Recent Results on Top Physics At ATLAS

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BNL Forum 2013 (May 01 – 03)

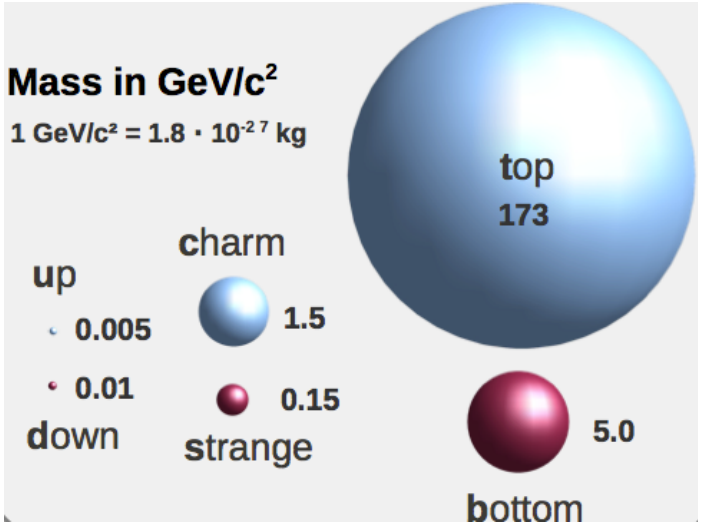
On behalf of the ATLAS Collaboration

The University *of* Oklahoma

The Top Quark

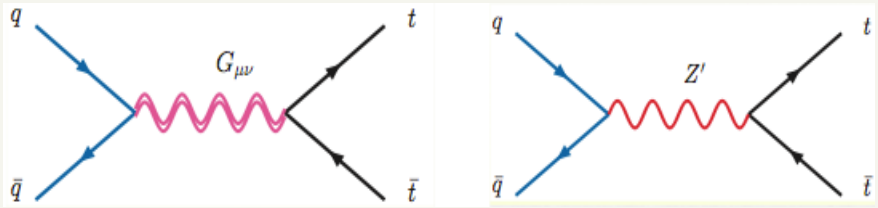
Why Interesting:

- ✓ Large mass ➡ Large coupling to the Higgs boson
- ✓ Decays as free quark (before hadronization)
- ✓ Precision measurement of cross section, branching ratio. Polarization could indicate presence of New Physics



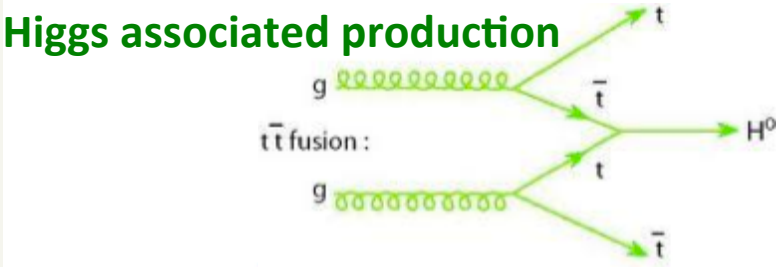
New Physics Searches :

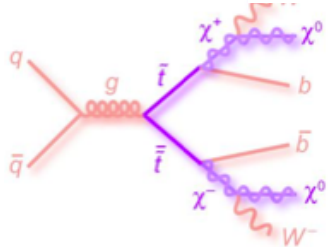
- ✓ Various scenarios **with direct/indirect coupling to new physics : (ttH, BSM --> resonance, KK gluon, stop production)**



- ✓ Major source of background for many searches

Higgs associated production



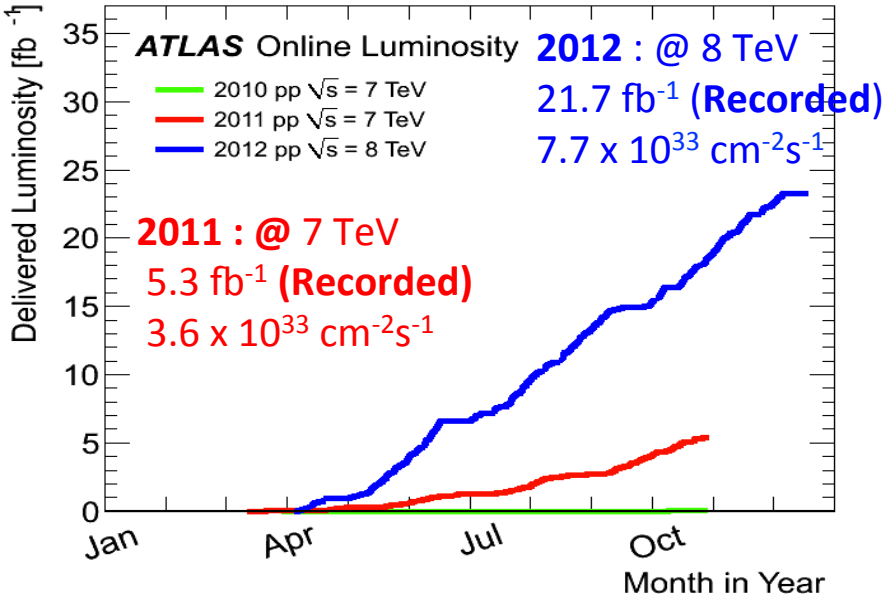


Stop search

Tool for precise tests of SM and an interesting hunting place for new physics !

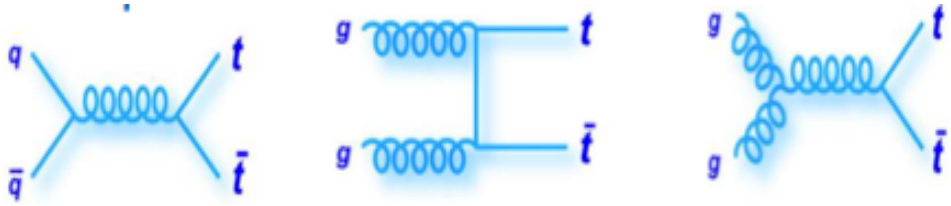
The tool of trade

- **LHC a top factory**
  - ✓ **ATLAS** (CMS) top observer



2012 : @ 8 TeV
21.7 fb^{-1} (**Recorded**)
7.7 x 10^{33} cm^{-2}s^{-1}

2011 : @ 7 TeV
5.3 fb^{-1} **(Recorded)**
3.6 x 10^{33} cm^{-2}s^{-1}



NNLO+NNLL cross section for m_t =173 GeV[arXiv:1303.6254]		
	@ √s = 7TeV (pb)	@ √s = 8TeV (pb)
$t\bar{t}$	$172.0^{+4.4}_{-5.8}{}^{+4.7}_{-4.8}$	$245.8^{+6.2}_{-8.4}{}^{+6.2}_{-6.4}$
Approx. NNLO cross section for m_t = 173 GeV [arXiv: 1210.7813]		
t-channel	$65.9^{+2.1}_{-0.7}{}^{+1.5}_{-1.7}$	$87.2^{+2.8}_{-1.0}{}^{+2.0}_{-2.2}$
s-channel	$4.56 \pm 0.07^{+0.18}_{-0.17}$	5.55 ± 0.08 ± 0.21
Wt-channel	15.6 ± 0.4 ± 1.1	22.2 ± 0.6 ± 1.4

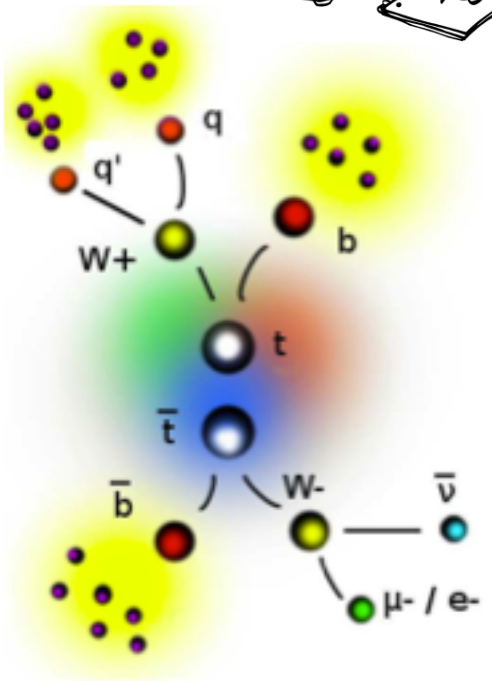
- ATLAS has recorded hundreds of thousands of top quarks
- Great opportunity to study the details of tt production mechanism
- Theory predictions & models need to be tuned & tested with measurements

Finding top quark and tt events

- In the SM top quark decays overwhelmingly as :

  $t \rightarrow W^{+}b$

- Gives several handles for identification (**Detector Calibration**)
  - e/μ/τ from W decays
  - b-jets
  - Missing transverse energy from neutrino
- Each must be understood with high precision
- Final state are categorized by the W decays



ATLAS top physics program:

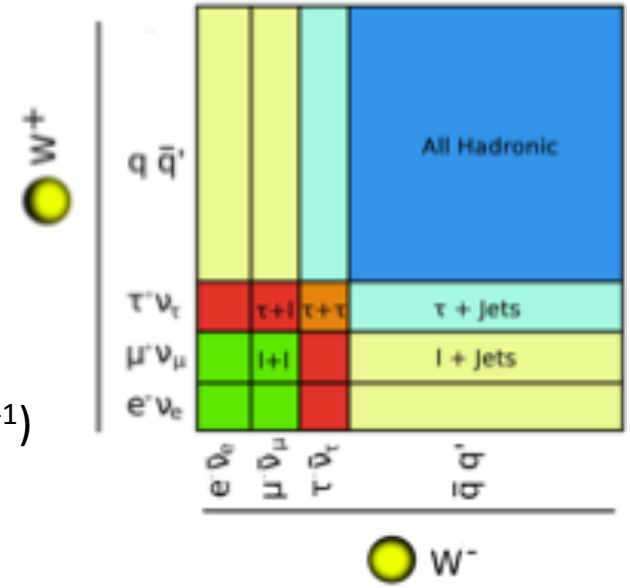
Several measurements performed

Most of them are now **syst. dominated**. Based on :

7 TeV data upto ~ 5 fb^{-1}

8 TeV data upto ~ 5.6 fb^{-1}

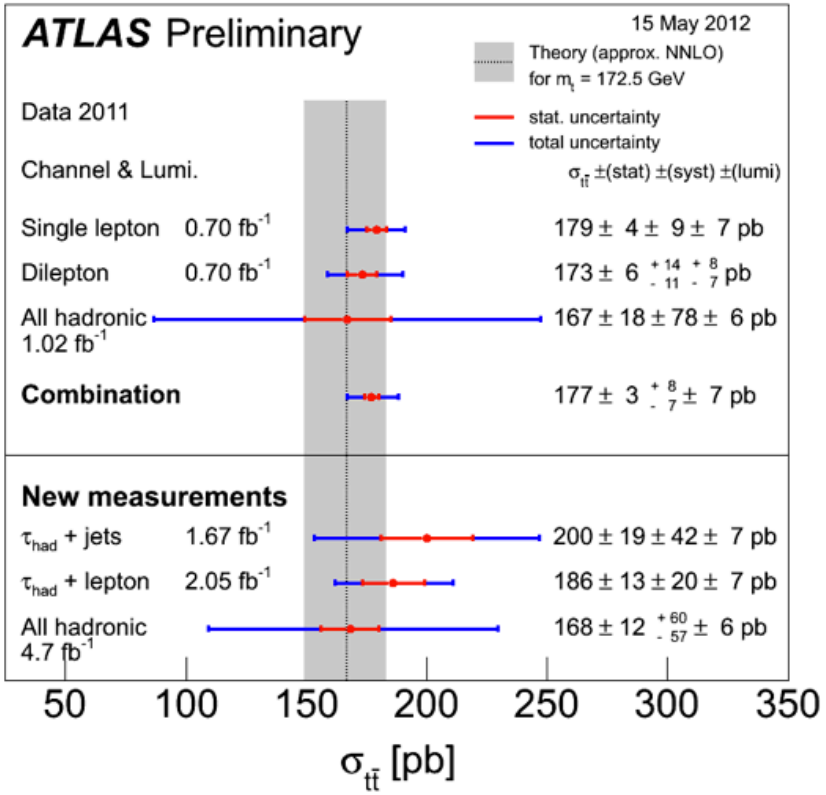
Analyses ongoing using full (21.7 fb^{-1}) 2012 data



Summary of σ_{tt} results @ 7 TeV

pp collisions, √s = 7 TeV ; upto 4.66 fb^{-1}

- ✓ Final state lepton+jets with 4.66 fb^{-1} ATLAS-CONF-2012-131
- ✓ 2 high p_T-lepton (in final state) JHEP 1205 (2012) 059
- ✓ Final state with e/mu and a hadronically decay tau: arXiv:1205.2067 [hep-ex] PLB
- ✓ Di-lepton final states: Phys. Lett. B707(2012) 459-477
- ✓ Combination : ATLAS-CONF-2012-024



First LHC combination !

(up to L = 1.1 fb^{-1})

ATLAS-CONF-2012-134

$$\sigma_{tt} = 173.3 \pm 2.3\,(\text{stat.}) \pm 9.9\,(\text{syst})\ \text{pb}$$

Total Uncertainty: 5.8%

Summary of σ_{tt} results @ 8 TeV

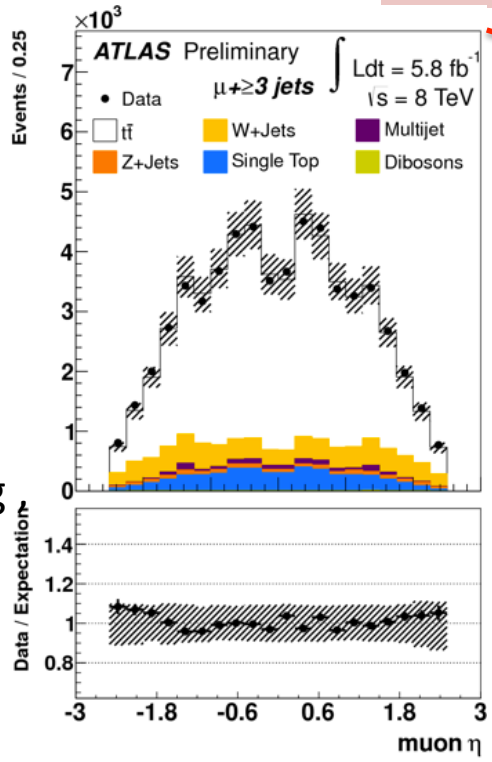
pp collisions, √s = 8 TeV ; upto 5.8 fb^{-1}

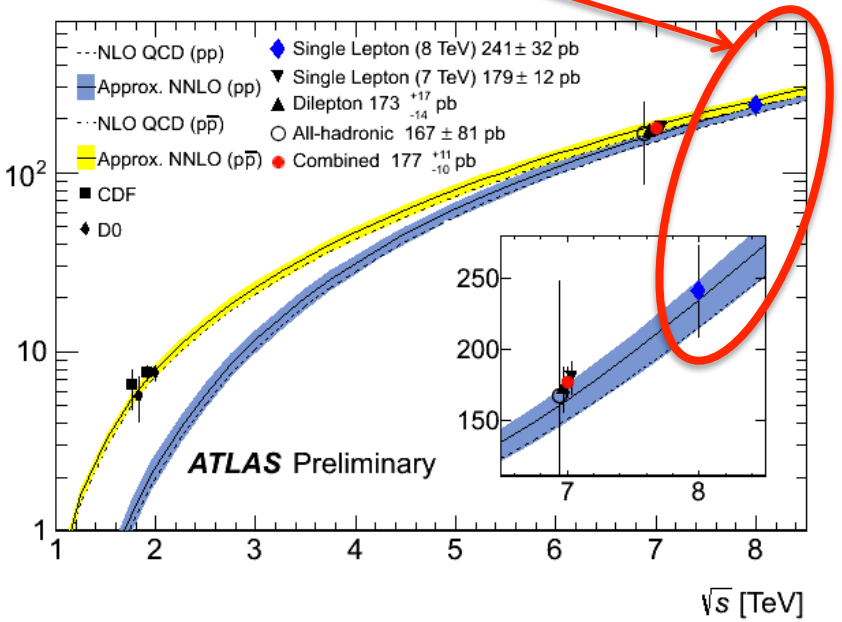
l + jets:

1 isolated high p_T μ/e ,
≥ 3 jets, ≥ 1 b-tagged jet

- Fit to Likelihood discriminant (lepton η, aplanarity)

Main syst : signal modelling Jet/E_t^{miss} reco.





ATLAS-CONF-2012-149

$$\sigma_{tt} = 241 \pm 2\,(\text{stat.}) \pm 31\,(\text{syst}) \pm 9\,(\text{lumi})\ \text{pb}$$

Measurements dominated by syst. uncertainties

Jet Multiplicity in tt events

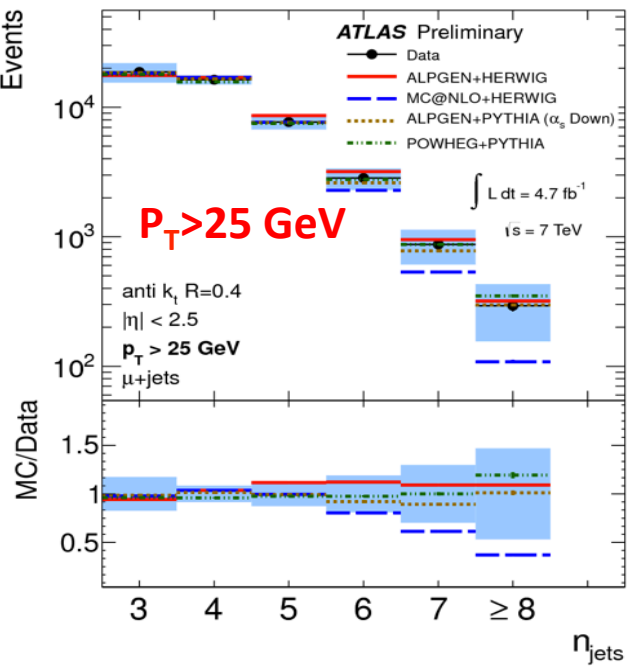
LHC: high fraction of tt events with extra hard jets from initial (final) state radiation

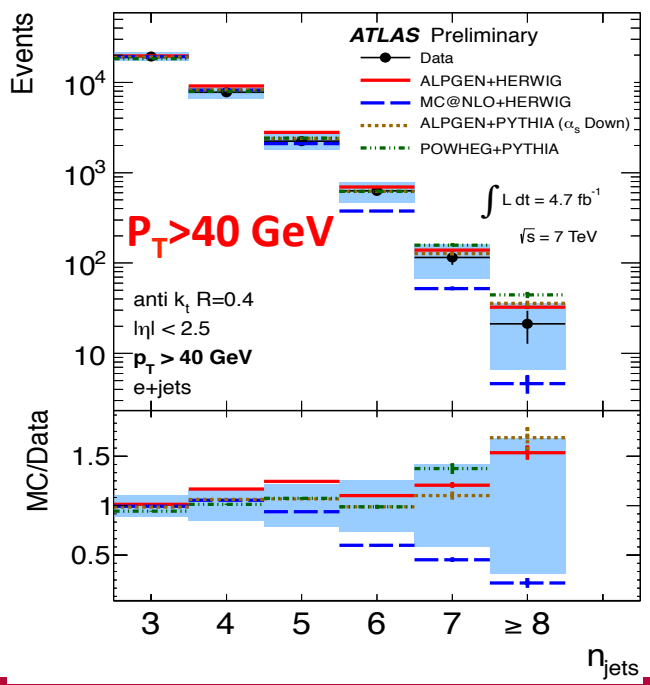
- ✓ **Tune & test** radiation modelling in MC with measurements
- ✓ Important for top, Higgs and many BSM studies

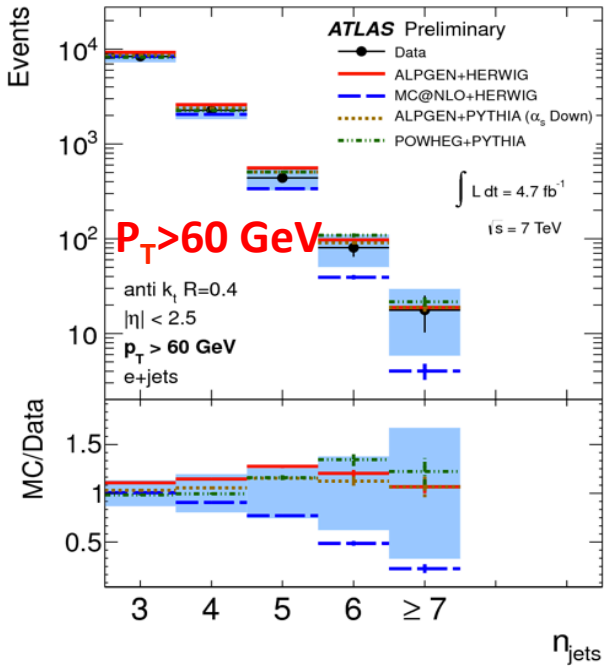
7 TeV , 4.7fb^{-1} , l+jets
ATLAS-CONF-2012-155

- ✓ **Measurement limited by systematic uncertaintiies** : (background modeling, JES)
  - ✓ Unfolded N_{jets} distribution compared with several MC predictions
  - ✓ Discrepency at large N_{jets} for **MC@NLO+HERWIG,** Reasonable agreement with **ALPGEN +HERWIG(or PTHIA)** and **POWHEG+PYTHIA**

Particle-jet multiplicity







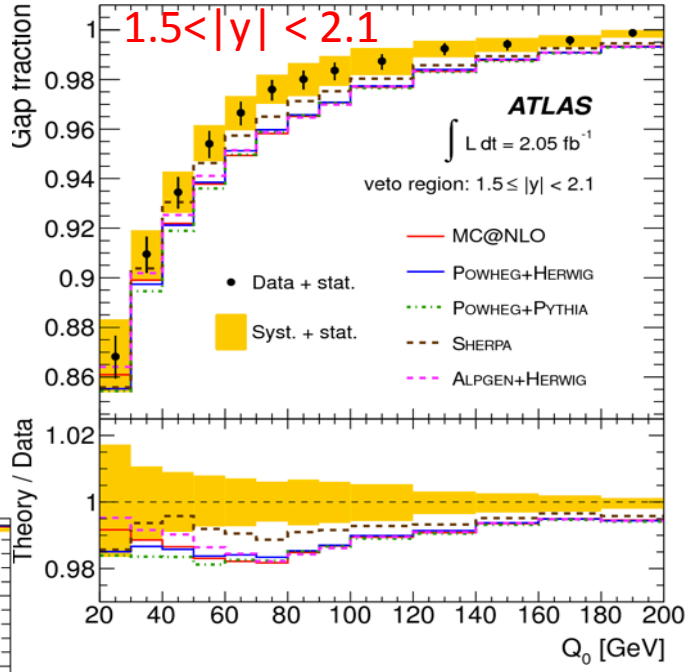
Jet Veto Gap fraction @ 7 TeV

Events selected in dilepton channel ; 2 fb^{-1}

Motivation: constrain the uncertainties arising from theoretical description of q/g radiation in simulation

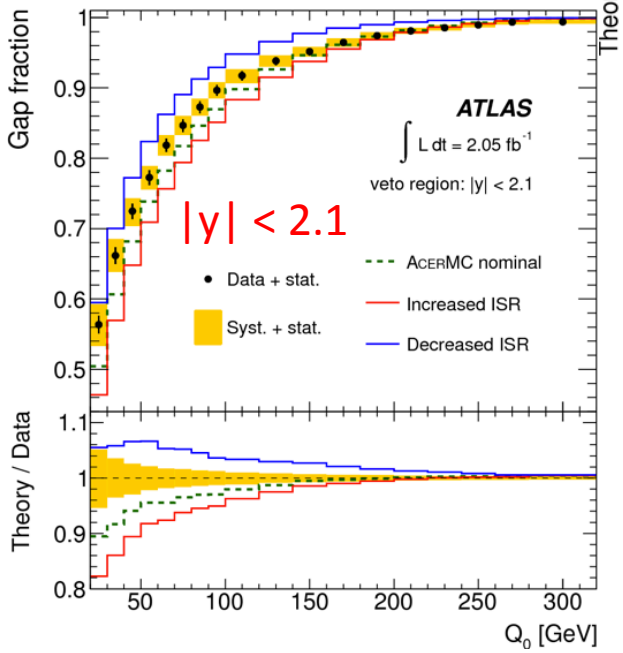
Gap fraction : $f(Q_0) = \sigma(Q_0) / \sigma$

ratio between the tt events cross section with no additional jets with $p_T > Q_0$ (in the central region) to the inclusive top pair cross section,



Data compared with MC@NLO, POWHEG, ALPGEN, SHERPA

- All four generators produce too much activity in the forward region



Data compared to ACER +PYTHIA ISR/FSR predictions

-Data allows for a reduction on the parameter variations used to estimate I/FSR uncertainties.

Eur. Phys. J C72 (2012) 2043

Differential tt cross section @ 7TeV

Measure top quark kinematic distributions:

- ✓ top, top pairs, b-jets, lepton lepton pairs, E_t^{miss}, …
- ✓ scrutinise theory predictions & models
- ✓ Enhance sensitivity to new physics
- ✓ In future, Extract/use for PDF fits

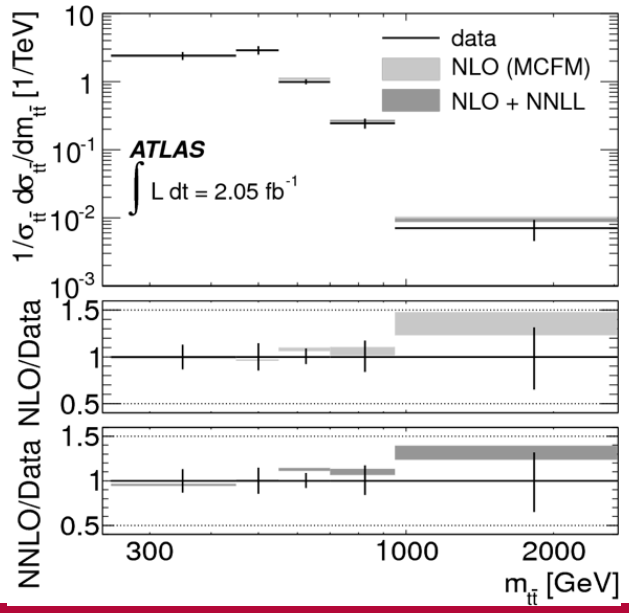
Main analysis ingredients:

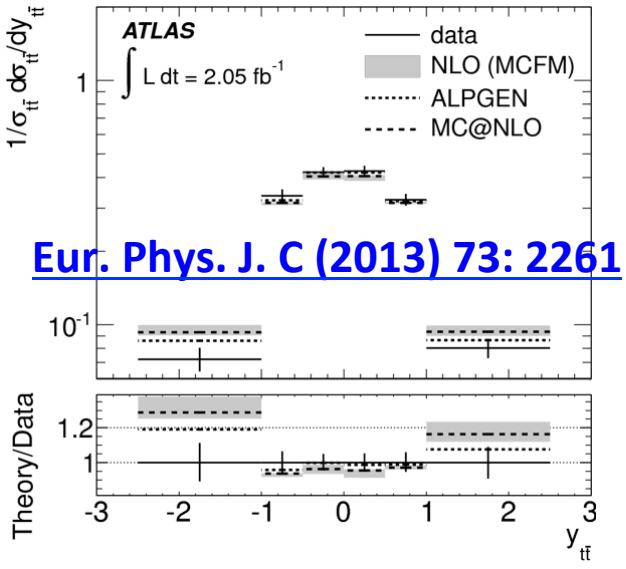
$$\frac{1}{\sigma_{t\bar{t}}}\frac{d\sigma_{t\bar{t}}}{dx}$$

- ✓ cross section measurement
- ✓ kinematic reconstructions of tt system
- ✓ unfolding: correct for detector effects & acceptance

Extrapolated to full phase space
Corrected to parton or particle level
l + jets (≥ 4 jets, ≥ 1b-tag)
Unfolding of m_{tt} , y_{tt} , p_{Ttt} compared with different predictions (MCFM,ALPGEN, MC@NLO (and approx. NNLO for m_{tt})
Syst: Jet/E_t^{miss} Reco. (10 ~ 20%)

All measurements in agreement with SM





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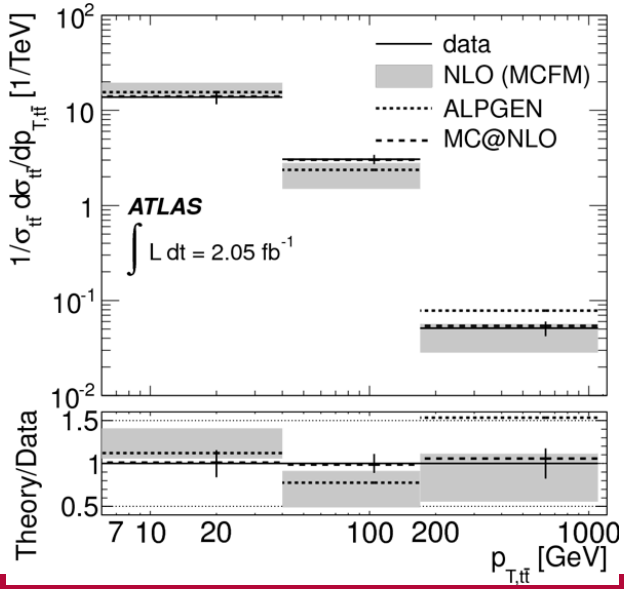
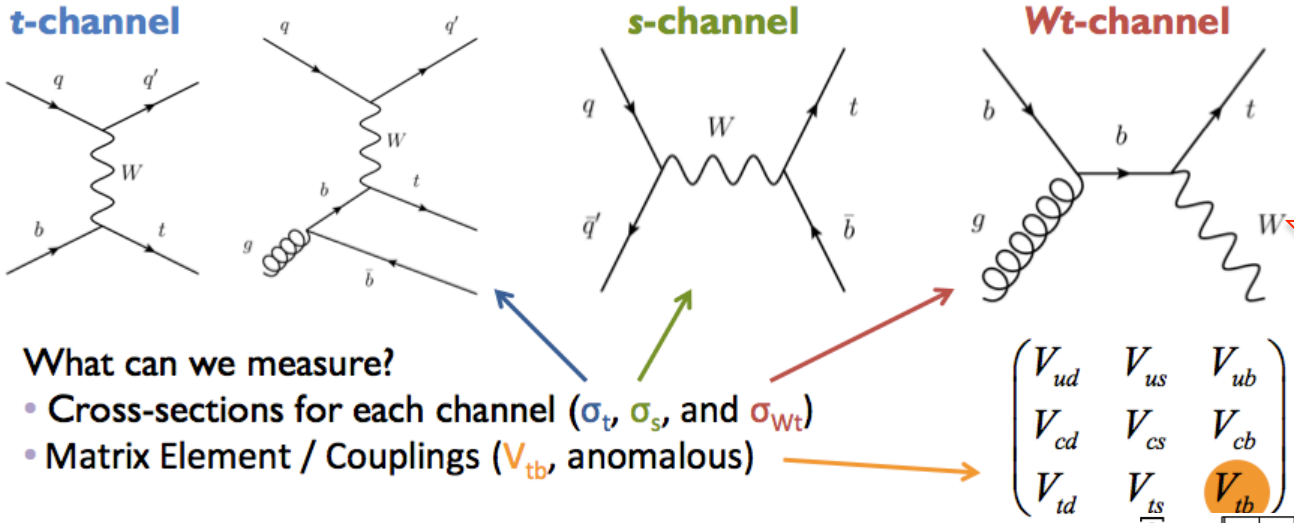


Single Top at ATLAS

Single tops are produced in *t-*, *Wt-*, *S-* channels

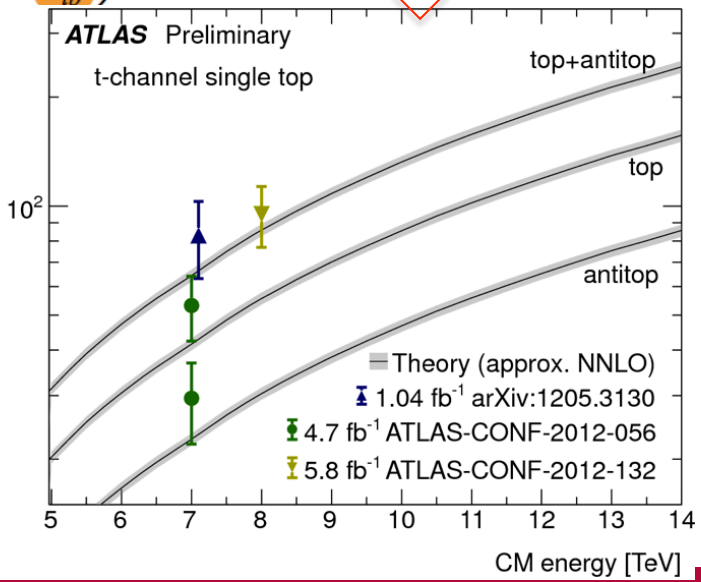


What can we measure?
- Cross-sections for each channel (σ_t, σ_s, and σ_{Wt})
- Matrix Element / Couplings (V_{tb}, anomalous)

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

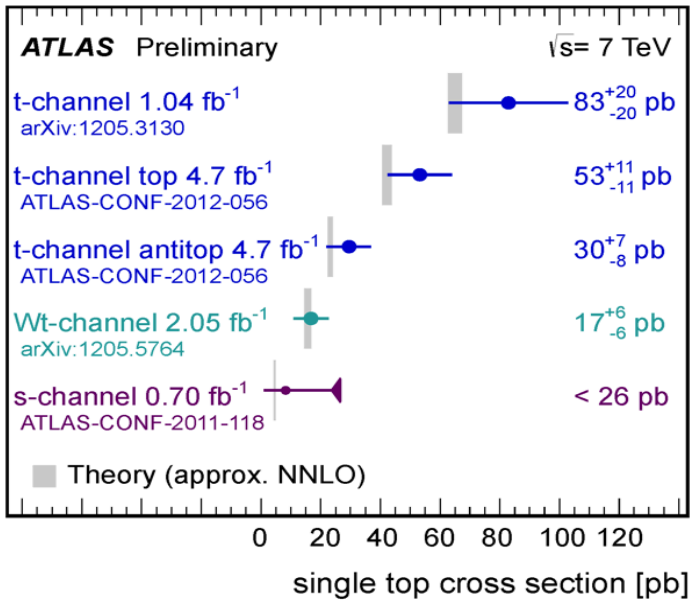
Results for the cross section @ √s =7 TeV and √s =8 TeV compared to the SM prediction (t-channel)

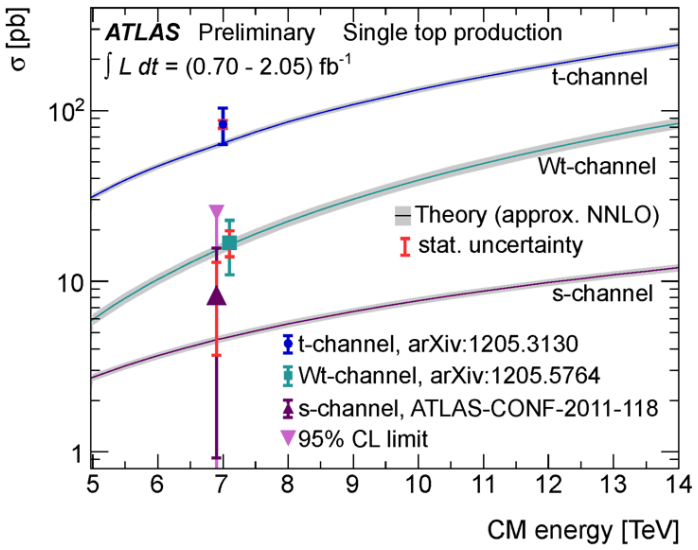
ATLAS :
Observed the t-channel
ATLAS-CONF-2012-132 @8TeV
Evidence for Wt- channel in dilepton mode
Phys. Lett. B 717 (2012) 330-350 @ 7 TeV
Upper limit on S- channel



Single Top Cross section

7 TeV





For Wt- channel @ 7TeV
Observed significance is 3.3 σ for an expected sensitive of 3.4 σ
Syst: JES, MC modeling
Phys. Lett. B 716 (2012) 142

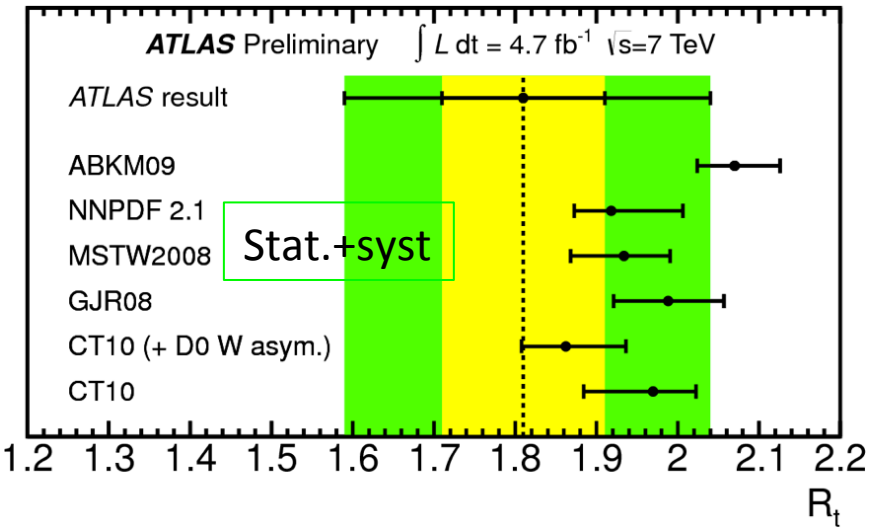
R_t: ratio of top and anti-top in t-channel

R_t is sensitive to PDF

ATLAS : 7 TeV , 4.7 fb^{-1}

Fit to NN outputs for l^+ and l^-

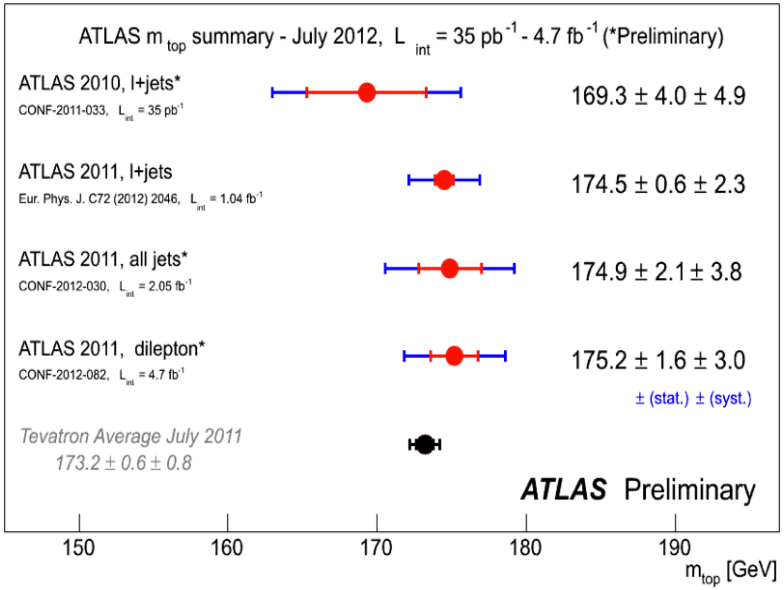
Results in agreement with the SM predictions



Top Quark Mass

Events selected in lepton + jets

Two methods:
1D analysis : reconstruct $R_{32} \cong m_t^{rec}/m_W^{rec}$
2D analysis : simultaneous fit to derive m_{top} and jet energy scale factor(JSF)



Dominant syst. :
JES, b-JES, I/FSR

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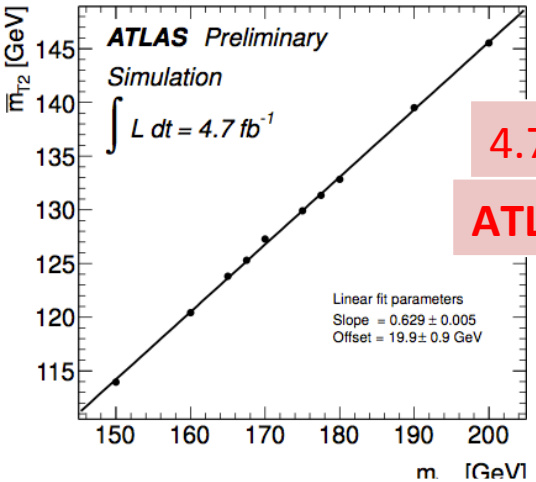
Events selected in di-lepton channel

define m_{T2} (transverse mass – a lower bound of the parent mass) as:

$$m_{T2}(m_{\text{invis}}) = \min_{\vec{p}_T^{(1)},\, \vec{p}_T^{(2)}} \left\{ \max\left[m_T(m_{\text{invis}}, \vec{p}_T^{(1)}), m_T(m_{\text{invis}}, \vec{p}_T^{(2)}) \right] \right\}$$

$$m_T(m_{\text{invis}}, \vec{p}_T^{(i)}) = \sqrt{m_{\text{vis}}^2 + m_{\text{invis}}^2 + 2(E_T^{\text{vis}} E_T^{\text{invis}} - \vec{p}_T^{\text{vis}} \cdot \vec{p}_T^{(i)})}$$

Calibration of m_{T2} v$_s$ m_t to extract the m_{top}
Average of m_{T2} distribution to obtain m_t
Dominant syst.: JES, b-JES, modeling



4.7 fb^{-1}

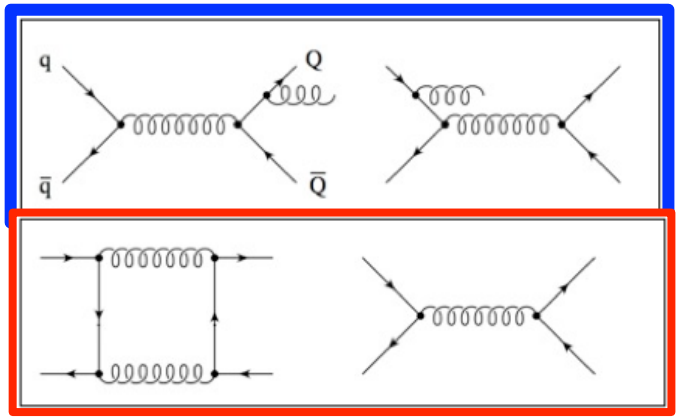
ATLAS-CONF-2012-082

$M_t = 175.2 \pm 1.6(\text{stat})\ ^{+3.1}_{-2.8}(\text{syst})$ GeV

Top charge asymmetry

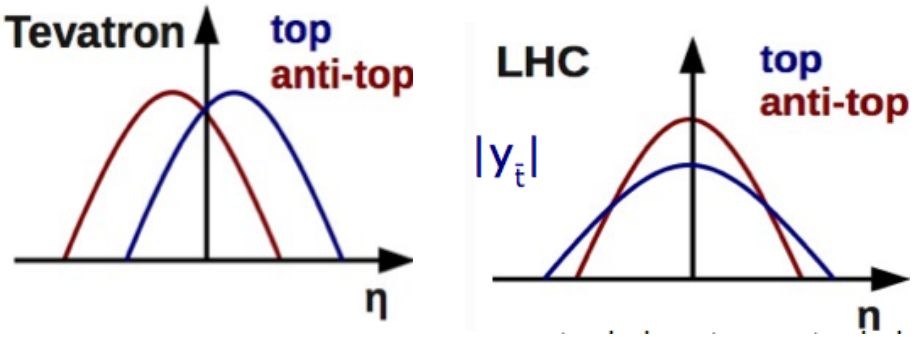
Charge asymmetry can appear in ttbar pair production through qqbar annihilaton at NLO in QCD:

- Interference b/w ISR and FSR
- Interference b/w the Born and Box diagrams.



At Tevatron A_{FB} : top(antitop) produce preferentially in the direction of the incoming proton(antiproton)

-**At LHC** :No FB asymmetry
Study asymmetry considering that top is produced more broadly than antitop
Select phase space region in order to enhance charge asymmetry: i.e. select high m(ttbar) to reduce gluon fusion and to enhance new bosons contributions



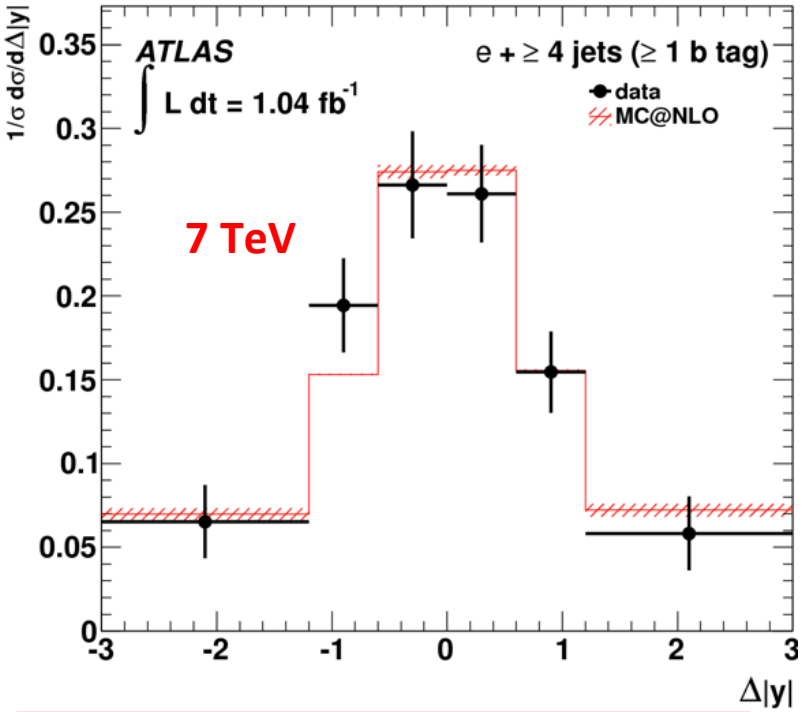
$$\Delta|Y| = |Y_t| - |Y_{\bar{t}}|$$

$$A_C = \frac{N(\Delta|Y| > 0) - N(\Delta|Y| < 0)}{N(\Delta|Y| > 0) + N(\Delta|Y| < 0)}$$

Charge of t and tbar is determined by charge of lepton

Top charge asymmetry

Lepton + jets channel



A_c = -0.018±0.028(stat) ±0.023(syst

In agreement with SM predictions

Eur. Phys. J. C7 (2012) 2039

dilepton channel

1. Lepton charge asymmetry:
(based on the difference of the absolute values of positively and negatively charged lepton pseudorapidities)

A^{ll}_c = 0.023±0.012(stat) ±0.008(syst)

2. Top charge asymmetry:
(based on the reconstructed $t\bar{t}$ final state)

A^{tt}_c = 0.057±0.024(stat) ±0.015(syst)

Both results are in agreement with SM predictions

ATLAS-CONF-2012-057

W boson polarization @ 7 TeV

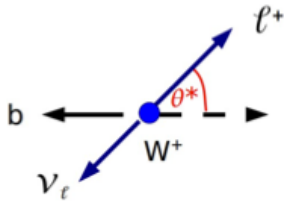
JHEP 1206 (2012) 088

Lepton+jets and dilepton events

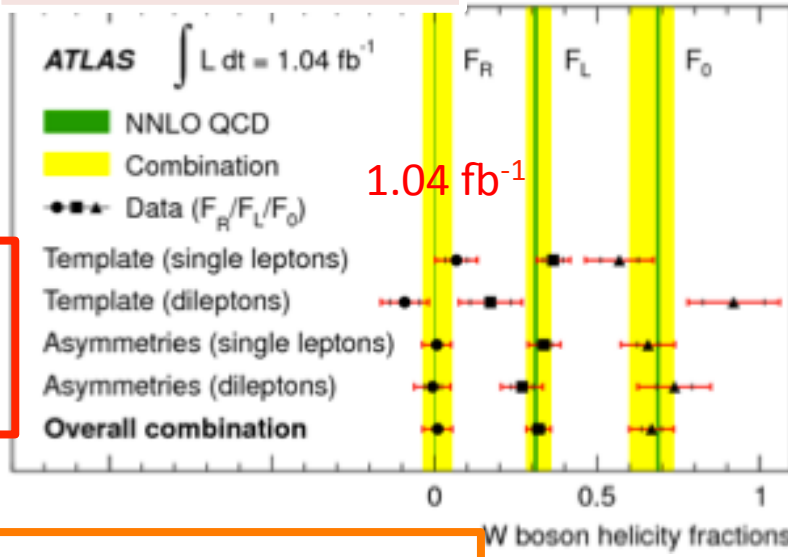
Probes Wtb structure; set a limit on new physics window

SM predicts helicity fraction of W from top:

$F_L = 0.3$, $F_0 = 0.7$, $F_R = 0$



$F_0 = 0.67 \pm 0.07$
$F_L = 0.32 \pm 0.04$
$F_R = 0.01 \pm 0.05$



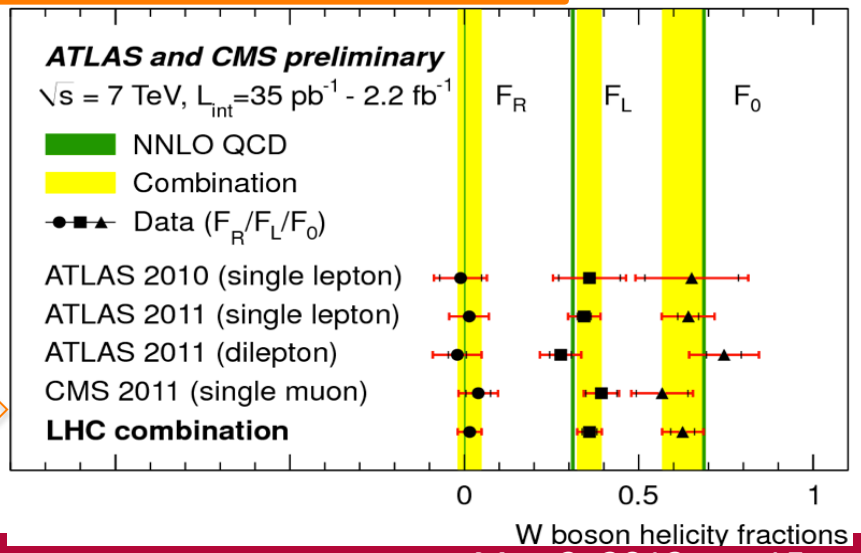
In agreement with NNLO QCD prediction

-Compare the observed cos θ* distribution with templates for different W boson helicity states obtained from simulation.

-Extracts angular asymmetries from an unfolded cos θ* spectrum corrected for background contributions.

First ATLAS , CMS combination @ 7 TeV

ATLAS-CONF-2013-033



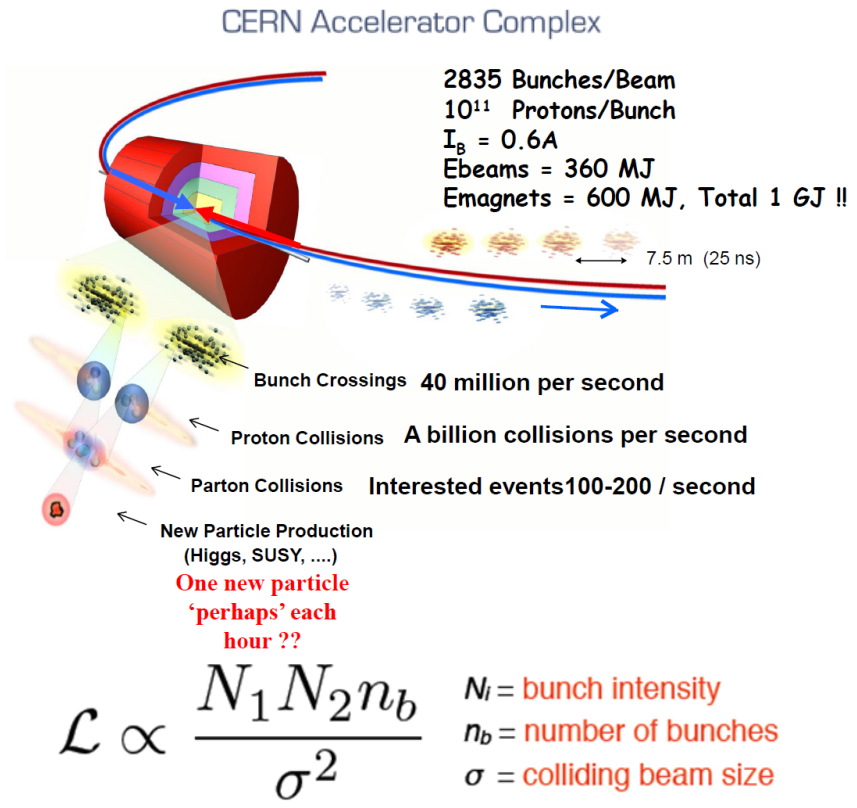
Summary

- ✓ **Top quark physics is one of the key elements of the LHC physics program with one of the most enjoyable playground in particle physics**
- ✓ **Large number of top events enable many interesting new analysis – performing precision tests of the SM**
- ✓ **High precision inclusive cross section measurements are in agreement with theoretical prediction**
- ✓ **and probing for new physics (or deviation from the SM)**
  - ✓ No evidence of new physics so far but…
- ✓ **Single top cross section measurement are performed in t- and Wt channel and the coupling strength at the W-t-b vertex is determined in both channel**
- ✓ **LHC and ATLAS detector performance are excellent**
  - ✓ **Some Results shown are up to ~5 fb^{-1} of 2011 data, results with 2012 data (~20 fb^{-1}) at 8 TeV C.o.M (more to come)**
- ✓ **ATLAS produced 29 papers on Top physics since 2010**

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

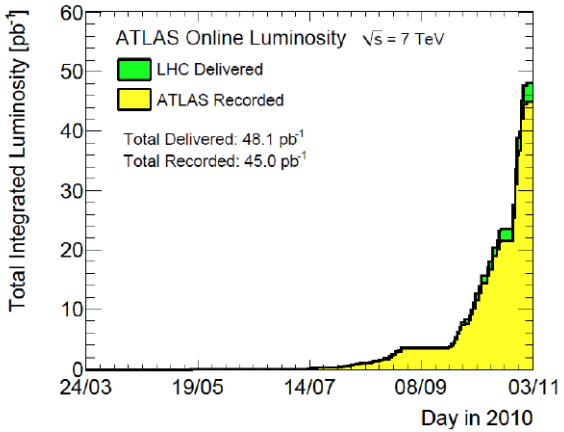
ATLAS experimen @ L

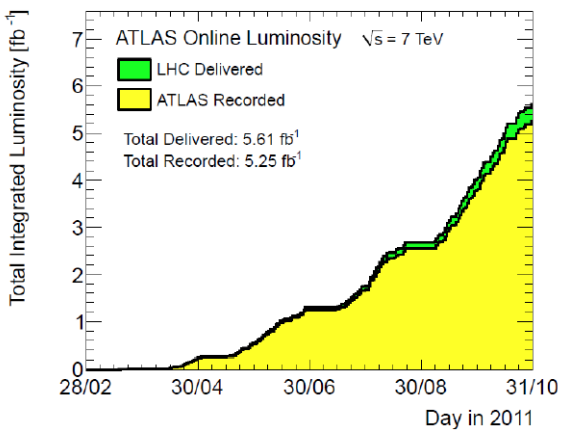
- ATLAS experiment:
  - ✓ 176 Institutions and 38 Countries, 3200 physicists
  - ✓ **1000 Students , 450 theses submitted from 2008 (over 120 till Nov. 2012)**
- Operation started end March 2010 @ √s=7TeV
  After start up performance improved very fast:
  - ✓ peak luminosity $2x10^{32}$ in 2010 and $3.6x10^{3}$ cm^{-2} sec^{-1} in 2011
  - ✓ 2012 data taking @ √s=8 TeV is going on smoothly : peak luminosity ~$6.5x10^{33}$ cm^{-2} sec^{-1}

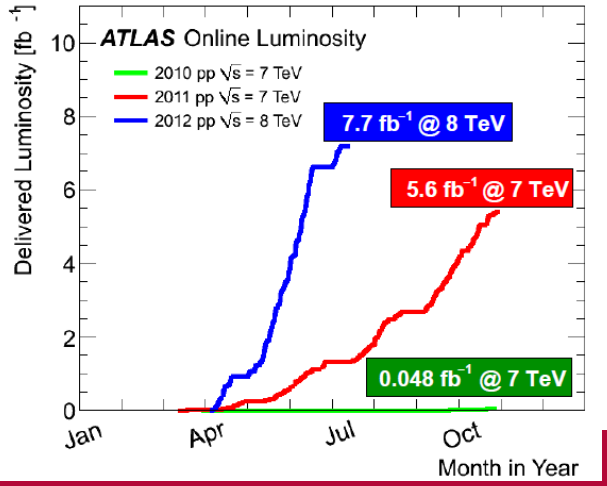


$$\mathcal{L} \propto \frac{N_1 N_2 n_b}{\sigma^2}$$

N_i = bunch intensity
n_b = number of bunches
σ = colliding beam size

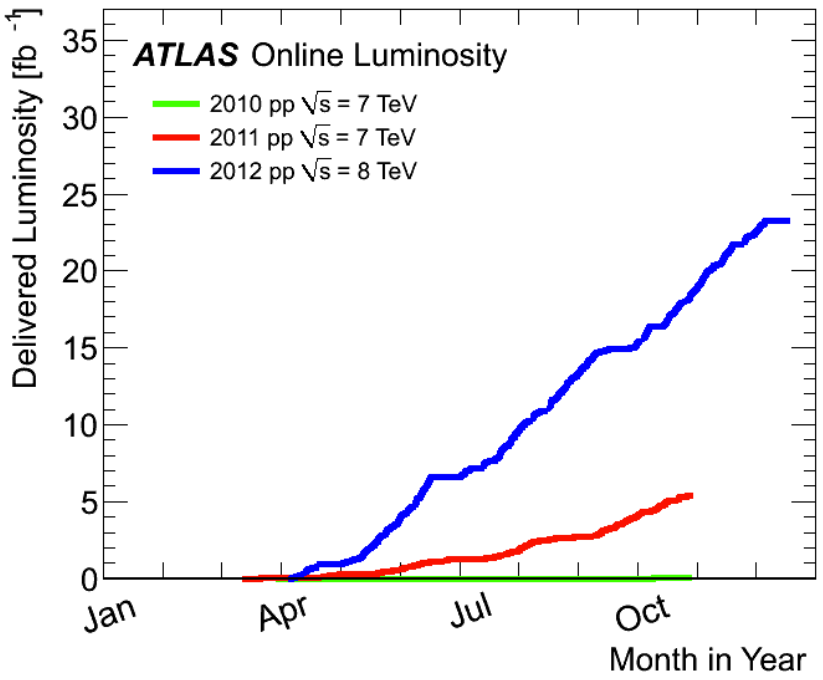


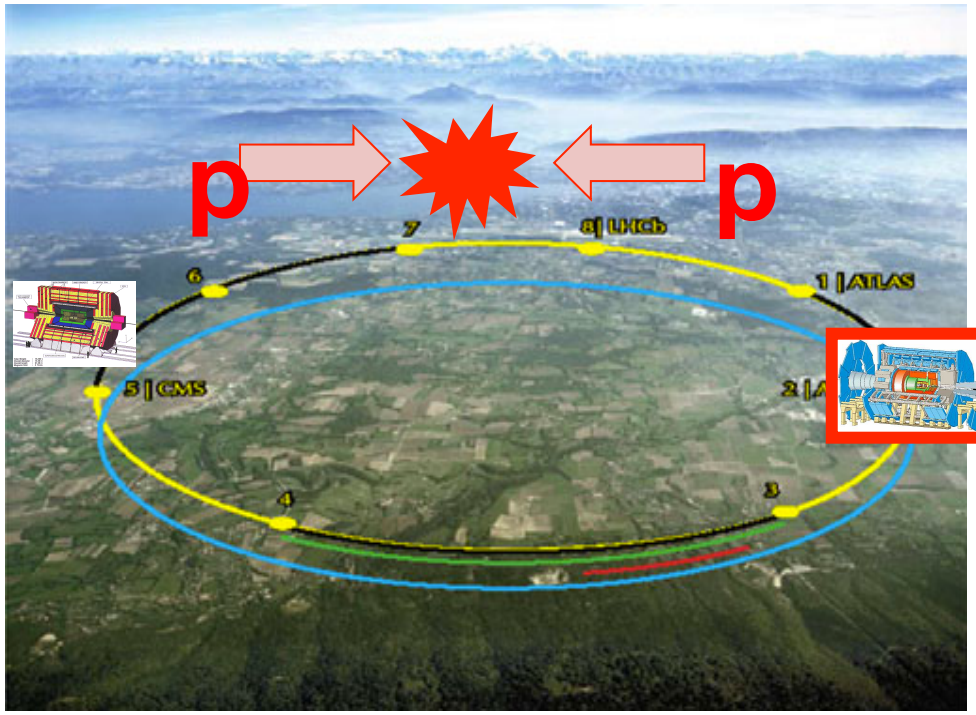




The tools of the trade

- **LHC a top factory**
  - ATLAS (CMS) top observer





2012 : Ecm = 8 TeV

Int. Lumi : 23.3 fb^{-1} (delivered)

Peak lumi: ~ 7.7 x 10^{33} $cm^{-2}s^{-1}$

2011 : Ecm = 7 TeV ;

Int. Lumi : 5.7 fb^{-1} (delivered)

Peak lumi: ~ 3.6 x 10^{33} $cm^{-2}s^{-1}$