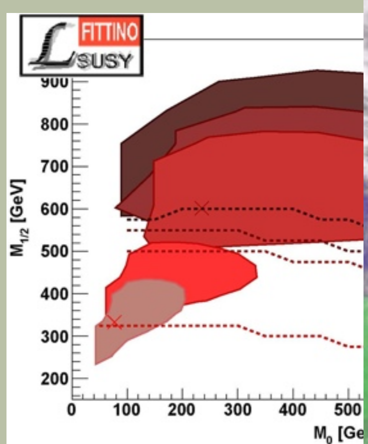
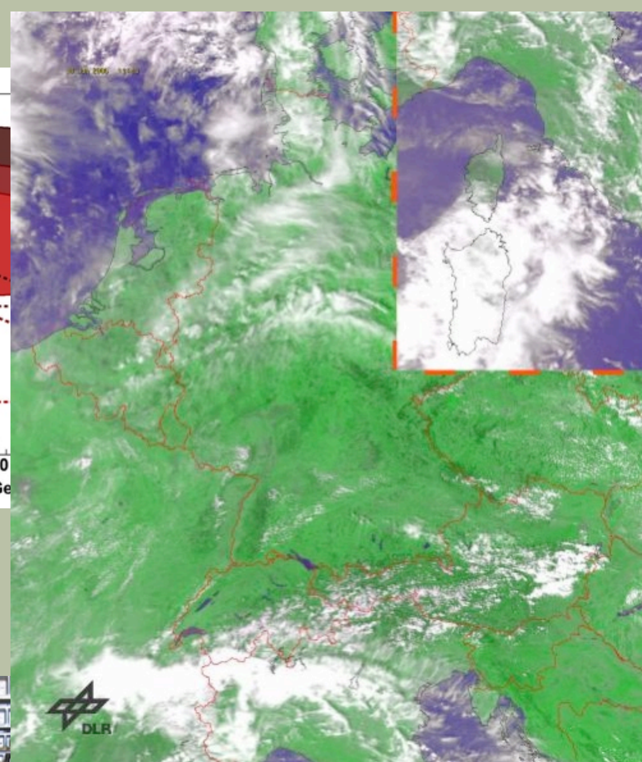
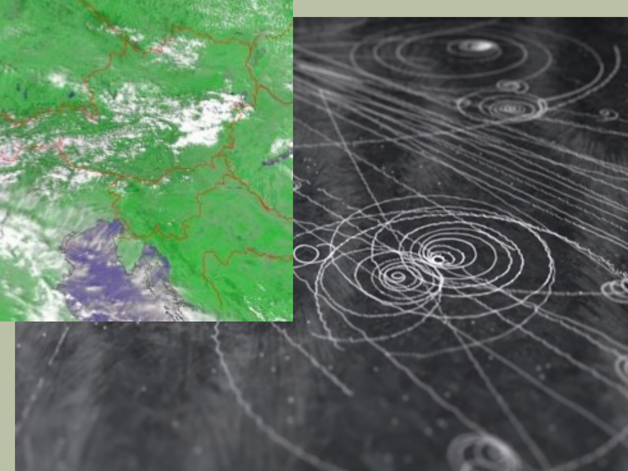
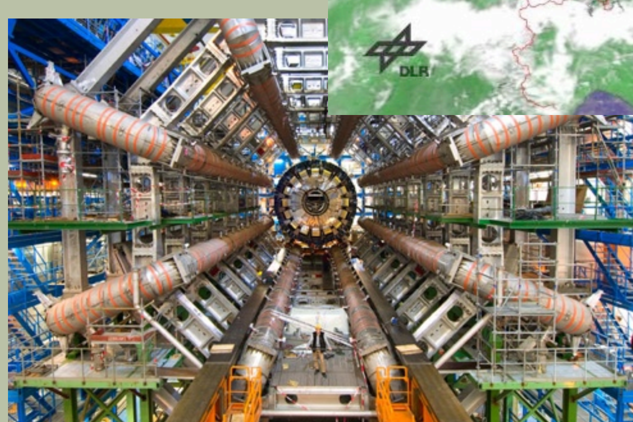
MSSM: Status & Forecast Part II









Young Scientists Workshop 2011
Wildbad Kreuth

Jonas M. Lindert
Max-Planck-Institut für Physik

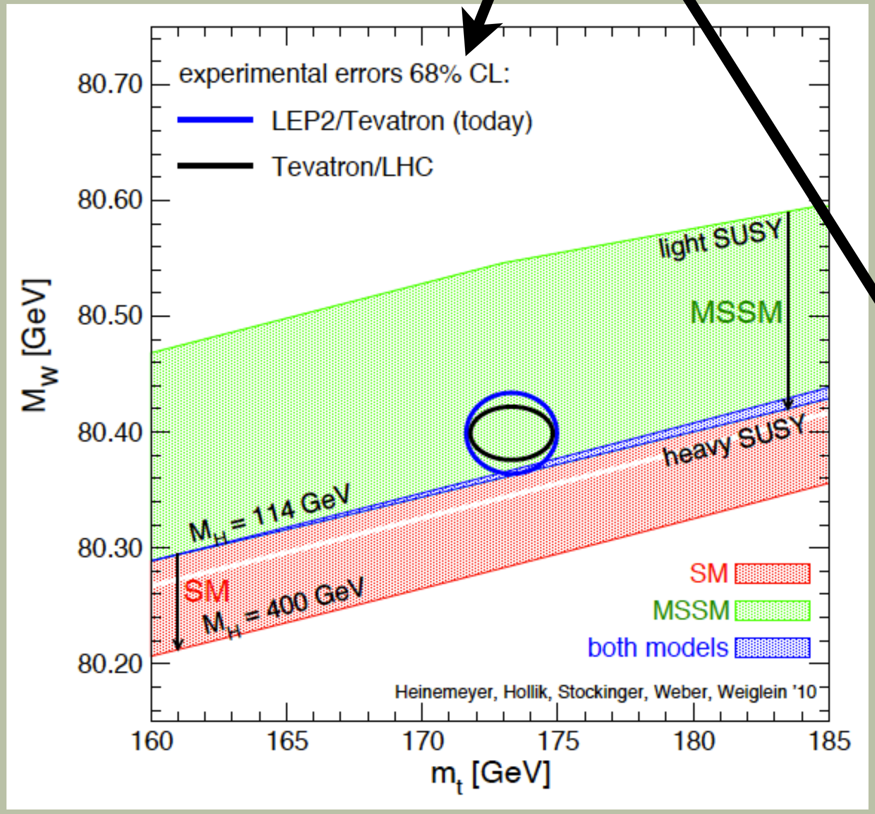
Outline

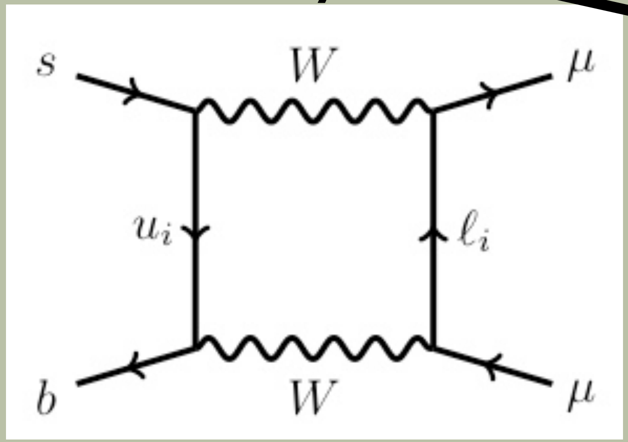
- **Pre-LHC**
- **Status Summer 2011**
- **Weather Forecast**

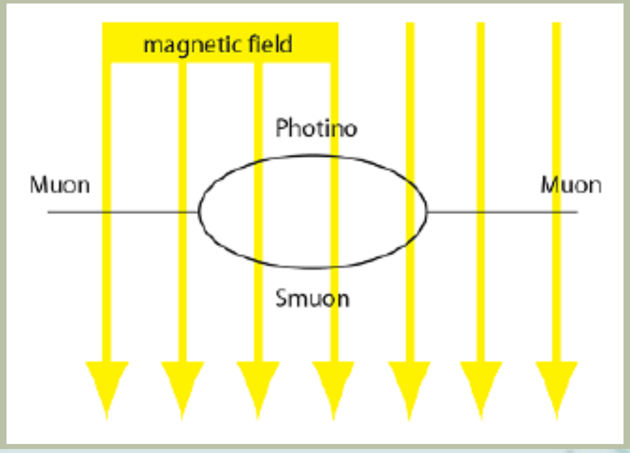
Disclaimer: I'm not going to explain
all new exclusion limits -> ask an experimentalist!

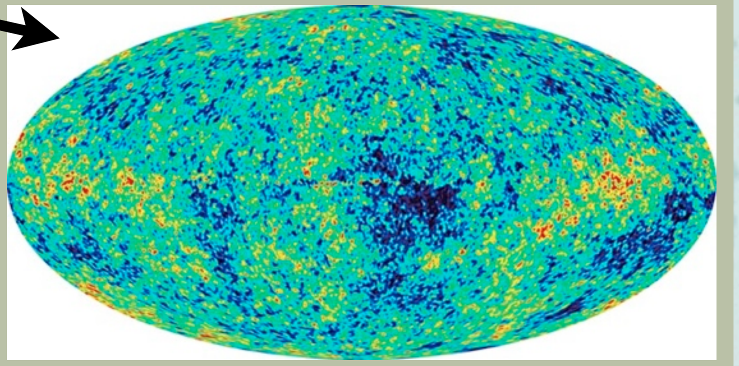
STATUS END OF 2010 (PRE-LHC)

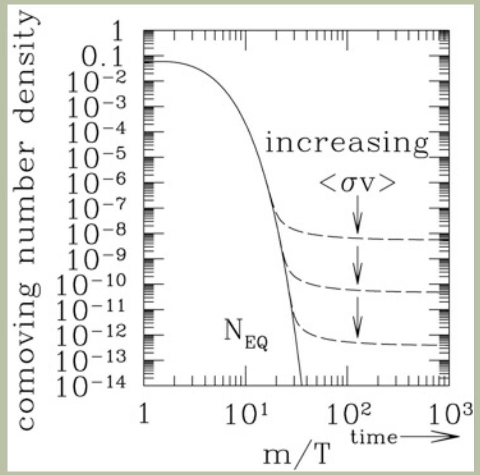
- "SUSY sits just around the corner"
- ...according to global fits within the CMSSM (and other constrained models) done by many different groups: MasterCode, Fittino, SFitter and more..
- Fit inputs: electroweak precision observables (EWPO), flavor- (especially B-) observables, relic density





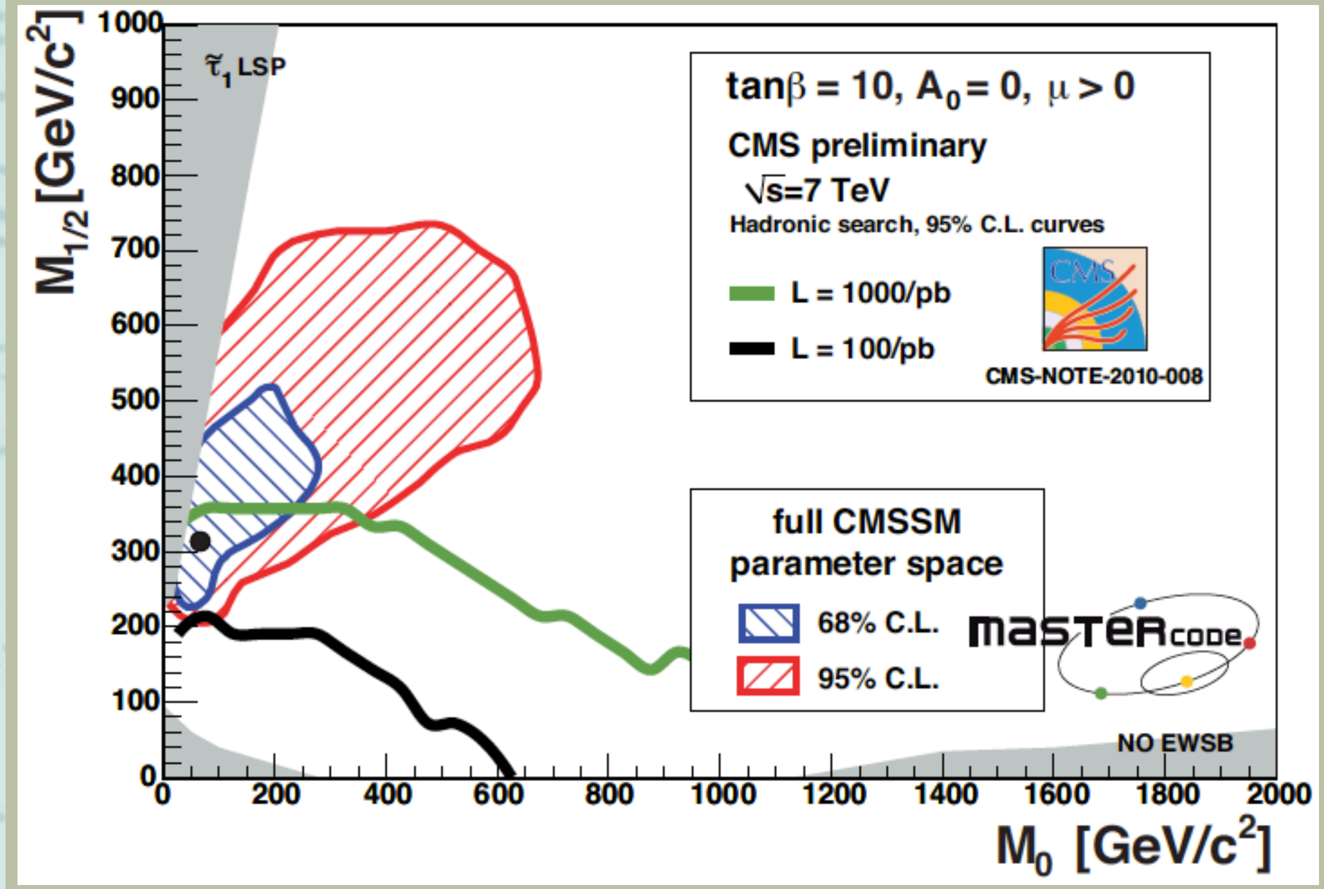




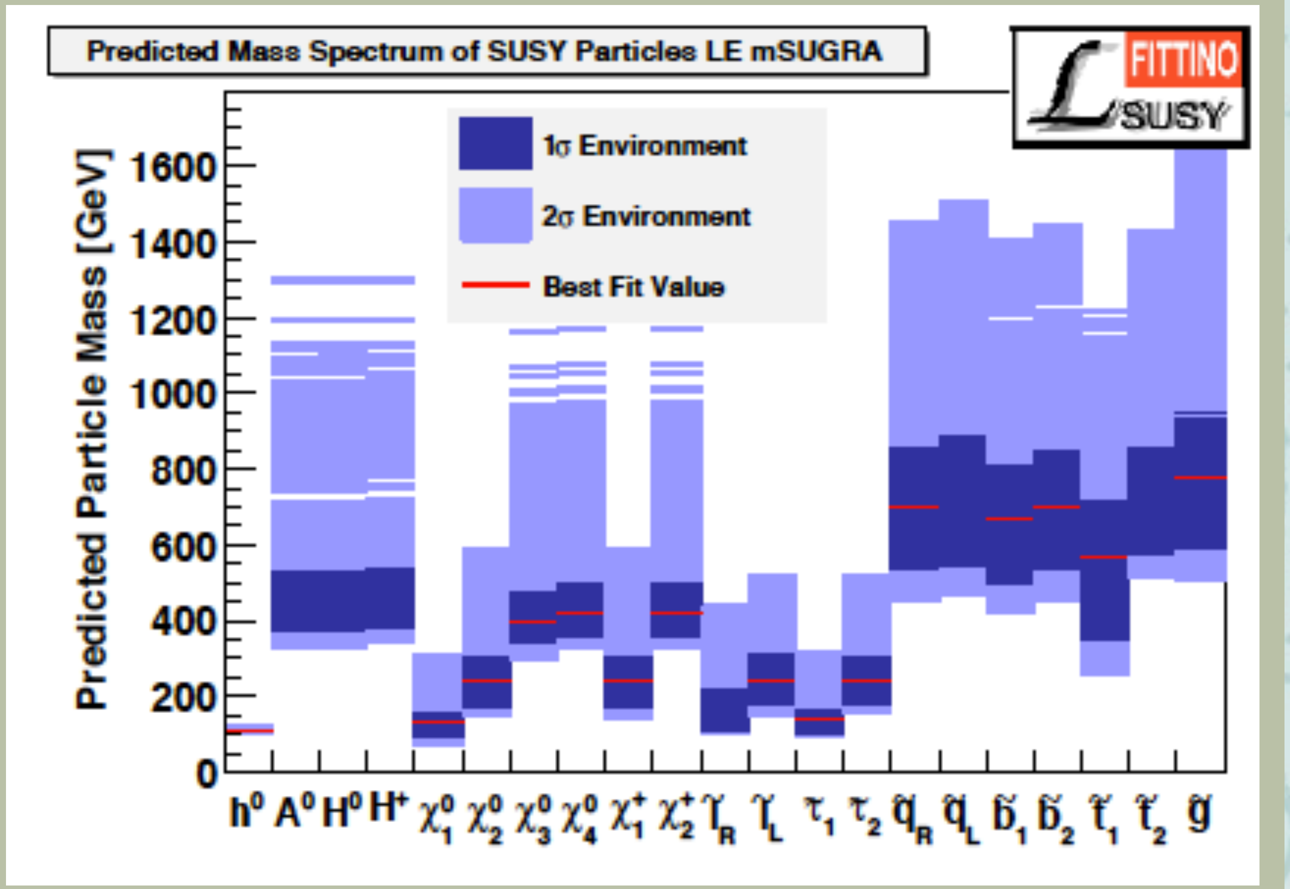


STATUS END OF 2010 (PRE-LHC)

- “SUSY sits just around the corner”.
- Global χ^2 likelihood fit (parameter space sampling usually via MCs).



[Buchmüller et. a., 2008]

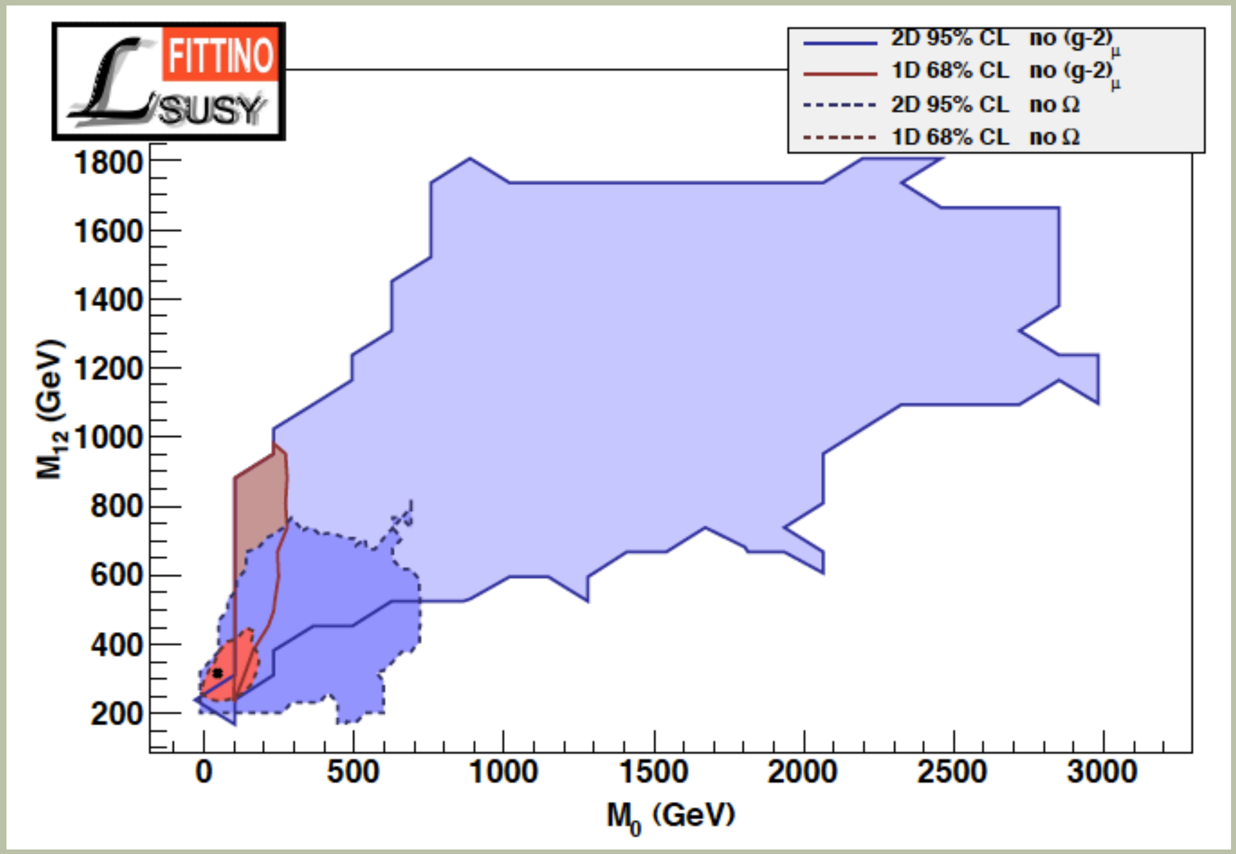


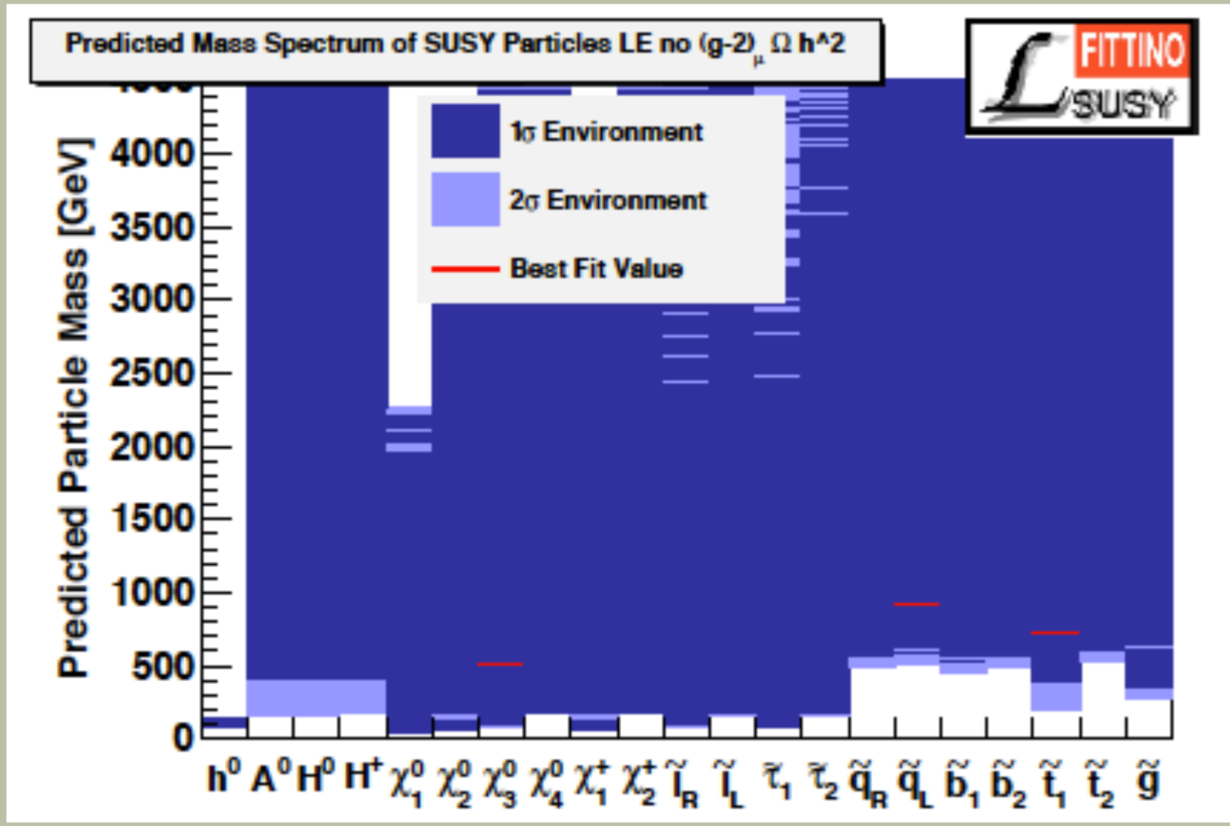
[Bechle et. al., 2008]

STATUS END OF 2010 (PRE-LHC)

- ... mostly driven by one observable: $(g-2)|_\mu$

$$a_\mu^{\mathrm{MSSM}} \propto \tan\beta \frac{m_\mu^2}{M_{\mathrm{SUSY}}^2}$$



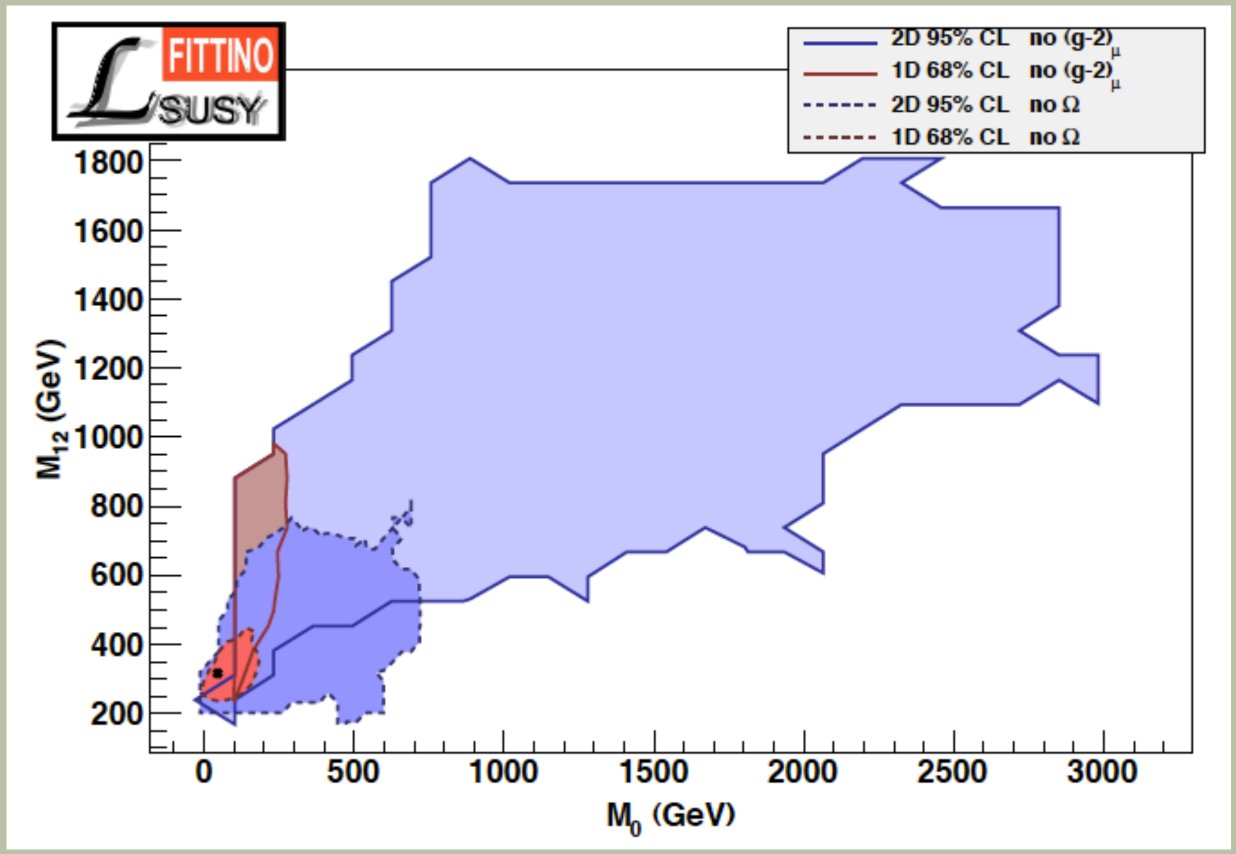


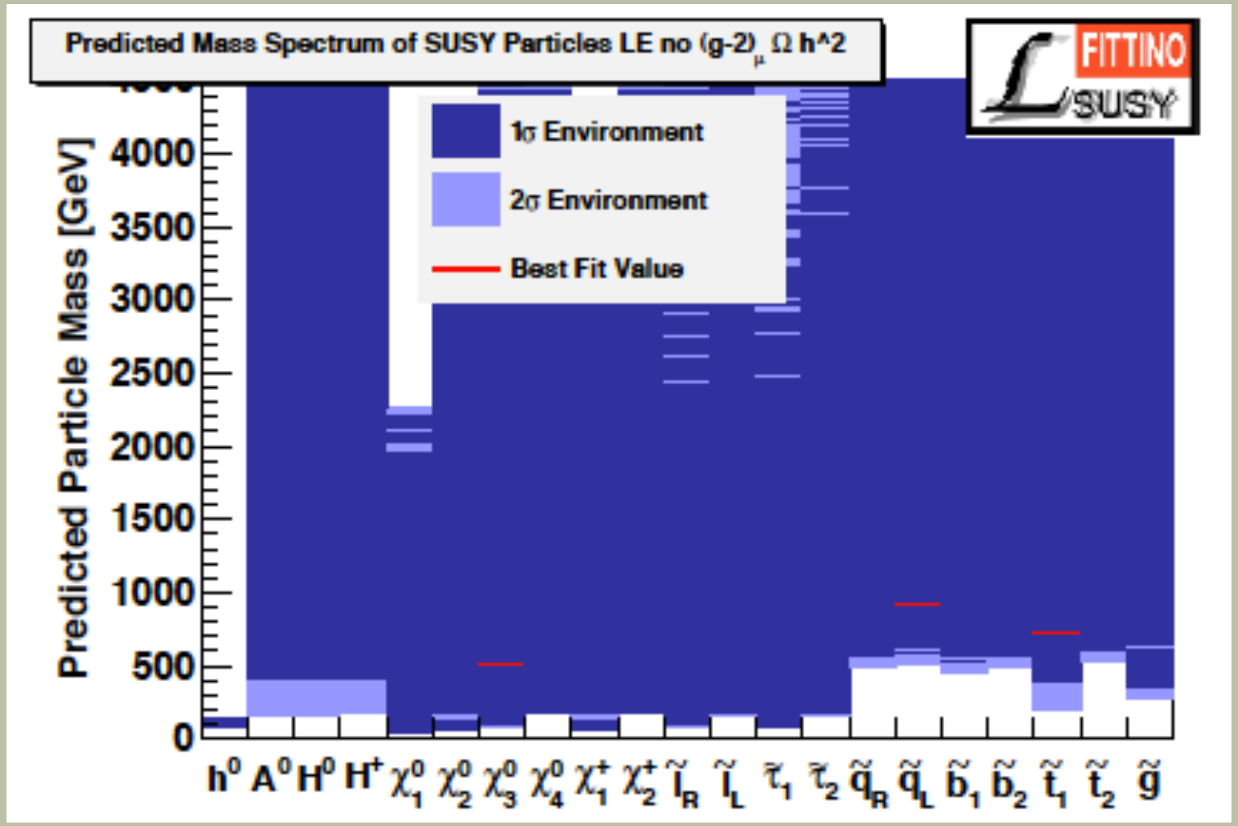
[Bechle et. al., 2008]

STATUS END OF 2010 (PRE-LHC)

- ... mostly driven by one observable: $(g-2)|_\mu$

$$a_\mu^{\rm MSSM} \propto \mathrm{sgn}(\mu)\tan\beta \frac{m_\mu^2}{m_{\tilde{\chi}}^2}\frac{m_{\tilde{\nu}}}{m_{\tilde{\chi}}}$$

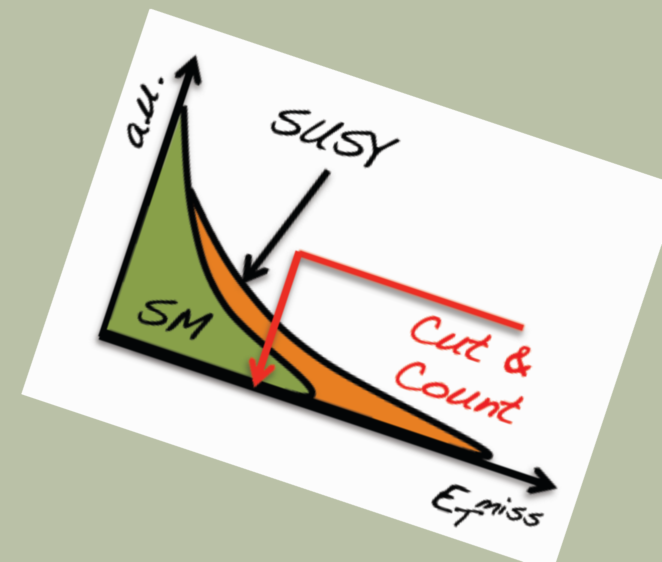


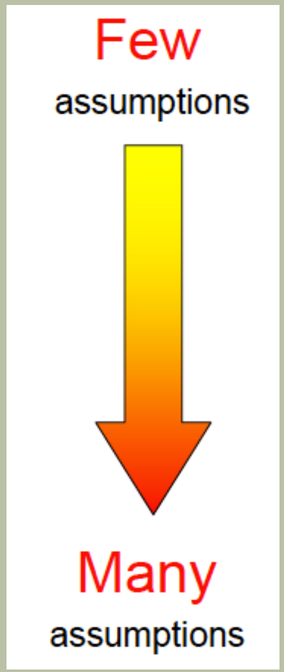


[Bechle et. al., 2008]

STATUS SUMMER 2011

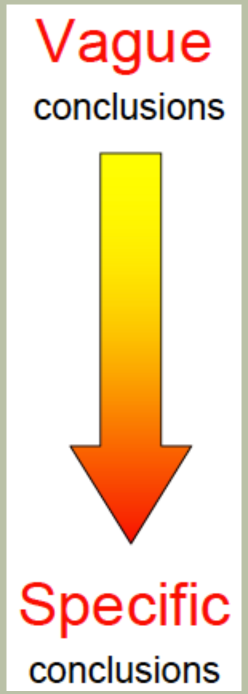
Possible LHC Signatures





Missing ET signatures:

- ☐ jets + missing transverse energy
- ☐ + 1 lepton
- ☐ + 2 lepton (OSSF/SSSF/)
- ☐ + more leptons (or without hard jets)
- ☐ + photons
- ☐ b-quark jets



Non Missing ET signatures:

- ☐ Charged Massive Particles (metastable)
- ☐ R-hadrons
- ☐ jets + leptons (R-parity violating SUSY)

Two Questions:

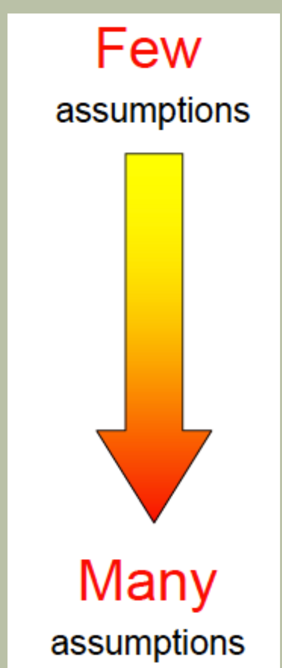
★ How to interpret exclusions?

★ How to make sure all parameter regions are covered?

Always a trade-off!

STATUS SUMMER 2011

Possible LHC Signatures



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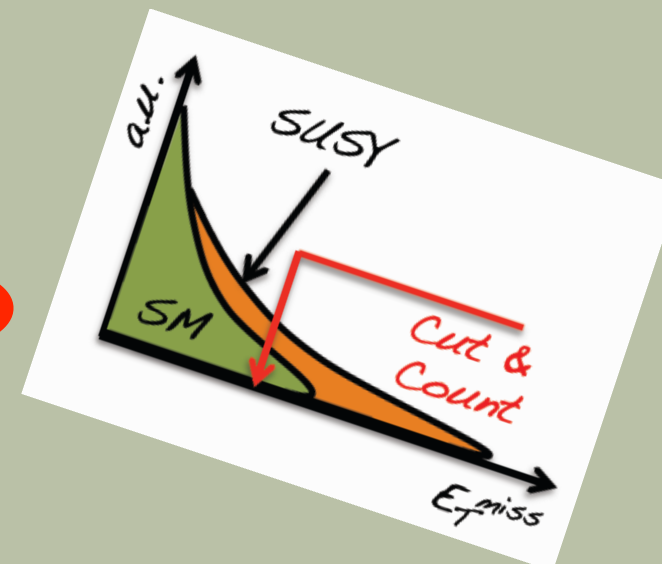

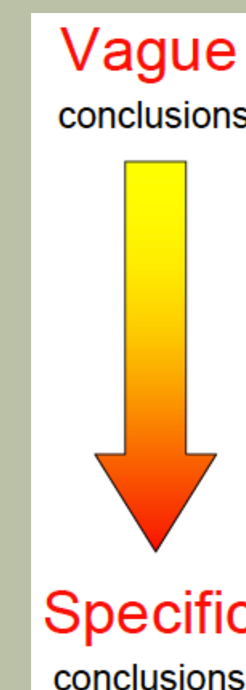

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Always a trade-off!

STATUS SUMMER 2011

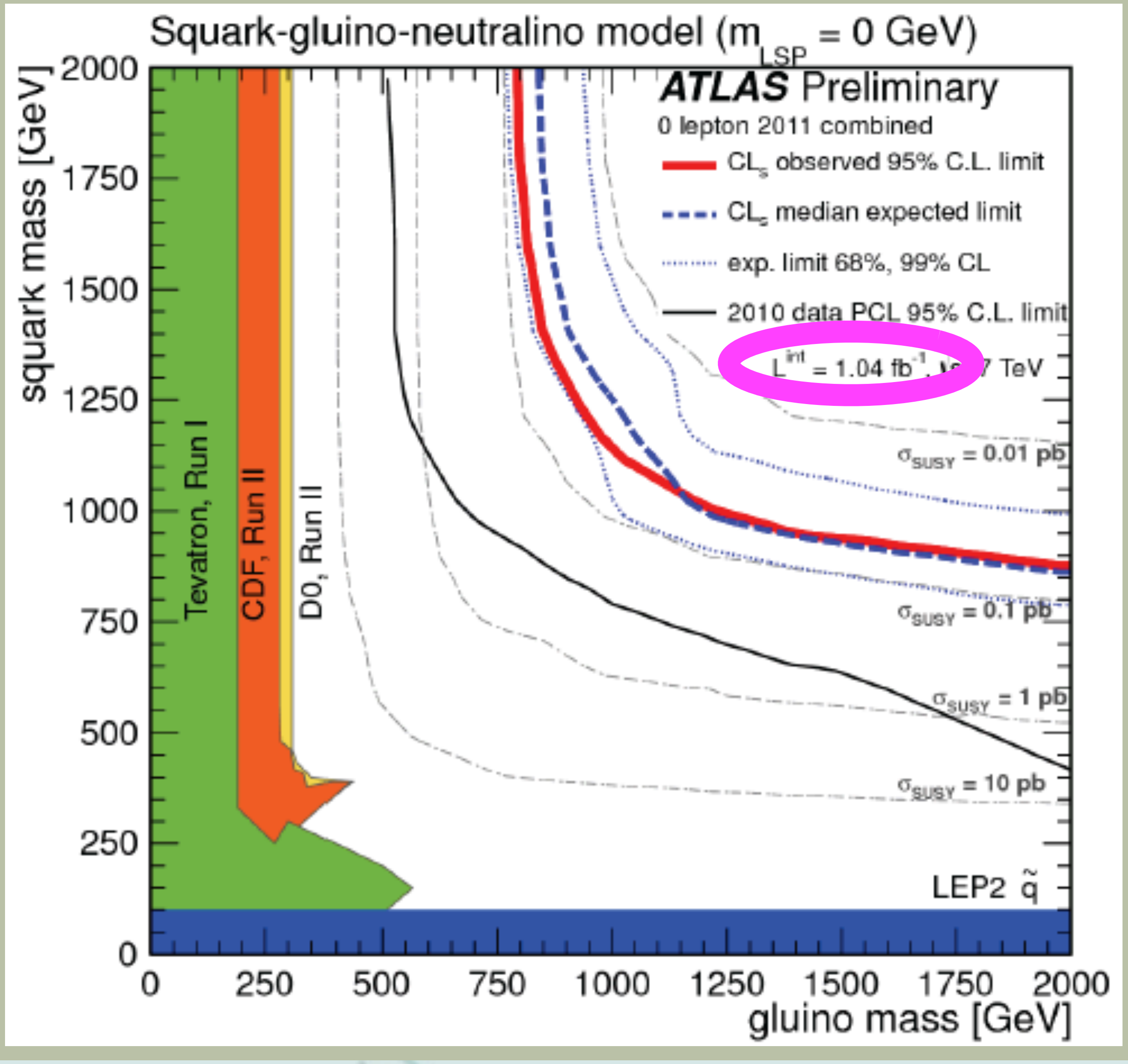
Simplified Model Interpretation

- jets+MET (>2j, >3j, >4j combined)
- "No excess over SM backgrounds is observed"
- "Light" squarks and gluinos constrained to be > 800-1050 GeV

Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets	High mass
E_T^{miss}	> 130	> 130	> 130	> 130
Leading jet p_T	> 130	> 130	> 130	> 130
Second jet p_T	> 40	> 40	> 40	> 80
Third jet p_T	–	> 40	> 40	> 80
Fourth jet p_T	–	–	> 40	> 80
$\Delta\phi(\text{jet}, E_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
m_{eff} [GeV]	> 1000	> 1000	$> 500/1000$	> 1100

$$m_{eff} \equiv \sum_{i=1}^{n} \left|\mathbf{p}_T^i\right| + E_T^{miss}$$

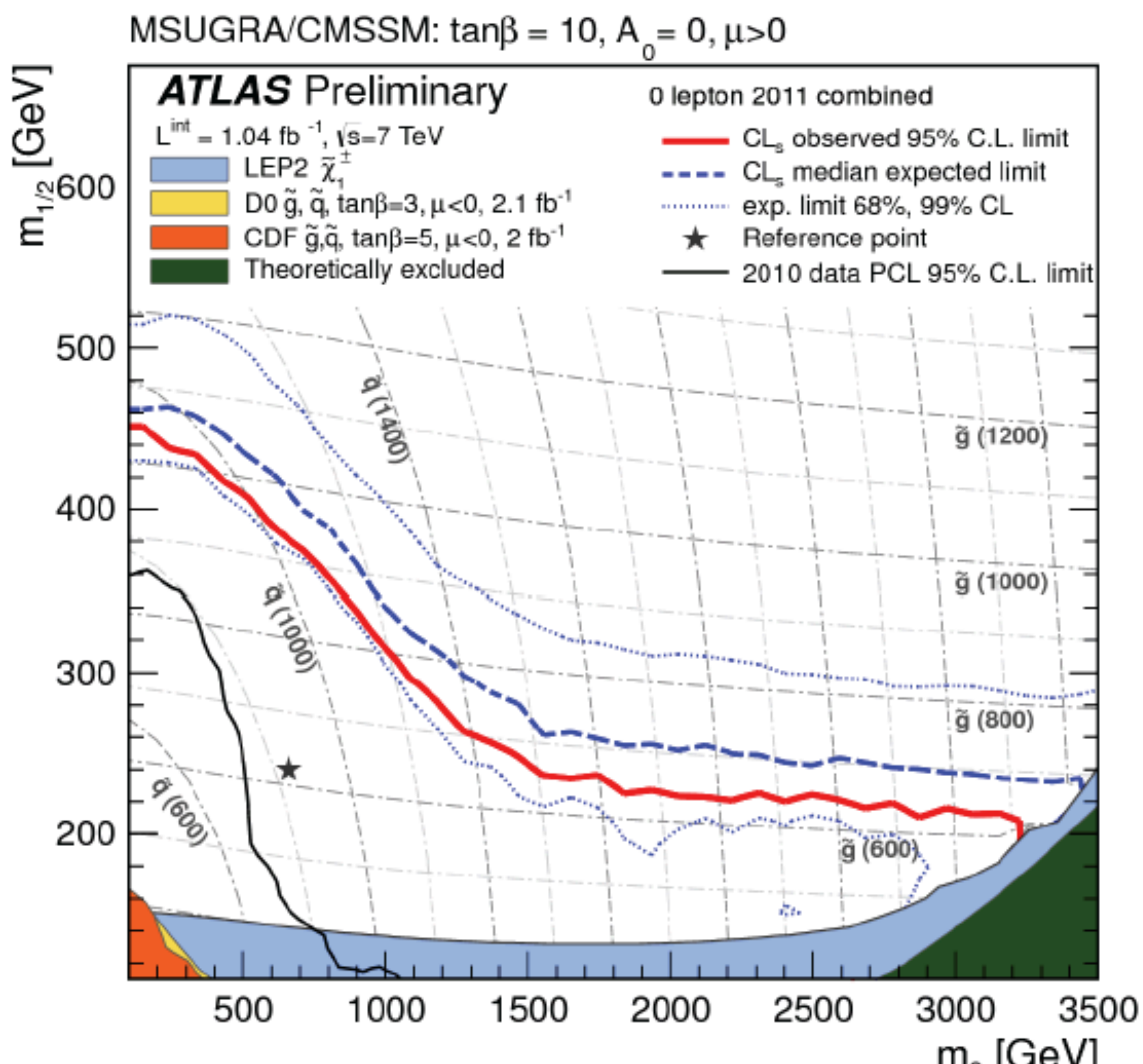
[Taffard,EPS 2011]



These are 'fairly' model-independent results!!

STATUS SUMMER 2011

MSUGRA/CMSSM A_0=0, tanβ=10, μ>0



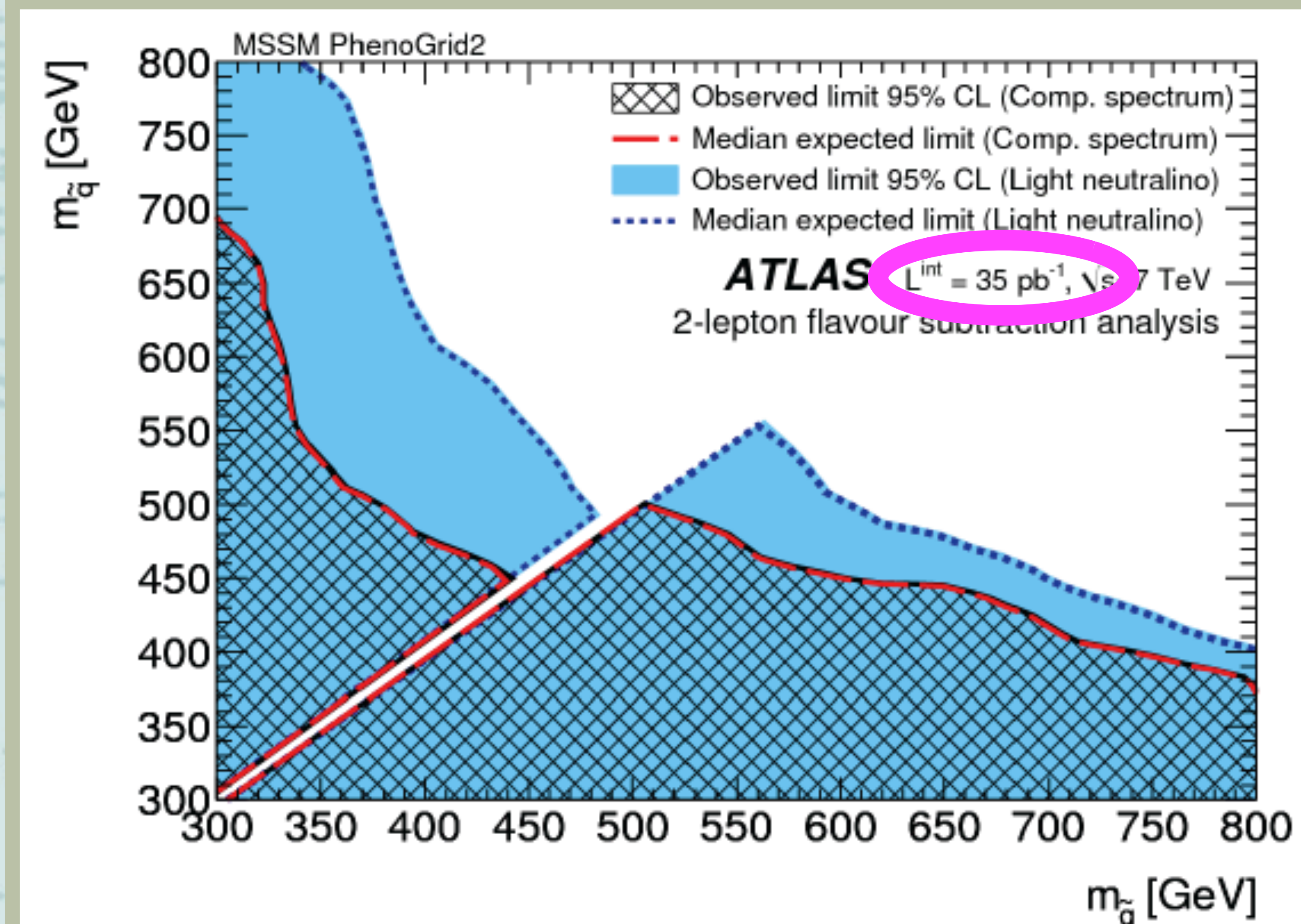
[Taffard,EPS 2011]

This is also 'fairly' model-independent !!

(when correctly interpreted)

STATUS SUMMER 2011

- Dilepton channel (OSSF-OSDF).



Event selection:

- Exactly 2 leptons, $p_l^T > 20$ GeV
  - Opposite-sign (OS)/Same-sign (SS)
- E_T^{miss}>100(150) GeV for SS(OS)

+ jets!

Compress Spectrum (CS)

$m_{\tilde{\chi}_2^0} = M - 50$ GeV; $m_{\tilde{\chi}_1^0} = M - 150$ GeV; $m_{\tilde{l}_L} = M - 100$ GeV

✓ With M=min(m_g,m_q)→soft final state kinematics

Light neutrino (LN)

$m_{\tilde{\chi}_2^0} = M - 100$ GeV; $m_{\tilde{\chi}_1^0} = 100$ GeV; $m_{\tilde{l}_L} = M/2$ GeV

✓ →harder kinematics

For larger statistics interpretation within direct electroweakino production feasible.
-> omit any jet cuts.

[Taffard,EPS 2011]

Much weaker limits!
(not just due to less statistics)

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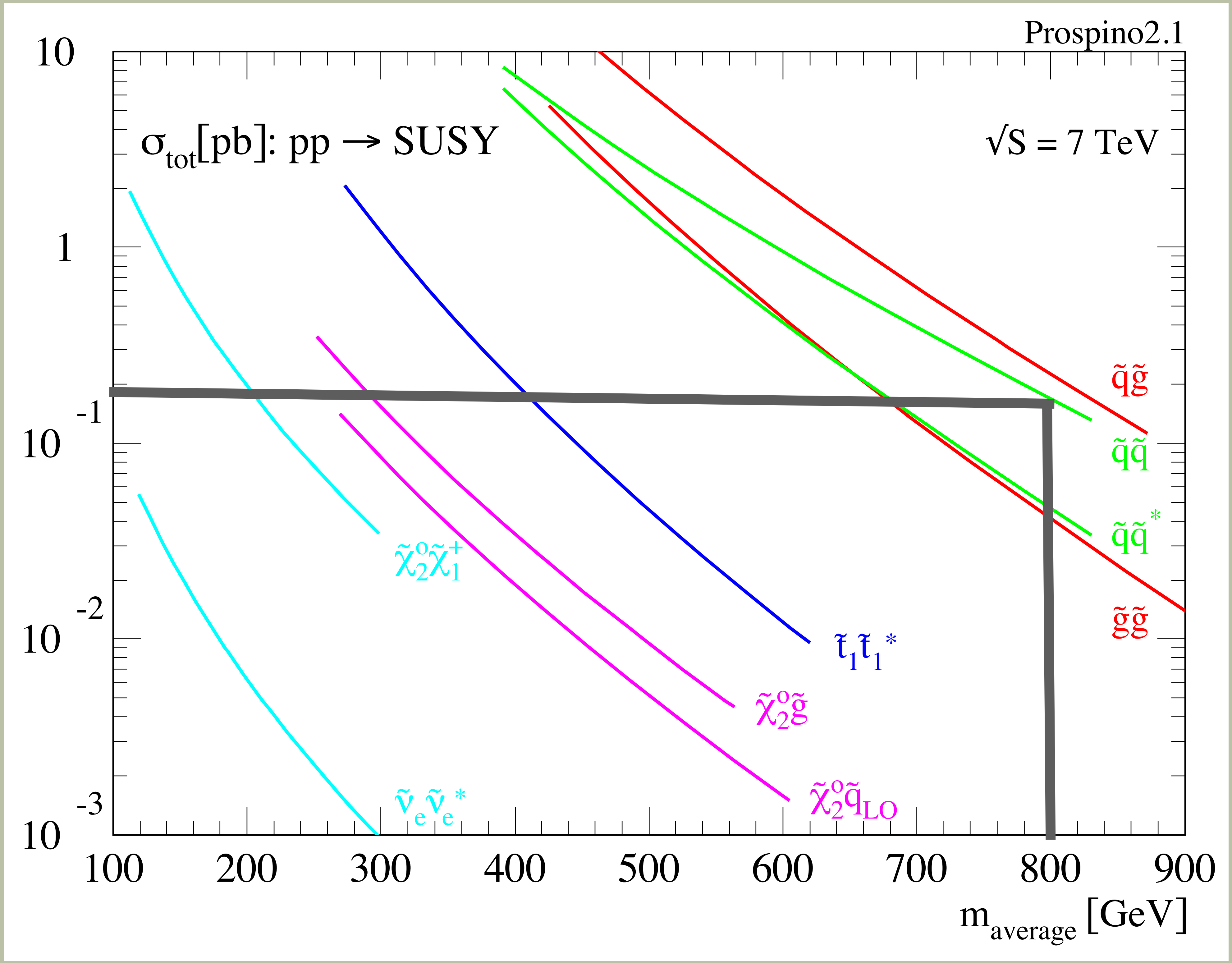
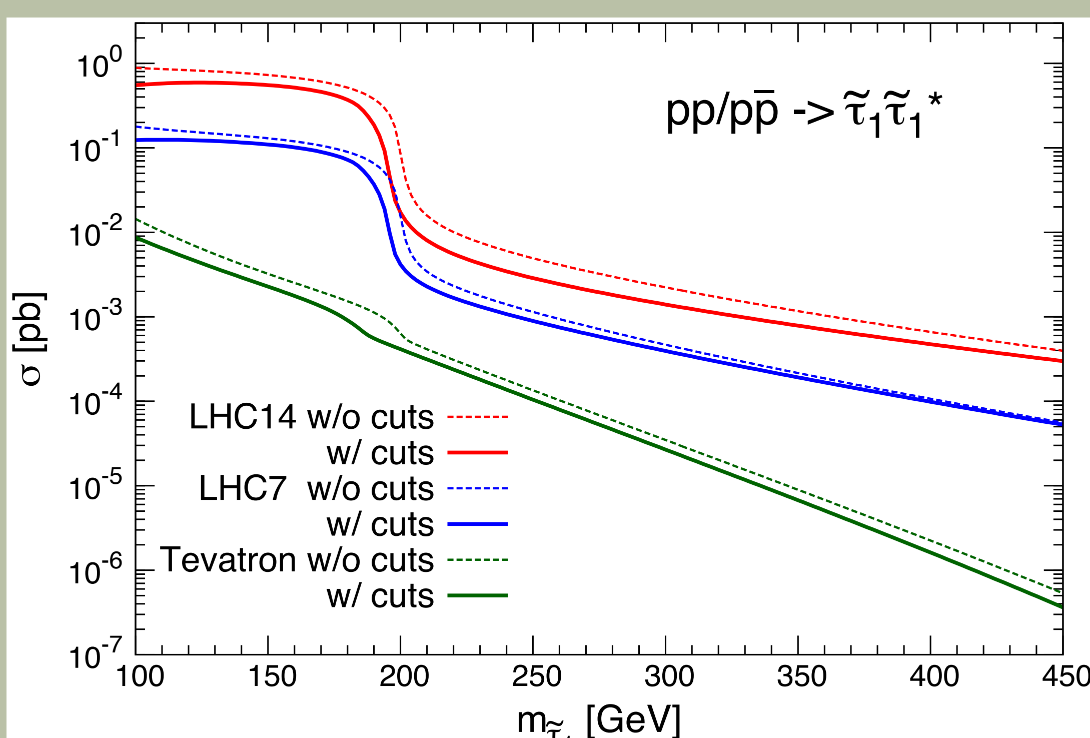


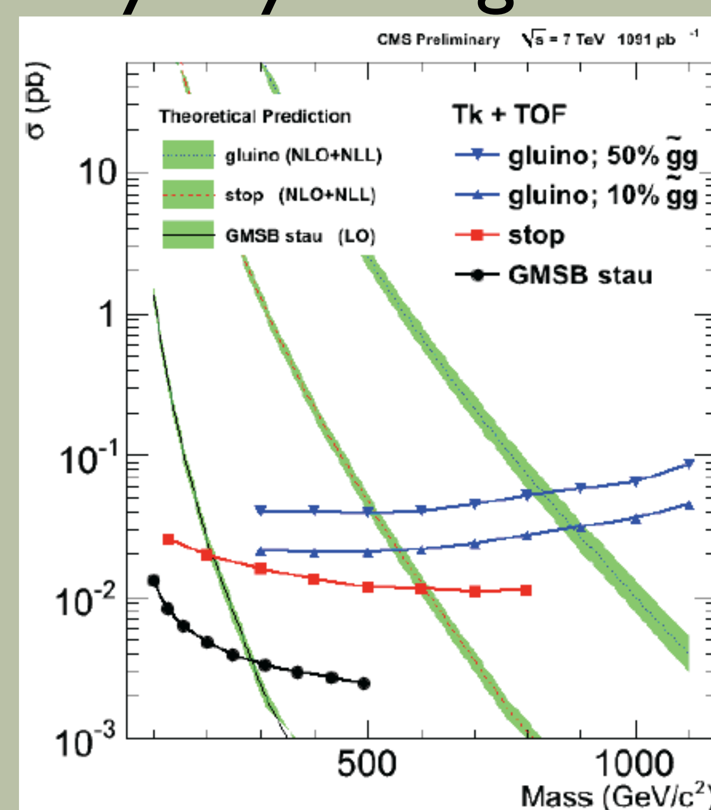
Not just light squark and gluinos are being produced at the LHC!

STATUS SUMMER 2011

- Searches with missing ET assume neutralino DM.
- But MSSM also offers other well motivated LOSPs, e.g. the lighter stau $\tilde{\tau}_1$.
  (Now gravitino and/or axino are assumed to be dark matter)
- Signature: Charged Massive Particles (CHAMP), i.e. slow but high p^T. Clear signature, hardly any backgrounds.



[JL, Steffen, Trenkel; 2011]



95% C.L. mass limits

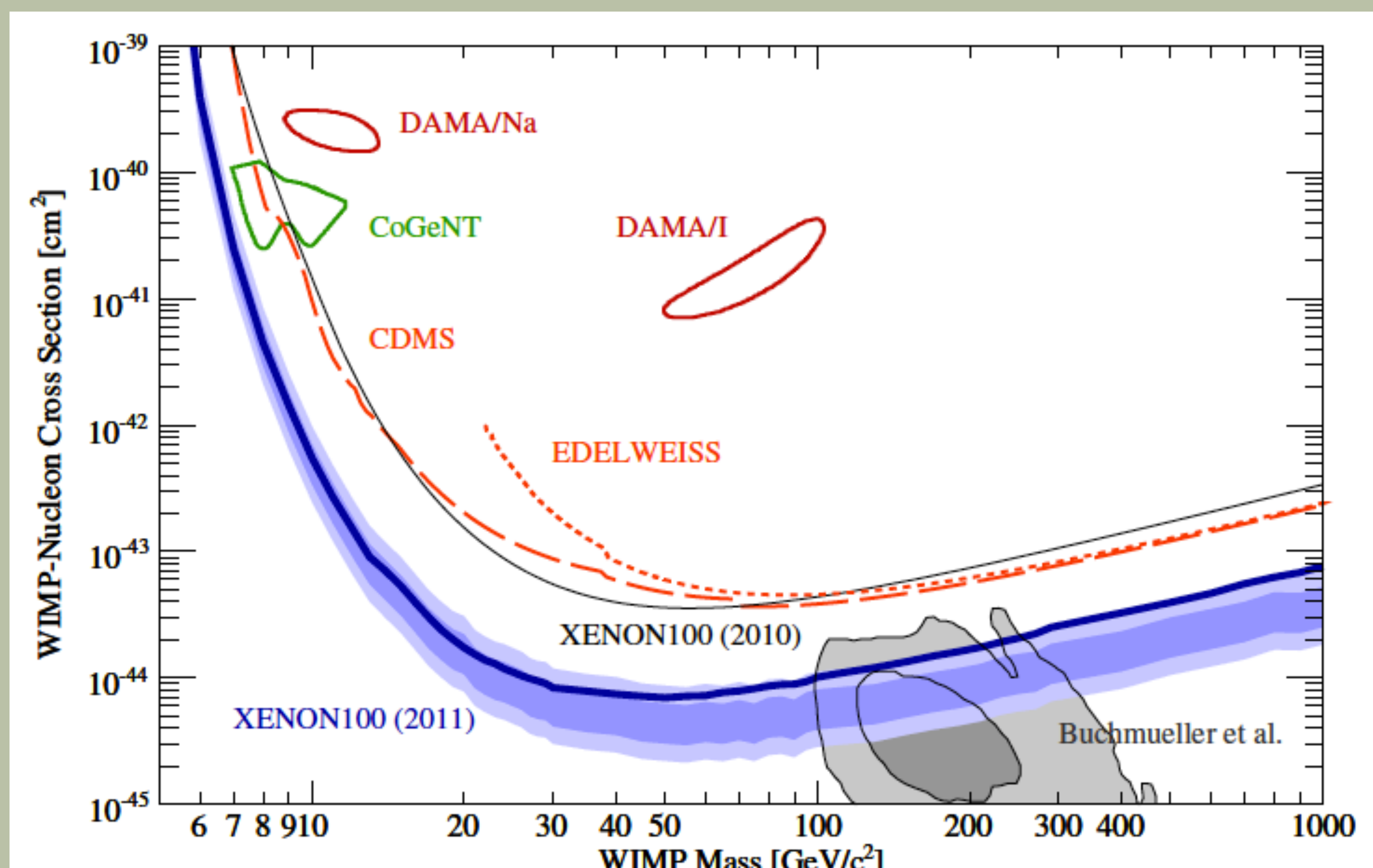
GMSB Stau:293 GeV

Stop: 620 GeV

[Chen, EPS 2011]

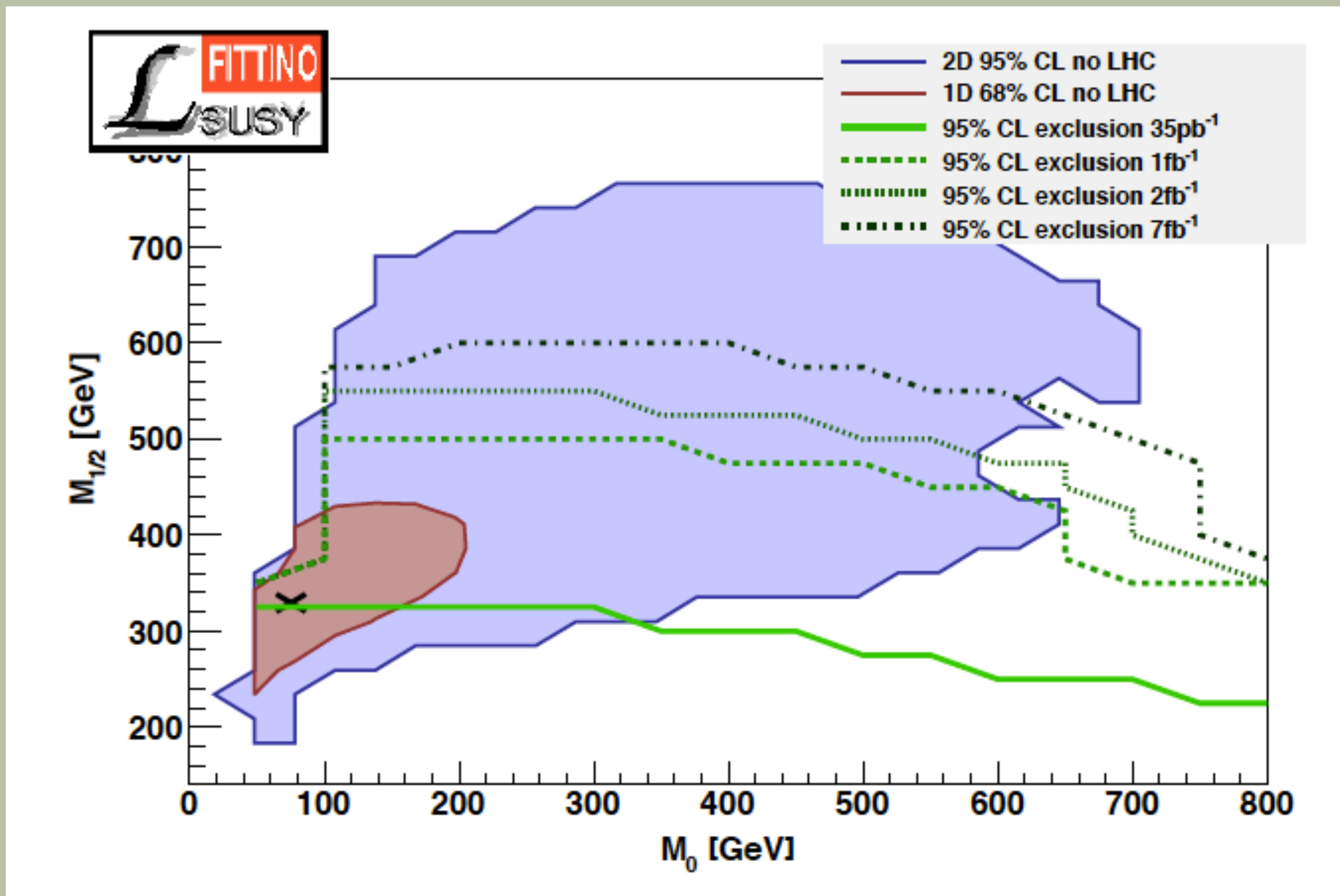
STATUS SUMMER 2011

- Not only the LHC directly challenges the SUSY parameter space.
- Strong new limits also from direct DM searches, e.g., XENON100.



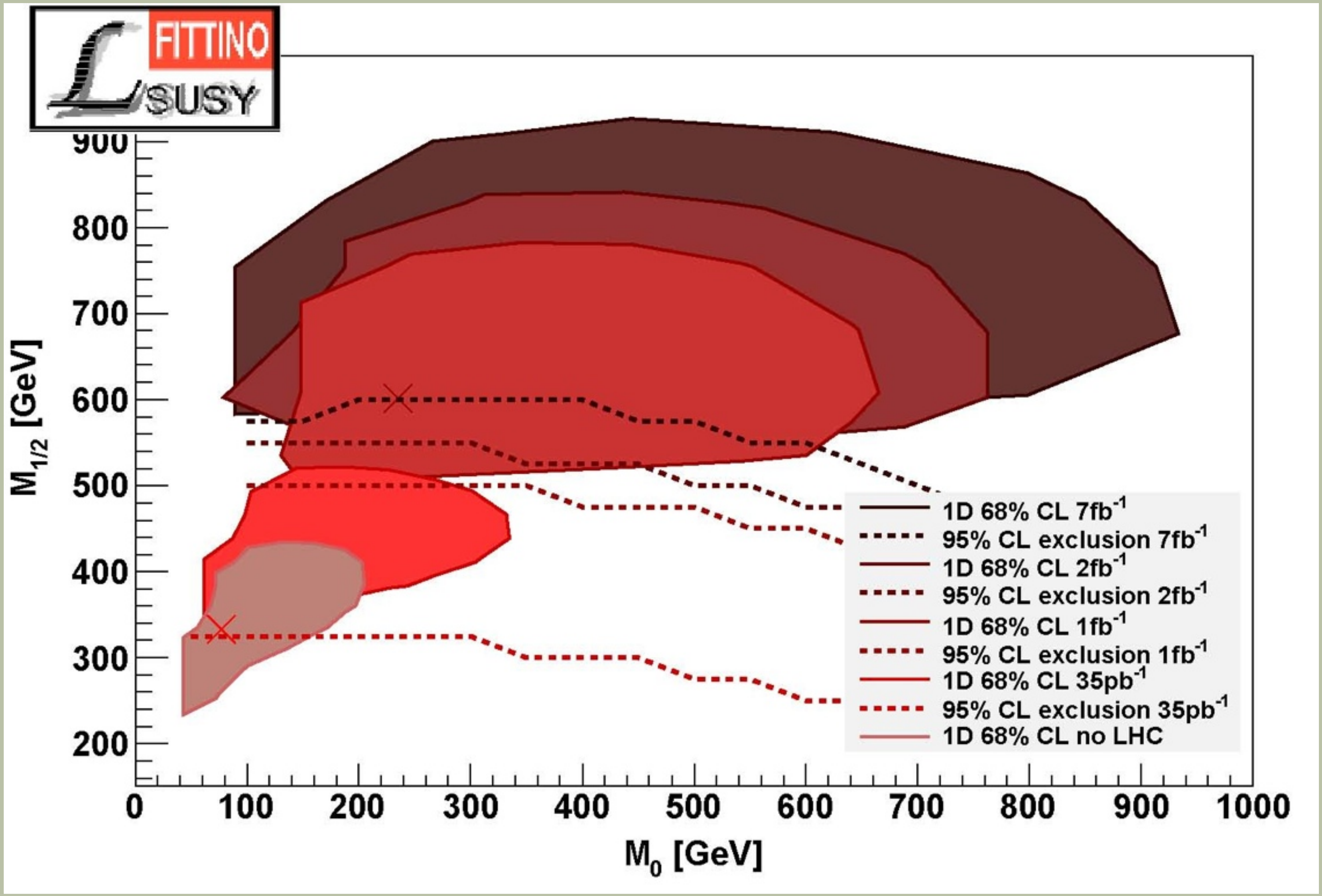
[Buchmüller et. a., 2011]

FORECAST



[Bechle et. al., 2011]

FORECAST

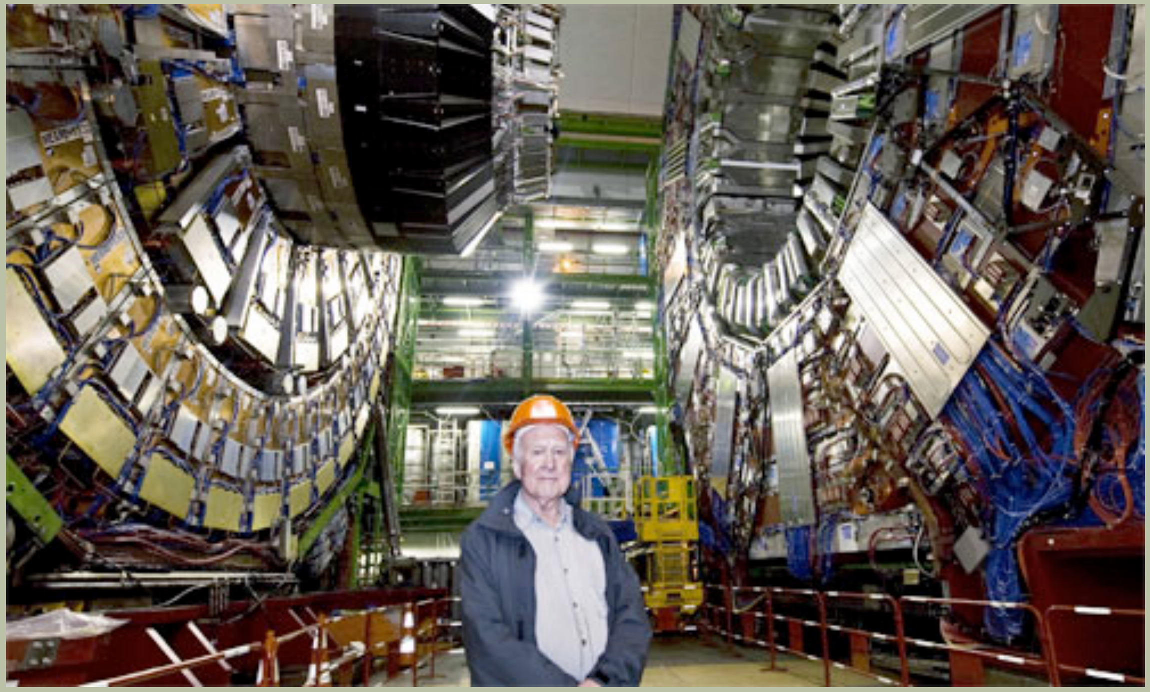


$\tan\beta \uparrow$

[Bechle et. al., 2011]

FORECAST

- Tension is building up in the global fits of constrained models (larger χ^2/ndf for best fit points).
- However, also the CMSSM will survive this and probably also the next year!
- Less constrained models still feasible for years of LHC exclusions.
- Only crucial measurement (as it has always been): $m_h \lesssim 140 \text{ GeV}$ for the MSSM and $m_h \lesssim 200 \text{ GeV}$ for extended Models (beyond NMSSM).



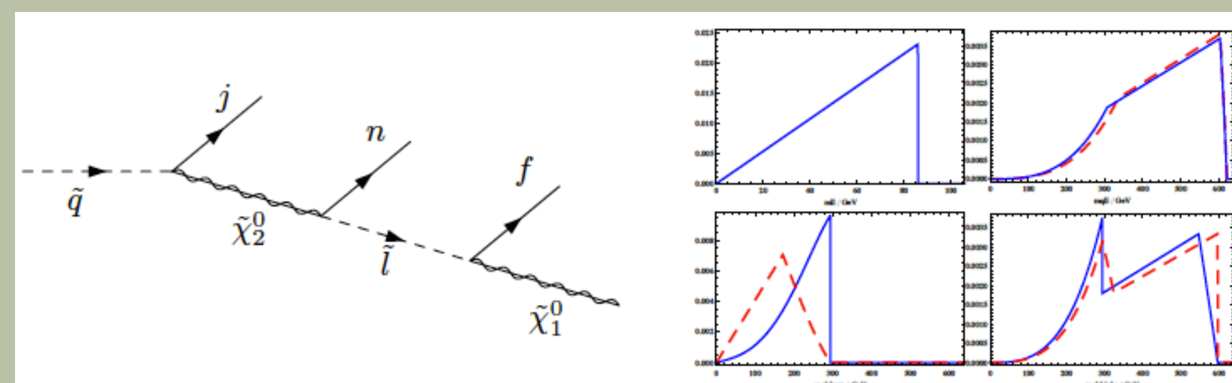
FORECAST

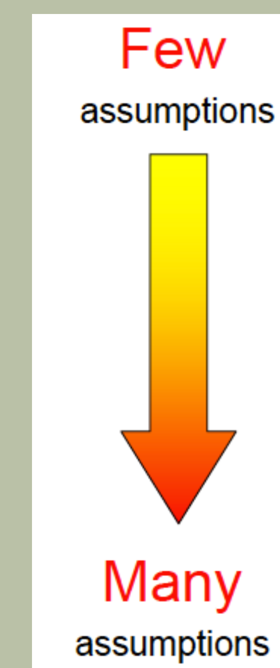
- possible ideas where SUSY is hiding:
  - "just around the corner" ;-)
  - **non-universal gaugino masses** -> heavy colored spectrum still in agreement with $(g-2)|_\mu$.
  - non-universal scalar masses -> (flavor) **split SUSY** with light third generation squarks and a not too heavy gluino *(light $\tilde{t}_1$ necessary to solve hierarchy problem; possible flavor issues)* .
  - **degenerate spectra**, i.e., small mass splittings: large x-section but low acceptance *(low scale SUSY breaking required)*.

- such loopholes have to be explored with more statistics!

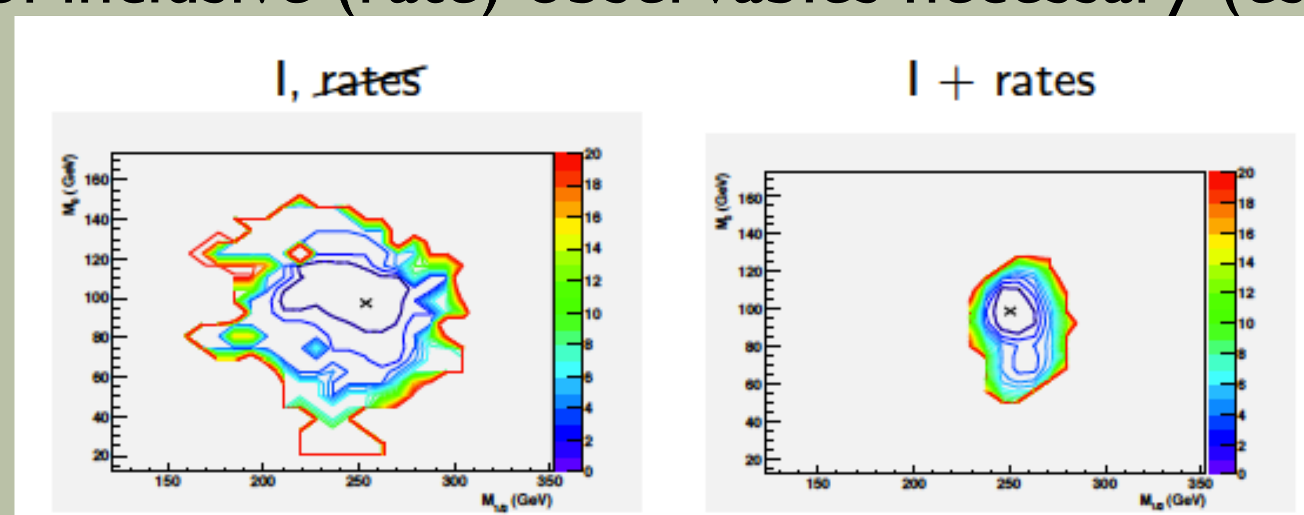
FORECAST

- Once SUSY is discovered (next year? after the upgrade to 14TeV?) parameters of the underlying model have to determined.
- Observables: Invariant mass distribution endpoints + other kinematical observables.





- Depend on the hierarchy (shapes might help to solve ambiguities)
- Additional use of inclusive (rate) observables necessary (especially with early data)



[Dreiner,JL, et. al., 2010]

- Precision calculation of SUSY cross sections, decay rates, distributions necessary!

CONCLUSIONS

- Available (C)MSSM parameter space started to shrink drastically.
- Not finding SUSY early does not make SUSY / the MSSM bad, just make the (constrained) models look bad!
- Possible loopholes have to be explored with more statistics.
- After discovery work just begins.
- Thrilling times ahead. ;-)

THANK YOU!

BACKUP

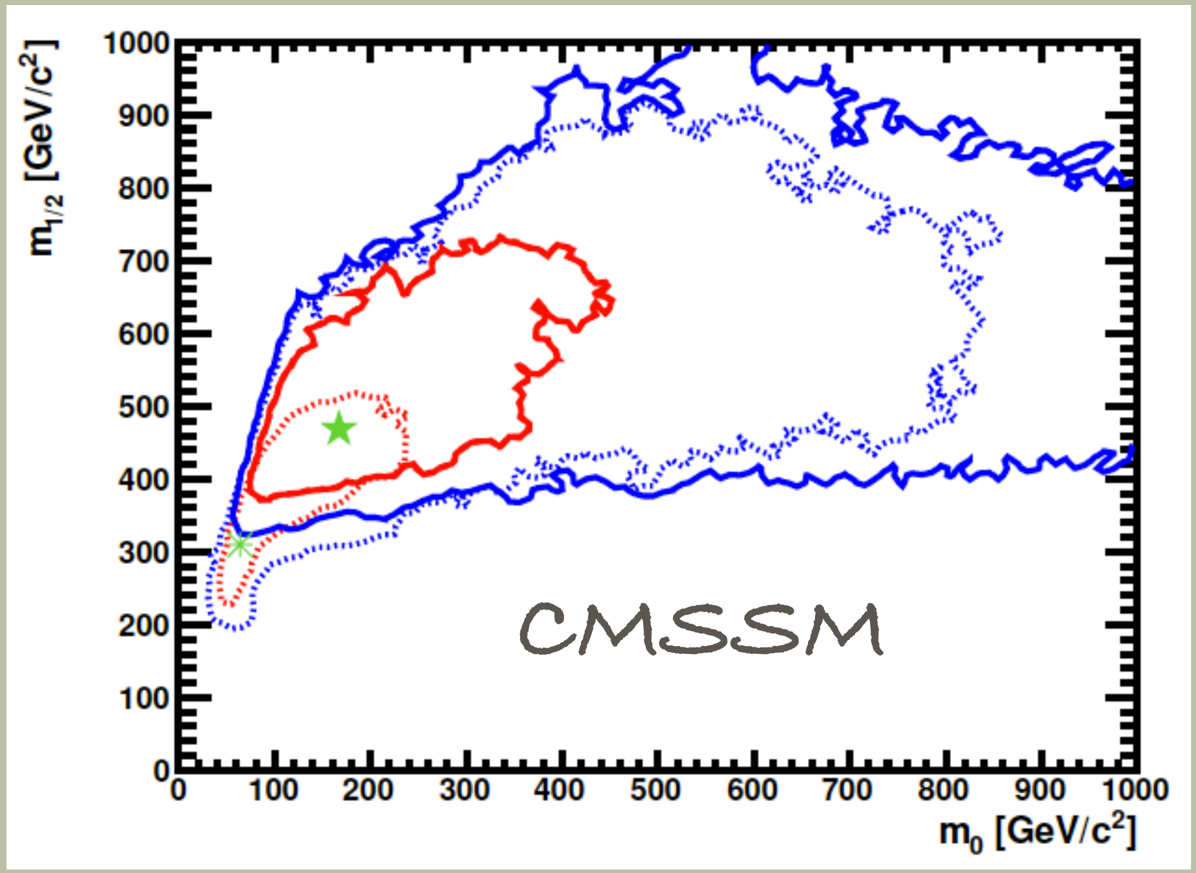
STATUS SUMMER 2011

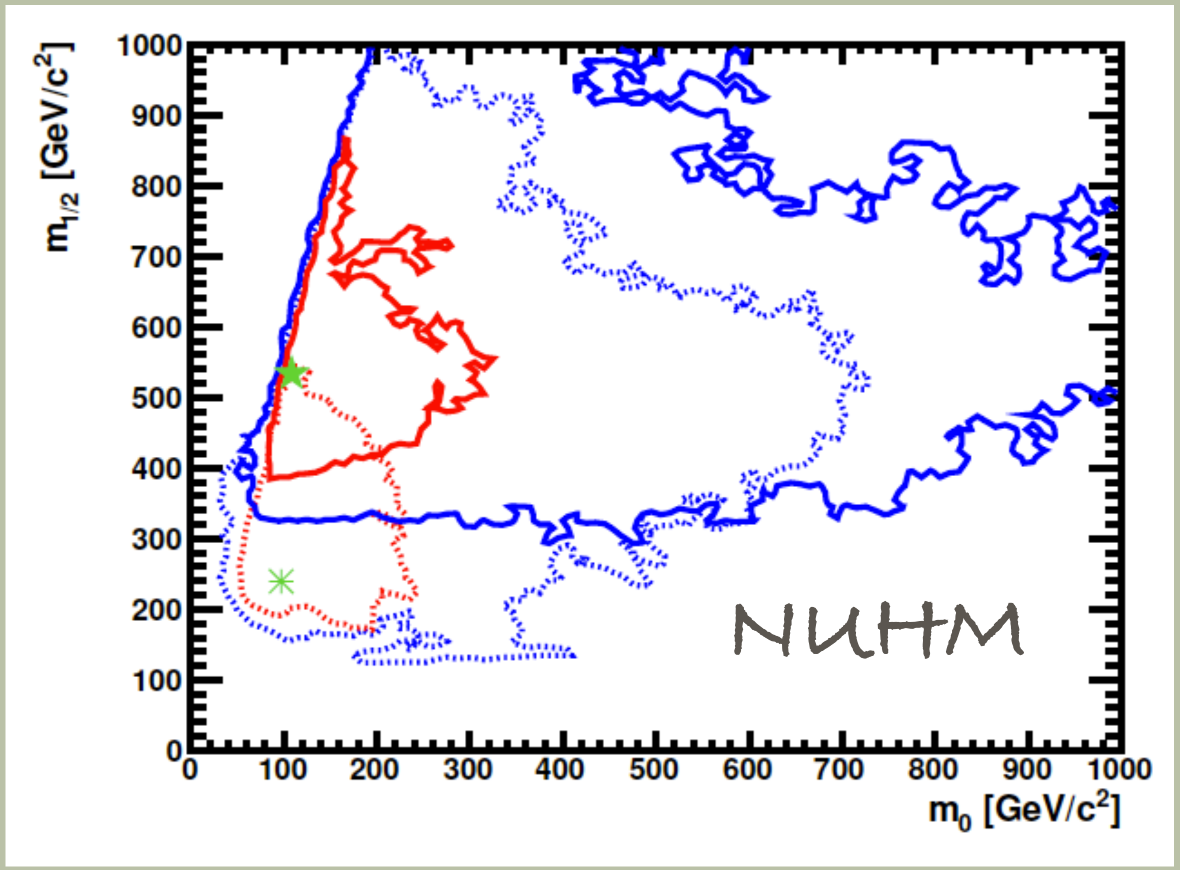
Benchmark scenarios with few parameters ⟷ Simplified Models

- always a trade-off
- less important as long as only exclusions are produced
- more important when interpreting these exlusions

STATUS SUMMER 2011

- CMSSM global fit 2010 vs 2011 (XENON100 + LHC 36pb $^{-1}$)





Model	Min χ^2	Prob	$m_{1/2}$	m_0	A_0	tan (β)	$M_h^{\rm no\ LEP}$
CMSSM	22.5/19	26%	310	60	-60	10	109
post-LHC/Xenon	26.2/20	16%	470	170	-780	22	116
NUHM1	20.5/17	25%	240	100	920	7	119
post-LHC/Xenon	24.2/19	19%	530	110	-370	27	118

[Buchmüller et. a., 2011]