Summary of Higgs and BSM physics at ATLAS

HIGGS AND BEYOND 2013
TOHOKU WORKSHOP ON HIGGS AND BEYOND

F. CONVENTI
(UNIVERSITA' DI NAPOLI "PARTHENOPE" AND INFN)

Overview:

Higgs:

Observation

Decay Channels

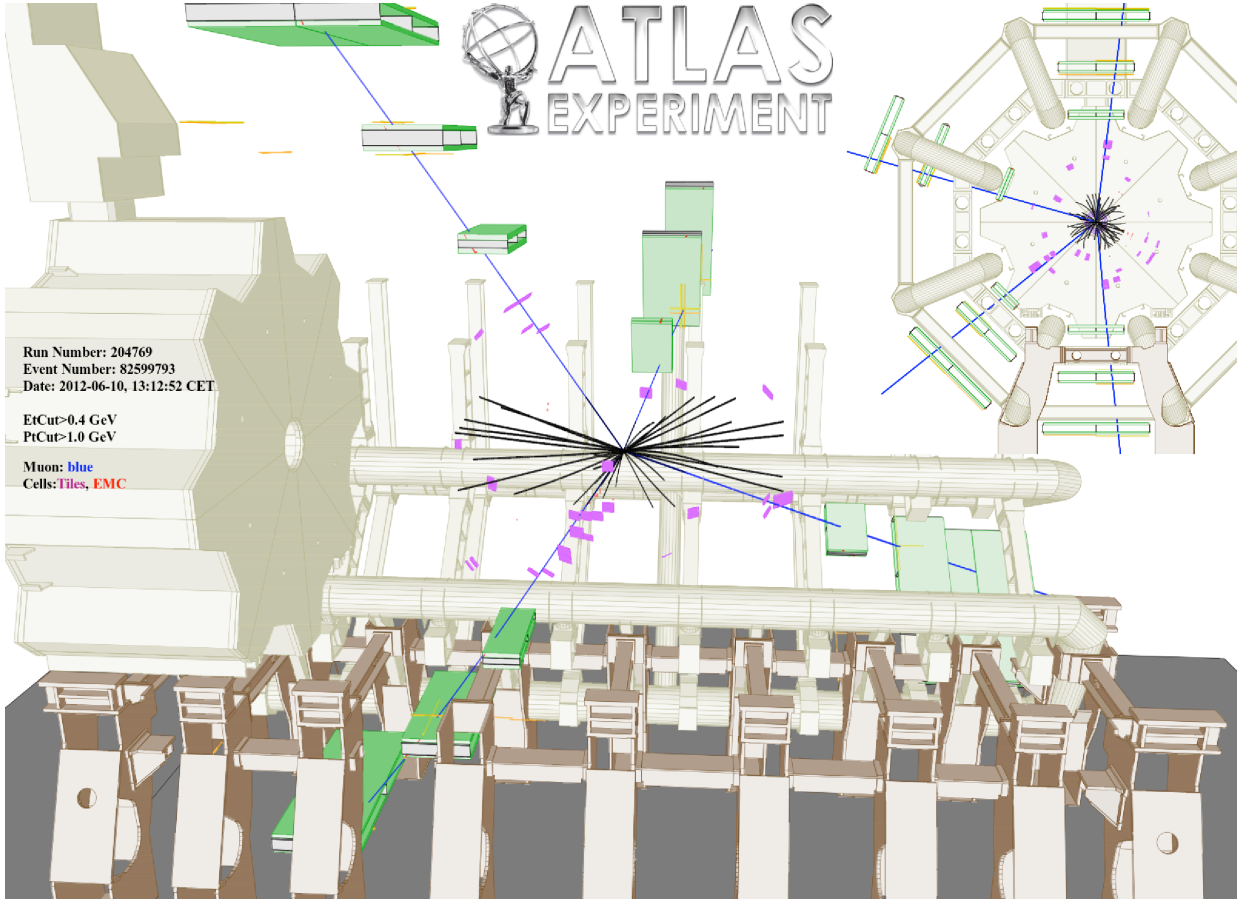
Combined properties

BSM:

SUSY searches

EXOTICS searches

HL-LHC



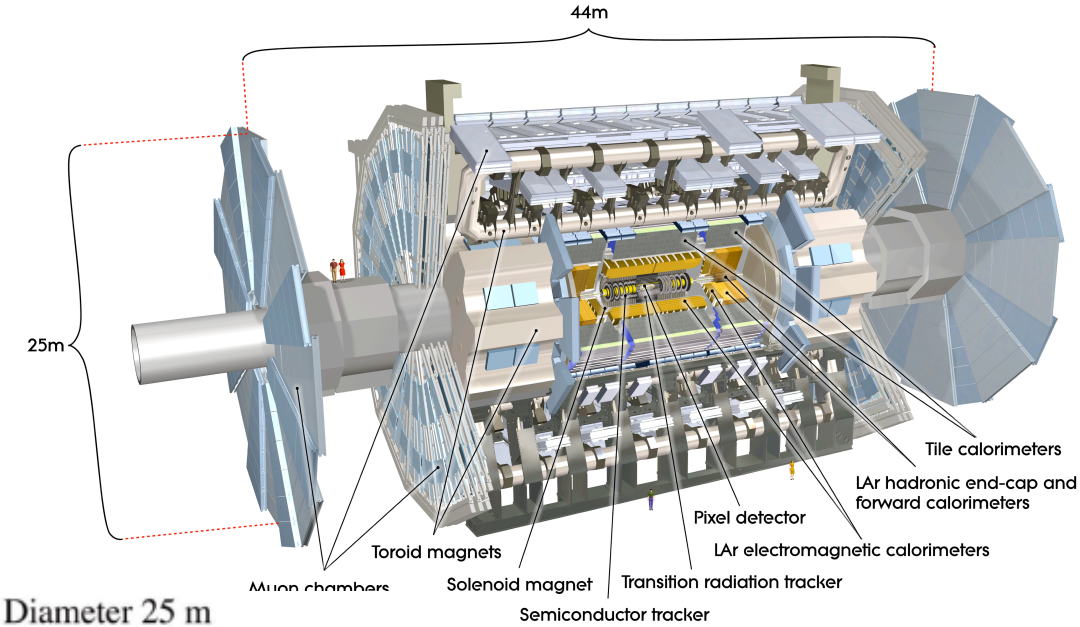
ATLAS EXPERIMENT

UNIVERSITA' DEGLI STUDI DI NAPOLI PARTHENOPE

INFN Istituto Nazionale di Fisica Nucleare

The ATLAS Detector

ATLAS is a general purpose detector, designed to be sensitive to a wide range of physical phenomena: EWK, Higgs, SUSY, BSM, flavour physics (Excellent muon detection and tracking performance)



- Diameter 25 m
- Length : 46 m
- Barrel toroid length 26 m
- Overall weight 7 000 tonnes
- ~ 100 million electronic channels
- ~ 3 000 km of cables

Inner tracker:

$\sigma/p_T \approx 3.8 \times 10^{-4}\ p_T\ (\text{GeV}) + 0.015$

Calorimetry:

ECAL: $\sigma/E \approx 10\%/\sqrt{E} + 0.7\%$

HCAL: $\sigma/E \approx 50\%/\sqrt{E} + 0.03\%$

Muon spectrometer:

$\sigma/p_T \geq 10\%$ @ 1 TeV

$\sigma/p_T \geq 2\%$ @ 100 GeV (with ID)

Magnets:

Solenoid: 2T

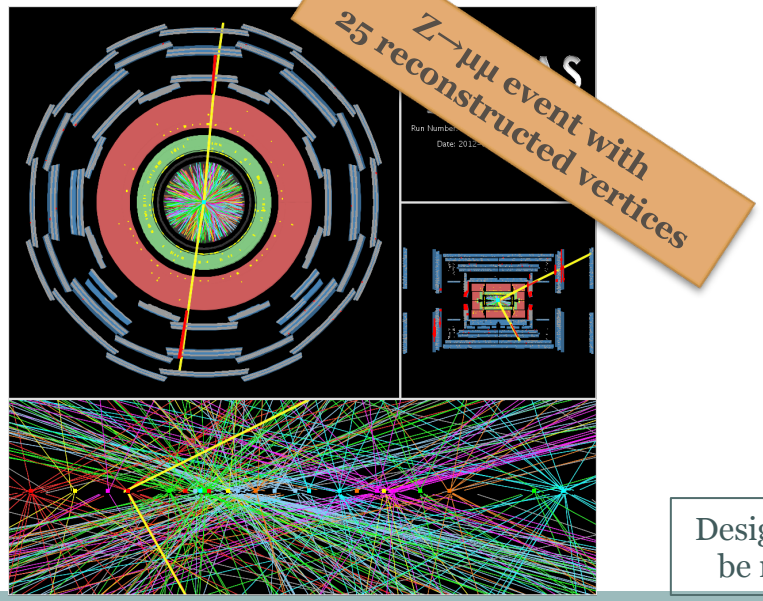
Toroid: 0.5 T (barrel), 1T (endcap)

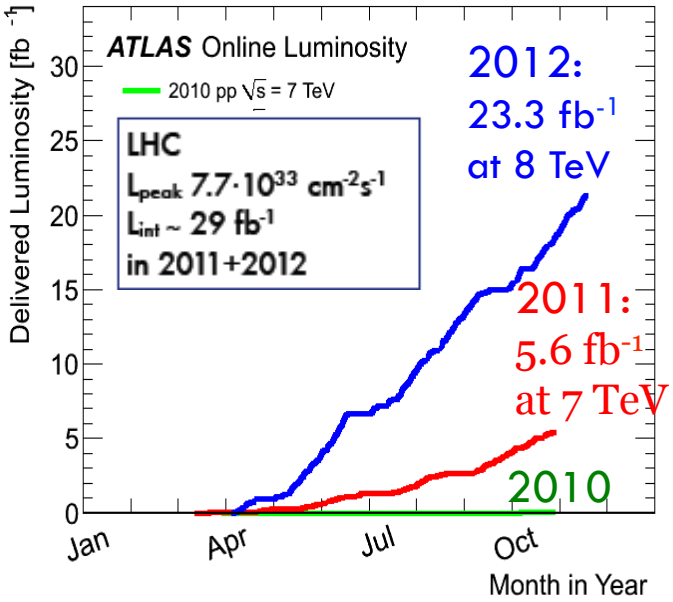
Trigger:

3 Levels, 40 MHz → 400 Hz

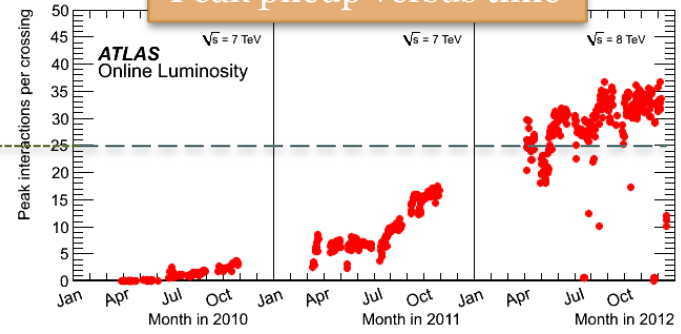
LHC and ATLAS performance

Excellent ATLAS performance
Data-taking efficiency: 93%
Good quality data fraction used for analysis: 95.8%
Challenge: harsh pile-up conditions
[trigger, computing, reconstruction of physics objects]





Peak pileup versus time



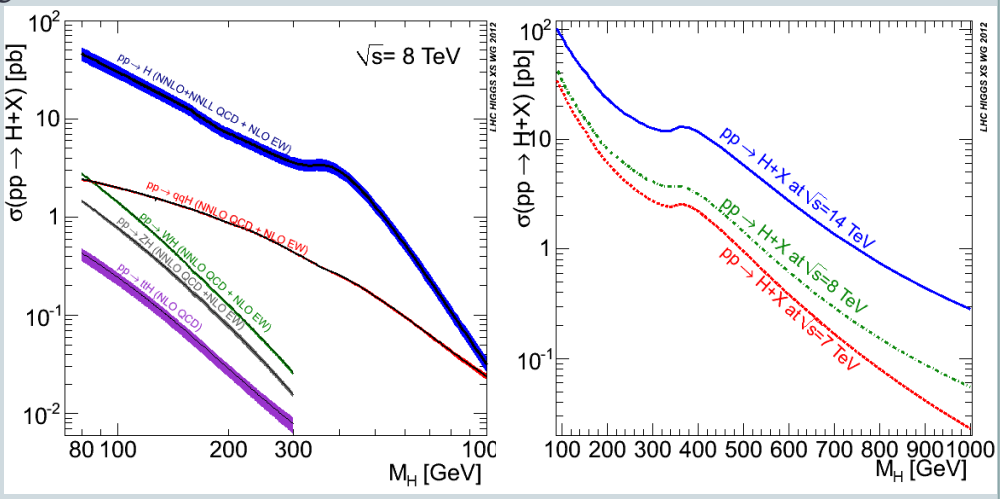
Design value (expected to be reached at L=10^{34}!)

SM and BSM Higgs Boson searches

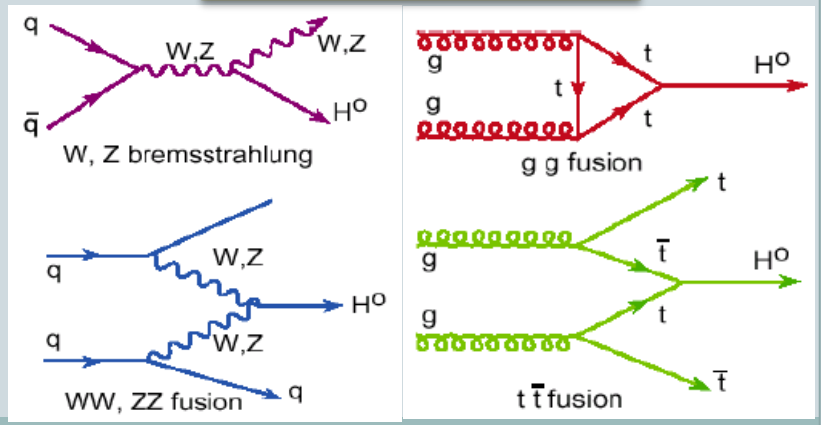
Measurements and searches in the context of SM Higgs boson search:

- golden bosonic decay channels:
  - ✧ γγ and ZZ→ 4l
  - ✧ WW
  - ✧ Zγ
- more high mass devoted:
  - ✧ ZZ→ llqq,
  - ✧ ZZ→ llνν, WW→ lνqq
- fermionic decay channels
  - ✧ ττ, bbar, μμ

Combination of analyses across different production and decay modes gives information about couplings



SM production modes



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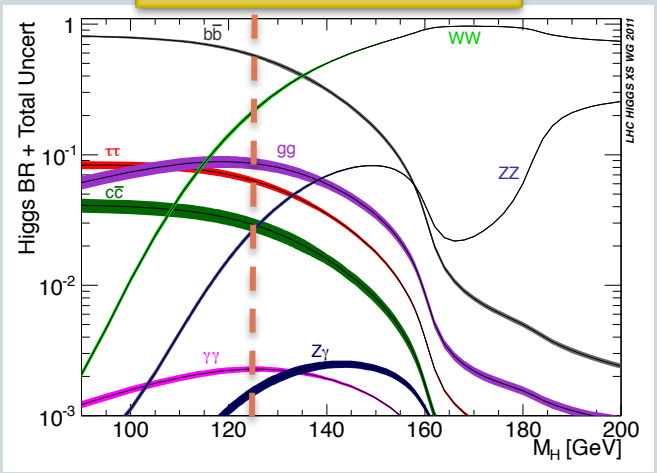
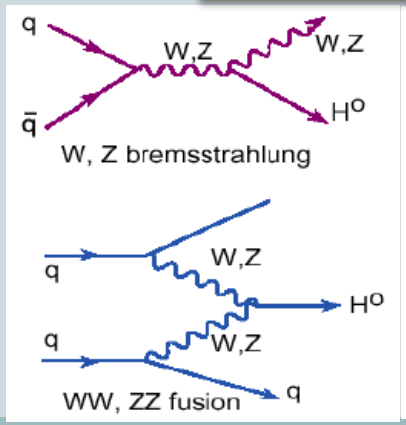
Production modes used both to enhance analysis sensitivity and to get information about couplings

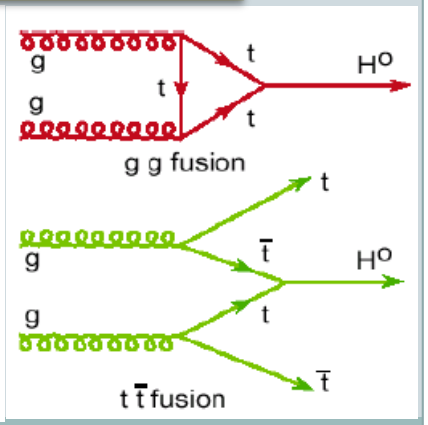
- Generic BSM: invisible decays
- MSSM: A/H → ττ, H±→τν or csbar

SM branching ratios



SM production modes

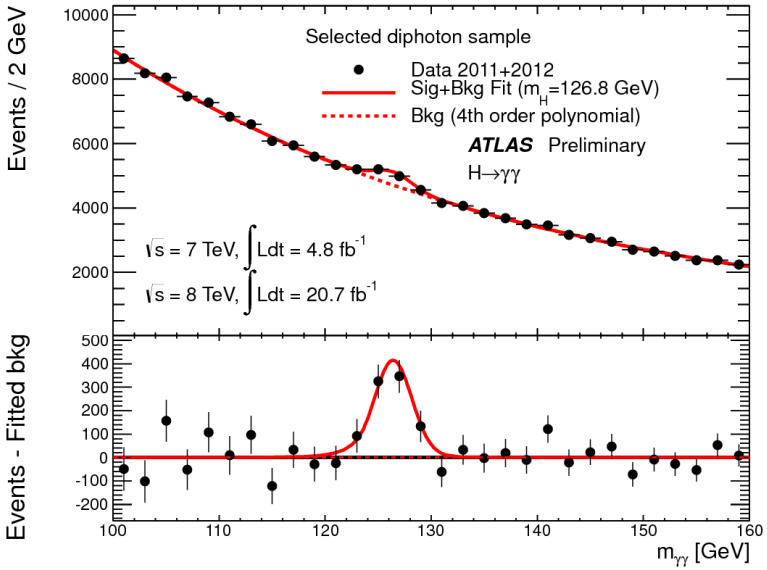




H→γγ Overview

ATLAS-CONF-2013-012

- Low BR (~0.2%) but very distinctive signature
- Main production mode and decay through loops: sensitive to new physics
- High mass resolution channel: σ_m ~ 1.7 7 GeV
  - stable against time and pileup
  - negligible uncertainty on primary vertex identification thanks to calorimeter pointing
- 14 categories targeting different production modes, VH (lepton, jets and MET) and two VBF categories. Different sensitivities and resolutions



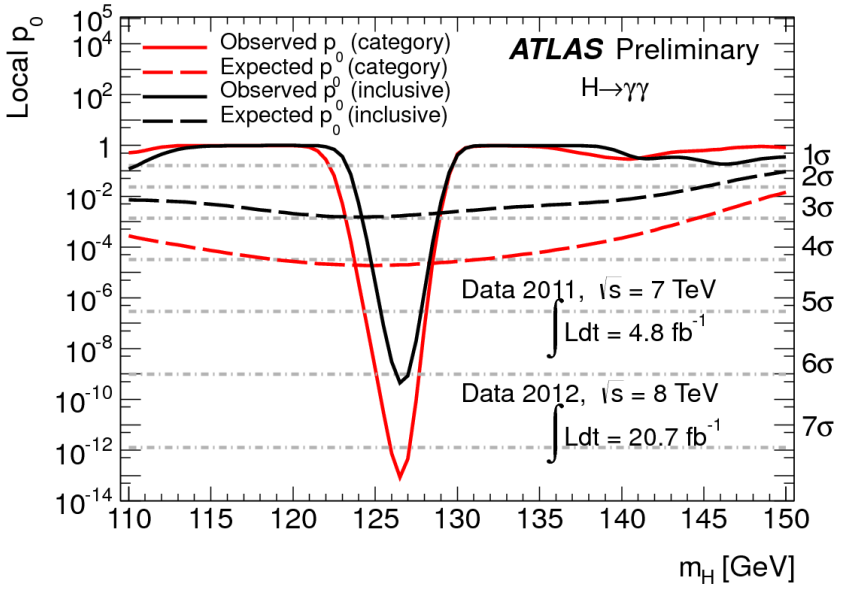
- Main backgrounds: γγ continuum (75%), γ-jet, jet-jet events (25%)
  - tight photon identification and isolation
  - background parametrised by an analytic function in each category, model chosen with MC to minimise biases
  - background extrapolated from side-bands in data
  - S/B ~ 3% in mass window

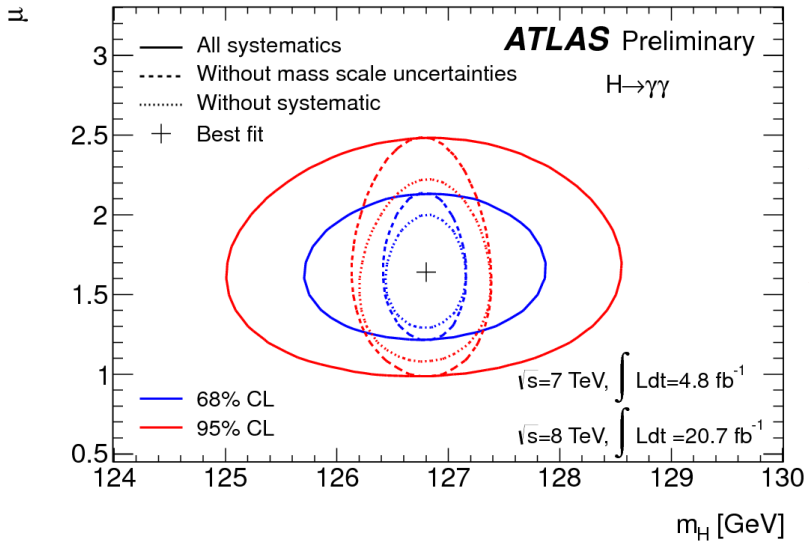
H→γγ signal strength and mass

- Signal extracted by $m_{\gamma\gamma}$ fit in each category
- Observed excess local significance:
  7.4σ (4.1σ SM expected)
- Signal strength at 126.5

μ = 1.65 +0.24(stat) +0.25-0.18 (syst)

- Inclusive fiducial cross section:
  σ_{fid} x BR = 56.2 ± 12.5 fb

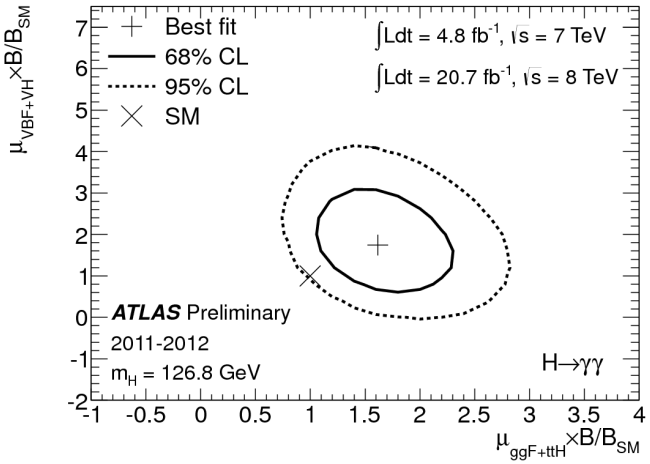




- Best fit mass:
  m_H = 126.8 ± 0.2 (stat) ± 0.7 (syst) GeV
- Main mass systematics:
  - Extrapolation of γ energy scale from Z→ee (0.3%)
  - Material modeling (0.3%)
  - Presampler energy scale (0.1%)

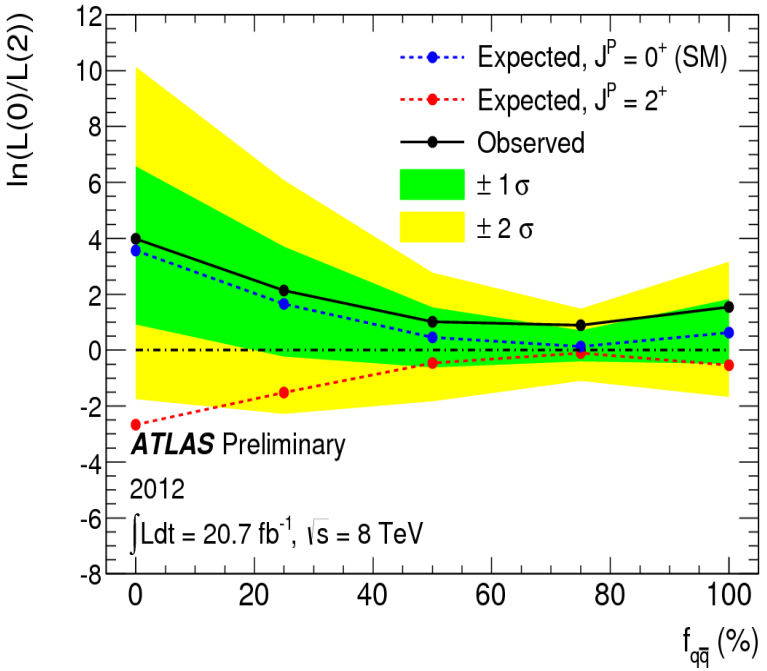
ATLAS-CONF-2013-012
ATLAS-CONF-2013-029

$H\rightarrow\gamma\gamma$ couplings and spin



- Grouped ggF+ttH and VBF+VH production modes (boson and fermion couplings)
- Compatibility with SM at 2σ level
- VBF production excess: 2σ level

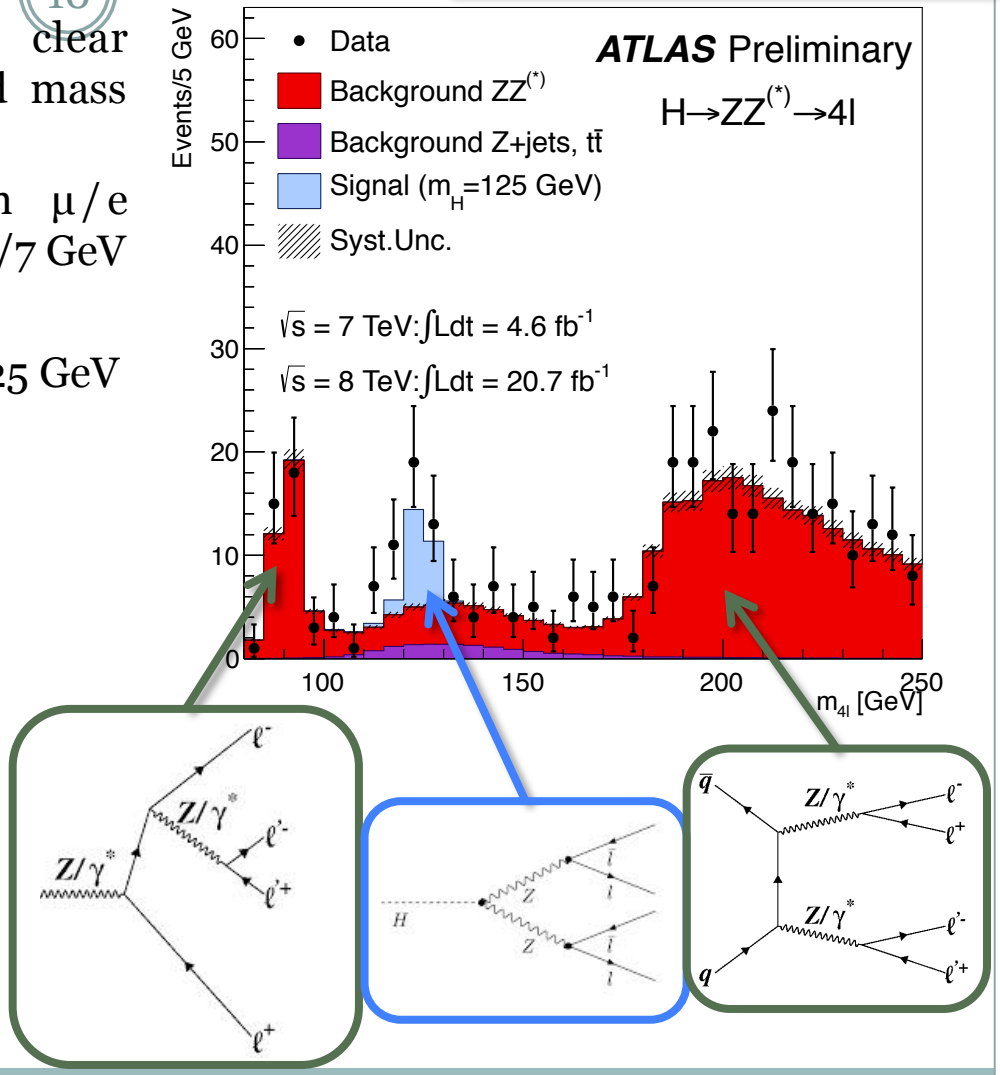
- From dN/d|cos$\boldsymbol{\theta}$*|, $\boldsymbol{\theta}$* angle of the photons in resonance rest frame
  - $0^+ \rightarrow$ flat before cuts
  - $2^+ \rightarrow 1+6\cos 2\theta^* + \cos 4\theta^*$ (graviton like model with minimal couplings, gg production)
- Inclusive analysis with different p_T cuts
- Signal region: ±1.5**σ** around peak
- Background from sidebands
- Five benchmarks of 2^+ production (qqbar fraction)
- Analyses based on mγγ and dN/d|cosθ*|



H→ZZ→4l Overview

ATLAS-CONF-2013-013

- Golden channel: small BR but very clear signature (two pairs l^+l^-) and very good mass resolution
- Maximize acceptance with high μ/e reconstruction and id efficiency down to 6/7 GeV
- FSR recovery (~ 4% of events)
- Mass resolution: 1.3%/1.9% for 4μ/4e @125 GeV
- Background
  - irreducible ZZ continuum (MC), including Z→4l
  - Z+jets, Z+bb, ttbar
    - isolation and impact parameter cuts
    - background measurement in data control regions
- Mass resolution improved by Z mass constraint
- 3 Categories reflecting different production modes (ggF, VBF, and VH)



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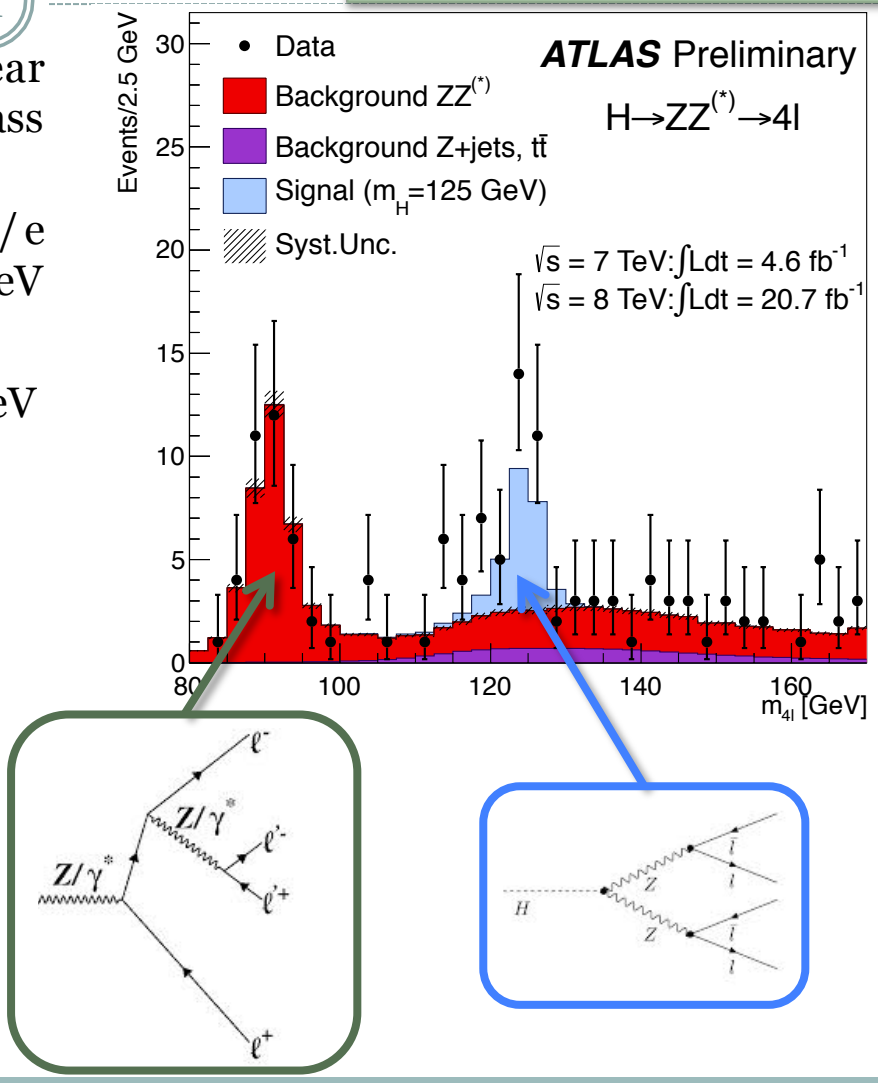
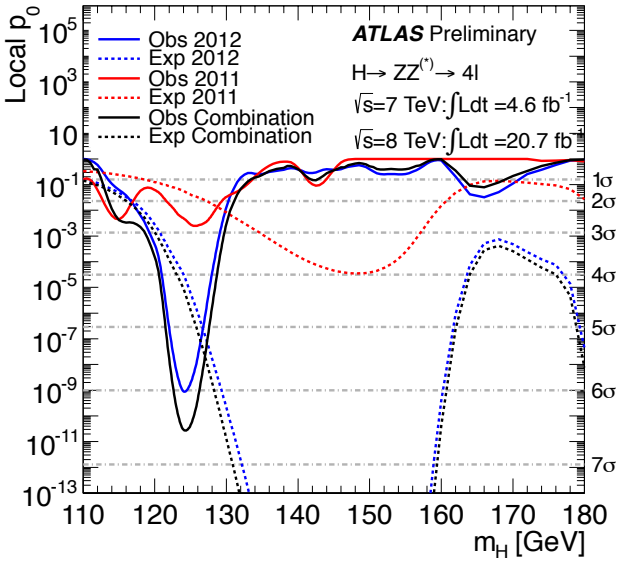
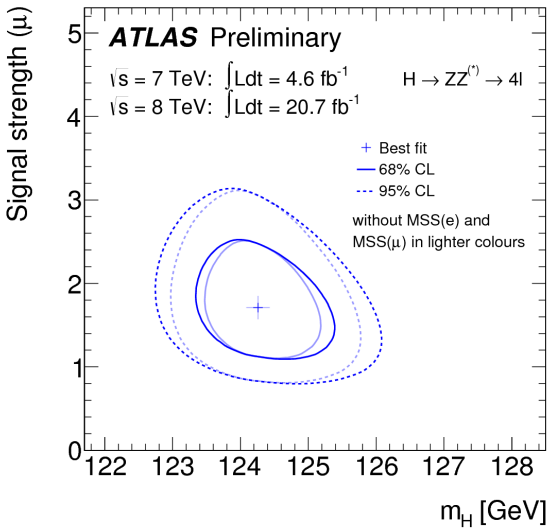
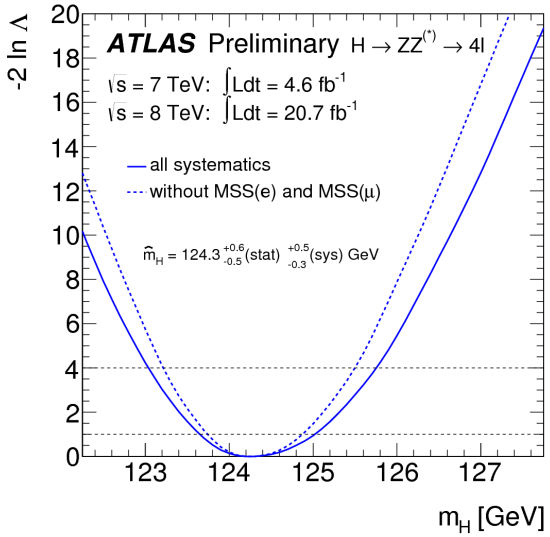


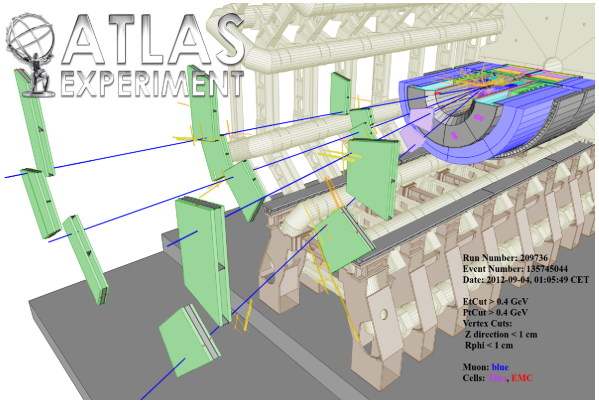
H→ZZ→4l signal strength and mass

6.6 σ local significance excess









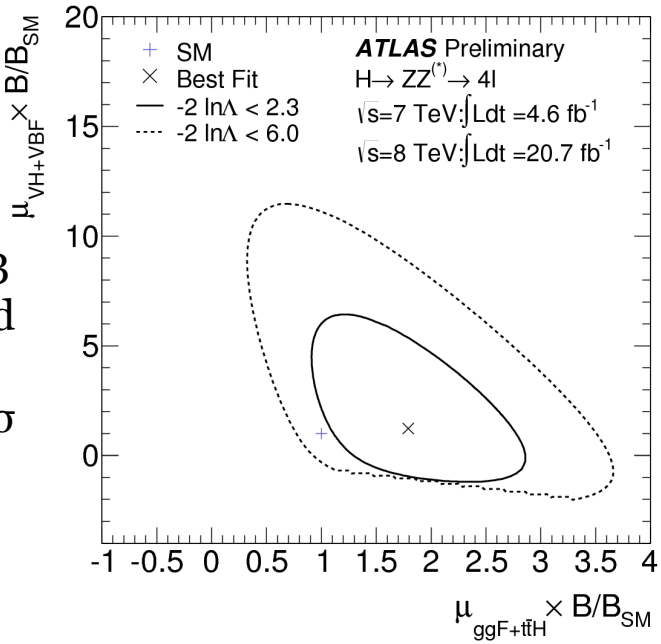
μ = 1.7+0.5 -0.4

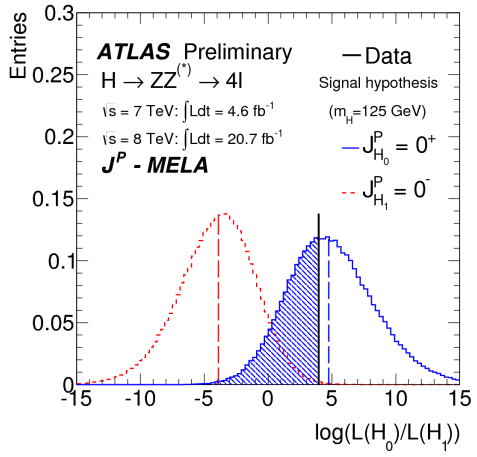
m_H = 124.3+0.6 -0.5 (stat)+0.5 -0.3(syst) GeV

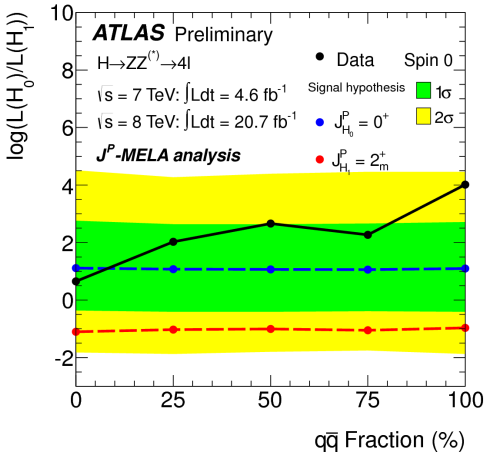
Details in "*H→ZZ,WW*" talk by S. Oda
Higgs@LHC section of HB workshop

H→ZZ→4l couplings and spin

- Categorization dedicated to coupling studies
  - VBF: 2 high p_T jets $\Delta\eta_{jj} > 3$ $m_{jj} > 350$ GeV
  - VH: additional lepton, non VBF
  - ggF: failing other categories
- $m_{4l} > 160$ GeV: 6 VBF events observed, expected 3.8±1.3
- 120 GeV < m_{4l} < 130 GeV: 1 event observed, expected from SM Higgs 0.71±0.10
- Signal strength per production mechanism: <2σ agreement with SM





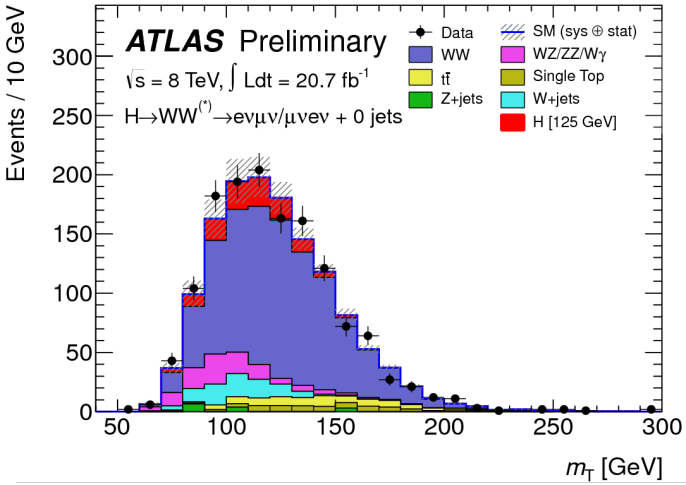


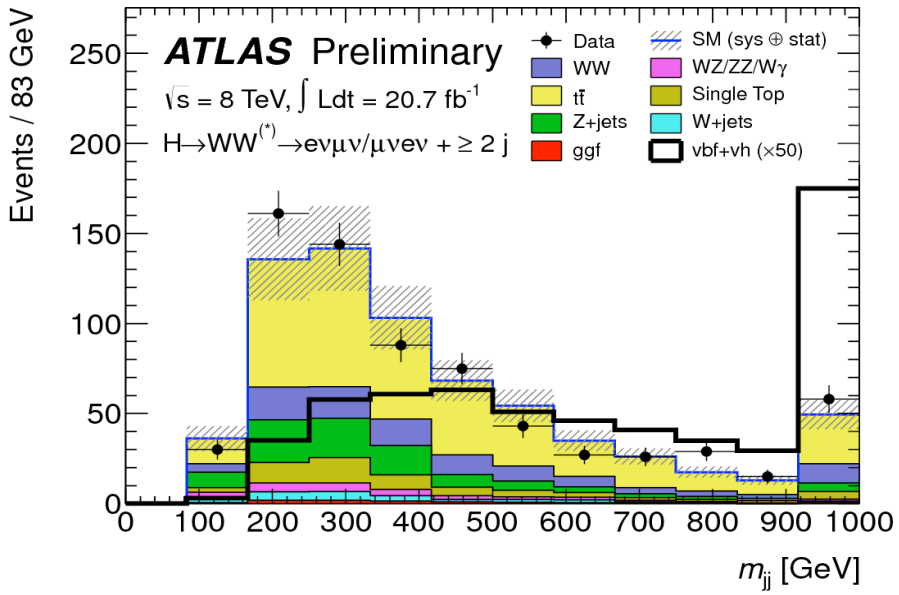
- Discriminants built from spin sensitive observables: Z1,Z2 masses, 2 production and 4 decay angles
- Tested on 43 events in signal region
- Pairwise JP test: 0^+, 0^-, 1^+, 1^-, 2^+, 2^-
- 0^- and 1^+ excluded at > 97.8% CLs
- 0^+ favored

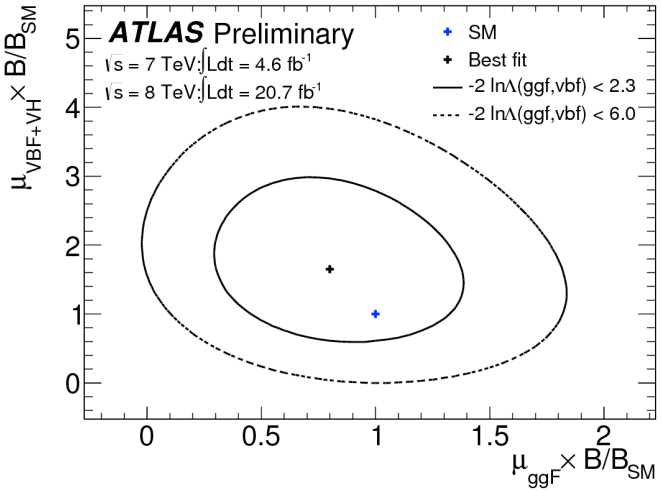
Details in "*H→ZZ,WW*" talk by S. Oda
Higgs@LHC section of HB workshop

H→WW Overview

- Large BR (~ 20%) despite being below real WW decay around 125 GeV
- Full mass reconstruction not possible
- Clear dilepton signature
- VBF dedicated channels
- Main backgrounds: irreducible continuum WW , ttbar, W→lν
- Backgrounds estimated from control regions



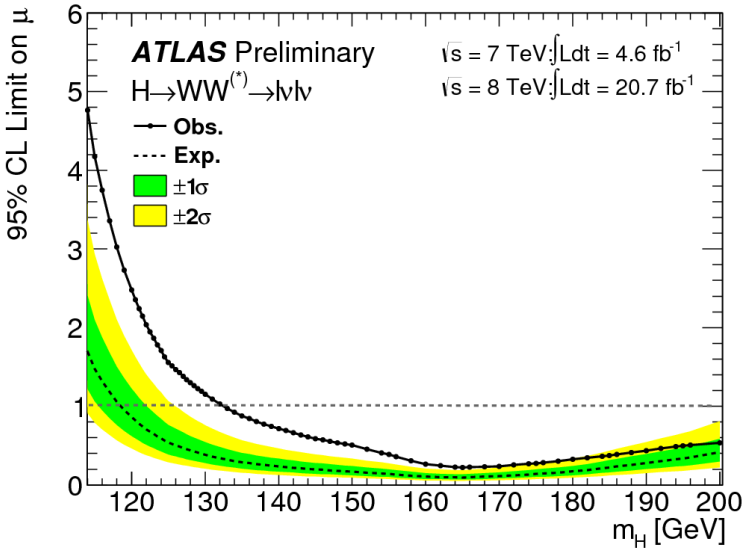


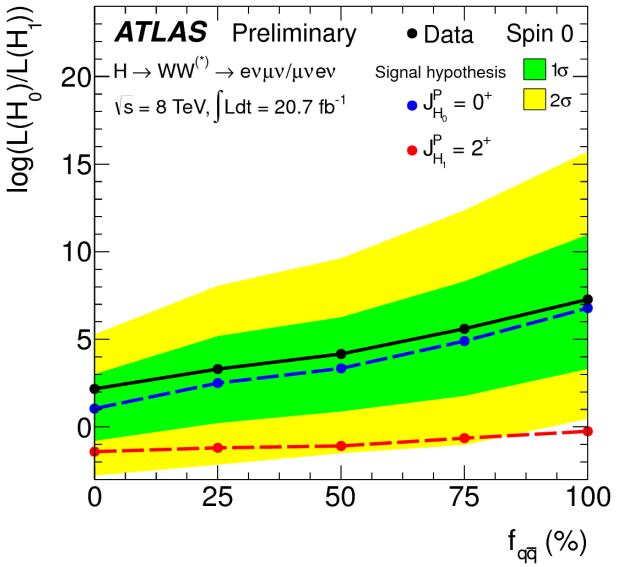


excess observed: 3.8 σ
VBF excess (signal + N_{jet} ≥ 2): 2.5 σ
VBF excess expected: 1.6 σ

H→WW signal strength and spin

- $\mu = 1.0 \pm 0.3$
- Measured cross section @8TeV:
  $\sigma \times BR = 6.0 \pm 1.5$ pb SM expected $= 4.8 \pm 0.7$ pb
- Spin tested exploiting angular distributions, main variables m_{ll} and $\Delta\varphi_{ll}$
- 0^+ and 2^+ hypotheses tested, 0^+ favored against 2^+ at 95% CLs
- Sensitive in the f_{qq} region where $\gamma\gamma$ looses discrimination power

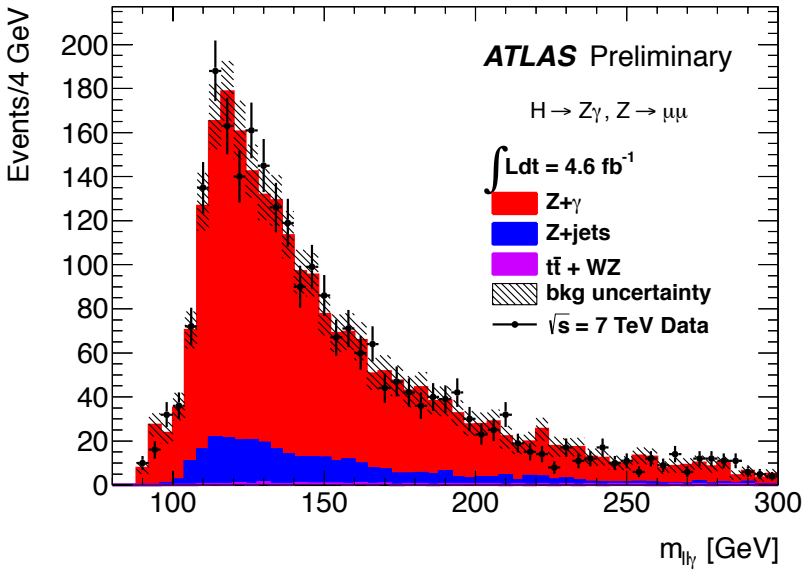


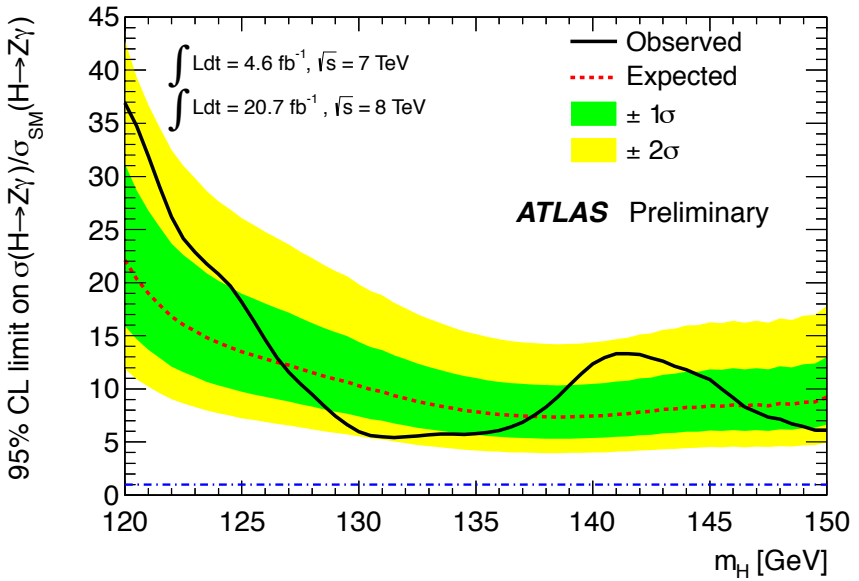


H→Zγ

ATLAS-CONF-2013-009

- Low BR, decay through loops → sensitivity to new physics
- Analysis with Z→ll (e/μ)
- Main backgrounds irreducible Z+γ and Z+jets
- Discriminating variable: $\Delta m = m_{ll\gamma} - m_{ll}$
- Background estimated from sidebands fit and cross checked with data-driven methods
- No excess observed, limits set at 18.2 x σ_{SM} at 125 GeV (expected 13.5 x σ_{SM})





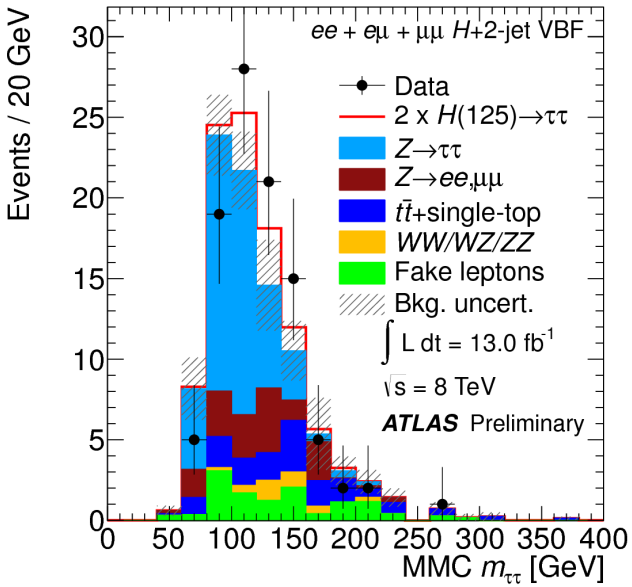
4.6 (7 TeV) + 13.0 fb^{-1} (8TeV) dataset

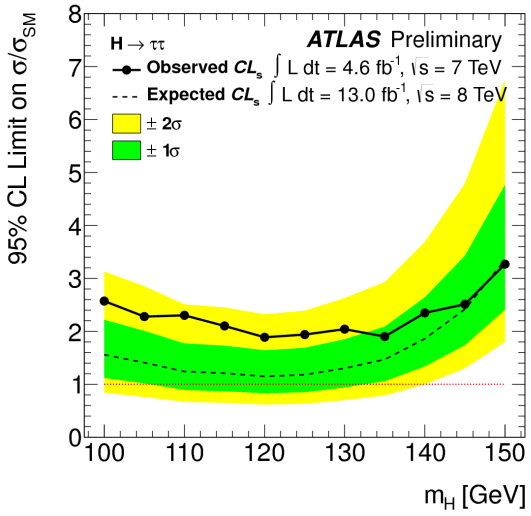
Details in "$H \to \tau\tau, \mu\mu$" talk by H. Fox
125 Higgs@LHC section of HB workshop

H→ττ

ATLAS-CONF-2012-160

- Second in branching ratio for decays to fermions but highest sensitivity due to experimental signature
- VBF categories have more sensitivity than the non-VBF categories
- Hadronic tau decays reconstructed from calorimeter jets and identified with Boost Decision Tree discriminator based on tracking and calorimeter information
- 10 categories based on tau decay type (ll, lhad, hadhad) and jet/event topology (targeting different production modes)



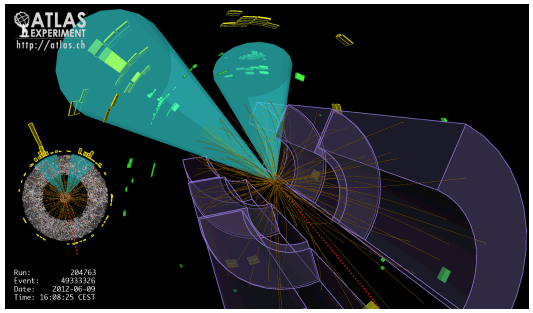


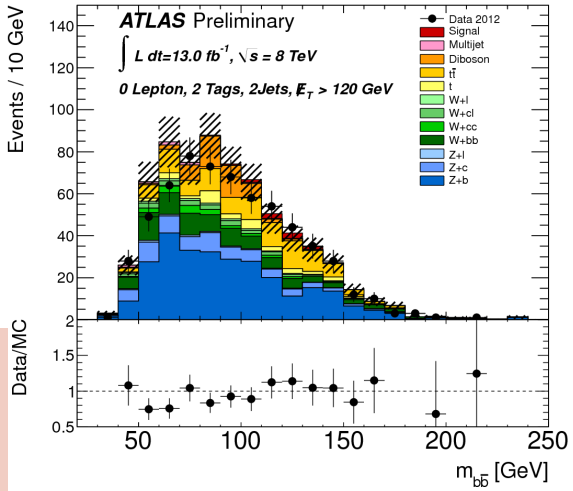
- Irreducible Z→ττ background from hybrid data-MC technique (Z→μμ data events with muons replaced by simulated taus)
- Z+jets, W+jets, top from MC, normalised/checked in data control regions, diboson from MC
- Multijet fully data driven
- Mass reconstruction exploiting knowledge of tau decay kinematics (MMC)
- No significant excess above SM is observed, limit at 125 GeV: 1.9 x σ_{SM} (expected 1.2 x σ_{SM}, 1 sigma excess)

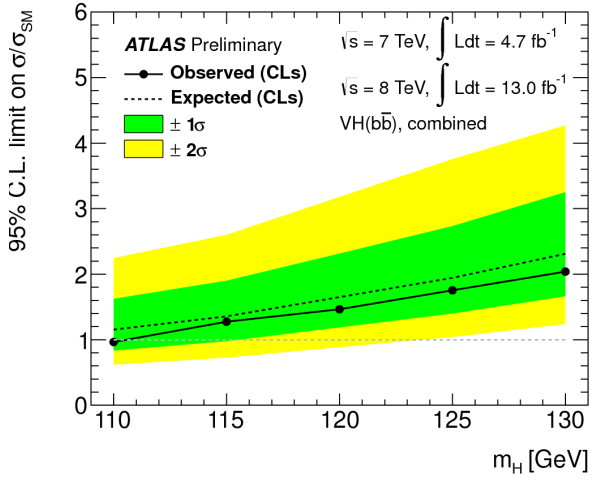
ATLAS-CONF-2012-161

H→bb (VH production mode)

- **H→bbar highest SM branching ratio, but experimentally difficult → need to exploit production modes**
- Associated production: three channels 0, 1, 2 leptons targeting Z→νν, W→lν, Z→ll
- 13 categories targeting different Higgs boost regime
- b-jets tagged combining information from different algorithms based on track impact parameter significance and or secondary decay vertex reconstruction
- Main backgrounds: top, W+jets and Z+jets
- Backgrounds taken from MC and normalised in control region (except multijets, fully data-driven and diboson, fully MC-driven)
- **No excess observed, limit at 125 GeV on σ_{SM}xBR 1.8 (1.9 expected)**
- **Cross checked method with 4σ observation of WZ, ZZ with Z→bbar**







Details in "*H→bb*"
by T. A. Du Pree
Higgs@LHC section of HB workshop

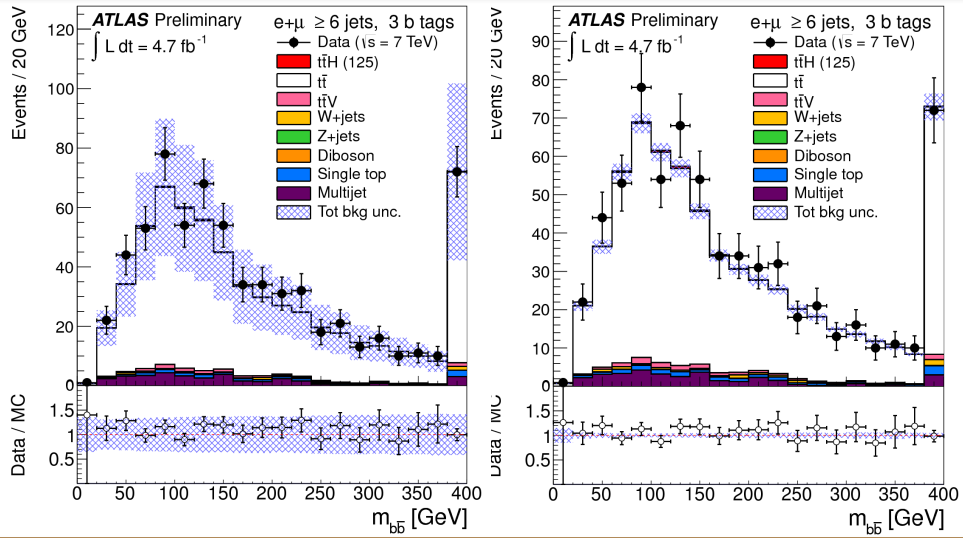
ATLAS-CONF-2012-135

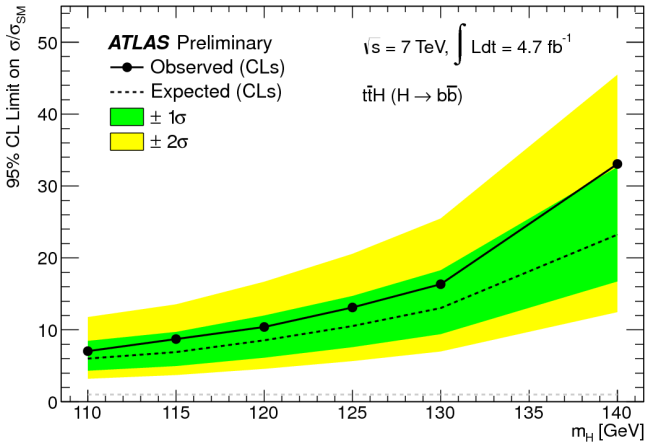
ttH, H→bb

Details in "*tth*" by M. Pianamonti
Higgs@LHC section of
HB workshop 06/06/2013

ttH → W+bW−b bb → l+νb qqb bb

- Events with ≥ 6 jets, of which ≥3 b-tagged
- Kinematic likelihood fitter used to assign objects in the detector to the objects above
- discriminating variable: mbbar
- Main background from ttbar
- Systematics due to b and c tagging efficiencies/mistag rate constrained in fit to data
- **No excess observed, limit σ_{SM} x BR 13.1 (10.5 expected)**





m_{bb} combined e+jets and μ+jets channels with >= 6 jets and 3 b-tags before and after fitting of the nuisance parameters to data (signal + background hypothesis)

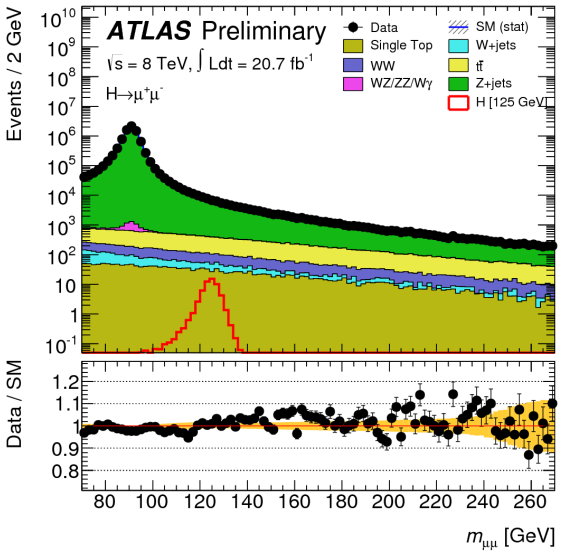
21 fb^{-1} 8TeV dataset

H→μμ

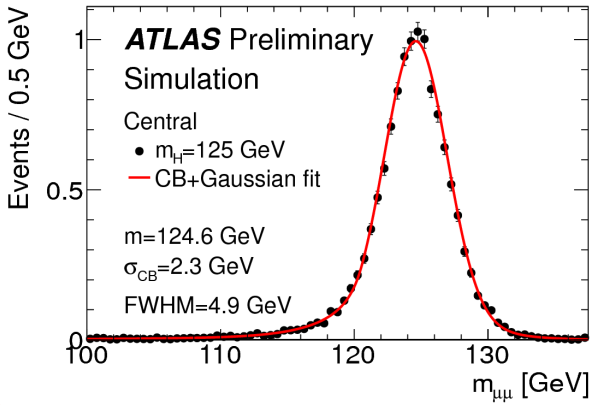
ATLAS-CONF-2013-010

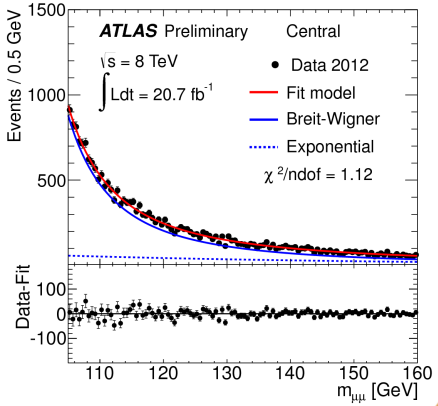
Details in "*H→ττ, μμ*" talk by H. Fox
125 Higgs@LHC section of HB workshop

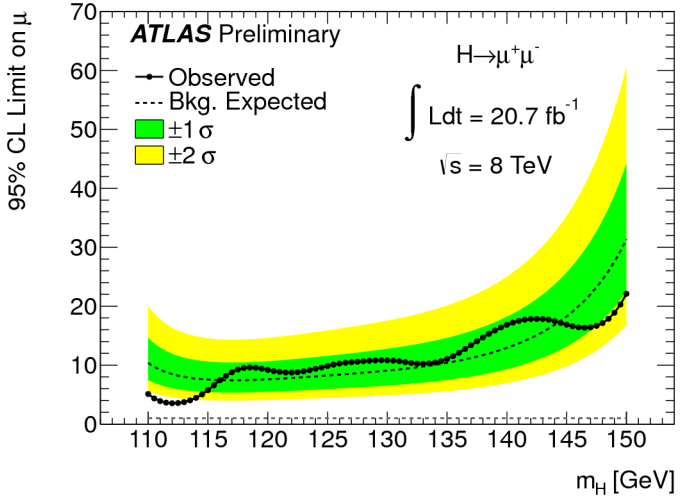
- Clean final state signature
- Testing couplings to second generation
- Branching ratio 28x10^{-5} - 6x10^{-5}
- Dominant irreducible Drell-Yan background
- 2 analysis categories depending on muon centrality
- The observed (expected) limit at the 95% CL for the Higgs boson with a mass of 125 GeV is 9.8 (8.2) times the Standard Model prediction.

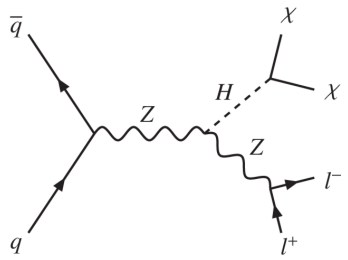


Binned likelihood fit
- background BW + exponential
- signal CrystalBall + gaussian







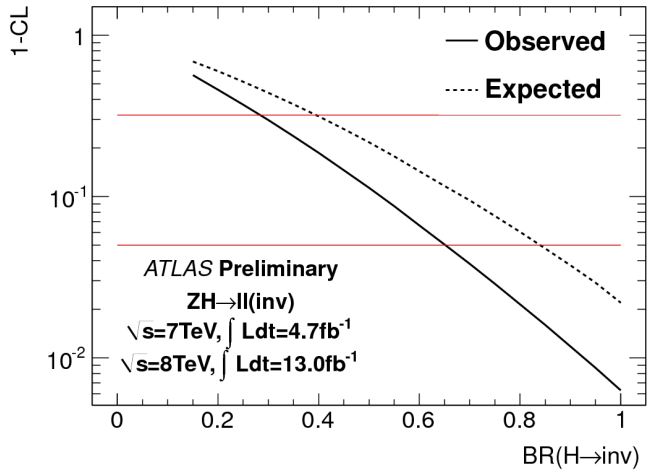


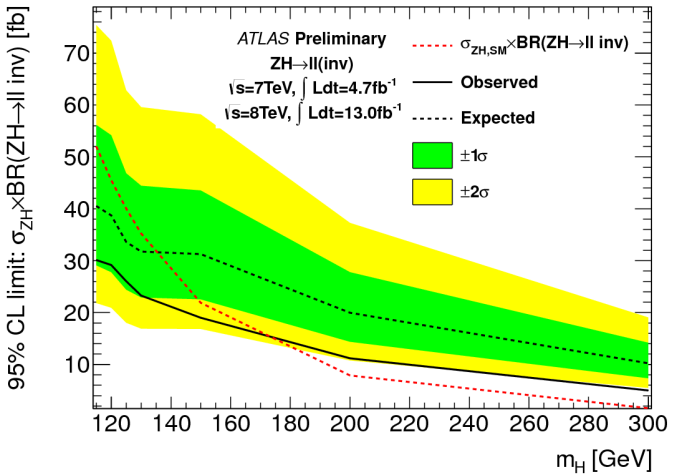
ATLAS-CONF-2013-011

ZH, H→ invisible

4.6 (7 TeV) + 13.0 fb^{-1} (8TeV) dataset

- For a SM Higgs BR to invisible particles is not measurable
- Could have contributions eg from dark matter particles
- Signature: Z→ee and Z→μμ with large MET (> 90 GeV)
- Main backgrounds from diboson production
- Cut optimization against ZH-like events
- Limits for a SM Higgs invisible branching ratio: assuming the *ZH* production rate for a 125 GeV SM Higgs boson, an invisible branching fraction greater than 65% is excluded with a 95% CL for the observed (84% with 95% CL for the expected)
- Limit on σ(ZH) x BR(invisible) for further Higgs-like states over the mass range 115 GeV <m_H<300 GeV





Details in "Combined analysis results" talk by A. Bonato
125 Higgs@LHC section of HB workshop

ATLAS-CONF-2013-014

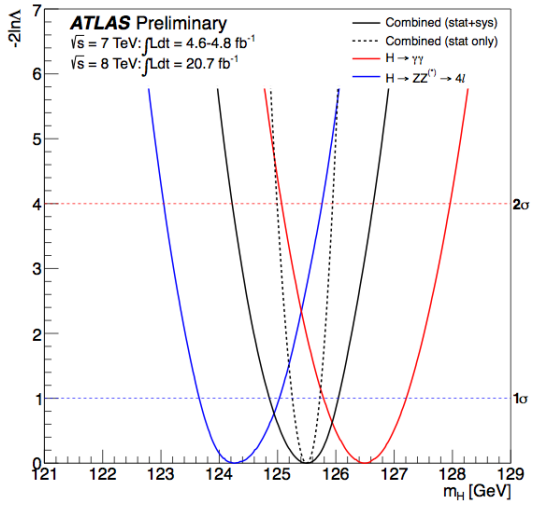
Combination: mass

From high mass resolution γγ and 4l channels H → ZZ:

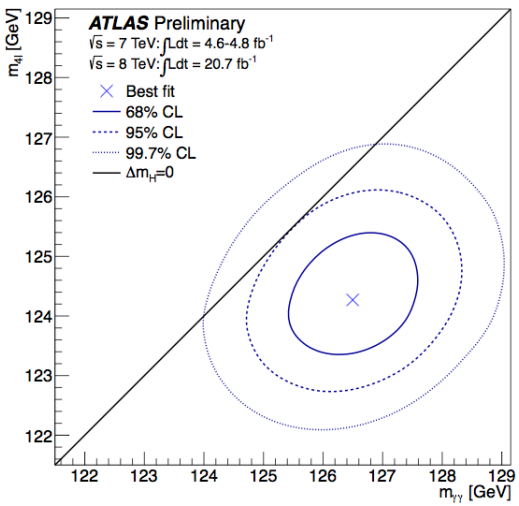
- 4l
  - dominated by 4 muons
  - muon momentum scale uncertainty 0.2%
- γγ
  - per category systematics + global uncertainty
  - total systematic uncertainty on mH is 0.55%

Results from profile-likelihood method:
γγ: 126.8±0.2(stat)±0.7(sys) GeV
4ℓ: $124.3^{+0.6}_{-0.5}(\text{stat})^{+0.5}_{-0.3}(\text{sys})$ GeV
combined: $125.5\pm0.2(\text{stat})^{+0.5}_{-0.6}(\text{sys})$ GeV

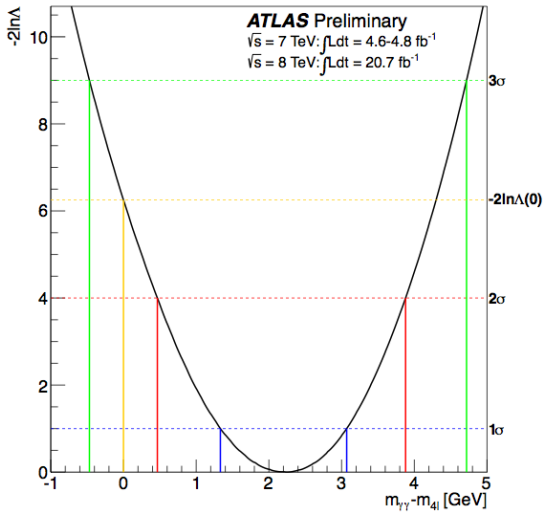
profile likelihood scan vs m_H



2D scan vs $m_H(4\ell)$, $m_H(\gamma\gamma)$



$-2\ln\Lambda(\Delta m_H)$ (m_H is profiled)

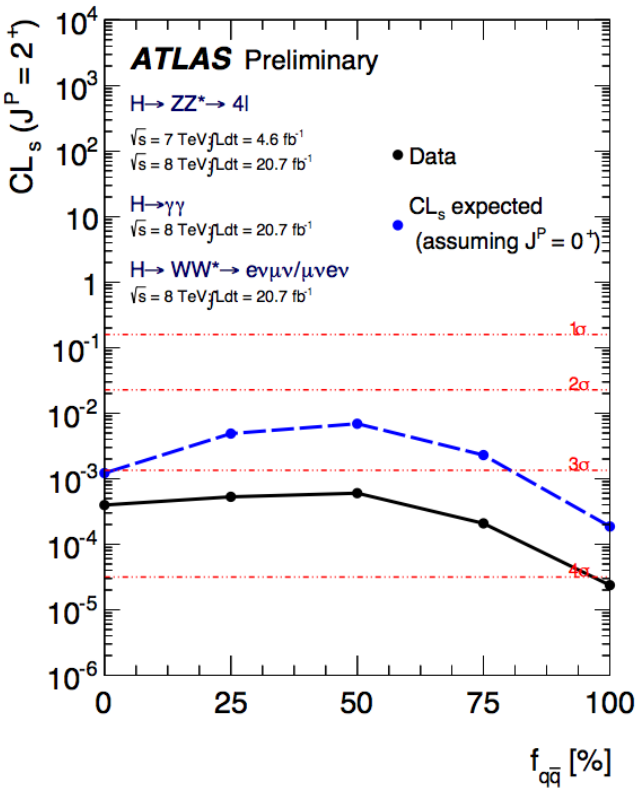


- main correlation from e/γ energy scale systematics
- individual measurements compatible at 1.5% (2.4σ) level

Combination: SPIN-parity

Combination: exclude 2^+ model against 0^+ at more than 99% CL

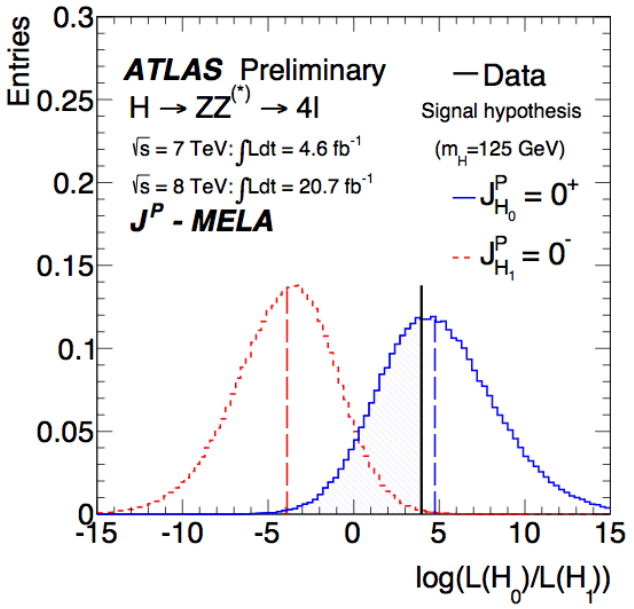
All combinations of qq/gg production excluded as well



H→ZZ→4ℓ channel alone:

exclude 0^-, 1^+, 1^- at more than 96.9% CL

test of 2^- against 0^+ still inconclusive

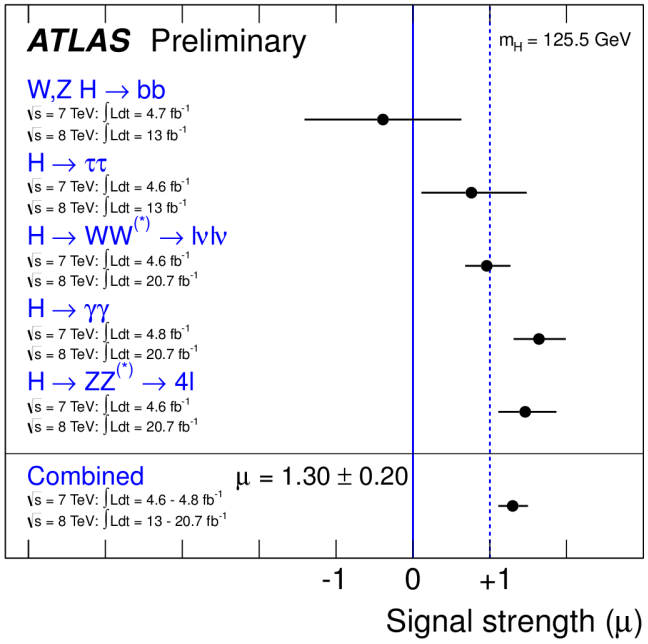


Combination: signal strength

Once m_H is measured, SM cross sections are uniquely determined

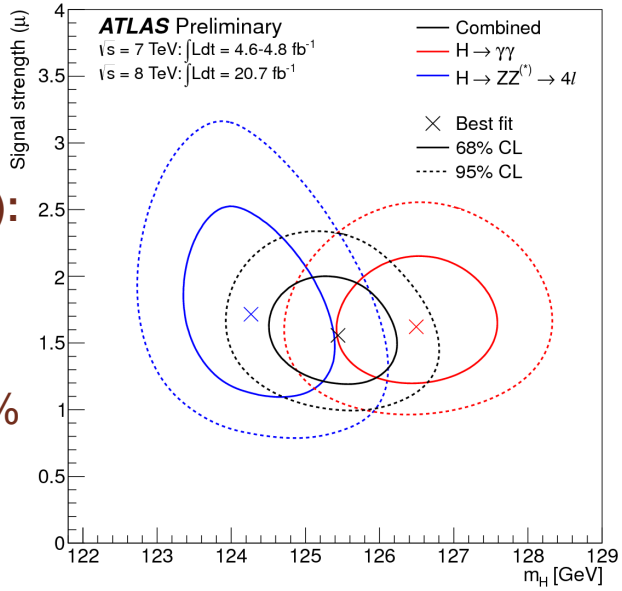
- we can test the agreement with SM measuring deviations from predicted yields
- assume $m_H = 125.5$ GeV and define a signal strength μ such as $N_{tot} = \mu \cdot N_{sig} + N_{bkg}$ ($N_{tot} > 0$)
- combine measurements from all decay channels

result is stable within ~4% for ±1 GeV variations of assumed m_H



Consistency with SM (μ=1):
- ❖ global μ: 9%
- ❖ 5 single channel μ_i: 8%

Consistency with μ = 1.43
- ❖ 5 single channel μ_i: 13%



Parameter of interest: μ (global)
μ = 1.30±0.13(stat)±0.14(sys)

Production modes and couplings

Analysis of signal strength depending on production modes
- grouped VBF + VH and ggF + ttH
- μVBF+VH/μggF+ttbarH = $1.2^{+0.7}_{-0.5}$:
  3σ evidence for VBF production

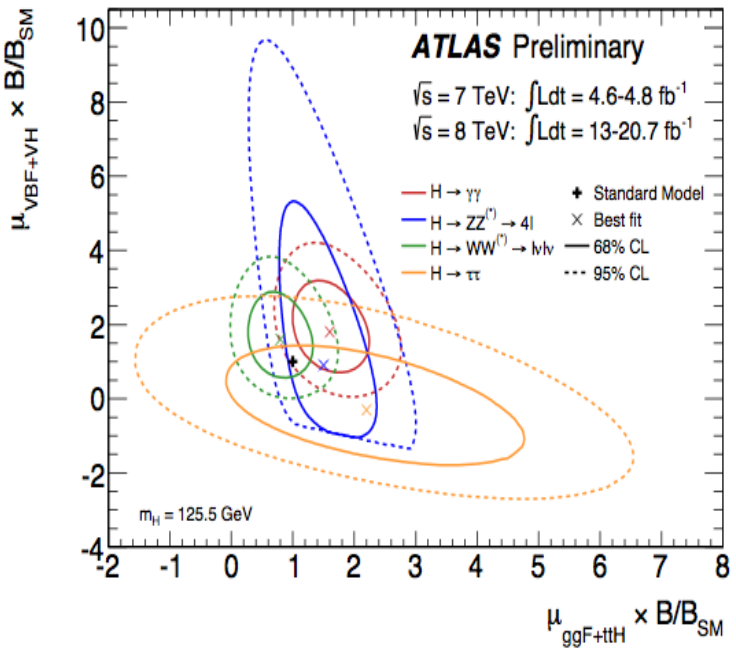
Analysis of fermion and vector boson couplings
- $k_v = k_w = k_Z$, $k_f = k_t = k_b = k_\tau$
- assume only SM particles involved
- compatibility with SM =8%

Custodial symmetry:
- ungroup k_W and k_Z, $\lambda_{WZ} = k_W/k_Z = 1$ within 95% CL

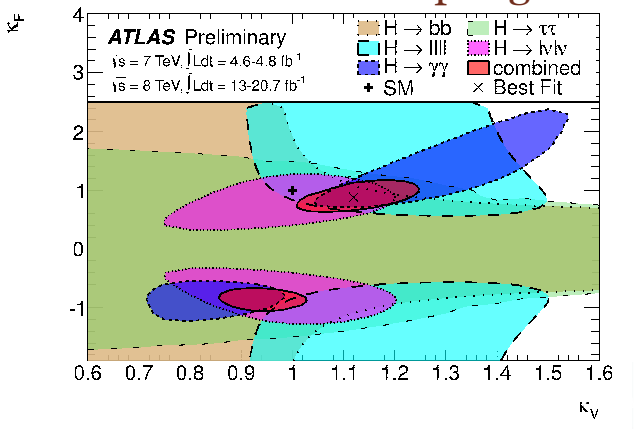
Contributions from BSM particles: assume SM k_i =1,

$k_g = 1.08 \pm 0.14$, $k_\gamma = 1.23^{+0.16}_{-0.13}$

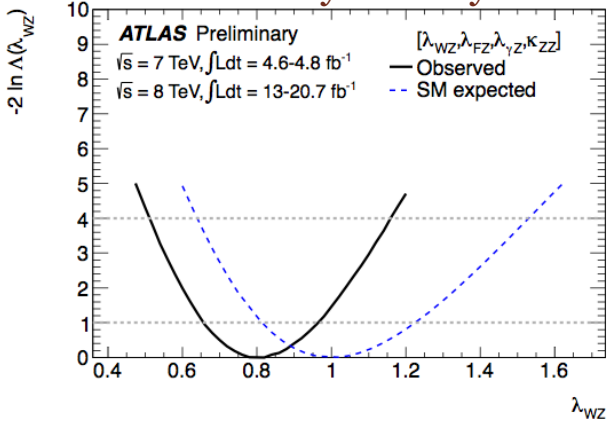
Production modes



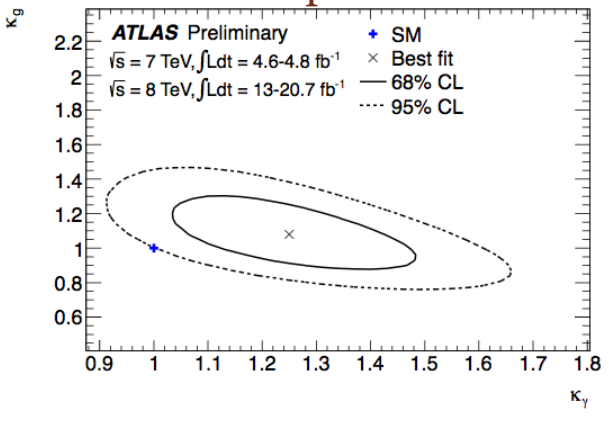
Fermion-boson couplings



Custodial symmetry



Non-SM particles



Couplings summary

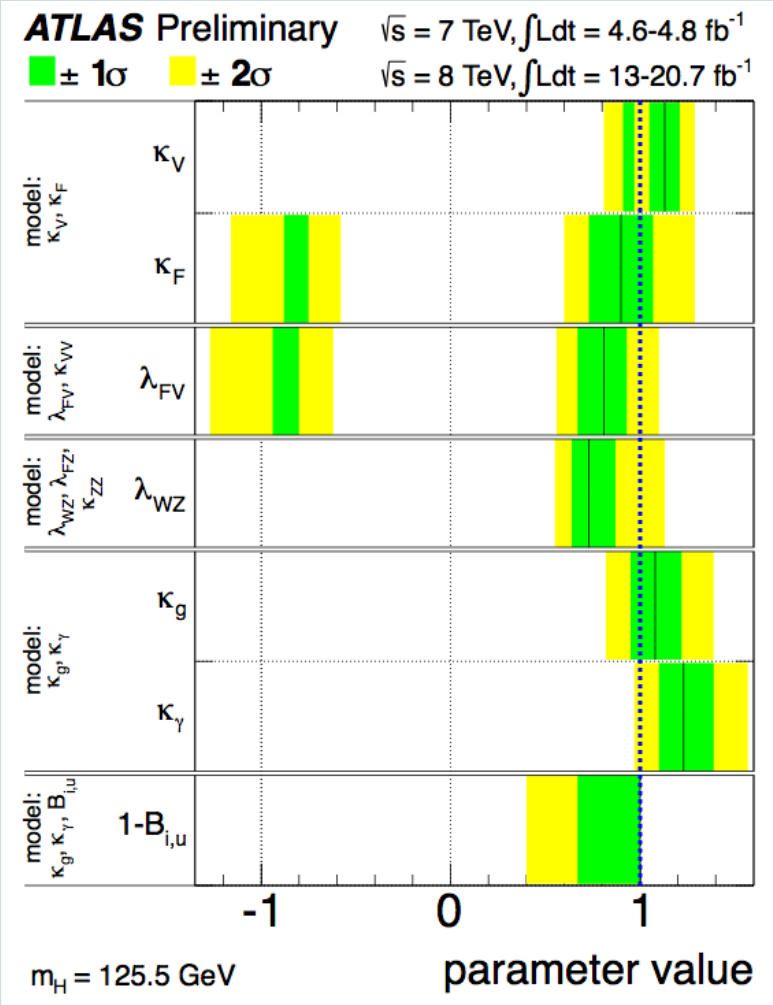
Many tested benchmark models

- common assumption: single resonance with SM-like tensor structure, zero width
- remark: various scenarios are correlated (based on same experimental data!)

no significant deviation

from Standard Model prediction

compatibility with SM at 5÷10% level

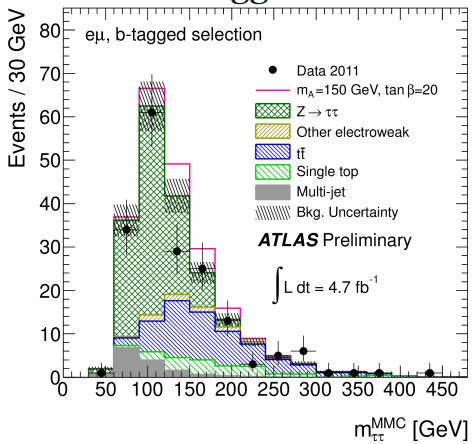


Details in the SUSY section of HB workshop

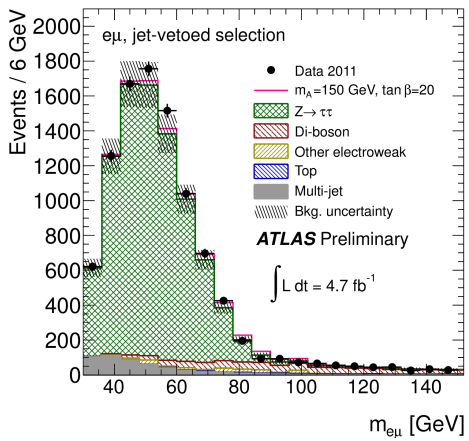
MSSM neutral Higgs searches

- MSSM Higgs branching ratios similar in structure to SM, but suppressed or enhanced according to tanβ
- At high tanβ τ and μ decays of A/H highly favored
- Decay channels considered: μμ, eμ, ehad, μhad, hadhad
- Exploiting two main MSSM production modes: ggF and b-associated production
- No statistically significant excess over the expected background is observed.

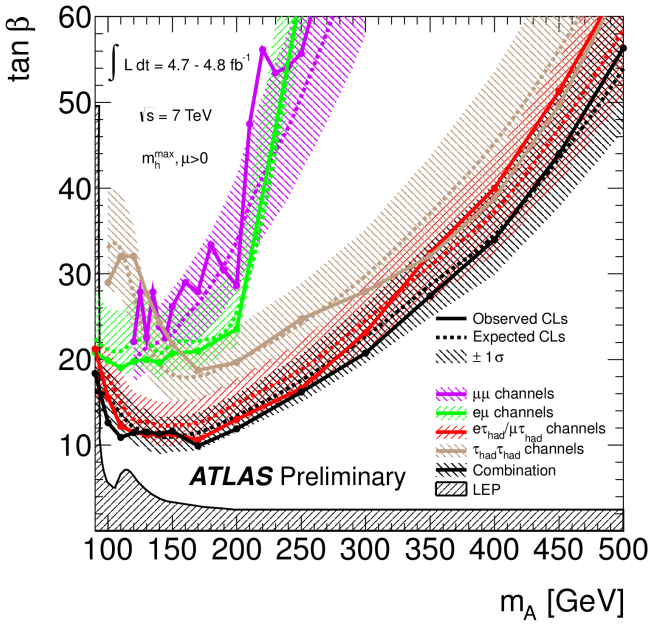
Missing Mass Calculator (MMC) mass observable for the b-tagged selection



Invariant mass of the selected leptons for jet-vetoed selection



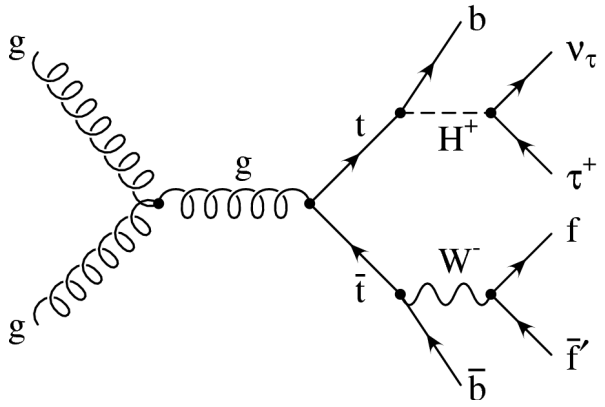
data are compared to the background expectation and an added hypothetical MSSM signal with m_A=150 GeV and tanβ=20

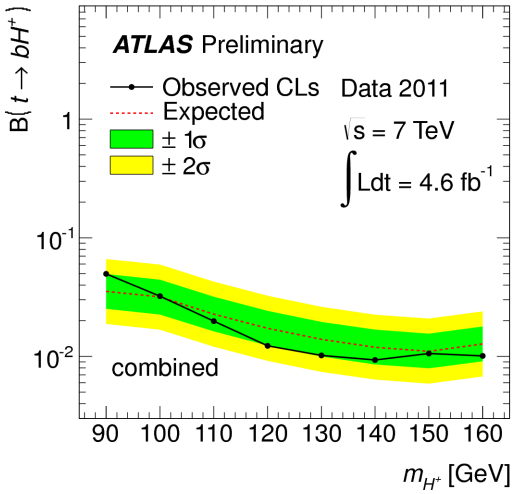


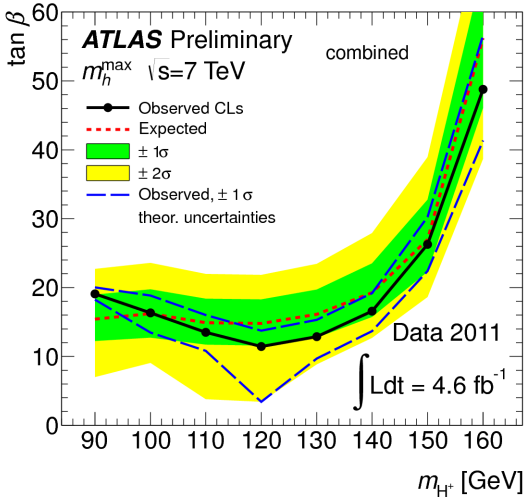
ATLAS-CONF-2012-011
ATLAS-CONF-2011-094

MSSM charged Higgs searches

- Charged Higgs fundamental in SUSY Higgs sector, since at least two Higgs doublets are needed
- Main production mode through top decays
- 3 final states considered, leptonic or hadronic τ decay, MET, b jets, and leptonically or hadronically decaying W boson
- Backgrounds: ttbar, single top multijet and diboson
- Mixed MC/data driven background estimation
- The data are consistent with the expected background from Standard Model processes
- csbar decay search with 35 pb^{-1} performed as well







Higgs Conclusions

- 4th July: announcement of the discovery of a Higgs-like boson, measurements and searched for other production modes ongoing
- Observation well established in γγ, 4l and WW channels with 7.4σ, 6.6σ and 3.8σ respectively
- Combined measurements from γγ and 4l:
  - m_H = 125.5 ± 0.2 (stat) +0.5-0.6 (syst) GeV,
  - μ = 1.30±0.13(stat)±0.14(sys)
  - $\mu_{VBF+VH}/\mu_{ggF+ttH} = 1.2^{+0.7}_{-0.5}$ 3.1σ evidence for VBF production
- Fermionic decays are being searched for… limits at 1.9xσSM and 1.8xσSM for ττ and bbbar respectively, still not full LHC dataset
- Combination for signal strength (γγ, 4l, WW, ττ, bbar): Results for couplings and spin compatible with the SM:
- **μ = 1.30±0.13(stat)±0.14(sys**
  - new boson is compatible with SM $J^{PC}=0^+$
  - excluded 0^-, 1^+, 1^-, 2^+ specific scenarios against SM at more than 96.9% CL
- No evidence for invisible Higgs decays
- No evidence for BSM Higgs states (stay tuned for full-statistics result)
- The characteristics of the observed boson are up to now compatible with those of a SM Higgs boson

Perspectives

- update fermion channels to full data sample
- optimization of coupling measurement in individual channels
- probe CP admixtures

Higgs discovery and BSM

- Overall compatibility
- Production modes
- Global fit on couplings
- Spin hypothesis 0+
- Custodial W/Z simmetry

...however...

- SM Higgs boson needs large corrections to have mH =126 GeV

- **Could the Standard Model be the final answer ?**

Some observed phenomena require extensions of the Standard Model

- Dark Matter
- Cosmic baryon-antibaryon asymmetry
- Inflation
- Neutrino mass (requires some new dim-5 operators)
- Suggestion of grand unification in fermion quantum numbers
- Anomalies in particle physics: muon g-2, top FB asymmetry, ...

but none of these -- except the last -- require new physics at TeV energies

Exotics Searches at Atlas (non-SUSY)

- Plethora of BSM "exotics" models:
  - Extra-dimensions, GUT, Technicolor(s), Leptoquarks, Hidden Valley, Compositeness, SeeSaw mechanism, etc…
- Searches for final state signature:
  - Heavy Resonances, monojet, multileptons, same-sign dileptons, long-lived particles, lepton jets…
- Results can be interpreted in the context of predictions of multiple models

See also: NON-SUSY session @ HB2013 07/06/2013

Exotics Searches at Atlas : Heavy Resonances

- Dileptons
- Diphotons
- Dijets
- Photon+jets
- Top-antitop resonances
- Top + b resonances
- Lepton + MET
- Dibosons

- Many BSM extensions predict heavy resonances:
  - GUT – heavy spin 1 boson Z' from broken E6, SO(10)
  - Little Higgs – heavy gauge boson(s) Z' and W'
  - Technicolor → narrow technihadrons
  - Extra Dimensions → spin 2 Randall-Sundrum graviton G*

- Heavy resonances in ATLAS: (experimental challenge):
  - Understand Detector effects (trigger, resolution, efficiency..)
  - Very high pT reconstructed objects close to TeV scale→ almost no control regions
  - Clean signal expected, often on SM distribution tail

Dilepton resonances

Full 8TeV dataset

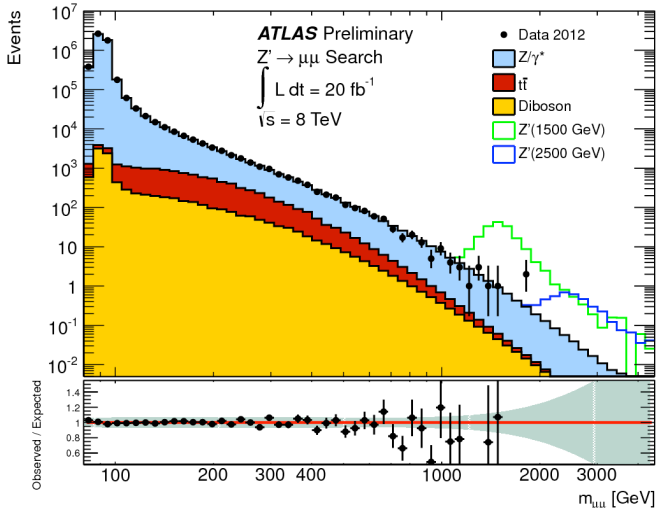
[ATLAS-CONF-2013-017]

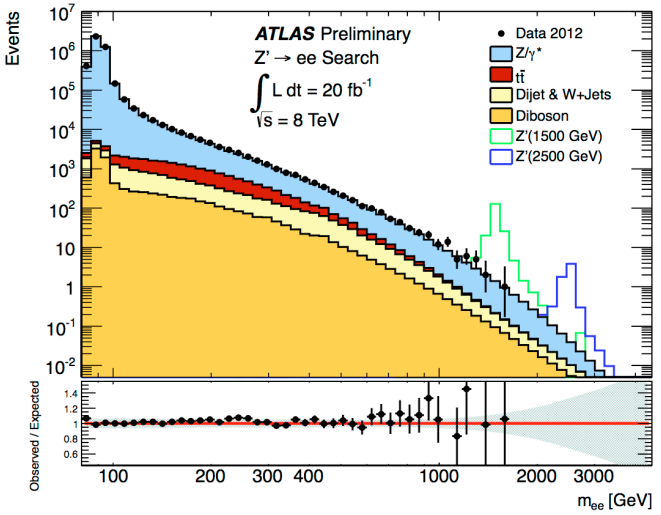
BSM extensions:

- Z' from GUT E6, SSM
- Randall-Sundrum graviton

Event selection:

- Single (double) muon (electrons) trigger
- 2 Same Flavor (Opposite sign for muons) leptons
- *Main backgrond:*
  - tt, Drell-Yan, Diboson
  - QCD multijets and W+jets (in electron channel)
- Number of events for most backgrounds from MC using SM predicted cross section (using NNLO K-factors)
- Jets background and Multi-jets from data template



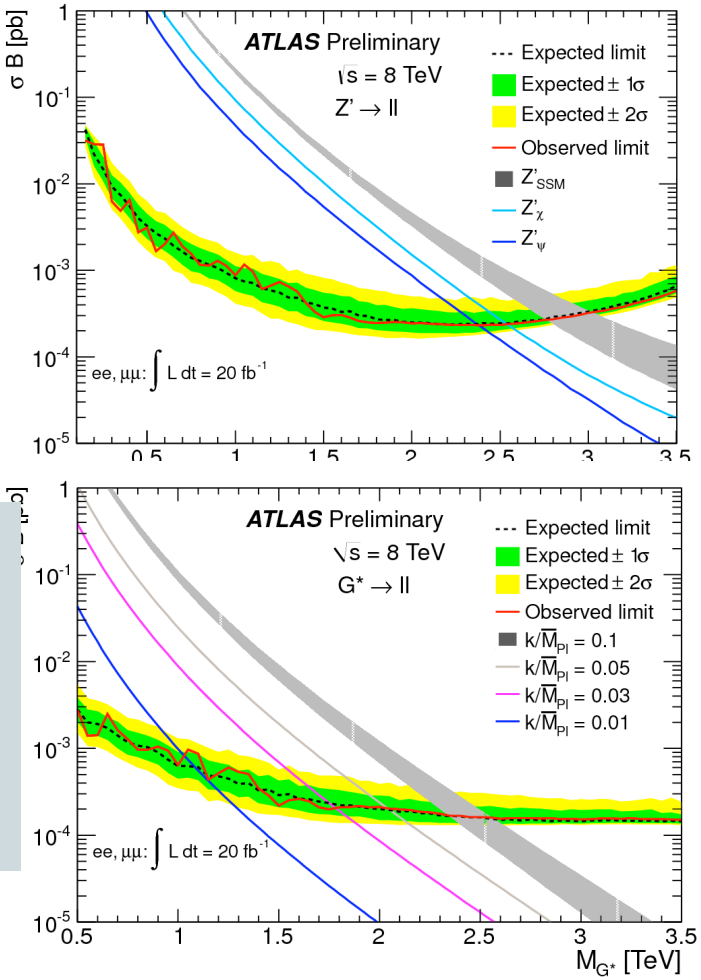


Dilepton resonances

Full 8TeV dataset

[ATLAS-CONF-2013-017]

- Upper limit on the number of signal events is determined at the 95% C.L. using a Bayesian approach



Exclusion regions:

$M_{Z'} < 2.86$ TeV @ 95% CL (SSM)
$M_{Z'} < 2.38$-2.54 TeV @ 95% CL (E_6 models)
$M_{G^*} < 2.47$ TeV @ 95% CL (RS gravitons, $k/M_{Pl}=0.1$)

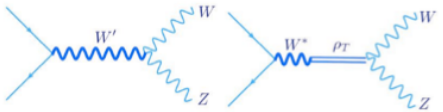
WZ resonance: lνl'l' final state

13 fb^{-1} 8TeV dataset

[ATLAS-CONF-2013-015]

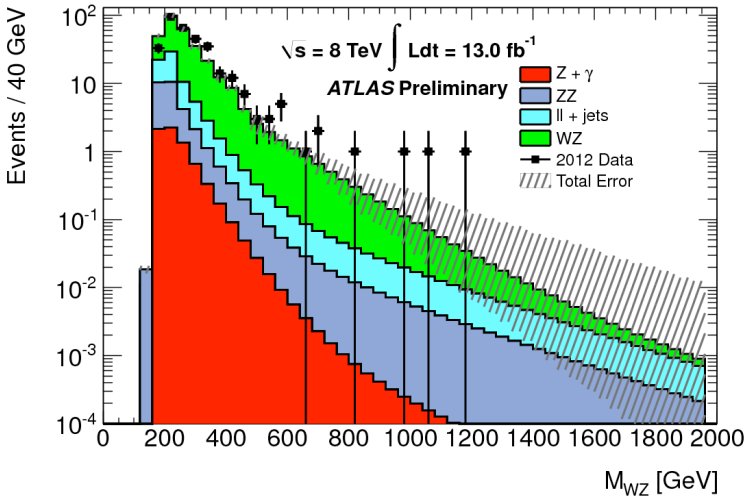
BSM extensions:

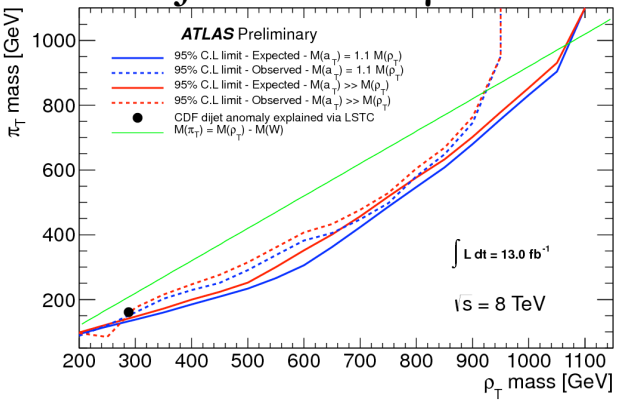
- Extended gauge models, Higgs/Little Higgs, low scale technicolor

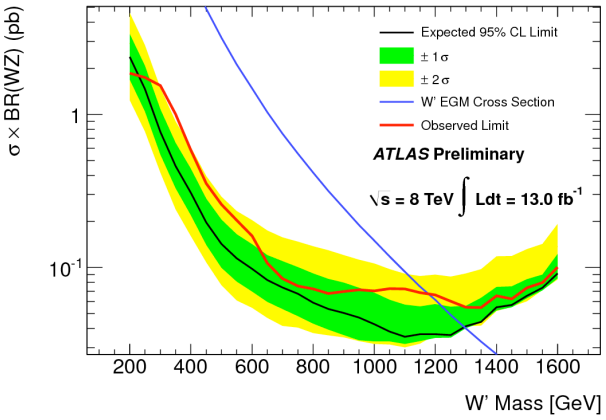


Event selection:

- Single lepton trigger
  - p_T thresholds ≈ 25 GeV
- 3 leptons + MET final state (veto on 4th lepton), Z-mass compatibility for l'l'
- *Main backgrond:*
  - Diboson (ZW, ZZ) from MC
  - ll+ jets and Z+γ data driven (MC check)







$M_{W'}$ < 1.18 TeV
@ 95% CL (EGM)
$M\rho_T$ (technimeson)**<920 GeV**
@ 95% CL
(low scale technicolor)

ZZ resonance: lljj final state

7.2 fb^{-1} 8TeV dataset

[ATLAS-CONF-2012-150]

BSM extensions:

- Bulk spin-2 RS graviton

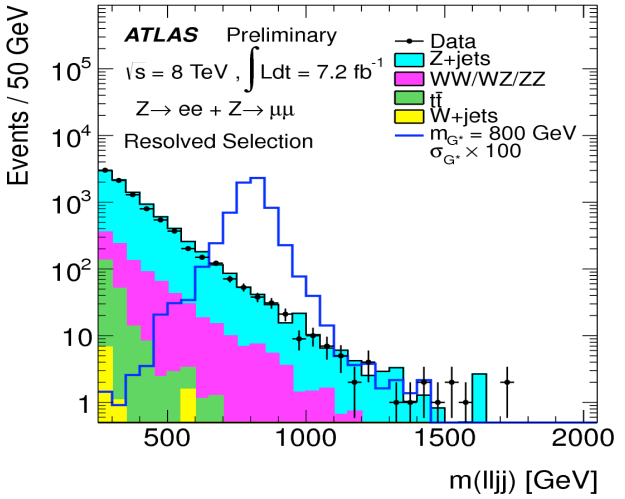
Event selection:

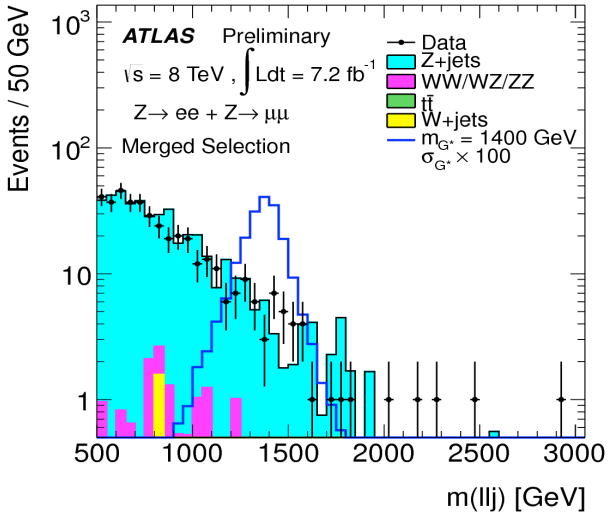
- High pT lepton trigger
- Split boosted/non-boosted regions
- Control region inverting cut on M(JJ) or M(J)

Main backgrond:

- Z+jets
- Diboson (WW,ZW, ZZ) from MC

Excluding Bulk RS graviton
(k/MPl = 1.0)
M_G < 850 (870 exp.) GeV
@ 95% CL





W'→tb resonance: $l\nu b_1 b_2$ final state

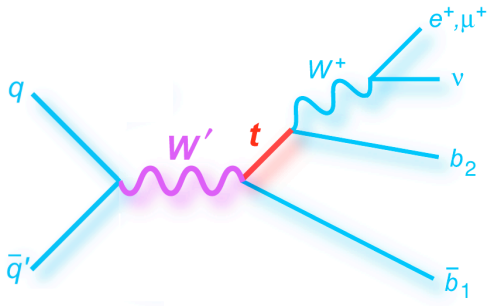
NEW!

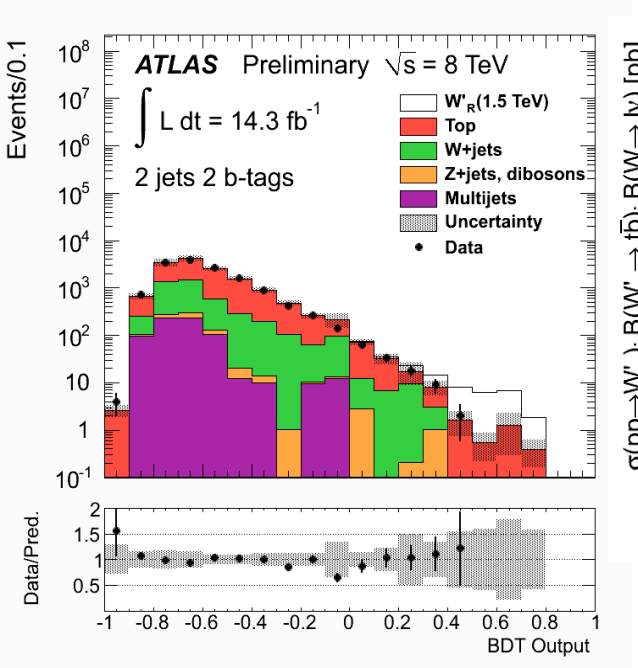
14.3 fb^{-1} 8TeV dataset

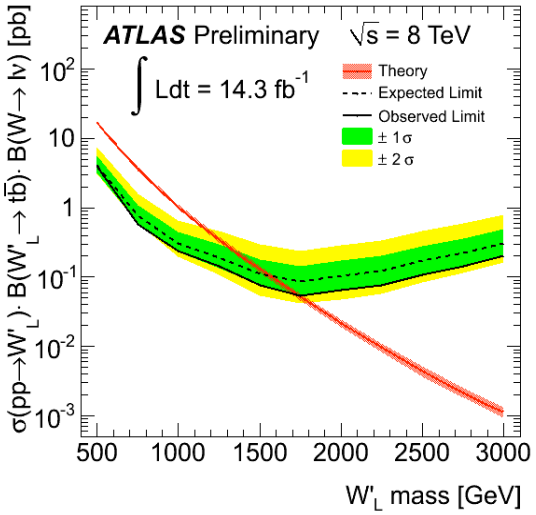
[ATLAS-CONF-2013-050]

Event selection:

- High pT lepton trigger, jets, MET
- Multivariate method based on BDT
- Search for both W' chiralities (W'_R and W'_L)
- BDT trained on W'_R MadGraph signal sample
- *Main backgrond:*
  - Multijets and W+jets (yields from data, bkg shape from simulation)
  - tt, dibosons, Z+jets from simulation







Exclusion regions:

$M_{W'_L}$ < 1.74 TeV
$M_{W'_R}$ < 1.84 TeV
@ 95% CL

Search for dijet resonance

13 fb^{-1} 8TeV dataset (for 2012 search)

[ATLAS-CONF-2012-148]
[JHEP01(2013)029]

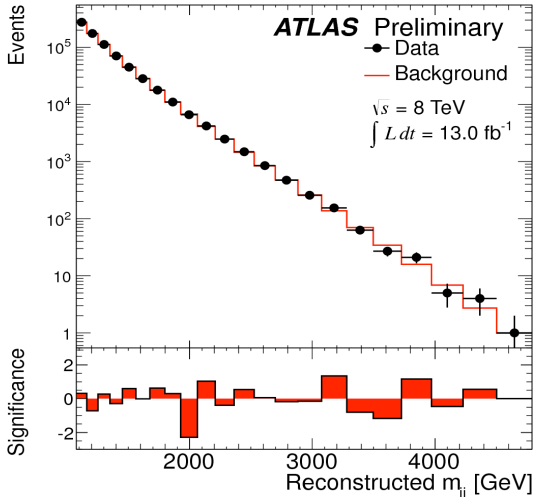
BSM extensions:

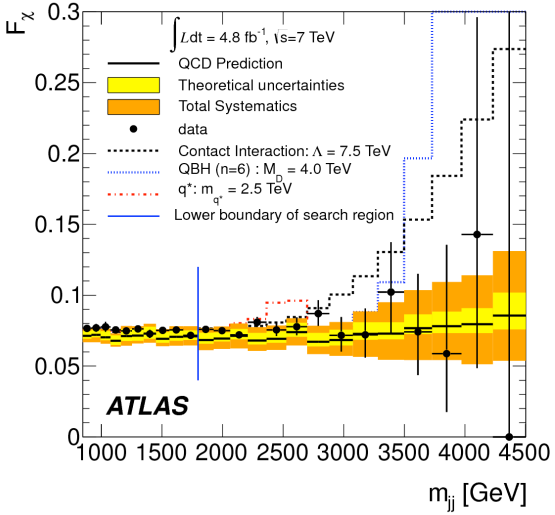
- Excited quarks, strong gravity, contact interaction

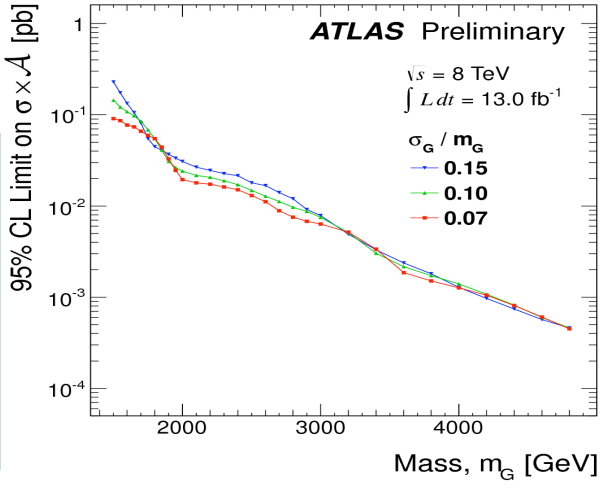
Event selection:

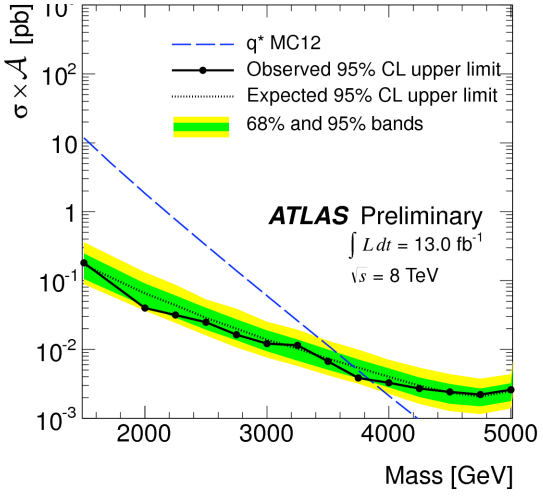
- Observables: dijet mass and angular distributions
- Larger BR (wrt to leptonic resonance) but also higher background (from QCD)
- Look for bump over smooth decreasing bkg

Lower Limit on σ x A
(excited quark model)
M_{q^*} < 3.84 TeV
@ 95% CL
95% CL Lower limit on quark contact interactions
Λ > 7.6 TeV









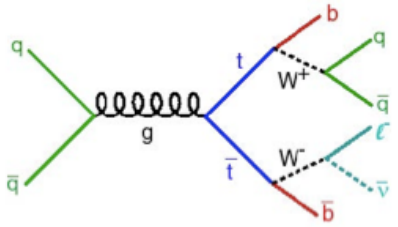
Search for top-antitop resonance

14.3 fb^{-1} 8TeV dataset

[ATLAS-CONF-2013-052]

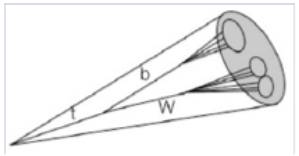
BSM extensions:

- leptophobic top-color Z', RS KK gluons

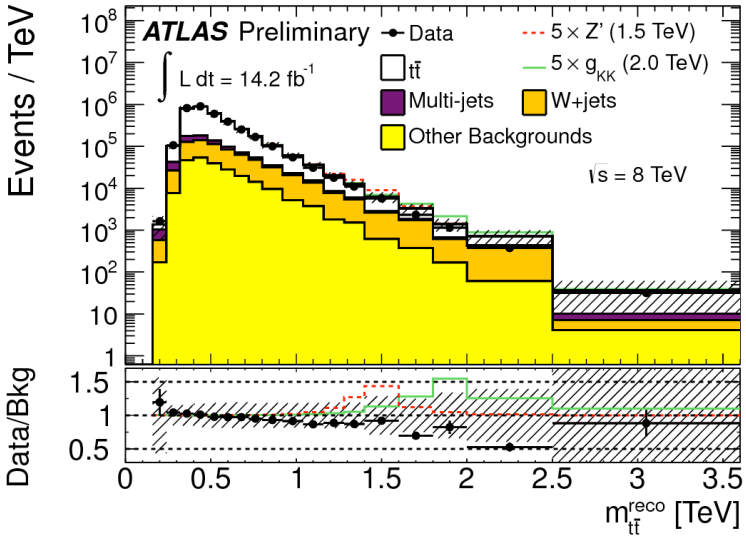


Event selection:

- **lepton+jets** final state
- Combine **resolved** (looks for individual hadronic jets from t decay) and **boosted** (large radius jet)



Lepton+jet final state:



Excluding top-color Z': $M_{Z'} < 1.8$ TeV
Excluding RS KK gluon $M_{g^*} < 2.0$ TeV
@ 95% CL

Search for Mono-Jet

10 fb^{-1} 8TeV dataset

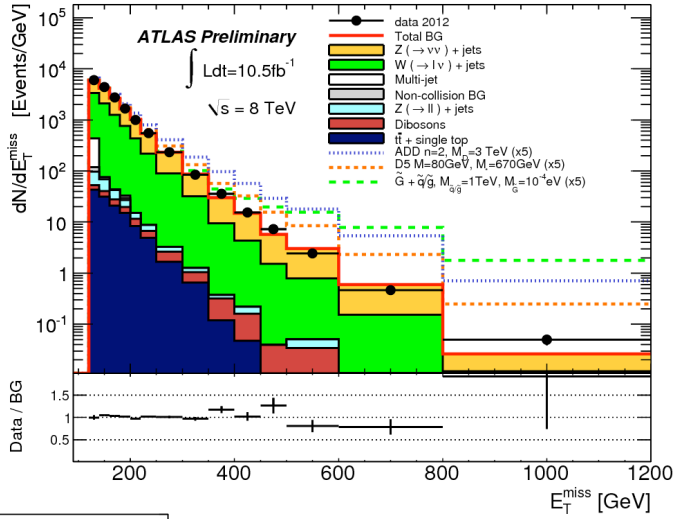
[ATLAS-CONF-2012-147]

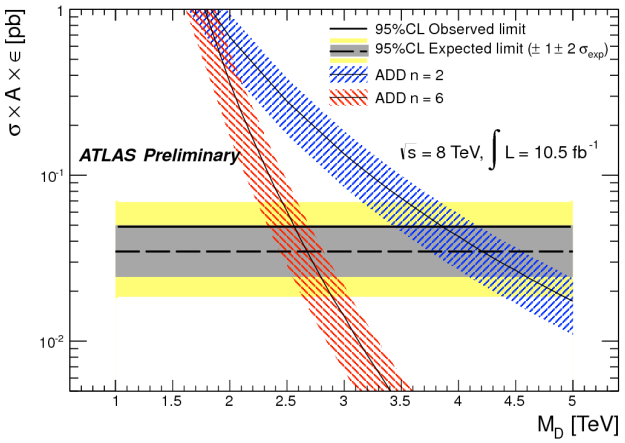
BSM extensions:

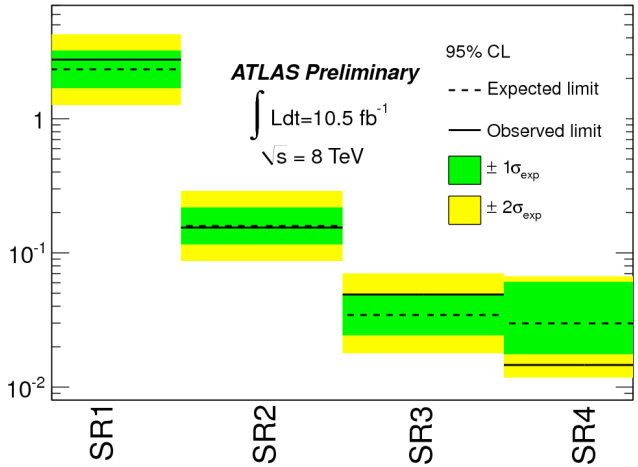
- DM, ADD, SUSY

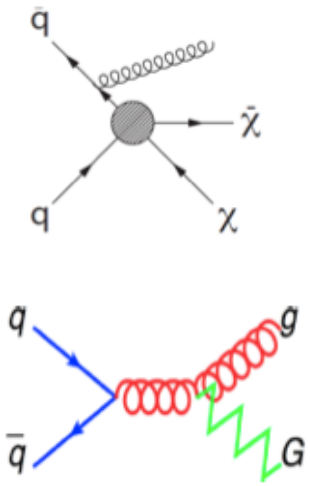
Event selection:

- ISR/FSR in events with new invisible particles (e.g. WIMPs) or radiation of new invisible particle
- Potential Dark Matter candidate
- Search for event with large p_T jet and missing E_T
- Set limits on LargeExtraDimension, WIMPs and Gravitinos









Search for Exotic New Particles

- BSM extensions:
  - 4^{th} generation and Heavy top-like quark
  - Leptoquark search
  - Search for type III Seesaw mechanism
  - Excited leptons
- Signature:
  - leptons + γ, mutlileptons, multijets +leptons + MET, same-sign leptons, top-quark decay + leptons,..

Search for Heavy top-like quark

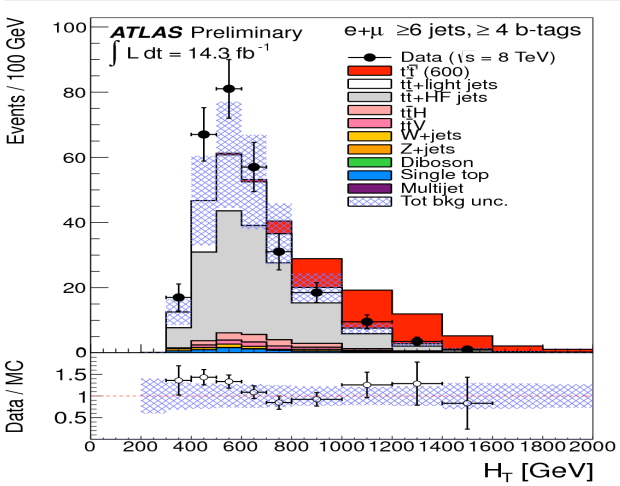
14.3 fb^{-1} 8TeV dataset

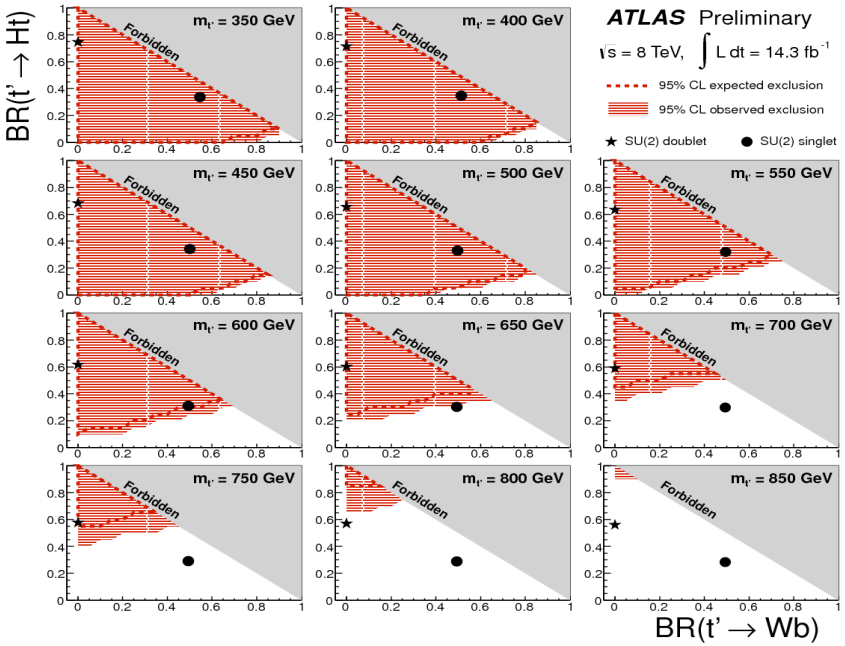
[ATLAS-CONF-2013-018]

Event selection:

- Search for heavy up-type quark pair, assuming a significant BR to Higgs and a top quark, as predicted by VectorLikeQuark models.
- Discriminant variable for most signals:
  high $\mathbf{H_T = \Sigma\, p_T}$

high multiplicity of b-jets for signal events with at least one Higgs boson decaying into bbar





95% CL exclusion in:

BR(t' -> Wb) vs. BR(t' -> Ht)

for different VLQ t' quark mass.

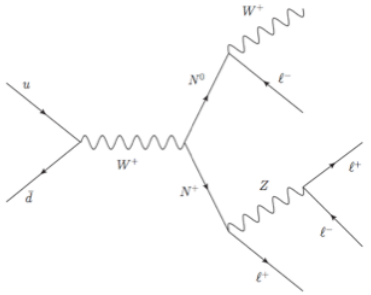
Type III seesaw search

5.8 fb^{-1} 8TeV dataset

[ATLAS-CONF-2013-019]

BSM extensions:

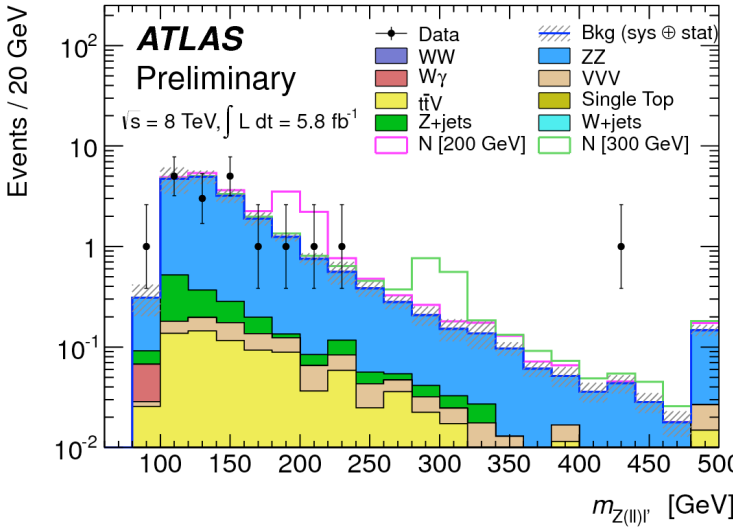
- New fermionic triplets ($N^{\pm}$, N^{0})added to SM to give (small) mass to neutrinos

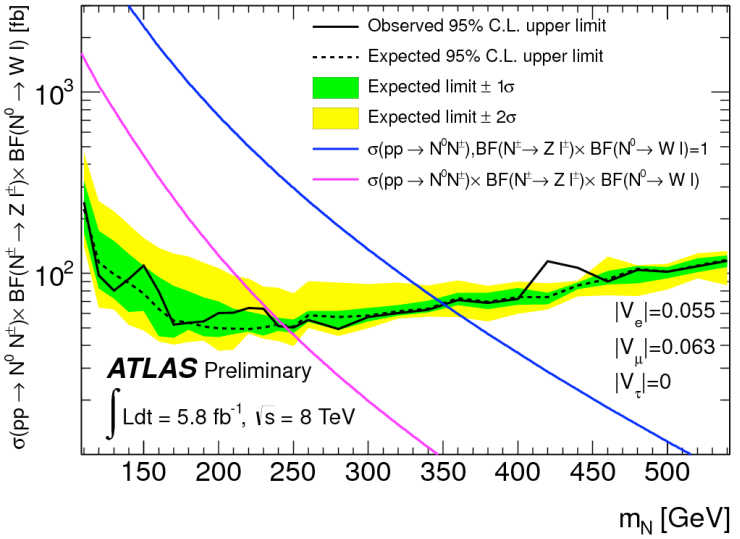


Event selection:

- Mutlilepton final state and single-lepton trigger Potential Dark Matter candidate
- At least one Z(ll) candidate, veto on ZZ
- $N^{\pm}$ mass reconstructed as $m_{Z(ll)l'}$

95% CL limits on σ×BR ($N^{\pm}$→Zl, N^{0}→Wl)
M_N > 245 GeV



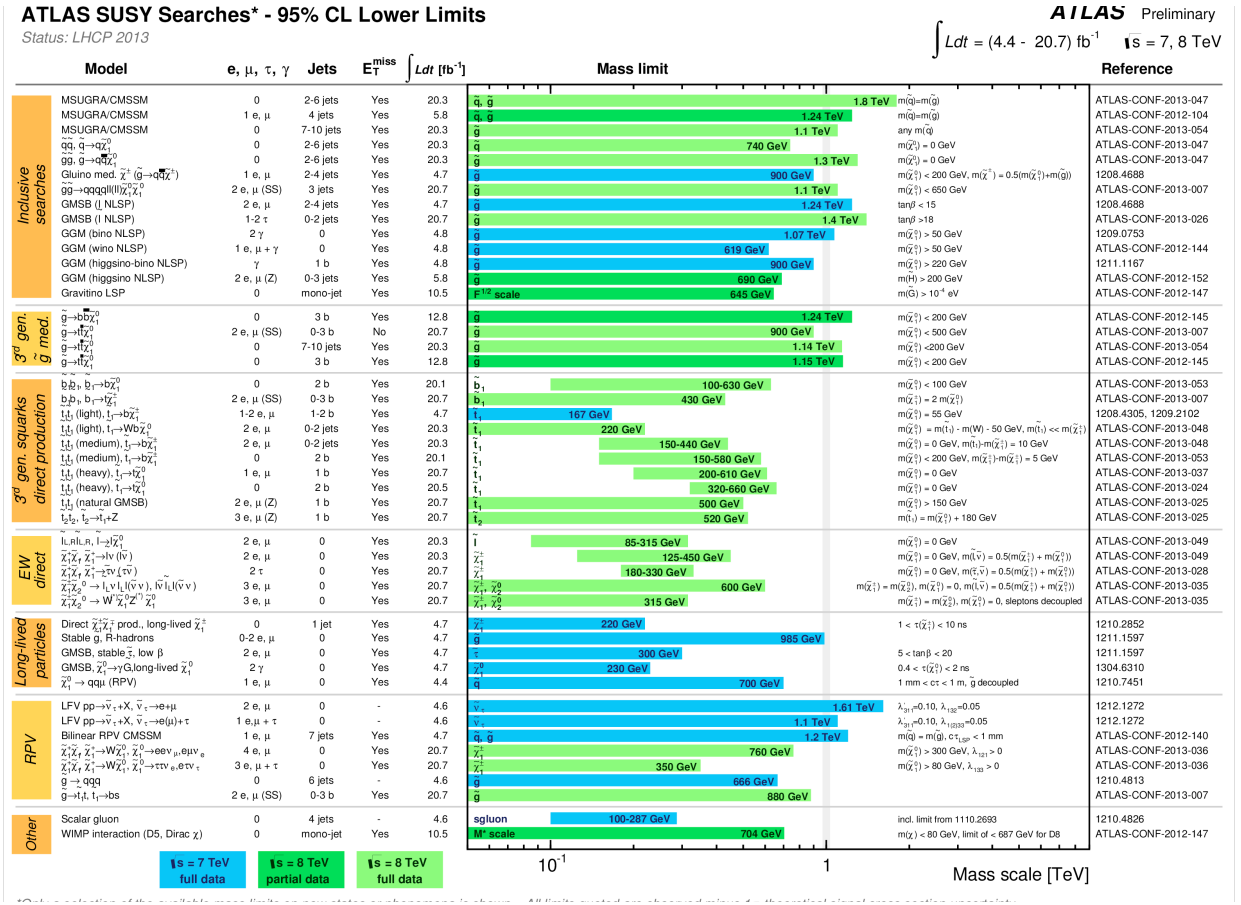


Natural SUSY searches:

- Gluino production
- Direct stop/sbottom production
- EW chargino and neutralino production
- Model independent searches

Other SUSY searches:

- Inclusive squark and gluino
- RPV searches
- LLP searches



SUSY searches in ATLAS

SUSY: squark and gluino searches

[ATLAS-CONF-2013-047]
[ATLAS-CONF-2013-054]

20.3 fb^{-1} 8TeV dataset

Event selection:

- Large jet multiplicities and large MET
- Divide signal in regions based on # (b) jets
- Control Region from data to estimate background contributions
- Main discriminant variables:

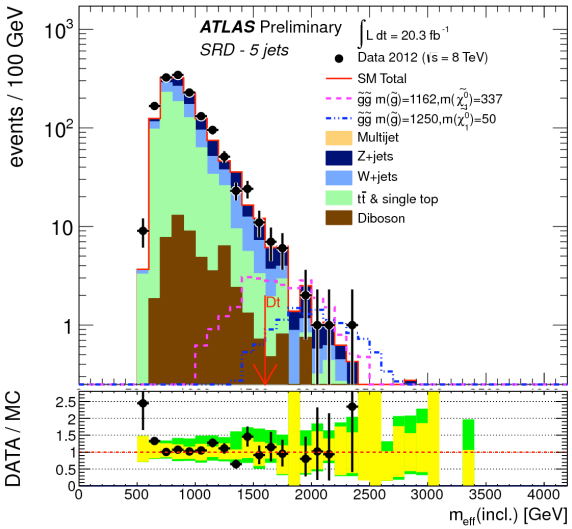
- Effective mass:

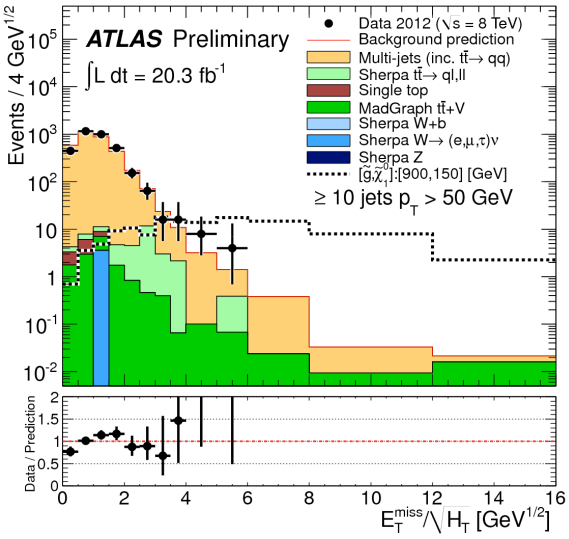
$$m_{eff} = \sum_{i=1}^{N_{jets}} p_T^{jet} + \not{E}_T \text{ (2-6 jets)}$$

- Invisible/visible transverse ratio:

$$\frac{\not{E}_T}{\sqrt{\sum_{i=1}^{N_{jets}} p_T^{jet}}} \text{ (7-10 jets)}$$

- Sum of jet masses within large-radius jet





No significant excess over background in 20.3 fb-1

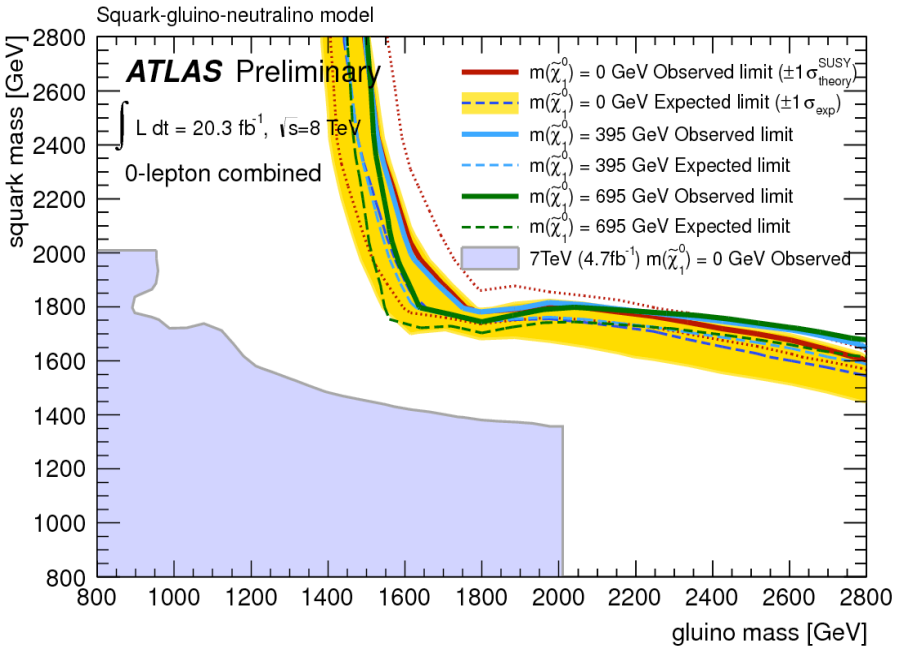
SUSY: squark and gluino searches

NEW!

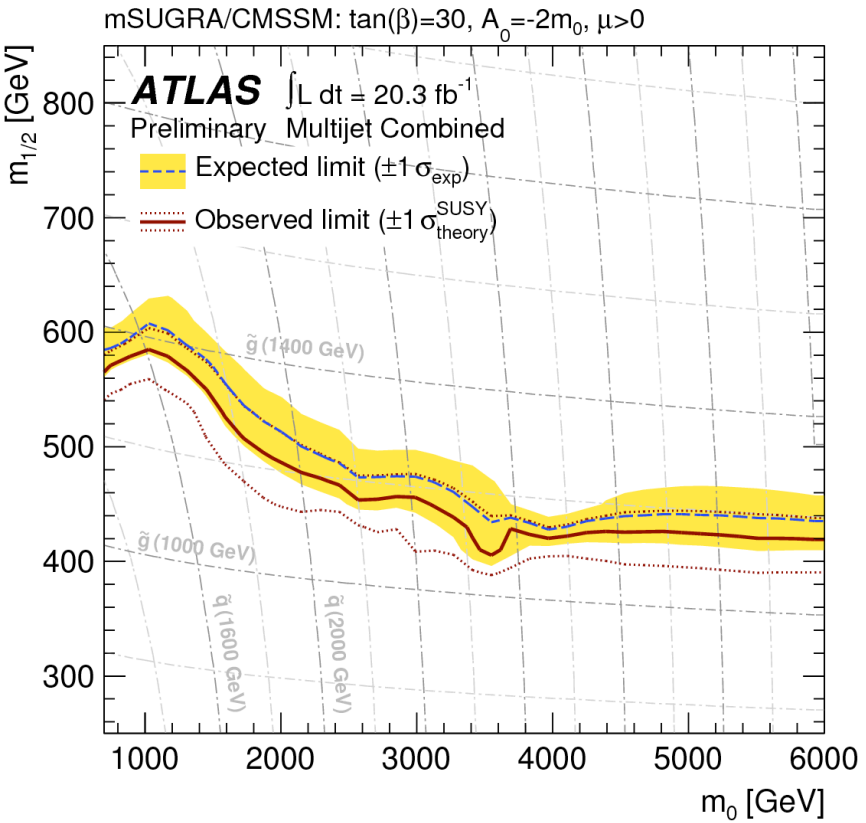
[ATLAS-CONF-2013-047]
[ATLAS-CONF-2013-054]

20.3 fb^{-1} 8TeV dataset

0 leptons + 2-6 jets + MET



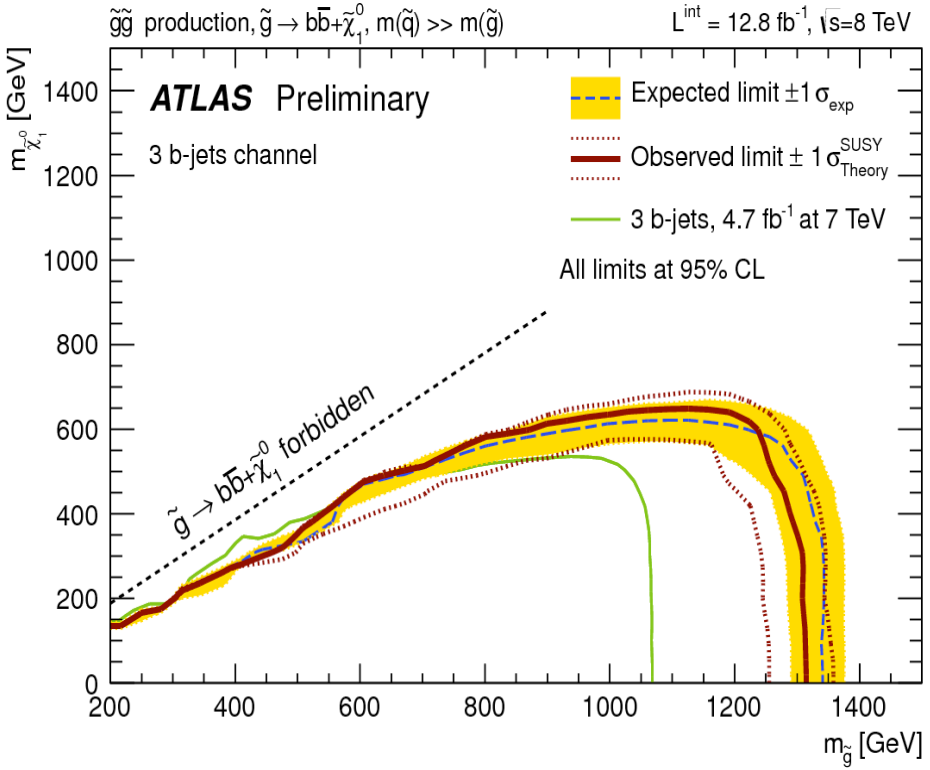
0 leptons + 7-10 jets + MET

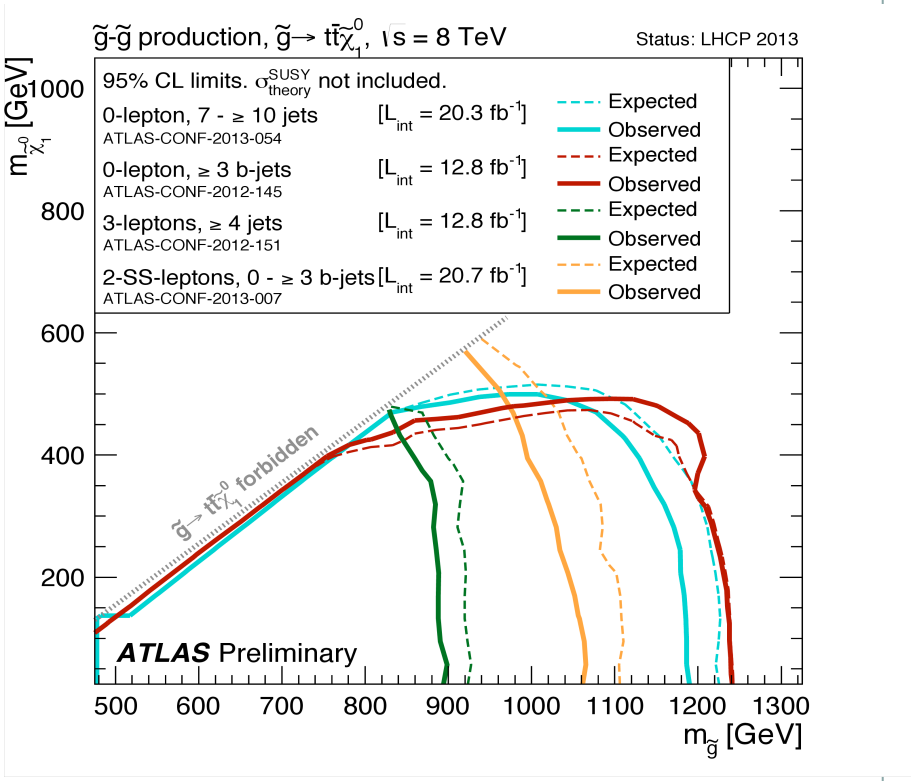


No significant excess over background in 20.3 fb-1

SUSY: gluino mediated stop/sbottom pair production

[ATLAS-CONF-2012-145]

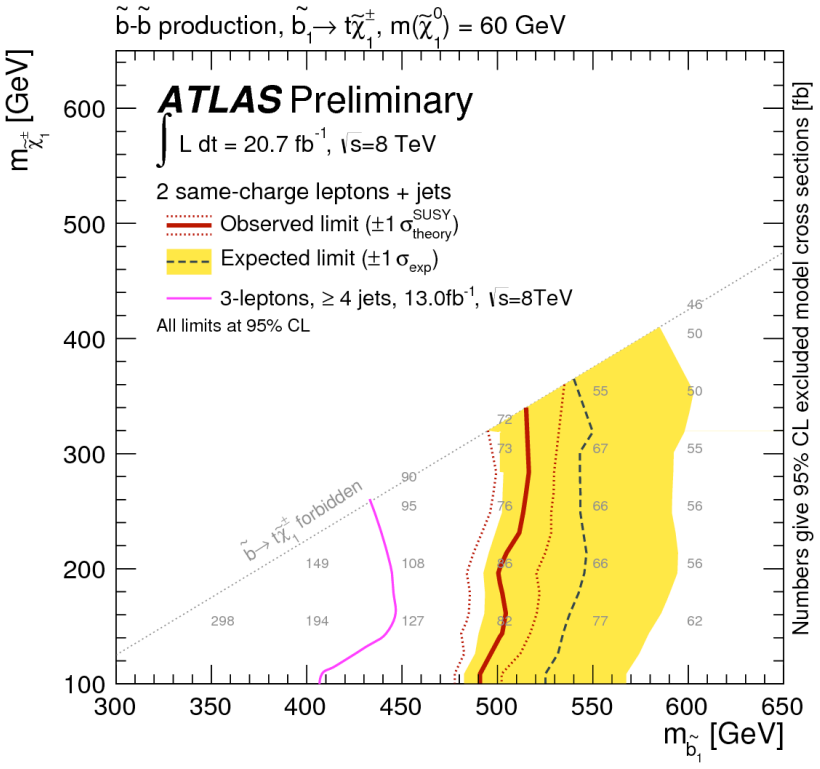


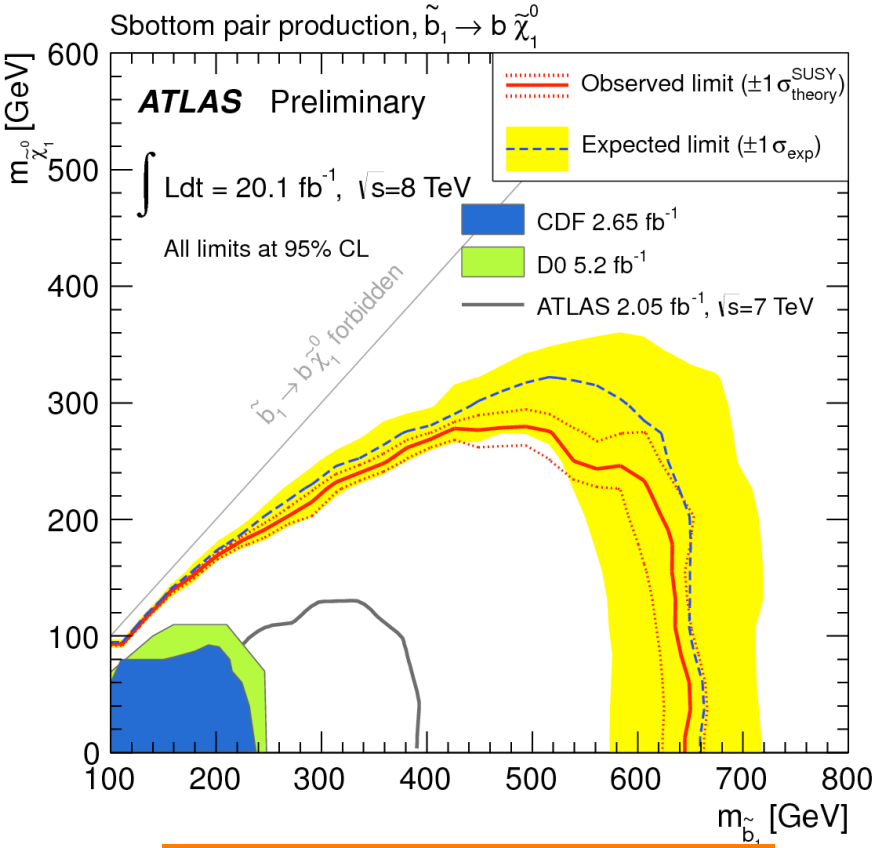


SUSY: direct sbottom pair production

[ATLAS-CONF-2013-07]
[ATLAS-CONF-2013-53]

21 fb^{-1} 8TeV dataset





2 same-sign leptons + 0-3 b-jets + MET

0 leptons + 2 b-jets + MET

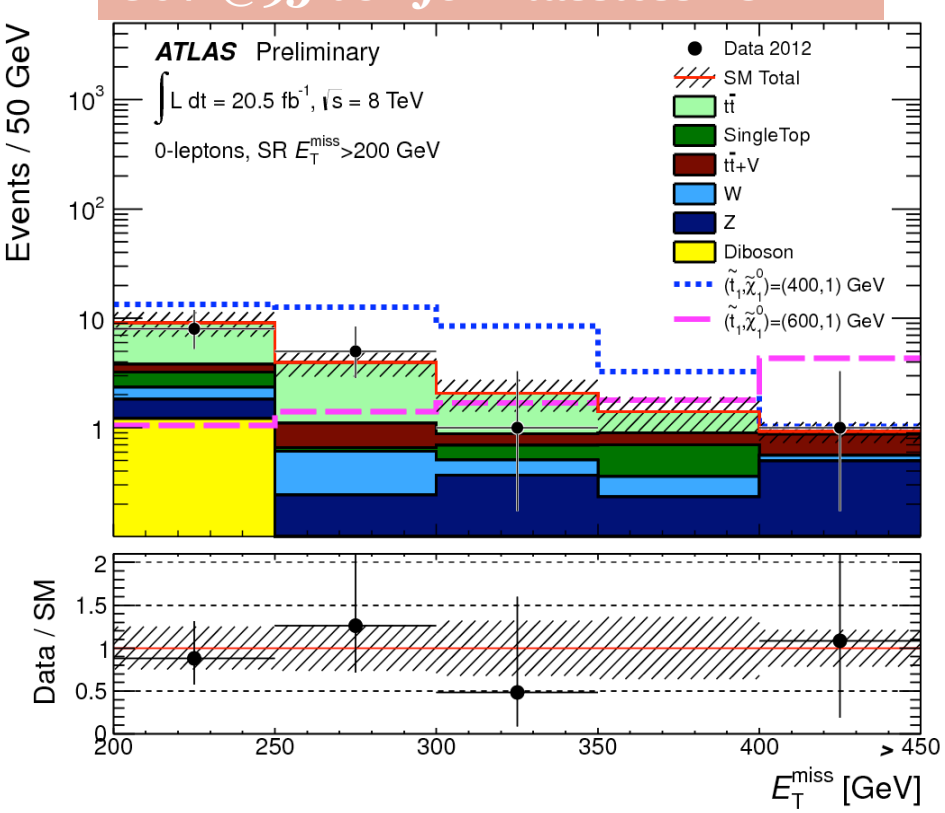
SUSY: direct stop pair production

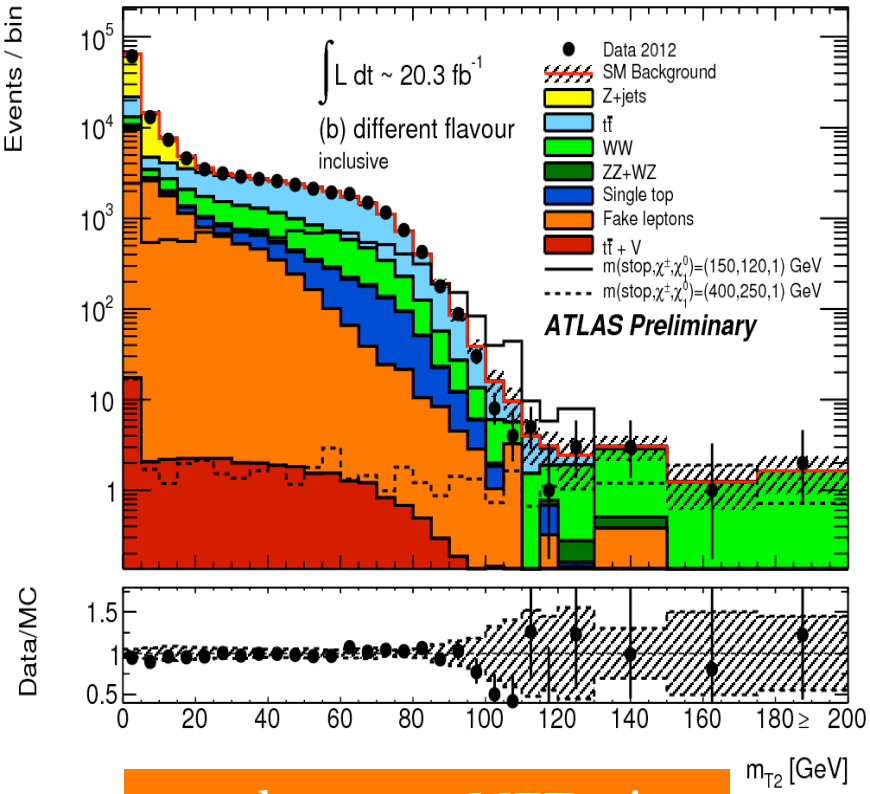
[ATLAS-CONF-2013-024]

[ATLAS-CONF-2012-037]

20.5/20.7 fb^{-1} - full 8TeV dataset

Exclude stop in the [320,660] GeV @95%CL for massless LSP





Fully hadronic + MET

Stop → top + LSP (BR = 100%)

0,1,2 leptons + MET + jets

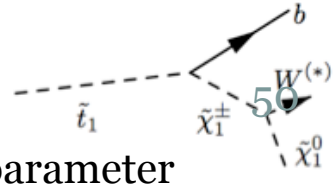
Stop → top + LSP

Stop → b + chargino

SUSY: direct stop pair production

[ATLAS-CONF-2013-048]
[ATLAS-CONF-2013-037]
[ATLAS-CONF-2013-053]

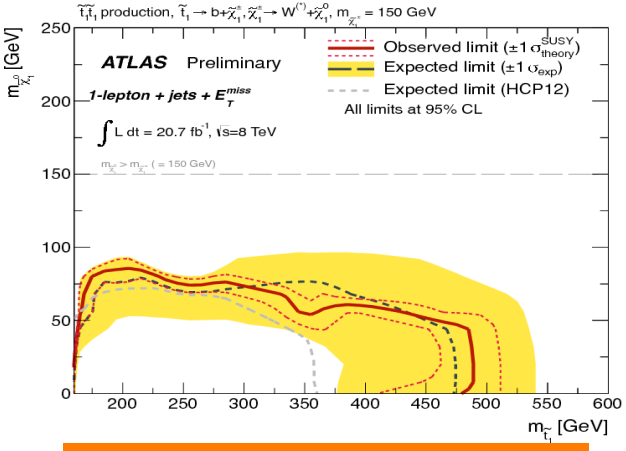
21 fb^{-1} 8TeV dataset



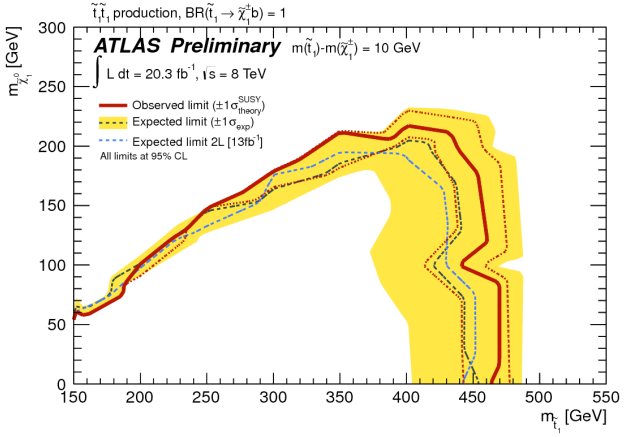
- Chargino mass is additional parameter

Hypothesis	Exp. signature
Gaugino universality: $m_{\chi^{\pm}} \approx 2m_{\chi^0}$	2 leptons, large leptons m_{T2} 1 lepton (dedicated SR)
Stop – chargino mass degeneracy	2 leptons, large leptons m_{T2}
Neutralino-chargino mass degeneracy	2 b-jets + MET, 0 leptons
Fixed chargino mass at 150 GeV	2 leptons, large leptons m_{T2} 1 lepton (dedicated SR)

1 leptons + jets + MET

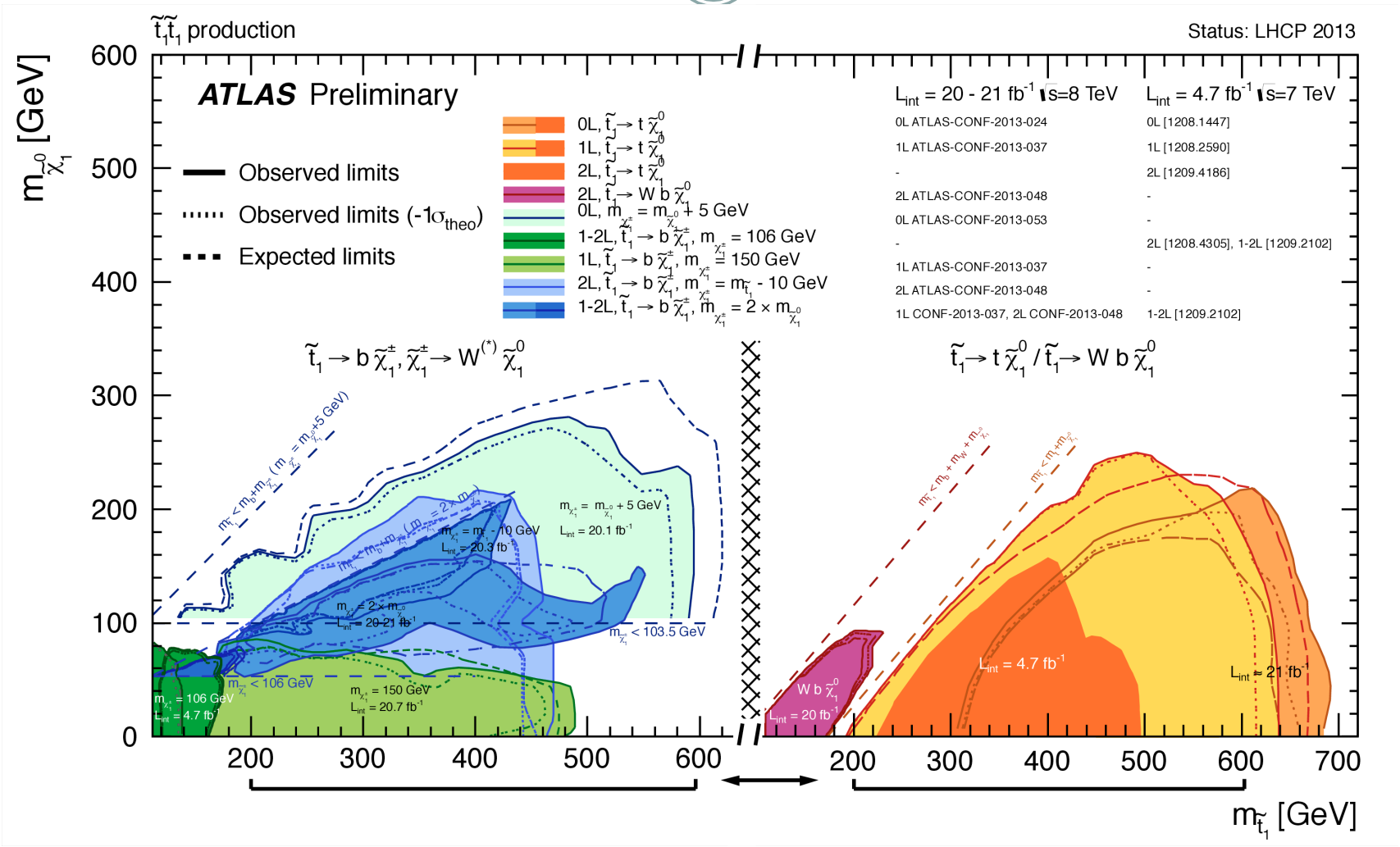


2 leptons + jets + MET



SUSY: stop searches summary plot

20.5/20.7 fb^{-1} - full 8TeV dataset



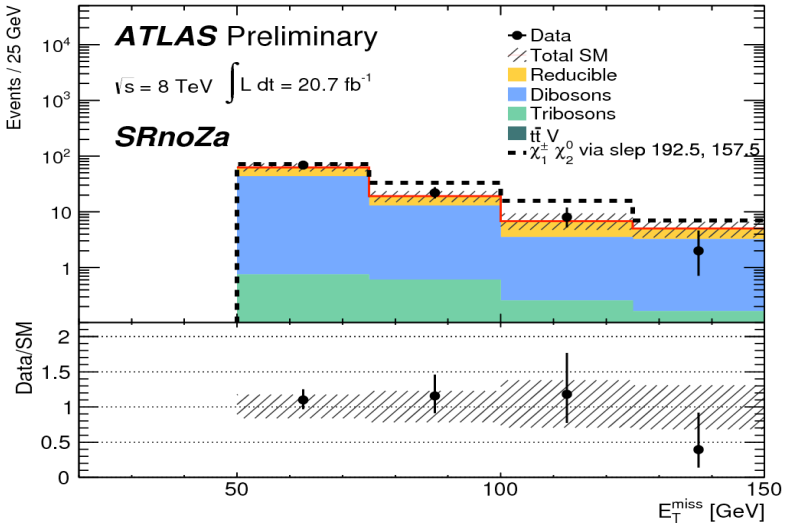
SUSY: electroweak production of sparticles

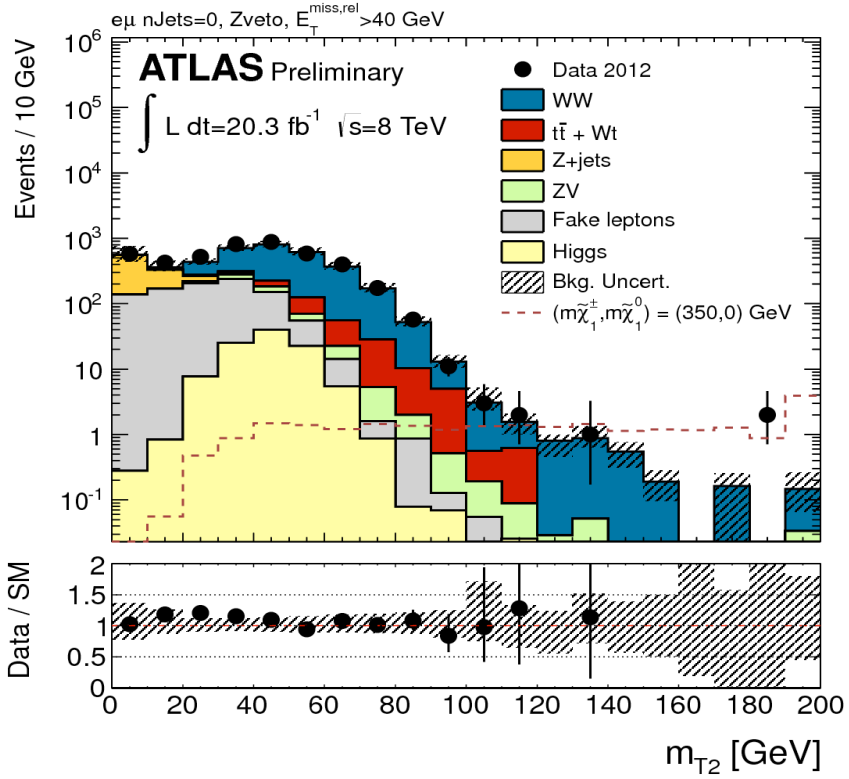
[ATLAS-CONF-2013-049]
[ATLAS-CONF-2013-035]

slepton, chargino pair, neutralino search

Event selection:

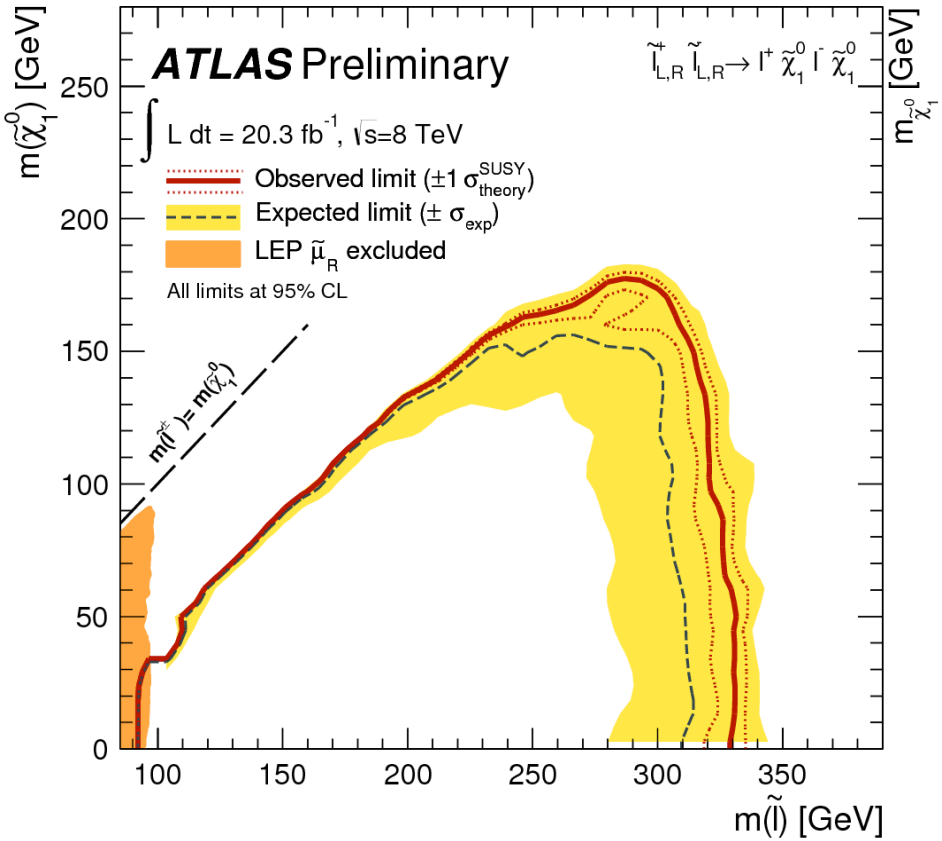
- **2-3 leptons in the final state and MET**
- Advantage: low background contamination, estimate from MC, control region or data-driven
- Fake-lepton contamination

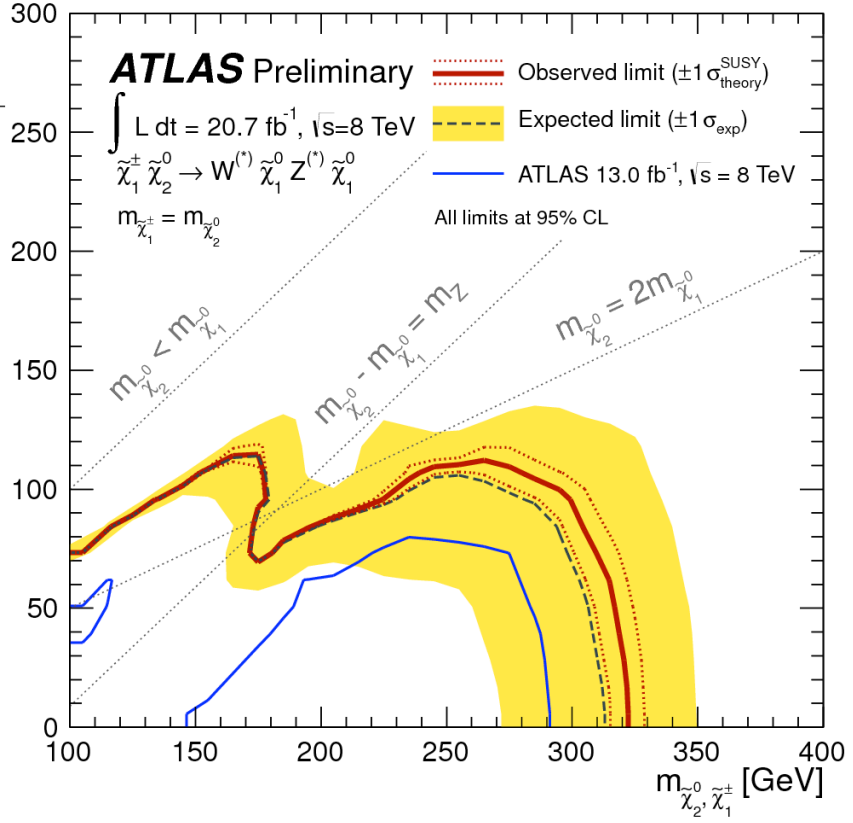




SUSY: electroweak production of sparticles

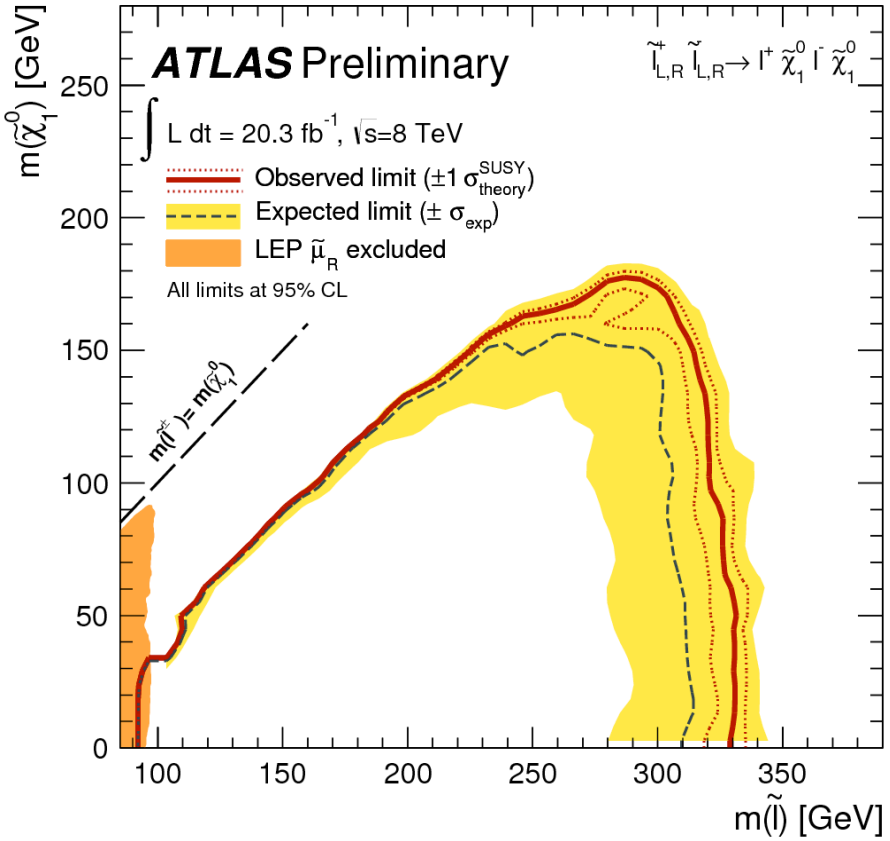
[ATLAS-CONF-2013-049]
[ATLAS-CONF-2013-035]

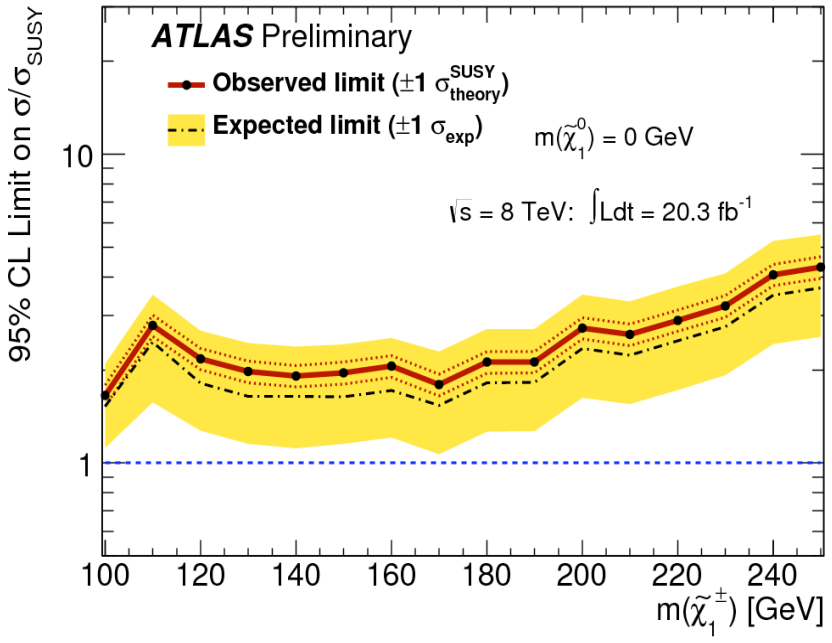




SUSY: electroweak production of sparticles

[ATLAS-CONF-2013-049]
[ATLAS-CONF-2013-035]





Also, searches for chargino pair production and chargino-neut2 in tau final states **(ATLAS-CONF-2013-028)**

LHC after the Long Shutdown

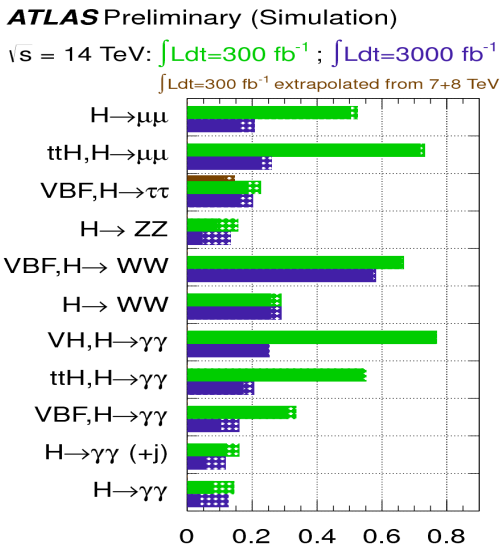
ATL-PHYS-PUB-2012-004

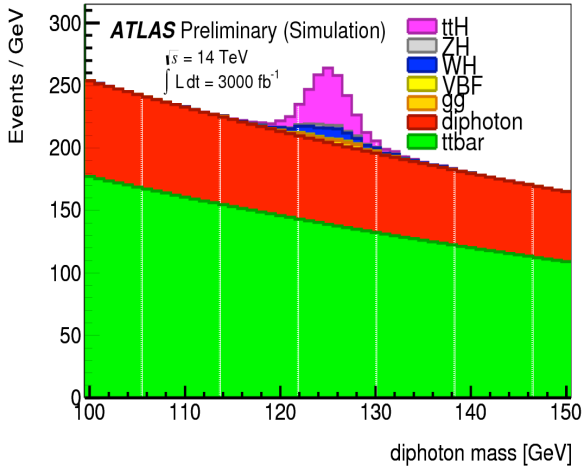
LHC after LS (2014):

- Energy and intensity upgrade Run-II (13-14 TeV)
- Detector consolidation and improvements →undertand detector/trigger performances at high luminosity

Higgs Boson measurements at HL-LHC Run-II

- **Spin/CP properties**
  - Study of the Higgs vertex tensor structure
  - Study of the CP violation in the Higgs sector (mainly HZZ)
- **Higgs boson couplings**
  - H→γγ, H→ZZ, H→WW, H→ττ,H→μμ
- **Observation of the Higgs self-coupling**

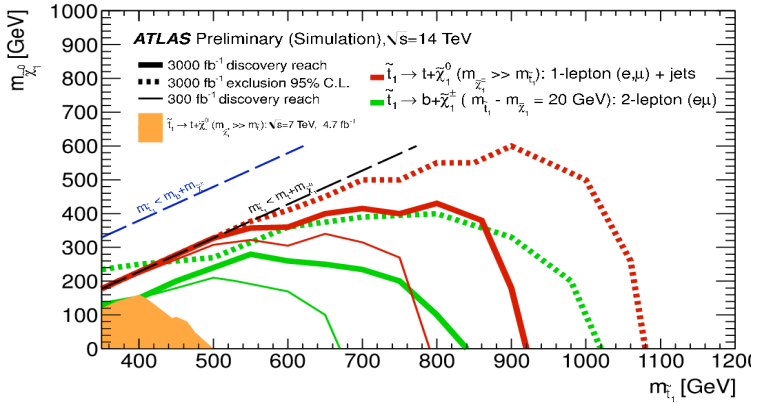


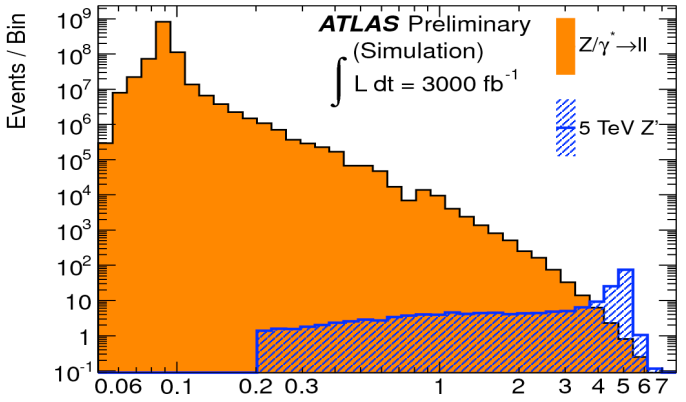


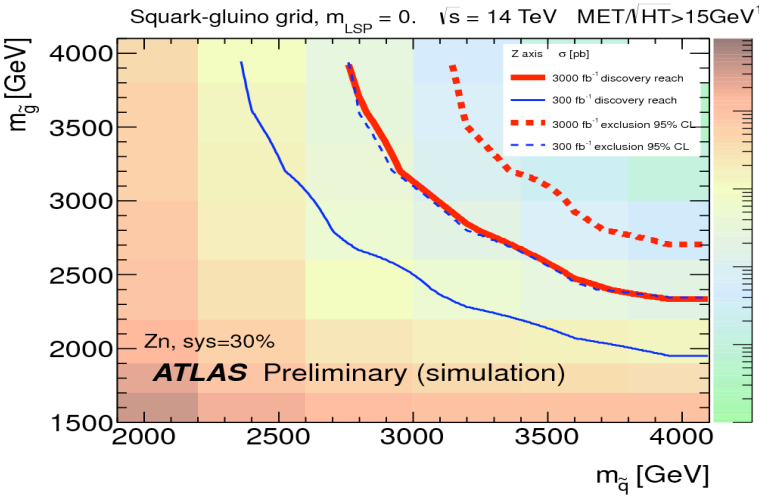
LHC after the Long Shutdown

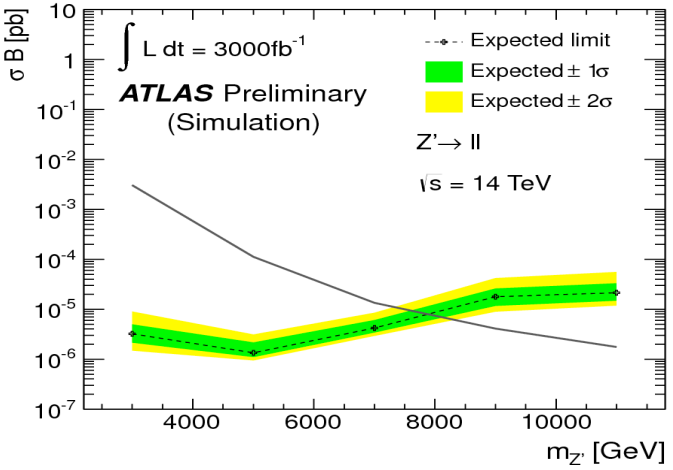
ATL-PHYS-PUB-2013-002

ATL-PHYS-PUB-2013-004









Conclusions

Higgs searches

- Overwhelming evidence for a new boson at

M = 125.5 ± 0.2 (stat) ± 0.6 (syst) GeV

- Measurements of **signal strength** in agreement with SM hypothesis.
- Data strongly favour the $\mathbf{J^P = 0+}$ Spin/CP hypothesis
- Measurements of couplings also in good agreement.
- Improved measurements of pre-shutdown data and after shutdown will further investigate this particle.
- **Higgs Boson measurements at HL-LHC Run-II**
- *Spin/CP properties*
- *Higgs boson couplings*
- *Observation of the Higgs self-coupling*

BSM searches

- **Supersymmetry:**
- **No superpartners in sight (yet)**
  Bounds on **stop** and **sbottom** quark partners reaching 500-700 GeV for neutralino masses below 300 GeV
  However…Nature might be less simplified:
  - **R-Parity Violating or compressed SUSY**

- **Exotic searches:**
- **No hints of new phenomena (yet)**
  Searches for heavy top and bottom partners: mass limits of ≈ 700 GeV
- Searches for resonances in hadronic and leptonic final states: pushing the limits to the multi-TeV scale
- Future searches: Search program continues to refine/extend current results and will continue with detector, energy and luminosity upgrades

Higgs Bibliography

- Individual channels
  - ATLAS-CONF-2013-013 (H→ZZ→4ℓ)
  - ATLAS-CONF-2013-012 (H→γγ)
  - ATLAS-CONF-2013-030 (H→WW)
  - ATLAS-CONF-2013-011 (ZH)
  - ATLAS-CONF-2013-027 (2HDM WW)
  - ATLAS-CONF-2013-010 (H→μμ)
  - ATLAS-CONF-2013-009 (H→Zγ)
  - ATLAS-CONF-2012-160 (H→ττ)
  - ATLAS-CONF-2012-161 (VH, H→bb)
  - ATLAS-CONF-2012-135 (ttH, H→bb)
  - ATLAS-CONF-2012-094 (MSSM Neutral H)
  - ATLAS-CONF-2012-011, ATLAS-CONF-2012-094 (MSSM Charge H)
- Mass measurement
  - ATLAS-CONF-2013-014
- Couplings
  - ATLAS-CONF-2013-034
- Spin
  - ATLAS-CONF-2013-040
  - ATLAS-CONF-2013-029 (H→γγ)
  - ATLAS-CONF-2013-031 (H→WW)
- Perspectives
  - ATL-PHYS-PUB-2012-004

BSM Bibliography

Heavy resonance

- ATLAS-CONF-2013-017
- ATLAS-CONF-2013-015
- ATLAS-CONF-2013-050
- ATLAS-CONF-2013-052
- ATLAS-CONF-2012-150
- ATLAS-CONF-2012-148

Other Exotics

- ATLAS-CONF-2012-147
- ATLAS-CONF-2013-018
- ATLAS-CONF-2013-019

SUSY

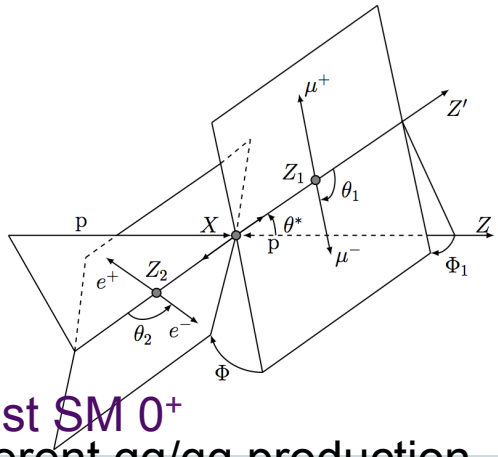
- ATLAS-CONF-2013-035
- ATLAS-CONF-2013-036
- ATLAS-CONF-2013-037
- ATLAS-CONF-2013-047
- ATLAS-CONF-2013-048
- ATLAS-CONF-2013-049
- ATLAS-CONF-2013-024
- ATLAS-CONF-2013-025
- ATLAS-CONF-2013-053
- ATLAS-CONF-2013-054
- ATLAS-CONF-2013-007
- ATLAS-CONF-2013-145

Backup

Spin-parity measurement

J^{PC} state influences final state kinematic distributions

e.g.: in H→ZZ→4ℓ, dilepton invariant masses and 5 production/decay angles



the idea: pair-wise test of different specific scenarios against SM 0^+

* γγ, WW, ZZ: test 2^+ minimal coupling model with different gg/qq production fractions
* ZZ: test also 0^-, 1^+, 1^-, 2^-

approach: build discriminant using input sensitive to different spin-parity hypotheses

- H→γγ: use $|\cos(\theta^*)|$ distribution ($m_{\gamma\gamma}$ for S/B separation)
- H→WW: train two BDT classifiers (0^+ vs bkg, 2^+ vs bkg) using $m_{\ell\ell}$, $p_{T\ell\ell}$, $\Delta\varphi_{\ell\ell}$, m_T
- H→ZZ→4ℓ: multivariate discriminant built using full 7D final state information (two approaches: matrix element technique and BDT)

discriminant distributions used to build test statistics $Q = \log (L(0^+)/L(J^P))$

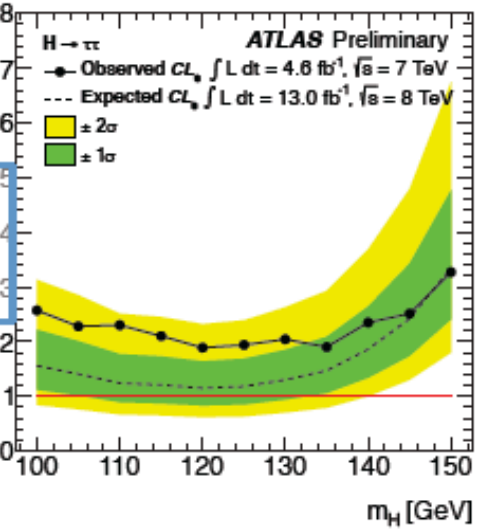
CLs method: $CL_s(J^P) = p_0(J^P) / (1 - p_0(0^+))$

13fb^{-1}@8TeV

H→ττ

1.9(1.2)xSM @125 GeV

[ATLAS-CONF-2012-160]

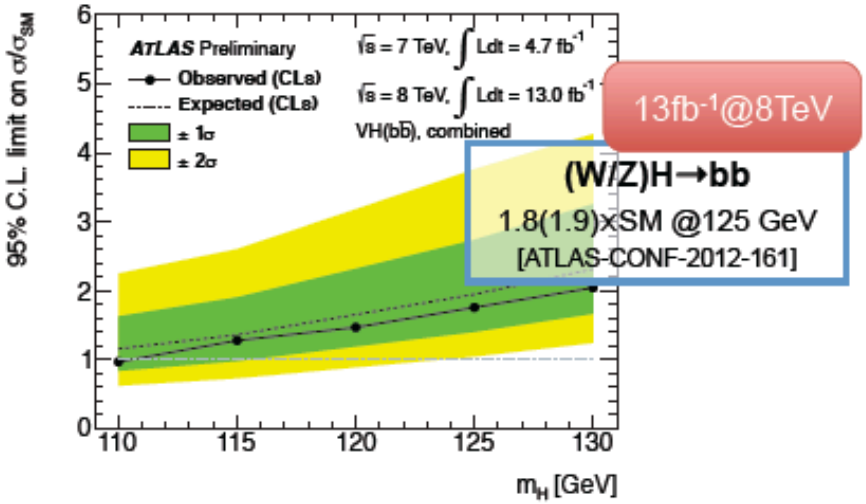


13fb^{-1}@8TeV

(W/Z)H→bb

1.8(1.9)xSM @125 GeV

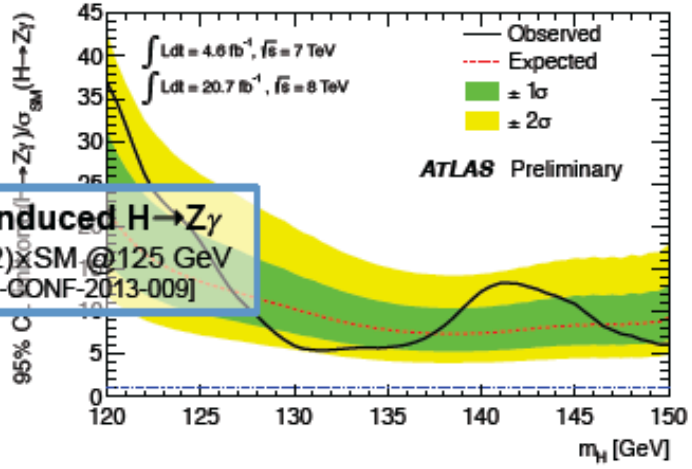
[ATLAS-CONF-2012-161]



Loop-induced H→Zγ

13.5(18.2)xSM @125 GeV

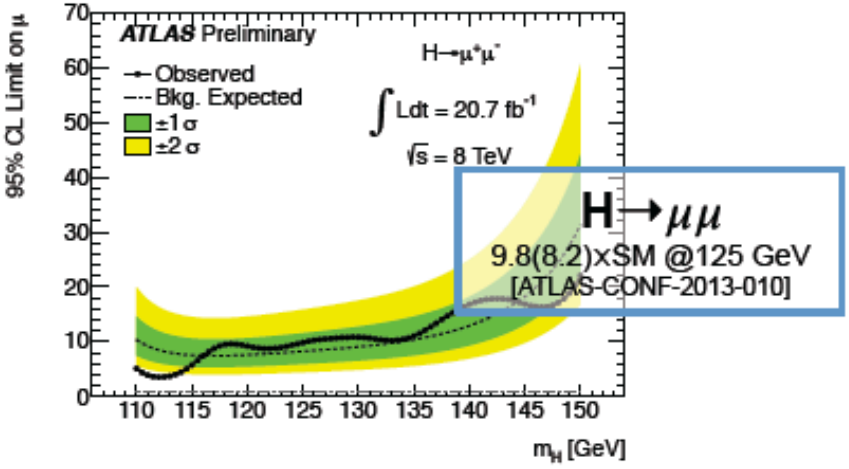
[ATLAS-CONF-2013-009]



H→μμ

9.8(8.2)xSM @125 GeV

[ATLAS-CONF-2013-010]



SUSY: direct stop pair production

[ATLAS-CONF-2013-024]
[ATLAS-CONF-2012-025]

20.5/20.7 fb^{-1} - full 8TeV dataset

- Search for stop pair production
- t_2 stop pair production with Z production:

- t_1 stop pair production:

$$\tilde{t}_1\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0 t\tilde{\chi}_1^0$$

$$\tilde{t}_1\tilde{t}_1 \rightarrow \tilde{t}_1 \rightarrow b\chi_1^{\pm}$$
$$\chi_1^{\pm} \rightarrow tW^* \chi_1^0$$

- Event with (b) jets and large missing E_T