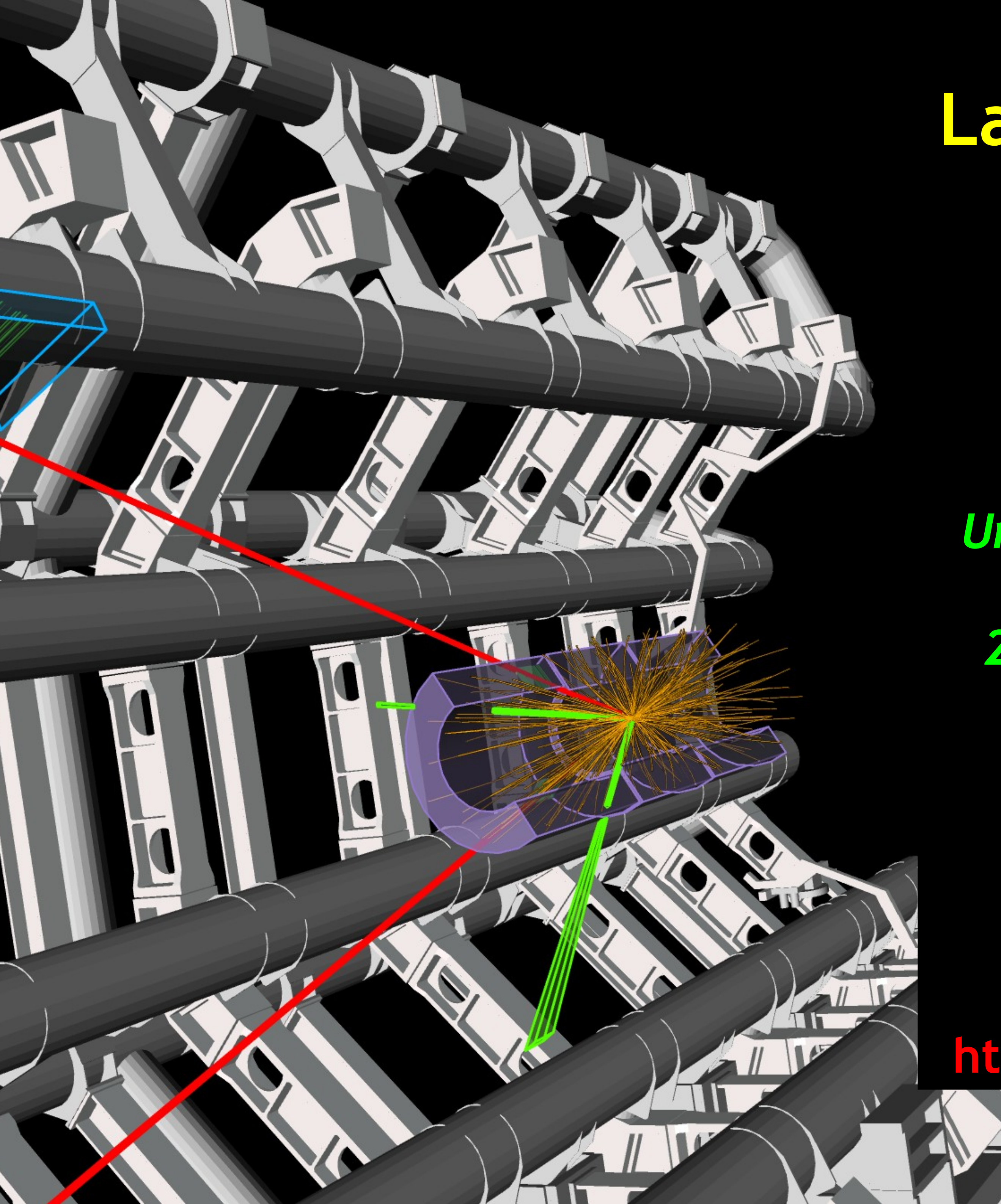


Latest from ATLAS

At the end of an Uncommon Year

Dave Charlton

University of Birmingham

2012 Annual UK Theory Meeting

Durham, 17 December 2012

http://cern.ch/atlasresults

Outline

Performance of the LHC and ATLAS

Measurements

- QCD processes
- Dibosons
- Top

Beyond the Standard Model

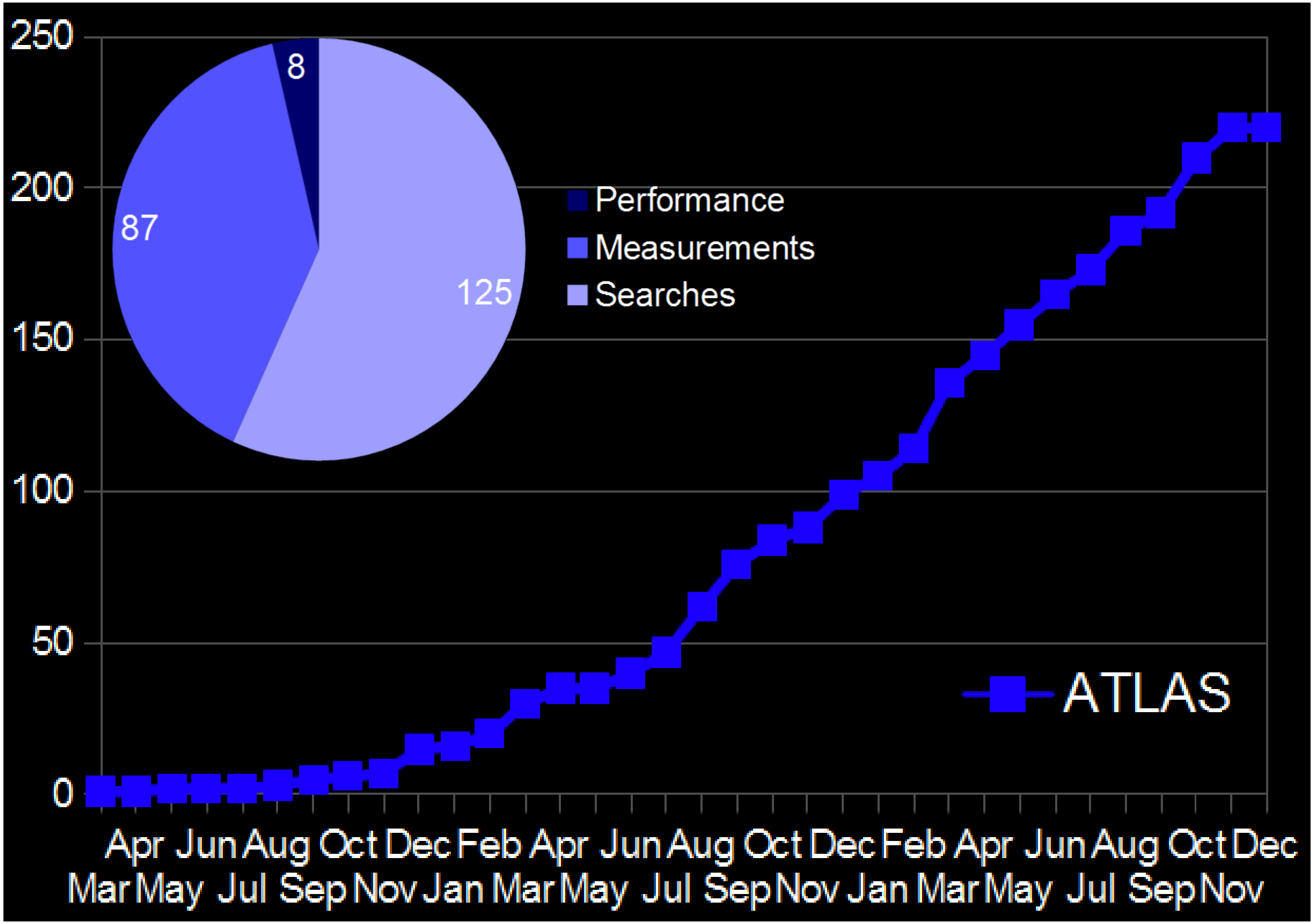
- Exotica
- SUSY

The new boson

- A retrospective from July
- What we've learned since

Some Statistics

Number of publications vs time

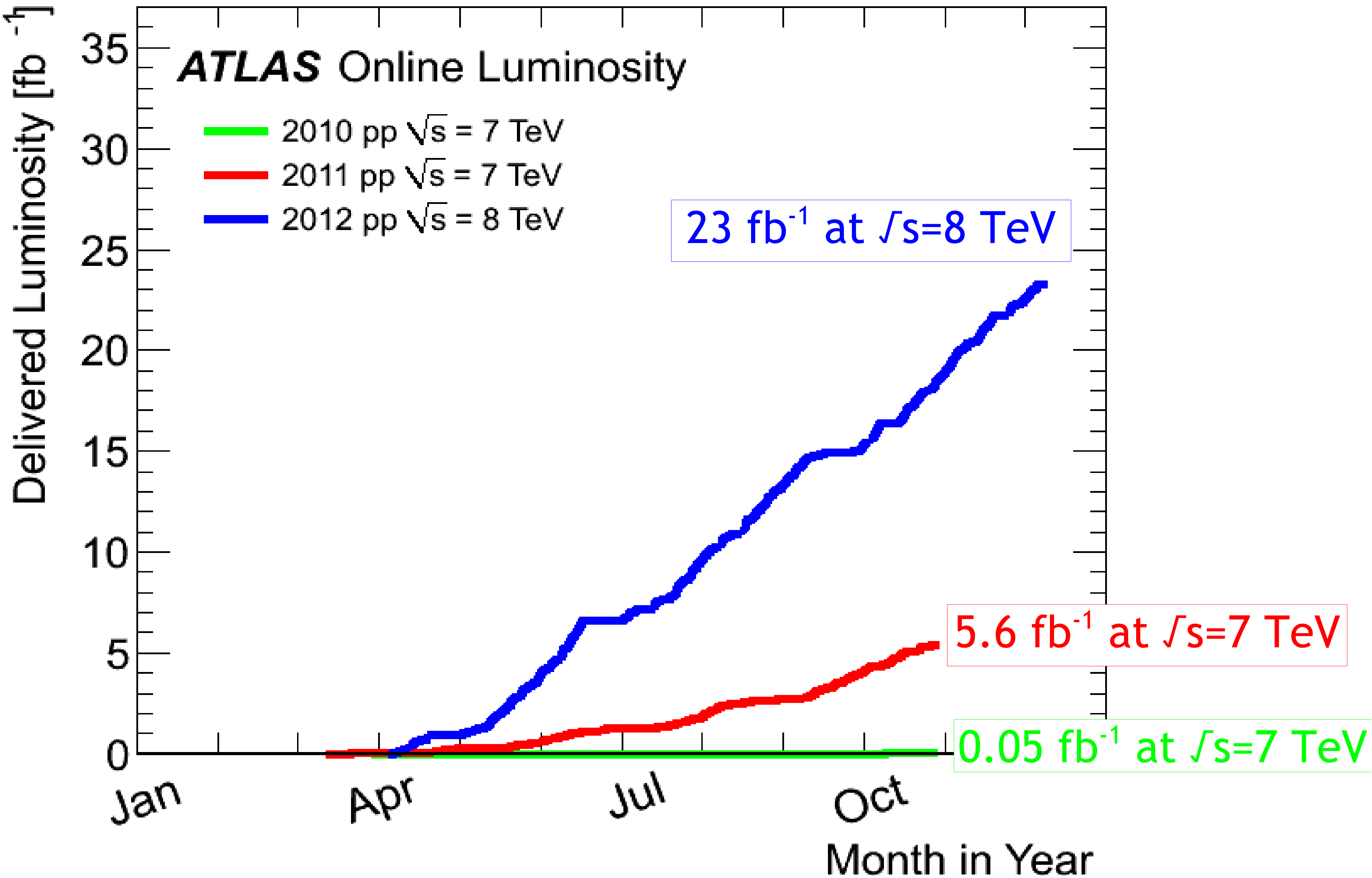


To date ATLAS has submitted 225 papers with collision data
...and 435 conference notes with preliminary results

I can only mention a rather small subset...!

Performance

Recorded Data over the Three Years of "Run-1"

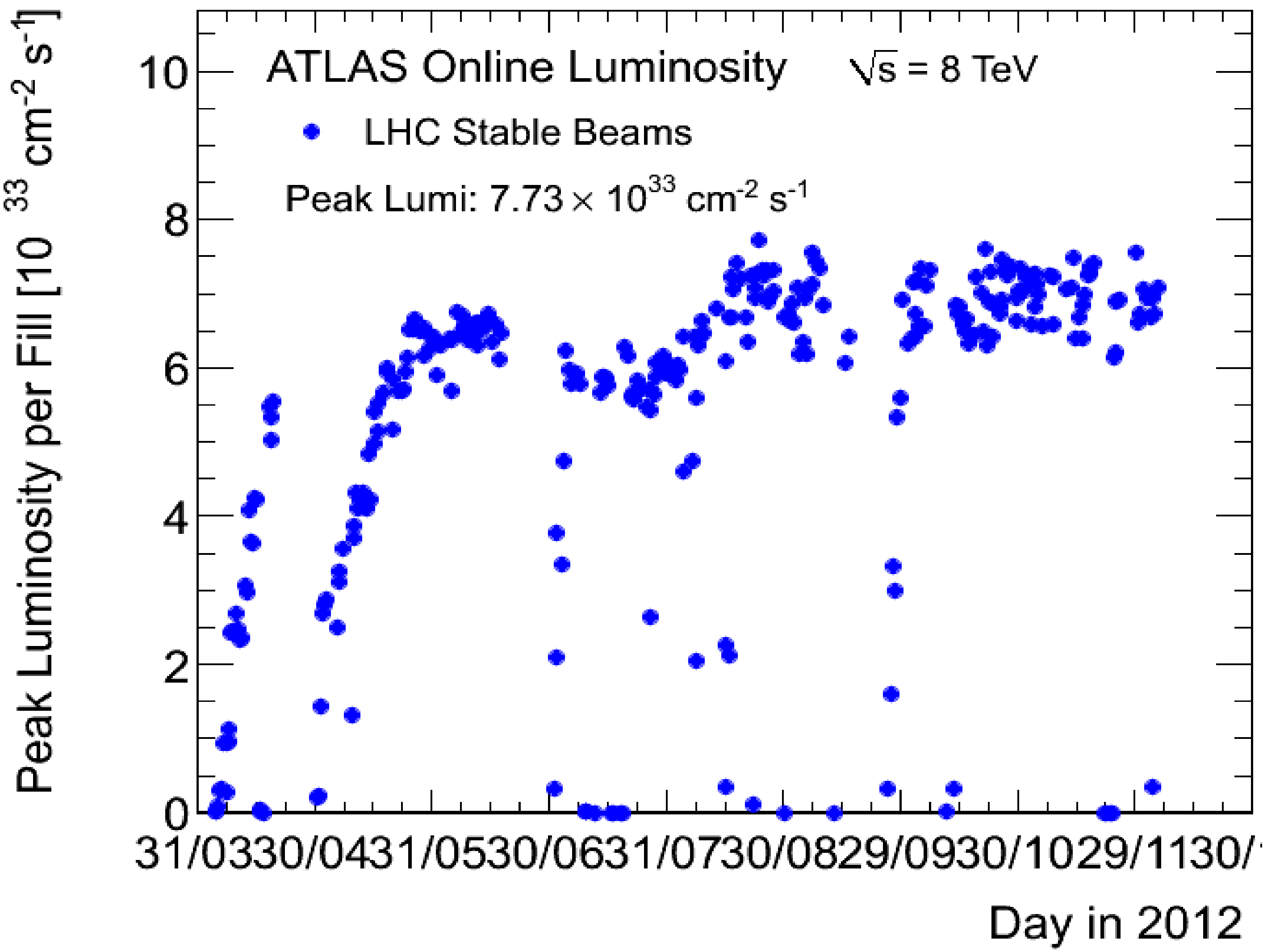


Regular 2012 operation with ~1400 bunches spaced by 50 ns

LHC Performance in 2012

LHC achieved peak performance early in the year and sustained it

- Peak $L = 7.7\times10^{33}$ s^{-1}cm^{-2}
- Max L/fill: 237 pb^{-1}
- Weekly record: 1350 pb^{-1}
- Longest stable beams: 23 h
- Fastest turn-around between stable beams: 2.1 h
- Best weekly data-taking efficiency: 92 h (55%)

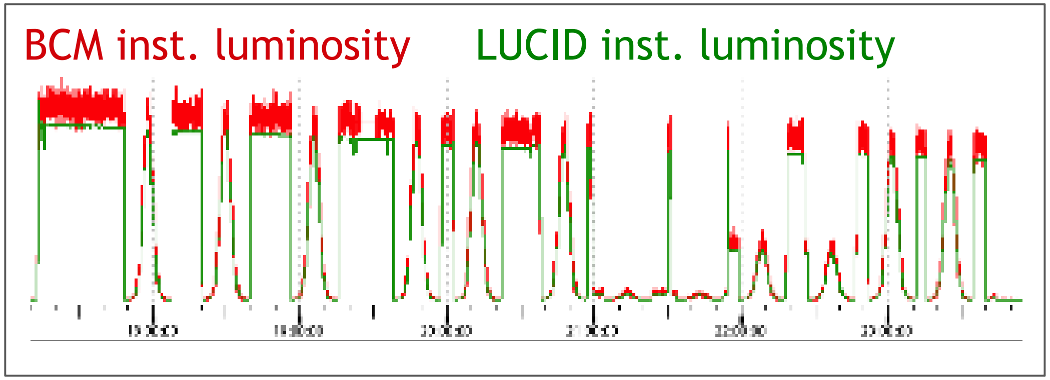


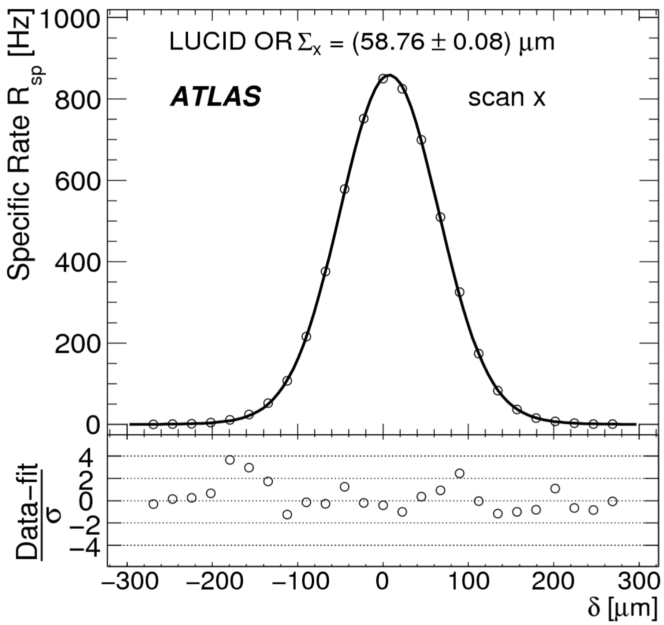
At $L = 7\times10^{33}$ s^{-1}cm^{-2} and 8 TeV *pp* collisions, 560 Higgs bosons of mass 125 GeV are produced in ATLASper hour

Or: every 45 min. 1 $H\rightarrow\gamma\gamma$, need ~2 typical 160 pb^{-1} fills to produced one $H\rightarrow 4\ell$ ($\ell=e/\mu$)

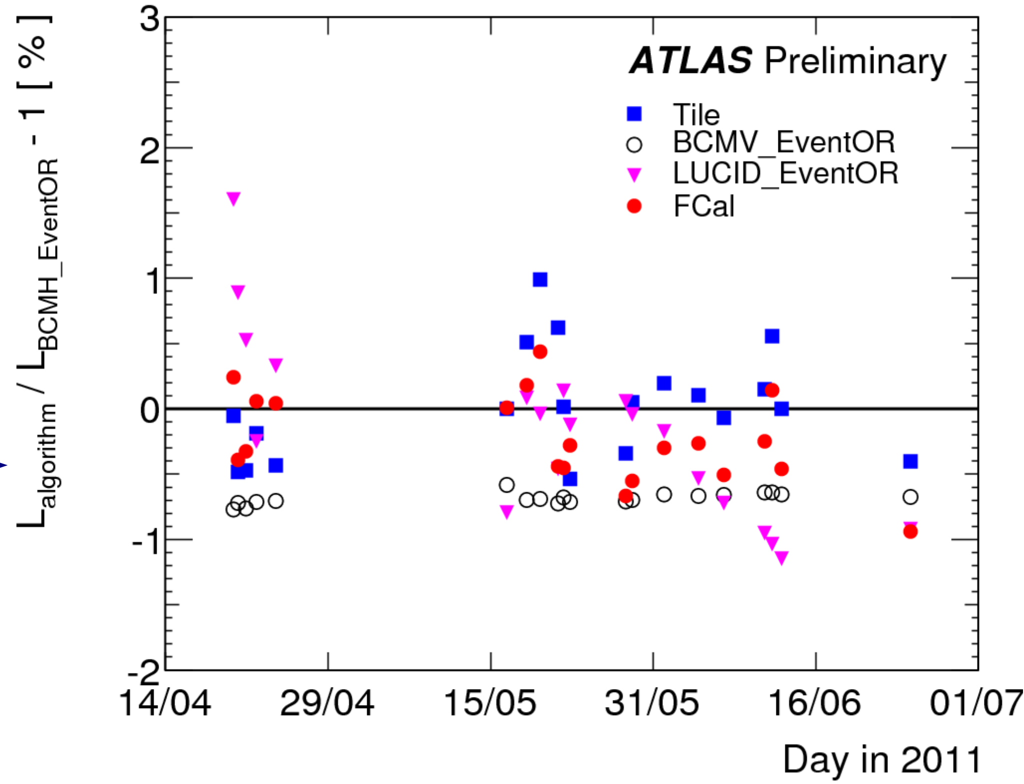
Luminosity Precision - van der Meer Scans

Absolute calibration comes from special fills with beam-separation scans in x & y





Calibration transported to all fills using a range of luminosity-measuring detectors and algorithms

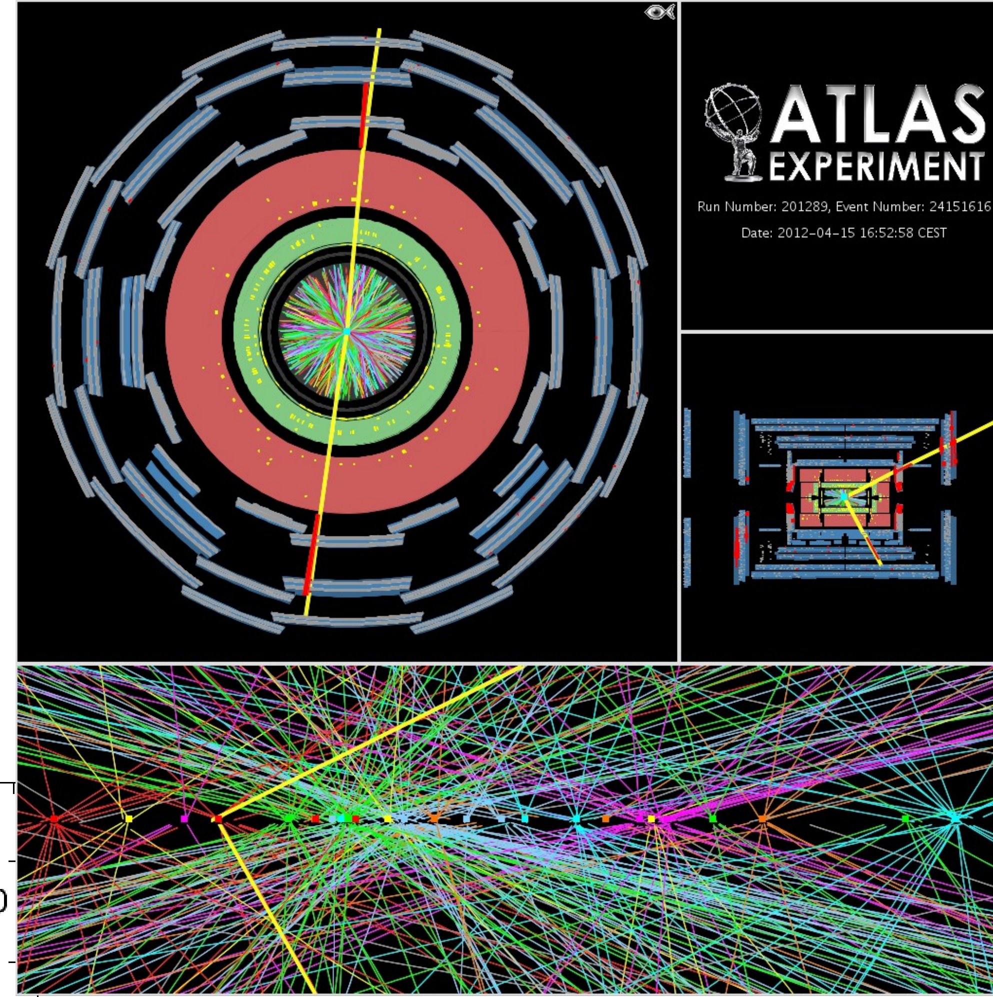


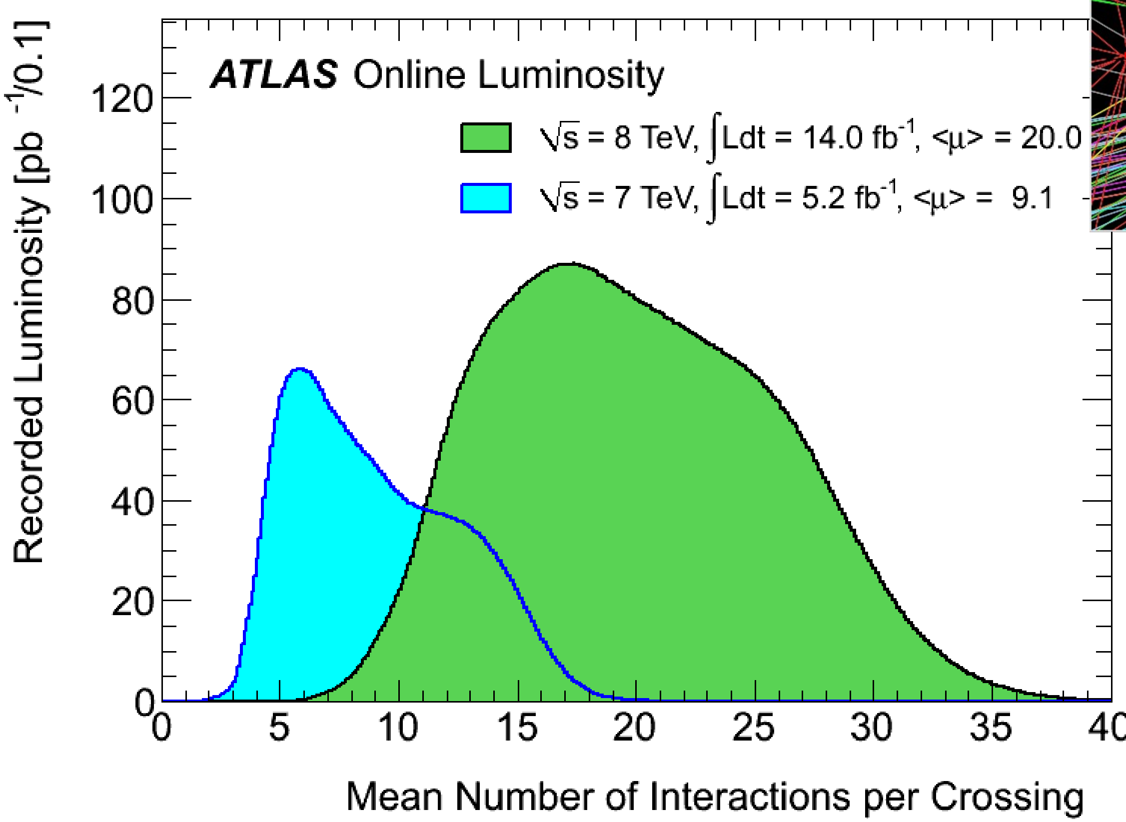
Preliminary luminosity error for 2011 currently 3.6%, goal ~2%

Pileup

Huge experimental challenge in 2011 and 2012 from multiple interactions per beam crossing, pileup

Pileup was so high because LHC was running with a bunch spacing of 50ns not the design 25ns





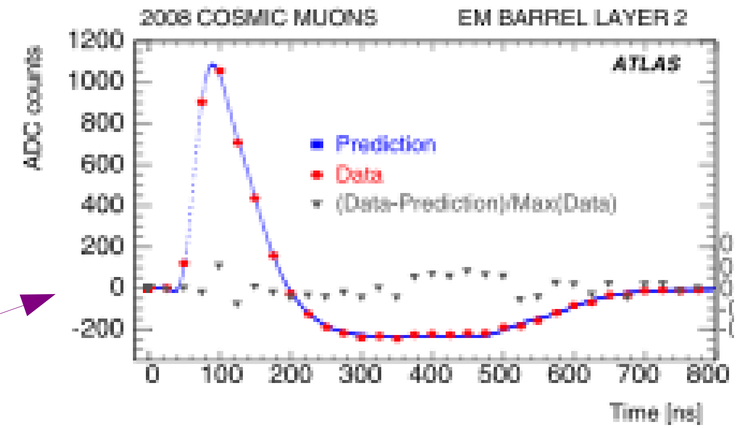
LHC and experiment design is for a peak pileup of ~25 events/crossing

Regularly exceeded in 2012

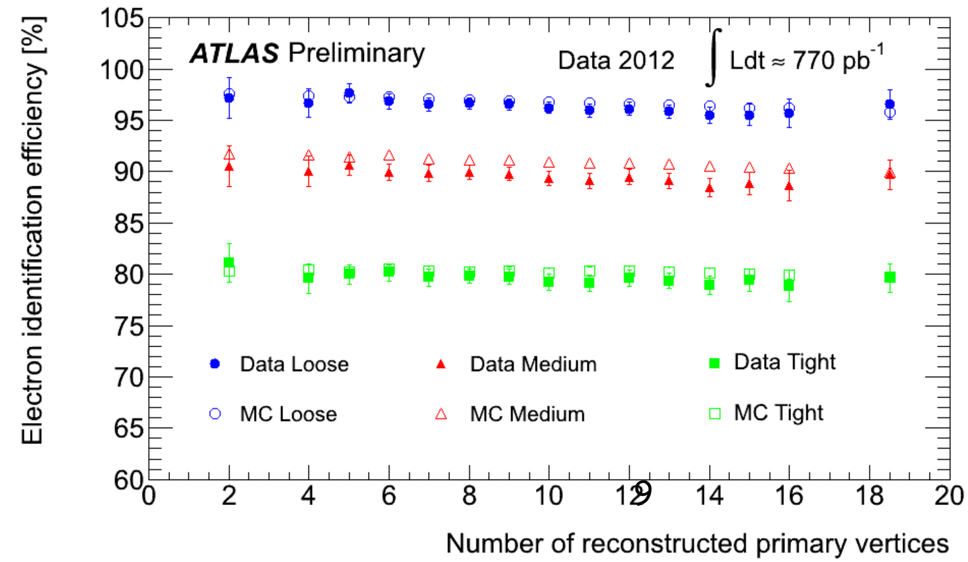
Reducing the Impact of Pileup

ATLAS is designed for high levels of pileup, up to a peak of ~25 interactions per crossing

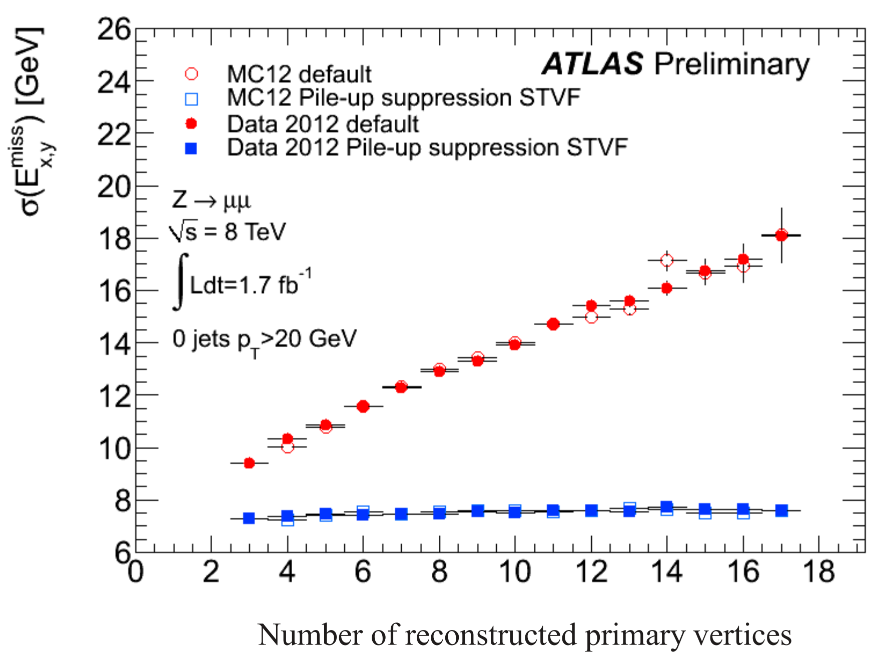
Example: calorimeter pulse shape



Intensive work has allowed impact of pileup to be reduced by the design of pileup-insensitive selections



Electron ID efficiency vs pile-up in Z→ee events after optimisation against pile-up



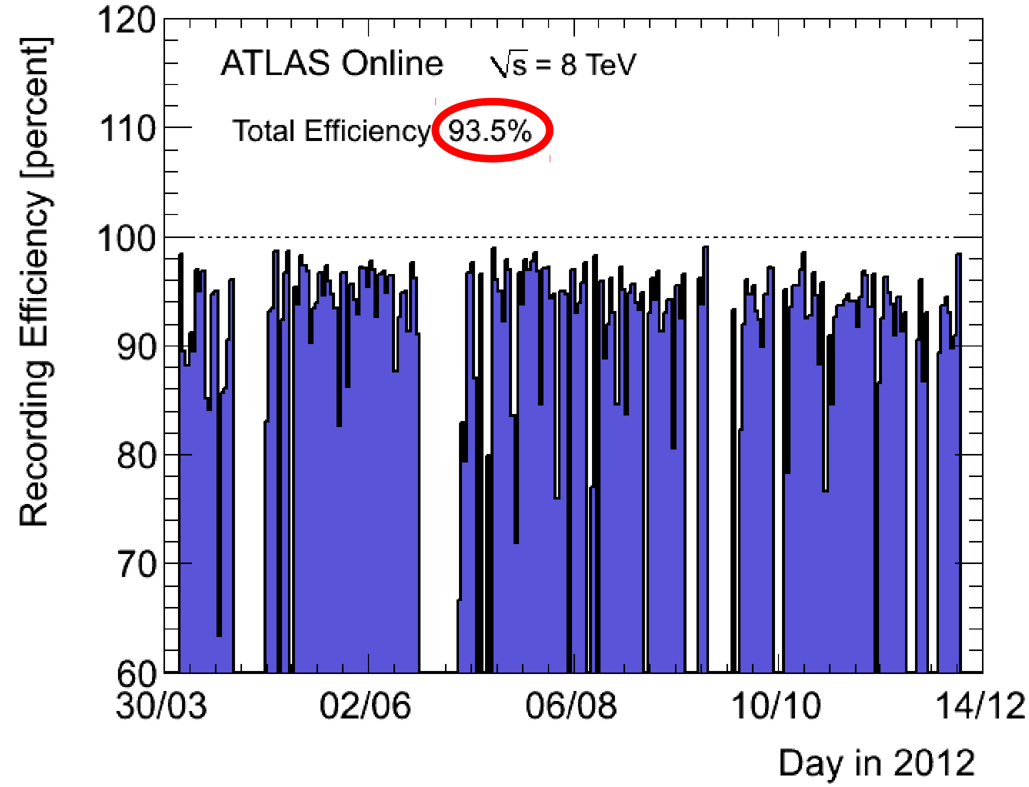
E_T^{miss} resolution vs pile-up in Z→μμ events
before and **after** pile-up suppression using tracking information

Note: number of reconstructed primary vertices is ~ 60% number of number of interactions per crossings

Data-Taking Efficiency and Data Quality

The data available for analysis is less than that delivered by the LHC due to data-taking inefficiency, <u>and</u> data quality losses

ATLAS (and CMS) have unprecedentedly high efficiencies for hadron collider experiments – takes a huge amount of constant care and attention (many people on-call 24/7)



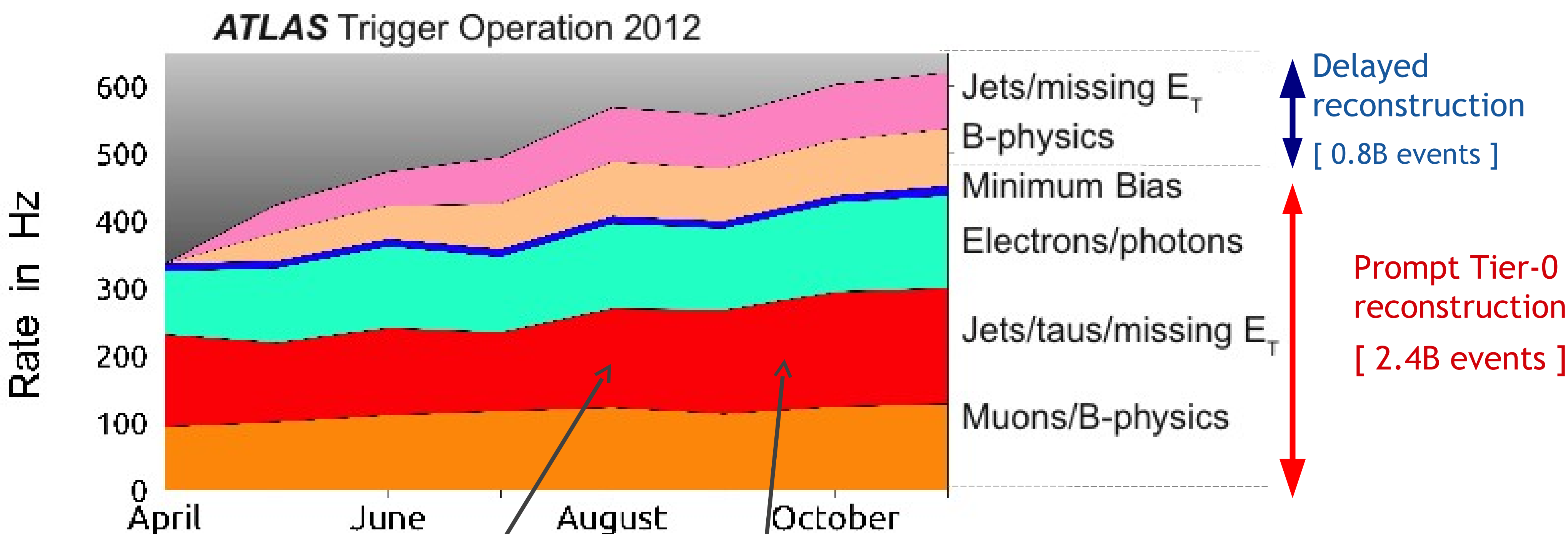
ATLAS p-p run: April-Sept. 2012										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
100	99.3	99.5	97.0	99.6	99.9	99.8	99.9	99.9	99.7	99.2
All good for physics: 93.7%										

Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at √s=8 TeV between April 4th and September 17th (in %) – corresponding to 14.0 fb^{-1} of recorded data. The inefficiencies in the LAr calorimeter will partially be recovered in the future.

Typically ~88% of data delivered by LHC is used for physics analysis

Triggering

This year the rather stable peak luminosity allowed a stable trigger menu
ATLAS subdivides triggered events into a few large data streams
In 2012 include “delayed streams” for reconstruction in 2013



Additional / looser E_T^{miss} & tau as well as VBF triggers added to increase sensitivity for 125 GeV Higgs in *bb* and ττ modes

Average rate of 400 Hz over 2012 run for prompt trigger streams

Main 2012 Triggers

Excluding the delayed streams

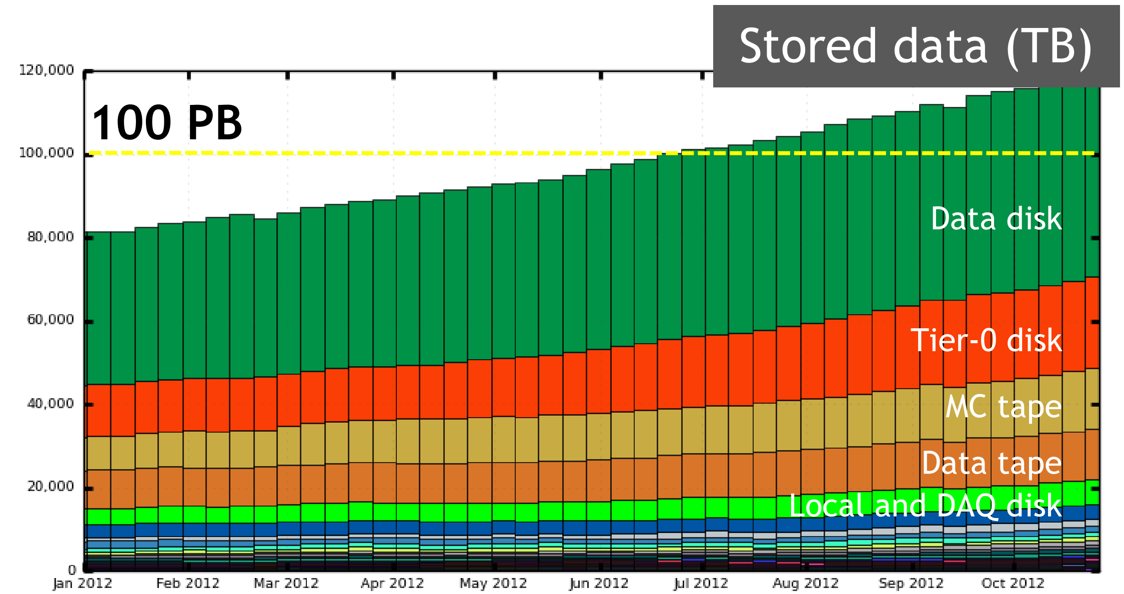
Signature	Offline selection	Trigger selection L1	Trigger selection EF	L1 Peak (kHz) *L*peak= 7×1033	EF Ave (Hz) *L*ave= 5×1033
Single leptons	Single muon pT > 25 GeV	15 GeV	24 GeV	**8**	**45**
	Single electron pT > 25 GeV	18 GeV	24 GeV	**17**	**70**
Two leptons	2 muons pT > 6 GeV	2 × 6 GeV (also 2mu4 barrel only)	2 × 6 GeV	**3**	**2**
	2 muons pT >15 GeV 2 muons pT > 20,10 GeV	2 × 10 GeV 15 GeV	2 × 13 GeV 18,8 GeV	**1** **8**	**5** **8**
	2 electrons, each pT > 15 GeV	2 × 10 GeV	2×12 GeV	**6**	**8**
	2 taus pT > 45, 30 GeV	15,11 GeV	29,20 GeV	**12**	**12**
Two photons	2 photons, each pT > 25 GeV 2 loose photons, pT > 40,30 GeV	2 × 10 GeV 12,16 GeV	2 × 20 GeV 35, 25 GeV	**6** **6**	**10** **7**
Single jet	Jet pT > 360 GeV	75 GeV	360 GeV	**2**	**5**
*ET*miss	*ET*miss > 120 GeV	40 GeV	80 GeV	**2**	**17**
Multi-jets	5 jets, each pT > 60 GeV 6 jets, each pT > 50 GeV	4×15 GeV	5 × 55 GeV 6 × 45 GeV	**1**	**8**
b-jets	*b* + 3 other jets pT > 45 GeV	4 × 15 GeV	4 × 45 GeV + *b*-tag	**1**	**4**
TOTAL				**< 75**	**~400 (avg)**

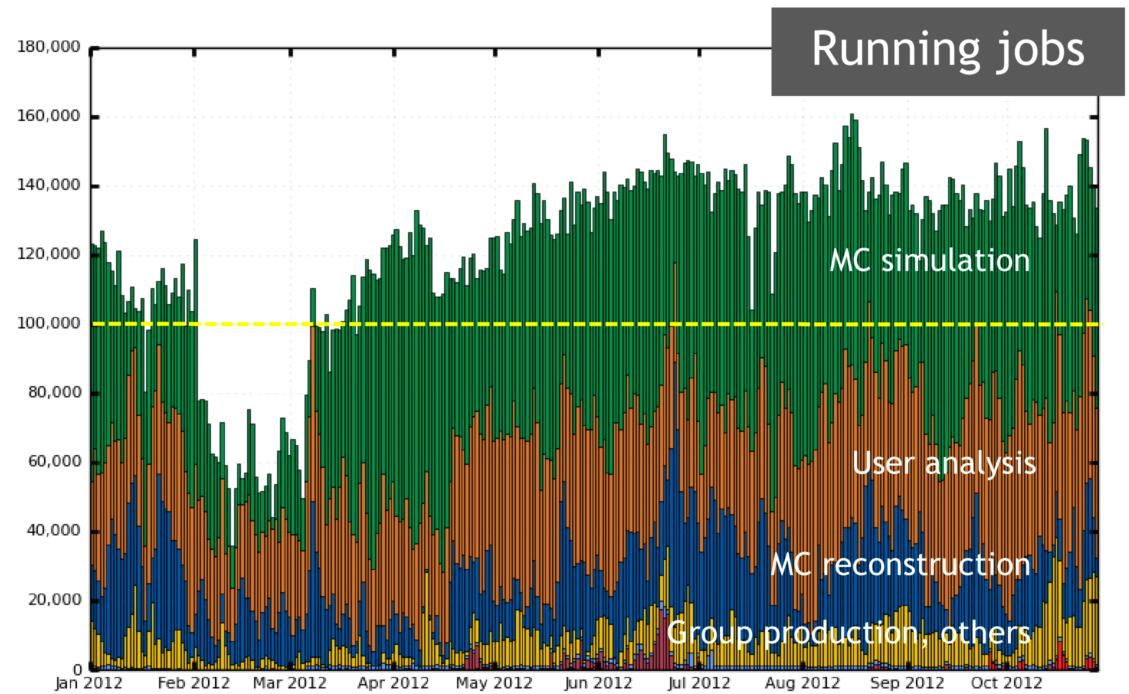
One Slide on Computing

The Worldwide LHC Computing Grid is crucial to be able to analyse these huge data sets and to generate the necessary Monte Carlo statistics

It works so well that we can produce selected results very quickly, <4 weeks, from data-taking to results, in selected cases

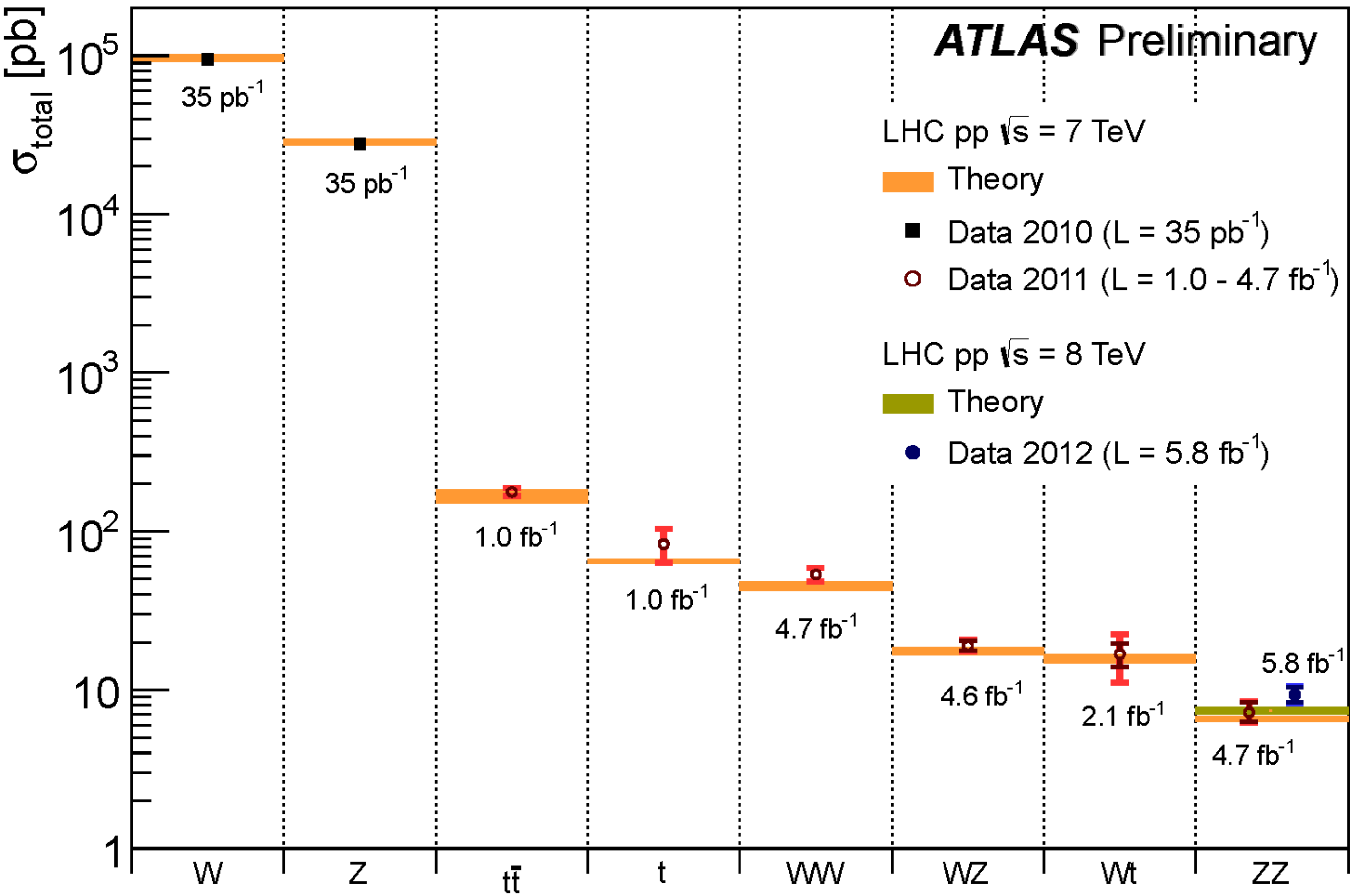
Pileup imposes a big challenge here too: ~triples CPU requirement for reconstruction





Measurements

Standard Model Measurements



Event statistics with ~22 fb^{-1} at 8 TeV

- 1.5 quadrillion (10^{15}) pp collisions
- 3 billion recorded (+PU)

After selections:
- 100 M $W \rightarrow \ell\nu$
- 10 M $Z \rightarrow \ell\ell$
- 400k $t\bar{t} \rightarrow \ell X$
- hundreds of H(125)

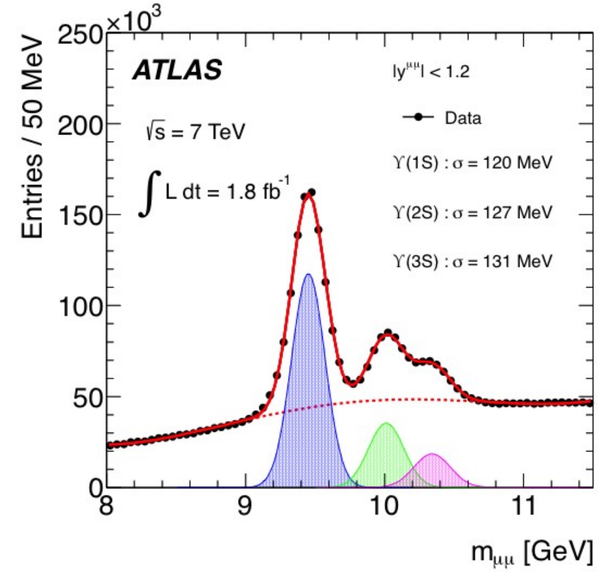
A wealth of high precision measurements are possible, and in progress – detailed and intricate studies which need careful analysis

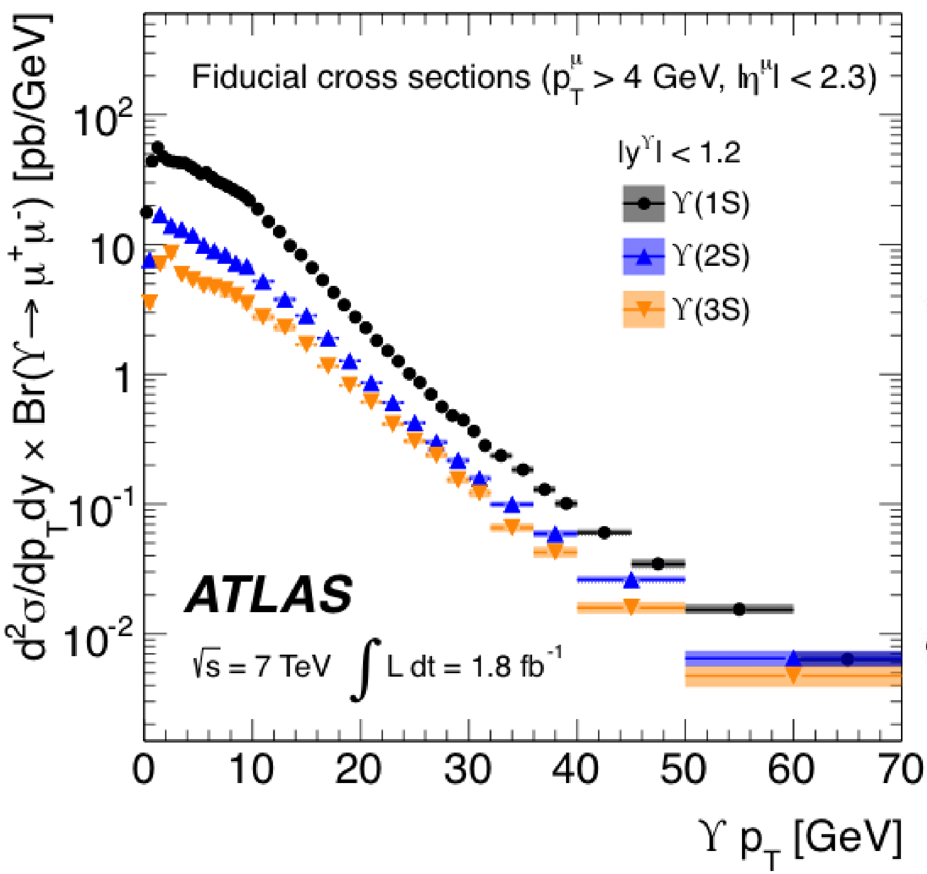
More complex topologies are important backgrounds for searches – validate MC models in more inclusive regions

Differential ϒ(1S,2S,3S) Measurements

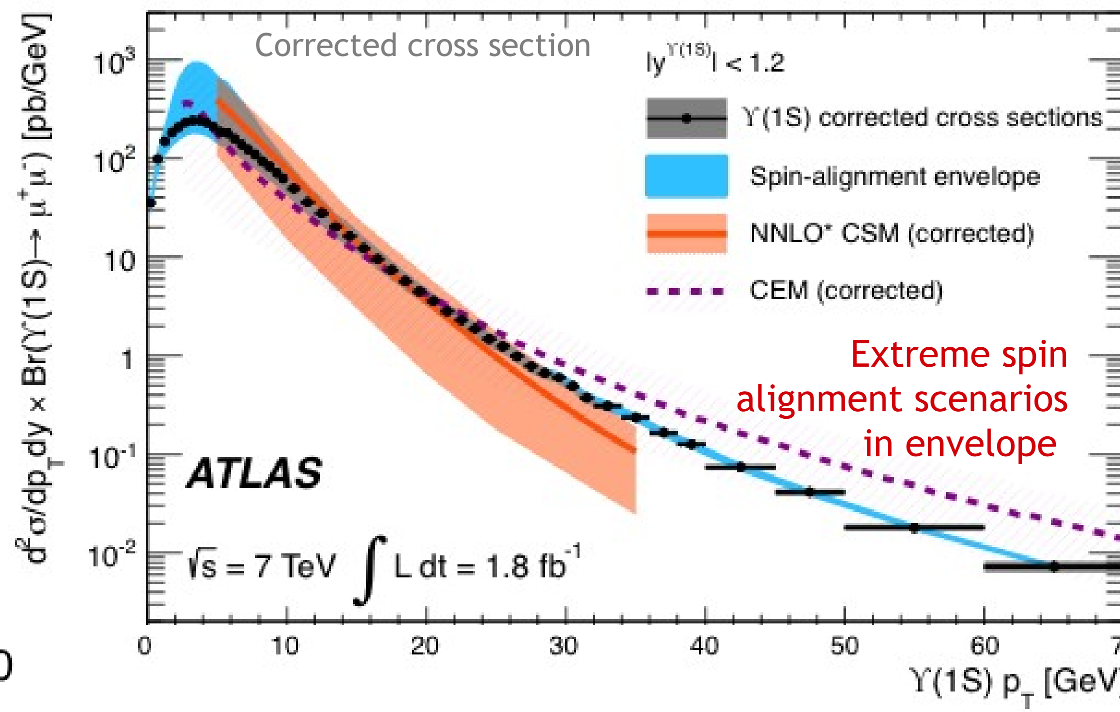
Dimuon final state with $p_T(\mu) > 4$ GeV, $|\eta^\mu| < 2.3$

- Comparison of the three states interesting because of contributions from direct production and feed-down from decays of higher mass states (ϒ's, χ's)
- Comparison with models reveals problems at high p_T





arXiv:1211.1255



Inclusive dijets

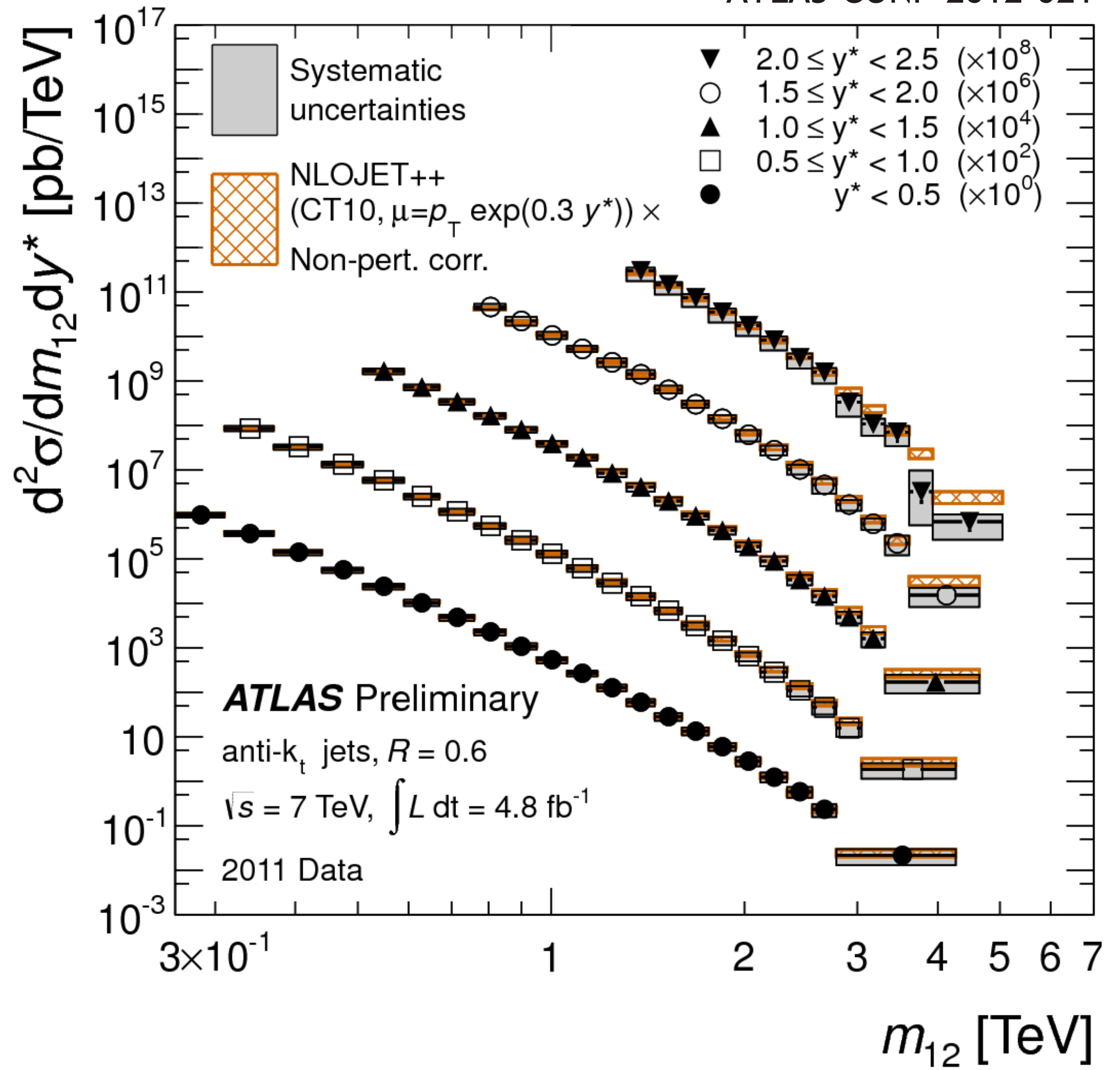
Jet differential cross-sections measured over $0.02 < p_T < 1.5$ TeV in PRD86 (2012) 014022

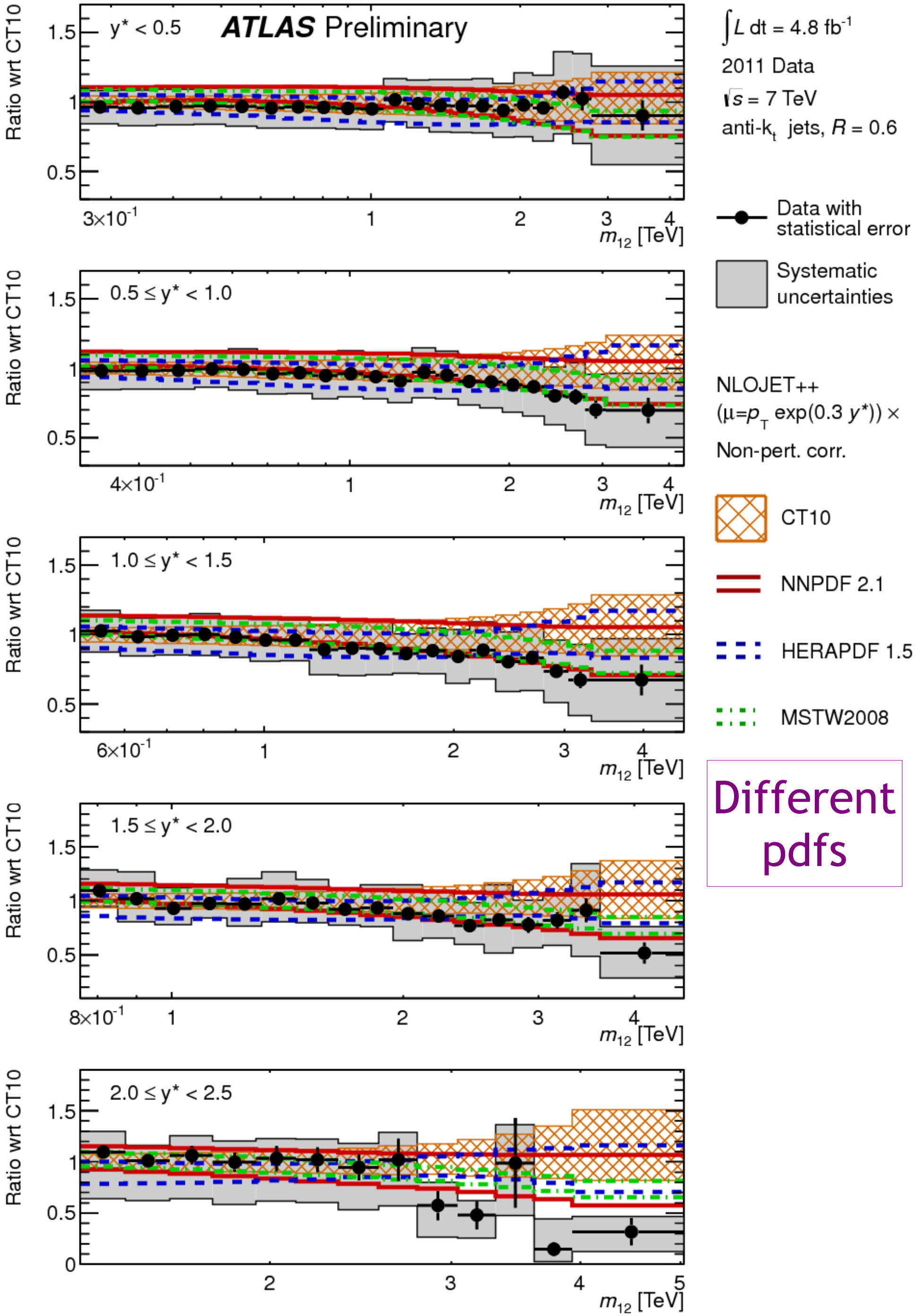
Double-differential measurements for high-mass dijets with full 7 TeV data sample (m_{12}, $y^*=|(y_1+y_2)/2|$)

Fully corrected to particle level, covering $0.26 < m_{12} < 4.6$ TeV, $y^* < 2.5$

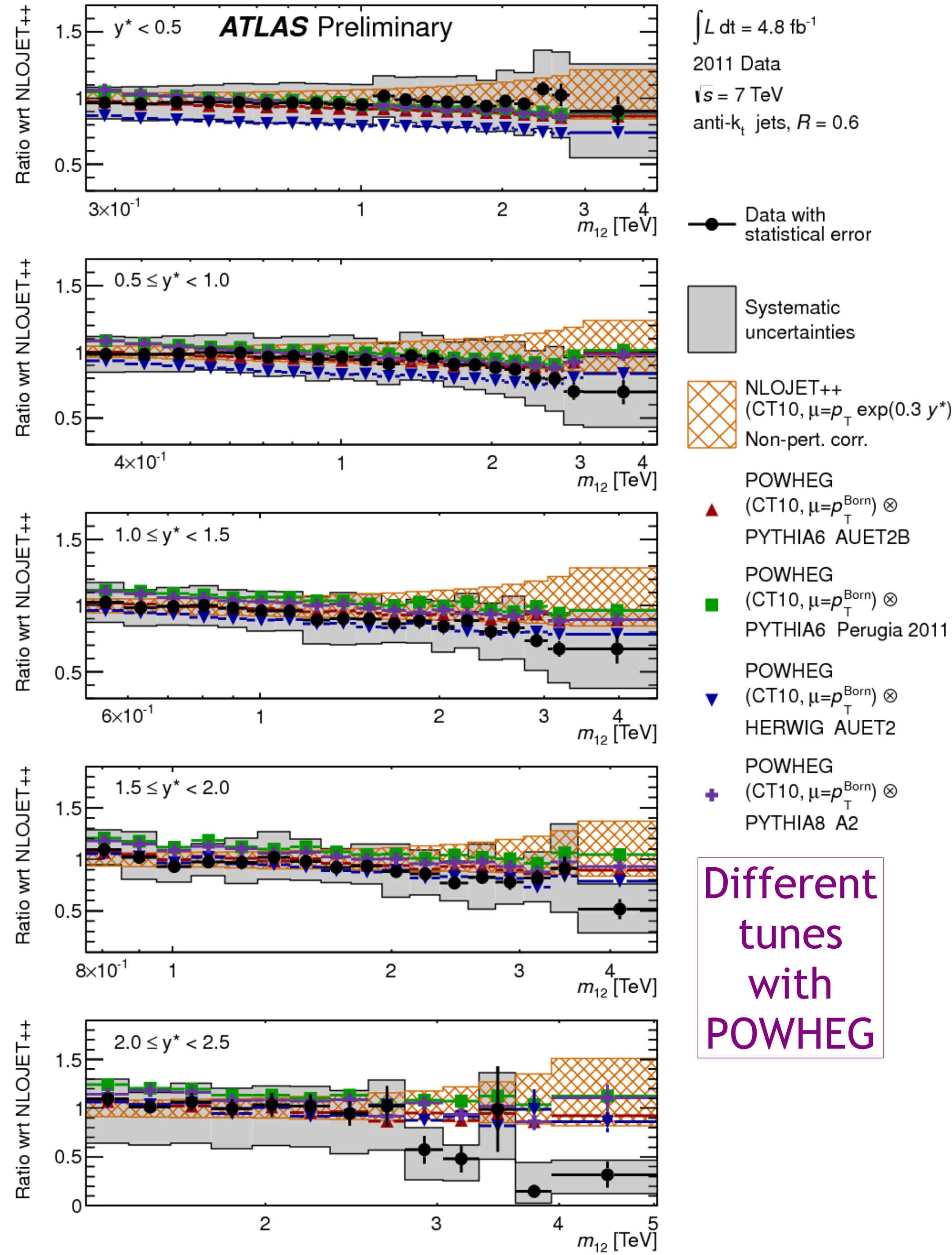
Reference calculation NLOJET++ with CT10 pdfs

ATLAS-CONF-2012-021





Different pdfs



Different tunes with POWHEG

Generally good description of the data, least good at high mass, y*
POWHEG with PYTHIA6 AUET2B tune does best

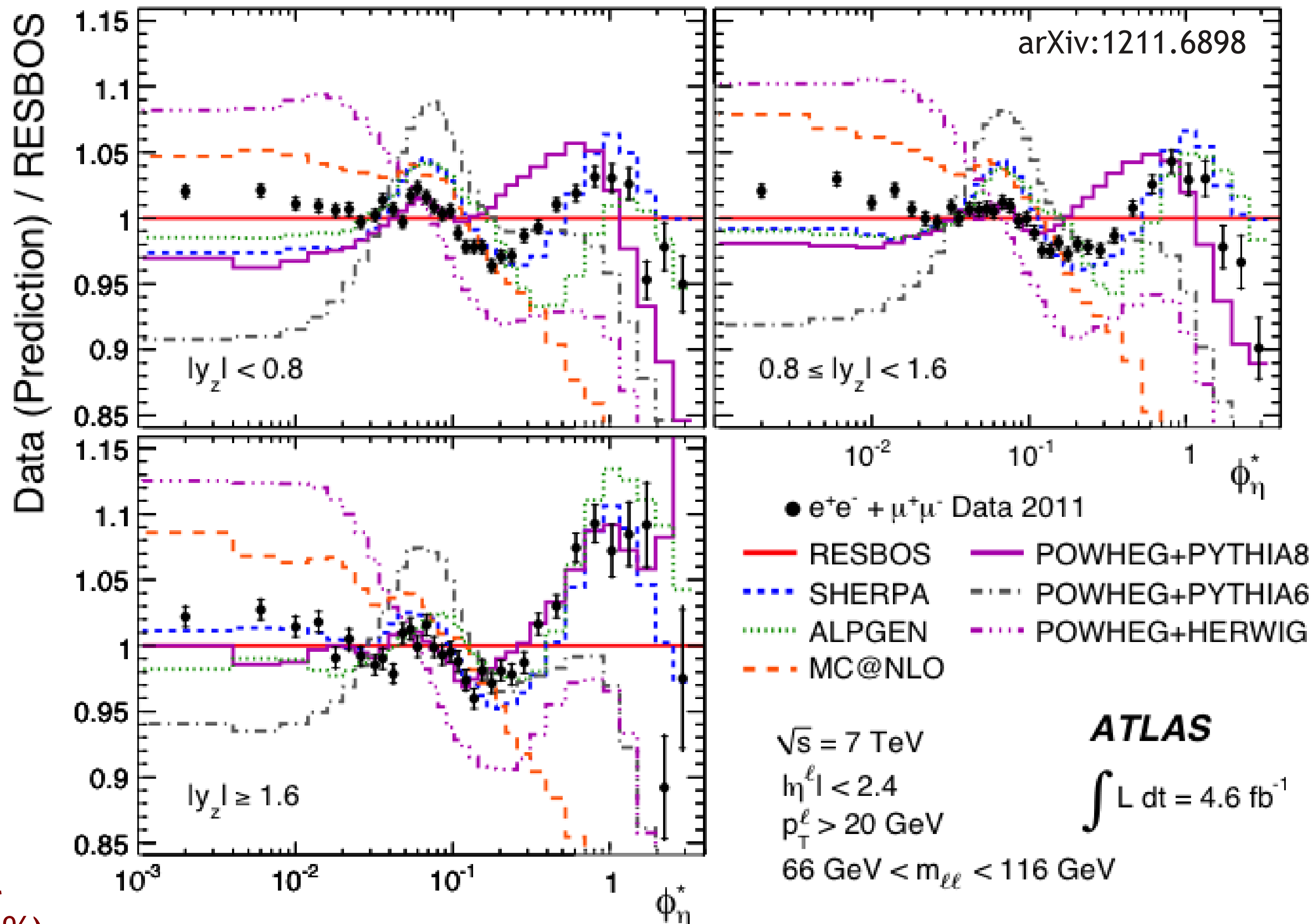
ATLAS-CONF-2012-021

Z Differential Cross-Section

Φ_η^*: A Banfi et al EPJC71(2011)1600

Measurement of Z/γ φ_η^* distribution

- φ_η^* is related to the scattering angle of leptons wrt. beam
- Depends on lepton angles only, more precisely measured than momenta
- φ_η^* correlated to $p_T(Z)/m_{ll}$ - probes same physics

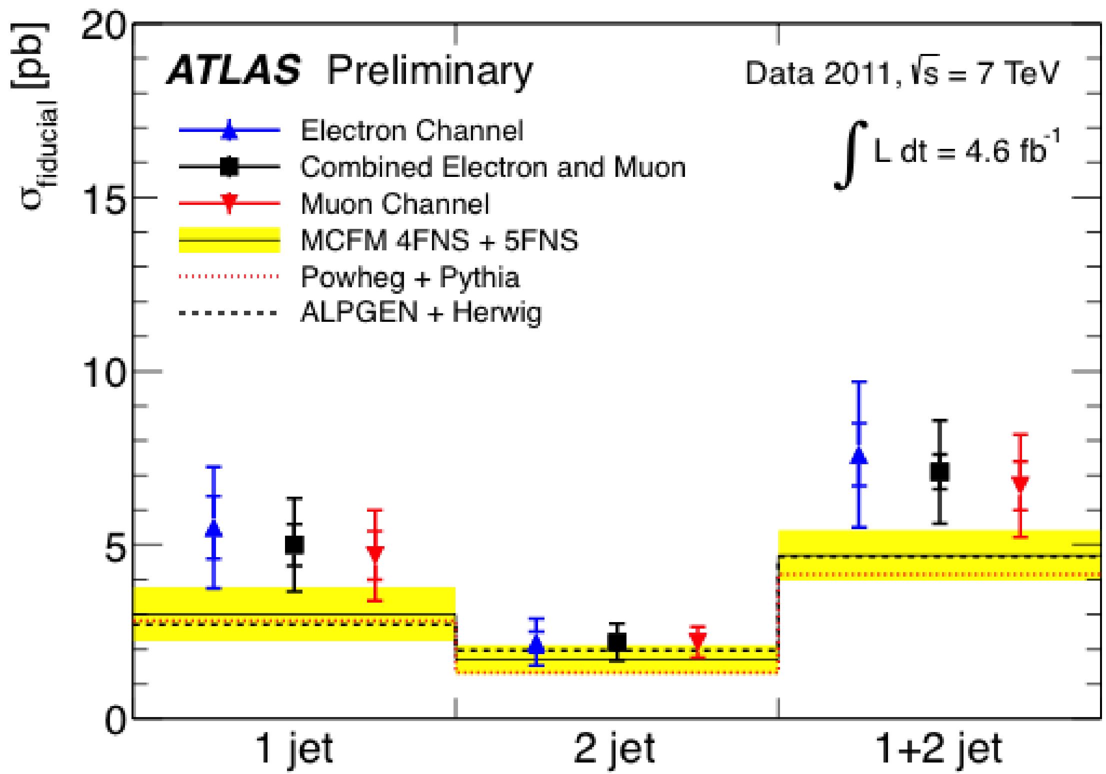


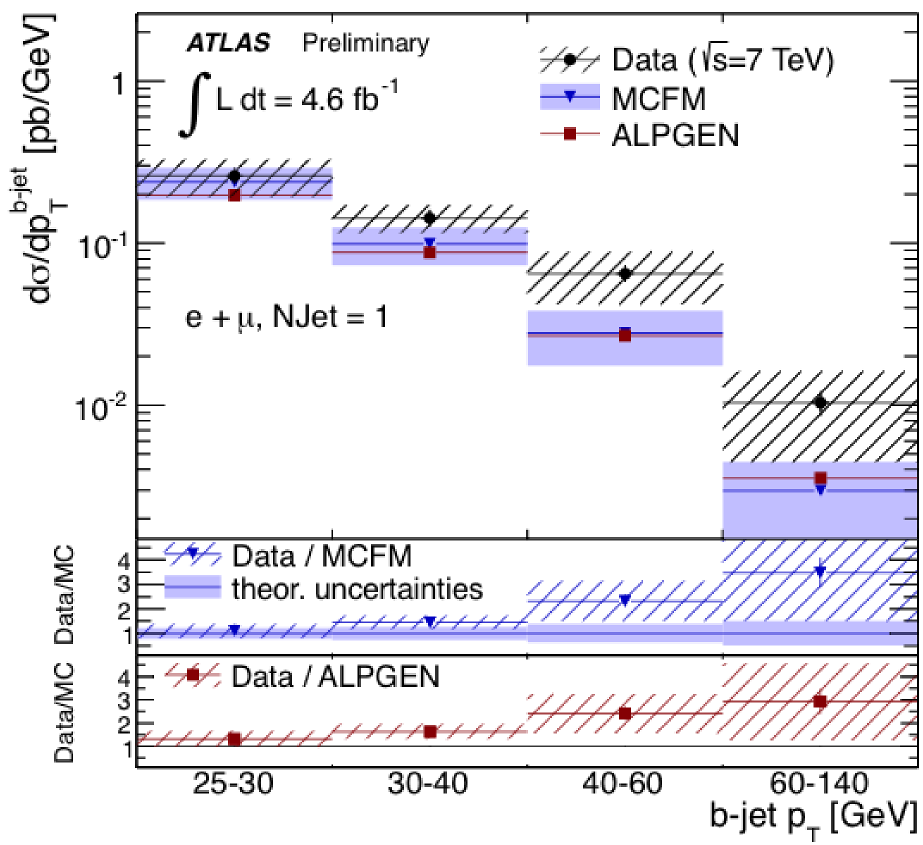
ResBos provides best description (within 4%), large deviations for POWHEG / MC@NLO

W and Z in Association with Heavy Flavour

Measurement of $W + b$-jets fiducial ($p_T > 25$ GeV, $|\eta| < 2.1$) and differential cross sections

ATLAS-CONF-2012-156





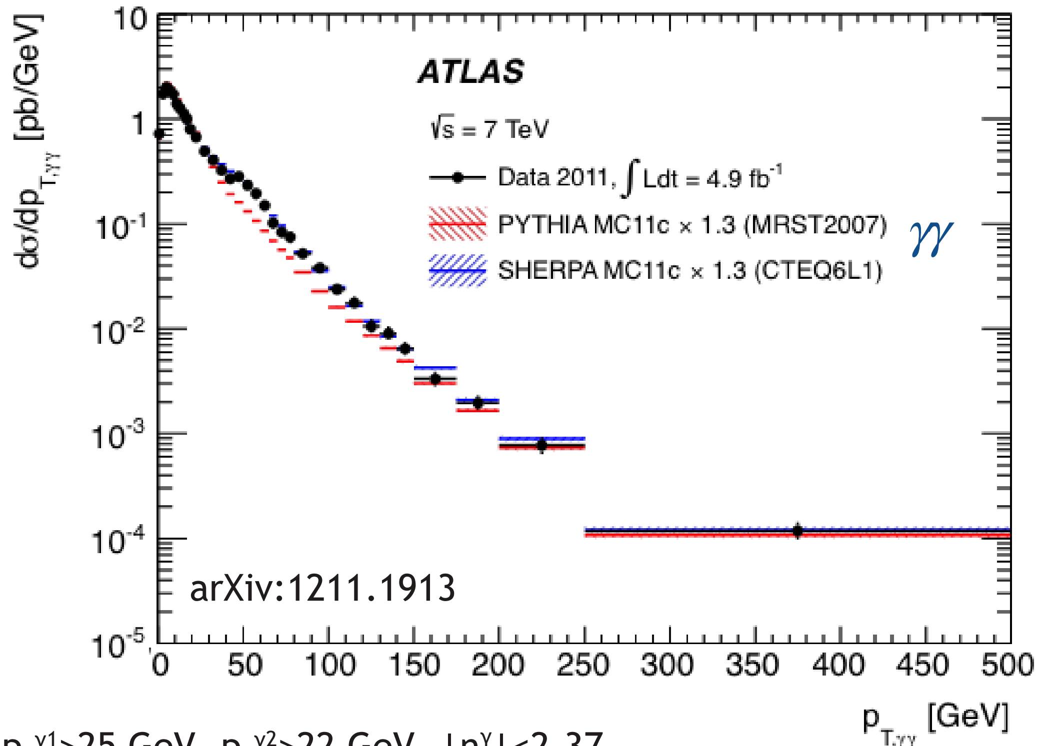
Fiducial cross section within 1.5σ of theory prediction

p_T spectrum a little harder in data, but compatible with generators

Dibosons - γγ

Diboson production is a common theme – for measurements, BSM searches and the Higgs...

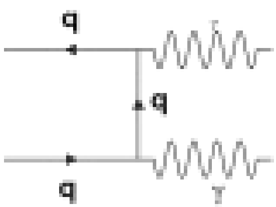
Example of differential cross section measurement: *γγ* (7 TeV, 4.9 fb^{-1})



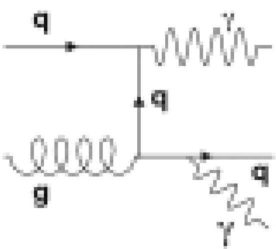
$p_T^{\gamma1}$>25 GeV, $p_T^{\gamma2}$>22 GeV, |η^γ|<2.37 and not in 1.37-1.52, ΔR(γγ)>0.4

Rescaled leading-order parton shower generators describe data better than higher-order fixed-order generators (DIPHOX, 2γNNLO) which lack soft gluon resummation

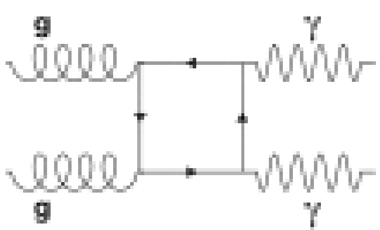
Powerful test of perturbative QCD and quark fragmentation



"Direct" quark annihilation (dominant: O(α^2))



Collinear fragmentation, *O*($\alpha^2\alpha_s$), but non-isolated γ



Box diagram, *O*($\alpha^2\alpha_s^2$), but due to *gg* luminosity comparable to LO terms

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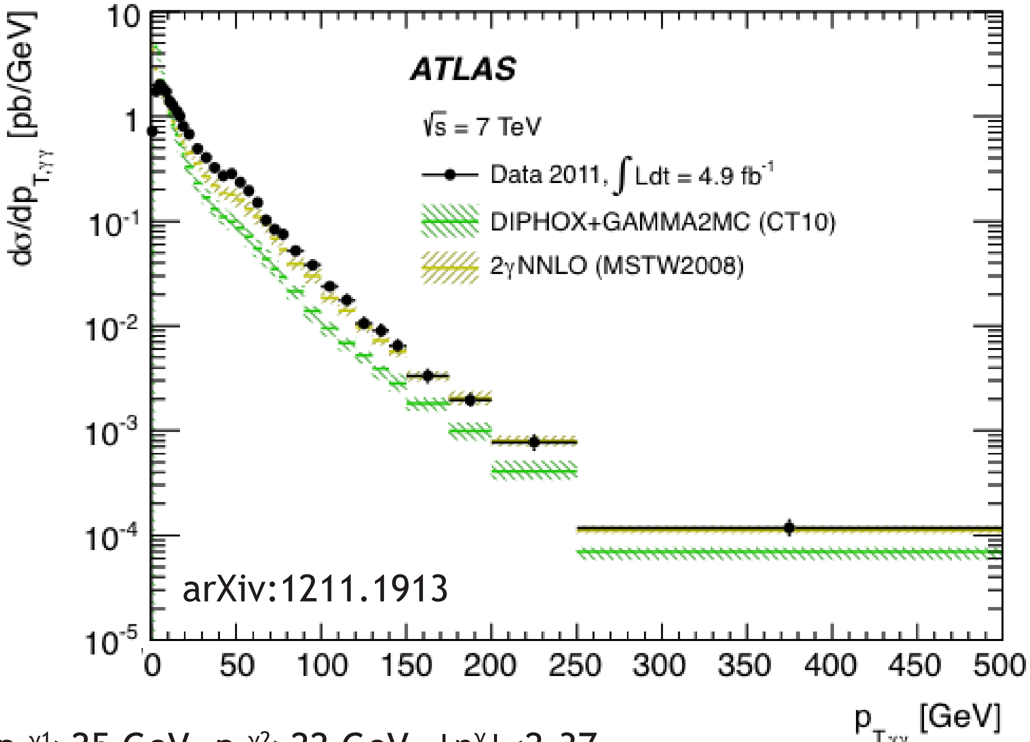

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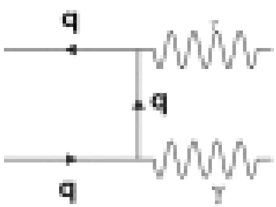

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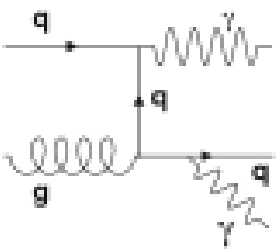

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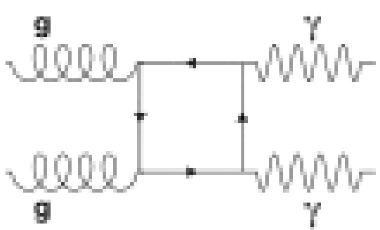

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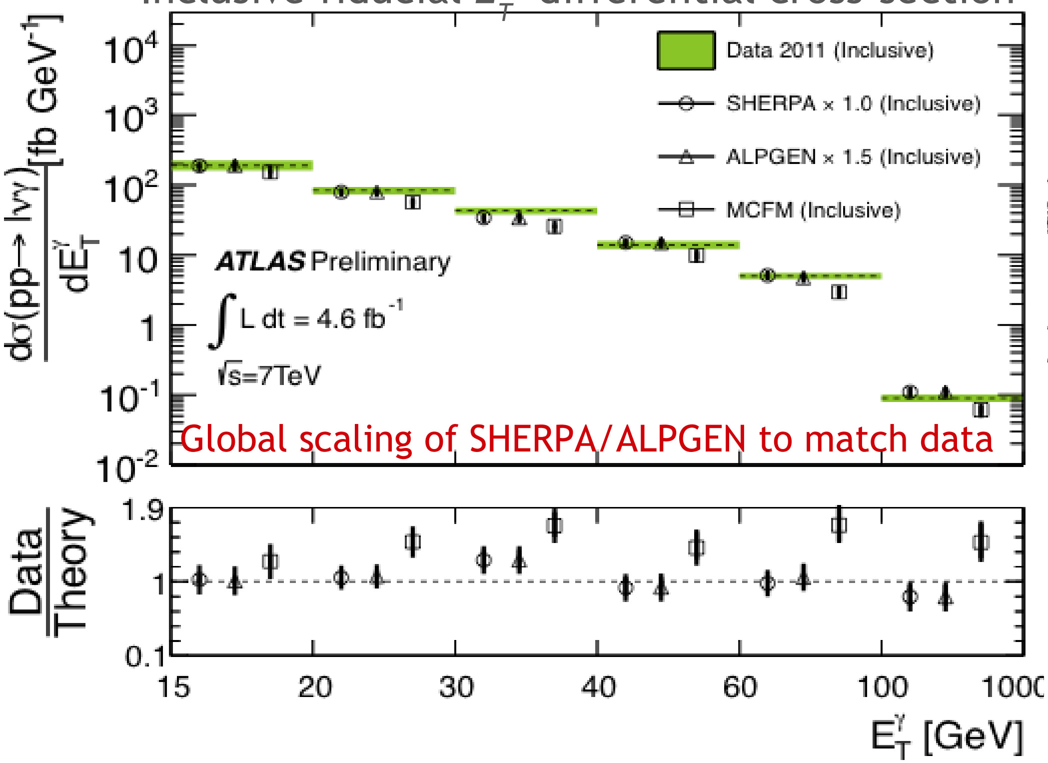
Dibosons – Wγ and Zγ

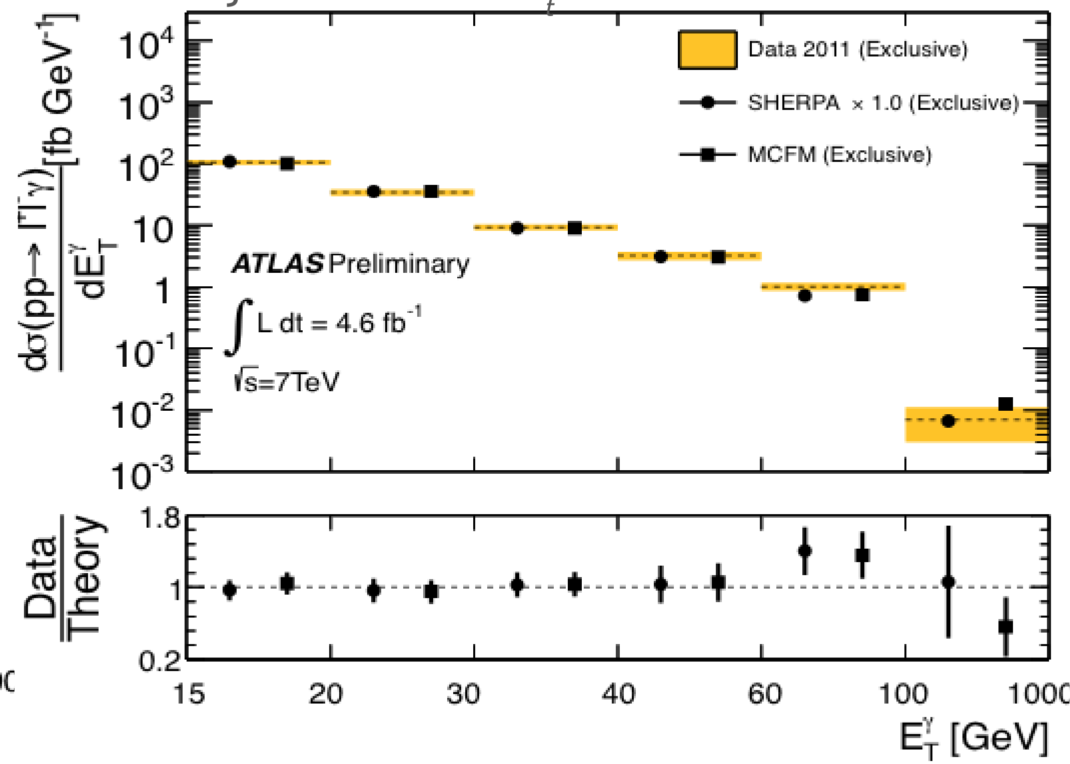
Phys. Lett. B 717 (2012) 49-69

Example differential cross-section measurements: *Wγ*, *Zγ* (7 TeV, 4.6 fb^{-1})
Fully corrected to respective fiducial regions

Inclusive fiducial E_T^{γ} differential cross-section



N-jet = 0 fiducial E_t^{γ} differential cross-section

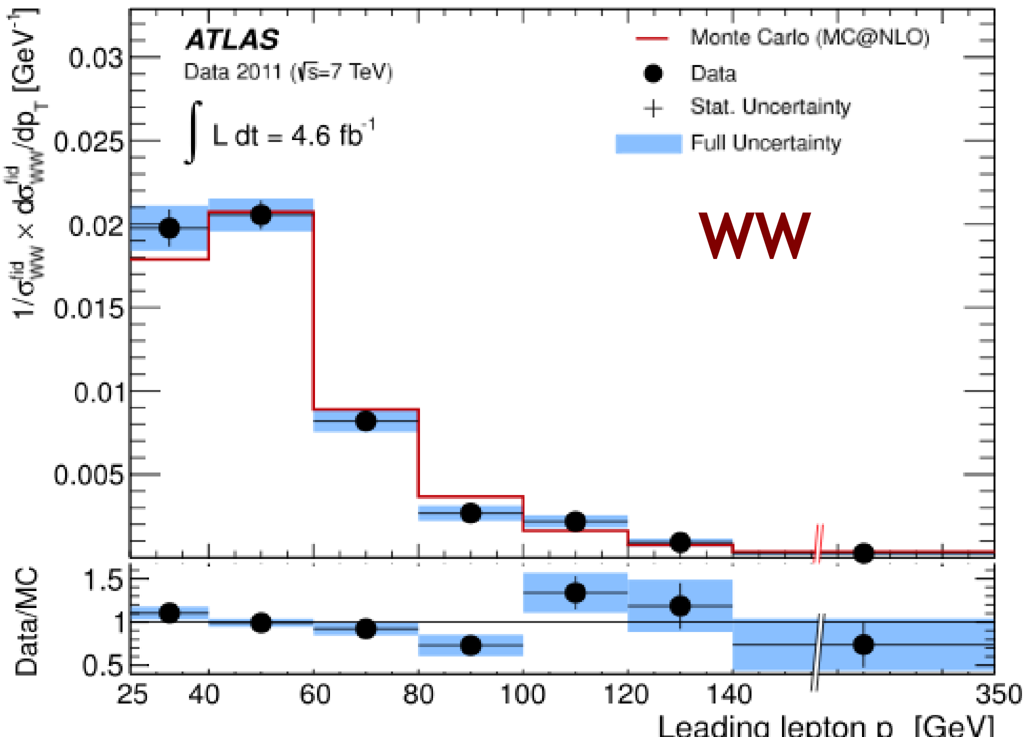


MCFM (NLO, parton level) undershoots the inclusive cross-section
Scaled LO ALPGEN/SHERPA with multiple quark/gluon emission in PS do better
Similar observation as for γγ

Dibosons – WW, WZ and ZZ

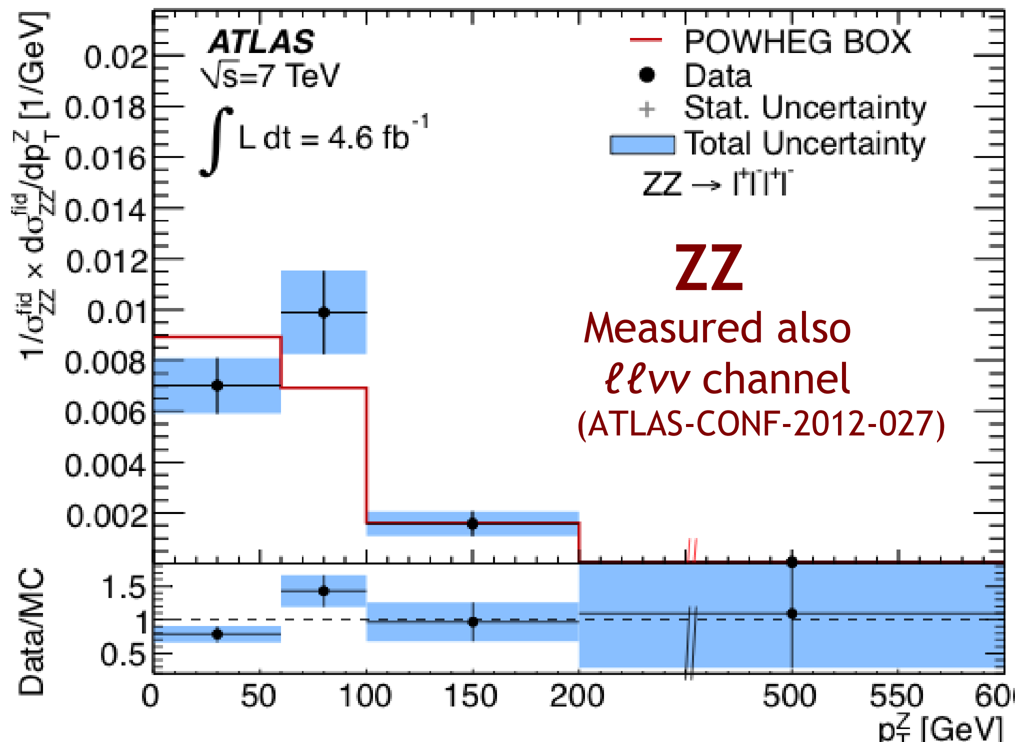
Example differential cross section measurements: *WW*, *ZZ* (7 TeV, 4.6 fb^{-1})

Normalised fiducial differential cross-section



arXiv:1210.2979

Normalised fiducial differential cross-section



arXiv:1211.6096

NLO generators provide a good description of the data with these statistics, also for the mass spectra. Same conclusion for *WZ*

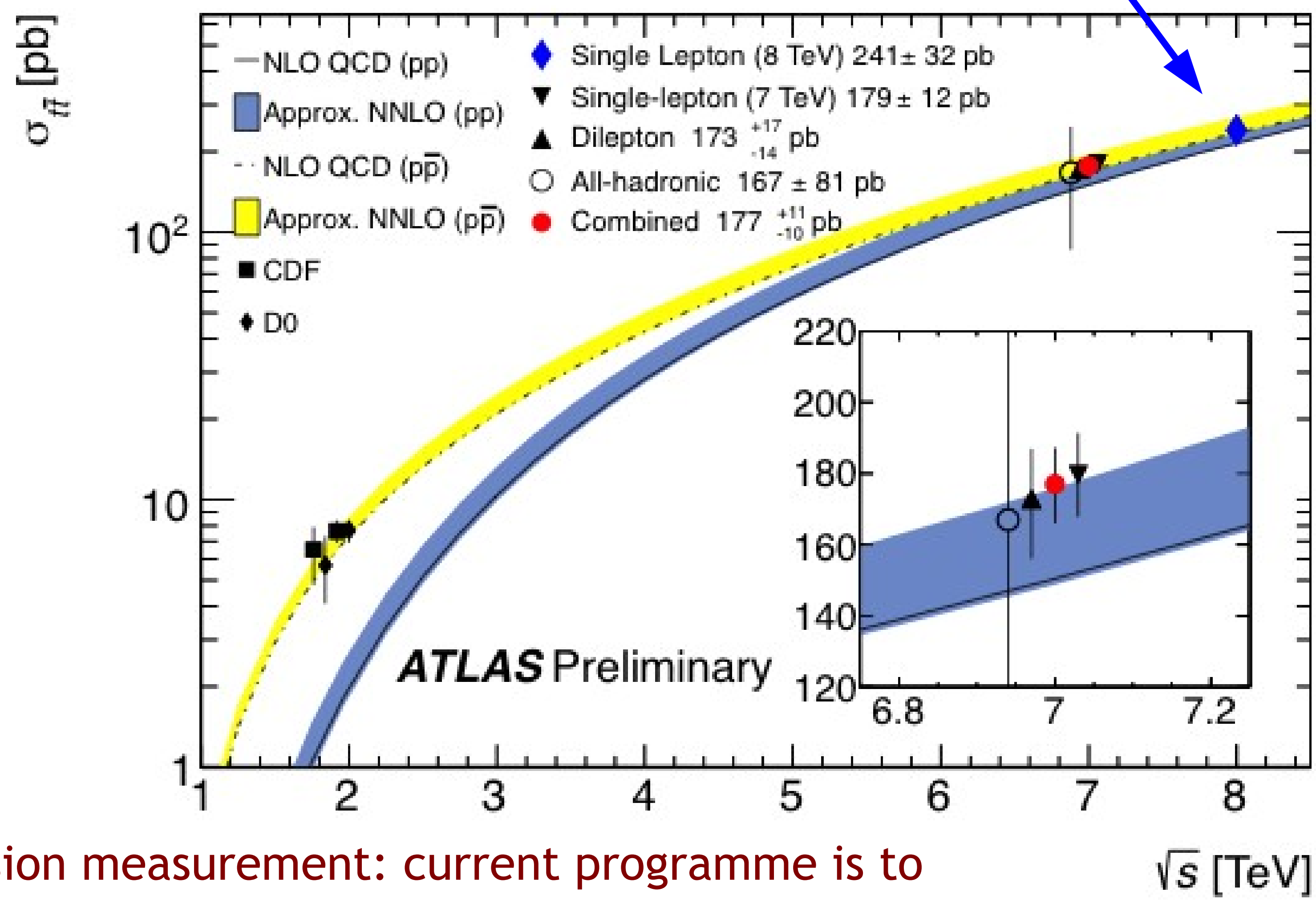
EPJC72 (2012) 2173

Top Pair Cross-Section

Large variety of 7 TeV measurements public:

 0/1/2-lepton (e, μ, τ) — well-described by calculations

Measurement of 8 TeV cross-section in 1-lepton channel (5.8 fb^{-1}) using likelihood template fit ATLAS-CONF-2012-149

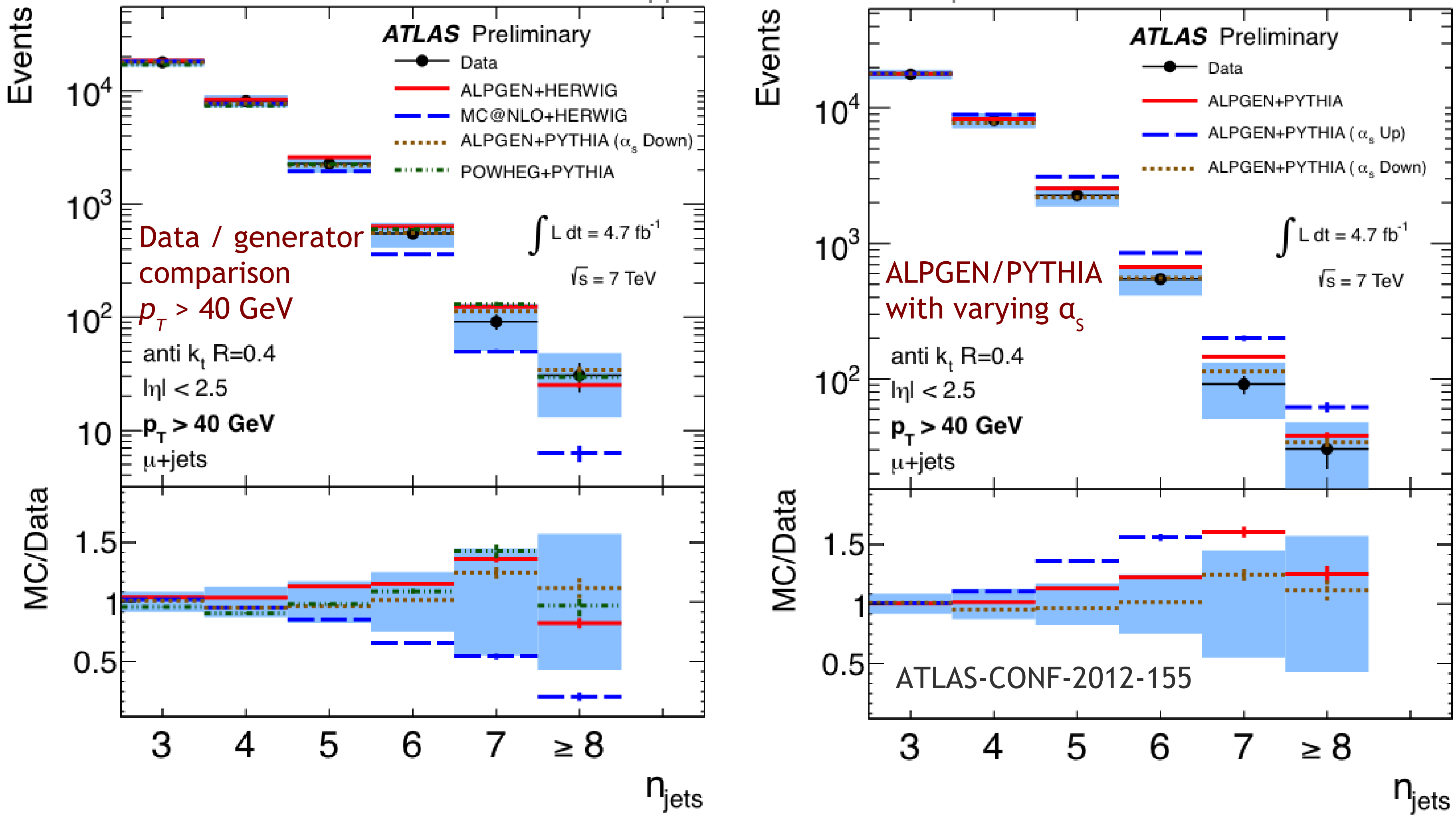


Precision measurement: current programme is to obtain and reduce robust systematic errors

$t\bar{t}$+jets

Significant background to more complex search topologies (e.g. SUSY cascade decay chains)

MC scaled to approx. NNLO inclusive prediction

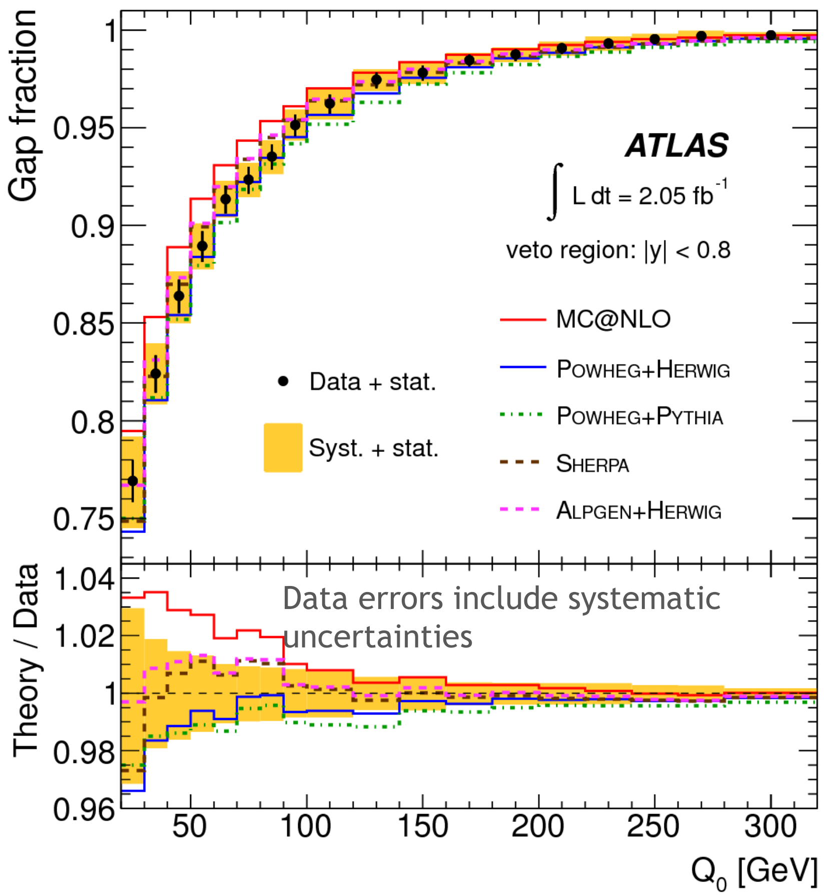


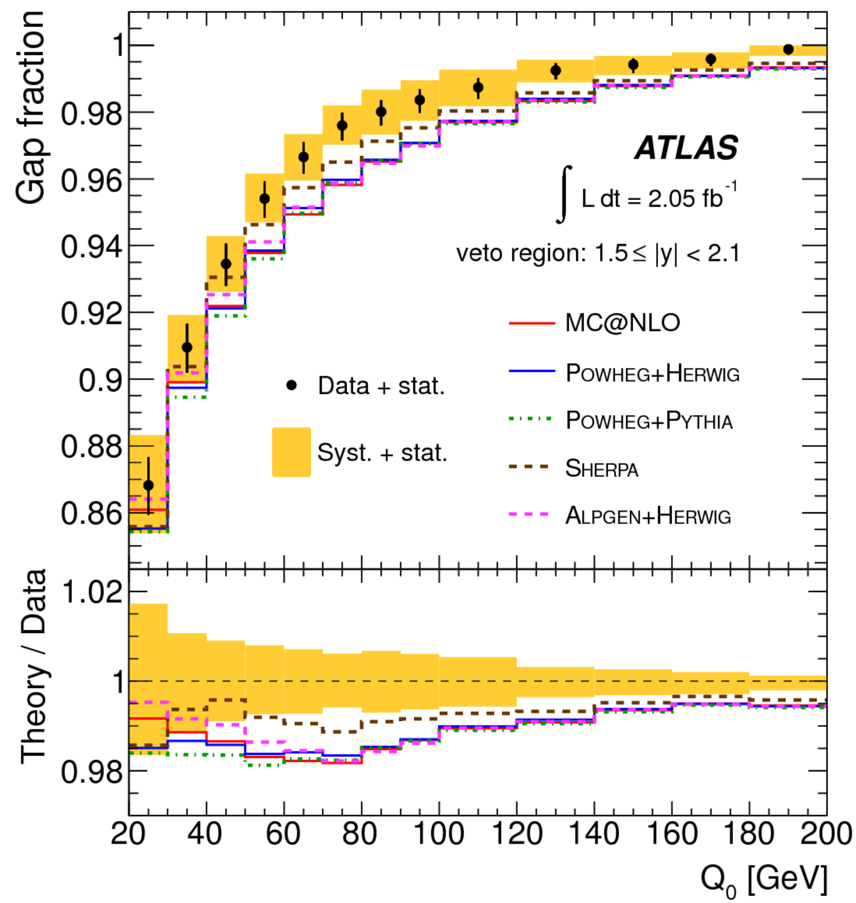
Jet multiplicity in fiducial region in $t\bar{t}$ production (ℓ+jets) at 7 TeV (4.7 fb^{-1})

Modelling of $t\bar{t}$ events

Rapidity gap fraction vs. |*y*| helps control modelling of ISR/FSR
→ targets large systematics on m_{top} measurement

Eur.Phys.J. C72 (2012) 2043





Gap fraction: fraction of selected $t\bar{t}$ events which do not have a jet with $p_T > Q_0$ in the |*y*| interval

Generally good description for |*y*| < 1.5, except MC@NLO (too little radiation)
For large |*y*| too much jet activity predicted

Searches

BSM Searches - Introduction

Comprehensive programme of measurements provides a solid basis for searches for physics Beyond the Standard Model

Nonetheless, generally we work hard to reduce any systematics from Monte Carlo modelling – very extensive use of data-driven background estimates using signal-suppressed control regions → allows to search before full programme of measurements is done!

MC typically is used to model smaller backgrounds, and to understand systematic errors coming from mapping control regions to background estimates in signal regions

BSM Searches - Introduction

A huge array of searches have been carried out, including:

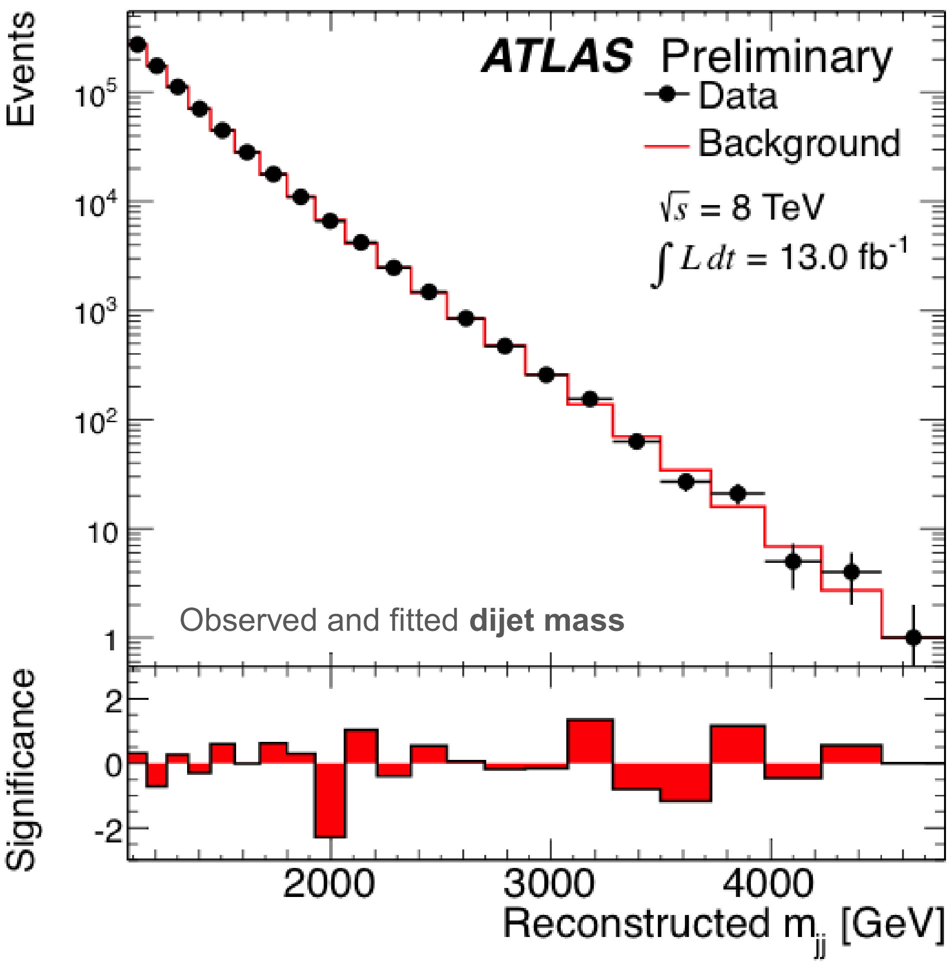
- Extra dimensions
- Excited vector bosons
- Contact interactions
- Leptoquarks
- New heavy quarks
- Excited fermions
- Technicolor
- Strongly produced $\tilde{q}$, $\tilde{g}$
- Gluino-mediated $\tilde{t}$, $\tilde{b}$ production
- Direct $\tilde{t}$, $\tilde{b}$ production
- Electroweak SUSY production
- Long-lived particles
- R-parity violating SUSY signatures
- … … …

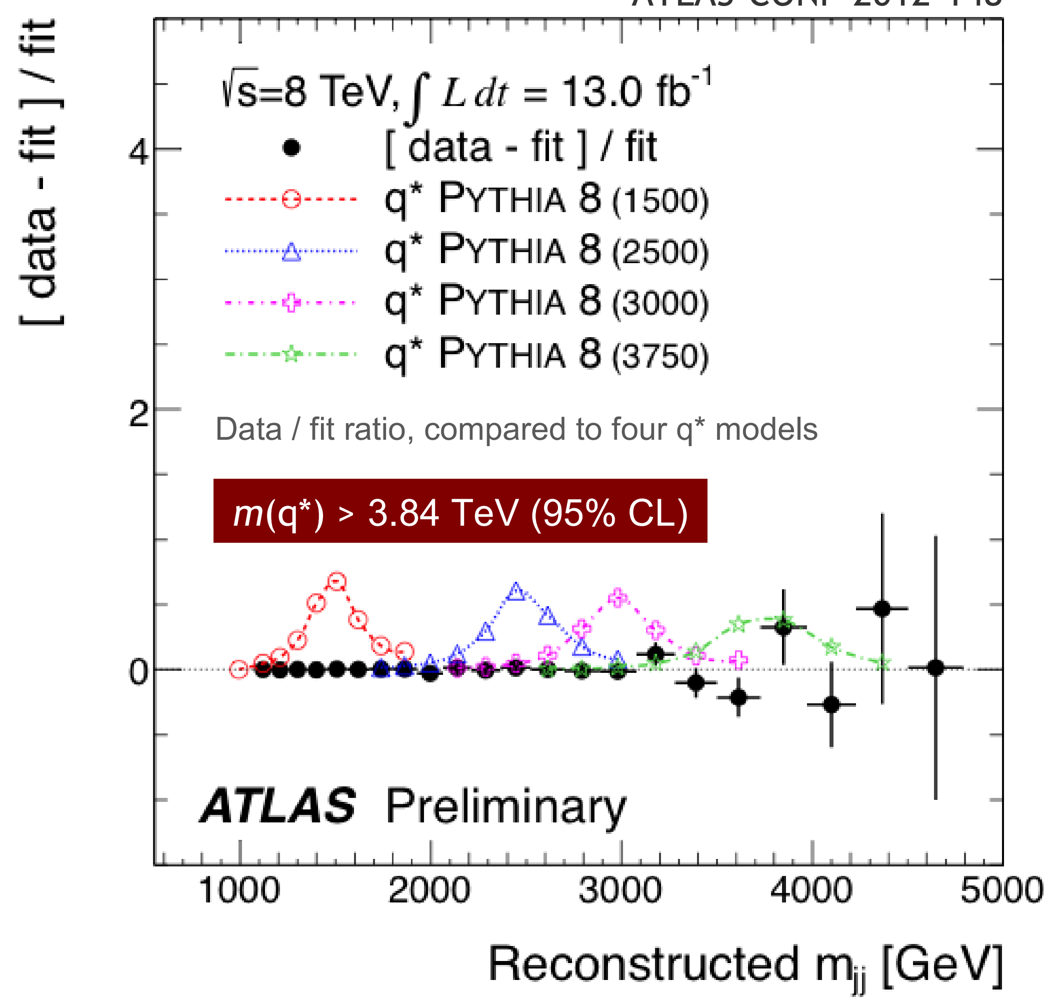
While a lot of the simpler signatures have been well explored at $\sqrt{s}$=8 TeV, much work is ongoing on more complex topologies

"Leave no stone unturned"

Multijet Topologies - Dijets

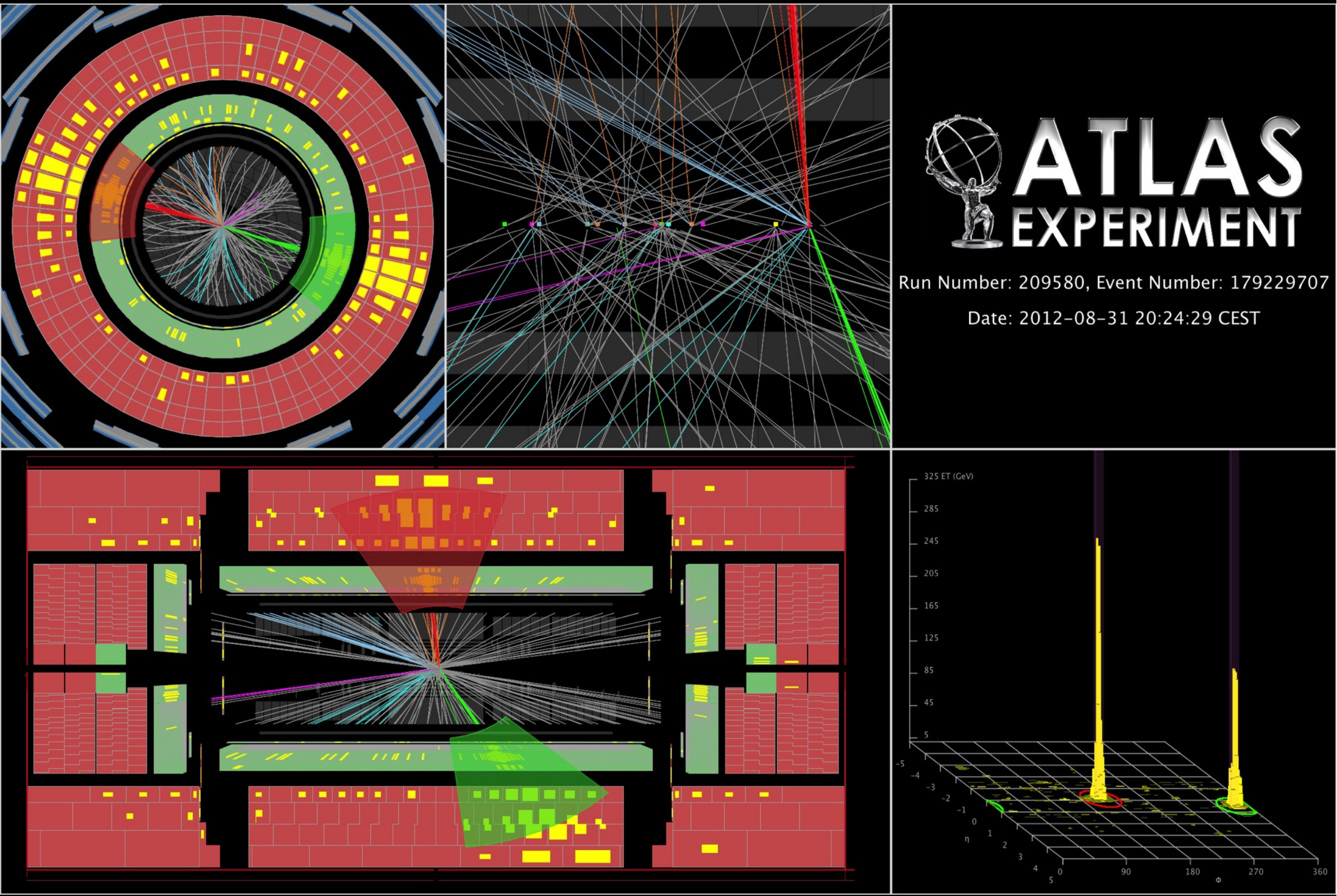
ATLAS-CONF-2012-148





In addition to limits on the benchmark q* model, also placed limits on generic gaussian resonances:
95% CL upper limits on $\boldsymbol{\sigma \times A}$ for σ_G/m_G = 0.07, 0.10 and 0.15

The highest-mass central dijet event. The two central high-p_T jets have an invariant mass of 4.69 TeV

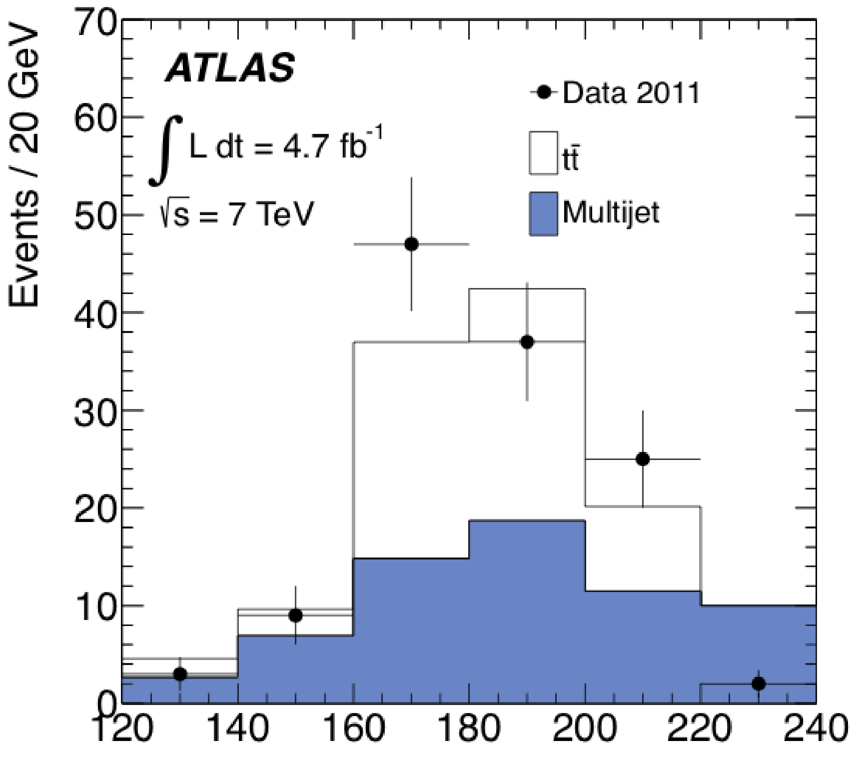


Multijet Topologies – Jet Substructure

Search for boosted hadronically decaying objects by looking at jet substructure

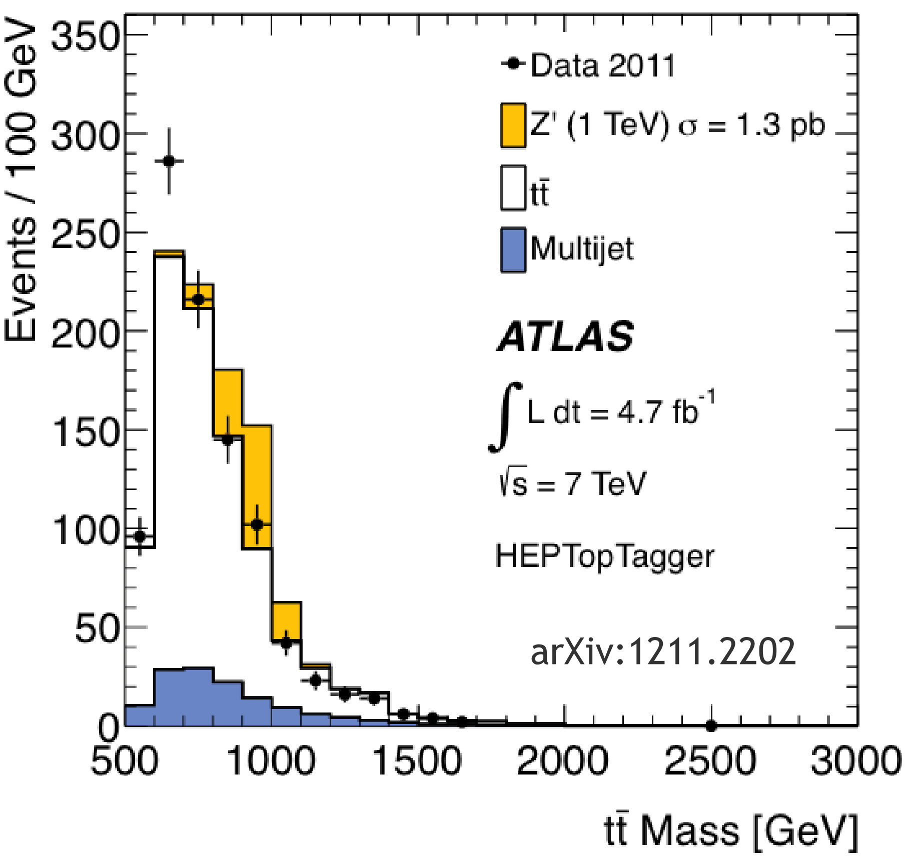
Two methods identify merged hadronic top decays

- ***HEP-Top-Tagger*** uses substructure of "fat jets"
- ***Top-Template-Tagger*** uses calorimeter templates



Jet mass of leading jets in Top-Template-Tagger signal region

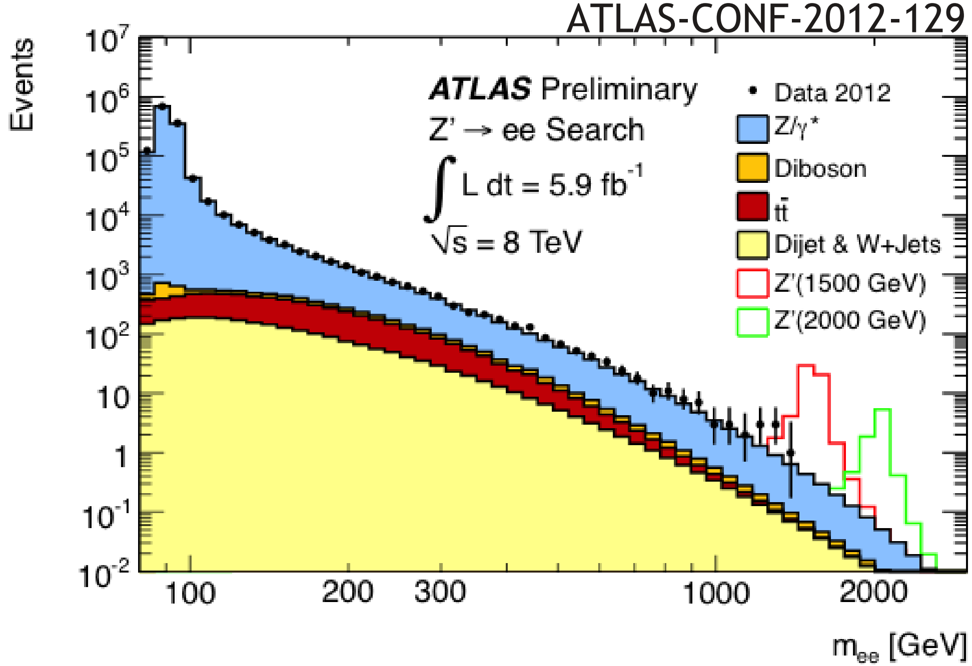
m(*tt*) after HEP-Top-Tagger identification



Leptophobic topcolour Z' excluded up to 1 TeV at 95% CL

Sequential Z' and W' in Leptonic Channels

ATLAS-CONF-2012-129



Z'→ℓℓ search extended with 8 TeV data

Sequential-SM Z'

$m(Z'_{SSM}) > 2.49$ TeV at 95% CL

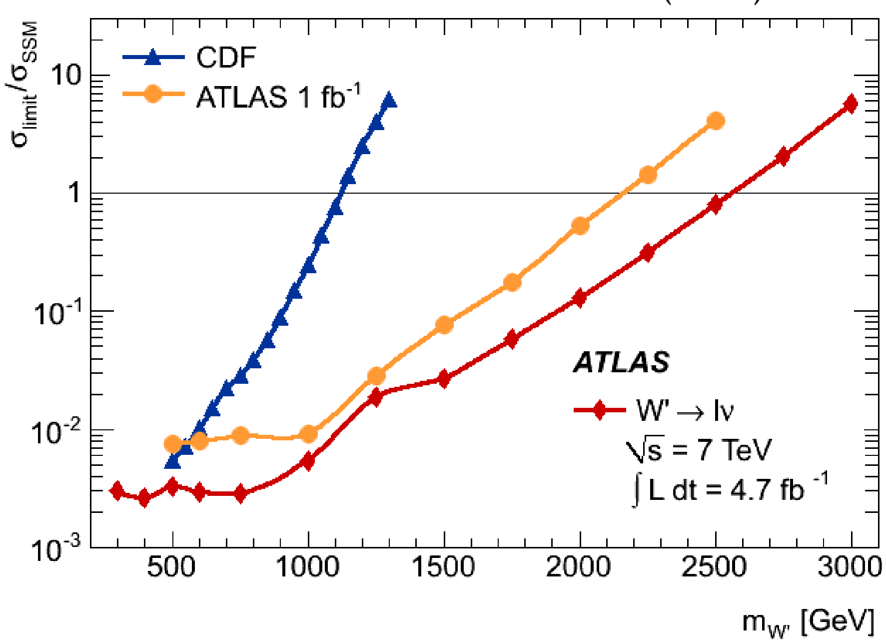
E6-motivated models:

$m(Z') > 2.09$ to 2.24 TeV at 95% CL

Also: new 7 TeV dilepton limits on *llqq* contact interaction between 9.5 and 12.9 TeV

arXiv:1211.1150

EPJC 72 (2012) 2241



W'→ℓν search – limits from

$m_T(\ell,\nu) = \sqrt{(2p_T^{\ell}E_T^{miss}(1-\cos\varphi_{\ell\nu}))}$

Sequential W'

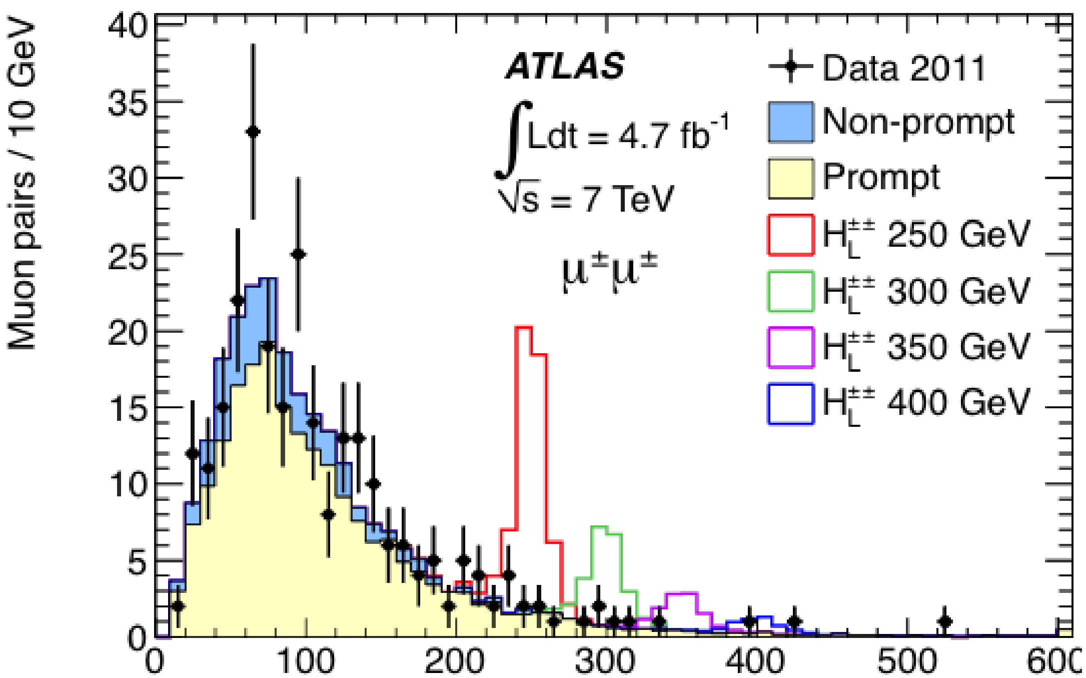
$m(W') > 2.55$ TeV at 95% CL

Chiral W*

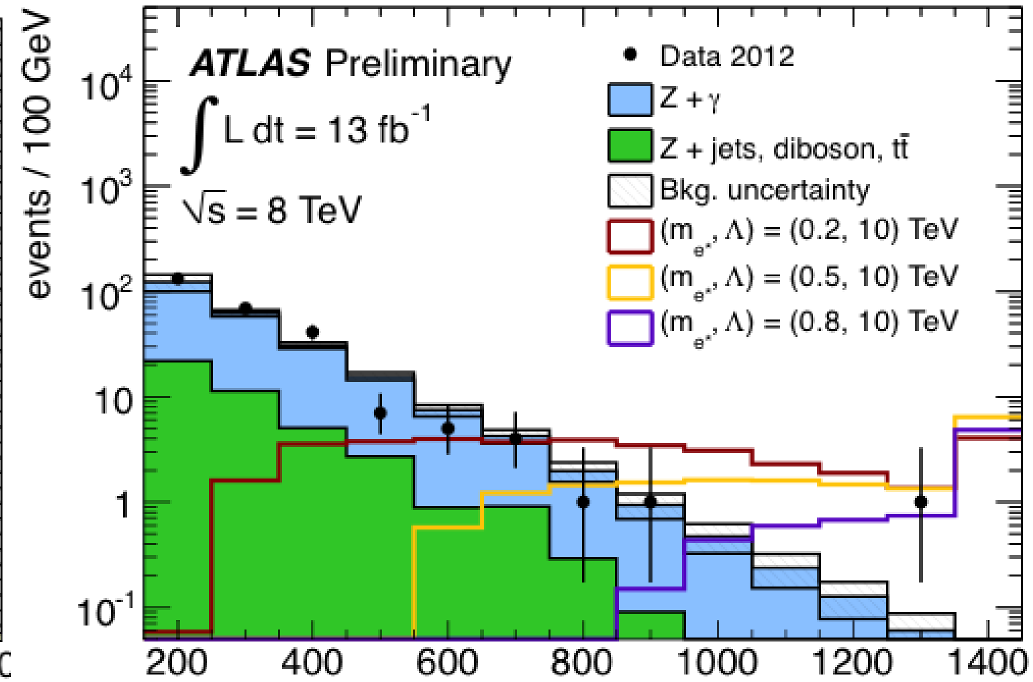
$m(W^*) > 2.42$ TeV at 95% CL

Hunting for other Peaks in ℓ/γ States

Doubly charged Higgs produce narrow like-sign resonance



Observed and predicted *eeγ* mass and signal models



EPJC 72 (2012) 2244
JHEP12(2012)007

ATLAS-CONF-2012-146

Prompt like-sign leptons powerful probe for many forms of new physics

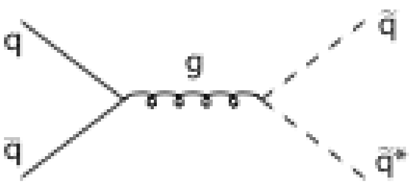
For compositeness scale $\Lambda = m(l^*)$: exclude excited leptons < 2.2 TeV at 95% CL

Other searches in trileptons, high-mass diphotons, ℓ+τ, ττ … …

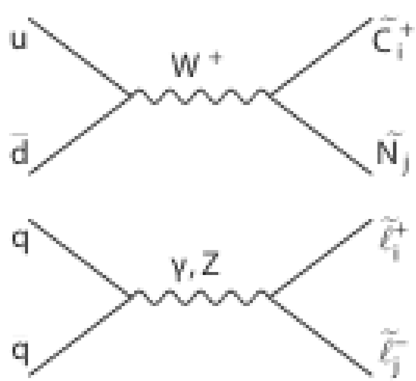
Still Seeking SUSY...

Extensive and deep programme of SUSY searches at ATLAS

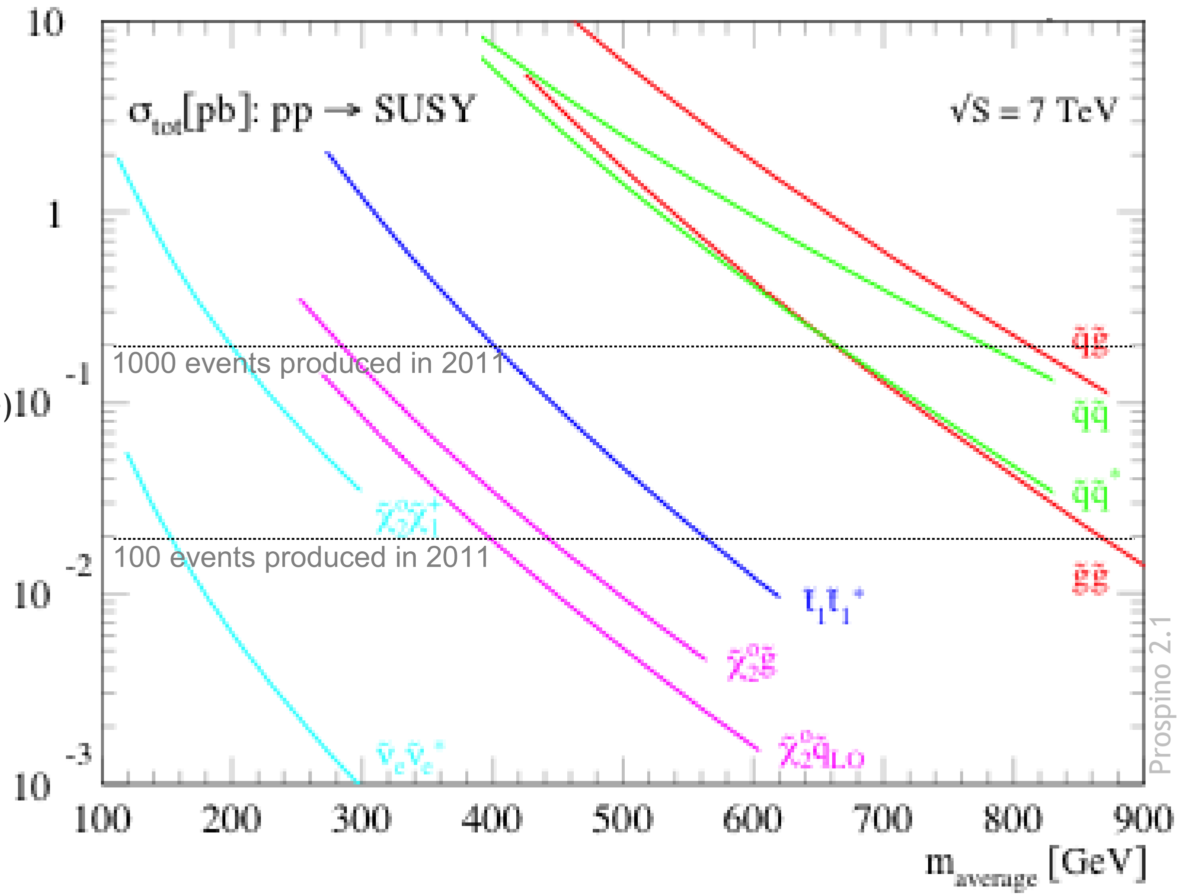
Direct squark pair production (example)



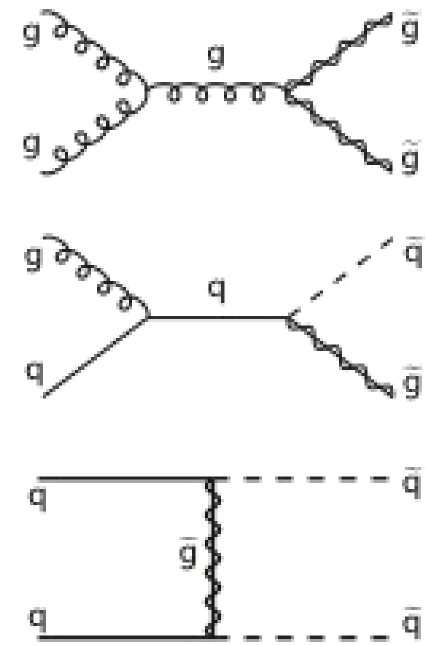
Direct gaugino/slepton pair production (example)



SUSY cross-section versus sparticle mass



Gluino & squark production (examples)

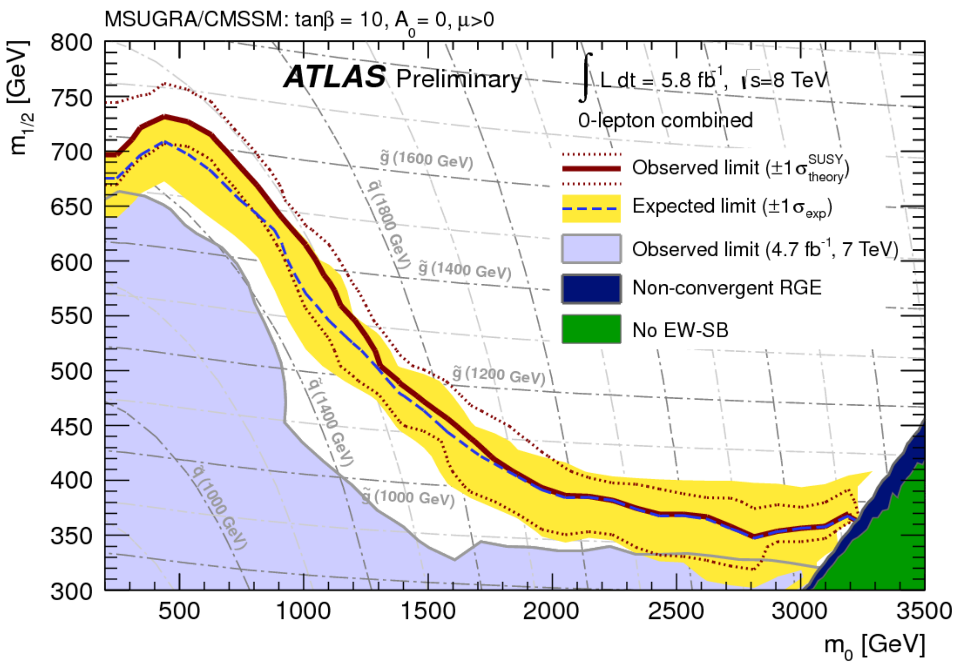


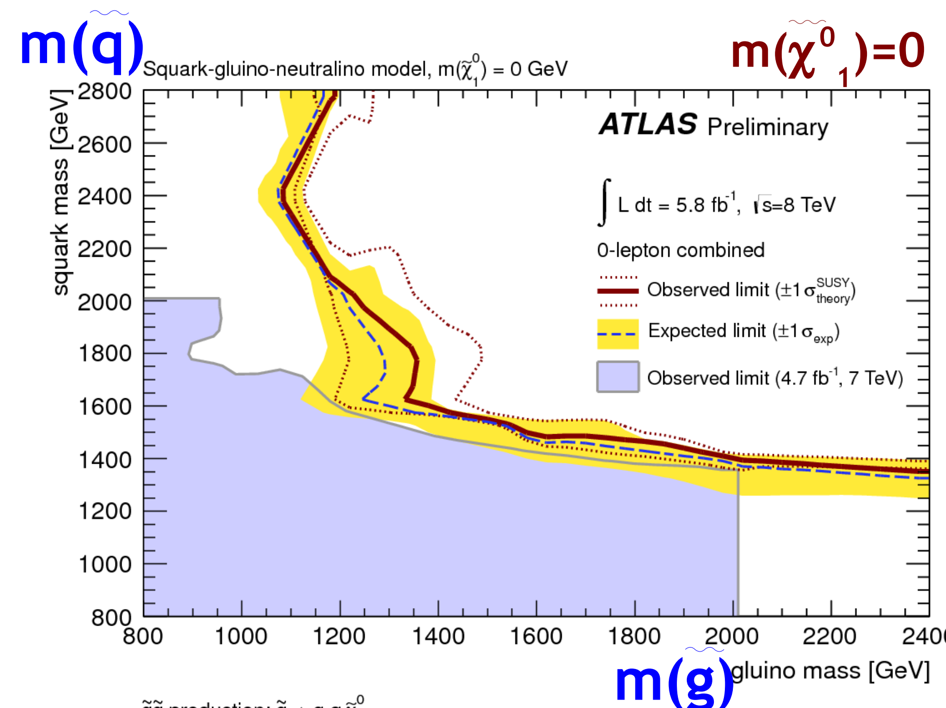
Strong Production of Squarks and Gluinos

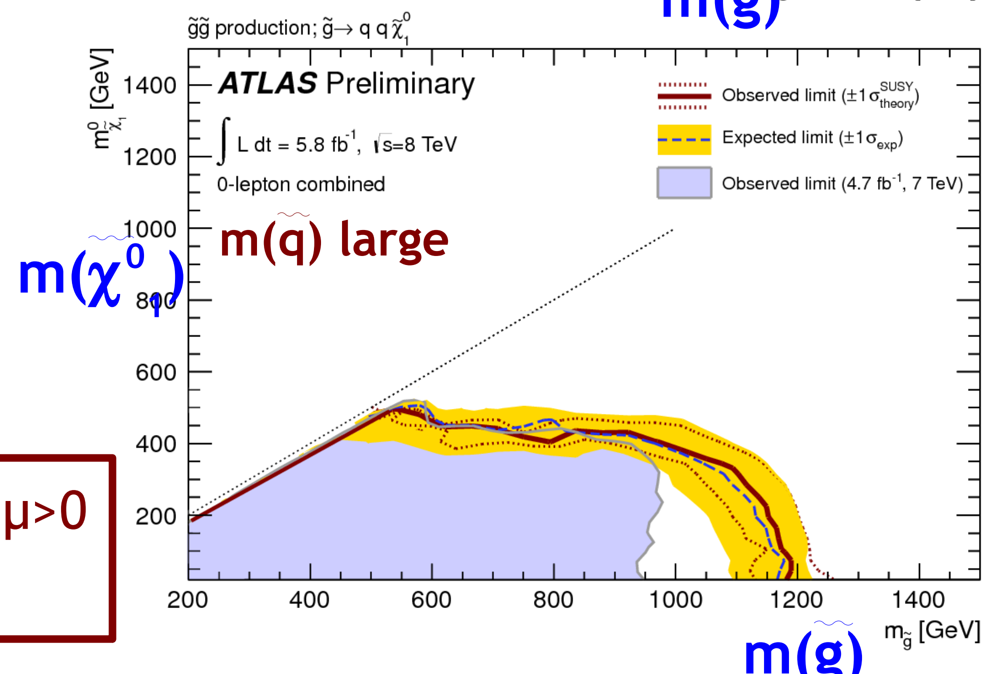
Complete "jets + X + E_T^{miss}" programme

Example: 0-lepton+(2-6 jets)+E_T^{miss}

Results presented in MSUGRA/CMSSM and in simplified models, to aid re-use







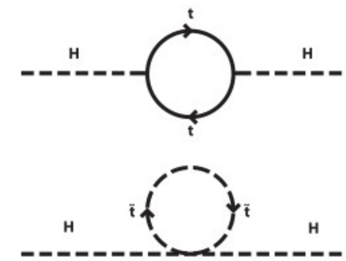
Multiple signal regions – selected according to best *expected* limit

Benchmark MSUGRA/CMSSM tanβ=10, A_0=0, μ>0

[m(q̃)=m(g̃)] > 1.5 TeV at 95% CL

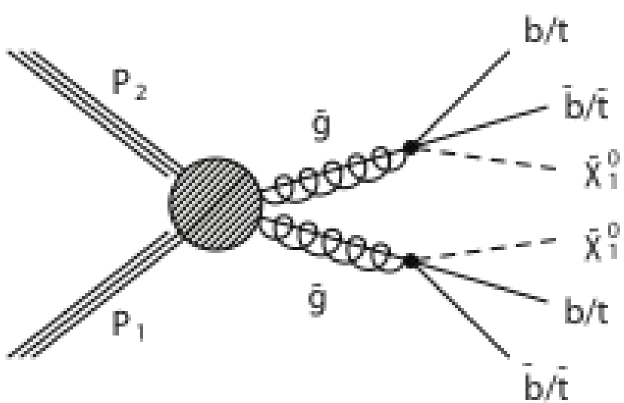
“Natural” Models – evading the absence of $\tilde{q}$ and $\tilde{g}$

In these models, the lightest squarks are $\tilde{t}/\tilde{b}$, gluinos possibly too heavy, gauginos may be accessible – but the Higgs mass can be stabilised

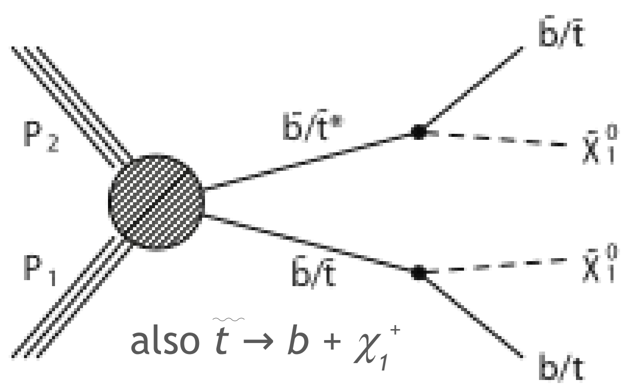


Lower cross-sections and larger SM backgrounds require dedicated searches

Systematic and comprehensive set of searches



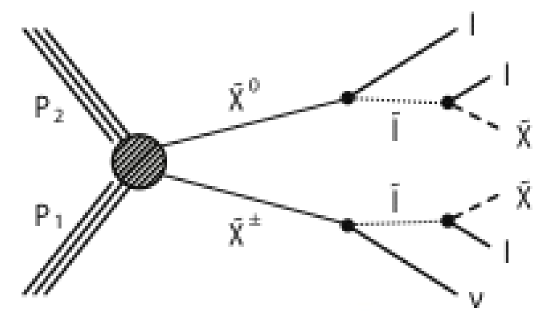
Gluino-mediated $\tilde{b}/\tilde{t}$ production

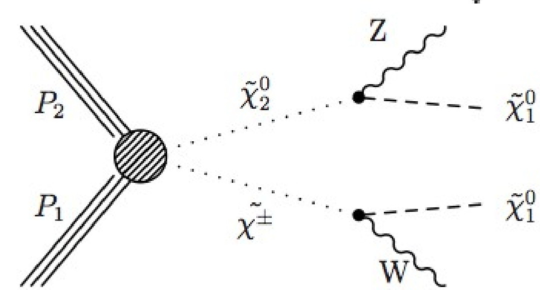


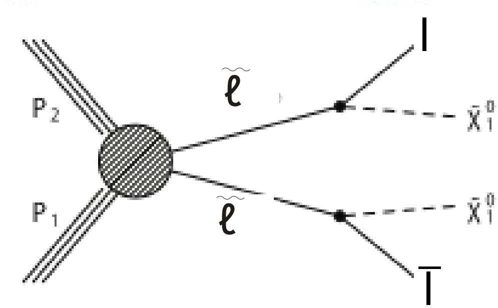
also $\tilde{t} \to b + \chi_1^+$

Direct $\tilde{b}/\tilde{t}$ pair production

Associated gaugino production







Direct slepton-pair production

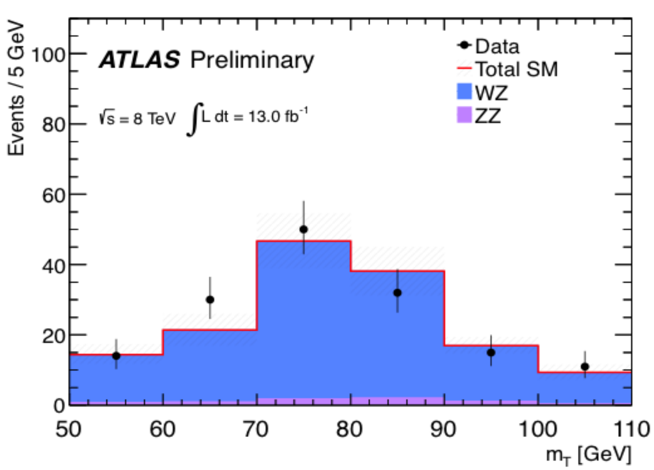
"Natural" Models – evading the absence of $\tilde{q}$ and $\tilde{g}$

Dedicated searches for EW slepton/gaugino production in multilepton final states published this summer; 8 TeV 13 fb^{-1} update of 3ℓ search

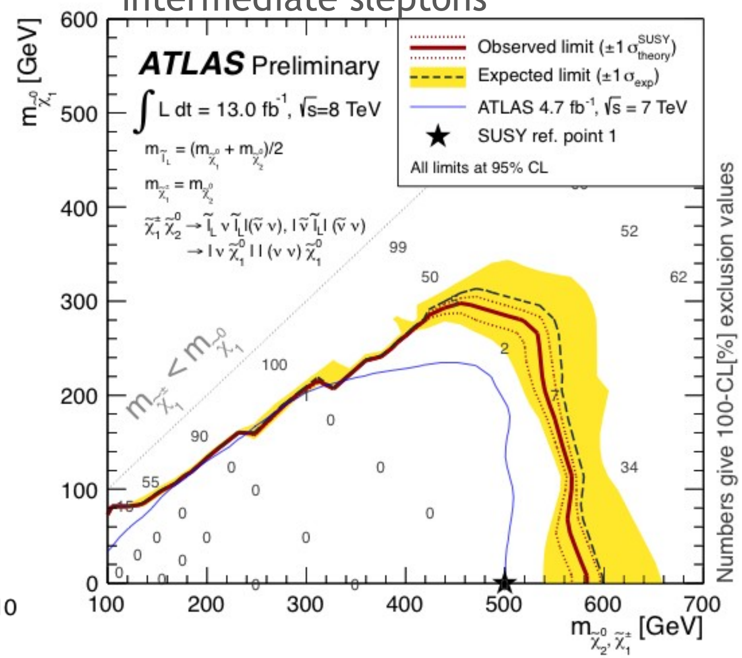
arXiv:1208.2884, arXiv:1208.3144, ATLAS-CONF-2012-154

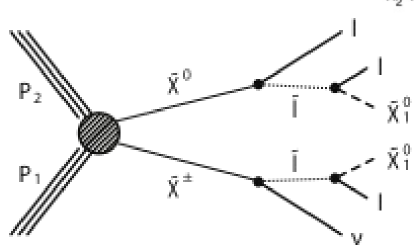
Interpretation in simplified models but also in a phenomenological MSSM model (less "naïve")

Significant background from *WZ* production; measured in dedicated control region

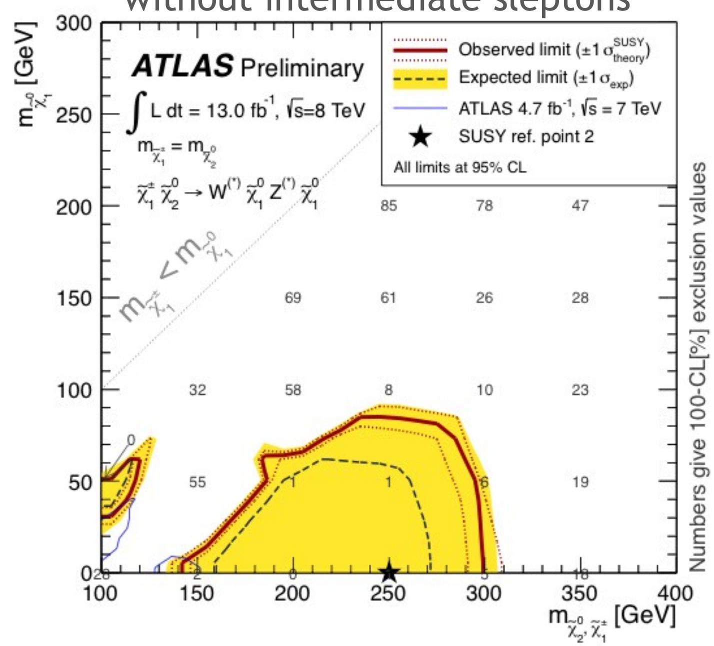


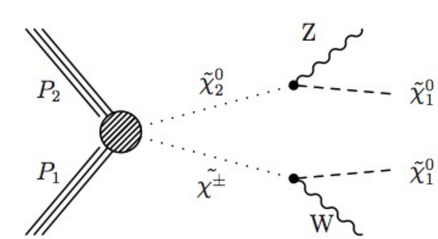
Limit on $\chi_1^+\chi_2^0$ production with intermediate sleptons



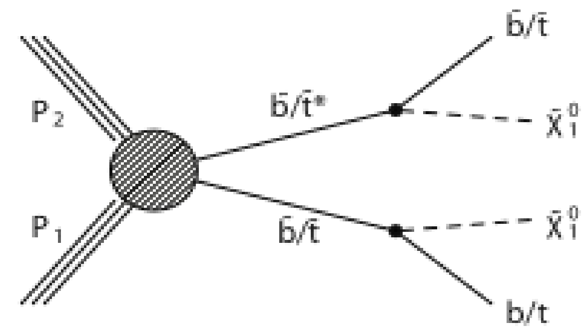


Limit on $\chi_1^+\chi_2^0$ production without intermediate sleptons



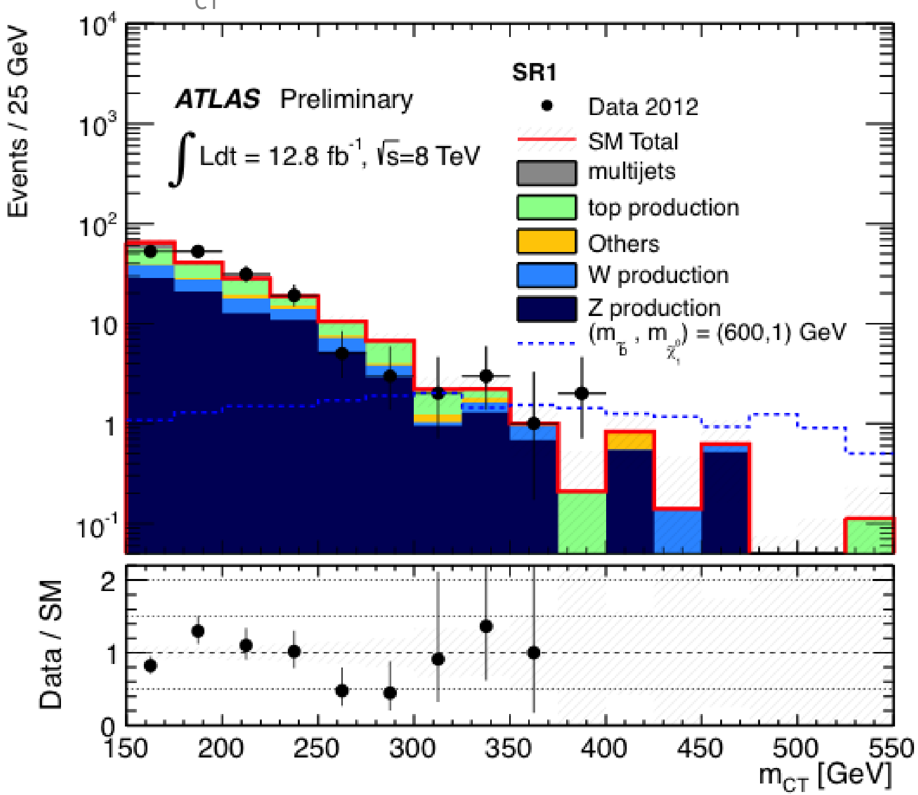


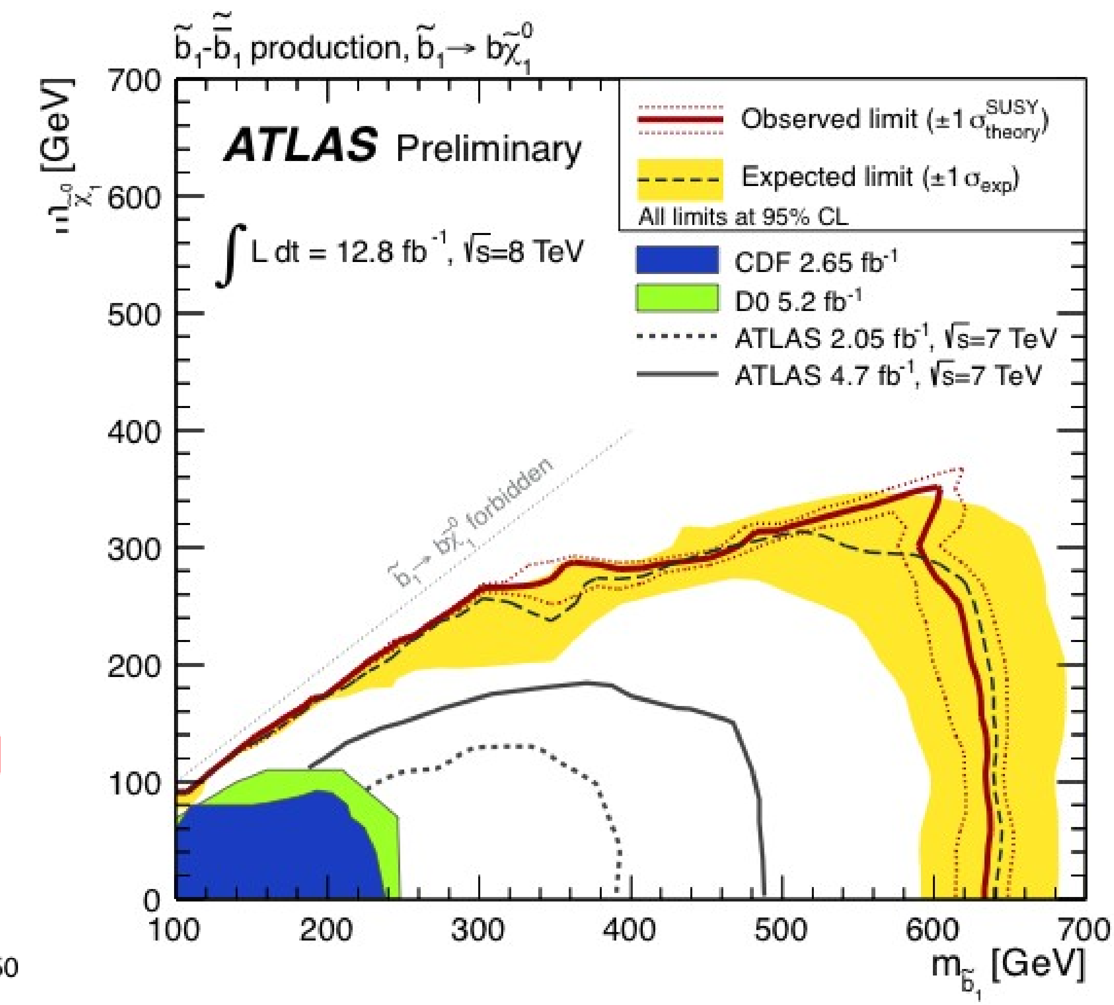
Direct Sbottom Production



Direct sbottom production can lead to $2b + E_T^{miss}$ (shown here) or also to multilepton + jets + E_T^{miss} final states

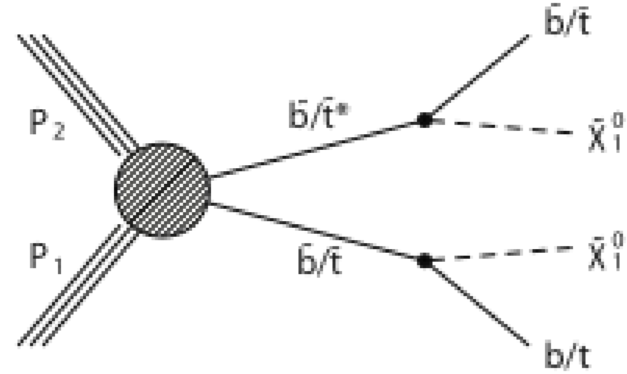
m_{CT} : boost-corrected contransverse mass





ATLAS-CONF-2012-151, ATLAS-CONF-2012-165

Direct Stop Production

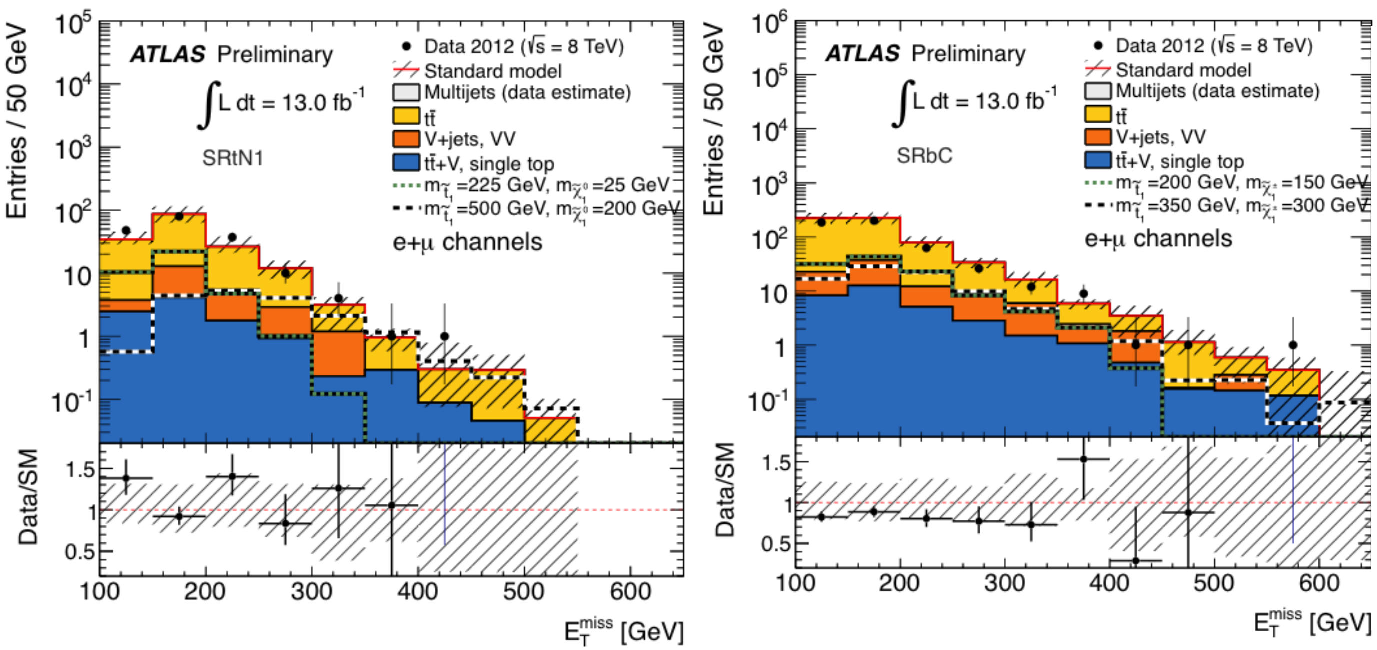


Similar final states as top pairs, searches use 0ℓ, 1ℓ, 2ℓ final states and depend on sparticle masses and stop decays

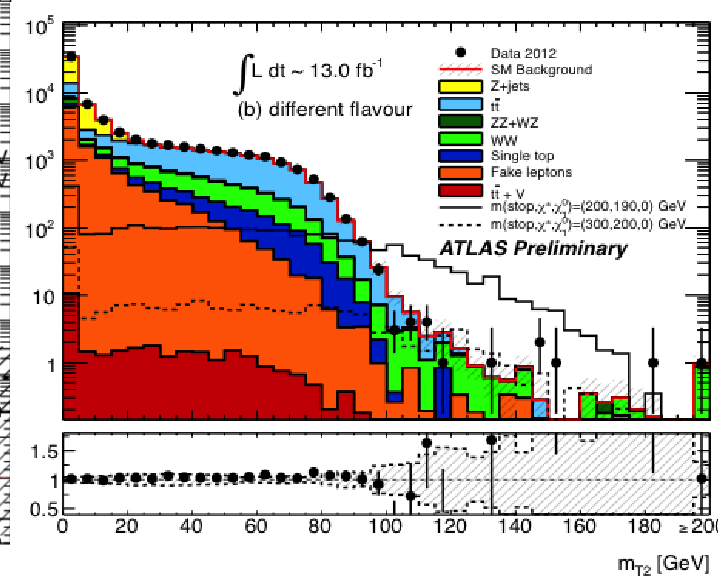
5 papers on 7 TeV: arXiv:1208.4305, arXiv:1209.2102, arXiv:1209.4186, arXiv:1208.2590, arXiv:1208.1447

New 8 TeV 13 fb^{-1} results in 1ℓ and 2ℓ final states, optimising for $\tilde{t} \rightarrow t + \chi^0$ and $\tilde{t} \rightarrow b + \chi^+$ decays

E_T^{miss} distributions in t + χ^0 (left) and b + χ^+ (right) signal regions [1ℓ analysis]

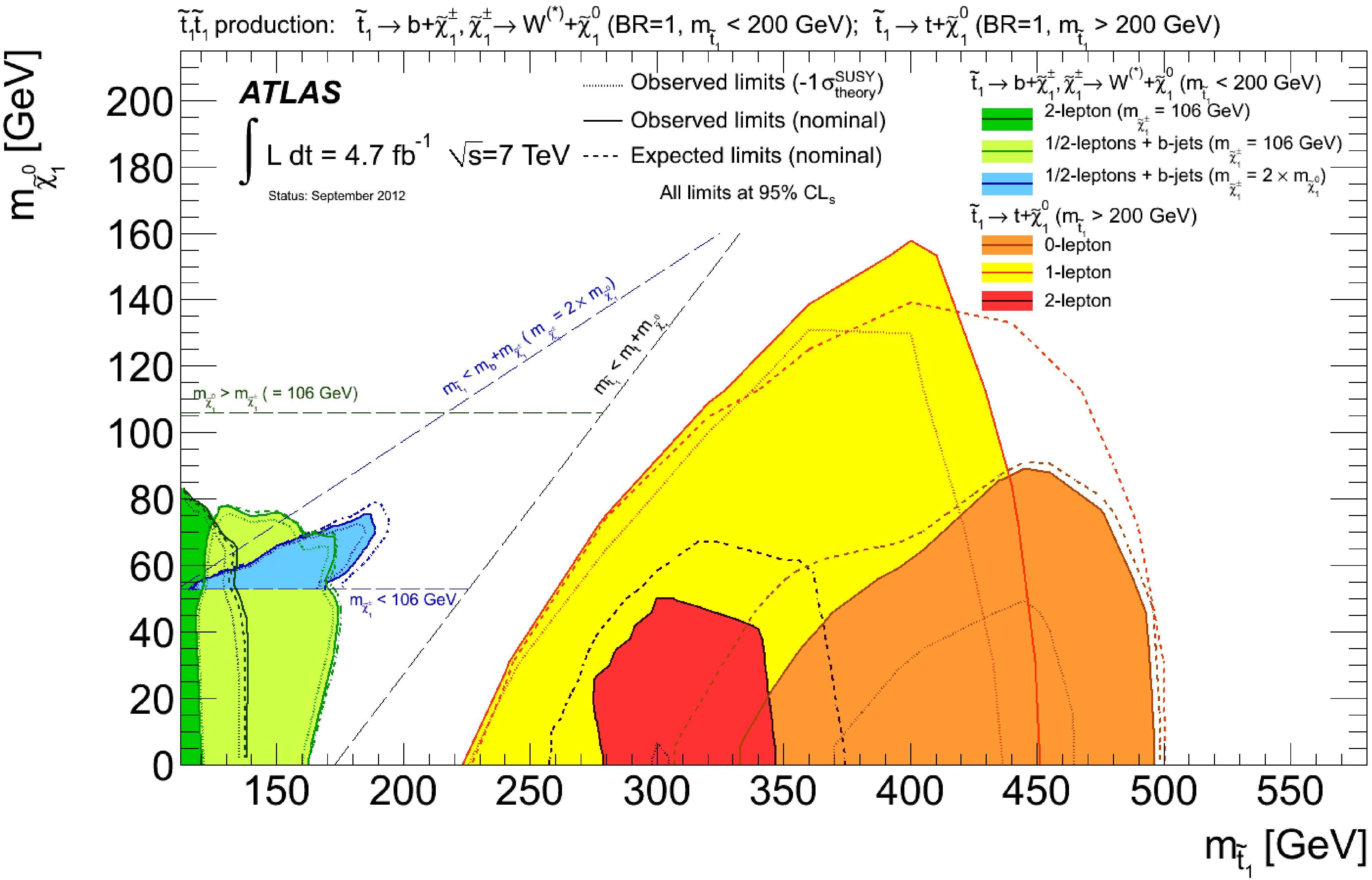


m_{T2} distributions in b + χ^+ (right) signal region [2ℓ analysis]

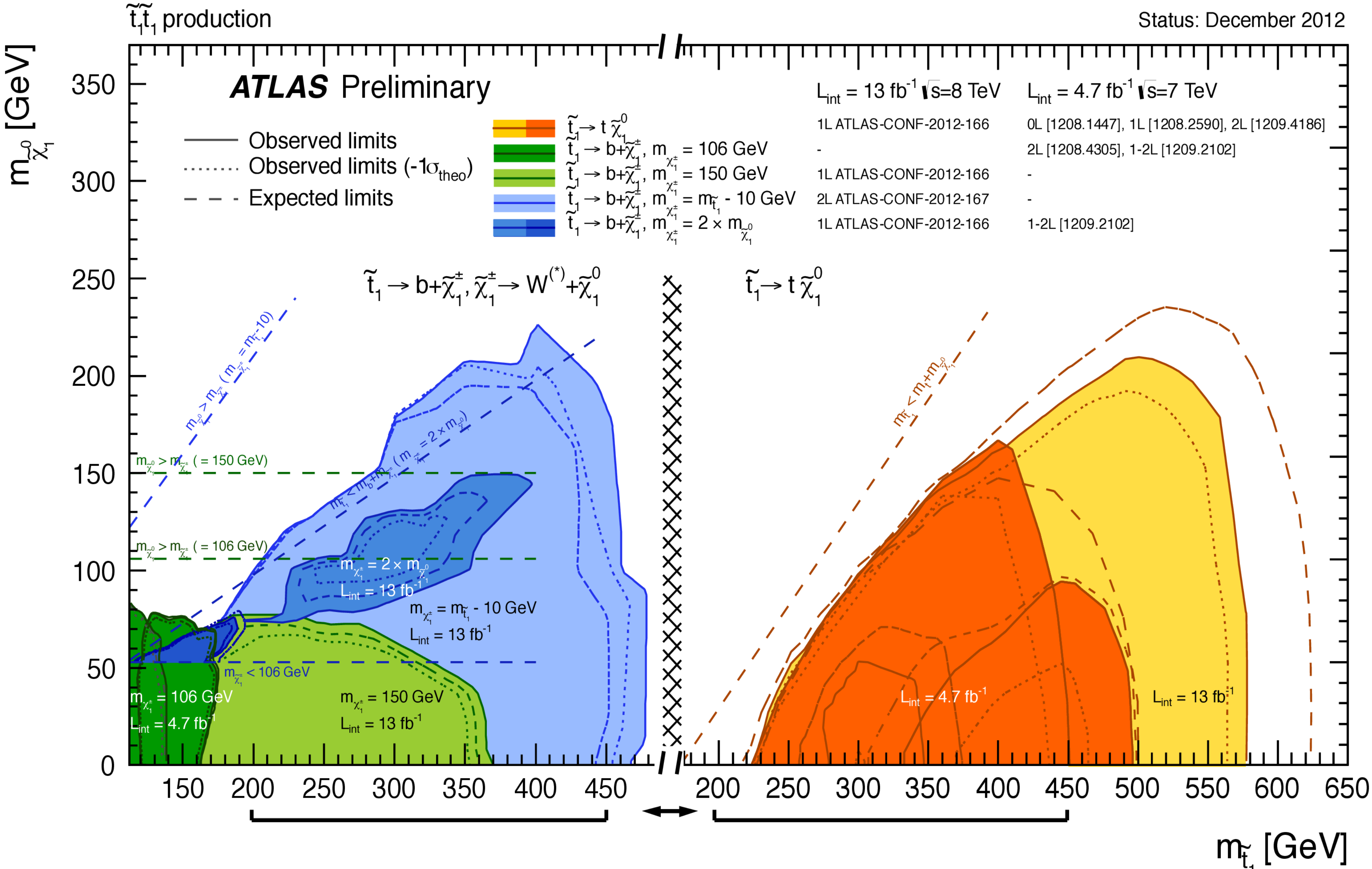


ATLAS-CONF-2012-166, ATLAS-CONF-2012-167

Direct Stop Summary - Status at SUSY12 this summer



Direct Stop Summary

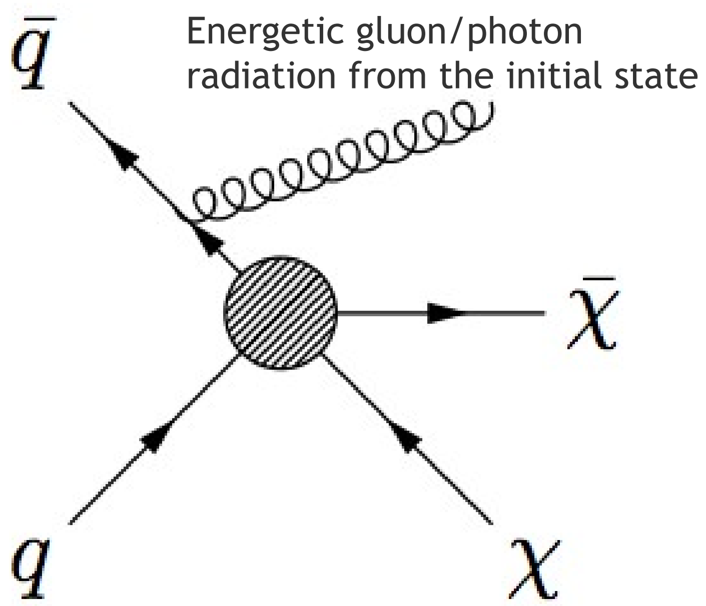


Significantly improved sensitivity at high stop mass with expected limits up to 620 GeV (prev. 500 GeV)
Also, strongly enhanced sensitivity for lower mass stop decaying into *b* + chargino
There is still room at low mass — remember: **our models are simplified**

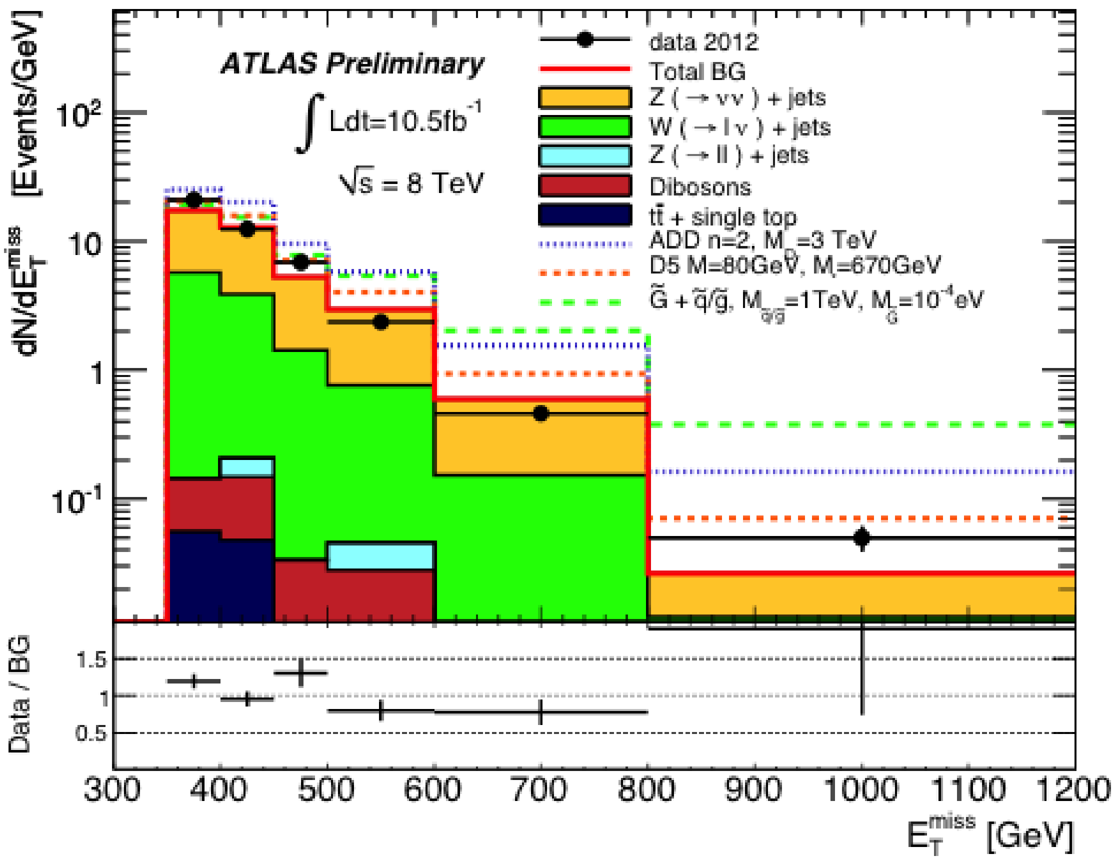
Looking more generically for Dark Matter?

An alternative approach: search directly for production on invisible WIMPs in proton-proton collisions

Exploit "ISR technique"



arXiv:1210.4491, ATLAS-CONF-2012-147



Signature: mono-jet events
We need the hard ISR jet to trigger the event

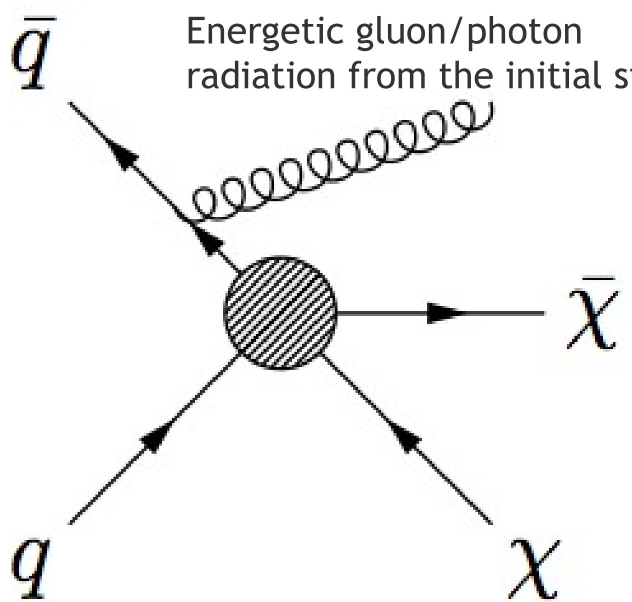
Interpretations in variety of models: extra dimensions, WIMP, gravitinos

Looking more generically for Dark Matter?

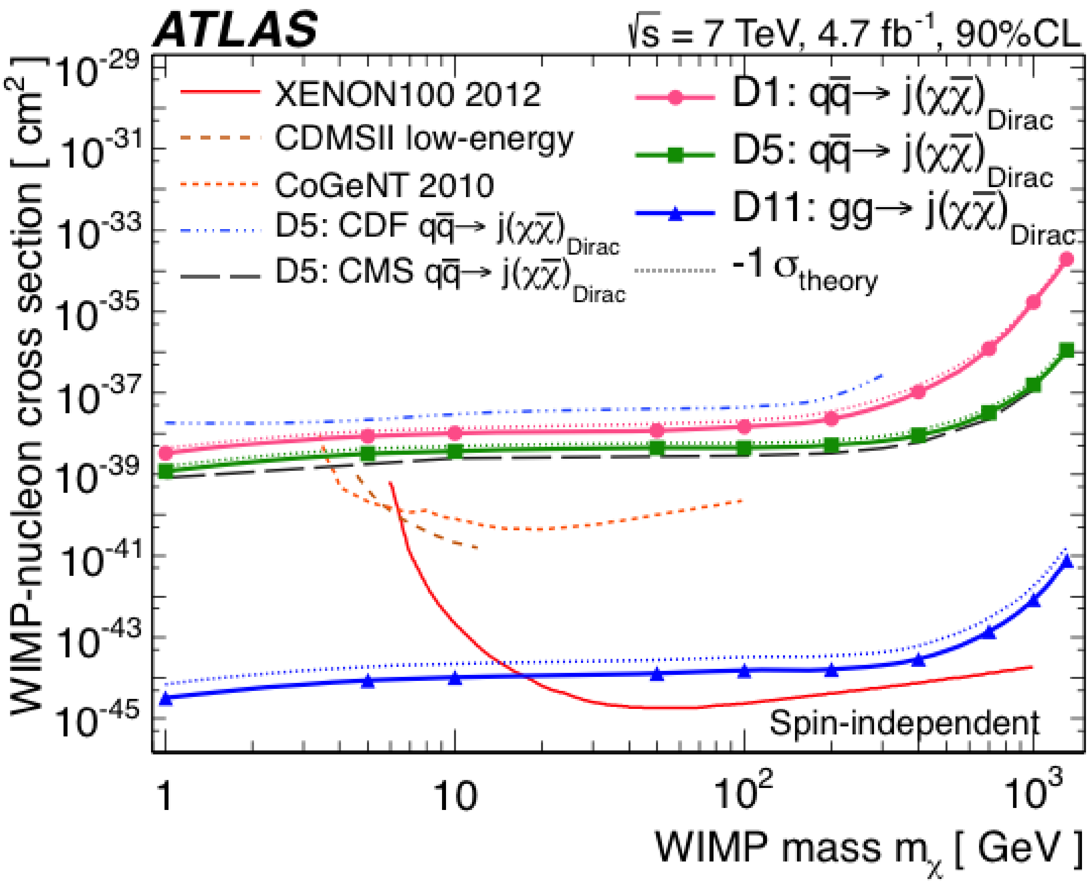
An alternative approach: search directly for production on invisible WIMPs in proton-proton collisions

Exploit "ISR technique"

Energetic gluon/photon radiation from the initial state



arXiv:1210.4491, ATLAS-CONF-2012-147



Signature: mono-jet events
We need the hard ISR jet to trigger the event

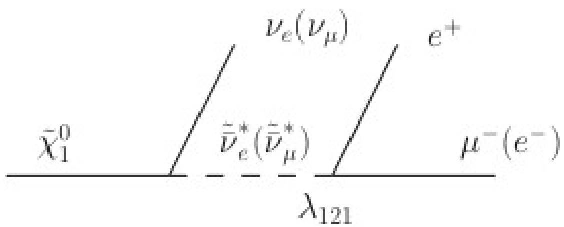
Interpretations in variety of models: extra dimensions, WIMP, gravitinos

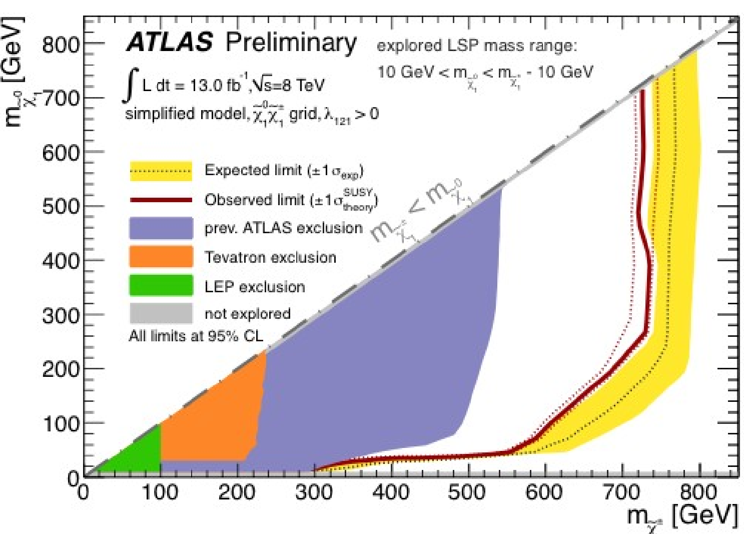
R-Parity Violating SUSY scenarios

Decays of the LSP in RPV models can lead to many leptons, jets and/or resonances

Dedicated programme to assess the extremely broad phenomenology

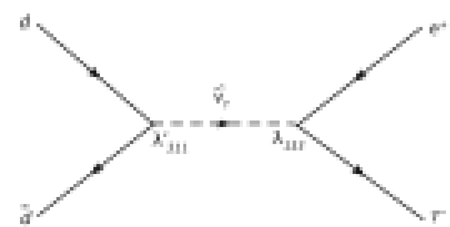
Search for strong and EW SUSY-RPV production in events with >=4ℓ

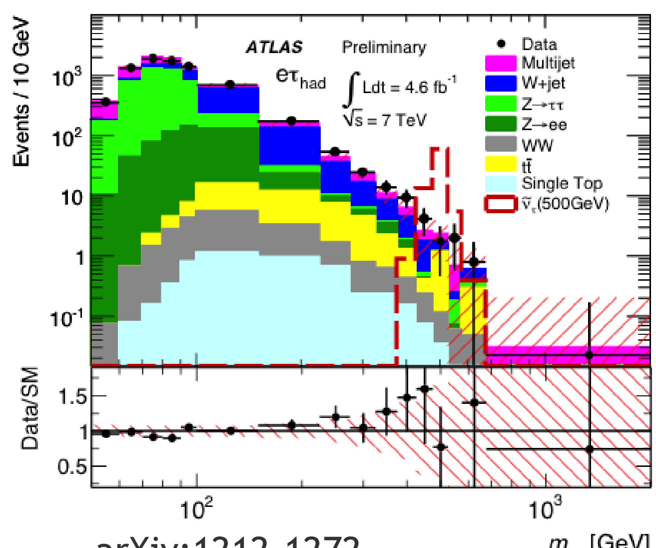




ATLAS-CONF-2012-153

Search for RPV sneutrino production and decay through LFV into $\ell\ell$'

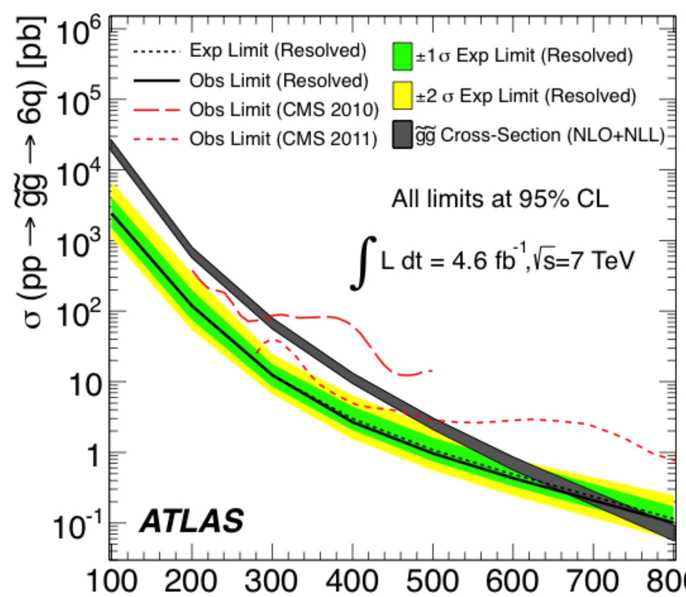




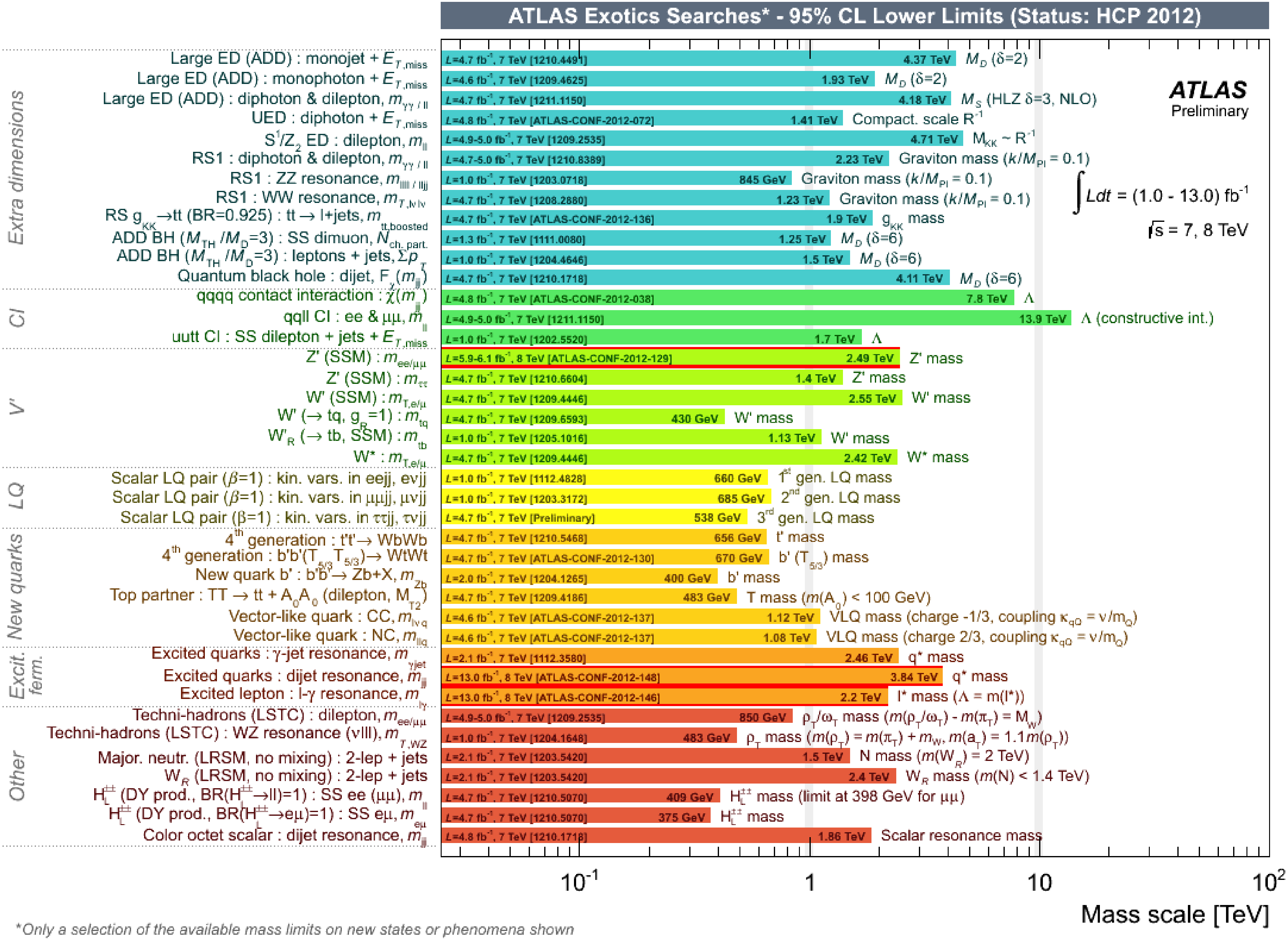
arXiv:1212.1272

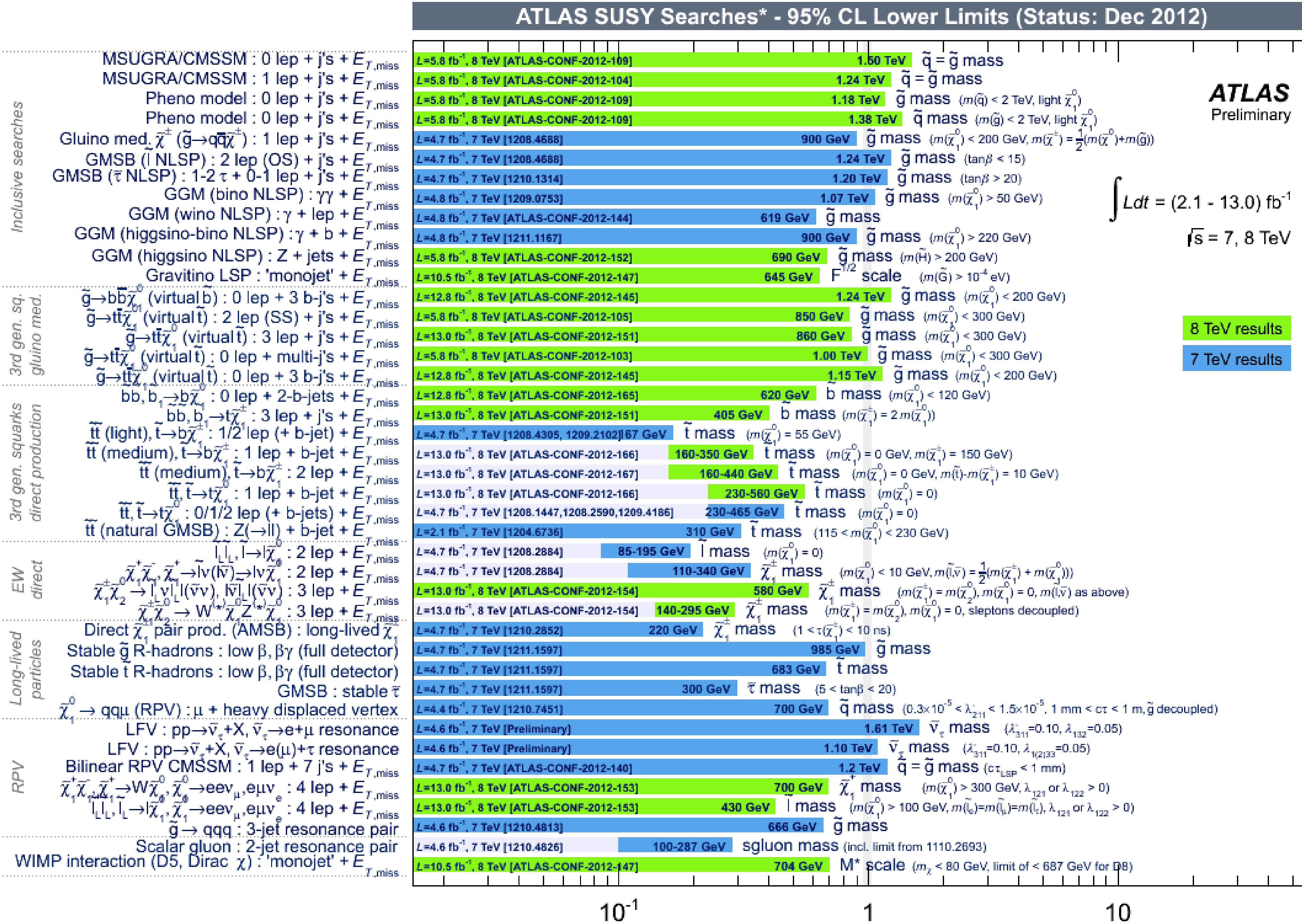
Search pairs of gluino decays to 3q

- Powerful limit from jet multiplicity and p_T (no mass reconstruction)
- Boosted and resolved jets analysis



arXiv:1210.4813

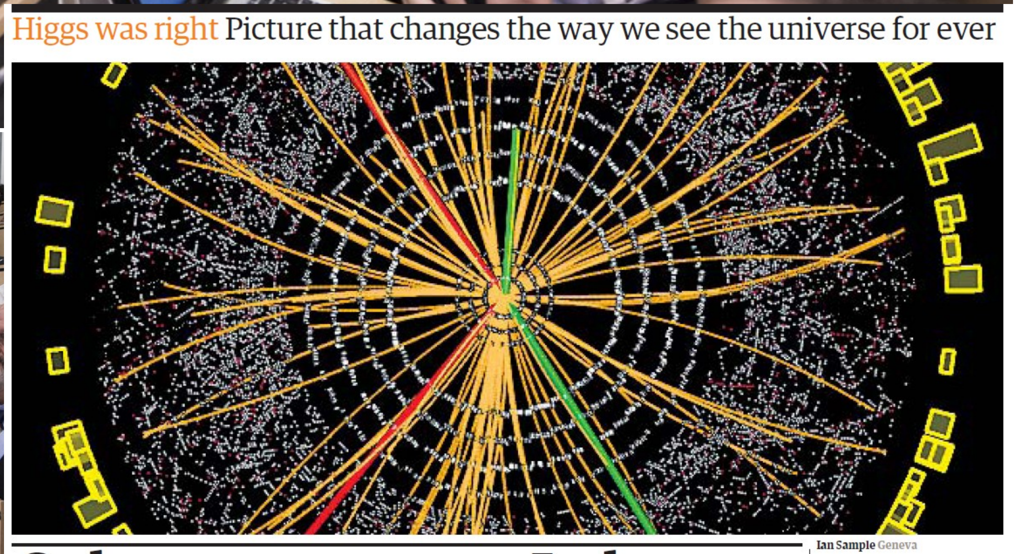

ATLAS Exotics Searches* - 95% CL Lower Limits (Status: HCP 2012)
ATLAS
Preliminary
∫Ldt = (1.0 - 13.0) fb^-1
√s = 7, 8 TeV
Extra dimensions
Large ED (ADD) : monojet + E_T,miss
L=4.7 fb^-1, 7 TeV [1210.4491]
4.37 TeV
M_D (δ=2)
Large ED (ADD) : monophoton + E_T,miss
L=4.6 fb^-1, 7 TeV [1209.4625]
1.93 TeV
M_D (δ=2)
Large ED (ADD) : diphoton & dilepton, m_γγ / ll
L=4.7 fb^-1, 7 TeV [1211.1150]
4.18 TeV
M_S (HLZ δ=3, NLO)
UED : diphoton + E_T,miss
L=4.8 fb^-1, 7 TeV [ATLAS-CONF-2012-072]
1.41 TeV
Compact. scale R^-1
S^1/Z_2 ED : dilepton, m_ll
L=4.9-5.0 fb^-1, 7 TeV [1209.2535]
4.71 TeV
M_KK ~ R^-1
RS1 : diphoton & dilepton, m_γγ / ll
L=4.7-5.0 fb^-1, 7 TeV [1210.8389]
2.23 TeV
Graviton mass (k/M_Pl = 0.1)
RS1 : ZZ resonance, m_llll / lljj
L=1.0 fb^-1, 7 TeV [1203.0718]
845 GeV
Graviton mass (k/M_Pl = 0.1)
RS1 : WW resonance, m_T,lνlν
L=4.7 fb^-1, 7 TeV [1208.2880]
1.23 TeV
Graviton mass (k/M_Pl = 0.1)
RS g_KK→tt (BR=0.925) : tt → l+jets, m_tt,boosted
L=4.7 fb^-1, 7 TeV [ATLAS-CONF-2012-136]
1.9 TeV
g_KK mass
ADD BH (M_TH /M_D=3) : SS dimuon, N_ch. part.
L=1.3 fb^-1, 7 TeV [1111.0080]
1.25 TeV
M_D (δ=6)
ADD BH (M_TH /M_D=3) : leptons + jets, Σp_T
L=1.0 fb^-1, 7 TeV [1204.4646]
1.5 TeV
M_D (δ=6)
Quantum black hole : dijet, F_χ(m_jj)
L=4.7 fb^-1, 7 TeV [1210.1718]
4.11 TeV
M_D (δ=6)
CI
qqqq contact interaction : χ(m_jj)
L=4.8 fb^-1, 7 TeV [ATLAS-CONF-2012-038]
7.8 TeV
Λ
qqll CI : ee & μμ, m_ll
L=4.9-5.0 fb^-1, 7 TeV [1211.1150]
13.9 TeV
Λ (constructive int.)
uutt CI : SS dilepton + jets + E_T,miss
L=1.0 fb^-1, 7 TeV [1202.5520]
1.7 TeV
Λ
V'
Z' (SSM) : m_ee/μμ
L=5.9-6.1 fb^-1, 8 TeV [ATLAS-CONF-2012-129]
2.49 TeV
Z' mass
Z' (SSM) : m_ττ
L=4.7 fb^-1, 7 TeV [1210.6604]
1.4 TeV
Z' mass
W' (SSM) : m_T,e/μ
L=4.7 fb^-1, 7 TeV [1209.4446]
2.55 TeV
W' mass
W' (→ tq, g_R=1) : m_tq
L=4.7 fb^-1, 7 TeV [1209.6593]
430 GeV
W' mass
W'_R (→ tb, SSM) : m_tb
L=1.0 fb^-1, 7 TeV [1205.1016]
1.13 TeV
W' mass
W* : m_T,e/μ
L=4.7 fb^-1, 7 TeV [1209.4446]
2.42 TeV
W* mass
LQ
Scalar LQ pair (β=1) : kin. vars. in eejj, eνjj
L=1.0 fb^-1, 7 TeV [1112.4828]
660 GeV
1st gen. LQ mass
Scalar LQ pair (β=1) : kin. vars. in μμjj, μνjj
L=1.0 fb^-1, 7 TeV [1203.3172]
685 GeV
2nd gen. LQ mass
Scalar LQ pair (β=1) : kin. vars. in ττjj, τνjj
L=4.7 fb^-1, 7 TeV [Preliminary]
538 GeV
3rd gen. LQ mass
New quarks
4th generation : t't'→ WbWb
L=4.7 fb^-1, 7 TeV [1210.5468]
656 GeV
t' mass
4th generation : b'b'(T_5/3T_5/3)→ WtWt
L=4.7 fb^-1, 7 TeV [ATLAS-CONF-2012-130]
670 GeV
b' (T_5/3) mass
New quark b' : b'b'→ Zb+X, m_Zb
L=2.0 fb^-1, 7 TeV [1204.1265]
400 GeV
b' mass
Top partner : TT → tt + A_0A_0 (dilepton, M_T2)
L=4.7 fb^-1, 7 TeV [1209.4186]
483 GeV
T mass (m(A_0) < 100 GeV)
Vector-like quark : CC, m_lνq
L=4.6 fb^-1, 7 TeV [ATLAS-CONF-2012-137]
1.12 TeV
VLQ mass (charge -1/3, coupling κ_qQ = ν/m_Q)
Vector-like quark : NC, m_llq
L=4.6 fb^-1, 7 TeV [ATLAS-CONF-2012-137]
1.08 TeV
VLQ mass (charge 2/3, coupling κ_qQ = ν/m_Q)
Excit. ferm.
Excited quarks : γ-jet resonance, m_γjet
L=2.1 fb^-1, 7 TeV [1112.3580]
2.46 TeV
q* mass
Excited quarks : dijet resonance, m_jj
L=13.0 fb^-1, 8 TeV [ATLAS-CONF-2012-148]
3.84 TeV
q* mass
Excited lepton : l-γ resonance, m_lγ
L=13.0 fb^-1, 8 TeV [ATLAS-CONF-2012-146]
2.2 TeV
l* mass (Λ = m(l*))
Other
Techni-hadrons (LSTC) : dilepton, m_ee/μμ
L=4.9-5.0 fb^-1, 7 TeV [1209.2535]
850 GeV
ρ_T/ω_T mass (m(ρ_T/ω_T) - m(π_T) = M_W)
Techni-hadrons (LSTC) : WZ resonance (νlll), m_T,WZ
L=1.0 fb^-1, 7 TeV [1204.1648]
483 GeV
ρ_T mass (m(ρ_T) = m(π_T) + m_W, m(a_T) = 1.1m(ρ_T))
Major. neutr. (LRSM, no mixing) : 2-lep + jets
L=2.1 fb^-1, 7 TeV [1203.5420]
1.5 TeV
N mass (m(W_R) = 2 TeV)
W_R (LRSM, no mixing) : 2-lep + jets
L=2.1 fb^-1, 7 TeV [1203.5420]
2.4 TeV
W_R mass (m(N) < 1.4 TeV)
H_L^±± (DY prod., BR(H_L^±±→ll)=1) : SS ee (μμ), m_ll
L=4.7 fb^-1, 7 TeV [1210.5070]
409 GeV
H_L^±± mass (limit at 398 GeV for μμ)
H_L^±± (DY prod., BR(H_L^±±→eμ)=1) : SS eμ, m_eμ
L=4.7 fb^-1, 7 TeV [1210.5070]
375 GeV
H_L^±± mass
Color octet scalar : dijet resonance, m_jj
L=4.8 fb^-1, 7 TeV [1210.1718]
1.86 TeV
Scalar resonance mass
10^-1
1
10
10^2
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena shown



*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

July 4th (CERN and Melbourne)

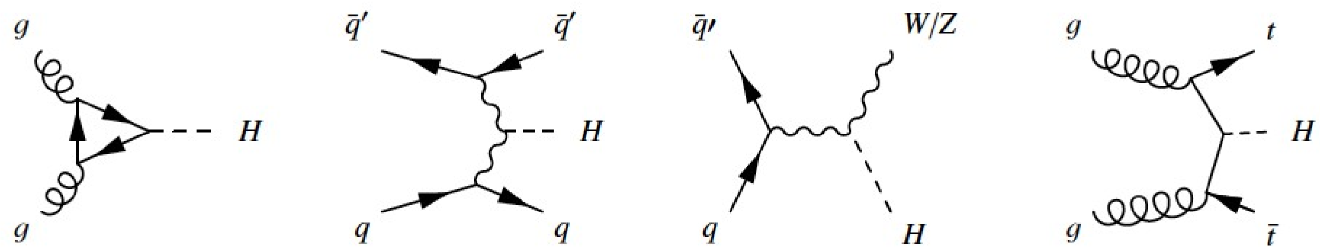
The New Boson


Higgs was right Picture that changes the way we see the universe for ever

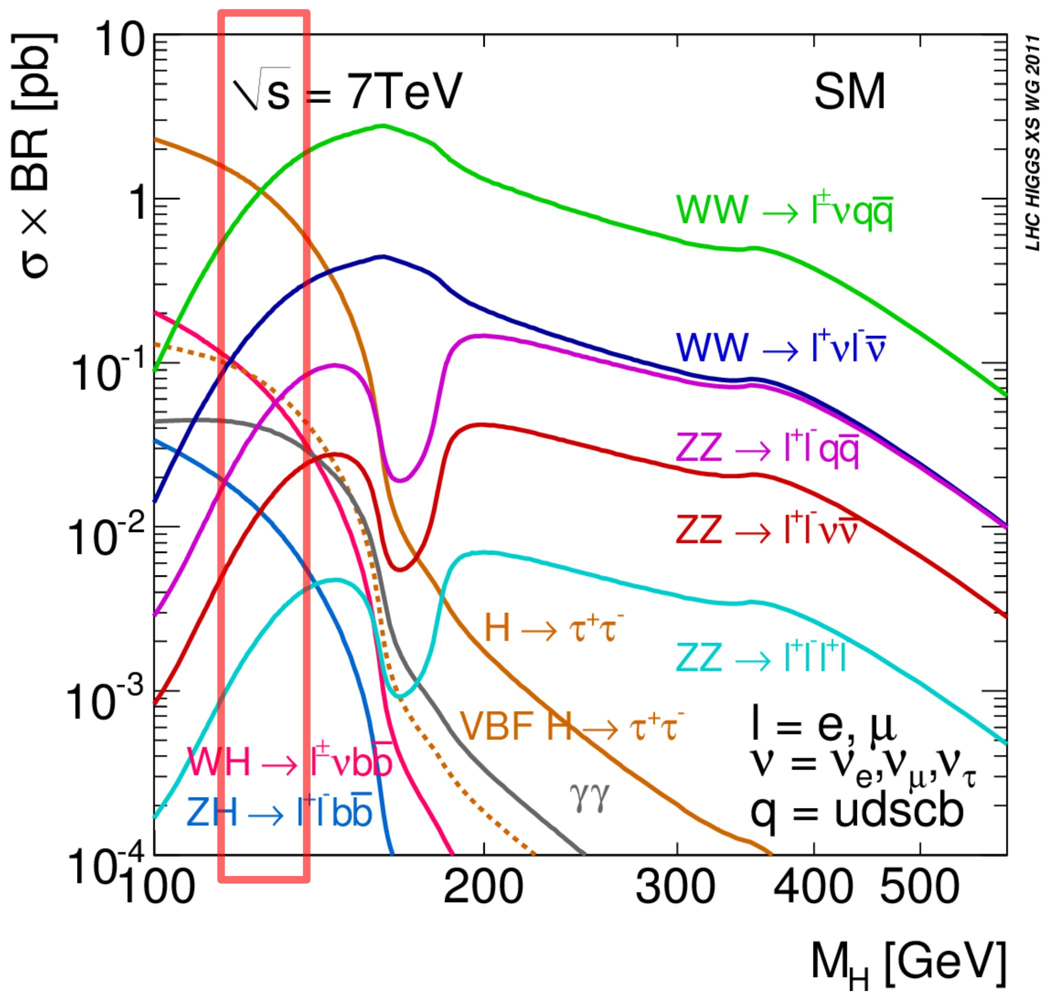
Ian Sample Geneva

Production and Decays – the Channel Map

Dominant production mechanisms (all important, depending how H decays)



(a) $gg \to H$ (b) VBF (c) VH (d) $t\bar{t}H$



For discovery, key was a clean signal with a clear mass signature

High-resolution channels were king...

- $H \to \gamma\gamma$
- $H \to 4\ell$

They are also experimentally *simpler* channels (none are simple...)

In the 125 GeV region, many channels are potentially observable

Since 4th July 2012...

ATLAS observation used

- 4.7 fb^{-1}@√s=7 TeV data
- 5.8 fb^{-1}@√s=8 TeV data for $H \rightarrow \gamma\gamma$ and $H \rightarrow 4\ell$

Added 5.8 fb^{-1}@√s=8 TeV for
$H \rightarrow WW \rightarrow \ell\nu\ell\nu$
for paper at end of July

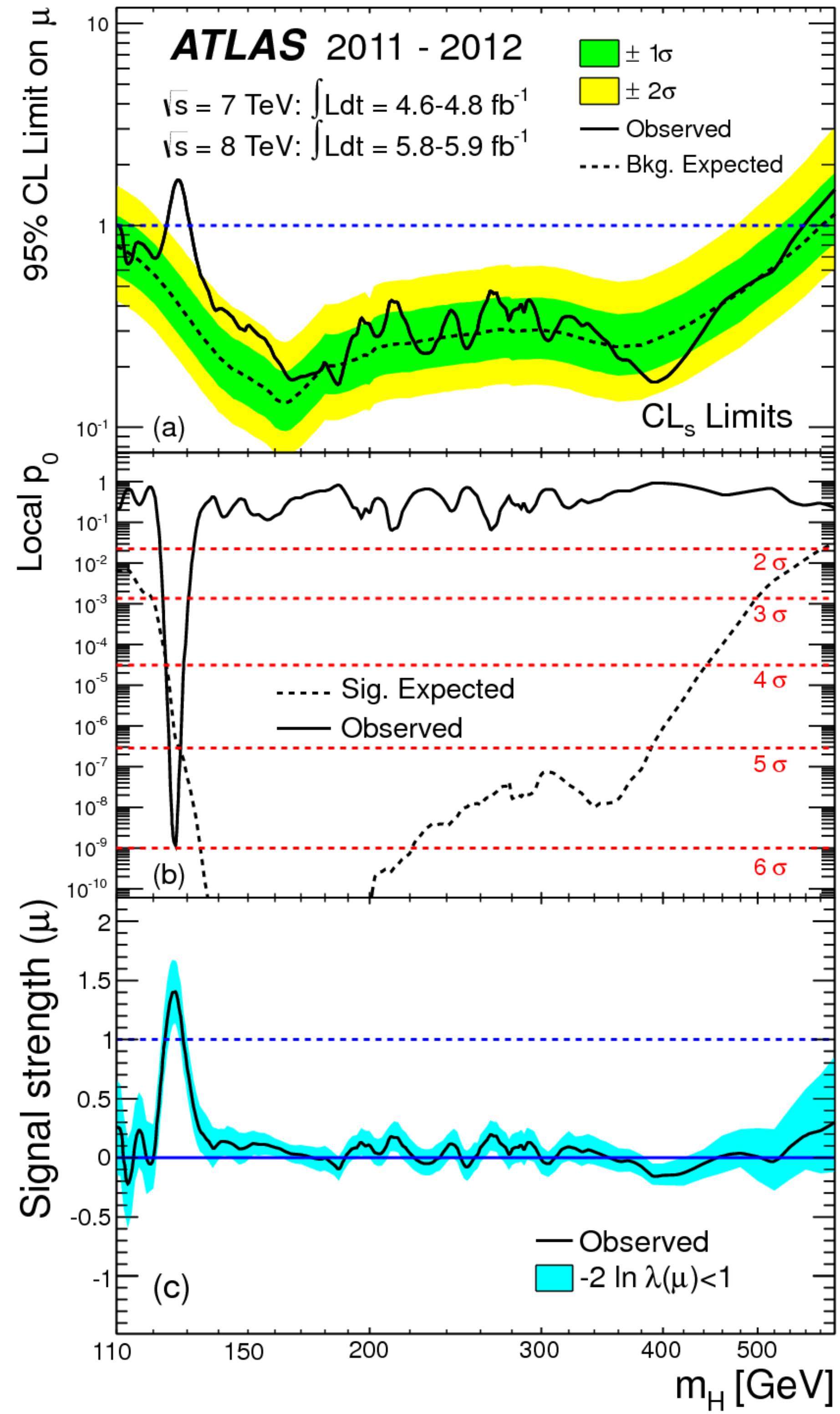
Couplings study in September

Updated results for HCP (Nov):

- VH, $H \rightarrow bb$ 4.7(@7)+13.0(@8) fb^{-1}
- $H \rightarrow \tau\tau$ 4.7(@7)+13.0(@8) fb^{-1}
- $H \rightarrow WW \rightarrow \ell\nu\ell\nu$ 13.0(@8) fb^{-1}

And last week, updates of

- $H \rightarrow \gamma\gamma$ 4.9(@7)+13.0(@8) fb^{-1}
- $H \rightarrow 4\ell$ 4.8(@7)+13.0(@8) fb^{-1}



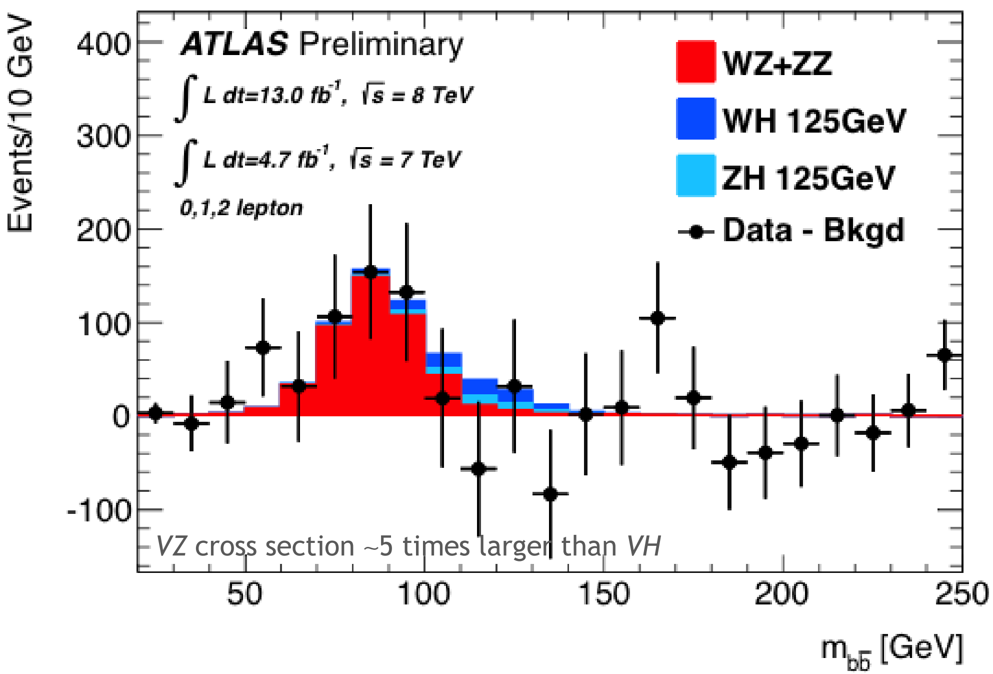
(W/Z)H, H → bb

Reoptimised 7+8 TeV analysis

Requires 2 b-tags and separates 0,1,2 lepton channels ~(W/Z)→νν,ℓν,ℓℓ

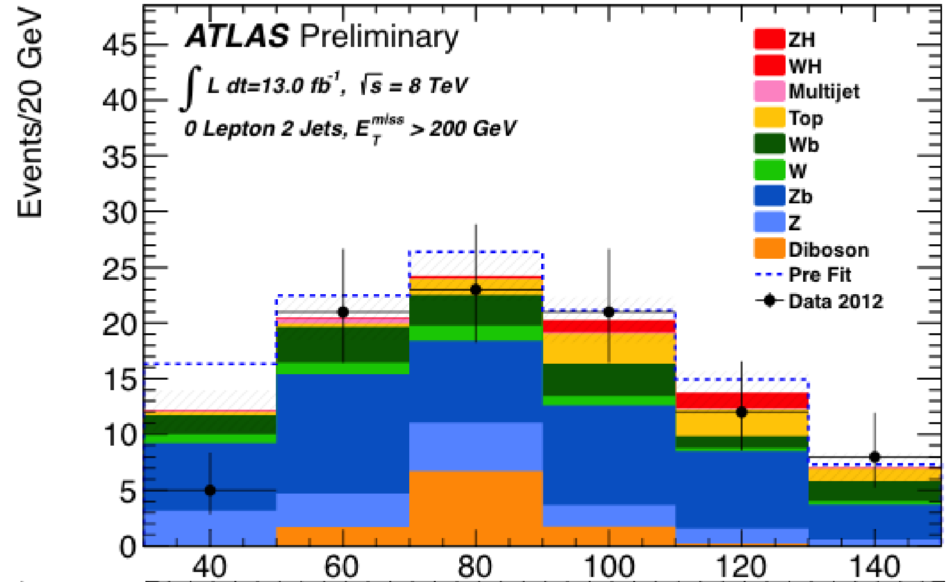
Discriminate via m_{bb}, resolution ~16%, improved by including muons

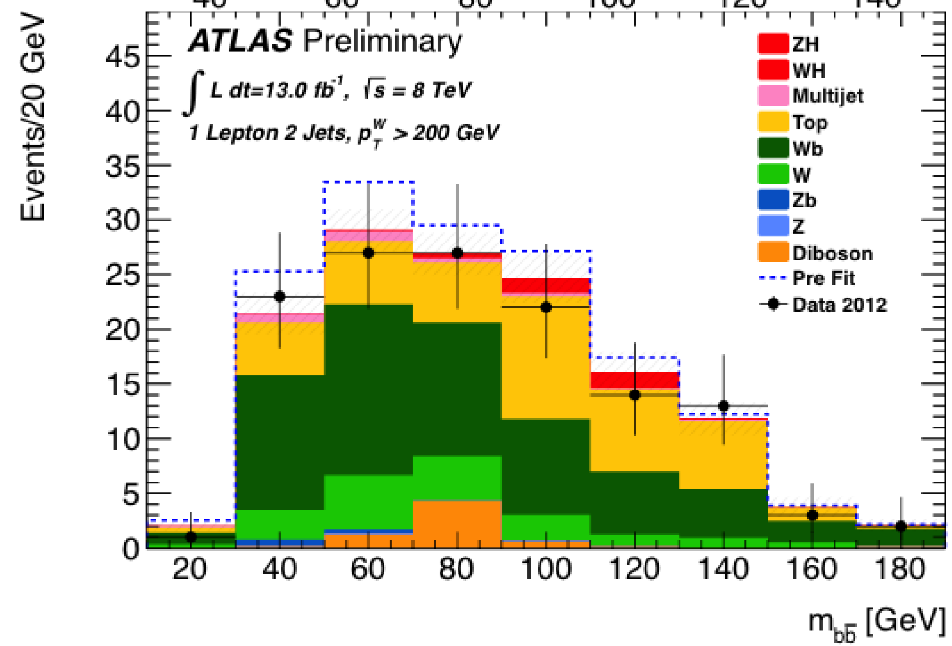
Control samples and final fit used to scale backgrounds



Cross-check: see expected *WZ* and *ZZ* peak with *Z* → *bb*

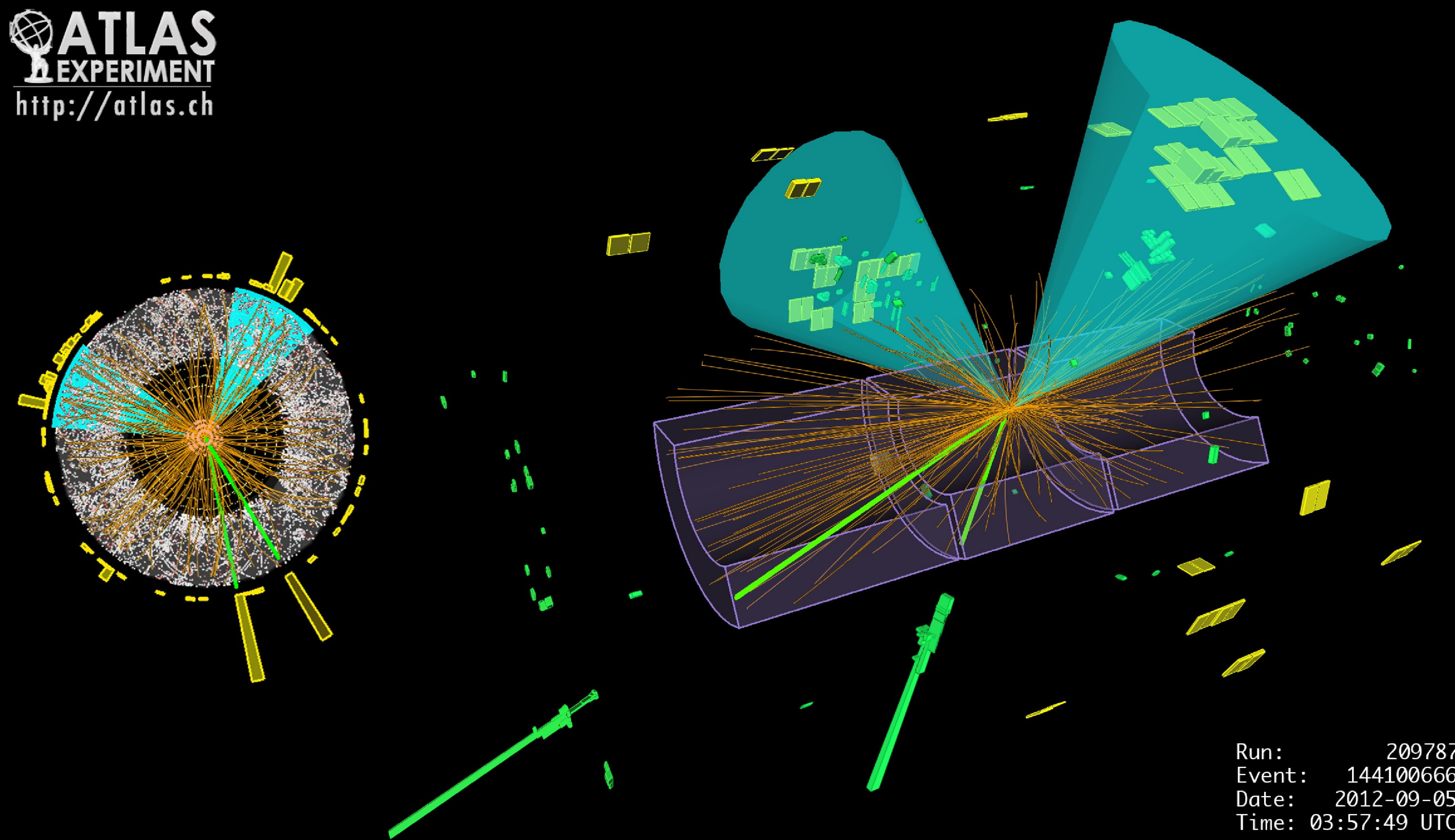
All non-diboson bkgs subtracted; Significance: 4σ





μ(125)=-0.4±0.7(stat)± 0.8(syst)
95% CL limit at μ=1.8

ATLAS-CONF-2012-161


ATLAS
EXPERIMENT
http://atlas.ch
Run: 209787
Event: 144100666
Date: 2012-09-05
Time: 03:57:49 UTC

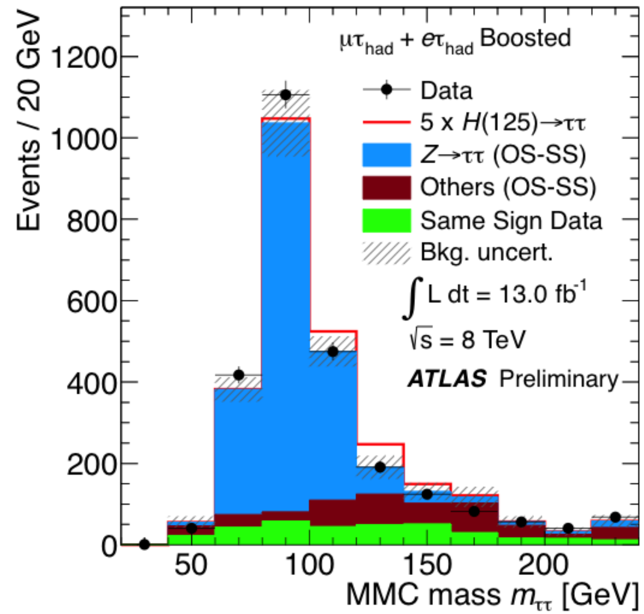
H → ττ

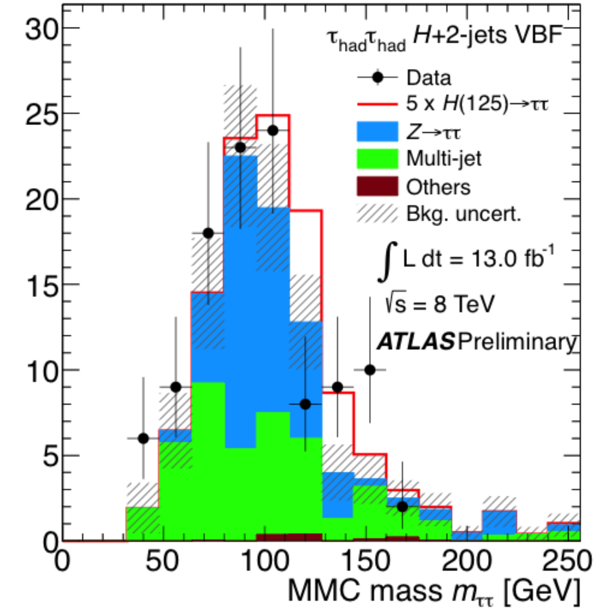
Reoptimised 7+8 TeV analysis

Analyse had-had, ℓ-had, ℓℓ ⊗ jet categories

Discriminate via MMC $m_{\tau\tau}$

Background from Z→ττ via “embedding” technique

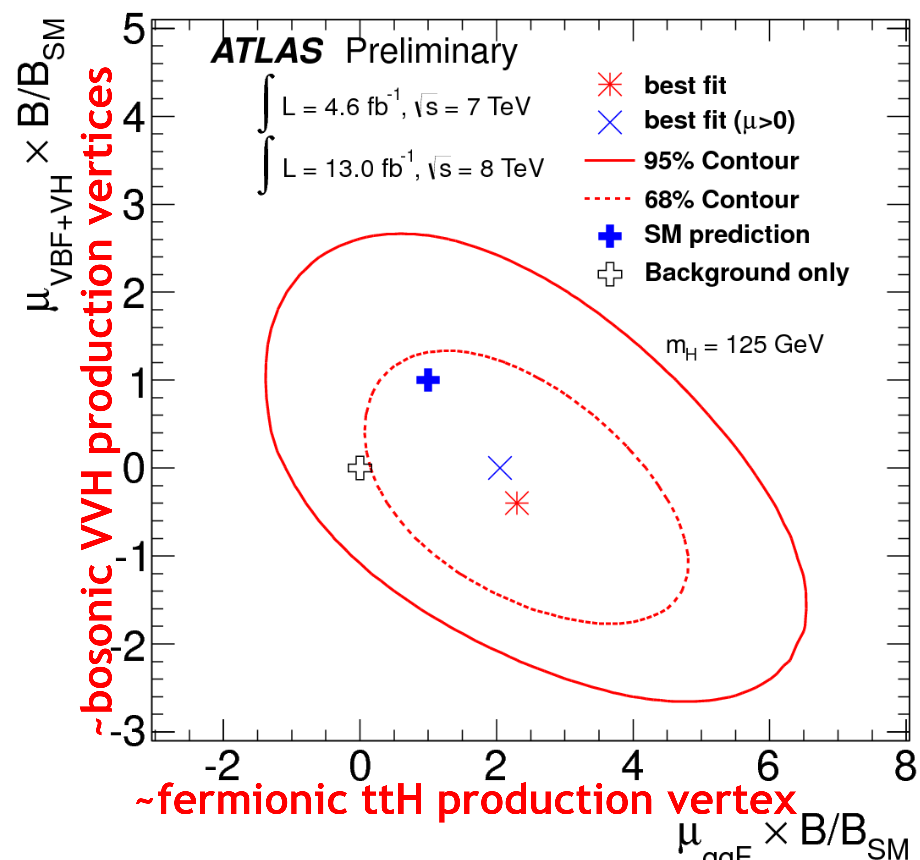




$\mu(125) = 0.7 \pm 0.7$
“significance” (125): 1.1σ
expected: 1.7σ

ATLAS-CONF-2012-160

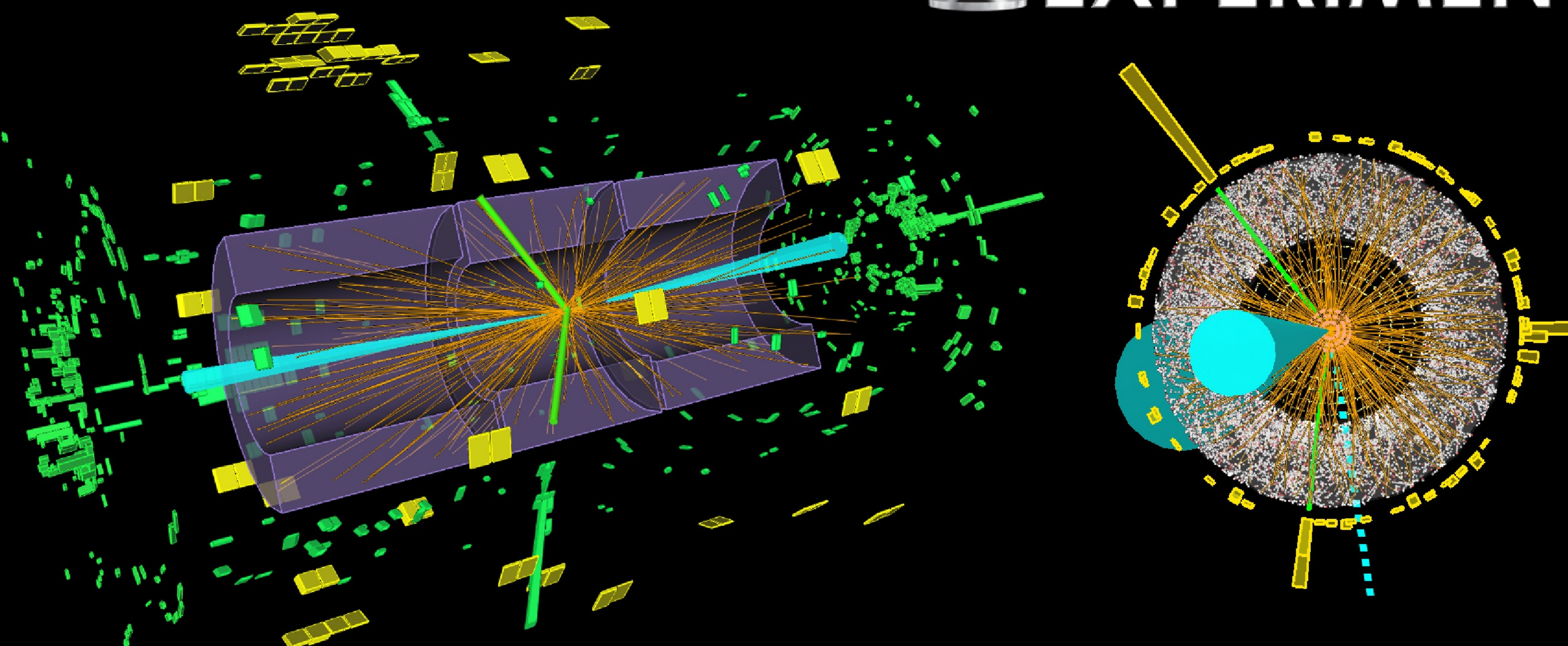
Division into categories provides some discrimination between the production mechanisms



Run Number: 209109, Event Number: 86250372

Date: 2012-08-24 07:59:04 UTC

ATLAS EXPERIMENT

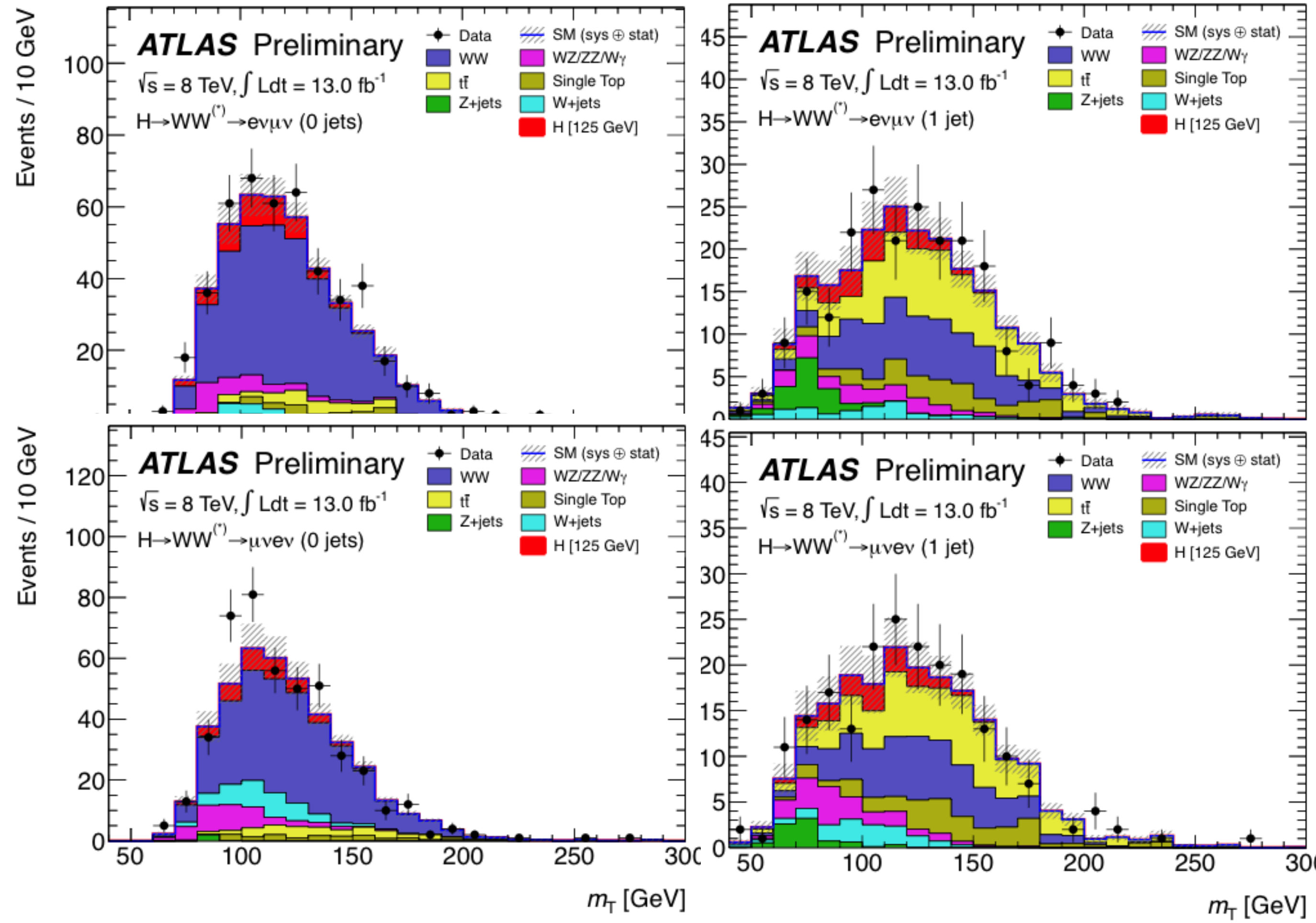


$H \rightarrow \tau\tau$ (doubly hadronic) candidate in VBF channel (m_{MMC} = 131 GeV)

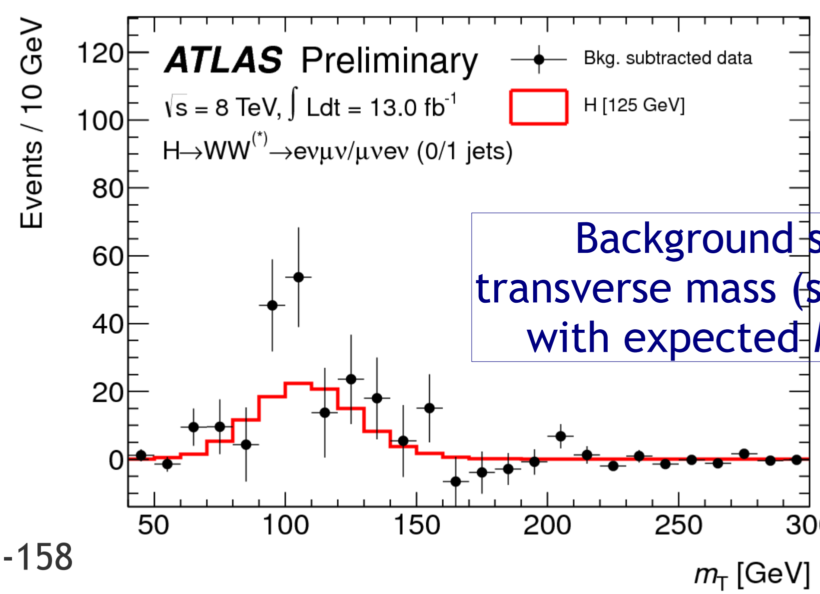
H → WW* → eνμν

Numerous relevant backgrounds: diboson, top, *W*/*Z*+jets, estimated from control regions

Distinguish 0/1 jet and leading lepton → 4 categories, main discrimination with: $m(\ell\ell)$, $\Delta\varphi(\ell\ell)$, m_T



Observed: 917 events
Expected from B: 774 ± 76
Expected from SM Higgs@125: 76 ± 15



Background subtracted transverse mass (stat errors only) with expected *H*(125) signal

$\mu(125) = 1.5 \pm 0.6$
significance (125): 2.6σ
expected: 1.9σ

ATLAS-CONF-2012-158

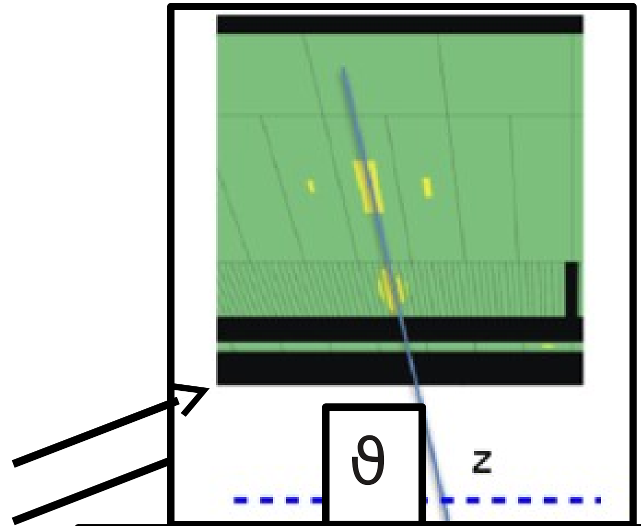
One H → γγ Ingredient

Design feature of the ATLAS LAr calorimeter: fine granularity, in η and depth, allows to determine direction of photon

Directly affects mass reconstruction

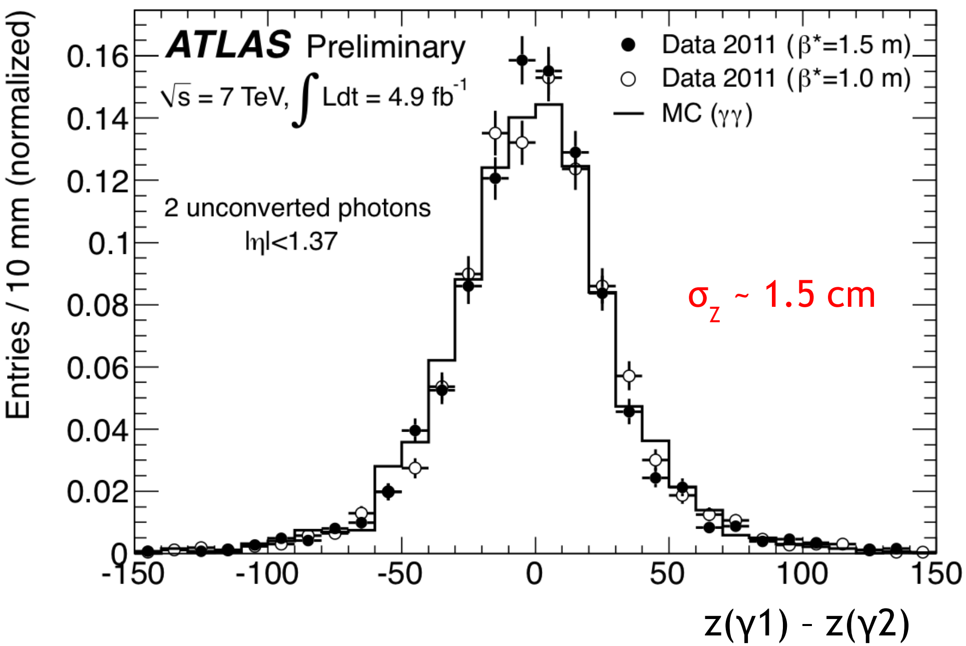
$$m^2(\gamma\gamma)=2E_1E_2(1-\cos\alpha)$$

where α is the opening angle of the two photons



Measure θ direction with calo
→ get z of primary vertex

z-vertex measured in γγ events from calorimeter "pointing"

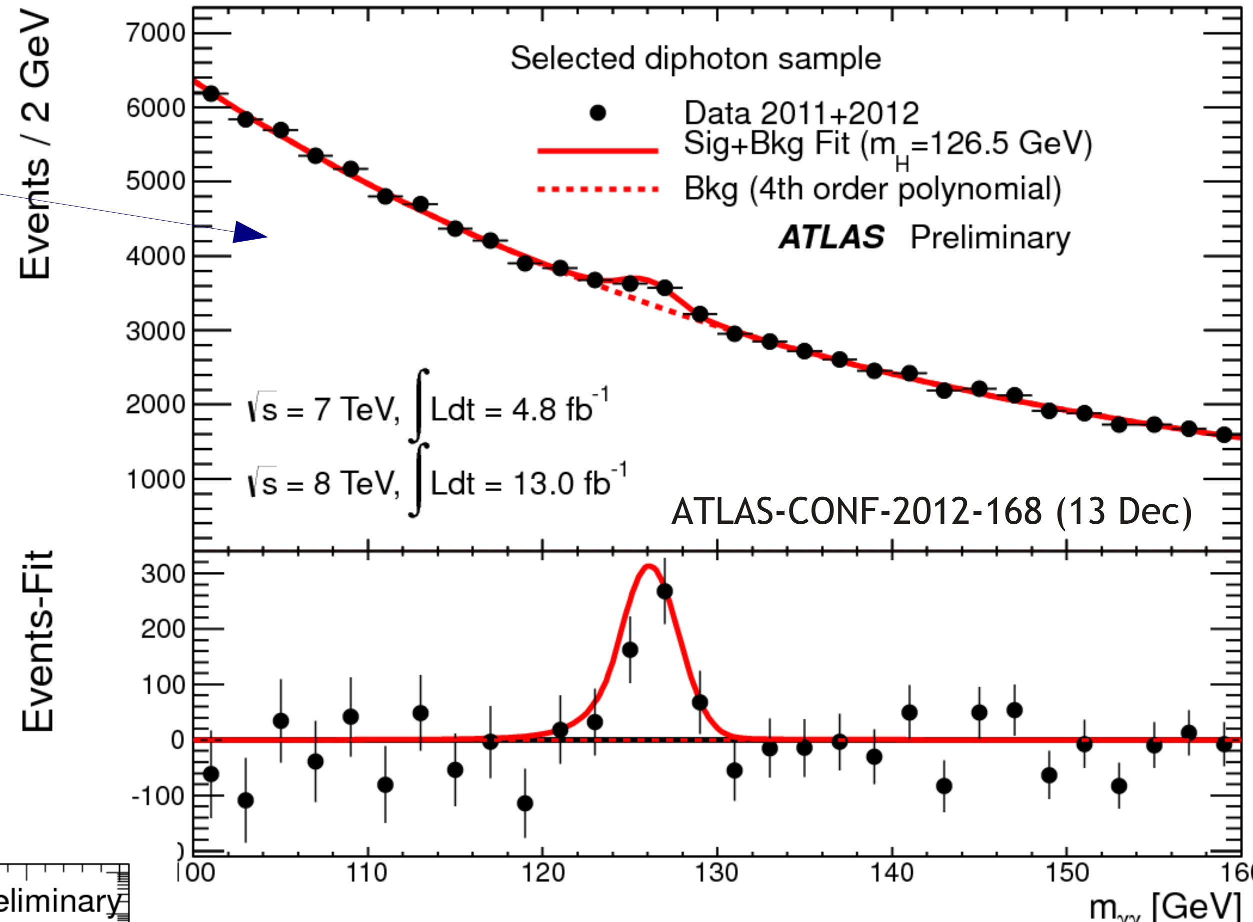


High pileup: many vertices distributed over σ_z~ 5-6cm (beam spot length)
→ tricky to know which vertex γγ came from

Calorimeter pointing alone reduces vertex error to ~ 1.5 cm and is robust against pile-up
→ good enough to make contribution to mass resolution from angular term negligible

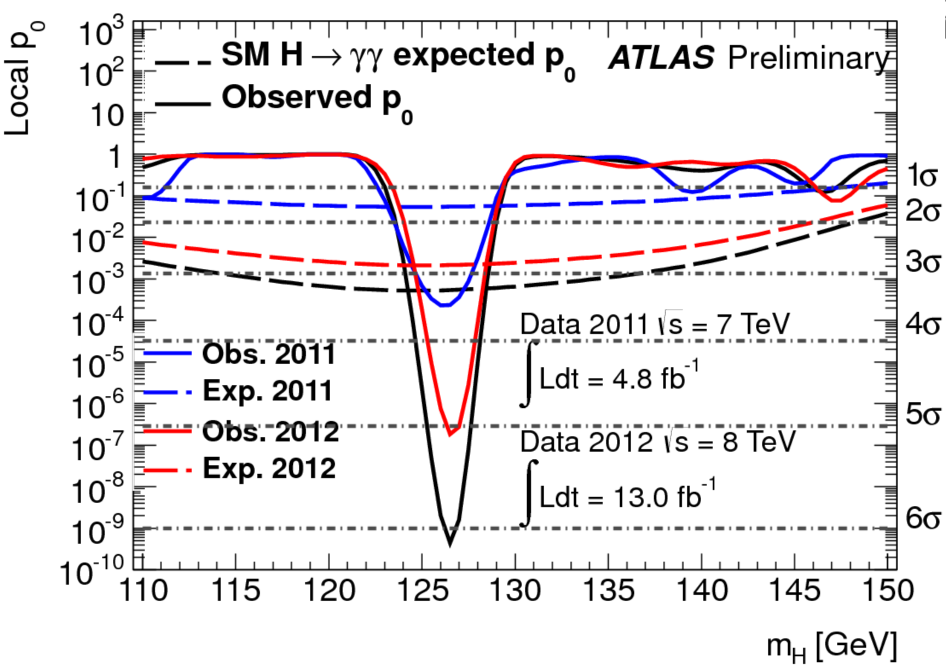
H → γγ

Invariant mass distribution



Analysis categorises events into 12 exclusive event categories with different S/B, to enhance sensitivity overall and to the different production processes

2011 126.0 GeV 3.5σ (exp. 1.6σ)
2012 127.0 GeV 5.1σ (exp. 2.9σ)



Now have a "single channel discovery" for H→γγ

Observed local significance 6.1σ
Expected 3.3σ

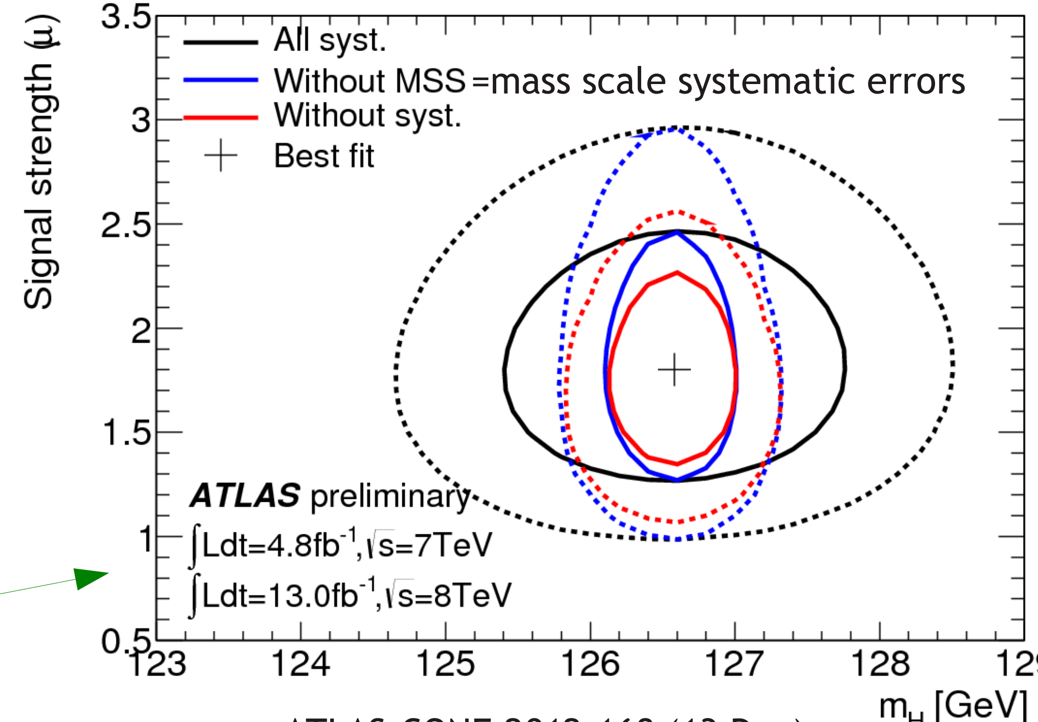
H → γγ Measurements

Mass measurement is systematics dominated in this channel

$$m_H = 126.6 \pm 0.3(\text{stat}) \pm 0.7(\text{syst})\ \text{GeV}$$

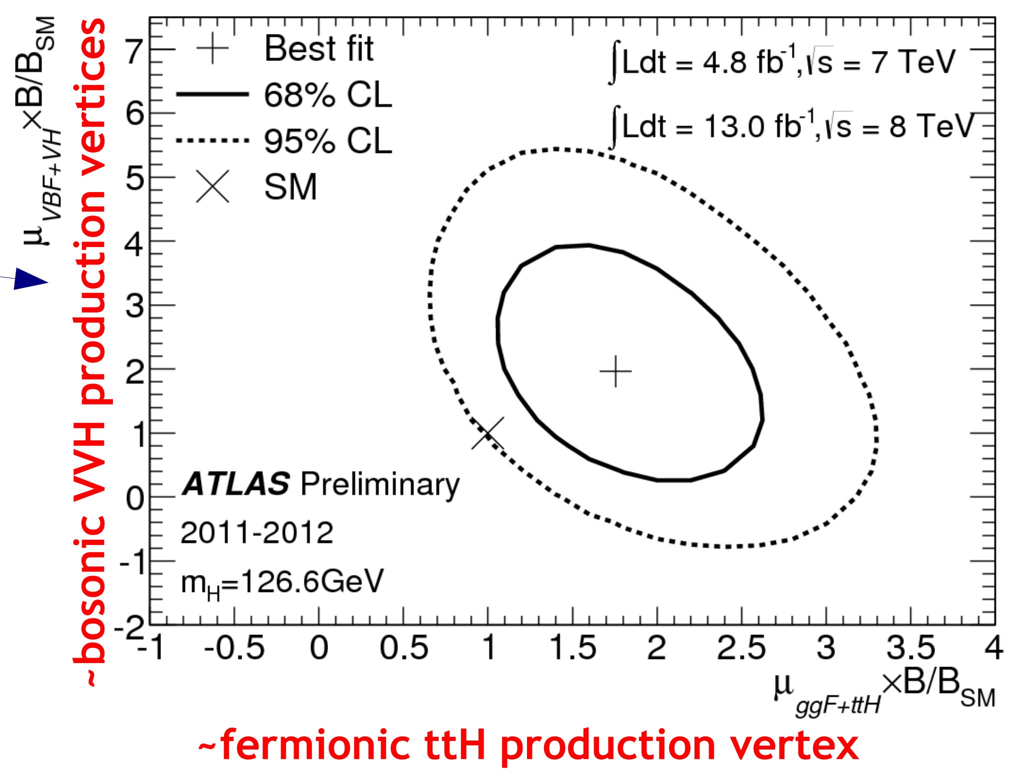
$$\mu = 1.80 \pm 0.30(\text{stat}) \pm^{0.21}_{0.15}(\text{syst}) \pm^{0.20}_{0.14}(\text{theo})$$

Or, allowing both to float



ATLAS-CONF-2012-168 (13 Dec)

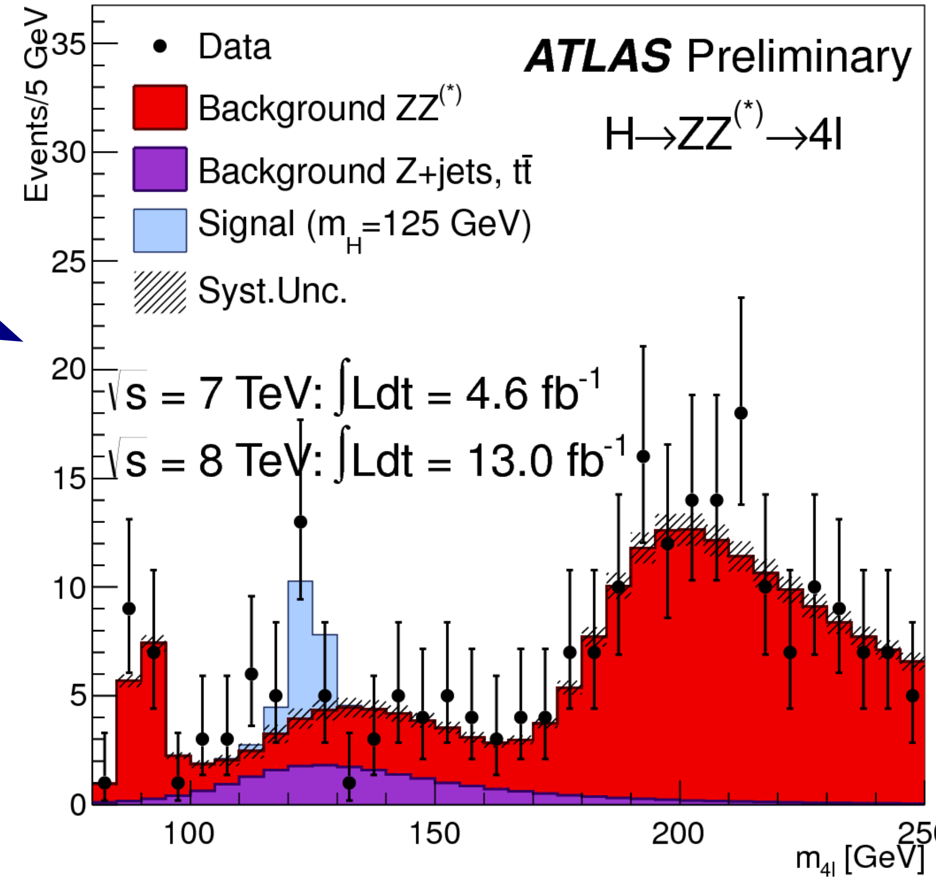
Observed signal strength in different categories (especially high-p_T, jets), gives some separation between couplings in different production modes



Common B/BSM branching ratio (production independent)

H → 4ℓ

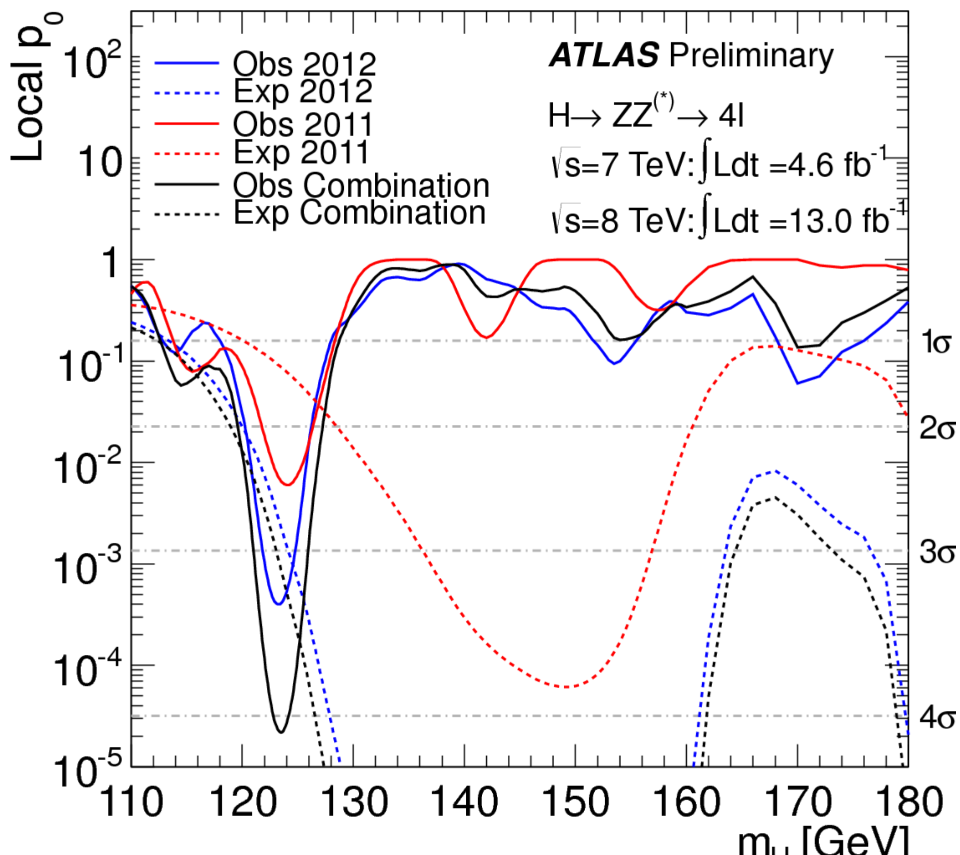
Invariant mass distribution



ATLAS-CONF-2012-169 (13 Dec)

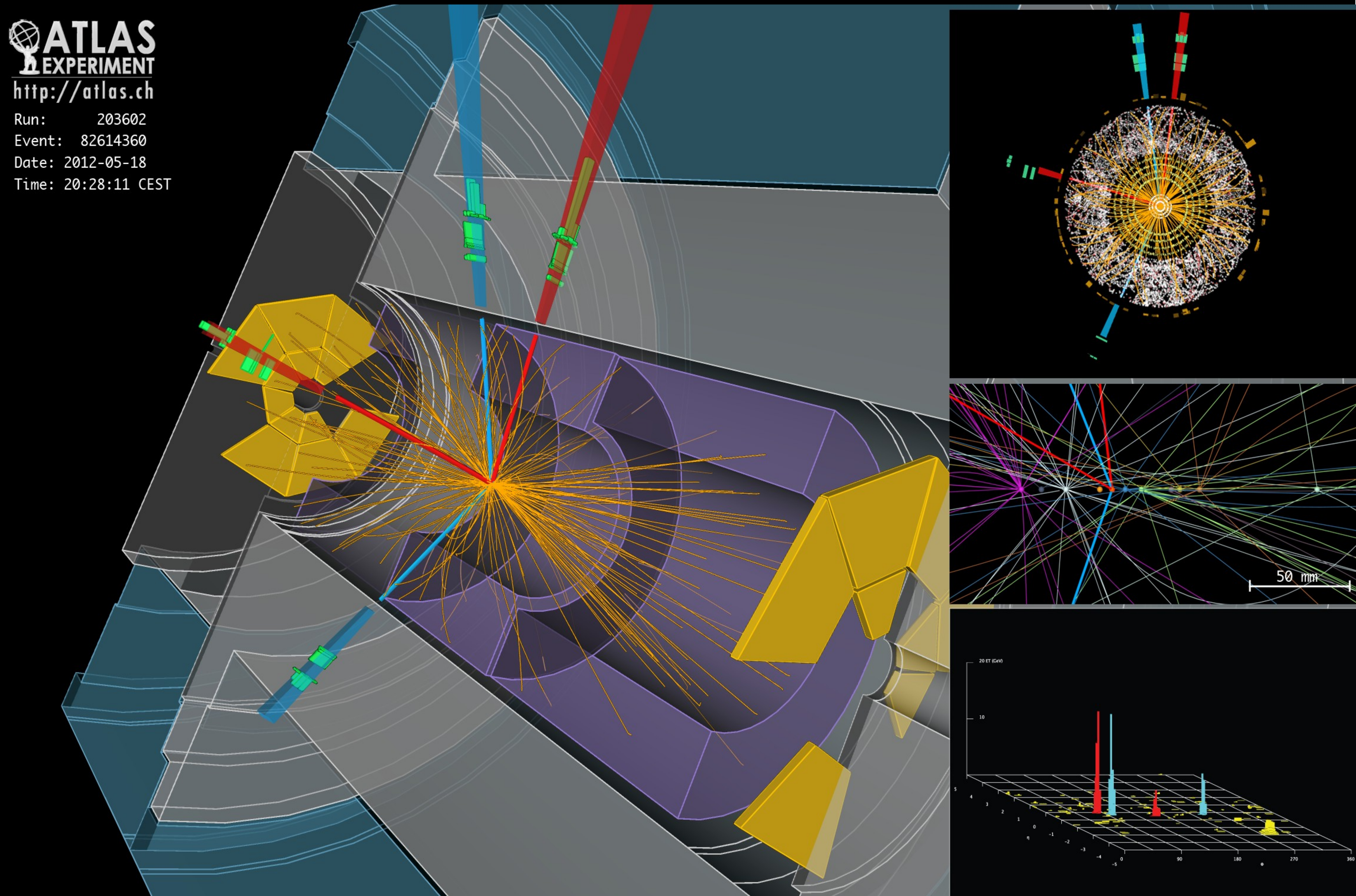
Data driven background estimates

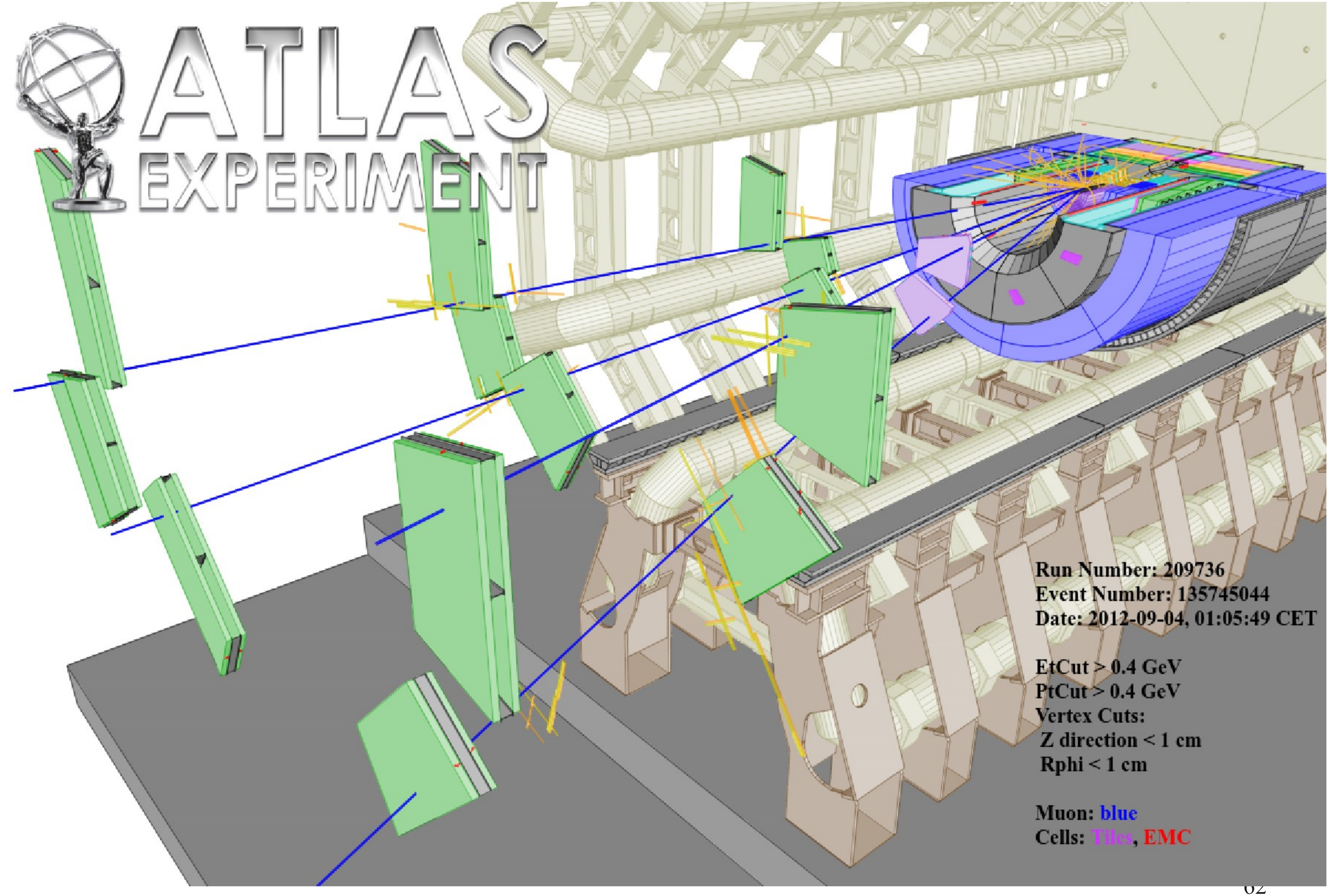
See clean Z→4ℓ signal around m_Z, as expected



Again, signal continues to grow

Observed local significance 4.1σ
Expected 3.1σ


ATLAS
EXPERIMENT
http://atlas.ch
Run: 203602
Event: 82614360
Date: 2012-05-18
Time: 20:28:11 CEST
50 mm


ATLAS EXPERIMENT
Run Number: 209736
Event Number: 135745044
Date: 2012-09-04, 01:05:49 CET
EtCut > 0.4 GeV
PtCut > 0.4 GeV
Vertex Cuts:
Z direction < 1 cm
Rphi < 1 cm
Muon: blue
Cells: Tiles, EMC

H → 4ℓ Measurements

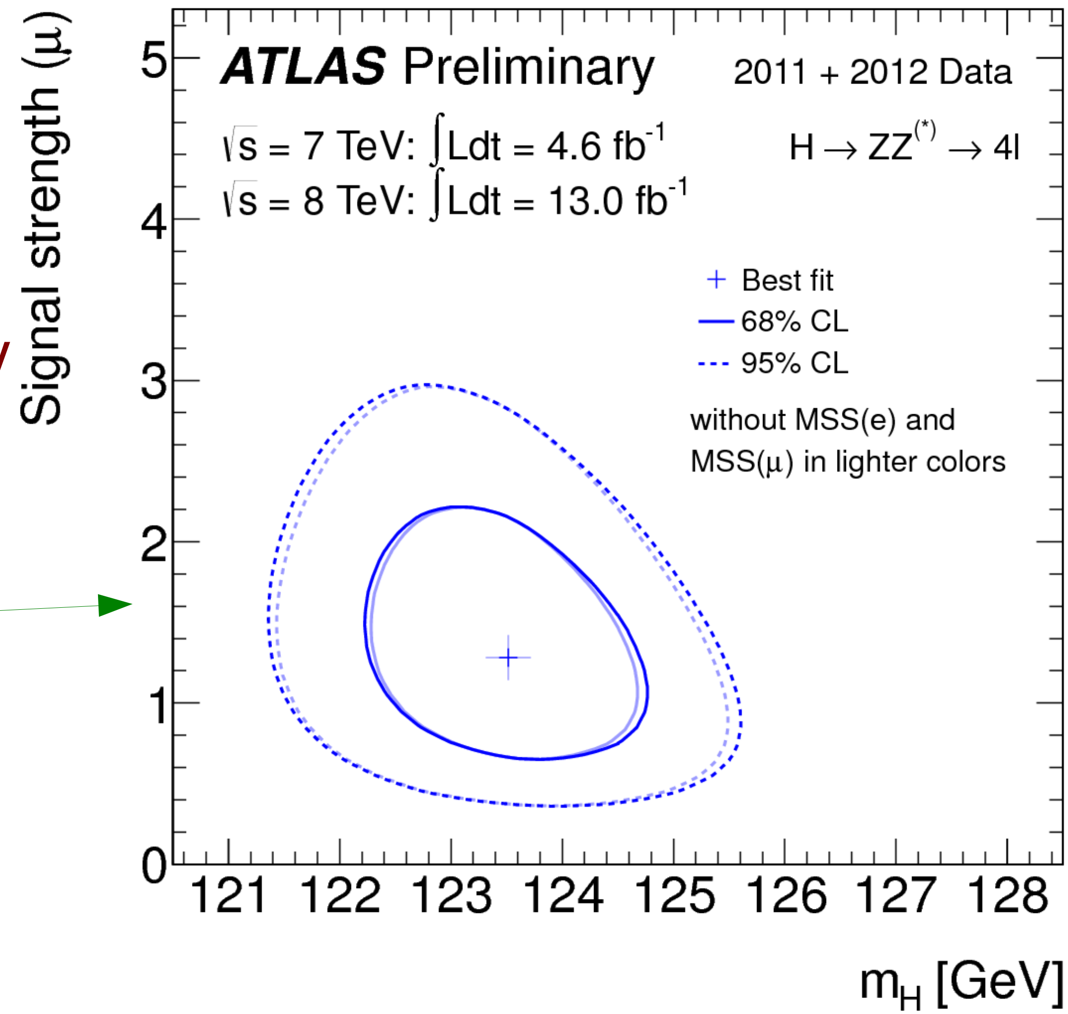
Mass measurement is statistics dominated in this channel

$m_H = 123.5 \pm 0.9(\text{stat}) \pm 0.3(\text{syst})$ GeV

$\mu = 1.3 \pm^{0.5}_{0.4}$

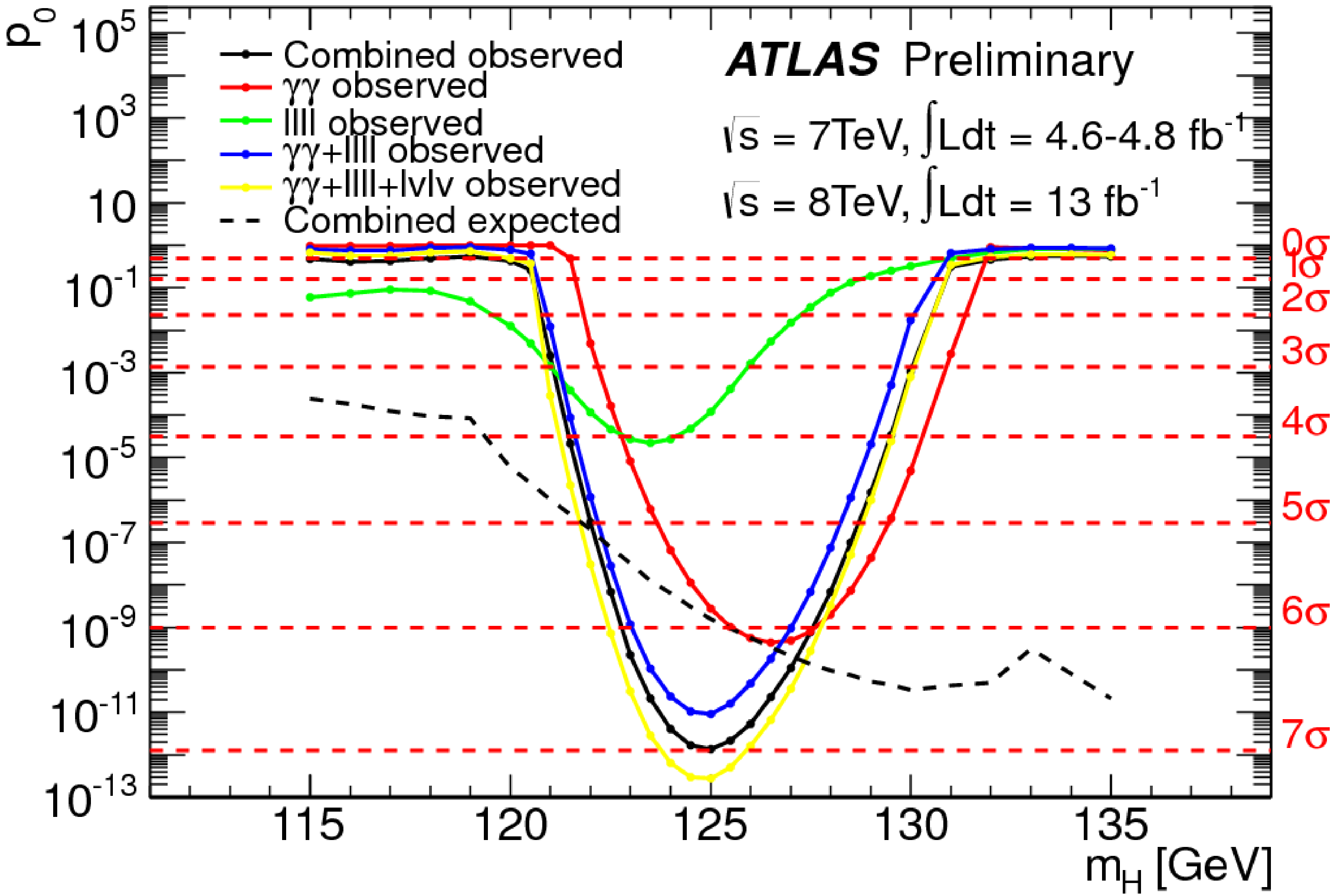
Or, allowing both to float

ATLAS-CONF-2012-169 (13 Dec)



Combined p_0 value

ATLAS-CONF-2012-170 (13 Dec)



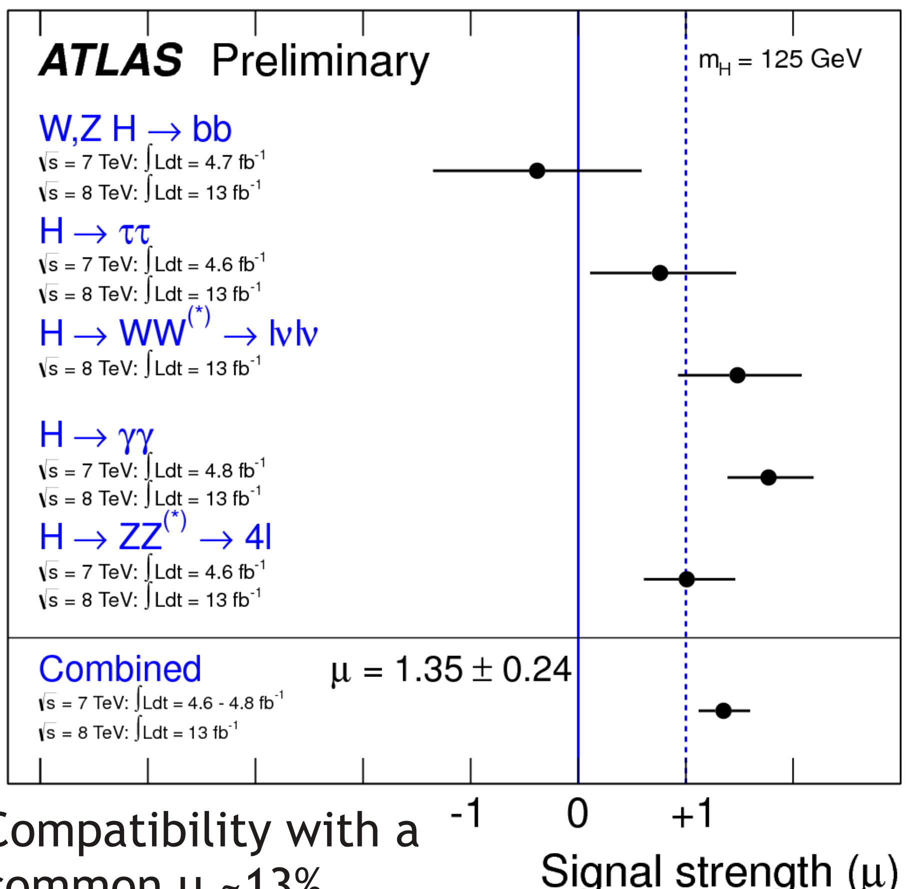
This search is over – you may not see this plot much more often!
(for measurements it doesn't answer the right questions)

Combined Mass and μ

Combining the high-precision channels

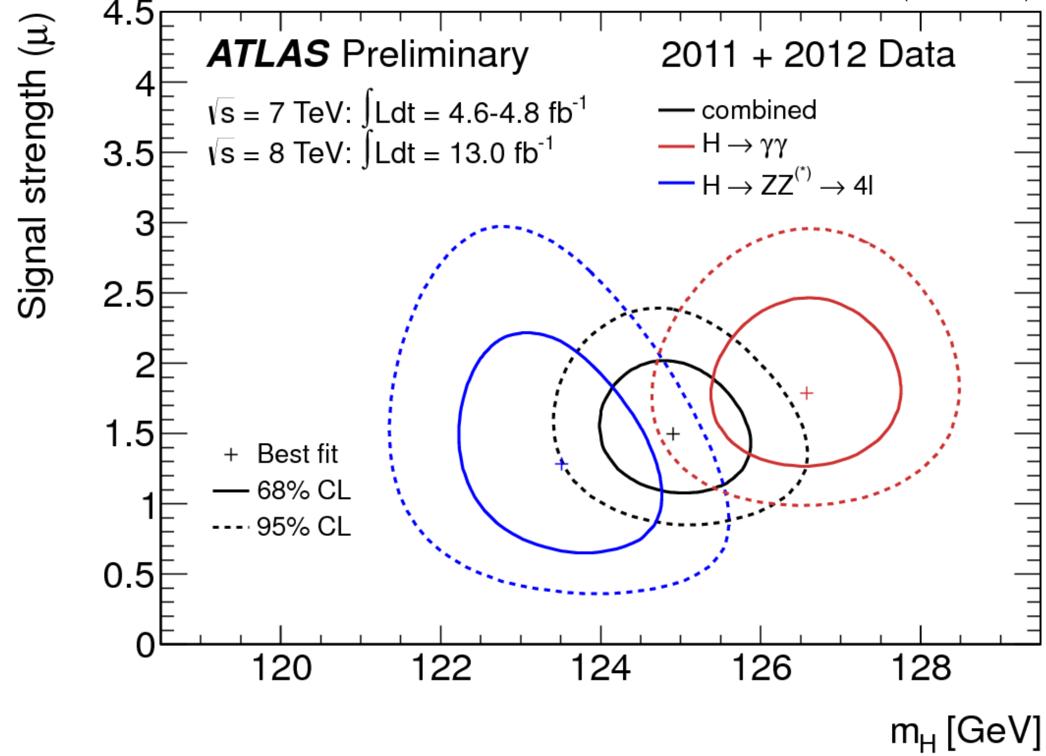
m_H = 125.2±0.3(stat)±0.6(syst) GeV

ATLAS-CONF-2012-170 (13 Dec)



Compatibility with a common μ ~13%

ATLAS-CONF-2012-170 (13 Dec)



Despite some rather misinformed reports in blogs, there is just one peak in the combined distribution

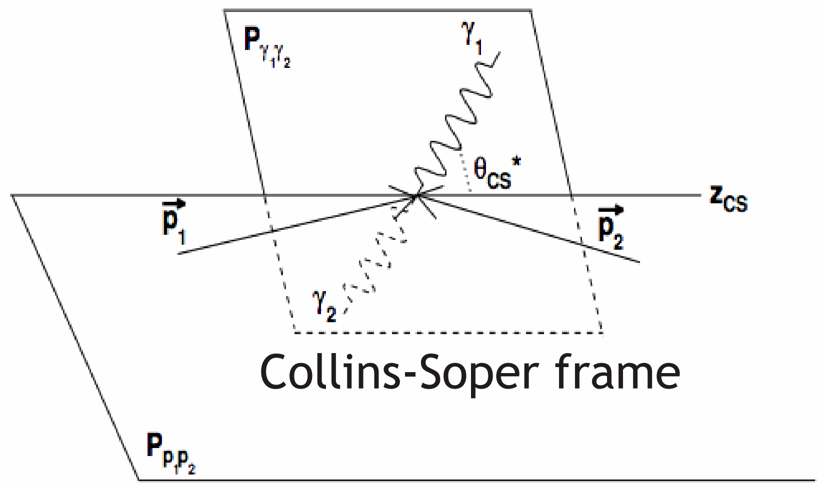
Combining all channels, assuming a common μ

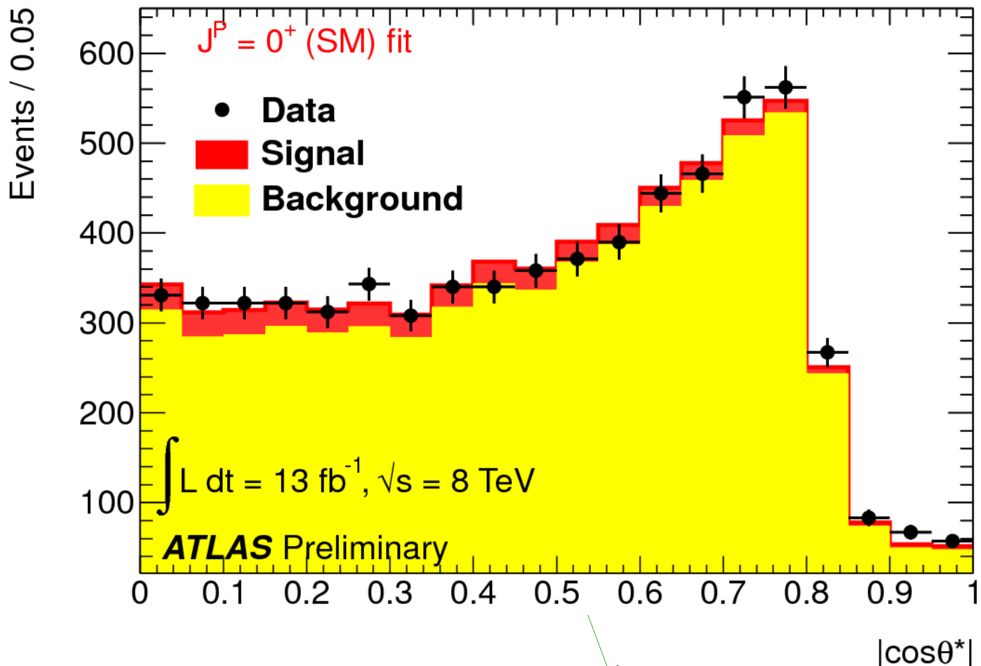
μ = 1.35 ± 0.24

Spin with γγ

Sensitive variable is diphoton cosθ* distribution in γγ system

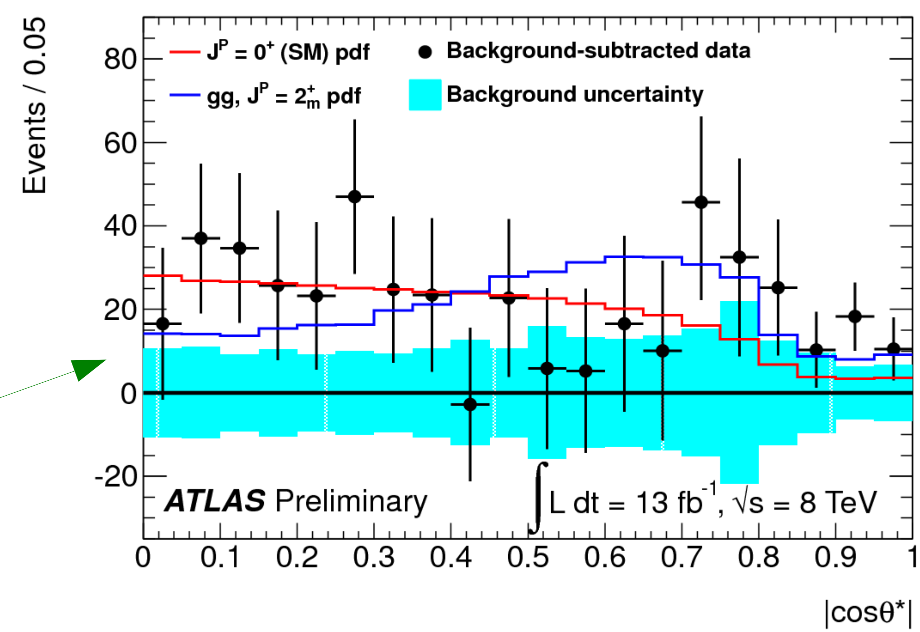
Use events within 1.5σ of the peak at 126.5 GeV, background shape from data sidebands





...subtracting background...

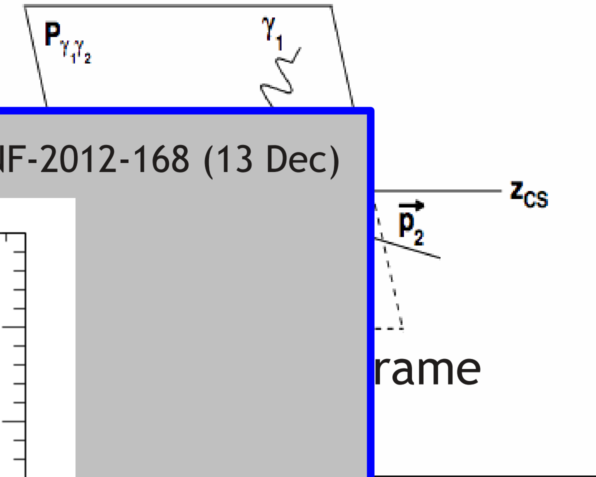
ATLAS-CONF-2012-168 (13 Dec)

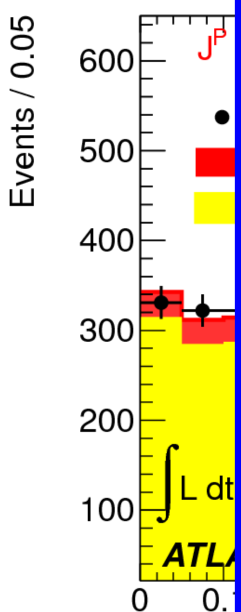


Spin with γγ

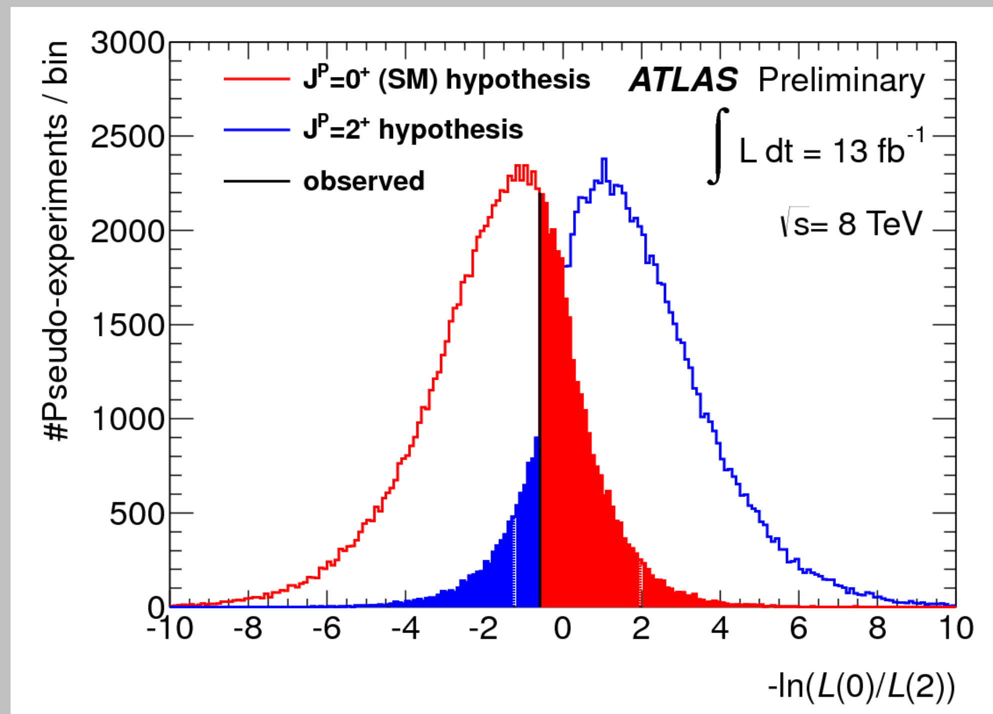
Sensitive
in γγ sys

Use ever
backgrou





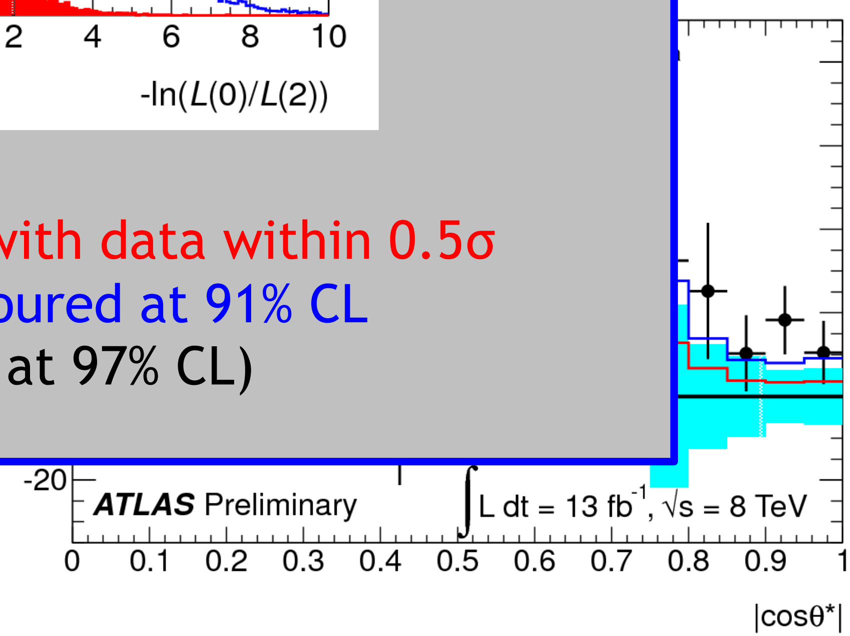
ATLAS-CONF-2012-168 (13 Dec)



Spin-0^+ hypothesis consistent with data within 0.5σ

Spin-2^+ hypothesis disfavoured at 91% CL

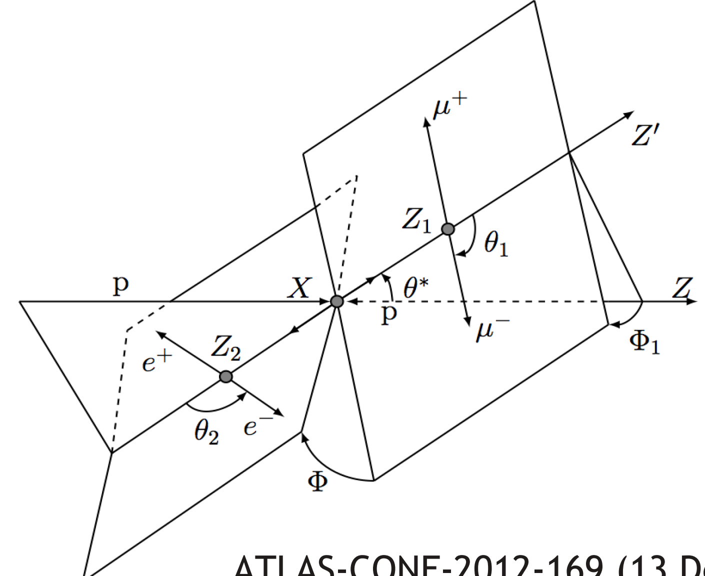
(expected exclusion at 97% CL)



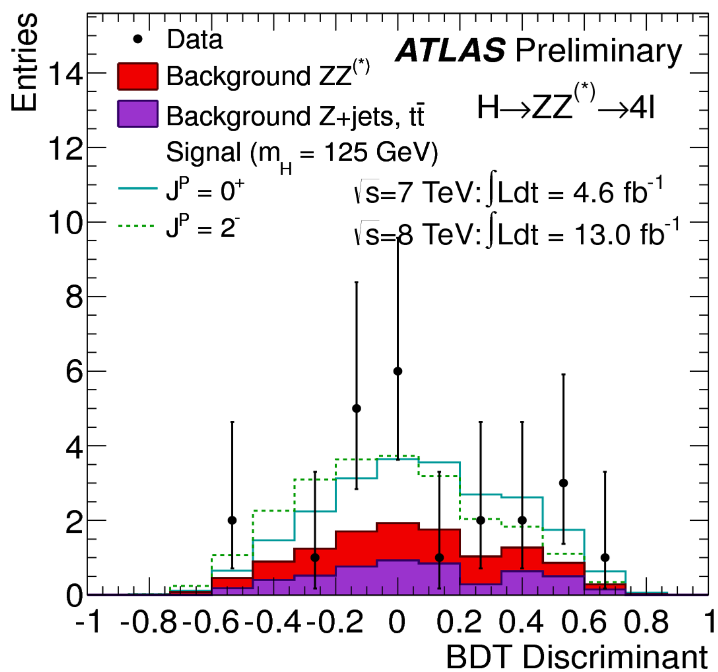
Spin with 4ℓ

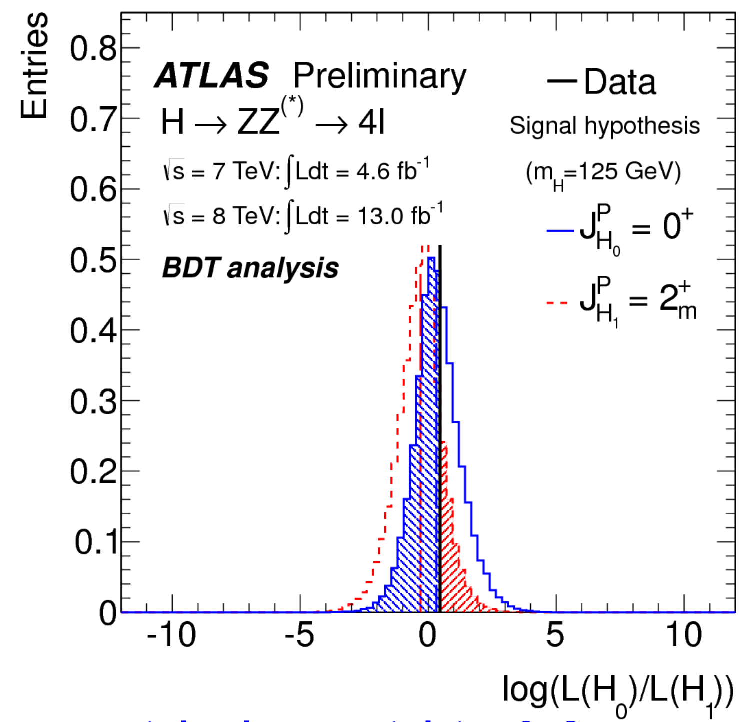
Use m_{12}, m_{34} and five production & decay angles in a BDT or MELA discriminant

Use events with $m_{4\ell}$ between 115 and 130 GeV



ATLAS-CONF-2012-169 (13 Dec)





Spin-0^+ hypothesis consistent with data within 0.2σ

Spin-2^+ hypothesis slightly disfavoured at 80% CL

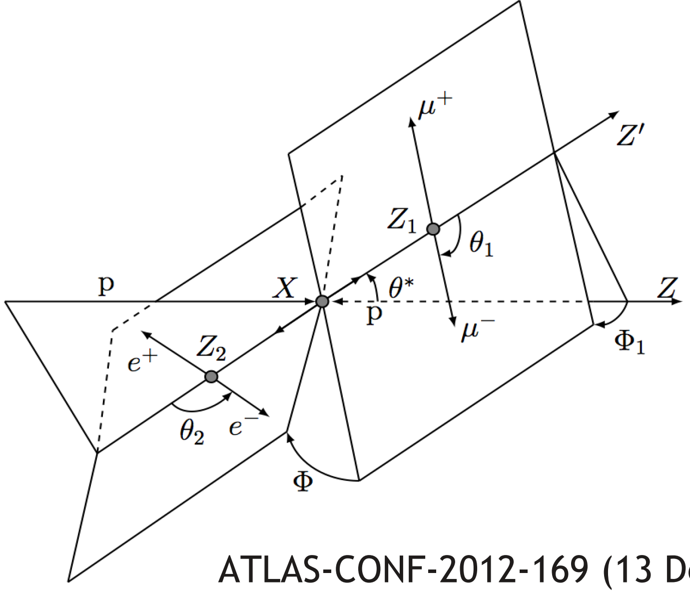
(expected disfavouring at 85% CL)

Not much sensitivity yet!

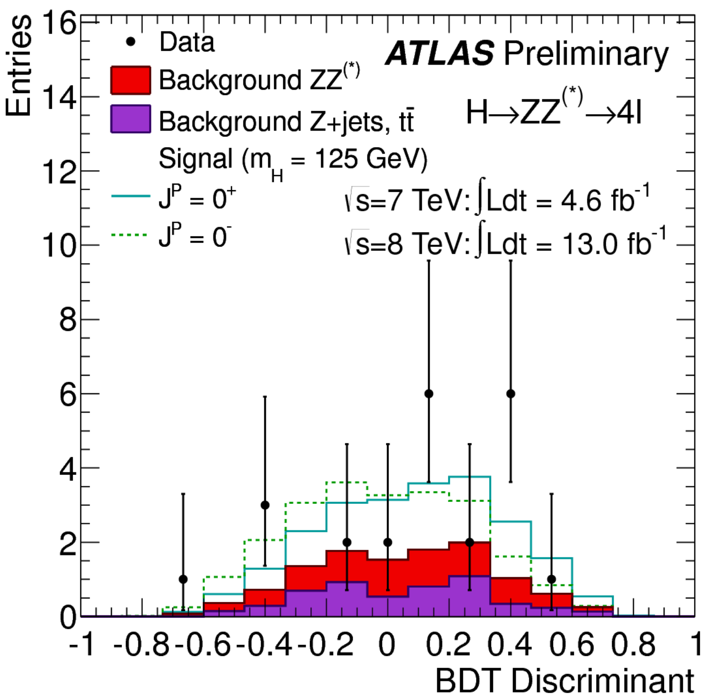
Parity with 4ℓ

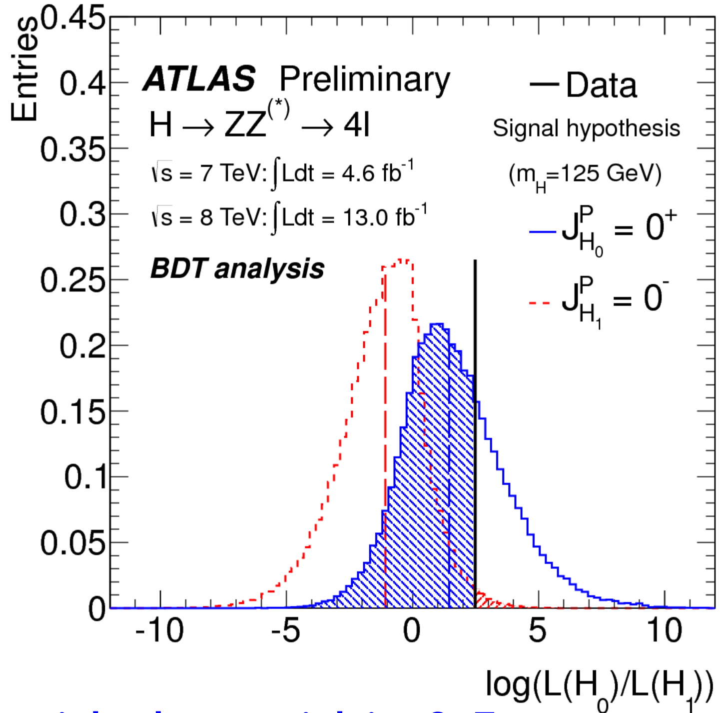
Use m_{12}, m_{34} and five production & decay angles in a BDT or MELA discriminant

Use events with $m_{4\ell}$ between 115 and 130 GeV



ATLAS-CONF-2012-169 (13 Dec)





0^+ hypothesis consistent with data within 0.5σ

0^- hypothesis excluded at 99% CL

(expected exclusion at 96% CL)

What's Next?

A big programme now to complete analyses of “Run-1” data

- Painstaking work to measure precisely the properties of the new boson - remember how hard it was to find – this is not easy work, it pushes the detector capabilities very hard
- Continue searching in plethora of other channels – are other new objects hiding there?
- Huge measurement programme underway on 8 TeV data – but this will run through the next two years

Long Shutdown 1, 2013-14

- Remedial work on all LHC dipole magnet interconnects
- Detector consolidation work, after >3 years with little access
- Back in early 2015 at 13+ TeV, and 25ns (→ lower pileup)
- Major increase in mass reach for all searches
- Luminosities ~double today

Beyond “Run-2” (2015-2017?), further luminosity increases at 14 TeV

Closing Words

It has been a quite remarkable year

Performance of the LHC, and of ATLAS, have been beyond expectations

The computing and analysis systems have delivered results incredibly fast with such a huge volume of data

The co-discovery of the new boson by ATLAS and CMS has revealed a new type of boson at 125 GeV

So far, it looks more-and-more “Higgs-like” - spin-2 and negative parity are disfavoured by the latest results

The new era has just begun


Season's Greetings and
a Happy New Year!
Thanks to Eric Lancon

Fin

Table 2: Signal resolution (σ_{CB}), FWHM, number of expected signal events (N_S), number of background events (N_B) and signal to background ratio (N_S/N_B) in a mass window around m_H = 126.5 GeV containing 90% of the expected signal events for each of the 12 categories of the 8 TeV data analysis. The number of background events are obtained from the background + signal fit to the $m_{\gamma\gamma}$ data distribution.

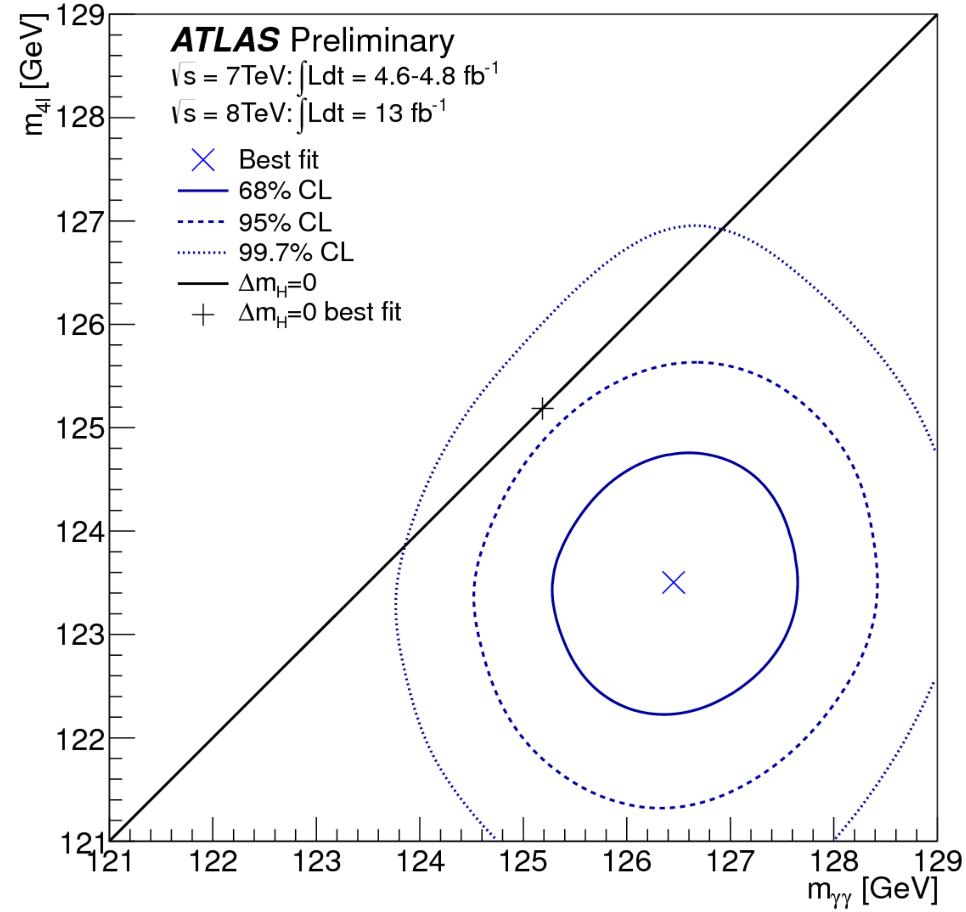
$\sqrt{s}$	8 TeV					
Category	$\sigma_{CB}(GeV)$	FWHM (GeV)	Observed	N_S	N_B	N_S/N_B
Unconv. central, low p_{Tt}	1.47	3.45	569	29	538	0.053
Unconv. central, high p_{Tt}	1.37	3.22	25	4.2	25	0.168
Unconv. rest, low p_{Tt}	1.59	3.75	2773	61	2610	0.023
Unconv. rest, high p_{Tt}	1.52	3.59	148	8.7	138	0.063
Conv. central, low p_{Tt}	1.64	3.86	446	18	417	0.044
Conv. central, high p_{Tt}	1.49	3.51	18	2.8	17	0.163
Conv. rest, low p_{Tt}	1.83	4.32	2898	54	2763	0.019
Conv. rest, high p_{Tt}	1.7	4.00	144	7.4	138	0.053
Conv. transition	2.35	5.57	1872	25	1825	0.014
High Mass two-jet	1.55	3.65	47	6.8	33	0.204
Low Mass two-jet	1.46	3.45	62	4.2	45	0.093
One-lepton	1.63	3.85	18	1.7	16	0.108
Inclusive	1.64	3.87	8802	223	8284	0.027

Mass Consistency

The mass measurements in the γγ and 4ℓ channels are consistent at the level of ~2.7σ using fully gaussian systematic errors, or 2.3σ using different error assumptions

A lot of effort has been made to seek out unexpected systematic error sources, but nothing substantial has been identified

The error on the difference of the two measurements has a substantial statistical component



$H \rightarrow \gamma\gamma$ and $H \rightarrow 4l$ Mass Scale Systematic Uncertainties

Main Mass Scale systematic uncertainties (considered in also ICHEP studies) :

Source	Relative Mass Scale Effect
Absolute Energy scale calibration from Z	0.3%
Upstream material simulation inaccuracies	0.3%
Pre-Sampler energy scale	0.1%

Further investigation and extensive checks lead to find additional sources of systematic uncertainties :

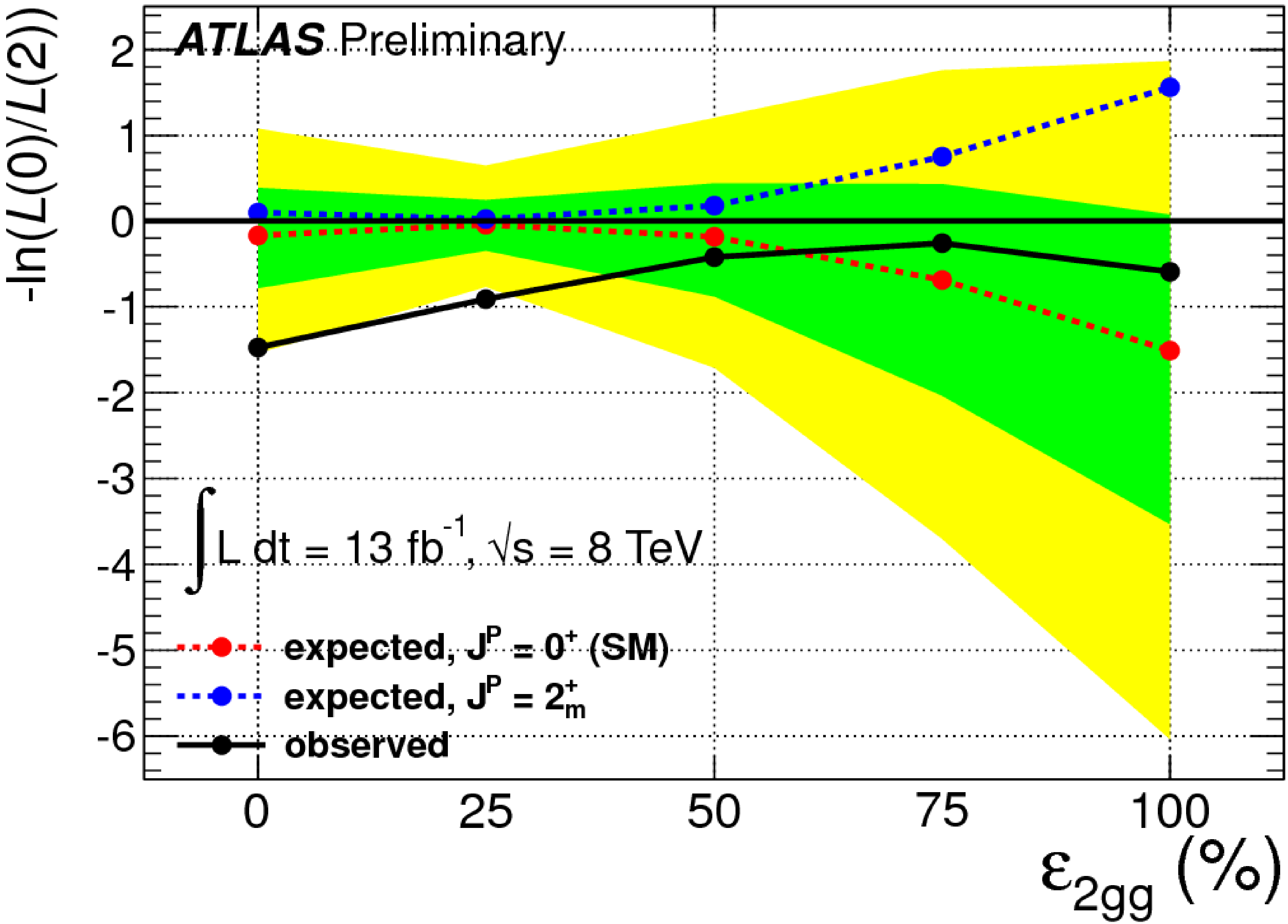
- LAr Strips relative calibration (0.2%)
- Photon energy resolution (0.15%)
- Calibration of the high gain (0.15%)
- Mis-classification due to fake conversions (0.13%)
- Backgound modeling (0.1%)
- Lateral shower development simulation (0.1%)
- Effect of PV choice (0.03%)

Main 4l Mass Scale systematic uncertainties :

Source	Relative Mass Scale Effect
Absolute Energy scale calibration from Z	0.4%
Low transverse energy electrons	0.2%
Muon momentum scale	0.2%

Further investigation and extensive checks have not lead to additional substantial sources of systematic uncertainty :

- Measurement with MS and ID alone
- Local detector biases checked event by event
- Local resolution effects checked using event-by-event error;
- kinematic distributions in agreement with expectation
- FSR simulation
- Different mass reconstruction using Z-mass constraint (+400 MeV shift)



ATLAS Preliminary
-ln(L(0)/L(2))
2
1
0
-1
-2
-3
-4
-5
-6
∫L dt = 13 fb⁻¹, √s = 8 TeV
expected, J^P = 0^+ (SM)
expected, J^P = 2^+_m
observed
0
25
50
75
100
ε_2gg (%)