Experimental introduction Higgs & BSM

Filip Moortgat (ETH Zurich)

PhysTeV, Les Houches, June 13, 2013

Outline

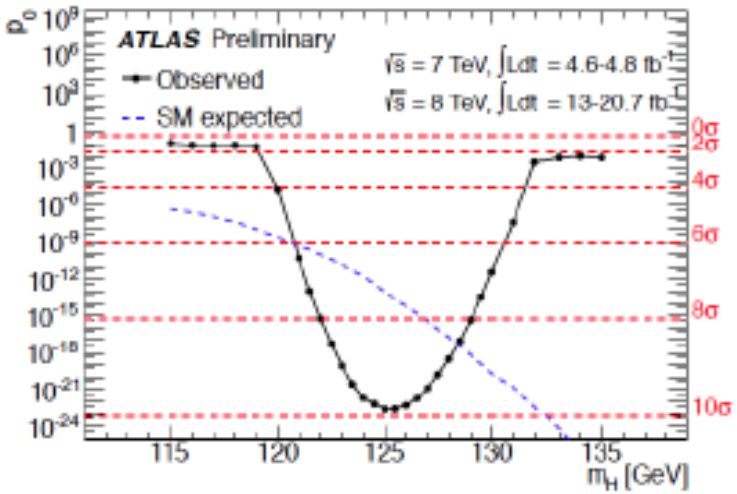
- Current status of searches:
  - H(125) measurements
  - SUSY searches
  - EXO searches

interleaved with

- Topics for Les Houches
  - Some potential topics to discuss here at Les Houches
  - More during round-table this afternoon

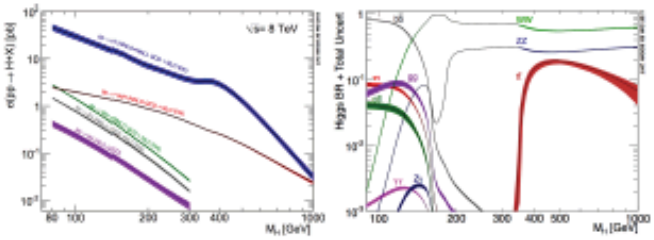
Searches for (SM) Higgs

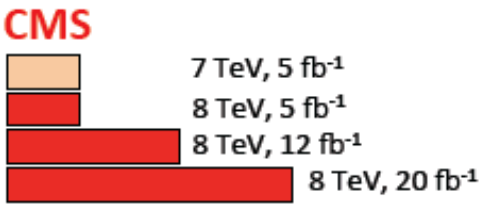
H(125)

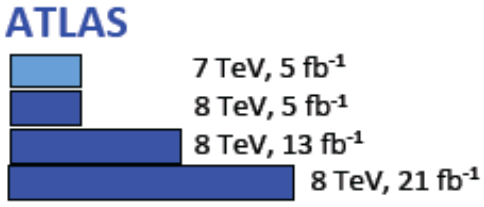


- Where are we with the H(125) search?
  - Signal strength for individual channels?
  - Mass?
  - Spin/Parity?
  - BR into BSM? 1 particle?

Various search channels







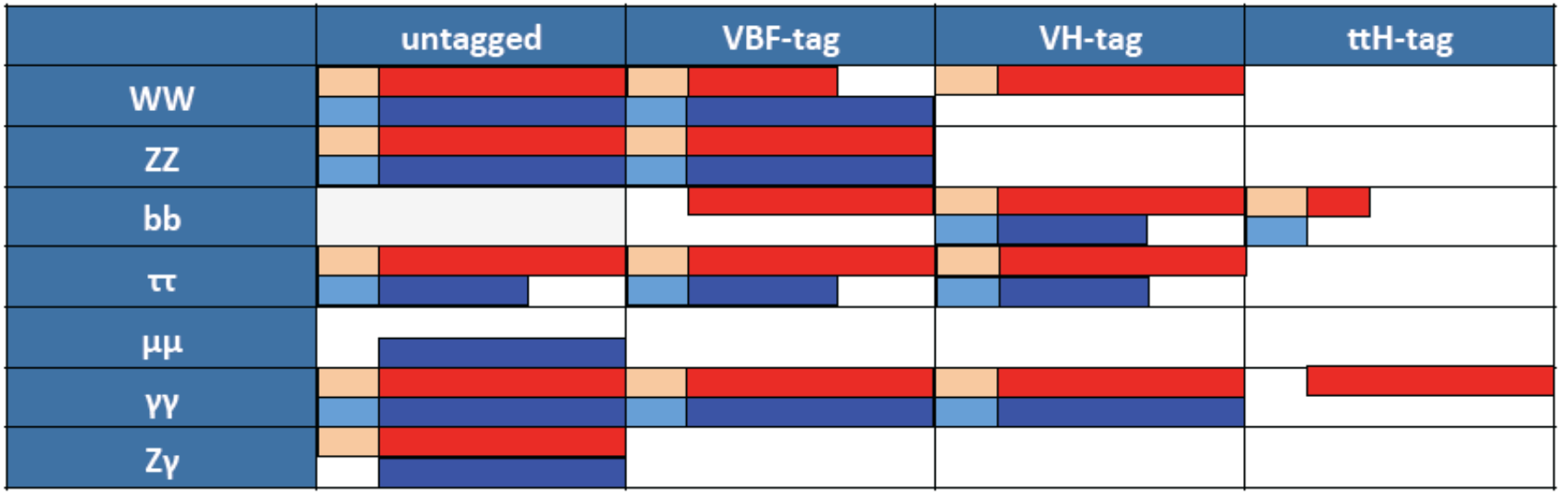


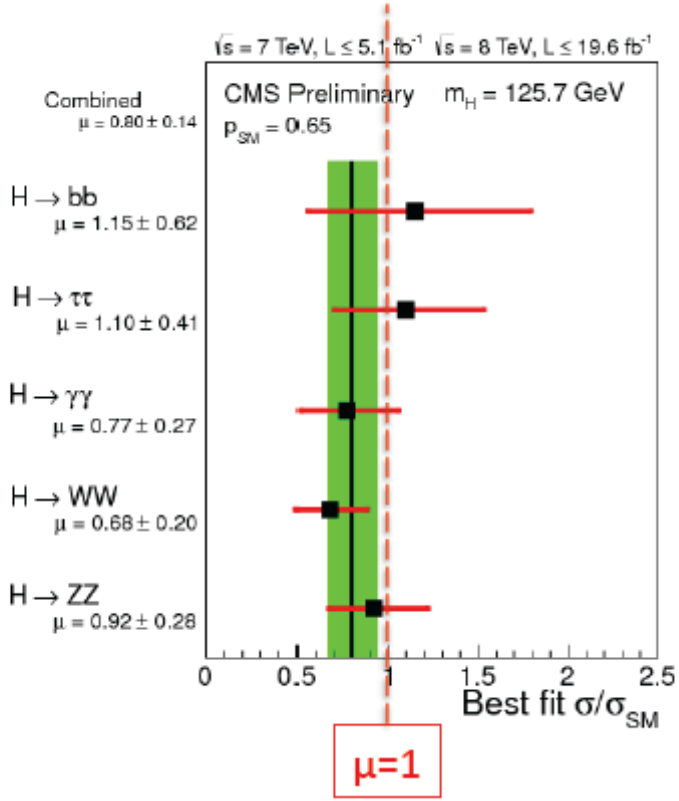
Table from A. Korytov

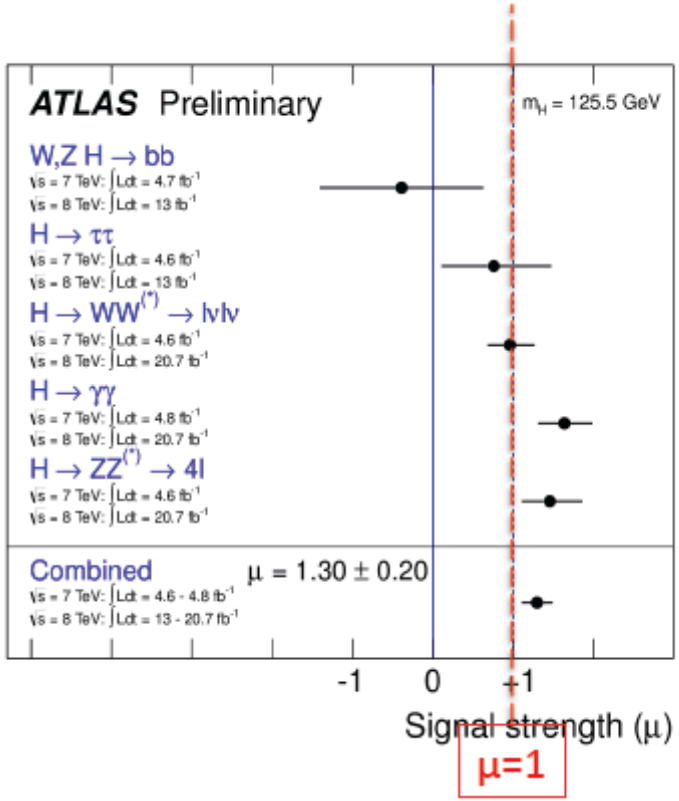
Significance per channel

	ATLAS		CMS	
	expected	observed	expected	observed
H→ZZ	4.4	6.6	7.1	6.7
H→γγ	4.1	7.4	3.9	3.2
H→WW	3.8	3.8	5.3	3.9
H→ττ	1.6	1.1	2.6	2.8
H→bb	1.0	0	2.1	2.1

Table from A. Korytov

Signal strength per channel





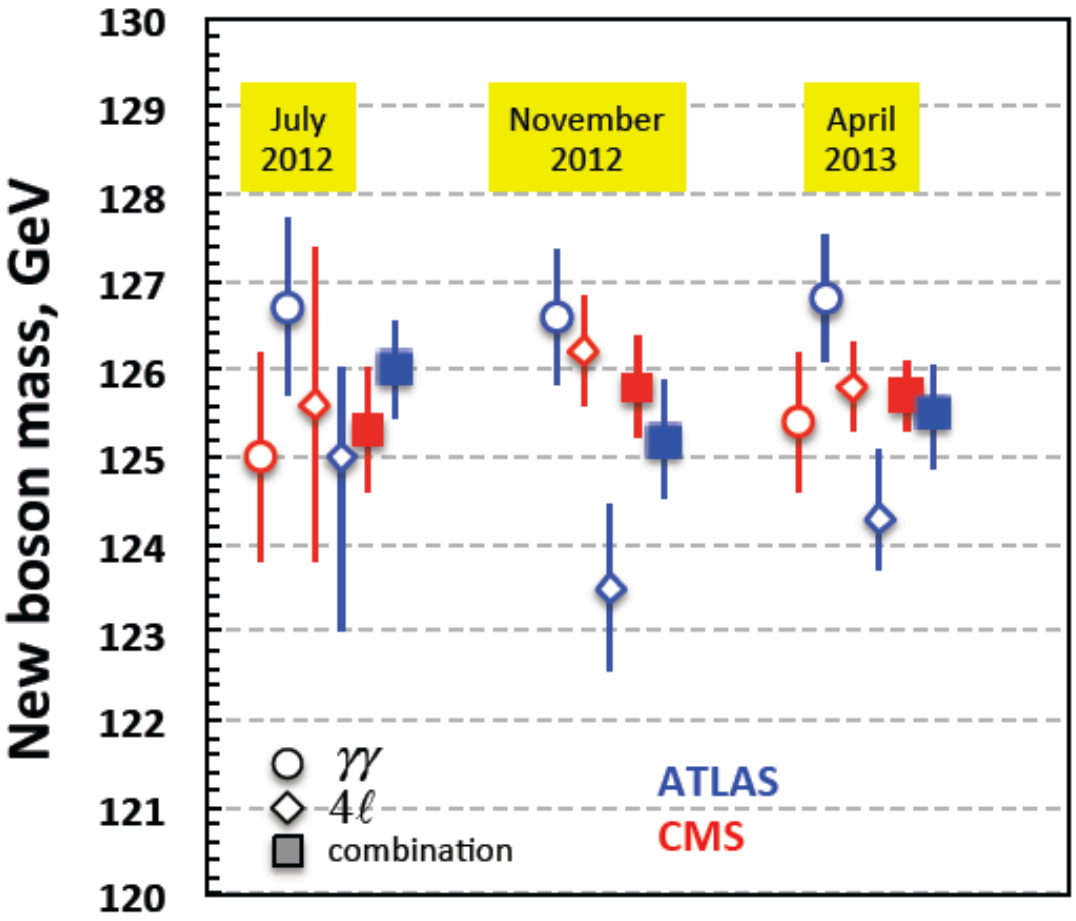
CMS best-fit signal strength

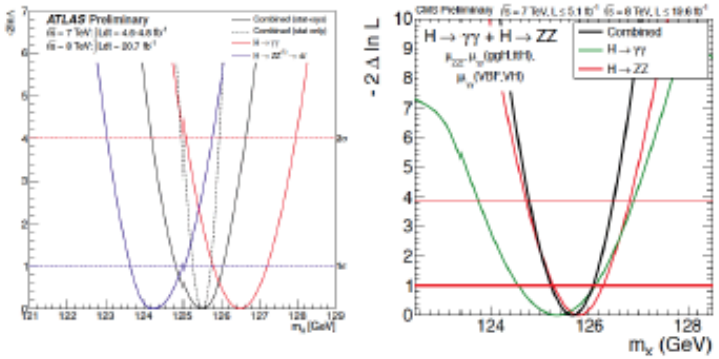
μ = 0.80 ± 0.14

ATLAS best-fit signal strength

μ = 1.30 ± 0.20

Mass

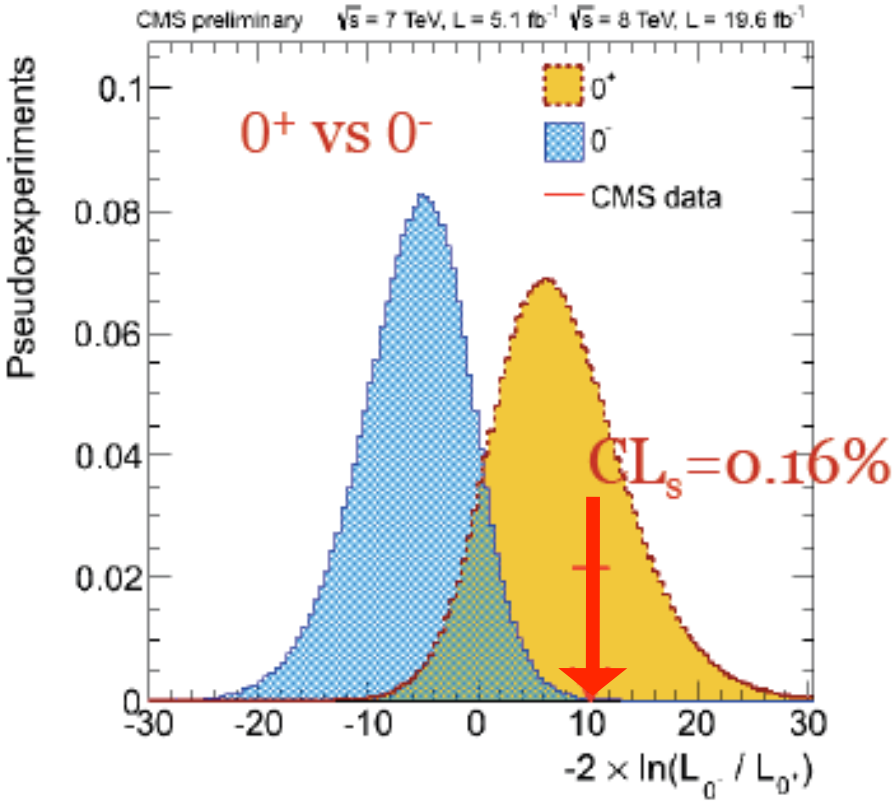




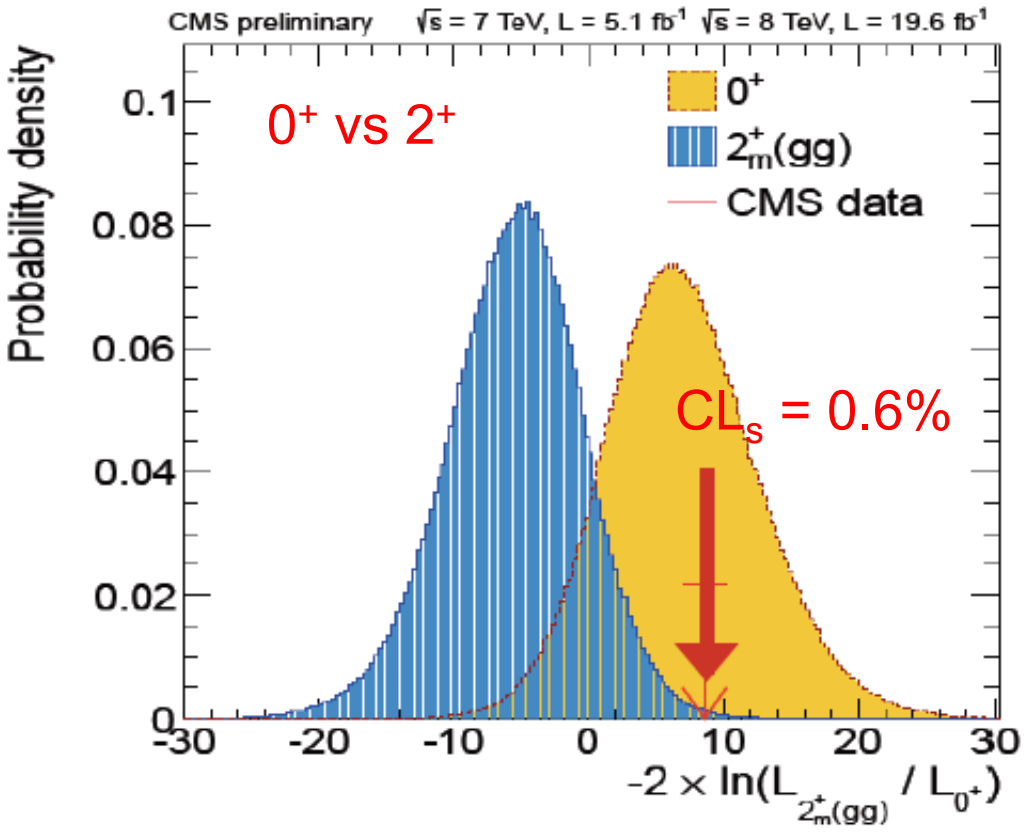
ATLAS: 125.5 ± 0.6 GeV
CMS: 125.7 ± 0.4 GeV

- ATLAS and CMS overall best-fit values agree
- ATLAS has 2.3σ tension between γγ and 4l

Spin/parity?



ZZ



ZZ + WW

Spin/parity alternatives

ETH Institute for Particle Physics

CL_s values for testing J^{CP} state hypotheses vs SM-like Higgs boson

$CL_s < 0.05$

$CL_s < 0.01$

	CMS				ATLAS			
	γγ	ZZ	WW	ZZ+WW	γγ	ZZ	WW	comb
~~0^-~~		0.0016				0.004		
0^+_h		0.081						
~~1^-~~	excluded	<0.001			excluded	0.031		
~~1^+~~	excluded	<0.001			excluded	0.002		
~~$gg \to 2^+_m$~~		0.015	0.04	0.006	0.007	0.182	0.05	<0.001
~~$qq \to 2^+_m$~~		<0.001			0.12	~3σ (?)	0.01	<0.001
$gg \to 2^-$						0.116		

Table from A. Korytov

Example:
Spin-0 Lagrangian
(lowest dimension terms)

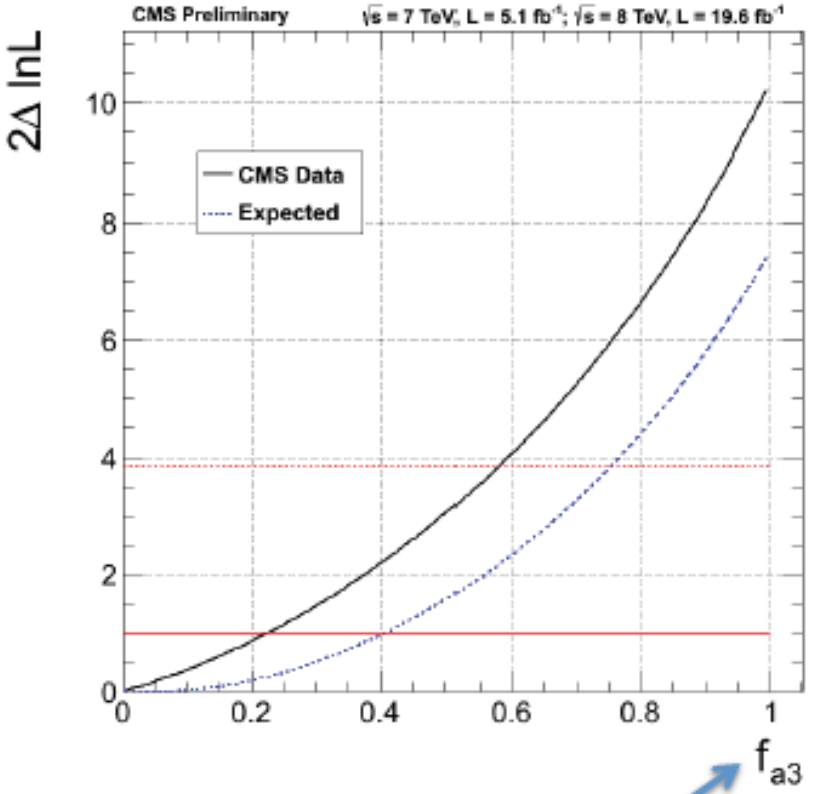
$$\mathcal{L} = X\left[\kappa_1 \frac{m_Z^2}{v} Z_\mu Z^\mu + \frac{\kappa_2}{2v} F_{\mu\nu}F^{\mu\nu} + \frac{\kappa_3}{2v} F_{\mu\nu}\tilde{F}^{\mu\nu}\right] + \ldots$$

Higgs | 0^+_h | 0^-

CP even + CP odd ?

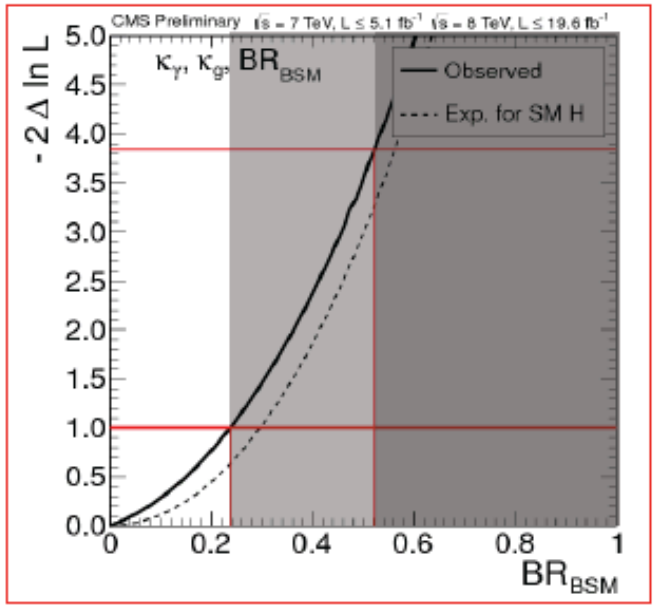
What if H(125) is a mixed state?

- CP-odd contribution (cross section fraction):
  $f(0^-) < 0.58$ at 95% CL
- Non-zero $f(0^-)$ may be due to
  - a 0^- particle with a nearly the same mass;
  - a single particle X = H(0^+) + A(0^-) with mixed CP-even/odd states



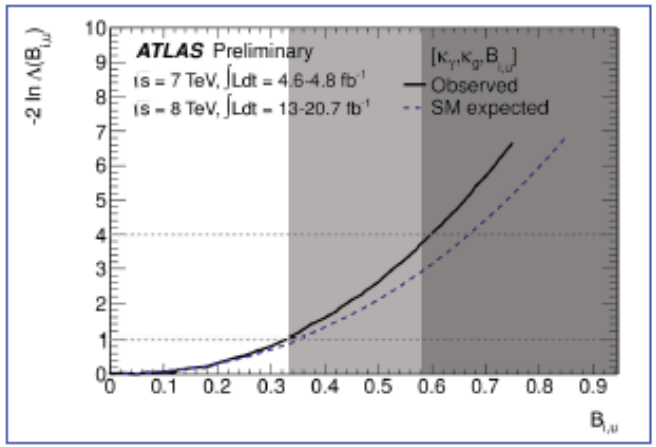
$$f_{a3} = f(0^-) = \frac{\sigma(0^-)}{\sigma(0^-) + \sigma(0^+_m)}$$

BR to BSM?



Three-parameter fit

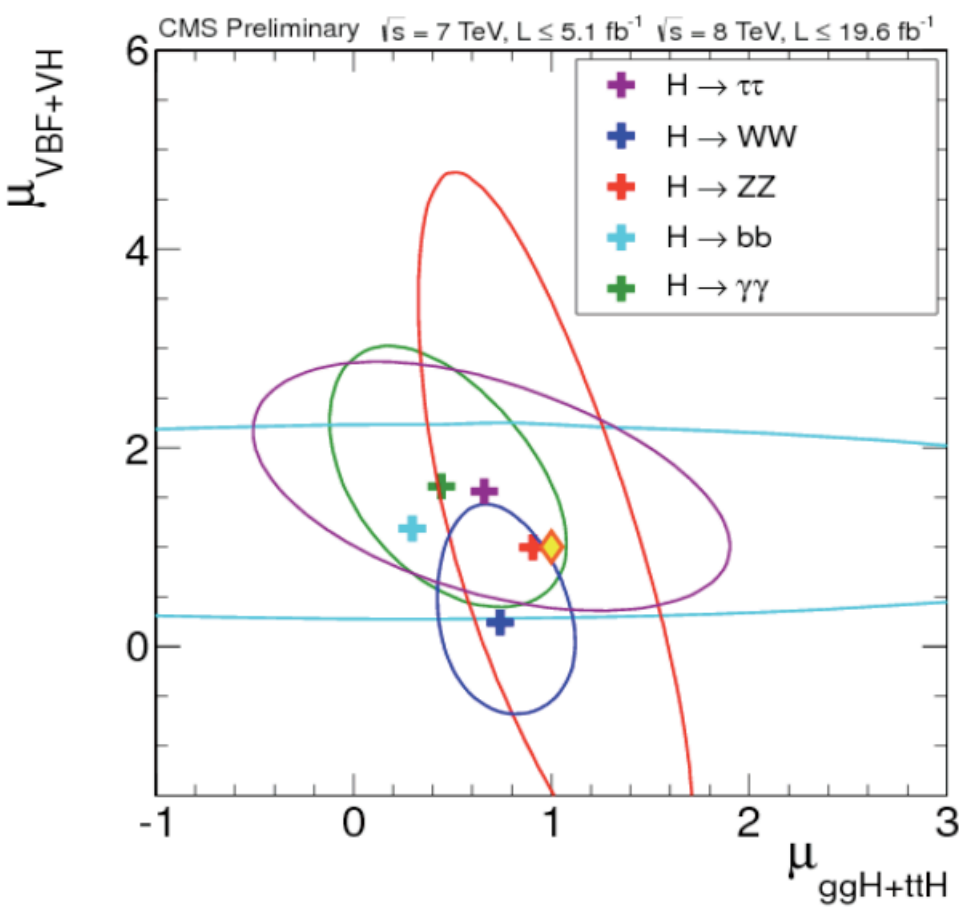
- use all channels
- assume **tree-level couplings = SM**
- allow for **BR(BSM) ≠ 0**
- **Fit for:** **BR("invisible"), κ_γ , κ_g**

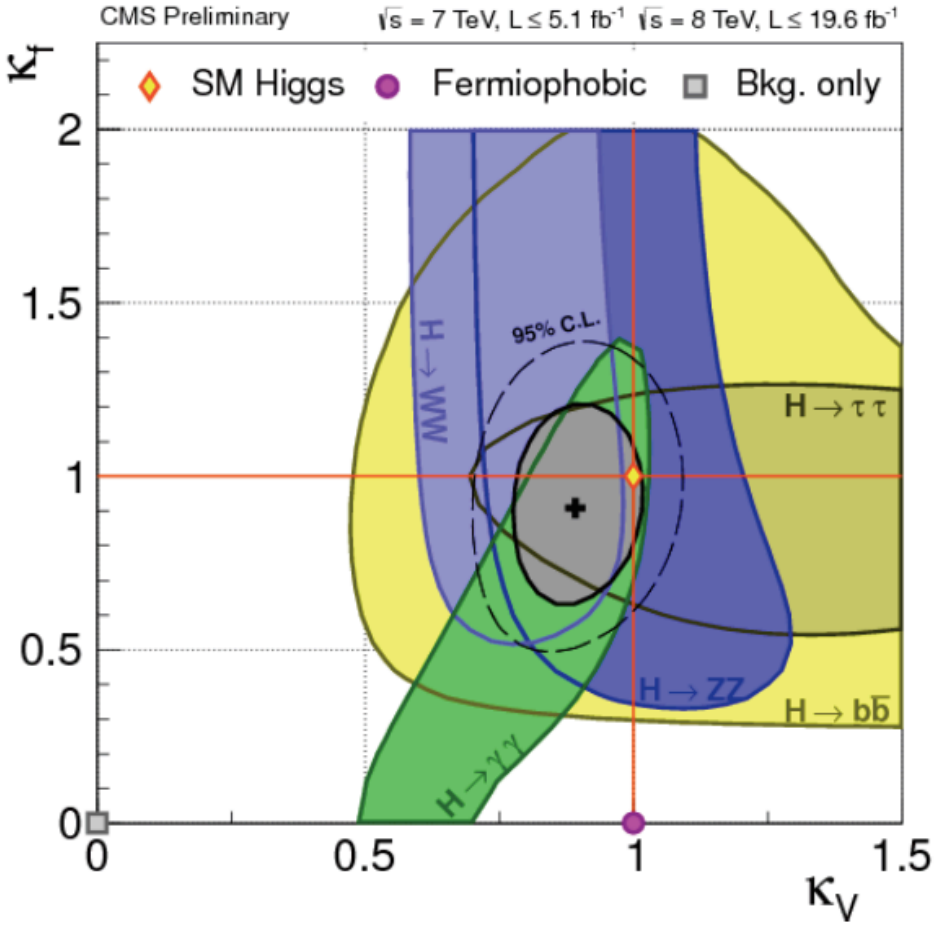


CMS: BR(BSM) < 0.52 at 95% CL
ATLAS: BR(BSM) < 0.58 at 95% CL

Direct ATLAS search for ZH→ (ll)+MET:
BR(inv)<0.65 at 95% CL
assuming SM HZZ coupling

SM Higgs boson?





Higgs summary

- In conclusion:
  - Properties of H(125) compatible with a SM-like Higgs boson
  - Still large uncertainties on various signal strengths (and thus couplings)

- General question: H(125) ← → New Physics
  - → What is the consequence of H(125) for New Physics searches?
  - ← What is the consequence of NP on H(125) properties?
    - What to measure? How much precision do we need?

Searches

- In general, concerning searches:

Q1: Are we missing something? A signature? A phase-space region?

→ tell us now! We have some time before the 13 TeV run.

Q2: how to interpret & present best the (neg or pos) search results?

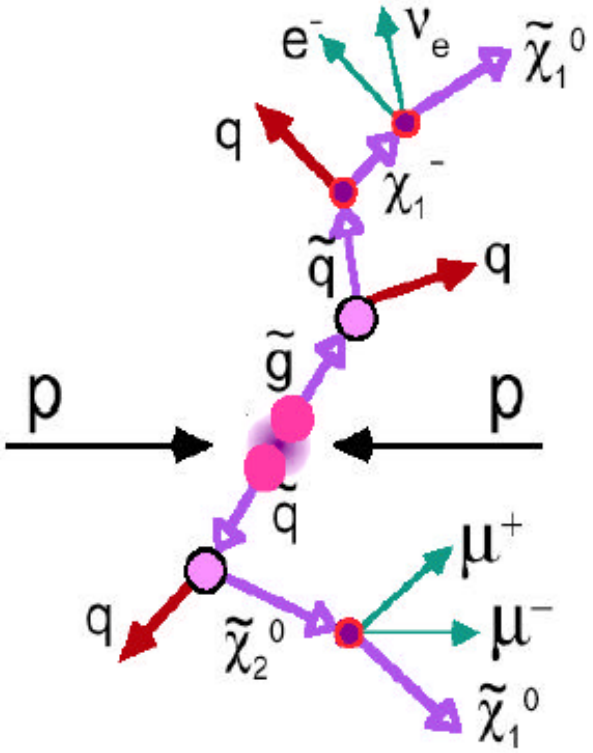
→ simplified models versus full models?

→ how to present results in a way that allows re-interpretation in different models. Cfr. previous Les Houches recommendations.

ETH Institute for Particle Physics

Searches for supersymmetry

"classic" SUSY searches



- Assume pair production of colored sparticles
- All inclusive searches require jets and MET

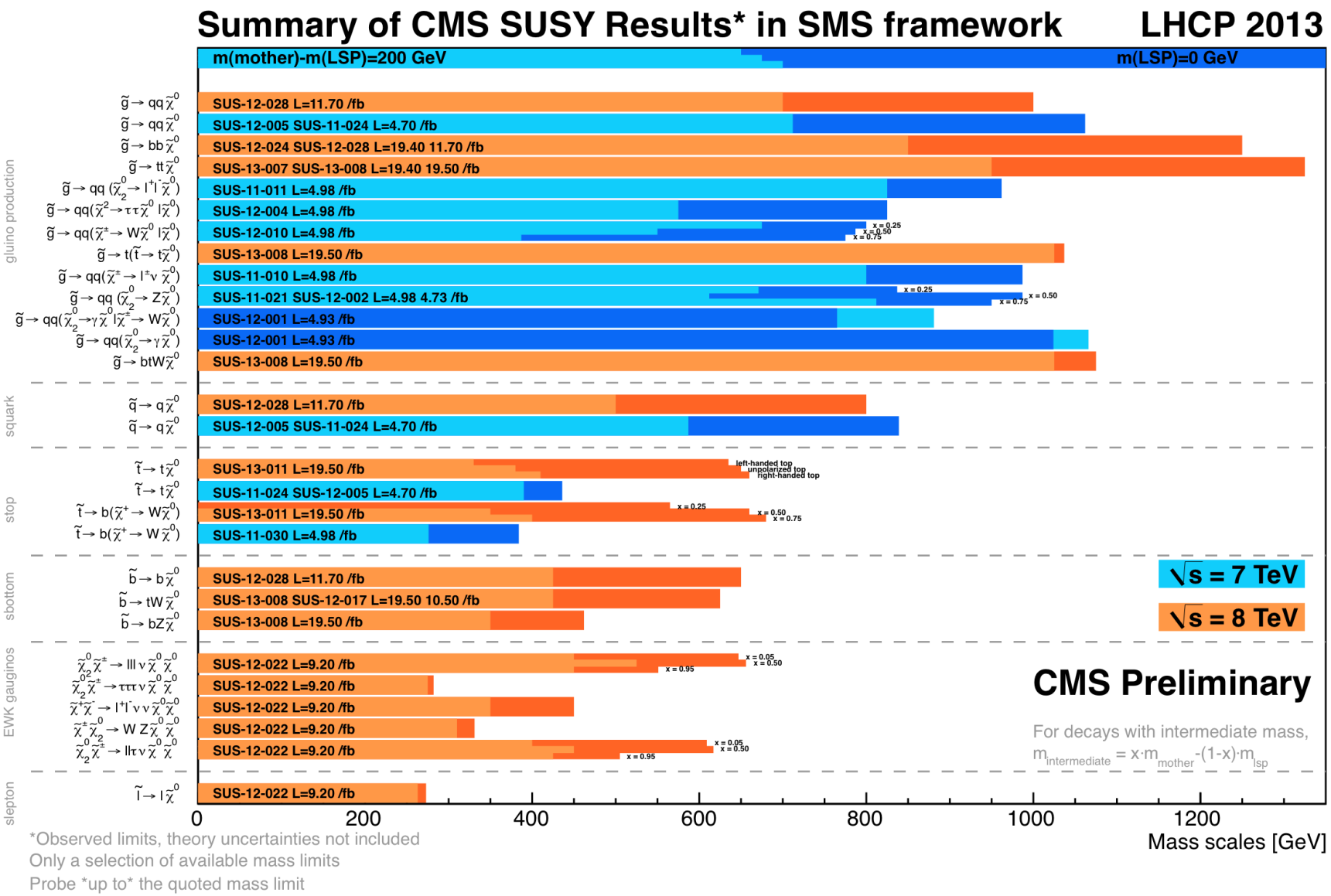
$$H_T = \sum_{j}^{\text{all jets}} \left| p_T^j \right|$$

- Further categorized by number of leptons or photons, also # of jets and b-jets

- Different searches have different dominant backgrounds

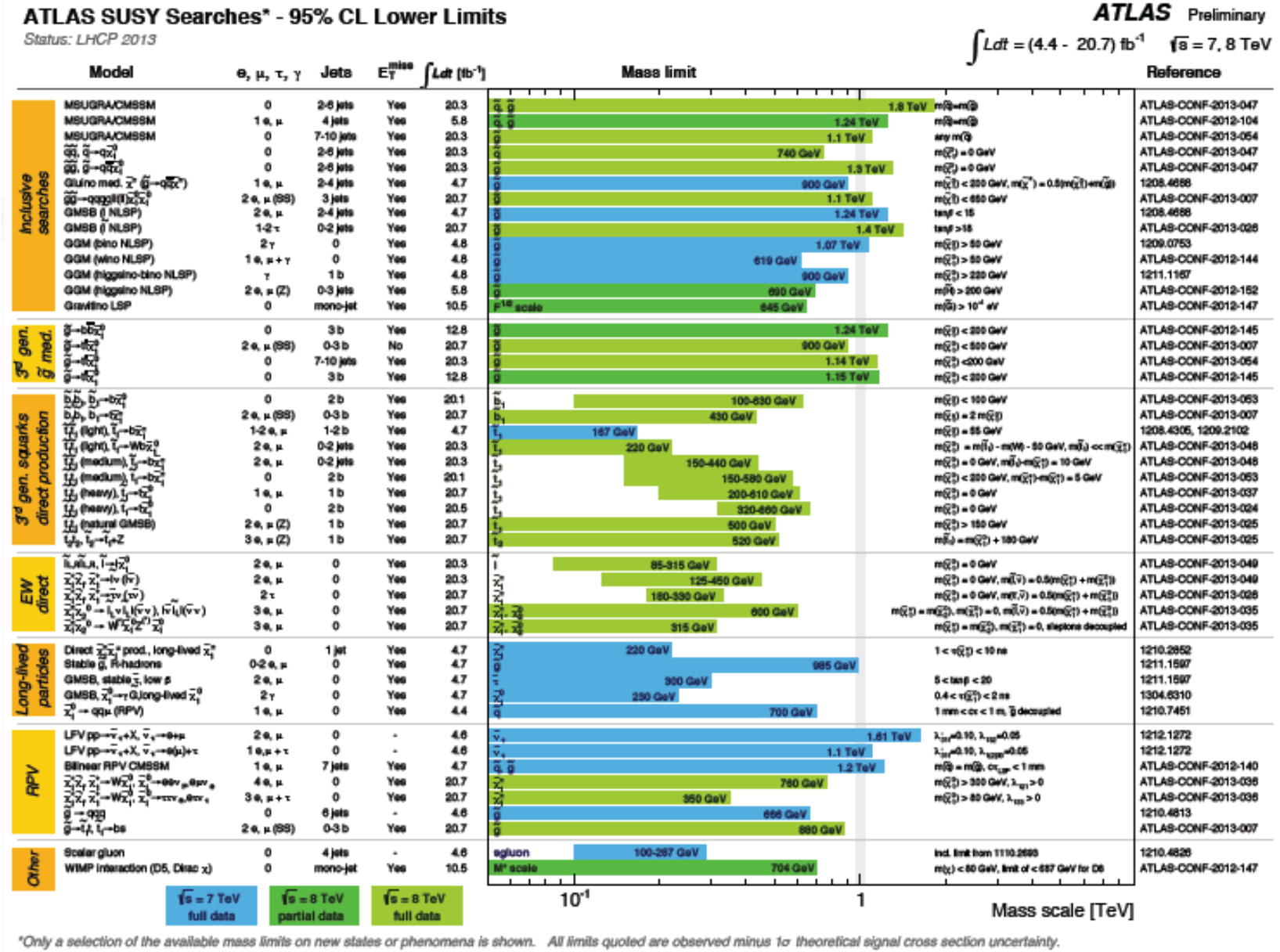
All hadronic	1-lepton	OS 2-lepton	SS 2-lepton	≥ 3-lepton
Jets + MET Lepton veto	Single lepton + jets + MET	Opposite-sign di-lepton + MET	Same sign di-lepton + jets + MET	Multi-lepton + MET

8 TeV results



*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

ATLAS SUSY results



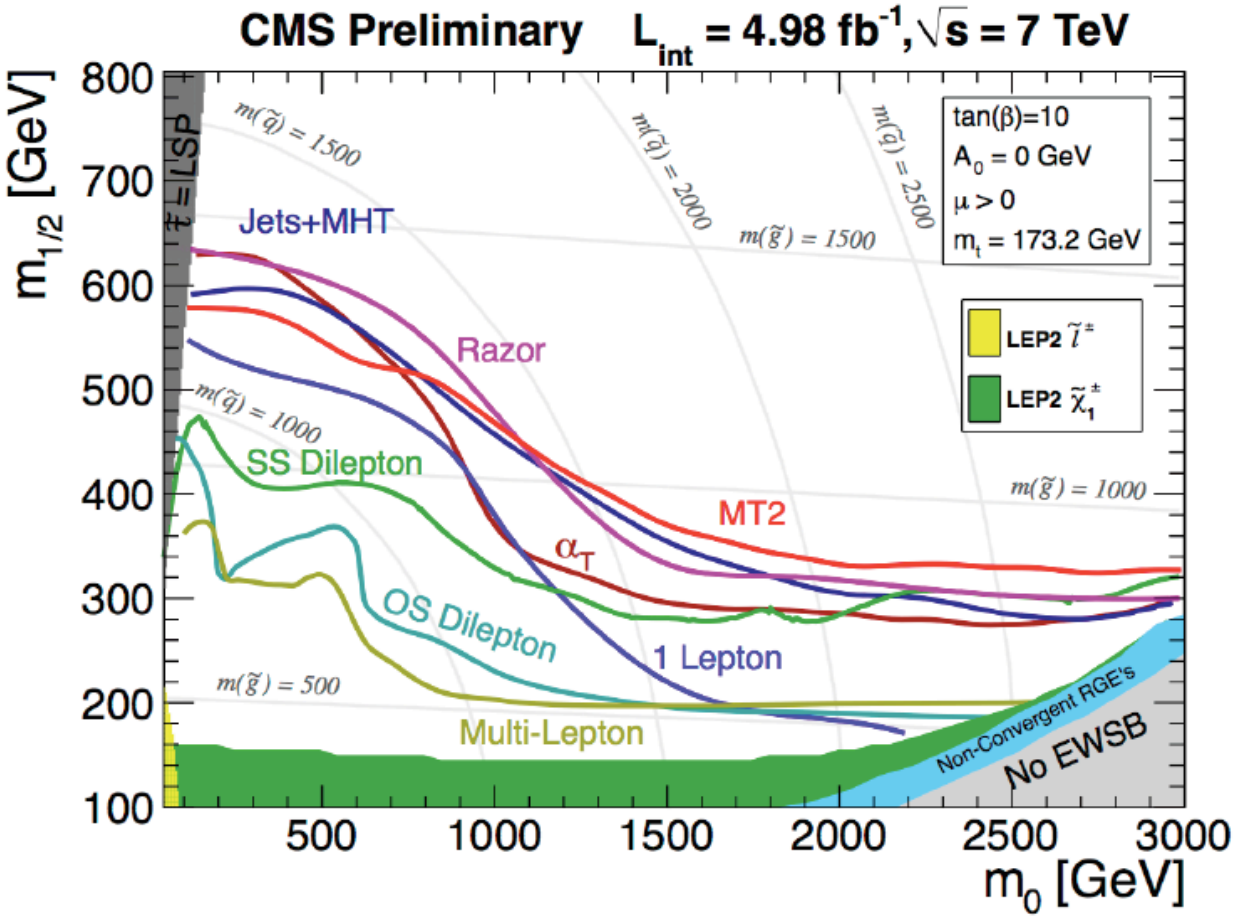
Warning

The SMS plots comes with some fine print:

- A LOT of assumptions going in!
  (degenerate 1&2 generation, spin, …)
- Branching ratio's usually assumed to be 100%
  - in particular for the leptonic final states, that's quite a drastic assumption
- Note that these limits typically hold for low LSP masses only and all limits disappear if the mass of the LSP is larger than a few hundred GeV
- So be careful when drawing conclusions on physics!

7 TeV exclusions in CMSSM

Full model: up to now still the historic CMSSM/mSUGRA

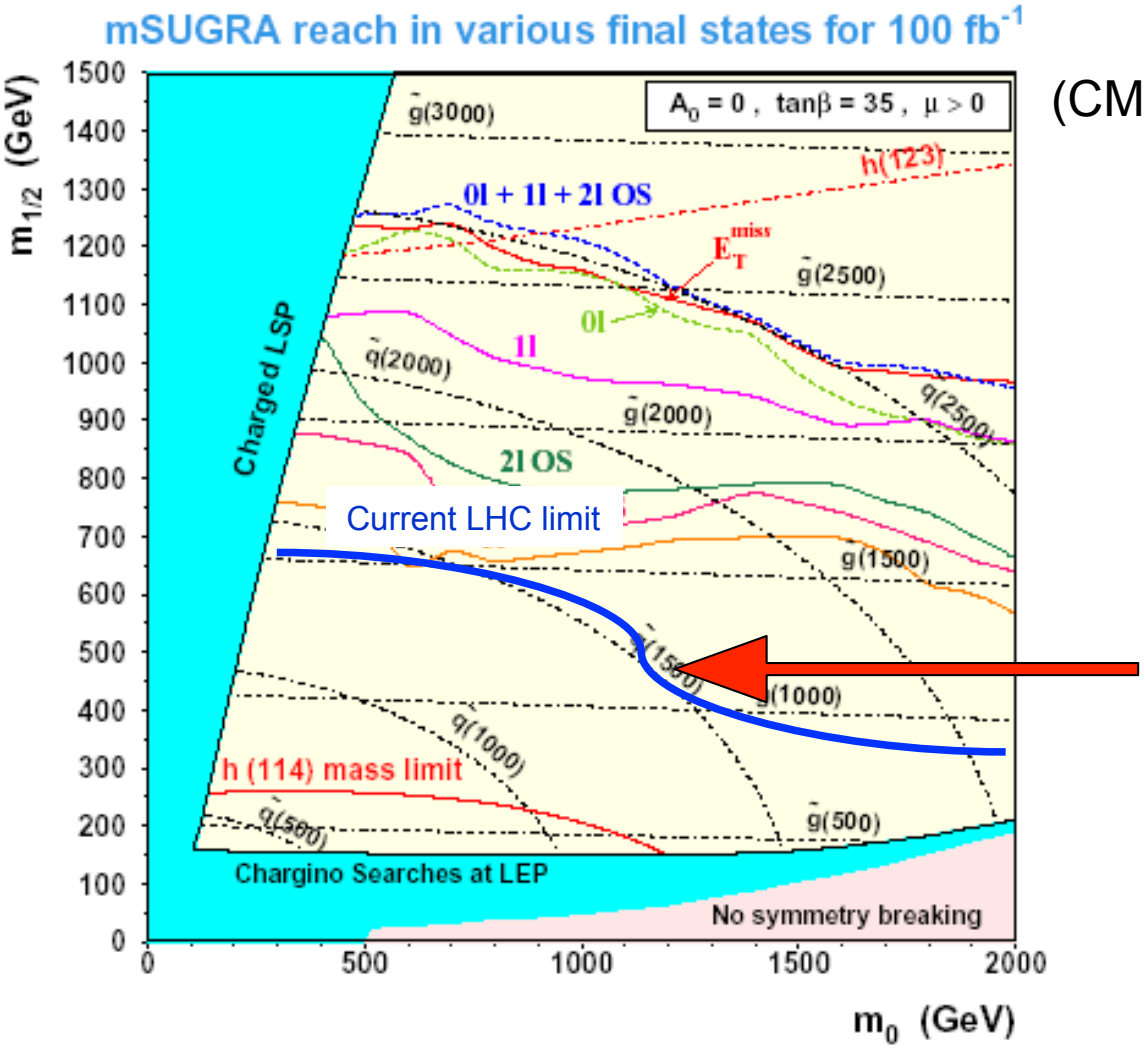


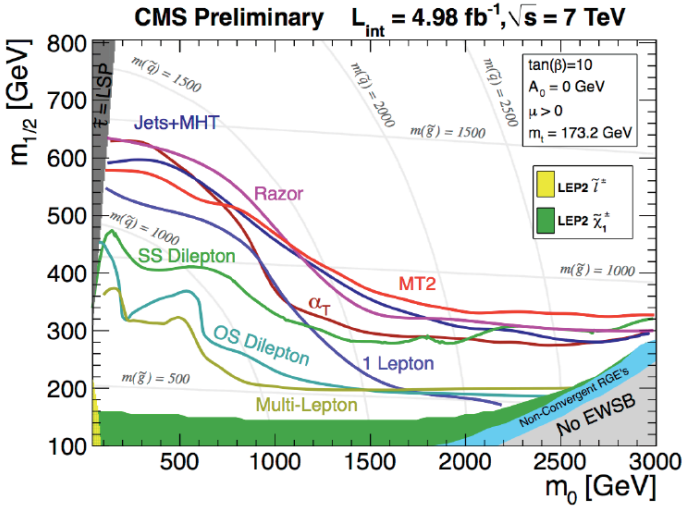
To put in perspective

What we wrote in our TDR:

LHC @ ~14 TeV

(CMS Physics TDR)





SUSY interpretation

- Still value in having interpretation in a complete model
  - Two perspectives nowadays:
    - 1) naturalness as a guiding principle, and
    - 2) the compatibility with H(125).

  - E.g. “Min.Nat. SUSY” (e.g. Tito d’Agnolo et al.):

CMS chose this one

$$m_{\tilde{g}},\ m_{\tilde{Q}_3,\tilde{u}_3},\ A_t,\ \mu$$

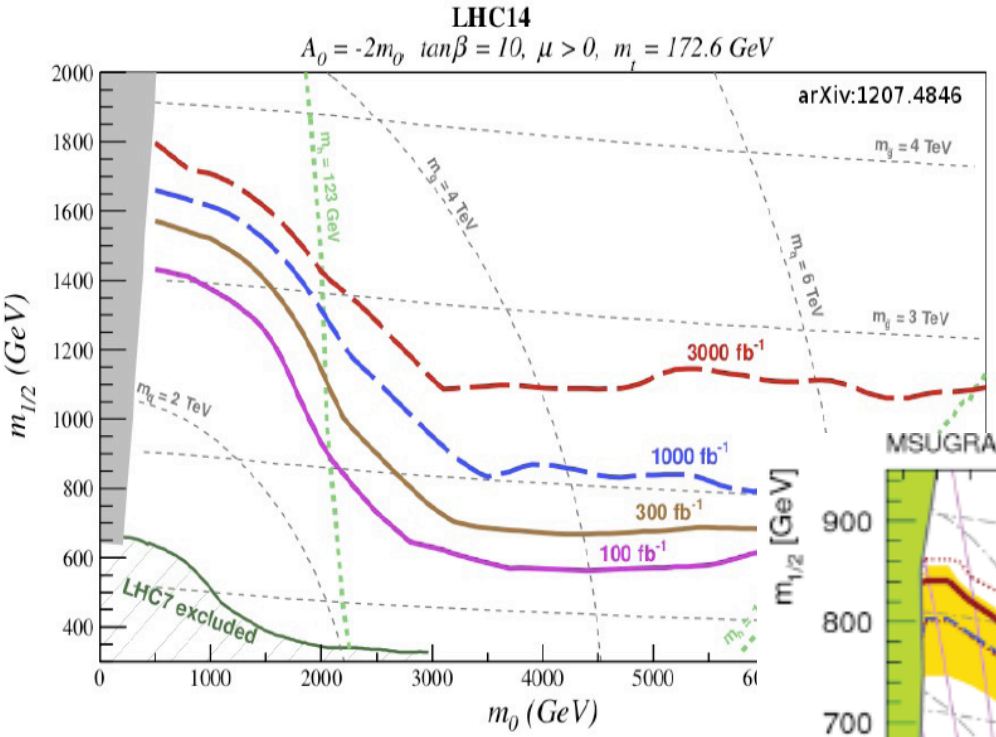
  - E.g. having CMSSM/mSUGRA with floating A_0,

so m_h ~ 125 GeV in the whole plane (e.g. Baer et al.)

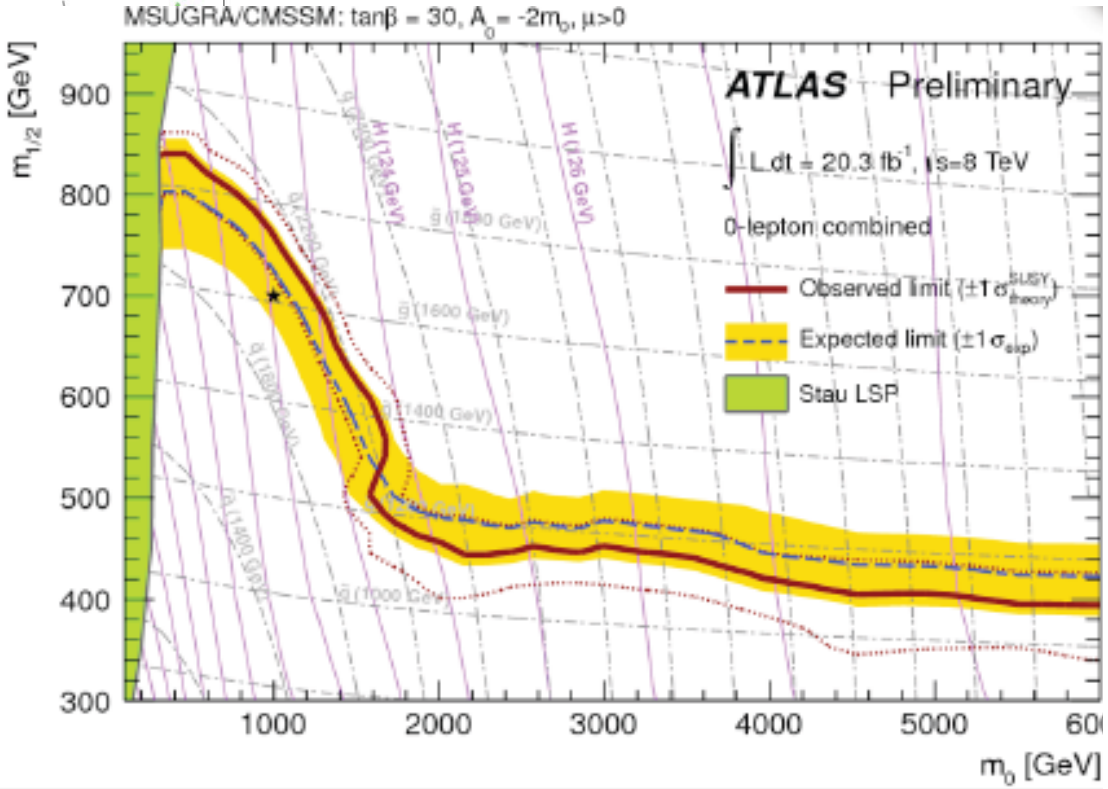
ATLAS chose this one

Don’t have a model that addresses both naturalness and H(125)!

Fixing the Higgs



Baer et al.



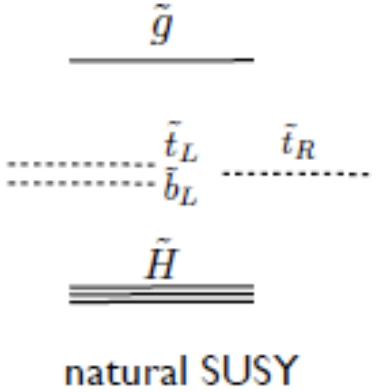
Natural SUSY

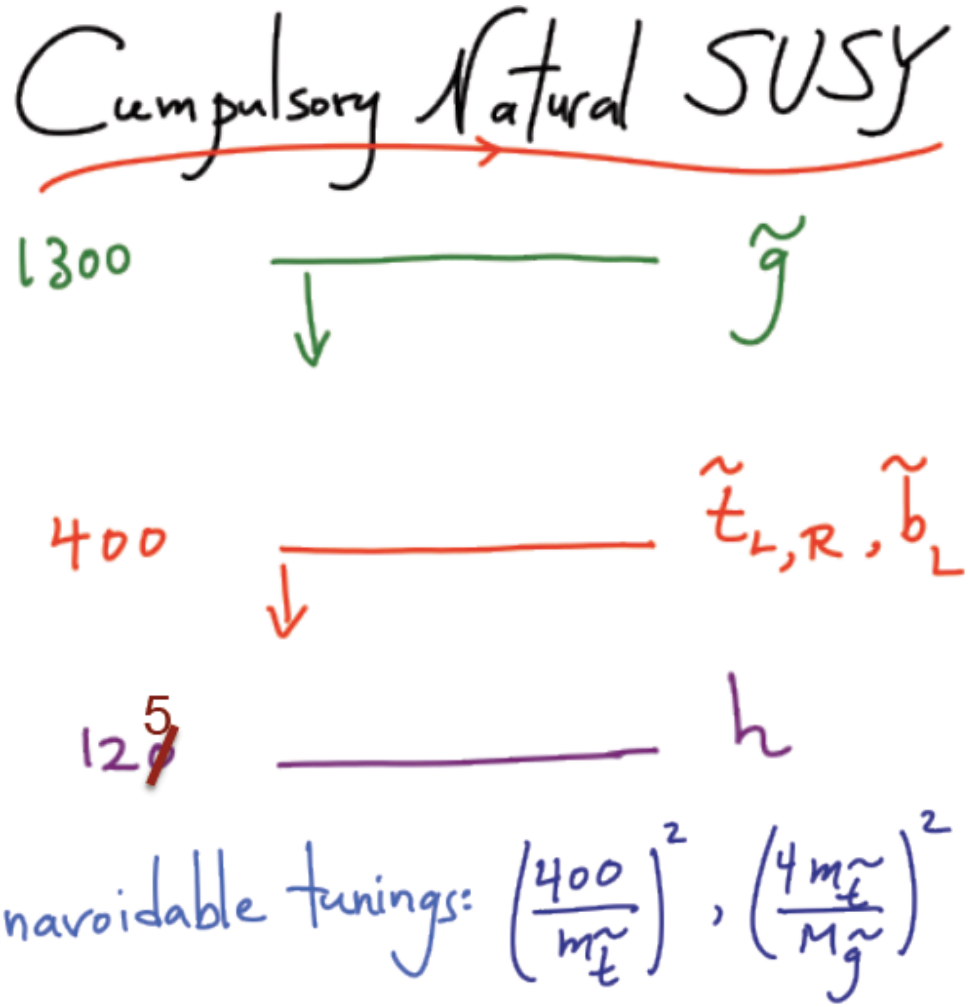
Nima A.-H.

The new (old) paradigm:

- Light stops/sbottoms
- Light higgsinos
- Not-too-heavy gluinos

are needed for a natural theory of EWSB





e.g. A. Weiler et al. arXiv:1110.6926

How to look for natural SUSY

How to look for natural SUSY?

- Existing searches are already sensitive
  (esp. the ones requiring b-tags)
  - Reinterpretation in this context
- Add dedicated searches
  - e.g. for direct stop production

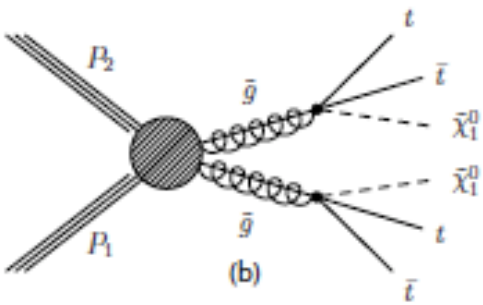
Two main directions:

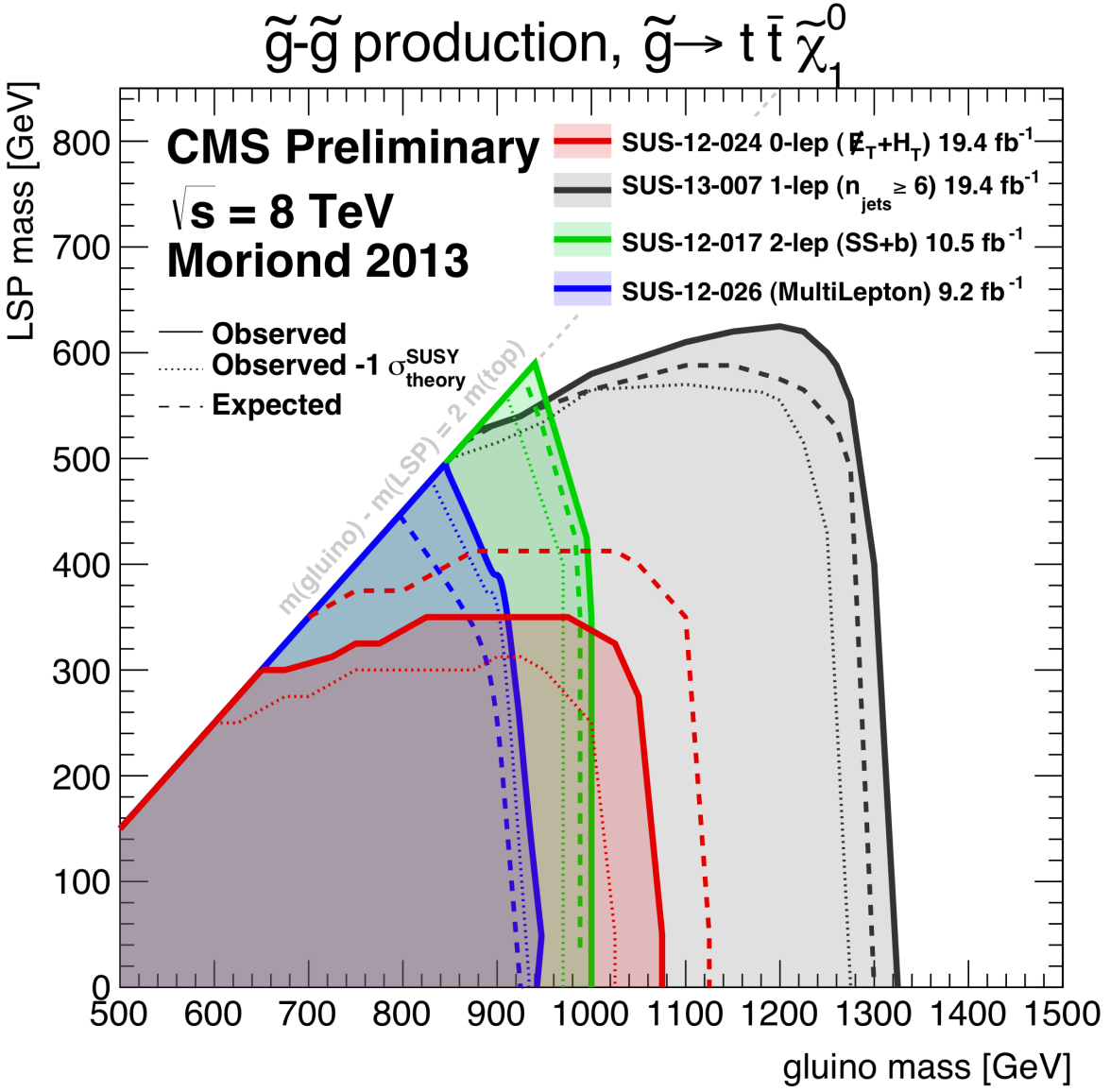
1) Gluino production (+ decay into stop-top or sbottom-bottom)
   - ➨ Focus on high jet multiplicity, high #b-jets, …

2) Direct stop/sbottom production
   - ➨ Difficult. Needs customized search strategies.

Gluino to 4 top

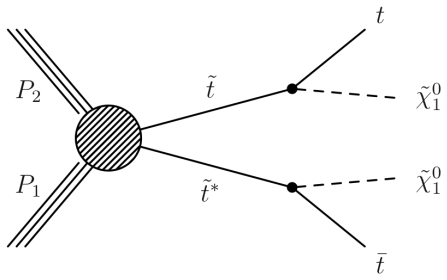
Summary:

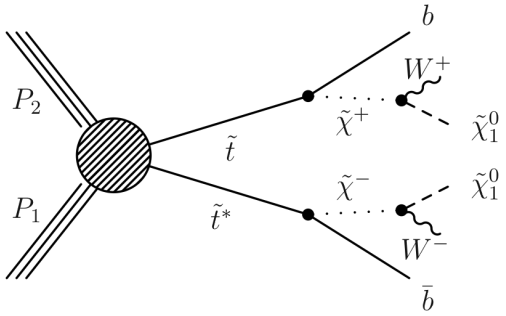


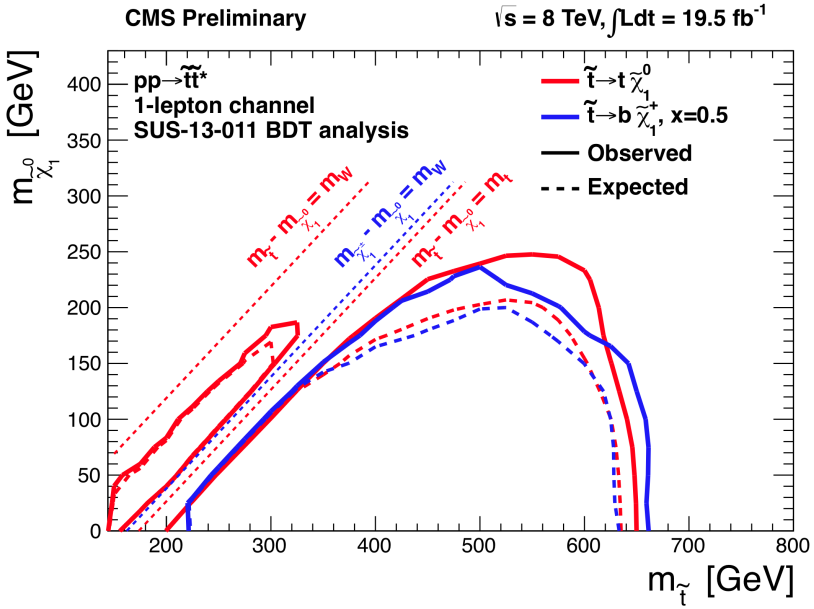


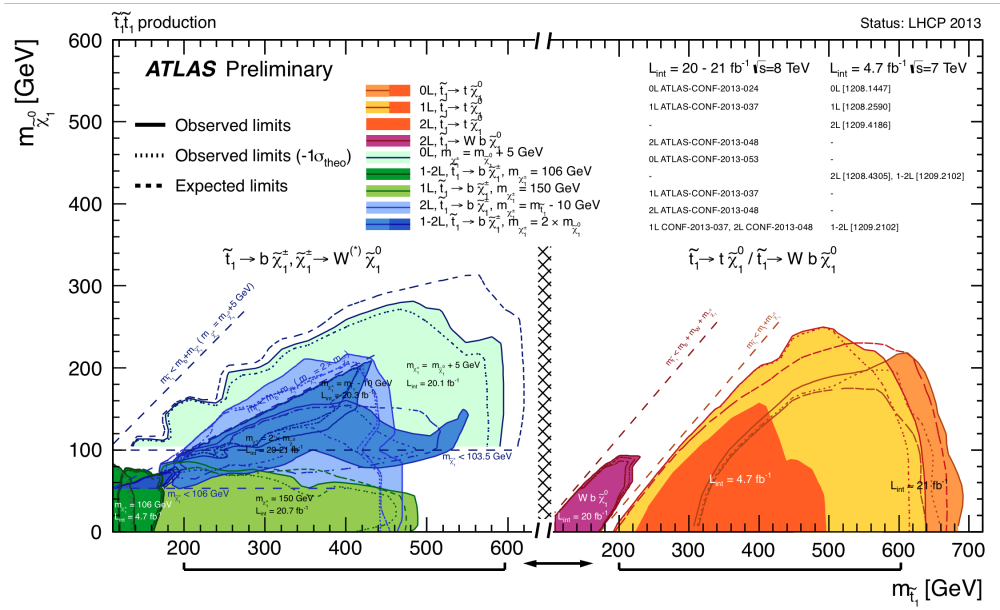
3rd generation: direct production

Direct stop production:







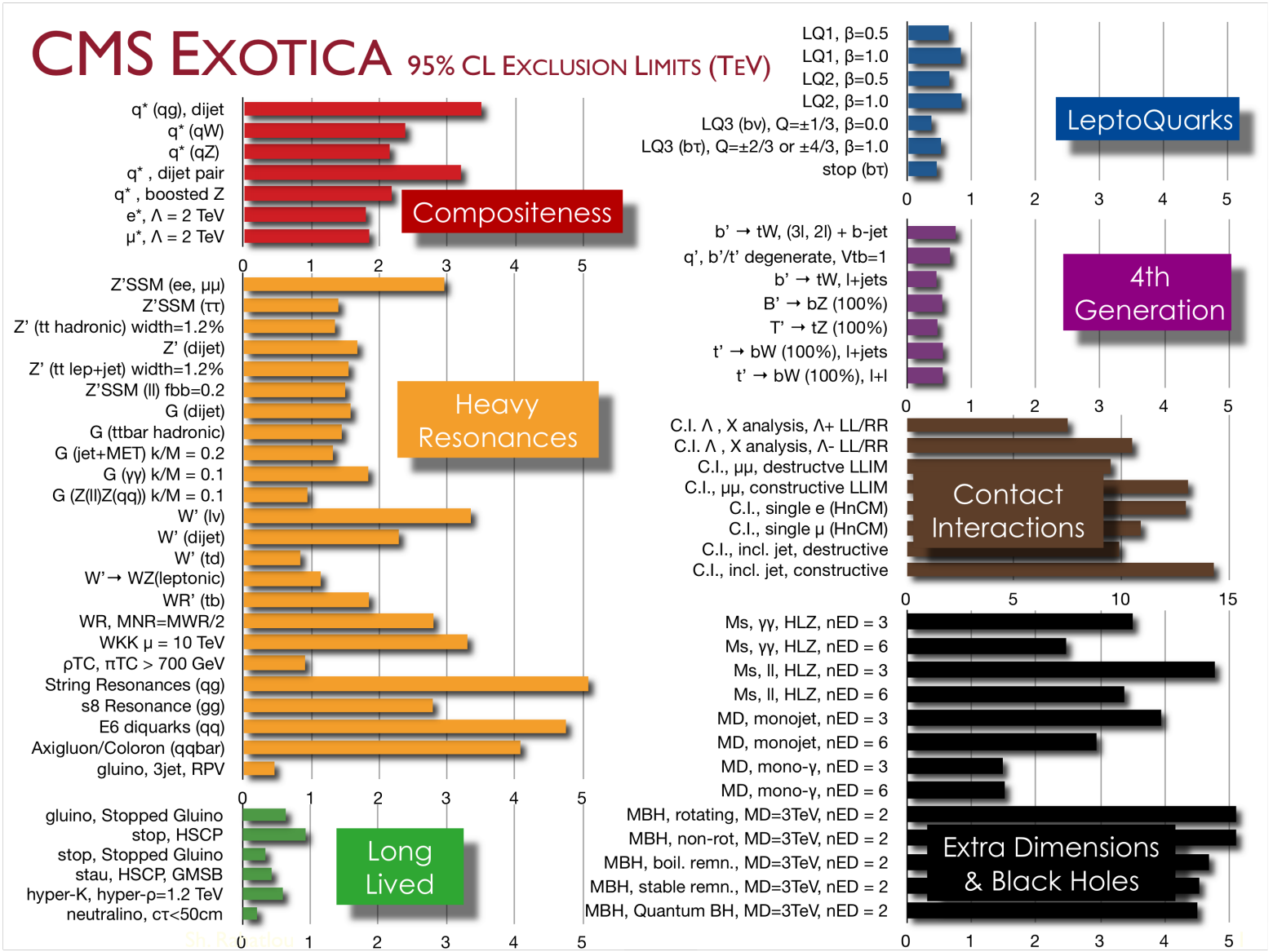


2012 data at 8 TeV (full statistics)

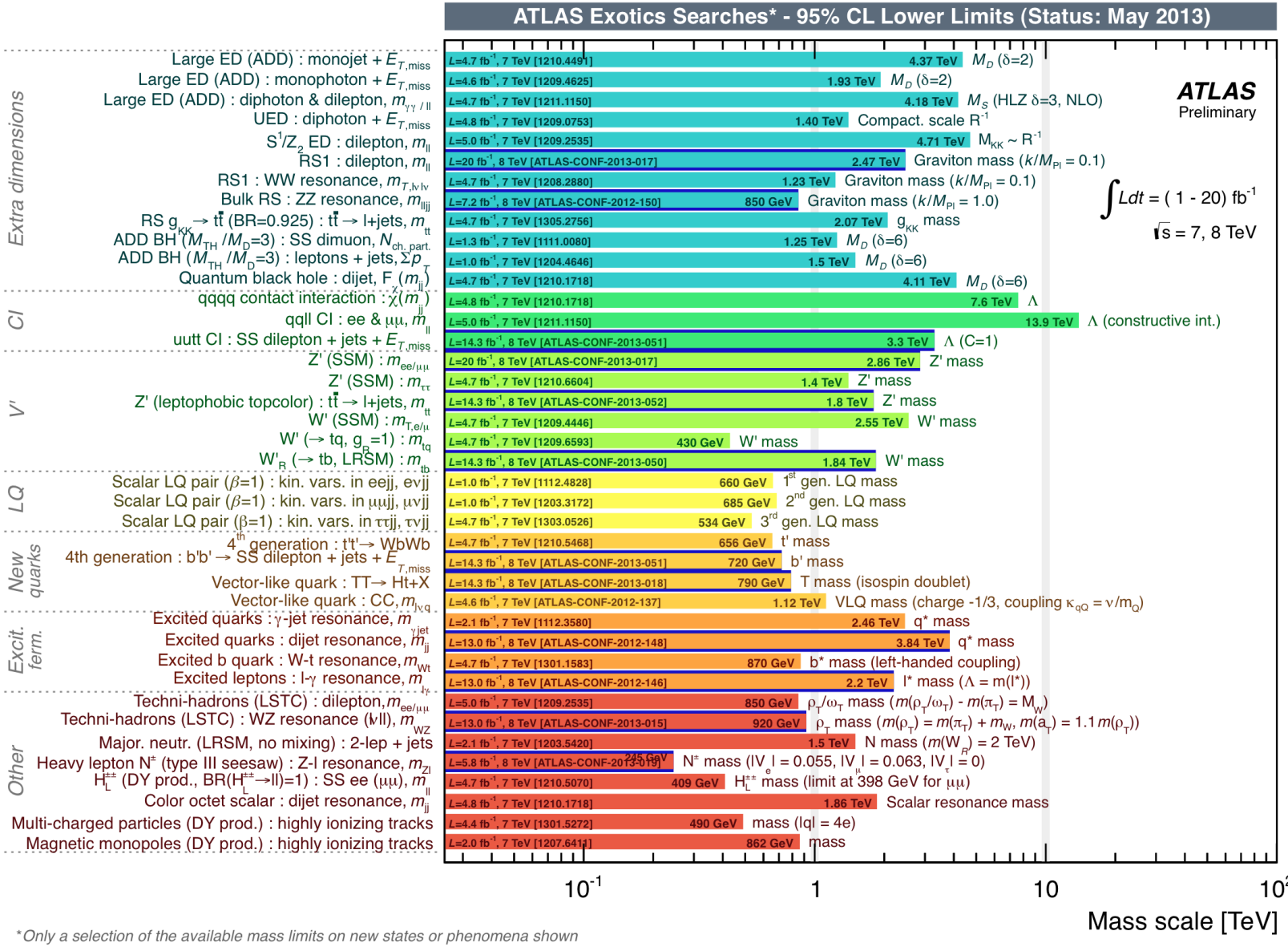
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS12023

Searches for Exotica

CMS Exotica 2013



ATLAS 2013



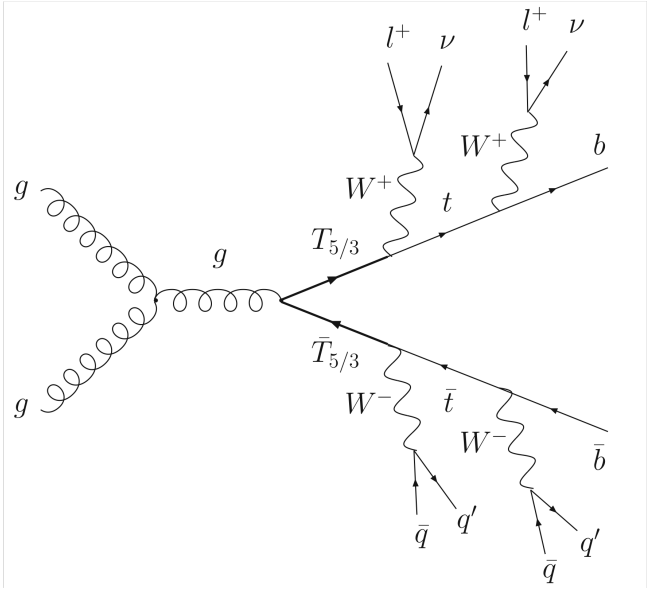
*Only a selection of the available mass limits on new states or phenomena shown

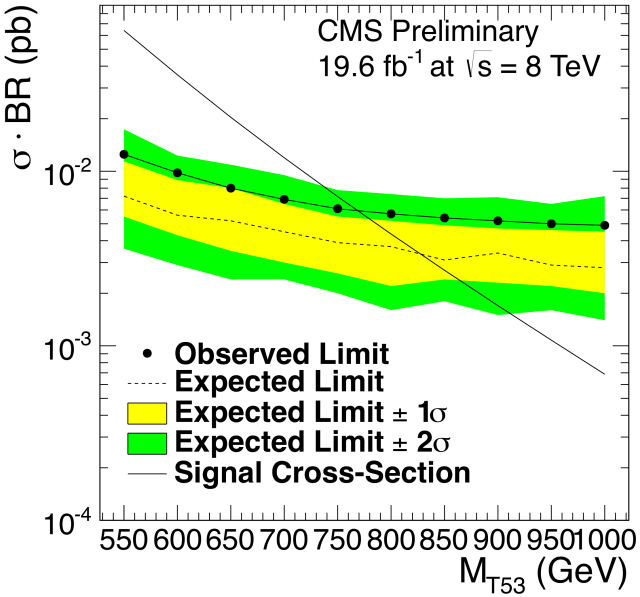
EXO result interpretation

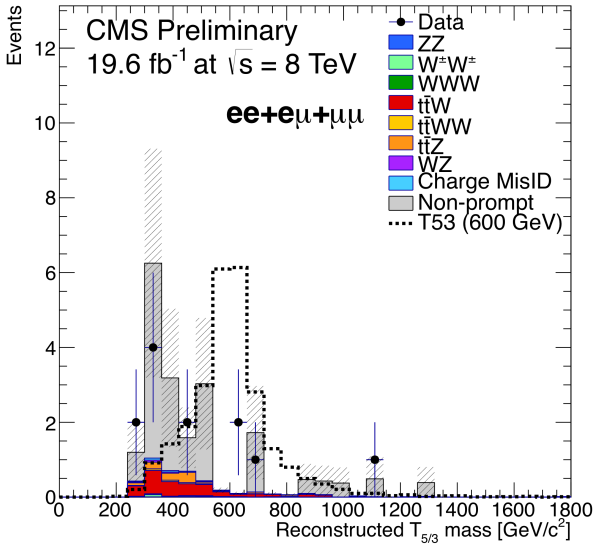
- In the EXO searches, results often in specific models
  - Need for Simplified Models like in SUSY?
  - In some cases, it's already there.
    - E.g. $T^{5/3}$ search, see next slide
  - In other cases, it's missing
    - E.g. Z' search, see following slide
    - Or HSCP search, see following slides
  - In the case of Z', proposals have been made in the past (e.g. Carena et al. PRD 70, 093009, 2004)

5/3-charged Top partners

- $T^{5/3}$
  - 2 same-sign dileptons
  - Significant HT
- 95% CL at 770 GeV



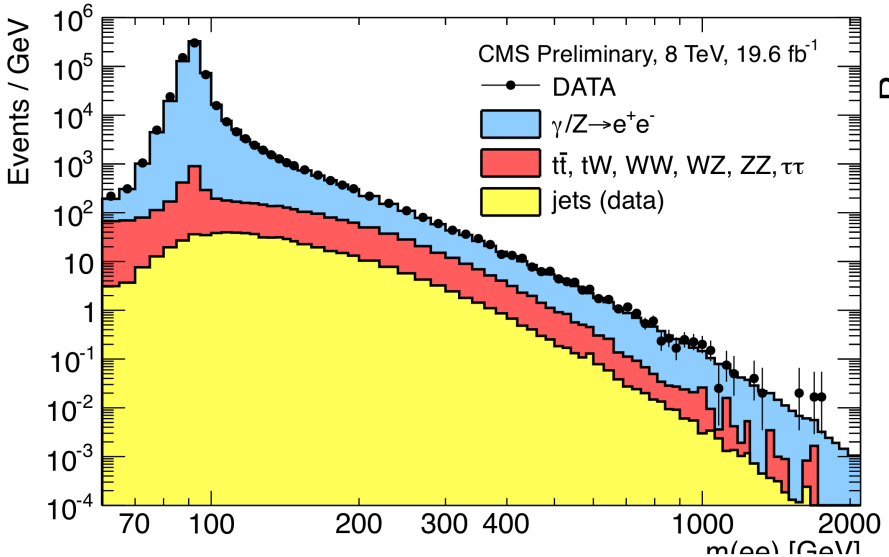


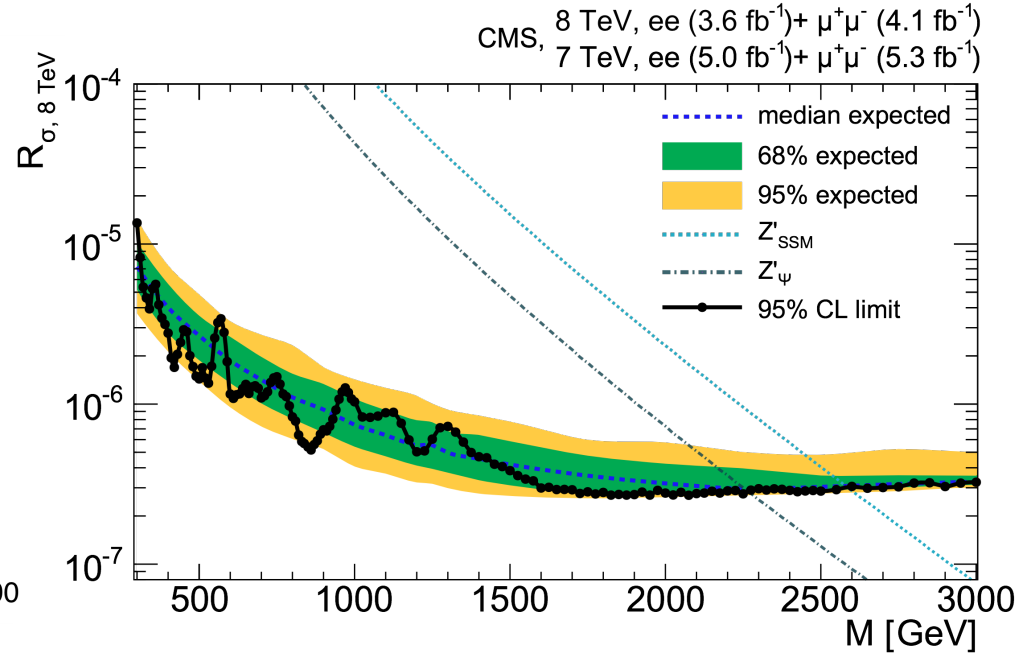


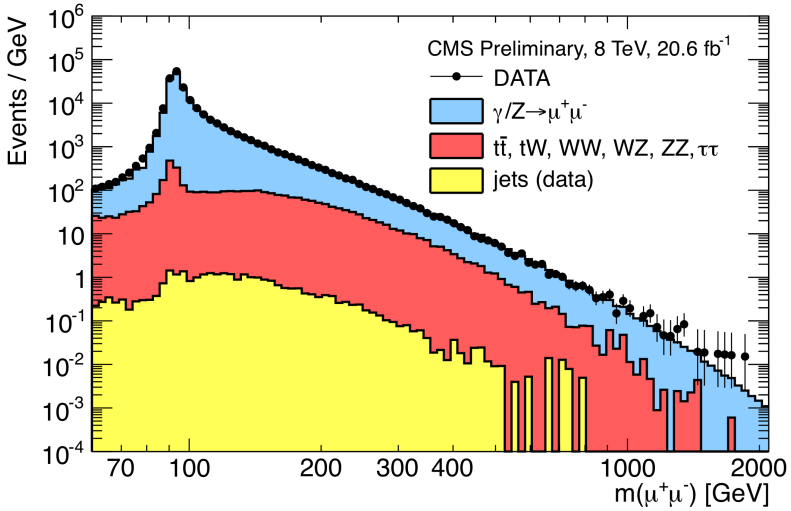
2012 data at 8 TeV (full statistics)

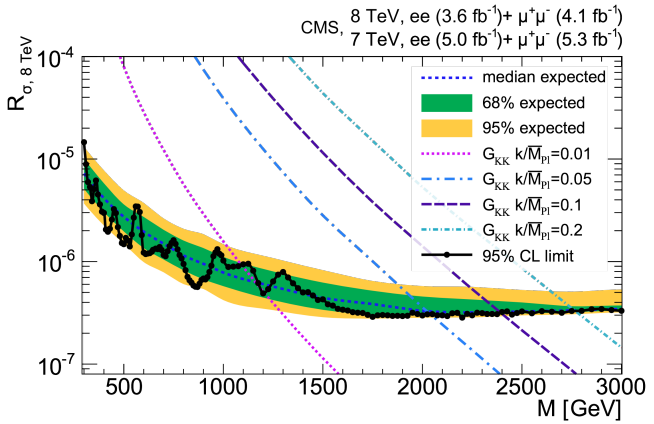
Dilepton resonances

- Dilepton resonances



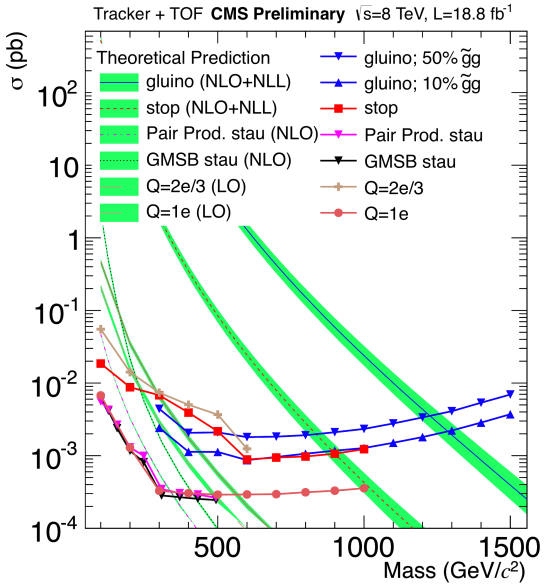


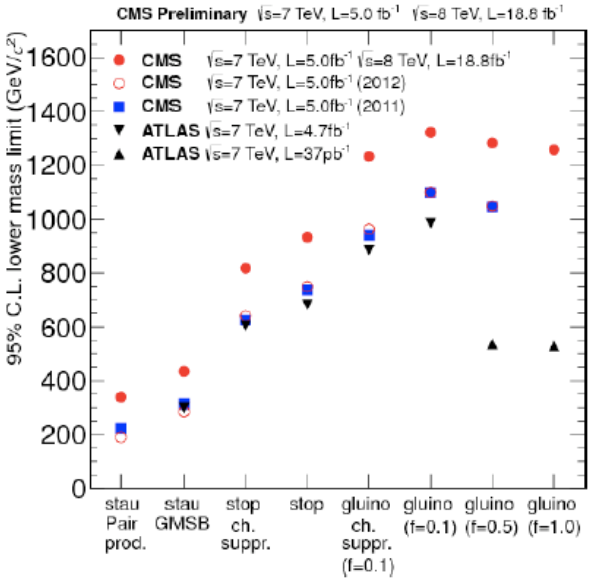


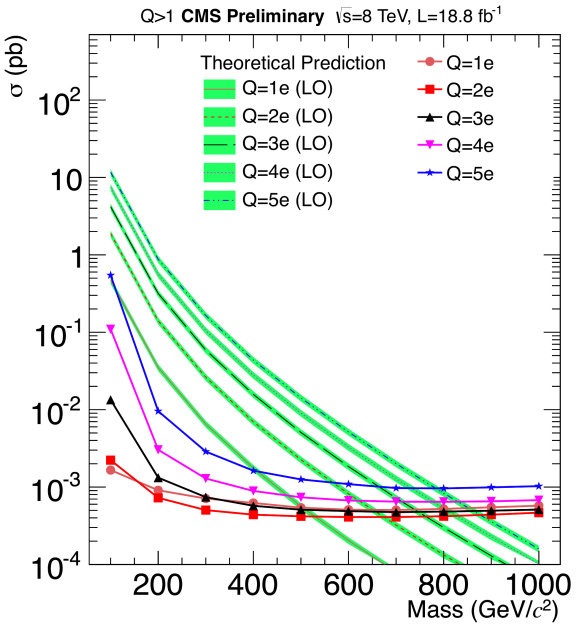


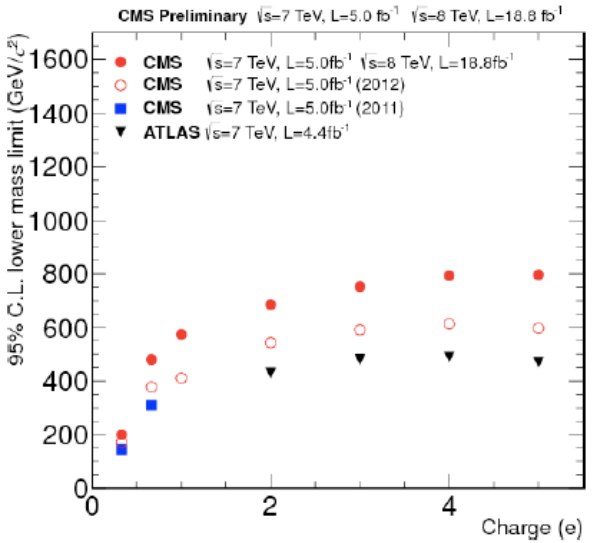
2012 data at 8 TeV (full statistics)

Heavy stable charged particles





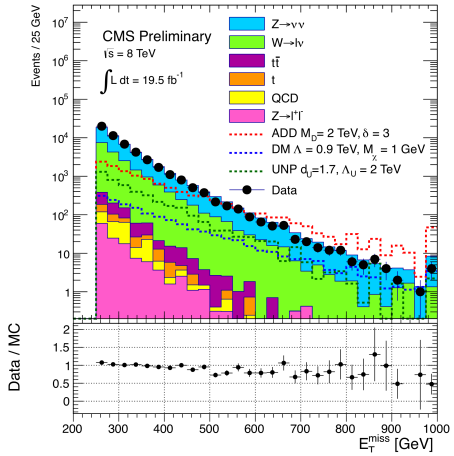


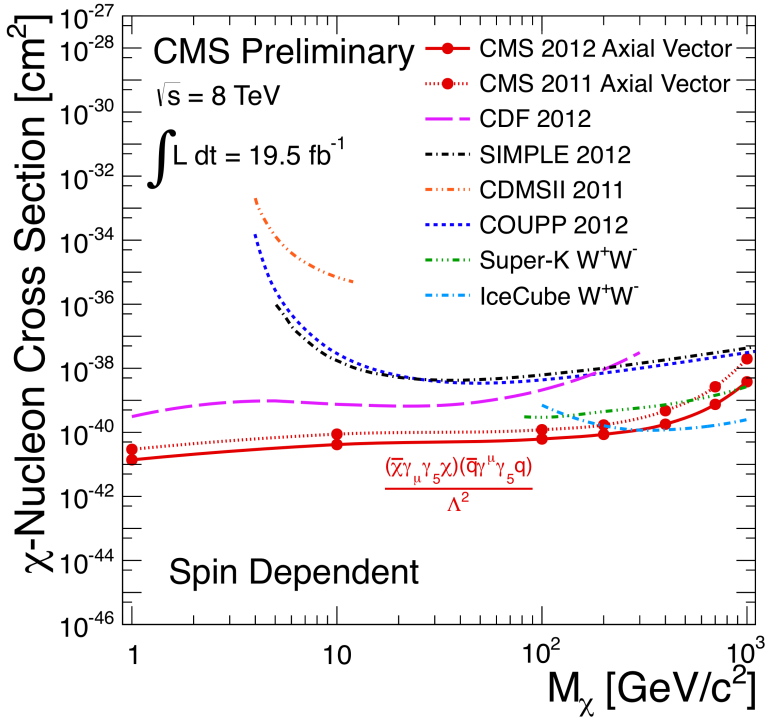


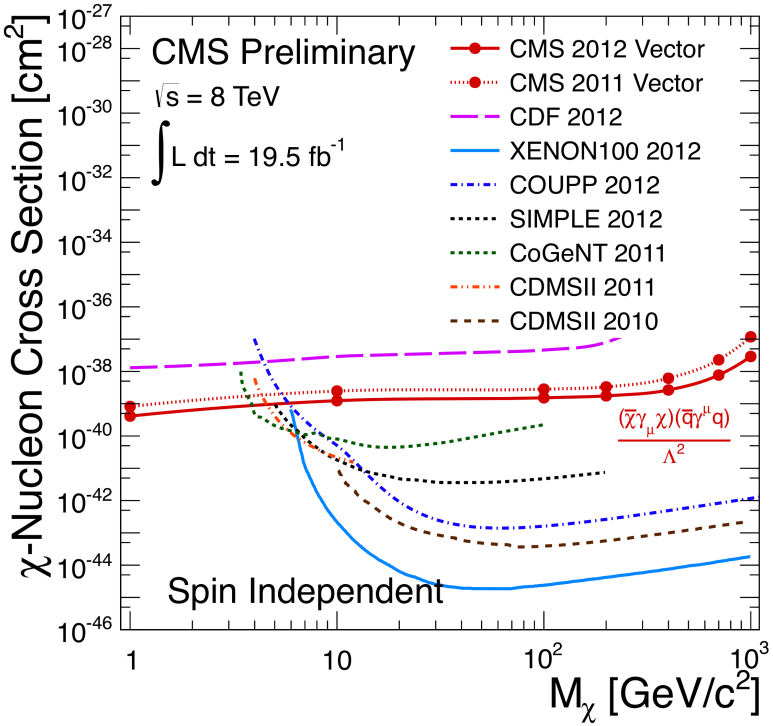
2012 data at 8 TeV (full statistics)

Monojets

- Monojets
  - Gaining fast in popularity
  - In particular, allows to derive limits on DM-nucleon scattering, using effective operators:







2012 data at 8 TeV (full statistics)

General idea

General idea in Les Houches:

- Brainstorming this afternoon:
  - Discuss potential projects. Put all ideas on the table.
  - Check for which projects there is critical mass.
- Coming days:
  - Subgroup meetings for the various projects.

- Reminder to (young) experimentalists:
  - Do not discuss non-approved internal ATLAS/CMS results here. If it's not yet approved, it's not yet mature.