Top Physics at Atlas

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INFN
Istituto Nazionale di Fisica Nucleare

ATLAS EXPERIMENT

Top Quark physics

- Why?
  - Precise tests of the Standard Model and verification of pQCD
  - Yukawa coupling with the Higgs ~1→Important role in the EWSB breaking
  - Privileged window to search for new physics
- Top quark studies in ATLAS presented in this talk
  - Top pair cross section
  - Top pair differential cross section
  - Single top cross section
  - Top-quark mass measurement

← Production mechanisms

← Intrinsic property

- Other top analyses in ATLAS
  - Spin correlation **Phys. Rev. Lett. 108, 212001 (2012)**
  - W helicity **JHEP 1206 (2012) 088**
  - Top pair associated with heavy flavor **arXiv:1304.6386**
  - Heavy resonances decaying in top-antitop (<u>see talk by F. Fassi</u>)
  - FNCN in top decays **JHEP 1209 (2012) 139**
  - Top pair charge asymmetry **Eur.Phys.J. C72 (2012) 2039**

Cross section measurements

$\sigma_{t\bar{t}}$:

- allows a direct measurement of α_s
- can put constraints on SM parameters
- current statistics allow the study of differential spectra

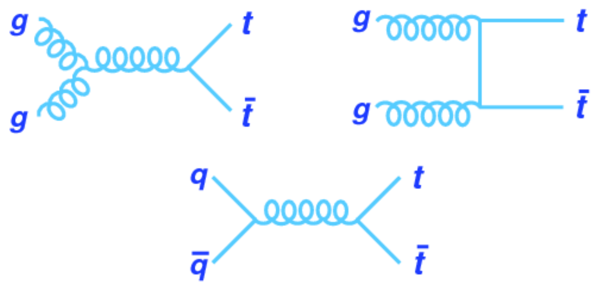
σ_t:

- Sensintive to electroweak physics involving Wtb vertex
- Sensitive to the pdf of the valence quarks

Top pair production

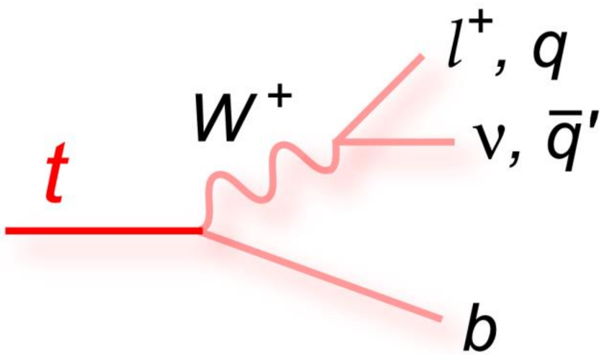
Production mechanisms at LHC

- Gluon-gluon fusion (~85%)
- Quark-antiquark annihilation



Decays

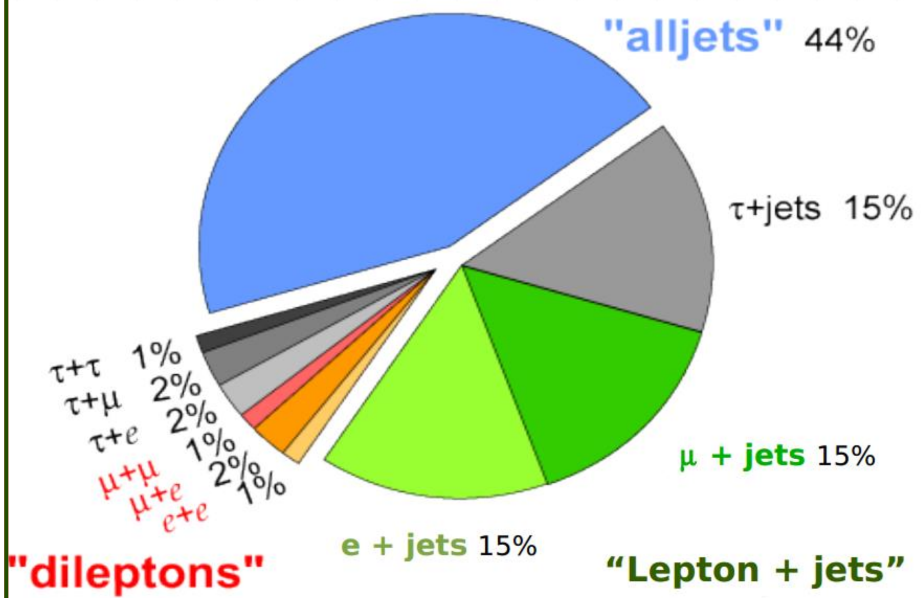
- $t \to Wb(\sim 100\%)$



$W \to l\nu_l \sim 33\%$

$W \to q\overline{q'} \sim 66\%$

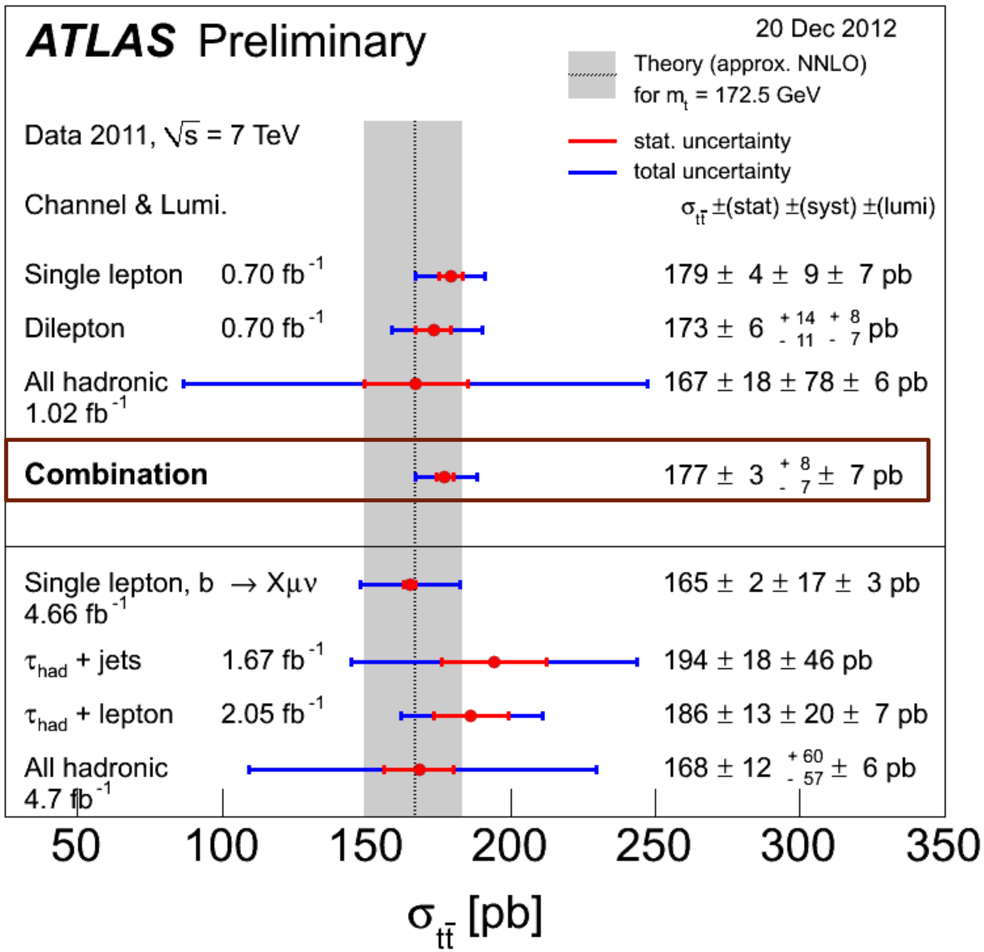
Top pair final states



Top pair cross section @ 7 TeV

Cross section summary at 7 TeV

ATLAS-CONF-2012-024



The measurements share several common sources of systematic uncertainty

A likelihood is defined for each channel

The full combination is implemented as a product of the individual likelihoods

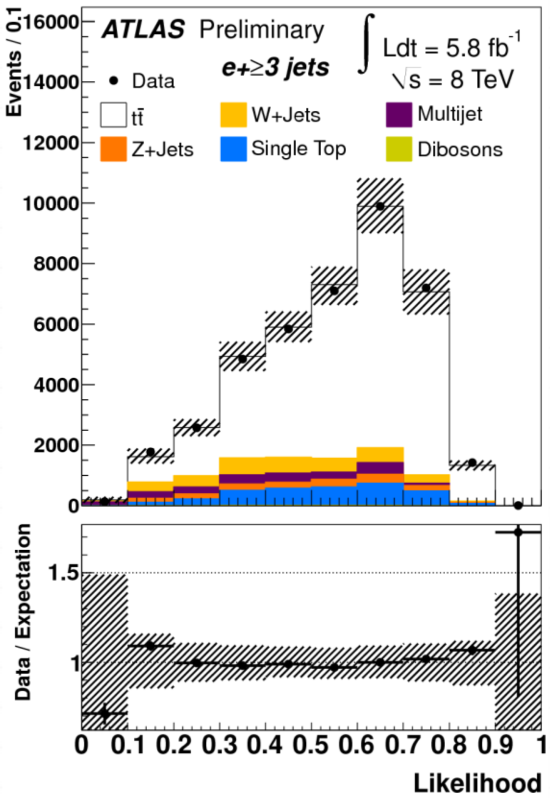
The achieved precision is already better than the uncertainties on the aNNLO predictions

Top pair cross section @ 8 TeV

ATLAS-CONF-2012-149

$\sqrt{s} = 8$ **TeV,** $\int Ldt = 5.8\ \mathrm{fb}^{-1}$

- Lepton+jets channel
  - Cut-based event selection (3 jets, 1 lepton and E_T^{miss})
- Template fit method
- Likelihood discriminant D based on 2 variables
  - η_{lep} and $A' = e^{-8A}$, A being the aplanarity
  - Evaluated from simulations of the signal and the W+jets background
- $\sigma_{t\bar{t}}$ is measured through a max-likelihood fit of the D in data and the templates from MC



$$\boldsymbol{\sigma_{t\bar{t}}(\sqrt{s} = 8\ \mathrm{TeV}) = 241 \pm 2(stat) \pm 31(syst) \pm 9(lumi)\ \mathrm{pb}}$$

$$\sigma_{t\bar{t}}^{aNNLO} = 238^{+22}_{-24}\ \mathrm{pb}$$

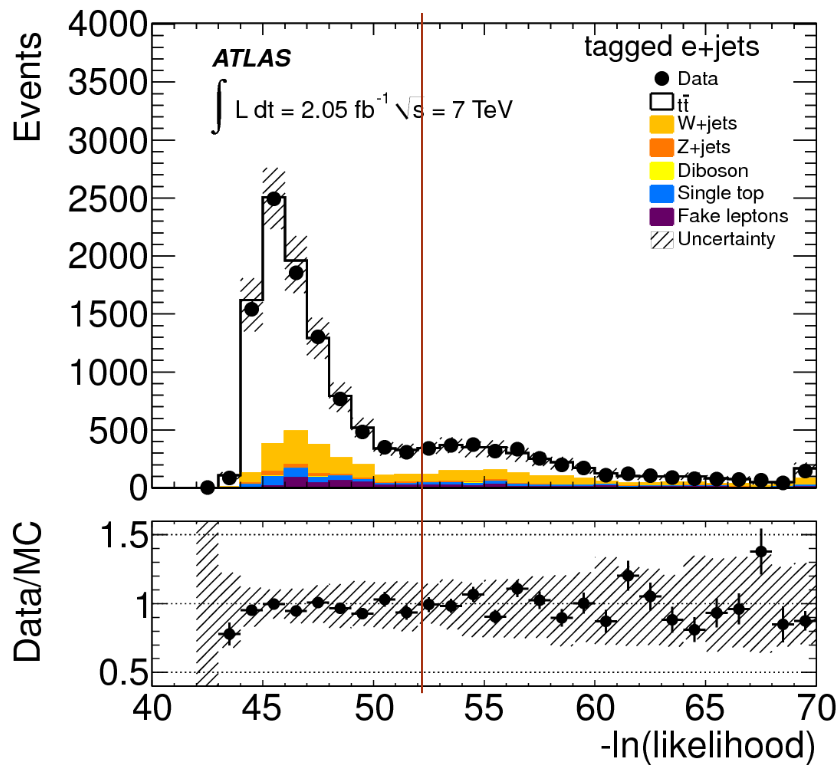
- Main systematics:
  - JES
  - Signal modeling (Hard scattering/IFSR/PDF)

Top pair differential cross section

Eur. Phys. J. C (2013) 73, 2261

$\sqrt{s} = 7\text{ TeV}, \int Ldt = 2.05\text{ fb}^{-1}$

- Total $\sigma_{t\bar{t}}$ measurements show very good agreement with the SM
  - New physics phenomena can still affect the *shape* of $\sigma_{t\bar{t}}$
- Top-antitop relative differential cross section $\left(\frac{1}{\sigma}\frac{d\sigma}{dX}\right)$ where $X = m_{t\bar{t}}, p_{\mathrm{T},t\bar{t}}$ and $Y_{t\bar{t}}$
  - *Relative* measurement more precise than the *absolute* →cancellation of correlated systematics
- Cut-based analysis in the l+jets channel
- $t\bar{t}$ system reconstructed via a kinematic likelihood fit.
  - Input: lepton and jets 4-momenta, E_T^{miss} and b-tag info
  - Fixed parameters: W and top masses and decays amplitudes
  - A cut on $\ln(L)$ is applied →improvement in the truth-reco correlation



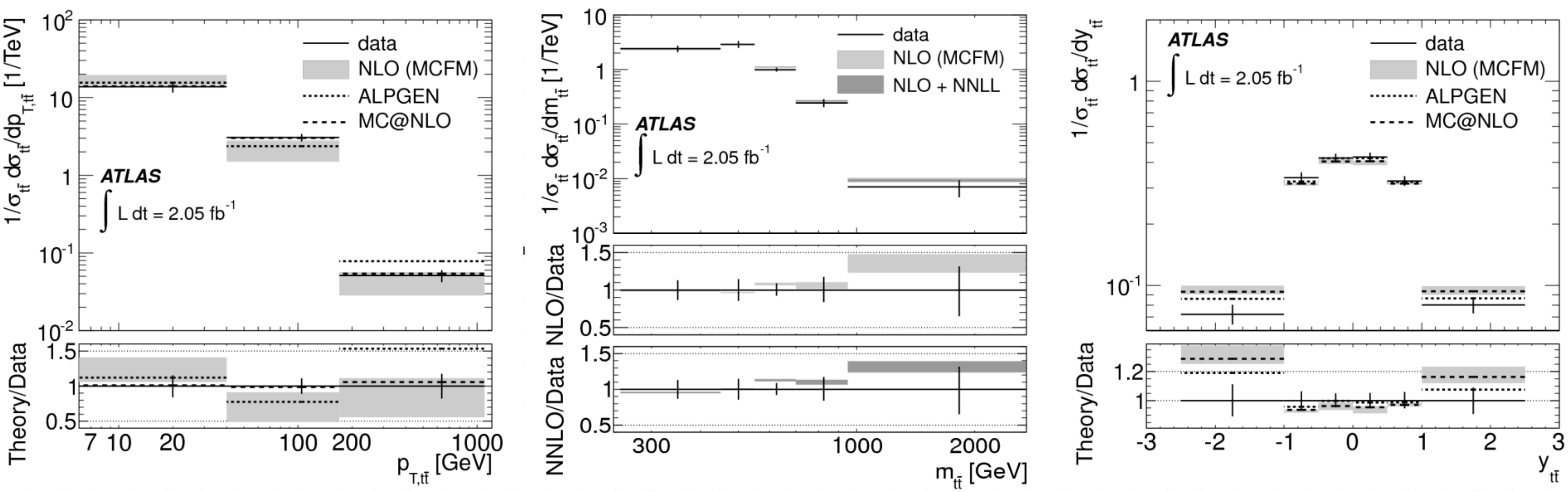
Top pair differential cross section

Eur. Phys. J. C (2013) 73, 2261

$\sqrt{s} = 7\ \text{TeV}, \int Ldt = 4.7\ \text{fb}^{-1}$

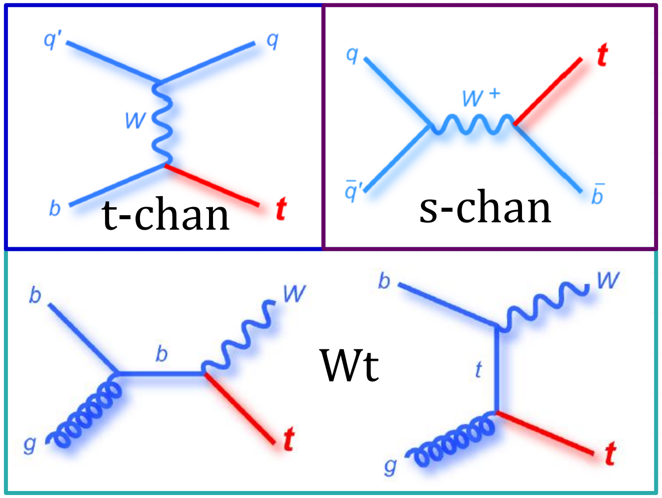
Reconstructed spectra → *Unfolding* → Parton level cross section

Simple matrix inversion

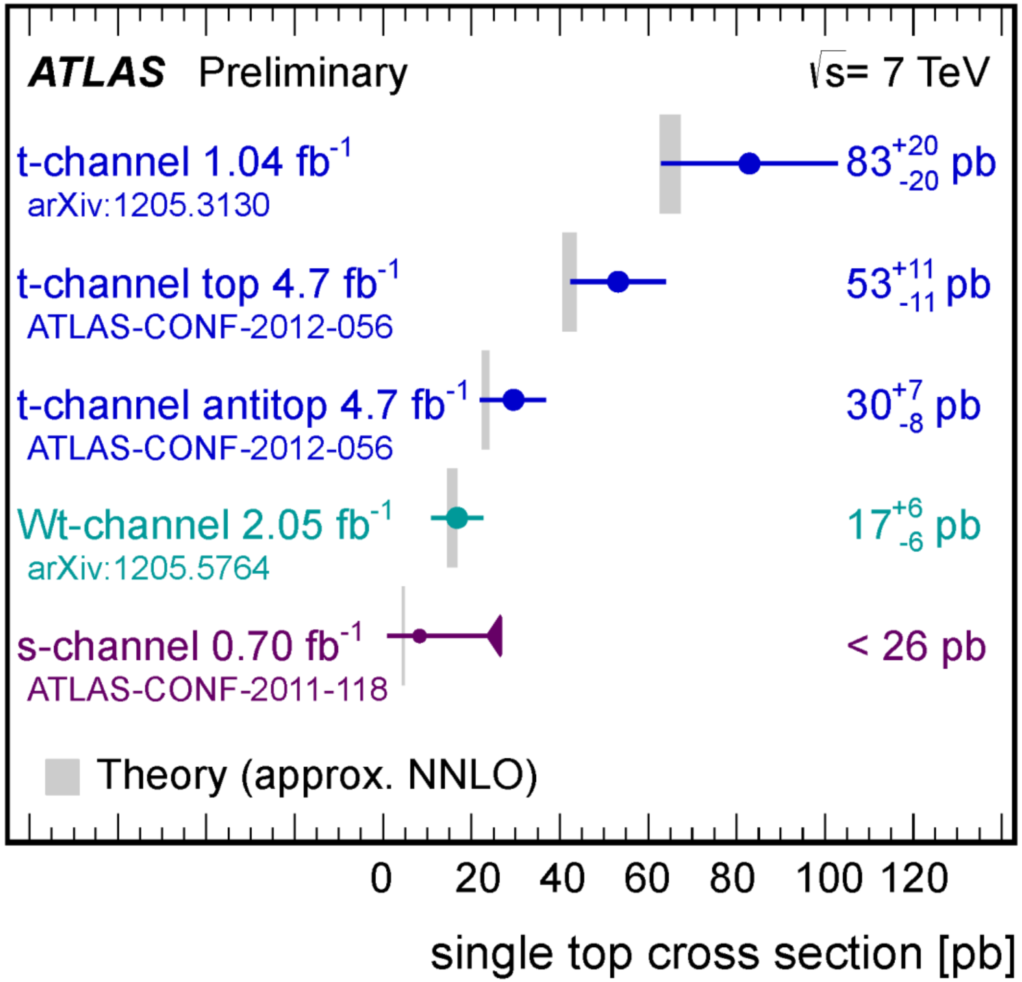


No significant deviations from the SM predictions are observed

Single top cross section



Cross section summary at 7 TeV



Measurements at 7 TeV:

- Cross section for all channels
  - *Wt* measured for the first time (3.3 σ level)
  - Upper limit for the s-channel
- Single top/antitop t-channel ratio

Measurements at 8 TeV:

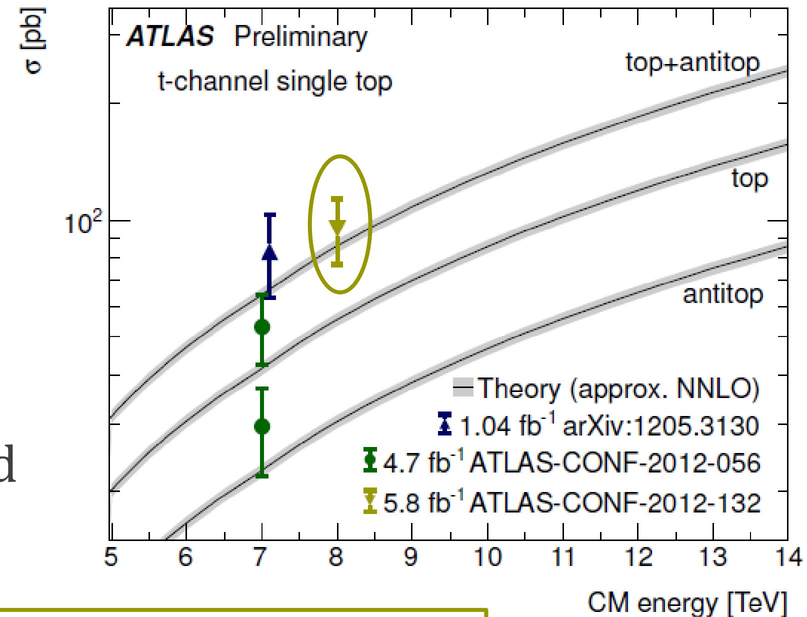
- Cross section in t-channel

Single top t-channel cross section (8 TeV)

ATLAS-CONF-2012-132

$\sqrt{s} = 8$ TeV, $\int Ldt = 5.8$ fb^{-1}

- A multivariate Neural Network (NN) discriminant trained with the most-sensitive variables
  - Two exclusive samples used: 2 jets and 3 jets
  - Contributions from signal and background evaluated via simulations
- Lepton + 2(3) jets channel, 1-btag
- $\boldsymbol{\sigma_{t-chan}}$ extracted via a maximum-likelihood fit of the NN output in the data



$$\boxed{\boldsymbol{\sigma_{t-chan}(\sqrt{s} = 8\ \mathrm{TeV}) = 95 \pm 2(stat) \pm 18(syst) \pm 3(lumi)\ \mathrm{pb}}}$$

$$\sigma_{t-chan}^{aNNLO}(\sqrt{s} = 8\ \mathrm{TeV}) = 87.8^{+3.4}_{-1.9}\ \mathrm{pb}$$

- Dominating uncertainties: JES, b-tag efficiency and $t\bar{t}$ normalization

Top mass measurements

- Free parameter in the SM
  - High mass → strong coupling ($\lambda \approx 1$) with the Higgs field
- Top quark decays before hadronizations

  →Unique possibility to measure the mass of a 'bare' quark

Top quark mass

Most precise measurement in ATLAS

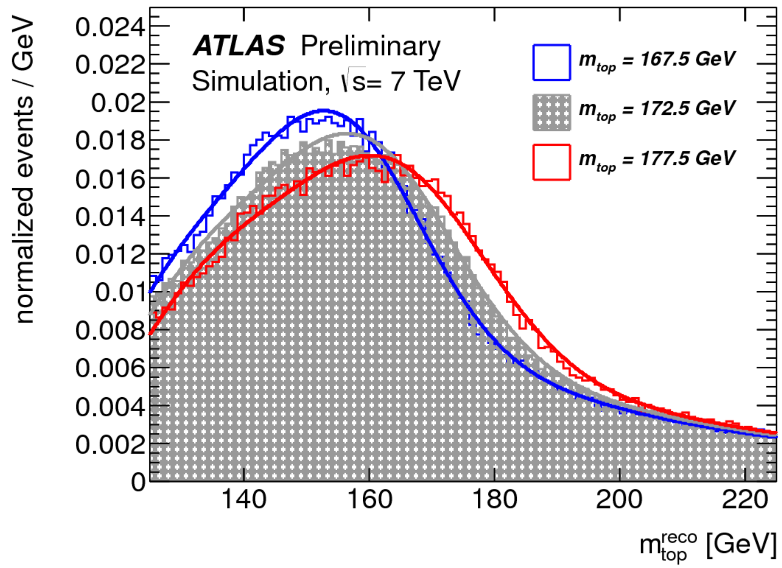
ATLAS-CONF-2013-046

$\sqrt{s} = 7\text{ TeV}, \int Ldt = 4.7\text{ fb}^{-1}$

- *3D template fit* in the lepton+jets channel
- Parameters: m_t, global jet energy scale factor (JSF) and bJet energy scale factor (bJSF)
- Simulated distributions: $m_{t,reco}$, $m_{W,reco}$ and R_{lb}^{reco}(ratio of the sum of the p_T of the bjets from the top and light jets from the W)
  - Templates built by varying the fit parameters in Monte Carlo

☑= linear dependency for signal and bg
✓= linear dependency for signal only

	m_t	JSF	bJSF
$m_{t,reco}$	✓	☑	☑
$m_{W,reco}$		☑	
R_{lb}^{reco}	✓		☑



- Probability density functions for each parameter evaluated by fitting each template distribution

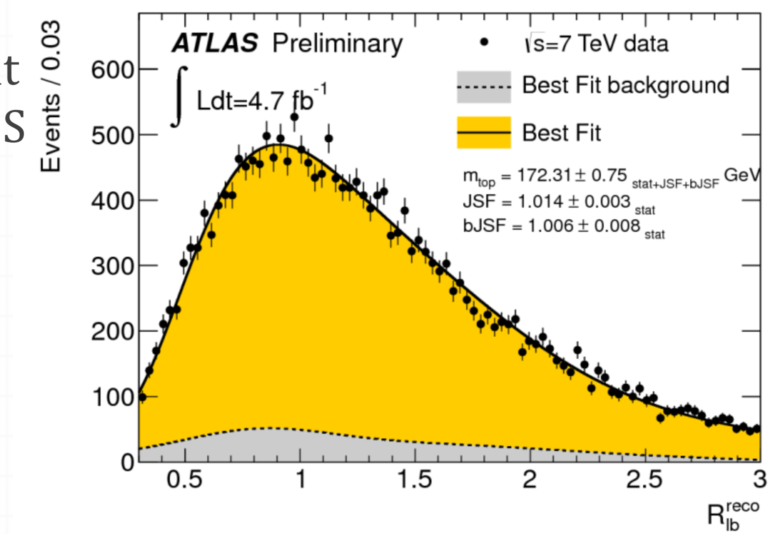
Top quark mass

- Lepton+jets channel
- $t\bar{t}$ kinematics reconstructed by a fit maximizing an event likelihood→ $m_{t,reco}$, $m_{W,reco}$ and R_{lb}^{reco}
  - m_t is not fixed in the fit
- Signal and background PDFs are used in an unbinned likelihood fit to the data for all events:

$$L(m_{t,reco}, m_{W,reco}, R_{lb}^{reco} | m_t, JSF, bJSF, n_{bkg})$$

- Results in the 1 btag and 2btag samples are in good agreement
- First time implementation of an m_t measurement with simultaneous constraint on m_t, JES and bJES
  - Systematic uncertainties reduced by 40% (at the cost of small contributions to the total stat error)

$$\boxed{\boldsymbol{m_t = 172.31 \pm 0.75(\mathrm{stat} + \mathrm{JSF} + \mathrm{bJSF}) \pm 1.35(\mathrm{syst})\ \mathrm{GeV}}}$$



Top quark mass

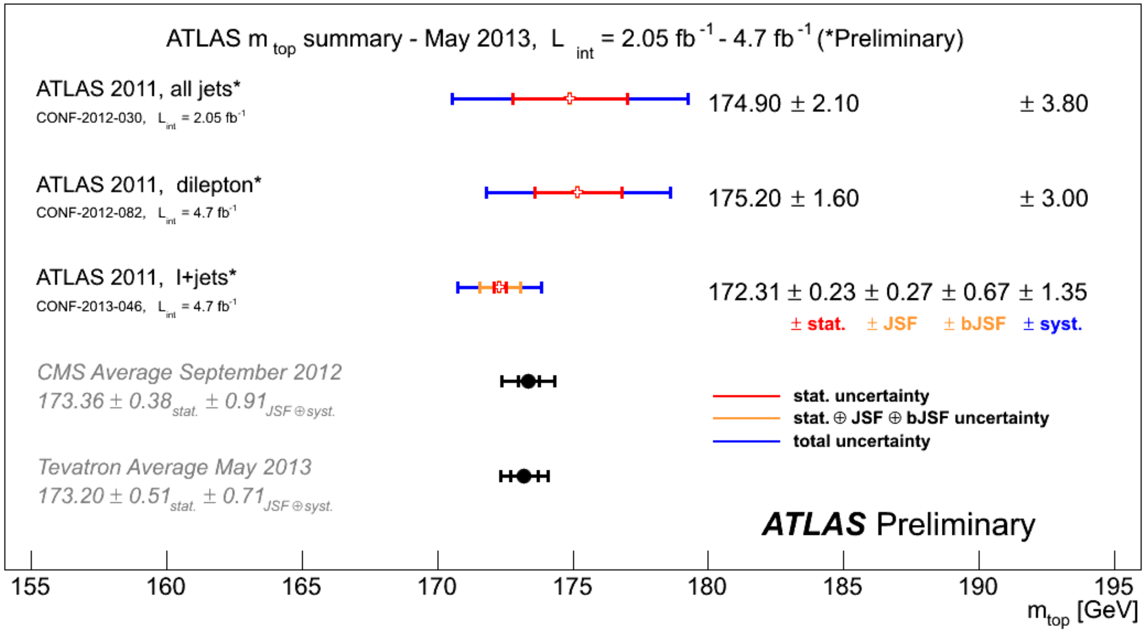
Top mass summary

Most precise measurement by ATLAS:

$m_t = 172.31 \pm 0.75 \pm 1.35$ GeV

ATLAS-CONF-2013-046

l+jets channel, $\int L dt$ =4.7fb^{-1}



Precision on m_t measurement at LHC is constantly improving and getting closer to the precision achieved at Tevatron

Summary

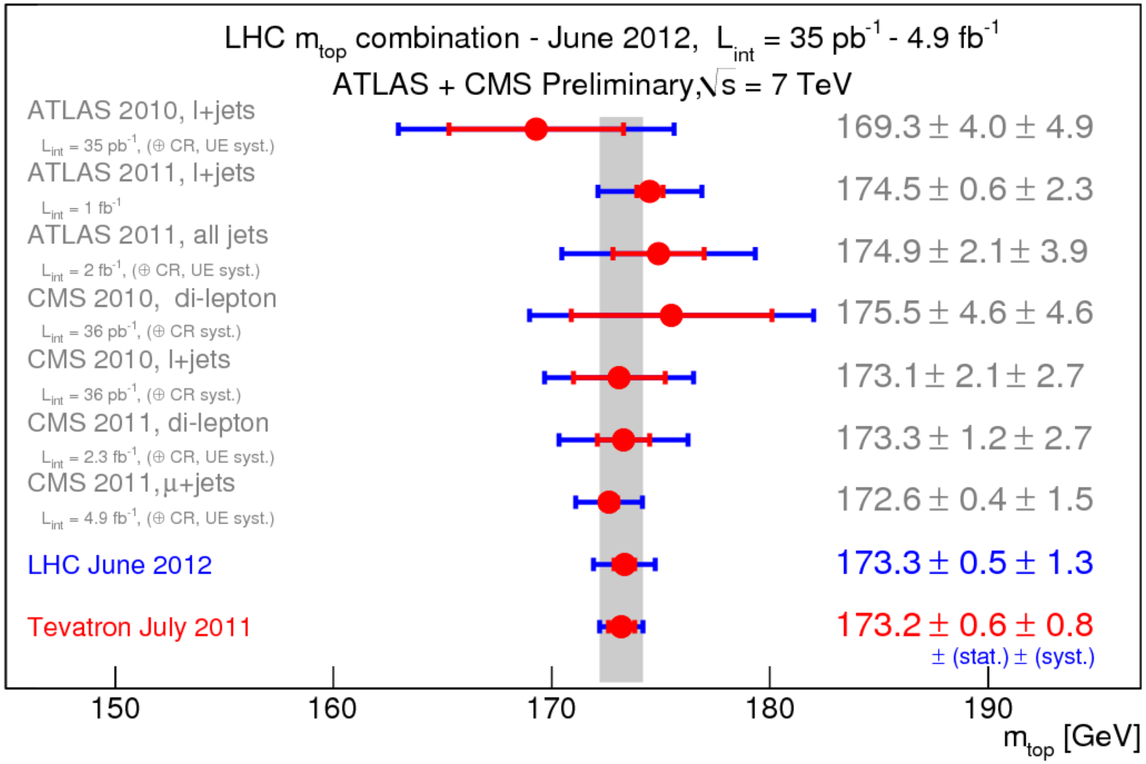
- Physics of the top quark can answer fundamental questions.
- So far all results agree with SM predictions
  - Most of the measurements are limited by systematics.
- Top analyses in ATLAS presented in this talk
  - Top pair cross section
  - Single top cross section
  - Top pair differential cross section
  - Top-quark mass measurement
  - Additional results can be found at the ATLAS public page https://twiki.cern.ch/twiki/bin/view/AtlasPublic/
- Stay tuned for more results with data collected in 2012 at 8 TeV, as well as for more refined studies at 7 TeV

BACKUP SLIDES

ATLAS & CMS top mass combination

ATLAS-CONF-2012-095 and CMS-PAS-TOP-12-001

$\sqrt{s} = 7$ TeV, $\int Ldt \leq 4.9$ fb^{-1}



Statistical combination performed using the Best Linear Unbiased Estimator (BLUE) method

LHC measurement suffer of greater systematic uncertainty respect to the result from Tevatron

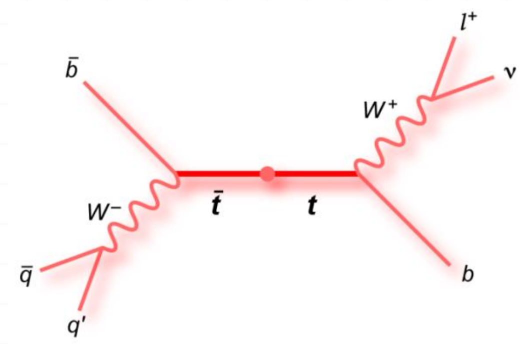
Common object definitions

- Details can vary among the different analyses
- Jets:
  - Reconstructed from topological clusters using the anti-kt algorithm ($R = 0.4$)
  - p_{T}> 25 GeV, $|\eta|$ <2.5
- B-tagging via a Neural network based algorithm (MV1) with average efficiency of 70% and light jet rejection factor $\sim$140
- Electrons:
  - EM cluster with track matched
  - Isolation in tracker and calorimeter
  - E_{T} > 25 GeV, $|\eta|$<1.37 or 1.52 < $|\eta|$ <2.47
- Muons:
  - Tracks in inner detector and muon spectrometer
  - Isolation in tracker and calorimeter
  - $p_{\mathrm{T}} >$ 20 GeV, $|\eta|$ <2.5
- Missing transverse energy
  - Vector sum of energy deposits in calorimeters, with corrections based on the associated reconstructed object

Reconstruction of the tt system via kinematic likelihood fit

- The tt system reconstruction is performed trough a kinematic fit using a maximum likelihood approach

$$
\begin{aligned}
\mathcal{L} \;=\; & \mathcal{B}\left(\widetilde{E}_{p,1}, \widetilde{E}_{p,2} | m_W, \Gamma_W\right) \cdot \mathcal{B}\left(\widetilde{E}_{l}, \widetilde{E}_{\nu} | m_W, \Gamma_W\right) \cdot \\
\cdot\; & \mathcal{B}\left(\widetilde{E}_{p,1}, \widetilde{E}_{p,2}, \widetilde{E}_{p,3} | m_t, \Gamma_t\right) \cdot \mathcal{B}\left(\widetilde{E}_{l}, \widetilde{E}_{\nu}, \widetilde{E}_{p,4} | m_t, \Gamma_t\right) \cdot \\
\cdot\; & \mathcal{W}\left(\widehat{E}_x^{miss} | \tilde{p}_{x,\nu}\right) \cdot \mathcal{W}\left(\widehat{E}_y^{miss} | \tilde{p}_{y,\nu}\right) \cdot \mathcal{W}\left(\widehat{E}_{lep} | \widetilde{E}_{lep}\right) \cdot \\
\cdot\; & \prod_{i=1}^{4} \mathcal{W}\left(\widehat{E}_{jet,i} | \widetilde{E}_{p,i}\right) \cdot P\left(b \text{ tag} \mid \text{quark}\right),
\end{aligned}
$$



- The likelihood assesses the compatibility of the event with a typical ttbar pair
- The algorithm is fed with the 4 or 5 reconstructed highest-pt jets (and their b-tag info), the lepton and the E_T^{miss}
- The output is the permutation of the four jets, lepton and E_T^{miss} that maximizes the likelihood

From the detector-level spectra to the cross section measurement

The ‘detector-level’ spectra are linked to the ‘parton level’cross section σ_j via

$$N_i = \sum_j M_{ij} \epsilon_j \sigma_j \beta L + B_i$$

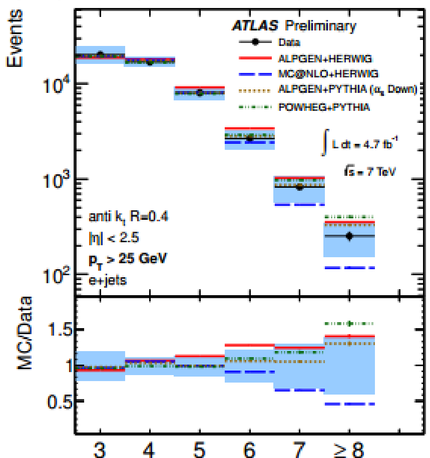
Where

- N_i is the number of observed data events in the bin j.
- L is the luminosity
- B_i is the number of background events in the bin i.
- β is the branching ratio
- M_{ij} is the ‘migration matrix’
- ϵ_j is the efficiency of the selection

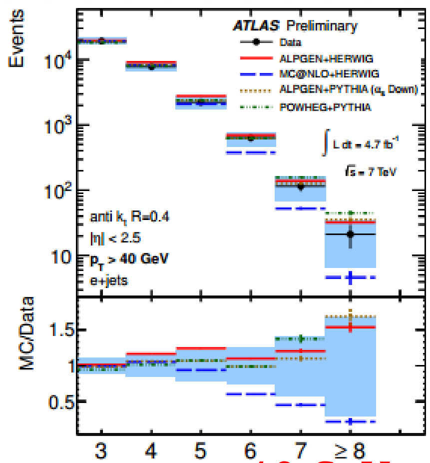
Jet multiplicity in top–anti-top final states

- Useful to constrain models of initial and final state radiation (ISR/FSR)
- Provides a test of perturbative QCD
- Single-lepton channel
  - Four jet p_T thresholds: (25, 40, 60, and 80 GeV)
- Results are corrected for all detector effects through unfolding
  - Reconstructed level → particle level
- Measurement is limited by systematic uncertainties,
  - background modelling (at lower jet multiplicities)
  - jet energy scale (at higher jet multiplicities)

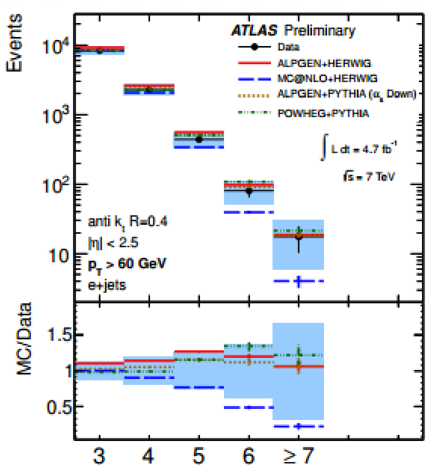
Jet multiplicity in top–anti-top final states



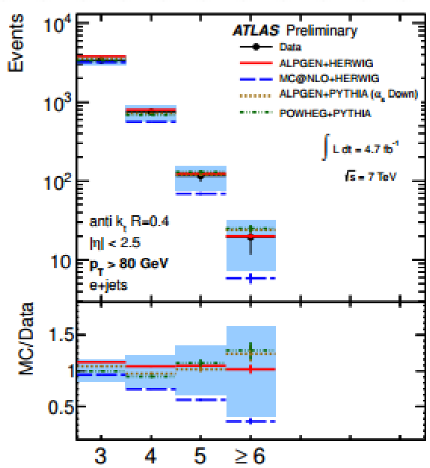
$p_T > 25$ GeV



$p_T > 40$ GeV



$p_T > 60$ GeV



$p_T > 80$ GeV

- MC@NLO modelling predicts a lower jet multiplicity spectrum and softer jets
- Predictions from ALPGEN + HERWIG or PYTHIA and POWHEG + PYTHIA are consistent with the data

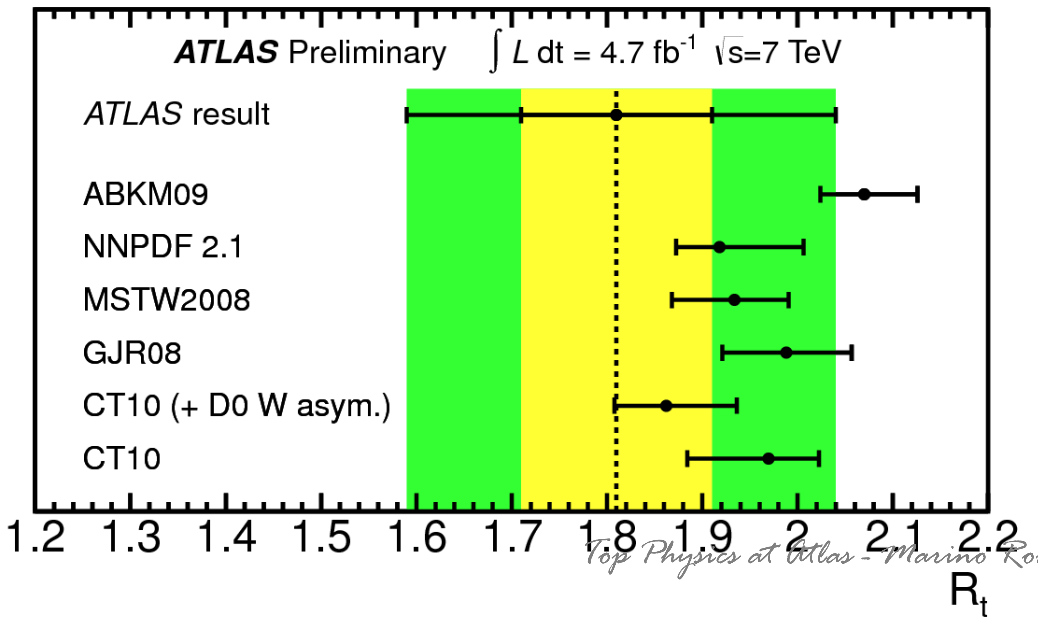
Single top/antitop t-chan ratio

$$R_t = \frac{\sigma_{ub\to td}}{\sigma_{d\bar{b}\to\bar{t}d}}$$

ATLAS-CONF-2012-056

$\sqrt{s} = 7$ TeV, $\int Ldt = 4.7$ fb^{-1}

- Very sensitive to the ratio of the PDF of the valence quark in the high *x* regime
  - Smaller uncertainties because of error cancelations
- Sensitive to new physics effects
- Same analysis technique used in the σ_{tchan} measurement

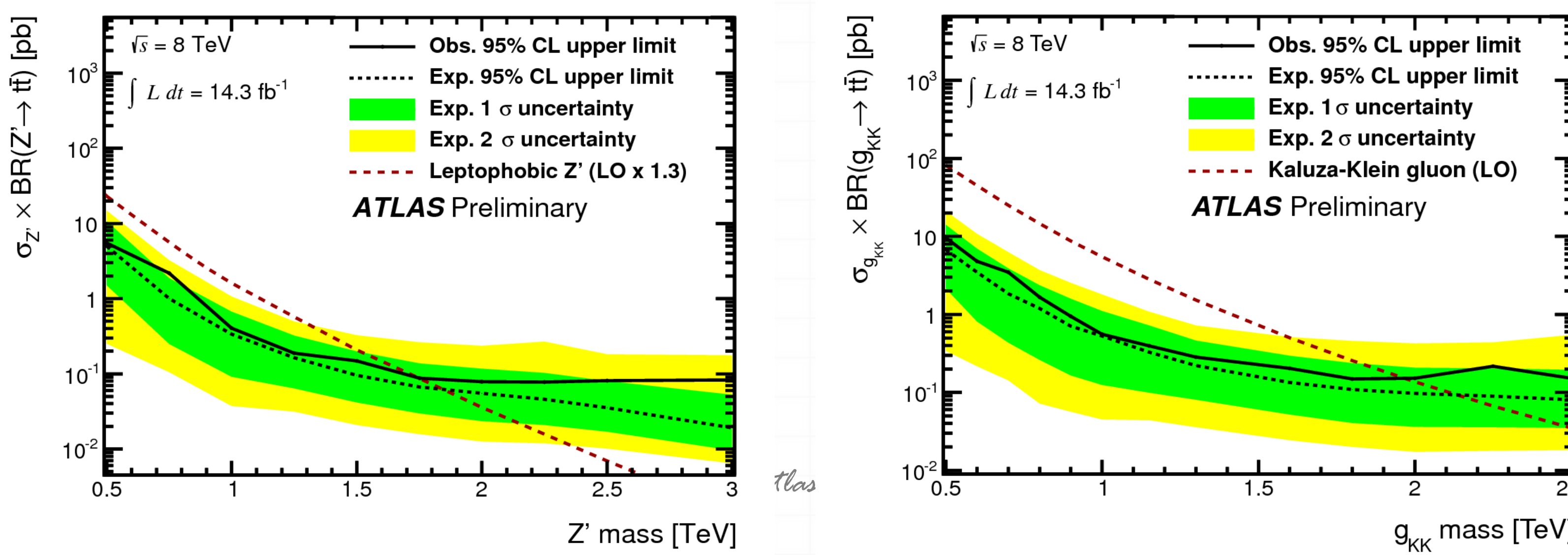


The measurement is in agreement with the predictions from different PDF sets and is dominated by systematic uncertainties

$t\bar{t}$ resonances

- $t\bar{t}$ resonances searches @ 7 TeV have been performed in the lepton+jets and full hadronic channels (**arXiv:1305.2756**)
- First measurement @ 8 TeV in the lepton+jets channel
  - Exploits both traditional 'resolved' jet analysis and a large-radius jet substructure analysis
- No significant deviation from the prediction
- Upper cross section limits are given for two benchmark models
  - 95% C.L. exclusion regions: Leptophobic Z' [0.5, 1.8] TeV; KK gluon [0.5, 2] TeV

ATLAS-CONF-2013-052 $\sqrt{s} = 8$ TeV, $\int L dt = 5.8$ fb^{-1}



Reconstruction of the tt system in the resonances searches

- 'Small' radius jet: anti-kt, $R = 0.4, p_{\mathrm{T}} > 25$ GeV, $|\eta| < 2.5$
- 'Large' radius jet: anti-kt, $R = 1.0$ $p_{\mathrm{T}} > 300$ GeV, $|\eta| < 2.0$
- 'Resolved' technique
  - χ^2 algorithm is used to select the best assignment of jets to the hadronically and semileptonically decaying top quarks
  - Neutrino built from the missing transverse energy (p_Z assigned using the W mass constraint
- 'Large jet substructure' technique
  - 'Large' jet tagged as the hadronic top
  - Leptonic top built from the lepton and the neutrino (leptonic W) and the remaining small radius jet