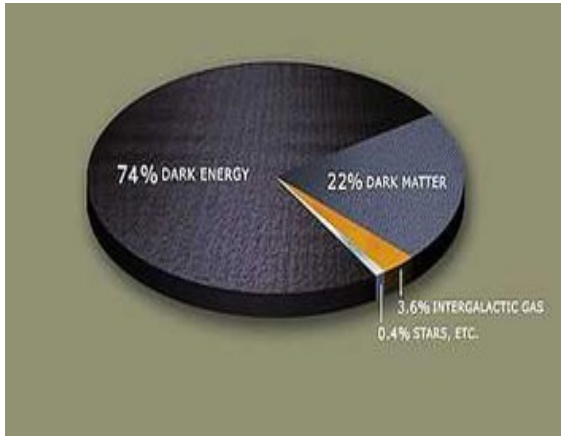
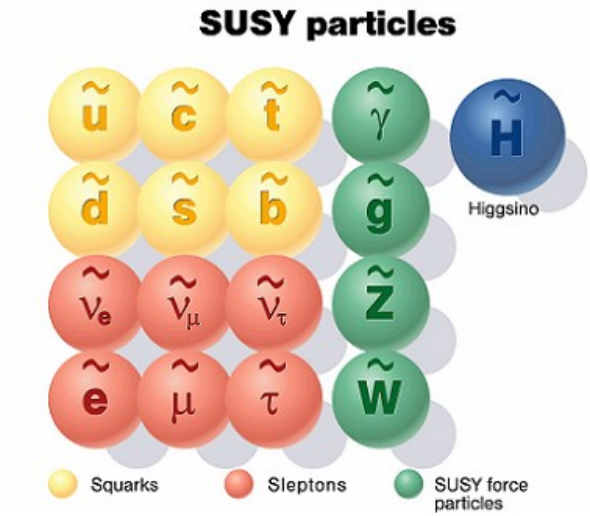
Karlsruher Institut für Technologie

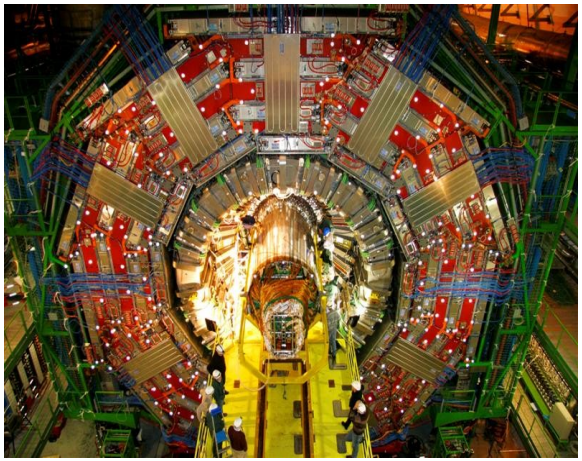
SUSY Constraints from Accelerators and Cosmology using a Multi-step Fitting Approach (MFA)

C. Beskidt, W. de Boer, D. Kazakov, F. Ratnikov, V. Zhukov, E. Ziebarth

Institut für Experimentelle Kernphysik

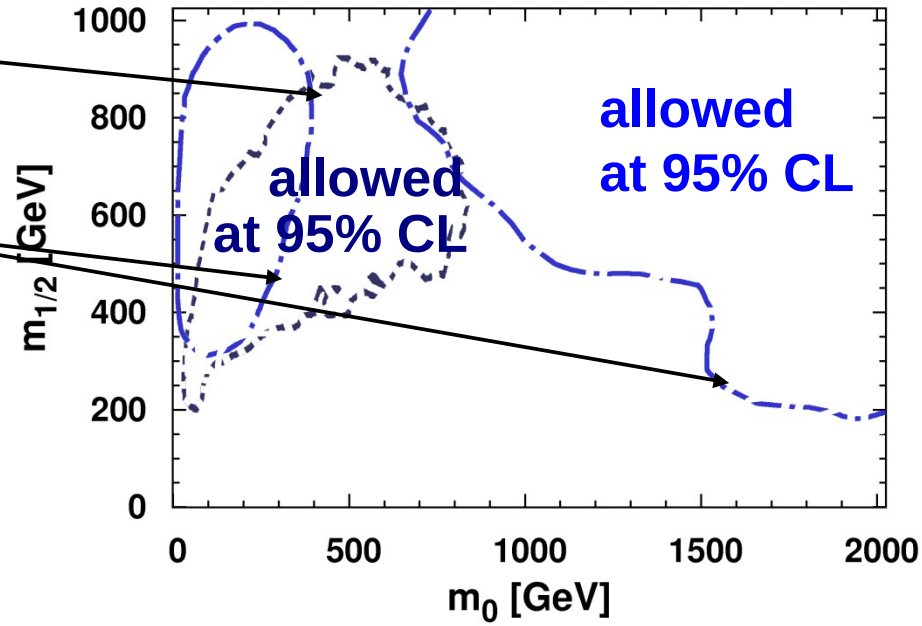






Outline

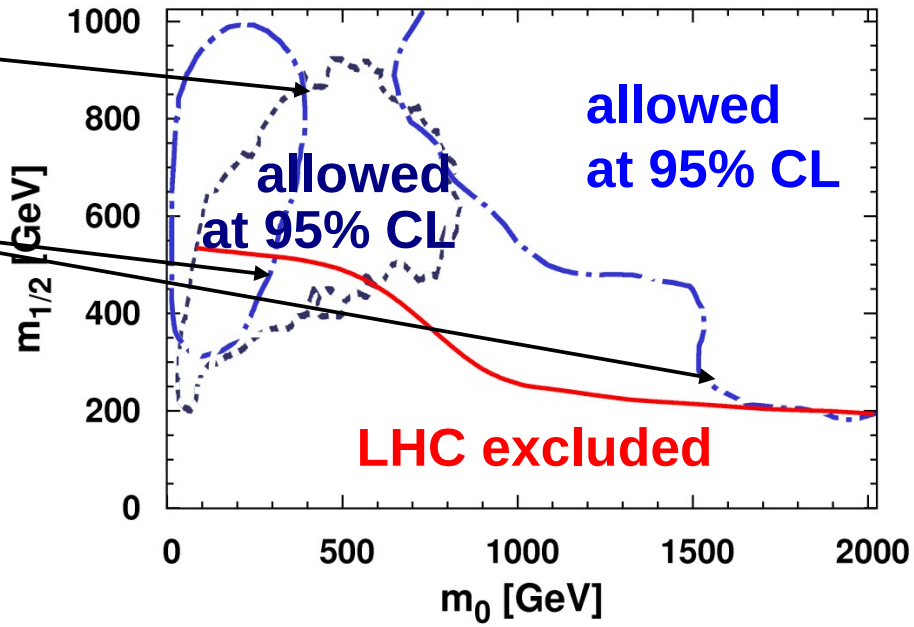
- Problem: different groups get different excluded regions
  - χ^2 -based method
    Buchmueller et al.
    arXiv: 0907.5568v1
  - MCMC sampling
    Trotta et al.
    arXiv: 0809.3792v2
  - Genetic Algorithms
    Akrami et al.
    arXiv: 0910.3950
  - Multinest
    Feroz et al.
    arXiv: 0807.4512



- Possible reasons:
  - by strong correlations some regions may be missed
  - different error treatments

Outline

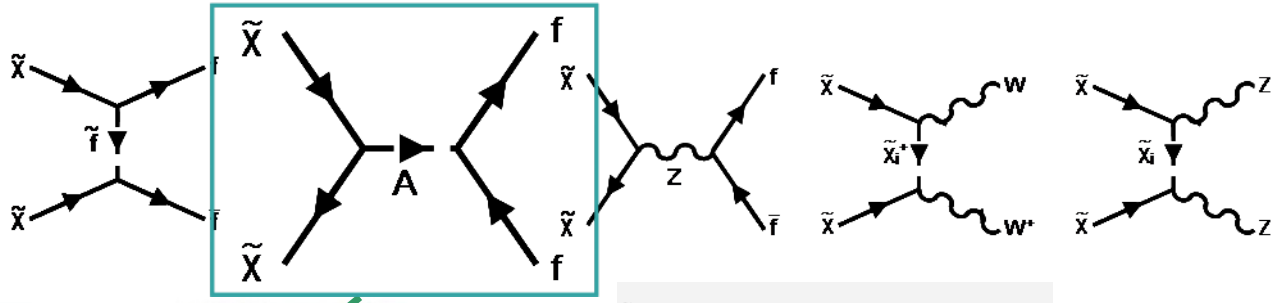
- Problem: different groups get different excluded regions
  - χ^2 -based method
    Buchmueller et al.
    arXiv: 0907.5568v1
  - MCMC sampling
    Trotta et al.
    arXiv: 0809.3792v2
  - Genetic Algorithms
    Akrami et al.
    arXiv: 0910.3950
  - Multinest
    Feroz et al.
    arXiv: 0807.4512

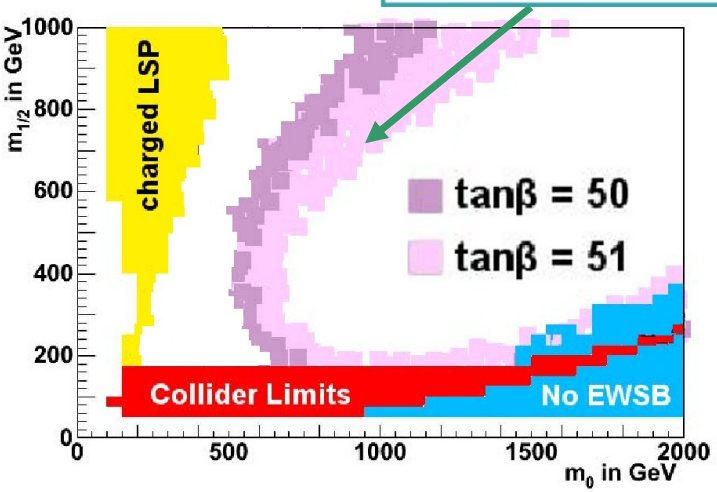


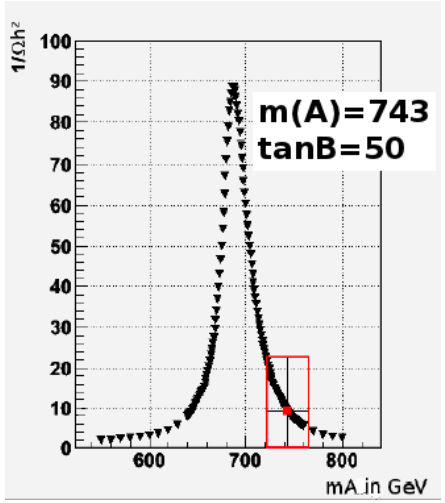
- Possible reasons:
  - by strong correlations some regions may be missed
  - different error treatments

Start with Relic Density Constraint

Problem: for excluded $m_{\tilde{q}}$ first diagram too small. Last diagram also small → can get correct relic density by m_A s-channel annihilation







$$\langle \sigma v \rangle \propto \frac{\tan\beta^2}{m_A^4}$$

$$\Rightarrow m_A \propto 2m_\chi \propto m_{1/2}$$

m_A can be tuned with tanβ for any $m_{1/2}$ → tanβ ≈ 50 (see next slide)

Relic Density Constraint – Dependence on tanβ

$$V_{tree}(H_1,H_2) = m_1^2|H_1|^2 + m_2^2|H_2|^2 - m_3^2(H_1H_2 + h.c.) + \frac{g^2+g'^2}{8}\left(|H_1|^2 - |H_2|^2\right)^2 + \frac{g^2}{2}\left|H_1^+H_2^-\right|^2$$

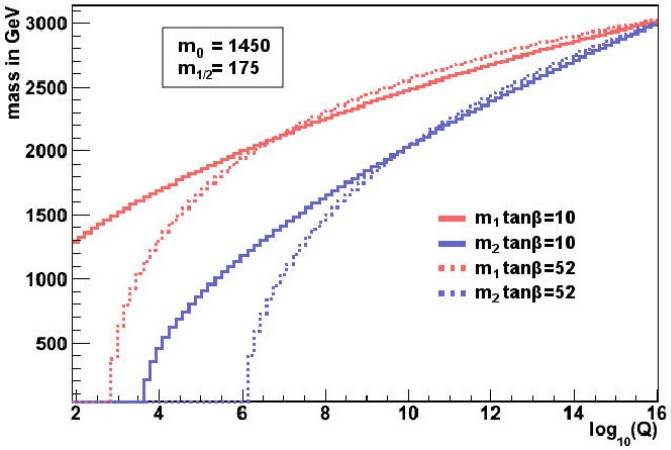
$m_A^2 = m_1^2 + m_2^2$ (Tree Level)

m_1 running $\propto h_t$

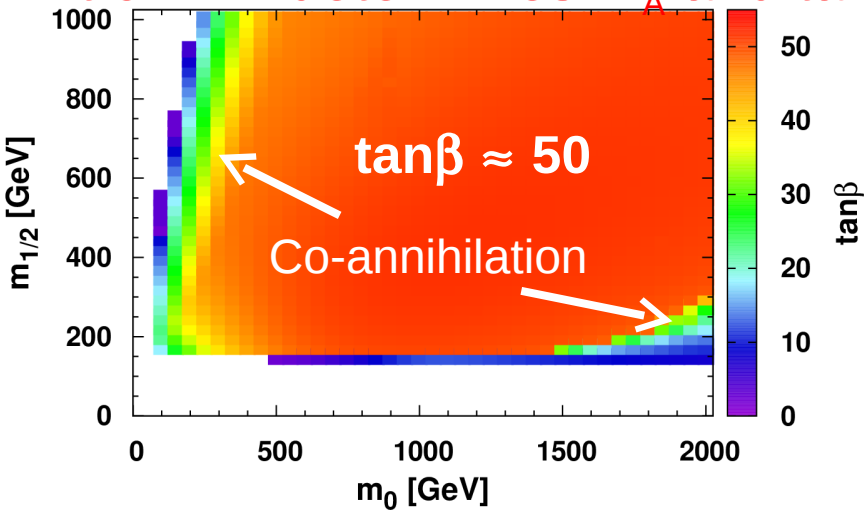
m_2 running $\propto h_b$

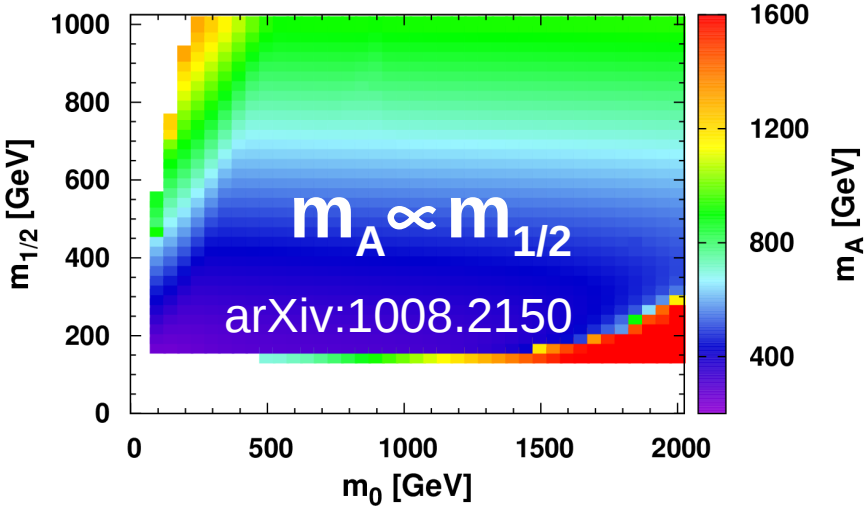
running < 0 → if h_t and h_b similar

→ small m_A for $\tan\beta = m_t/m_b \approx 50$

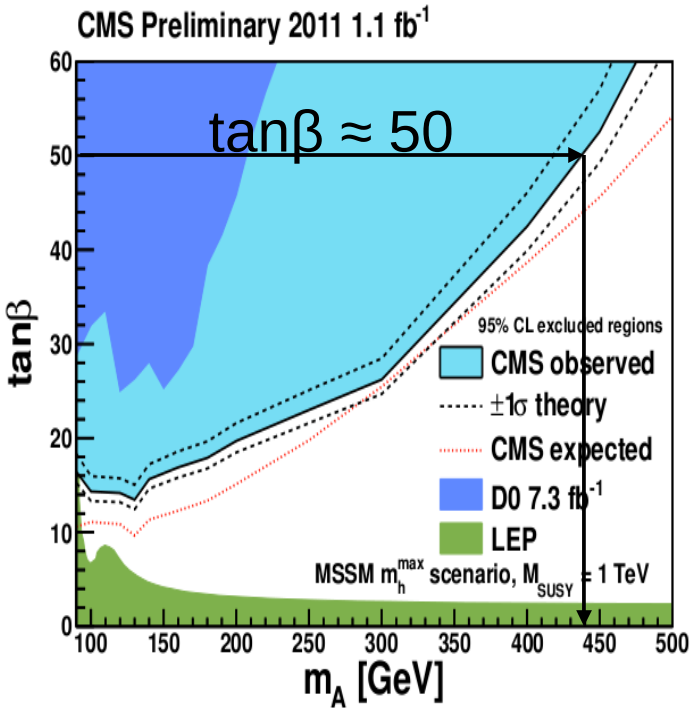


Fit of Ωh^2 determines m_A and tanβ



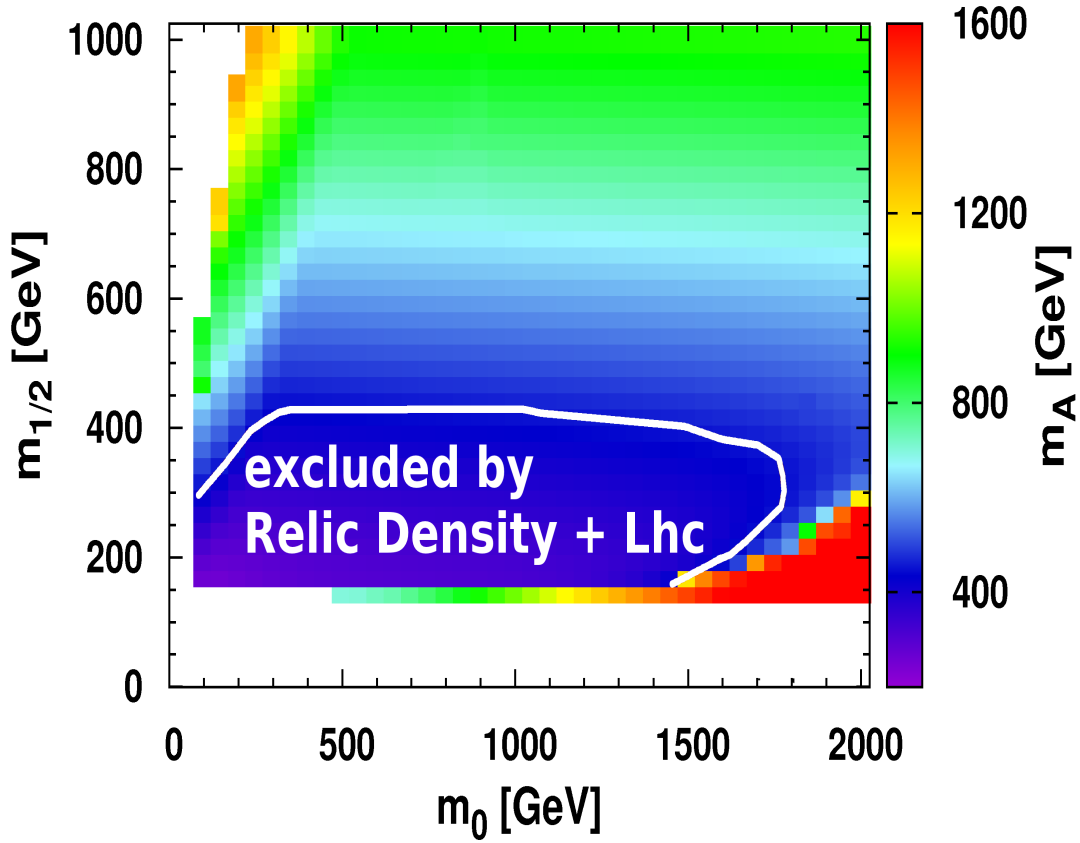


What about Higgs m_A limit?



(CMS PAS HIG-11-009)
Atlas similar

For tanβ ≈ 50
m_A > 440 GeV



CMSSM – electroweak and other Constraints

- Higgs Mass m_h — $m_h > 114.4$ GeV
- Myon g-2 — $\Delta a_\mu = a_\mu^{\exp} - a_\mu^{theo} = (30.2 \pm 12.4) \cdot 10^{-10}$
- $b \to s\gamma$ — $BR^{exp}(b \to s\gamma) = (3.55 \pm 0.24) \cdot 10^{-4}$
- $B_s \to \mu\mu$ — $BR^{exp}(B_s \to \mu\mu) < 1.1 \cdot 10^{-8}$
- $B \to \tau\nu$ — $BR^{exp}(B \to \tau\nu) = (1.68 \pm 0.31) \cdot 10^{-4}$
- Finding consistent points by minimizing a χ^2-function

$$\chi^2 = \left(\frac{\chi_{\mathrm{mod}} - \chi_{\exp}}{\sigma_{\exp}} \right)^2$$

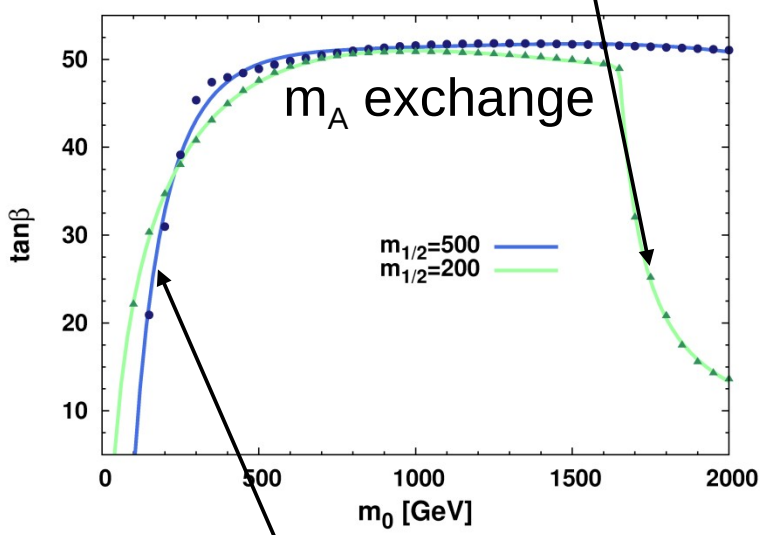
- Minimization by Minuit

$\longrightarrow$ Problem: 3 of 4 free CMSSM parameters are HIGHLY correlated

Examples for high correlation

For given m_0 only very specific values of tanβ

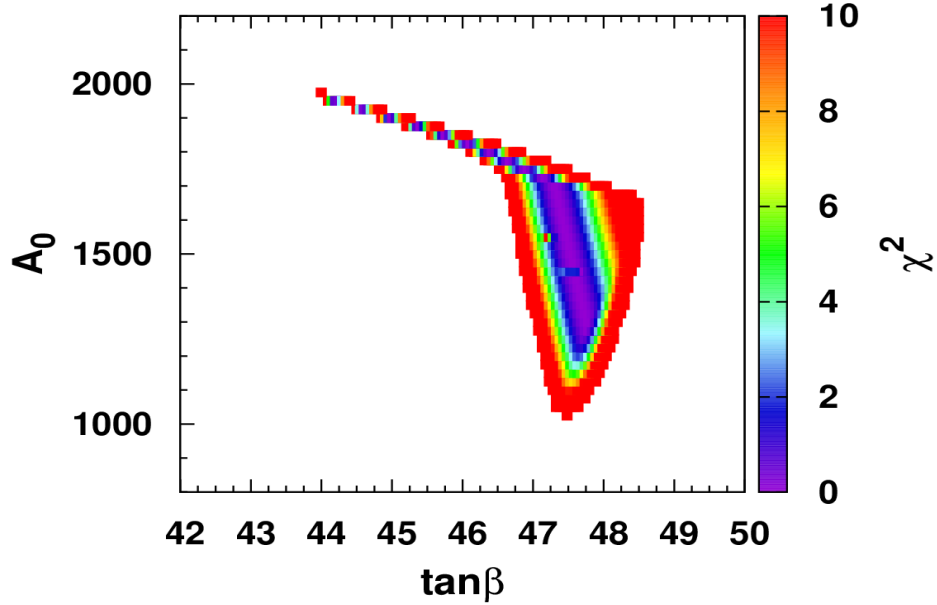
focus point region



co-annihilation region

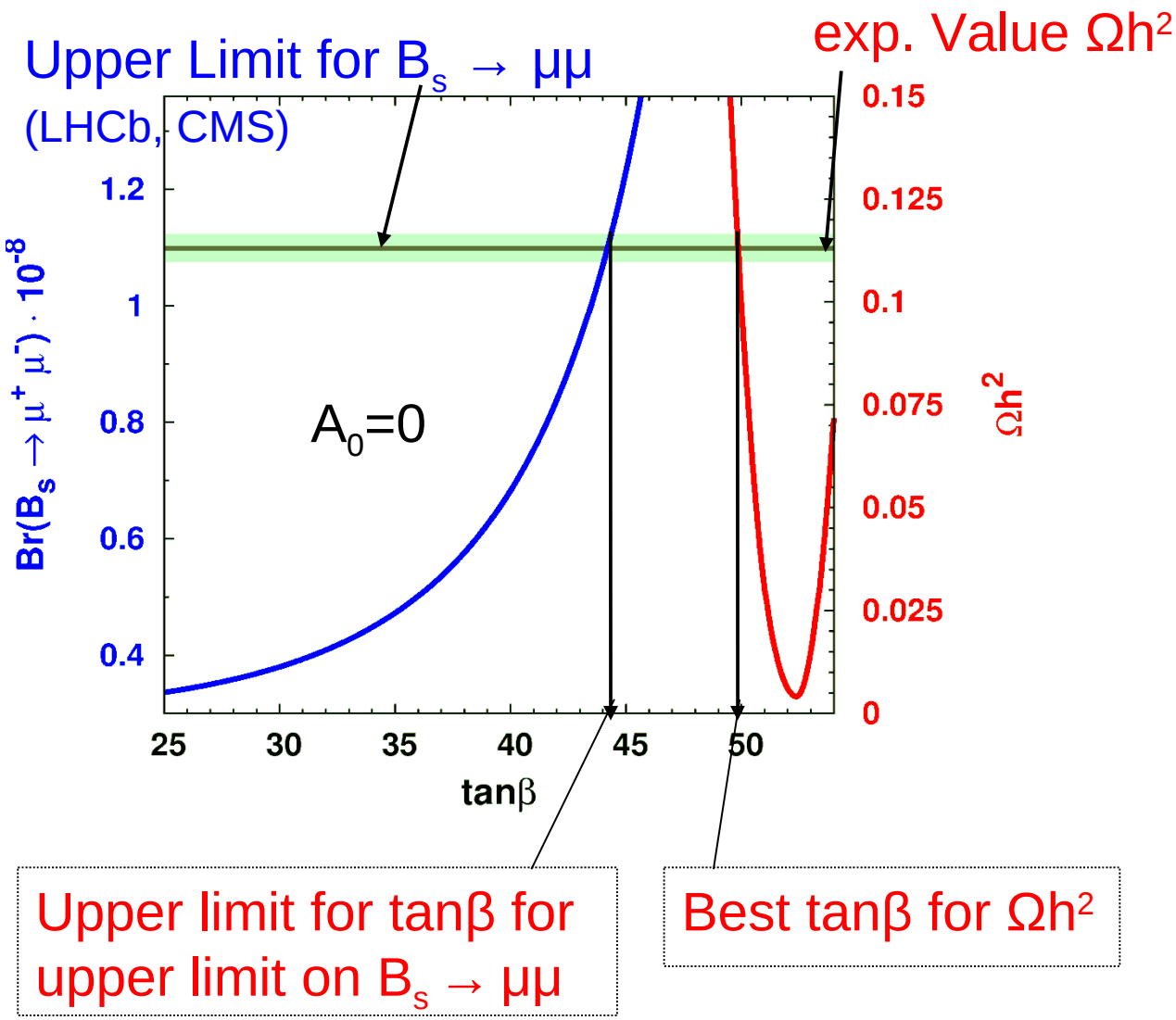
For given tanβ only very specific values of A_0

χ^2 for $B_s \to \mu\mu$ and Ωh^2



Origin of correlation: $B_s \to \mu\mu$, Ωh^2 } Both strongly dependent on tanβ

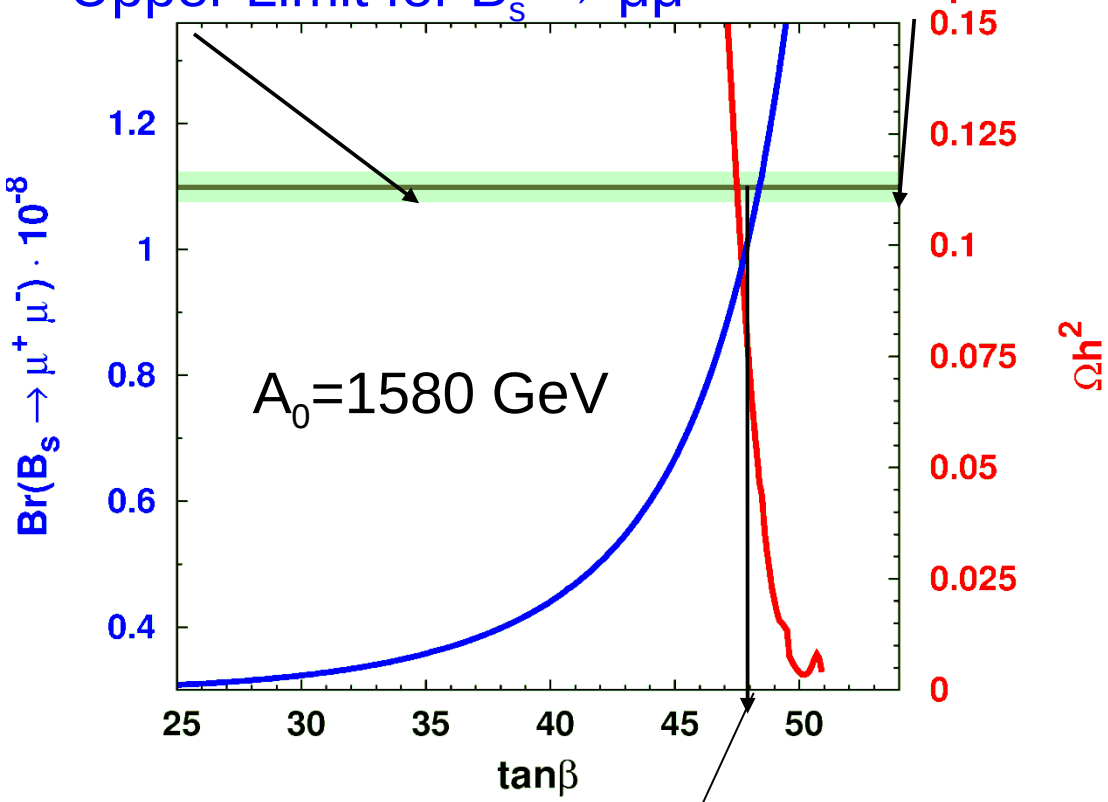
Origin of correlation

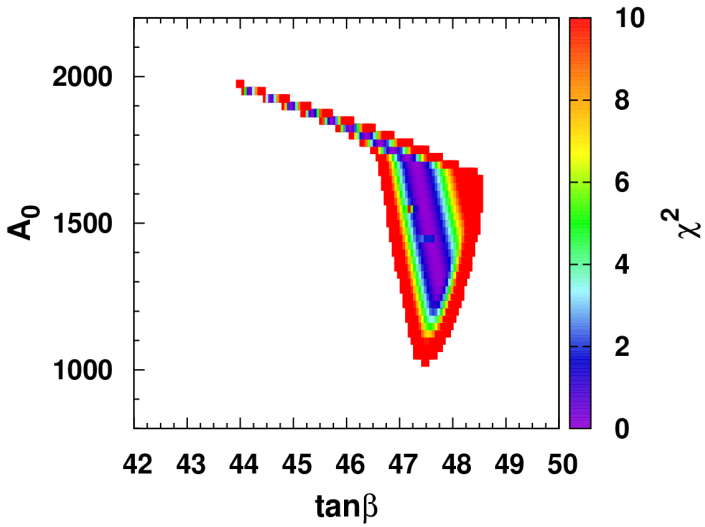


Origin of correlation

Upper Limit for $B_s \rightarrow \mu\mu$

exp. Value Ωh^2





Common tanβ can only be found for specific A_0 value

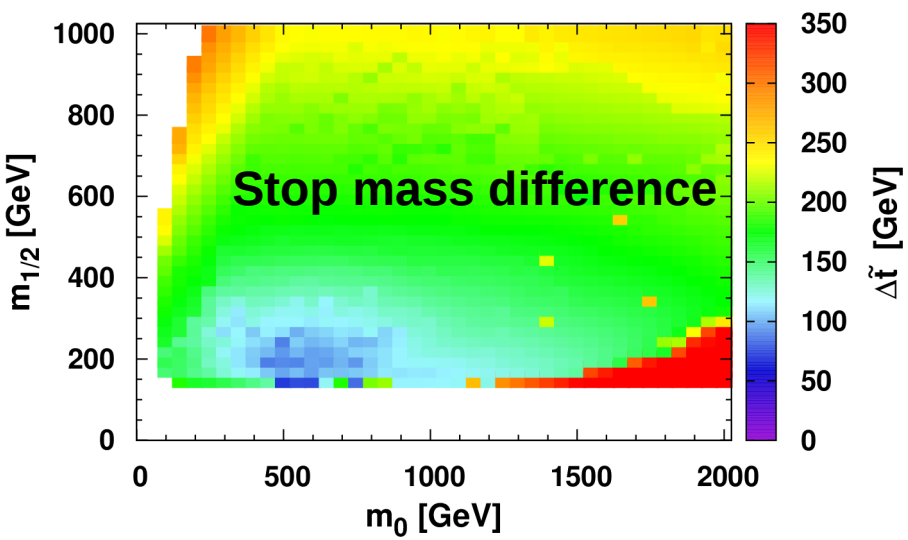
Best tanβ for $B_s \rightarrow \mu\mu$ and Ωh^2 simultaneously

Reason for strong A_0 dependence of $B_s \to \mu\mu$

arXiv:hep-ph/0203069v2

$$Br[B_s \to \mu^+\mu^-] = \frac{2\tau_B M_B^5}{64\pi} f_{B_s}^2 \sqrt{1-\frac{4m_l^2}{M_B^2}} \left[\left(1-\frac{4m_l^2}{M_B^2}\right)\left|\frac{(C_S-C_S')}{(m_b+m_s)}\right|^2 + \left|\frac{(C_P-C_P')}{(m_b+m_s)} + 2\frac{m_\mu}{M_{B_s}^2}(C_A-C_A')\right|^2\right]$$

$$C_S \simeq \frac{G_F\alpha}{\sqrt{2}\pi} V_{tb}V_{ts}^* \left(\frac{\tan^3\beta}{4\sin^2\theta_W}\right)\left(\frac{m_b m_\mu m_t \mu}{M_W^2 M_A^2}\right)\frac{\sin 2\theta_{\tilde{t}}}{2}\left(\frac{m_{\tilde{t}_1}^2 \log\left[\frac{m_{\tilde{t}_1}^2}{\mu^2}\right]}{\mu^2 - m_{\tilde{t}_1}^2} - \frac{m_{\tilde{t}_2}^2 \log\left[\frac{m_{\tilde{t}_2}^2}{\mu^2}\right]}{\mu^2 - m_{\tilde{t}_2}^2}\right)$$

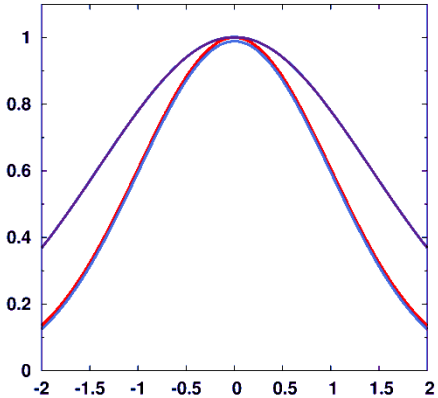


Becomes small, if $\tilde{t}_1 \approx \tilde{t}_2$ can be achieved by adjusting A_t, till mixing term ~ (A_t – μ/tanβ) becomes small.
Important only for light SUSY masses (see blue region)

How to treat theoretical errors?

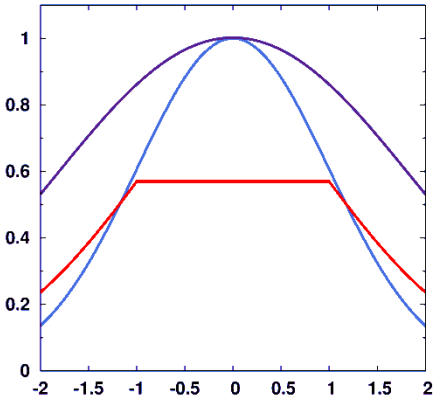
- Theoretical errors can be treated as nuisance parameters and integrated over in the probability distribution (=convolution for symm. distr.)
- If errors Gaussian, this corresponds to adding the experimental and theoretical errors in quadrature
- Assume $\sigma_{theo} \sim \sigma_{exp}$ (only then important)

Convolution of 2 Gaussians



$$\sigma_+^2 = \sigma_{theo}^2 + \sigma_{\exp}^2$$

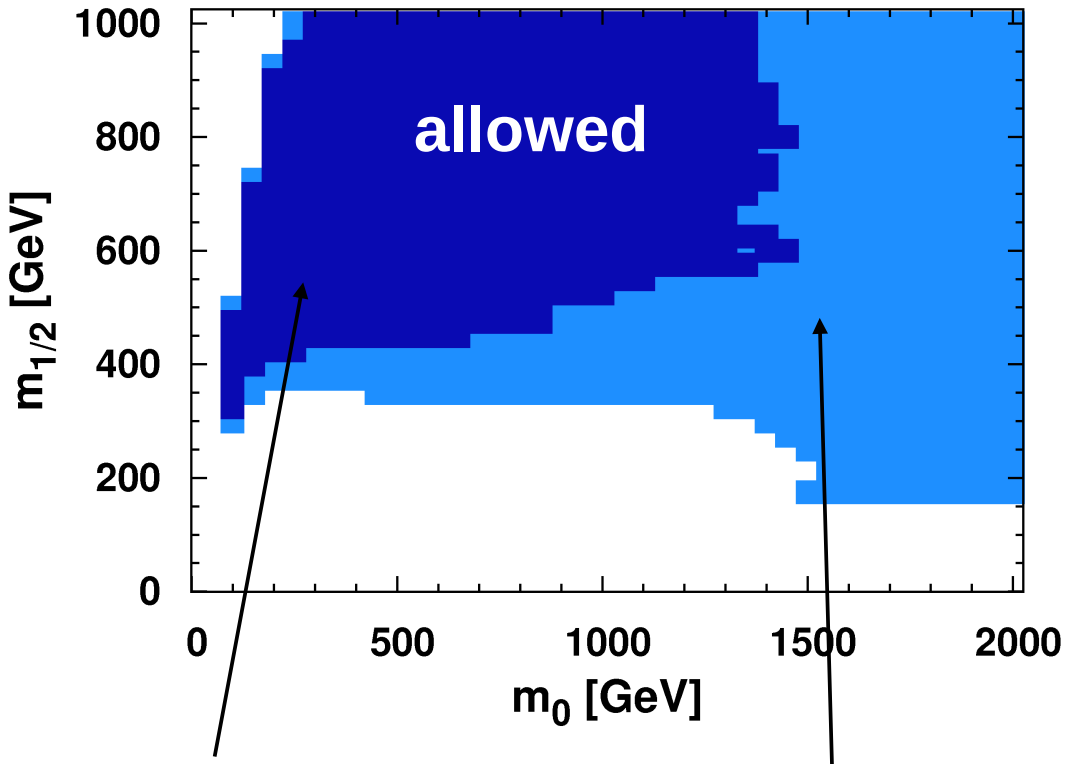
Convolution of Gaussian + “flat top Gaussian” (expected if theory errors indicate a range)



$$\sigma_+ \sim \sigma_{theo} + \sigma_{\exp}$$

Adding errors linearly more conservative approach for theory errors.

Difference between linear and quadratic error addition



95% CL (quad. Add.)

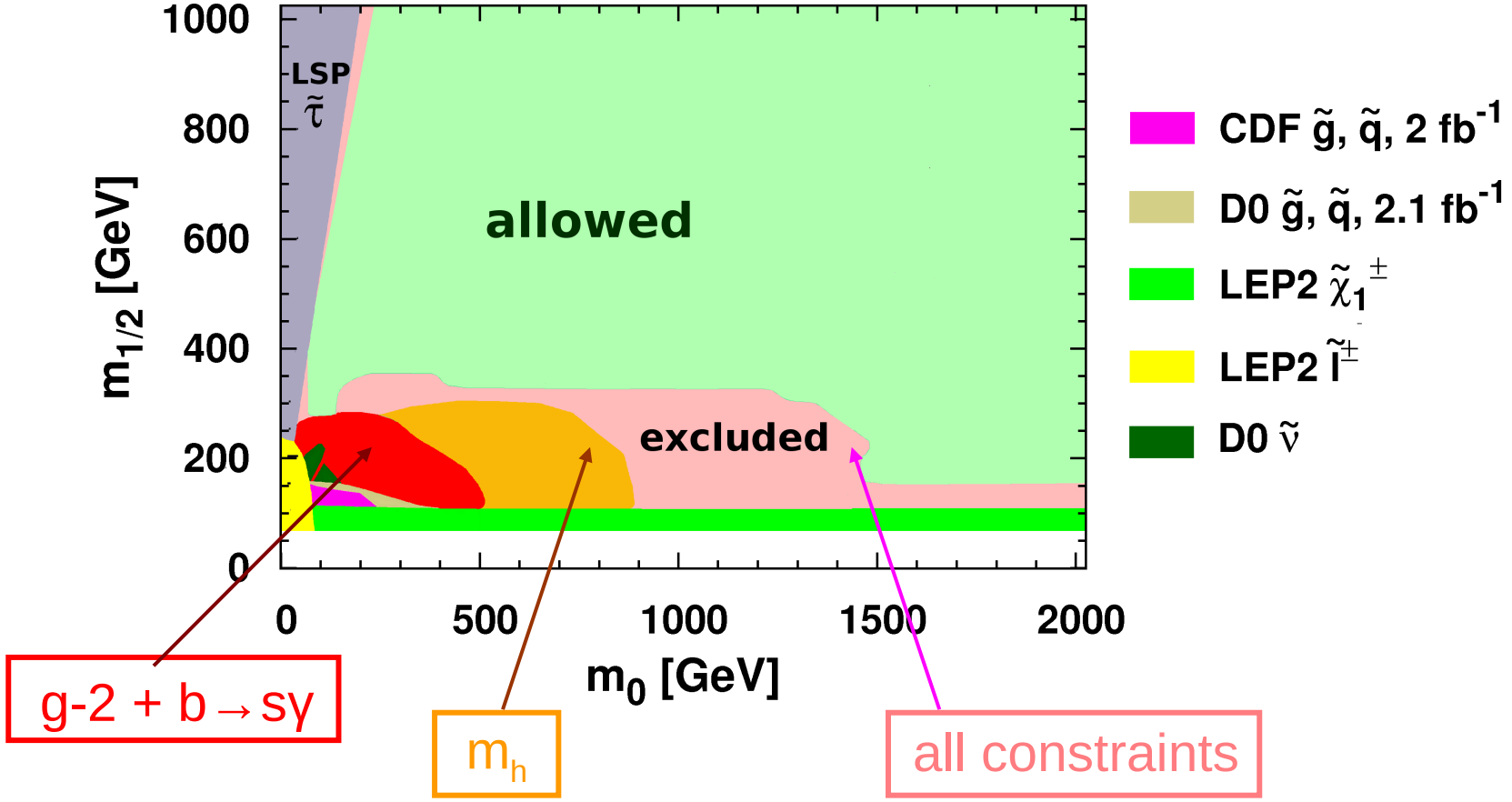
95% CL (lin. Add.)

mainly important for g-2, where theory and exp. Errors are similar and deviation from SM 3σ, so very sensitive for exclusion limit

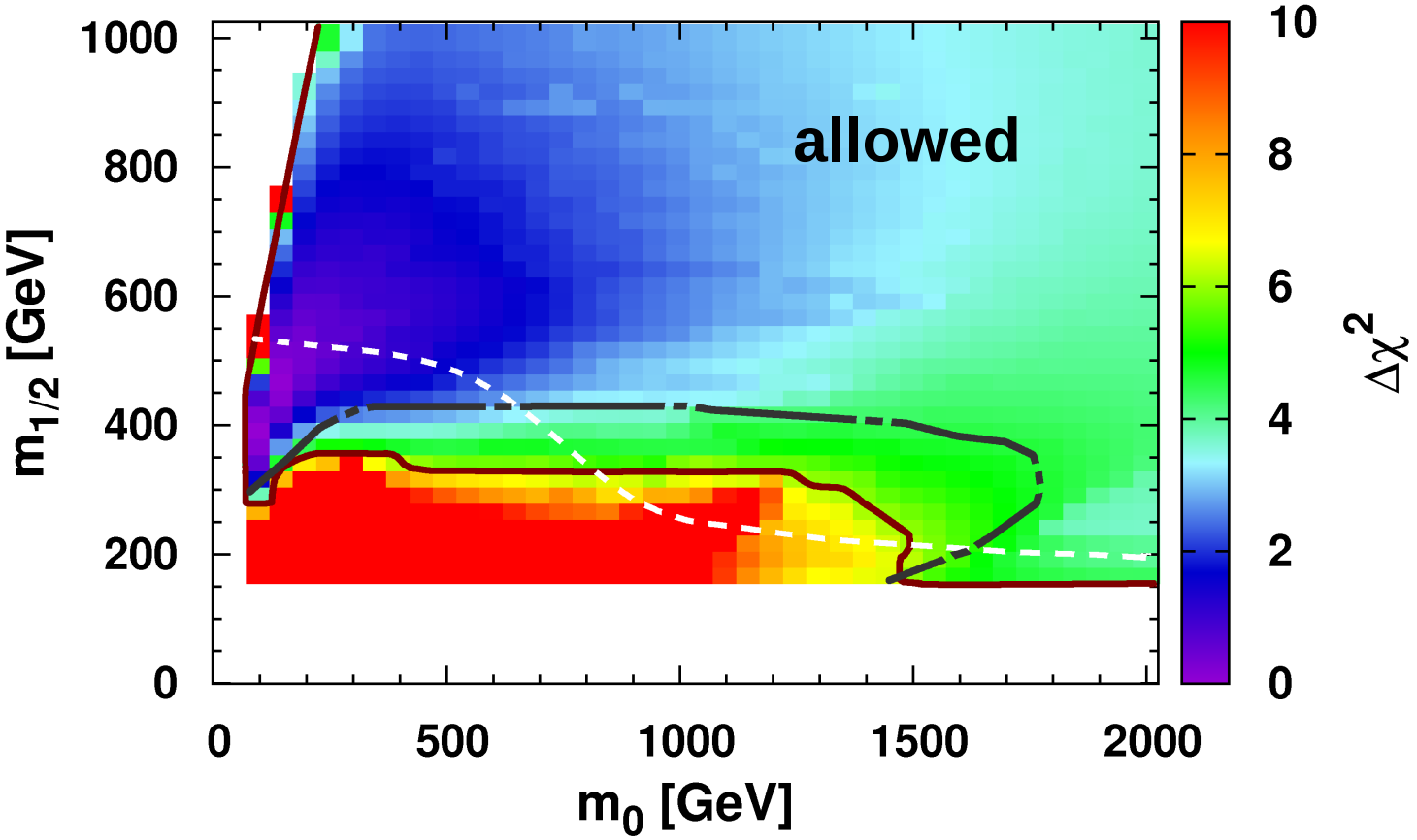
Errors for g-2 dominated by QCD LO- and NLO Corrections and light-by-light Contributions → not necessarily Gaussian error distribution

95% CL exclusion from cosmology/EW

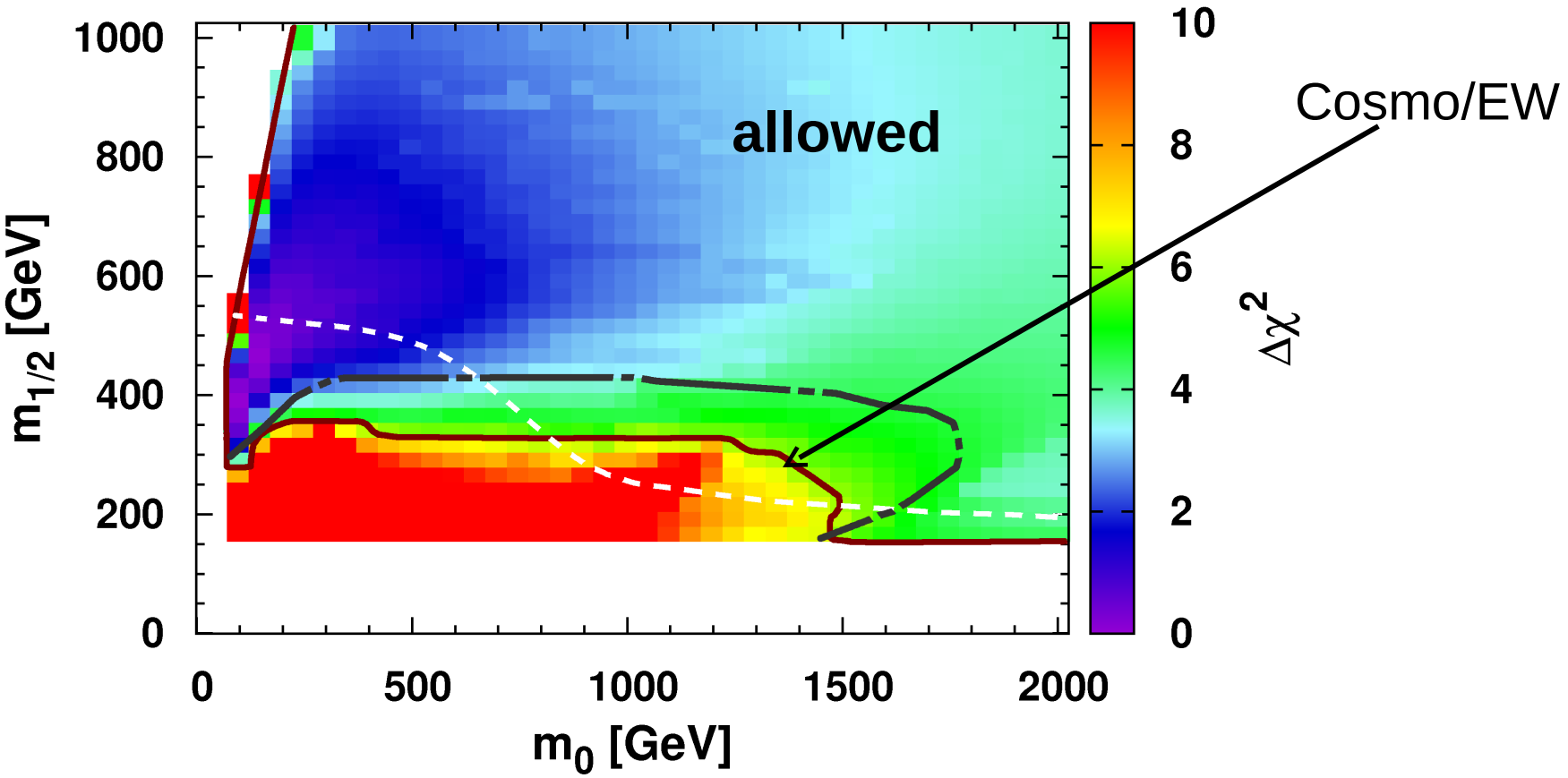
- Allowed parameter space (95% CL contour) in the m_0-$m_{1/2}$ plane including all constraints



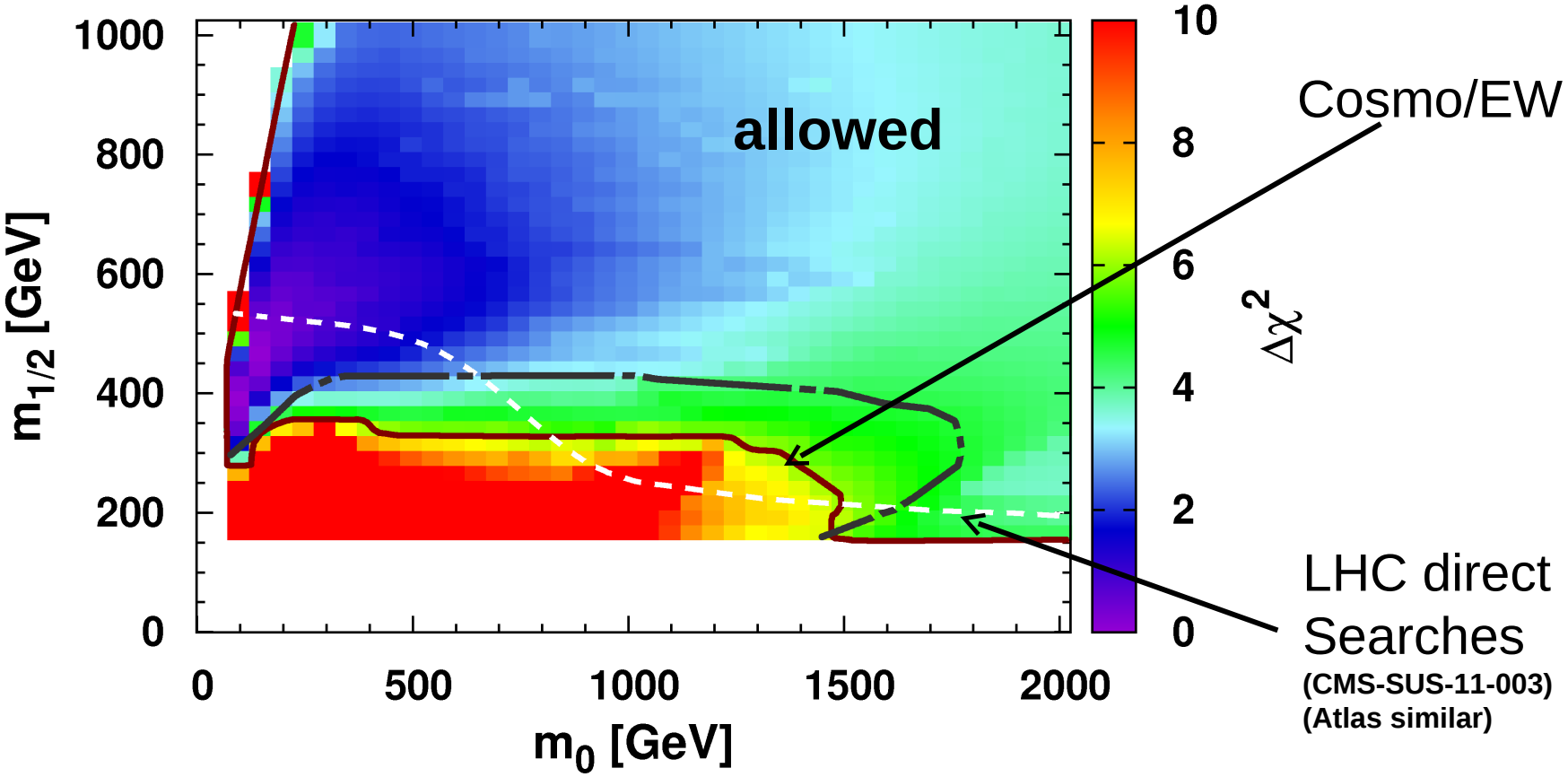
95% C.L. ($\Delta\chi^2$=5.99) exclusion contours



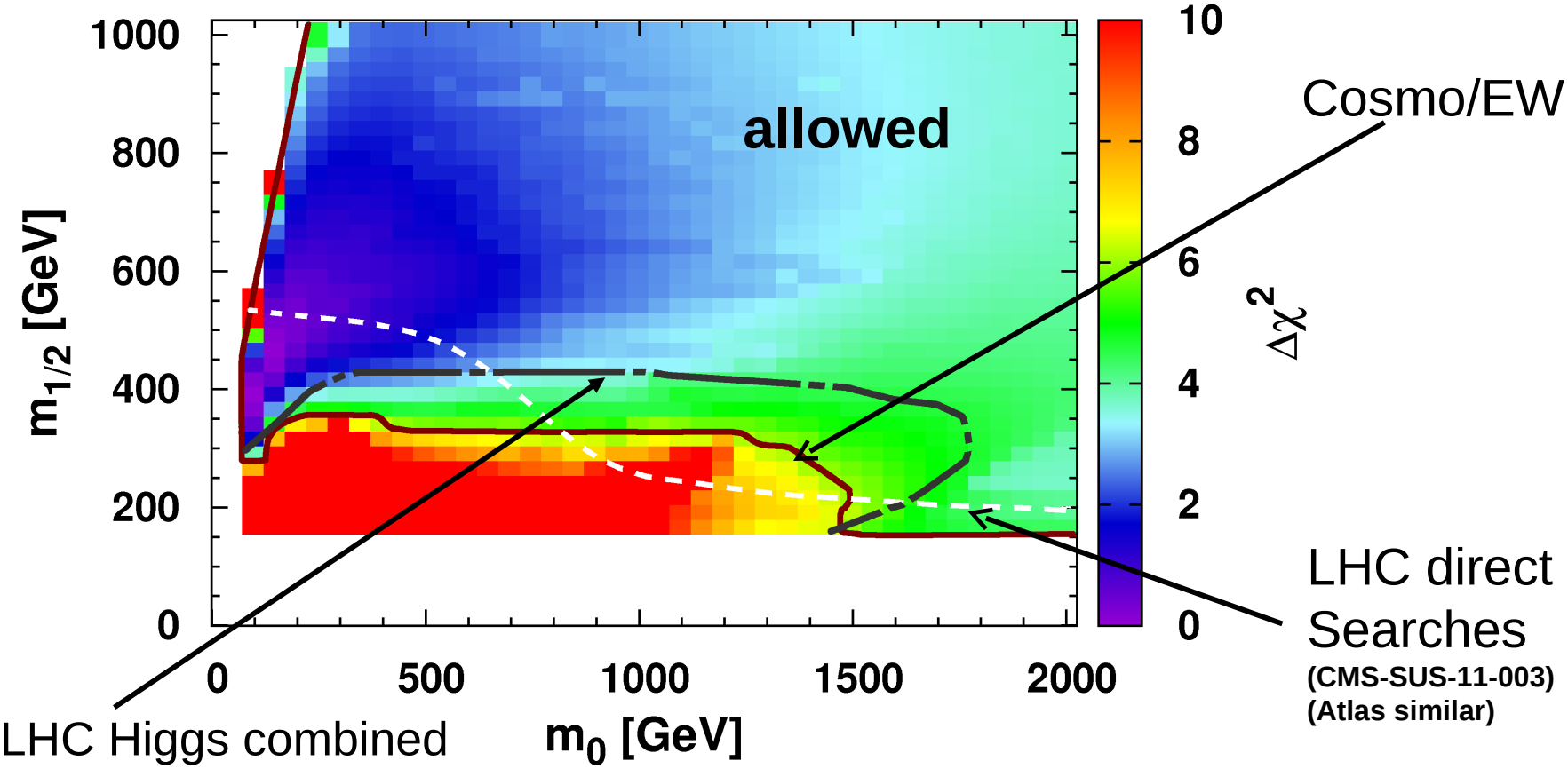
95% C.L. ($\Delta\chi^2$=5.99) exclusion contours



95% C.L. ($\Delta\chi^2$=5.99) exclusion contours



95% C.L. ($\Delta\chi^2$=5.99) exclusion contours



LHC Higgs combined
with cosmology (p. 6)

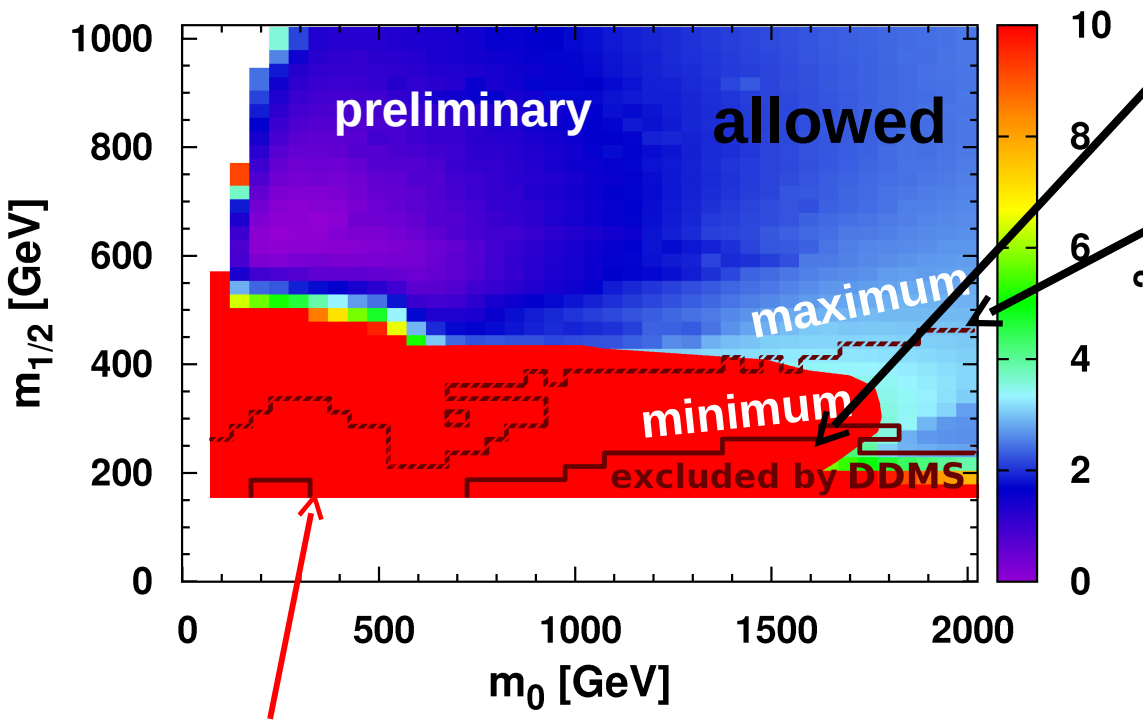
Including Direct Dark Matter Search

Problem: χN scattering cross sections depends on form factors

Lattice has strange quark in nucleus similar to light quarks (arXiv:0806.4744v3)

To be conservative use this smaller form factor-> excluded region small!

arXiv:0803.2360v2



minimum	**maximum**
$f_u^p = 0.02;$	$f_u^p = 0.023;$
$f_d^p = 0.026;$	$f_d^p = 0.033;$
$f_s^p = 0.02;$	$f_s^p = 0.26;$
$f_u^n = 0.014;$	$f_u^n = 0.018;$
$f_d^p = 0.036;$	$f_d^p = 0.042;$
$f_s^p = 0.02;$	$f_s^p = 0.26;$

arXiv:0806.4744v3
arXiv:1006.4811v2

Red=95% C.L. excluded by combined LHC/COSMO/EW

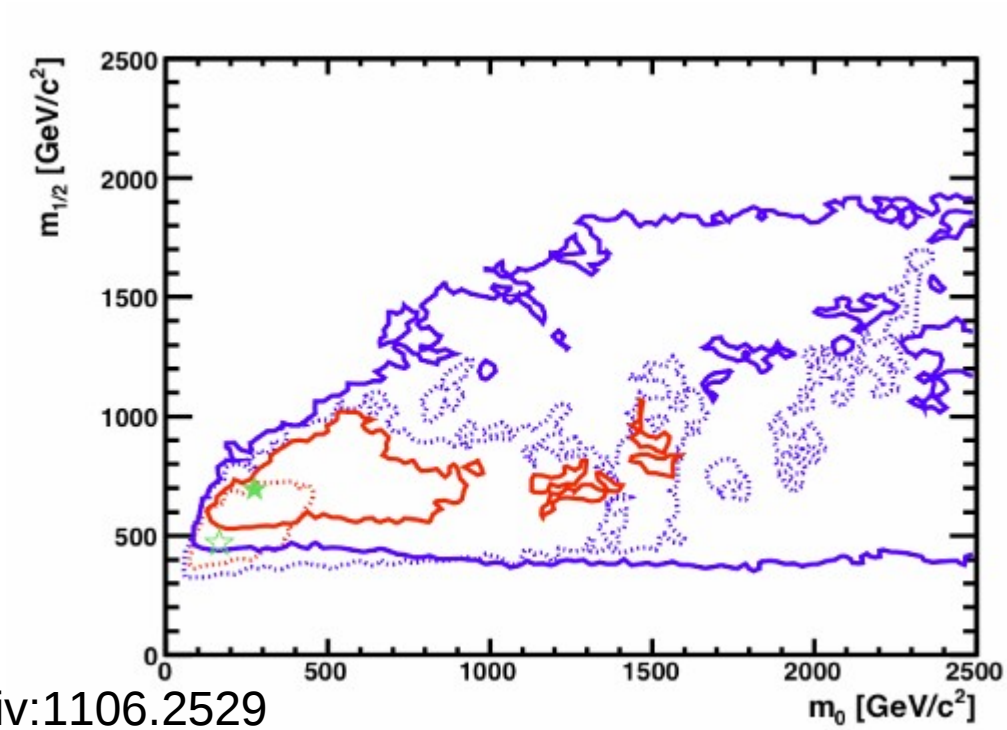
Conclusion

- Strong correlations between at least 3 of the 4 CMSSM parameters requires careful fitting strategies
- The multi-step strategy, which fits highly correlated parameters first, works efficiently
- The allowed region of CMSSM parameter space depends on the error assumptions → non-Gaussian errors more conservatively treated by linear addition of errors
- The relic density constraint requires large $\tan\beta$ ($\approx$50) outside co-annihilation regions
- Tension at large $\tan\beta$ from $B_s \to \mu\mu$ can be removed by large A_0

- No sign for SUSY yet, but lots of parameter space still allowed

Effect of LHC limit on allowed region

If added to χ^2 → not much changed
(in contrast to case when we would have added errors quad. → large shifts in allowed region by adding LHC to SHALLOW χ^2
(since minimum $\chi 2$ is increasing)



arXiv:1106.2529