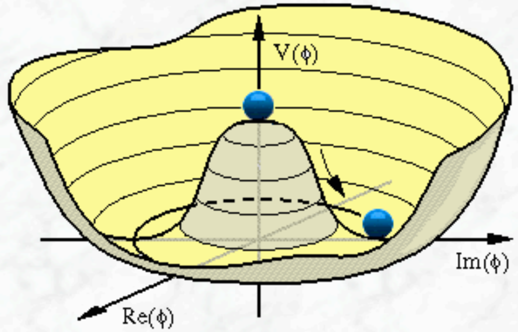
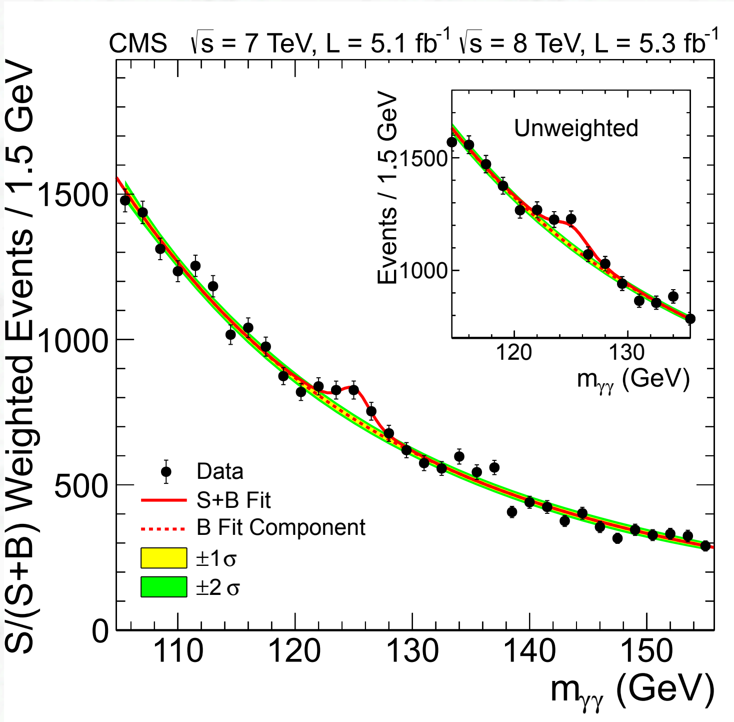
Part 4: Search for the Higgs Boson



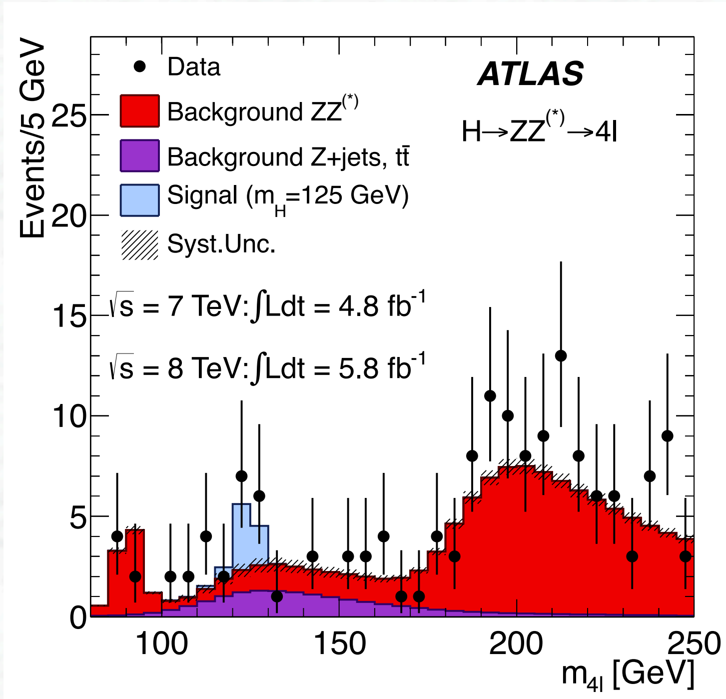
4th July 2012 A great day for science / particle physics

Some convincing signals

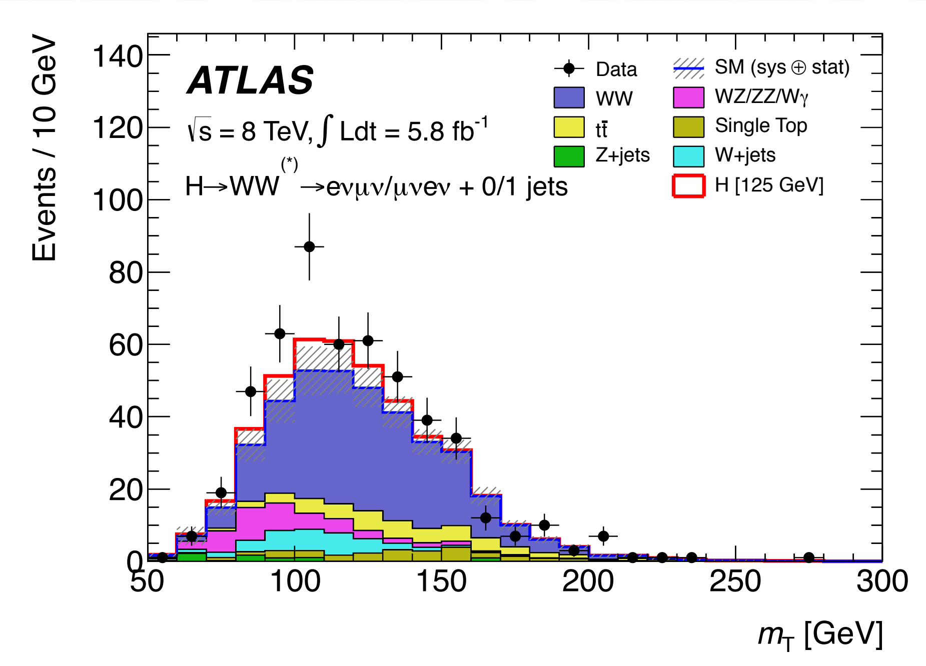
$H \rightarrow \gamma\gamma$

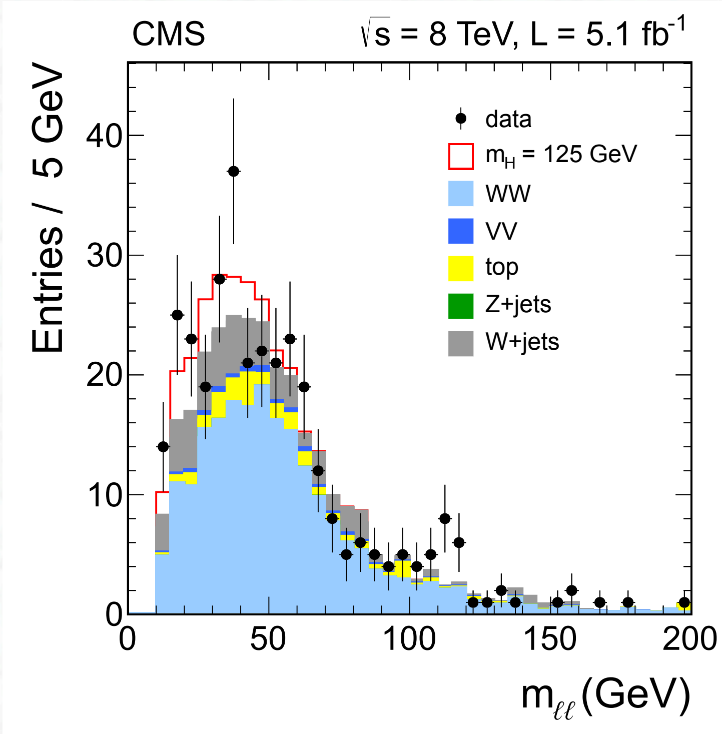


$H \rightarrow ZZ^{(*)} \rightarrow \ell^+\ell^- \ell^+\ell^-$



H → WW → ℓν ℓν

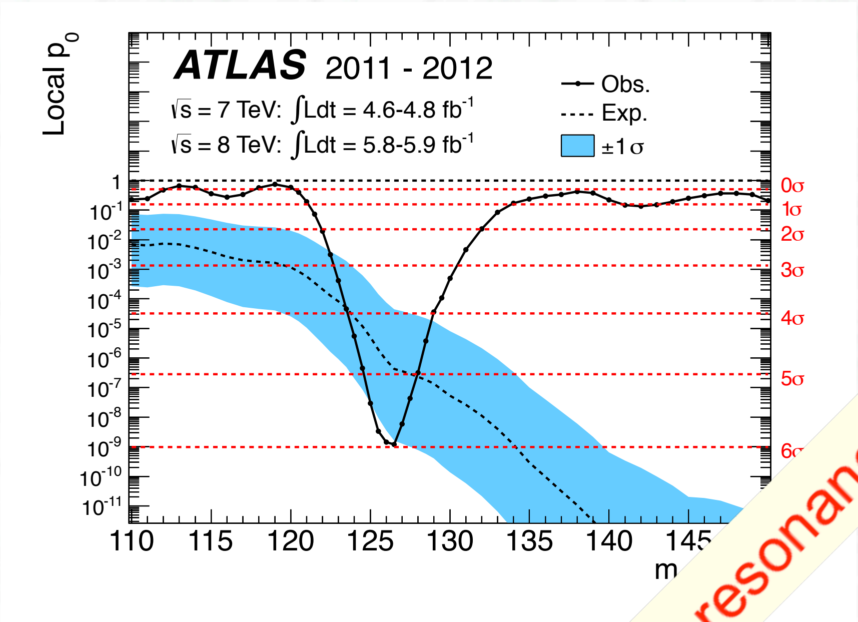


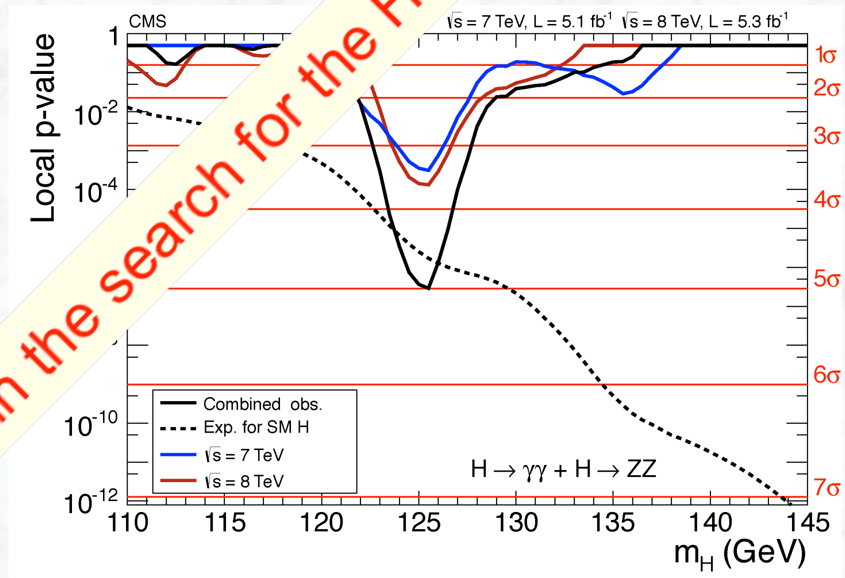


Updated ATLAS analysis (since 4th July) including the 2012 data

new

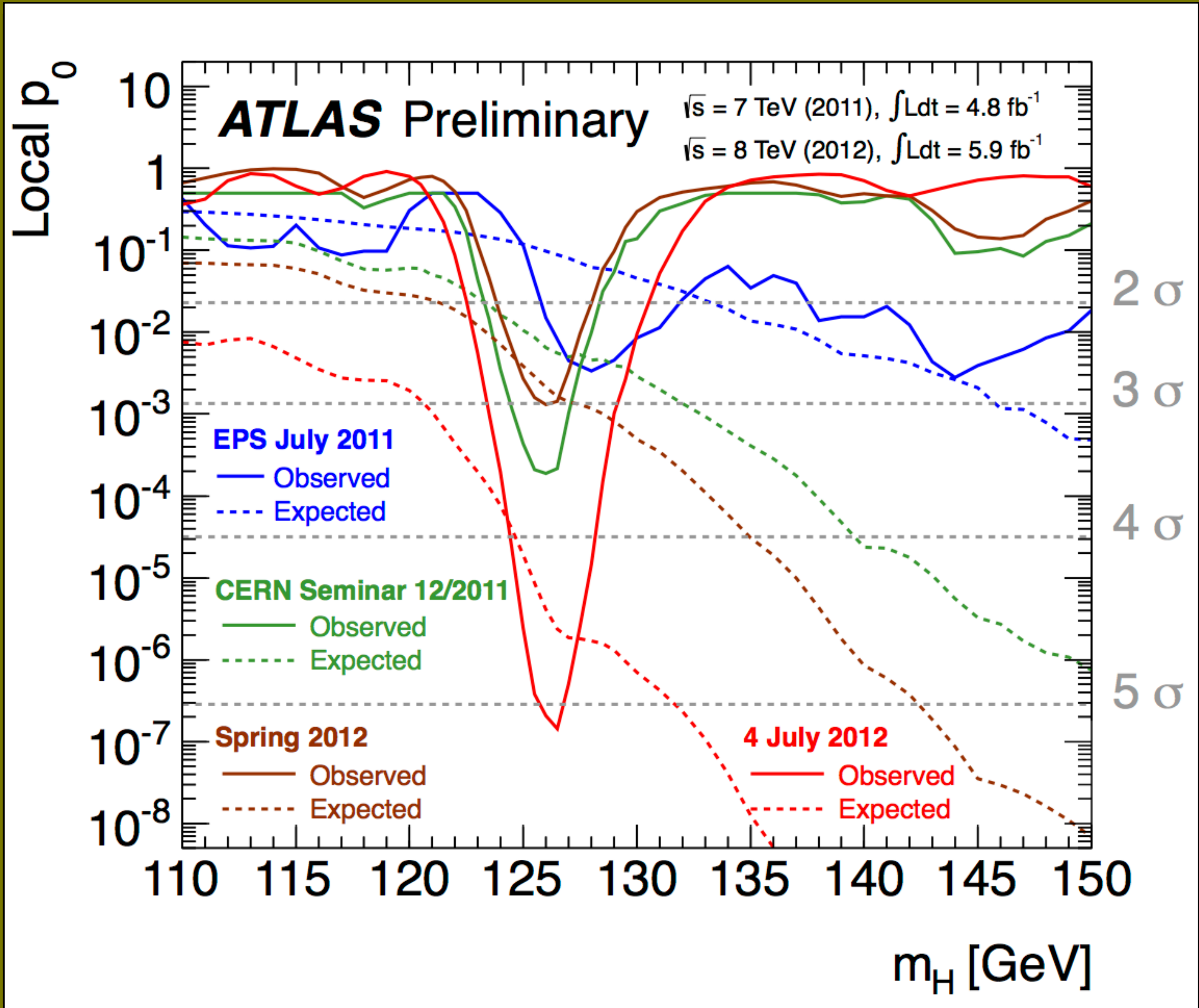
Compatibility with background only hypothes





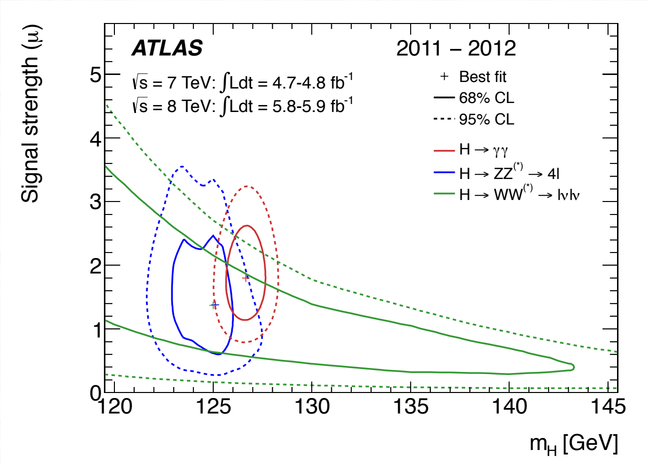
Observation of a new resonance in the search for the Higgs boson

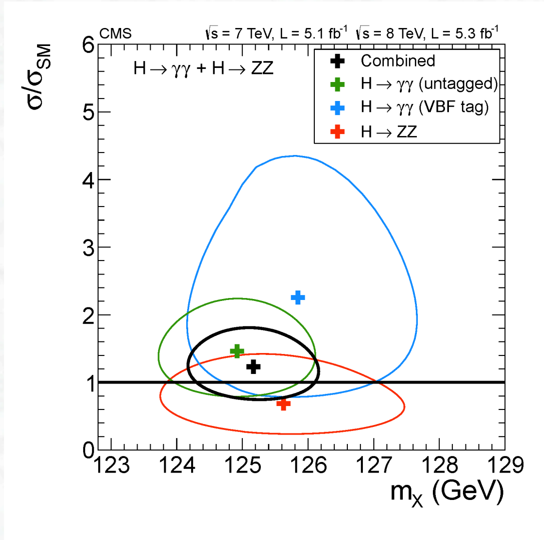
Evolution of the excess with time

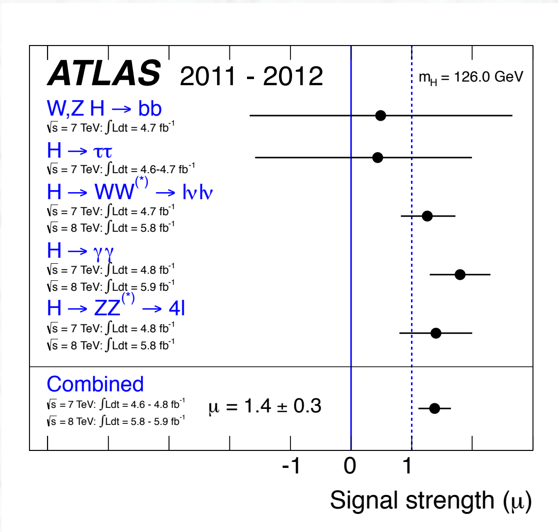


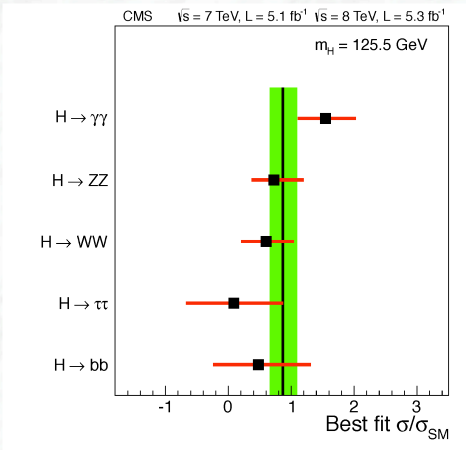
Energy-scale systematics not included

Signal strengths in individual channels, mass estimates







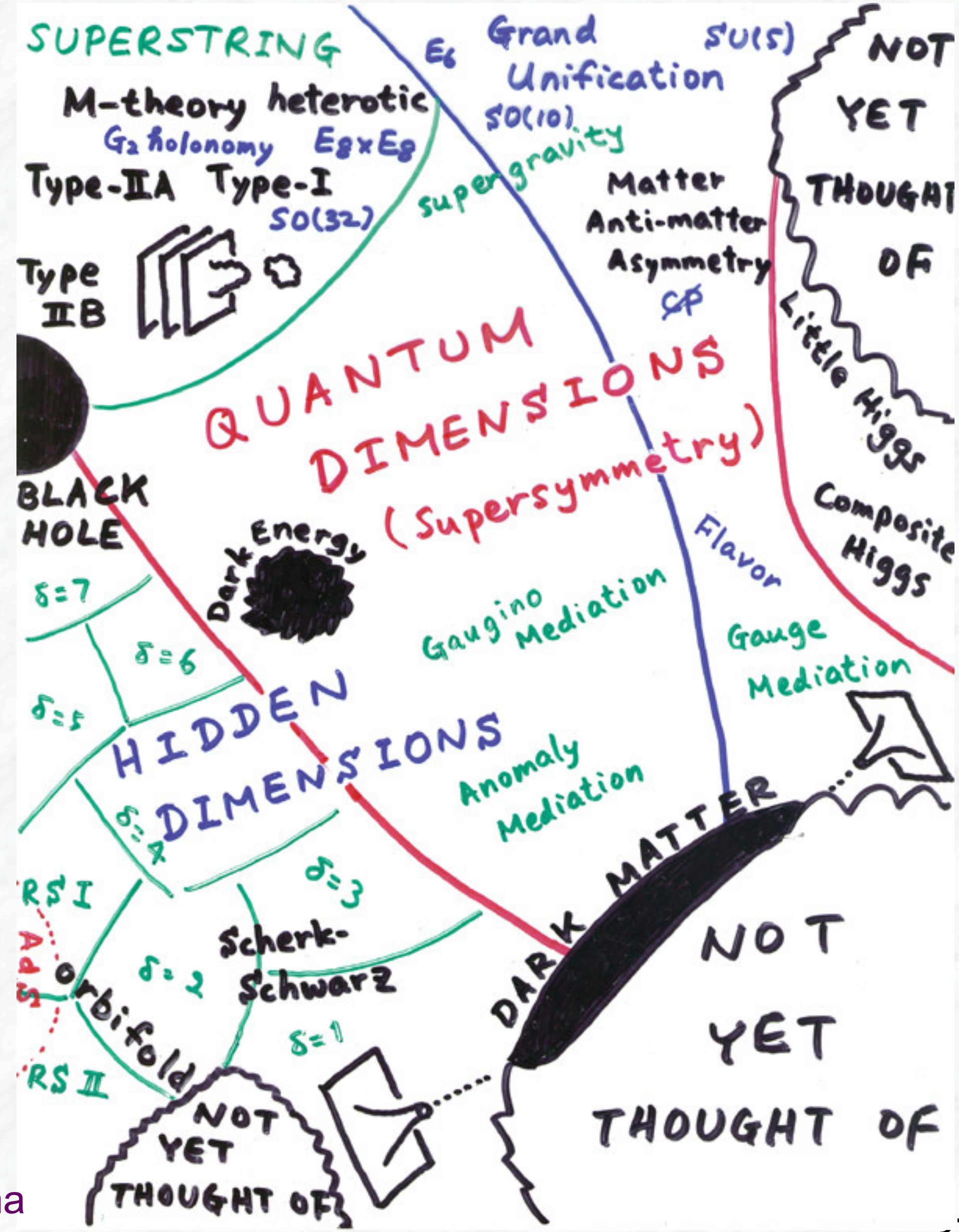


Next important steps: - updated ATLAS analyses on tt and bb channels awaited
- Determination of parameters of the resonance
(mass, spin / CP, couplings)

Part 5: Searches for Physics Beyond the Standard Model

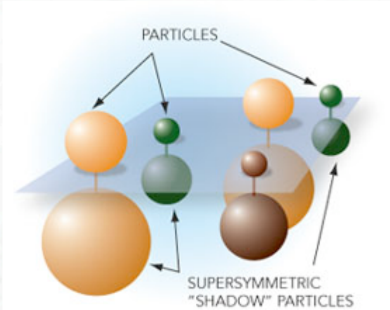
- Most of this will be summarized in the dedicated lecture by Meenakshi Narain

- I will conentrate on a few important SUSY results in the following

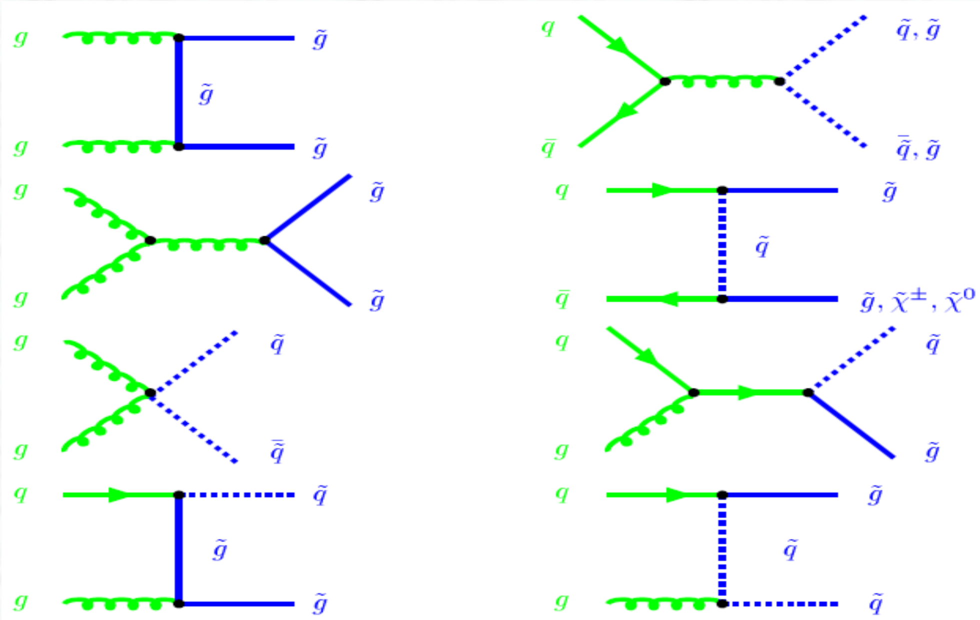


Hitoshi Murayama

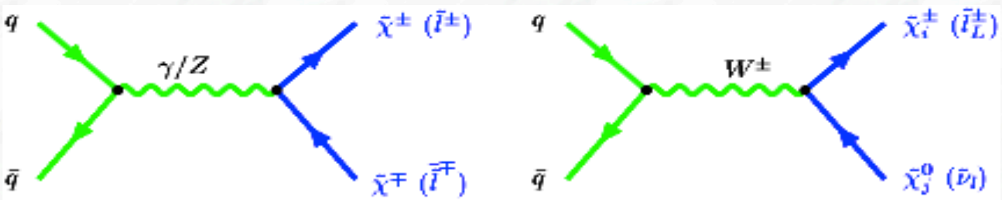
5.1 Search for Supersymmetry



- qq, qg or gg in the initial state → production of coloured SUSY particles is dominant, via strong interaction

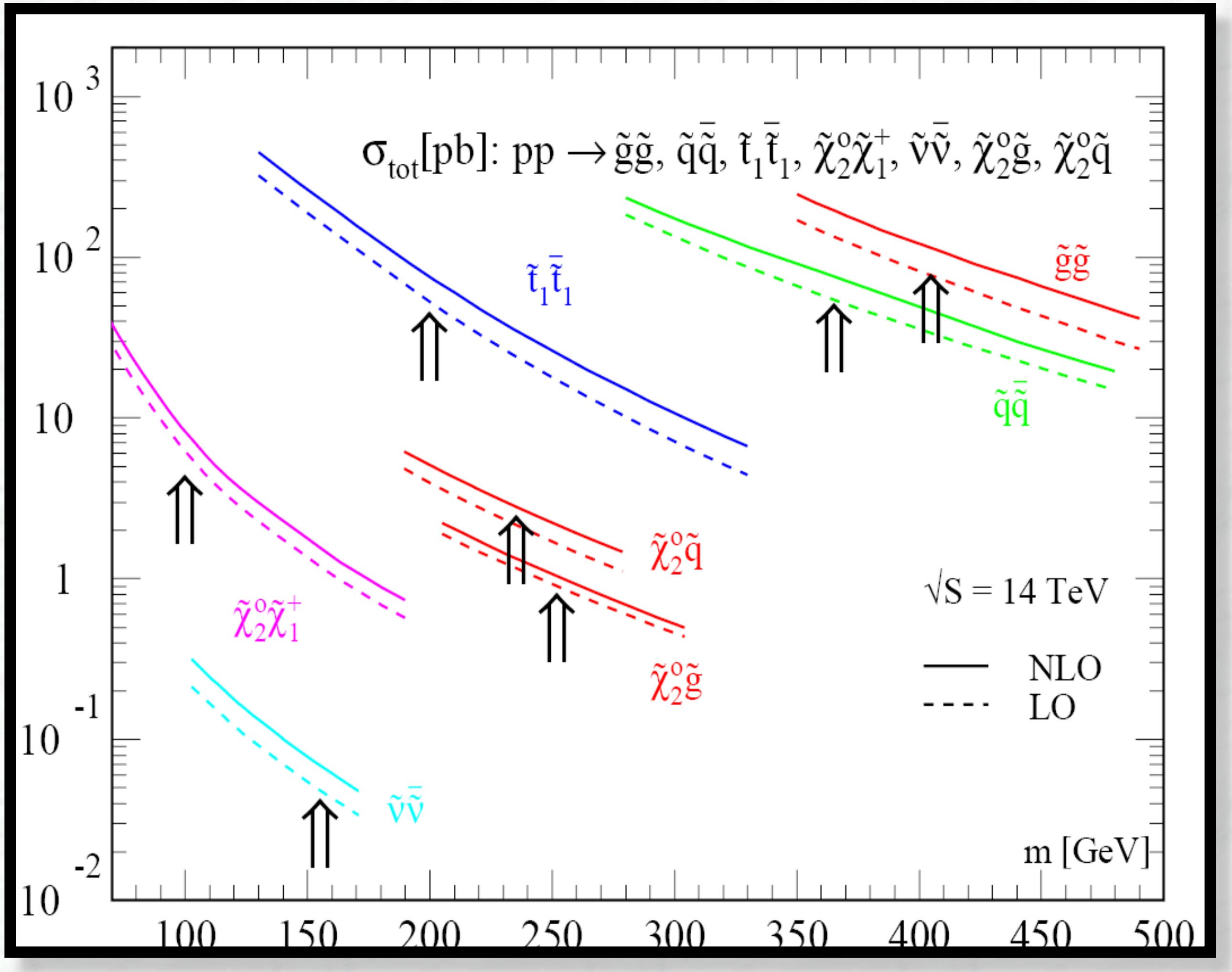


- Drell-Yan production of sleptons, charginos and neutralinos (lower cross sections)



Cross sections for SUSY production processes

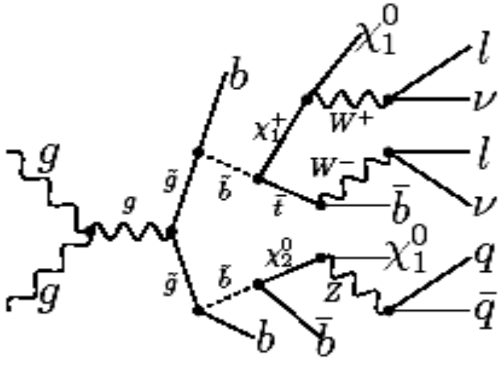
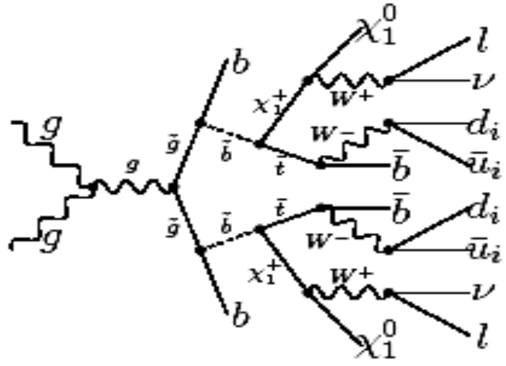
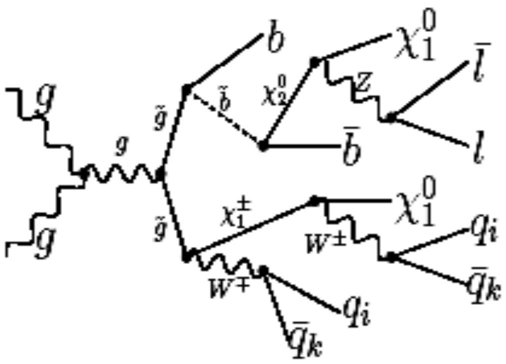
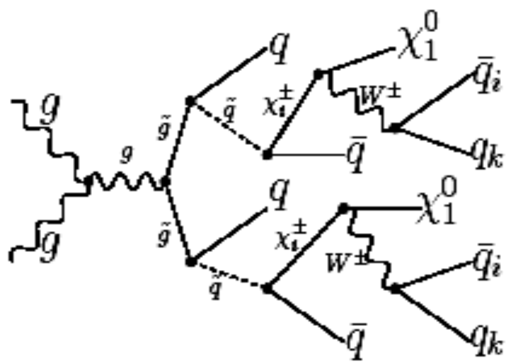
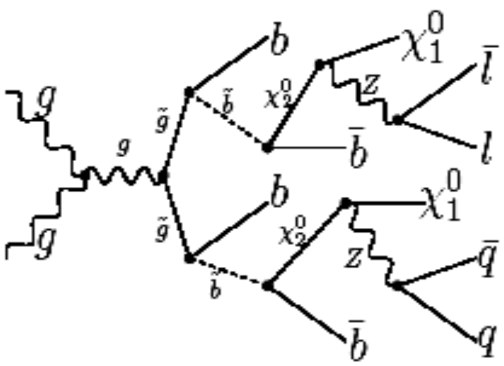
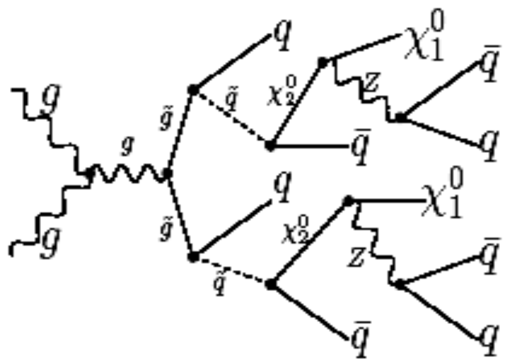
σ (pb)



M (GeV)

NLO corrections in QCD perturbation theory are known

Decays of heavy SUSY particles → long and complex decay chains
Invariants in R-parity conserving SUSY: jets, E_T^{miss} (2 LSPs)

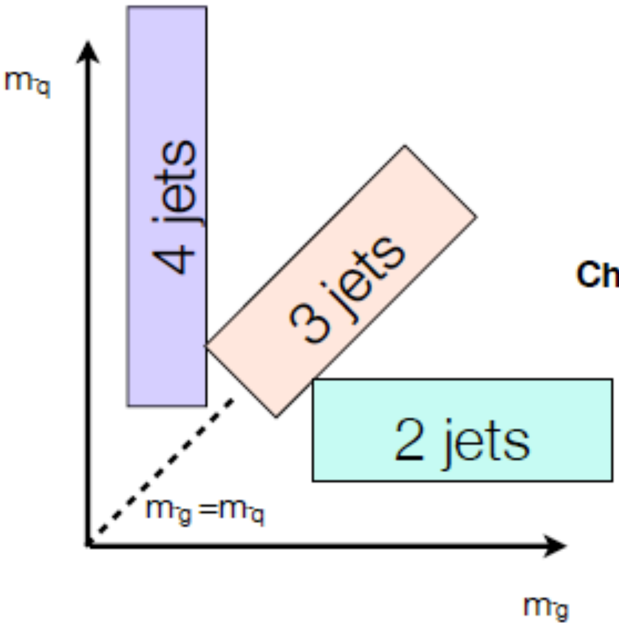
process	final states	process	final states
	2ℓ 2ν $6j$ $\not{E}_T$		2ℓ 2ν $8j$ $\not{E}_T$
	2ℓ $6j$ $\not{E}_T$		$8j$ $\not{E}_T$
	2ℓ $6j$ $\not{E}_T$		$8j$ $\not{E}_T$

An example of a search for E_T^{miss} + jets (1.04 fb^{-1})

Selection of events with E_T^{miss} + jets

Split the analysis according to jet multiplicities: 2, 3 and 4 jets
(different sensitivity for different squark/gluino mass combinations,
i.e. in different regions of SUSY parameter space)

Definition of signal regions:



	Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets	High mass
Trigger requirements	E_T^{miss}	> 130	> 130	> 130	> 130
	Leading jet p_T	> 130	> 130	> 130	> 130
Channel definition	Second jet p_T	> 40	> 40	> 40	> 80
	Third jet p_T	–	> 40	> 40	> 80
	Fourth jet p_T	–	–	> 40	> 80
Reduce QCD	$\Delta\phi(\text{jet}, E_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
	E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
Enhance signal	m_{eff} [GeV]	> 1000	> 1000	> 500/1000	> 1100

$$m_{eff} = \sum_{i=1}^{n} |\vec{p}_T^{\,jet\ i}| + E_T^{miss}$$

- Three different analyses, depending on squark / gluinos mass relations:

  (i) dijet analysis
  small m_0, m(squark) < m(gluino)

  $$\tilde{q}\,\bar{\tilde{q}} \rightarrow q\,\tilde{\chi}_1^0\,\bar{q}\,\tilde{\chi}_1^0$$

  (ii) 3-jet analysis
  intermediate m_0 m(squark) ≈ m(gluino)

  $$\tilde{q}\,\tilde{g} \rightarrow q\,\tilde{\chi}_1^0\,q\,\bar{q}\,\tilde{\chi}_1^0$$

  (iii) Gluino analysis
  large m_0, m(squark) > m(gluino)

  $$\tilde{g}\,\tilde{g} \rightarrow q\,\bar{q}\,\tilde{\chi}_1^0\,q\,\bar{q}\,\tilde{\chi}_1^0$$

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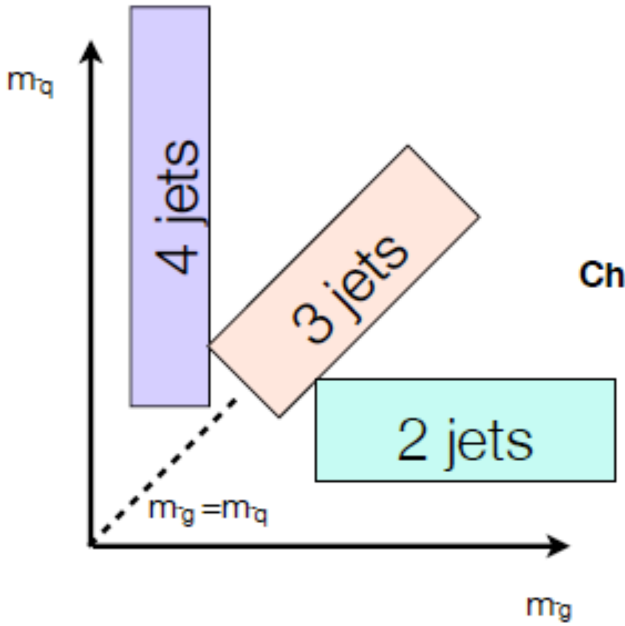

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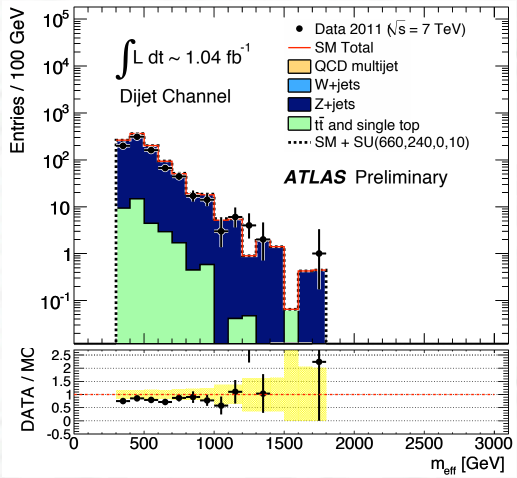
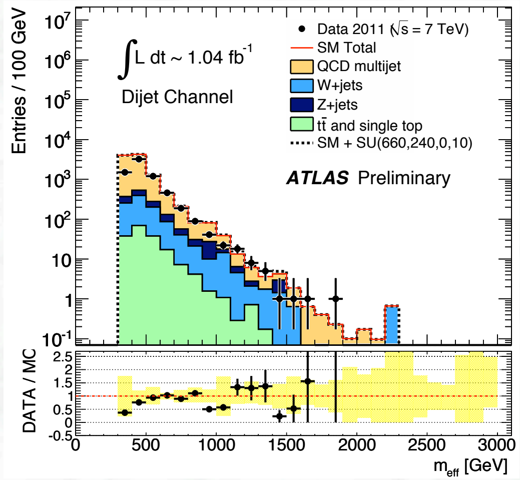
	E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
Enhance signal	m_{eff} [GeV]	> 1000	> 1000	> 500/1000	> 1100

$$m_{eff} = \sum_{i=1}^{n} |\vec{p}_T^{\,jet\ i}| + E_T^{miss}$$

Summary on control of backgrounds using data

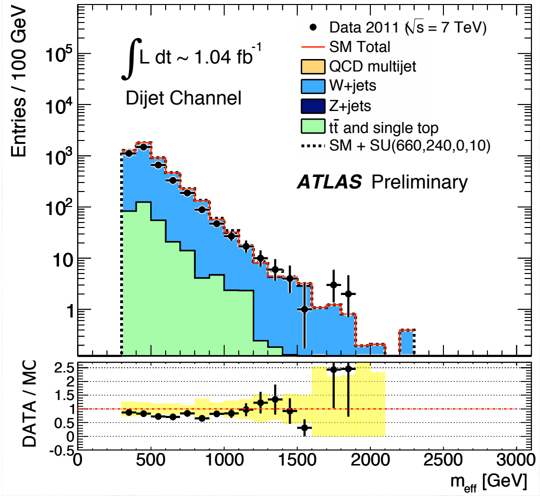
(control regions, very important !!)

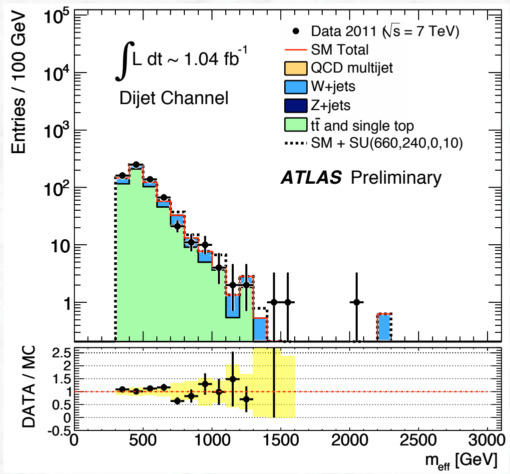




A: Z + jet events, Z → ee
(to estimate Z → νν background, likewise γ + jet events were used)

B: QCD multijet background
(reverse cut on $\Delta\phi$ (jet, E_T^{miss})





C: W → lν + jet control region
(select events with one lepton, $30 < M_T(l,E_T^{miss}) < 100$ GeV, no b-jet to suppress top contribution)

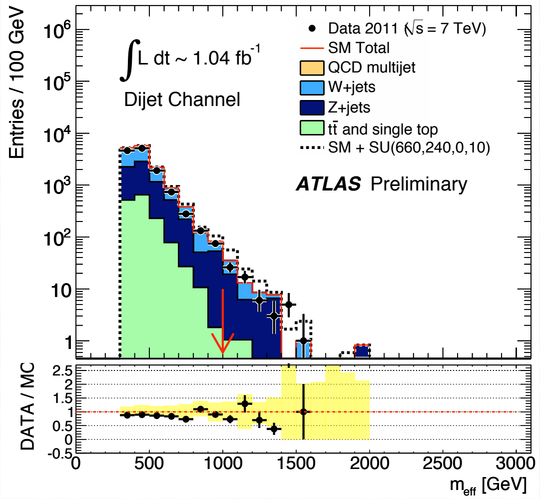
D: top quark control region
(same selection as for W events, but require b-tag)

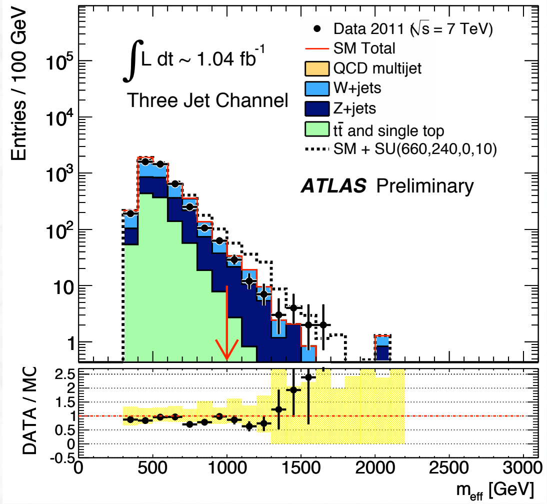
Process	Signal Region				
	≥ 2-jet	≥ 3-jet	≥ 4-jet, $m_{\text{eff}} > 500$ GeV	≥ 4-jet, $m_{\text{eff}} > 1000$ GeV	High mass
Z/γ+jets	32.5 ± 2.6 ± 6.8	25.8 ± 2.6 ± 4.9	208 ± 9 ± 37	16.2 ± 2.1 ± 3.6	3.3 ± 1.0 ± 1.3
W+jets	26.2 ± 3.9 ± 6.7	22.7 ± 3.5 ± 5.8	367 ± 30 ± 126	12.7 ± 2.1 ± 4.7	2.2 ± 0.9 ± 1.2
$t\bar{t}$+ Single Top	3.4 ± 1.5 ± 1.6	5.6 ± 2.0 ± 2.2	375 ± 37 ± 74	3.7 ± 1.2 ± 2.0	5.6 ± 1.7 ± 2.1
QCD jets	0.22 ± 0.06 ± 0.24	0.92 ± 0.12 ± 0.46	34 ± 2 ± 29	0.74 ± 0.14 ± 0.51	2.10 ± 0.37 ± 0.83
Total	62.3 ± 4.3 ± 9.2	55 ± 3.8 ± 7.3	984 ± 39 ± 145	33.4 ± 2.9 ± 6.3	13.2 ± 1.9 ± 2.6
Data	58	59	1118	40	18

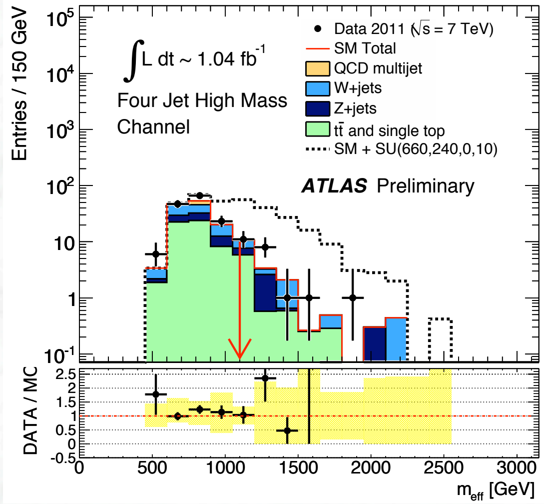
Observed and expected event numbers (from Standard Model processes)

dominant backgrounds:
- W/Z + jets
- tt production

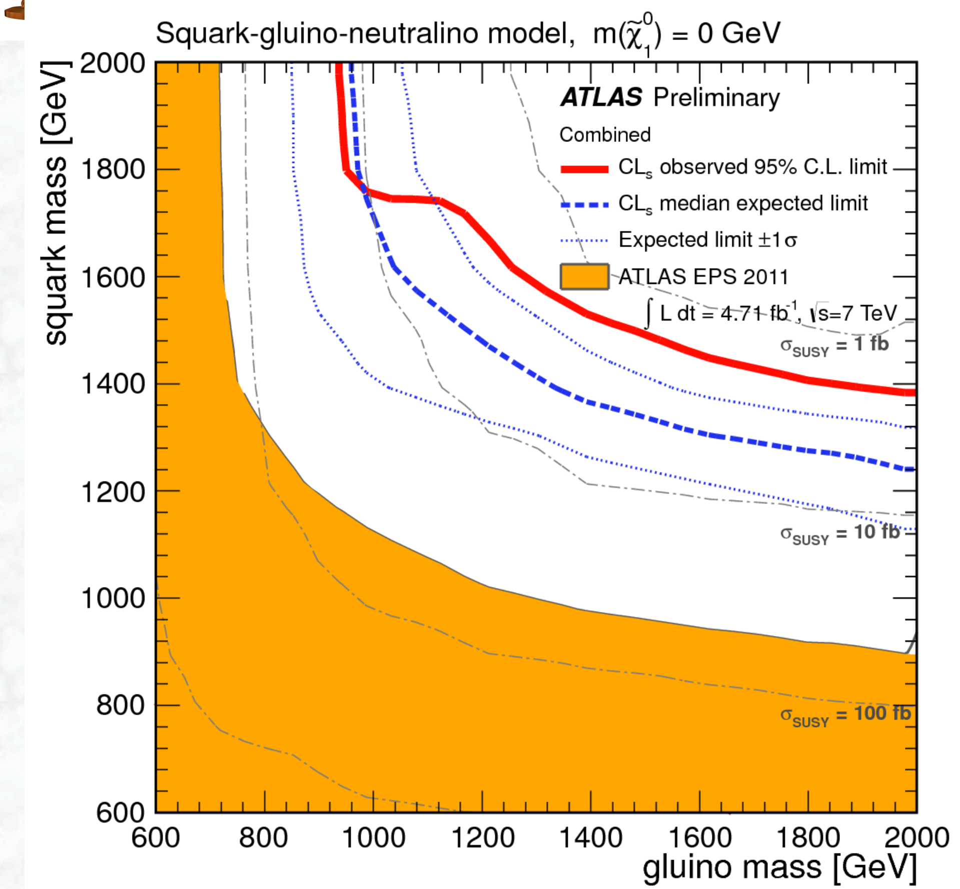
Normalized in control regions !
(as explained on the previous slide)







Results from 2011 data, 4.7 fb^{-1}

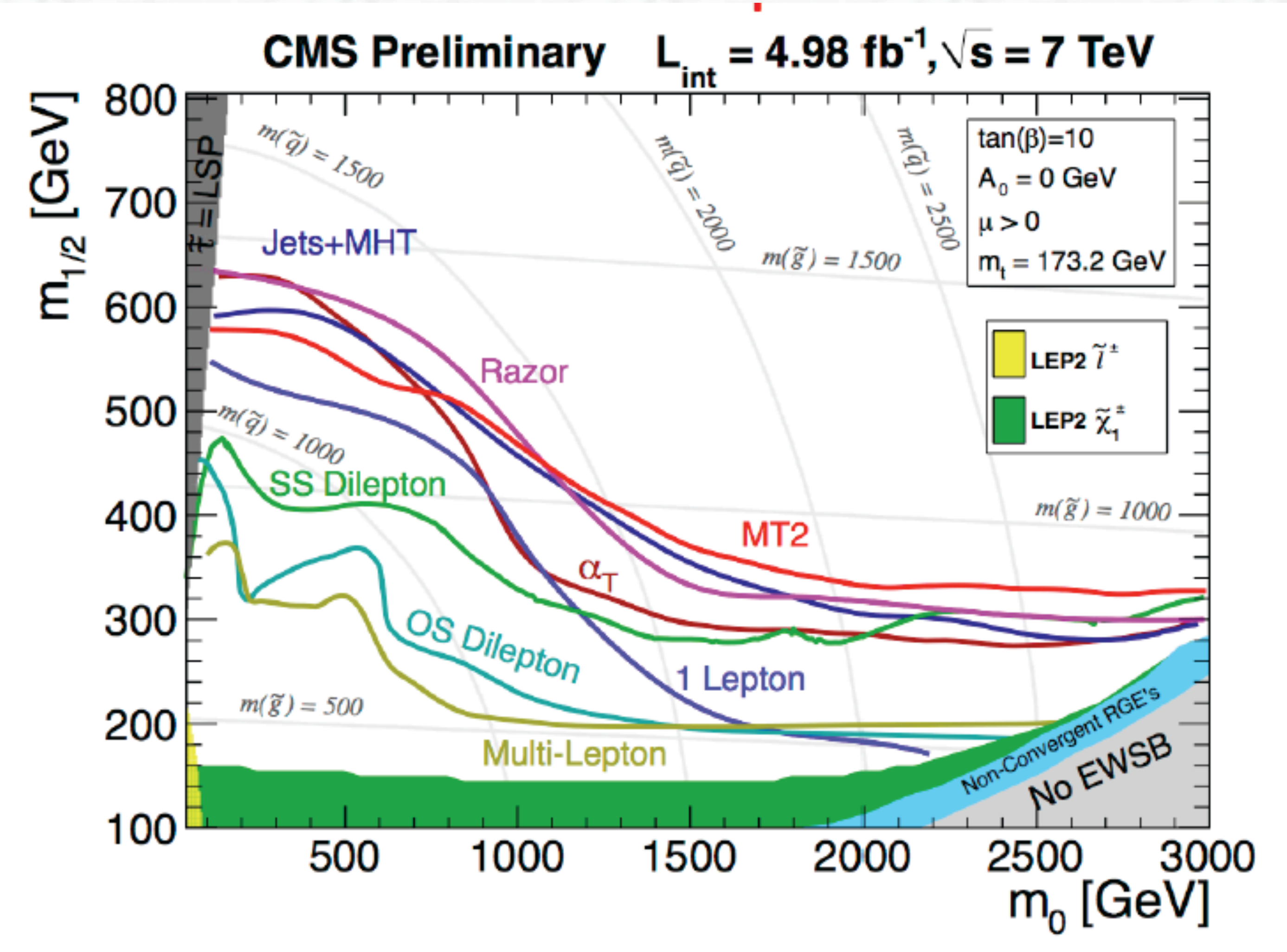


Interpretation of the results in the (m_{gluino}, m_{squark})-plane as 95% C.L. exclusion limits in a simplified SUSY model:

- $m_\chi = 0$
- masses of gluinos and of 1st and 2nd generation squarks as given on plot
- all other SUSY masses are assumed to be decoupled, with masses of 5 TeV

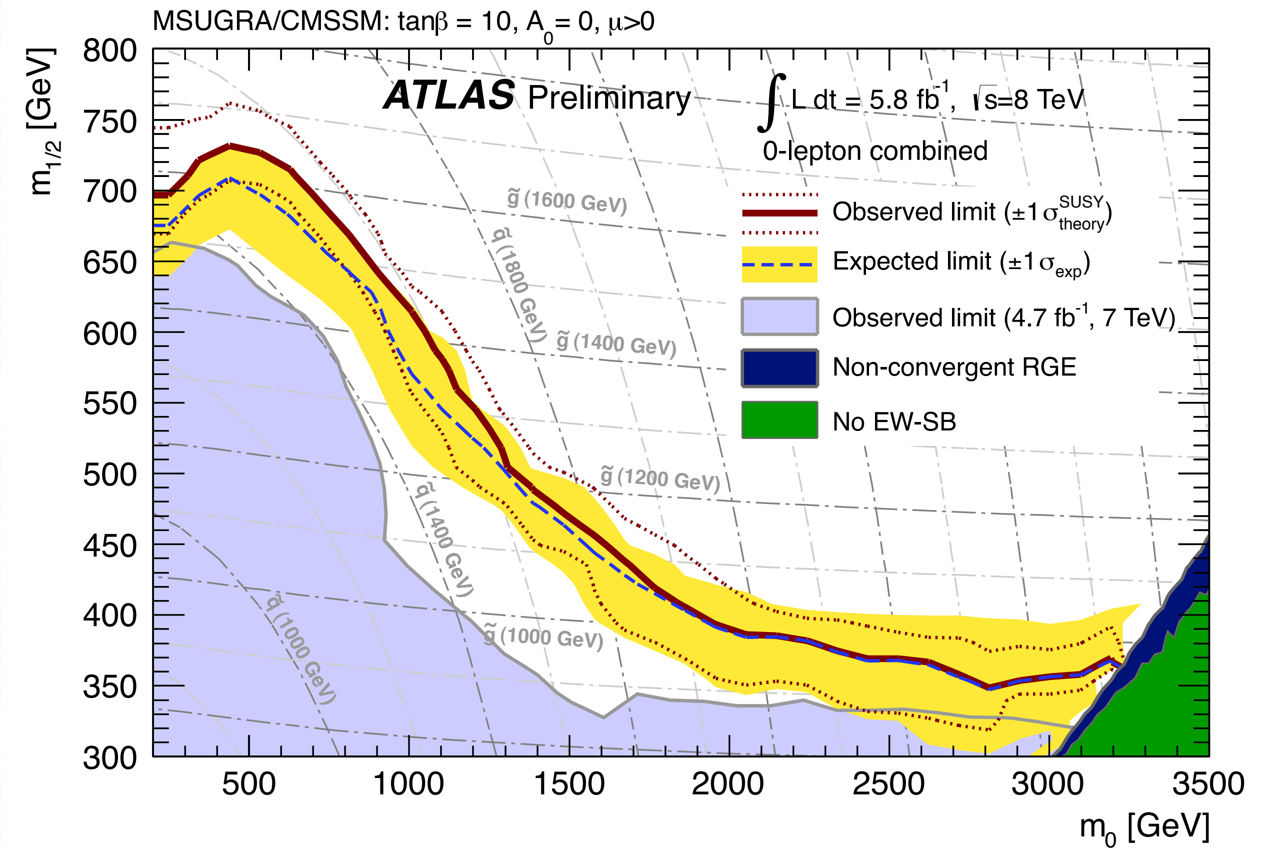
Large area of mass combinations excluded;
Limits do not apply to stop / sbottom production

mSUGRA interpretation



tan β = 10,
A_0 = 0, μ > 0

mSUGRA interpretation, including 2012 data



$\tan\beta = 10$,
$A_0 = 0$, $\mu > 0$

MSSM/cMSSM interpretation (for equal squark and gluino masses):

$L = 5.8\ fb^{-1}$ at $\sqrt{s} = 8$ TeV m(squark), m(gluino) > 1500 GeV

Looking for “natural” SUSY

- Search for stops and sbottoms in gluino decays

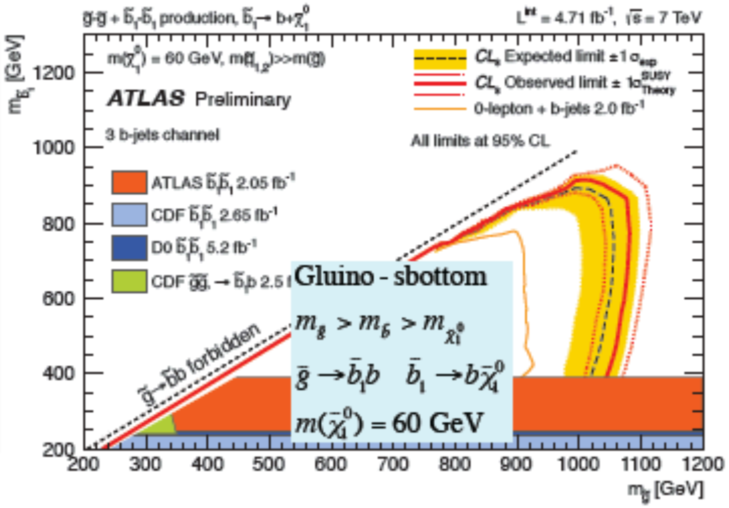
  - if other squarks are very heavy, gluino will decay into sbottoms and stops with high branching ratio

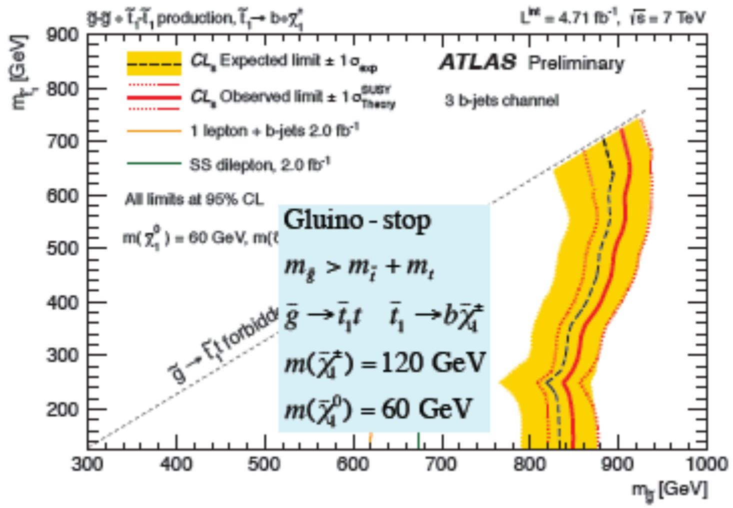
- Search for stop and sbottom pair production
  - to close the loophole that the “gluino is too heavy”

ATLAS: $\tilde{g} \rightarrow \tilde{t}\ ,\tilde{b}$

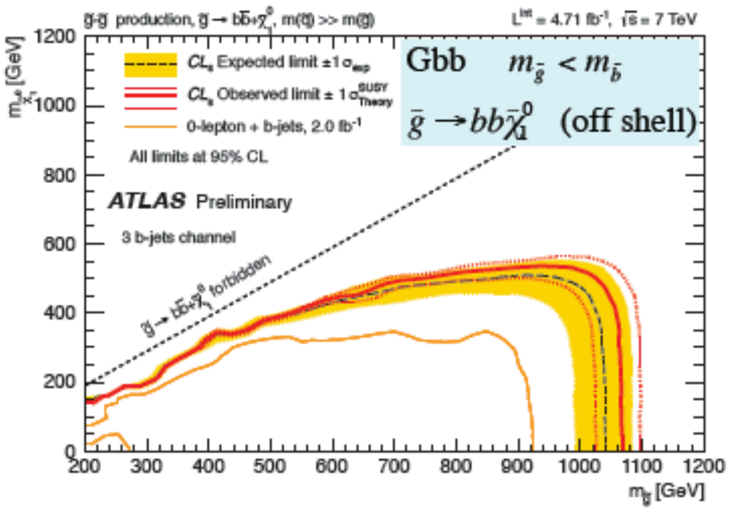
4-6 jets (≥3 b-jets), no leptons. **Allowed decays depend on masses**

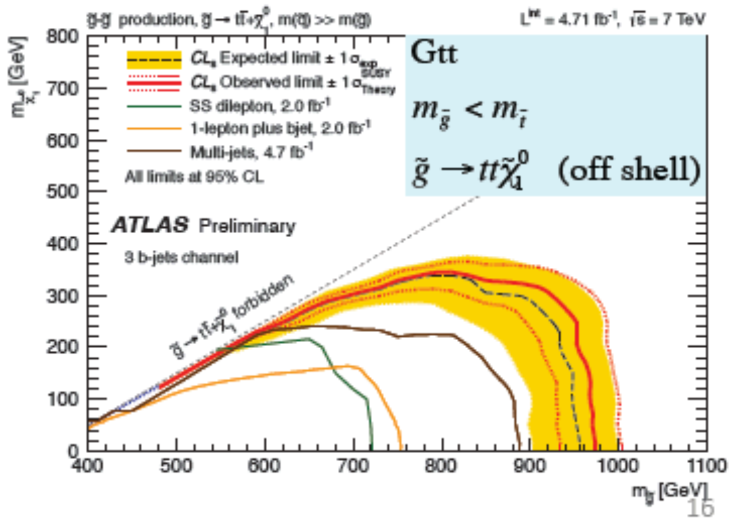
Upper plots – 2-body cascade decays





Lower plots – 3-body decays

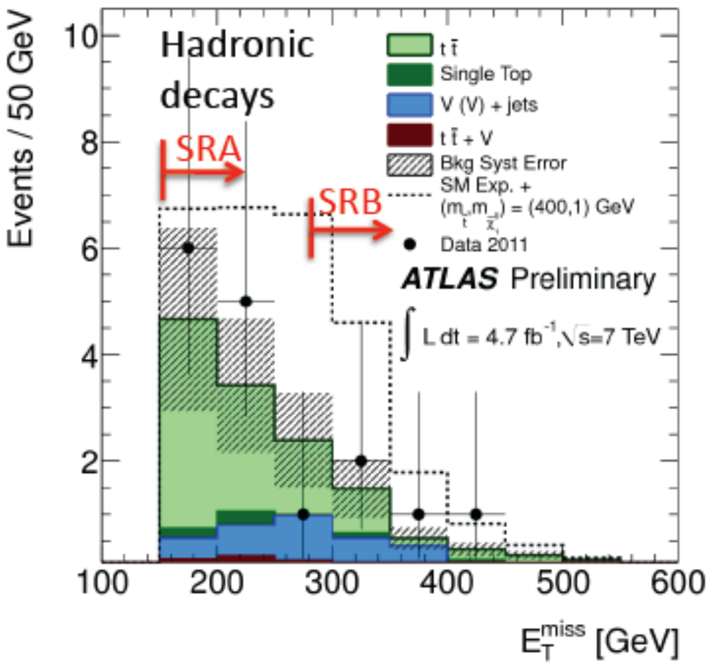




Direct Stop searches

Heavy stop > m_t : look for hadronic or leptonic top decays with extra E_T^{miss}

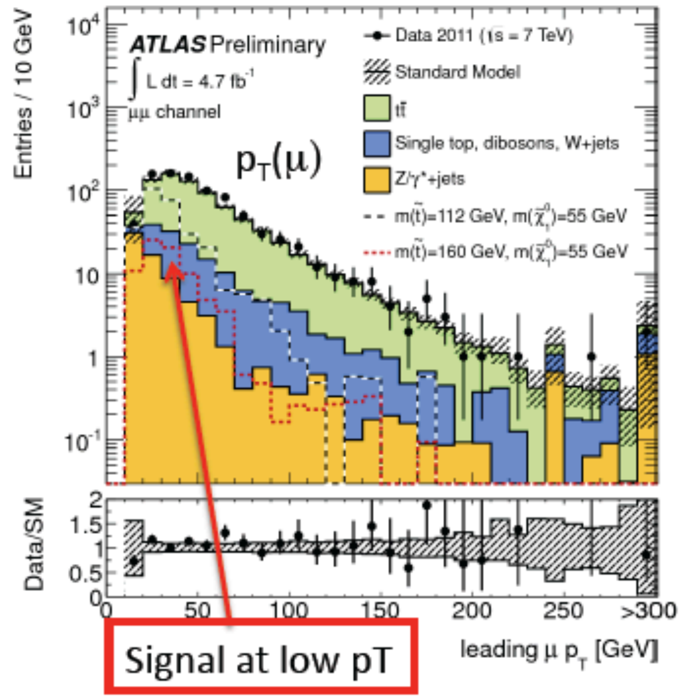
$$\tilde{t}_1 \rightarrow t\,\tilde{\chi}_1^0 \rightarrow Wb\,\tilde{\chi}_1^0$$



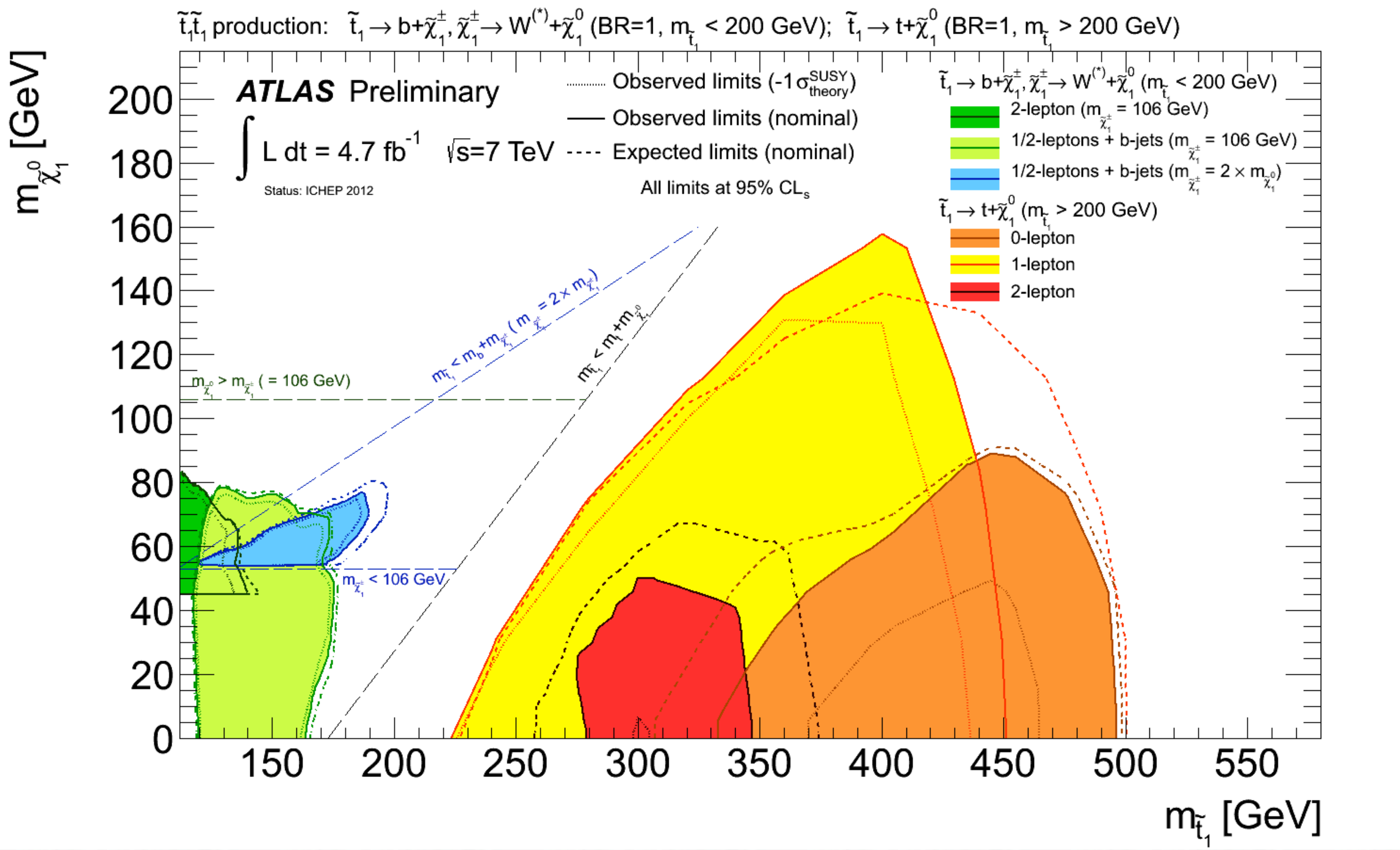
Light stop <m_t : look for top-like decay via chargino. Signal events contain lower p_T leptons, and subsystem mass below $2m_t$

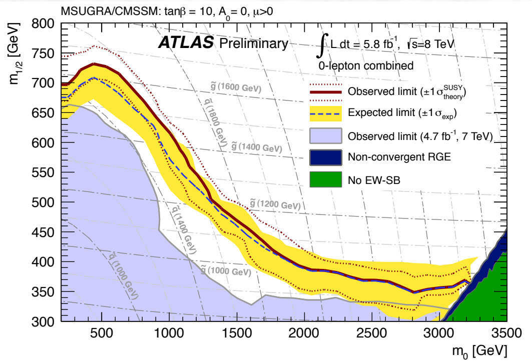
$$m_t > m_{\tilde{t}} > m_{\tilde{\chi}_1^\pm}$$

$$\tilde{t} \rightarrow b\,\tilde{\chi}_1^\pm \rightarrow bW^{(*)}\tilde{\chi}_1^0$$

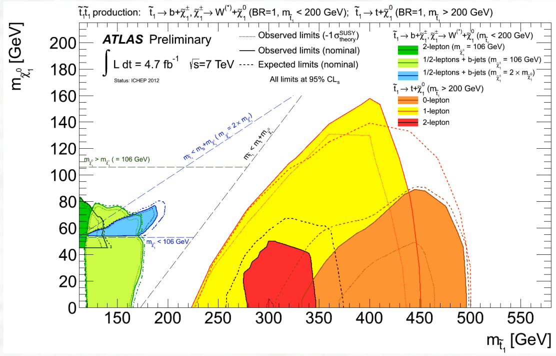


Combined stop exclusion





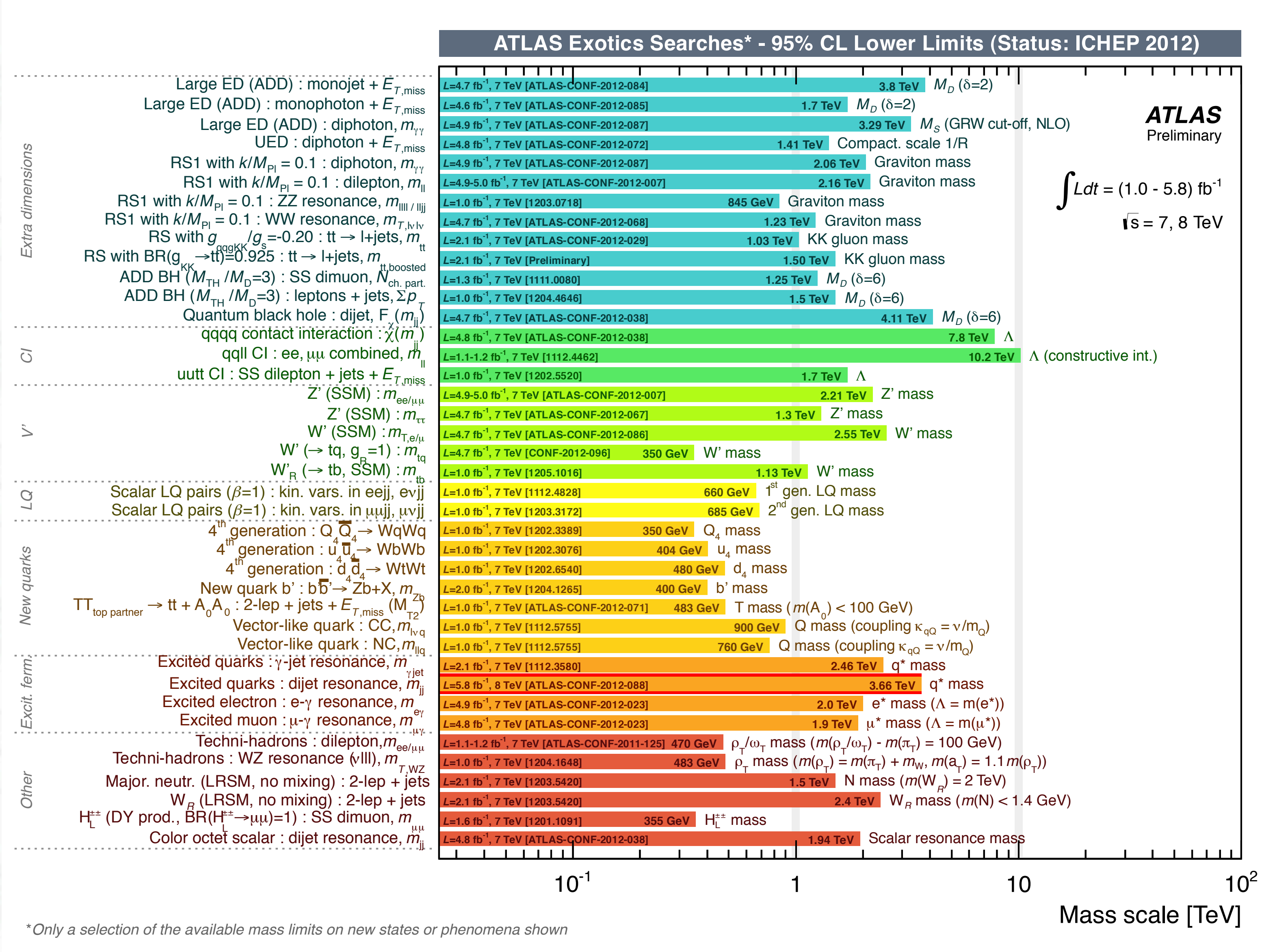
Is SUSY dead ?



A. Parker, ICHEP 2012, SUSY summary talk

- Under attack from all sides, but not dead yet.
- The searches leave little room for SUSY inside the reach of the existing data.
- But interpretations within SUSY models rely on many simplifying assumptions, and so care must be taken when making use of the limit plots
- Plausible “natural” scenarios still not ruled out: stop and/or RPV scenarios have few constraints.
- There is no reason to give up hope of finding SUSY at the LHC.

Summary of results on searches for Physics Beyond the Standard Model in ATLAS in ATLAS



Summary of the lectures

- After a long way of design, construction, installation, commissioning of both machine and experiments the LHC had an excellent start in 2010

- The performance of the accelerator and the experiments is superb;
  (In 2012: an integrated luminosity > 12 fb^{-1} already)

- The Standard Model has been established, all relevant processes measured;
  In many areas measurements have reached the precision phase

- A new boson has been discovered with a mass around 125/126 GeV;
  Exiting analyses ahead of us to understand the nature of this new particle

- So far: no deviations from the Standard Model seen, but the LHC potential has by far not yet been fully exploited !

End of lectures

$$
\begin{aligned}
\mathcal{L}_{\mathrm{TGC}} &= ieg_1^{\gamma}(A_\mu(\partial_\mu W_{-\nu}(\partial_\nu W_{-\mu})W_{+\nu} - A_\mu(\partial^\mu W^{+\nu} - \partial^\nu W^{+\mu})W_{-\nu}) \\
&+ ie\kappa_\gamma(\partial_\mu A_\nu - \partial_\nu A_\mu)W^{+\mu}W^{-\nu} \\
&+ ie\cot\theta_W g_1^Z Z_\mu(\partial_\mu W_{-\nu} - \partial_\nu W_{-\mu})W_\nu^+ - Z_\mu(\partial^\mu W^{+\nu} - \partial^\nu W^{+\mu})W_\nu^-) \\
&+ ie\cot\theta_W \kappa_Z(\partial_\mu Z_\nu - \partial_\nu Z_\mu)W^{+\mu}W^{-\nu} \\
&+ ie\frac{\lambda_\gamma}{M_W^2}((\partial_\mu A_\rho - \partial_\rho A_\mu)(\partial^\rho W^{+\nu} - \partial_\nu W^{+\rho})(\partial_\nu W^{-\mu} - \partial_\mu W^{-\nu})) \\
&+ ie\cot\theta_W \frac{\lambda_Z}{M_W^2}((\partial_\mu Z_\rho - \partial_\rho Z_\mu)(\partial^\rho W^{+\nu} - \partial_\nu W^{+\rho})(\partial_\nu W^{-\mu} - \partial_\mu W^{-\nu}))
\end{aligned}
$$