Fully hadronic $t\bar{t}$ cross section measurement with ATLAS detector

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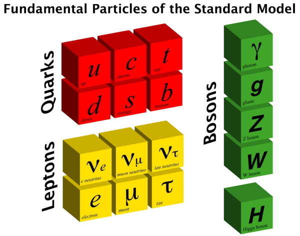
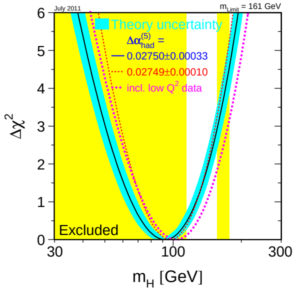
Top physics: an introduction

- **The top quark**, discovered at Fermilab in 1995, completed the three generation structure of the SM
- The top quark is distinguished by
  - **short lifetime**: it decays before hadronizing
  - **high mass** : $m \sim 172$ GeV
- Why is it interesting?:
  - **Test of Standard Model predictions:**
    - Precision measurements of cross section, branching ratio, polarization
    - Higgs associated production : $t\bar{t}H$ ($H \to b\bar{b}$)
  - **Search for new physics:**
    - Beyond Standard Model particles: Z' resonances, Kaluza-Klein gluons, fourth generation ($b'b' \to t\bar{t}W^-W^+$)
  - **Detector calibration:**
    - Top quark decay presents a striking signature: possibility of indentifing pure samples of electrons, muons, jets, b-jets

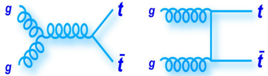




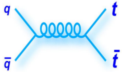
Top pair production

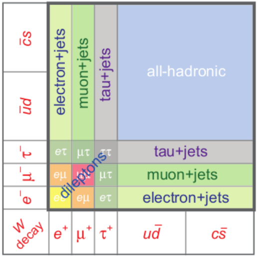
- In proton-proton collisions, top quark pairs are created when partons inside the protons interact through the strong force
- **The production mechanisms at the LHC at $\sqrt{s} = 7$ TeV are the gluon-gluon fusion (85%) and $q\bar{q}$ annihilation (15%)**
- **In the SM, the top quark decays into a W boson and a b-quark almost 100% of the time**
- The W boson subsequently decays into:
  - lepton+neutrino (33%)
  - di-jets (67%)
- In the fully hadronic $t\bar{t}$ production final state both Ws decay hadronically

$\sigma_{gg} = 139$ pb @ 7 TeV



$\sigma_{q\bar{q}} = 24$ pb @ 7 TeV

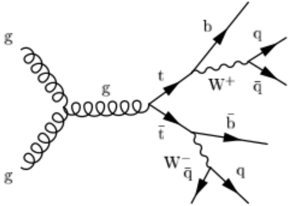


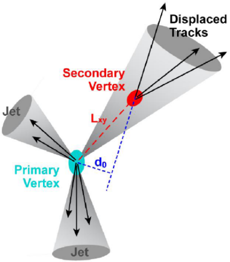


Fully hadronic $t\bar{t}$ channel: signature

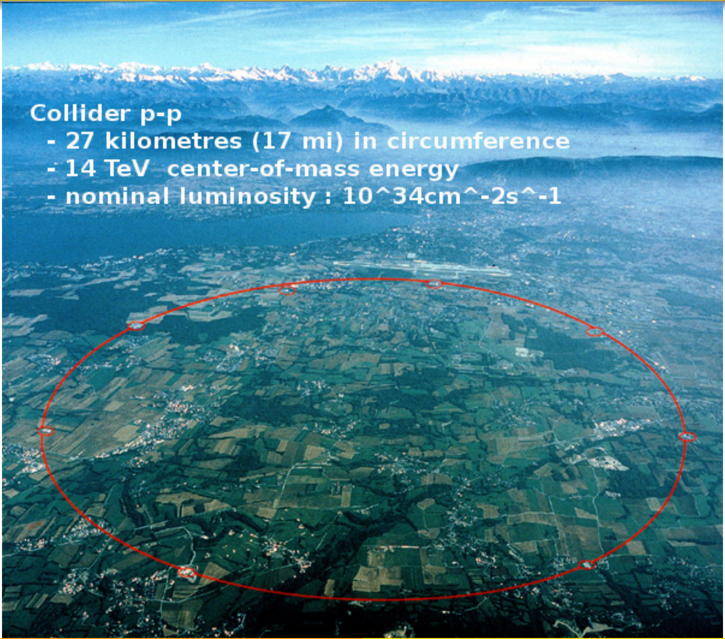
- Experimental signature consist of **high jet multiplicity and b-jets**
  - b-tagging :
    - Long lifetime of hadrons containing b-quarks: $\tau \sim 1.5\ ps$ corresponding to $c\tau \approx 450 \mu m$
    - Identification of jets originating from b-quark is performed using a secondary-vertex-based tagging algorithm
  - Trigger :
    - Selection based on multijet trigger
    - Very challenging to keep unprescaled multijet trigger
- Kinematics that can be fully reconstructed
- **Very large background from QCD multijet production** which makes the isolation of the signal rather challenging
  - Difficult of separation from QCD background
  - Need for data driven background estimation since QCD difficult to simulate

$$\sigma_{t\bar{t}} = 164 \text{ pb} @ 7\ TeV$$
$$BR_{fullyhadronic} \sim 46\%$$

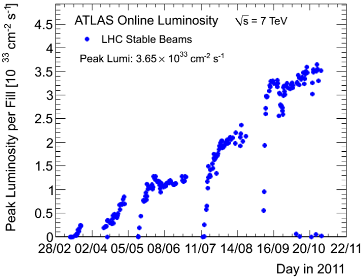


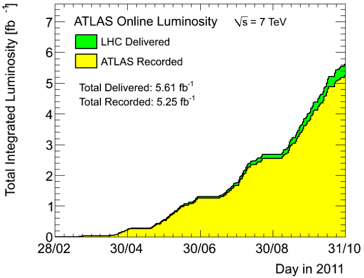


LHC: Large Hadronic Collider



- **Late 2009** : Startup of LHC and first event collisions at a total energy of 0.9 TeV and later at 2.36 TeV
- **March 2010** : First event collisions at a total energy of 7 TeV.
- **March 2011** : Event collisions at a total energy of 7 TeV; few weeks of heavy ion collisions; winter shutdown (Dec. 2011 - Feb. 2012).
- **2013** : Long shutdown to prepare for an increase of the total energy towards 14 TeV.

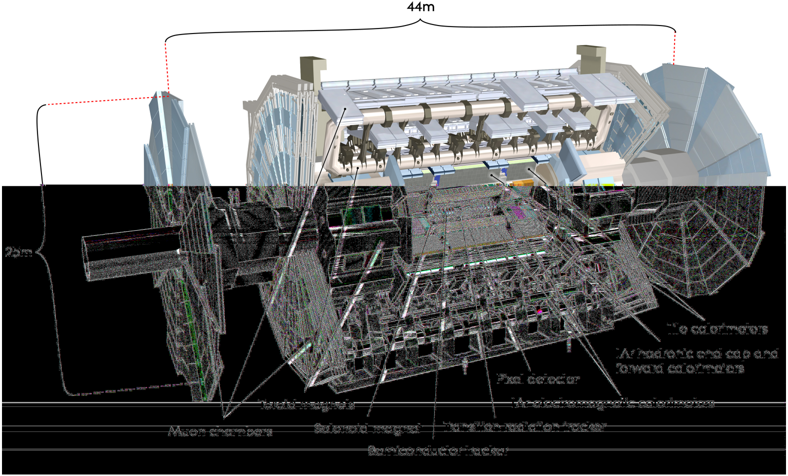




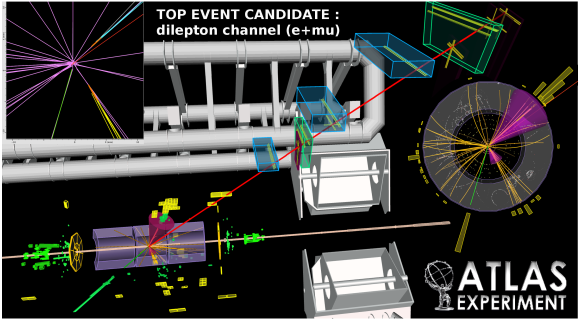
- **3**.65 $\times 10^{33}\mathbf{cm^{-2}s^{-1}}$: Luminosity peak in 2011

- **35** $\mathbf{pb^{-1}}$: all data collected in 2010
- **1** $\mathbf{fb^{-1}}$: data collected until July
- **5** $\mathbf{fb^{-1}}$: all data collected in 2011

ATLAS : A Toroidal Lhc ApparatuS



- Two magnet systems: solenoidal (2T) in the inner detector, toroidal in the muon spectrometer (4T peak)



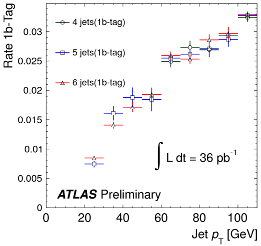
- **Inner Detector** reconstructs charged particle trajectories and measures their momentum.
- **Calorimeters**: The Electromagnetic calorimetry identifies and measures the electrons and photons. The Hadronic calorimeter identifies jets formed by the hadronization of quarks
- **Muon Spectrometer** identifies muon particles and measures their p_T together with the Inner Detector

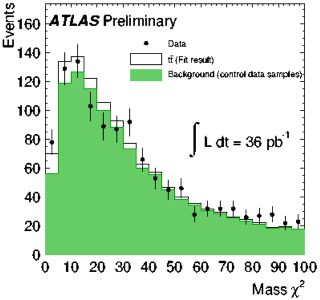
Fully hadronic $t\bar{t}$ cross section: 35 pb^{-1}

- Event selection :
  - Multijet triggers: at least four jets with $|\eta| < 3.2$ and $E_T > 30$ GeV
  - At least four offline jets with $E_T > 60$ GeV
  - 2 b-tag jets
- Backgroud modeling :
  - Data driven background estimation: estimate background in low jet multiplicity region and extrapolate to signal region $\rightarrow$ **tag rate functions**
- Mass χ^2 discrimination variable

$$\chi^2 = \sum_{i=1}^{2} \left(\frac{m_{jjb}^{(i)} - m_t}{\sigma_t}\right)^2 + \left(\frac{m_{jj}^{(i)} - m_W}{\sigma_W}\right)^2$$

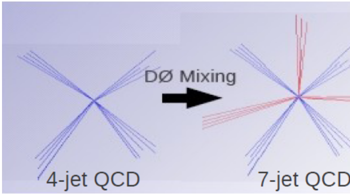
- The final mass χ^2 distribution is fitted with signal and background template
- $\sigma_{t\bar{t}} < \mathbf{26}$ pb @ $\mathbf{95\%}$ **C.L.**



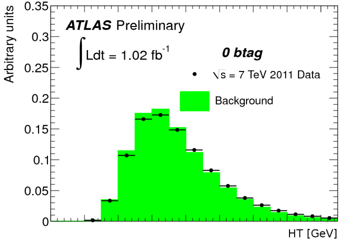


Fully hadronic $t\bar{t}$ cross section: 1.02 fb^{-1}

- Event selection :
  - **At least 5 jets with** $p_T > 55$ **GeV**, 6th with $p_T > 30$ GeV and additional jets only if $p_T > 20$ GeV, within $|\eta| < 4.5$
  - **At least two b-tagged jets** ($p_T > 20$ GeV) are required
  - $\Delta R(b, B) > 1.2$
  - Missing E_T significance $\frac{\mathbf{E_T}}{\sqrt{\mathbf{HT}}} > \mathbf{3}$, H_T is the scalar sum of the transverse momentum of all jets in the event



- Background modeling :
  - **Event Mixing technique** uses a sample with a lower number of jets to model a sample with a large multiplicity: the target multiplicity is made up by adding jets to the initial sample
  - First used in $D\emptyset$
  - The technique is used to **model events with at least 6 jets from events with a jet-multiplicity equal to exactly 4 or 5**
    - The multi-jet QCD background six or more jet sample is modeled by attaching low-pT jets selected from events with 6-jet or more jets to events with 4 or 5 jets



Fully hadronic $t\bar{t}$ cross section: 1.02 fb^{-1}

- A χ^2 based discriminant observable is implemented to extract the $t\bar{t}$ signal from the mutlijet background

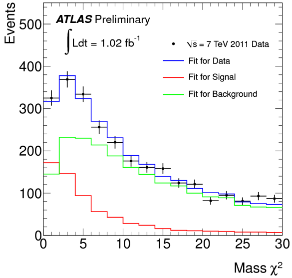
$$\chi^2 = \frac{(M_{j1,j2} - M_W)^2}{\sigma_W^2} + \frac{(M_{j1,j2,b} - M_t)^2}{\sigma_t^2} + \frac{(M_{j3,j4} - M_W)^2}{\sigma_W^2} + \frac{(M_{j3,j4,b} - M_t)^2}{\sigma_t^2}$$

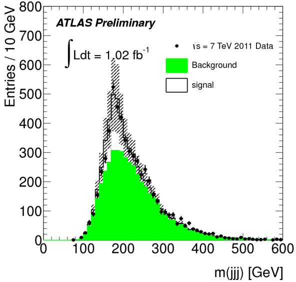
- $t\bar{t}$ signal fraction is extracted from a binned likelihood fit to the data mass χ^2 distribution

$$\sigma_{t\bar{t}} = \mathbf{167 \pm 18(stat.) \pm 78(syst) \pm 6(lumy)}$$

Source of uncert.	Event Mixing (%)
JES	13.7
b-tagging	23.0
ISF/FSR	23.4

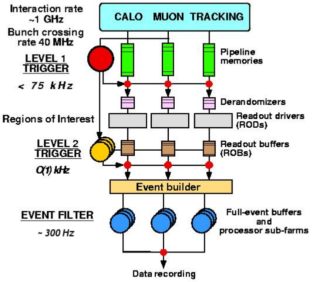
- Top mass recostructed by removing the m_{top} constraint from th χ^2 definition, only constraints the masses of the two triplets to be equal

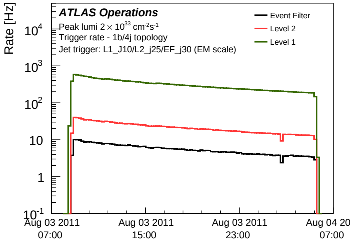




b-jet Trigger

- At the high instantaneous luminosity foreseen for LHC data taking, most multi-jet trigger will be prescaled unless their threshold and jet multiplicity are constantly increased to keep the trigger rate under control
- ATLAS trigger and data acquisition system is based on three levels
  - Trigger levels must provide a rejection to reduce the 40 MHz bunch-crossing rate to an output of about few hundred Hz
- b-tagging at HLT is a possibility for collecting $t\bar{t}$ in the full hadronic final state with an acceptable data taking rate
  - ATLAS has put in place a combination of multijet and b-jet trigger to efficiency select events with final states containing several b-jets
  - b-jet trigger for hadronic top requires four **EF-jets with $E_T > 30$ GeV at EM scale and 1 b-jet with $E_T > 10$ GeV at EM scale and tight instance for the b-tagging** criteria
  - Signal efficiency is $\sim 40.4\%$





Conclusion

- Top physics is important for several reasons:
  - Standard model test: cross section, branching ratio, polarization
  - Search of new physics: Z' resonances, K-K gluons, fouth generation,etc
  - Detector calibration: pure samples of e, μ, b-jets
- First fully hadronic $t\bar{t}$ cross section measurement in 2010 :
  - upper limit $\sigma_{t\bar{t}} > 261$ pb@95% C.L
- Fully hadronic $t\bar{t}$ cross section measurement in 2011 :
  - performed using $L = 1.02$ fb^{-1}
  - $\sigma_{t\bar{t}} = 167 \pm 18(stat.) \pm 78(syst) \pm 6(lumy)$ with 1fb^{-1}
  - result dominated by the systematic uncertainty
- Plans for 2012 :
  - Analysis using all data collected in 2011: $L = 5$fb^{-1}
    - Different background estimation techinque to predict shape and normalization
    - New kinamatical variables to discriminate the signal and background
    - Kinematical Likehood Fitter : uses the known $t\bar{t}$ decay topology in order to properly assign the jets to the decay products
    - Profile Likehood Fit to reduce the systematic uncertanties
    - quark/gluon-tagging to decrease the QCD background
  - Analysis the data collected with b-jet trigger
  - Search for new physics: Z' resonances