Beyond the SM searches: 'LHC14' prospects

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LCH France 2013, Annecy

6 April *2013*

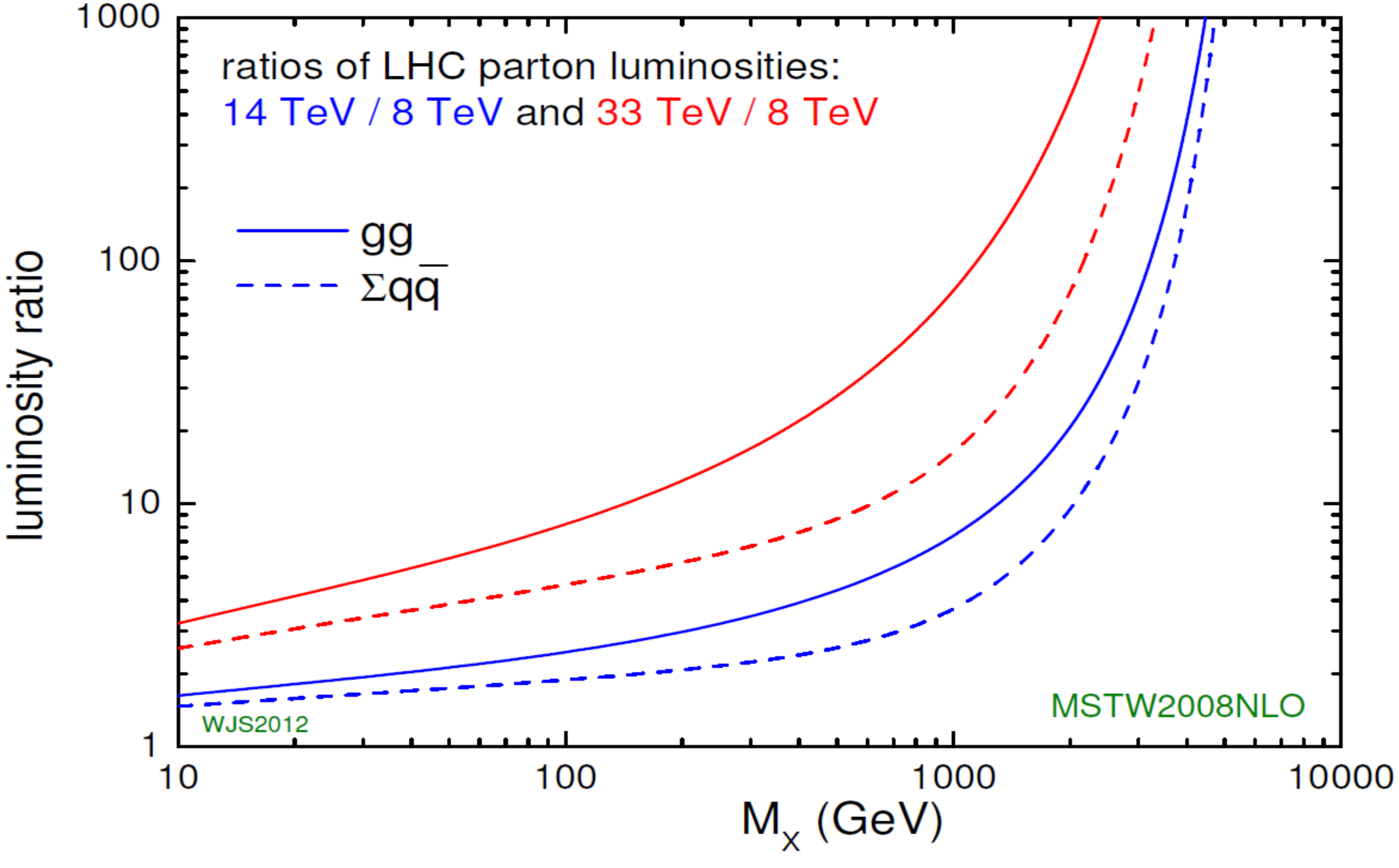
Present status and BSM

- Let us assume in this talk that the Standard Model is a solid baseline:
  - At least in the sense that we have discovered a particle that matches – as long as we could test – the last missing piece of the SM puzzle

- So now we are really entering a true BSM phase, exploring new territory. Next discoveries will surely be 'unpredicted' to a higher or lesser extent...

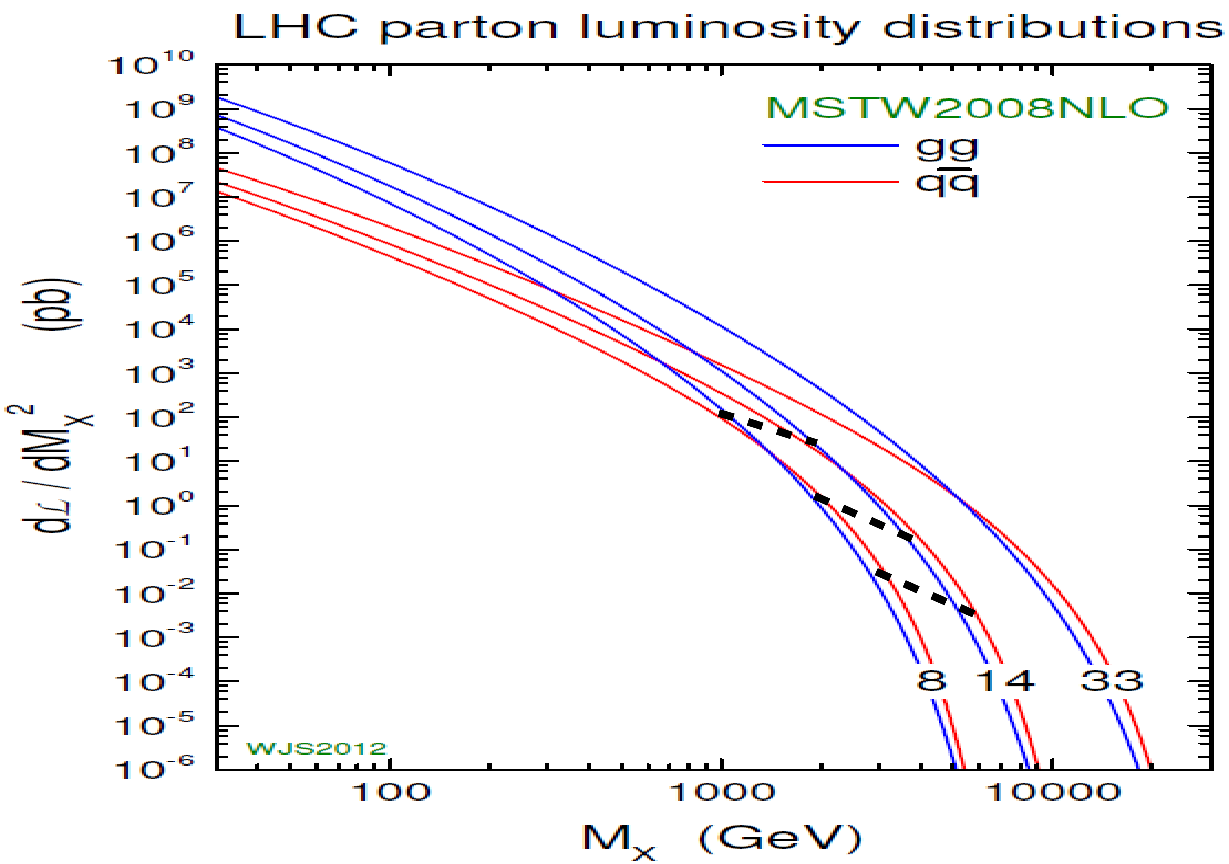
Basic picture

- $\sqrt{s} \approx 13$ TeV versus $\sqrt{s} \approx 8$ TeV: big step in physics reach at the highest scales/masses



Basic picture: highest mass reach

- $\sqrt{s} \approx 13$ TeV, L ≈ 300 fb^{-1} vs $\sqrt{s} \approx 8$ TeV, L ≈ 20 fb^{-1}
  - > 1.5 times the current center-of-mass energy
  - ≈ 15 times the current integrated luminosity: ≈ 4 increase in sensitivity



1 TeV → ≈2 TeV

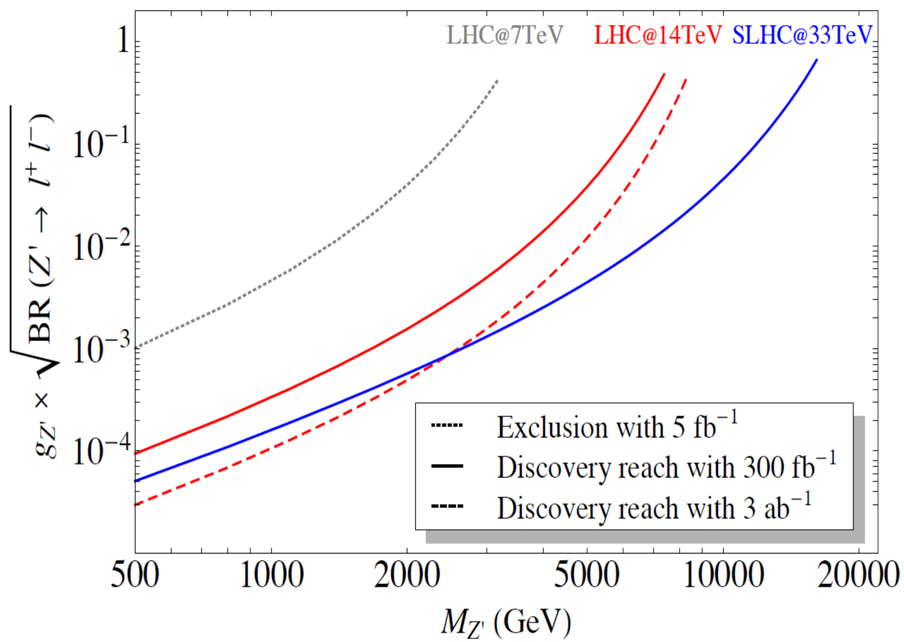
2 TeV → ≈4 TeV

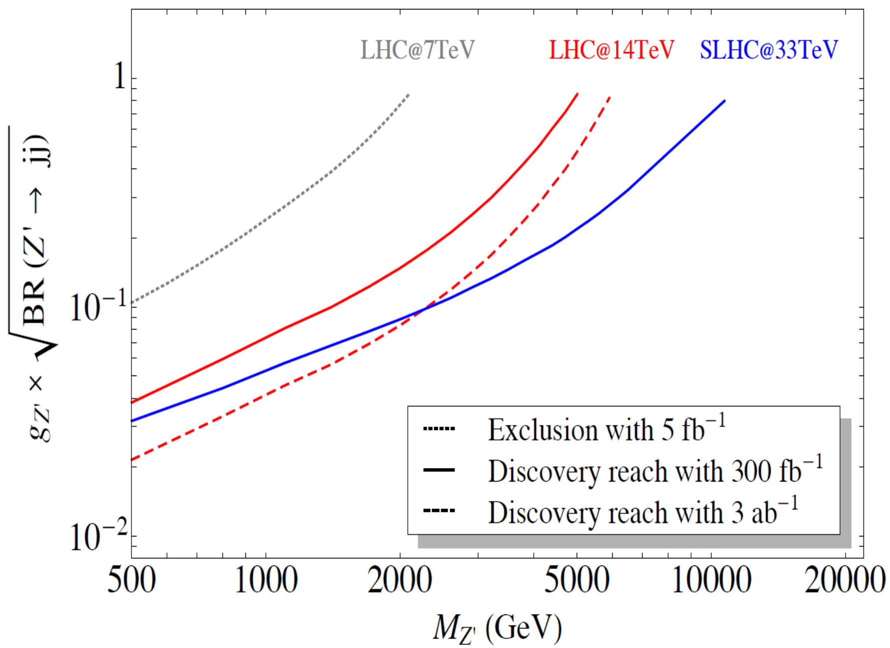
3 TeV → ≈6 TeV

- Correspondence in mass reach largely independent of the parton composition in the inital state

Other simple estimates

Contribution from the LHCC WG on Exotics tp ESG-Krakow

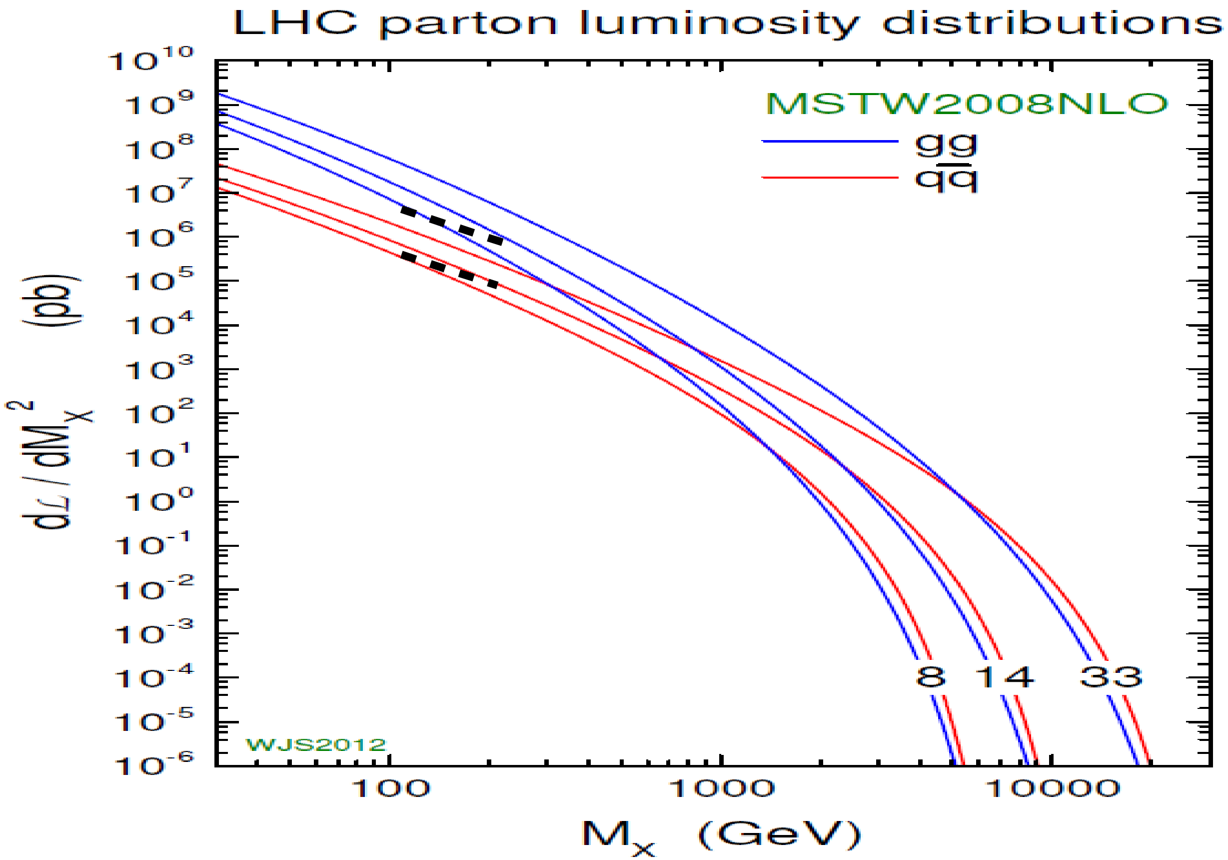




- For dilepton and dijet final state resonances: just confirming the previous numbers (1 TeV → ≈2 TeV, 2 TeV → ≈4 TeV, 3 TeV → ≈6 TeV)

New physics at lower masses

- $\sqrt{s} \approx 13$ TeV, L ≈ 300 fb^{-1} vs $\sqrt{s} \approx 8$ TeV, L ≈ 20 fb^{-1}
  - > 1.5 times the current center-of-mass energy
  - ≈ 15 times the current integrated luminosity: ≈ 4 times more sensitivity

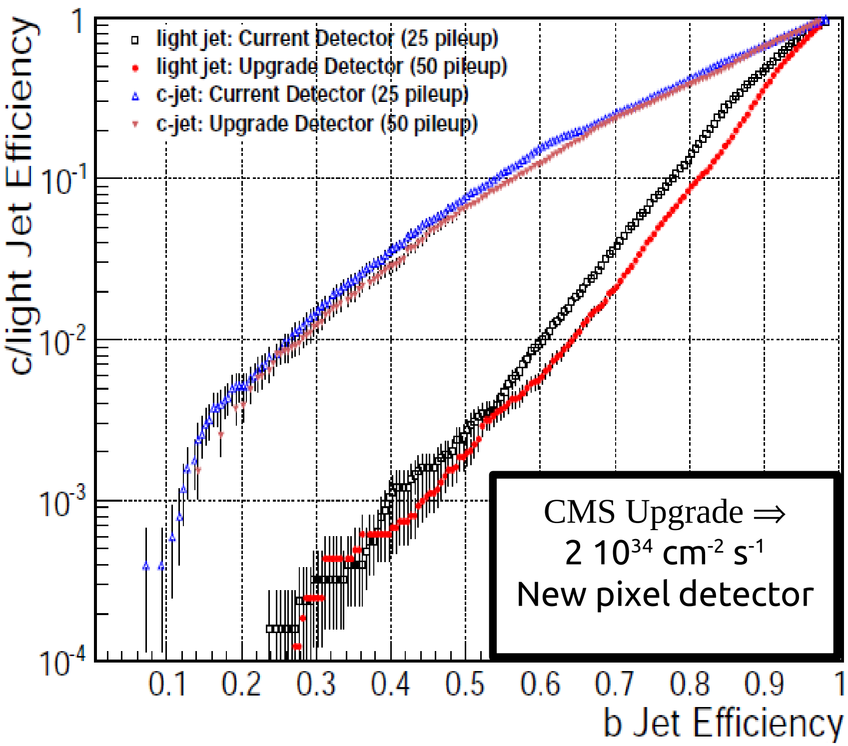


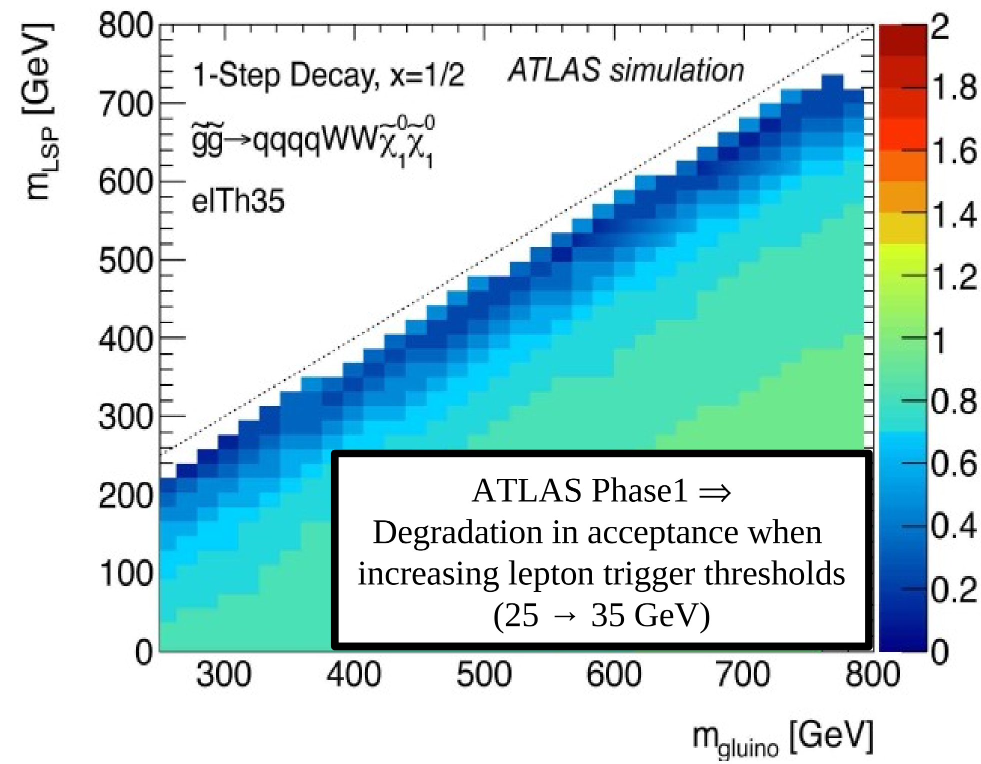
100 GeV → ≈200 GeV

- Correspondence in mass reach depends more on parton composition. Larger qqbar improvements with luminosity in relative terms with respect to gg (flatter slope)

Experimental environment

- All these 'rule of thumb' estimates assume no changes in performance at the detector level or in the collision environment:
  - Planned improvements (better granularity, trigger, tracking, ...)
  - Higher collision rate, multiplicity, pileup ⇒ higher trigger thresholds, more complicated pattern recognition, ...

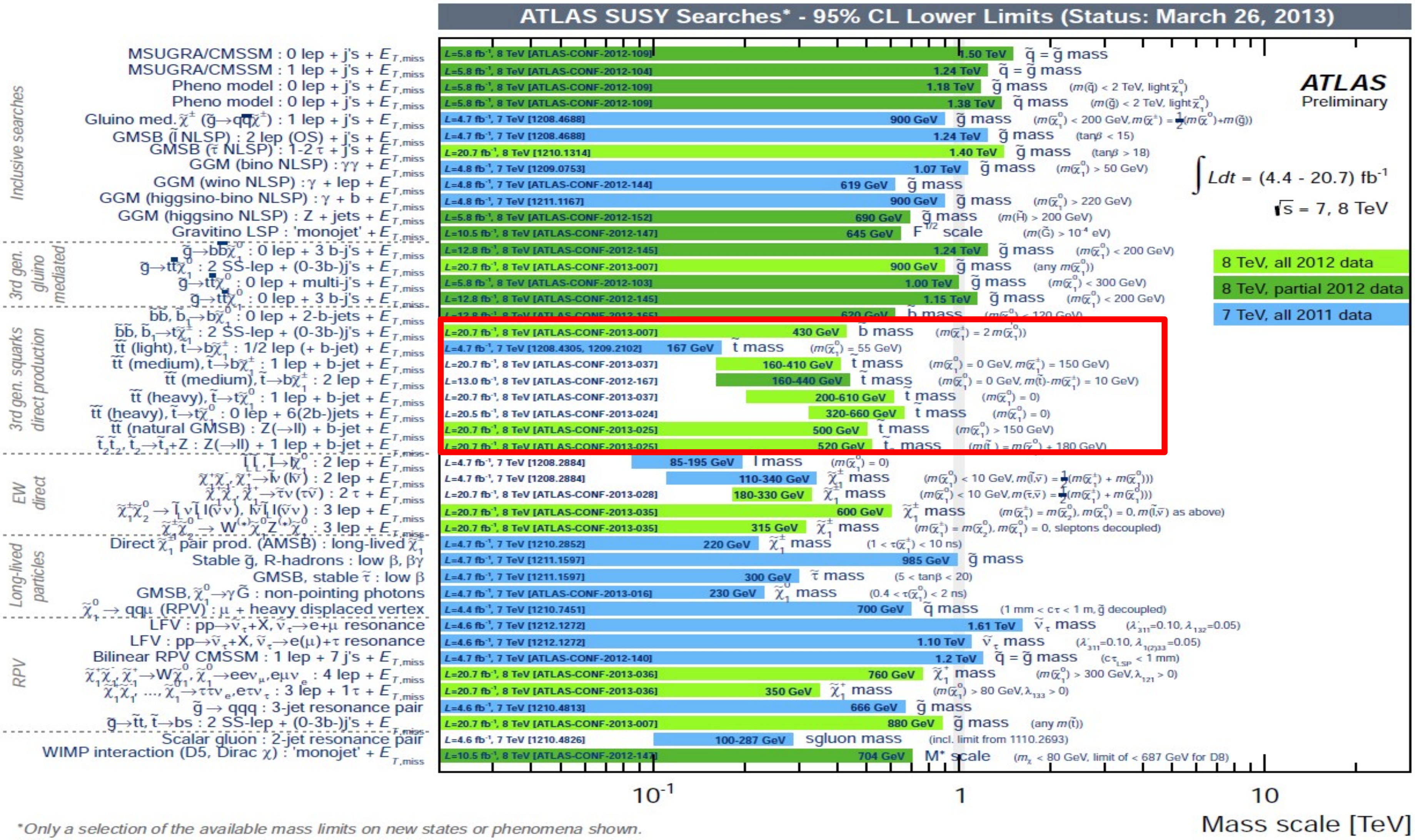




New physics at the TeV?

- What we know today:
  - The scalar that we have found looks rather 'standard' at first sight
  - No SUSY found until now (simplest scenarios excluded for the s-particles and masses that can be accessed at $\sqrt{s}$ = 8 TeV)
  - No strict need for SUSY at the TeV scale to explain why $M_H \approx 126$ GeV
- The good news:
  - It still seems 'unnatural' the absence of new physics at the TeV scale
  - Dark matter explanations point to WIMPs at the electroweak scale
- Our most promising links to new physics:
  - Neutrinos (but probably connecting to physics >> TeV scale)
  - Higgs: already at the weak scale, connected to mass (and gravity?)
  - Top: highest mass and coupling to Higgs, key ingredient to find any natural explanation for the light value of the Higgs mass

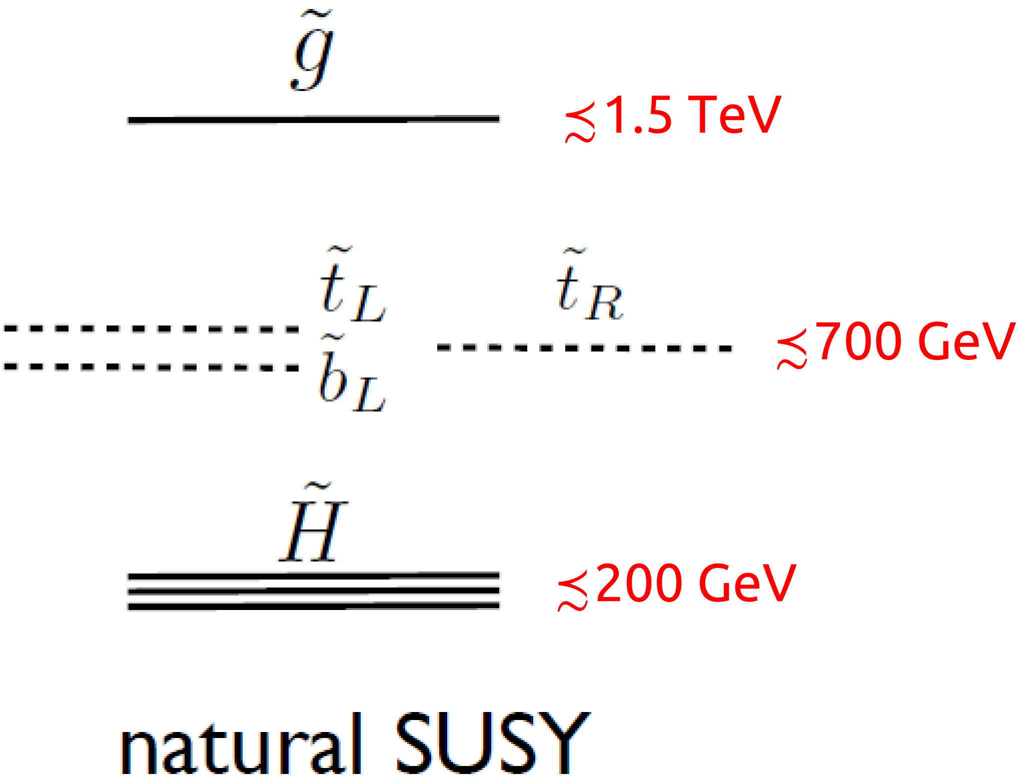
Current ATLAS status: SUSY



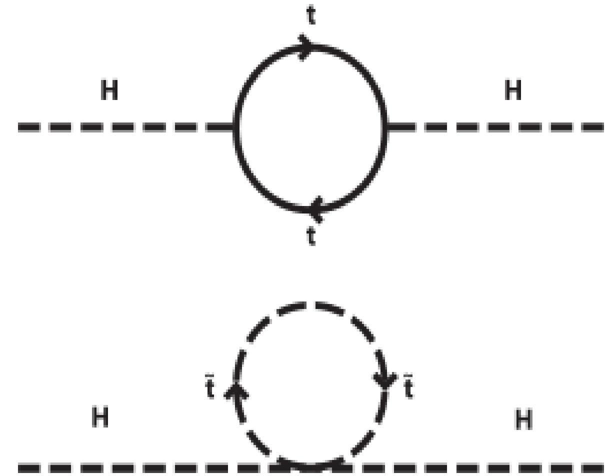
*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

Naturalness and SUSY

- Choosing masses appropriately to evade current SUSY limits (little hierarchy problem):



(plot from arXiv:1110.6926)



Large tanβ:

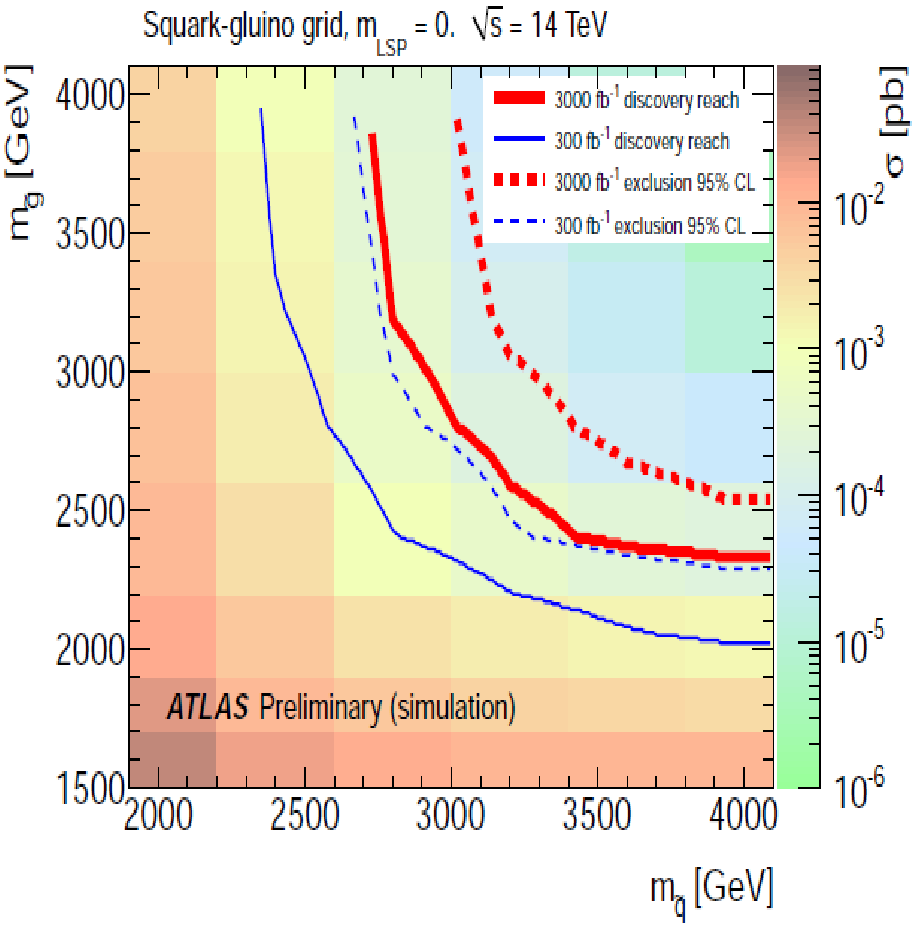
Stop, gluino

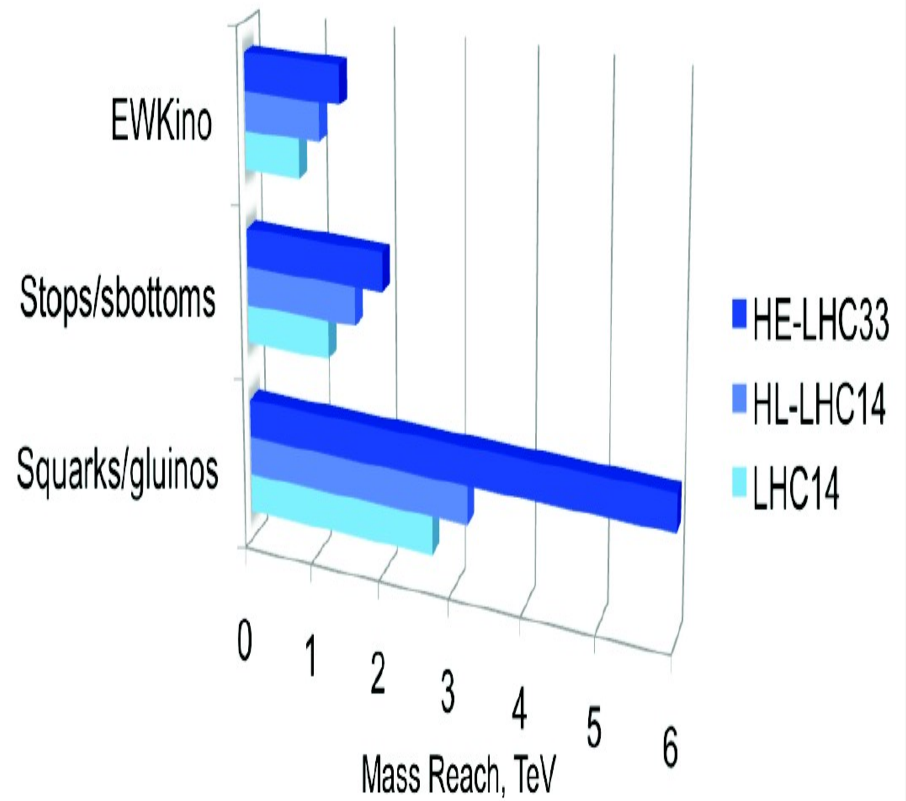
$$-\frac{m_Z^2}{2} = |\mu|^2 + m_{H_u}^2$$

Higgsino

SUSY expectations

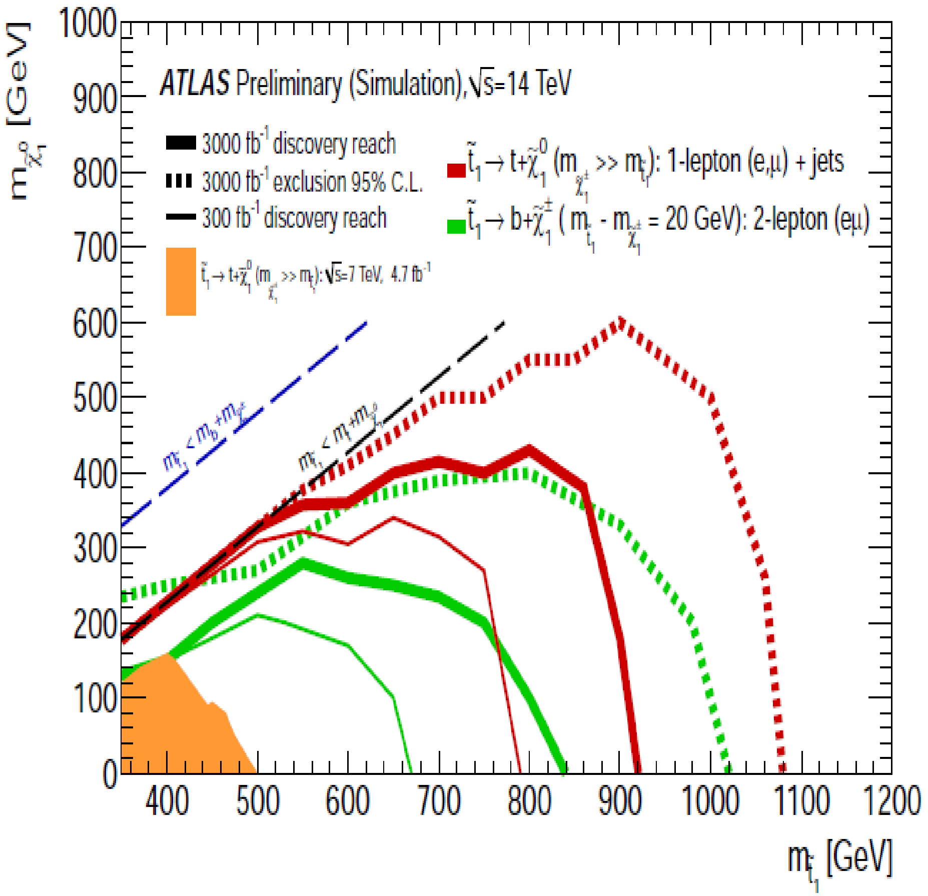
- Current limits in s-hadron decay chains (m_{LSP}=0): ≈ 1 TeV
- Estimated reach for √s ≈ 14 TeV, 300 fb^{-1}: ≈ 2-2.5 TeV

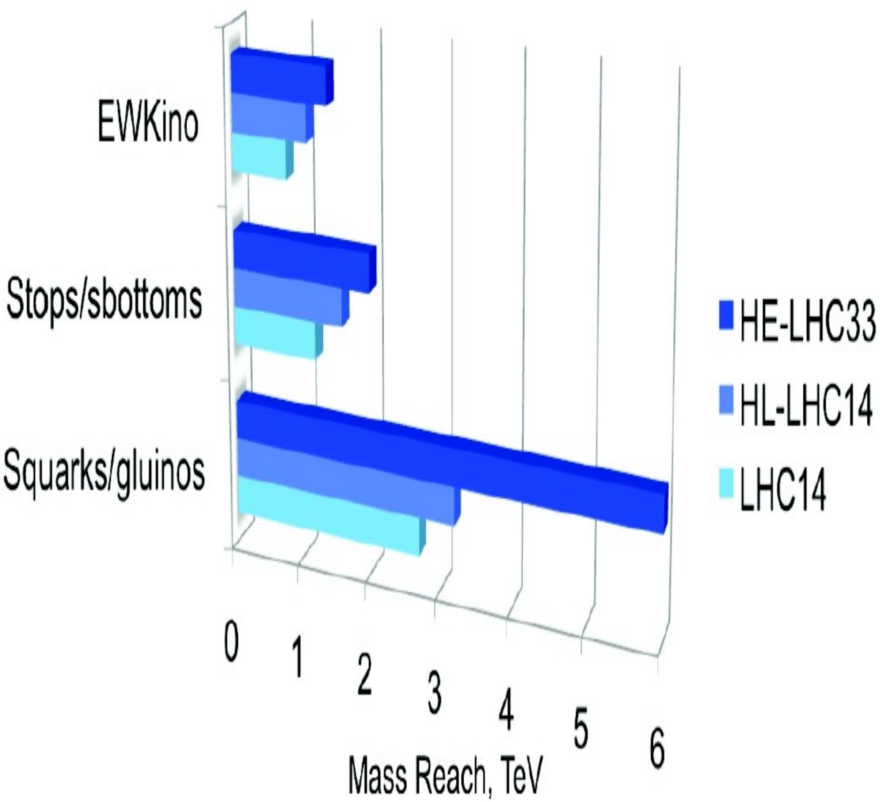




SUSY expectations

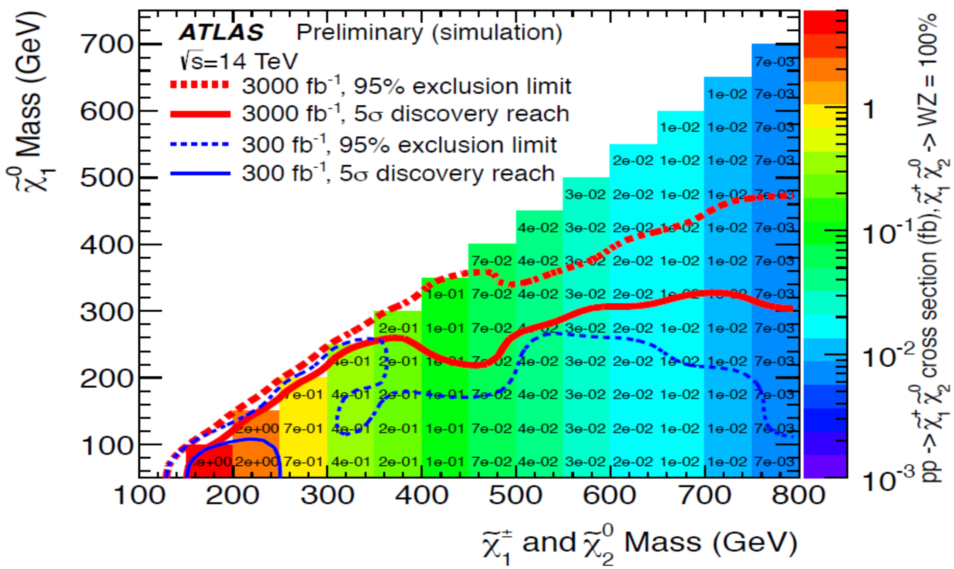
- Current limits in direct stop production decay ($\rightarrow t\chi^0, m_{LSP}$ small) ≈ 600 GeV
- Estimated reach in stop$\rightarrow t\chi^0$ for $\sqrt{s}$ ≈ 14 TeV, 300 fb^{-1}: approaching 1 TeV

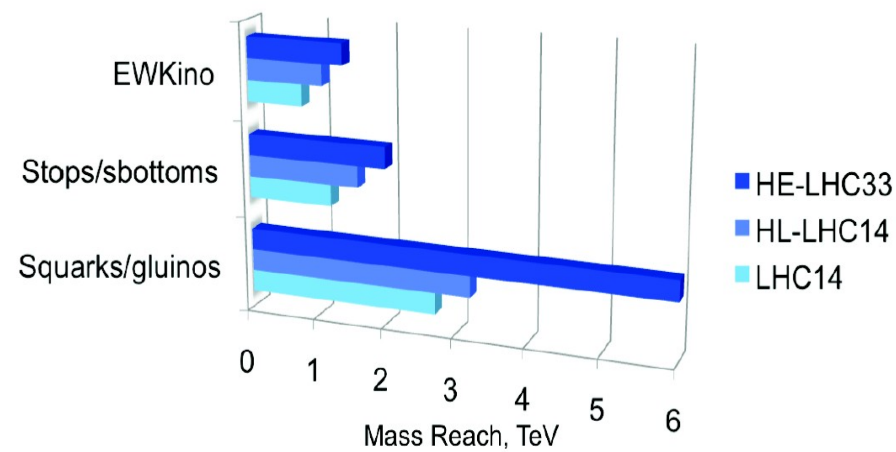




More SUSY expectations

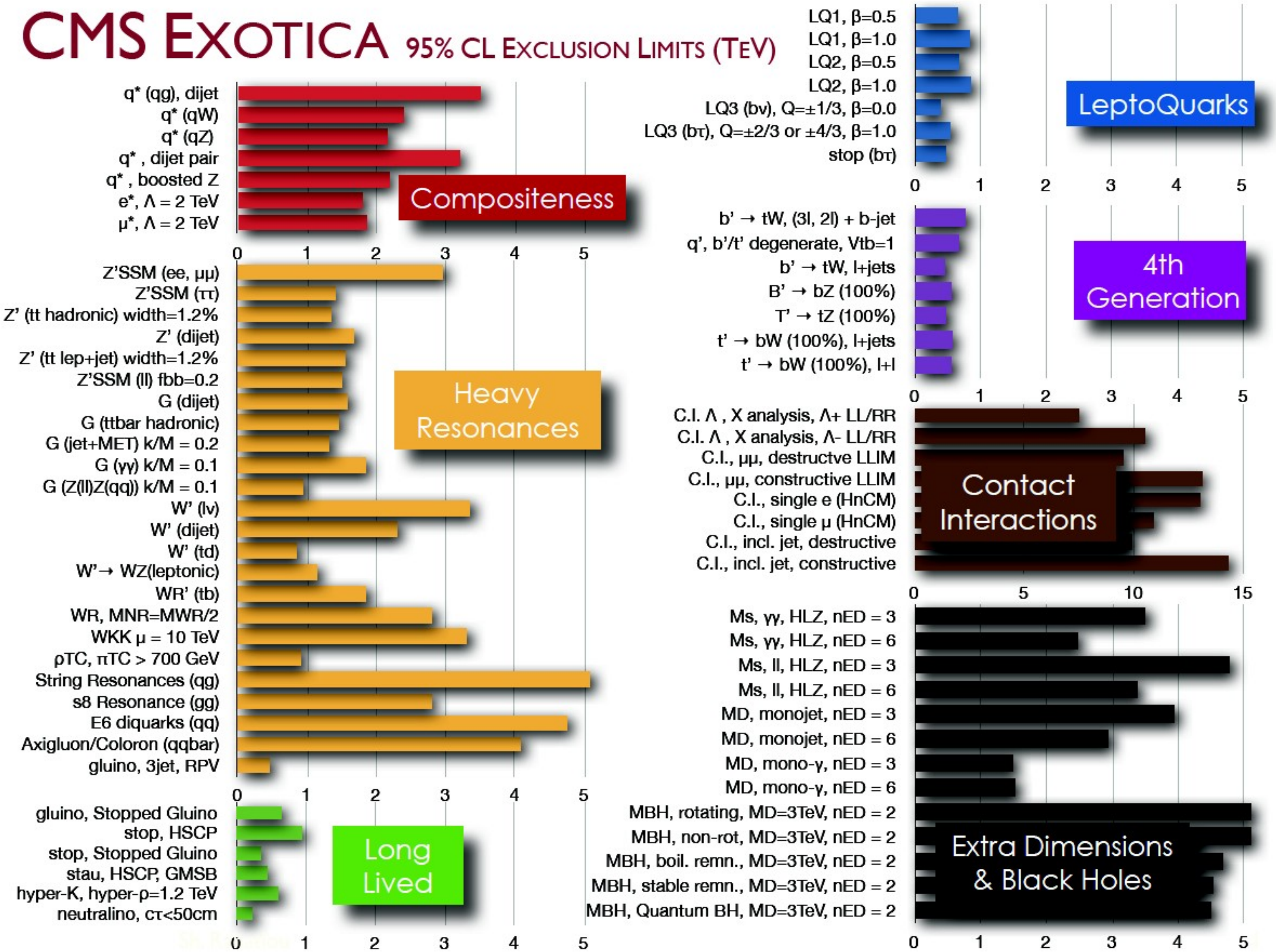
- Current tightest limits in ewkino masses via EWK production (with sleptons decoupled, $m_{LSP} \approx 0$) ≈ 300 GeV.
- Significant improvements expected for $\sqrt{s} \approx 14$ TeV, 300 fb^{-1}





- If we do not see hints of natural SUSY in the presence of significant missing energy, we should still exploit other possibilities:
  - Compressed spectra (small missing energy, pathological signatures)
  - R-parity violation models
  - More exotic SUSY possibilities?

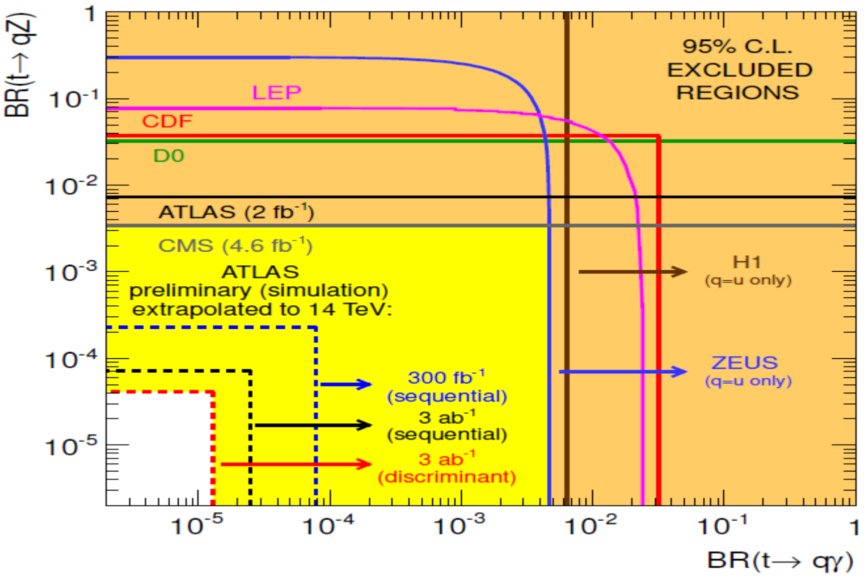
Current CMS searches: exotics



New resonances, FCNC

- Typical lower limits with 8 TeV data for Z' SSM: ≈ 3 TeV (CMS)
  - Expected limits for √s ≈ 14 TeV, 300 fb^{-1}: ≈ 6.5 TeV (ATLAS)
- Current Z' → ttbar limit ≈ 1.5 TeV (CMS)
  - Expected limit for √s ≈ 14 TeV, 300 fb^{-1}: ≈ 3.3 TeV (ATLAS)
- Leptoquark limit (first generation): 0.8 TeV (CMS)
  - Expected limit for √s ≈ 14 TeV, 300 fb^{-1}: ≈ 1.6-1.7 TeV (CMS)
- Significant increase in sensitivity for FCNC in the top sector

Model	ATLAS expected limit (300 fb^{-1})	CMS expected limit (300 fb^{-1})
Z' (SSM) → ee	**6.5 TeV**	
Z'(SSM) → μμ	6.4 TeV	
LQ (eejj)		1.6-1.7 TeV
g_{KK} (→ttbar)	4.3 TeV	
Z' (→ ttbar)	3.3 TeV	
Br(t→Zq)	< 2 10^{-4}	$\lesssim 10^{-5}$



New physics via effective Lagrangians

- A different way to look for deviations, more model independent, giving access (potentially) to higher energy scales but without specifying any particular model. Extending the SM in a linear way:

$$\mathcal{L}(\sqrt{s} \ll \Lambda) = \mathcal{L}_{SM} + \sum_{n=5}^{\infty} \frac{1}{\Lambda^{n-4}} \left(\sum_j f_{nj}\, \mathcal{O}_{nj} \right)$$

where:

- $\mathcal{O}_{nj}$ are terms containing SM fields
- f_{nj} are adimensional couplings of order "1"
- Λ is large, of the order of the scale of new physics
- Corrections to the SM are suppressed by powers of $\frac{\sqrt{s}}{\Lambda}$ (and also $\frac{v}{\Lambda}$, with $v = 246$ GeV)
- Dominant terms respecting the $SU(2)_L \times U(1)_Y$ symmetry of the SM were collected already in 1986 (W. Buchmüller and D. Wyler, Nucl.Phys.B268:621,1986)

- Many examples: searches for anomalous couplings, contact interactions, effects of (non-resonant low-scale gravity), ...

Limits on new scales, anomalous couplings, ...

- Anomalous coupling limits:

$$\Delta g_1^Z \quad \rightarrow \quad i\,\frac{f}{\Lambda^2}(D_\mu\Phi)^\dagger(\vec{\tau}\vec{W^{\mu\nu}})(D_\nu\Phi)$$

$$\Delta k_Z \quad \rightarrow \quad i\,\frac{f}{\Lambda^2}(D_\mu\Phi)^\dagger B^{\mu\nu}(D_\nu\Phi)$$

$$\lambda_\gamma \quad \rightarrow \quad \frac{f}{\Lambda^2}\,\epsilon_{IJK}\;W_\mu^{I\nu}\;W_\nu^{J\rho}\;W_\rho^{K\mu}$$

(CMS estimates, based on Eur.Phys.J. C39 (2005) 293)

coupling	LHC	Approximate scale probed
g_1^Z	0.0030	4.5 TeV
λ_γ	0.0009	2.7 TeV
λ_Z	0.0023	1.7 TeV
κ_γ	0.026	1.5 TeV
κ_Z	0.037	1.3 TeV

- Testing new physics effects via loops at the TeV scale...

Deviations in boson-boson scattering

- Vector boson scattering effective interactions (EWK chiral Lagrangian):

$$a_4 [\mathrm{Tr}(V_\mu V_\nu)]^2$$

  - 300 fb^{-1} at 14 TeV are sensitive to a_4>0.066 (ATLAS); precision electroweak constraints of order 10^{-3}-10^{-2}

- They also lead to resonances (using unitarization of amplitudes):

Table 2: Summary of sensitivity to various resonance hypotheses in the semi-leptonic *WW* channel.

model	baseline	500 GeV scalar	800 GeV vector	1150 GeVvector
(a_4, a_5)	$(0, 0)$	$(0.01, 0.009)$	$(0.009, -0.007)$	$(0.004, -0.004)$
S/B	$(3.3 \pm 0.3)\%$	$(0.7 \pm 0.1)\%$	$(4.9 \pm 0.3)\%$	$(5.8 \pm 0.3)\%$
$S/\sqrt{B}$ $(L = 300\mathrm{fb}^{-1})$	2.3 ± 0.3	0.6 ± 0.1	3.3 ± 0.4	3.9 ± 0.4

Outlook

- In general, the LHC with $\sqrt{s} \approx 13$ TeV and $L = 300\ fb^{-1}$ represents a significant step forward in the search for physics effects beyond the SM:
  - In most cases we will be sensitive to twice the value of the mass limits set at $\sqrt{s} \approx 8$ TeV
  - We will be able to study in detail new particles with masses not so far from the present exclusion limits
  - Effects from higher physics scales could also manifest in several precision measurements/searches: contact interactions, anomalous couplings, FCNC searches, …

- If SUSY is close to 'natural' we should be able to see new physics signals, although the experimental path could be rather complicated in some pathological scenarios

- It is probably time to find something unexpected at the TeV scale, and for sure non-SM, so stay tuned!