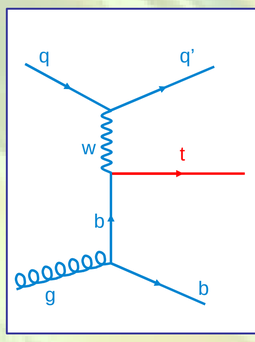
Single-top cross section measurements in the *t*-channel at CMS

EPS HEP 2013 Stockholm, 18-24 Jul 2013, Stockholm (Sweden)

Alberto Orso Maria Iorio

References: JHEP 12 (2012) 035, CMS PAS TOP-12-011, CMS PAS TOP-12-038

The single-top *t*-channel process



Single-top: electroweak top quark production mechanism

- tWb vertex in the production: unbiased measurement of the Cabibbo Kobayashi Maskawa Matrix element $|V_{tb}|$

- Sensitive to physics beyond the standard model affecting the coupling.

- Asymmetry in the production of top-antitop quark, consequence of the proton parton distribution functions.

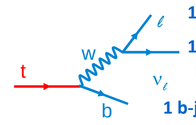
- Polarisation of the top quark : reflected in angular properties of the final state objects (leptons, jets)

***t*-channel Cross sections**

pp @1.96 TeV (N. KidonakisPhys. Rev. D 82, 054018 (2010) and arxiv:0909.0037	2.08±0.12 pb
pp @7 TeV (N. Kidonakis, arXiv:1205.3453)	64.6±2.1 pb
pp @8 TeV (N. Kidonakis, arXiv:1205.3453)	87.1±2.8 pb

Topology and backgrounds

Signal: t-channel leptonic decays



1 lepton from the W-boson decay

1 neutrino manifesting as missing energy in the detector

1 b-jet from top decay, BR (t → bW) ~ 100%

In association with:

- **1 jet in the forward region** from the recoil light parton

- **2nd b-jet** from the b quark due to gluon splitting

Background processes:

top – antitop pair (tt) :
- Cross section ~ 3 times greater than t-channel
- Leptonic top cascades as the t-channel

W+Jets:
- Cross section ~ 500 times greater than the t-channel
- Contribution of jets from heavy and light quarks: different topologies

Multi-jet QCD :
- Cross section several orders of magnitude greater than t-channel
-Reduced to extreme corners of phase space by topological cuts.

Shared analysis procedures (7,8 TeV)

Event selection: general criteria

Leptons
- Trigger with 1 isolated lepton
-7TeV, electron only: trigger-level b-tagged jet
- Select exactly 1 muon with p_T > 20(7TeV) or 26 GeV(8TeV) within the trigger acceptance, or exactly 1 electron with E_T ,>30 GeV. Isolation requirements to remove QCD
- Veto other leptons with loose selection criteria

Jets
- Use AntiK_T jets, in the pseudorapidity range $|\eta|< 4.5$, with a p_T cut of 30 (7 TeV) or 40 (8TeV).
Require 2-4 jets depending on the analysis

b-tagging
- Use algorithm based on significance of the jet tracks' impact parameter to discriminate the jets stemming from a B meson decay.
- Require 1-2 b-tagged jets depending on the analysis.

Missing energy/Transverse mass
- Use cut on the missing energy $E_{T,miss}$ for the electron channel or the transverse mass m_T for the muon channel.

Top quark 4-momentum reconstruction

Reconstructed taking the 4 momenta of the lepton, a b-tagged jet and the $E_{T,miss}$ with the following procedure:

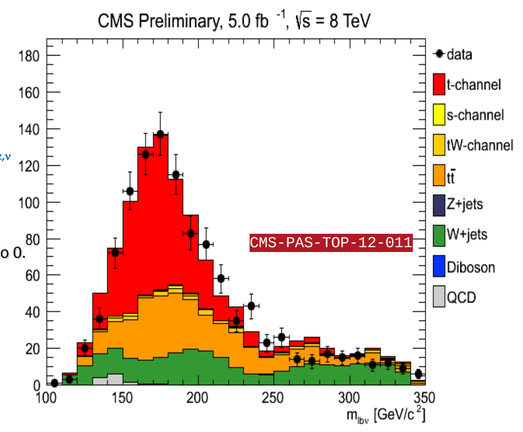
1) take $(p_{x,\nu},p_{y,\nu})= (E_{T,miss,x} ,E_{T,miss,y})$

2) constrain the mass of the lν pair ln to the PDG value of m_W: **get 2nd order equation in $p_{z,\nu}$**

3) two real solutions: take the one with lowest $|p_{z,\nu}|$

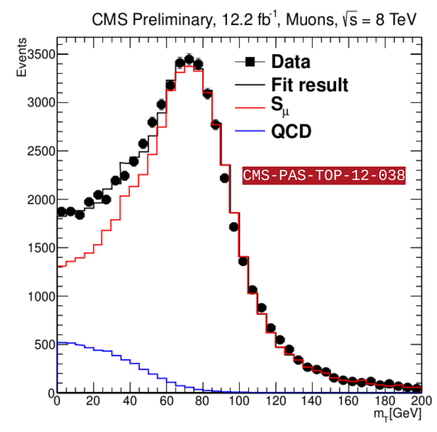
4) two imaginary solutions: put discriminant to 0. In this case the 1) is not valid anymore, but impose 2 can still be imposed.

5) Choose $p_{x,\nu},p_{y,\nu}$ with minimum distance from the $E_{T,miss}$ in the p_x/p_y plane



Right plot: reconstructed top mass at 8 TeV in a *t*-channel enriched sample with 2 jets and 1 b-tag, muon channel

QCD treatment



Yield of the QCD contribution in all samples is extracted from a **fit to the distribution of m_T (muons) or $E_{T,miss}$(electrons)** prior to any cut

- Distributions of the QCD m_T and $E_{T,miss}$ are extracted from **control samples obtained inverting the lepton isolation cuts**

- Fit extrapolated to the region above the m_T and $E_{T,mis}$ cuts

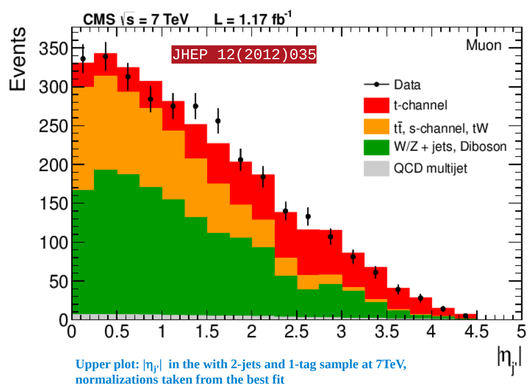
- QCD distributions of discriminating variables used for signal extraction are **taken from the QCD enriched region**.

Left plot: Fit to the m_T distribution in the region with 2-jets and 1 b-tag for muons at 8TeV. Signal is considered grouping all non-QCD processes.

$|\eta_{j'}|$ analysis (7,8 TeV)

Based on a maximum likelihood fit to the pseudorapidity of the light quark jet

- Fit performed in a region with 2-jets, 1 of which b-tagged
- Extra cut on m_{lbv} restricting to in the central top mass window
- Analysis performed at 7 and 8 TeV
- QCD distribution for $|\eta_{j'}|$ extracted from the QCD enriched sample



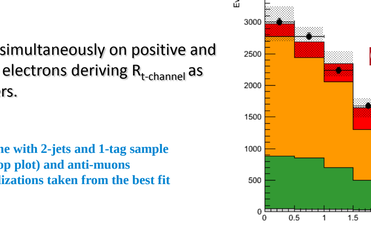
Upper plot: $|\eta_{j'}|$ in the with 2-jets and 1-tag sample at 7TeV, normalizations taken from the best fit

8TeV analysis extra features:
- additional pileup rejection cuts are applied to the two leading jets
- tt distribution remodeled after data in the region with 3-jets, 2 of which b-tagged
- analysis extended to measure top/antitop ratio

Sideband extraction method

Cut on the top mass window defines two regions:
- Signal Region : 130 < mlbn < 220 GeV
- Sideband Region : outside the signal region window

W+jets shape extracted from the sideband:
- Perform the QCD extraction in the sideband
- Perform the tt shape extrapolation in the sideband
-Subtract the data-driven QCD and tt from the sideband data distribution
- Subtract all other processes that are not W+jets taking them from the standard model prediction



The distribution so obtained the data-driven W+jets
- Used for |hj'| fit in the signal region

Upper plot: reconstructed top mass in a control sample with 3-jets and 1-tag at 8TeV, displaying the signal and sideband regions

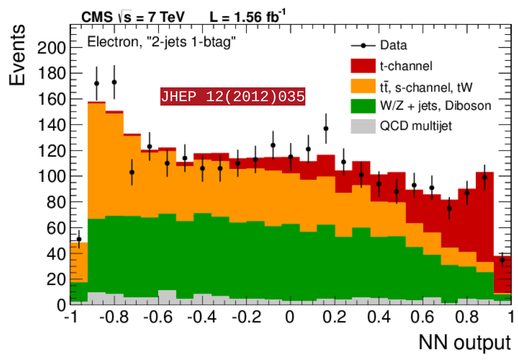
Neural Network and Boosted Decision Tree analyses (7 TeV)

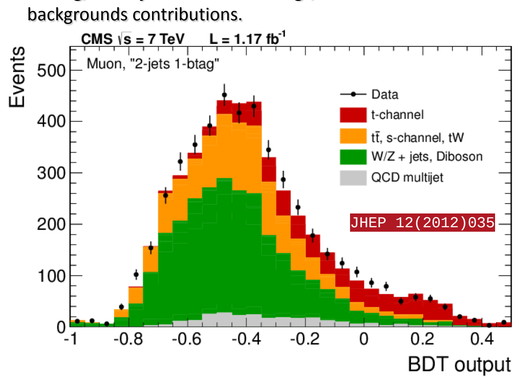
Two multivariate analyses:

- Based on a **Neural Network** and a **Boosted Decision Trees** discriminant
- Complementary approach to the $|\eta_{j'}|$analysis: exploit the full topology of the *t*-channel in several regions simultaneously

Analyses performed in 6 samples:

- 2 signal enriched regions with 2 jets, one of which b-tagged, and 3 jets, 2 of which b-tagged
- 4 signal depleted samples with 2 jets and 2 b-tags, 3 jets and 1 b-tag, and 4 jets and 1 or 2 b-tags, enriched with different backgrounds contributions.





Bayesian inference:

- Background yields and most of the systematics treated as **nuisance parameters**

- **Marginalisation performed using Markov Chain Monte Carlo** to integrate over the nuisance parameters, taking the central 68% quantile as measurement.

-Theoretical, and signal and background modeling uncertainties are not marginalize

- Simultaneous use of several samples allows to precisely constrain the backgrounds and systematics

Left plots: Neural Network and Boossted Decision Trees discriminants in the region with 2-jets and 1 b-tag for electrons and muons respectively. Normalizations are taken from the best fit result

Combined results and $|V_{tb}|$ extraction

7 TeV results of the three analyses combined with the BLUE method

- statistical correlation between analyses evaluated reproducint the signal
- extraction on pseudo-experiments

Measured cross sections :

$\sigma_{(t\text{-channel,7 TeV})}$= 67.2 ±3.7(stat) ±3.0(syst) ±3.5(th.) ± 1.7 (lumi)

$\sigma_{(t\text{-channel,8 TeV})}$= 80.4 ±5.7(stat) ±11.0(syst+th.) ±4.0 (lumi)

Ratio of 8/7 cross sections was obtained comparing the hj' at the two energies:

$R_{(8/7)} = \sigma_{(t\text{-ch.,8 TeV})}/\sigma_{(t\text{-ch.,7 TeV})}$ = 1.14 ± 0.12 (stat) ± 0.14 (syst)

Cabibbo Kobayashi Maskawa matrix element V_{tb} extraction:

- tWb vertex in production → cross section depends on V_{tb}
- assuming $|V_{td}|, |V_{ts}| << |V_{tb}| \rightarrow |V_{tb}| = \sqrt{(\sigma_{t\text{-ch.}}/\sigma_{t\text{-ch}})}$:

7TeV: $|V_{tb}| = 1.020 \pm 0.046$ (meas.) ± 0.017 (theor.)

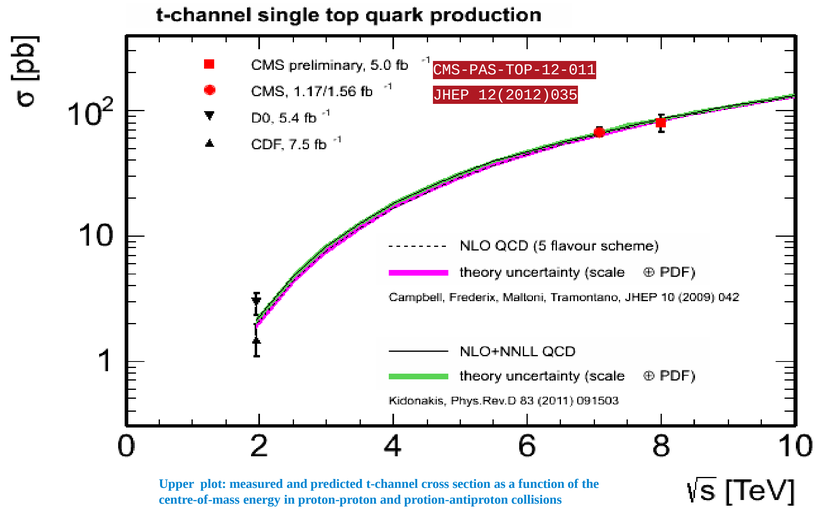
8TeV: $|V_{tb}| = 0.96 \pm 0.08$ (meas.) ± 0.02 (theor.)

In the assumption of $|V_{tb}| < 1$ the following limits are extracted at 95% confidence level:

7TeV: $0.92 < |V_{tb}| <= 1$ at 95% confidence level.

8TeV: $0.86 < |V_{tb}| <= 1$ at 95% confidence level.

t-channel single top quark production



Upper plot: measured and predicted t-channel cross section as a function of the centre-of-mass energy in proton-proton and protion-antiproton collisions

Charge ratio measurement (8 TeV)

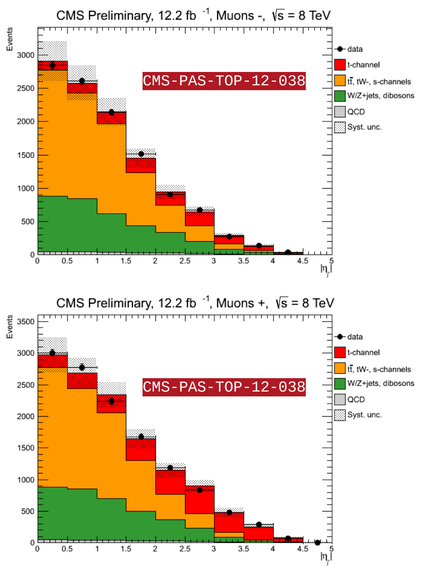
Cross section of top and antitop:

- sensitive to valence u and d quarks parton distribution functions respectively
- ratio can be used to check different pdf models
- lepton in the final state inherits the sign of the top quark

$|\eta_{j'}|$ analysis performed on datasets separated by lepton charge, measuring the charge ratio:

$$R_{t\text{-channel}} = \frac{\sigma(\text{tops})}{\sigma(\text{anti-tops})}$$

The fit is performed simultaneously on positive and negative muons and electrons deriving $R_{t\text{-channel}}$ as one of the parameters.



Right plots: $|\eta_{j'}|$ in the with 2-jets and 1-tag sample at 8TeV, for muons (top plot) and anti-muons (bottom plot), normalizations taken from the best fit

Separate charge cross section mearsurement:

$\sigma_{(t\text{-ch., 8TeV, top})}$= 49.9 ±1.9(stat) ±8.9(syst.+th.+lumi.)

$\sigma_{(t\text{-ch.,8 TeV, antitop})}$= 28.8 ±2.4(stat) ±4.9(syst.+th.+lumi)

$R_{(t\text{-ch.})} = \sigma_{(t\text{-channel, 8TeV, top})}/\sigma_{(t\text{-channel, 6TeV, antitop})}$ =

= 1.76 ± 0.15 (stat) ± 0.22(syst)

Right plots: R(*t*-channel, 8TeV) compared with the predictions of several parton distribution functions