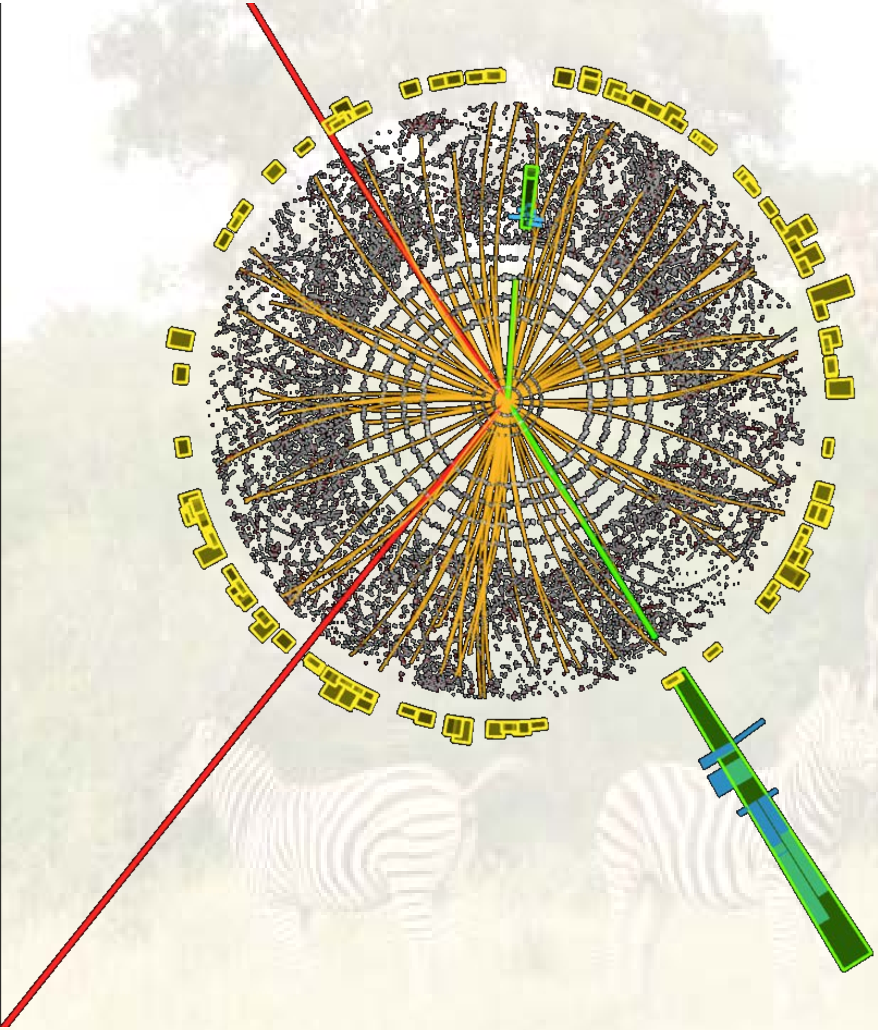
Selected Highlights from Precision Studies in ATLAS



Discovery Physics at the LHC
International Workshop
1 – 6 December, 2014
Kruger Gate, SA

Hans Peter Beck
On behalf of the ATLAS Collaboration

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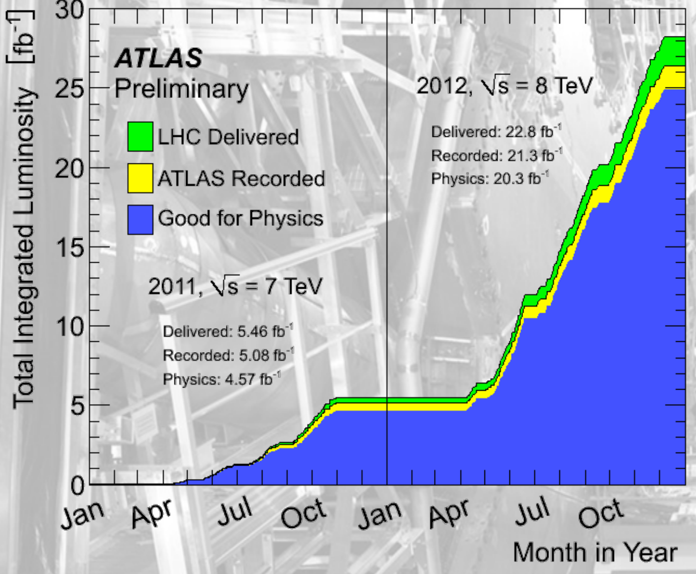
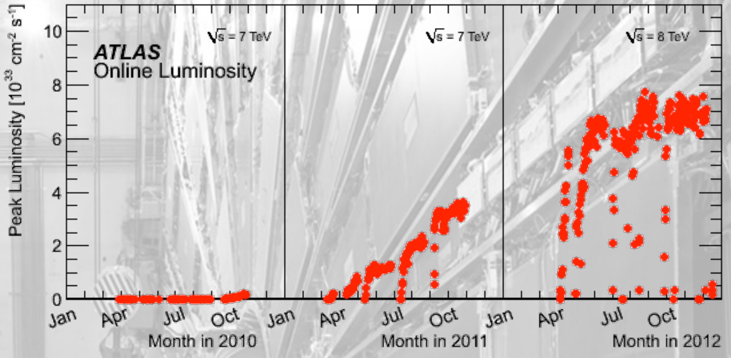
FOR FUNDAMENTAL PHYSIC

ATLAS Run 1 data taking

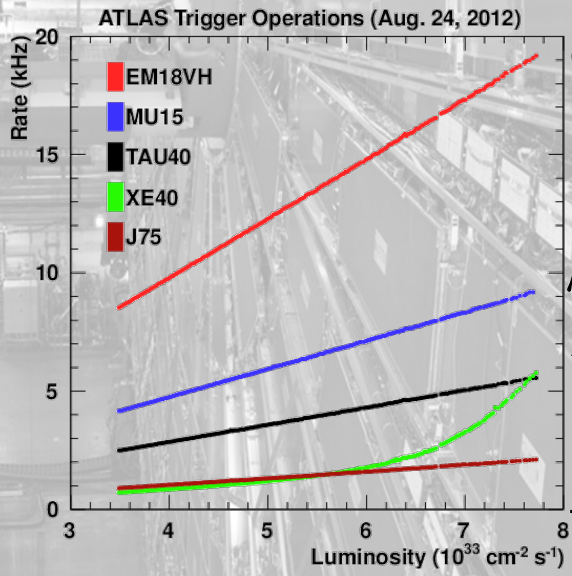


Integrated luminosity and data quality



$8\times10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Peak luminosity



e/γ	p_T>18 GeV
μ	p_T>15 GeV
$\tau\rightarrow h$	p_T>15 GeV
E_T^{miss}	p_T>40 GeV
jet	p_T>75 GeV

Run I

data good for physics

7 TeV 2010-2011 4.6 fb^{-1}

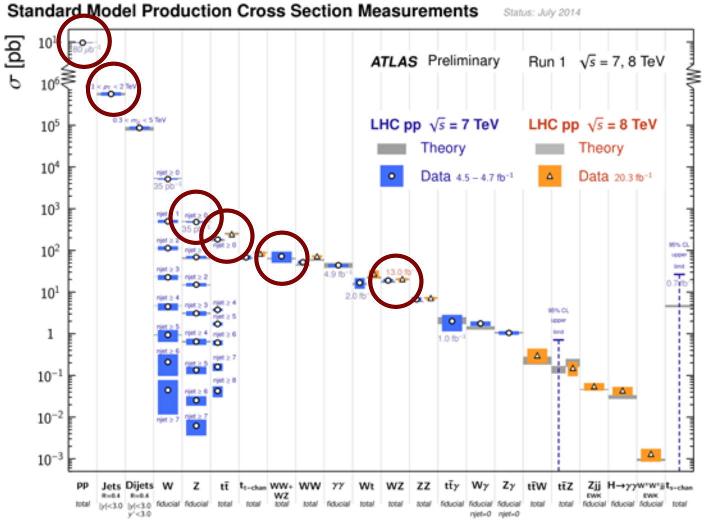
8 TeV 2012 20.3 fb^{-1}

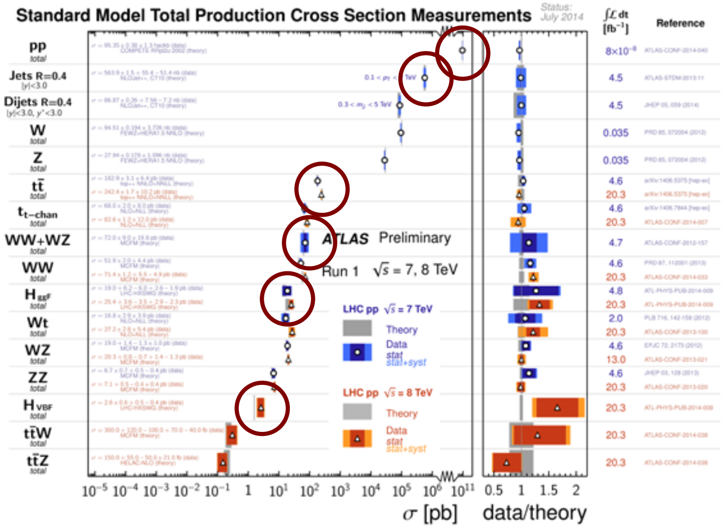
~90% of the luminosity delivered
by LHC good for physics!

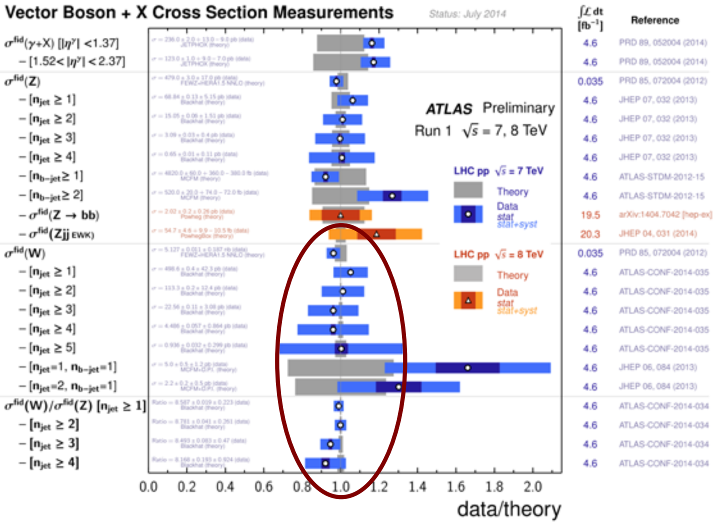
Level-1 trigger rates for single object triggers.
E_T^{miss} most sensitive to pile-up !

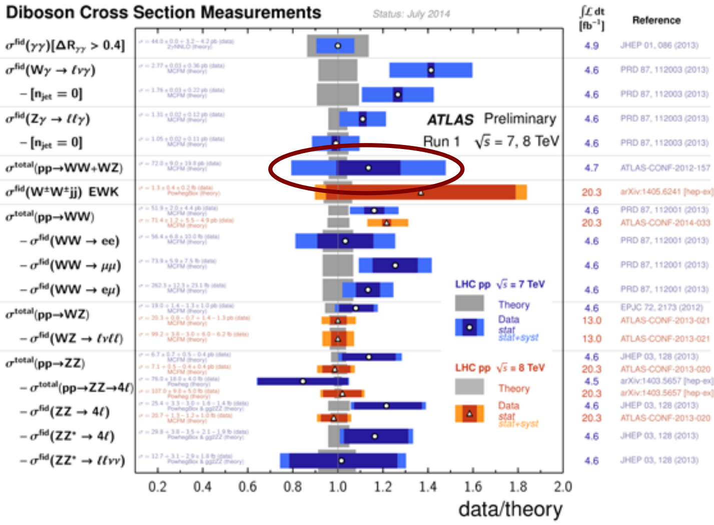
Selected Highlights

Many highlights in ATLAS precision measurements









impossible to highlight all...

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

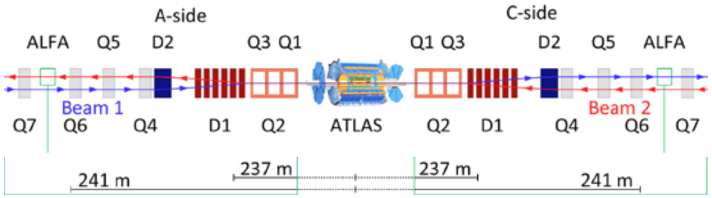
New

Total elastic cross section

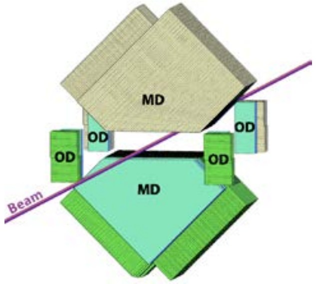
arXiv:1408.5778
Nucl. Phys. B (2014) 486-548

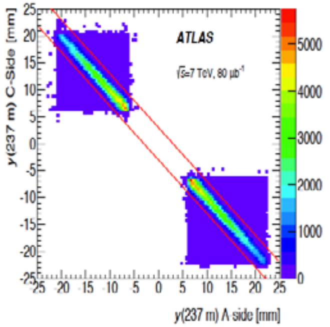
7 TeV with 80 μb^{-1}

ALFA (Absolute Luminosity For ATLAS) measure small-angle elastic proton-proton scattering.



Two scintillating fibre detector tracking stations are placed on each side of the central ATLAS detector at distances of 237 m and 241 m from the interaction point.



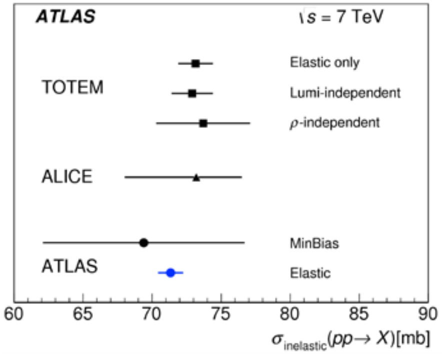


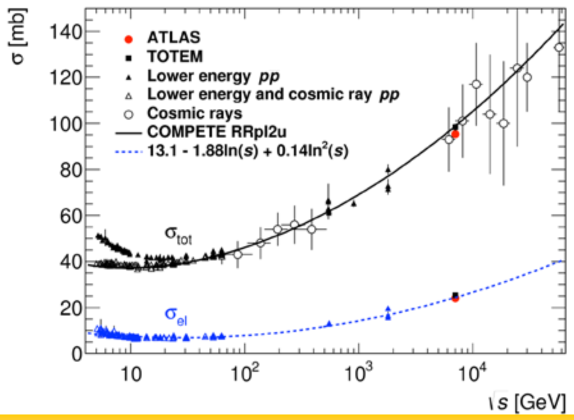
Special high β* run at 7 TeV with 80 μb^{-1}
(4 h run, very low inst. luminosity., very clean)

Correlations in the vertical coordinate between the two sides of the interaction point.

$$\sigma^2_{\mathrm{tot}} = \frac{16}{1+\rho^2}\left.\frac{d\sigma_{el}}{dt}\right|_{t\to0}$$

Optical theorem for σ_{tot}





$\sigma_{el}(pp \to pp)$ = 24.00 ± 0.19$_{\mathrm{stat}}$ ± 0.57$_{\mathrm{stat}}$ mb (2.5%)

$\sigma_{tot}(pp \to X)$ = 95.35 ± 0.38$_{\mathrm{stat}}$ ± 1.25$_{\mathrm{exp}}$ ± 0.37$_{\mathrm{extr}(t\to0)}$ mb (1.4%)

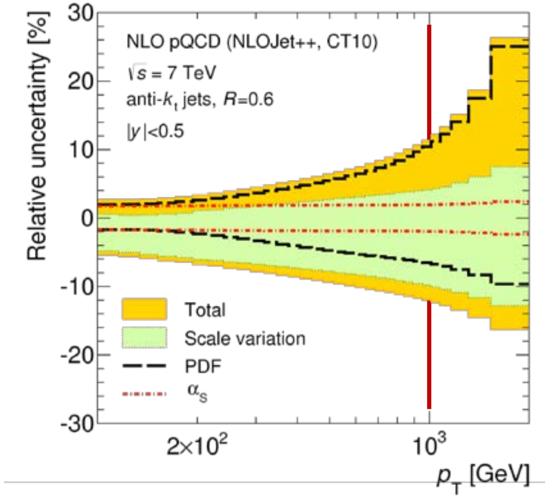
From these, σ_{inel} is deduced and compared with direct measurements in ATLAS.
At low diffractive masses M_X<15.7 GeV Pythia and PHOJET predict significantly lower cross sections.

New

Inclusive jet cross section

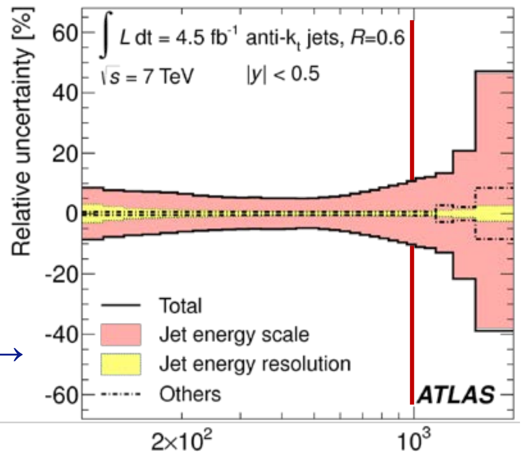
arXiv:1410.8857
submitted to JHEP

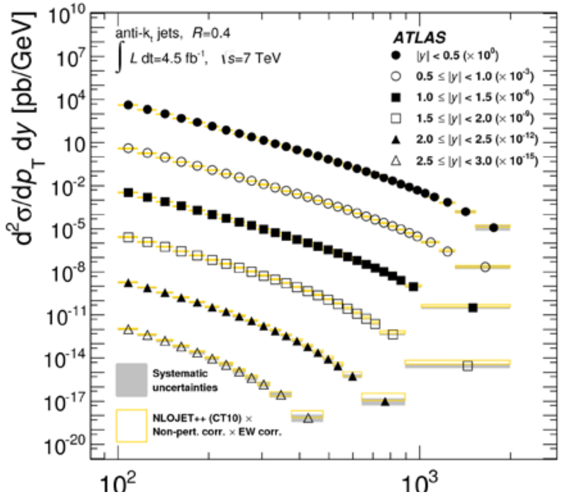
at 7 TeV with 4.5 fb^{-1}



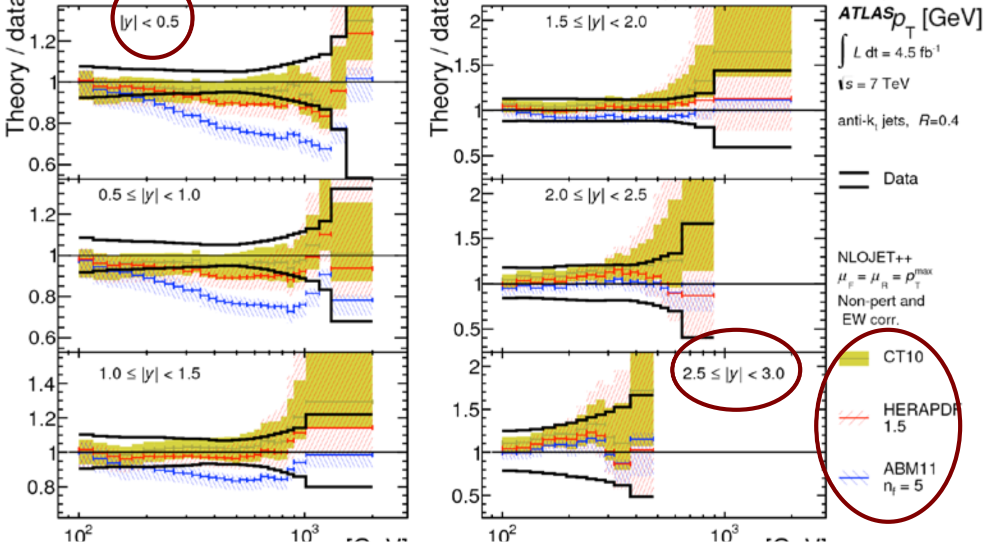
← **NLO pQCD prediction uncertainty**
(NLOjet++, CT10)
increasing uncertainties with high p_T jets
~10% @ 1 TeV for |η|<0.5 jets and
~80% for 2.5<|η|<3.0

JES⊕JER @ 1 TeV also ~10% →
for |η|<0.5





Jet p_T from 100 GeV to 2 TeV



NLO pQCD / data ratio from 100 GeV to 2 TeV of Jet p_T
various bins in |η| + various PDFs

Differences between NLO pQCD and data of the order of the theory accuracy and measurement resolution for most of the PDF sets over 8 orders of magnitude in x-sec.

New

Three-jet production cross-sections

arXiv:1411.1855
submitted to Eur. Phys. J. C

at 7 TeV with 4.5 fb^{-1}

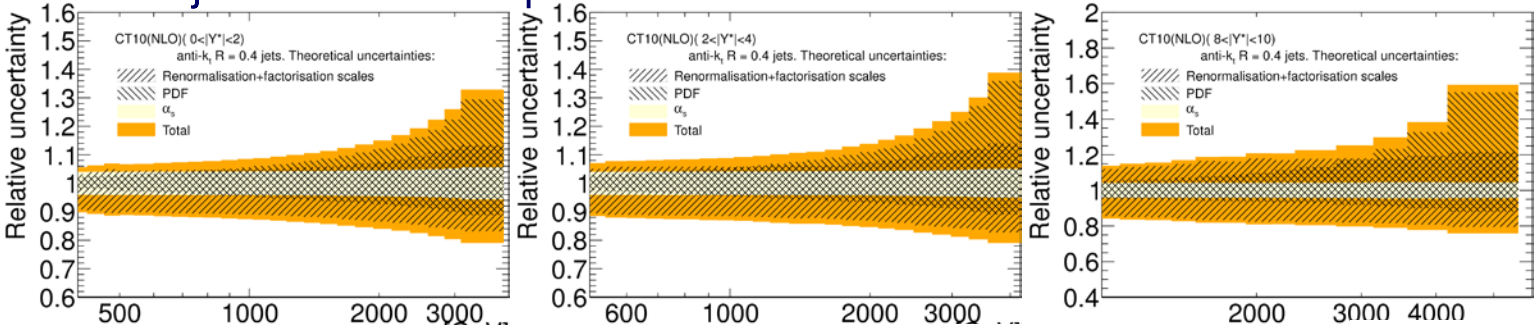
$$m_{jjj} = \sqrt{(p_1 + p_2 + p_3)^2}$$

$$|Y^*| = |y_1 - y_2| + |y_2 - y_3| + |y_3 - y_1|$$

all 3-jets have similar η

5 bins in |Y*| studied

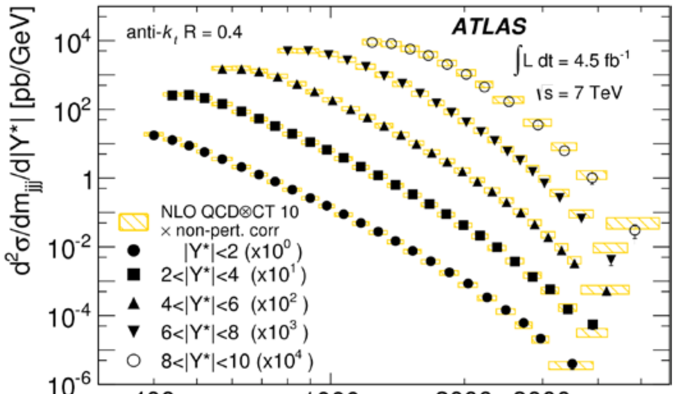
jets differ in η



m$_{jjj}$ [GeV] **m$_{jjj}$ [GeV]** **m$_{jjj}$ [GeV]**

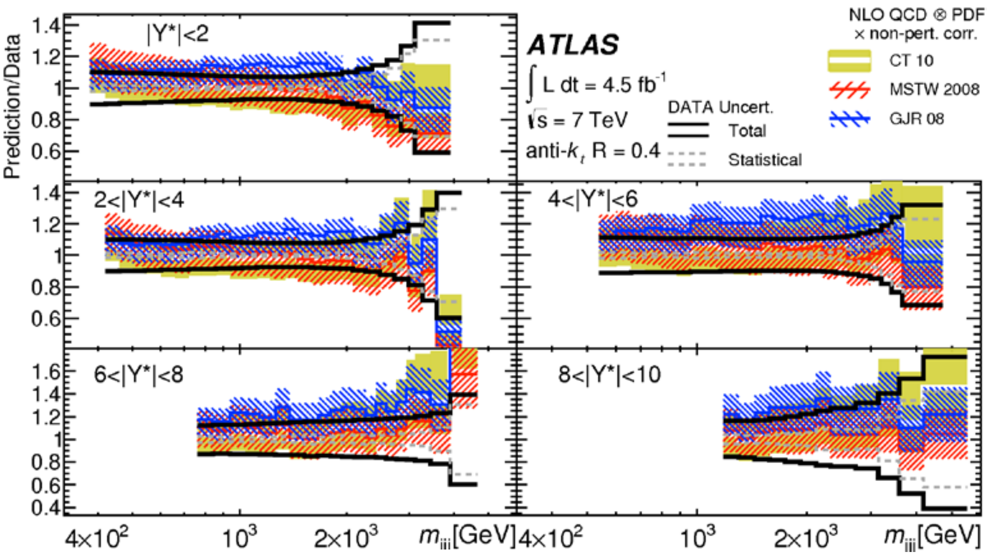
NLO pQCD predictions as a function of m$_{jjj}$ up to 5 TeV

in various bins of absolute rapidity



m$_{jjj}$ [GeV]

m$_{jjj}$ up to 5 TeV for 8<|Y^*|<10



m$_{jjj}$ [GeV] **m$_{jjj}$ [GeV]**

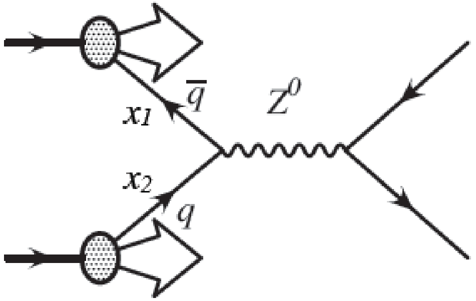
Good agreement between the data NLO pQCD predictions for most PDFs, over the full kinematic range, covering almost seven orders of magnitude in x-sec.

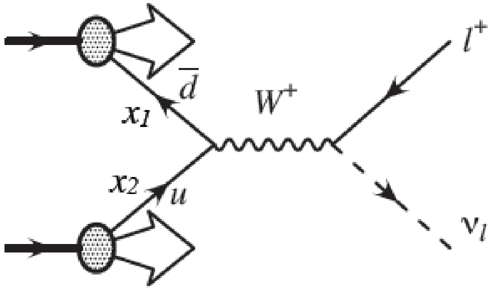
NLO pQCD (NLOJEZ++) / data ratio

various bins in |Y*| + various PDFs

Measuring Spin – 1 Bosons

Basic selection strategy:





Trigger on **lepton p_T** and select **isolated high quality leptons** offline

electron selection	muon selection
$p_T > 25\,\mathrm{GeV}$	$p_T > 25\,\mathrm{GeV}$
$\lvert\eta\rvert < 2.47 \,\&\&!\left(1.37 < \lvert\eta\rvert < 1.52\right)$	$\lvert\eta\rvert < 2.4$

$Z \to \ell\ell$	$W \to \ell\nu$
$2\ \ \mathrm{OS}\ \ \ell$	$1\ \ell$
$\Delta R\left(ee\right) > 0.2$	$E_T^{\mathrm{miss}} > 25\,\mathrm{GeV}$
$66 < m_{\ell\ell} < 116\,\mathrm{GeV}$	$m_T > 40\,\mathrm{GeV}$

example cuts, analysis specific

Main background from
- ✧ **QCD multijet** events, with fake lepton(s)
- ✧ **$t\bar{t}$ events** with real but not wanted W's

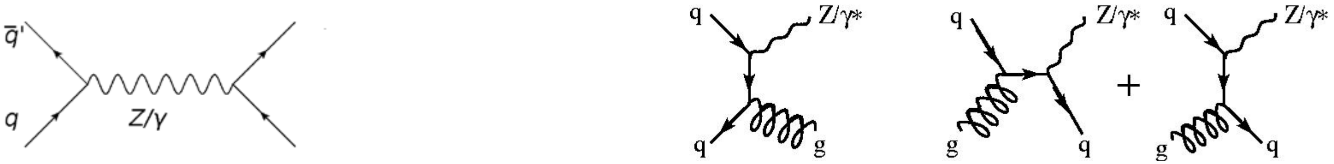
Background contributions estimated using **data driven methods**:
- ✧ fitting template shapes from MC in side bands and other control regions
- ✧ using relaxed selection criteria to estimate fake rates

arXiv:1406.3660
JHEP09(2014)145

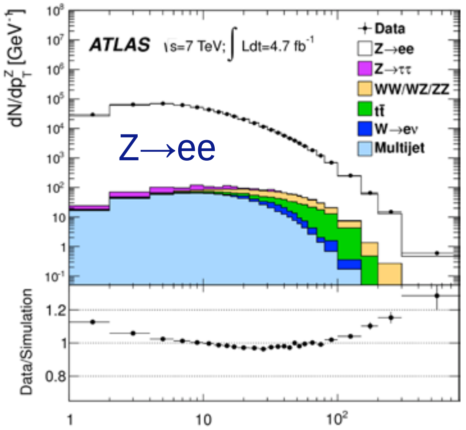
Transverse momentum distribution of Z/γ*

at 7 TeV with 4.6 fb^{-1}

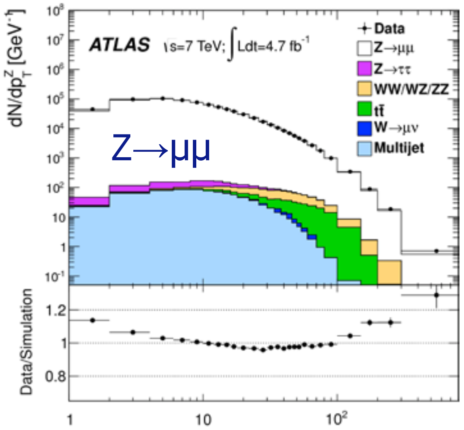
P_T distributions of lepton pairs offer crucial tests of pQCD.
With FEWZ and DYNNLO, NNLO predictions are available that require precision testing.
RESBOS in turn applies best in the soft p_T domain where a resummation of soft gluons is important.



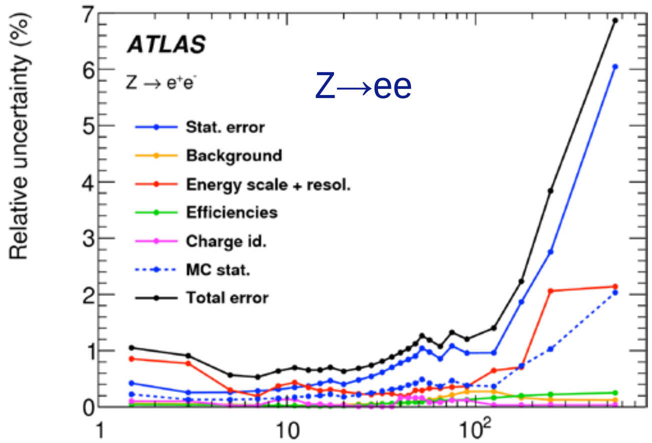
Leading order Feynman diagrams for Z/γ* production without (left) and with (right) extra parton responsible for high p_T $m_{\ell\ell}$.



p_T $m_{\ell\ell}$



p_T $m_{\ell\ell}$



p_T $m_{\ell\ell}$

p_T $m_{\ell\ell}$ up to 500 GeV

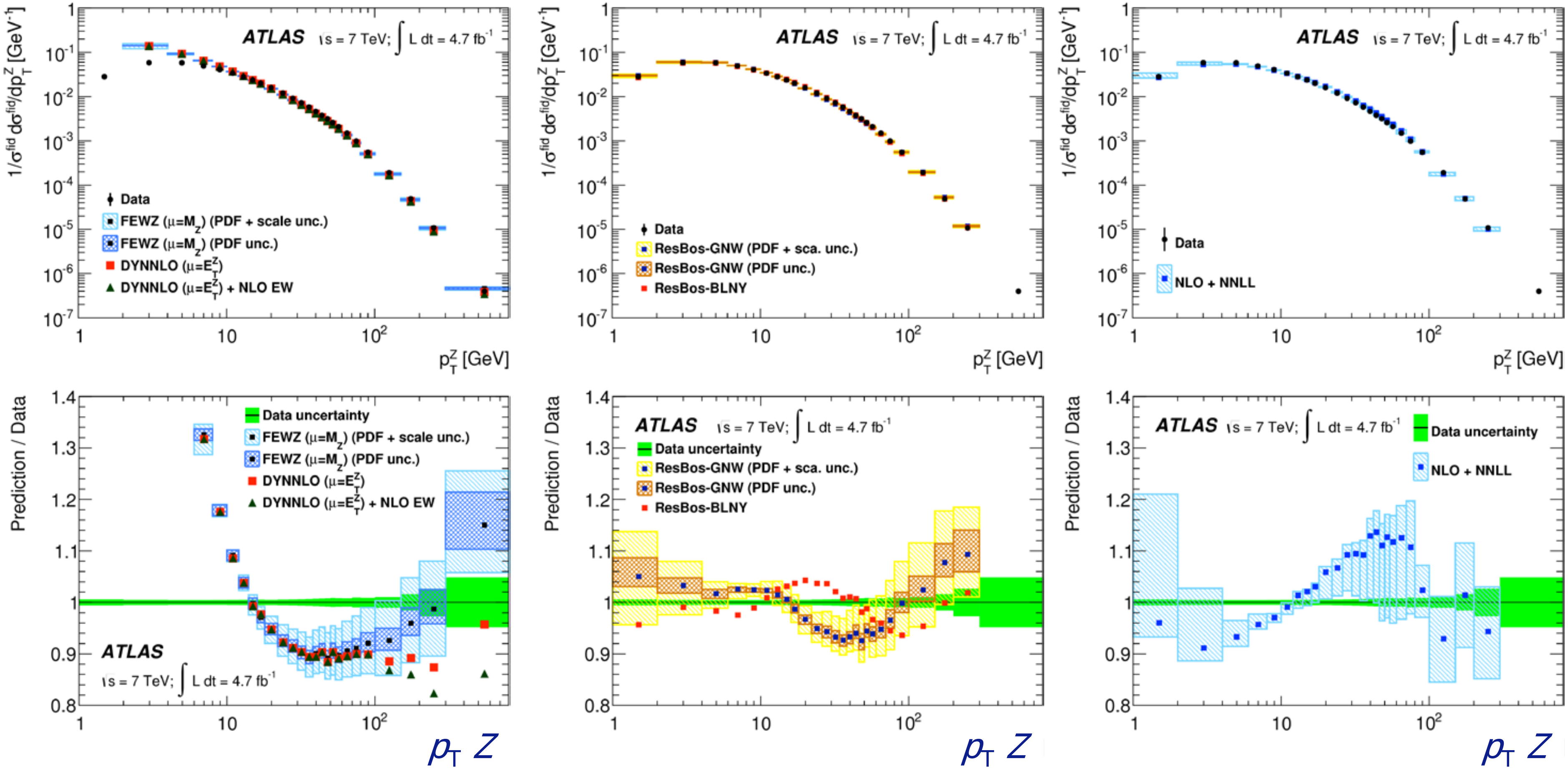
relative error per bin <1% for p_T $m_{\ell\ell}$ < 40-50 GeV

For higher p_T: dominated by statistics.
(similar for Z→μμ)

Transverse momentum distribution of Z/γ^*

arXiv:1406.3660
JHEP09(2014)145

at 7 TeV with 4.6 fb^{-1}



Unfolded spectra to the born parton level and comparison with various calculations

FEWZ and DYNNLO are NNLO predictions, RESBOS is a resummation over soft gluons and matching for high p_T. NLO+NNLL is described in Phys. Lett. B 715 (2012) 152-156

None of the MC (NNLO, resummation, NLO+NNLO) are capable to describe the full spectrum accurately. The measured data has been used for tunes of PYTHIA8 and POWHEG+PYTHIA8.

New

W+jets production cross section

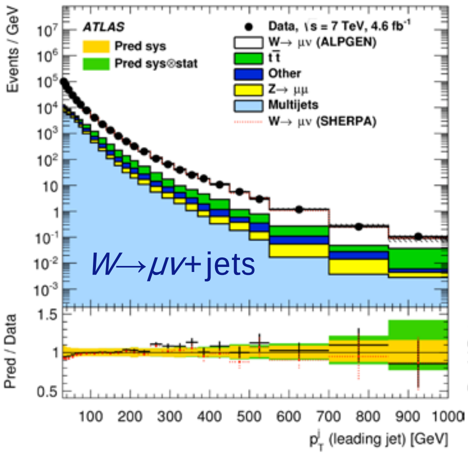
arXiv:1409.8639
submitted to EPCJ

at 7 TeV with 4.6 fb^{-1}

Precise measurements of the production of vector bosons in association with jets are important **tests of QCD** and provide **constraints on background processes** to **Higgs boson** studies and to **searches** for new physics.

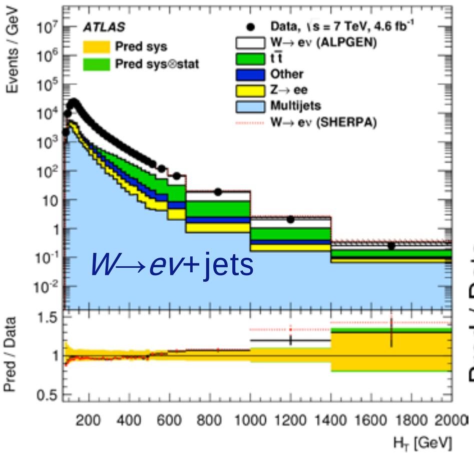
Select W and Z events with extra jets with

jet transverse momentum $p_T > 30$ GeV
Jet rapidity $|\eta_{jet}| < 4.4$
Jet–lepton angular separation $\Delta R_{\ell\text{-jet}} > 0.5$



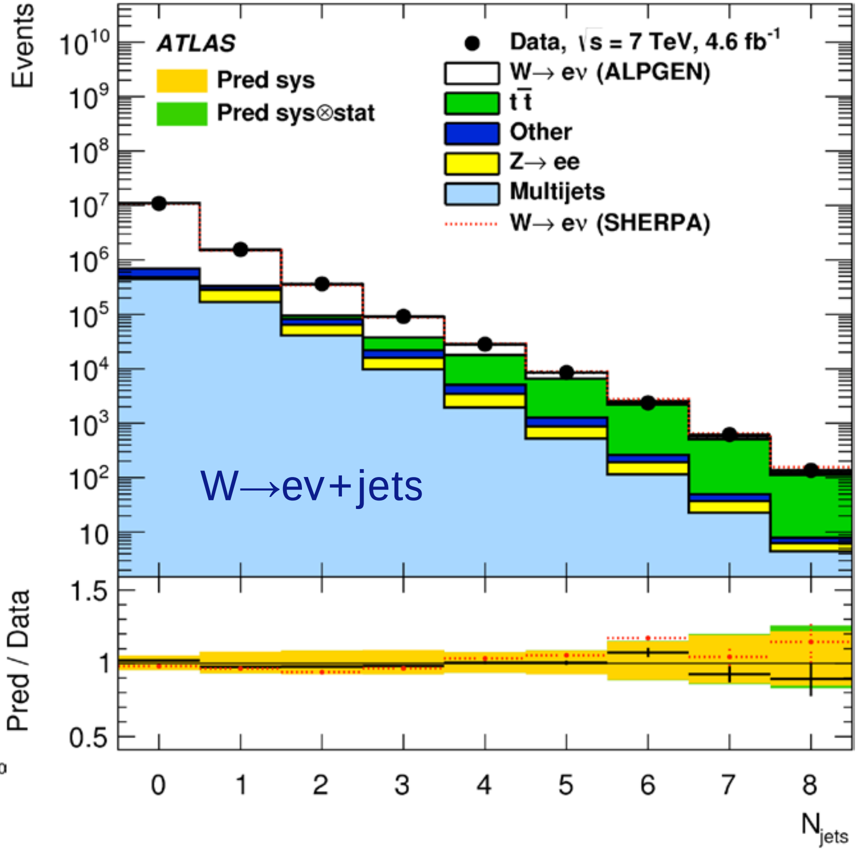
leading jet p_T

1 TeV leptons from W decay



H_T total scalar sum

H_T up to 2 TeV



jet multiplicity N_{jet}

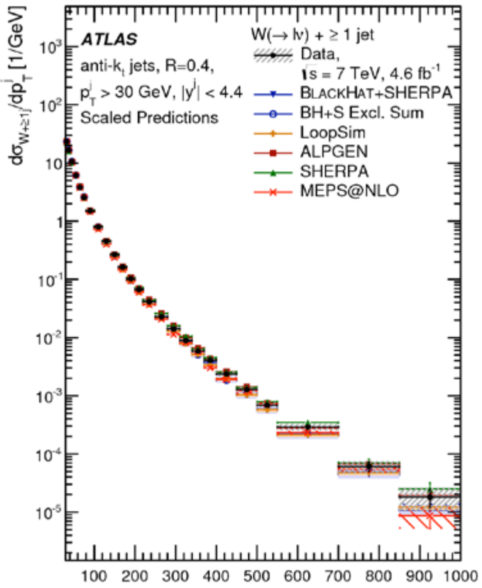
up to 8 jets

New

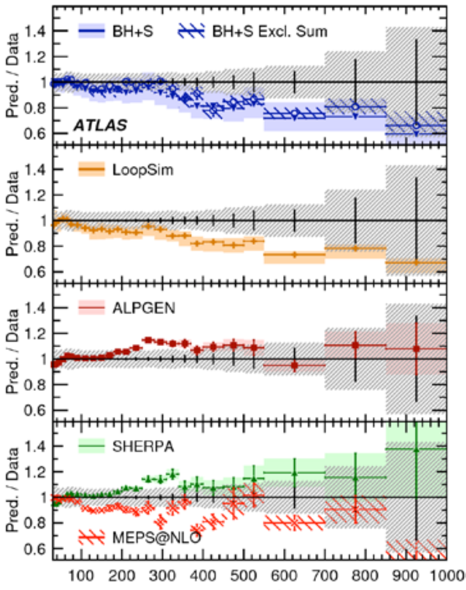
W+jets production cross section

arXiv:1409.8639
submitted to EPCJ

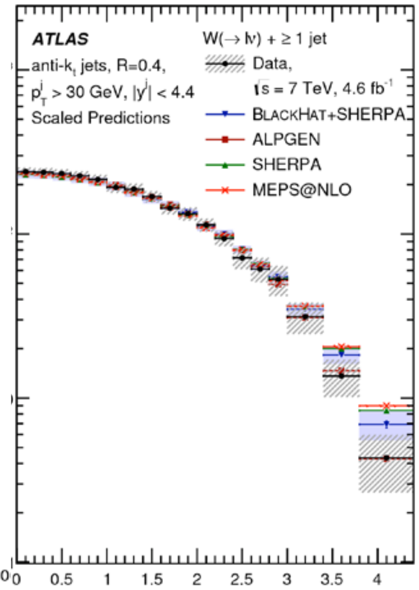
at 7 TeV with 4.6 fb^{-1}



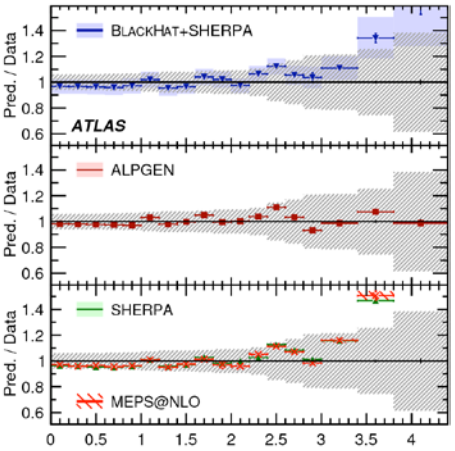
leading jet p_T



leading jet p_T



leading jet $|\eta|$



leading jet $|\eta|$

x-sec for of W+jets for n_{jets}>=1 events compared with

- ✧ LO (Alpgen, Sherpa)
- ✧ NLO calculations (Blackhat+Sherpa, MEPS@NLO),
- ✧ beyond NLO calculations (LoopSim, Blackhat+Sherpa exclusive sums).

A plethora of kinematical distributions in W+jets → food for theory.
Here only a small snapshot of what is available.

In general good agreement between the data theory.
At high jet p_T, and large |η| rigorous higher-order calculations tend to underestimate the data.

No silver bullet to describe the full kinematic accessible phase space with one description only.

New

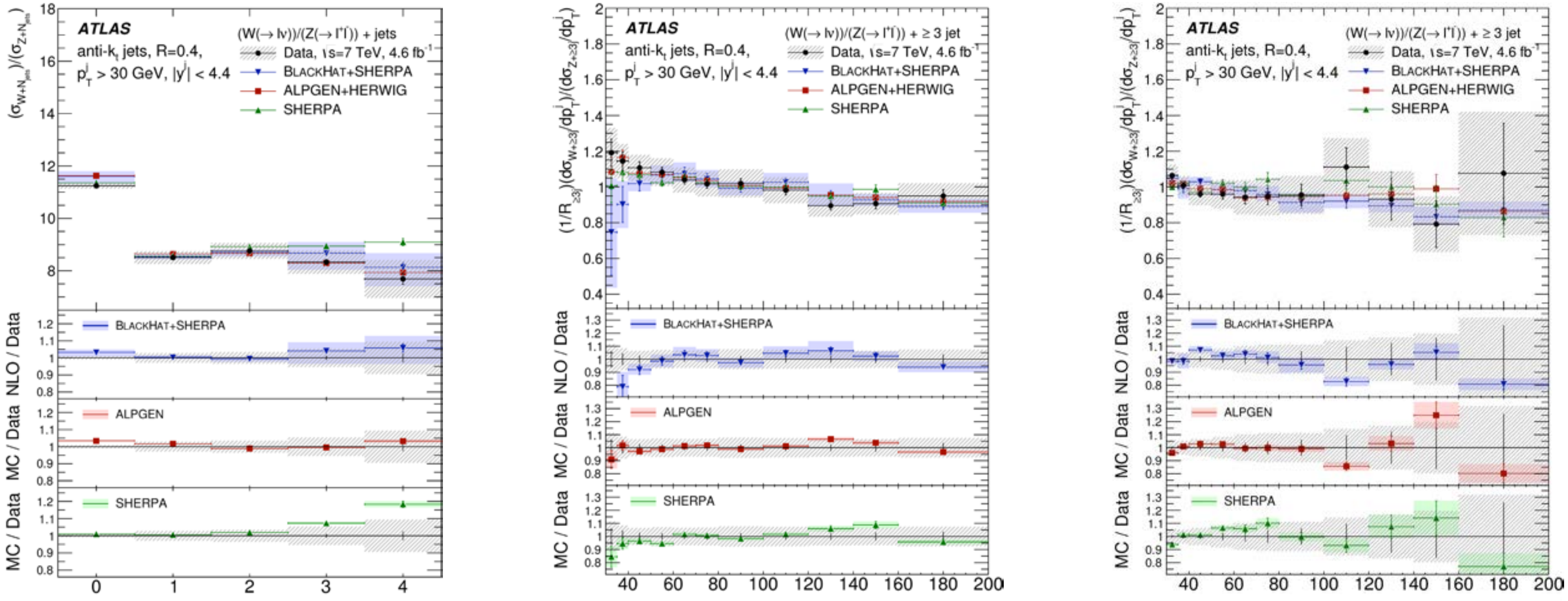
Ratio of W+jets and Z+jets production

at 7 TeV with 4.6 fb^{-1}

arXiv:1408.6510
accepted in EPJC-14-08-090

W+jets / *Z+jets* cross-section ratios provide information complementary to individual *W*+jets and *Z*+jets measurements.

- ✧ Sensitive to differences between *W*+jets and *Z*+jets events
- ✧ large cancellations of experimental systematic uncertainties and non-perturbative QCD effects



N$_{jet}$ | **leading jet p_T for N$_{jet}$≥3** | **3rd leading jet p_T for N$_{jet}$≥3**

N$_{jet}$ up to 4 | **jet p_T up to 200 GeV** | **jet p_T up to 200 GeV**

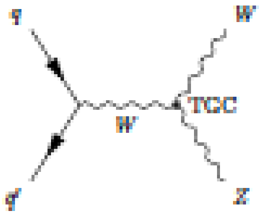
In general good agreement between the data and the theoretical predictions.

BLACKHAT+SHERPA at high jet multiplicity and large leading jet p_T validated and consistent with tuned MC.

Di-Bosons

Di-Bosons provide **important tests of the electroweak sector** of the Standard Model (SM) at the highest available energies.

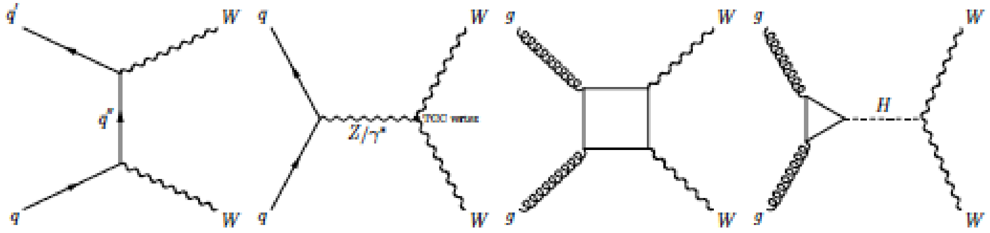
Deviations observed from the SM predictions may arise
- ✧ from anomalous triple gauge boson interactions
- ✧ from new particles decaying into vector bosons
- ✧ from incomplete SM predictions



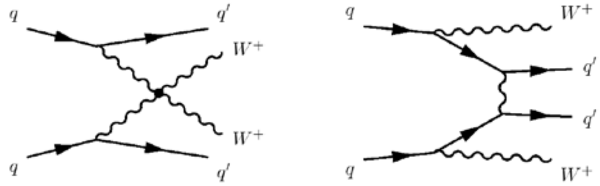
arXiv:1410.7238

New

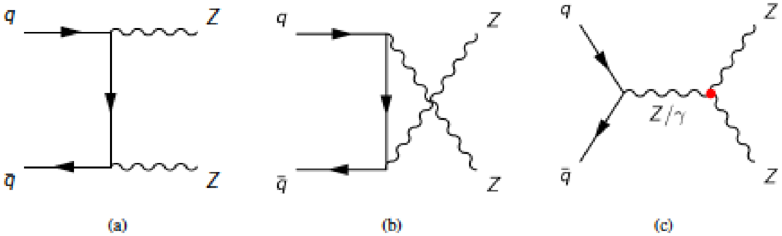
WZ

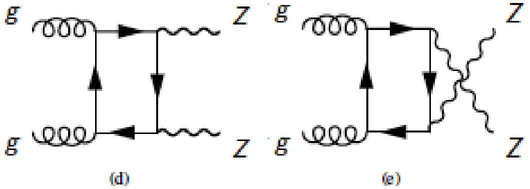


ATLAS-CONF-2014-033 ***WW***



Evidence for like sign WW **Phys. Rev. Lett. 113, 141803**





ZZ

ATLAS-CONF-2013-020

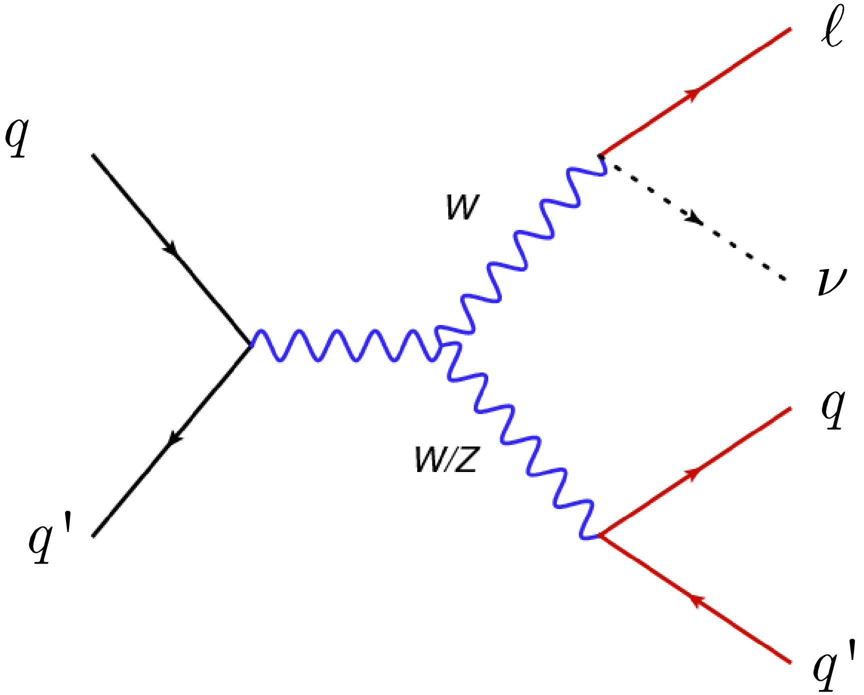
Vector boson pair production is also an important source of background in studies of the Higgs boson and in searches for signals of physics beyond the SM.

New

$WW+WZ \rightarrow \ell\nu qq$ and aTGC

arXiv:1410.7238
Submitted to JHEP

7 TeV with 4.6 fb^{-1}



Trigger on charged lepton

Require missing ET

m_T > 40 GeV

Look for exactly two jets and form di-jet mass

$$\Delta\eta\left(j_1, j_2\right) < 1.5$$

$$\Delta R\left(j_1, j_2\right) > 0.7 \quad \text{for} \quad p_T^{j_1 j_2} < 250\,\mathrm{GeV}$$

Strategy: Fit signal+background di-jet invariant mass shape to extract di-boson cross-section

WW+WZ signal on top of the **enormous W+jets background** (S/B<4%)

Requires careful understanding of di-jet invariant mass spectrum

$WW+WZ \to \ell\nu qq$ and aTGC

arXiv:1410.7238
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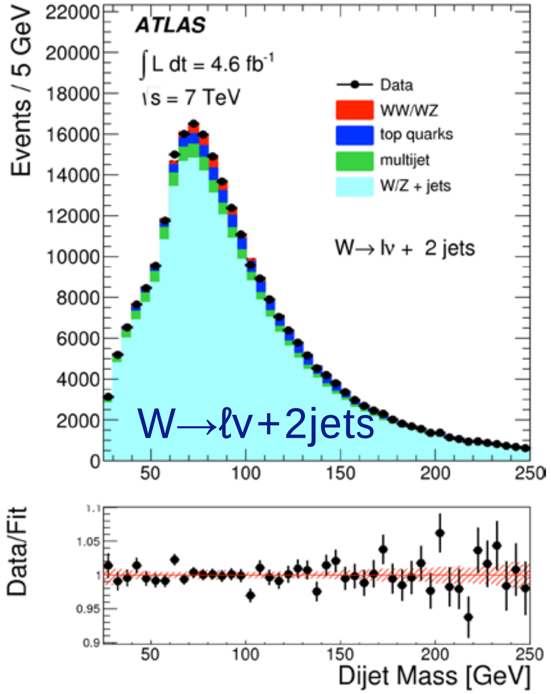
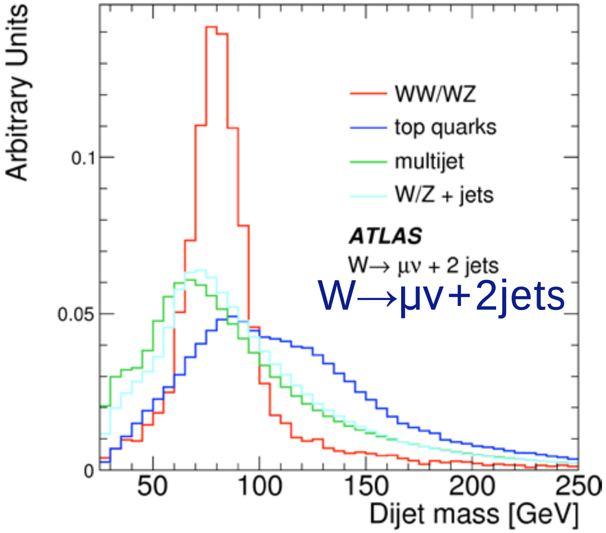
7 TeV with 4.6 fb^{-1}



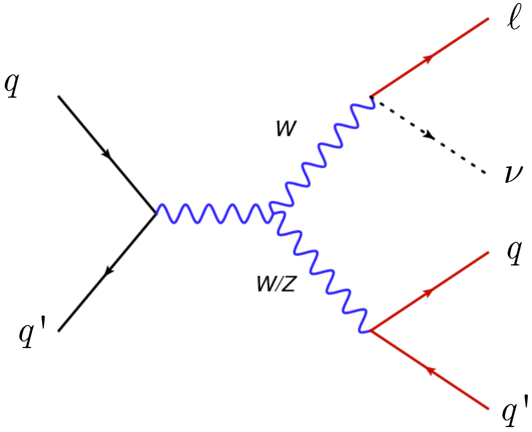
W→ℓν+2jets

Di-jet invariant mass distribution



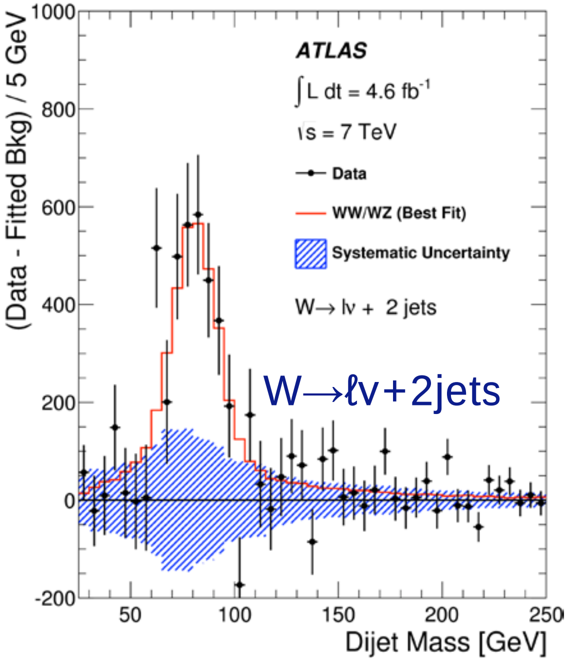
W→μν+2jets

nominal **templates** for the reconstructed di-jet invariant mass



Di-jet invariant mass after the likelihood fit.

The contribution from WW+WZ events is clearly seen.



W→ℓν+2jets

New

$WW+WZ \to \ell\nu qq$ and aTGC

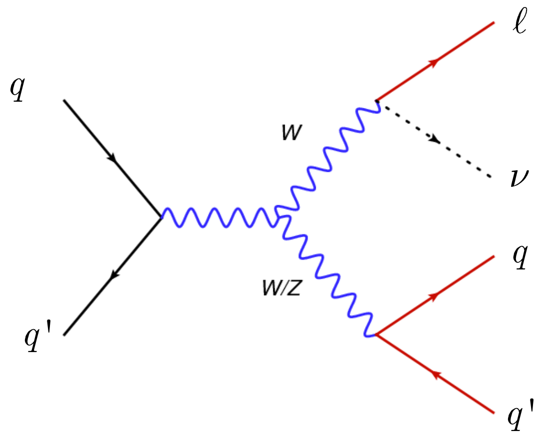
arXiv:1410.7238
Submitted to JHEP

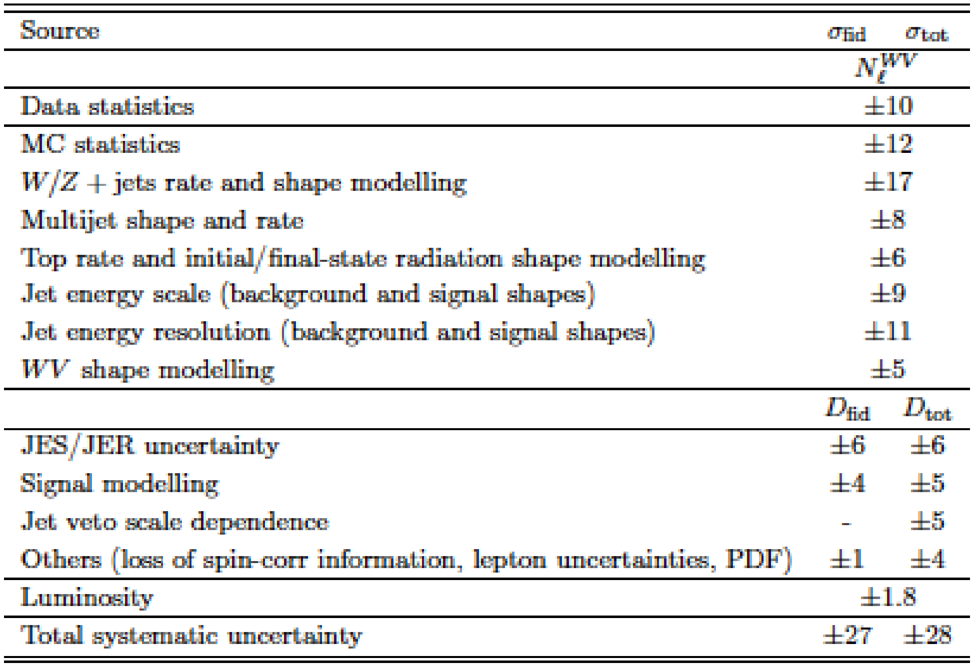
7 TeV with 4.6 fb^{-1}

The combined WW + WZ cross section is measured with a significance of 3.4σ

$$\sigma_{WW+WZ} = 68 \pm 7_{\text{stat}} \pm 19_{\text{syst}}\ \text{pb}$$

SM expected (MC@NLO): $\sigma_{WW+WZ} = 61.1 \pm 2.2\,\text{pb}$





Source	σ_{fid}	σ_{tot}
	N_ℓ^{WV}	
Data statistics	±10	
MC statistics	±12	
W/Z + jets rate and shape modelling	±17	
Multijet shape and rate	±8	
Top rate and initial/final-state radiation shape modelling	±6	
Jet energy scale (background and signal shapes)	±9	
Jet energy resolution (background and signal shapes)	±11	
WV shape modelling	±5	
	D_{fid}	D_{tot}
JES/JER uncertainty	±6	±6
Signal modelling	±4	±5
Jet veto scale dependence	-	±5
Others (loss of spin-corr information, lepton uncertainties, PDF)	±1	±4
Luminosity	±1.8	
Total systematic uncertainty	±27	±28

I.e.
A precise understanding of W+jets allows for more challenging measurements.

Compatible with SM, dominated by systematics

Systematic uncertainty driven by

- **W/Z+jets rate and shape**
- **jet energy resolution**

New

$WW+WZ \rightarrow \ell\nu qq$ and aTGC

arXiv:1410.7238
Submitted to JHEP

7 TeV with 4.6 fb^{-1}

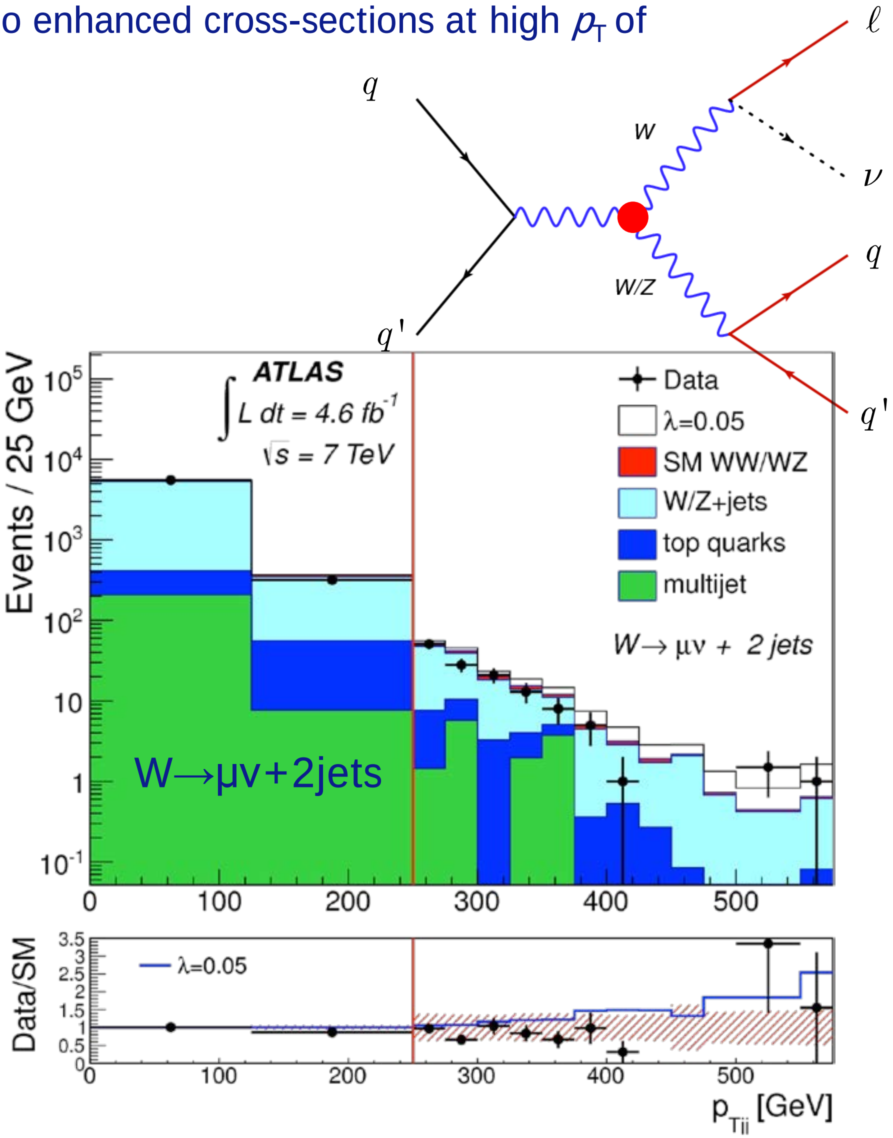
Anomalous Triple Gauge Couplings (aTGC's) typically lead to enhanced cross-sections at high p_T of kinematic spectra. The p_T of the W/Z can be used for this.

Fitting the **di-jet invariant transverse momentum p_T** spectrum and **extract limits on aTGCs**.

Range of the di-jet invariant mass m_{jj} spectrum reduced to improve sensitivity: 75 < m_{jj} < 95 GeV.

m_T range and p_T binning have been optimized to optimize the expected aTGC limits.

di-jet invariant p_T spectrum similar for W→eν+2jets



red line visualizes ΔR cut

$$\Delta R\left(j_1, j_2\right) > 0.7 \quad \text{for} \quad p_T^{j_1 j_2} < 250\,\text{GeV}$$

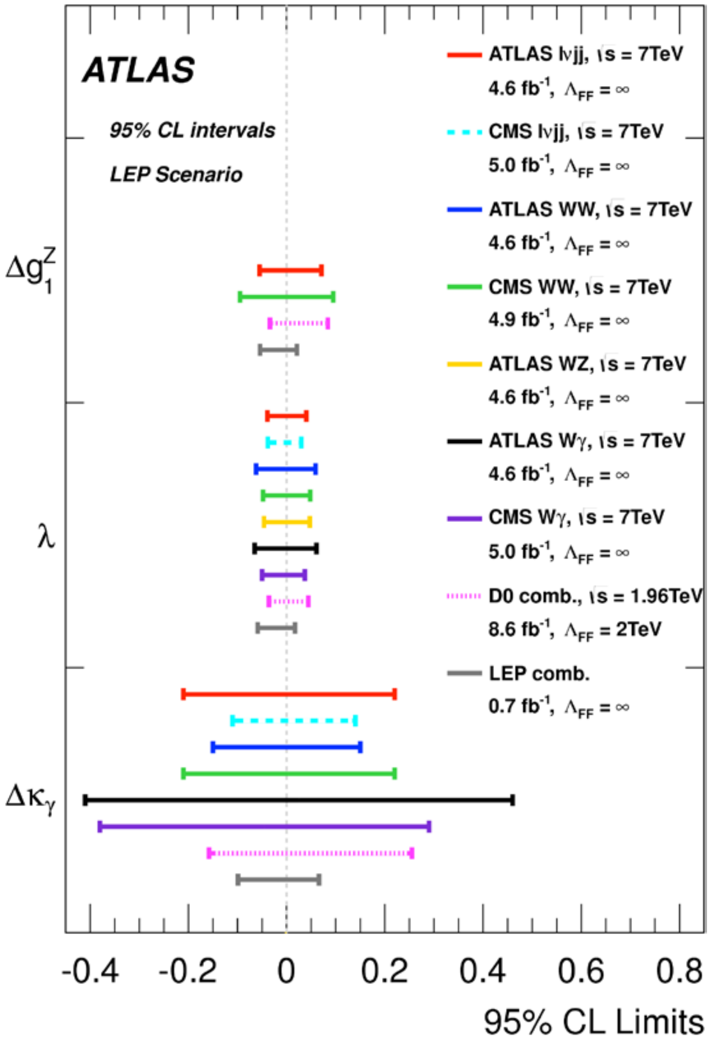
New

$WW+WZ \rightarrow \ell\nu qq$ and aTGC

arXiv:1410.7238
Submitted to JHEP

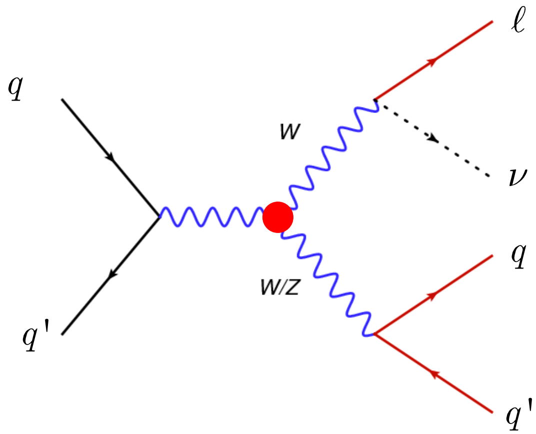
7 TeV with 4.6 fb^{-1}

WWZ and WWγ couplings parameterized using five parameters: $\lambda_\gamma, \lambda_Z, \kappa_\gamma, \kappa_Z,$ and g_1^Z



In SM:

$$\lambda_\gamma = \lambda_Z = 0$$
$$\kappa_\gamma = \kappa_Z = g_1^Z = 1$$

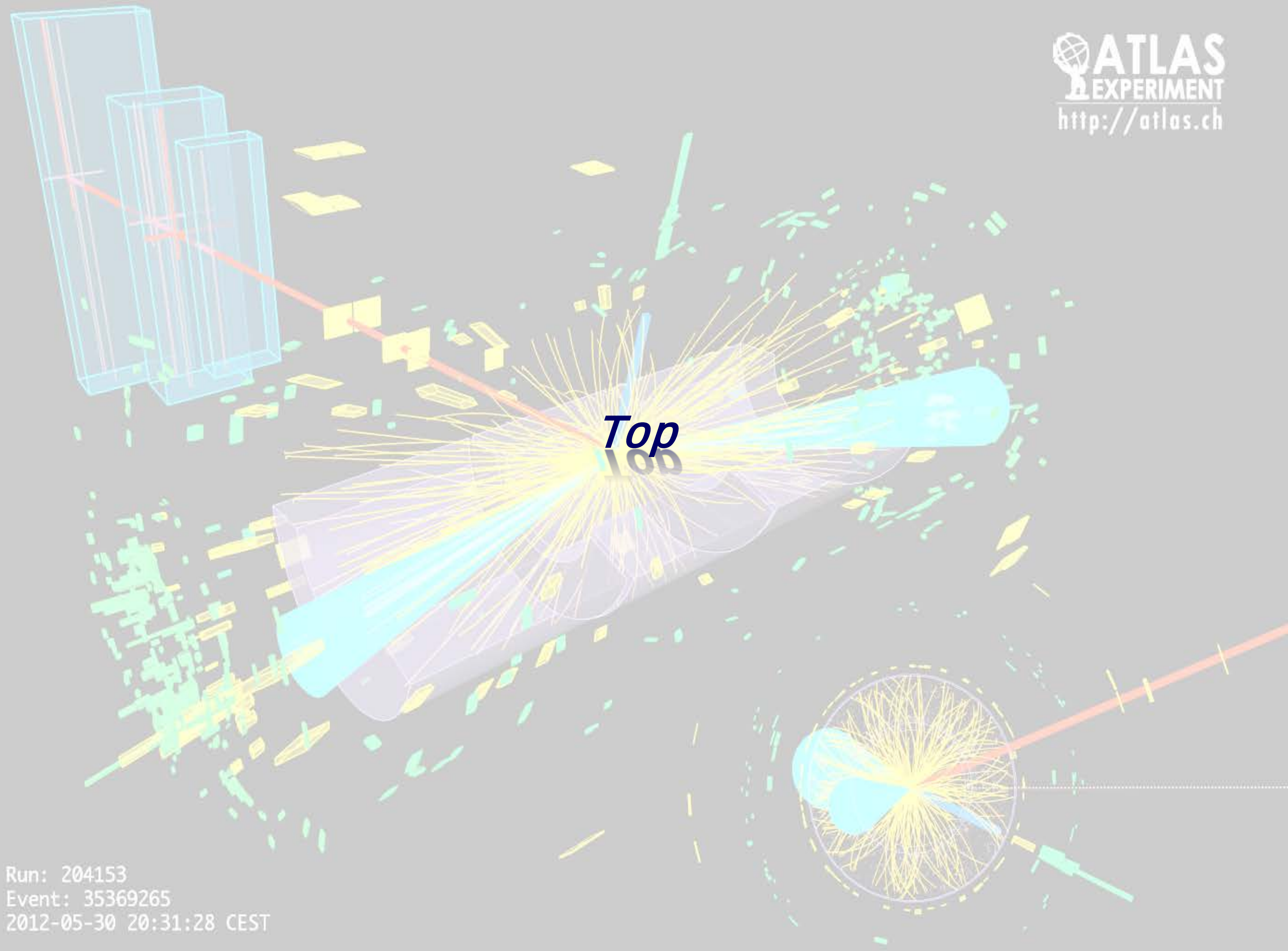


The couplings are constraint further in the fit:

$$\lambda_\gamma = \lambda_Z \equiv \lambda$$
$$\Delta\kappa_Z = \Delta g_1^Z - \Delta\kappa_\gamma \tan\theta_W$$
$$\text{with} \quad \Delta\kappa_Z = \kappa_Z - 1, \Delta\kappa_\gamma = \kappa_\gamma - 1, \Delta g_1^Z = g_1^Z - 1$$

95% CL limits on anomalous couplings are derived and are similar to limits set in other di-boson analyses.

Top


ATLAS EXPERIMENT
http://atlas.ch
Run: 204153
Event: 35369265
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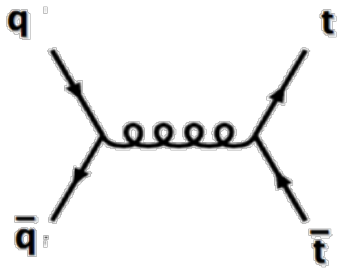
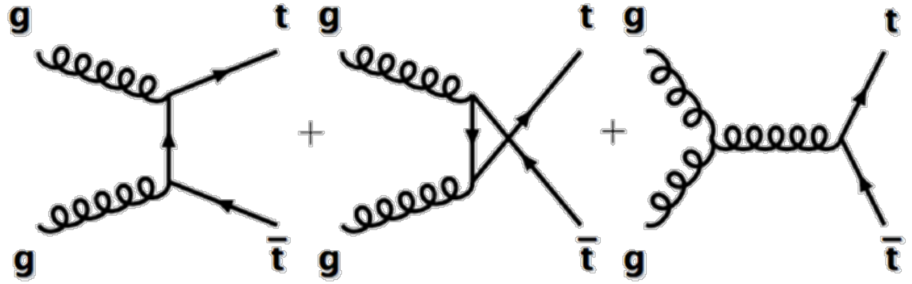
Top pair production at the LHC

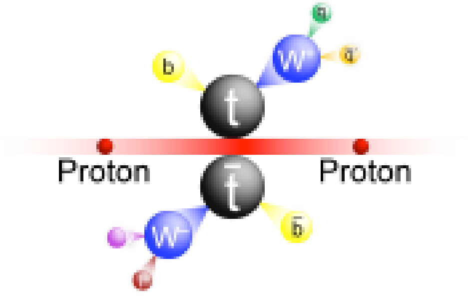


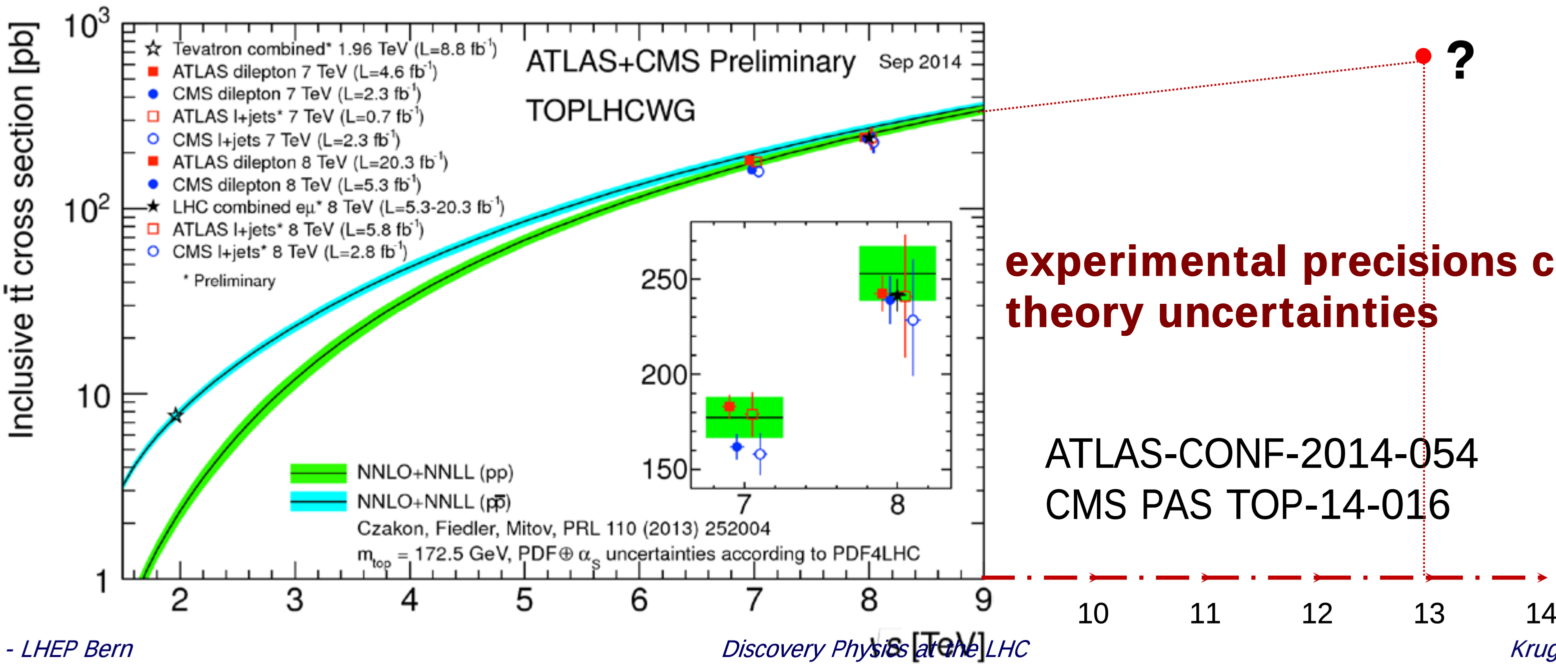
~13% @ 8 TeV



~87% @ 8 TeV

At LHC production of $t\bar{t}$ pairs predominantly through gluon fusion

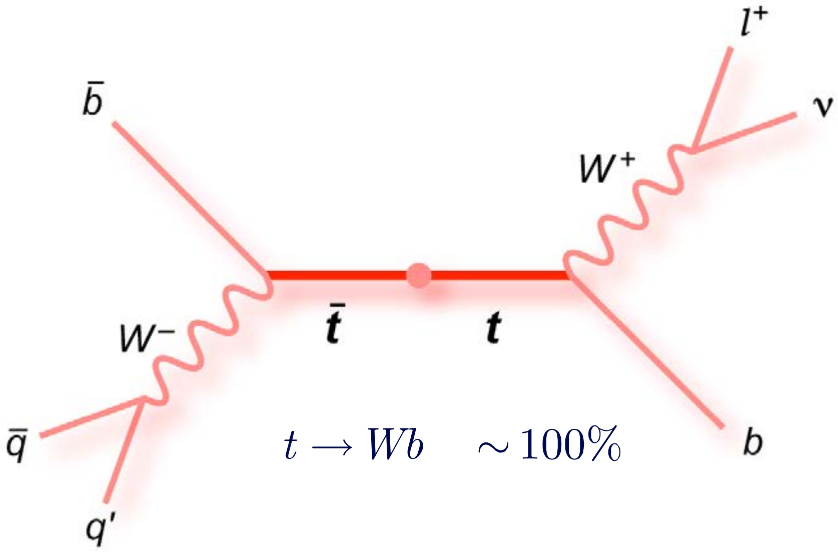




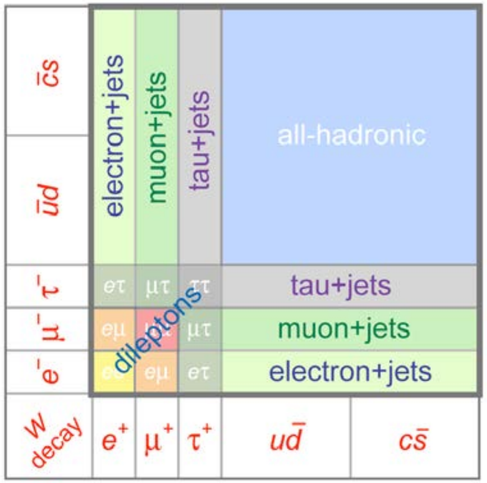
experimental precisions challenging theory uncertainties

ATLAS-CONF-2014-054
CMS PAS TOP-14-016

Top pair decay



$t \to Wb \quad \sim 100\%$



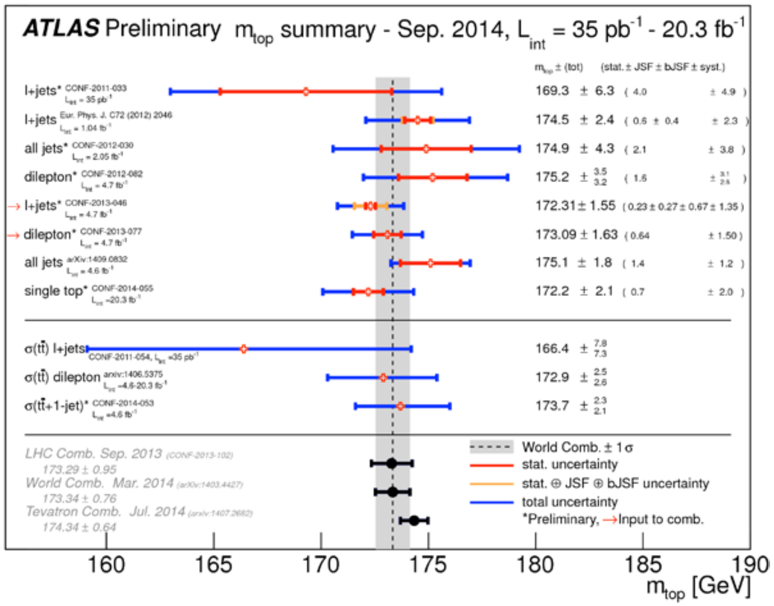
e/μ+jets 34%

all jets 46%

τ 14%

e/μ dilepton 6%

select
- ✧ high p_T leptons, missing E_T
- ✧ jets
- ✧ b-jets



ATLAS measured m_{top} in many decay modes.

World combination (ATLAS+CMS+Tevatron):

m_{top}=173.3±0.8 GeV (0.5%)

arXiv:1406.5375
Eur.Phys.J. C74 (2014) 3109

New

x-sec of $t\bar{t} \to e\mu$ and b jets

7 TeV with 4.6 fb^{-1} and 8 TeV with 20.3 fb^{-1}

Use only **opposite sign $e\mu$ dilepton** events (cleanest final state, plenty of statistics)

Use *b*-tagging, but fit the combined efficiency of b-tagging and jet p_T / η acceptance as part of the analysis.

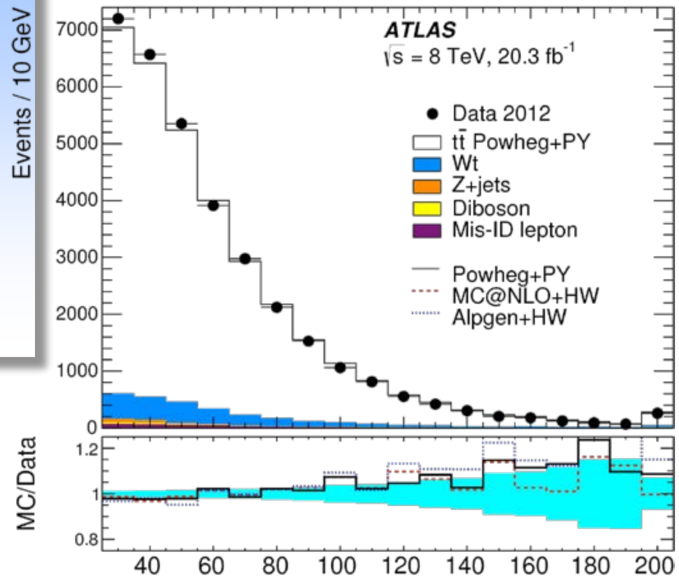
$$N_1 = \sigma_{t\bar{t}}\, 2\varepsilon_{e\mu}\varepsilon_b\left(1 - C_b\varepsilon_b\right) + N_1^{\text{bkg}} \qquad \text{exactly one b-tagged jet}$$

$$N_2 = \sigma_{t\bar{t}}\,\varepsilon_{e\mu}\varepsilon_b C_b \varepsilon_b + N_2^{\text{bkg}} \qquad \text{exactly two b-tagged jets}$$

2-parameter fit for $\sigma_{t\bar{t}}$ and ε_b

→ 2 equations, 2 unknowns

$\varepsilon_{e\mu}$	fraction of $t\bar{t}$ events with reconstructed opposite electron and muon
ε_b	probability to reconstruct and tag a b-jet in a $t\bar{t}$ event (incl. fiducial acceptance)
C_b	tagging correlation correction - change of ε_b when one jet already tagged
$N_{1,2}^{\text{bkg}}$	number of non-tt events in the respective samples



Muon p_T

μ p_T and e p_T up to 200 GeV

$$\sigma_{t\bar{t}} = 182.9 \pm 3.1_{\text{stat}} \pm 4.2_{\text{exp}} \pm 3.6_{\text{theo}} \pm 3.3_{\text{lumi}}\ \text{pb} \quad (3.9\%) \quad 7\,\text{TeV}$$

$$\sigma_{t\bar{t}}^{\text{theory}} = 177.3 \pm 9.0^{+4.6}_{-6.0}\ \text{pb} \quad (5.9\%)$$

$$\sigma_{t\bar{t}} = 242.4 \pm 1.7_{\text{stat}} \pm 5.5_{\text{exp}} \pm 7.5_{\text{theo}} \pm 4.2_{\text{lumi}}\ \text{pb} \quad (4.3\%) \quad 8\,\text{TeV}$$

$$\sigma_{t\bar{t}}^{\text{theory}} = 252.9 \pm 11.7^{+6.4}_{-8.6}\ \text{pb} \quad (5.5\%)$$

NNLO+NNLL (top++2.0; m_t =172.5GeV)

experimental precision is challenging NNLO+NNLL calculation for $t\bar{t}$ production

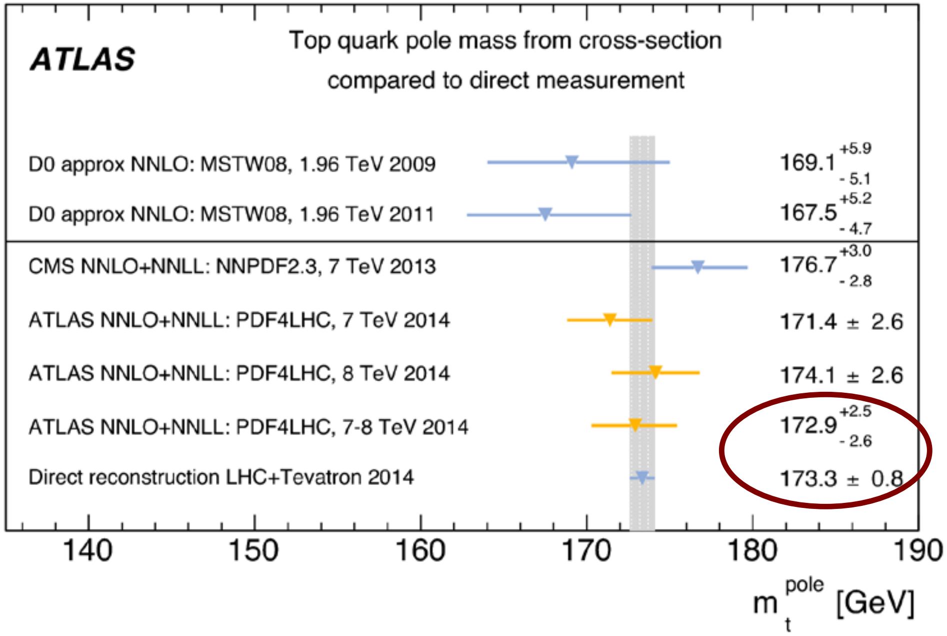
New

top pole mass from cross section

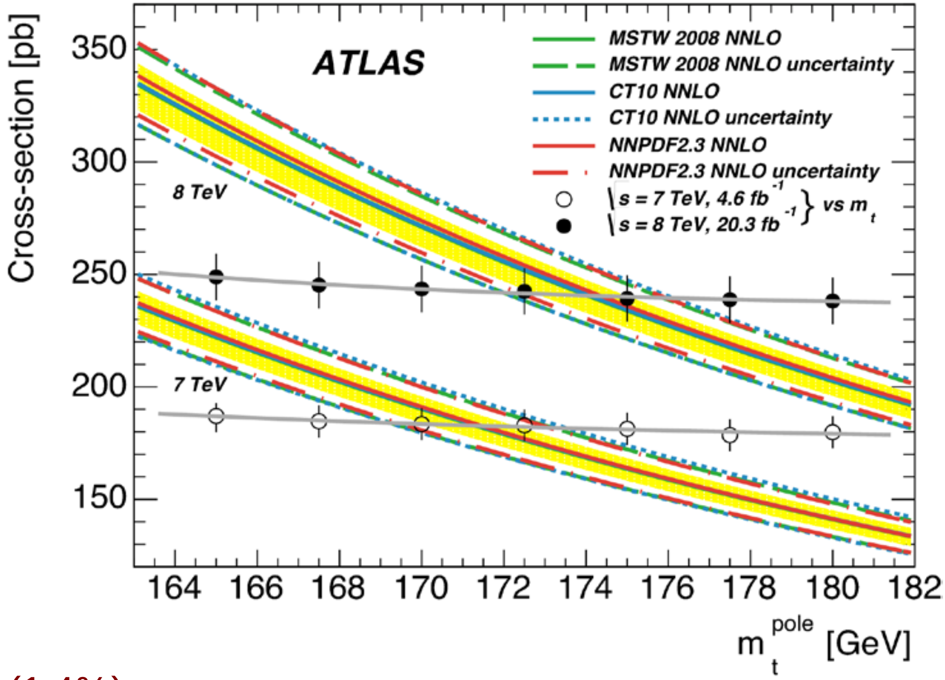
arXiv:1406.5375
Eur.Phys.J. C74 (2014) 3109

7 TeV with 4.6 fb^{-1} and 8 TeV with 20.3 fb^{-1}

With the precise measurement of $\sigma_{t\bar{t}}$ using opposite sign eμ dileptons, we can now extract m_t^{pole} form it.



(1.4%)



NNLO+NNLL $t\bar{t}$ production cross-sections at 7 and 8 TeV as a function of m_t^{pole}

Measurements of $\sigma_{t\bar{t}}$, with their dependence on the assumed value of m_{top} through acceptance and background corrections parameterised with m_t^{ref}=172.5 GeV

Top quark pole mass extracted from cross section measurement

agree with

top mass from kinematic reconstruction of top pair events.

New

boosted top quarks $p_T^{top} > 300$ GeV

ATLAS-CONF-2014-057
30 Sep 2014

8 TeV with 20.3 fb^{-1}

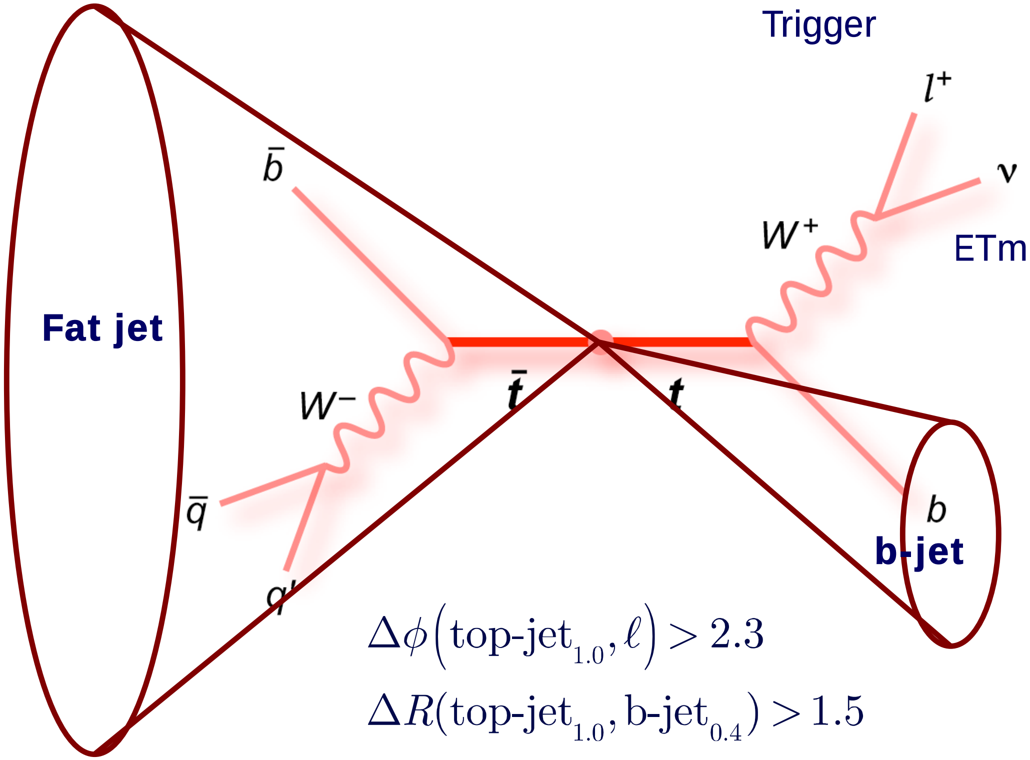
anti-k$_t$ R=1.0 jet

$p_T^{\rm jet} > 300\,{\rm GeV}$

$m_{\rm jet} > 100\,{\rm GeV}$

$\sqrt{d_{12}} > 40\,{\rm GeV}$

$\eta_{\rm jet} < 2$



$p_T^{\rm jet} > 25\,{\rm GeV}$

$\eta_{\rm jet} < 2.5$

$p_T^{\ell} > 25\,{\rm GeV}$

$E_T^{\rm miss} > 20\,{\rm GeV}$

$m_T^{W} > 60\,{\rm GeV}$

$\Delta{\rm R}\left(\ell, {\rm jet}\right) < 1.5$

anti-k$_t$ R=0.4

$\Delta\phi\left(\text{top-jet}_{1.0}, \ell\right) > 2.3$

$\Delta R(\text{top-jet}_{1.0}, \text{b-jet}_{0.4}) > 1.5$

Topology and selection strategy of boosted top quark events

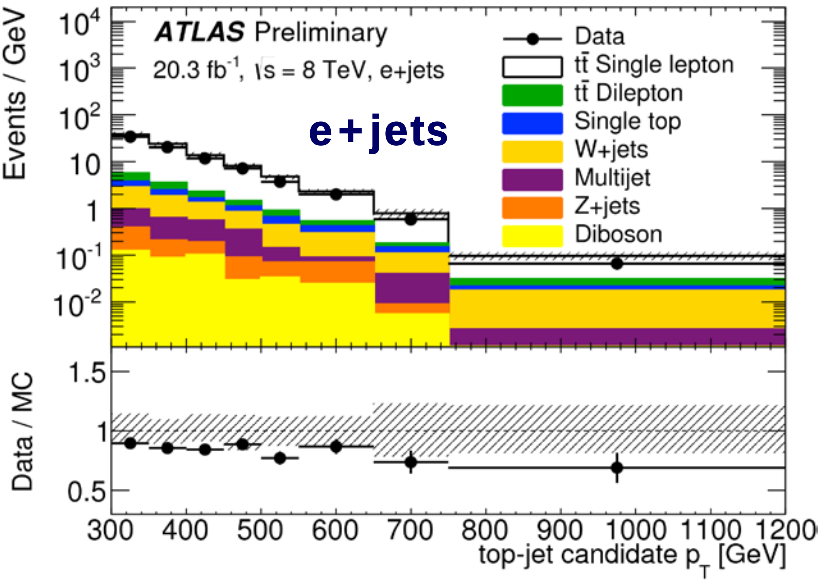
k_t splitting scale $\sqrt{d_{12}} > 40\,{\rm GeV}$ $\sqrt{d_{12}} = \min(p_T^{\text{jet}_1}, p_T^{\text{jet}_2})\Delta R_{12}$ of the two proto-jets in the final step of the k_t-clustering algorithm.

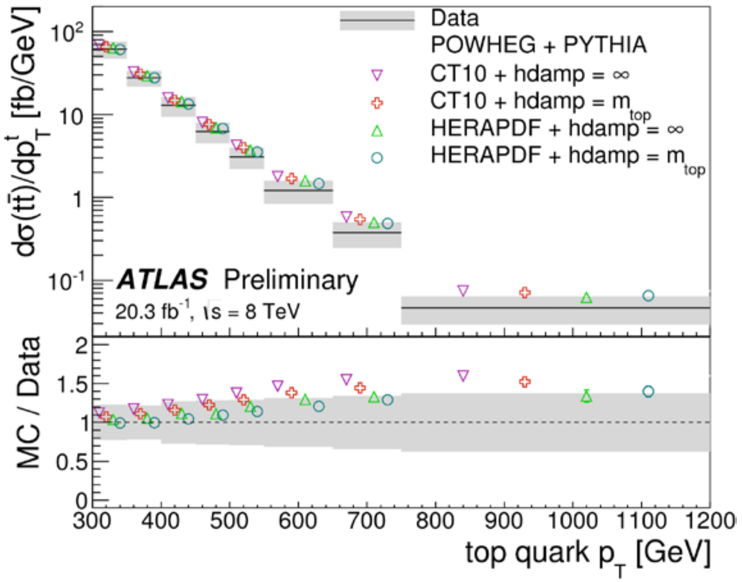
New

boosted top quarks $p_T^{top} > 300$ *GeV*

ATLAS-CONF-2014-057
30 Sep 2014

8 TeV with 20.3 fb^{-1}





p_T of fat jet

Parton-level unfolded p_T^{top}

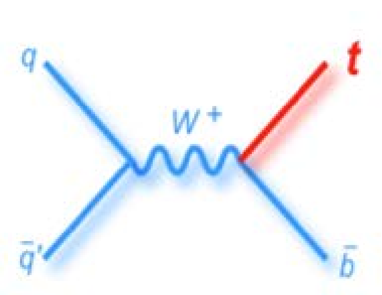
Top candidates with p_T^{top} up to 1 TeV

compared with NLO Powheg+Pythia normalized to **NNLO top++2.0** with m_t=172.5 GeV

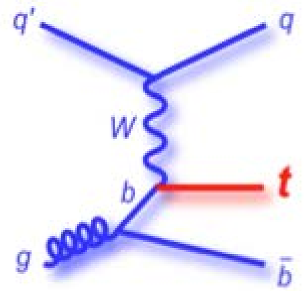
The measurement uncertainty ranges from 15% to 29% dominated by large-R jets energy scale.

The predictions of next-to-leading-order and leading-order matrix element plus parton shower Monte Carlo generators are found to generally overestimate the measured cross-sections.

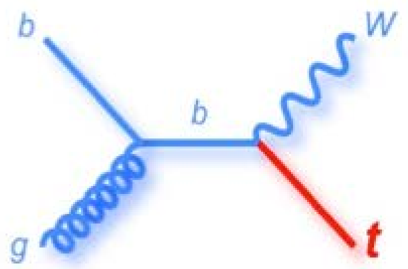
Single top production



s-channel

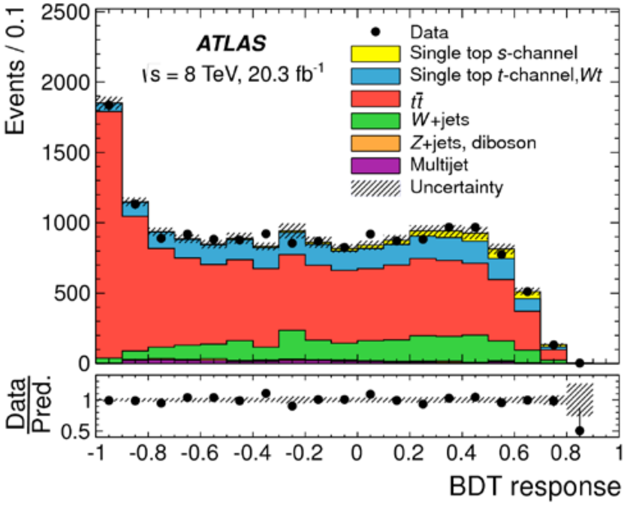


t-channel



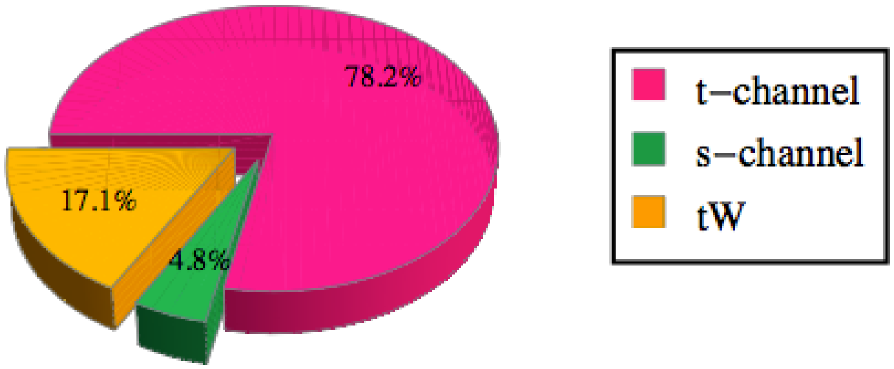
associated Wt production

Single top production predominantly in the t-channel at the LHC.



multivariate analysis

LHC (7 TeV)

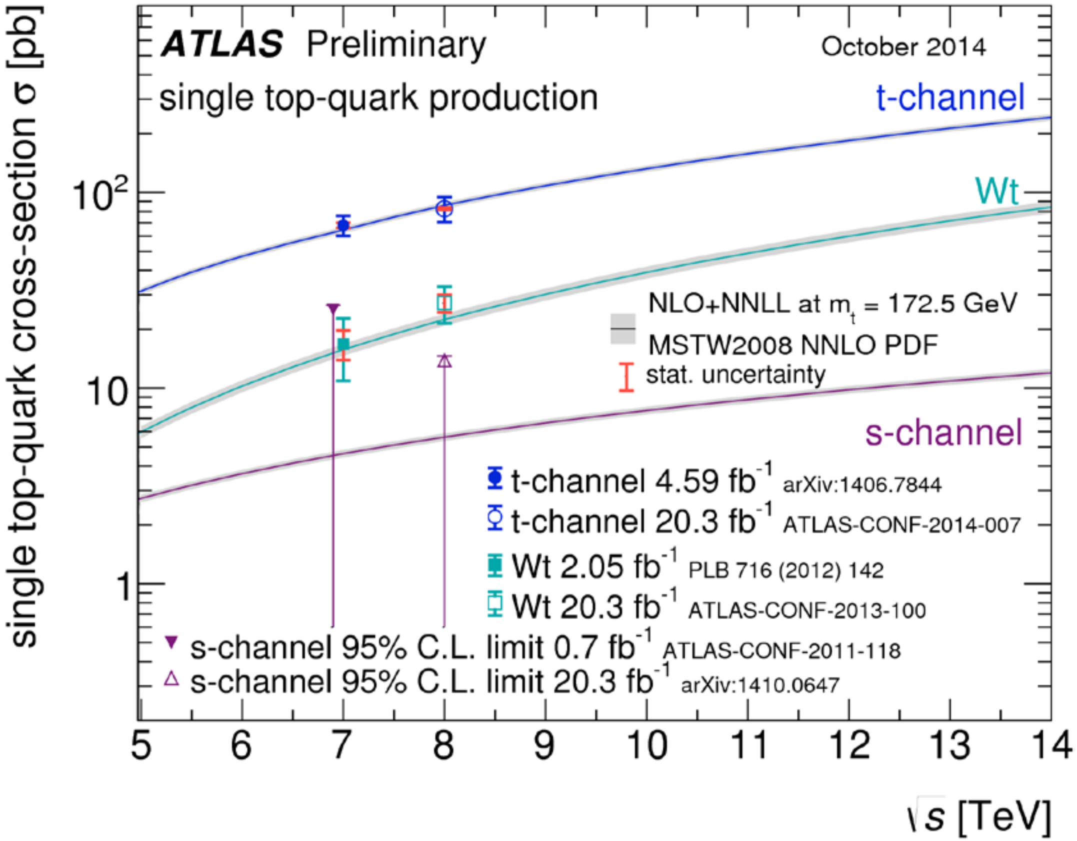


Evidence for s-channel single top
arXiv:1410.0647
submitted to Phys. Lett. B

ATLAS single top production cross-sections

Single top production
in **t-channel** and in associated
***Wt* production** measured.

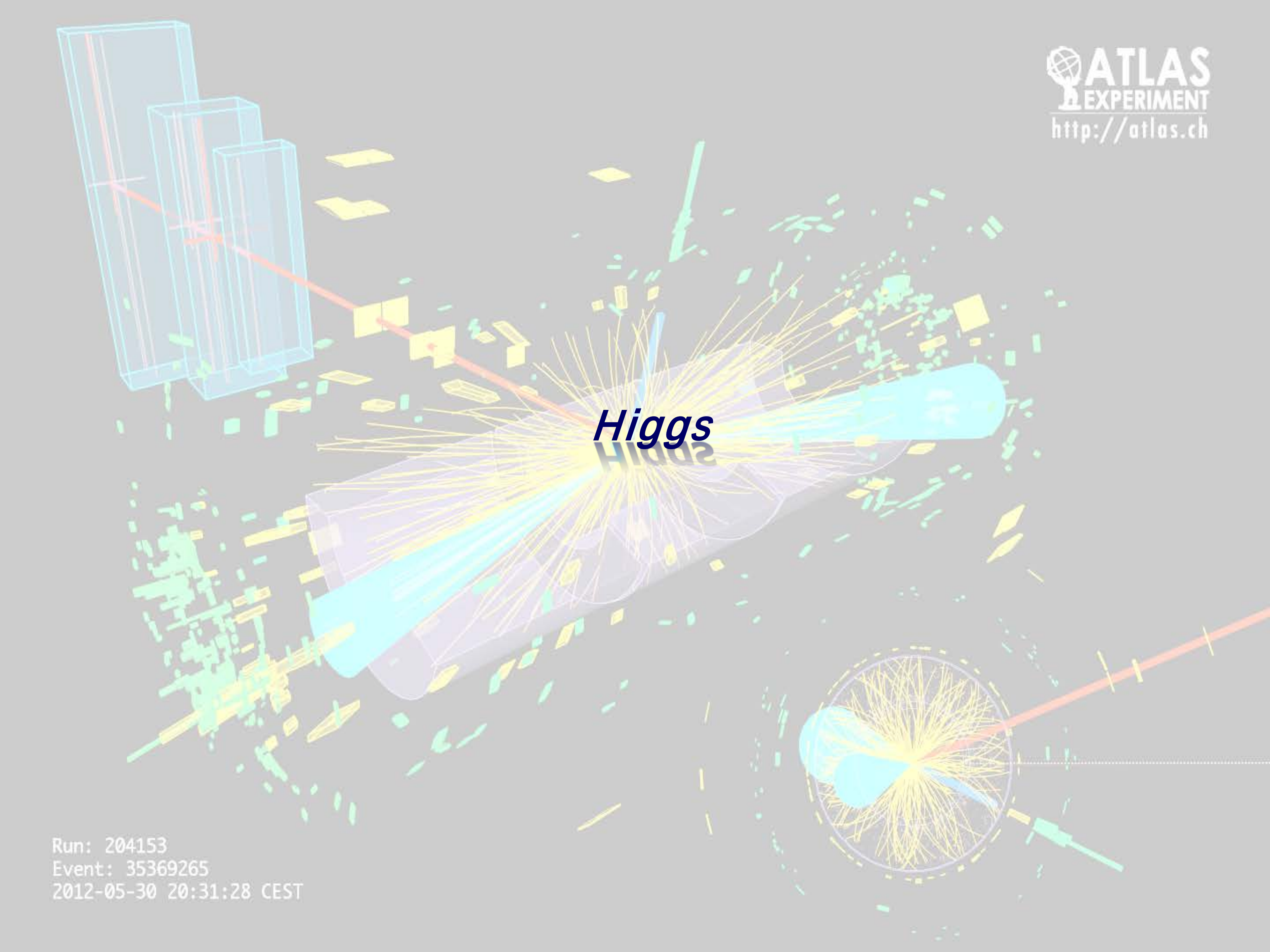
s-channel upper limits
are shown.
(signal 'seen' with 1.3σ
where 1.4σ expected.)



Single top production cross-sections
compared **NLO QCD complemented with NNLL resummation**.
For the s-channel only an upper limit is shown.

NNLO + resummation describe well the measured single top cross sections in all production modes.

Higgs


ATLAS EXPERIMENT
http://atlas.ch
Run: 204153
Event: 35369265
2012-05-30 20:31:28 CEST

One year ago…

Nobelpriset 2013

The Nobel Prize 2013

The Nobel Prize in Physics 2013

KUNGL. VETENSKAPS AKADEMIEN

François Englert
Université Libre de Bruxelles, Belgium

Peter W. Higgs
University of Edinburgh, UK

"För den teoretiska upptäckten av en mekanism som bidrar till förståelsen av massans ursprung hos subatomära partiklar, och som nyligen, genom upptäckten av den förutsagda fundamentala partikeln, bekräftats av ATLAS- och CMS-experimenten vid CERN:s accelerator LHC."

"For the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted
adron Collider."

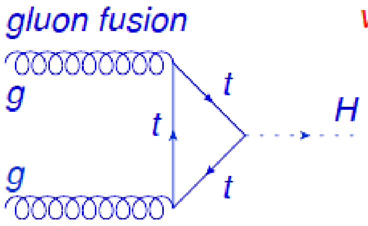
Nobelprize.org

Discovery of the Higgs boson is the beginning of a new era!!

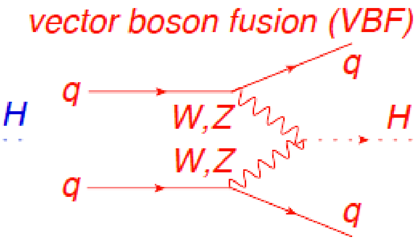
- ✧ Mass?
- ✧ Coupling to the Higgs boson?
- ✧ Spin/CP?

Since the discovery of the Higgs boson, we have improved analyses for precise property measurements

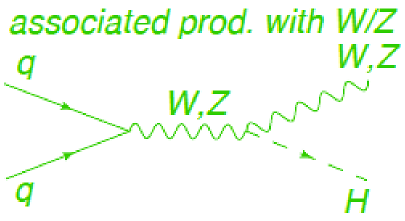
Higgs production


gluon fusion

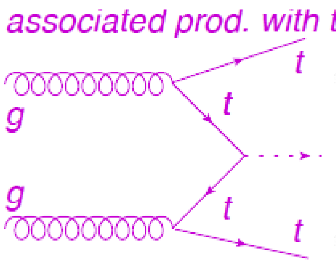
NNLO + NNLL QCD
+ NLO EW


vector boson fusion (VBF)

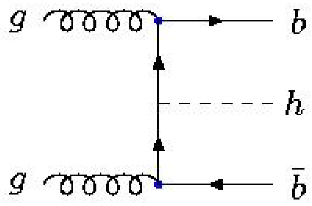
NNLO QCD + NLO EW


associated prod. with W/Z

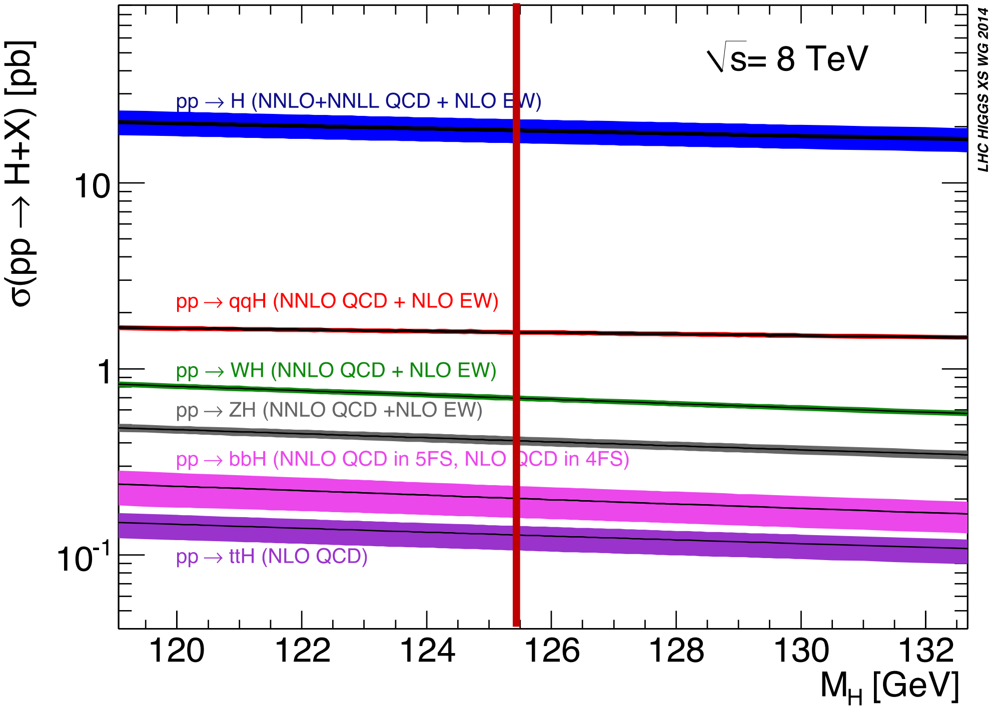
NNLO QCD + NLO EW


associated prod. with tt

NLO QCD



N(N)LO QCD

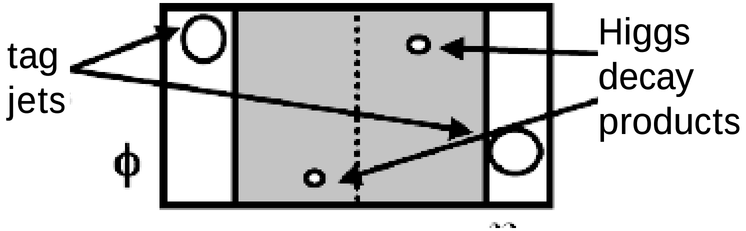


Gluon fusion process (ggF)

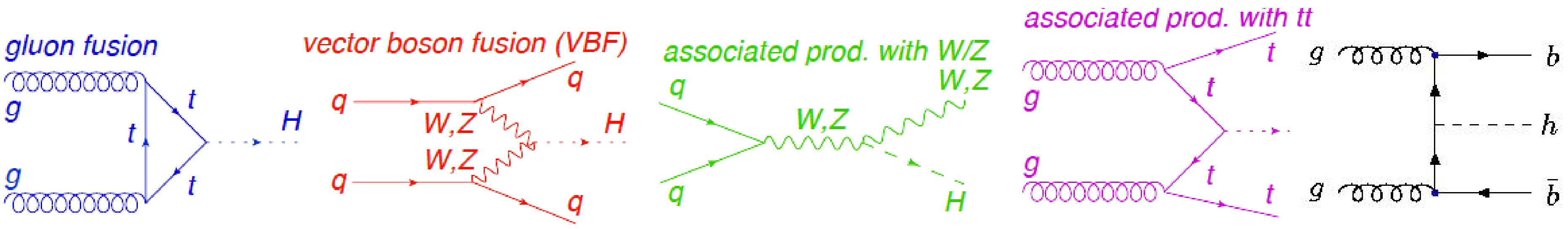
- Largest cross section : 19.15pb at 125.4 GeV
- Large theory uncertainty : ~10%

Vector boson fusion (VBF) process

- Second largest cross section : 1.57pb (±~2.7%)
- VBF topology : tagged by 2jets with large $\Delta\eta_{jj}$,m_{jj}



Higgs production



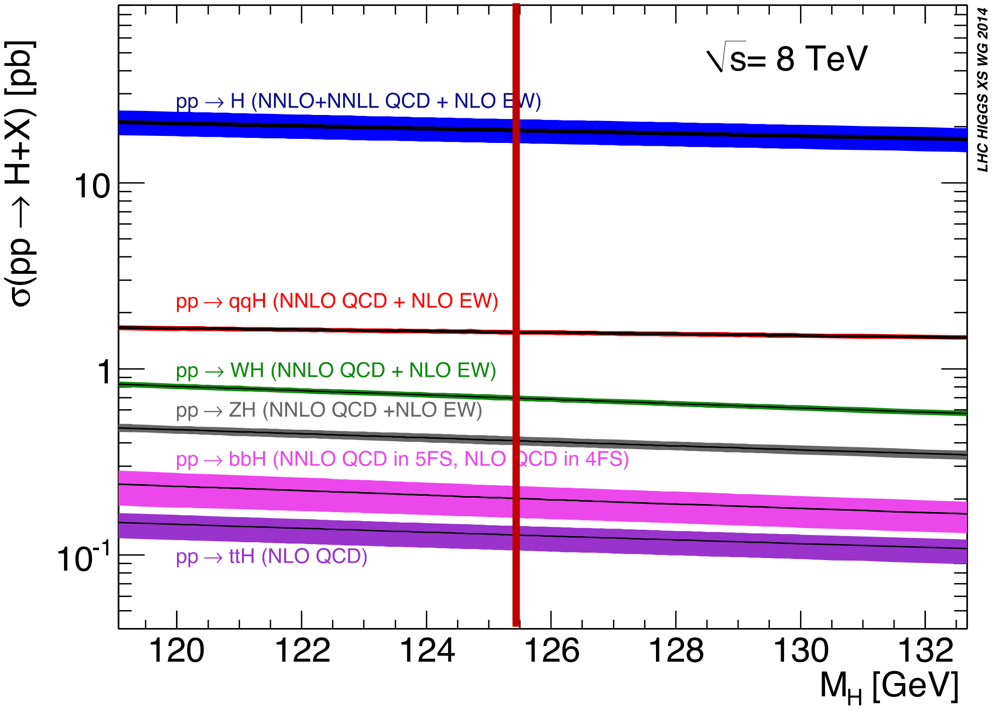
NNLO + NNLL QCD + NLO EW

NNLO QCD + NLO EW

NNLO QCD + NLO EW

NLO QCD

N(N)LO QCD



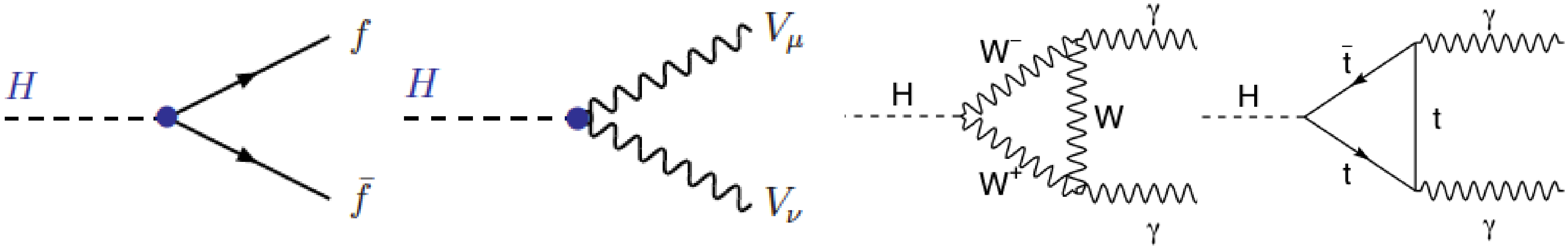
VH process

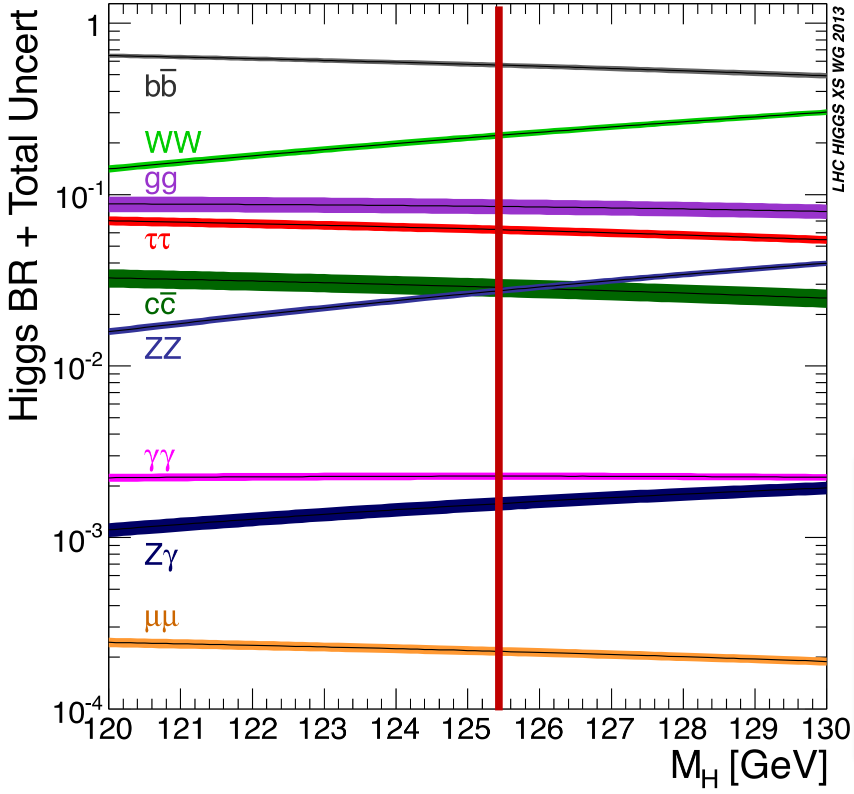
- Cross section: 0.70pb(WH),0.41pb(ZH)
- Associated W/Z helps triggering events, background suppression (lepton, MET)
- Main process for H→bb analysis

ttH process

- Cross section: 0.13pb
- Complex final state due to $t\bar{t}$ signature
- Provides an opportunity of direct y_t measurement

.. and decay





A 125.4 GeV Higgs makes all decay channels accessible.

- ✧ fermionic decays (bb, $\tau\tau$, $\mu\mu$)
- ✧ bosonic decays (WW, ZZ)
- ✧ loop modes ($\gamma\gamma$, $Z\gamma$)

Offering a rich field to precisely measure and test against SM predictions.

SM Branching ratio at 125.4 GeV

bb	WW	$\tau\tau$	ZZ	$\gamma\gamma$	$Z\gamma$	$\mu\mu$
57%	22%	6.3%	2.7%	0.23%	0.15%	0.02%

New

Higgs mass

arXiv:1406.3827
Phys. Rev. D. 90, 052004 (2014)

7 TeV with 4.5 fb^{-1} and 8 TeV with 20.3 fb^{-1}

Higgs boson mass
from combining
$H\to\gamma\gamma$ and $H\to ZZ^{*}\to 4\ell$

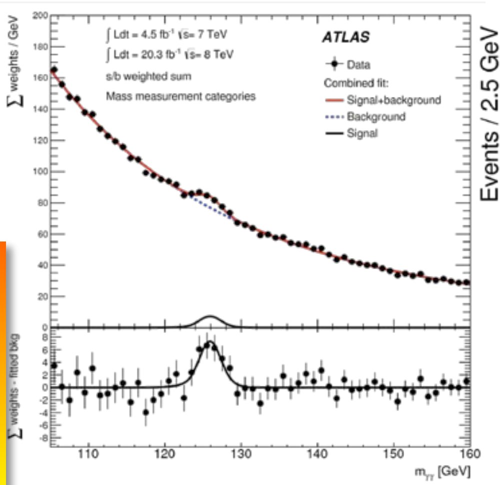
$m_{\gamma\gamma}$ = 125.98 ± 0.42$_{stat}$± 0.28$_{sys}$ GeV
m_{4l} = 124.51 ±0.52$_{stat}$± 0.06$_{sys}$ GeV
Δm_H = 1.47 ± 0.67$_{stat}$± 0.28$_{sys}$GeV
m_H = 125.36±0.37$_{stat}$±0.18$_{sys}$ GeV
P (ΔmH =0) = 4.8 % (1.98 σ)

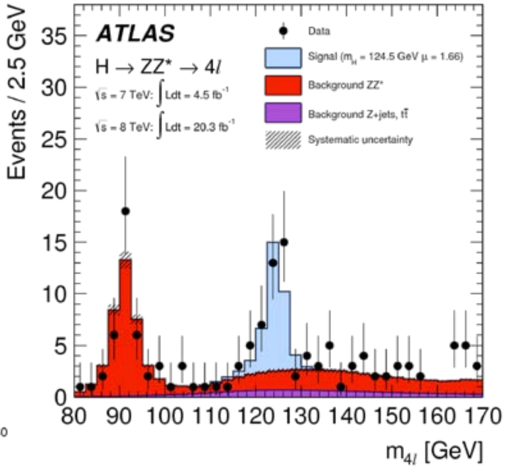
3 per mil precision on Higgs mass !

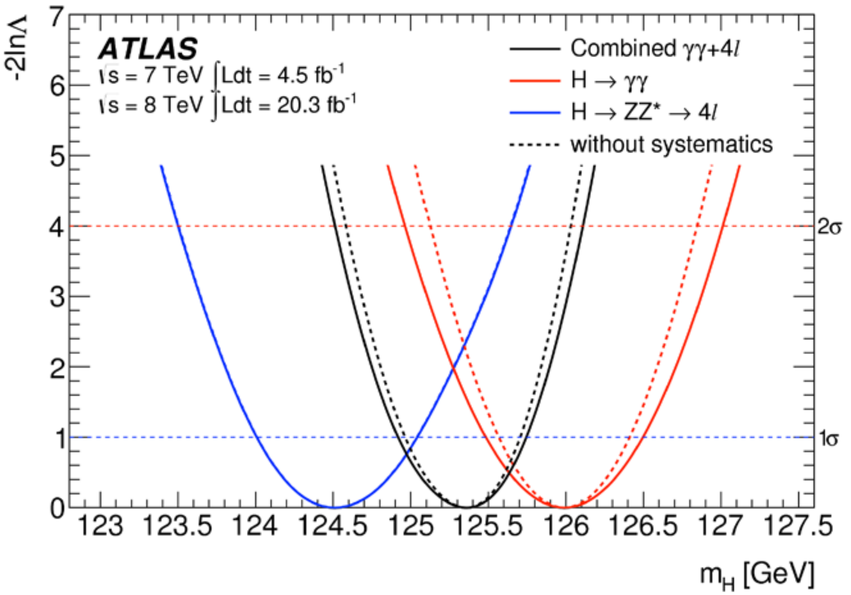
previous results published in Phys. Lett. B
Phys. Lett. B 726 (2013), pp. 88-119

$m_{\gamma\gamma}$ = 126.8 ± 0.24$_{stat}$± 0.68$_{sys}$ GeV
m_{4l} = 124.3 +0.6/-0.5$_{stat}$+0.5/-0.3$_{sys}$ GeV
m_H = 125.49 ± 0.24$_{stat}$+0.50/-0.58$_{sys}$ GeV
Δm_H = 2.3 +0.6/-0.7$_{stat}$± 0.6$_{sys}$ GeV
P (ΔmH =0) = 1.2 % (2.5 σ)

5 per mil precision







New

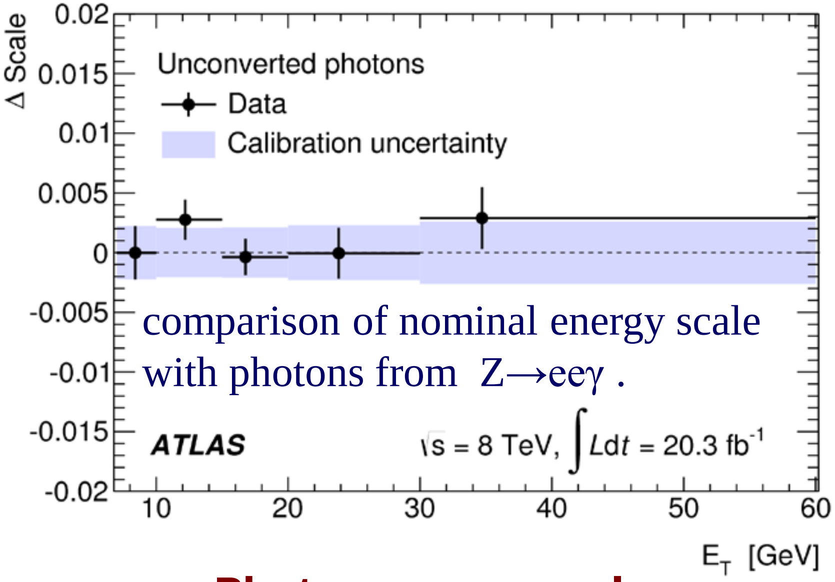
Higgs mass

arXiv:1406.3827
Phys. Rev. D. 90, 052004 (2014)

7 TeV with 4.5 fb^{-1} and 8 TeV with 20.3 fb^{-1}

Improvements in mass precision due to hard work in understanding detector performance, and material in front of EM calorimeter, with improved alignment and improved calibration

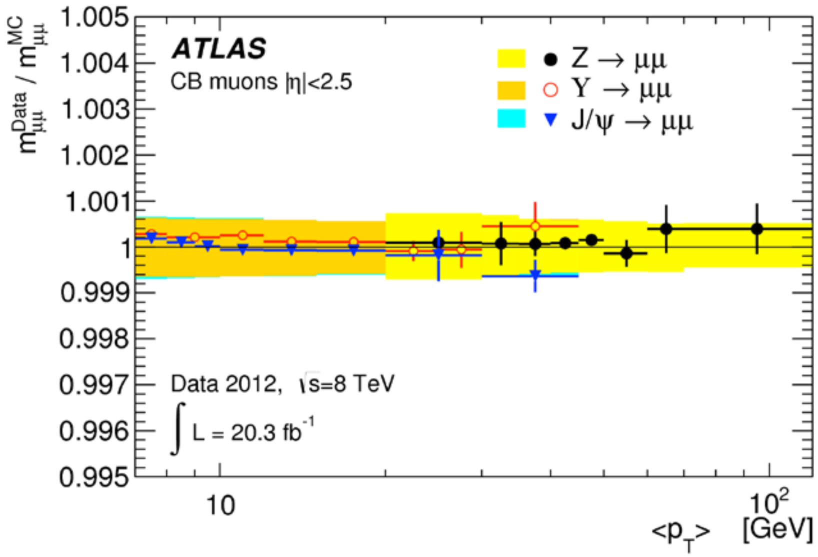
using Z, and J/ψ events with di-lepton final states, and including radiative decays $Z \rightarrow ee\gamma$.



comparison of nominal energy scale with photons from $Z \rightarrow ee\gamma$.

Photon energy scale

~0.2-0.3% up to E_T = 60 GeV



Muon momentum scale

< 0.1% up to p_T = 100 GeV

Main systematics still driven by the EM calorimeter per cell linearity and understanding of detector material in front of it.

Higgs properties

Precise knowledge of the Higgs properties allow to decide whether this is SM or beyond.

New

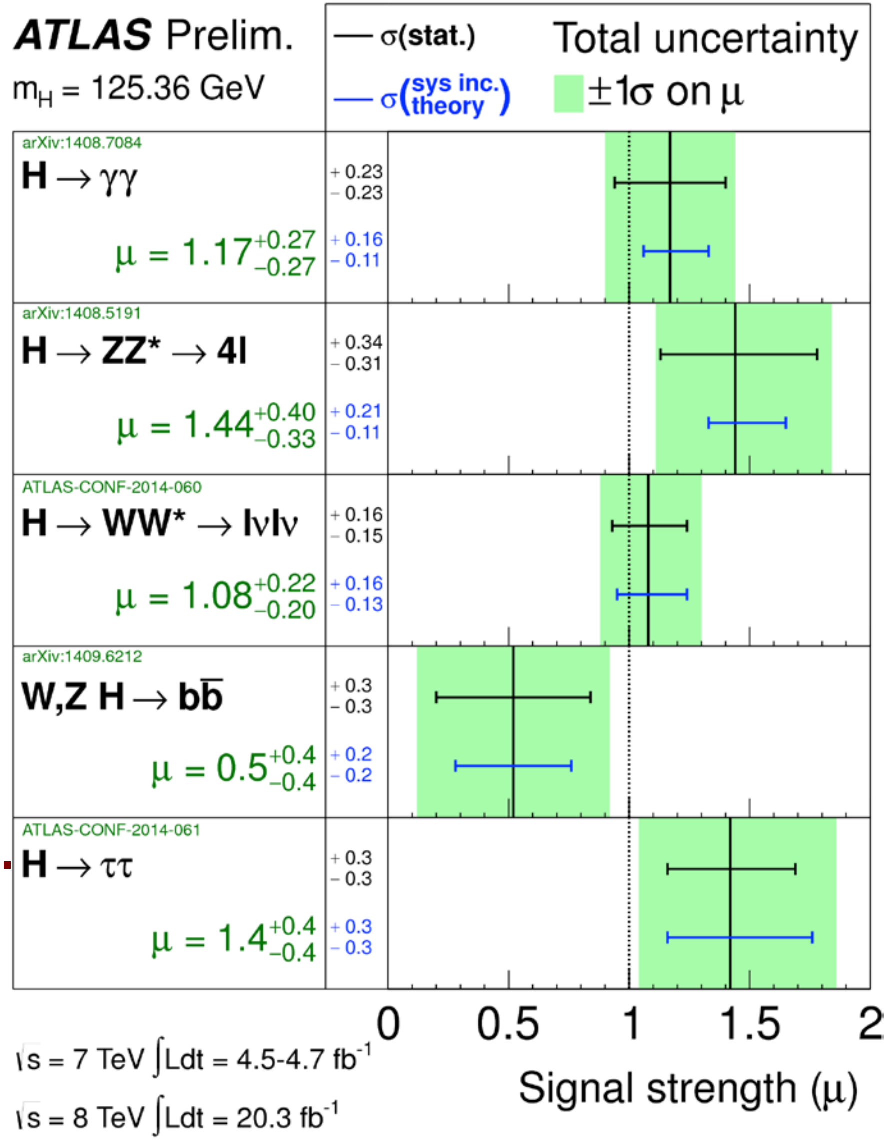
Recent updates on Higgs properties:		
x-sec and couplings $H\to 4\ell$	21 Nov 2014	accepted in PRD [arXiv:1408.5191]
x-sec and couplings $H\to\gamma\gamma$	07 Nov 2014	accepted in PRD [arXiv:1408.7084]
observation of $H\to WW^*$	13 Oct 2014	ATLAS-CONF-2014-060
evidence for $H\to\tau\tau$	07 Oct 2014	ATLAS-CONF-2014-061
fiducial and differential x-sec of $H\to 4\ell$	24 Sep 2014	Phys. Lett. B 738 (2014) 234-253 [arXiv:1408.3226]

Higgs production – signal strengths

Higgs decays measured by ATLAS.

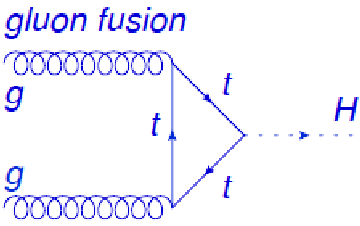
- ✧ fermionic decays,
- ✧ bosonic decays,
- ✧ and loop decays all seen.

Higgs couples to fermions and to bosons.
→ need to extract couplings

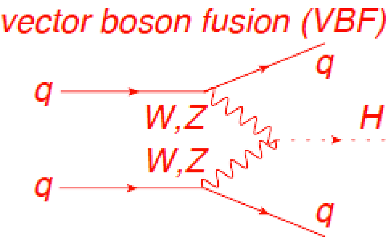


Signal strengths for a 125.36 GeV Higgs.
Within ~1σ within SM prediction.

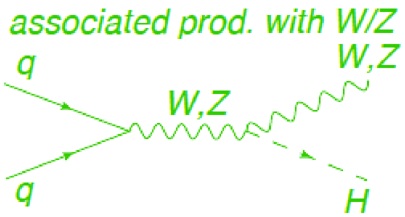
Higgs couplings


gluon fusion

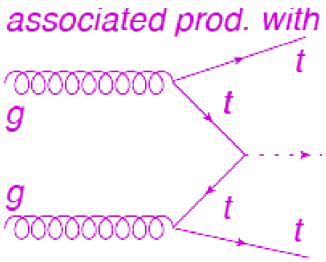
NNLO + NNLL QCD
+ NLO EW


vector boson fusion (VBF)

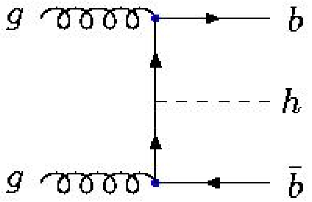
NNLO QCD + NLO EW


associated prod. with W/Z

NNLO QCD + NLO EW


associated prod. with tt

NLO QCD



N(N)LO QCD

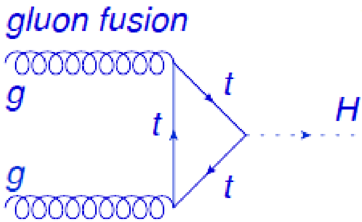
Higgs production depend on fermionic couplings (ggF, ttH, bbH),
and bosonic couplings (VBF, VH)

All measured production cross sections measure indeed σ×BR, the production cross section times the branching ratio of the selected final state.

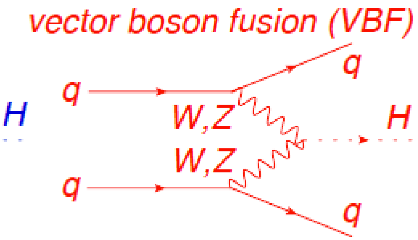
Need to categorize events with enriched samples of ggF, VBF, or VH, according to the
- presence of high mass tagging jets (VBF)
- presence of low mass jets (VH)
- presence of extra lepton (VH)
- none of the above (ggF)

Measuring the event yields in these categories allows to extract the fermionic coupling and the bosonic couplings separately.

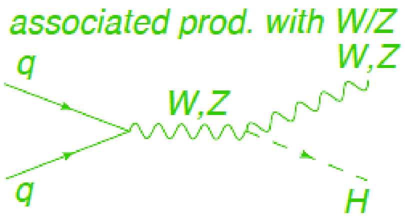
Higgs couplings



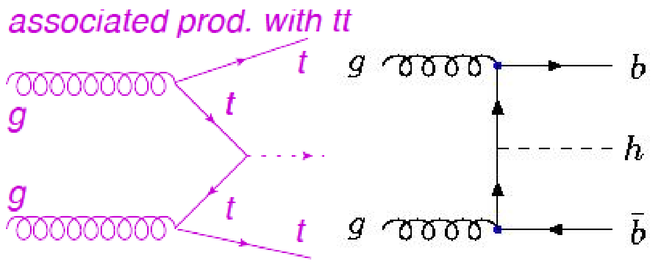
NNLO + NNLL QCD
+ NLO EW



NNLO QCD + NLO EW



NNLO QCD + NLO EW



NLO QCD

N(N)LO QCD

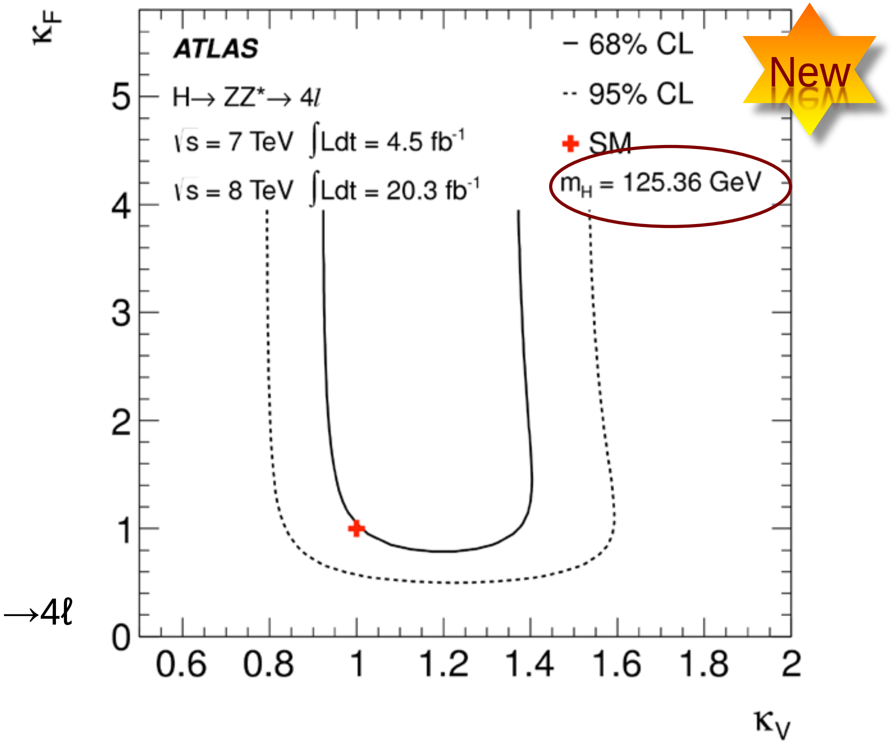
κ_F is the with the SM value normalized fermionic coupling. For SM fermionic coupling: κ_F=1

κ_V is the with the SM value normalized bosonic coupling. For SM bosonic coupling: κ_V=1

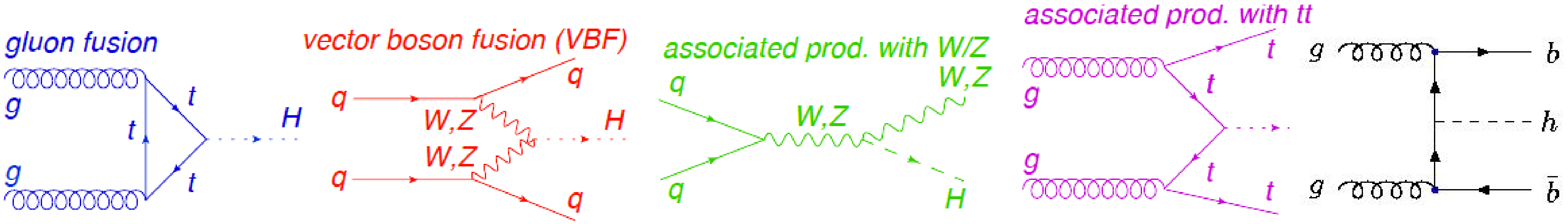
Likelihood contours at 68% CL (solid line) and 95% CL (dashed line) in the κ_V - κ_F plane.

SM expected value directly on 95% contour.

x-sec and couplings $H\rightarrow 4\ell$
21 Nov 2014
accepted in PRD
arXiv:1408.5191



Higgs couplings



NNLO + NNLL QCD
+ NLO EW

NNLO QCD + NLO EW

NNLO QCD + NLO EW

NLO QCD

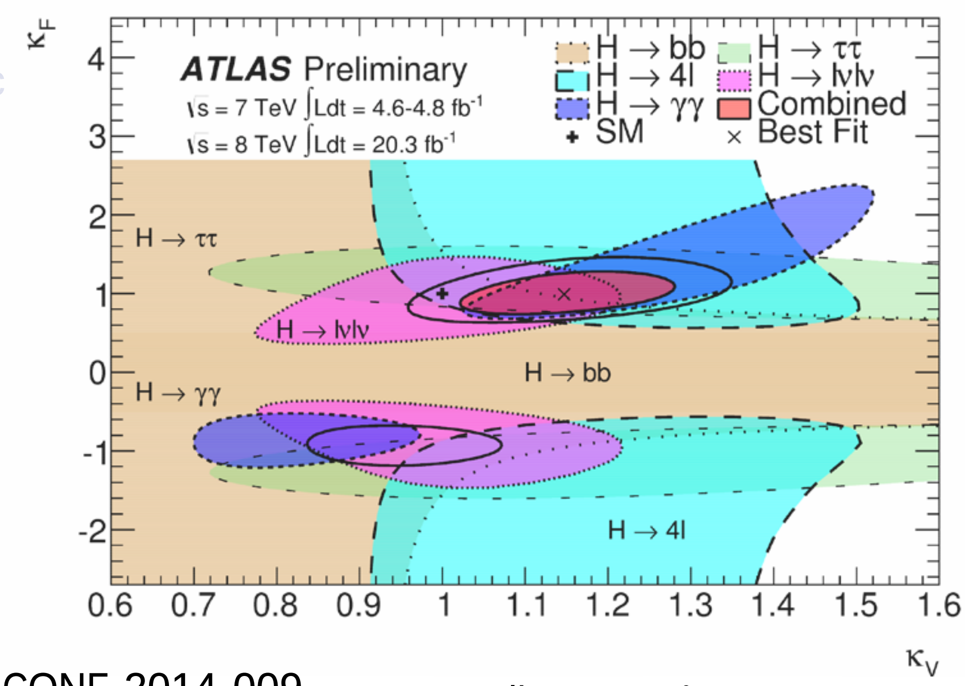
N(N)LO QCD

κ_F is the with the SM value normalized fermionic coupling. For SM fermionic coupling: $\kappa_F=1$

κ_V is the with the SM value normalized bosonic coupling. For SM bosonic coupling: $\kappa_V=1$

And showing the full picture form an earlier combined fit.

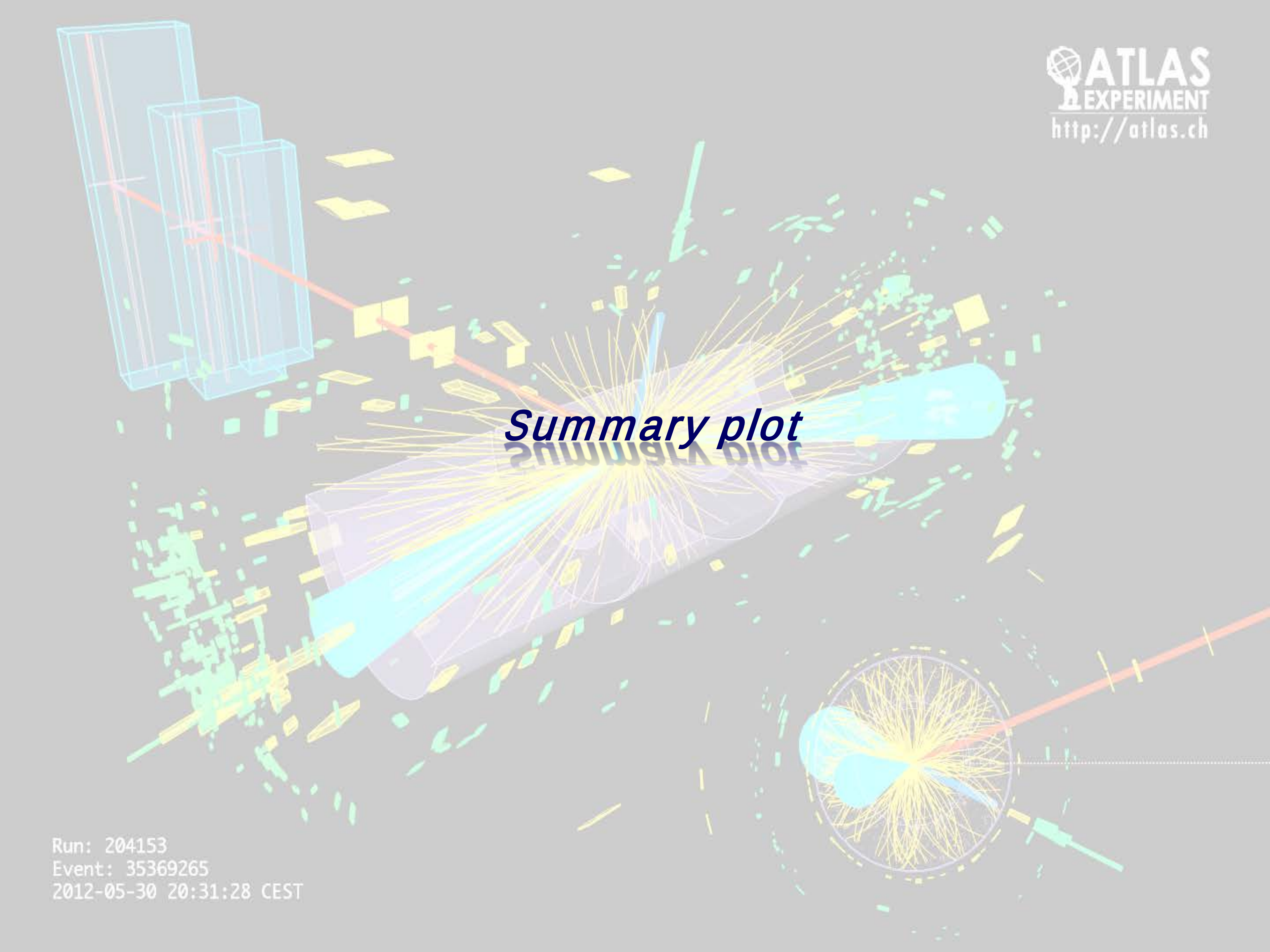
Fermionic and bosonic couplings agree with SM.



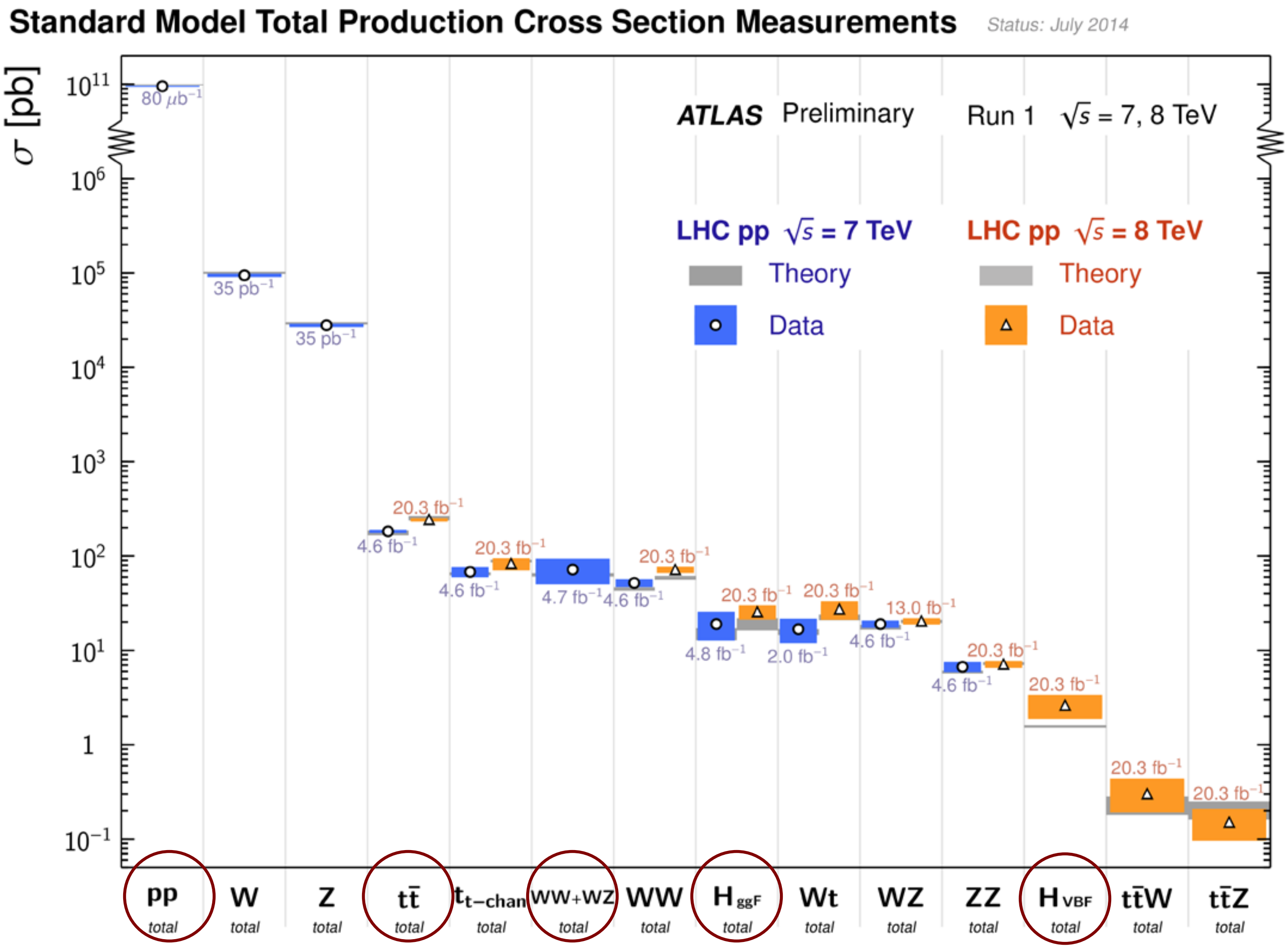
ATLAS-CONF-2014-009
March 2014

couplings H→4ℓ

Summary plot



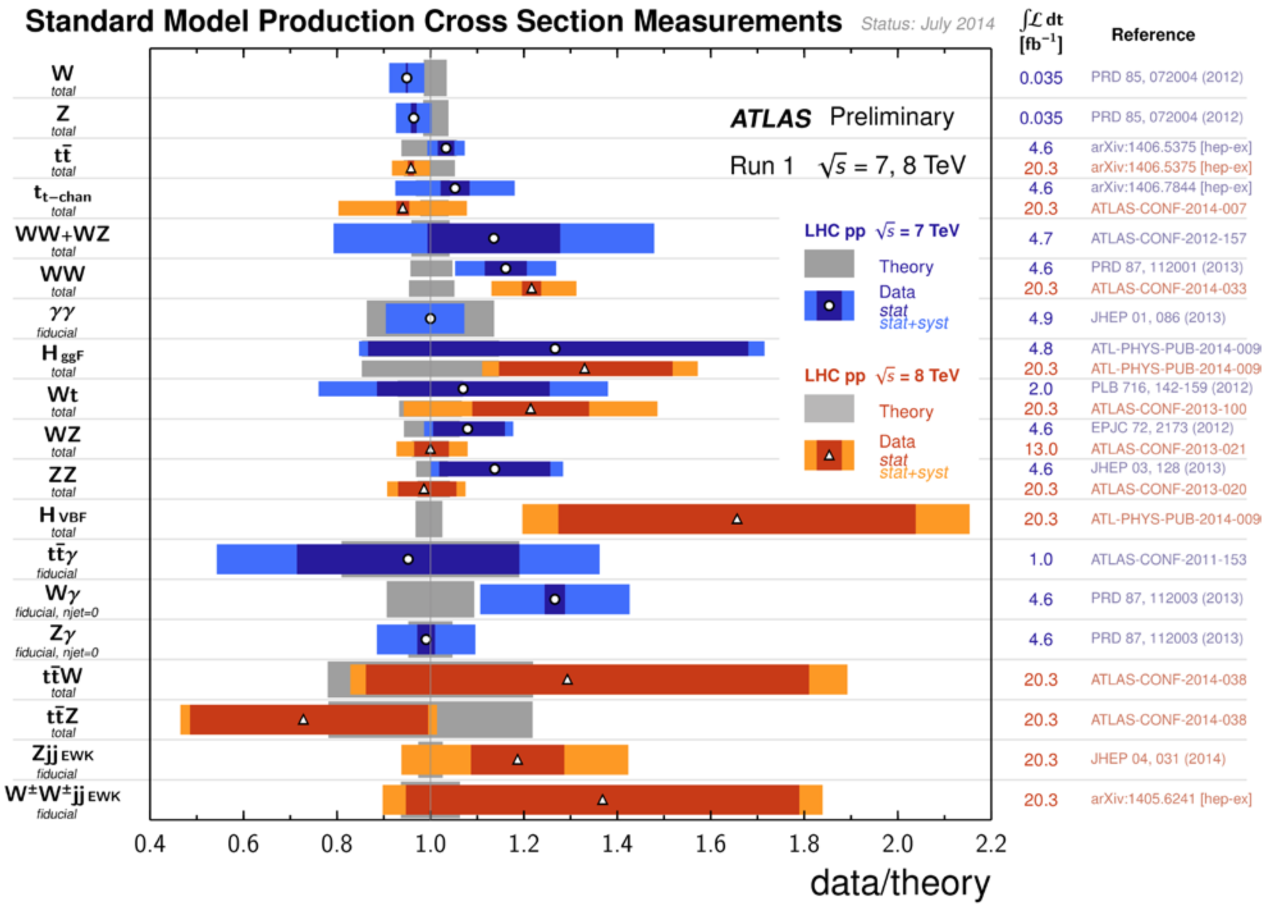
Summary of production cross section measurements



Higgs entered the SM summary plots in ATLAS.

Precise measurements of cross sections (fiducial, total, differential, differential unfolded) and their comparison with SM predications are precise tests of the physics at the energy frontier. They are the of utmost importance for searches beyond the SM.

Summary of production cross section measurements

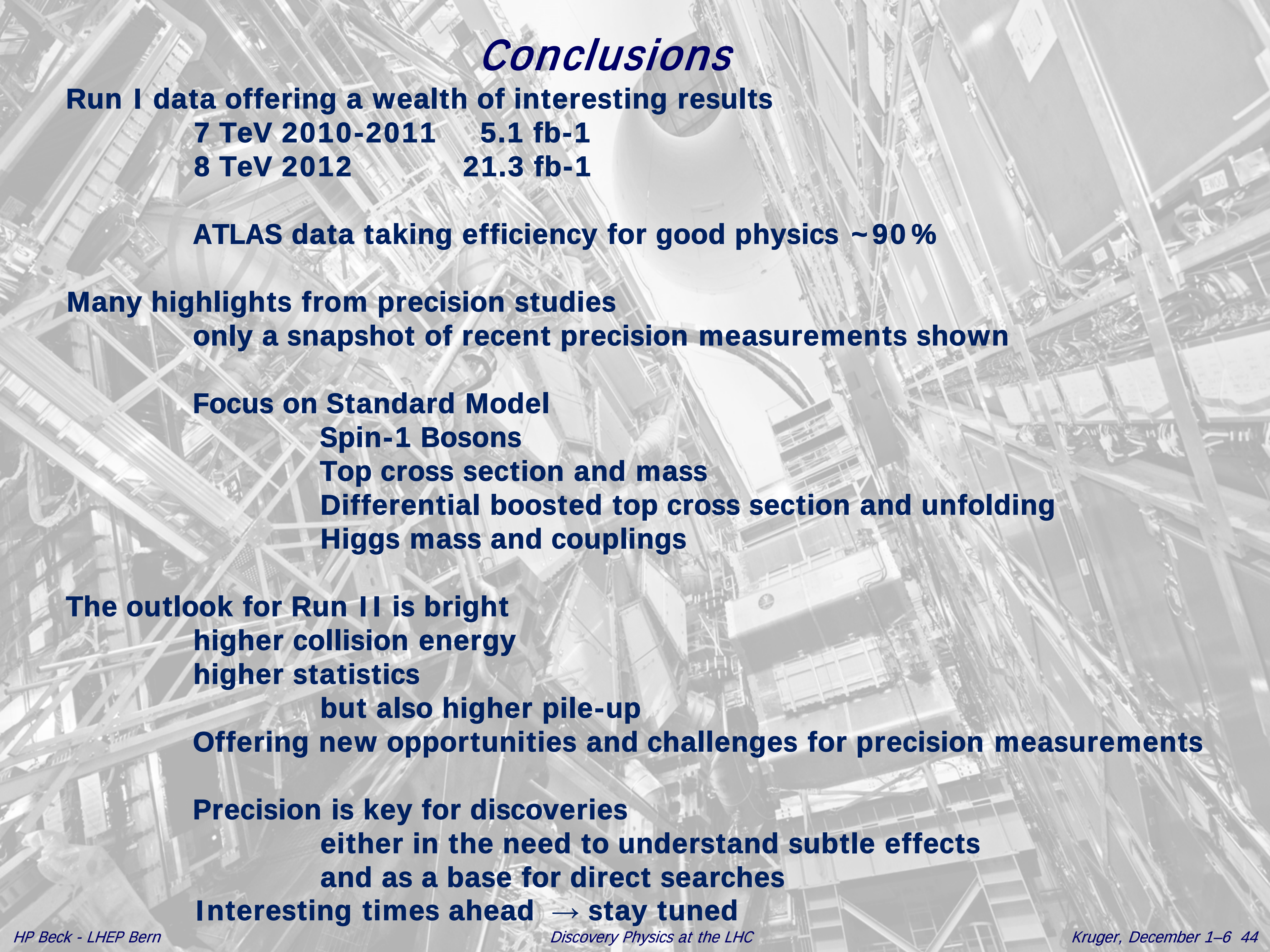

Standard Model Production Cross Section Measurements

	$\int\mathcal{L}\,dt$ [fb^{-1}]	Reference
W *total*	0.035	PRD 85, 072004 (2012)
Z *total*	0.035	PRD 85, 072004 (2012)
$t\bar{t}$ *total*	4.6 20.3	arXiv:1406.5375 [hep-ex] arXiv:1406.5375 [hep-ex]
$t_{t\text{-chan}}$ *total*	4.6 20.3	arXiv:1406.7844 [hep-ex] ATLAS-CONF-2014-007
WW+WZ *total*	4.7	ATLAS-CONF-2012-157
WW *total*	4.6 20.3	PRD 87, 112001 (2013) ATLAS-CONF-2014-033
$\gamma\gamma$ *fiducial*	4.9	JHEP 01, 086 (2013)
H ggF *total*	4.8 20.3	ATL-PHYS-PUB-2014-009 ATL-PHYS-PUB-2014-009
Wt *total*	2.0 20.3	PLB 716, 142-159 (2012) ATLAS-CONF-2013-100
WZ *total*	4.6 13.0	EPJC 72, 2173 (2012) ATLAS-CONF-2013-021
ZZ *total*	4.6 20.3	JHEP 03, 128 (2013) ATLAS-CONF-2013-020
H VBF *total*	20.3	ATL-PHYS-PUB-2014-009
$t\bar{t}\gamma$ *fiducial*	1.0	ATLAS-CONF-2011-153
$W\gamma$ *fiducial, njet=0*	4.6	PRD 87, 112003 (2013)
$Z\gamma$ *fiducial, njet=0*	4.6	PRD 87, 112003 (2013)
$t\bar{t}W$ *total*	20.3	ATLAS-CONF-2014-038
$t\bar{t}Z$ *total*	20.3	ATLAS-CONF-2014-038
Zjj EWK *fiducial*	20.3	JHEP 04, 031 (2014)
$W^{\pm}W^{\pm}jj$ EWK *fiducial*	20.3	arXiv:1405.6241 [hep-ex]

Comparing precise measurements with SM NLO + NNLO pQCD look mostly OK.

NLO+NNLO+resummation of soft gluon and understanding of different renormalization scales with every event necessary.

Stay tuned for Run II



Conclusions

Run I data offering a wealth of interesting results
- **7 TeV 2010-2011 5.1 fb-1**
- **8 TeV 2012 21.3 fb-1**

- **ATLAS data taking efficiency for good physics ~90%**

Many highlights from precision studies
- **only a snapshot of recent precision measurements shown**

- **Focus on Standard Model**
  - **Spin-1 Bosons**
  - **Top cross section and mass**
  - **Differential boosted top cross section and unfolding**
  - **Higgs mass and couplings**

The outlook for Run II is bright
- **higher collision energy**
- **higher statistics**
  - **but also higher pile-up**
- **Offering new opportunities and challenges for precision measurements**

- **Precision is key for discoveries**
  - **either in the need to understand subtle effects**
  - **and as a base for direct searches**
- **Interesting times ahead → stay tuned**

Back-up

top mass from cross section measurement

Theoretical prediction of the cross-section depends on m_{top} **pole mass**

(~ a free particle, of most interest in EW fit)

Differs from the ‘Monte Carlo’ mass measured in direct reconstruction of $t\bar{t}$ events by O(1 GeV) – interesting to infer it from the measured cross-section

NNLO+NNLL calculation depends on m_{top}, which can be parameterized as:

$$\sigma_{t\bar{t}}\left(m_t\right) = \sigma_{t\bar{t}}\left(m_t^{\mathrm{ref}}\right)^4 \left(1 + a_1 \frac{m_t - m_t^{\mathrm{ref}}}{m_t^{\mathrm{ref}}} + a_2 \left(\frac{m_t - m_t^{\mathrm{ref}}}{m_t^{\mathrm{ref}}}\right)^2\right)$$

in addition, uncertainties due to PDFs, α_s, QCD scale

Experimental result also depends on **assumed** m_{top} value:

For calculating the pre-selection efficiency $\varepsilon_{e\mu}$ for $t\bar{t}$ events, and for the cross-section and acceptance of *Wt* background

This dependence is modest: $d\sigma/dm_{top} = -0.28 \pm 0.03$ %/GeV

Operation and performance Overview

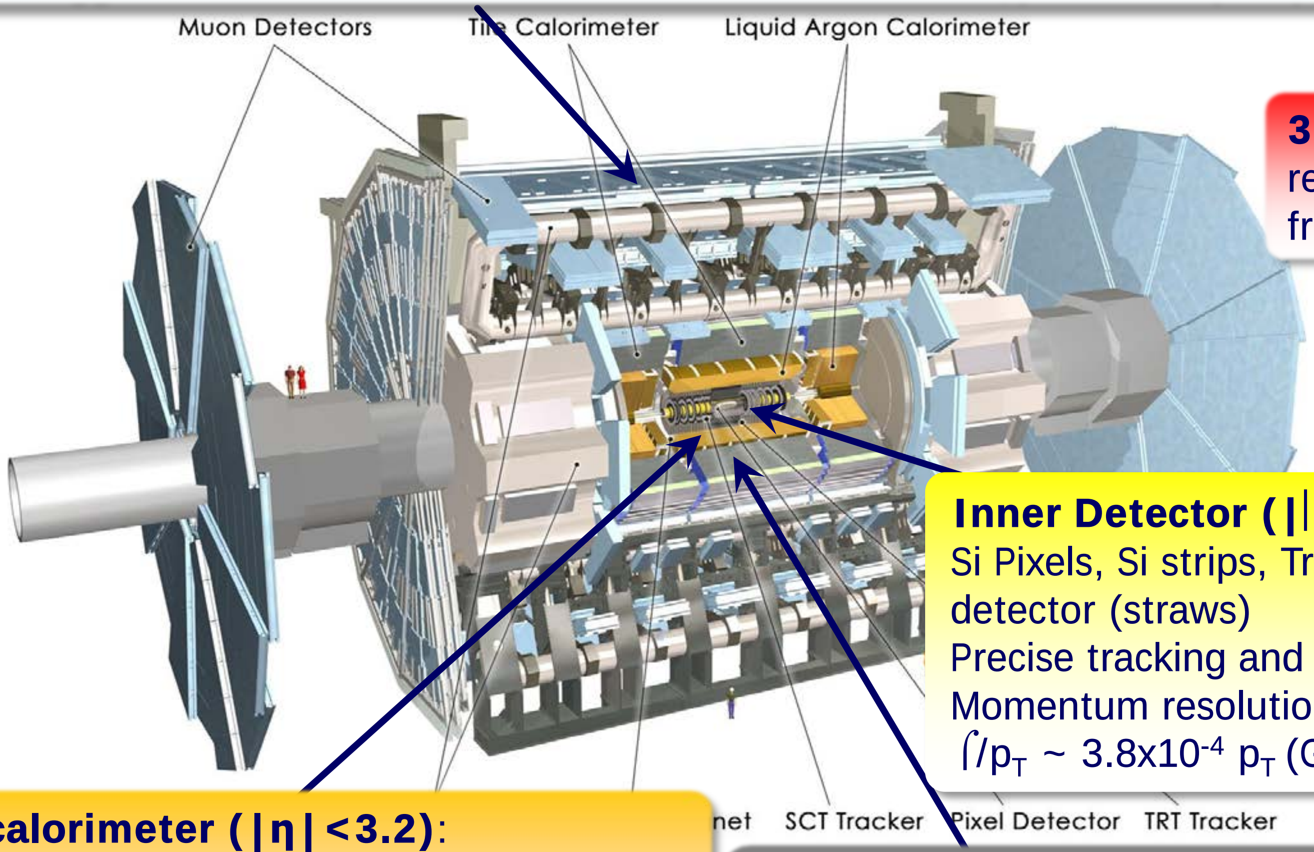
Run I

7 TeV 2010-2011 5.1 fb^{-1}

8 TeV 2012 21.3 fb^{-1}

The ATLAS Detector

Muon Spectrometer ($|\eta|<2.7$): air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution $\sigma/p < 10\%$ up to $p_\perp \sim 1$ TeV



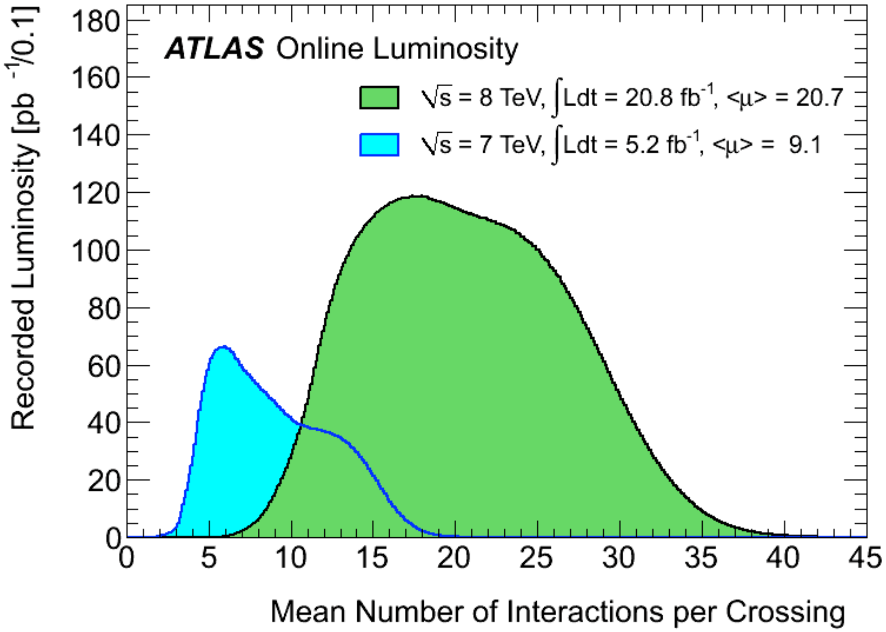
3-level trigger
reducing the rate
from 40 MHz to ~200 Hz

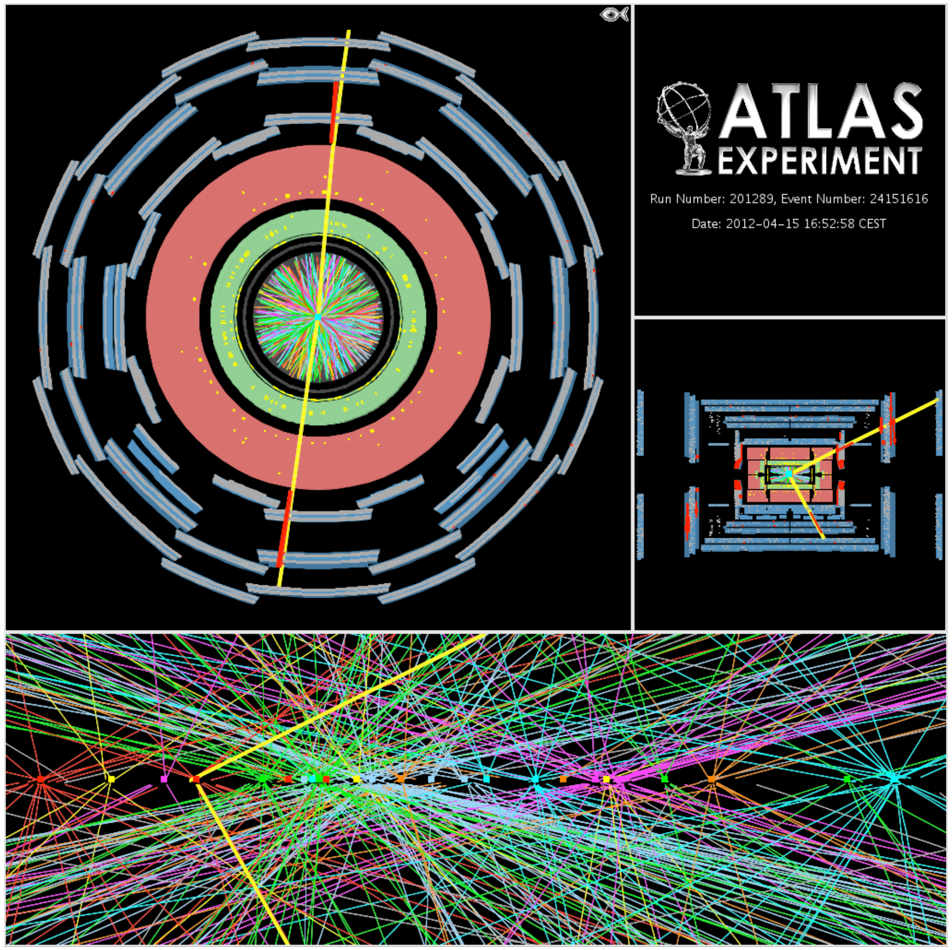
Inner Detector (| |<2.5, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws)
Precise tracking and vertexing, e/□ separation
Momentum resolution:
$\int/p_T \sim 3.8\mathrm{x}10^{-4}\, p_T\,(\mathrm{GeV}) \oplus 0.015$

EM calorimeter ($|\eta|<3.2$):
Pb-LAr Accordion
e/© trigger, identification and measurement
E-resolution: $\int/E \sim 10\%/\sqrt{E}$

HAD calorimetry ($|\eta|<5$):
segmentation, hermeticity, Fe/scintillator Tiles (central), Cu/W-LAr (fwd), Trigger and measurement of jets and missing E_T
E-resolution: $\int/E \sim 50\%/\sqrt{E} \oplus 0.03$

Pile-up



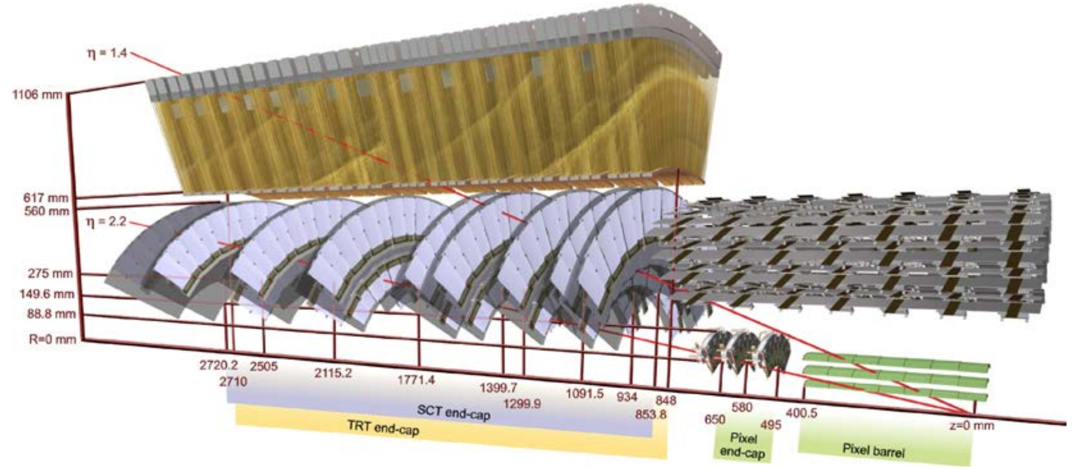


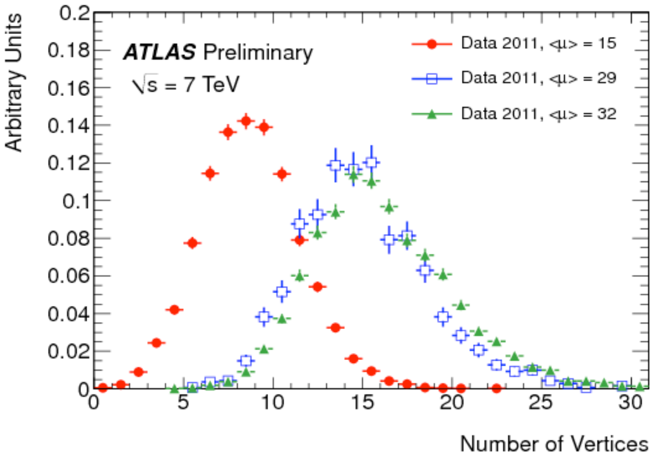
Pile-up poses a challenge for precision physics, but learned how to cope with.

Need good high quality tracking, finding the hard interaction primary vertex and ignore tracks, energy deposits from pile-up events...

Z→μμ event with 25 pile-up interactions

Tracking with pile-up

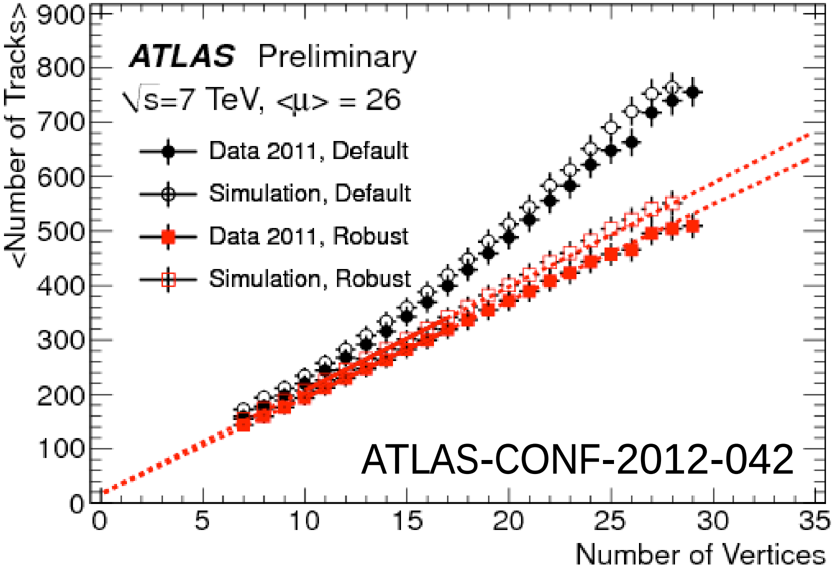




ATLAS-CONF-2012-042

The number of reconstructed vertices with the robust track requirements in data containing different amounts of pile-up

- Efficiency ~95%
- Resolution (vertices with 70 tracks)
  - transverse: ~30 μm
  - longitudinal: ~50 μm



The average number of tracks per event as a function of the number of vertices

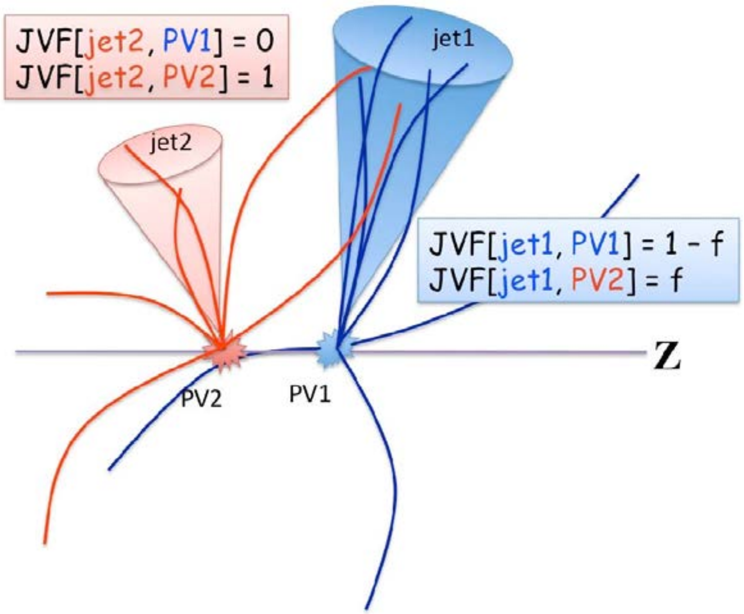
With robust tracking, the average number of tracks grows linearly with the number of vertices per event.

Removing pile-up jets: Jet Vertex Fraction

For every jet and every primary vertex a jet vertex fraction qualifier is defined.

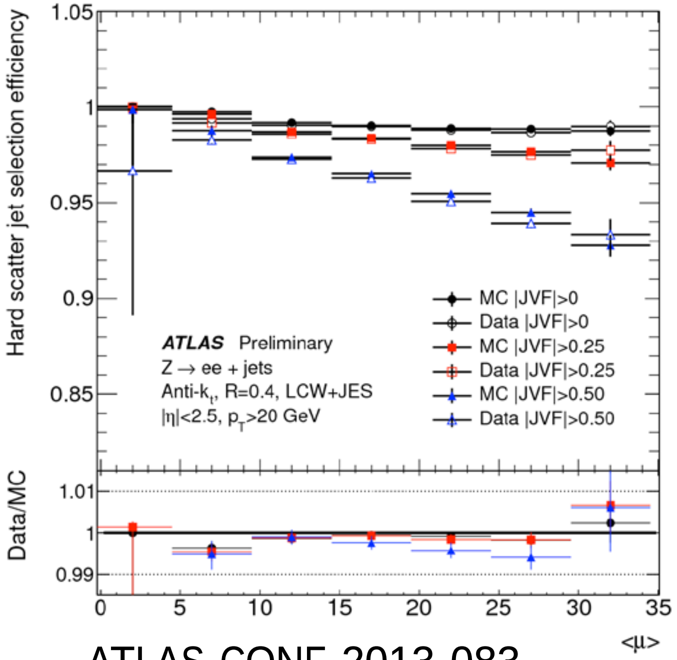
$$\mathrm{JVF}\left[\mathrm{jet}_j, \mathrm{PV}_k\right] = \frac{\sum_{\mathrm{tracks}\, i \in \mathrm{PV}_k} p_{\mathrm{T},i}}{\sum_{\mathrm{tracks}\, i \in \mathrm{jet}_j} p_{\mathrm{T},i}}$$

JVF measures the fraction of track pT in a jet j coming from primary vertex k.



The hard scatter primary vertex is defined as the one with the highest

$$\sum_{\mathrm{tracks}\, i \in \mathrm{jet}_j} p_{\mathrm{T},i}^2$$



ATLAS-CONF-2013-083

Jet selection efficiency in Z->ee events as a function of <mu>, the average pile-up.

Pile-up and missing ET

Etmiss measured from jets, electrons, photons, taus, muons and 'Soft term'.

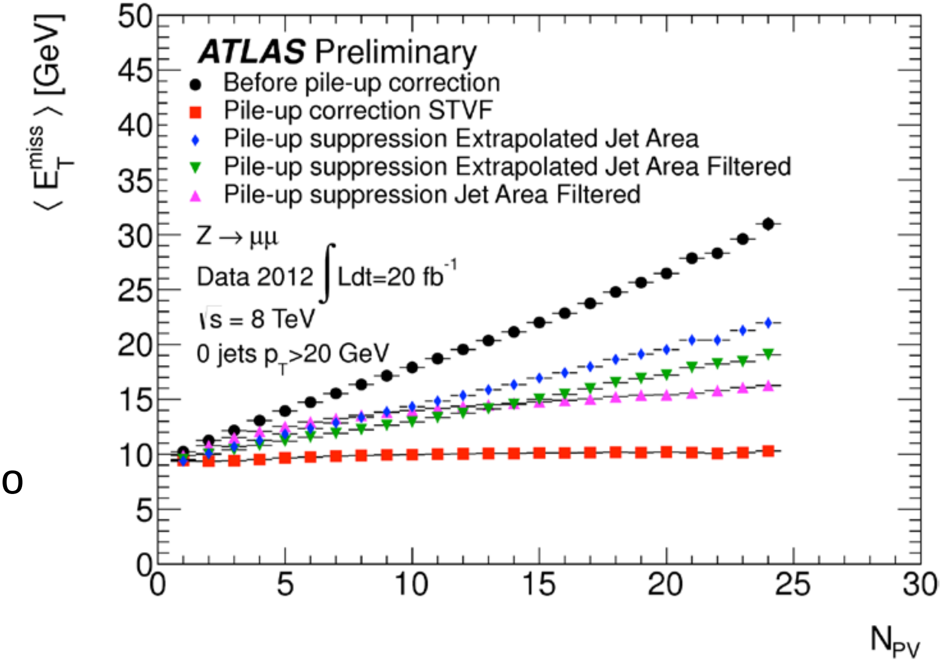
$$E_{\mathrm{T}}^{\mathrm{miss}} = \sqrt{(E_x^{\mathrm{miss}})^2 + (E_y^{\mathrm{miss}})^2}$$

$$E_{x(y)}^{\mathrm{miss}} = -\left(E_{x(y)}^{\mathrm{jets}} + E_{x(y)}^{e} + E_{x(y)}^{\gamma} + E_{x(y)}^{\tau} + E_{x(y)}^{\mu} + E_{x(y)}^{\mathrm{Soft\ Term}}\right)$$

'Soft term' carries the strongest pile-up dependence – all other can be associated to the hard scatter primary vertex.

A 'soft term' correction factor based on a measurement of the overall pile-up activity in an event improves the Etmiss:

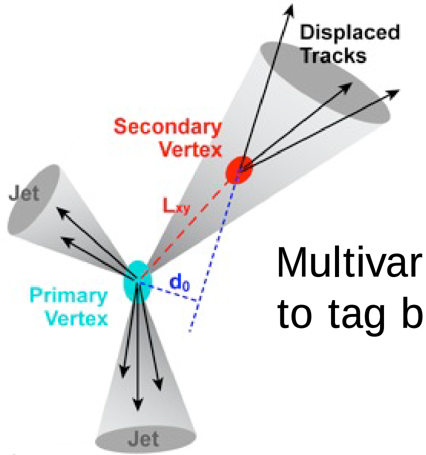
$$\mathrm{STVF} = \frac{\sum_{\mathrm{i} \in \mathrm{PV0}} \mathrm{p_T^{track\ i}}}{\sum_{\mathrm{j}} \mathrm{p_T^{track\ j}}}$$



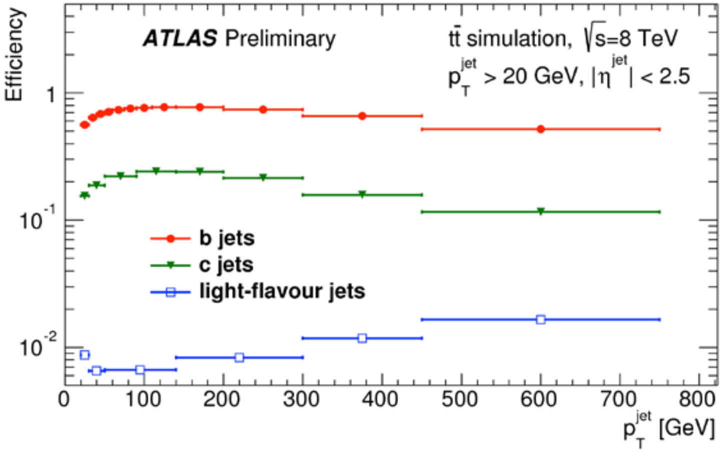
ATLAS-CONF-2014-019

The dependence of the average reconstructed transverse momentum ⟨ETmiss⟩ on NPV, for the exclusive hard scatter Z→μμ data samples.

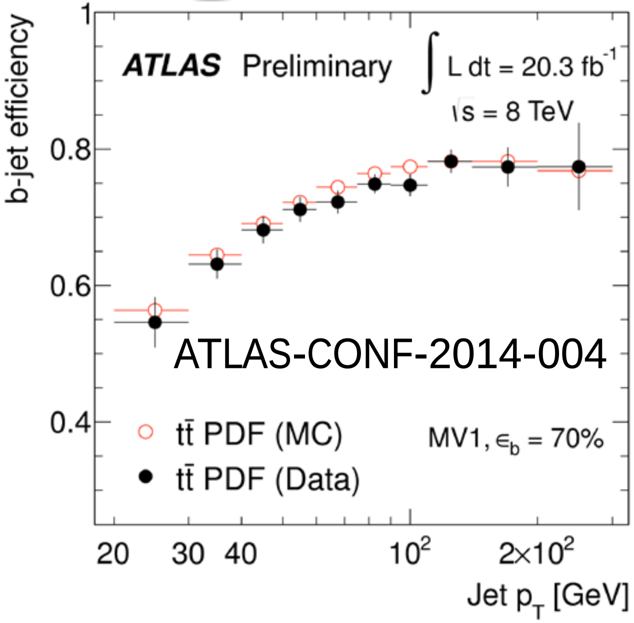
jet tagging



Multivariate techniques used to tag b-jets

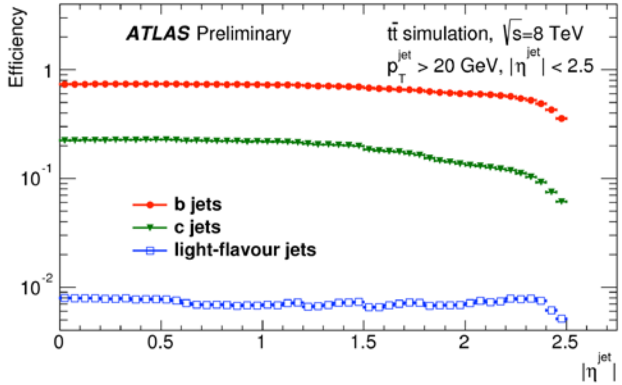


Tagging efficiencies for b, c, and light-flavour jets, at the 70% b-jet efficiency working point, as a function of jet pt and jet eta.



ATLAS-CONF-2014-004

b-jet tagging efficiencies at the 70% b-jet efficiency working point for $t\bar{t}$ events in data and MC.



ATLAS-CONF-2014-046