Single Top Production in CMS

Outline:

- Single Top at the LHC
- t-channel analysis
- tW channel analysis
- Conclusions

Gabriele Benelli On behalf of the CMS Collaboration





Gabriele.Benelli@cern.ch



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- Weak interaction production (Wtb, btW) and decay vertices (tWb)
- Access to CKM matrix element V_{tb}
- Sensitive to new physics
- Top cross-sections at the LHC (and Tevatron)

Top mass = 173 GeV

N. Kidonakis arxiv.org/pdf/ 1205.3453v1 (2012)	Cross sections (pb)	s-channel	t-channel	tW channel	top pairs
	Tevatron: <u>ppbar@1.96TeV</u>	1.05	2.08	0.22* *arxiv.org/pdf/0909.0037	7.08
	LHC: pp @ 7 TeV	4.56	65.9	15.6	163
	LHC: pp @ 8 TeV	5.55	87.2	22.2	234
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t-channel QCD background

- Data-driven QCD multi-jet estimate:
 - QCD model from reversed iso/ID control region
 - QCD yield from 2j1btag fit of $m_{T,W}$ for muons and E_t^{miss} for electrons



• Suppress fake W leptonic decay events with $m_{T,W}$ and E_t^{miss} cut

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t-channel W+heavy flavor

Event yield in signal region after **m_{lvb}** cut:

	Process	muon yield	electron yield
	<i>t-</i> channel	604.1 ± 2.6	332.9 ± 2.1
	tW channel	107.0 ± 1.0	70.13 ± 0.89
	s-channel	25.38 ± 0.46	14.70 ± 0.38
MC	tī	637.1 ± 5.4	472.7 ± 5.0
Oimulation	W + light partons	90.0 ± 6.9	48.2 ± 5.5
Simulation	Wc(ē)	437 ± 14	213.8 ± 9.9
	Wb(b)	528 ± 15	244 ± 10
	Z + jets	81.5 ± 2.7	11.35 ± 0.90
	Dibosons	23.54 ± 0.36	11.03 ± 0.26
data-driven	QCD	76.1 ± 2.9	61.2 ± 3.3
	Total	2610 ± 22	1480 ± 17
	Data	3108	1581

- W+heavy flavor mostly responsible for the data excess:
- In situ $|\eta_{j'}|$ distribution extracted from the m_{lvb} sidebands by subtracting all other processes from data
- W+heavy flavor + di-boson fit as EWK component of the signal region $|\eta_{j'}|$ fit





t-channel Signal Extraction

- Maximum Likelihood Fit to $|\eta_{j'}|$ •
- Simultaneous fit in μ and e channels •
- Signal model is taken from • simulation
- QCD fixed to the data-driven • estimate, W+HF in situ
- Fit results cross-checked in signal • and control regions









t-channel Results

- All systematics are folded into the statistical evaluation
- Main systematic uncertainties:
 - JES (9%), W+HF extraction (7%), b-tagging (3%)
 - Theoretical uncertainties: Q² scale (7% t-channel, 4% top pairs)
- Cross section results per channel and combined:

 $\sigma_{t-ch.} = 76.9 \pm 6.6 (\text{stat.}) \pm 11.4 (\text{syst.}) \pm 3.7 (\text{lumi.}) \text{ pb}$ (muons) $\sigma_{t-ch.} = 59.3 \pm 8.2 (\text{stat.}) \pm 11.9 (\text{syst.}) \pm 2.8 (\text{lumi.}) \text{ pb}$ (electrons) $\sigma_{t-ch.} = 70.2 \pm 5.2 (\text{stat.}) \pm 10.4 (\text{syst.}) \pm 3.4 (\text{lumi.}) \text{ pb}$ (combined)

• Theoretical value:

 $\sigma_{t-ch.}^{th} = 64.57^{+2.09}_{-0.71} \text{ (scale)}^{+1.51}_{-1.74} \text{ (PDF) } \text{pb}$

N. Kidonakis Phys. Rev. D83 (2011) 091503

• CKM matrix element $|V_{tb}|$ in the assumption $|V_{td}|$, $|V_{ts}| << |V_{tb}|$

$$|V_{\rm tb}| = \sqrt{\frac{\sigma_{t-{\rm ch.}}}{\sigma_{t-{\rm ch.}}^{\rm th}}} = 1.04 \pm 0.09 \,({\rm exp.}) \pm 0.02 \,({\rm th.})$$





CMS PAS TOP-11-022 Single top tW channel

- tW associated production observable at LHC for the first time!
- Interesting topology (background to Higgs->WW searches)
- Only leptonic (e, μ) decays of W considered:
 - **Di-lepton** topology:



- No chance to fully reconstruct W or top
- Main backgrounds:
 - Top pairs, Z+jets, all other processes very small







tW channel Event Selection

Selection (3 final states ee, $\mu\mu$, $e\mu$):

- Exactly 2 isolated leptons
- Exactly 1 b-tagged jet
- Z mass veto $(m_{11} < 81 \text{GeV}, m_{11} > 101 \text{GeV})$
- $E_T^{miss} > 30 \text{ GeV}$
- Two variables inspired by LO tW process description:
 - $\vec{p}_T^{system} = \vec{p}_{T,\ell 1} + \vec{p}_{T,\ell 2} + \vec{p}_{T,jet} + \vec{E}_T^{miss}$
 - $H_T = p_{T,\ell 1} + p_{T,\ell 2} + p_{T,jet} + E_T^{miss}$
- Final cuts:
 - $H_T > 160 GeV$
 - $p_T^{\text{system}} < 60 \text{GeV}$
- Signal region defined by 1j1btag, other jet/b-tag multiplicities used as control regions to constrain top pair cross-section

eµ

• Z+jets (reverse Z mass veto) control region to get data-driven estimate

All states

All states







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tW channel Analysis

- Data-driven estimate of Z+jets:
 - Invert Z mass veto and extract normalization for signal region
- Top pairs background estimate:
 - Two top pairs enriched control regions (2j1btag, 2j2btag)
 - Yield in these control regions to constrain top pair contamination in signal region
- Signal extracted using simultaneous fit to signal and control regions









tW Analysis Results

- Main systematic uncertainties:
 - b-tagging (10%), JES (2.5% tW signal,6% top pairs)
 - Theoretical: Q² scale (10% tW signal, 12% top pairs)
- With Poisson statistical model, combining all three channels and taking into account all systematic uncertainties:
 - Expected significance 1.8 +/- 0.9 σ away from null-hypothesis
 - Observed significance **2.7** σ
 - Measured value of the cross-section and 68% C.L. interval:
 - $\sigma_{tw} = 22^{+9} 7$ (stat \oplus sys) pb
 - Theoretical value $(m_{top}=173 \text{GeV})$:
 - $\sigma_{tW} = 15.6 \pm 0.4(scale)^{+1.0}_{-1.2}(PDF)$

N. Kidonakis arxiv.org/pdf/1205.3453v1 (2012)





Conclusions



- First measurement of tW cross-section:
 - $\sigma_{tw} = 22^{+9} ... (stat \oplus sys) pb$
 - Expected significance: **1.8** +/- **0.9** σ Observed: **2.7** σ
- Improved t-channel measurement, already dominated by systematics:

$\sigma_{t-ch.} = 76.9 \pm 6.6 (stat.) \pm 11.4 (syst.) \pm 3.7 (lumi.) \text{ pb}$	(muons)
$\sigma_{t-ch.} = 59.3 \pm 8.2 (stat.) \pm 11.9 (syst.) \pm 2.8 (lumi.) \text{ pb}$	(electrons)
$\sigma_{t-ch.} = 70.2 \pm 5.2(\text{stat.}) \pm 10.4(\text{syst.}) \pm 3.4(\text{lumi.}) \text{ pb}$	(combined)

• $|V_{tb}|$ measurement with 10% uncertainty from t-channel analysis:

$$|V_{\rm tb}| = \sqrt{\frac{\sigma_{t-{
m ch.}}}{\sigma_{t-{
m ch.}}^{
m th}}} = 1.04 \pm 0.09 \,({
m exp.}) \pm 0.02 \,({
m th.})$$

• Both results are in agreement with Standard Model predictions

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• Stay tuned for new results!

CMS PAS TOP-11-021

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Back-up





Cross-section table



• With all uncertainties (first due to renormalization/factorization scale, second due to the parton distribution function)

Cross sections (pb) [m _{top} = 173 GeV]	s-channel	t-channel	tW channel	top pair
Tevatron: <u>ppbar@1.96TeV</u>	1.046 ^{+0.002} -0.01 ^{+0.06} -0.056	2.08 ^{+0.00} -0.04 ± 0.12	0.22 ± 0.08	7.08 +0.00 -0.24 +0.36 -0.27
LHC: pp @ 7 TeV	4.56 ± 0.07 ^{+0.18} -0.17	65.9 ^{+2.1} -0.7 ^{+1.5} -1.7	15.6 ± 0.4 ^{+1.0} -1.2	163 ⁺⁷ -5 ± 9
LHC: pp @ 8 TeV	5.55 ± 0.08 ± 0.21	87.2 + ^{2.8} -1.0 ^{+2.0} -2.2	22.2 ± 0.6 ± 1.4	234 ⁺¹⁰ -7 ± 12

N. Kidonakis arxiv.org/pdf/0909.0037 (2009) N. Kidonakis arxiv.org/pdf/1205.3453v1 (2012)





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t-channel systematics



Uncertainty source	in pb	in %
Statistical	±5.2	$\pm 7.4\%$
W+heavy flavours extraction	± 5.0	$\pm 7.1\%$
Jet energy scale	-4.4/+6.5	-6.2/+9.2%
Jet energy res.	-0.48/+0.87	-0.69/+1.2%
Unclustered $E_{\rm T}$	± 0.37	$\pm 0.53\%$
t ī rate	-2.4/+2.8	-3.5/+4.0%
Q^2 , tt	-2.8/+1.5	-4.0/+2.1%
Q ² , <i>t</i> -channel	± 4.9	$\pm 7.0\%$
<i>t</i> -channel generator	± 3.5	$\pm 5.0\%$
Muon trigger + reco.	-1.1/+1.2	-1.5/+1.7%
Electron trigger + reco.	-0.53/+0.66	-0.76/+0.94%
Pile up	-0.23/+0.13	-0.33/+0.18%
QCD, muon	-0.67/+0.63	-0.95/+0.89%
QCD, electron	-0.26/+0.21	-0.37/+0.29%
<i>s-,</i> tW-channel, dibosons	± 0.38	$\pm 0.54\%$
b-tagging	± 2.2	$\pm 3.1\%$
Hadronic trigger	± 0.95	$\pm 1.4\%$
PDF	± 1.8	$\pm 2.5\%$
Total syst.	±10	$\pm 15\%$
Total	±12	$\pm 17\%$

Gabriele Benelli, University of Kansas





tW systematics



Systematic uncertainty $(ee/e\mu/\mu\mu)$ [%]	signal tW	tī	Z/γ^{\star}	other
Luminosity	4.5	4.5	-	4.5
Pile-up multiplicity	0.48/0.55/0.73	*	-	*
Trigger Efficiency	1.5	1.5	-	1.5
Muon reconstruction and identification	- /1/1	- /1/1	-	- /1/1
Electron reconstruction and identification	2/2/ -	2/2/ -	-	2/2/ -
JES	$^{-2.5}_{+1.6}/^{-2.4}_{+0.1}/^{-0.6}_{+1.0}$	$^{-5.6}_{+4.4}/^{-6.0}_{+4.7}/^{-5.9}_{+2.3}$	-	*
JER	1.1/0.5/0.4	3.1/3.9/4.4	-	*
B-tagging	$^{-9.5}_{+10}/^{-9.8}_{+9.8}/^{-9.5}_{+10}$	$^{-8.5}_{+10}/^{-11}_{+10}/^{-9.1}_{+11}$	-	*
Factorization/Normalization Scale (Q^2)	7.7/6/10	7.7/11/12	-	*
ME/PS matching thresholds	-	5.7/0.7/2.3	-	*
ISR/FSR	-	8.9/7.3/7.3	-	*
DR/DS scheme	8.2/9.1/6.6	-	-	*
E ^{miss} modeling	2.3/0.9/0.9	*	-	*
PDF uncertainties	4.5/4.5/4.5	*	-	*
Background Normalization	-	15/15/15	50/ 50/ 50	*
Simulation statistics	3.5/1.9/2.7	-	-	17/21/11





Cross-section vs. sqrt(s)



