13 TeV: The Final Frontier...

Fermilab
UIC University of Illinois at Chicago

...for now!

Richard Cavanaugh, Fermilab / UIC

LPC JetMET Workshop
27 February, 2014

LPC LHC Physics Center

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    - First time in history that we have been able to do this!!

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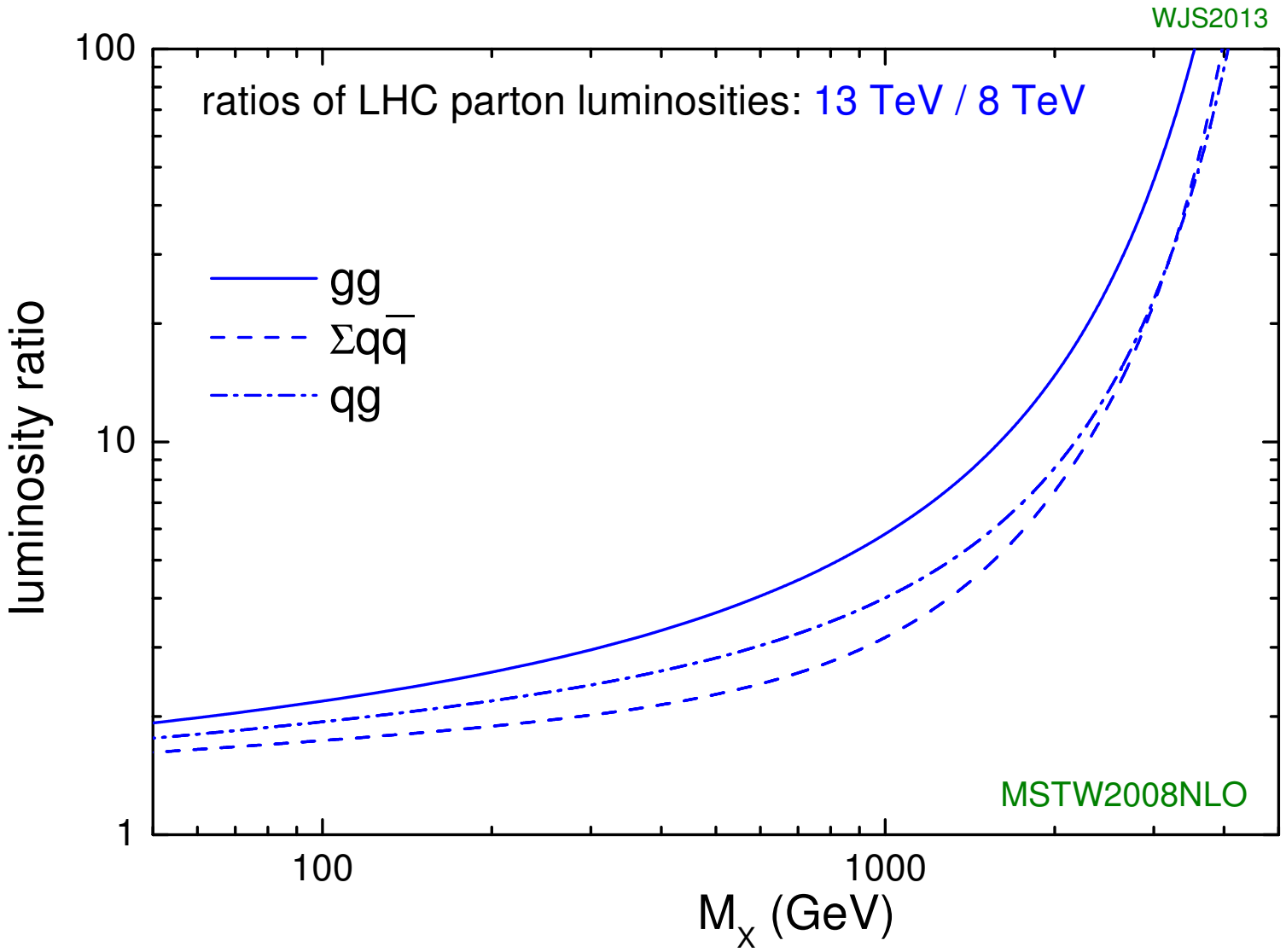
- **This talk is neither an exhaustive nor an official list of 2015 CMS physics goals!**
  - It is an incomplete overview of "some" of the analyses which are possibly interesting! ...sprinkled with some personal opinions...
  - Example: I believe that boosted objects, jet-substructure, etc, will play a transformative role in the 2015 searches...but I don't discuss it in this talk (apologies!).

8 TeV compared with 13 TeV



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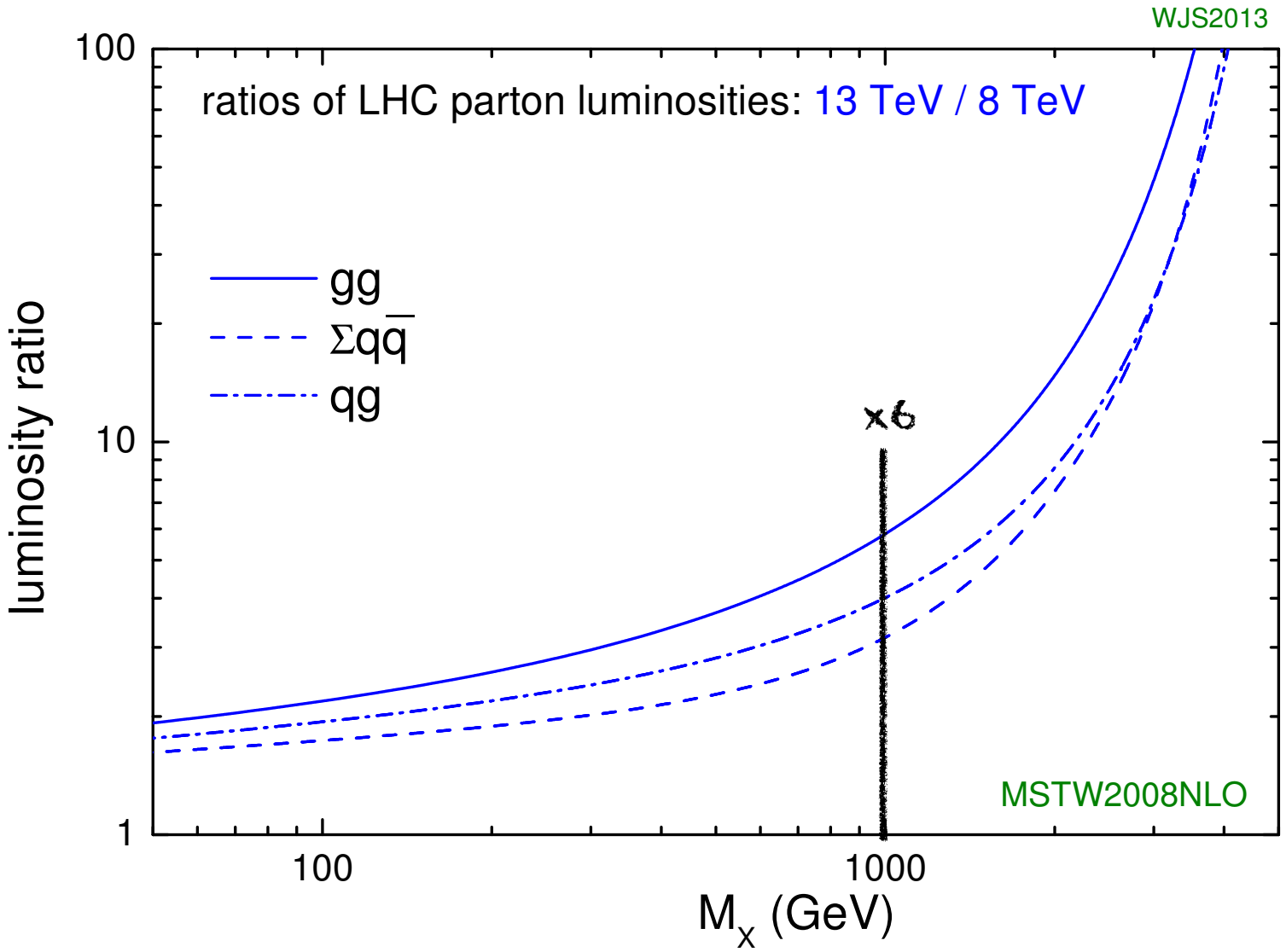

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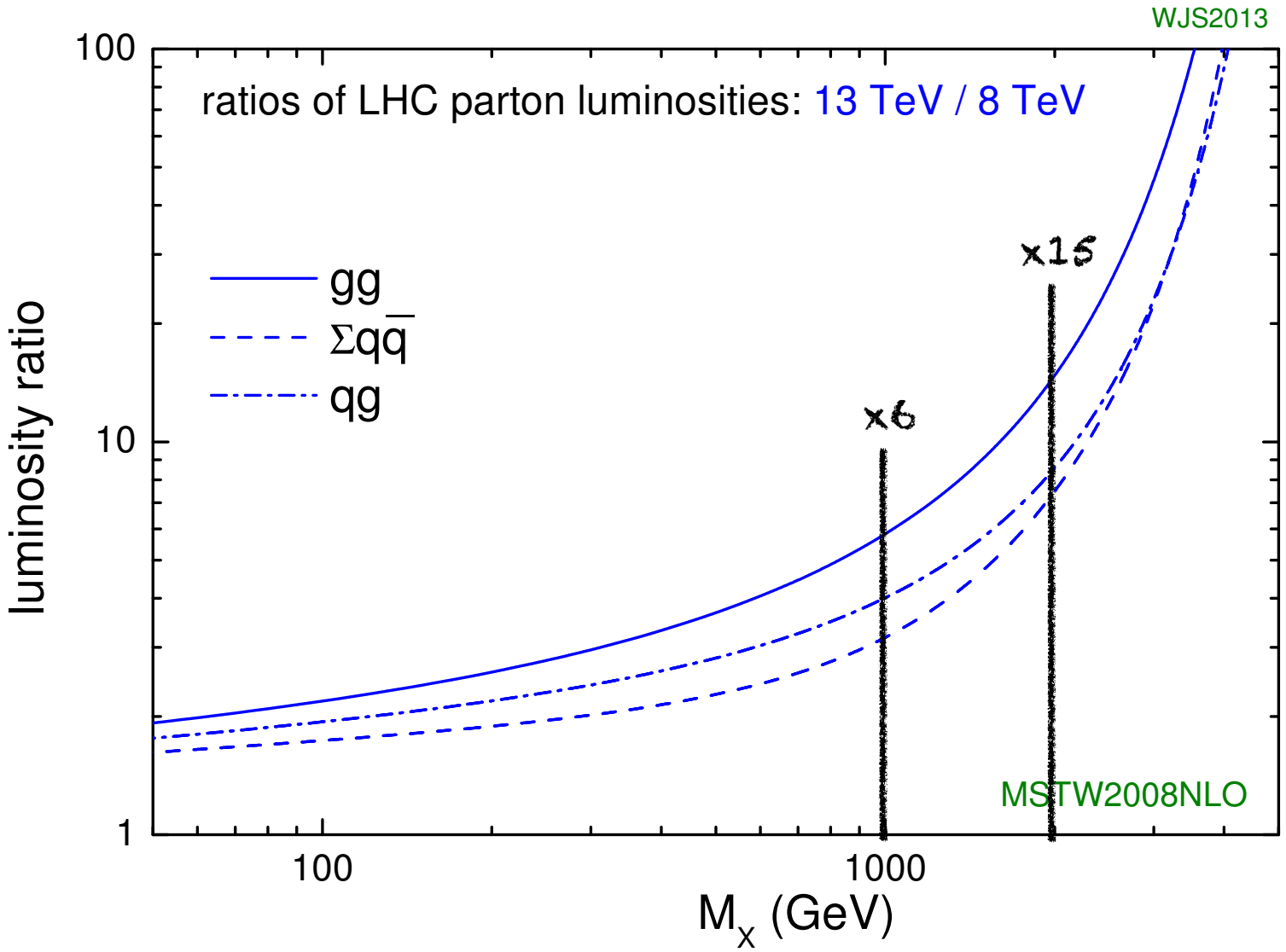

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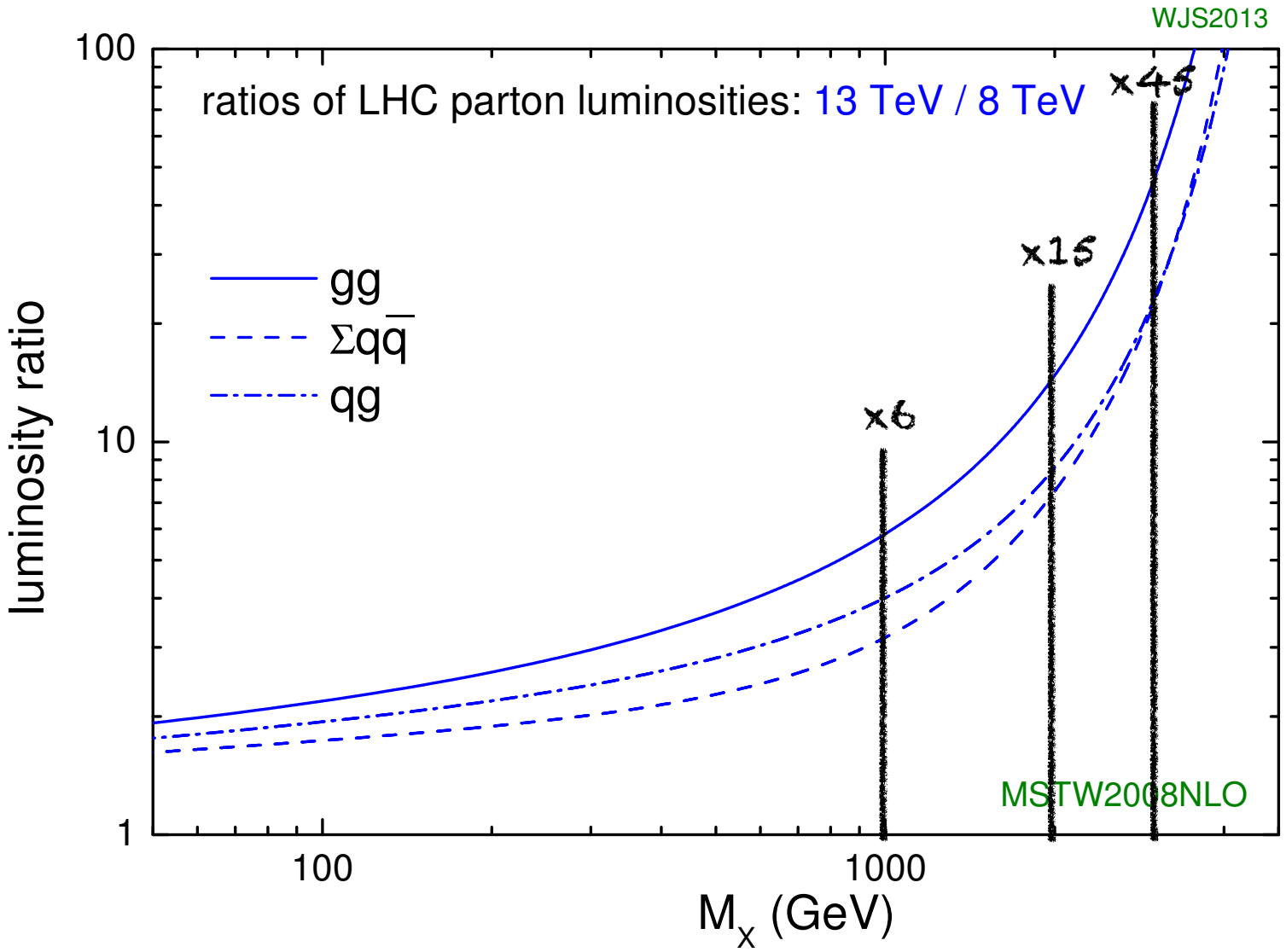

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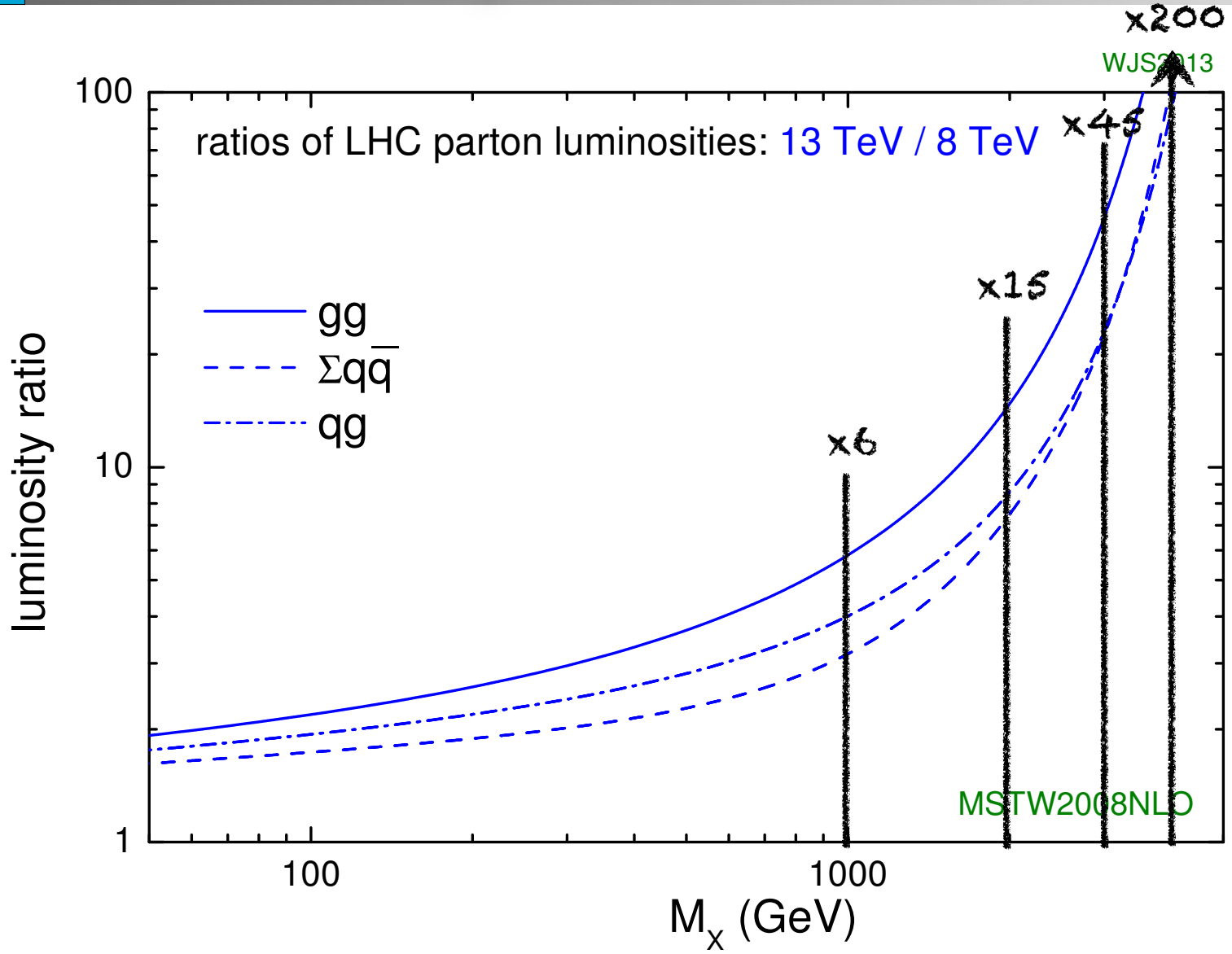

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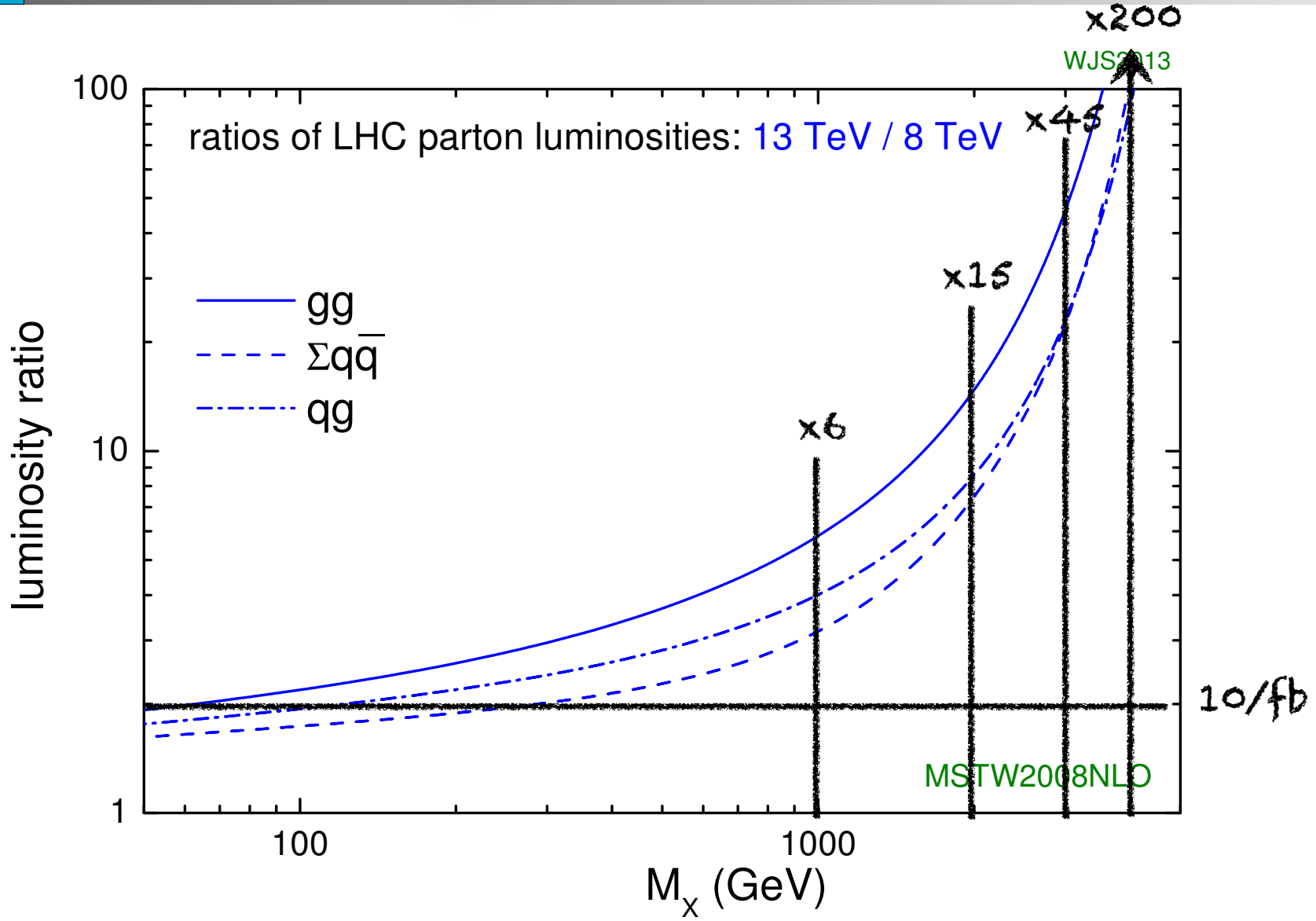

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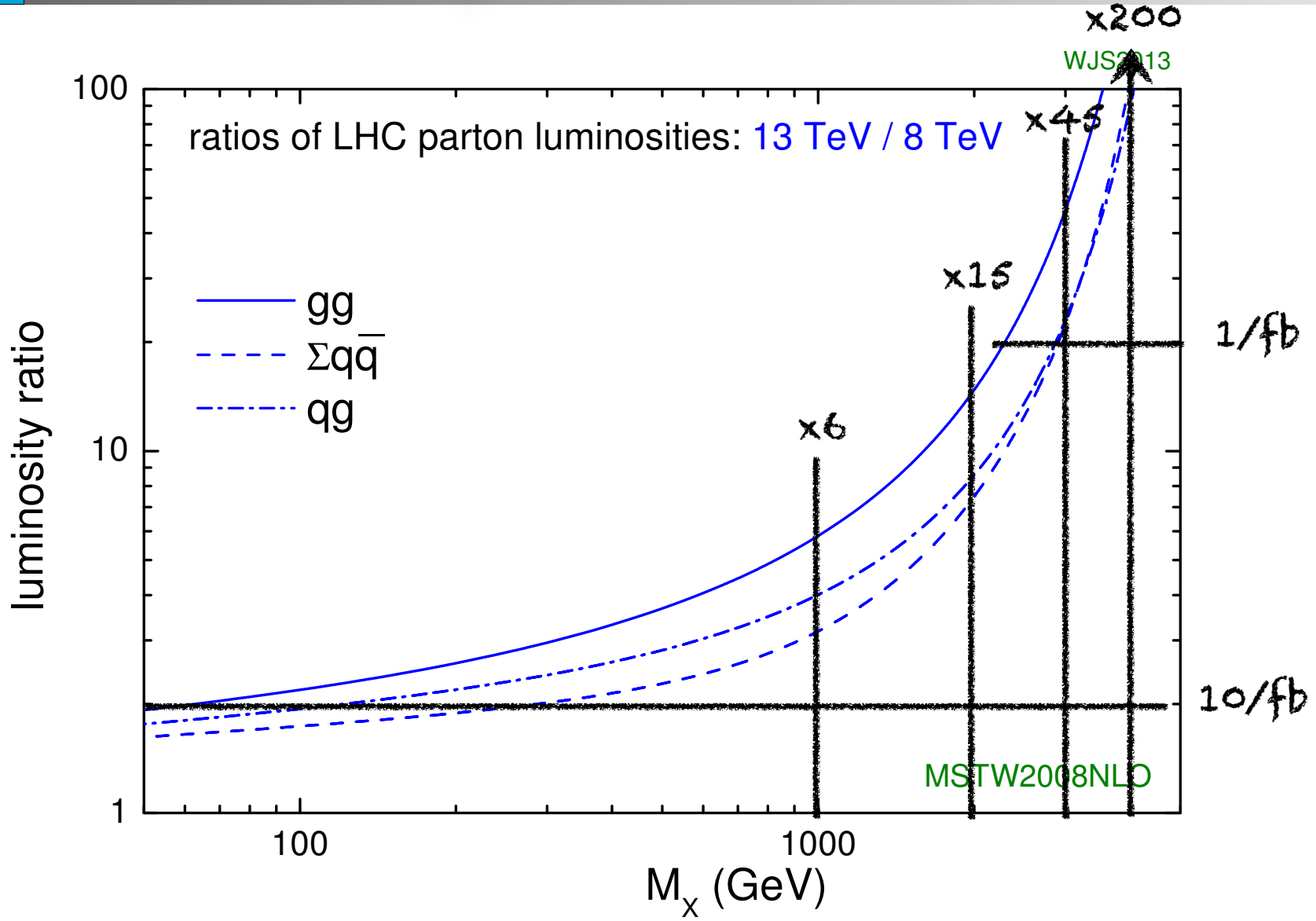

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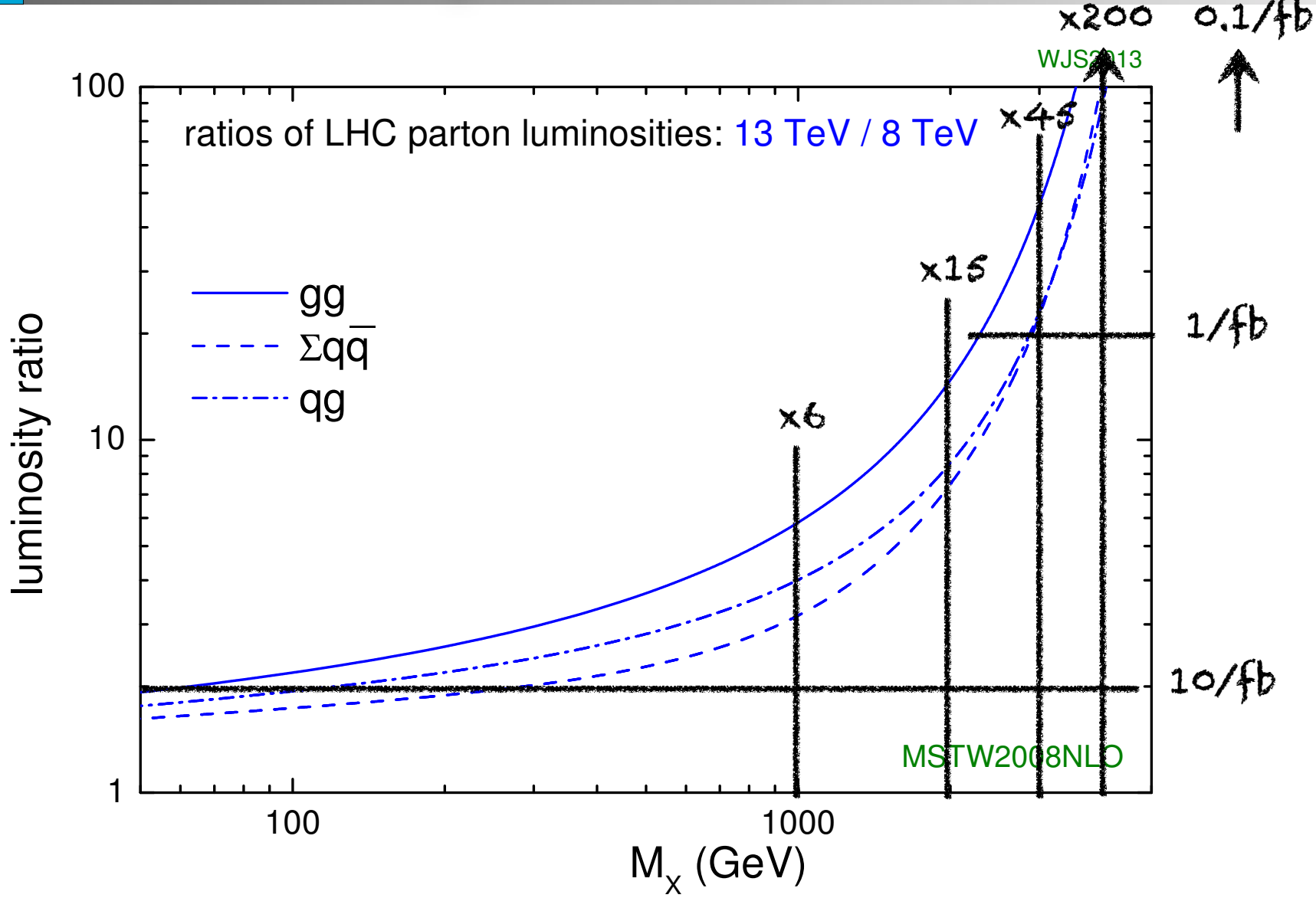

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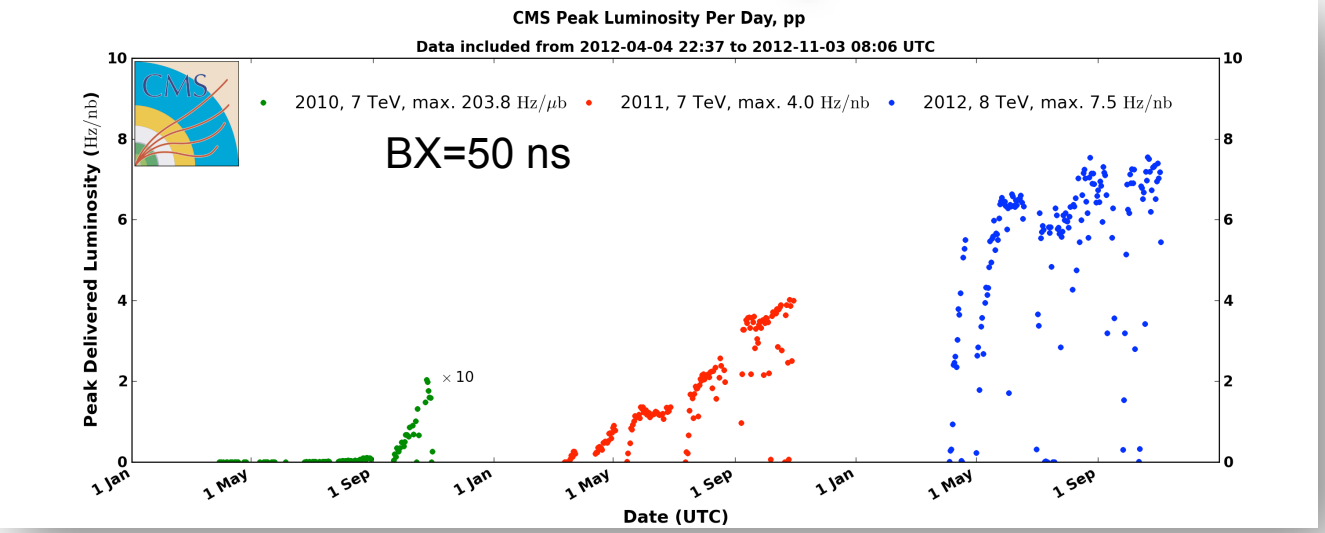

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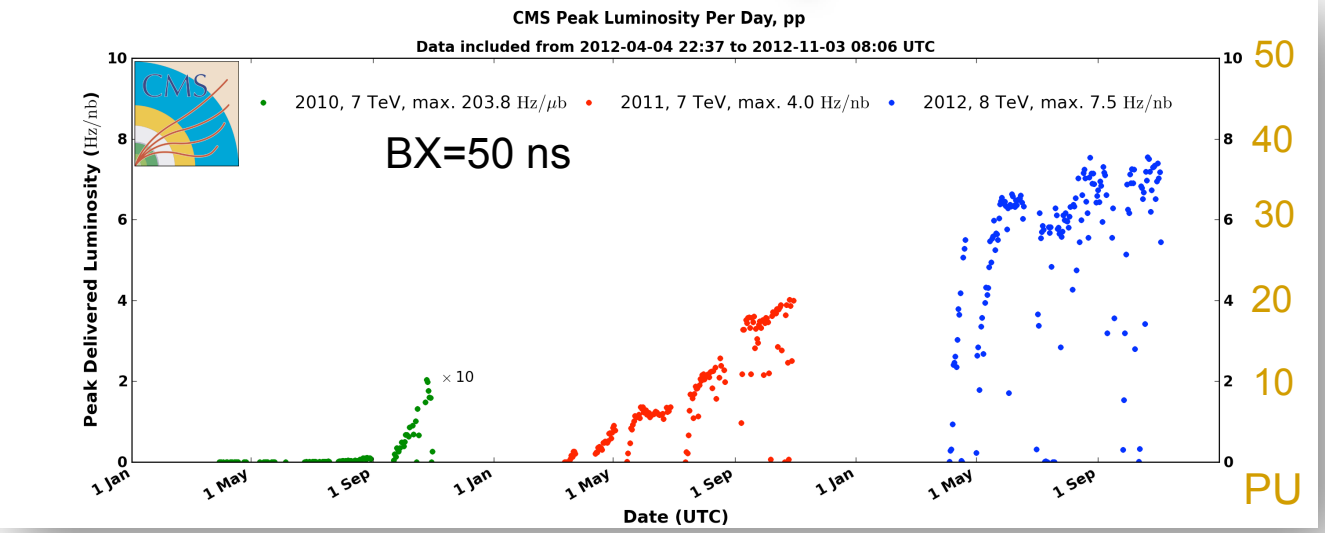

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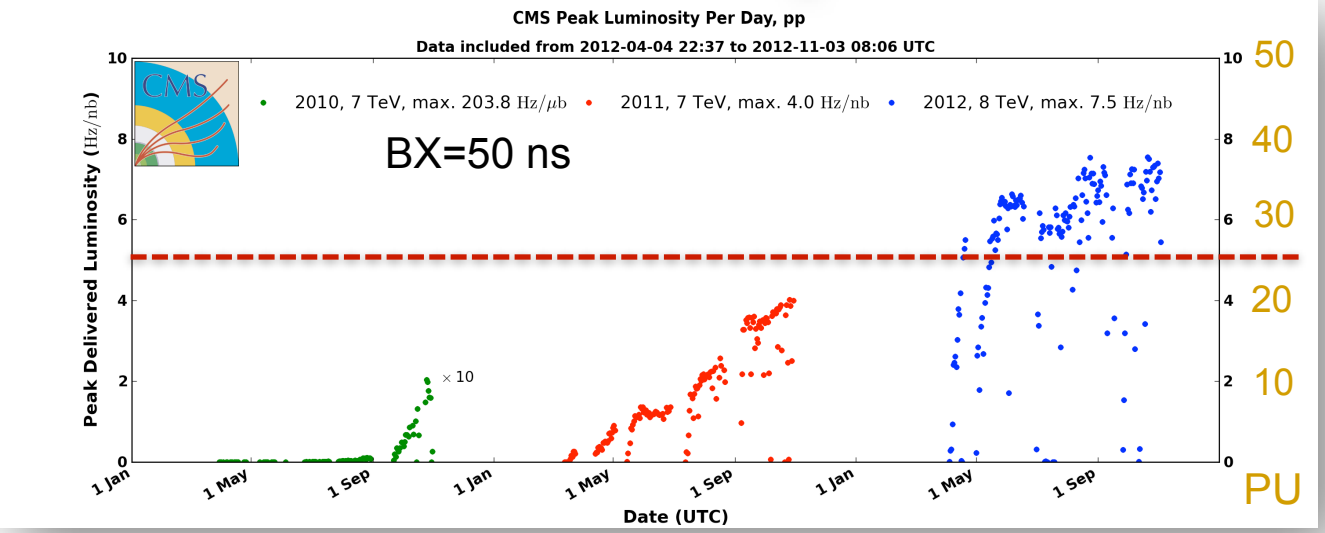

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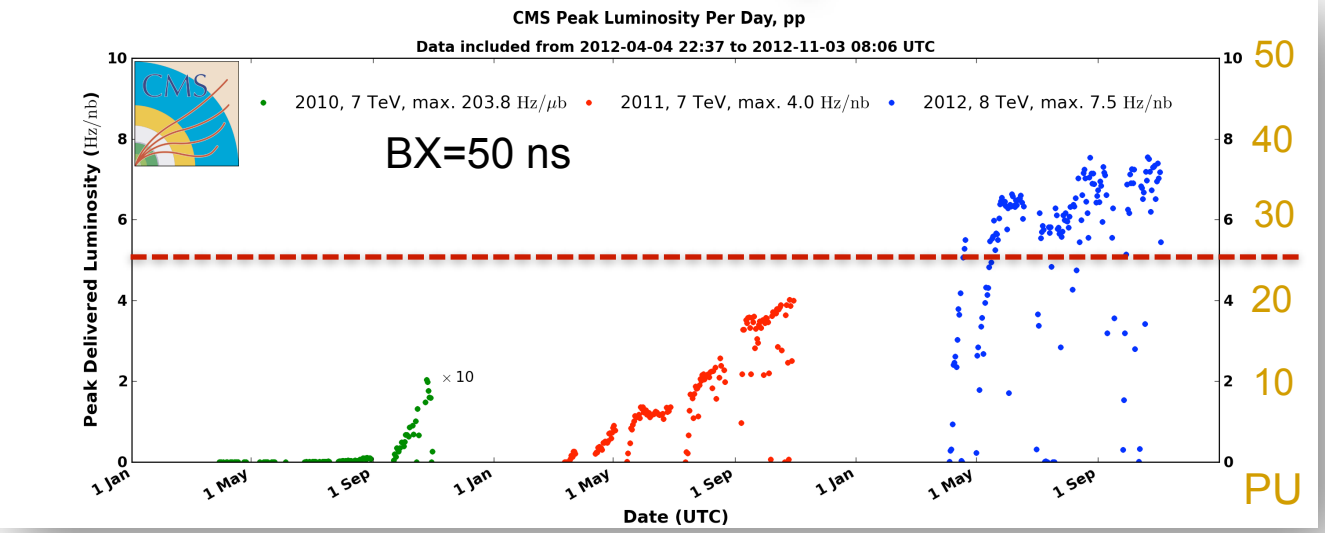

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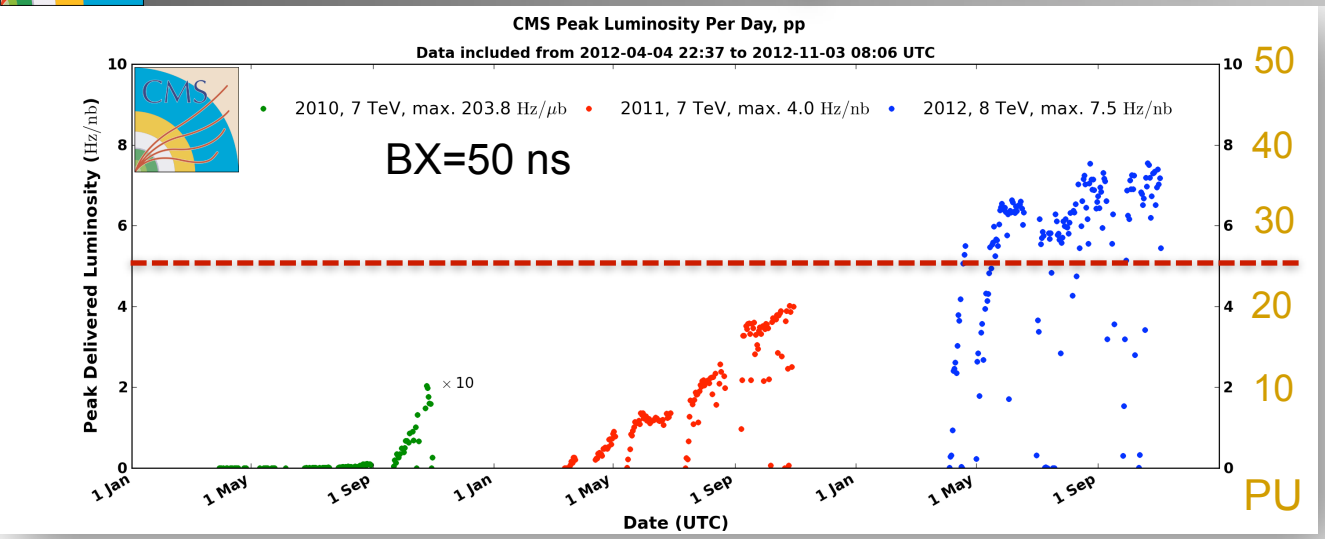

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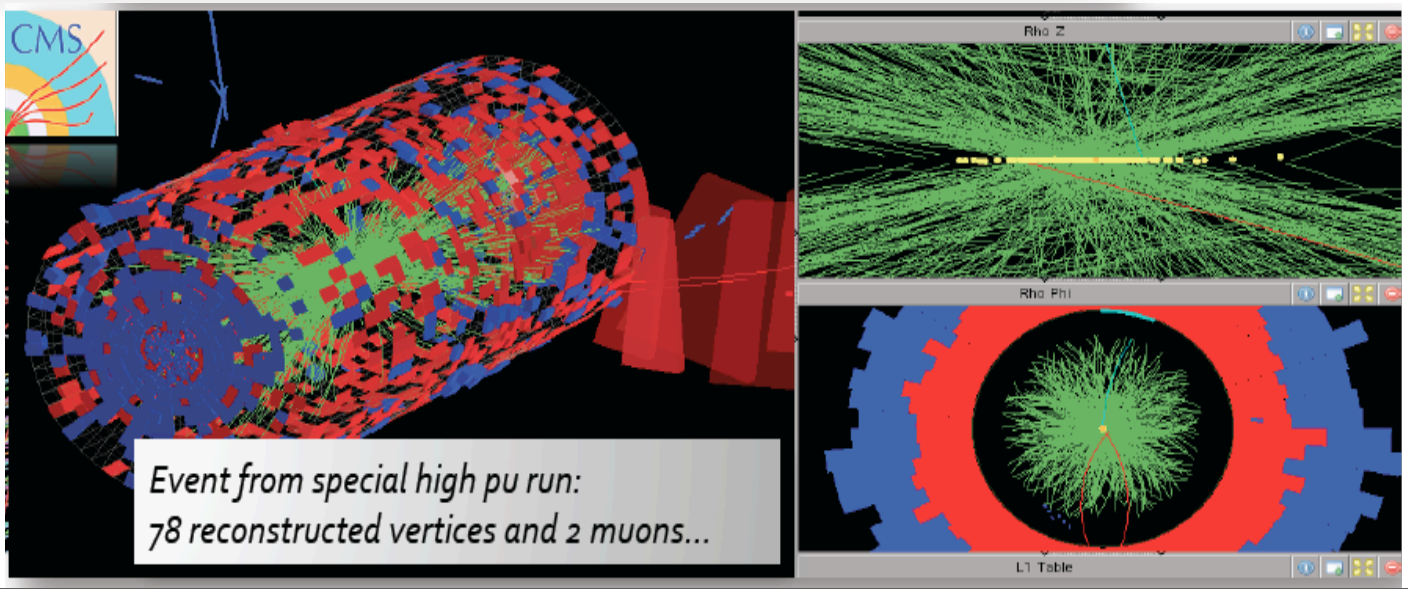
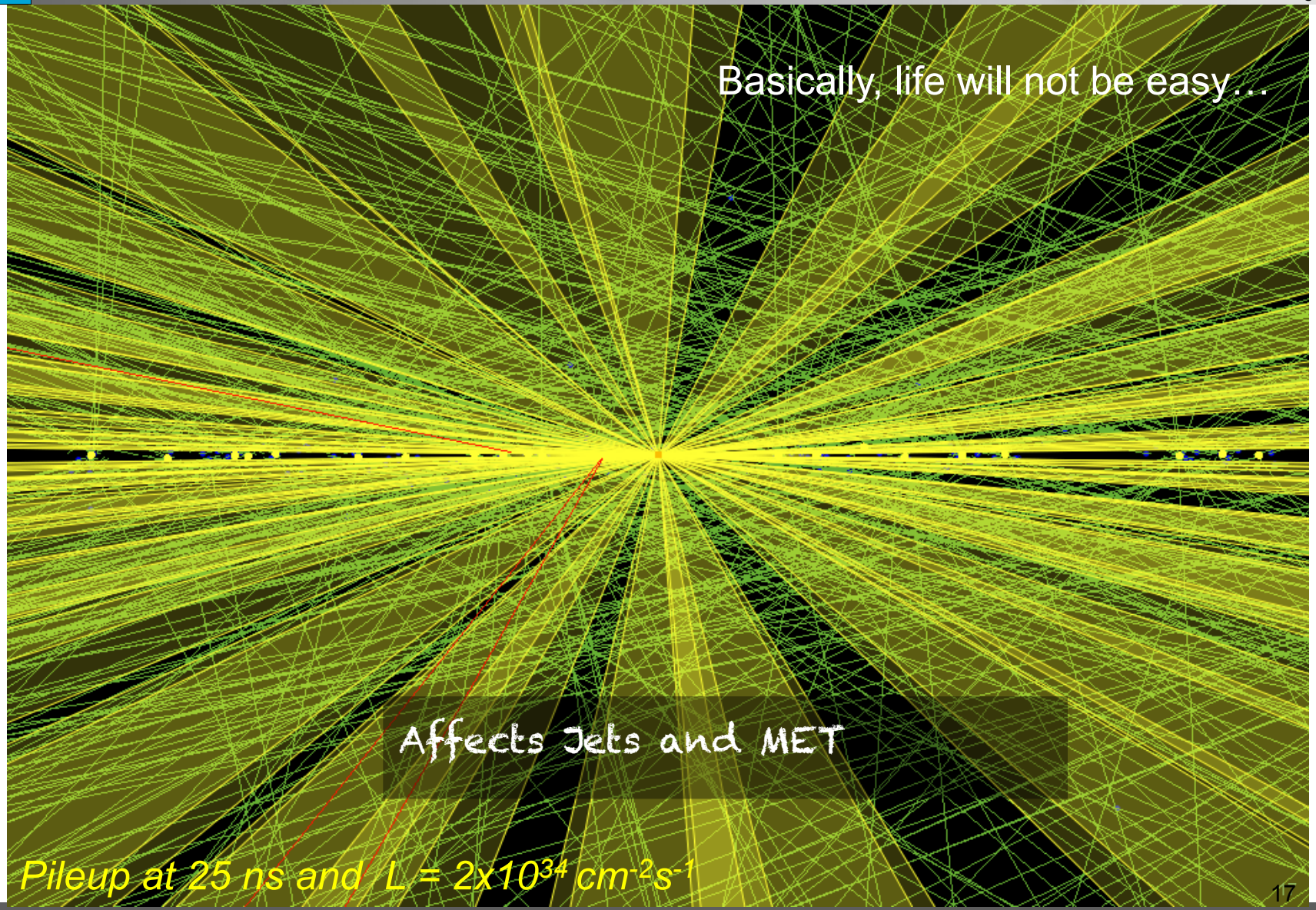


Pile-up at Design Luminosity



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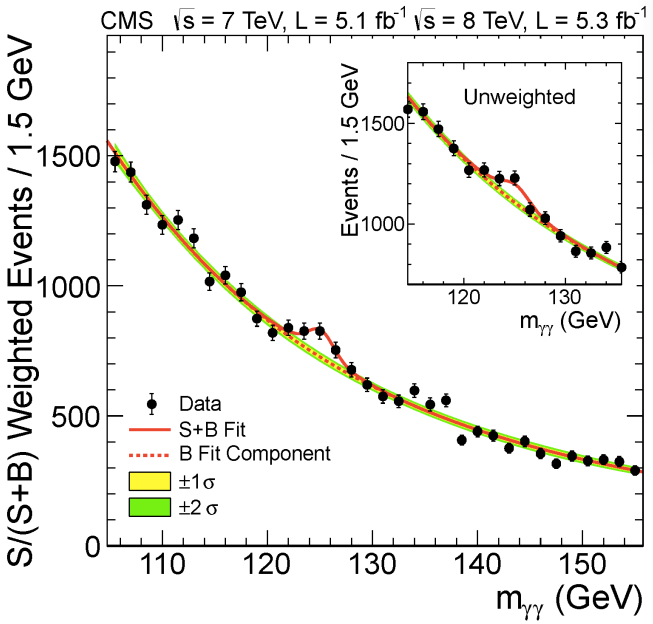

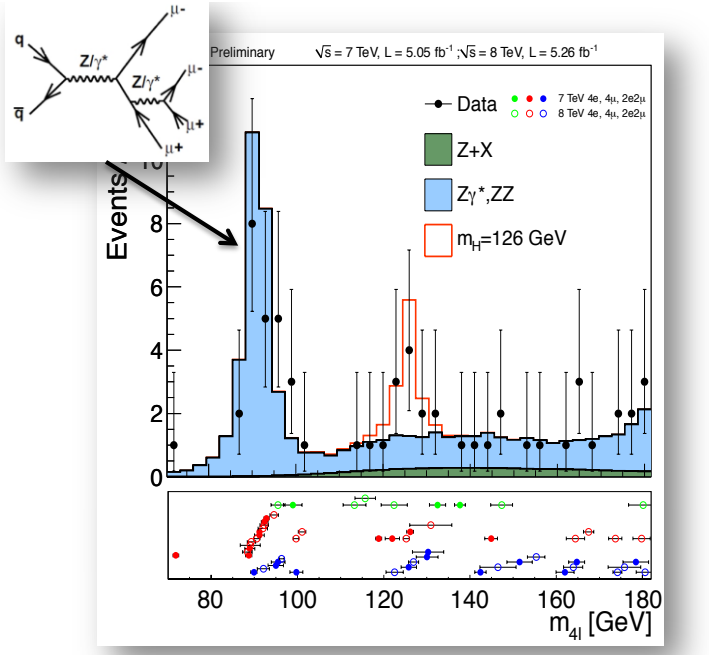

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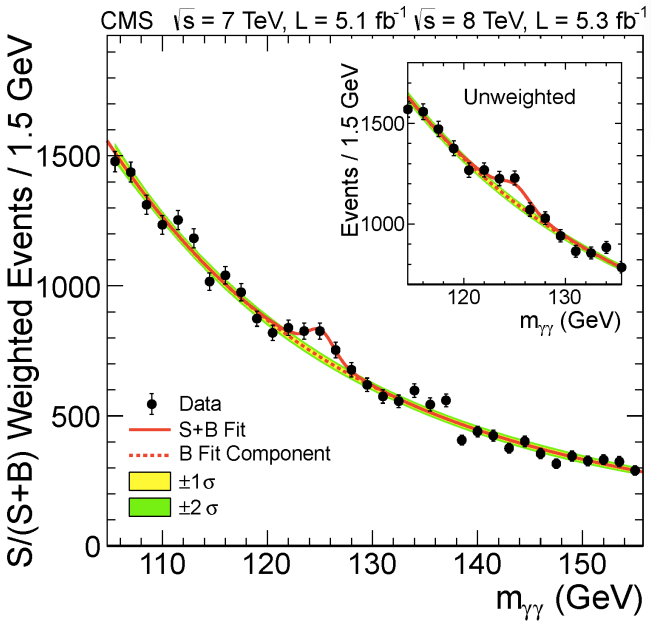

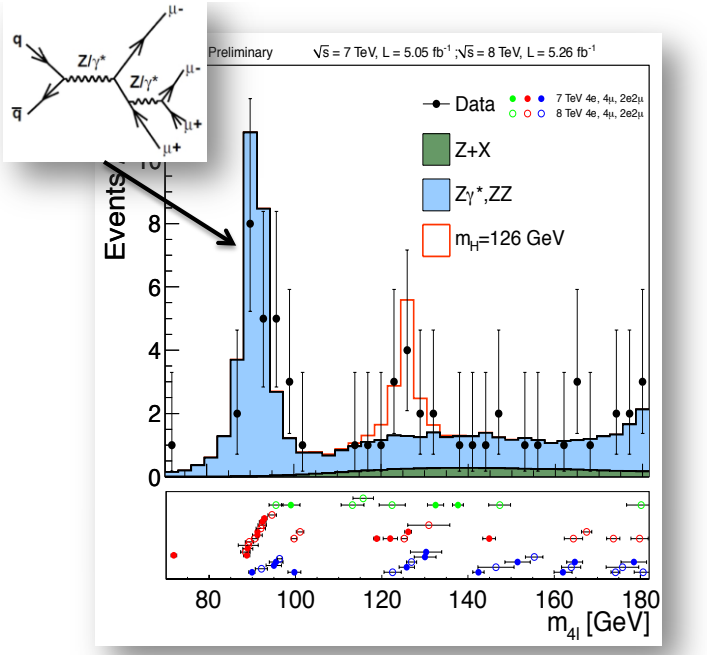

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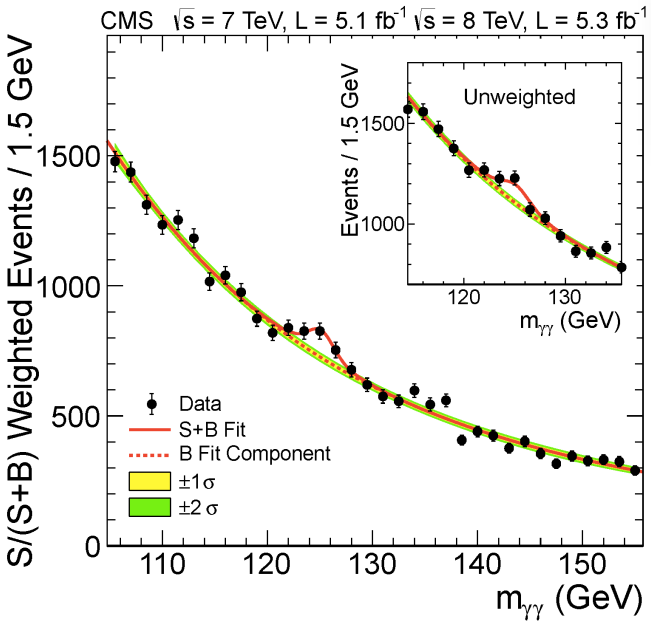

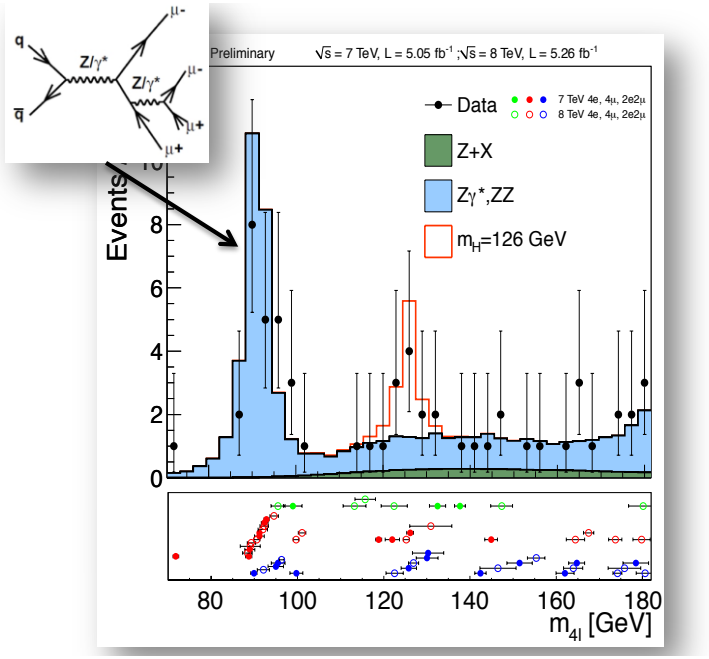

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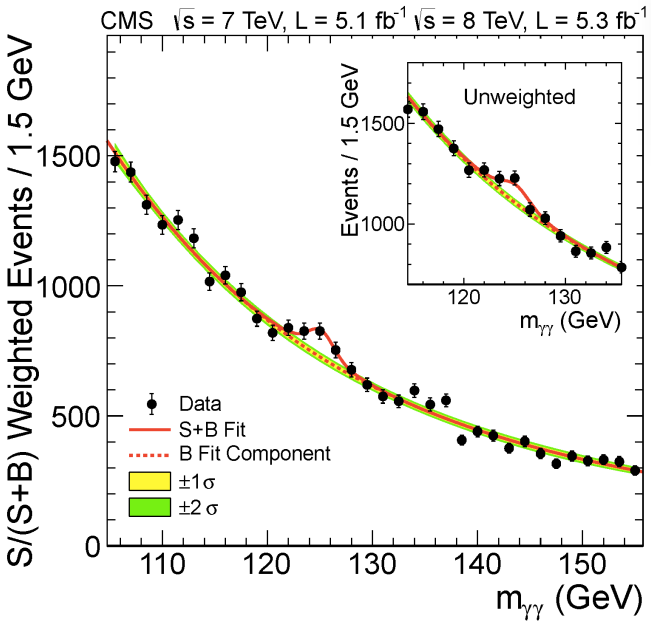

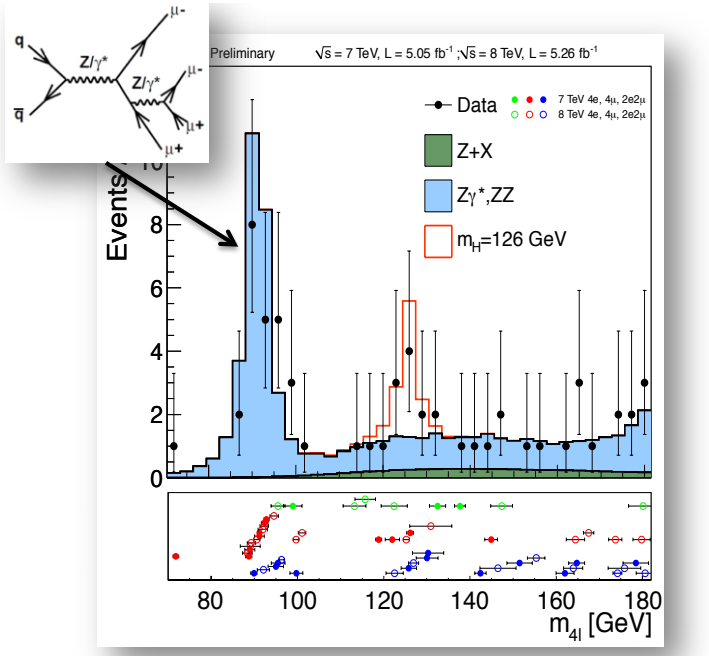

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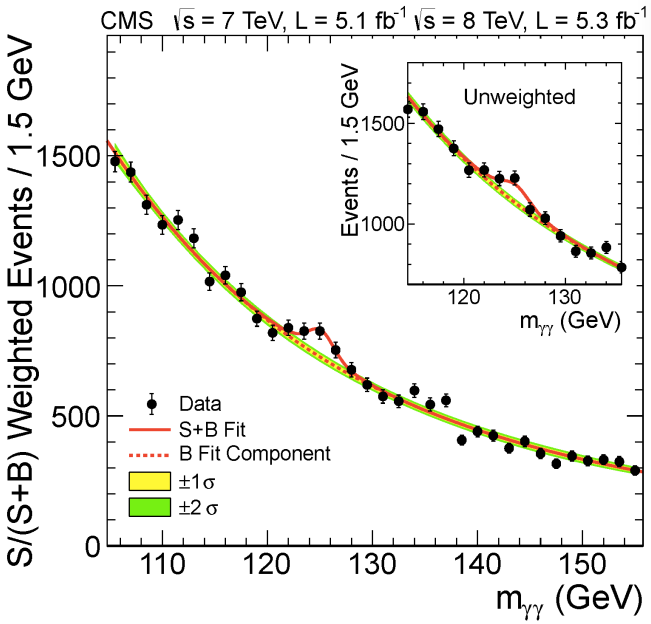

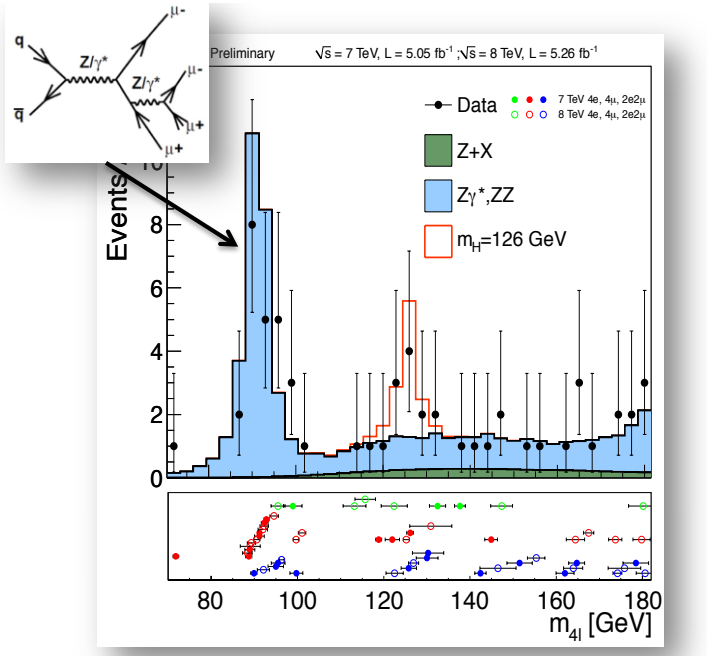

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4 July, 2012: The dawning of a new age!

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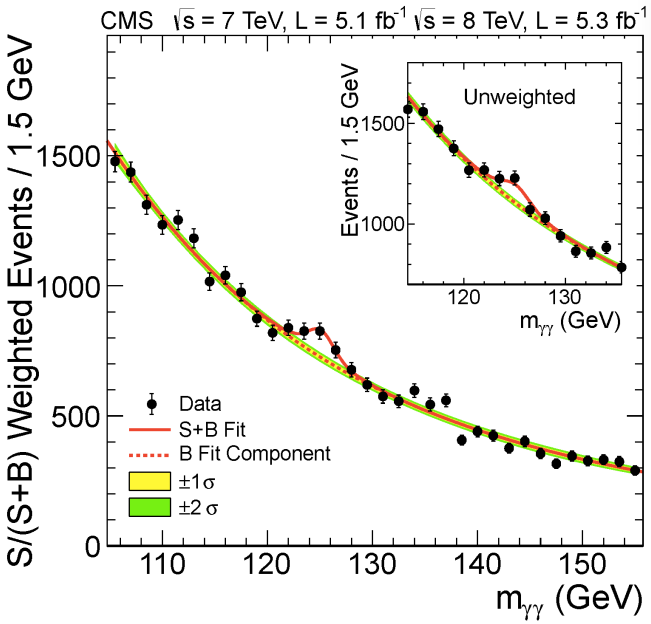

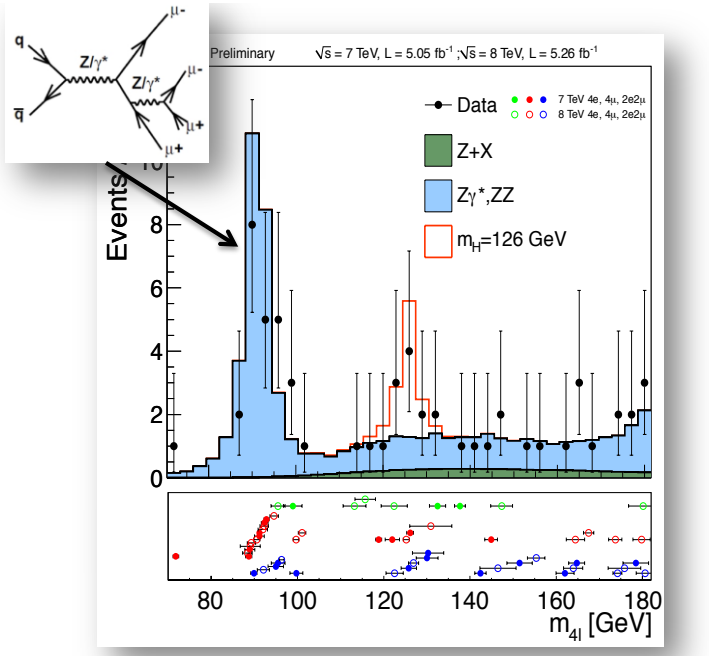

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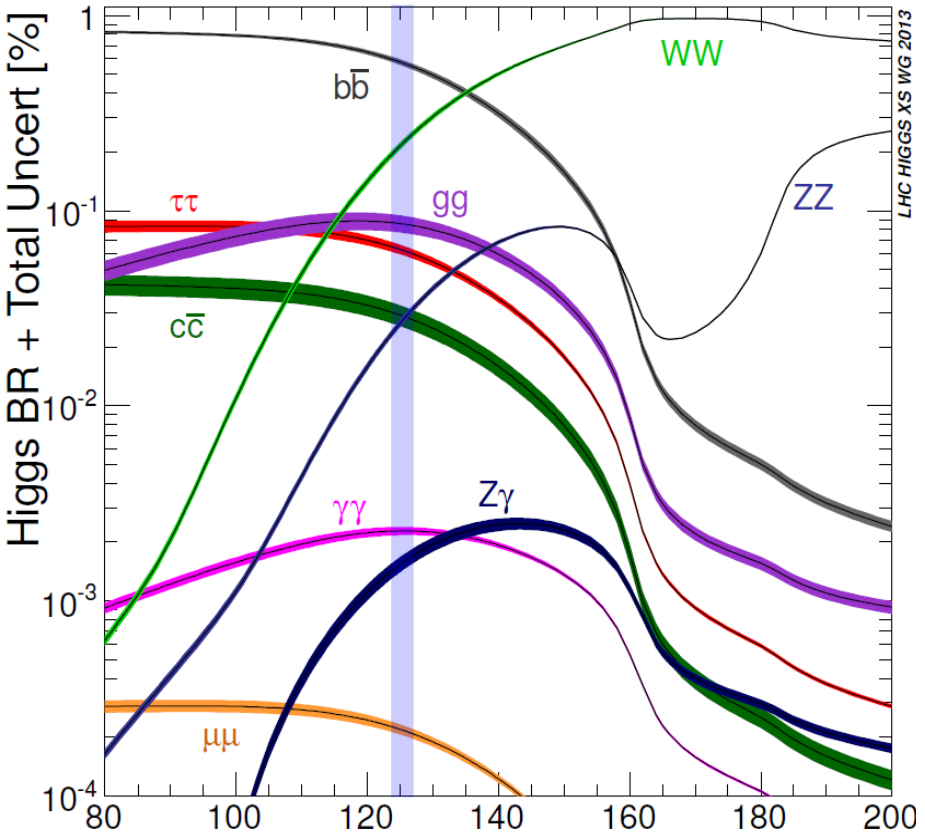
- **Either spin-0 or spin-2**
  - could (in principle) be higher spin, but really disfavoured

Does it behave like a Higgs boson?

- **Does it couple like the Higgs boson? (i.e. to mass)**
- **What is it's spin and CP?**



Coupling to particles

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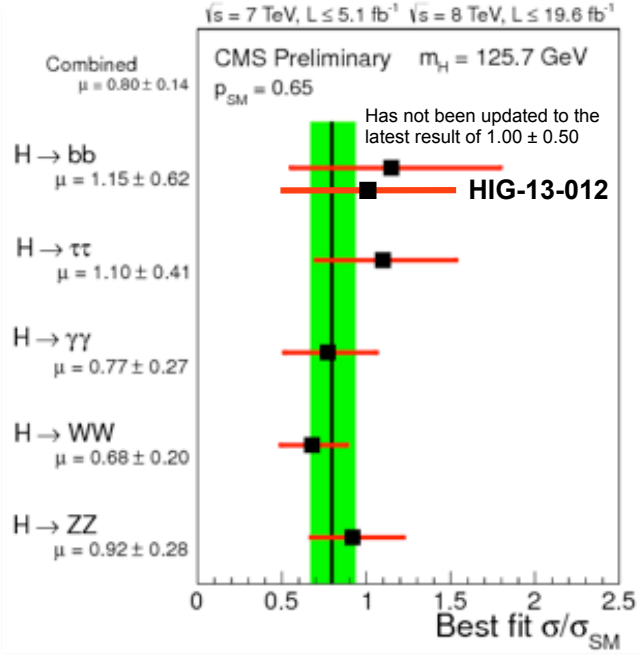
CMS PAS HIG-13-005



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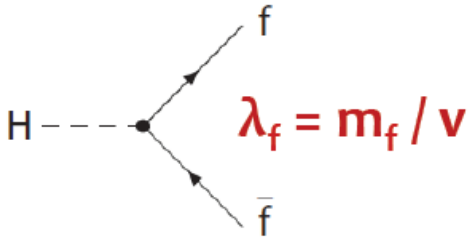
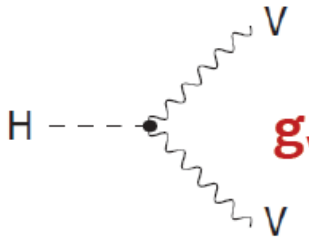


$\lambda_f = m_f / v$



$g_V = 2 m_V^2 / v$

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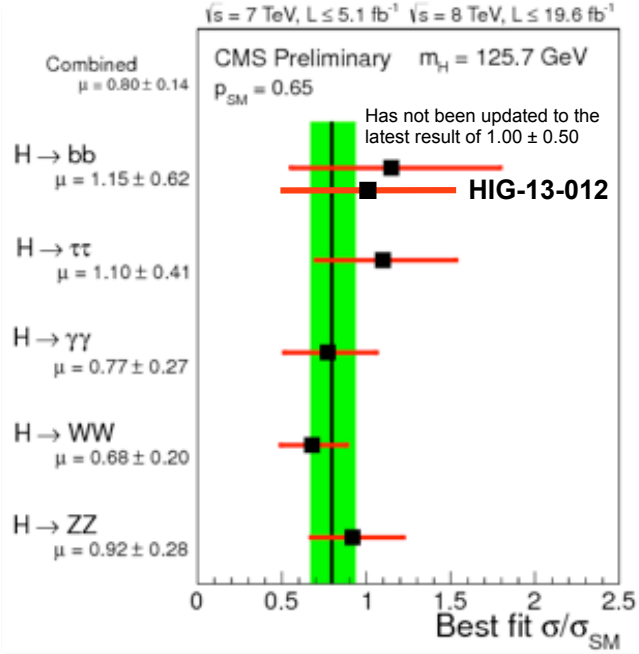

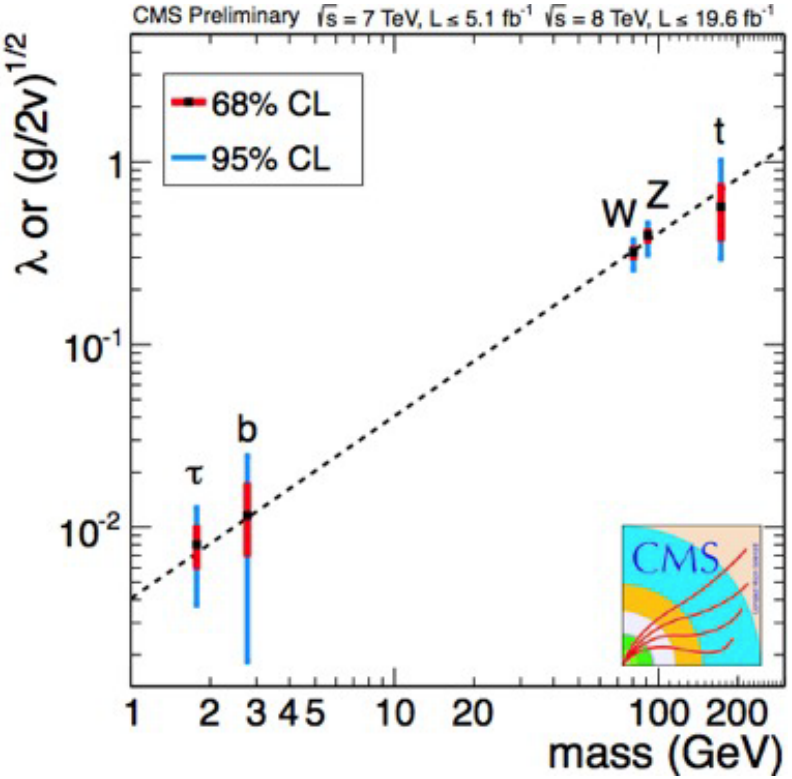

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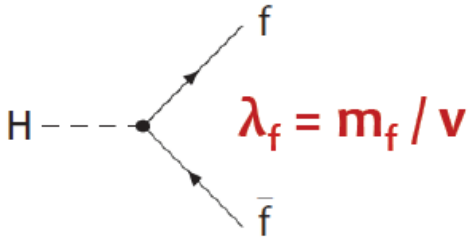

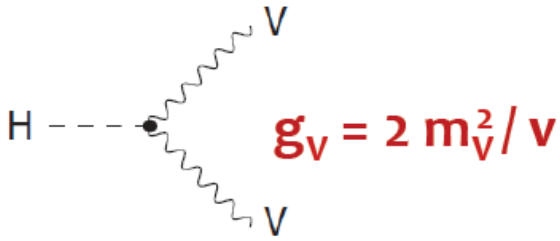

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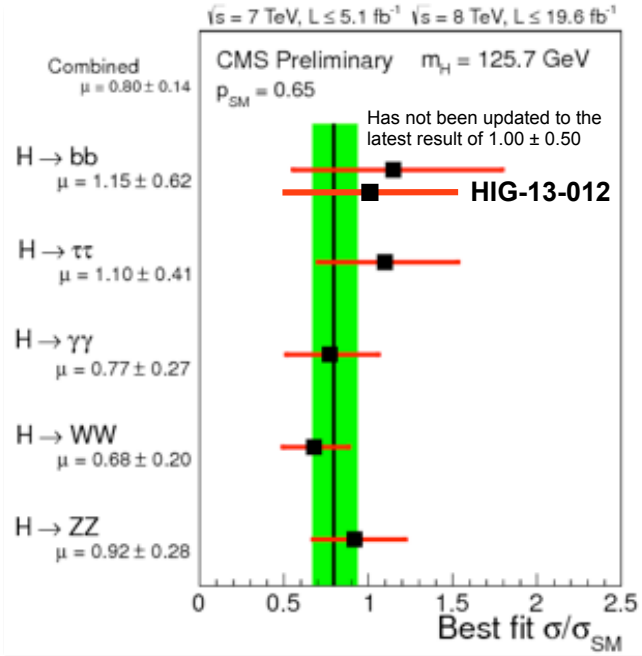

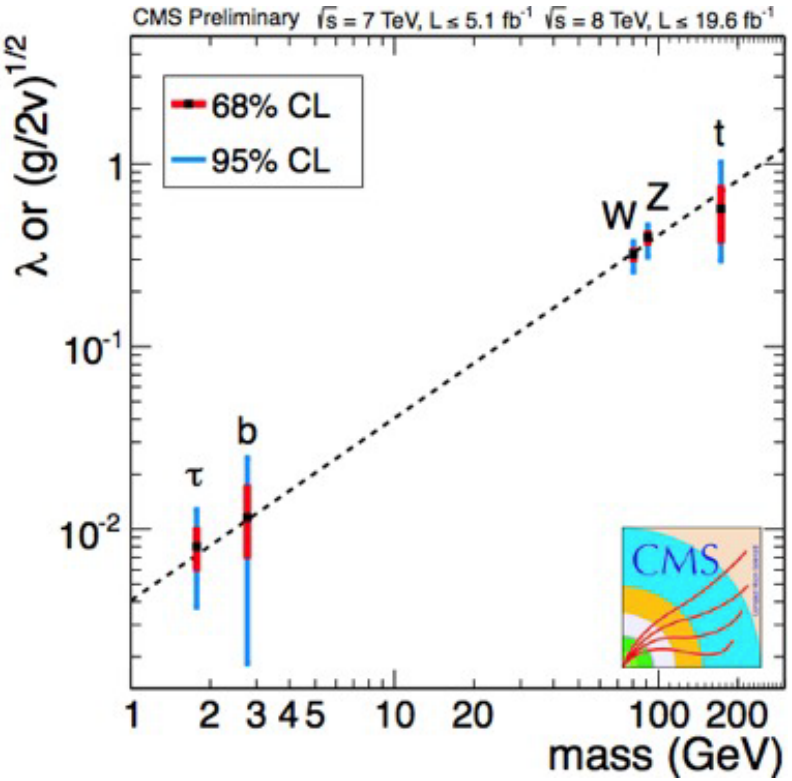

Yes! It couples to mass!

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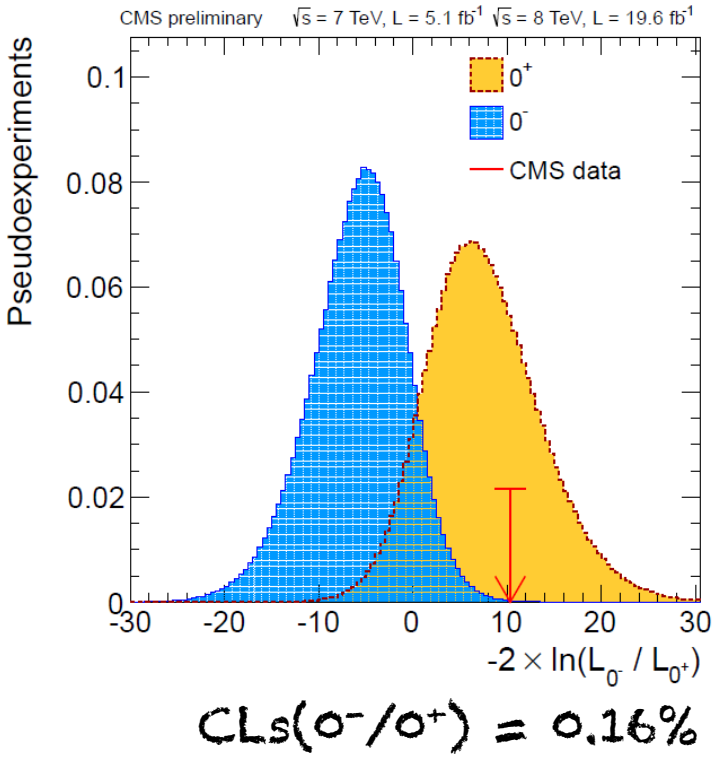

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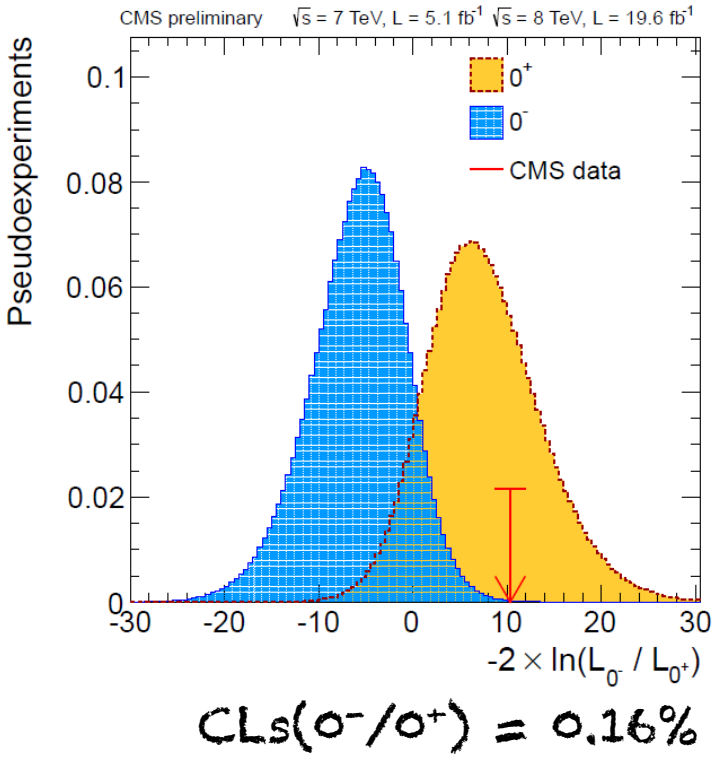

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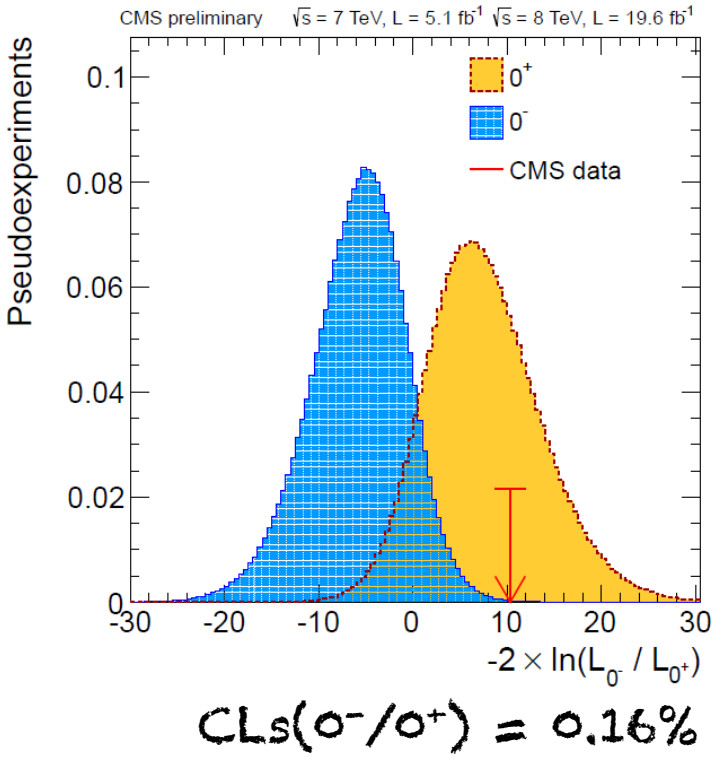

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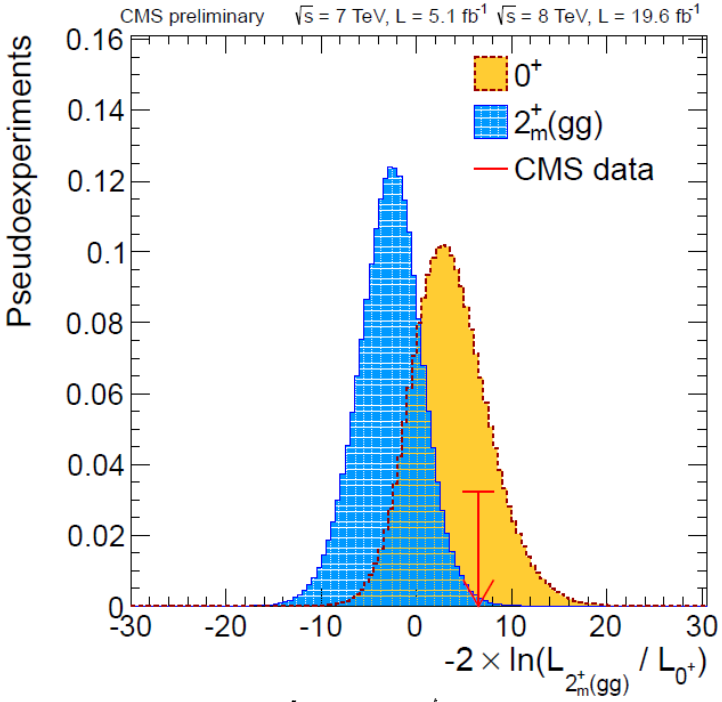

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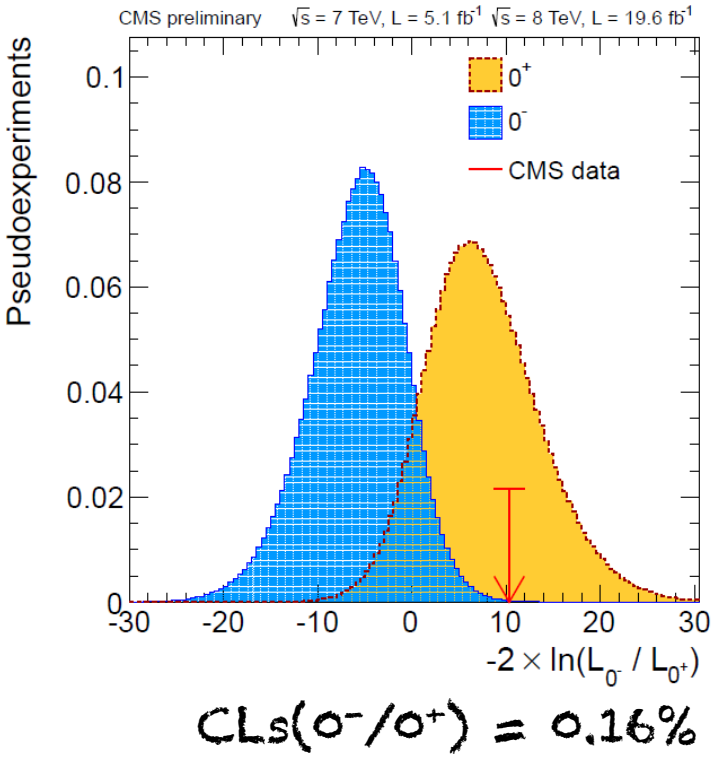

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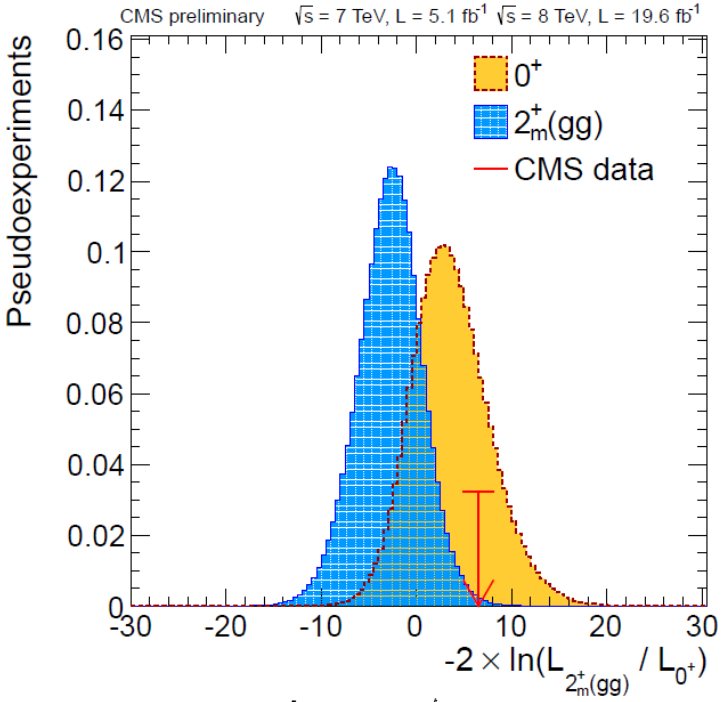

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Yes, it is a scalar!

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    - Multileptons will play leading role (and they are good for other things, too!)

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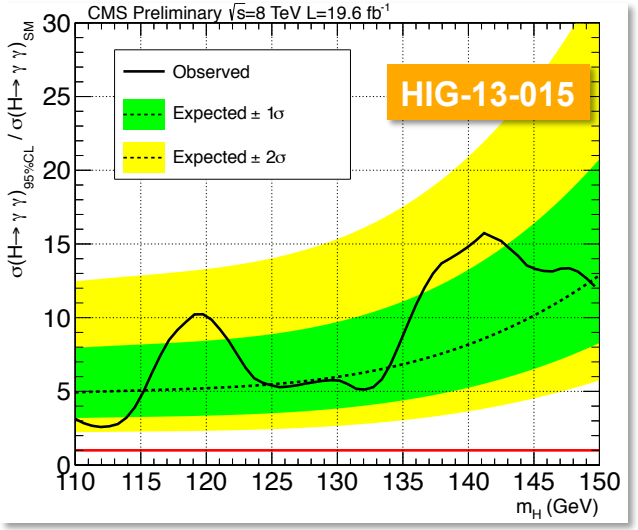

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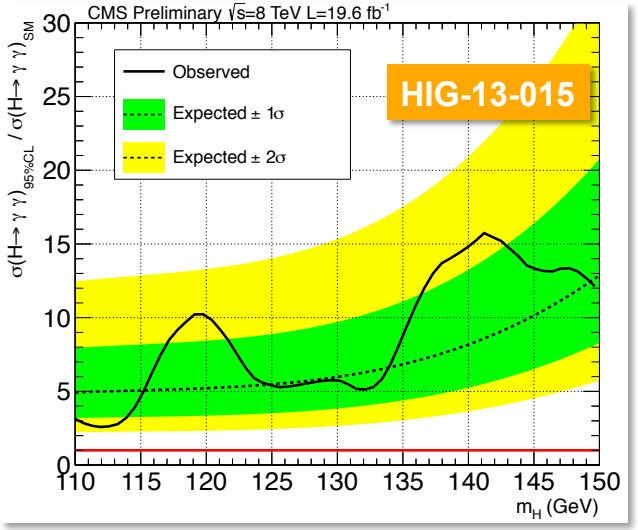

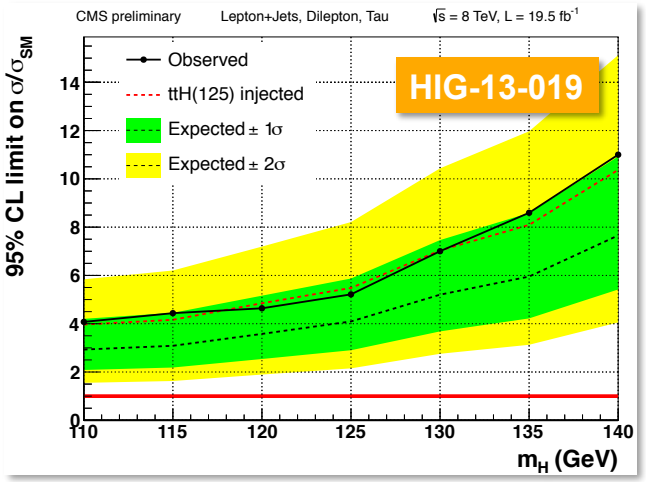

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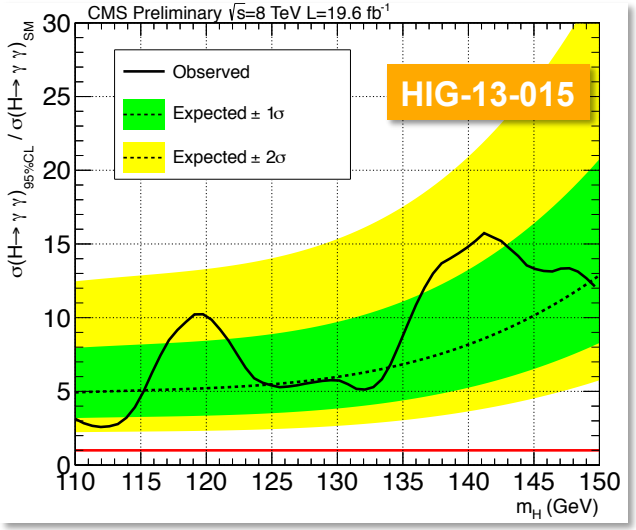
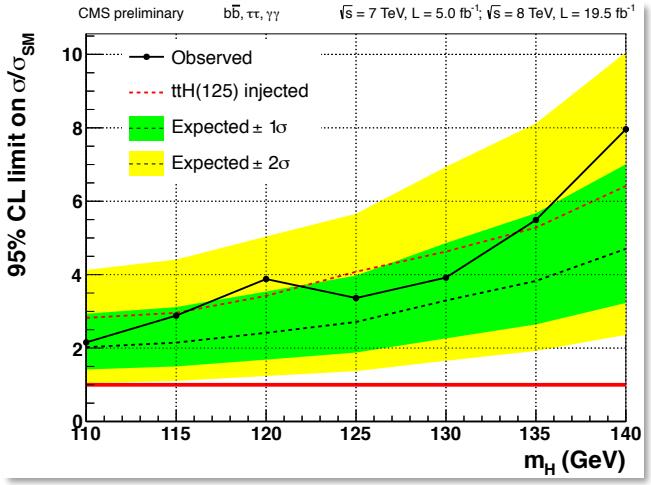
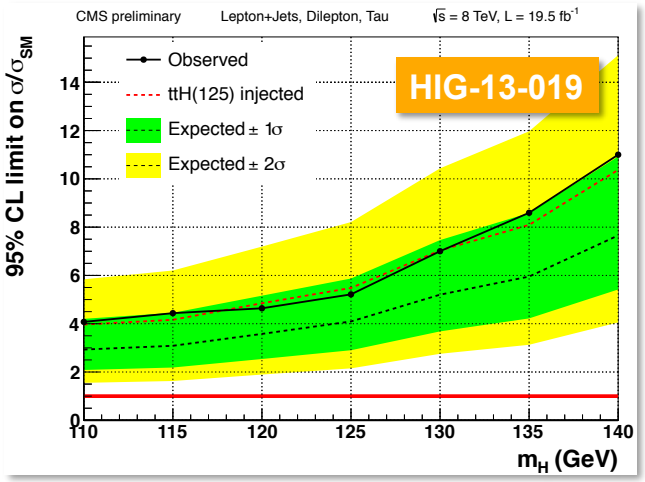


HIG-13-015+HIG-13-019+ arXiv:1303.0763





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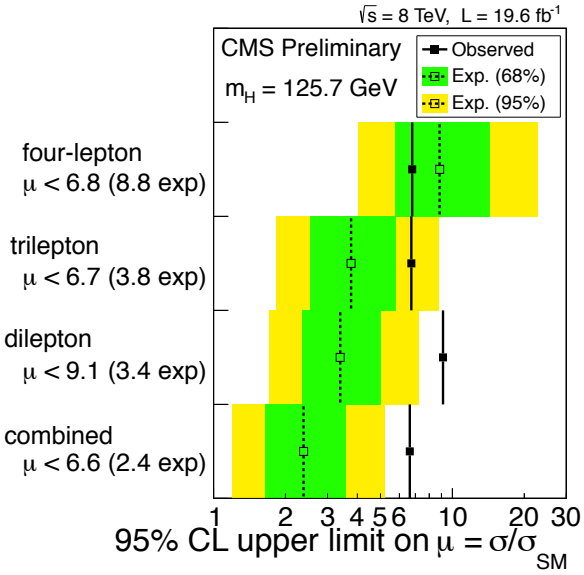
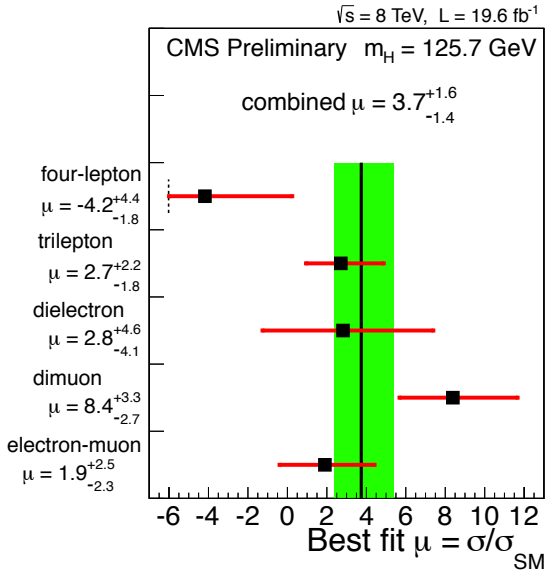
HIG-13-020





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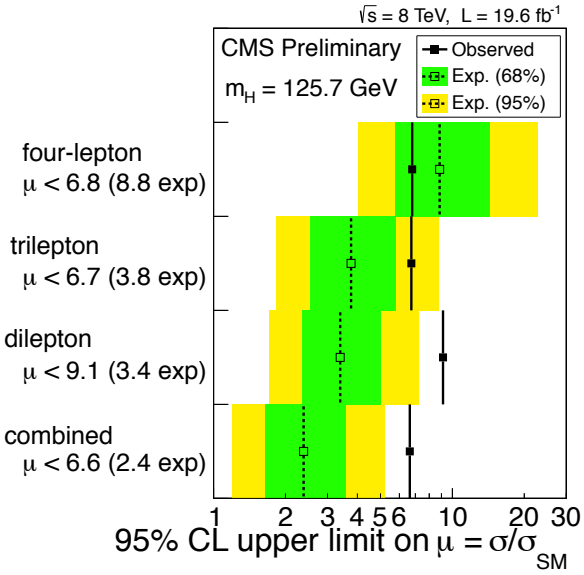

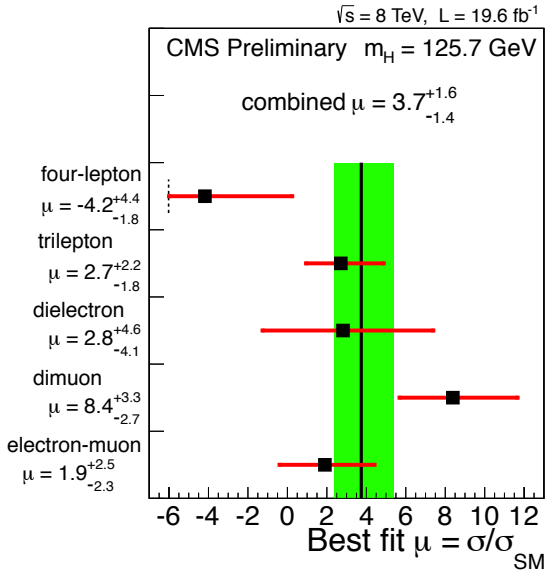

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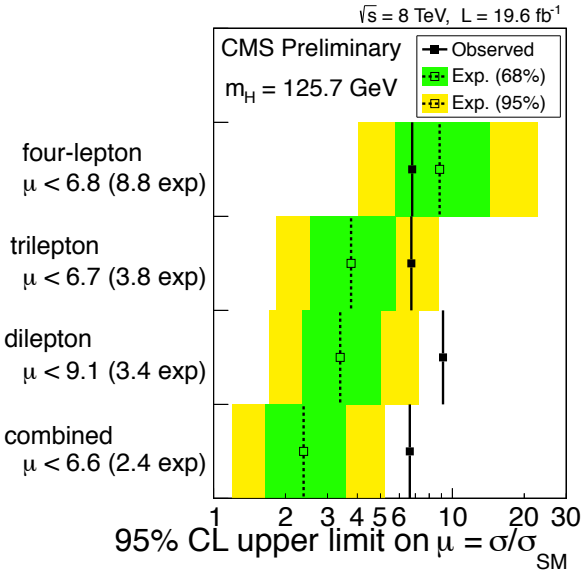

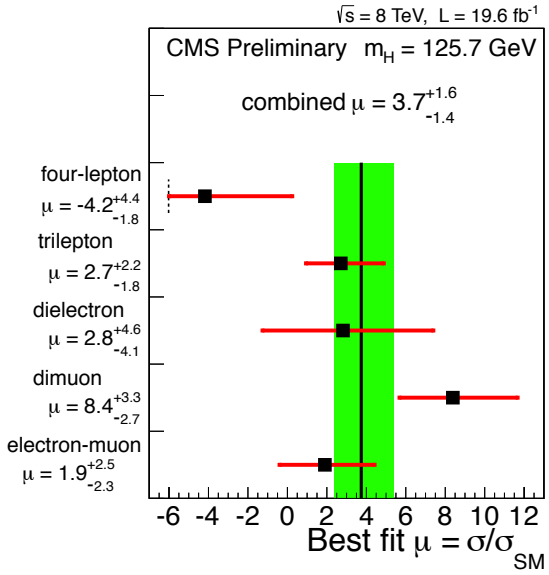

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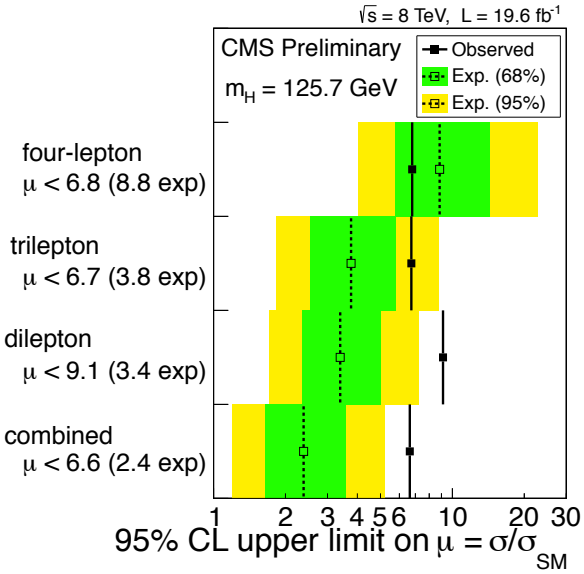
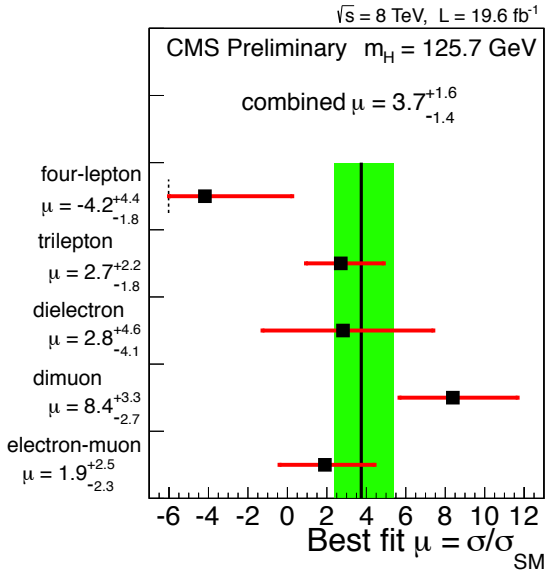
- The analysis has been approved earlier this month; the documentation and combination with the other ttH channels are being finalised

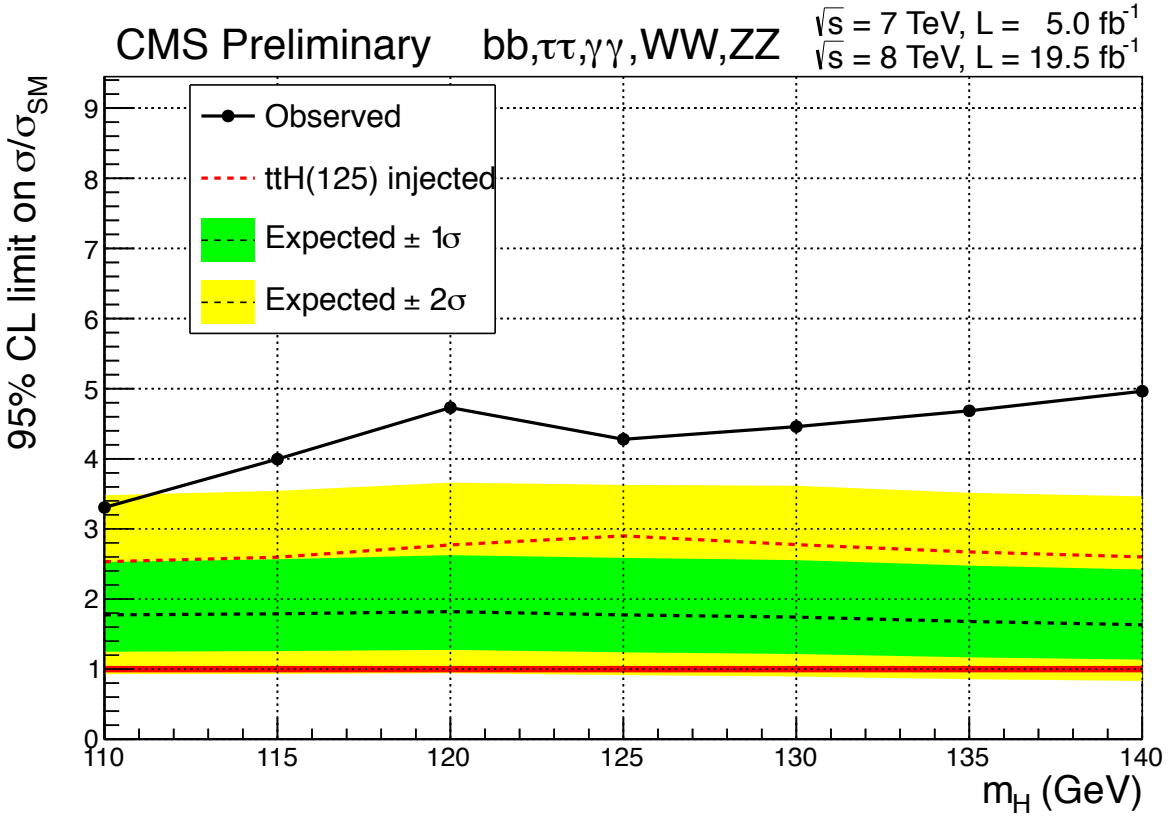
HIG-13-020





ttH Grand Combination

- **All channels combined**
- **Impressive expected sensitivity μ < 2 dominated by the multilepton final state!**
  - **Excess is driven by the dimuon excess in the multilepton analysis**



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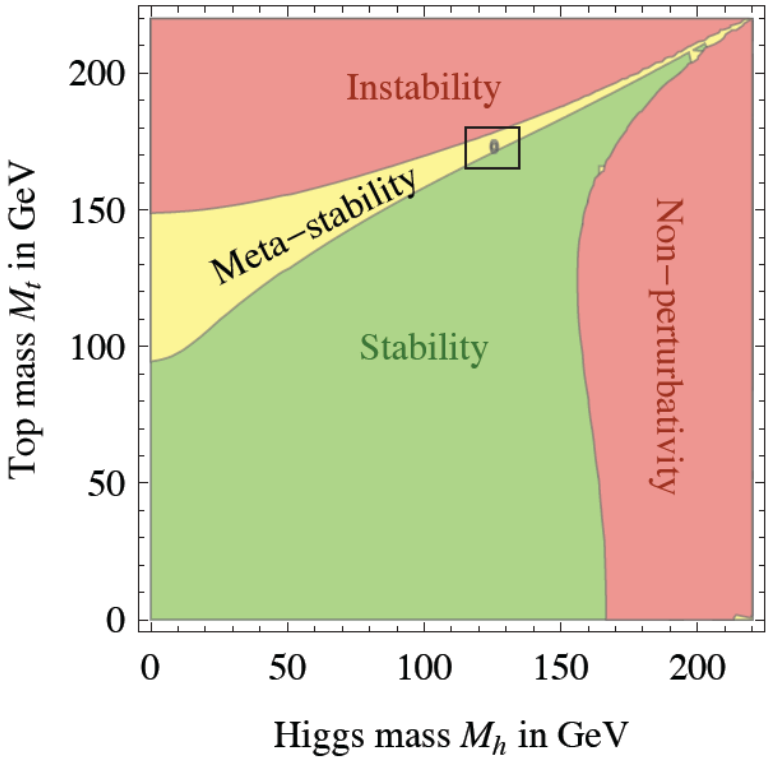
M(H) ≈ 126 GeV! A Farce?

The Higgs opens a window to BSM!



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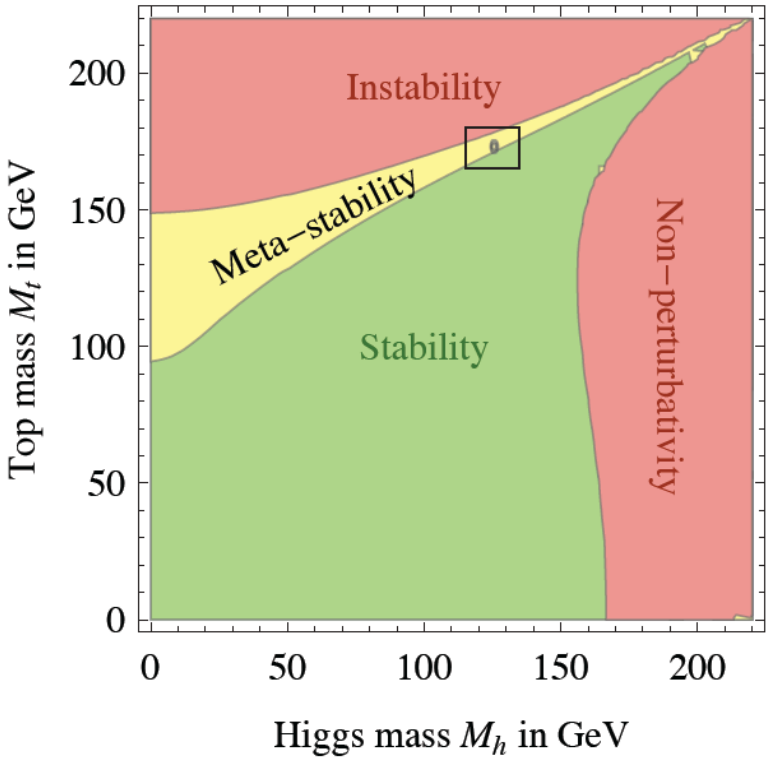

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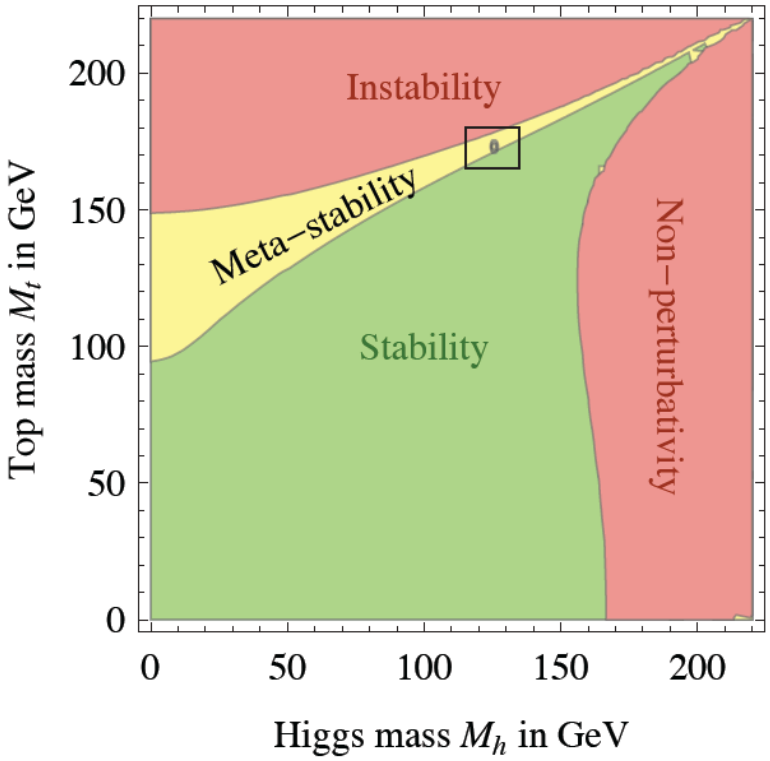

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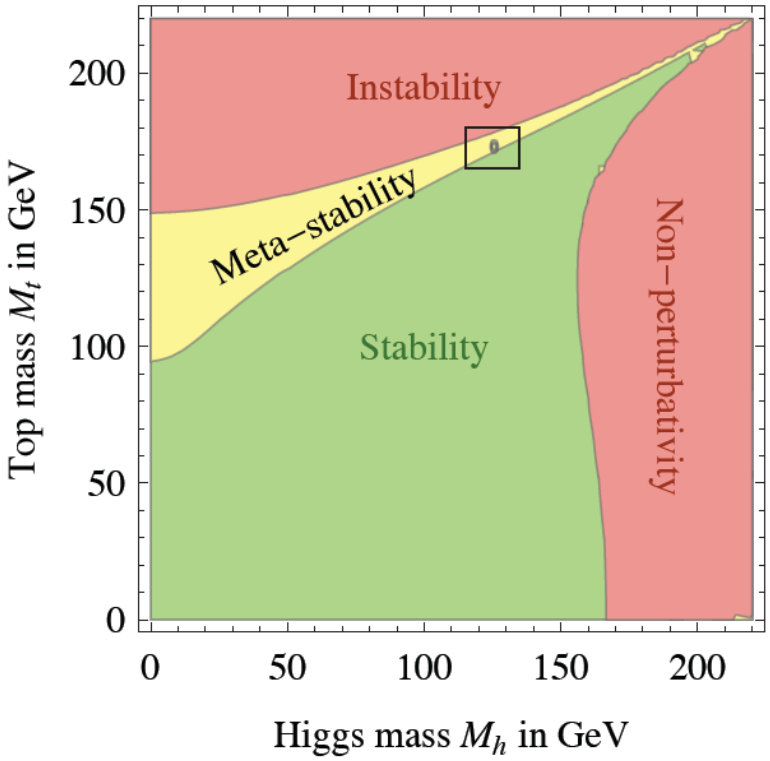

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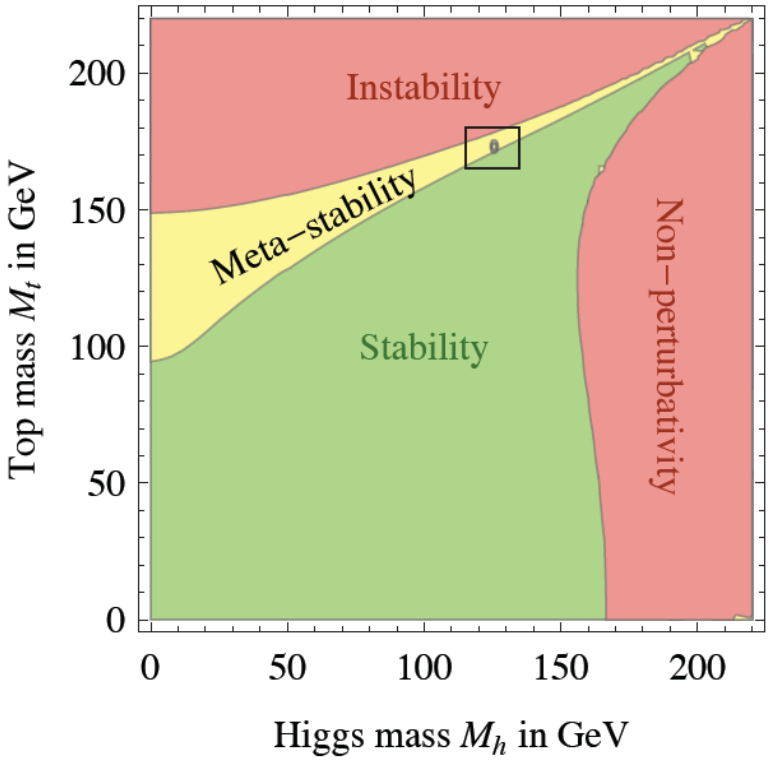
  - Real Reasons: Dark Matter & neutrino masses

The Higgs opens a window to BSM!

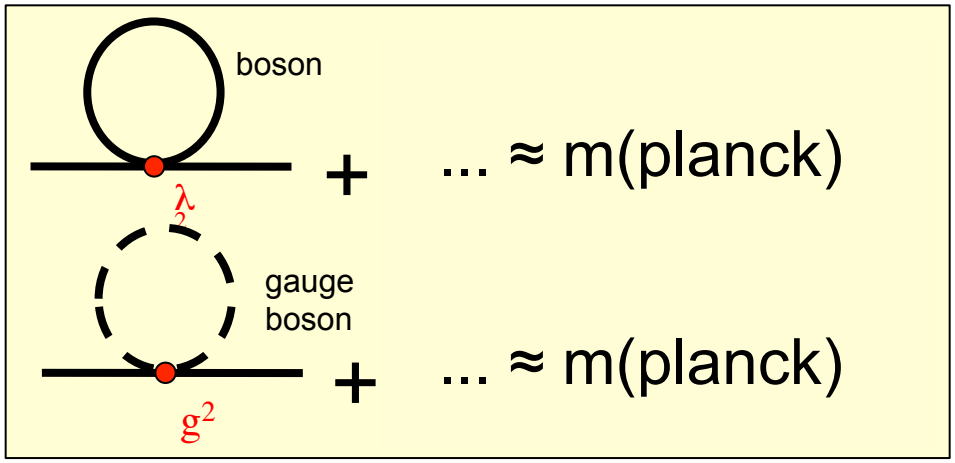


Plenty of room for new physics...

...even beyond this magic of the m(H) vs m(t) mass

- **Some real & some virtual reasons to believe in new physics**
  - Real Reasons: Dark Matter & neutrino masses
  - Virtual Reasons: Naturalness

Higgs (mass) is natural ?!



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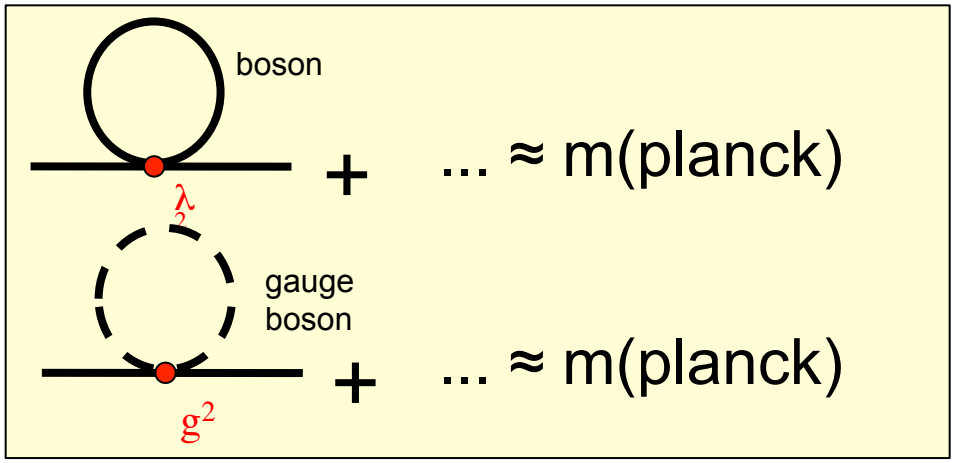

Supersymmetry

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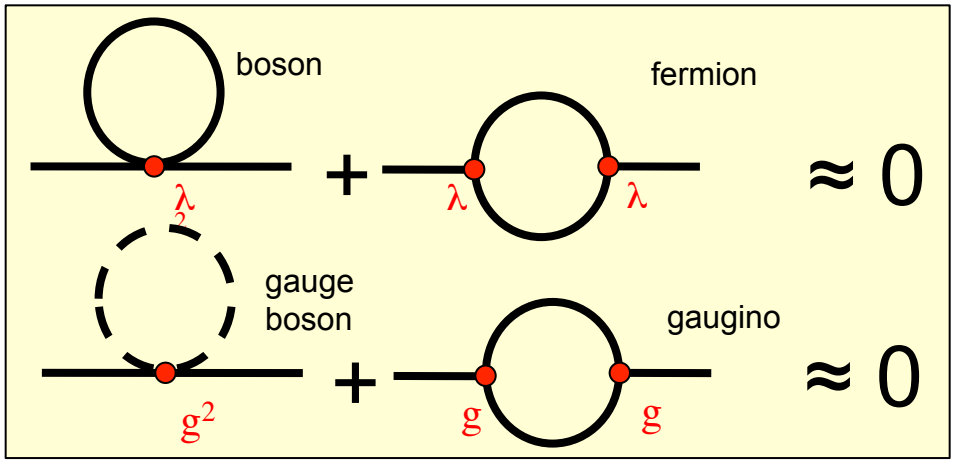

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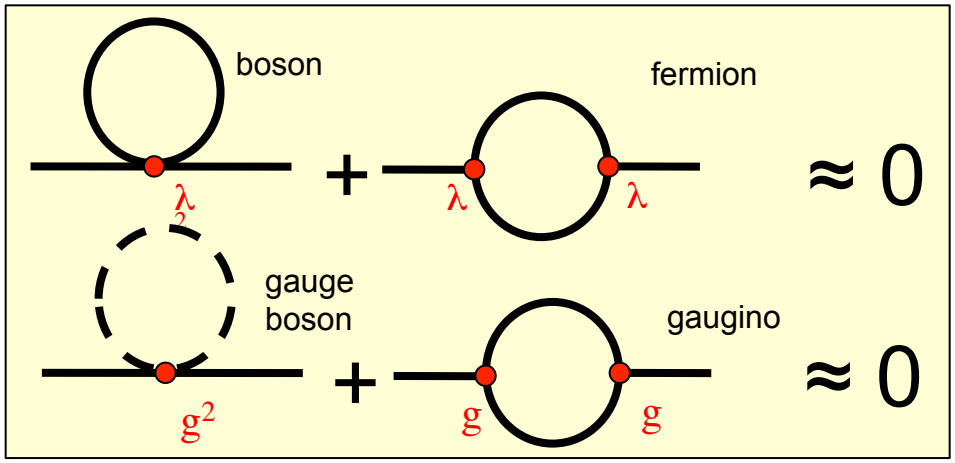

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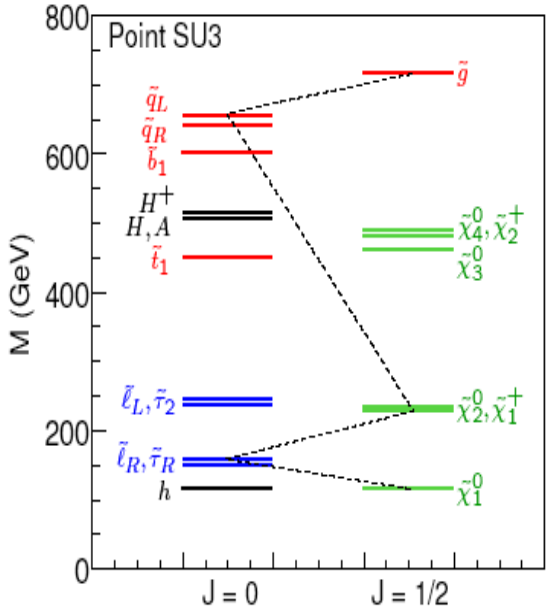
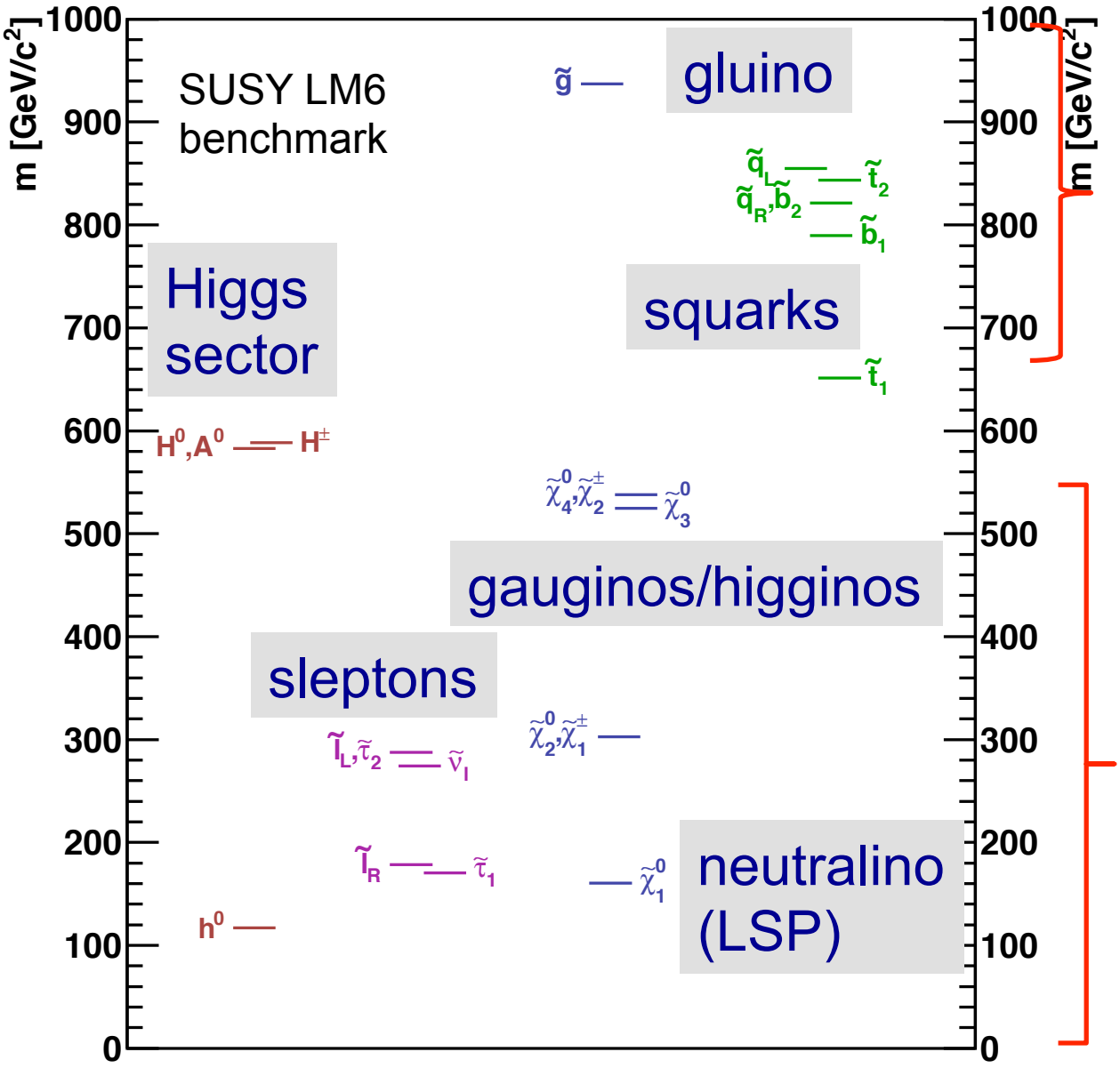


Dark Matter candidate

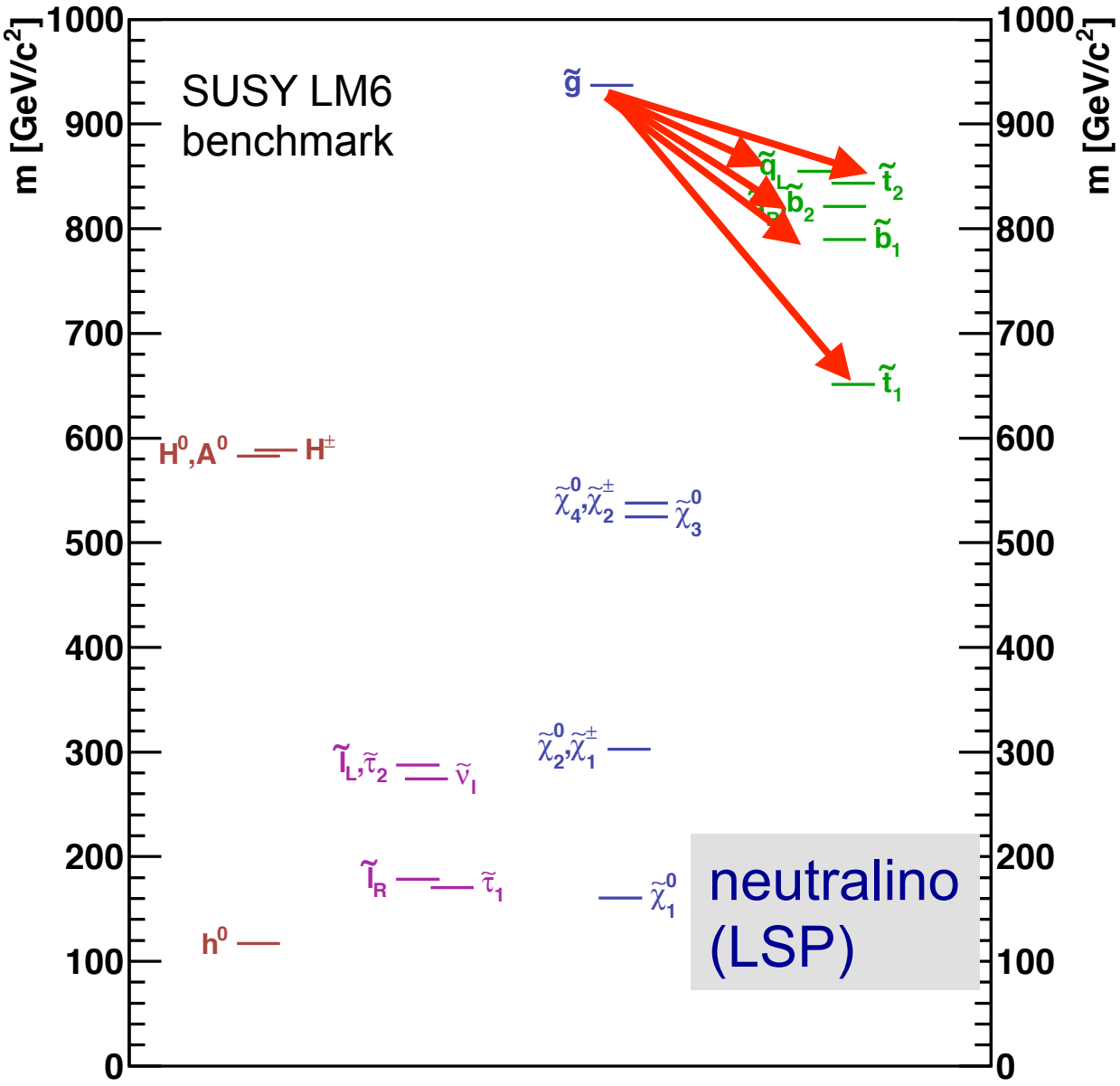
Experimental SUSY Signatures

- **SUSY must be broken!**
  - spins and couplings fully specified! (the unbroken part of SUSY)
  - masses not specified (the broken part of SUSY, model dependent!)
    - many new particles, many mass parameters, many possible signatures
- **Matter Parity Conservation**
  - (additional symmetry -- completely unrelated to SUSY!)
  - Consequences:
    - Models have stable proton; stable weakly interacting LSP; MET
- **Matter Parity Violation**
  - (just SUSY, no additional assumed symmetry)
  - Consequence:
    - Hadronic modes, challenging: no MET (to first order); Leptonic modes, easier
- **Dominant strong production (at hadron colliders); but several new EWK production mechanisms interesting**
  - Long cascades: many jets, some leptons, lots of MET (RPC) or little/no MET (RPV)

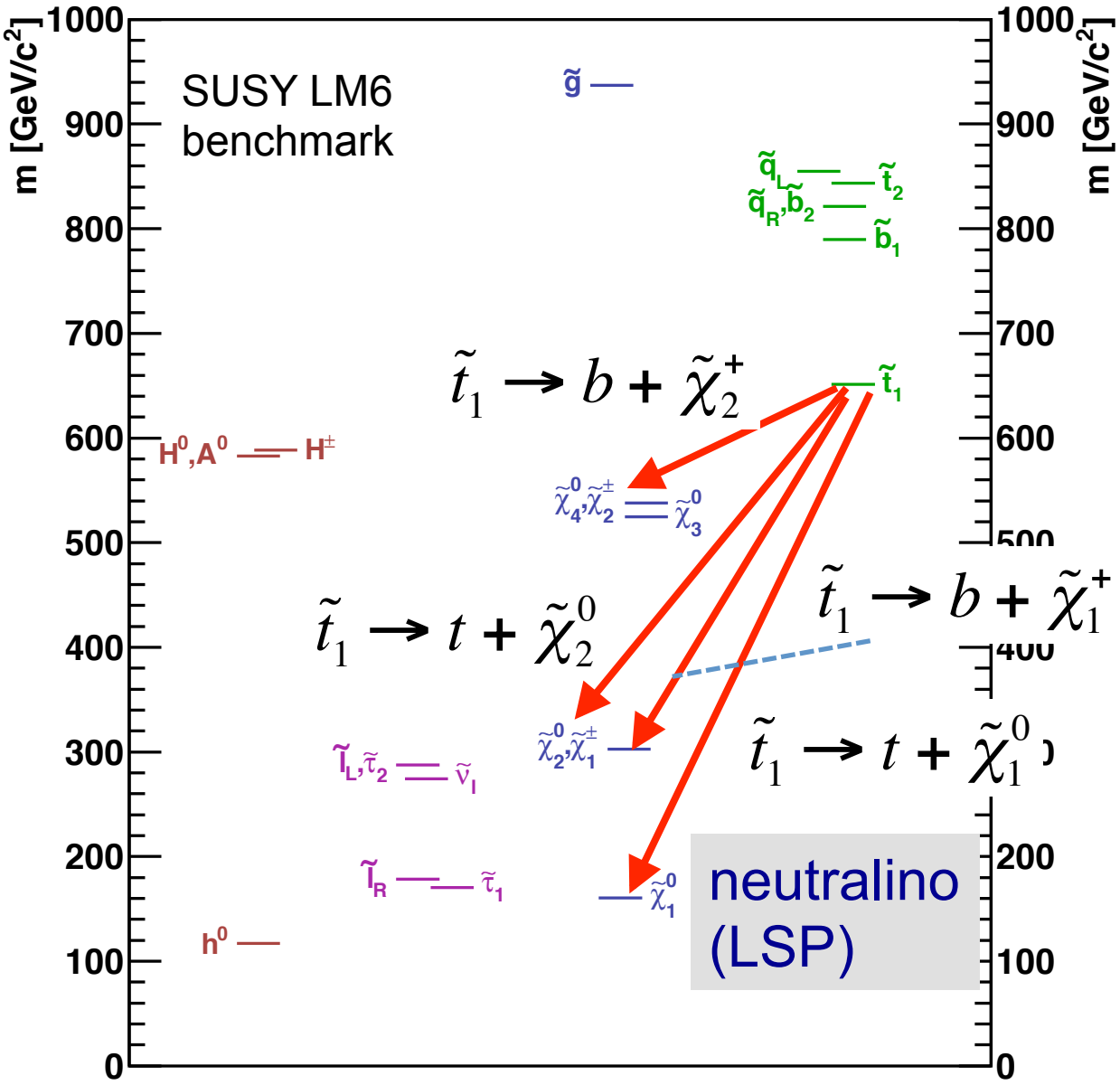
Big themes: many (& complex) signatures



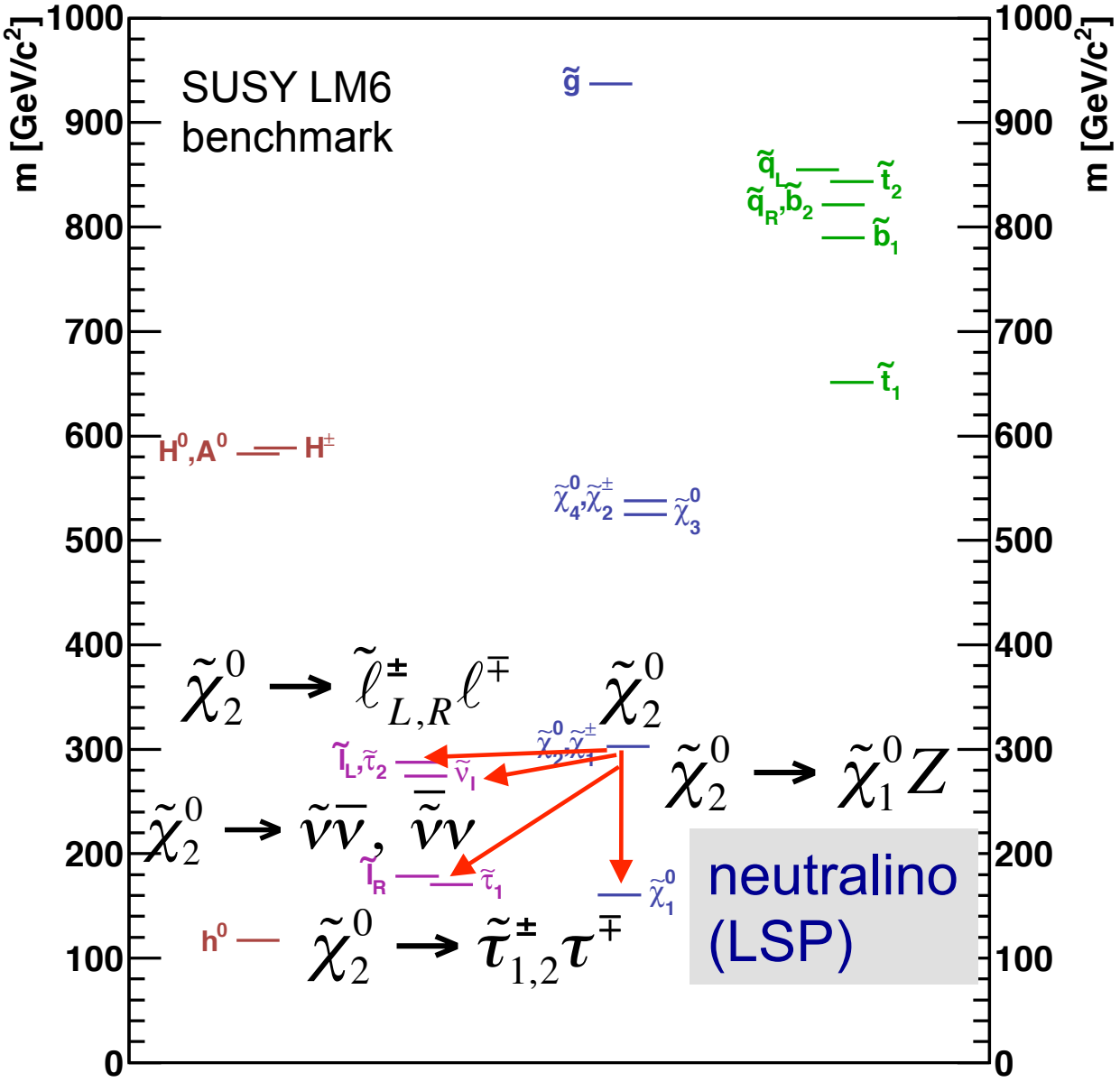
SUSY cascade starting from gluino decay



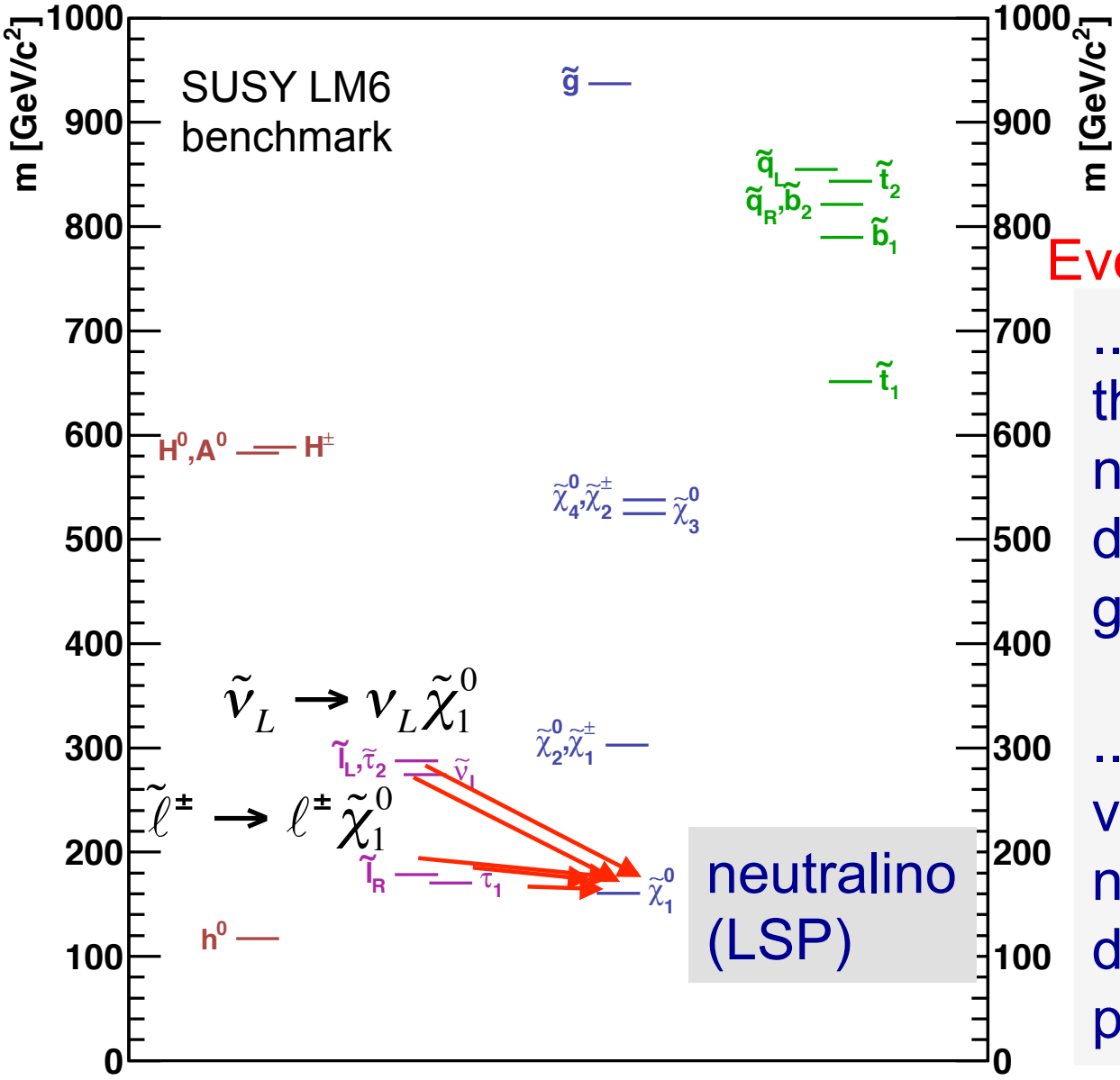
Decays of ~t_1 → neutralinos, charginos



Decays of $\tilde{\chi}_2^0$: here come the leptons!



Decays of $\tilde{\ell}^{\pm}_{L,R}$, $\tilde{\tau}^{\pm}_{1,2}$, $\tilde{\nu}_L$: more leptons!



Even more possibilities

...and in GMSB, the lightest neutralino can decay into a gravitino → MET

... and in R-parity violating SUSY, the neutralino can decay into SM particles →no MET

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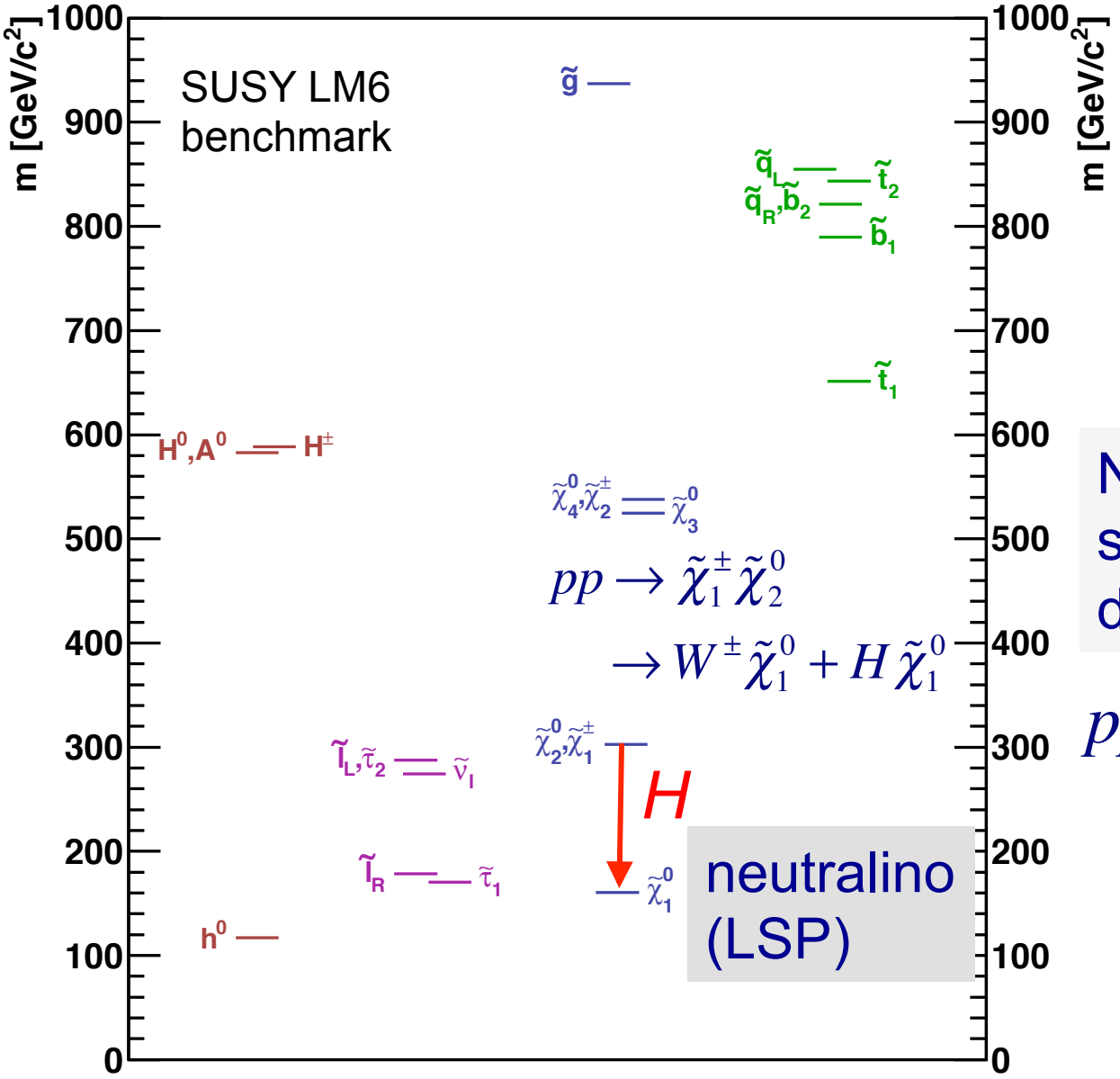
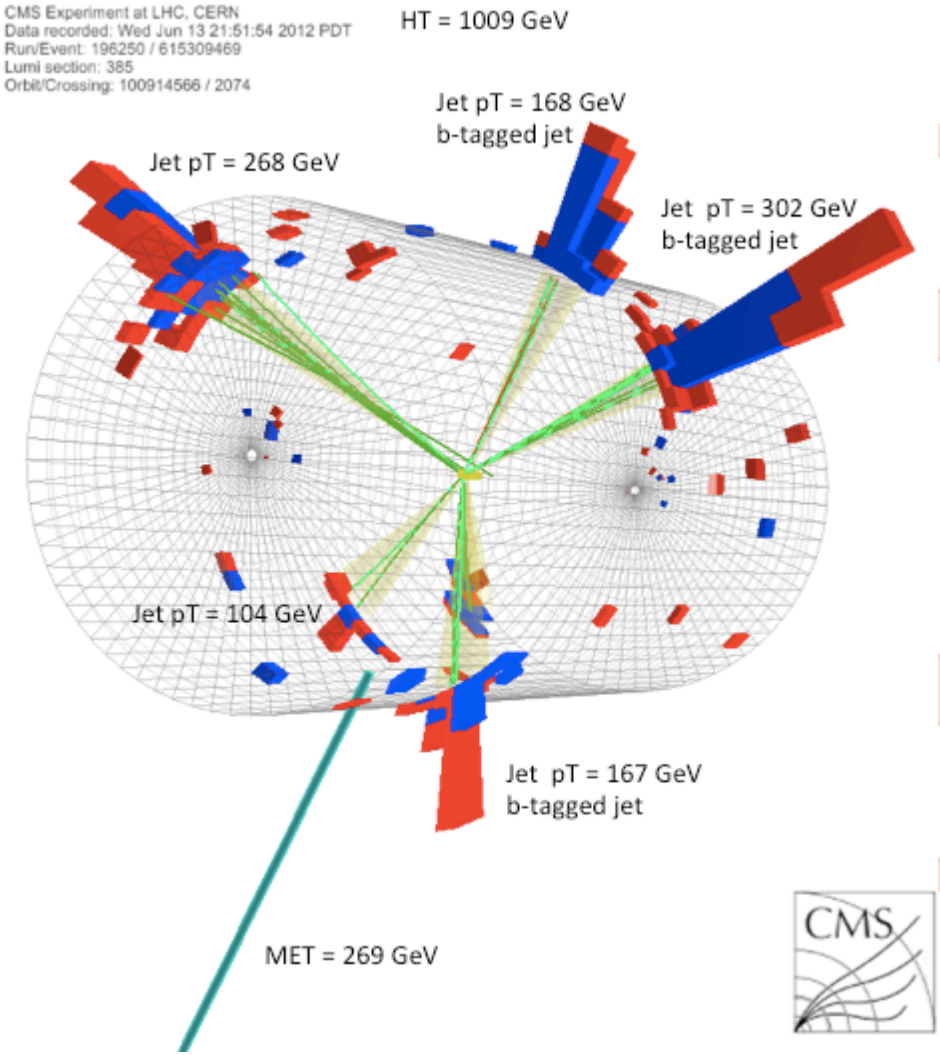
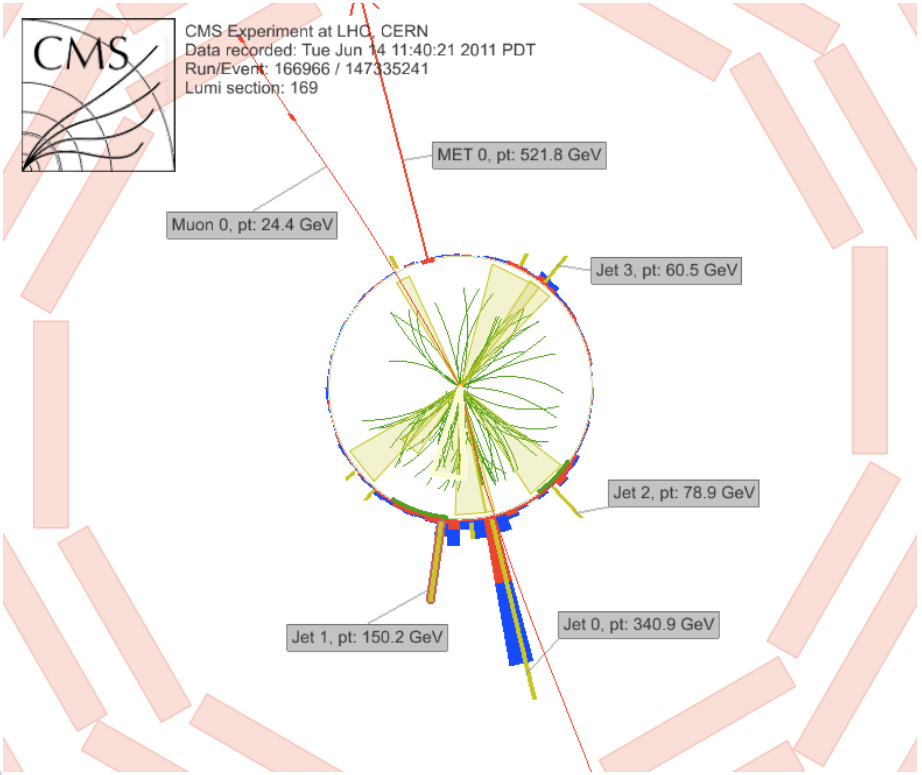


New program of searches for SUSY decays with Higgs.

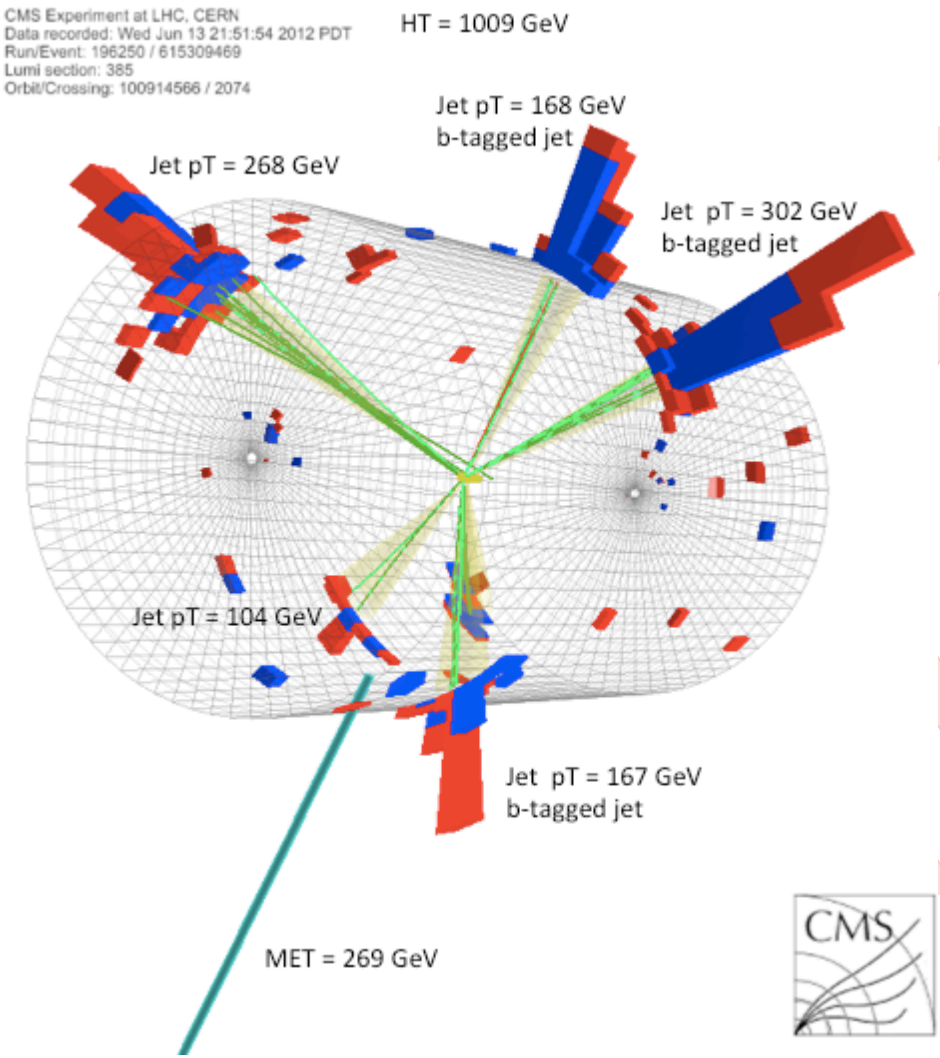
$$pp \to \tilde{\chi}^{\pm}_1 + \tilde{\chi}^0_2$$
$$\to W^{\pm} \tilde{\chi}^0_1 + H \tilde{\chi}^0_1$$

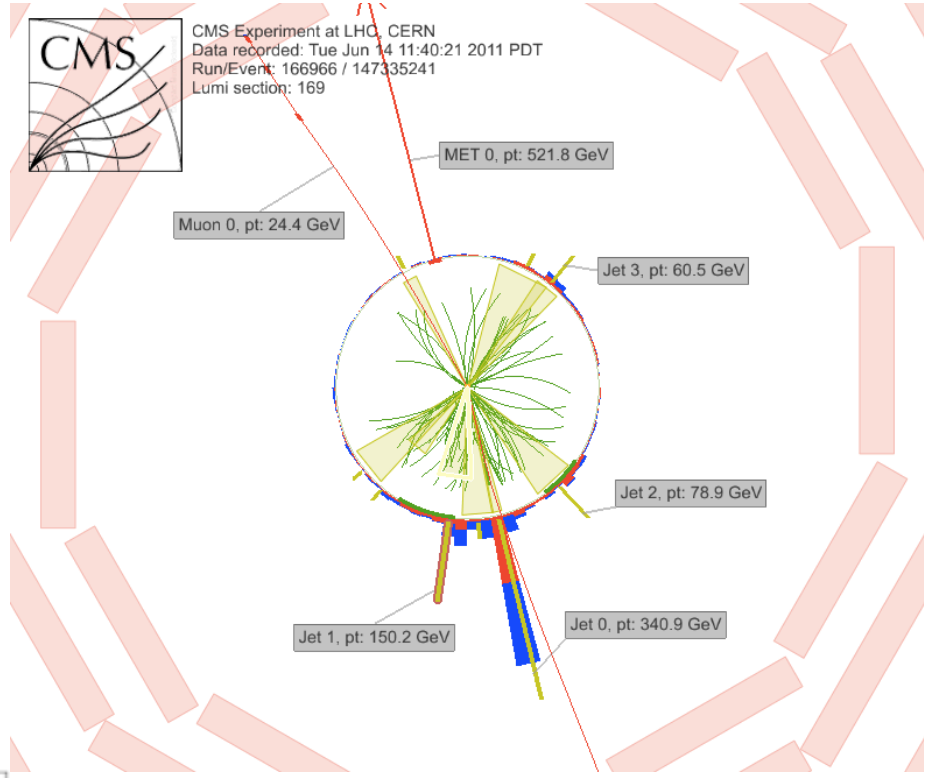
What we have been looking for...





What we have found: QCD, W/Z+jets, tt+jets

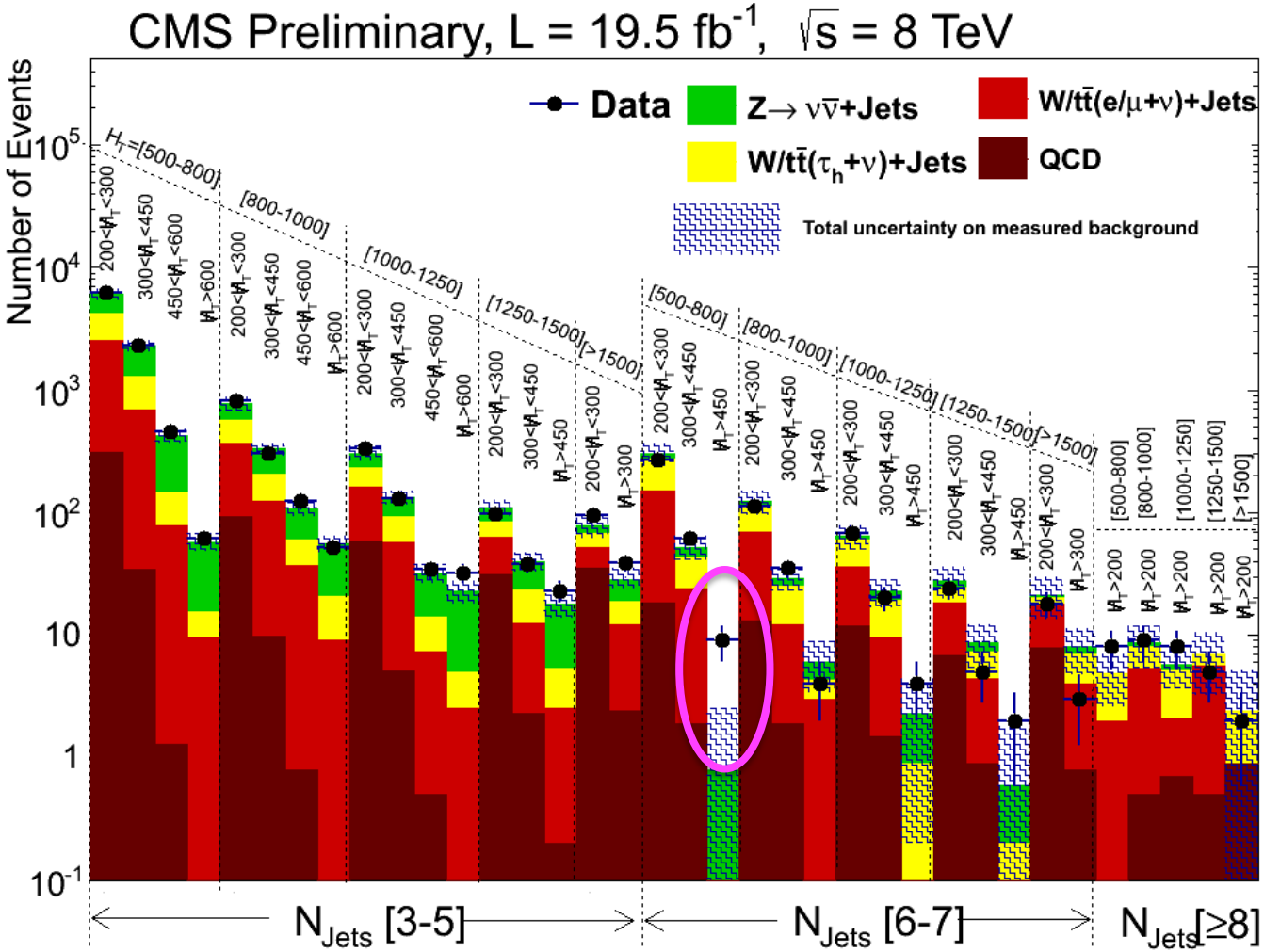




Ingenuity in developing new methods

- **Hadronic (0-lepton) searches**
  - New topological variables help (kinematics well constrained)
    - αT (the QCD "killer")
    - Razor (the bump hunt)
    - MT2 (extensions of W decays to massless neutrinos)
  - Understand full hadronic component (HT, MET distributions)
    - cut on highest mass scales (e.g. Meff)
- **Leptonic (1-, 2-, multi-lepton) searches**
  - Look at tails of distributions
  - Topological variables often help less (kinematics less constrained)
    - Because of confusion between LSP and additional neutrinos (W decays)
    - Can nevertheless be useful in special cases (MT, MT2 in stop searches)
- **Will need a lot more ingenuity to cover "holes" left behind at 8 TeV**
  - compressed spectra scenarios: low MET, low pT jets, etc

Remarkable agreement between data and SM prediction



One bin shows an excess! Do we have to get exited?

N_{bg} = 0.7"±"1.8
N_{data} = 9

p (≥9|0.7"±"1.8) ~ 0.004
→ ~2.7 σ

To observe such (or a larger) fluctuation in any of the 36 bins:

p ~ 0.11 → ~1.2 σ

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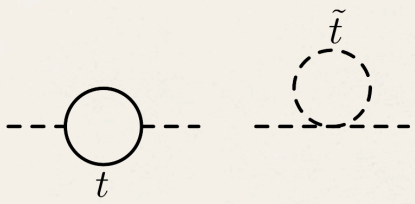
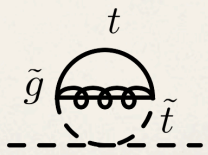
m_h^2 $\sim (125\ \text{GeV})^2$

Tree μ^2 Higgsinos

1 loop  Top Squarks

2 loop  Gluinos

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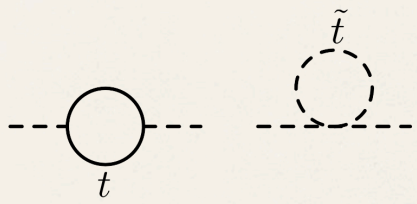
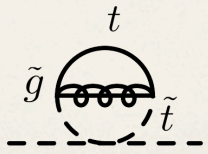
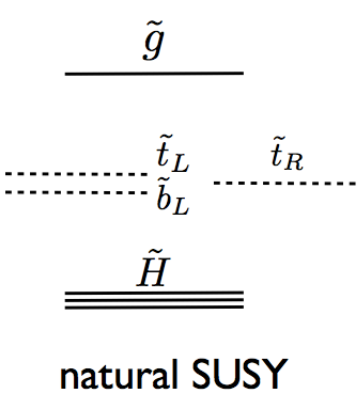
1 loop —  — Top Squarks

2 loop —  — Gluinos



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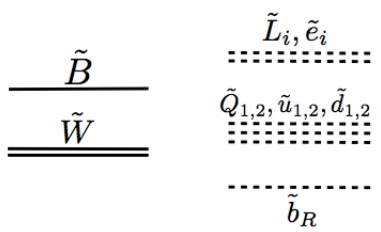

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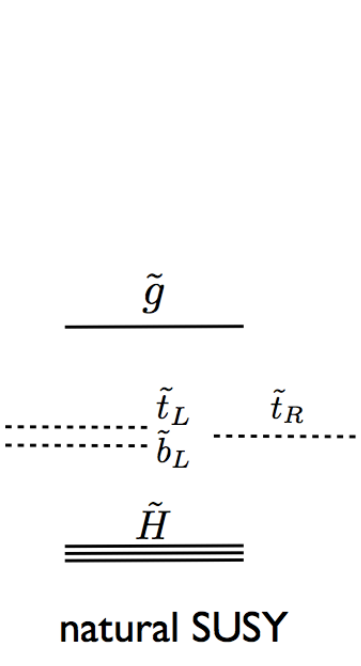

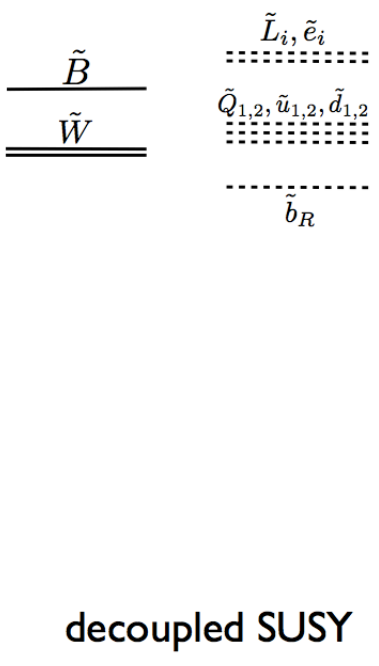

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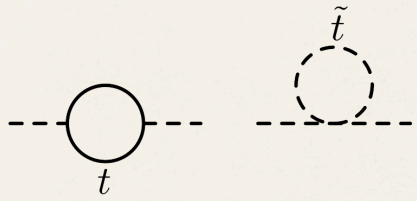
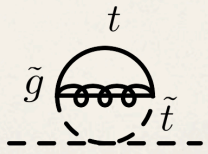
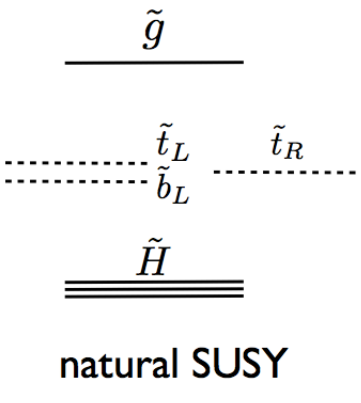
1 loop  Top Squarks

2 loop  Gluinos



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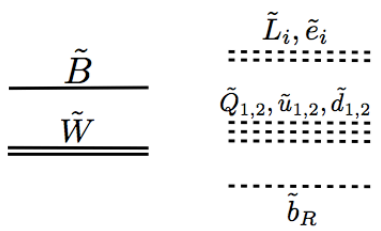

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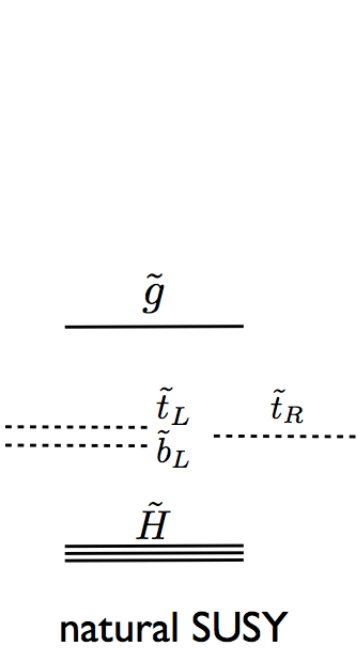

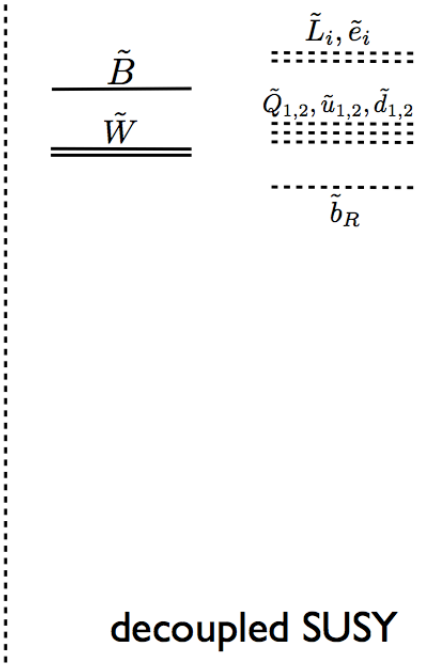

Natural Relationship between Higgs & SUSY

Naive quantum corrections put the Higgs near the planck scale
Something must protect it so that it can be 126 GeV!

Higgs couples to mass; 3rd gen squarks most dangerous

Natural Susy

10% Fine Tuning

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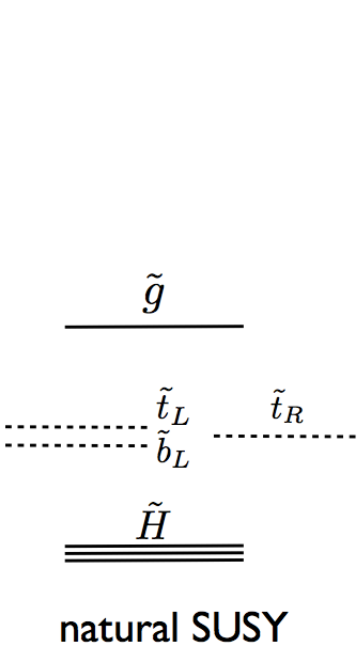

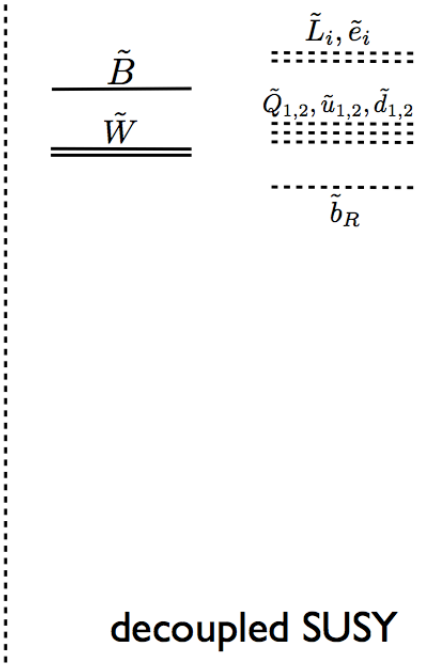

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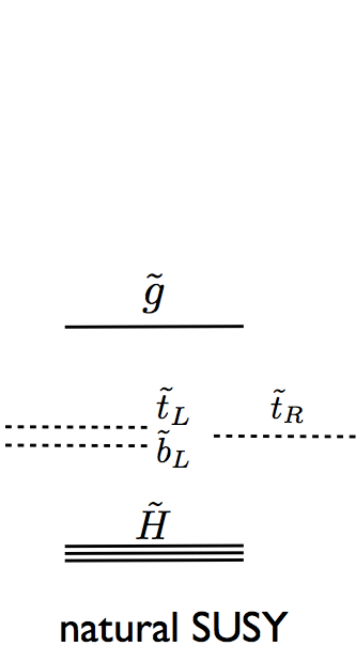

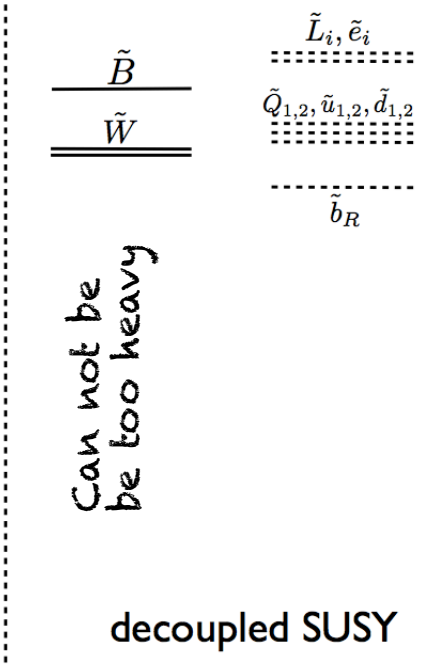

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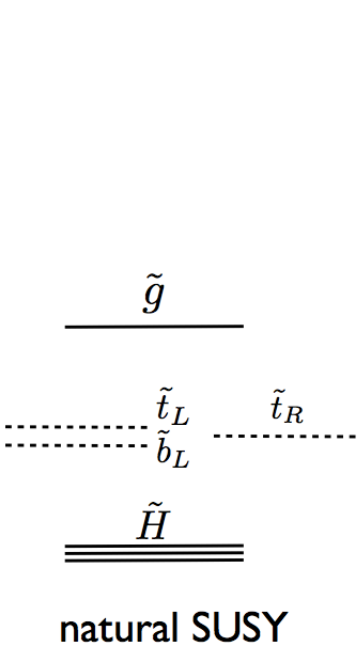

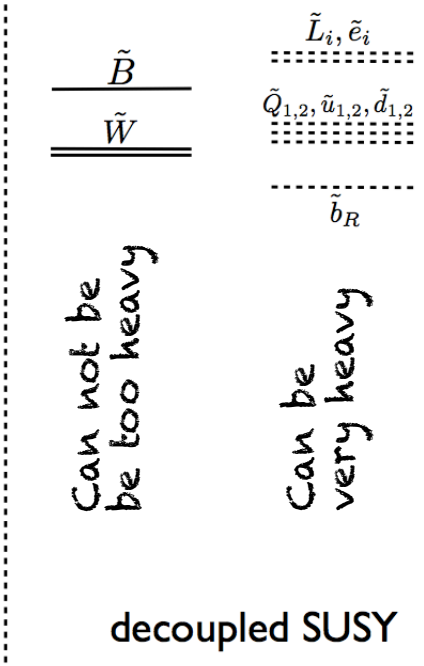

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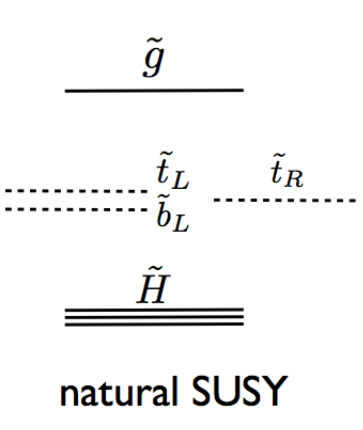

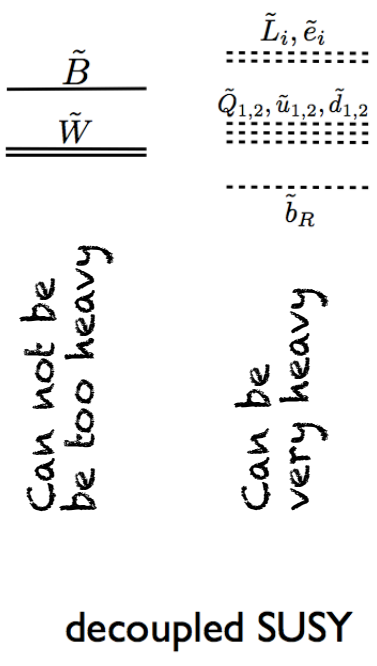

Note: even 1% Fine Tuning is far better than 10^{-35} Fine Tuning!

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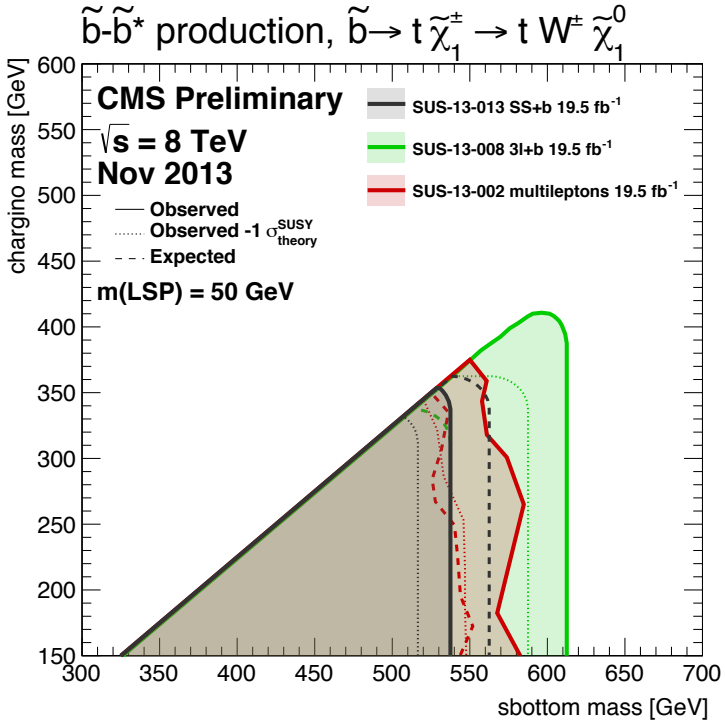

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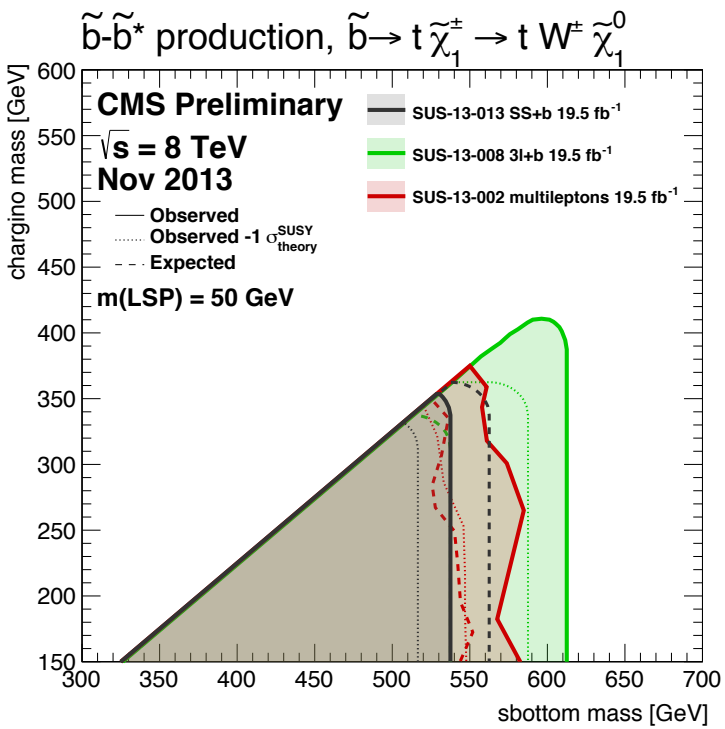

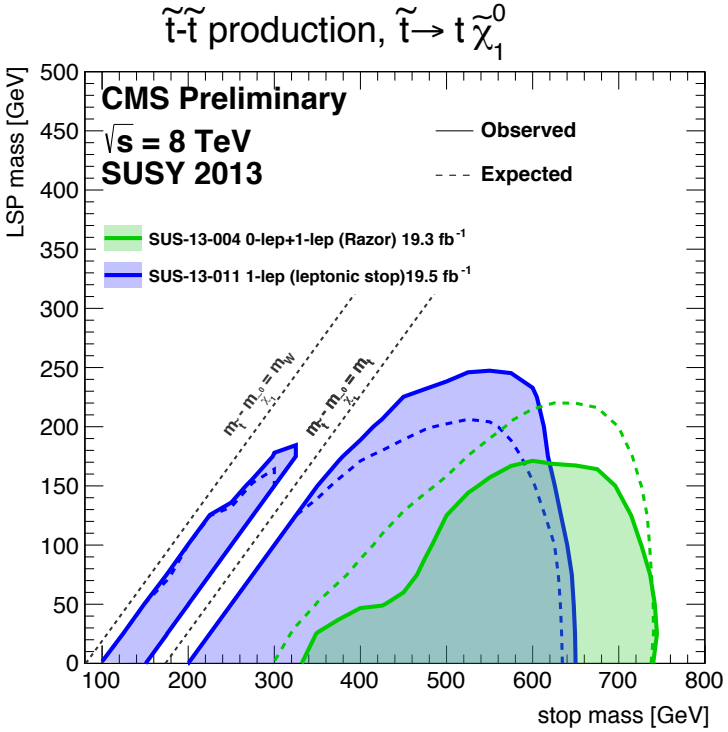

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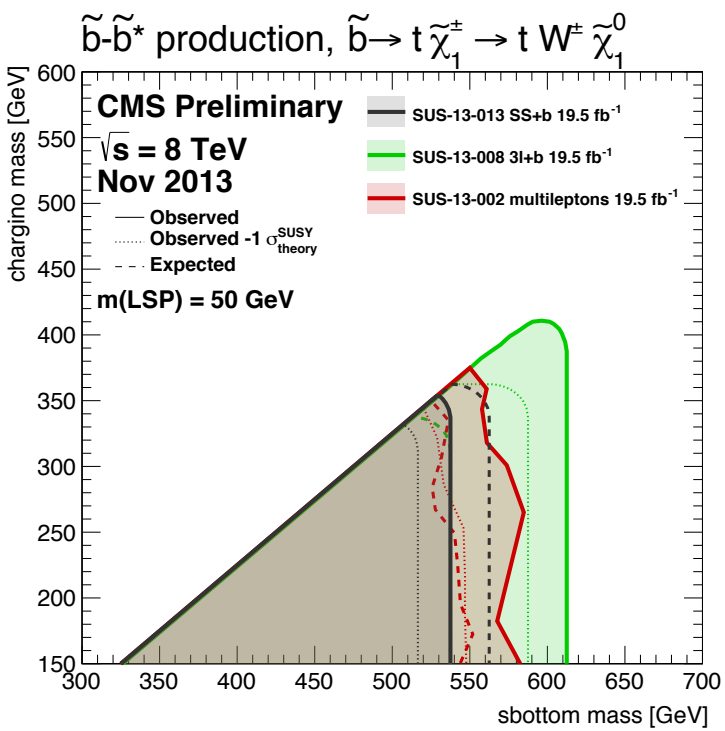

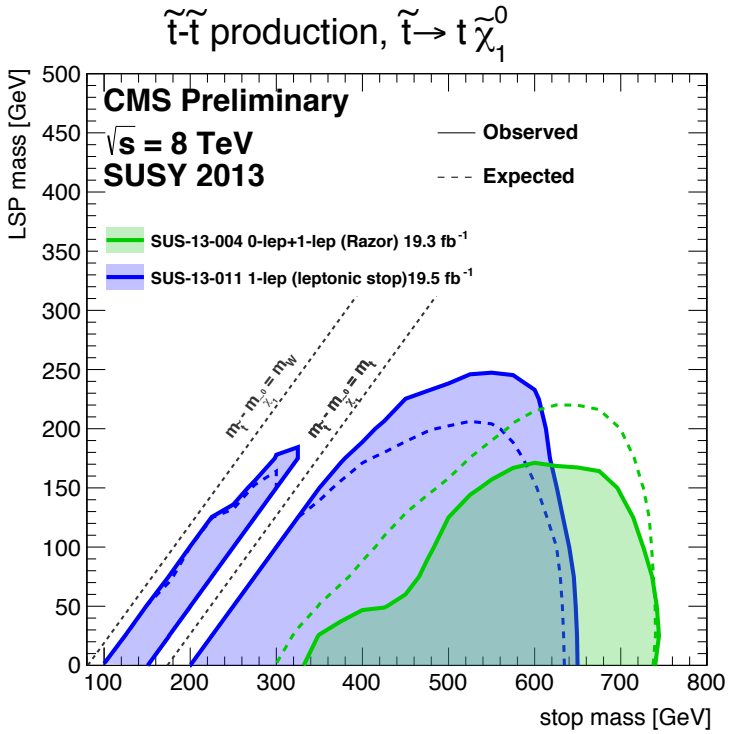

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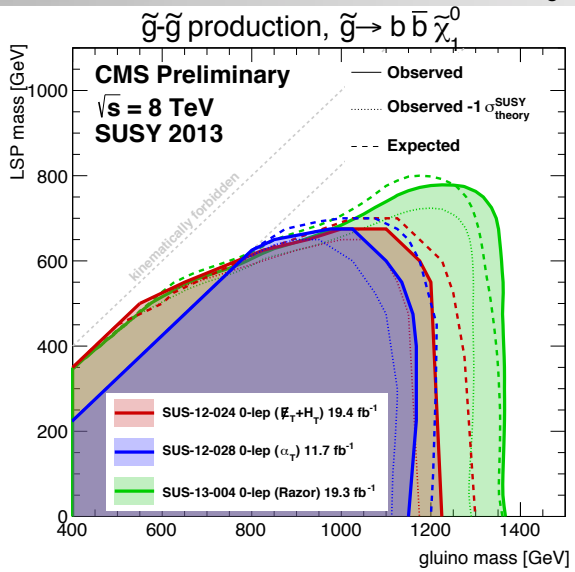

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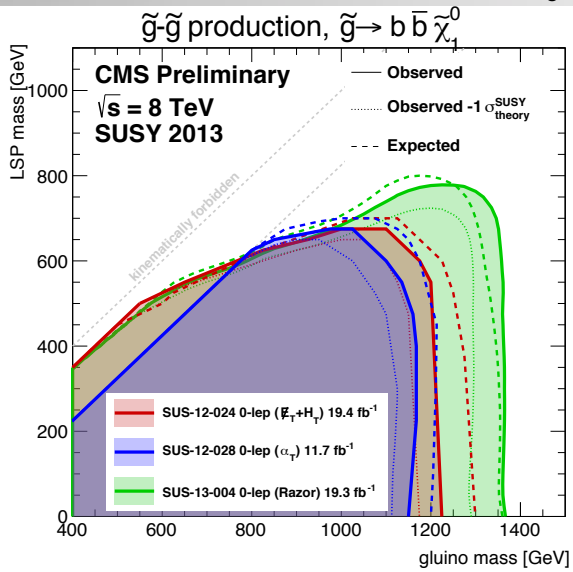

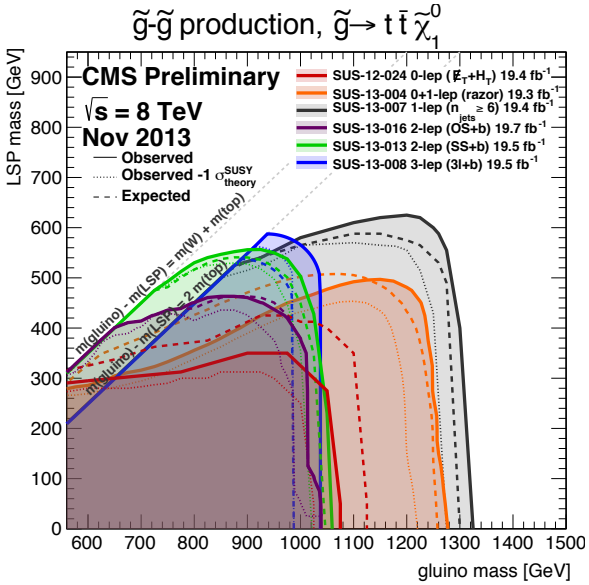

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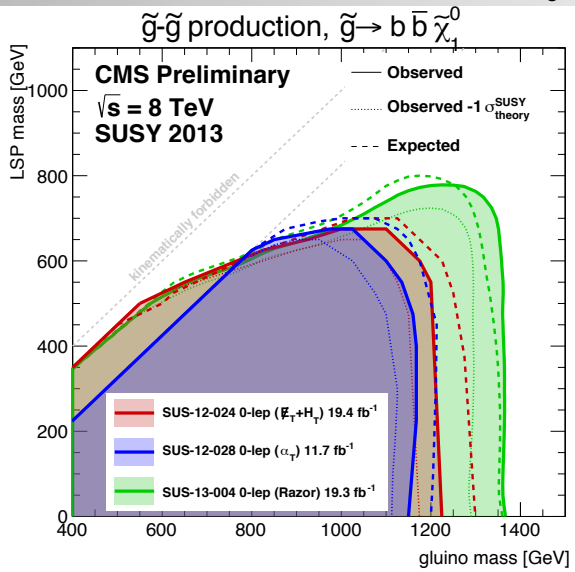

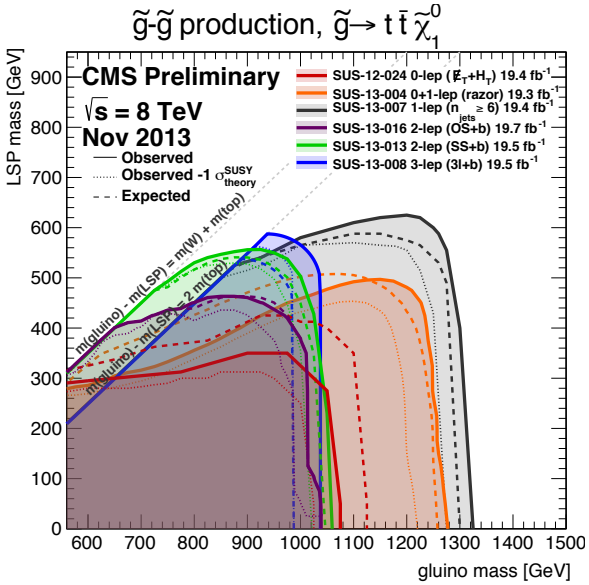

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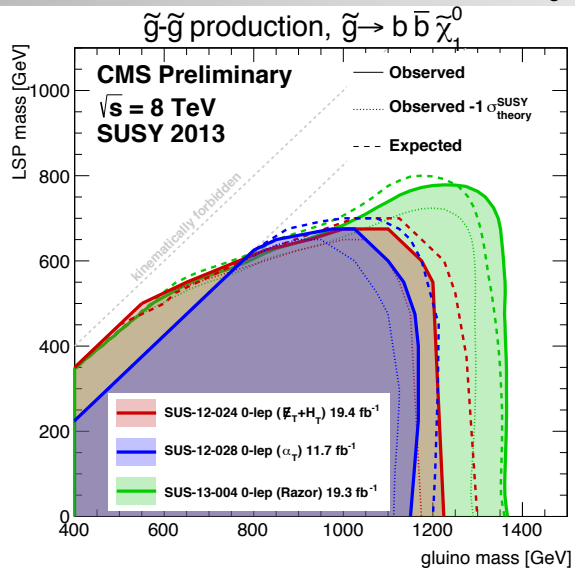

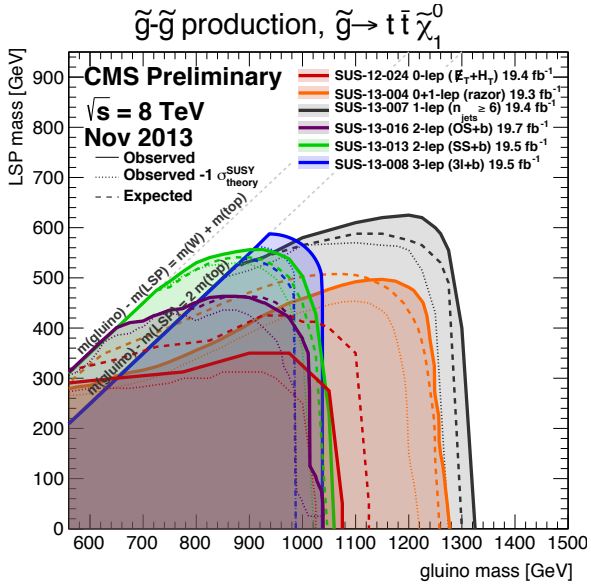

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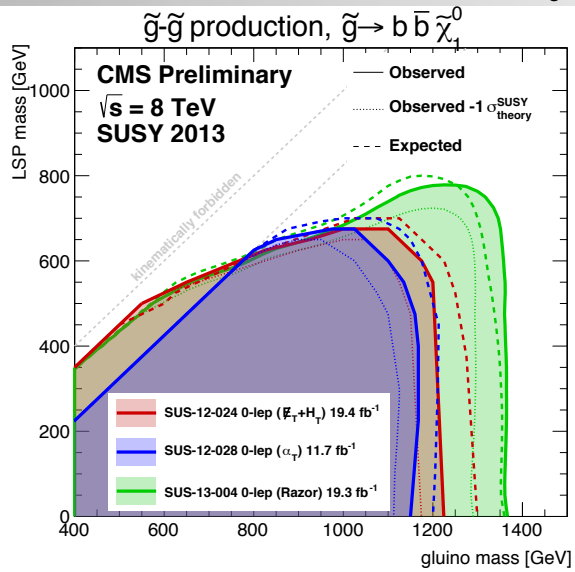

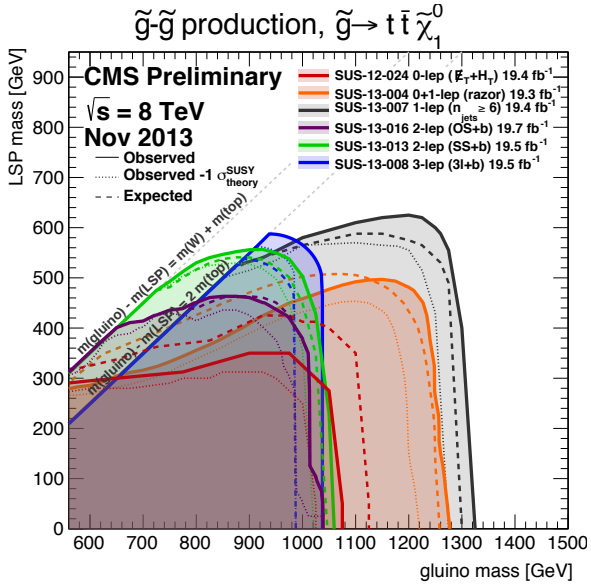

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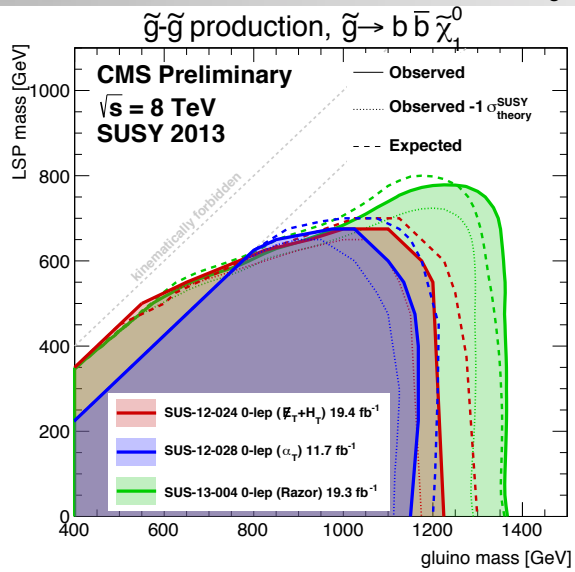

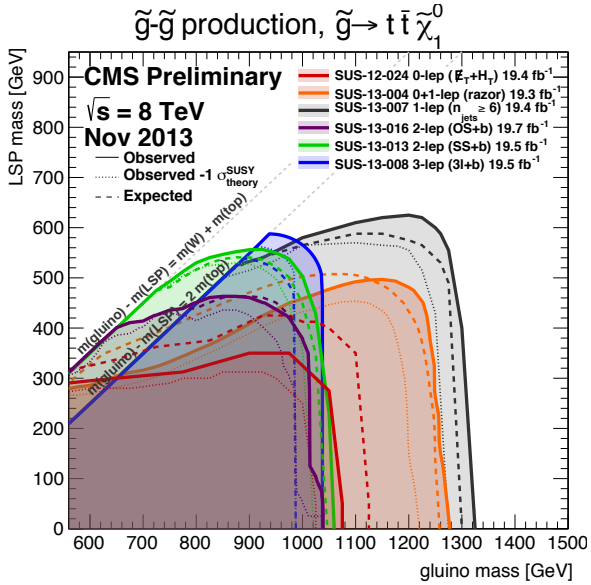

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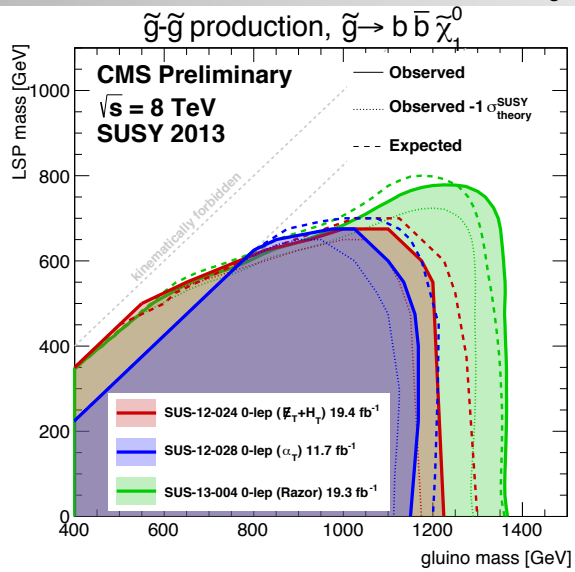

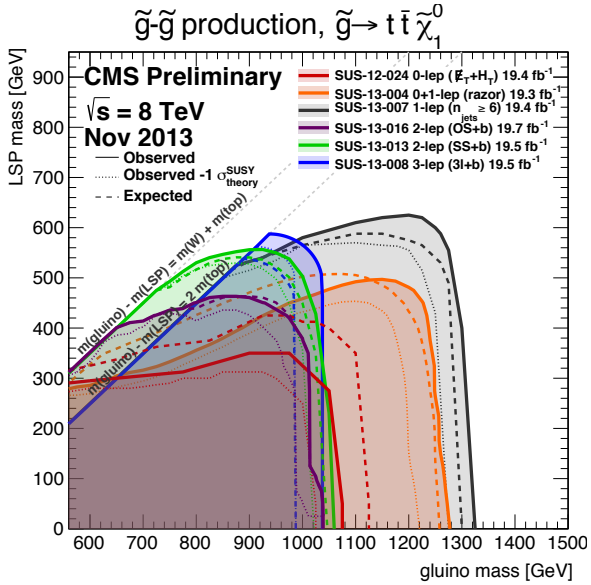

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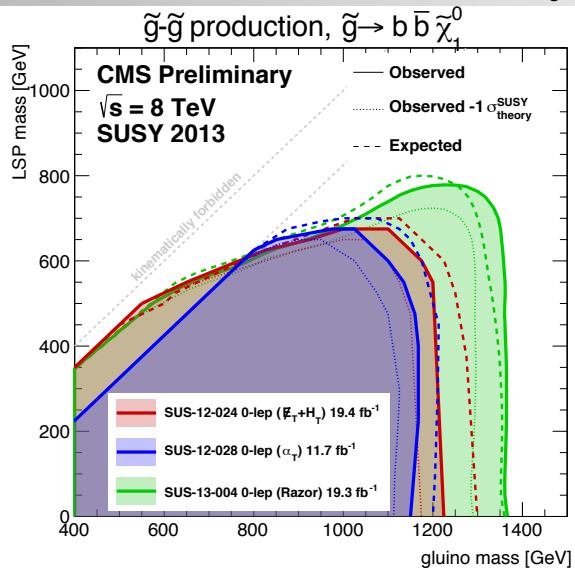

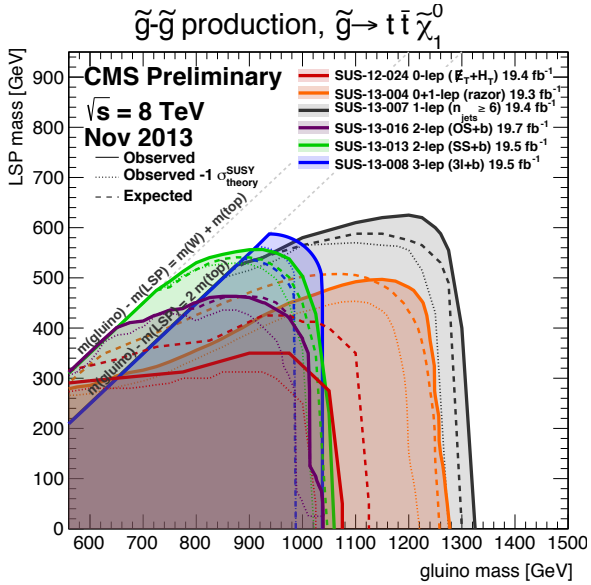

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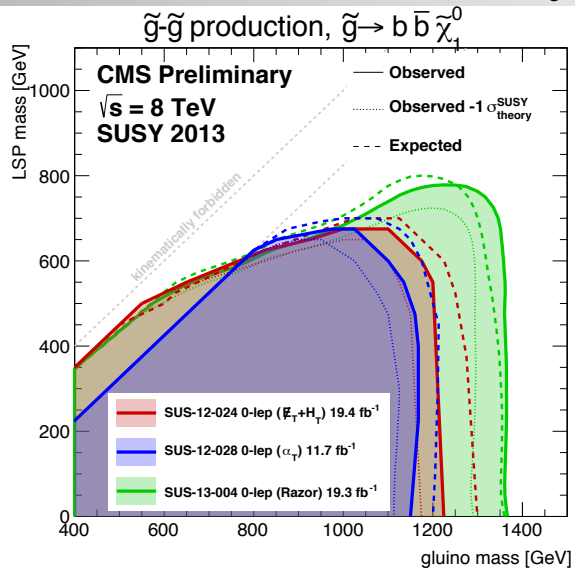

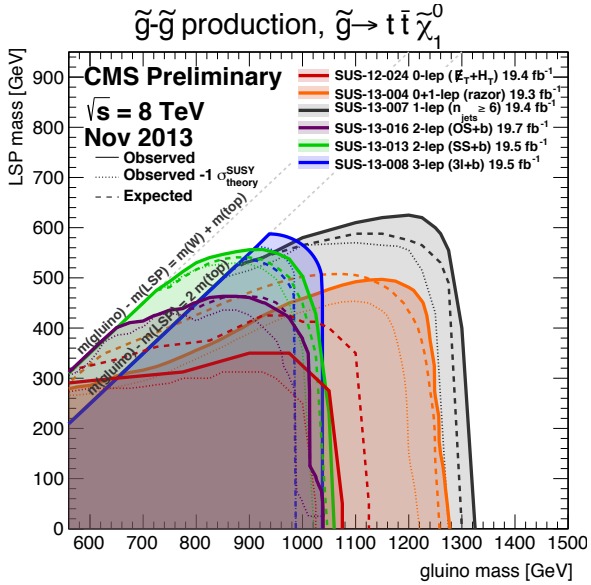

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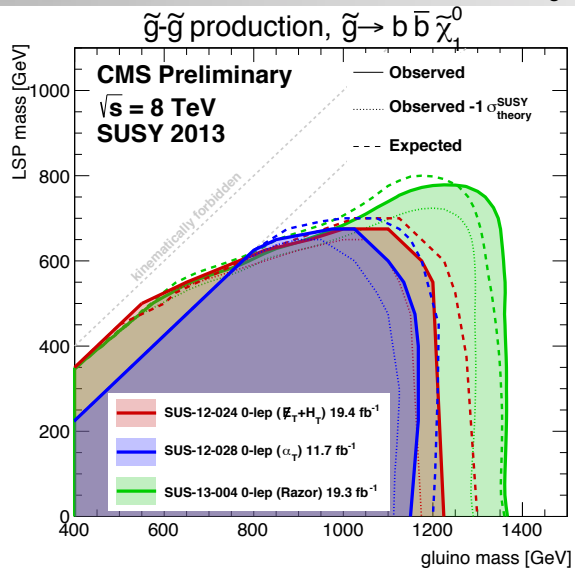

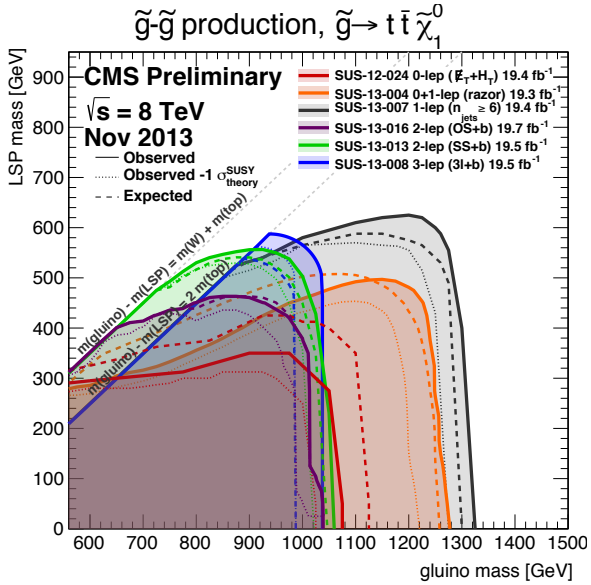

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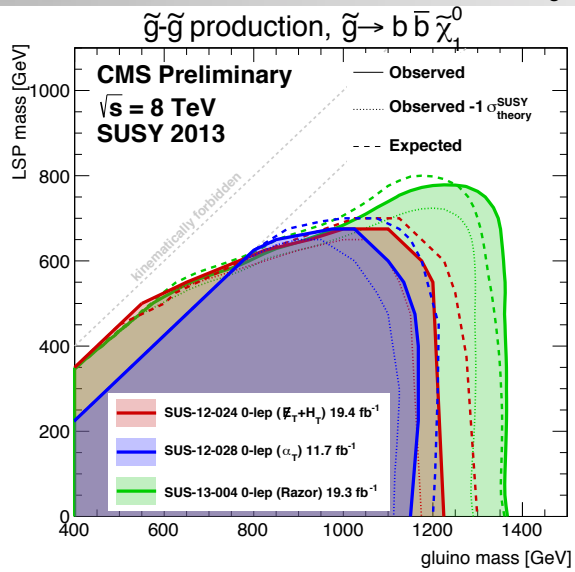
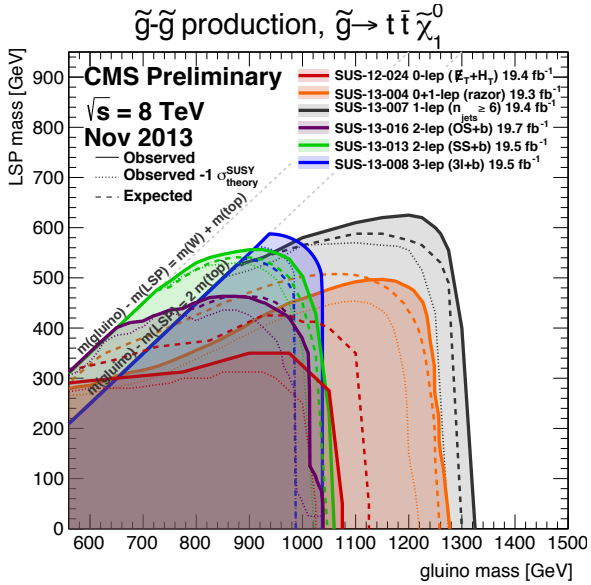
- **Gluino-mediated searches will have the highest priority in early 2015!**





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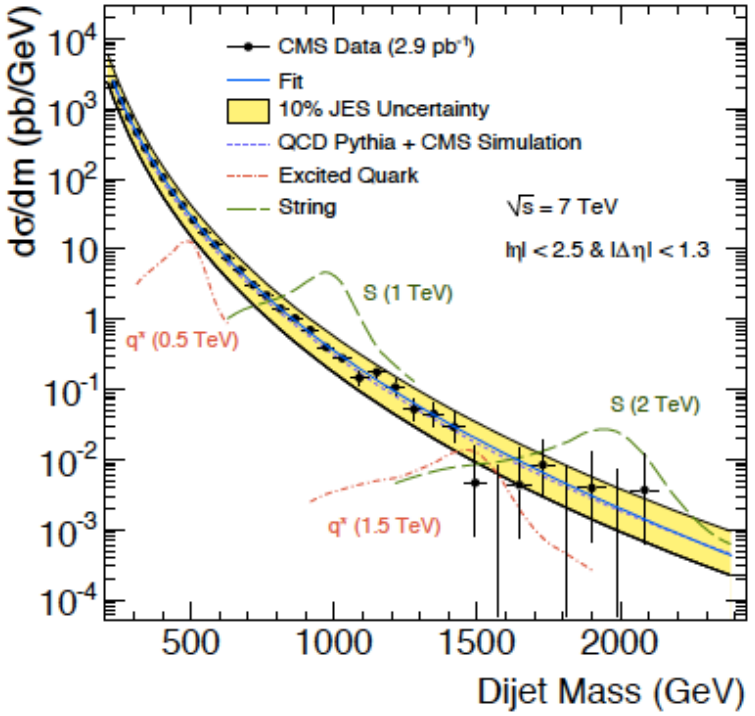

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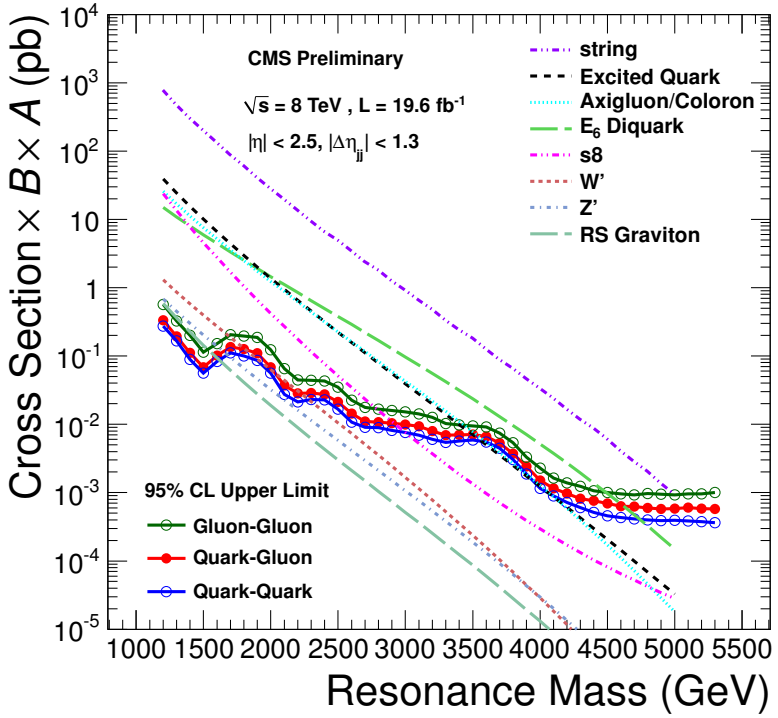

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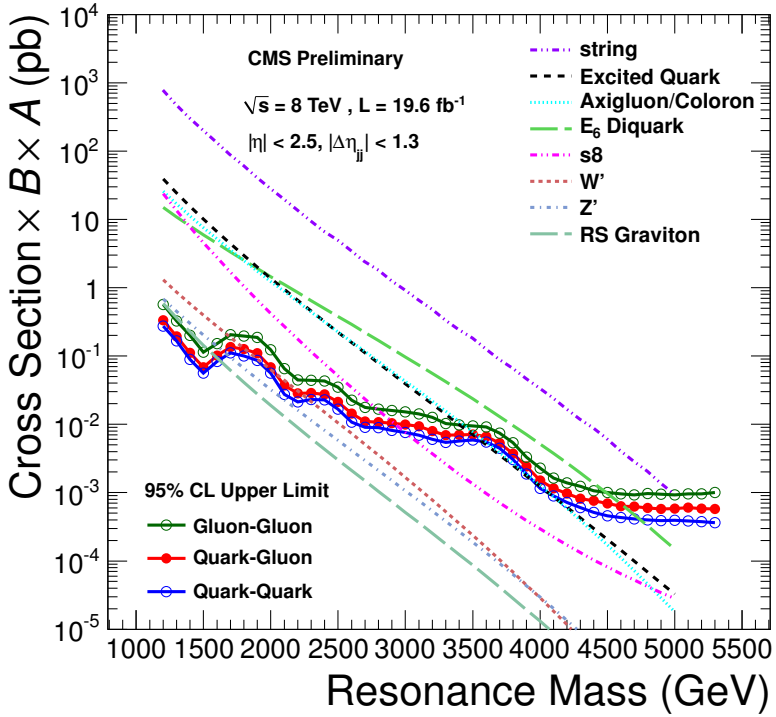

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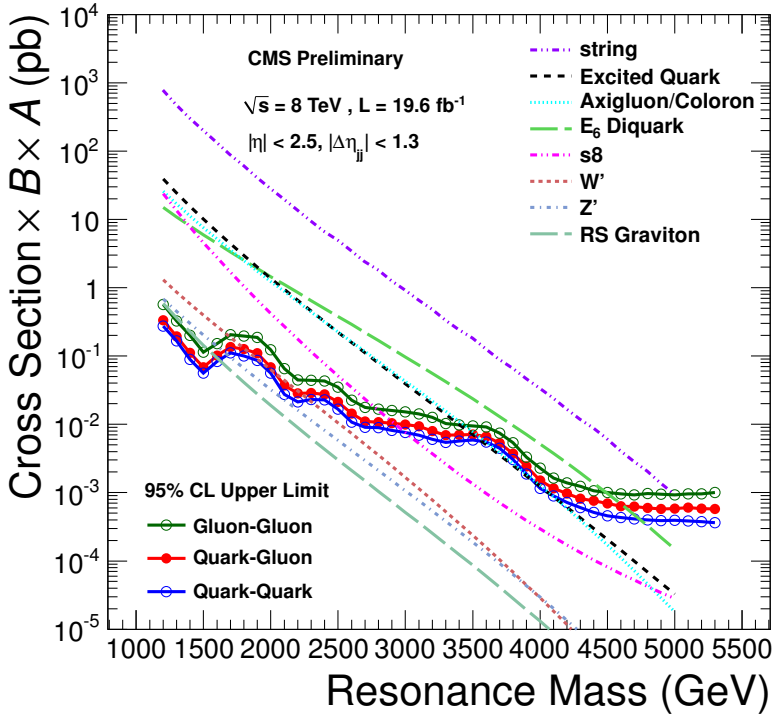

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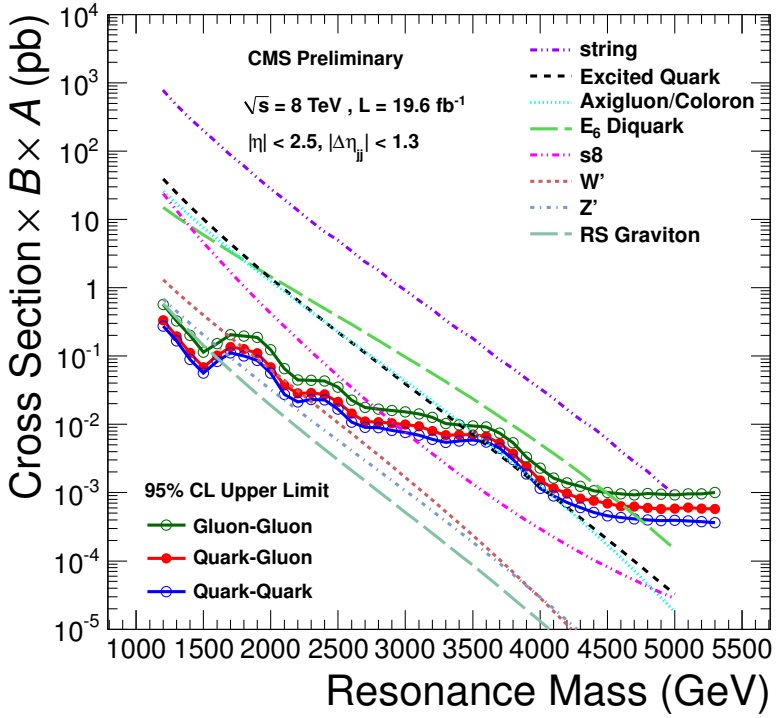

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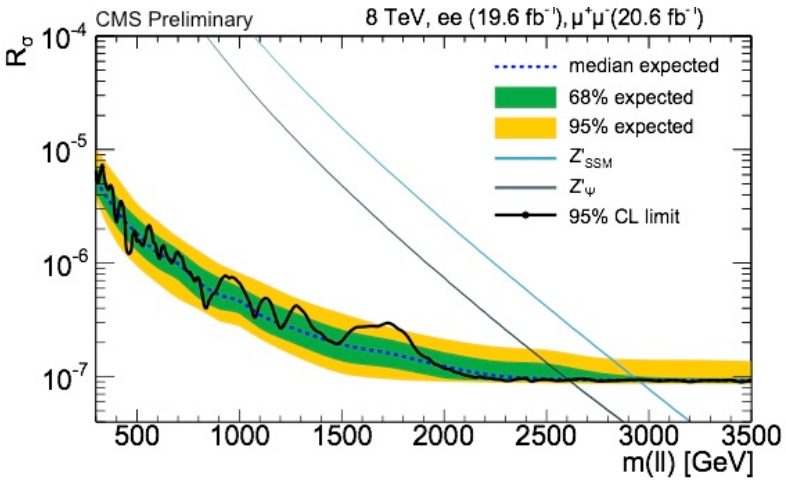

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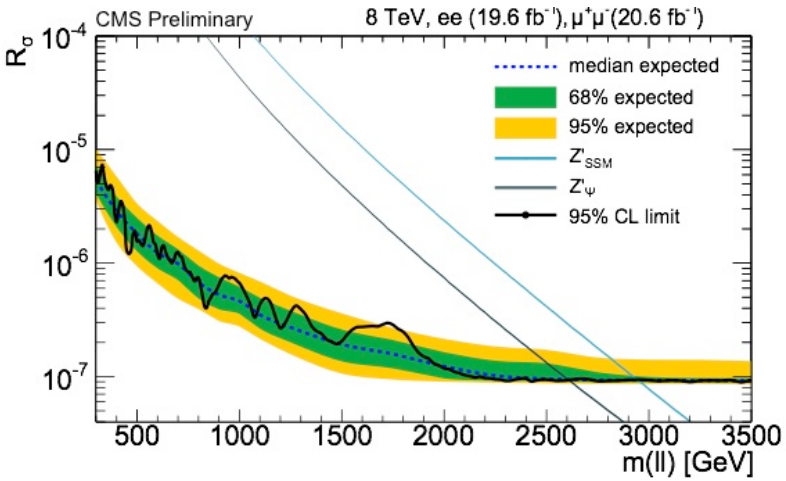

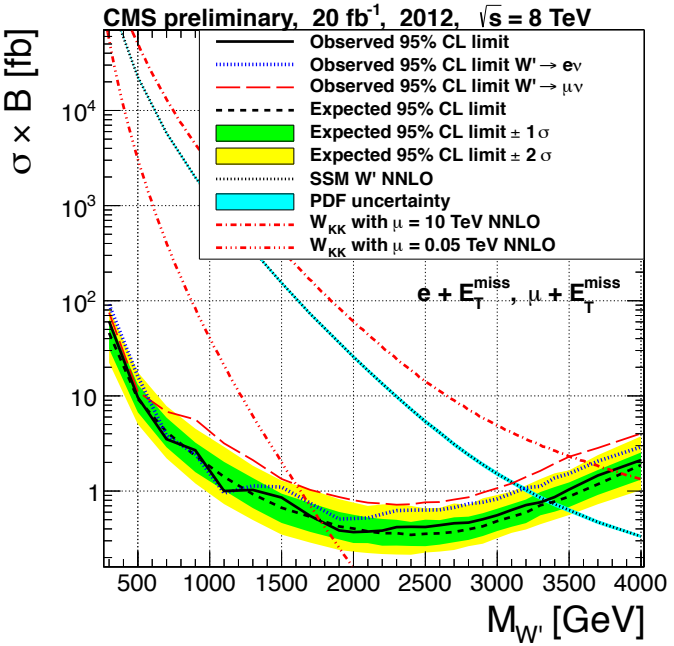

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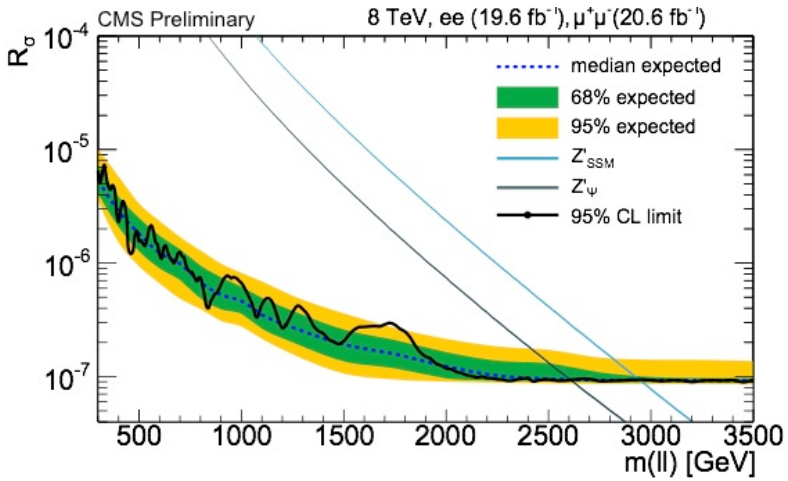

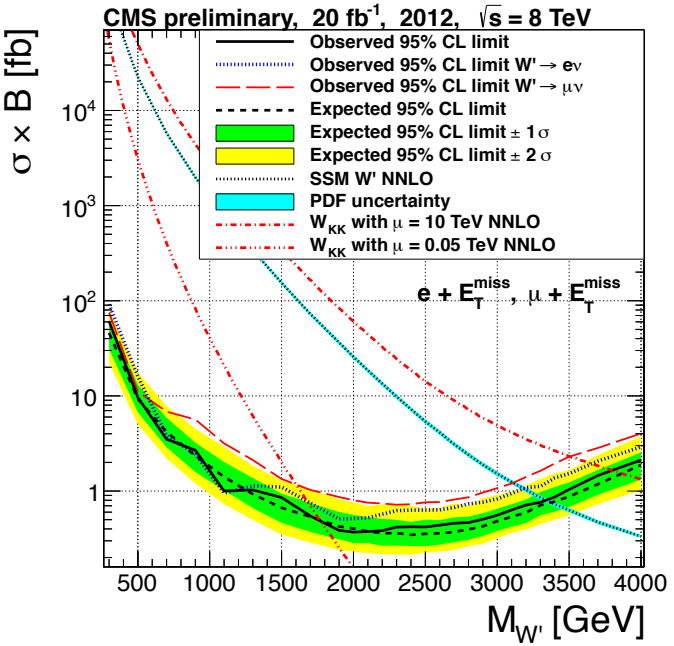

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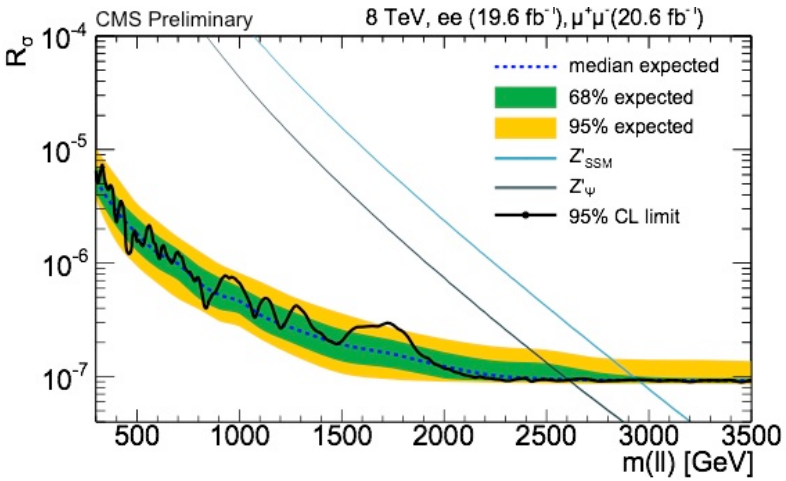

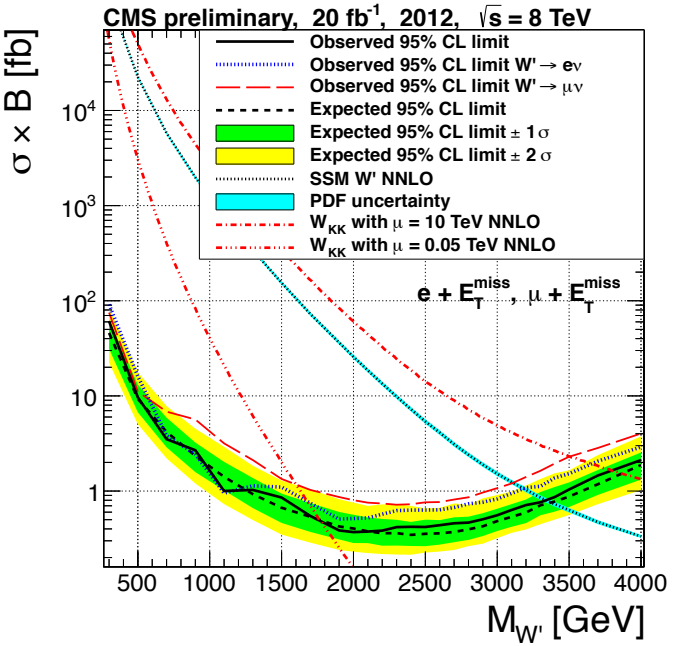

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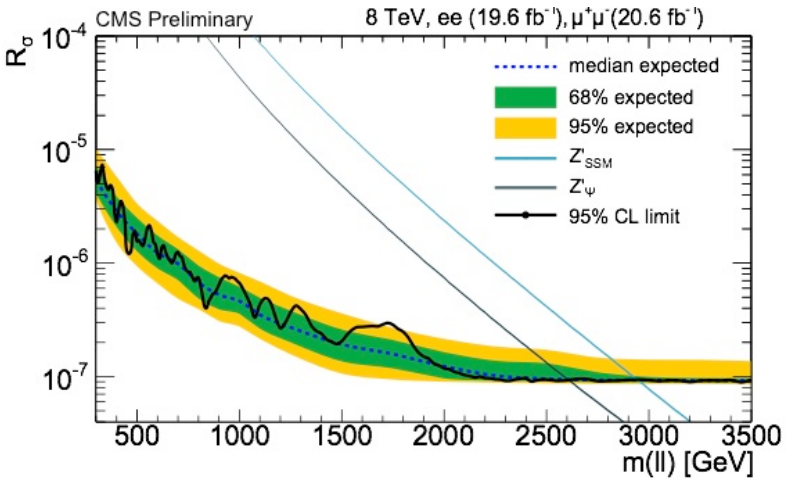

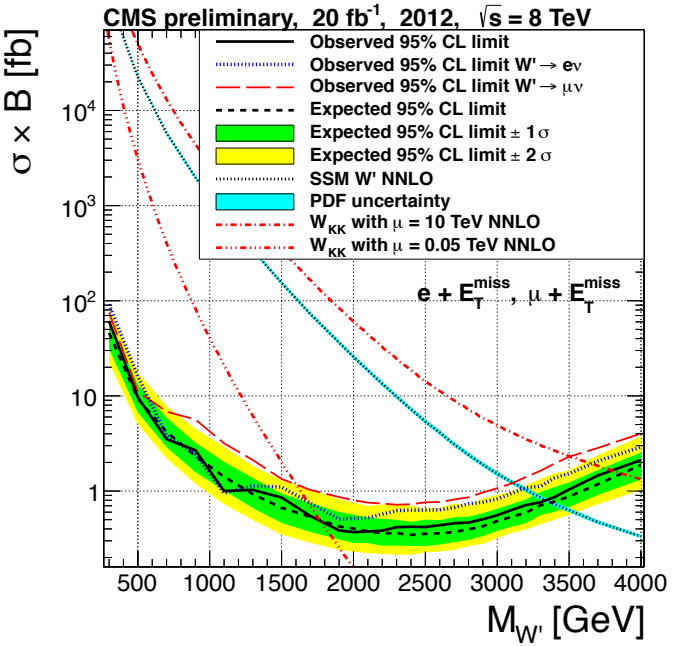

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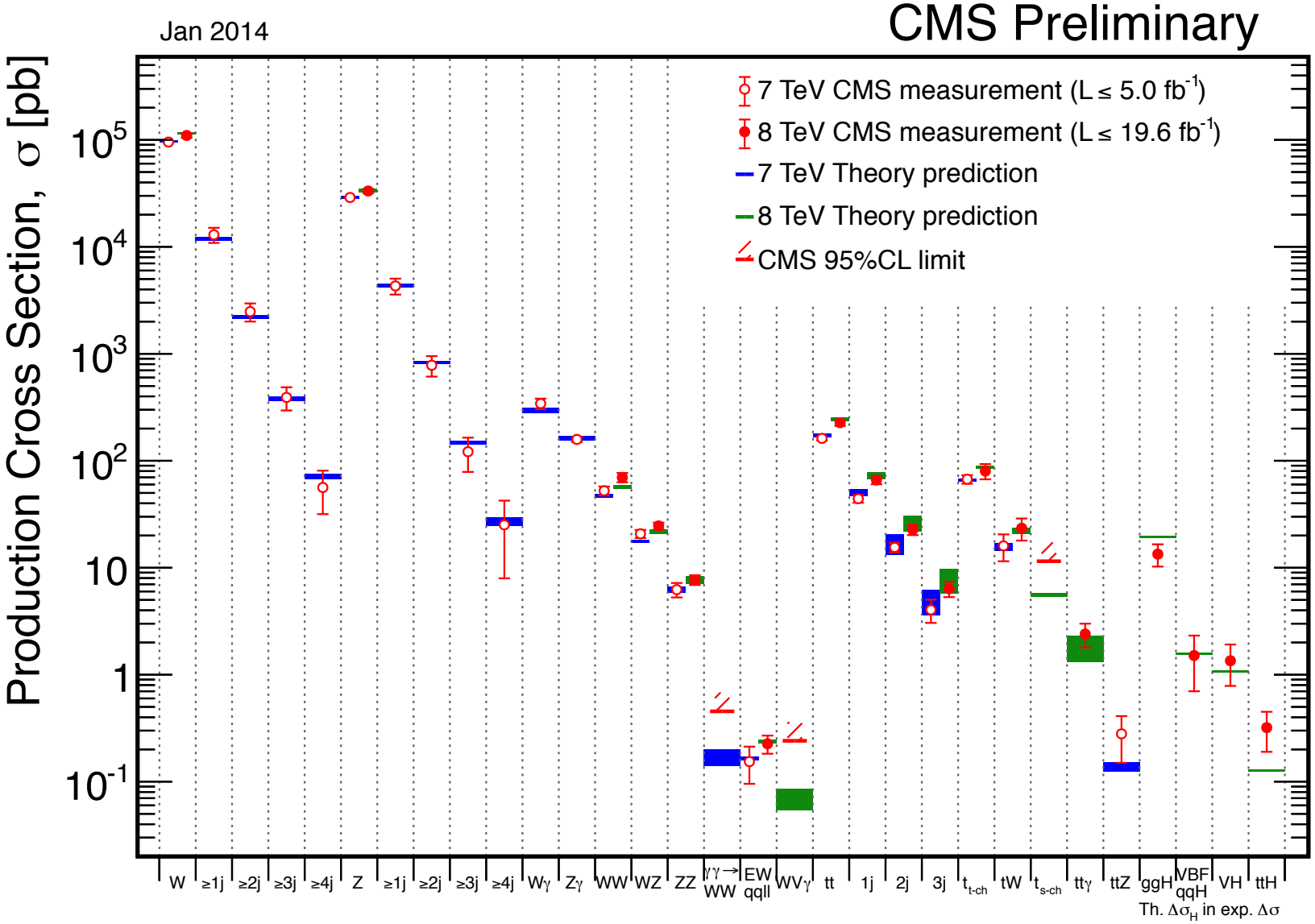
- We did it going from 2 TeV to 7 TeV, and from 7 TeV to 8 TeV; we are going to do it at 13 TeV

The Full Standard Model!



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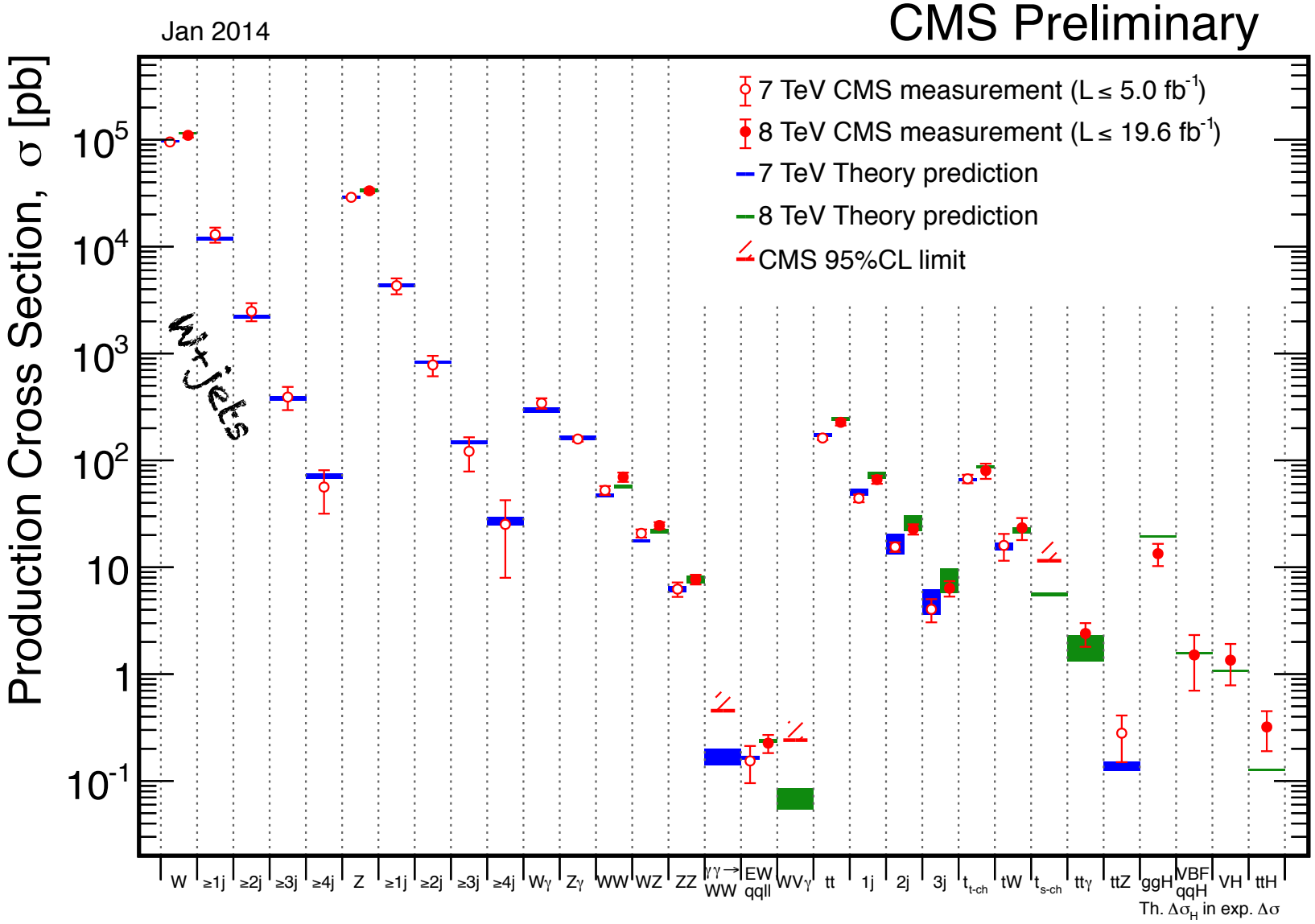

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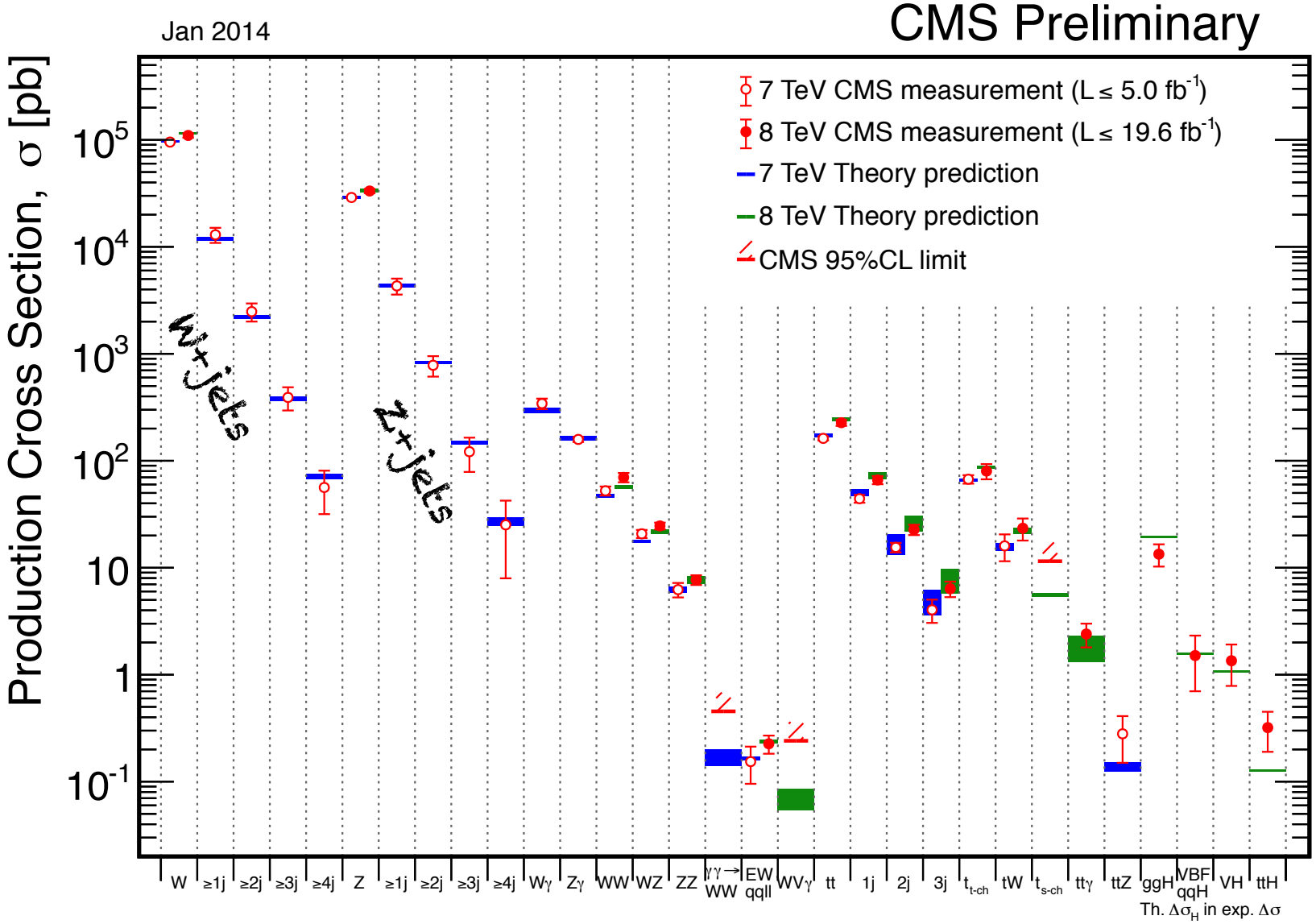

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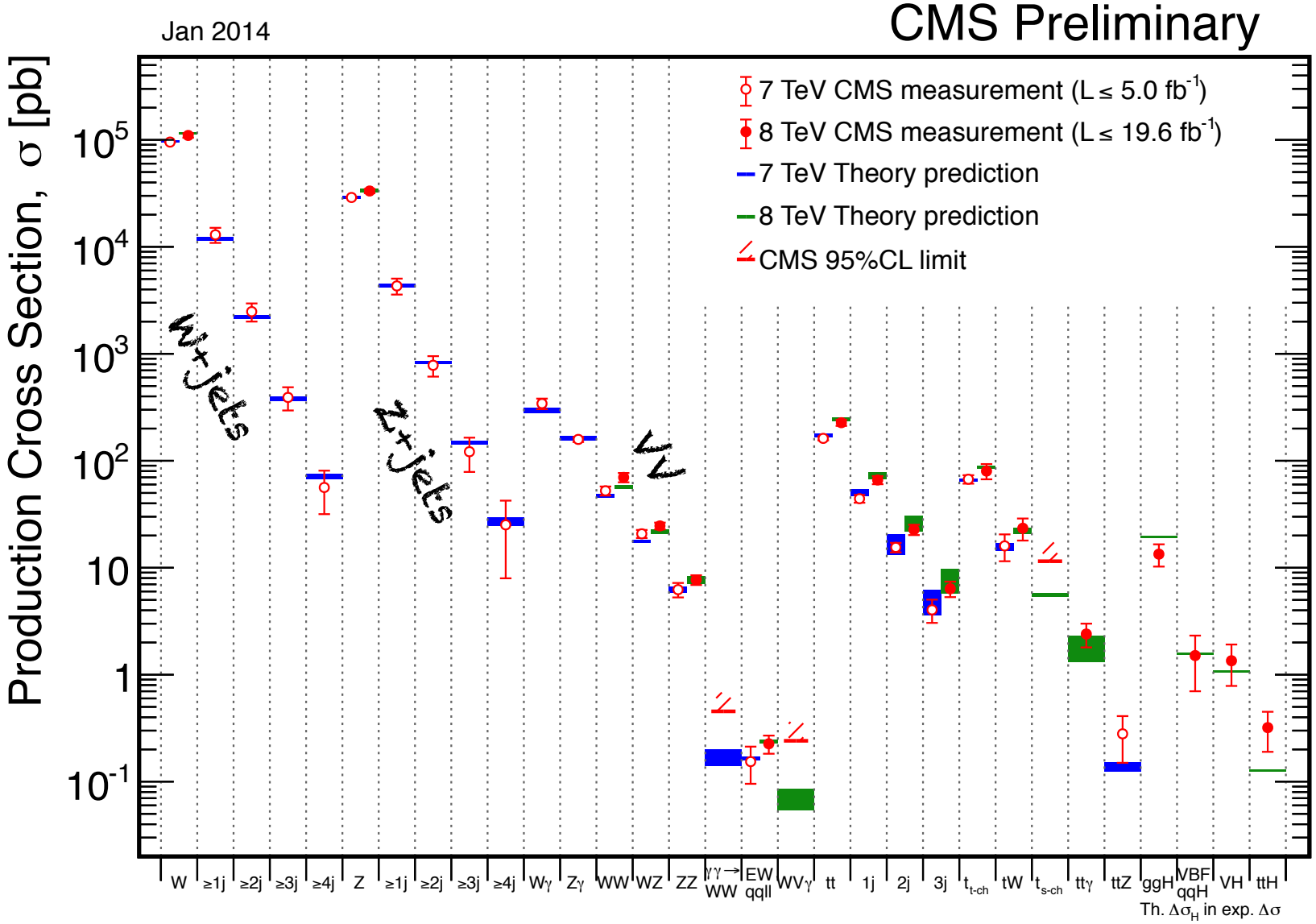

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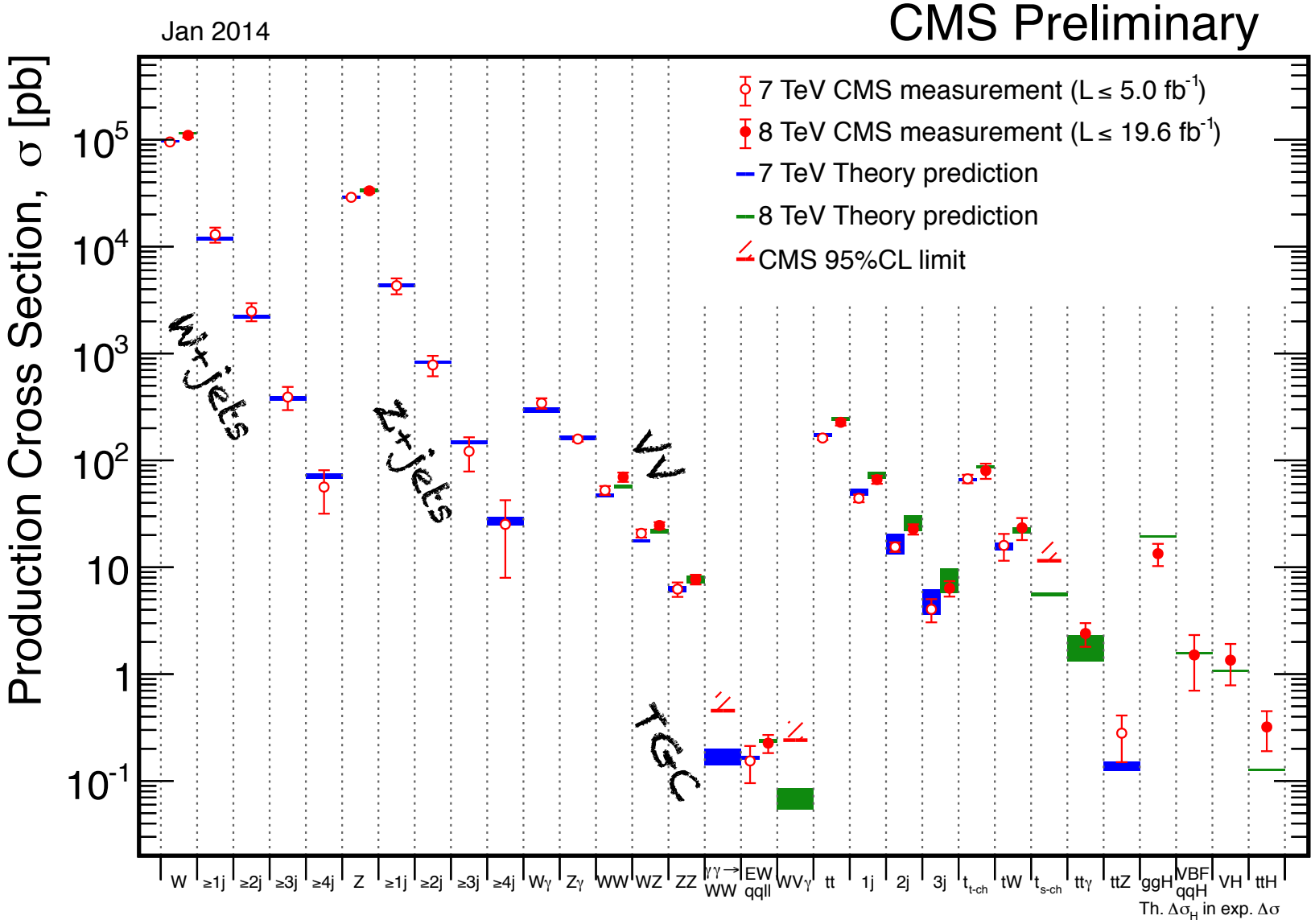

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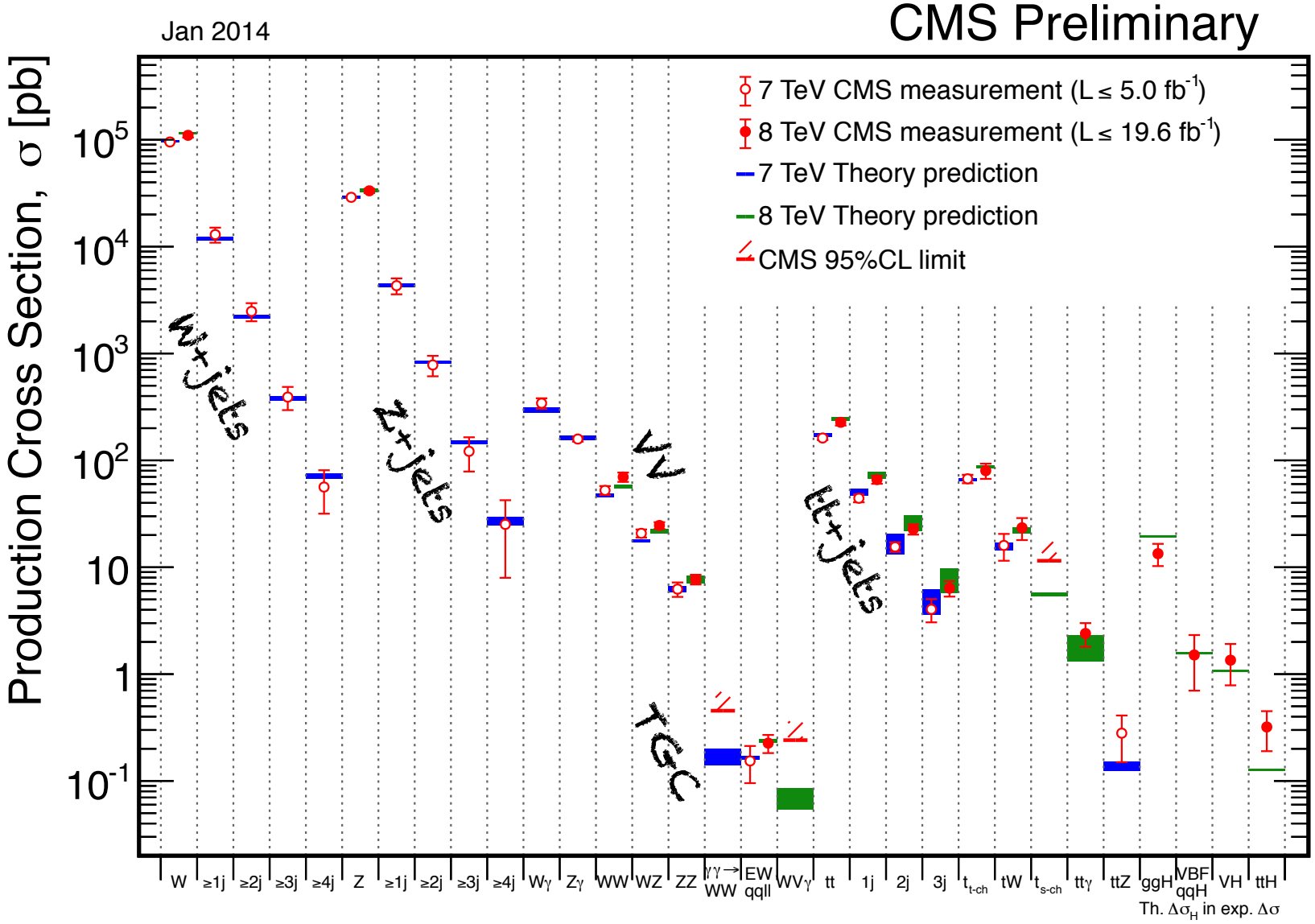

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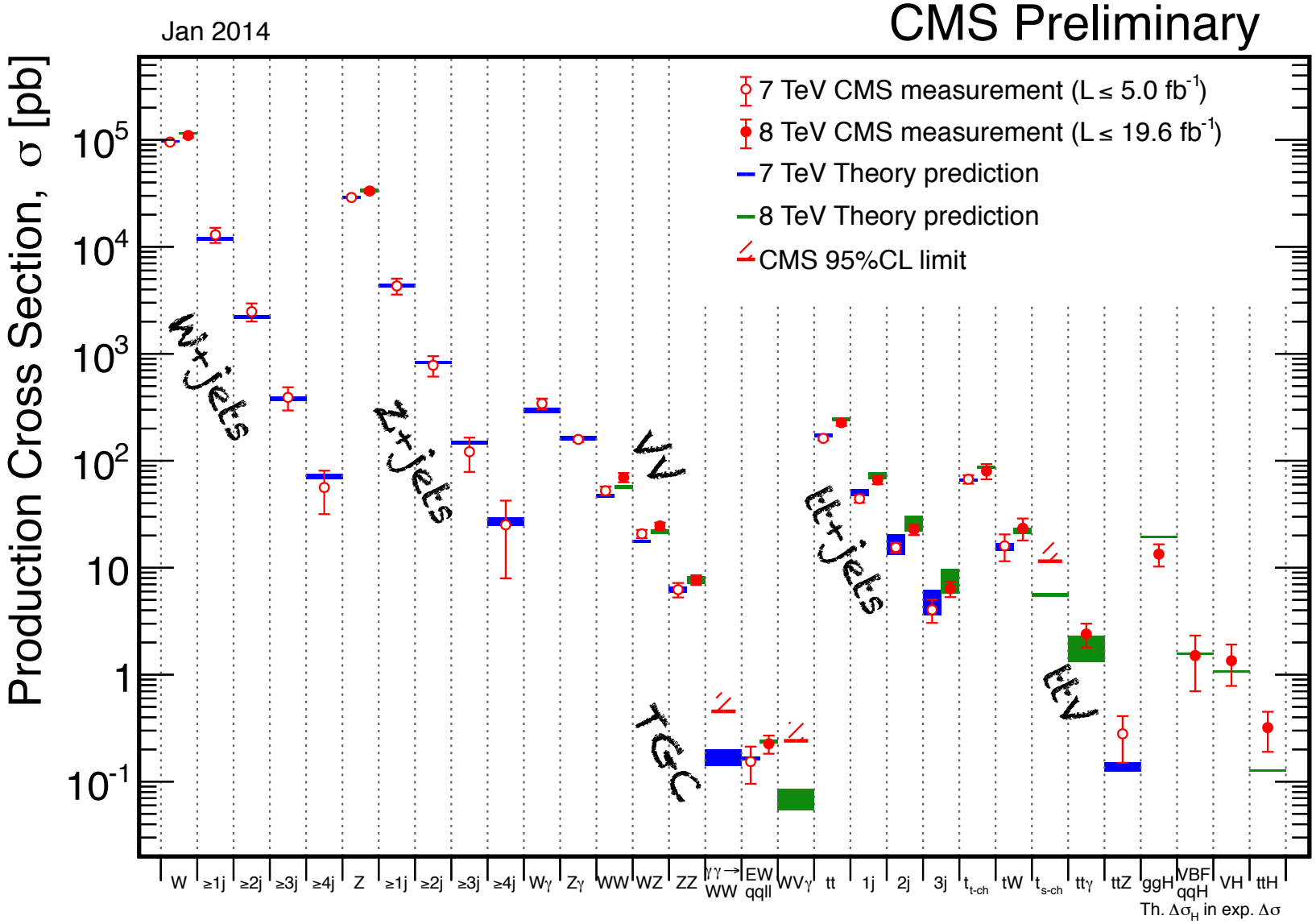

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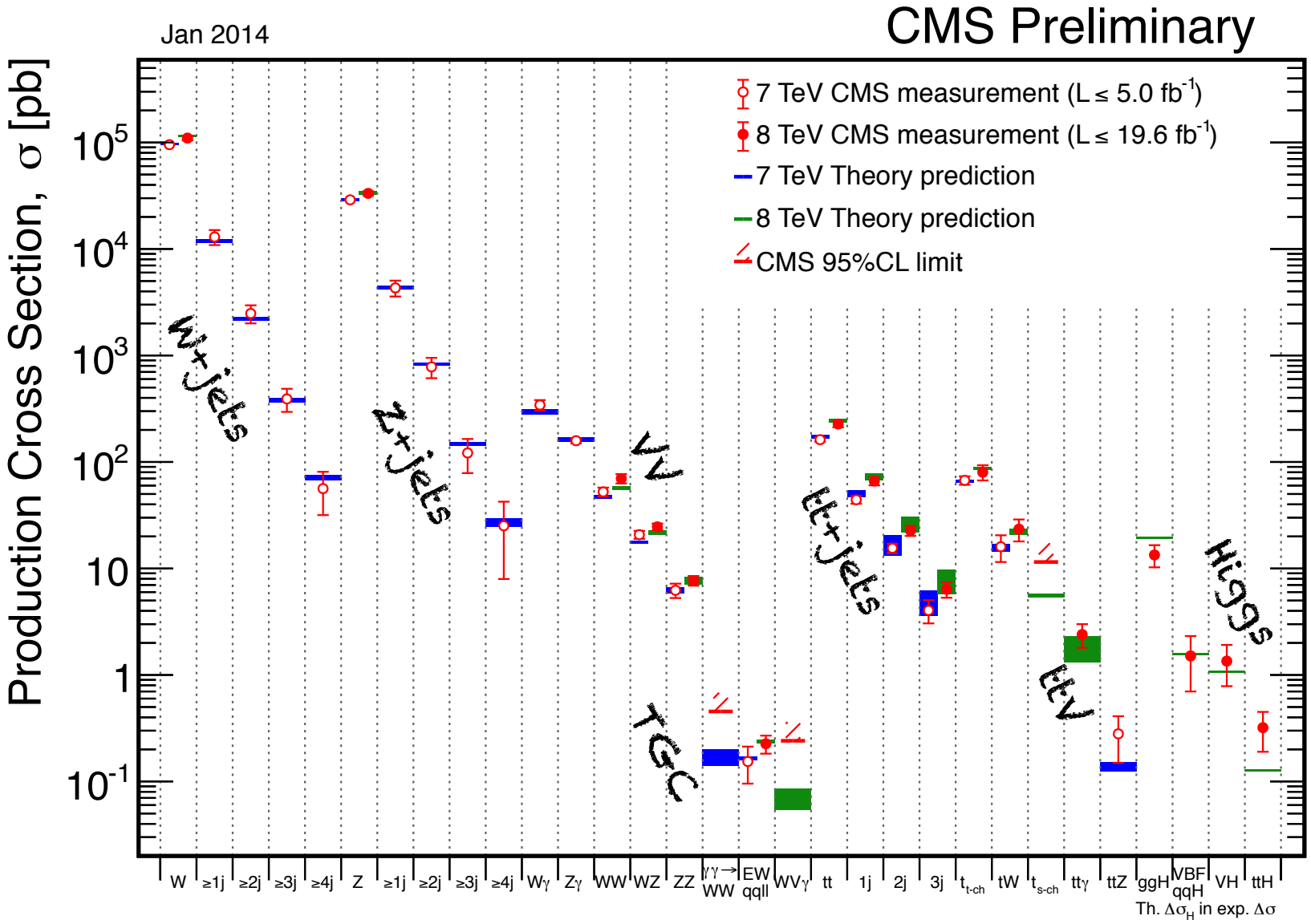

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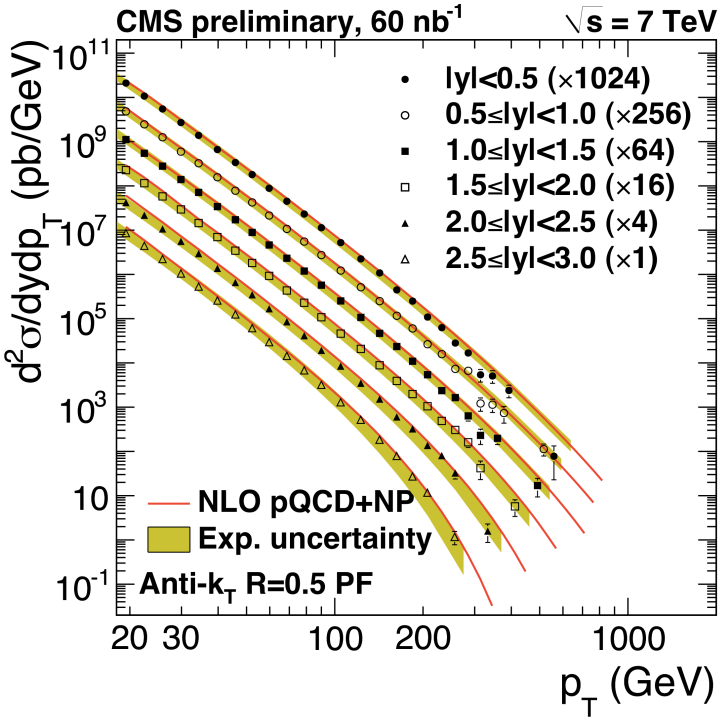
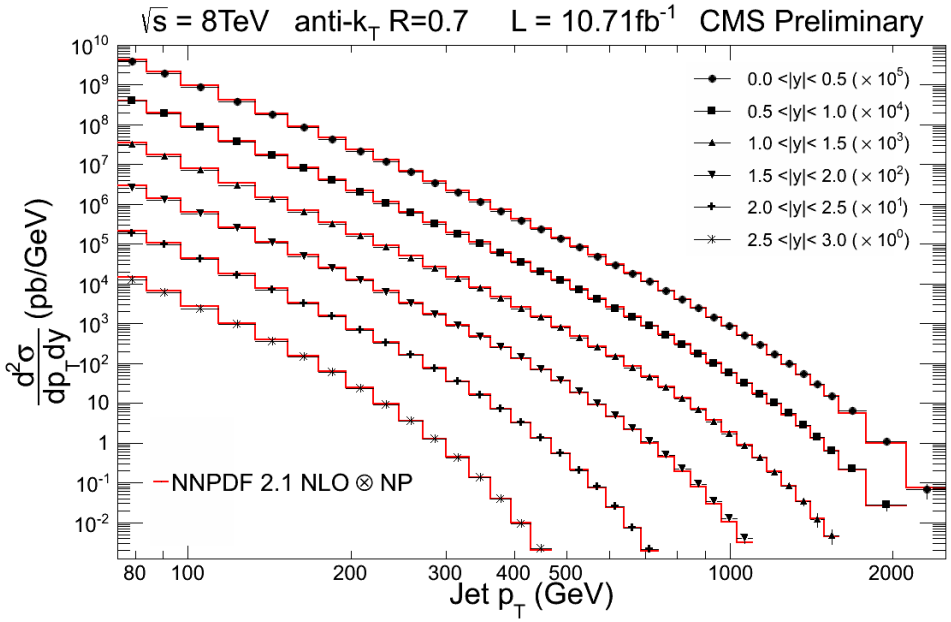
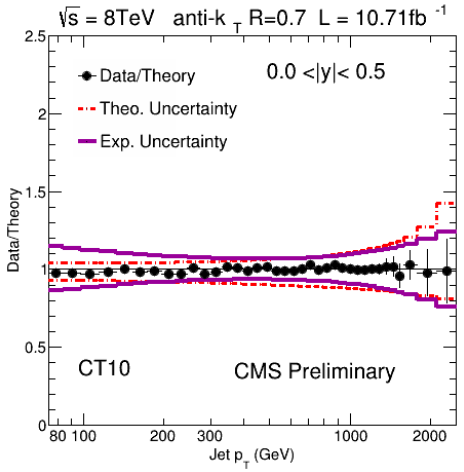
- Precision measurements (leading to interesting constraints on new physics) will take longer...

QCD Jets







- **Probe the hard scatter:**
  - The hard scatter: jet P_T and η, dijet correlations, dijet mass

Excellent agreement with QCD

Syst. Unc. (~10%) dominated by JES (1-2%) & PDFs

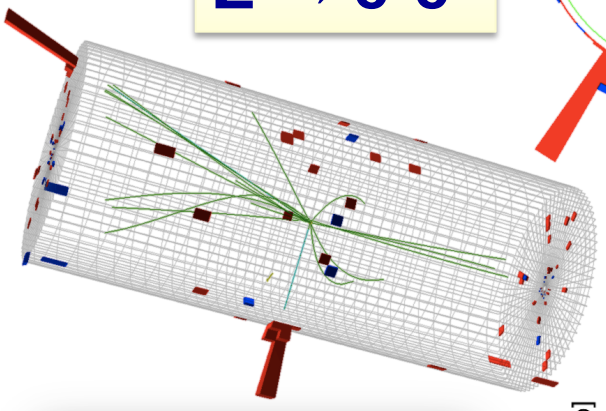
W/Z at 7 TeV

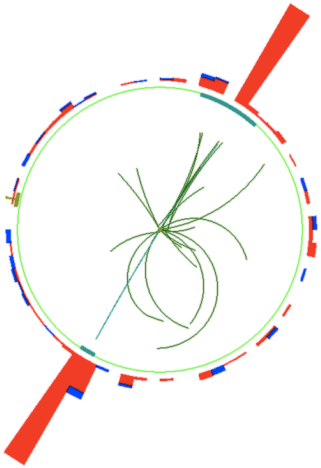
Fermilab
UIC University of Illinois at Chicago

CMS Experiment at LHC, CERN
Run 133877, Event 28405693
Lumi section: 387
Sat Apr 24 2010, 14:00:54 CEST

Electrons $p_T = 34.0, 31.9$ GeV/c
Inv. mass $= 91.2$ GeV/c^2

$Z \rightarrow e^+e^-$

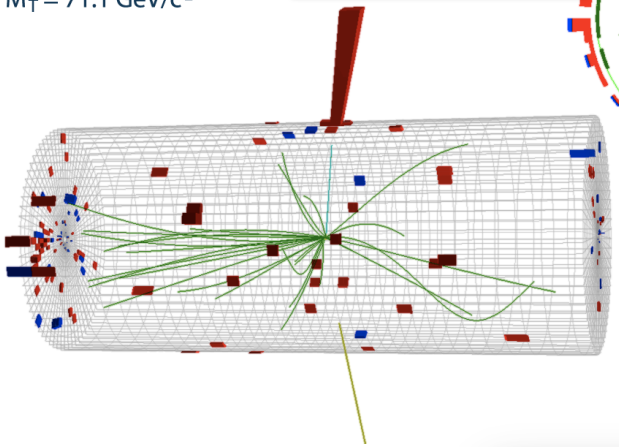


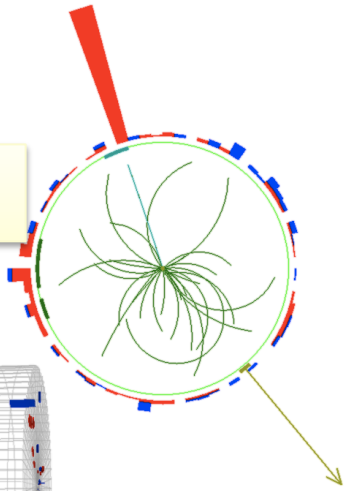


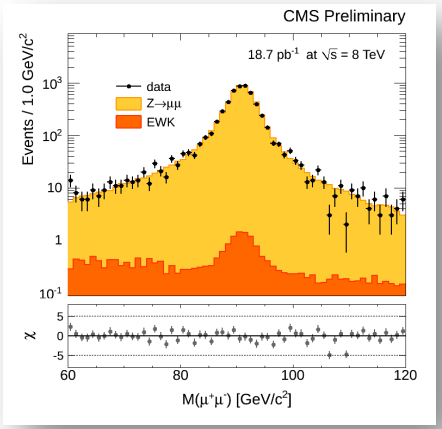
CMS Experiment at LHC, CERN
Run 133874, Event 21466935
Lumi section: 301
Sat Apr 24 2010, 05:19:21 CEST

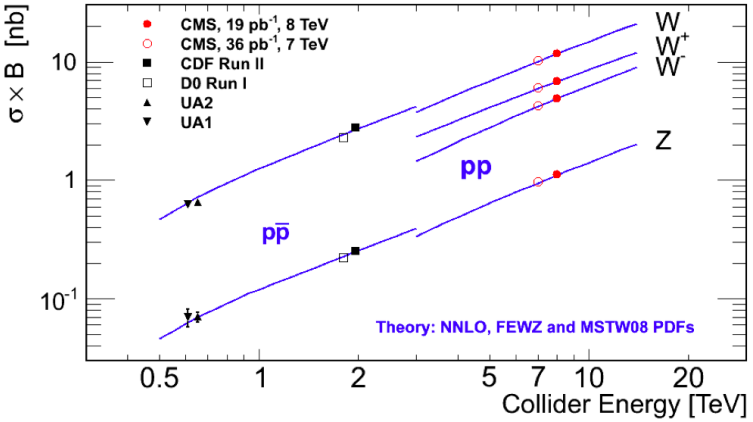
Electron $p_T = 35.6$ GeV/c
$ME_T = 36.9$ GeV
$M_T = 71.1$ GeV/c^2

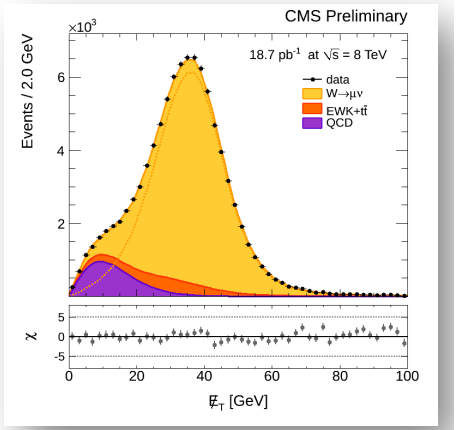
$W \rightarrow e \nu$



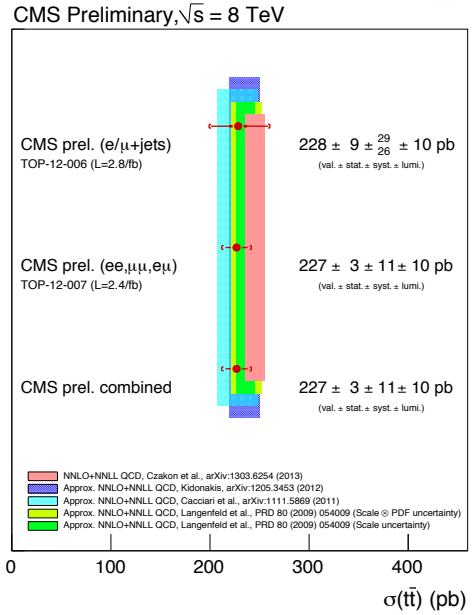


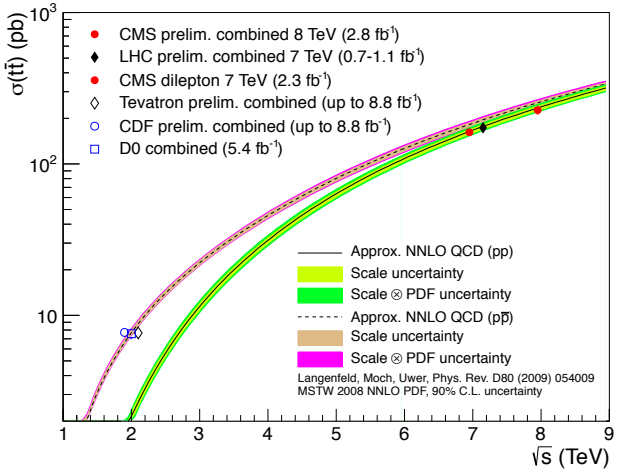


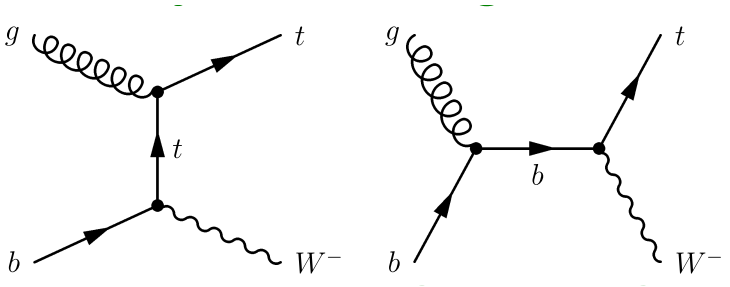




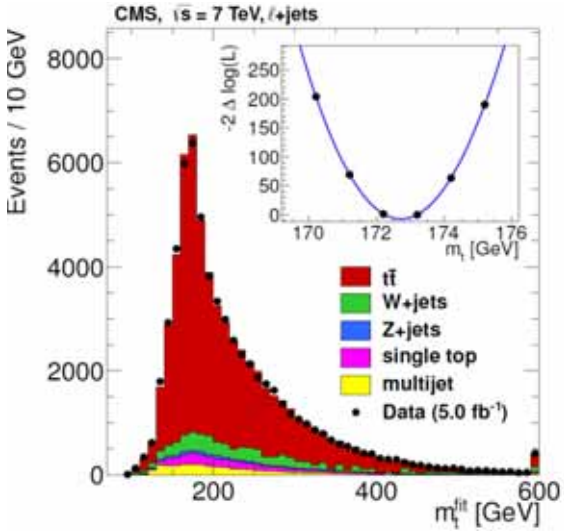
Top (single and double)

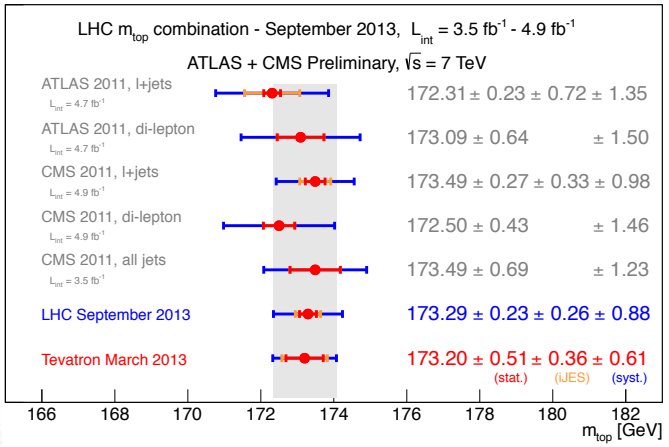


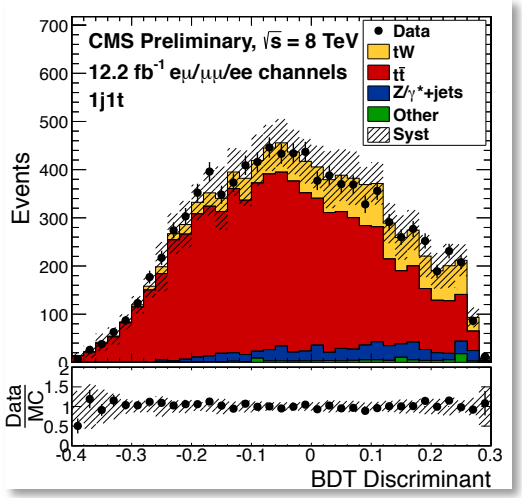




Significance: 6σ
Expected: 5.4σ
xsec=23+5.5–5.4 pb







LHC Physics Center

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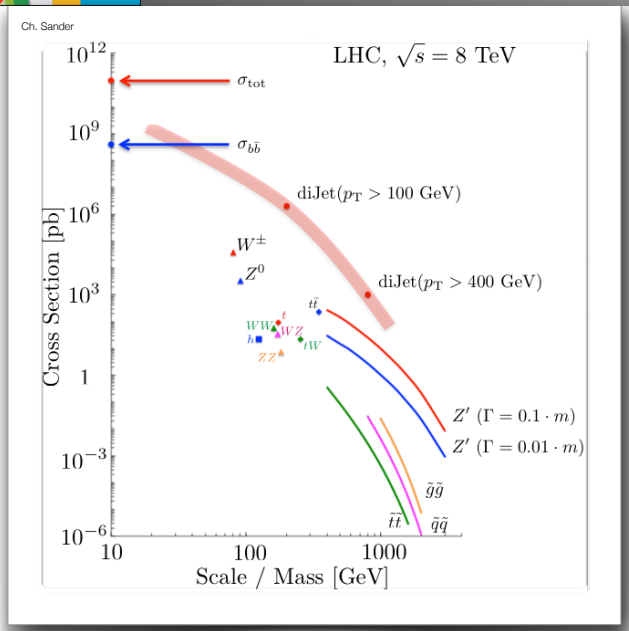
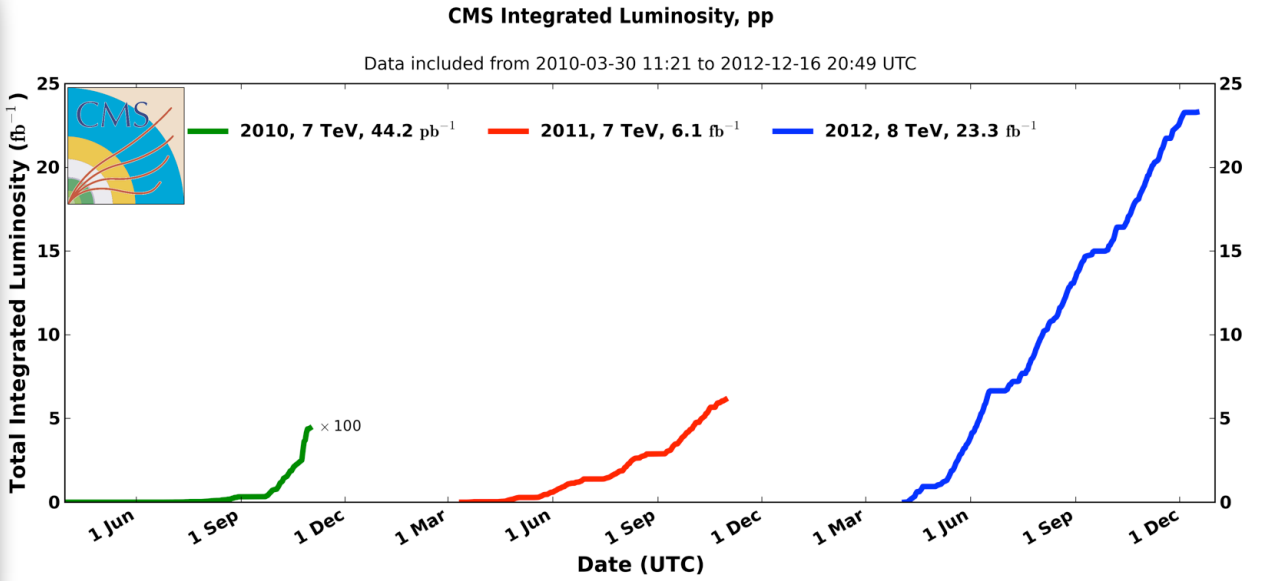
Look Familiar? Of course it does…





From G. Dissertori (ETH)

δ .. relative uncert.
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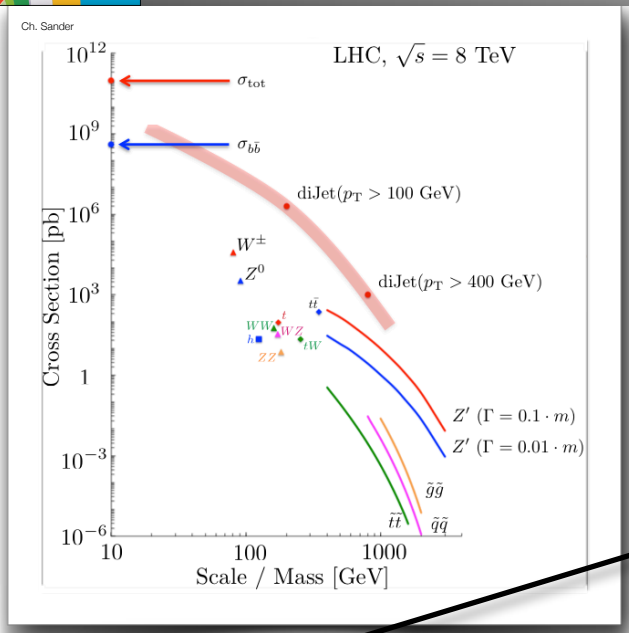

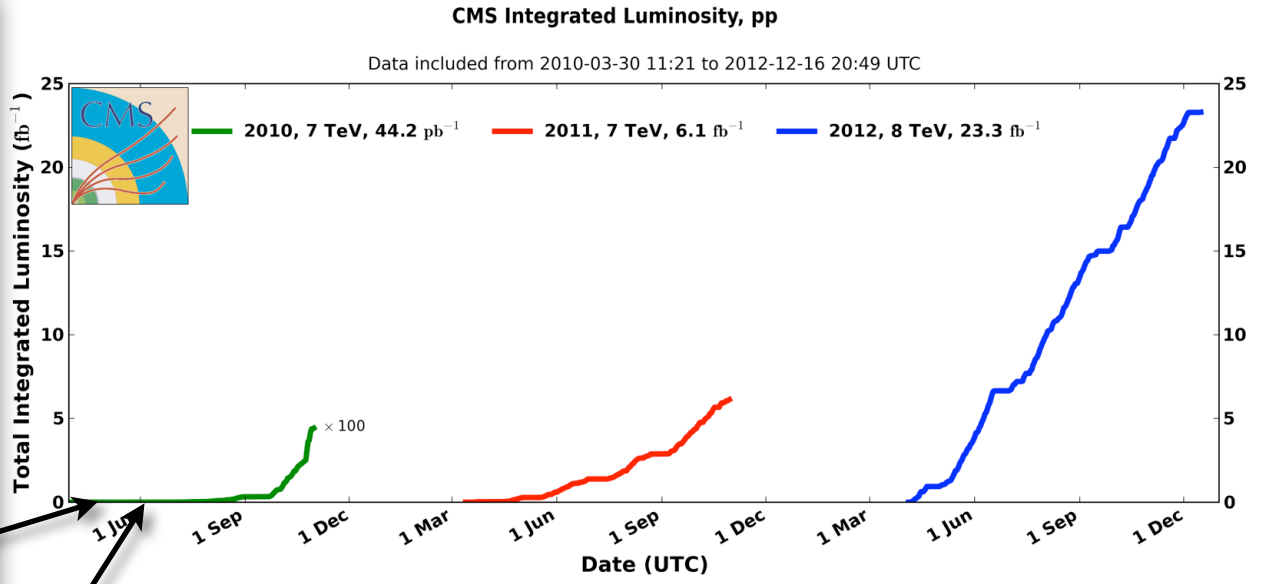

first MinBias / UE
studies, particle multiplicities

first incl. jet x-section, PF jets
60/nb δ ~ 20-30%

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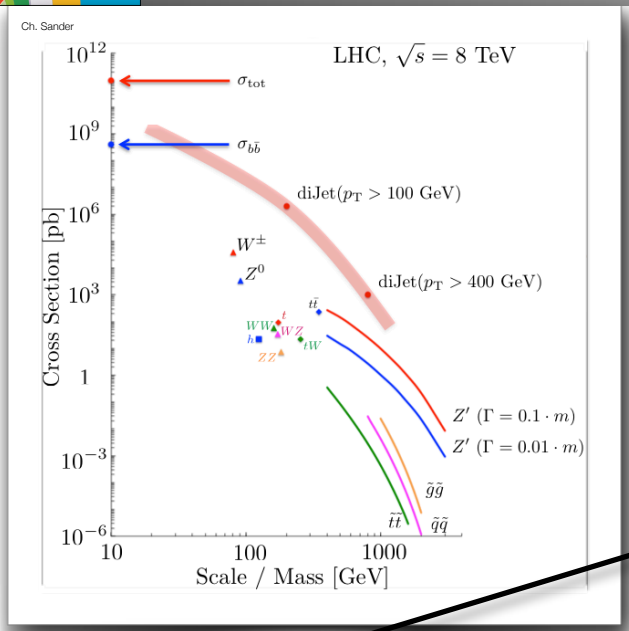

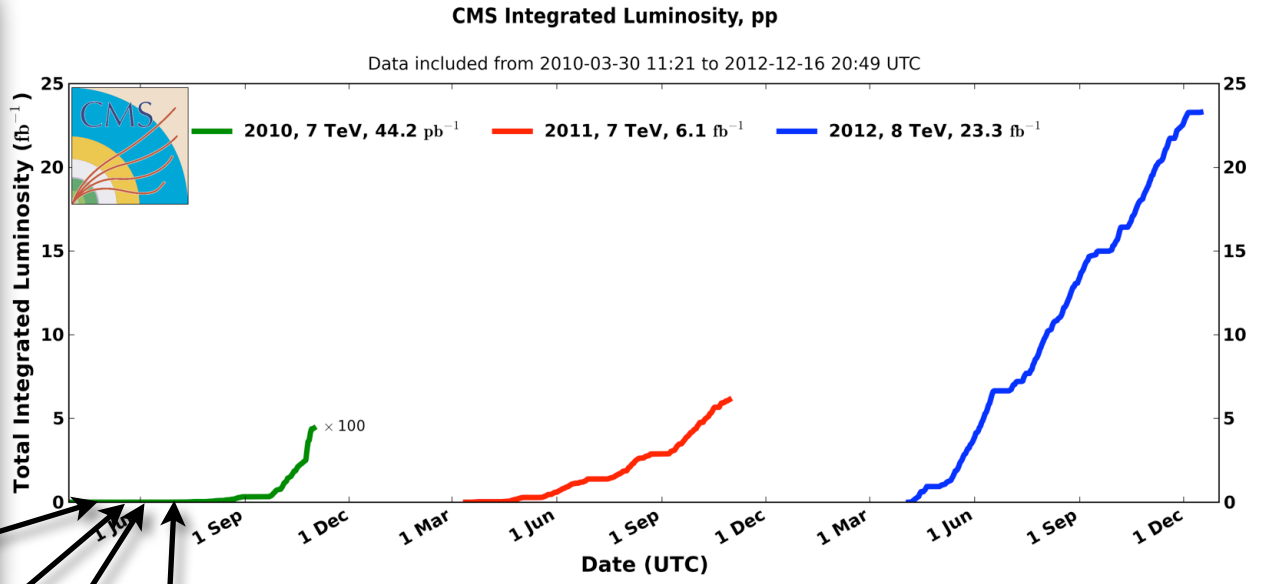

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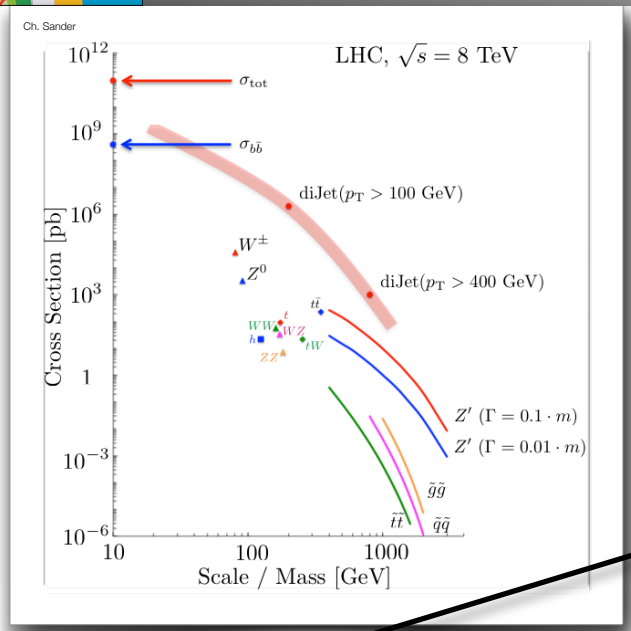

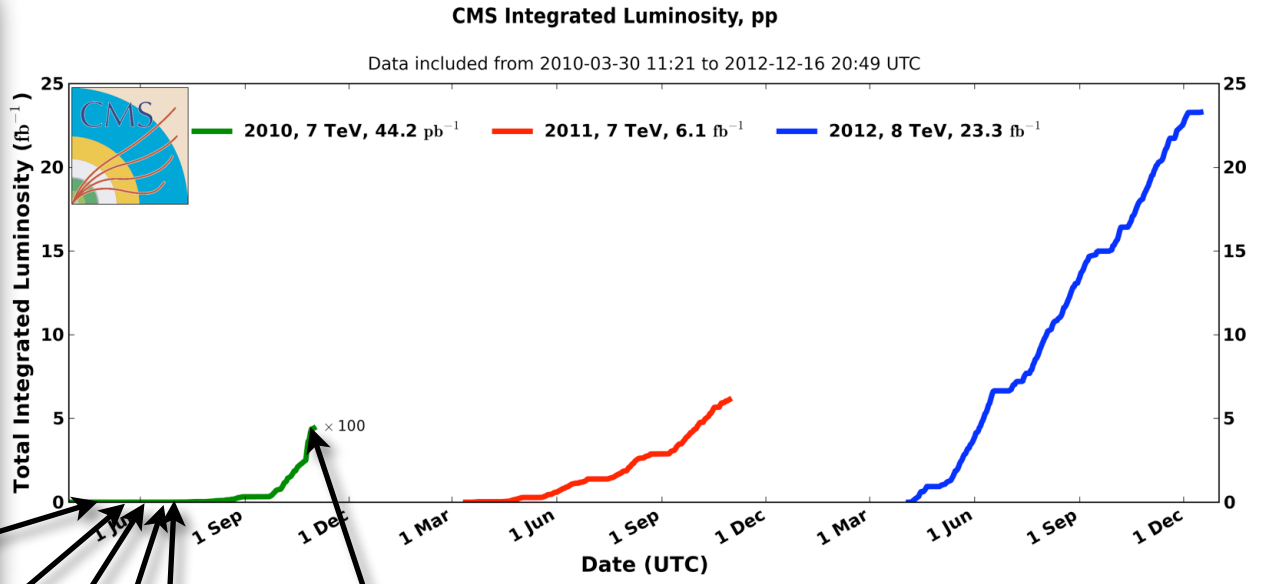

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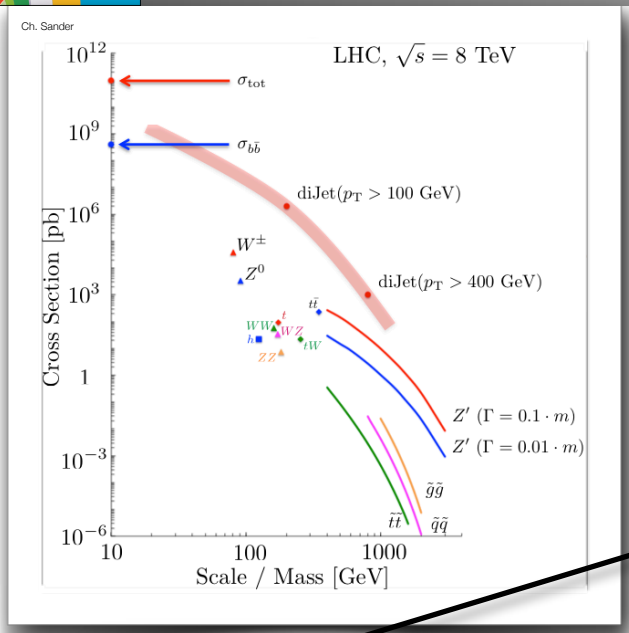

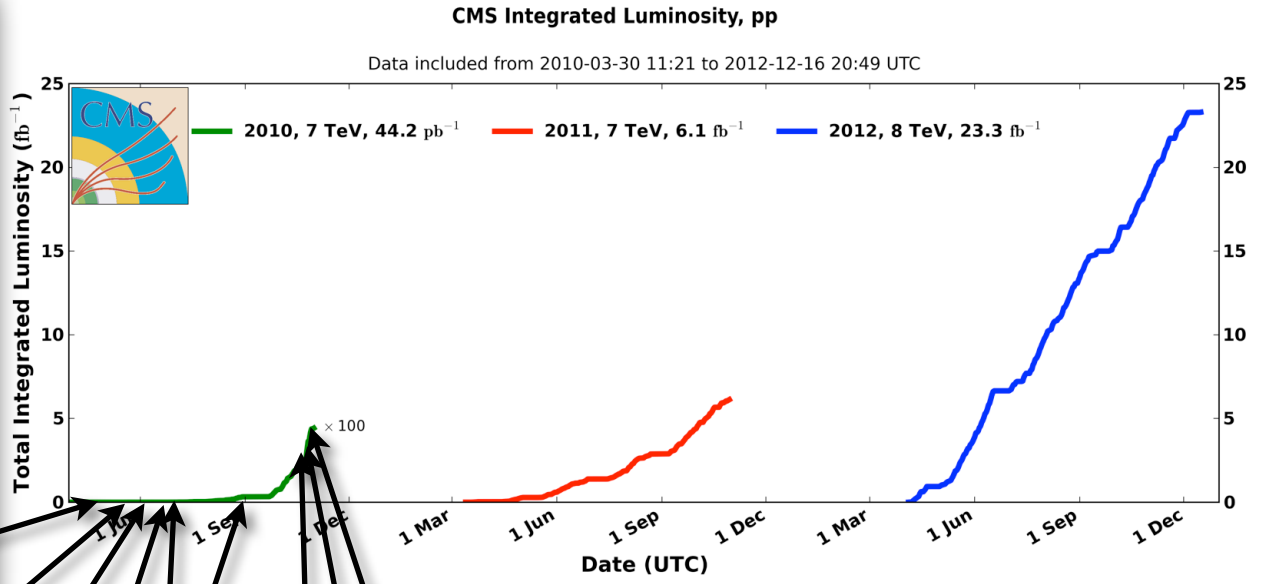

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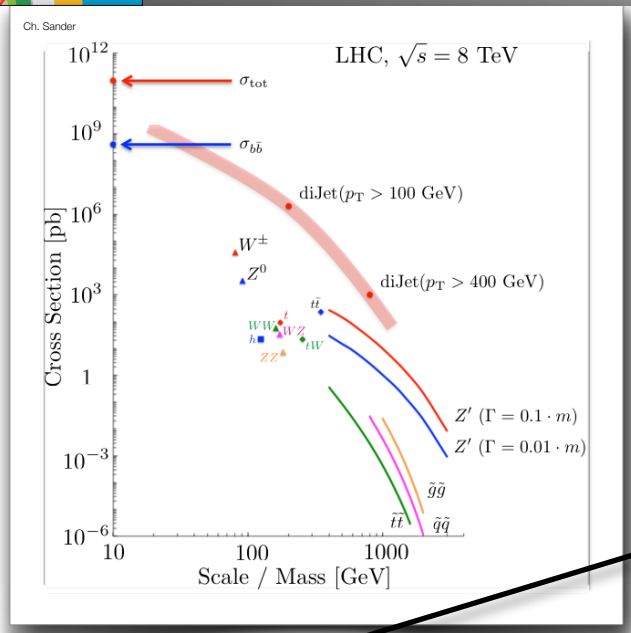

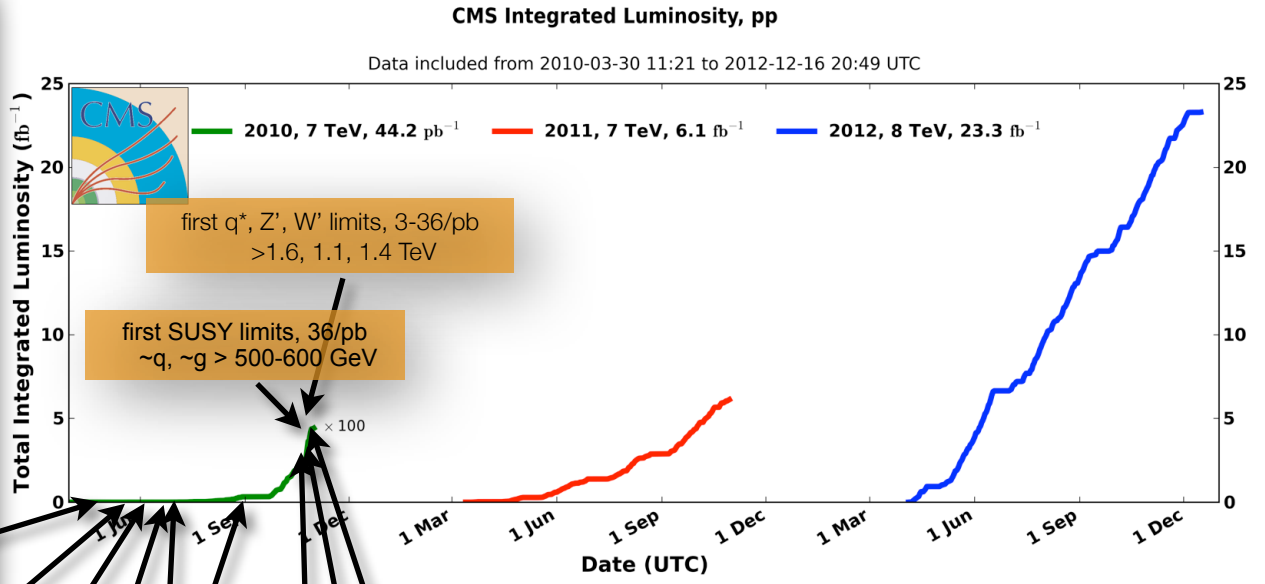

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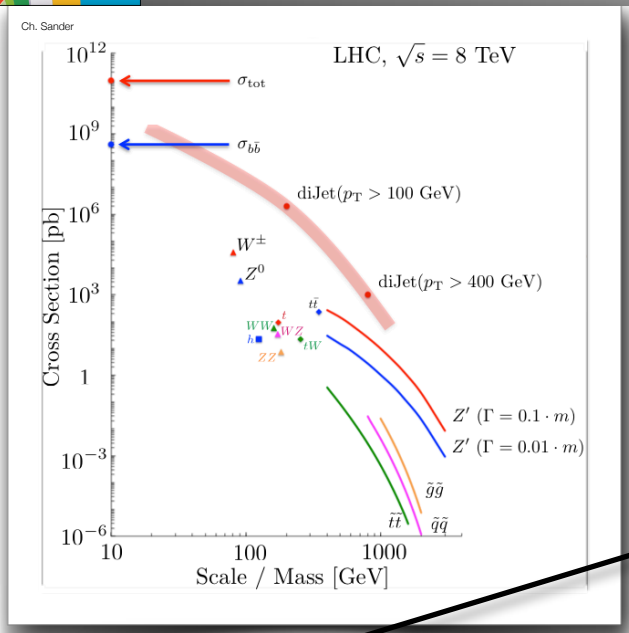

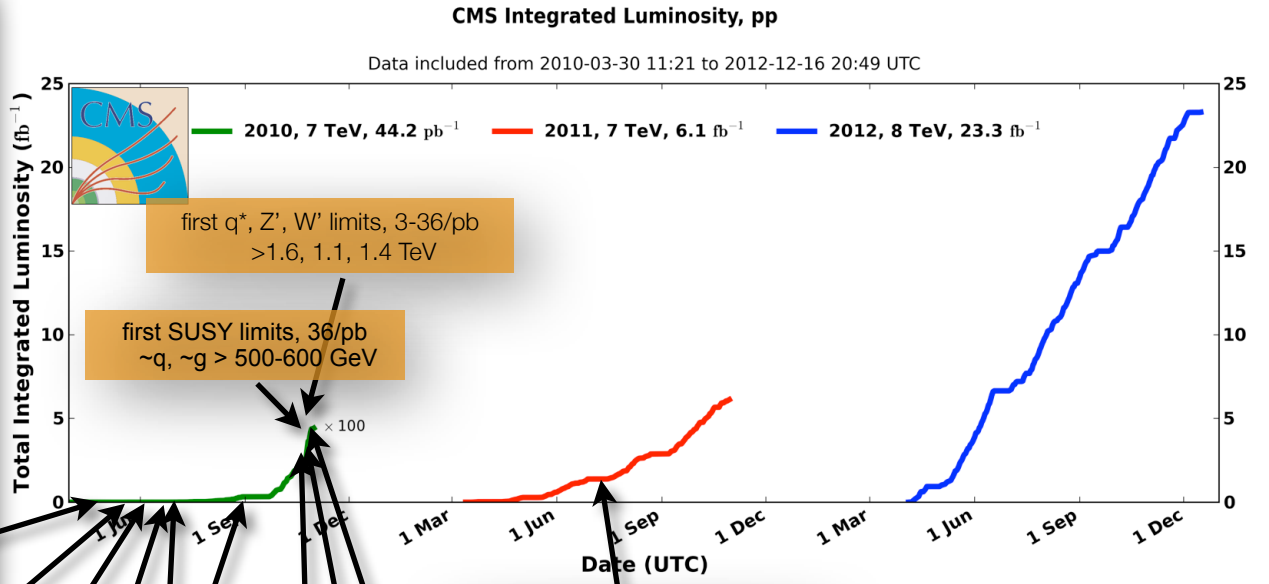

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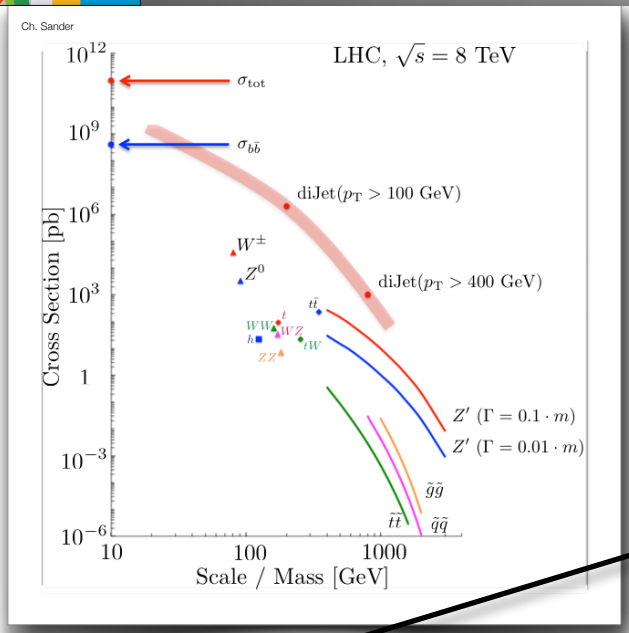

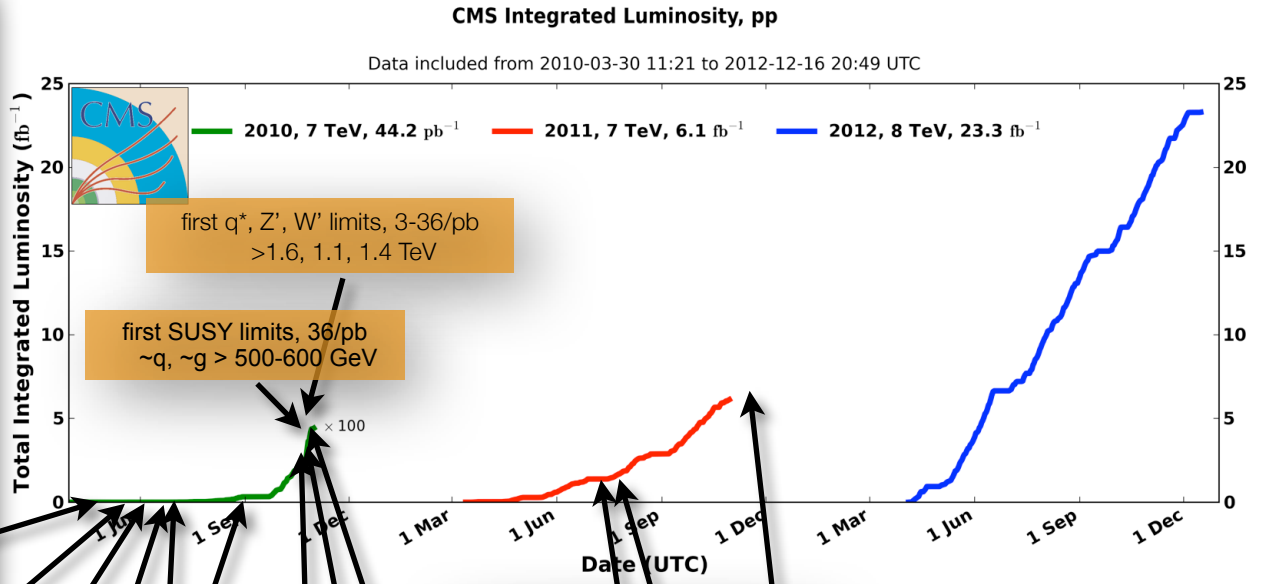

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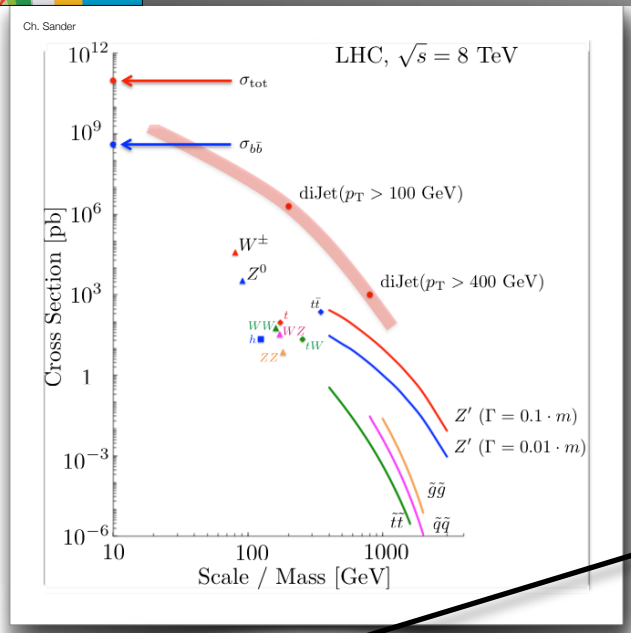

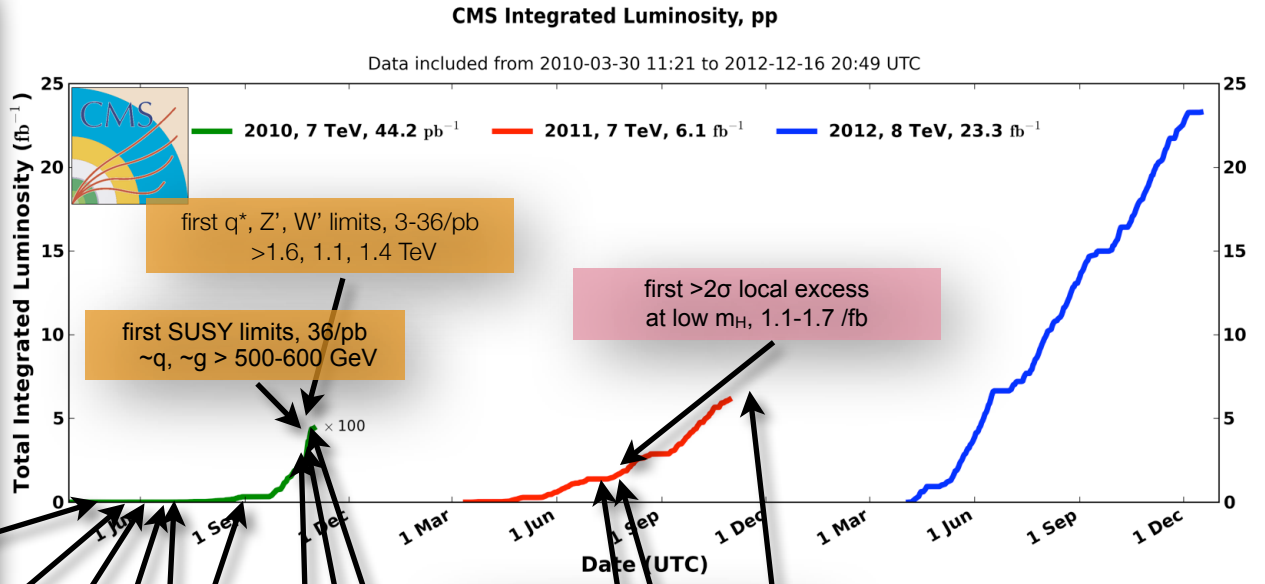

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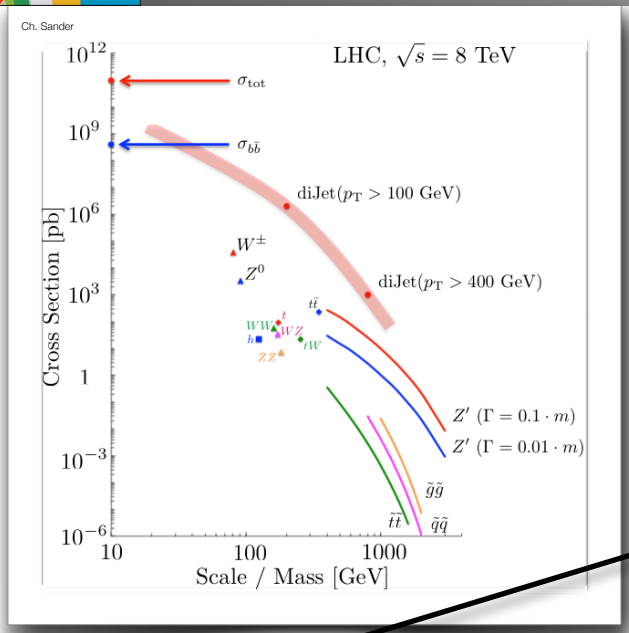

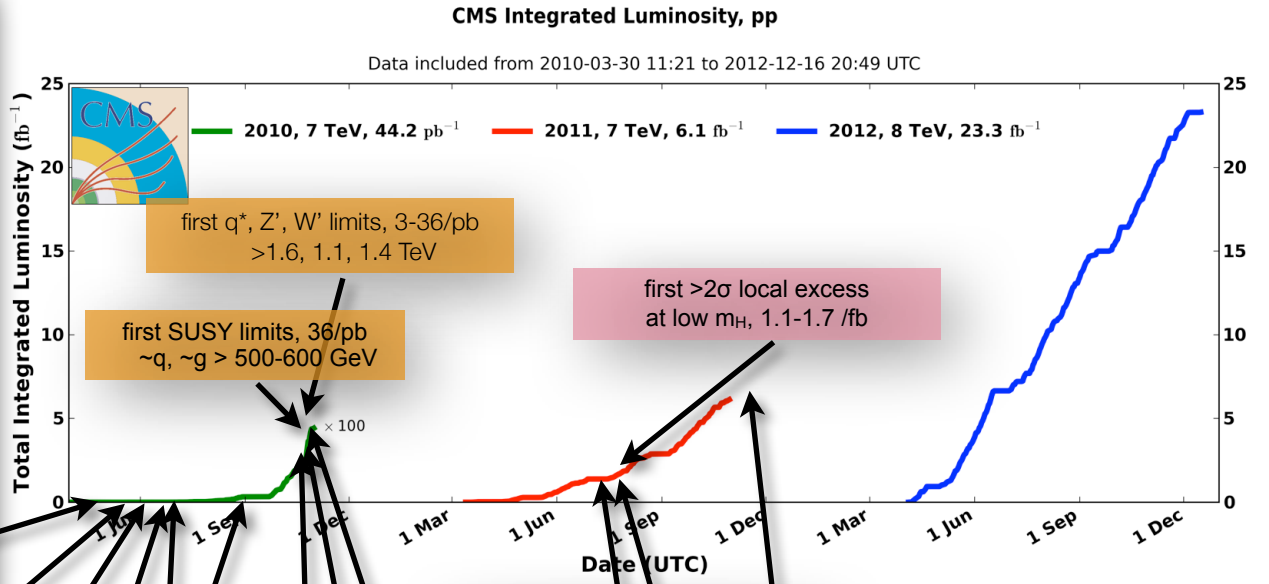

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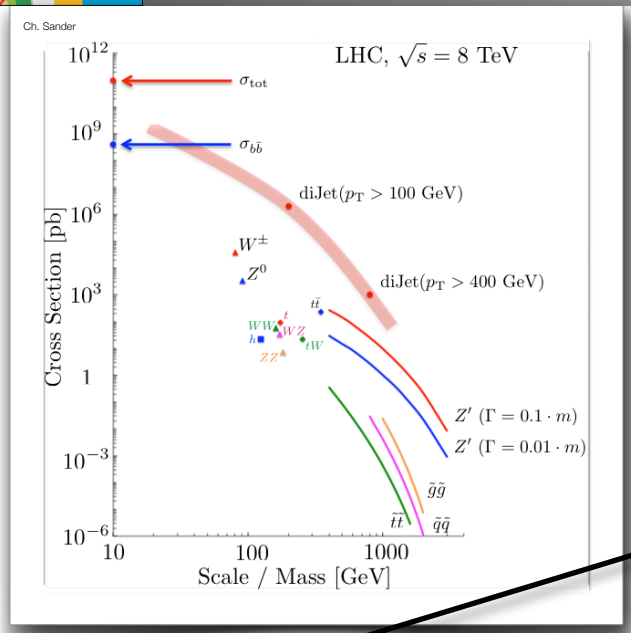

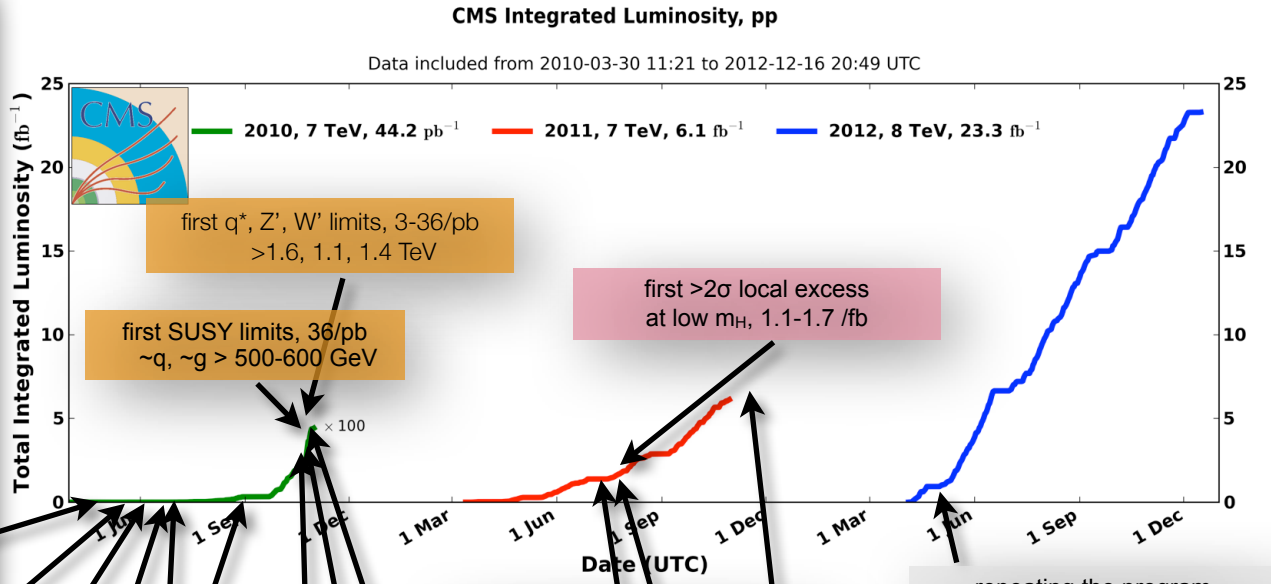

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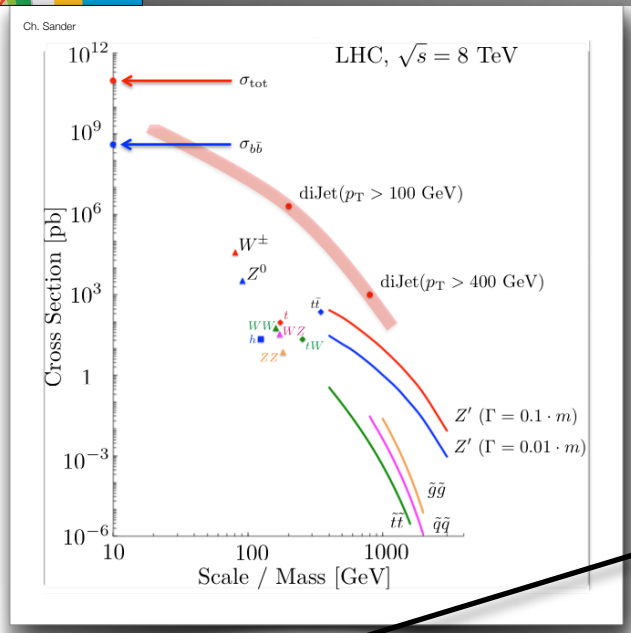

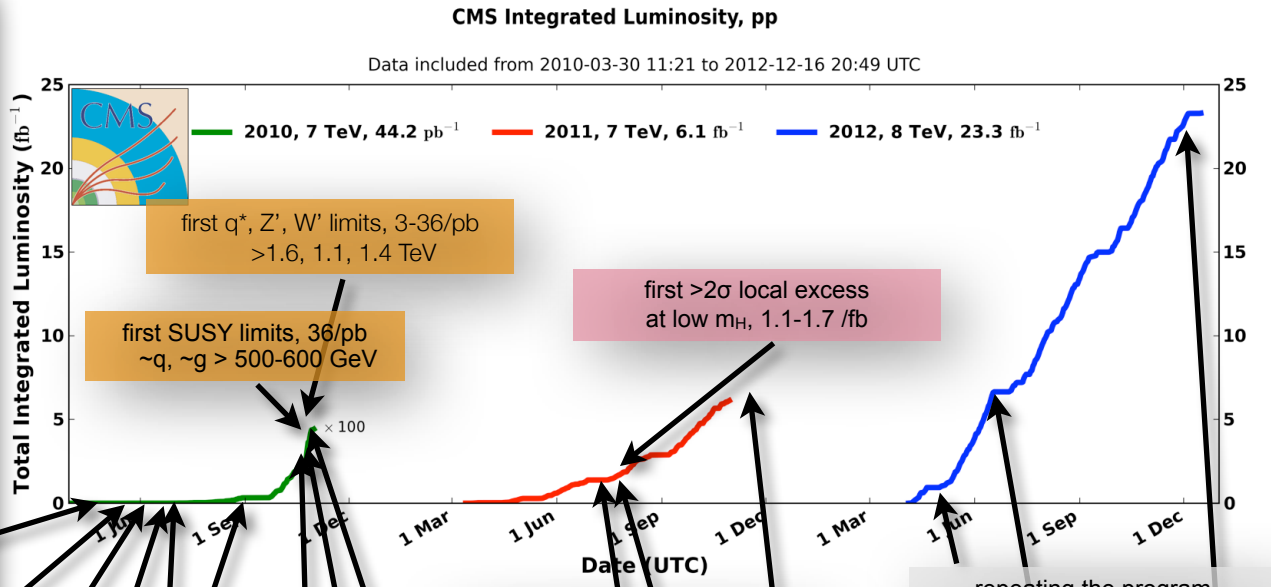

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repeating the program
at 8 TeV

a new boson is
announced, 5 /fb

first spin parity analysis
of the boson, 17 /fb

δ .. relative uncert.
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LPC LHC Physics Center

Planning is Crucial

- **What did it take to discover Higgs boson in July 2012?**
  - MC generation started in Nov 2011
    - Gambled on 8 TeV
    - Allowed CMS to analyze all five main channels for discovery paper
      - **ATLAS had just two; third added for paper**
  - Strong case made to the machine
    - Prevailed and convinced the community to run at 8 TeV in 2012
  - Early pileup mitigation studies
    - Started in January 2012
    - Allowed to be prepared for early LHC data
- **Without any of these crucial steps, the discovery would not have been possible that early**
- **Planning is everything, and needs to be done in advance, for both bunch spacing options in parallel!**

Greg Landsberg CMSDAS 2014

To boldly go where no one has gone before…

To explore strange new worlds…

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Backups

(VERY!) Broad PAG plans

SM/Precision Physics HPA (to be detailed and discussed)

SMP+FSQ+BPH:

- integrated lumi is not an issue here, cross section will be high enough.
- Essential is a low PU run early both for physics analyses (inclusive X-sec, etc.) and for MC tuning as we have done in 2009/2010. Only a (very) low int. lumi is needed!
- inclusive Xsec (W, Z, VV) accessible with 0.1-1.0fb^{-1}
- aQGC limits, VV scattering need > 5 fb^{-1}

TOP

- first ttbar X-sec can be obtained with few pb^{-1}.
- important to develop a dynamical trigger strategy: simple paths up to the 1st fb^{-1}, more complex (b-tag, MET, combined, etc.) for later on.

HIG

- "re-discovery" with first 5-10 fb^{-1} (but BSM heavy Higgs searches probably earlier).
- maintaining trigger performance is a must (actively working on it)

Luca Malgeri

(VERY!) Broad PAG plans

Searches/HPA (to be detailed and discussed)

B2G:

- Crucial for B2G to develop non-isolated lepton trigger and merged hadronic tops (boosted top)
- priority analyses:
  - l+j and dilepton, single lepton
  - Z'->ttbar, W'->tb
- request a flexible approach to reco (computing train?) such that new development, especially in jet substructure, may go in production quickly

EXO:

- Natural high priority analysis:
  - Z', W'
  - di-jet, di-photon
  - VV resonance
- On the trigger side, the long-lived paths should be rethought

SuSy:

- exceeding 8 TeV reach after 2-5 fb^{-1} of 13TeV data
- natural SuSy will still be under the spot (Mgluino <1.5 TeV, Mstop<800 GeV) but if nothing pops up, next frontier is small mass splitting, long-lived, stealth (a nightmare for trigger)

Luca Malgeri