Implications of Initial LHC Searches for Supersymmetry

Matthew Dolan

IPPP
University of Durham

arXiv:1011.6118, 1102.4585, forthcoming

The MasterCode Collaboration

Theorists

M. Dolan, J. Ellis, S. Heinemeyer, G. Isidori, K. Olive, G. Weiglein

Experimentalists (CMS)

O. Buchmüller, R. Cavanaugh, D. Colling, A. de Roeck, H. Flächer, S. Rogerson, F. Ronga

Global Fits

Confronting a Model with Data

- Combine measurements
- Compare with predictions
- Constrain parameters
- Exclude model?

Key ingredients

- Consistent measurements (and errors)
- State-of-the-art predictions (and errors)

Global Fits

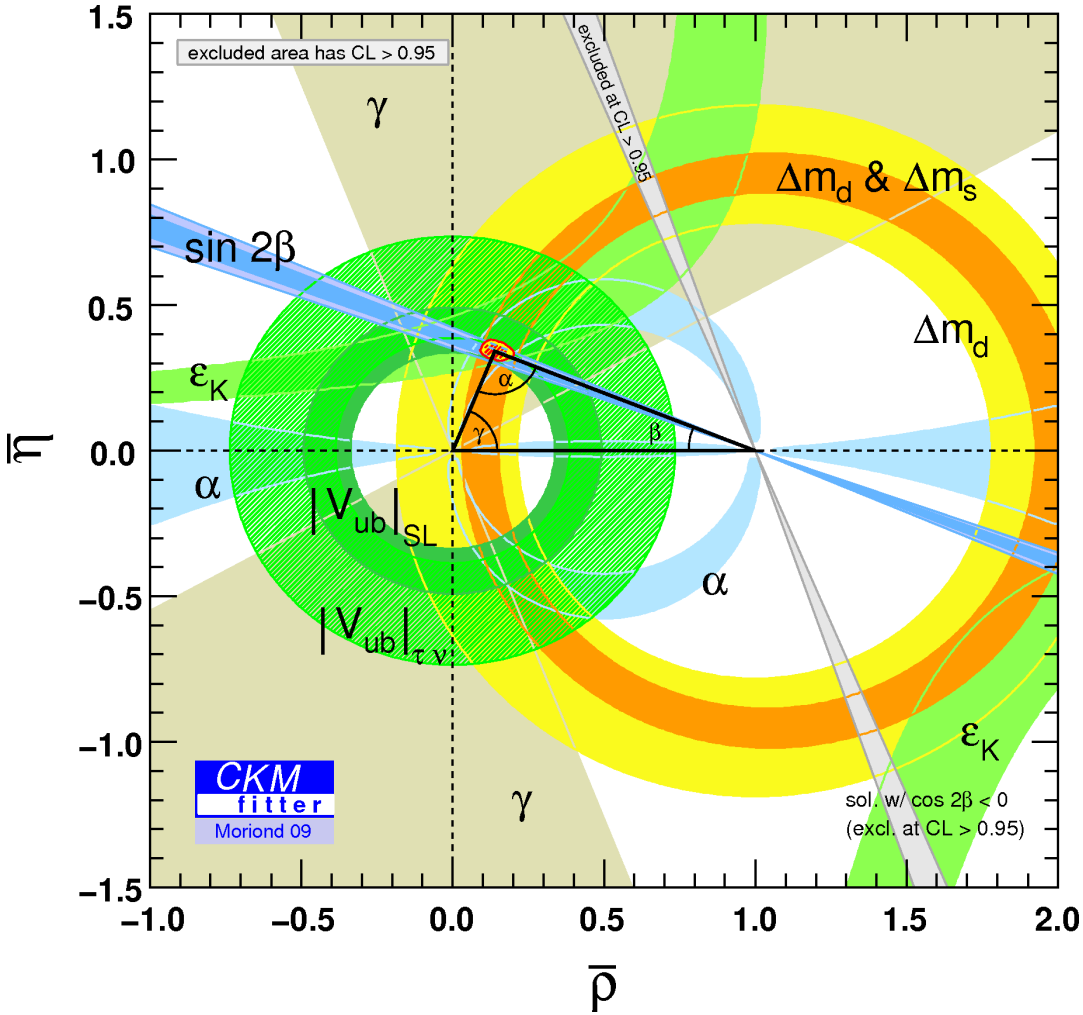
Confronting a Model with Data

- Combine measurements
- Compare with predictions
- Constrain parameters
- Exclude model?

Key ingredients

- Consistent measurements (and errors)
- State-of-the-art predictions (and errors)

A famous example of a global fit



The MSSM

- Take the field content of the SM and promote all fields to superfields. Adds superpartners differing by $s = 1/2$.
- SUSY partners should have masses $\sim$ 0.1–1 TeV.

The Higgs Sector

- Superpartner of Higgs boson is a fermion $\implies$ anomalies don't cancel anymore.
- Solution: Add extra Higgs doublet.
- Physical states: $h^0, H^0, A, H^\pm$ and Goldstone bosons: $G^0, G^\pm$
- $\tan\beta = v_2/v_1$

Why SUSY?

The Standard Model is in good shape, but SUSY offers:

Stability of the Higgs mass against higher order corrections.

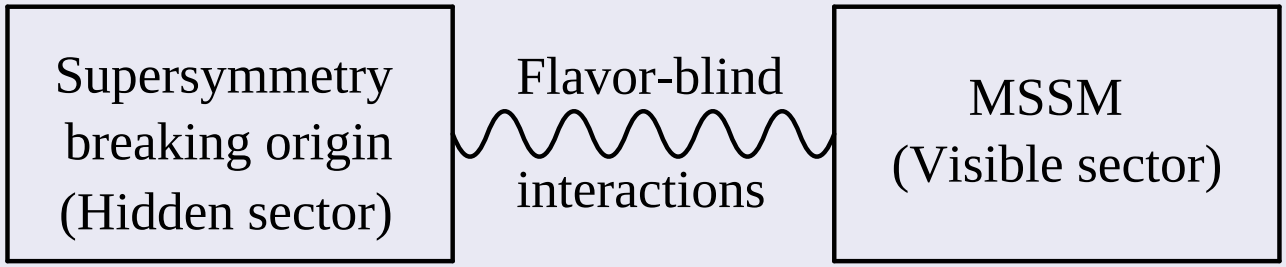
Unification of gauge couplings in the MSSM, but not in SM.

Spontaneous symmetry breaking via Higgs mechanism is automatic in SUSY GUTs (radiative EWSB).

Cold dark matter candidate: the neutralino.

SUSY Breaking

- Spontaneous breaking: Sum rule implies spartners too light.
- Mediation: SUSY broken in hidden sector, communicated via messenger sector to visible sector.



Gravity Mediation

SUSY breaking via non-renormalisable terms in supergravity Lagrangian.

The Models

CMSSM: 4 parameters

- m_0: Universal scalar mass
- $m_{1/2}$: Universal gaugino mass
- A_0: Universal trilinear coupling
- $\tan\beta$: Ratio of Higgs vevs.

NUHM1: 5 parameters

As in CMSSM, but Higgs masses become an independent parameter $\Longrightarrow$ equivalent to M_A free parameter at EW scale.

The Models

VCMSSM: 3 parameters

- As in CMSSM, with auxiliary condition from SUGRA: $A_0 = B_0 + m_0$.
- $A_0 = B_0 + m_0 \implies \tan\beta$ is a prediction at the weak scale.

mSUGRA: 3(ish) parameters

- $A_0 = B_0 + m_0$ and $m_{3/2} = m_0$, a prediction from supergravity.
- In this scenario $\tilde{G}$ DM is ruled out by considering long-lived χ_1^0 decays $\implies m_0 > m_{\chi_1^0}$.

Constraints on SUSY

Low Energy Precision Data

Flavour physics (in particular B-physics): $BR(B \to X_s\gamma)$, $B \to \tau\nu$, $B_s \to \mu^+\mu^-$. Also $(g-2)_\mu$

High Energy Precision Data

Precision electroweak observables: M_W

Cosmology/Astrophysics

Relic density: $\Omega_{DM}h^2 = 0.1109 \pm 0.0056$ (WMAP7)
DM direct detection: CDMS, XENON...

Fit Methods

Statistical Measure

$$\chi^2_{tot} = \sum_{obs} \chi^2_i = \sum_{obs} \frac{\left(C_i^2 - P_i^2\right)}{\sigma_i^2}$$

- For derived quantities σ_i incorporates both experimental and theoretical errors.
- Frequentist fit, no priors.

Fit Method

- Use Markov Chain Monte Carlo for sampling, with χ^2 minimisation using `Minuit` as an 'afterburner'.
- Sample $\sim$ 25 million points for CMSSM/NUHM

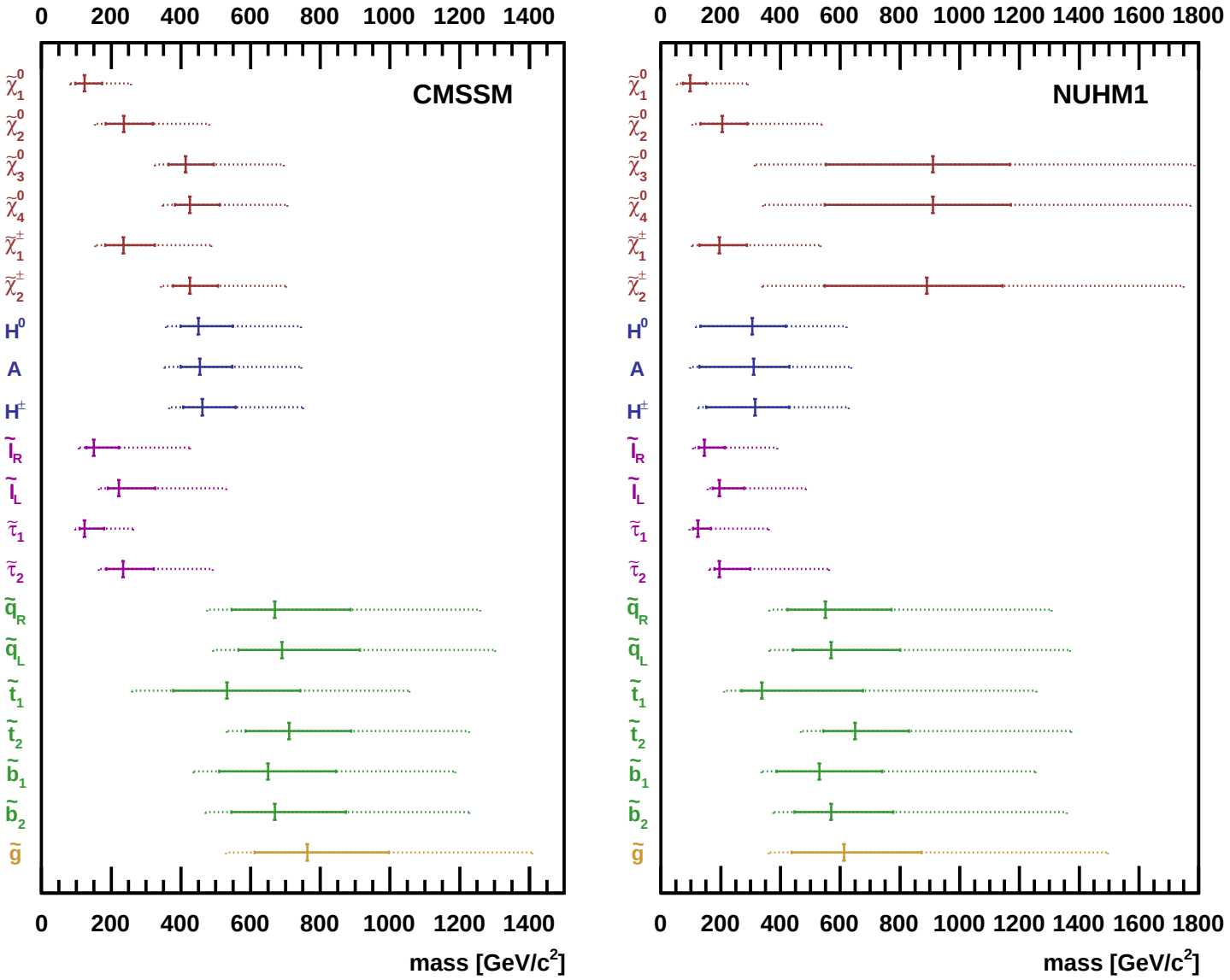
Best-fit Points (before LHC data)

Model	Min χ^2	Prob	$m_{1/2}$	m_0	A_0	$\tan\beta$
mSUGRA	29.4	6.0%	550	230	430	28
VCMSSM	22.5	31%	300	60	30	9
CMSSM	21.3	32%	320	60	-160	11
NUHM1	19.3	31%	260	100	1010	8

Comments

- (V)CMSSM/NUHM: Preference for light SUSY, small $\tan\beta$, with $\tilde{\tau}$ co-annihilation.
- mSUGRA: somewhat disfavoured.

CMSSM/NUHM Spectra

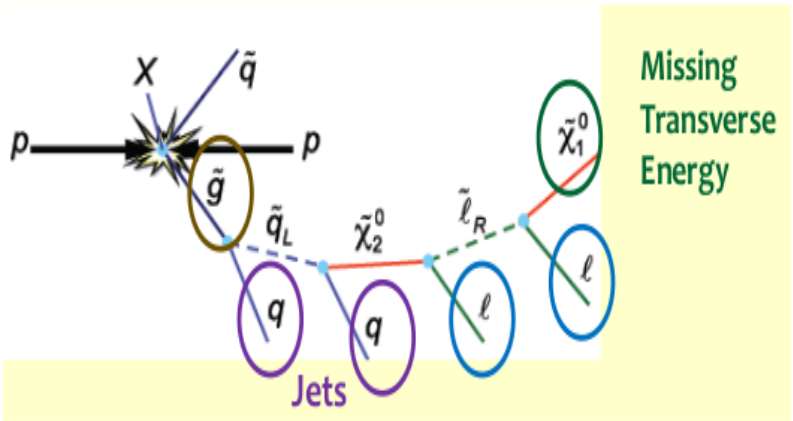


Desperately Seeking SUSY

SUSY events often involve

Missing energy $\not{E}_T$ and one or more of the following:

- Jet production
- Leptons



The CMS α_T search[1]

Details

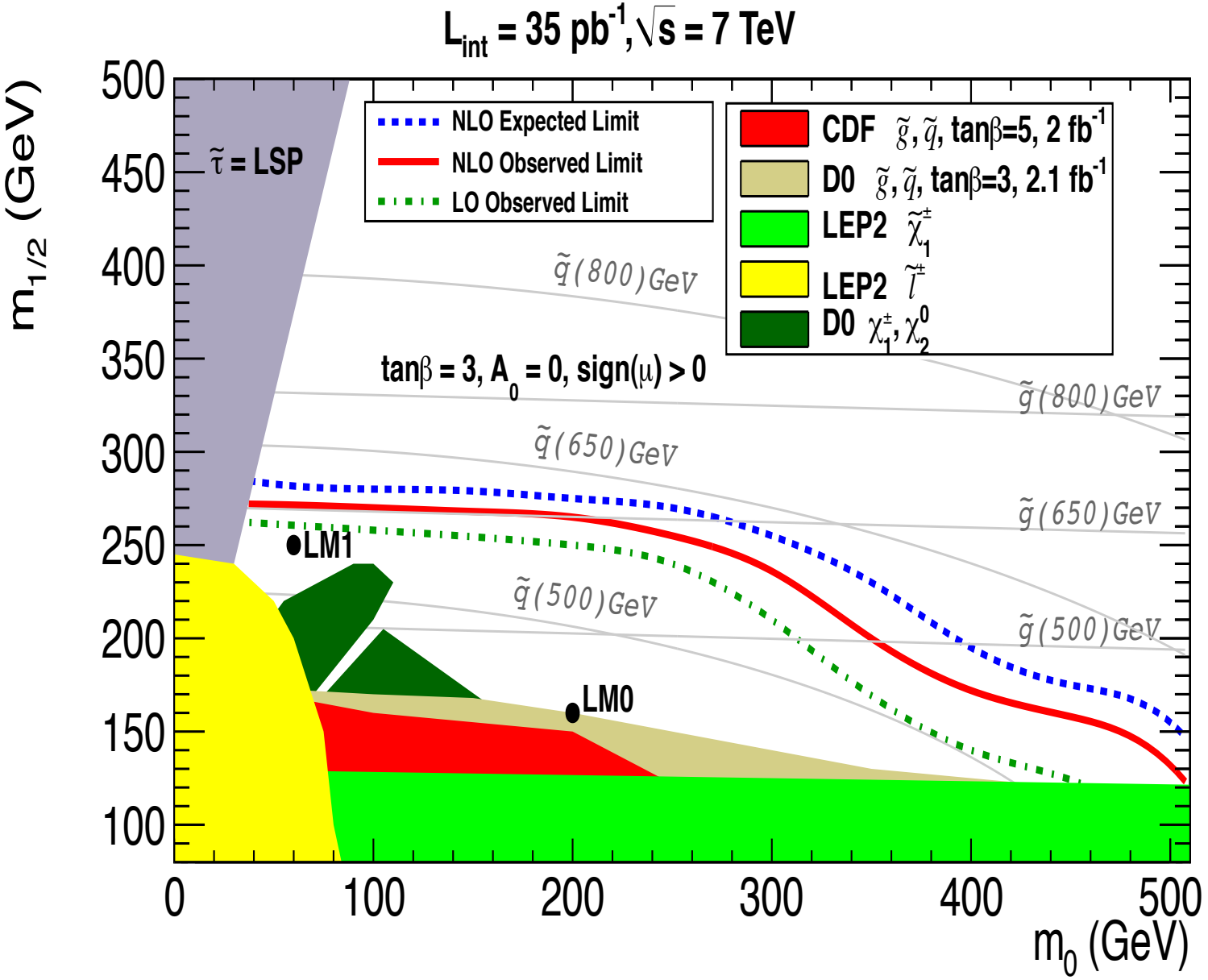
- Searched for multijet + $\not{E}_T$ without leptons
- Saw 13 events with 10.5 expected from SM background, compatible with probability 30%.
- Set a 95% upper CL of 13.4 events.

Note

CMS present results for the CMSSM for $\tan\beta = 3$, $A_0 = 0$. The sensitivity of a jets + $\not{E}_T$ search is largely independent of these parameters.

[1] 1101.1628

CMSSM with $\tan\beta = 3, A_0 = 0.$



Modelling the CMS Likelihood

- 13.4 events is 95% C.L. $= 1.96\sigma \implies \Delta\chi^2 = 5.99$ along observed exclusion line.
- This corresponds to $2.5 \pm (13.4 - 2.5)/1.96 = 2.5 \pm 5.56$ events for any possible signal.
- The expected exclusion line corresponds to 10.9 events, an apparent significance of $(10.9 - 2.5)/5.56 = 1.4\sigma, \implies \Delta\chi^2 = 4$ along expected exclusion line.

Modelling the CMS likelihood

- Approximate the CMS likelihood by

$$\Delta\chi^2_{CMS} = \chi^2_{\infty,CMS}\,|(M_C/M) - 1|^{-p_C}$$

- $\chi^2_{\infty,CMS} = 0.85$ is the χ^2 at very high sparticle masses corresponding to no (SUSY) signal.
- M= $\sqrt{m_0^2 + m_{1/2}^2}$ and M_C, p_C are fitted to the CMS expected/observed C.L. contours.
- Validated using $LM1$ point, corresponding to 19.2 events.

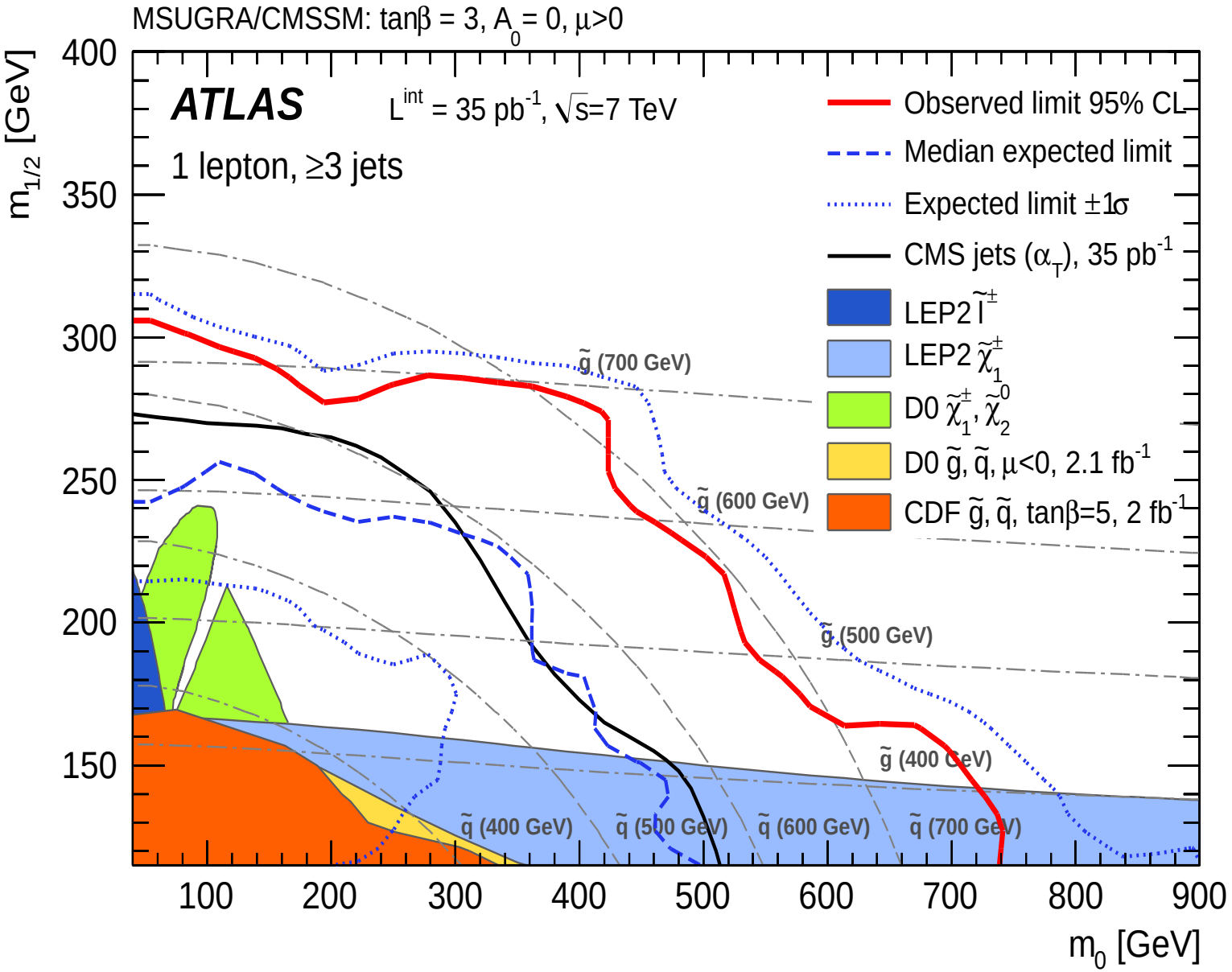
The ATLAS 1l Search[3]

- ATLAS searched for jets $+\not{E}_T$ with accompanying e or μ.
- Still have approximate $\tan\beta$, A_0 independence.
- 2 events seen compared with 4.1 expected, 4.8 events 95% C.L.
- Use effective mass[2] $\mathcal{M} \propto \mathcal{L}^{1/4}$
- Implies event rate $\mathcal{L} \propto \mathcal{M}^4$
- $\Delta\chi^2 = \chi^2_{\infty,ATLAS} + |M/M_A|^{-p_A}$

[2] ATL-PHYS-PUB-2011-003, ATL-PHYS-PUB-2010-010

[3] 1102.2357

CMSSM w/ $\tan\beta = 3, A_0 = 0$



Comments

- There will be non-trivial correlations between the searches, and we leave a combined limit to the experiments.
- We consider the ATLAS/CMS searches individually and form

$$\chi^2_{total} = \chi^2_{indirect} + \chi^2_{CMS/ATLAS}$$

Key to Plots

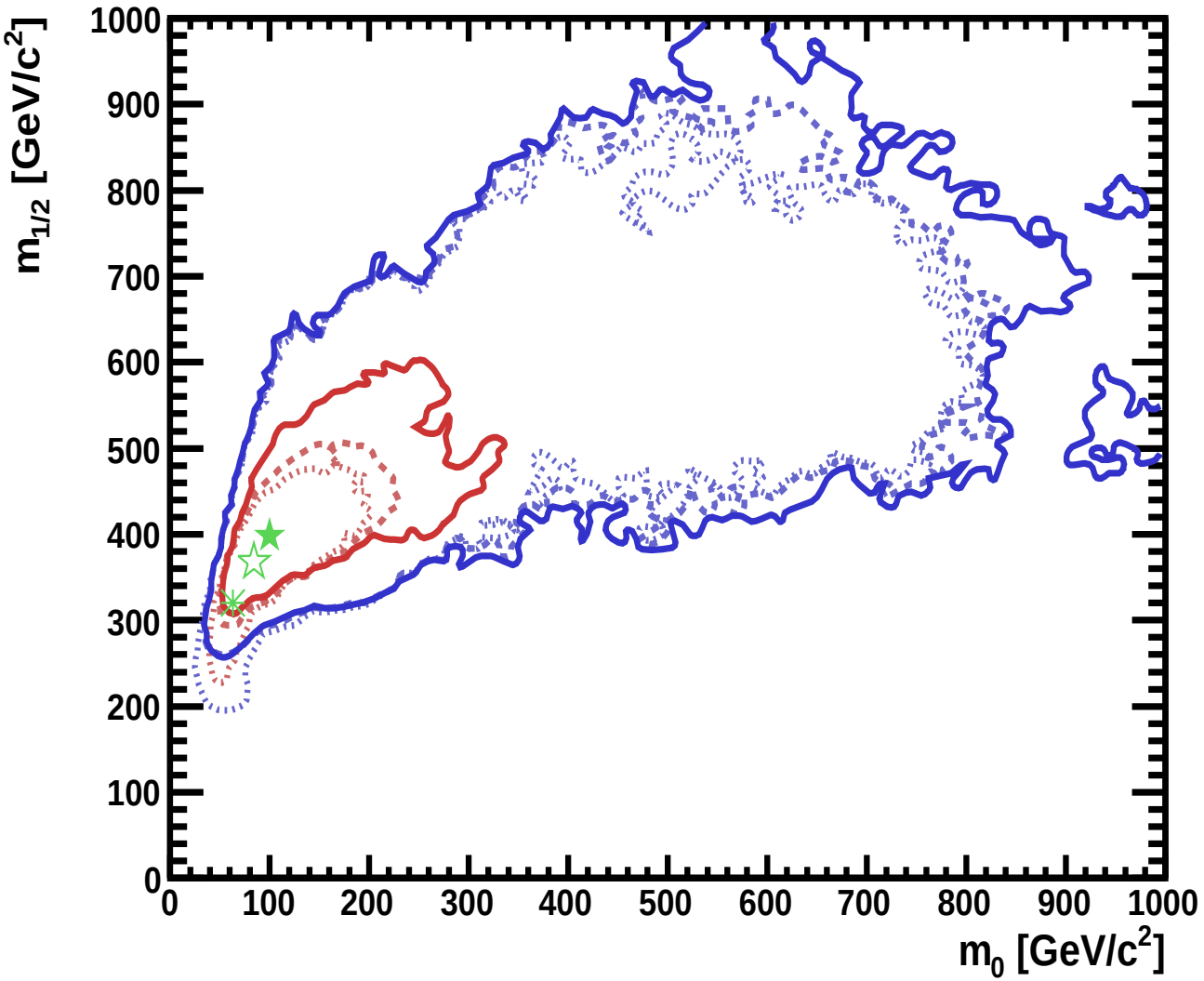
Best-fit points

- Pre-LHC: snowflake
- CMS: open star
- ATLAS: filled star

1σ and 2σ contours

- Pre-LHC: dotted
- CMS: dashed
- ATLAS: solid

CMSSM m_0–$m_{1/2}$



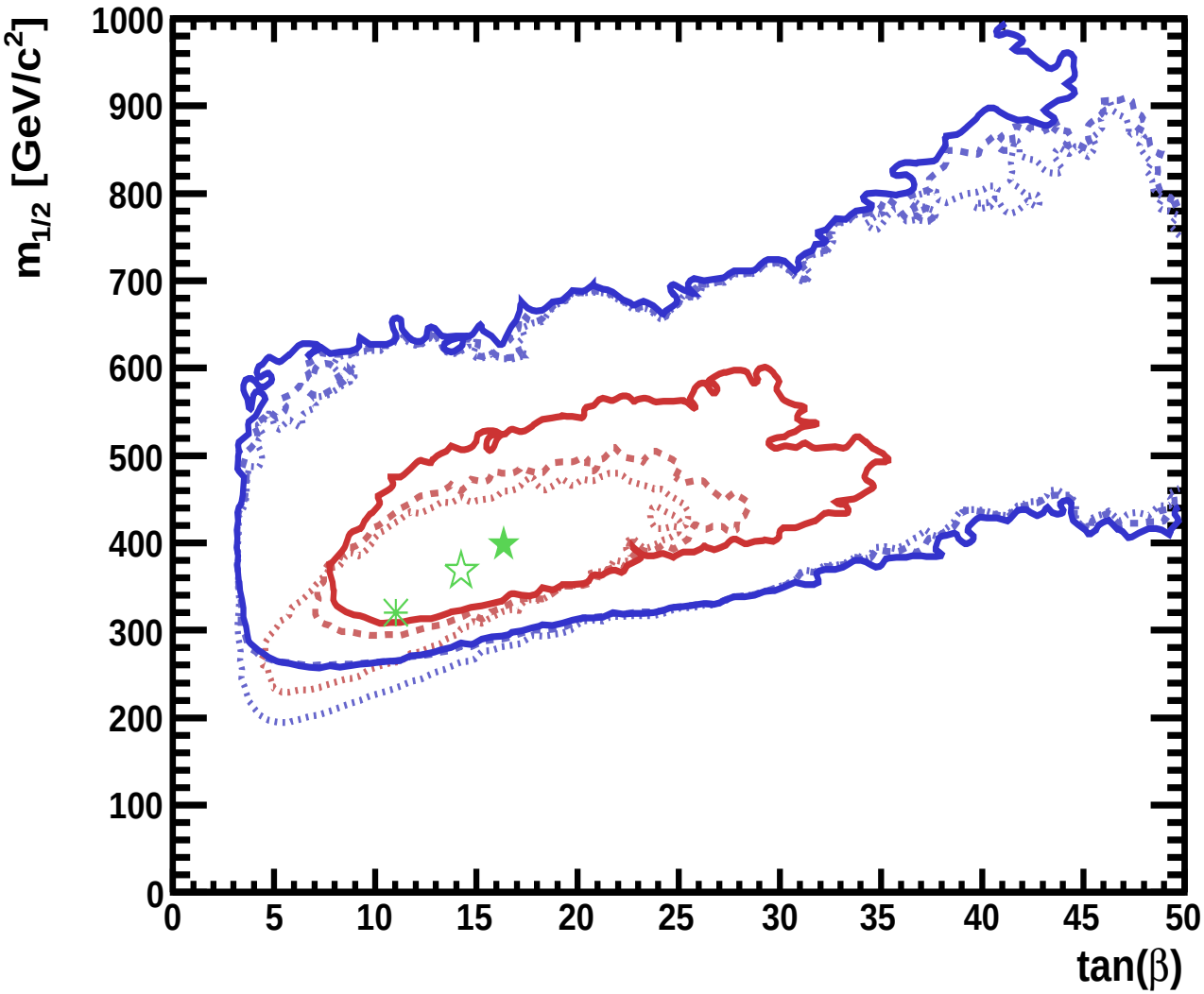
Best-fit points: CMSSM

Model	Minχ^2	Prob	$m_{1/2}$	m_0	A_0	tan β
CMSSM	21.3	32%	320	60	-170	11
w CMS	22.0	29%	370	80	-340	14
w ATLAS	24.9	16%	400	100	-430	16

Comments

- $\Delta\chi^2_{min} = 3.6$ for ATLAS search.
- $m_{1/2}$ value increases by 80 GeV
- m_0 increases by 40 GeV

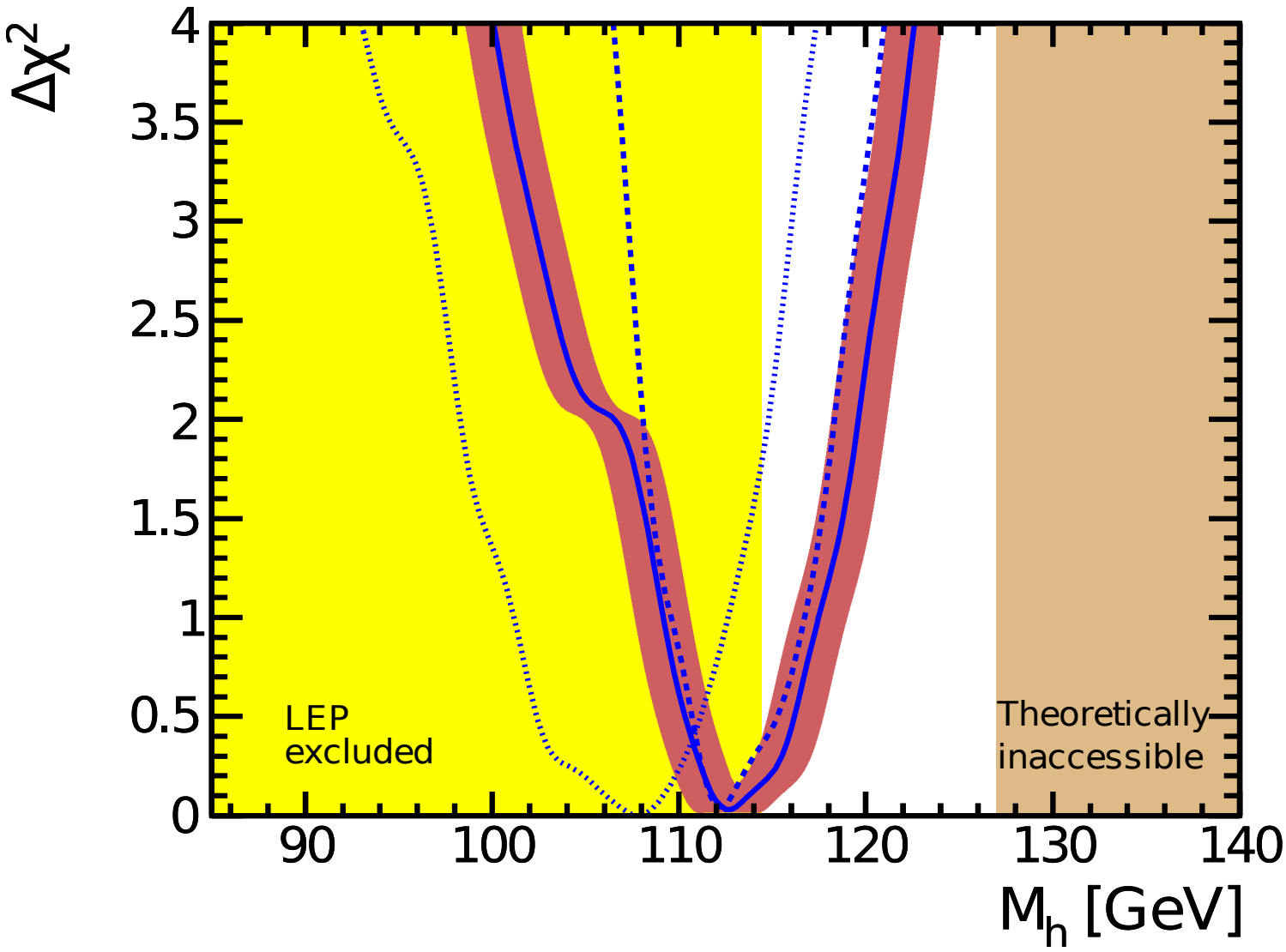
CMSSM $\tan\beta$–$m_{1/2}$



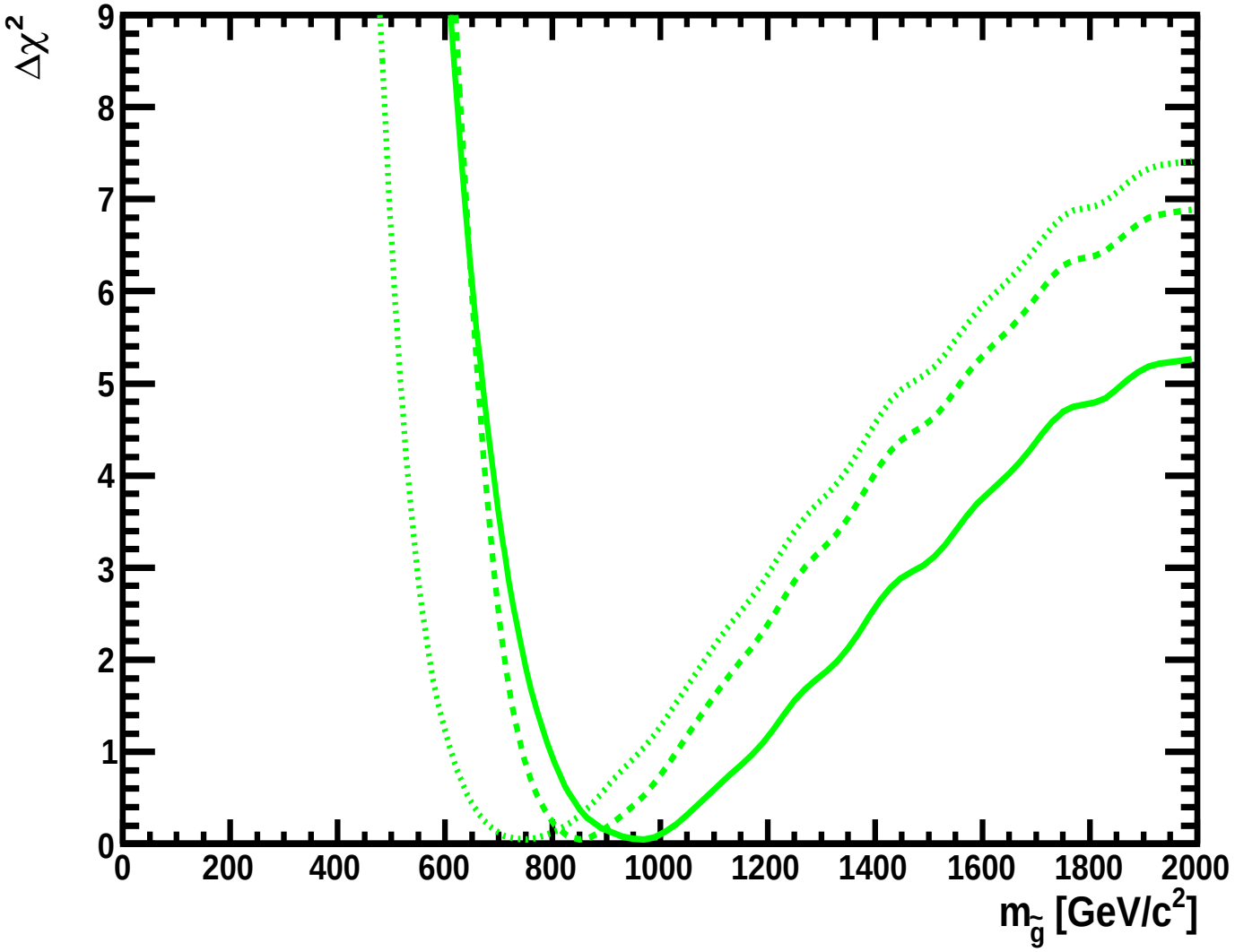
Comments

- Including the LHC results increases consistency with LEP Higgs result.
- Does not significantly increase fine-tuning required: one part in 100 $\rightarrow$ 140 in CMSSM.
- Gluino mass increases by $\delta m_{\tilde{g}} \approx 200$ GeV from 750 GeV to 950 GeV in CMSSM at the best-fit point.

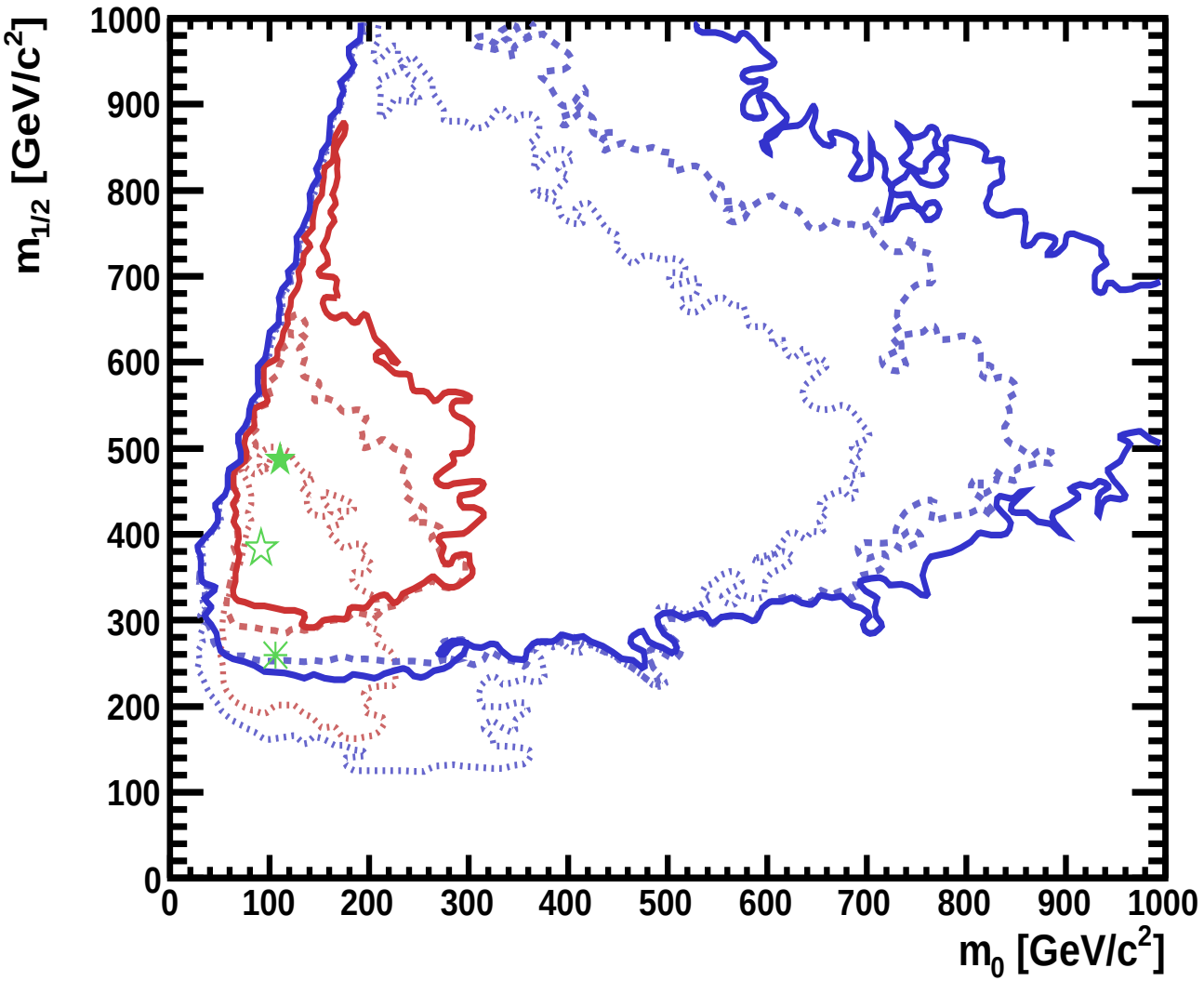
Higgs mass m_h in CMSSM



Gluino mass $m_{\tilde{g}}$ in CMSSM



NUHM1 m_0–$m_{1/2}$



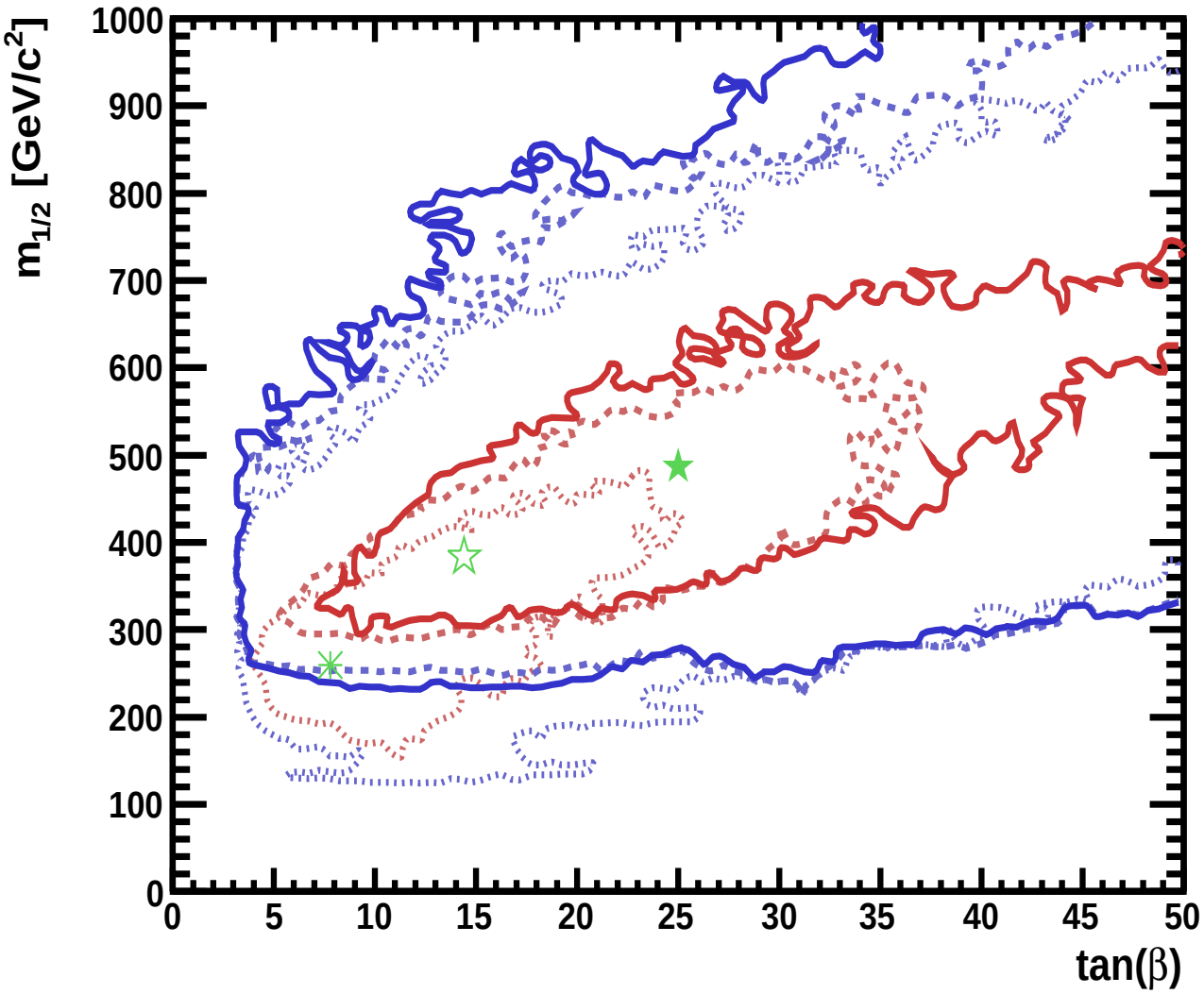
Best-fit points: NUHM1

Model	Minχ^2	Prob	$m_{1/2}$	m_0	A_0	tan β
NUHM1	19.3	31%	260	110	1010	8
w CMS	20.9	28%	380	90	70	14
w ATLAS	23.3	18%	490	110	-630	25

Comments

- $\Delta\chi^2_{min} = 4$ for the ATLAS constraint.
- $m_{1/2}$ increases by 230 GeV $\implies$ shallow minimum.
- tan β increases by ≈ 15.

NUHM1 $\tan\beta$–$m_{1/2}$

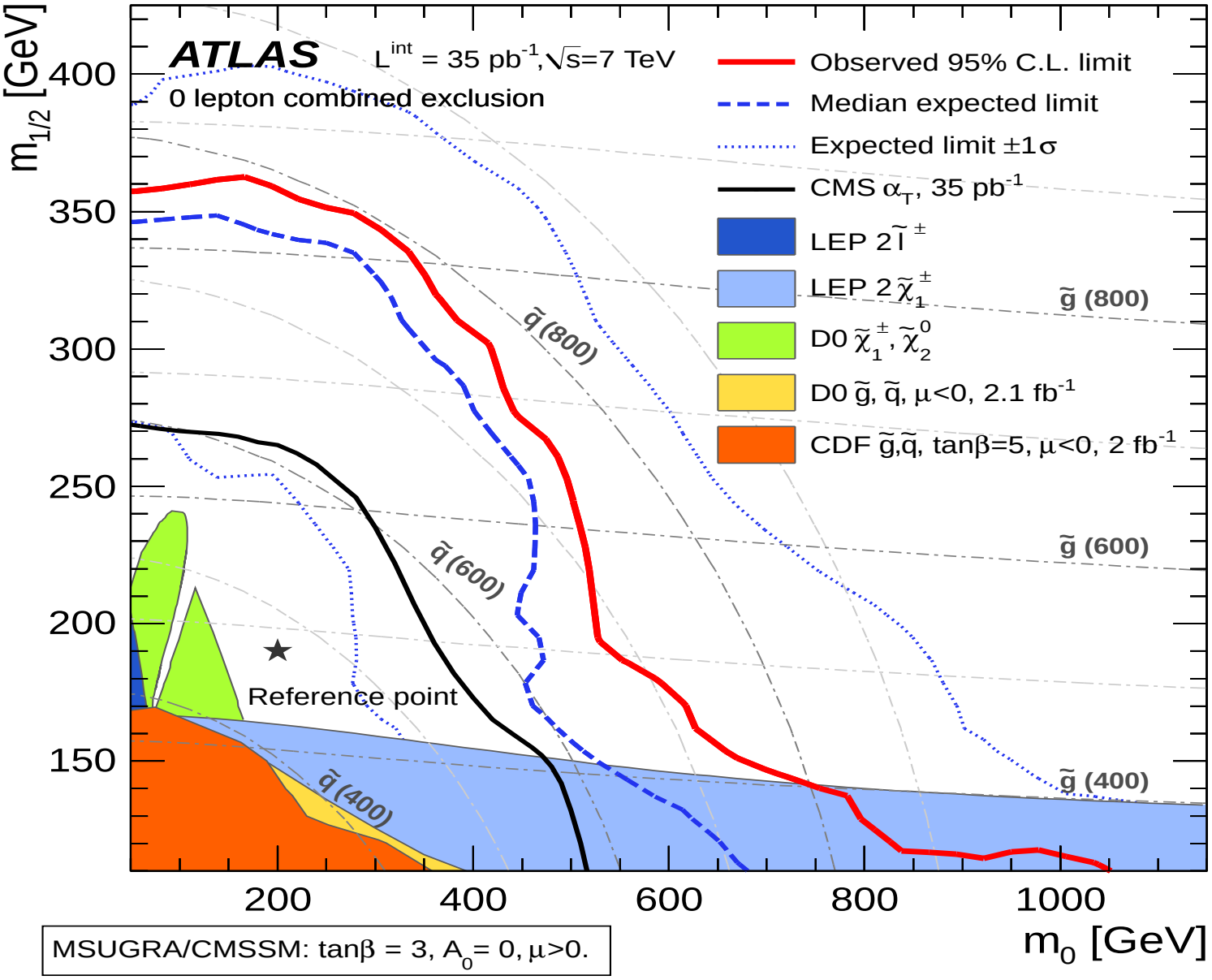


VCMSSM and mSUGRA

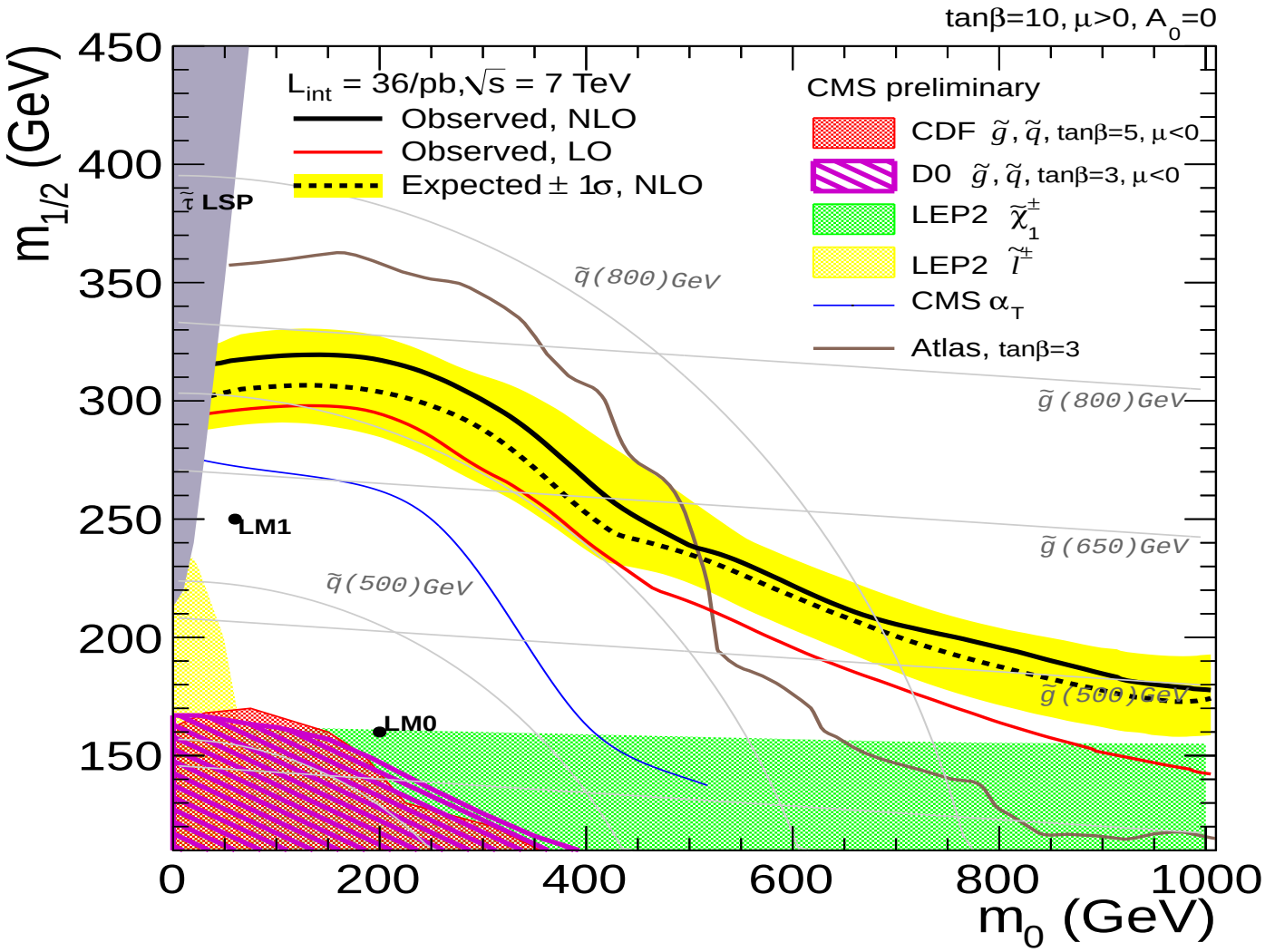
Model	Minχ^2	Prob	$m_{1/2}$	m_0	A_0	tan β
VCMSSM	22.5	31%	300	60	30	9
w CMS	23.8	25%	340	70	50	9
w ATLAS	27.1	13%	390	90	70	11
mSUGRA	29.4	6.1%	550	230	430	28
w CMS	29.4	6.1%	550	230	430	28
w ATLAS	30.9	5.7%	550	230	430	28

- Similar to CMSSM, in VCMSSM $\Delta\chi^2$ increases and $m_{1/2}$ limit is now 390 GeV
- No change in mSUGRA bf point, although χ^2 is greater.

ATLAS 0leptons search



CMS Jets + Missing Energy Search



Current Work

Forthcoming work will include

- CMS/ATLAS (0l) missing energy searches.
- New limits on $BR(B \rightarrow \mu^+\mu^-)$.
- $h \rightarrow \tau\tau$ search.
- XENON100 results on DM direct detection.

More integrated luminosity

- Currently: $312 pb^{-1}$ (ATLAS)
- End of the year: 3-5fb^{-1} (?)

Extras

Observables

Low Energy Obs	Electroweak Observable
$BR(B \to X_s\gamma)$	m_W
$BR(B_s \to ll)$	$\sin^2\theta^l_{eff}$
$BR(B_d \to ll)$	$A^{0,b}_{fb}$
$R_{\Delta M_s}$	$A^{0,c}_{fb}$
$R_{B\tau\nu}$	R^0_l
$R(B \to X_s ll)$	σ^0_{had}
$R(K \to \pi\nu\bar{\nu})$	$\Delta\alpha^{(0)}_{had}(m_Z^2)$
$BR(K \to \tau\nu)$	$\mathcal{A}_c$
$R_{\Delta M_K}$	$A^0_{LR}(SLD)$
Δ_{0-}	R^0_b
$(g-2)_\mu$	R^0_c
	m_t
m_h	m_Z
$\Omega_{\rm DM}h^2$	$\mathcal{A}_b$