ATLAS Top Physics Results

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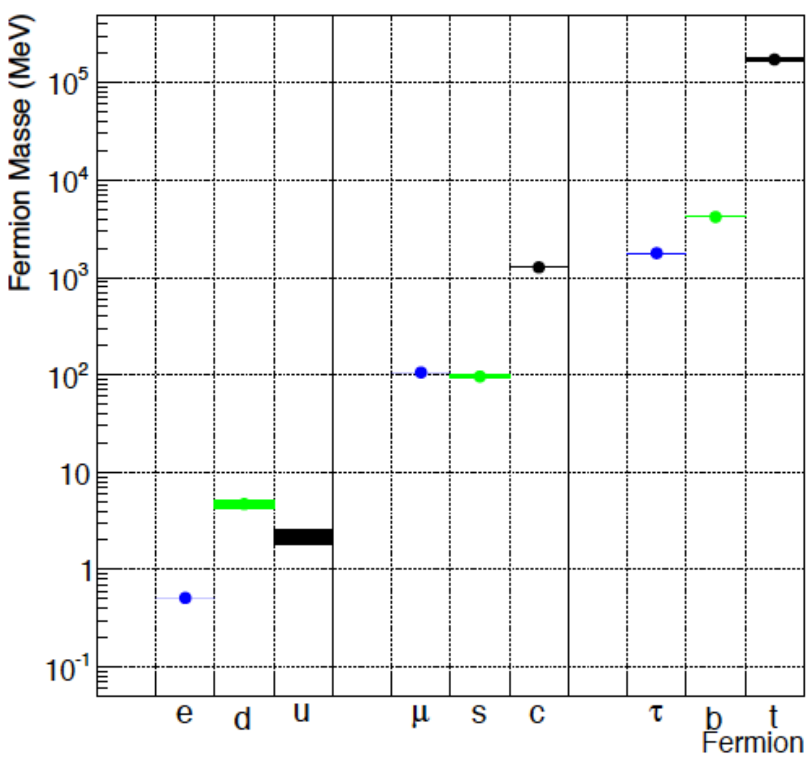
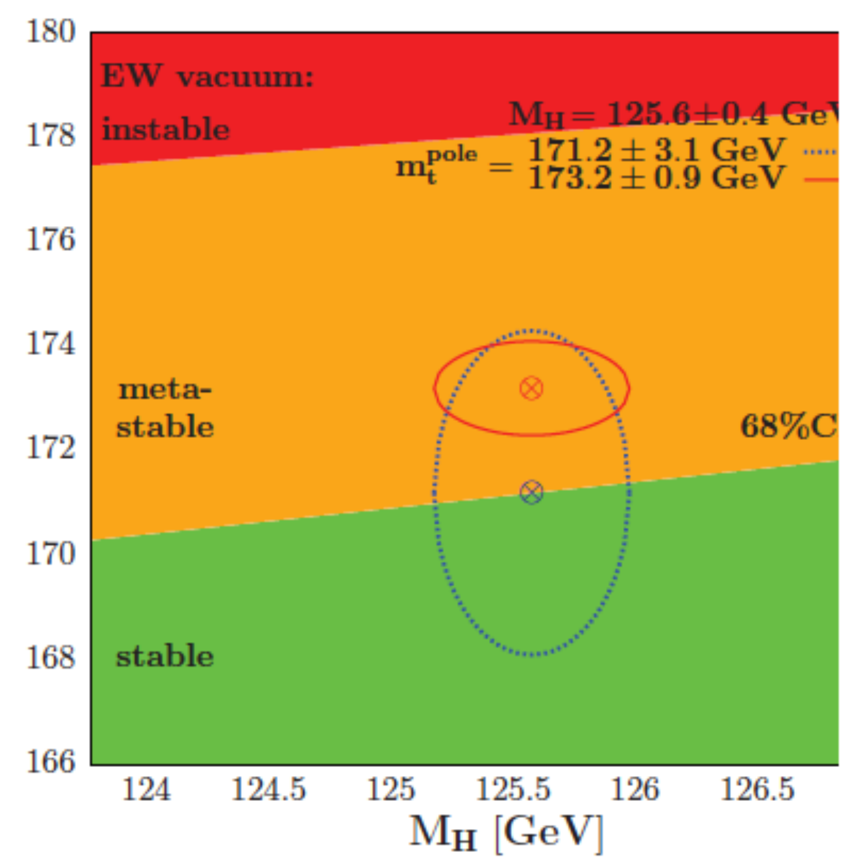
ATLAS EXPERIMENT

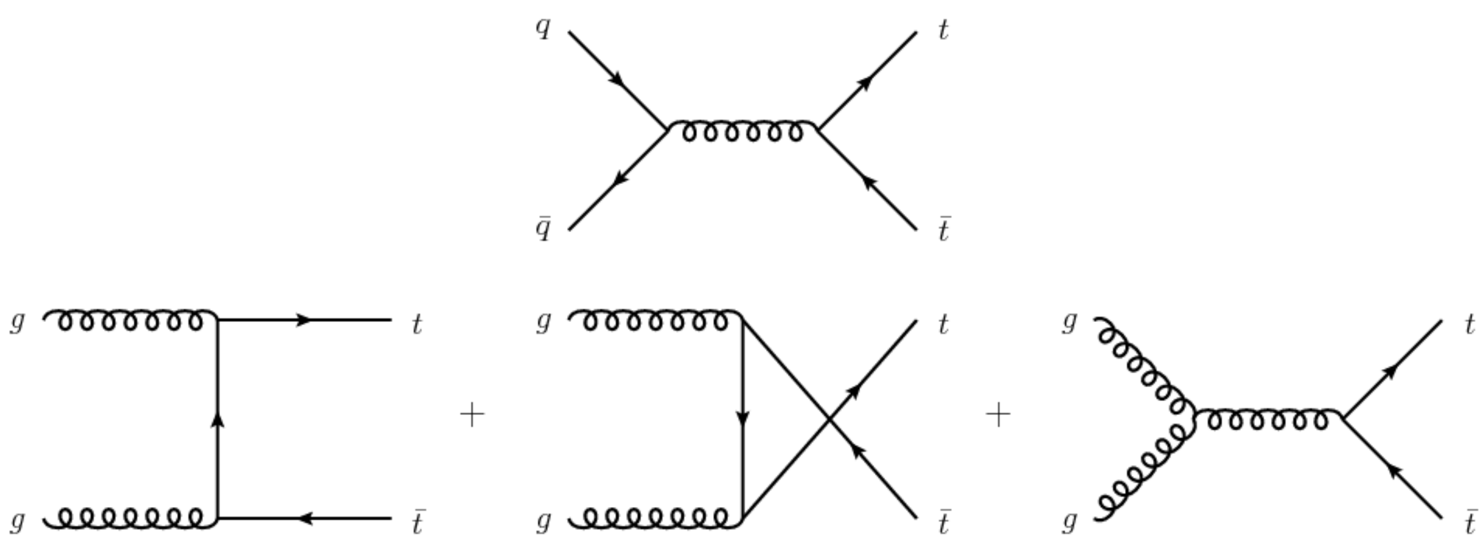
Uniqueness of the Top Quark

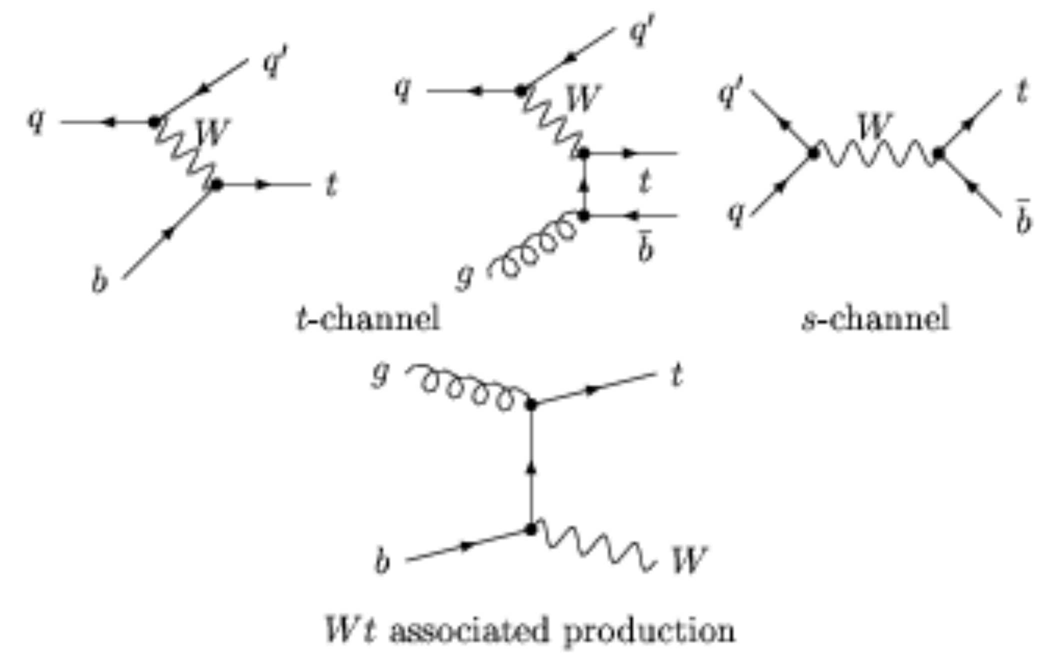
- Lifetime (10^{-25} s) < Hadronization (10^{-24} s)
- Yukawa Coupling ~ 1
- Largest mass of known fundamental particles -> largest correction to Higgs Boson Mass
- Driving input - along with Higgs Boson mass on the stability of the electroweak vacuum
- Important background for many searches





Top Production At The LHC

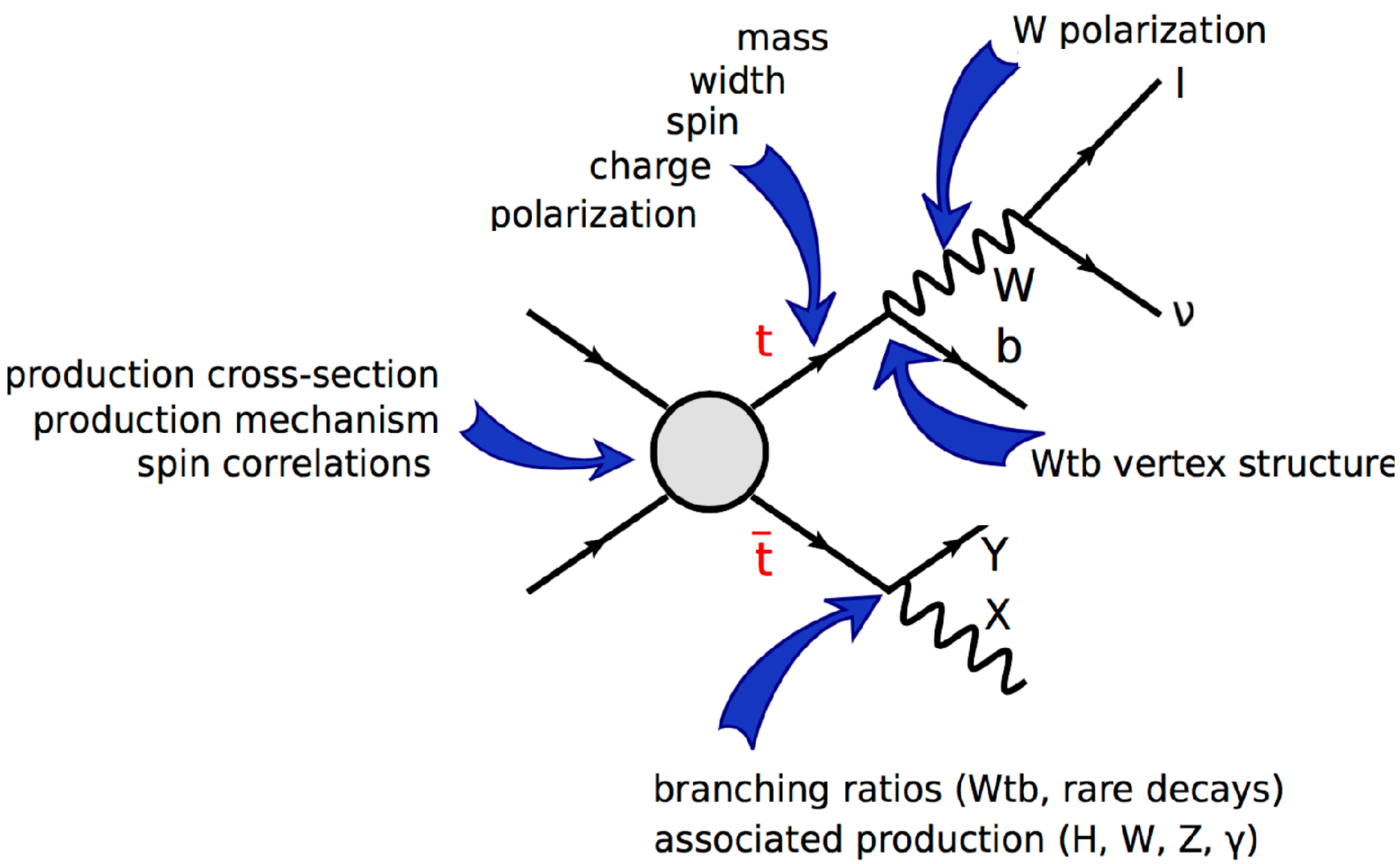


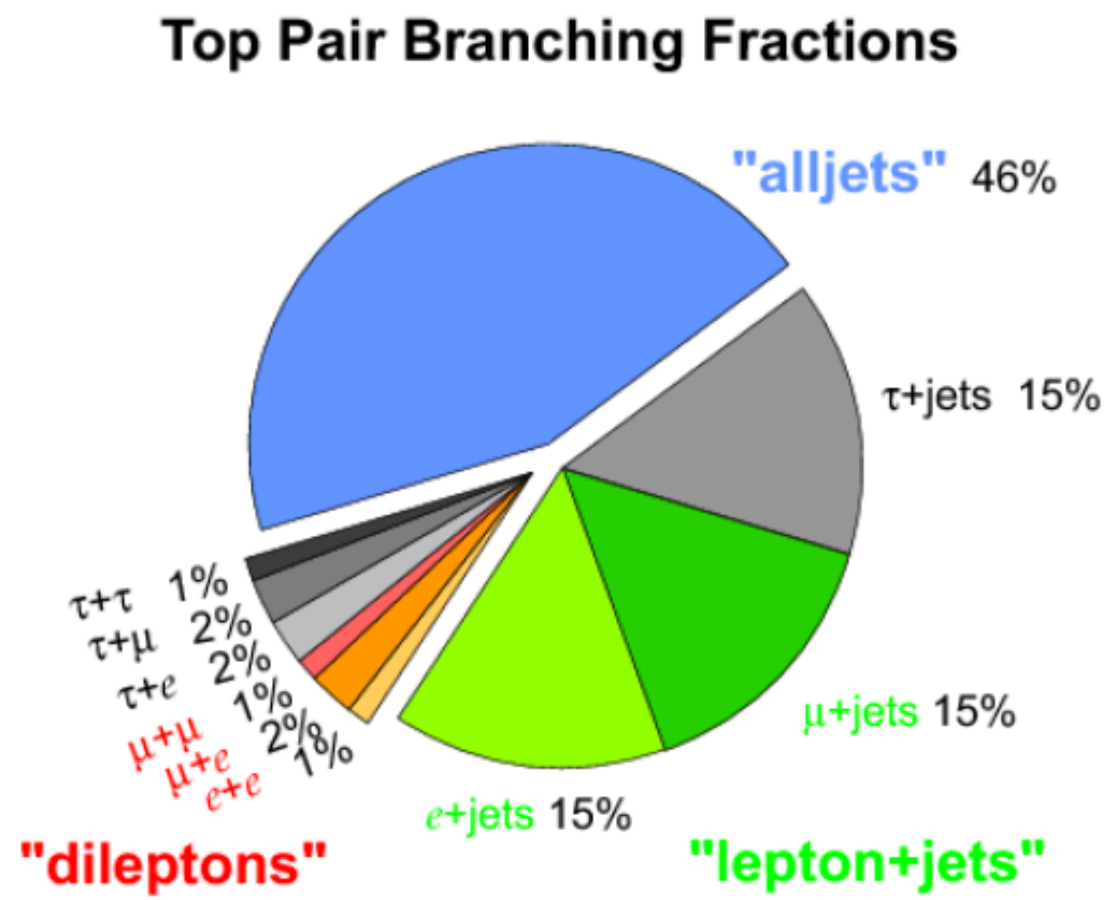


Pair Production via quark-quark annihilation and gluon fusion

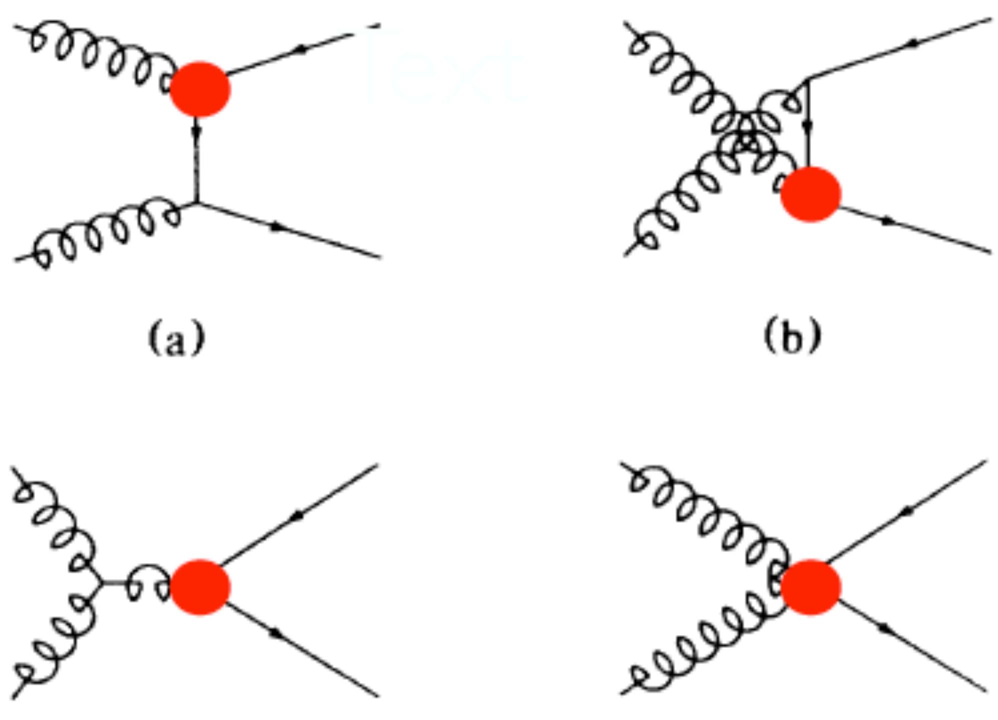
Single Top via three electroweak processes

Top Decays and Properties





Pair Production

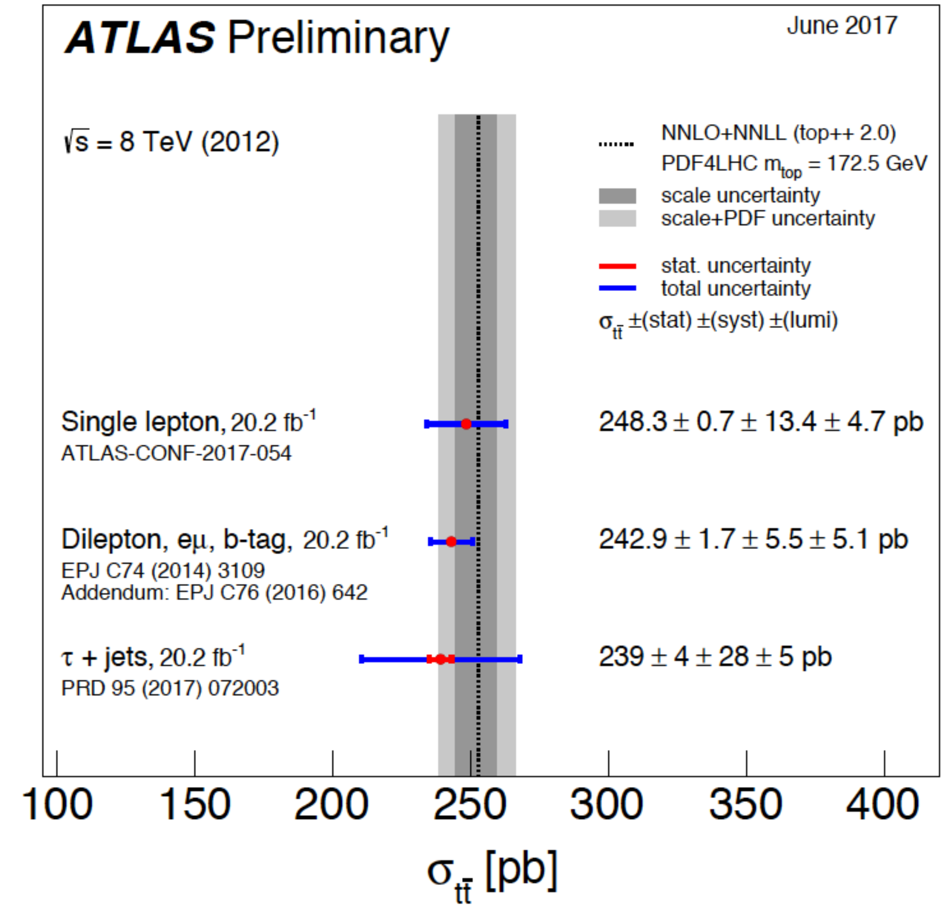


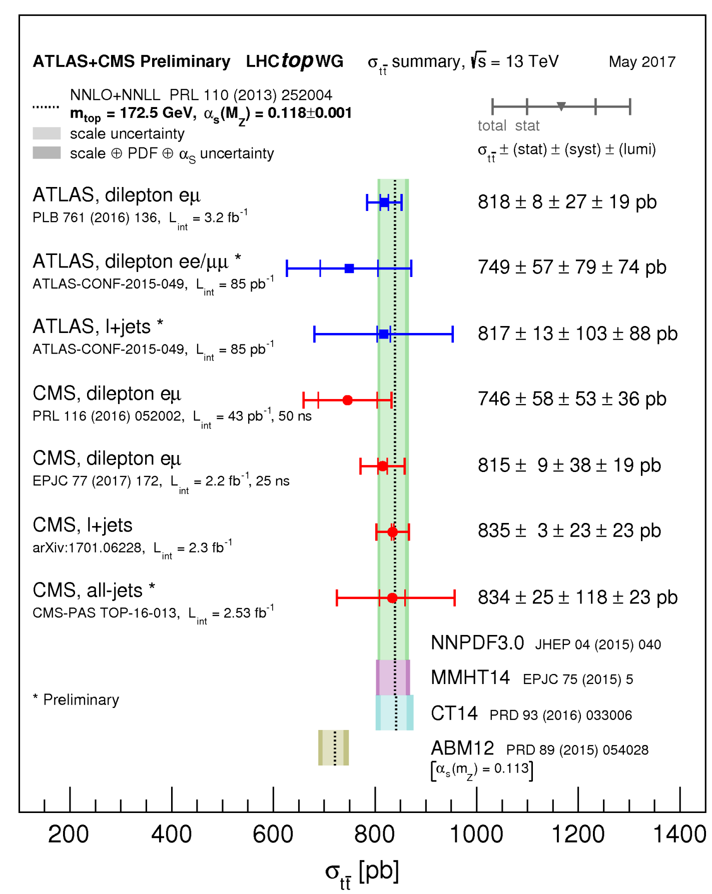
(a) (b)

(c) (d)

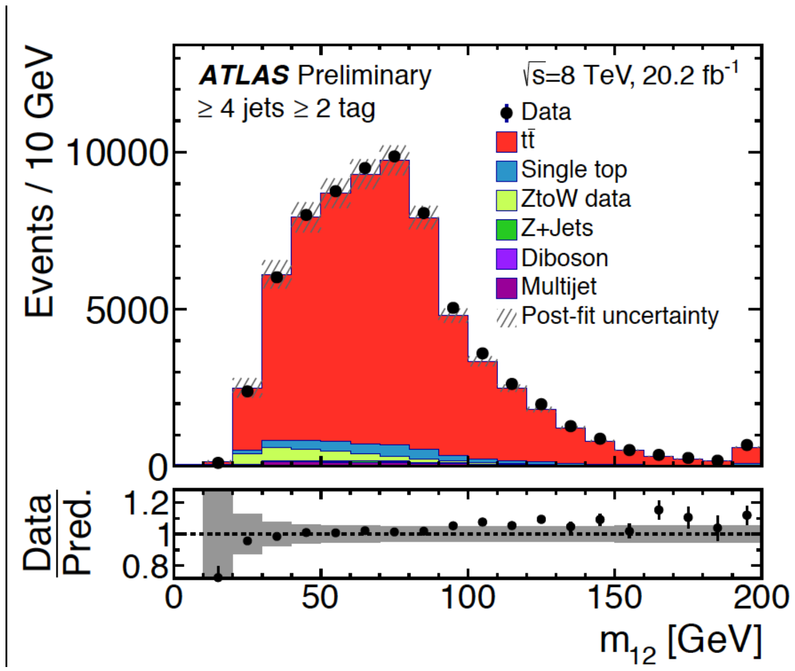
$$\sigma_{tt} \propto \sigma_{SM}\left(1 + c\frac{s}{\Lambda^2} + \ldots\right)$$

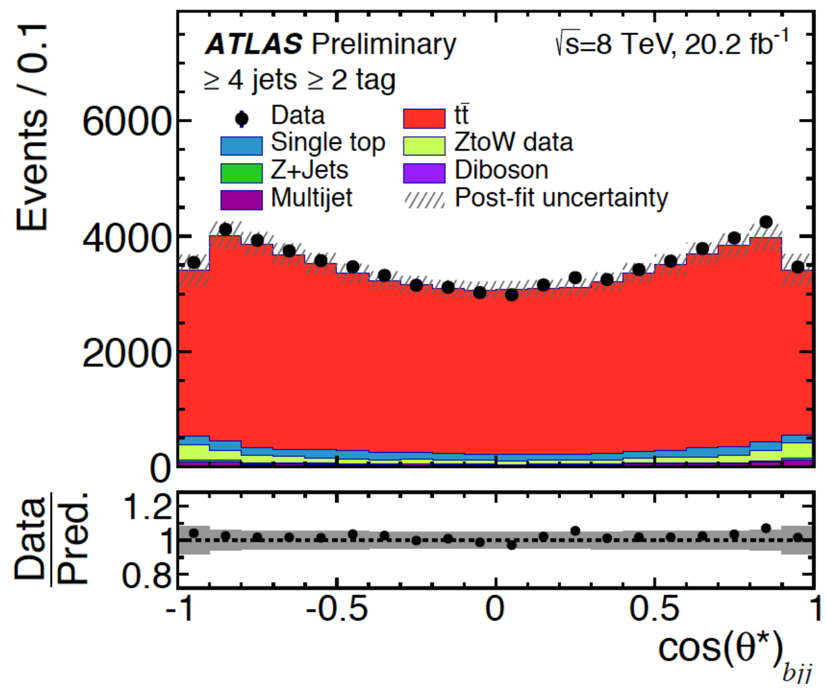
Precision test of QCD - search for new interactions in top production

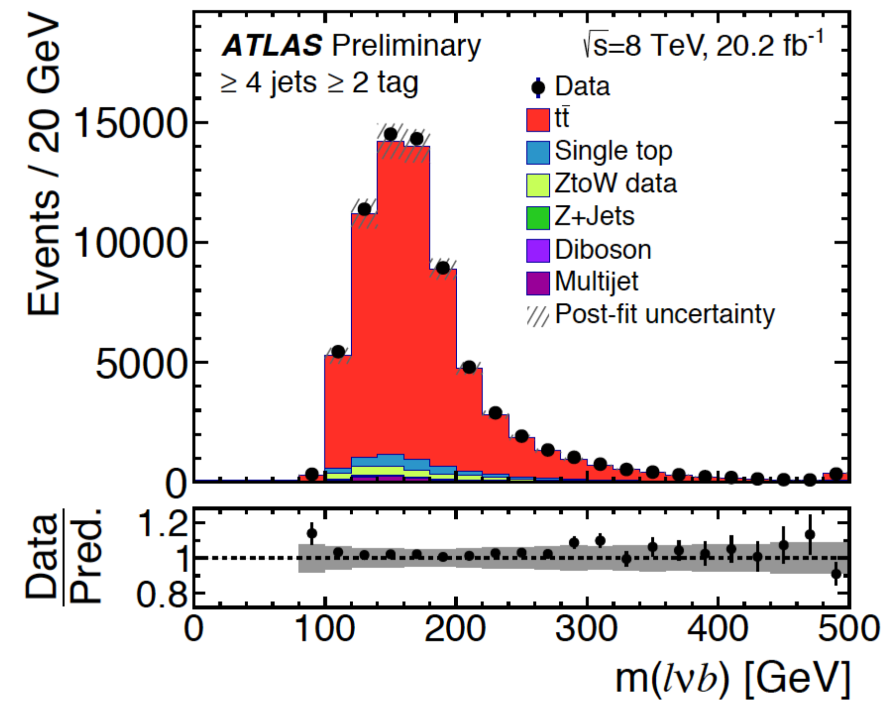


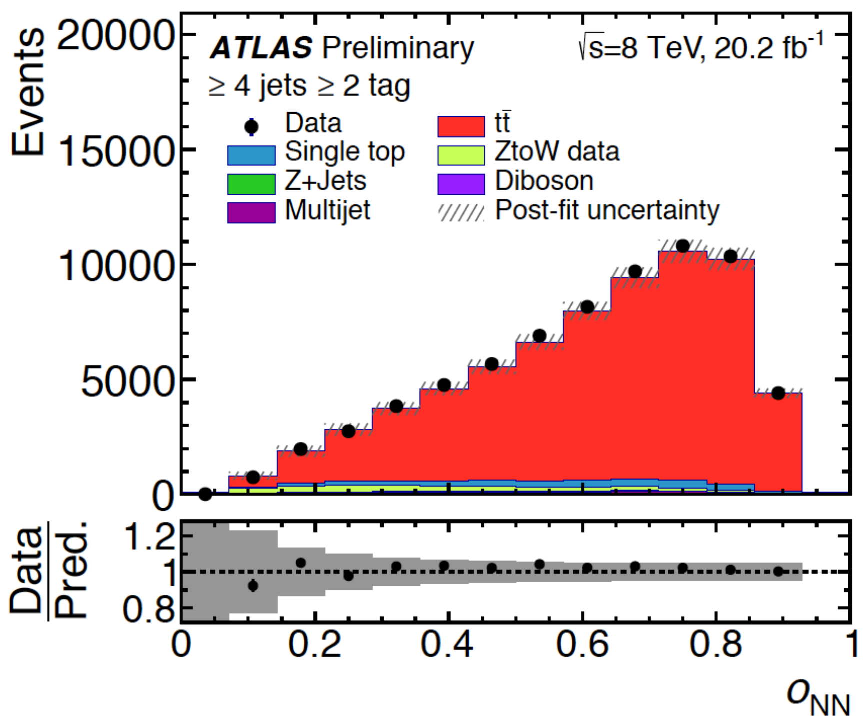


Precision Lepton+Jets Measurement









$$\sigma_{t\bar{t}} = 248.3 \pm 0.7\ \text{(stat.)} \pm 12.8\ \text{(syst.)} \pm 4.7\ \text{(lumi.)}\ \text{pb}$$

at 8 TeV

TOPQ-2016-08

4 or more high Pt jets
(2 or more b-tags)
1 high Pt lepton (e or mu)
Large Missing Transverse Energy

Neural Network constructed from kinematic variables

Cross-Section Extracted by maximum likelihood Method

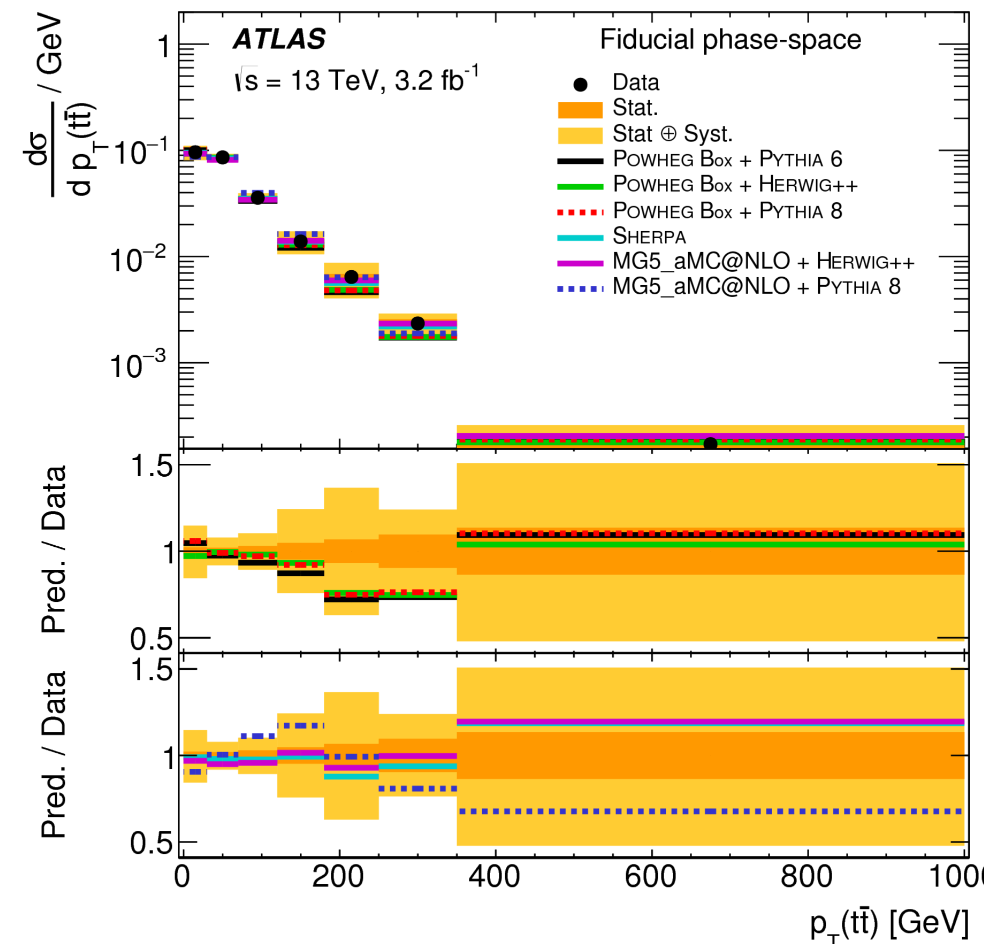
Differential Cross-Section Results

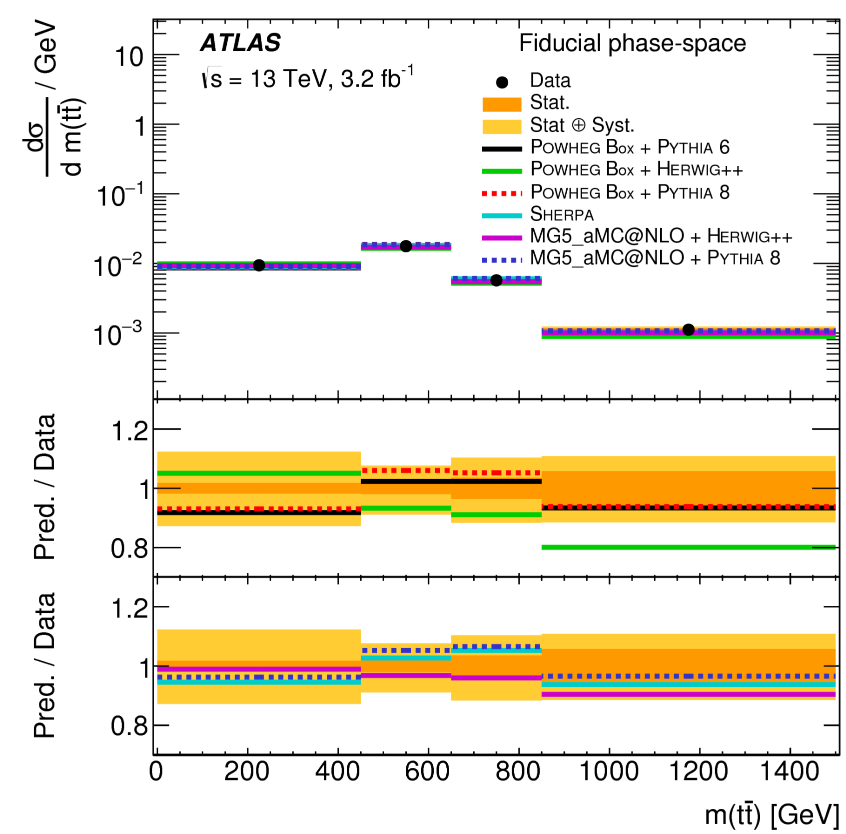
- Total Cross-section is sensitive to overall production but more information and precision tests in looking at the differential cross-section

- Sensitive to parton-distribution functions

- As an example , recent 13 TeV measurement in the dilepton (e-mu)

- New physics (Z'->tt) could show up as a bump in the cross-section as a function of mass or if the top system recoils off another new particle in the transverse momentum of the top system





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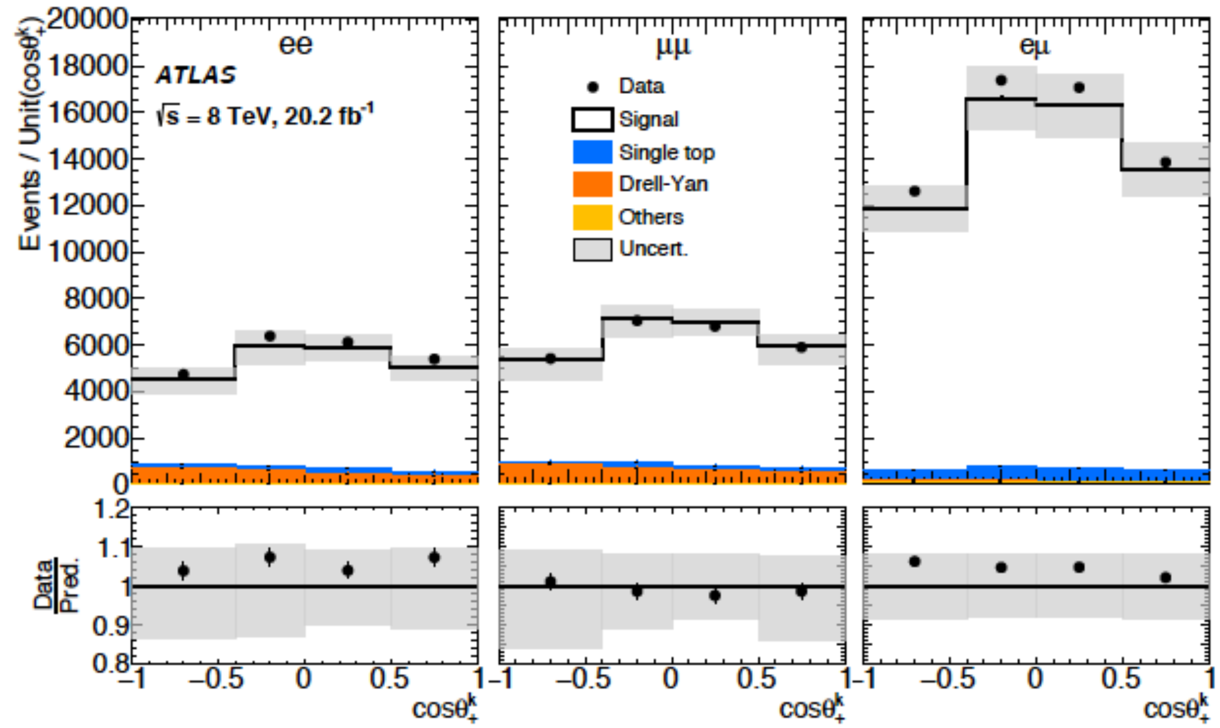
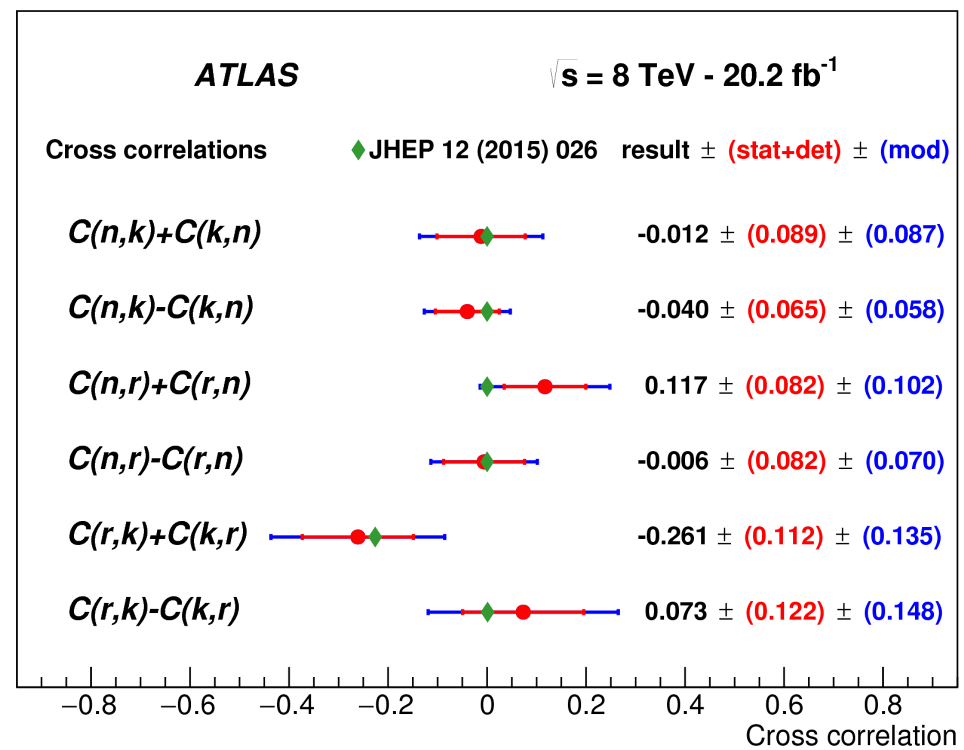
Spin Correlation Top Pair Production

- Measure spin correlations between the two tops in top pair production
- a, b are defined as the spin quantization axis of the two tops (+ = top quark, - = anti top quark)
- Spin correlation using helicity axis of top quark in tt rest frame (labeled k), the axis between the top quark direction and the beam direction (labeled n) , the orthogonal axis to k and n labeled r
- Sensitive to anomalous chromo-magnetic and chromo-electric dipole moments of the top quark
- Measurement of the full spin density matrix elements for the first time!

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_+^a d\cos\theta_-^b} = \frac{1}{4}(1 + B_+^a\cos\theta_+^a + B_-^b\cos\theta_-^b - C(a,b)\cos\theta_+^a\cos\theta_-^b)$$

$$C(a,b) = -9 < \cos\theta_+^a\cos\theta_-^b >$$

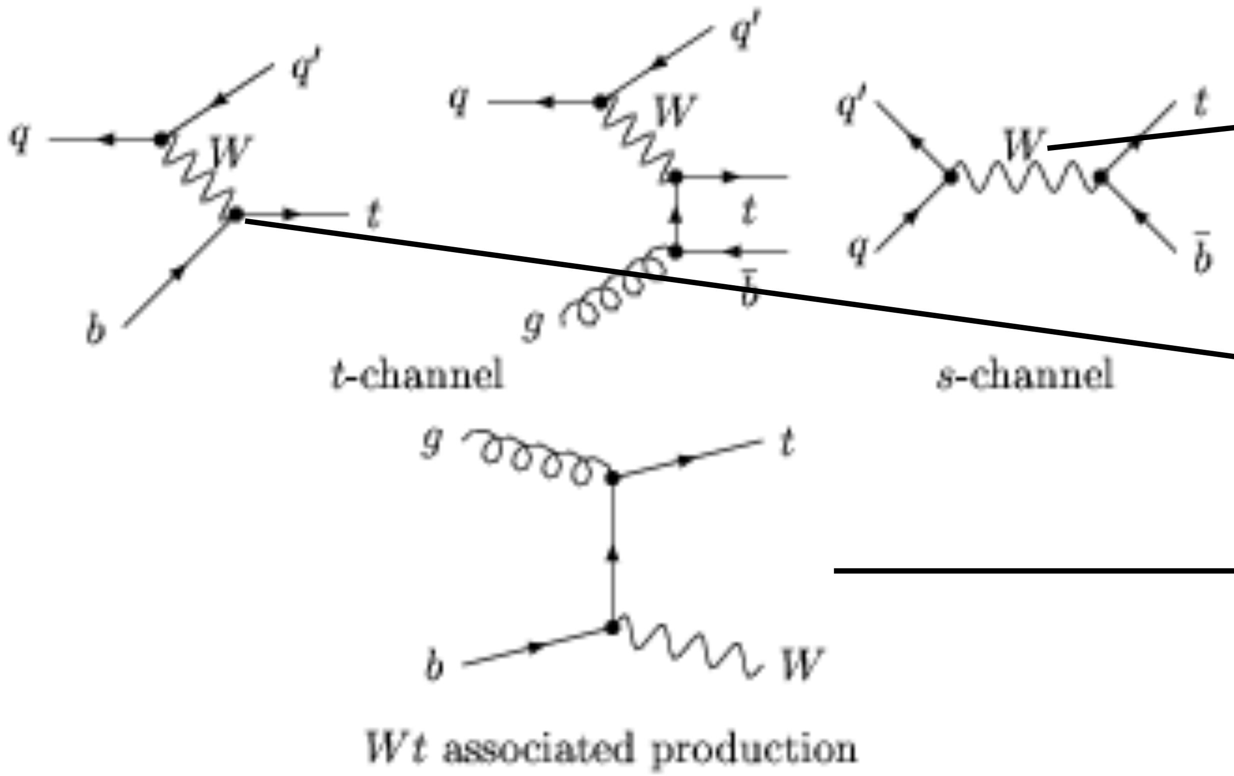




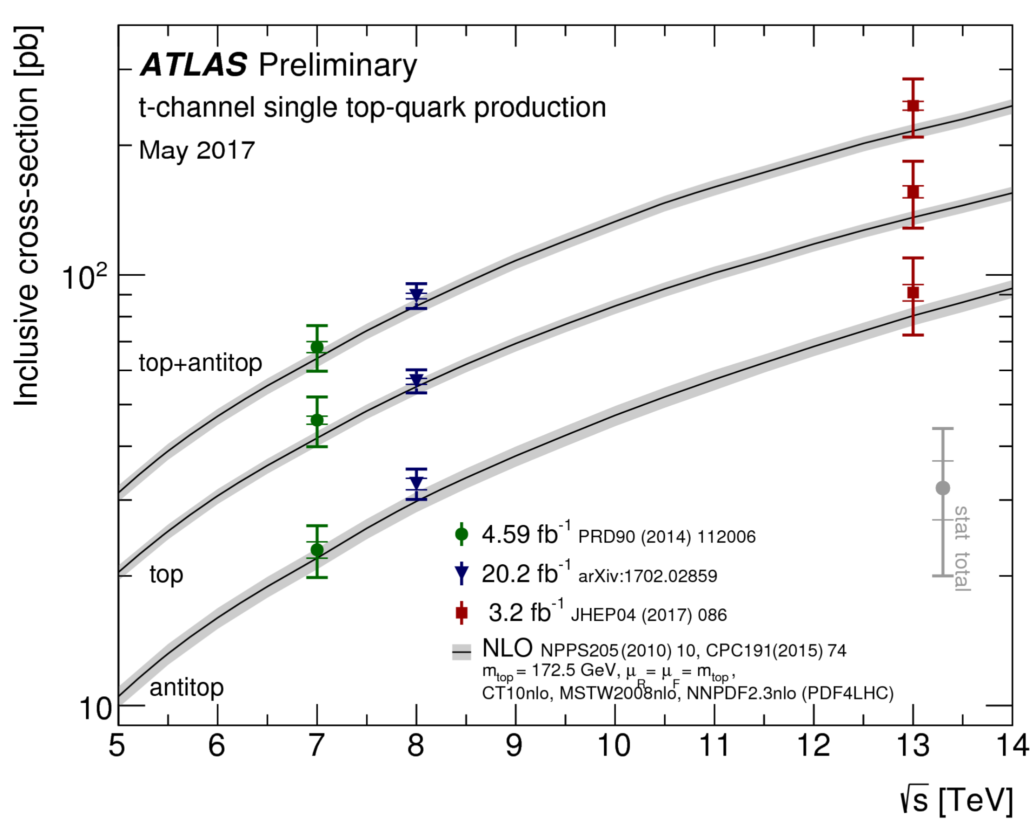
Good Agreement with the SM

http://dx.doi.org/10.1007/JHEP03(2017)113

Single Top Production



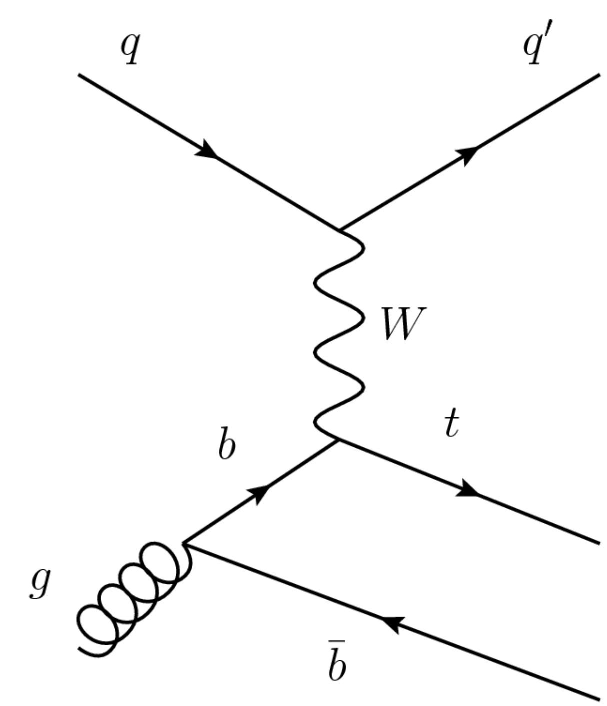
- Sensitive to new physics contributions in production (eg W' new Gauge Boson)
- Measurement of CKM matrix element directly
- Measurement of b-quark parton-distribution function

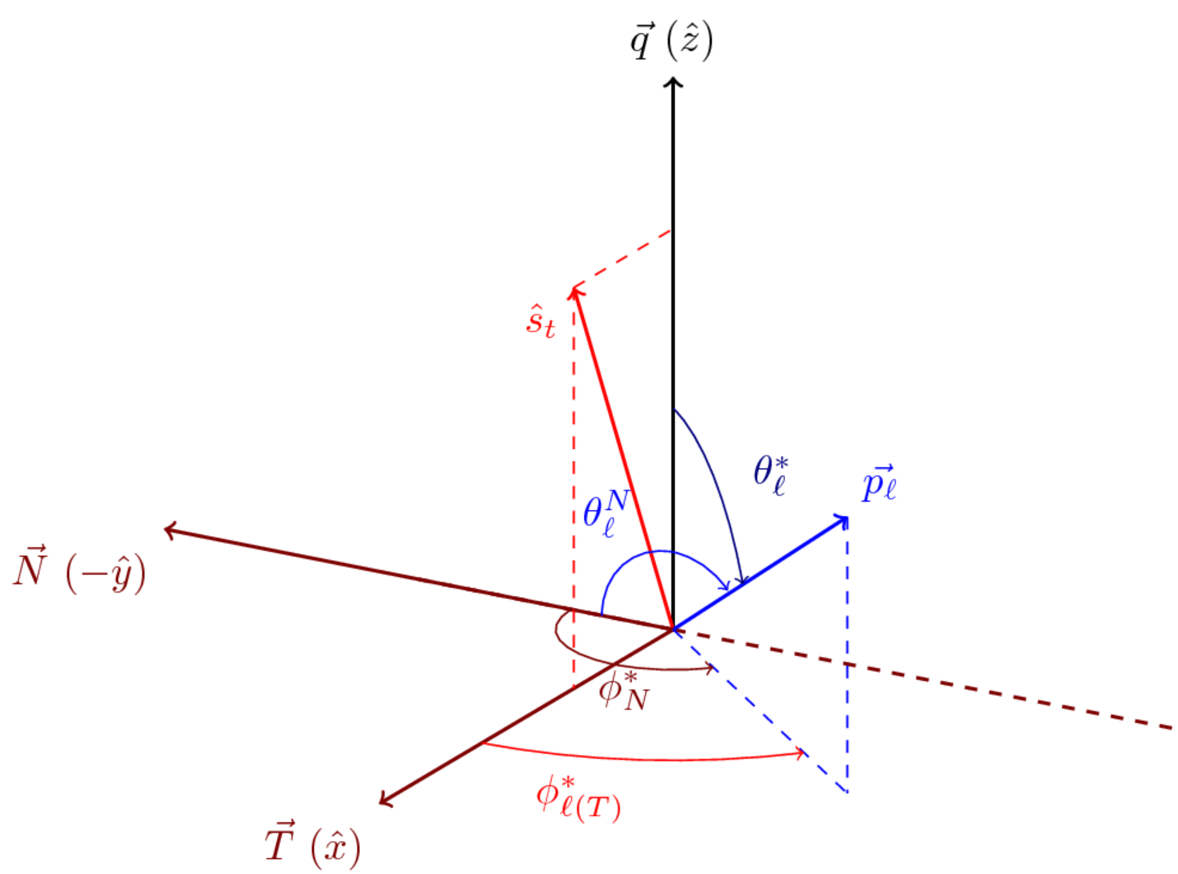


Example: t-channel production cross-section for top, anti-top, and the sum as a function of center of mass energy

Wt vertex

- Probe the Wtb vertex directly in single top with Wt production
- Measurement of the top quark polarization via the angular distribution of its decay products
- Since we measure the decay products measure using the charged lepton decay angles in the W rest frame





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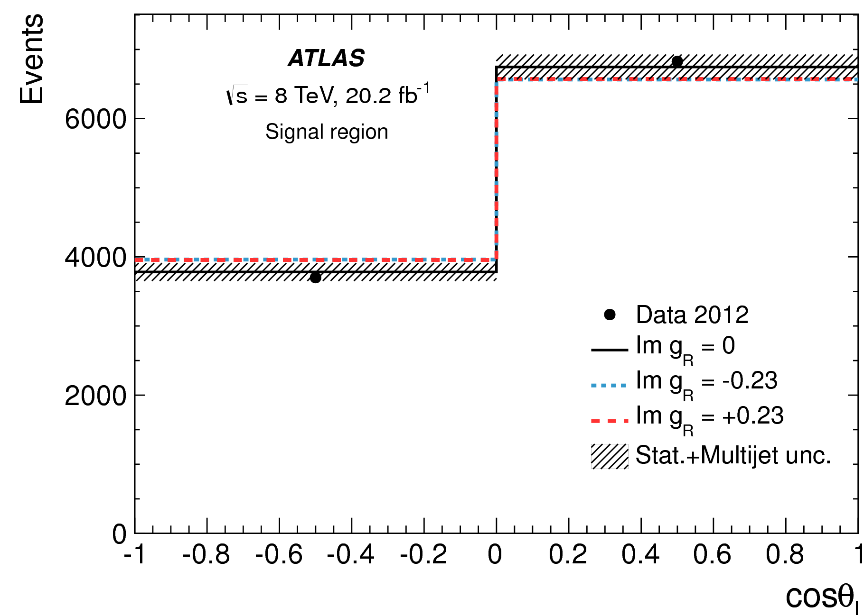
$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^\mu (V_L P_L + V_R P_R) t W^-_\mu - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_\nu}{m_W}(g_L P_L + g_R P_R) t W^-_\mu + \text{h.c.}$$

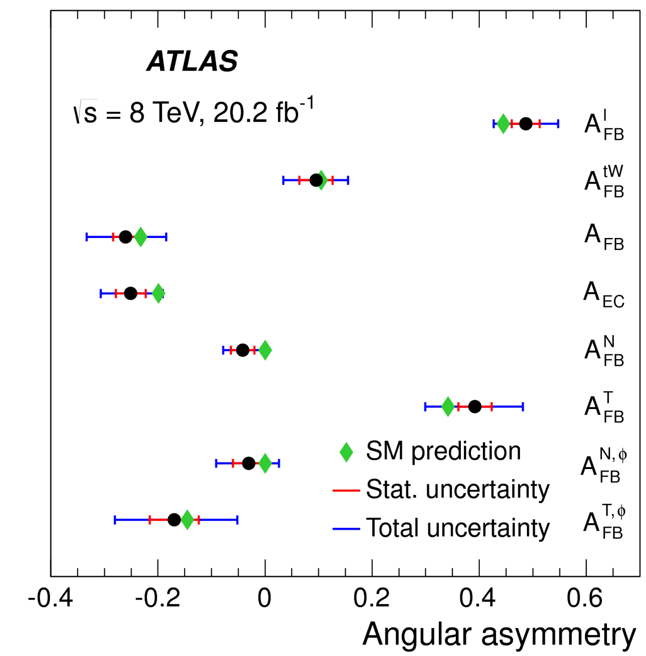
$$\frac{1}{\Gamma}\frac{d\Gamma}{d(\cos\theta_X)} = \frac{1}{2}(1 + \alpha_X P \cos\theta_X)$$

$$\frac{1}{\Gamma}\frac{d\Gamma}{d(\cos\theta_\ell^*)d\phi_\ell^*} = \frac{3}{8\pi}\Big\{\frac{2}{3} + \frac{1}{\sqrt{6}}\langle T_0\rangle\left(3\cos^2\theta_\ell^* - 1\right) + \langle S_3\rangle\cos\theta_\ell^*$$
$$+ \langle S_1\rangle\cos\phi_\ell^*\sin\theta_\ell^* + \langle S_2\rangle\sin\phi_\ell^*\sin\theta_\ell^*$$
$$- \langle A_1\rangle\cos\phi_\ell^*\sin 2\theta_\ell^* - \langle A_2\rangle\sin\phi_\ell^*\sin 2\theta_\ell^*\Big\}.$$

Wt vertex

Asymmetry	Angular observable	Polarisation observable	SM prediction
A_{FB}^{ℓ}	$\cos\theta_\ell$	$\frac{1}{2}\alpha_\ell P$	0.45
$A_{FB}^{\ell W}$	$\cos\theta_W \cos\theta_\ell^*$	$\frac{3}{8}P(F_R + F_L)$	0.10
A_{FB}	$\cos\theta_\ell^*$	$\frac{3}{4}\langle S_3\rangle = \frac{3}{4}(F_R - F_L)$	−0.23
A_{EC}	$\cos\theta_\ell^*$	$\frac{3}{8}\sqrt{\frac{3}{2}}\langle T_0\rangle = \frac{3}{16}(1 - 3F_0)$	−0.20
A_{FB}^{T}	$\cos\theta_\ell^T$	$\frac{3}{4}\langle S_1\rangle$	0.34
A_{FB}^{N}	$\cos\theta_\ell^N$	$-\frac{3}{4}\langle S_2\rangle$	0
$A_{FB}^{T,\phi}$	$\cos\theta_\ell^* \cos\phi_T^*$	$-\frac{2}{\pi}\langle A_1\rangle$	−0.14
$A_{FB}^{N,\phi}$	$\cos\theta_\ell^* \cos\phi_N^*$	$\frac{2}{\pi}\langle A_2\rangle$	0



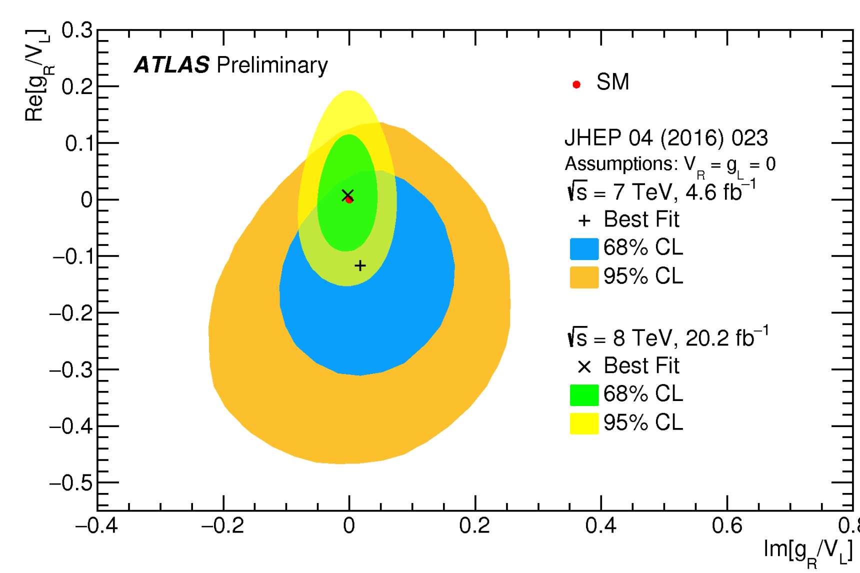


Comparison of various asymmetries compared to the SM prediction

See no deviations with SM prediction

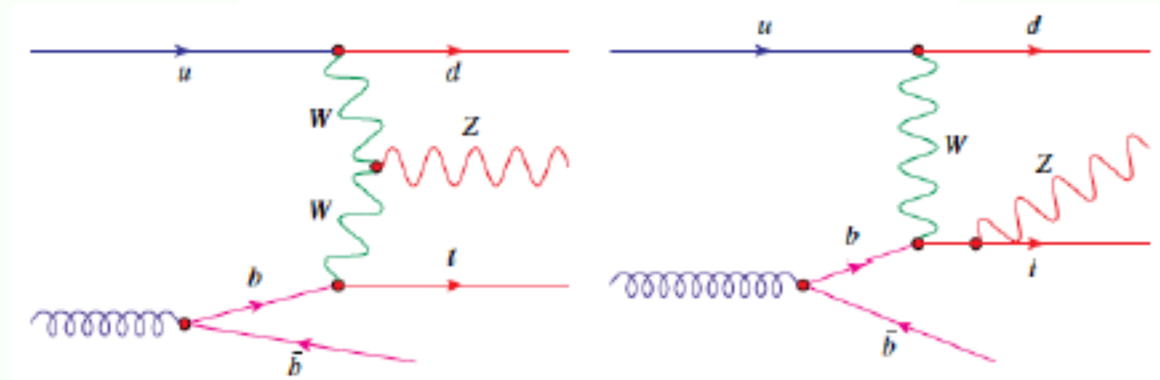
[JHEP04 (2017) 124]

- Decompose measured angular distribution into spherical harmonics
- Measure the real and imaginary component of a potential right anded component to the tW coupling
- Measurement consistent with SM

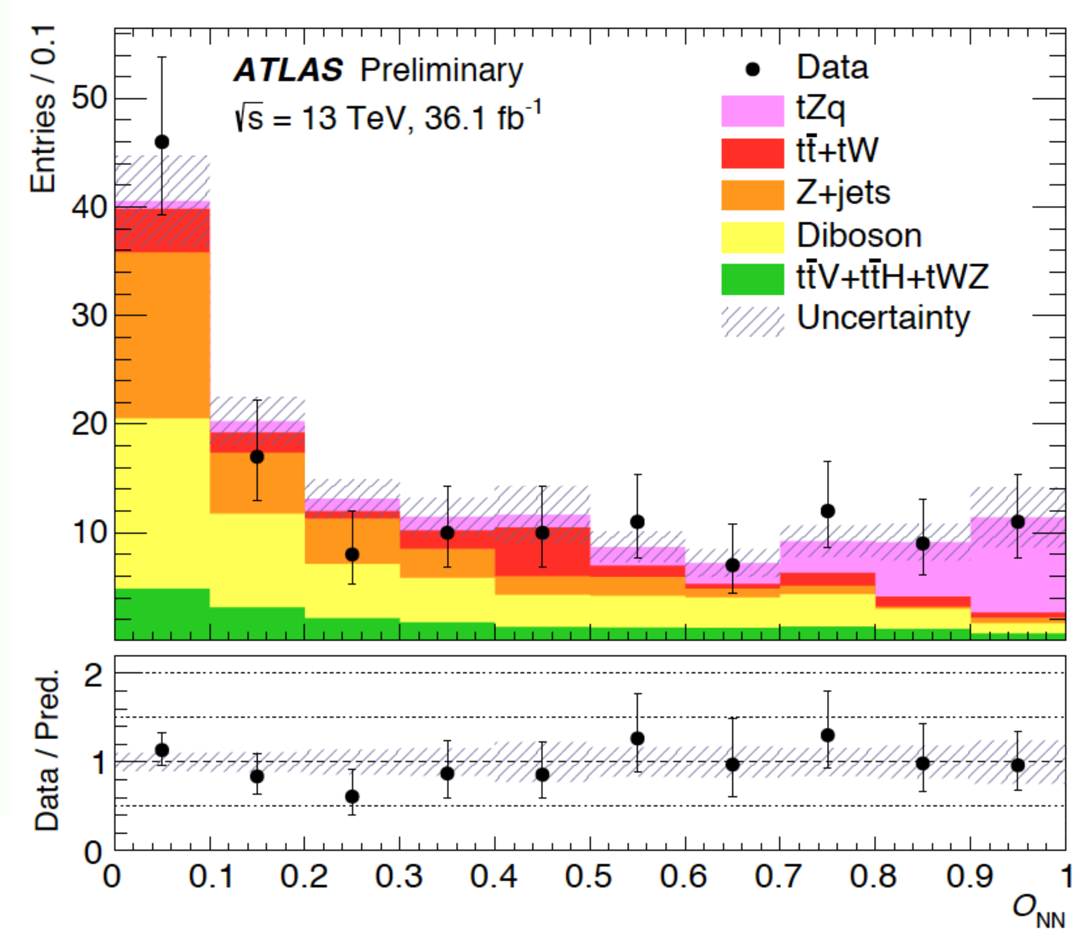


Evidence for Zt production

- First evidence of a Z boson and a single top quark production
- Theoretical 800 fb cross-section
- Major backgrounds : Diboson, Z+jets
- With more data probe the Zt vertex with precision



TOPQ-2016-14

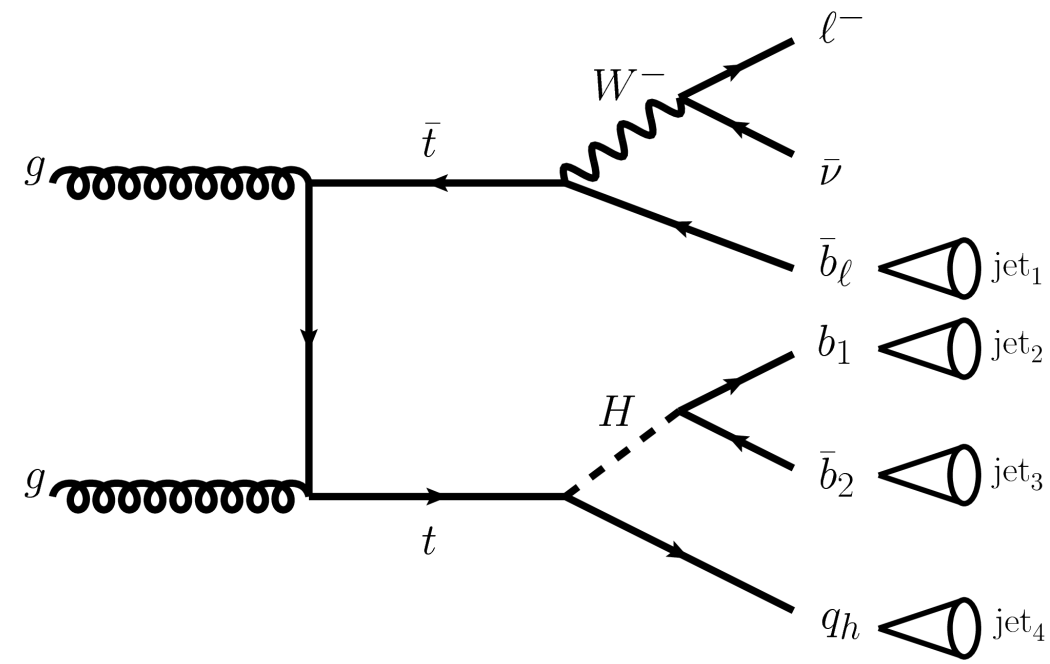


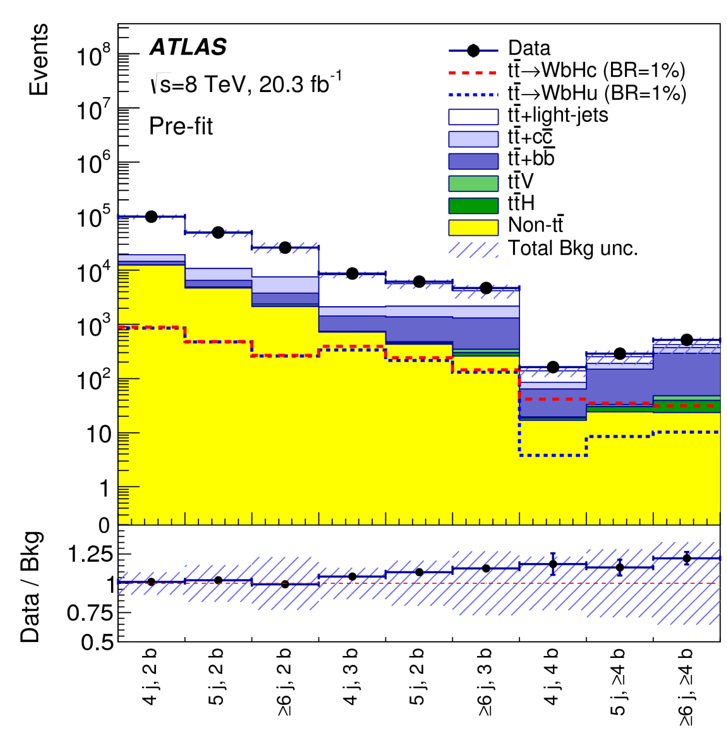
620 ± 170 (stat.) ± 160 (syst.) fb, 4.2 σ

ATLAS-CONF-2017-052

Flavor Changing Neutral Currents

- Search for tree level flavor changing neutral currents with a top quark into a Higgs Boson and a light quark
- Search in pair production where one top quark decays into Wb with the W decaying leptonically and look for the other top quark decaying into a Higgs Boson decaying into a bb pair and a light quark (u,d,s,c,b)
- Background dominated by tt + extra jets

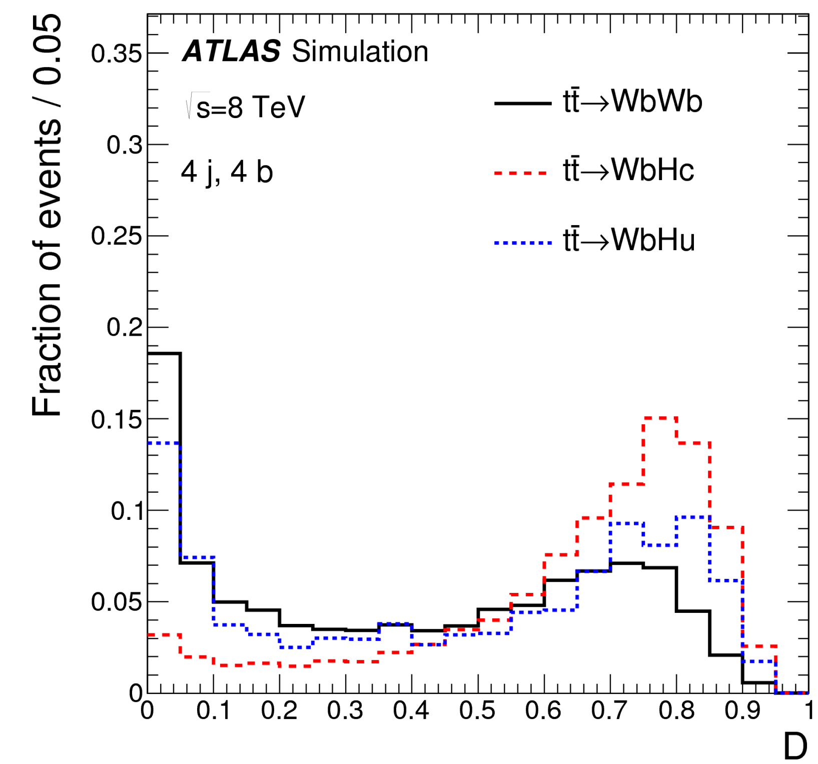


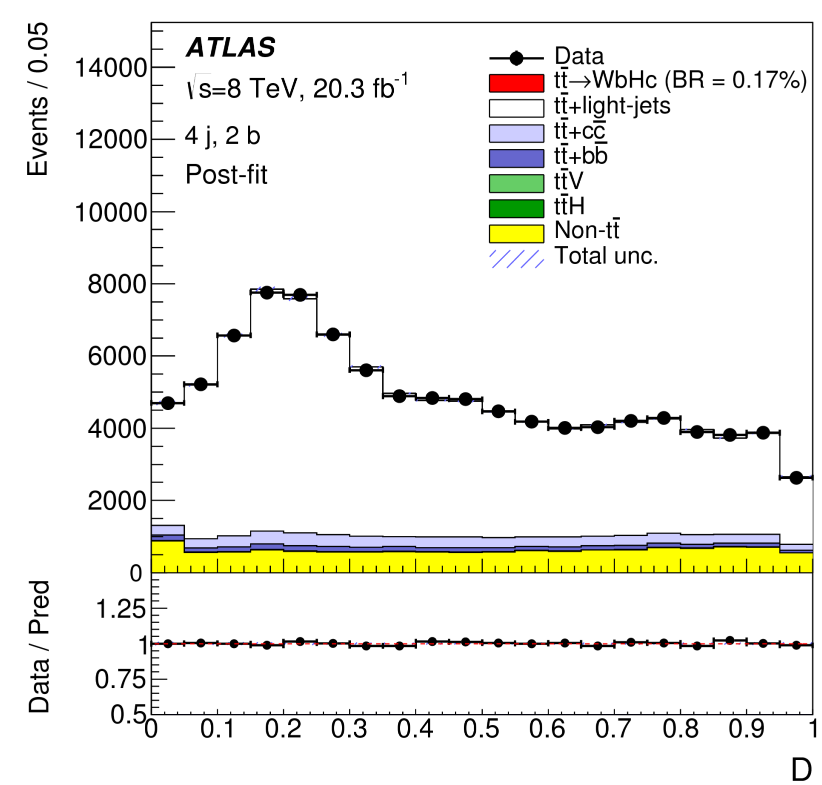


JHEP 12 (2015) 061

Flavor Changing Neutral Current Search

- Create multi-variate discriminates using all-four vectors of all final state particles in the nominal decay + number of extra jets
- Create several multi-variates for different hypothesis of signal and background for different quark in t->Hq decay
- No evidence of BSM FCNCs





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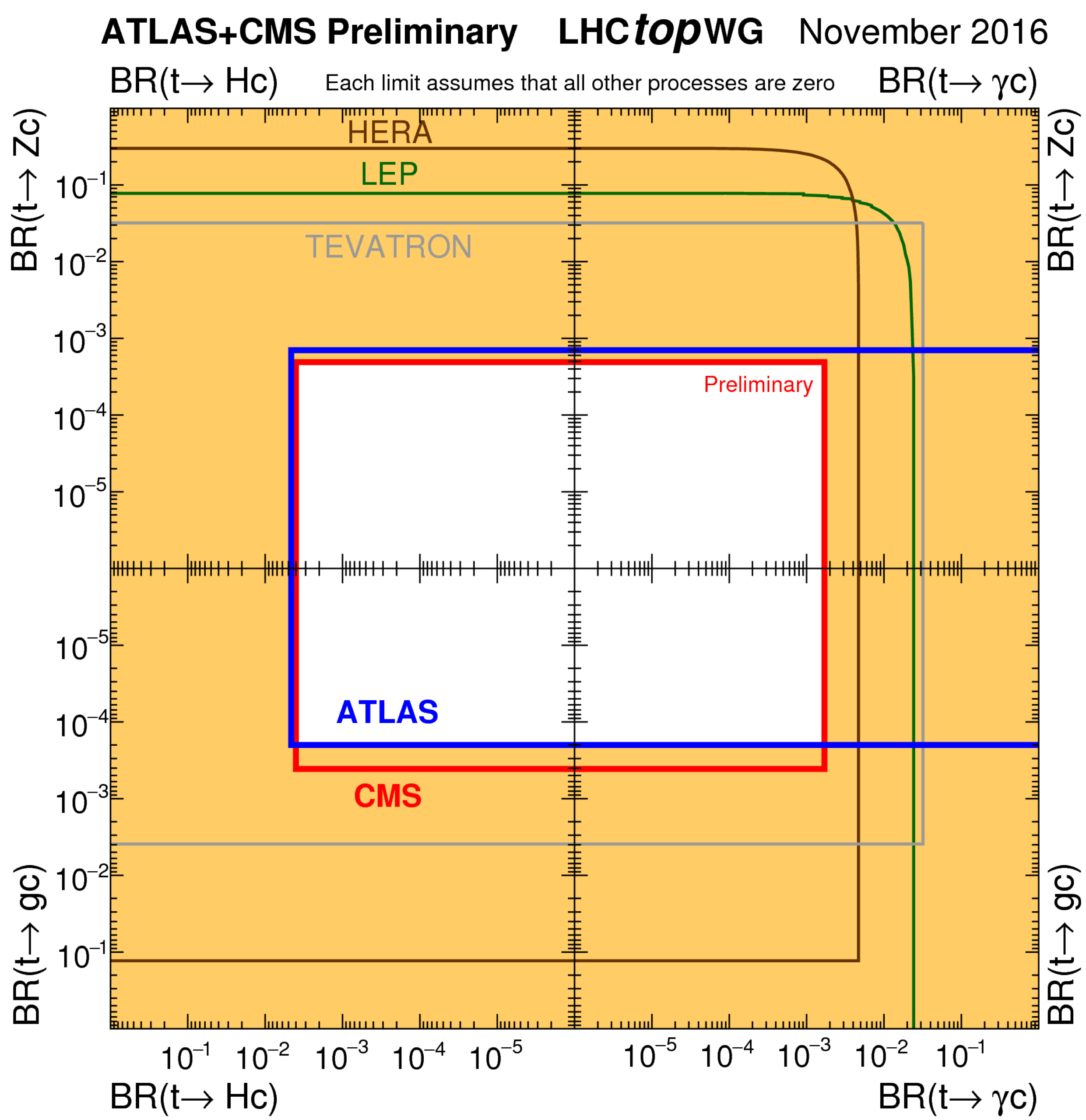
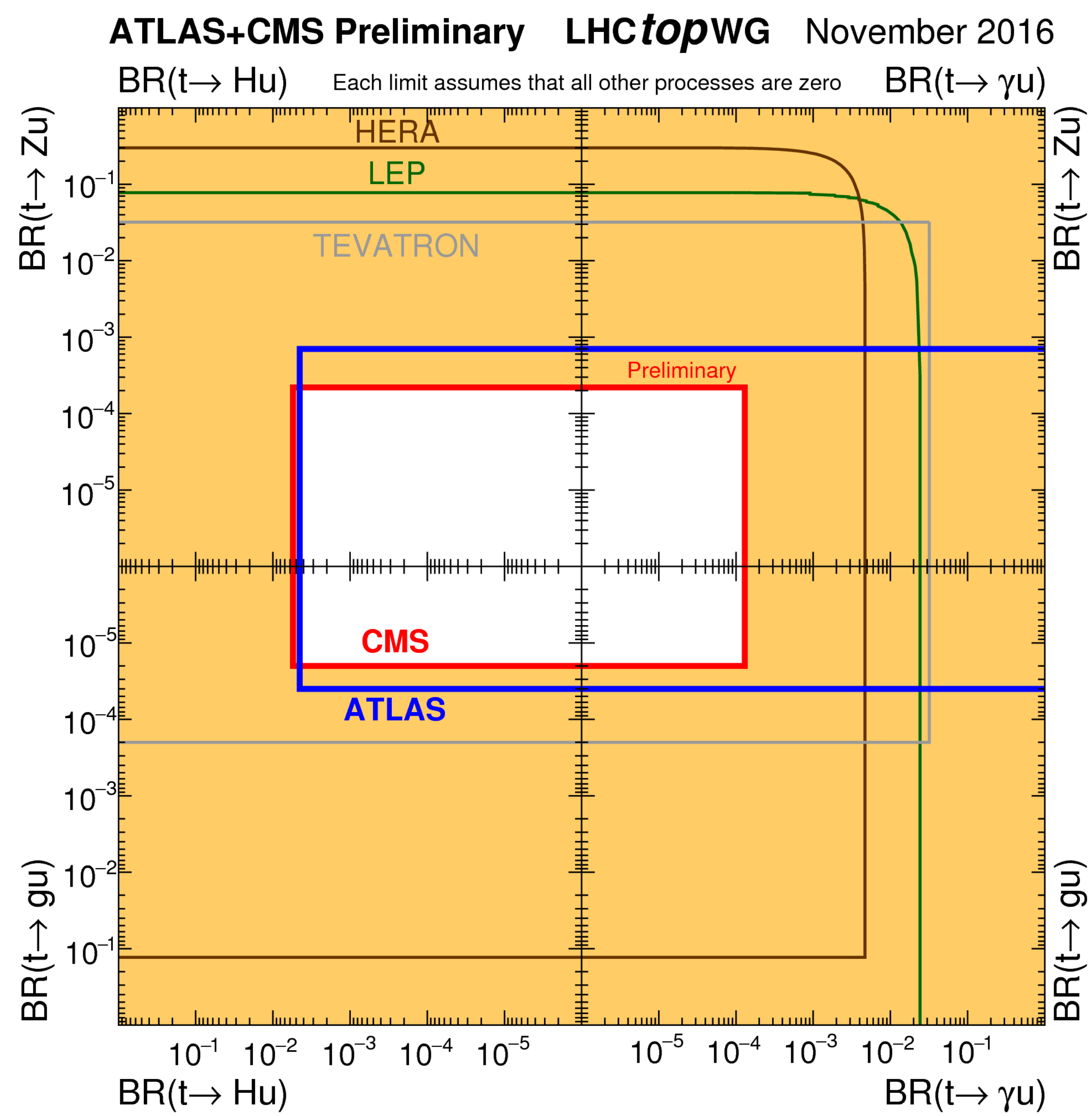
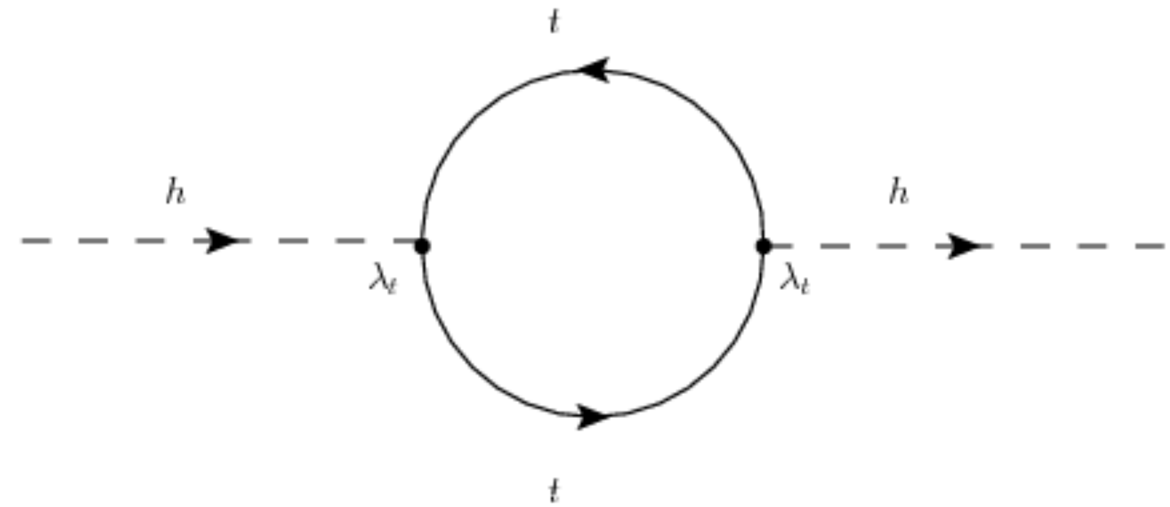
Summary of FCNC from rare top quarks



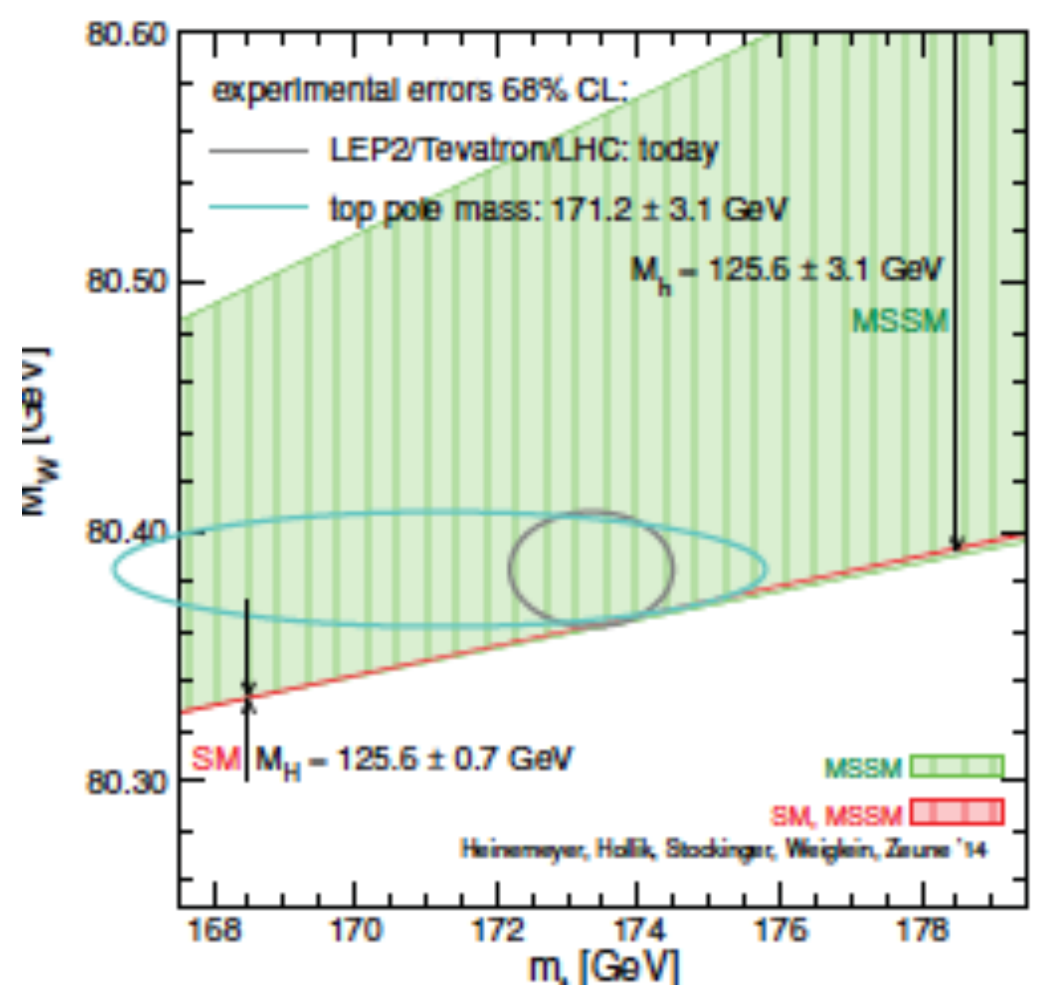


Top Quark Mass



- Top quark is an important parameter in testing the consistency of the SM via loop corrections

- The top quark has the largest mass and is therefore the largest contribution in many of these diagrams (including famously the correction to the Higgs Boson Mass)



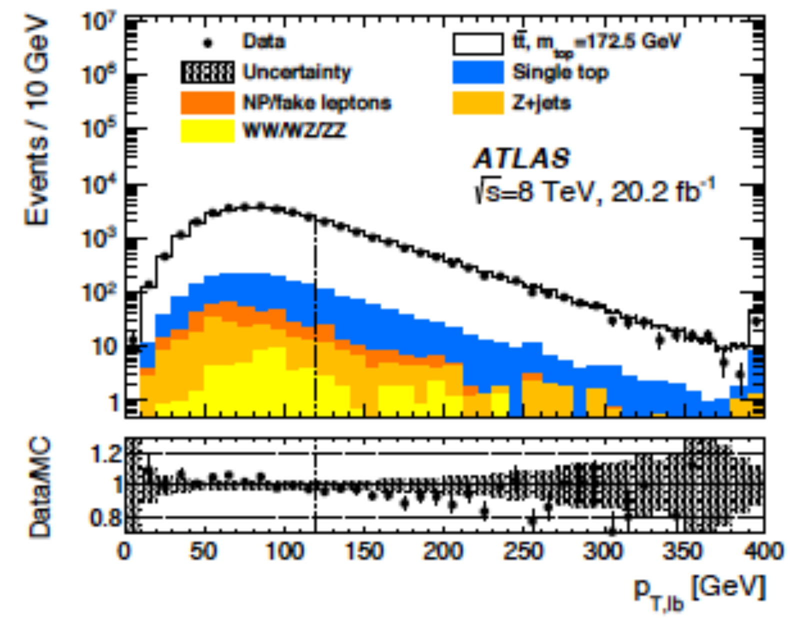
Top Quark Mass

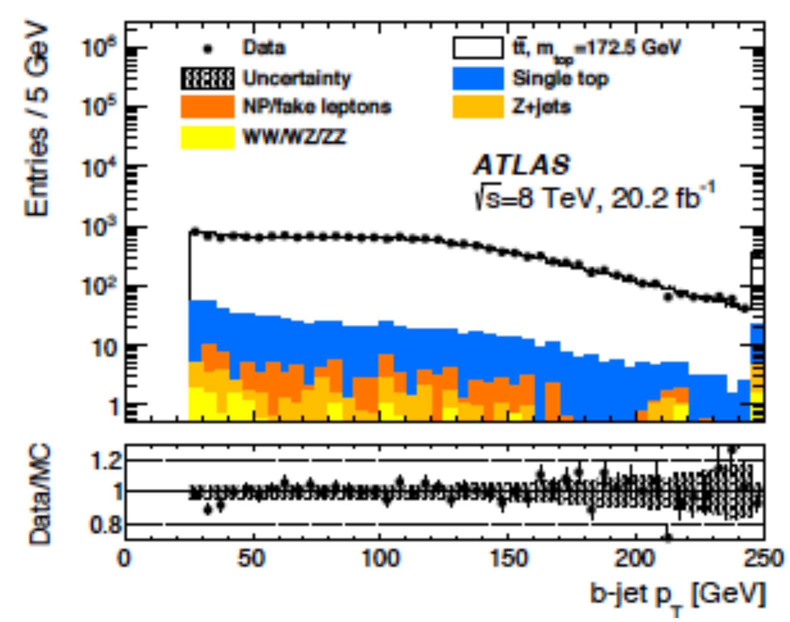
- Definitions of top quark mass we measure:
  - pole-mass: mass that appears in the top quark propagator
  - MS mass: defined in the running scheme for short distance physics
  - MC mass: parameter in MC that experimenters use to compare with distributions
- Active work from the theory side to assess the size of the difference between the MC and pole mass. Now some evidence that the size of the difference, or the uncertainty on a relation between the two is around ~< 500 MeV

Top Mass in Dilepton

- Exactly two oppositely charged central leptons (ℓ)
- In the same-lepton-flavor channels an $E_T^{Miss} > 60\,\mathrm{GeV}$ is required, with an invariant mass of the lepton pair $m_{\ell\ell} > 15\,\mathrm{GeV}$
- In the $e\mu$ channel the scalar sum of p_T of the two ℓ and all jets is required to be $> 130\,\mathrm{GeV}$
- Two jets with $p_T > 25\,\mathrm{GeV}$ and $|\eta| < 2.5$, one of this is a b-tagged jet

Phys. Lett. B 761 (2016) 350-371

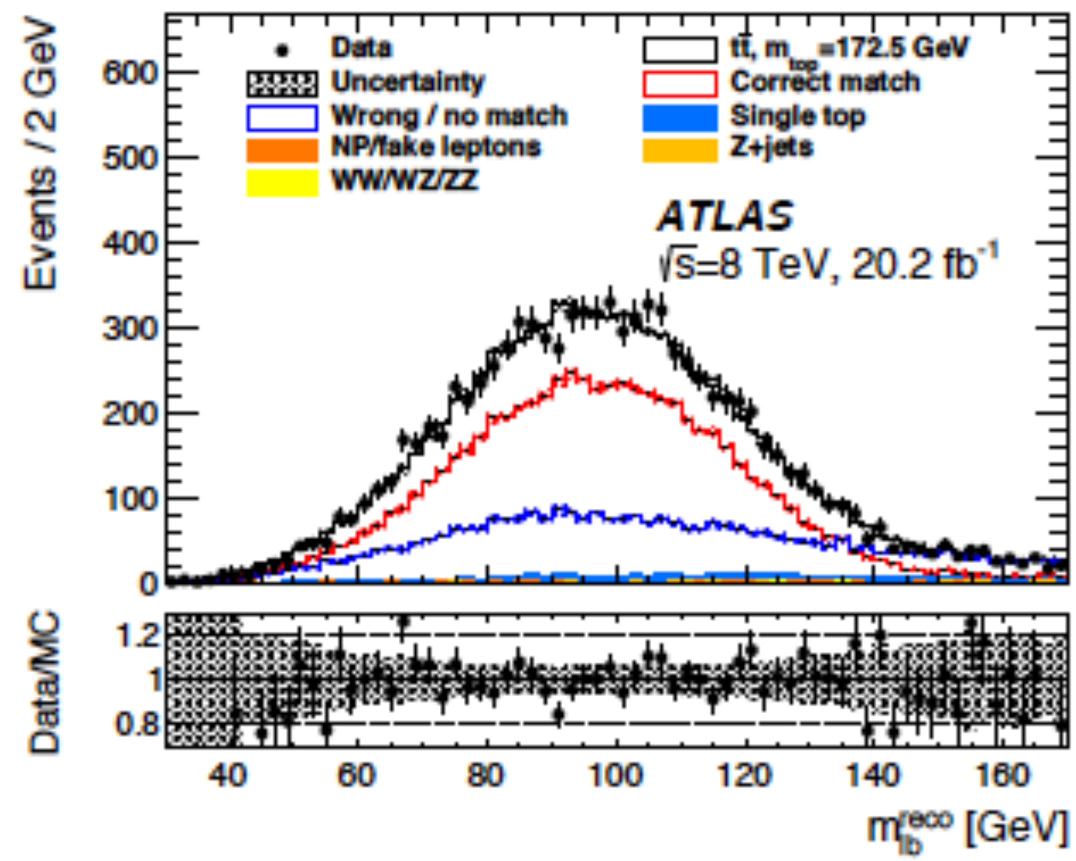




Top Mass in Dileptons

- Compare this to a MC templates
- Maximum Likelihood fit
- Largest systematics Jet energy Scale and b-jet jet to light jet energy scale
- Done in a restricted phase space to reduce ISR/FSR uncertainty

Phys. Lett. B 761 (2016) 350-371

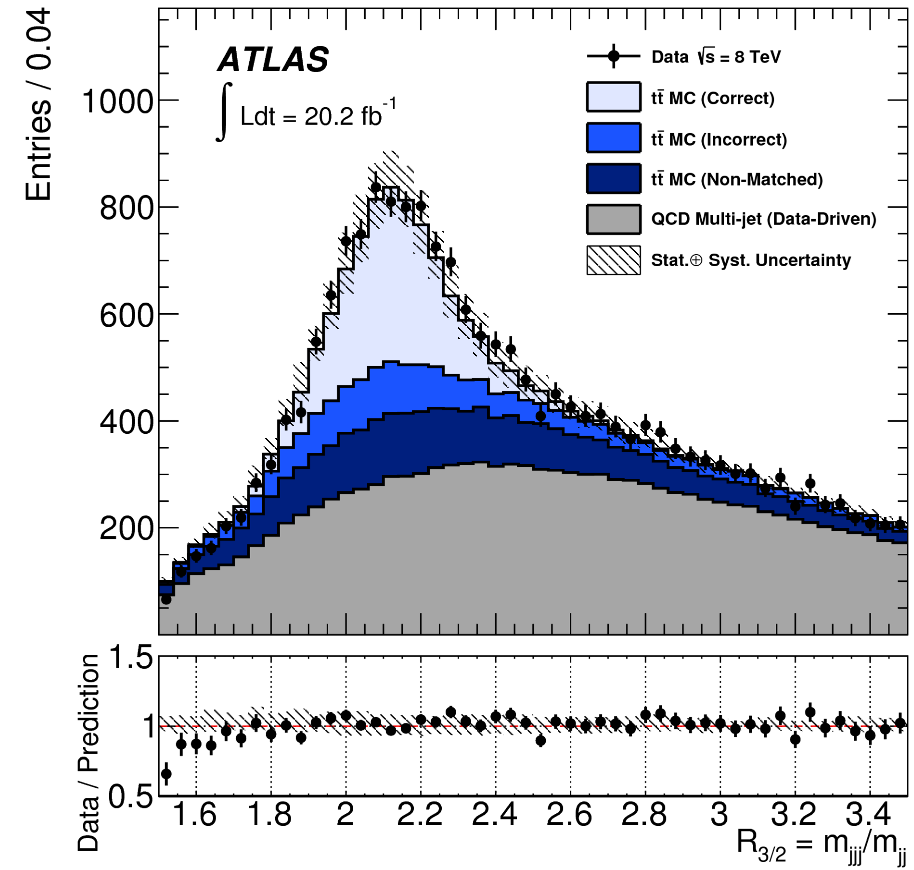


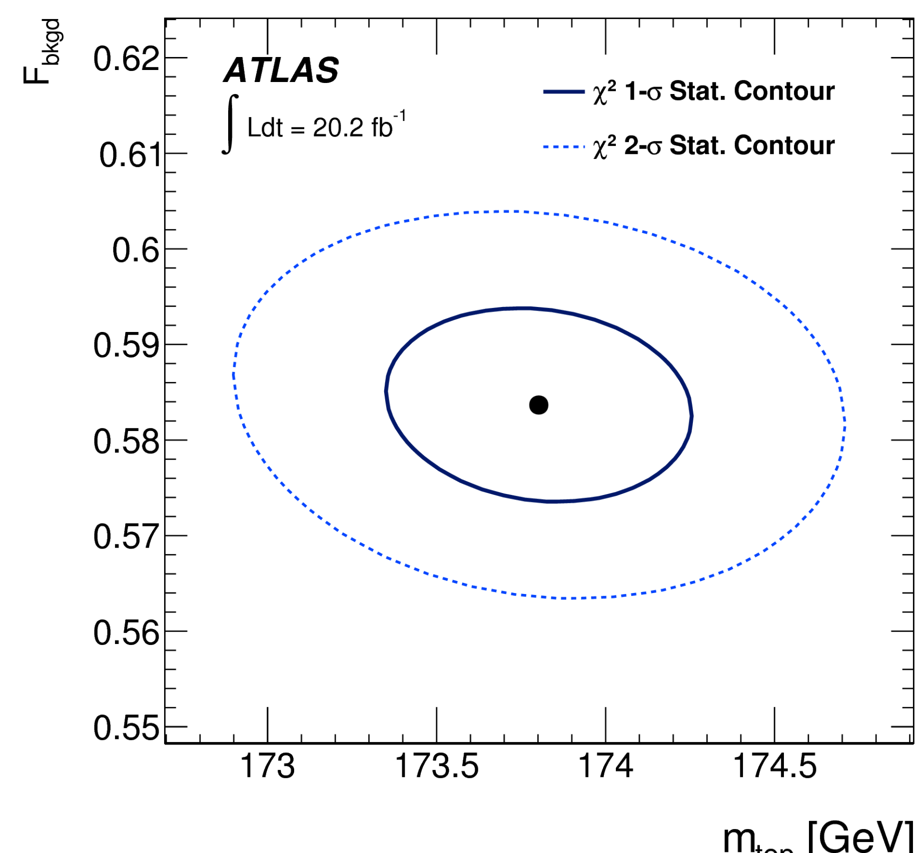
$$m_{top} = 172.99 \pm 0.41\,(stat.) \pm 0.72\,(syst.)\ \mathrm{GeV}$$

Top Mass in All Jets

- Compare the ratio of the trijet to diet mass ratio
- Minimum chi2 method
- Largest systematic again jet energy scale

$$m_{top} = 173.72 \pm 0.55\,(stat.) \pm 1.01\,(syst.)\,\mathrm{GeV}$$



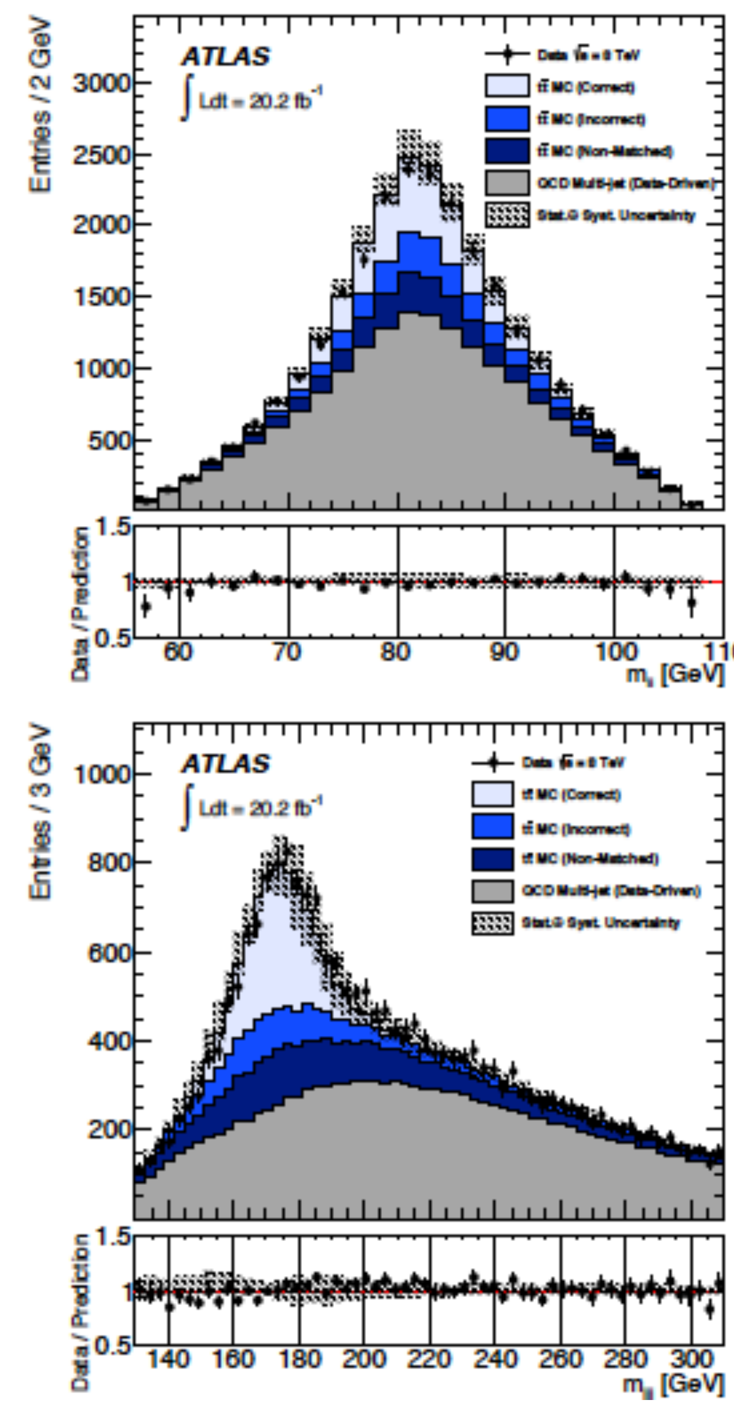


TOPQ-2015-03

Top Mass in All Jets

$t\bar{t} \rightarrow W^{+}bW^{-}\bar{b} \rightarrow q\bar{q}'bq''\bar{q}'''\bar{b}$

arXiv:1702.07546



No leptons $\geq$ jets with $p_T > 60\,\mathrm{GeV}$ and $|\eta| < 2.5$, two of them b-tagged

Small $E_T^{Miss} < 60\,\mathrm{GeV}$

Topological cuts applied to reduce background: large distance of b-tagged jets; small distance of W, b pairs from best kinematic solution

Extraction of Pole Mass from Cross-Section

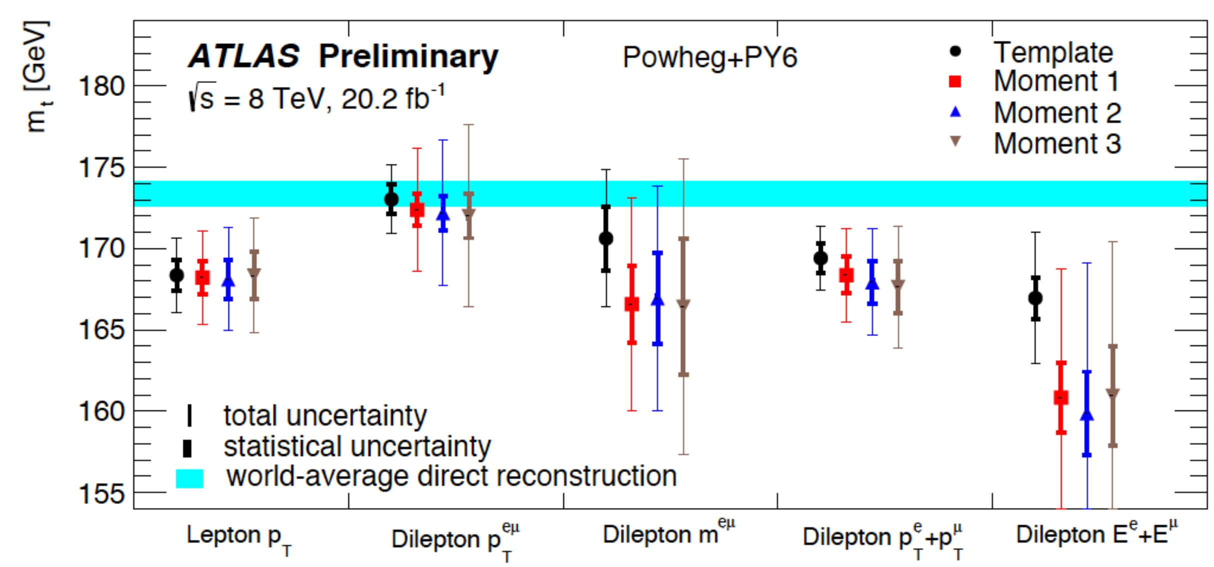
- Top cross-section has a dependence on the top quark mass

- Extract the top quark pole mass from the differential cross-section

$$\mu^{(k)} = \frac{1}{\sigma_{\text{fid}}} \int x^k D(x)\, \mathrm{d}x$$

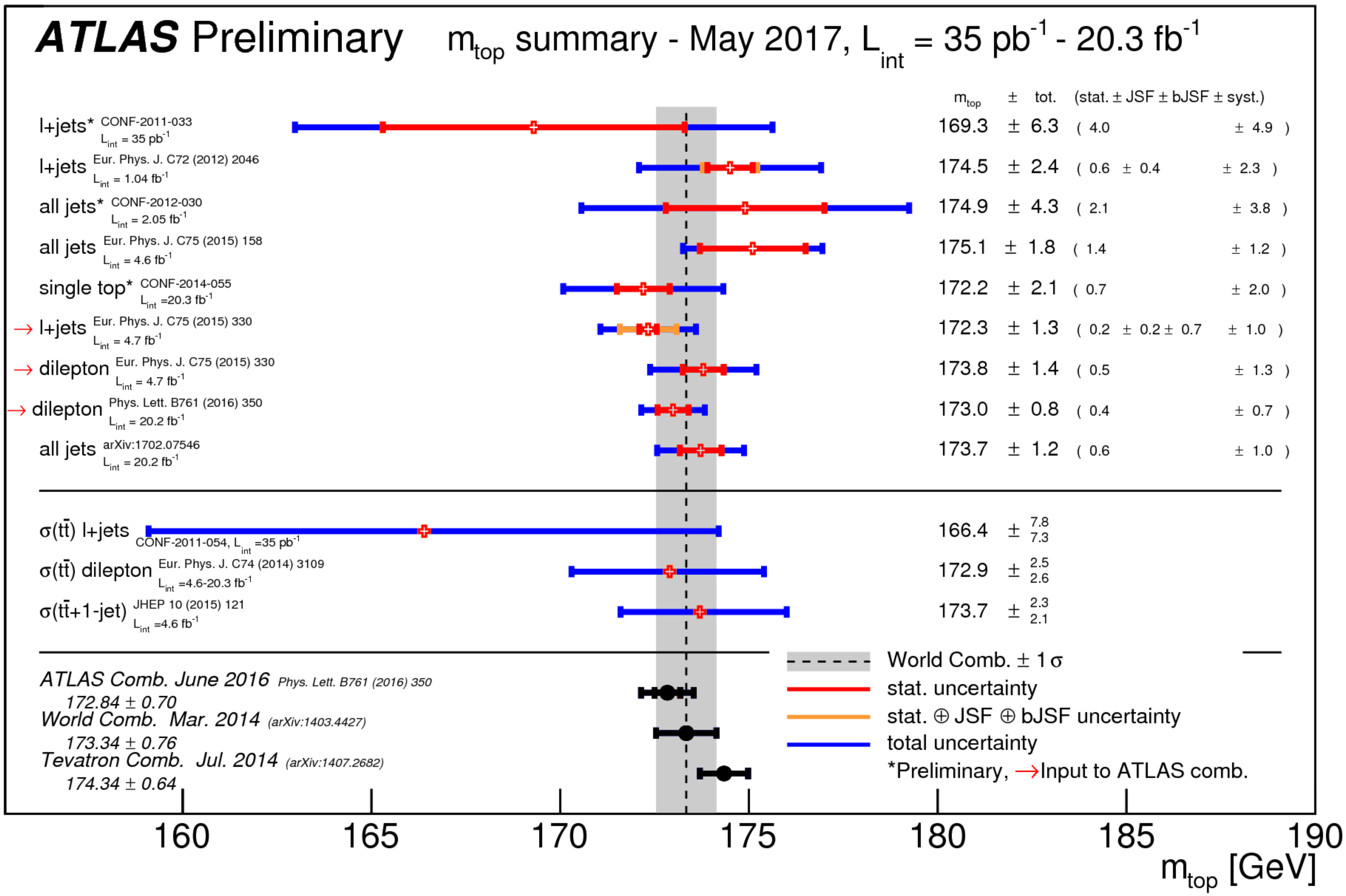
$$\sigma_{\text{fid}} = \int D(x)\, \mathrm{d}x.$$

Template	p_{T}^{ℓ}	$p_{\mathrm{T}}^{e\mu}$	$m^{e\mu}$	$p_{\mathrm{T}}^{e+\mu}$	$E^{e+\mu}$
χ^2/N_{dof}	8.1/8	7.5/7	13.9/10	8.0/6	12.5/8
m_t [GeV]	168.4 ± 2.3	173.0 ± 2.1	170.6 ± 4.2	169.4 ± 2.0	166.9 ± 4.0
Data statistics	± 1.0	± 0.9	± 2.0	± 0.9	± 1.3
Expt. systematic	± 1.6	± 1.0	± 3.1	± 1.6	± 1.5
PDF uncertainty	± 1.0	± 0.2	± 1.6	± 0.6	± 3.4
$t\bar{t}$ generator	± 0.4	± 1.4	± 1.4	± 0.4	± 1.1
QCD radiation	± 0.7	± 0.8	± 0.5	± 0.2	± 0.2



TOPQ-2015-02

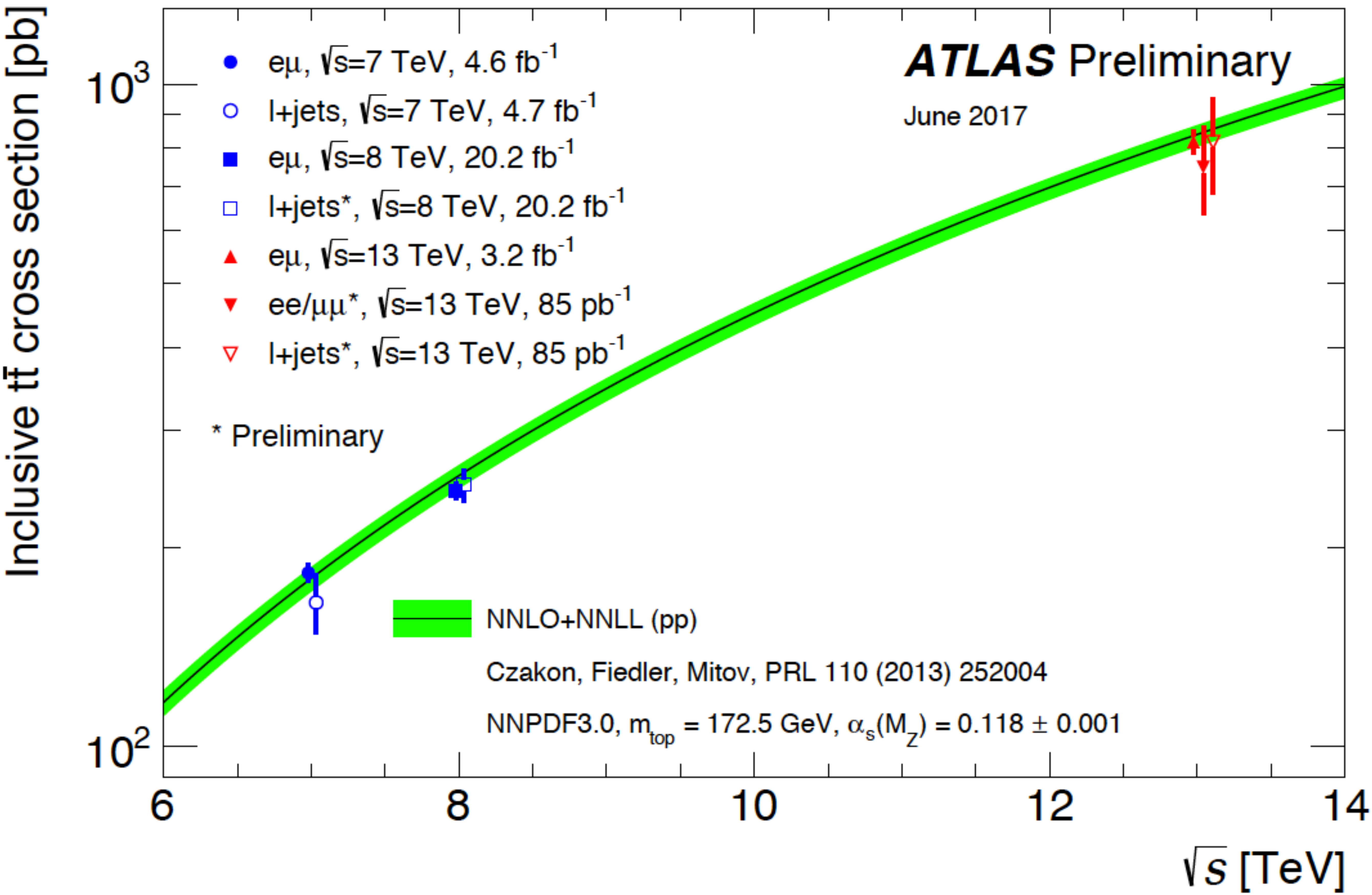
Top Mass Overview



Summary

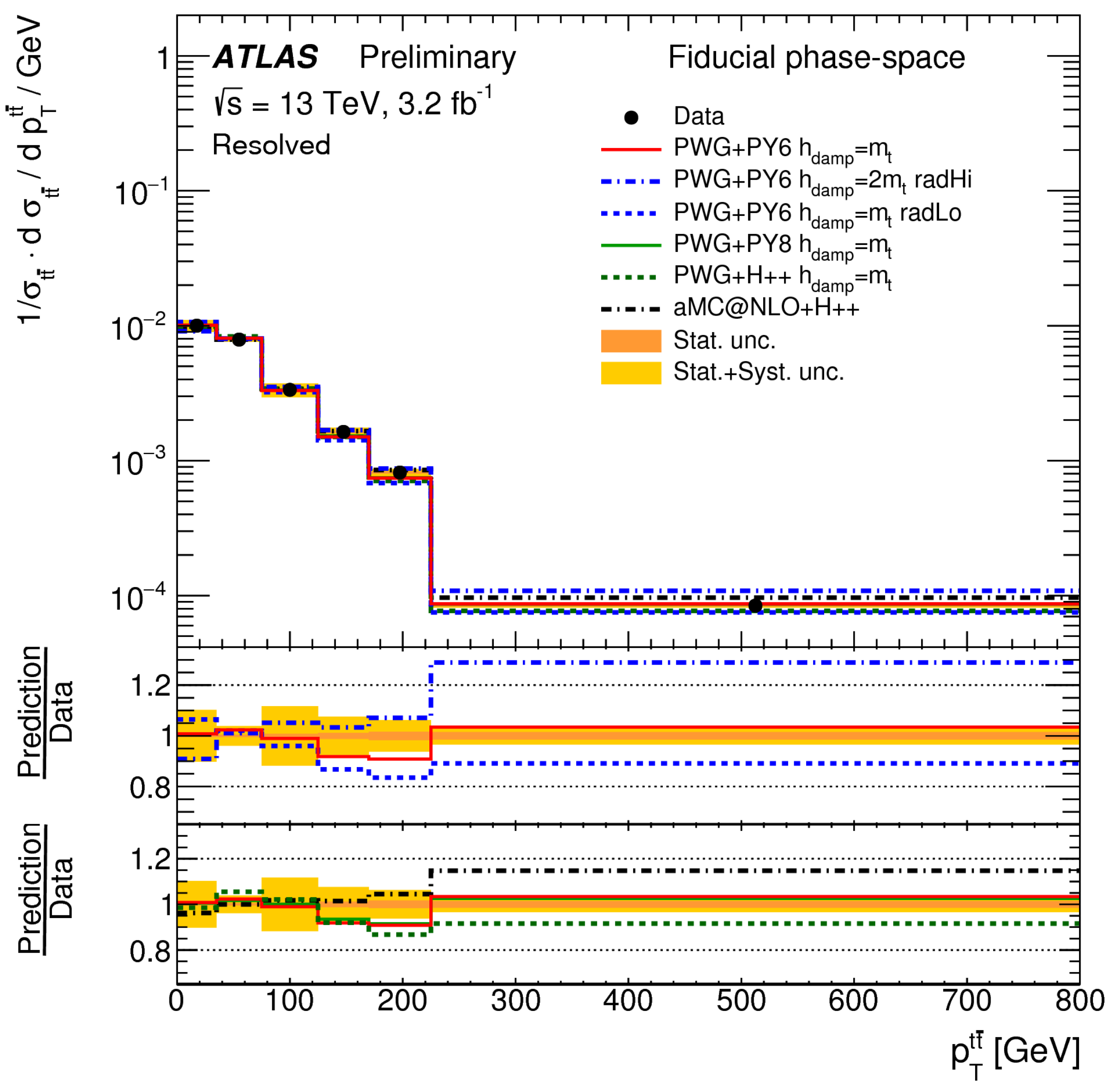
- The LHC has taken top quark physics into the precision era
- Many measurements of top quark production, decay, searches, and fundamental properties
- Near term improvements to many BSM searches that will improve with the large datasets to be collected in the next few years

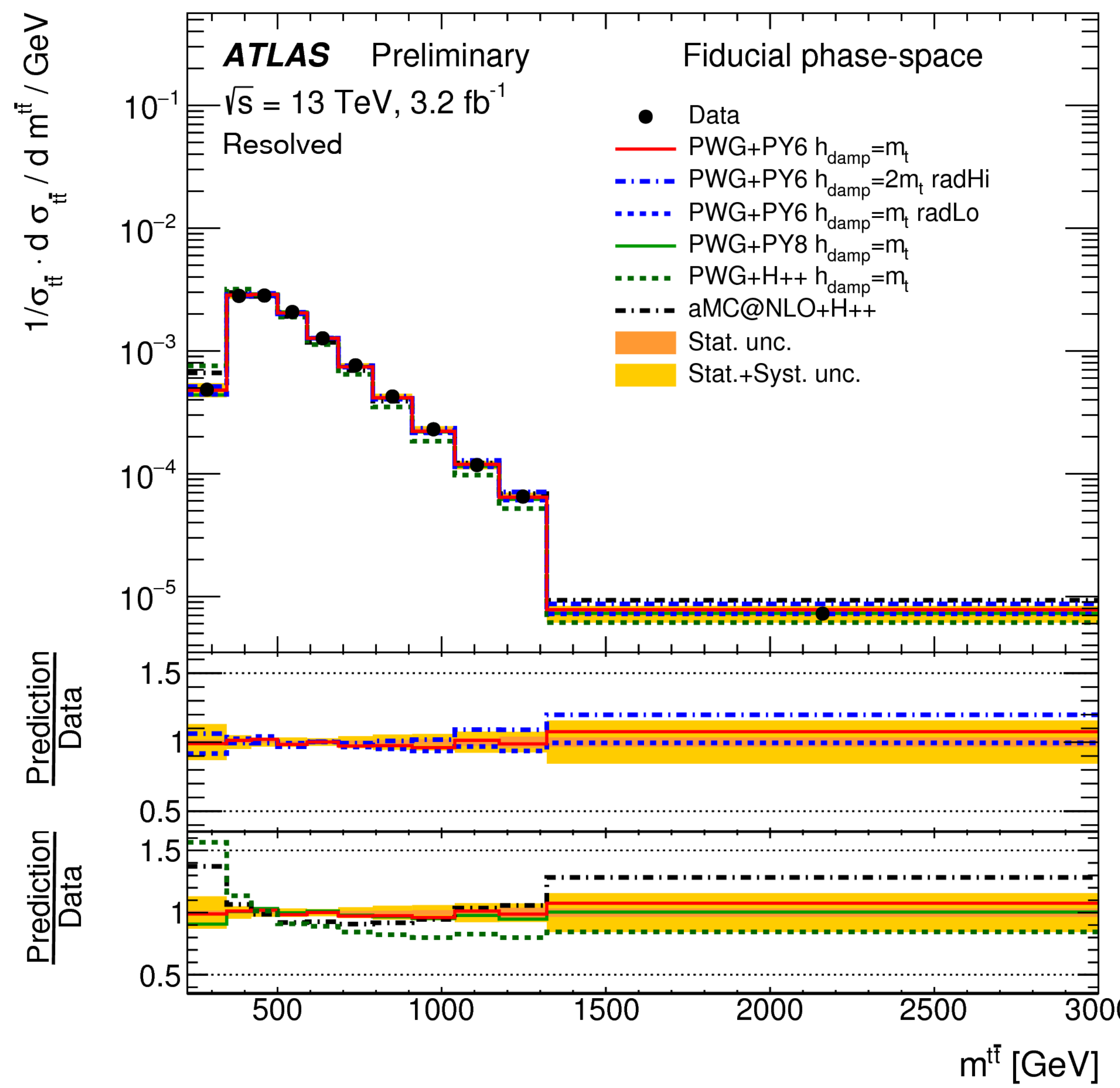
Backup



Inclusive tt̄ cross section [pb]
10^3
10^2
eμ, √s=7 TeV, 4.6 fb⁻¹
l+jets, √s=7 TeV, 4.7 fb⁻¹
eμ, √s=8 TeV, 20.2 fb⁻¹
l+jets*, √s=8 TeV, 20.2 fb⁻¹
eμ, √s=13 TeV, 3.2 fb⁻¹
ee/μμ*, √s=13 TeV, 85 pb⁻¹
l+jets*, √s=13 TeV, 85 pb⁻¹
* Preliminary
ATLAS Preliminary
June 2017
NNLO+NNLL (pp)
Czakon, Fiedler, Mitov, PRL 110 (2013) 252004
NNPDF3.0, m_{top} = 172.5 GeV, $\alpha_s(M_Z)$ = 0.118 ± 0.001
6
8
10
12
14
√s [TeV]

Cross-Section in Dilepton





ATLAS-CONF-2016-040