CKM Physics with Top

Jyothsna Rani Komaragiri
Centre for High Energy Physics (CHEP),
Indian Institute of Science (IISc), Bengaluru

for CMS & ATLAS collaboration

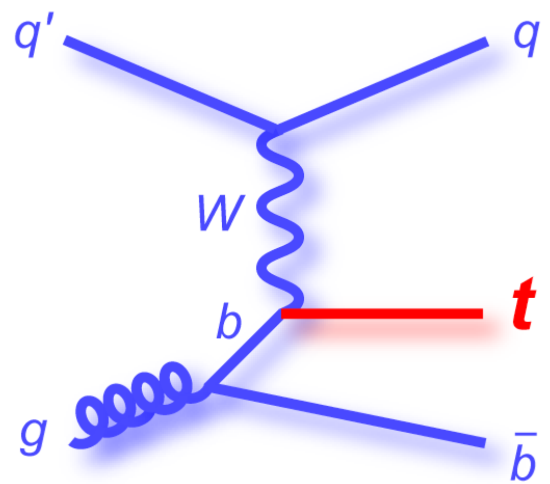
CKM2016:
9th International Workshop on the CKM Unitarity Triangle
28th Nov - 2nd Dec 2016
TIFR, Mumbai

Outline

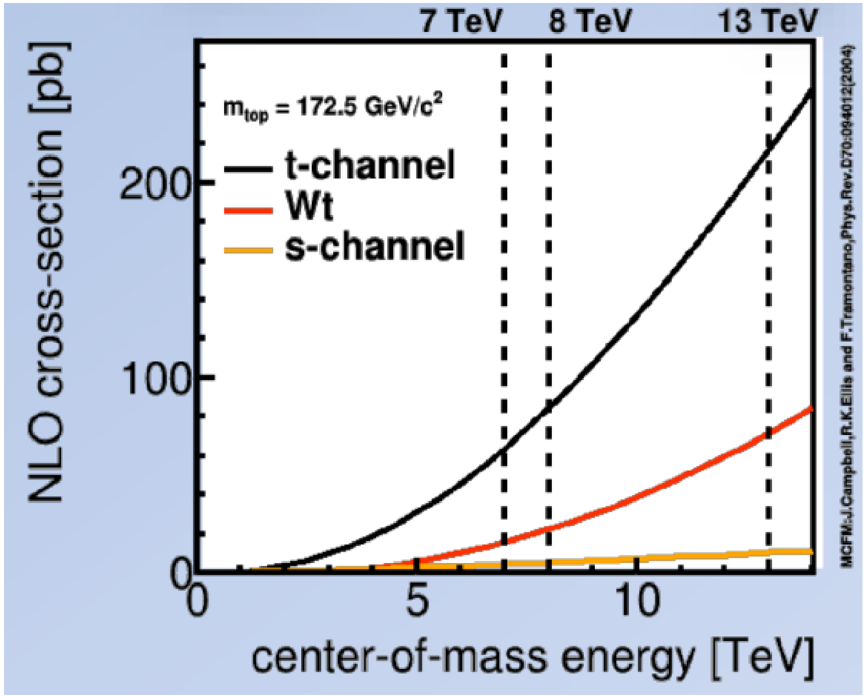
- CKM Physics with Single Top
  - Single top measurements at CMS & ATLAS
    - Cross section
    - CKM matrix element V_{tb}
    - Ratio of cross section in t-channel ($R_{t\text{-}ch}$)
- CKM Physics with Top pairs
  - Top pair production at CMS
    - $Br(t \rightarrow Wb)/Br(t \rightarrow Wq)$ where q = d, s, b & indirect determination of CKM matrix element V_{tb}
- Summary

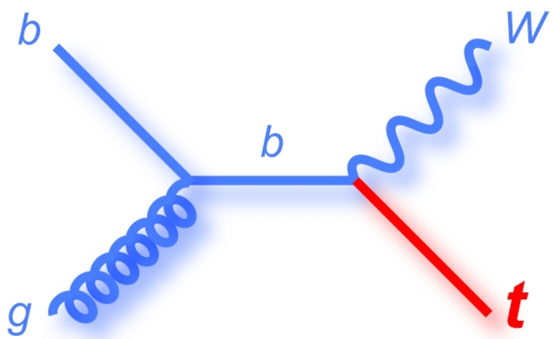
CKM Physics with Single Top

Single top quarks are produced via electroweak interaction:

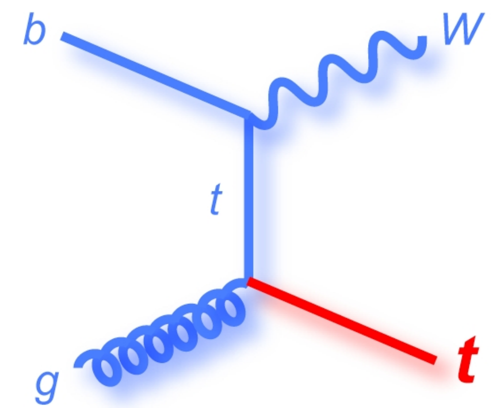


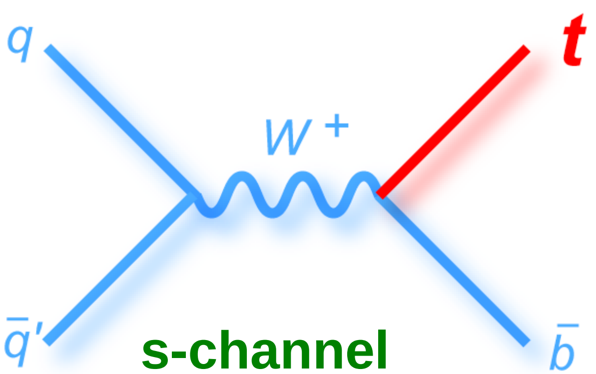
t-channel





tW-channel





s-channel

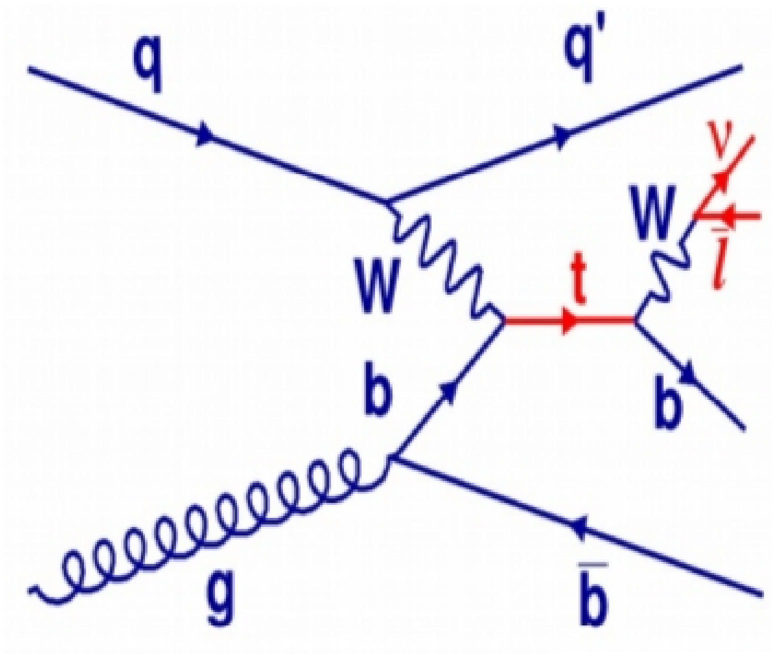
Interesting features of single top

The production of single top quarks provides a unique testing ground for the study of electroweak processes:

- **Single top production cross section is proportional to the strength of Wtb interaction**
  - **Probe anomalous Wtb couplings**
- **Direct measurement of the Cabibbo–Kobayashi–Maskawa (CKM) matrix element |Vtb|**
- **Provide additional handle to constrain PDFs**
  - **The cross-section ratio top-quark/top-antiquark production is sensitive to the u/d-quark ratio in the PDF sets.**
- **Polarized sample:**
  - **Allows study of top quark polarization**
- **Sensitive to FCNC with top quarks**
- **Looking for signs of new physics:**
  - **sensitive to new physics via s-channel (new resonances like $H^{\pm}$, W')**

t-channel Single top

Final state signature



Light jet in forward region

Missing Energy

Isolated lepton

Signal Region:
2 jets & 1 b-tagged jet (2jet 1tag)

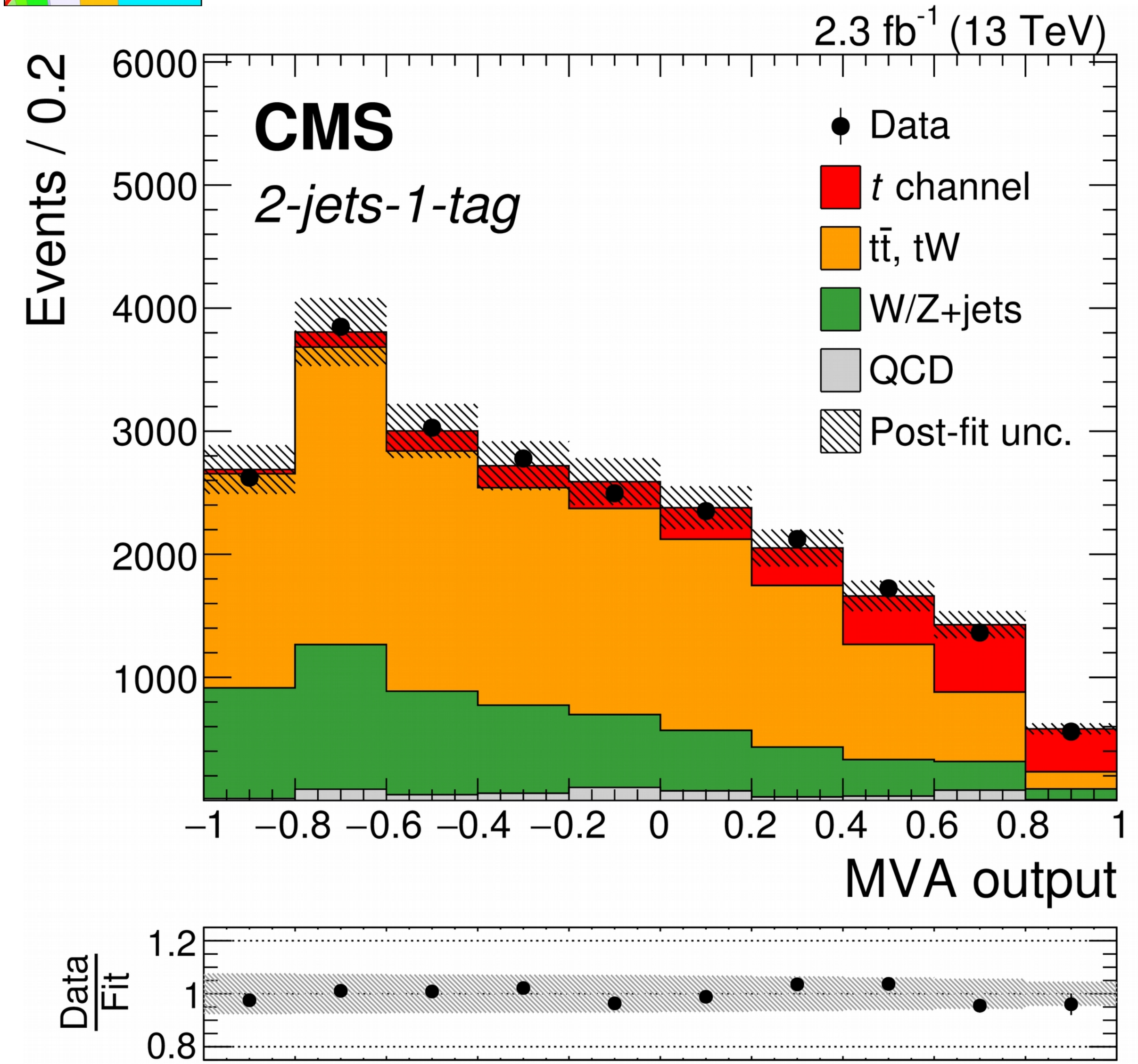
b-tagged jet

Out of acceptance

Control/Validation Regions:

- **CMS: ttbar (3jet 2tag, 3jet 1tag), QCD & W+jets (2jet 0tag)**
- **ATLAS: ttbar (3jet 2tag), W+jets (2jet 1loose-tag)**

Cross section @ 13 TeV



Signal discrimination:
artificial neural network is trained in 2jet 1tag
Important inputs:
light jet |η|,
reconstructed top mass

Events with non-isolated lepton and low mT(W) are used in QCD estimation

Analysis Strategy:
simultaneous fit in 3 regions 2jet 1tag, 3jet 1tag, 3jet 2tag

arXiv:1610.00678,
Submitted to Phys.Lett.B

$\sigma\ (t + \bar{t}\ ) = 232 \pm 13\ (\ \text{stat}\ ) \pm 12(\ \text{exp}) \pm 26\ (\text{theo}) \pm 6(\ \text{lumi}) = 232 \pm 31$ pb

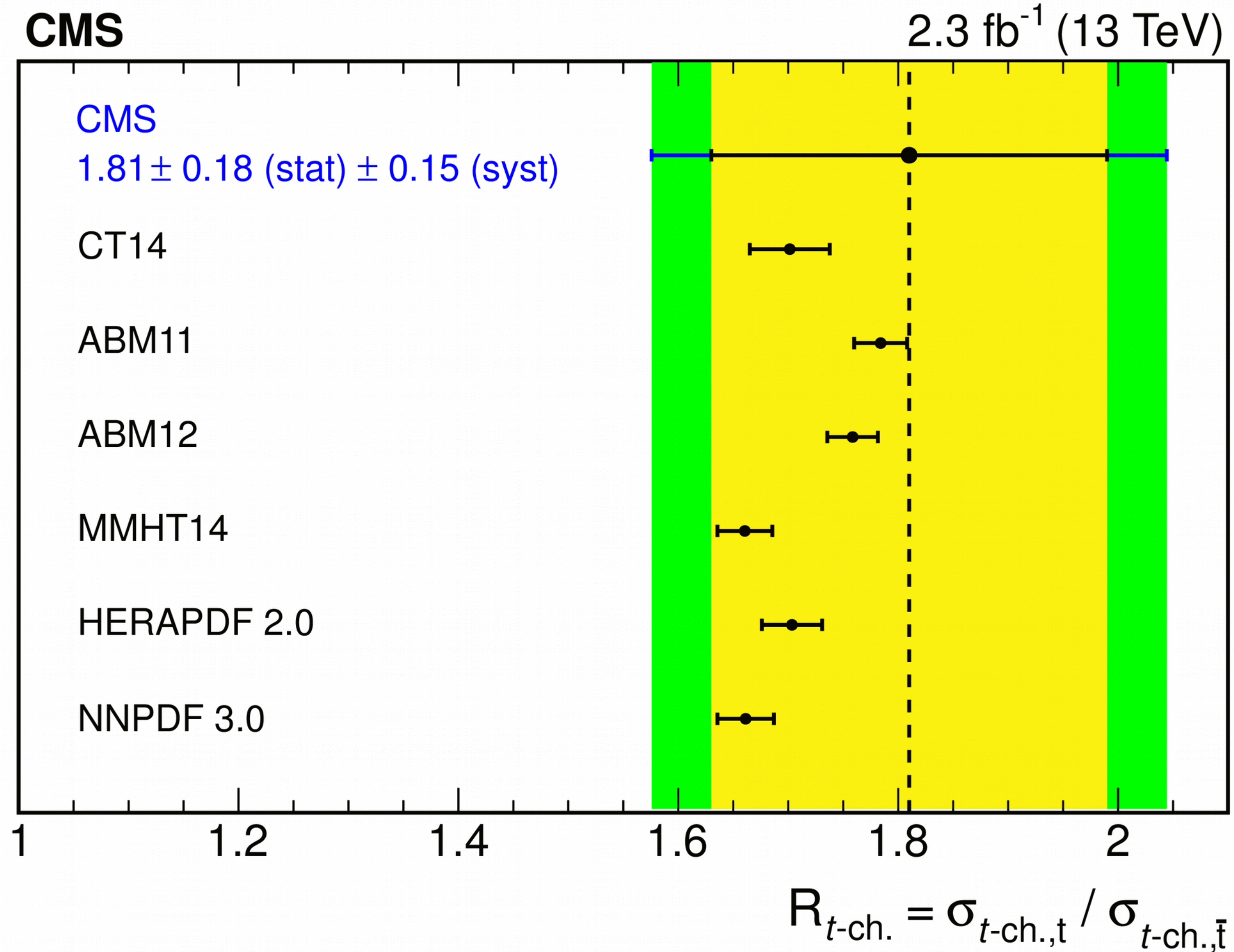
Cross section ratio @ 13 TeV

The charge of the top quark is connected to the type of the incoming light-flavour quark

→ top-quark/top-antiquark production is sensitive to d/u-quark ratio

All PDF predictions are in agreement with the measurement

arXiv:1610.00678, Submitted to Phys.Lett.B



$\sigma_{\text{t-ch, t}}$ = 150 ± 8 (stat) ± 9 (exp) ± 18 (theo) ± 4(lumi) pb = 150 ± 22 pb

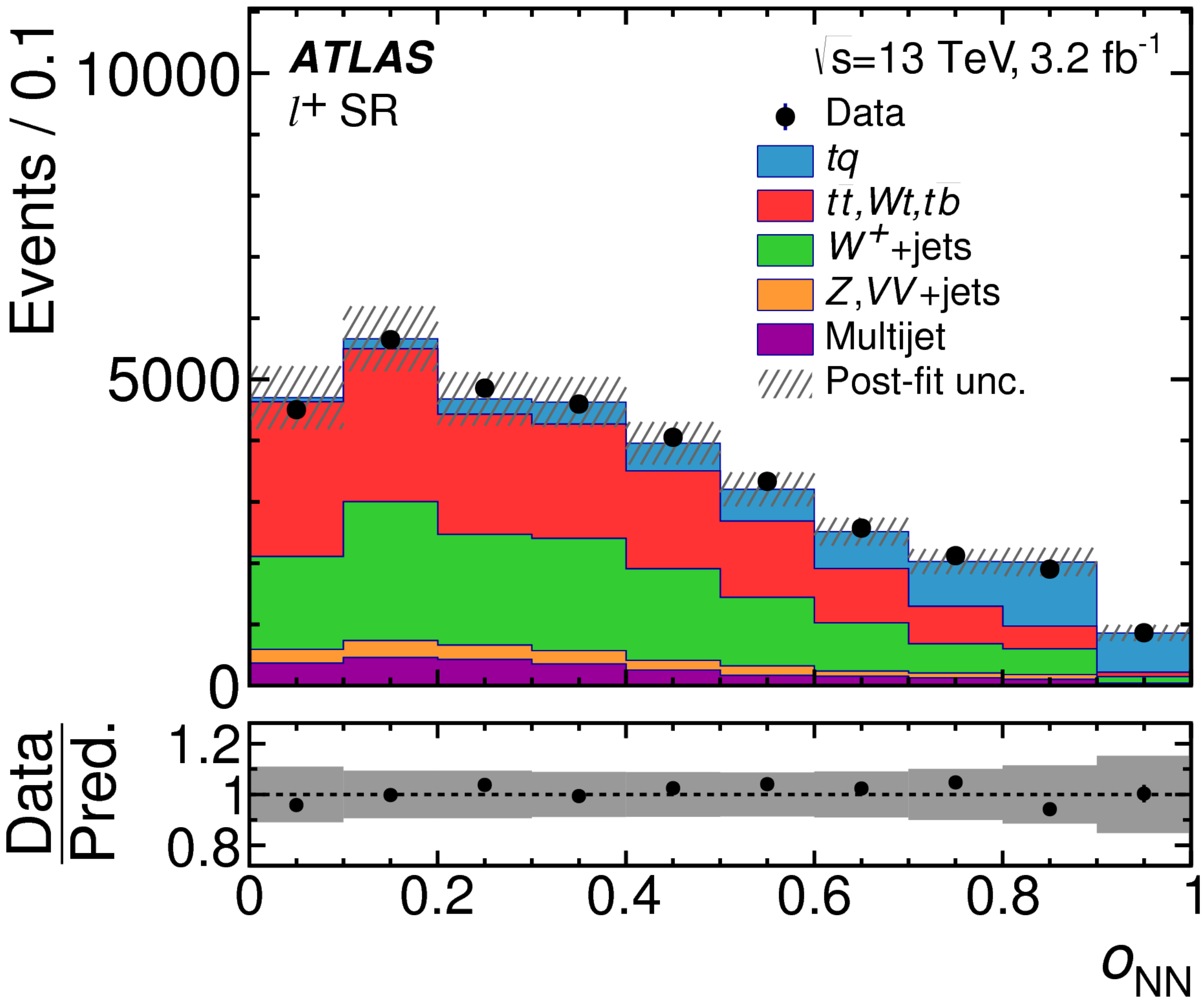
$\sigma_{\text{t-ch, }\bar{\text{t}}}$ = 82 ± 10 (stat) ± 4 (exp) ± 11 (theo) ± 2 (lumi) pb = 82 ± 16 pb

$R_{\text{t-ch}}$ = 1.81 ± 0.18(stat) ± 0.15 (syst)

CKM matrix element V tb (|V tb | >> |V ts | >> |V td |):

$|f_{LV} V_{tb}|$ = 1.03 ± 0.07(exp) ± 0.02(theo)

Cross section @ 13 TeV



Signal discrimination

Neural Network is trained in 2jet 1tag

Important inputs:

reconstructed top mass,
jet pair mass m(jb),
transverse W boson mass
light jet |η|

Analysis regions are separated into + and – lepton charge
$t\bar{t}$ normalisation is controlled by using 3jet 2tag events
W+jets normalisation is estimated using 2jet 1loose-tag

arXiv:1609.03920
Submitted to JHEP

$\sigma(tq + \bar{t}q) = 247 \pm 6\ (\text{stat}) \pm 45\ (\text{syst}) \pm 5\ (\text{lumi})\ \text{pb} = 247 \pm 46\ \text{pb}$

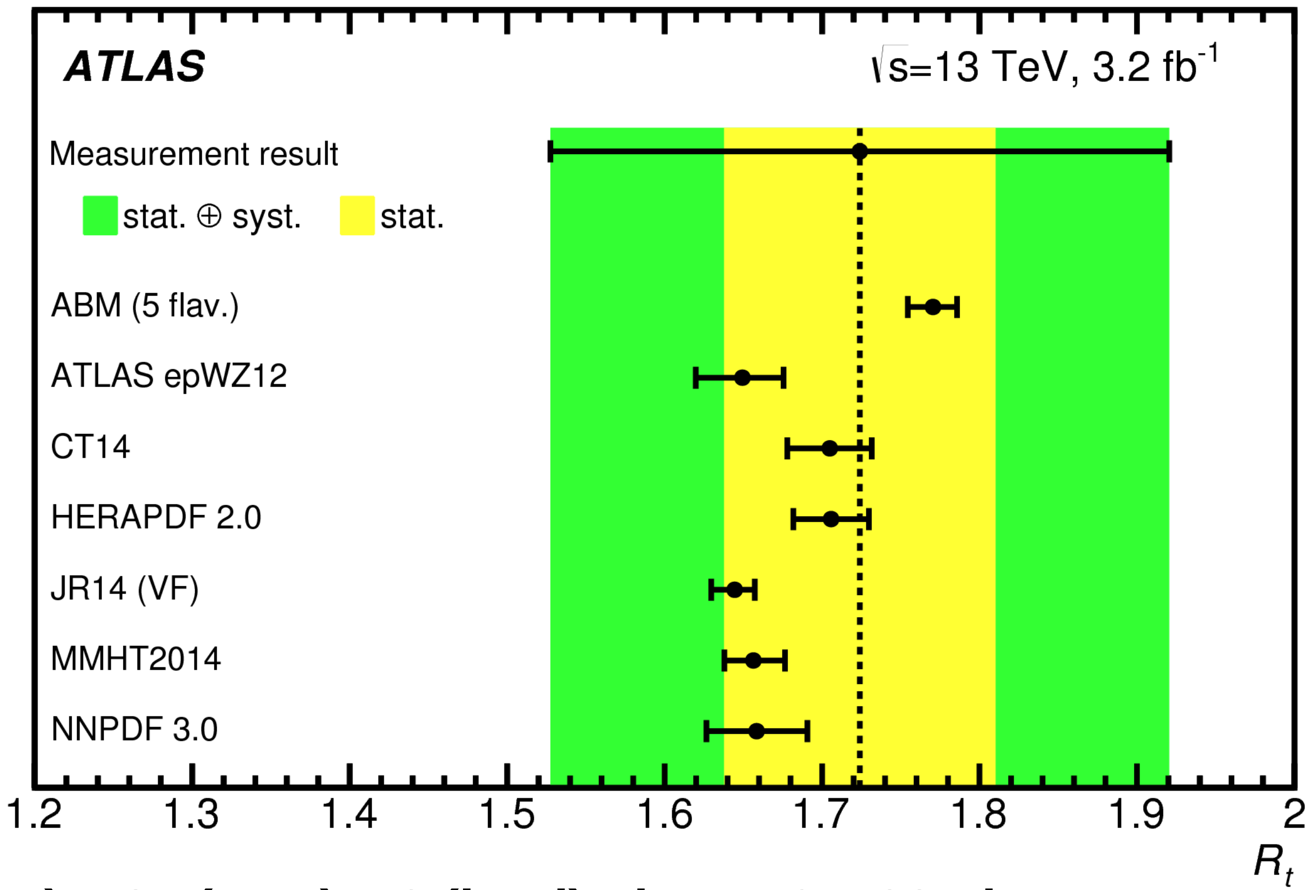
Cross section ratio @ 13 TeV

The charge of the top quark is connected to the type of the incoming light-flavour quark

→ top-quark/top-antiquark production is sensitive to d/u-quark ratio

All PDF predictions are in agreement with the measurement

arXiv:1609.03920
Submitted to JHEP



$\sigma(tq) = 156 \pm 5\ (\mathrm{stat}) \pm 27\ (\mathrm{syst}) \pm 3\ (\mathrm{lumi})\ \mathrm{pb} = 156 \pm 28\ \mathrm{pb}$

$\sigma(\bar{t}q) = 91 \pm 4\ (\mathrm{stat}) \pm 18\ (\mathrm{syst}) \pm 2\ (\mathrm{lumi})\ \mathrm{pb} = 91 \pm 19\ \mathrm{pb}$

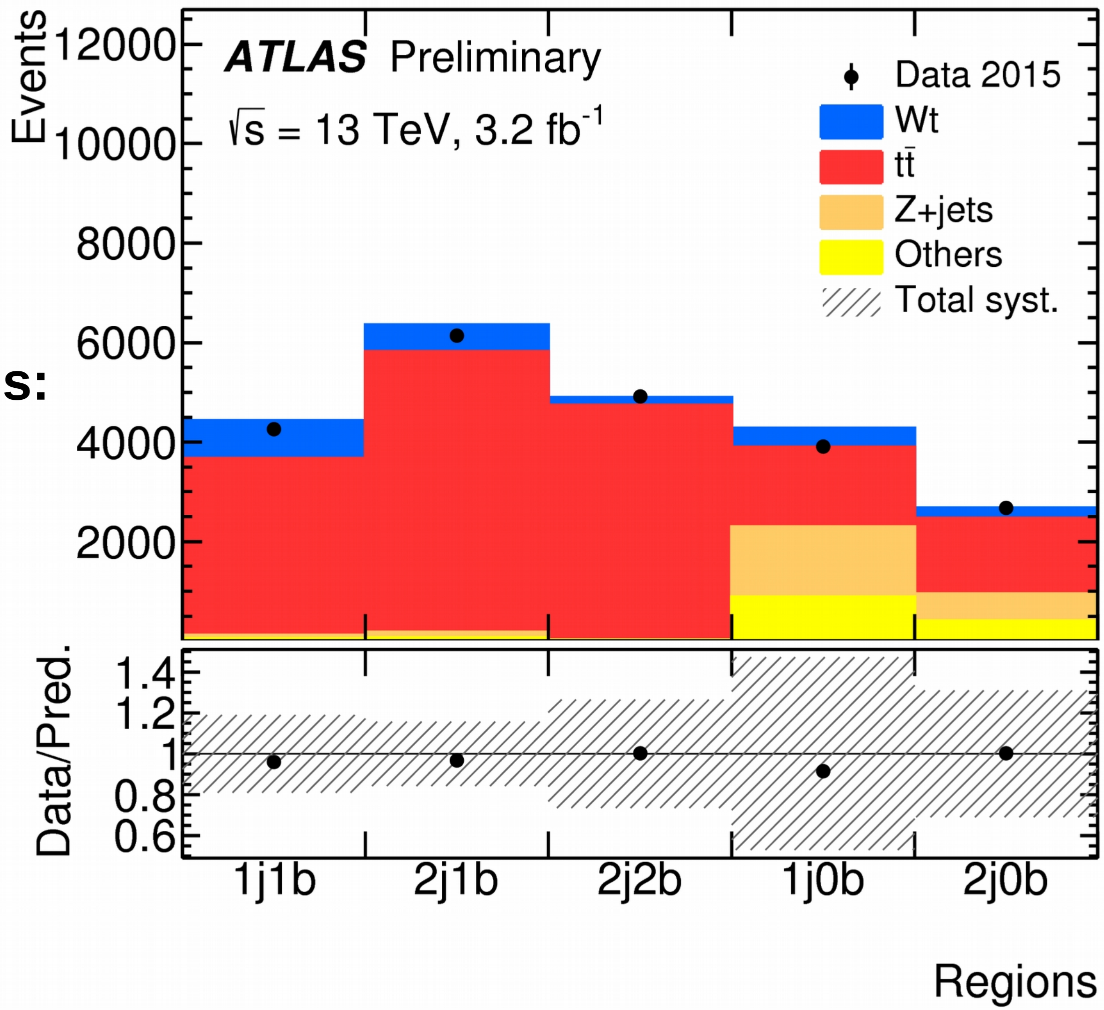
$R_t = 1.72 \pm 0.09\ \mathrm{stat} \pm 0.18\ \mathrm{syst}$

CKM matrix element V_{tb} ($|V_{tb}| >> |V_{ts}| >> |V_{td}|$):

$|f_{LV} V_{tb}| = 1.07 \pm 0.01\ (\mathrm{stat.}) \pm 0.09\ (\mathrm{syst.}) \pm 0.02\ (\mathrm{theor.}) \pm 0.01\ (\mathrm{lumi.})$

tW-channel Single top @ 13TeV

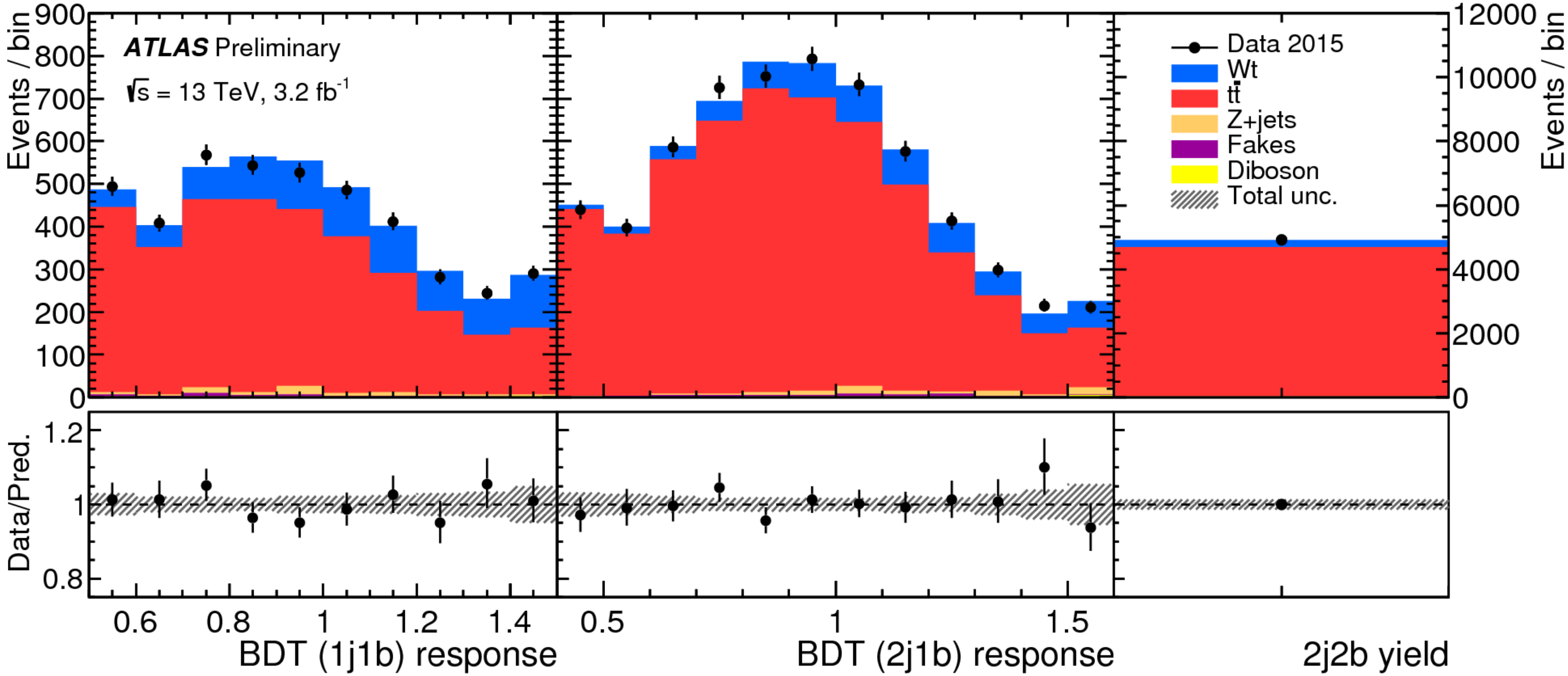
- **Dilepton (ee, eμ, μμ) Channel**
- **Signal Regions:**
  1jet 1tag, 2jet 1tag
- **Two BDTs are trained tW and ttbar for the two signal regions:**
- **1jet 1tag (1j1b) region:**
  - **pTsys(ℓ1 ℓ2 ETmiss j1),**
  - **ΔpT(ℓ1 ℓ2 ETmiss j1)**
- **2jet 1tag (2j1b) region:**
  - **pTsys(ℓ1, ℓ2)**
  - **Δ R(ℓ1 ℓ2, ETmiss j1 j2)**



ATLAS-CONF-2016-065

tW-channel Single top @ 13TeV

Signal extraction: Profile maximum likelihood fit



ATLAS-CONF-2016-065

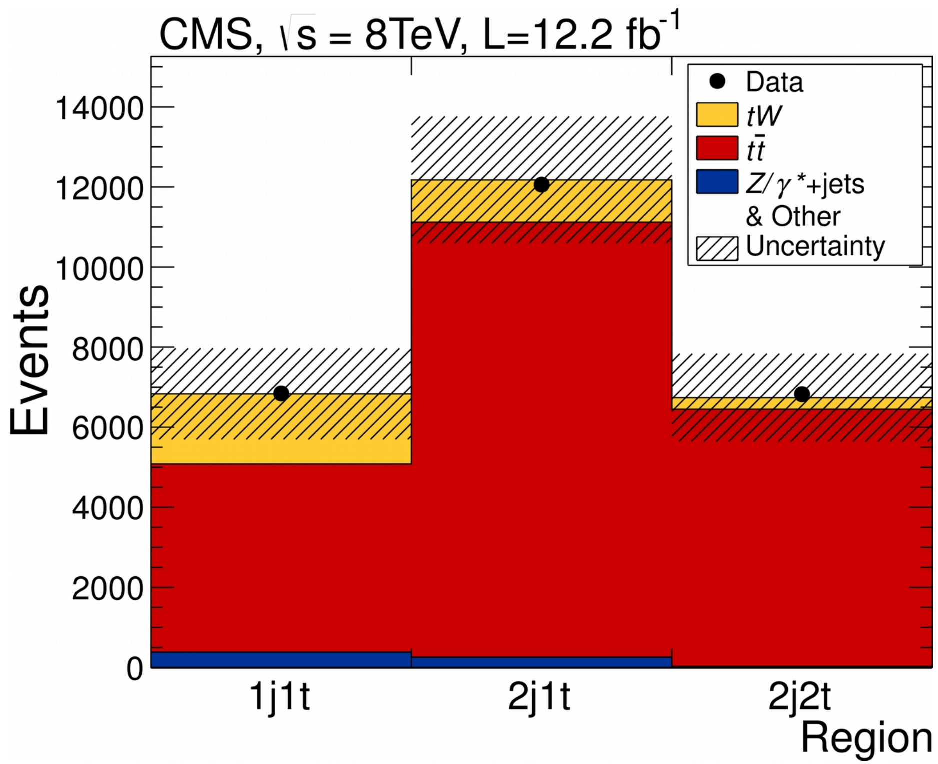
Measured cross section: $\sigma(Wt) = 94 \pm 10$ stat $^{28}_{-23}$ syst pb

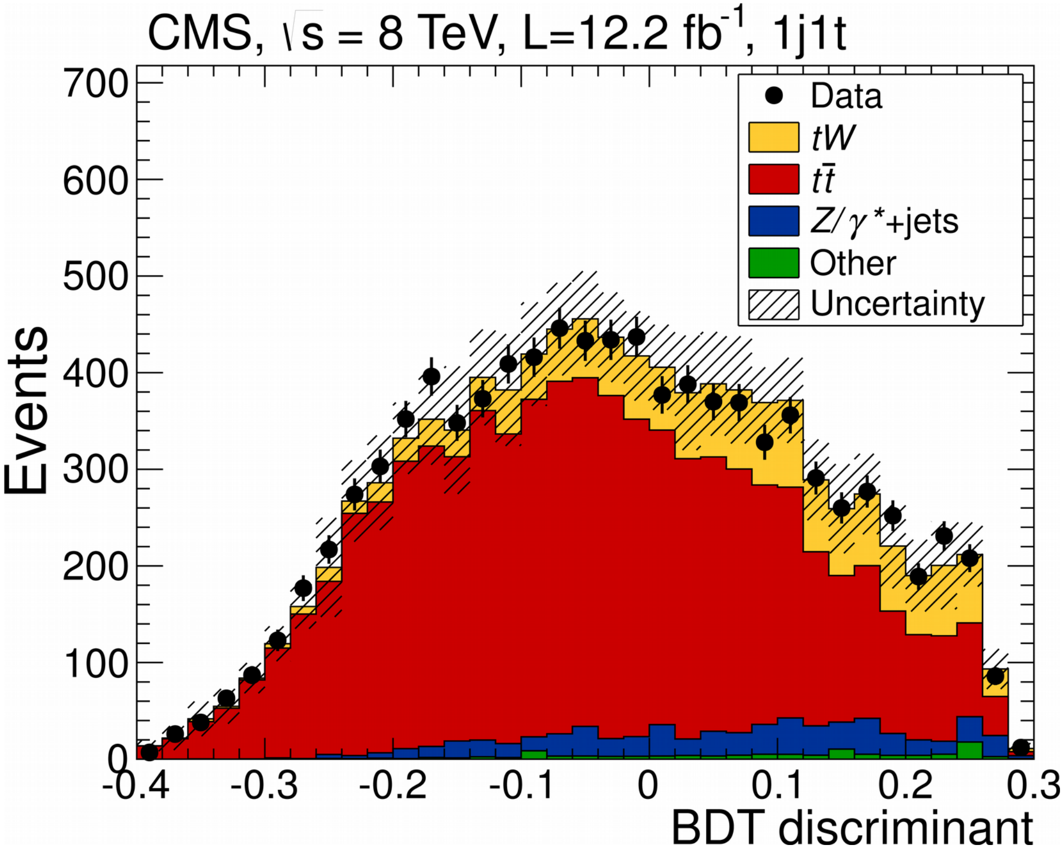
SM: σ (Wt) = 71.1 ± 3.9 pb

Significance: 4.5 σ

tW-channel Single top observation @ 8TeV

- **Dilepton (ee, eμ, μμ) Channel**
- **Signal Region: 1jet 1tag**
- **BDT is trained tW and ttbar for the signal region**





σ_{meas} = 23.4 ± 5.4 pb

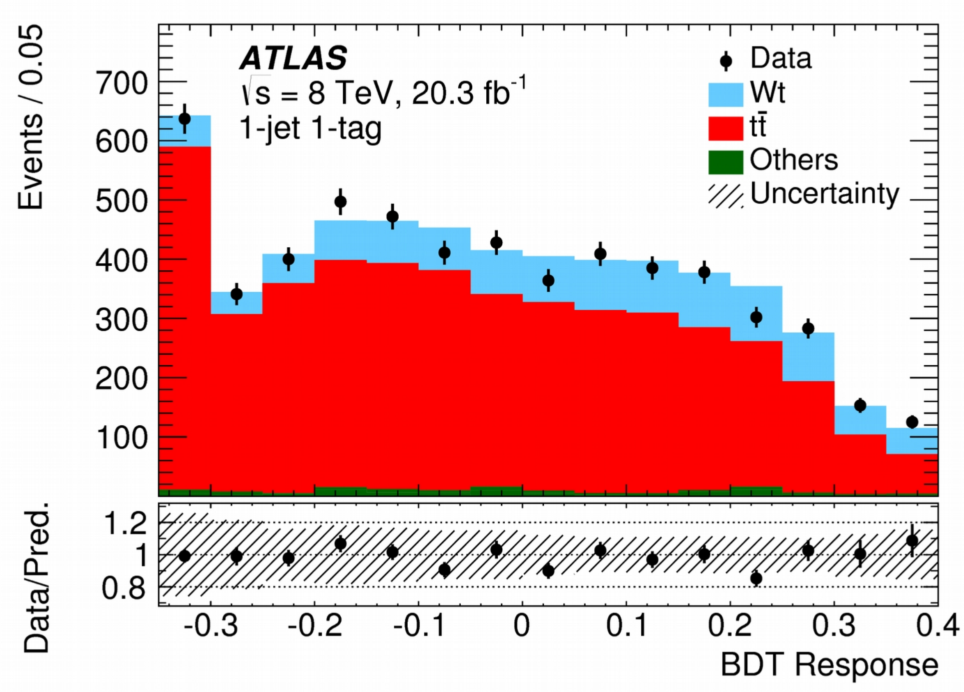
6.1σ significance, First observation

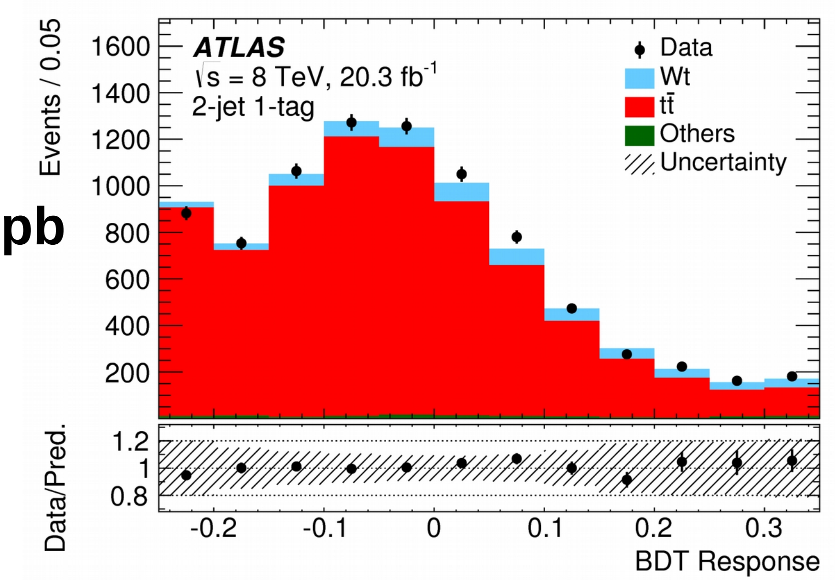
|V tb | = 1.03 ± 0.12 (exp.) ± 0.04 (th.)

Phys. Rev. Lett. 112 (2014) 231802

tW-channel Single top @ 8TeV

- **Dilepton (ee, eμ, μμ) Channel**
- **Signal Region: 1jet 1tag**
- **BDT used to discriminate signal and background**
- **Profile likelihood fit to BDT discriminant simultaneously in 1jet 1tag, 2jet 1tag and 2jet 2tag regions**





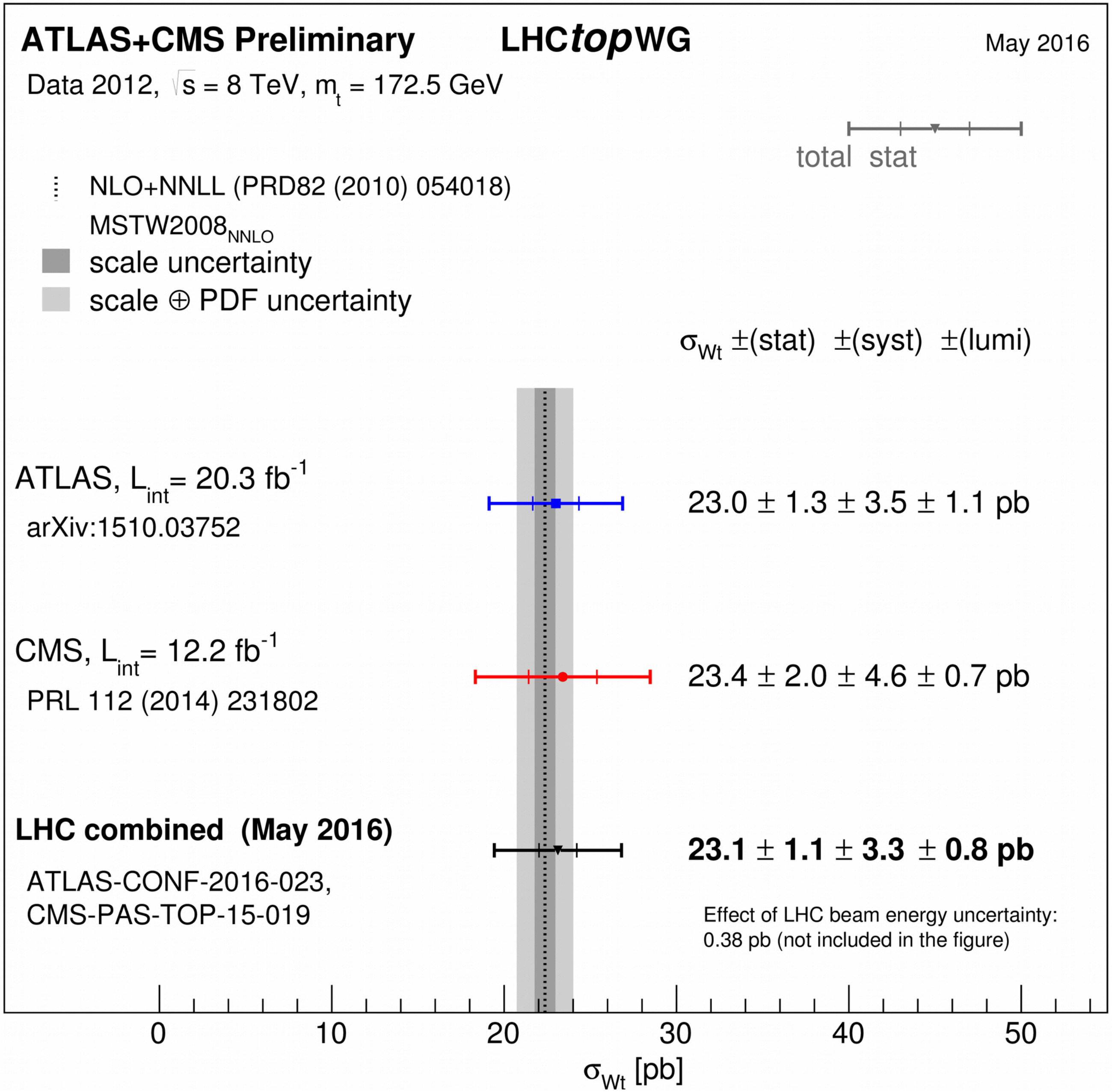
$$\sigma_{tW} = 23.0 \pm 1.3\ (\text{stat.})\ ^{+3.2}_{-3.5}\ (\text{syst.}) \pm 1.1\ (\text{lumi.})\ \text{pb}$$

7.7σ observed significance

$|f_{LV}\, V_{tb}| = 1.01 \pm 0.1$

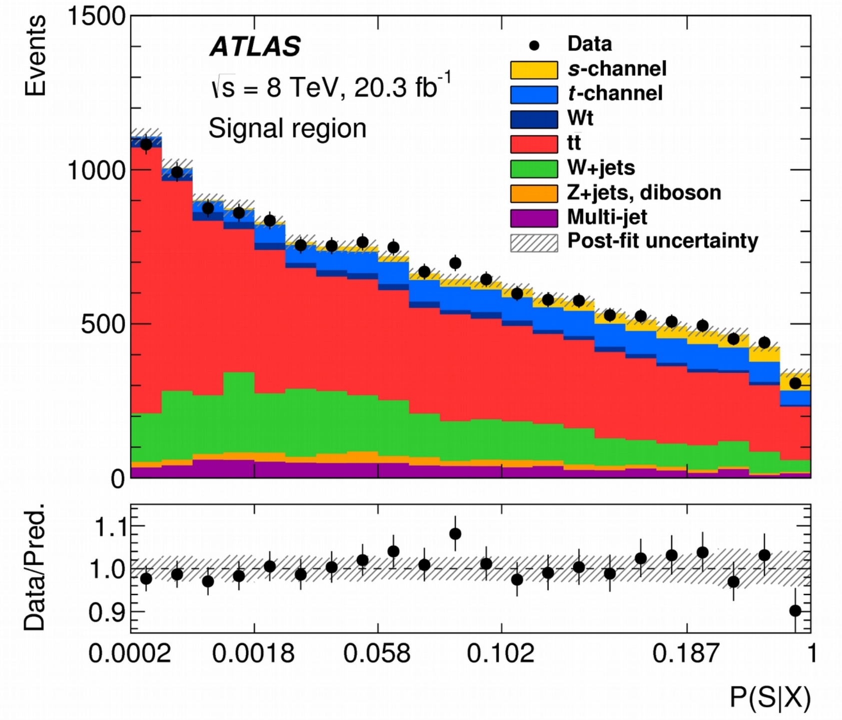
JHEP01(2016)064

Combination of tW cross-section measurements @ 8TeV

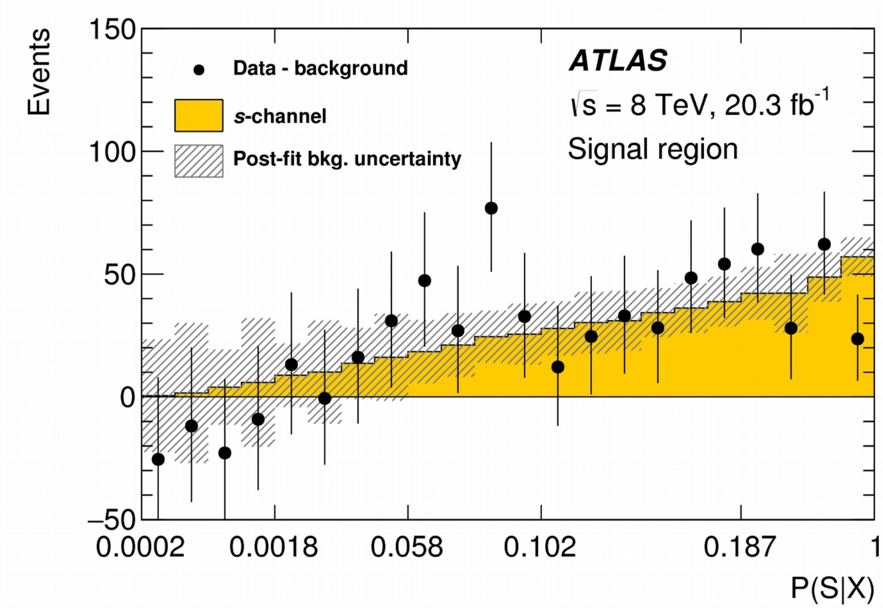


CMS-PAS-TOP-15-019

s-channel Single top evidence @ 8TeV



- **Signal Region: 2jet 2tag**
- **Matrix element method to separate signal and background**
- **Profile likelihood fit of the signal and background templates of signal probability P(S|X)**



$\sigma(tb) = 4.8 \pm 0.8\ (stat)\ ^{1.6}_{-1.3}\ (syst)$ pb

SM: $\sigma = 5.2 \pm 0.2$ pb

Significance: 3.2 σ

Phys. Lett. B 756 (2016) 228-246

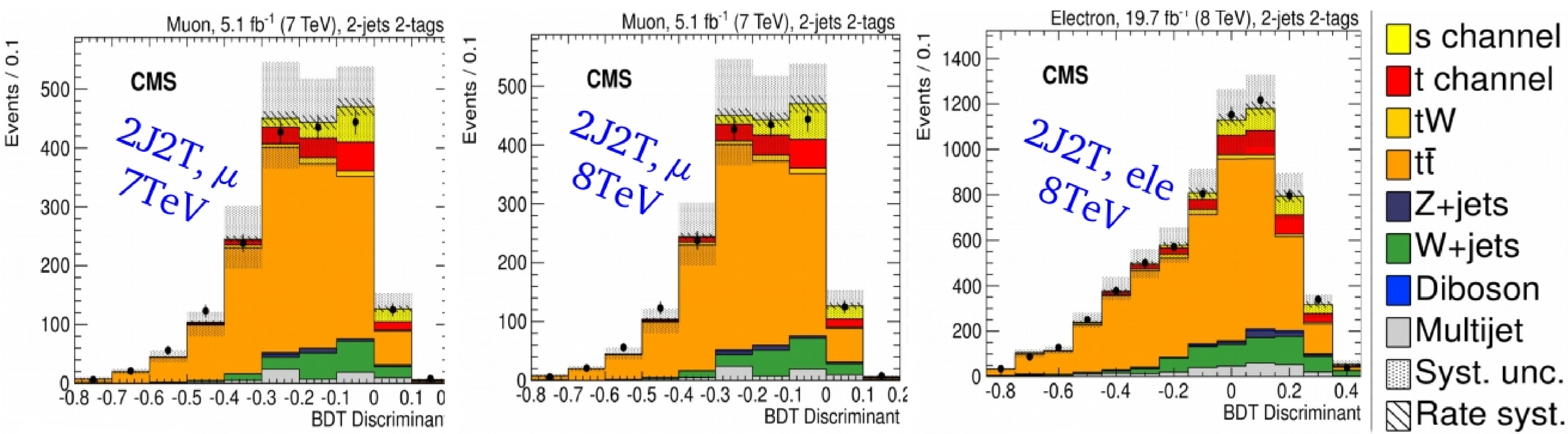
s-channel Single top @ 7 & 8TeV

Signal extraction Strategy

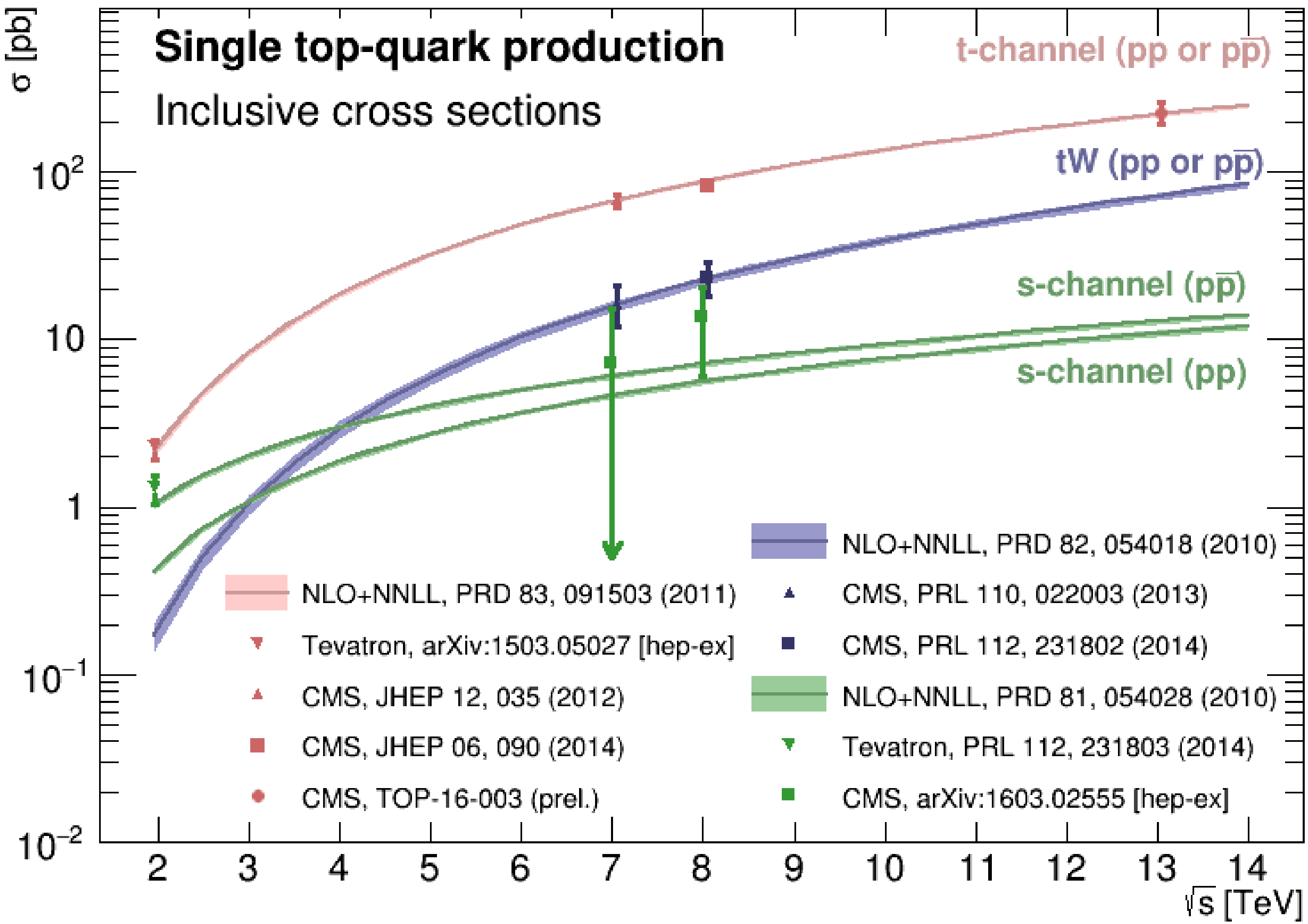
- **For electron & muon at 7 & 8TeV, BDTs trained in 2jet 1tag (2J2T), 2jet 1tag (2J1T) and 3jet 2tag (3J2T)**
  - **In 2J2T: schannel vs rest**
  - **In 3J2T: ttbar vs rest**
  - **In 2J1T: W+jets vs rest**
- **Simultaneous fit in signal and control regions**

$$\sigma_s = 7.1 \pm 8.1\,(\mathrm{stat}+\mathrm{syst})\,\mathrm{pb}, \quad \text{muon channel, 7 TeV;}$$
$$\sigma_s = 11.7 \pm 7.5\,(\mathrm{stat}+\mathrm{syst})\,\mathrm{pb}, \quad \text{muon channel, 8 TeV;}$$
$$\sigma_s = 16.8 \pm 9.1\,(\mathrm{stat}+\mathrm{syst})\,\mathrm{pb}, \quad \text{electron channel, 8 TeV;}$$
$$\sigma_s = 13.4 \pm 7.3\,(\mathrm{stat}+\mathrm{syst})\,\mathrm{pb}, \quad \text{combined, 8 TeV.}$$

JHEP 09 (2016) 027

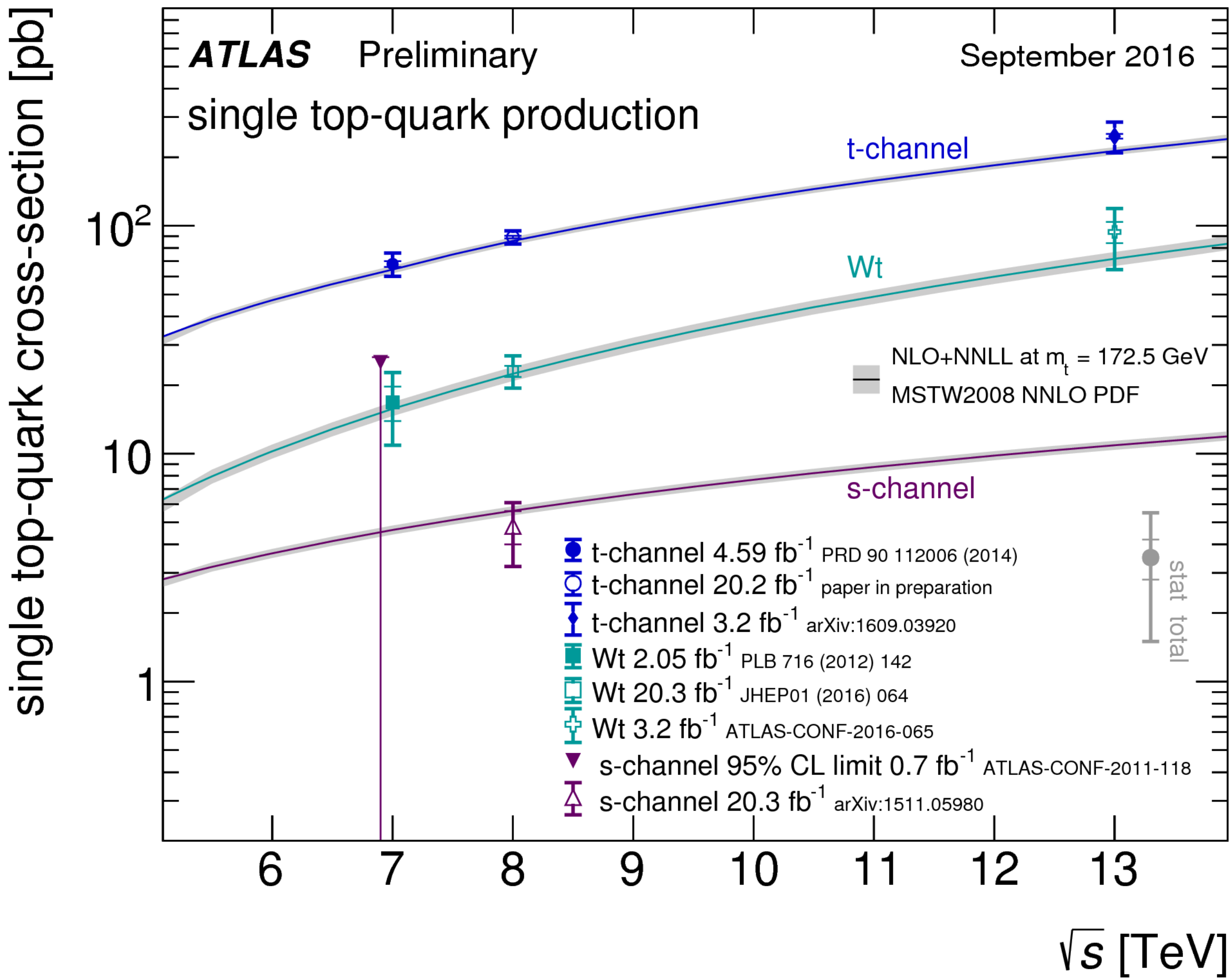


Summary of single top cross section measurements



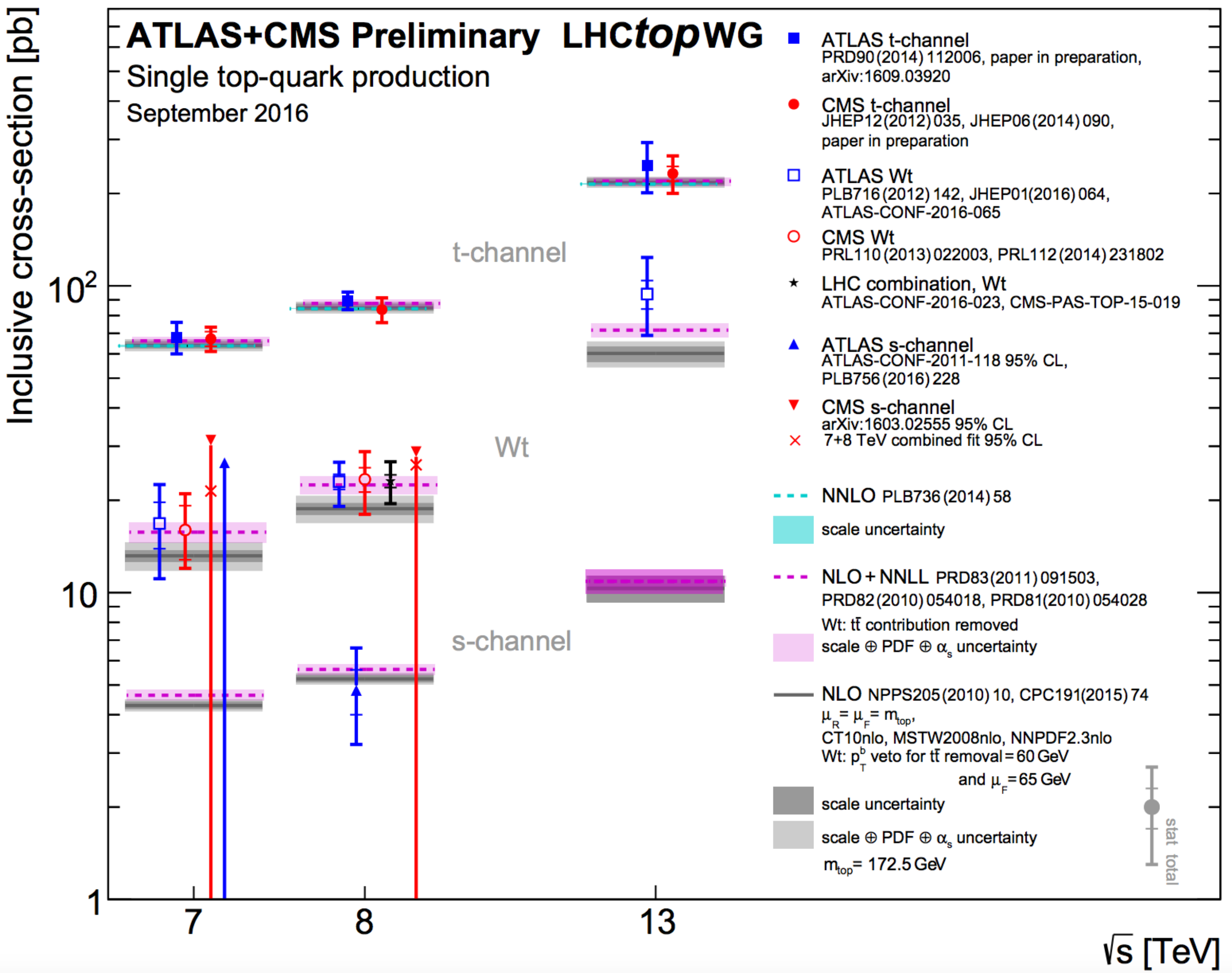
From CMS PhysicsResultsTOPSummaryFigures

Summary of single top cross section measurements



From ATLAS CombinedSummaryPlotsTOP

Summary of cross-section measurements



From LHCTopWGSummaryPlots

Summary of CKM matrix element Vtb

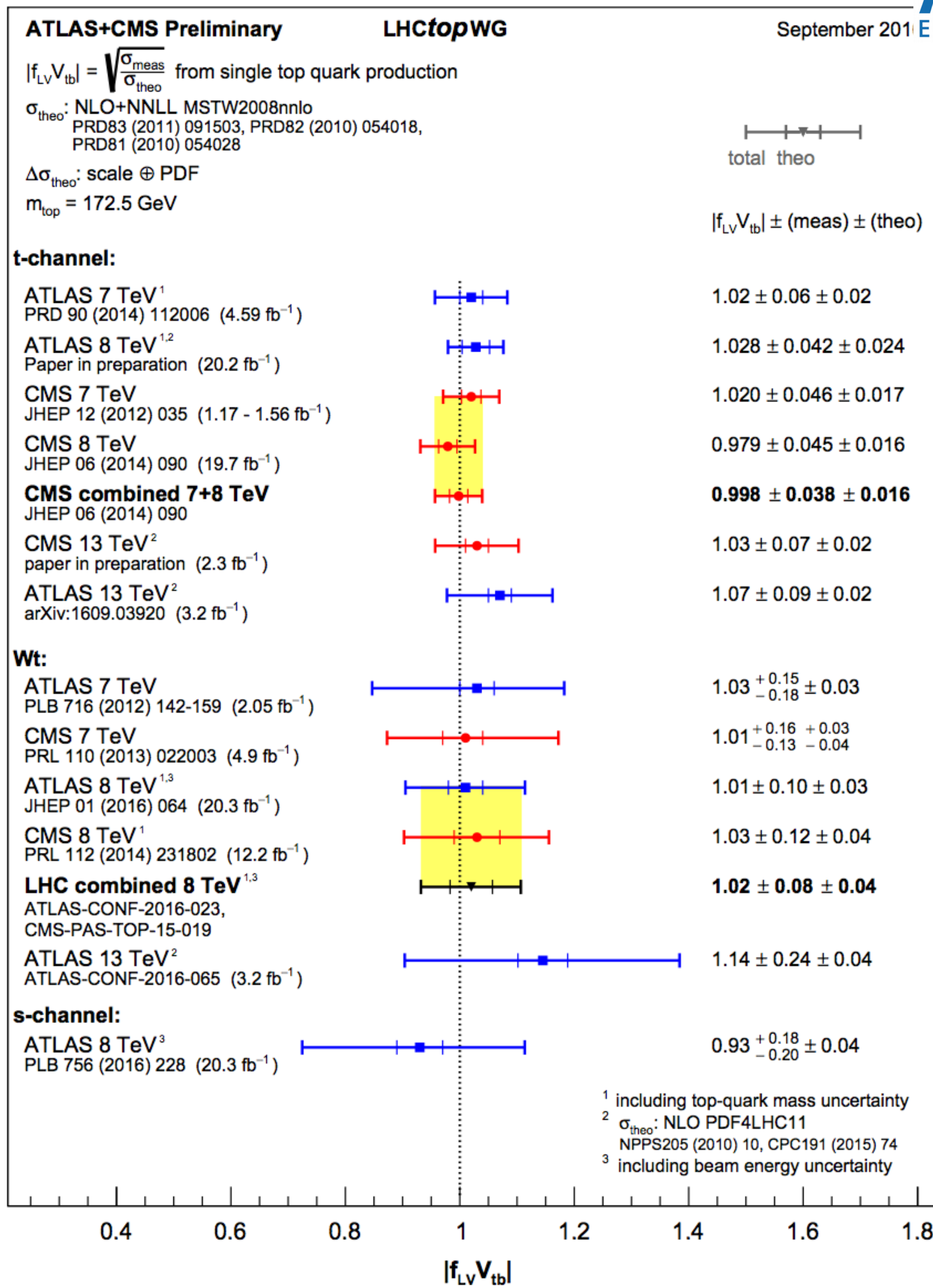
- **Cross section is proportional to $|V_{tb}|^2$**
  - **In the Standard Model with 3 quark generation**
  - **one expects $V_{tb} \sim 1$ (unitarity):**

$$|V_{tb}^{\mathrm{obs}}| = \sqrt{\frac{\sigma^{\mathrm{obs}}}{\sigma^{\mathrm{theo}}}}$$

- **Assumptions for the extraction:**
  - **Independence of 3 quark generations**
  - **Left-handed weak interaction**
  - **Top quark decays only into b quarks: (V_{td} , $V_{ts} \ll V_{tb}$)**

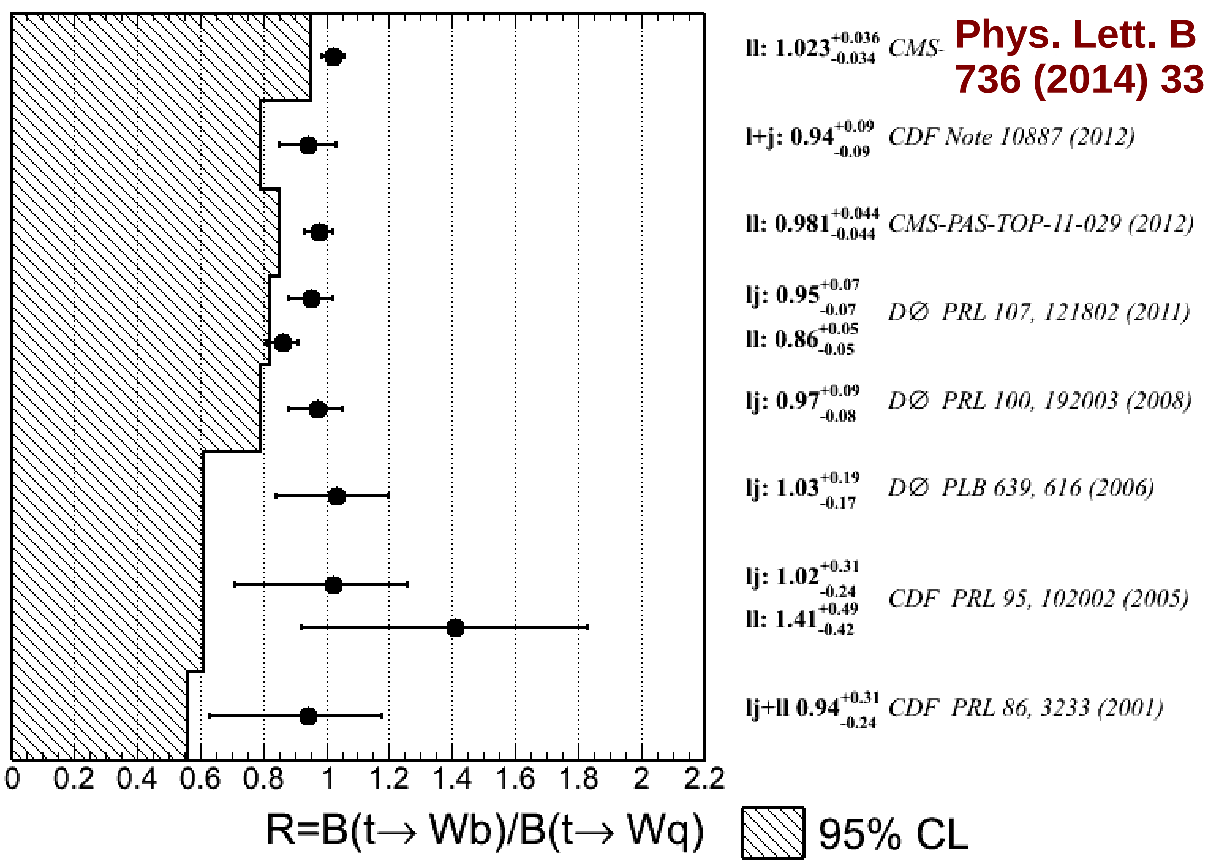
- **Can be done with all three single top processes**

From
LHCTopWGSummaryPlots



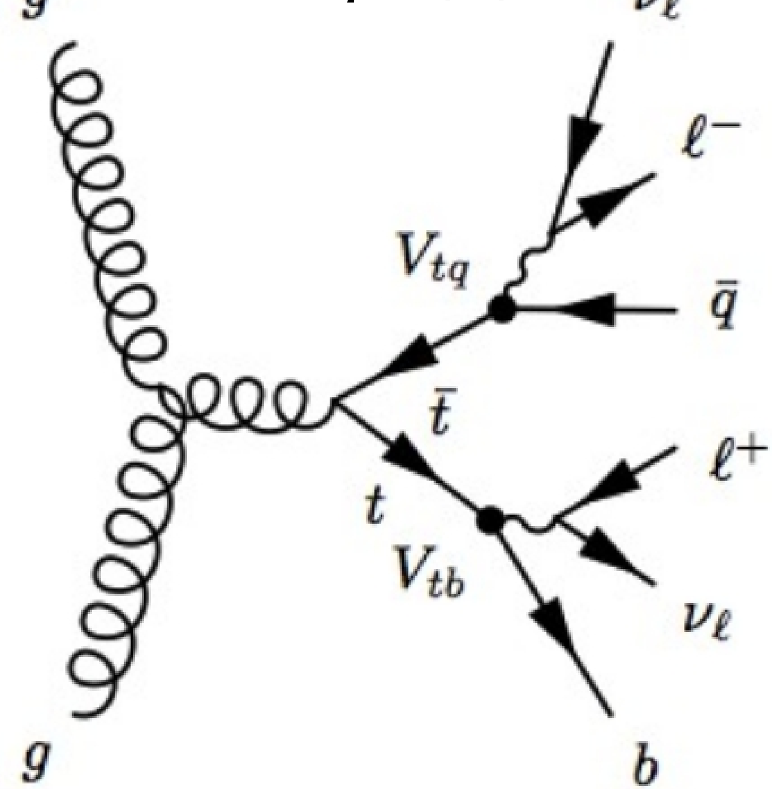
CKM Physics with Top Pairs @8TeV

- **Measure the flavor content of quarks/jets in top pairs**
- **Indirect measurement of |Vtb|: Under the assumption of the unitarity of the 3 × 3 CKM matrix, R = |Vtb|2**
- **Long history of measurements:**



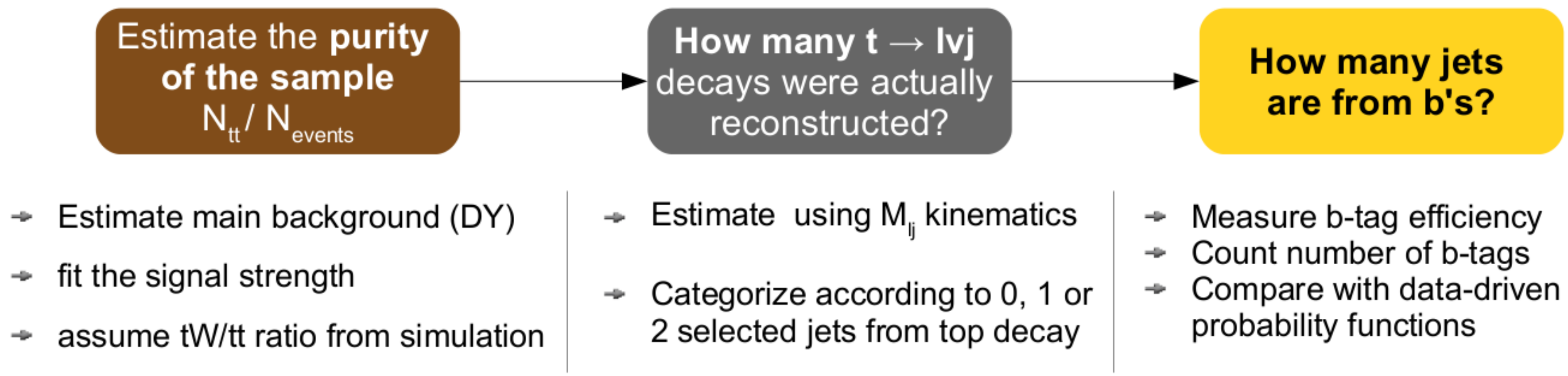
$$R = \frac{B(t \to Wb)}{\sum B(t \to Wq)}$$

where q = d, s, b



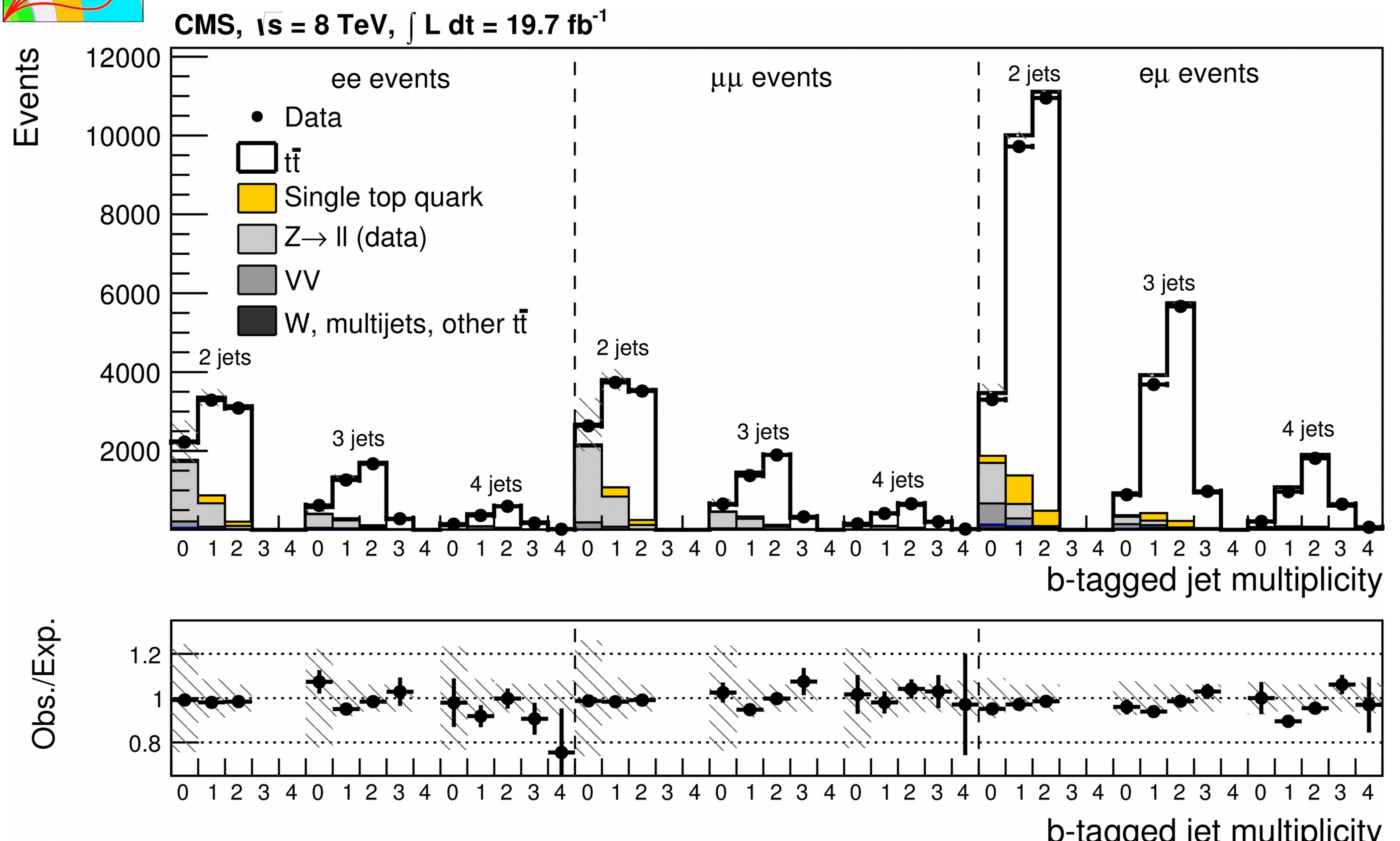
Strategy

- **Top pairs: We select dilepton events in data**
  - **Lower branching ratio (≈0.065) but cleaner signature (S/S+B≈70-90%)**
  - **≥ 2 isolated prompt leptons with op. sign + ≥ 2 jets + ETmiss >40 GeV for ee/μμ channels**
- **Count N(t → Wb) and compare to the total N(t → Wq)**



- **R = B(t → Wb) / B (t → Wq) is extracted from a fit to 36 event categories**
  - **Corresponding to dilepton channel x number of jets x number of b-tagged jets**

b-tagged jet multiplicity in dilepton channels



Phys. Lett. B 736 (2014) 33

Extraction of R & V_{tb}

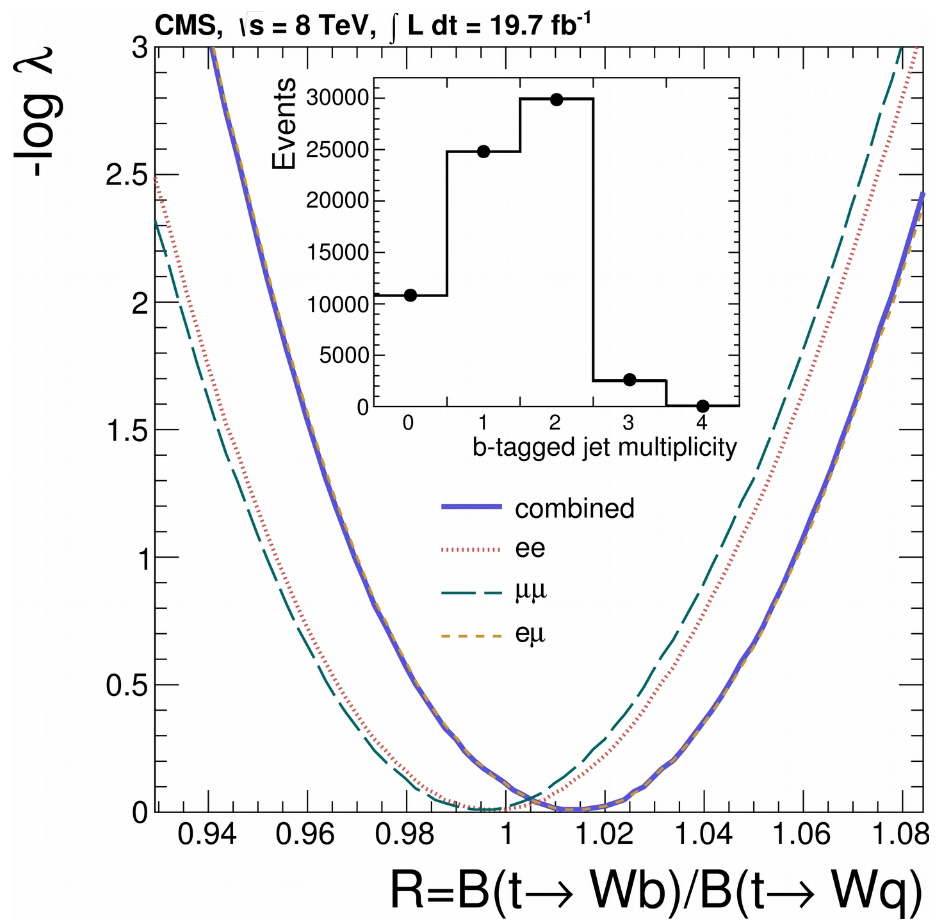
- **By counting the number of b jets per event, an unconstrained value of**

  R = 1.014 ± 0.003 (stat) ± 0.032 (syst) is measured.

- **Measured R is in good agreement with the standard model prediction.**

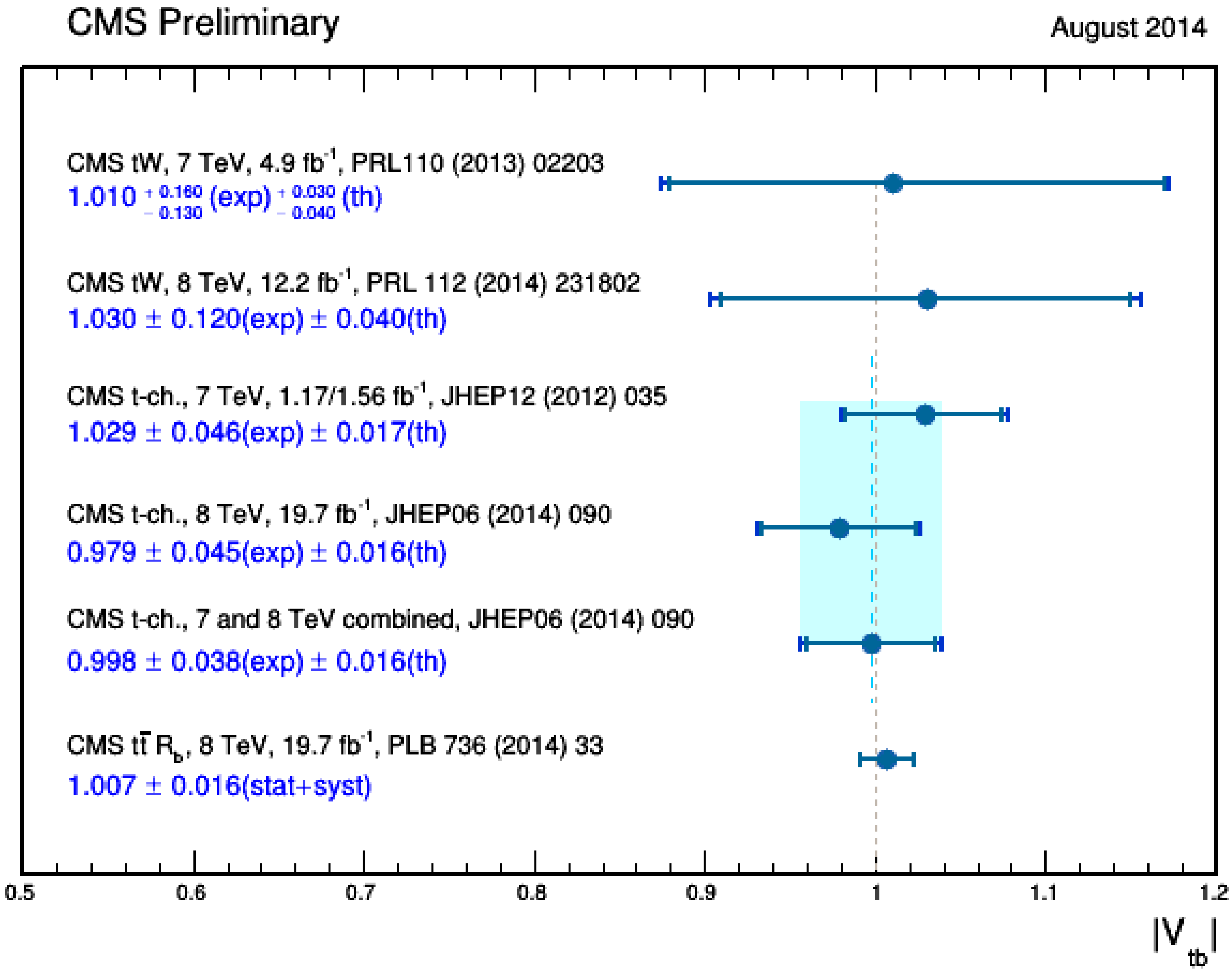
- **A lower limit R > 0.955 at the 95% confidence level is obtained after requiring R lower than one, and a lower limit on the Cabibbo-Kobayashi-Maskawa matrix element**

  | V tb | > 0 . 975 is set at 95% confidence level when assuming the unitarity of the three-generation CKM matrix.



Phys. Lett. B 736 (2014) 33

Summary of Vtb from single top and top pairs @ 7 & 8TeV



From CMS PhysicsResultsTOPSummaryFigures

Summary

- **Direct measurement of CKM matrix element V_{tb} using single top production channels with CMS and ATLAS is presented.**
- **Indirect measurement of V_{tb} by measuring the ratio of top quark branching fractions in top pairs dilepton final state at CMS is presented.**
- **Stay tuned to more results from already collected 13TeV data!**

Thanks