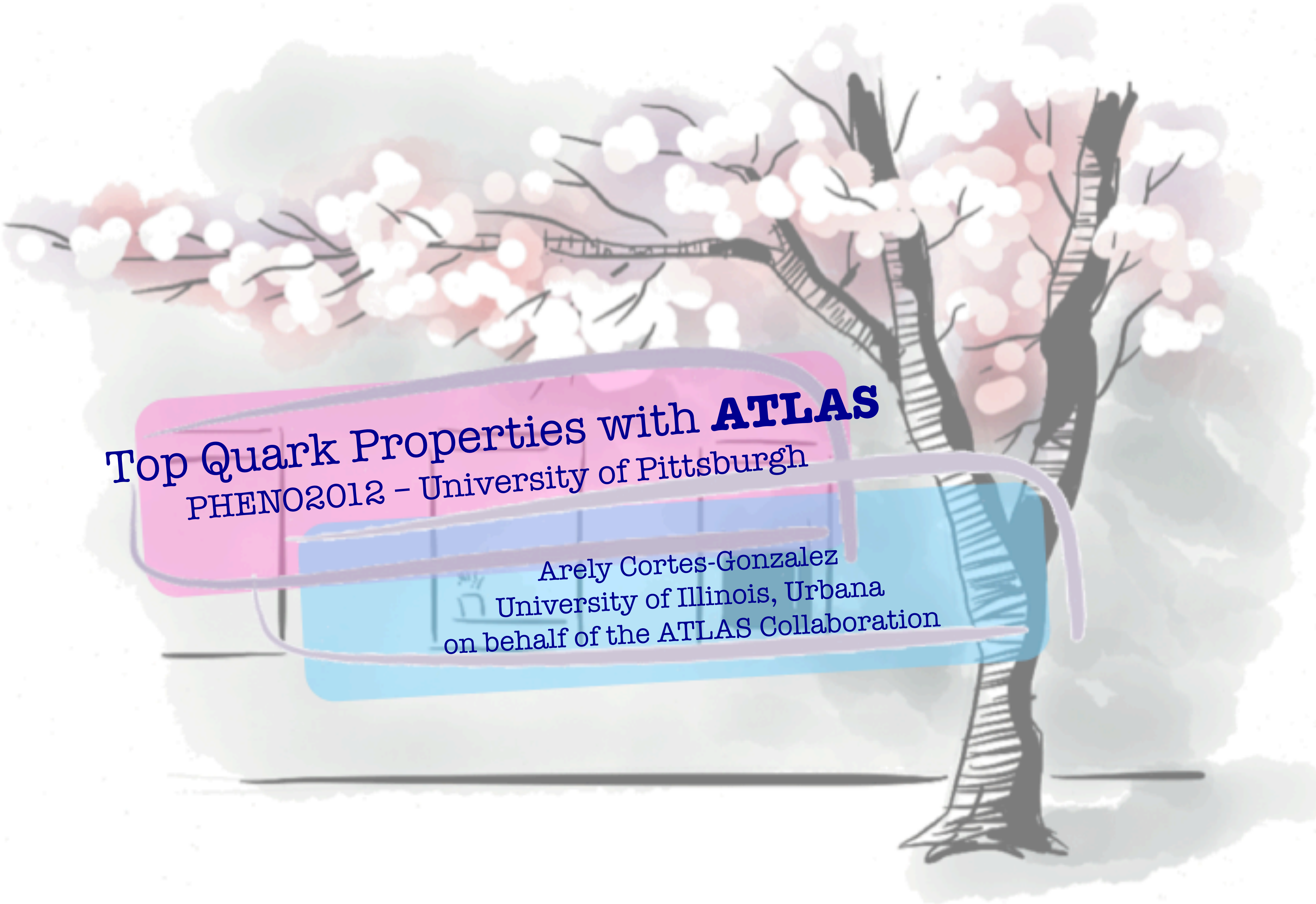

Top Quark Properties with **ATLAS**

PHENO2012 – University of Pittsburgh

Arely Cortes-Gonzalez
University of Illinois, Urbana
on behalf of the ATLAS Collaboration

Top quark

The Top quark, the heaviest known elementary particle, provides an interesting probe of the Standard Model.

It is part of important backgrounds for other searches, and precision measurements

Furthermore, because of its large mass, it might be a window onto physics *beyond* the Standard Model.

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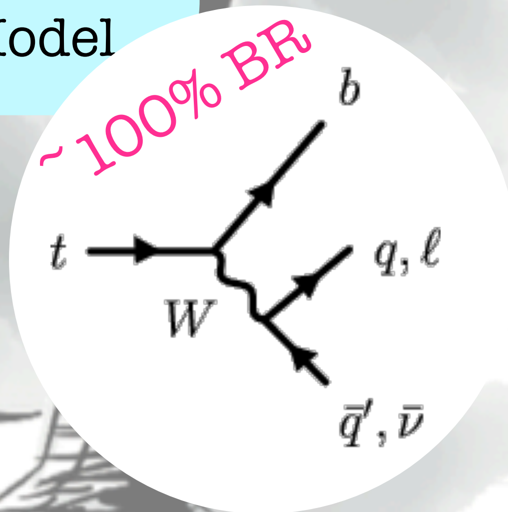

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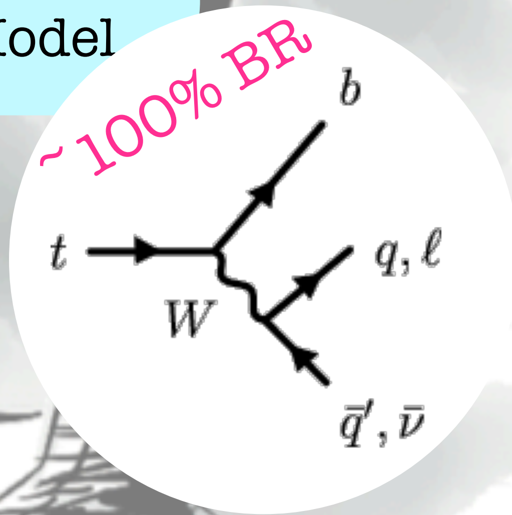
Furthermore, because of its large mass, it might be a window onto physics *beyond* the Standard Model

Many results have been produced at the LHC in the last couple of years... And more to come this year !



Outline

Top Quark Mass

Template Method in all-hadronic Channel, 2 fb^{-1}

Template Method in lepton + jets Channel, 1 fb^{-1}

From t-tbar Cross Section, 35 pb^{-1}

Outline

Top Quark Mass

Template Method in All-Hadronic

Ter

Fro

Top Quark Charge

Track charge weighting and

soft lepton techniques

in lepton + jets channel, 0.7 fb^{-1}

Outline

Top Quark Mass

Template Method in All-Hadronic

Ter

Frc

Top Quark Charge

nd

b^{-1}

W-boson polarization in top decays

Measurement of angular asymmetries

and template method in

lepton + jets and dilepton channels, 0.7 fb^{-1}

Outline

Top Quark Mass

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Ter

Frc

Top Quark Charge

d

b^{-1}

W

lepton + jets and dilepton channels, 0.7 fb^{-1}

Flavor Changing Neutral Currents

Count & Cut method in

all-leptonic final states, 0.7 fb^{-1}

Outline

Top Quark Mass

Template Method in All-Hadronic Channel, 2 fb^{-1}

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Top Quark Mass

Template Method in All-Hadronic Channel, 2 fb^{-1}

Template Method i
Channel,

From t-tbar cross s

Top Quark Charge

Track charge weighting and

n techniques

s channel, 0.7 fb^{-1}

t-tbar cross Section?

Dustin Urbaniec's talk on "Top Quark Pair Production Cross Section with ATLAS".

W-boson polarization

Measurement of angular

d in

channels,

0.7 fb

Other t-tbar properties?

Venkat Kaushik's talk on "Top Quark Pair Properties with ATLAS".

FCNC

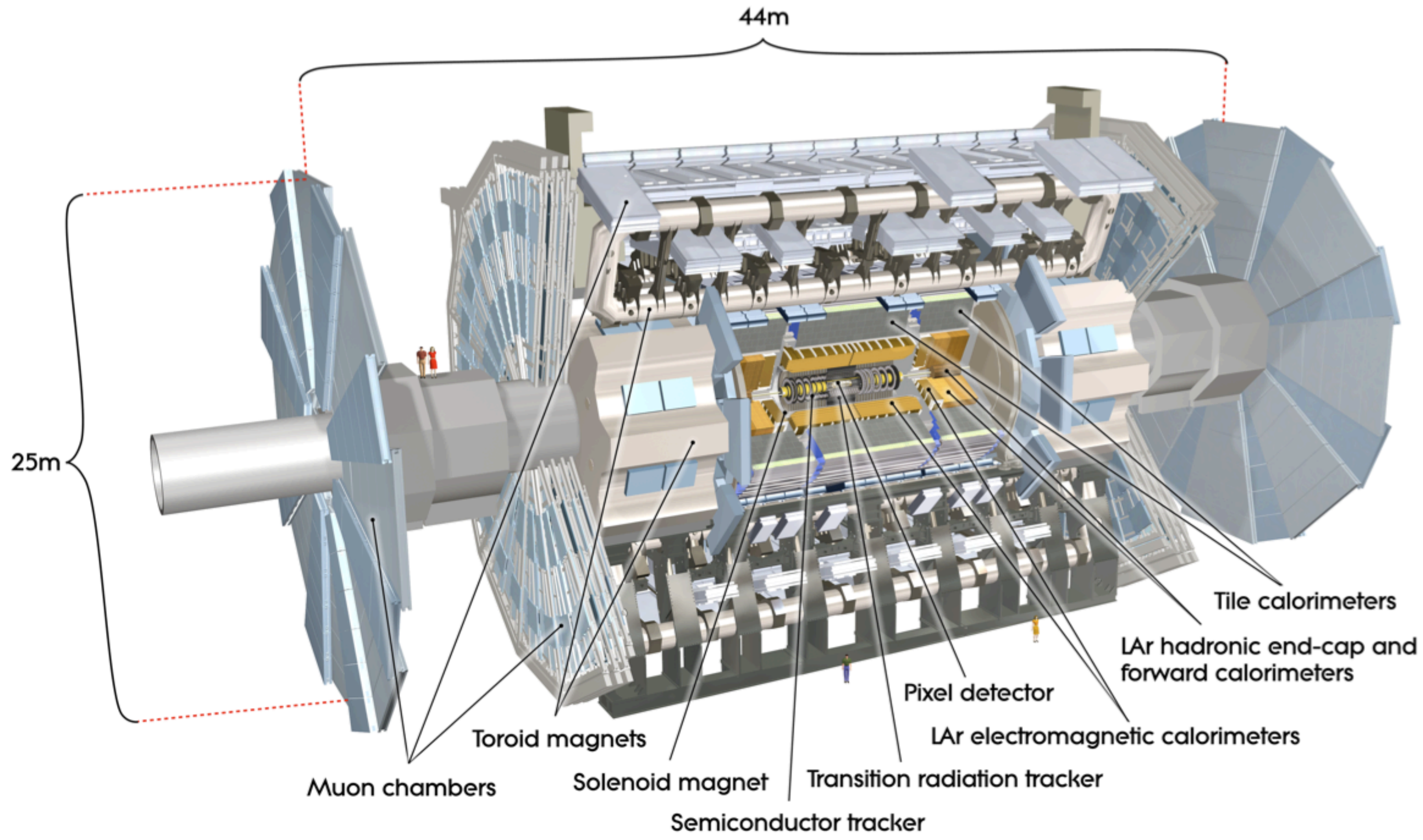
Count & Cut method in

all-lepto

FCNC in Top-Production?

Robert Calkins talk on "Measurement on single top quark production with ATLAS".

ATLAS Detector



Top Quark Mass

The top quark mass is a fundamental parameter of the Standard Model.

The top quark mass is measured using
the **template method** in two channels.

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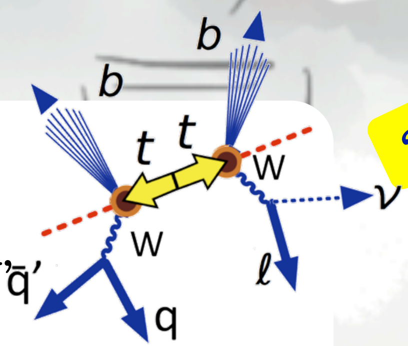
1.04 fb^{-1}

Lepton + jets

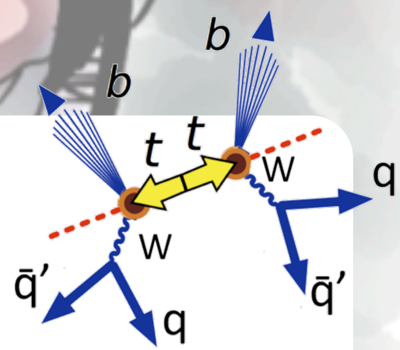
Events with one lepton,
at least 4 jets,
and cuts on E_T^{miss} and
W-transverse mass.



2.04 fb^{-1}

All hadronic

Events with at
least 5 jets with large
transverse momenta,
two of them b-tagged.



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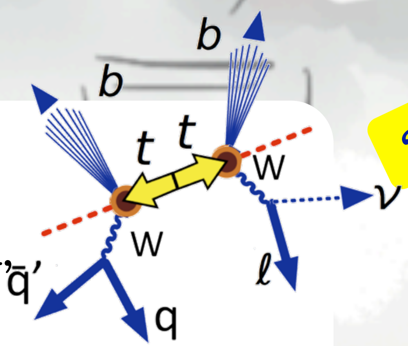

One and Two-
dimensional
Template analyses.

$2.04\ fb^{-1}$

All hadronic

Events with at
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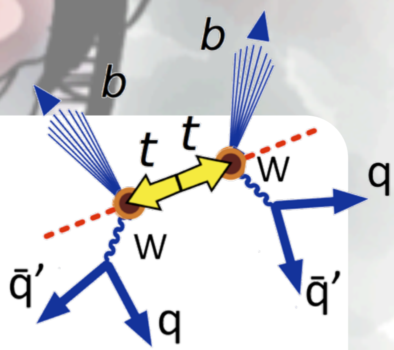
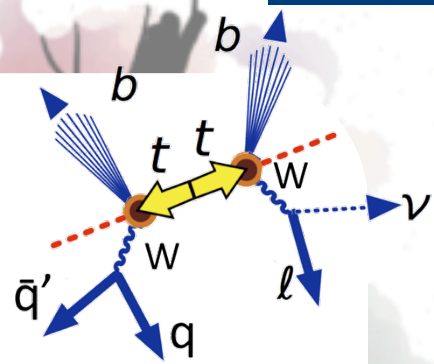
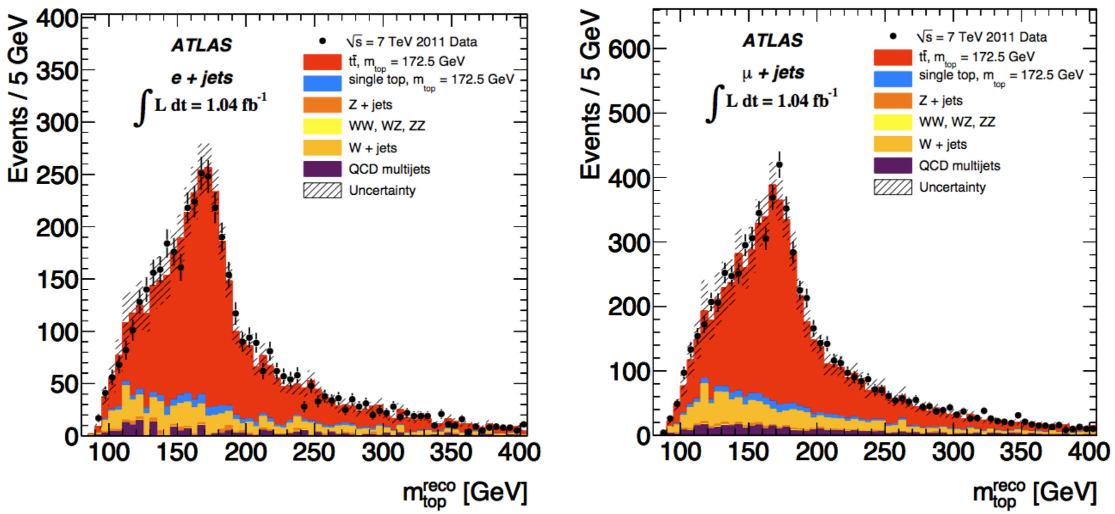


One -dimensional
Template analysis.



Lepton + jets
2-dimensional template

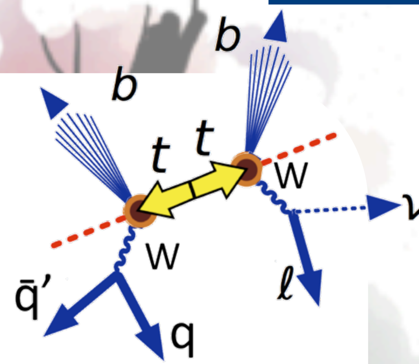
m_t and a global jet energy scale factor are determined simultaneously using m_t^{reco} and m_W^{reco} distributions.



(c) e+jets channel (d) μ+jets channel

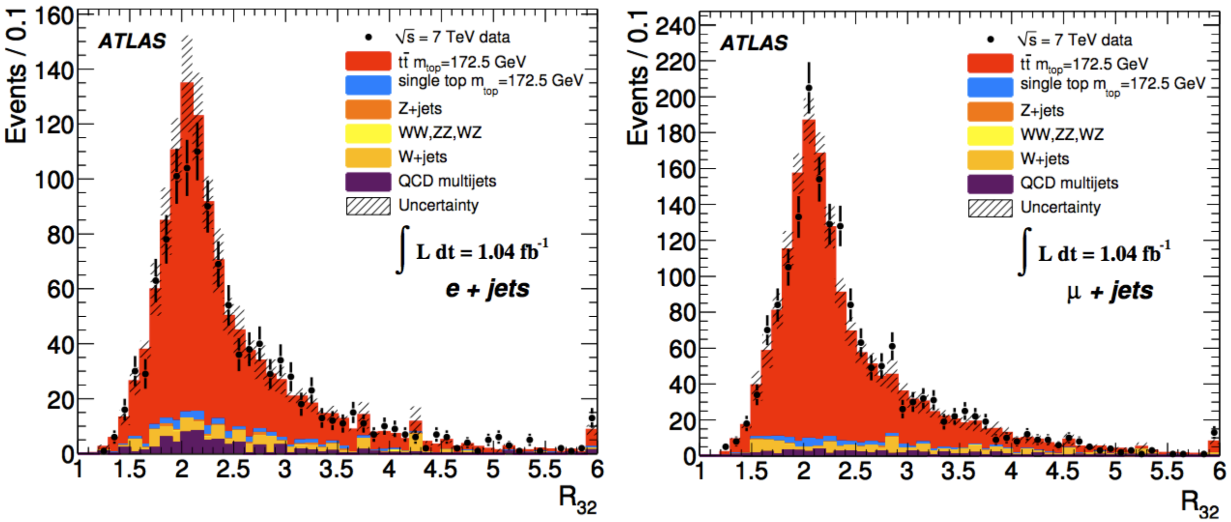
$$m_{\rm top} = 174.3 \pm 0.8_{\rm stat} \pm 2.3_{\rm syst}\ \text{GeV} \quad (\text{2d } e\text{+jets}),$$
$$m_{\rm top} = 175.0 \pm 0.7_{\rm stat} \pm 2.6_{\rm syst}\ \text{GeV} \quad (\text{2d } \mu\text{+jets})$$

Top Quark Mass



Lepton + jets
1-dimensional template

We reconstruct the mass ratio: $R_{32} \equiv \frac{m_{\text{top}}^{\text{reco}}}{m_{\text{W}}^{\text{reco}}}$

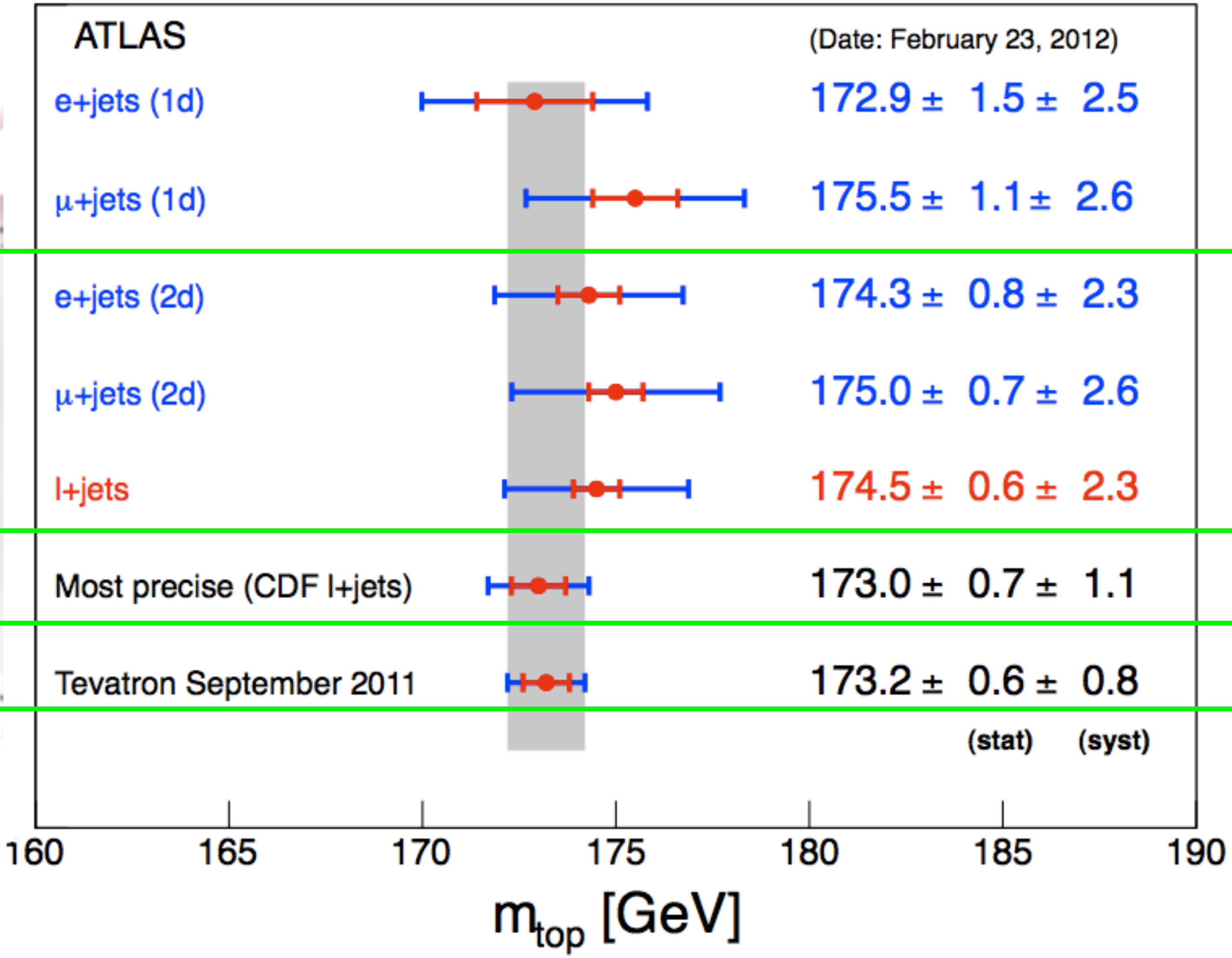


(a) e+jets channel (b) μ+jets channel

$$m_{\text{top}} = 172.9 \pm 1.5_{\text{stat}} \pm 2.5_{\text{syst}}\ \text{GeV} \quad (\text{1d } e\text{+jets})$$

$$m_{\text{top}} = 175.5 \pm 1.1_{\text{stat}} \pm 2.6_{\text{syst}}\ \text{GeV} \quad (\text{1d } \mu\text{+jets})$$

Top Quark Mass



ATLAS l+jets

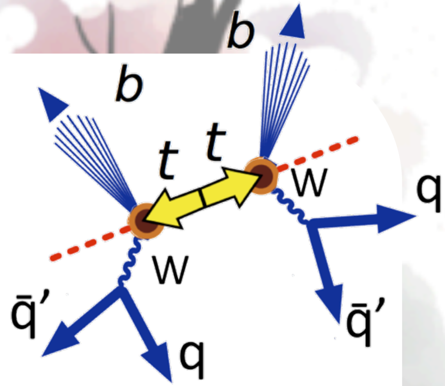
World's best

$1.0\ fb^{-1}$

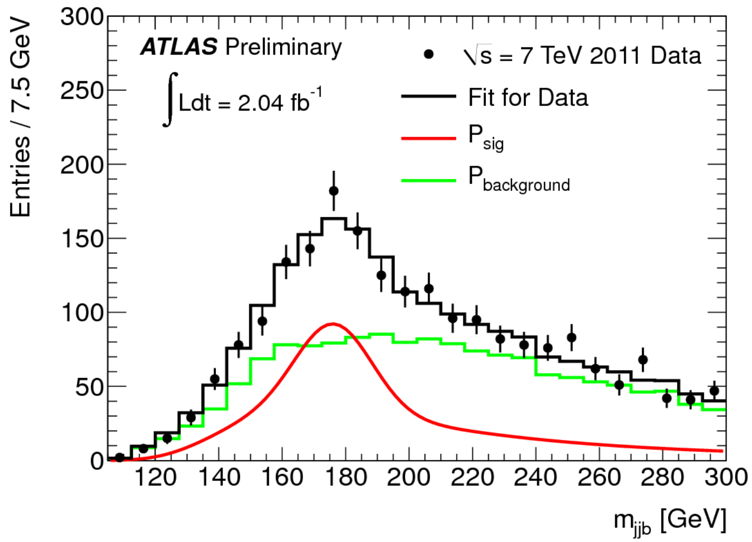
arxiv: 1203.5755

Top Quark Mass

All hadronic
1-dimensional template



Five quark mass values were used in the generation of the templates.
Fitting templates to the three-jet mass combination of selected jet-triplets.



$$m_t = 174.9 \pm 2.1\ (\text{stat.}) \pm 3.8\ (\text{syst.})\ \text{GeV}$$

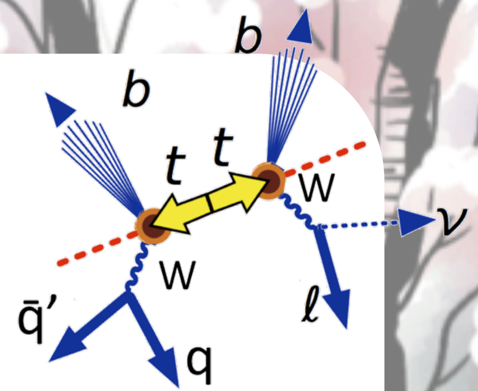
2.0 fb^{-1}

ATLAS-CONF 2011-030

Top Quark Charge

The charge measurement is based on reconstruction of the top quark decay products.

Use lepton + jets events with at least one b-tagged jet.



Top Quark Charge in the Standard Model:

$$t^{(2/3)} \rightarrow b^{(-1/3)} + W^{(+1)}, W^{+} \rightarrow \ell^{+} + \nu_{\ell}$$

Top-Quark with exotic charge:

$$\tilde{t}^{(-4/3)} \rightarrow b^{(-1/3)} + W^{(-1)}, W^{-} \rightarrow \ell^{-} + \bar{\nu}_{\ell}$$

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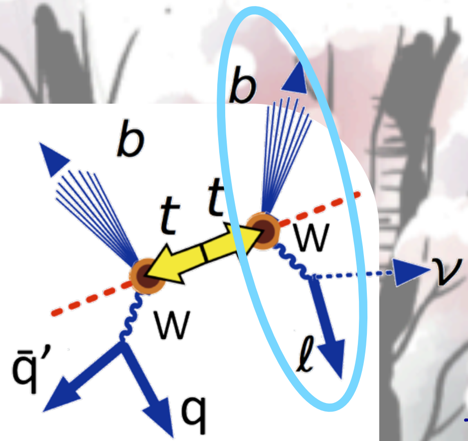


Measure the charge of the lepton and b-jet!

Top Quark Charge in the Standard Model:

$$t^{(2/3)} \rightarrow b^{(-1/3)} + W^{(+1)}, W^{+} \rightarrow \ell^{+} + \nu_{\ell}$$

Top-Quark with exotic charge:

$$\tilde{t}^{(-4/3)} \rightarrow b^{(-1/3)} + W^{(-1)}, W^{-} \rightarrow \ell^{-} + \bar{\nu}_{\ell}$$

track charge weights

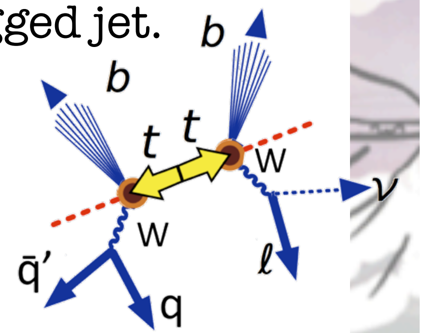
soft lepton

Top Quark Charge

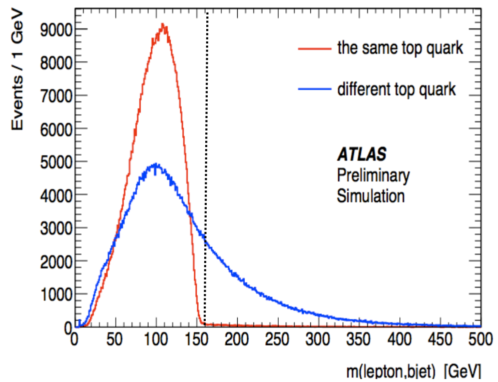
track charge weights

- Require a second b-tagged jet.

Which b-jet to use?



Find lepton-jet assignment using lepton-jet invariant mass constraint



$m(\ell, bjet_a) < m_{cr}$ and $m(\ell, bjet_b) > m_{cr}$

$m_{cr} = 155$ GeV

soft lepton

Top Quark Charge

track charge weights

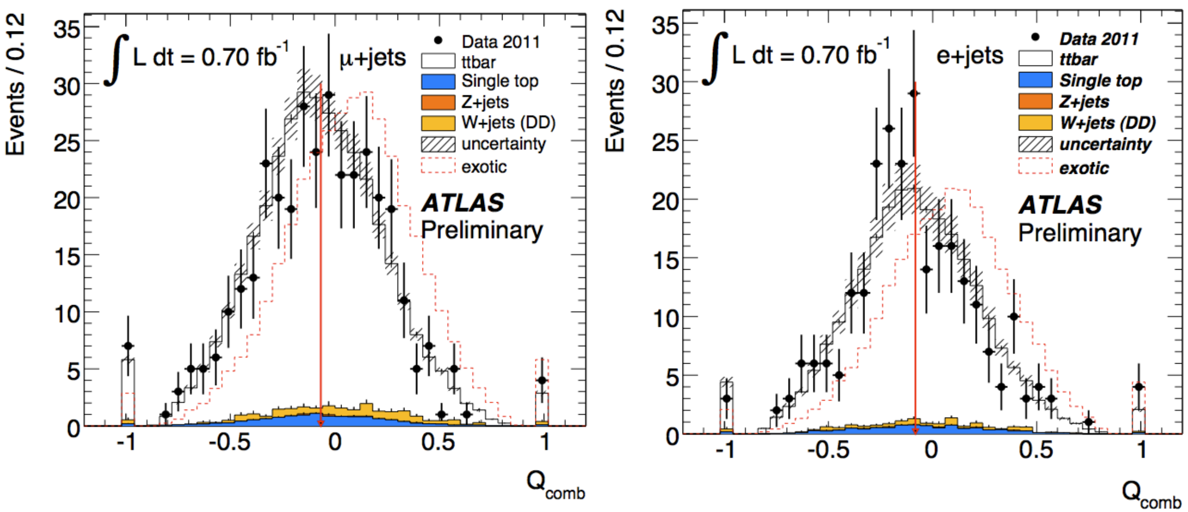
soft lepton

- Require a second b-tagged jet.
- Select b-jet with:

$$m(\ell, b\,jet_a) < m_{cr} \quad \text{and} \quad m(\ell, b\,jet_b) > m_{cr}$$

Measure the b-jet charge as a weighted sum of b-jet track charges

$$Q_{comb} = Q_{bjet} \cdot Q_{\ell}$$



Top Quark Charge

track charge weights

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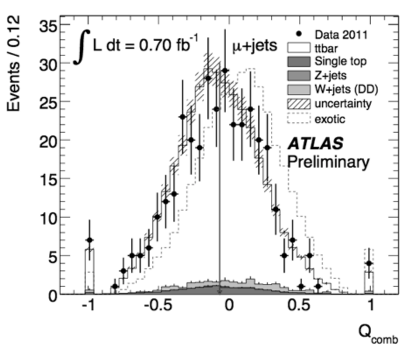
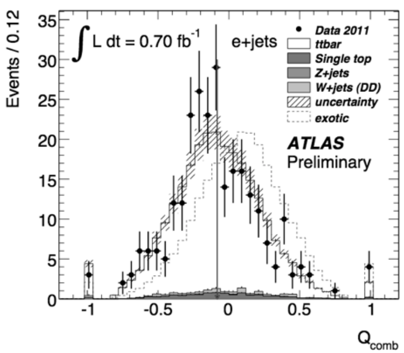




soft lepton

Use semileptonic decays of B-hadrons

$$BR(b \rightarrow \mu + \nu + X) \approx 11\%$$

same charge

Look for a soft (p_T>4GeV) muon in a b-jet

Suppress other sources (like B-hadrons decay to D-hadrons):

$$BR(b \rightarrow c \rightarrow \mu + \nu + X) \approx 10\%$$

opposite charge

p_T^{rel} > 800 MeV (p_T of muon wrt jet)

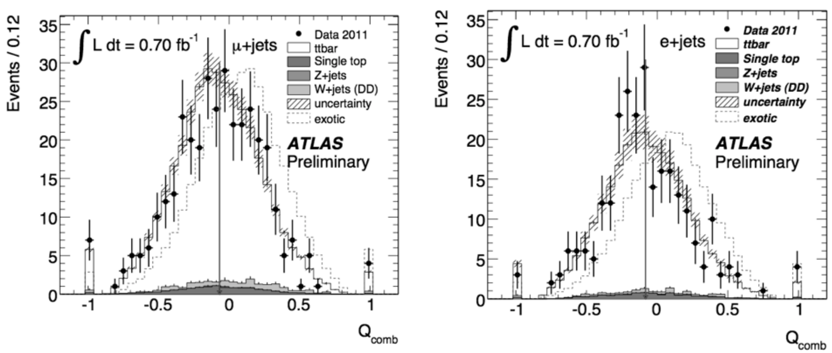
track charge weights

- Require a second b-tagged jet.
- Select b-jet with:

$m(\ell, b\,jet_a) < m_{cr}$ and $m(\ell, b\,jet_b) > m_{cr}$

Measure the b-jet charge as a weighted sum of b-jet track charges

$$Q_{comb} = Q_{bjet} \cdot Q_\ell$$



soft lepton

Look for a soft (p_T>4GeV) muon in a b-jet

p_T^{rel} > 800 MeV (p_T of muon wrt jet)

Lepton – b-jet pairing done with a Kinematic Likelihood Fitter Using E_T^{miss}, 4 leading jets, lepton.

Use the soft-muon and the lepton charge:

$$Q^{soft}_{comb} = Q^{soft}_{muon} \cdot Q_\ell$$

Top Quark Charge

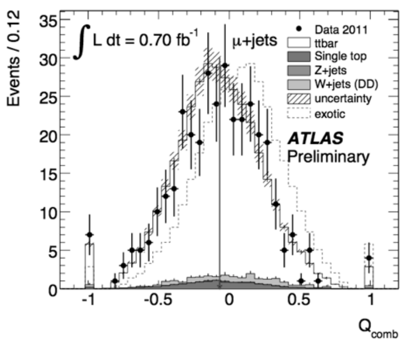
track charge weights

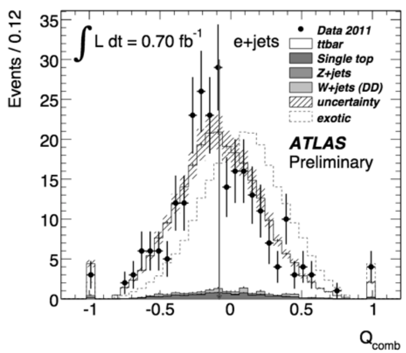
- Require a second b-tagged jet.
- Select b-jet with:

$$m(\ell, b\,jet_a) < m_{cr} \quad \text{and} \quad m(\ell, b\,jet_b) > m_{cr}$$

Measure the b-jet charge as a weighted sum of b-jet track charges

$$Q_{comb} = Q_{bjet} \cdot Q_{\ell}$$



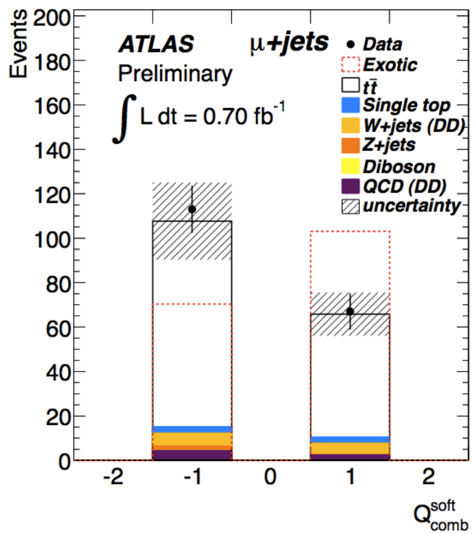


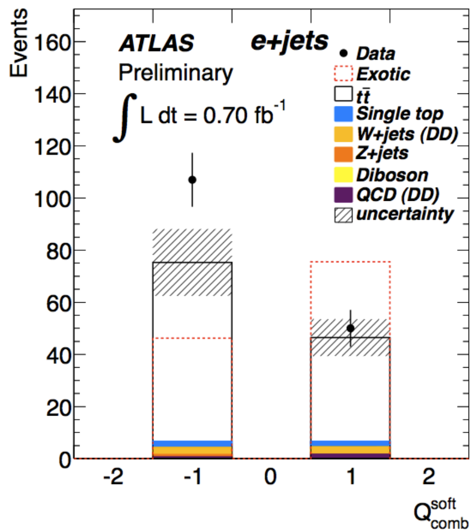
soft lepton

Look for a soft (p_T>4GeV) muon in a b-jet

p_T^{rel} > 800 MeV (p_T of muon wrt jet)

$$Q^{soft}_{comb} = Q^{soft}_{muon} \cdot Q_{\ell}$$

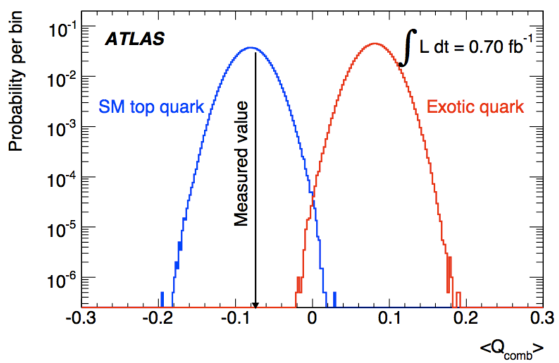




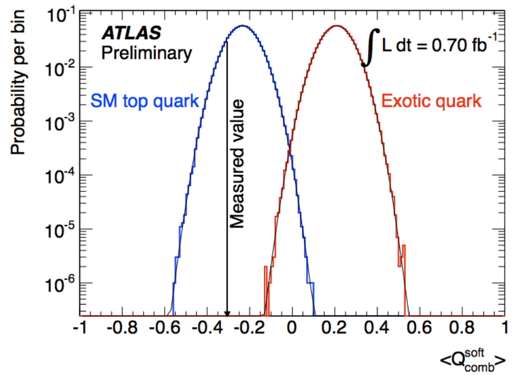
results

We measure Q_{comb} in both methods,
and the prediction in both cases is in good agreement with SM

$Q_{comb} = Q_{bjet} \cdot Q_{\ell}$



$Q^{soft}_{comb} = Q^{soft}_{muon} \cdot Q_{\ell}$



Set limits with standard likelihood approach comparing two hypotheses: SM and exotic quark.

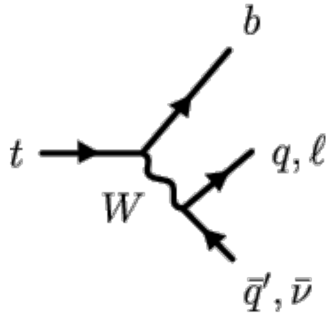
The exotic scenario is excluded at more than 5 σ.

0.7 fb^{-1}

ATLAS-CONF 2011-141

W-boson polarization

We can probe the structure of the *Wtb-vertex* by measuring the polarization of the W-bosons produced in top quark decays



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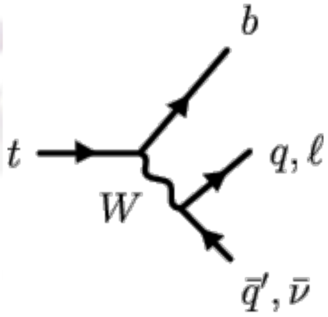
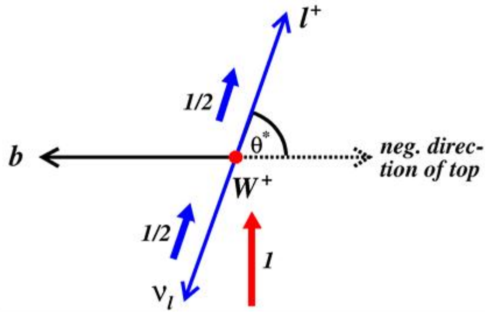


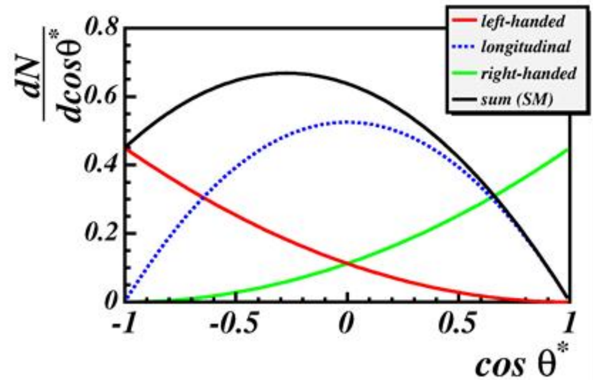
The helicity fractions, as predicted in the SM:

$$F_0 = 0.687 \pm 0.005$$
$$F_L = 0.311 \pm 0.005$$
$$F_R = 0.0017 \pm 0.0001$$

These fractions can be extracted from angular distributions of the decay products of the top-quark

cos θ* = angle between charged lepton and top-direction in W rest frame





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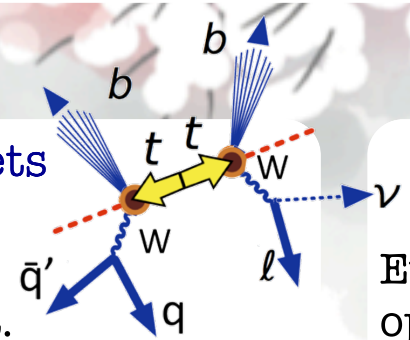
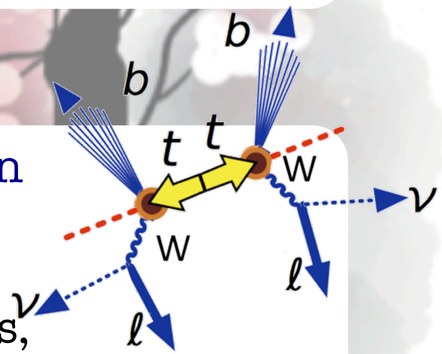
Lepton+ Jets



Events with one lepton, at least one b-tagged jet.

Dilepton



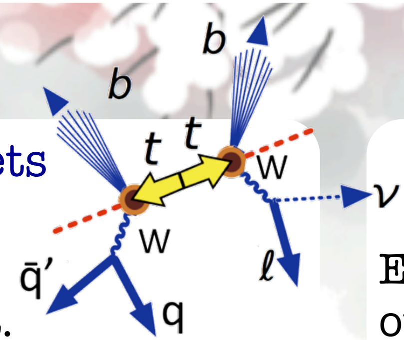
Events with two opposite signed leptons, no b-tagging.

W-boson polarization

We can probe the structure of the *Wtb-vertex* by measuring the polarization of the W-bosons produced in top quark decays

These fractions can be extracted from angular distributions of the decay products of the top-quark

Lepton+ Jets



Events with one lepton,
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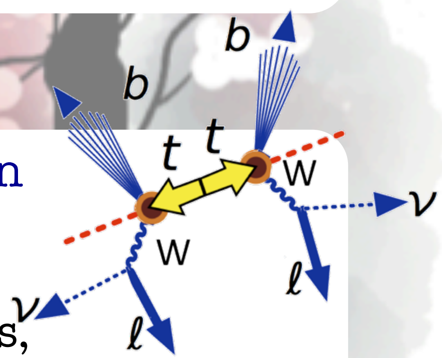
Dilepton



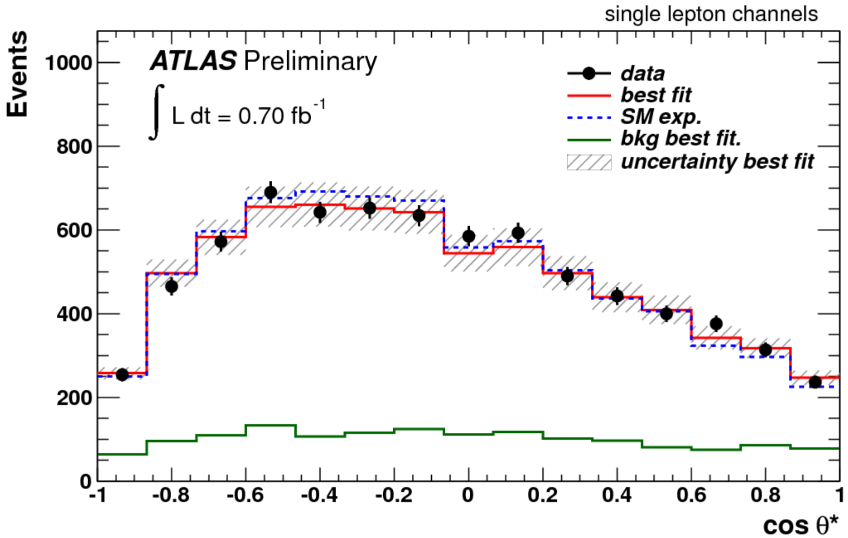
Events with two
opposite signed leptons,
no b-tagging.

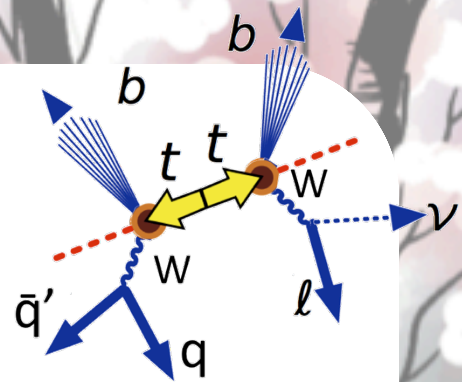
Measurement of helicity fractions

Templates fitted to the observed cos θ^* distribution.
Angular asymmetries are measured using the cos θ^* distribution.

W-boson polarization

Lepton + jets template fit





We extract the helicity fractions from the fit:

$$F_0 = 0.57 \pm 0.07\,(\text{stat.}) \pm 0.09\,(\text{syst.})$$
$$F_L = 0.35 \pm 0.04\,(\text{stat.}) \pm 0.04\,(\text{syst.})$$
$$F_R = 0.09 \pm 0.04\,(\text{stat.}) \pm 0.08\,(\text{syst.})$$

combining the e+jets and μ+jets channels.

W-boson polarization

Lepton + jets helicity fractions:

$$F_0 = 0.57 \pm 0.07\,(\text{stat.}) \pm 0.09\,(\text{syst.})$$
$$F_L = 0.35 \pm 0.04\,(\text{stat.}) \pm 0.04\,(\text{syst.})$$
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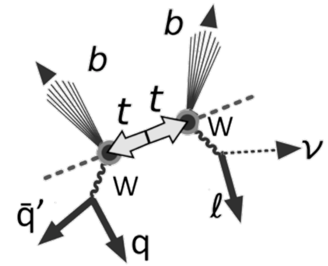
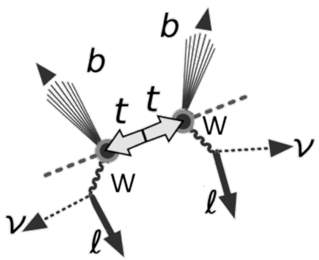


Dilepton helicity fractions (setting F_R=0):

$$ee : F_0 = 0.66 \pm 0.26\,(\text{stat.} + \text{syst.})$$
$$e\mu : F_0 = 0.72 \pm 0.16\,(\text{stat.} + \text{syst.})$$
$$\mu\mu : F_0 = 0.74 \pm 0.19\,(\text{stat.} + \text{syst.})$$



Combination of lepton + jets and dilepton channels

$$F_0 = 0.75 \pm 0.08\ (\text{stat.+syst.})$$
$$F_L = 0.25 \pm 0.08\ (\text{stat.+syst.})$$

setting F_R = 0 (Not enough data to fit F_0 and F_L in dilepton)

0.7 fb^{-1}

ATLAS-CONF 2011-122

W-boson polarization

Angular Asymmetries

$$A_{\pm} = \frac{N(\cos\theta^* > z) - N(\cos\theta^* < z)}{N(\cos\theta^* > z) + N(\cos\theta^* < z)}$$

$$z = \mp(2^{2/3} - 1) \text{ for } A_{\pm}$$

In SM at NNLO

$$A_+ = 0.537 \pm 0.004$$
$$A_- = -0.841 \pm 0.006$$

$0.7\ fb^{-1}$

ATLAS-CONF 2011-122

W-boson polarization

Combination of lepton + jets and dilepton channels:

Angular Asymmetries

$$A_+ = 0.54 \pm 0.02\ (\text{stat.}) \pm 0.04\ (\text{syst.})$$
$$A_- = -0.85 \pm 0.01\ (\text{stat.}) \pm 0.02\ (\text{syst.})$$

Helicity Fractions

$$F_0 = 0.70 \pm 0.10\ (\text{stat} + \text{syst})$$
$$F_L = 0.31 \pm 0.07\ (\text{stat} + \text{syst})$$
$$F_R = -0.01 \pm 0.04\ (\text{stat} + \text{syst})$$

$0.7\ fb^{-1}$

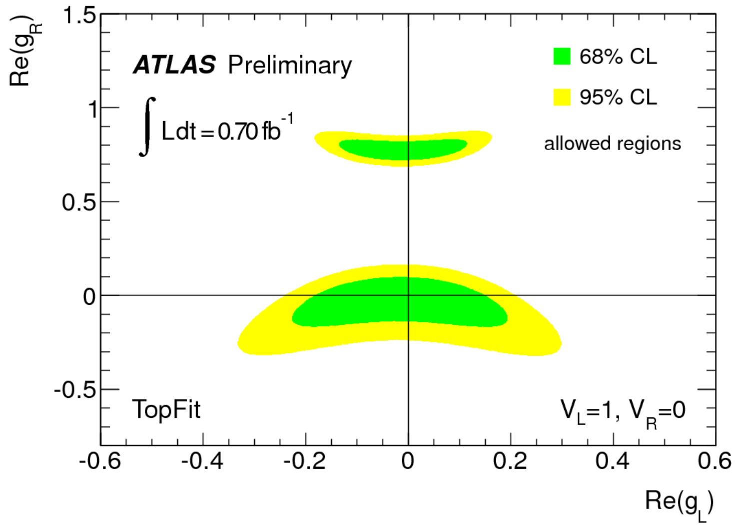
ATLAS-CONF 2011-122

W-boson polarization

Anomalous couplings

$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\,\gamma^{\mu}\,(V_{\mathrm{L}}P_L + V_{\mathrm{R}}P_R)\,t\;W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\,(g_{\mathrm{L}}P_L + g_{\mathrm{R}}P_R)\,t\;W_{\mu}^{-} + \mathrm{h.c.}$$

Constraints from angular asymmetries



$$\mathrm{Re}\,V_{\mathrm{R}} \in [-0.34, 0.39] \rightarrow \frac{\mathrm{Re}\,(C_{\phi\phi}^{33})}{\Lambda^2} \in [-11.2, 12.7]\ \mathrm{TeV}^{-2},$$

$$\mathrm{Re}\,g_{\mathrm{L}} \in [-0.20, 0.16] \rightarrow \frac{\mathrm{Re}\,(C_{dW}^{33})}{\Lambda^2} \in [-2.28, 1.90]\ \mathrm{TeV}^{-2},$$

$$\mathrm{Re}\,g_{\mathrm{R}} \in [-0.19, 0.13] \rightarrow \frac{\mathrm{Re}\,(C_{uW}^{33})}{\Lambda^2} \in [-2.27, 1.57]\ \mathrm{TeV}^{-2}.$$

Constraints from W helicity fractions

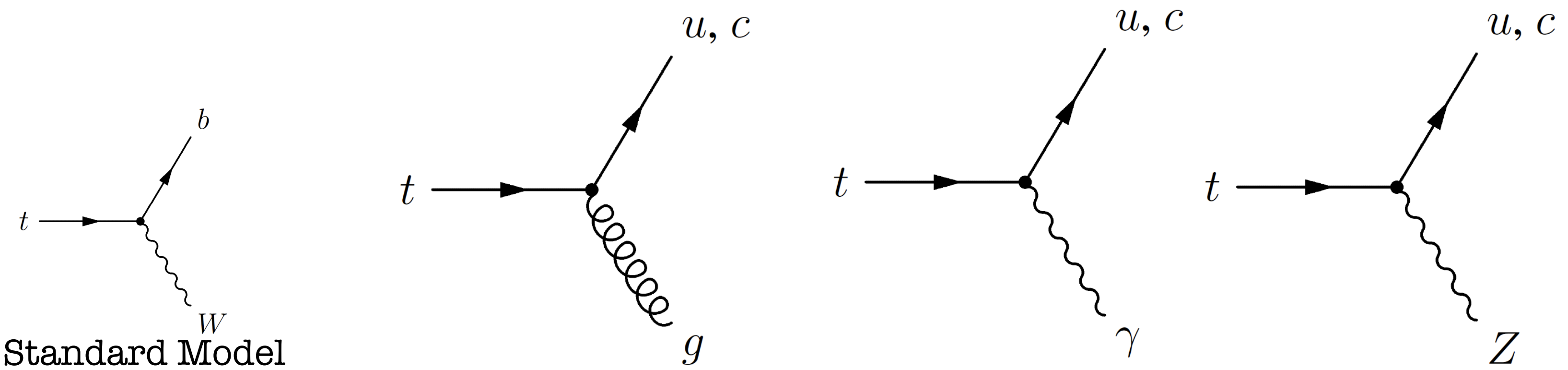
$$\frac{\mathrm{Re}(C_{uW}^{33})}{\Lambda^2} \in [-3.45,\ 1.80]\ \mathrm{TeV}^{-2}$$

0.7 fb^{-1}

ATLAS-CONF 2011-122

Flavor Changing Neutral Currents

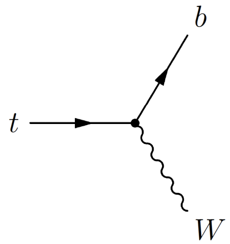
In the Standard Model Flavor Changing Neutral Currents are forbidden at tree level, and are allowed at one-loop level with a branching ratio of the order of 10^{-14}



Standard Model dominant decay

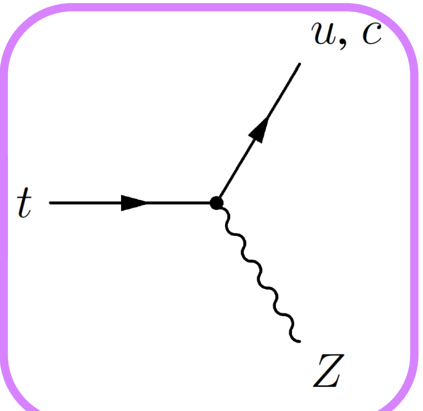
Flavor Changing Neutral Currents

In the Standard Model Flavor Changing Neutral Currents are forbidden at tree level, and are allowed at one-loop level with a branching ratio of the order of 10^{-14}



Standard Model dominant decay

The BR for this decay can be enhanced up to 10^{-4} in other SM extensions



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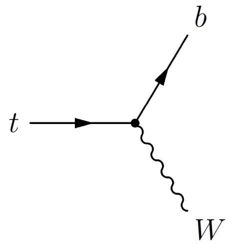

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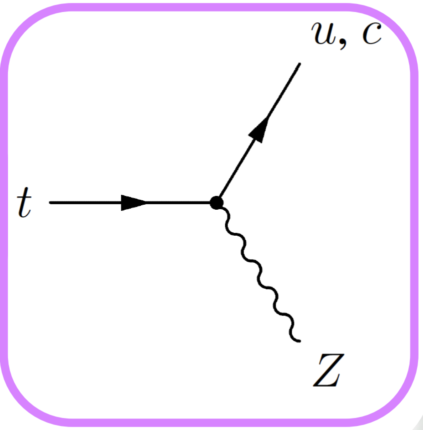
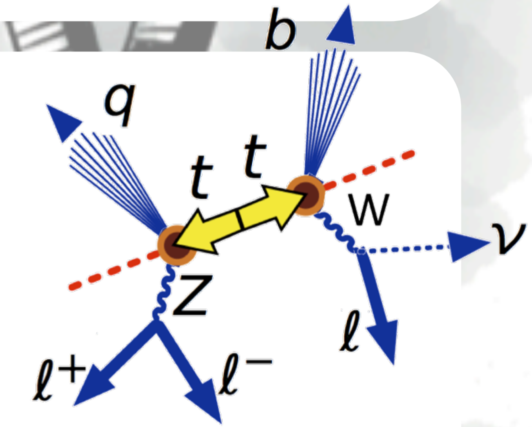


We search for
Flavor Changing Neutral Currents
in t-tbar events.

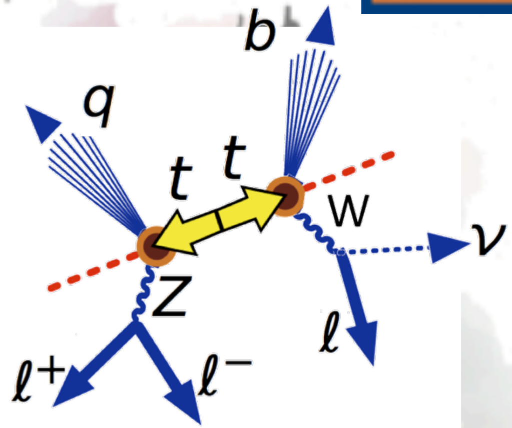
With one top quark decaying through $t \rightarrow qZ$,
and the other through the SM dominant mode $t \rightarrow bW$.



Only leptonic decays of the bosons (W, Z) are considered signal.

Flavor Changing Neutral Currents

We search for
Flavor Changing Neutral Currents
in t-tbar events.



With one top quark decaying through $t \rightarrow qZ$,
and the other through the SM dominant mode $t \rightarrow bW$.

Only leptonic decays of the bosons (W, Z) are considered signal.

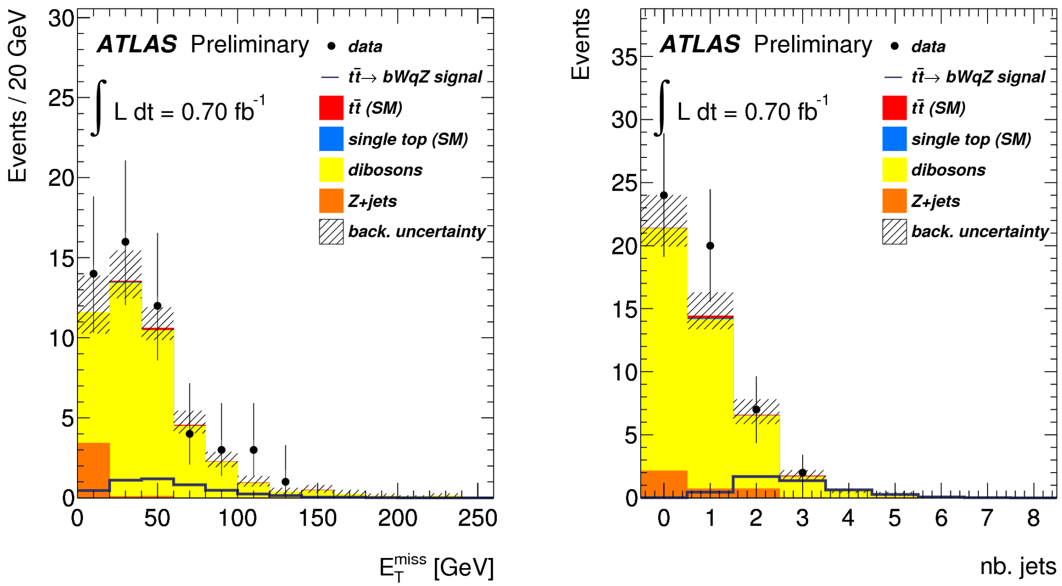
- Select events with 3 leptons, 2 large p_T jets, and large E_T^{miss}.
- We should have at least two leptons with opposite sign, same flavor ('Z-candidate')
- Reconstruct the objects by minimizing:

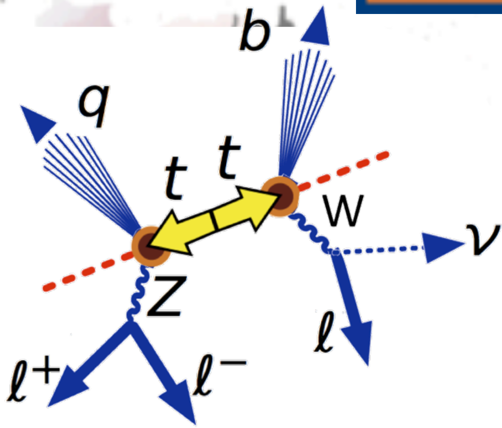
$$\chi^2 = \frac{(m_t^{FCNC} - m_t)^2}{\sigma_{m_t}^2} + \frac{(m_t^{SM} - m_t)^2}{\sigma_{m_t}^2} + \frac{(m_W^{SM} - m_W)^2}{\sigma_{m_W}^2} + \frac{(m_Z^{SM} - m_Z)^2}{\sigma_{m_Z}^2}$$

and apply mass constraints in both top-quarks, the W- and the Z-boson.

Flavor Changing Neutral Currents

Distributions at a pre-selection level





Final selection level

ZZ and *WZ*	2.4 ± 0.3
1+2+3 fake leptons (DD)	$0.0\ ^{+\ 1.8}_{-\ 0.0}$
Expected background	$2.4\ ^{+\ 1.8}_{-\ 0.3}$
Data	2
Signal efficiency	$(0.209 \pm 0.004)\%$

Good agreement between data observation and expected SM background.
No evidence of Flavor Changing Neutral Currents
is found, we derive **95% CL** limits on the BR for this decay

$$BR(t \to qZ) < 1.1\%$$

$0.7\ fb^{-1}$

ATLAS-CONF 2011-154

Summary

Top Quark Mass

Template Method in All-Ha
Channel, 2 fb^{-1}

Template Method in Lepto
Channel, 1 fb^{-1}

From t-tbar cross section,

1.0 fb^{-1}
arxiv: 1203.5755

2.0 fb^{-1}
ATLAS-CONF 2011-030

Top Quark Charge

Track charge weighting and

soft lepton techniques

in lepton + jets channel, 0

0.7 fb^{-1}
ATLAS-CONF 2011-141

W-boson polarization

Measurement of angular asymmetries

and template method in

lepton + jets and dilepton ch
0.7 fb^{-1}

0.7 fb^{-1}
ATLAS-CONF 2011-122

FCNC

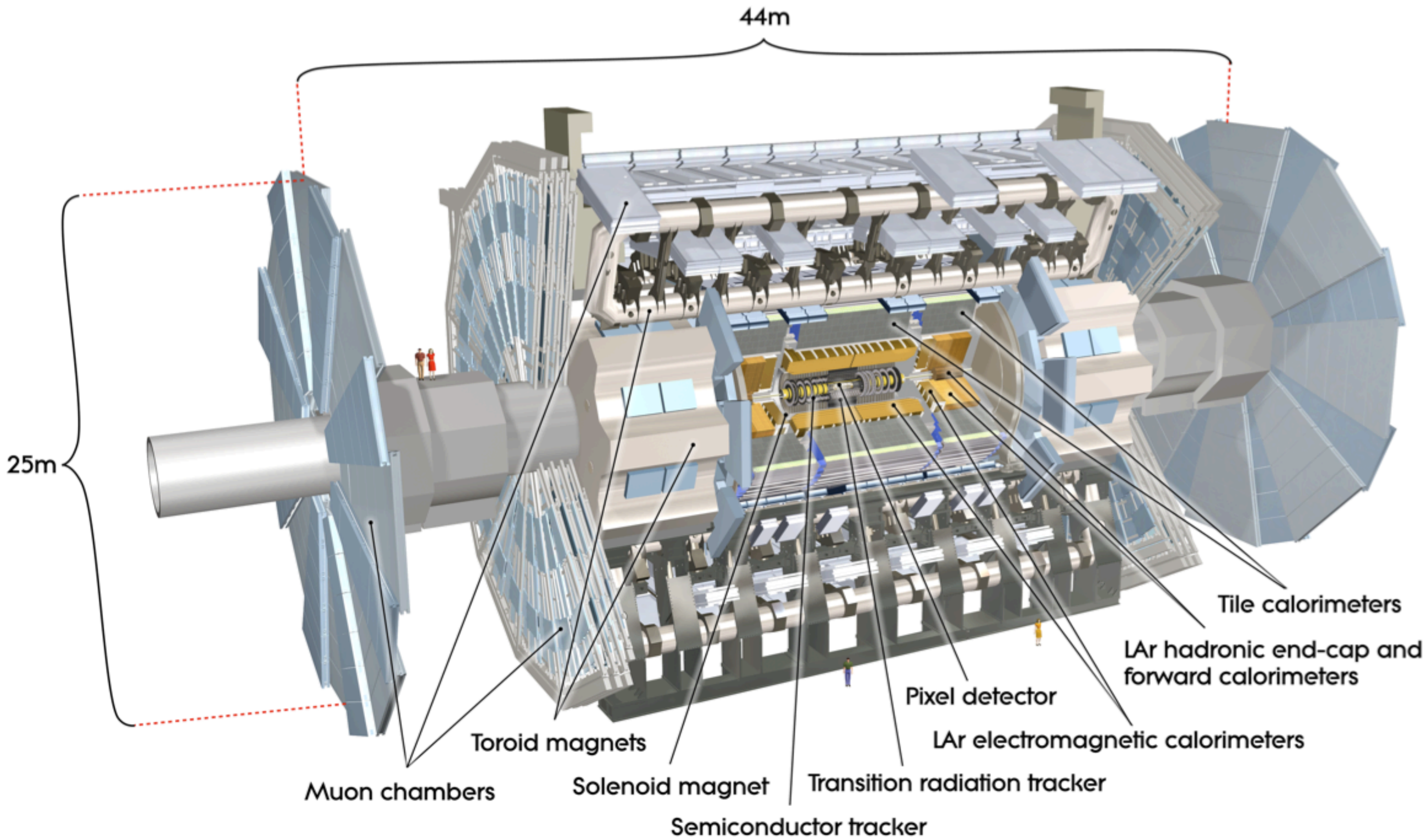
Count & Cut method in

all-leptonic final states, 0.7 fb^{-1}

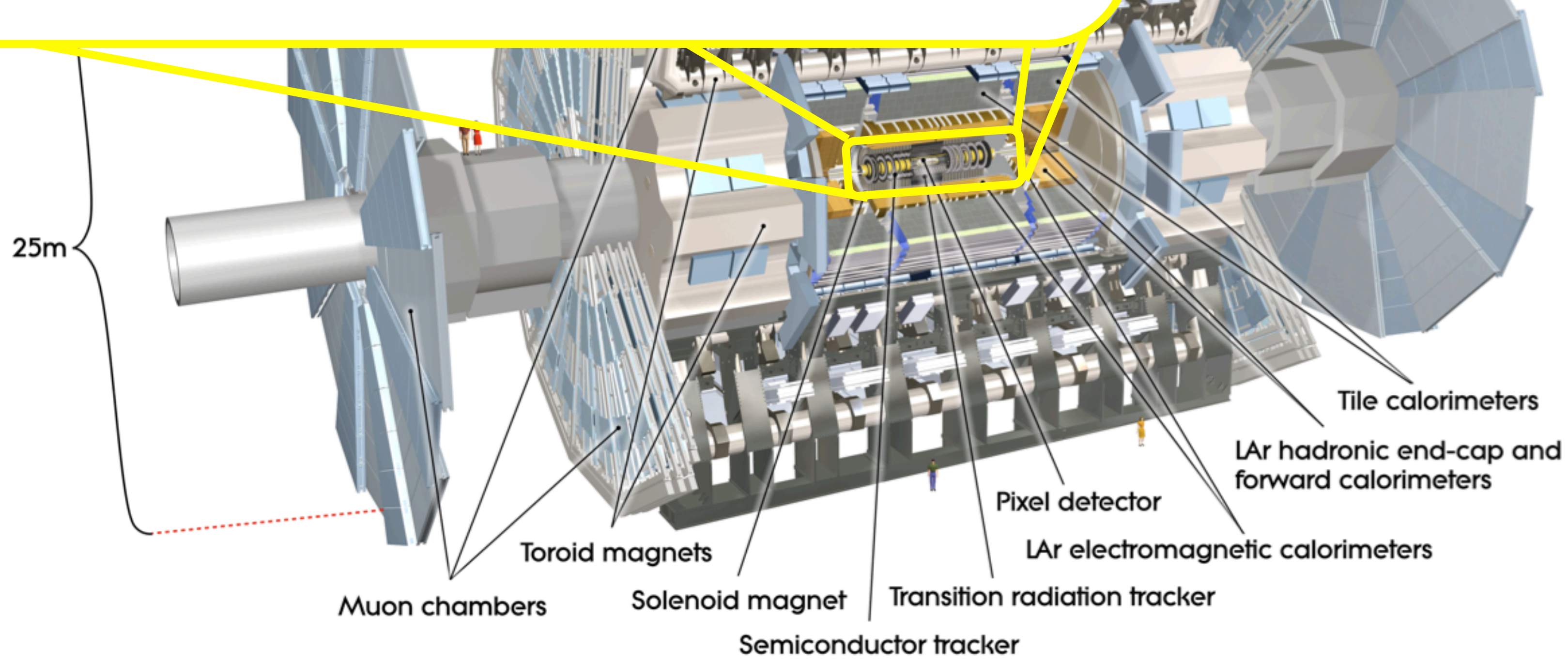
0.7 fb^{-1}
ATLAS-CONF 2011-154

Thank you!

ATLAS Detector

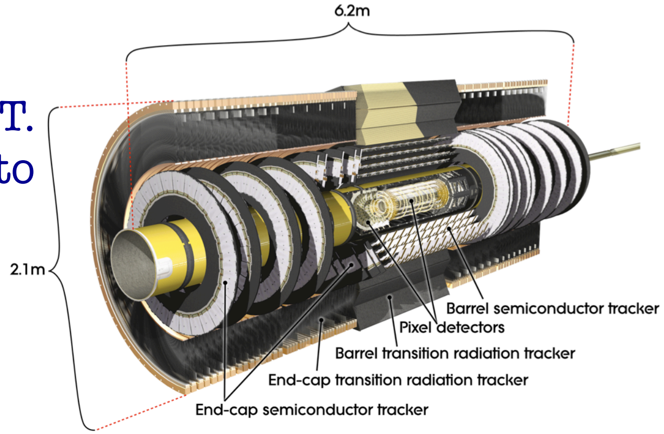


ATLAS Detector

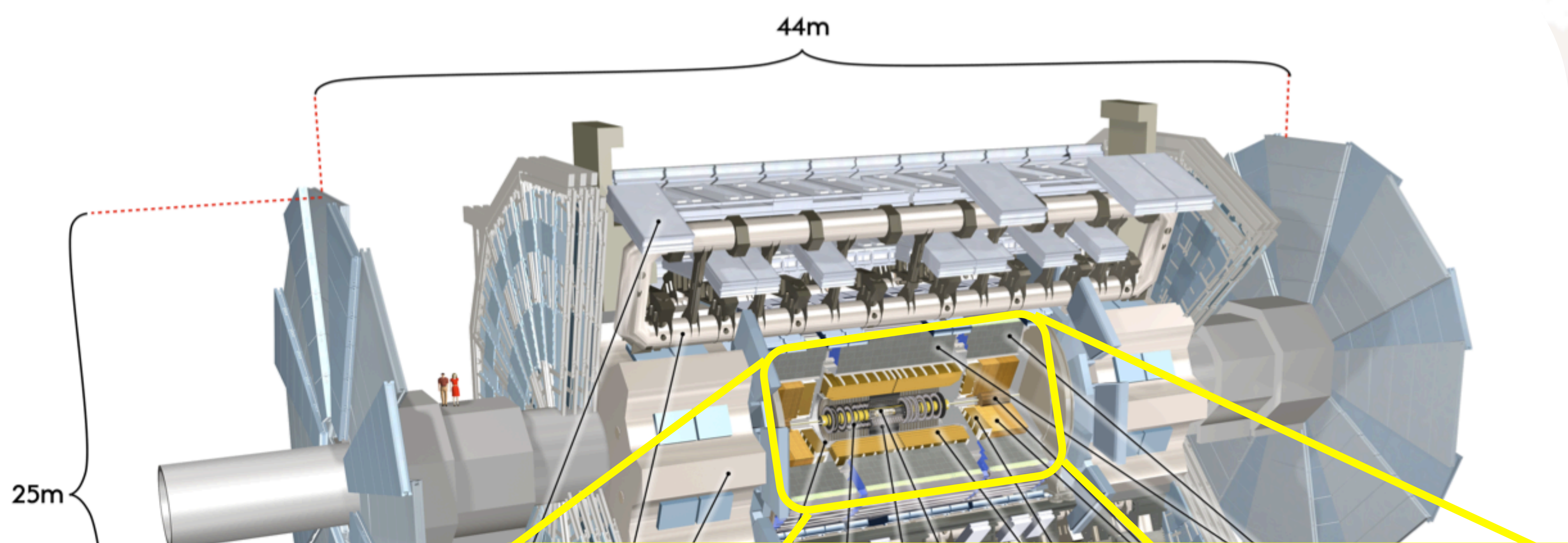


Inner Detector

Silicon pixels and strips, TRT.
Use solenoid magnetic field to measure momentum.
High efficiency tracker, performs precise measurements of leptons.



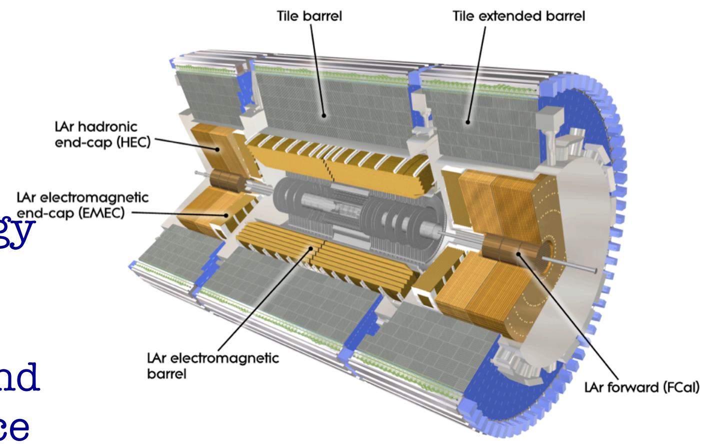
ATLAS Detector



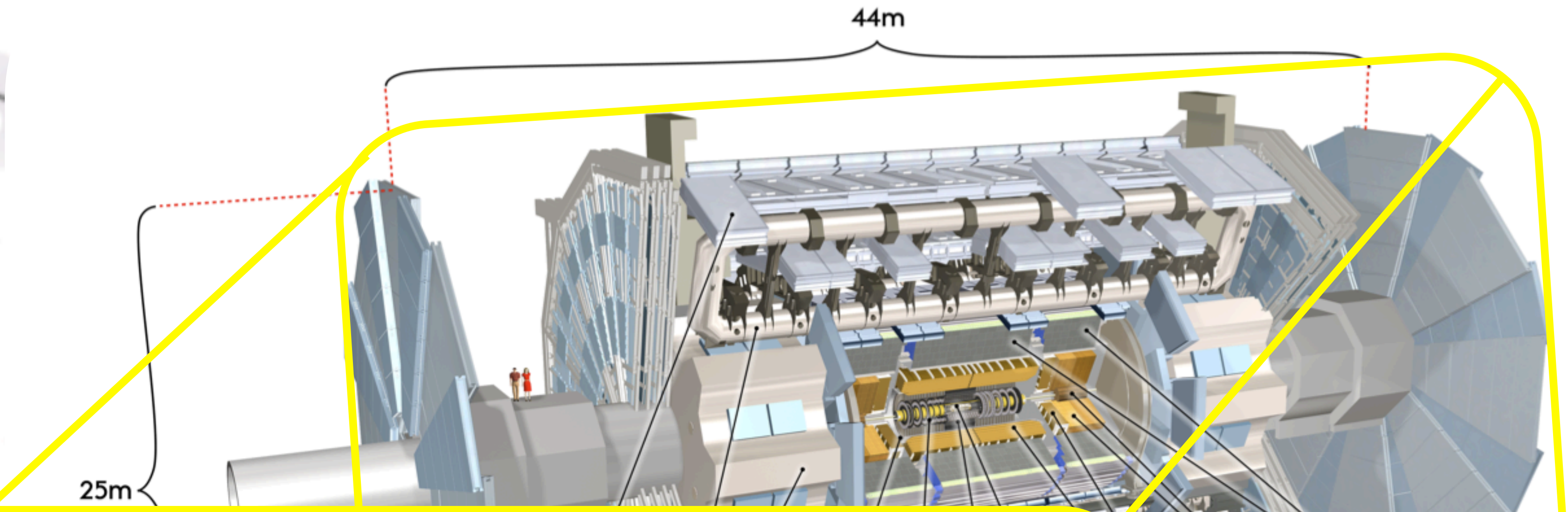
Calorimeters

The LAr electromagnetic calorimeter identifies electron/photons has excellent angular and energy resolution.

The scintillation-tile calorimenter has good jet and missing energy performance

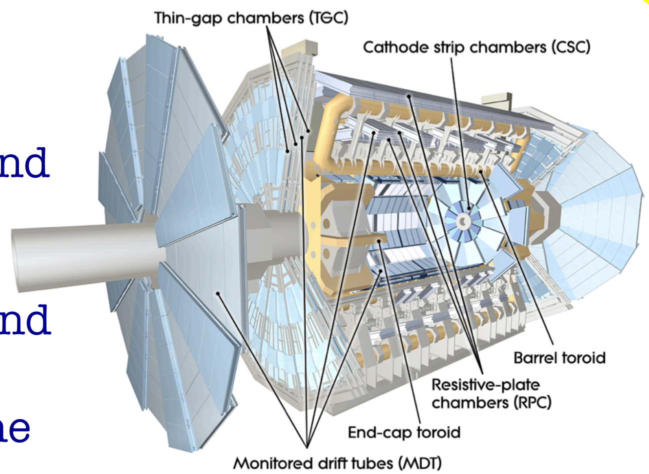


ATLAS Detector

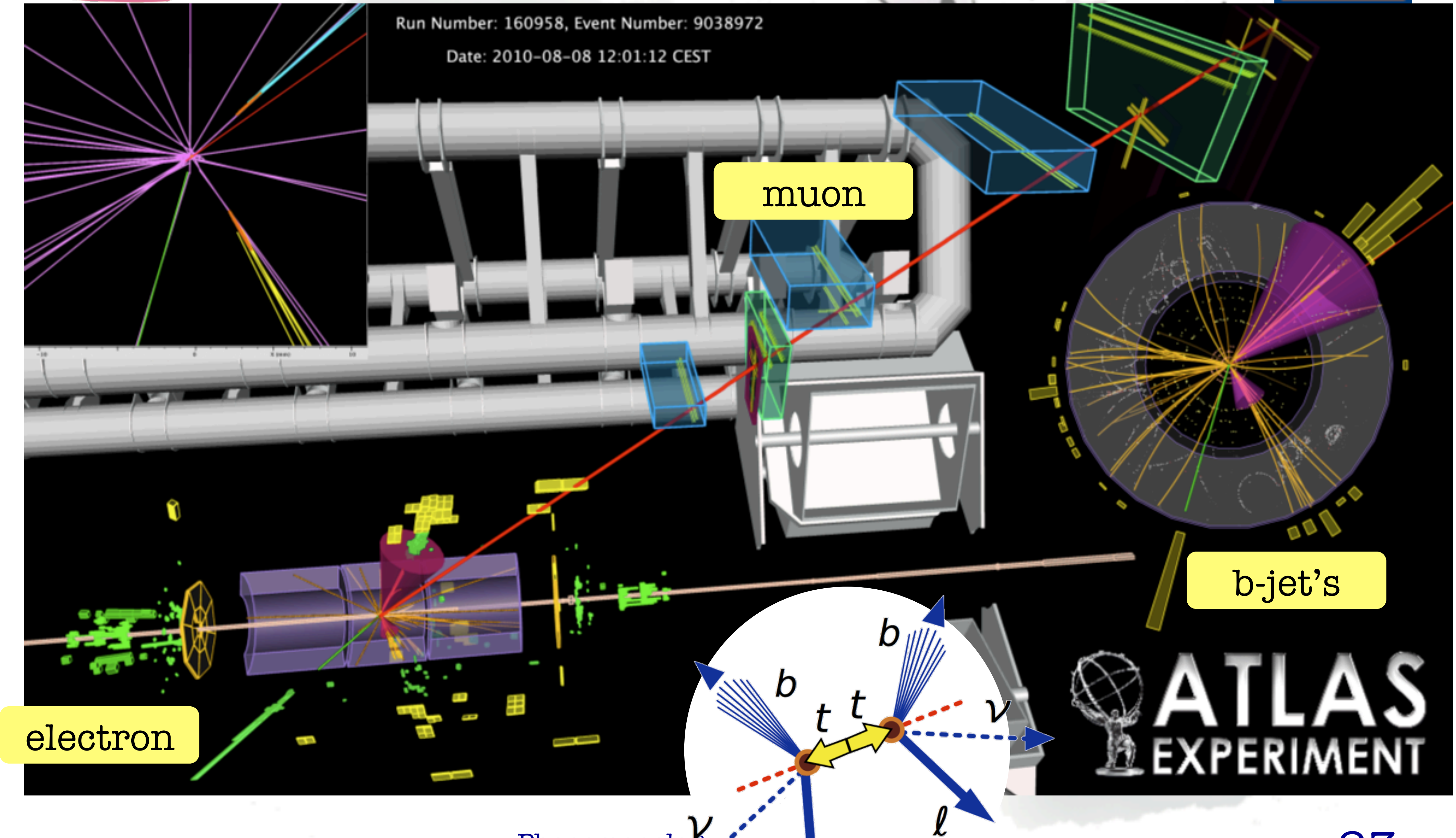


Muon Spectrometer

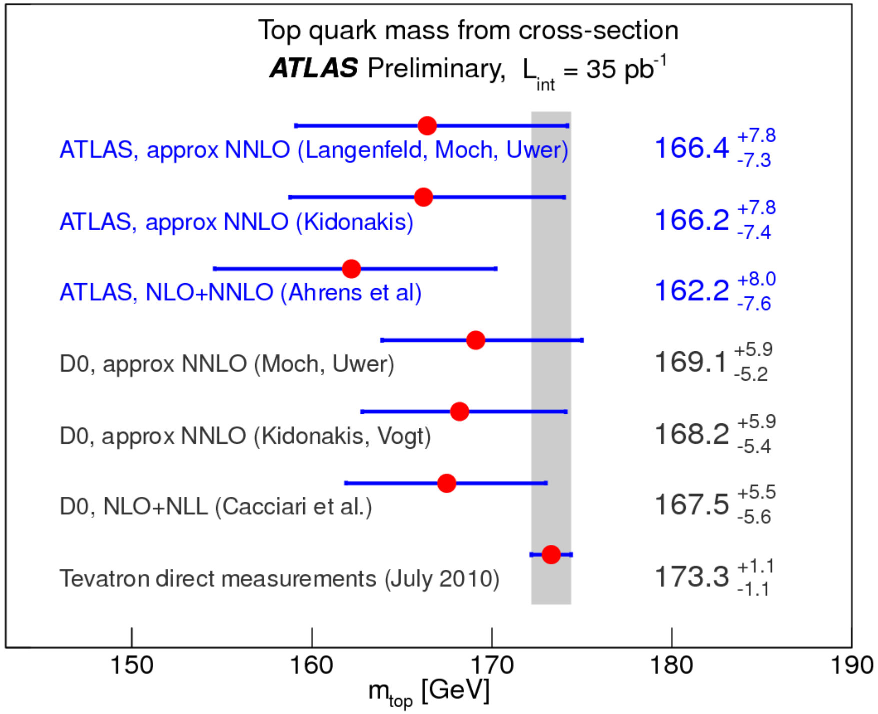
Instrumented with trigger and high-precision tracking chambers.
Muon tracks are identified and reconstructed, and their momentum measured, in the spectrometer.

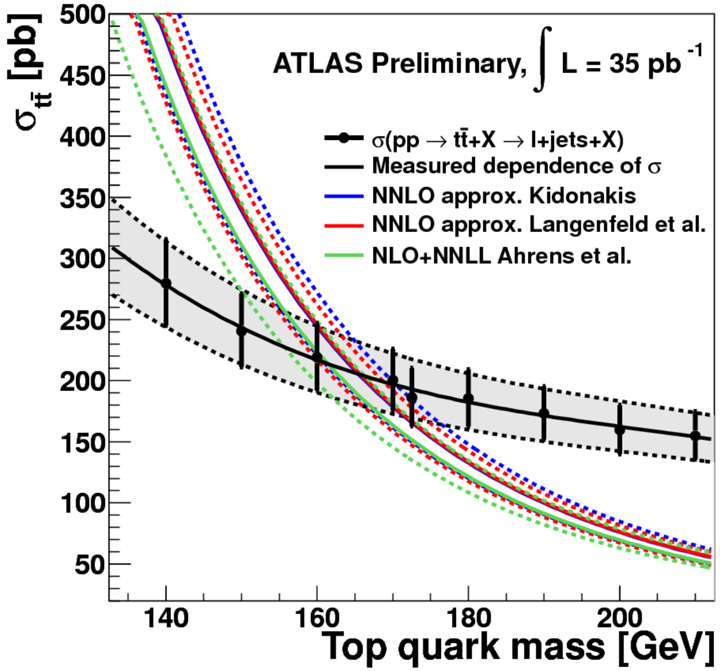


t-tbar event observed in ATLAS



Top Quark Mass from t-tbar cross section

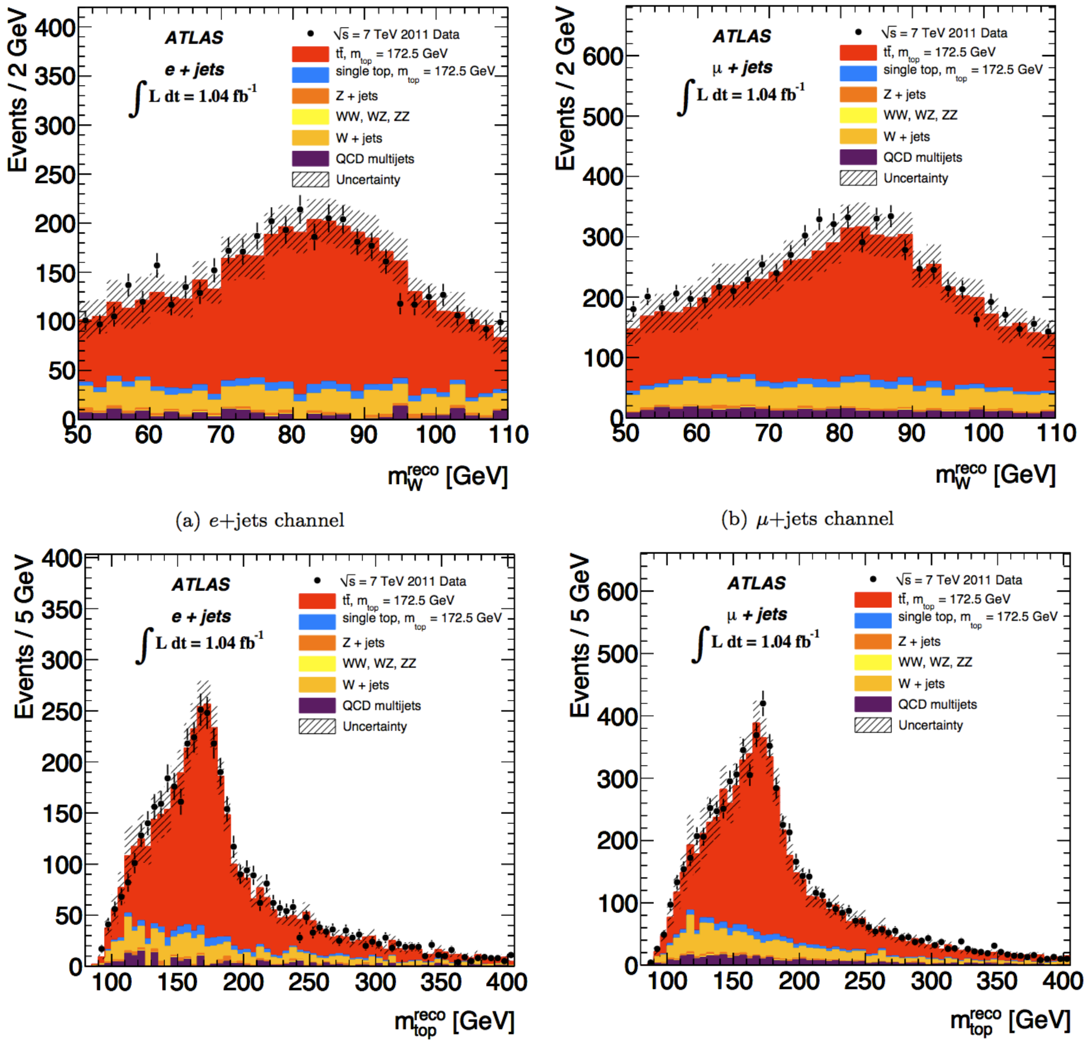




$35\ pb^{-1}$

ATLAS-CONF 2011-054

Top Quark Mass – Lepton + Jets (2D)



(a) e+jets channel (b) μ+jets channel

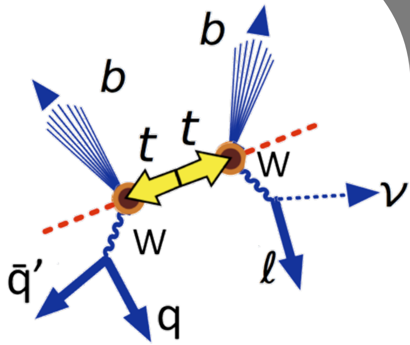
(c) e+jets channel (d) μ+jets channel

W-boson polarization

Angular Asymmetries

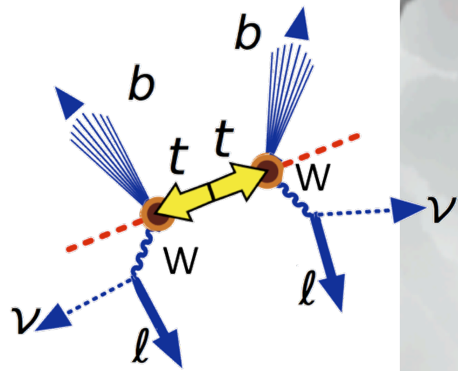
Measured in lepton + jets:

$$A_+ = 0.54 \pm 0.02\,(\text{stat.}) \pm 0.05\,(\text{syst.})$$
$$A_- = -0.84 \pm 0.01\,(\text{stat.}) \pm 0.02\,(\text{syst.})$$



Measured in dilepton channel:

$$A_+ = 0.54 \pm 0.03\,(\text{stat.}) \pm 0.05\,(\text{syst.})$$
$$A_- = -0.85 \pm 0.02\,(\text{stat.}) \pm 0.03\,(\text{syst.})$$



Combination of both channels:

$$A_+ = 0.54 \pm 0.02\,(\text{stat.}) \pm 0.04\,(\text{syst.})$$
$$A_- = -0.85 \pm 0.01\,(\text{stat.}) \pm 0.02\,(\text{syst.})$$

0.7 fb^{-1}

ATLAS-CONF 2011-122