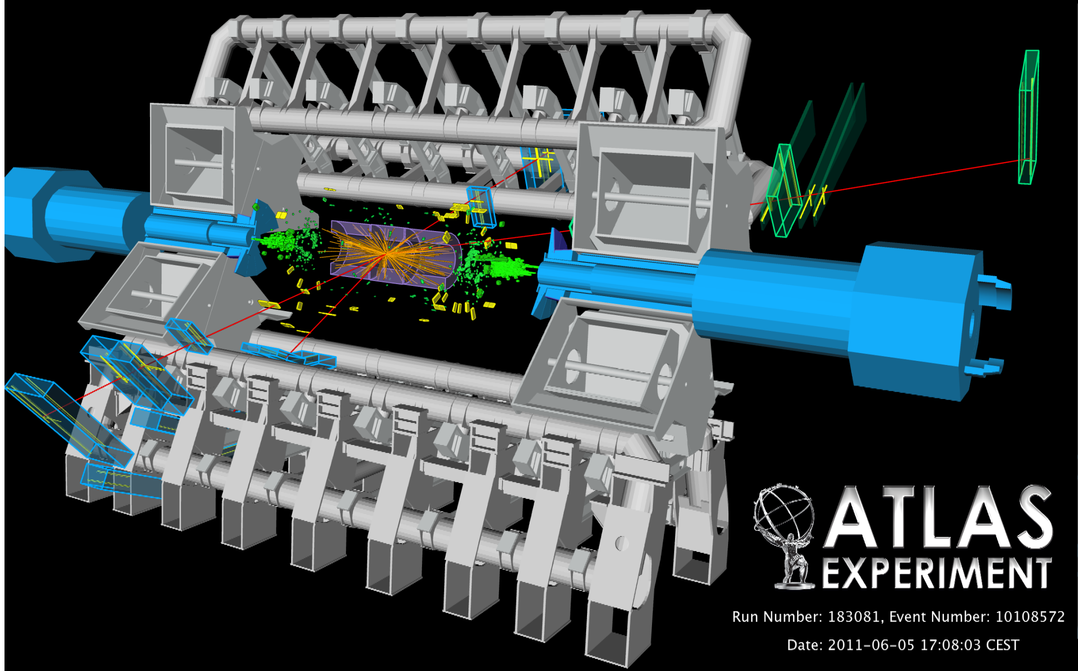
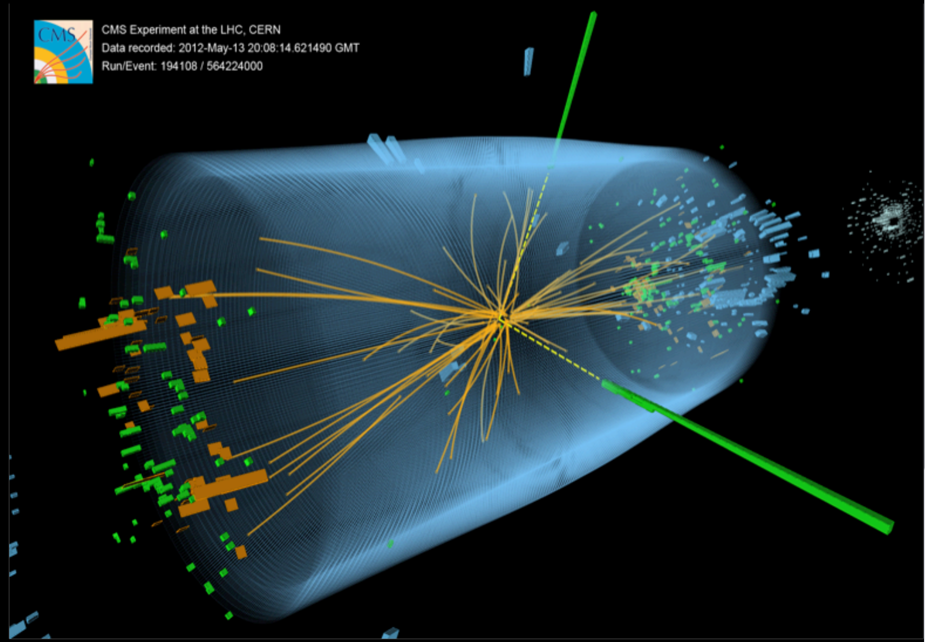




Higgshlights from the LHC: Searching for anosmalies

Tony Doyle

University of Glasgow

CERN

Outline

Experiment: Status

Standard Model Candles:
W/Z bosons, top production

Beyond the Standard Model:
Exotics, SUSY

Theory: Higgs and everything else..

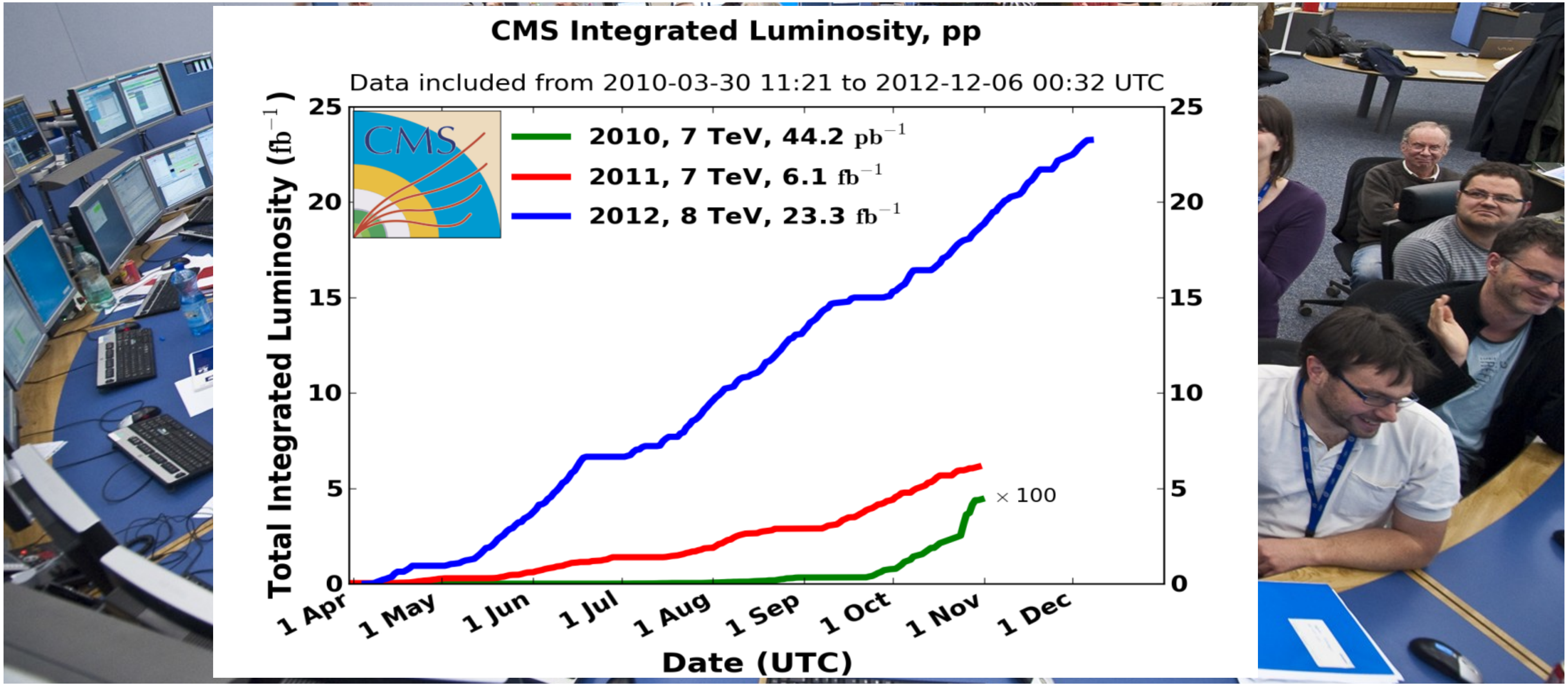
Higgs Voyage of Discovery

Selected Newsworthy Higgshlights

"Do you see over yonder, friend Sancho,
thirty or forty hulking giants?
I intend to do battle with them and slay them."
— Miguel de Cervantes Saavedra, Don Quixote

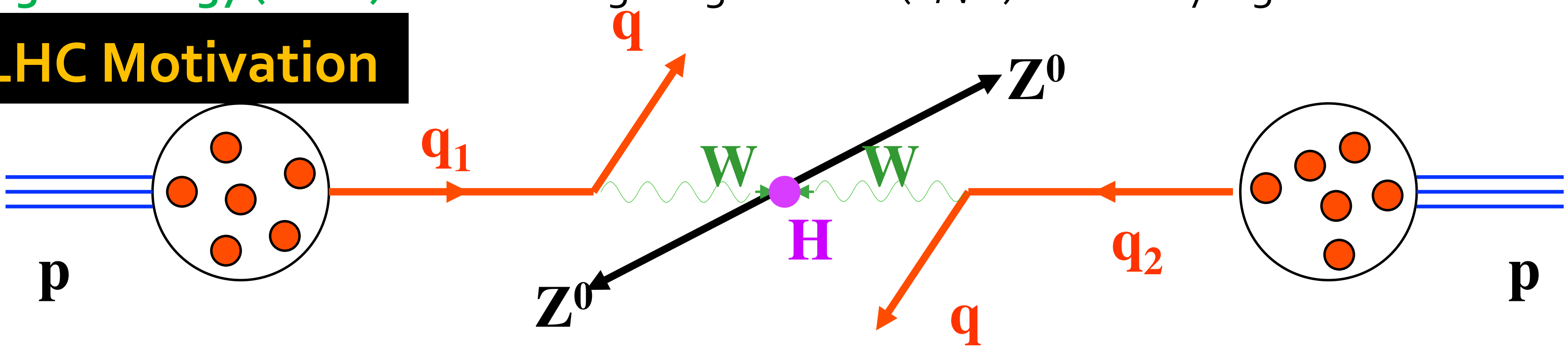
LHC Machine

- High luminosity

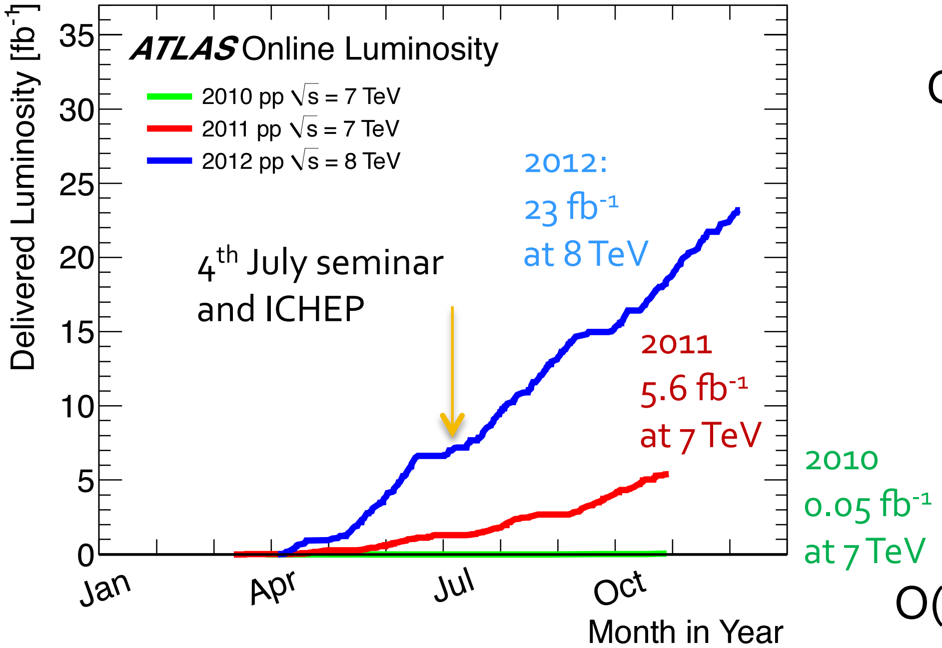


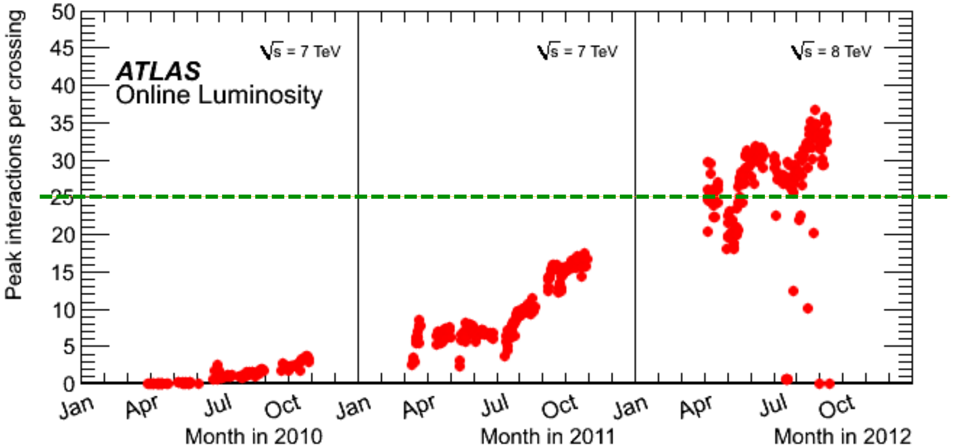
- Higher energy (8 TeV) -> ~10% Larger significance (S/√B): discovery ingredient

→ LHC Motivation



Three Years of Remarkable LHC operations at the Energy frontier



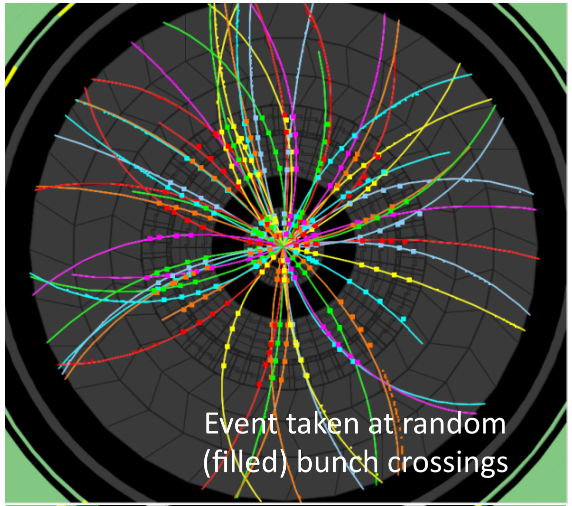


Design value (expected to be reached at $L=10^{34}$!)

2010

O(2) Pile-up events

150 ns inter-bunch spacing



2011

O(10) Pile-up events

50 ns inter-bunch spacing

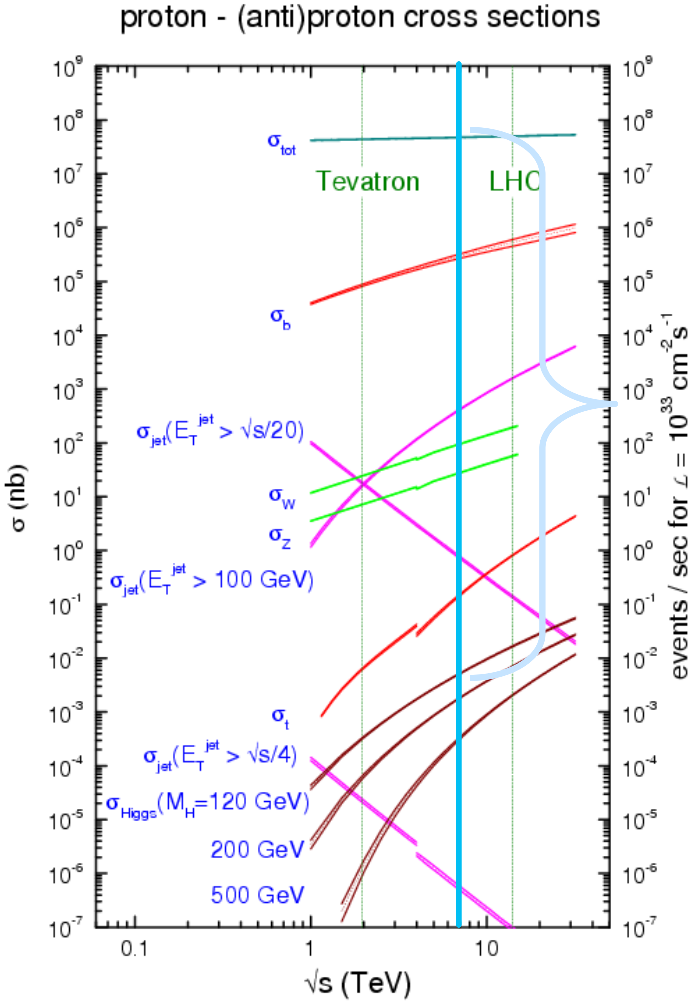
2012

O(20) Pile-up events

50 ns inter-bunch spacing

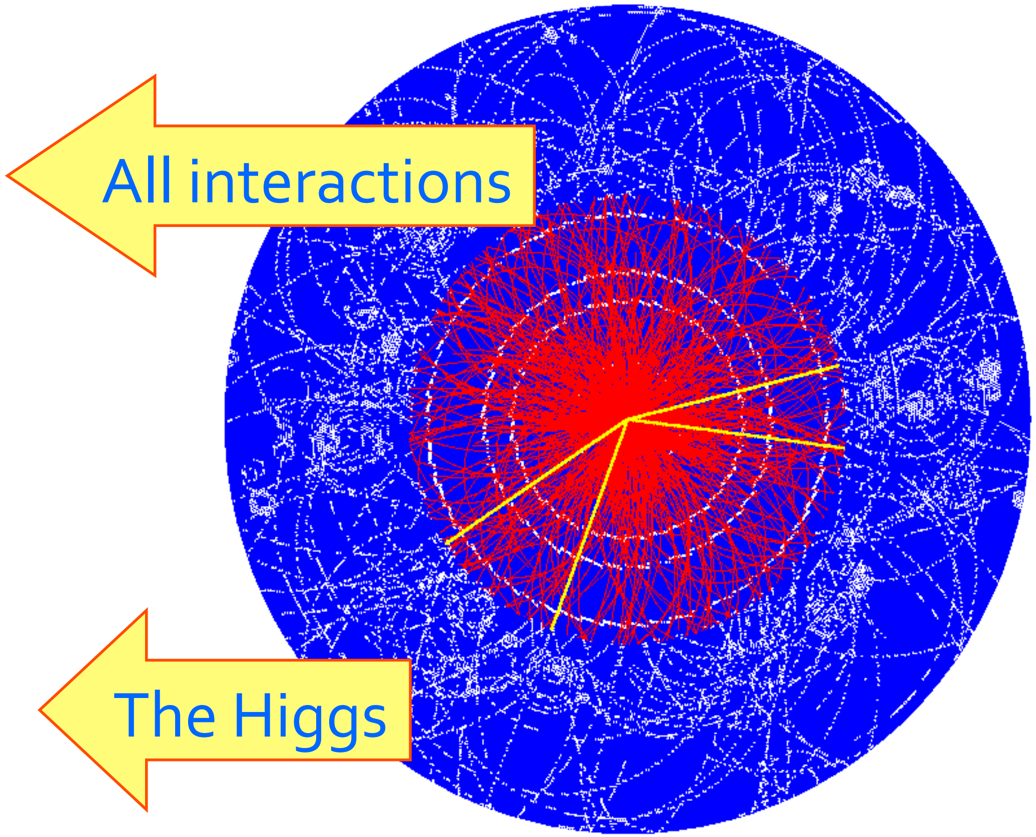
Higgs Challenge

a. Rare Phenomena
Huge Background



10 orders of magnitude

b. Complexity



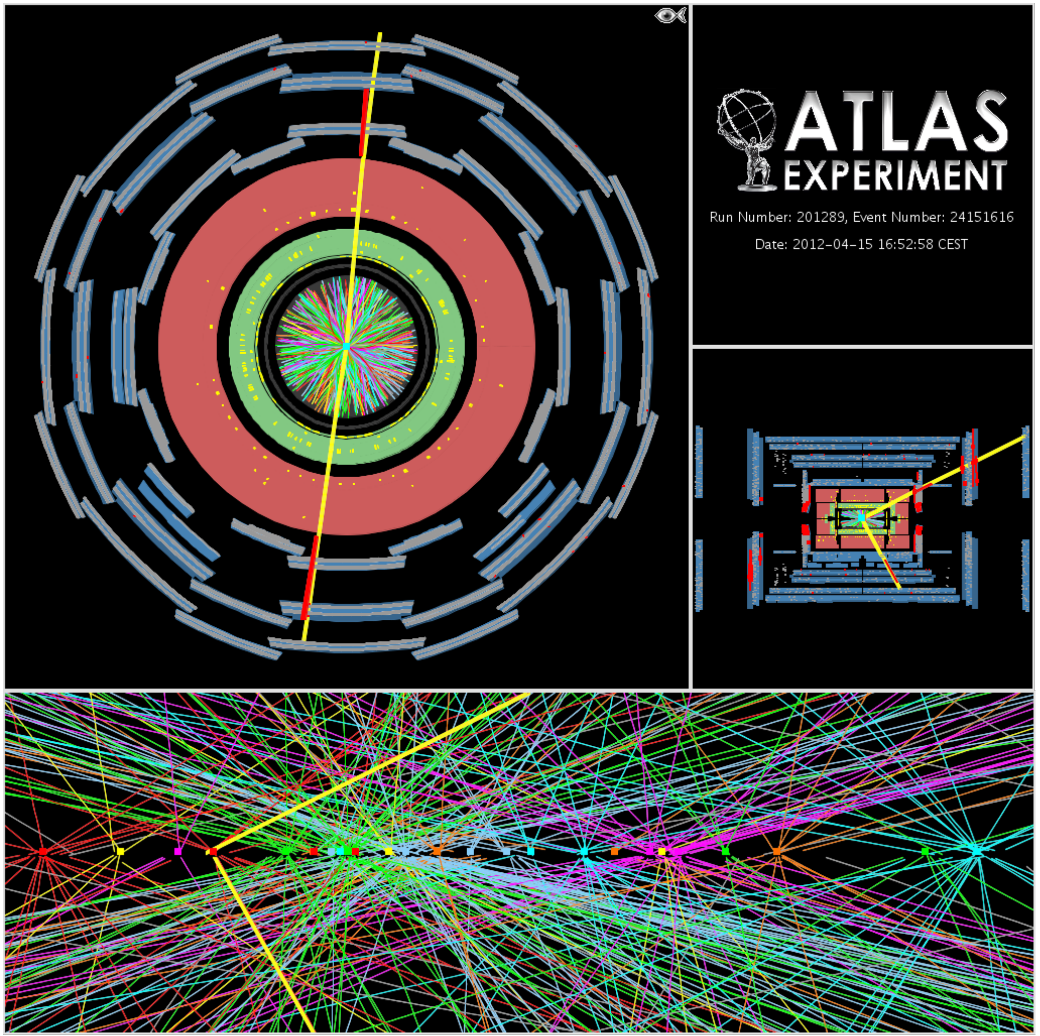
"one in 10 billion events"

"90 million readout channels"

Pileup in 2012

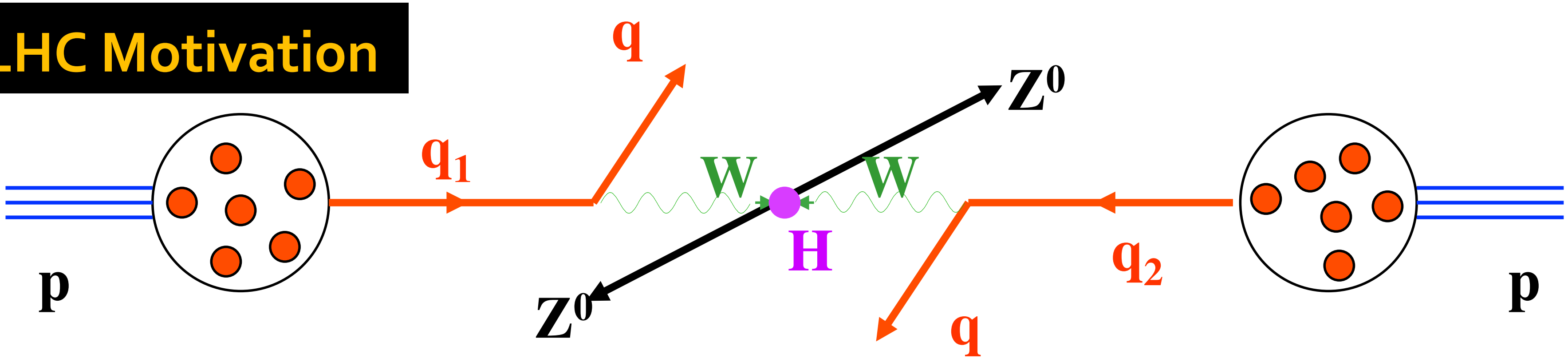
In general, do not expect a significant impact on tracking, nor muons, nor even electrons and photons

However, sizable impact on jets, E_T^{miss} and tau reconstruction as well as on trigger rates and computing



$Z \rightarrow \mu\mu$ event in ATLAS with 25 reconstructed vertices
Display with track p_T threshold of 0.4 GeV and all tracks are required to have at least 3 Pixel and 6 SCT hits

→ LHC Motivation



The Grid - Physics Delivery

Data preparation:

- First-pass reco. at Tier-0 within ~2 days
- Calibration/DQ good for physics analysis
- Data analysable on Grid within ~1 week

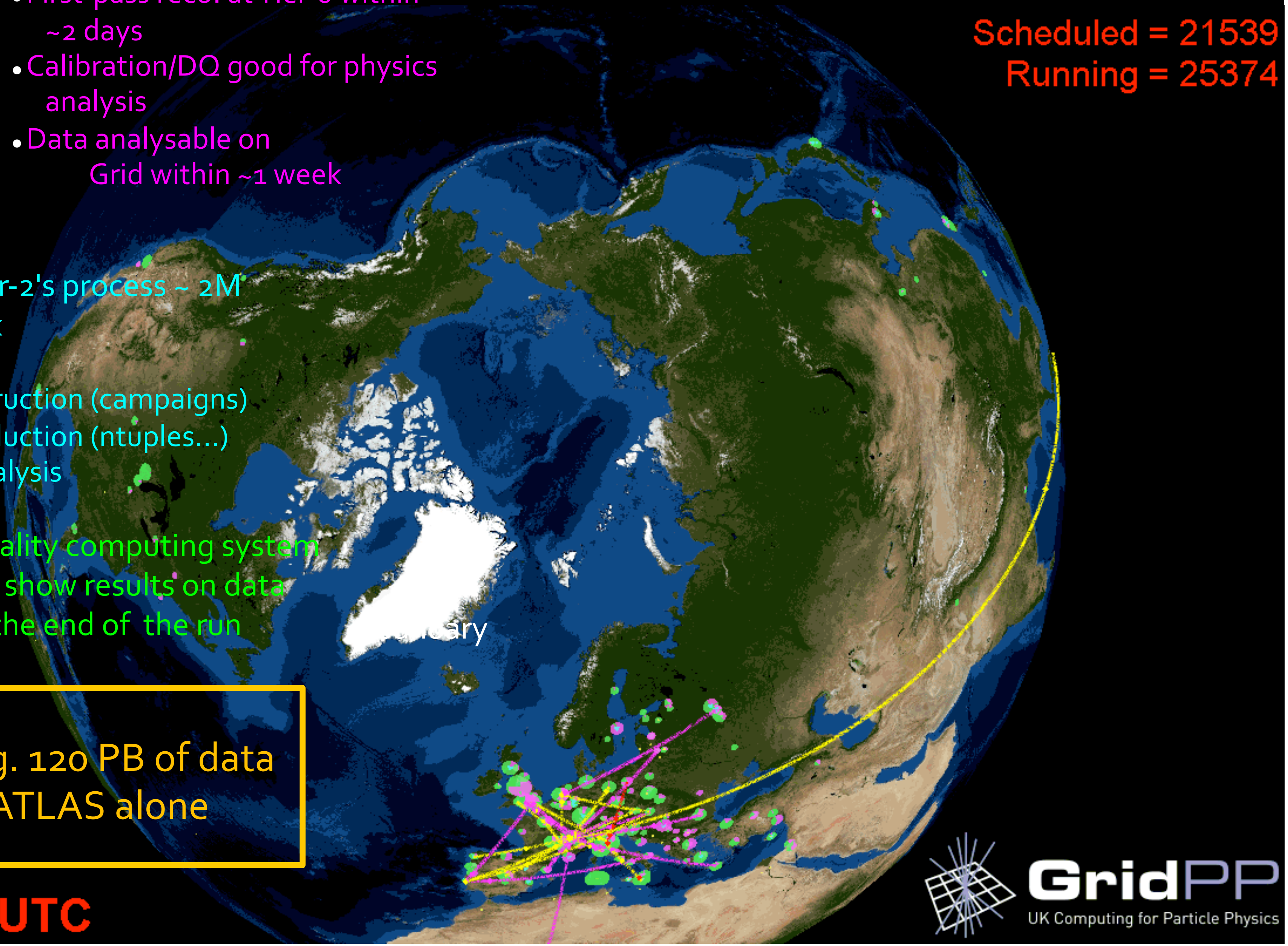
eGee
Enabling Grids for E-sciencE

Tier-1 and Tier-2's process ~ 2M jobs per week

- simulation
- re-reconstruction (campaigns)
- group production (ntuples...)
- physics analysis

The high quality computing system allows us to show results on data taken until the end of the run

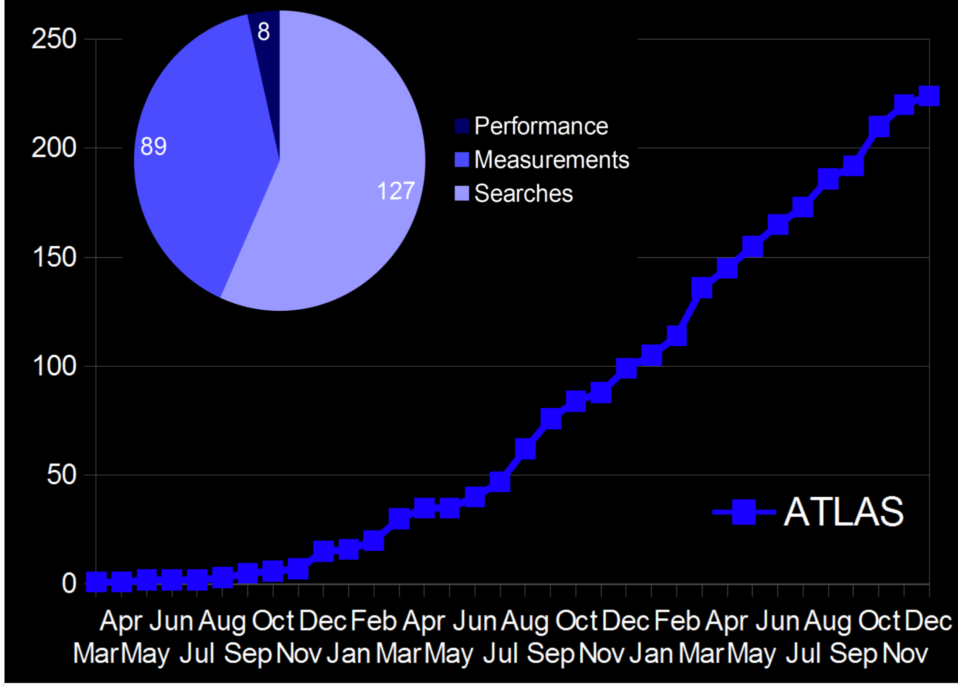
Now e.g. 120 PB of data for ATLAS alone

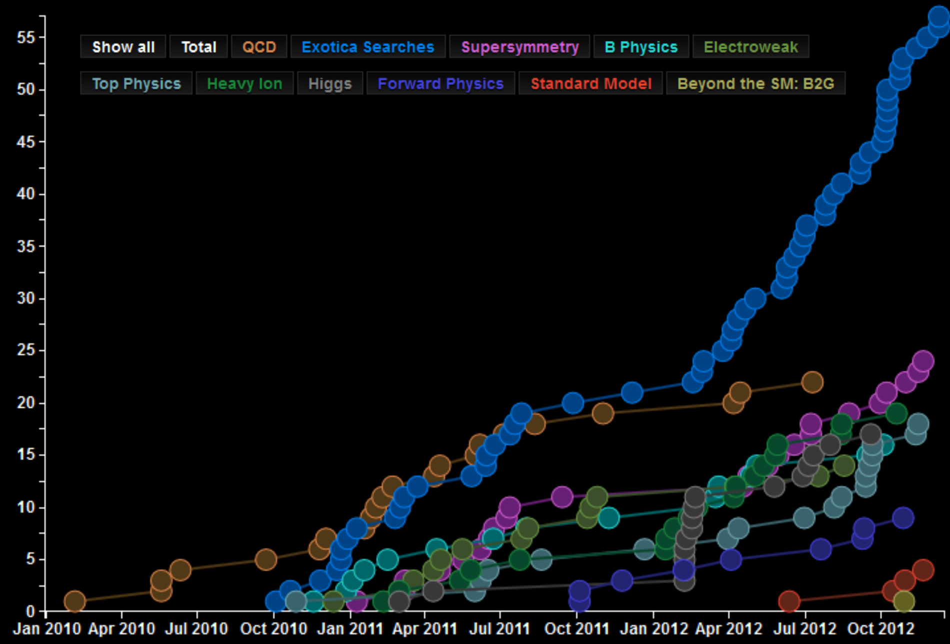


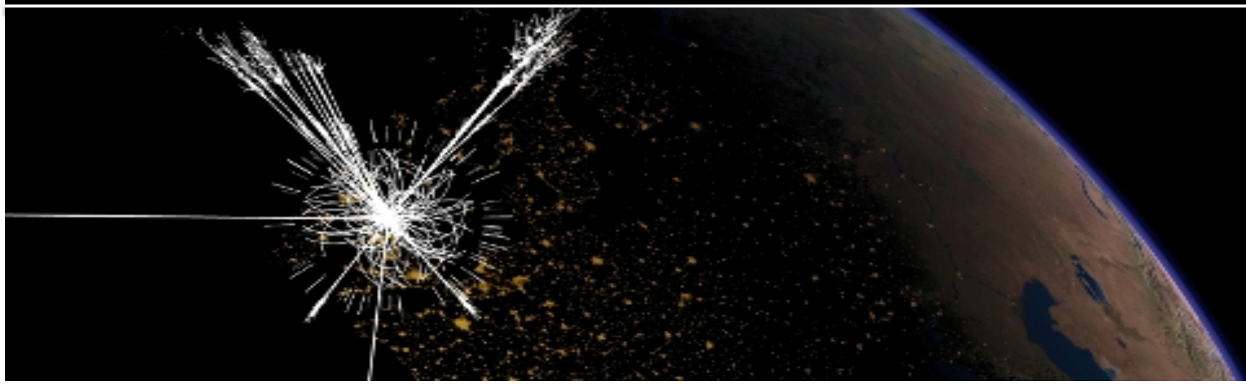
GridPP
UK Computing for Particle Physics

3 years of physics delivery

224+200=424 submitted papers







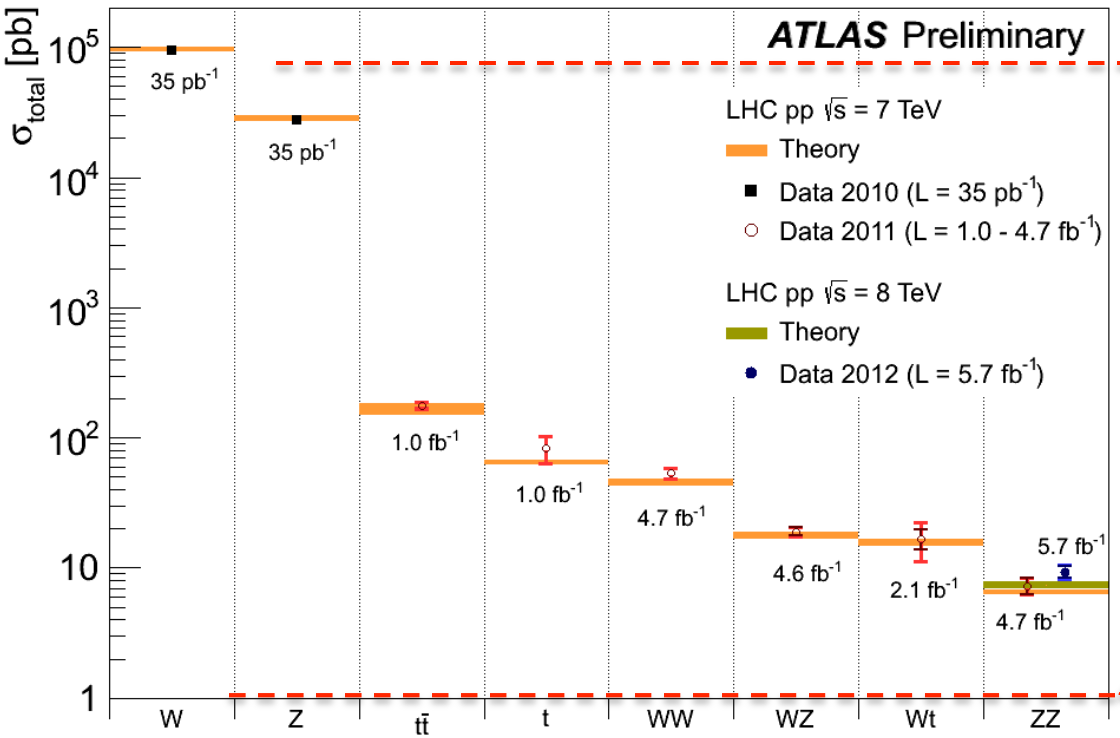
(17/12/12)

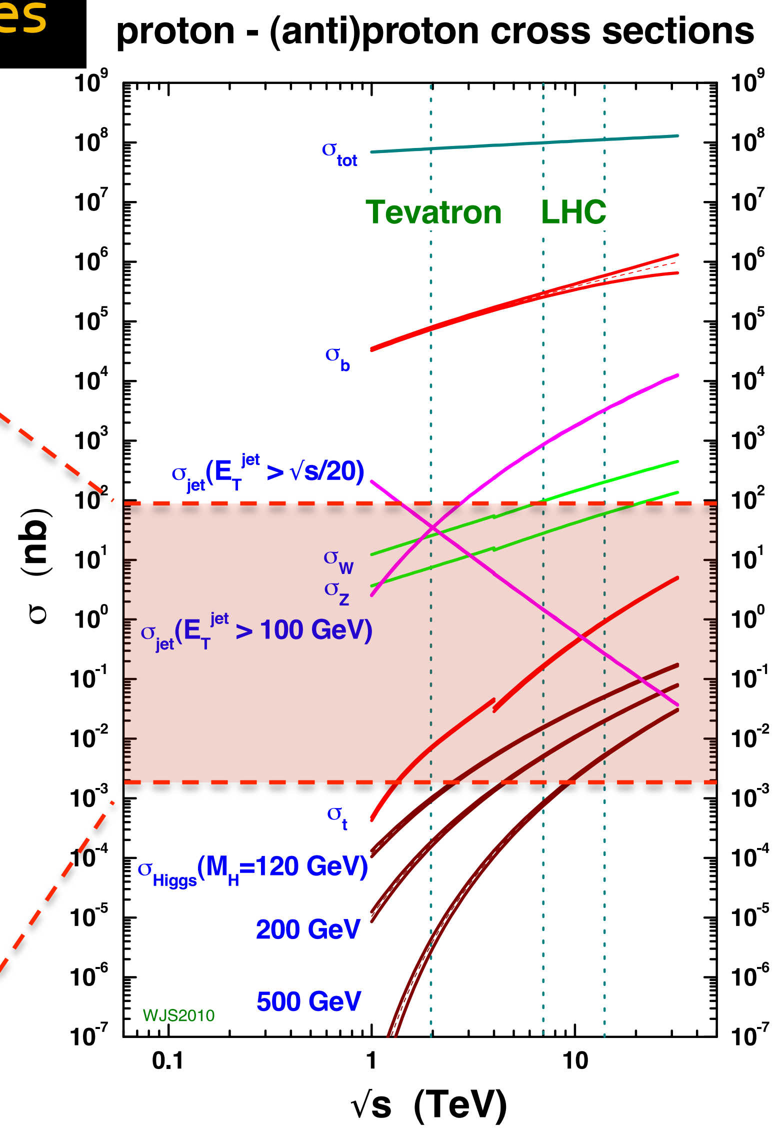
Publications

Overview of electroweak and top processes

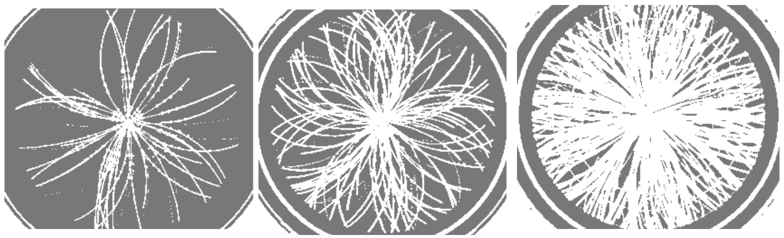
Theory and simulation "Next-to…" revolution :

- NNLO PDFs sets
- Calculations at unprecedented order in perturbation theory
- Parton Shower (and Matrix Element matching) improvements





No PU



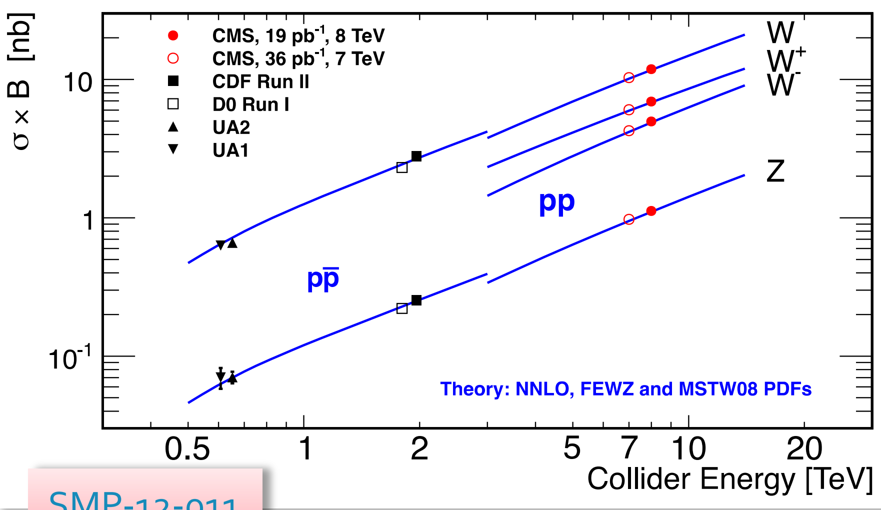
Number of events selected in full 2010-12 dataset

W → lν ~ 100 M
Z→ ll ~ 10 M
tt → l+X ~ 0.4 M (top factory)

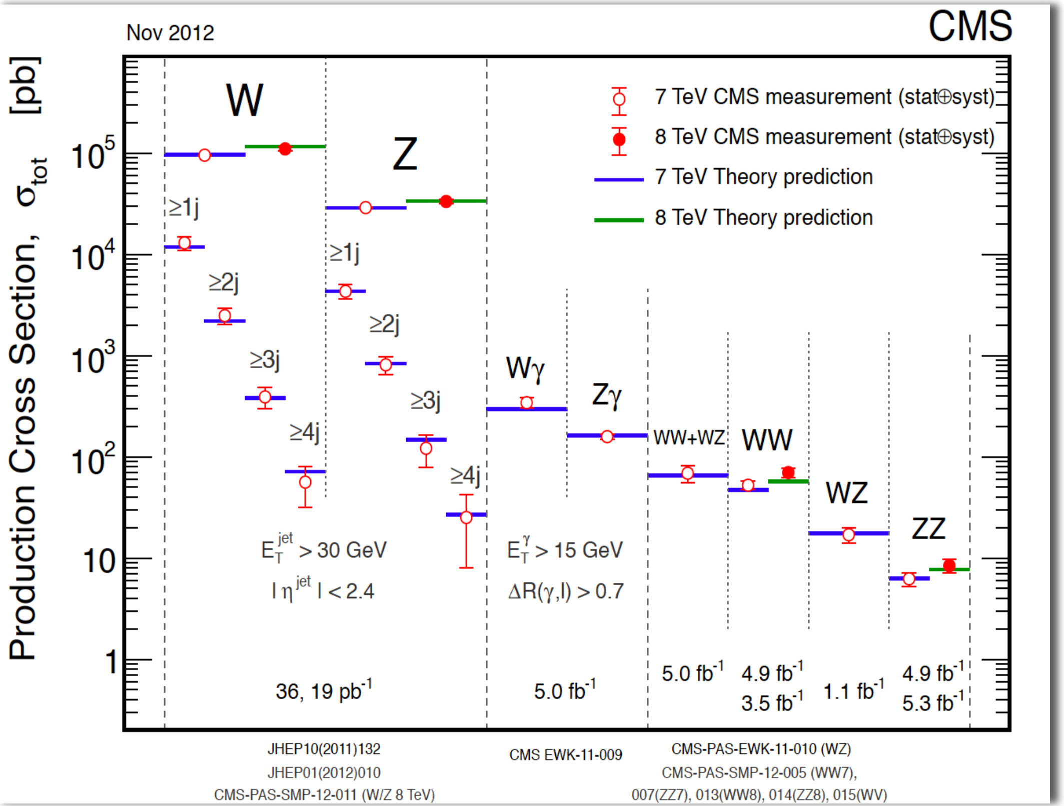
Electroweak Highlights

[SMP-12-013](#)
[SMP-12-014](#)

W, Z, WW and ZZ **cross sections at 8 TeV**
(Special Low pile-up runs used for W,Z at 8 TeV)



[SMP-12-011](#)



$\sigma(pp \rightarrow Wx) \times Br(W \rightarrow l\,\nu) = 11.88 \pm 0.56$ nb
$\sigma(pp \rightarrow Zx) \times Br(Z \rightarrow l^+ l^-) = 1.12 \pm 0.05$ nb
Predicted increase of the cross sections with energy is confirmed by measurements

8 TeV

Measured σ (ZZ) = 8.4 ± 1.3 pb
SM (NLO) σ (ZZ) = 7.7 ± 0.4 pb
Measured σ (WW) = 69.9 ± 7.0 pb
SM (NLO) σ (WW) = 57.3 ± 2.0 pb

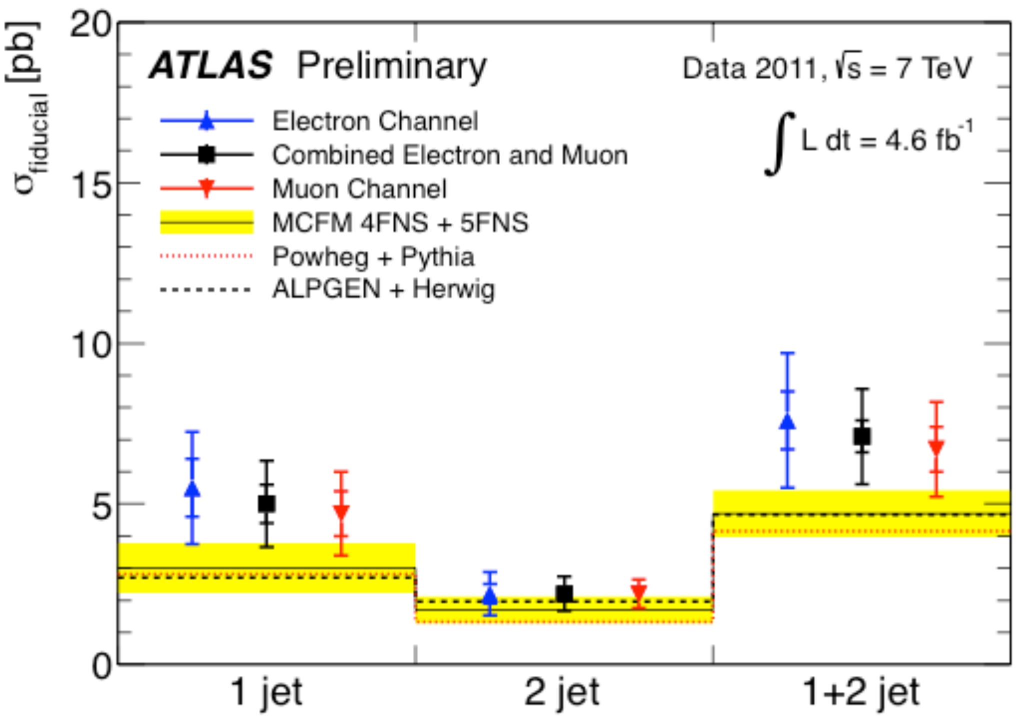
Excellent understanding of the Standard Model at 7,8 TeV…

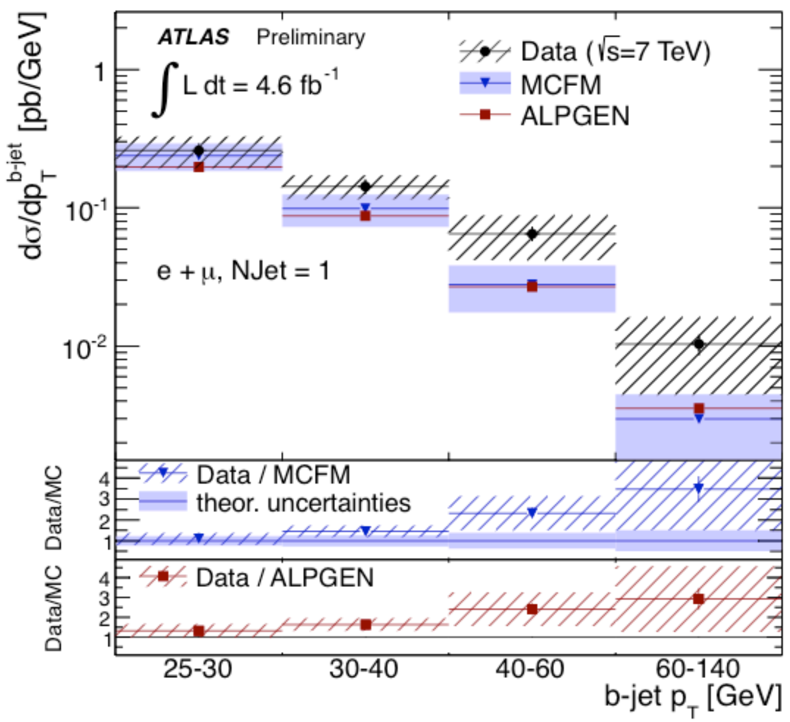
Electroweak highlights — differential x-sns

Large statistics allows precise tests of generators/theory, PDFs and bkgd to searches

ATLAS-CONF-2012-156

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





Fiducial cross section within 1.5σ of theory prediction

p_T spectrum harder in data, but compatible within uncertainties with generators

EW dibosons — WW, WZ, ZZ, Wγ, Zγ, γγ

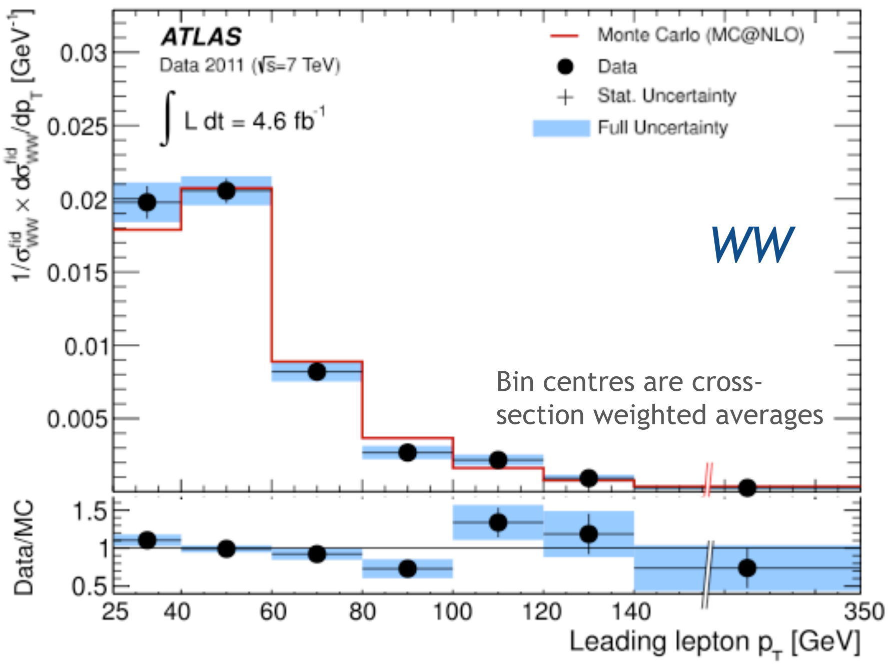
Total, fiducial & differential diboson cross-sections measurements

Measured 11 diboson fiducial cross-sections: most are slightly above theory expectation (but sys. and theory errors correlated)

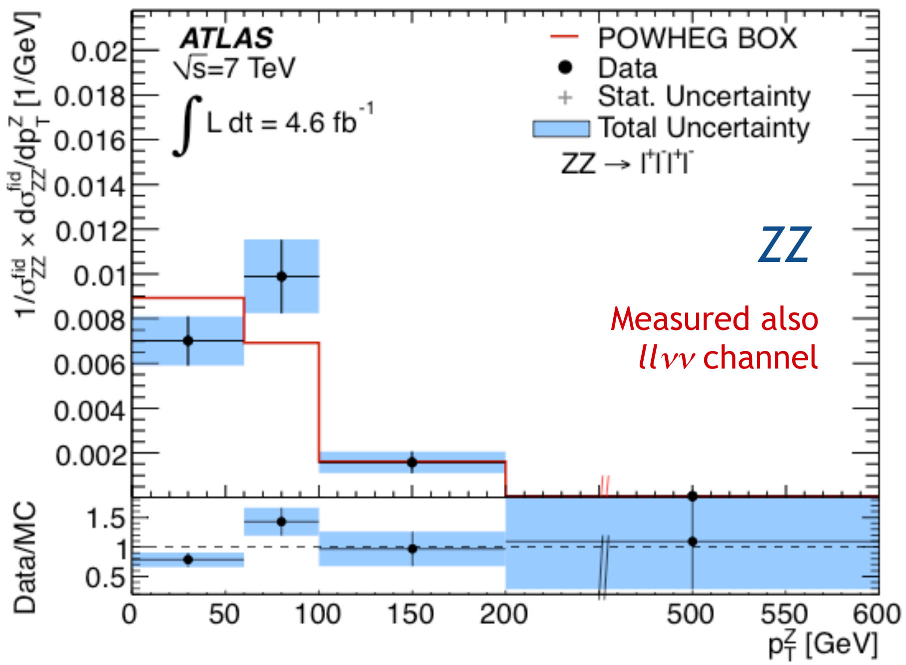
1210.2979, 1208.1390, 1211.6096

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

Normalised fiducial differential cross-section (→ unfolded)



Normalised fiducial differential cross-section



So far, satisfying agreement with NLO generators, also for mass spectra. Same for *WZ*

Also searched for diboson resonance production (*ZZ* [8 TeV, ATLAS-CONF-2012-150], *Wγ*, *Zγ*)

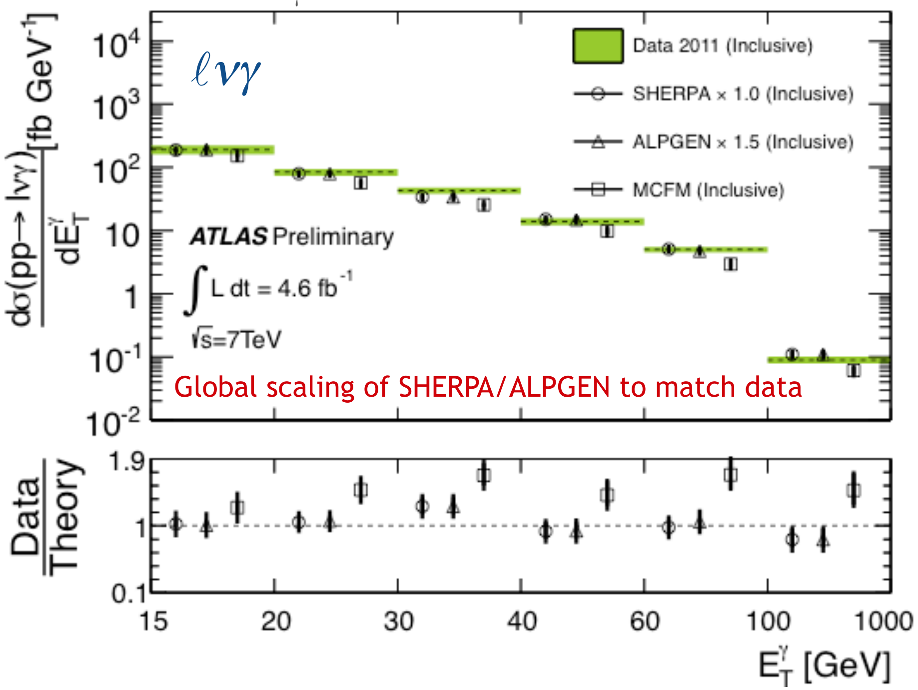
EW dibosons — WW, WZ, ZZ, Wγ, Zγ, γγ

Total, fiducial & differential diboson cross-sections measurements

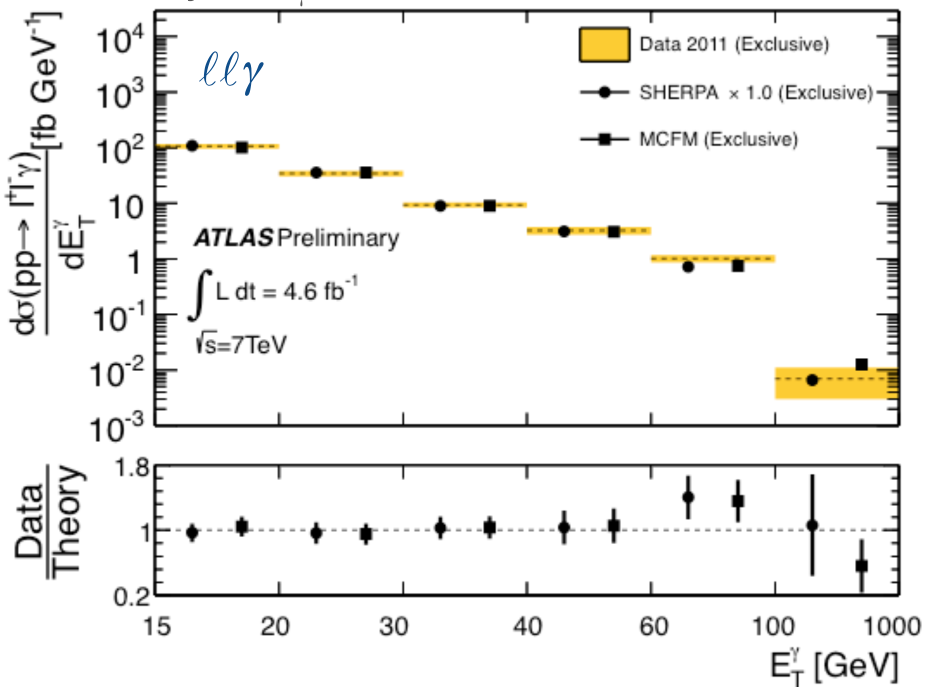
Measured 11 diboson fiducial cross-sections: most are slightly above theory expectation (but syst. and theo. errors correlated)

Examples for differential cross section measurements: $W\gamma$, $Z\gamma$ (7 TeV, 4.6 fb^{-1})

Inclusive E_γ fiducial differential cross-section

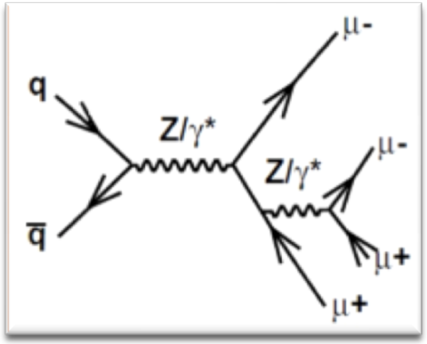


N-jet = 0 E_γ fiducial differential cross-section

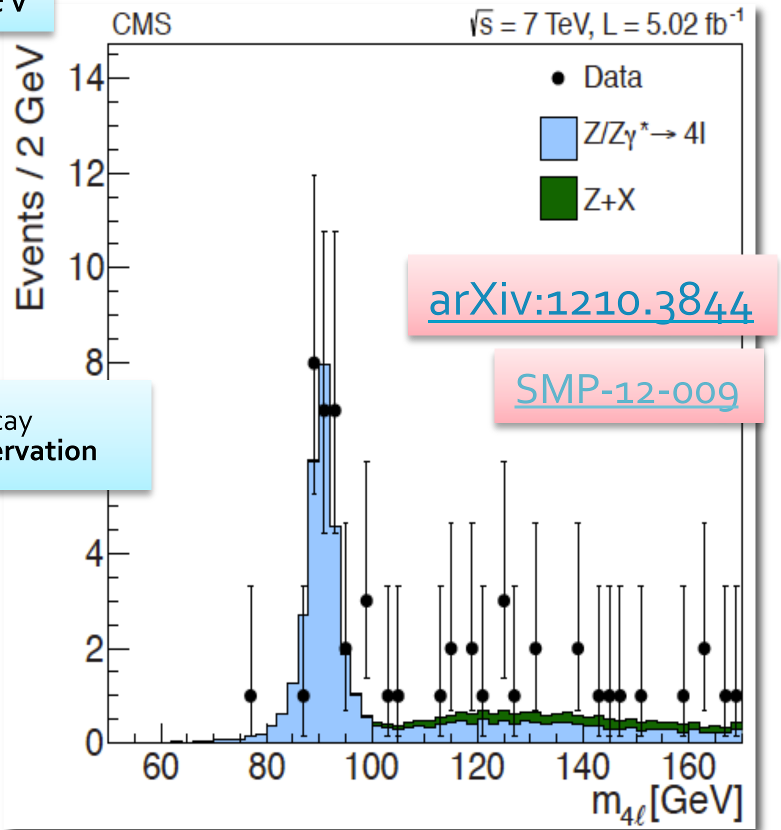


Too low incl. cross-section by MCFM (NLO, parton-level). Scaled ALPGEN/SHERPA (LO) with multiple quark/gluon emission in ME more accurate → Similar for $\gamma\gamma$ [1211.1913]

Electroweak Highlights



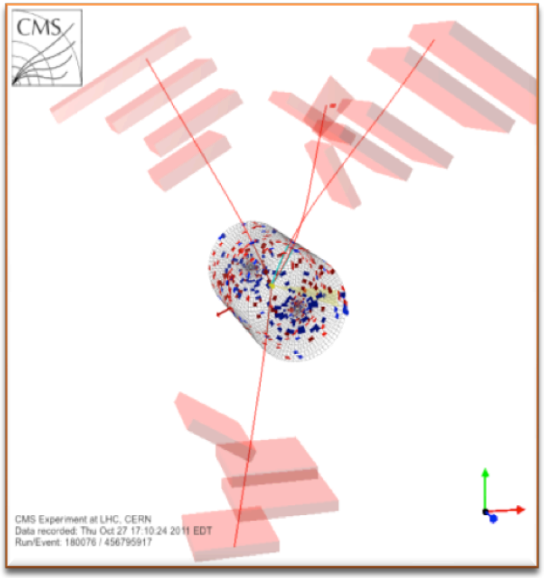
7 TeV



arXiv:1210.3844

SMP-12-009

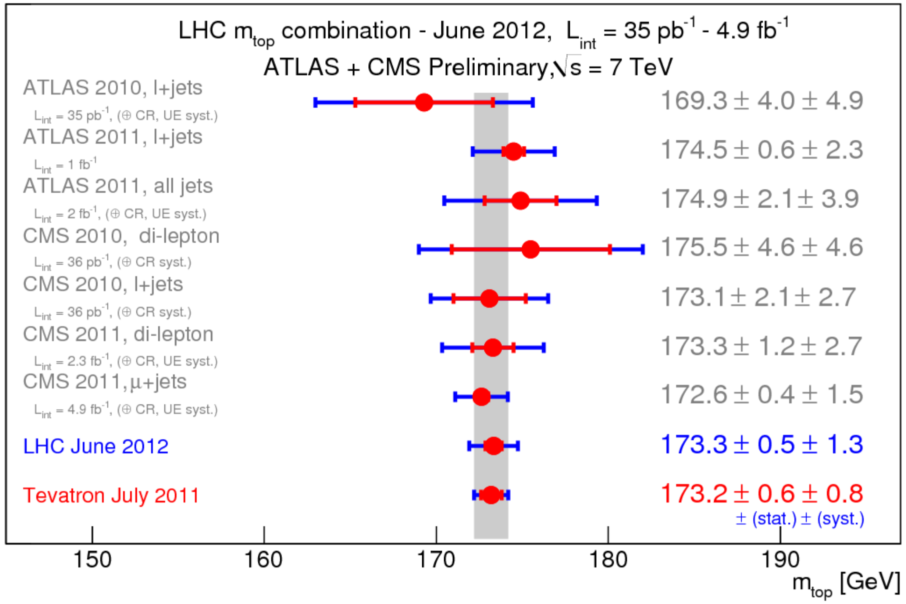
Z−> 4l decay
9.7 σ **observation**

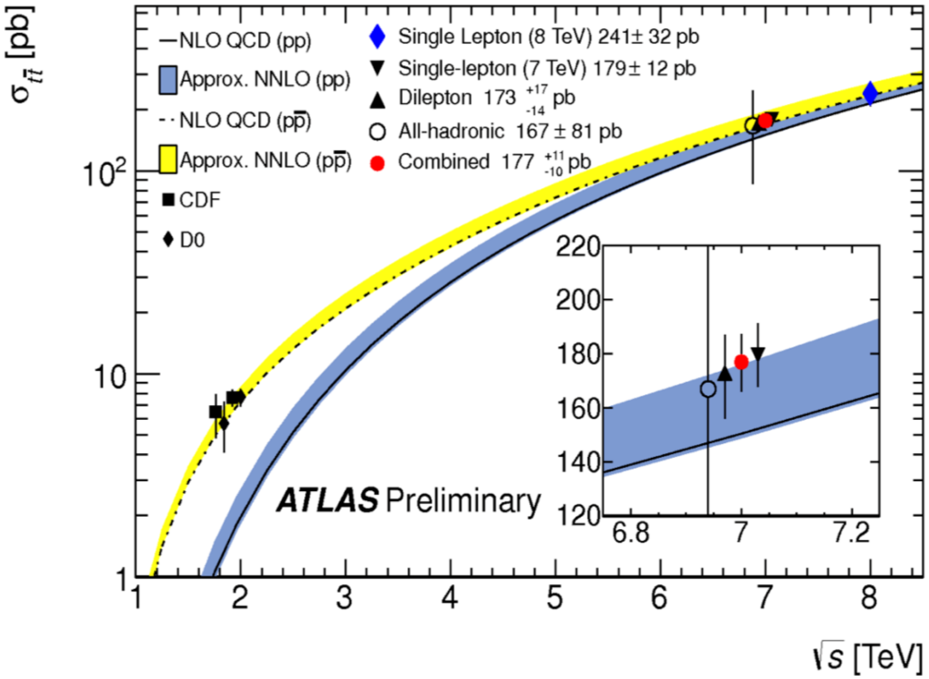


Final state channels	4e	4μ	$2e2\mu$	4ℓ
Irreducible background ($pp \to Z\gamma^* \to 4\ell$)	0.07	0.25	0.14	0.46 ± 0.05
Other (reducible) backgrounds	0.01	0.01	0.05	0.07 ± 0.1
Expected signal ($pp \to Z \to 4\ell$)	3.8	13.6	12.0	29.4 ± 2.6
Total expected (simulation)	3.9	13.9	12.2	30.0 ± 2.6
Observed events	2	14	12	28
Yield from fit to the observed mass distribution	-	13.6 ± 3.8	11.5 ± 3.1	27.3 ± 5.4

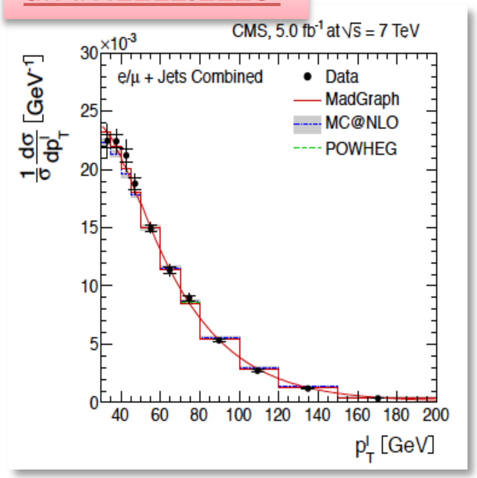
- Cross-check of Higgs mass calibration
  - Use Z−> 4l to understand the mass of 4 leptons for H −>ZZ−> 4l
  - Gives up to 10x more events
  - Low lepton p_T down to ~1 GeV

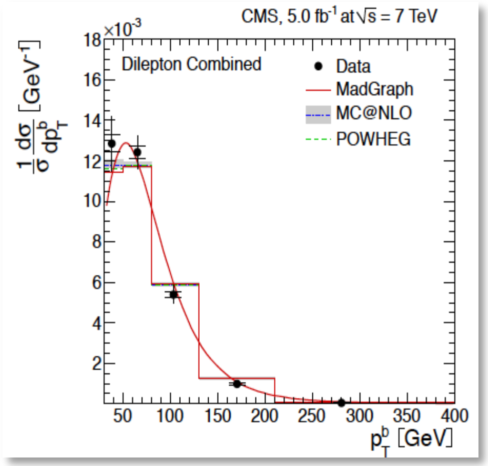
Top Highlights

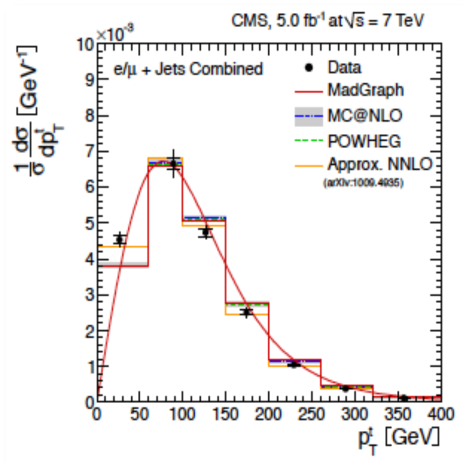


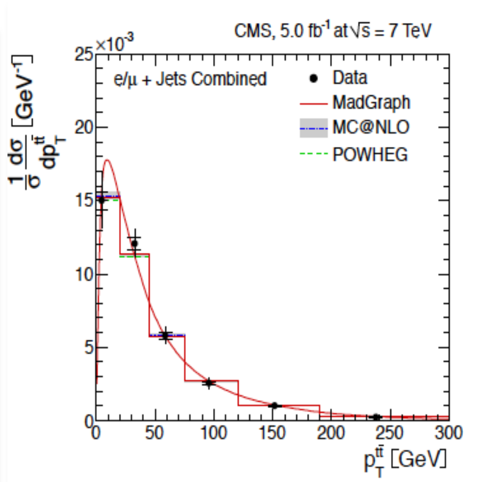


arXiv:1211.2220

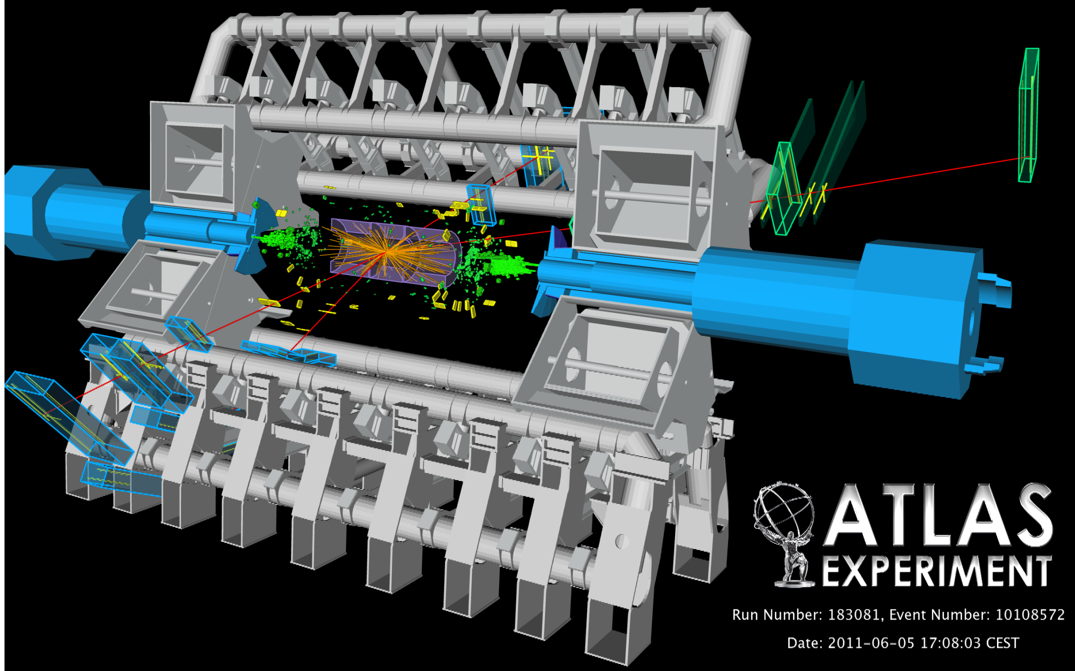


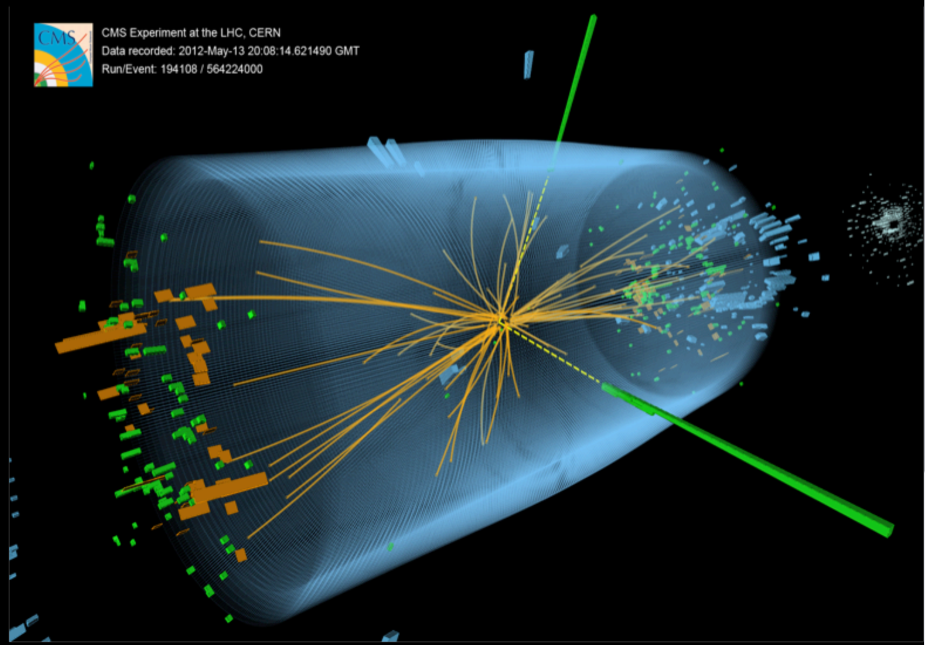






Differential σ_{tt} as function of the kinematic properties: good agreement Data vs MC





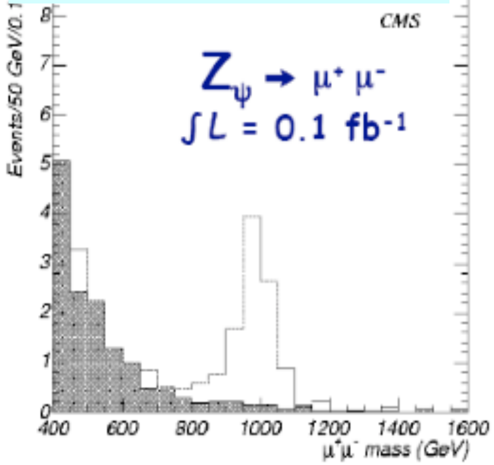
Searching for anosmalies

KEEP
CALM
AND
BARYON

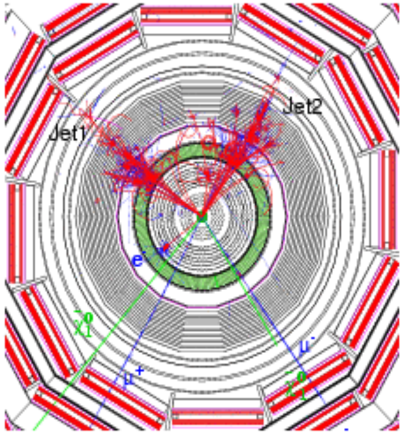
www.decayfilm.com

Anomalies beyond the Standard Model?

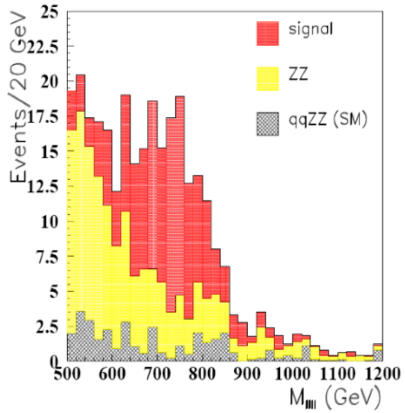
New Gauge Bosons



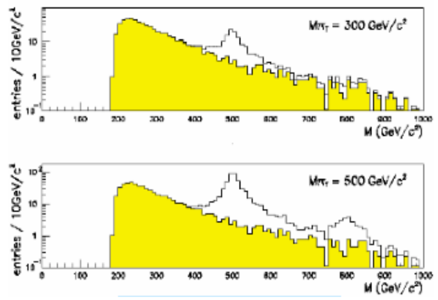
Supersymmetry



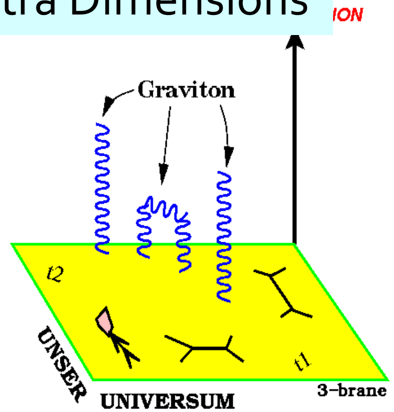
ZZ/WW resonances



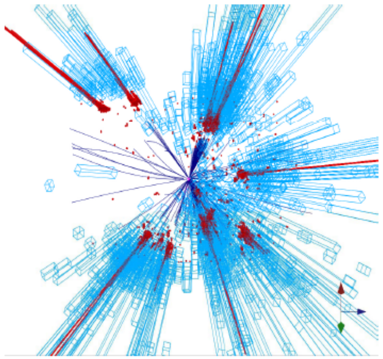
Technicolor



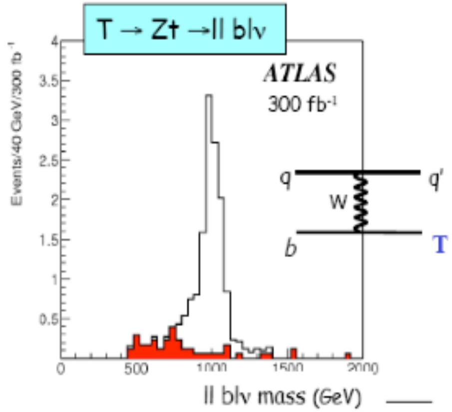
Extra Dimensions



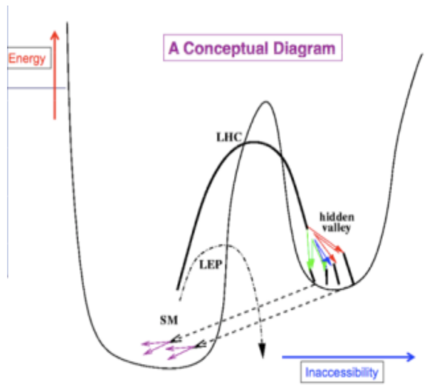
Black Holes



Little Higgs



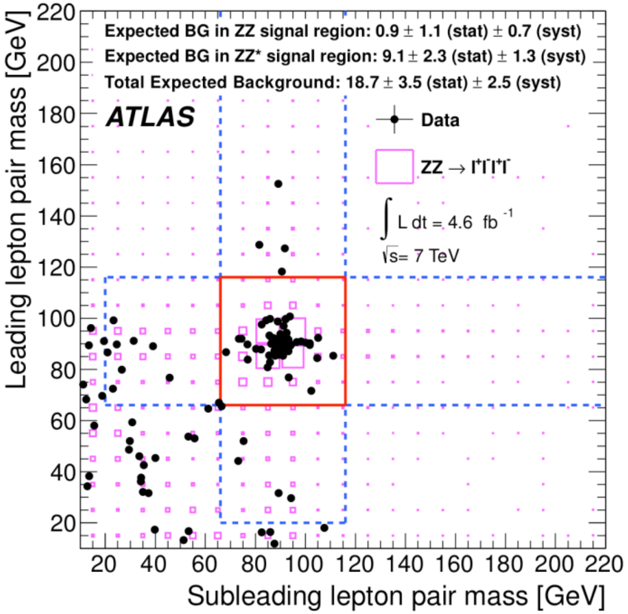
Hidden Valleys



A large variety of possible signals

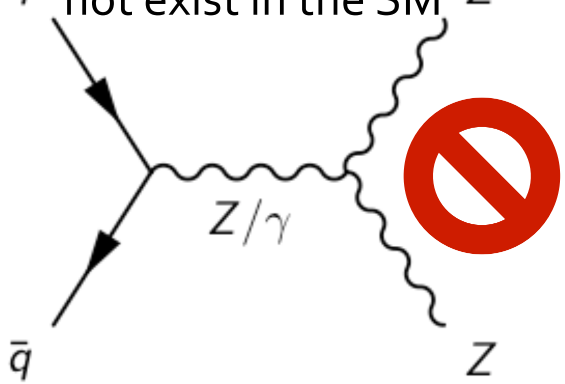
ZZ anomalous gauge couplings

arXiv: 1211.6096

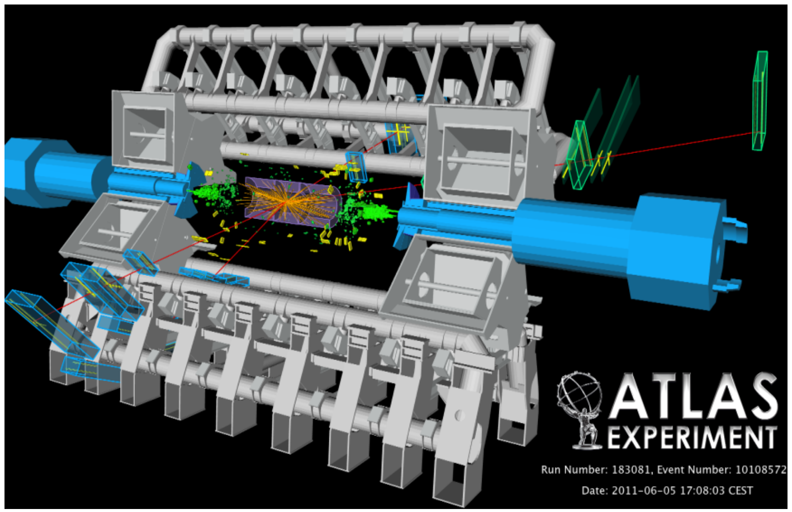


Only three parameters - G_F, α and $\sin^2(\theta_W)$ - determine all couplings

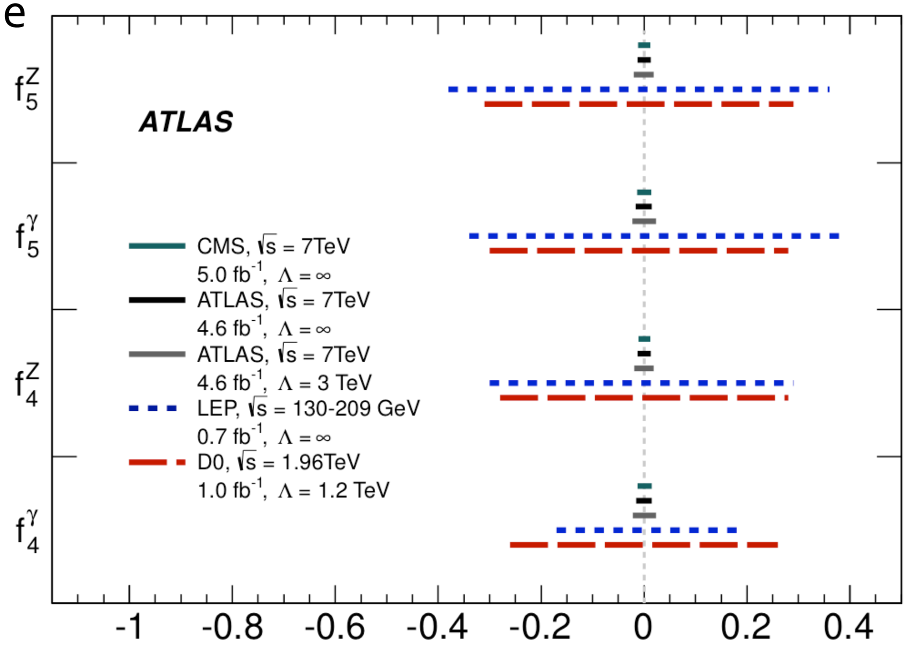
ZZZ and ZZγ TGC vertices do not exist in the SM



New ATLAS and CMS limits improve earlier limits by an order of magnitude



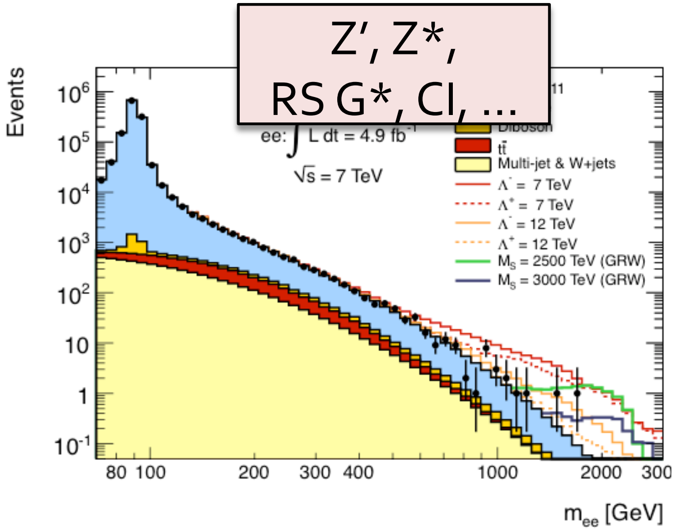
A $ZZ^*\rightarrow4\mu$ event $m_{Z,1}$=90.6 GeV, $m_{Z^*,2}$=47.4 GeV ($m_{4\mu}$=143.5 GeV)

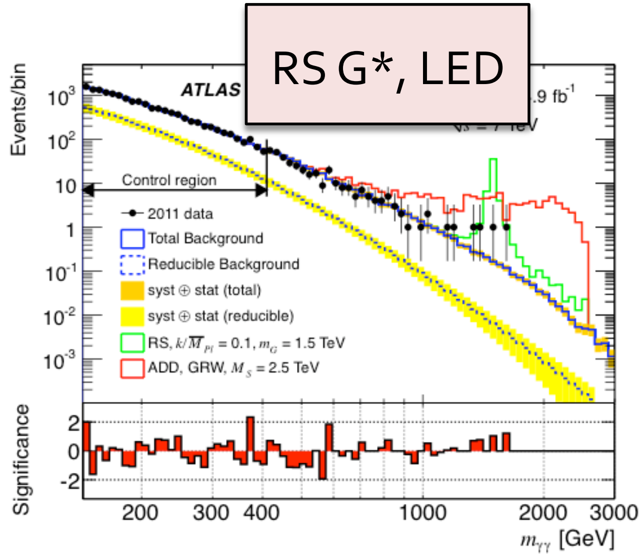


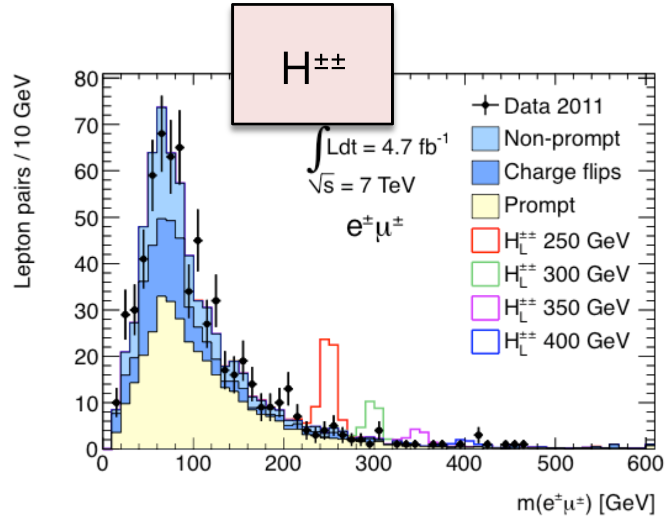
Similarly limits on anomalous TGCs in WZ

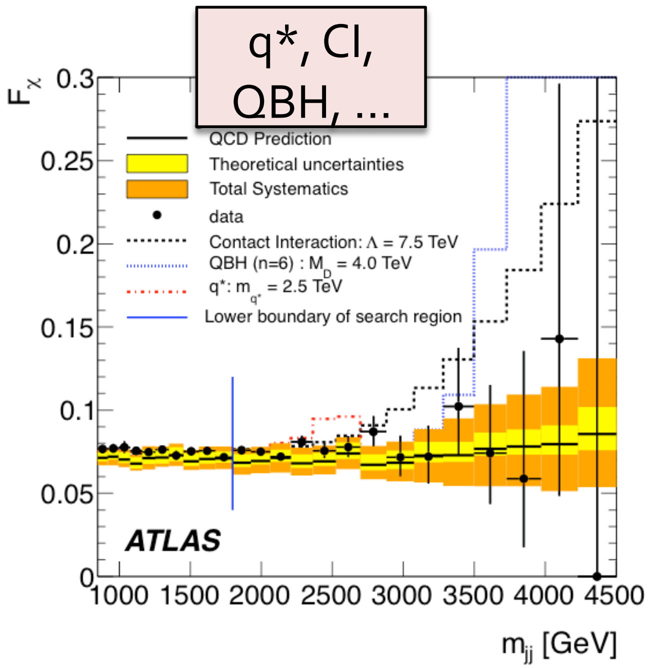
Among 7 TeV results..

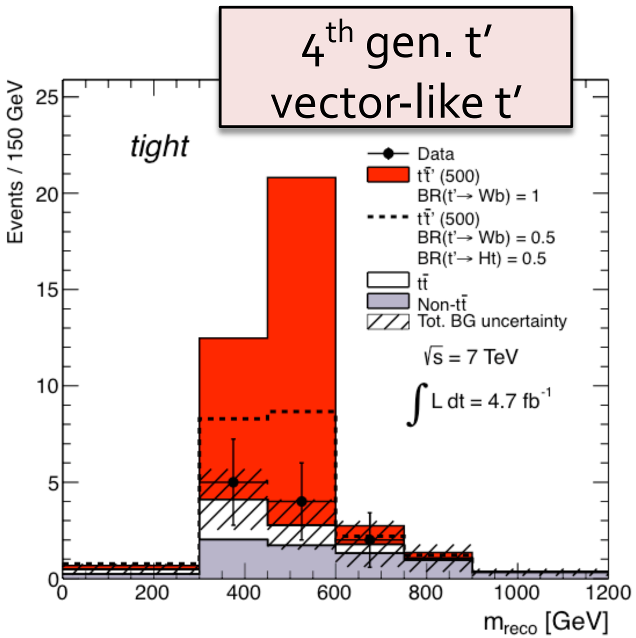
More on next slides

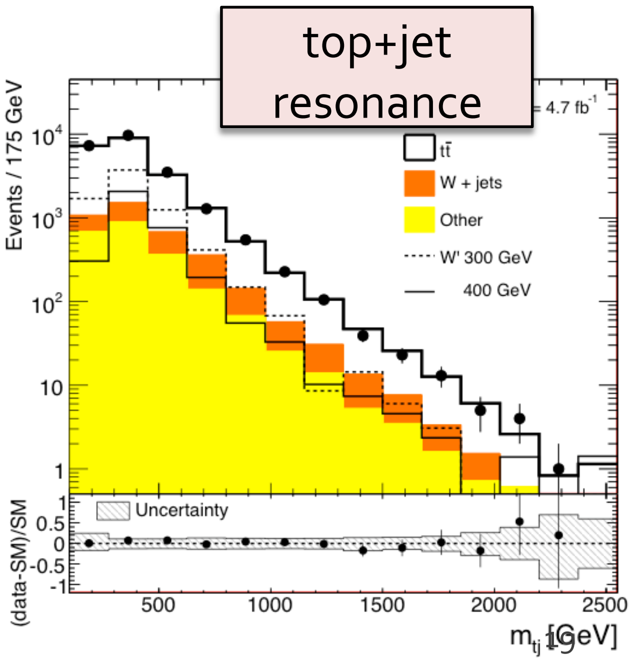




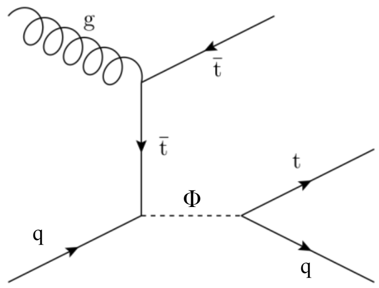








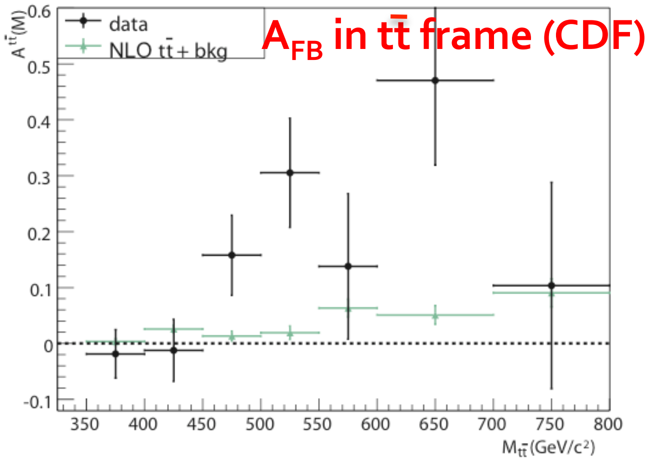
top+jet resonance in $t\bar{t}$+jet events

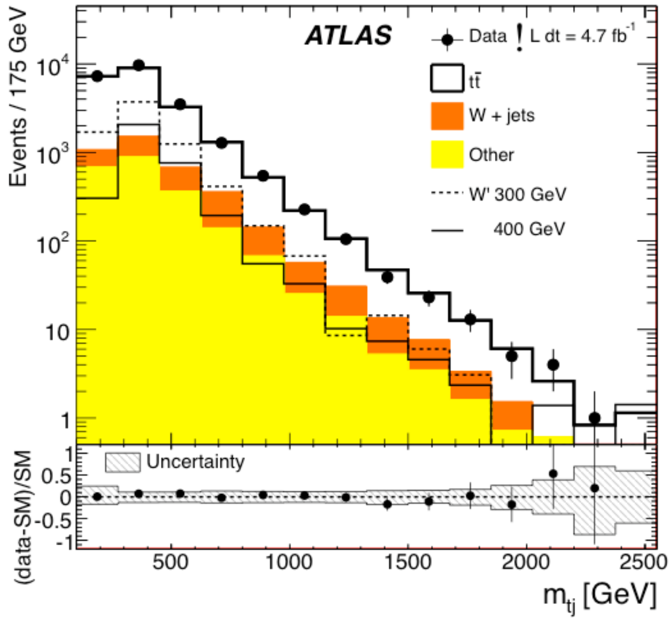


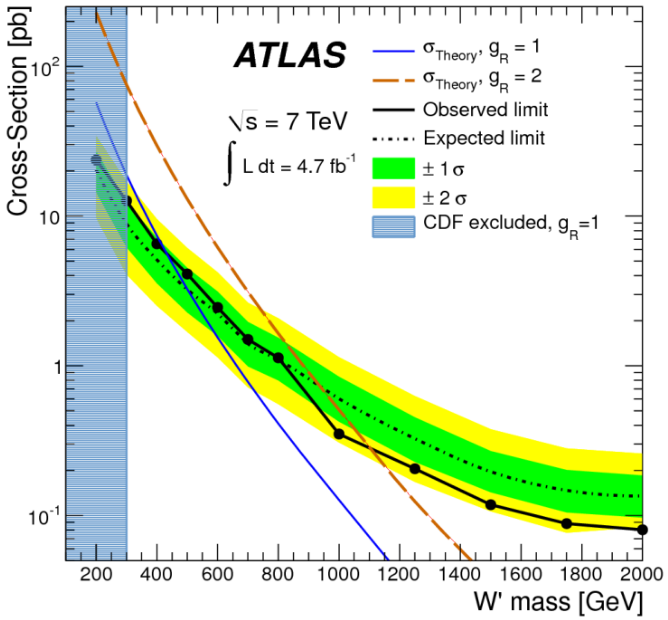
Latest CDF measurement of $t\bar{t}$ A_{FB} shows a 3.4σ deviation.
No direct comparison possible at pp colliders, but expect effects in top+jet
[ATLAS 1 fb^{-1} 7 TeV $t\bar{t}$ A_c: data consistent with MC@NLO]

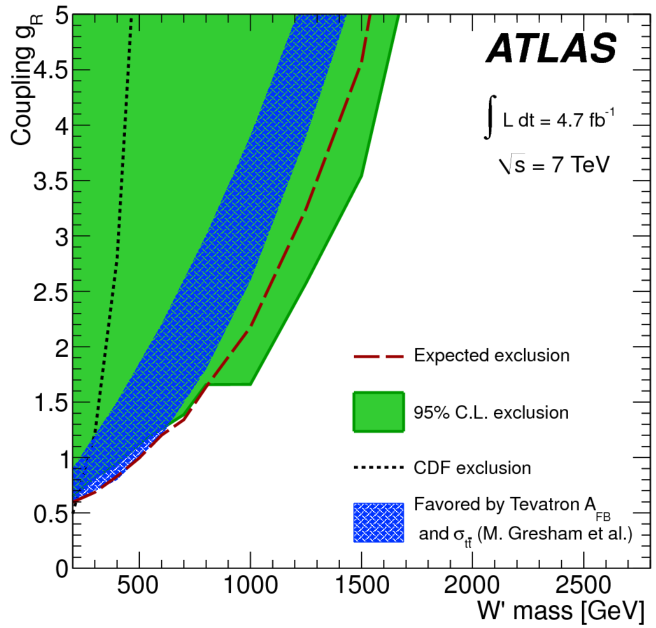
Change in $t\bar{t}$+jet contribution can affect A_{FB}: W' -> tq, Φ -> tq.

Signal region in [m_{tj} , $m_{\bar{t}j}$] plane (asymmetric).



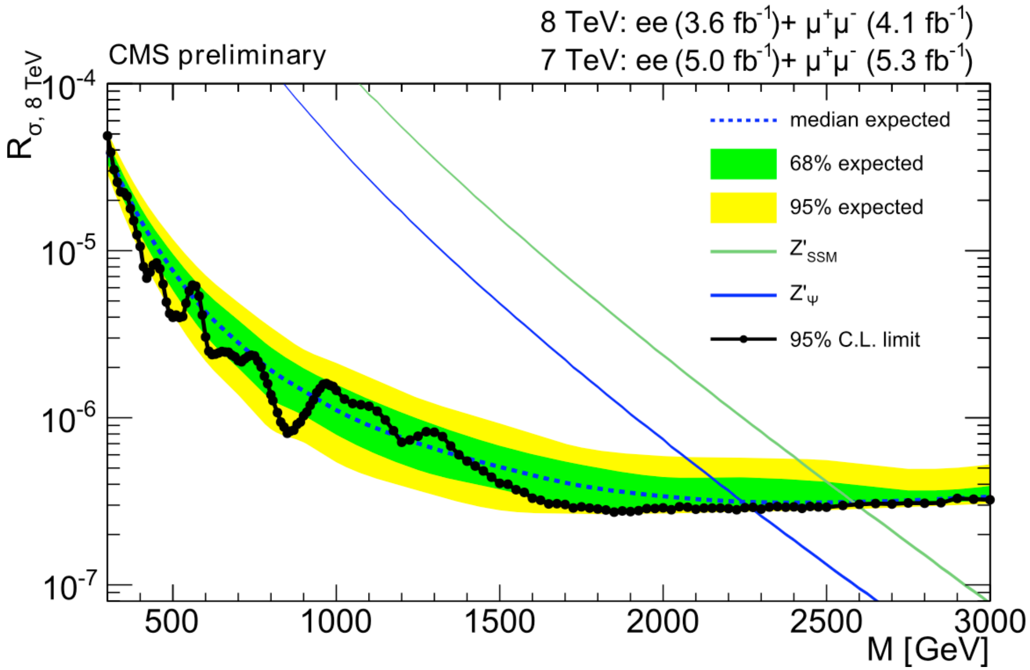


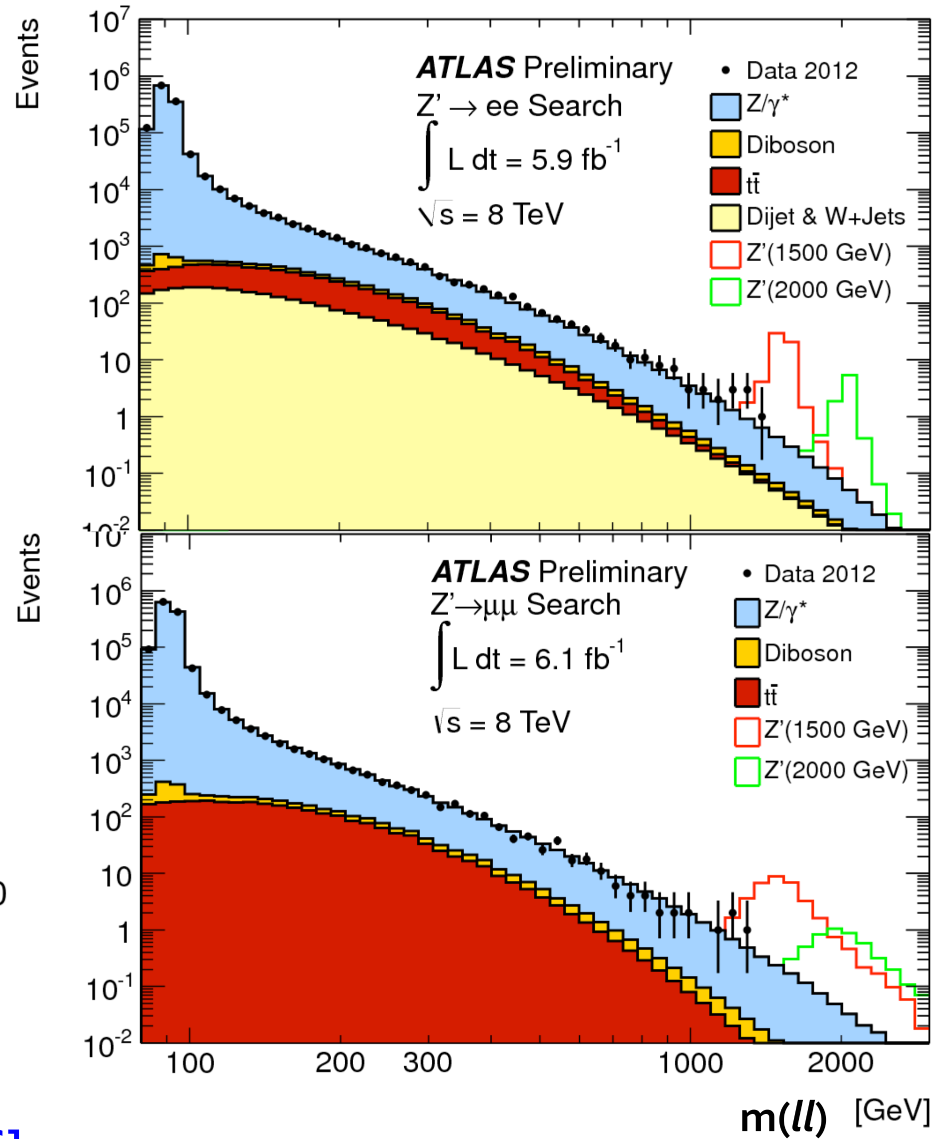




Z' → ee, μμ

- First 8 TeV results on Z' → ee, μμ are available from both
  CMS [4 fb^{-1}, EXO-12-015] and
  ATLAS [6 fb^{-1}, CONF-2012-129]





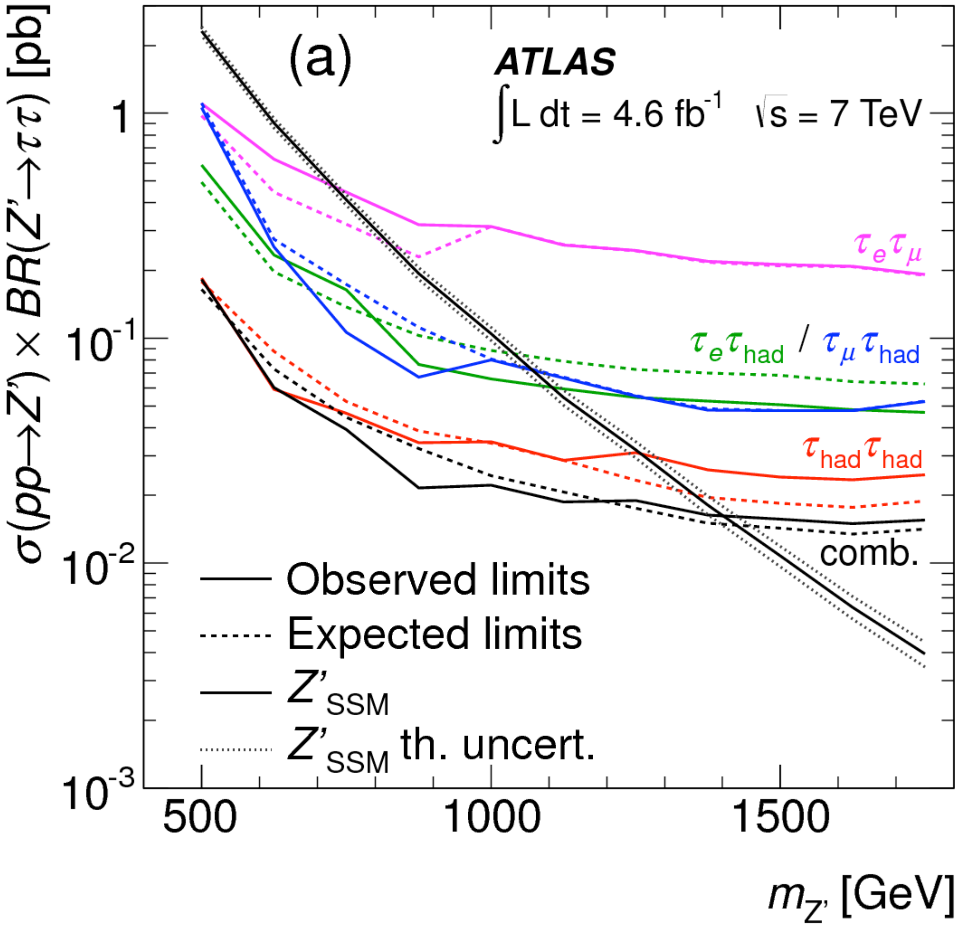
- Example 95% CL Limits :

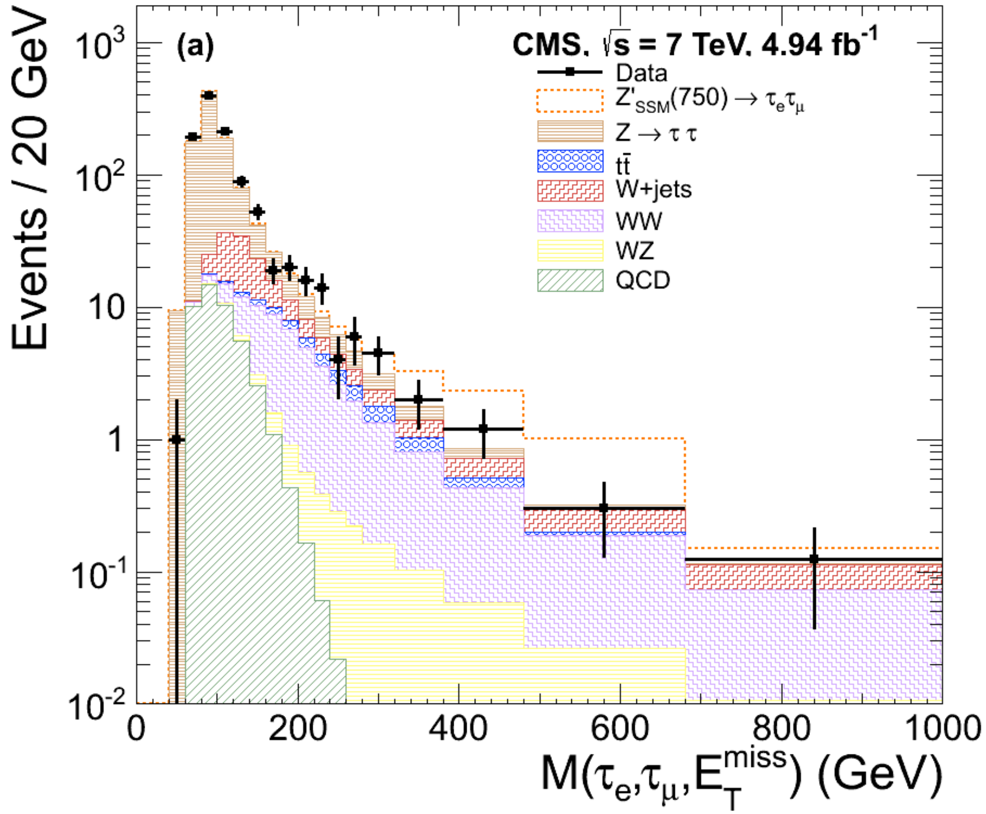
  m(SSM Z') > 2.59 TeV [CMS]

  > 2.49 TeV [ATLAS]

Z' → ττ

- Both ATLAS/CMS have results for full 2011 dataset (5 fb^{-1} @ 7 TeV)
  - Analyses combine e+μ, e+h, μ+h, and h+h channels



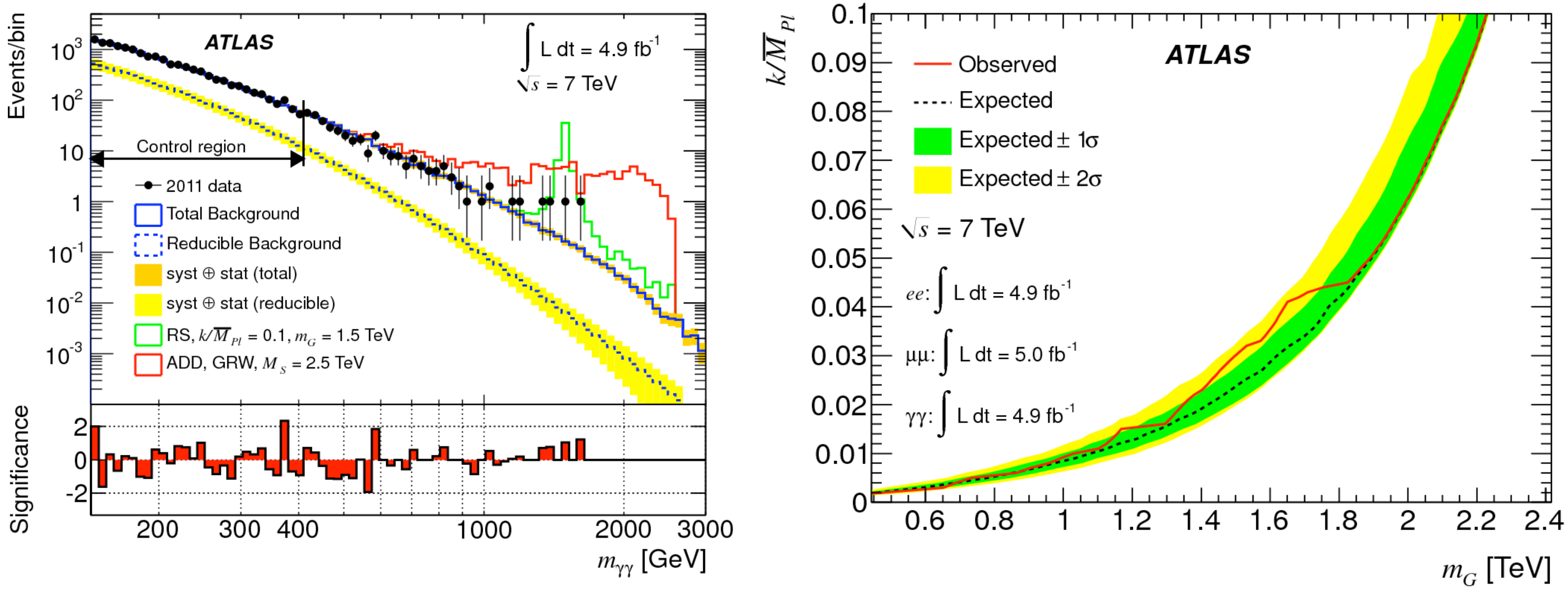


- 95% CL Limits (5 fb^{-1} @ 7 TeV):
  m(SSM Z') > 1.4 TeV [CMS]
  > 1.3 TeV [ATLAS]

ATLAS arXiv:1210.6604
CMS PLB 07, 062 (2012)

Randall-Sundrum G → γγ

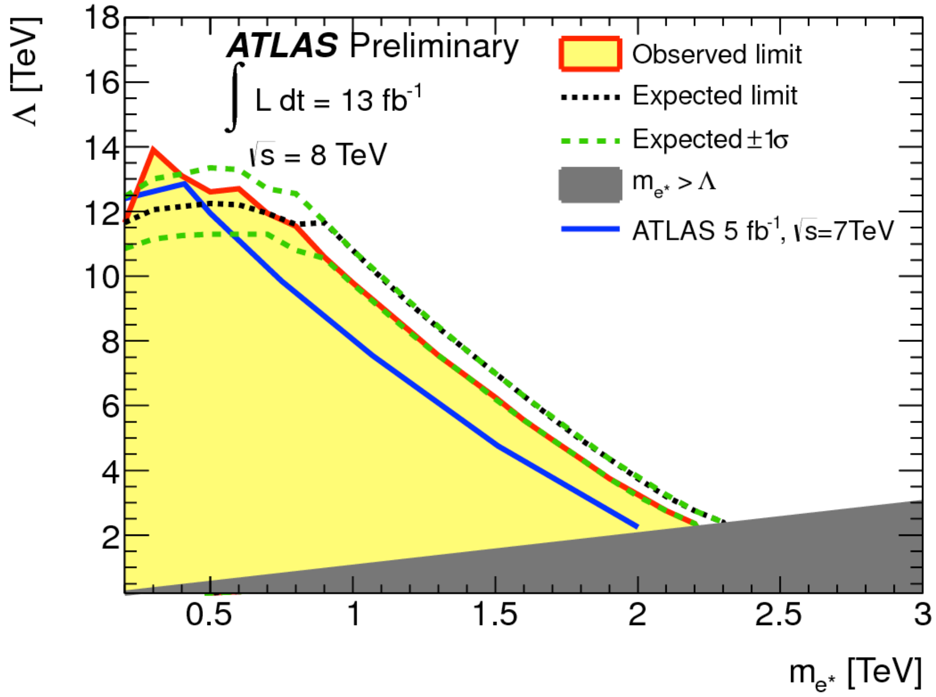
- In a similar way, the high mass tail of the diphoton mass spectrum can be searched for evidence of RS graviton decay
  - γγ has 2x higher BR (and lower bkgd since no DY) than leptonic modes
  - γγ decay would eliminate spin-1 interpretation of any new resonance
- ATLAS and CMS have published γγ results with ~ 2 fb^{-1} @ 7 TeV
  - ATLAS has updated result, combining γγ/ee/μμ for 5 fb^{-1} @ 7 TeV
  - Limits set in plane of dimensionless coupling (k/M_{PL}) versus m(G)

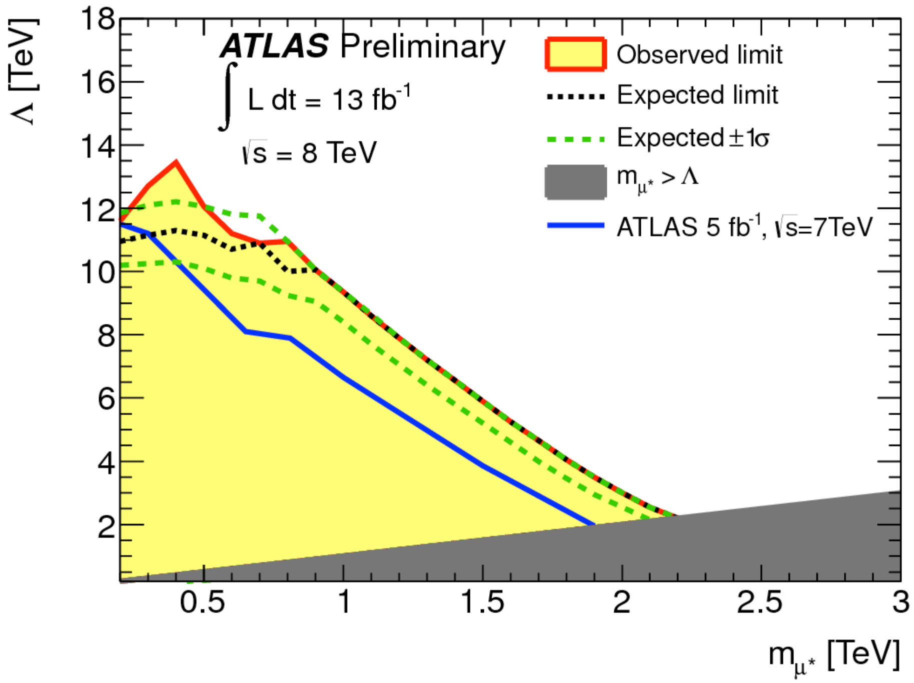


m(RS G) > 2.23 TeV (for k/M_{PL} = 0.10) @ 95% CL **ATLAS** (arXiv:1210.8389)

Excited Leptons

- Excited lepton production depends on the compositeness scale, Λ
- ATLAS (CONF-2012-008) and CMS (arXiv:1210.2422) both have limits using full 2011 dataset (5 fb^{-1} @ 7 TeV)
  - Shown below in Λ vs m(*l**) plane are new ATLAS results using 13 fb^{-1} @ 8 TeV



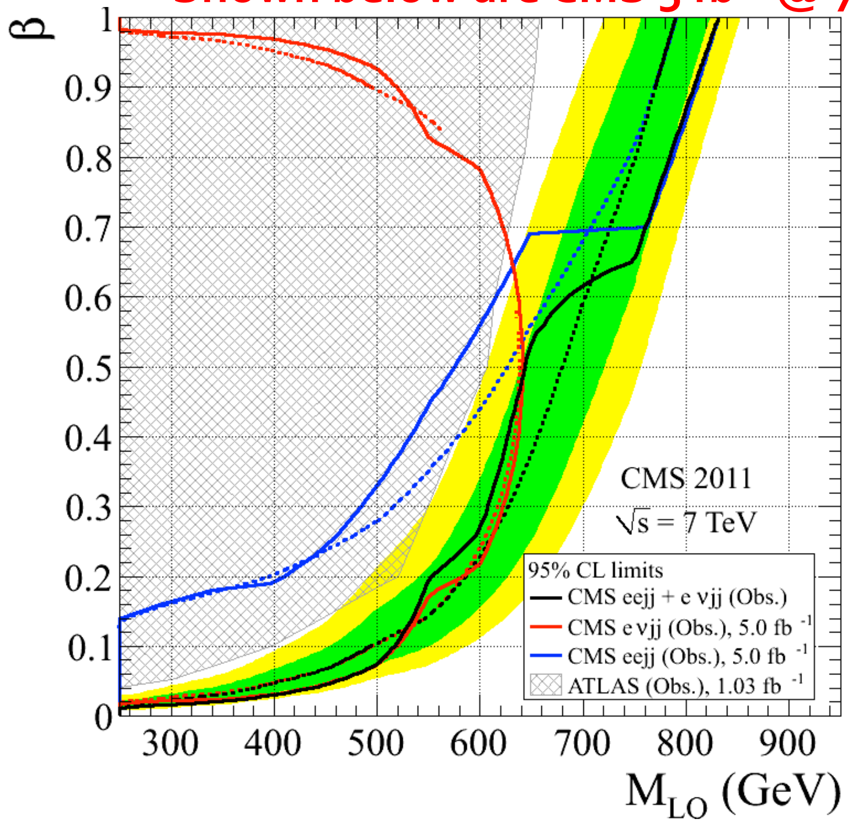


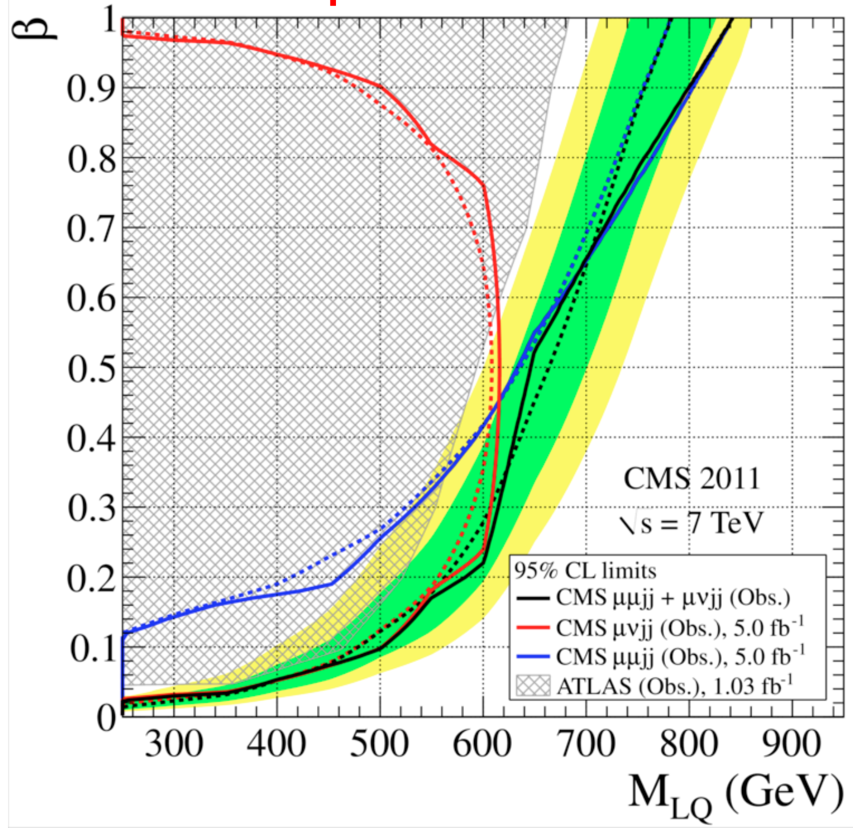
- 95% CL Limits [for Λ = m(*l**)] :

  m(e*) > 2.2 TeV   m(μ*) > 2.2 TeV [ATLAS]   (CONF-2012-146)

Leptoquarks (First and Second Generation)

- Final states of eejj or eνjj (μμjj or μνjj), with weights which depend on β
  - ATLAS has 1 fb^{-1} @ 7 TeV results [PLB 709 (2012) 158; EPJ C72 (2012) 2151]
  - Shown below are CMS 5 fb^{-1} @ 7 TeV results in comparison





- CMS 95% CL limits with 5 fb^{-1} @ 7 TeV :

  m(LQ1) > 830 GeV   for β = 1 [PRD 86, 052013 (2012)]

  m(LQ2) > 840 GeV

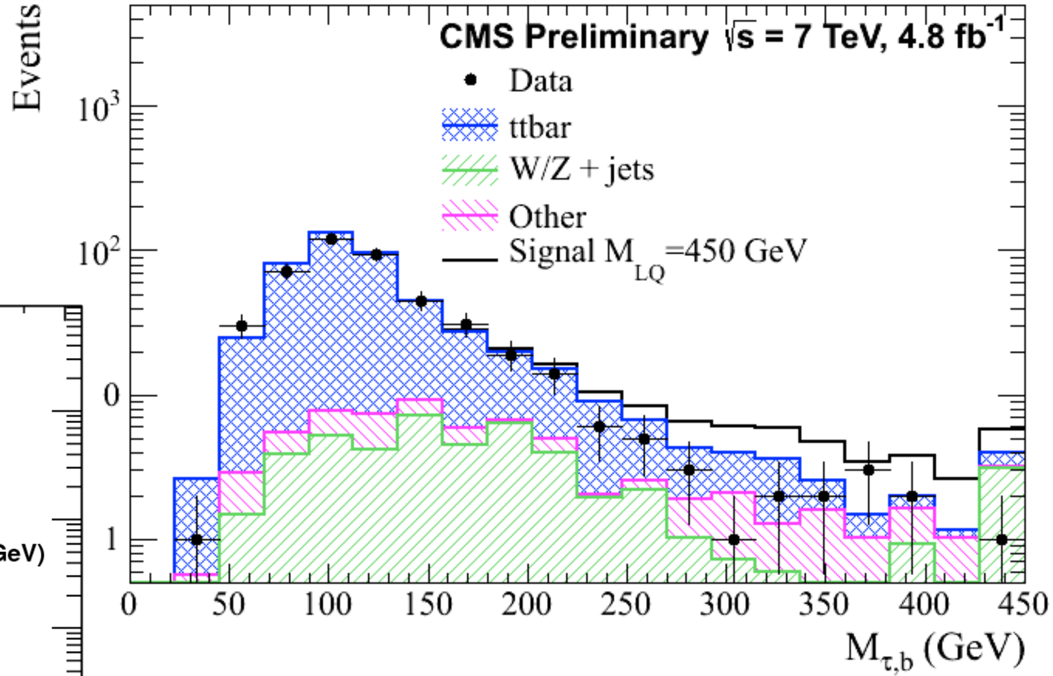
Leptoquarks (Third Generation)

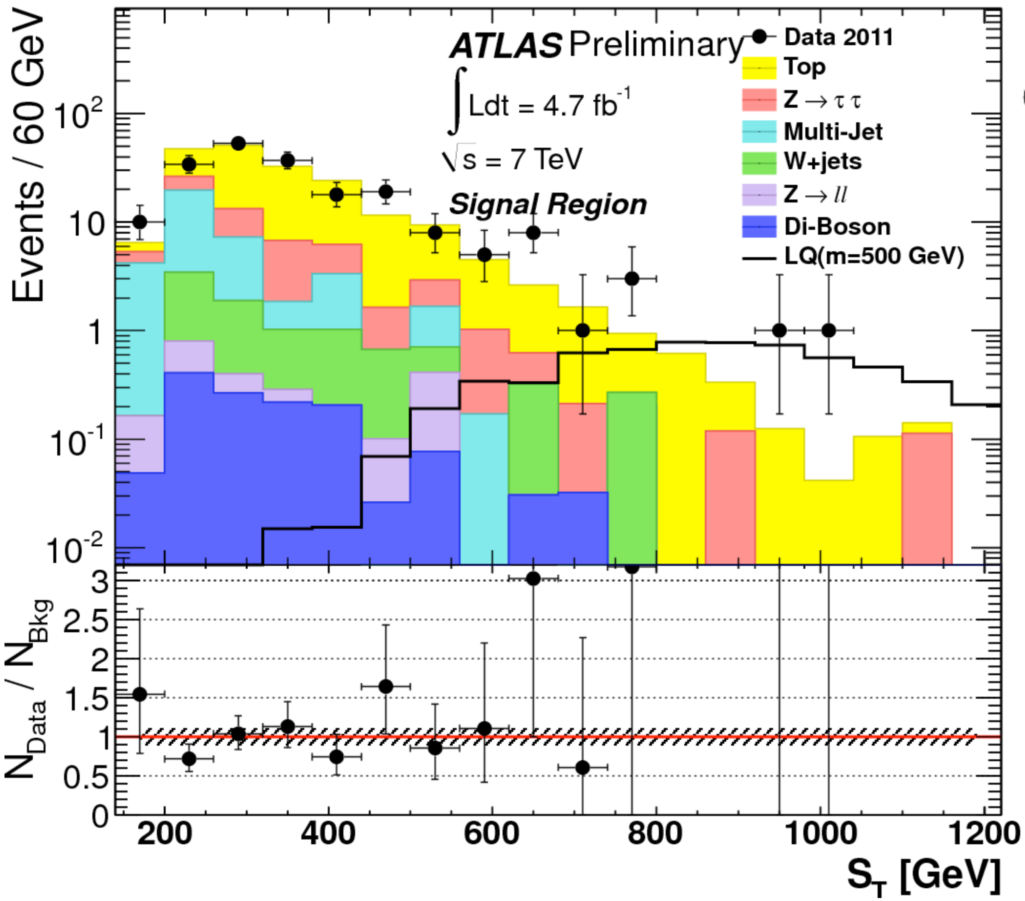
- CMS results with 5 fb^{-1} @ 7 TeV:

  LQ3 → b + τ [arXiv:1210.5629]

  e/μ + h channels

  m(LQ3) > 525 GeV for β = 1





- New ATLAS result, 5 fb^{-1} @ 7 TeV :

  LQ3 → b + τ [EXOT-2012-14]

  e and μ decay channels of the τ

  m(LQ3) > 538 GeV for β = 1

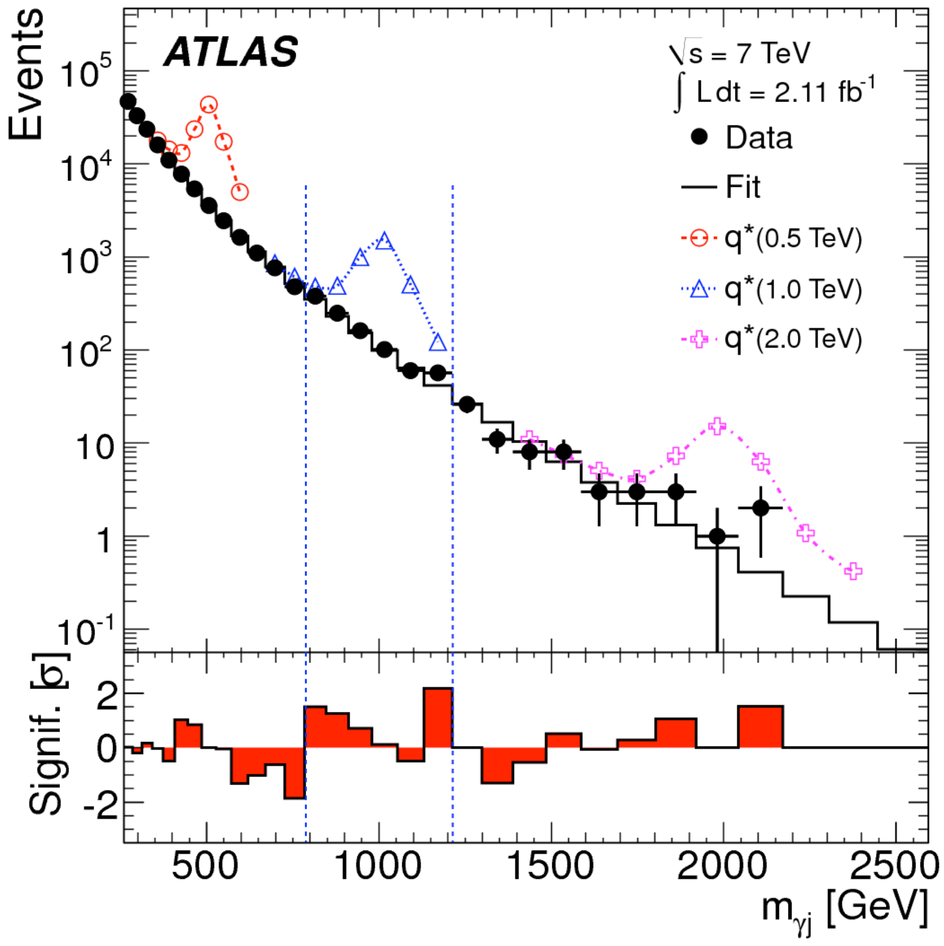
Excited Quarks

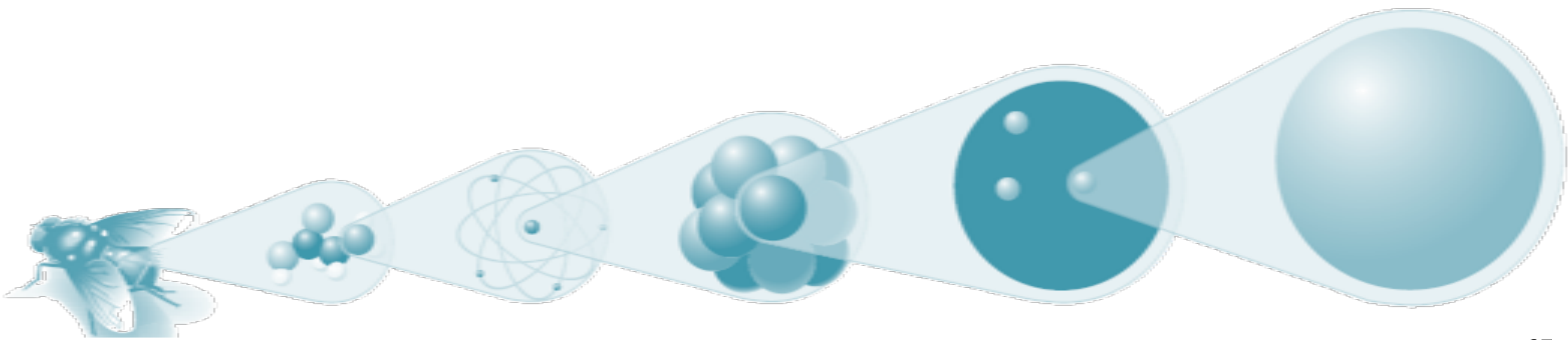
- As for leptons, could have high mass "excited" quarks
  - As for *l**, consider EM decays, i.e. q* → q + γ (jet+photon) resonances

ATLAS result for 2.1 fb^{-1} @ 7 TeV

m(q*) > 2.46 TeV

[PRL 108, 211802 (2012)]

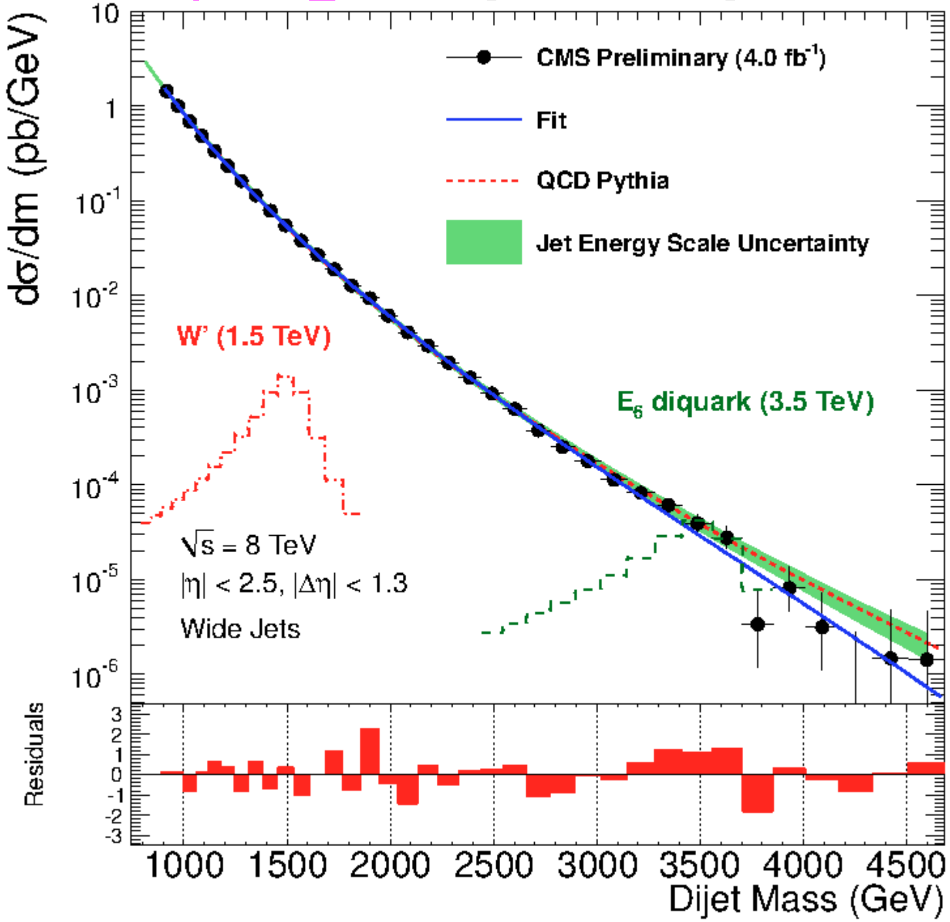




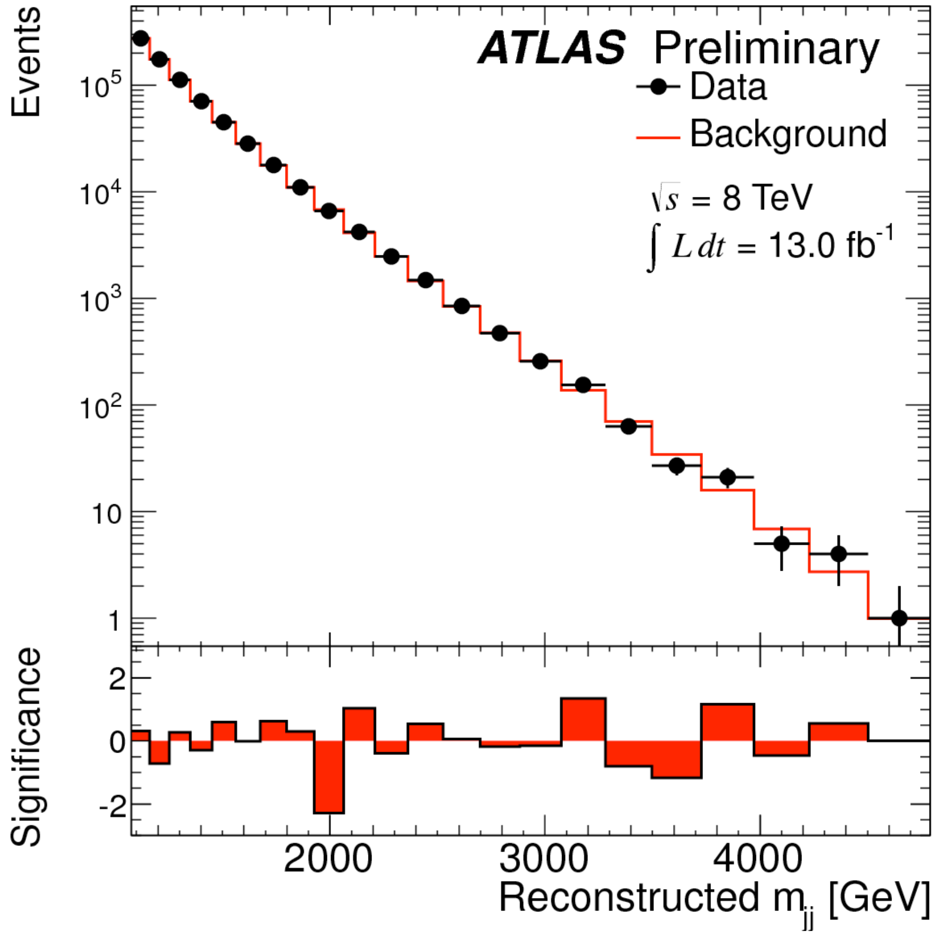
Dijet Resonances

- A variety of BSM models include dijet resonances of various types
  - Both ATLAS/CMS have released search results with 8 TeV data
  - Approaching the limits of phase space

CMS 4 fb^{-1} @ 8 TeV [EXO-12-016]



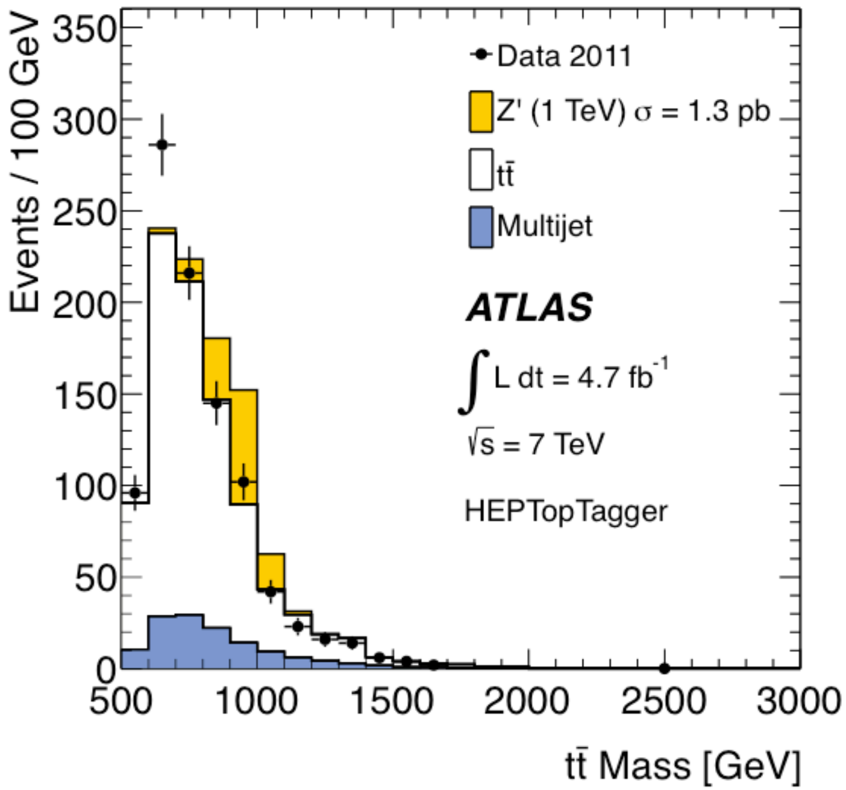
ATLAS 13 fb^{-1} @ 8 TeV [CONF-2012-148]

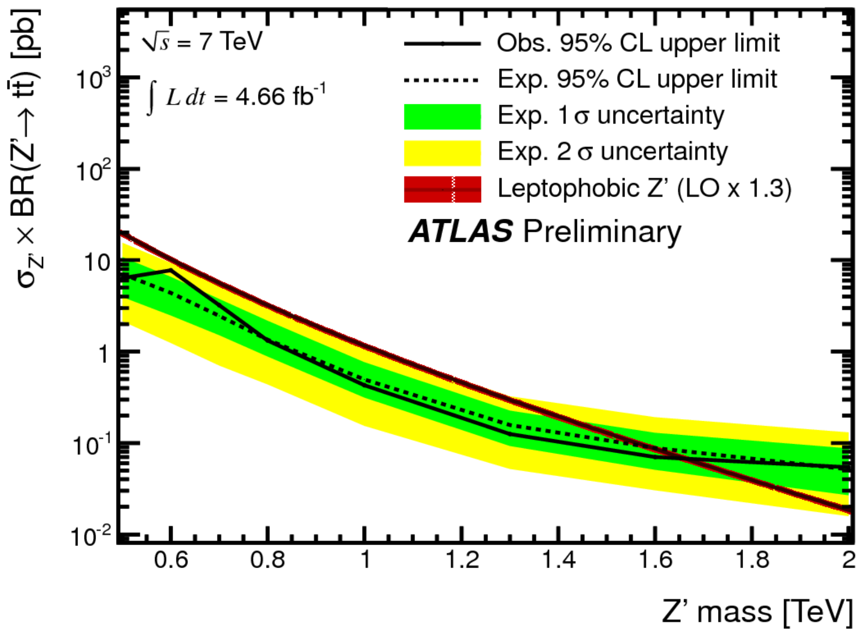


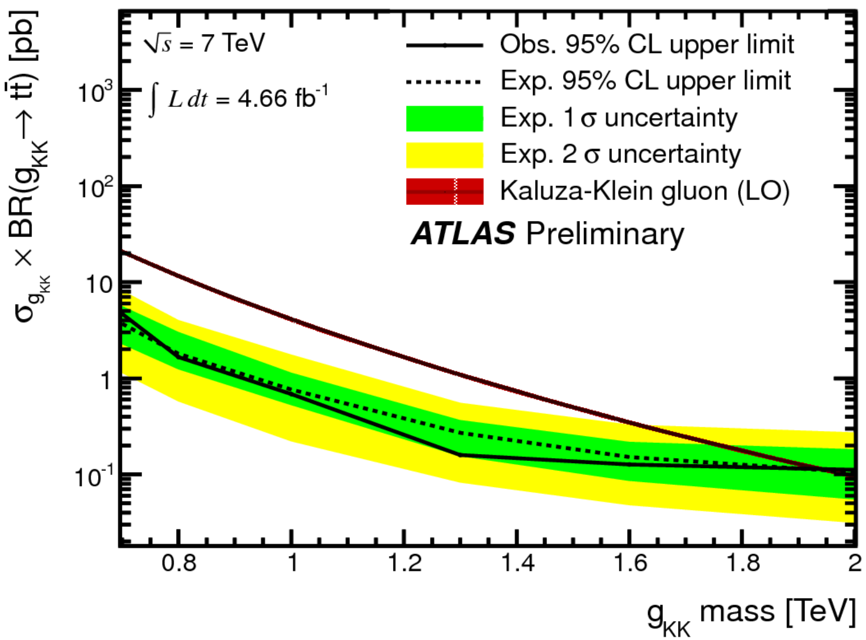
$t\bar{t}$ Resonance Search

Reconstruct semileptonic tt events

Examine m(tt) distribution for possible resonances







Limits on

- narrow resonance: topcolour Z'→tt in a leptophobic scenario
- wide resonance (RS model) g_{KK}→tt

Limits on σ.B in few pb range for m_{tt} ~ 1 TeV

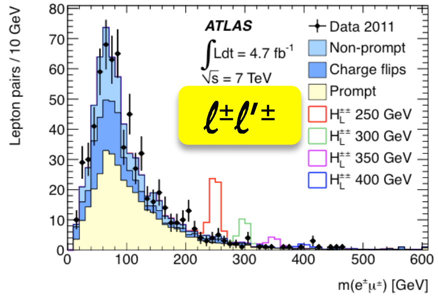
Dijet Resonances

- **CMS 4 fb^{-1} @ 8 TeV dijet result interpreted in a number of different models**
  [EXO-12-016]

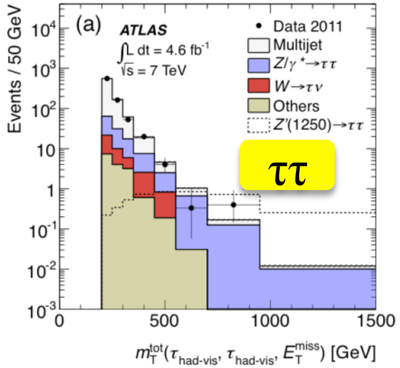
Model	Final State	Obs. Mass Excl. [TeV]
String Resonance (S)	qg	[1.0, 4.69]
Excited Quark (Q*)	qg	[1.0, 3.19]
E_6 Diquark (D)	qq	[1.0, 4.28]
Axigluon (A)/Coloron (C)	$q\bar{q}$	[1.0, 3.28]
s8 Resonance (s8)	gg	[1.0, 2.66]
W′ Boson (W′)	$q\bar{q}$	[1.0, 1.74]
		[1.97, 2.12]
Z′ Boson (Z′)	$q\bar{q}$	[1.0, 1.60]
RS Graviton (RSG)	$q\bar{q}$+gg	[1.0, 1.36]

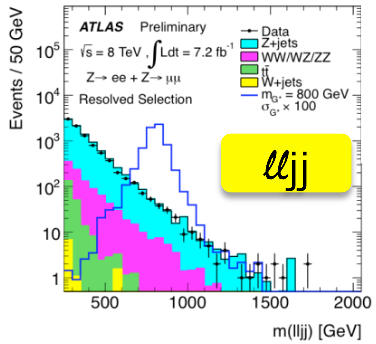
- **ATLAS has new result with 13 fb^{-1} @ 8 TeV : 95% CL limit of**
  m(q*) > 3.84 TeV **[CONF-2012-148]**

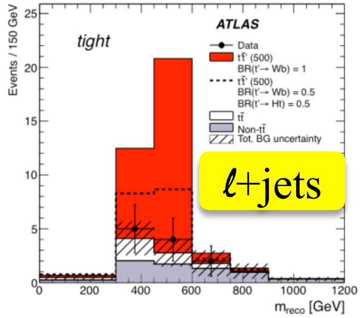
LHC dijet resonance searches typically consider dijet masses above ~ 1 TeV

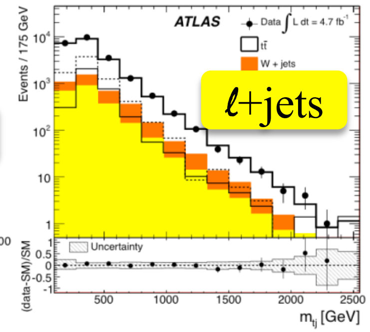


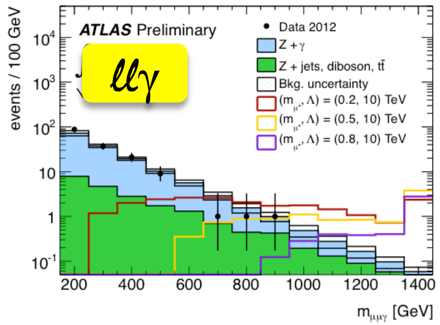
ATLAS Summary

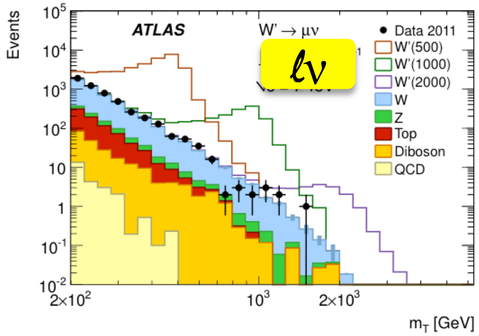


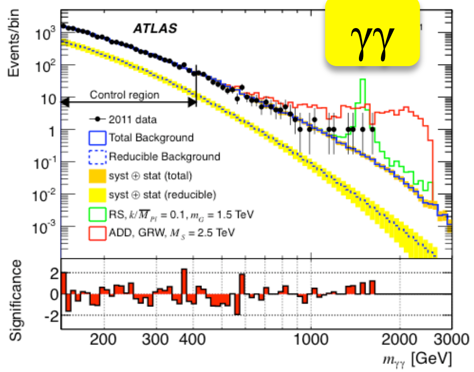










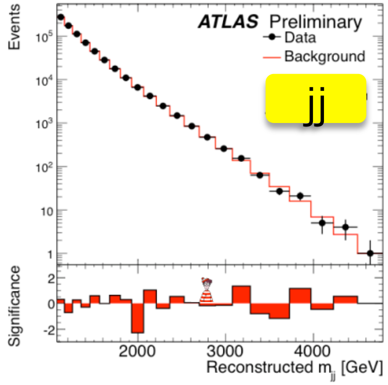


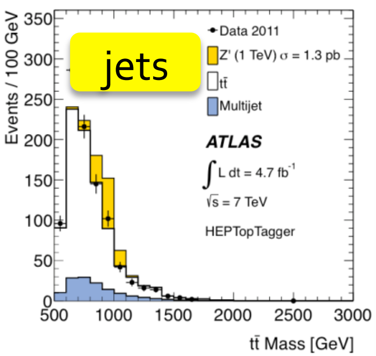
7 TeV analyses to be concluded soon.

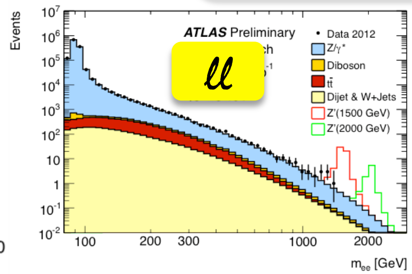
First results on 8 TeV data.

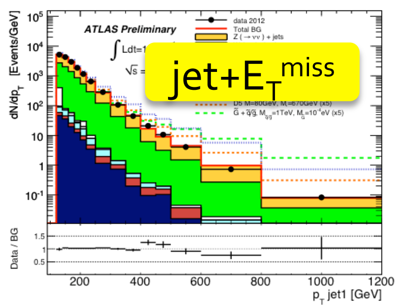
No sign of new physics so far, but

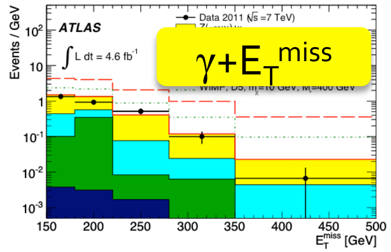
lots of 8 TeV analyses in the pipeline..

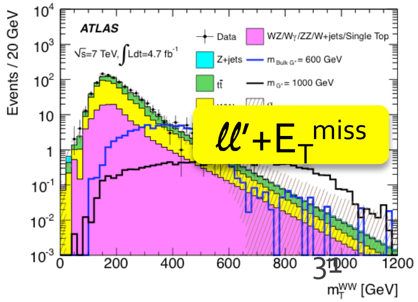






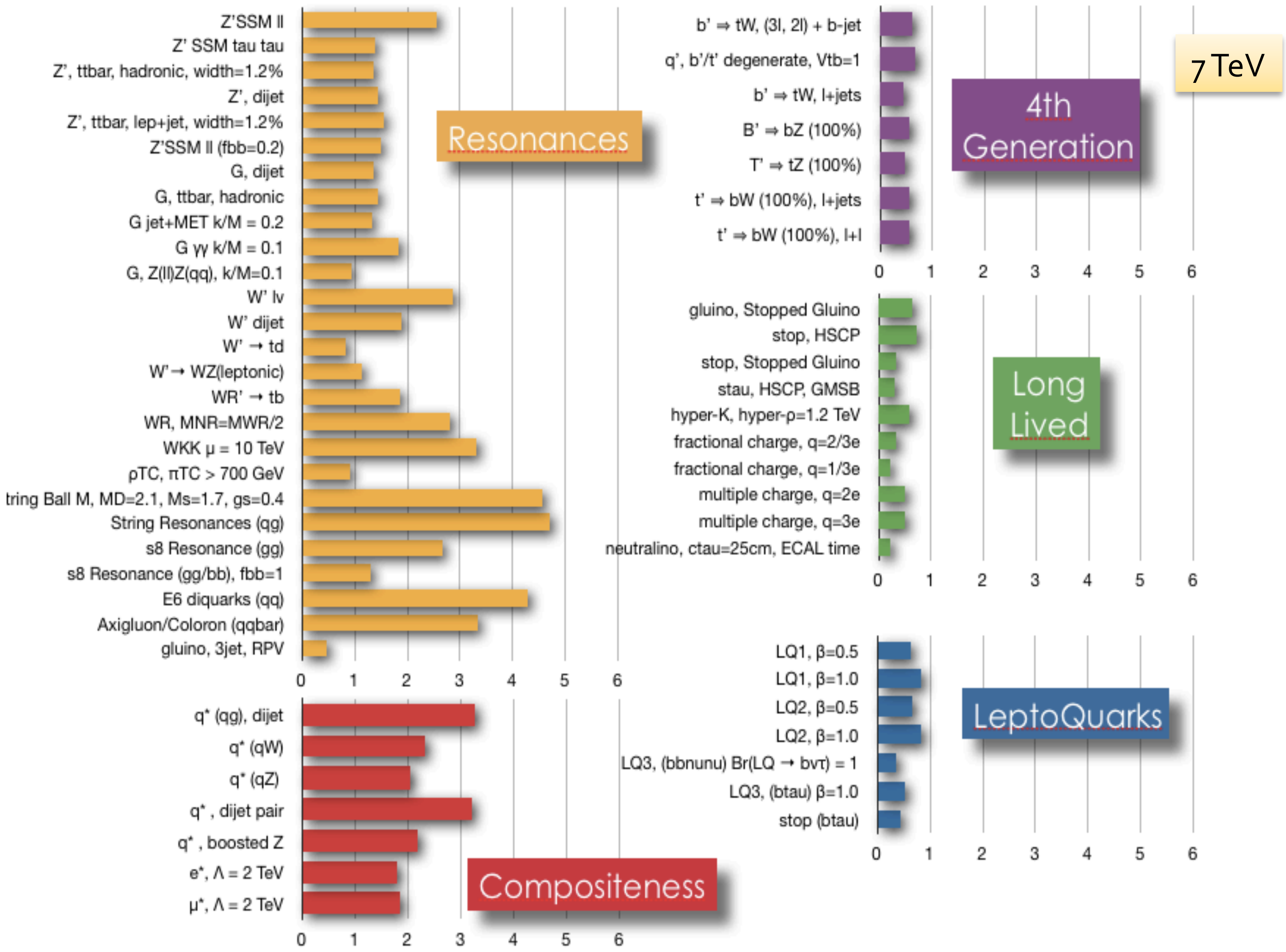






CMS Summary

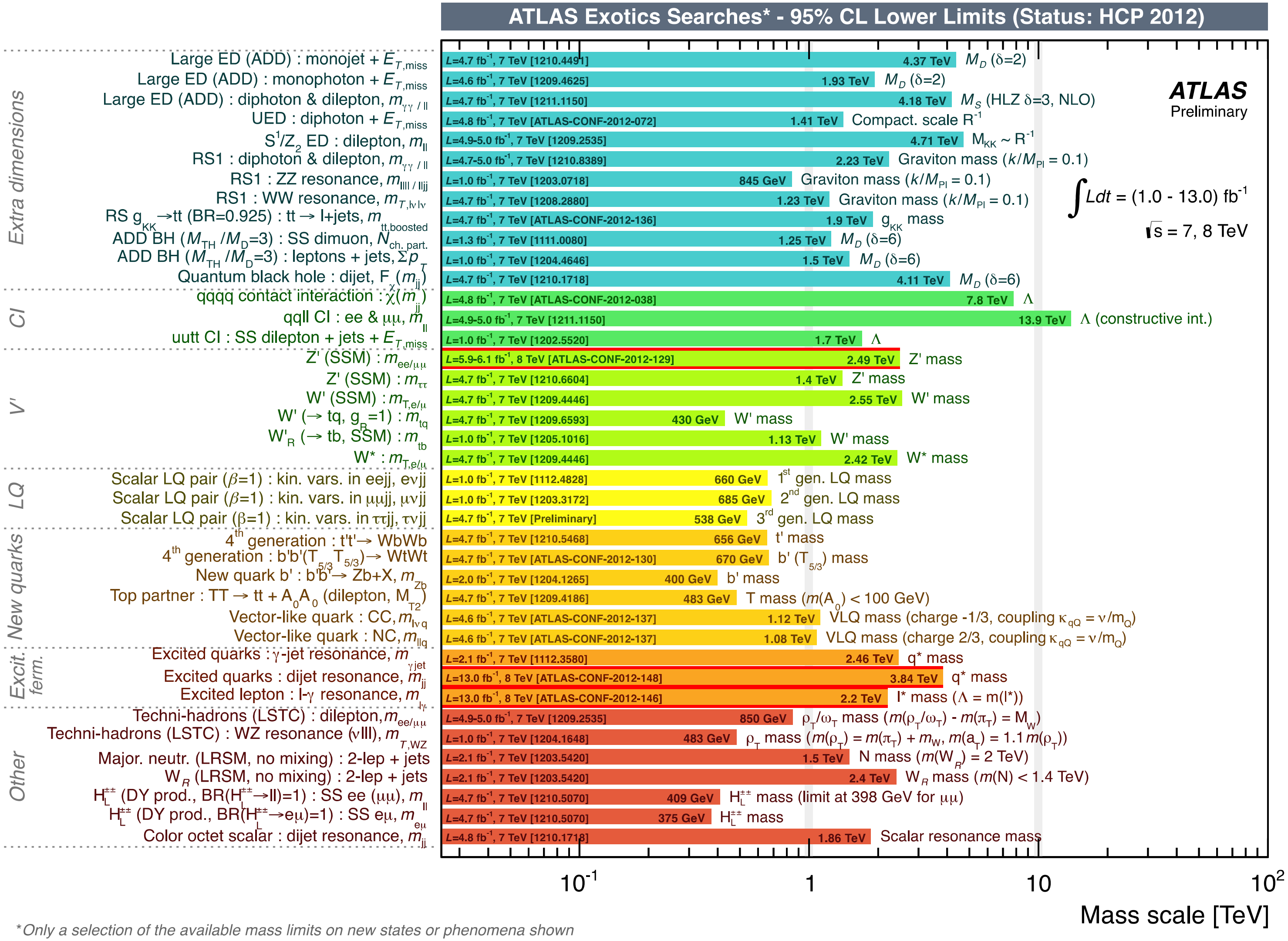
95% CL Exclusion Limits [TeV]



ATLAS Summary

Vast number of models investigated in large number of topologies… but only fraction of data investigated in various cases…

Surprises might be waiting in the present data, and/or data to come at higher energy in 2015



Exotics Models:

Extra dimensions:
- RS KK Graviton
  - (dibosons, dileptons, diphotons)
- RS KK gluons (top antitop)
- ADD (monojets, monophotons, dileptons, diphotons)
- KK Z/gamma boosns (dileptons)

Grand Unification symmetries
- (dielectons, dimuons, ditaus)
- Leptophobic topcolor Z' boson
  - (dilepton ttbar, l+j, all had)

S8- color octet scalars (dijets)
String resonance (dijets,)
Benchmark Sequential SM Z', W'
W' (lepton+MET, dijets, tb)
W* (lepton+MET, dijets)
Quantum Black Holes (dijet)
Black Holes (l+jets, same sign leptons)
Technihadrons (dileptons, dibosons)
Dark Matter
- WIMPs (Monojet, monophotons)

Excited fermions
- q*, Excited quarks (dijets, photon+jet)
- l*, excited leptons (dileptons+photon)

Leptoquarks (1st, 2nd, 3rd generations)
Higgs -> hidden sector
- (displaced vertices, lepton jets)

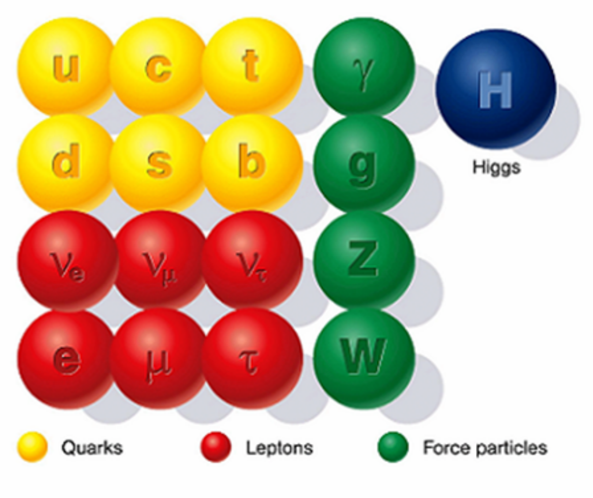
Contact Interaction
- llqq CI
- 4q CI (dijets)

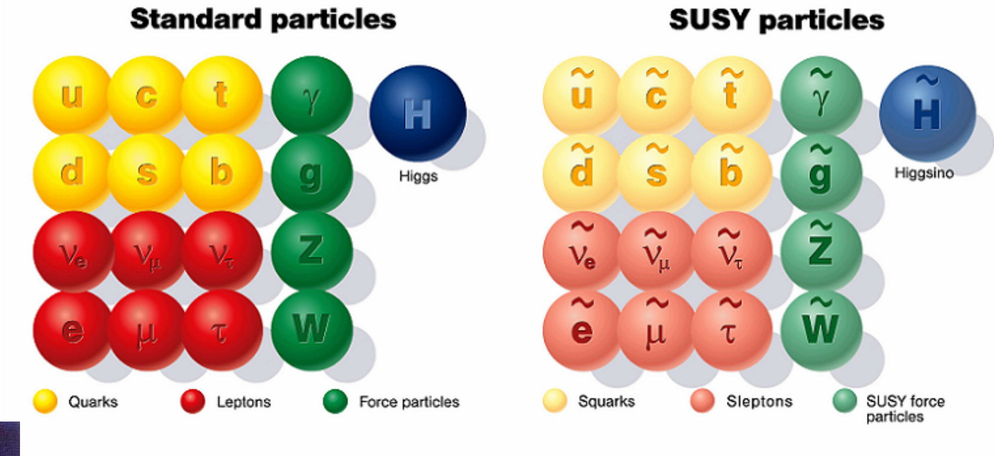
Doubly charged Higgs (
- multi leptons, same sign leptons)

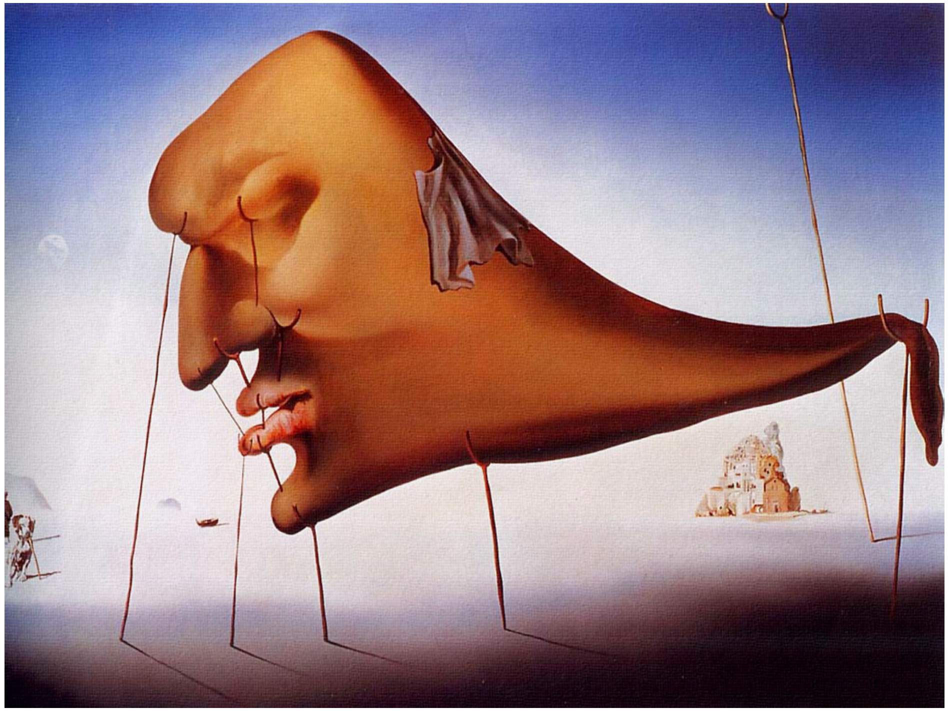
4th generation
- t'->Wb, t'->ht, b'-Zb, b'->Wt
  - (dileptons, same sign leptons, l+J)

VLQ-Vector Like quarks
Magnetic Monopoles (and HIP)
Heavy Majorana neutrino and RH W

Dali Higgs – which picture do you prefer?

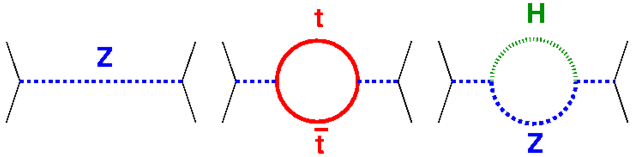






SUrrealSY

Electroweak Fit



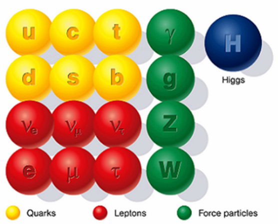
No apparent tensions between m_H and $\{m_W\ m_t\}$

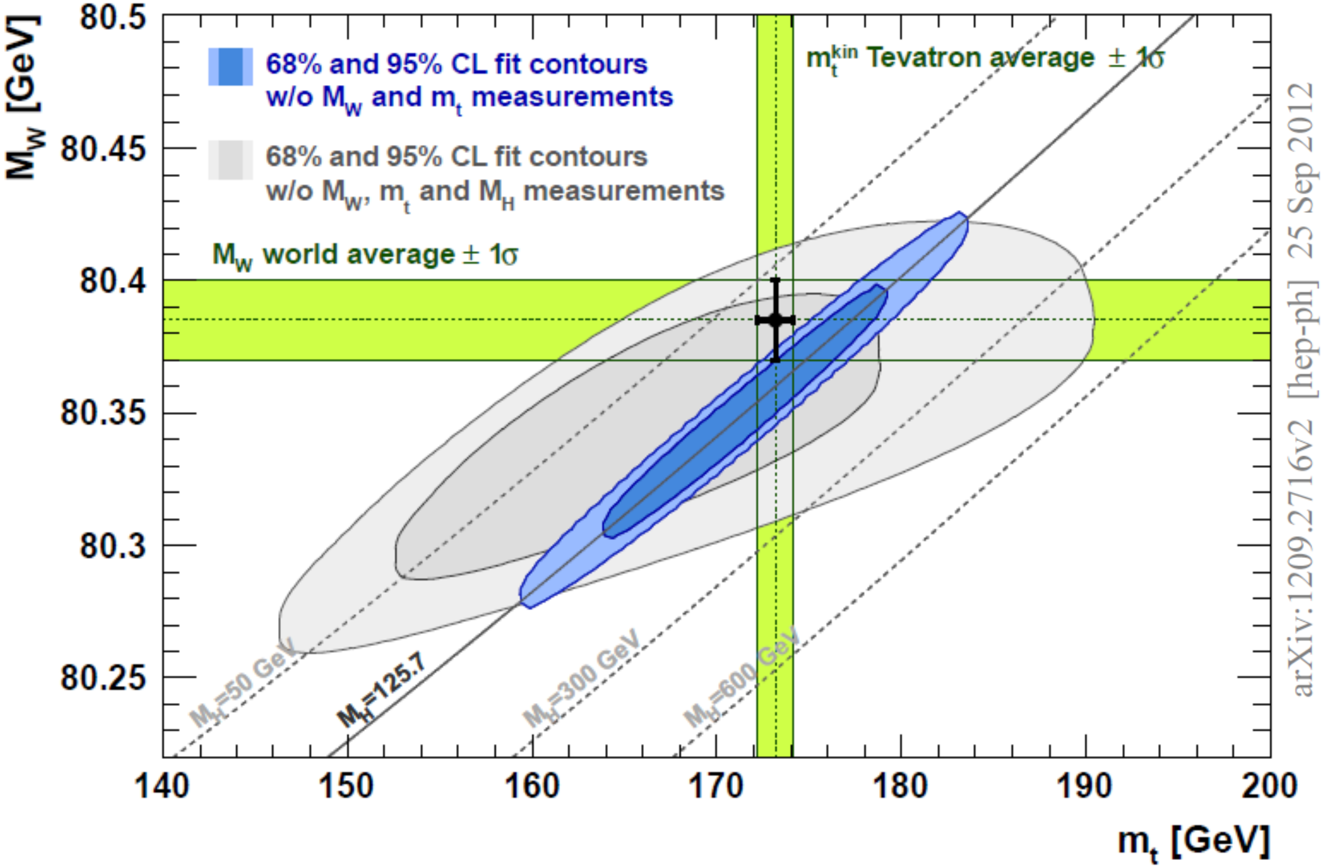
Possible due to

- precision measurements
- known higher order electroweak corrections

Quadratic ,Logarithmic

$$\propto \left(\frac{M_t}{M_W}\right)^2, \ln\left(\frac{M_h}{M_W}\right)$$





Parameter	Input value	Free in fit	Fit result incl. M_H	Fit result not incl. M_H	Fit... but no...
M_H [GeV]$^{(\circ)}$	125.7 ± 0.4	yes	125.7 ± 0.4	94^{+25}_{-22}	
M_W [GeV]	80.385 ± 0.015	–	80.367 ± 0.007	80.380 ± 0.012	8...
m_t [GeV]	173.18 ± 0.94	yes	173.52 ± 0.88	173.14 ± 0.93	

MSSM

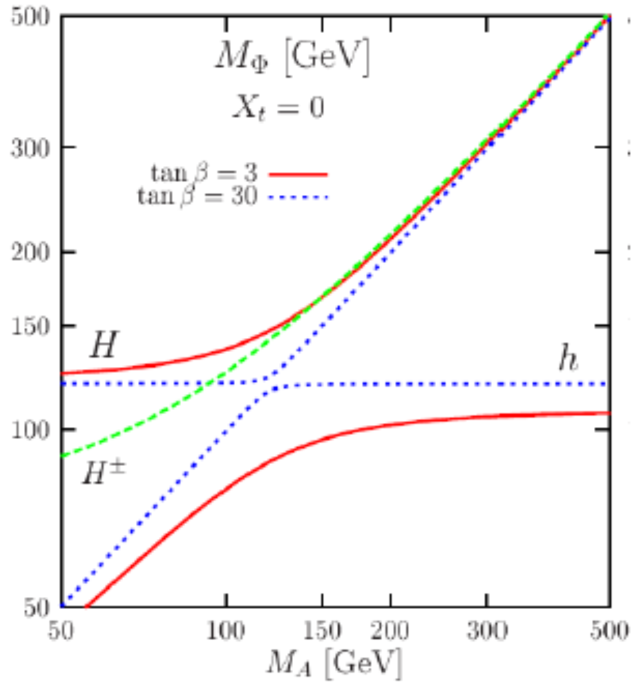
5 Higgs bosons
(3 neutrals and 2 charged)

couplings to down
part of doublets
(b , τ , μ) enhanced
at high tan(β)

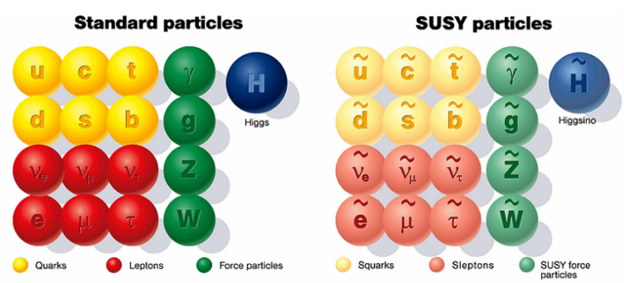
D.Rainwater hep-ph/0702124

	Φ	$\frac{g_{\Phi u\bar{u}}}{g_f}$	$\frac{g_{\Phi d\bar{d}}}{g_f}$	$\frac{g_{\Phi VV}}{g_V}$	$\frac{g_{\Phi ZA}}{g_V}$
	h	$-\frac{\cos\alpha}{\sin\beta}$	$-\frac{\cos\alpha}{\sin\beta}$	$\sin(\beta-\alpha)$	$-\frac{1}{2}i\cos(\beta-\alpha)$
	H	$-\frac{\sin\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\sin\beta}$	$\cos(\beta-\alpha)$	$\frac{1}{2}i\sin(\beta-\alpha)$
	A	$-i\gamma_5\cot\beta$	$i\gamma_5\cot\beta$	0	0
MSSM	h	$-\frac{\cos\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\cos\beta}$	$\sin(\beta-\alpha)$	$-\frac{1}{2}i\cos(\beta-\alpha)$
MSSM	H	$-\frac{\sin\alpha}{\sin\beta}$	$-\frac{\cos\alpha}{\cos\beta}$	$\cos(\beta-\alpha)$	$\frac{1}{2}i\sin(\beta-\alpha)$
MSSM	A	$-i\gamma_5\cot\beta$	$-i\gamma_5\tan\beta$	0	0

Type I (upper) and II (lower) 2HDMs



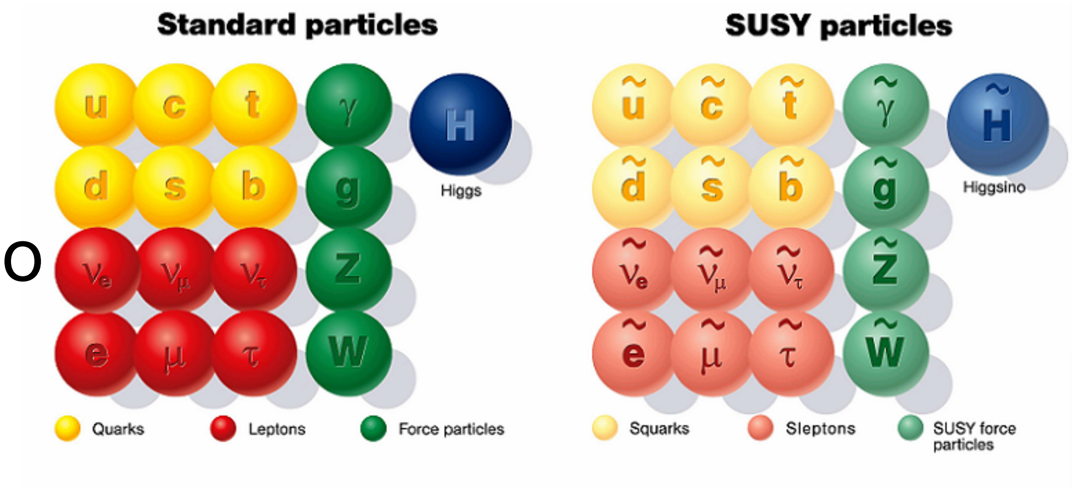
at LO MSSM Higgs sector depends on 2 parameters
M_A tan(β) (= v2/ v1)
at NLO more SUSY parameters

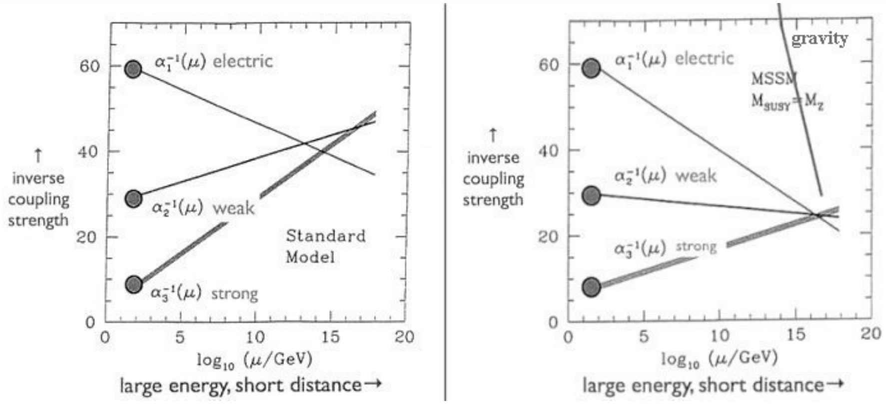


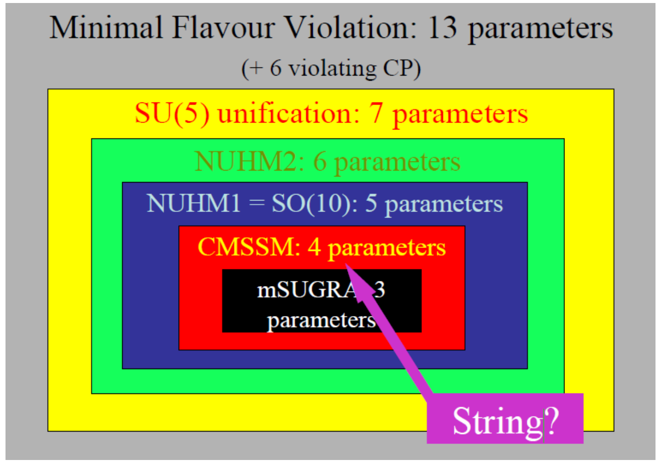
A (0^-) does not give H ⟶ ZZ and WW

Supersymmetry

- Conventional method to fix Higgs mass
- Double the number of states in model
- Fermion/boson loops cancel
  - Help to unify forces
- 105 new parameters (MSSM)
- → 13(+6) → 7 → 6 → 5 → 4
- R-parity conservation → LSP (dark matter candidate) → **missing energy signatures**

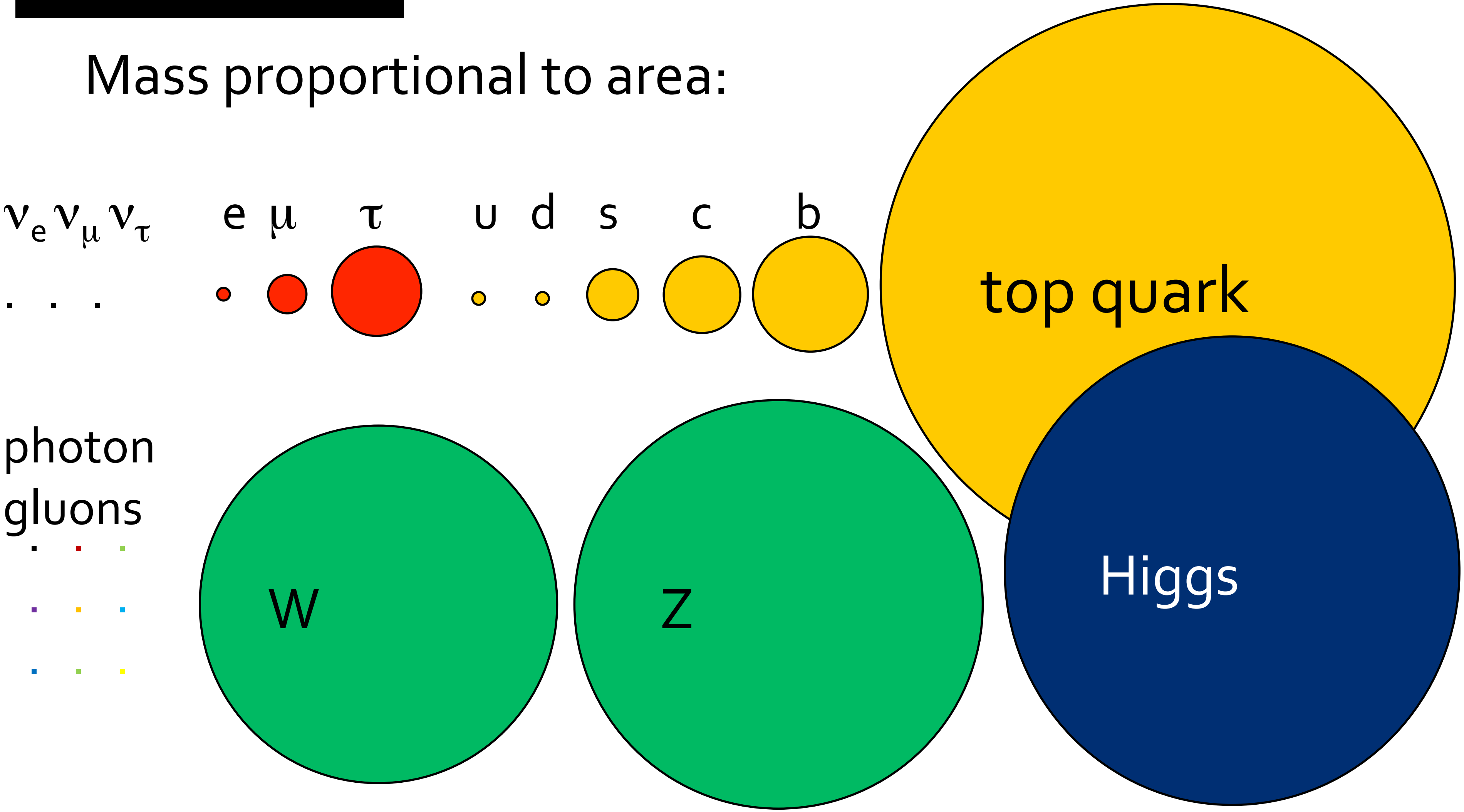






Particle Masses

Mass proportional to area:

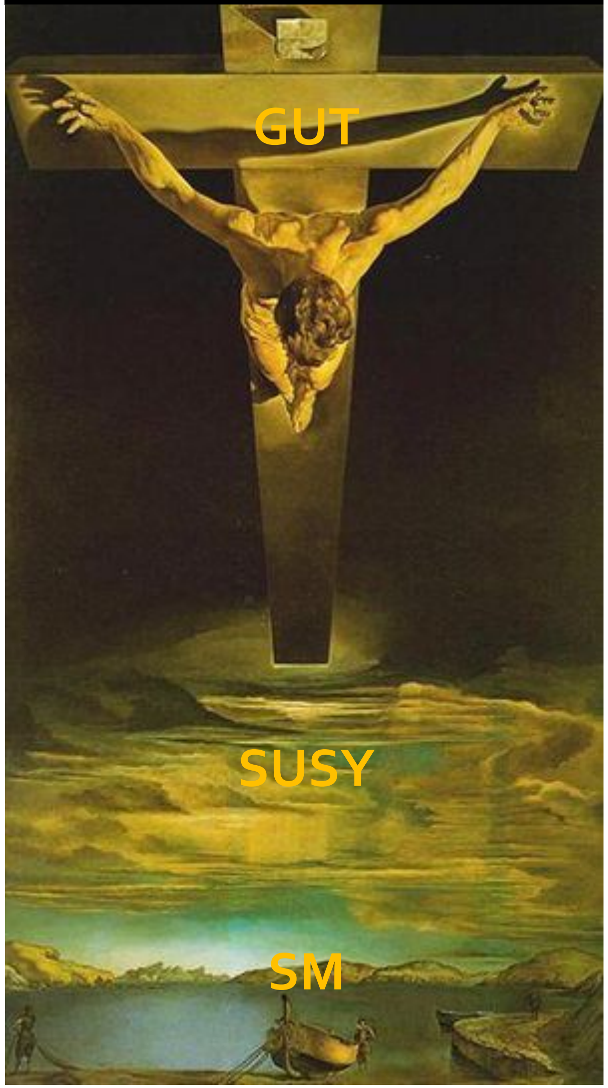


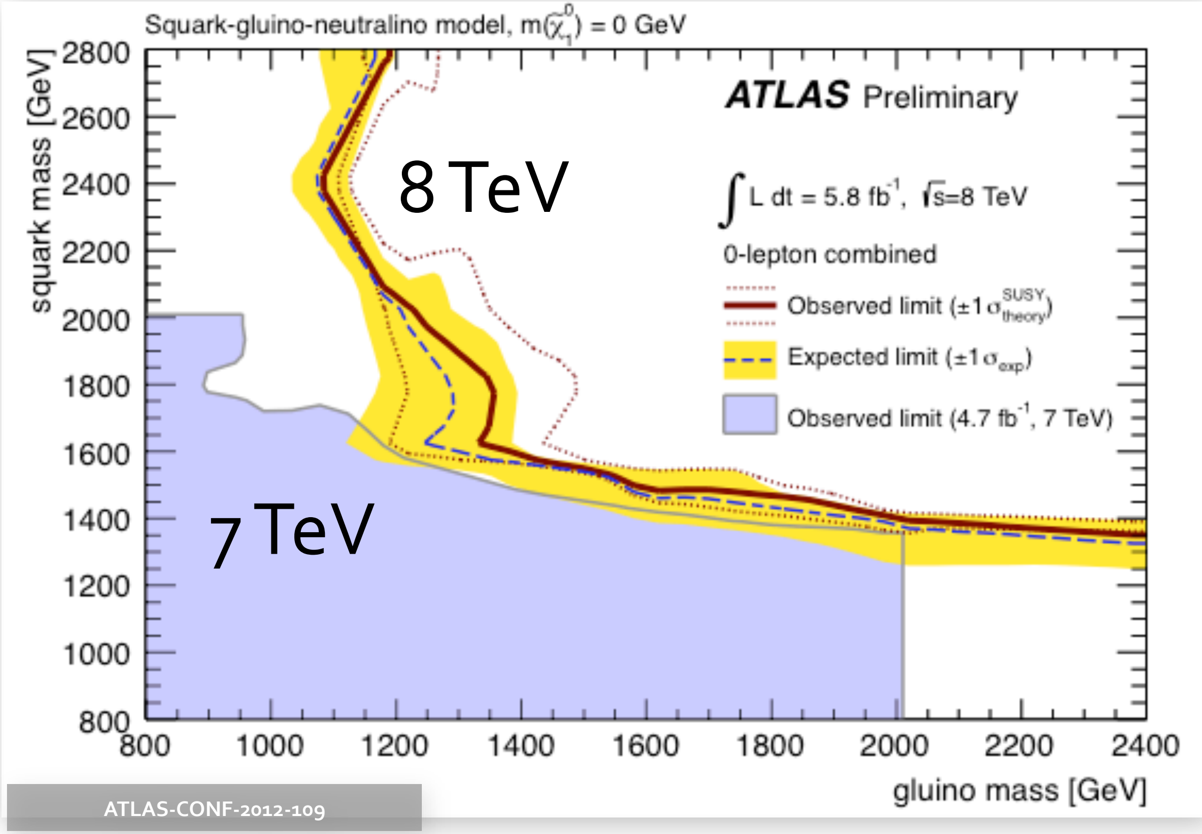
Higgs - self-consistent standard model - preserve gauge symmetry

Need a Yukawa interaction to incorporate individual fermion masses

Need QCD to generate massive nucleons from light u, d quarks

SUSY Landscape?



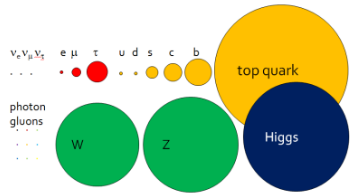


Key signatures:
Jets (>=*2-6 jets in this analysis)* pT 1,2(N)> 100 (20)GeV
E_t^{miss} /meff ~ 0.3

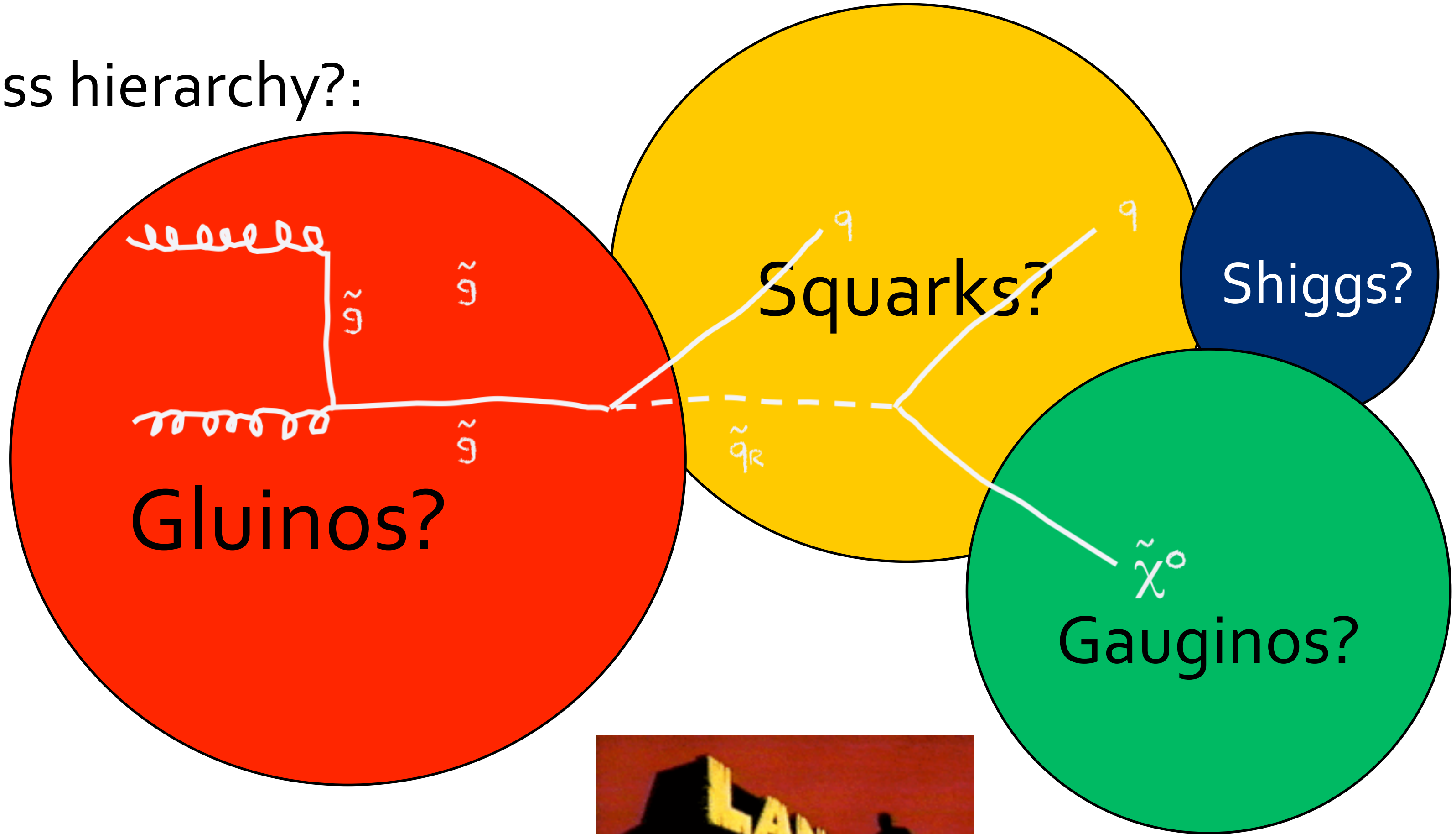
Simplified MSSM scenario with only strong production of gluinos and first- and second-generation squarks, with direct decays to jets and neutralinos

SUSY Particle Masses?

Mass proportional to area:



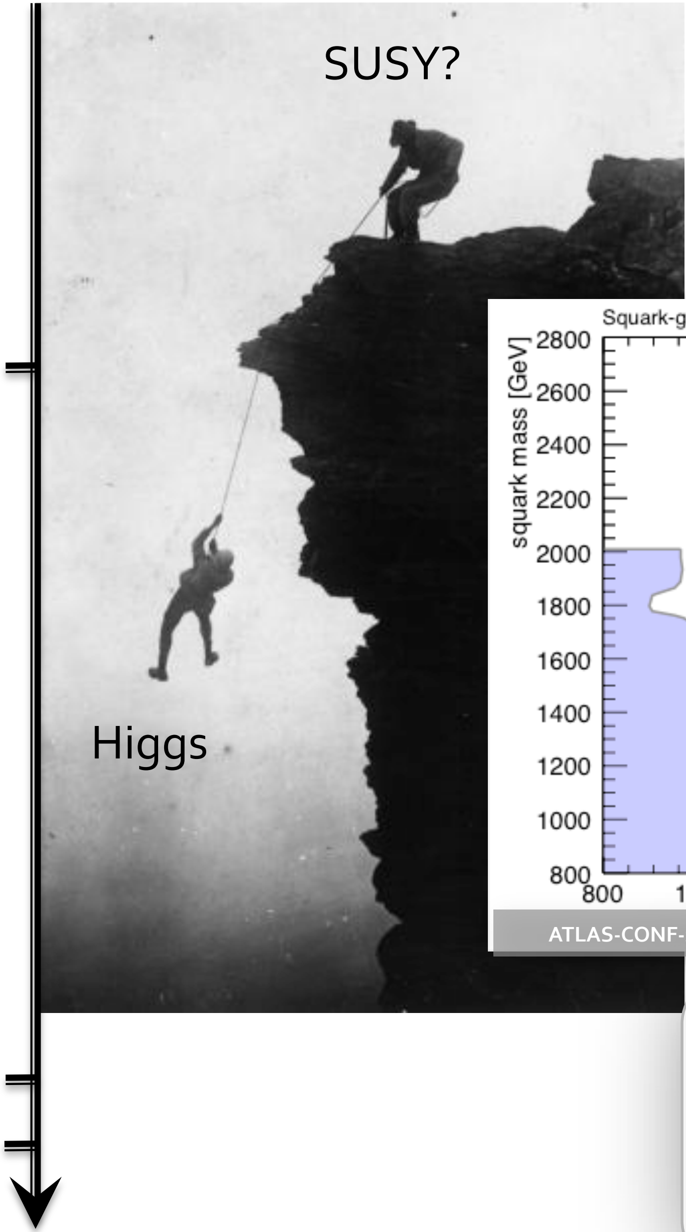
Mass hierarchy?:



SUbtleSY

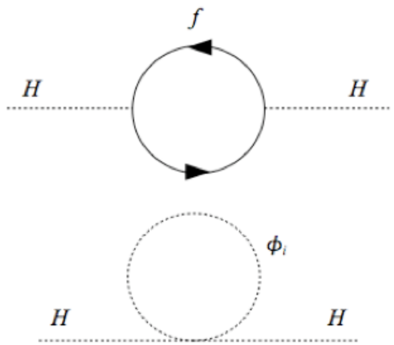
The scalar precipice

EW scale^{-1}

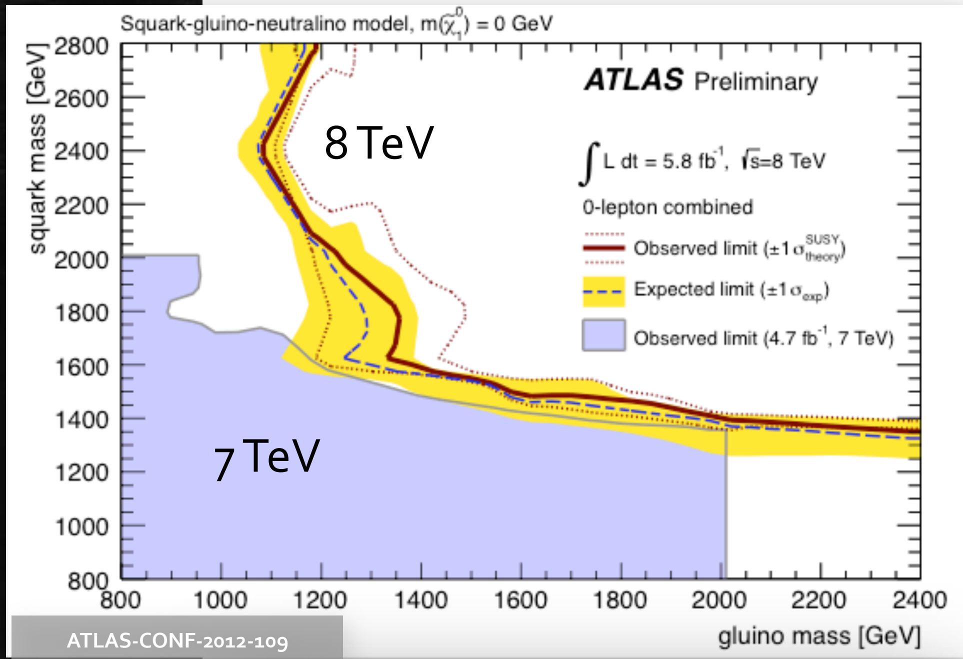


GUT scale^{-1}

Fundamental scalar length scale



StretchedUSY?



e.g. Limits from this model:

M(squarks, gluinos) >~ 1-2 TeV

More prolematic than ever

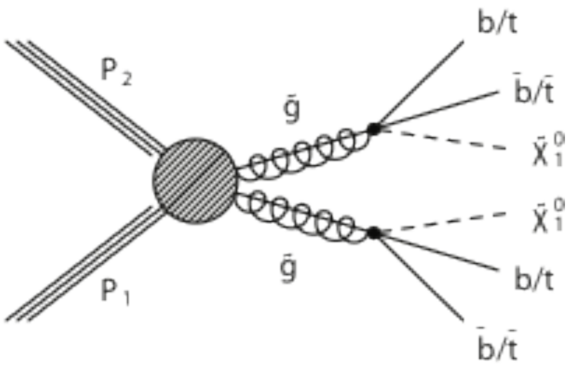
SUbtleSY

Natural" SUSY

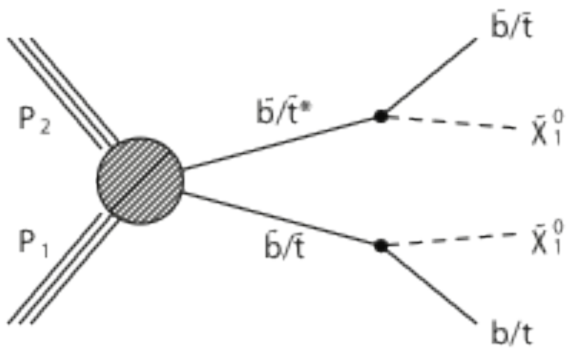
Lightest squarks are stop/sbottom, gluinos possibly too heavy, gauginos accessible ?

1208.2884, 1208.3144, ATLAS-CONF-2012-154

Lower cross-sections and larger SM backgrounds require dedicated searches

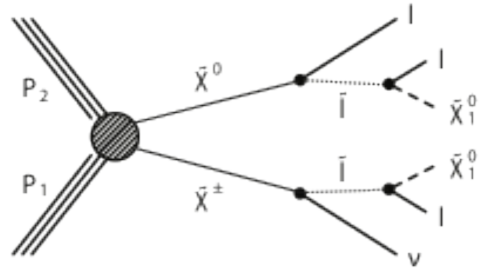


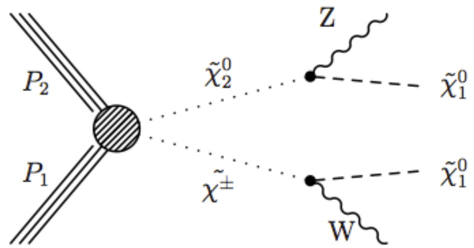
Gluino-mediated $\tilde{b}/\tilde{t}$ production

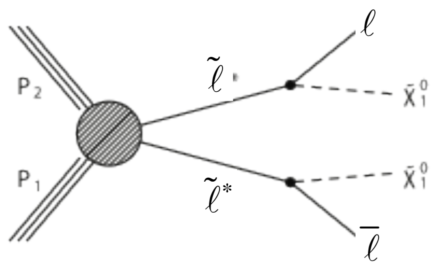


Direct $\tilde{b}/\tilde{t}$ pair production

Associated gaugino production





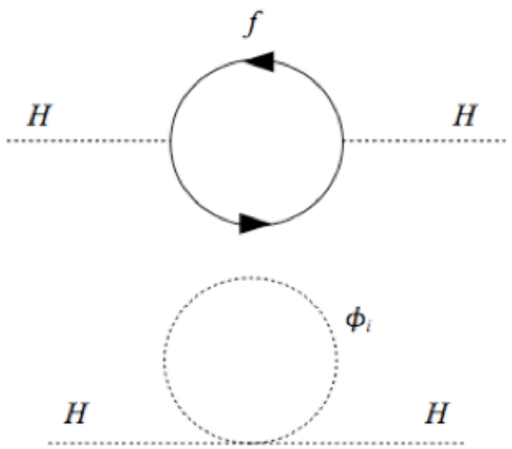


Direct slepton-pair production

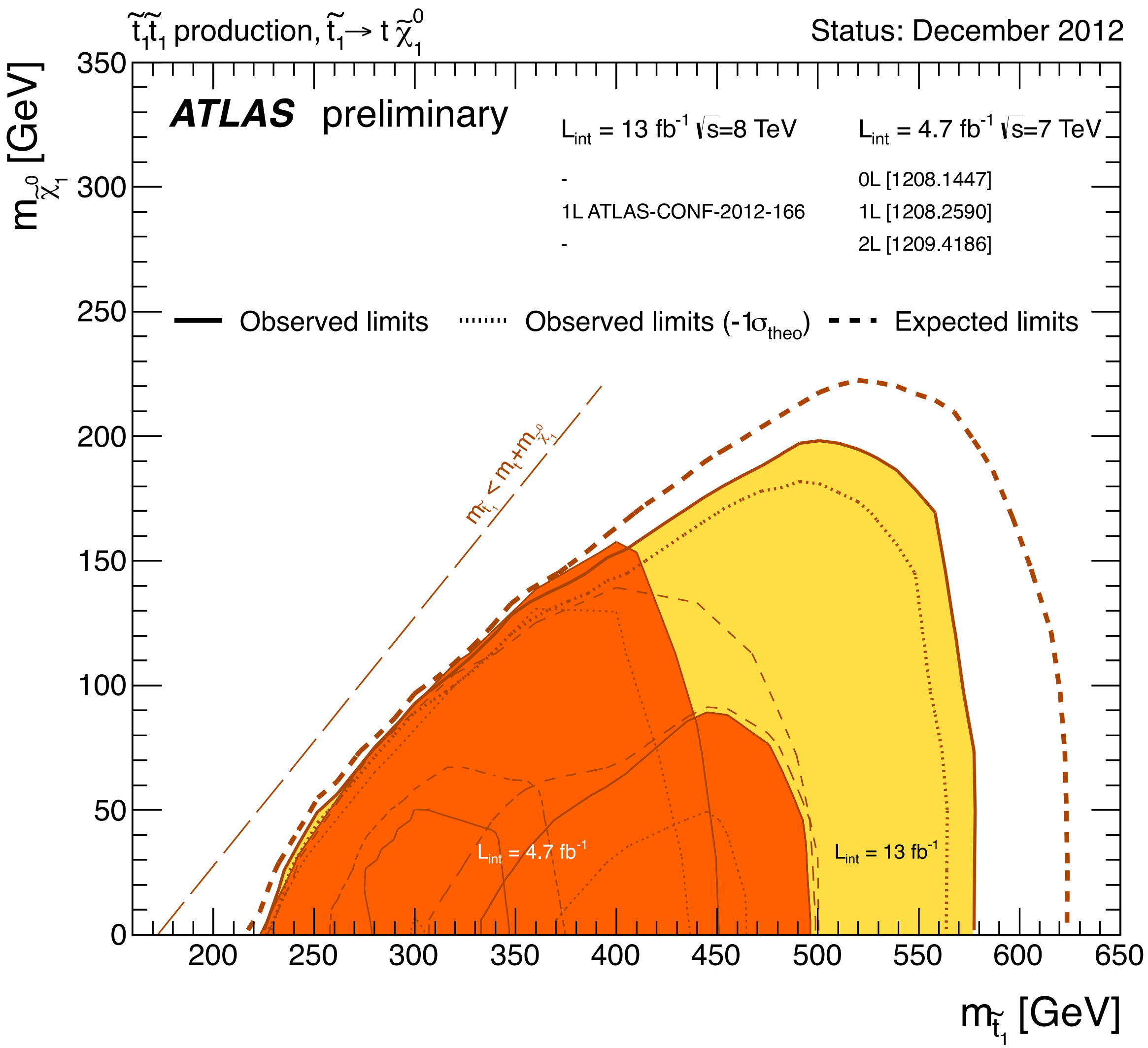
Searching for "natural" SUSY with Tops

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

Seeking solutions to stabilise the Higgs mass… Hierarchy problem



$$\tilde{t} \rightarrow t\chi$$

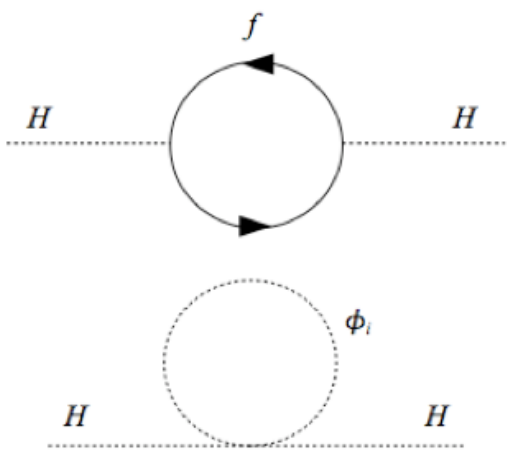


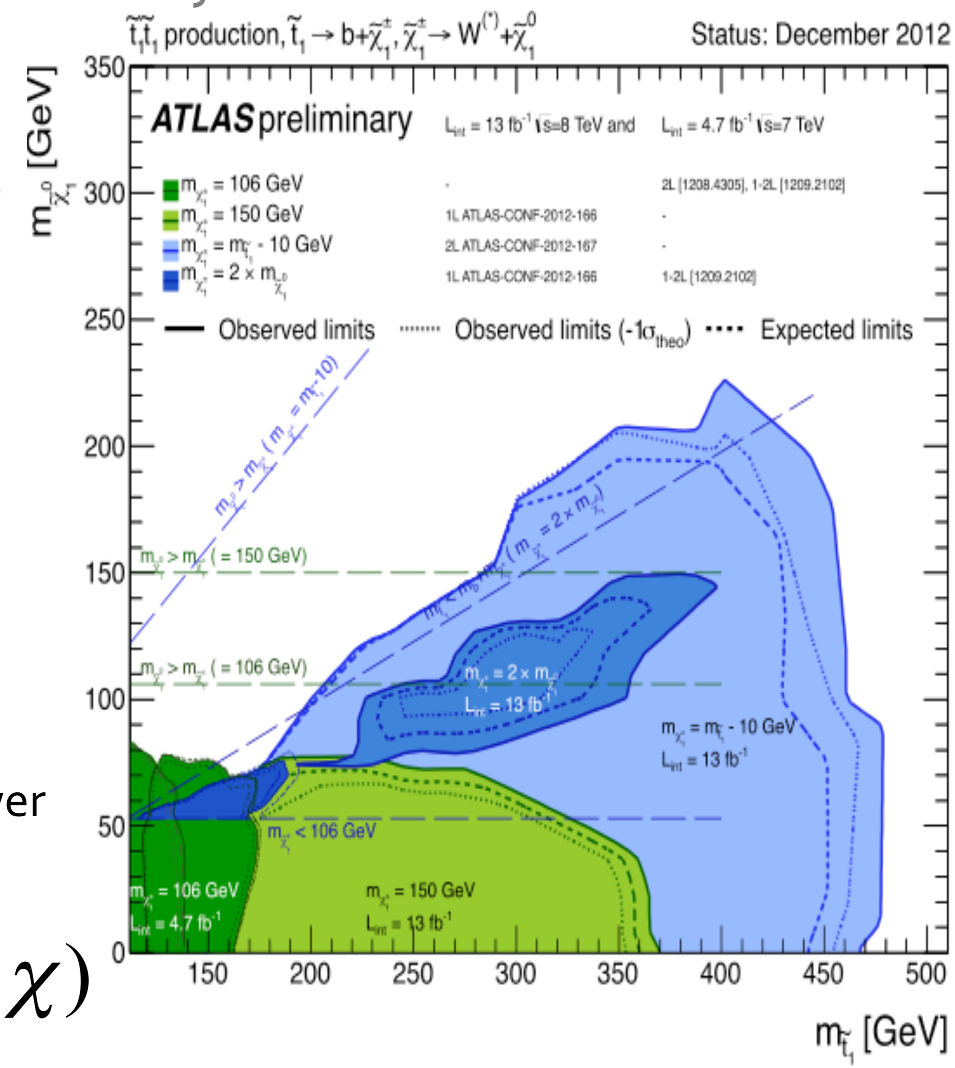
Significantly improved sensitivity at high stop masses with expected limits up to 620 GeV

Searching for SUSY with Tops

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

Seeking to Solve the Hierarchy Problem...





$$\tilde{t} \to t\chi$$

Complemented in the lower mass range by:

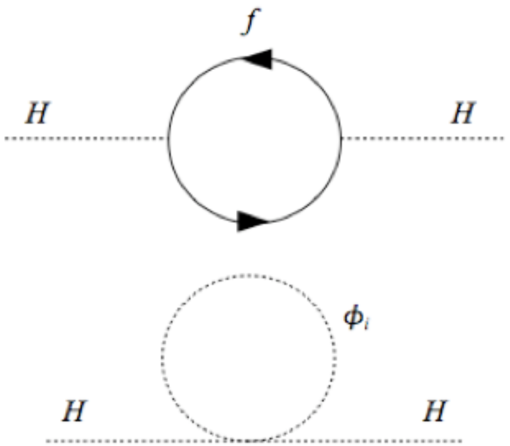
$$\tilde{t} \to b(\chi^{\pm} \to W^{\pm}\chi)$$

Significantly improved sensitivity at high stop masses with expected limits up to 620 GeV
Also, strongly enhanced sensitivity for lower mass stop decaying into *b* + chargino

Searching for SUSY with Tops

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

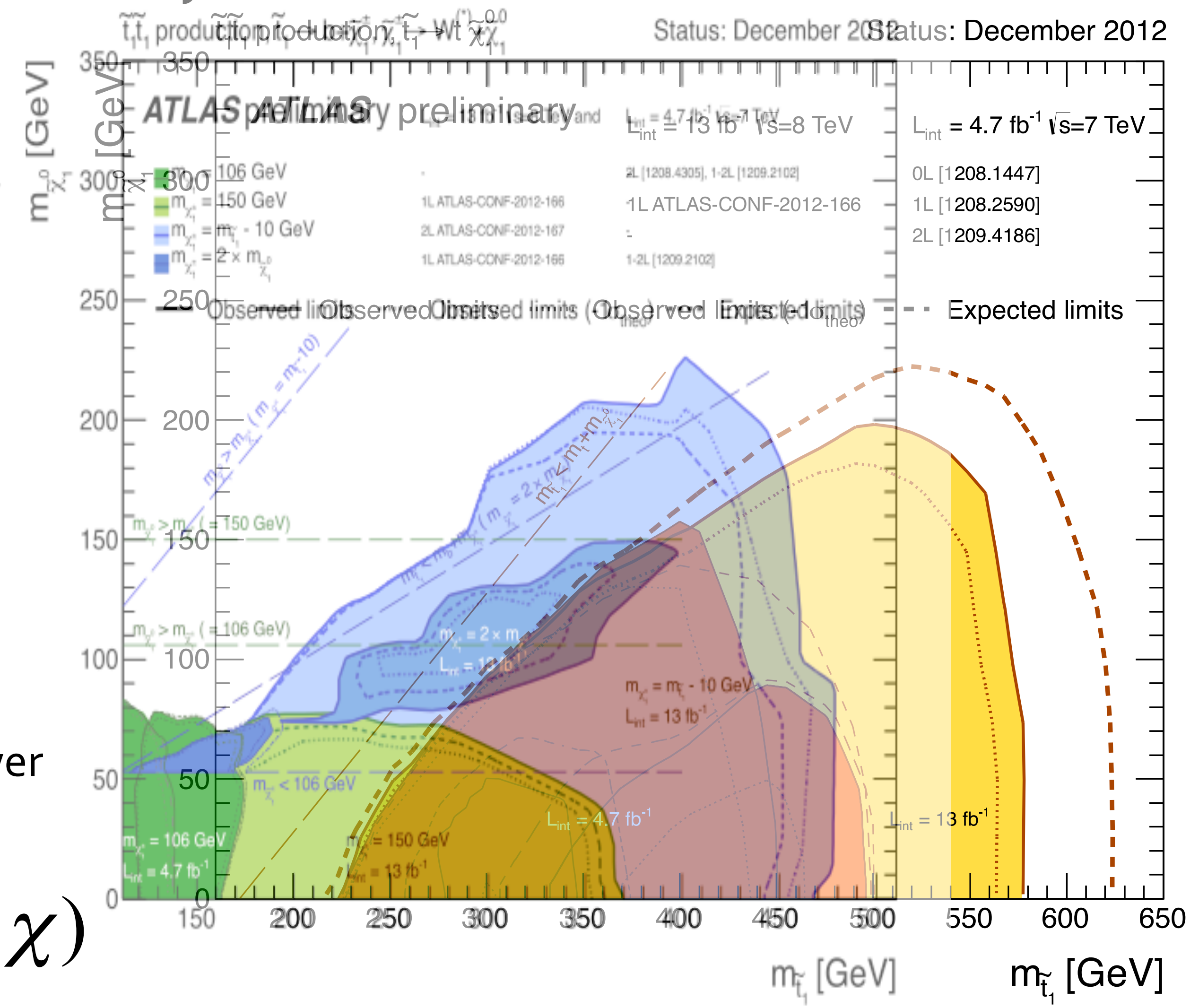
Seeking to Solve the Hierarchy Problem…



$$\tilde{t} \rightarrow t\chi$$

Complemented in the lower mass range by:

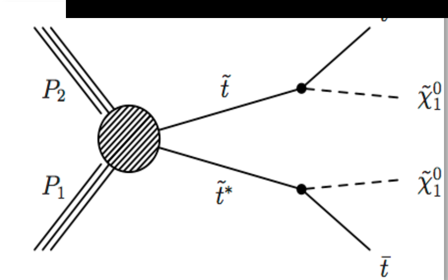
$$\tilde{t} \rightarrow b(\chi^{\pm} \rightarrow W^{\pm}\chi)$$

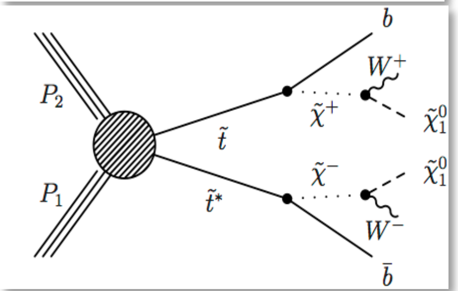


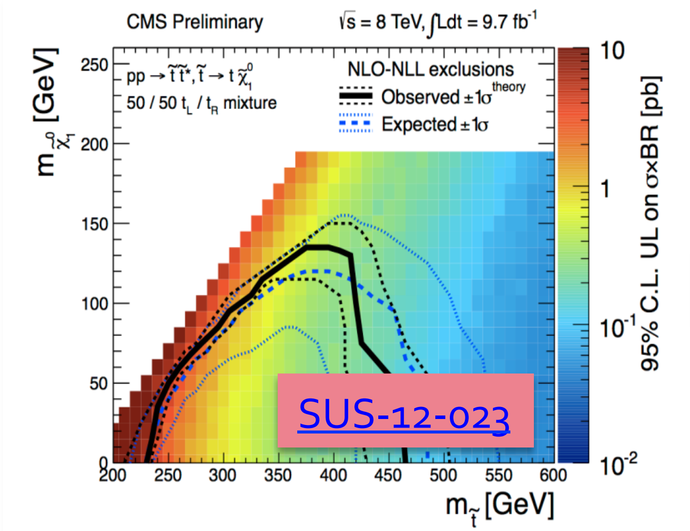
Significantly improved sensitivity at high stop masses with expected limits up to 620 GeV
Also, strongly enhanced sensitivity for lower mass stop decaying into *b* + chargino

Natural" SUSY

Search for direct top squark pair production

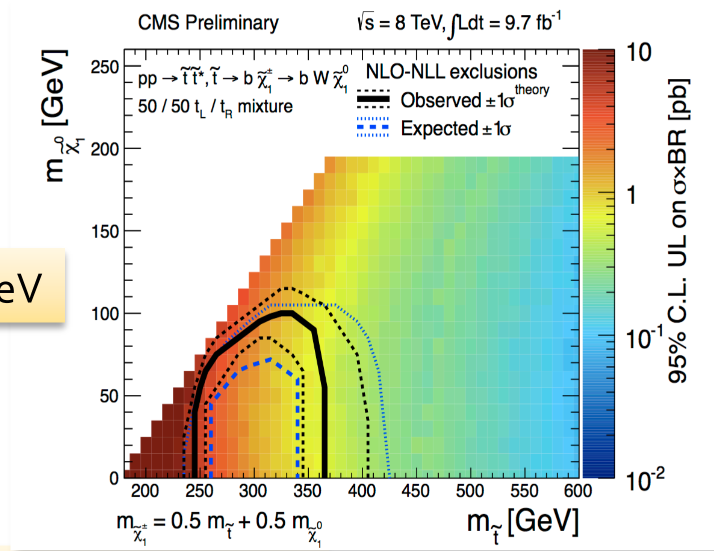






SUS-12-023

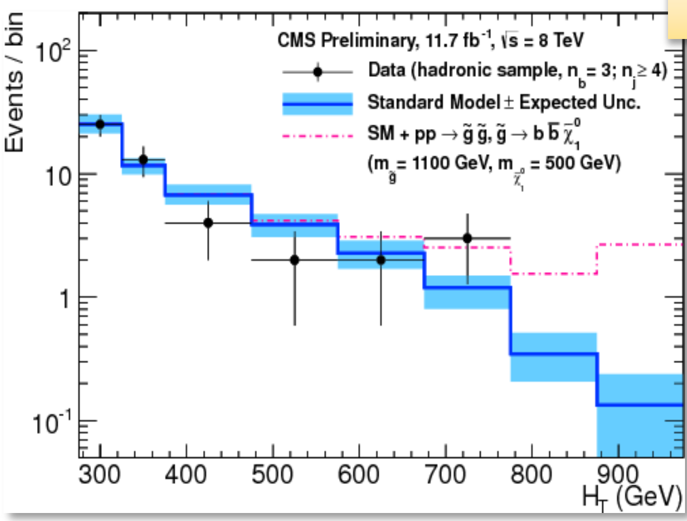
8 TeV

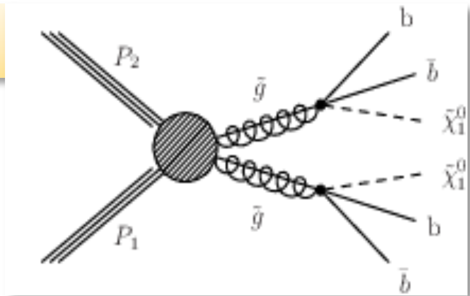


Search for supersymmetry in final state with E_T and 0,1,2,3, >= 4 b jets

No excess in data observed above expected SM background.

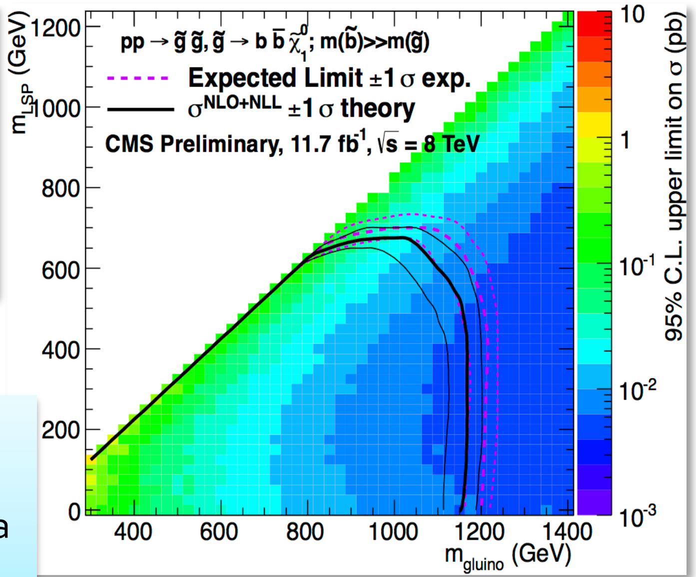
8 TeV





SUS-12-028

Exclusion for pair-produced gluinos, each decaying to a bottom quark-antiquark pair and a neutralino LSP.



What about Dark Matter ?

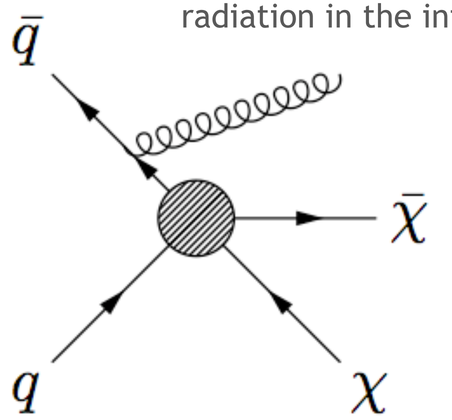
Detection of invisible particle production

1210.4491, ATLAS-CONF-2012-147

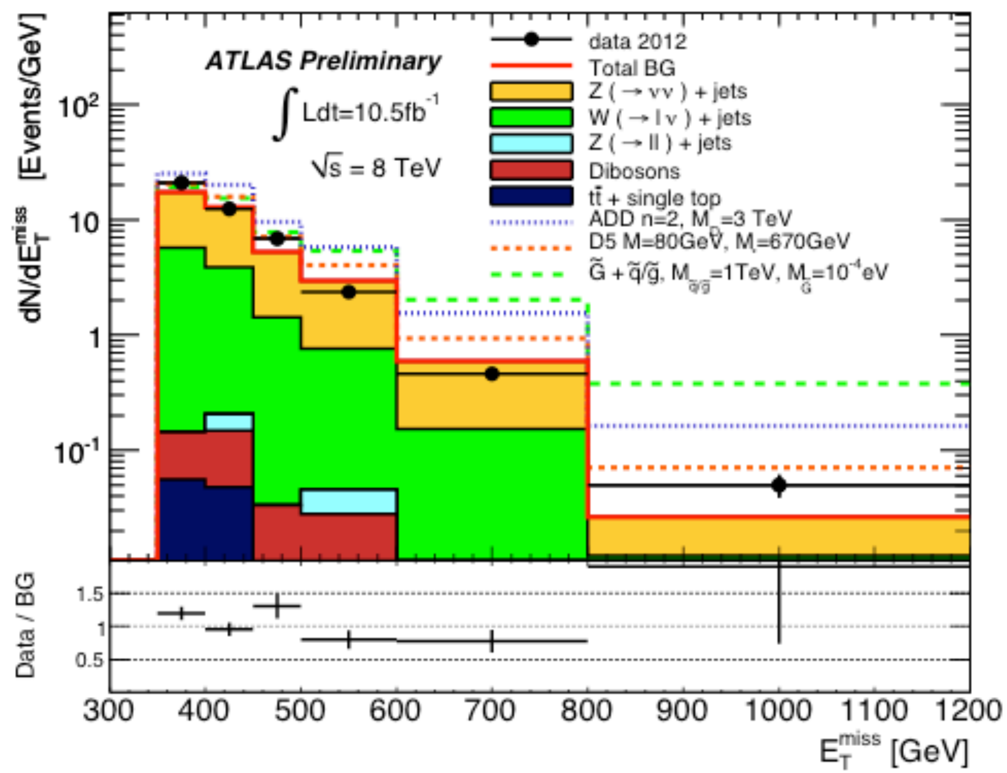
Should we give up on natural SUSY and directly search for WIMP (dark matter) production in proton−proton collisions ?

Exploit "ISR technique" (huge potential)

Energetic gluon/photon radiation in the initial sate



→ Search for mono-jets events



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

What about Dark Matter ?

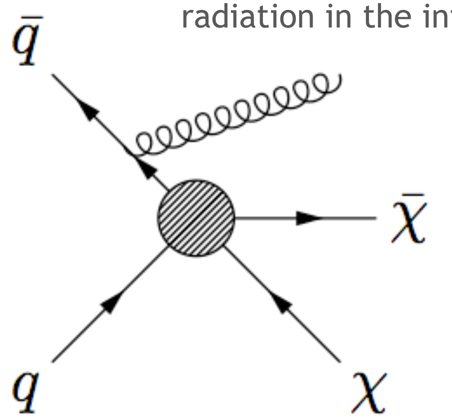
Detection of invisible particle production

1210.4491, ATLAS-CONF-2012-147

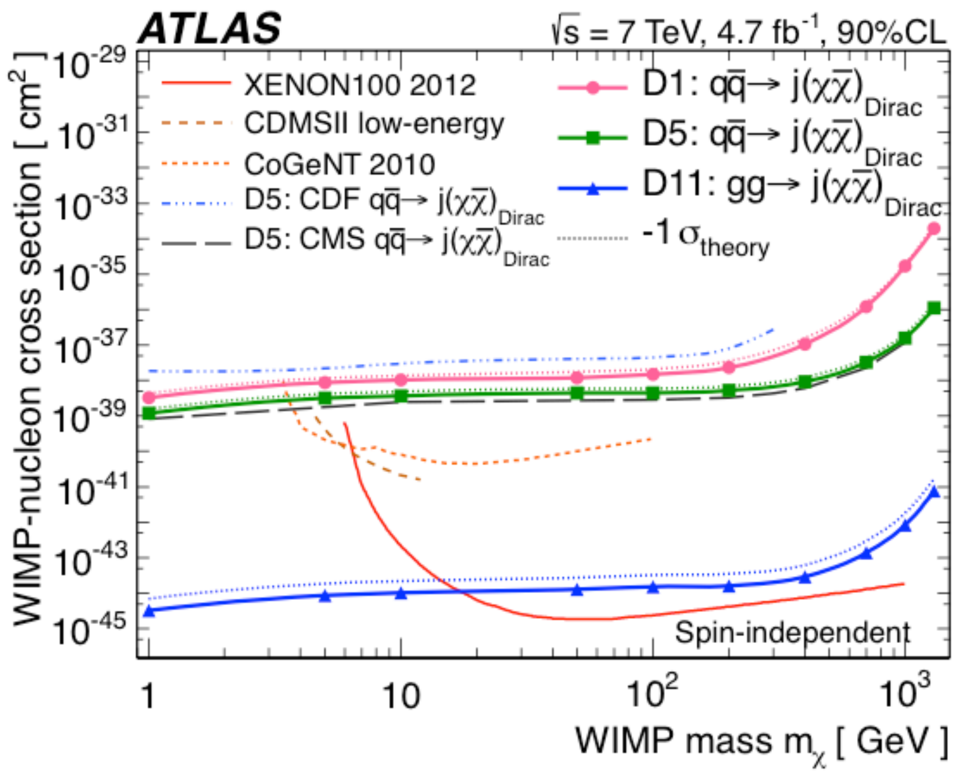
Should we give up on natural SUSY and directly search for WIMP (dark matter) production in proton–proton collisions ?

Exploit "ISR technique" (huge potential!)

Energetic gluon/photon radiation in the initial sate



→ Search for mono-jets events



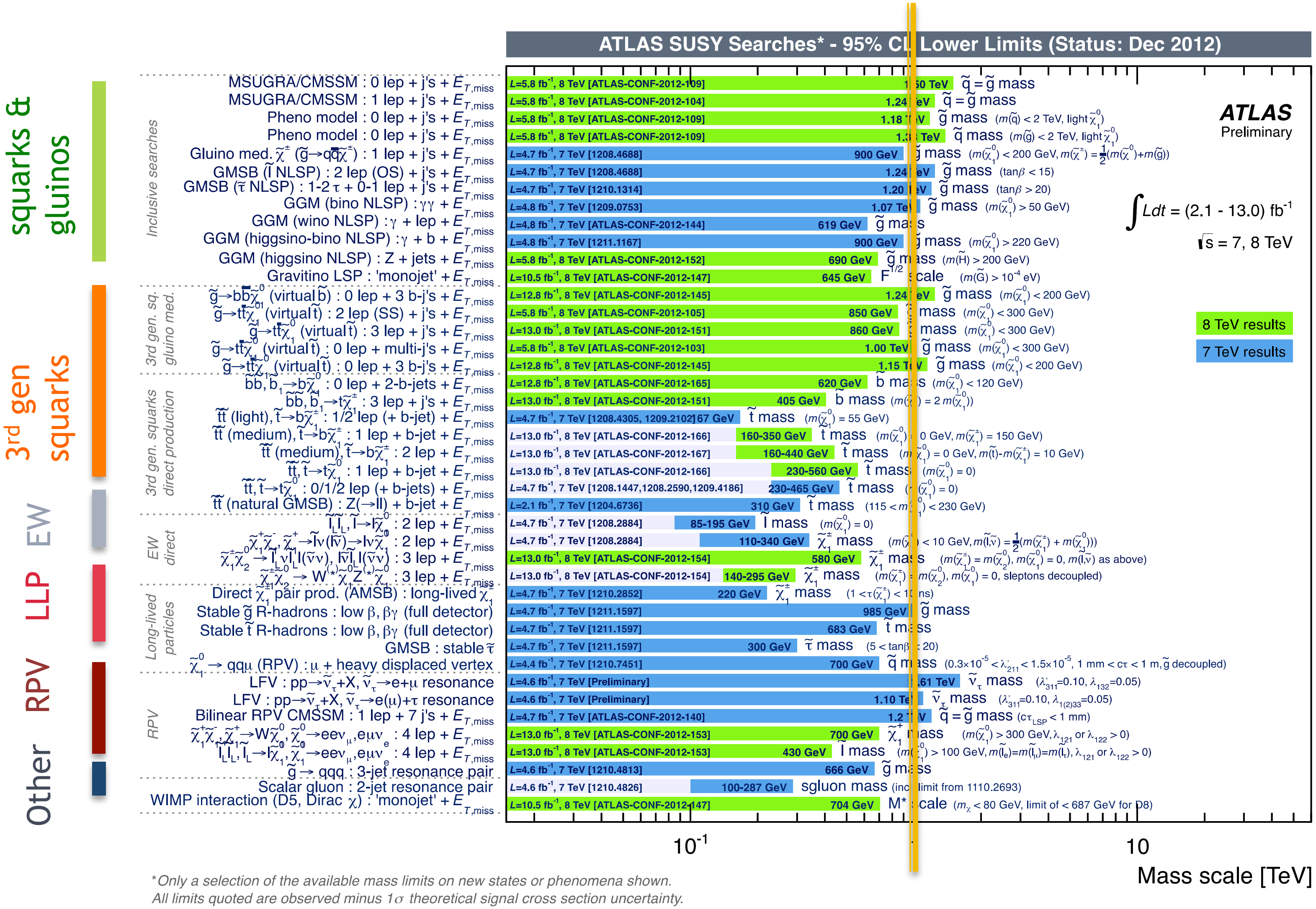
Complementarity between accelerator-based and space-based particle physics

Overview of SUSY Searches

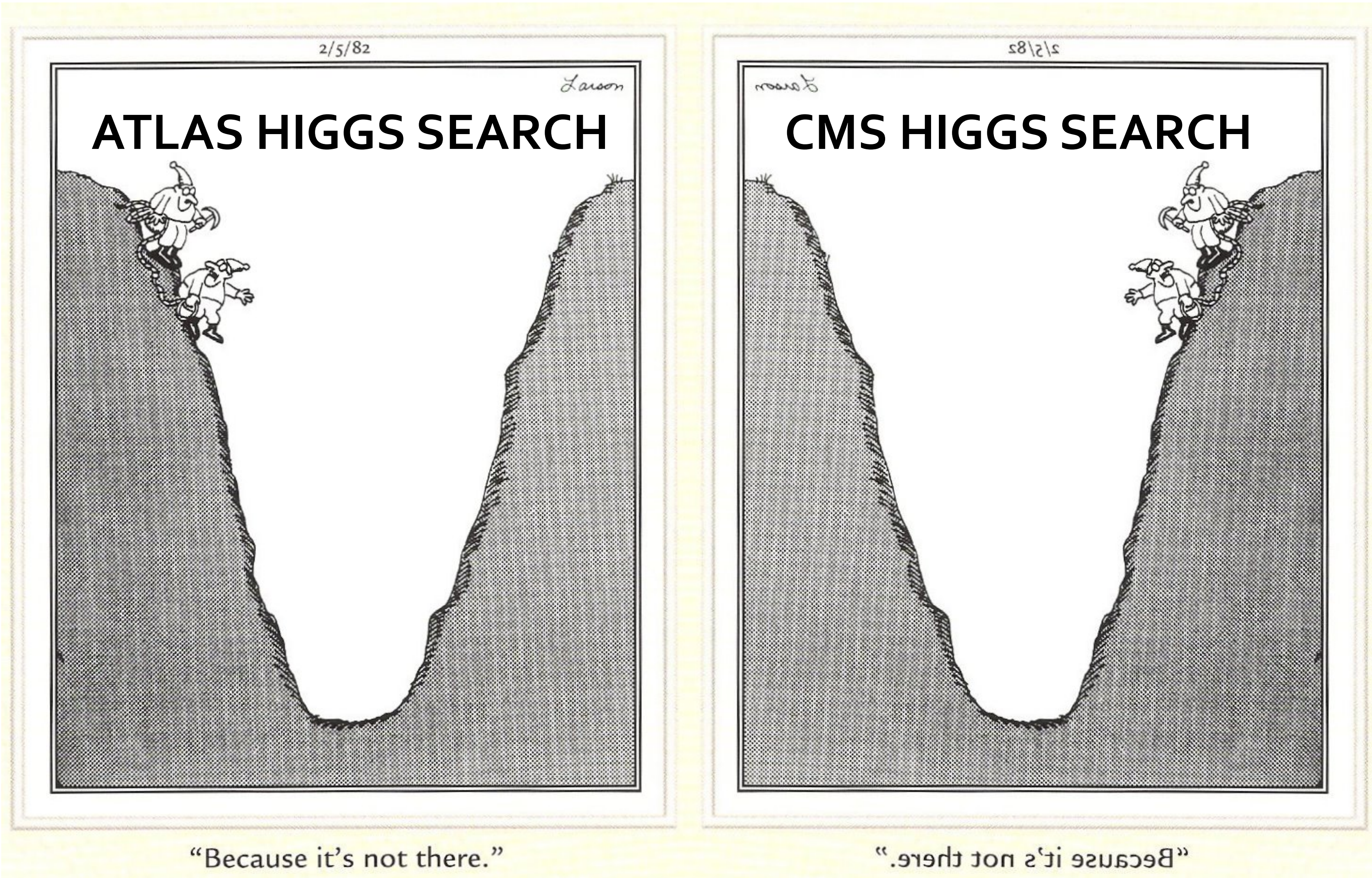
Vast number of SUSY models studied… Concentrating on the most “Natural ” scenarios

Still many analyses to be completed with 8 TeV data, surprises might be waiting in the present data, and/or data to come at higher energy in 2015

1 TeV



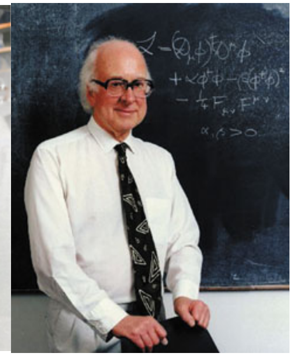
Higgs Discovery and Properties (including latest LHC data)



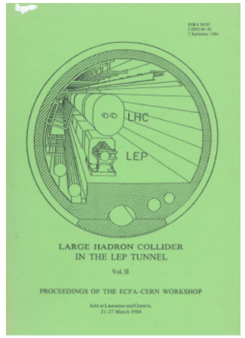
Historical Perspective

1950 Ginzburg-Landau
1959 Nambu
1960 Goldstone
1961 Schwinger
1962 Anderson
1964 Brout, Englert, Higgs, Guralnik, Hagen, Kibble
1967 Weinberg, Salam   Faddeev, Popov
1972 Glashow, Iliopoulos,
Maiani, 't Hooft, Veltman.....



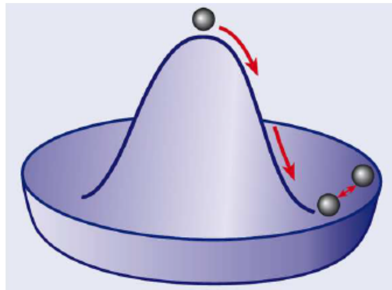


1983 Rubbia, van der Meer, Banner, Darriulat, Di Lella, ...   discovery of W and Z at CERN
1984   Lausanne

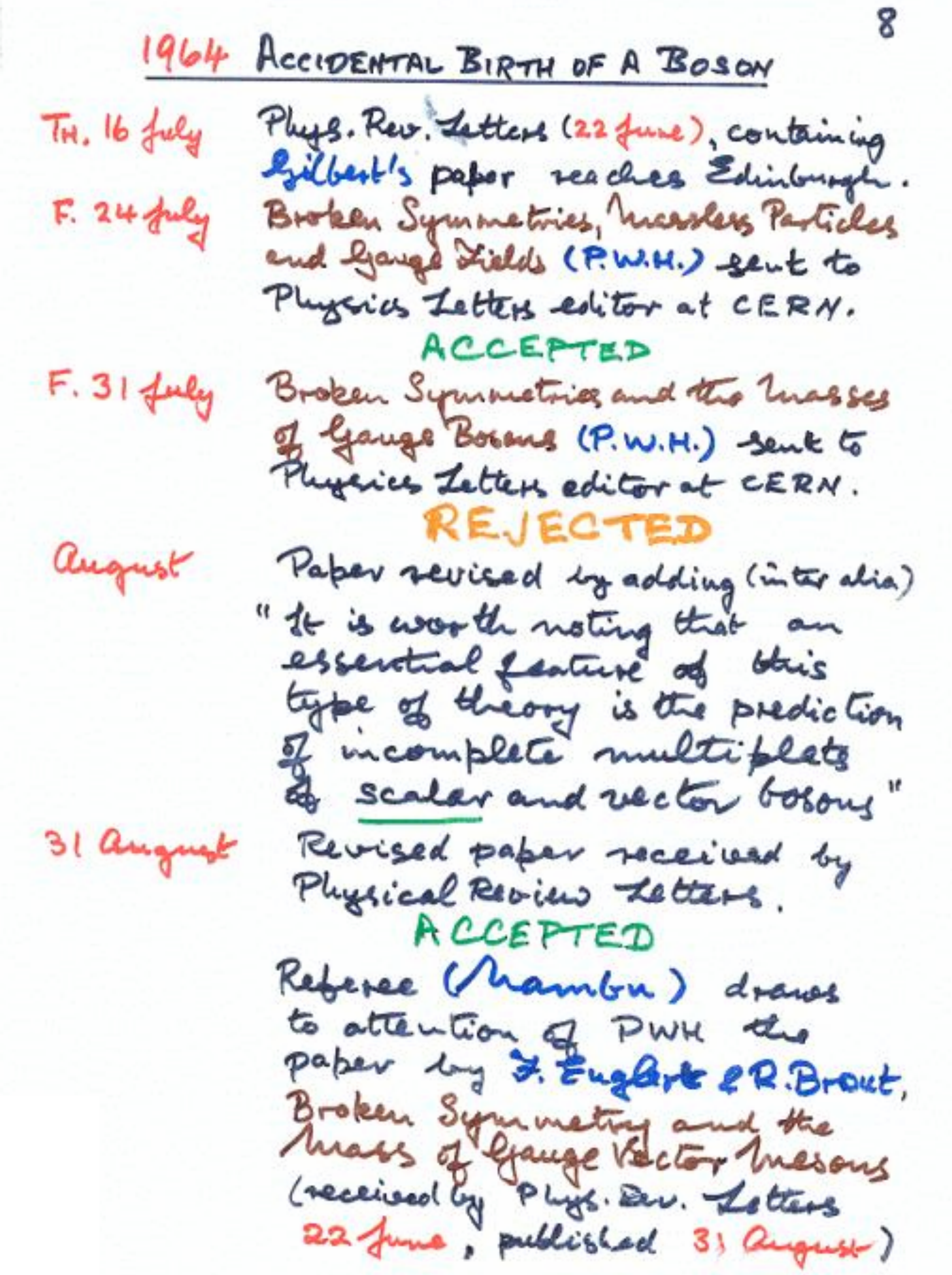
1989 construction of the LEP (e+ e- collider) tunnel finished
beginning of the R & D of LHC experiments

1992 ← LOI of 'large' LHC experiments
1994 ← TP of ATLAS and CMS   approval of LHC
1995 discovery of top by CDF and Do
1996 ← approval of LHC in one step
1998 ← approval of the 4 largest LHC experiments (ATLAS, CMS, LHCb, ALICE)
1999 ← ATLAS Physics TDR CERN/LHCC/99-14   CERN/LHCC/99-15



2006 ← CMS Physics TDR J. Phys. G: Nucl. Part. Phys. 34 (2007) 995–1579
2008 ← ATLAS Expected Performance arXiv:0901.0512
2010 ← start-up at 3.5 + 3.5 TeV
2012 ← 4th July discovery of boson

Where Theory Meets Experiment



8

1964 ACCIDENTAL BIRTH OF A BOSON

TH. 16 July — Phys. Rev. Letters (22 June), containing Gilbert's paper reaches Edinburgh.

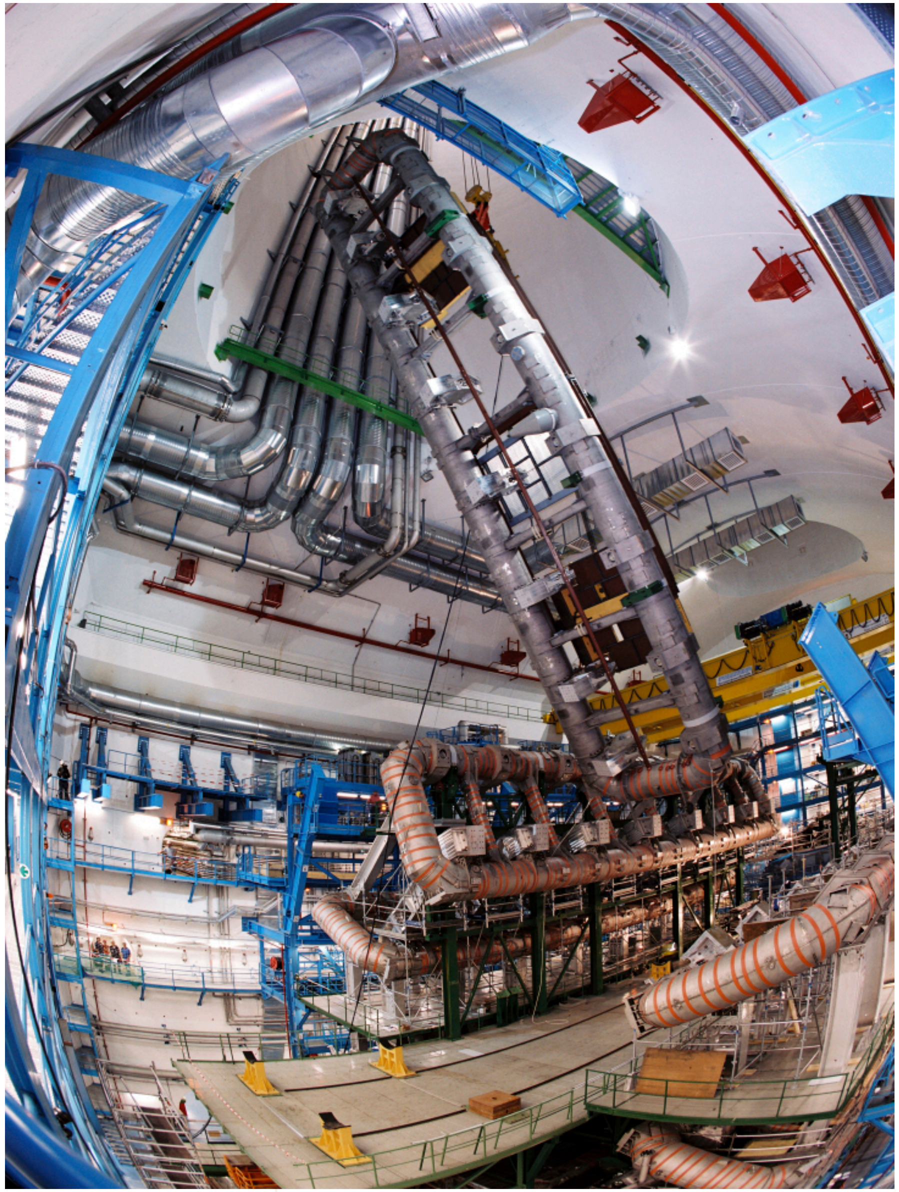
F. 24 July — Broken Symmetries, Massless Particles and Gauge Fields (P.W.H.) sent to Physics Letters editor at CERN.
ACCEPTED

F. 31 July — Broken Symmetries and the Masses of Gauge Bosons (P.W.H.) sent to Physics Letters editor at CERN.
REJECTED

August — Paper revised by adding (inter alia) "It is worth noting that an essential feature of this type of theory is the prediction of incomplete multiplets of scalar and vector bosons"

31 August — Revised paper received by Physical Review Letters.
ACCEPTED

Referee (Nambu) draws to attention of PWH the paper by F. Englert & R. Brout, Broken Symmetry and the Mass of Gauge Vector Mesons (received by Phys. Rev. Letters 22 June, published 31 August)



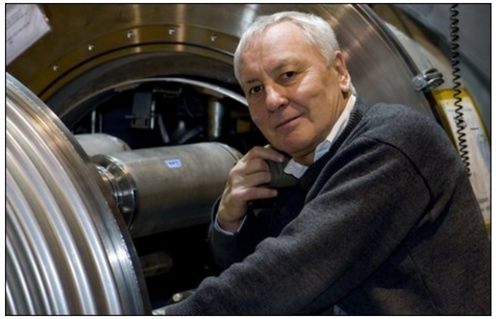
2008

10th september 2008 : first beams around

19th september 2008 : incident

14 months of major repairs

New Quench Protection system



2009

20th november 2009 : first beams around (again)

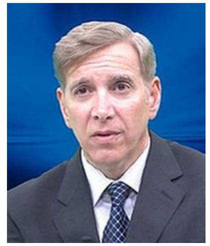
december 2009 : collisions at 2.36 TeV cms

January 2010 : decided scenario 2010-11 7 TeV cms instead of 14 TeV

2010

30th march 2010 : first collisions at 7 TeV cms

august 2010 : luminosity of 10^{31} cm^{-2} s^{-1}



2011

may 2011 : luminosity > 10^{33} cm^{-2} s^{-1}

november 2011 : integrated luminosity ~ 5 fb^{-1}

13^{th} december 2011 : first 'signal' around 126 GeV

2012

march 2012 : start again at 8 TeV

4^{th} July 2012 : evidence for a new boson

(integrated luminosity ~ 6 fb^{-1})

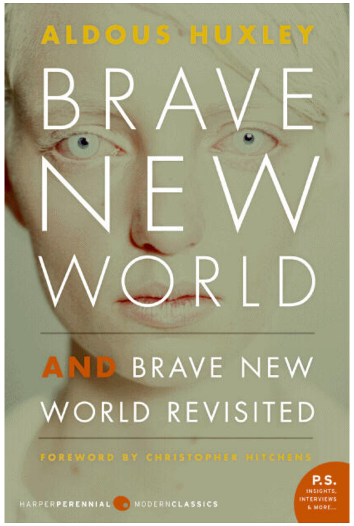
11^{th} December 2012: Milner Foundation: Special Fundamental Physics Prize

18^{th} December 2012: XVIII IFT-UAM/CSIC Christmas Workshop

JULY 2012						
SUN	MON	TUE	WED	THU	FRI	SAT
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

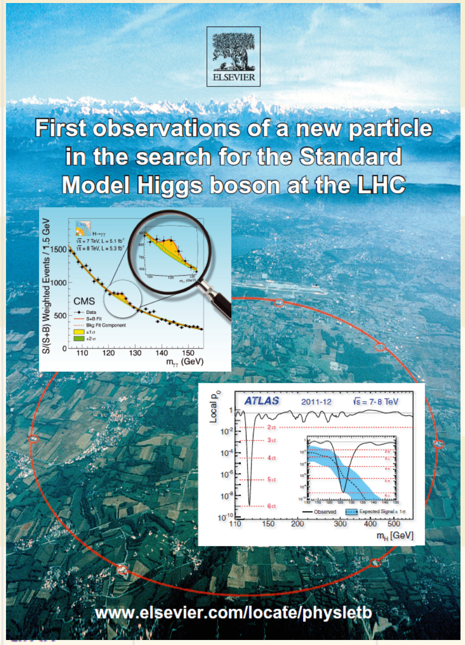
July 2012 Revolution

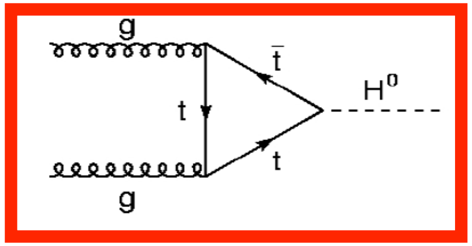
NewWorld



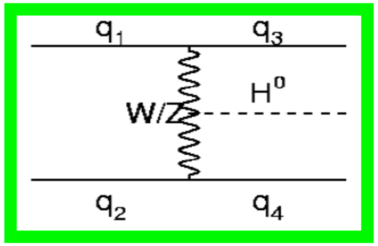
Old World

Full Title	Journal	Links	Status	Lead Group
NEW Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC	PLB	Figures, Inspire, arXiv	Submitted: 2012/07/31	HIGGS
NEW Measurement of charged-particle event shape variables in √s = 7 TeV proton-proton interactions with the ATLAS detector	PRD			
NEW Search for magnetic monopoles in √s = 7 TeV pp collisions with the ATLAS detector	PRL			
NEW Measurements of top quark pair relative differential cross-sections with ATLAS in pp collisions at √s = 7 TeV	EPJC			
NEW Search for top and bottom squarks from gluino pair production in final states with missing transverse energy and at least three b-jets with the ATLAS detector	EPJC			
NEW A search for ttbar resonances in lepton+jets events with highly boosted top quarks collected in pp collisions at √s = 7 TeV with the ATLAS detector	JHEP			
NEW Measurement of the Lambda_b lifetime and mass in the ATLAS experiment	PRD			
Combined search for the Standard Model Higgs boson in pp collisions at √s = 7 TeV with the ATLAS detector	PRD	Figures, Inspire, arXiv	Accepted (Submitted: 2012/07/02)	HIGGS

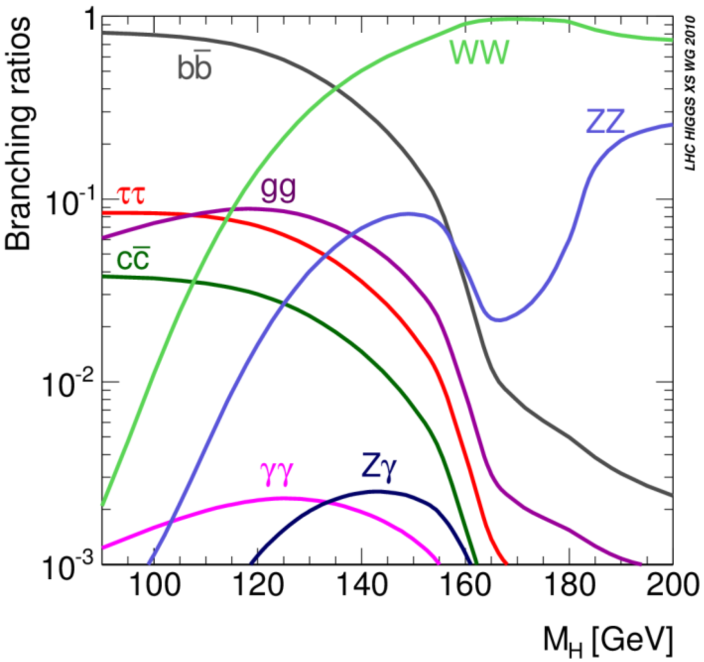




GF H → WW , ZZ , γγ , bb, ττ

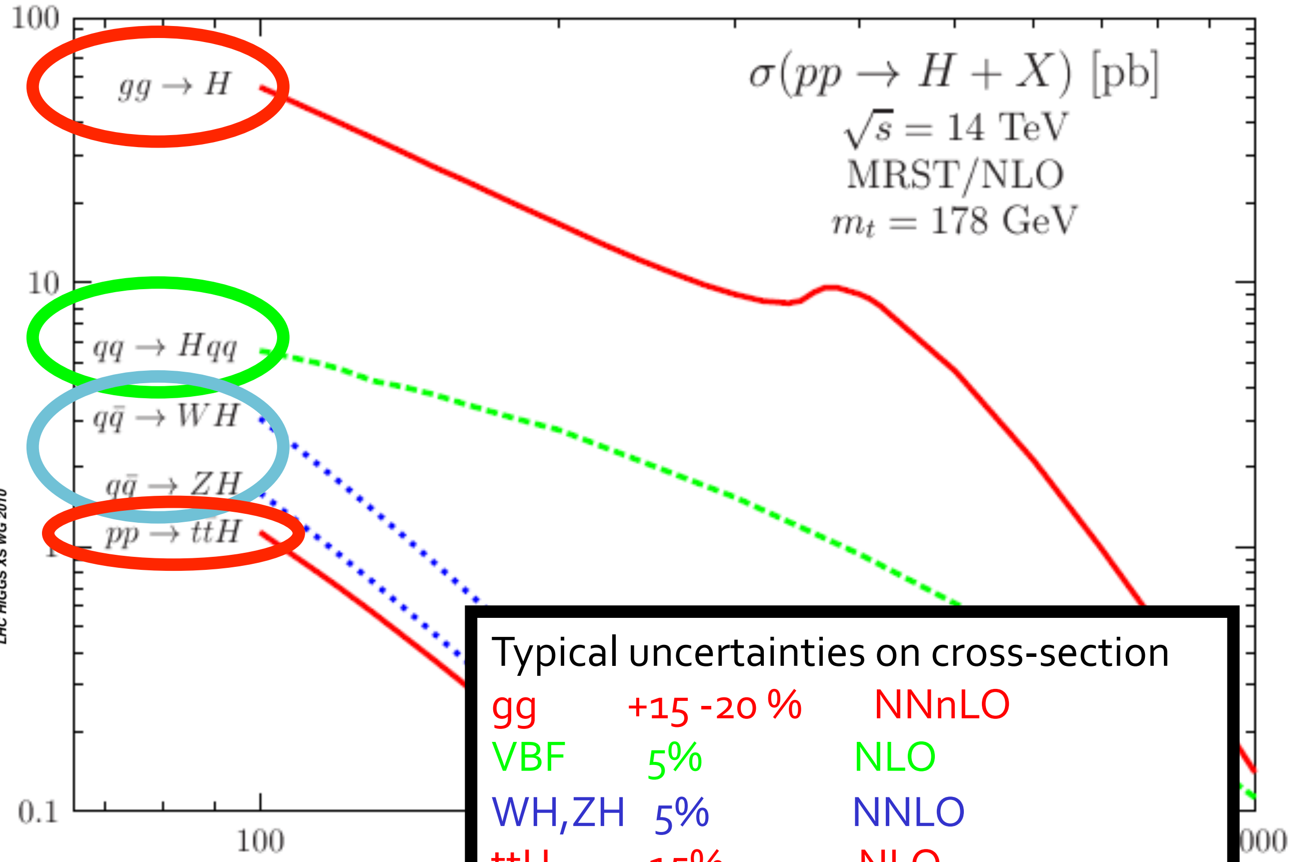


VBF H → WW, ZZ , γγ , ττ



- A.Djouadi Phys.Rept.457:1-216
- Huge progress in theory: signals and (complex) backgrounds

→ Major achievement of the theory community; very fruitful discussions with the experiments (e.g. through LHC Higgs x-sn WG,LPCC..)



Typical uncertainties on cross-section

gg	+15 -20 %	NNnLO
VBF	5%	NLO
WH,ZH	5%	NNLO
ttH	15%	NLO

These production cross sections are used with the decays bb , ττ , WW , ZZ , γγ

HXSWG

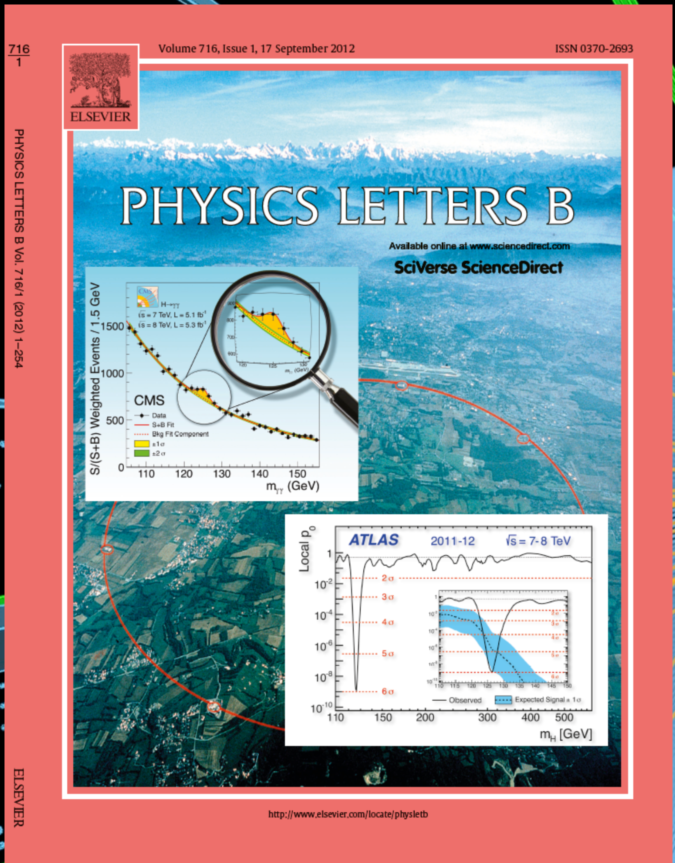
From Discovery to Measurements

I. (nano) Review of Recent Results on SM Higgs Channels

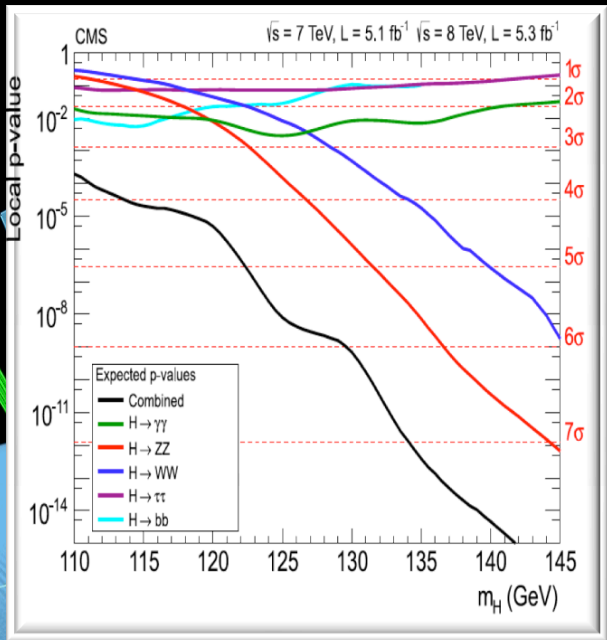
II. Update of Higgs analyses in $H \rightarrow \gamma\gamma$ and $H \rightarrow 4l$ Channels

III. First Spin and Parity Studies

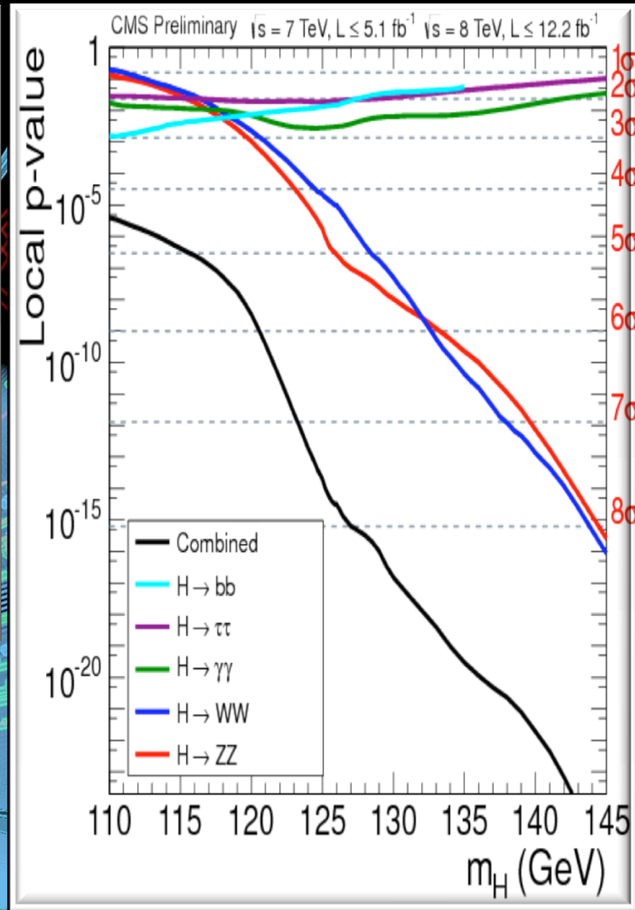
Higgs



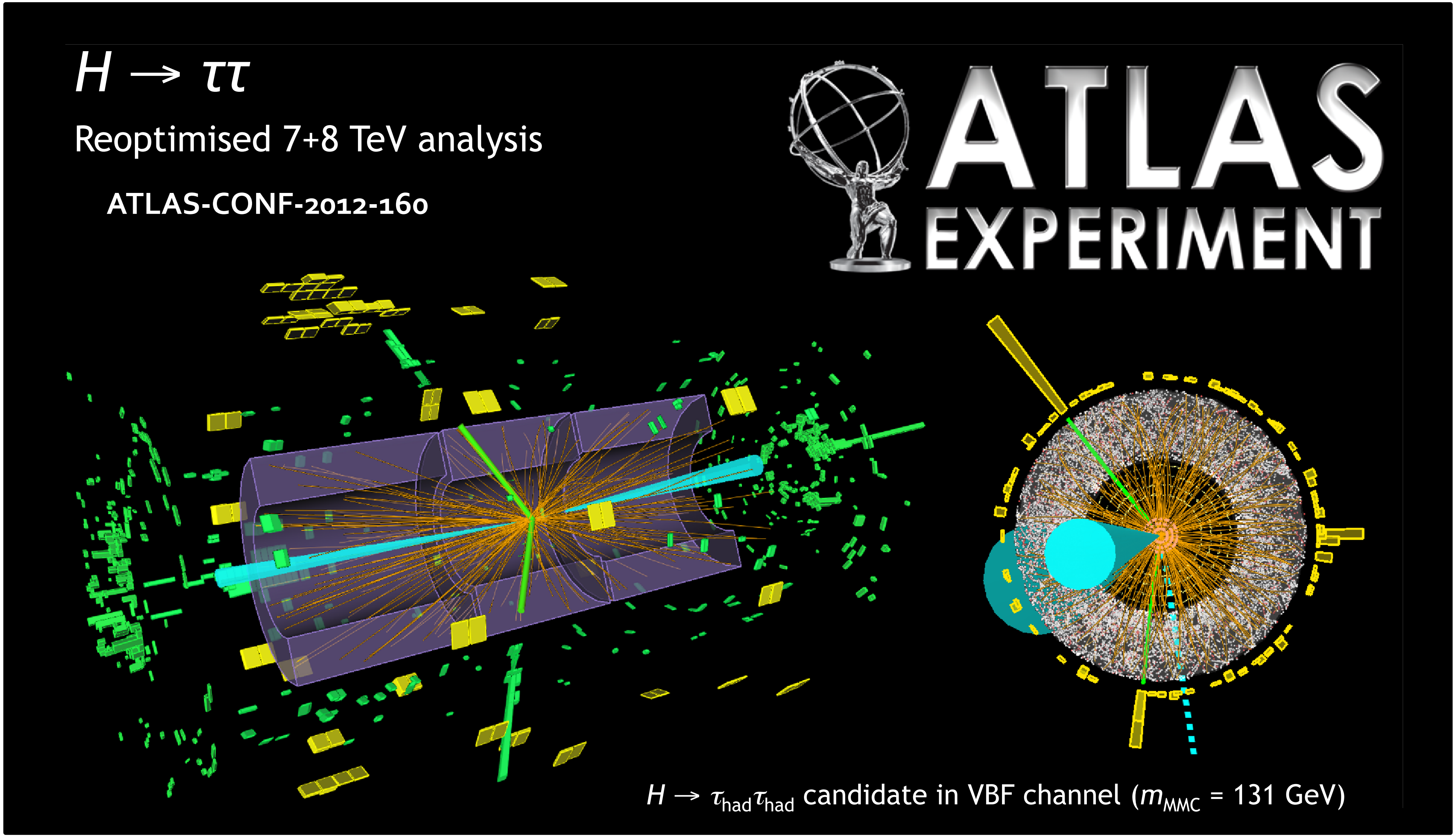
Jul 4th 2012



HCP Nov 2012



CMS performance increase:
Sensitivity up from 5.8 to 7.8 σ

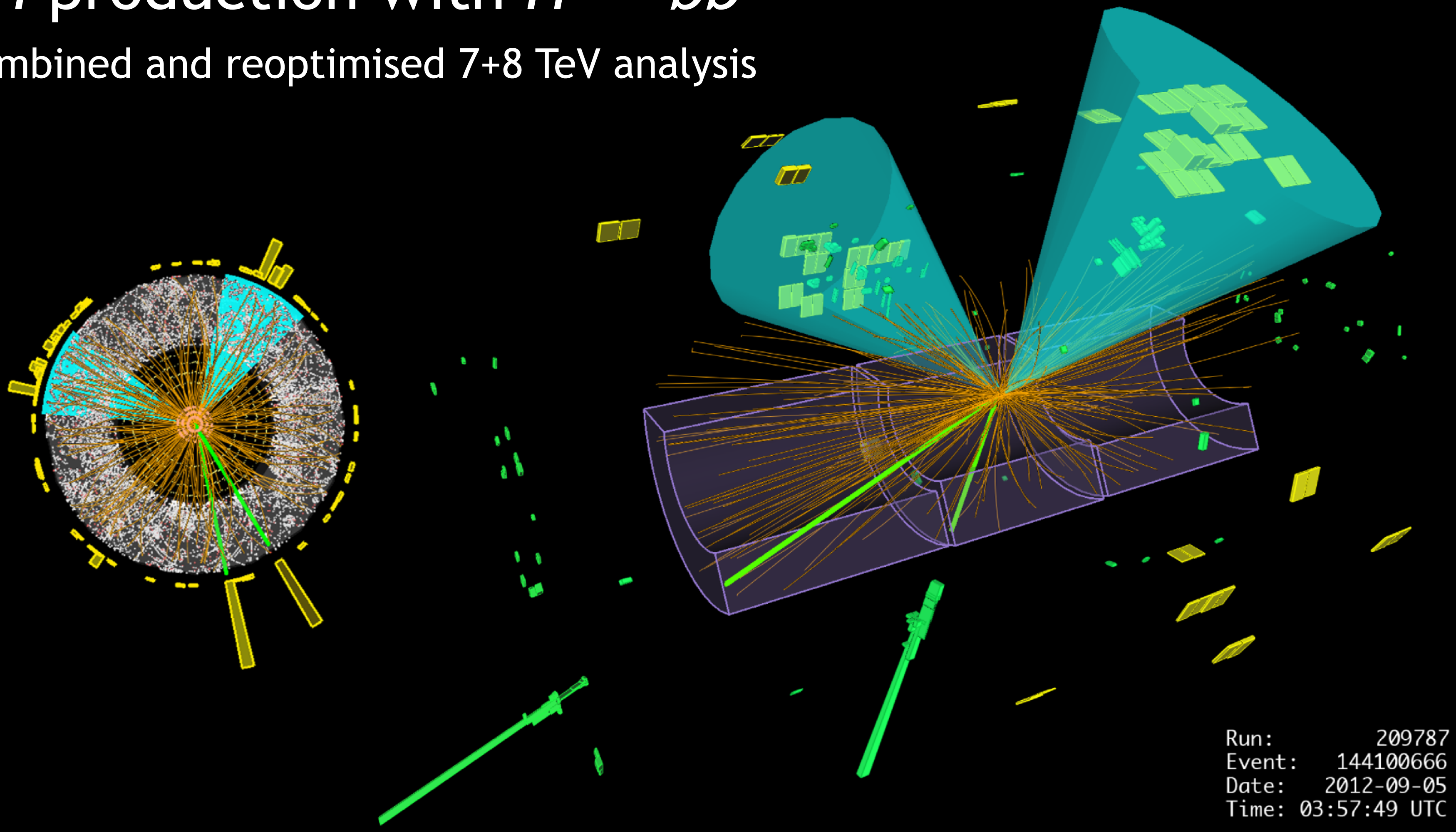


ττ channel basic facts sheet :

Signal (SM)	Signal purity s/b	Main backgrounds	Production	7 & 8 TeV $\int L\,dt$
~330	0.3% - 30%	ZZ, Z+jets, top	VBF, Hgg, VH	4.9 & 13 fb^{-1}

VH production with $H \rightarrow bb$

Combined and reoptimised 7+8 TeV analysis

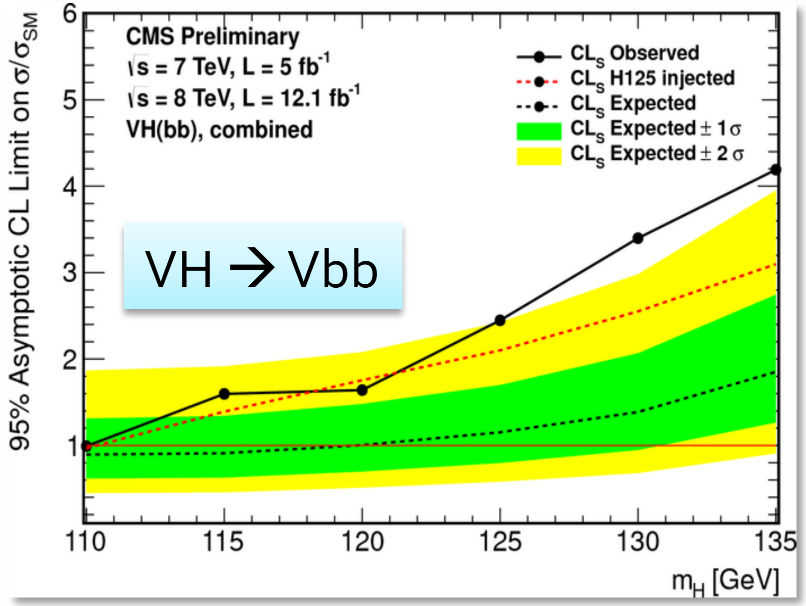


VH(bb) channel basic facts sheet :

Signal (SM)	Signal purity s/b	Main backgrounds	Production	7 & 8 TeV $\int L\,dt$
~50	~1% - 10%	Wbb,Zbb, top, etc…	VH	4.9 & 13 fb^{-1}

Fermions

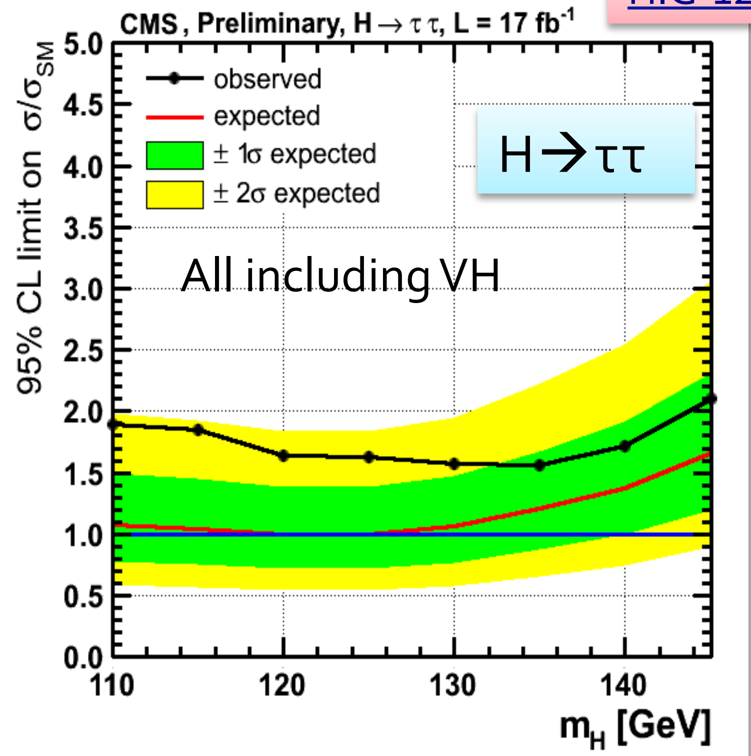
HIG-12-044

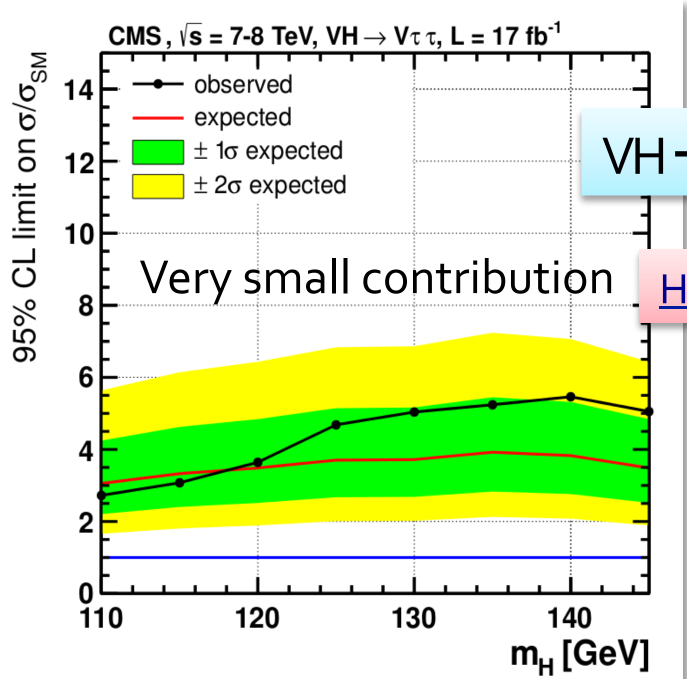


Mild excess of 2.2 σ building up

- Coherent picture between the sub channels Z(ll)H(bb); Z(νν) H(bb); W(lν) H(bb) need more statistics

HIG-12-043





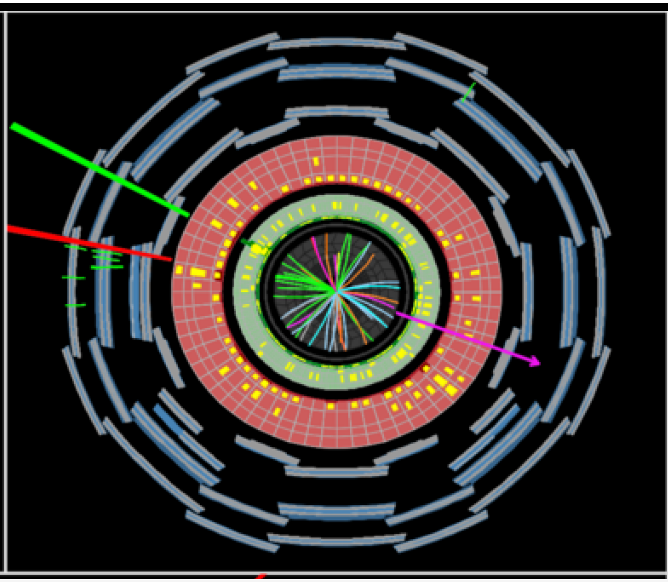
HIG-12-051

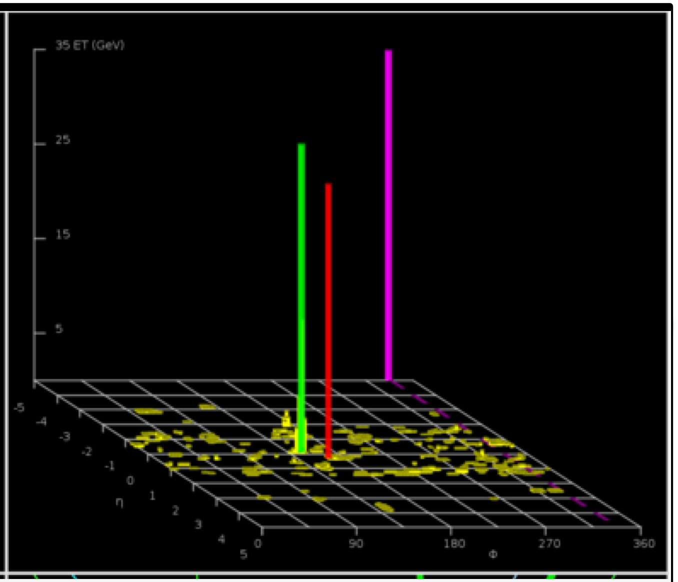
Very mild excess is building up at 1.3 σ level

$H \to WW^{(*)}$
$e\mu + 2\nu$

0,1 jet Channel

ATLAS-CONF-2012-158





- ❑ Most sensitive channel over ~ 130-180 GeV (σ ~ 200 fb)
- ❑ However: challenging: 2ν → no mass reconstruction/peak → “counting channel”
- ❑ 2 isolated opposite-sign leptons, large E_T^{miss}
- ❑ Main backgrounds: WW, top, Z+jets
  - → $m_{ll} \neq m_Z$, b-jet veto, ...
  - → Topological cuts against “irreducible” WW background: p_{Tll}, m_{ll}, $\Delta\phi_{ll}$ (smaller for scalar Higgs), m_T (ll, E_T^{miss})

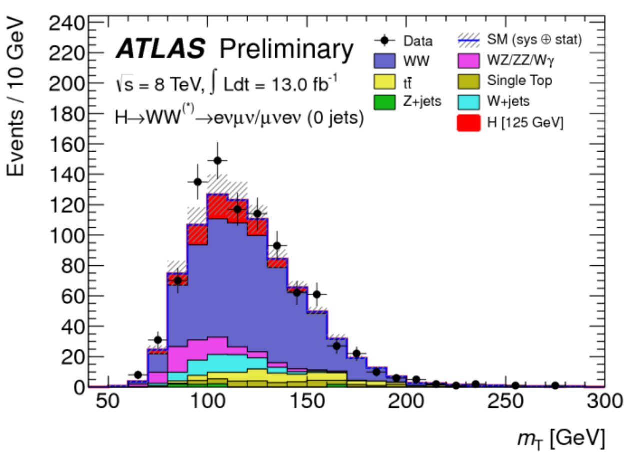
WW channel basic facts sheet :

Signal	Signal purity s/b	Main backgrounds	Production	8 TeV $\int L\,dt$
~110	~10%	WW, W+jets, top, etc...	ggH	13 fb^{-1}

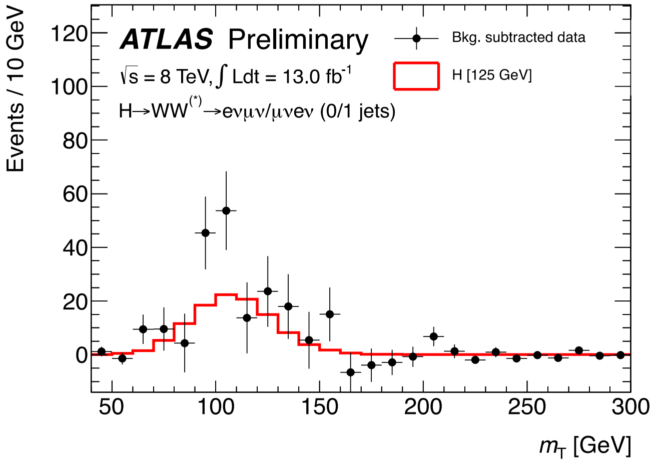
ATLAS-CONF-2012-158

$H \rightarrow WW^{(*)} \rightarrow e\mu + 2\nu$

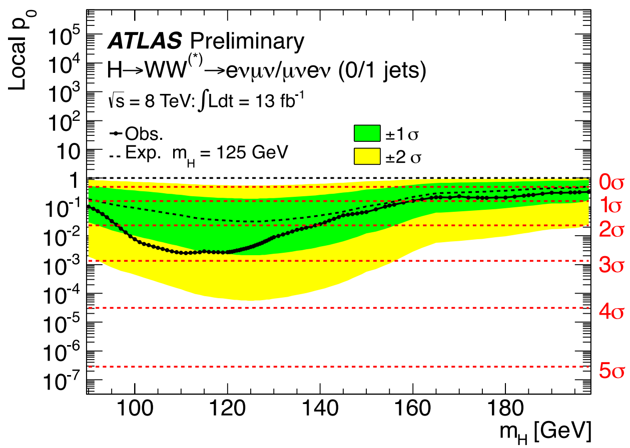
Different-flavour channel and 8 TeV (13 fb^{-1}) 0 and 1-jet



Transverse mass (signal region)



Background subtracted transverse mass



- Main discrimination with: m_{ll}, Δf_{ll}, m_T
- Main backgrounds estimated from control regions

$\mu = \sigma/\sigma_{SM}$ Signal strength:

Ratio of measured event yield to that expected from the Standard Model Higgs signal

μ(125 GeV) = 1.5 ± 0.6

Observed Significance (125 GeV): 2.6σ

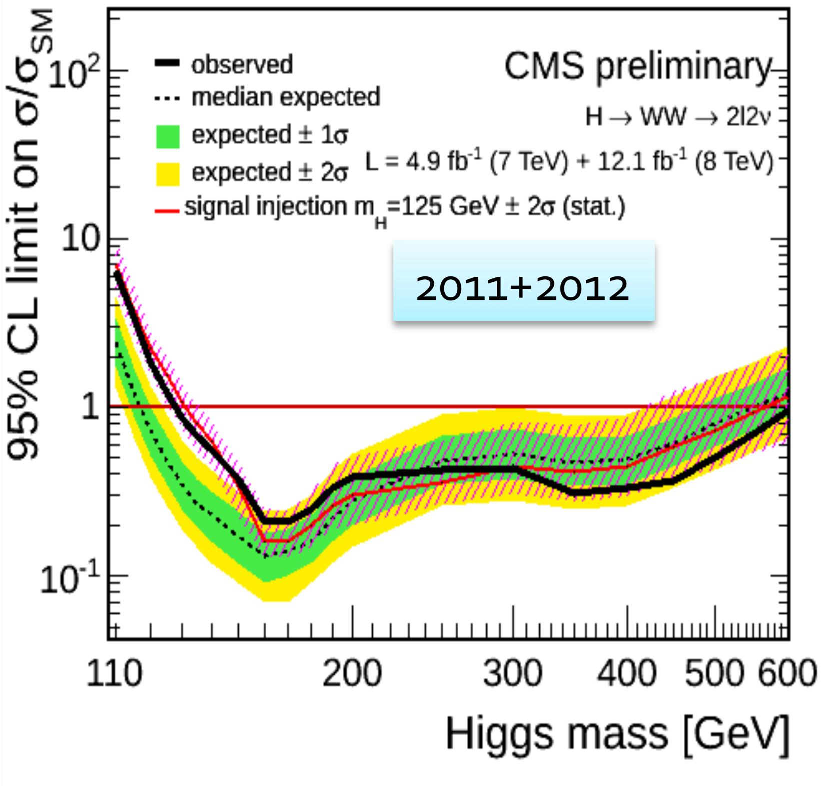
Expected Significance : 1.9σ

$H \rightarrow WW^{(*)}$

7 TeV L=5.1 fb^{-1}, 8 TeV, L=12.2 fb^{-1}

WW→2l2ν

HIG-12-042



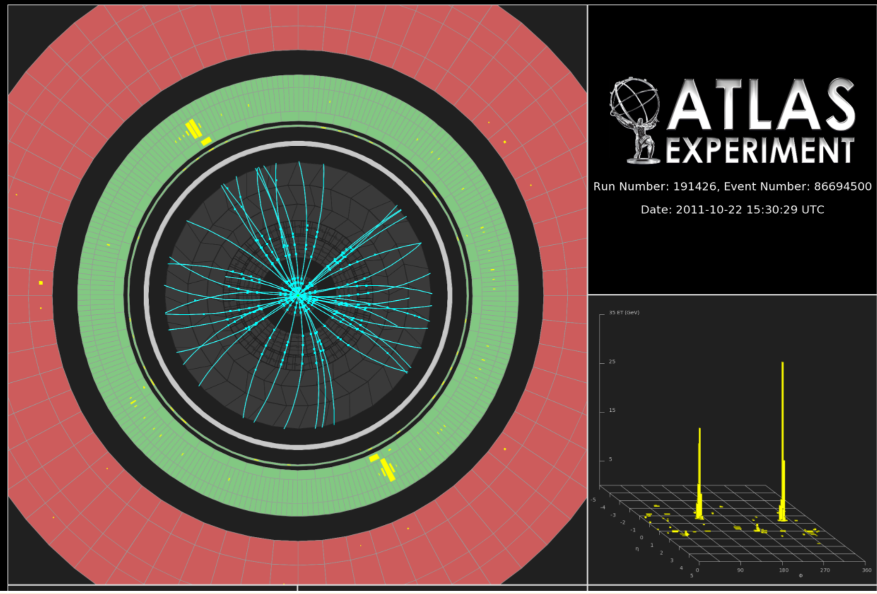
Significant excess

- Observed: 3.1 σ and expected: 4.1 σ

$H \rightarrow \gamma\gamma$ Update

Since "Discovery Paper" PLB 716

ATLAS-CONF-2012-168



- Small cross-section: $\sigma \sim 40$ fb
- Simple final state: two high-p_T photons
  $E_T(\gamma_1, \gamma_2) > 40, 30$ GeV
- Main background: $\gamma\gamma$ continuum (irreducible, smooth, ..)
- Events divided into categories based on η-photon
  (e.g. central, rest, …), converted/unconverted, $p_T^{\gamma\gamma}$ along thrust axis

$\gamma\gamma$ channel basic facts sheet :

Signal ($SM_{126\,GeV}$)	Signal purity s/b	Main backgrounds	Production	7 & 8 TeV
~330	2% - 20%	$\gamma\gamma$, γj and jj	Hgg, VBF, VH	4.9 & 13 fb^{-1}

$H \rightarrow \gamma\gamma$

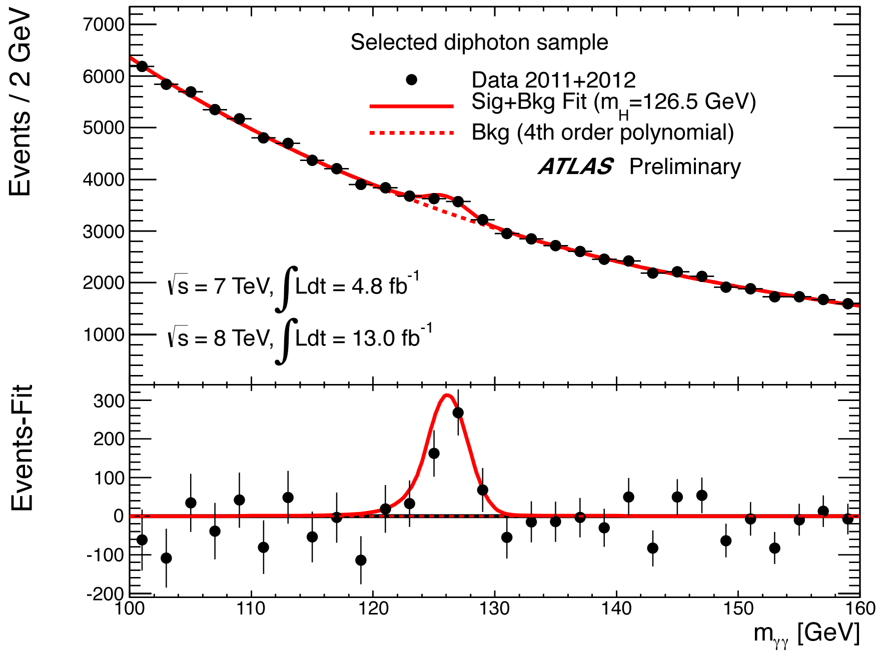
Simple topology: two high-p_T isolated photons E_T (γ_1, γ_2) > 40, 30 GeV

To increase sensitivity, overall and to specific production processes 12 exclusive categories:

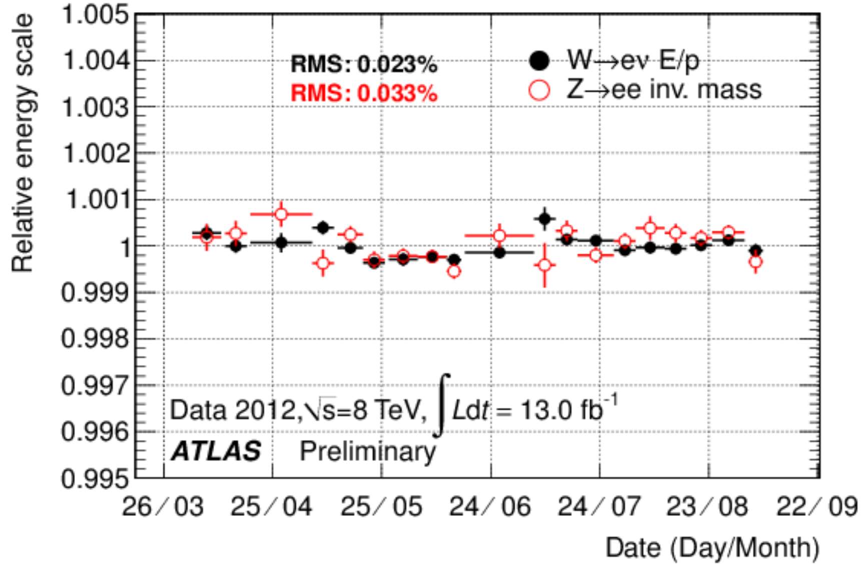
- γ rapidity, converted/unconverted γ, p_{Tt}($p_T^{\gamma\gamma}$ perpendicular to $\gamma\gamma$ "thrust" axis)
- presence of 2 high-mass (m_{jj} 400 GeV) forward jets target VBF process

- 1 lepton → target W/Z/ttH
- Low-mass di-jet (60 <m_{jj}<100 GeV) jets → target W/ZH

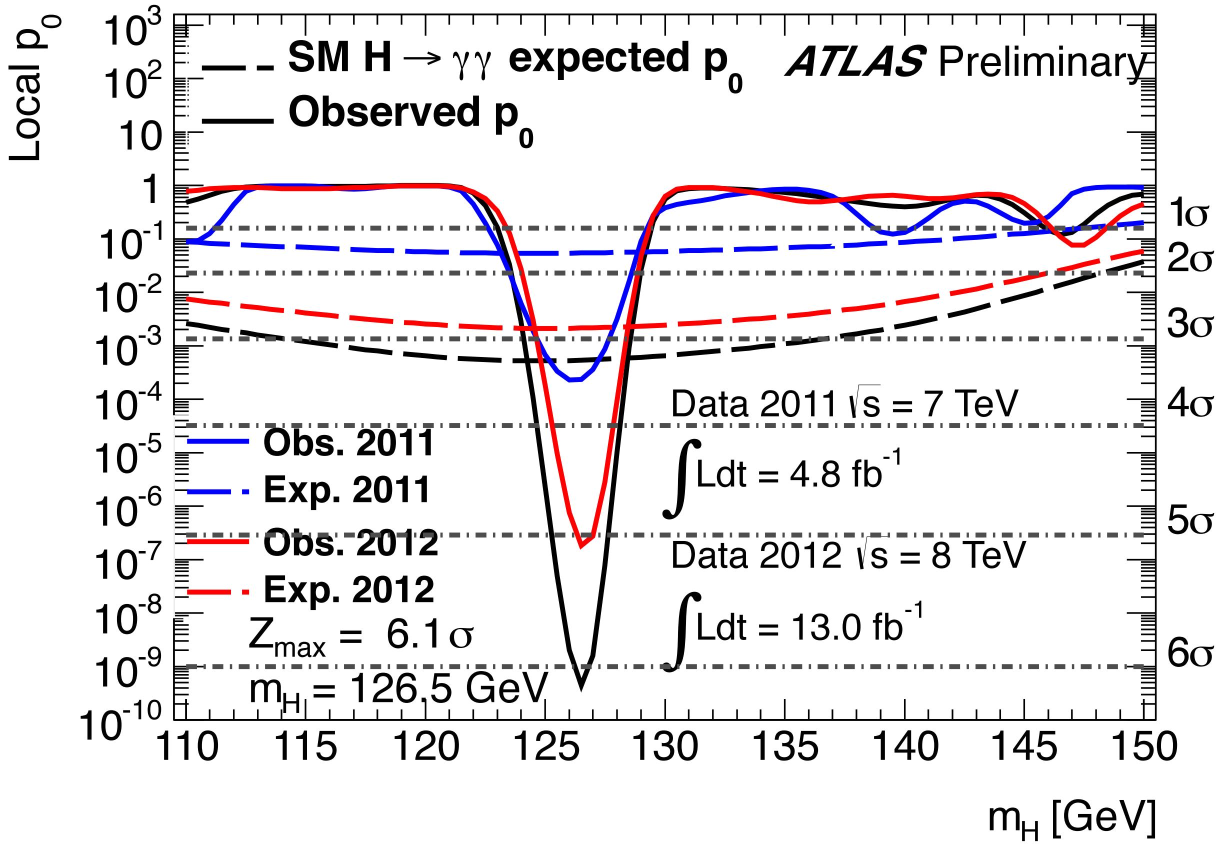
NEW since PLB716



Stability of EM calorimeter response vs time (and pile-up) <0.1%



$H \to \gamma\gamma$ Signal Confirmation and Single Channel Discovery



Observed local significance:

6.1σ

Expected local significance:

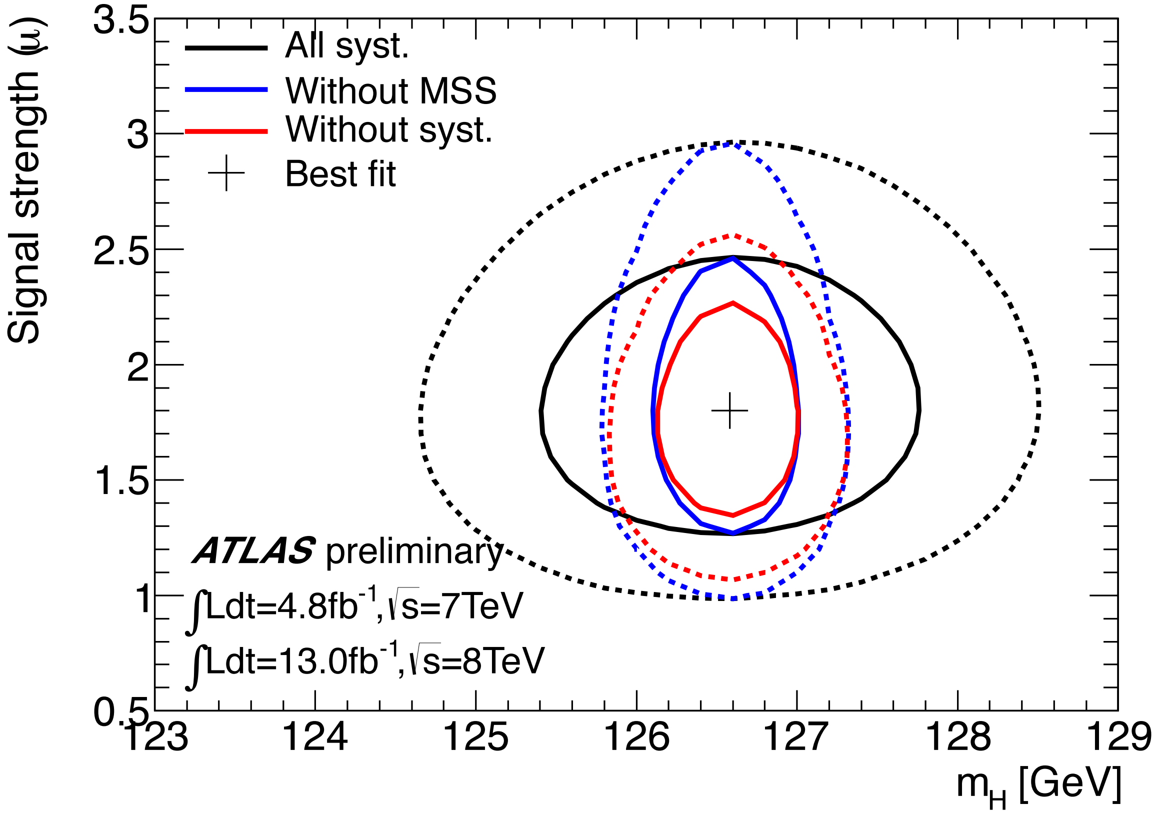
3.3σ

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

$H \to \gamma\gamma$ signal is confirmed

$H \rightarrow \gamma\gamma$ mass measurement

ATLAS-CONF-2012-168

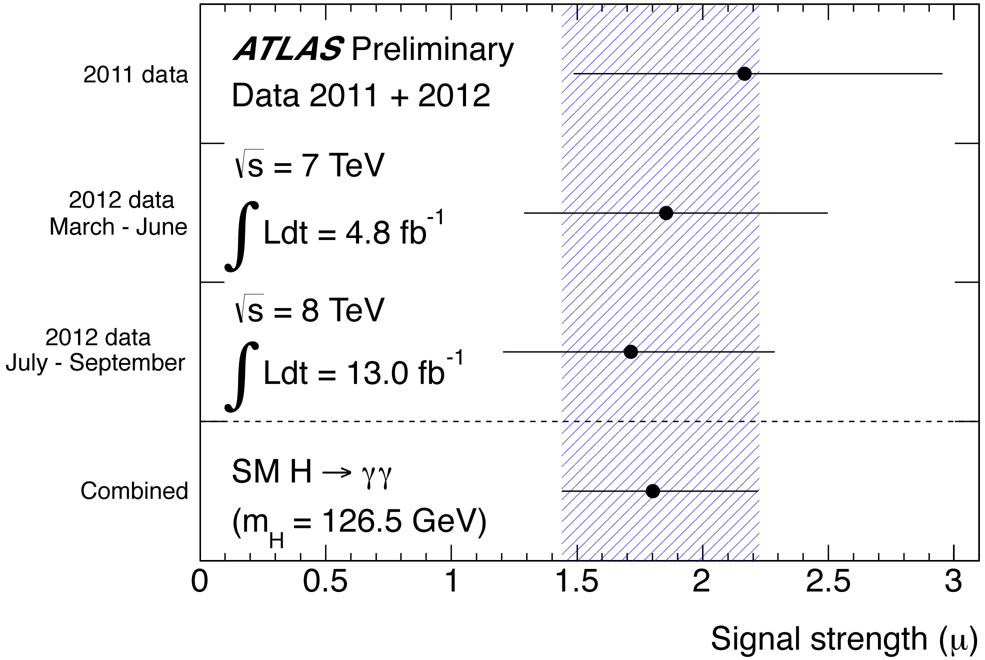


Measurement of a narrow resonance:

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

$H \to \gamma\gamma$ Signal Strength

ATLAS-CONF-2012-168



Measurement of signal strength :

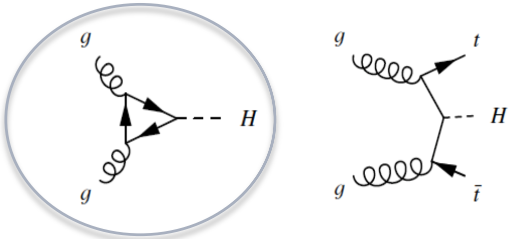
(at best fit mass 126.5 GeV)

$$\hat{\mu} = 1.8 \pm 0.3\ (stat)^{+0.29}_{-0.21}\ (syst)$$

Signal strength for different production modes :

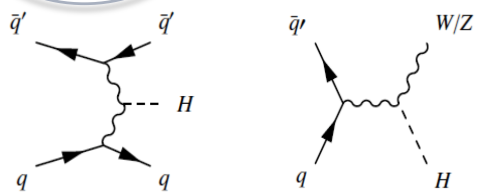
Fermion couplings dominated modes

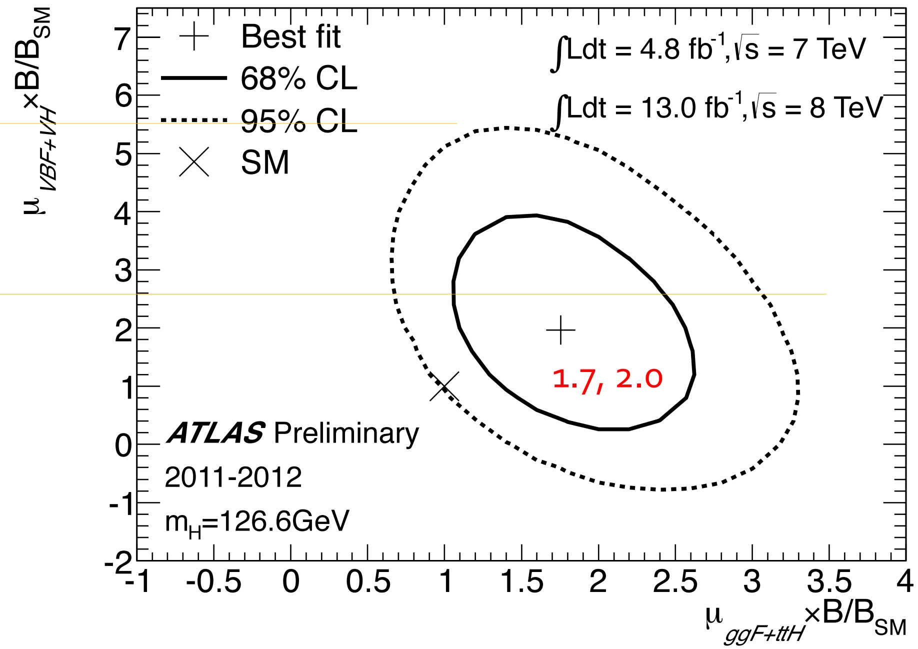
ggH+ttH



Vector boson dominated modes

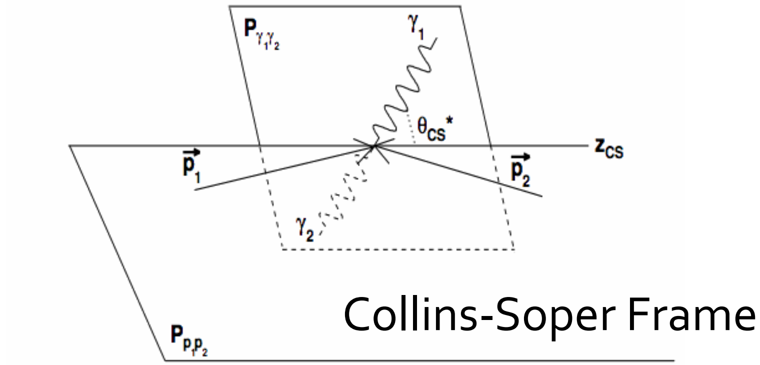
VBF+VH





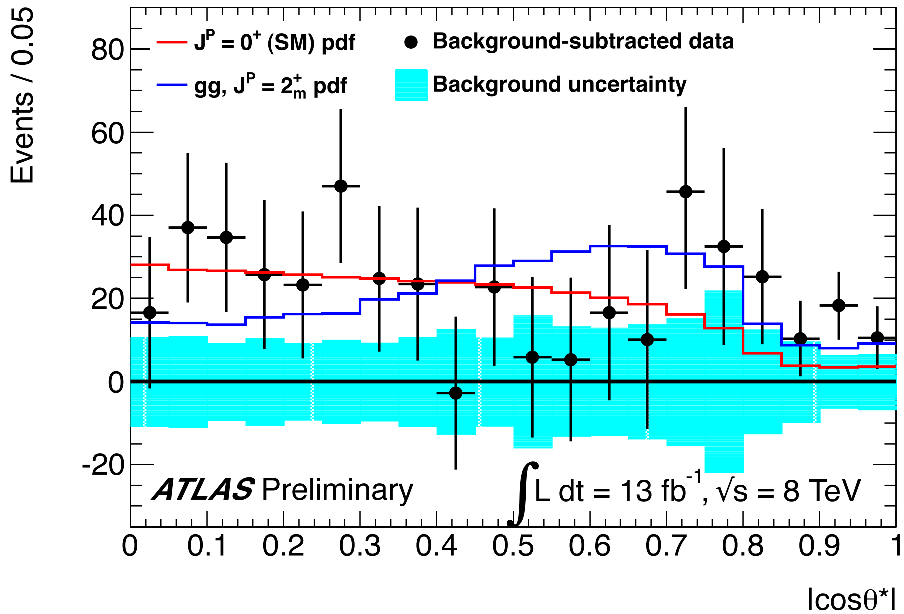
Spin Analysis in the $H \to \gamma\gamma$ Channel

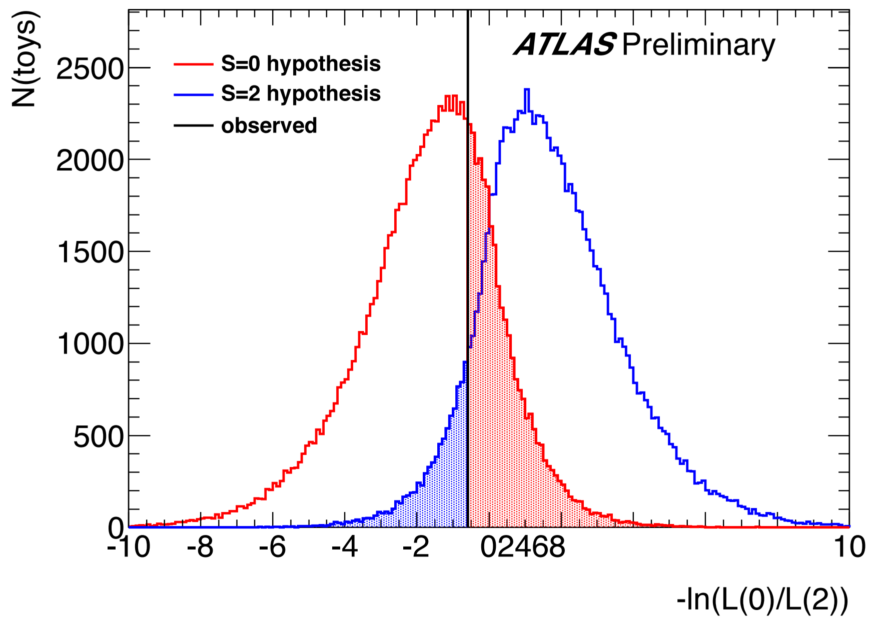
0^+ vs 2^+



Using the inclusive analysis

- Sensitive variable is dihoton cos θ* distribution
- Use events within 1.5σ of the peak (m_H=126.5 GeV)



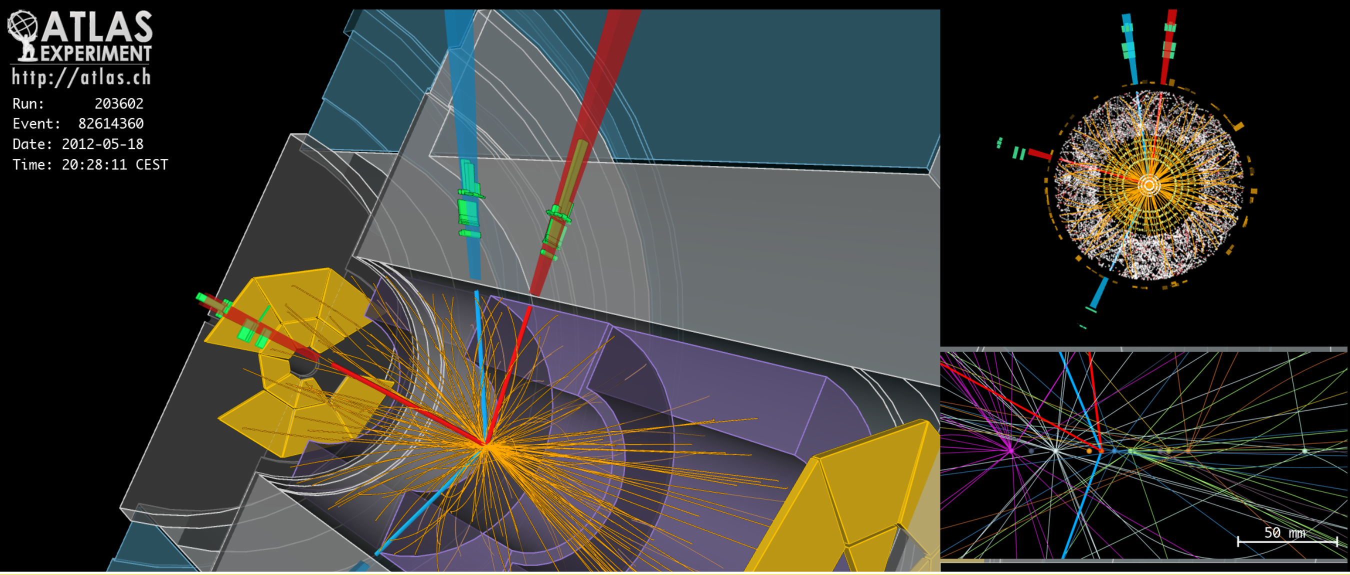


- Expected sensitivity: exclusion of the spin 2^+ hypothesis at the 97% CL
- Observed exclusion of spin 2^+ hypothesis at the 91% CL

Observation compatible with spin 0 (within 0.5σ)

ATLAS-CONF-2012-168

$H \rightarrow 4l$



σ ~ 2-5 fb

Crucial experimental aspects:

- ❑ High lepton reconstruction and identification efficiency down to lowest p_T
- ❑ Good lepton energy/momentum resolution
- ❑ Good control of reducible backgrounds (Zbb, Z+jets, tt) in low-mass region:
  - → cannot rely on MC alone (theoretical uncertainties, b/q-jet → l modeling, ..)
  - → need to compare MC to data in background-enriched control regions (but: low statistics ..)

→ Conservative/stringent p_T and m(ll) cuts used at this stage

4l channel basic facts sheet :

Signal	Signal Purity s/b	Main backgrounds	Production	7 & 8 TeV
~10	~1	ZZ, Z+jets, top	All inclusive	4.9 & 13 fb⁻¹

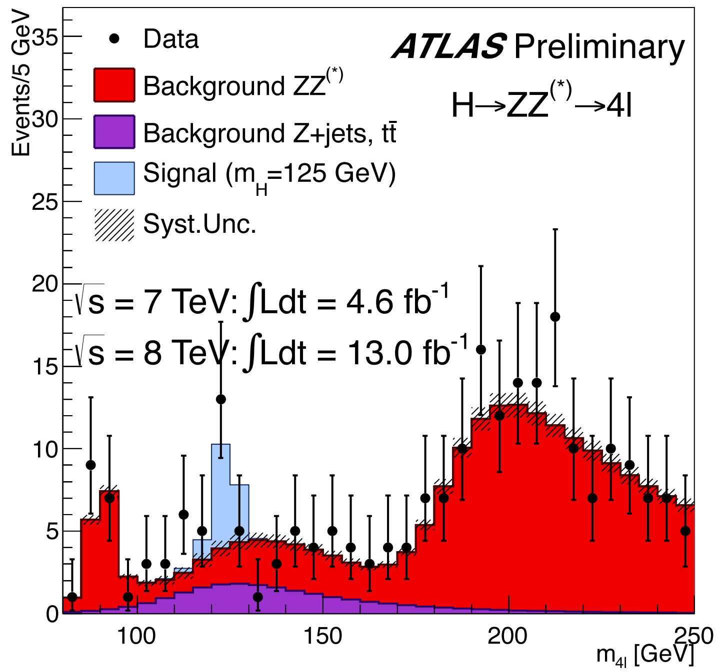
$H \to 4l$

Simple selection :

- 4 leptons: $p_T^{1,2,3,4}$ > 20,15,10,7-6 (e-μ) GeV
- 50 < m_{12} < 106 GeV
- m_{34} > 17.5 GeV

In the signal region 125 ± 5 GeV

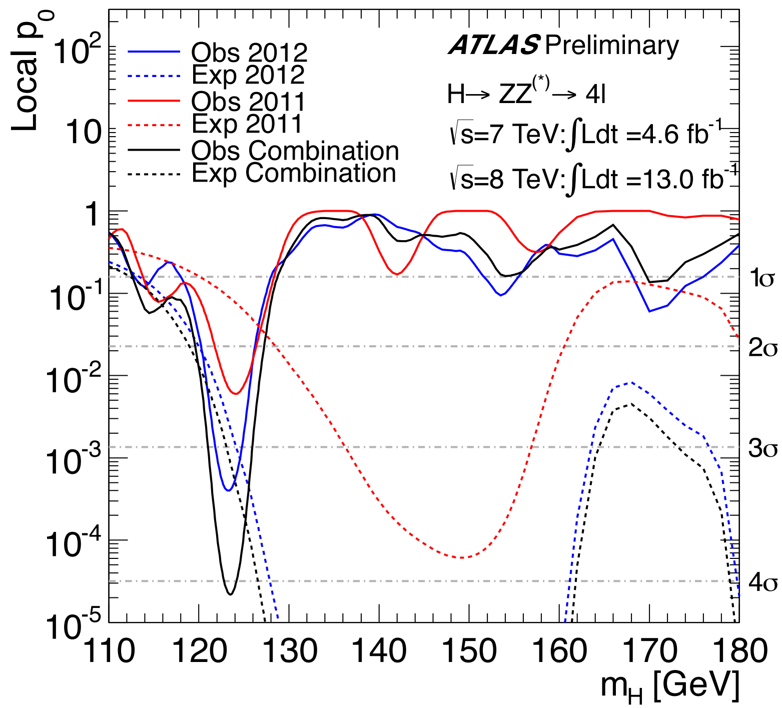
Observed	18 events
Expected from bkg only	8.3 ± 0.3
Expected from SM Higgs	9.9 ± 1.3



Observed local significance: 4.1σ

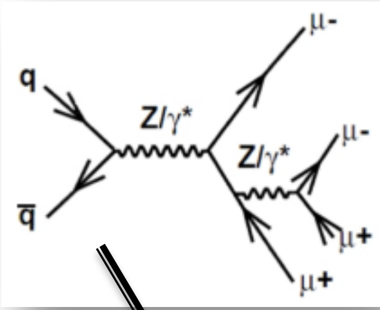
Expected local significance: 3.1σ

2011	124.1 GeV	2.5σ	(exp. 1.4σ)
2012	123.3 GeV	3.4σ	(exp. 2.8σ)



$H \to 4l$ signal is confirmed

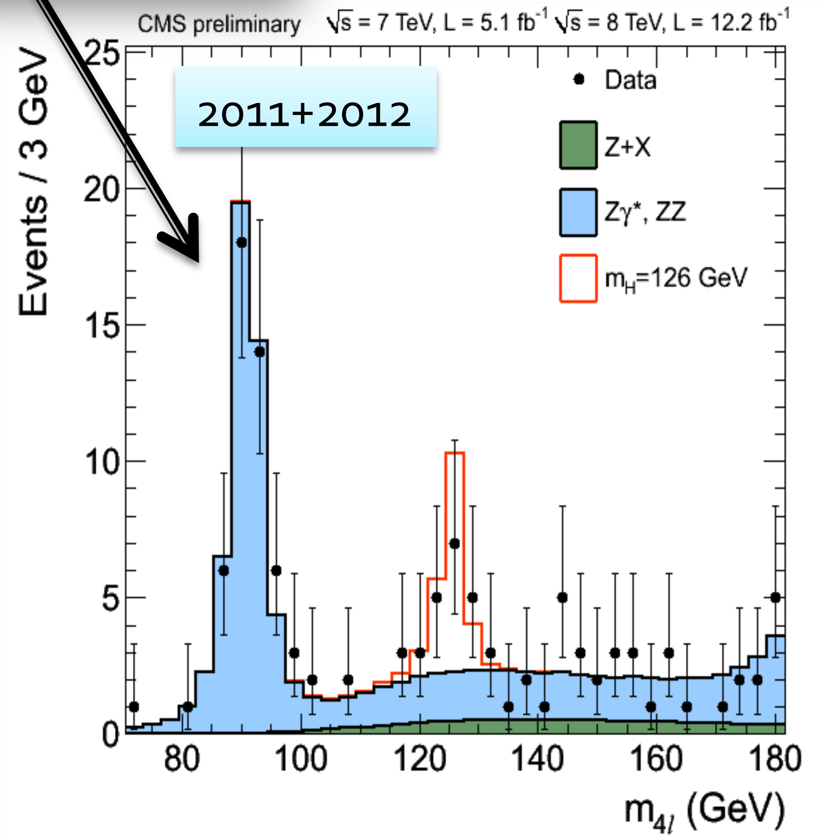
$H \to 4l$

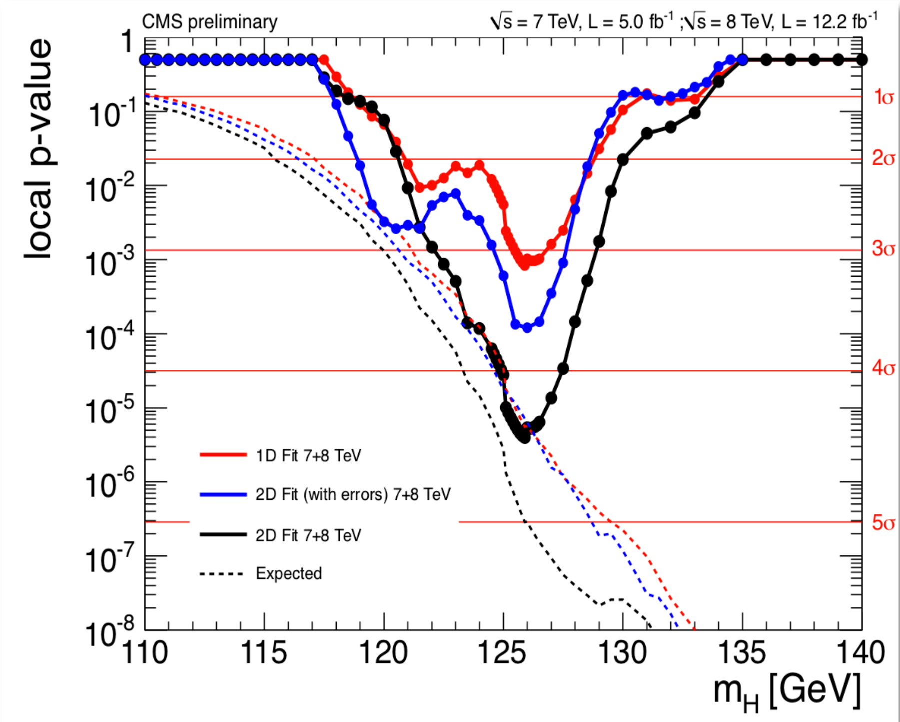


ZZ→4l

HIG-12-041

2011+2012





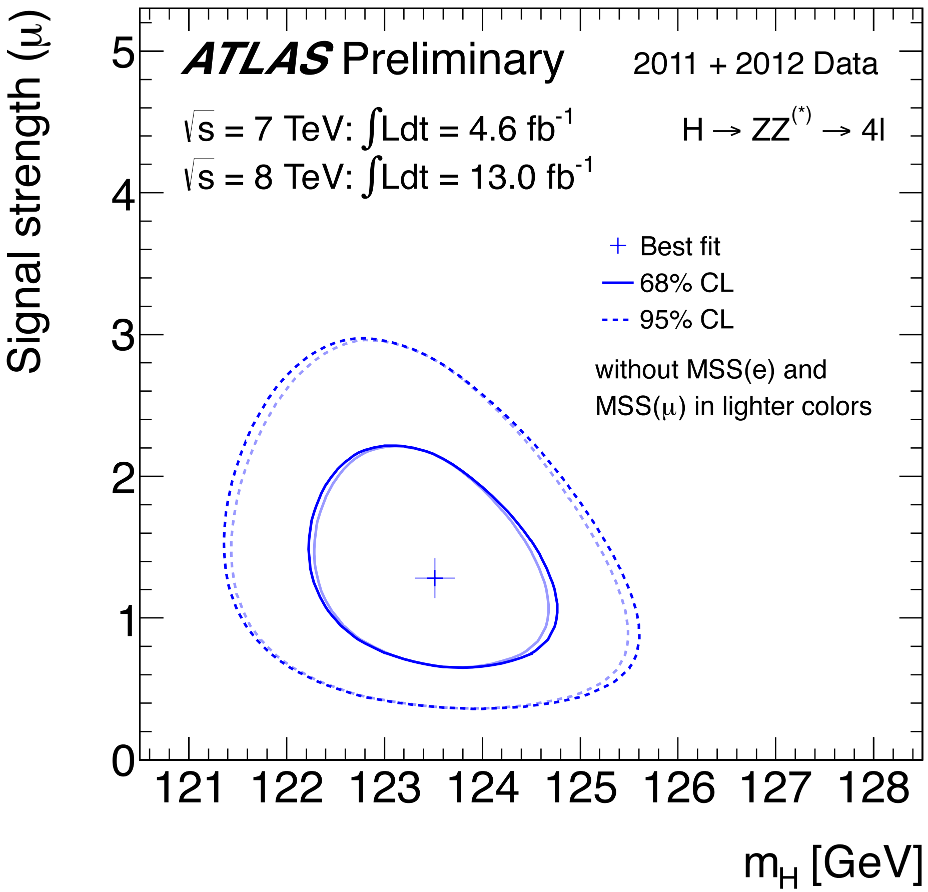
Significance now 4.6 σ

Channel	4e	4μ	2e2μ	4ℓ
ZZ background	4.7 ± 0.6	9.6 ± 1.0	12.5 ± 1.4	26.8 ± 1.8
Z+ X	$3.4^{+3.0}_{-2.3}$	$1.6^{+1.2}_{-0.9}$	$5.6^{+5.4}_{-3.6}$	$10.6^{+5.3}_{-4.4}$
All backgrounds	$8.0^{+3.1}_{-2.3}$	$11.2^{+1.6}_{-1.4}$	$18.1^{+5.6}_{-3.8}$	$37.3^{+6.6}_{-4.7}$
m_H = 125 GeV	2.4 ± 0.4	4.6 ± 0.5	5.9 ± 0.7	12.9 ± 0.9
m_H = 126 GeV	2.7 ± 0.4	5.1 ± 0.6	6.6 ± 0.8	14.4 ± 1.1
Observed	12	16	19	47

Yields for m(4l)=110..160 GeV

$H \rightarrow 4l$ Mass and Signal Strength Measurements

ATLAS-CONF-2012-169



Measurement of signal strength

$$\hat{\mu} = 1.3 \pm 0.4$$

Measurement of narrow resonance mass

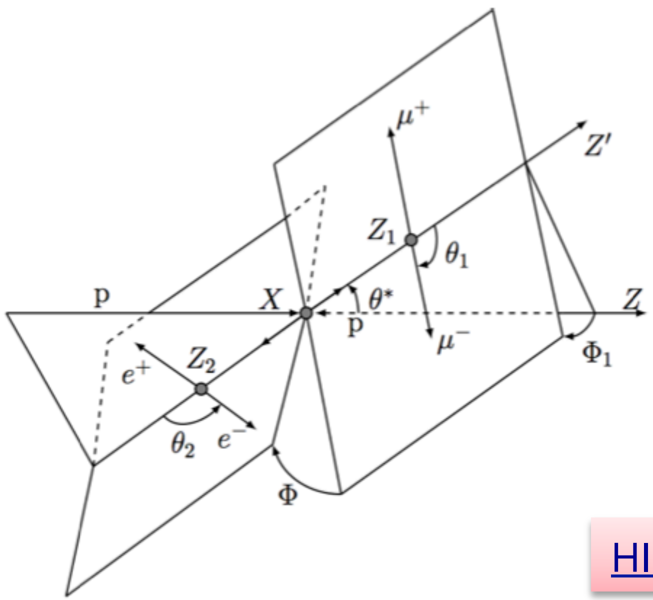
$$m_H = 123.5 \pm 0.9\ (stat)\ ^{+0.4}_{-0.2}\ (syst)\ \text{GeV}$$

Parity Analysis in the $H \to 4l$ Channel

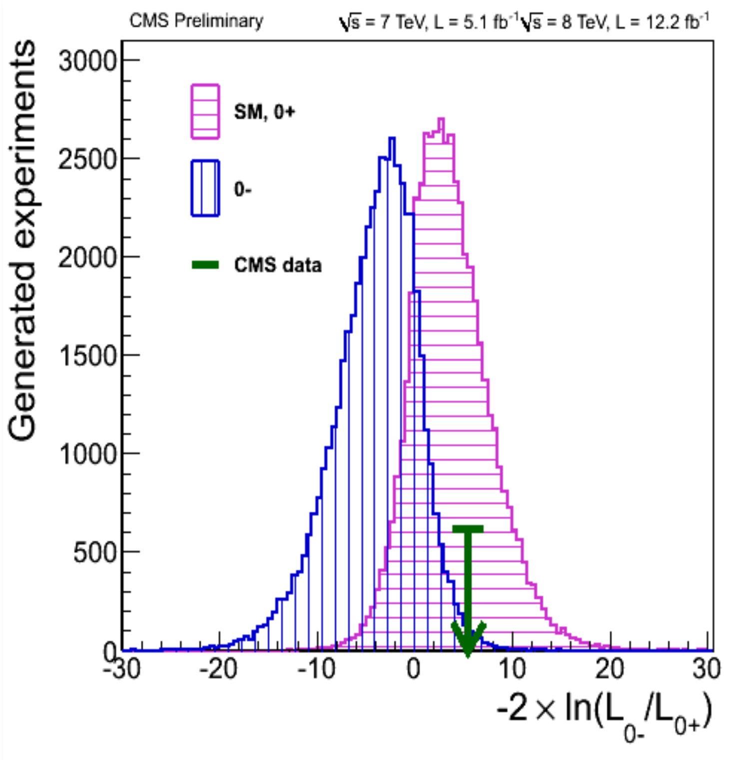
0^+ vs 0^-

$$\text{pseudo MELA} = \left[1 + \frac{\mathcal{P}_{0^-}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{0^+}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

7 TeV L=5.1 fb^{-1}, 8 TeV, L=12.2 fb^{-1}



HIG-12-041



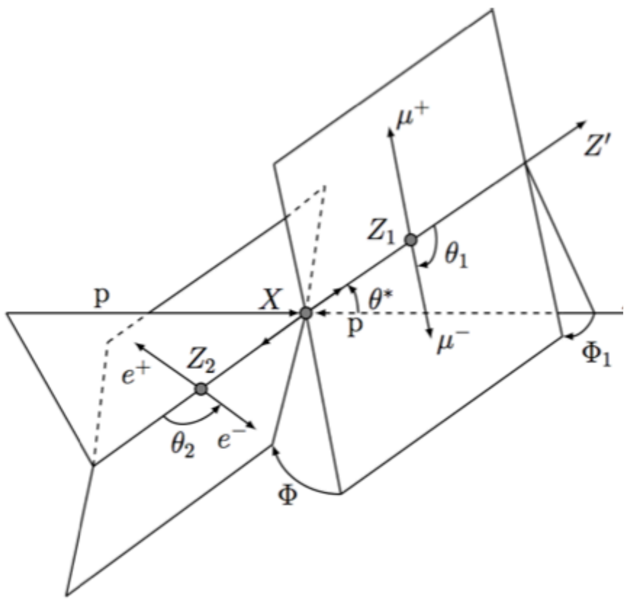
Expected separation between 0^+ and 0^- : 2σ
Scalar (0^+): data consistent (0.5 σ)
Pseudo-scalar (0^-): data different by 2.4 σ

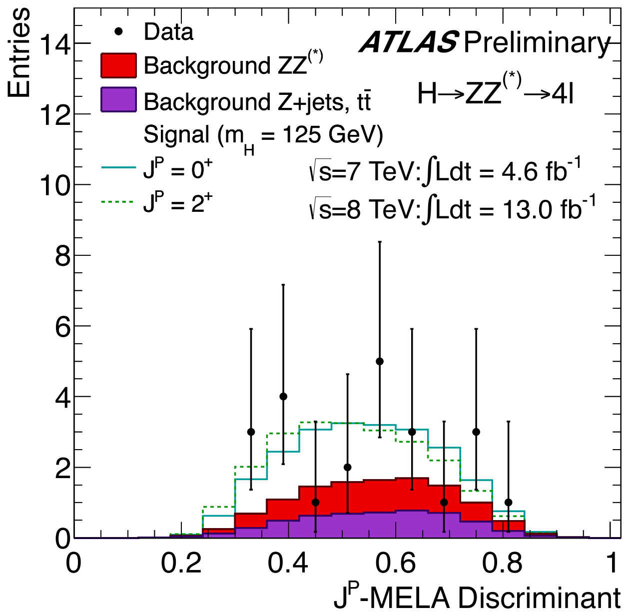
Spin Analysis in the $H \rightarrow 4l$ Channel

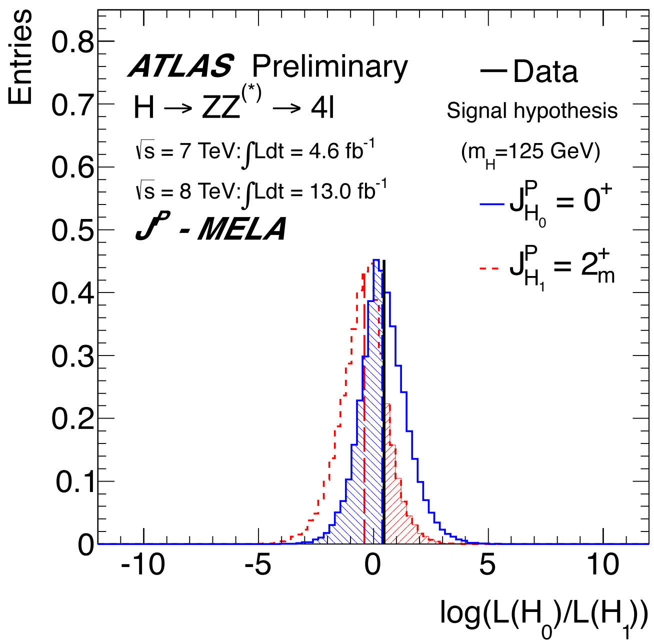
0^+ vs 2^+

ATLAS-CONF-2012-169

Using the distributions of 5 production and decay angles combined in BDT or Matrix Element (MELA) discriminants







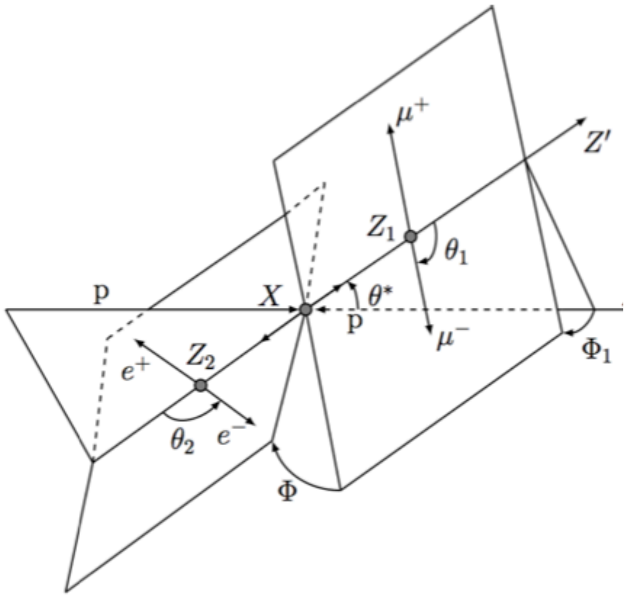
- 0^+ vs 2^+ : (Low) Expected Exclusion of 2^+ at the 80% CL
- Observed exclusion of spin 2^+ at the 85% CL

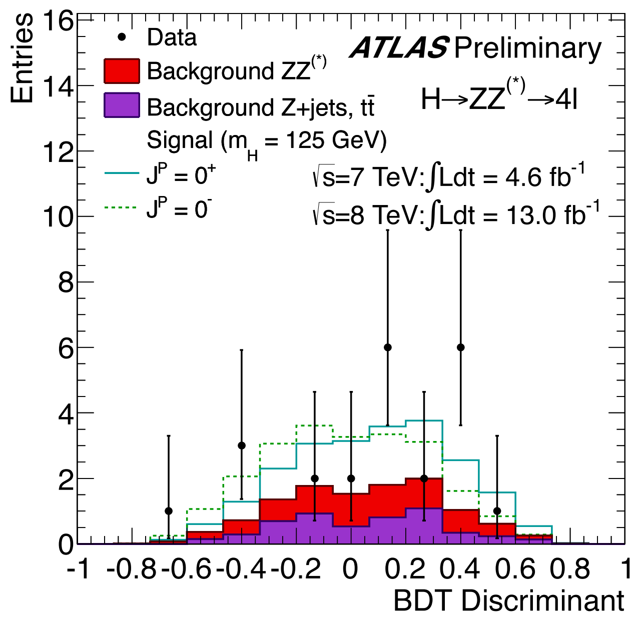
Observation fully compatible with spin 0 (within 0.18 σ)

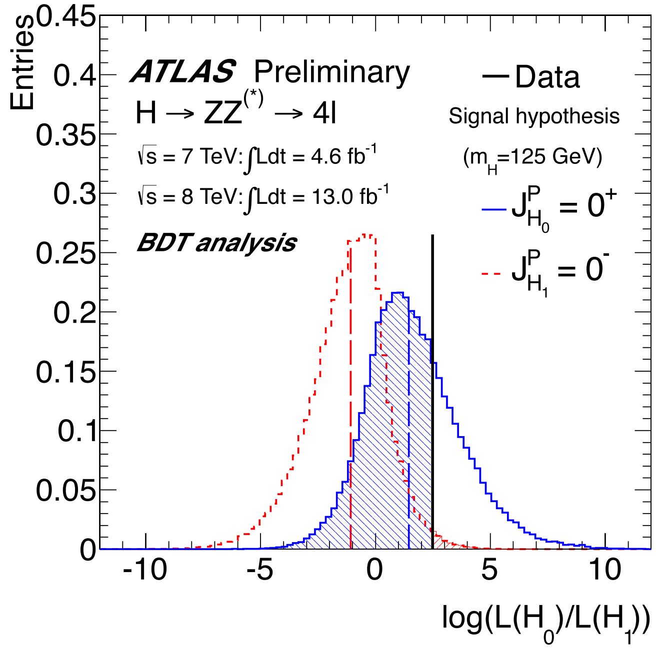
Parity Analysis in the $H \rightarrow 4l$ Channel 0^+ vs 0^-

ATLAS-CONF-2012-169

Using the distributions of 5 production and decay angles combined in BDT or Matrix Element (MELA) discriminants







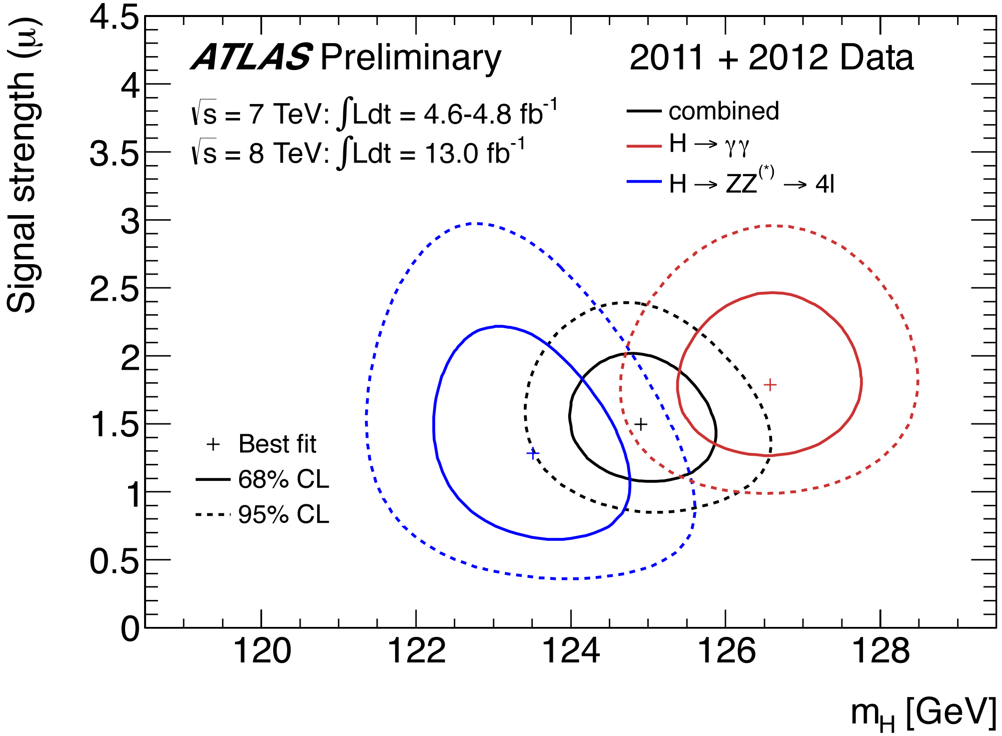
- 0^+ vs 0^- : Expected Exclusion of 0^- at the 96% CL
- Observed exclusion of 0^- at the 99% CL

Observation fully compatible with spin 0 (within 0.5 σ)

$H \rightarrow \gamma\gamma$ and $H \rightarrow 4l$ Combination

ATLAS-CONF-2012-170

Best fit signal strength $\hat{\mu} = 1.5^{+0.33}_{-0.29}$



Combined Mass Measurement :

$$m_H = 125.2 \pm 0.3\ (stat)\ \pm\ 0.6\ (syst)\ \text{GeV}$$

Taking mass scale systematic uncertainties and their correlations into account the compatibility of the two measurements is estimated to be at the 2.7σ level

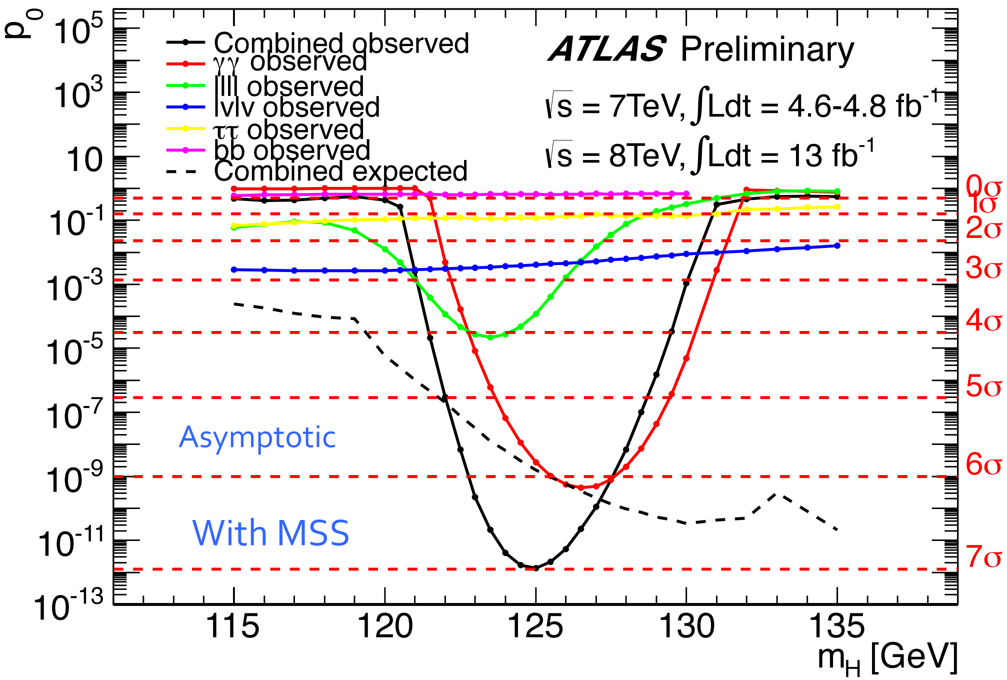
An alternative treatment of systematic uncertainties yields a compatibility at the level of 2.3σ

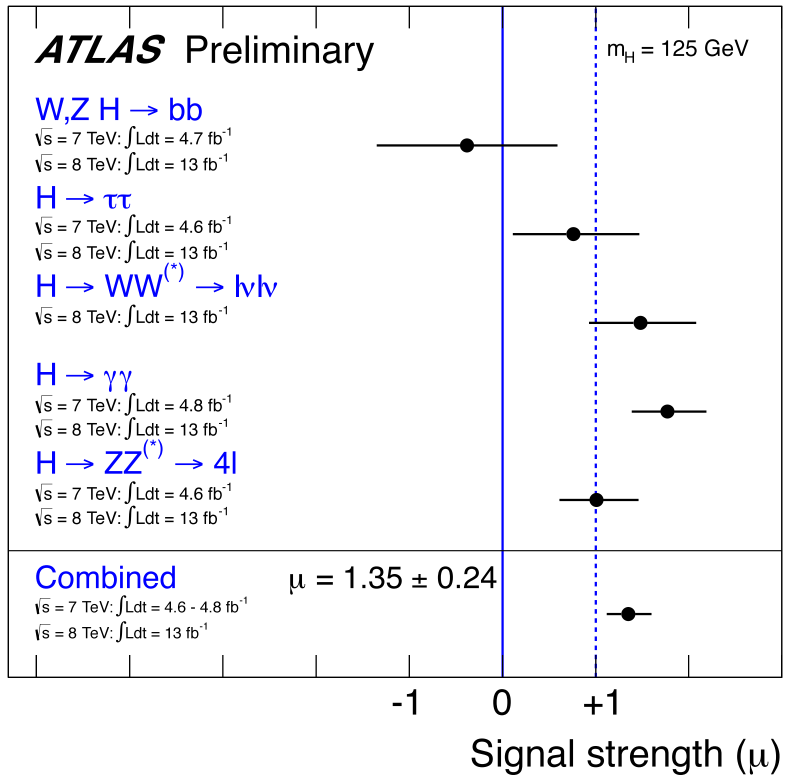
Combination of All Channels

Updated with 13 fb^{-1} of 2012 8 TeV data

ATLAS-CONF-2012-170

Summary of the signal strength in all SM Higgs search channels





Observed local significance (w/ MSS): 7.0σ

Without MSS: 6.6σ

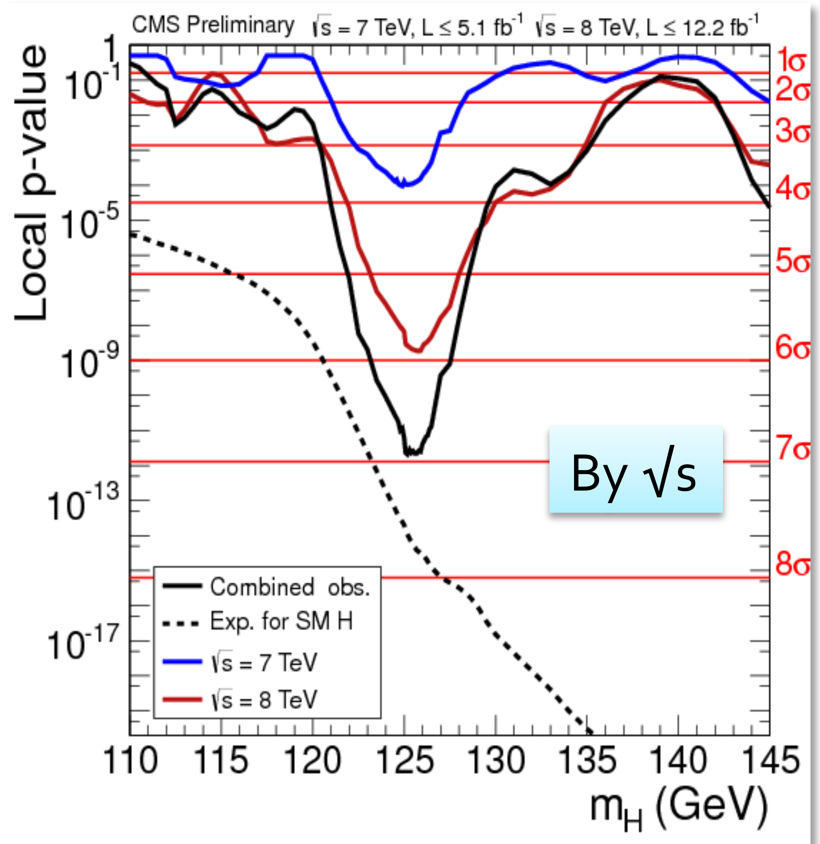
Expected local significance: 5.9σ

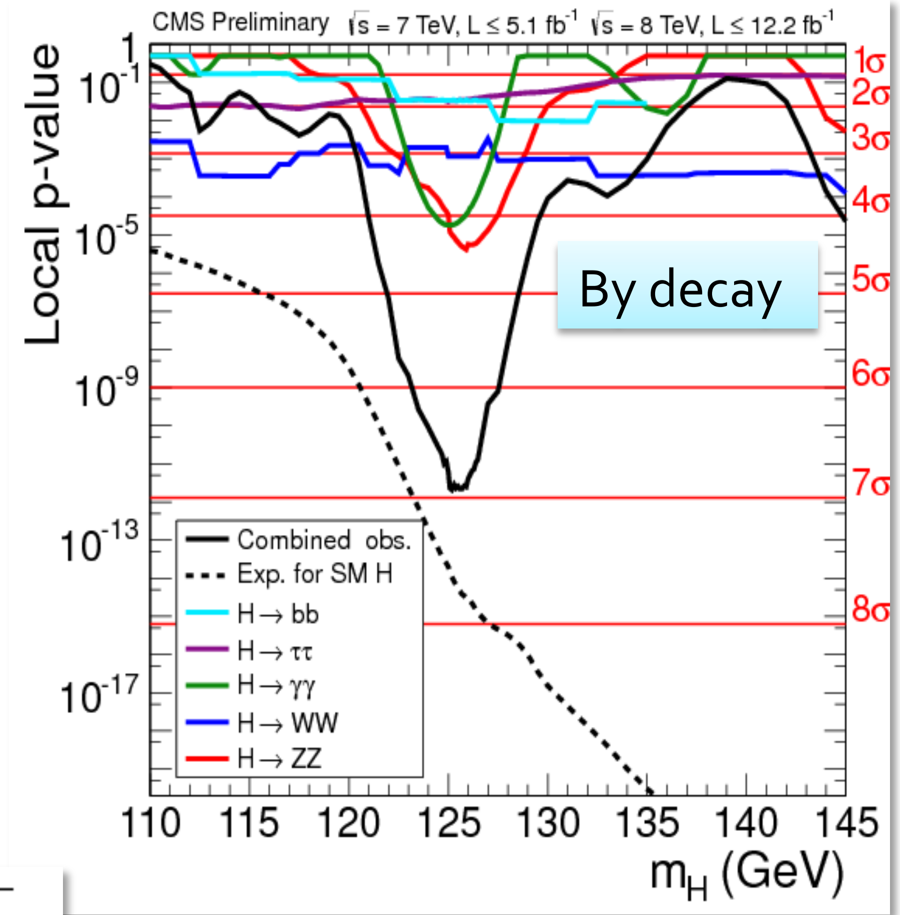
$$\hat{\mu} = 1.35 \pm 0.19\ (stat) \pm 0.15\ (syst)$$

Overall agreement with the SM Higgs boson hypothesis

Combination of All Channels

HIG-12-045



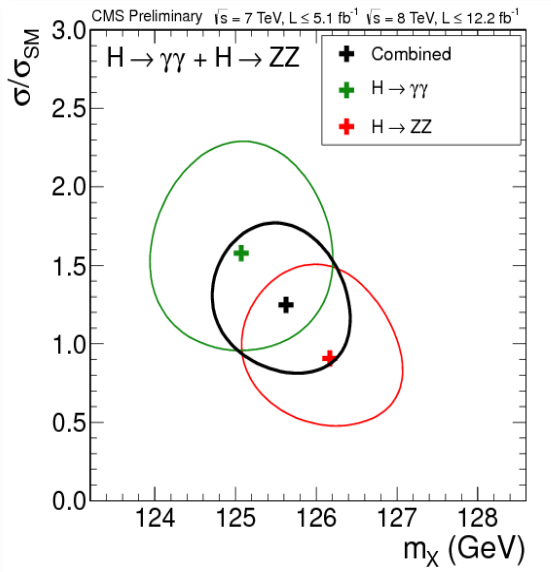


Decay mode or combination	Expected (σ)	Observed (σ)
ZZ	5.0	4.4
$\gamma\gamma$	2.8	4.0
WW	4.3	3.0
bb	2.2	1.8
$\tau\tau$	2.1	1.8
$\gamma\gamma$ + ZZ	5.7	5.8
$\gamma\gamma$ + ZZ + WW + $\tau\tau$ + bb	7.8	6.9

Overall significance:
6.9σ observed versus
7.8σ expected

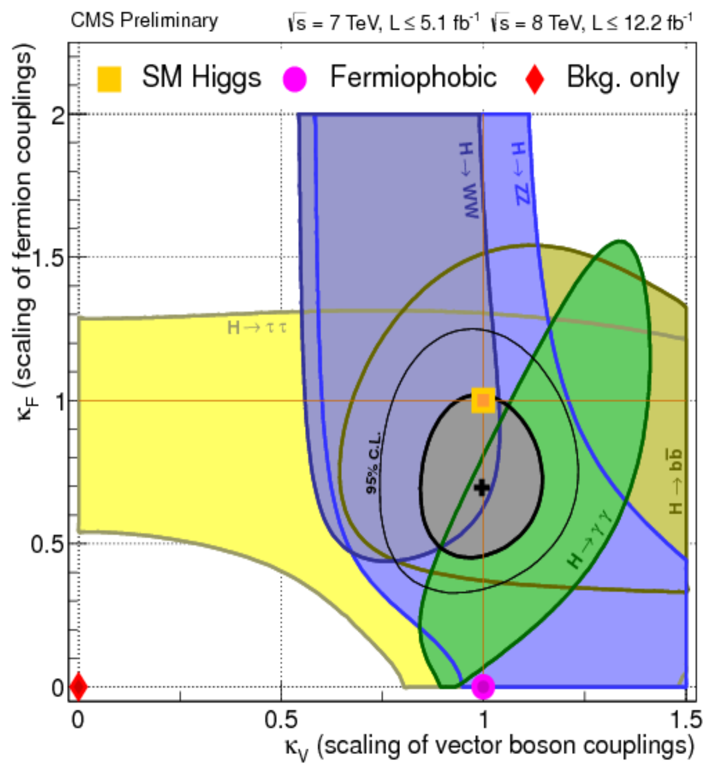
Signal strengths, mass and couplings

[HIG-12-045](#)



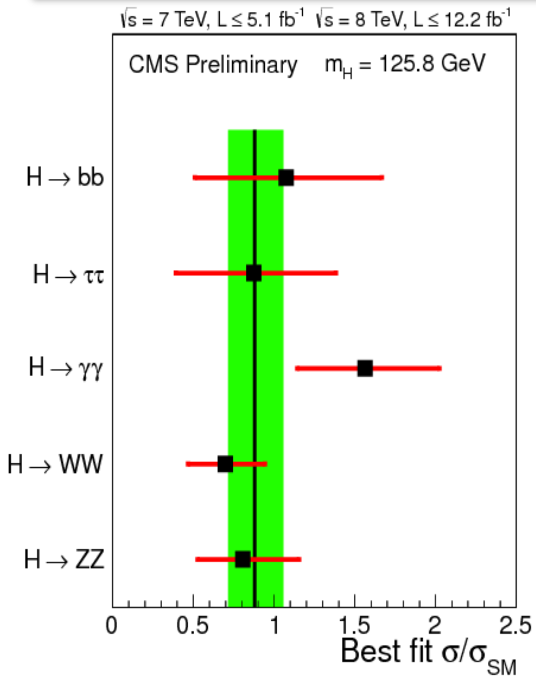
2D scan in 3 channels

m = 125.8 ± 0.4 (stat) ± 0.4 (syst)



Signal strengths

- Compared to SM
- Significant discrepancies could indicate new physics



$$\frac{\sigma}{\sigma_{SM}} = 0.88 \pm 0.21$$

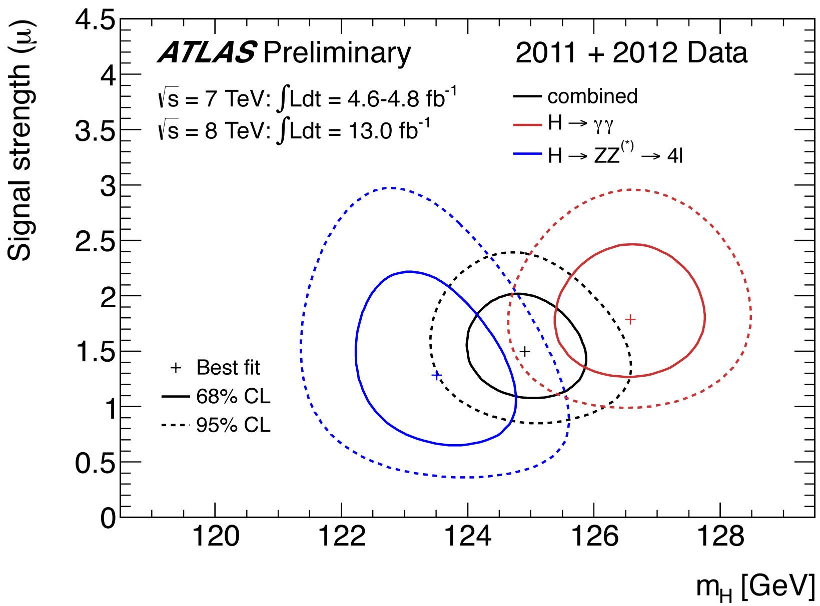
K_V and K_F:

- Couplings of Higgs to W,Z,γ (bosons) and to quarks and leptons (fermions)

Higgs mass?

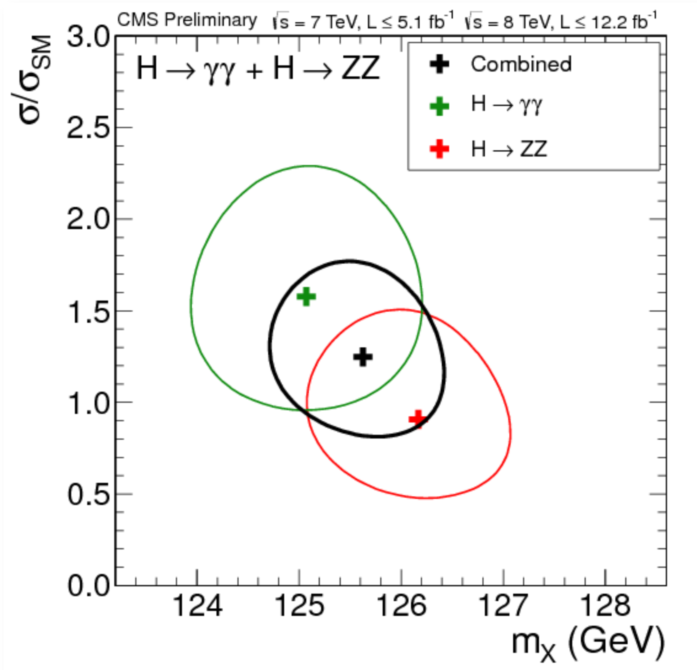
ATLAS

m = 125.2 ± 0.3 (stat) ± 0.6 (syst)



CMS

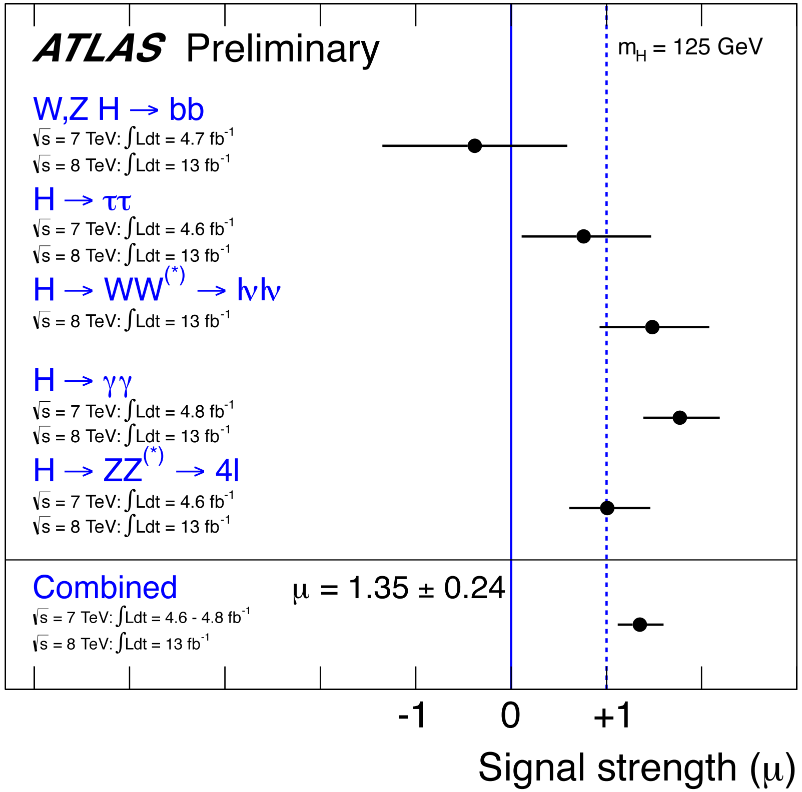
m = 125.8 ± 0.4 (stat) ± 0.4 (syst)



Higgs Decay Properties?

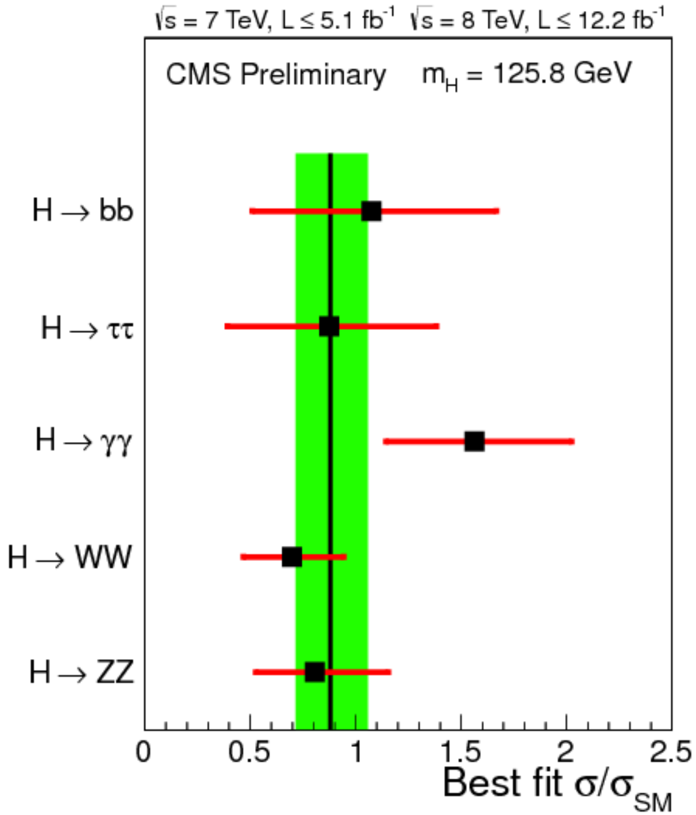
ATLAS

$$\hat{\mu} = 1.35 \pm 0.19\ (stat) \pm 0.15\ (syst)$$



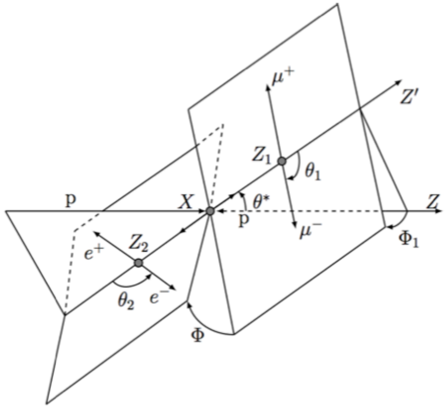
CMS

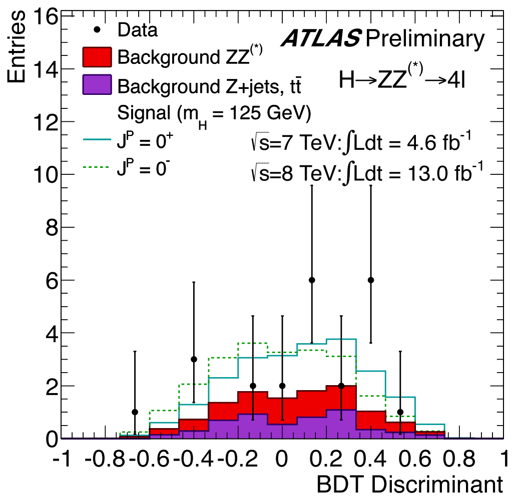
$$\frac{\sigma}{\sigma_{SM}} = 0.88 \pm 0.21$$



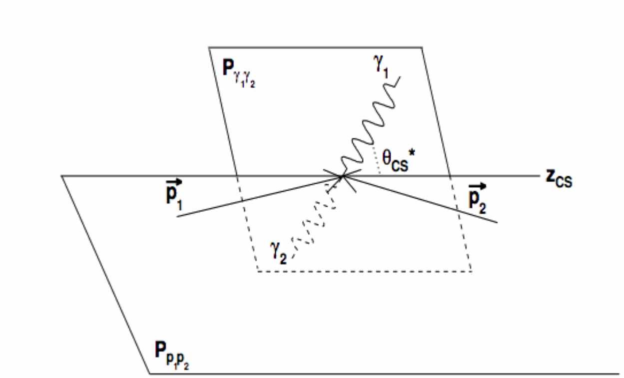
Higgs Spin?

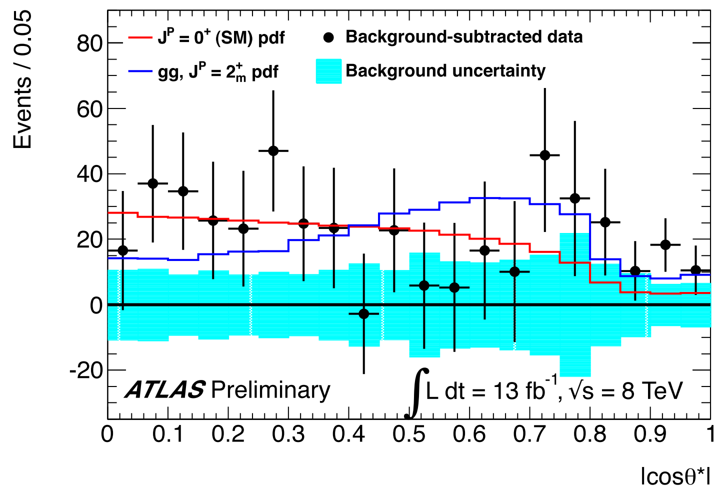
0^+ vs 0^-
Observed exclusion of 0^- at ~99% CL (4l, each experiment)

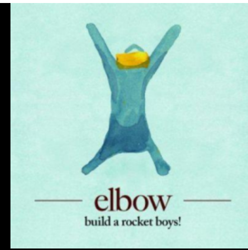




0^+ vs 2^+
Observed exclusion of 2^+ at the 85% CL (4l)
Observed exclusion of spin 2^+ at the 91% CL ($\gamma\gamma$)







2012: Apollo 11 moment
We're entitled to be over the moon..

"dry run" for the Apollo 11 mission, testing all of the procedures and components of a Moon landing without actually landing on the Moon itself.

Apollo 11 was the spaceflight that landed the first humans on the Moon.

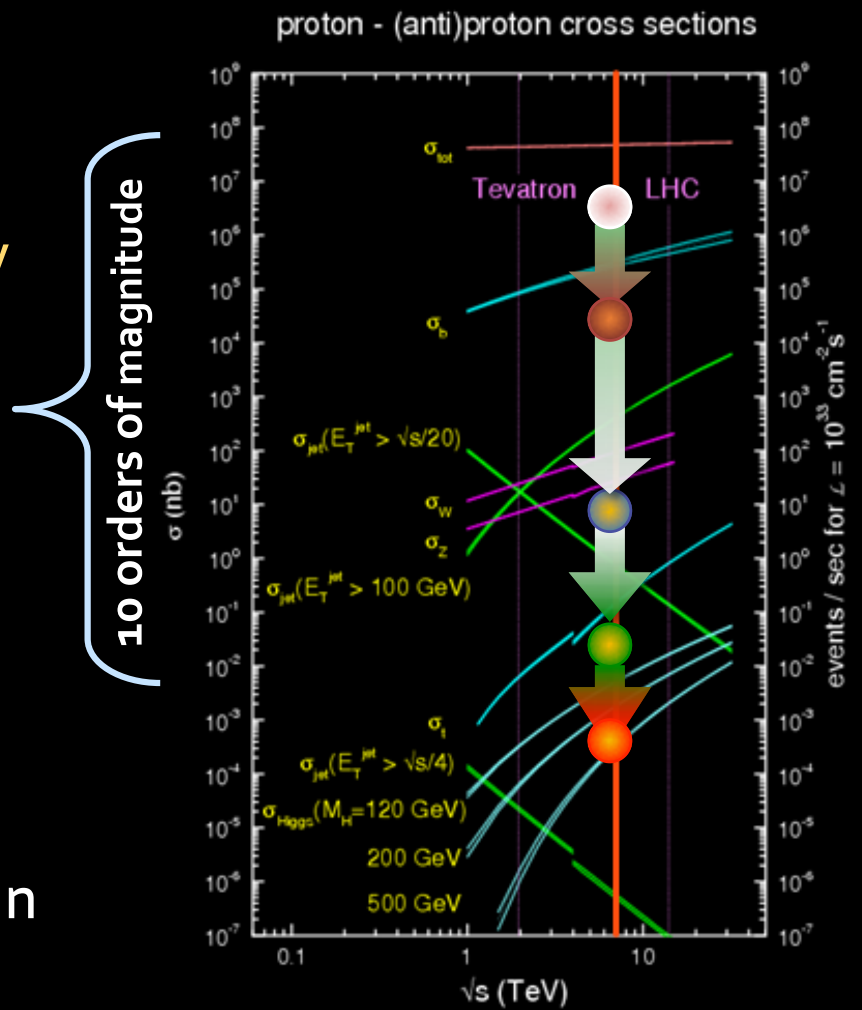
Conclusion

Many important measurements now available at $\sqrt{s}$ = 7, 8 TeV

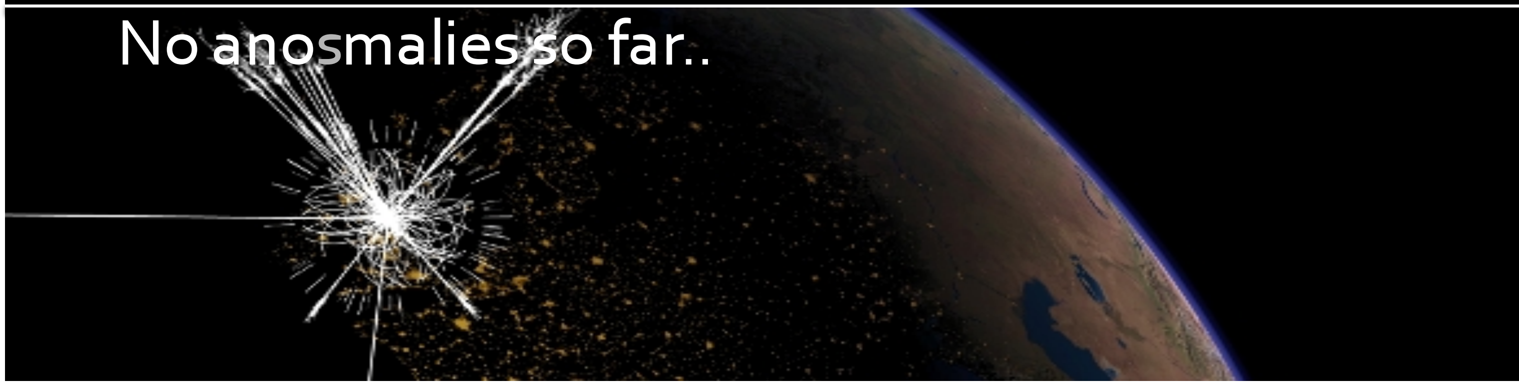
Standard Model Candles:
W/Z bosons, top production

Beyond the Standard Model:
Exotics, SUSY – limits O(TeV) range

Higgs Voyage of Discovery – we are in new and uncharted territory



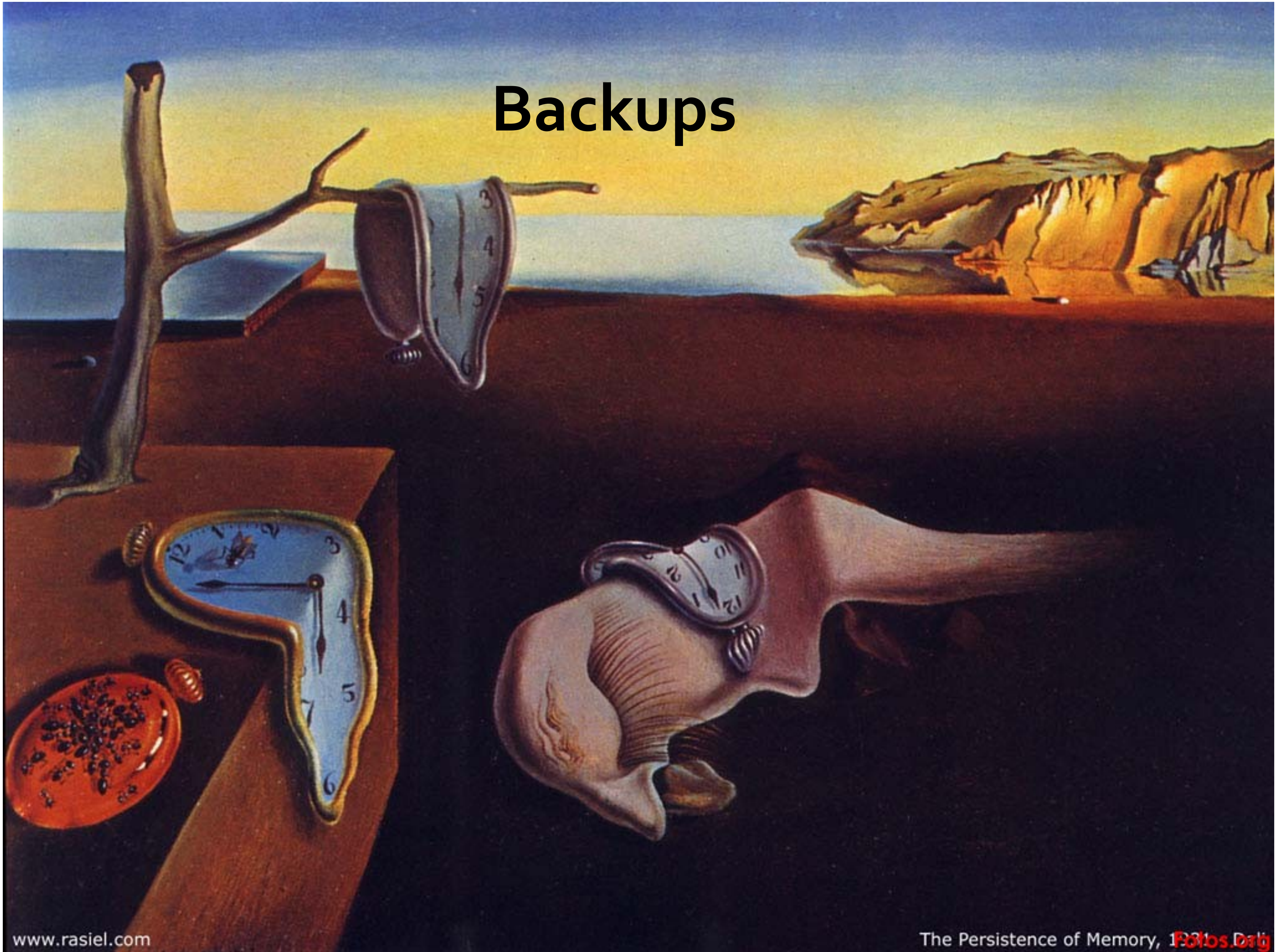
No anosmalies so far..



UNIVERSITY of GLASGOW

Thanks to all the members of ATLAS and CMS who've helped to make this talk possible.
Esp. Sara Bolognesi, Louis Fayard, Fabiola Gianotti, Andreas Hoecker, Marumi Kado, Bertrand Martin, John Parsons, Lucia Silvestris
We get by with a little help from our friends...

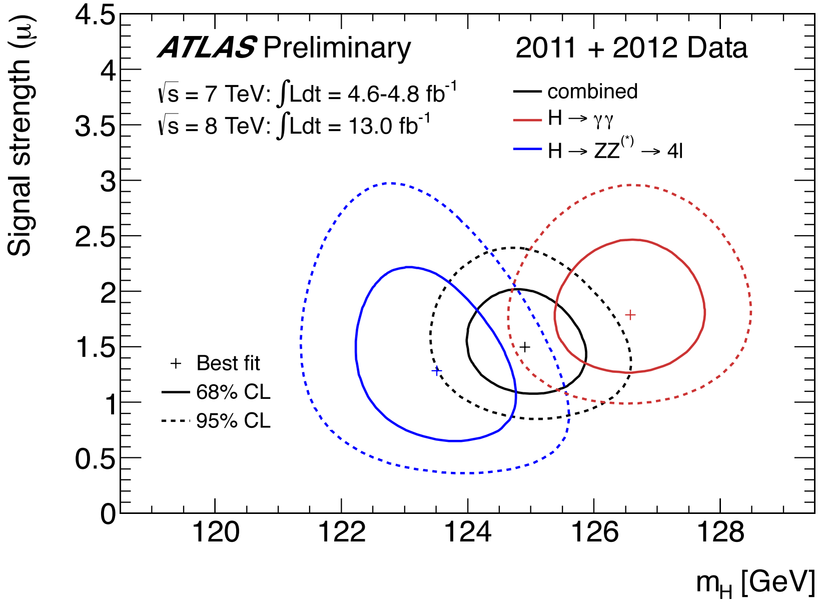
Backups

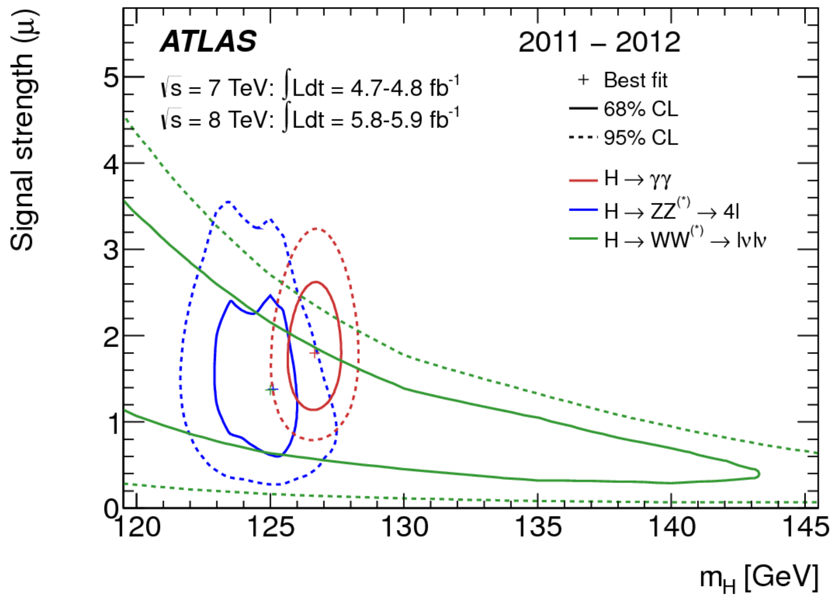


ATLAS Higgs mass?

ATLAS (new)
m = 125.2 ± 0.3 (stat) ± 0.6 (syst)

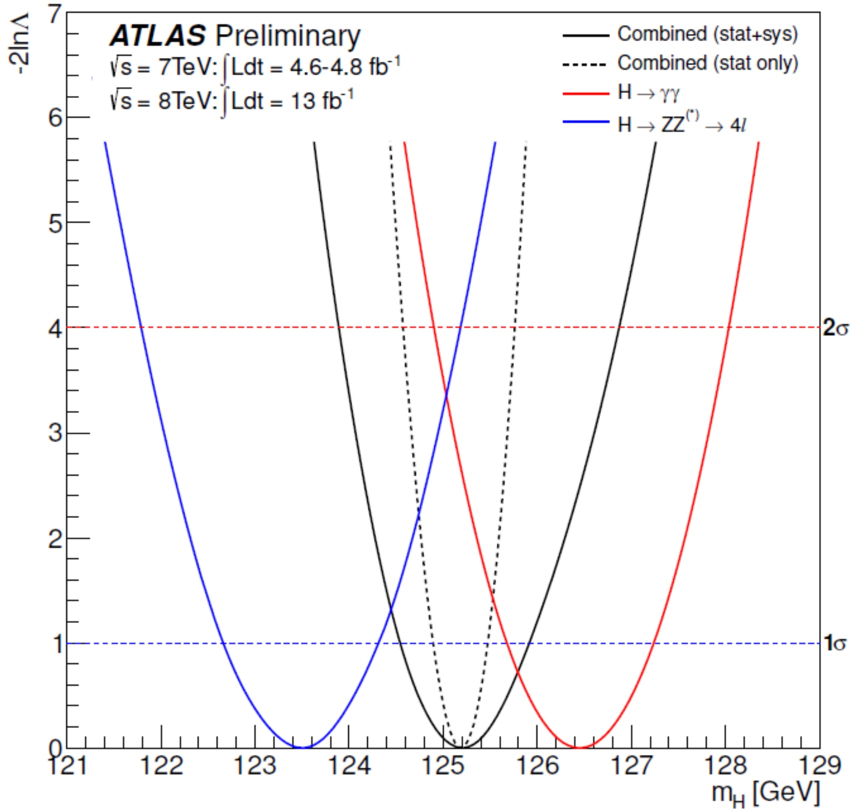
ATLAS (discovery paper)
m = 126.0 ± 0.4 (stat) ± 0.4 (syst)

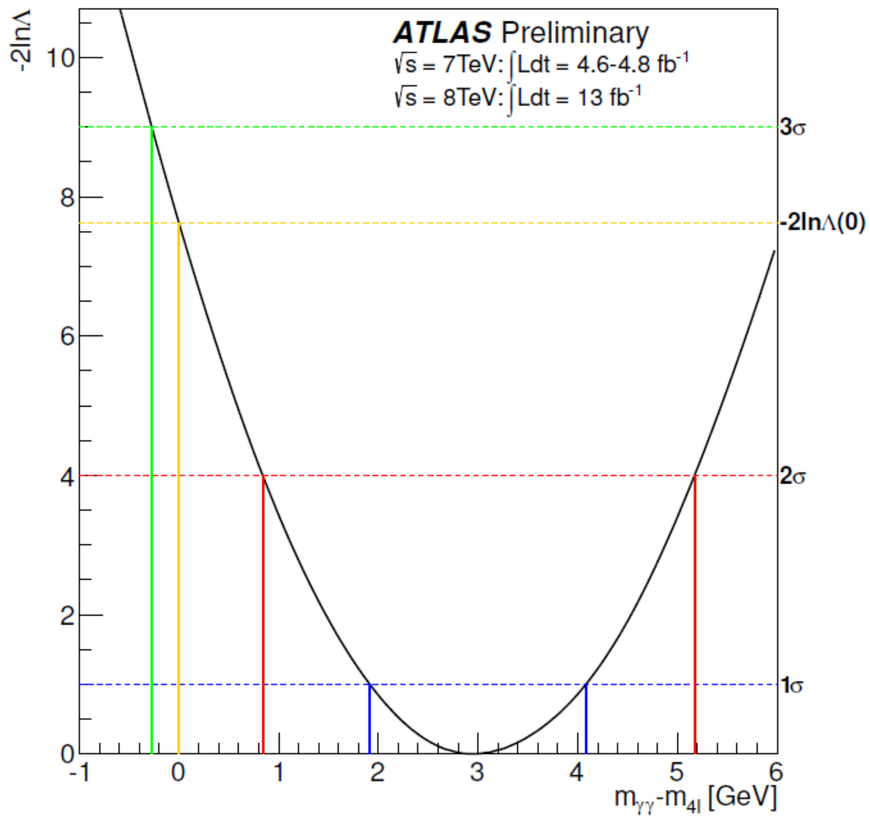




ATLAS Higgs mass?

$$\Delta\hat{m}_H = \hat{m}_H^{\gamma\gamma} - \hat{m}_H^{4\ell} = 3.0^{+1.1}_{-1.0}\ \text{GeV} = 3.0 \pm 0.8\,(\text{stat})\ ^{+0.7}_{-0.6}\,(\text{sys})\ \ \text{GeV}$$





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

Main Mass Scale systematic uncertainties (also considered in 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 additional sources of systematic uncertainties:

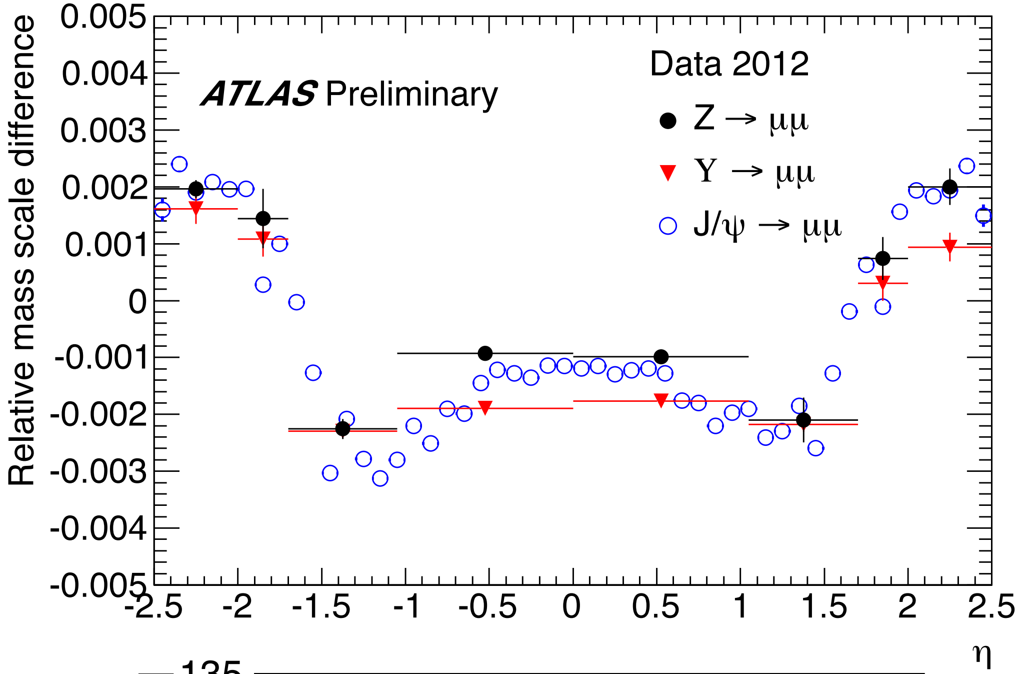
- LAr Strips relative calibration (0.2%)
- Photon energy resolution (0.15%)
- Calibration of the high gain (0.15%)
- Mis-classification due to fake conversions (0.13%)
- Backgound modeling (0.1%)
- Lateral shower development simulation (0.1%)
- Effect of PV choice (0.03%)

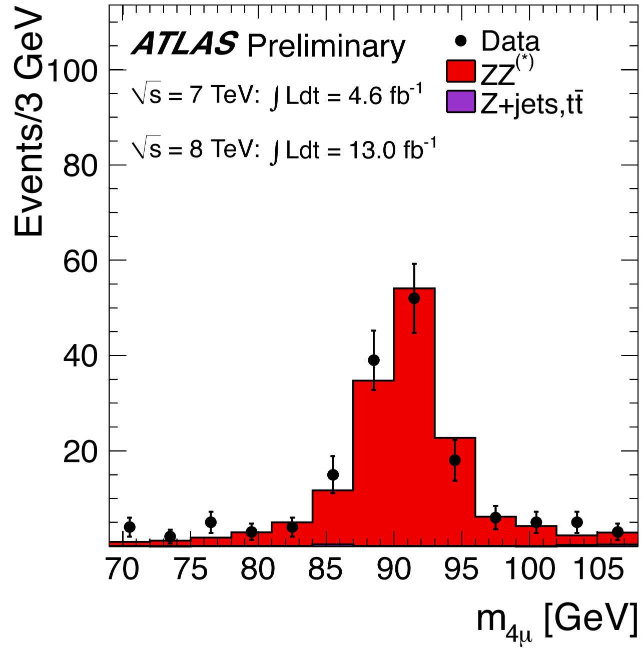
Main 4l Mass Scale systematic uncertainties :

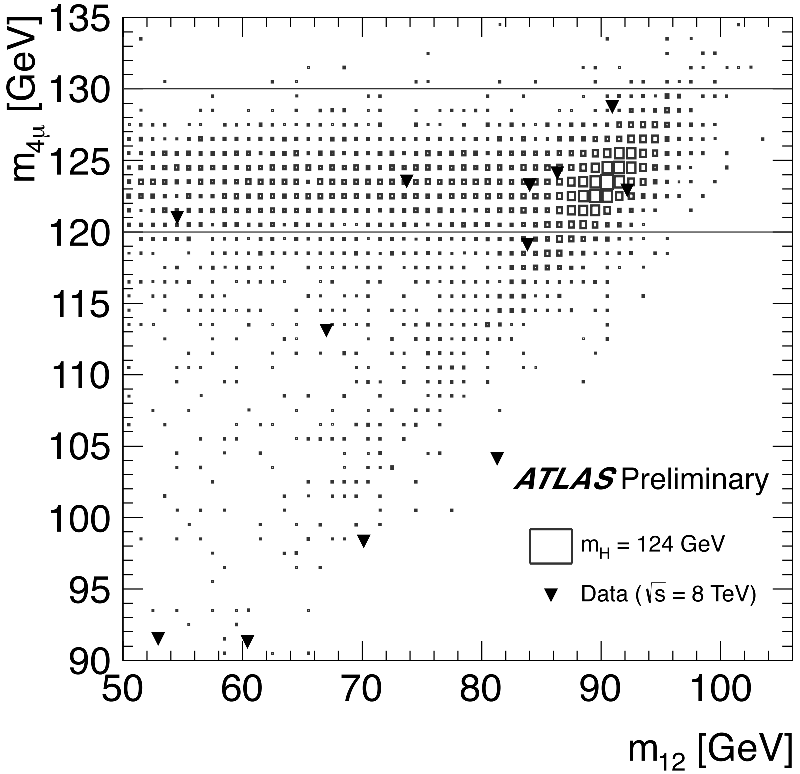
Source	Relative Mass Scale Effect
Absolute Energy scale calibration from Z	0.4%
Low transverse energy electrons	0.2%
Muon momentum scale	0.2%

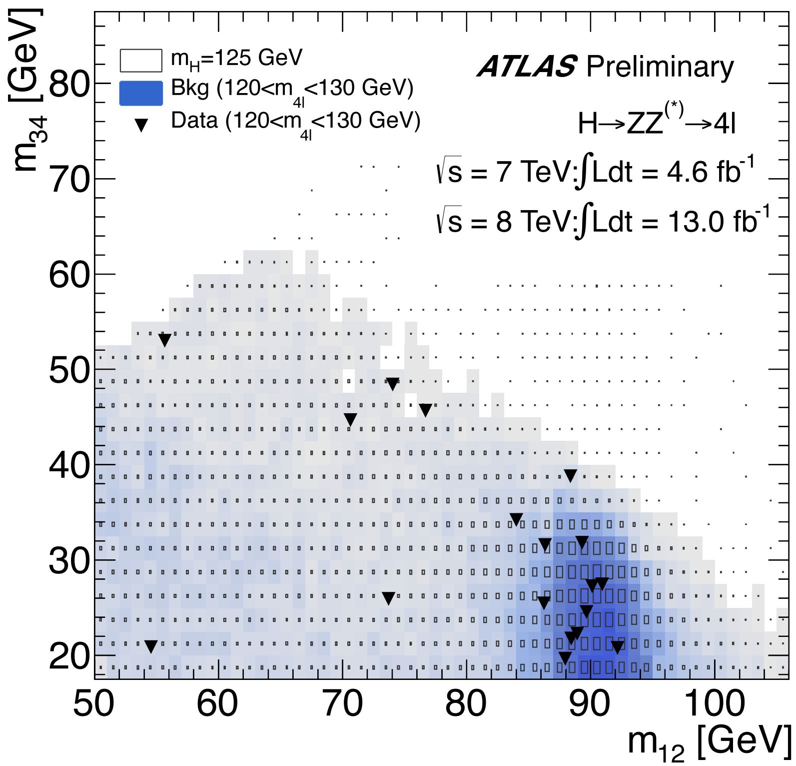
Further investigation and extensive checks have not led to additional substantial sources of systematic uncertainty:

- 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 expecta
- FSR simulation
- Different mass reconstruction using Z-mass constraint (+400 MeV shift)


ATLAS Preliminary
Data 2012
Z → μμ
Υ → μμ
J/ψ → μμ
Relative mass scale difference
η


ATLAS Preliminary
√s = 7 TeV: ∫Ldt = 4.6 fb-1
√s = 8 TeV: ∫Ldt = 13.0 fb-1
Data
ZZ(*)
Z+jets,tt̄
Events/3 GeV
m4μ [GeV]


ATLAS Preliminary
mH = 124 GeV
Data (√s = 8 TeV)
m4μ [GeV]
m12 [GeV]


mH=125 GeV
Bkg (120<m4l<130 GeV)
Data (120<m4l<130 GeV)
ATLAS Preliminary
H→ZZ(*)→4l
√s = 7 TeV:∫Ldt = 4.6 fb-1
√s = 8 TeV:∫Ldt = 13.0 fb-1
m34 [GeV]
m12 [GeV]

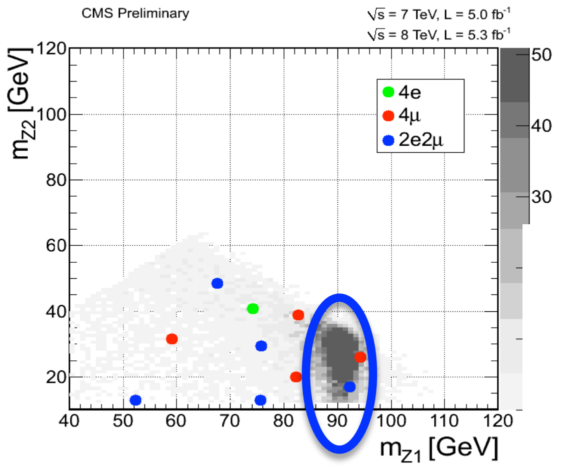
$H \rightarrow \gamma\gamma$ Normalization Systematic Uncertainties

Main systematics on Yield and Migration

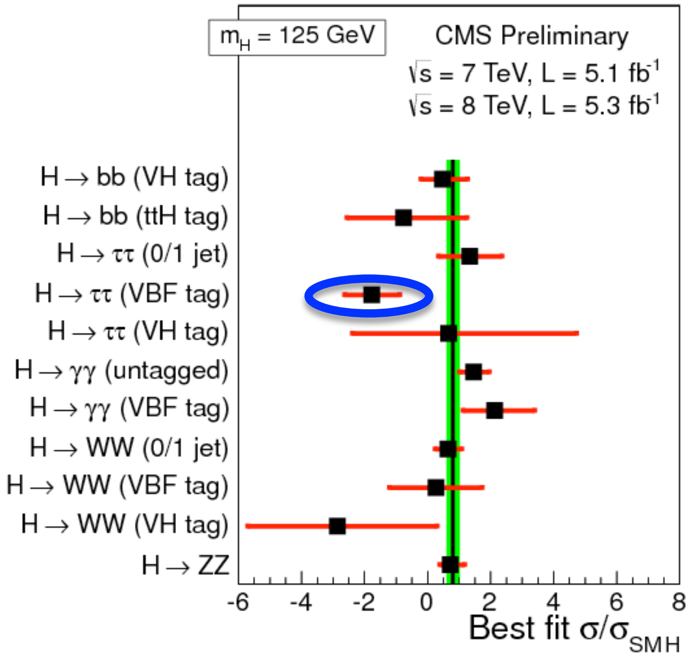
Theory (PDF, scales, a_s)	~12% (overall)
g Efficiency	5.3%
Background Model	~3%
Luminosity	3.9% and 3.6%
Trigger	0.5%
Isolation	1%
Energy Scale	0.5%
JES	4% - 19% (HM 2-jets)
pTt Modeling	0.8%
Material mis-modeling	~4%
UEPS	7% - 30% (LM HM 2-jets)
Leptons	~2%

Higgs: Some Puzzles Resolved

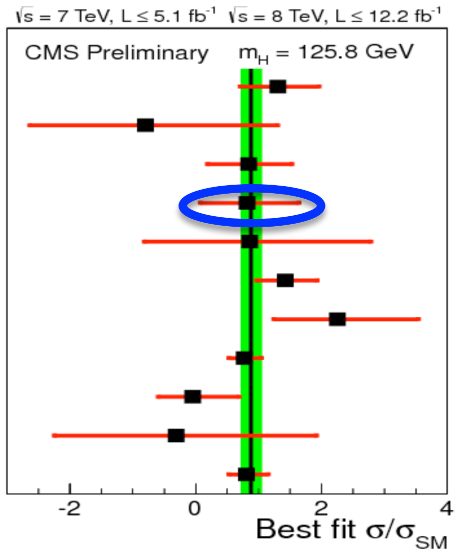
- A couple of puzzling features of the CMS discovery dataset have been resolved
  - The $M(Z_1)$ vs. $M(Z_2)$ distribution filled in and now shows a clear cluster at $M(Z_1)$ = 90 GeV
  - The 2σ deficit in $\tau\tau$ VBF category is gone



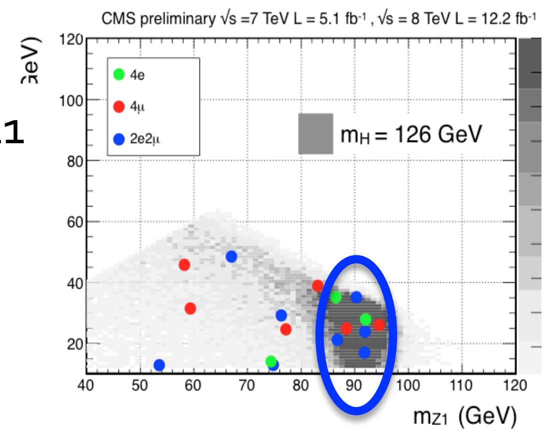
HIG-12-020



HIG-12-045



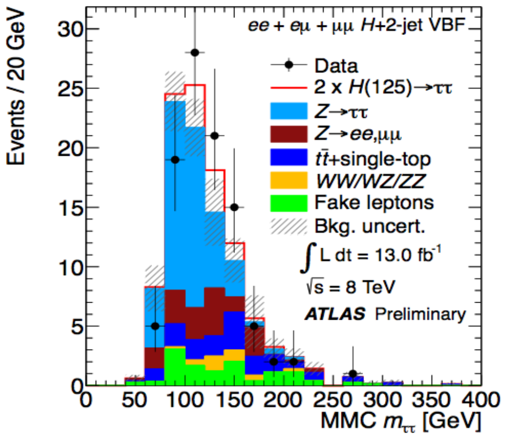
HIG-12-041

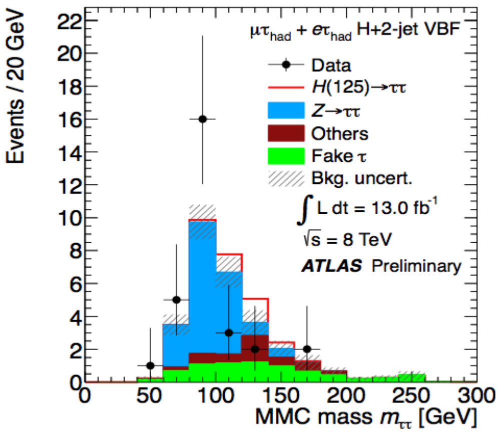


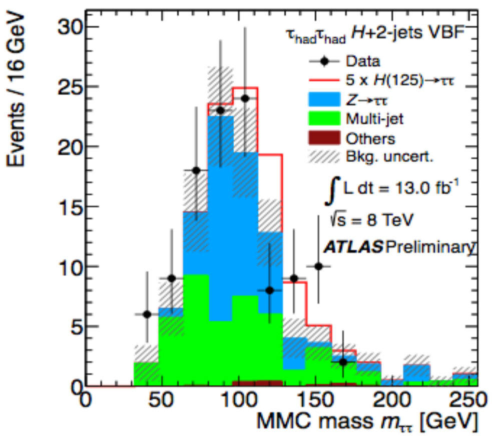
$H \rightarrow \tau\tau$

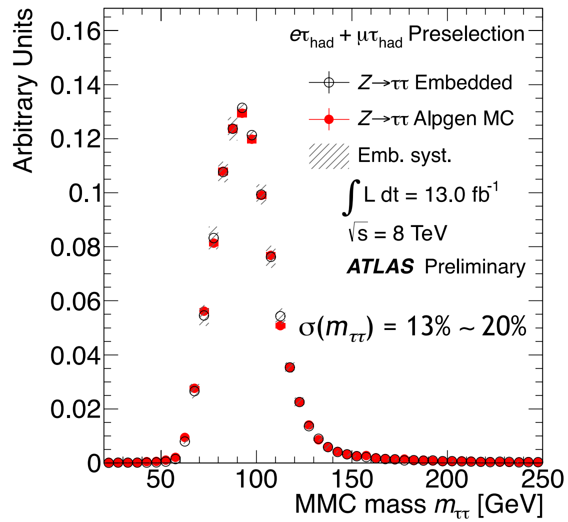
Reoptimised 7+8 TeV analysis

- Search in exclusive categories: lep-lep, lep-had, had-had and jets: 0, 1 (boosted or not), 2 (VBF, VH)





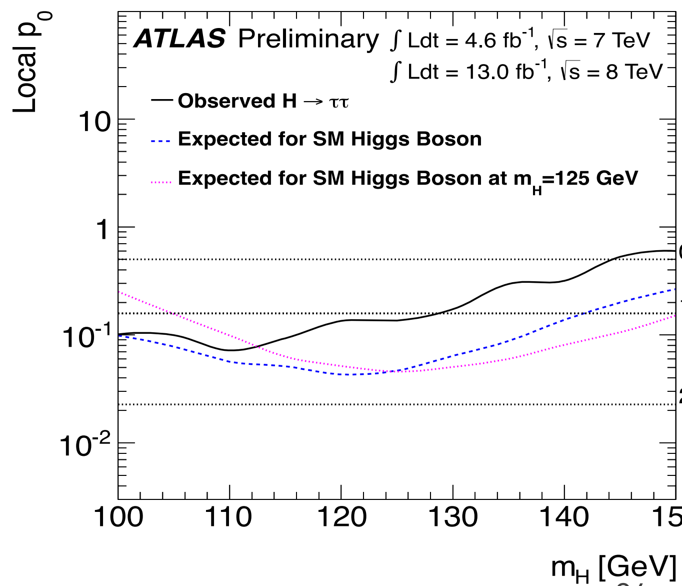




- Background modeling is critical especially in specific environments such as VBF production : Use embedding

- Use of MMC mass

- Most powerful channel VBF



$\mu(125) = 0.7 \pm 0.7$

95% CL limit (125): 1.9 [exp: 1.2] × SM

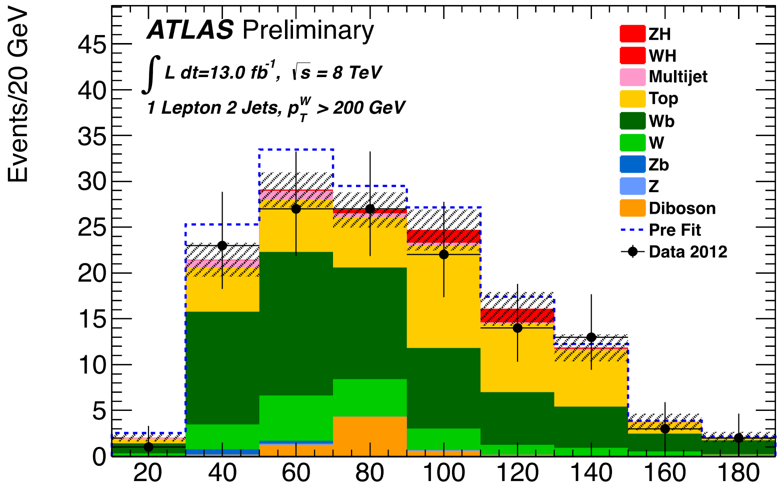
Significance (125): 1.1σ [exp: 1.7σ]

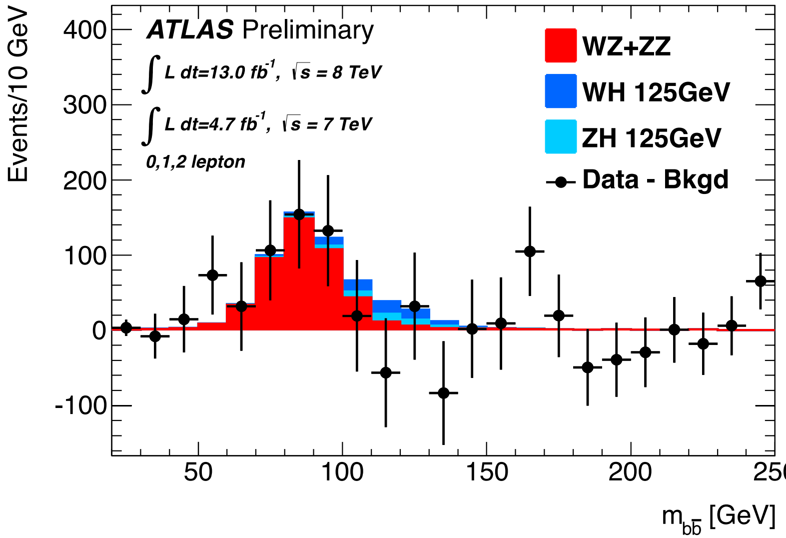
VH production with $H \rightarrow bb$

Reoptimised 7+8 TeV analysis

ATLAS-CONF-2012-161

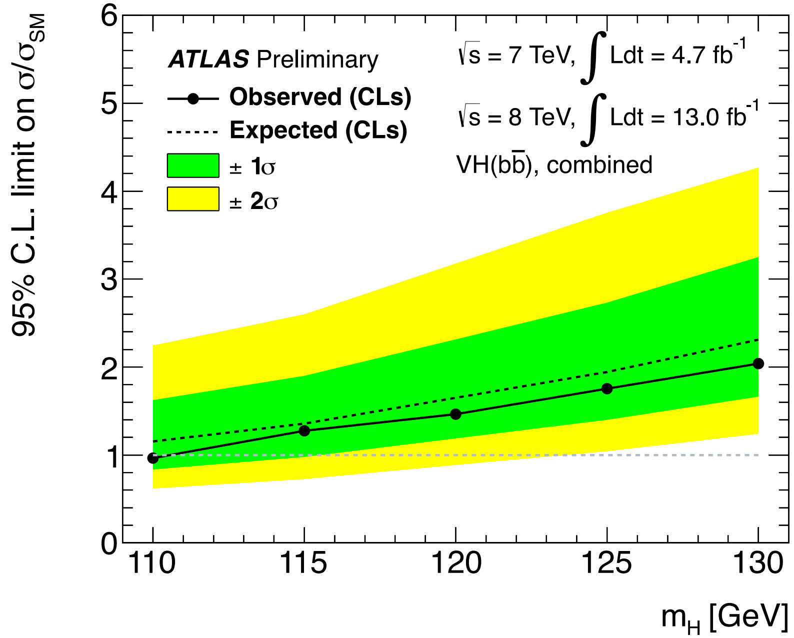
Also new 7 TeV analysis of tt+H, with $H \rightarrow bb$ [ATLAS-CONF-2012-135]





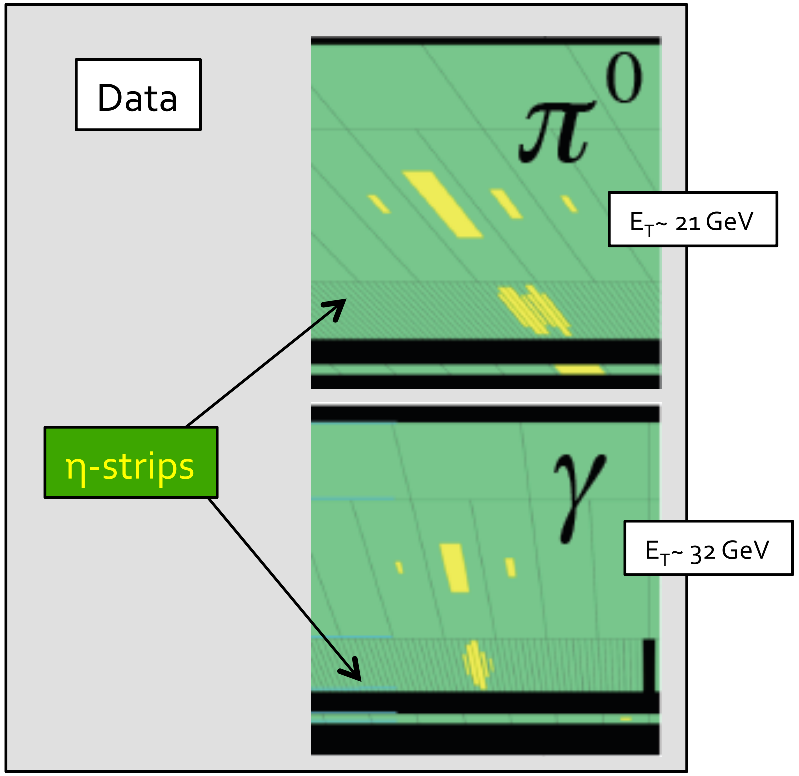
$\mu(125) = -0.4 \pm 0.7(\text{stat}) \pm 0.8(\text{syst})$
95% CL limit (125): 1.8 [exp: 1.9] × SM

- Require 2 *b*-tags and distinguish 0, 1, 2 lepton channels
- Higgs discrimination based on m_{bb}, resolution of ~16%, improved by including muons and partial neutrino correction
- Categories in boost (w/o sub structure)



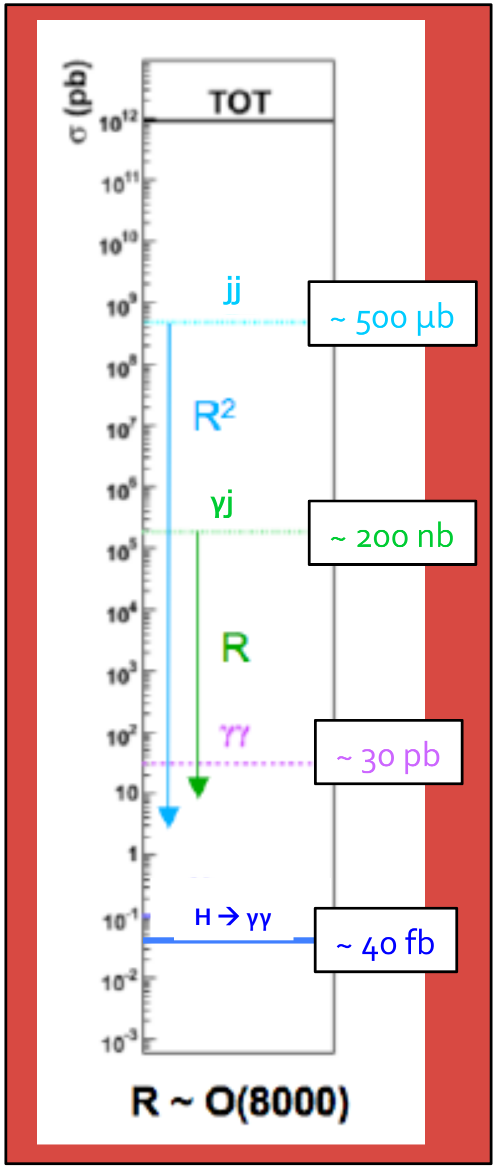
Potentially huge background from γj and jj production with jets fragmenting into a single hard π^0 and the π^0 faking single photon

Determined choice of fine lateral segmentation (4mm η-strips) of the first compartment of ATLAS EM calorimeter



However: huge uncertainties on σ (γj, jj) !!
→ not obvious γj, jj could be suppressed
well below irreducible γγ until we measured with data

H → γγ



Higgs Combination

Outlook

Improve analysis sensitivities:

- ❑ update all channels with full 2012 luminosity 13 fb^{-1} → 20 fb^{-1}
- ❑ relax kinematic cuts (e.g. lepton p_T) to increase acceptance at low masses?
- ❑ multivariate techniques, exclusive channels (e.g H→ γγ + 0/1/2 jets), additional

discriminating variables beyond mass spectra (p_T, angular distributions, etc.)

In parallel: improvements of the detector performance and modelling

Lesson from the Tevatron: experiments can do much better than expectation with data and ingenuity
Lesson from the LHC: rapid improvements in analyses

Combination between ATLAS and CMS: being discussed …
Not before results from individual experiments are published

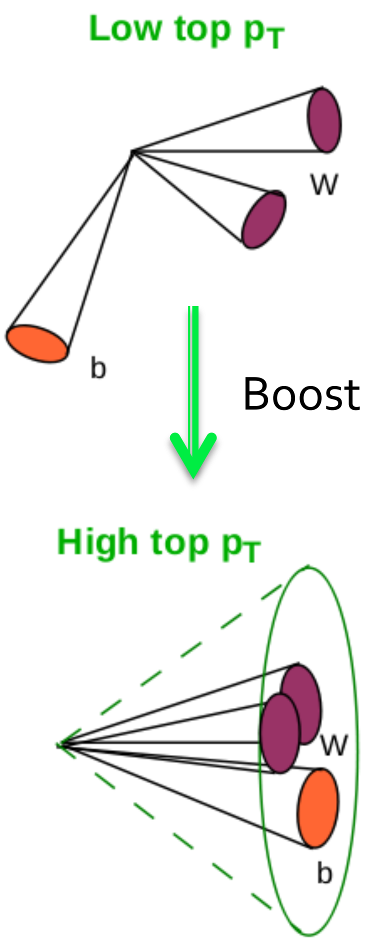
Searching for Exotic top pair Resonances

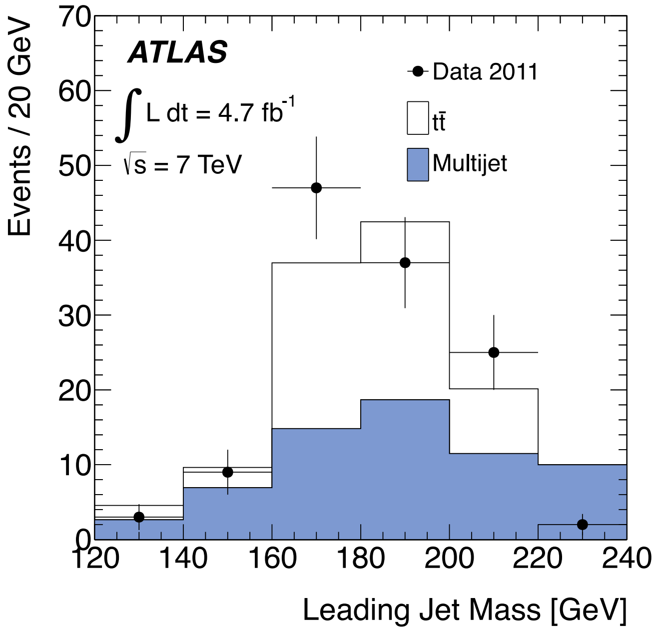
With fully boosted analyses

Two methods identify merged hadronic top decays

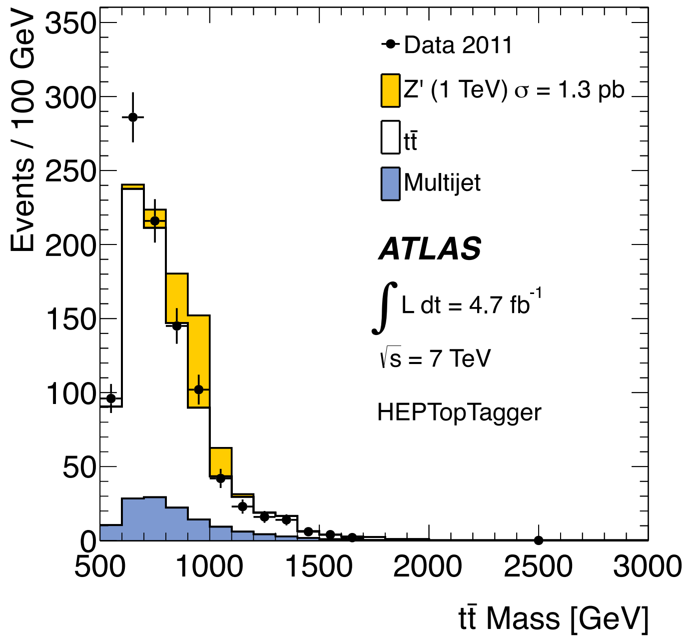
- ***HEP-Top-Tagger*** uses substructure of "fat jets"
- ***Top-Template-Tagger*** uses calorimeter templates (higher pT)

1211.2202
Lepton+jets analysis see : ATLAS-CONF-2012-136





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



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

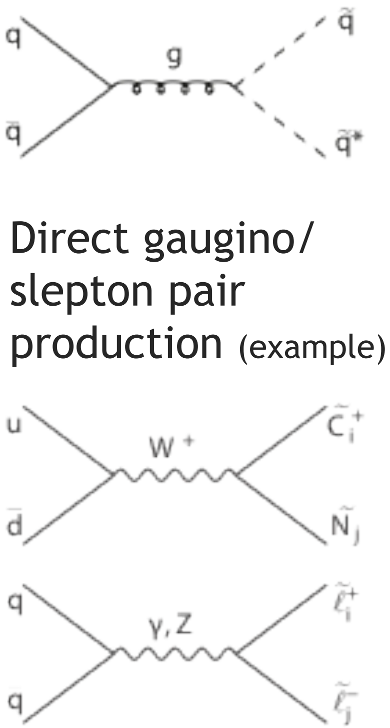
(Leptophobic topcolour) *Z'* excluded up to 1 TeV at 95% CL

Once mass spectrum fixed, all cross-sections predicted

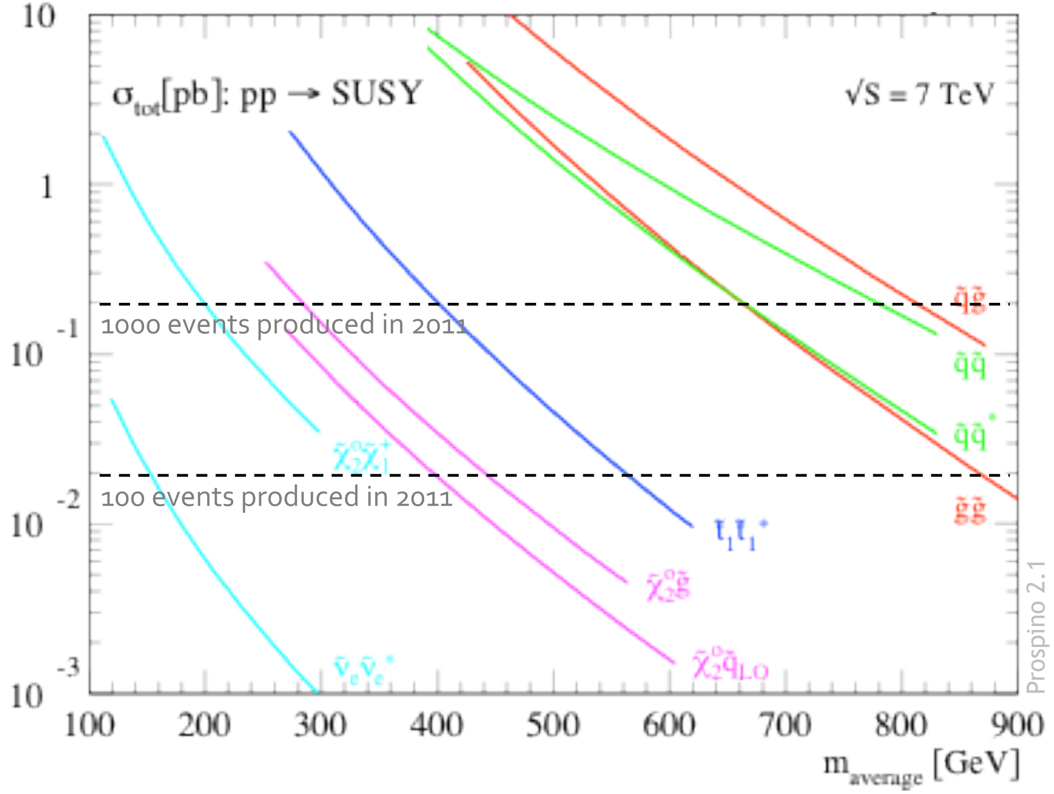
Spin structure of SUSY spectrum: lower σ than other BSM models, harder to find !

Direct squark pair production (example)

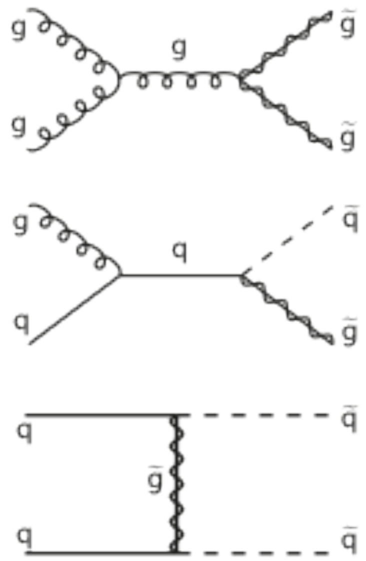
Direct gaugino/ slepton pair production (example)



SUSY cross-section versus sparticle mass



Gluino & squark production (examples)

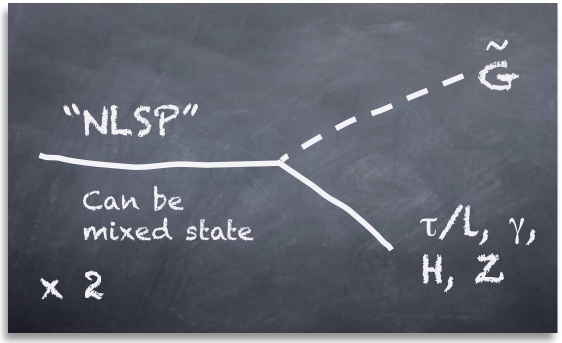


Also: dedicated searches for SUSY with long-lived particles and *R*-parity violation

Recent (Oct 23) ATLAS seminar by Nick Barlow reviewing results on long-lived particle searches with ATLAS

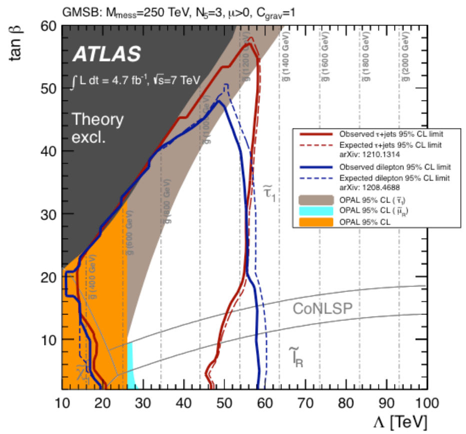
Inclusive squark and gluino searches

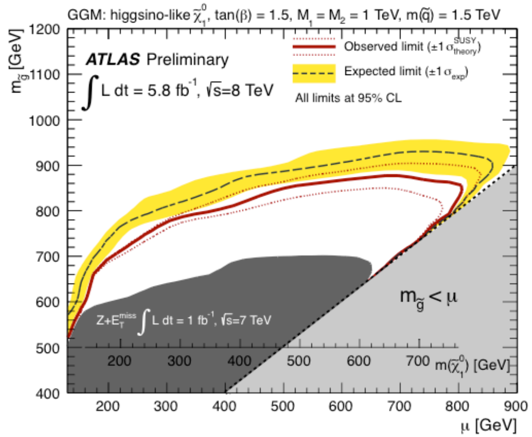
Complete "jets + X + E_T^{miss} " programme, for example: GM

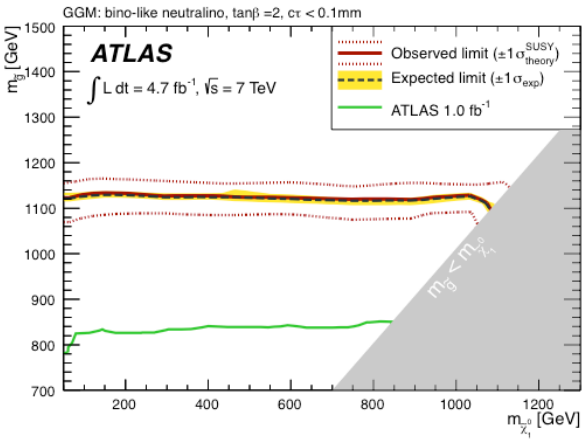


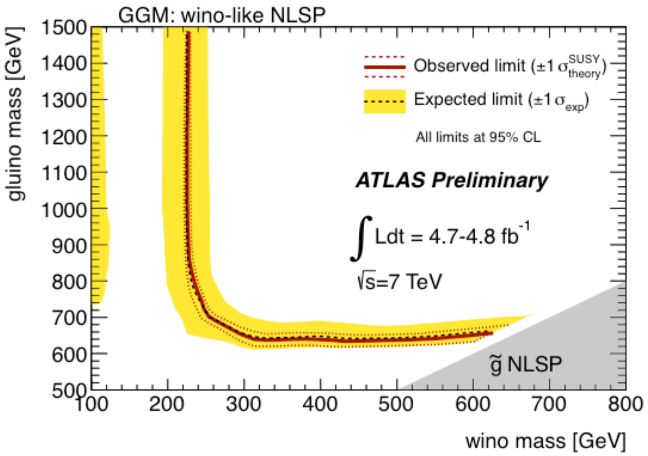
Gauge-mediated SUSY breaking scenarios feature very light gravitino. Phenomenology determined by nature of next-to-LSP

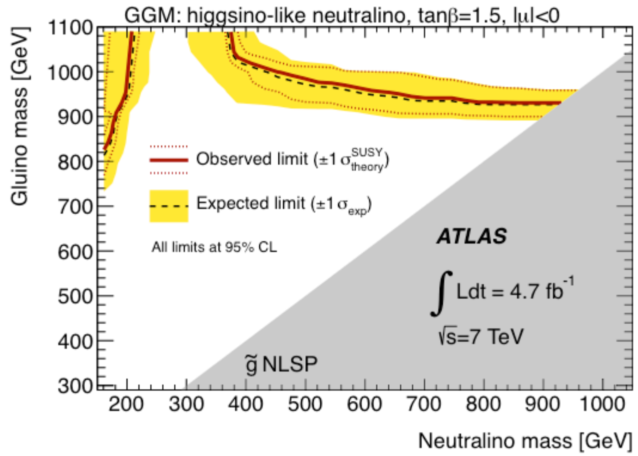
Dedicated search programme including final states with E_T^{miss} + taus, dilepton (Z & non-Z), diphotons, photon + lepton, photon + b











Top-left to bottom-right: 1210.1314, ATLAS-CONF-2012-152, 1209.0753, ATLAS-CONF-2012-144, 1211.1167

“Natural” SUSY

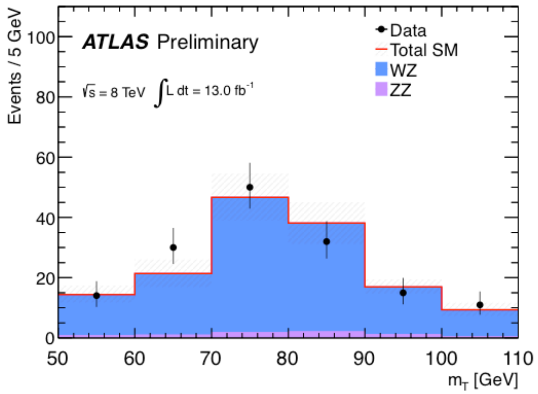
Are squarks & gluinos too heavy to be produced at 8 TeV ? Look at EW production !

1208.2884, 1208.3144, ATLAS-CONF-2012-154

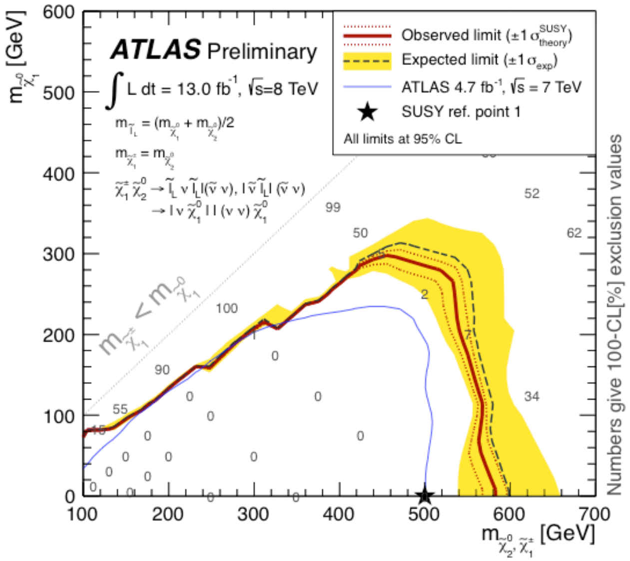
Dedicated searches for EW slepton/gaugino production in multilepton final states published this summer; 8 TeV 13 fb^{-1} update of 3-*L* search

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

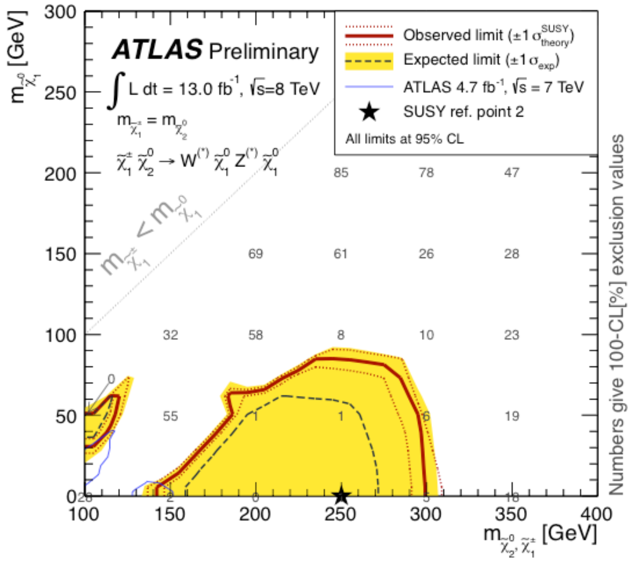
Significant background from *WZ* production; measured in dedicated control region



Limit on C+N2 production with intermediate sleptons



Limit on C+N2 production without intermediate sleptons



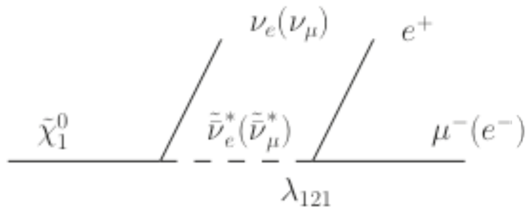
R-parity violating SUSY scenarios

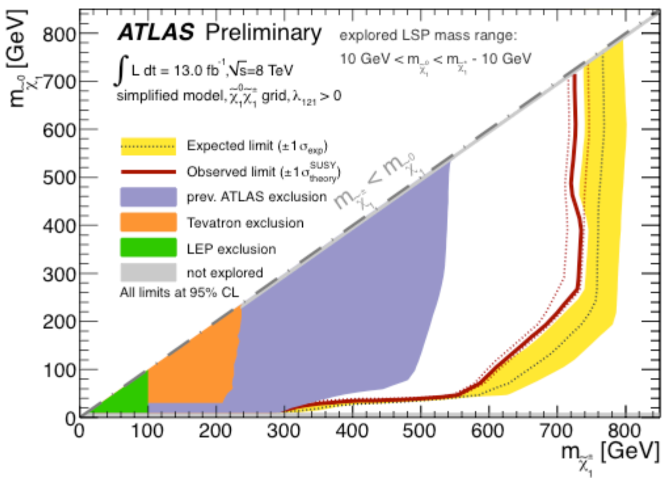
Decays of LSP in RPV models can lead to many leptons, many jets, resonances

ATLAS-CONF-2012-153, Preliminary, 1210.4813

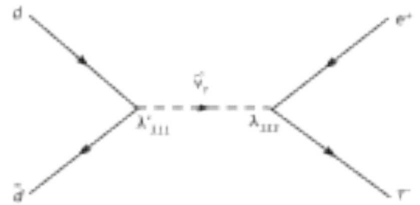
Dedicated research programme designed to assess extremely broad RPV phenomenology

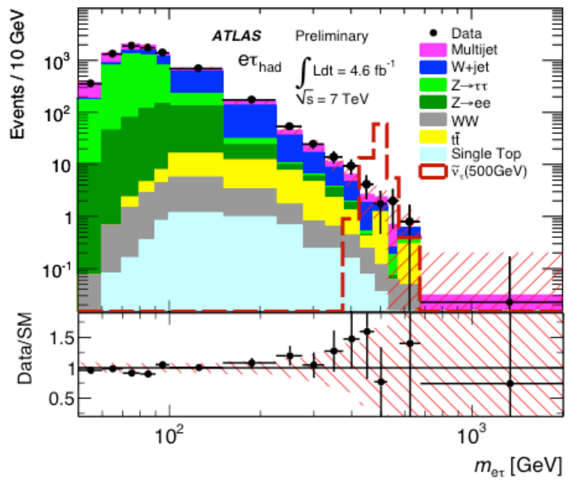
Search for strong and EW SUSY-RPV production in events with >=4-L





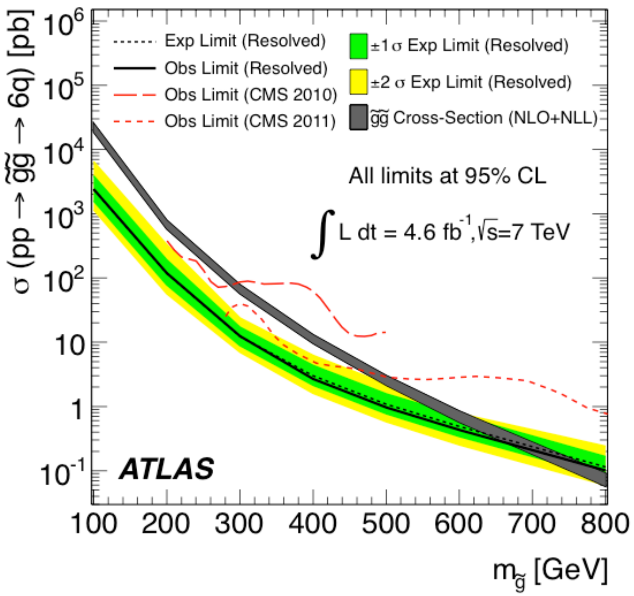
Search for RPV sneutrino production and decay through LFV into LL'





Search pairs of gluino decays to 3 q

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



What about Dark Matter ?

Limits on WIMP production assuming high-scale contact interaction

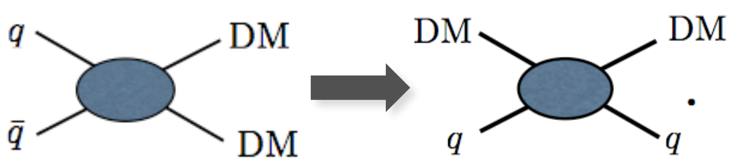
1210.4491, ATLAS-CONF-2012-147

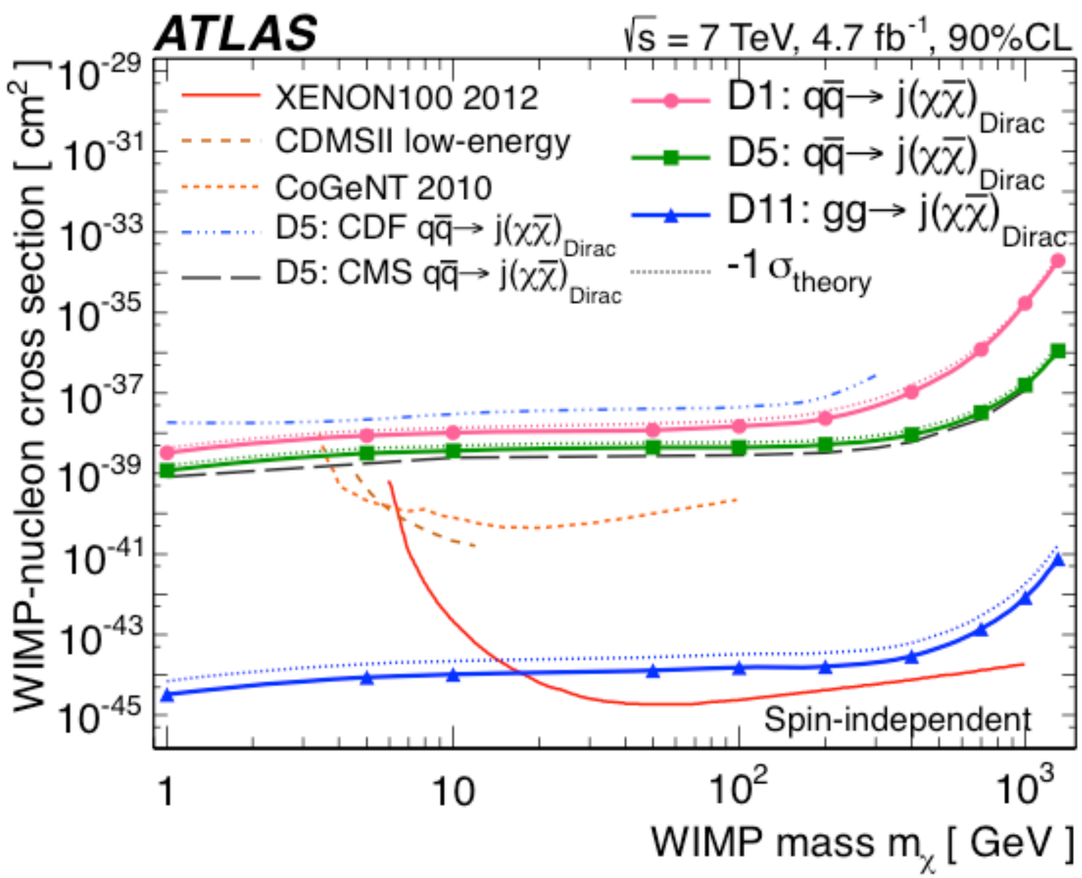
Limit on WIMP pair production cross-section can be transformed into limit on effective WIMP-hadronic contact interaction:

Vector (SI): $(\bar{\chi}\gamma_{\mu}\chi)(\bar{q}\gamma^{\mu}q)\cdot\Lambda^{-2}$

Axial-v. (SD): $(\bar{\chi}\gamma_{\mu}\gamma^{5}\chi)(\bar{q}\gamma^{\mu}\gamma^{5}q)\cdot\Lambda^{-2}$

WIMP-nucleon scattering cross-section: $\sigma \propto \frac{1}{\Lambda^4}$



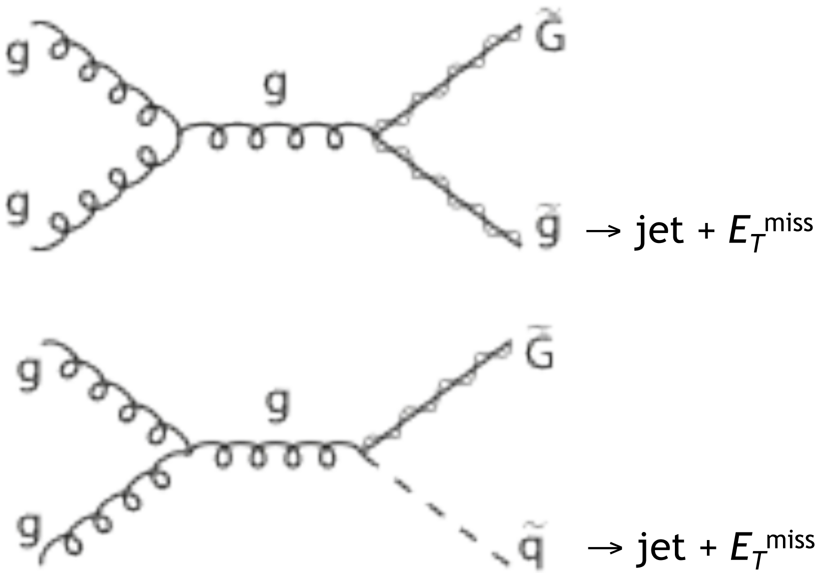


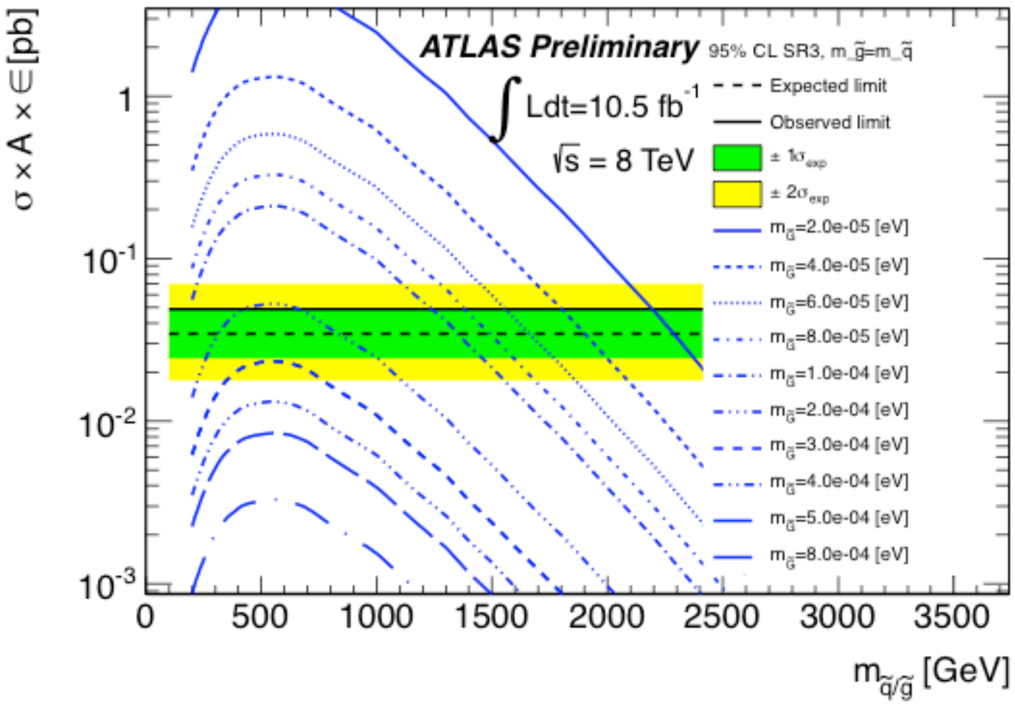
Monojet analysis as search for gravitino production

Same signature as WIMP production, but not ISR search (similar to ADD)

ATLAS-CONF-2012-147

In GM SUSY, gravitino LSP with mass related to SUSY breaking scale
At LHC with low-scale SUSY breaking, direct $\tilde{G}+\tilde{q}$ or $\tilde{G}+\tilde{g}$ production can dominate. Cross-section ~ $1/m^2(\tilde{G})$





Lower limits on gravitino mass as function of squark/gluino masses

Improves existing limits by O(magnitude)

SUSY in 1-lepton channel: bRPV limits

"Turn off" R-parity conservation via bilinear terms in the superpotential

• Leads to mixing of neutrinos and neutralinos

– Reasonably natural way to give neutrinos a small mass

• Also leads to decay of the lightest neutralino (normally LSP) $\chi_1^0 \rightarrow l\,W$

• Don't set limits where cτ>15 mm – SUSY Long-Lived Particle search is better in this region...

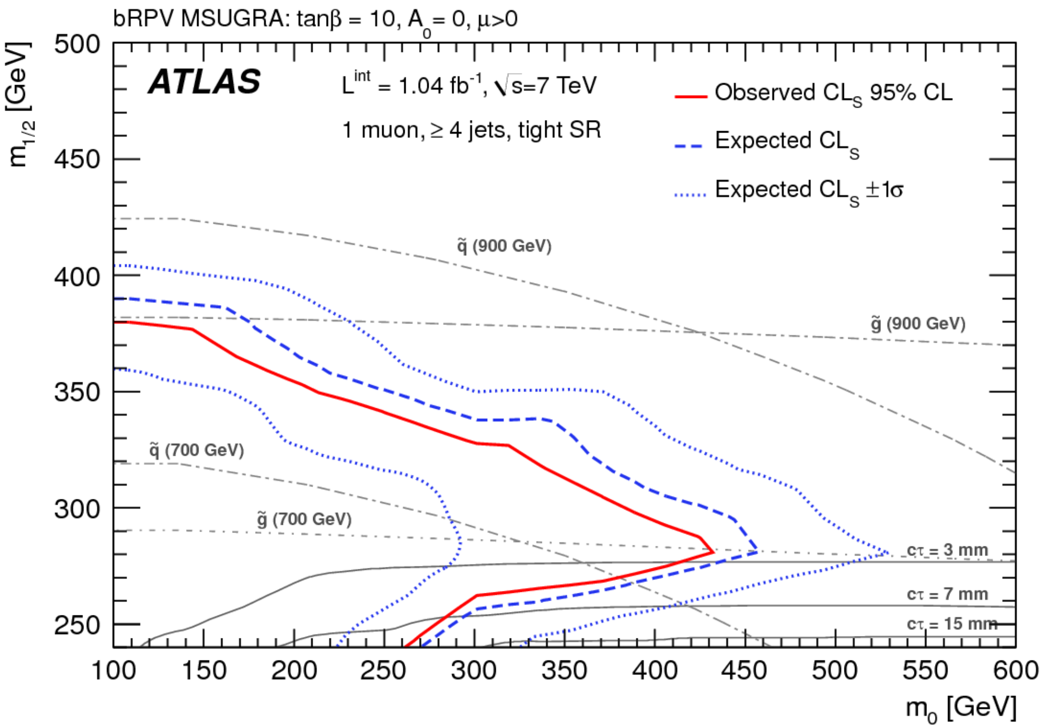
• Same theory space as mSUGRA/CMSSM – Adding neutrino oscillation data constrains the other free parameters

• Muon channel favoured theoretically

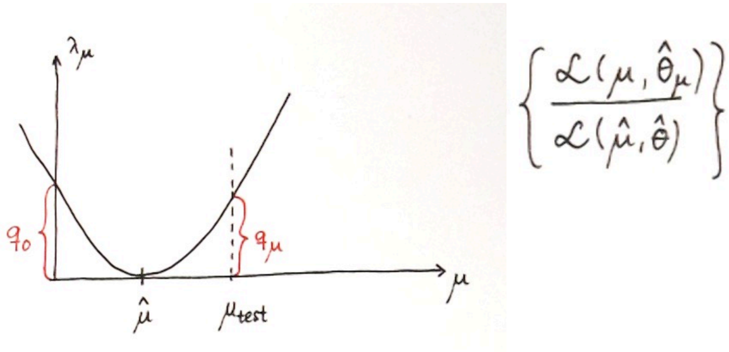
–four jet tight signal region dominates everywhere

→ exclusion plot for bilinear R-parity violation model

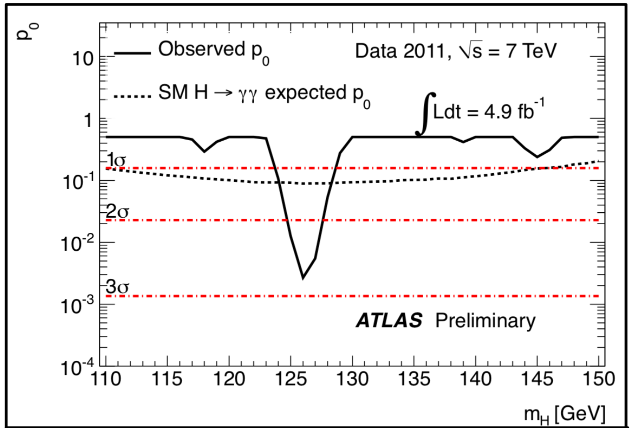
(first time at the LHC)

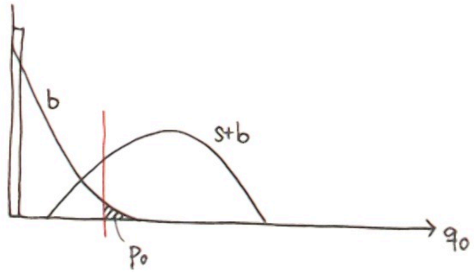


Profile likelihood ratio, p_o and CL_s

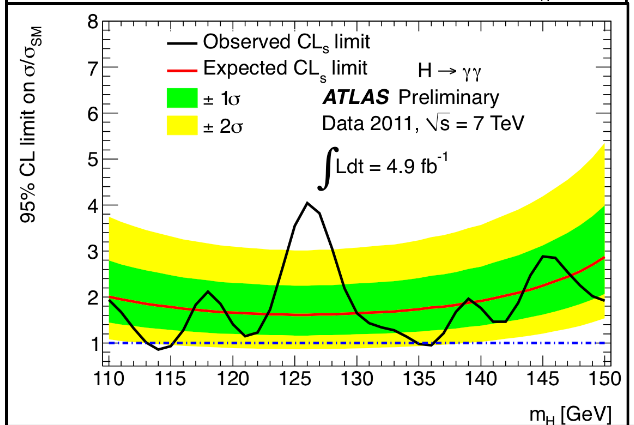


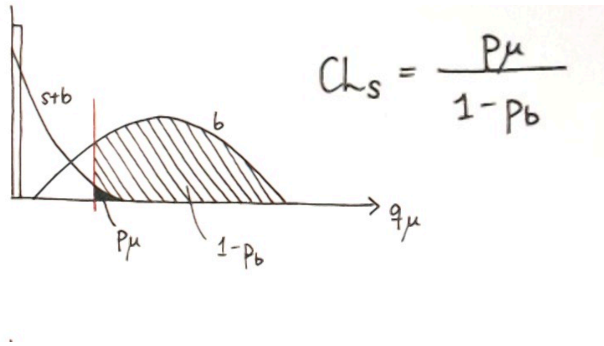
- Local significance p_o to test background hypothesis



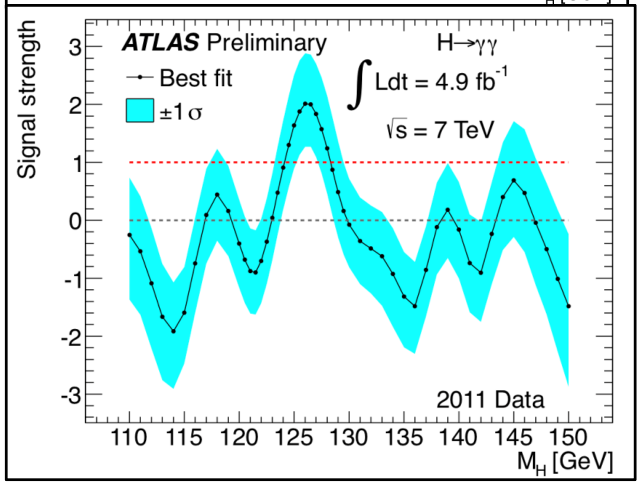


- $CL_s = CL_{s+b}/CL_b$ (log-likelihood ratio) to test signal hypothesis





- $\hat{\mu}$ to estimate signal strength (relative to expectation)



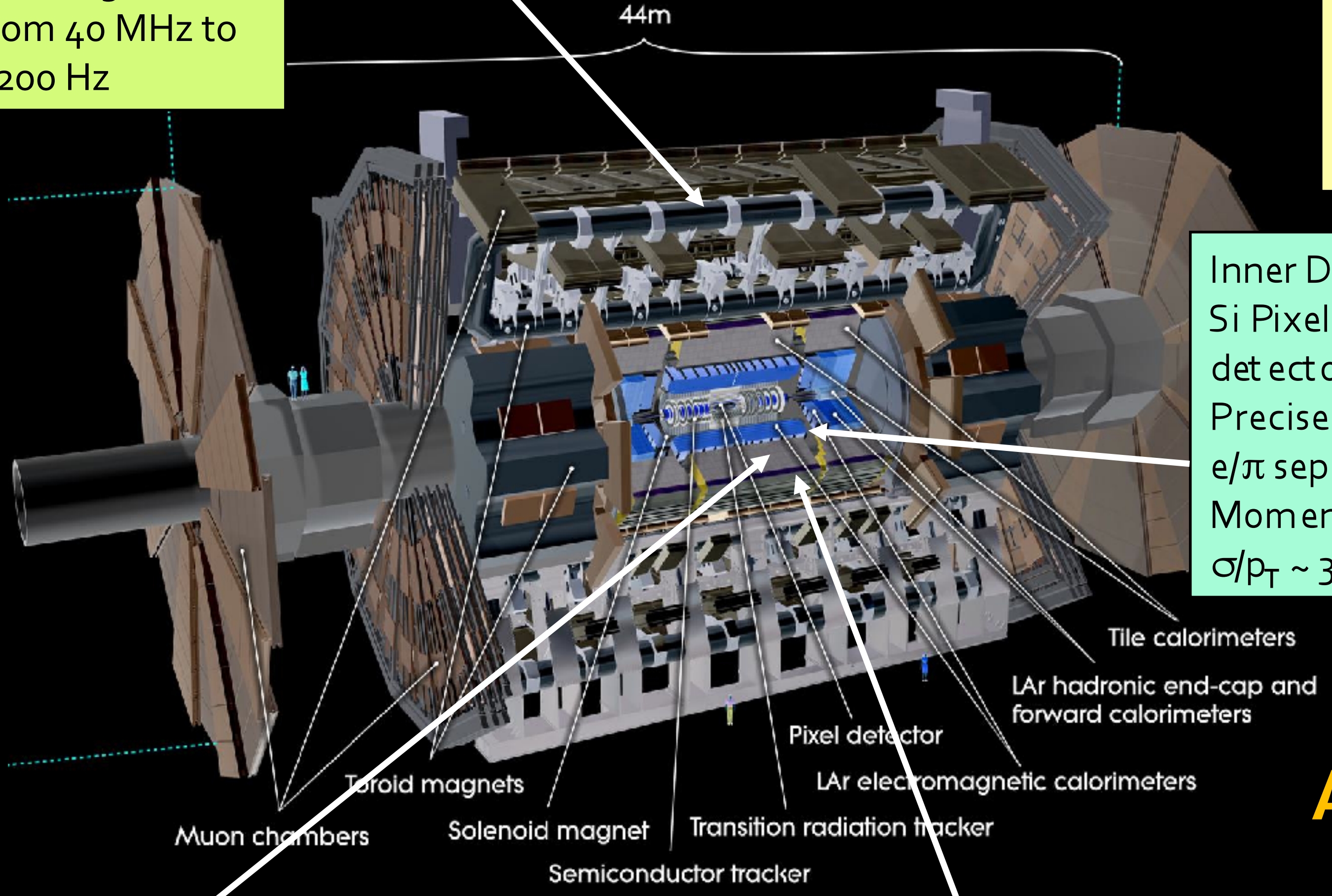
[Follow LHCHCG Combination Procedures]

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

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

38 Countries 174 Institutions
3000 Scientists 1000 Students

Length : ~ 44 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables



Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws)
Precise tracking and vertexing,
e/π separation
Momentum resolution:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T\,(\mathrm{GeV}) \oplus 0.015$

ATLAS Detector

EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

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