Adam Falkowski

LPT Orsay

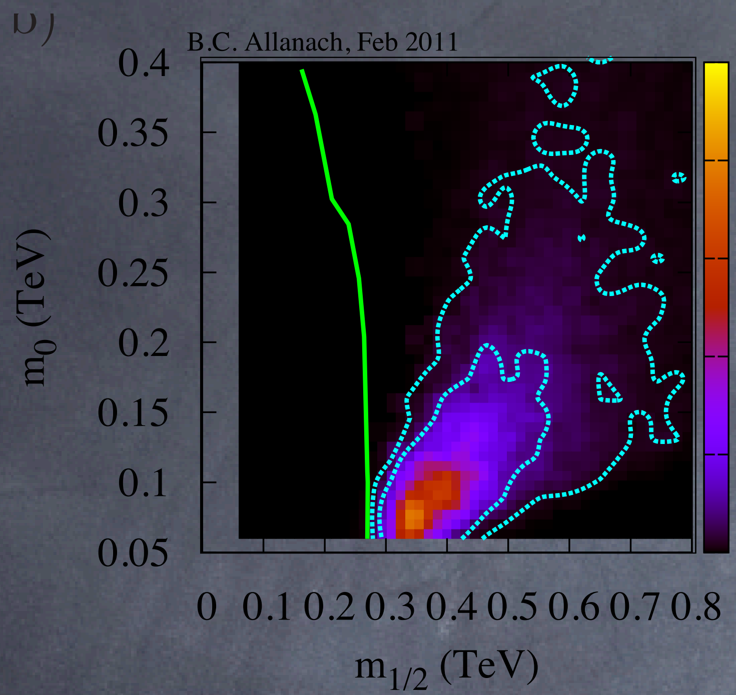
Supersymmetry

After the First LHC Results

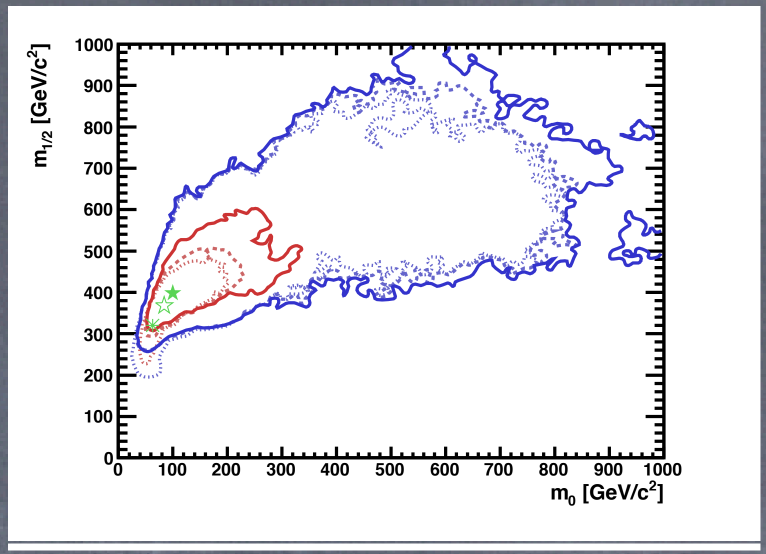
SUSY's portrait borrowed from C.Bernet's talk at Moriond'11

What is the impact of the first LHC limits on viability of SUSY

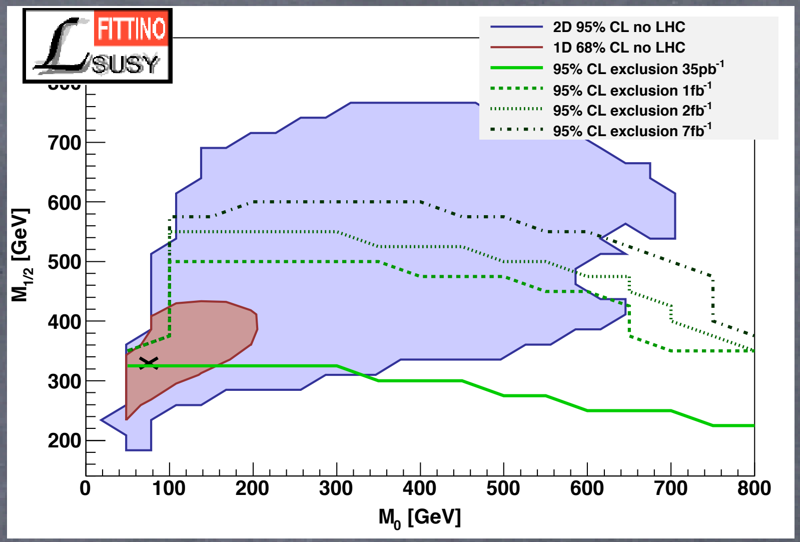
What Do Experts Say



Allanach, 1102.3149



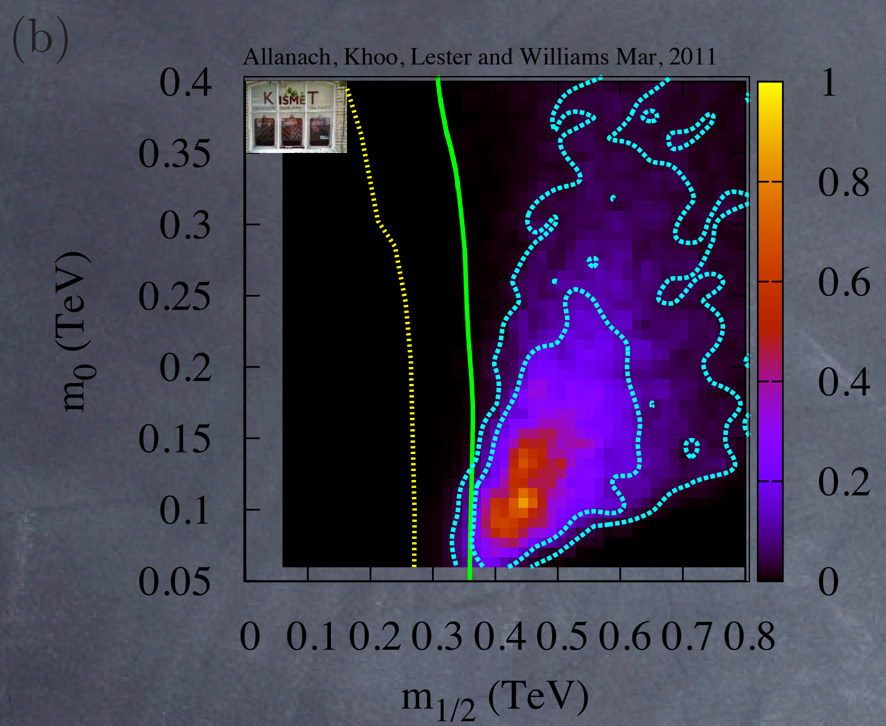
Buchmuller et al, 1102.4585



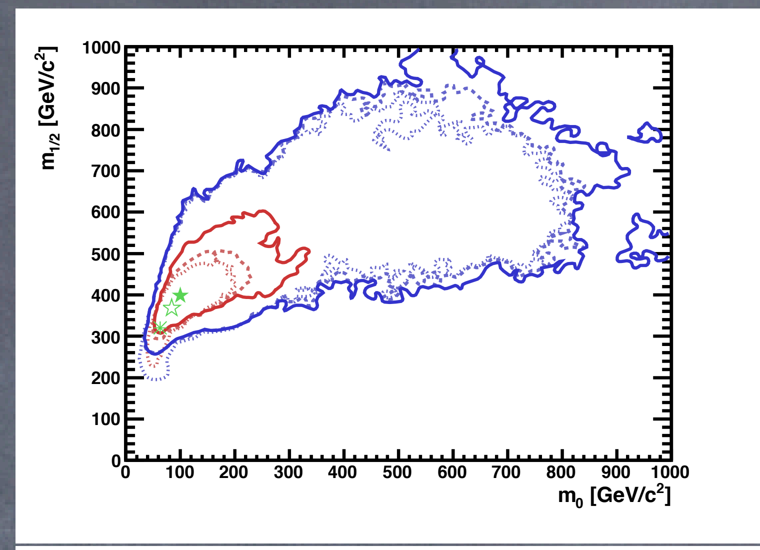
Bechtle et al, 1102.4693

Supersymmetry is just behind the corner!!!

What Do Experts Say



Allanach et al, 1103.0969



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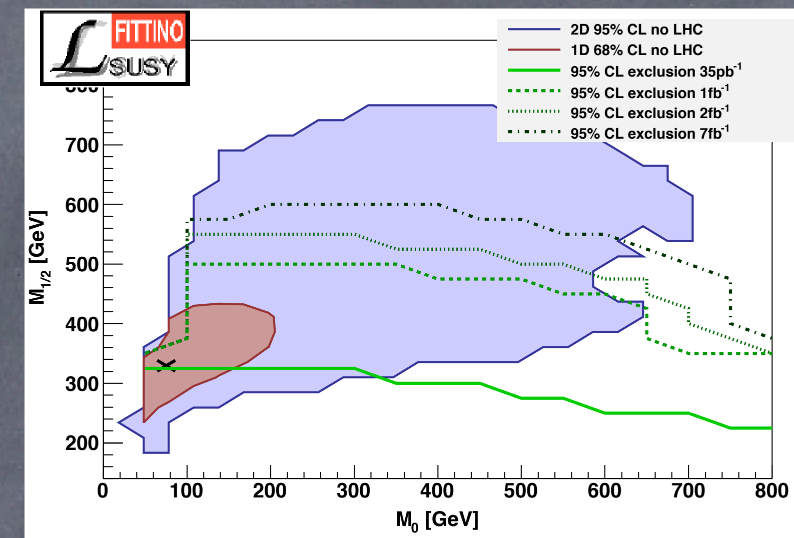

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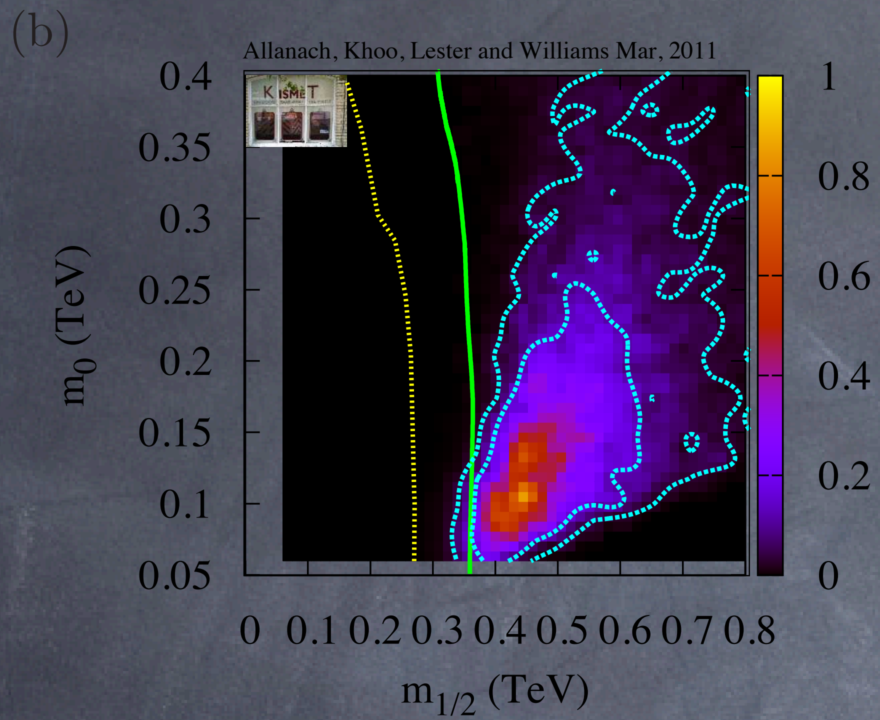

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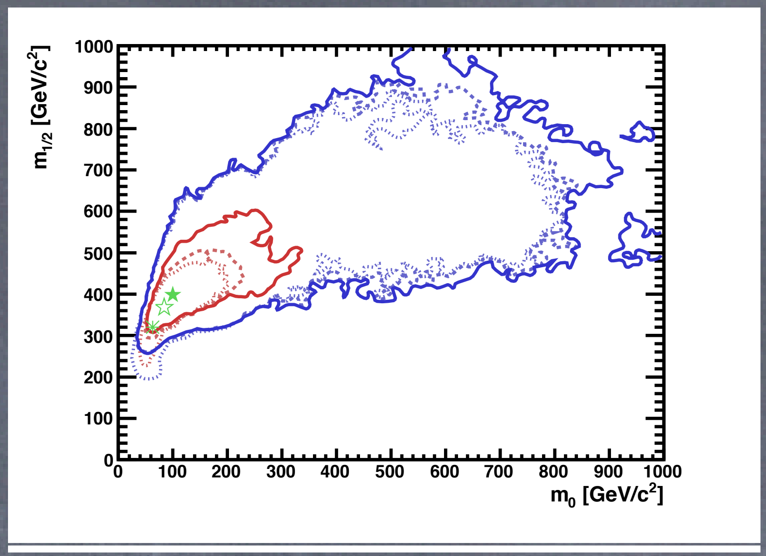

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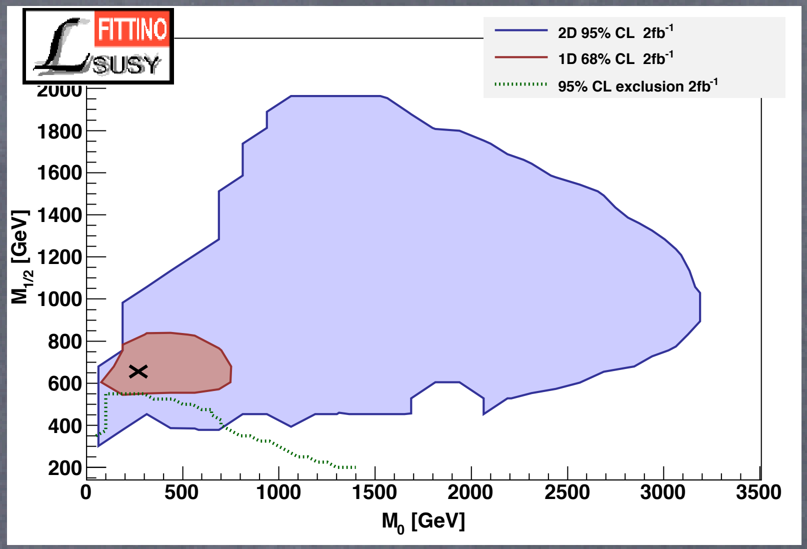


Bechtle et al, 1102.4693

Supersymmetry is just behind the corner!!!

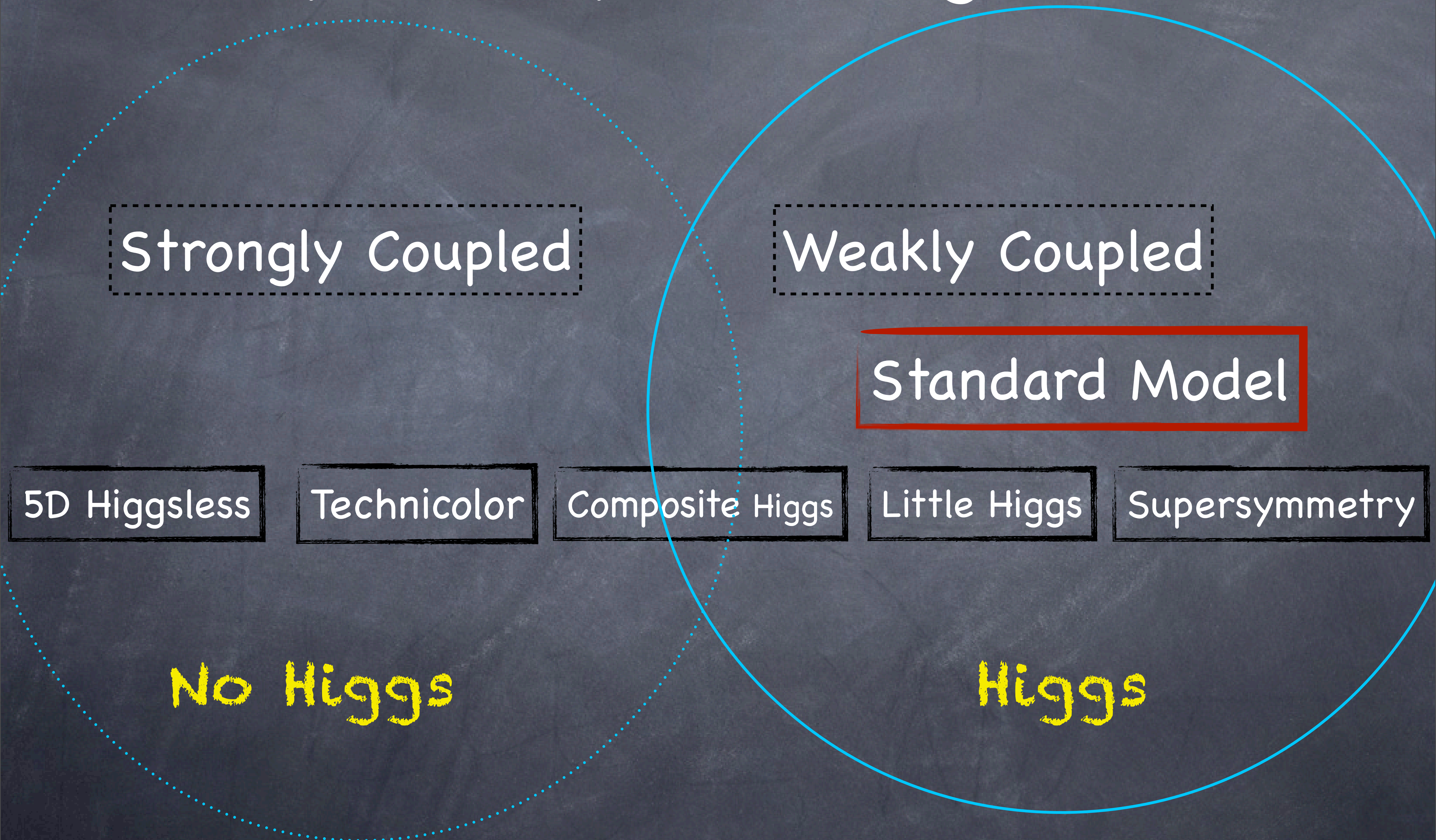
(although the corner may move around)

" ...the more he looked inside the more Piglet wasn't there... "

Plan

- Who ordered SUSY?
- How do we search for SUSY?
- What have we learnt?

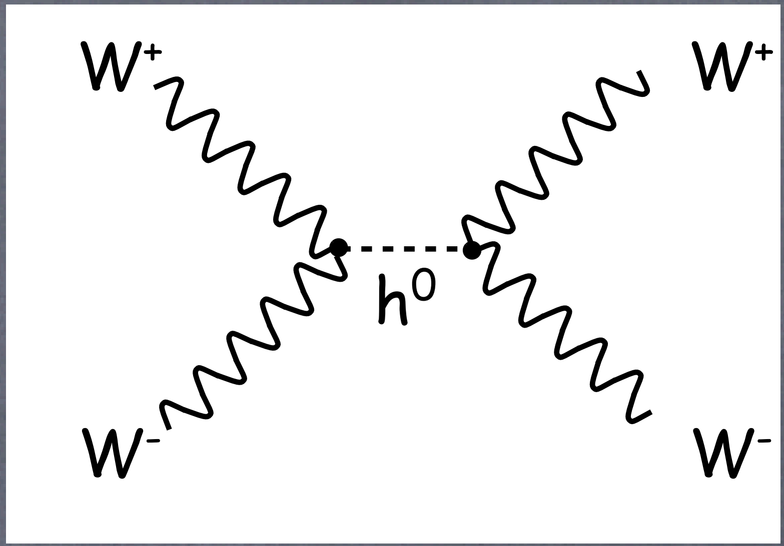
EW symmetry breaking chart



In the following, weakly coupled only...

Weakly Coupled Models

- Contain a narrow scalar particle(s) coupled to W and Z bosons whose contribution unitarizes VV scattering
- Simplest example is the Standard Model



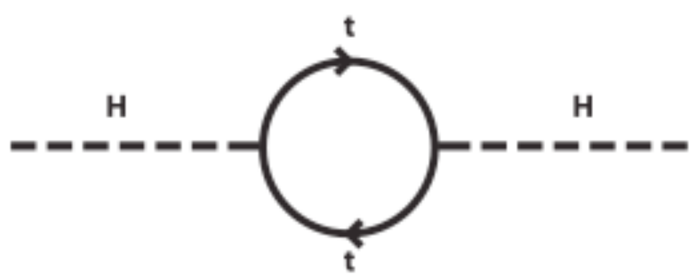
Standard Model

One Higgs field that acquires vacuum expectation value

$$V(H) = m_0^2 H^\dagger H + \lambda (H^\dagger H)^2$$

$$\langle H \rangle = \begin{pmatrix} 0 \\ v/\sqrt{2} \end{pmatrix} \qquad v = \sqrt{\frac{-m_0^2}{\lambda}}$$

Problem: the mass term, and therefore the vev, receive large quantum corrections

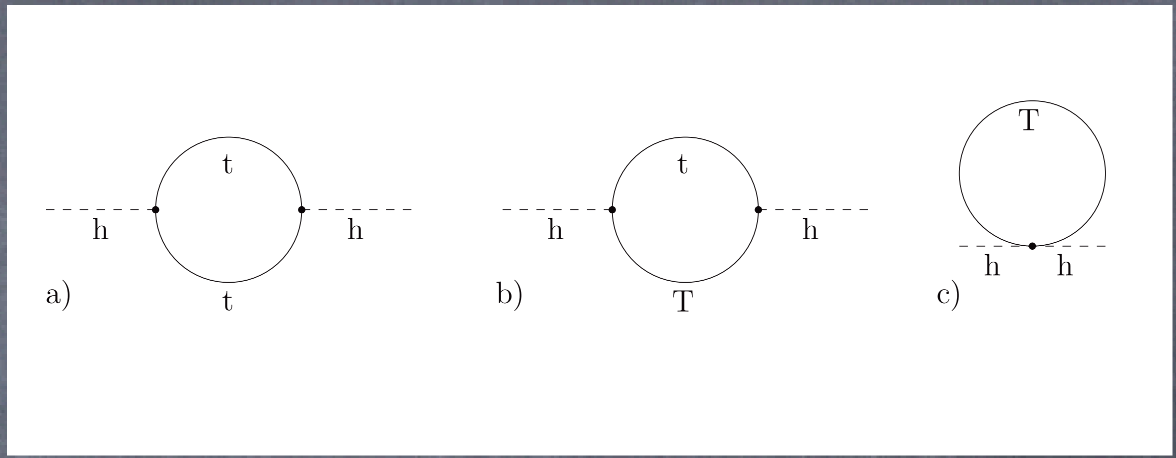


$$\Delta m_0^2 \approx \frac{m_{top}^2}{4\pi^2 v^2} \Lambda_{UV}^2 + \ldots$$

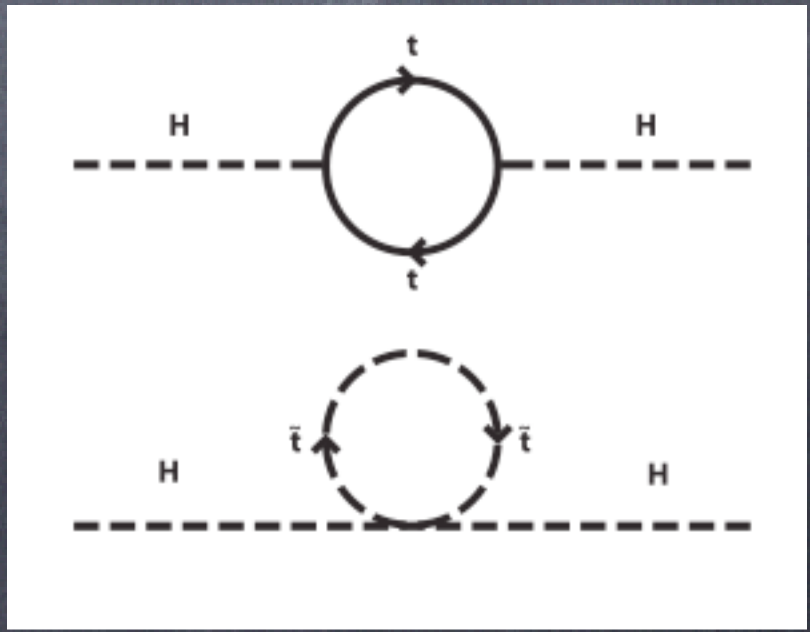
If the cutoff >> 1 TeV, we either need find tuning or new structure/particles that soften the quantum corrections

Who can stabilize Higgs potential ?

- Global symmetries: quantum corrections cancel between particles of the same statistics



- Supersymmetry: quantum corrections cancel between particles of opposite statistics



Supersymmetry: the good and the bad and the ugly

- Stabilizes Higgs
- (together with R-parity) Provides dark matter candidates
- Allows for better gauge coupling unification

- Flavor problem
- CP problem
- μ problem
- Doublet-triplet splitting problem

Problems in the Nutshell

- SUSY says: there is ~100 new degrees of freedom at the weak scale
- Generically they could be indirectly seen in numerous low energy experiments

- Experiment says: no new degrees of freedom show up in kaon mixing, D-mixing, B-mixing, $Bs \to \mu\mu$, neutron EDMs, $\mu \to e\gamma$, electroweak precision tests, proton decay, etc
- Approximate symmetries of the SM unexpectedly well respected by new physics

But at least SUSY solves the hierarchy problem... does she?

Higgs potential in the MSSM depends on Higgs soft masses and μ-term:

$$\begin{aligned} V &= (|\mu|^2 + m_{H_u}^2)|H_u^0|^2 + (|\mu|^2 + m_{H_d}^2)|H_d^0|^2 - (b\, H_u^0 H_d^0 + \text{c.c.}) \\ &\quad + \frac{1}{8}(g^2 + g'^2)(|H_u^0|^2 - |H_d^0|^2)^2. \end{aligned}$$

The Higgs vev (equivalently Z-boson mass) can be expressed by these parameters:

$$m_Z^2 = \frac{|m_{H_d}^2 - m_{H_u}^2|}{\sqrt{1 - \sin^2(2\beta)}} - m_{H_u}^2 - m_{H_d}^2 - 2|\mu|^2.$$

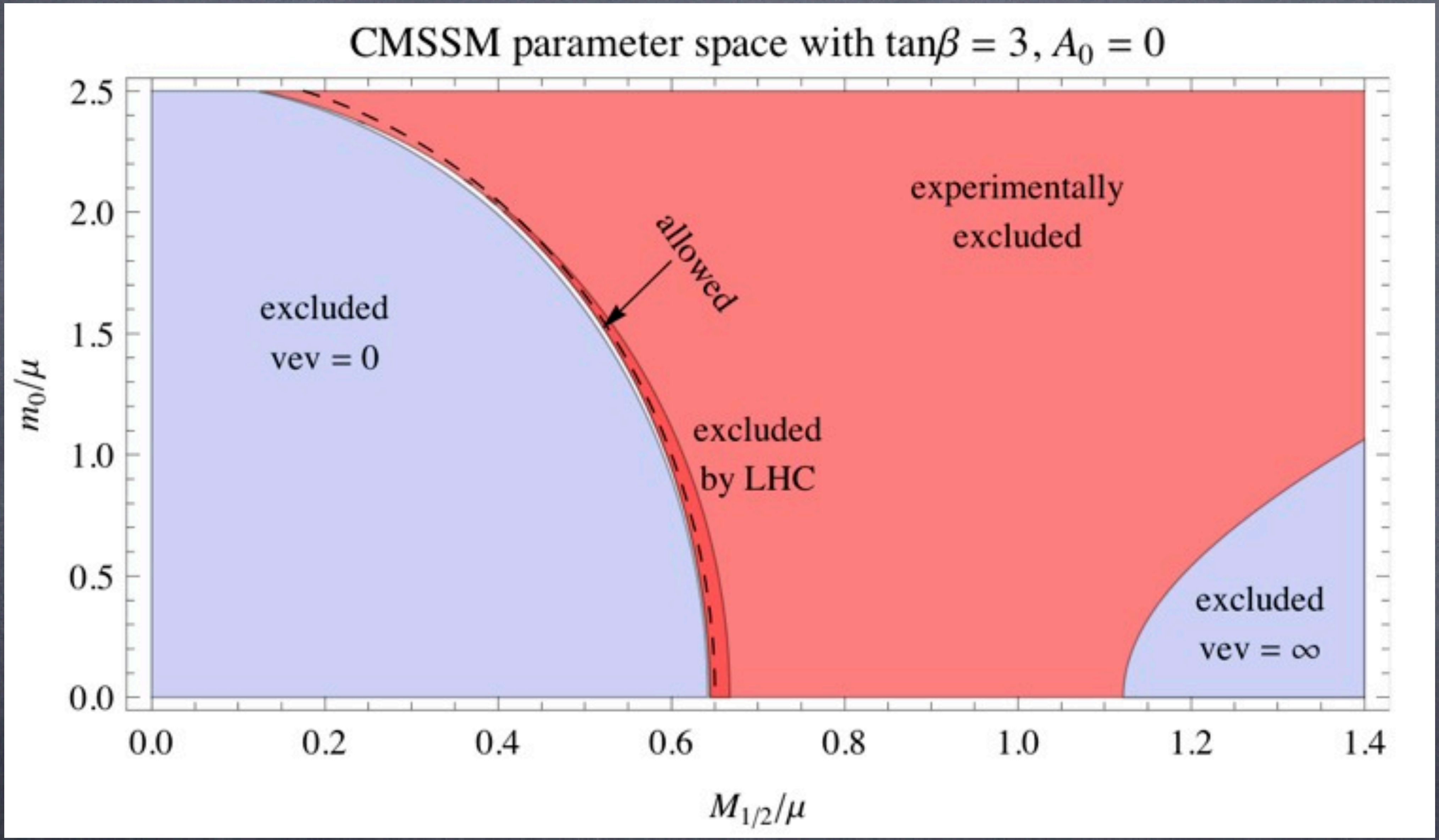
But due to loop corrections:

$$m_{H_u}^2 \sim \frac{\log \Lambda}{4\pi^2} M_{Susy}^2 \sim M_{Susy}^2 \Rightarrow M_{Susy} \sim m_Z$$

Susy particles should be at the Z-boson mass, otherwise fine-tuning!

Fine-tuning in CMSSM, Strumia 1101.2195

$$M_Z^2 \approx 0.2 m_0^2 + 0.7 M_3^2 - 2\mu^2 = (91\ \text{GeV})^2 \times 50\left(\frac{M_3}{780\ \text{GeV}}\right)^2 + \cdots$$



Already LEP constraints on SUSY and Higgs seriously constrain the parameter space. Only a small strip on the boundary between EW breaking and no EW breaking remains viable

Frog Metaphor

If a frog is placed in boiling water, it will jump out, but if it is placed in cold water that is slowly heated, it will never jump out.

Measuring S and T parameters at LEP1 was like hot water for Technicolor Frogs, and like cold water for SUSY Frogs. SUSY and Higgs searches at LEP2 and Tevatron are like heating the water.

Enters LHC

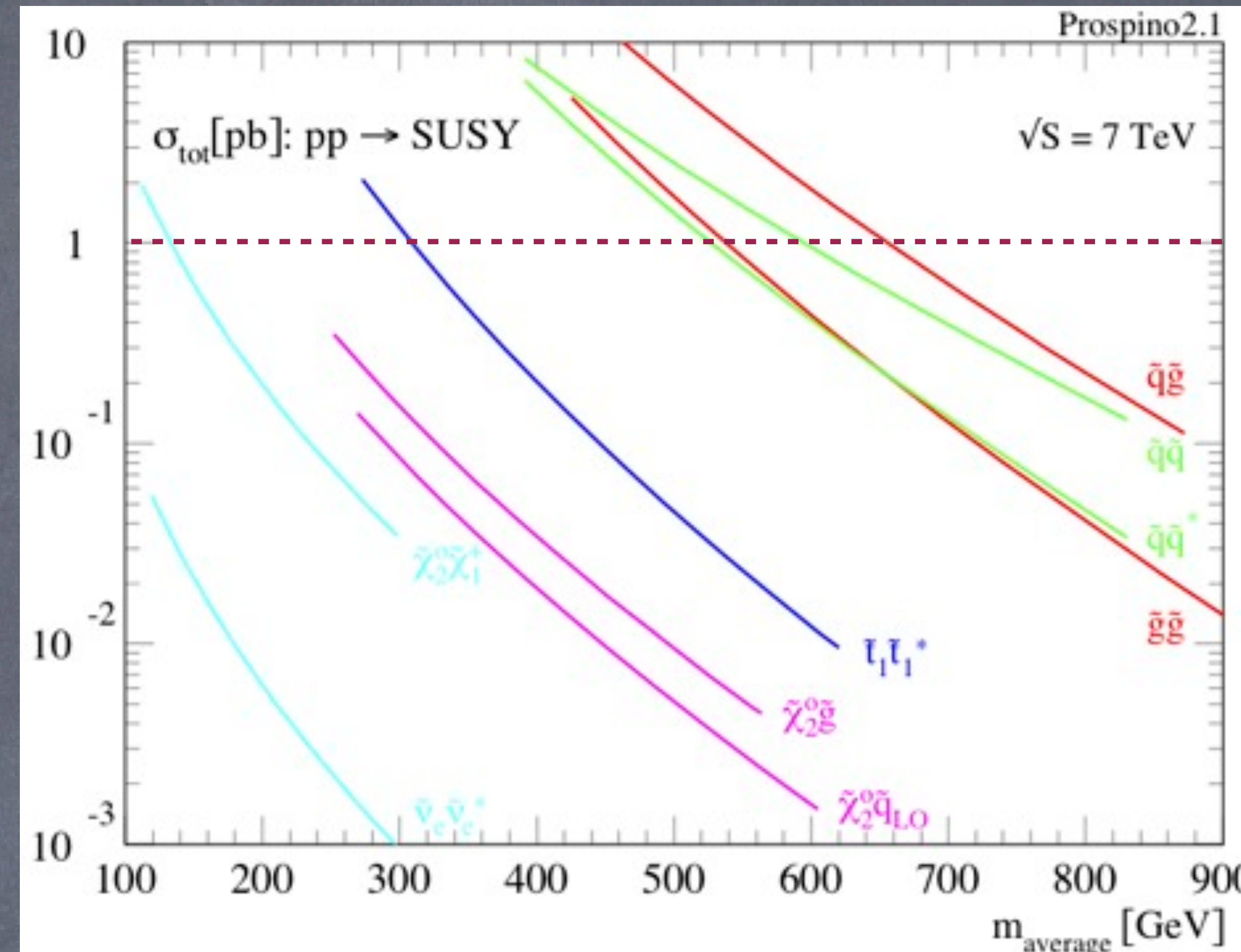
In the rest of this talk:

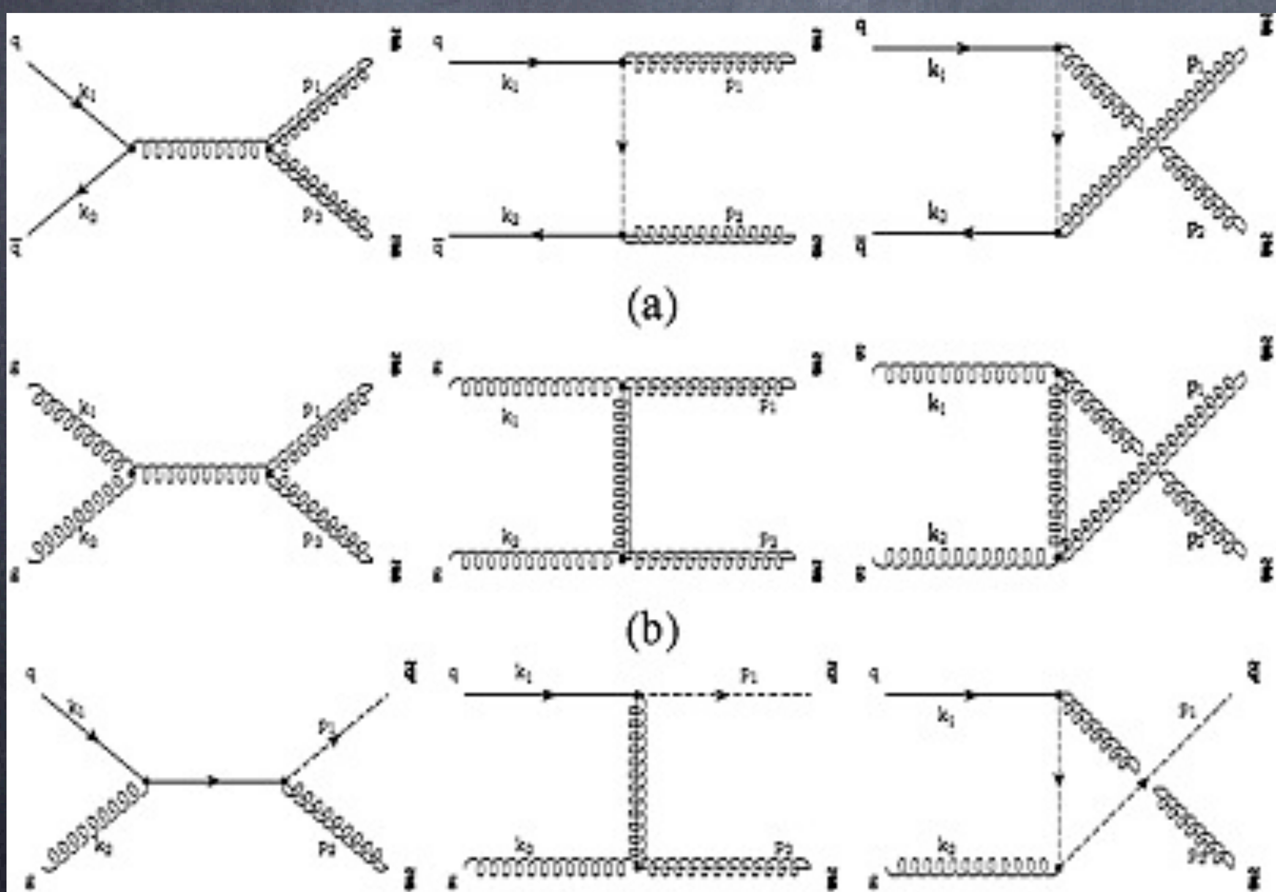
- How LHC searches for SUSY
- What have we learnt so far

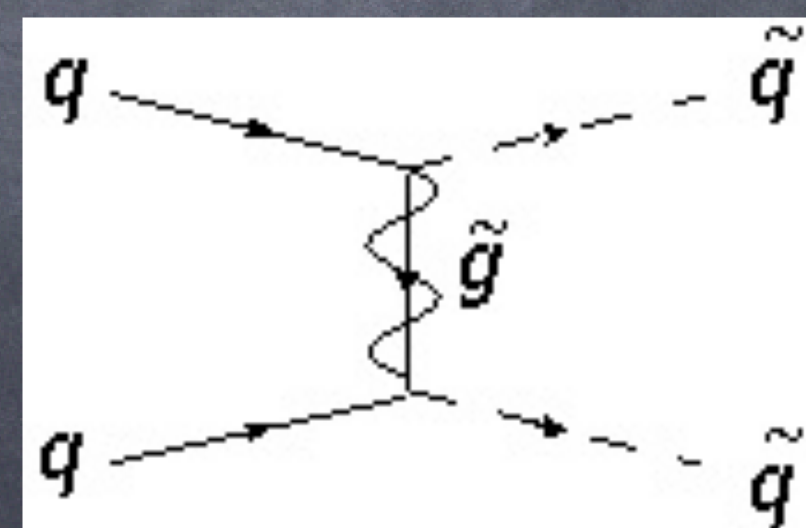
I'm borrowing heavily from results and plots presented at Moriond by CMS (M.Chiorboli, C. Bernet) and ATLAS (N. Barlow, S. Caron)

SUSY @ LHC

- In the early phase LHC can only produce colored superpartners
- In 2010, sensitivity to ~ 500 GeV 1st generation squark and gluinos (~ 700 GeV if both are present), and to ~300 GeV stops.

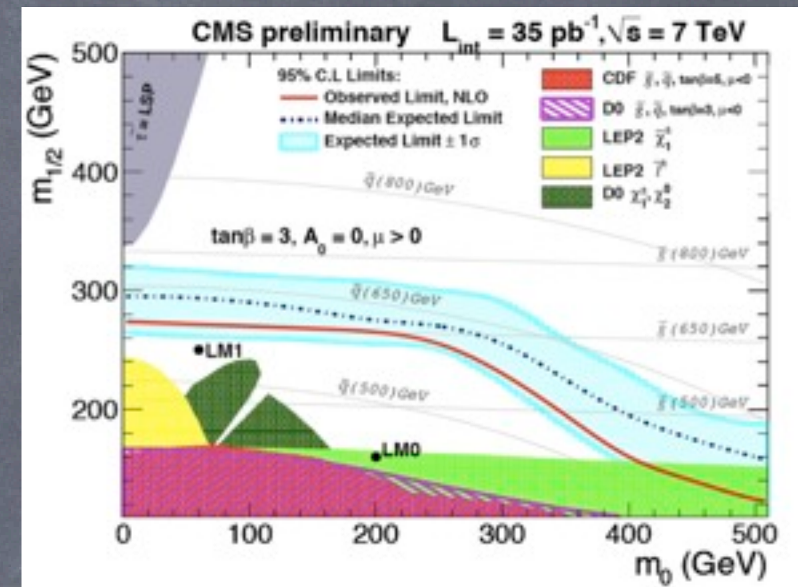






SUSY Limits:Topological Approach

- Results of SUSY searches usually presented as limits on mSUGRA parameters



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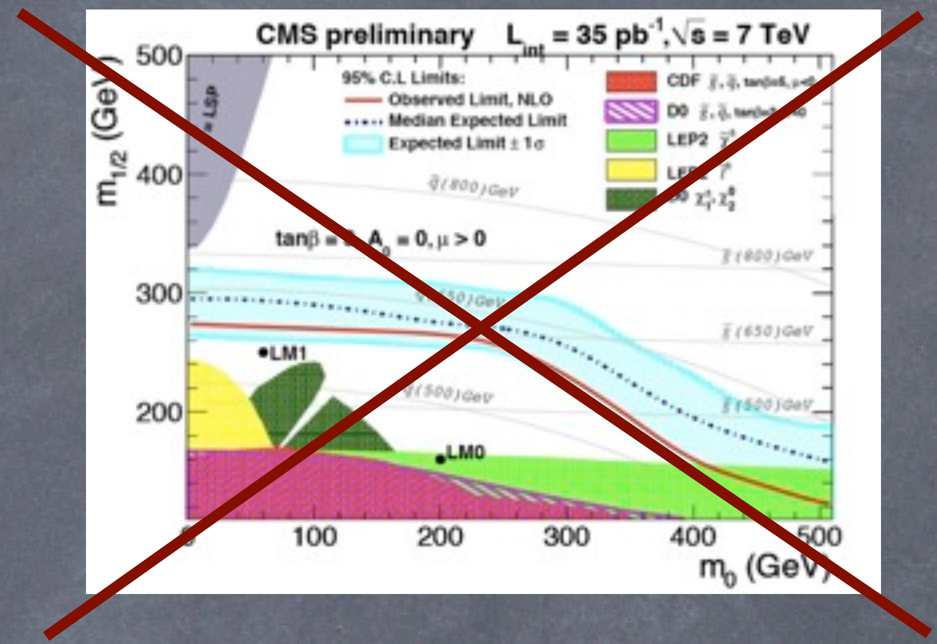
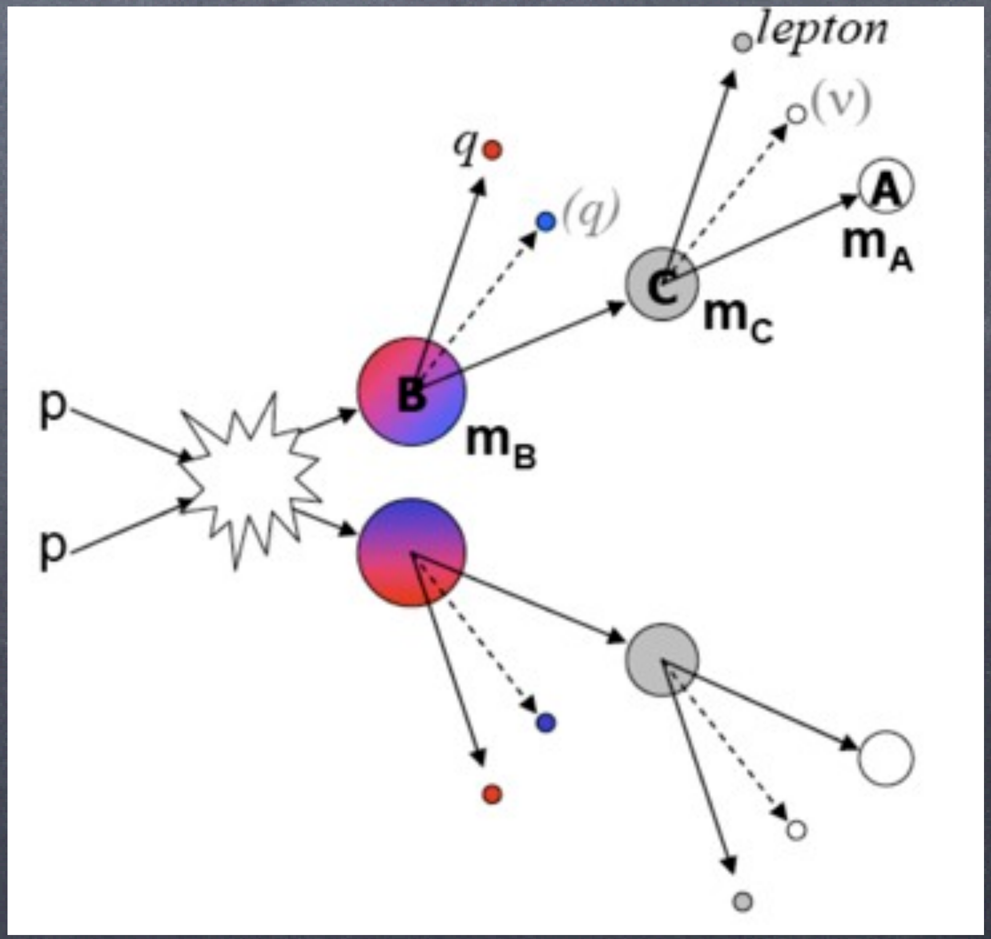
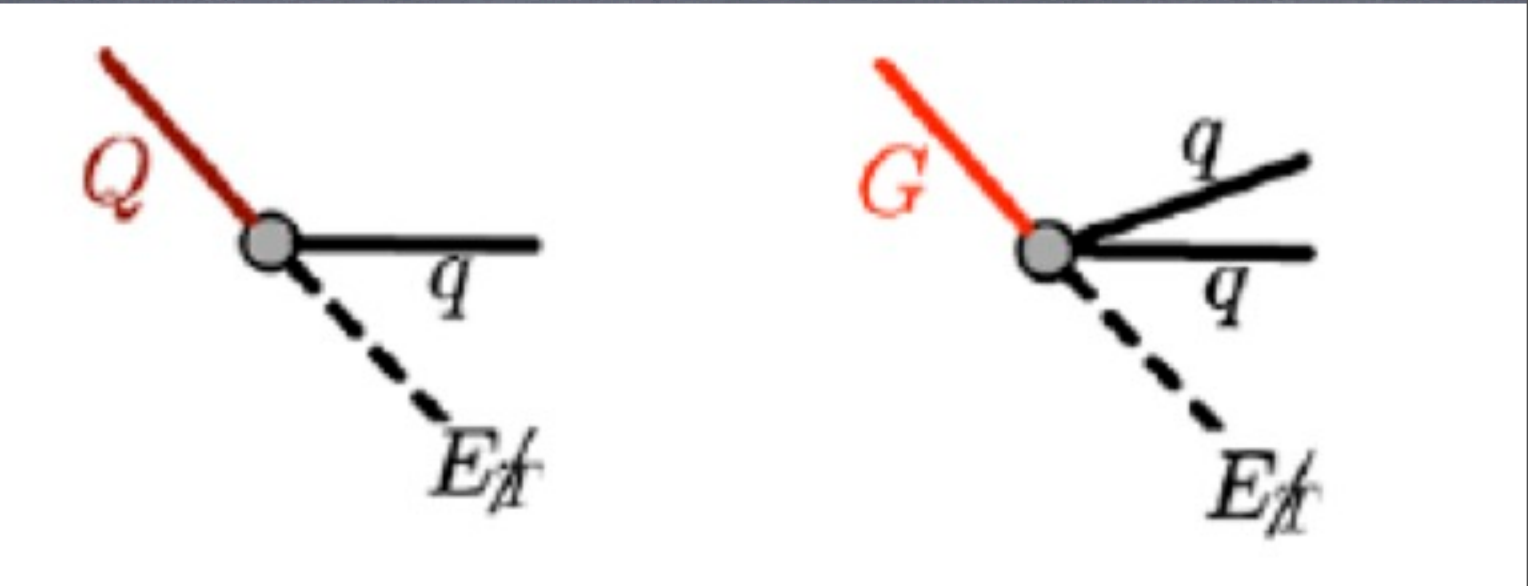


- More practical and illuminating are limits on cross-section times branching fractions for given decay topologies of gluinos and squarks

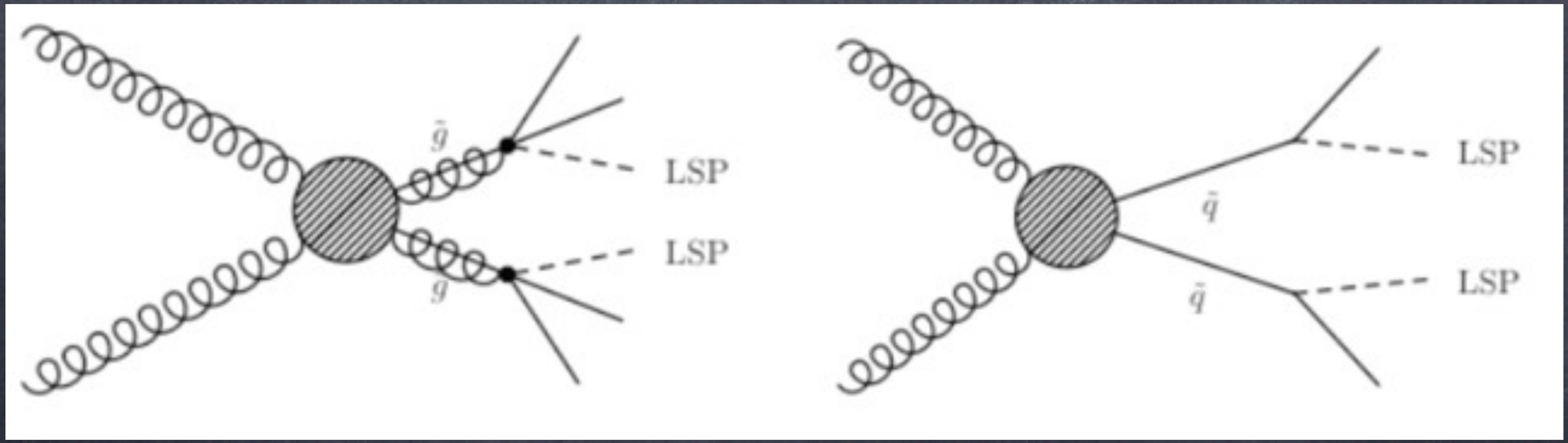


Simplest Topology: Jets + MET

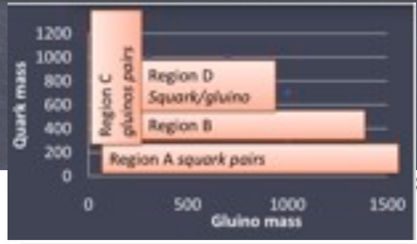
- Assume R-parity conservation and neutralino LSP
- Squark can decay to 1 quark + neutralino LSP
- Gluino can decay to 2 quarks + neutralino LSP
- Most generic SUSY signatures, model independent if inclusive



$$\tilde{q} \rightarrow q\tilde{\chi}_1^0 \qquad \tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$$

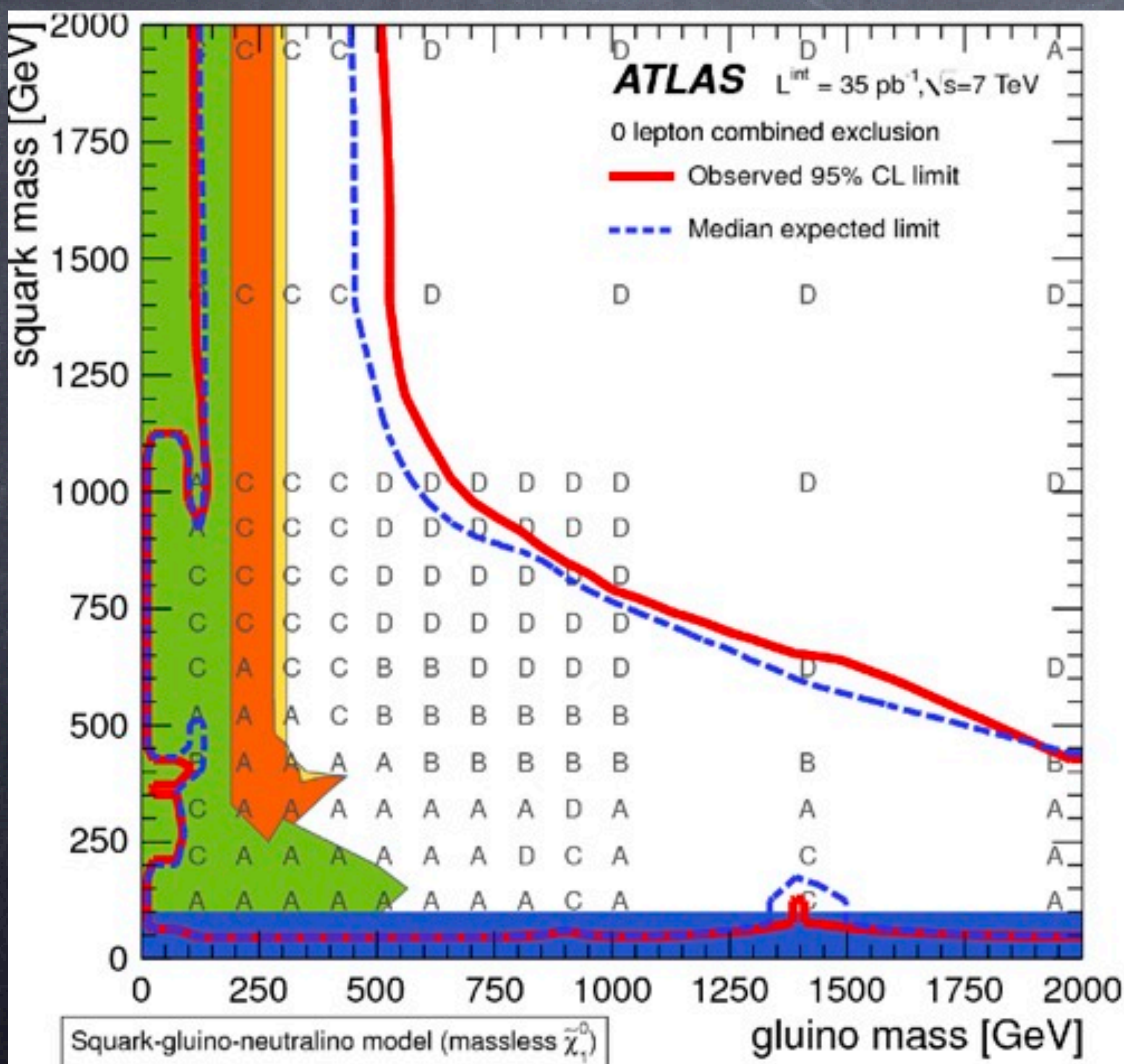


Jets+MET searches at ATLAS



		A	B	C	D
Pre-selection	Number of required jets	≥ 2	≥ 2	≥ 3	≥ 3
	Leading jet p_T [GeV]	> 120	> 120	> 120	> 120
	Other jet(s) p_T [GeV]	> 40	> 40	> 40	> 40
	E_T^{miss} [GeV]	> 100	> 100	> 100	> 100
Final selection	$\Delta\phi(\text{jet}, \vec{P}_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
	E_T^{miss}/m_{eff}	> 0.3	–	> 0.25	> 0.25
	m_{eff} [GeV]	> 500	–	> 500	> 1000
	m_{T2} [GeV]	–	> 300	–	–

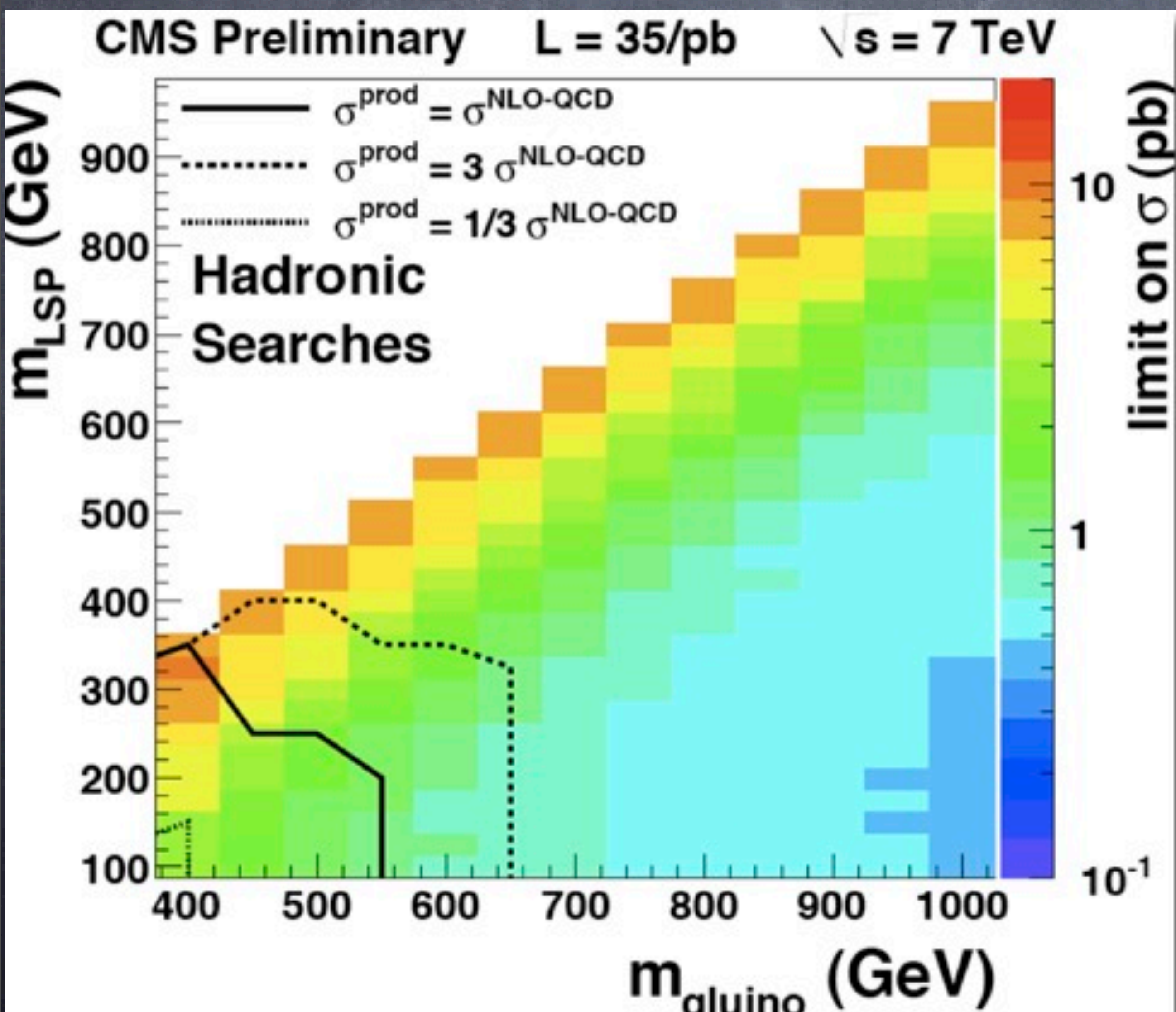
	Signal region A	Signal region B	Signal region C	Signal region D
QCD	7^{+8}_{-7}[u+j]	$0.6^{+0.7}_{-0.6}$[u+j]	9^{+10}_{-9}[u+j]	$0.2^{+0.4}_{-0.2}$[u+j]
W+jets	50 ± 11[u] $^{+14}_{-10}$[j] $\pm$ 5[$\mathcal{L}$]	4.4 ± 3.2[u] $^{+1.5}_{-0.8}$[j] $\pm$ 0.5[$\mathcal{L}$]	35 ± 9[u] $^{+10}_{-8}$[j] $\pm$ 4[$\mathcal{L}$]	1.1 ± 0.7[u] $^{+0.2}_{-0.3}$[j] $\pm$ 0.
Z+jets	52 ± 21[u] $^{+15}_{-11}$[j] $\pm$ 6[$\mathcal{L}$]	4.1 ± 2.9[u] $^{+2.1}_{-0.8}$[j] $\pm$ 0.5[$\mathcal{L}$]	27 ± 12[u] $^{+10}_{-6}$[j] $\pm$ 3[$\mathcal{L}$]	0.8 ± 0.7[u] $^{+0.6}_{-0.0}$[j] $\pm$ 0.
$t\bar{t}$ and t	10 ± 0[u] $^{+3}_{-2}$[j] $\pm$ 1[$\mathcal{L}$]	0.9 ± 0.1[u] $^{+0.4}_{-0.3}$[j] $\pm$ 0.1[$\mathcal{L}$]	17 ± 1[u] $^{+6}_{-4}$[j] $\pm$ 2[$\mathcal{L}$]	0.3 ± 0.1[u] $^{+0.2}_{-0.1}$[j] $\pm$ 0.
Total SM	118 ± 25[u] $^{+32}_{-23}$[j] $\pm$ 12[$\mathcal{L}$]	10.0 ± 4.3[u] $^{+4.0}_{-1.9}$[j] $\pm$ 1.0[$\mathcal{L}$]	88 ± 18[u] $^{+26}_{-18}$[j] $\pm$ 9[$\mathcal{L}$]	2.5 ± 1.0[u] $^{+1.0}_{-0.4}$[j] $\pm$ 0.
Data	87	11	66	2

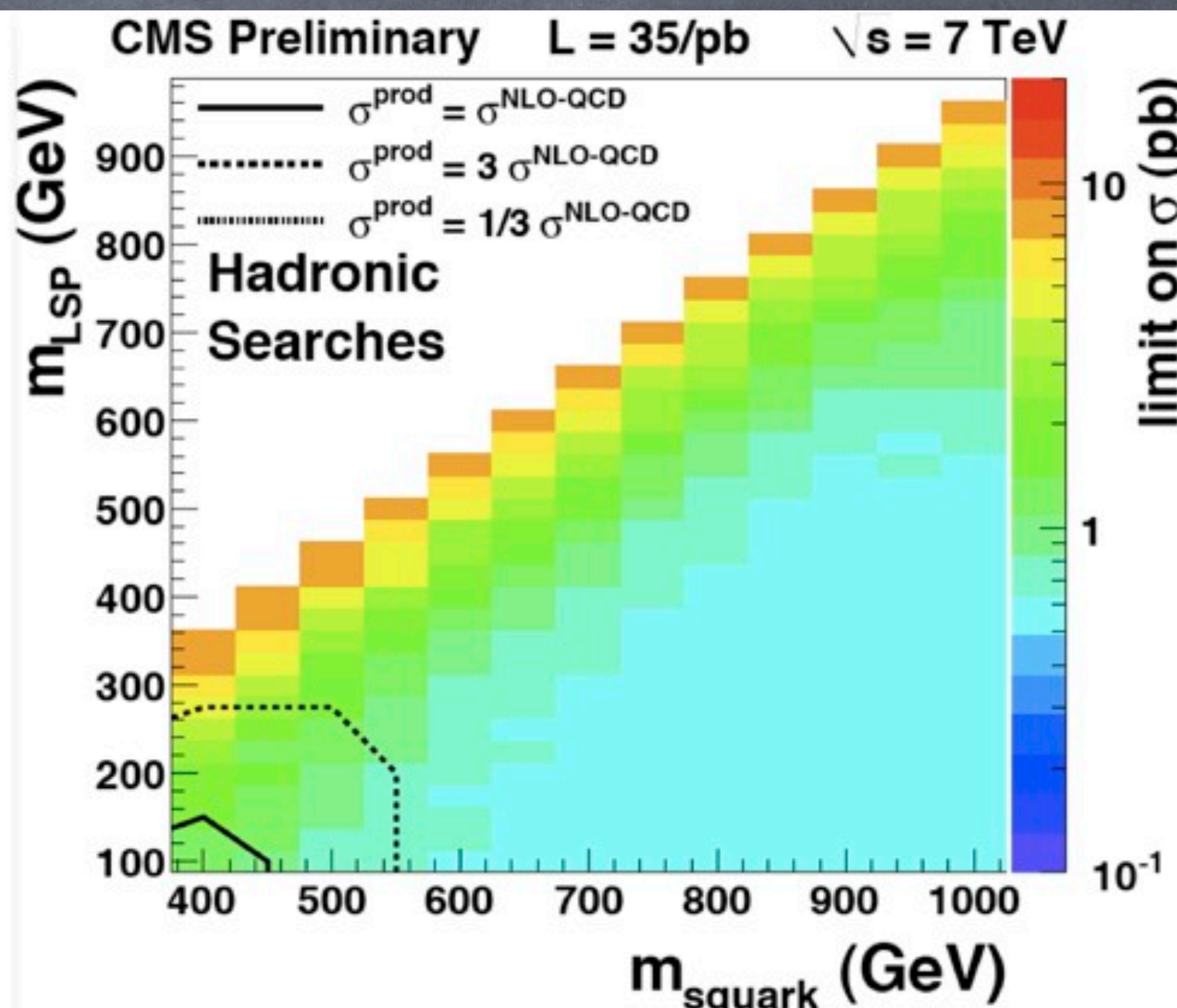


- 4 search regions targeting different squark/gluino masses
- Robust limit of 500 GeV on the gluino mass
- For equal squark and gluino masses the limit is more stringent, roughly 800 GeV

CMS JETS+MET search

- Several searches with different methods: HT and αT variables, "Razor" variable
- Model independent limits as a function of the LSP mass

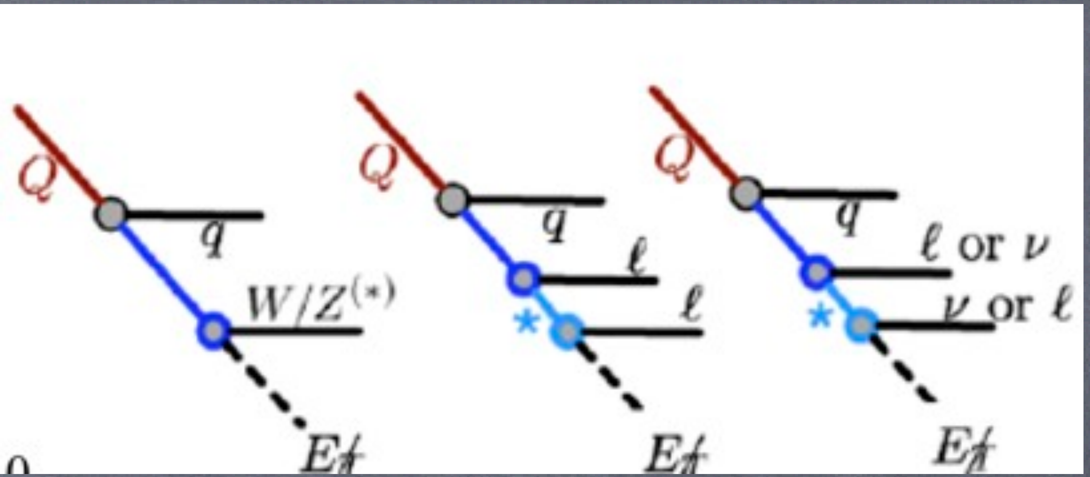




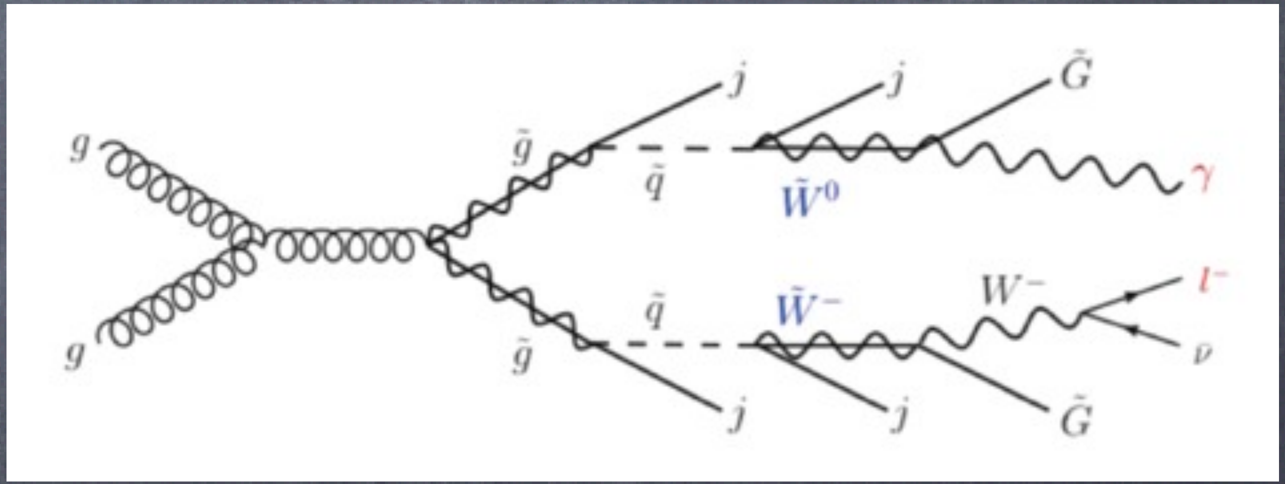
Other SUSY Topologies

If other superpartners (charginos, neutralino sleptons) lighter than squarks and/or gluinos, then decay topologies with leptons in the final state may occur

- Gluino or squark can undergo a cascade decay producing 1 or more charged leptons

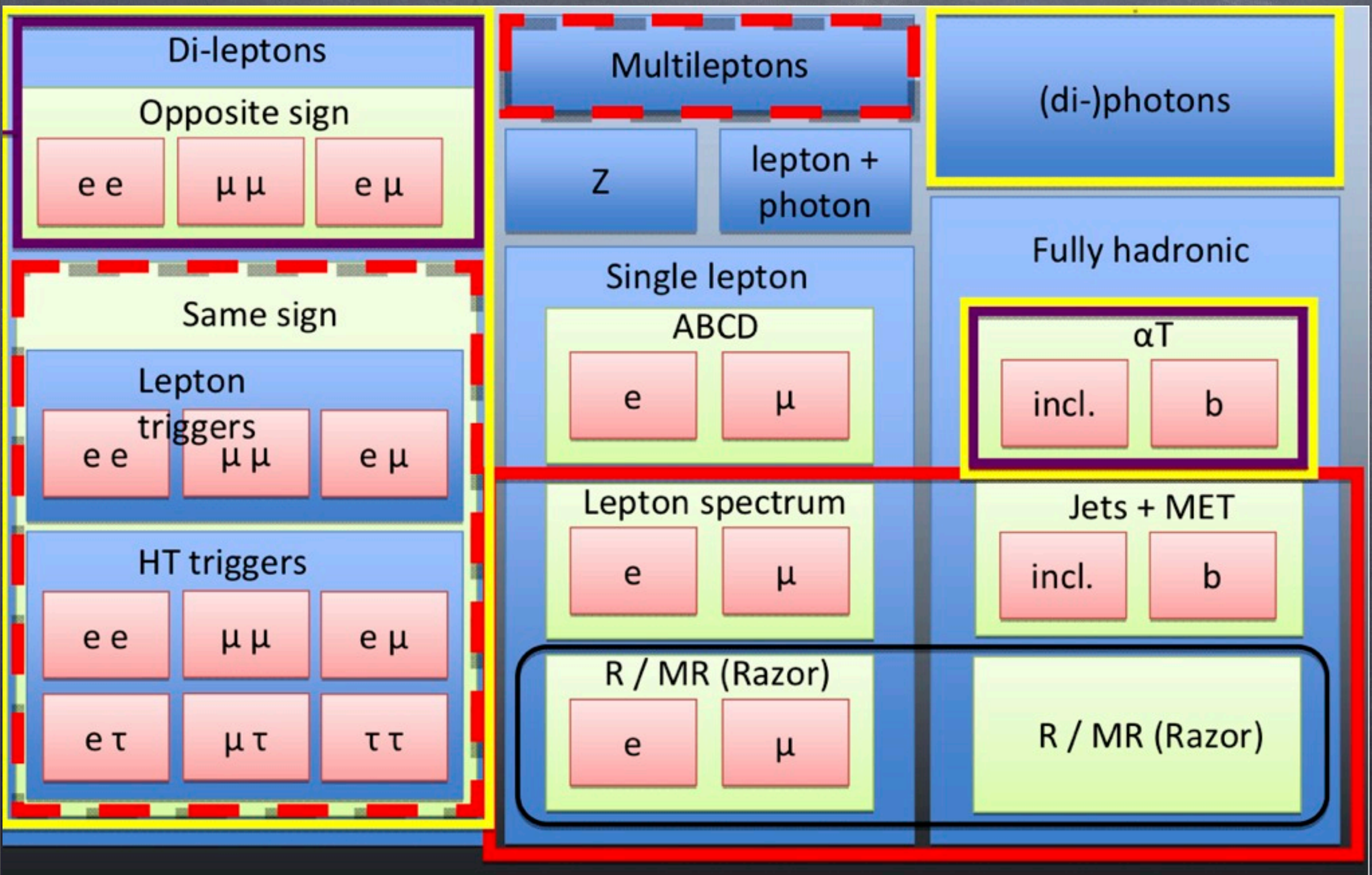


- Leptons can also show up e.g. when gravitino is the LSP and chargino + slepton is the NLSP



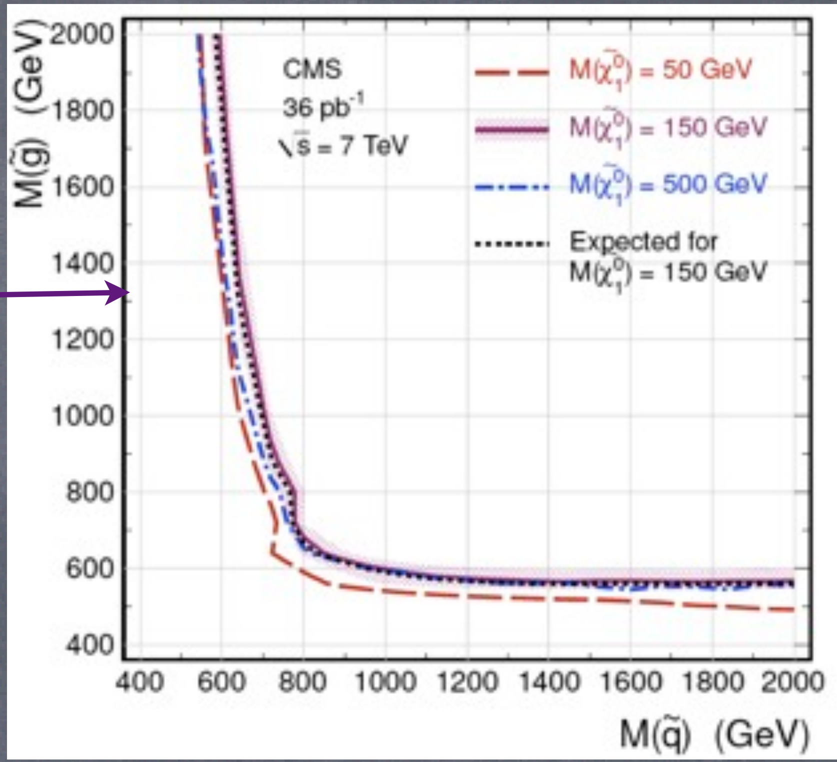
- Photons can show up e.g. if gravitino is the LSP and neutralino is the NLSP

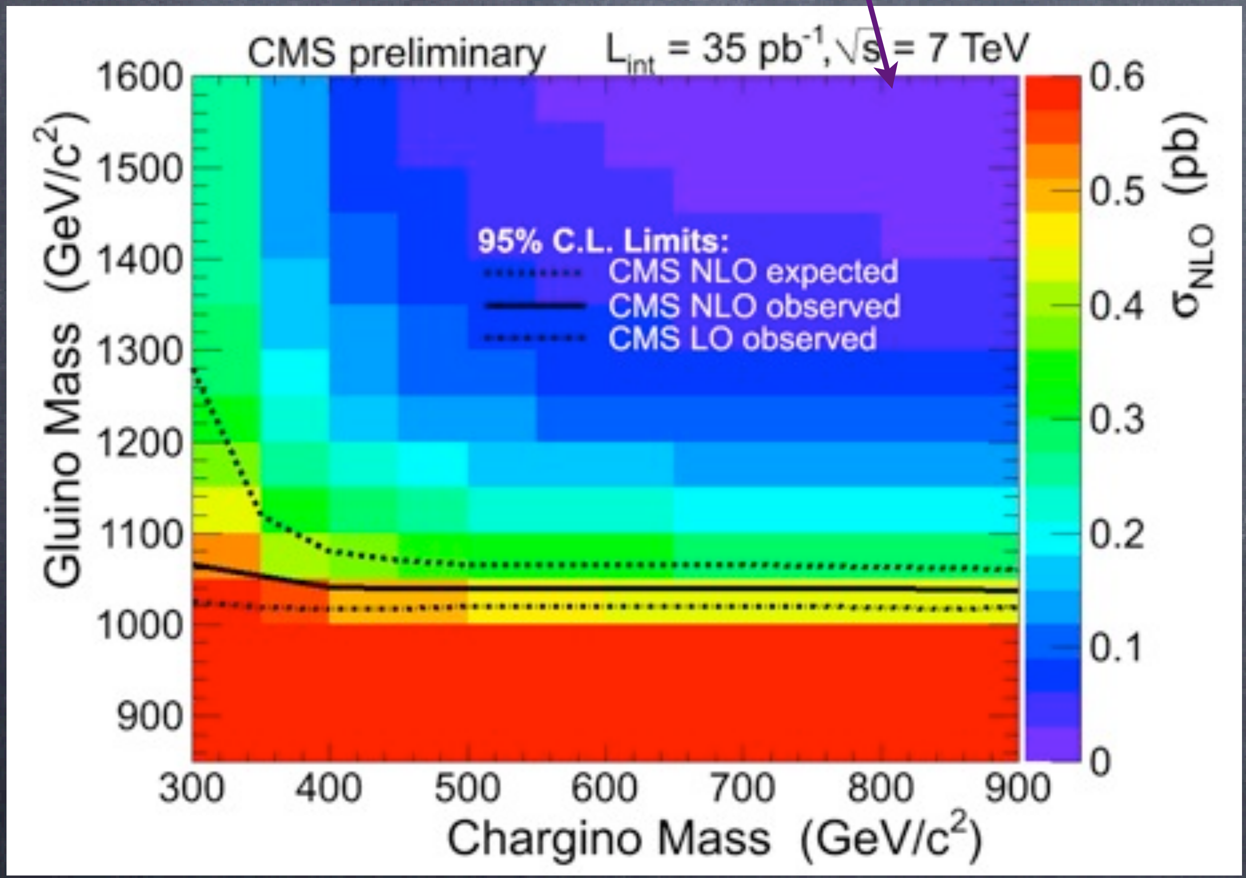
SUSY is fun for experimentalists!

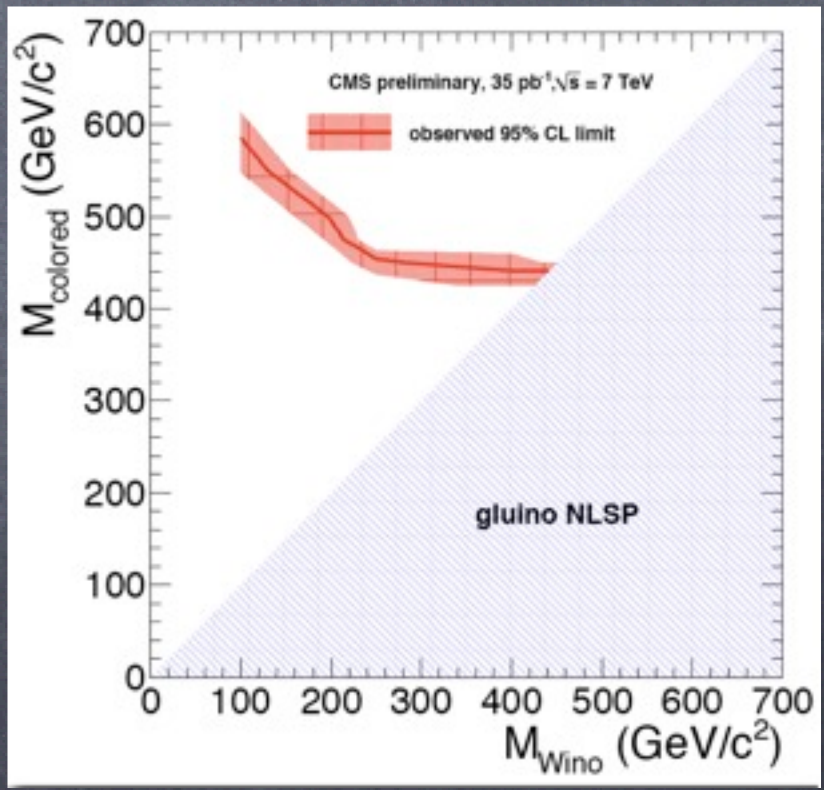


Some More Results

- ✳Diphoton + Jets + MET
- ✳Photon + Lepton + Jets + MET
- ✳3 or Leptons + MET





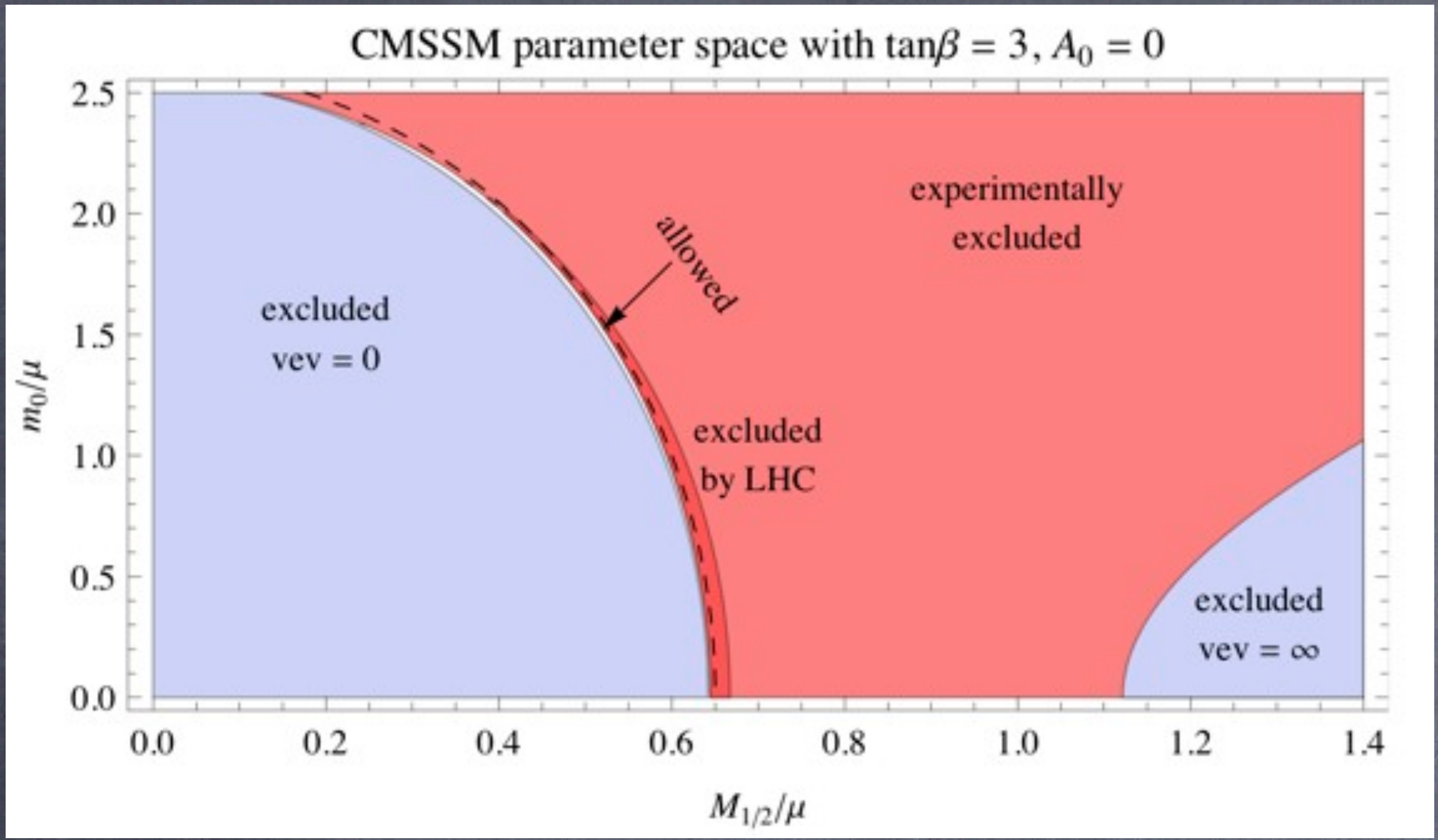


SUSY limits summary

- Robust limit of 500 GeV on gluino mass
- If squarks and gluinos have comparable masses, the limit goes up to 800 GeV
- Even stronger limits possible if the dominant decay chain produces 2 leptons
- No new limits on stops yet, currently mstop > mtop

Interpretation of LHC SUSY Limits

$$M_Z^2 \approx 0.2 m_0^2 + 0.7 M_3^2 - 2\mu^2 = (91\ \text{GeV})^2 \times 50(\frac{M_3}{780\ \text{GeV}})^2 + \cdots$$



- LHC further shrinks the parameter space, kettling the parameters toward the no EW-breaking boundary

Strumia, 1101.2195

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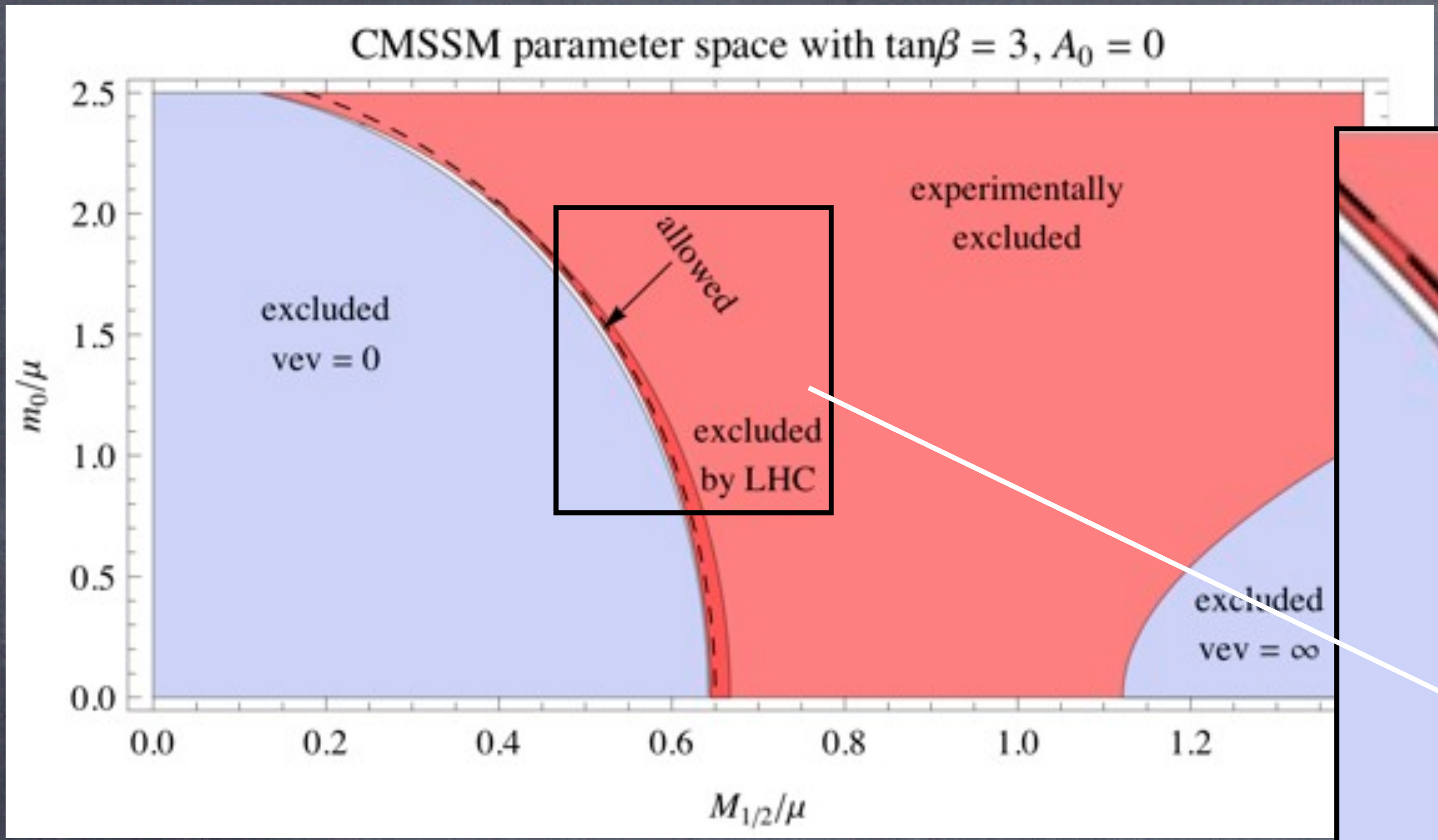

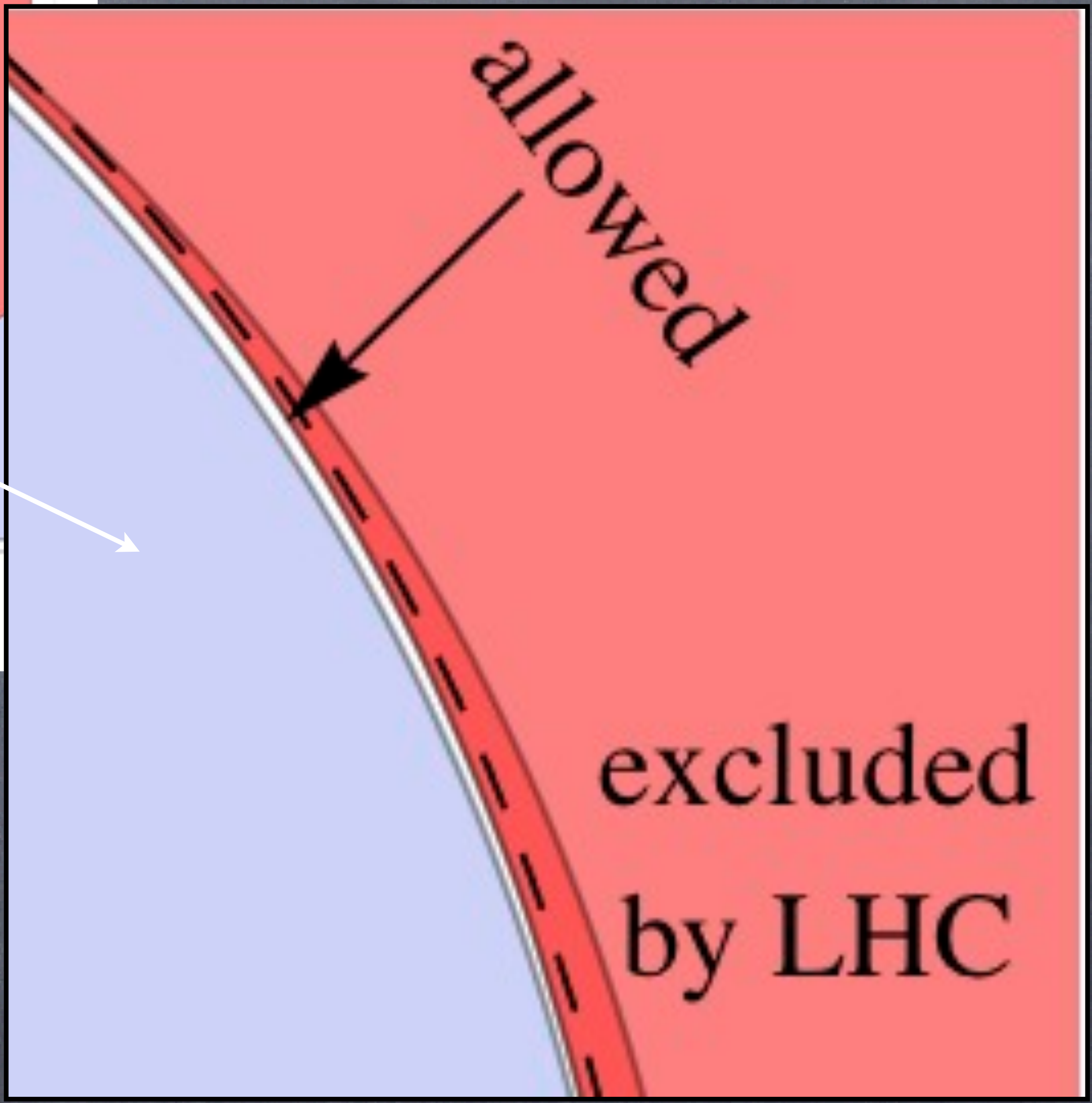

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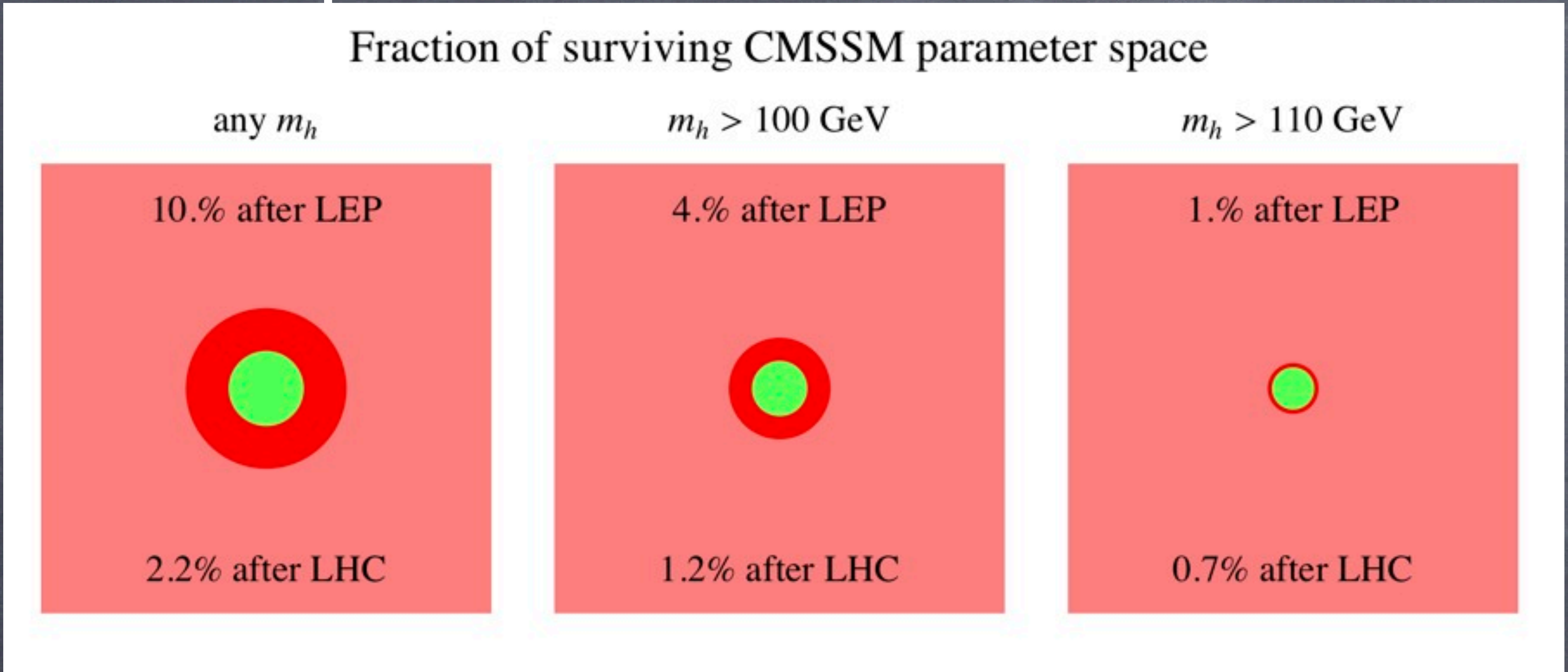
Interpretation of LHC SUSY Limits

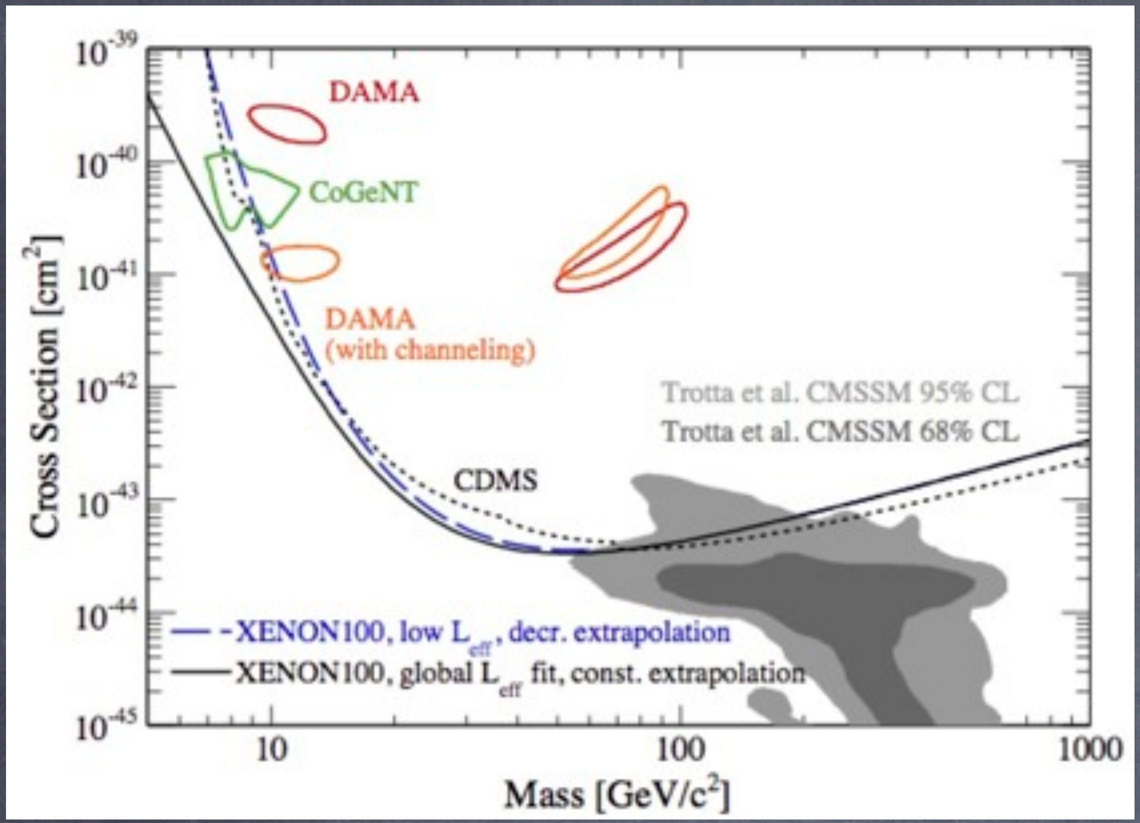


- LHC impact on MSSM-like scenarios is not significant. LEP limits on the Higgs mass already required that SUSY is heavy and fine-tuning is severe. LHC just confirmed that independently.
- But important impact on non-MSSM SUSY scenarios that avoid fine-tuning thanks to additional contributions to the Higgs mass. Now it's probably impossible to find a SUSY scenario where fine-tuning is better than 1 percent.

Back to the Frog Metaphor

The Water is Boiling...

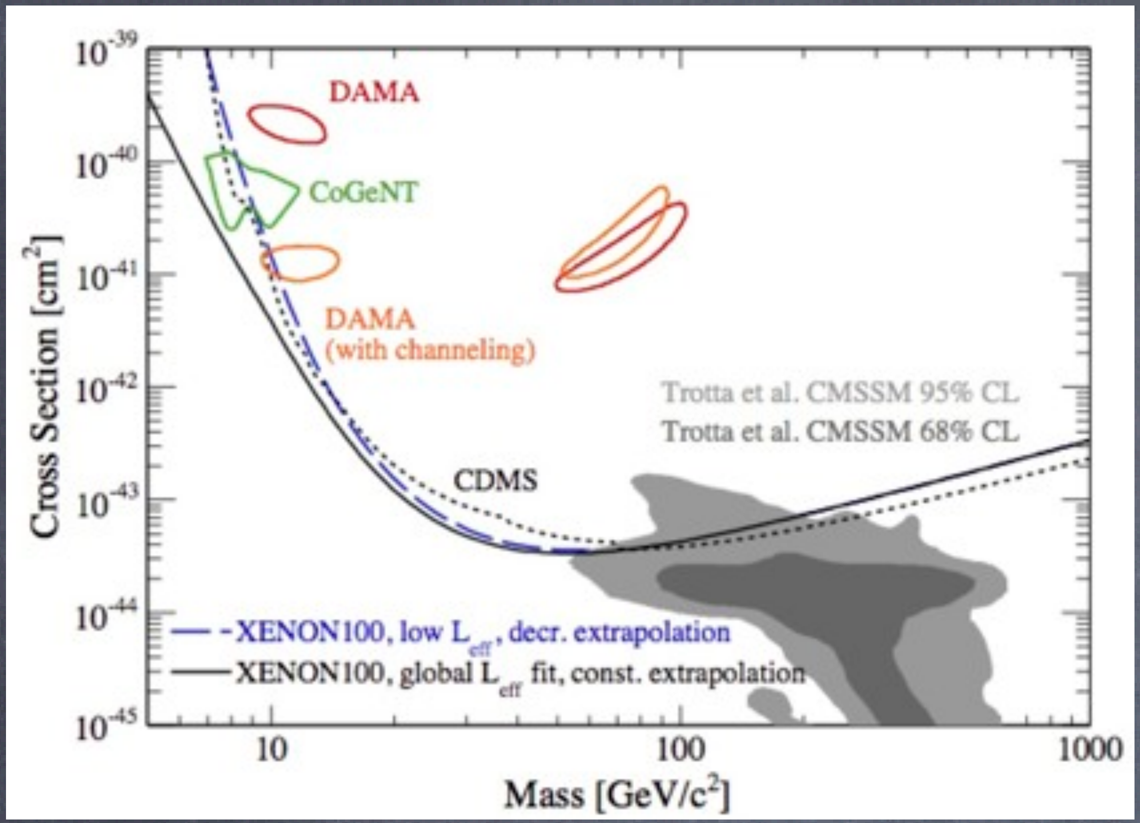
MSSM and Dark Matter



We are about to explore the most interesting region of the SUSY parameter space. Dark matter is just behind the corner!

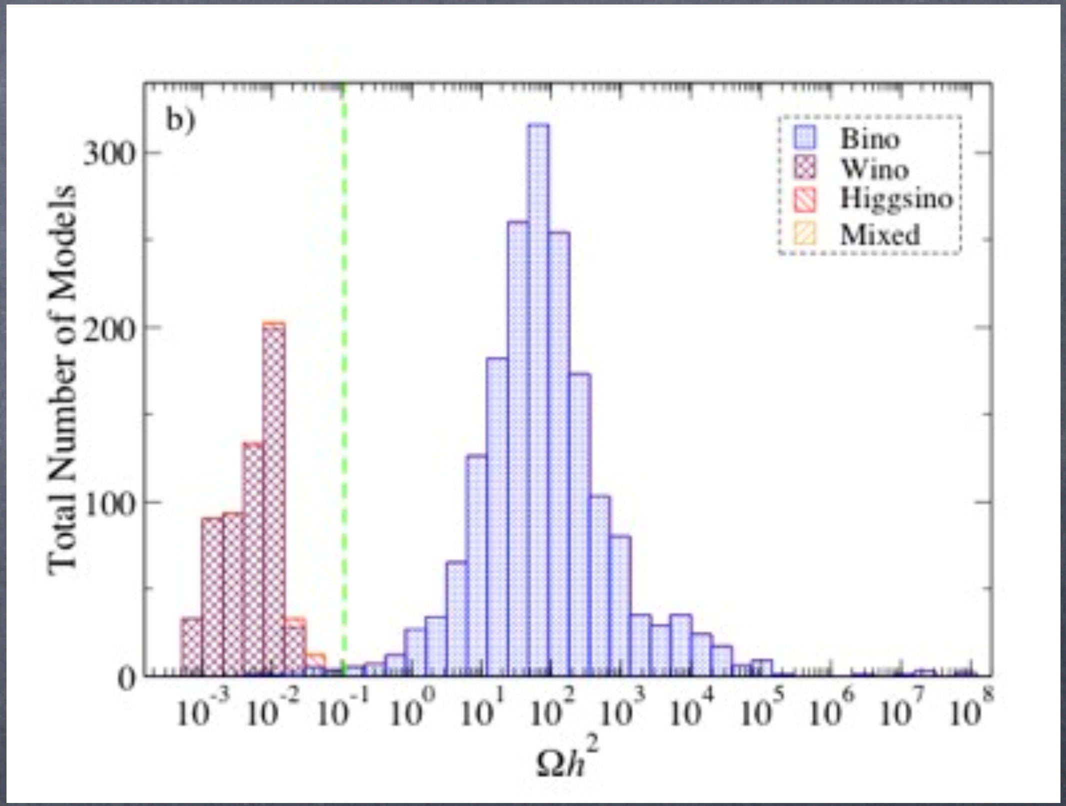
Baer, 1012.0248

MSSM and Dark Matter



We are about to explore the most interesting region of the SUSY parameter space. Dark matter is just behind the corner!

Dark matter in MSSM is fine-tuned, on top of electroweak fine-tuning
Bino dark matter typically gives too much relic abundance, whereas wino or Higgsino give too little.

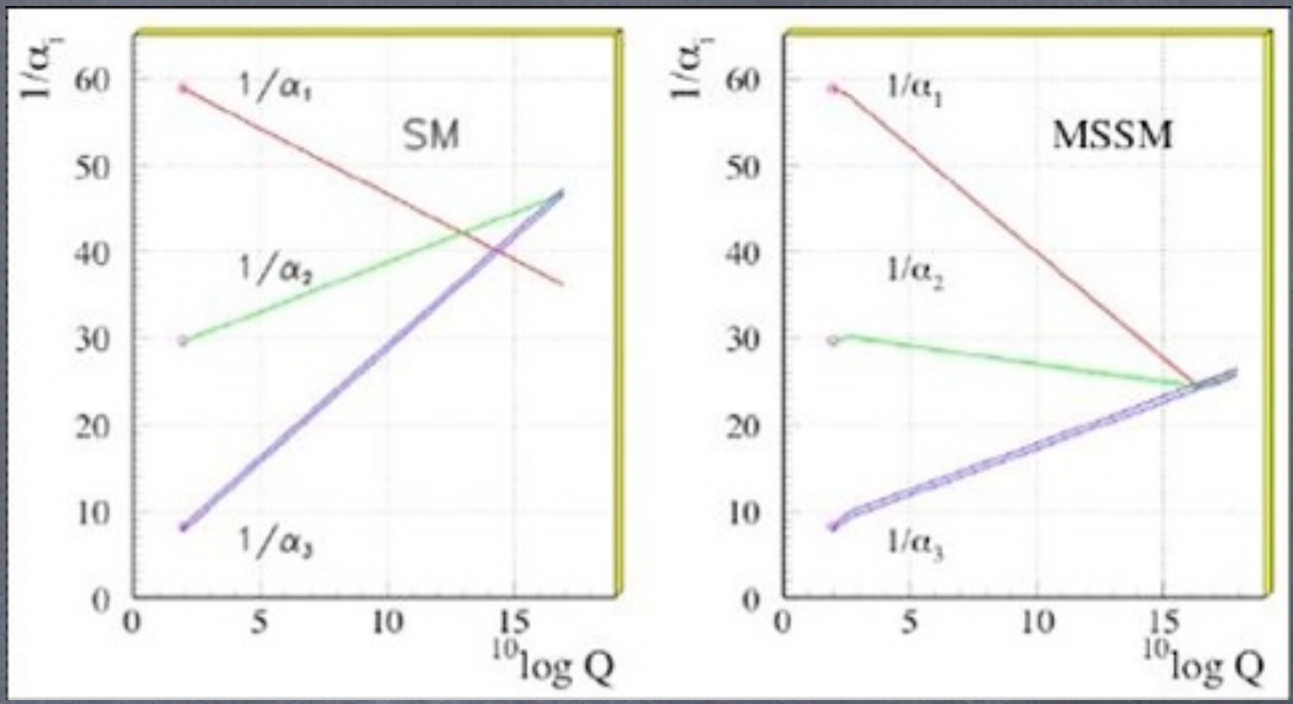


Baer, 1012.0248

lundi 28 mars 2011

MSSM and Unification

- I have no snide remarks about this one...
- ...except that the strongest argument for SUSY is its connection to another hypothetical theory ;-)



90's

00's

10's

Images drawn by sister of Colin Bernett and presented by CMS at Moriond

My take on SUSY

- SUSY explains the weak scale by connecting it to the supersymmetry breaking scale:

  $m_{SUSY} \sim m_Z$

- If SUSY was there it probably would have shown up at LEP. It would probably also show up indirectly in thousands low-energy measurements.

- Limits from Higgs searches at LEP and direct limits from the LHC imply m_{SUSY} of order 1 TeV, which corresponds to at least 1% fine-tuning

- If one can leave with 1% fine-tuning one can probably leave with 0.1% fine-tuning. The latter corresponds to $m_{SUSY} \geq 3$ TeV, that is no SUSY at the LHC.

Should we then search for SUSY?

✤ It predicts well defined signatures that can be searched for in colliders and in other experiments

✤ Signature-based SUSY searches apply to a much wider class of models (dark matter, extra dimensions, T-parity little Higgs, etc.)

Should we then search for SUSY?

YES

✤ It predicts well defined signatures that can be searched for in colliders and in other experiments

✤ Signature-based SUSY searches apply to a much wider class of models (dark matter, extra dimensions, T-parity little Higgs, etc.)

Estimated LHC Reach after 1fb-1

Alves et al. 1102.5338