Top pair production cross-section measurement in full hadronic mode with ATLAS+CMS

C. Bertella (CPPM)

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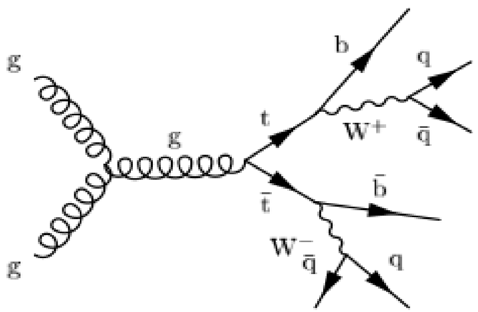
Outline



- $t\bar{t}$ production cross section in the multijet final state
  - ATLAS: measurement performed @ $\sqrt{s}$ = 7 TeVwith 4.7 fb^{-1} ATLAS-CONF-2012-031
  - CMS: measurement performed @ $\sqrt{s}$ = 7 TeV with 3.54 fb^{-1} arXiv:1302.0508
- Analysis steps:
  - Multijet trigger
  - Event Selection
  - Discriminant variable: reconstructed top mass with a kinematic fit
  - Model of the QCD background
  - Cross section extraction by an unbinned likelihood fit on the reconstructed top mass
- Conclusions and Outlook

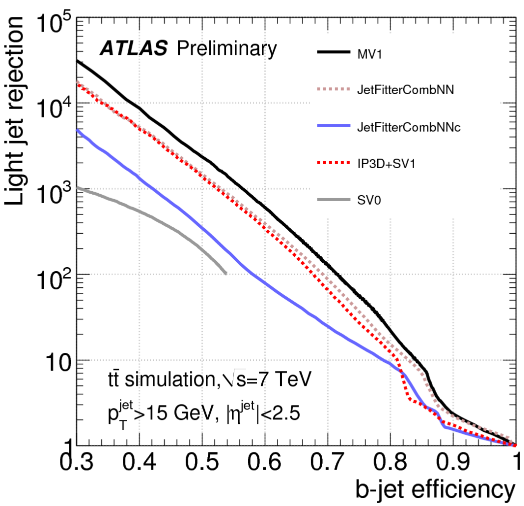
Multi-jet trigger

- Single symmetric trigger:
  - At least five jets with
    - E_T>10 GeV at L1
    - E_T>25 GeV at L2
    - E_T>30 GeV at EF
- To assure high signal efficiency an offline cut of p_T> 55 GeV on the fifth leading jets is added
  - The value derived from the five-jet trigger dependence on the fifth leading jet
    - corresponds to a 90 % efficiency
  - To reach a full efficiency w.r.t the offline jet p_T and remove the residual difference in the applied a cut on jet isolation
    - Minimum ΔR between two closest jets optimized to be 0.6

- Two asymmetric multijet triggers:
  - At least four jets in the calorimeter with p_T> 50 GeV, a fifth jet with p_T> 40 GeV
  - An additional sixth jet with p_T> 30 GeV
- Trigger efficiencies definition
  - ratio between events pass the analysis triggers and the offline selection and the events pass trigger with a of at least four jets with p_T> 40 GeV and the offline selection
  - Combined efficiency for ttbar signal is 96^{+4}_{-5} %

Event Selection

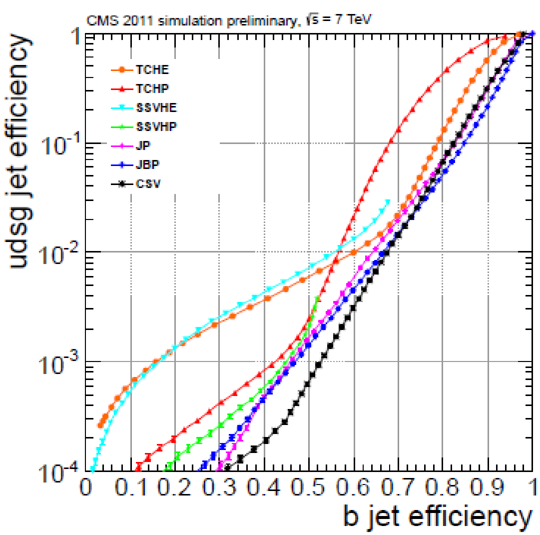
- Jets (anti-K_T, R<0.4) with $|\eta| < 2.5$
- At least five jets with p_T> 55 GeV
  - sixth jet with p_T> 30 GeV
  - Additional jet p_T> 20 GeV
  - Minimun ΔR between two closest jets (ΔR>0.6)
- At least two *b*-tagged jet
  - Identification of jets originating from *b*-quark is performed using a secondary-vertex-based tagging algorithm



- MVA technique used for computing tagging discriminant variable
- MVA weight (MV1) chosen provides an efficiency of 60%

ATLAS-CONF-2012-043

- Jets (anti-K_T, R<0.5) with $|\eta| < 2.4$
- At least four jets with p_T> 60 GeV, fifth jet with p_T> 50 GeV
  - sixth with p_T> 40 GeV
  - Additional jet p_T> 30 GeV
- At least two *b*-tagged jets
  - Jets originating from *b*-quark are classified as a *b*-tagged jets through an algorithm based on the reconstruction of secondary vertex

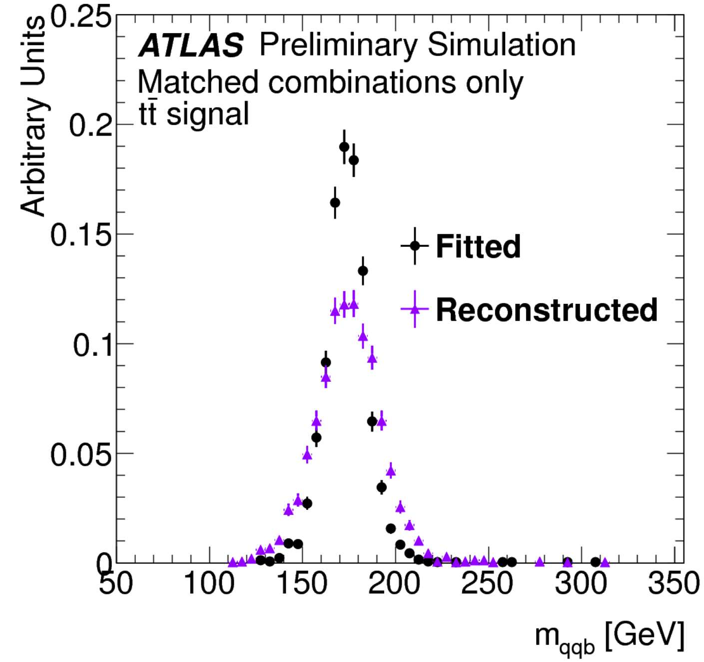


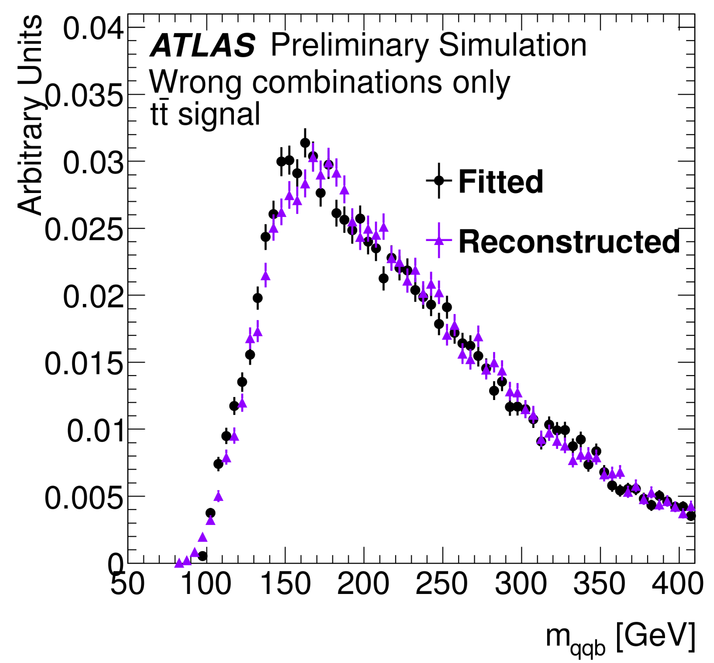
- A discriminant variable significance of decay length
- The working point provides an efficiency of 47± 1%

CMS-PAS-BTV-11-004

Kinematic Fit

- The Kinematic Likelihood Fitter uses the known $t\bar{t}$ decay topology in order to properly assign the jets to the decay products
- For each permutation a likelihood function is defined
  - The likelihood consists of three parts:
    - Transfer functions maps the measured energy of a jet to the energy of the final state parton
    - Breit-Wigner functions used to constrain the di-jet and the tri-jet masses to the W boson and to top quark
    - The b-tagging efficiency
  - The two Ws masses and width are fixed to the known values
  - The top mass is a free parameter, but it is constrained to be equal to the anti-top one





Validation kinematic fit:

Fraction of events in which top and anti-top are fully reconstructed ~ 30%

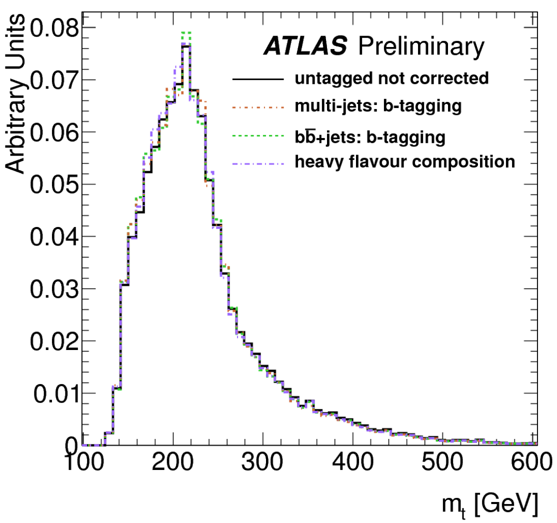
Kinematic Fit

- Kinematic least-squares (χ^2) fit is performed for the final selection of $t\bar{t}$ candidate events
- It exploits the topology of the top events
  - Two W bosons reconstructed with untagged jets and with a mass constrain $m_W = 80.4$ GeV
  - Two top reconstructed from the W bosons and the b-tagged jets
    - Top masses are assumed equal
- For each permutation, the sixth jets four momentum are fitted to the $t\bar{t}$ final state for finding the most likely combination
- The *b*-tagged jets are taken as a bottom quark candidate and the remaining as light quark candidates
- The permutation with smaller χ^2 is taken to represent the event
- Only the events with $P(\chi^2) > 0.09$ are accepted
- Number of events remaining in the data after the selection and the fraction of signal expected for a $t\bar{t}$ production cross section of 163 pb

Selection	Events	Fraction of $t\bar{t}$
At least 6 jets	786741	0.02
At least two b-tags	21783	0.18
Kinematic fit	3136	0.41

Backgroung Modeling

- Background shape in the signal region was derived from untagged data (all cuts applied but *b*-tagging requirement)
- Validated this hypothesis using ALPGEN MC multi-jet event sample
  - With generic multi-jet production and exclusive *bb*+jets
- Correction factor derived from ratio m_t before and after b-tagging for each sample and apply to untagged data sample
  - the maximum taken variation as uncertainty on the background modeling

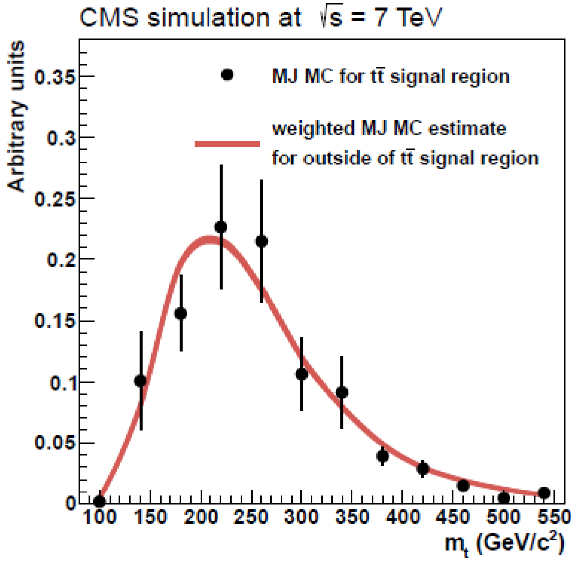


- Multijet background estimated in a sample with at least 6 jets passing the analysis selection except the *b*-tagging requirement
- Extract tag rate function for weighting the untagged events

$$R(p_T, |\eta|) = \frac{N(p_T, |\eta|, d_B > 2)}{N(p_T, |\eta|, d_B < 2)}$$

- Kinematic fit implemented on the untagged events and a weight is computed for each permutation of jet with $P(\chi^2) > 0.09$

$$w = R(p_T^b, |\eta^b|) \times R(p_T^{\bar{b}}, |\eta^{\bar{b}}|)$$



Cross section extraction

- Extract the signal and the QCD background fraction from an unbinned likelihood fit to the top mass distribution

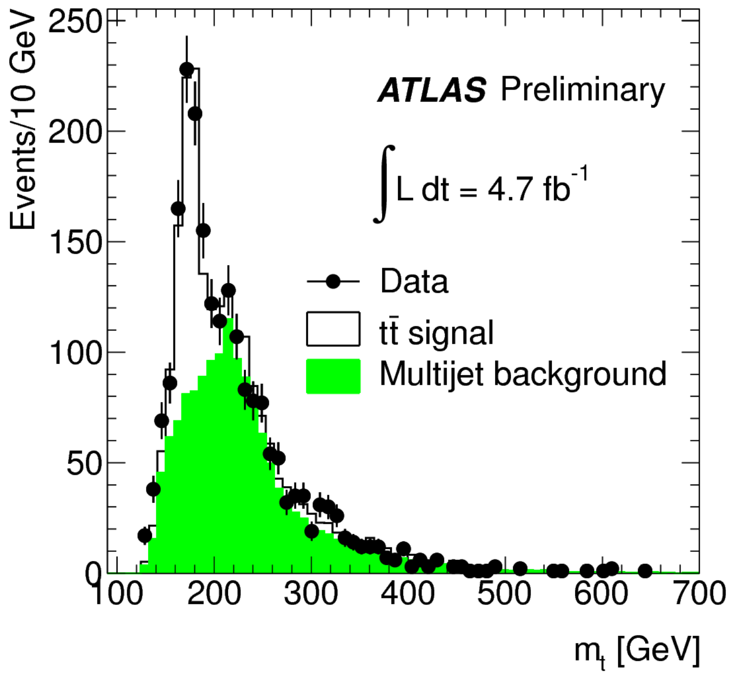
$$\sigma_{t\bar{t}} = \frac{f_{sig} \cdot N}{\varepsilon \cdot L}$$

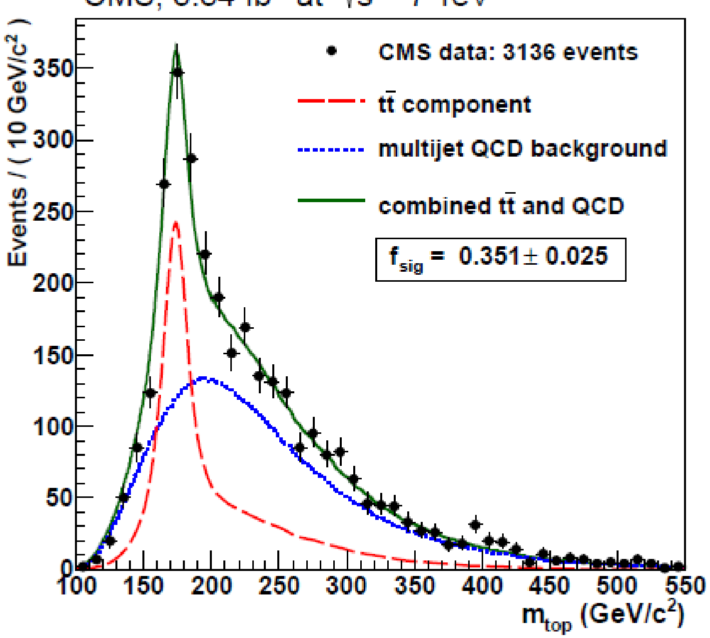
- f_{sig} is the signal fraction
- N number of candidate events
- ε efficiency of tt events estimate on MC

- ATLAS: to achieve more discrimination between the S and B
  - $6 \leq N_{jet} \leq 10$
  - Mass $\chi^2 < 30$
  - Event Probability > 0.8

σ_{tt} = 168 ± 12 (stat.) pb

σ_{tt} = 139 ± 10 (stat.) pb





Systematic Uncertainties

Source of uncertainty	Contribution(%)
Jet Energy Scale (JES)	+20/-11
b-tagging	+17/-17
(JER)	+3/-3
(JRE)	<+1/-1
Initial/Final state radiation	+17/-17
Parton Shower/Hadronization	+13.0/-13.0
Trigger modelling	+10.0/-10.0
Generator	+7/-5.1
Parton density function	+7.0/-4.0
Background model	+4/-4
Total systematic uncertainty	+36/-34
Luminosity	+4/-4

Source of uncertainty	Contribution(%)
Jet Energy Scale (JES)	10.1
Background contribution	9.0
Tagging of b jets	6.0
Renormalization and factor scale	5.8
Tune for underlying event	5.5
Trigger	5.0
Jet energy resolution	4.0
Matching matrix elements /parton shower	4.0
Mass of the top quark	2.1
Pileup	0.8
Total systematic uncertainty	18.6
Luminosity	2.2

- Main Systematic
  - JES
    - Both experiment follow similar prescription, still some differences in the strategies
  - *b*-tagging:
    - ATLAS: total uncertainties are ranging from 5% to 15% when subdividing the data into bin of jet p_T per jet uncertainty
    - CMS: total uncertainties of a few percents per jet uncertainty
  - ISR/FSR
    - Different prescription are used by the two experiments

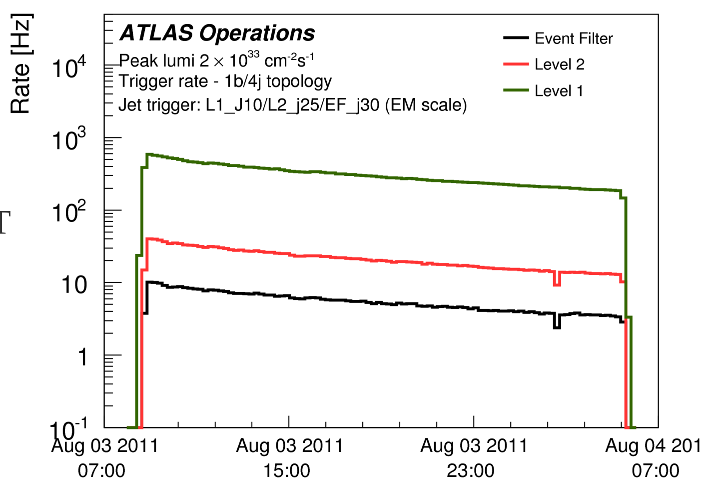
Conclusion

- $t\bar{t}$ cross section measurement performed using 4.7 fb^{-1} luminosity collected by ATLAS experiment during 2011 @ $\sqrt{s}$ = 7 TeV *ATLAS-CONF-2012-031*
  - Cross section extract using an unbinned likelihood fit from reconstructed top quark mass with a kinematic fit
  - $\sigma_{tt} = 168 \pm 12\ (\text{stat.})_{+36}^{-34}\ (\text{sys.})$ pb
  - Working on the paper
- $t\bar{t}$ cross section measurement performed using 3.54 fb^{-1} luminosity collected by CMS experiment during 2011 @ $\sqrt{s}$ = 7 TeV *arXiv:1302.0508*
  - Main analysis based on a reconstruction of the candidate events through a kinematic fit to the tt hypothesis
  - Cross-check analysis performed using a neural-network-based selection
  - $\sigma_{tt} = 139 \pm 10\ (\text{stat.}) \pm 26.\ (\text{sys.})$ pb
- ATLAS and CMS measured cross section are compatible with the Standard Model expectation of $\sigma_{t\bar{t}}^{SM} = 167_{-18}^{+17}\ pb$ *

* arXiv:1007.1327

Outlook
Analysis @ √s = 8TeV

- Perform a cross section measurement on data collected with a *b*-jet trigger
  - With the high instantaneous luminosity, in 2012 most of multi-jet trigger were prescaled
  - *b*-tagging at HLT is a possibility for collecting tt in the full hadronic final state
    - combinations of multijet and *b*-jet trigger available to efficiency select events with final states containing several *b*-jet
- *b*-jet trigger for hadronic top
  - 4 EF-jets with ET > 30 GeV
  - 1 b-jet with ET > 10 GeV



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/BJetTriggerPublicResults

- Optimization of the analysis is ongoing on the top mass measurement
- The aim is to address the main uncertainties, such as JES
- Given the technique followed the the cross section could be measurement simultaneously
  - Need a careful evaluation of the efficiency of the event selection, e.g the trigger requirement
- Main improvements:
  - Use of a NN to select the best jets-to-partons assignment in reconstructing the template to be used in the likelihood fit
  - Optimization of selection requirement to obtain the smallest uncertainty on the top mass

Backup

Systematic Uncertainties : ATLAS

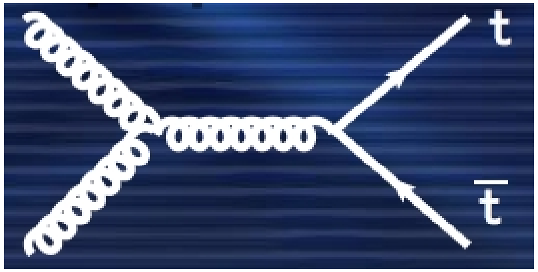
- Jet Energy Scale (JES)
  - Derived by combining information from test beam data, LHC collision data and MC simulation
  - Various components : calibration method, calibration response, detector simulation
    - Depends on jet p_T and η
    - Includes uncertainties in the flavour composition, pile-up, b-jet and light-jet
- b-tagging efficiency
  - Takes into account differences in the b-tagging efficiency between data and MC simulation
    - Set of scale factors are derived from b-tagging calibration studies are applied to b-, c- and light jets as a function of p_T and η
- Trigger efficiency
  - multi-jet trigger with an additional cut on the fifth-jet p_T provides an associated efficiency range between 90% and 100%, so a conservative 10% uncertainties is considered
- Background modelling
  - The m_t shape for the background modelling is derived in untagged data sample
    - Uncertainty is estimated on the ALPEGN MC sample, multi-jet and bbar-jet production, w/o b-tagging requirement
- Initial and Final State Radiation
  - Effect of variation in the amount of initial and final state QCD radiation is studied using AcerMC generator by varying the parameters controlling ISR/FSR

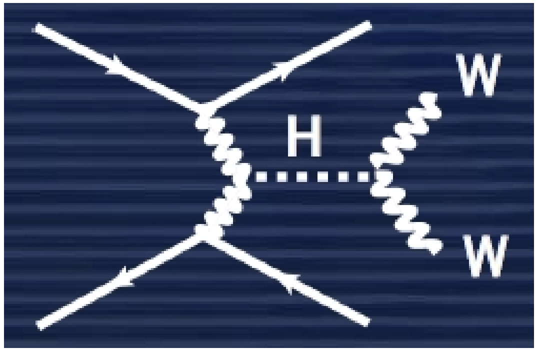
Systematic Uncertainties : CMS

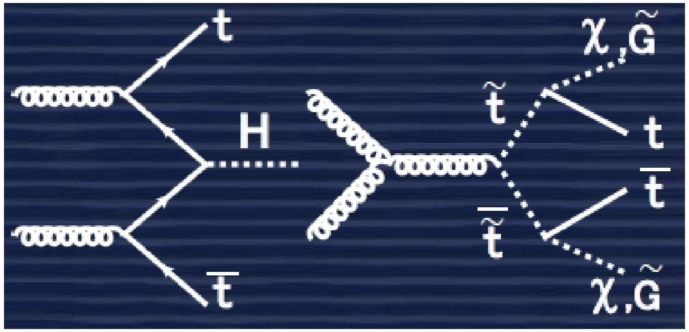
- Jet Energy Scale (JES)
  - Is assessed by shifting the jet energy by +/-1 Standard deviation relative to the nominal value, as a function of jet pT and η
- b-tagging efficiency
  - B-tagging and mistag rate are changed by +/1 SD corresponding of about 2% and 9% in their values
- Trigger efficiency
  - The trigger efficiency of 96% observed in data is changed by -5% and +4%, Th SD is determinate by emulating the two trigger. The energy of the jets reconstructed at trigger level is also changed by +/1 SD and provides a +/1 SD limits of the uncertainty for the trigger
- Background modelling
  - The systematic uncertainty from the distribution of the backgorund as a function of the top mass is determinated using a Γ function fitted to the background distribution astimated from MJ data
    - The parameter of Γ are changed by amounts that corrispond to the difference observed in the MC simulation of MJ for the region of ttbar selection
      - The uncertainty is defined by half of the difference in the fitted parameters of the Γ function
- Renormalaization and factorisation scale:
  - To study the dependece of the analysis on the renormalizatin and factor scale (μ) used in ttbr MC, the nomianl common value for the hard scattering and for the parton showering are simulated changed by a factor 0.5 and 2.0. This also reflects the uncertainty in the amount of initial and final-state radioation for change s in the strong coupling α_S in parton showering by a facto 0.5 and 2.0

Introduction: Why do we study Top Quark?

- Why is it interesting?
  - **Precision measurement of cross section, branching ratio, polarization**
  - Understanding of background in the new physics and Higgs boson
- Search for new physics:
  - **Higgs associated production** : ttH(H->bb)
  - **Beyond Standard Model particles**: Z' resonances, Kaluza-Klein gluons, fourth generation (b'b'->ttWW)
- Detector calibration:
  - Top quark decay presents a striking signature: possibility of identifing pure samples of electrons, muons, jets, b-jets







Top pair production

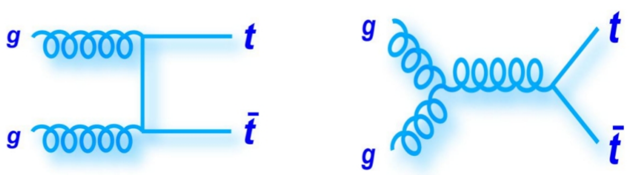
- In proton-proton collision, top quark pairs are created when partons inside the protons interact through the strong force

- The production mechanisms at the LHC at centre-of mass energy of 7 Tev are the gluon gluon fusion (85%) and qq annihilation(15%)

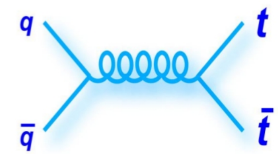
- **In the SM, the top quark decay into W boson and *b*-quarks almost 100% of the time**
  - The W boson subsequently decay into
    - Lepton-neutrino (33%)
    - Di-jet (67%)

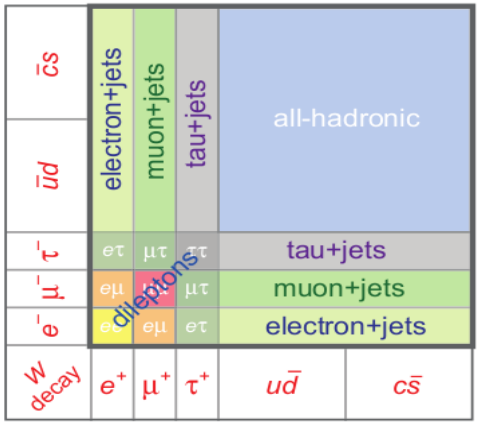
- In the fully hadronic tt production final state both Ws decay hadronically
  - A signature with the largest branching ratio BR~ 46%
  - Final state: at least 6 jets and 2 jets coming from b-quarks, no lepton, no MET

σ_{gg} = 139 pb @ 7 TeV



σ_{qq} = 24 pb @ 7 TeV



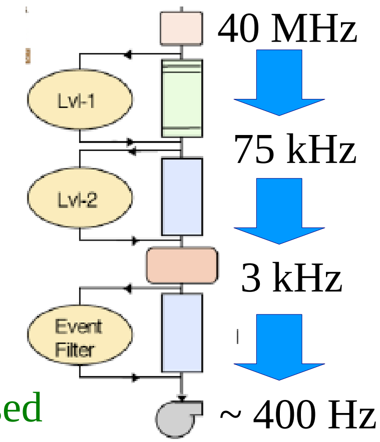


$$\sigma_{t\bar{t}}^{SM} = 167^{+17}_{-18}\ pb$$

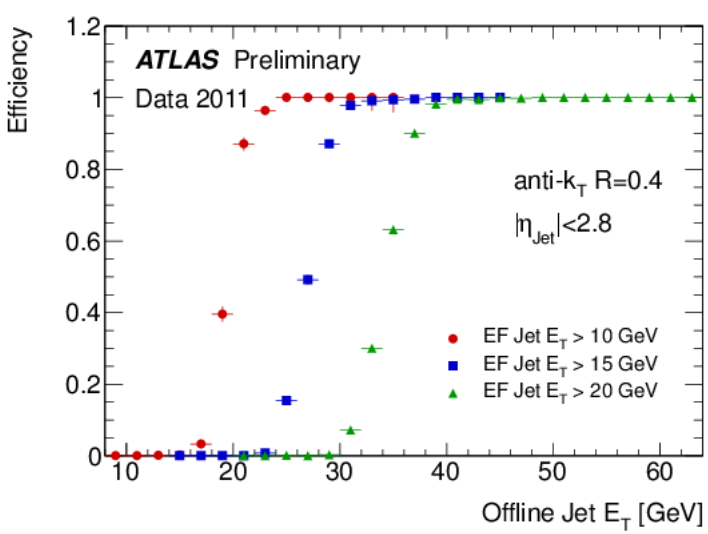
* M. Aliev et al., HATHOR: hadronic top and heavy quarks cross section calculator, Comput. Phys. 334 Commun. 182 (2011) 1034–1046, arXiv:1007.1327[hep-ph]

Jet trigger

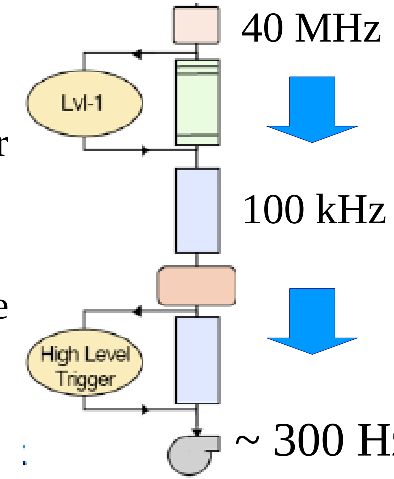
Trigger system divided in three level:



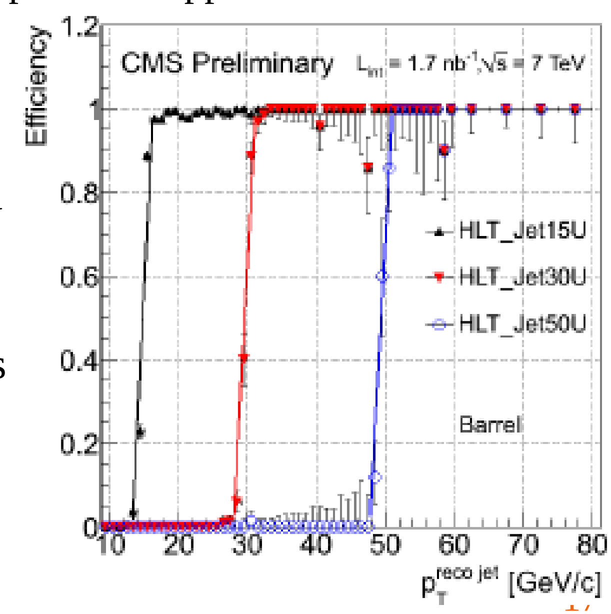
- First level (L1) is hardware based
  - uses a coarse granularity
  - Jet algorithm consists of a sliding window of size applied to calorimeter tower ηxφ= 0.2x0.2
- Second Level (L2) is software based
  - the geometrical position of the L1 objects are used as seeds (RoI)
  - RoI approach suffers from reduced performance in the multijet event
  - In 2012 full calorimeter reconstruction implement
- Third level (EF) uses offline- like algorithm on the RoI or on the full event readout



Trigger system divided in two level:



- First level (L1)
  - makes use of the calorimeter and muon detector with a coarse granularity
  - Jet algorithm uses transverse energy sums computed in calorimeter regions ηxφ= 0.348x0.348
- High Level Trigger (HLT)
  - access the full detector readout
  - performs only the minimal amount of reconstruction needed to determine if an event has to be accepted or dropped
- Partial event reconstruction in the detector to minimize the CPU at HLT. The reconstruction of the physics objects is driven by the candidates identified at L1

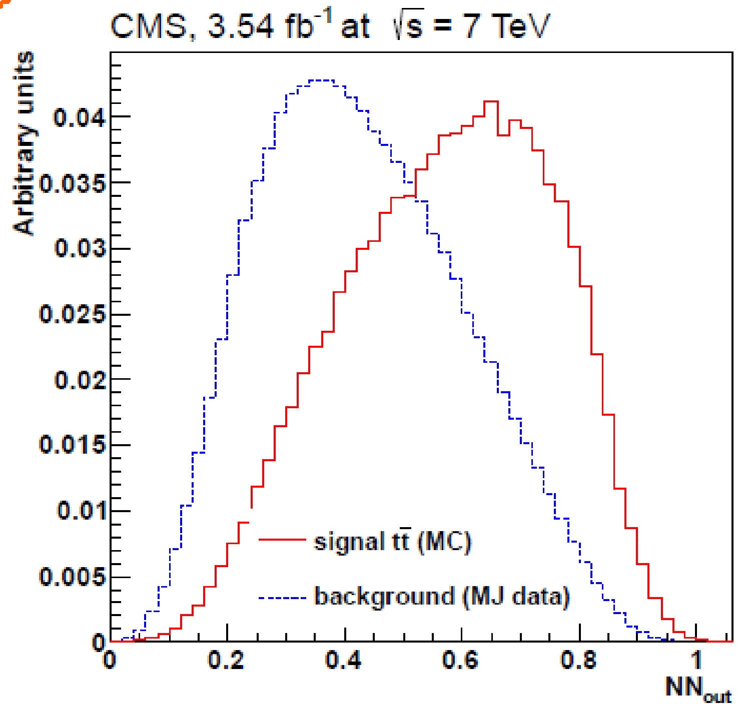


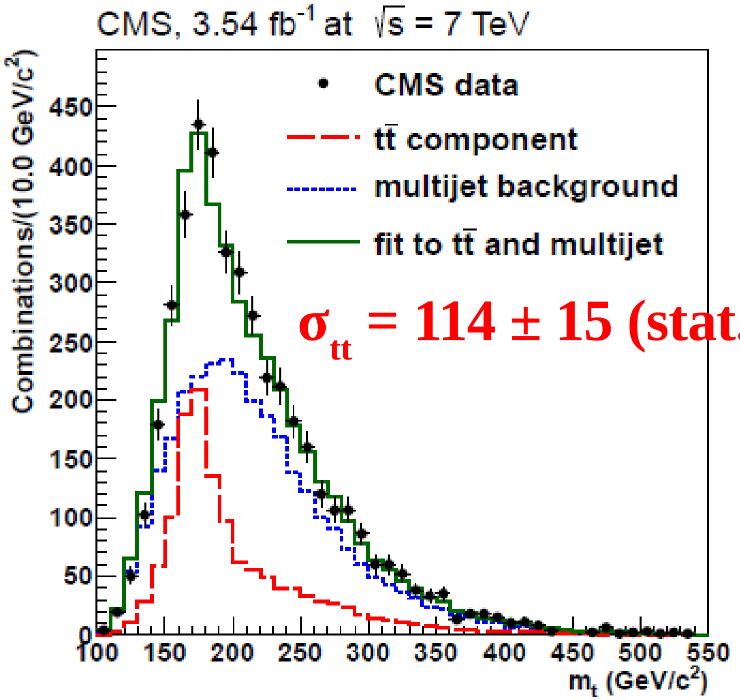
Alternative Analysis using a Neural-Network

- The kinematic proprieties of signal and background events are used as input for a neural-network (NN) procedure
  - NN trained on jet multiplicity $5 \leqq N_{jets} \leqq 9$ using six topological variables
  - $t\bar{t}$ signal purity is enhanced by a cut on $NN_{out} > 0.65$
- Improvement on event selection and background estimation
  - More efficiency *b*-tagging
    - efficiency improves of 30%
  - Multijet background estimate on a data sample with just five jets
    - TRF are computed w.r.t a looser b-tagging requirement

$$R_{LL}^{MM}(\langle p_T \rangle, |\langle \eta \rangle|, \Delta R) = \frac{N(\langle p_T \rangle, |\langle \eta \rangle|, \Delta R, d_B > 3.3)}{N(\langle p_T \rangle, |\langle \eta \rangle|, \Delta R, d_B > 1.7)}$$

  - The expected background from pairs of *b*-tagged jets is obtained by weighting each pair of looser *b*-tags with the R_{LL}^{MM}
- To increase $t\bar{t}$ purity a cut on the separation between the two *b*-tagged jets is added $\Delta R(b,b') > 1.5$





σ_{tt} = 114 ± 15 (stat.)pb