Implications of Initial LHC Searches for Supersymmetry

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arXiv:1011.6118, 1102.4585, forthcoming

The MasterCode Collaboration

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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)

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Key ingredients

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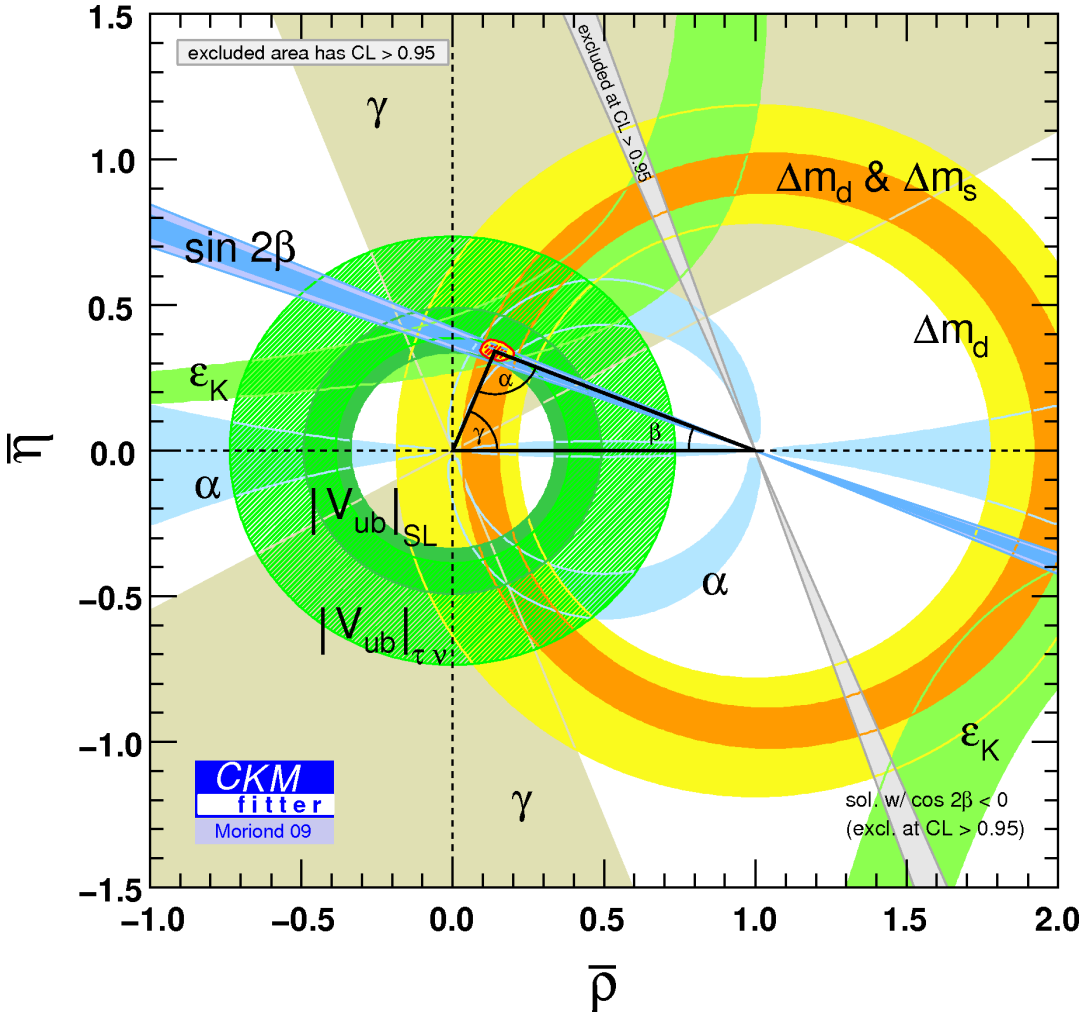
- State-of-the-art predictions (and errors)

A well-known global fit



The Models

CMSSM: 4 parameters

- The usual story: $m_0, m_{1/2}, A_0$ and $\tan\beta$

NUHM1: 5 parameters

- As in CMSSM, but Higgs masses become an independent parameter
- $m_{H_u}^2 = m_{H_d}^2 \neq m_0^2$
- Equivalent to M_A free parameter at EW scale.

The Models[1]

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 $\implies m_0 > m_{\chi_1^0}$.

[1] For gauge mediation: see Khoze/Jaeckel, AbdusSalam,MJD et al. 0906.0957, Heinemeyer et al. 0805.2359

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...

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
$\Omega_{\rm DM}h^2$	$\mathcal{A}_b$

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

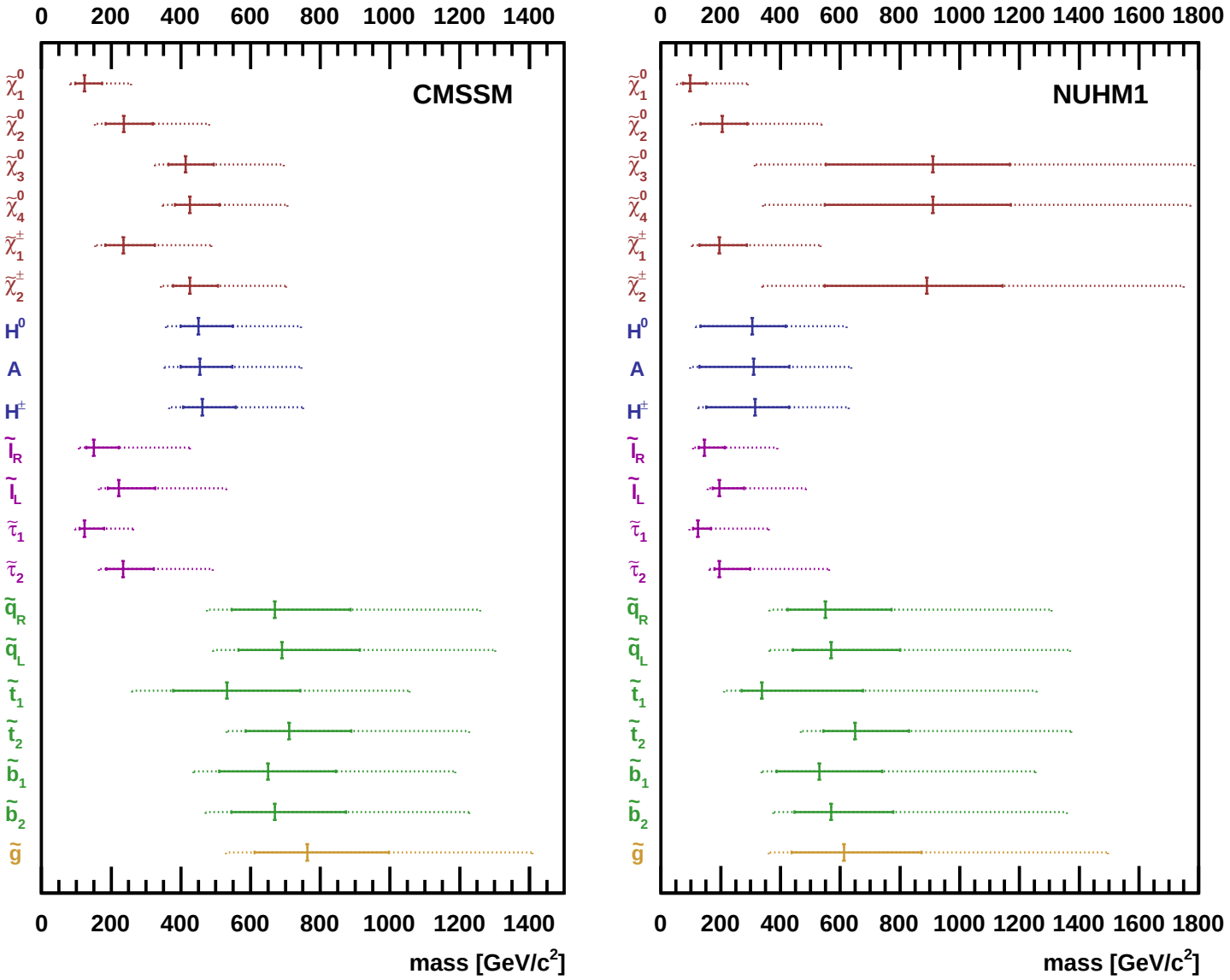
Best-fit Points (before LHC data)

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

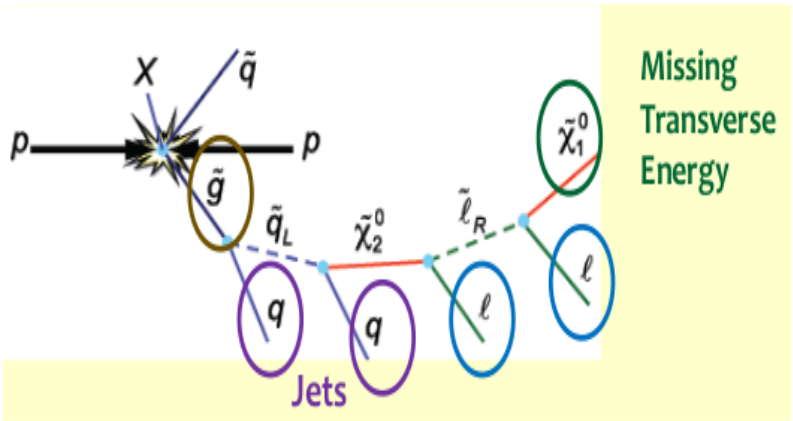


Desperately Seeking SUSY

SUSY events often involve

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

- Jet production
- Leptons



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Last Year

- To end of 2010 LHC had $35 pb^{-1}$ taken at 7 TeV C.o.M.
- A number of new SUSY searches have been published.

The CMS α_T search[2]

Details

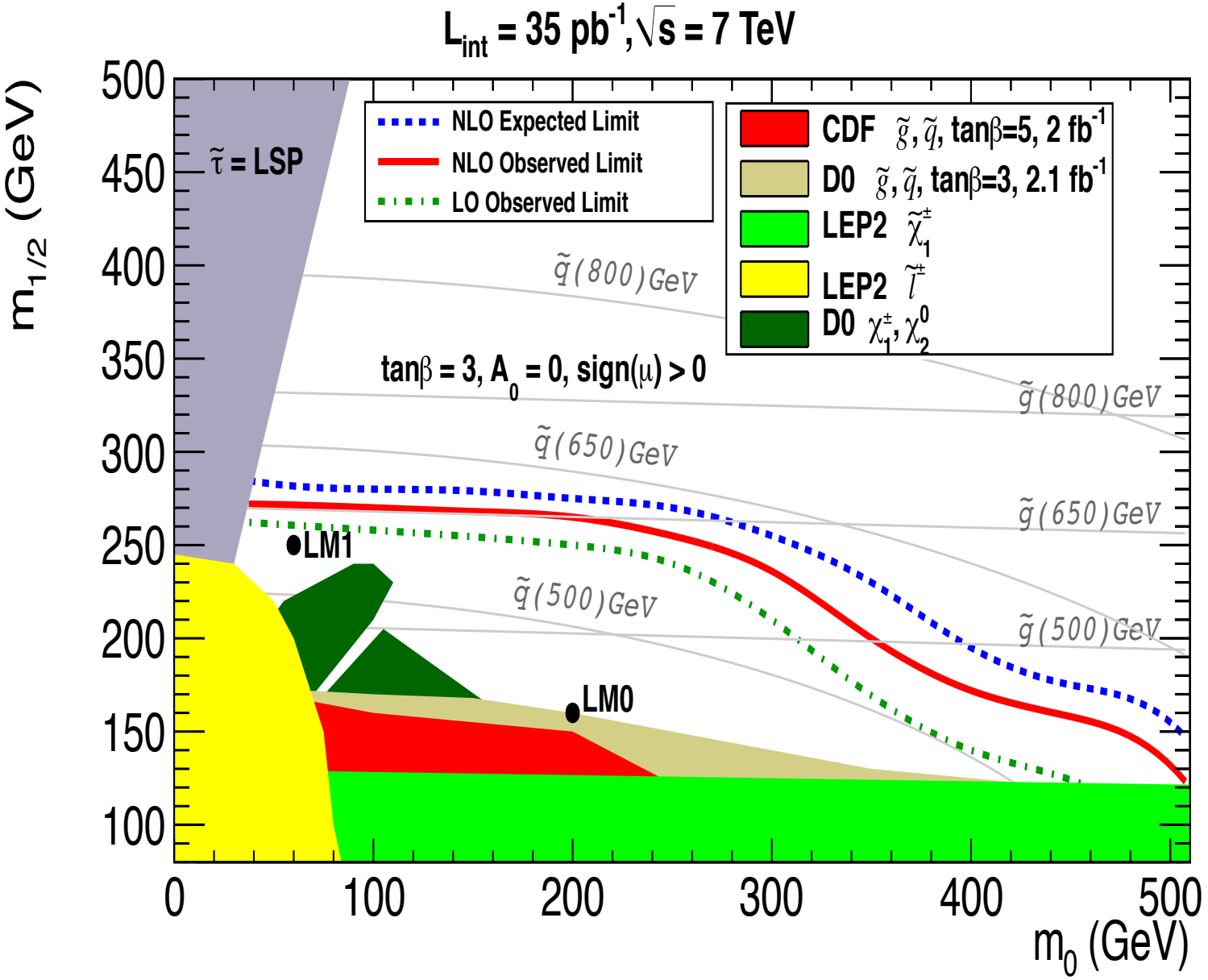
- Searched for multijet + $\not{E}_T$ without leptons
- Saw 13 events with 10.5 expected from SM background, compatible with probability 30%.
- Set a 95% upper CL of 13.4 events.

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.

[2] 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.

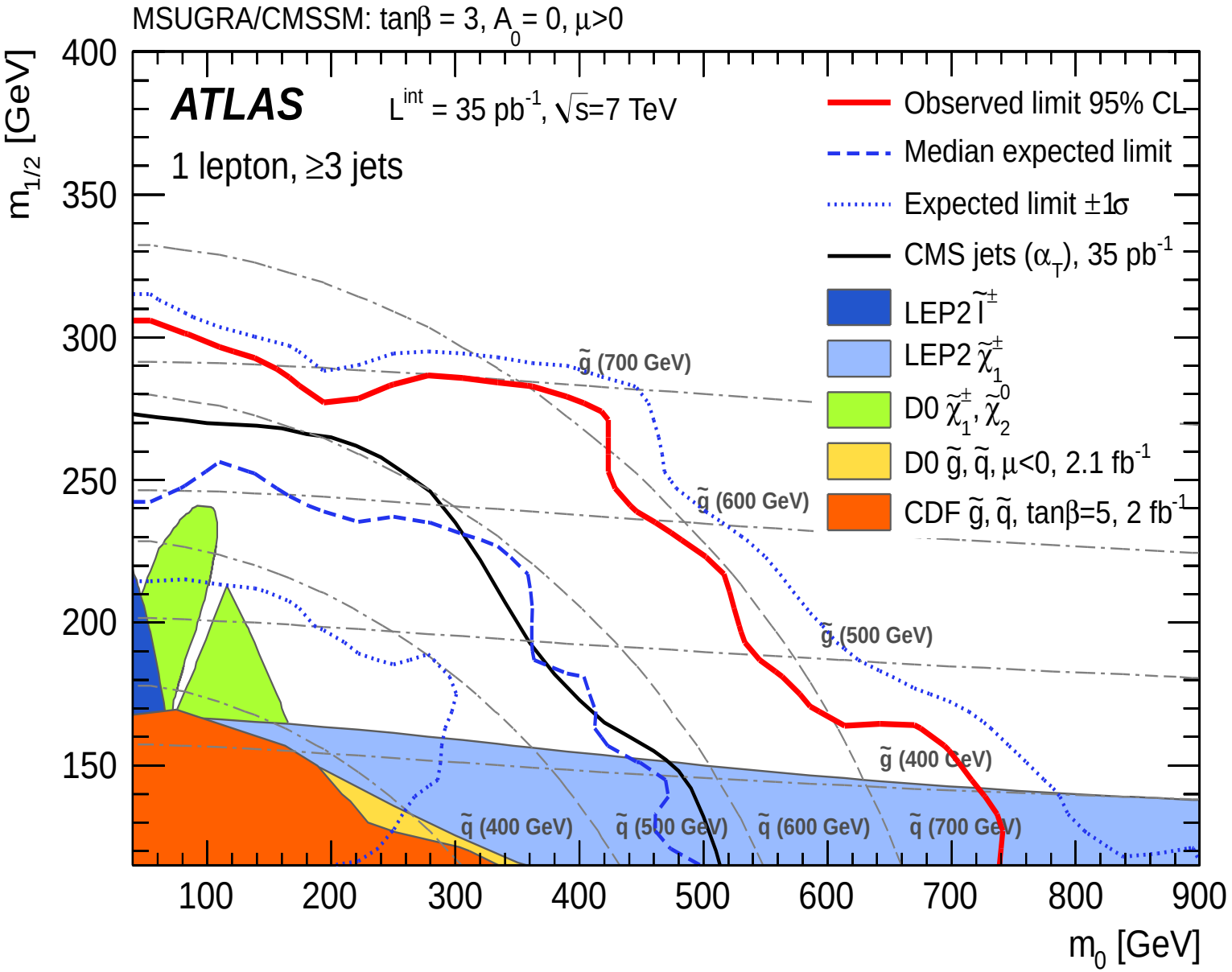
The ATLAS 1l Search[4]

- 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[3] $\mathcal{M} \propto \mathcal{L}^{1/4}$
- Implies event rate $\mathcal{L} \propto \mathcal{M}^4$
- $\Delta\chi^2 = \chi^2_{\infty,ATLAS} + |M/M_A|^{-p_A}$

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

[4] 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

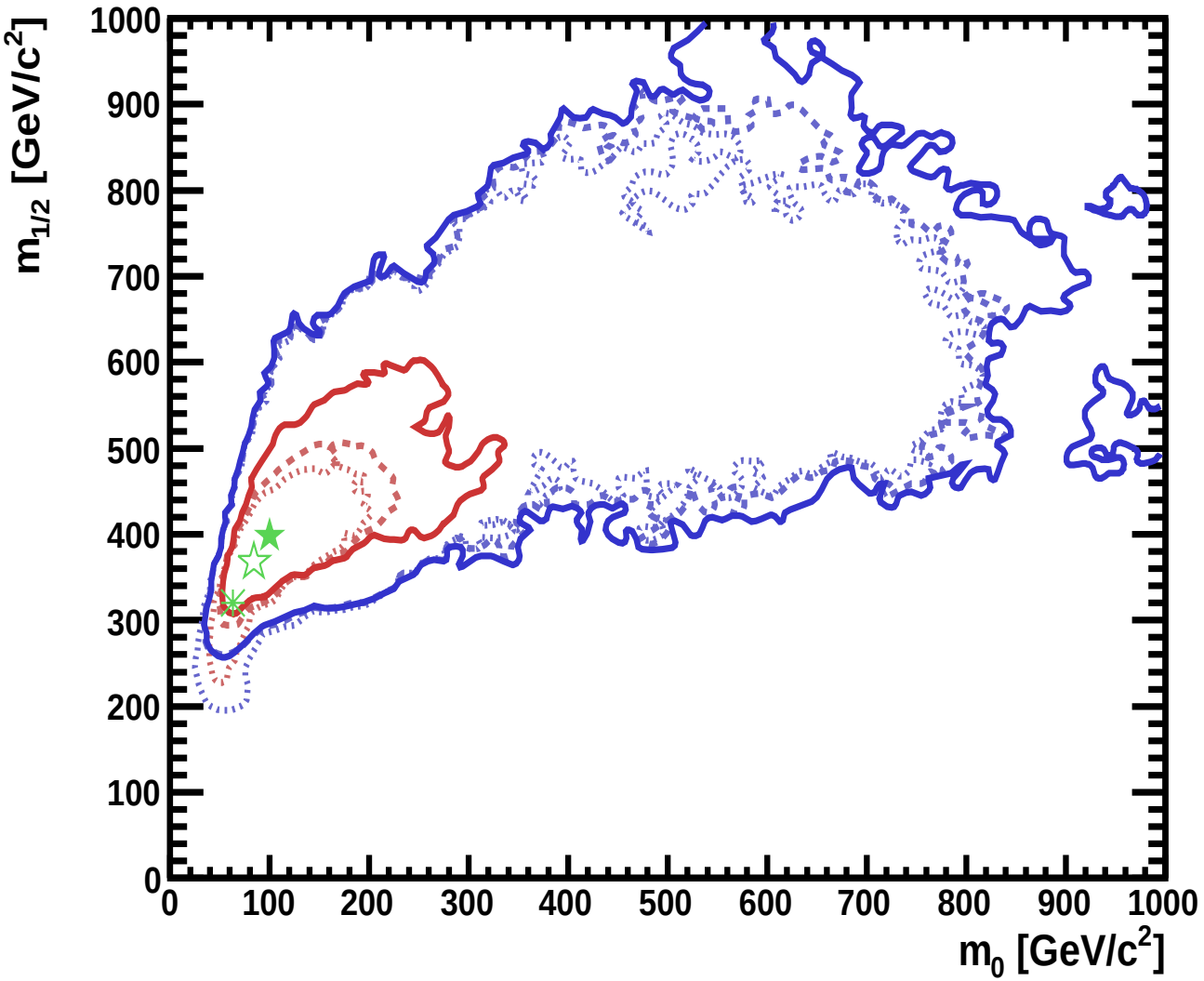
Best-fit points

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

1σ and 2σ contours

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

CMSSM m_0–$m_{1/2}$



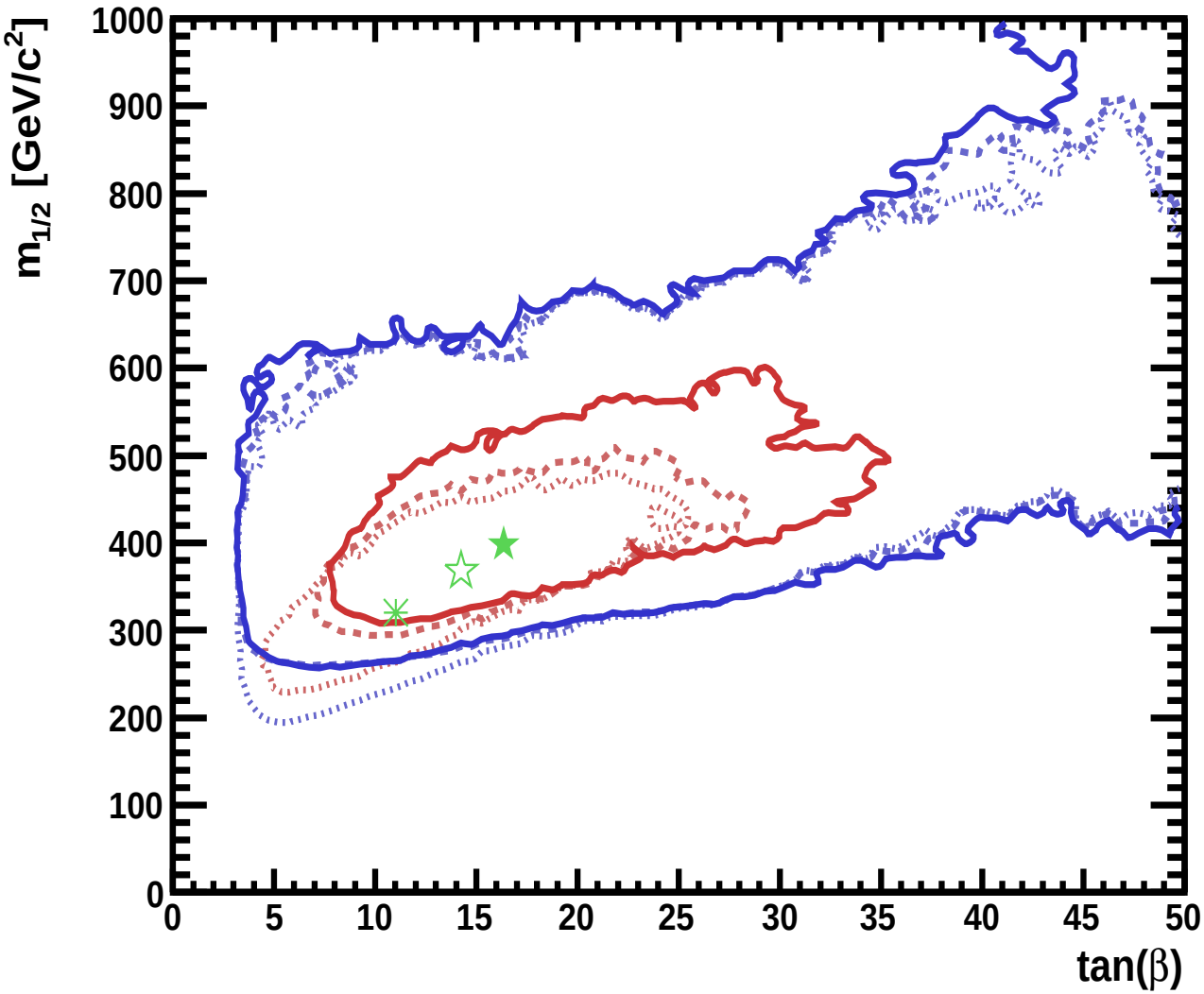
Best-fit points: CMSSM

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 $\tan\beta$–$m_{1/2}$



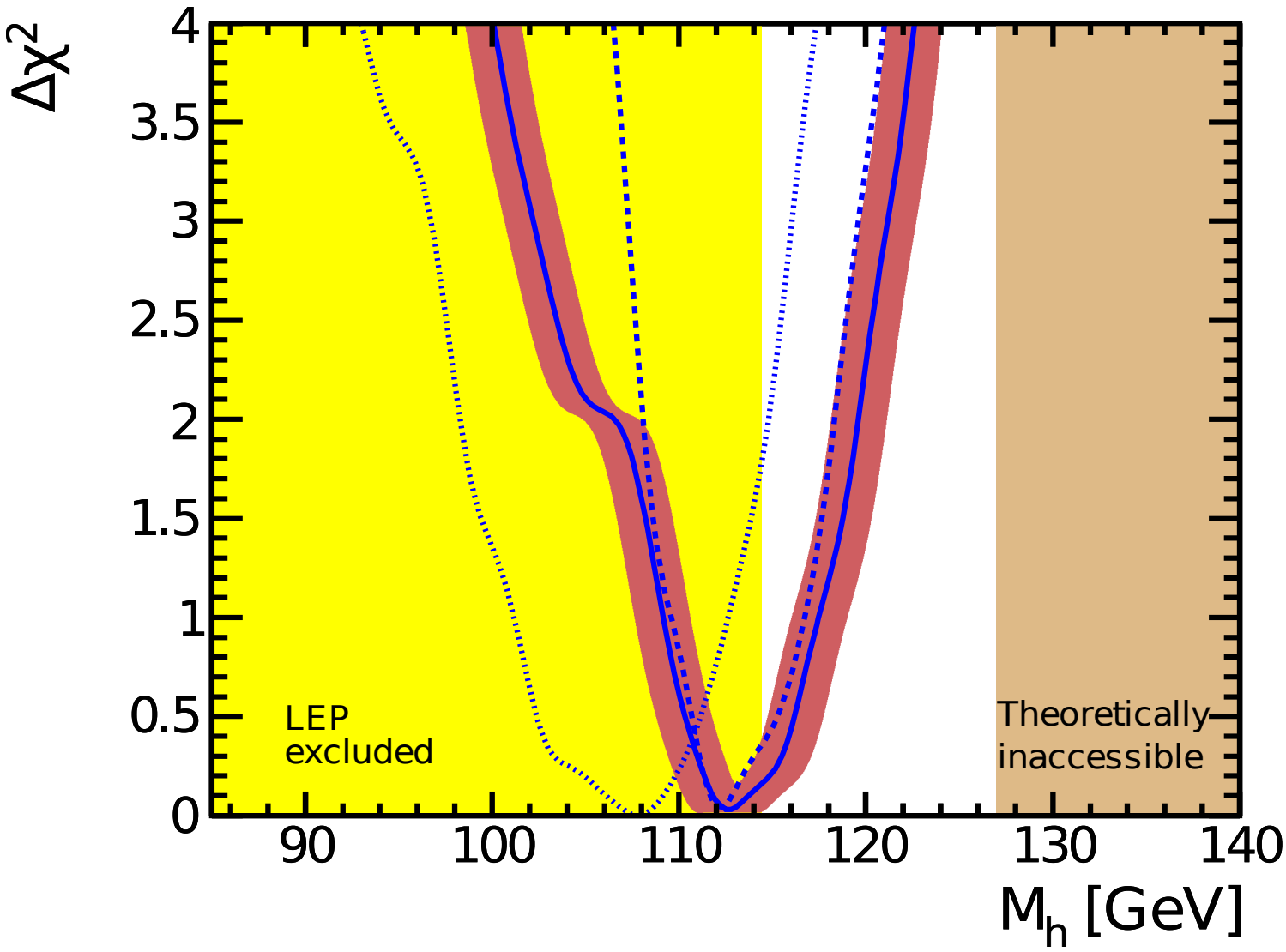
Comments

Fine-tuning

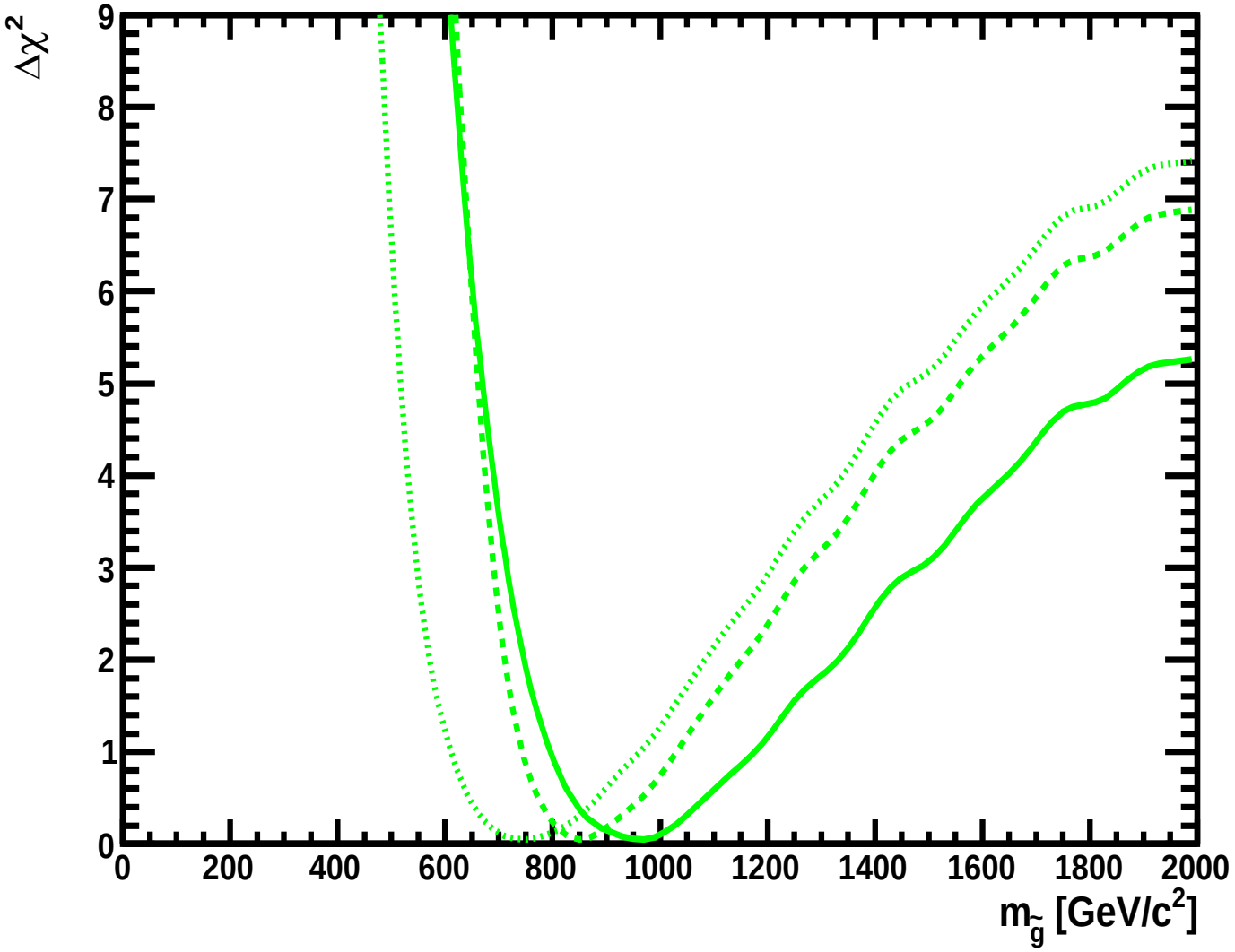
- Including the LHC results increases consistency with LEP Higgs result.
- Does not significantly increase fine-tuning required: one part in 100 $\rightarrow$ 140 in CMSSM.
- GR/DG: Include relic-density, more observables, best fit-point.

- Gluino mass increases by $\delta m_{\tilde{g}} \approx 200$ GeV from 750 GeV to 950 GeV in CMSSM at the best-fit point.

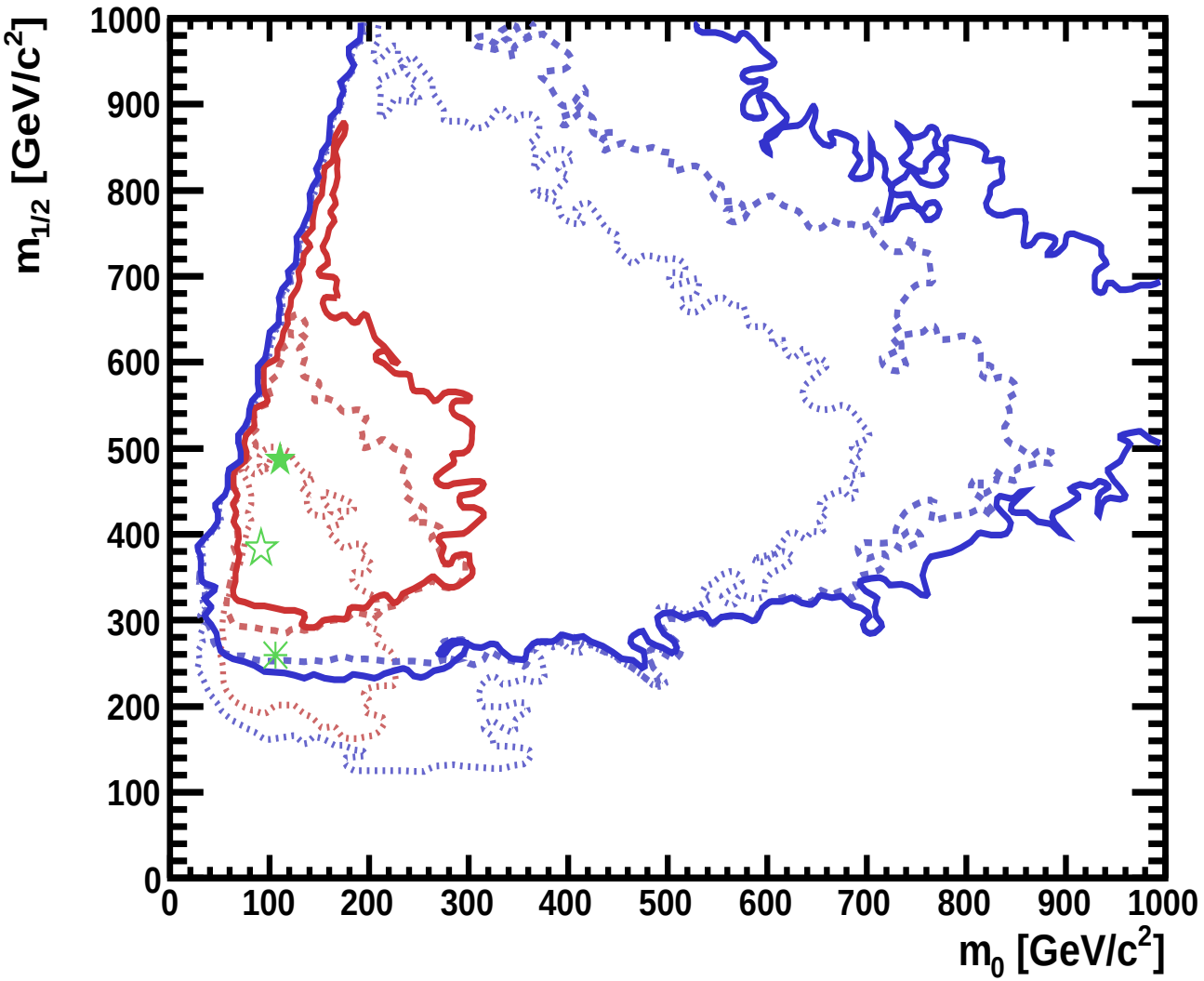
Higgs mass m_h in CMSSM



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



NUHM1 m_0–$m_{1/2}$



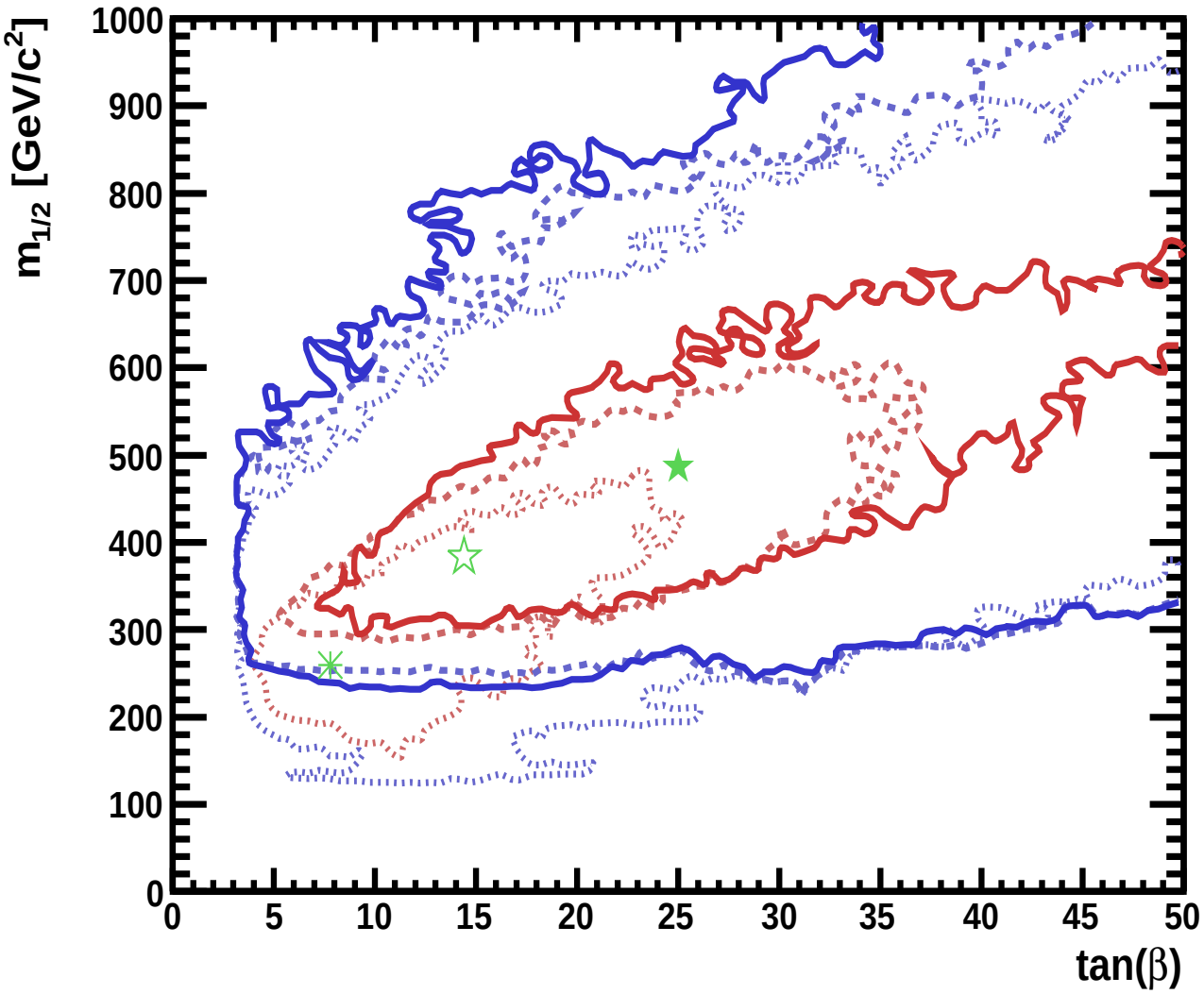
Best-fit points: NUHM1

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 $\tan\beta$–$m_{1/2}$

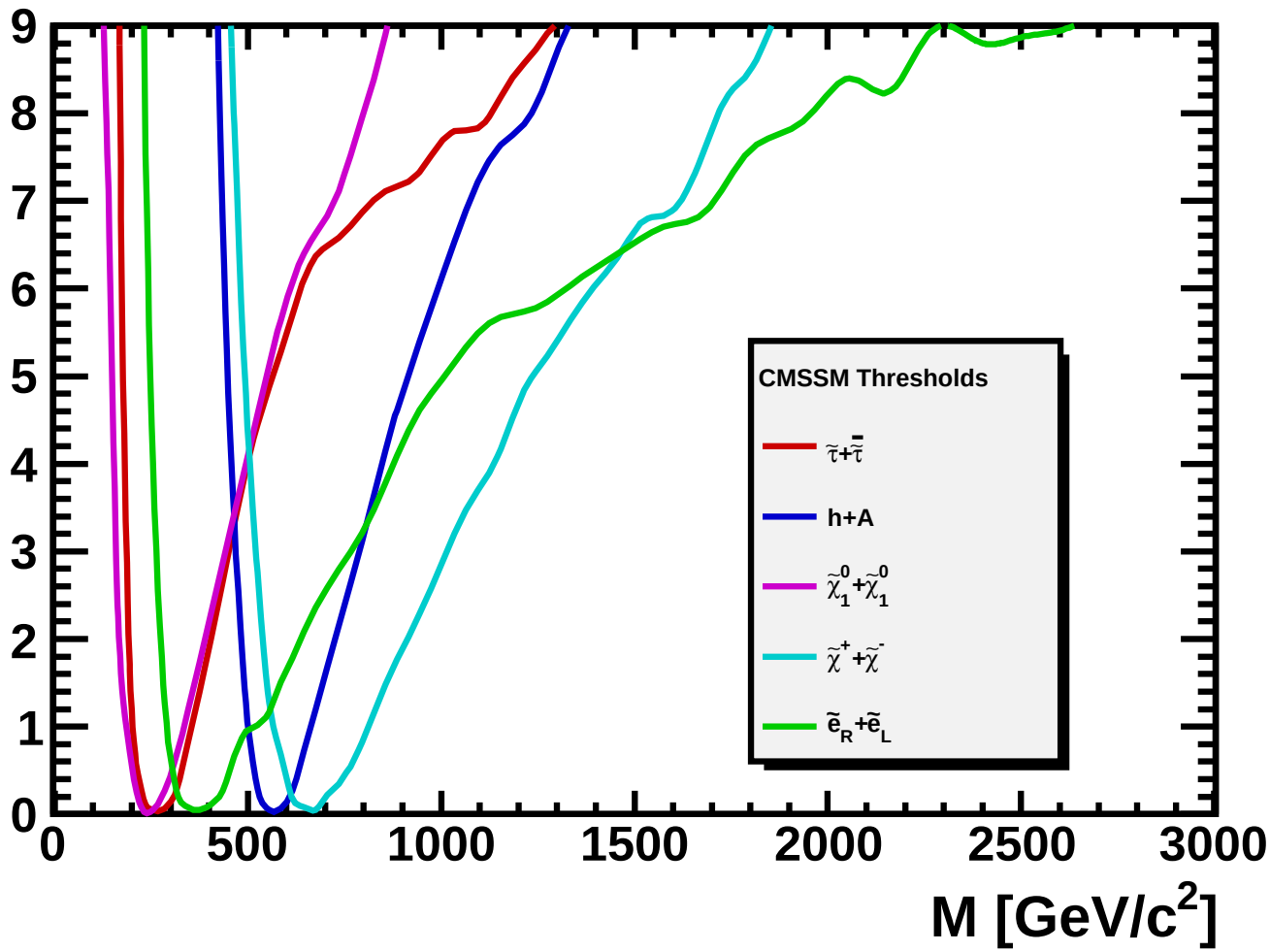


VCMSSM and mSUGRA

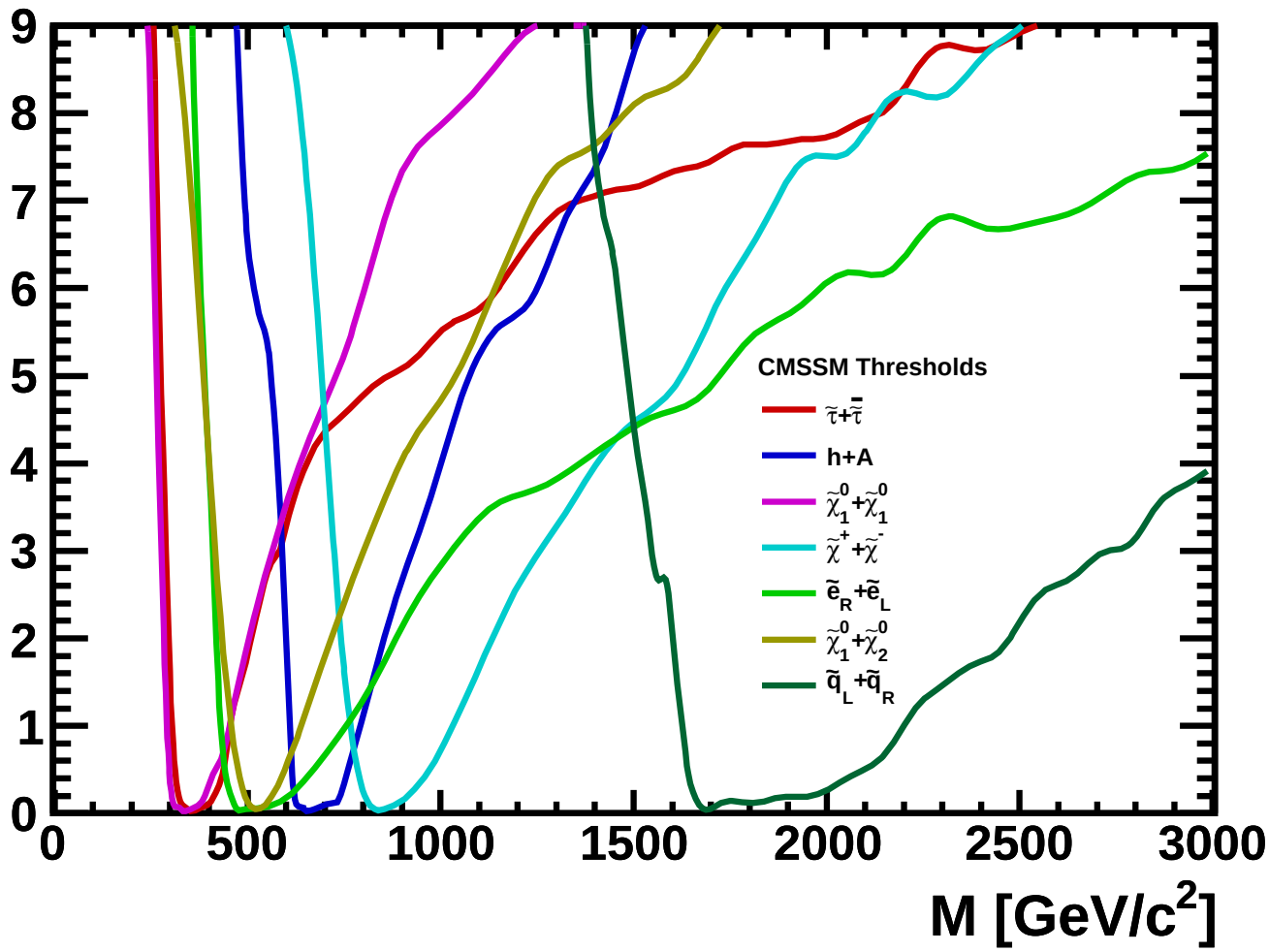
Model	Minχ^2	Prob	$m_{1/2}$	m_0	A_0	tan β
VCMSSM	22.5	31%	300	60	30	9
w CMS	23.8	25%	340	70	50	9
w ATLAS	27.1	13%	390	90	70	11
mSUGRA	29.4	6.1%	550	230	430	28
w CMS	29.4	6.1%	550	230	430	28
w ATLAS	30.9	5.7%	550	230	430	28

- 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.

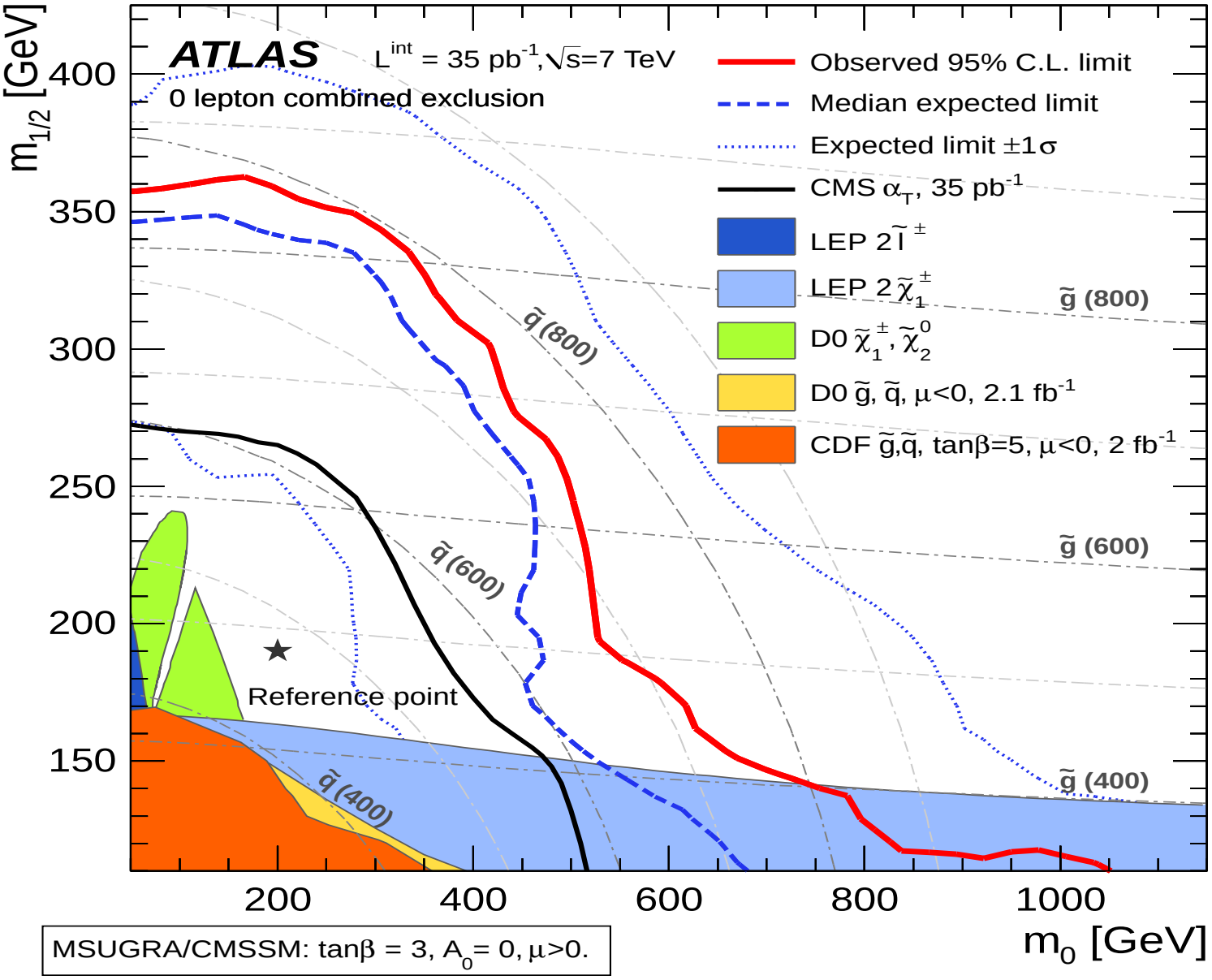
Pair production thresholds in e^+e^-: pre-LHC



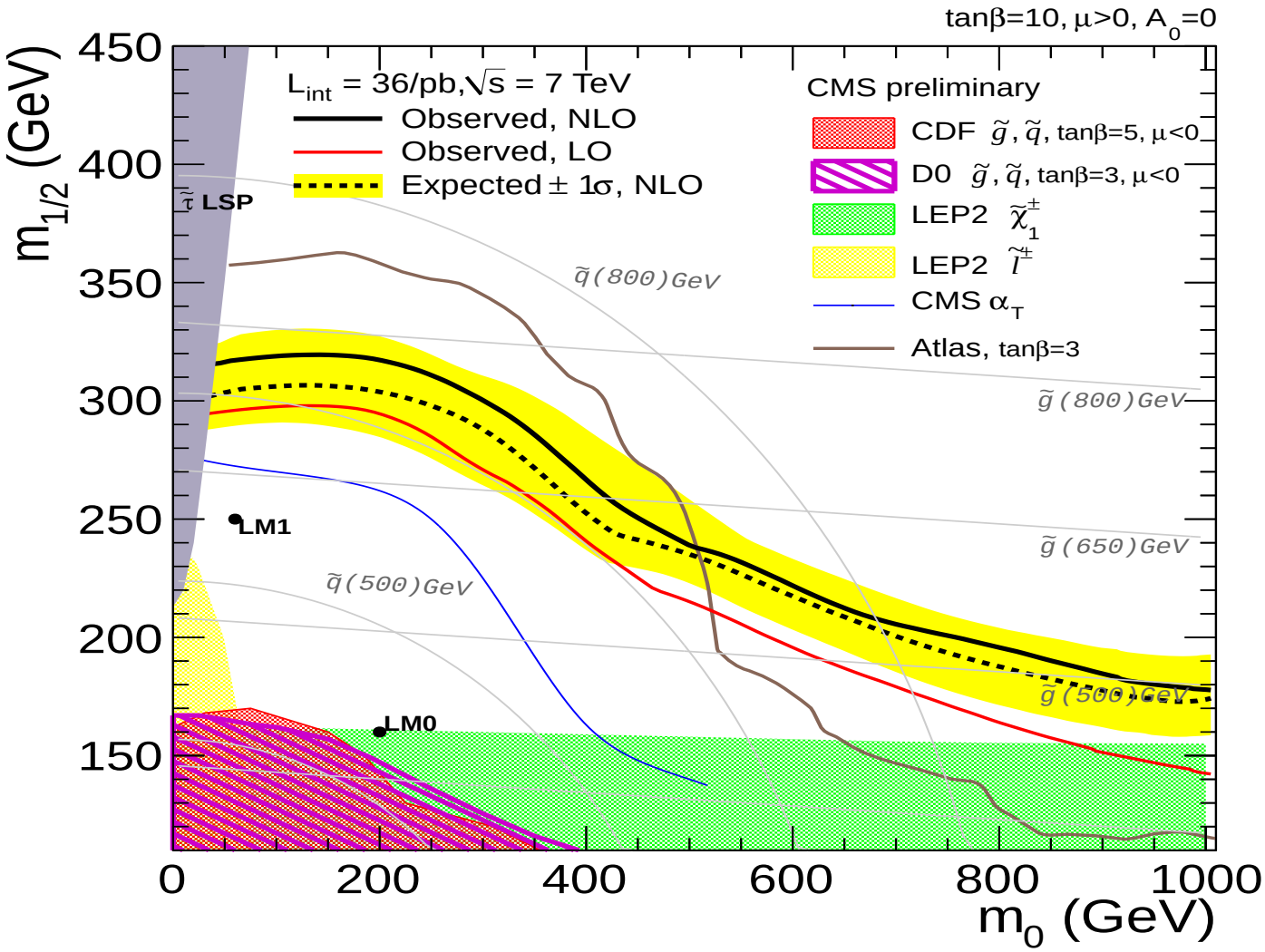
Pair production thresholds in e^+e^-: post-LHC



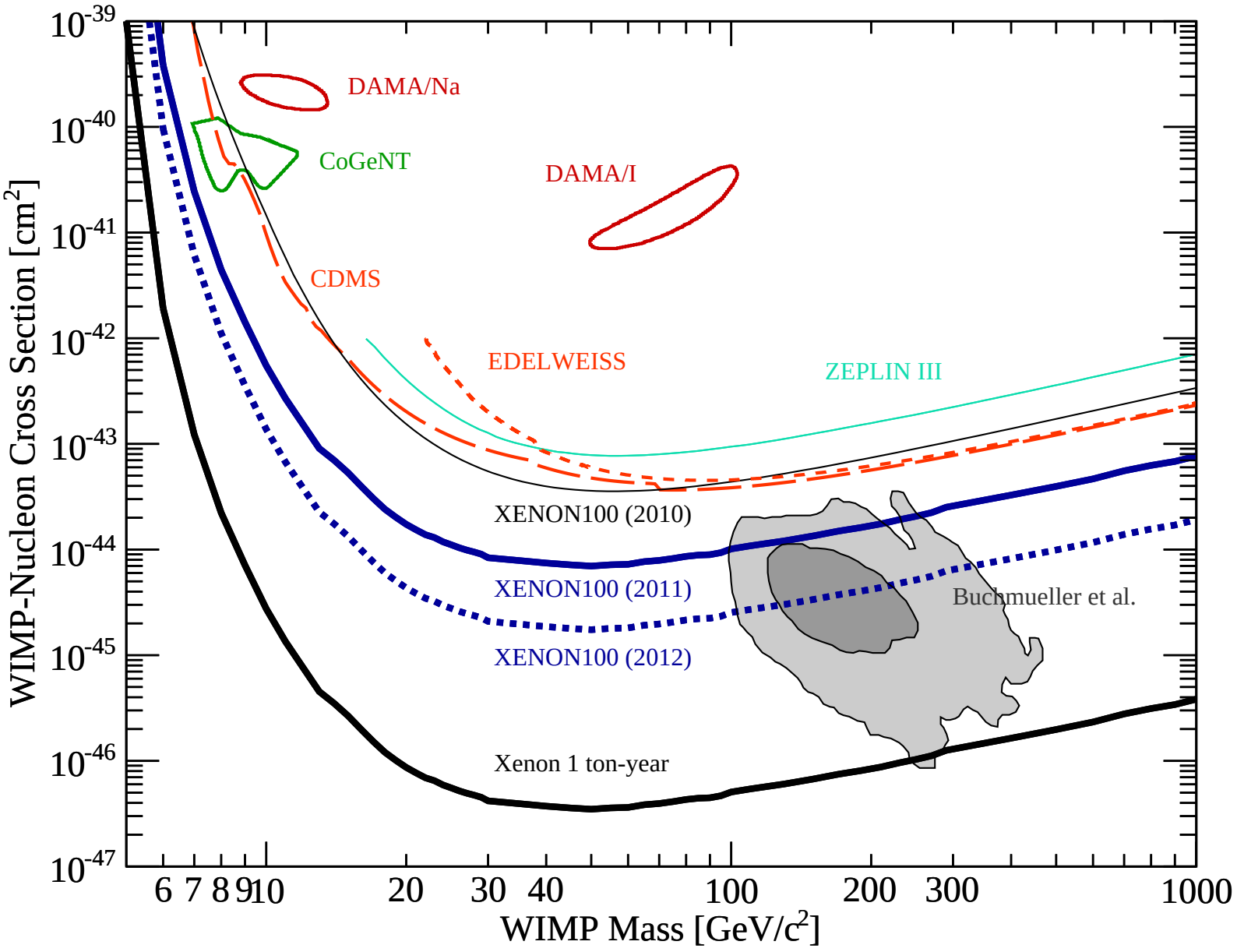
ATLAS 0leptons search



CMS Jets + Missing Energy Search



Prospects from XENON



Current Work

Forthcoming work will include

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

More integrated luminosity

- Currently: $297 pb^{-1}$ (ATLAS), $275 pb^{-1}$ (CMS)
- End of the year: 3-5fb^{-1} (?)