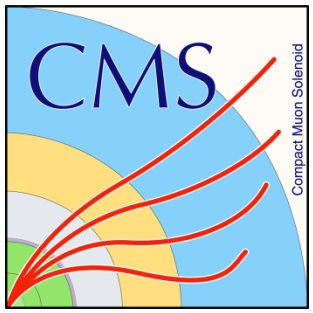
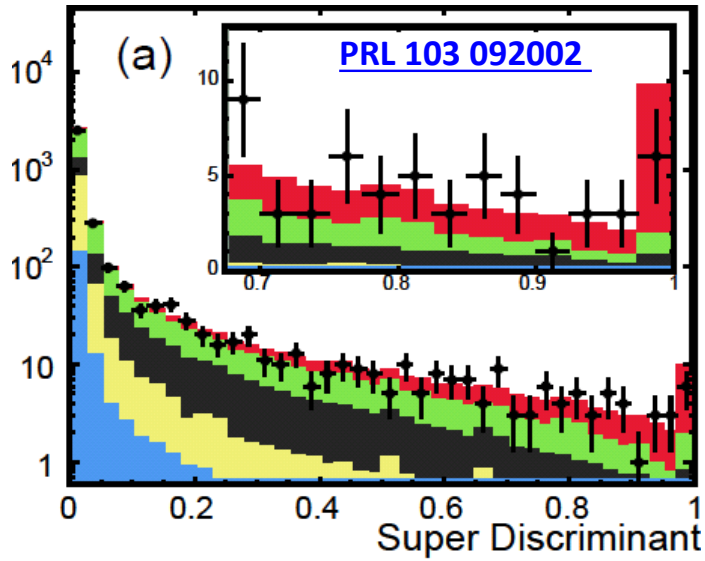


CMS Single Top Measurements
(Standard model)

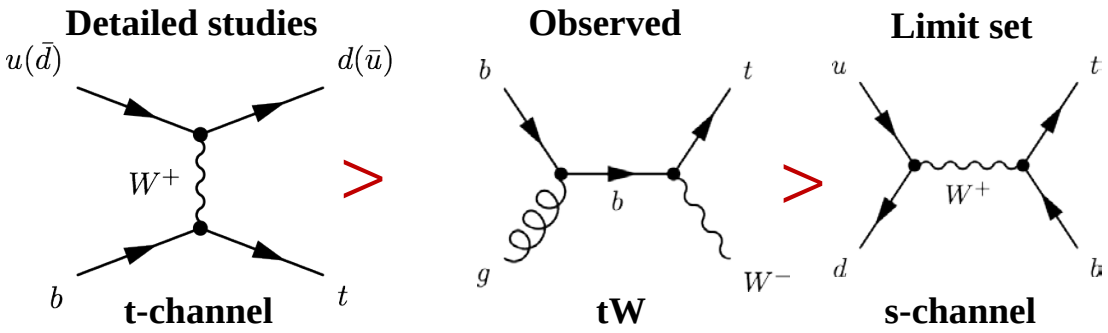
Abideh Jafari
UCLouvain and FNRS

2nd CMS Single-Top Workshop
4-5 December, Naples, Italy

Introduction



- **At hadron colliders:**
- **Dominant: Pair production via strong interactions**
- **Sub-dominant: single production via EWK interaction**



Discovery at Tevatron via Super Discriminant while LHC is a top factory

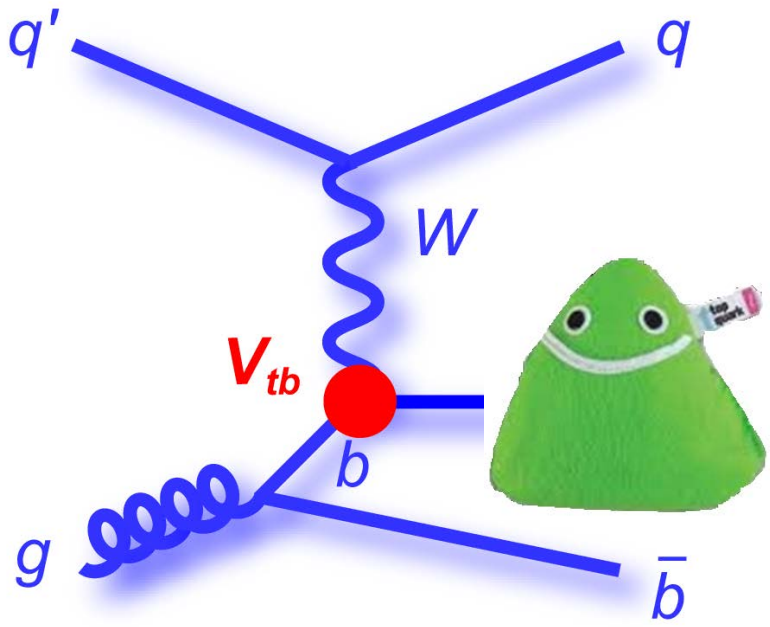
Why single-top?

- Sensitive to **new physics**!
  - FCNC, Anomalous couplings
  - New particles (W', $H^{\pm}$)
- Characteristic scenario for **SM measurements**
  - Top polarization, W helicity, top mass, $|V_{tb}|$
- **Background** in searches
  - SUSY, Higgs

We will look at production cross sections (all), $|V_{tb}|$ (t-, tW-channel), properties (t-channel)

Cross section

Properties



Differential

T-CHANNEL

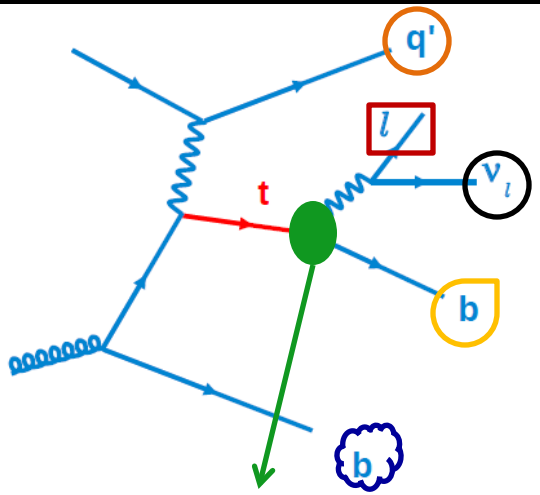
FOCUS ON NEW RESULTS

Wtb couplings

N. Kidonakis (Phys. Rev. D 83 2011):

- 8 TeV: $87.8^{+3.4}_{-1.9}$ pb
- 7 TeV: 64.6 ± 3.4 pb

t-channel cross section

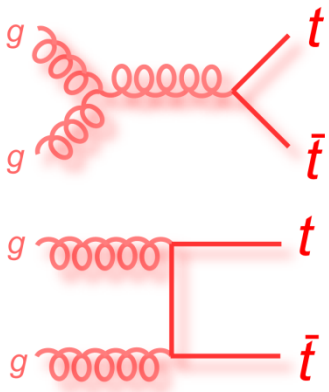


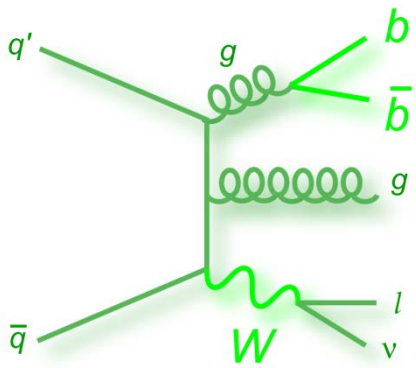
σ(t) depends on $|V_{tb}|$

- Light jet (j') with large pseudorapidity, $\eta_{j'}$
- High p_T lepton (μ, e)
- Missing transverse energy (MET)
- b-quark jet, high p_T, in the central part of the detector
- Additional soft b-quark jet with broader η

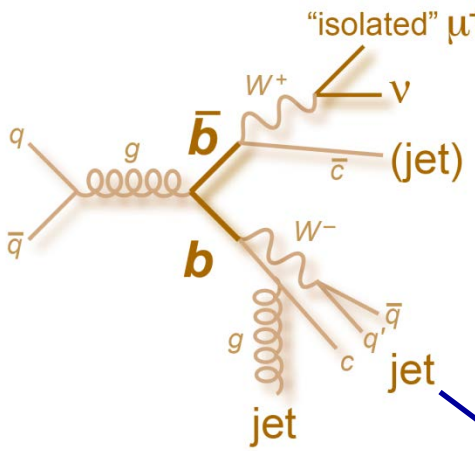
Generic Selection:
1 lepton + **2** Jet , **1** is b-Tagged + MET-related criteria

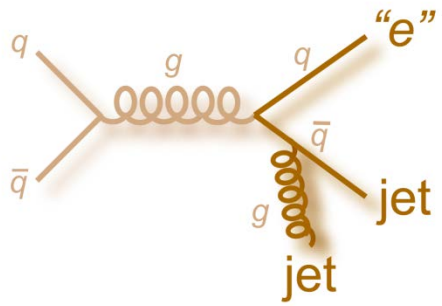
Backgrounds:





norm. from data



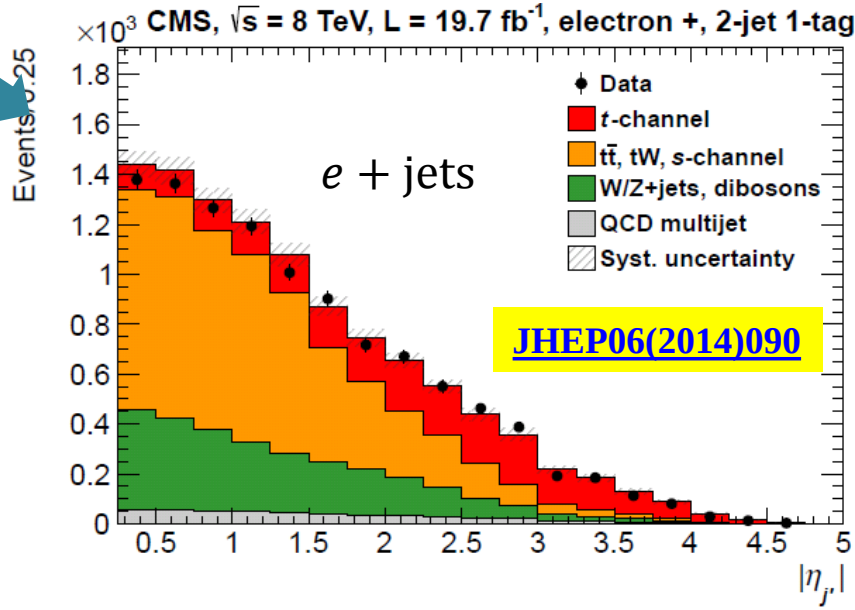


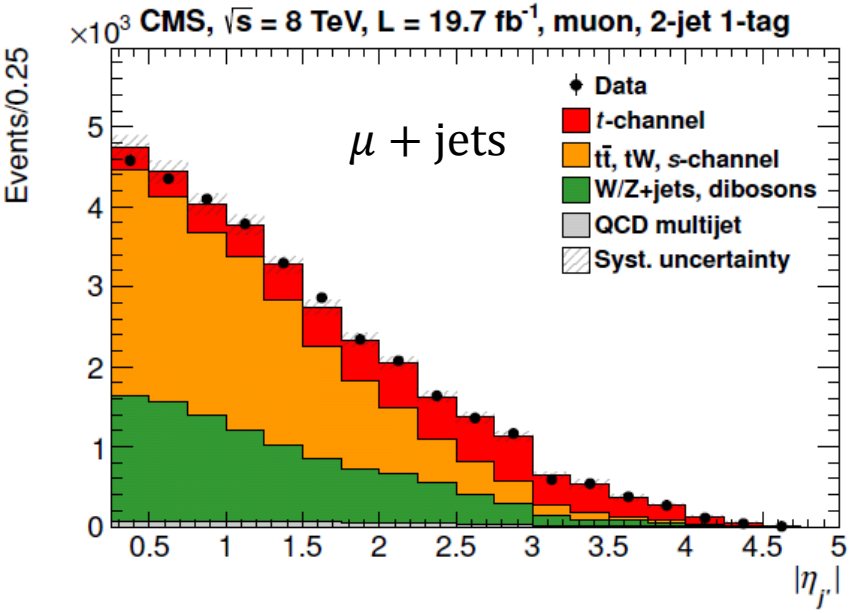
Shape and norm. from data

t-channel cross sections at 8TeV (19.7 fb^{-1})

NEW

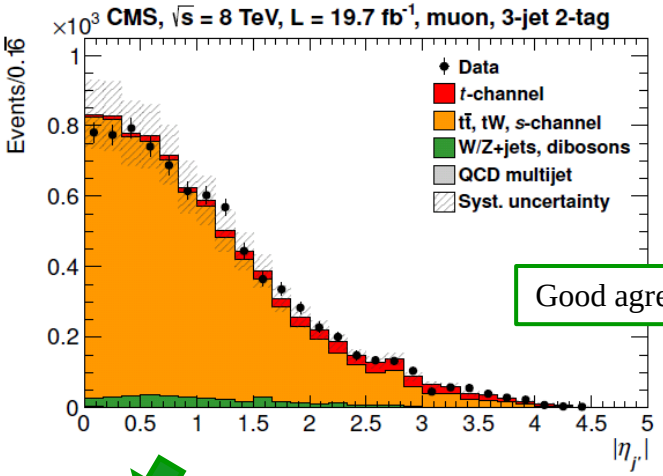
- Generic selection in 2J1T for signal



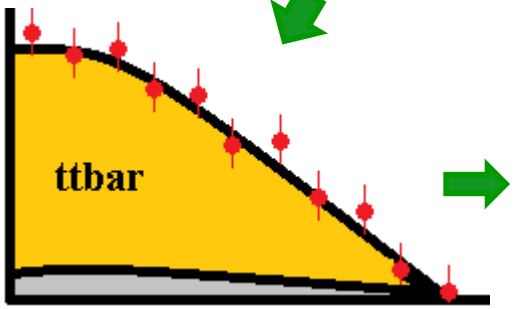


t-channel cross sections at 8TeV (19.7 fb^{-1})

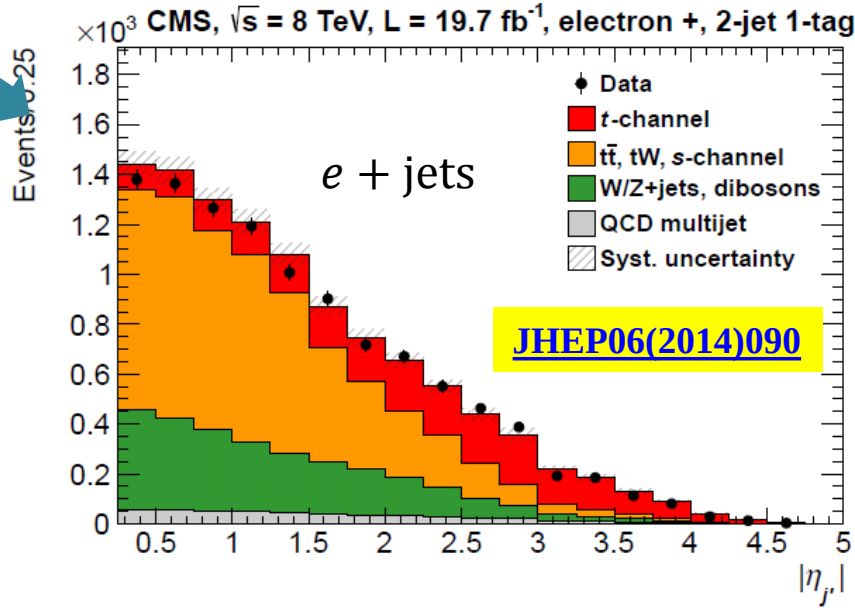
- Generic selection in 2J1T for signal
- $t\bar{t}$ background is corrected using 3J2T

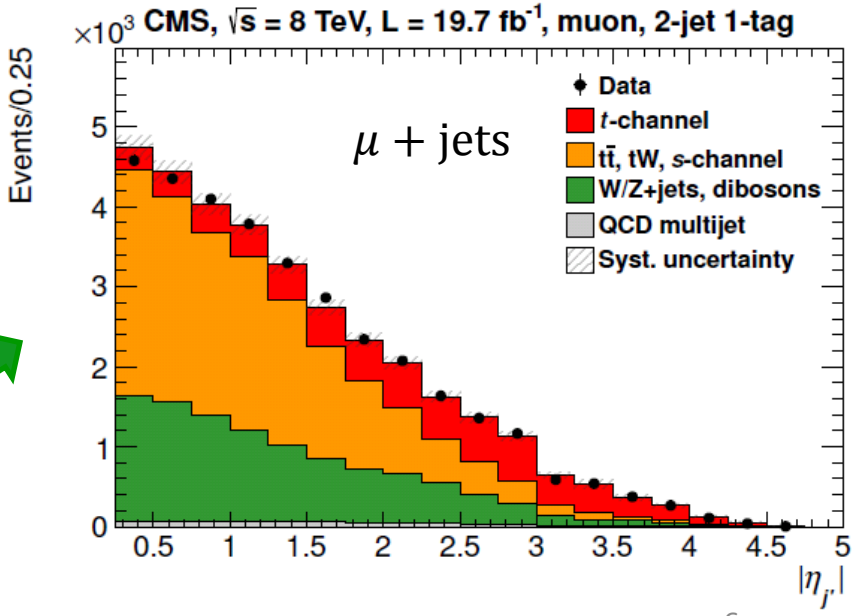


Good agreement



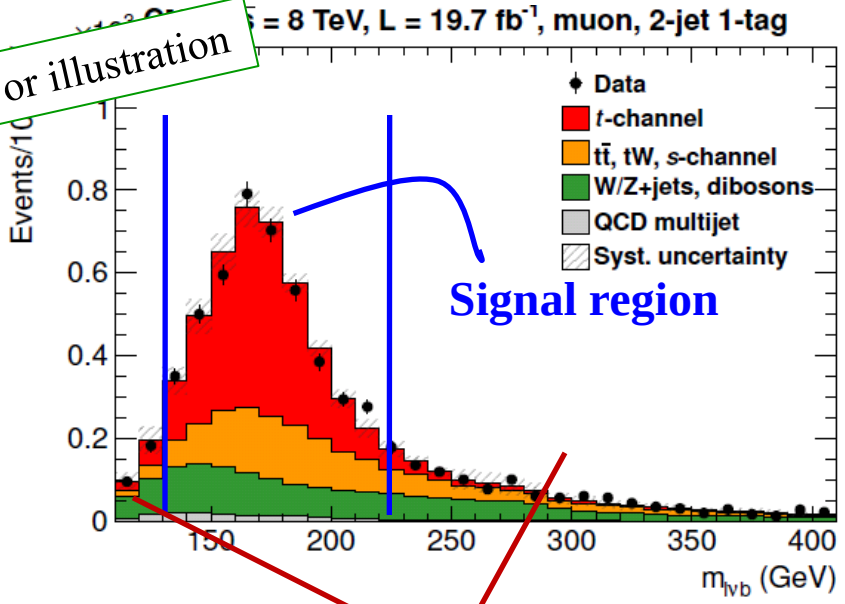
$$\omega^i = \frac{N^i_{data} - N^i_{rest}}{N^i_{t\bar{t}}}$$

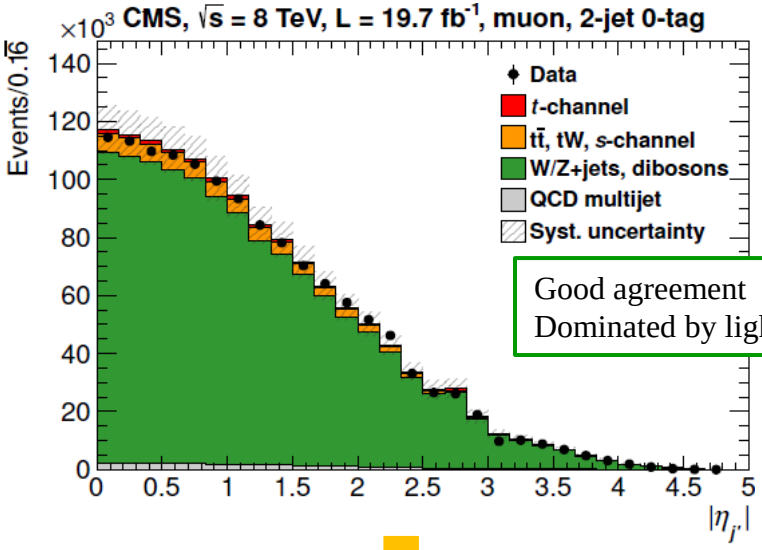




t-channel cross sections at 8TeV (19.7 fb^{-1})

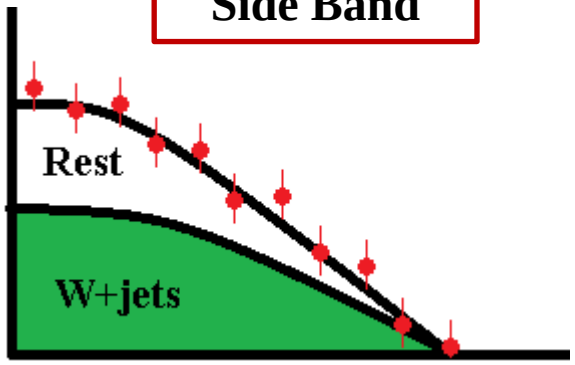
- Generic selection in 2J1T for signal
- $t\bar{t}$ background is corrected using 3J2T
- W/Z+jets validated in 2J0T





Good agreement
Dominated by light flavored jets

Side Band



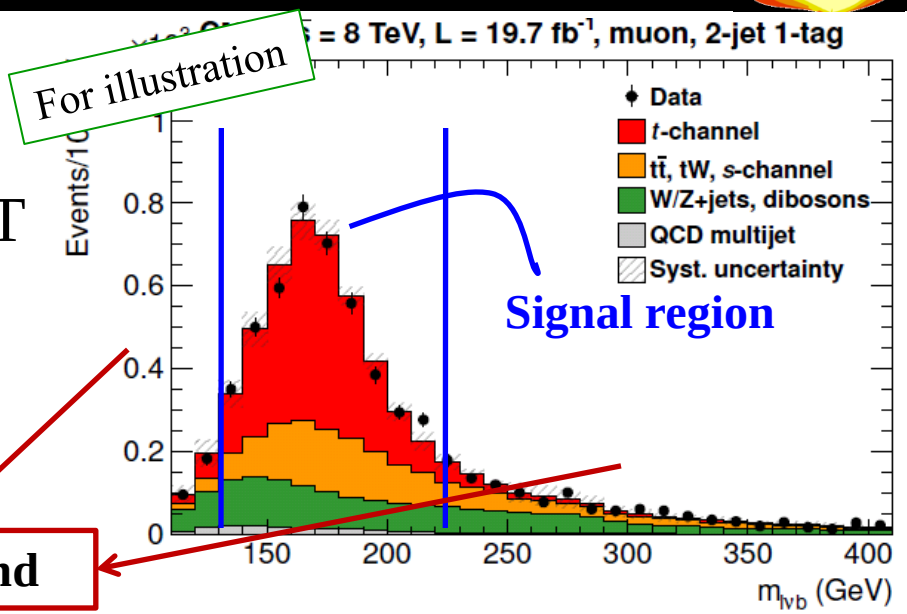
- Shape is taken from SB data
  - Similar heavy-flavor content

$$\beta_{Wjets} = \beta_{data} - \beta_{rest}$$

t-channel cross sections at 8TeV (19.7 fb^{-1})

NEW

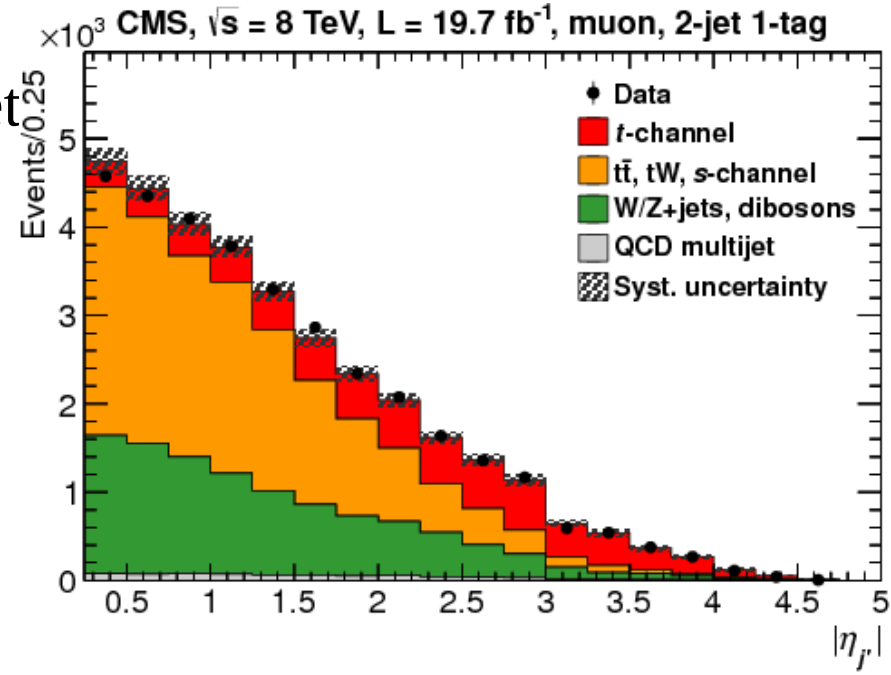
- Generic selection in 2J1T for signal
- $t\bar{t}$ background is corrected using 3J2T
- W/Z+jets validated in 2J0T
- Shape is taken from SB data
  - Similar heavy-flavor content



CMS

JHEP06(2014)090

- Template fit to |η| of the non-tagged jet
- Backgrounds treated as constrained parameters
- Other systematics from pseudo-experiments
- Fit is done inclusively and for ℓ^+ and ℓ^-



t-channel cross sections at 8TeV (19.7 fb^{-1})

NEW

- Template fit to |η| of the non-tagged jet

JHEP06(2014)090

$$\sigma_{tot} = 83.6 \pm 2.3(stat.) \pm 7.4(syst.)\ pb$$

$$\sigma_{t} = 53.8 \pm 1.5(stat.) \pm 4.4(syst.)\ pb$$

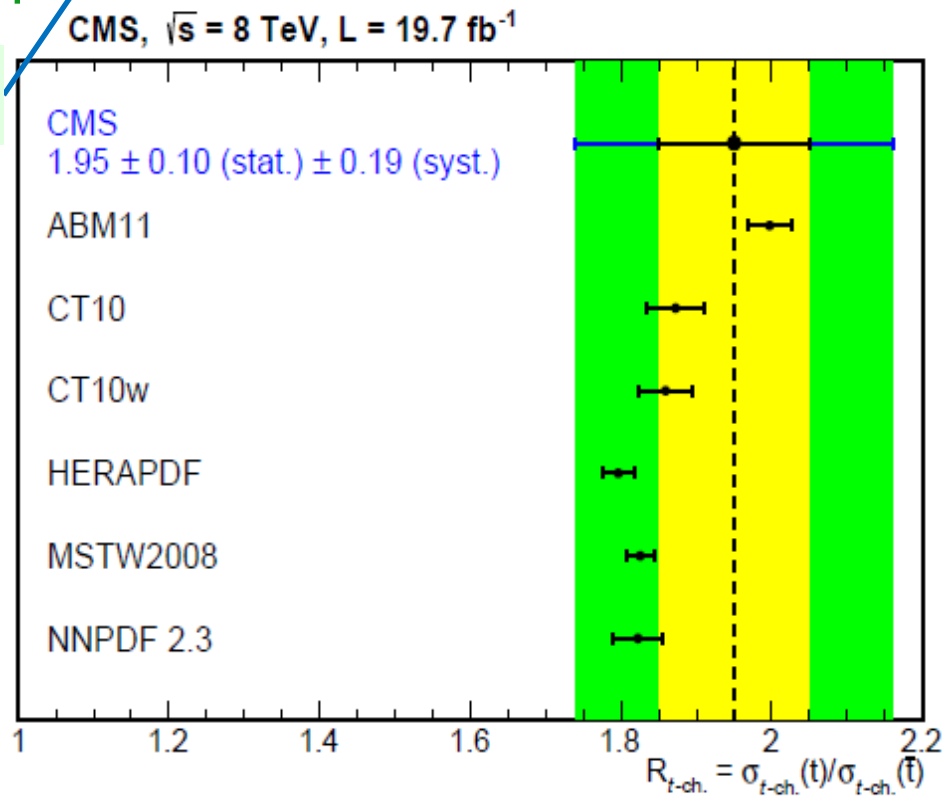
$$\sigma_{\bar{t}} = 27.6 \pm 1.3(stat.) \pm 3.7(syst.)\ pb$$

Signal modeling

$$R_{t-ch} = 1.95 \pm 0.1(stat.) \pm 0.19(syst.)$$

$m_t = 172.5$ GeV

PDF



t-channel cross sections at 8TeV (19.7 fb^{-1})

NEW

- **The ratio between cross sections at 7 and 8 TeV:**

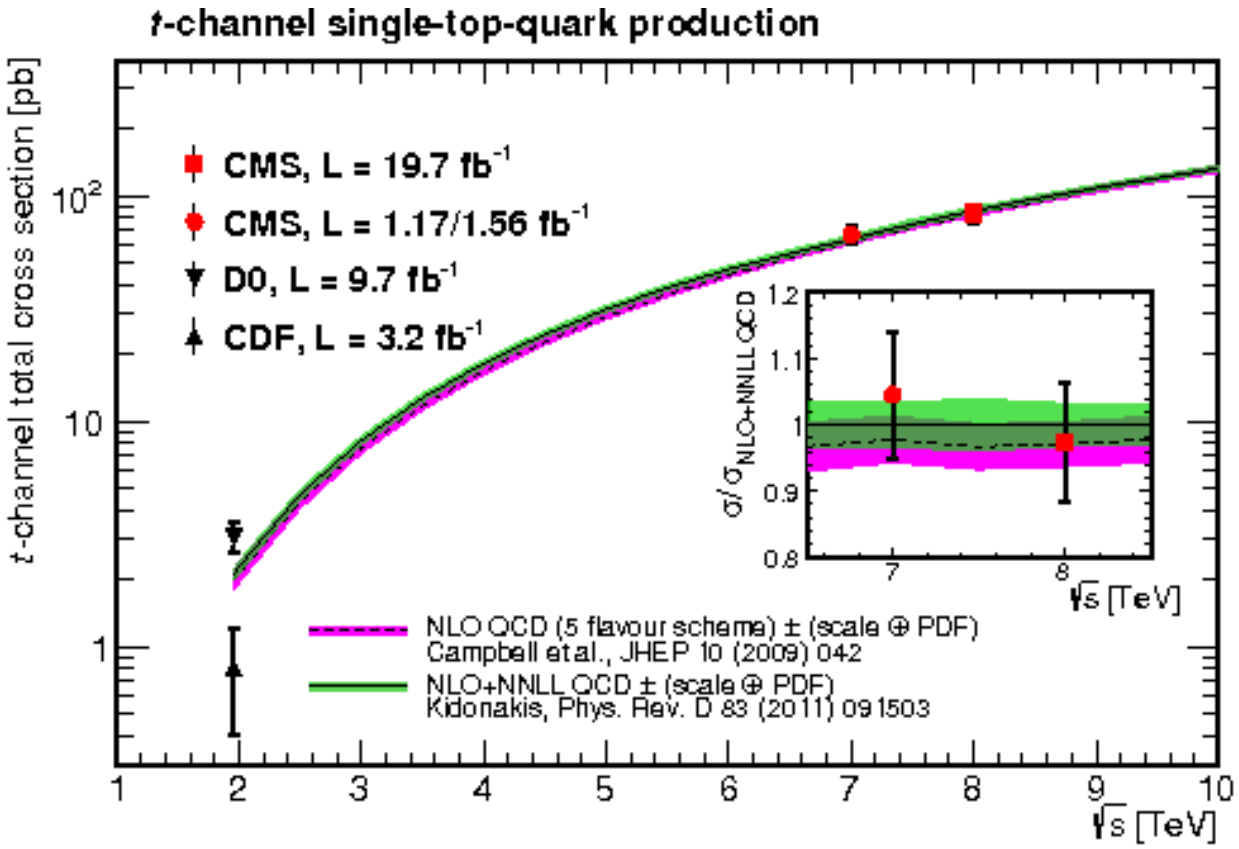
$$R_{8/7} = \frac{\sigma_{8TeV}}{\sigma_{7TeV}} = 1.24 \pm 0.08\,(\text{stat.}) \pm 0.12\,(\text{syst.})$$

- **The $|V_{tb}|$ results are also combined with BLUE:** Assuming $|V_{tb}| \gg |V_{ts}|, |V_{td}|$,

$$\left|f_V^L V_{tb}\right| = 0.998 \pm 0.038\,(\text{exp.}) \pm 0.016\,(\text{th.})$$

$7 \oplus 8$

PDG: **0.89 ± 0.07**



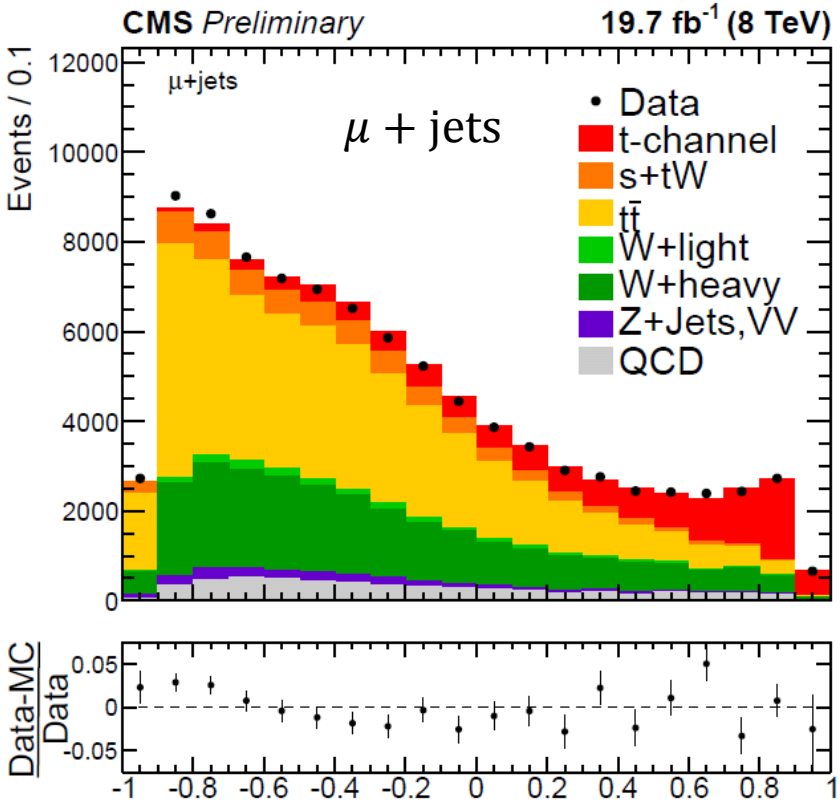
JHEP06(2014)090

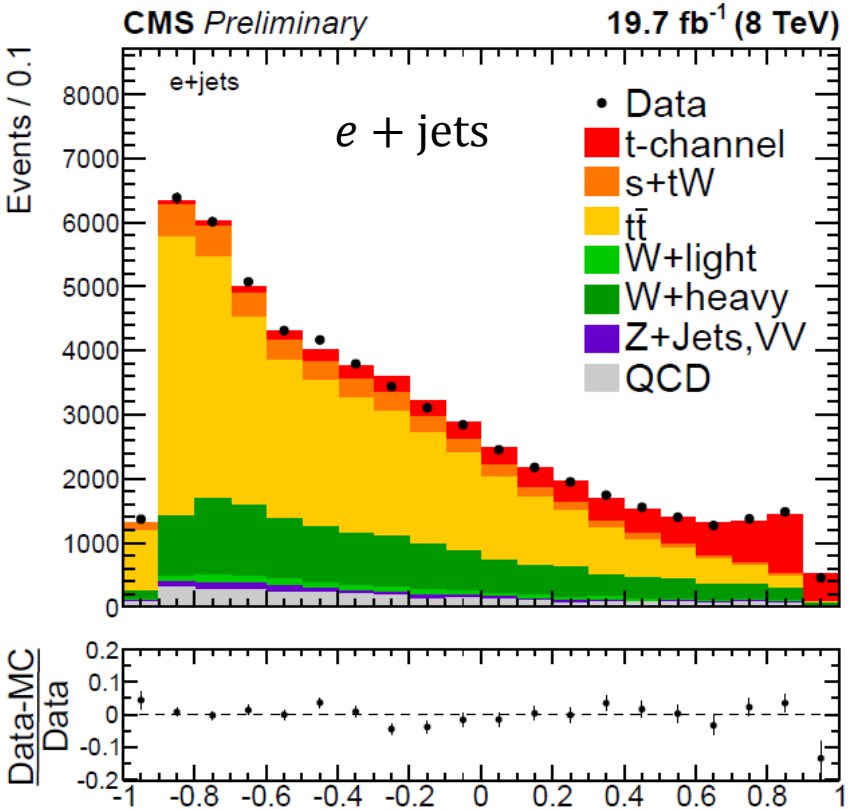
Differential t-channel at 8TeV (19.7 fb^{-1})

NEW

- Similar selection to inclusive cross section is used
- An artificial neural network is trained in signal region
  - Same NN output applied to control regions
- Background modeling is validated in 3J2T for $t\bar{t}$ and 2J0T for W+jets
- Likelihood fit to NN output in 2J1T and 3J2T
- Backgrounds treated as constrained parameters

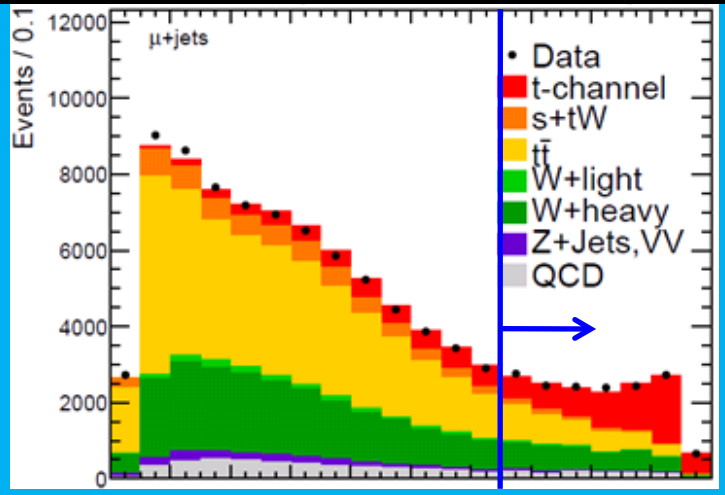
TOP-14-004

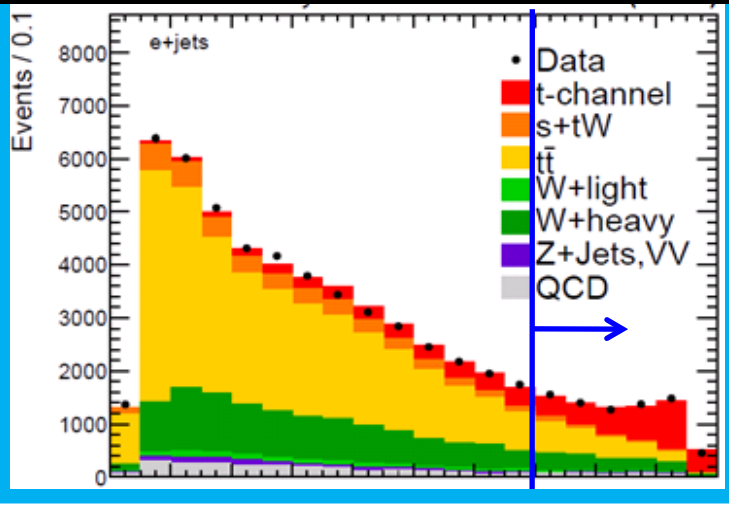




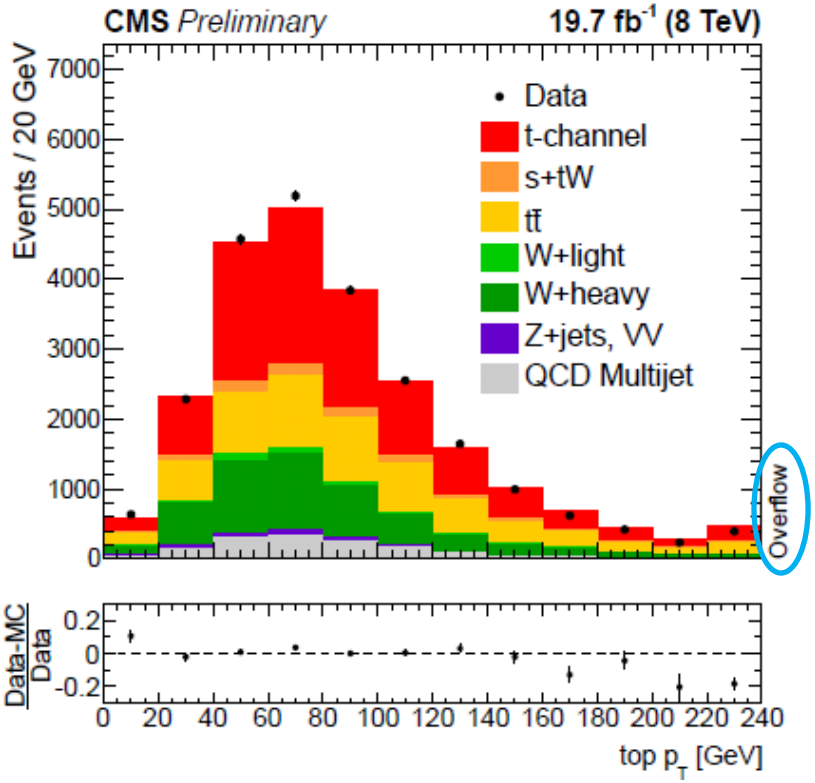
Differential t-channel at 8TeV (19.7 fb^{-1})

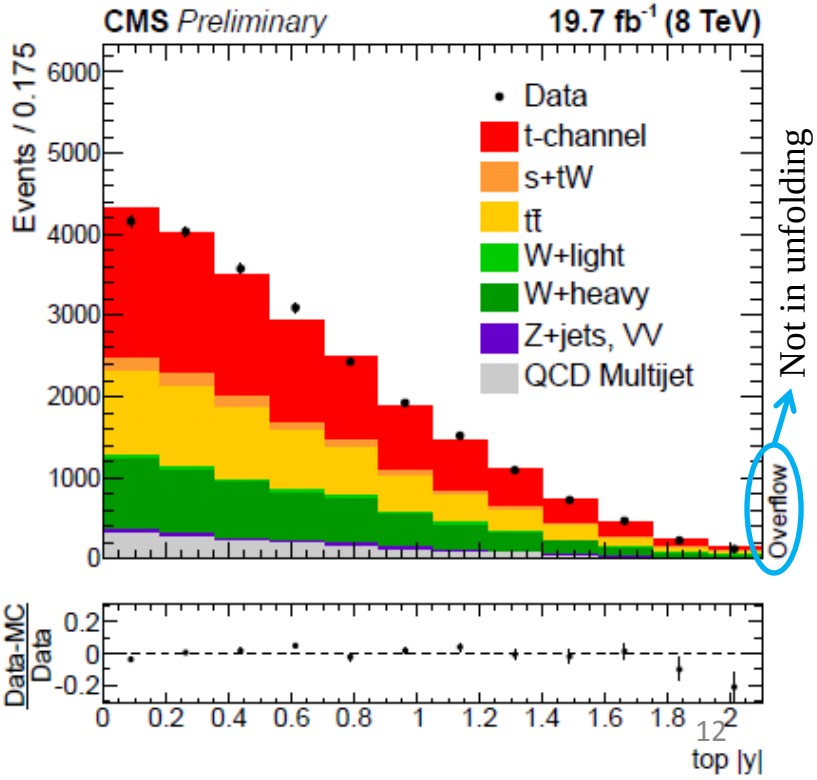
NEW





TOP-14-004

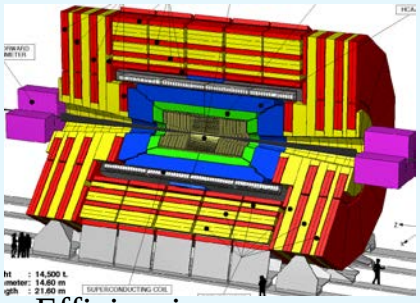




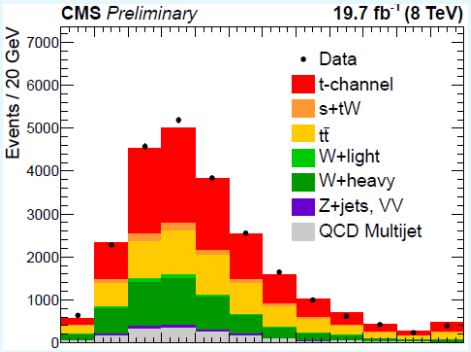
Differential t-channel at 8TeV (19.7 fb^{-1})

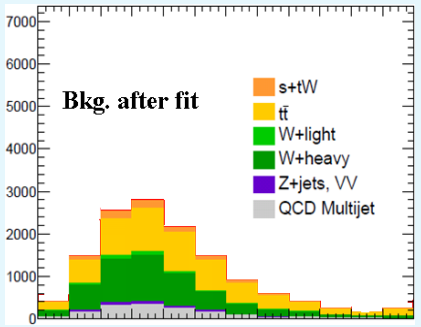
NEW

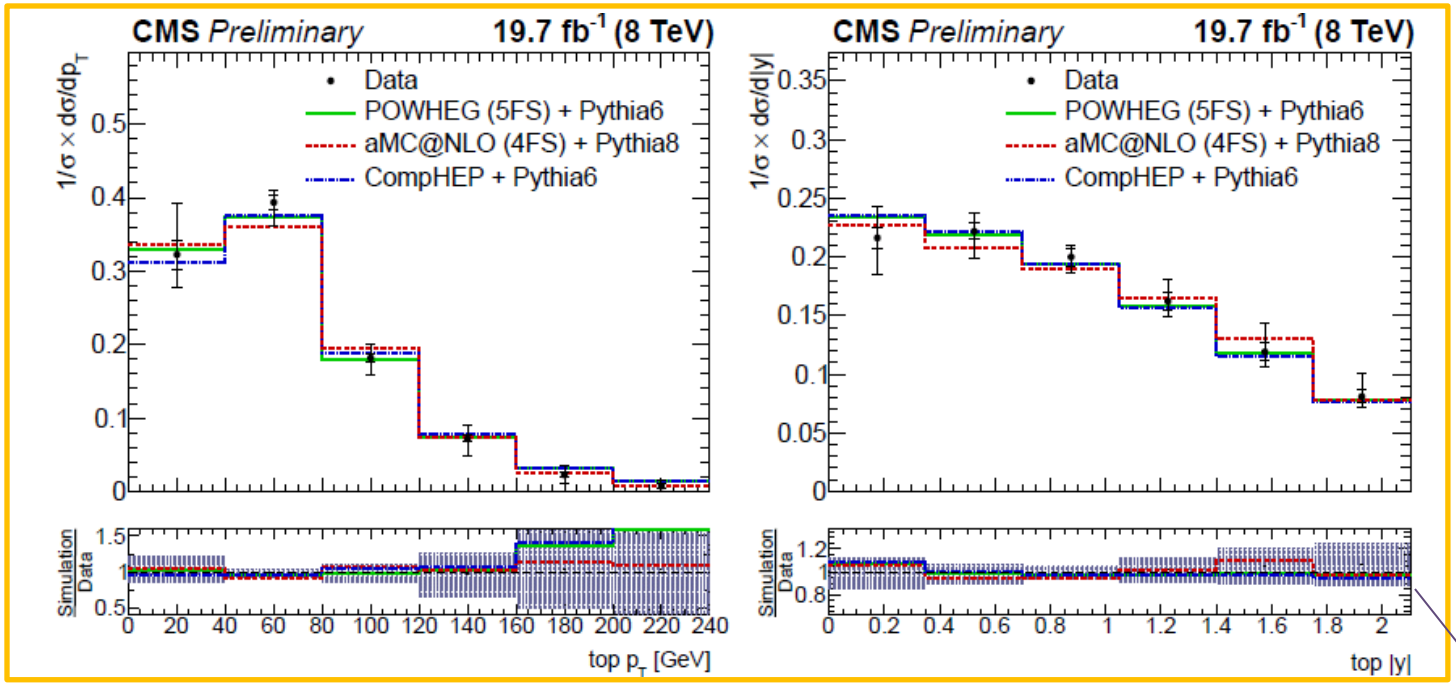
$\left[\frac{1}{\sigma}\right]^{-1}$



Efficiencies, …





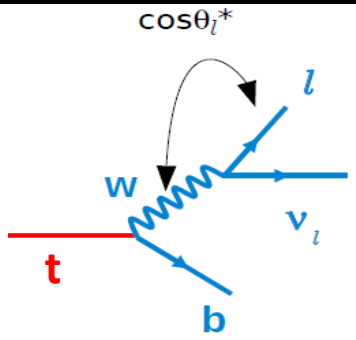


- Background subtracted distributions unfolded to parton-level
- Unfolding is verified to be stable and unbiased
- Impressive agreement with the theory!

E_T^{miss}, JES

W-helicity, single-top topology 8TeV (19.7fb^{-1})

NEW



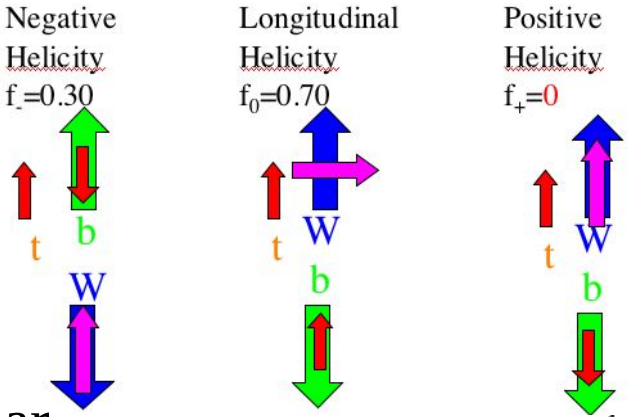
- Partial decay of top quark with $F_i \equiv \frac{\Gamma_i}{\Gamma}$

arXiv:1410.1154

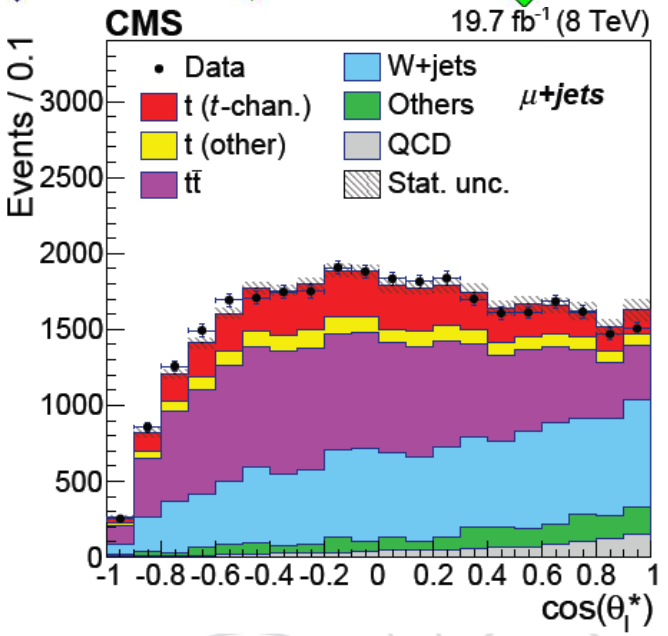
$$\rho_{\vec{F}} \equiv \frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_l^*} = \frac{3}{8}(1-\cos\theta_l^*)^2\, F_L + \frac{3}{4}\sin\theta_l^*\, F_0 + \frac{3}{8}(1+\cos\theta_l^*)^2\, F_R$$

Talk by J. Andrea

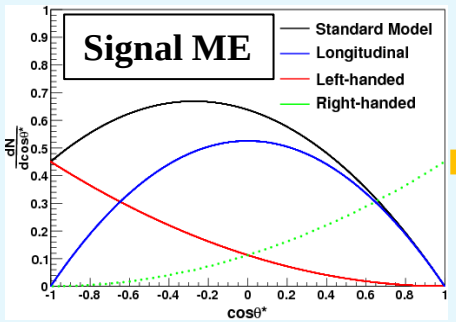
$$\Gamma_{0\,(L,R)} \propto \frac{m_t^2}{m_W^2}\left[\left|f_V^L\right|^2 + \left|f_V^R\right|^2\right]\mathcal{F}_{1\,(2)}(m_W^2, m_b^2) + \left[\left|f_T^L\right|^2 + \left|f_T^R\right|^2\right]\mathcal{F}_{2\,(1)}(m_W^2, m_b^2) + \cdots$$



- tWb anomalous couplings are reflected in angular decay distribution of $\cos\theta_l^*$
- Looking at the same physics in different phase space than $t\bar{t}$
- Same selection as t-channel cross section
- Signal is every process that includes $t \to b\ell\nu$
  - Contributions from $t\bar{t}$ are taken into account
- Results at e- and μ-channels are combined using their likelihoods

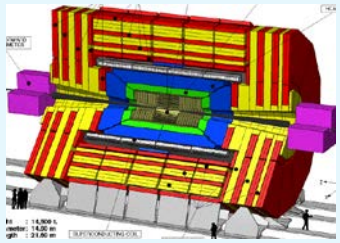


W-helicity, single-top topology 8TeV (19.7fb^{-1})



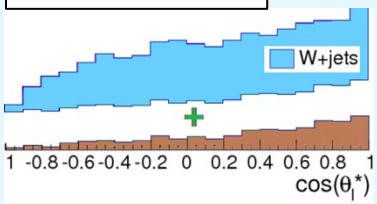
Reweighting

$$\omega = \frac{\rho(\cos\theta_\ell^*|\vec{F})}{\rho(\cos\theta_\ell^*|\vec{F}_{SM})}$$

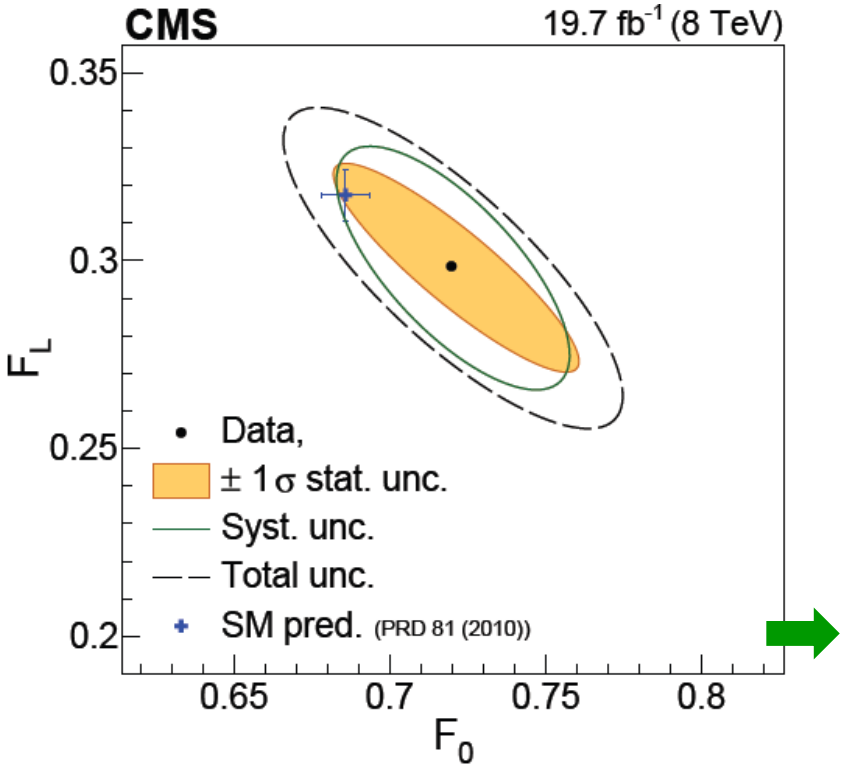


Efficiencies, …

Backgrounds



Likelihood fit, W-helicities and W+jets contamination simultaneously



e + μ: consistent with SM

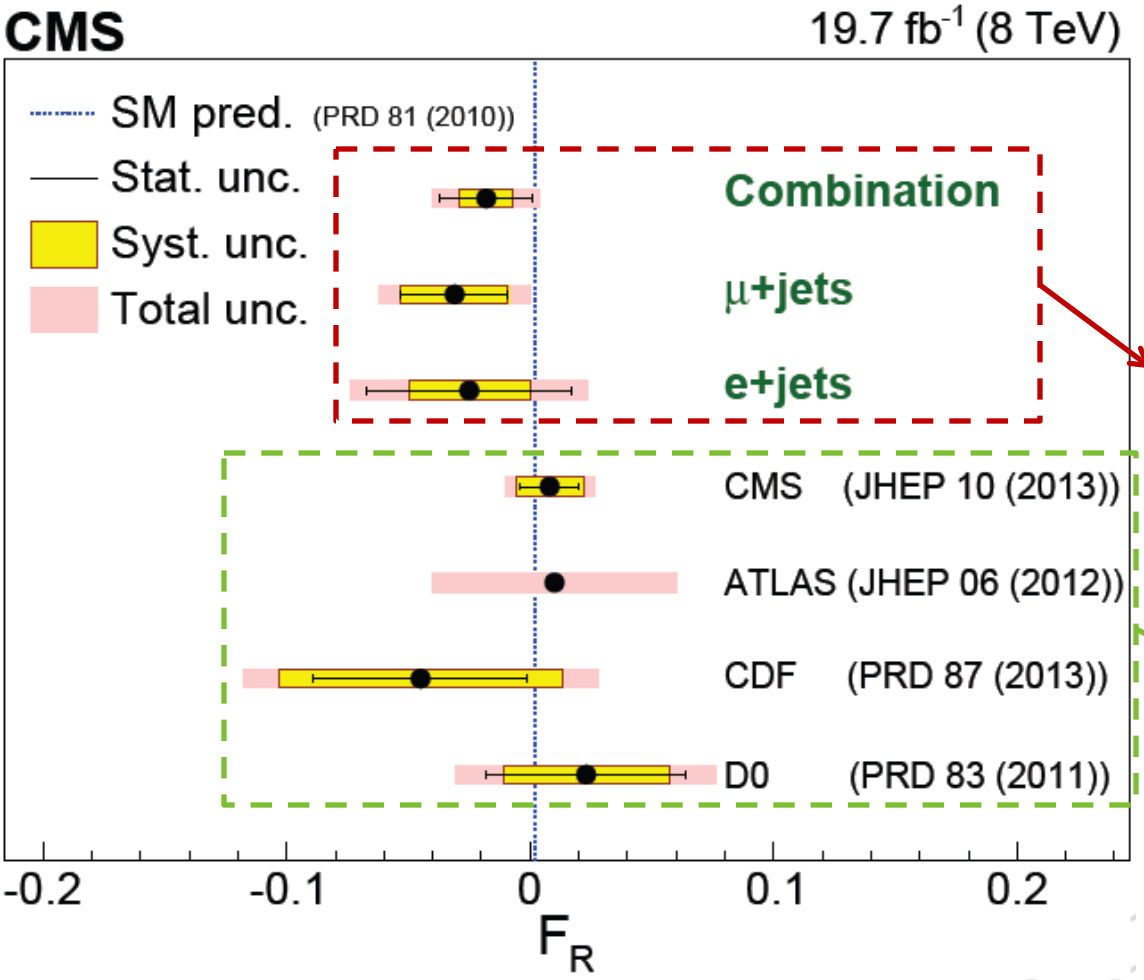
arXiv:1410.1154

$$F_L = 0.298 \pm 0.028\,(\text{stat.}) \pm 0.032\,(\text{syst.}),$$
$$F_0 = 0.720 \pm 0.039\,(\text{stat.}) \pm 0.037\,(\text{syst.}),$$
$$F_R = -0.018 \pm 0.019\,(\text{stat.}) \pm 0.011\,(\text{syst.})$$

Signal modeling

Used to set limits on anomalous couplings (talk by J. Andrea)

W-helicity, single-top topology 8TeV (19.7fb^{-1})

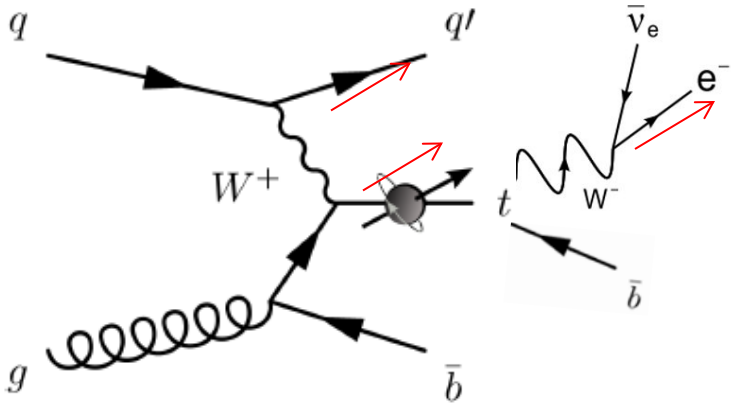


- Results from single-top are competitive, despite smaller statistics
- Single-top and top-pairs: independent datasets: gain in combination.

All in $t\bar{t}$ sector

arXiv:1410.1154, accepted by JHEP

Top quark polarization



- The sample is statistically a mix of ↑ and ↓ top quarks
- We measure the spin asymmetry:

$$A_l \equiv \frac{N(\uparrow) - N(\downarrow)}{N(\uparrow) + N(\downarrow)} = \frac{1}{2} \cdot P_t \cdot \alpha_l$$

Test of the SM in the tWb vertex via the top polarization

Single-top quark in t-channel:
produced 100% polarized in the direction of charged lepton due to V-A coupling

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{1}{2}(1 + P_t \alpha_l \cos\theta^*)$$

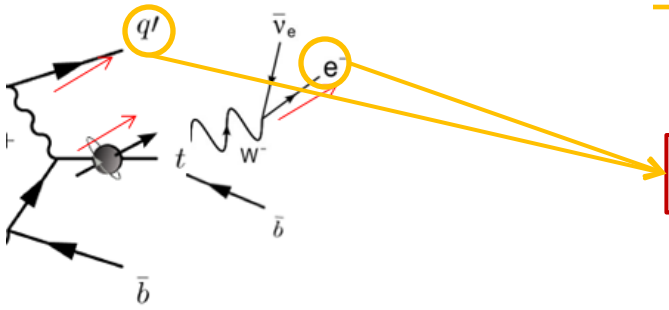
top polarization

$\theta^* \equiv \sphericalangle(l, q')$ in top rest frame

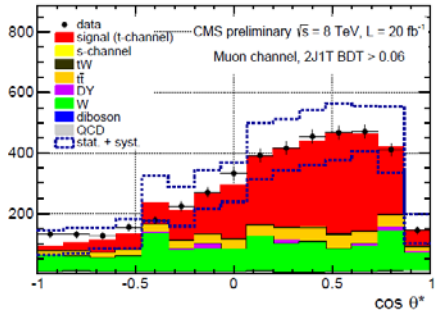
Correlation degree or spin analyzing power
SM: $\alpha_l \approx 1$ for charged lepton

CMS-TOP-13-001

Experimentally:
we select the t-channel event: 1 lepton + 1 light jet + 1 b-tagged jet + …



$\theta^* \equiv \sphericalangle(l, q')$

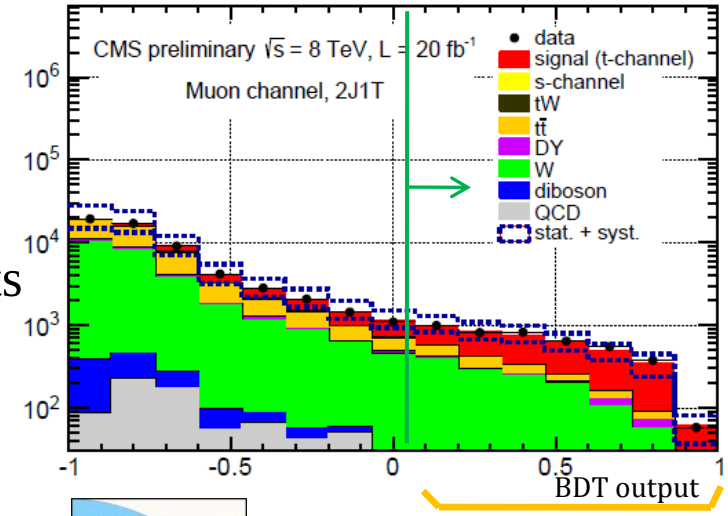


Top quark polarization

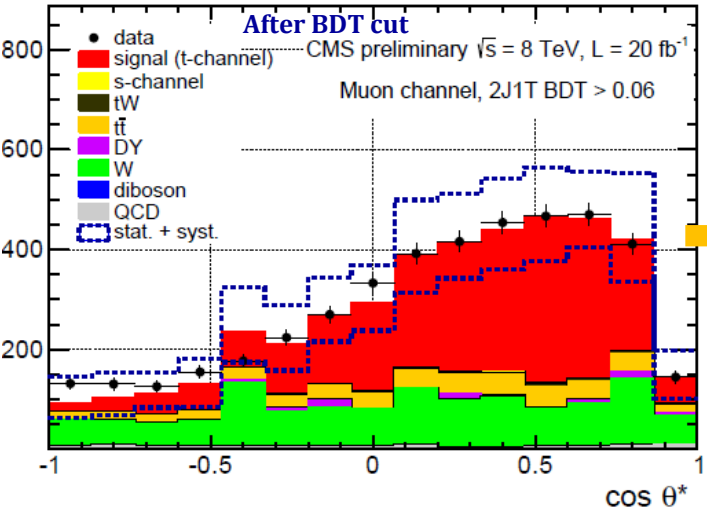
The output of a Boosted Decision Tree is used to

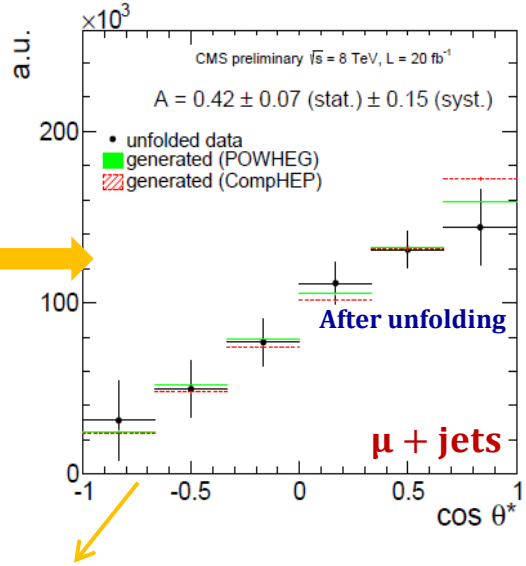
1. Determine the background contributions
2. Enrich the signal sample

Background validation: 3J1T, 3J2T ($t\bar{t}$), 2J0T W+jets
MadGraph **W+jets shape** is corrected with **SHERPA**



The detector effects are resolved via **unfolding**





Combination

$$A_l = 0.41 \pm 0.06(\text{stat.}) \pm 0.16(\text{syst.})$$

$$A_l \equiv \frac{1}{2} P_t \cdot \alpha_l \quad \text{and} \quad \alpha_l \approx 1$$

JEC

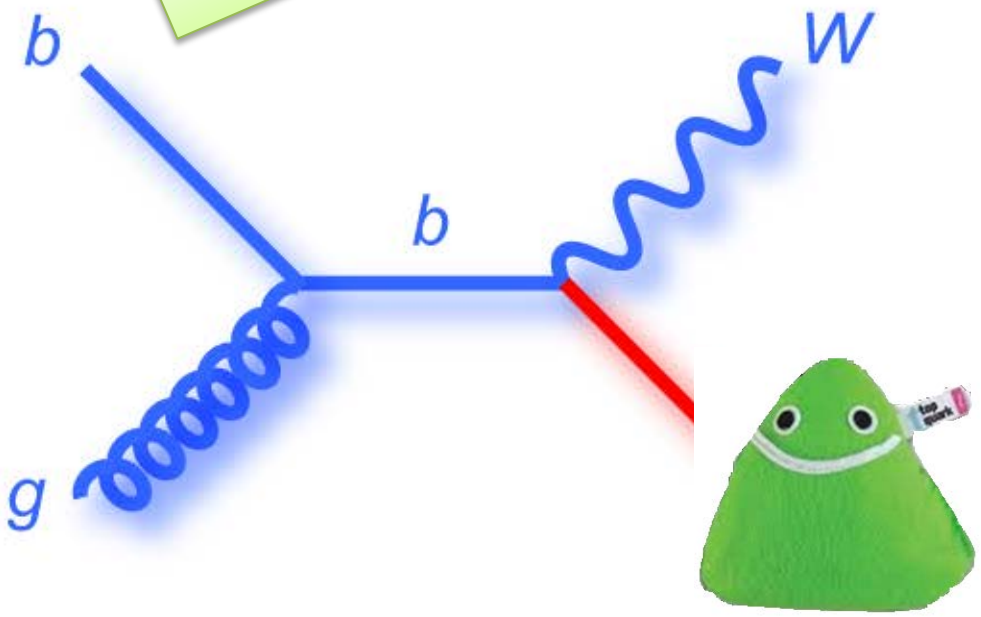
Muon $A_l = 0.42 \pm 0.07(\text{stat.}) \pm 0.15(\text{syst.})$

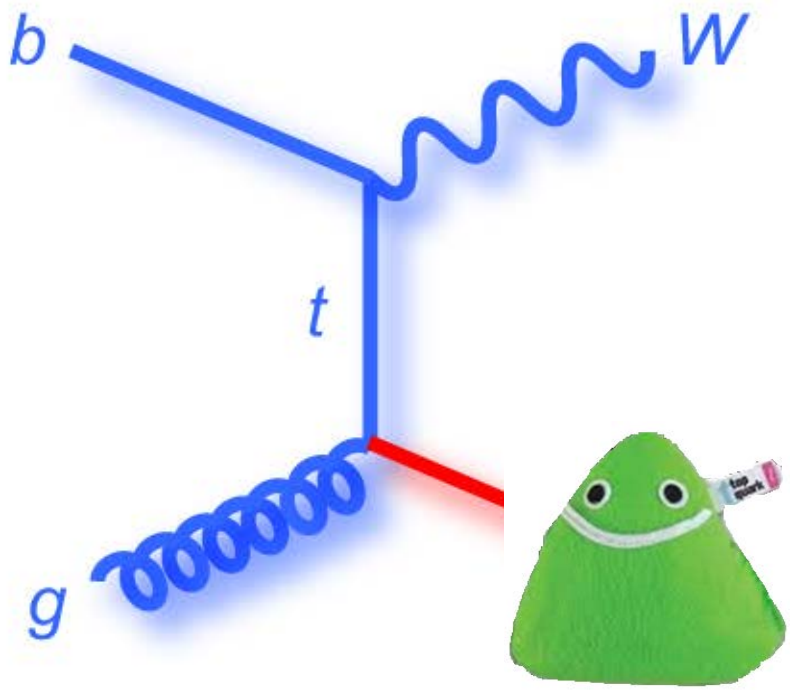
Electron $A_l = 0.31 \pm 0.11(\text{stat.}) \pm 0.23(\text{syst.})$

$$P_t = 0.82 \pm 0.12(\text{stat.}) \pm 0.32(\text{syst.})$$

CMS-TOP-13-001

Cross section





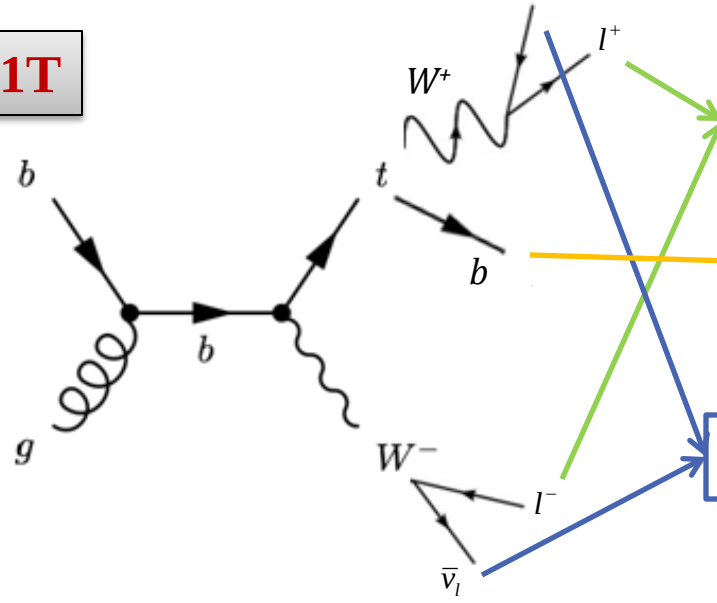
TW-CHANNEL

FOCUS ON NEW RESULTS

σ_{th}: 22.2 ± 0.6 ± 1.4 pb
Kidonakis, arXiv:1210.7813

tW cross section and combination with ATLAS

1J1T



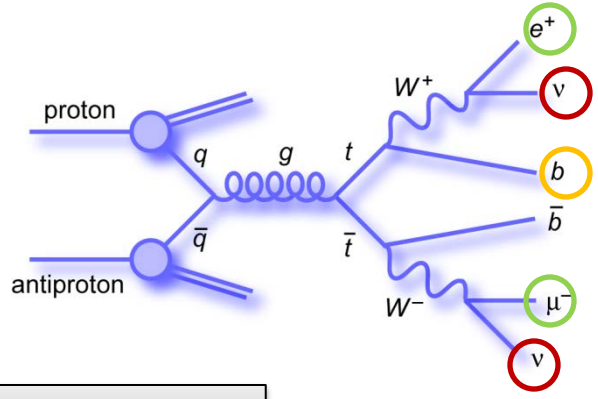
Two isolated leptons (μμ, eμ, ee)

One b-jet from top decay b-quark (1j1t)

Missing energy from two neutrinos (MET)

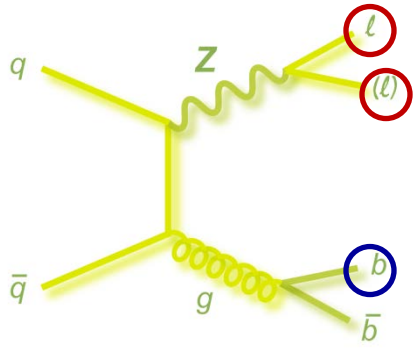
MET ambiguity: Not possible to fully reconstruct the top quark or W-boson

Same and different lepton flavor



2J1T, 2J2T to control tt

Same lepton flavor



- Remove the Z-peak
- Apply the MET cut
- correct the yield using events inside Z-peak

Small contribution from fake leptons, i.e. QCD , W+jets

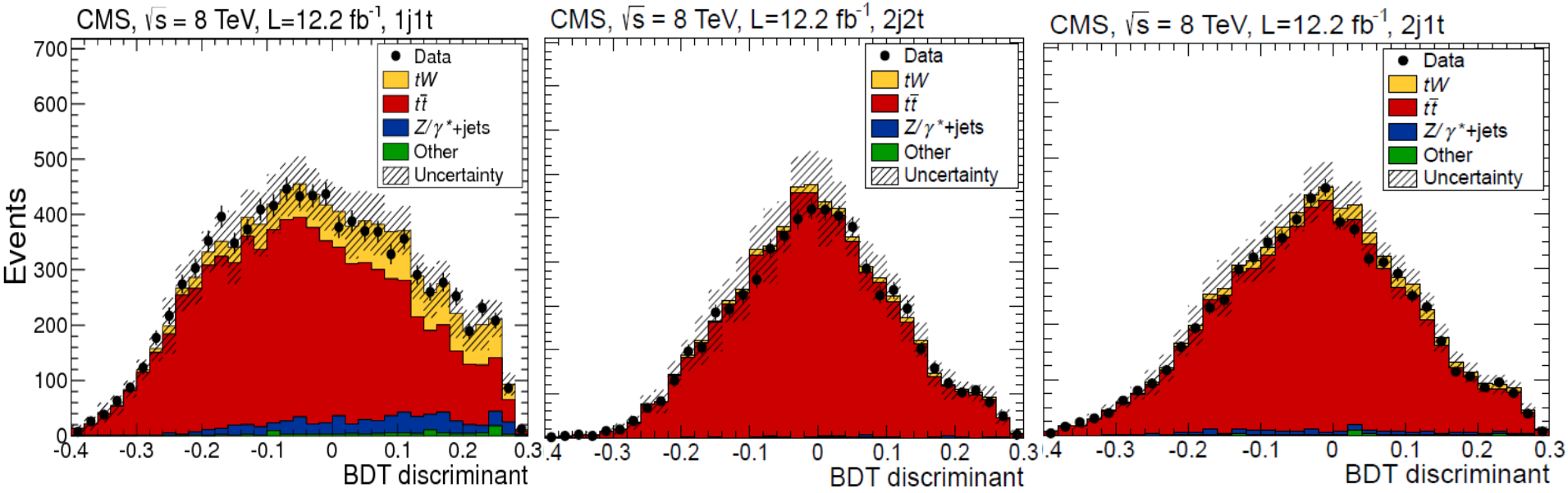
tW cross section at 8 TeV (12.2 fb^{-1})

- A **Likelihood fit** is performed on a **BDT (13 var.)**output over all three channels (μμ, eμ, ee) and all three regions (1j1t, 2j1t, 2j2t)

- **Templates** for signal and background taken from **simulation**

- **Uncertainties** as nuisance parameters in the fit
  - All constrained with data except **theory** and **luminosity**
  - **Main:** modeling of $t\bar{t}$ and scale

Phys. Rev. Lett. 112



1J1T (ℓℓ) 2J2T (ℓℓ) 2J1T (ℓℓ)

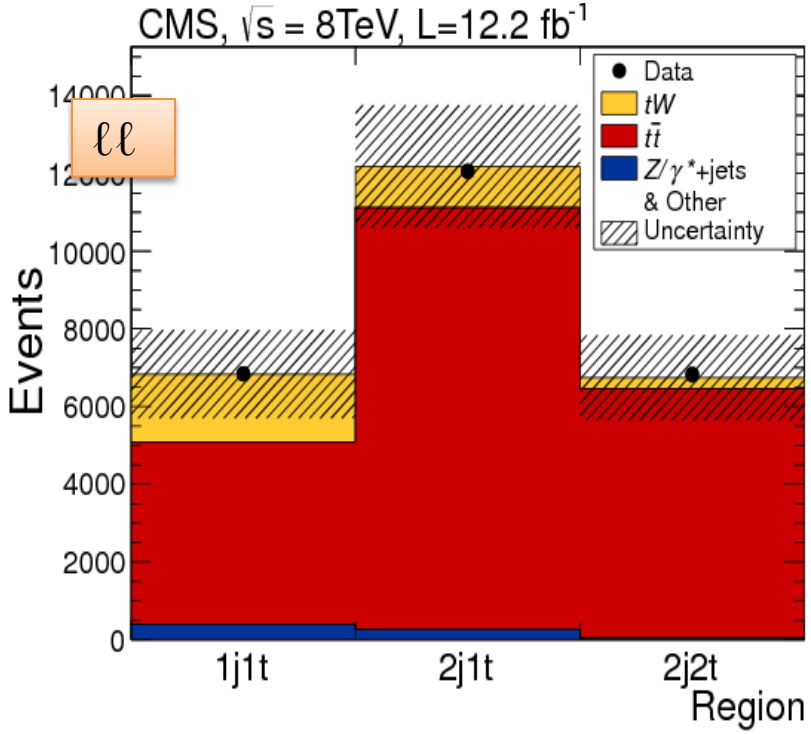
tW cross section at 8 TeV (12.2 fb^{-1})

Observation with a Significance of

6.1σ (expected: 5.4 ± 1.4)

Phys. Rev. Lett. 112

Cross section 23.4 ± 5.4 pb *(th. : 22.2 ± 0.6 ± 1.4 pb)*



Assuming $|V_{tb}| \gg |V_{ts}|, |V_{td}|$**:** $|\mathbf{V_{tb}}| = 1.03 \pm 0.12(\text{exp.}) \pm 0.04(\text{th.})$

Constrained $|\mathbf{V_{tb}}| < 1$: $|V_{tb}| > 0.78$ @95% C.L.

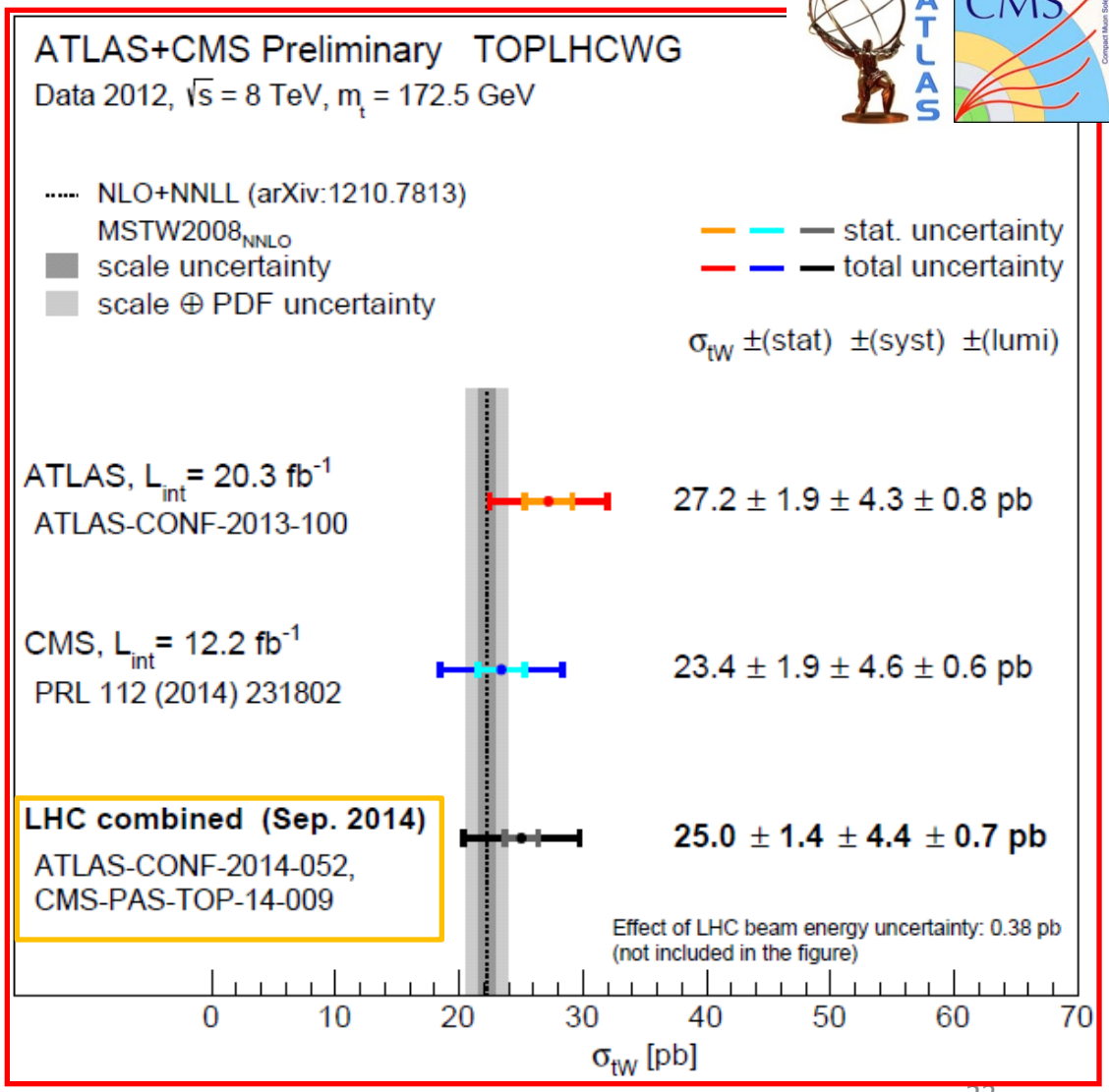
tW cross section at 8 TeV (combination)

NEW

- The results of the two experiments are combined using BLUE

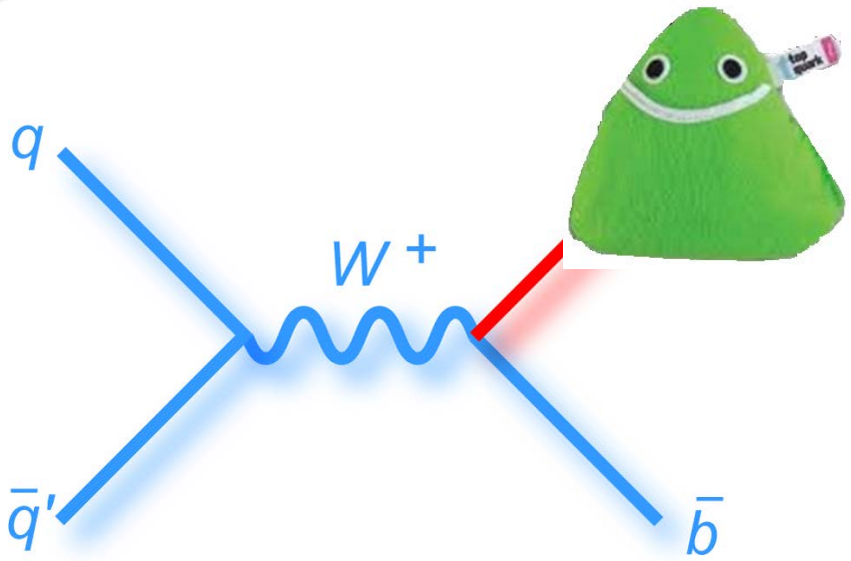
- $|f_V^L V_{tb}| = 1.06 \pm 0.11$

- **Constrained $|f_V^L| = 1$ & $|V_{tb}| \leq 1$:**
  $|V_{tb}| > 0.79$ @95% C.L.



Hear more in the talk by L. Lista

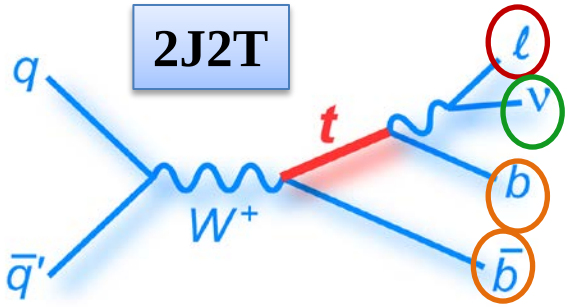
Cross section



S-CHANNEL

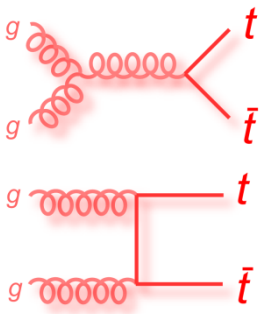
FOCUS ON NEWER RESULTS

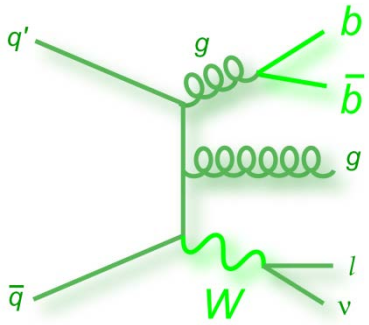
s-channel cross section

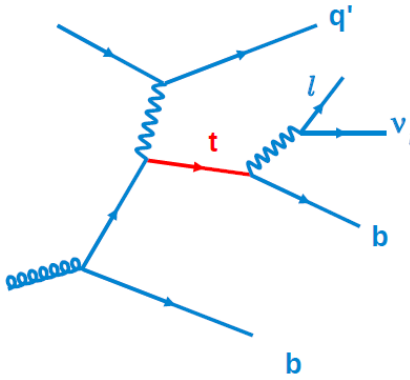


- **SM expectation at 8 TeV:**
  $\sigma_{s\text{-}ch} = 5.55 \pm 0.08 \pm 0.21$ pb
  N. Kidonakis (1205.3453)

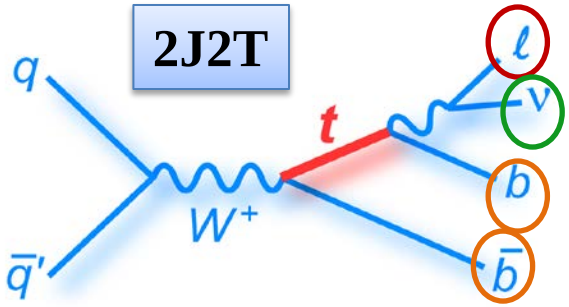
- **Signature:** 1 lepton + 2 b-jets + MET-related quantities
- **Backgrounds:** tt, W+jets, t-channel





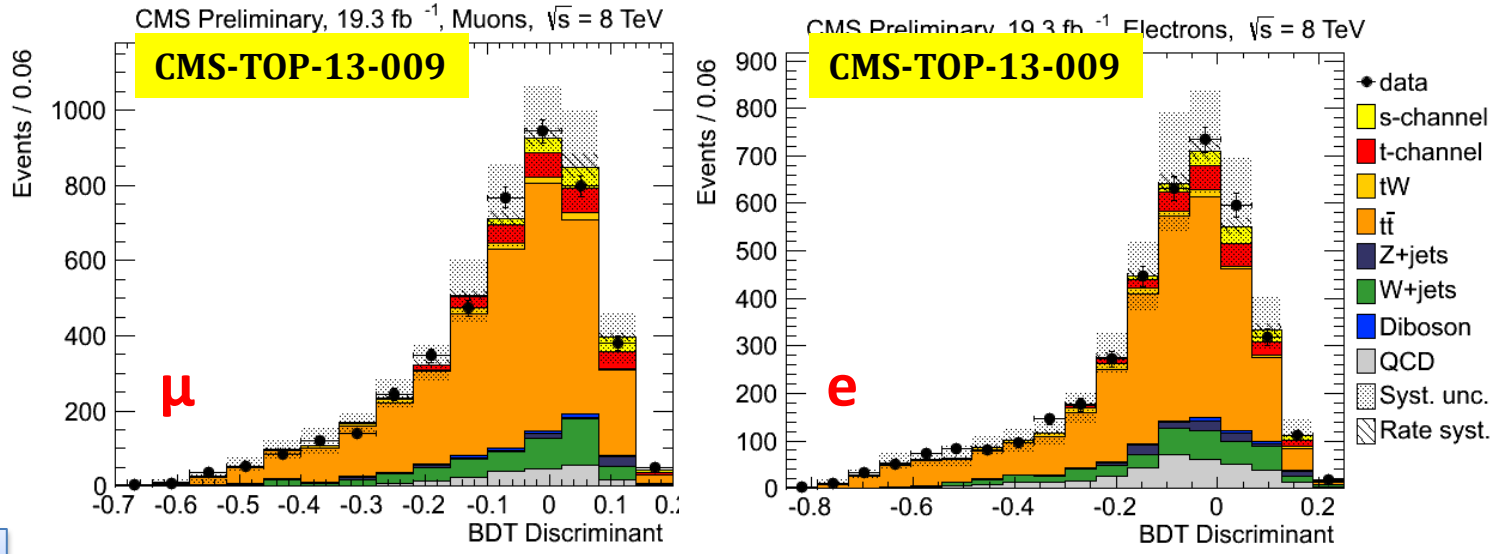


s-channel cross section at 8 TeV (19.3 fb^{-1})



- **Signature:** 1 lepton + 2 b-jets +MET-related quantities
- **Backgrounds:** tt, W+jets, t-channel
- **SM expectation at 8 TeV:** $\sigma_{s\text{-ch}} = 5.55 \pm 0.08 \pm 0.21$ pb

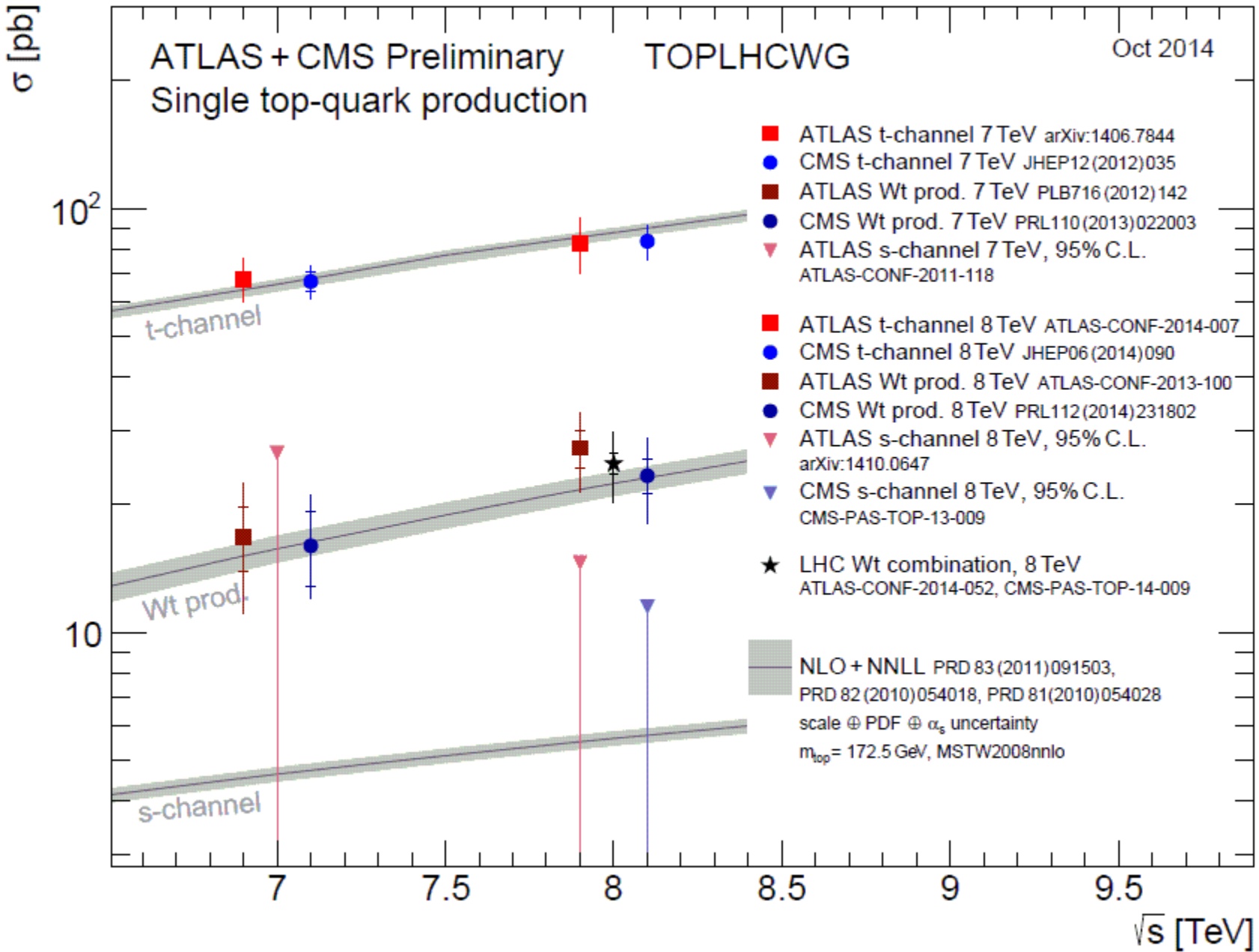
- A **likelihood fit** on the **BDT output** in signal (2J2T) and tt (3J2T) control regions
- **Backgrounds** (tt, W+jets) are constrained in the fit
- Pseudo experiments for theory and instrumental systematics



Scale

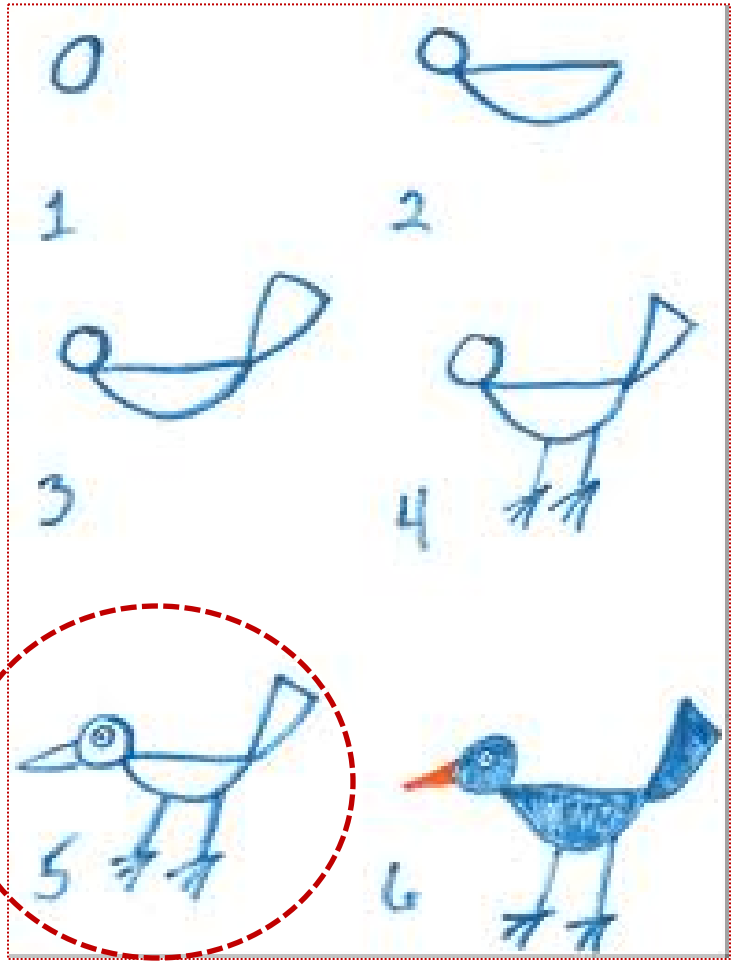
- **Observed @ 95% CL :** $\sigma_{s\text{-ch.}} < 11.5$ pb
- **Expected @ 95% CL :** $\sigma_{s\text{-ch.}} < 17.0$, 9.0 pb (SM sig., bkg.)

Summary on single-top cross sections



Complementarities to Run I Analyses

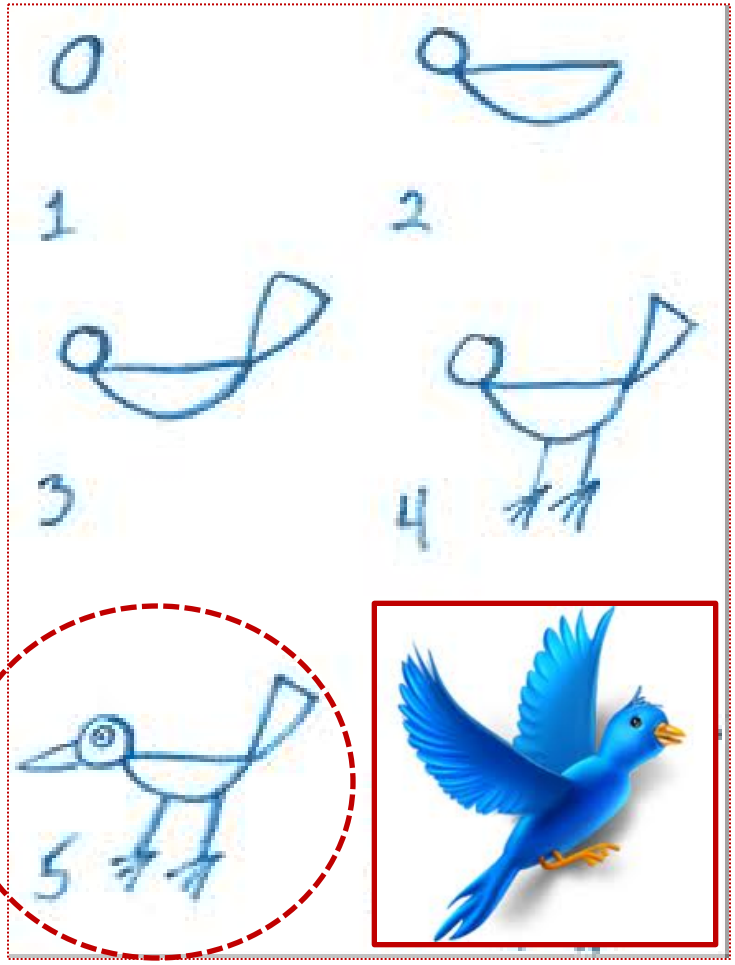
An step-wise view of CMS single-top analyses in Run I



We are here!!

Complementarities to Run I Analyses

An step-wise view of CMS single-top analyses in Run I



We are here!!

t-channel

- Cross section in a fiducial volume
  - Less model-dependent
  - Understand the acceptance w.r.t the inclusive measurement
- Top mass measurement

tW

- Looking for evidence in alternative final states (l + jets)

s-channel

- Combination with 7 TeV to gain in sensitivity

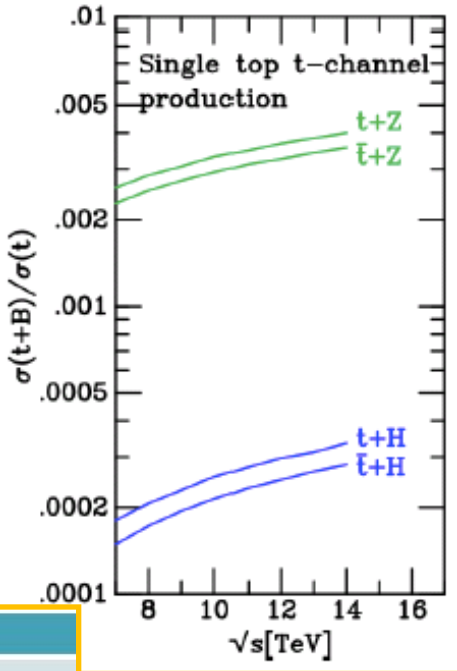
Run II: a possible plan

Last year in Naples

By Luca Lista

- Plan for the very first data (first on fb^{-1}):
  - Measure the t channel cross section at 14 TeV ("rediscovery"), including charge ratio
  - Study top polarization and differential distributions check the agreement with the Standard Model
  - Look for deviations for SM: FCNC (tZ, tγ)
  - Measure the top mass in single-top events
    - Should be done also at 7, 8 TeV!
- With more data (10 fb^{-1}):
  - Rediscover tW
  - Look for SM tZ, few % of t channel
- With even more data
  - Try again with the s channel may require hundreds of fb^{-1}!

We're on it



	t ch.	tW ch.	s ch.	tt~
7 TeV	64.6pb	15.6pb	4.59pb	172.0pb
8 TeV	87.6pb	22.2pb	5.55pb	245.8pb
14 TeV	248.1pb (×3.2)	84.8pb (×3.8)	11.86pb (×2.1)	953.6pb (×3.9)

Preliminary plan for Run II

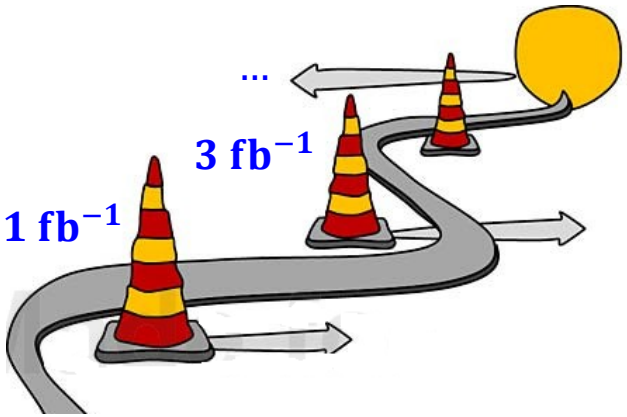
- **LHC data at 13 TeV is arriving …**

LHC beam, June 2015 ©CERN

Are we ready?!

Preliminary plan for Run II

The roadmap



- We are approaching the first collisions at highest energy ever reached
- With very first fb^{-1} of data we plan to rediscover t-channel
- Search for (possibly rediscover) tW ~ 3 fb^{-1}
- Redraw the single-top bird with ~ 10 fb^{-1}
  - s-channel might be too challenging

Where we stand

- A lot of effort invested into the trigger design
  - Main triggers and backup paths prepared
- Benefit from detailed generator studies, developments
- The baseline of the high priority analyses will be checked on simulated samples provided by CMS
- We will be ready by the time of the data taking …

Summary

- **CMS** has performed very well during run I
  - Precise cross section measurements
  - Observation and stringent upper limit
  - Precise property measurements
- Additional results are coming to sharpen the image even more
- Stay tuned
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

- The plan is established for the first few fb^{-1} of pp collisions
  - t-channel at ~1 fb^{-1} and tW at 3 fb^{-1}

- Within a CMS-wide effort, the single-top team is ready for new data

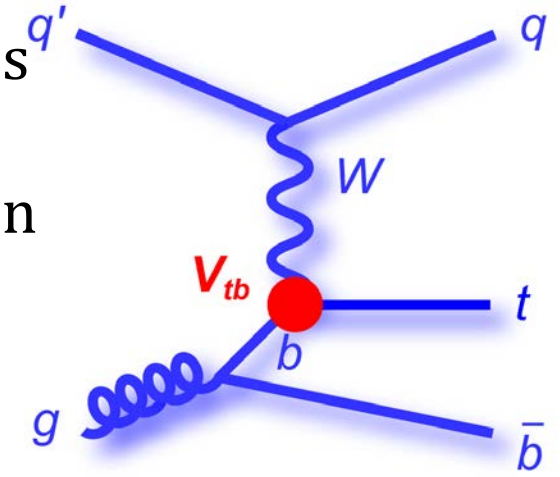
BACKUP

t-channel cross sections: $|V_{tb}|$ in 7 TeV

	Theory PRD 83 (2011)	ATLAS 4.6 fb^{-1} 1406.7844v1	CMS 1.14 fb^{-1} JHEP12(2012) 035
σ (t-chan)	64.6 ± 3.4 pb	68 ± 8 pb	67.2 ± 6.1 pb

- With tWb vertex in production, t-channel cross section depends on $|V_{tb}|$
- Assuming $|V_{td}|$, $|V_{ts}| << |V_{tb}|$ and the interaction being purely left-handed

$$|V_{tb}| = \sqrt{\frac{\sigma_{meas}}{\sigma_{theo}}}$$



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

$|V_{tb}| < 1$ ➡ $0.88 < |V_{tb}| <= 1$ @ 95% C.L.

CMS: $|V_{tb}| = 1.020 \pm 0.049$

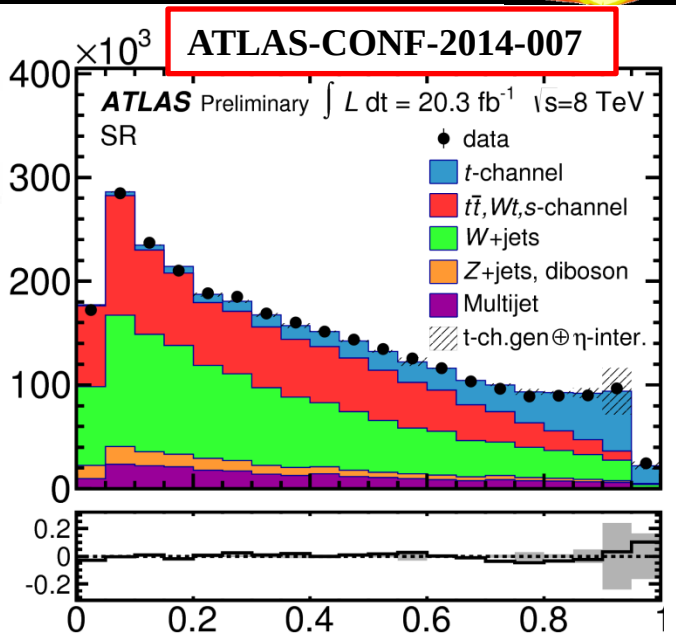
$|V_{tb}| < 1$ ➡ $0.92 < |V_{tb}| <= 1$ @ 95% C.L.

$m_t = 172.5$ GeV

t-channel cross sections at 8TeV (20.3 fb^{-1})

NEW

- Measurement in a fiducial volume



- Fit to NN output in the signal (2J1T) region
- Backgrounds as constrained nuisance parameters
  - Validated in 2J2T ($t\bar{t}$) and 2J0T (W+jets)
- Systematics from pseudo-experiments

- **How?** A **truth (fiducial)** phase space close to ***selected data***
  - Truth objects (leptons, jets,…) defined close to reco. ones using final state particles.

$$\sigma_{\text{fid}} = 3.37 \pm 0.05(\text{stat.}) \pm 0.47(\text{syst.}) \pm 0.09(\text{lumi.})\ \text{pb}$$

Signal generator

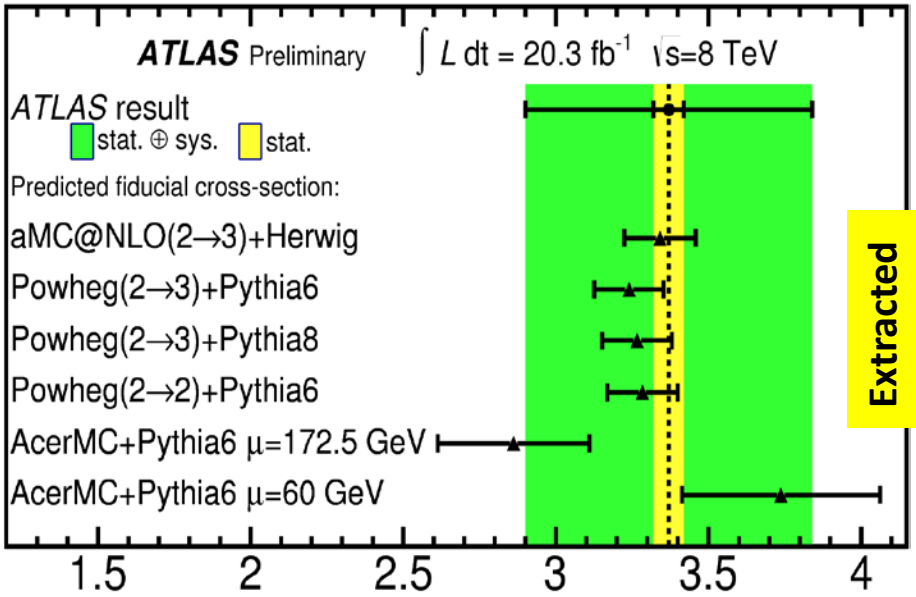
JES

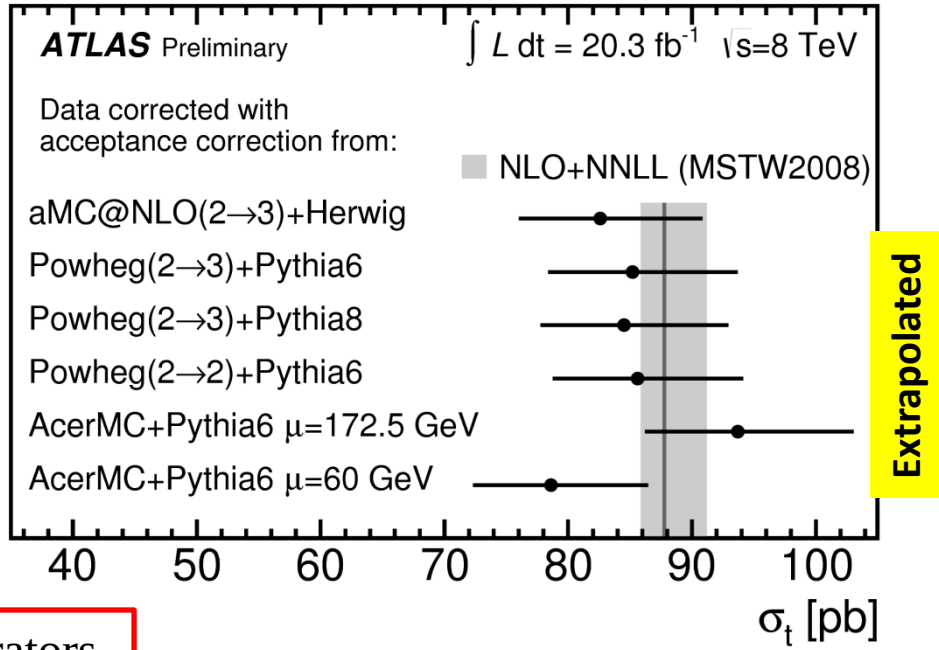
- **Main benefit:**
  - Marginal effect due to acceptance
  - Affected mainly by efficiencies so less model-dependent
  - Understand the acceptance in comparison with the inclusive measurement

	Generator	PDF	Total
Fiducial	8%	1%	14%
Inclusive	13%	4%	17%

t-channel cross sections at 8TeV (20.3 fb^{-1})

NEW





ATLAS-CONF-2014-007

With different generators

$$\sigma = \frac{1}{\epsilon_{fid}} . \sigma_{fid}$$

aMC@NLO + Herwig

Model-dependence $\gg \delta_{th}$

$$\sigma = 82.6 \pm 1.2(\text{stat.}) \pm 11.4(\text{syst.}) \pm 3.1\ (\text{PDF}) \pm 2.3\ (\text{lumi.})$$

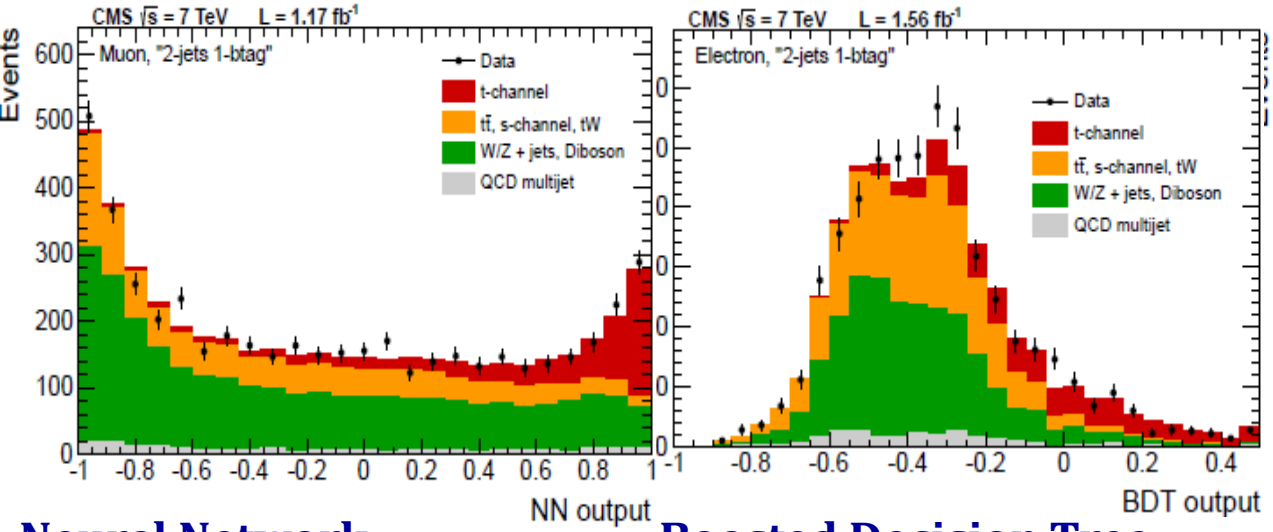
$$|V_{tb}| = 0.97^{+0.09}_{-0.1}$$

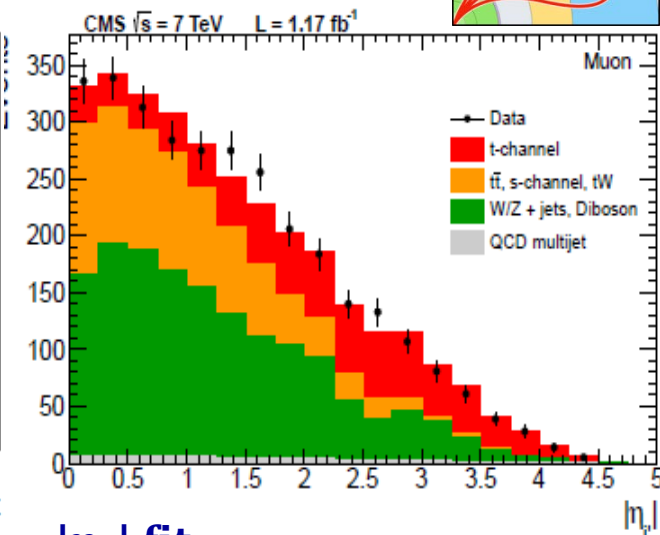
Assuming $m_t = 172.5$ GeV

t-channel cross sections at 7 TeV (~1. fb^{-1})

- Generic selection (see backup).
- Different categories number of jets and b-tagged jets

JHEP12(2012) 035





Neural Network:

- Backgrounds and systematics as nuisance parameters
- Signal: 2J1T, 3J1T
- Constraining backgrounds, b-tag efficiency, etc.: 4J1T, 2J2T, 3J2T, 4J2T

Boosted Decision Tree:

- Backgrounds and systematics as nuisance parameters
- Signal: 2J1T, 3J1T
- Constraining backgrounds, b-tag efficiency, etc.: 4J1T, 2J2T, 3J2T, 4J2T

$|\eta_{j'}|$ fit:

- Template fit with data-driven backgrounds
- Signal: 2J1T
- Check the modeling of backgrounds: 3J2T, 2J0T

t-channel cross sections CMS 8 TeV

μ and e combined

Uncertainty source	$\sigma_{t\text{-ch.}}$ (%)
Statistical uncertainty	± 2.7
JES, JER, MET, and pileup	± 4.3
b-tagging and mis-tag	± 2.5
Lepton reconstruction/trig.	± 0.6
QCD multijet estimation	± 2.3
W+jets, $t\bar{t}$ estimation	± 2.2
Other backgrounds ratio	± 0.3
Signal modeling	± 5.7
PDF uncertainty	± 1.9
Simulation sample size	± 0.7
Luminosity	± 2.6
Total systematic	± 8.9
Total uncertainty	± 9.3
Measured cross section	83.6 ± 7.8 pb

Uncertainty source	$\sigma_{t\text{-ch.}}(t)$ (%)	$\sigma_{t\text{-ch.}}(\bar{t})$ (%)	$R_{t\text{-ch.}}$ (%)
Statistical uncertainty	± 2.7	± 4.9	± 5.1
JES, JER, MET, and pileup	± 4.2	± 5.2	± 1.1
b-tagging and mis-tag	± 2.6	± 2.6	± 0.2
Lepton reconstruction/trig.	± 0.5	± 0.5	±0.3
QCD multijet estimation	± 1.6	± 3.5	±1.9
W+jets, $t\bar{t}$ estimation	± 1.7	± 3.6	± 3.0
Other backgrounds ratio	± 0.1	± 0.2	± 0.6
Signal modeling	± 4.9	± 9.4	± 6.1
PDF uncertainty	± 2.5	± 4.8	± 6.2
Simulation sample size	± 0.6	± 1.1	± 1.2
Luminosity	± 2.6	± 2.6	—
Total systematic	± 8.2	± 13.4	± 9.6
Total uncertainty	± 8.7	± 14.2	± 10.9
Measured cross section or ratio	53.8 ± 4.7 pb	27.6 ± 3.9 pb	1.95 ± 0.21

$$\sigma^{\text{theo.}}_{t\text{-ch.}}(t) = 56.4^{+2.1}_{-0.3}\,(\text{scale}) \pm 1.1\,(\text{PDF})\,\text{pb},$$

$$\sigma^{\text{theo.}}_{t\text{-ch.}}(\bar{t}) = 30.7 \pm 0.7\,(\text{scale})^{+0.9}_{-1.1}\,(\text{PDF})\,\text{pb}.$$

$$\sigma^{\text{theo.}}_{t\text{-ch.}} = 87.2^{+2.8}_{-1.0}\,(\text{scale})^{+2.0}_{-2.2}\,(\text{PDF})\,\text{pb},$$

N. Kidonakis, 1205.3453

t-channel top polarization CMS

Similar processes in shape are combined:

- **tt, s, tW QCD 20% constraint**
- **VV and V+jets (unconstrained)**

Wjets systematics:

- **light of 11%,**
- **reweighting 50%,**
- **HF 0.5 and 2**

Constant unfolding bias treated as systematic

Combination with BLUE

Only lepton efficiencies uncorrelated

Uncertainty source	δA_l^μ	δA_l^e
generator	0.025	0.009
Q^2 scale t-channel	0.024	0.055
Q^2 scale, $t\bar{t}$	0.015	0.005
Q^2 scale, W+jets	0.036	0.038
top quark mass	0.058	0.042
W+jets shape	0.016	0.007
W+jets flavour	0.005	0.008
top p_T, $t\bar{t}$	0.010	0.025
matching, $t\bar{t}$	0.028	0.052
matching, W+jets	0.025	0.038
PDF	0.013	0.014
JES	0.074	0.074
JER	0.016	0.179
unclustered $\not{E}_T$	0.013	0.006
lepton ID and isolation	0.001	0.002
lepton trigger	0.001	0.002
pileup	0.015	0.002
b tagging	0.007	0.009
mistagging	0.001	0.003
lepton weight	0.001	0.009
anti-isolation range of QCD	0.010	0.053
QCD fraction	0.092	0.028
background fractions	0.007	0.018
unfolding bias	0.002	0.003
total systematics	0.15	0.23
statistical	0.07	0.11
total	0.17	0.26

tW-channel CMS

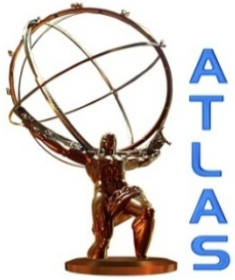
Systematic uncertainty	$\Delta\sigma$ (pb)	$\Delta\sigma/\sigma$	Notes
ME/PS matching thresholds	3.3	14%	Matching threshold 2× and 1/2× nominal 20 GeV value in $t\bar{t}$ simulation
Renormalization/factorization scale	2.9	12%	Scale value 2× and 1/2× nominal value of $m_t^2 + \sum p_T^2$ in $t\bar{t}$ and tW simulation
Top-quark mass	2.2	9%	m_t varied in tW and $t\bar{t}$ simulation by ± 2 GeV
Fit statistical	1.9	8%	Remaining uncertainty in fit when all other systematic uncertainties are removed
Jet energy scale	0.9	4%	Jet energy scale varied up/down
Luminosity	0.7	3%	2.6% uncertainty in the measured luminosity
Z+jets data/simulation scale factor	0.6	3%	Varying scale factors used for correcting Z+jets E_T^{miss} simulation
tW DR/DS scheme	0.5	2%	Difference between DR and DS scheme used for defining tW signal
$t\bar{t}$ cross section	0.4	2%	Uncertainty in the cross section of $t\bar{t}$ production
Lepton identification	0.4	2%	Uncertainty in scale factors for lepton efficiencies between data/simulation
PDF	0.4	2%	From choice of PDF
Jet energy resolution	0.2	1%	Energy resolution for jets varied up/down
b-tagging data/simulation scale factor	0.2	<1%	Variations in scale factors
$t\bar{t}$ spin correlations	0.1	<1%	Difference between $t\bar{t}$ simulation with/without spin correlations
Pileup	0.1	<1%	Varying effect of pileup
Top-quark p_T reweighting	0.1	<1%	Uncertainty due to differences in top quark p_T between data and $t\bar{t}$ simulation
E_T^{miss} modeling	0.1	<1%	Uncertainty in amount of unclustered E_T^{miss}
Lepton energy scale	0.1	<1%	Uncertainty in energy of leptons
Total	5.5	24%	

tW-channel combination

ATLAS and CMS have similar event yields for signal and background. However, the discriminant distributions in the signal-dominated one-jet region differ. CMS has more expected signal events in the high-discriminant region, and more bins in that region than ATLAS.

tW cross section at 8 TeV (20.3 fb^{-1})

- A **Likelihood fit** is performed on a **BDT (19 var.)** output over eμ channel and the two regions (1j1t, 2j≥1t)
- **Templates** for signal and background taken from **simulation**
- **Normalization for fake** from data
- **Uncertainties** estimated using pseudo-experiments
  - **Main:** Wt and $t\bar{t}$ modelling



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Significance: 4.2σ (expected: 4.0)

Cross section (tW+X):

27.2 ± 2.8 (stat.) ± 5.4 (syst.) pb

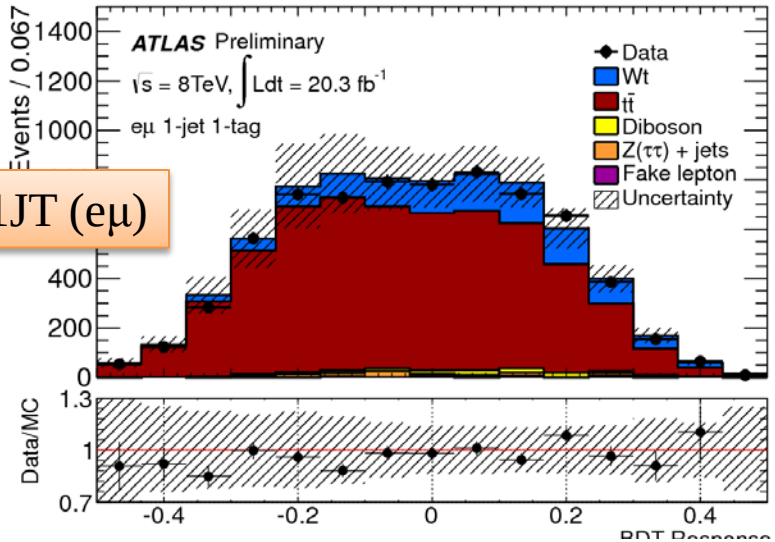
(th. : 22.2 ± 0.6 ± 1.4 pb)

With $|V_{tb}| \gg |V_{ts}|, |V_{td}|$:

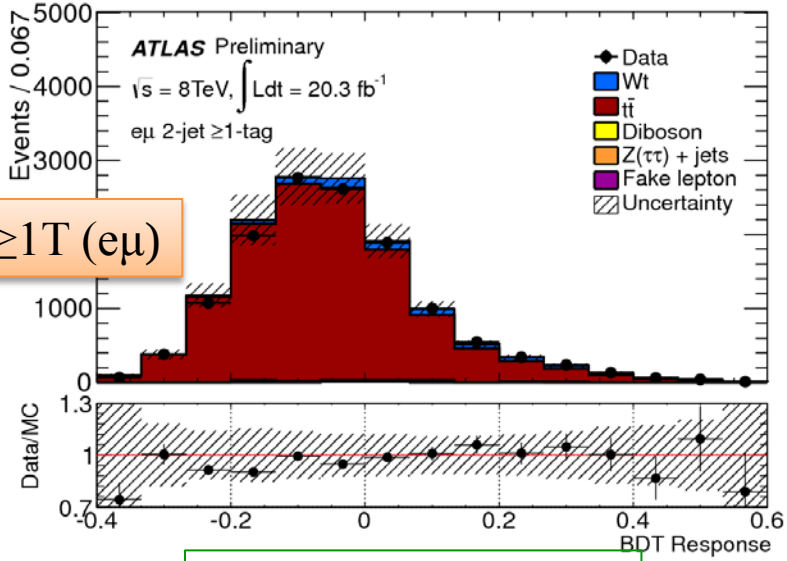
$|f_V^L V_{tb}|$: 1.10 ± 0.12(exp.) ± 0.03(th.)

Constrained $|f_V^L| = 1$: $|V_{tb}| > 0.72$ @95% C.L.

1JT (eμ)



2J≥1T (eμ)



Assuming $m_t = 172.5$ GeV

tW cross section at 8 TeV (combination)

NEW

- The results of the two experiments are combined using BLUE

- **Correlated systematics**
  - Theory modeling (ρ =1)
  - Luminosity (ρ =0.31)
  - B-tagging (ρ =0.5)
- Stability checked for different ρ assumptions
- **Dominant systematic:**
  - Theory modeling

- $|f_V^L V_{tb}|$: 1.06 ± 0.11

- **Constrained $|f_V^L| = 1$ & $|V_{tb}| \leq 1$:**
  $|V_{tb}| > 0.79$ @95% C.L.