Latest ATLAS results on Higgs and BSM physics

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Strong Coupling Gauge Theories in the LHC Perspective (SCGT 12)

KMI-GCOE Workshop, Nagoya University

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Introduction

- ...Homework...
  - If you have a good (brain) memory, you may recall this

Summary SCGT09, S.Asai

(1) LHC is back now and We have real data @ 900GeV. (also 2.36TeV)
ATLAS and CMS (ALICE, LHCb) detectors work well.
In 2010, LHC is operated at ECM=8−10TeV L=200pb−1
(Start 14th Feb. @ 7TeV)

(2) Plan after 2011 is not clear. It will be determined in Chamonix Feb.

2011 L〜O(1)fb−1 ECM = 10−13TeV ? → L = ~5 /fb 7TeV
2012 L〜O(10)fb−1 ECM=10−13TeV ? → L = ~20 /fb 8TeV

(3) Light Higgs + SUSY scenario can be checked before 2012.
(4) Low mass TC model scenario can be checked before 2012.
(5) Mixed (TC + SUSY) models also possible.

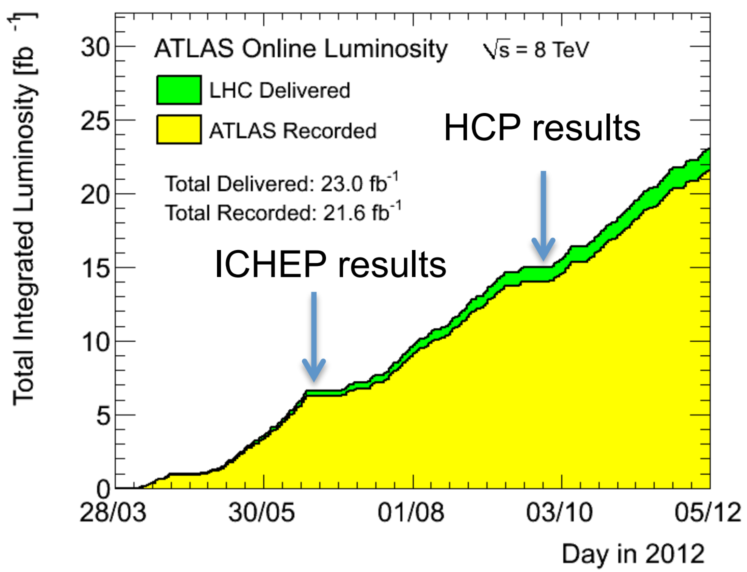
} will address today

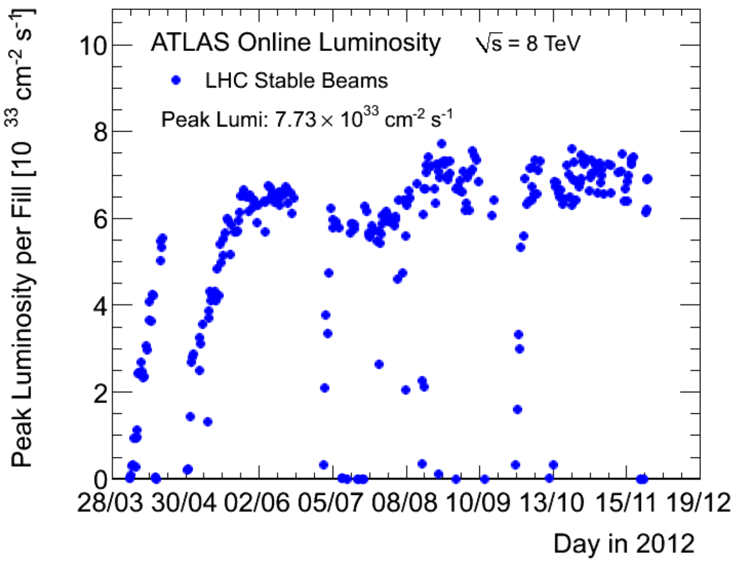
(6) WW scatters we need more luminosity.

Next SGCT2012(?), we will have answer (except for 6).

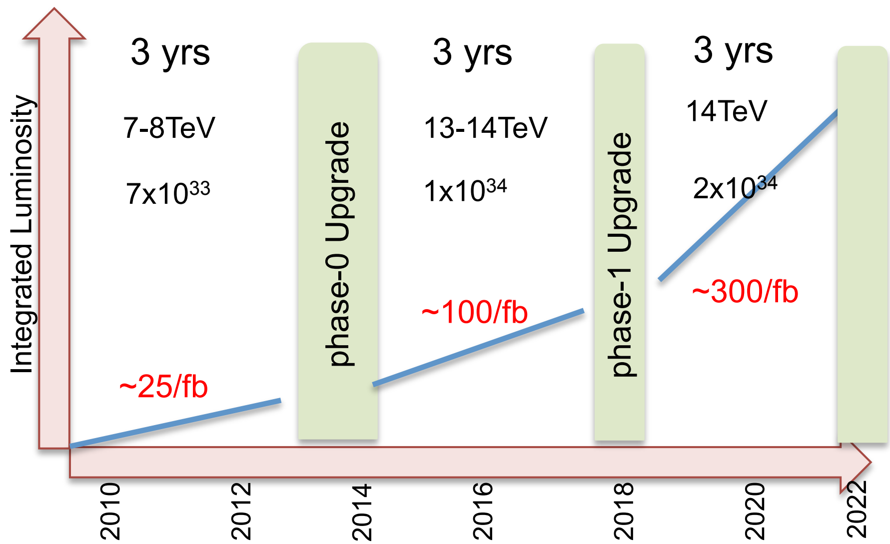
This was a pretty good prediction!

LHC status + schedule





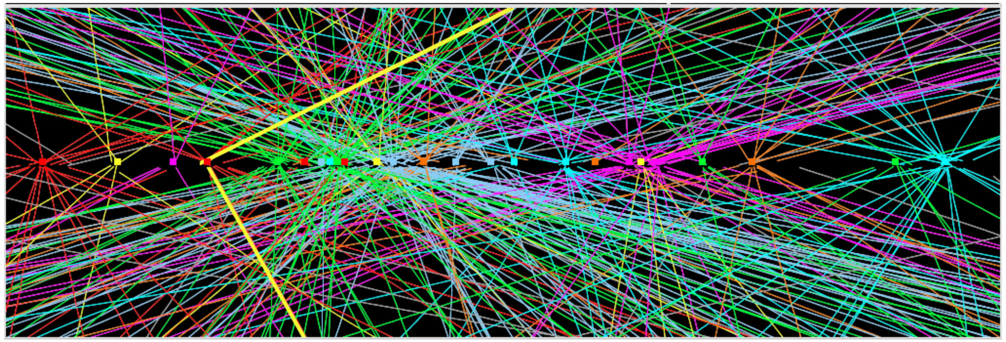
- 2012 : running with 8TeV (pp run ends 12/11)
- Accelerator conditions were largely stable
- LHC will shutdown 2013,2014 and come back on 2015
- So, no new data for two years

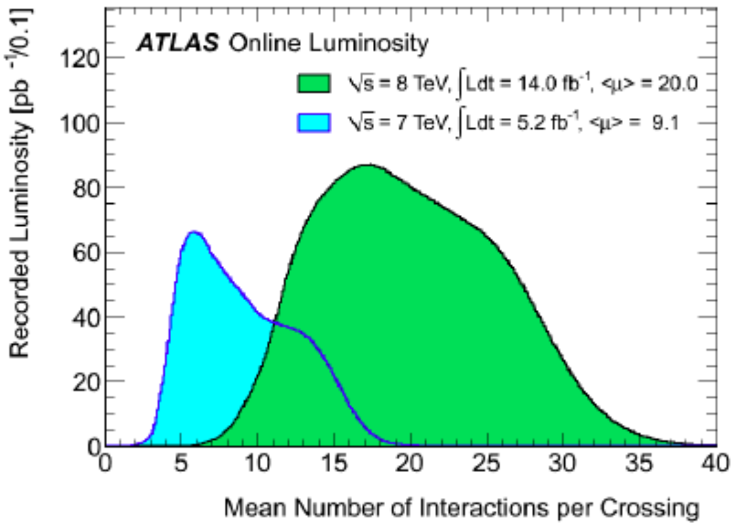


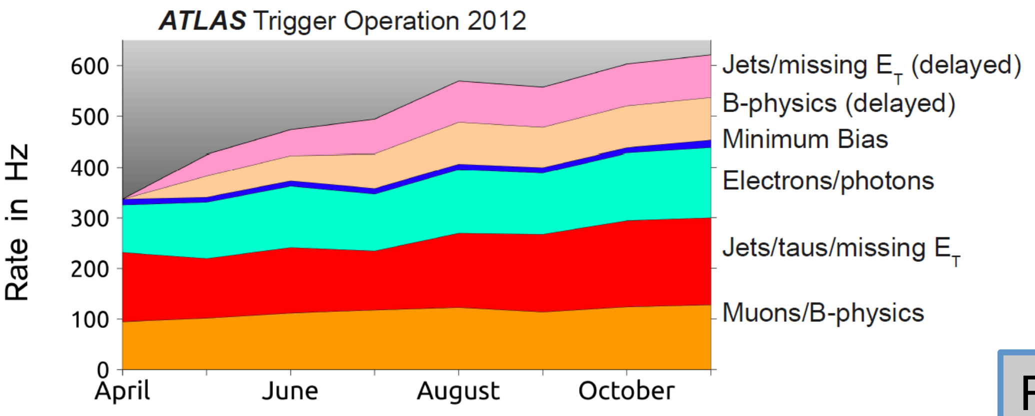
ATLAS status

- continuously it is still very efficient
  - > 93% DAQ efficiency
  - > 93% flagged as good data for physics

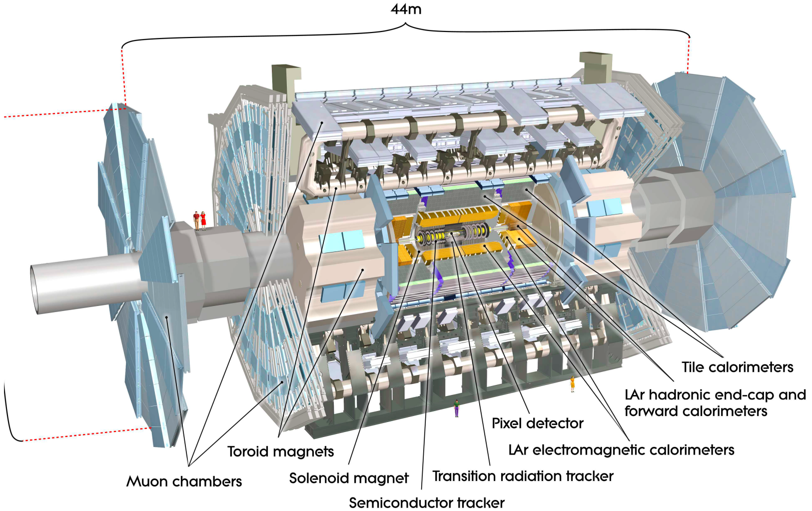
22 multi-interactions on top of Z→ mumu event







balance btw physics menu
delayed stream (dump data for later reconstruction in 2013)

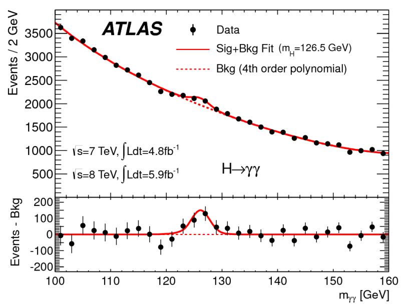


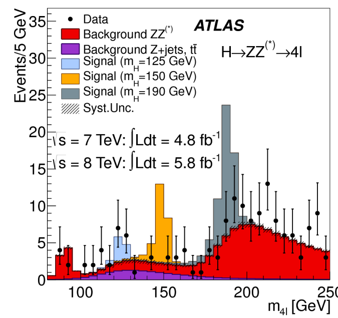
Results shown today are never achieved without supreme works from Accelerator and Detector groups

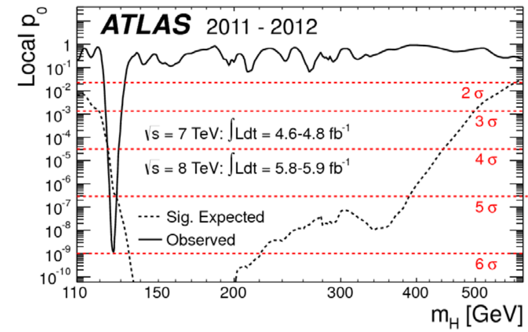
Disclaimer

Due to the time constrains, I will not go into the followings subjects (assuming these are well known facts ?)

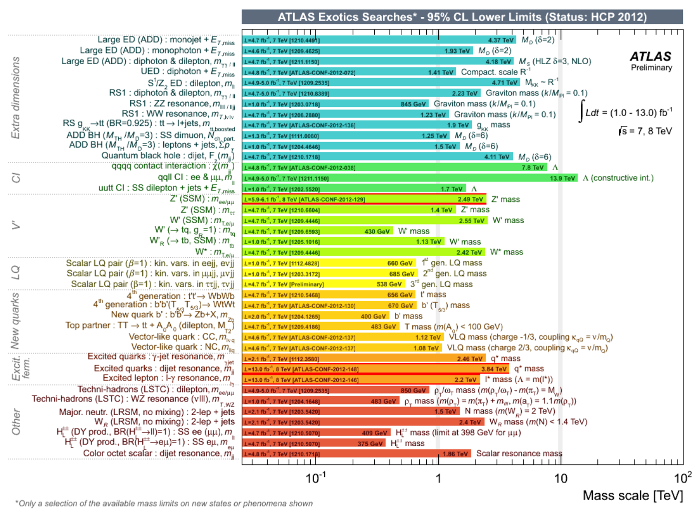
- discovery of the Higgs like boson particle







- No hint for SUSY and other BSM searches in “golden channel”



I would skip these, and instead

Outline of this talk

1) Latest results on 'Higgs like particle' property measurements

2) Searches in SUSY signatures with natural/complex scenarios

3) Status of Low scale Technicolor search
Although getting disfavored by appearance of a new particle ...

4) Physics sensitivities with the coming years

This talk is based on ATLAS results
Will refer to CMS when necessary

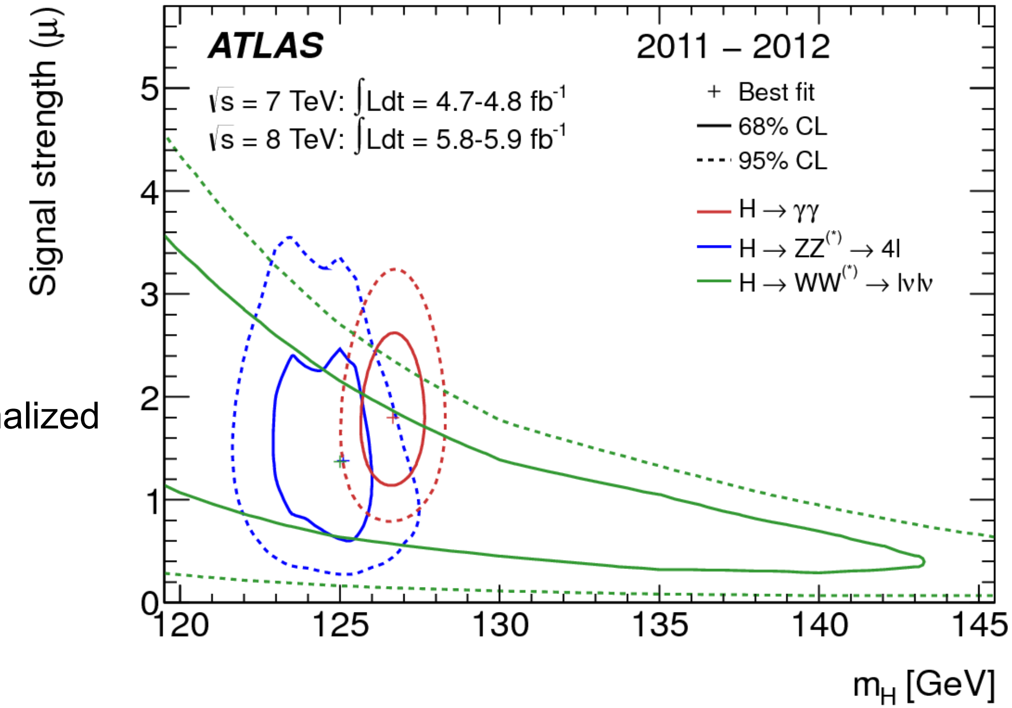
latest results on the Properties of

"Higgs like particle"

It's Measurement Time !

- Discovery of new neutral, boson is reported in July arXiv:1207.7214, PLB 716(2012) 1
  - combined 5.8σ : $\gamma\gamma$(4.5σ), ZZ(3.4σ) and WW(2.8σ)
  - similar report from CMS arXiv:1207.7235, PLB 716 (2012) 30
  - signal significance is not so important anymore
- Changing gear to the property measurement in order to "identify the particle"
  - electric charge Q=0 (we knew already !)
  - mass ~ 126 GeV
  - Couplings (to the particles)
  - Spin = 0,(1),2,... (1 is disfavored from $\gamma\gamma$ signal, cf. Yang's theorem)
  - P = even or odd (C=+1 as $\gamma\gamma$ decay& C-parity conservation)
- So far, ATLAS released the results on mass and coupling study (CMS has also shown CP study though...)

Mass measurement



μ: signal strength normalized by SM Higgs

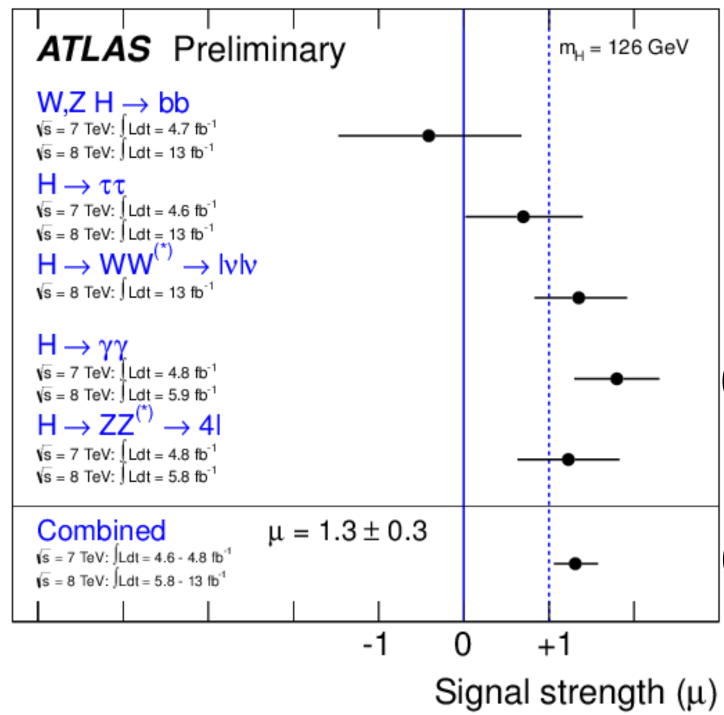
- Most precise value is obtained with the two highest resolution channels, i.e. $\gamma\gamma$ & 4 lepton channels
- best-fit value is found to be
  m = 126.0 ± 0.4 (stat) ± 0.4 (syst) it is already 0.45% precision
  consistent within the expt. uncertainty
- dominant systematic e/γ energy scale/resolution

Signal strength

- news since July paper (arXiv 1207.7214)
  results with 8TeV (13fb^{-1}) + 7TeV (5fb^{-1})
  - update • H→WW$^{(*)}$→$\ell\nu\ell\nu$ ATLAS-CONF-2012-158
  - new • H→$\tau\tau$ ATLAS-CONF-2012-160
  - new • H→bb ATLAS-CONF-2012-161

- (updated) overall signal strength
  - $\mu = \sigma/\sigma_{SM} = 1.3 \pm 0.3$
  - $\gamma\gamma$ rate is possibly enhanced
    - H→$\gamma\gamma$ occurs via loops, this channel is sensitive to BSM

ATLAS-CONF-2012-162

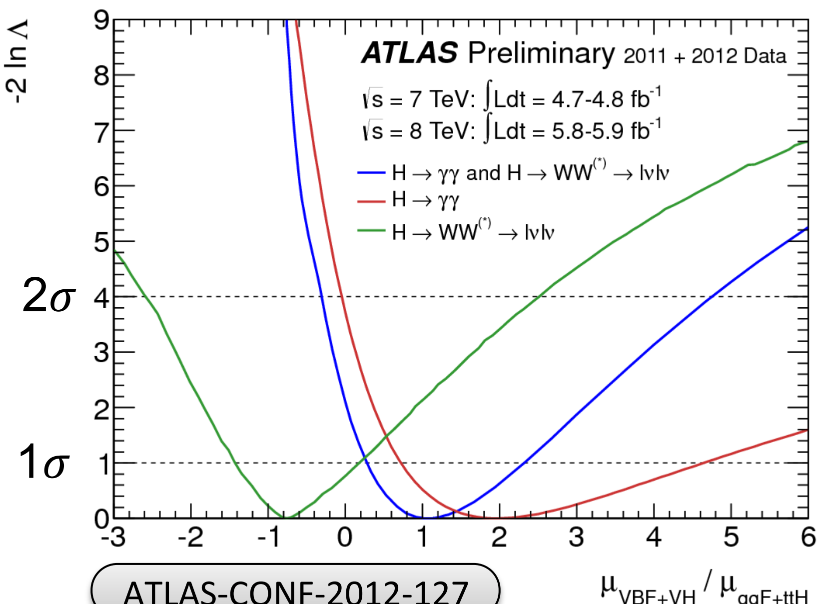


$\Delta\mu$
1.1
0.7
0.6
0.5
0.6
0.3

- Overall compatibility with SM (μ=1) is 23%

Coupling strength btw production modes

- based on the profiled likelihood fit method parameterization for signal strength in each channel
- m_H is fixed to 126 GeV (from mass meas.)
- use $\gamma\gamma$, WW to separate two production modes (H→ZZ→4l is inclusive)
  - ggF & ttH (fermionic couplings)
  - VBF & VH (vector boson couplings)
- total decay width cancelled out with μ ratio



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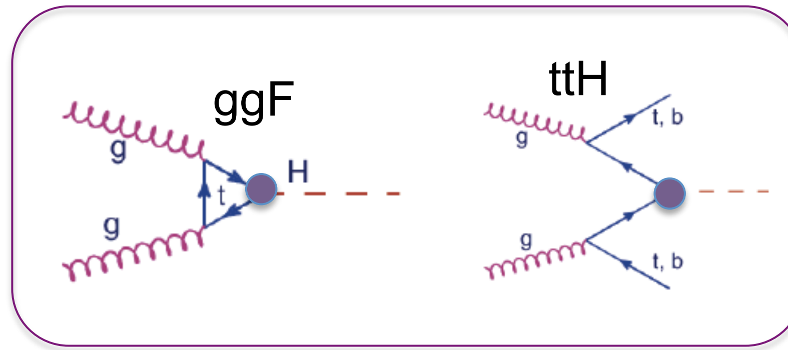

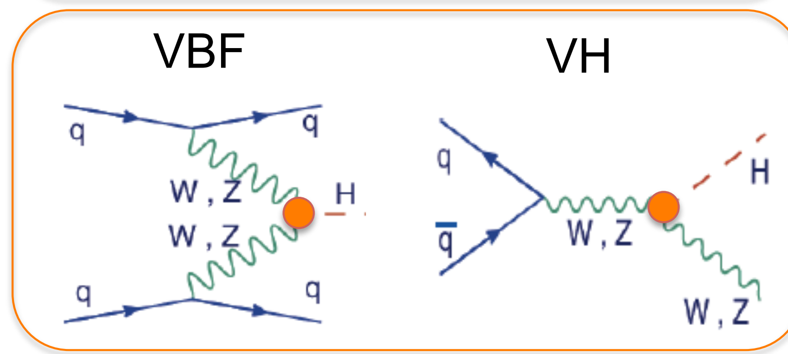

measurements consistent with SM within 1~2σ

Coupling measurements

- like to measure the couplings to see any deviation from SM
- the parameters κ represent coupling strength, defined w.r.t. SM

- coupling measurements followed benchmark models LHC Higgs XS WG

arXiv:1209.0040

- proved following (7 symmetries) x (with or without fix of Higgs total width)
- $\kappa = \mathrm{sqrt}(\mu)$: universal scaling of coupling
- κ_V vs. κ_F : Spin – vector bosons vs. fermions
- κ_W vs. κ_Z : Custodial symmetry – W vs. Z boson
- κ_q vs. κ_ℓ : Fermion flavor – quarks vs. leptons
- κ_u vs. κ_d : Fermion type – up vs. down
- κ_g vs. κ_γ : Effective loop couplings for effects of heavy BSM particles
- κ_H & BR_{inv} : Allow decays to light invisible BSM particles

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$$\sigma \times BR(ii \to \mathrm{H} \to ff) = \frac{\sigma_{ii} \cdot \Gamma_{ff}}{\Gamma_{\mathrm{H}}}$$

example

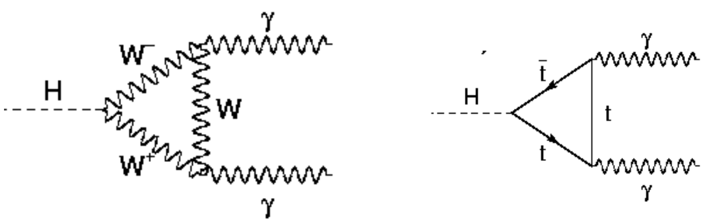
$$\frac{\sigma_{ggH}}{\sigma_{ggH}^{SM}} = \kappa_g^2$$

$$(\sigma \cdot \mathrm{BR})(gg \to \mathrm{H} \to \gamma\gamma) = \sigma_{\mathrm{SM}}(gg \to \mathrm{H}) \cdot \mathrm{BR}_{\mathrm{SM}}(\mathrm{H} \to \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_\mathrm{H}^2}$$

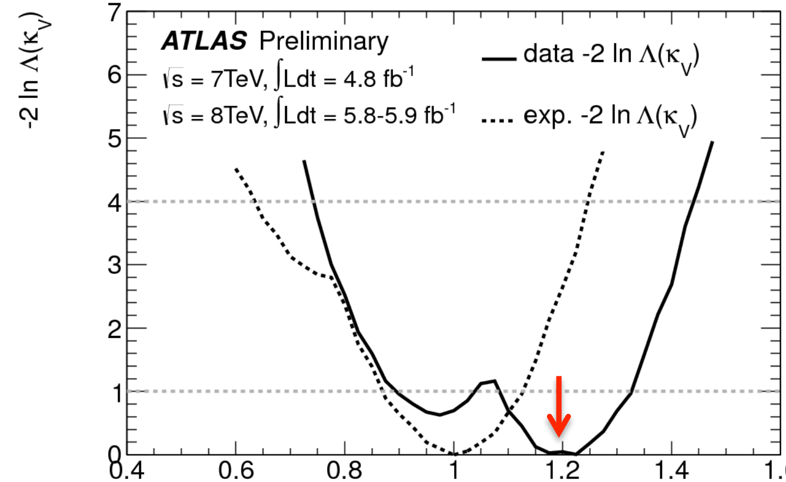
Vector bosons vs. Fermions

solid line = data
dashed line = Asimov dataset with SM Higgs properties

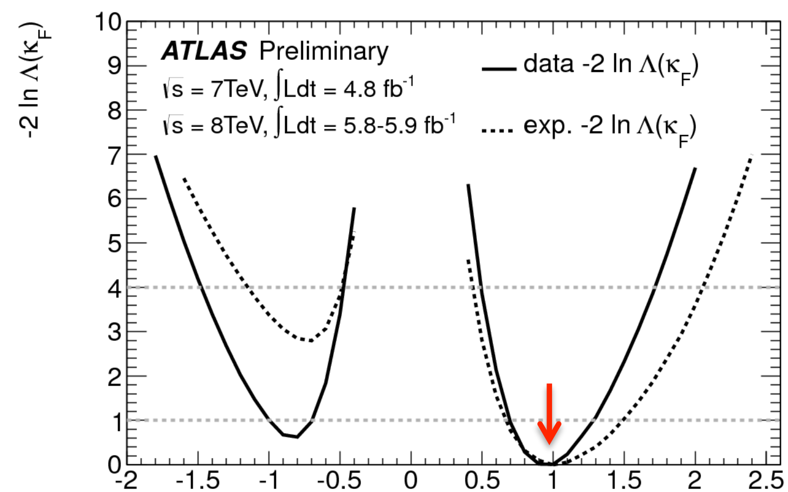
- Suppose common coupling strength for vector bosons and independent strength for fermions
  κ_V vs. κ_F
- Due to interference between W and Top in H→$\gamma\gamma$ (constructive or destructive) asymmetry of double minima in likelihood ratio



~ $= |1.28\ \kappa_W - 0.28\ \kappa_t|^2$



κ_V



κ_F

68% CL
κ_V =[0.9, 1.0] or [1.1, 1.3]

κ_F=[-1.0, -0.7] or [0.7,1.3]

Fermiophobic Higgs strongly disfavored

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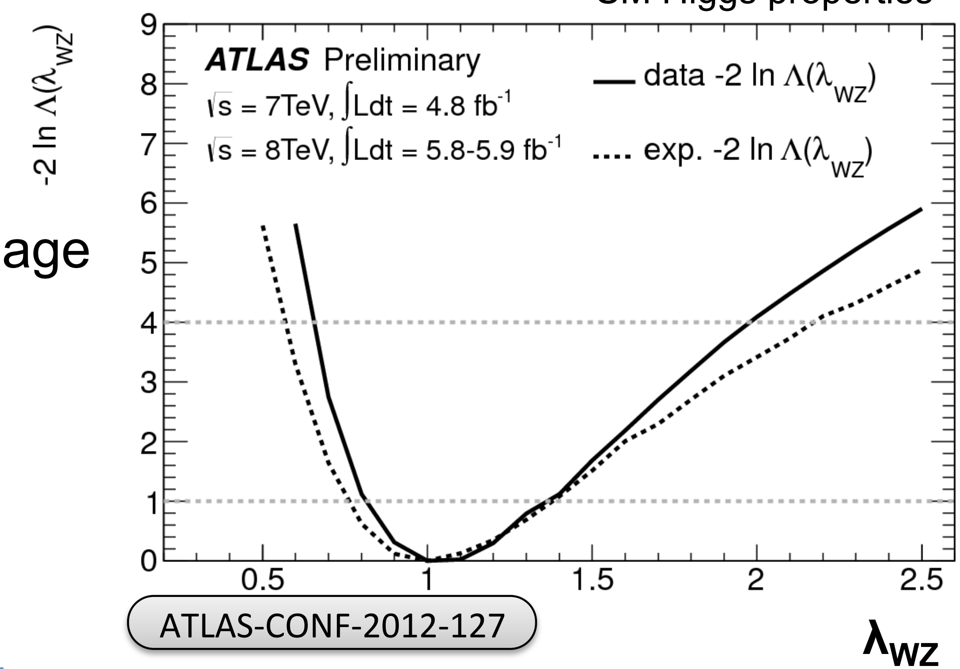
Custodial symmetry (W vs. Z)

- Suppose the W and Z couplings have different strengths w.r.t. SM
  - $K_W = g_W / g_{W,SM}$
  - $K_Z = g_Z / g_{Z,SM}$
  - $\lambda_{WZ} = K_W / K_Z$ = 1.07+0.35-0.27
- Consistent with SM expectation → custodial symmetry hold
- updated H→WW results (smaller μ) pull λ_{WZ} down a bit but would not change the message

(these studies are based on ICHEP (July) data)

solid line = data
dashed line = Asimov dataset with SM Higgs properties



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Loop couplings

- SM processes H→$\gamma\gamma$ and gg→H occur in one-loop: BSM effects may manifest in such loop diagrams

- effective couplings κ_g, κ_γ includes loop contributions
- other couplings are fixed to 1 (=SM)

- κ_g=1.13, κ_γ=1.22 (best fit)
- consistent with the Standard Model with current experimental uncertainty

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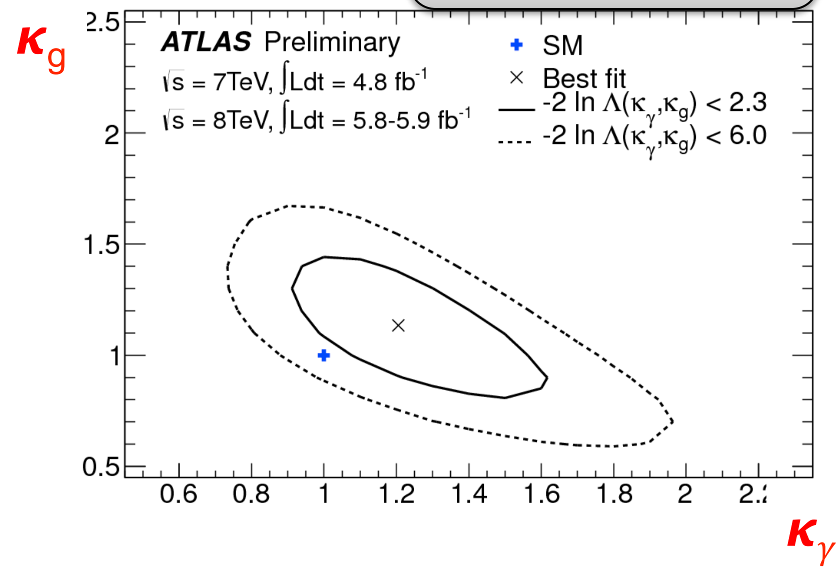


compatibility to SM (p-value) = 18%

Other studies on property measurements

The other coupling studies:

κ_q vs. κ_ℓ : Fermion flavor – quarks vs. leptons:

not enough data to distinguish btw $\kappa_\ell/\kappa_q=1$ (SM) and $\kappa_\ell/\kappa_q=0$

κ_u vs. κ_d : Fermion type – up vs. down:

not enough data to distinguish btw $\kappa_d/\kappa_u=1$ (SM) and $\kappa_d/\kappa_u=0$

κ_H & BR_{inv}: Allow decays to light invisible BSM particles:

course agreement with SM

- Parity measurement
  - CMS showed results on J^P study, based on the angle information in $H \rightarrow ZZ^{(*)} \rightarrow 4l$
  - CMS result : 0^- excluded at > 97% CL
  - ATLAS has not shown yet

CMS-PAS HIG-12-045

- Spin determination
  - require large statistics and good control over systematics
  - no results yet from both experiments

searching for
SUPERSYMMETRY

Today's search strategies for SUSY

- Despite enthusiastic investigation, SUSY has not been found
- SUSY seems not an easy game; three main directions

[1] (Orthodox) Strong production with R-parity conserving (RPC)

- gluino, 1st and 2nd generation squarks productions
- m_{sq}~m_{gl}>1.5TeV → explore even higher mass region

+ etc

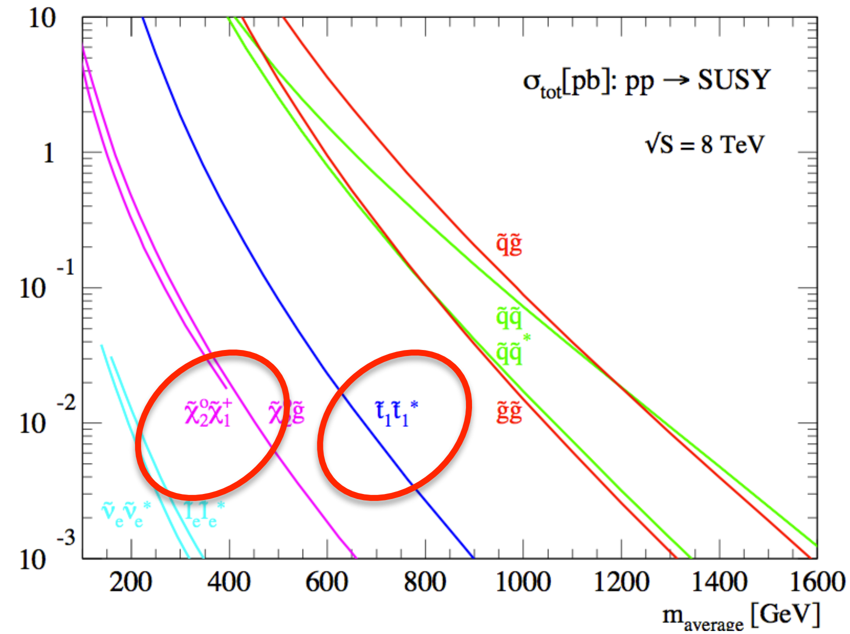
ATLAS-CONF-2012-103

ATLAS-CONF-2012-104

ATLAS-CONF-2012-109

[2] Natural spectrum in RPC scenario

- 3rd generation squarks and weak gauginos could be light
- stop, sbottom productions, and direct gaugino productions



[3] R-parity violating scenarios, or long-lived SUSY particles

arXiv:1210.7451

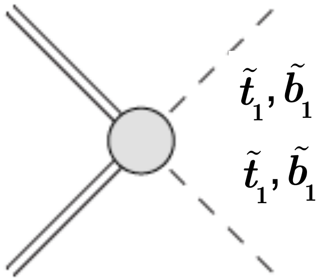
arXiv:1210.2852

+ etc

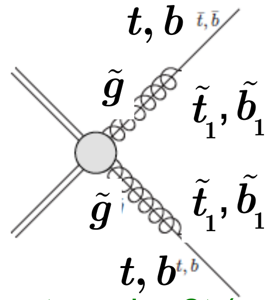
3rd gen. sparticle production & decay

[1] production

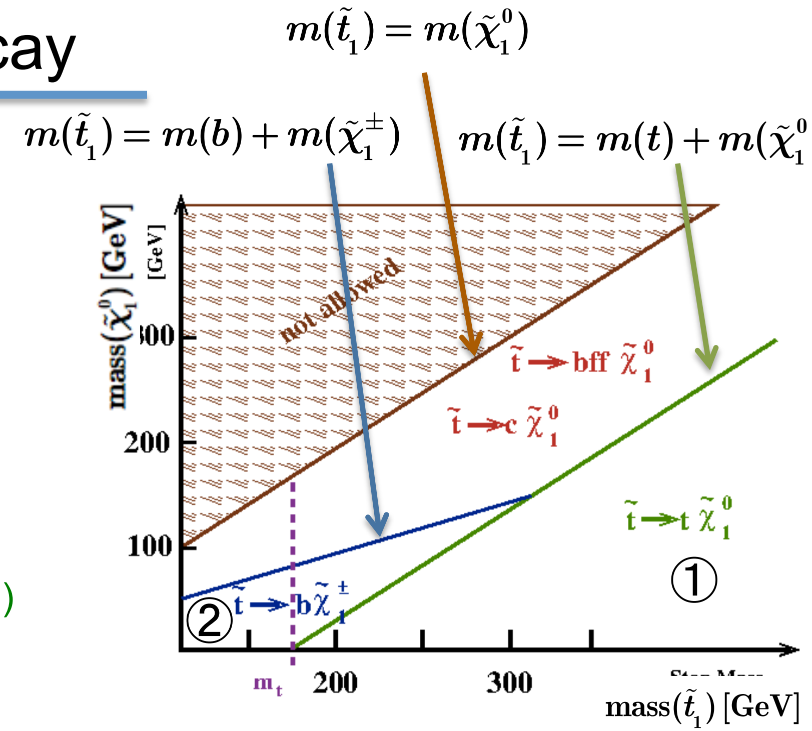
direct production



gluino mediated

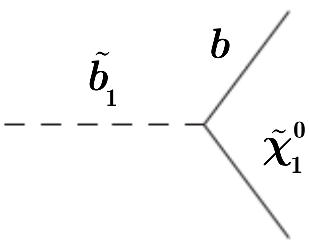


direct prod + 2t (or 2b)



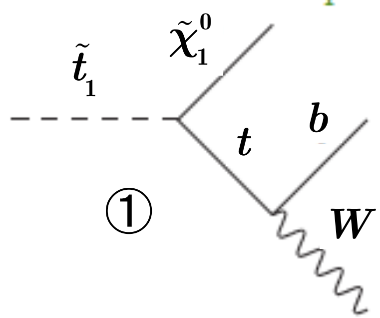
[2] decay

sbottom

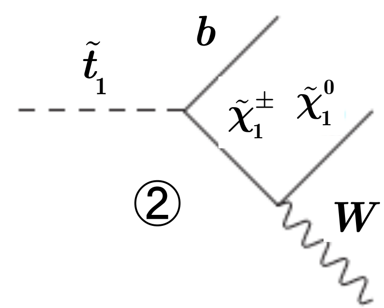


stop

$m_{\tilde{t}_1} > m_t + m_{\tilde{\chi}_1^0}$:

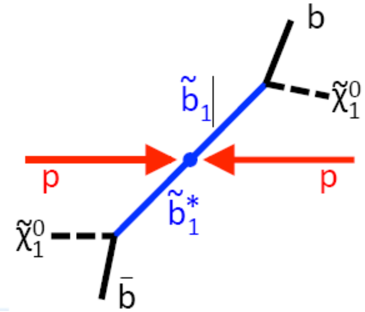


$m_{\tilde{t}_1} < m_t + m_{\tilde{\chi}_1^0}$:



complex categorization needed

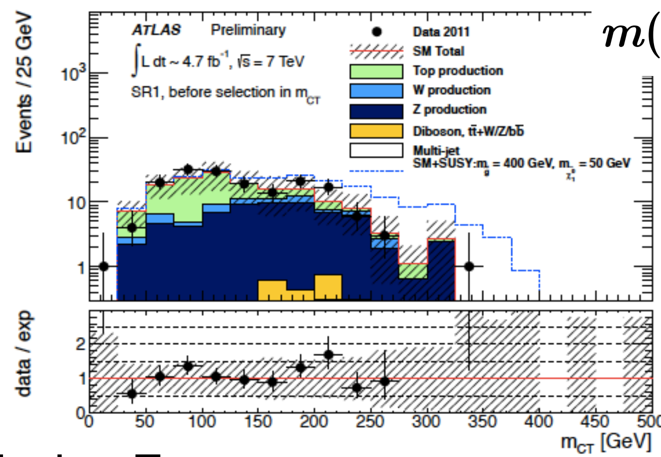
sbottom direct production



- 7TeV (2011) full stat 4.7/fb

(1) decay to b-jets

- 0-lepton + 2-bjets + missing E_T (+ISR)
- top pair rejection
- improve ~100GeV limit against 2/fb
- m($\tilde{b}$) < 500 GeV excluded



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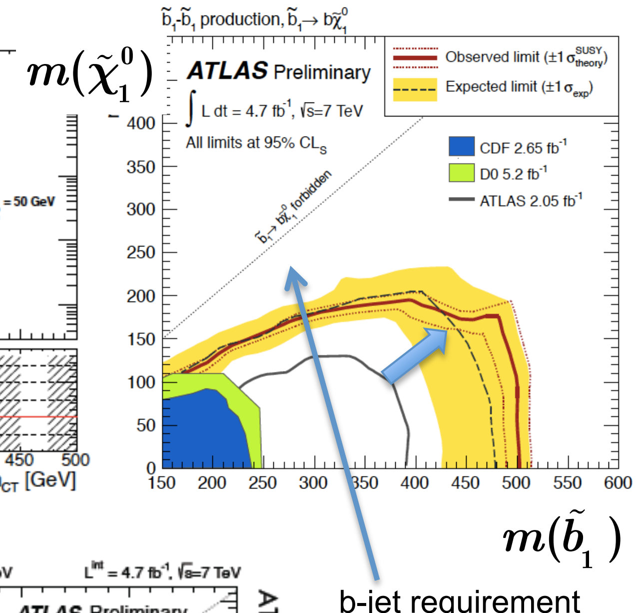
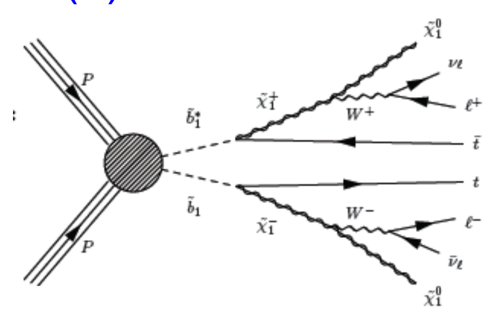


(2) decay to chargino

- 3 lepton + ≥4jet + missing E_T
- m($\tilde{b}$) < 430 GeV excluded



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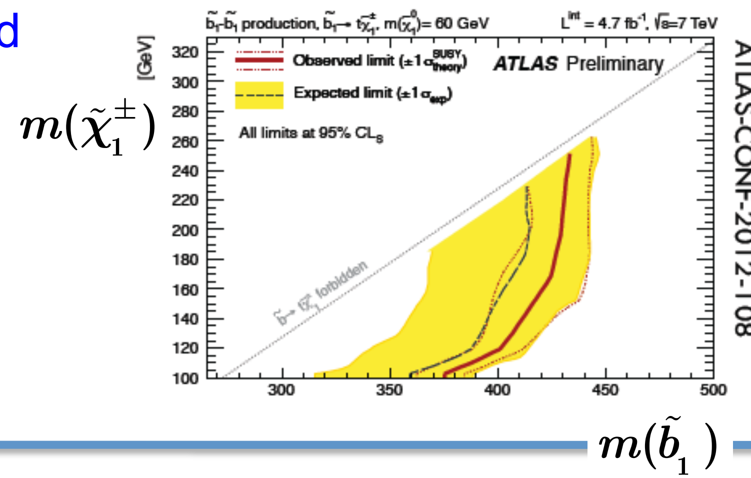


stop direct production (summary)

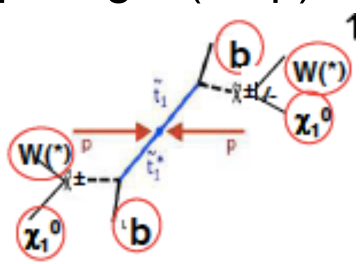
ATLAS-CONF-2012-059
ATLAS-CONF-2012-070
ATLAS-CONF-2012-071
ATLAS-CONF-2012-073
ATLAS-CONF-2012-074

① if stop is very light (soft decay product)

$$m(\tilde{\chi}_1^{\pm}) < m(\tilde{t}_1) < m(t) \quad \tilde{t}_1 \to b\tilde{\chi}_1^{\pm} \to bW^{(*)}\tilde{\chi}_1^0$$

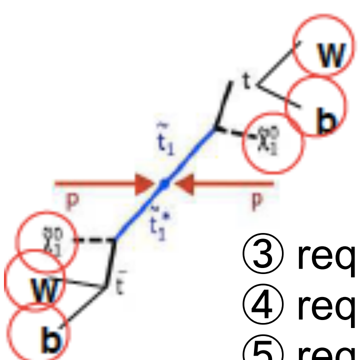
requirement : 2 x low p_T leptons < 30GeV (top veto)

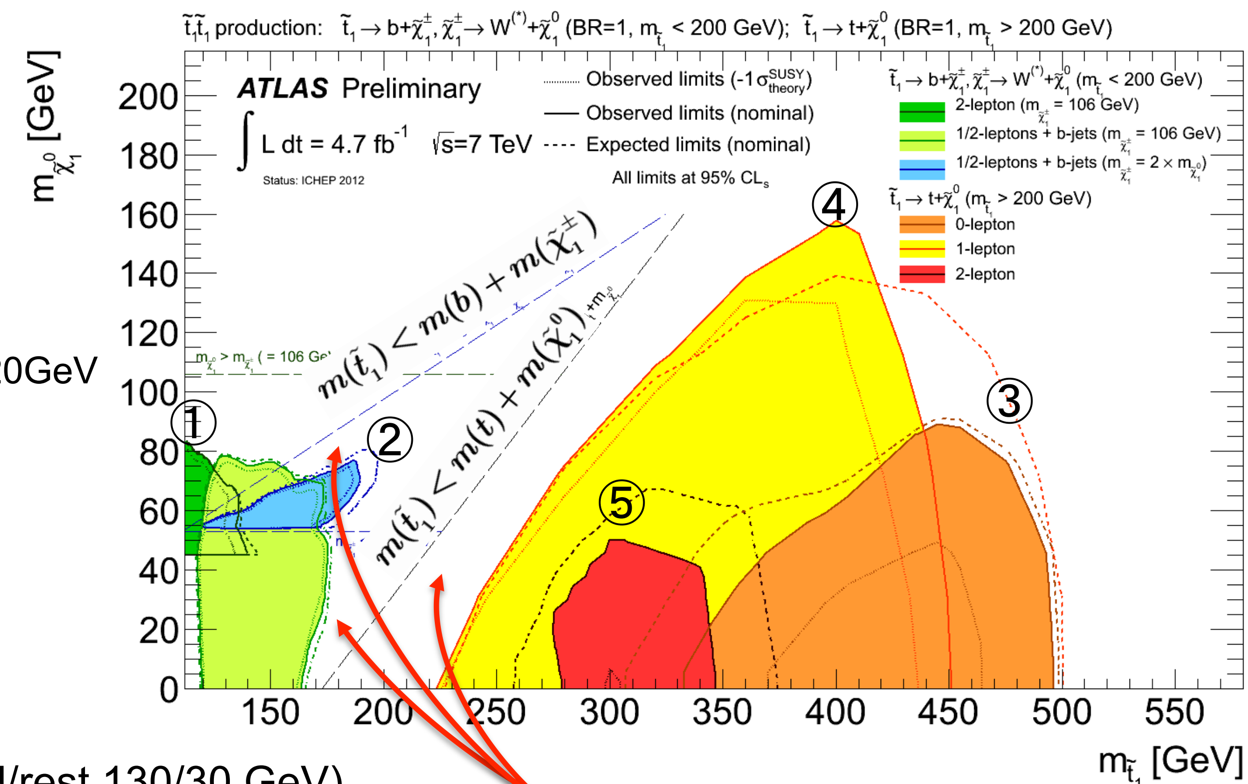
② stop is light (~top)



min requirement; b-jet p_T > 20GeV

③④⑤ m(stop) > m(top)

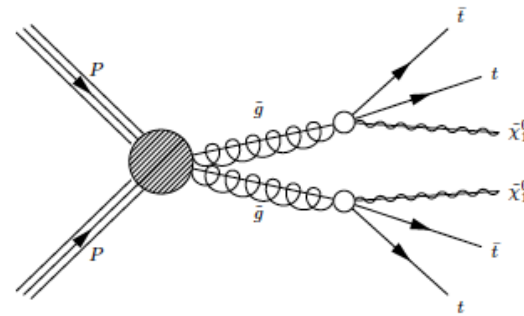




The areas close to border lines are experimentally difficult

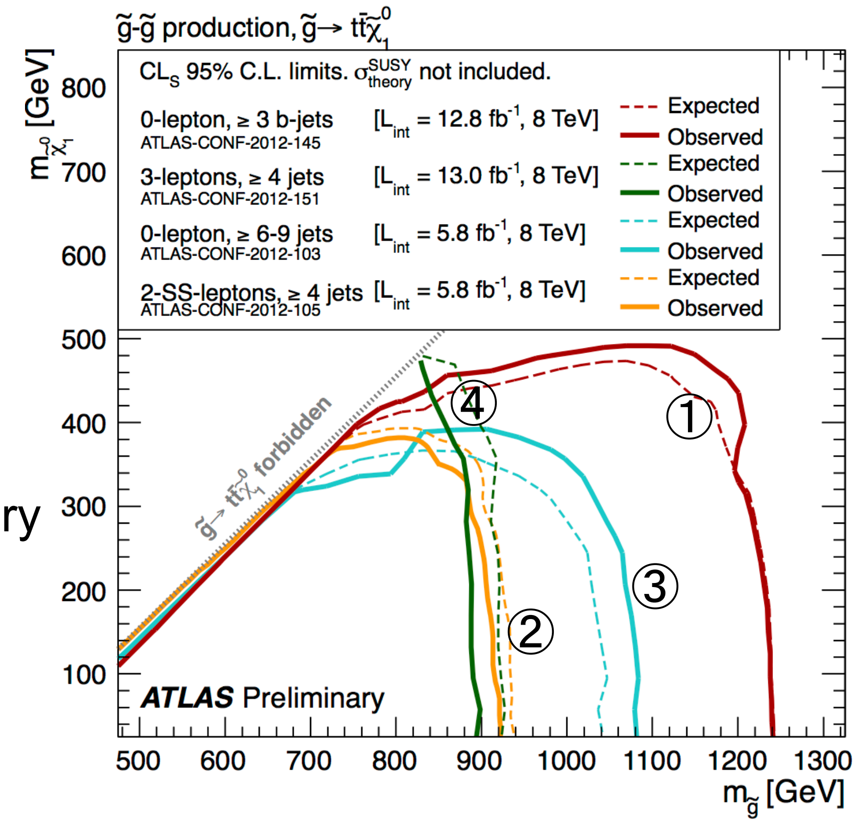
③ require 6jets (lead/rest 130/30 GeV)
④ require 4jets (80/60/40/25 GeV)+1lepton
⑤ require 2jets + 2leptons

Gluino mediated stop decay



new 8TeV results (significant update from 7TeV)

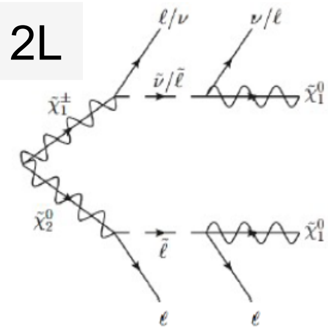
- having 4 tops in final state
  - need to effectively veto ttbar
    - ① 0-lepton + 3b-jets
      - ATLAS-CONF-2012-145
    - ② same sign lepton pairs
      - ATLAS-CONF-2012-105
    - ③ 0-lepton 6-9jets
      - ATLAS-CONF-2012-103
    - ④ 3-lepton+jets+MET
      - ATLAS-CONF-2012-151
  - 3-lepton channel complementary ay near border line
  - m(gluino) < 1240GeV m(neutralino) < 500GeV



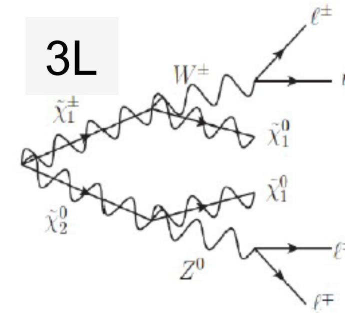
Direct gaugino production

- Candidate of the naturalness scenarios
- look for evts w/ low jet activity +multi leptons
- Backgrounds
  - 2L: tt, Z+jets, WW
  - 3L: W+Z/γ*
  - estimations based on MC (normalized to Data)

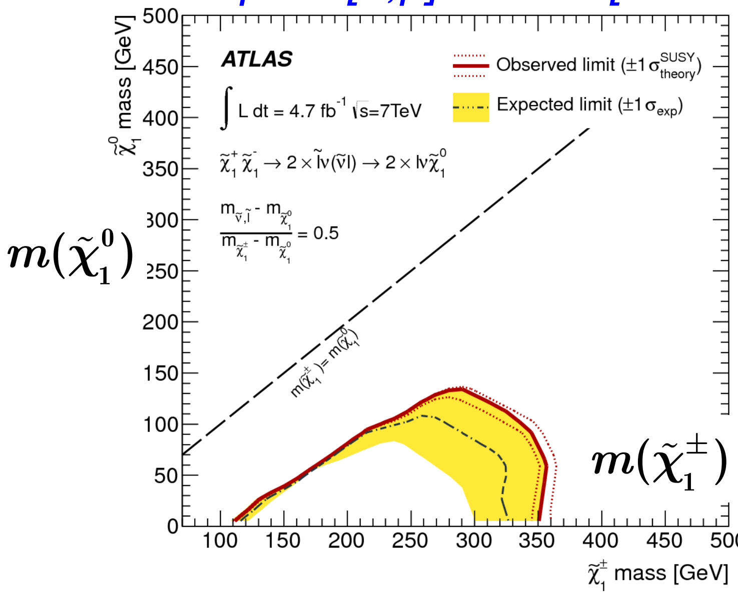
2L



3L

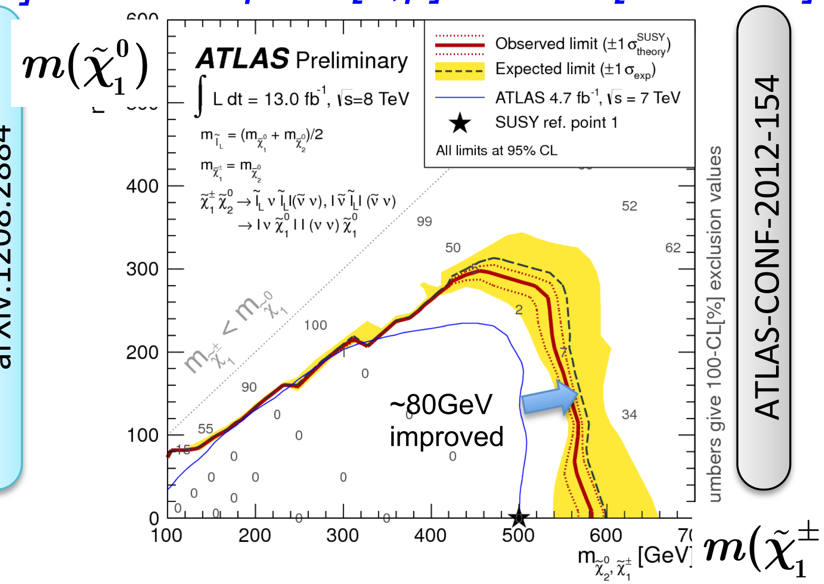


2lepton [e,μ] + MET [at 7TeV]



arXiv:1208.2884

3lepton [e,μ] + MET [at 8TeV]



interpret in simplified model: squarks, gluino very heavy, m(N2)=m(C1)

excluded m(C1) < 380GeV (in the presence of light sleptons)

current status of the EXOTICs

There are too many channels ...
review here only results connected to LSTC

SGCT scenarios at LHC

- Look for di-lepton and di-boson resonances (typical clean LHC signal)
- Low Scale TechniColor (LSTC)
  - ρ_{TC}, ω_{TC}, a_{TC} states (400~800GeV)
  - some published papers consider the LSTC models in resonance search for setting the limit
  - the others do not based on specific models but e.g. just SSM then the spectrum or model indep. XS limits are important

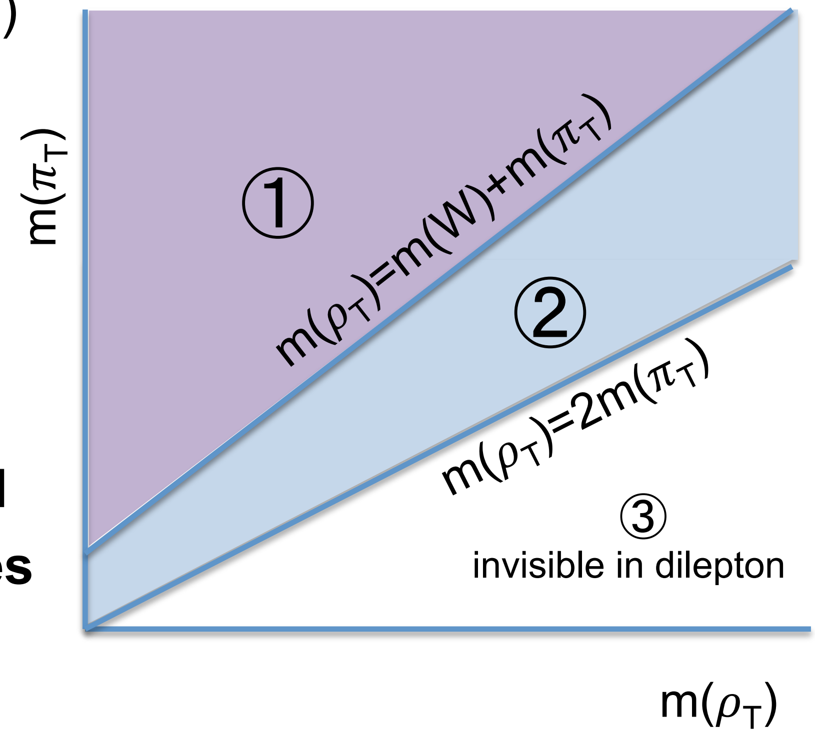
(1) Vector states ρ_{TC}, ω_{TC} decaying into di-leptons

(2) narrow resonance decaying into di-bosons WZ, $Z\gamma$, $W\gamma$

- High energy WW scatters
  - still important even if we confirm the SM Higgs boson
  - require a large luminosity → for the future upgrades

LSTC search in ATLAS

- QCD-like spectrum with scale $O(\Lambda_{TC})$
  - $\Lambda_{TC} \sim 100$GeV
  - technipions: π_T
  - technimesons: ρ_T, ω_T, a_T



- Walking coupling suppresses the
  $V \rightarrow n\ \pi_T$ decay (region ③)
  then narrow resonances expected
- **ATLAS look for narrow resonances**
  - $\rho_T^0 \rightarrow \ell\ \ell$
  - $\rho_T^\pm \rightarrow W^\pm Z$

- Previous limits from Tevatron
  - CDF: looked for $\rho_T \rightarrow W\ \pi_T$, (region ②) best limit $M(\rho_T)<250$ GeV
  - D0 : looked for $\rho_T \rightarrow WZ$, (region ①) best limit $M(\rho_T)<400$ GeV

CDF PRL 104 (2010) 111802 | D0 PRL 104 (2010) 061801

Resonance search in di-lepton channel

arXiv : 1209.2535

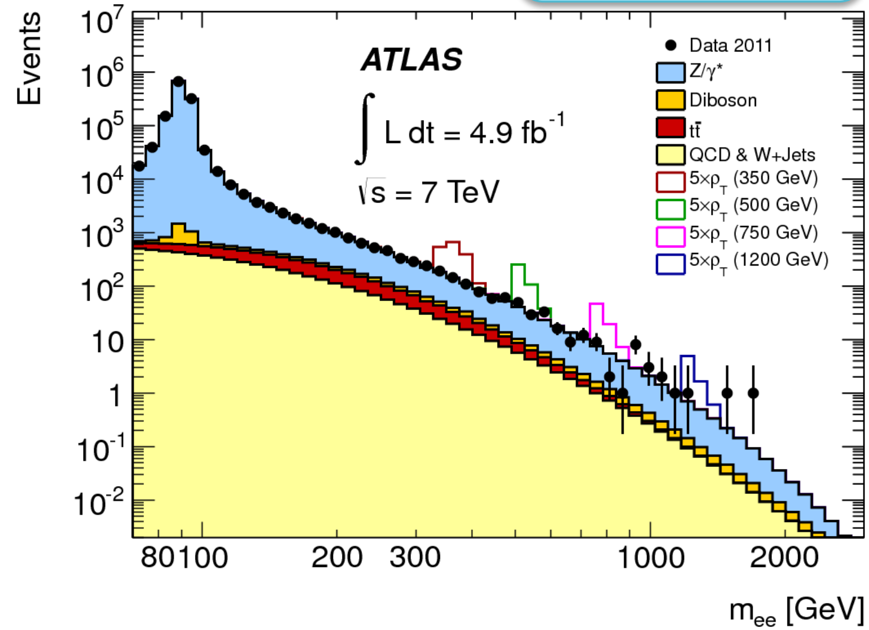
- The primary focus of the analysis lies in high mass tail (>1TeV)
- Limits can be reinterpreted in terms of LSTC
  - smaller signals at lower mass
- Backgrounds
  - main: Drell-Yan
  - di-boson, W+jets, top-pair
  - QCD data driven method estimation

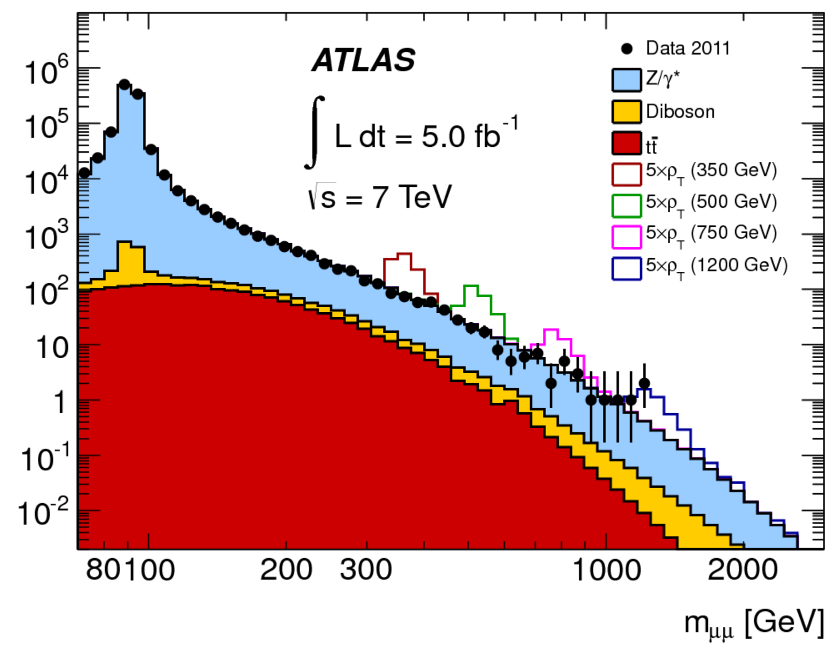
Electrons

E_T>25GeV
ID cuts on track, EM shower
Isolation E_T<7GeV in ΔR<0.2
correction for pileup and leakage from electron cluster

Muons

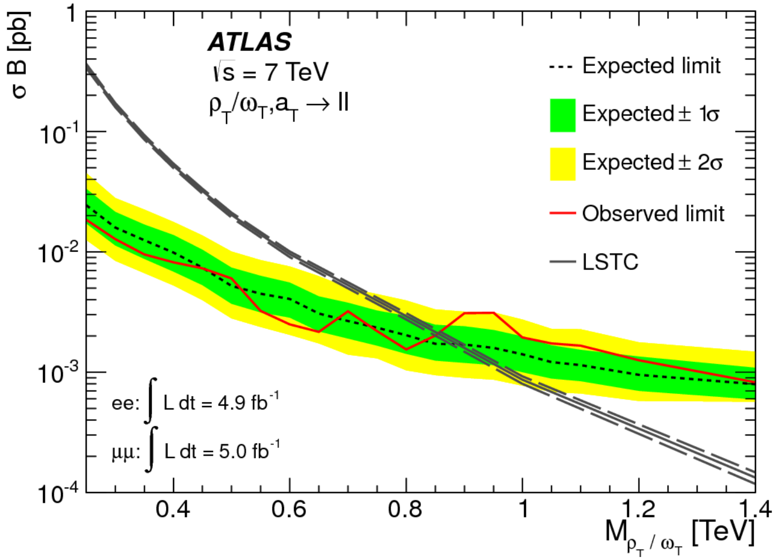
p_T>25GeV
combined track : ID + Muon spectrometer
isolation : track sum p_T (ΔR<0.3) < 0.05 p_T

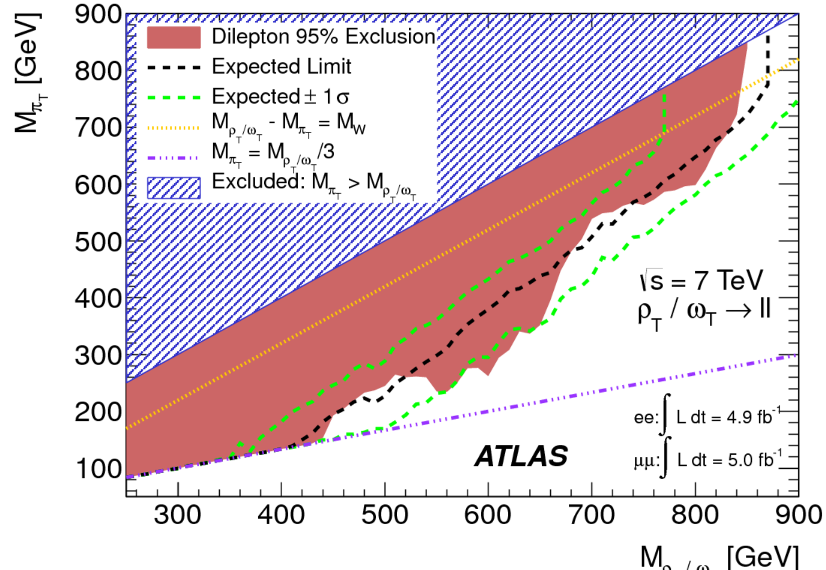




Resonance search in di-lepton channel

- good agreement between data and MC in LSTC region (200-600 GeV)
- set limit under assumptions
  - $m(\omega_T)=m(\rho_T)$ degenerate
  - $m(a_T) = 1.1 \times m(\omega_T)$
  - $m(\rho_T)$, $m(\pi_T)$ ratio impacts the a_T,ρ_T cross section ratio
- with 7TeV $L\sim5fb^{-1}$
  - 95% CL lower limit
    $m(\omega_T)=m(\rho_T)$ > 0.85 (0.89) TeV
    observed (expected)
  - significant improvement since Tevatron & previous ATLAS result (7TeV ~1.2/fb ATLAS-CONF-2011-125)



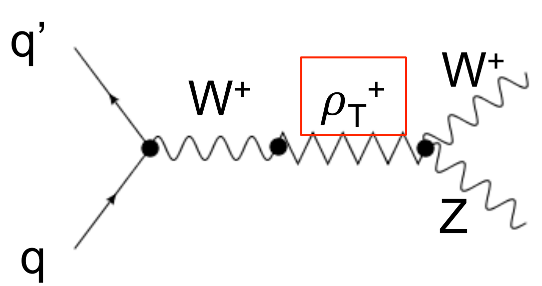


hot news 8TeV 6.1/fb note (ATLAS-CONF-2012-129) is out (no LSTC interpretation)

VV final state resonance search

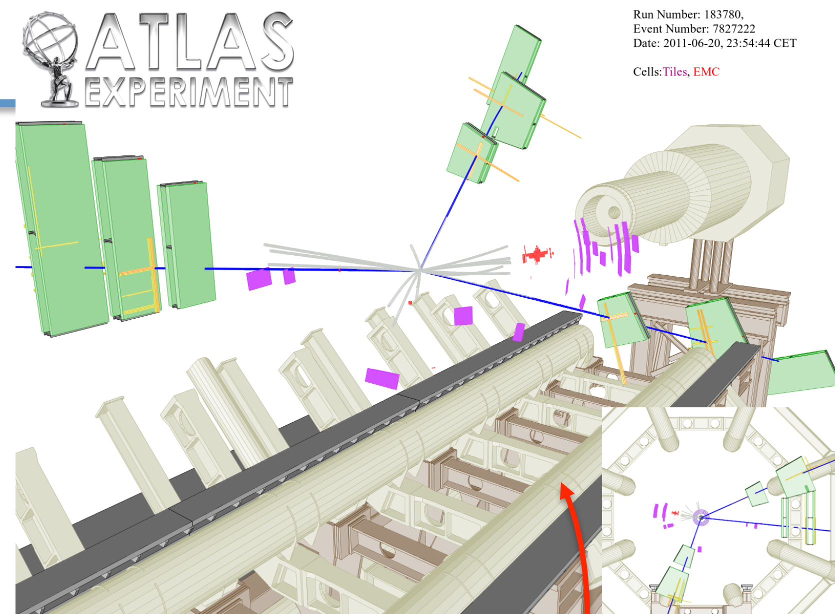
- In many possible BSM scenarios, new heavy particles decays into a pair of vector bosons, are important
- Final states are categorized by decay modes i.e. number of leptons
- In ATLAS, various searches carried out
  - ZZ → $\ell\ell\ell\ell$ (7TeV 1/fb arXiv : 1203.0718)
  - WZ → $\ell\nu\ell\ell$ (7TeV 1/fb PRD 85 (2012) 112012)
  - WW → $\ell\nu\ell\nu$ (7TeV 5/fb arXiv : 1208.2880)
  - Z + W/Z → $\ell\ell$qq (8TeV 7/fb ATLAS-CONF-2012-150)

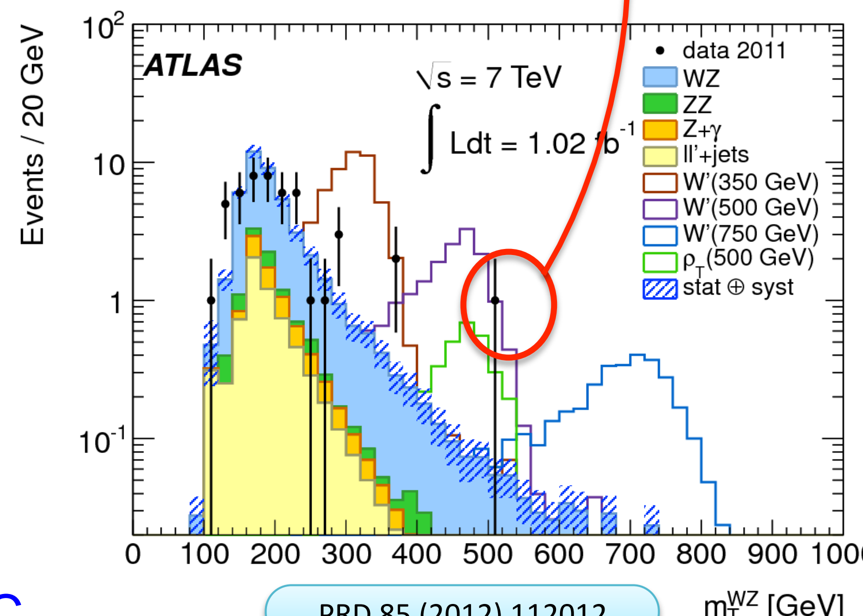
  so far these analyses showed null results
- LSTC interpretation is performed in WZ channel



Resonant WZ production

- Search in the final state with 3charged leptons + MET
- Electrons
  - E_T>25GeV, track and calo shape quality selection
  - isolation (<4GeV in ΔR=0.3)
- Muons
  - pT>25GeV, track quality cut
  - isolation (track pT sum < 0.1pT in ΔR=0.2)
- Event selection
  - two opposite sign, same flavor leptons ($|M_{ll}-M_Z|$<20GeV)
  - 3rd lepton & MET > 25GeV
  - $M_T(W)$>15GeV (QCD veto)
- Background
  - dominant WZ : estimated by MC

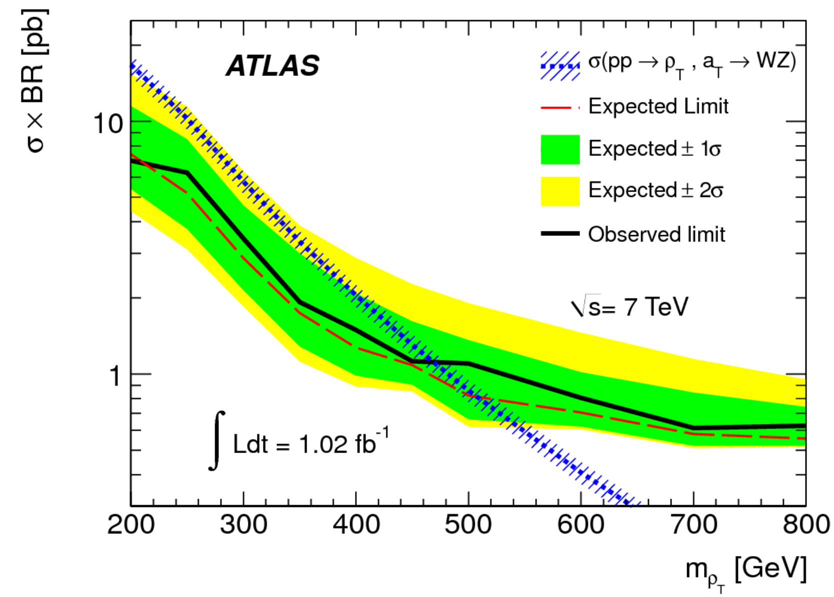


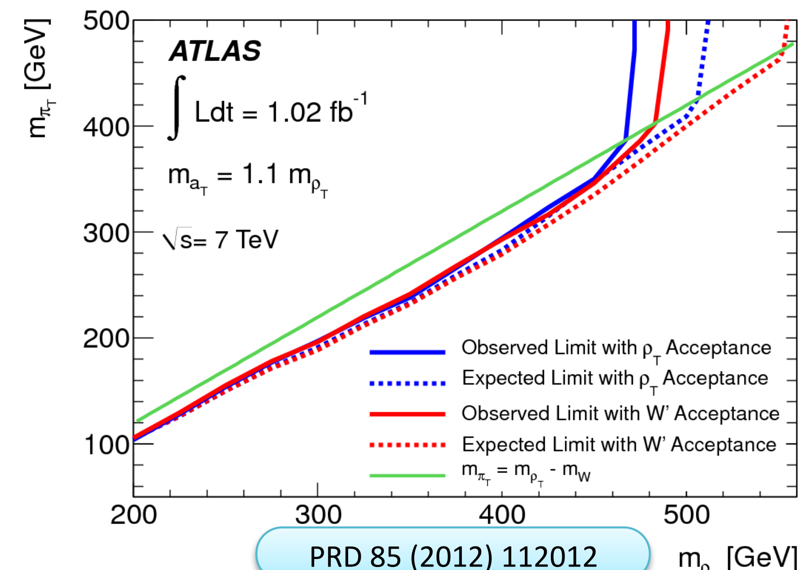


PRD 85 (2012) 112012

Resonant WZ production cont'd

- 48 candidates observed with SM prediction $45.0 \pm 1.0(\text{stat})^{+4.6}_{-5.2}(\text{sys})$
- dominant systematic sources are theoretical uncert. and luminosity
- no significant excess observed
  → set limit on σ x Br assuming
  $m(a_T) = 1.1 \times m(\omega_T)$
  acceptance calc. with unpol W/Z
- **$m(\rho_T) > 467$ (506) GeV**
  for observed (expected) limit
  (blue solid/dashed lines)
- N.B. limit slightly changed by using W' acceptance (polarized case : red lines)





PRD 85 (2012) 112012

prospects for

Sensitivities for data in coming years

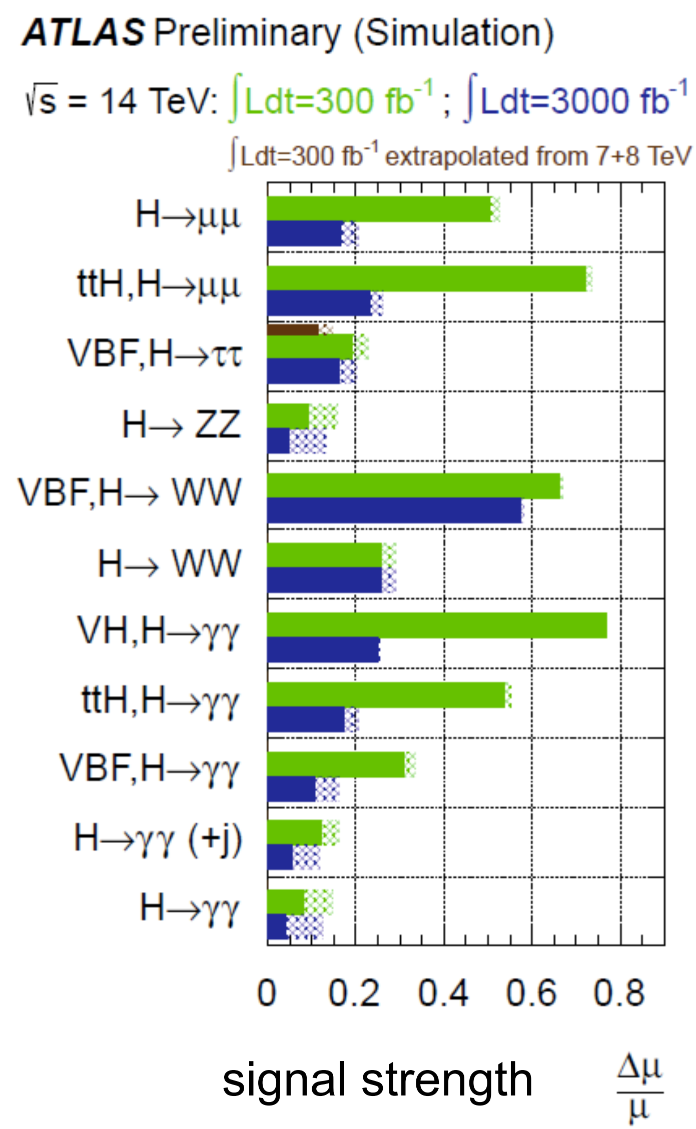
Higgs properties measurements

2011-2012

- Current efforts with 2011-2012 data are targeting Moriond-2013
- (see ATLAS-PHYS-PUB-2012-001 & -004 for detail)
- data 2011-2012 would allow the spin & parity measurement

After upgrade

- for the data after shutdown, we envisage
  - until 2021: 14 TeV ~400/fb
  - after 2022 (for 10 years):
    14 TeV ~3000/fb
- overview of the expected precision on signal strength is on right figure
- the expected precision on independent coupling strength (300/fb):
  κ_V=3%, κ_F=9%



Dilepton resonances in high energy end

- higher the integrated luminosity → better reach in high energy
- new Z' resonances in SSM, RS-graviton states
- Separate issues for "extremely" high energy region
  - saturation of readout electronics for EM calorimeter (max energy per cell < ~3TeV)
  - muon momentum resolution deterioration (10% @ 1TeV)
  - thus different sensitivity between ee and mm

Current limit

$Z'_{SSM} \rightarrow \ell\ell$	$\sqrt{s}$ =7TeV, 4.9/fb	2.21 TeV
$Z'_{SSM} \rightarrow \ell\ell$	$\sqrt{s}$ =8TeV, 6.1/fb	2.49 TeV

arXiv : 1209.2535

ATLAS-CONF-2012-129

Prospects

model	300/fb	3000/fb
$Z'_{SSM} \rightarrow ee$	6.5 TeV	7.8 TeV
$Z'_{SSM} \rightarrow \mu\mu$	6.4 TeV	7.6 TeV

$\sqrt{s}$ = 14TeV sensitivity (expected limit) for Sequential SM
considered only DY background

Summary

- Higgs like particle
  - no question about its existence anymore
  - various measurements started
    - signal strength measurements agree with SM with current experimental uncertainties
    - some of the coupling measurements have sensitivity and favor SM, the others still have no sensitivities
- SUSY
  - no hint of event excess yet
  - search strategies evolved from simple golden channels to various natural scenarios to explore undetected regions
- LSTC
  - ATLAS has set severe constrains to the model
  - $m(\rho_T) < 0.85$TeV excluded for $\rho_T \rightarrow \ell\ell$ channel
  - $m(\rho_T) < 0.47$TeV excluded for $\rho_T \rightarrow WZ \rightarrow 3\ell$+MET channel

STAY TUNED