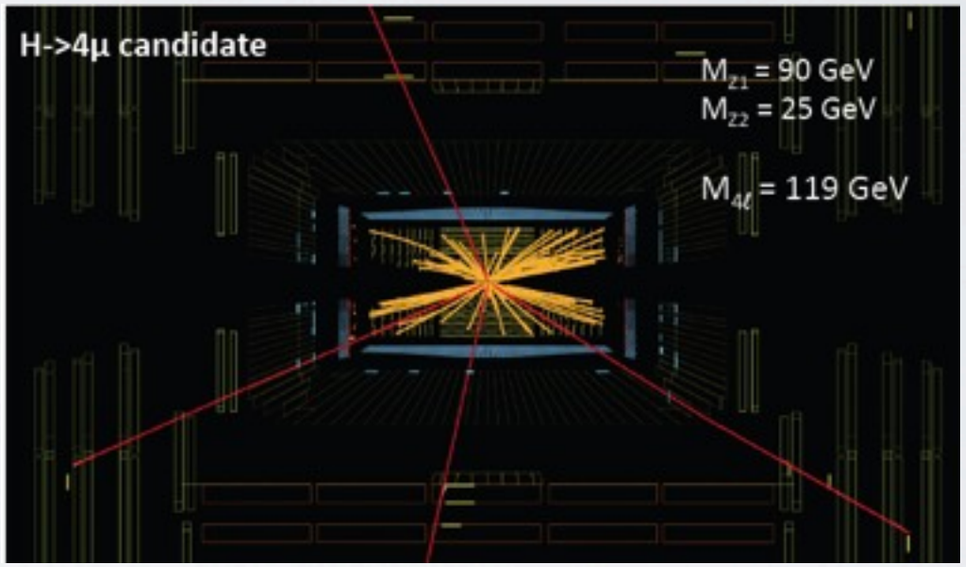
PROSPECTS FOR HIGGS AND BSM FROM RECENT DATA

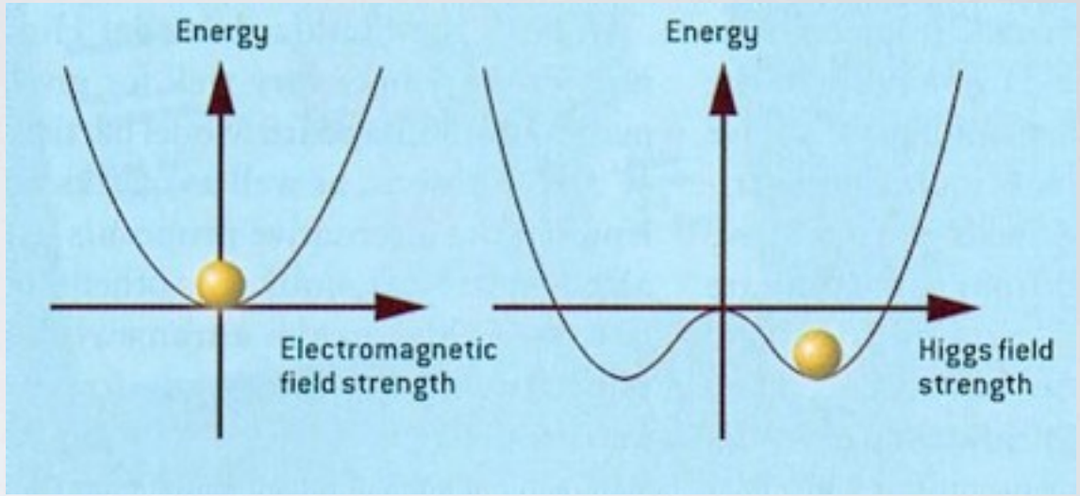


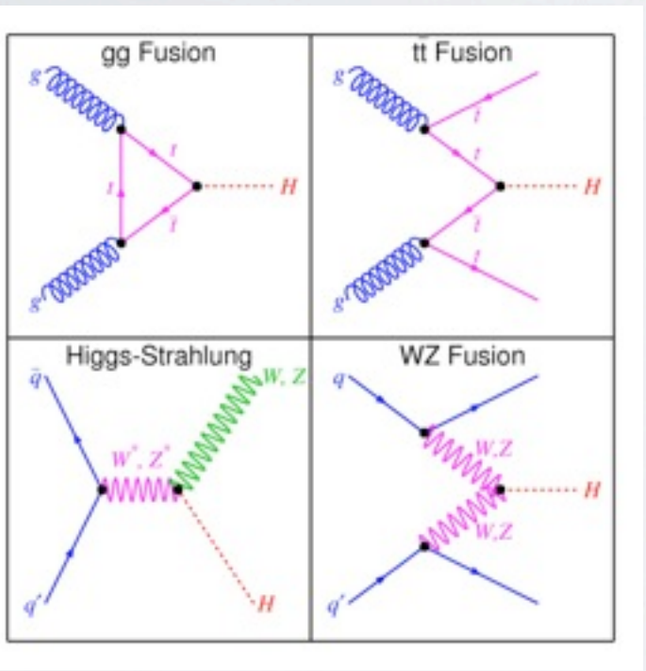
Jürgen R. Reuter, DESY

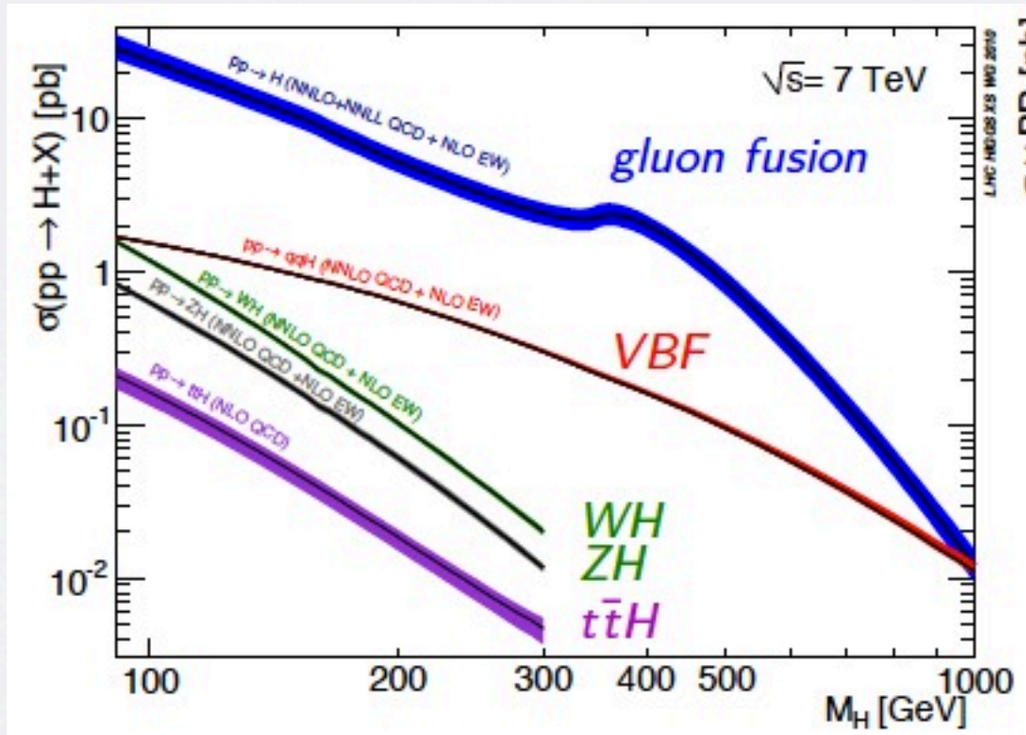
AIDA 1st annual Meeting, DESY 28.3.2012

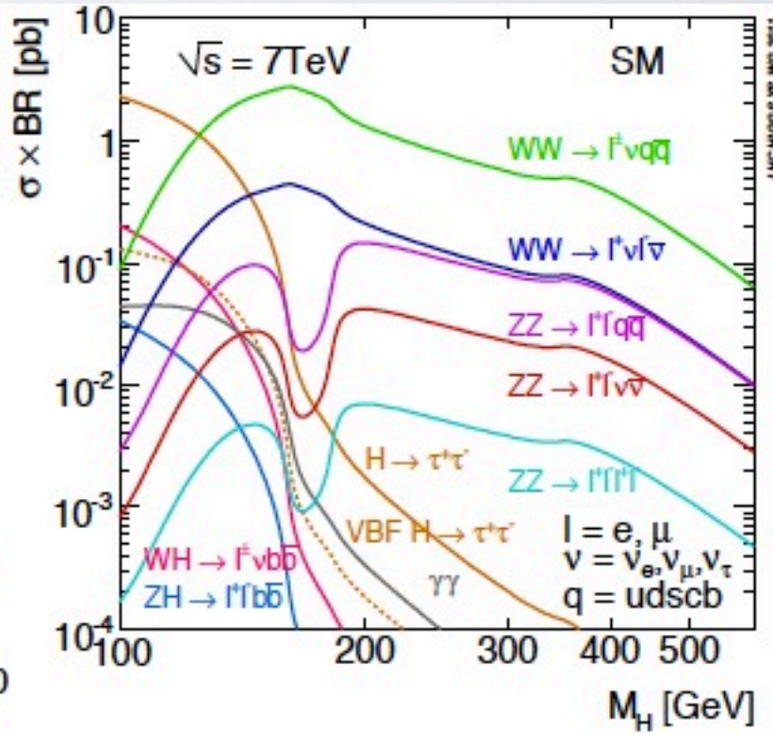
THE BOSON WHICH MUST NOT BE NAMED

- Short-hand: Higgs boson
- Breaks the electroweak symmetry
- Four different production modes at hadron colliders:









HIGGS SEARCH CHANNELS

ATLAS search channels and mass ranges vs. CMS search channels and mass ranges

Channel	m_H range (GeV)	bkgd.	$\mathcal{L}(fb^{-1})$	m_H resolution
$H \to \gamma\gamma$	$110 - 150$	$\gamma\gamma, \gamma j, jj$	4.9	1-2 %
	$110 - 150$		4.8	
$H \to ZZ^{(*)} \to \ell\ell\ell\ell$	$110 - 600$	$ZZ^{(*)}, Z + \text{jets}, t\bar{t}$	4.8	1-2 %
	$110 - 600$		4.7	
$H \to WW^{(*)} \to \ell\nu\ell\nu$	$110 - 600$	$WW^{(*)}, t\bar{t}, W/Z + \text{jets}$	4.7	20 %
	$110 - 600$		4.6	
$H \to \tau\tau$ $(\ell\ell, \ell h, hh)$	$100 - 150$	$Z \to \tau\tau, t\bar{t}$	4.7	20 %
$H \to \tau\tau$ $(\ell\ell, \ell h)$	$110 - 140(5)$		4.5(6)	
$H \to VH, H \to bb$	$110 - 130$	$W/Z + \text{jets}, t\bar{t}$	4.7	10 %
	$110 - 135$		4.7	
$WH \to W(WW^{(*)}) \to 3\ell 3\nu$	$110 - 200$	$W/Z + \text{jets}, t\bar{t}, VVV$	4.6	20 %
$H \to ZZ^{(*)} \to \ell\ell\nu\nu$	$200 - 600$	$VV, t\bar{t}, Z + \text{jets}$	4.7	7 %
	$250 - 600$		4.6	
$H \to ZZ^{(*)} \to \ell\ell jj$	$200 - 600$	$Z + \text{jets}, t\bar{t}, VV$	4.7	3 %
	$130 - 164, 200 - 600$		4.6	
$H \to WW \to \ell\nu jj$	$300 - 600$	$W + \text{jets}, t\bar{t}, \text{multijets}$	4.7	
$H \to ZZ \to \ell\ell\tau\tau$	$190 - 600$	$W/Z + \text{jets}, t\bar{t}, \text{multijets}$	4.7	10-15 %

Test signal strength $\mu = \sigma/\sigma_{SM}$ by profile likelihood ratio

Exclusion limits using on μ at 95 % confidence level with the CL_s method

HIGGS SEARCHES IN ATLAS

FROM S. KORTNER, MORIOND 2012

- Largest excess in $H \to \gamma\gamma$ at 126.5 GeV

  Local significance: 2.8 σ (1.5 σ with Look-Elsewhere Effect)

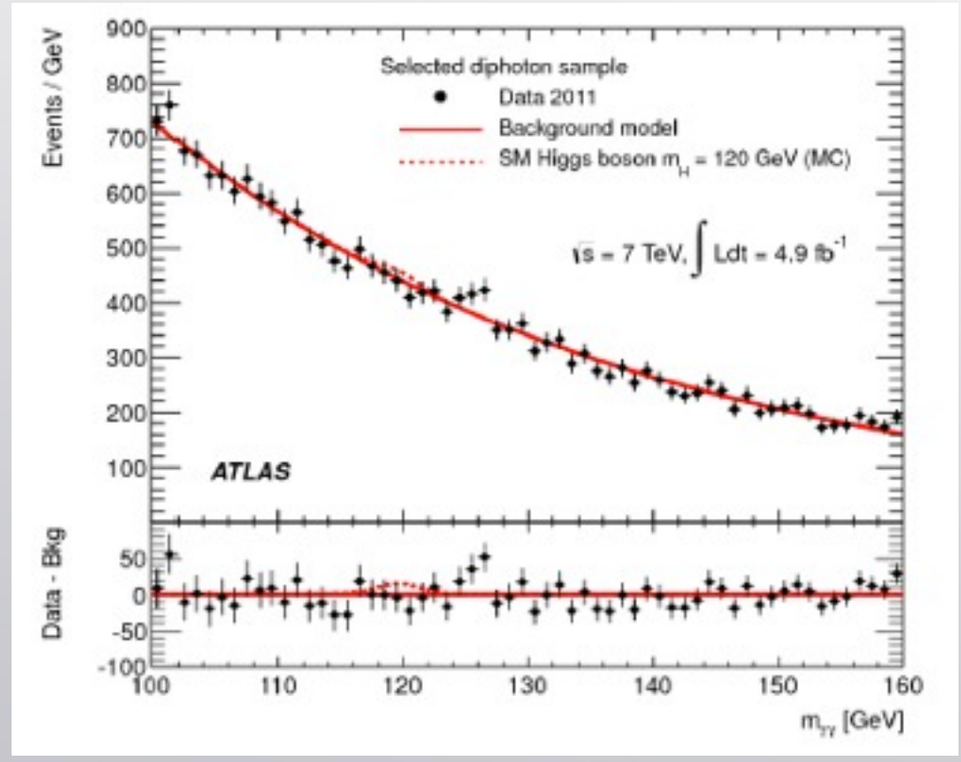
- $H \to WW^* \to \ell\nu\ell\nu$ inconclusive (no real excess)

- $H \to ZZ^* \to \ell\ell\ell\ell$: 3 excesses at 125 GeV, 244 GeV, 500 GeV (2.1-2.2 σ local significance)

Combined exclusion limit:

95% CL: 110-117.5, 118.5-122.5, 129-539 GeV

99% CL: 130-486 GeV



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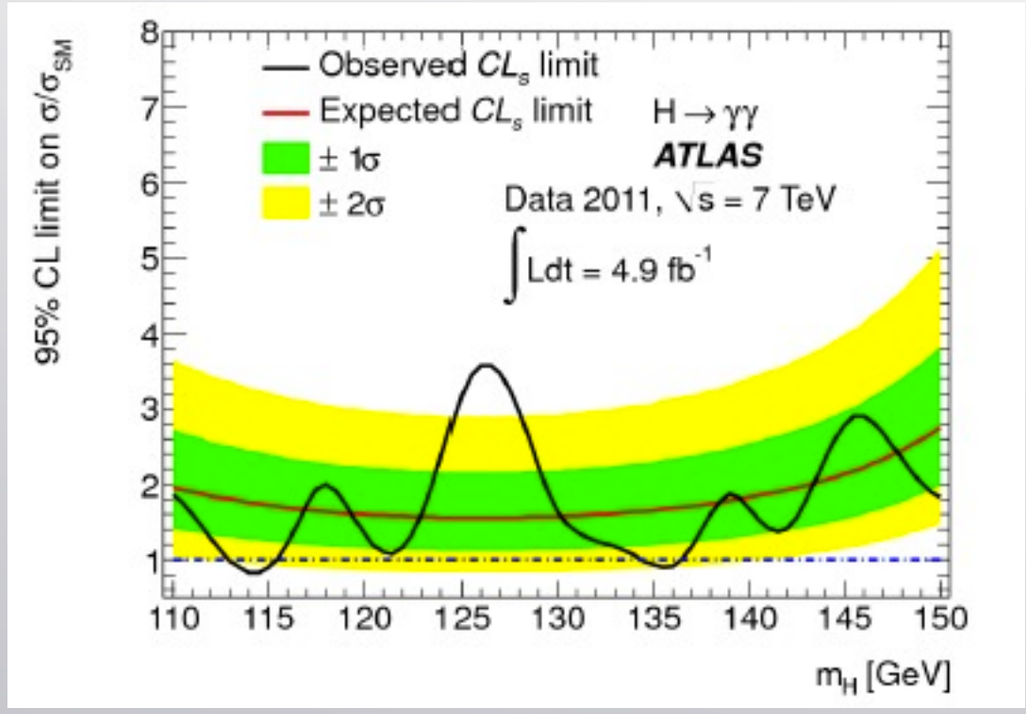

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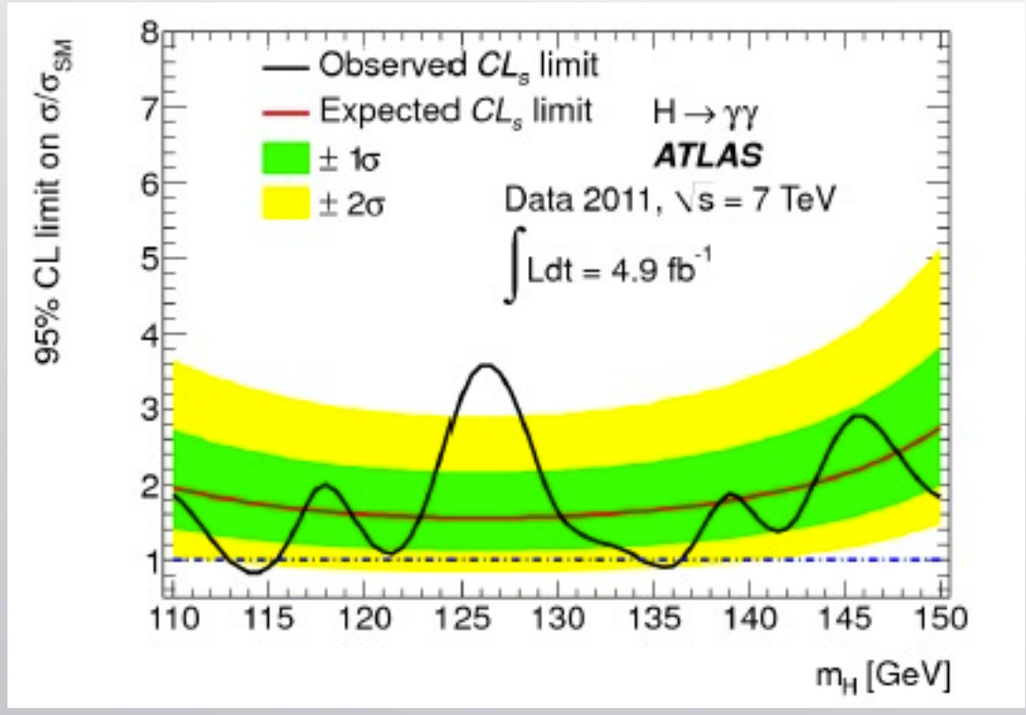

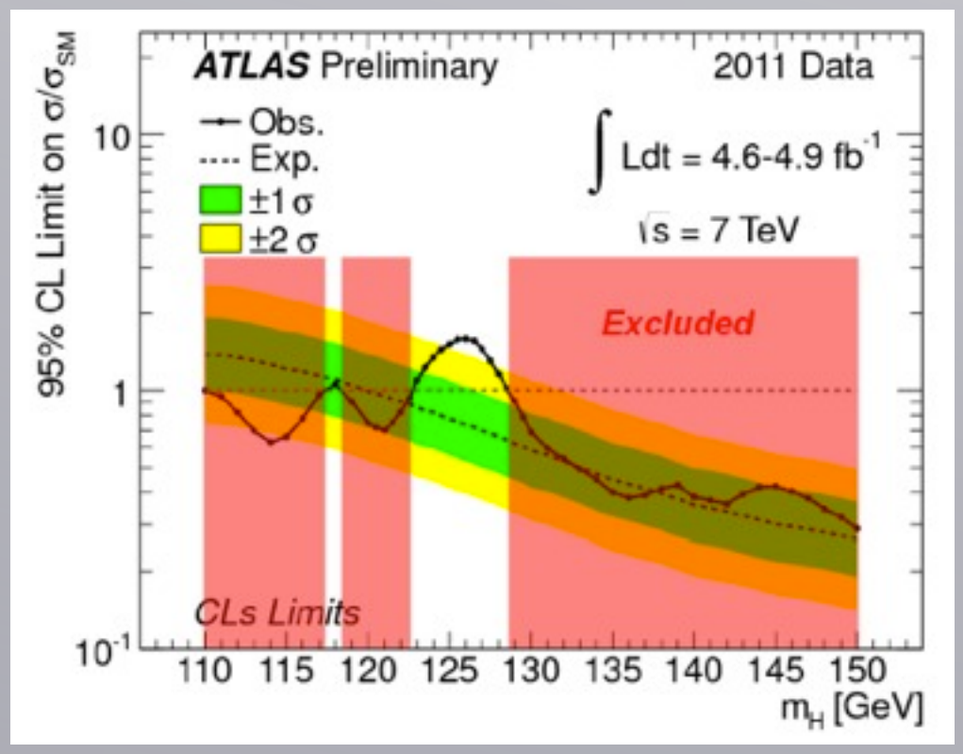

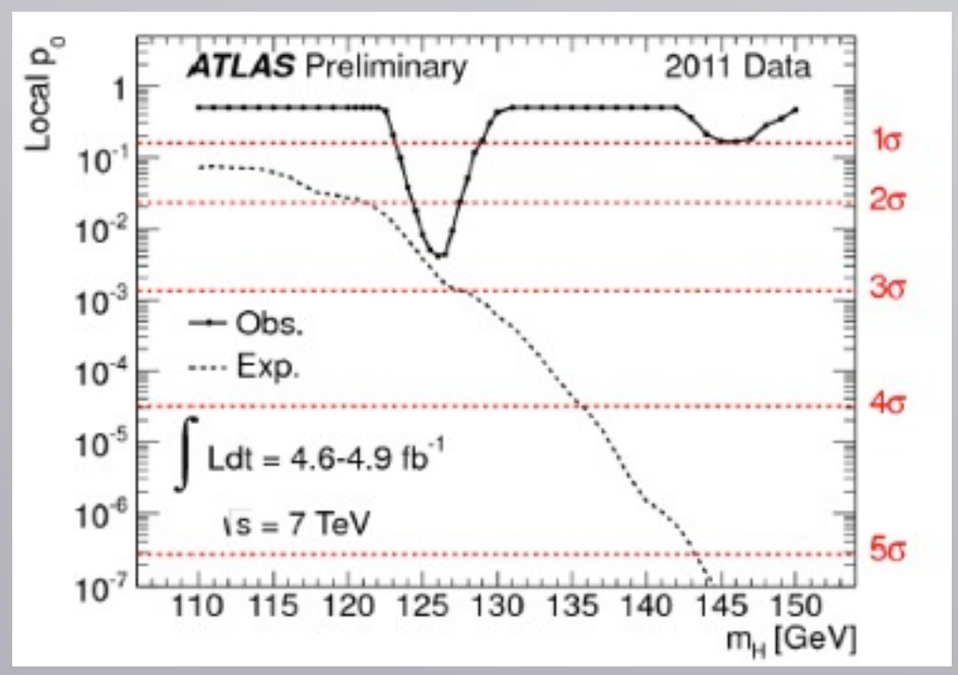

Local significance: 2.5 σ, best fit signal strength $\mu = 0.9^{+0.4}_{-0.3}$

HIGGS SEARCHES IN CMS

FROM M. PIERI, MORIOND 2012

- Largest excess in $H \to \gamma\gamma$ at roughly 125 GeV

  Local significance: 2.9 σ (1.6 σ with Look-Elsewhere Effect)

- Like ATLAS: nothing from $H \to bb, H \to \tau\tau$

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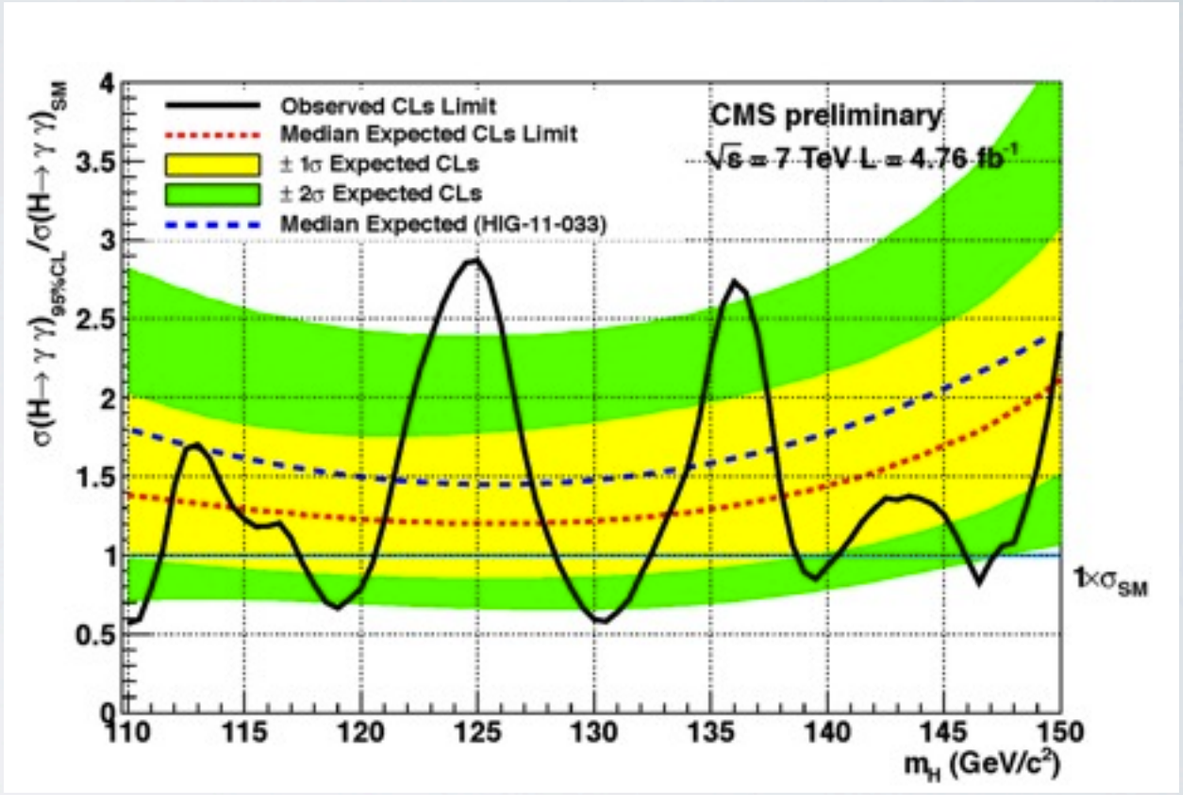

Combined exclusion limit:

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allowed mass range: 114.4 - 127.5 GeV (95% CL)

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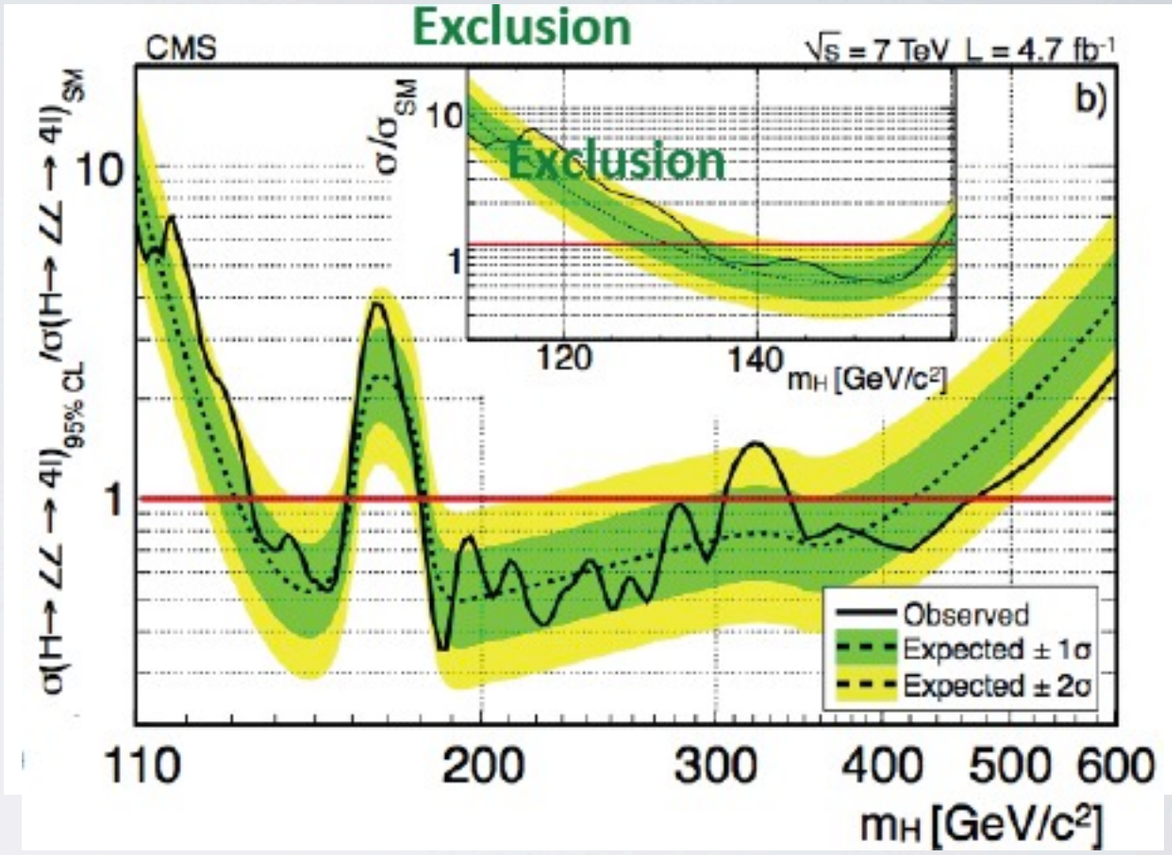

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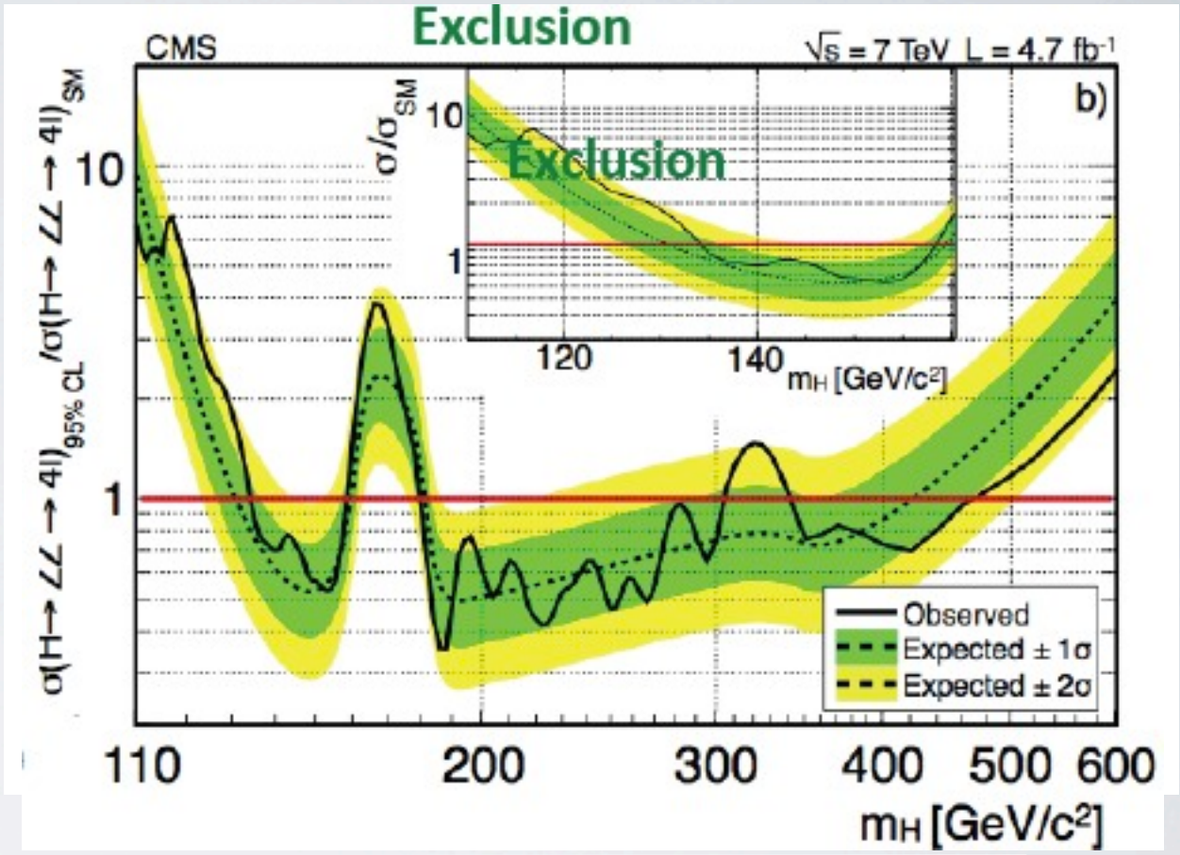

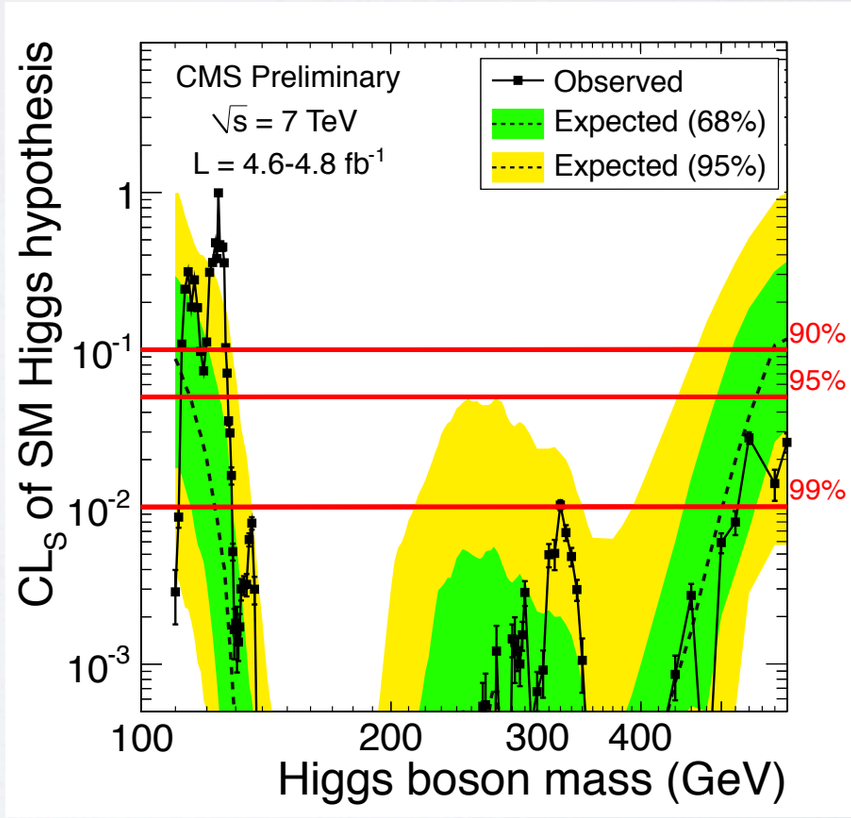

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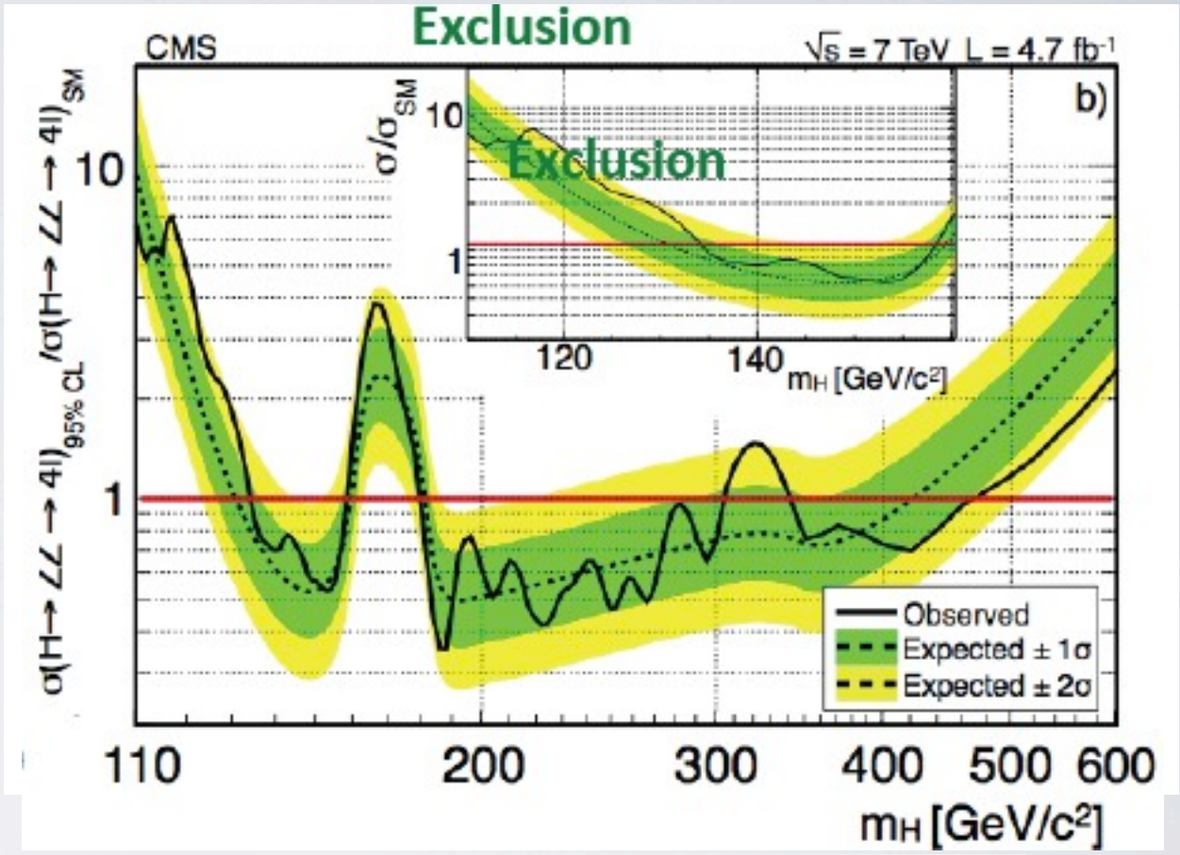

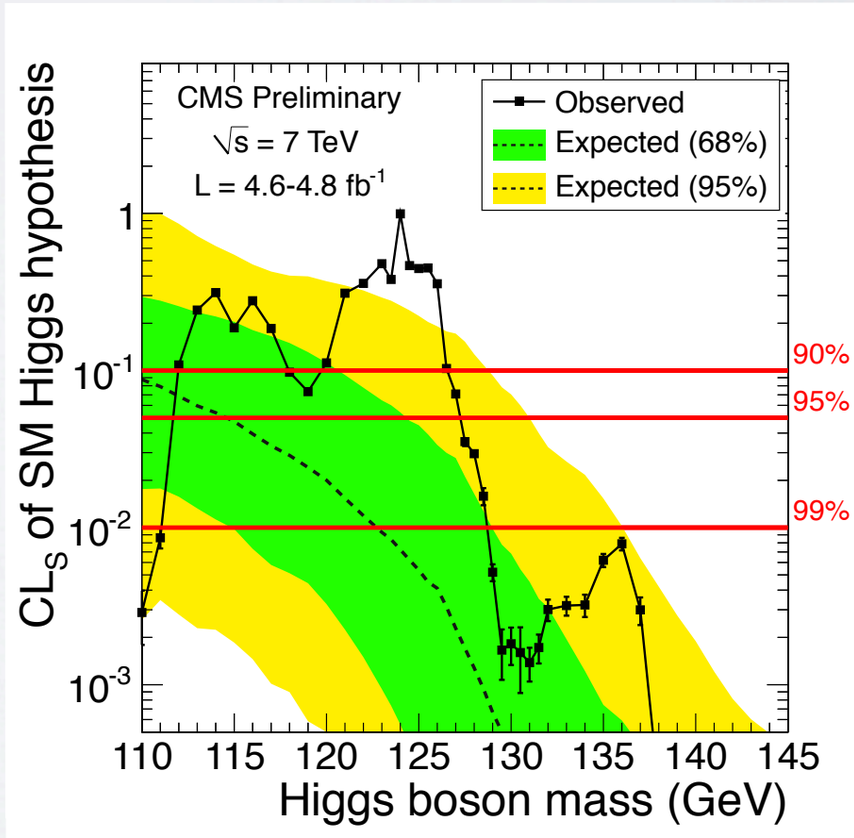

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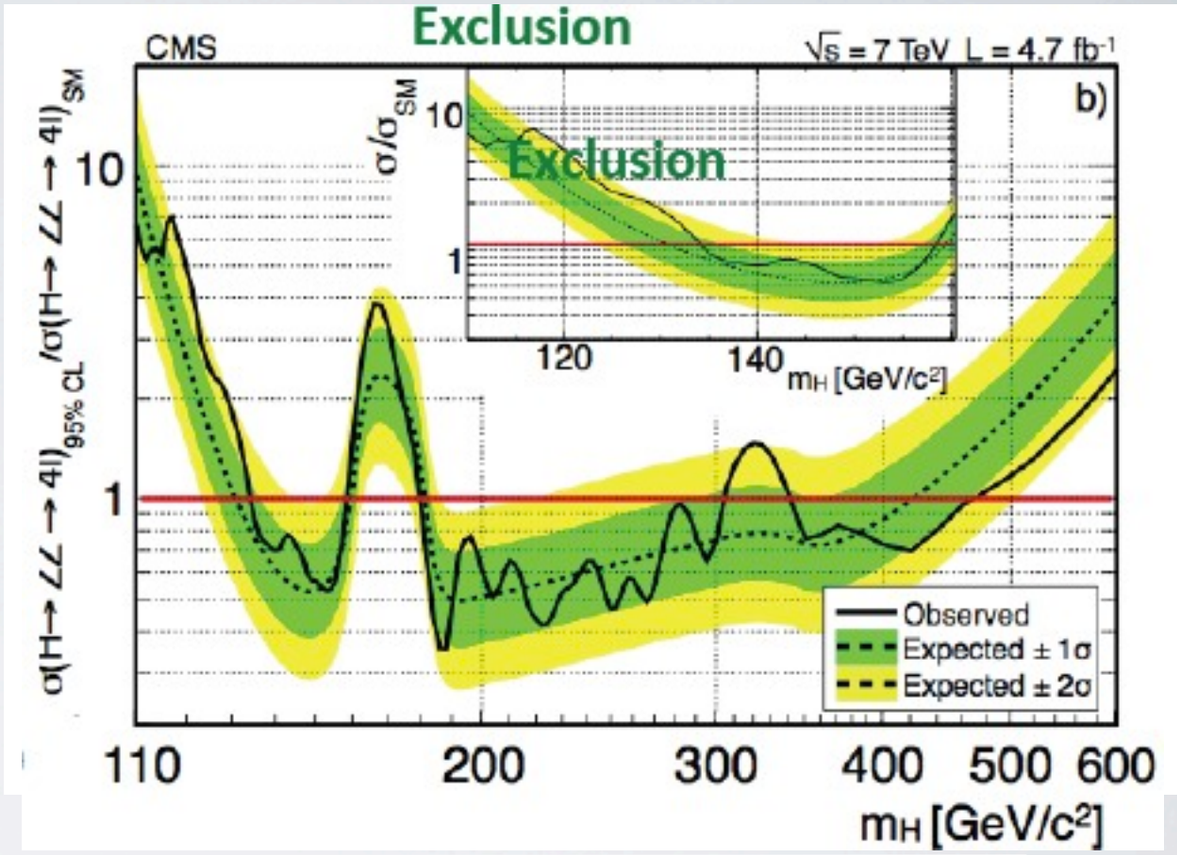

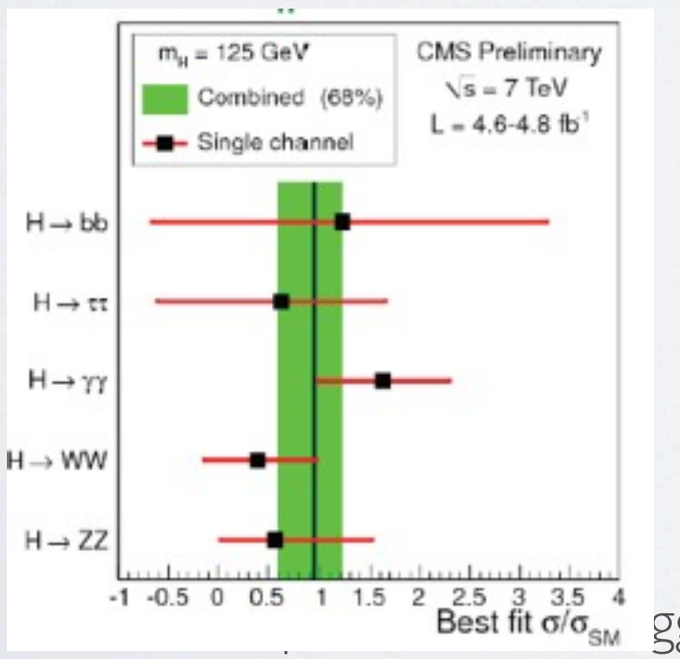

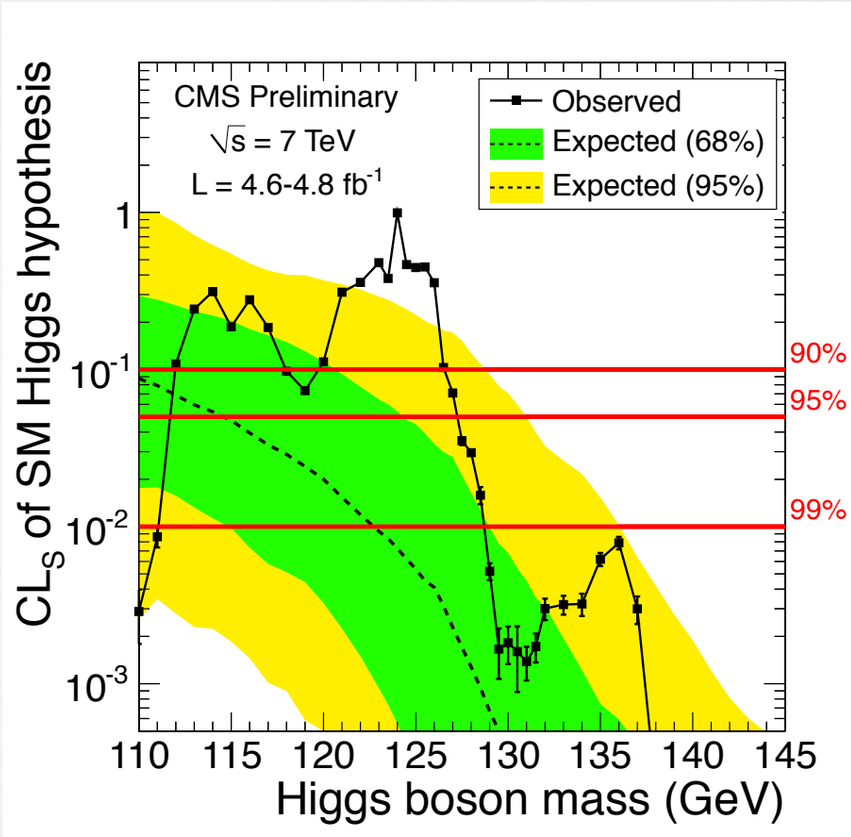

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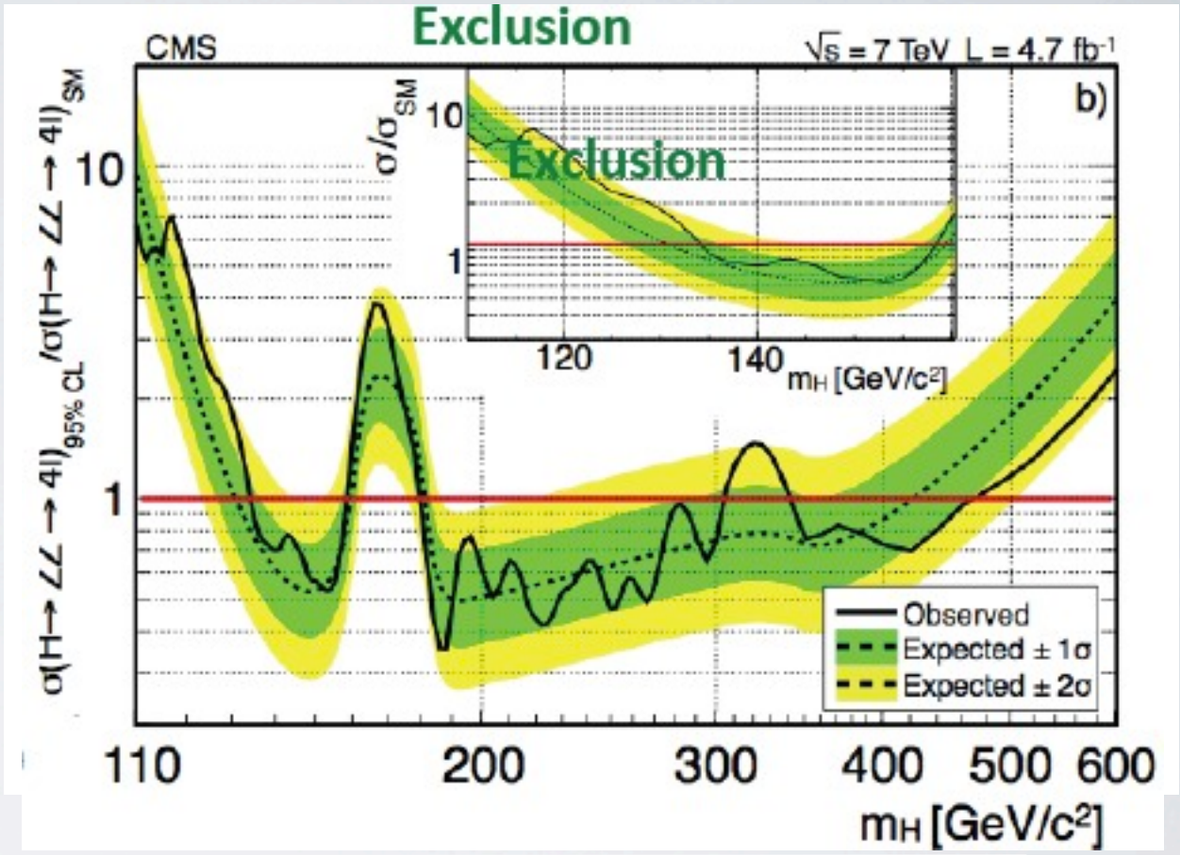
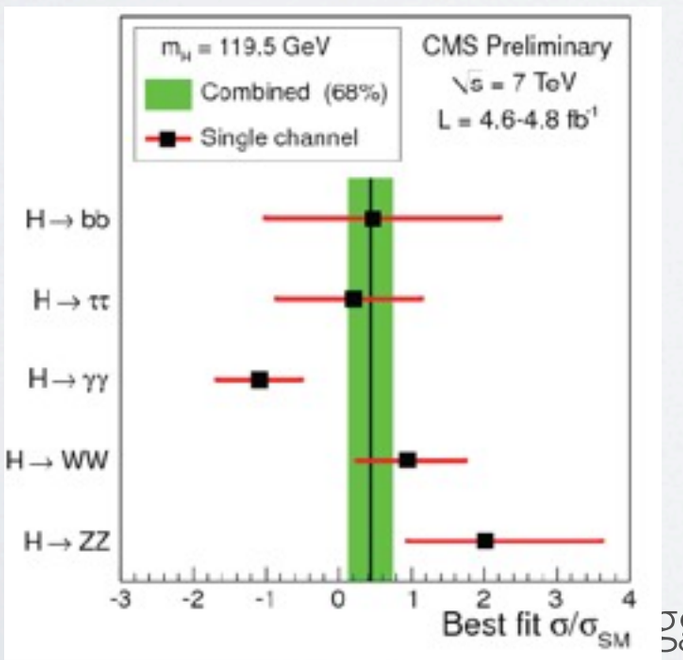
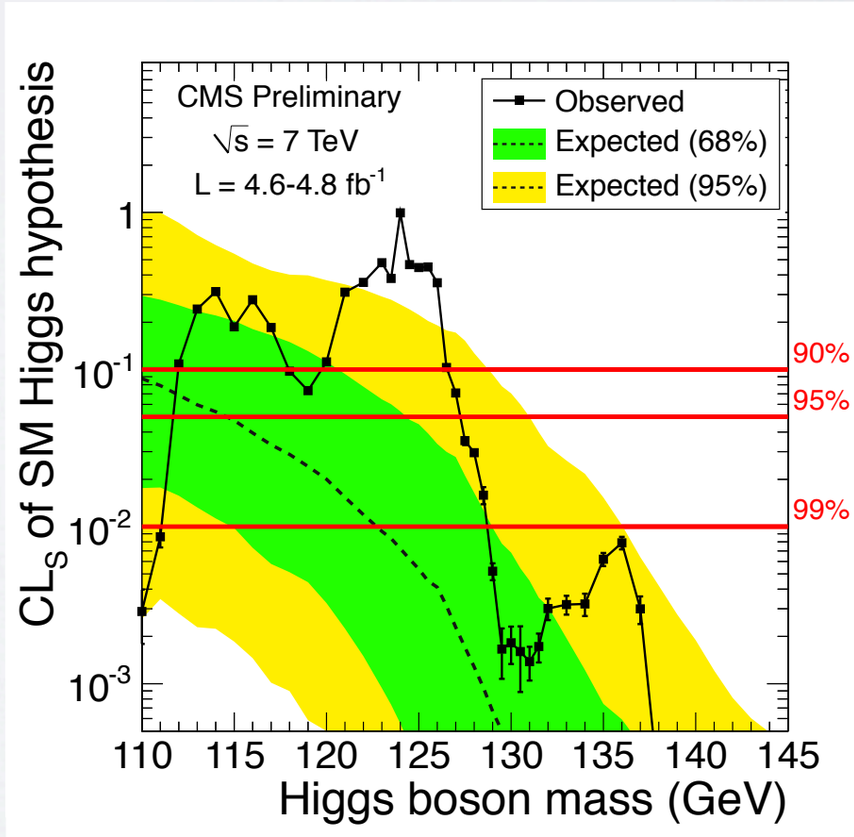
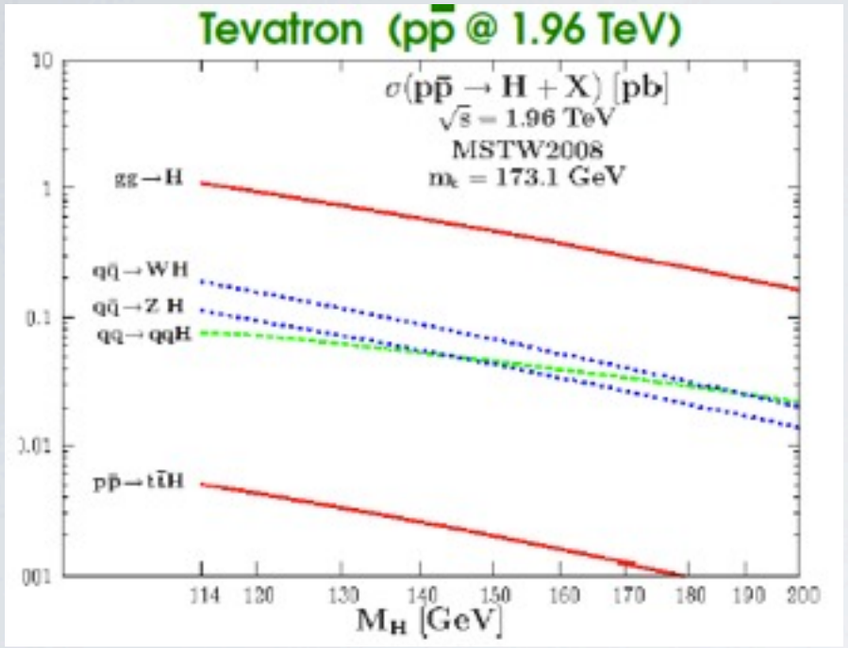


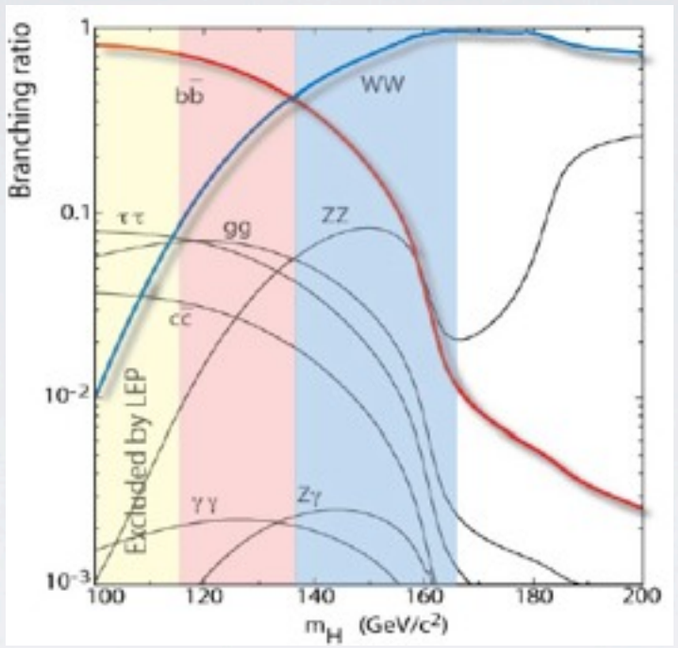


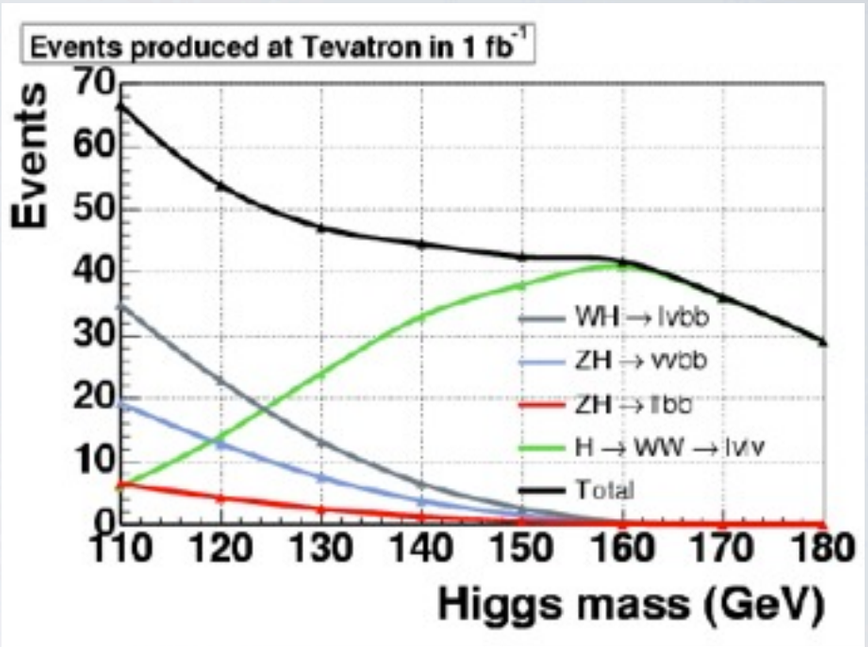


TEVATRON STRIKES BACK

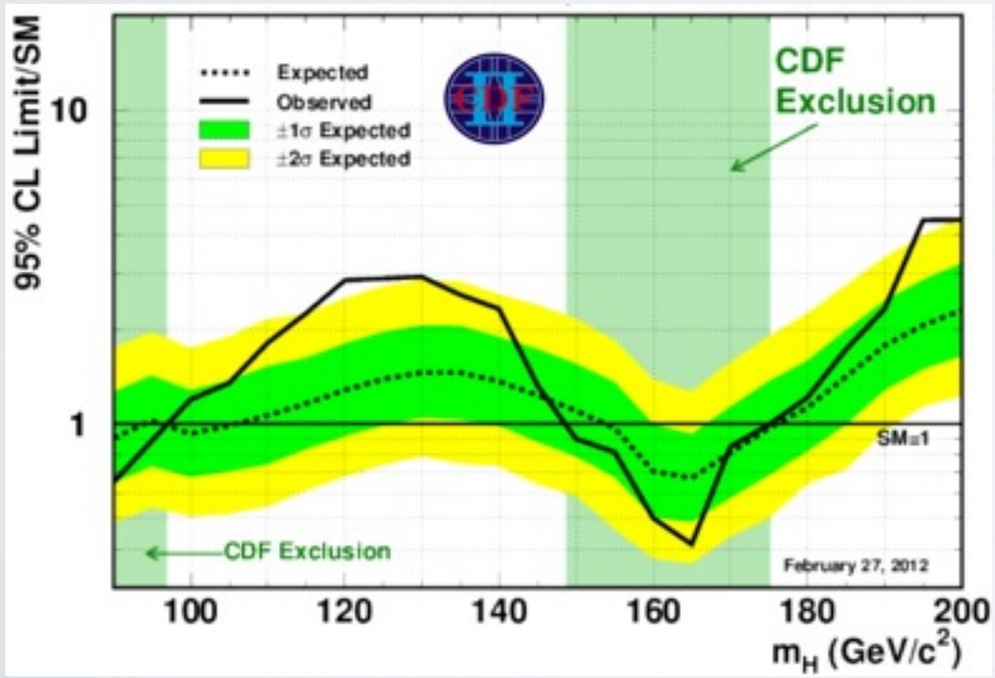
- Two major search channels: $H \to bb$ and $H \to WW$



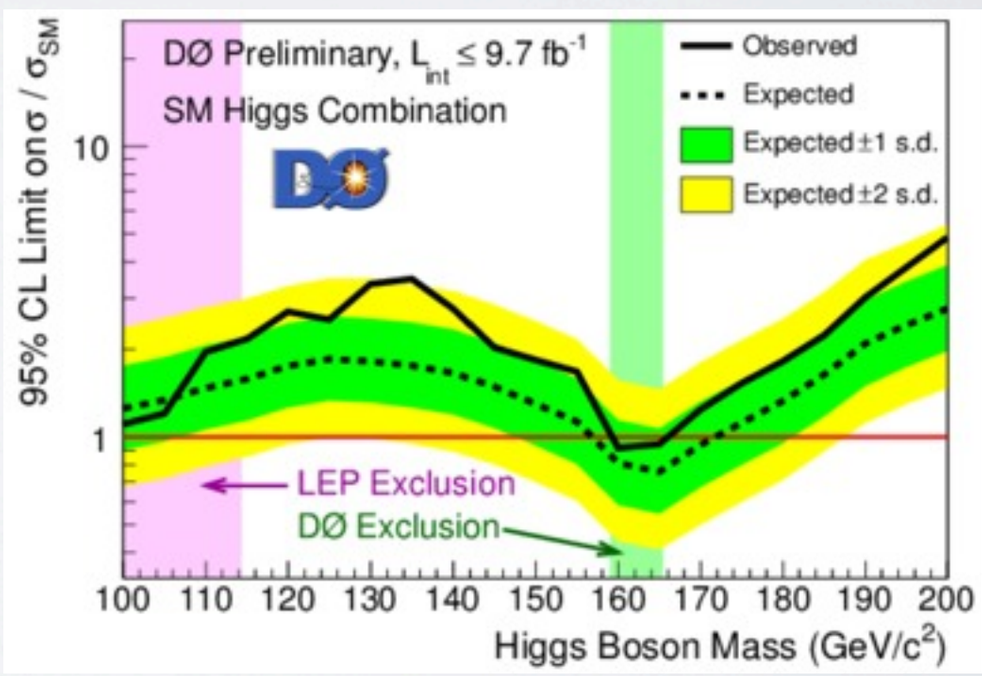




CDF excl. 147 < M(H) < 175 GeV



DØ excl. 159 < M(H) < 166 GeV



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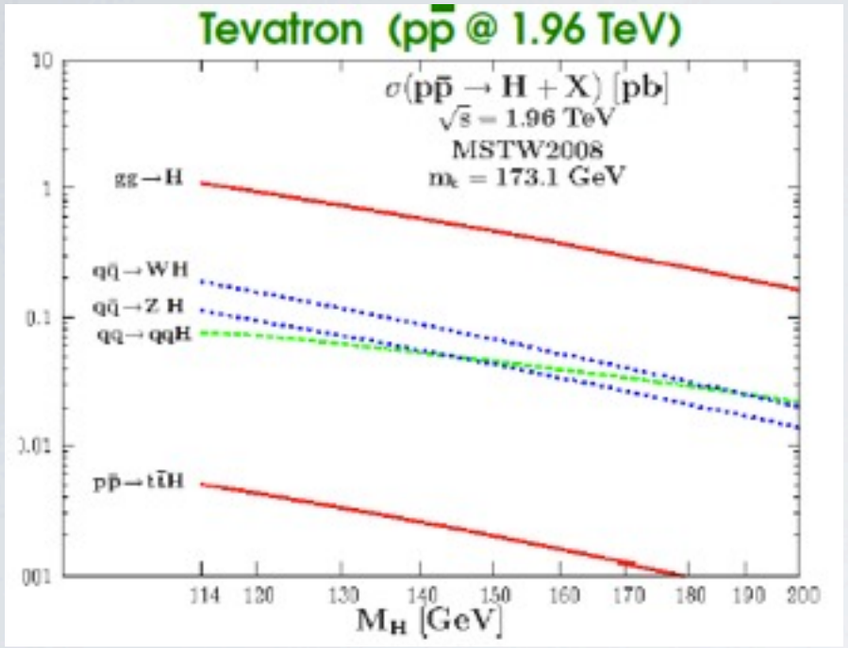

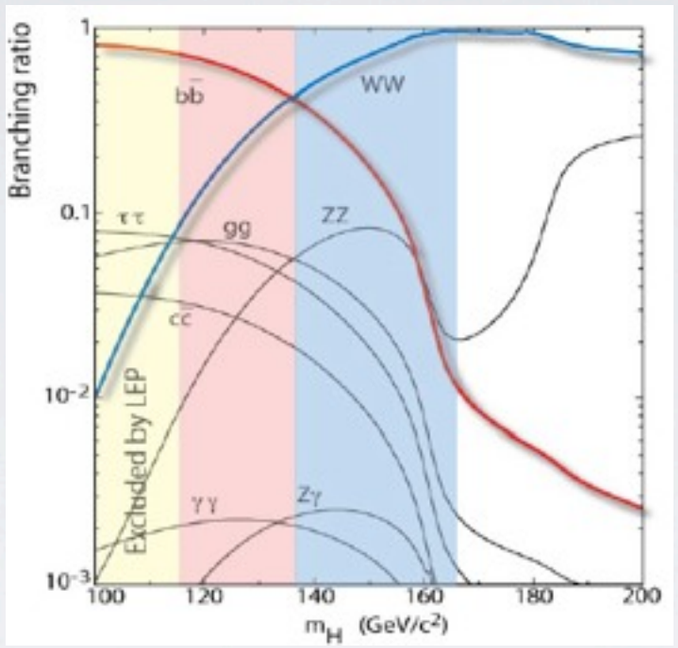

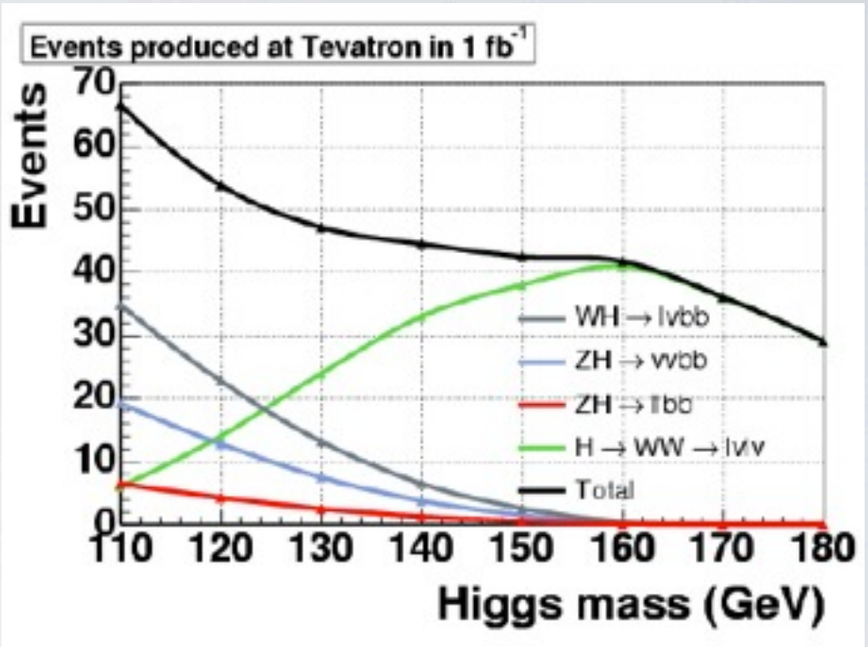

Tevatron combination

- ★ Full dataset 10/fb in almost all channels
- ★ Combined exclusion: 100 - 106 GeV
  147 - 179 GeV (95% CL)
- ★ Broad excess in region 115 - 135 GeV
  2.7 σ local (2.2 σ local)
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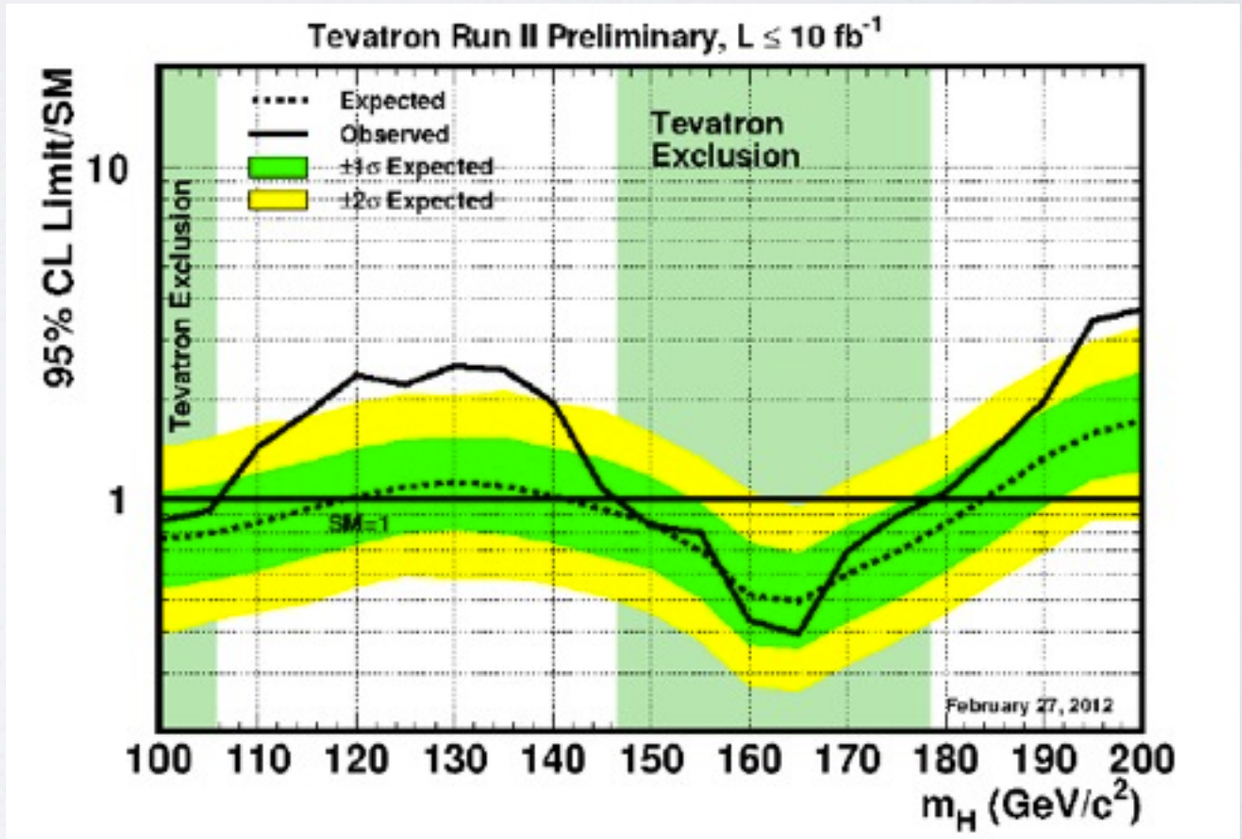

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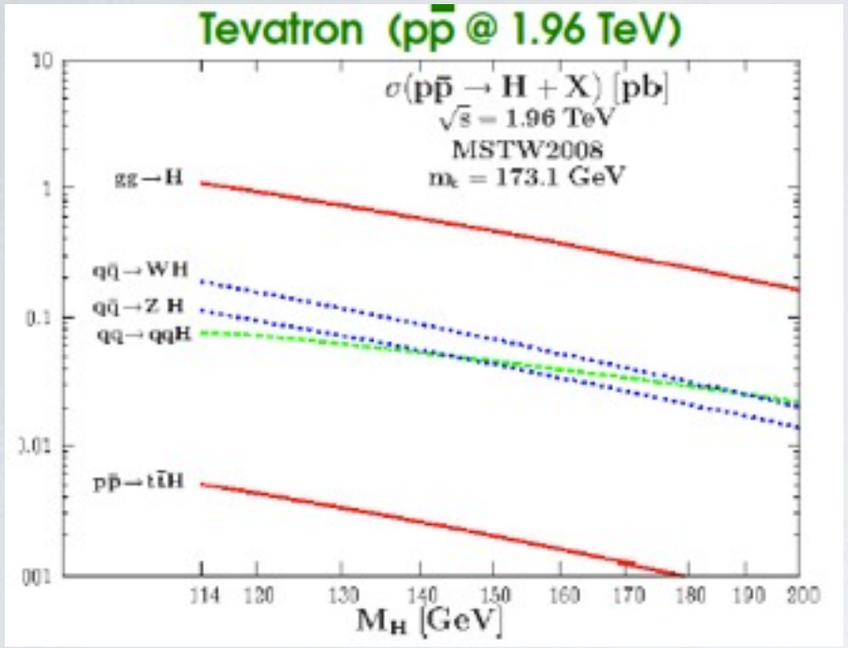

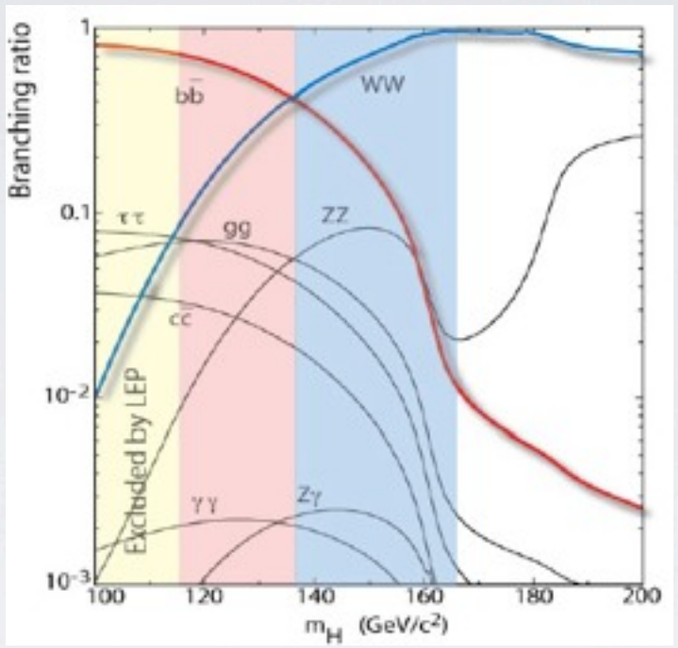

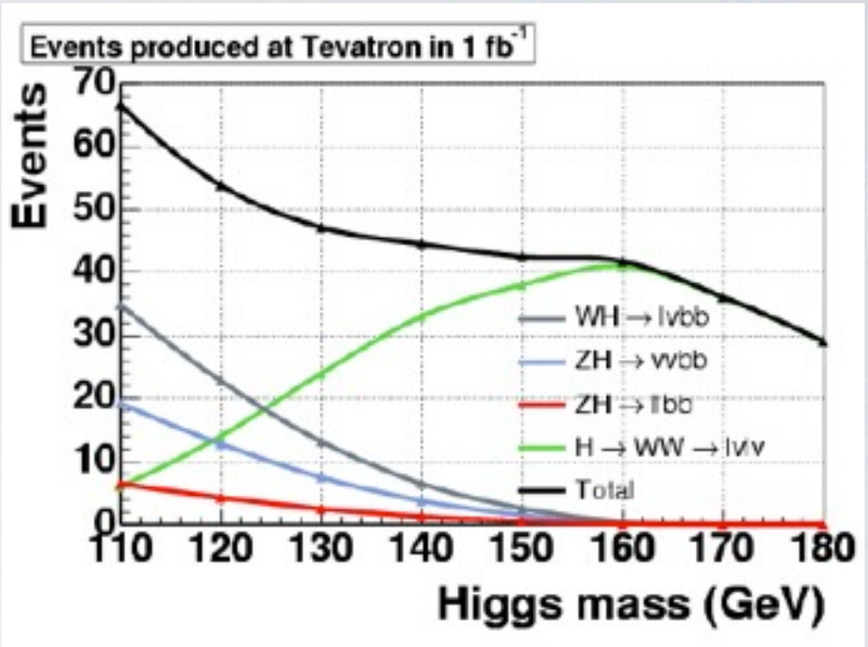

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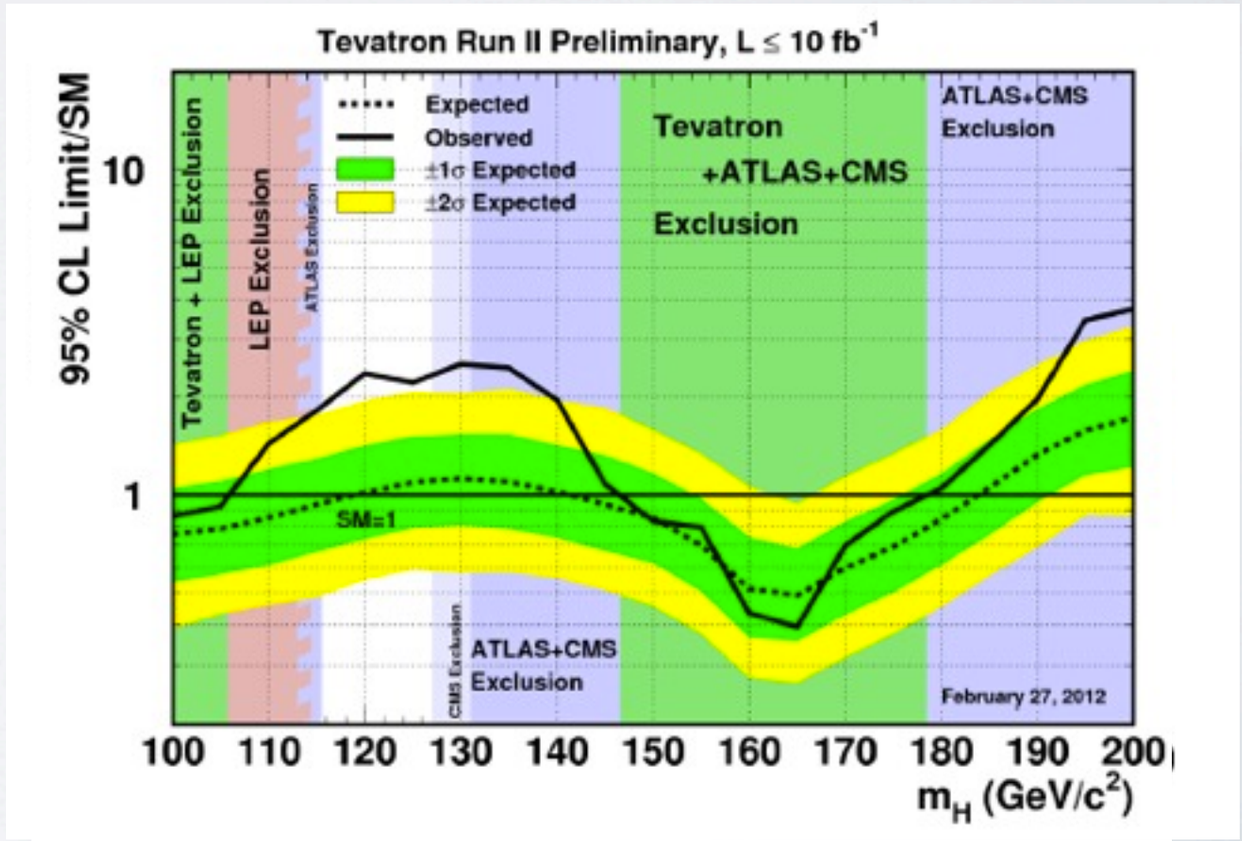
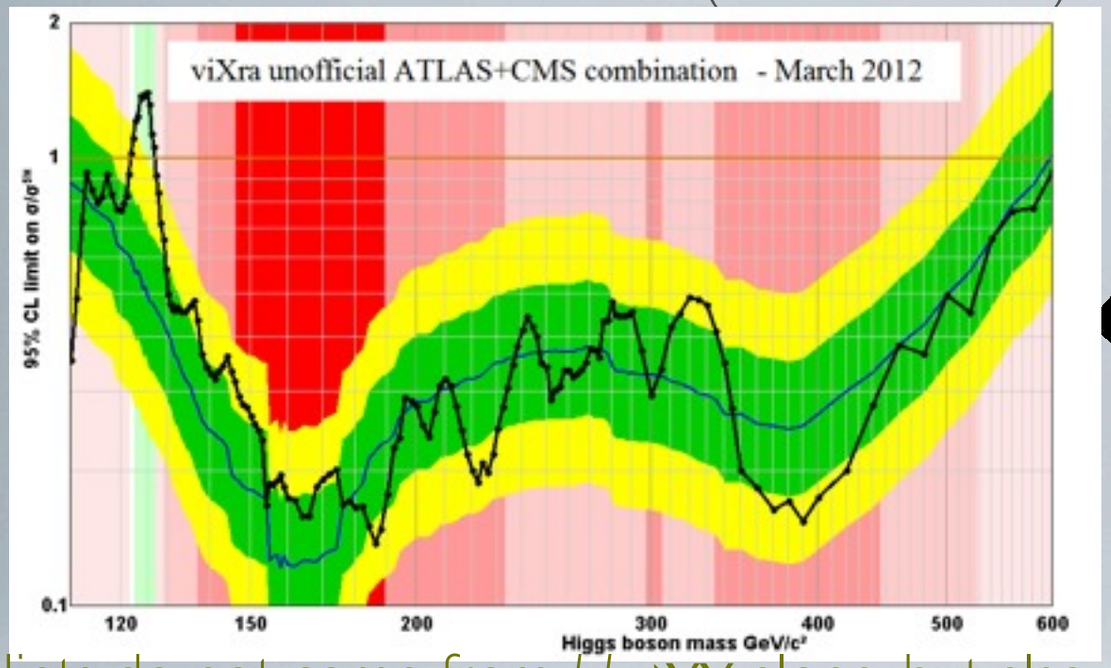
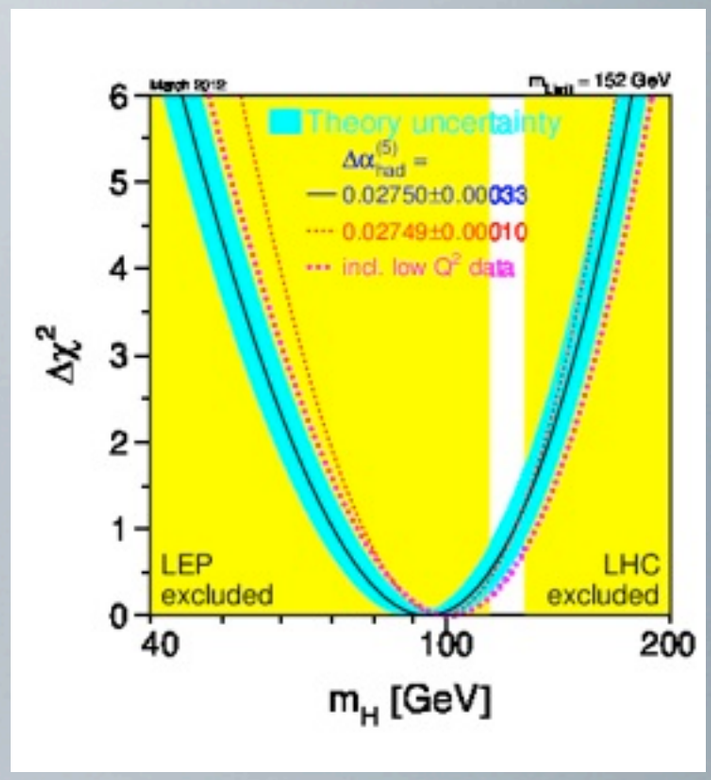


COMBINATION AND INTERPRETATION

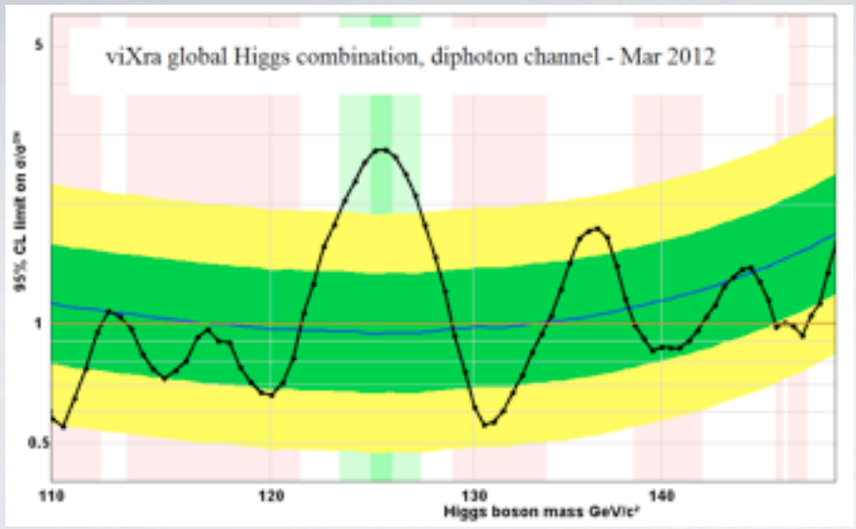
- Allowed region for SM Higgs boson: 117.5-118.5 or 122.5-127.5 GeV (95% CL)
- Expected exclusion roughly: 120 - 555 GeV (ATLAS) 114.5-543 GeV (CMS)

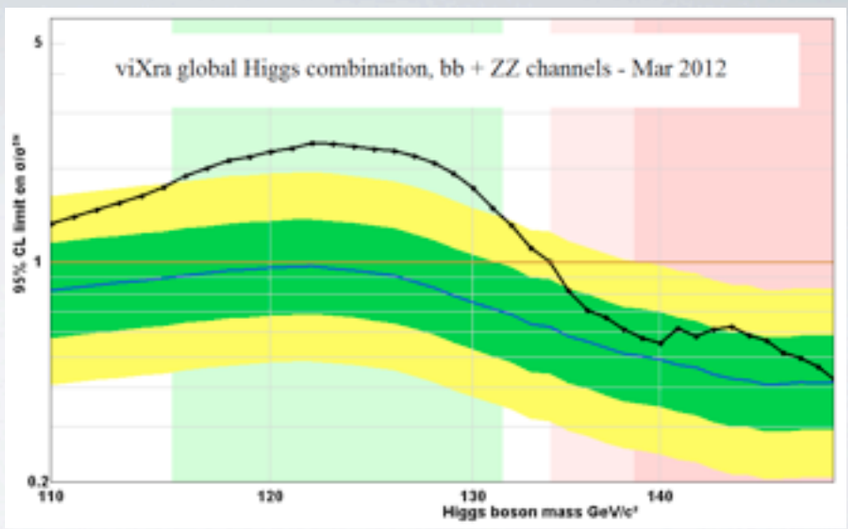
- What did we expect? ..... Well, exactly what we see? Don't we?
- Inofficial combination of two (and even four) experiments





- Hints do not come from $H \to \gamma\gamma$ alone, but also $H \to bb$ and $H \to ZZ \to llll$: [blog.vixra.org]

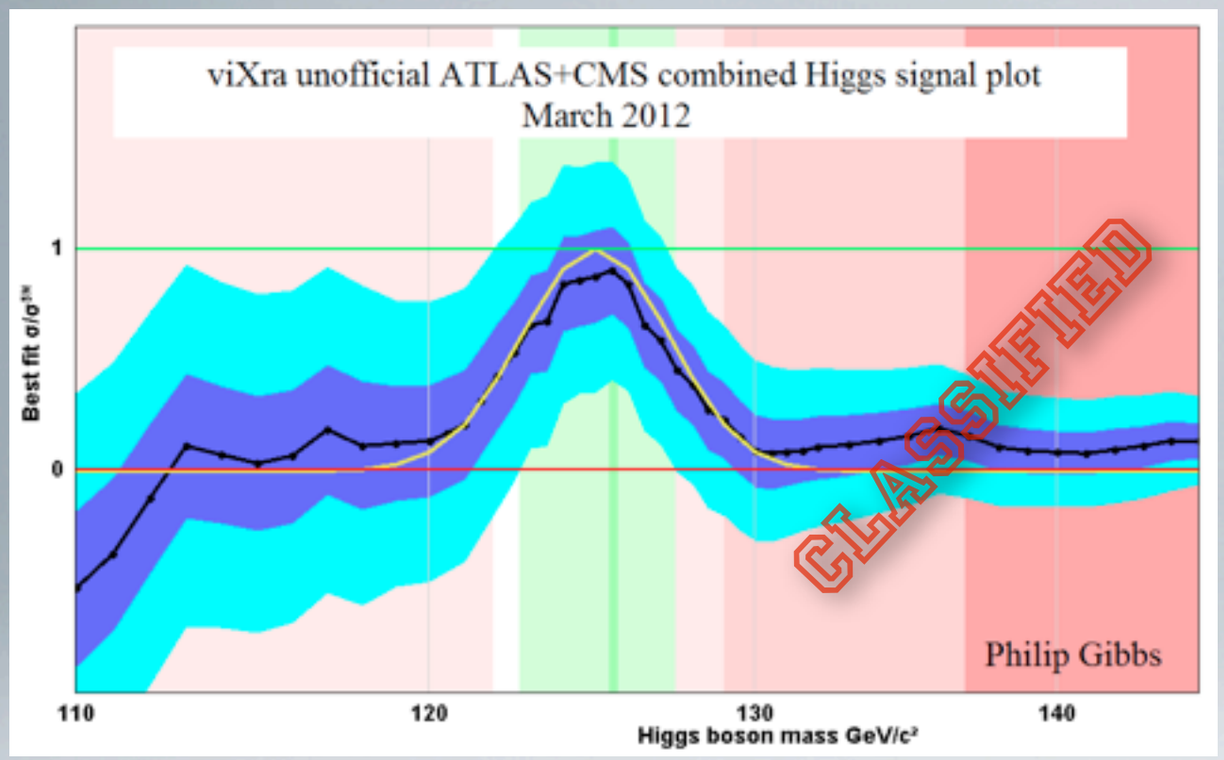


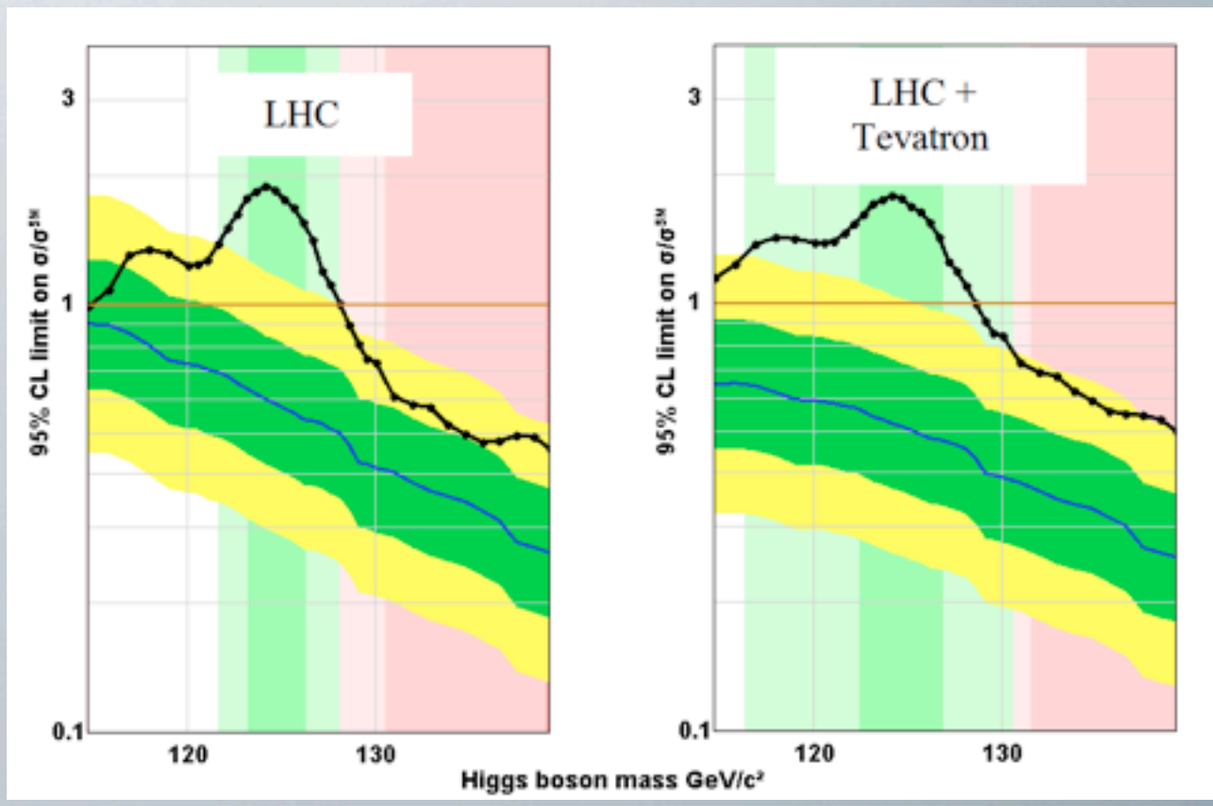


COMBINATION AND INTERPRETATION

- Tevatron shifts the excess a teeny bit upwards:

Very compelling picture: All (?) looks like SM Higgs





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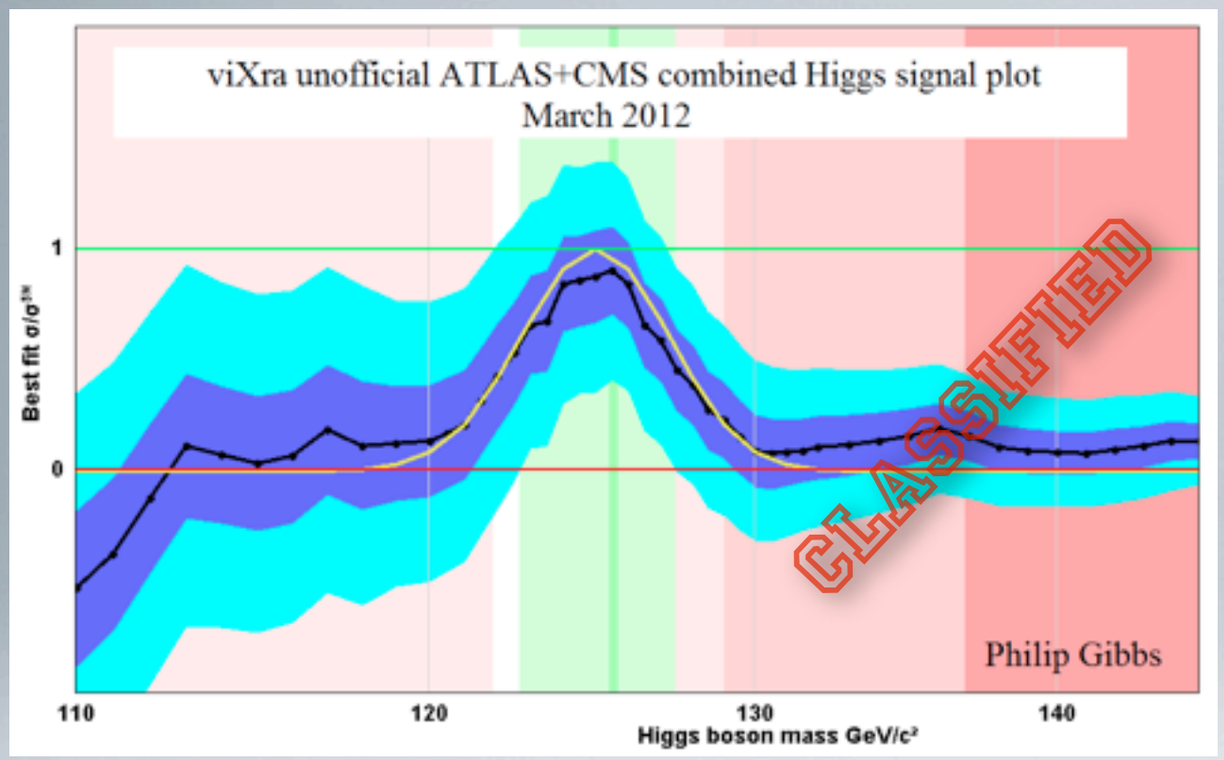
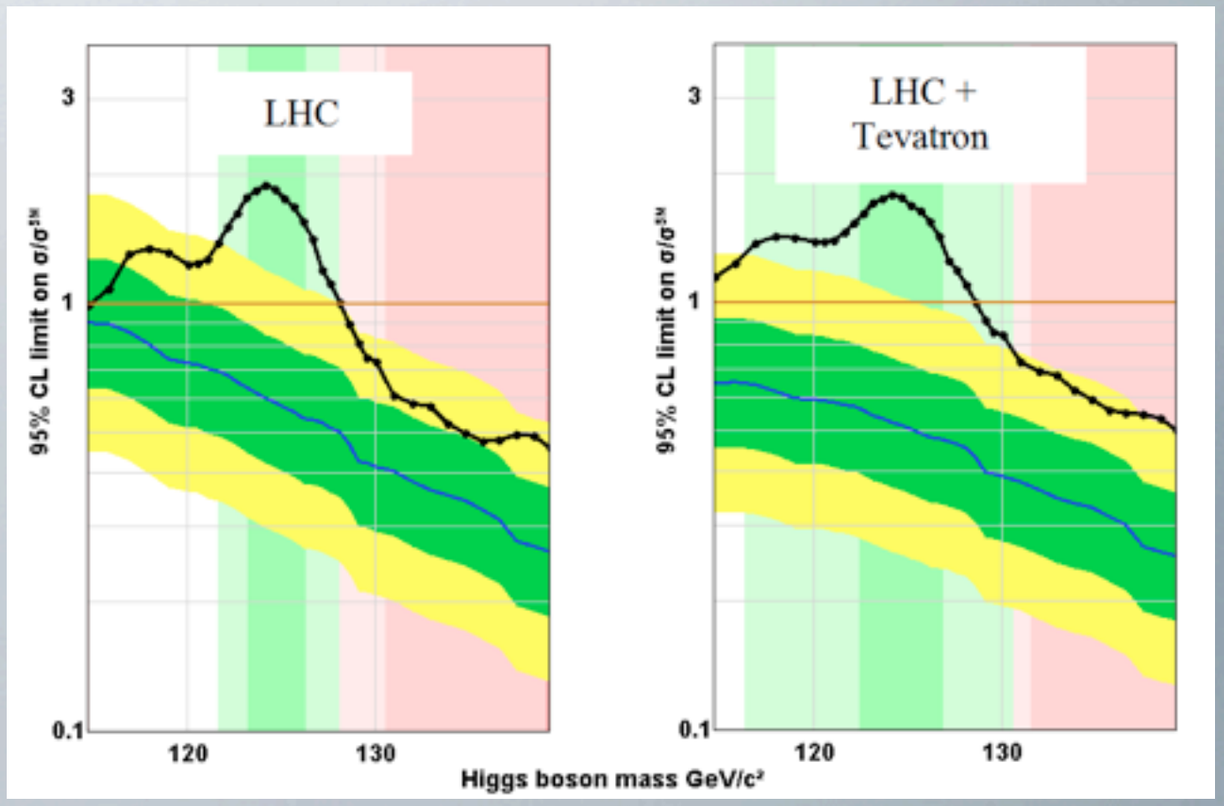
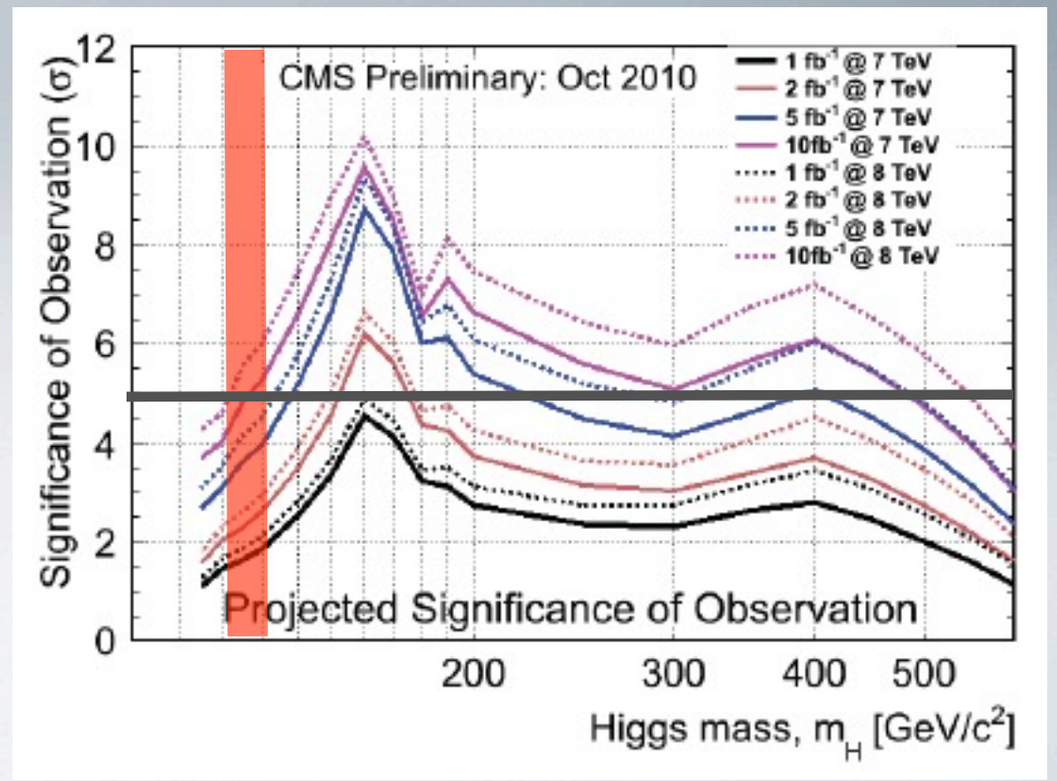






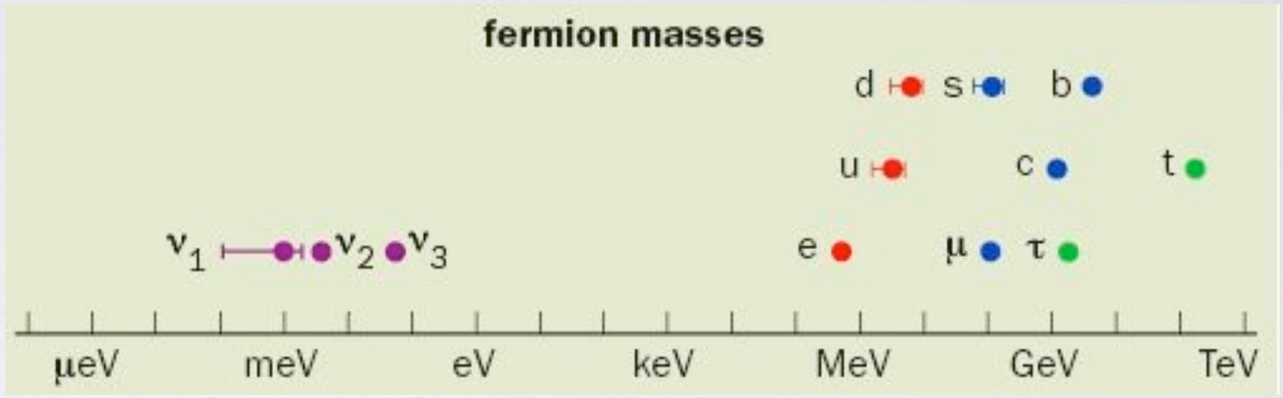
* BEWARE: STILL COMPATIBLE WITH BACKGROUND
* 2012 decisive year (and 8 TeV might be helpful)

BEYOND THE STANDARD MODEL

The Quest for the known and unknown Unknowns …

THE STANDARD MODEL - DOUBTS

- describes microcosm (too good?)
- 28 free parameters



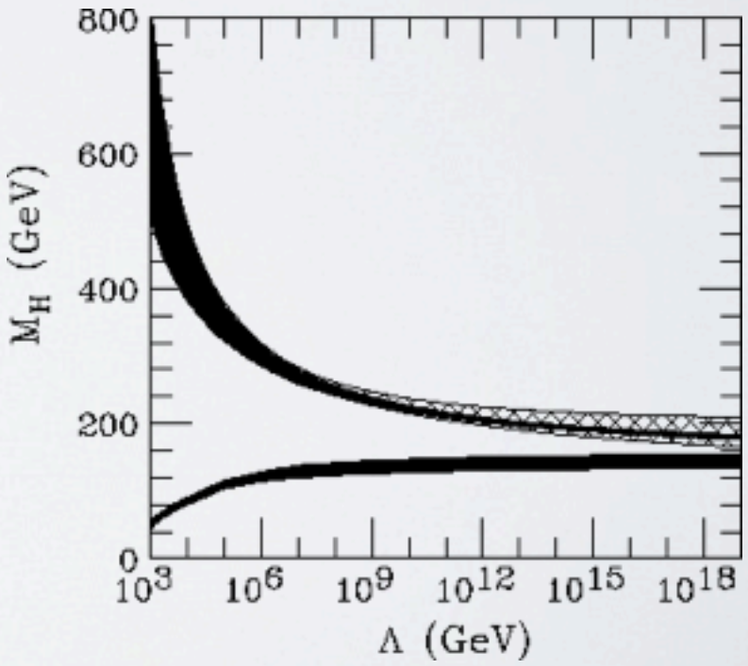
- Form of the Higgs potential?

HIERARCHY PROBLEM

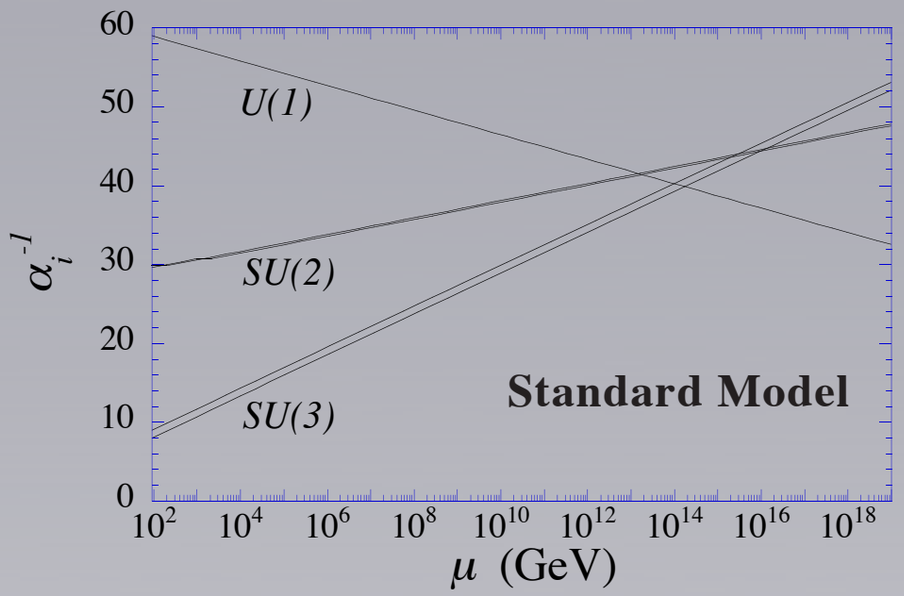
- chiral symmetry:
- no symmetry for quantum corrections to the Higgs mass:

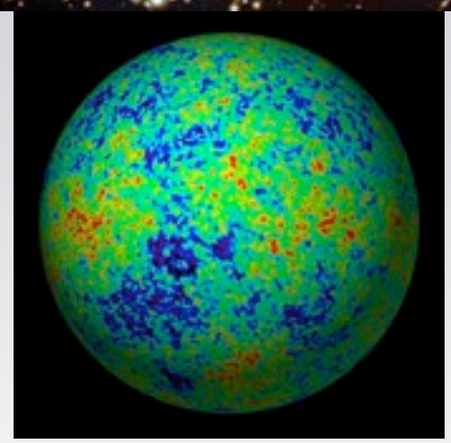
$$\boxed{\delta M_H^2 \propto \Lambda^2 \sim M^2_{\text{Planck}} = (10^{19})^2\,\text{GeV}^2}$$

$$20000\ \text{GeV}^2 = (\ 10000000000000000000000000000020000 - 10000000000000000000000000000000000\ )\ \text{GeV}^2$$



- Unification of all Interactions
- Baryon asymmetry $\Delta N_B - \Delta N_{\bar{B}} \sim 10^{-9}$
  (missing CP violation)
- Flavor (three generations)
- Tiny neutrino masses: $m_\nu \sim \frac{v^2}{M}$
- Dark Matter
  - stable particle
  - weakly interacting
  - $m_{DM} \sim 100\ \mathrm{GeV}$
- Quantum Theory of Gravity
- Cosmic Inflation
- Cosmological Constant





THE THEORY ANSWER

THE THEORY ANSWER

IDEAS FOR NEW PHYSICS (SINCE 1970)

(1) SYMMETRY FOR ELIMINATION OF QUANTUM CORRECTIONS

- SUPERSYMMETRY: Spin-statistics → Corrections of particles of like statistics cancel each other
- LITTLE HIGGS/TWIN HIGGS: Global symmetries → Corrections of particles of like statistics cancel each other

(2) NEW BUILDING BLOCKS, NEW SUBSTRUCTURE

- TECHNICOLOR/TOPCOLOR/SILH: Higgs a bound state of new strongly interacting particles (with new strong interactions)

(4) NON-TRIVIAL SPACETIME ELIMINATES HIERARCHY

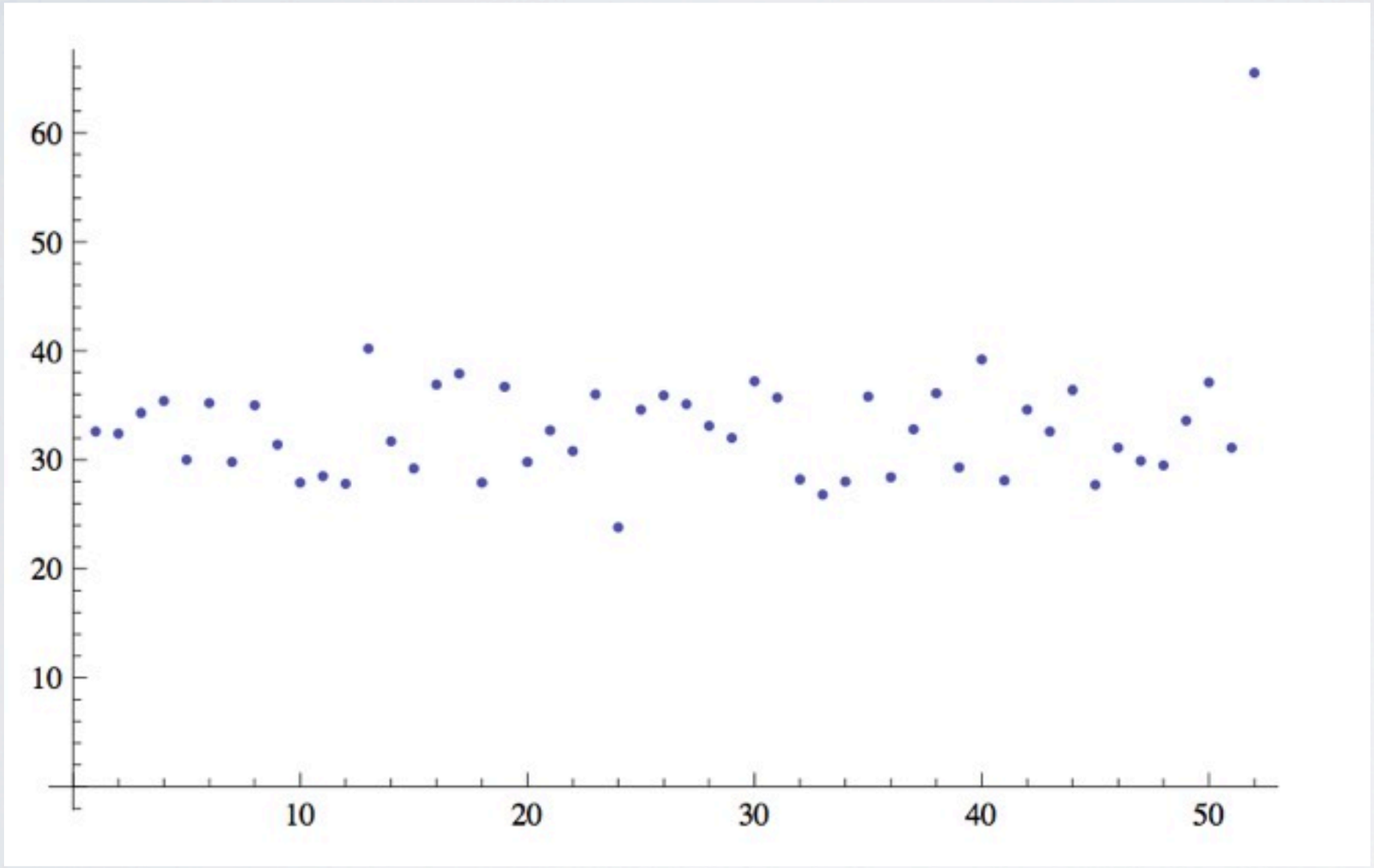
- ADDITIONAL SPACE DIMENSIONS: Gravity appears only weak
- WARPED SPACE DIMENSIONS: Geometric interpretation of hierarchy
- NON-COMMUTATIVE SPACE-TIME: Space-Time coarse-grained

(5) IGNORING THE HIERARCHY (RESISTANCE IS FUTILE!)

- THE A-WORD PRINCIPLE: Values are the way they are, *because* we (can) observe them!

HOW DOES A SIGNAL LOOK LIKE?

M. PERELSTEIN, 3/2012



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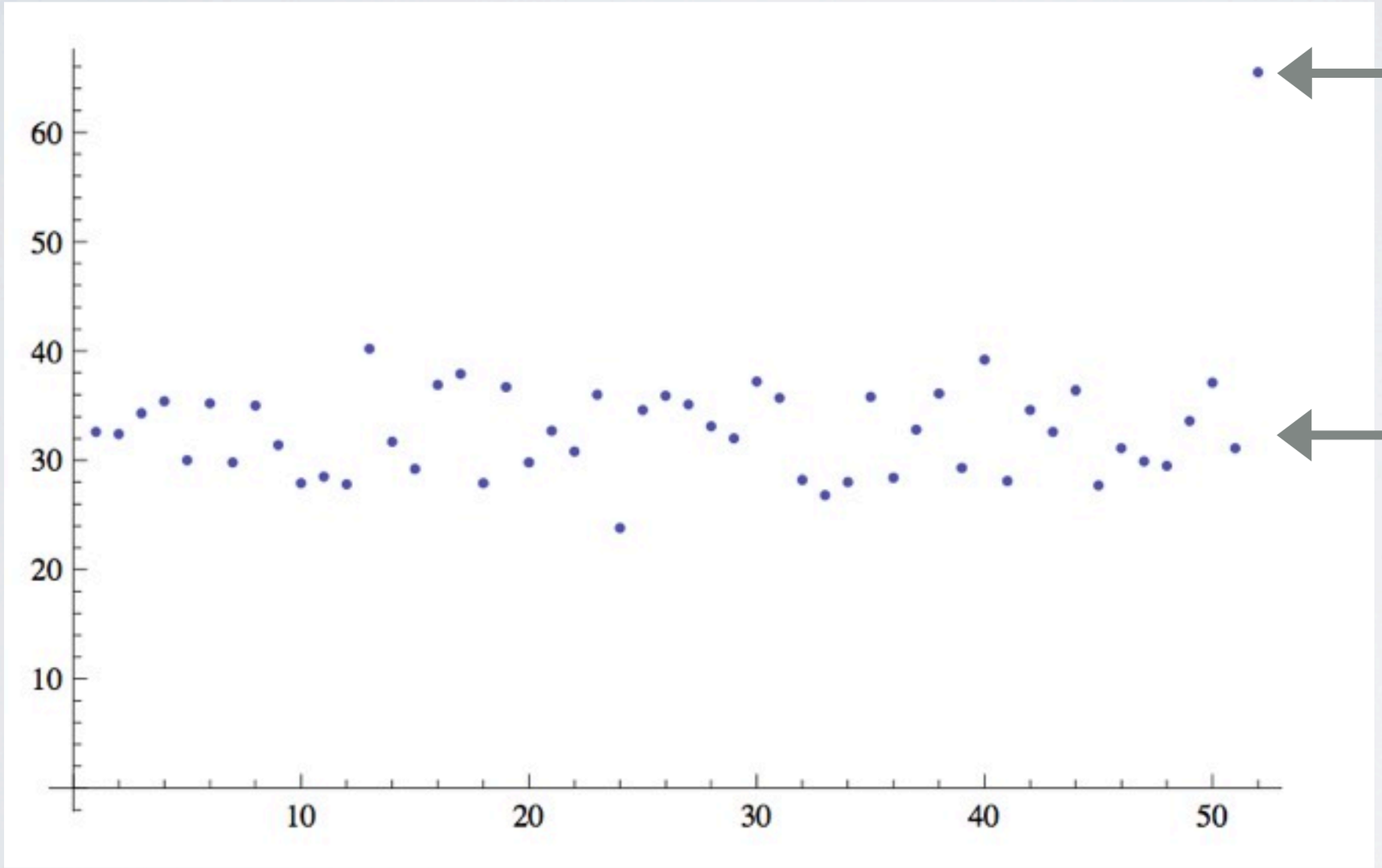
Cornell T(˚F)



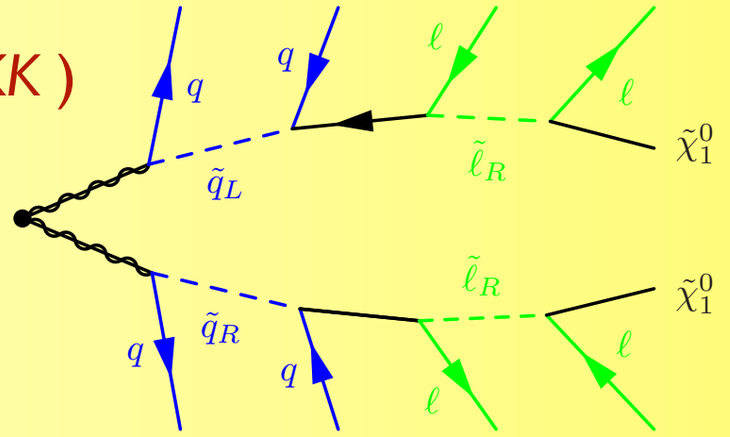
March, 21 2012
(MC4BSM 2012)
T =65.5 (9 σ)

March average
T = 32.4 ±3.7

Year: 1961 + x

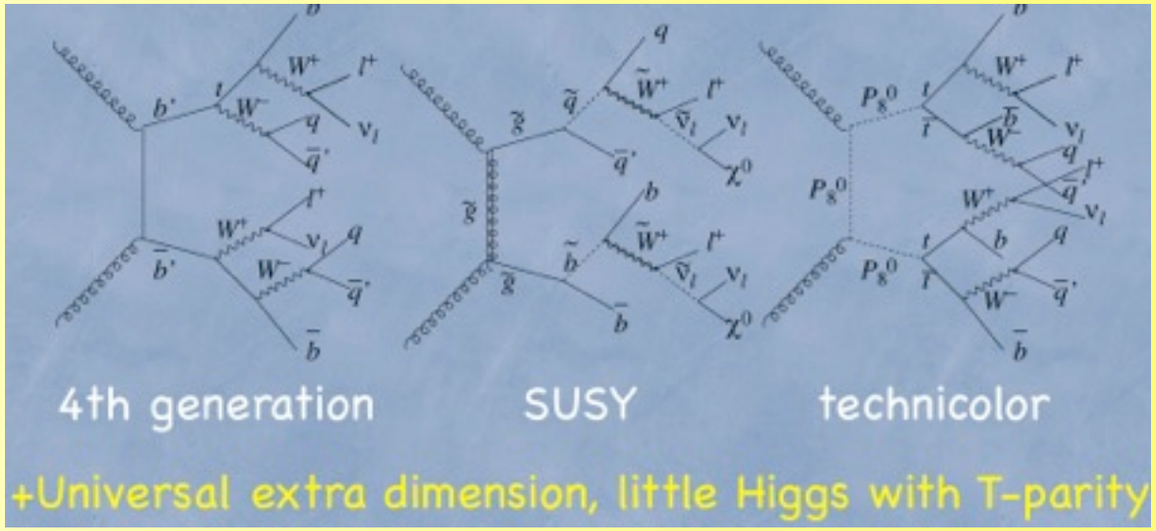
TAXONOMY OF SEARCHES

- Looking for decay products of heavy new particles ⇒ usually high p_T jets, hard leptons
- Production: mainly strongly interacting particles
- Weakly interacting stuff (almost) only in decays
- **Dark Matter ⟺ Discrete Parity (name it the way you like: *R, T, KK*)**



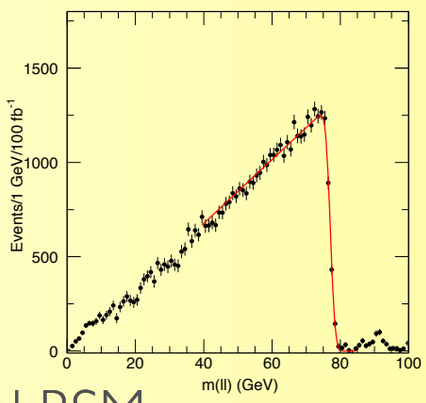
- ✳ Pair production of new particles (Phase space price tag!)
- ✳ Shorter or longer decay chains
- ✳ Dark Matter ⟹ **Missing energy (MET) in the detector**

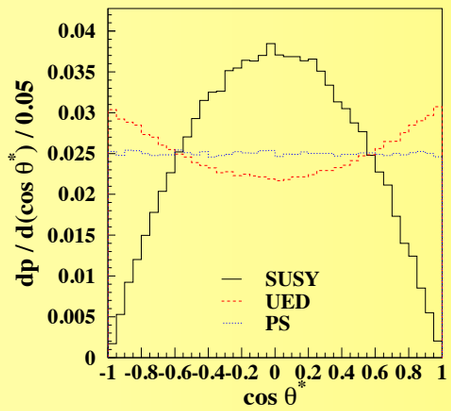
Different models lead to identical exclusive chains:



Crucial experimental steps:

1. In the high-energy tails find a deviation from SM
2. Mass determination of new physics (a.k.a. Edges)
3. Spin determination of new physics (a.k.a. angular correlations)
4. Identify new physics model





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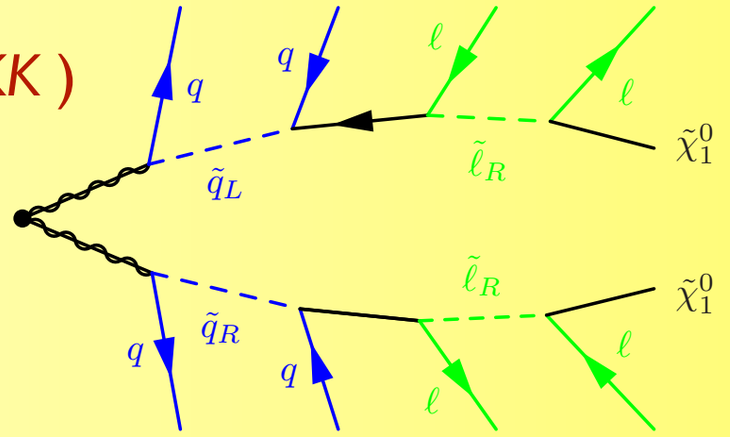

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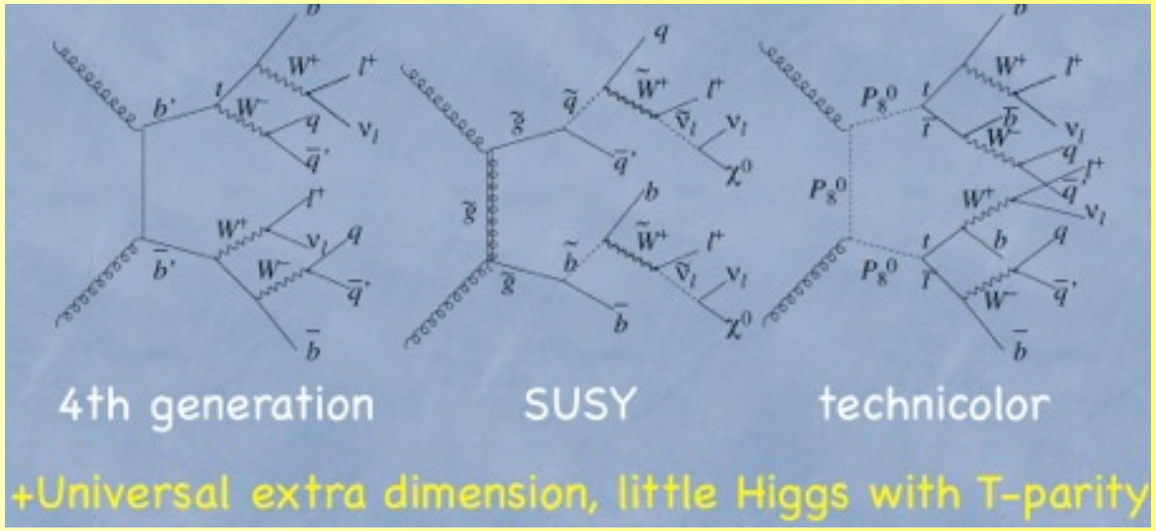

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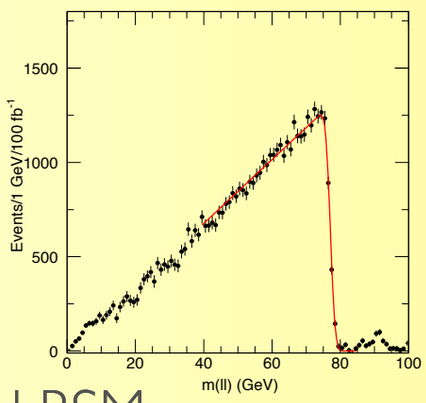
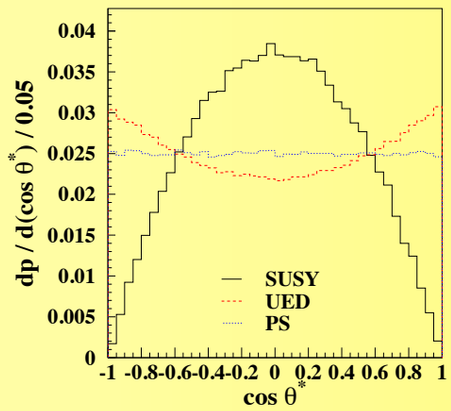
Of course, theorists screw this up!

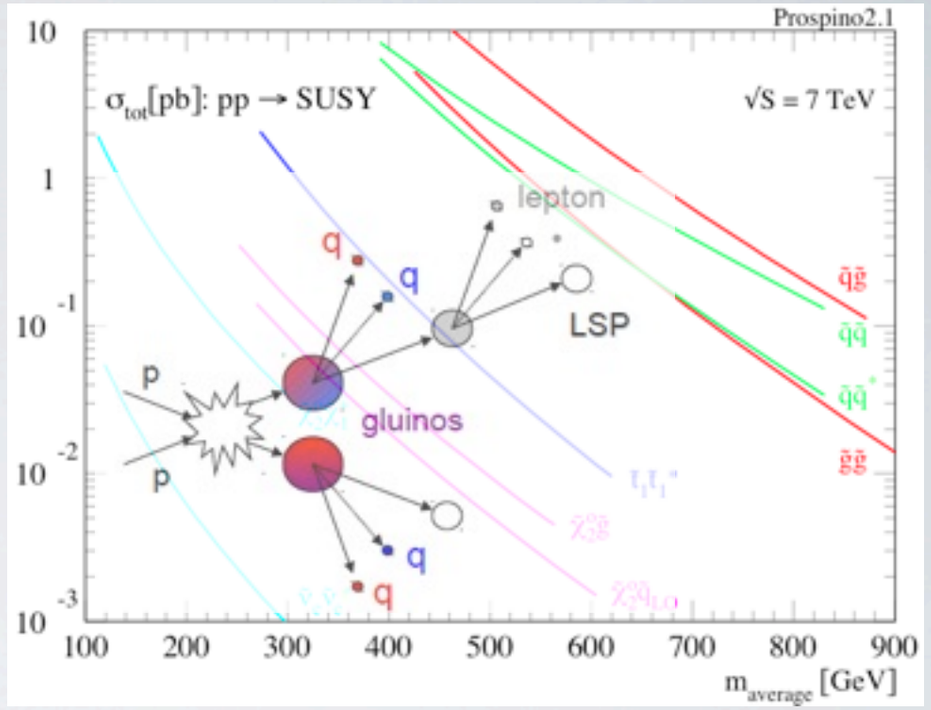




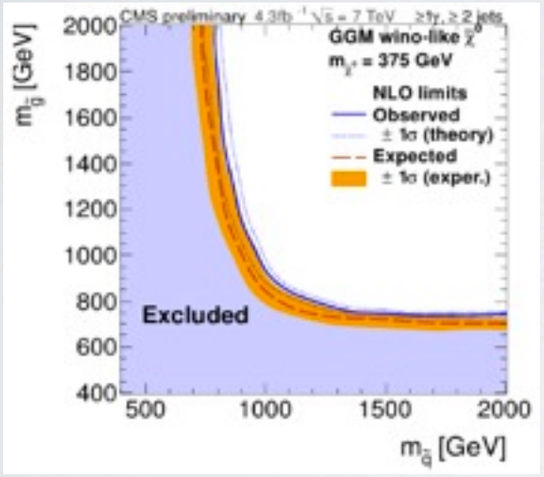
MAXIMUM BIAS: SUSY SEARCHES

- Production dominated for squarks and gluinos
- Decays and signatures are very model-dependent
- Dominant experimental signatures:
  MET, hadronic stuff (HT), (multi-) leptons, photons, heavy flavors

Procedure: Simplified Model for Limit setting, new variables for discrimination (α_T , razor, M_{T2})

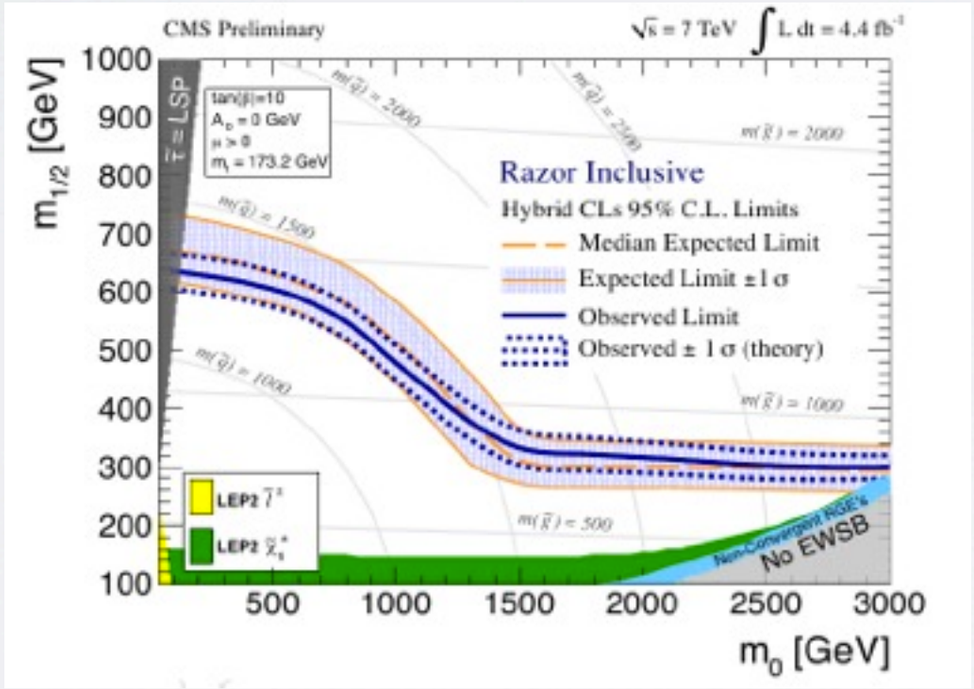


1 photon + MET: GGMSB search

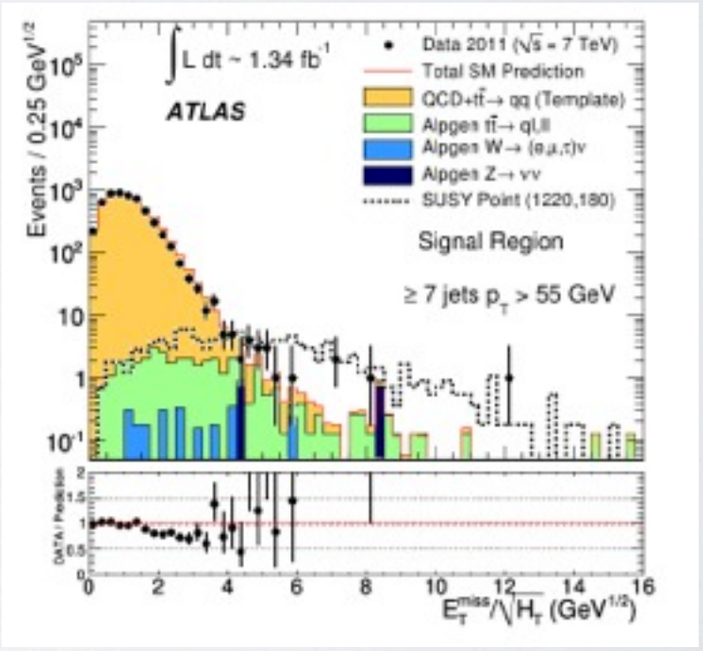


recast as a UED search

CMS Razor analysis:
Balance of visible and missing momentum



Multi-Jet searches:
MET/√HT > 3.5 discriminator



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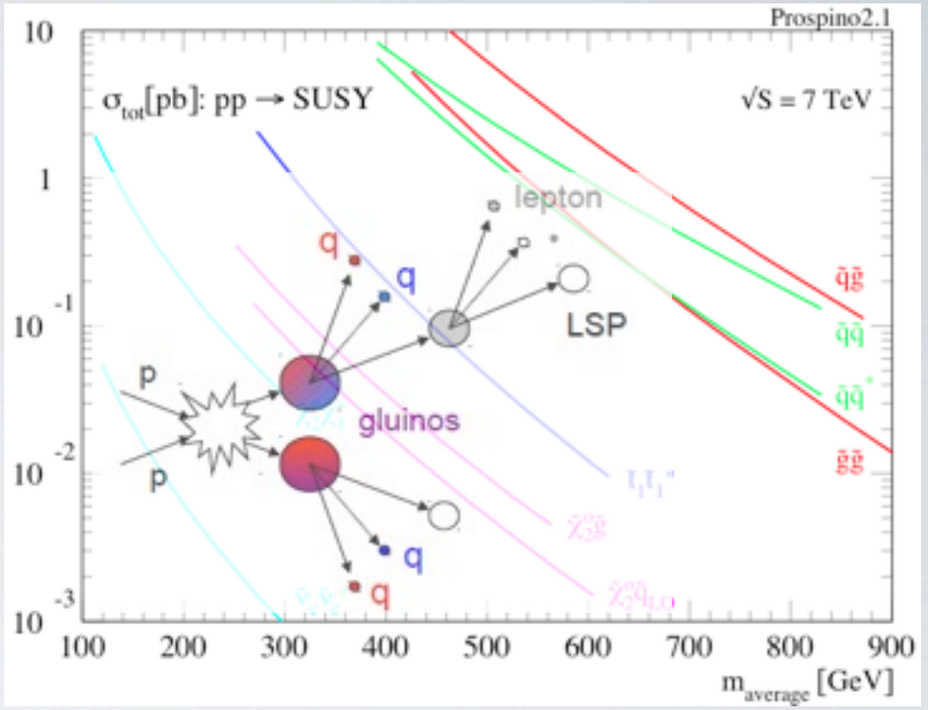
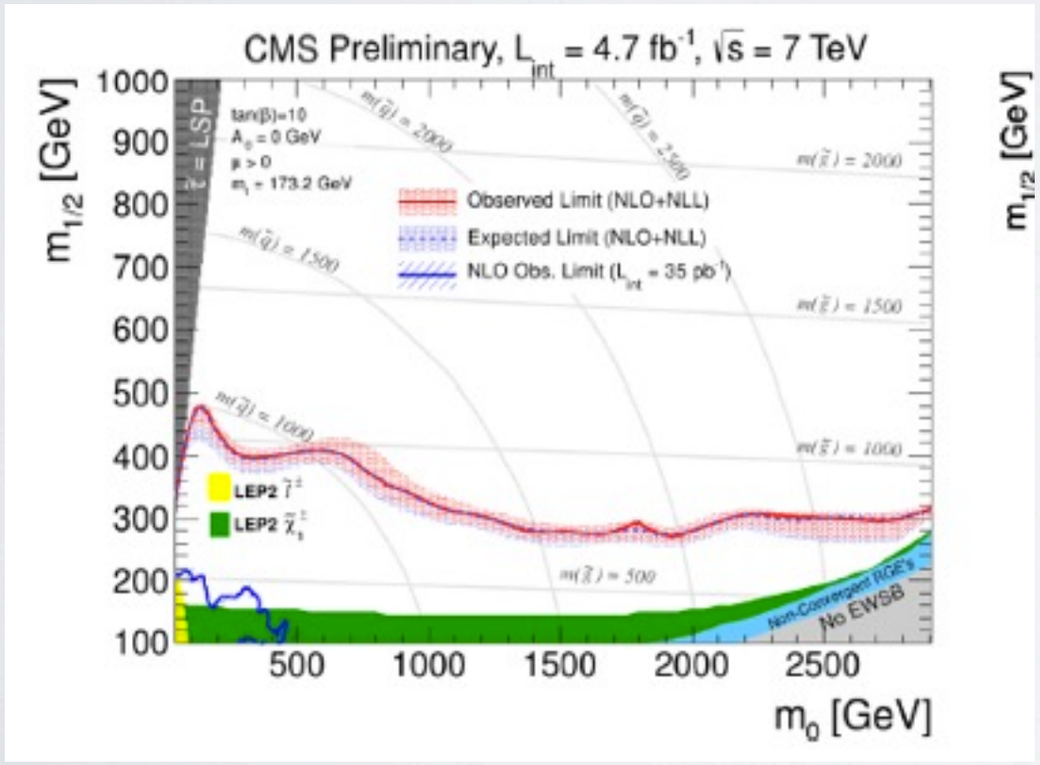
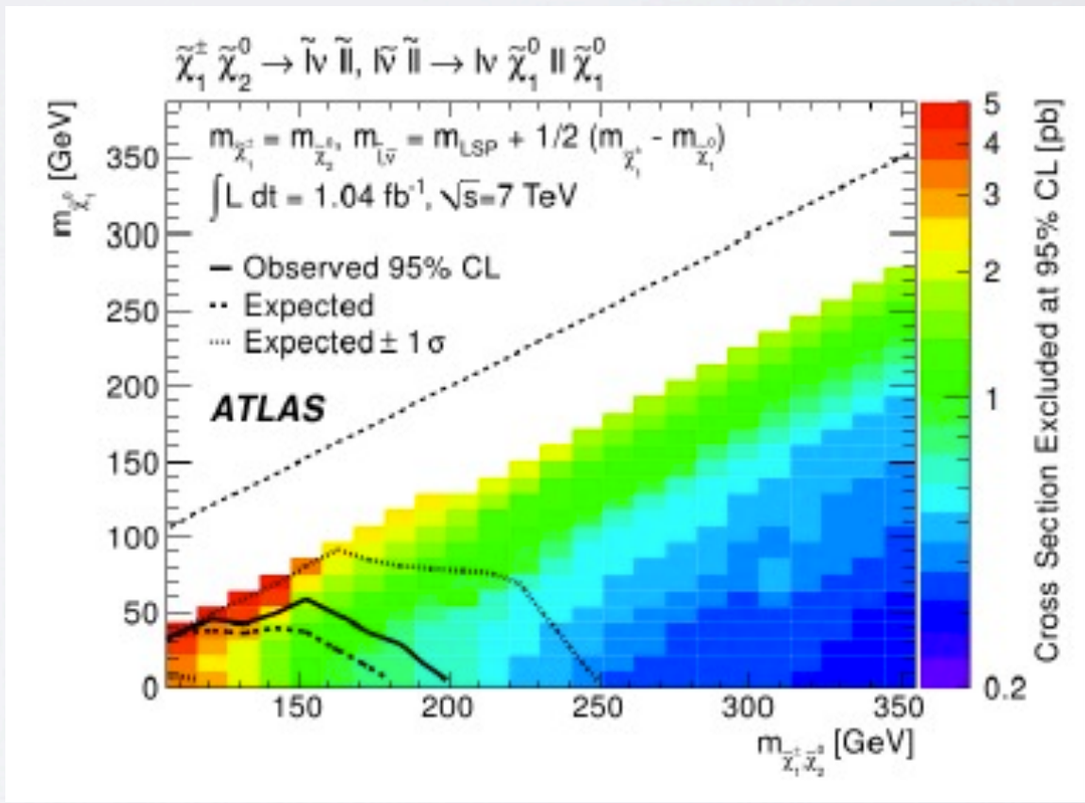
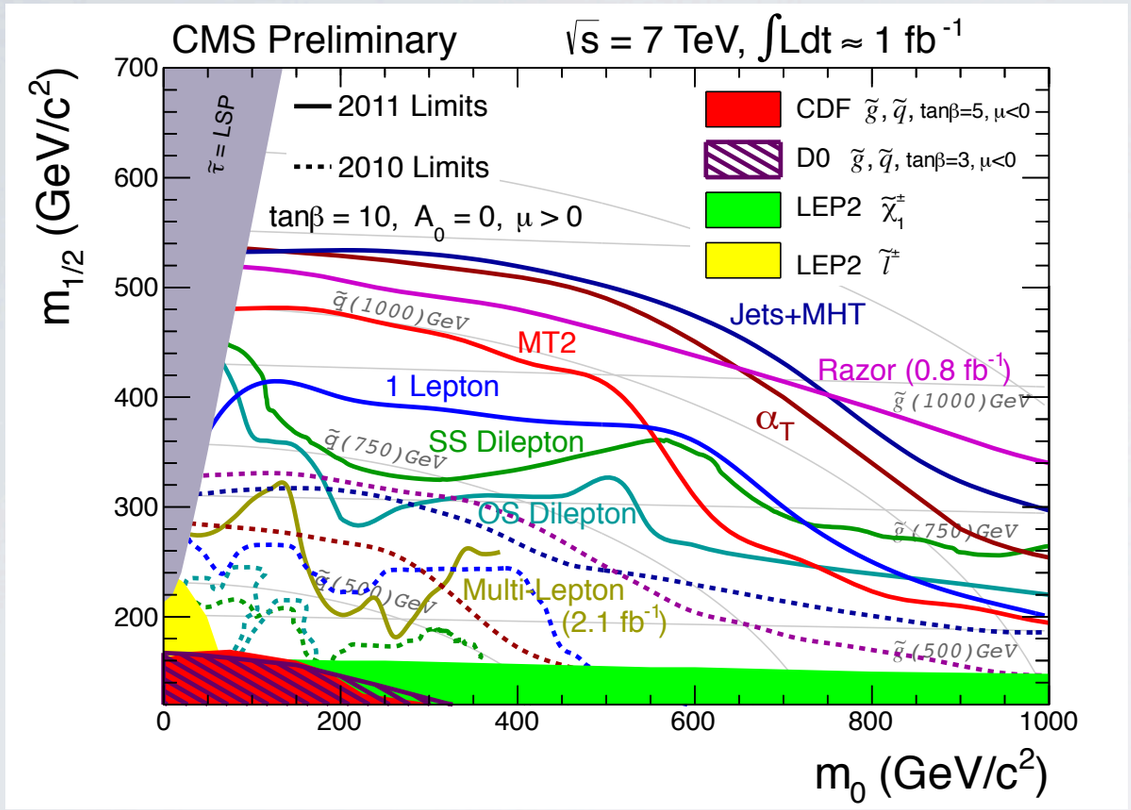


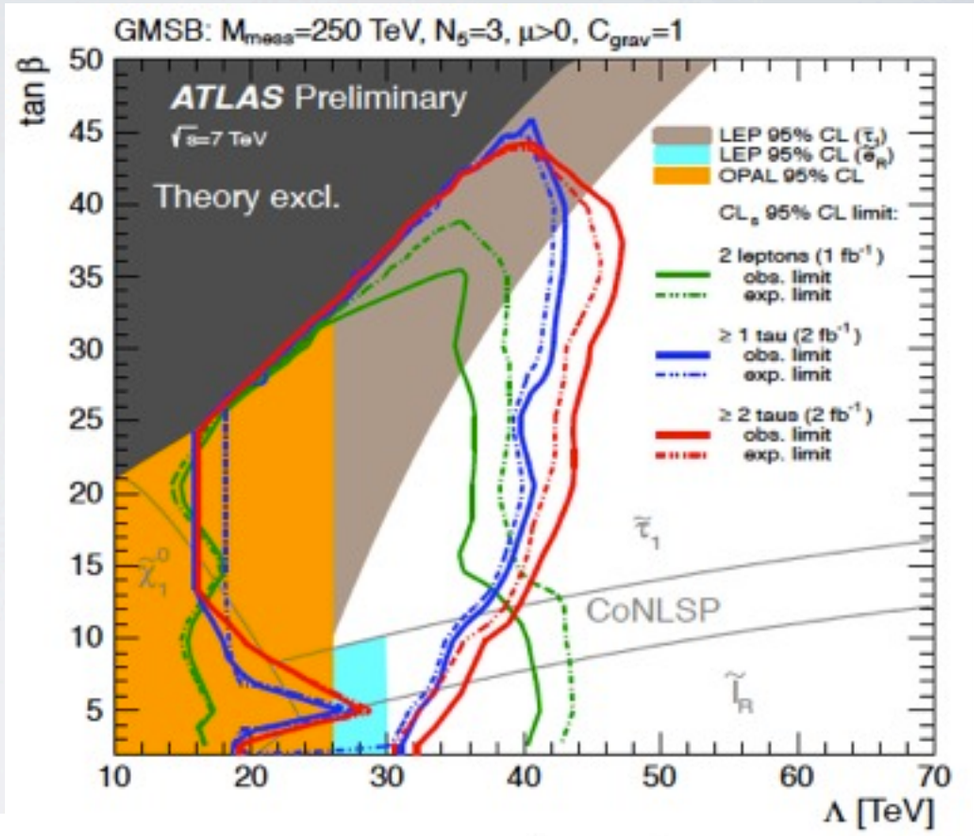
Same-Sign Dilepton Searches:

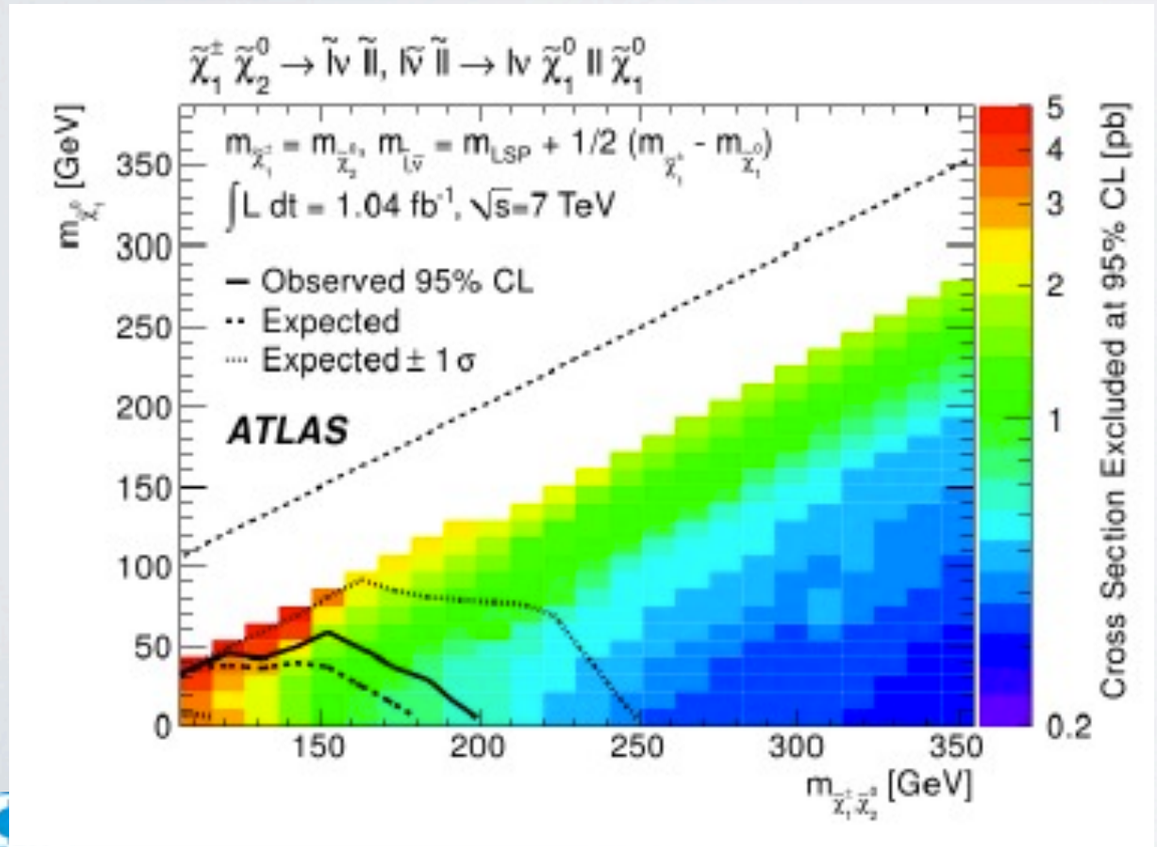


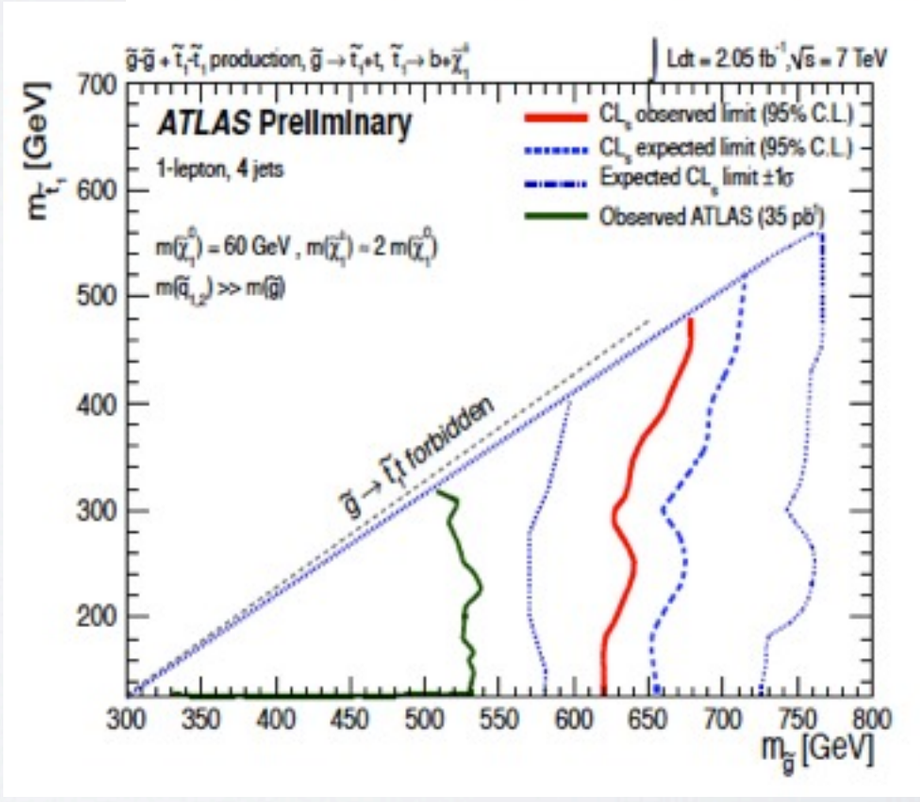


CMSSM vs. SUSY W\ PREJUDICE

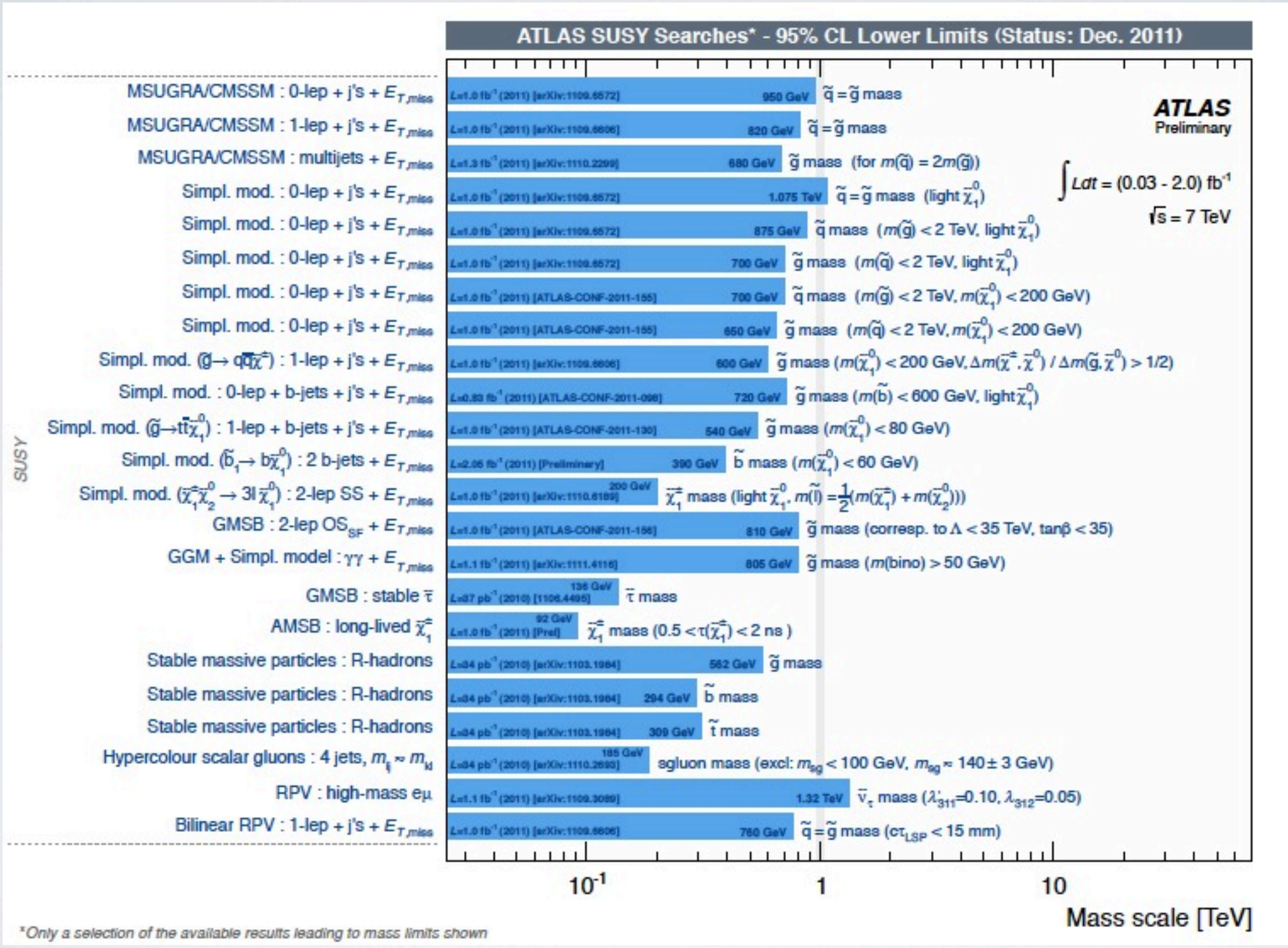








SUMMARY SUSY SEARCHES



*Only a selection of the available results leading to mass limits shown

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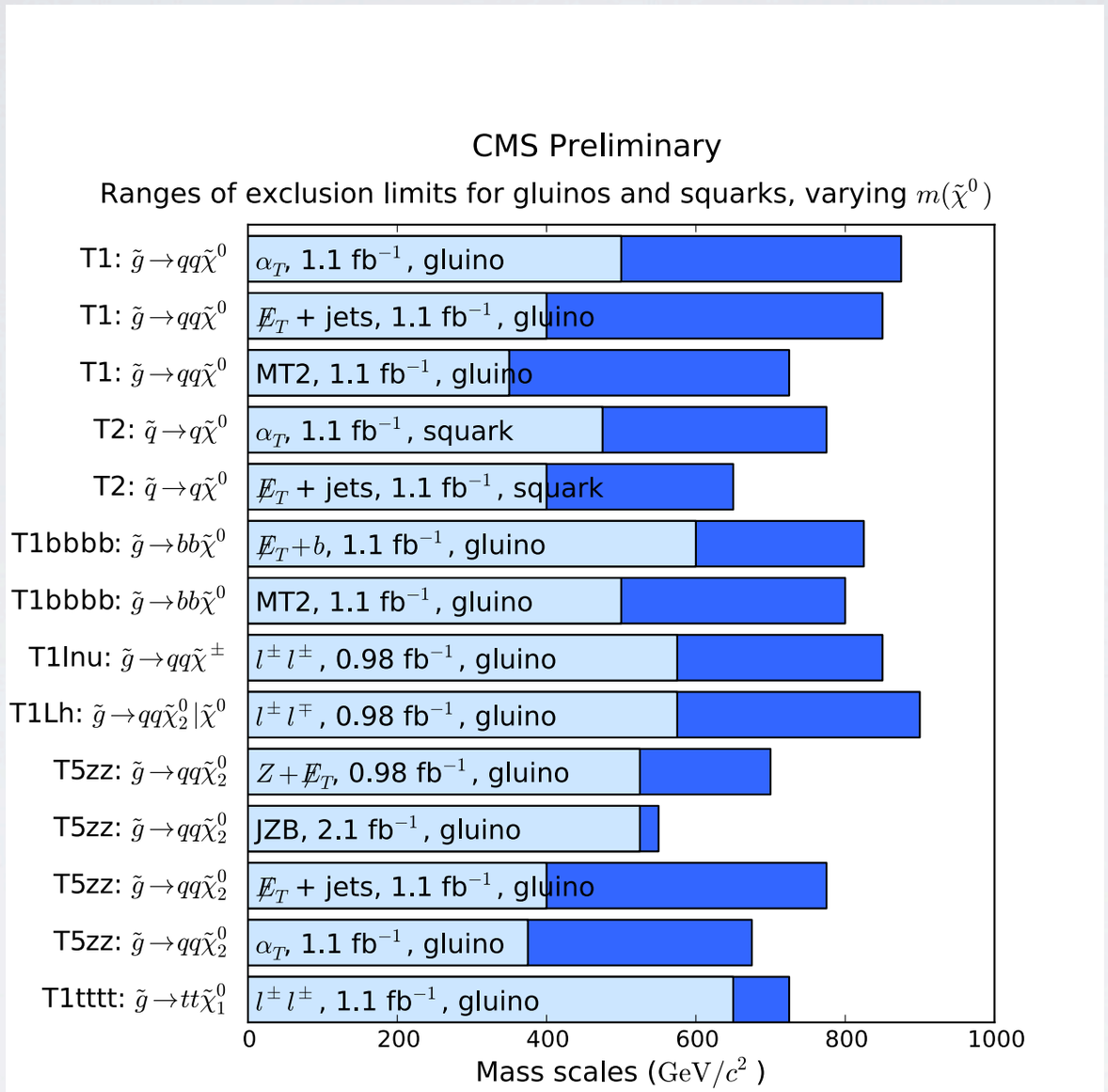


For limits on $m(\tilde{g}) \gg m(\tilde{q})$ (and vice versa). $\sigma^{\text{prod}} = \sigma^{\text{NLO-QCD}}$.
$m(\tilde{\chi}^{\pm}), m(\tilde{\chi}_2^0) \equiv \frac{m(\tilde{g}) + m(\tilde{\chi}^0)}{2}$.
$m(\tilde{\chi}^0)$ is varied from 0 GeV/c^2 (dark blue) to $m(\tilde{g})-200$ GeV/c^2 (light blue).

SUMMARY SUSY SEARCHES

SUSY LESSONS TO BE LEARNED

1. Gluinos heavier than 700 - 900 GeV (except for freakily tuned cases)
2. Squarks (1./2. gen.) heavier than 800 - 1200 GeV (except for freakily tuned cases)
3. 3rd generation squarks begin to be tickled (limits of rather 250-400 GeV)
4. Electroweakinos rather weakly constrained: roughly heavier than 150 - 350 GeV
   (very model-dependent)
5. What does the "Higgs evidence" tell us about SUSY?

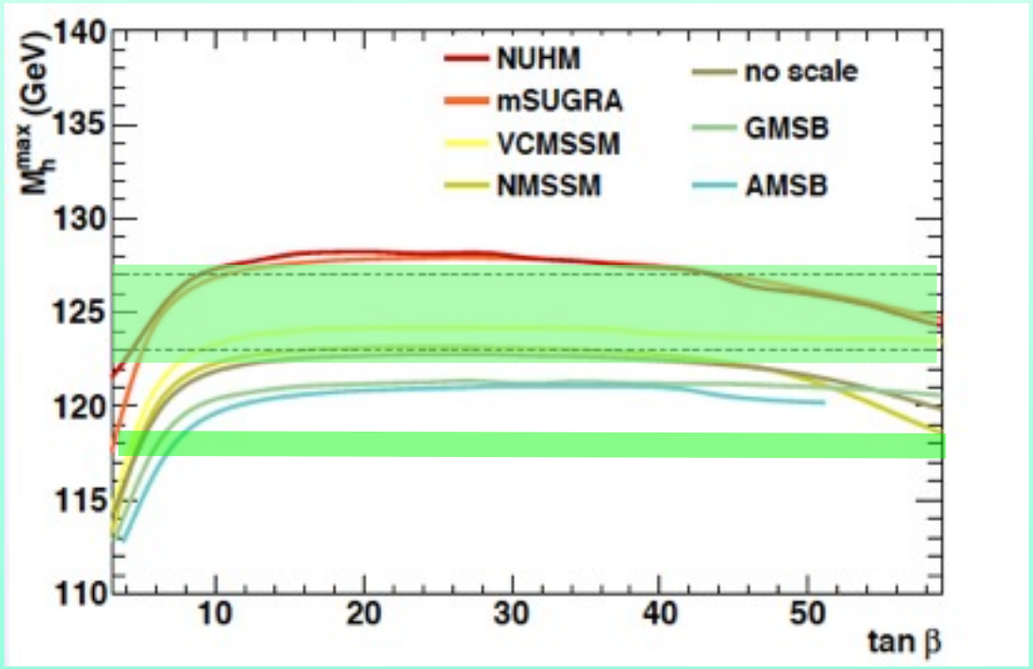
SUSY & THE LIGHT HIGGS OXYMORON

- SUSY predicts a light Higgs boson: $60\ \mathrm{GeV} \lesssim M_H \lesssim 130\,[135]\ \mathrm{GeV}$

$$M_h^2 \approx M_Z^2 \cos^2(2\beta) + \frac{3y_t^4}{8\pi^2}\left[\log\frac{M_{SUSY}^2}{m_t^2} + \frac{X_t^2}{M_{SUSY}^2}\left(1 - \frac{1}{12}\frac{X_t^2}{M_{SUSY}^2}\right)\right]$$

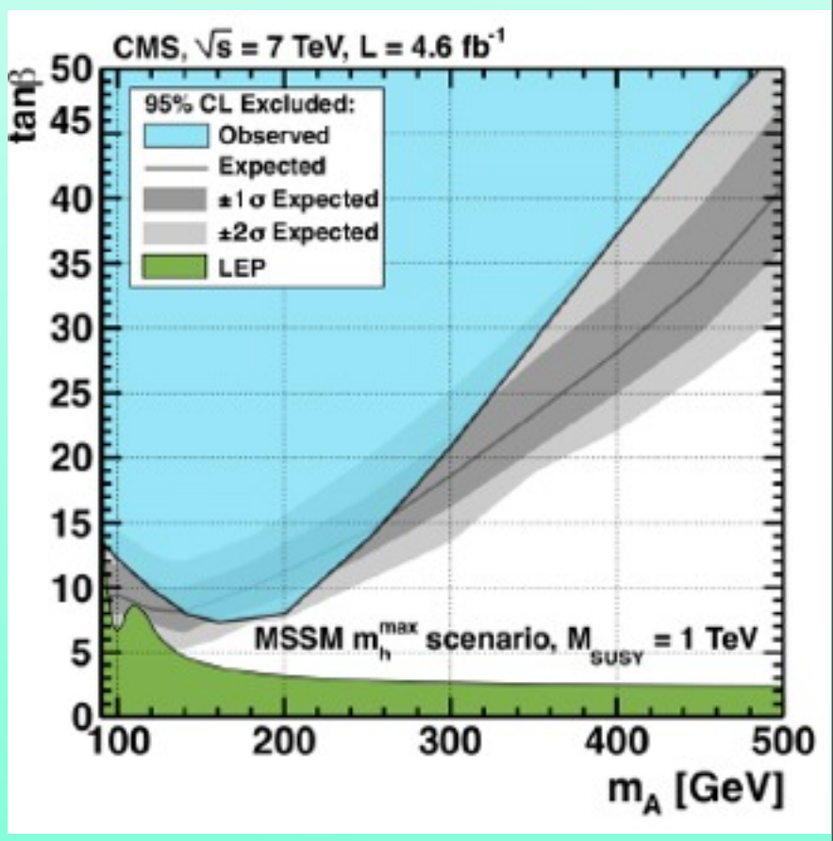
- Large Higgs mass (120 - 130 GeV) for :

1. Decoupling regime (Higgs very SM-like, heavy SUSY-Higgses ***O(1 TeV)***)
2. Moderate to large ***tan*** β ≳ 10
3. Heavy stops
4. Large Mixing



Scenario	Mh/max
AMSB	121.0 GeV
GMSB	121.5 GeV
mSUGRA	128.0 GeV
no-scale	123.0 GeV
cNMSSM	123.5 GeV
NUHM	128.5 GeV

Arbey et al., 2012



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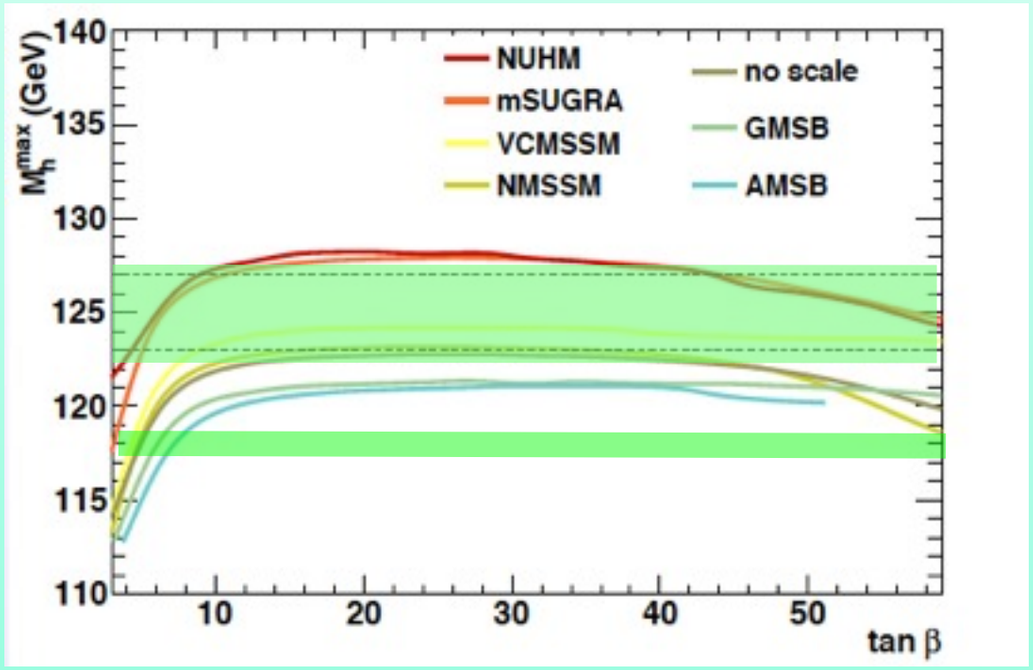

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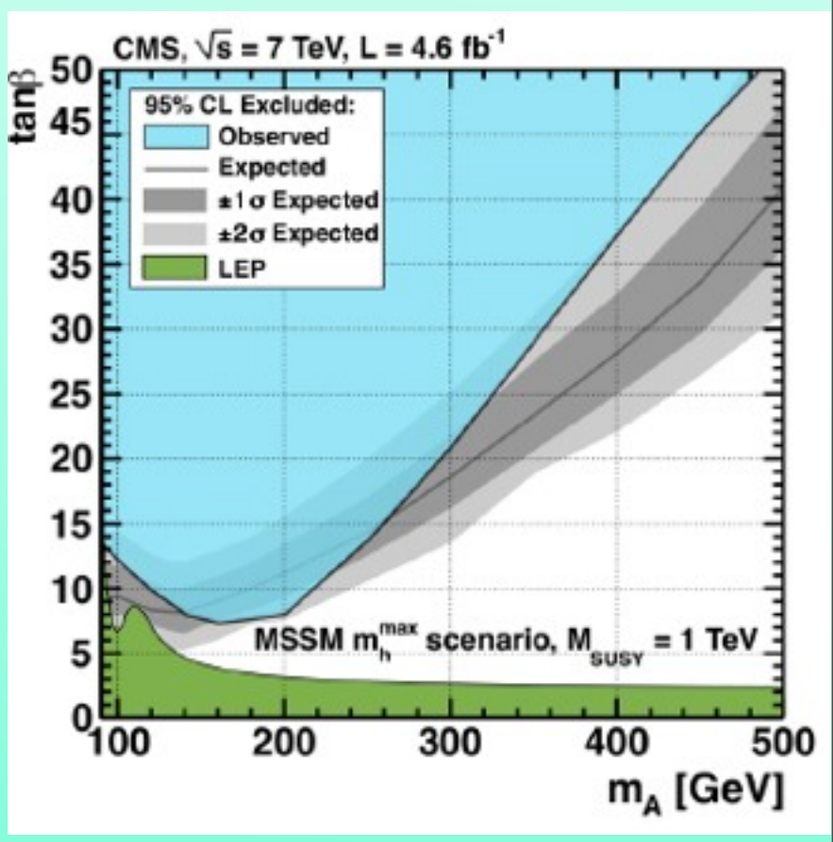

- Severe constraints on SUSY from Higgs sector
- Other models (LHM, RS, ADD, SILH, ...) less predictive for M_H $\Longrightarrow$ much less constrained

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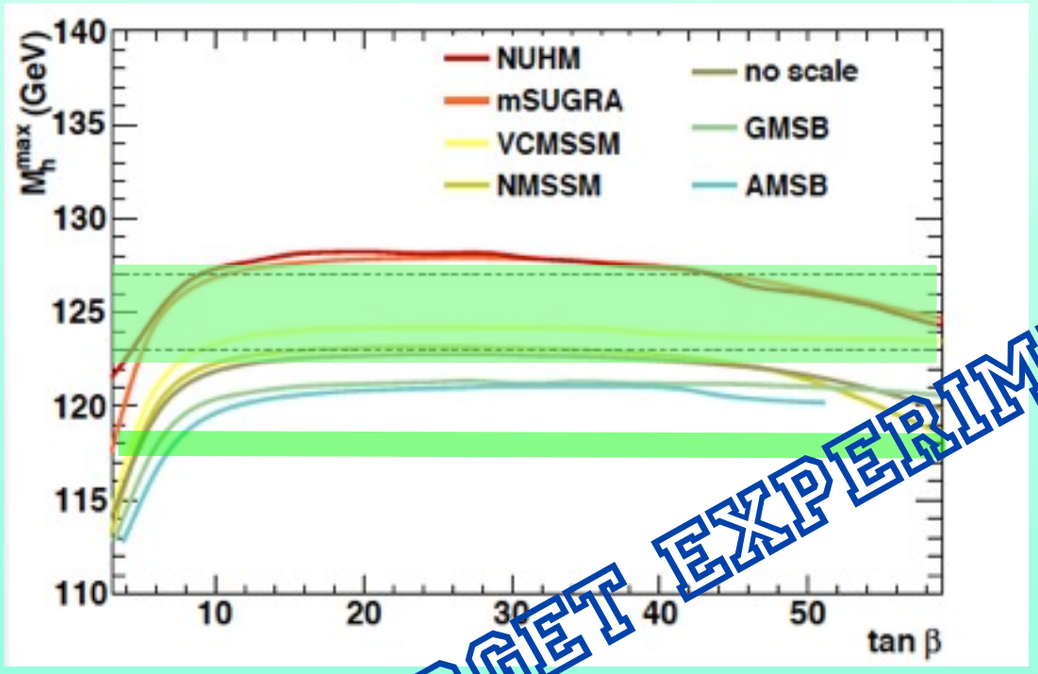

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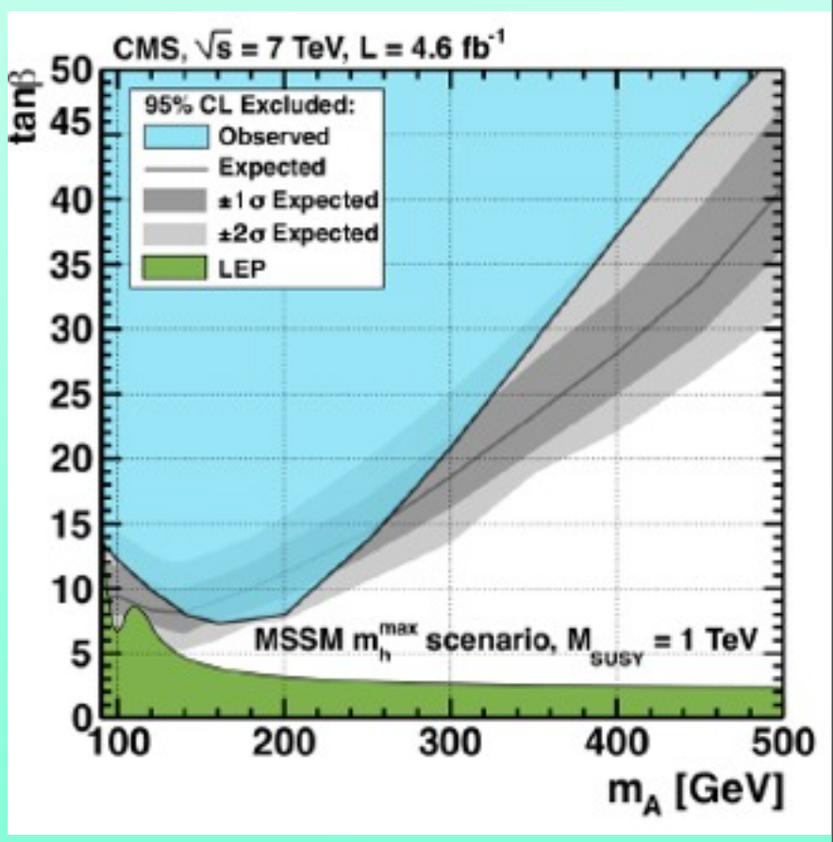

DON'T FORGET EXPERIMENTAL AND THEORY ERRORS

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GENERAL BSM SEARCHES

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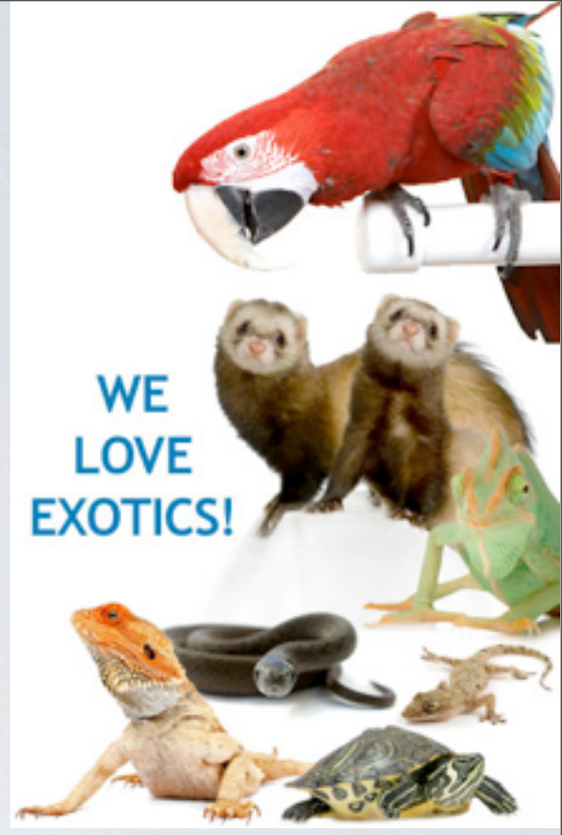
*"If I'd only knew **which** haystack....."*

EXOTIC SEARCHES



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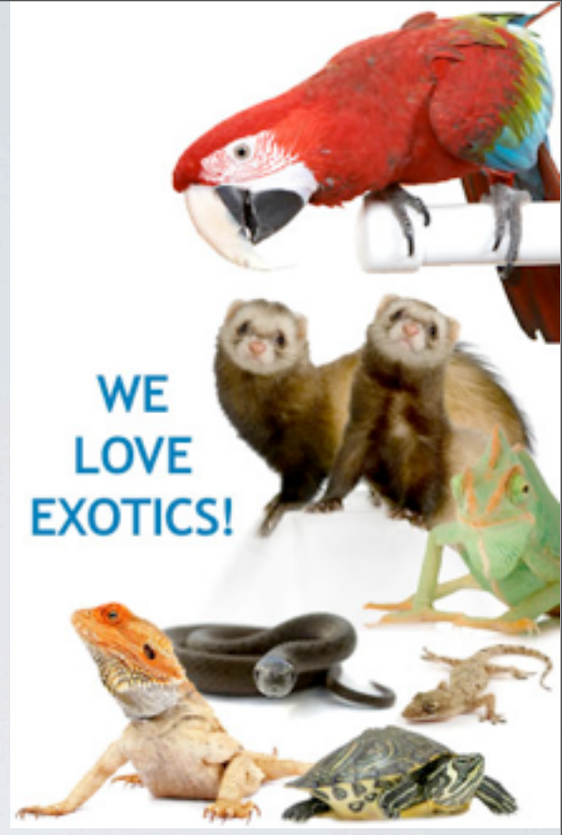

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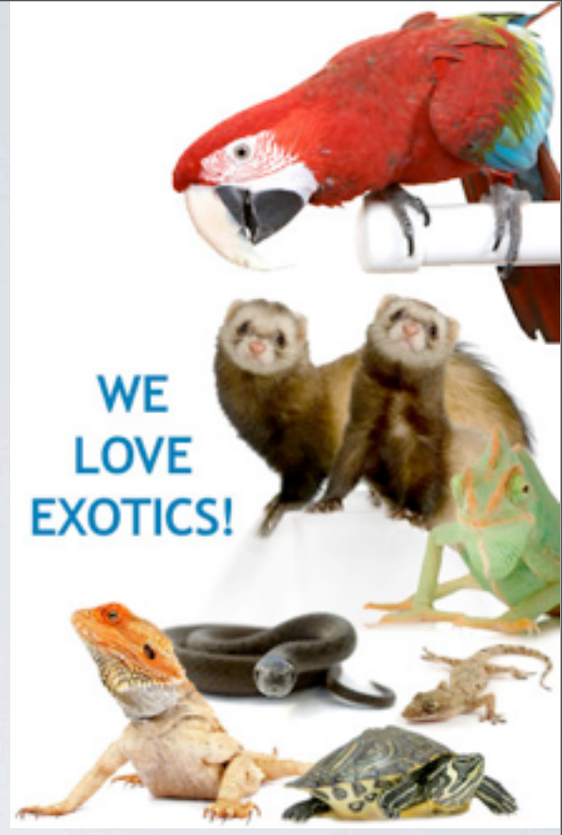

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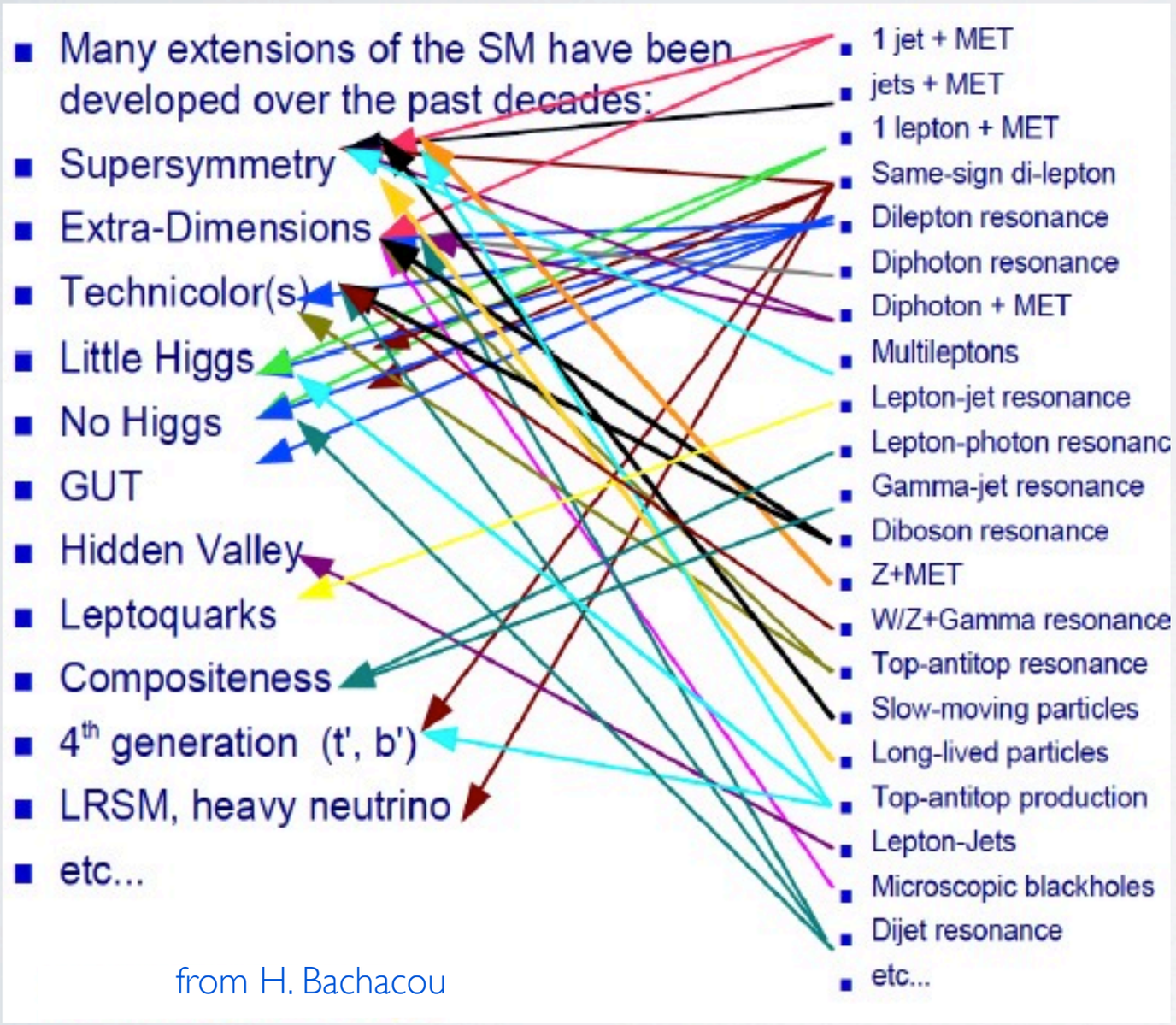
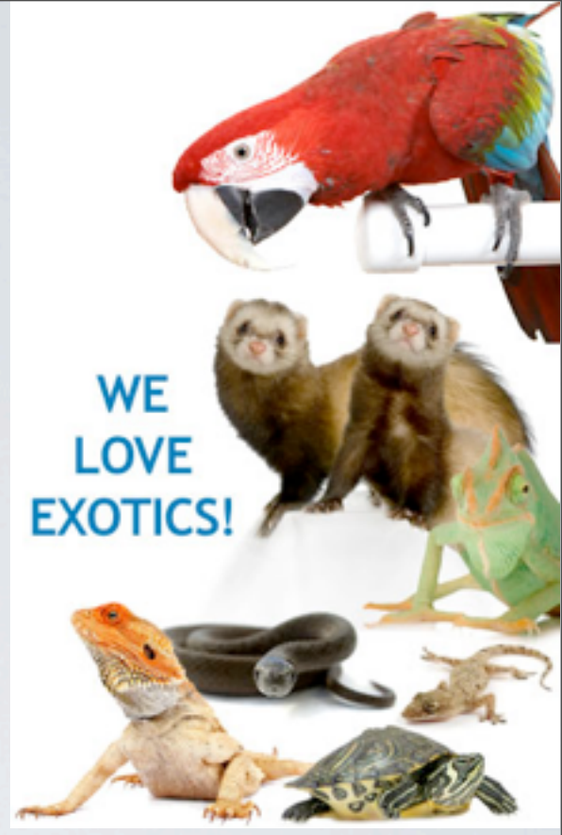


from H. Bachacou



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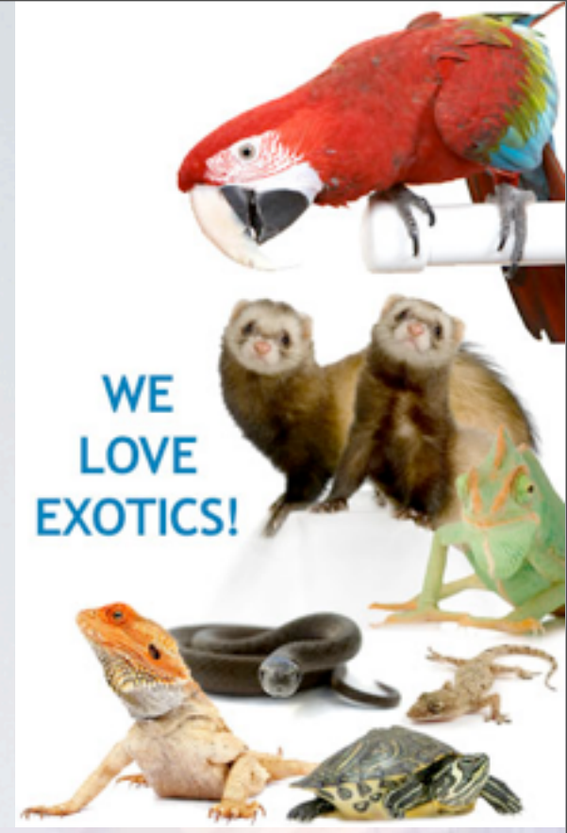

- Many extensions of the SM have been developed over the past decades:
- Supersymmetry
- Extra-Dimensions
- Technicolor(s)
- Little Higgs
- No Higgs
- GUT
- Hidden Valley
- Leptoquarks
- Compositeness
- 4th generation (t', b')
- LRSM, heavy neutrino
- etc...

- 1 jet + MET
- jets + MET
- 1 lepton + MET
- Same-sign di-lepton
- Dilepton resonance
- Diphoton resonance
- Diphoton + MET
- Multileptons
- Lepton-jet resonance
- Lepton-photon resonanc
- Gamma-jet resonance
- Diboson resonance
- Z+MET
- W/Z+Gamma resonance
- Top-antitop resonance
- Slow-moving particles
- Long-lived particles
- Top-antitop production
- Lepton-Jets
- Microscopic blackholes
- Dijet resonance
- etc...

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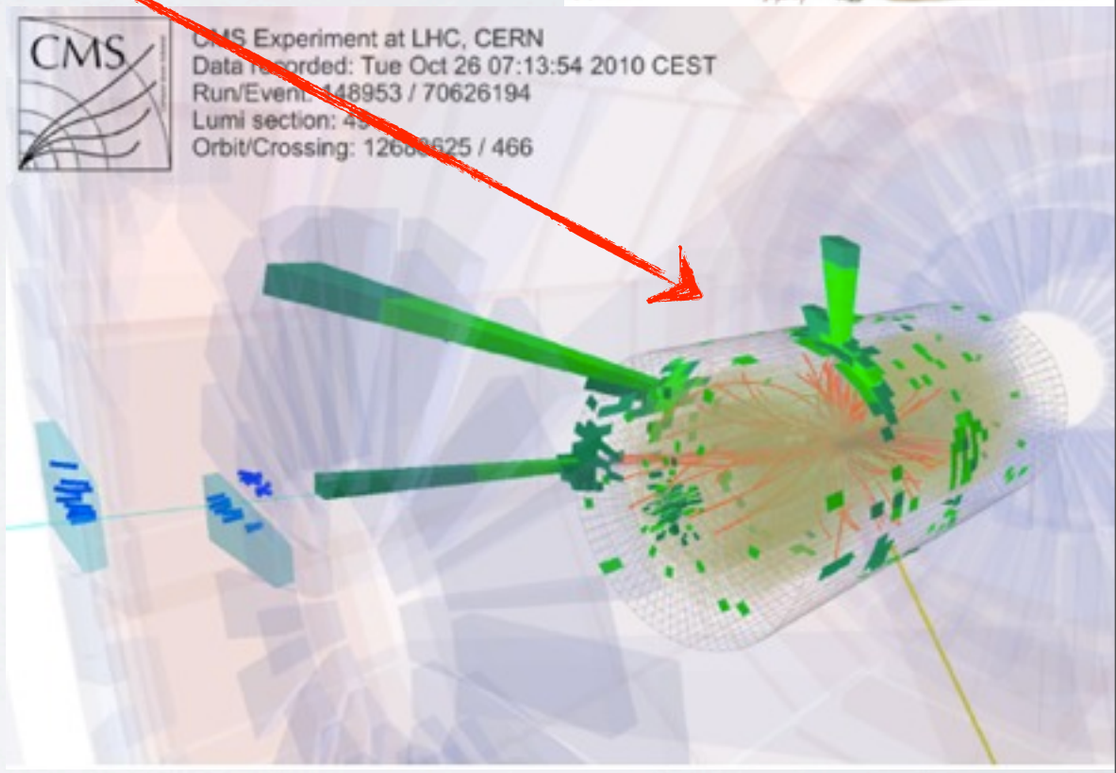
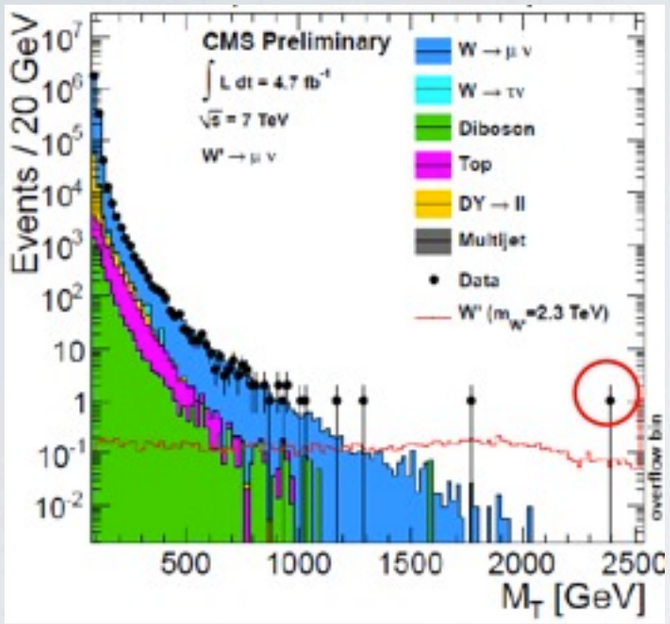


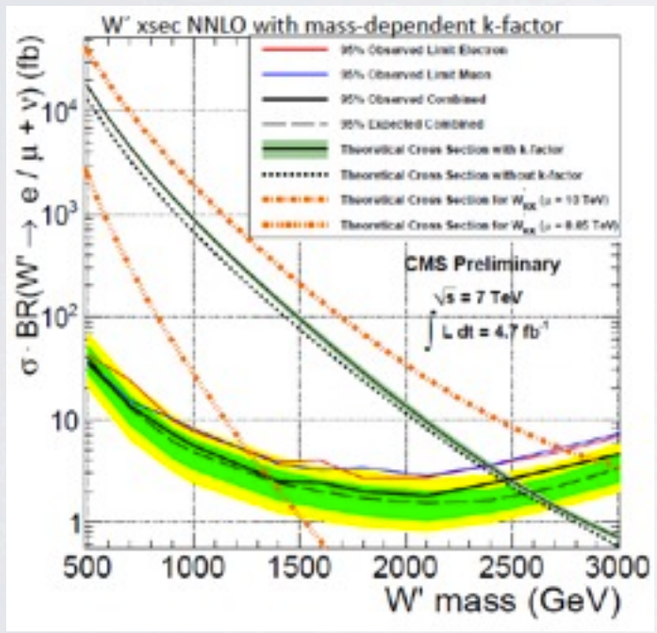
5 jets, $H_T = 1132$ GeV

$\not{H}_T = 693$ GeV

GENERIC SEARCHES

Example $W \to l\nu$: Search variable M_T leads to exclusion plot:





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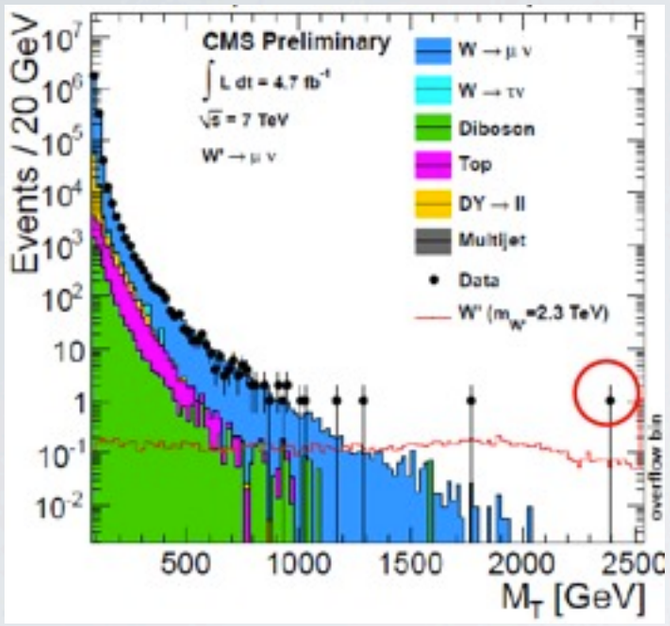

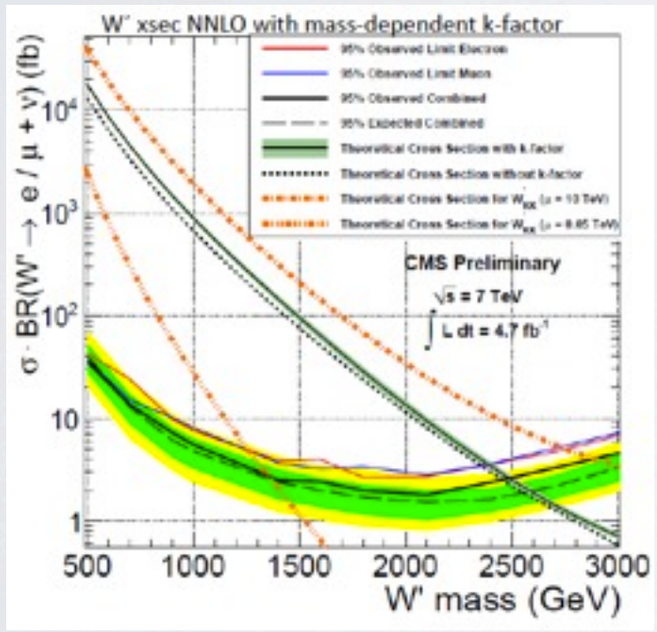

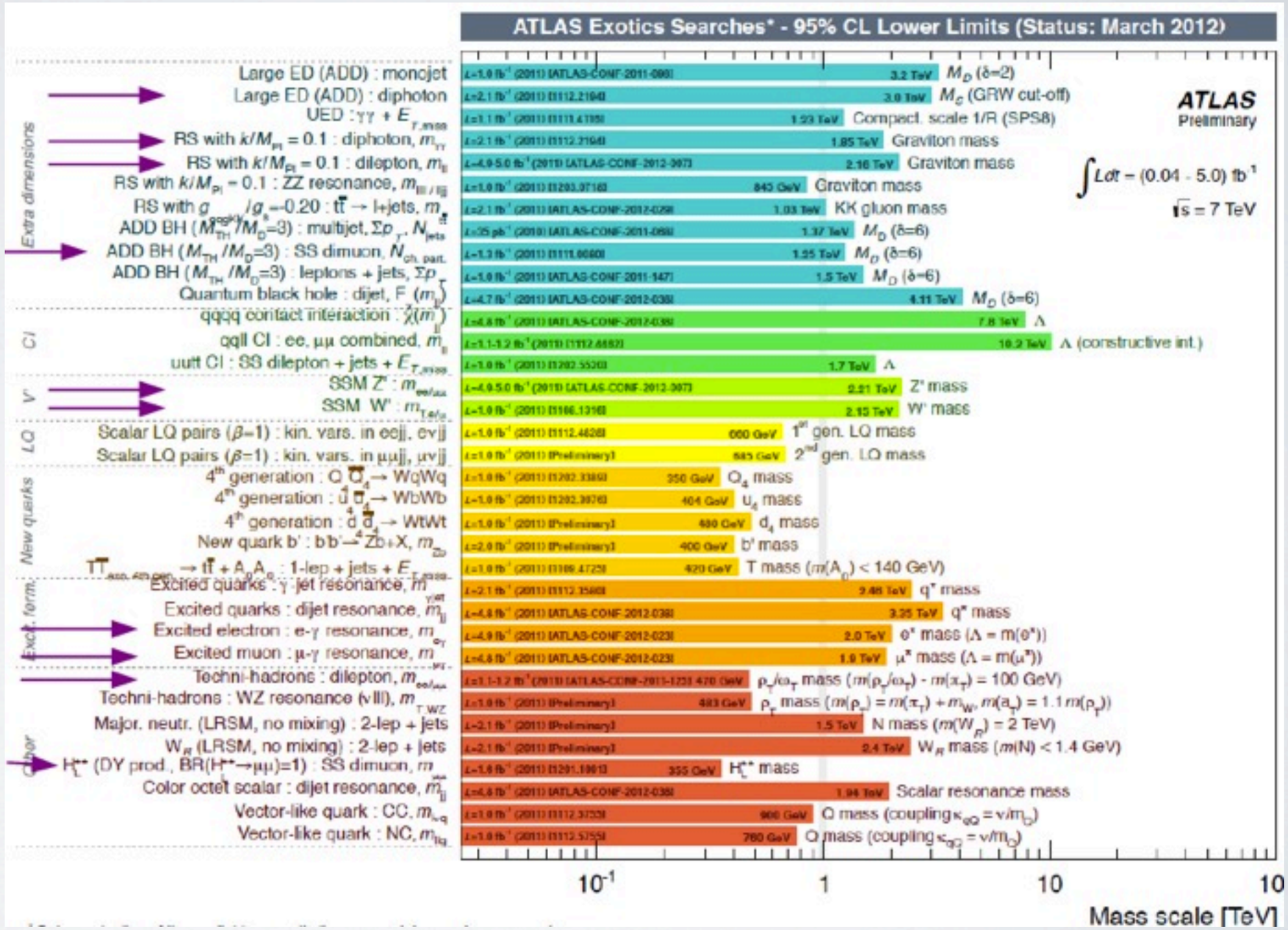

LESSONS LEARNED FROM LHC RUN I

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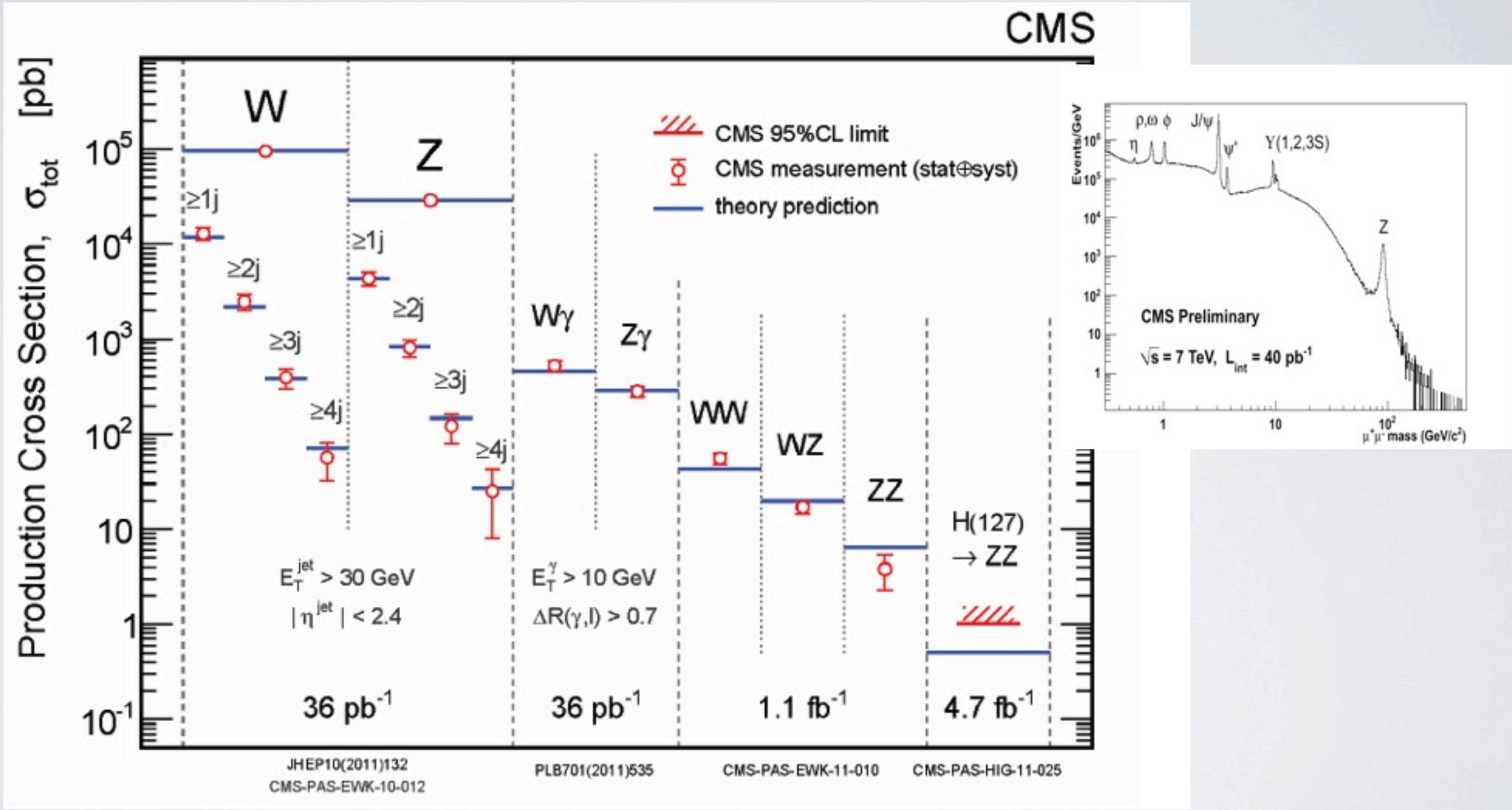
We really understood the Standard Model !!!



BSM LESSONS LEARNED

- **4th generation almost ruled out** (Higgs search, 4th gen. quarks enter non-perturbative regime)
- *Z'* limits: roughly 0.9 - 2.3 TeV (but very model-dependent, zillions of models!)
- *W'* limits: roughly 1.2 - 2.5 TeV (but very model-dependent, fermions vs. weak bosons)
- Graviton resonances: 1.1 - 2.1 TeV (but very model-dependent: RS, ADD, generic spin-2)
- Technicolor resonances: only below 0.7 TeV
- Leptoquarks: still only 0.35 - max. 0.6 TeV
- Top Resonances: roughly 1 TeV (entering boosted top regime now!)
- Black holes: have you seen any? CLEARLY NO

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(I) 2012: 3x luminosity, 1.14x energy

(II) BSM has to wait for Run II, i.e. 14-ε TeV & O(100/fb)

OH MY GOD-PARTICLE: HIGGS REVISITED

Forgot to mention: a theorist's interpretation of statistics J. Erler, 1201.0695

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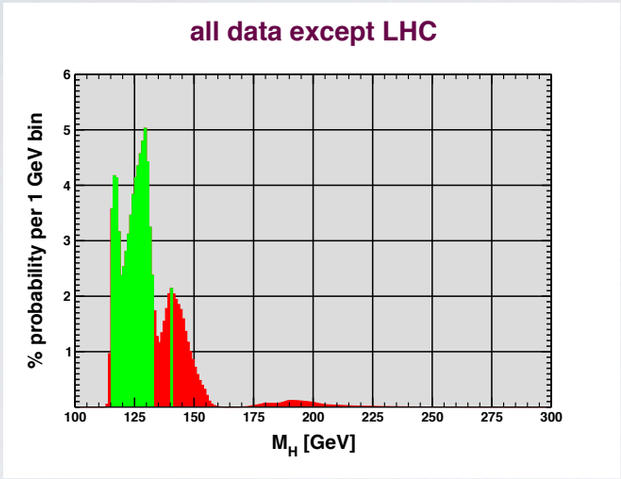

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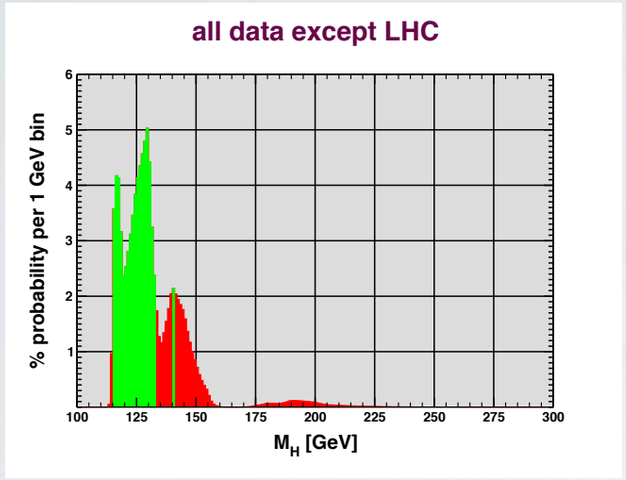

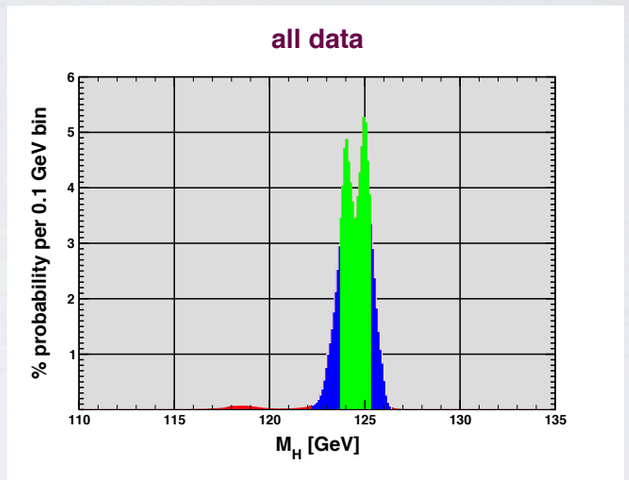

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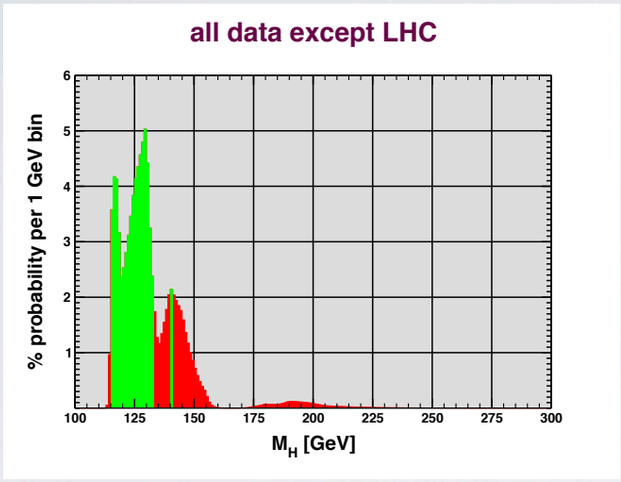

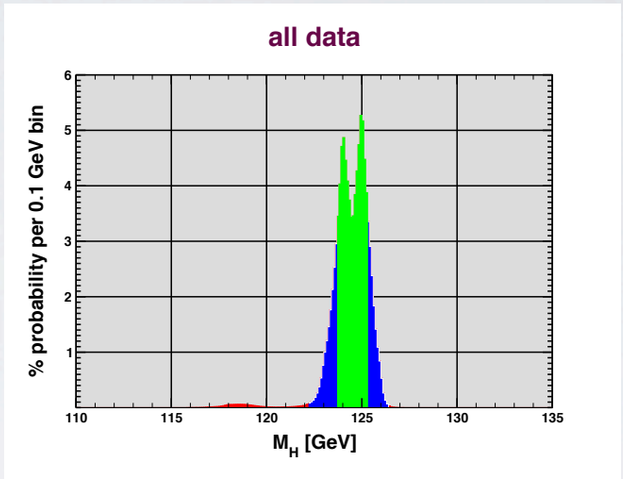

Why does M_H proof the existence of BSM ???

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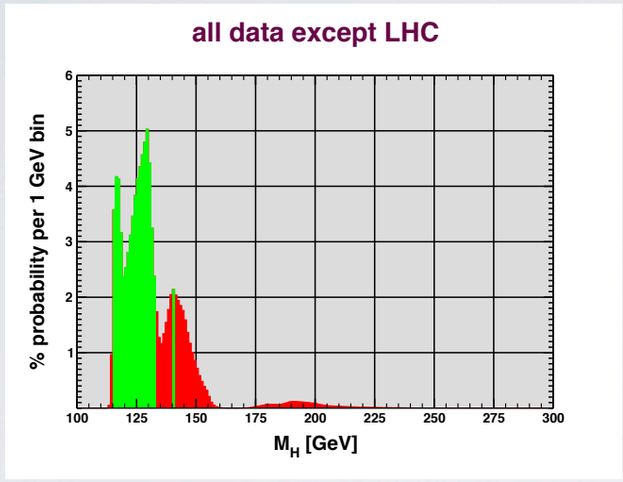

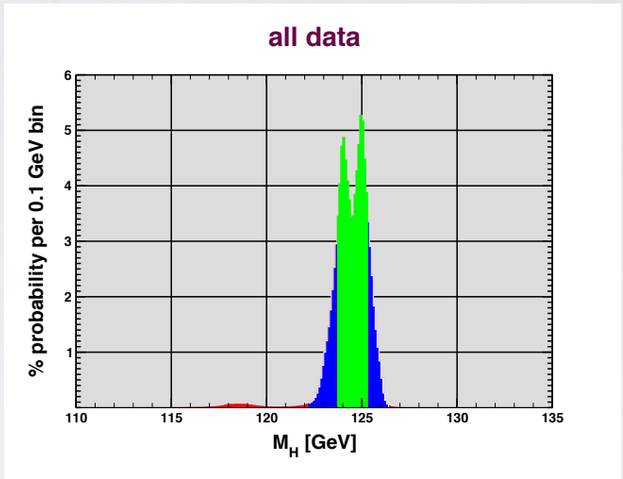

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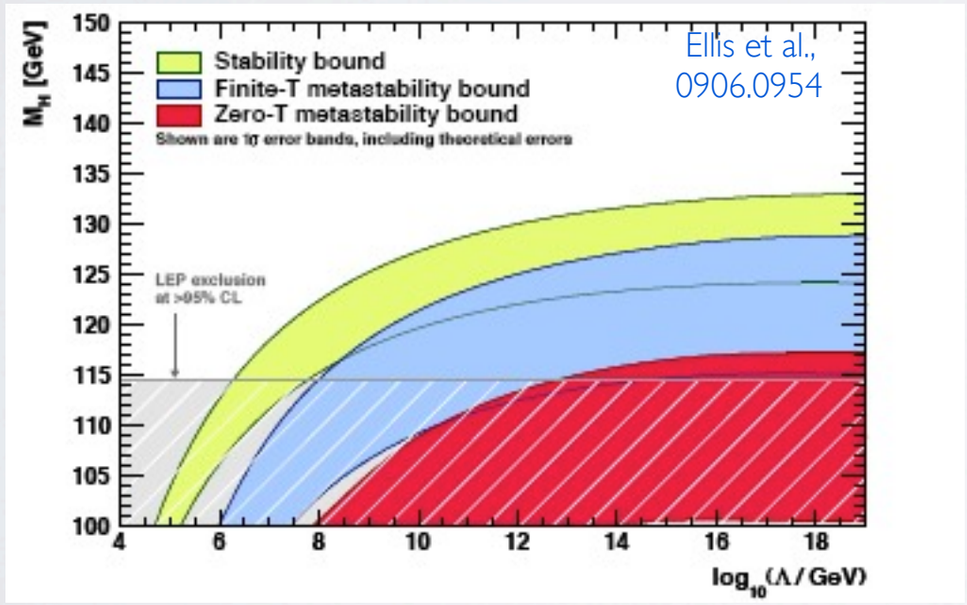

Ellis et al., 0906.0954

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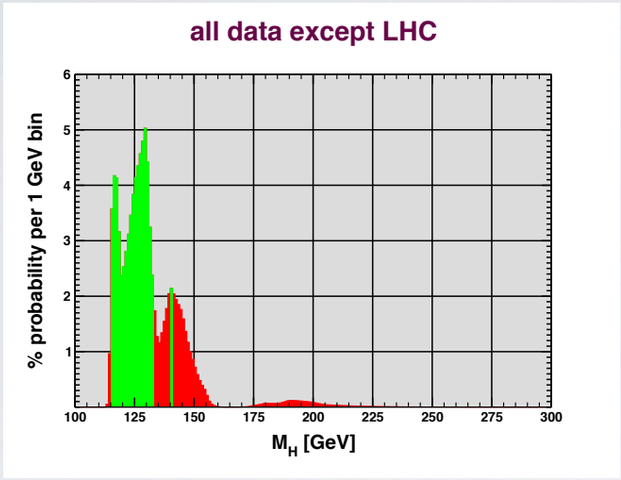

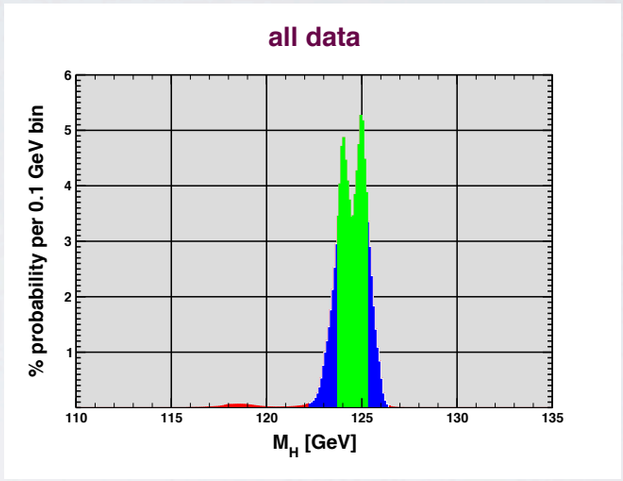

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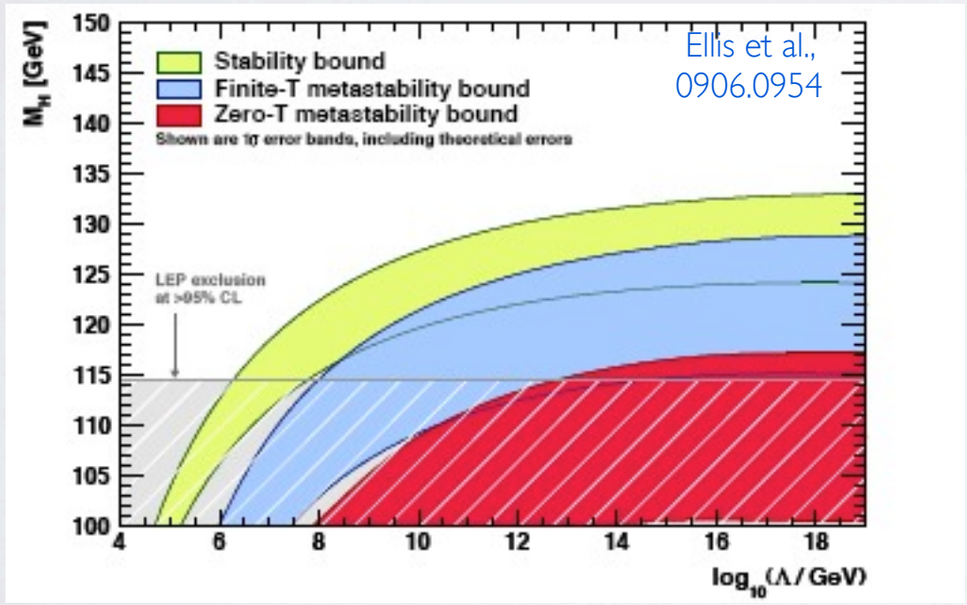

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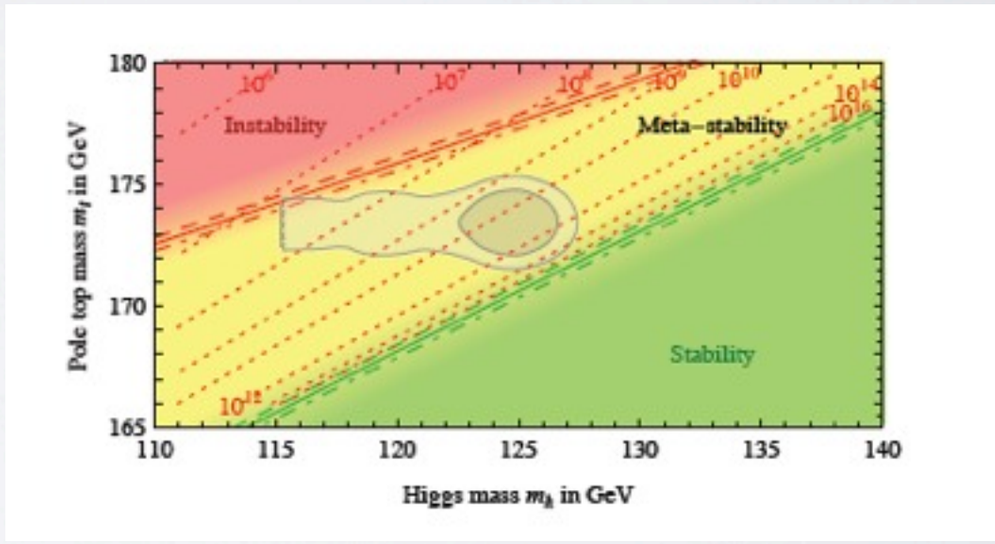
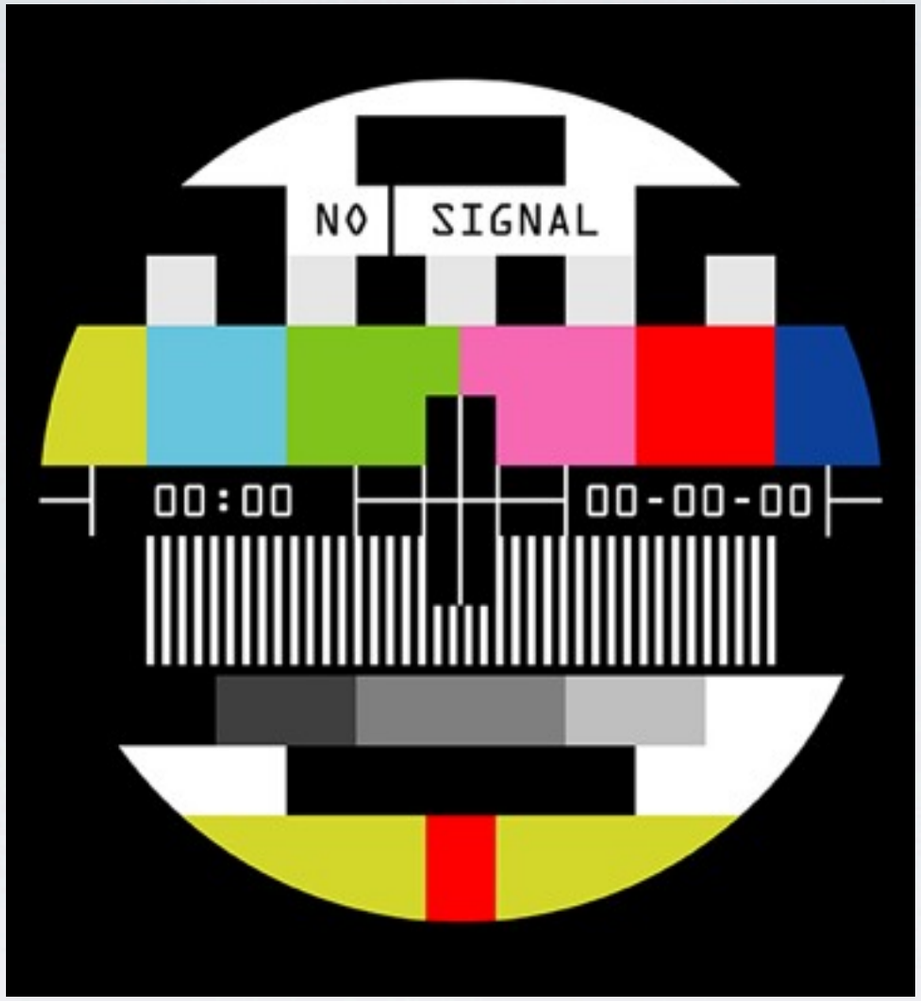


Elias-Miro et al., 1112.3022

SM at most valid up to 10^{12} GeV



NO SIGNAL AT THE MOMENT - BUT STAY TUNED

SORRY FOR NO EASTER-HIGGS

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