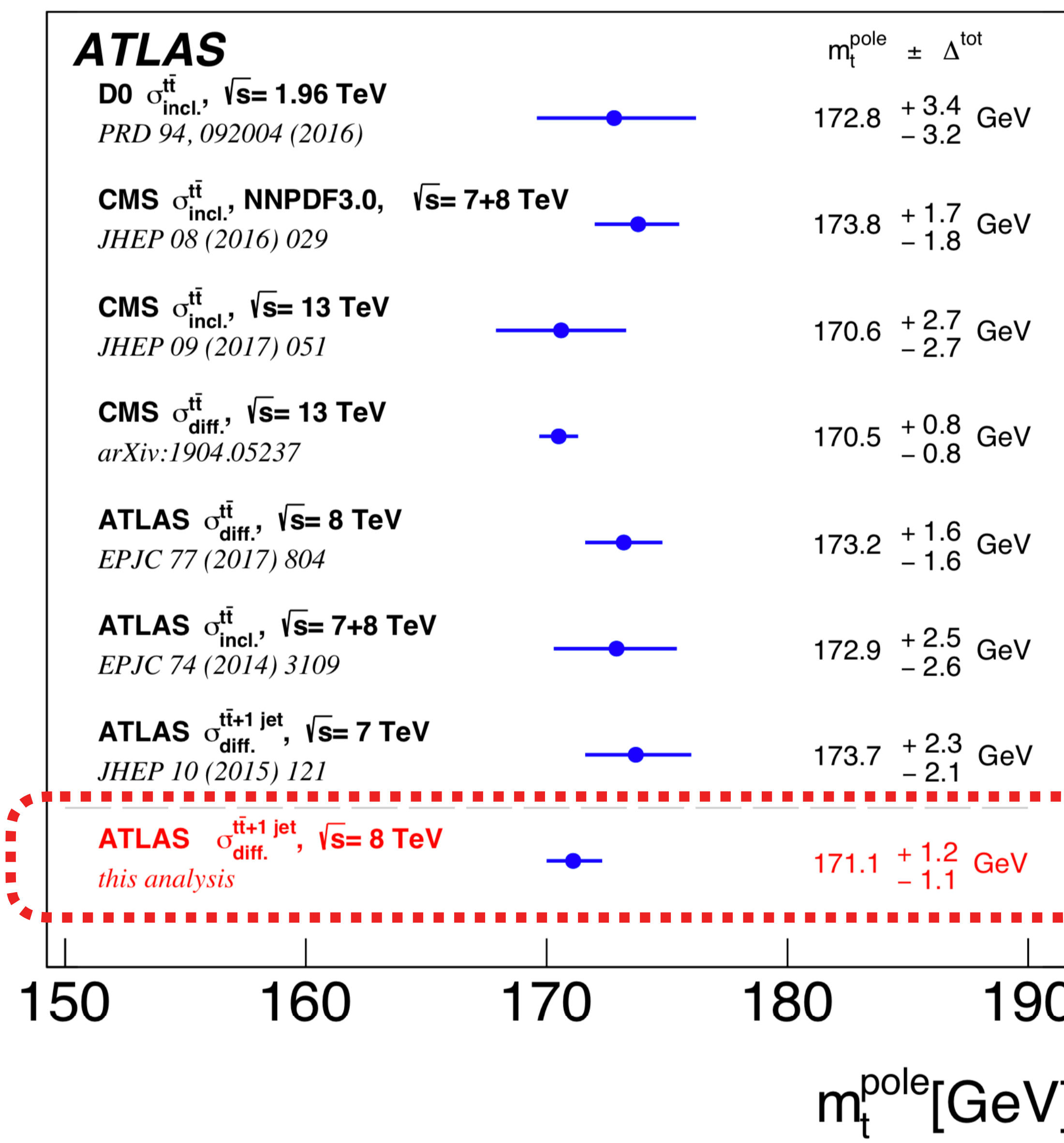
$$\rho_S = \frac{2m_0}{m_{t\bar{t}+1j}} = \frac{2\cdot 170\,\text{GeV}}{m_{t\bar{t}+1j}}$$

**sensitive to $m_{top}^{pole}$**




In ℓ+jets channel @8TeV

- $\sigma_{t\bar{t}+1j}$ more sensitive than $\sigma_{t\bar{t}}$
- unfold to parton and particle level



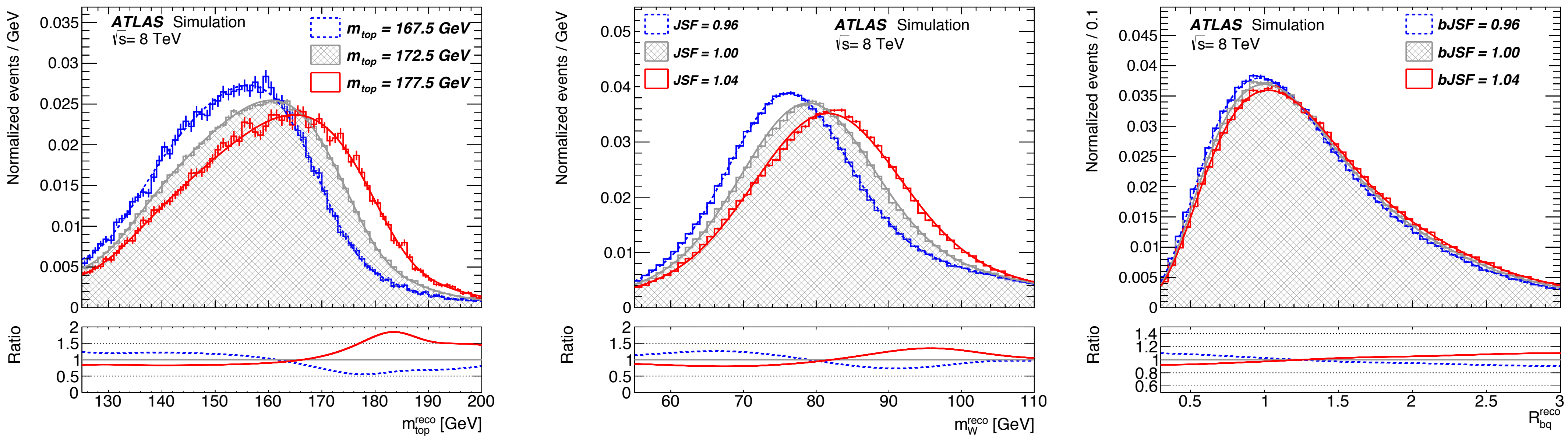

- $m_{top}^{pole}$ = 171.1 ± 1.2 GeV (0.7 %)

Best individual differential measurement

- dominated by JES and MC modelling uncertainties

# Mass combination

[EPJC 79 (2019) 290](EPJC 79 (2019) 290)



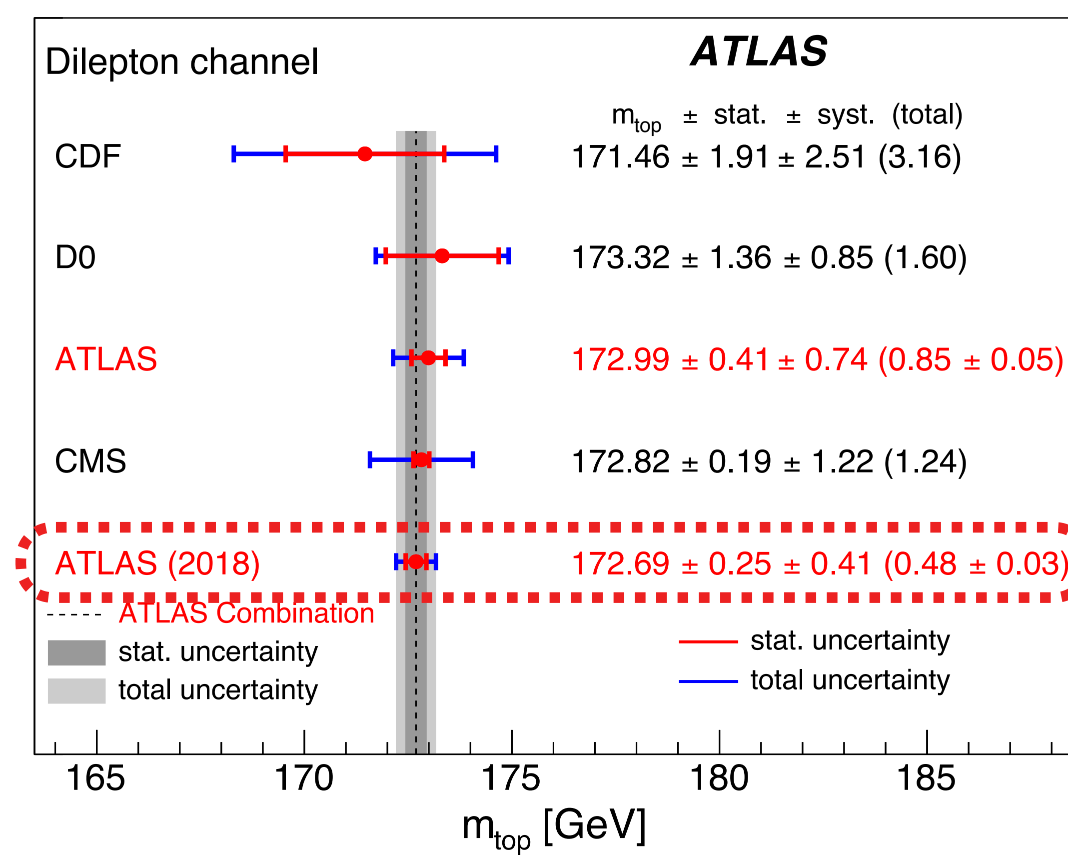

$$R_{bq}^{reco} = \frac{p_T^{b_{had}} + p_T^{b_{lep}}}{p_T^{W_{j1}} + p_T^{W_{j2}}}$$

In lepton+jets channel @8TeV

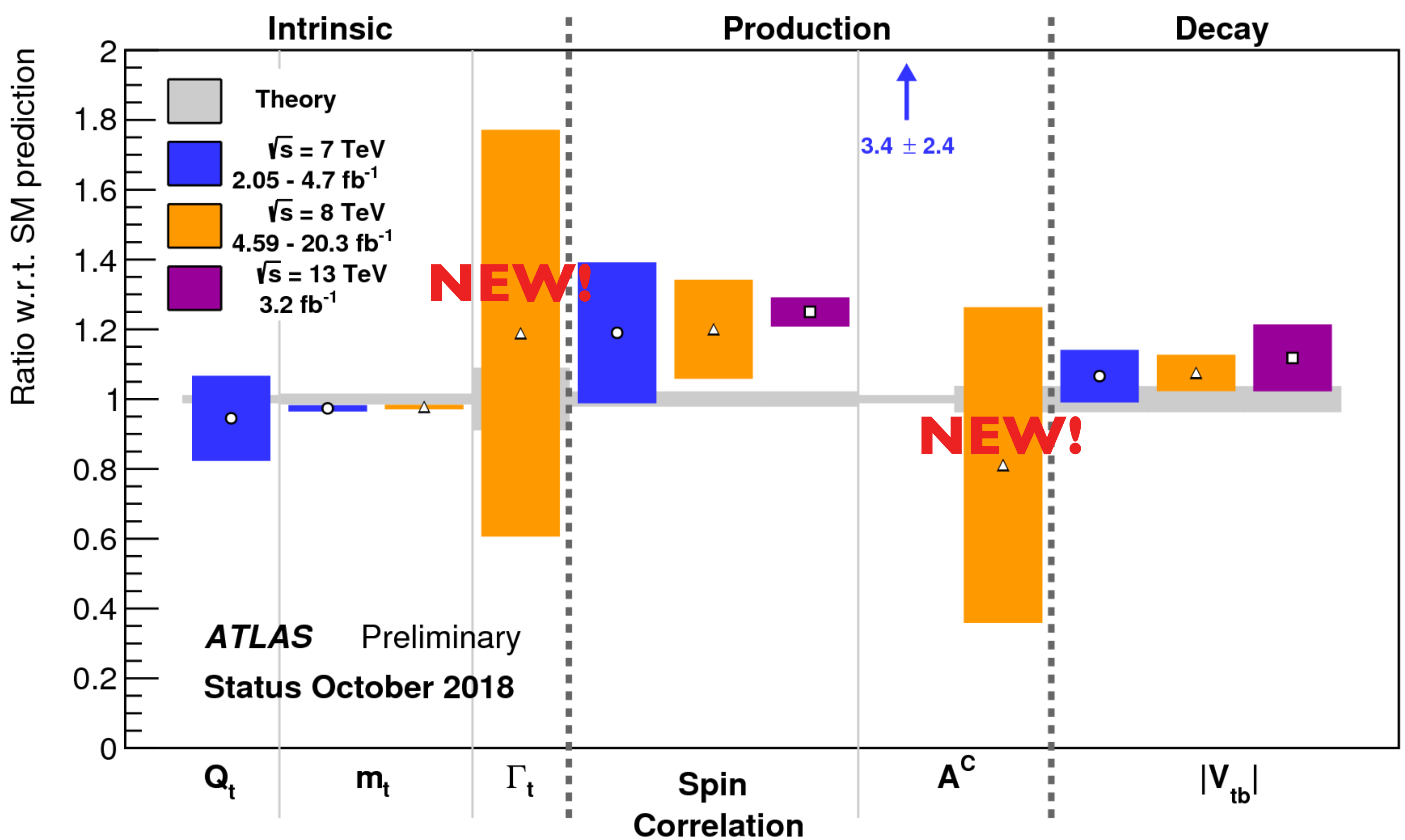
- sizeable uncertainties from JES and bJES
- ⇒ 3-D fit + BDT (19% improvement in $\Delta m_{top}$)
- $m_{top}$ = 172.08 ± 0.39 (stat) ± 0.82 (syst) GeV

Combination of 6 measurements @7,8TeV

- → **relative uncertainty 0.29%!**



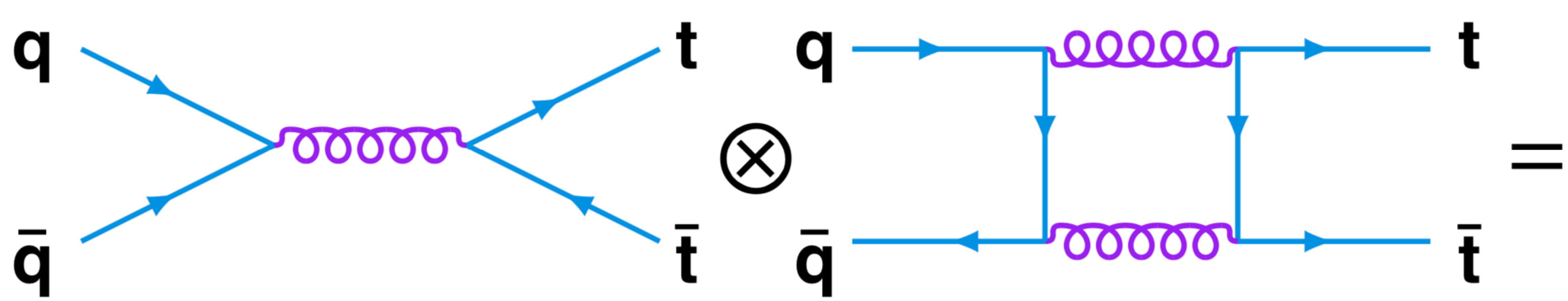
# Properties

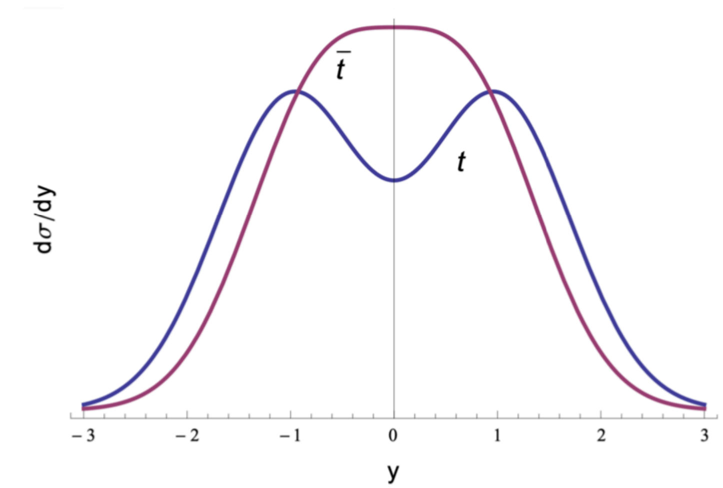


Intrinsic
Production
Decay
Ratio w.r.t. SM prediction
Theory
√s = 7 TeV
2.05 - 4.7 fb-1
√s = 8 TeV
4.59 - 20.3 fb-1
√s = 13 TeV
3.2 fb-1
3.4 ± 2.4
NEW!
NEW!
ATLAS Preliminary
Status October 2018
Qt
mt
Γt
Spin Correlation
AC
|Vtb|

# Charge asymmetry

ATLAS-CONF-2019-026 - **NEW!**




Induced by Interference between Born and Box diagrams

- analogue of Tevatron forward-backward asymmetry

"Charge asymmetry" only exists in higher-order $q\bar{q}$ production,

- gg-fusion is symmetric to all orders
- challenging to measure at the LHC ($q\bar{q}$ ~10% of production fraction at 13 TeV)

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

# Charge asymmetry

ATLAS-CONF-2019-026 - **NEW!**

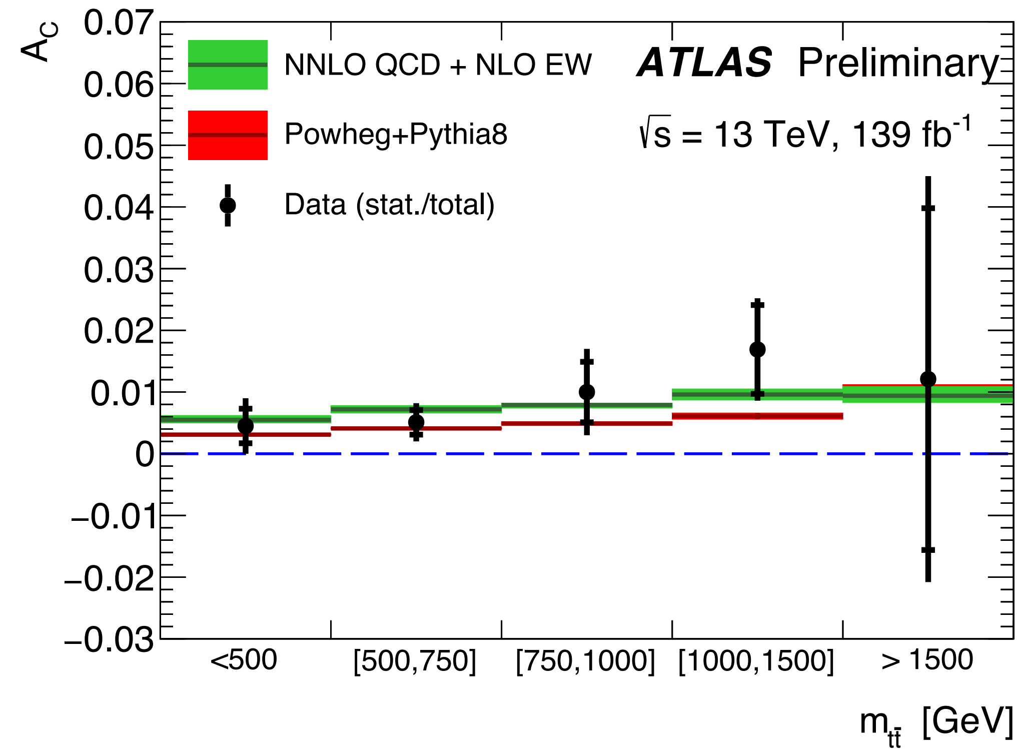
Extracted from 139 $fb^{-1}$ @13TeV data using single lepton (e/μ) selections

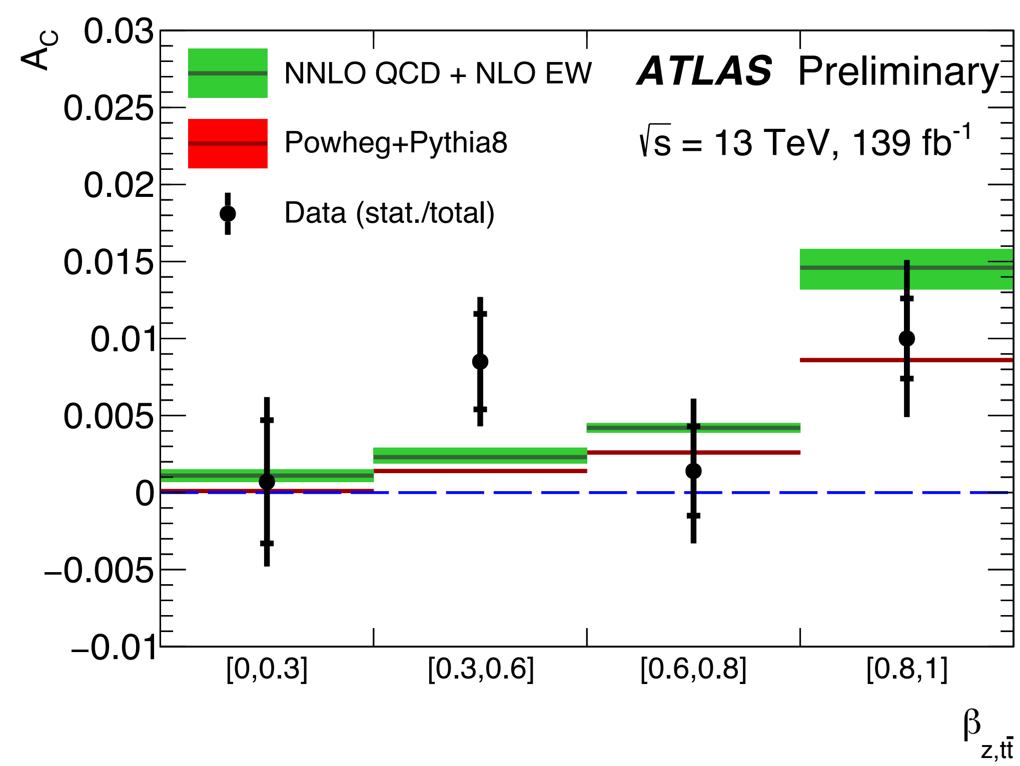
- resolved+boosted ($p_T$(t) ≳ 400 GeV)
- |Δ*y*| unfolded using a likelihood-based technique called "fully bayesian unfolding"

Charge asymmetry measured inclusively to be **$A_C$ = 0.6% ± 0.15%**

- in agreement with NNLO QCD + NLO EW predictions
- 4σ from 0-asymmetry hypothesis
- measurements reinterpreted in EFT

**First evidence for charge asymmetry in pp collisions!**



# Top width

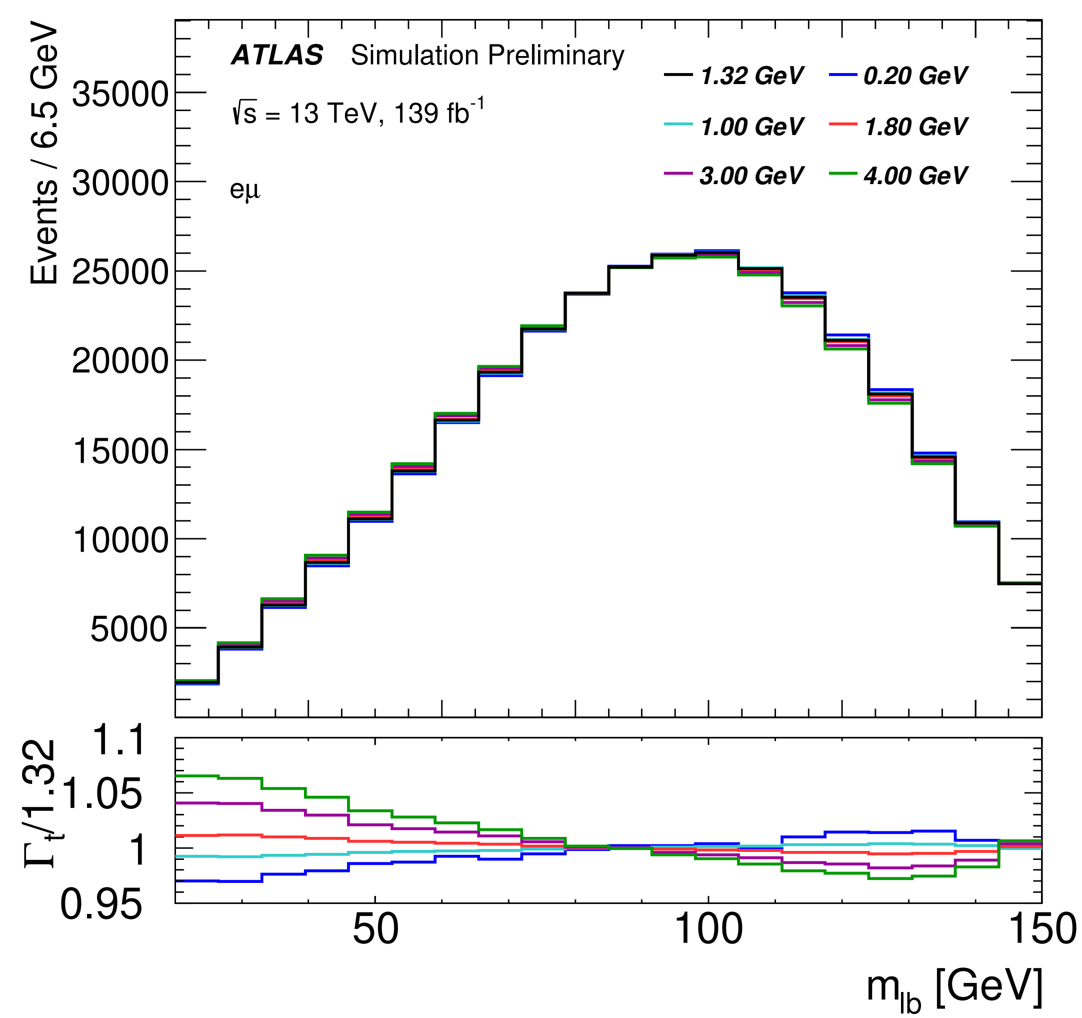
ATLAS-CONF-2019-038 - **NEW!**

Decay width (Γ) is an important property of any particle

- BSM models predict different $\Gamma_t$ compared to SM
- prediction: $\Gamma_t^{SM}$ = 1.32 GeV for $m_t$ = 172.5 GeV (NNLO)
- precise 8 TeV measurement, still not enough to constrain BSM
  - $\Gamma_t = 1.76 \pm 0.33\,(\text{stat.}) {}^{+0.79}_{-0.68}\,(\text{syst.})$ GeV [Eur. Phys. J. C 78 (2018) 129]

Measurement performed with dilepton $t\bar{t}$ events, full Run II data (139 $fb^{-1}$)

- $m_{lb}$ very sensitive to $\Gamma_t$
  - templates created with different Γt
- profile likelihood with multiple templates
- control regions ($m_{bb}$ in ee/μμ channels)



# Top width

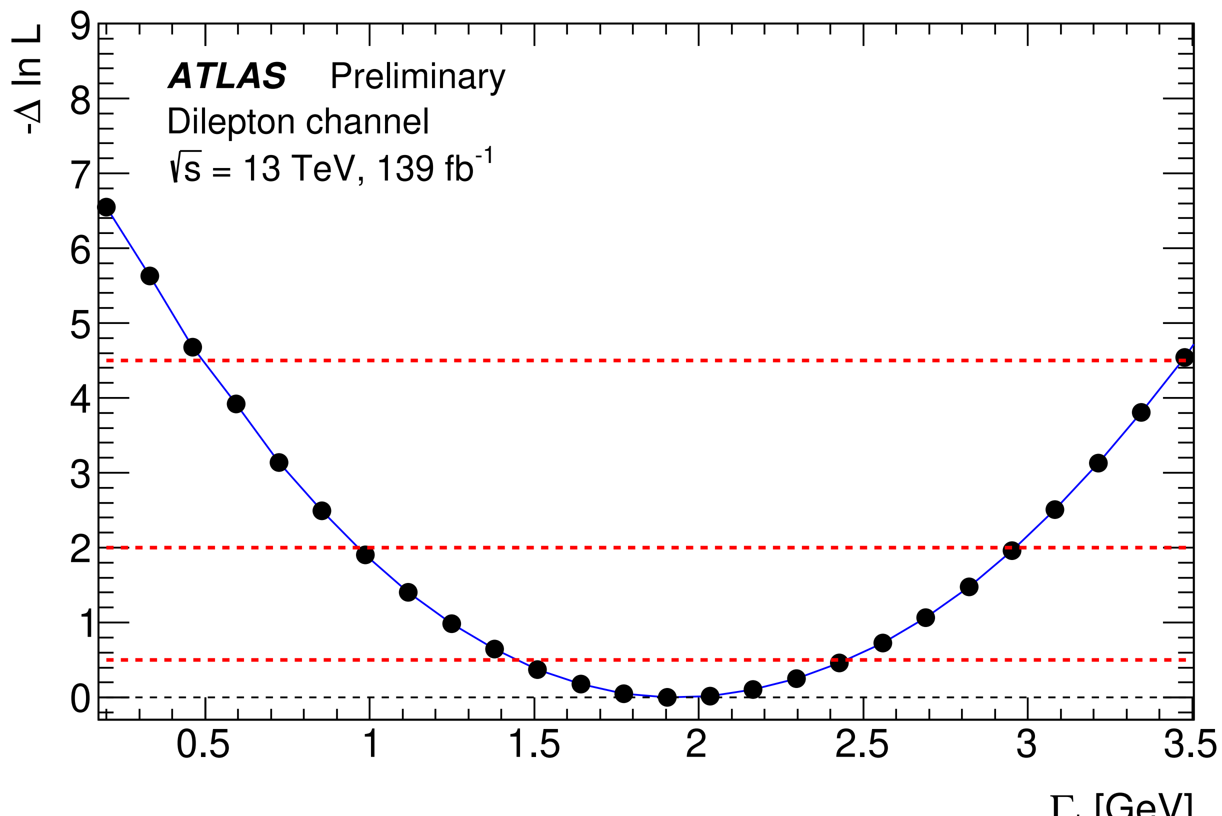
ATLAS-CONF-2019-038 - **NEW!**

| | $m_t$ = 172 GeV | | $m_t$ = 172.5 GeV | | $m_t$ = 173 GeV | |
|---|---|---|---|---|---|---|
| | Mean [GeV] | Unc. [GeV] | Mean [GeV] | Unc. [GeV] | Mean [GeV] | Unc. [GeV] |
| Measured | 2.01 | $^{+0.53}_{-0.50}$ | 1.94 | $^{+0.52}_{-0.49}$ | 1.90 | $^{+0.52}_{-0.48}$ |
| Theory | 1.306 | < 1% | 1.322 | < 1% | 1.333 | < 1% |

$\Gamma_t$ measured for different $m_{top}$

- good agreement with SM preditions

Significant improvement w.r.t. previous measurements




| Source | Impact on $\Gamma_t$ [GeV] |
|---|---|
| Jet reconstruction | ±0.24 |
| Signal and bkg. modelling | ±0.19 |
| MC statistics | ±0.14 |
| Flavour tagging | ±0.13 |
| $E_T^{miss}$ reconstruction | ±0.09 |
| Pile-up and luminosity | ±0.09 |
| Electron reconstruction | ±0.07 |
| PDF | ±0.04 |
| $t\bar{t}$ normalisation | ±0.03 |
| Muon reconstruction | ±0.02 |
| Fake-lepton modelling | ±0.01 |

# $t\bar{t}$ spin correlation

Submitted to EPJC

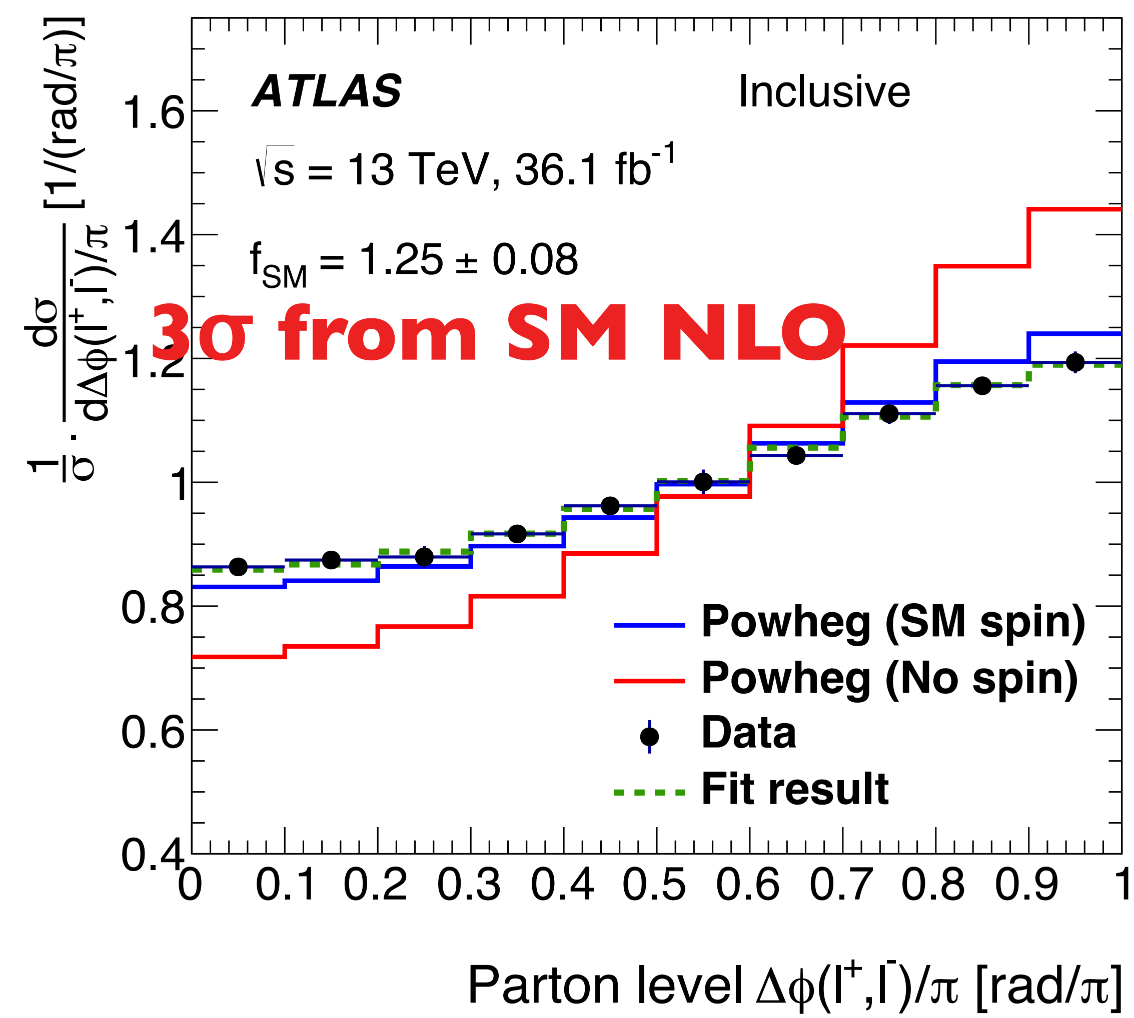
$$C = A\alpha_1\alpha_2 = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow)}$$

Correlated spins between top pairs produced at LHC

- accessible via $|\Delta\phi_{\ell\ell}|$, in dilepton $t\bar{t}$ decays, no top reconstruction required

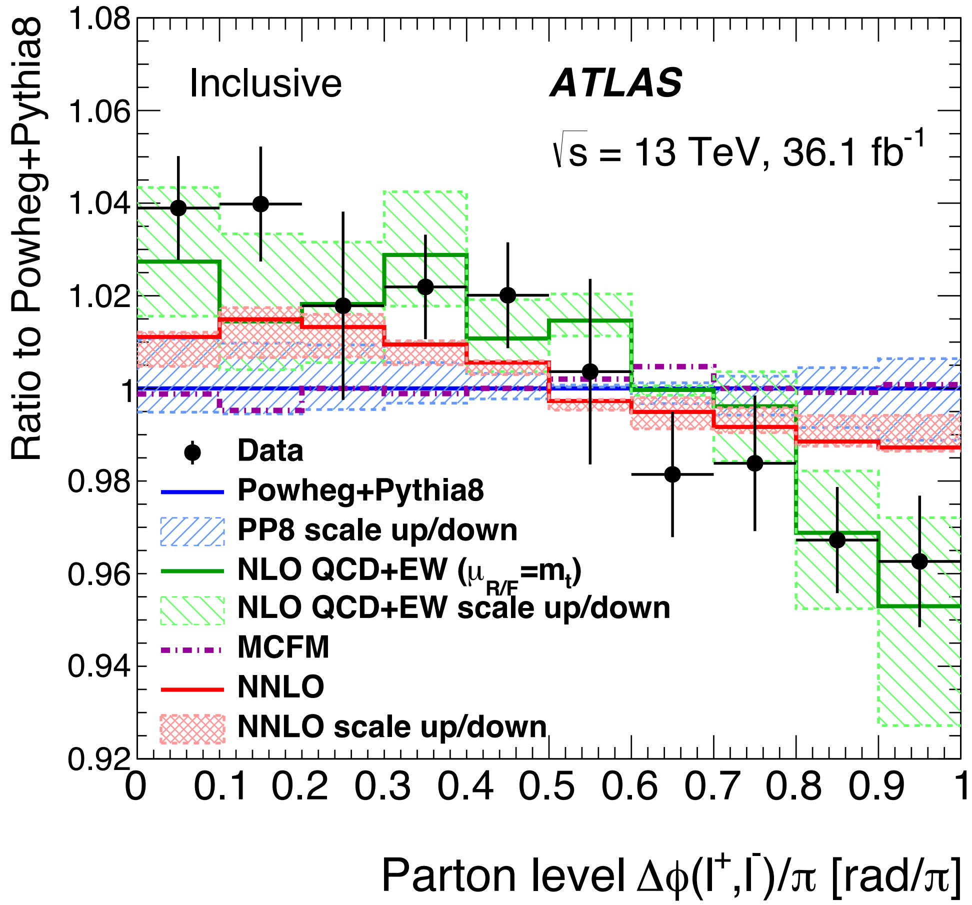
Measured @13TeV (36 fb$^{-1}$) in eμ+2b channel

- also differentially in $m(t\bar{t})$
- also measured the $|\Delta\eta_{\ell\ell}|$ observable, sensitive to SUSY production
- unfolded to fiducial particle level and full phase-space parton level

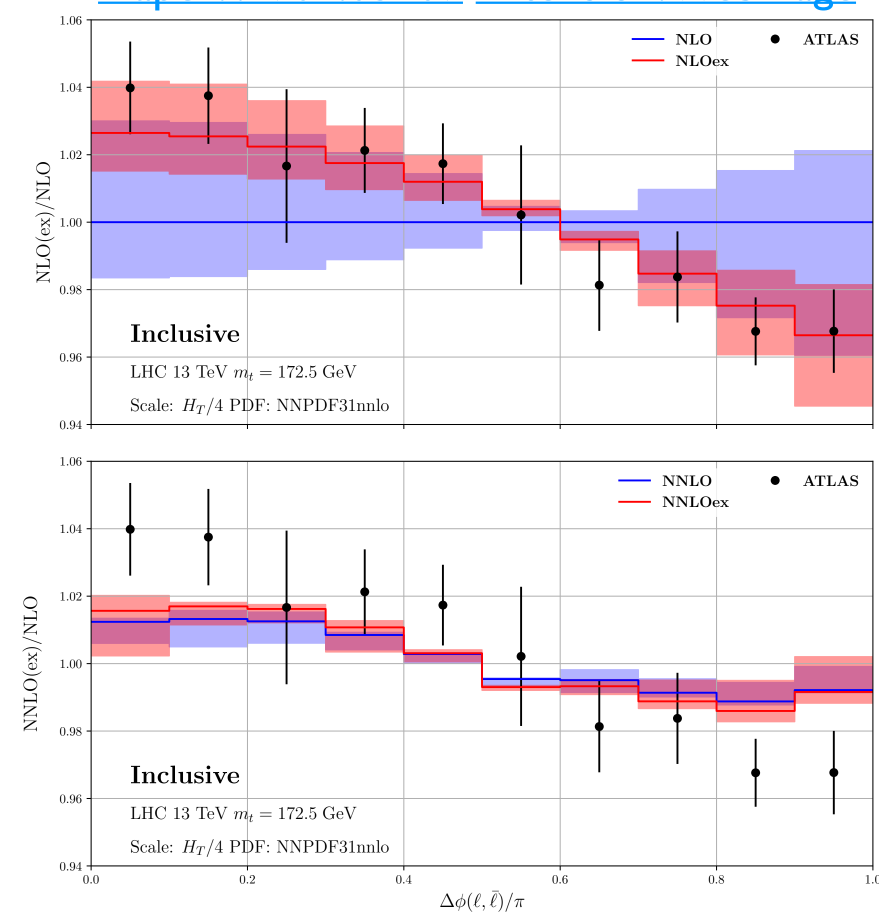


# $t\bar{t}$ spin correlation

Submitted to EPJC




Paper: :1901.05407 Extension: Web Page

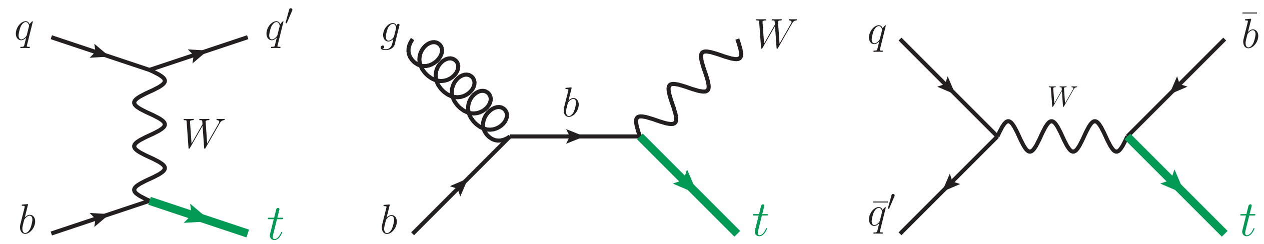



Lots of discussions in the theory community

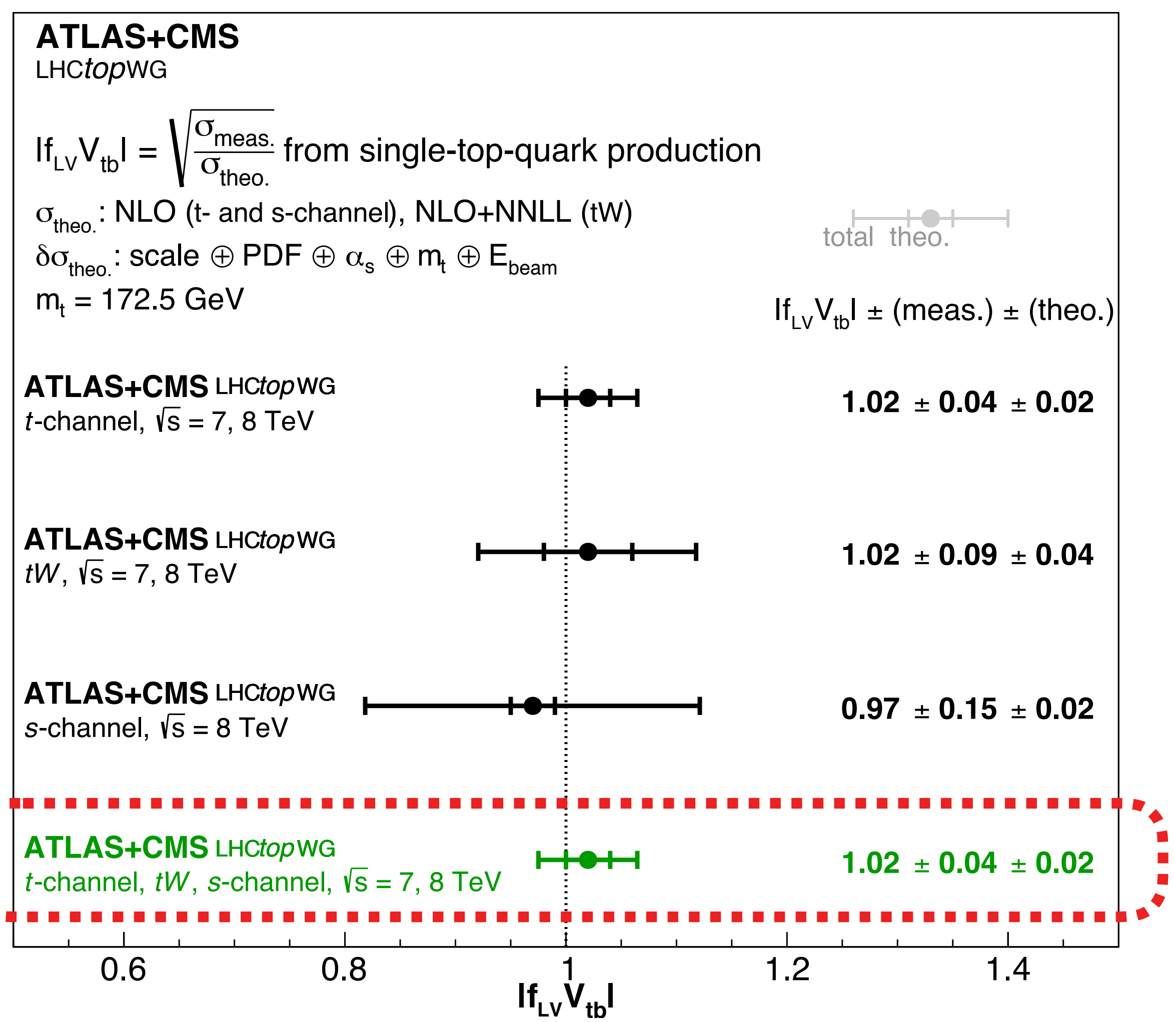
- focus on the assumptions involved in the template hypotheses
- **NLO + Parton** shower MC consistent with fixed-order calculations from **MCFM**
- state-of the art **NNLO-QCD** predictions (Brun et. al.) closer to data (2.2σ)
- **NLO-QCD + EW** prediction agrees with data but with large scale uncertainties
  - agreement driven by ratio expansion method
- when **ratio expanded at NNLO**, the agreement disappears

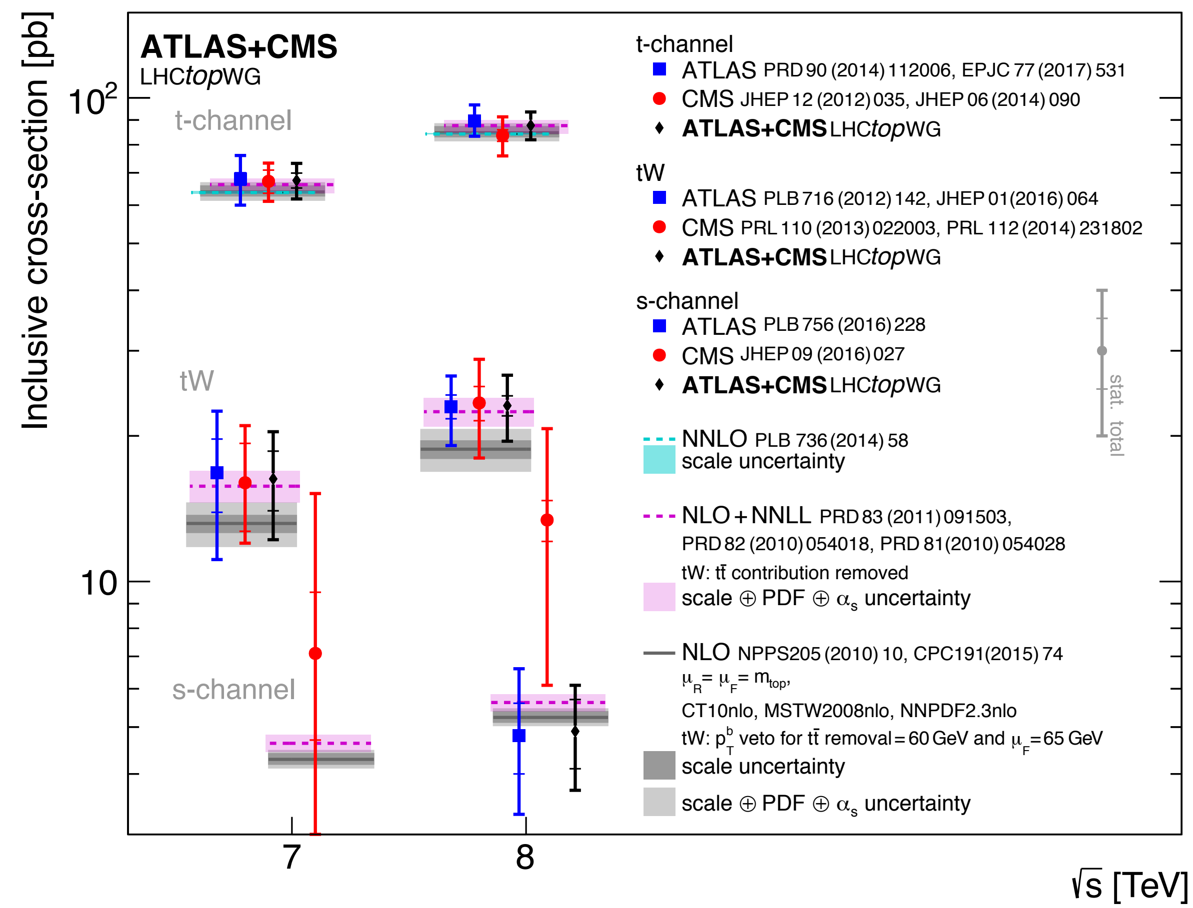
# $V_{tb}$: ATLAS+CMS

JHEP 05 (2019) 088




| **t-channel** | **tW-channel** | **s-channel** |
|---|---|---|
| Most abundant, Constrains PDF | Interference with $t\bar{t}$ | Small cross-section, BSM resonances? |



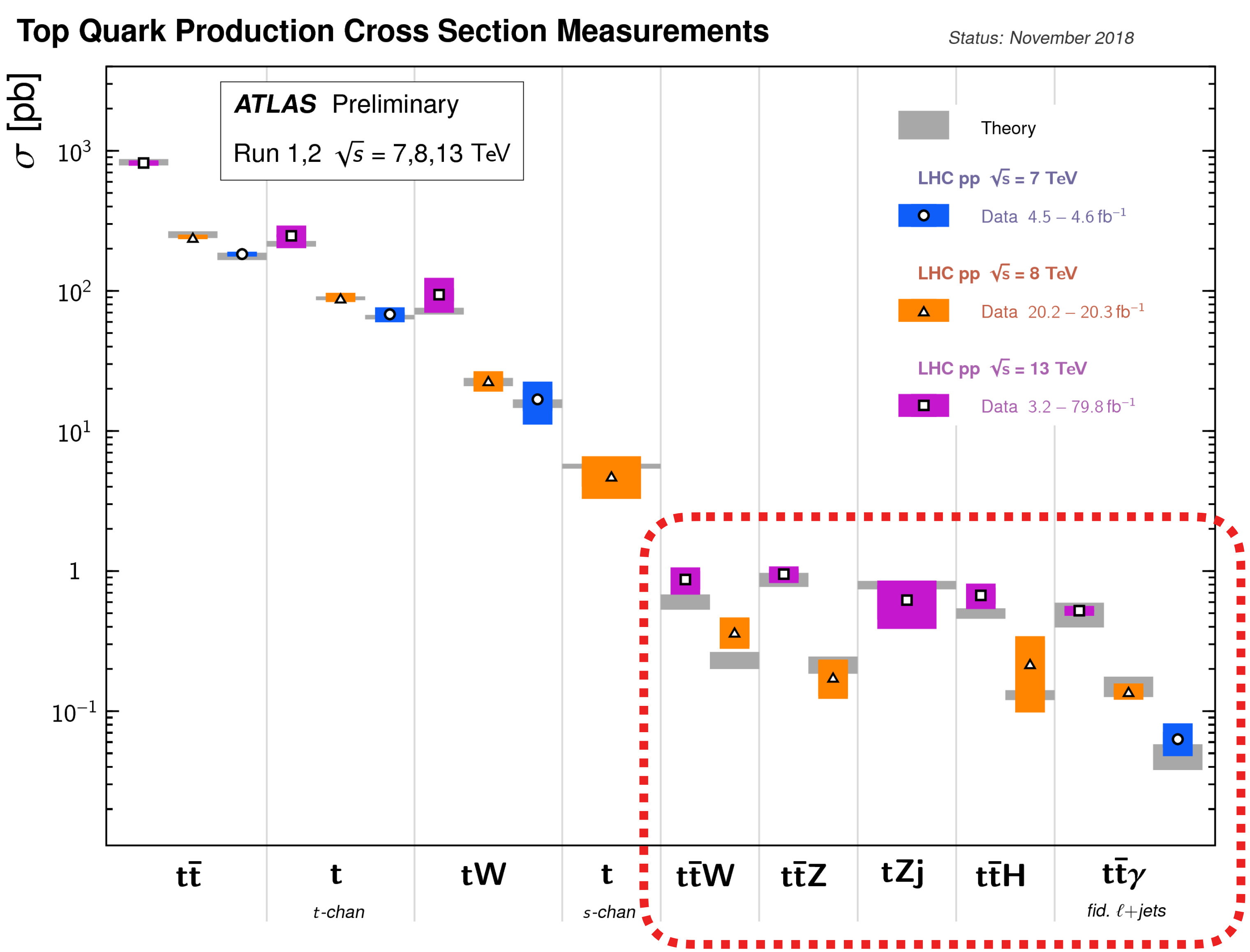

Combinations of single-top x-sections

- data from pp collisions @7+8TeV
- all combined measurements consistent with corresponding SM predictions

# Associated production: $t(\bar{t}) + W/Z/\gamma$

Talk: "*Measurements of $t\bar{t}$ pairs produced in association with electroweak gauge bosons using the ATLAS detector*"
Paul Glaysher - **28/08 h16:50**

Poster: "*Searches for four top quarks production using the ATLAS detector*"
Thibault Chevalerias - **26/08 h20:30**



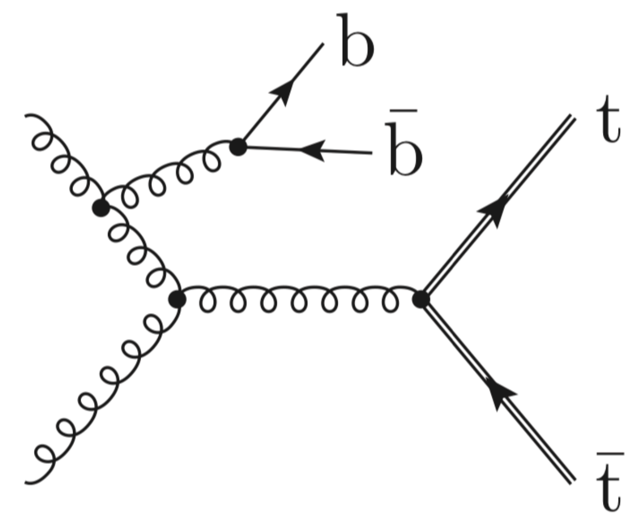
# $t\bar{t}+b\bar{b}$

JHEP 04 (2019) 046

ATLAS EXPERIMENT

Important for new physics and rare searches

- state-of-the-art NLO predictions suffer from large uncertainty
- experimental input needed to test predictions

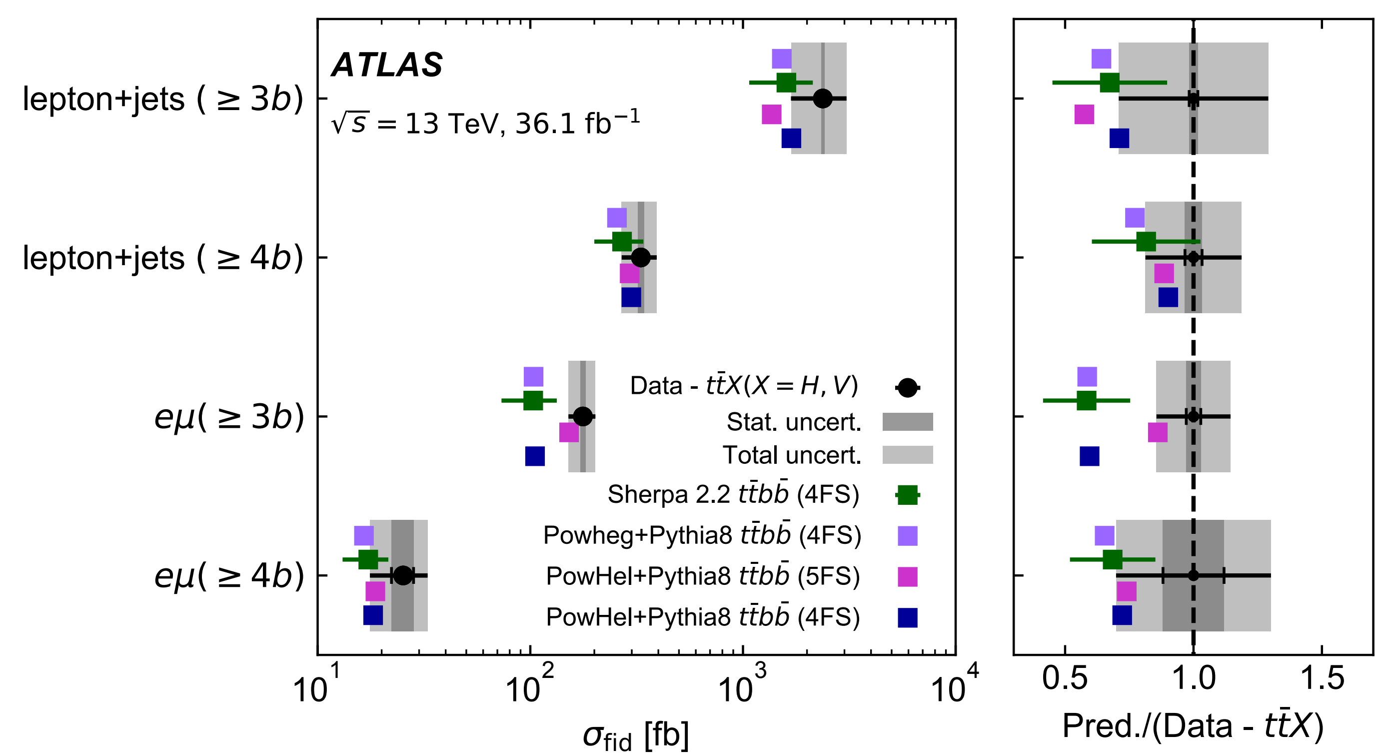



Fiducial and differential $t\bar{t}+b\bar{b}$ cross sections in $\ell$+jets and dilepton channels using 36 fb$^{-1}$ (@13TeV)

- unfolded to particle level

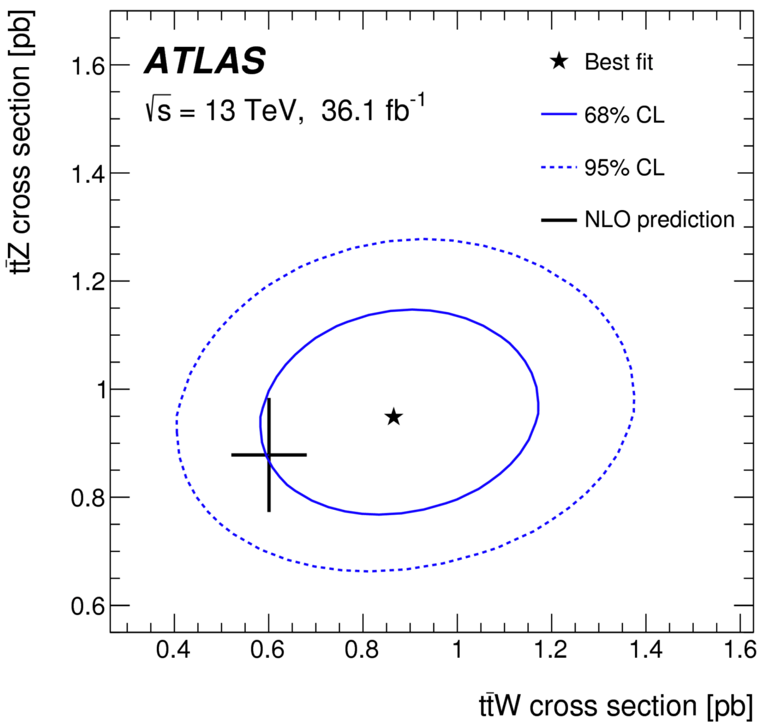
General excess w.r.t. various NLO predictions

- still compatible within total uncertainties
- **experimental uncertainty smaller than theory one**



# $t\bar{t}$+W/Z/g/$t\bar{t}$

ATLAS EXPERIMENT

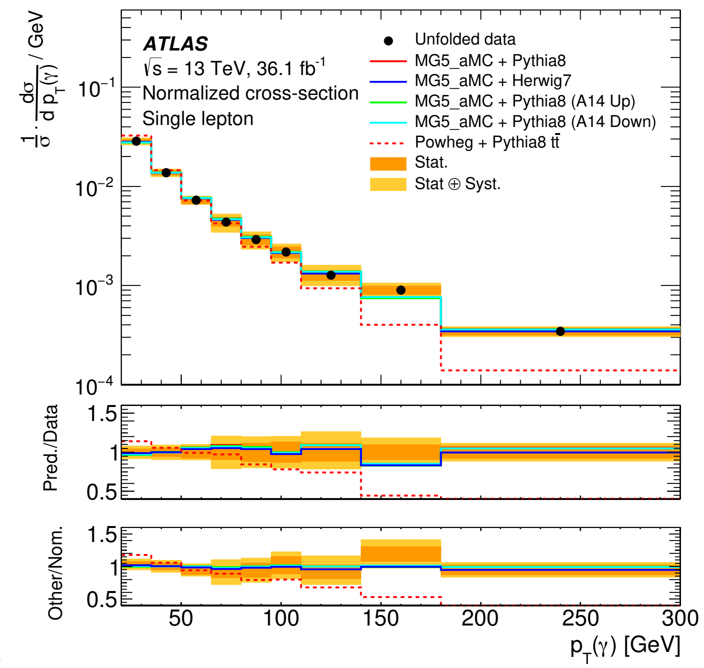



## ttW/Z

**Observed x-sections in agreement with SM**

Limits set to EFT O₆ Wilson coefficients

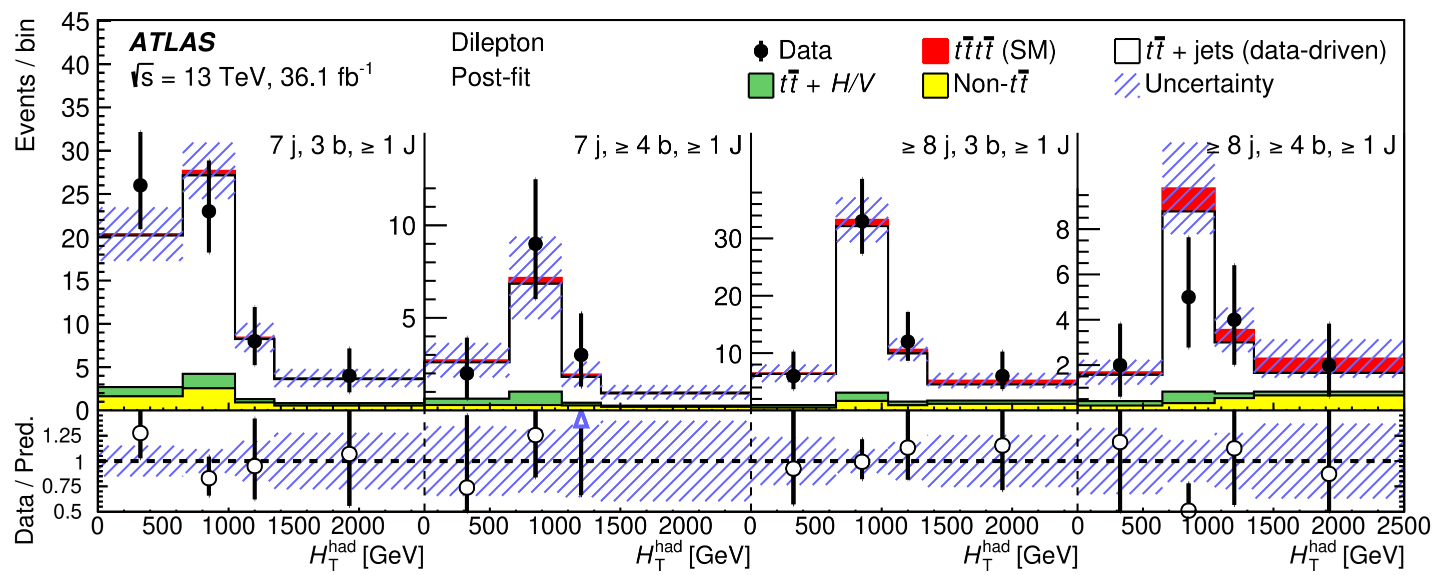
[PRD 99 (2019) 072009]




## ttγ

Measurement in $\ell$+jets and dilepton γ observables in **agreement with SM**

[Eur. Phys. J. C 79 (2019) 382]




## 4tops

x-section enhanced in BSM models

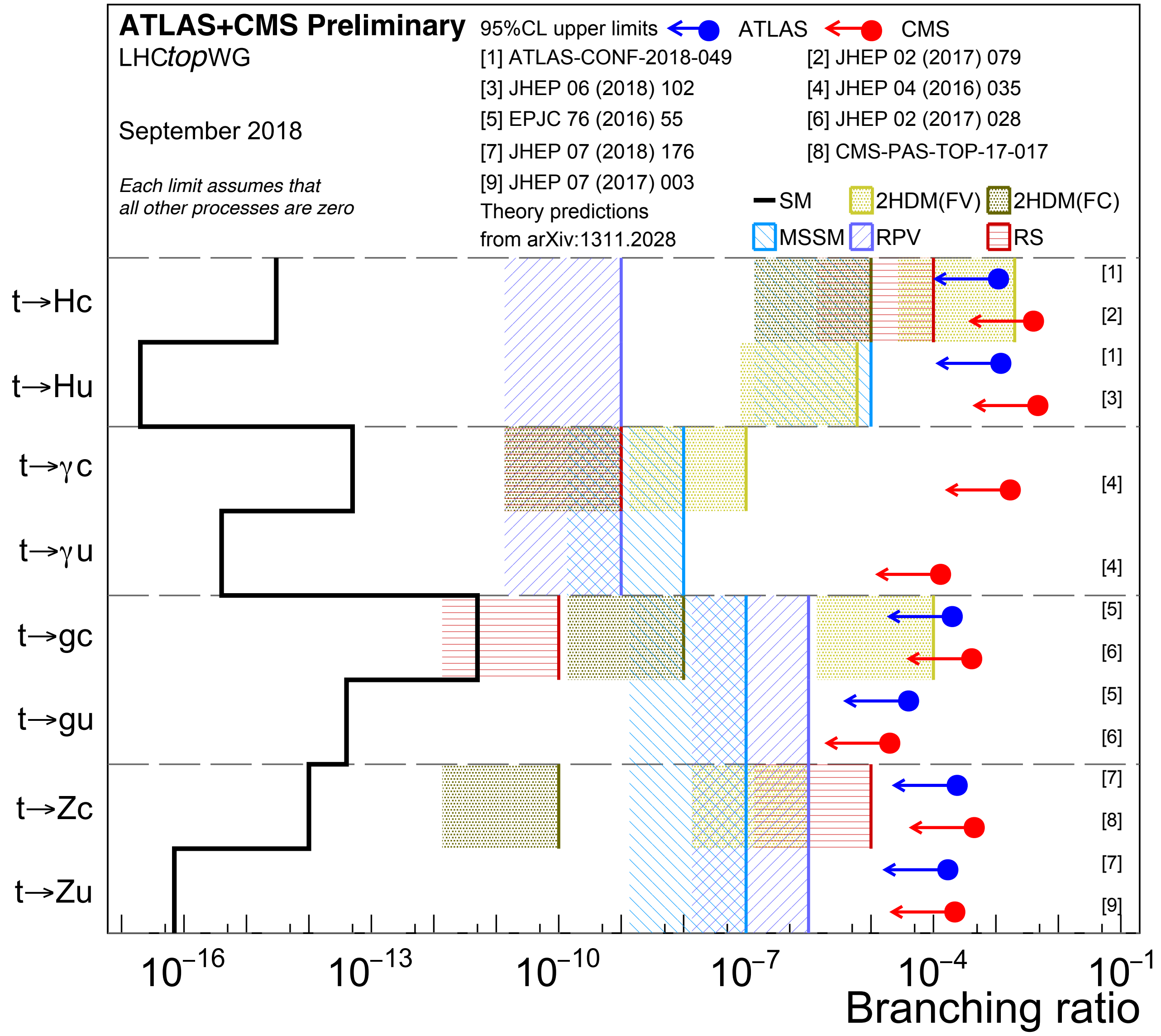
Background to $t\bar{t}$+H

**No significant excess observed**

[Phys. Rev. D 99 (2019) 052009]

Further public results:
[twiki.cern.ch/twiki/AtlasPublic/TopPublicResults]

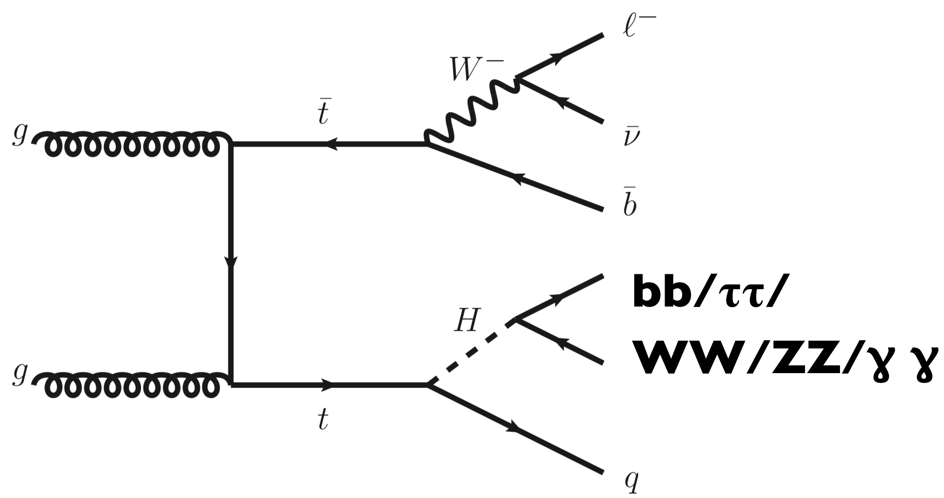
# Searches



ATLAS+CMS Preliminary
LHCtopWG
September 2018
Each limit assumes that all other processes are zero
95%CL upper limits ATLAS CMS
[1] ATLAS-CONF-2018-049
[2] JHEP 02 (2017) 079
[3] JHEP 06 (2018) 102
[4] JHEP 04 (2016) 035
[5] EPJC 76 (2016) 55
[6] JHEP 02 (2017) 028
[7] JHEP 07 (2018) 176
[8] CMS-PAS-TOP-17-017
[9] JHEP 07 (2017) 003
Theory predictions from arXiv:1311.2028
SM
2HDM(FV)
2HDM(FC)
MSSM
RPV
RS
t→Hc
t→Hu
t→γc
t→γu
t→gc
t→gu
t→Zc
t→Zu
$10^{-16}$
$10^{-13}$
$10^{-10}$
$10^{-7}$
$10^{-4}$
$10^{-1}$
Branching ratio

# FCNC tH

JHEP 05 (2019) 123




Flavour-changing neutral currents (FCNC)

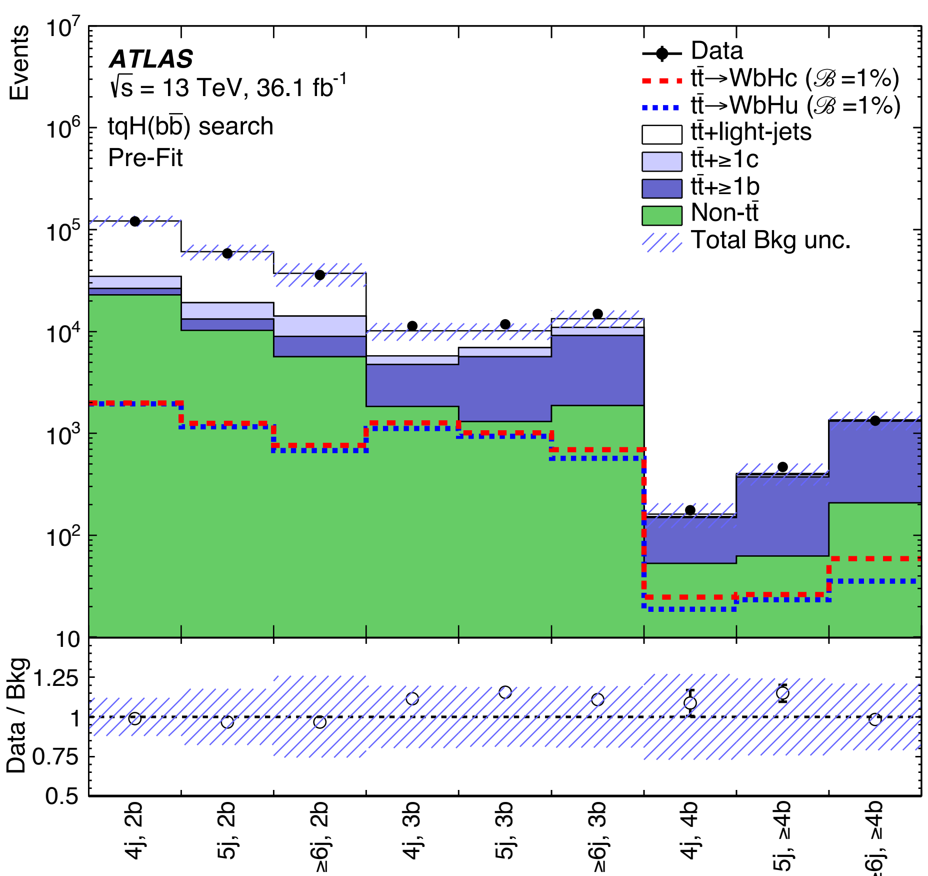
- forbidden at tree level
- BSM can enhance FCNC production

$H \to b\bar{b}$: several regions ($N_{jets}$, $N_{b\text{-}tags}$)

- likelihood discriminant employed

$H \to \tau_{had}\tau_{had}/\tau_{lep}\tau_{had}$: 4 regions (based on $N_{\tau had}$)

- event reco. ($\chi^2$) + MVA technique



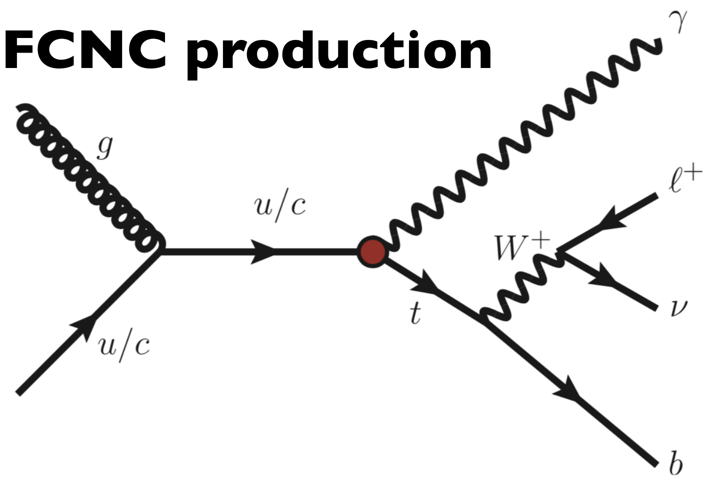

Combination with γγ and multilepton

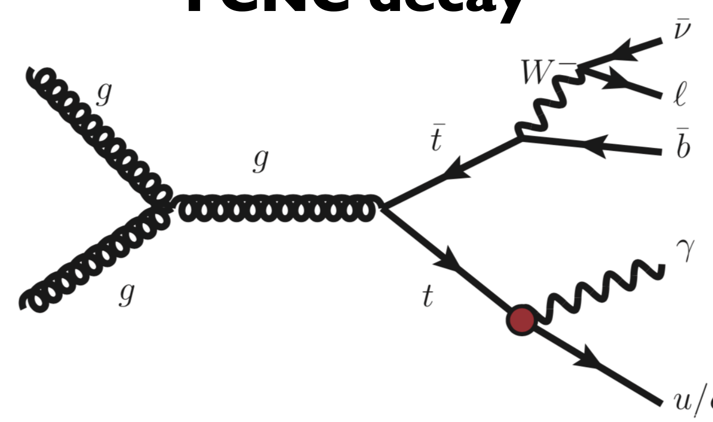
- $BR(t \to uH) < 12 \times 10^{-4}$ ($8.3 \times 10^{-4}$)
- $BR(t \to cH) < 11 \times 10^{-4}$ ($8.3 \times 10^{-4}$)
- $|\lambda_{tuH}| < 0.066$ (0.055)
- $|\lambda_{tcH}| < 0.064$ (0.055)

# FCNC tqγ

Submitted to Phys. Lett. B - **NEW!**

**FCNC production** **FCNC decay**



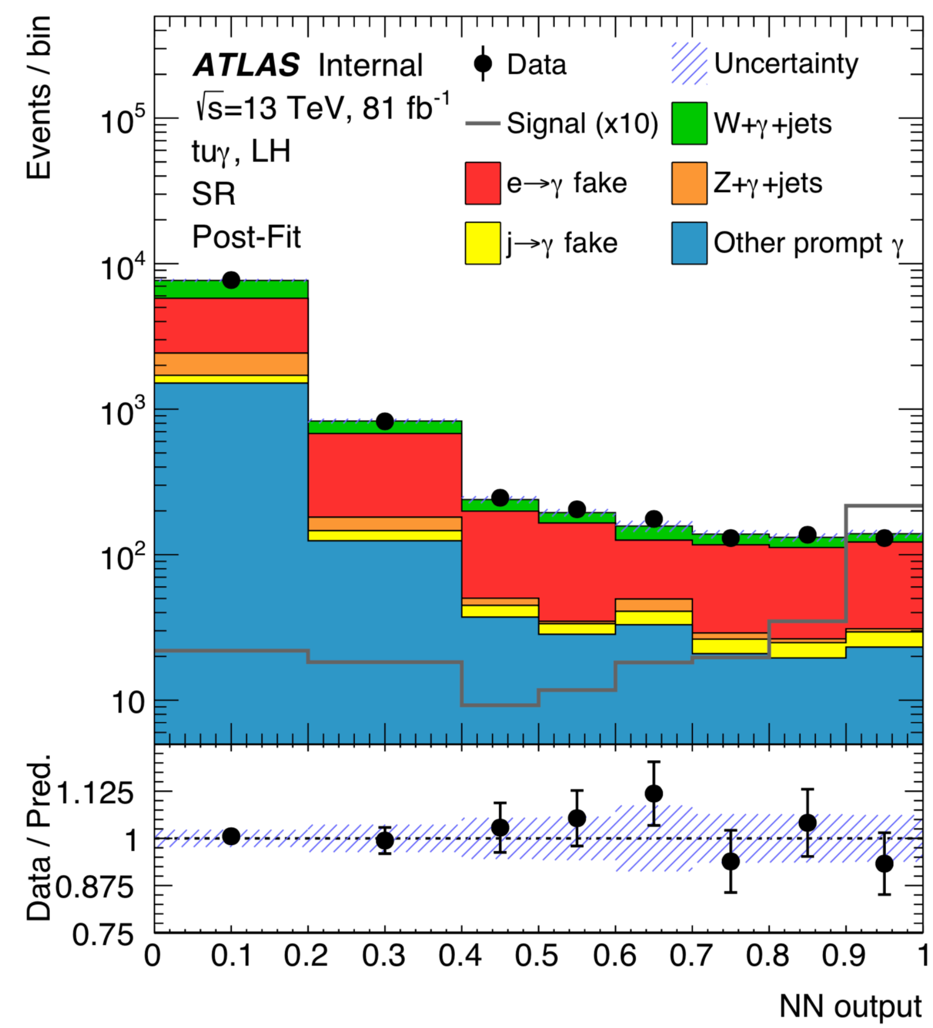




Analysis performed @13TeV (81 fb$^{-1}$)

- lepton + 1 photon channel
- NN to discern tγu/tγc vs. background

Consistent with background-only hypothesis

| Observable | Vertex | Coupling | Obs. | Exp. |
|---|---|---|---|---|
| $\sigma(pp \to t\gamma)$ [fb] | $tu\gamma$ | LH | 36 | $52^{+21}_{-14}$ |
| $\sigma(pp \to t\gamma)$ [fb] | $tu\gamma$ | RH | 78 | $75^{+31}_{-21}$ |
| $\sigma(pp \to t\gamma)$ [fb] | $tc\gamma$ | LH | 40 | $49^{+20}_{-14}$ |
| $\sigma(pp \to t\gamma)$ [fb] | $tc\gamma$ | RH | 33 | $52^{+22}_{-14}$ |
| $\mathcal{B}(t \to q\gamma)\,[10^{-5}]$ | $tu\gamma$ | LH | 2.8 | $4.0^{+1.6}_{-1.1}$ |
| $\mathcal{B}(t \to q\gamma)\,[10^{-5}]$ | $tu\gamma$ | RH | 6.1 | $5.9^{+2.4}_{-1.6}$ |
| $\mathcal{B}(t \to q\gamma)\,[10^{-5}]$ | $tc\gamma$ | LH | 22 | $27^{+11}_{-7}$ |
| $\mathcal{B}(t \to q\gamma)\,[10^{-5}]$ | $tc\gamma$ | RH | 18 | $28^{+12}_{-8}$ |



# Conclusions

The top quark has come a long way since 1977

- back then: missing quark, assumed to be similar to other quarks
- today: know that top quark is special

In precision era, top quark is key to an abundance of different research areas

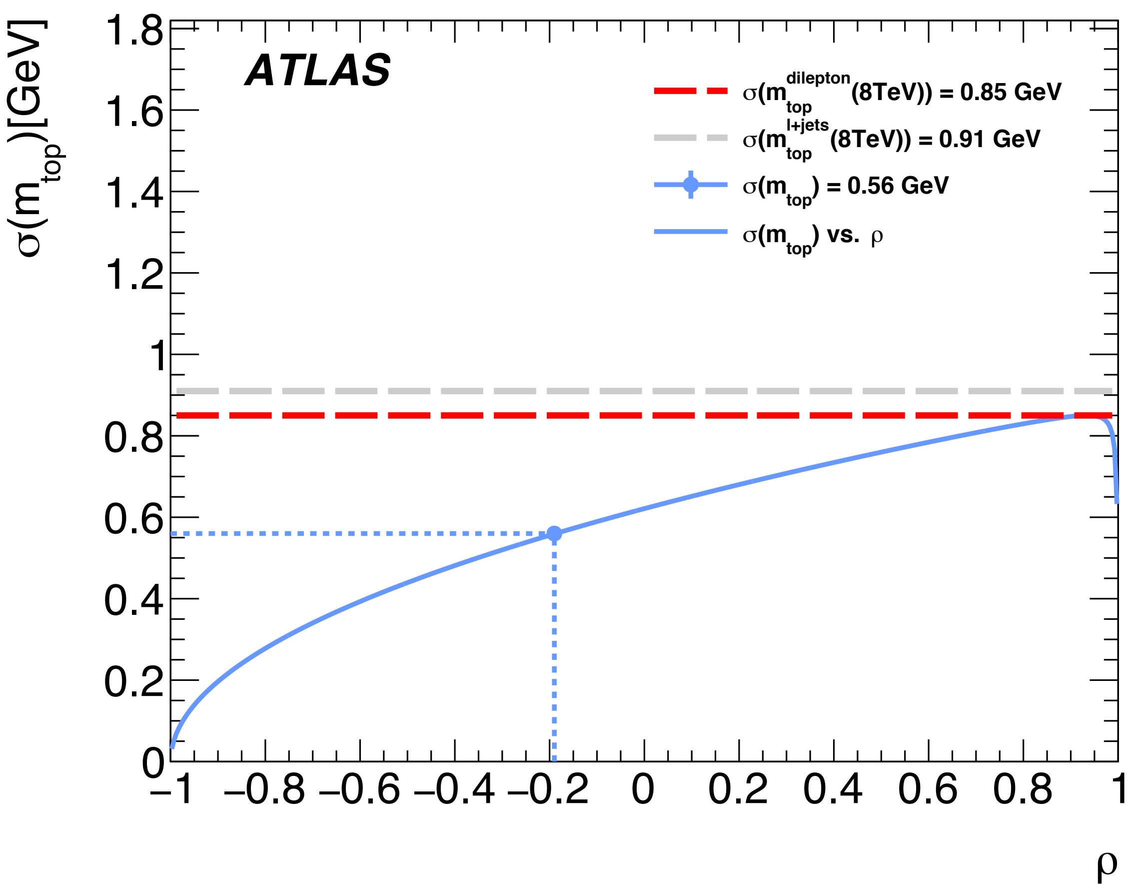
- production cross-section measurements of increasing precision….
  - confirm Standard Model NLO predictions
- **pole-mass analyses start to become competitive**
  - theory community very active, important to state what mass we measure!
- properties of top quark measured with ever-increasing precision
  - **first evidence of non-zero top charge asymmetry!**
  - **first top width measurement @13TeV! Competitive with $\Delta m_{top}^{pole}$**
  - spin correlation: data/predictions tensions→ limitations in understanding of $t\bar{t}$
- $t\bar{t}$ associated production
  - moving towards differential measurements for $t\bar{t}$+W/Z/ɣ
- top-related searches
  - 1 order improvement on FCNC tqɣ limits

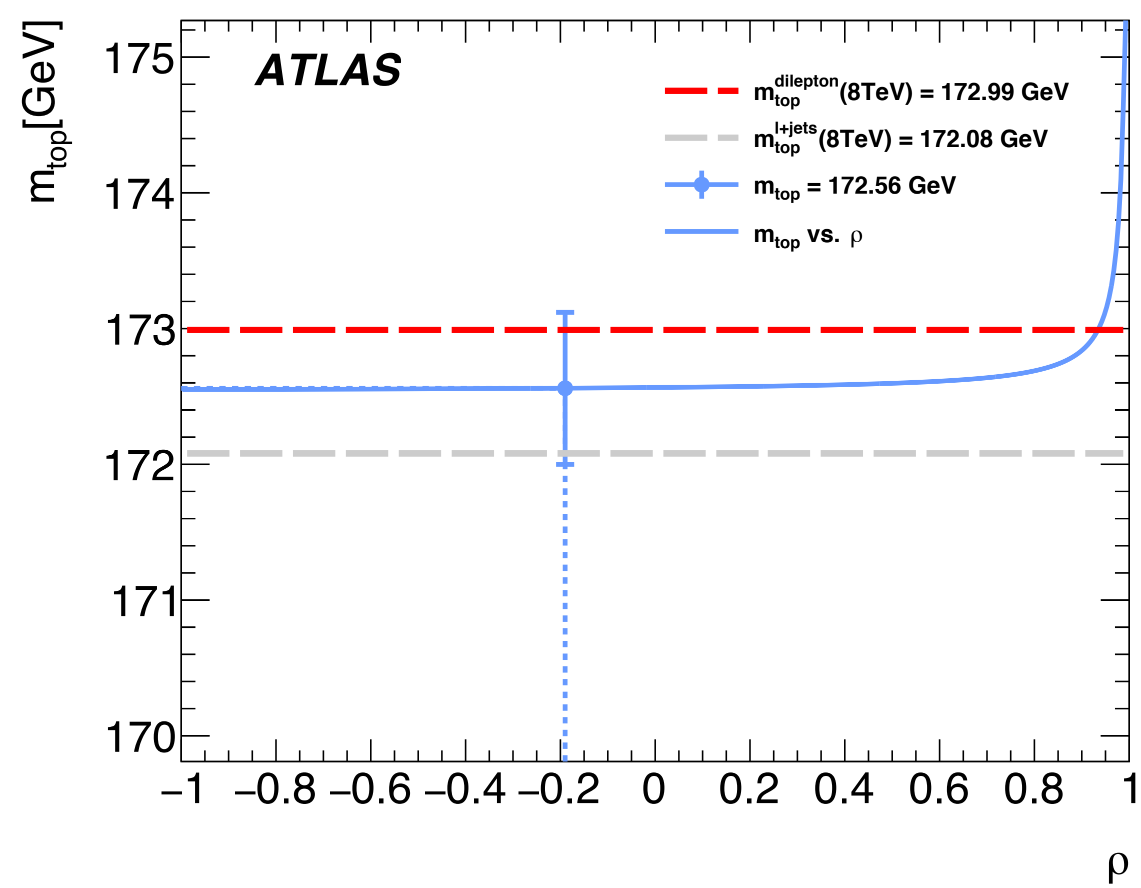
Thank you

# Backup

# Mass combination

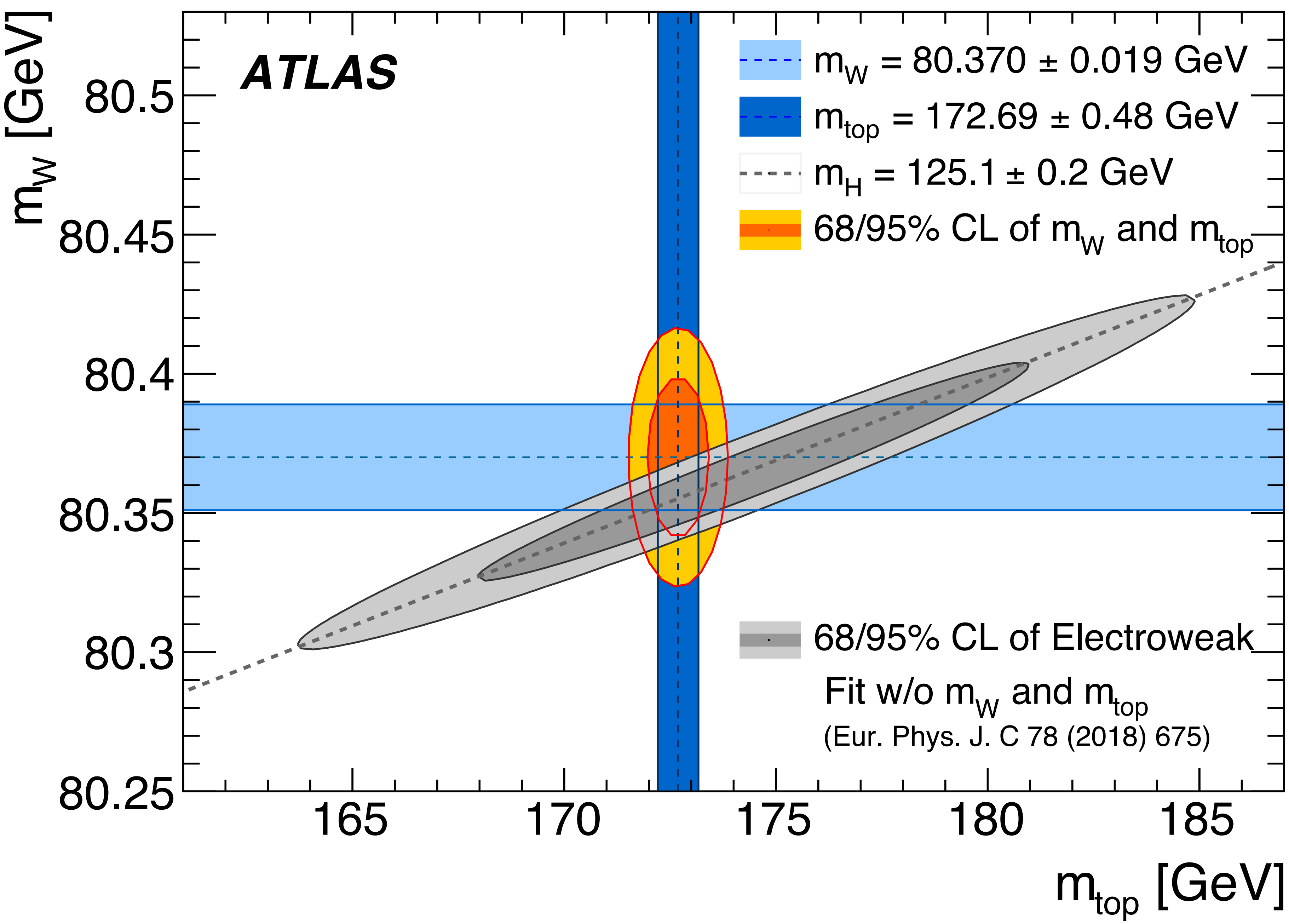
EPJC 79 (2019) 290



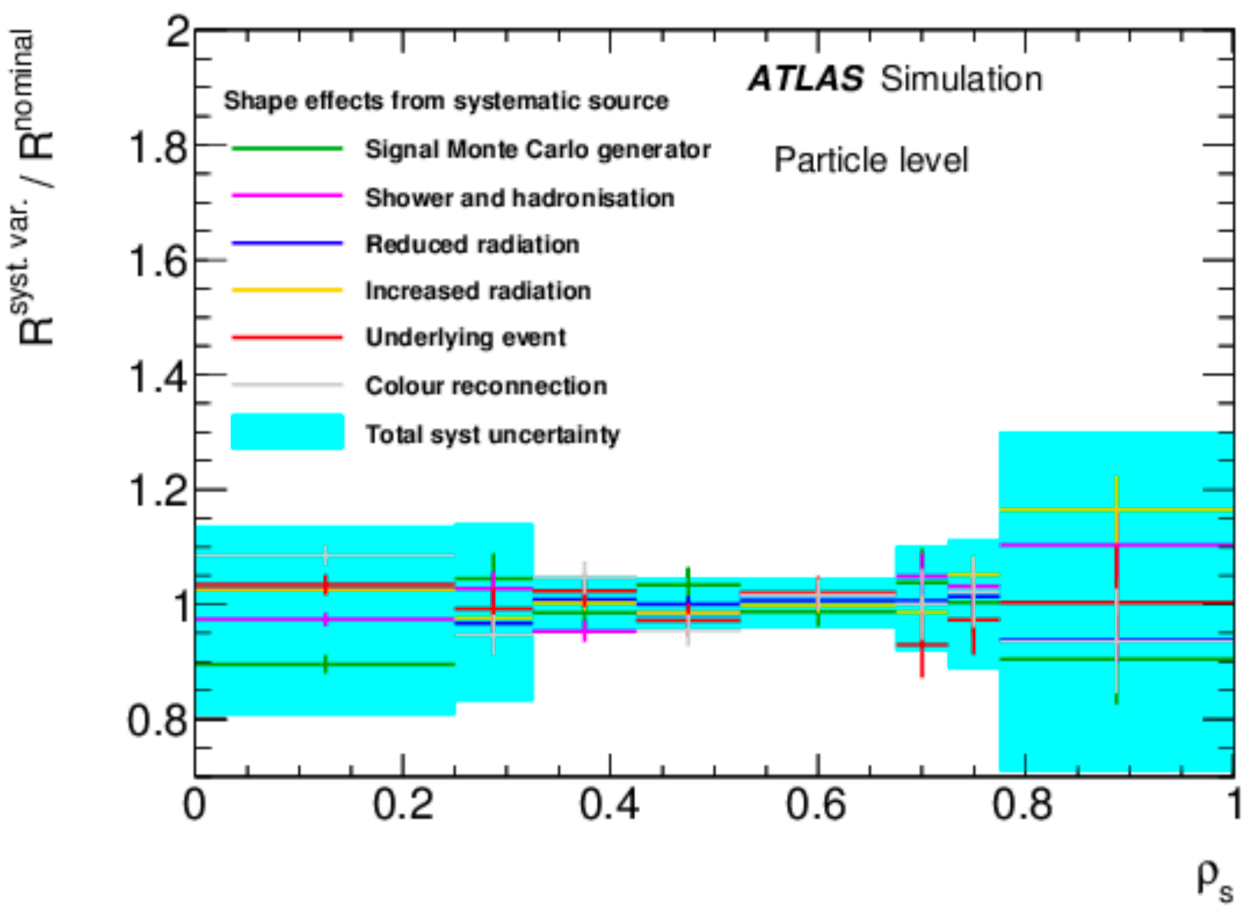
# Mass: comp. w/ EW fit

EPJC 79 (2019) 290



# Mass with $t\bar{t}$+1 jet

Submitted to JHEP - **NEW!**

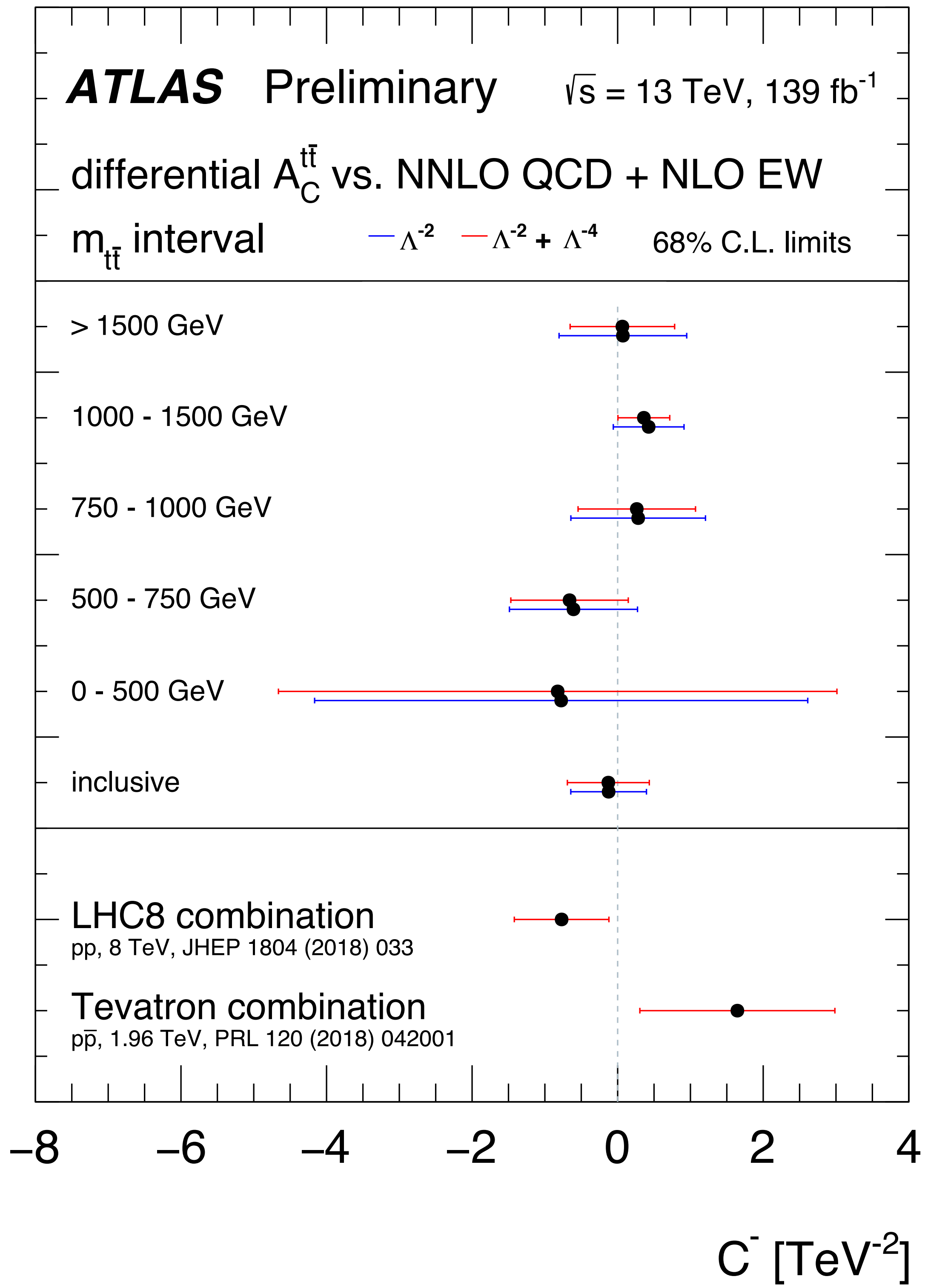



Differential $t\bar{t}$+1 jet: dominated by JES and MC modelling unc. (0.7 %)

| Mass scheme | $m_t^{\text{pole}}$ [GeV] | $m_t(m_t)$ [GeV] |
|---|---|---|
| **Value** | **171.1** | **162.9** |
| **Statistical uncertainty** | **0.4** | **0.5** |
| *Simulation uncertainties* | | |
| Shower and hadronisation | 0.4 | 0.3 |
| Colour reconnection | 0.4 | 0.4 |
| Underlying event | 0.3 | 0.2 |
| Signal Monte Carlo generator | 0.2 | 0.2 |
| Proton PDF | 0.2 | 0.2 |
| Initial- and final-state radiation | 0.2 | 0.2 |
| Monte Carlo statistics | 0.2 | 0.2 |
| Background | <0.1 | <0.1 |
| *Detector response uncertainties* | | |
| Jet energy scale (including $b$-jets) | 0.4 | 0.4 |
| Jet energy resolution | 0.2 | 0.2 |
| Missing transverse momentum | 0.1 | 0.1 |
| $b$-tagging efficiency and mistag | 0.1 | 0.1 |
| Jet reconstruction efficiency | <0.1 | <0.1 |
| Lepton | <0.1 | <0.1 |
| *Method uncertainties* | | |
| Unfolding modelling | 0.2 | 0.2 |
| Fit parameterisation | 0.2 | 0.2 |
| **Total experimental systematic** | **0.9** | **1.0** |
| Scale variations | (+0.6, −0.2) | (+2.1, −1.2) |
| Theory PDF⊕$\alpha_s$ | 0.2 | 0.4 |
| **Total theory uncertainty** | **(+0.7, −0.3)** | **(+2.1, −1.2)** |
| **Total uncertainty** | **(+1.2, −1.1)** | **(+2.3, −1.6)** |

# Charge asymmetry

ATLAS-CONF-2019-026 - **NEW!**



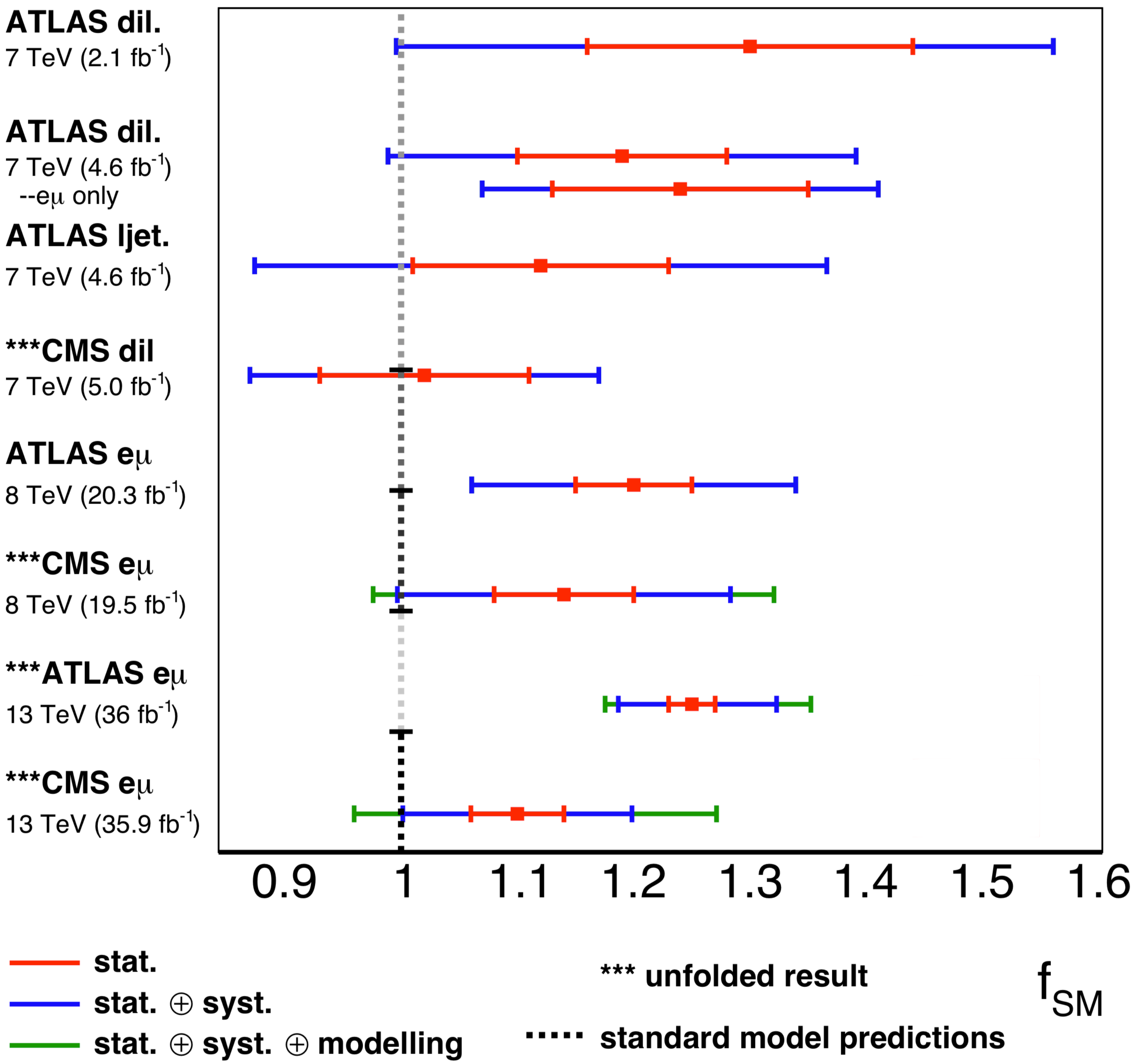

Measurements reinterpreted in EFT

- $C^-$ = 4-fermion operator assuming flavour conservation and equal *u-d* type couplings (simple axion model)

Inclusive and differential results surpass ATLAS+CMS Run I combination

- no large dependence on quadratic terms
- dimension 6 approach is stable and appropriate

# Spin corr. @LHC




Property measured many times by ATLAS and CMS, at each collision energy

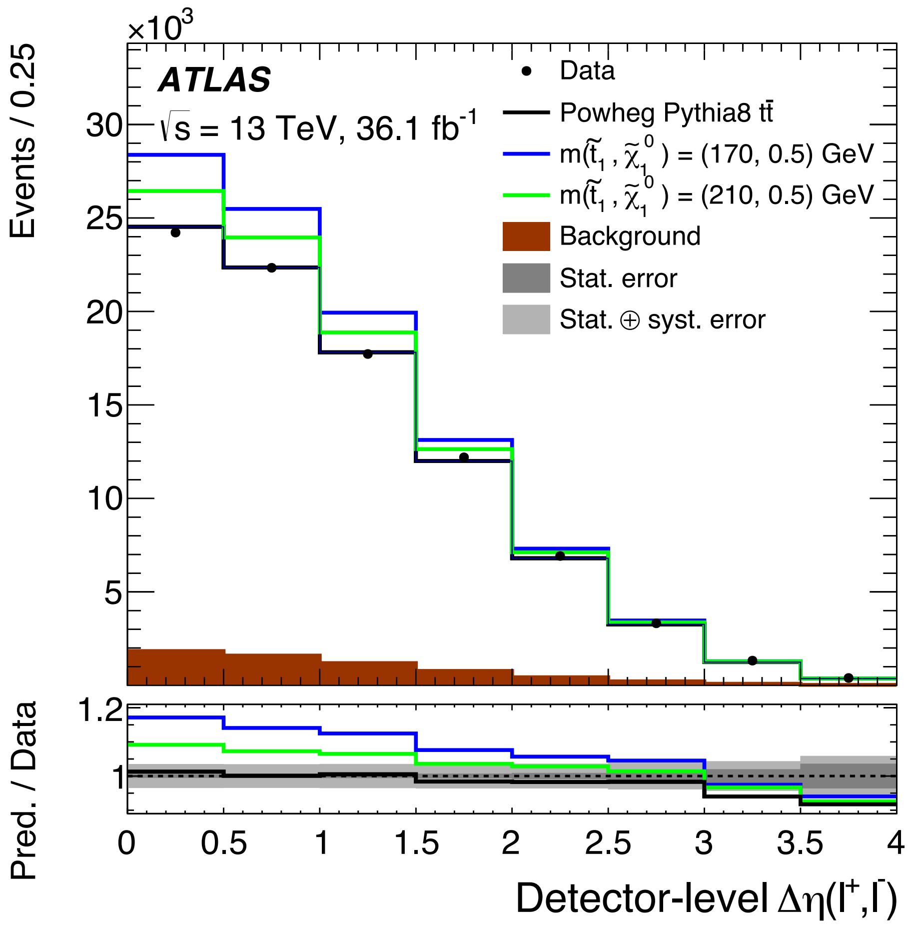
$f_{SM}$ = fraction of SM-like spin correlation

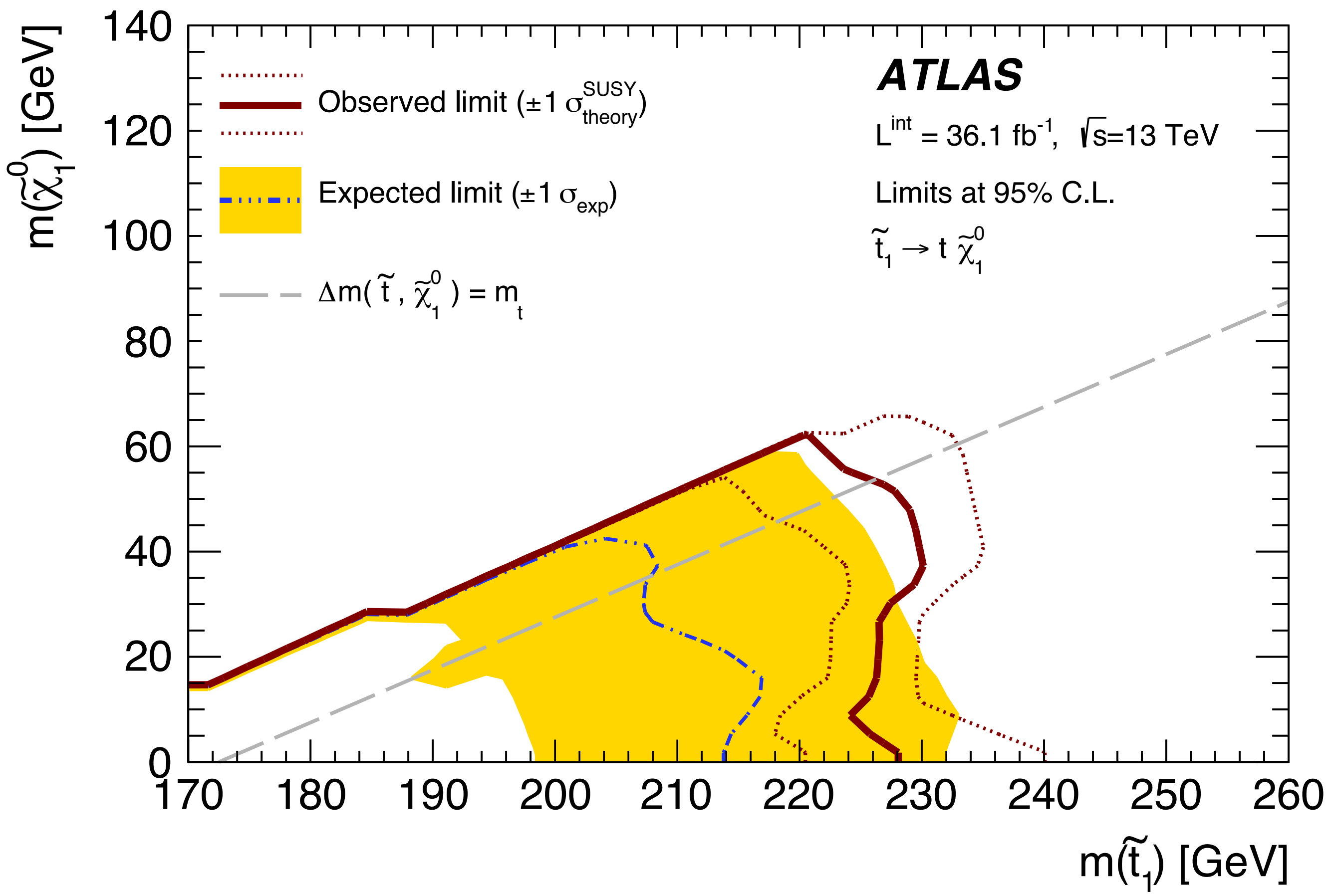
- $f_{SM}$ = 1 is SM-like
- $f_{SM}$ = 0 is uncorrelated

ATLAS and CMS consistently measure stronger than SM spin correlations using $|\Delta\phi_{\ell\ell}|$

# Spin corr. (SUSY)

Submitted to EPJC - **NEW!**



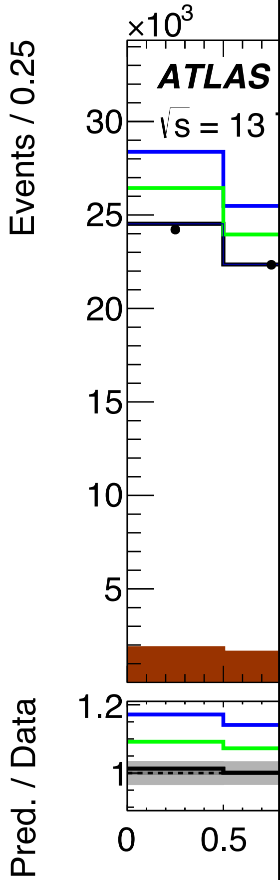



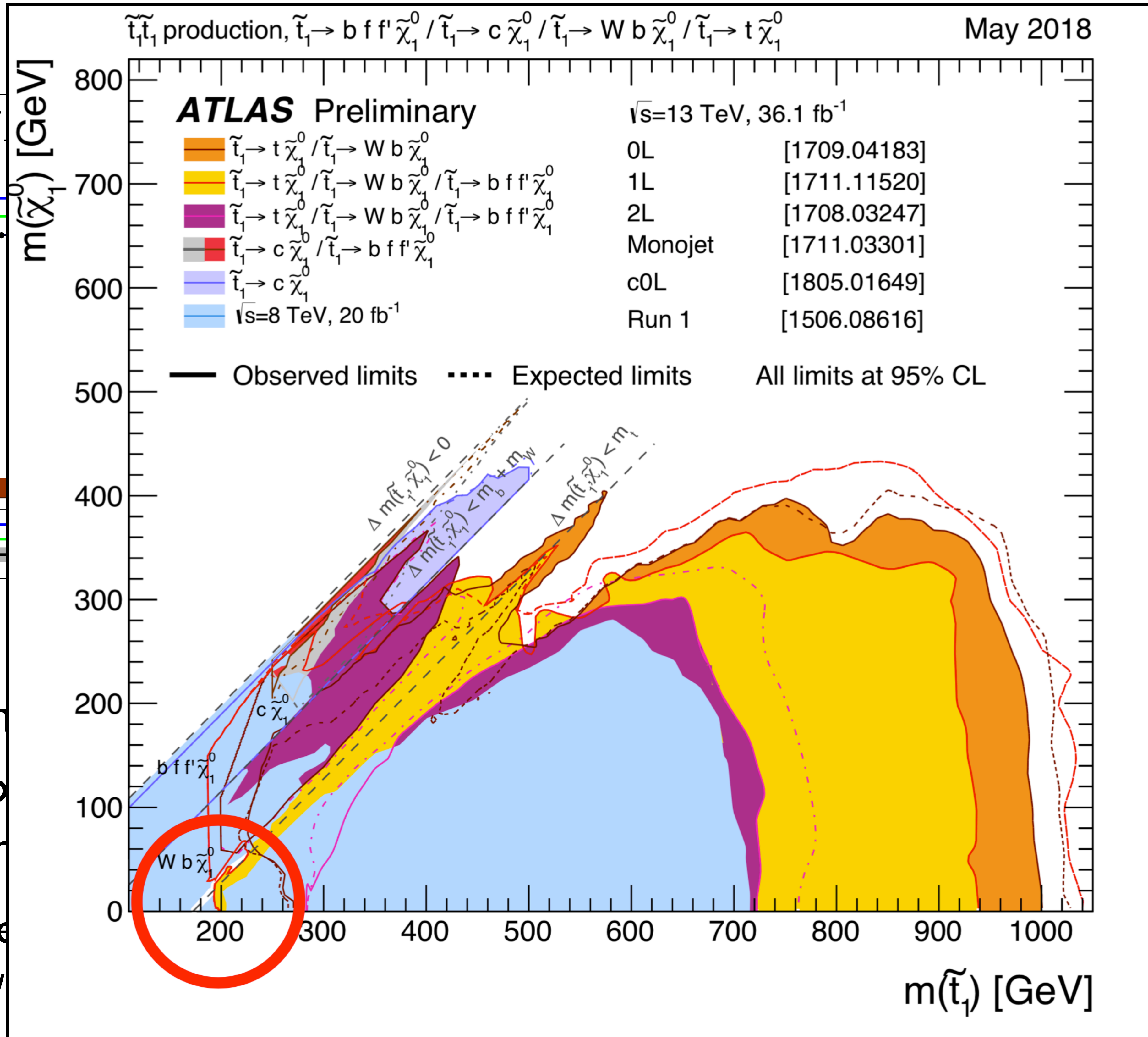

Use both the |Δφll| and |Δηll| to set limits on SUSY stop production

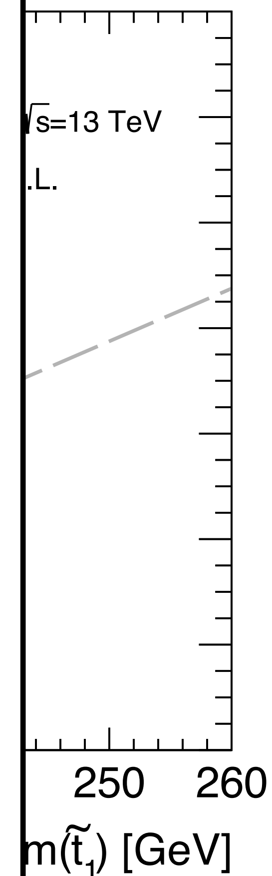
Exclude Stops with a mass below ~ 220 GeV for all kinematically-allowed neutralino masses

- limit driven by | Δηll| but additional modelling uncertainties included to account for the Data/Prediction disagreement in | Δφll |

# Spin corr. (SUSY)



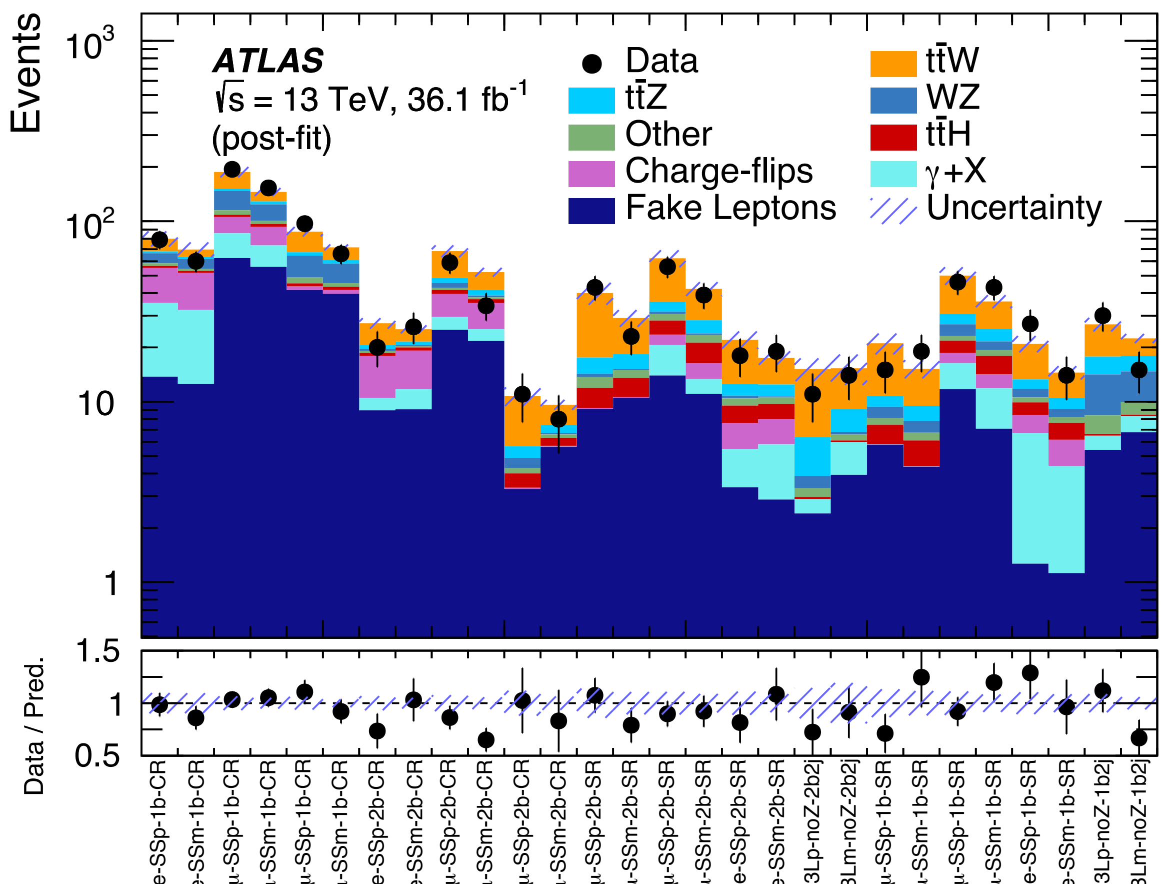

Use both th … n

Exclude Sto … owed

neutralino r …

- limit drive … account for the Data/

PRD 99 (2019) 072009

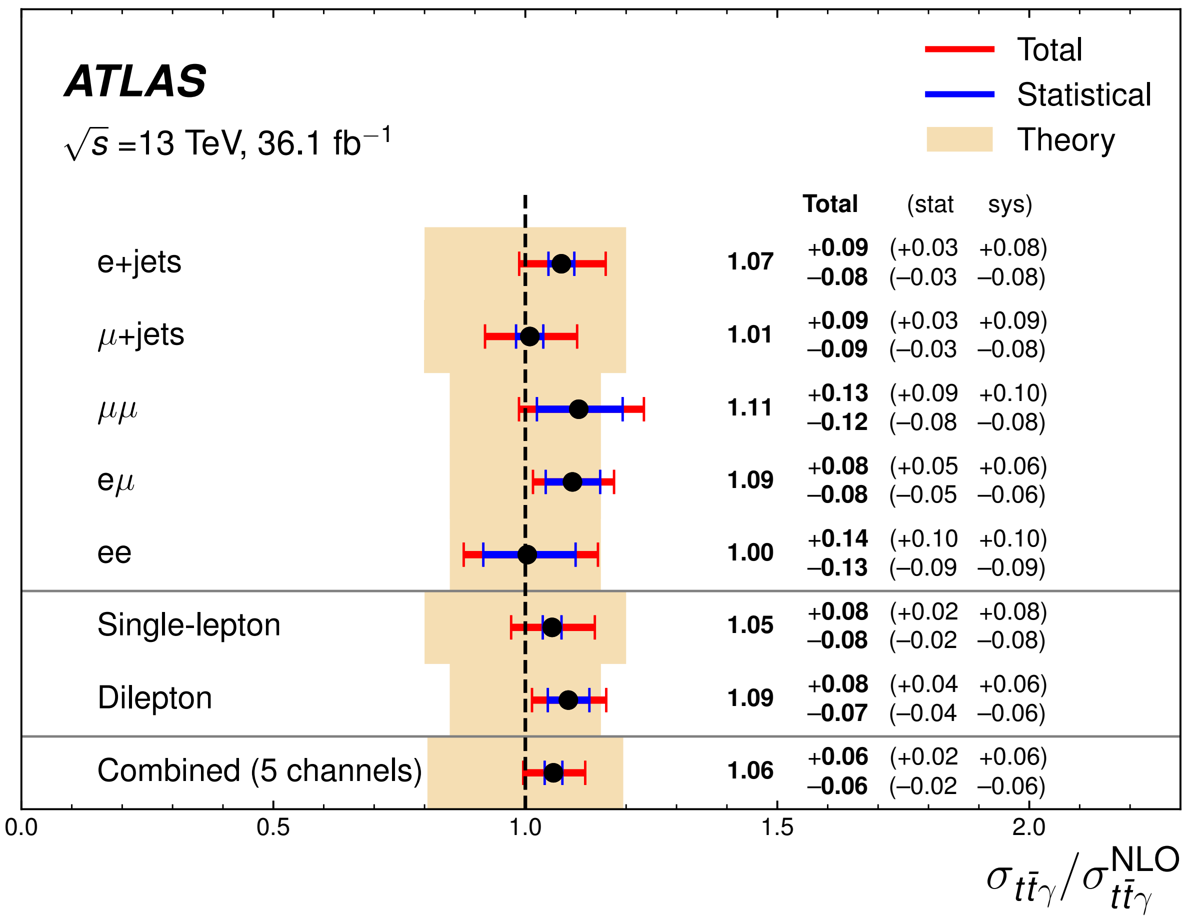



| Uncertainty | $\sigma_{t\bar{t}Z}$ | $\sigma_{t\bar{t}W}$ |
|---|---|---|
| Luminosity | 2.9% | 4.5% |
| Simulated sample statistics | 2.0% | 5.3% |
| Data-driven background statistics | 2.5% | 6.3% |
| JES/JER | 1.9% | 4.1% |
| Flavor tagging | 4.2% | 3.7% |
| Other object-related | 3.7% | 2.5% |
| Data-driven background normalization | 3.2% | 3.9% |
| Modeling of backgrounds from simulation | 5.3% | 2.6% |
| Background cross sections | 2.3% | 4.9% |
| Fake leptons and charge misID | 1.8% | 5.7% |
| $t\bar{t}Z$ modeling | 4.9% | 0.7% |
| $t\bar{t}W$ modeling | 0.3% | 8.5% |
| Total systematic | 10% | 16% |
| Statistical | 8.4% | 15% |
| Total | 13% | 22% |

| Operator | Expression |
|---|---|
| $\mathcal{O}_{\phi Q}^{(3)}$ | $(\phi^\dagger i \overleftrightarrow{D}^I_\mu \phi)(\bar{Q}\gamma^\mu \tau^I Q)$ |
| $\mathcal{O}_{\phi Q}^{(1)}$ | $(\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{Q}\gamma^\mu Q)$ |
| $\mathcal{O}_{\phi t}$ | $(\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{t}\gamma^\mu t)$ |
| $\mathcal{O}_{tW}$ | $(\bar{Q}\sigma^{\mu\nu}\tau^I t)\tilde{\phi}W^I_{\mu\nu}$ |
| $\mathcal{O}_{tB}$ | $(\bar{Q}\sigma^{\mu\nu} t)\tilde{\phi}B_{\mu\nu}$ |

| Coefficients | $\mathcal{C}_{\phi Q}^{(3)}/\Lambda^2$ | $\mathcal{C}_{\phi t}/\Lambda^2$ | $\mathcal{C}_{tB}/\Lambda^2$ | $\mathcal{C}_{tW}/\Lambda^2$ |
|---|---|---|---|---|
| Previous indirect constraints at 68% CL | [−4.7, 0.7] | [−0.1, 3.7] | [−0.5, 10] | [−1.6, 0.8] |
| Previous direct constraints at 95% CL | [−1.3, 1.3] | [−9.7, 8.3] | [−6.9, 4.6] | [−0.2, 0.7] |
| Expected limit at 68% CL | [−2.1, 1.9] | [−3.8, 2.7] | [−2.9, 3.0] | [−1.8, 1.9] |
| Expected limit at 95% CL | [−4.5, 3.6] | [−23, 4.9] | [−4.2, 4.3] | [−2.6, 2.6] |
| Observed limit at 68% CL | [−1.0, 2.7] | [−2.0, 3.5] | [−3.7, 3.5] | [−2.2, 2.1] |
| Observed limit at 95% CL | [−3.3, 4.2] | [−25, 5.5] | [−5.0, 5.0] | [−2.9, 2.9] |
| Expected limit at 68% CL (linear) | [−1.9, 2.0] | [−3.0, 3.2] | – | – |
| Expected limit at 95% CL (linear) | [−3.7, 4.0] | [−5.8, 6.3] | – | – |
| Observed limit at 68% CL (linear) | [−1.0, 2.9] | [−1.8, 4.4] | – | – |
| Observed limit at 95% CL (linear) | [−2.9, 4.9] | [−4.8, 7.5] | – | – |

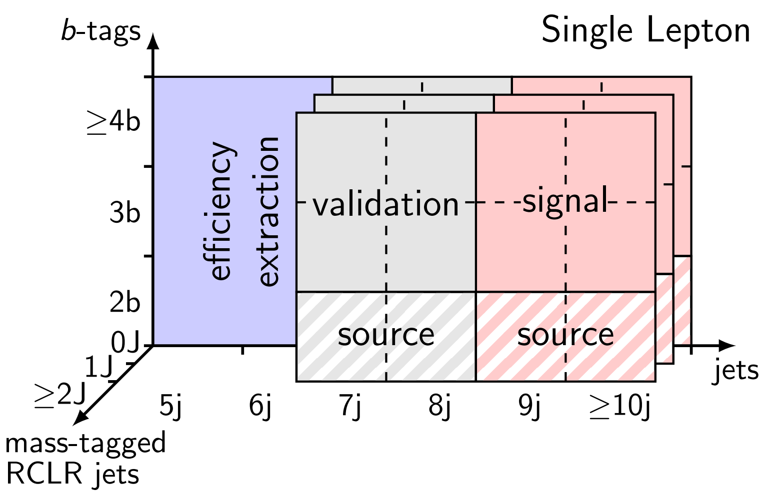
[PRD 99 (2019) 072009]

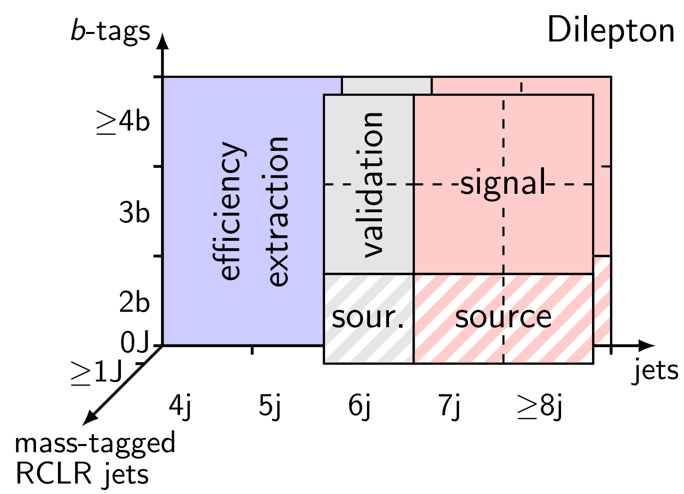



| Source | Single lepton (%) | Dilepton (%) |
|---|---|---|
| Signal modelling | ± 1.6 | ± 2.9 |
| Background modelling | ± 4.8 | ± 2.9 |
| Photon | ± 1.1 | ± 1.1 |
| Prompt-photon tagger | ± 4.0 | - |
| Leptons | ± 0.3 | ± 1.3 |
| Jets | ± 5.4 | ± 2.0 |
| $b$-tagging | ± 0.9 | ± 0.4 |
| Pile-up | ± 2.0 | ± 2.3 |
| Luminosity | ± 2.3 | ± 2.3 |
| MC sample size | ± 1.9 | ± 1.7 |
| Total systematic uncertainty | ± 7.9 | ± 5.8 |
| Data sample size | ± 1.5 | ± 3.8 |
| Total uncertainty | ± 8.1 | ± 7.0 |

# 4 tops

Phys. Rev. D 99 (2019) 052009




| Uncertainty source | $\pm\Delta\mu$ | |
|---|---|---|
| $t\bar{t}$+jets modeling | $+1.2$ | $-0.96$ |
| Background-model statistical uncertainty | $+0.91$ | $-0.85$ |
| Jet energy scale and resolution, jet mass | $+0.38$ | $-0.16$ |
| Other background modeling | $+0.26$ | $-0.20$ |
| $b$-tagging efficiency and mis-tag rates | $+0.33$ | $-0.10$ |
| JVT, pileup modeling | $+0.18$ | $-0.073$ |
| $t\bar{t}+H/V$ modeling | $+0.053$ | $-0.055$ |
| Luminosity | $+0.050$ | $-0.026$ |
| Total systematic uncertainty | $+1.6$ | $-1.4$ |
| Total statistical uncertainty | $+1.1$ | $-1.0$ |
| Total uncertainty | $+1.9$ | $-1.7$ |