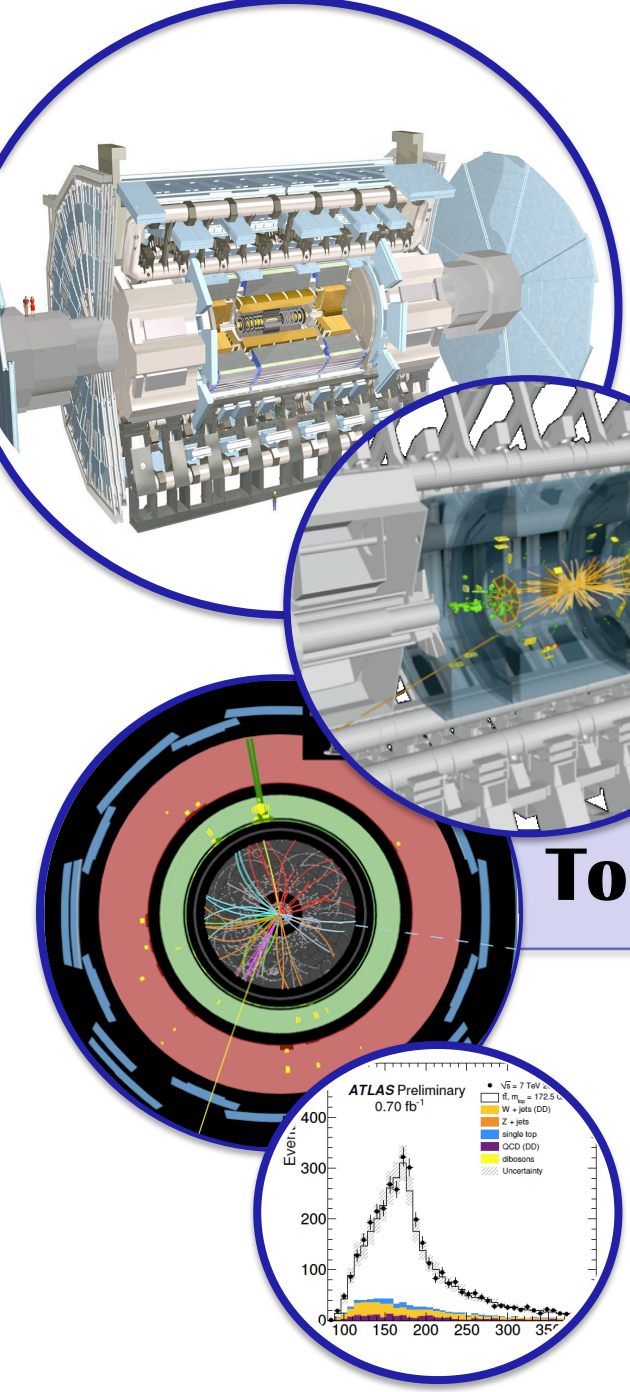



# Top Quark Physics in ATLAS Detector

**On behalf of the ATLAS Collaboration**

**Regina Moles-Valls**
**IFIC – Universitat de València**

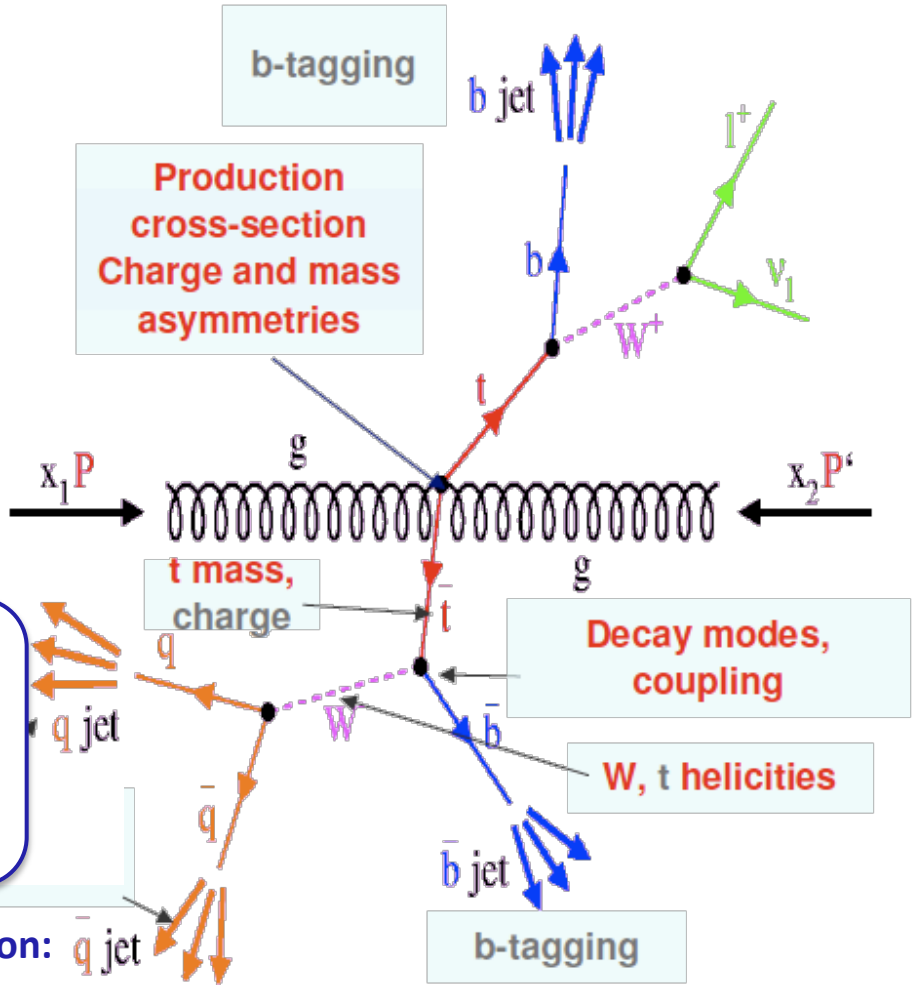
# Top Physics Outline

ATLAS Top Physics results presented in this talk:

**Top production:**
- Top quark pair cross section
- Single top quark cross section

**Top Properties:**
- Top quark Mass
- Top quark charge asymmetry
- W polarization
- Spin correlation

**New physics in top sector**
- **F**lavour **C**hanging **N**eutral **C**urrent
- ttbar resonances
- Exotics heavy quark searches
- …




**Studies on event and object reconstruction:**
bJES , jet shapes, τ trigger, jet structure,…

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IFAE

M.Bosman, P.Casado, C.Conidi, L.Fiorini, D.Gerbaudo, C.Helsens, A.Juste, M.LL.Mir, J.Montejo, J.Nadal, I.Riu, F.Rubbo, A.Succurro, V.Vorwerk

IFIC INSTITUT DE FÍSICA CORPUSCULAR

S.Cabrera, **M.J.Costa(*)**, F.Fassi, J.Fuster, C.García, A.Irles, S.Martí, R.Moles, M.Moreno-Llàcer, S.González, E.Oliver, S.Pedraza, T.Pérez, E.Ros, J.Salt, V.Sánchez, E.Valladolid, M.Villaplana, M.Vos, A.Wildauer **(*) Top Group Convener**

ugr Universidad de Granada

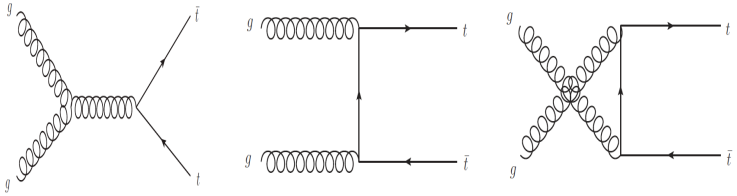
J. A. Aguilar-Saavedra

# Top quark physics at LHC

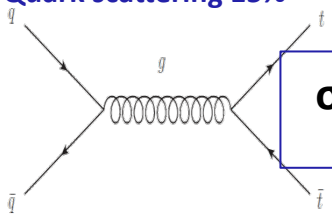

## *Top pair production*

***Strong interaction***

**Gluon fusion 85%**



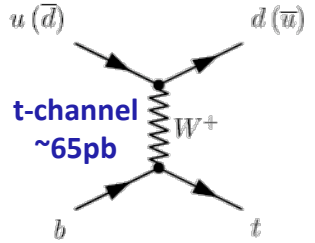
**Quark scattering 15%**

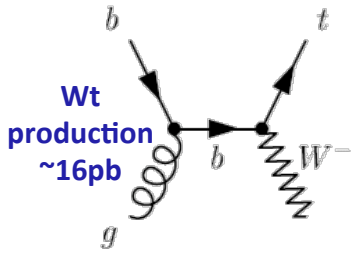


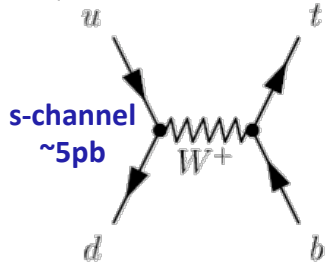
$\sigma_{top}$ (7TeV)= $165^{+11}_{-16}$ pb
(theoretical NLO+NNLO)

## *Single top production*

***Weak interaction***



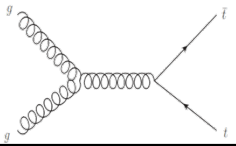



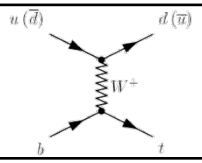
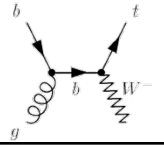
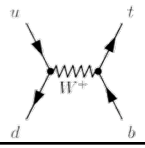

$\sigma_{top}$ (7TeV)≈ **84 pb**
(theoretical NLO+NNLO)

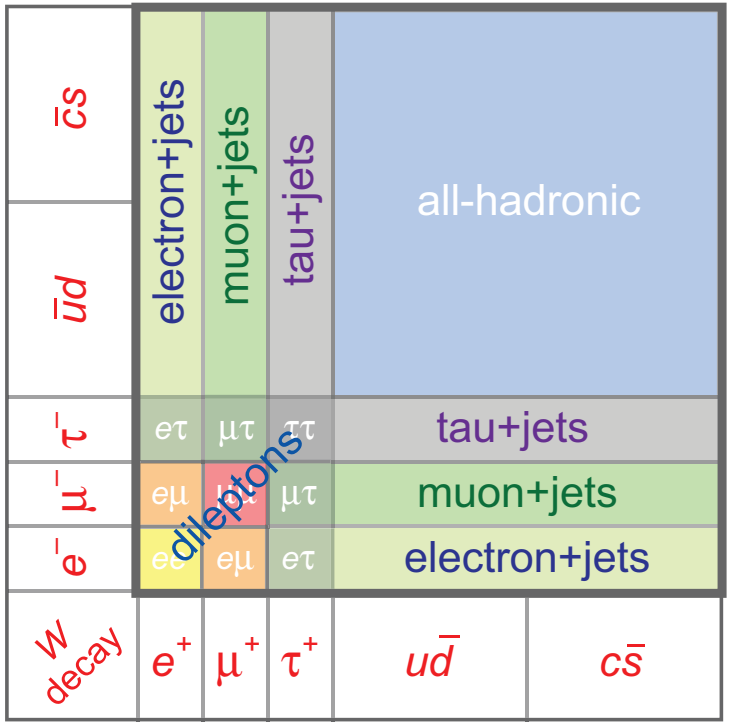
# Top quark Physics in ATLAS Detector

Top quark decays take place almost exclusively:

**t ⟹ W+b**

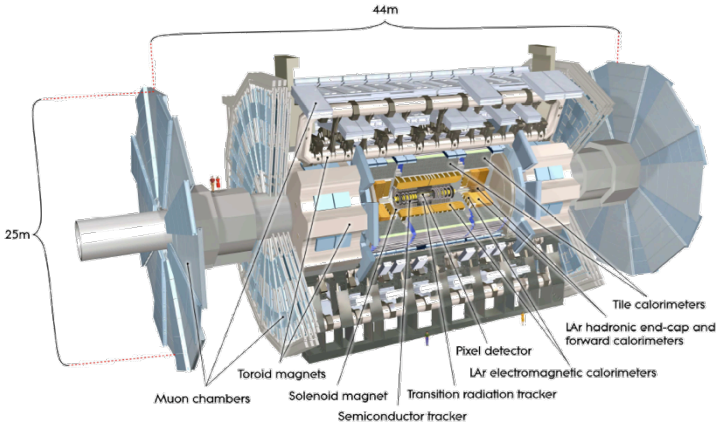
| **ttbar** |  | | |
|---|---|---|---|
| **Channel** | Full Hadronic (45%) | Semi-leptonic (30%) | Di-leptonic (11%) |
| **Products** | 6 jets | l+MET+4jets l=(e,μ) | 2l+MET+2jet l=(e,μ,τ) |
| **Background** | ☹ | 😐 | ☺ |

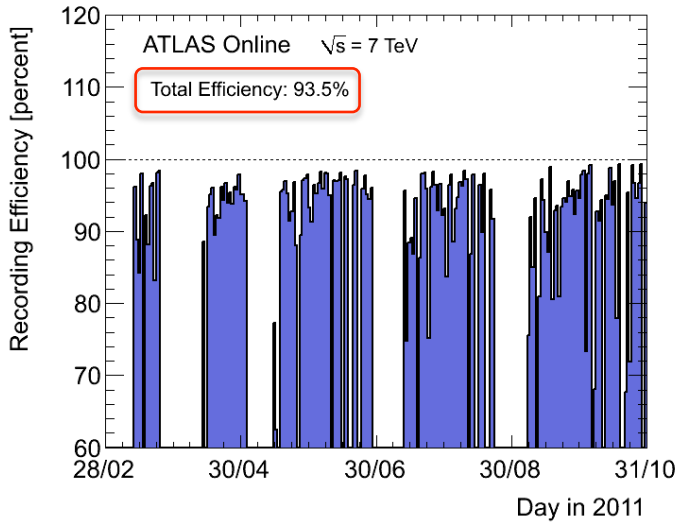
| **Single top** |  |  |  |
|---|---|---|---|
| **Channel** | t-channel | Wt production | s-channel |
| **Products** | 1,2 l+MET+2,3 jets | | |
| **Background** | ☹ | | |

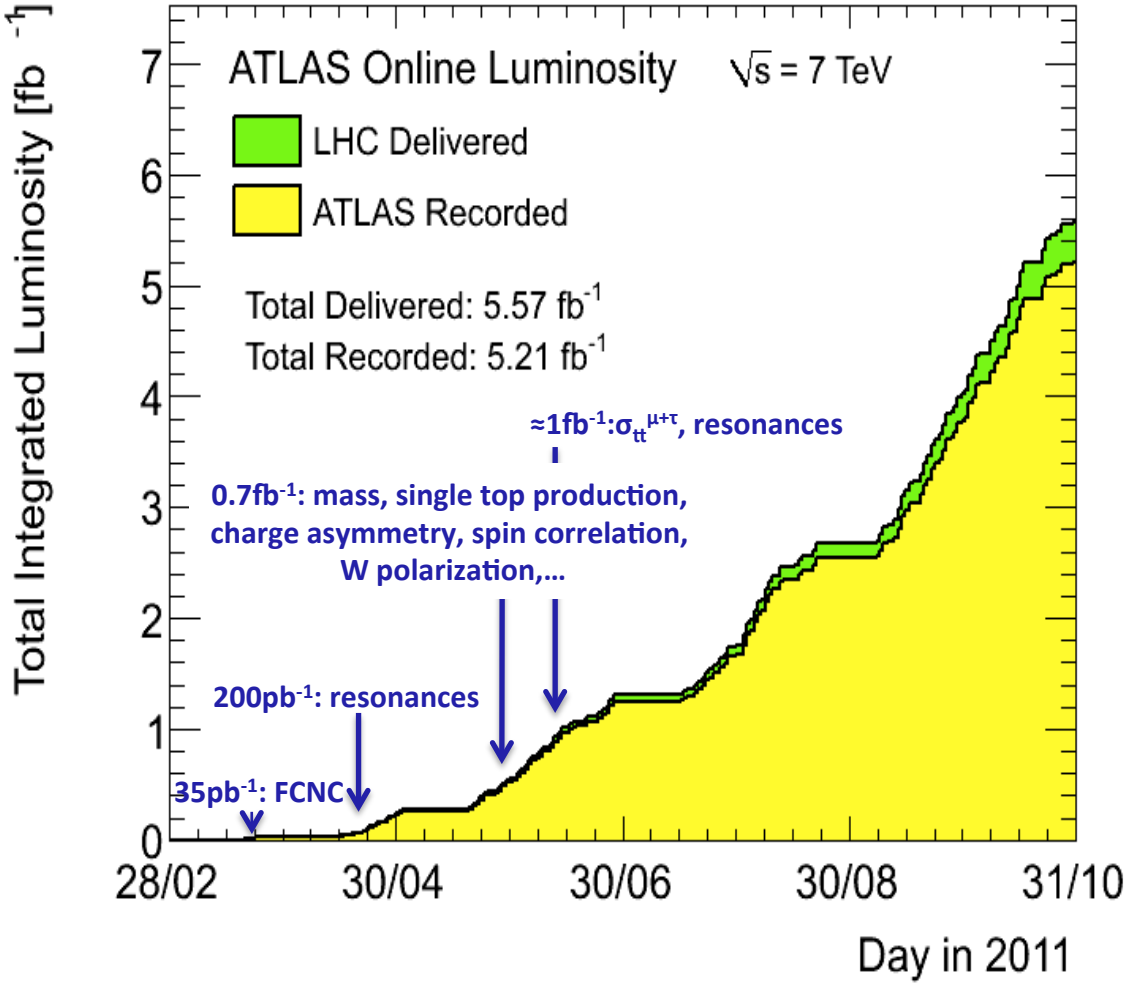


# ATLAS Performance for Top Physics

✧ **Collecting useful data:**



# ATLAS Performance for Top Physics

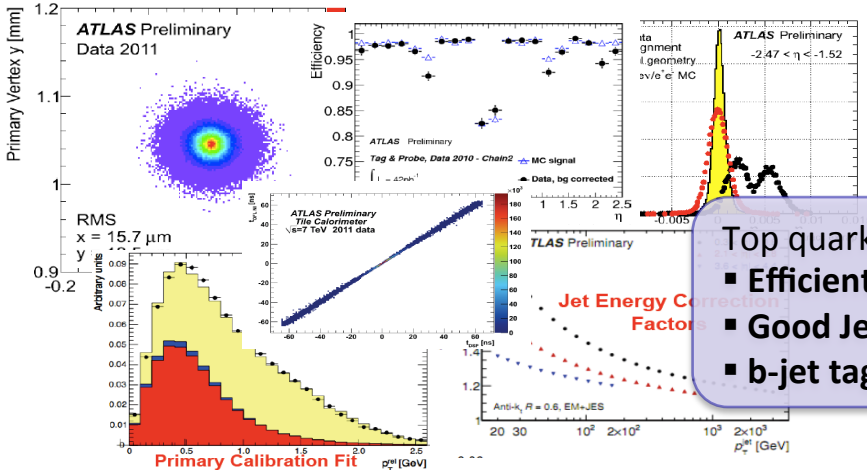
✧***Electron:*** Energy deposits in **EM calorimeter** with associated well reconstructed track in the **ID**

✧***Muon:*** Track segments in different layers of **muon chambers** are combined and matched with **ID** track

✧***Jets:*** Anti-kt4 algorithm is used starting from energy cluster of adjacent calorimeters jets. Calibration is done using **EM+HAD calorimeter** information

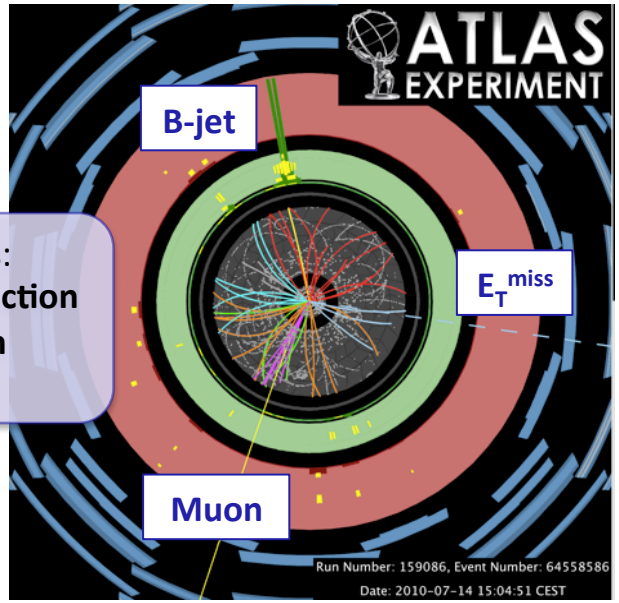
✧***b-tagging:*** Based on impact parameter. It requires a good **ID** tracking performance

✧***Trigger:*** Trigger is based on signatures of e, μ and jets, as well as missing transverse energy




Top quark in ATLAS needs:

- **Efficient e,μ,τ reconstruction**
- **Good Jet reconstruction**
- **b-jet tagging capability**




***Top physics ⇨ Full detector working!!!***

**Top production:**

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- Spin correlation

**New physics in top sector**

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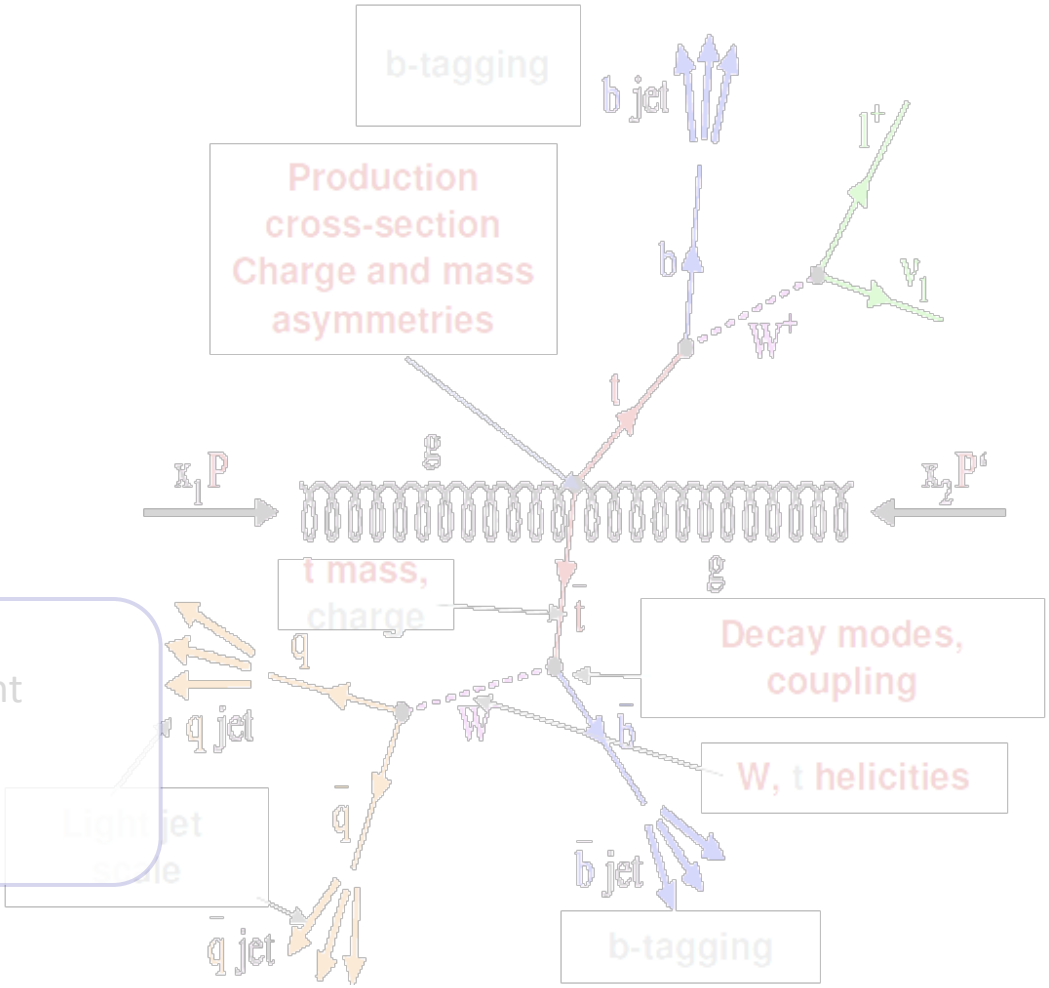


# Measurement of ttbar cross section

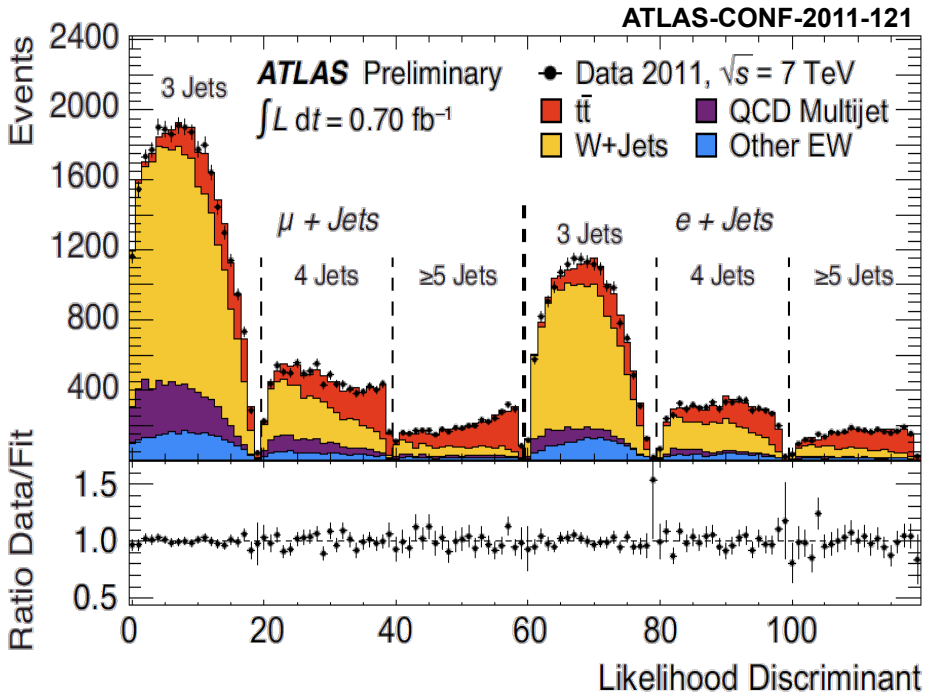
- ✧ Precise measurements of cross-section allow precision tests of perturvative QCD
- ✧ Validation of the SM at high energies: $\sigma_{tt}^{SM}=165^{+11}_{-16}$ pb
- ✧ Some of these measurements open new windows to new physics
- ✧ ttbar sample important background in searches for physics BSM

***σ(tt) in lepton+jets final states***

- ✧ Signature: lepton (e/μ), $E_T^{miss}$, at least 3 jets
- ✧ Multivariate Analysis:
  $\eta_l$, $p_T^{leading\ jet}$, aplanarity and $H_{T3}$

**$\sigma_t(tt)=179 \pm 3.9(stat) \pm 9.9(syst) \pm 6.6(lumi)$ pb**

- ✧ Uncertainty systematically dominated
- ✧ Challenging theoretical uncertainty:
  - ✧ $\Delta\sigma/\sigma$ = 6.6%



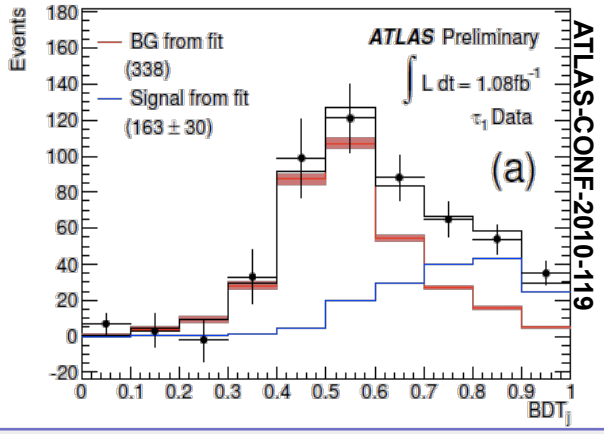
# Measurement of ttbar cross section

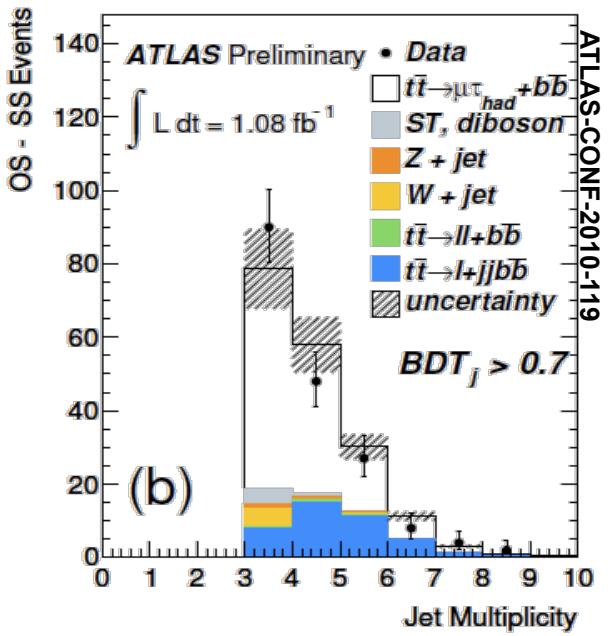
***ttbar cross-section in μ+τ final states***

**IFIC :** ATLAS-CONF-2010-119

**IFAE+IFIC:** Analysis update in progress

- ✧ Signature: μ and τ leptons, $E_t^{miss}$, 2 or more jets(1$b^{tag}$)
- ✧ Identification of τ-leptons uses a multivariate technique based on **B**oosted **D**ecision **T**ree




$\sigma_t$(μ+τ channel)=142 ±21(stat)$^{+20}_{-16}$(syst)±5(lumi) pb

The cross-section measurements has been performed in most of the ttbar final states:

- ✧ Single lepton+jets channel (w/wo b-tagging)
- ✧ Dilepton channel including all lepton flavour
- ✧ All hadronic channel

**IFAE:** ATLAS-CONF-2011-035
Analysis update in progress

Most of them are dominated by systematic errors

# Measurement of single top production

✧ Single top quark production via weak interaction provides a direct probe of W-t-b coupling and it is sensitive to new physics

✧ Measurement of the cross-section determines the quark mixing matrix element $V_{tb}$ without assumption of quark generations

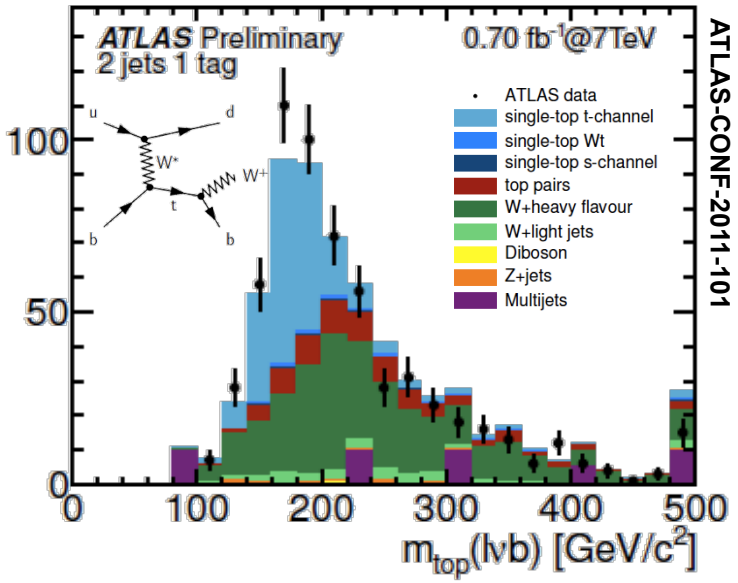
**t-channel** $\sigma_t^{SM}=64.6^{+3.3}_{-2.6}$ pb

✧ Signature: lepton (e/μ), $E_T^{miss}$, 2-3 jets($b^{tag}$)

✧ Cut-Based Analysis using discriminating variables: m(l,ν,$b^{tag}$), $H_T$, Δη(b,$j_1$),|η($j_1$)|

$\sigma_t$(t-chan)=$90^{+9}_{-9}$(stat)$^{+32}_{-20}$(syst) =$90^{+32}_{-22}$ pb

✧ Neural Network method has been used too




**Wt production** $\sigma_t^{SM}=15.7^{+1.3}_{-1.4}$ pb

✧ Signature: 1/2 leptons(e/μ), $E_T^{miss}$, 1/3 jets($b^{tag}$)

✧ Cut-Based Analysis

$\sigma_t$(Wt-channel)<39.1pb @95CL

**s-channel** $\sigma_t^{SM}=4.6\pm0.3$ pb

✧ Signature: lepton (e/μ), $E_T^{miss}$, 2 $b^{tag}$

✧ Cut-Based Analysis

$\sigma_t$(s-channel)<26.5pb @95CL

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**New physics in top sector**

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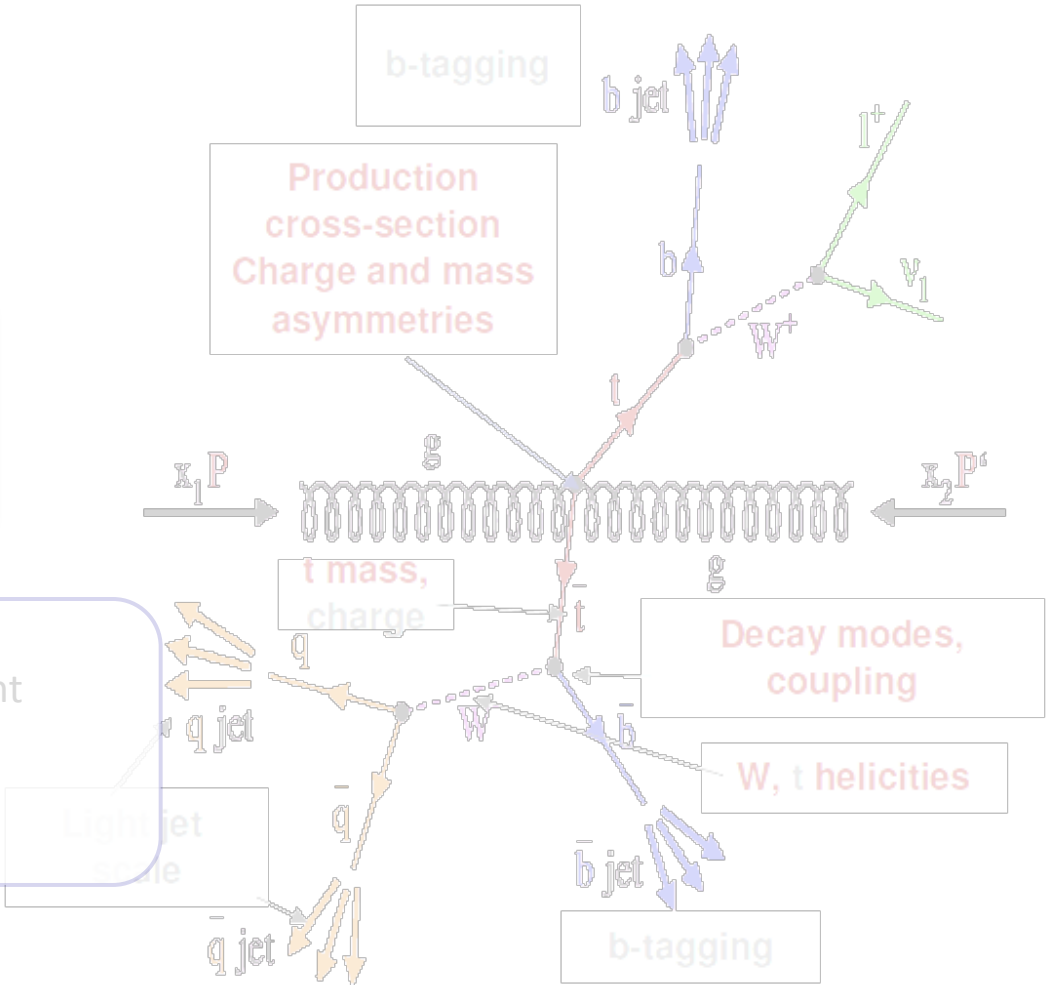
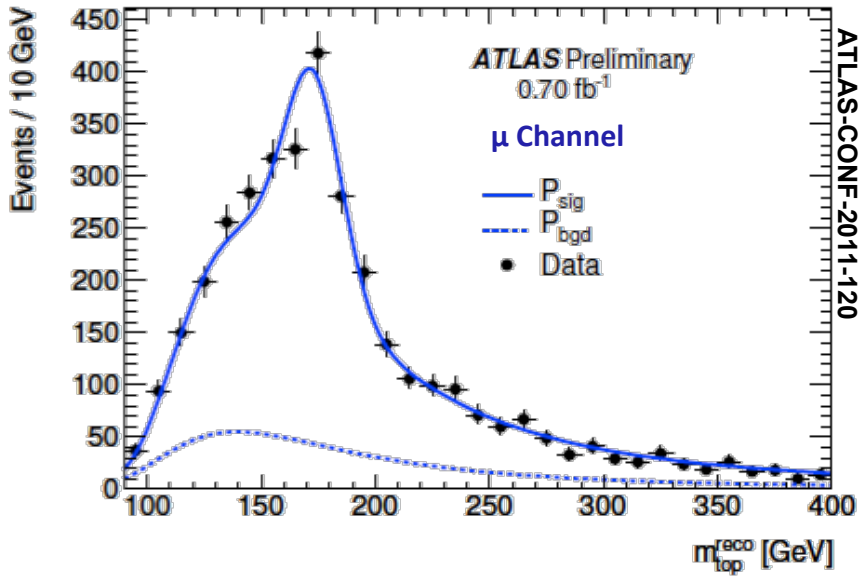


# Top Quark Mass

- ✧ Top quark mass is a fundamental parameter of the SM particle physics
- ✧ Several ATLAS top mass measurements has been performed:
  - ✧ Signature: 1 lepton (e/μ), $E_T^{miss}$, 4 jets($b^{tag}$)
  - ✧ Different methods:
    - 1-dimensional Template ($R_{32}$= $m_W/m_{top}$)
    - 2-dimensional template ($m_{top}$ & JES)




| | e+jets | μ+jets | ρ |
|---|---|---|---|
| Statistics | 1.2 | 1.0 | 0 |
| Method calibration | < 0.05 | 0.1 | 0 |
| Signal MC generator | 1.2 | 1.2 | 1 |
| Hadronization | < 0.05 | 0.4 | 1 |
| Pileup | < 0.05 | < 0.05 | 1 |
| Color reconnection | 0.6 | 0.9 | 1 |
| ISR and FSR (signal only) | 1.6 | 0.7 | 1 |
| Proton PDF | 0.1 | 0.1 | 1 |
| *W*+jets background normalization | 0.2 | 0.1 | 1 |
| *W*+jets background shape | < 0.05 | 0.1 | 1 |
| QCD background normalization | 0.4 | 0.4 | 0 |
| QCD background shape | 0.2 | 0.3 | 0 |
| Jet Scale Factor | 1.0 | 0.7 | 0 |
| Jet energy scale | 0.7 | 0.8 | 1 |
| *b*-jet energy scale | 2.0 | 1.7 | 1 |
| *b*-tagging efficiency and mistag rate | 0.1 | 0.3 | 1 |
| Jet energy resolution | 0.3 | 0.2 | 1 |
| Jet reconstruction efficiency | < 0.05 | < 0.05 | 1 |
| Missing transverse energy | 0.1 | 0.1 | 1 |
| Total systematic uncertainty | 3.1 | 2.7 | |

✧ Combination: **$m_{top}$= (175.9 ± 0.9$_{stat}$ ± 2.7$_{syst}$) GeV**

The uncertainty of the results is dominated by the systematic uncertainties:
- JES Uncertainty for b-jets and light-jets
- Initial and final state radiation
- Some aspects of the MC modelling

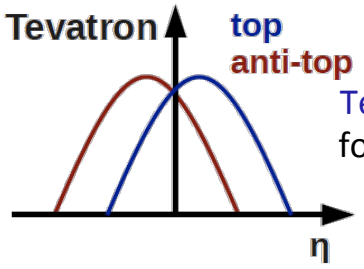
**IFIC: New methods to measure top quark mass in progress**

# Top Quark Charge Asymmetry

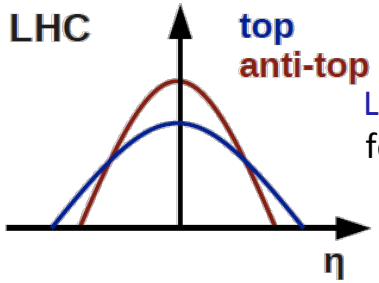
**IFAE & UV.GRANADA:** arXiv:1109.3710v1

**IFAE:** *ATLAS-CONF-2011-106*

- SM expects ttbar production symmetric under charge conjugation at LO and small asymmetry due to the ISR and FSR at NLO:
  - gg ⟹ ttbar: symmetric
  - $q\bar{q}$ ⟹ ttbar: top quarks emitted in the direction of the incoming quark
    anti-top quarks in the direction of the incoming anti-quark




Tevatron (proton-antiproton): forward-backward asymmetry
$q\bar{q}$ ⟹ ttbar (90%)



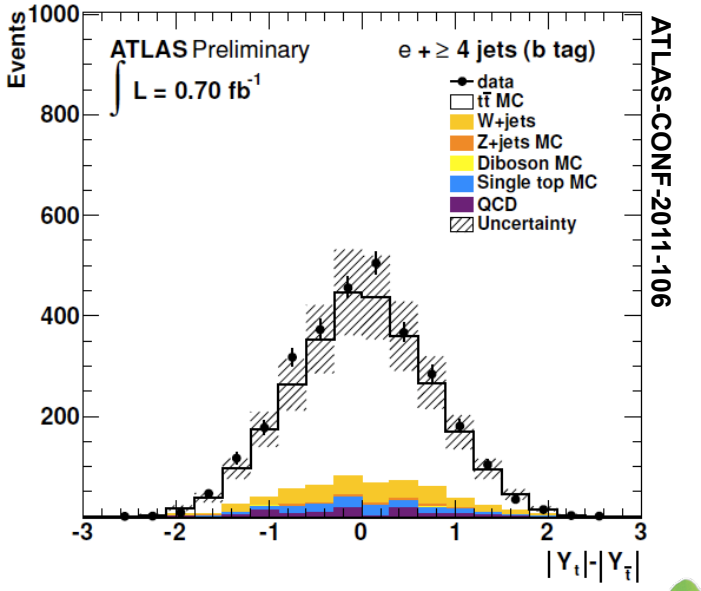

LHC (proton-proton): top goes into forwards regions whereas anti-top keep more in the central region
$q\bar{q}$ ⟹ ttbar (15%)

- Several processes BSM can alter this asymmetry

$$A_C = \frac{N(\Delta|Y| > 0) - N(\Delta|Y| < 0)}{N(\Delta|Y| > 0) + N(\Delta|Y| < 0)} \qquad \Delta|Y| \equiv |Y_t| - |Y_{\bar{t}}|$$

SM prediction $A_C \approx 0.01$ **(G.Rodrigo)**

- Signature: lepton (e/μ), $E_T^{miss}$, >4 jets
- Unfolding: Rapidity distribution for ttbar are distorted by detector effects and acceptance




**$A_C$= -0.024±0.016(stat)±0.023(syst)**

# W Polarization

✧Polarization of W bosons in top quark decays are sensitive to the structure Wtb-vertex

(used to set limits on the anomalous contributions to the Wtb-vertex)

| | |
|---|---|
| W polarization helicity fractions | $F_0^{NNLO}$=0.587±0.005 |
| | $F_L^{NNLO}$=0.311±0.005 |
| | $F_R^{NNLO}$=0.0017±0.001 |

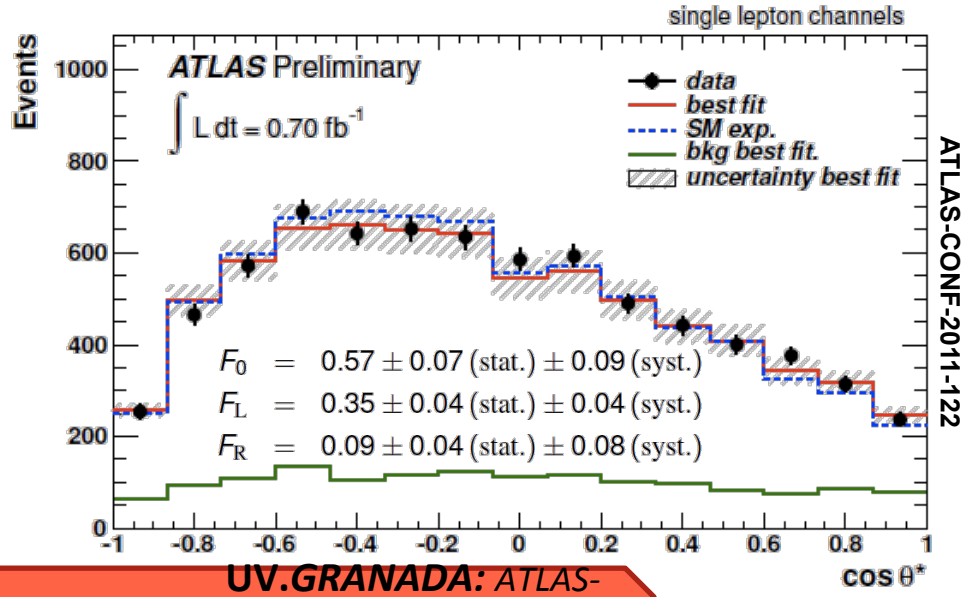
New physics can be parametrised in terms of an effective Lagrangian:

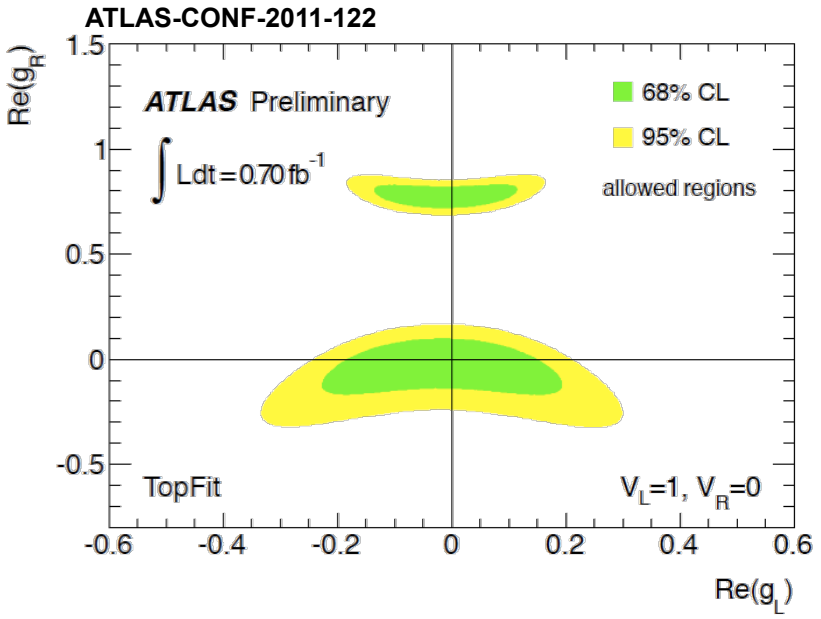
$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(V_L P_L + V_R P_R)\,t\,W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(g_L P_L + g_R P_R)\,t\,W_{\mu}^{-} + \text{h.c.}$$

Anomalous coupling $V_R$, $g_L$ and $g_R$ are absent in the SM at tree level

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{8}(1+\cos\theta^*)^2 F_R + \frac{3}{8}(1-\cos\theta^*)^2 F_L + \frac{3}{4}(1-\cos^2\theta^*) F_0$$

Cosθ*: angle between charged lepton form the W decay and b quark form the top decay in the W boson rest frame




**UV.GRANADA:** *ATLAS-CONF-2011-122*

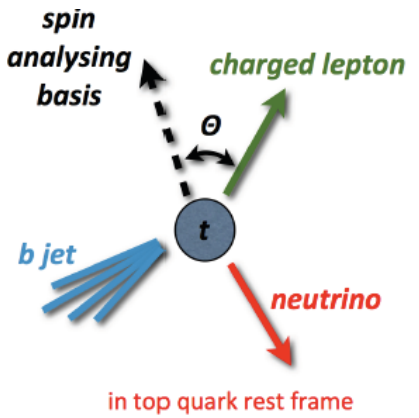
**IFIC: W in single top analysis in progress**

# Spin Correlations

✧ Top quark has short lifetime: $\tau_t = (3.3^{+1.3}_{-0.9}) \times 10^{-25}$ s

✧ Top decays before spin can flip

✧ Spin information is contained in the decay products (angular distributions)

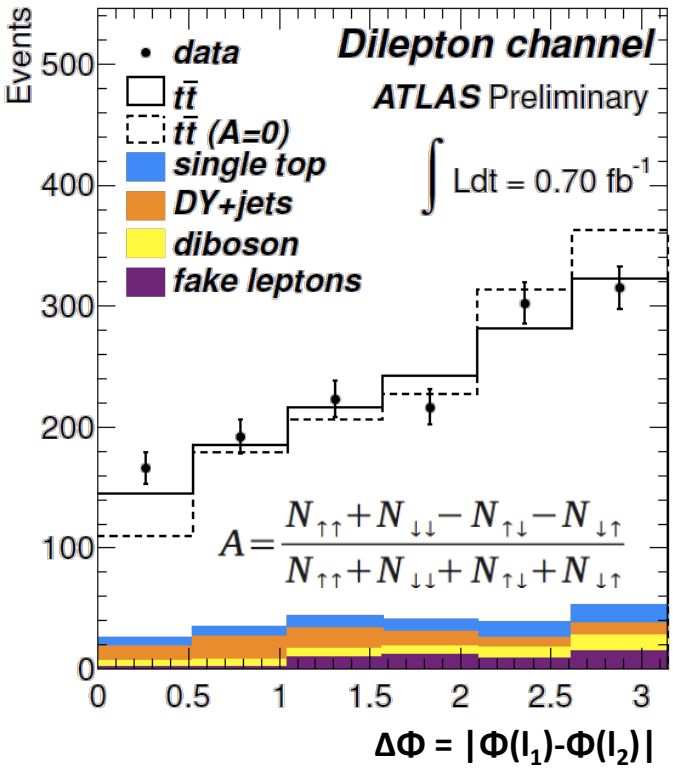



In the quark decay the V-A couplings fix the angular distribution of the decay products according to the polarization of the parent top quark via:

$$\frac{1}{N}\frac{dN}{d\cos(\theta_i)} = \frac{1}{2}[1 + \alpha_i \cos(\theta_i)]$$

| | $b$-quark | $W^+$ | $l^+$ | $\bar{d}$-quark or $\bar{s}$-quark | $u$-quark or $c$-quark |
|---|---|---|---|---|---|
| $\alpha_i$ (LO) | -0.41 | 0.41 | 1 | 1 | -0.31 |
| $\alpha_i$ (NLO) | -0.39 | 0.39 | 0.998 | 0.93 | -0.31 |

✧Dilepton channel promise larger sensitivity:
2 leptons, $E_t^{miss}$,≥2jets




✧ $f^{SM}$ is the SM template strength:

$f^{SM} = N_{SM}/(N_{SM}+N_0)$ in SM $f^{SM}=1$

$$f^{SM} = 1.06^{+0.46}_{-0.34} \qquad A_{helicity} = 0.34^{+0.15}_{-0.11}$$

✧Results in agreement with $A^{SM}_{helicity}$=0.32

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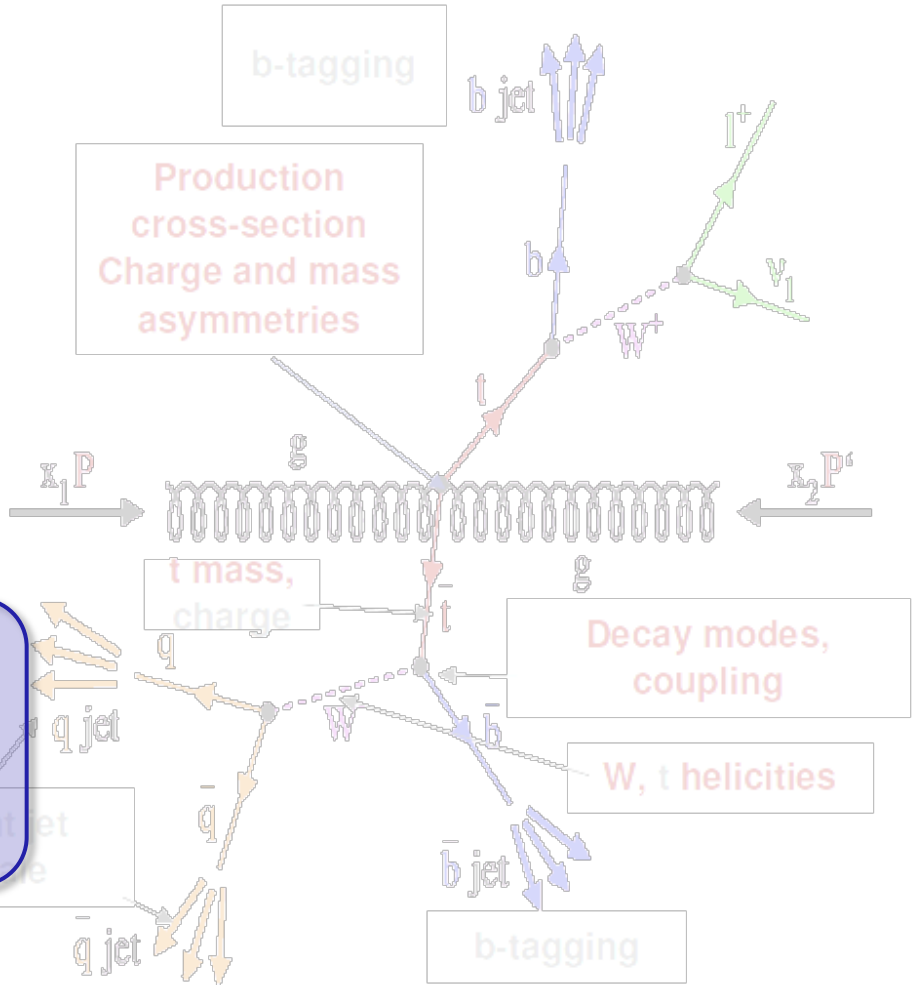
- Exotics heavy quark searches
- …



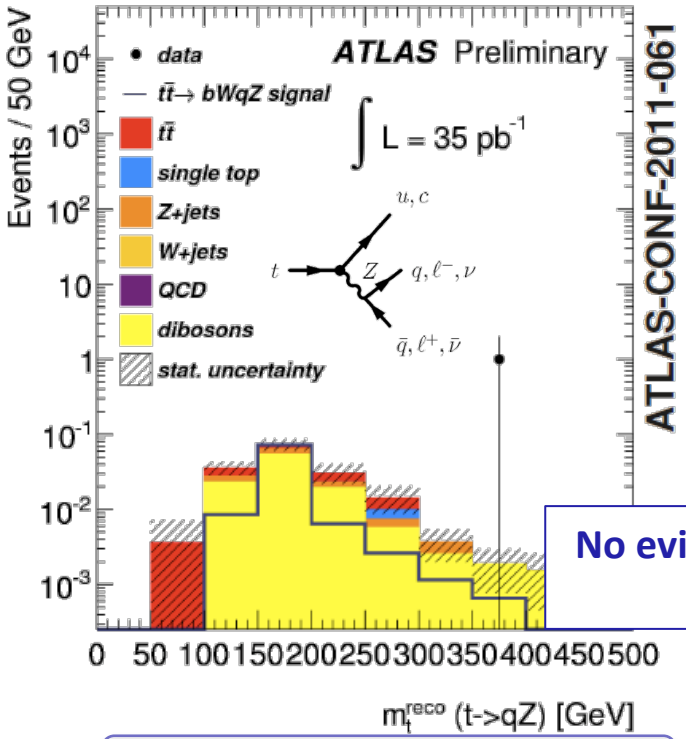
# Flavour Changing Neutral Current searches

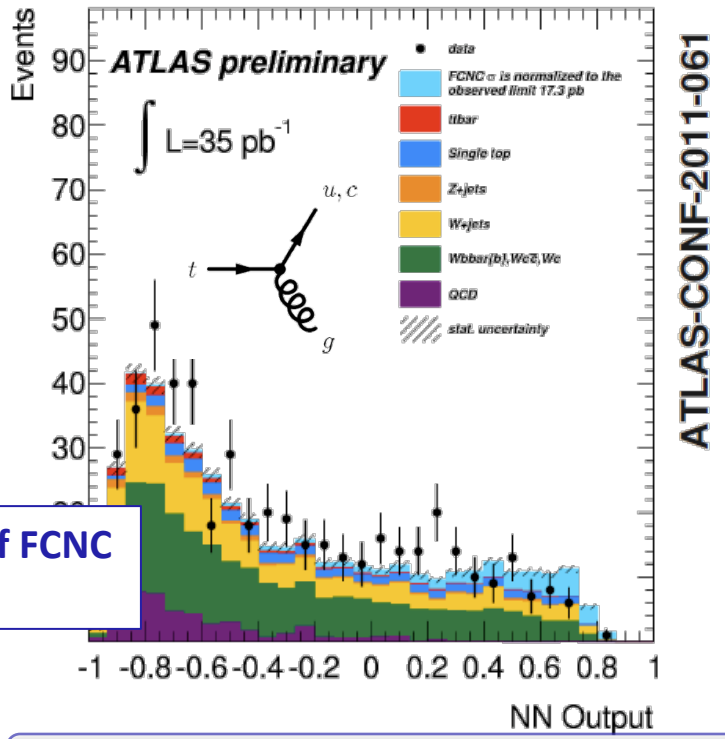
- According to the SM, FCNC are forbidden at tree level and much smaller at one loop.
- Several SM extensions predicts higher branching fractions for top quark FCNC decays.

**Top Pair**

- One top decaying through SM and the other trough FCNC

**Single top**




**No evidence of FCNC is found**

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

$\sigma_{qg \rightarrow t} \times BR(t \rightarrow bW) < 17.3$ pb at 95%

# ttbar resonance searches

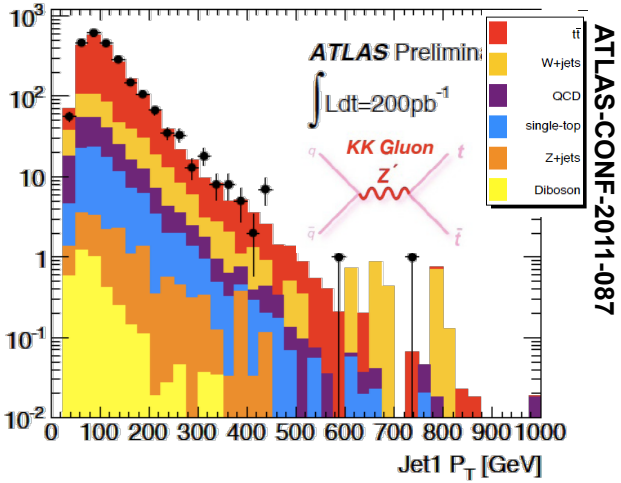
✧Many models of physics BSM predict the existence of new resonances that decay predominantly into top quark pairs

***Mass resonances in semi-leptonic channel***

✧ **Z' resonance in the leptophobic scenario**

- ✧ Special attention on top mass reconstruction ($m_{tt}$):
- ✧Comparison of top quark pair invariant mass with background only and signal+background hypoteses:
  - ✧If no excess in the comparison with SM predictions is found ⟹ limit on the (σxBR) vs $m_{tt}$ is set

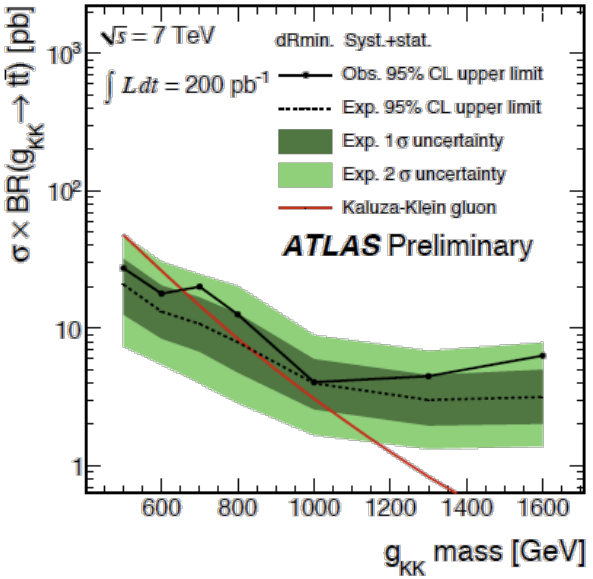
✧ Narrow resonances predicted by leptophobic topcolour model can not be excluded




✧ **Kaluza-Klein gluon resonance in the Randall-Sundrum model**

- ✧ K-K gluons with masses below 650GeV are excluded @ 95CL

*For resonance masses above 1TeV, the top quark decay products start to become strongly collimated, so reconstruction of these resonances is the subject of forthcoming studies: boosted topology*



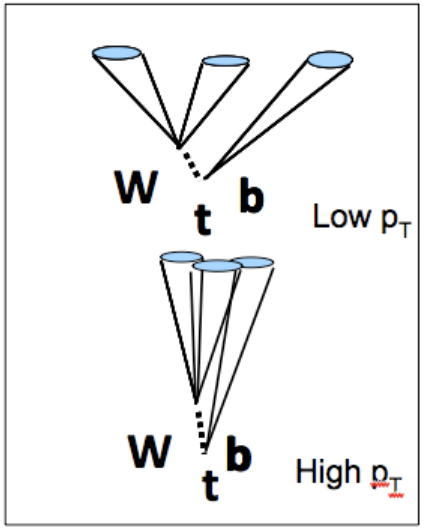

**IFIC:** *ATLAS-CONF-2011-087*

# Boosted tops

✧ For resonance masses higher than 1TeV the top quark candidates are ***Boosted tops***

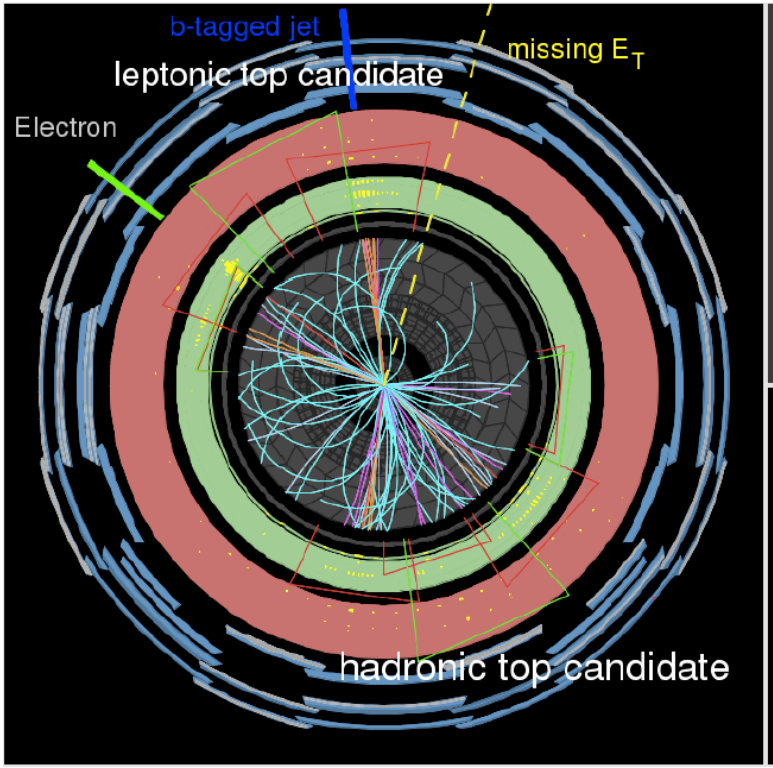
✧ Classical "resolved" algorithms, developed for tops at rest, are not adequate for highly boosted top decays:

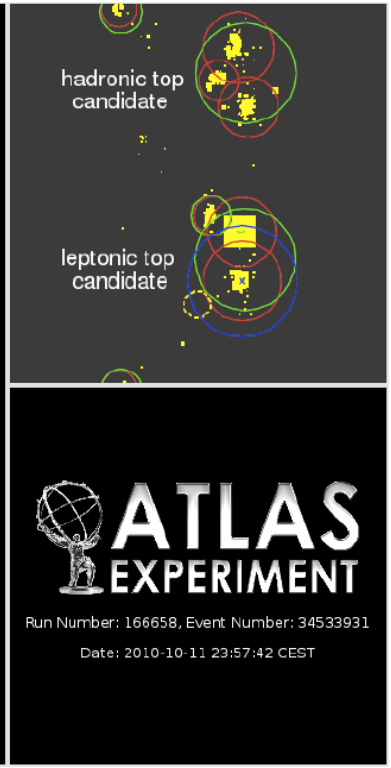
- ✧Jets from hadronic top decay not resolved
- ✧Isolation of leptons




✧In the "boosted" topology tops are reconstructed as "fat" jets

ATLAS-CONF-2011-073




**IFIC: Imminent publication of ATLAS-CONF-2011-073**

# top partner searches

***ttbar events with large Missing transverse energy***

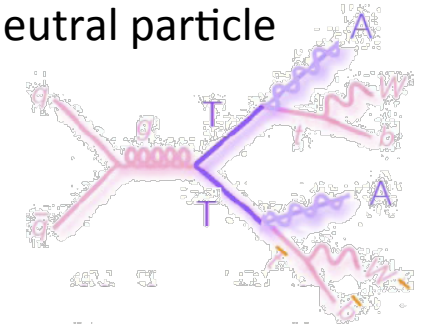
✧ Model where new top quark partner are pair-produced and each top decay to an on-shell top (or anti-top) quark and long-lived undetected neutral particle

✧ **TT->ttA$_0$A$_0$:**

✧ ttbar signature

✧ Large $E_t^{miss}$ form undetected $A_0$

✧ Many models present this signature



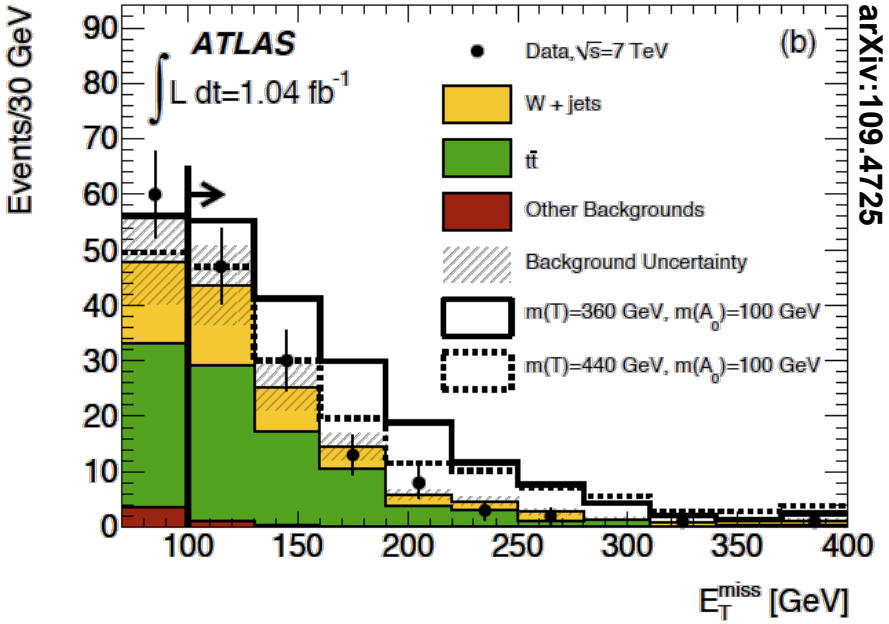

✧ Data consistent with the SM predictions

✧ No evidence of an excess of $E_T^{miss}$

✧ In absence of of signal an upper limit on the (σxBR) is quoted:

✧ (σxBR) of 1.1pb for m(T)=420GeV and m($A_0$)<1o GeV excluded @ 95%CL

✧ In the exotic model of 4$^{th}$ generation m(T)>420GeV and m($A_0$)>140GeV are excluded

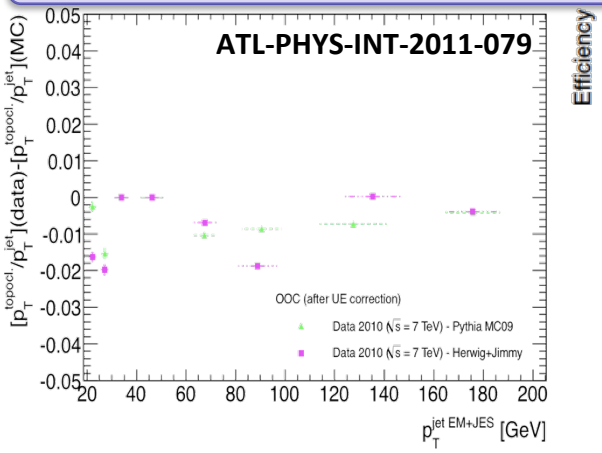



**IFAE: Top quark 4$^{th}$ generation work in progress**

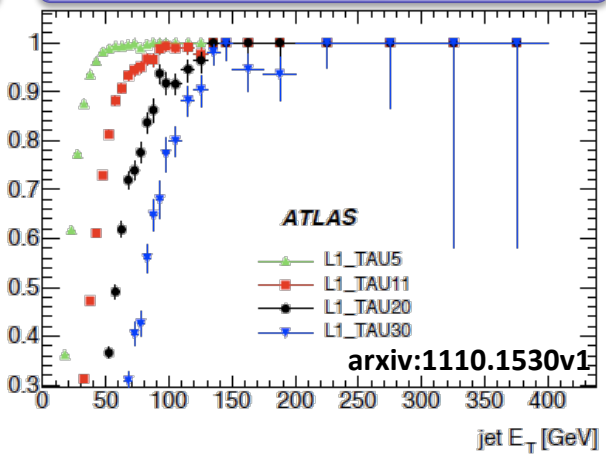
# Studies on event and object reconstruction

✧Top analysis require a hard work in reconstruction, performance detector,…

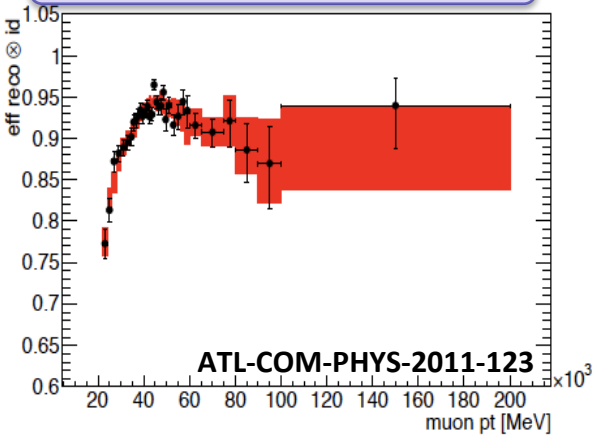
## Jet Shapes data/MC comparison



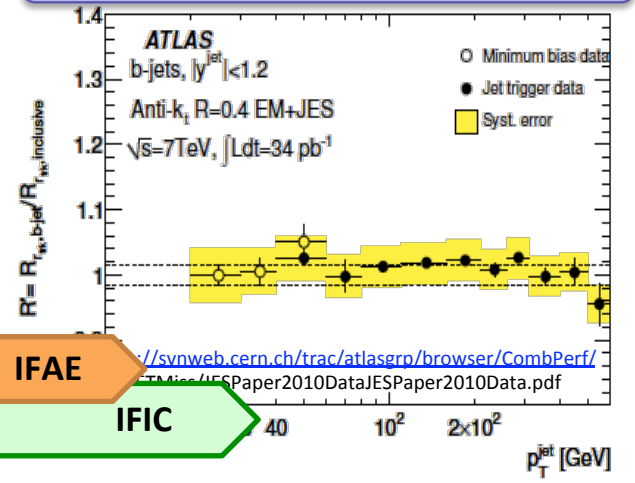

## Tau trigger




## Muon Scale Factor



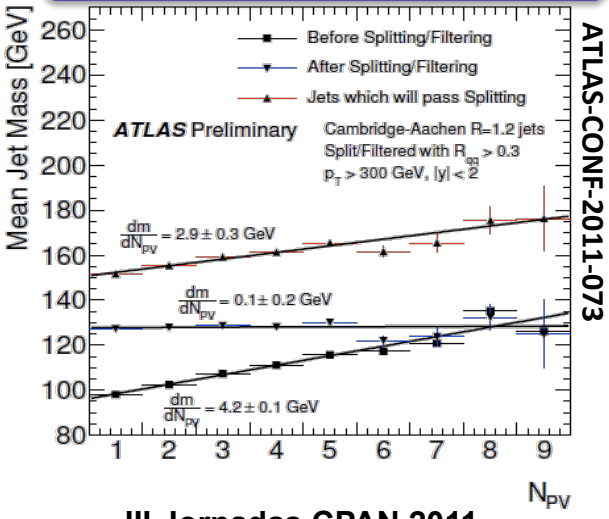

## B-jes uncertainty validation



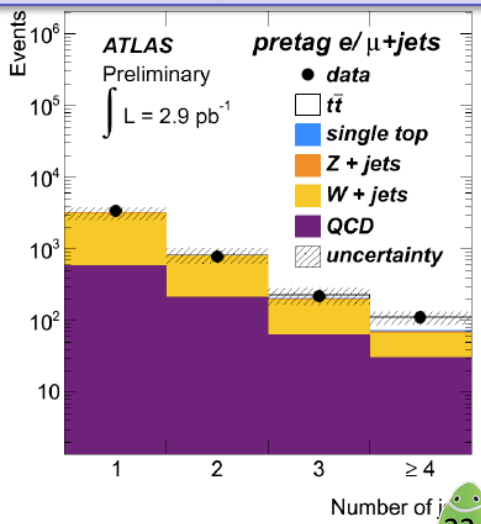

IFAE

IFIC

## Fat Jet systematics




## QCD Background studies



# Summary

- The top quark physics program in ATLAS is really huge!
- Many measurements has been done:
  - Top Cross section:
    - Top pair cross section has been performed in almost all the final states
    - Single top cross section has been measured too
  - Top quark properties:
    - These ones have been extensively studied
  - Searched for new physics:
    - Studies are on-going and many results will arrive for next conferences

- At this moment many studies are on-going:
  - Using more statistic (ATLAS has now 5.2fb$^{-1}$)
  - Increasing understanding of the detectors is continously improving
- New top precision measurements and observation are coming!!!

**The Spanish contribution to top quark physics in ATLAS is and will be really important**


# Thank you very much

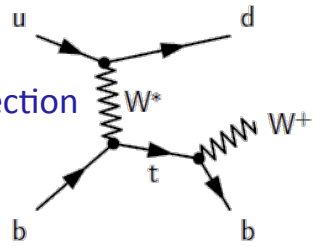
# Measurement of single top production

- Single top quark production via weak interaction
- Provides a direct probe of W-t-b coupling and is sensitive to new physics
- Measurement of the cross-section determines the quark mixing matrix element $V_{tb}$ without assumption of quark generations

***t-channel***

- Leptonic decay mode: e/μ, $E_t^{miss}$,2-3jets($b^{tag}$)

Single top higher cross section
$\sigma_t^{SM}=64.6^{+3.3}_{-2.6}$ pb




***Cut-Based analysis***

- 4 discriminan variable: m(l,ν,$b^{tag}$), $H_T$, Δη(b,$j_1$),|η($j_1$)|

**$\sigma_t$(t-chan)=$90^{+9}_{-9}$(stat)$^{+32}_{-20}$(syst) =$90^{+32}_{-22}$ pb**

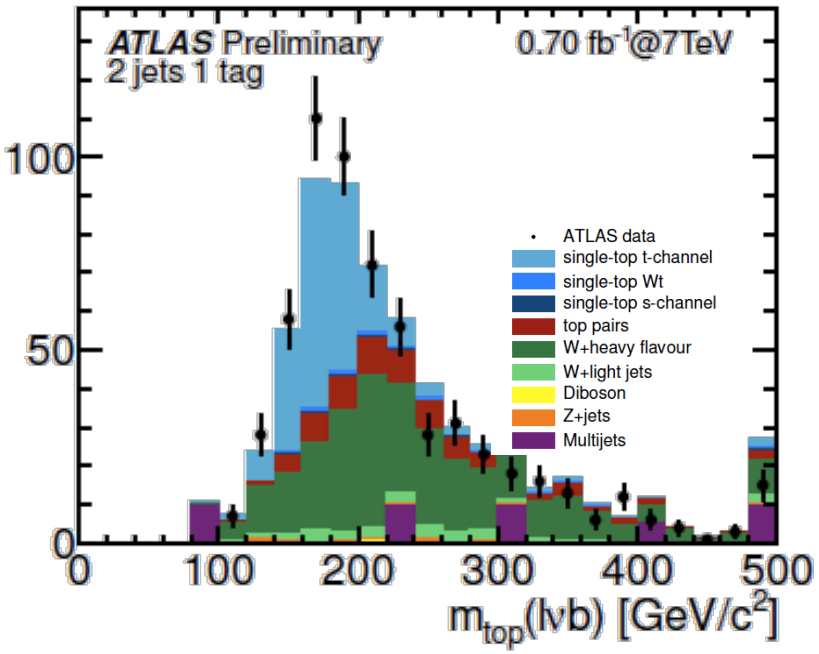
- Consistent with SM t-channel expectation

***Neural network analysis***

- 13 variables used

**$\sigma_t$(t-chan)=105±7(stat)$^{+36}_{-30}$(syst) pb**

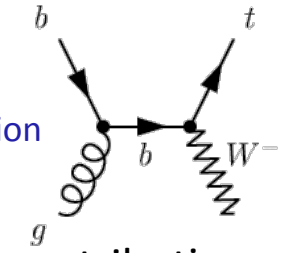
ATLAS-CONF-2011-101



# Measurement of single top production

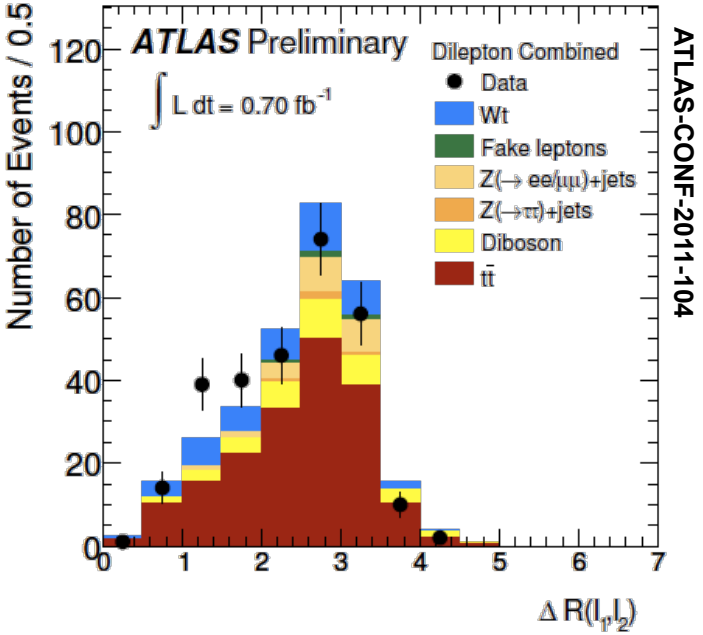
## *Wt production*

Single top higher cross section
$\sigma_t^{SM}=15.7^{+1.3}_{-1.4}$ pb



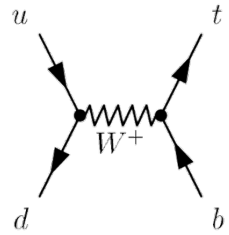

- Cut-Based method to select Wt contribution
- After selection (15% purity)

**$\sigma_t$(Wt-channel)<39.1pb @95CL**



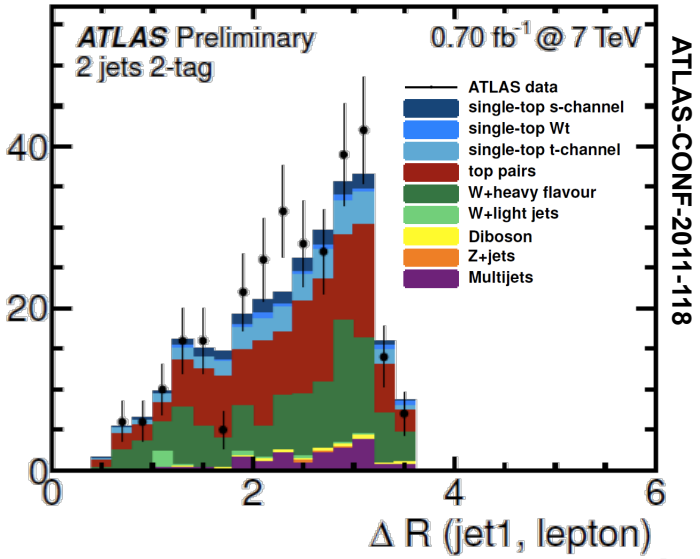

## *s-channel*

Single top higher cross section
$\sigma_t^{SM}=4.6\pm0.3$ pb




- Leptonic decay mode: e/μ, $E_t^{miss}$,2 jets($b^{tag}$)
- Cut-based analysis method
- Many variables as potential discriminators between signal and background
- Signal purity in the signal region ~6%

**$\sigma_t$(s-channel)<26.5pb @95CL**



# ttbar resonance searches

✧Many models of physics BSM predict the existence of new resonances that decay predominantly into top quark pairs

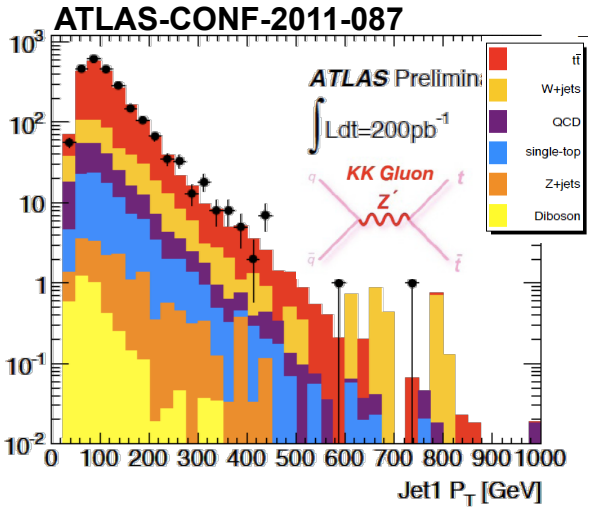
***Mass resonances in semi-leptonic channel***

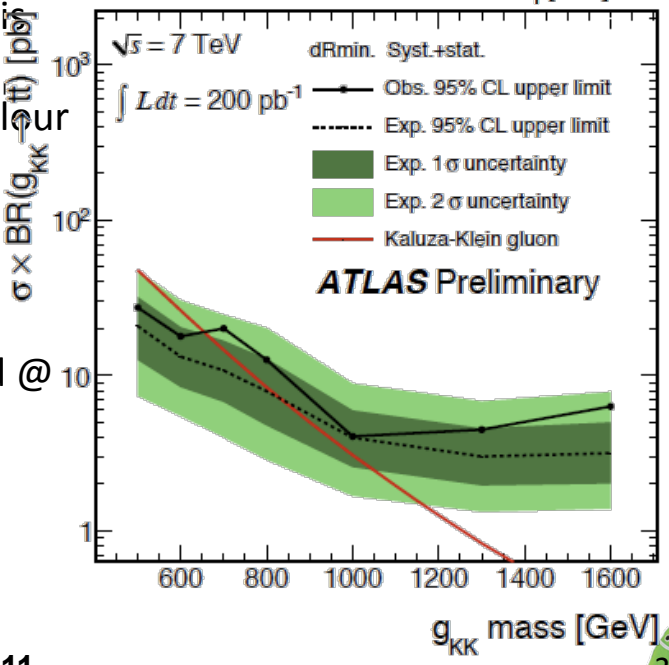
✧ **Z' resonance in the leptophobic scenario**

- ✧ Special attention on top mass reconstruction ($m_{tt}$):
- ✧ DeltaRmin algorithm to reduce IFS/FSR
- ✧ Comparison of top quark pair invariant mass with background only and signal-plus-background hypoteses:
  - ✧ Comparison to SM predictions
  - ✧ If no excess is found limit on the (σxBR) vs $m_{tt}$ is set
- ✧ Narrow resonances predicted by leptophobic topcolour model can not be excluded.

✧ **K-K gluon resonances in the Randall-Sundrum model**

- ✧ Semileptonic channel
- ✧ K-K gluons with masses below 650GeV are excluded @ 95CL




**IFIC:** *ATLAS-CONF-2011-087*

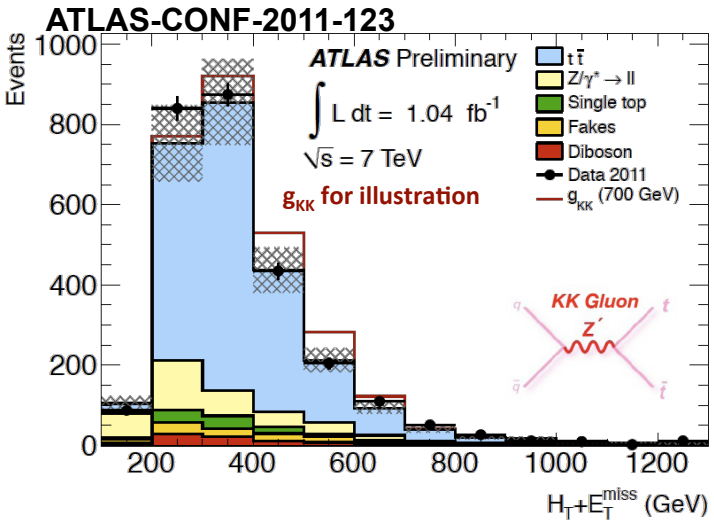
# ttbar resonance searches

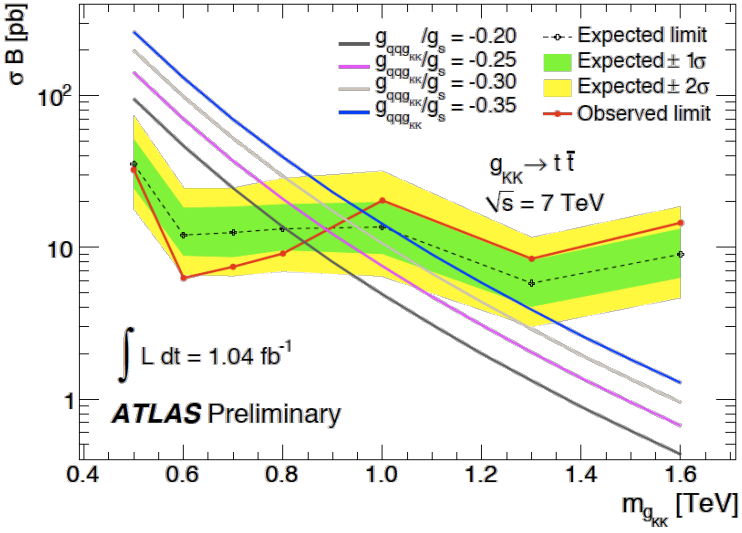
## *Mass resonances in dileptonic resonances*

- K-K gluon resoances in the Randall-Sundrum model
- Interesting variables:
  - $H_T + E_t^{miss}$ : searches for an excess of this distribution (KK gluon resonances harder spectrum than SM quark production)

- Resonance searches in the dilepton ttbar final state don't show significant excess in $H_T + E_t^{miss}$ spectrum.
- Set limits on σB for KK gluon production
- Mass of the KK-gluon in the Randall-Sundrum model higher than 0.84TeV @95CLMass

*For resonance masses above 1TeV, the top quark decay products start to become strongly collimated, so reconstruction of these resonances is the subject of forthcoming studies: boosted topology*




**IFIC:** *ATLAS-CONF-2011-123*

# Measurement of ttbar cross section

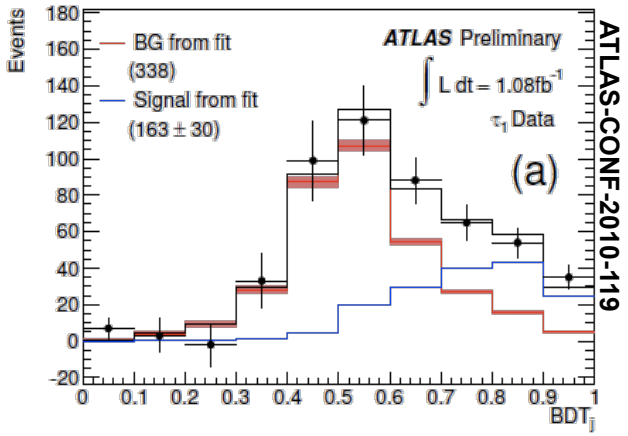
- ✧ Precise measurements of cross-section allow precision tests of perturvative QCD
- ✧ Validation of the SM at high energies: $\sigma_{tt}^{SM}=164^{+11}_{-16}$ pb
- ✧ Some of these measurements open new windows to new physics
- ✧ ttbar sample important background in searches for physics BSM

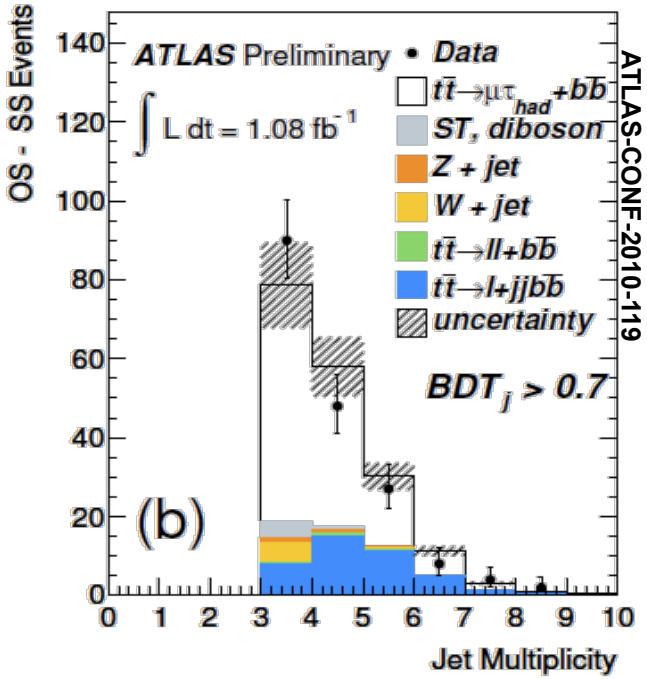
## *ttbar cross-section in μ+τ final states*

**IFIC :** ATLAS-CONF-2010-119

**IFAE+IFIC:** Analysis update in progress

- ✧ Signature: μ and τ leptons, $E_t^{miss}$, 2 or more jets(1$b^{tag}$)
- ✧ Identification of τ-leptons uses a multivariate technique based on **B**oosted **D**ecision **T**ree




$\sigma_t$(μ+τ channel)=142 ±21(stat)$^{+20}_{-16}$(syst)±5(lumi) pb

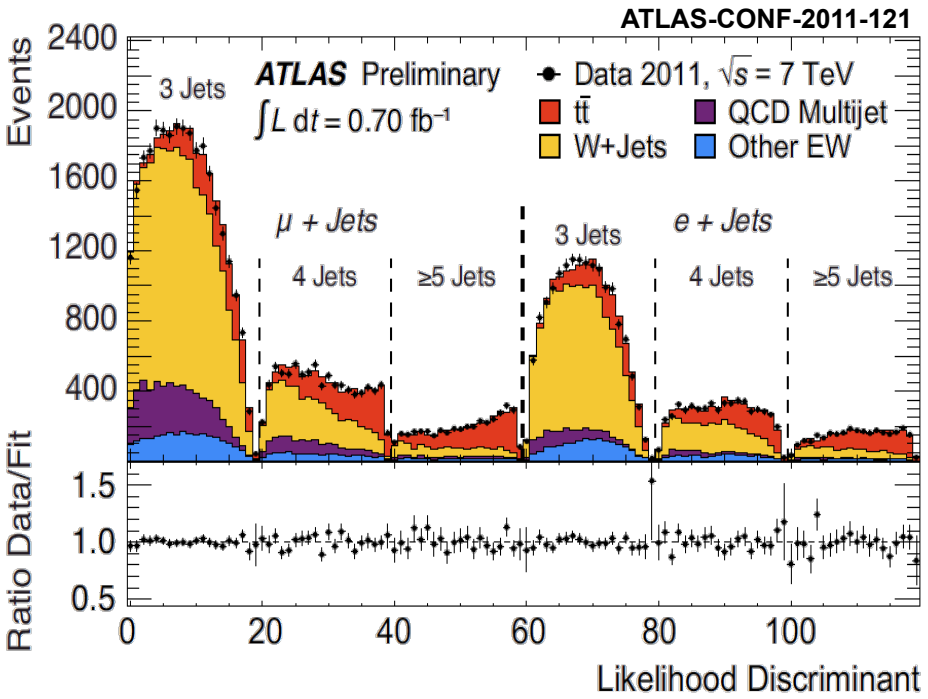
# Measurement of ttbar cross section

***σ(tt) in lepton+jets final states***

- Signature: lepton (e/μ), $E_T^{miss}$, at least 3 jets
- Multivariate Analysis:
  $\eta_l$, $p_T^{leading\ jet}$, aplanarity and $H_{T3}$

**$\sigma_t$(tt)=179 ±3.9(stat)±9.9(syst)±6.6(lumi) pb**

- Uncertainty systematically dominated
- Challenging theoretical uncertainty:
  - $\Delta\sigma/\sigma$ = 6.6%




The cross-section measurements has been performed in most of the ttbar final states:

- Single lepton+jets channel (w/wo b-tagging)
- Dilepton channel including all lepton flavour
- All hadronic channel

**IFAE:** ATLAS-CONF-2011-035
Analysis update in progress

Most of them are dominated by systematic errors