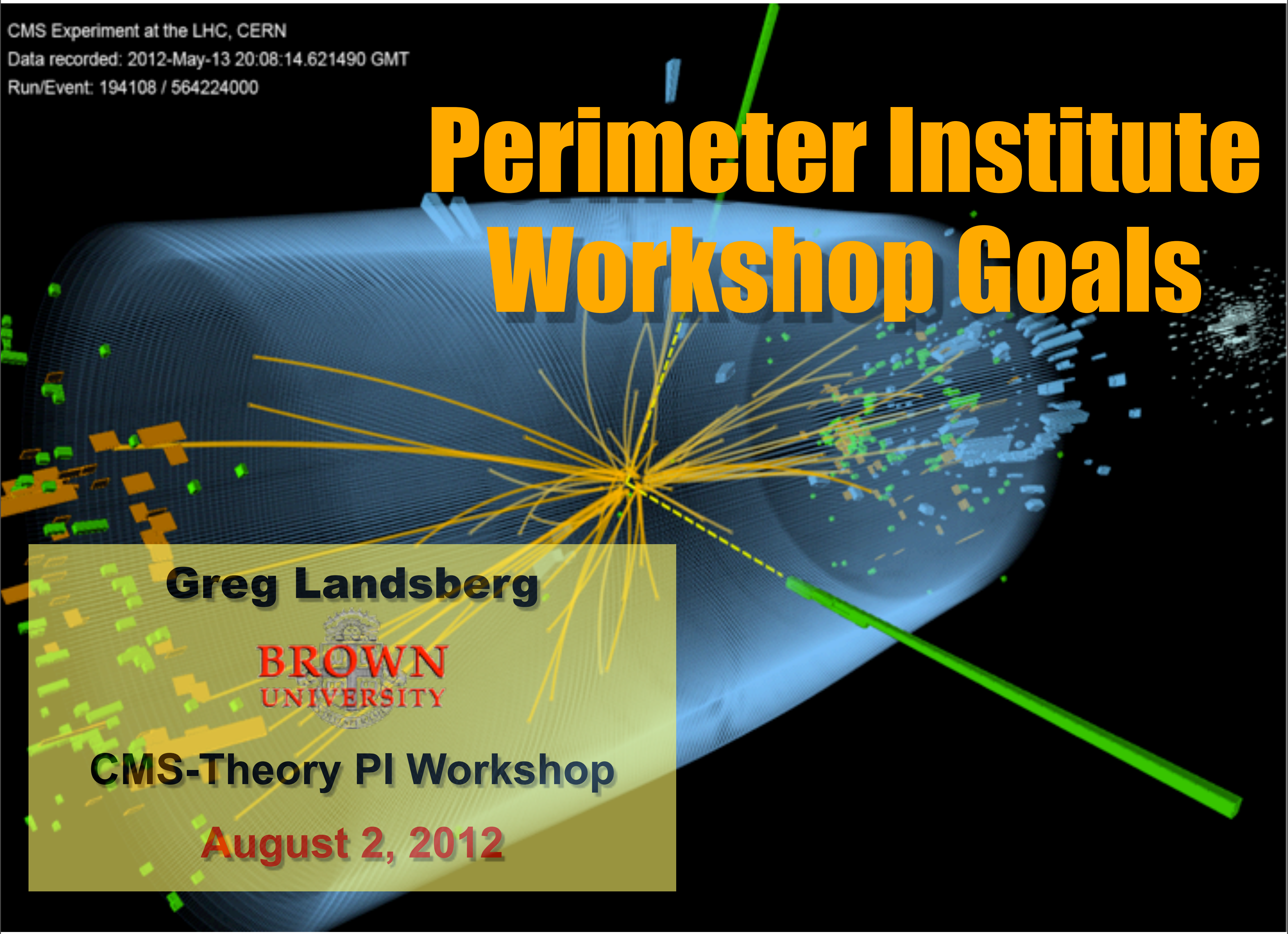


Perimeter Institute Workshop Goals

Greg Landsberg

BROWN UNIVERSITY

CMS-Theory PI Workshop

August 2, 2012

Outline

- *Workshop Goals*
- *The discovery of a new heavy boson*
- *Implications for new physics*
- *Where we stand and what's next?*

Workshop Goals

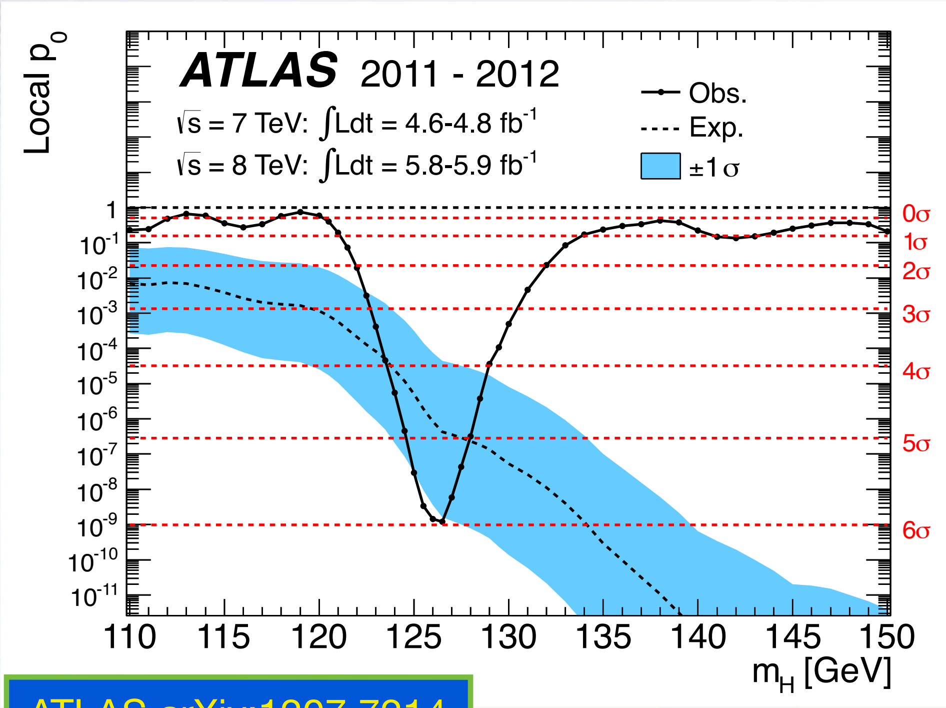
- Generally would like to pursue two main goals:
  - **Collect critical input from our theory colleagues on the CMS physics strategy for 2013 in the light of most recent developments in the field, including an observation of a new heavy boson, and collect any new ideas that may potentially affect our physics program for the next year (new searches, triggers, parking, scouting, ...)**
  - **Foster face-to-face contact and communication between the CMS experimentalists (many of them are physics group conveners) and the leading theorists with the idea to build on these informal contacts in the future**
- I'd like to add my THANK YOU to our generous hosts!

Workshop Format

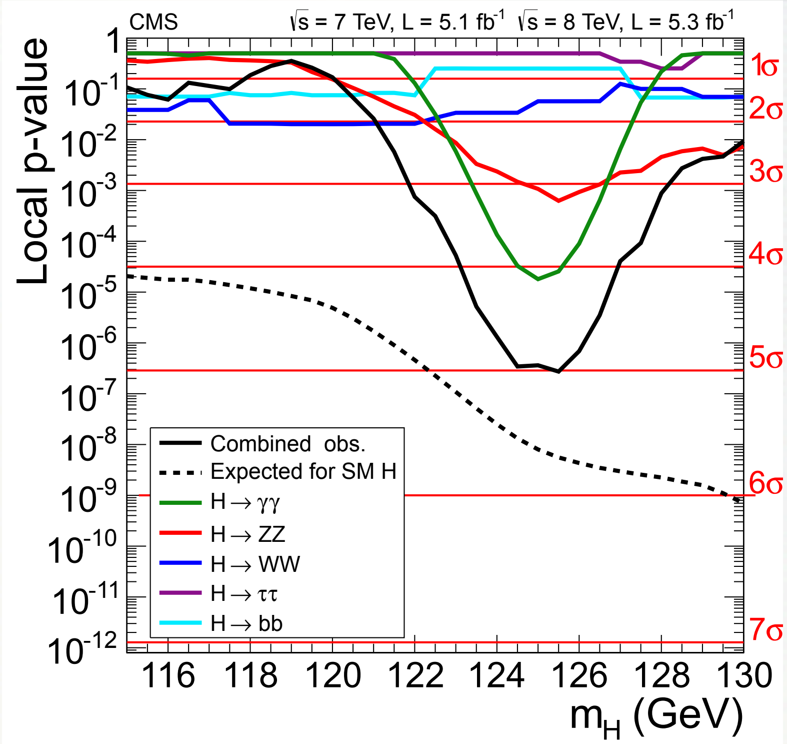
- Relatively few formal talks and plenty of time for informal meetings and discussions
- Wrap-up sessions on Saturday to summarize the working group discussions and new ideas
- Follow-up presentation to the CMS at one of CMS General meetings
- Continuing communication and collaboration between the experimenters and theorists after the workshop

4th of July Fireworks

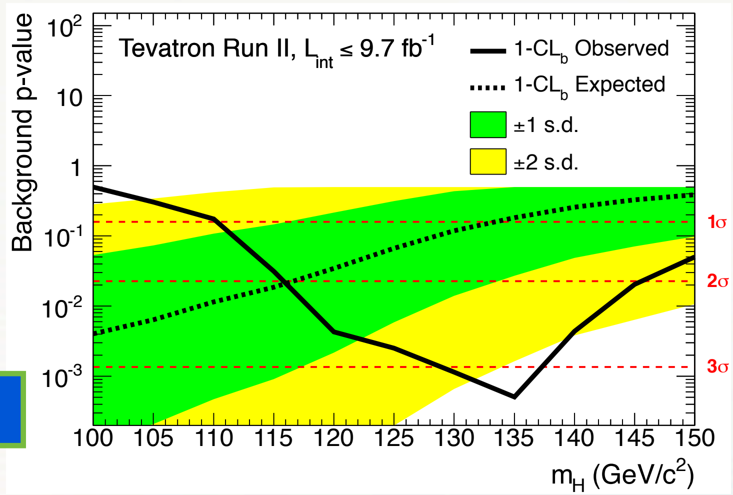
We discovered the Goddamn Thing - Now What?



ATLAS arXiv:1207.7214



CMS arXiv:1207.7235



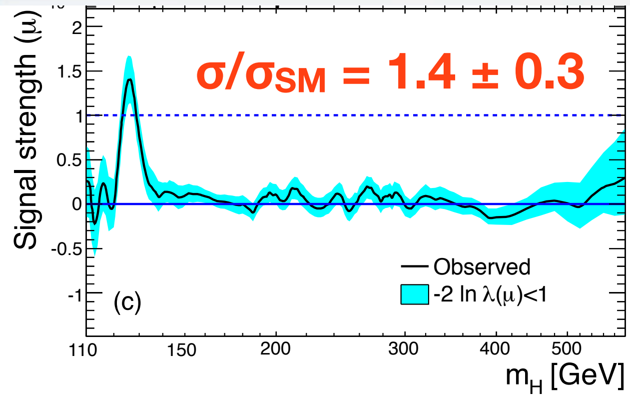
Tevatron arXiv:1207.6436

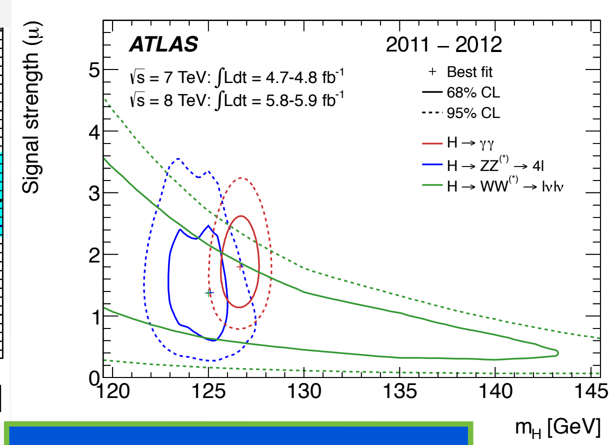
Post-Discovery Questions

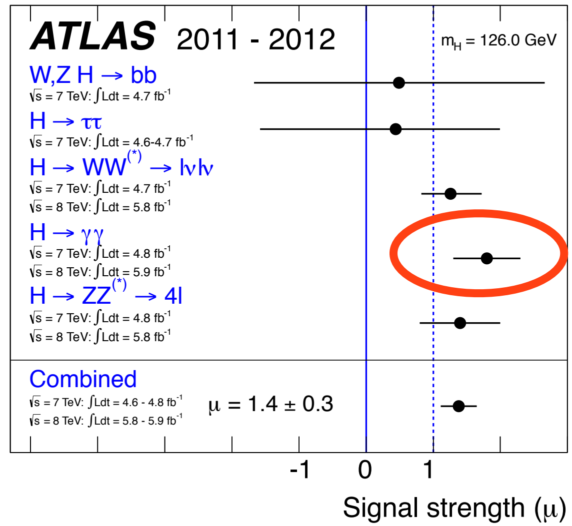
- ATLAS and CMS both discovered a new, narrow resonance in the 125-126 GeV range with >5σ significance in each experiment independently
  - The two discovery papers have been submitted simultaneously, on July 31 @ 14:00 CET, to Phys. Lett. B
    - Tevatron published an "evidence" for a 125 GeV particle a couple of days before
- Are we seeing one and the same particle?
- What are the properties of this particle?
- Have we discovered a Higgs boson?
  - If so, is this the SM Higgs boson?
- What's next?

Anatomy of the Discovery

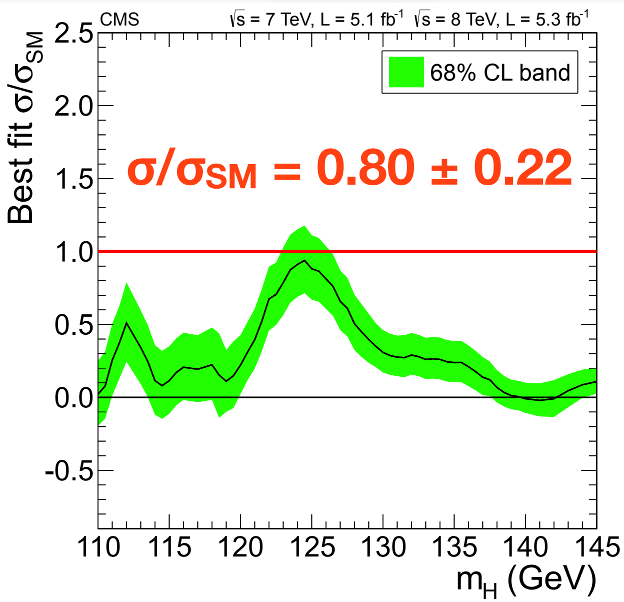
- Both collaborations are quite consistent in their findings



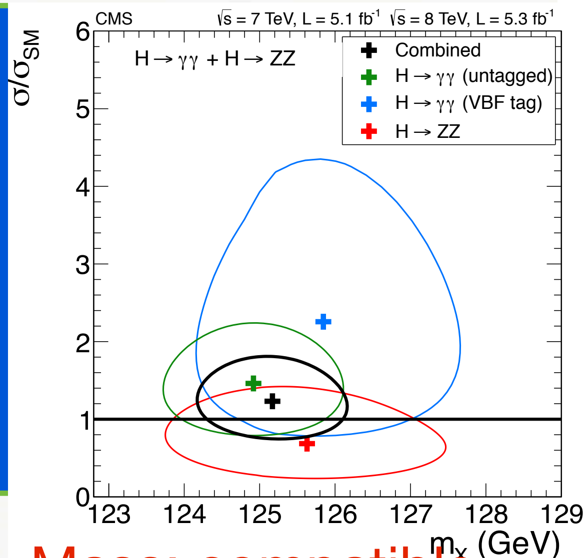


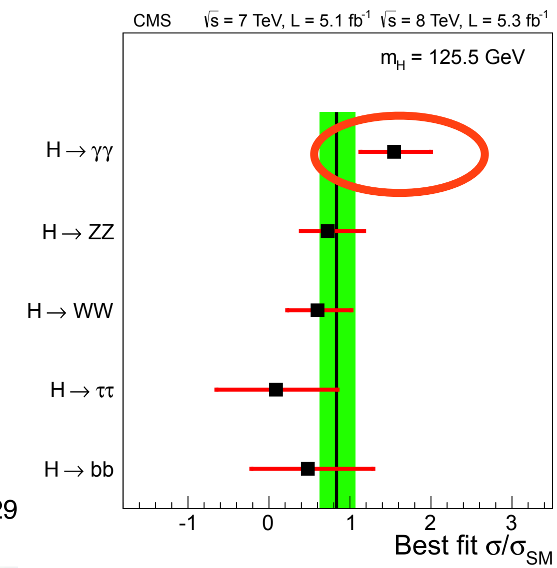


ATLAS arXiv:1207.7214



CMS arXiv:1207.7235



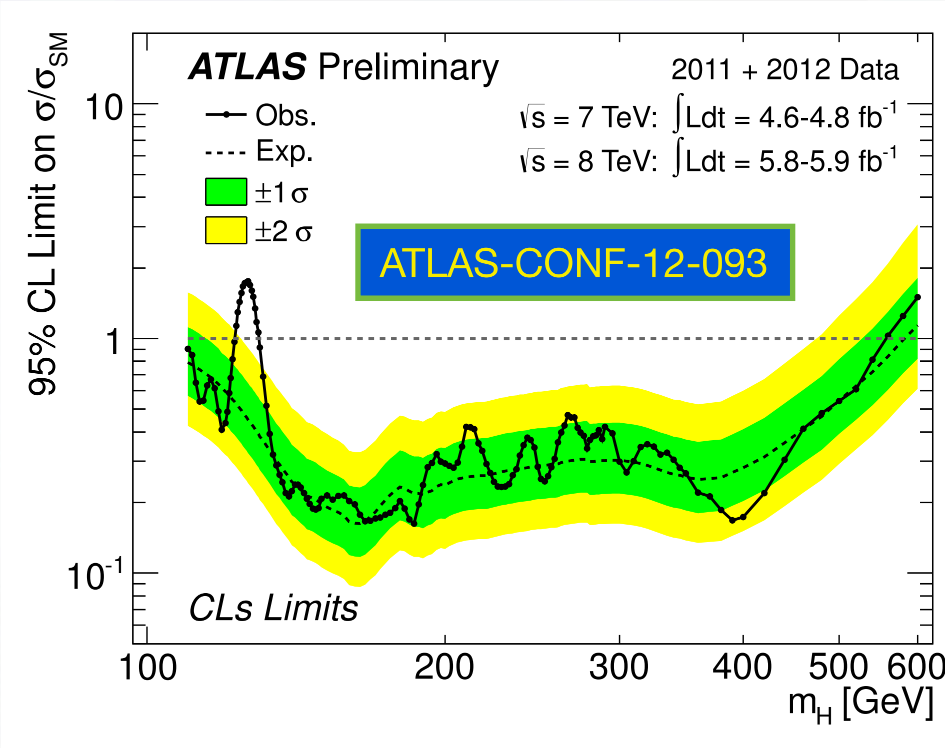


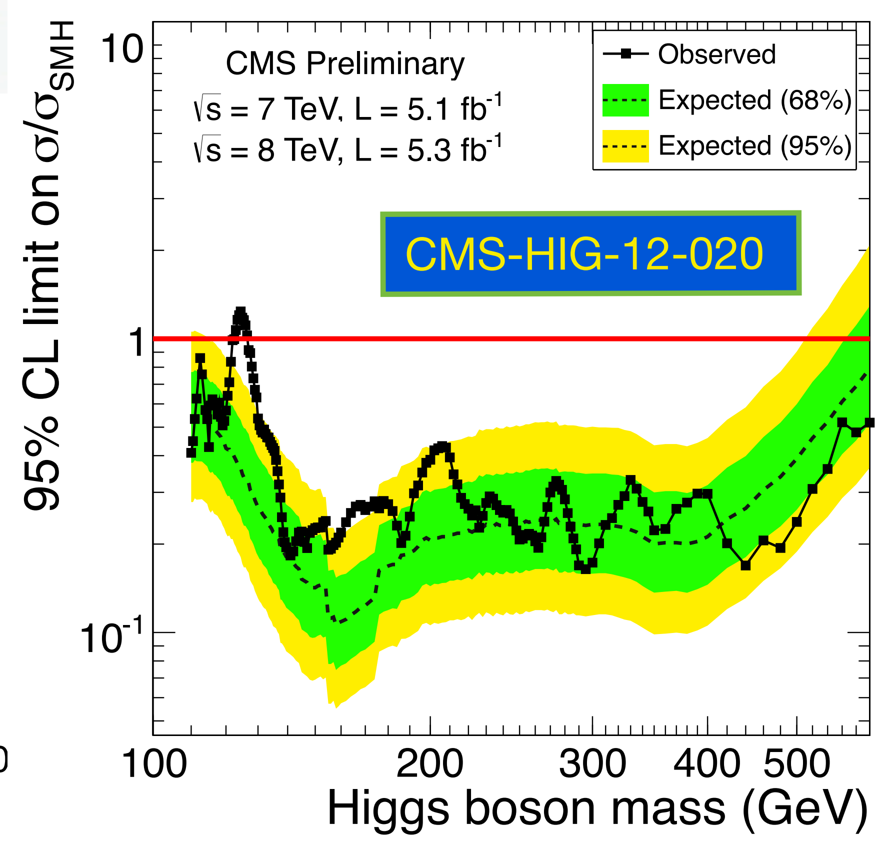
Signal strength: SM-like

Mass: compatible

What About High Masses?

- Nothing exciting is going on there....





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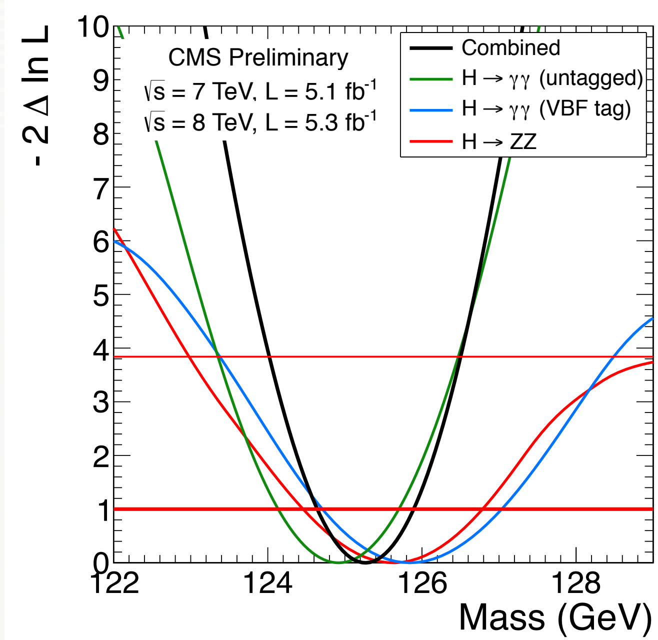
Properties of the New Particle

- Certain things we can already say now:
  - The newly discovered particle is a boson with J = 0 or 2
    - Spin 1 is ruled out by the Landau-Yang theorem, as it can't decay into two photons
  - The newly discovered boson has narrow width, smaller than the experimental resolution of ~1% in the $\gamma\gamma$ and ZZ channels
  - The newly discovered particle is not inconsistent with the SM Higgs, but it also may be different from the SM Higgs boson
    - Low rate in the fermionic channels (CMS)
      - On the other hand Tevatron sees a lot in bb?
    - Slightly higher rate in the $\gamma\gamma$ channel (ATLAS+CMS)
  - ATLAS and CMS both observe one and the same boson with the mass between 125 and 126 GeV

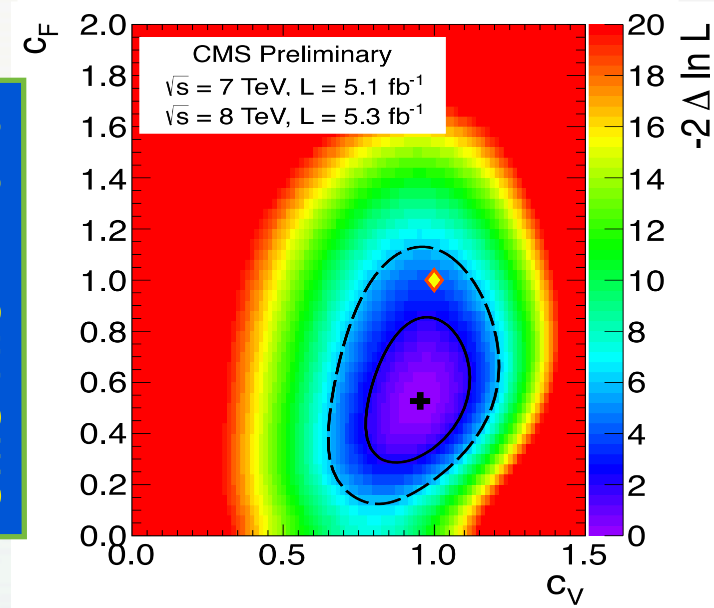
More on Properties

- ATLAS and CMS have determined the mass of the new boson:
  - CMS: M_X = 125.3 ± 0.4 (stat) ± 0.5 (syst) GeV
  - ATLAS: M_X = 126.0 ± 0.4 (stat) ± 0.4 (syst) GeV
- CMS also tested the custodial symmetry by comparing couplings to the W and Z bosons:
  - $R_{W/Z} = 0.9^{+1.1}_{-0.6}$
- First attempt in CMS to measure couplings to fermions (C_F) and bosons (C_V)

CMS-HIG-12-020



CMS-HIG-12-020



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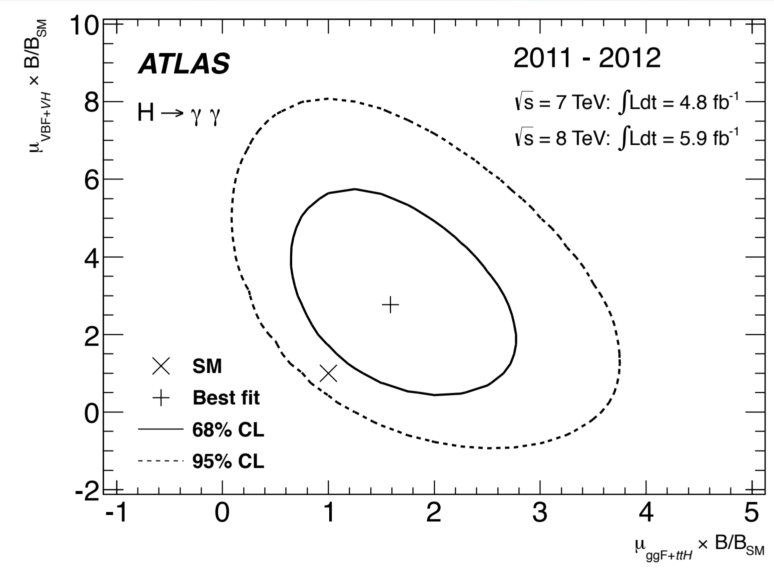
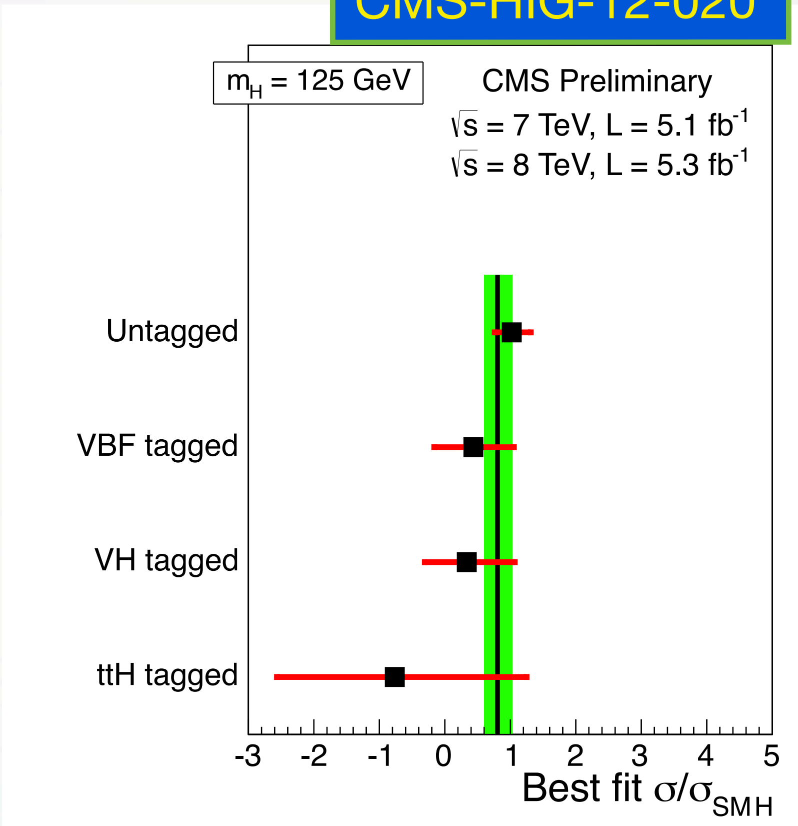
More on Properties

- ATLAS also quotes the relative VBF and associated production w.r.t. gg fusion + ttH in the $\gamma\gamma$ channel
- CMS produced information for various production mechanisms in all channels

CMS-HIG-12-020





ATLAS arXiv:1207.7214

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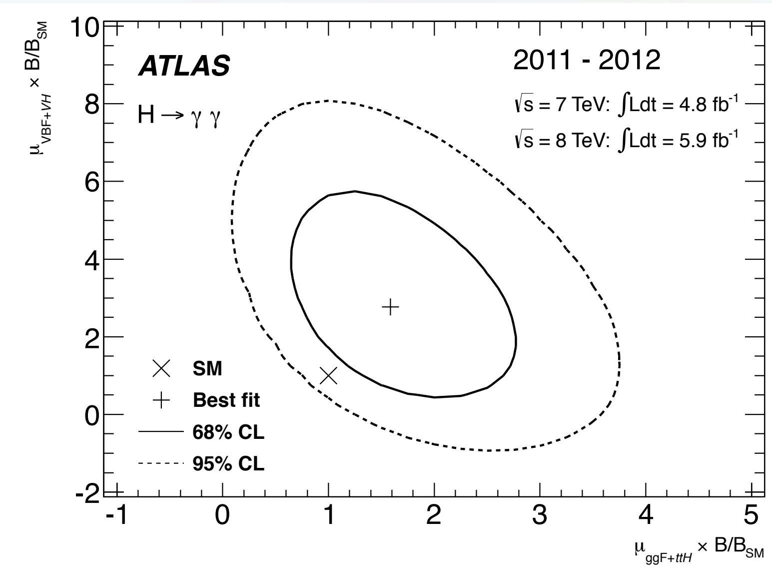
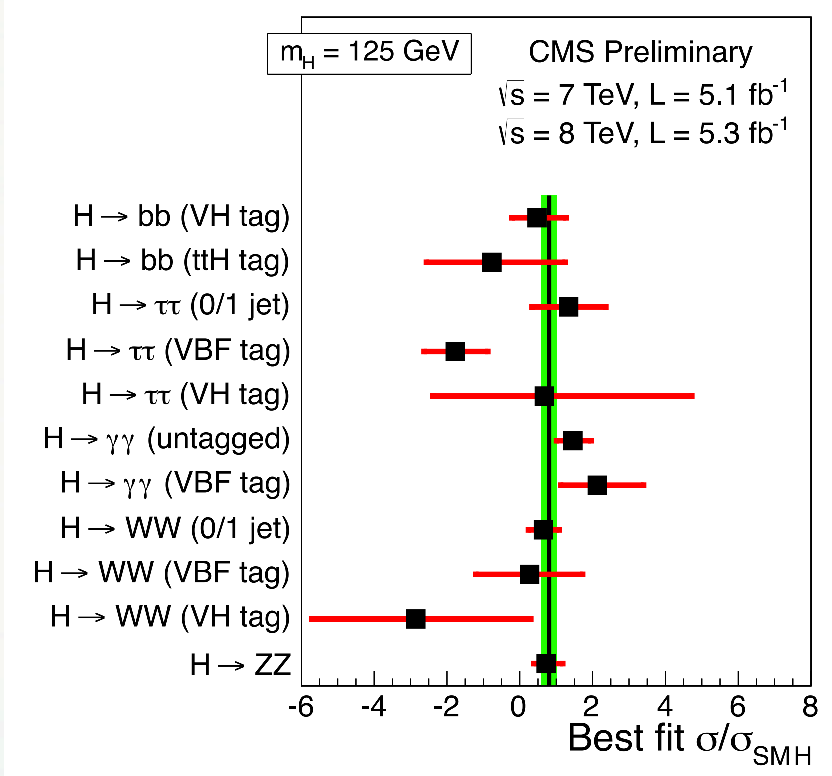
CMS-HIG-12-020

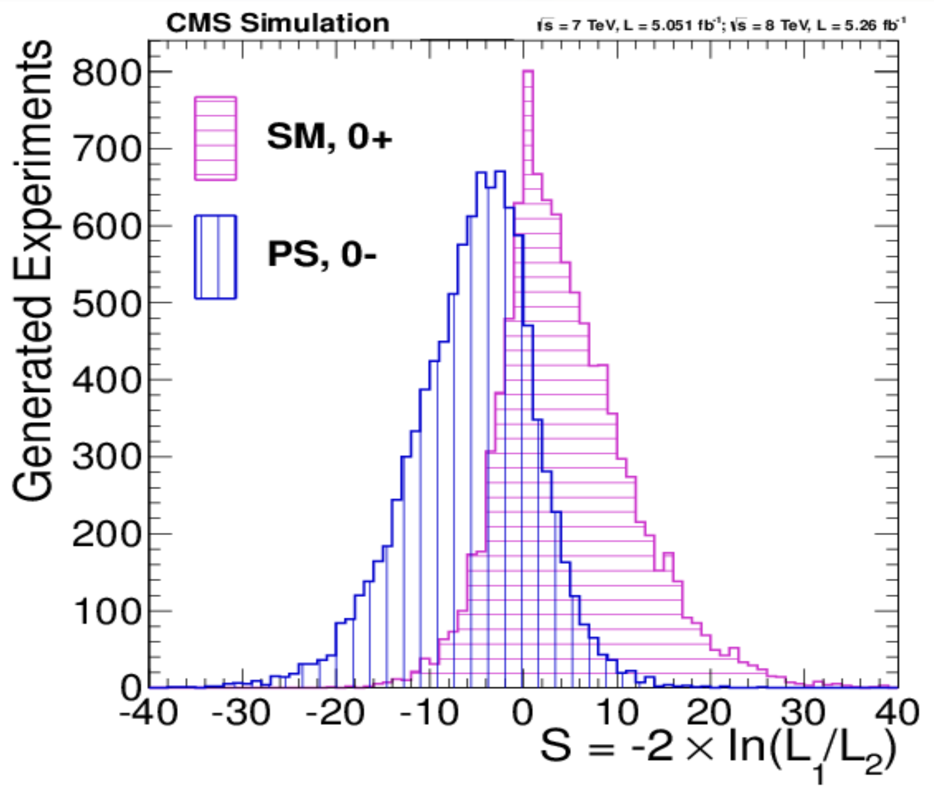




ATLAS arXiv:1207.7214

Determining the Spin-Parity

- CMS made projections based on MELA in the ZZ channel
  - Can separate 0^{-+} from 0^{++} at a 3σ level with ~30 fb^{-1} Distinguishing spin 0 from spin 2 is much harder - need other channels, like WW and $\gamma\gamma$



integrated lumi (7 TeV, 8 TeV)	expected separation
5/fb, 20/fb	2.6 σ
5/fb, 30/fb	3.1 σ
10/fb, 60/fb	4.4* σ

* - simple lumi scaling

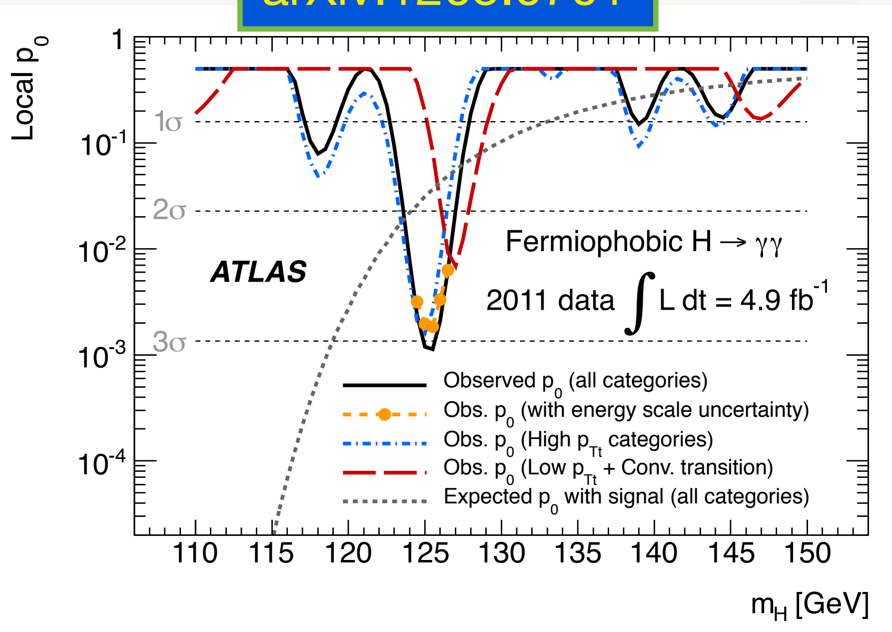
Could it be a Fermiophobic Higgs?

- In the Standard Model, EWSB and fermion masses both incorporated economically via the Englert-Brout-Higgs mechanism and couplings to the Higgs field, respectively
- This doesn't have to be the case: Higgs may very well couple only to gauge bosons - a fermiophobic (FP) Higgs boson; fermion masses will have to be explained via a different mechanism
- Consequences:
  - Gluon fusion is not possible as it proceeds through the top-quark loop; VBF and associate production remain
  - H decays to WW/ZZ, and also $\gamma\gamma$, via W loop
  - Conspiracy: for the Higgs mass of ~135 GeV $\sigma \times Br(H \rightarrow \gamma\gamma)$ is essentially the same for the FP Higgs and the SM Higgs (and grows at lower masses)
- Could we have observed a FP Higgs? Or Leptophobic?

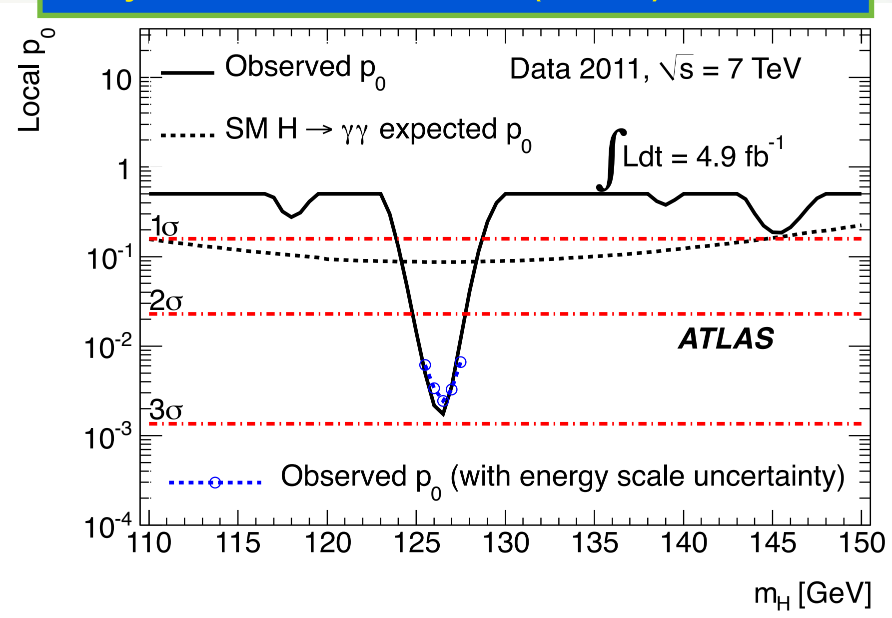
ATLAS Fermiophobic Higgs Search

- Both ATLAS (2011 data) and CMS (2011+2012 data) analyzed this possibility:
- ATLAS has analyzed only $\gamma\gamma$ channel, and as expected, the excess can be interpreted either as a SM or FP Higgs boson with essentially the same p-value
- It's crucial to add other bosonic channels!

arXiv:1205.0701



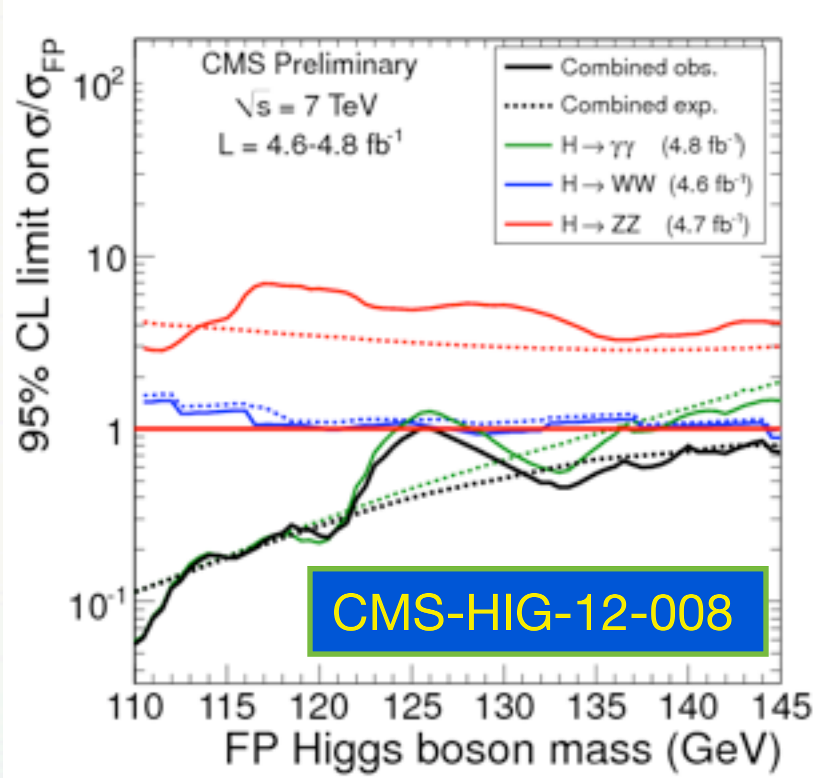
Phys. Rev. Lett. **108** (2012) 111803



CMS Fermiophobic Higgs Search

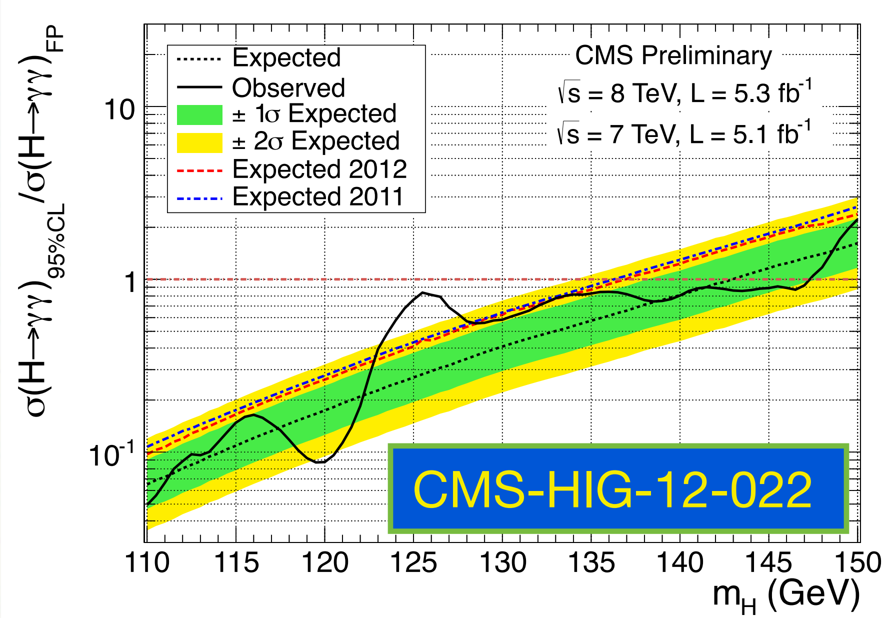
- CMS analyzed γγ, WW, and ZZ via VBF and associated production in 2011 data and γγ only in 2011+2012
- Excluded FP interpretation of the excess in 110-192 GeV range at the 95% CL
- However, can't exclude ~125 GeV mass at the 99% CL

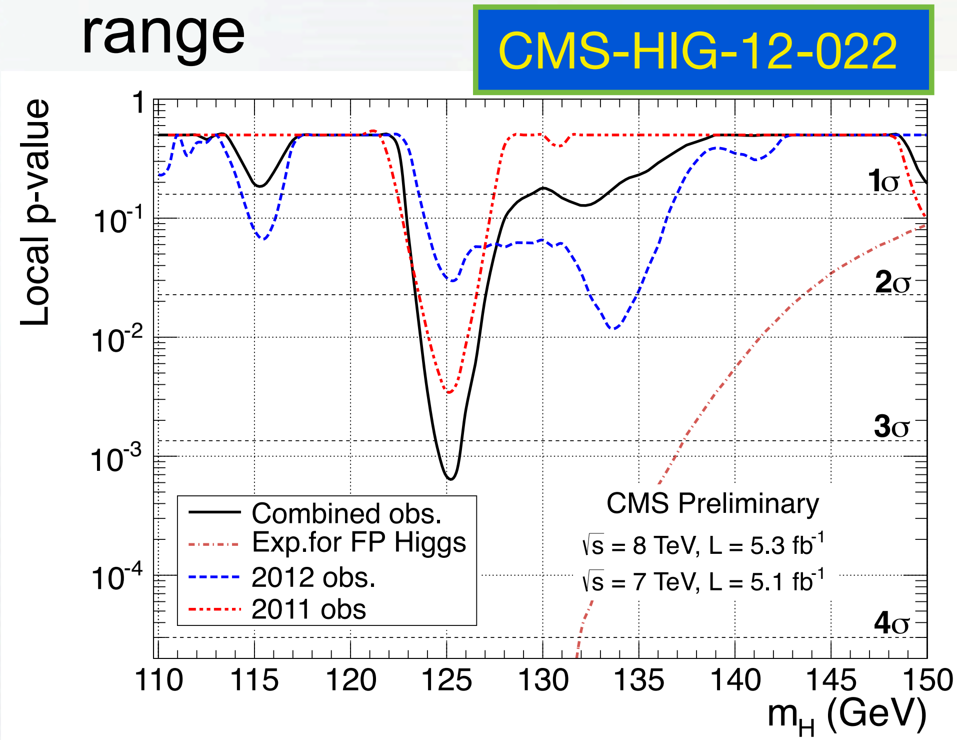
Channel	m_H range (GeV)	Sub-channels	Luminosity (fb^{-1})
$H \to \gamma\gamma$	110–150	4	5.1
$H \to \gamma\gamma$ + dijet	110–150	1	5.1
$H \to \gamma\gamma$ + lepton	110–150	2	5.1
$H \to WW \to 2\ell 2\nu$	110–300	4	4.9
$H \to WW \to 2\ell 2\nu$ + dijet	110–300	1	4.9
$H \to WW \to 2\ell 2\nu$ + lepton	110–300	1	4.9
$H \to ZZ \to 4\ell$	110–300	3	5.0
$H \to ZZ \to 2\ell 2\nu$	250–300	2	5.0
$H \to ZZ \to 2\ell 2q$	130–165, 200–300	6	5.0
$H \to ZZ \to 2\ell 2\tau$	180–300	8	5.0

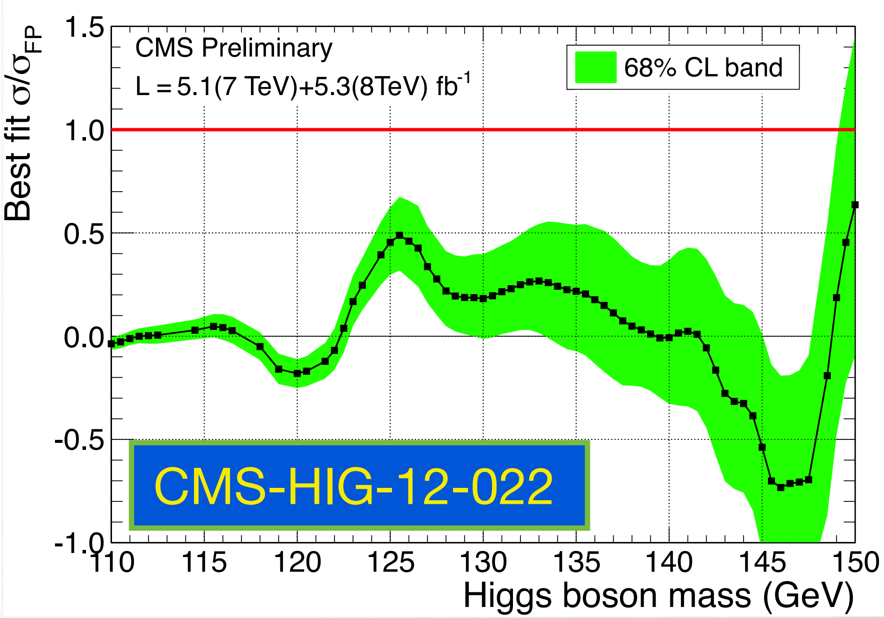


And now even with γγ alone!

- Combining γγ channel in VBF and associated production in 2011 and 2012 data
- FP hypothesis is excluded at 99% CL for the FP Higgs mass in the 110-134 GeV range







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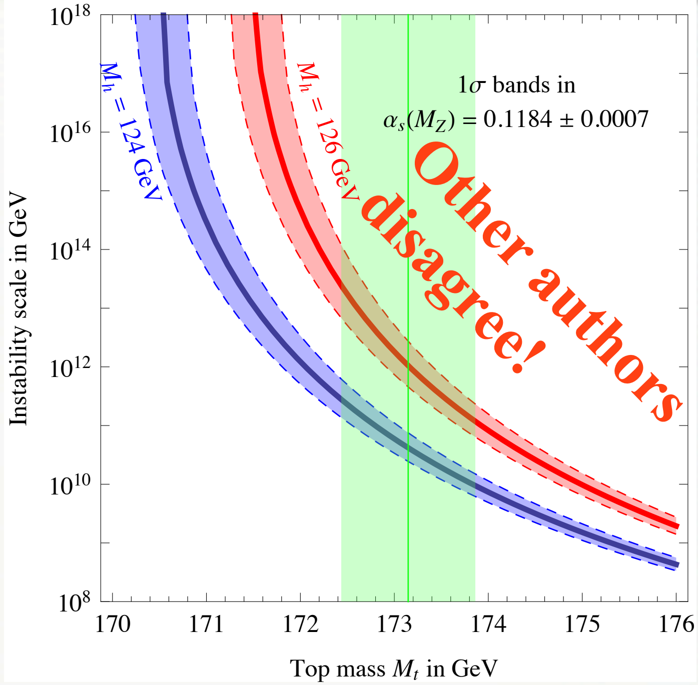
We are at the Crossroads

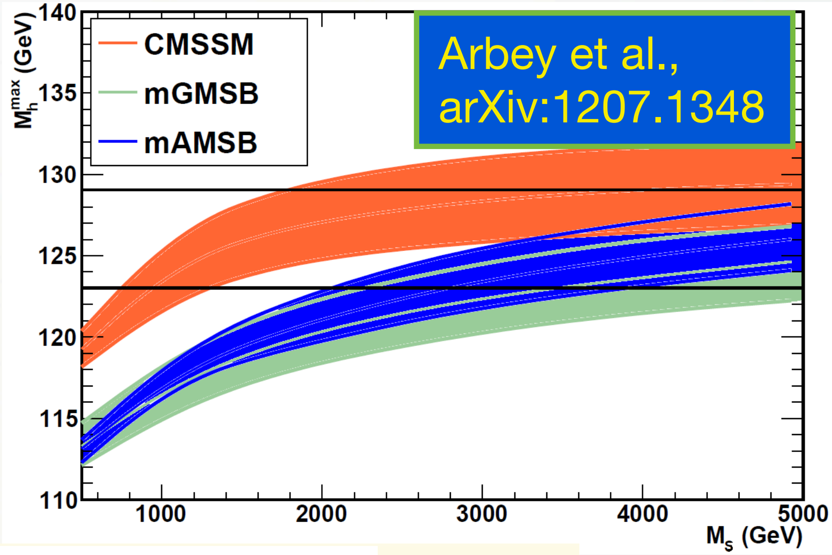
- Light Higgs implies that the Standard Model can not be a complete theory up to the Planck scale
- Vacuum stability arguments require new physics to come at a scale ~10^{11} GeV or less
- Curiously points to a similar scale as suggested by the neutrino mass hierarchy via see-saw mechanism
- If we found a SM Higgs boson, we now need to explain the EWSB mechanism
- If what we found is not a Higgs boson, we need to understand what it is and what plays the role of the Higgs
- In a sense, a 125 Higgs is maximally challenging and rich experimentally, but also inflicts "maximum pain" theoretically, as it is not so easy to accommodate



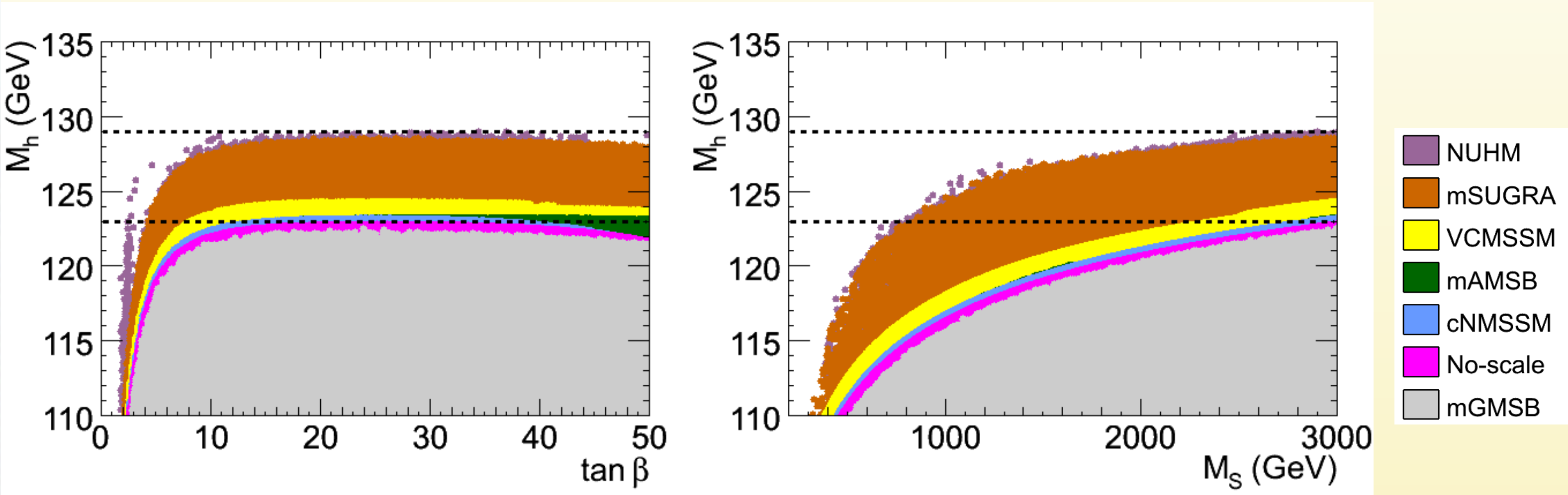
Degrassi et al arXiv1205.6497

SUSY: the Aftermath

- A 125 GeV Higgs is challenging to accommodate in constrained versions of SUSY, particularly for "natural" superpartner masses
- Started to constrain some of the simpler models
- If SUSY exists, is it really "natural"?



Mahmoudi, ICHEP 2012



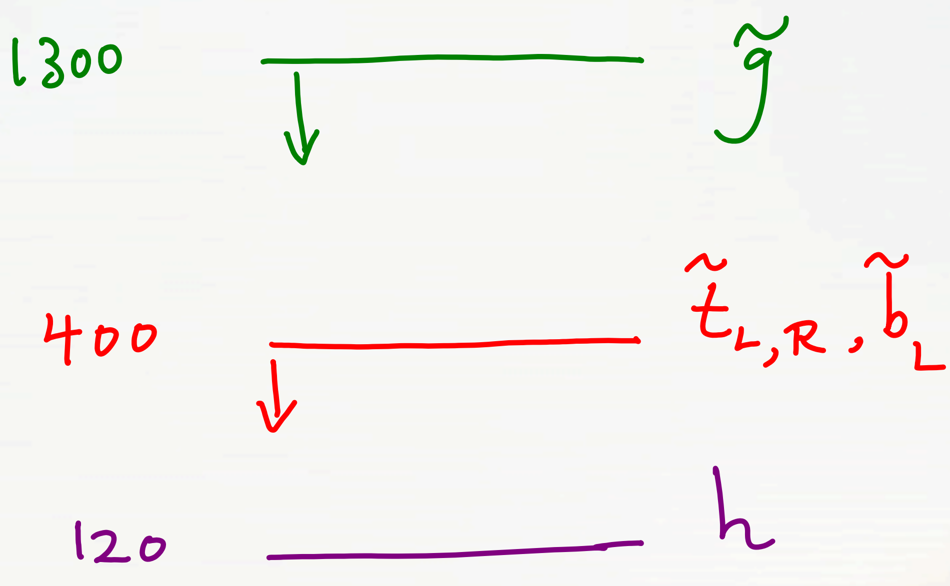
We are at a SUSY Crossroad

- Light 125 GeV Higgs boson strongly prefers SUSY as the fundamental explanation of the EWSB mechanism
- But what kind of SUSY?
- The "canonic" mSUGRA-like SUSY has been largely excluded
- SUSY can still be "natural," but much of the parameter space has been probed
  - Necessary would imply 3rd generation signatures for discovery
- SUSY can be fine-tuned, which would result in a very different mass spectrum and signatures
  - Look for long-lived particle in various decay modes
- Can we prove or essentially rule out natural SUSY case?

Natural SUSY

- If SUSY is natural, we should find it soon:
- And we most likely will find it by observing 3rd generation SUSY particles first!
- Requires rethinking of SUSY search strategies

Compulsory Natural SUSY

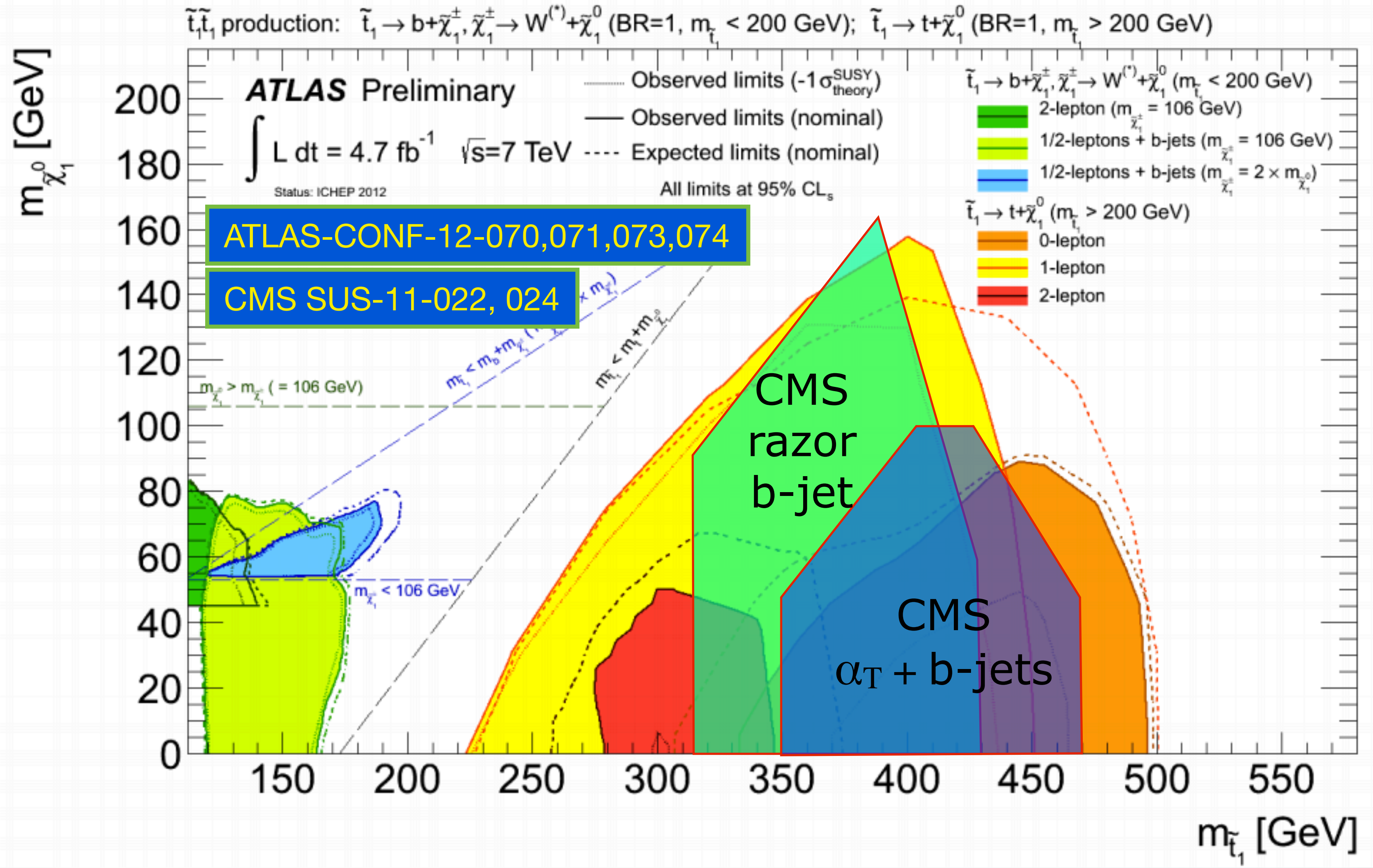


Unavoidable tunings: $\left(\frac{400}{m_{\tilde{t}}}\right)^2, \left(\frac{4 m_{\tilde{t}}}{M_{\tilde{g}}}\right)^2$

Nima Arkani-Hamed, SavasFest 2012

Grand Summary of Stop Searches

- Impressive coverage of the new territory



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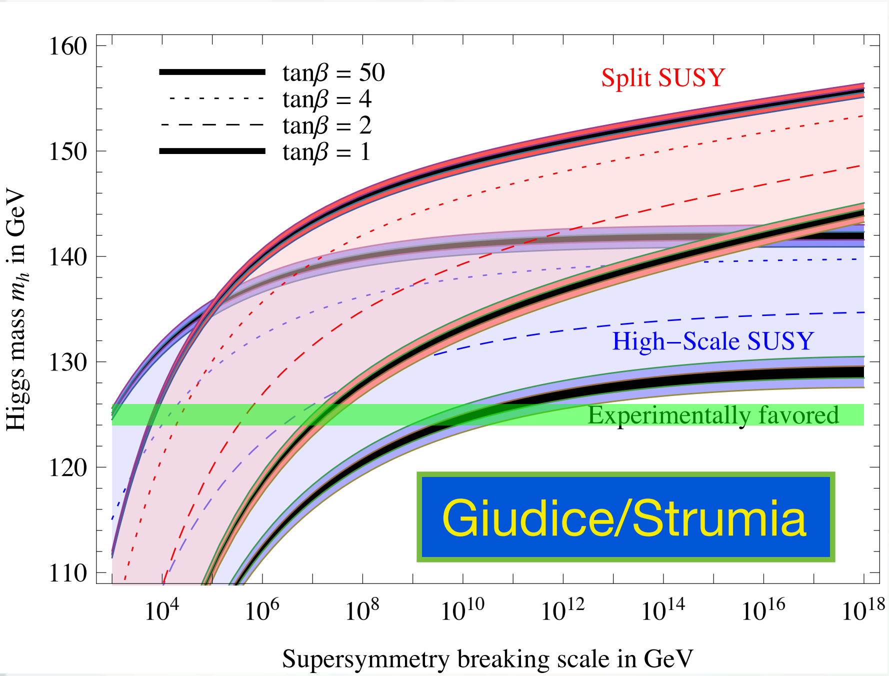
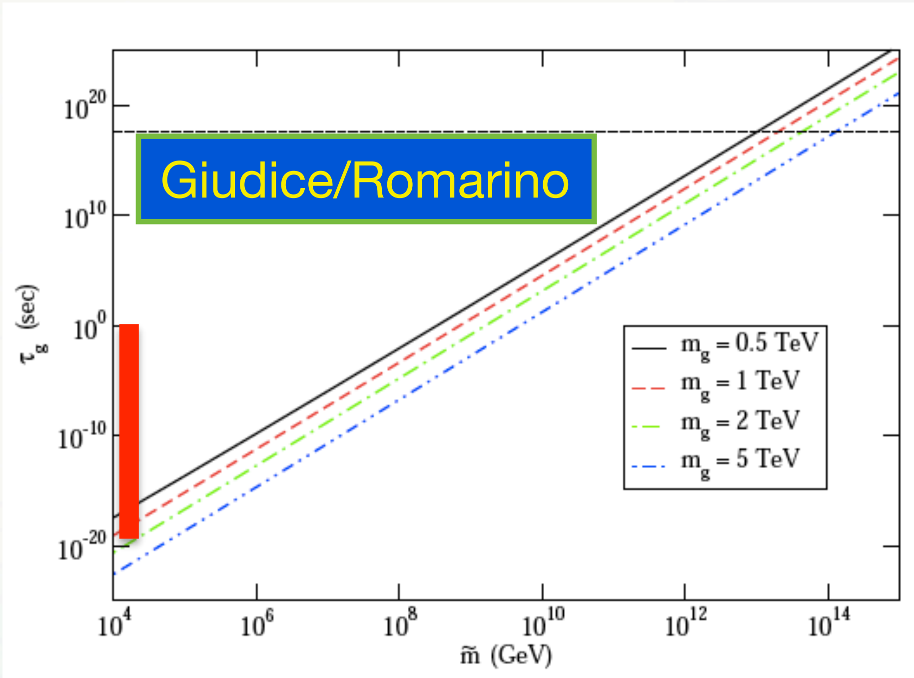
The Case for Long-Lived Particles

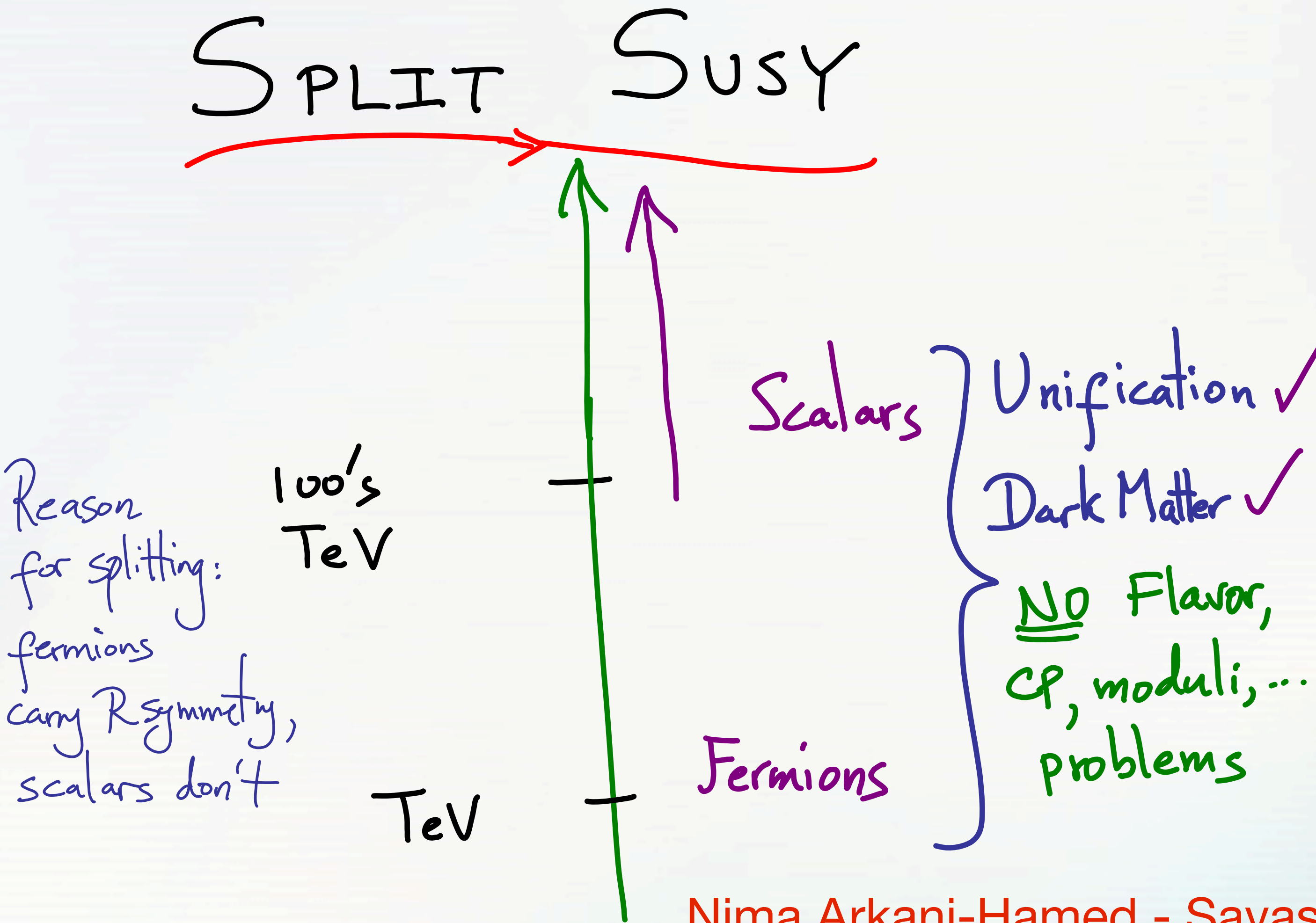
- The light Higgs implies particular characteristic cτ both in case of split SUSY and generic case of heavy SUSY
- Preferred SUSY breaking scale of 10^4-10^{10} TeV implies cτ ~ 10^{-20} - 1 s
- For the mid-range of 10^8 TeV, cτ ~ 1-100 ns - very challenging range experimentally





Example: Split Supersymmetry

- Wells, hep-ph/0306127
- Arkani-Hamed, Dimopoulos JHEP **06** (2005) 073
- Guidice, Romanino, Nucl.Phys. **B699** (2004) 65

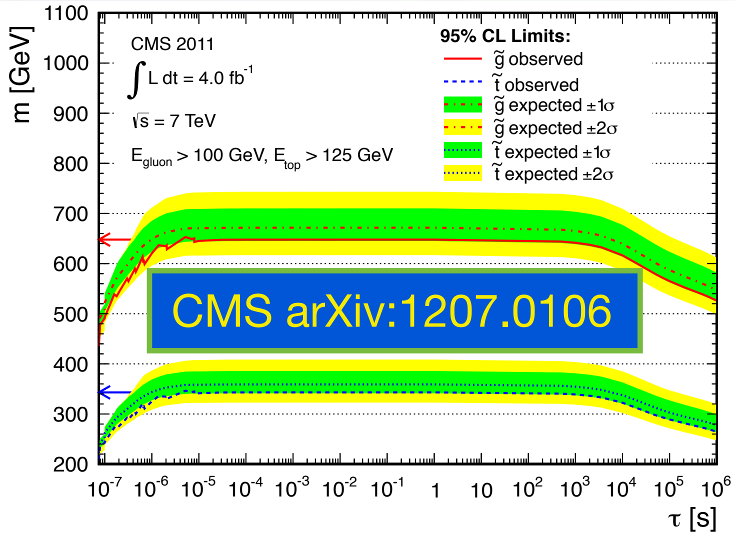


Nima Arkani-Hamed - SavasFest 2012

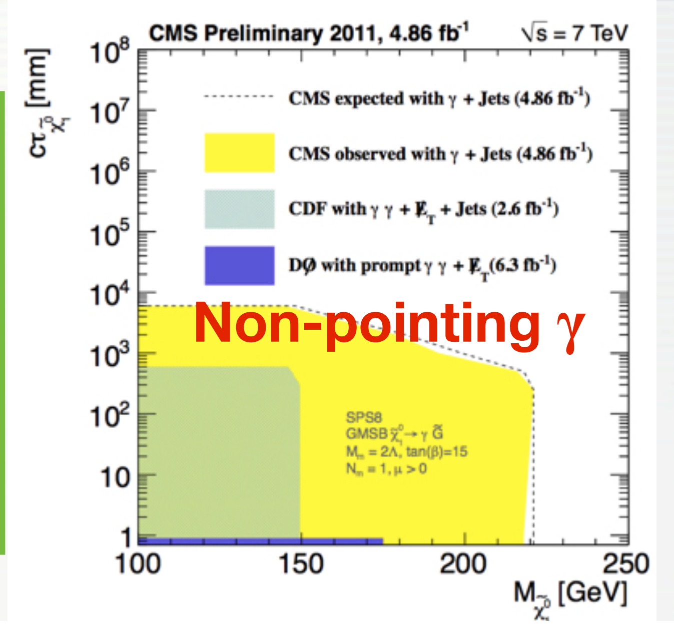
Long-Lived Particle Searches

- ...in full swing in both ATLAS & CMS

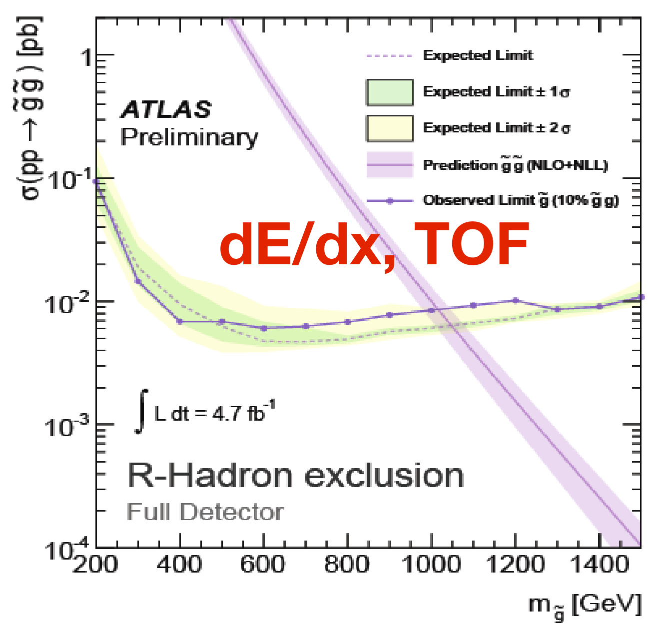
Stopped gluinos & stops decaying during no-beam periods



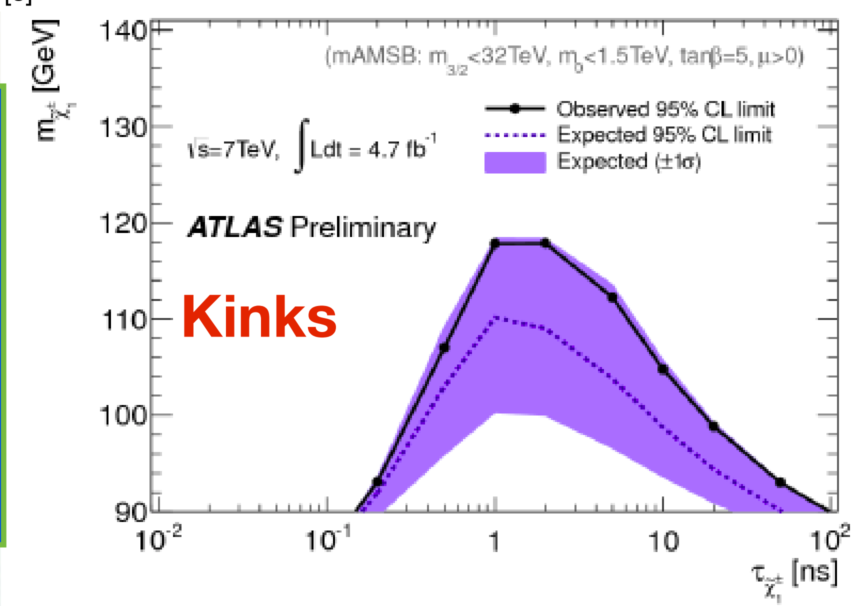
CMS-EXO-11-035



ATLAS-CONF-12-075



ATLAS-CONF-12-034



Workshop Homework List

- Natural SUSY:
  - Do we cover all the territory with the existing searches?
  - What can be gain by smarter data parking and scouting?
  - Precision top cross section measurement
    - How well can it be calculated theoretically?
- Fine-Tuned SUSY:
  - Novel long-lived signatures?
  - Do we have all the triggers in place?
  - Do we cover full lifetime range?
- Other “natural” model searches?
- Higgs Properties:
  - Rare decays
  - Spin-parity determination
  - Looking for other Higgses
- SM measurements as windows on new physics

And now let’s get to Work!