Xth Recontres du Vietnam

Flavour Physics Conference

ICISE, Quy Nhon, Vietnam, 27th July – 2nd August 2014

Determination of the V_{tb} CKM element in single top production at Tevatron and LHC

Kate Shaw on behalf of the ATLAS, CMS, D0 and CDF Collaborations

ATLAS Udine/ICTP Group

LHC and Tevatron

Large Hadron Collider

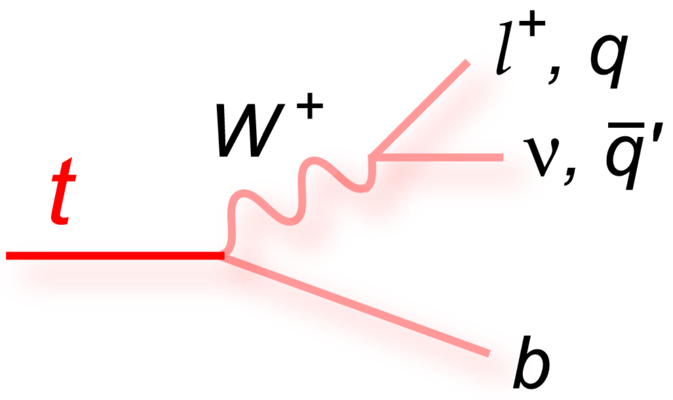
- Proton-proton collider
- Operated at a center of energy of 7 (8) TeV in 2011 (2012)
- Experiments ATLAS and CMS each collected up to 5 (20) fb^{-1} of data

Tevatron

- Proton-antiproton collider
- Run II ended operation in 2011 at a center of mass energy of 1.96 TeV
- Experiments CDF and D0 each collected 10 fb^{-1} of data.

Top Quark

- Top-quark is the most massive known fundamental particle
- It was discovered in 1995 at the Tevatron by CDF and D0
- Its mass is of the order of the electroweak symmetry breaking scale - probe for new physics



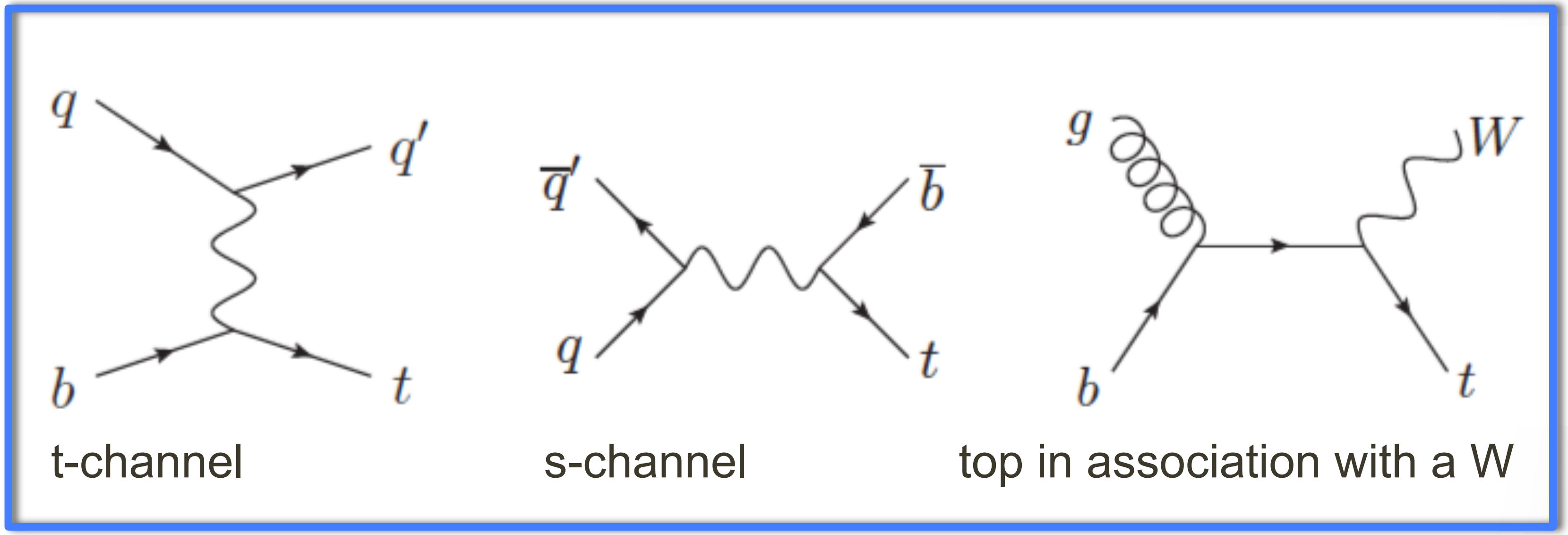
Lifetime of the top is shorter than the timescale of hadronisation

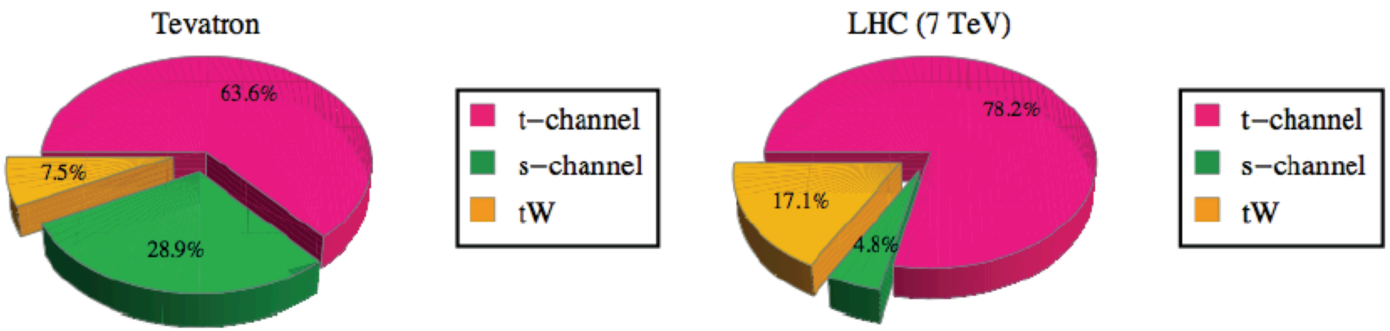
Top-quarks decay almost 100% to W-boson and Bottom-quark $|V_{tb}| \sim 1$

Final state topology is dictated by the leptonic or hadronic decay of the W-boson

Single top production

- Single top production proceeds via electroweak interaction involving a tWb vertex





CKM matrix element $|V_{tb}|$

- Quark mixing described by unitary CKM matrix V_{CKM}

$$|V_{ub}|^2 + |V_{cb}|^2 + |V_{tb}|^2 = 1$$

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} \equiv \hat{V}_{\mathrm{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- The matrix elements are determined from weak decays of the relevant quarks

  - Is the matrix 3 x 3?
  - Is there a fourth generation?
  - Does unitarity hold?

CKM matrix element $|V_{tb}|$

- Quark mixing described by unitary CKM matrix V_{CKM}

$$|V_{ub}|^2 + |V_{cb}|^2 + |V_{tb}|^2 = 1$$

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} \equiv \hat{V}_{\mathrm{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

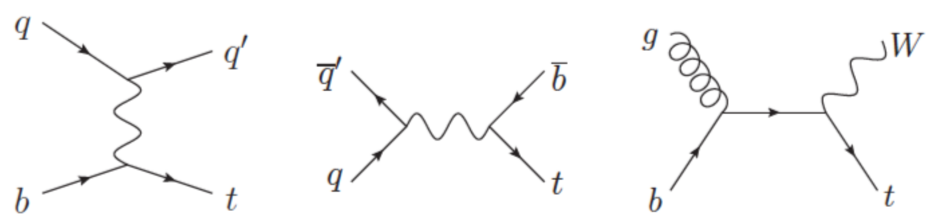
- $|V_{tb}|$ govern the decay rate of the top and its decay width to Wb

- Assuming there are three generations of quarks and applying the unitarity constraint $|V_{tb}|$ approaches unity

Directly Measuring $|V_{tb}|$

- The single top cross-section is directly proportional to the square of the coupling at the production vertex, thus proportional to $|V_{tb}|^2$
  - Assuming $|V_{tb}| >> V_{ts}$ and $|V_{tb}| >> V_{td}$
  - Assuming Wtb interaction is a SM-like left-handed weak coupling

$$|V_{tb}| = \sqrt{\sigma_{meas.}/\sigma_{theory}}.$$

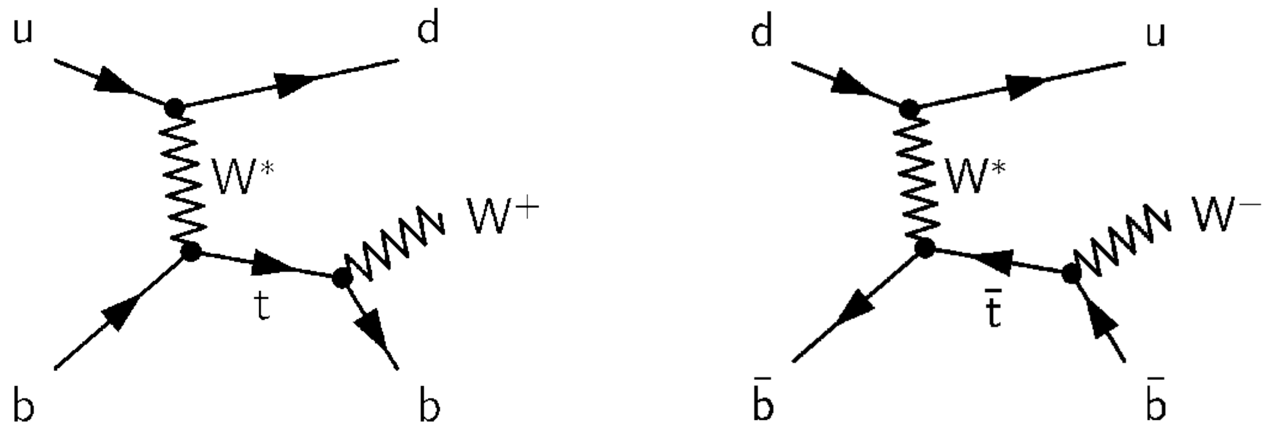


σ_{theory} assumes $|V_{tb}| = 1$

- No dependence on unitarity of CKM matrix, thus a good test for unitarity and probe for fourth quark generation or BSM physics

t-channel

t-channel is the dominant production mode for single top at the LHC and the Tevatron



Leading order

Analysis based on leptonically decaying W $t \to Wb \to b\ell\nu$

Dominant backgrounds are QCD-mulitjets, W+jets and Z+jets

[1] JHEP 12 (2012) 035, TOP-11-021
[2] JHEP 06 (2014) 090, TOP-12-038

CMS: t-channel

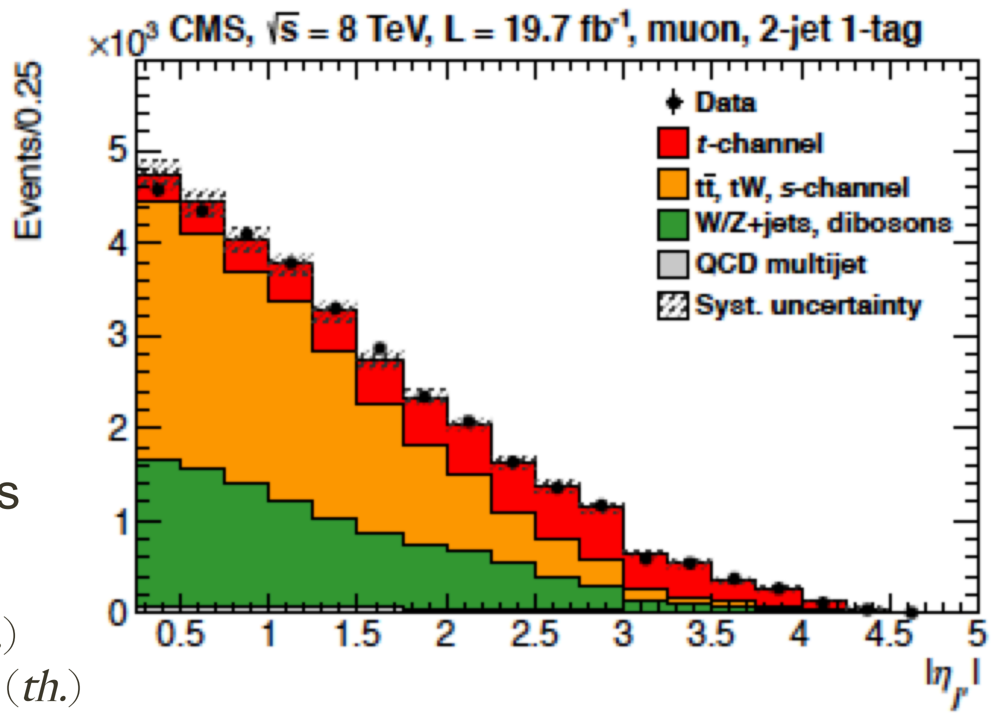
Constraints placed on $|V_{tb}|$ using the measured cross-section of single top production in the t-channel with 7[1] and 8[2] TeV data

Event selection:

- One lepton
- At least two jets
- One b-tagged jet

Cross-section extracted from maximum-likelihood fits to the pseudorapidity of the light jet $|\eta_{j'}|$

- 7 TeV analysis also used BDTs and NNs



7TeV: $|V_{tb}| = 1.04 \pm 0.09\,(exp.) \pm 0.02\,(th.)$
8TeV: $|V_{tb}| = 0.979 \pm 0.045\,(exp.) \pm 0.016\,(th.)$

$$|V_{tb}| = 0.998 \pm 0.038\,(\text{meas.}) \pm 0.016(\text{th.})$$

$$0.92 < |V_{tb}| < 1 \;@\; 95\%\,\text{confidence level} \quad (7+8\ \text{TeV}).$$

Most stringent lower limit

[1] arXiv: 1406.7844
[2] ATLAS-CONF-2014-007

ATLAS: t-channel

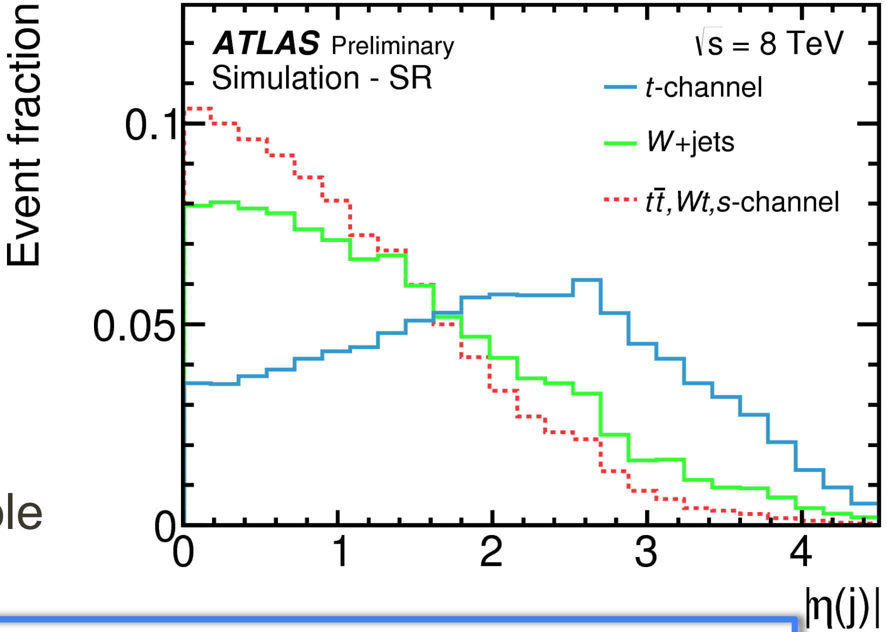
$|V_{tb}|$ determined using the measured combined (aMC@NLO extrapolated) cross-section of t-channel single top production in lepton +jets channel with 7[1] (8[2])TeV data

Event selection:

- One lepton
- At least two jets
- One b-tagged jet

Binned maximum-likelihood fit to neutral network distributions

- $|\eta_{j'}|$ important discriminating variable



7 TeV $|V_{tb}| > 0.88$ @ 95% C.L.

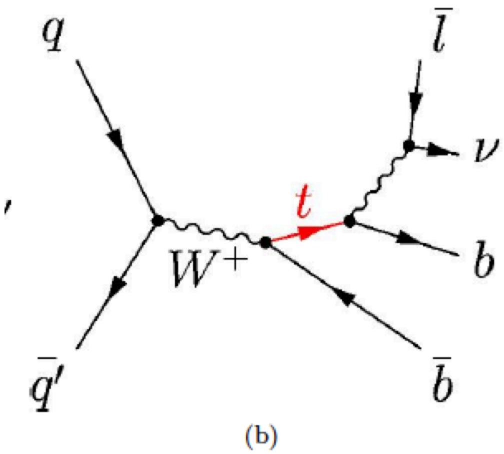
$$|V_{tb}| = 1.02 \pm 0.01\,(\text{stat.}) \pm 0.06\,(\text{syst.}) \pm 0.02\,(\text{theo.})\,^{+0.01}_{-0.00}\,(m_t)$$

8 TeV $|V_{tb}| > 0.78$ @ 95% C.L.

$$|V_{tb}| = 0.97 \pm 0.01\,(\text{stat.})^{+0.06}_{-0.07}\,(\text{syst.}) \pm 0.06\,(\text{gen. + PDF})^{+0.02}_{-0.01}\,(\text{theor.}) \pm 0.01\,(\text{lumi.})$$

s-channel

s-channel has a small cross-section at the LHC and Tevatron



Leading order

Analysis based on leptonically decaying W $t \to Wb \to b\ell\nu$

Dominant backgrounds are W+jets, QCD-mulitjets and ttbar

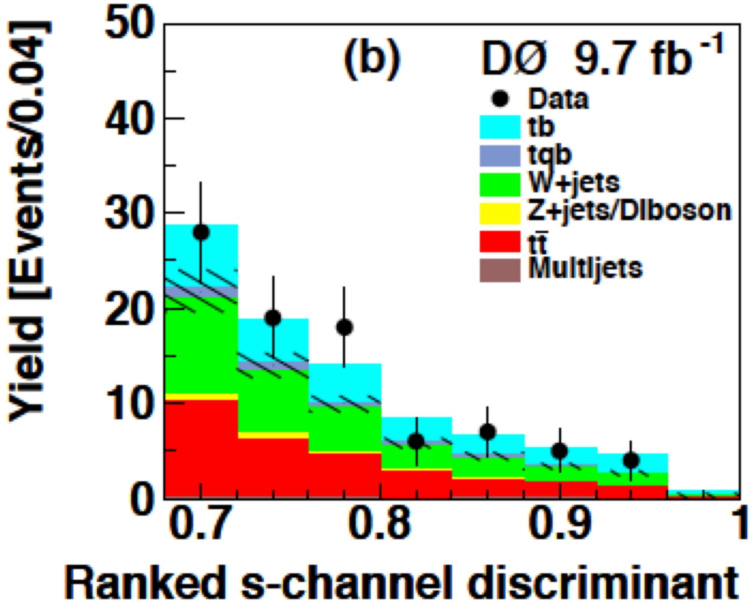
[1]PLB 726 656 (2013)

D0: s- and t-channel

Lower limit defined on $|V_{tb}|$ using the measured cross-section of single top production in the s+t combined channel with 1.96 TeV data

Event selection:
- One lepton
- Two or three jets
- One or two b-tagged jet
- Missing Et

Multivariate methods applied to data
- Boosted Decision Trees (BDT)
- Bayesian Neutral Network (BNN)
- Matrix Element probability calculations



Optimised to measure s- and t- channel independently

$|V_{tb}| = 1.12 + 0.09 - 0.08$

$0.92 < |V_{tb}| < 1$ @ 95% CL.

Most stringent lower limit

[1] CDF PUB NOTE 10793
[2] CDF PUB NOTE 11033

CDF: s- and t-channel

Lower limit defined on $|V_{tb}|$ combing single top production in the lνbb[1] and METbb[2] s+t combined channel with 1.96 TeV data

Event selection for METbb recovering non-reconstructed leptons and W decay to tau (hadronic)

- Lepton veto
- At least two jets (one b-tagged)
- Missing Et

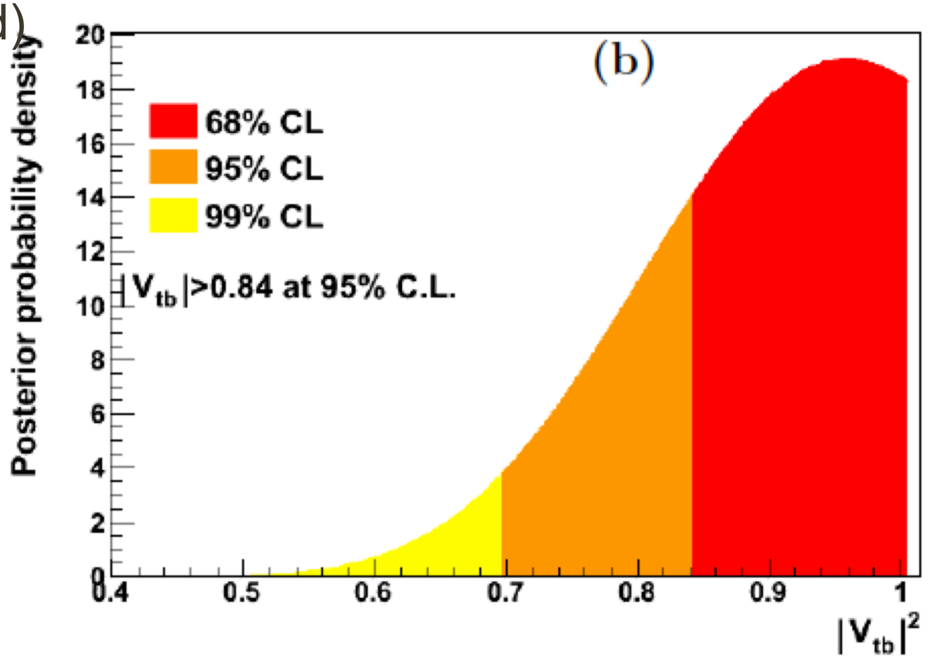
Event selection for lνbb[1]

- One lepton
- Two or three jets (one b-tagged)
- Missing Et

Combination of METbb & lνbb

- Product of likelihoods
- Simultaneously vary correlated uncertainties

0.84 < $|V_{tb}|$ < 1 @ 95% CL.

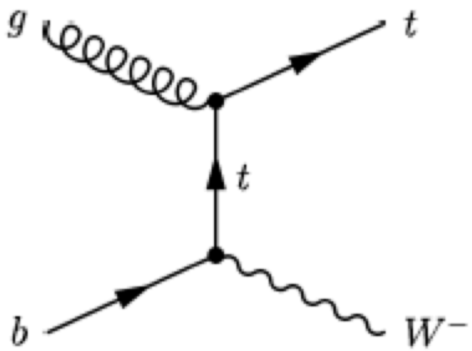


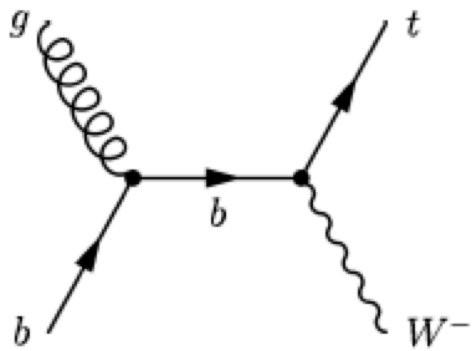
Wt associated production

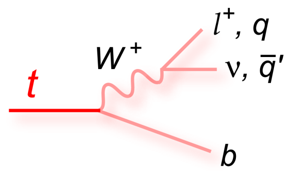
Associated Wt production very small at Tevatron, but significant at LHC

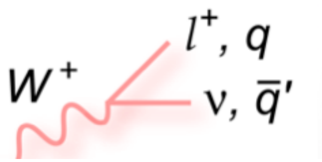
Production of special interest because of it sensitivity to non-SM couplings of the Wtb vertex

While being relatively insensitive to scenarios that affect the other single top top quark production channels









Leading order

Analysis is based on both W-bosons decaying leptonically

Dominant background is ttbar

$$t \to Wb \to b\ell\nu,$$

[1] PRL 112 (2014) 231802, CMS-TOP-12-040
[2] ATLAS_CONF-2013-100

Wt associated production

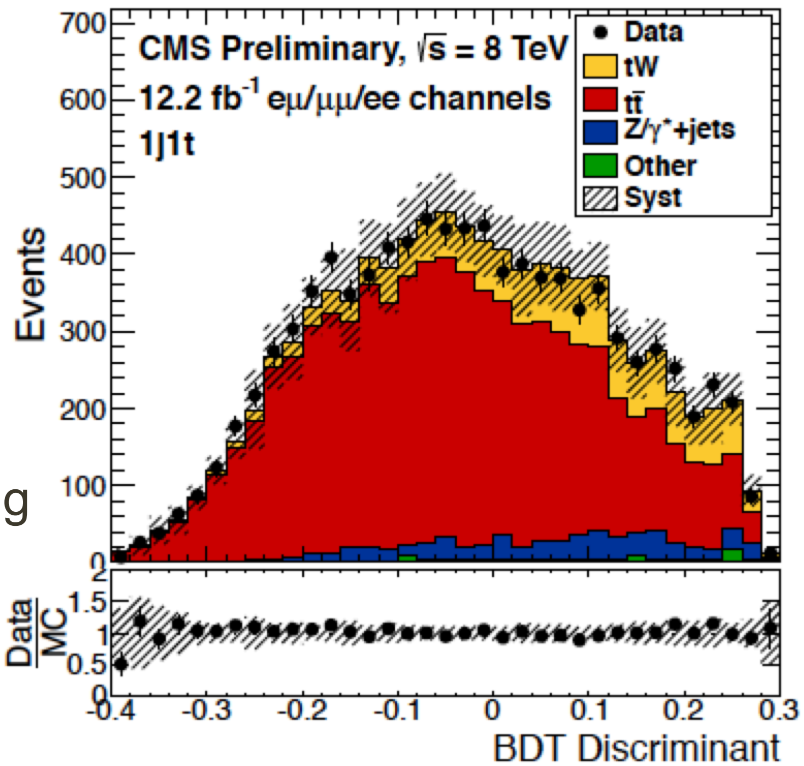
$|V_{tb}|$ determined using measured cross-section of associated production of a single top quark and a W boson at 8 TeV where both W-bosons decay leptonically

Event selection:

- Two leptons (e μ only atlas)
- Missing Et
- One b-tagged jet

Multivariate analysis based on BDT

- Most powerful variables are those involving loose b-tagged jets



$$|V_{tb}| = \sqrt{\frac{\sigma_{tW}}{\sigma_{tW}^{th}}} = 1.03 \pm 0.12(exp.) \pm 0.04(th.)$$

0.78 < $|V_{tb}|$ < 1 @ 95% CL. **[1]**

$|V_{tb}|$ = 1.10 ± 0.12 (*exp.*) ± 0.03 (*th.*)

0.72 < $|V_{tb}|$ < 1 @ 95% CL. **[2]**

Summary

$|V_{tb}|$ determination in single top production without unitarity constraint

	ch.	< $|V_{tb}|$	$|V_{tb}|$ measured value
CDF (1.96 TeV)	s+t	0.84	
D0 (1.96 TeV)	s+t	0.92	1.12 +0.09 – 0.08
CMS (7+8 TeV)	t	0.92	0.998 ± 0.038 (exp.) ± 0.016 (th.)
ATLAS (7 (8) TeV)	t	0.88 (0.78)	1.02 ± 0.07 (0.97 +0.09 – 0.10)
CMS	Wt	0.78	1.03 ± 0.12 (exp.) ± 0.04 (th.)
ATLAS	Wt	0.72	1.10 ± 0.12 (exp.) ± 0.03 (th.)

Back up

Measuring $|V_{tb}|$

Indirect measurement

- Assuming the unitarity of the CKM matrix, the ratio of branching fractions can be used to set limits on $|V_{tb}|$

$$R = \mathcal{B}(t \to Wb)/\mathcal{B}(t \to Wq) = |V_{tb}|^2/(\sum_q |V_{tq}|^2) = |V_{tb}|^2$$

  - Where $q = b,s,d$