Top Quark physics results from LHC

Luca Fiorini
Luca.Fiorini@cern.ch
(IFIC - U. of Valencia)
on behalf of ATLAS and CMS collaborations

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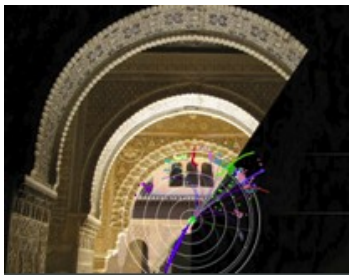
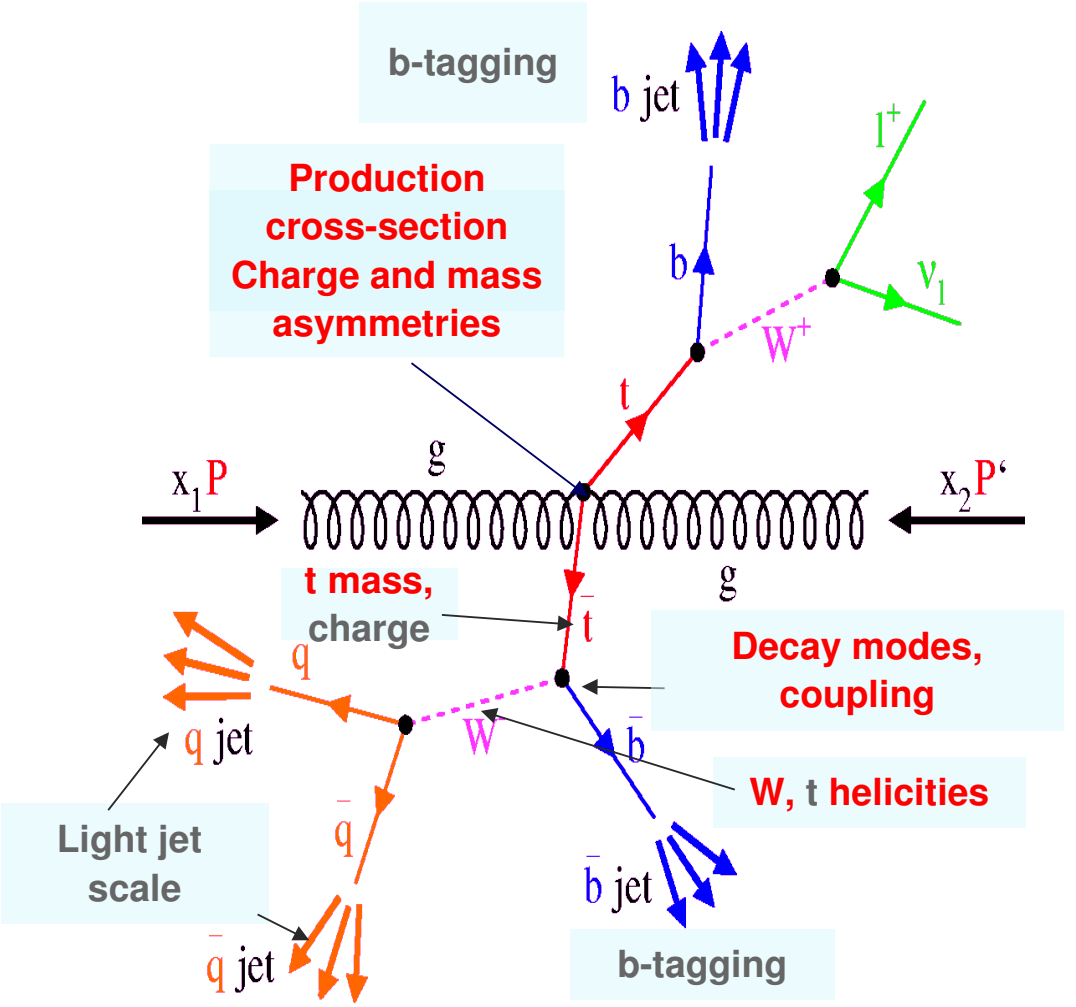


Outline

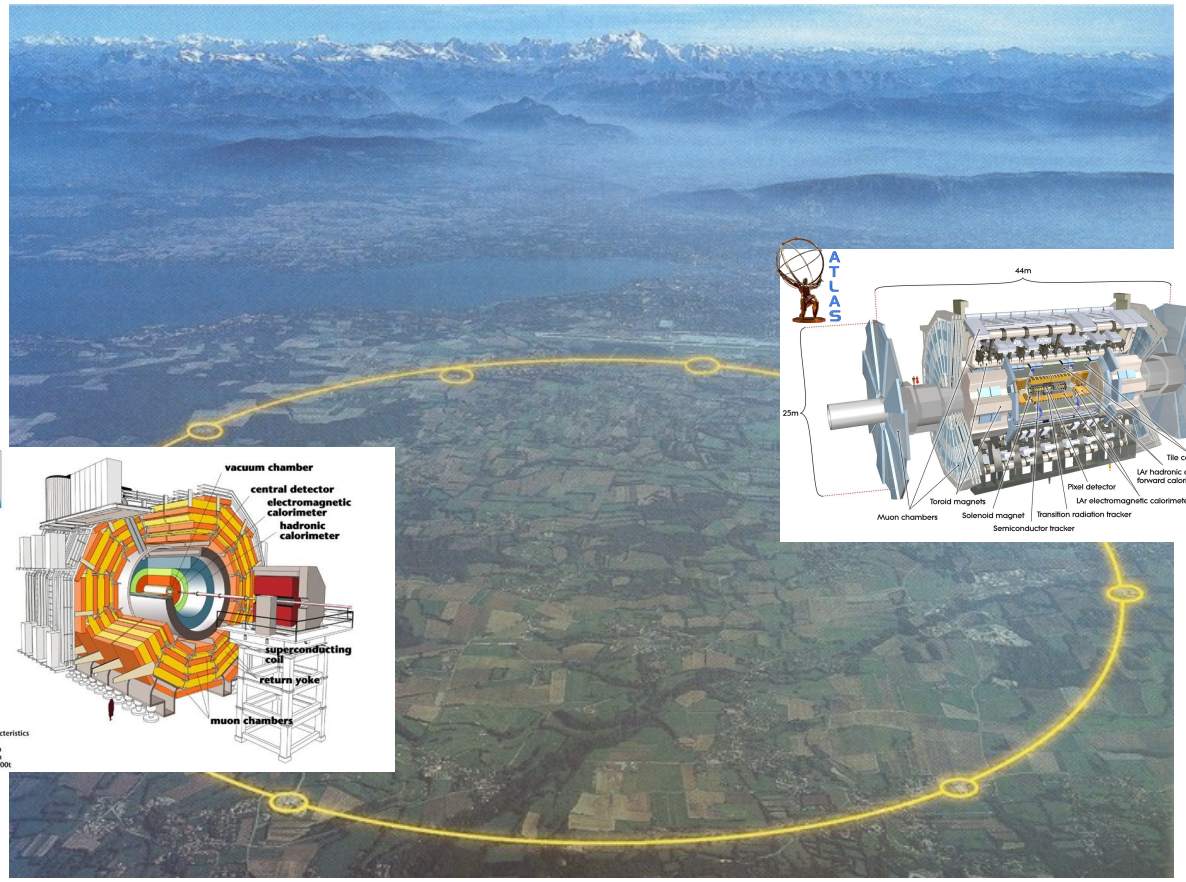
Top Physics in this talk:

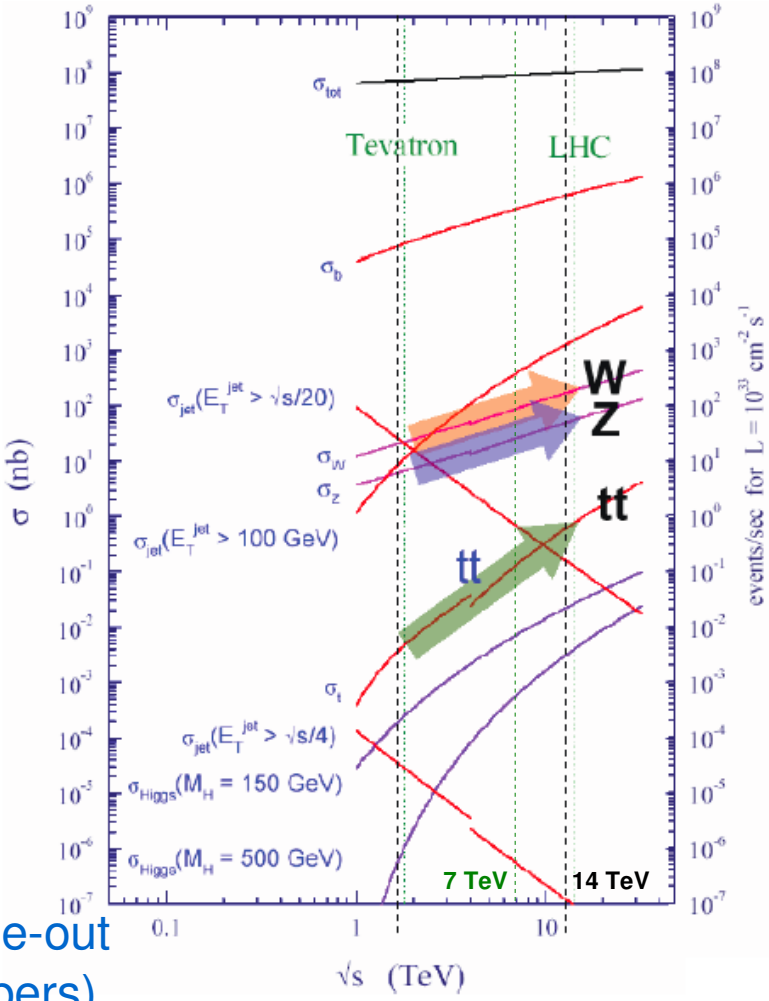
- Cross-section measurement
  - top pair production
  - single top production

- Top Quark Properties and New physics in the top sector:
  - Top Mass
  - Mass Asymmetry
  - Charge Asymmetry
  - Top Quarks Spin correlation
  - W polarization and anomalous coupling
  - FCNC search : $t \rightarrow qX$ ($X=\gamma,Z,g$)
  - Anomalous E_T^{Miss} in ttbar production
  - ttbar Resonances (Z', g_{KK})



LHC top quark physics





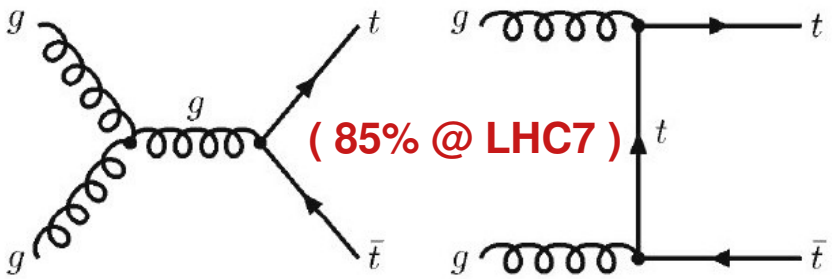
Both are general purpose detectors, with similar inside-out design (Si detector, EM+HAD calorimeters, Muon chambers), but with different particle detection technology.

Better S/B for Top quark production at LHC than TeVatron compared to other QCD processes and W/Z+jets production.

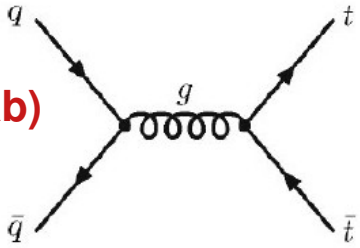
top quark production measurement

Moch, Uwer, Langenfeld, Kinodakis, Ahrens et al.

LHC: Gluonic production dominates



(85% @ LHC7)



(90% @ FermiLab)

$\sigma(t\bar{t}\ 1.96\ \text{TeV})^{\text{approx NNLO}} = 7.5 \pm 0.5$ pb

$\sigma(t\bar{t}\ 7\ \text{TeV})^{\text{approx NNLO}} = 165\ ^{+11}_{-16}$ pb

$\sigma(t\bar{t}\ 14\text{TeV})^{\text{approx NNLO}} = 874\ ^{+14}_{-33}$ pb

$\Rightarrow$ ***1 tt/sec @ L=5•10 ^{33} cm^{-2} s^{-1}*** *(LHC7)*

Cross section LHC ~ 20 x Tevatron

Background LHC ~ 8 x Tevatron

Use of b-tagging is not strictly essential to establish ttbar signal at LHC

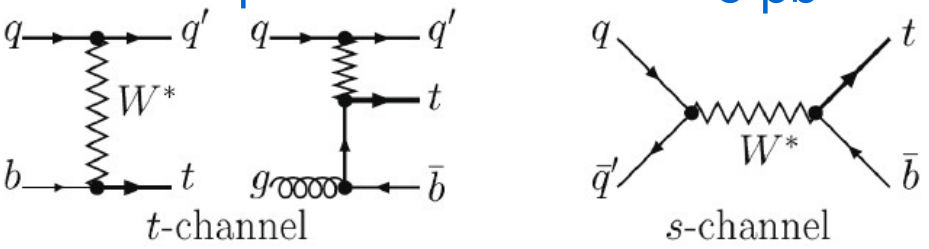
Kinodakis et al.

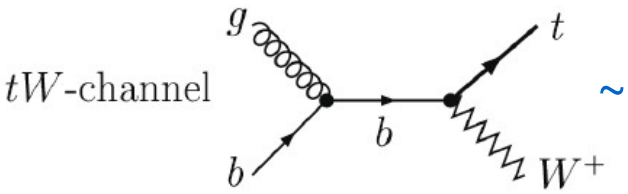
LHC Single top production

$\sigma(t, 7\ \text{TeV}) \cong 84$ pb

dominated by t-channel

~65 pb **@ LHC7** ~5 pb



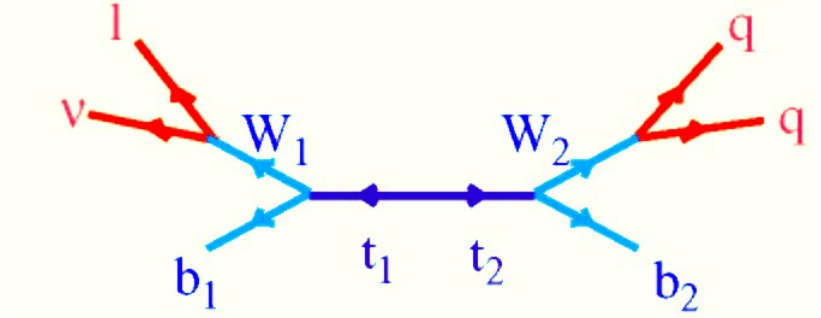


~16 pb

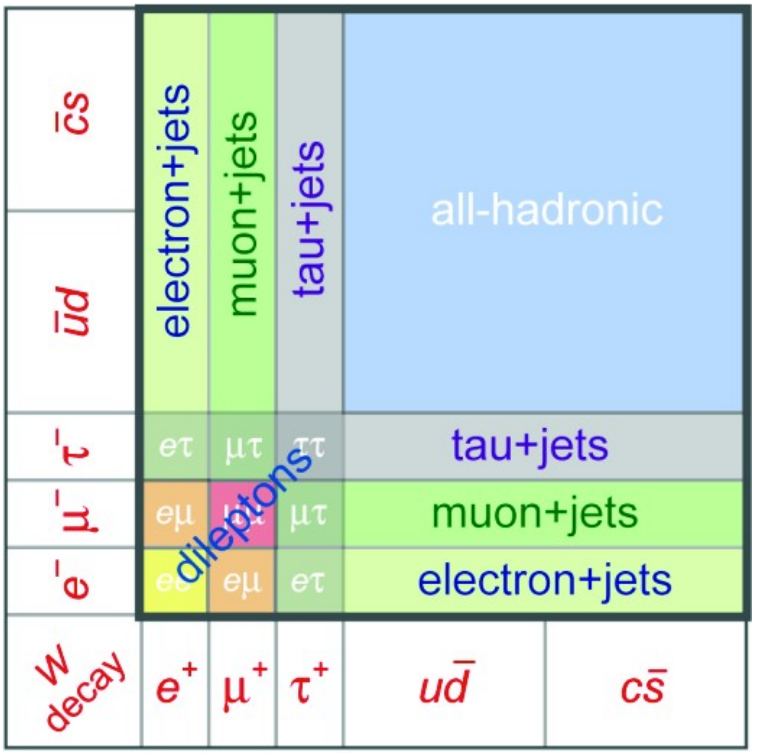
LHC7 = LHC @ sqrt(s)=7TeV

top quark production measurement

ttbar final states for the cross section measurement



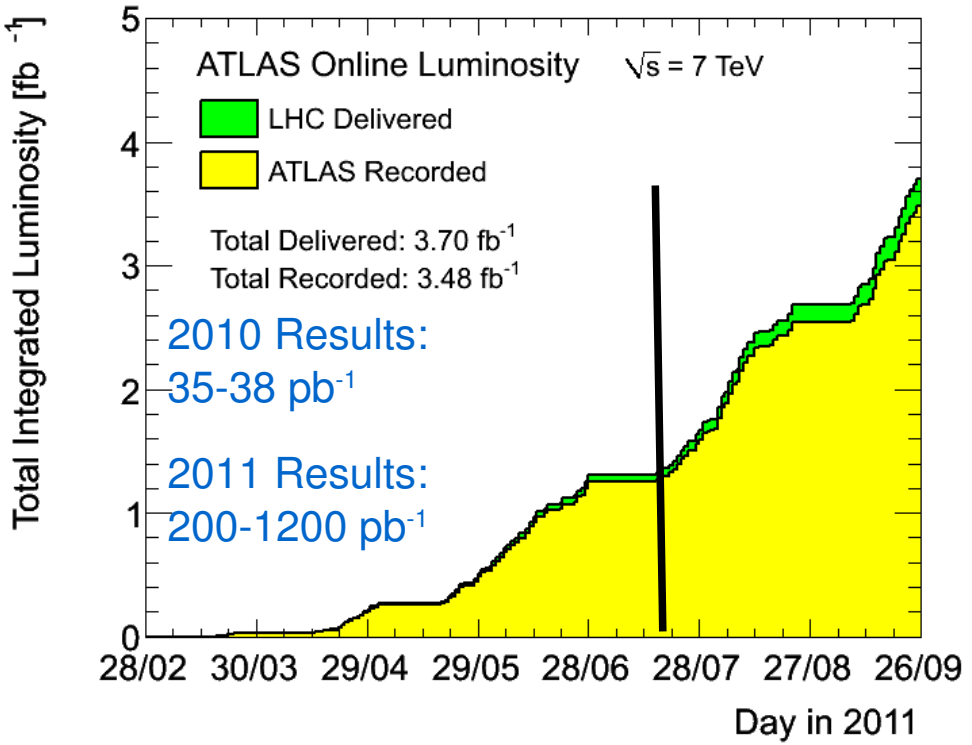
- Full hadronic **45%**: 6 jets
  - High bkgs (mainly QCD)
- Semi-leptonic **30%**: ℓ+ MET+ 4 jets
  - (ℓ=e,μ)
  - Moderate bkgs (mainly W)
- Di-leptonic **11%**: 2ℓ+ MET+ 2 jets
  - (ℓ=e,μ,τ)
  - Low bkgs (mainly Z+jets)



- Single top: 1,2 ℓ+ MET+2,3 jets
  - High bkg, mainly W+HF and ttbar

Most of the results for ttbar and single top production already with 2010 data!
Results with τ and full hadronic from 2011 data

Data and Integrated luminosity



2010 Data taking

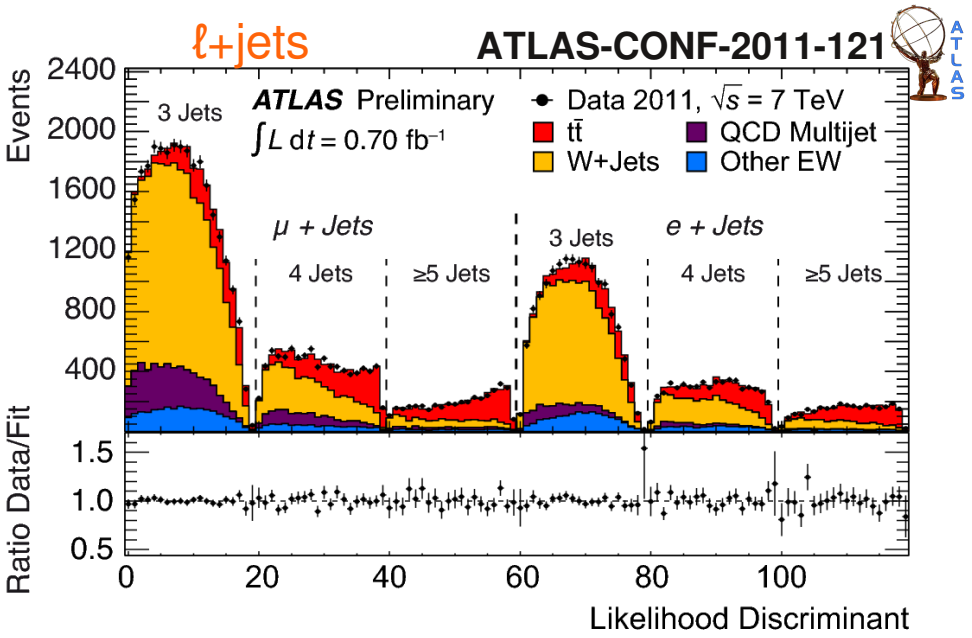
- Peak L: 2.1×10^{32} cm^{-2}s^{-1}
- Max. aver. pile-up ~4 interactions per b.c.
- Max L in a Fill: 6.3 pb^{-1}

2011 Data taking (to date, still on-going)

- Peak L: 3.3×10^{33} cm^{-2}s^{-1}
- Max. aver. pile-up ~16 interactions per b.c.
- Max L in a Fill: 116 pb^{-1}

Thanks to accelerator group for the LHC performance!

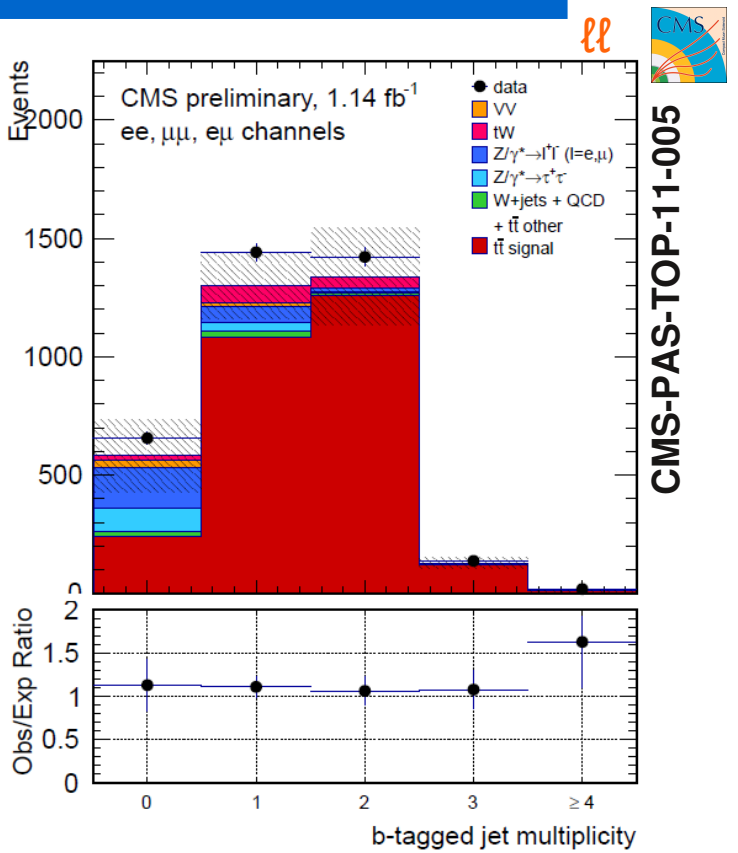
Measurement of ttbar cross-section



$$\sigma_{t\bar{t}} = 179.0 \pm 3.9\,(\text{stat}) \pm 9.0\,(\text{syst}) \pm 6.6\,(\text{lumi})\ \text{pb}$$

MVA analysis in the ℓ+jets channel (ℓ=e,μ):

- Variables used are: η_l, p_T leading jet, Aplanarity and H_{T3}
- Profiling of the likelihood allows a relevant reduction of the systematic uncertainties.
- Statistics is such now that uncertainty is systematically dominated.
- $\Delta\sigma/\sigma$ ~ 6.6% : challenging theo. uncertainty!

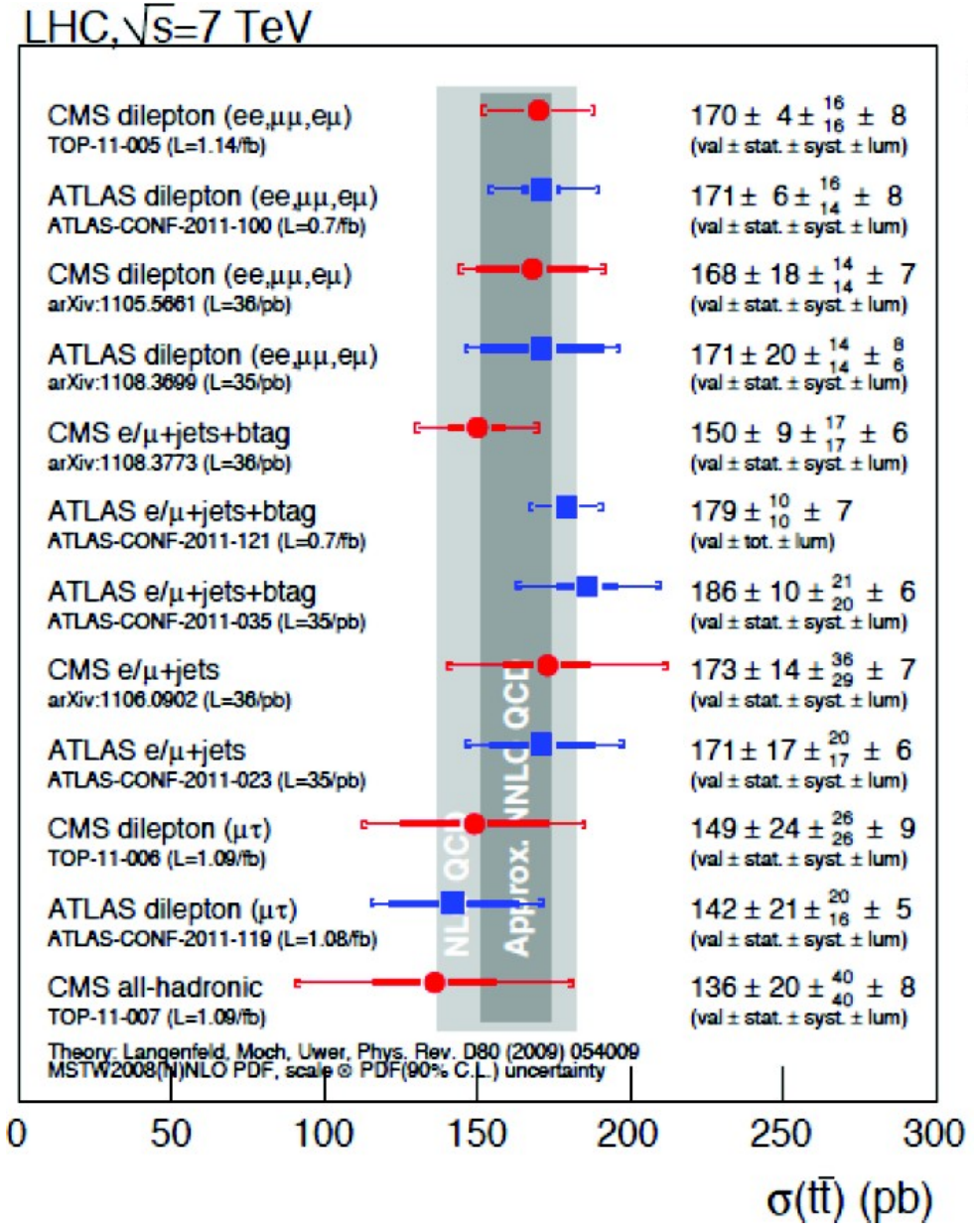


$$\sigma_{t\bar{t}} = 169.9 \pm 3.9\,(\text{stat.}) \pm 16.3\,(\text{syst.}) \pm 7.6\,(\text{lumi.})\ \text{pb}$$

C&C analysis in the ℓℓ channel (ℓ=e,μ):

- B-tagged jets are required
- Systematics can still be reduced by improving the modeling of the pile-up and understanding of the detector response and backgrounds

Summary of ttbar cross-section

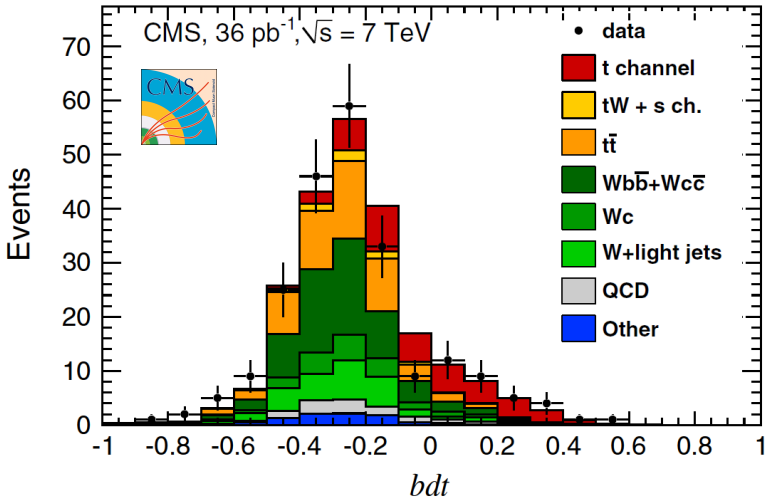


- The amount of ttbar events collected by LHC experiments is already a **few times** the statistics collected by TeVatron experiments.
- Uncertainty of the most accurate single cross-section measurement **is comparable** to the theoretical uncertainty.
- The xsec measurement has been performed in most the ttbar final states (more recently **full hadronic and μτ** final states). Most of them are dominated by systematics.
- A combined TOPLHCWG is working on the combination of CMS and ATLAS results to obtain a more precise measurement of the ttbar production rate. Measurements are now dominated by detector and theoretical systematics.

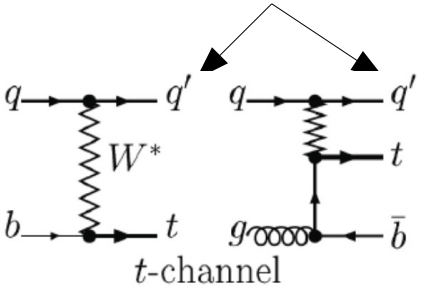
Single Top production measurement

t-channel

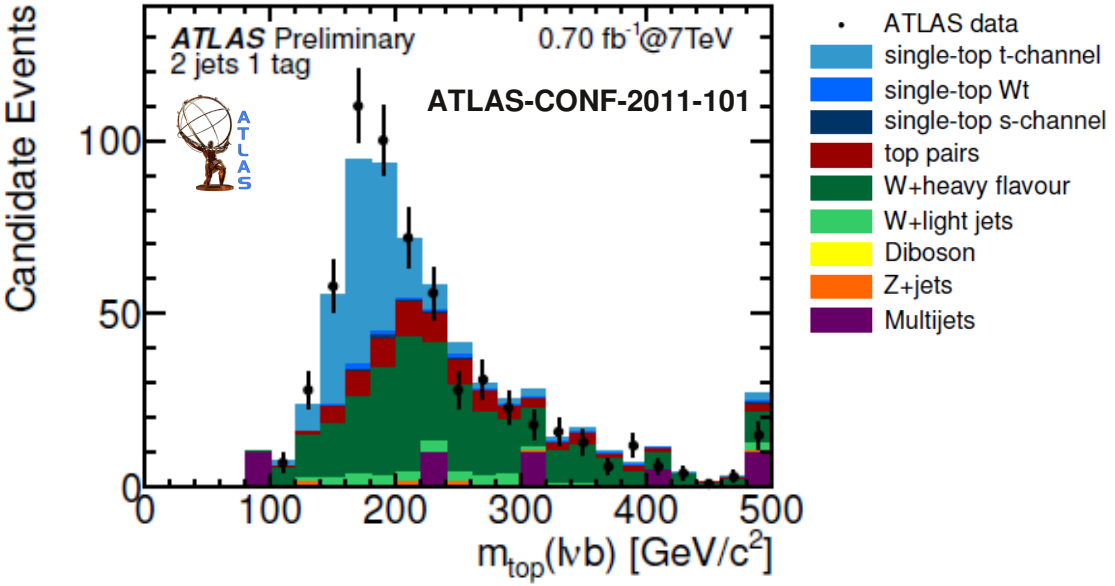
arXiv:1106.3052



Tagging forward jets



$$\sigma^{\exp} = 83.6 \pm 29.8(\text{stat} + \text{syst}) \pm 3.3(\text{lumi})\ \text{pb}$$



$$\sigma_t = 90^{+9}_{-9}(\text{stat})\,^{+31}_{-20}(\text{syst})\ \text{pb}$$

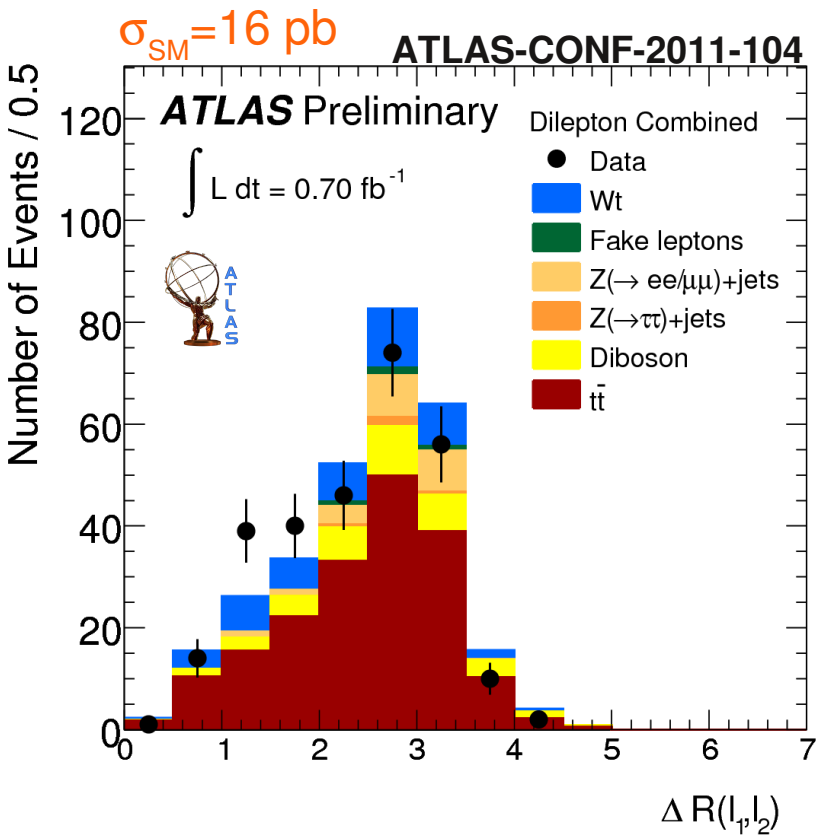
2D+BDT analyses:

- Combining 2 analyses with ~50% statistical correlation
- 2D employs distribution of 2 kinematic variables to form the likelihood and veto on second b-jet
- BDT analysis exploits 37 kinematic variables.
- Based on 2010 data

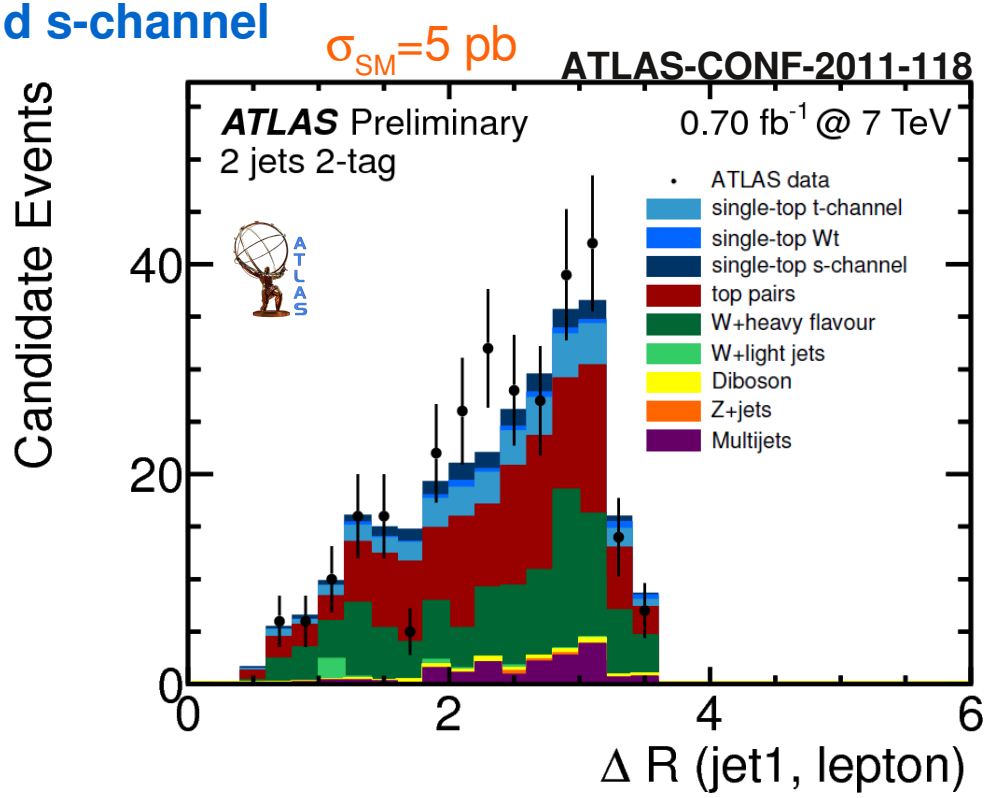
Cut&Count analyses:

- Combining 2 jets and 3 jets final states.
- Confirmed by NN analysis with 13 variables
- Based on 2011 data and dominated by systematics

Single Top production measurement



Wt and s-channel



$$\sigma(pp \to Wt + X) < 39.1 \text{ pb (obs.)} @ 95\% \text{ CL}$$

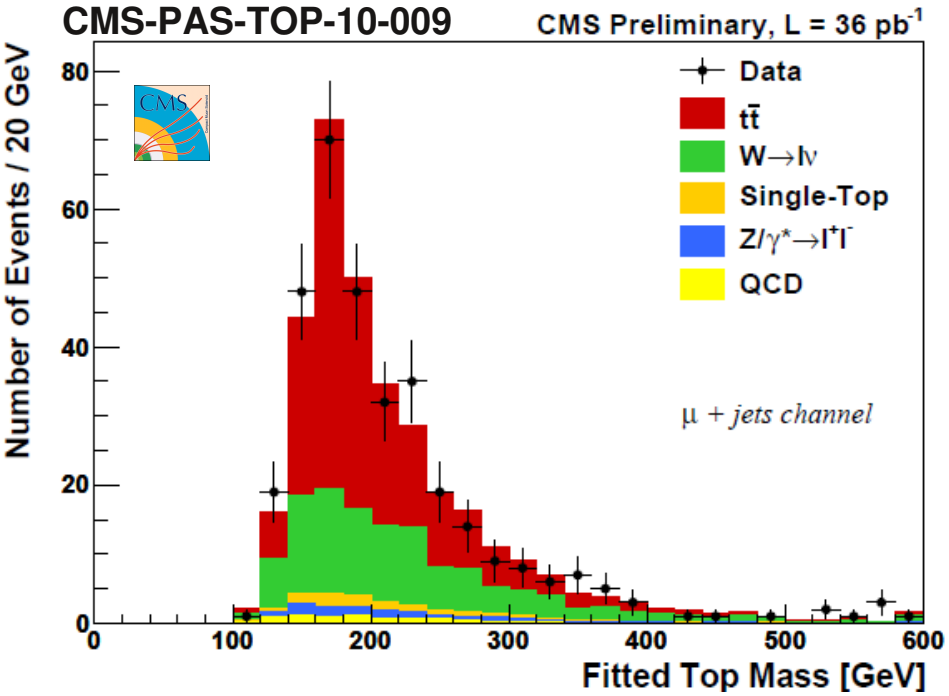
$$\sigma(pp \to Wt + X) = 14.4^{+5.3}_{-5.1}(\text{stat})^{+9.7}_{-9.4}(\text{syst})$$

Cut&Count analysis:
- Cut based analysis
- Signal purity in the signal region is ~15%
- Bkg-only rejected at 1.2 σ

σ_t (s-chan) < 26.5 pb @ 95 CL

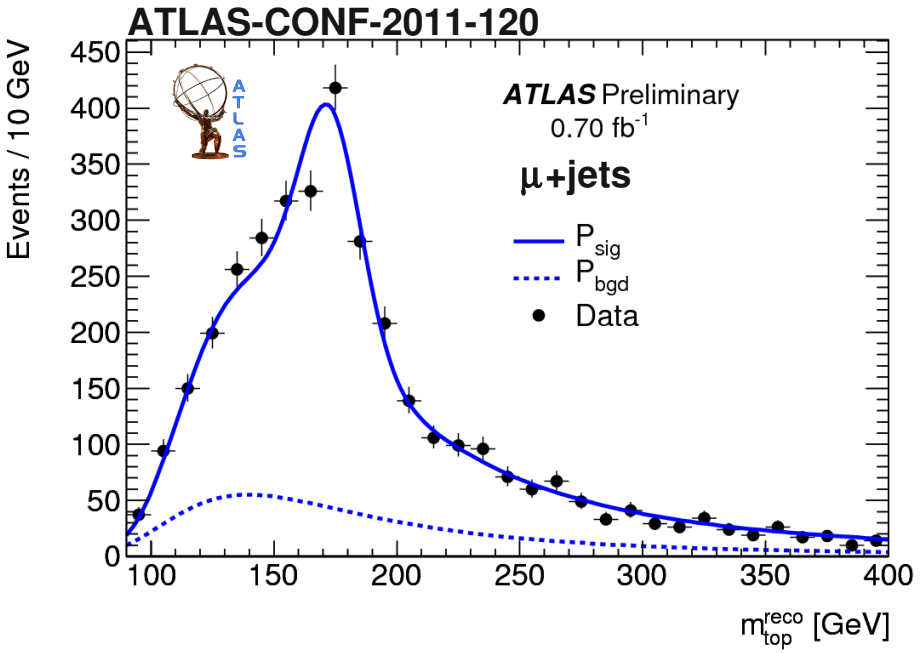
Cut&Count analysis:
- Cut based analysis
- Signal purity in the signal region is ~6%

Top Mass Measurement



$$m_t = 173.4 \pm 1.9(\text{stat}) \pm 2.7(\text{syst}) \text{ GeV}.$$

arxiv:1105.5661 (L=36 pb^{-1}) dilep channel!
m_{top} = 175.5 ±4.6(stat) ±4.6(syst) GeV



$$m_{top} = \left(175.9 \pm 0.9_{stat} \pm 2.7_{syst}\right) \text{ GeV}.$$

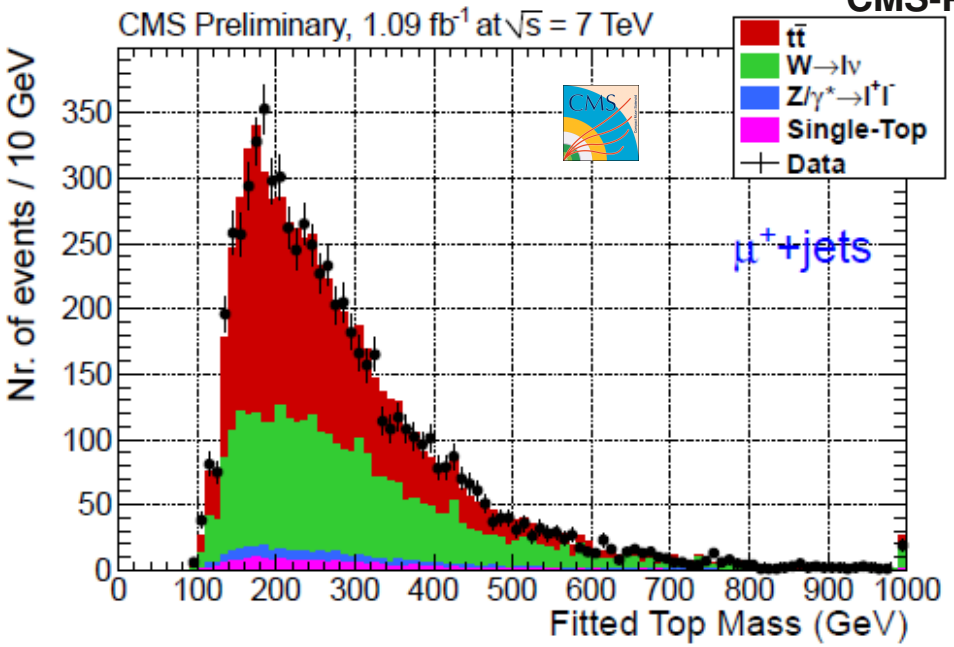
Pole mass from fit of xsec and m_{top} (L=35 pb^{-1})
$m_{pole} = 166.4\ ^{+7.8}_{-7.3}$ (stat+syst) GeV

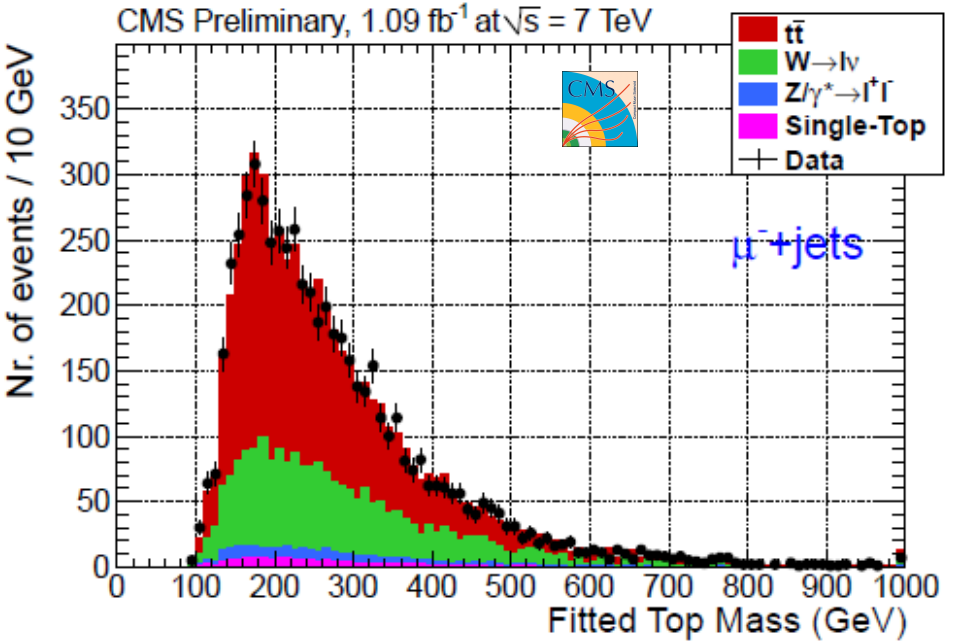
Kinematic Fit:
- Combining l+jets and di-lepton final states (l=e,μ)
- Cross check with m_{top} and JES fit, correlation is ~ -0.68

Template method :
- Combining l+jets final states (l=e,μ)
- Main syst: JES for light and b-jets, ISR,FSR
- Cross check with m_{top} and JES fit, correlation is ~ -0.60

Top-AntiTop Mass Difference

CMS-PAS-TOP-11-019





The measurement of the top/anti-top mass difference is a test of CPT invariance.

μ+jets channel:

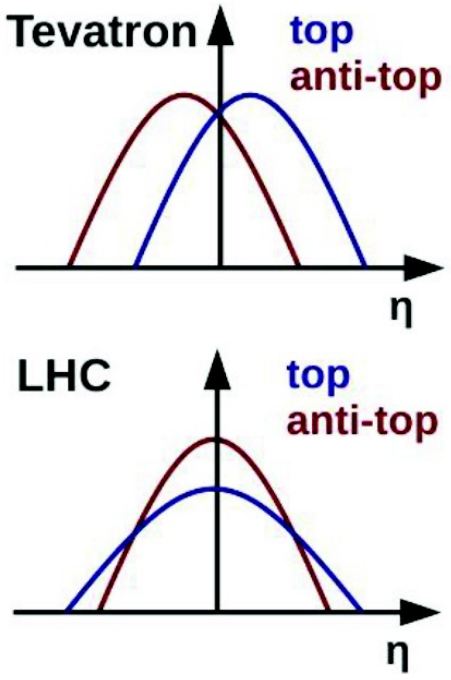
- Data Sample is split in two samples based on the muon charge:
  6919 μ^++jets and 5933 μ^-+jets events.

Kinematic fit of the hadronically decaying top is used to reconstruct the top mass.

$$\Delta m_t^{\text{measured}} = -1.20 \pm 1.21\ (\text{stat}) \pm 0.47\ (\text{syst})\ \text{GeV}$$

ttbar Charge Asymmetry

- Small charge asymmetry is expected at the NLO from interference in the production diagrams (~1% @LHC).
- TeVatron experiments reported ~2σ discrepancy wrt NLO QCD.
- LHC: qqbar fraction is much smaller (~15%) than @ TeVatron and it is measured in a different way, due to the overall symmetry of the distribution (pp vs ppbar)
- Results obtained in the l+jets final state, after full reconstruction of the event.

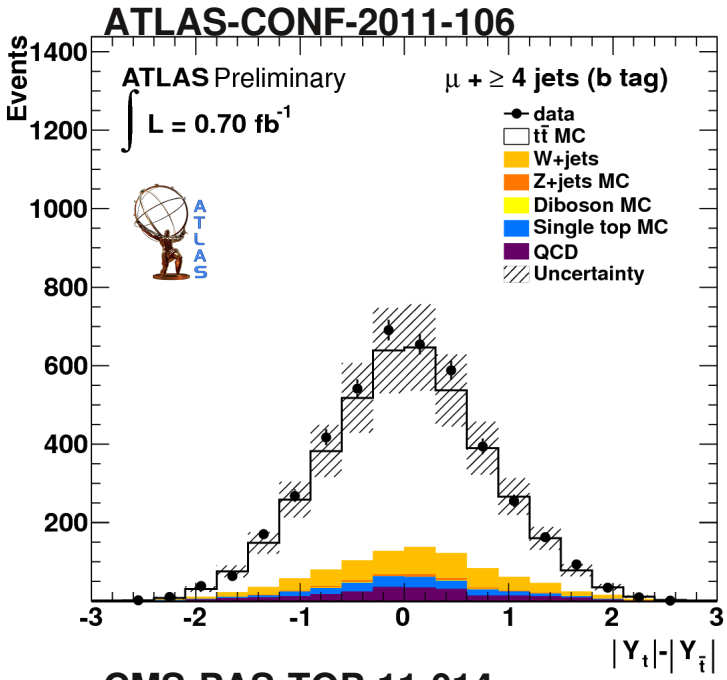


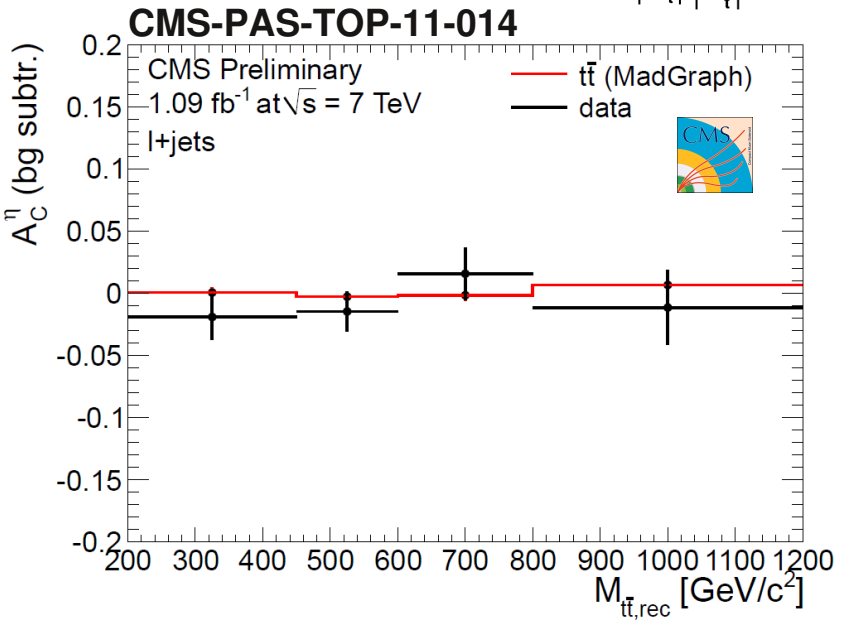
η=pseudo-rapidity **Y=rapidity**

$$\Delta|\eta| = |\eta|_t - |\eta|_{\bar{t}}$$ and cross check with $\Delta(Y^2)$

$$\Delta|Y| = |Y|_t - |Y|_{\bar{t}}$$

ttbar Charge Asymmmetry

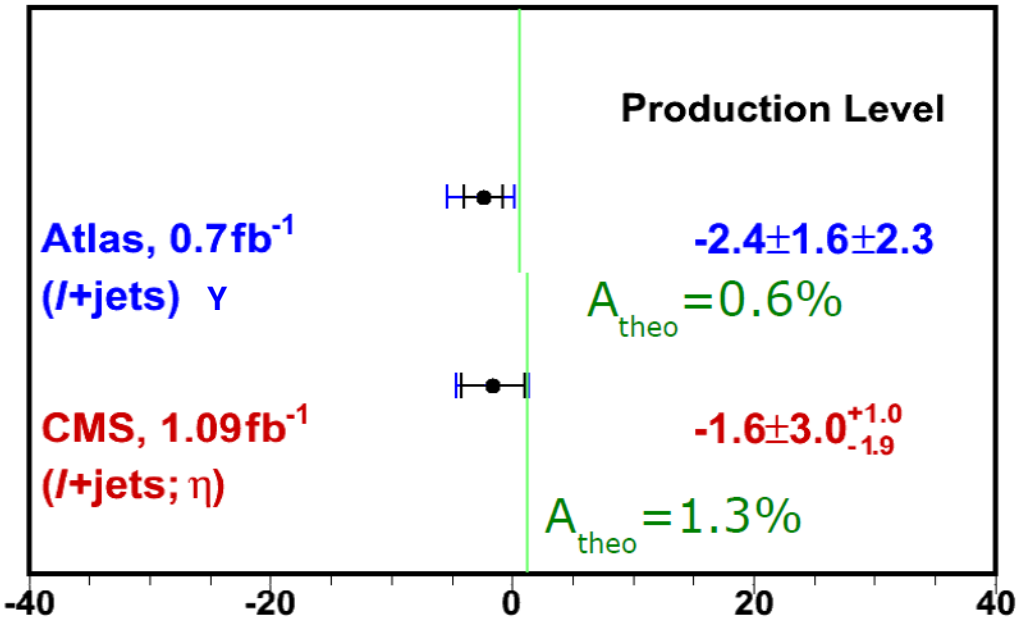




Unfolding of detector effects and acceptance is performed for $\Delta(|Y|)$ and $\Delta(\eta)$.

- ATLAS: Results start to be limited by systematics.
- CMS is using $|\eta|$ observable and $\Delta(Y^2)$ as cross-check. Asymmetry is measured as a function of the ttbar system mass.

Top-Antitop Charge Asymmetry %



W helicity measurement

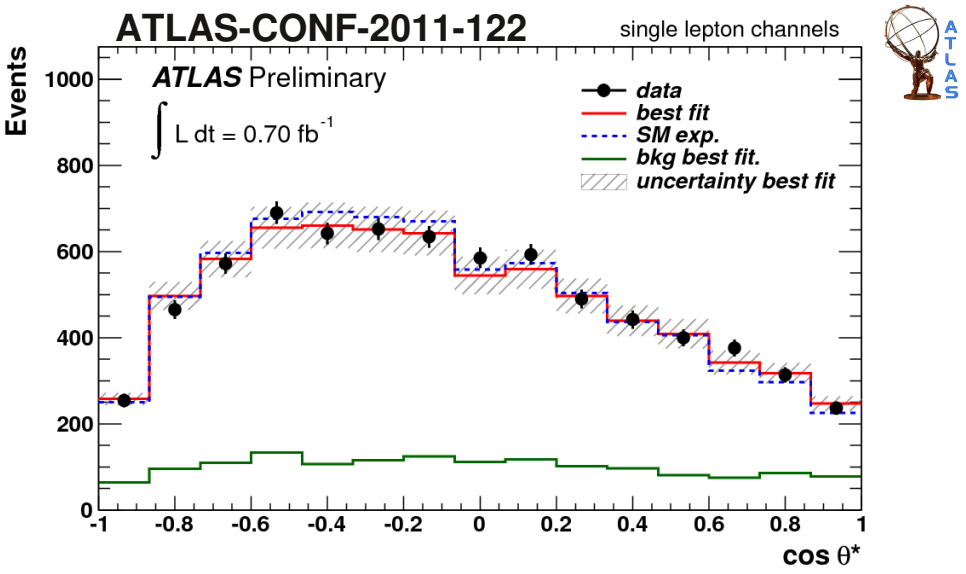
W helicity in top decays obtained in l+jets and di-lepton final states

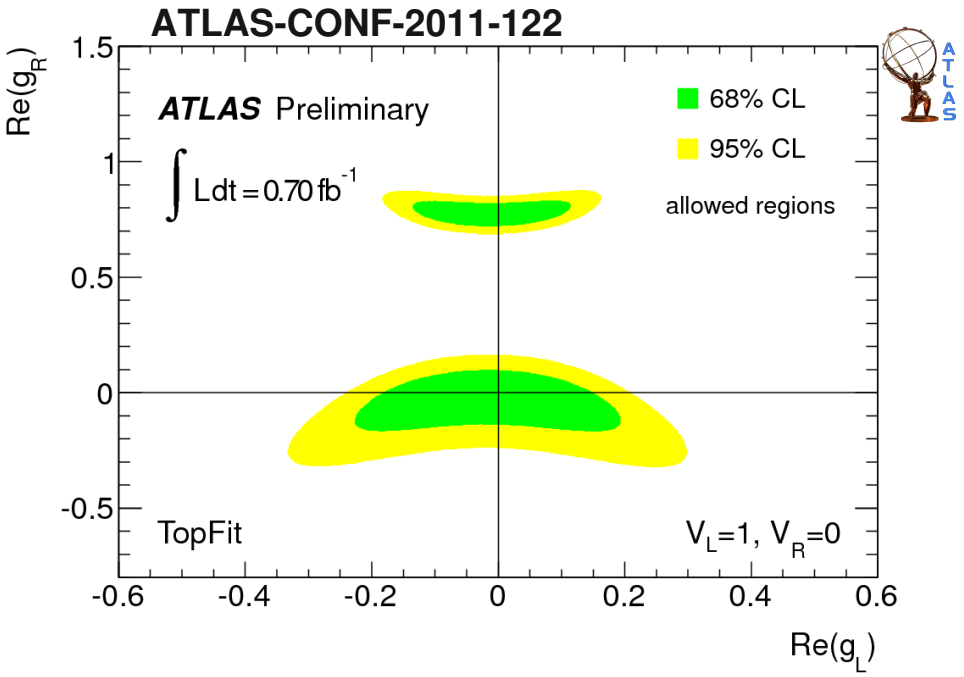
Template fit of cos(θ*) in the W rest frame

The result is also used to obtain the limits on the anomalous copling of the Wtb vertex

$$\mathscr{L} = -\frac{g}{\sqrt{2}}\bar{b}\,\gamma^{\mu}\,(V_L P_L + V_R P_R)\,t\,W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\,(g_L P_L + g_R P_R)\,t\,W_{\mu}^{-} + \text{h.c.}$$

In SM: $V_L P_L = 1$; $V_R P_R = G_L P_L = G_R P_R = 0$





ttbar spin correlation

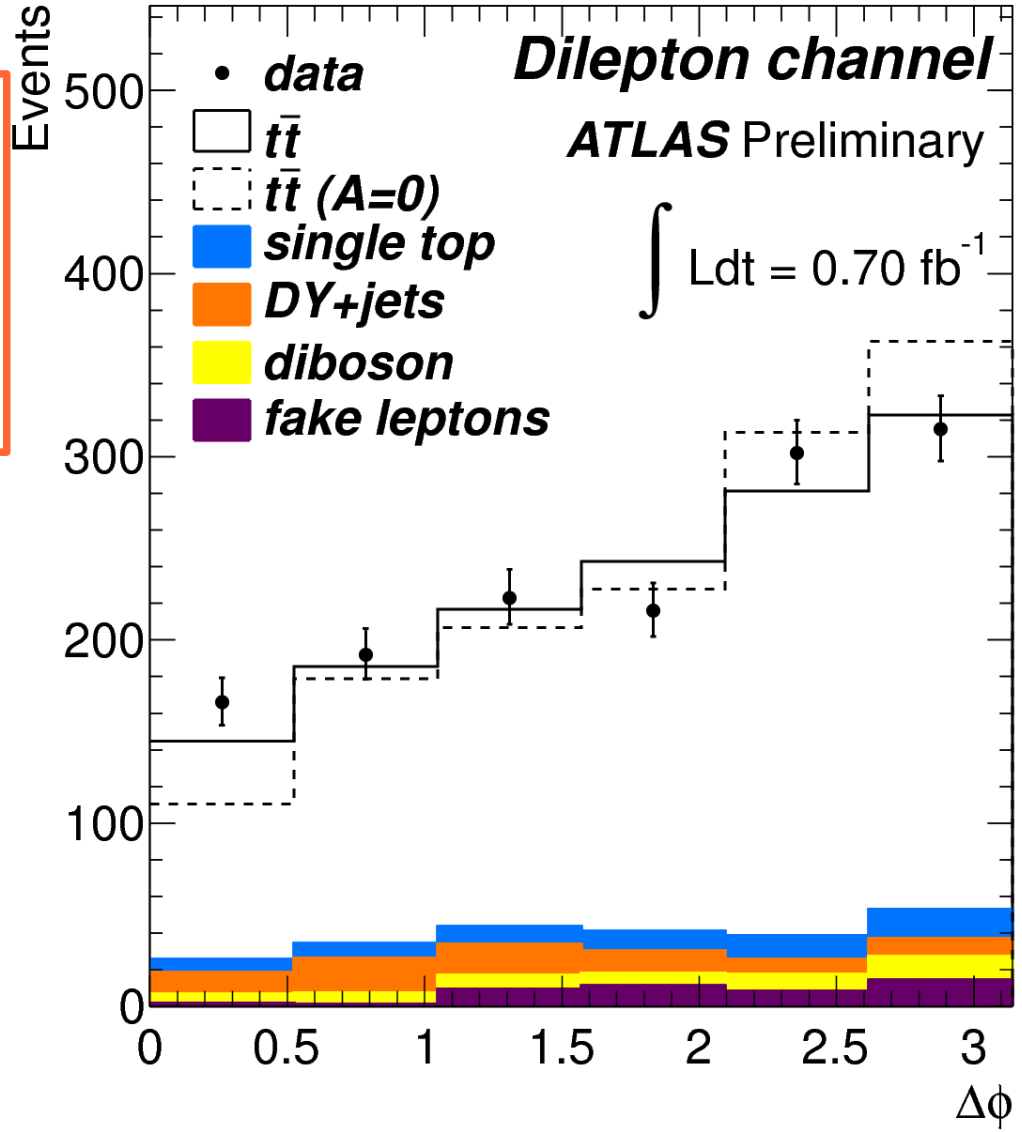
Dilepton Channel
- Requires 2ℓ (ℓ=e,μ) and at least 2 jets
- No requirements on b-tagging, no need to perform top reconstruction.
- Template fit of the $\Delta\phi_{\ell\ell}$ distribution

$$f^{SM} = 1.06 \pm 0.21$$

f^{SM} is the SM template strength, (in SM, $f^{SM}=1$)

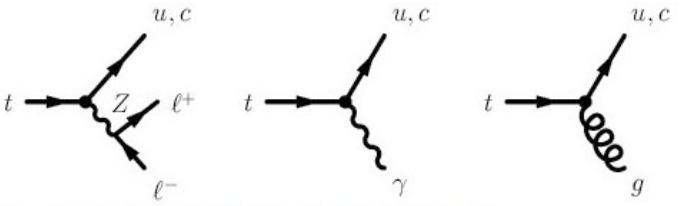
$$A_{helicity} = 0.34^{+0.15}_{-0.11}$$

Results is in good agreement with SM: NLO QCD predicts $A_{helicity}=0.32$



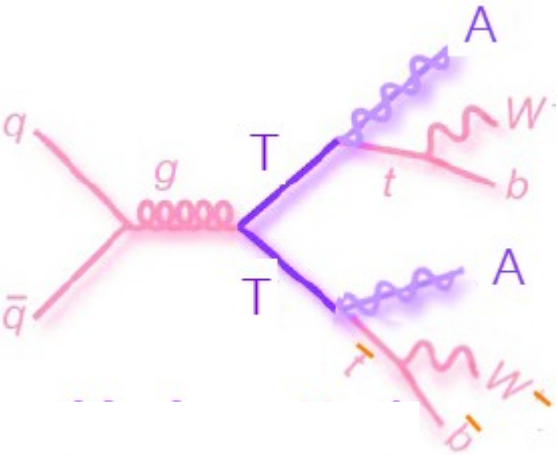
Top Production in NP scenarios

- FCNC decays t→(Z,γ,g)q
  Searches in final states with 3 leptons and
  qg → t production.



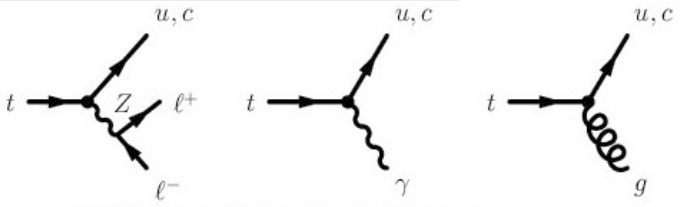
- Heavy neutral particles decaying to top pairs (Z', g_{KK}. …)
  top can be heavily boosted and final products can be reconstructed as merged objects.

- Heavy Top partner and long lived neutral particle
  predicted in some exotic 4th generation,
  stop to top + neutralino, UED, leptoquarks,...

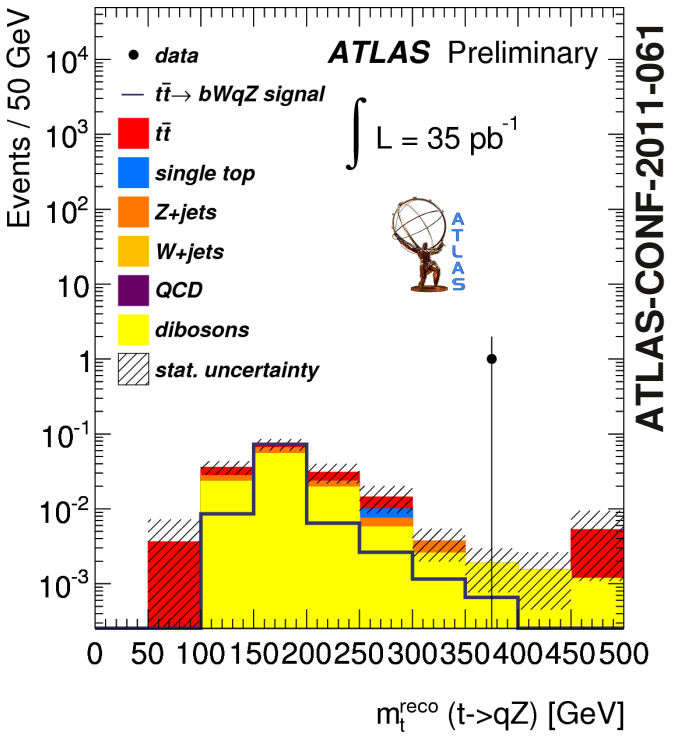


FCNC Searches

FCNC decays t→(Z,γ,g)q is suppressed in SM (10^{-10})

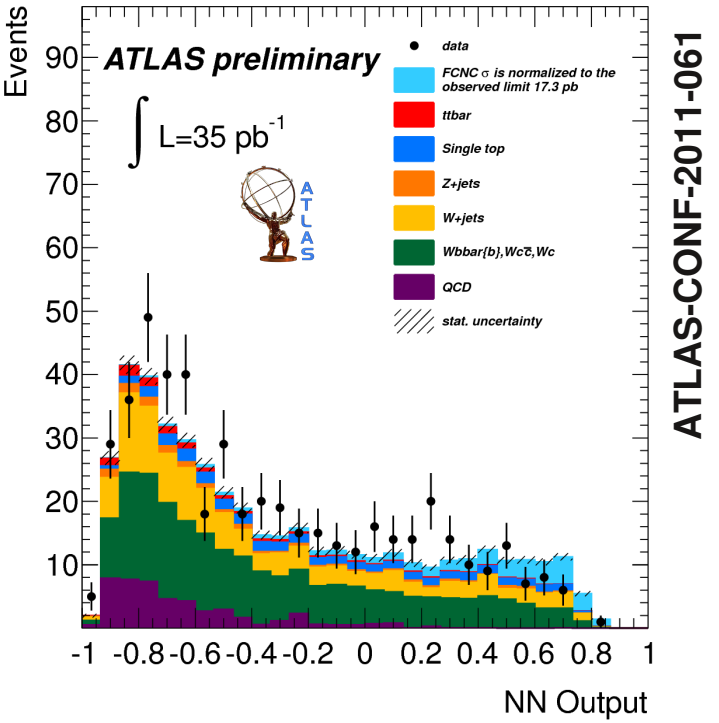


t → qZ(Z → ll) search performed in the 3 leptons final states



$BR(t \rightarrow qZ) < 17\%$ @ 95 CL

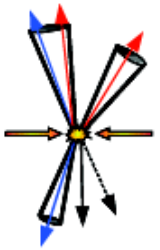
FCNC in single top production performed in the l+jets final states



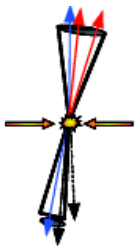
$\sigma_{qg\rightarrow t} \times \mathrm{BR}(t \rightarrow bW) < 17.3$ pb @ 95 CL

High mass narrow Resonances

2 jets merged



3 jets merged



In case the ttbar pair is decaying from an high mass resonance the top can be heavily boosted and the 2 jets from W or even the 3 jets from the top decay can be merged in the final state

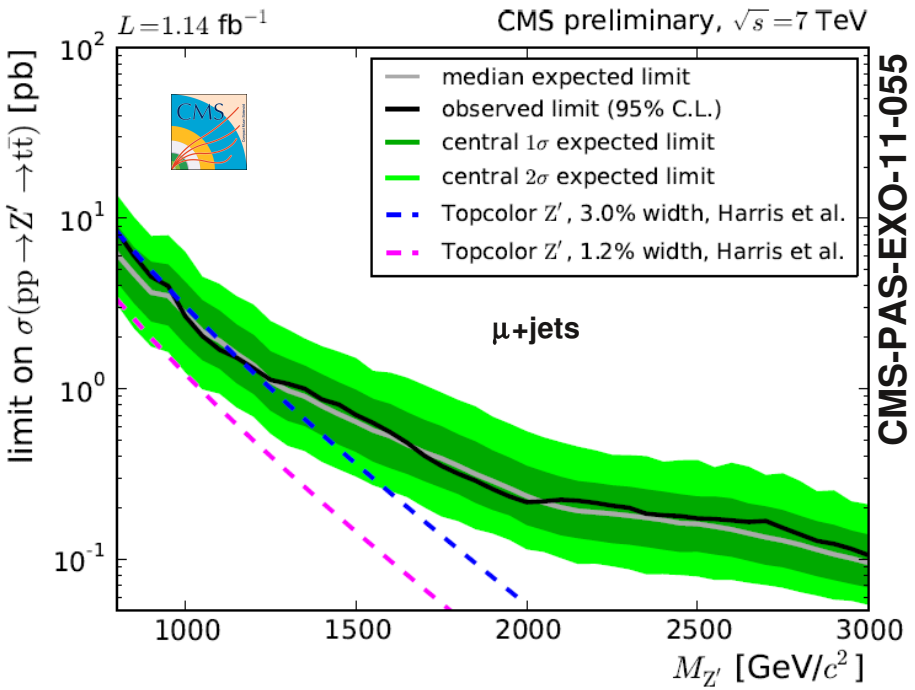
@LHC several different final states where explored.
Upper Limits on Z' and g_{KK} production are obtained:

ATLAS

- l+jets (0.20 fb^{-1}) ATLAS-CONF-2011-087

CMS

- μ+jets (1.14 fb^{-1}) CMS-PAS-EXO-11-055
- Full hadronic (0.89 fb^{-1}) CMS-PAS-EXO-11-006
  With R=0.8 jets in 1+1 and 1+2 configurations.
  Jets of p_T>350 GeV and
  "Top tagging" with m_{jet}, $m_{sub\text{-}jet}$

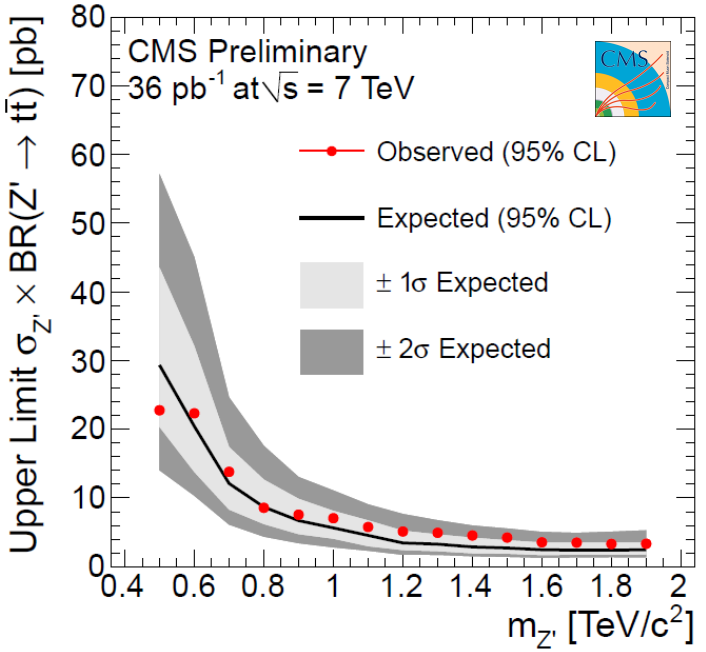


Low mass narrow Resonances

In case the ttbar pair is decaying just above the ttbar production threshold, the top quarks are less boosted and top decay products can be resolved.
Upper Limits on Z' and g_{KK} production are obtained:

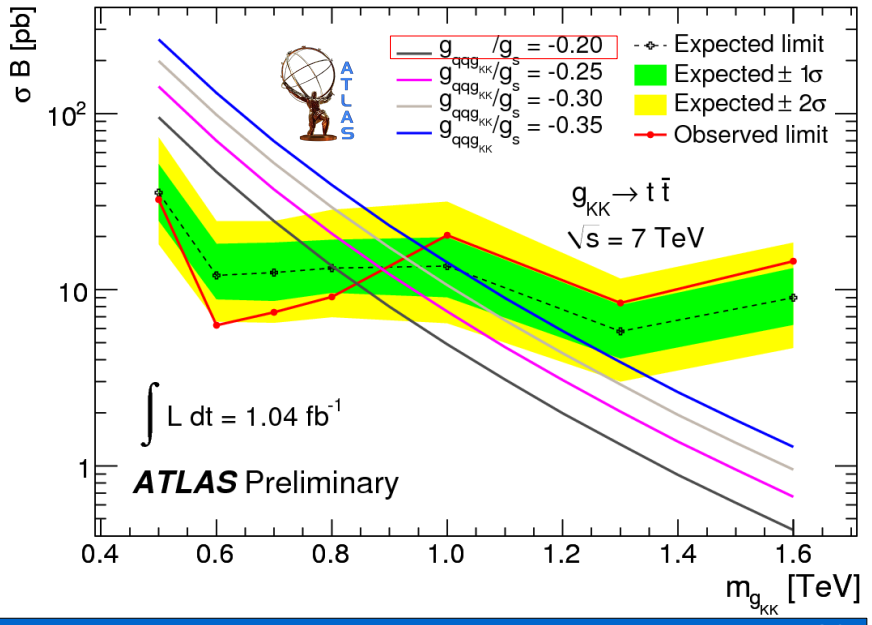
CMS

- Low mass: ℓ+jets ℓ=e,μ (36 pb-1) CMS-PAS-TOP-10-007
  Considering a leptophobic Z' with small width (1%)
  The discriminant variables is the m_{tt}

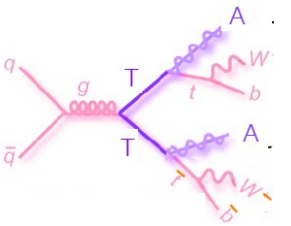


ATLAS

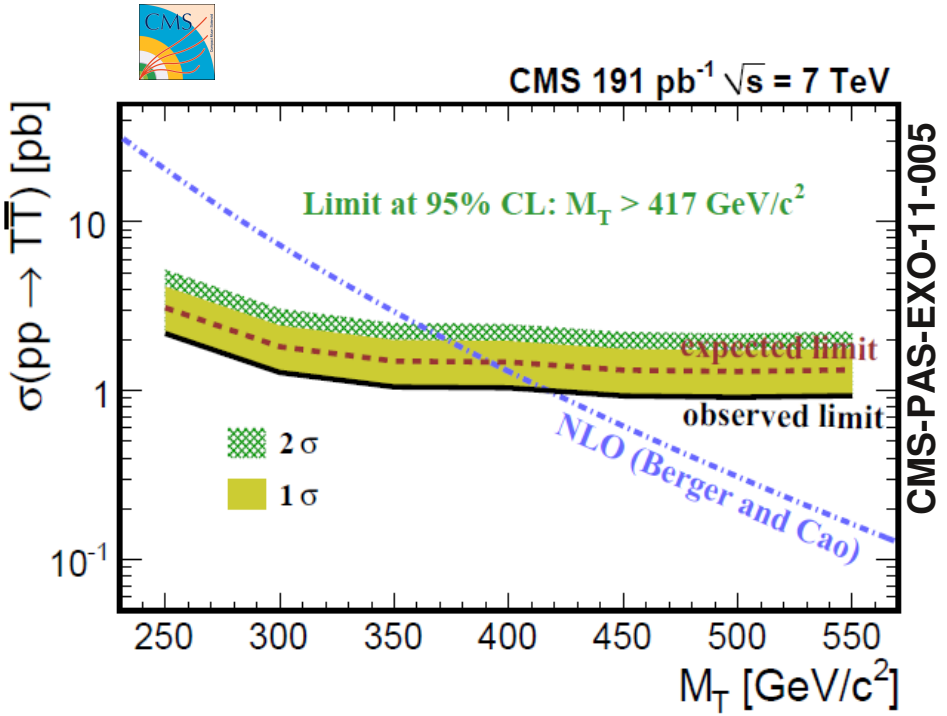
- Di-lepton (1.04 fb^{-1}) ATLAS-CONF-2011-123
  Using standard di-lepton selection and looking for excess in the $H_T+E_T^{Miss}$ distribution.

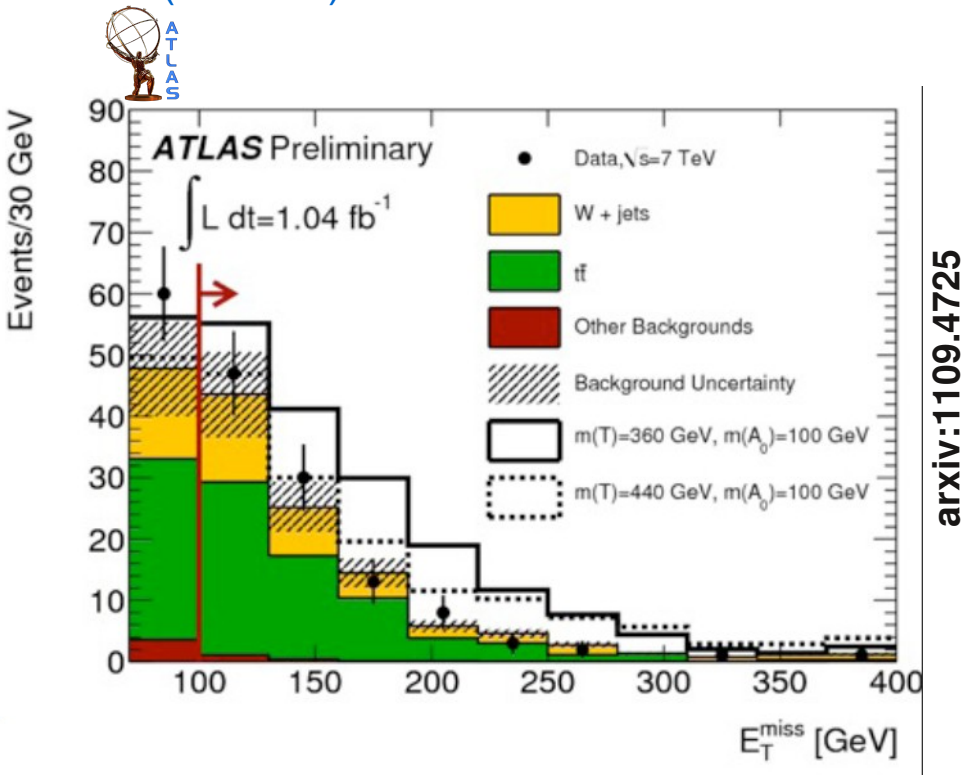


Top Partners Searches



Searches of top partners in $T \rightarrow tZ$ (CMS) and $T \rightarrow tA^0$ (ATLAS) final states





Assuming that T decays to tZ
3 Leptons final states
m_T> 417 GeV @ 95 CL

Assuming that T decays to tA^0
ttbar l+jets final state with large MET (>100 GeV)
95% CL Limit on the production is:
σ*BR~1.1 pb for
(mT,mA^0)=(420 GeV,10GeV)

Summary and Discussion

• The top physics program at LHC is extremely vast and complete.

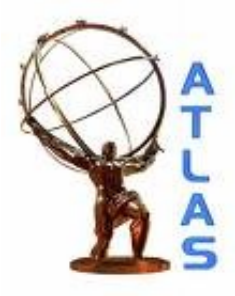
• Less than 1 year ago, we delivered the first LHC ***"top observation"*** results, now we have already ***"precision measurements"***!

• **Top pairs cross section measurement** has been performed in almost all the final states. The most accurate single measurement has <7% uncertainty, challenging the present theoretical uncertainty.
Single top cross section measurement has been established too.

•Top Mass and other properties (mass difference, charge asymmetry, spin correlation, W helicity, etc.) have been successfully measured at LHC. In some cases, results are the world most accurate ones.

• Searches for new physics coupled to the top-quark sector is on-going.
Many results delivered in summer 2011 (FCNC, ttbar resonances, top partner, …).
Expect more stringent limits to come as the data samples are quickly increasing and the understanding of the detectors is continuously improving.

References

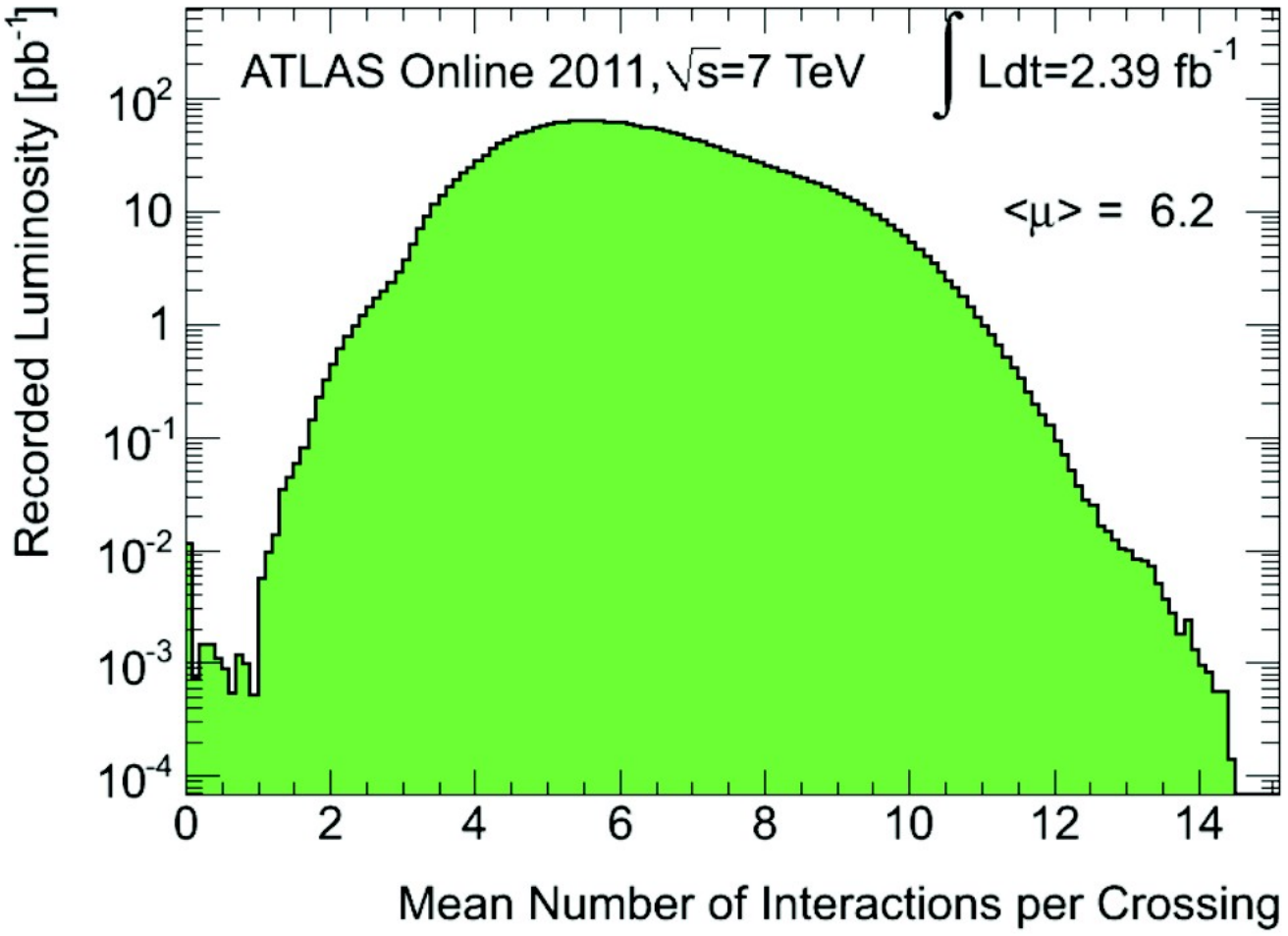


- ATLAS Public Results:
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/AtlasResultsEPS2011

- CMS Public Results:
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

Bonus Slides

Pile-up



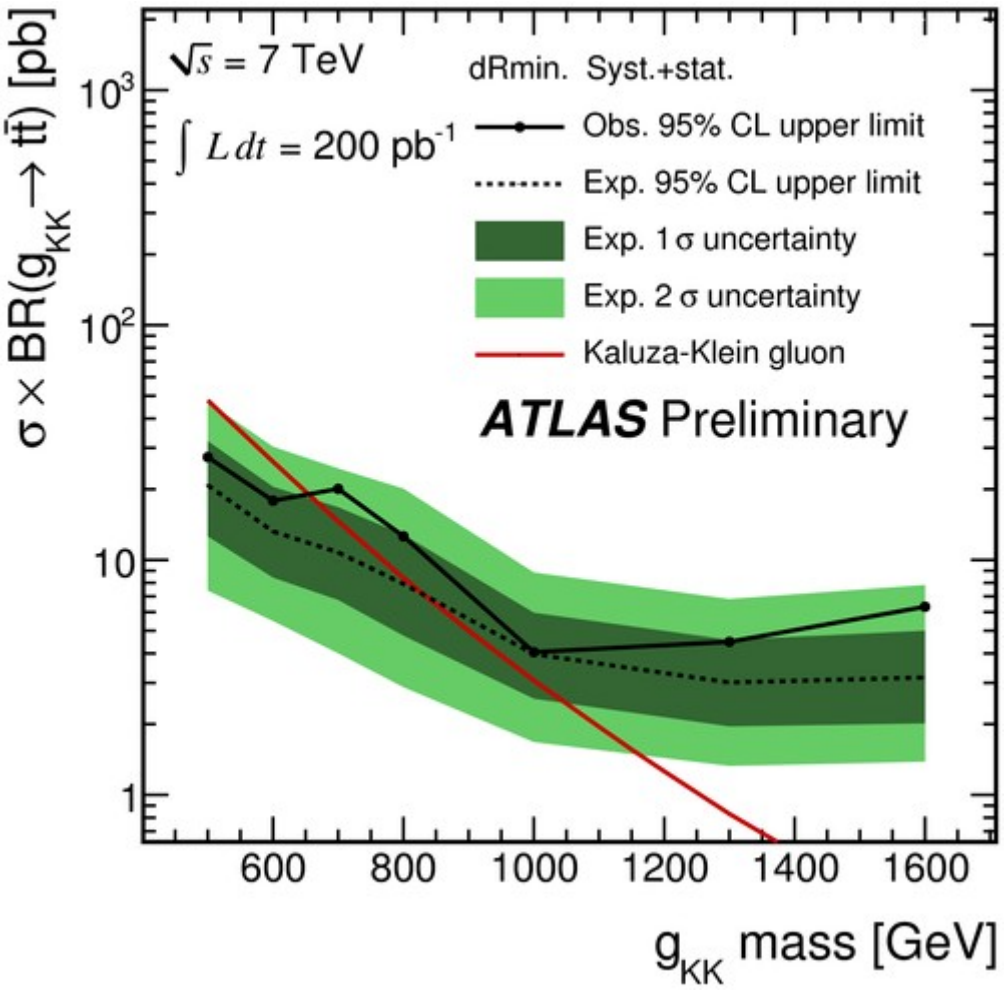
Obtained from the measurement of the luminosity

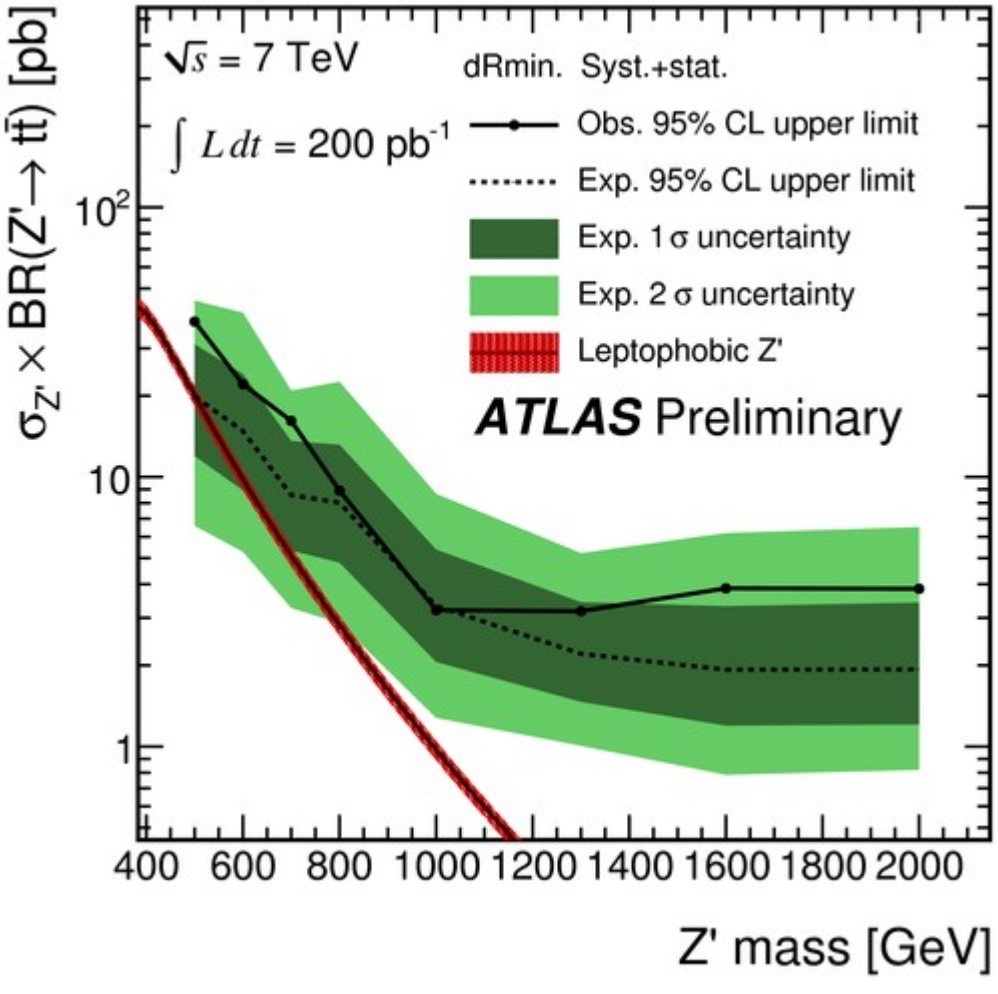
$\mu = L \times \sigma_{inel} / (n_{bunch} * f_r)$

Currently, the typical values of mu is well above 10.

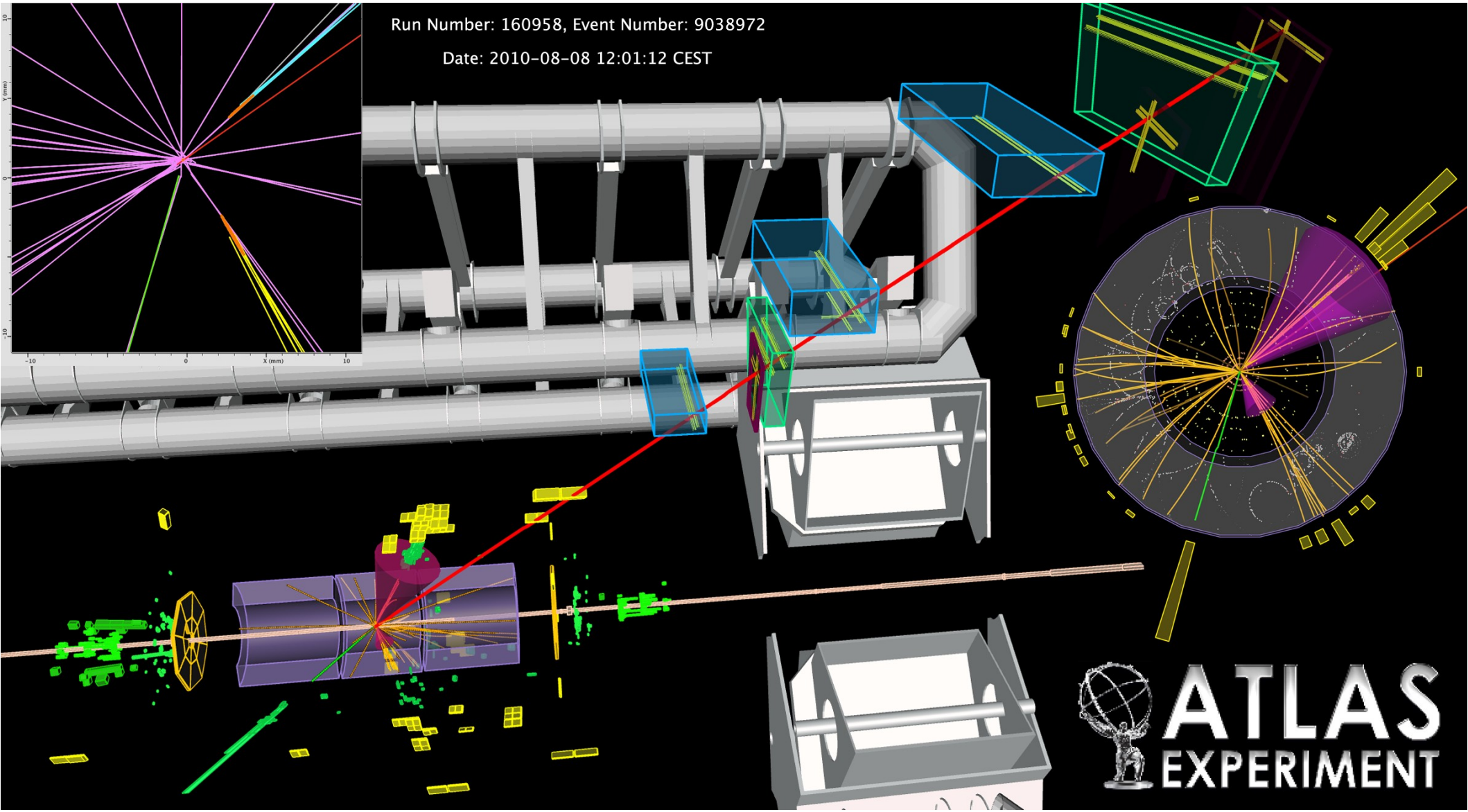
High mass narrow Resonances

- ATLAS-CONF-2011-088

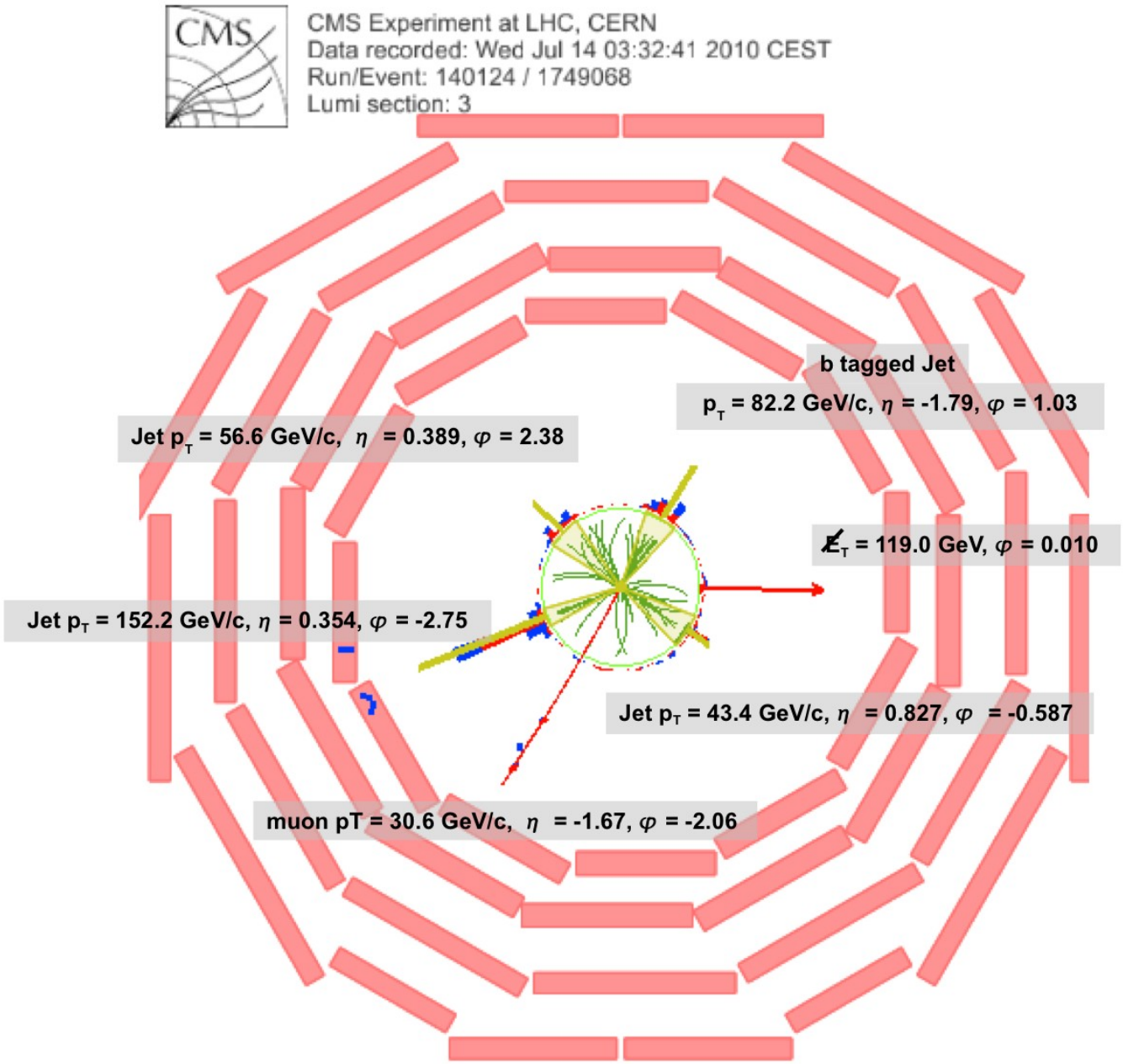




Top e-mu event



Top μ+jets event



Muon Performance

μμ spectrum and resonances