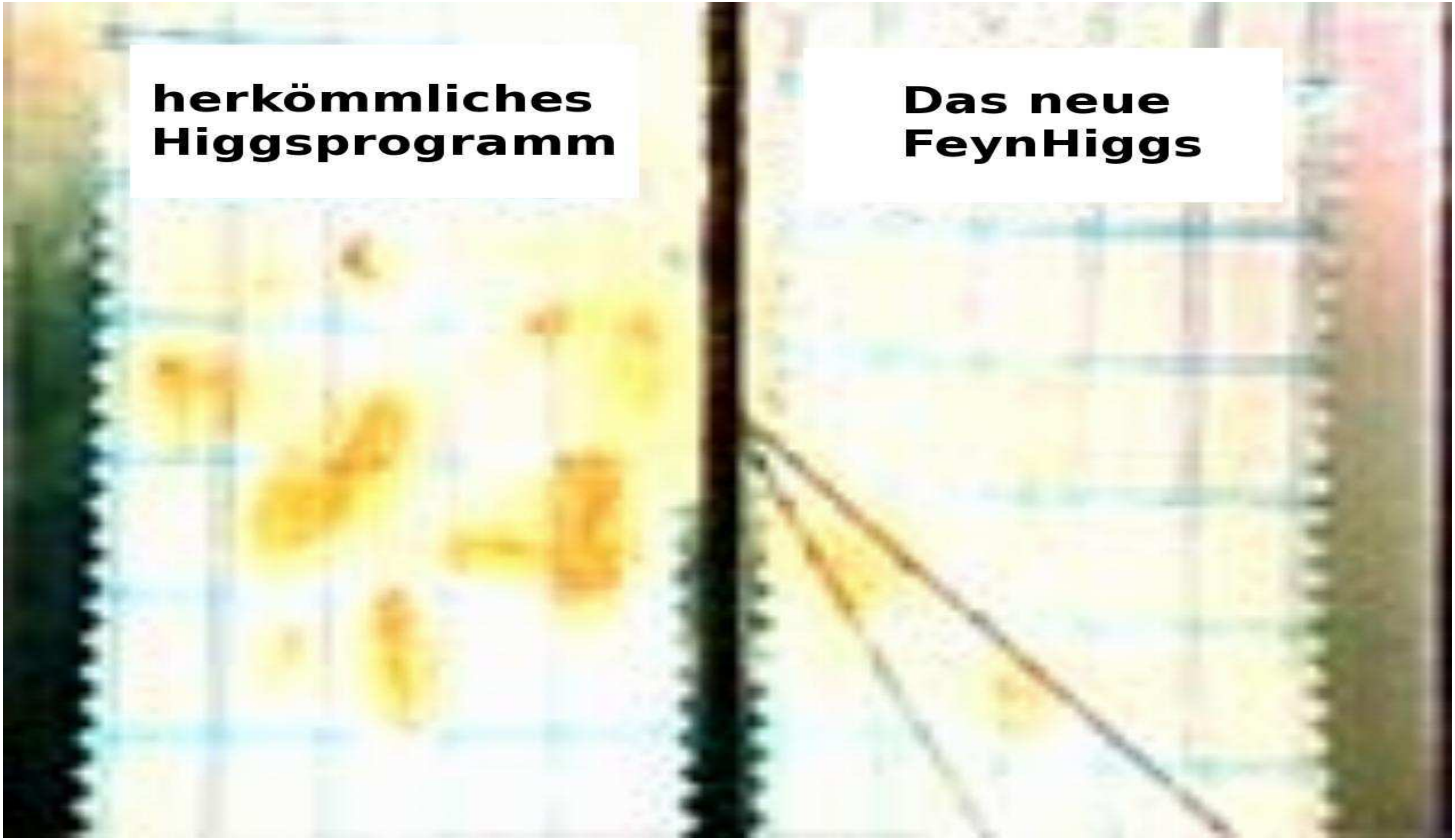

herkömmliches
Higgsprogramm
Das neue
FeynHiggs

# SUSY Prediction for Early LHC Data

*Sven Heinemeyer, IFCA (CSIC, Santander)*

CERN, 02/2009

based on collaboration with

*O. Buchmüller, R. Cavanaugh, A. de Roeck, J. Ellis, G. Isidori, K. Olive, P. Paradisi, F. Ronga, G. Weiglein*

1. Introduction and motivation

2. Predictions for early LHC data

3. Conclusions

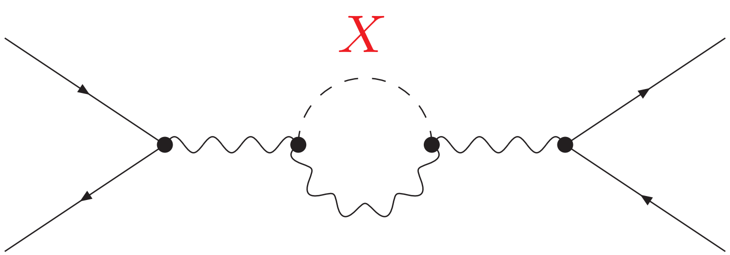
## 1. Introduction and motivation

Comparison of electro-weak precision observables with theory:

| EW Precision data: | | Theory: |
|---|---|---|
| $M_W, \sin^2\theta_{\rm eff}, a_\mu$ | $\leftrightarrow$ | SM, MSSM , . . . |

$\Downarrow$

Test of theory at quantum level: Sensitivity to loop corrections



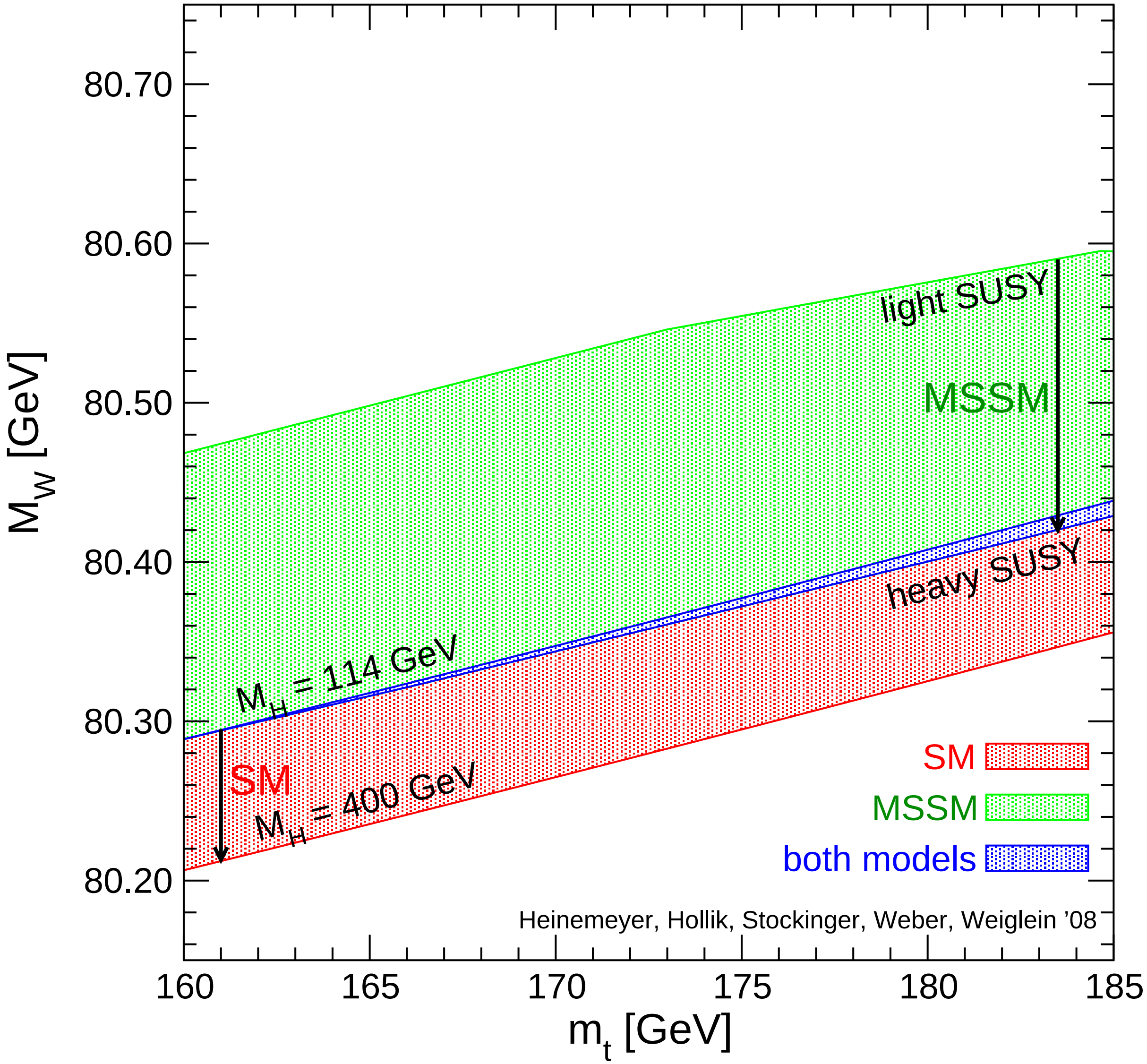

$\Downarrow$

Very high accuracy of measurements and theoretical predictions needed

- Which model fits better?
- Does the prediction of a model contradict the experimental data?

## Example: Prediction for $M_W$ in the SM and the MSSM :

[S.H., W. Hollik, D. Stockinger, A.M. Weber, G. Weigglein '07]




MSSM band:
scan over
SUSY masses

overlap:
SM is MSSM-like
MSSM is SM-like

SM band:
variation of $M_H^{\text{SM}}$

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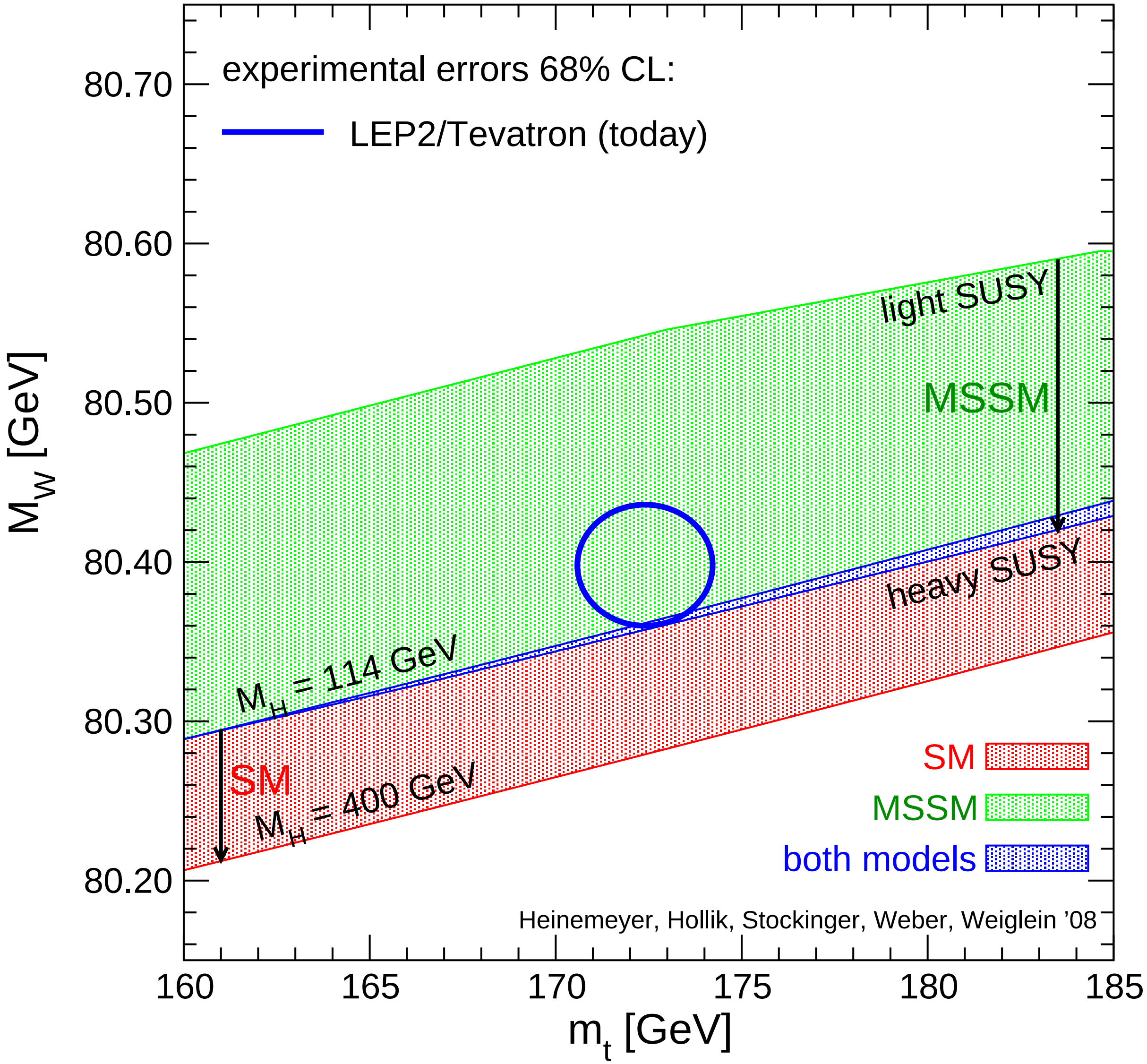


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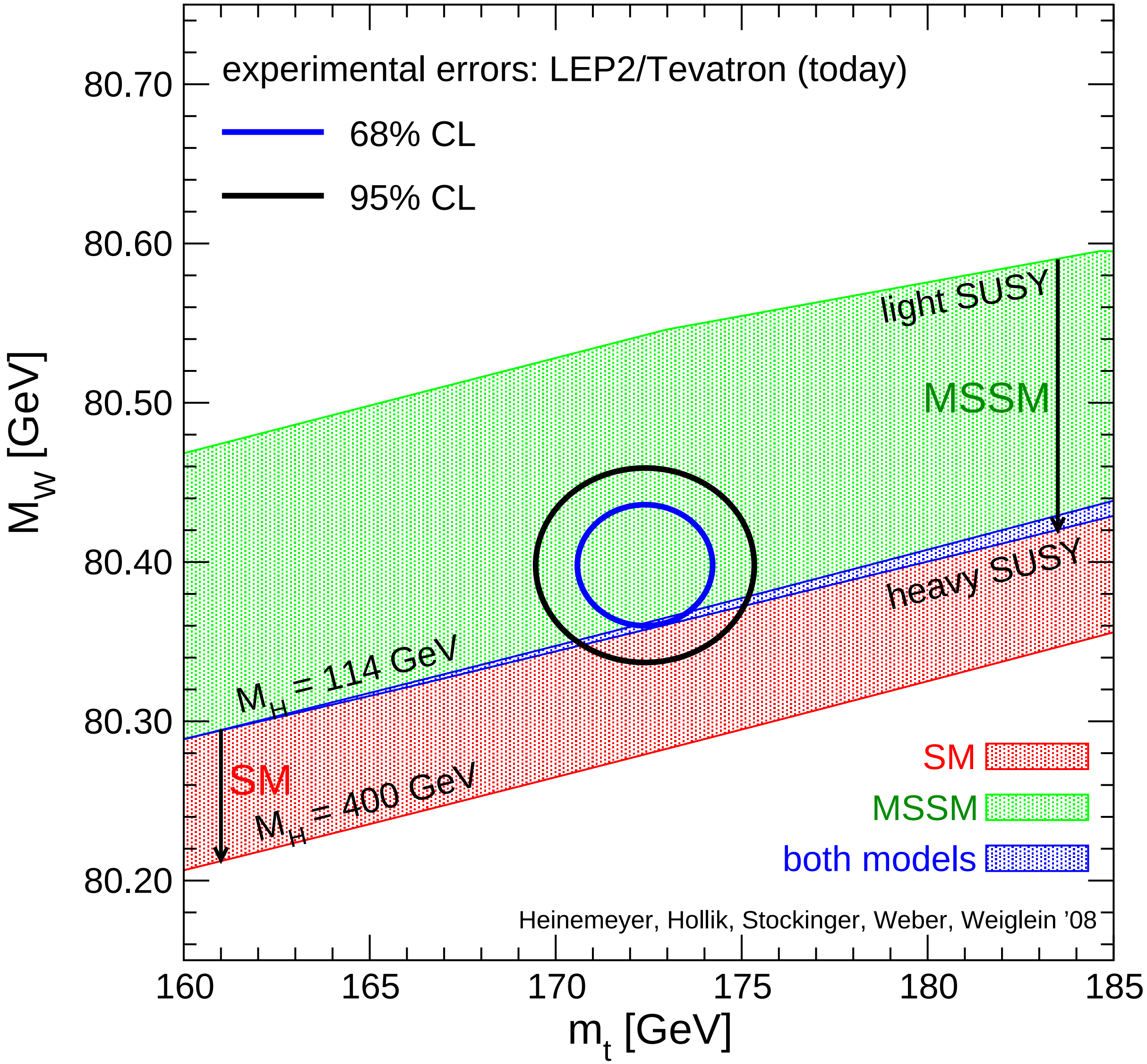


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## Indirect constraints on $M_{\text{SUSY}}$ from existing data?

- Electroweak precision observables (EWPO) ?
- $B$ physics observables (BPO) ?
- Cold dark matter (CDM) ?

$\Rightarrow$ combination of EWPO, BPO, CDM ?

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EWPO $M_W$ : information on $m_{\tilde{t}}$, $m_{\tilde{b}}$ or $M_A$, $\tan\beta$ or . . .

EWPO $(g-2)_\mu$ : information on $\tan\beta$ and/or $m_{\tilde{\chi}^0}$, $m_{\tilde{\chi}^\pm}$ and/or $m_{\tilde{\mu}}$, $m_{\tilde{\nu}_\mu}$

BPO BR$(b \to s\gamma)$ : information on $\tan\beta$ and/or $M_{H^\pm}$ and/or $m_{\tilde{t}}$, $m_{\tilde{\chi}^\pm}$

CDM (LSP gives CDM) : information on $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\tau}}$ or $M_A$ or . . .

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CDM (LSP gives CDM) : information on $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\tau}}$ or $M_A$ or ...

$\Rightarrow$ combination makes only sense if all parameters are connected!
$\Rightarrow$ GUT based models, ...

## Existing analyses for GUT based models: (involving precision observables)

### CMSSM/mSUGRA:

[J. Ellis, S.H., K. Olive, G. Weiglein '04, '06, '07] [J. Ellis, S.H., K. Olive, A.M. Weber, G. Weiglein '07]

[E. Baltz, P. Gondolo '04]

[R. de Austri, R. Trotta and L. Roszkowski '06, '07]

[B. Allanach, C. Lester and A.M. Weber '06, '07]

[O. Buchmueller et al. '07]

### NUHM (Non-Universal Higgs Mass model):

[J. Ellis, S.H., K. Olive, G. Weiglein '06]

[J. Ellis, S.H., K. Olive, A.M. Weber, G. Weiglein '07]

[J. Ellis, T. Hahn, S.H., K. Olive, G. Weiglein '07]

### VCMSSM (Very Constrained MSSM):

[J. Ellis, S.H., K. Olive, G. Weiglein '06]

### mSUGRA (GDM) (Gravitino Dark Matter):

[J. Ellis, S.H., K. Olive, G. Weiglein '06]

### CMSSM, mGMSB, mAMSB:

[S.H., X. Miao, S. Su, G. Weiglein '08]

### Finite Unified Theories:

[S.H., M. Mondragón, G. Zoupanos '07]

## Different methods:

### 1.) Scanning:

– 3-dim scans (possibly with CDM fixing one dimension)

[*J. Ellis, T. Hahn, SH, K. Olive, A.M. Weber, G. Weiglein '04, '06, '07*]

– multi-dim scans

[*O. Buchmueller et al. '07*] [*S.H., X. Miao, S. Su, G. Weiglein '08*]

– multi-dim scans (with Markov Chain Monte Carlo technique)

[*E. Baltz, P. Gondolo '04*] [*R. de Austri, R. Trotta and L. Roszkowski '06, '07*]

[*B. Allanach, C. Lester and A.M. Weber '06, '07*] [*O. Buchmueller et al. '08*]

⇒ here: results using last two

### 2.) Fitting:

– Frequentist

[*J. Ellis, T. Hahn, SH, K. Olive, A.M. Weber, G. Weiglein '04, '06, '07*]

[*O. Buchmueller et al. '07, '08*] [*S.H., X. Miao, S. Su, G. Weiglein '08*]

– Bayesian (⇒ see talk by L. Roszkowski last week)

[*R. de Austri, R. Trotta and L. Roszkowski '06, '07*]

[*B. Allanach, C. Lester and A.M. Weber '06, '07*]

⇒ focus on Frequentist here

### 3.) Priors . . . (flat)

## The models: 1.) CMSSM (or mSUGRA):

⇒ Scenario characterized by

$$m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ \mathrm{sign}\,\mu$$

$m_0$ : universal scalar mass parameter

$m_{1/2}$ : universal gaugino mass parameter

$A_0$ : universal trilinear coupling

} at the GUT scale

$\tan\beta$ : ratio of Higgs vacuum expectation values

$\mathrm{sign}(\mu)$ : sign of supersymmetric Higgs parameter

⇒ particle spectra from renormalization group running to weak scale

## The models: 2.) NUHM1: (Non-universal Higgs mass model)

Assumption: no unification of scalar fermion and scalar Higgs parameter at the GUT scale

⇒ effectively $M_A$ or $\mu$ as free parameters at the EW scale

> ⇒ besides the CMSSM parameters
>
> $M_A$ or $\mu$

Further extension: NUHM2:

Assumption: no unification of the Higgs parameters at the GUT scale

⇒ effectively $M_A$ and $\mu$ as free parameters at the EW scale

> ⇒ besides the CMSSM parameters
>
> $M_A$ and $\mu$

## 2. Predictions for early LHC data

– combine all electroweak precision data as in the SM
– combine with $B$ physics observables
– combine with CDM and $(g-2)_\mu$
– include SM parameters with their errors: $m_t$, $M_Z$, $\Delta\alpha_{\text{had}}$

⇒ $\chi^2$ function

→ scan over the full CMSSM/NUHM1 parameter space

$\sim$ 2.5 $10^7$ points samples with MCMC

(comparison: L.R. et al.: 0.04 $10^7$ points)

statistical measure: $\chi^2$ function (Frequentist, no priors)

→ final minimum: Minuit

$\Delta\chi^2$: 68, 95% C.L. contours

⇒ preferred CMSSM/NUHM1 parameters
⇒ LHC/ILC reach

## Best-fit points:

CMSSM:

$m_{1/2} = 310$ GeV, $m_0 = 60$ GeV, $A_0 = 240$ GeV,

$\tan\beta = 11$, $\mu = 380$ GeV, $M_A = 410$ GeV

$\chi^2/N_{\rm dof} = 20.4/19$ (37.3 % probability)

$\Rightarrow$ very similar to SPS 1a :-)

NUHM1:

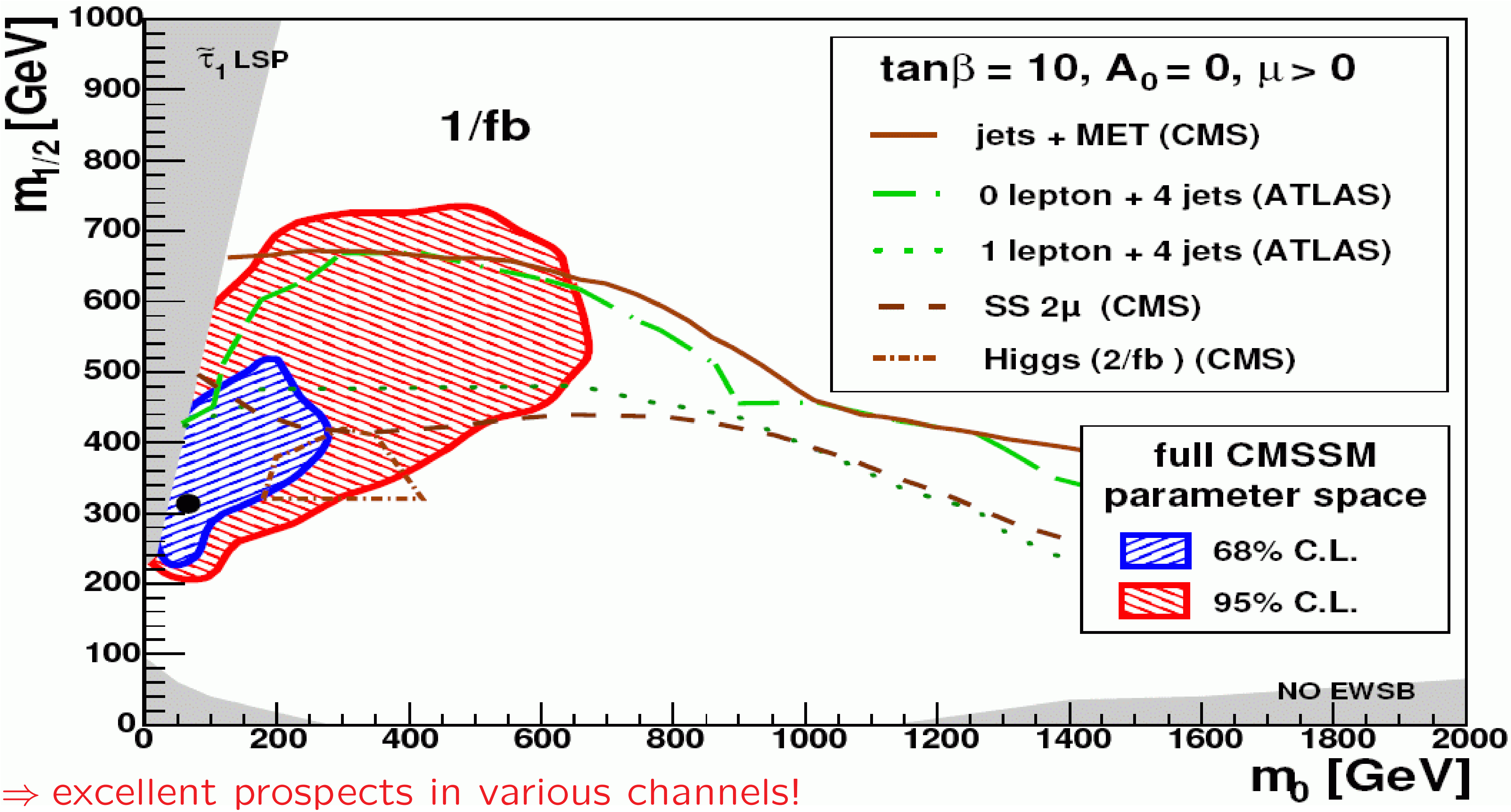
$m_{1/2} = 240$ GeV, $m_0 = 100$ GeV, $A_0 = -930$ GeV,

$\tan\beta = 7$, $\mu = 870$ GeV, $M_A = 300$ GeV

(39 % probability)

## LHC (CMS) reach with 1 $fb^{-1}$:

[CMS '07]




⇒ excellent prospects in various channels!

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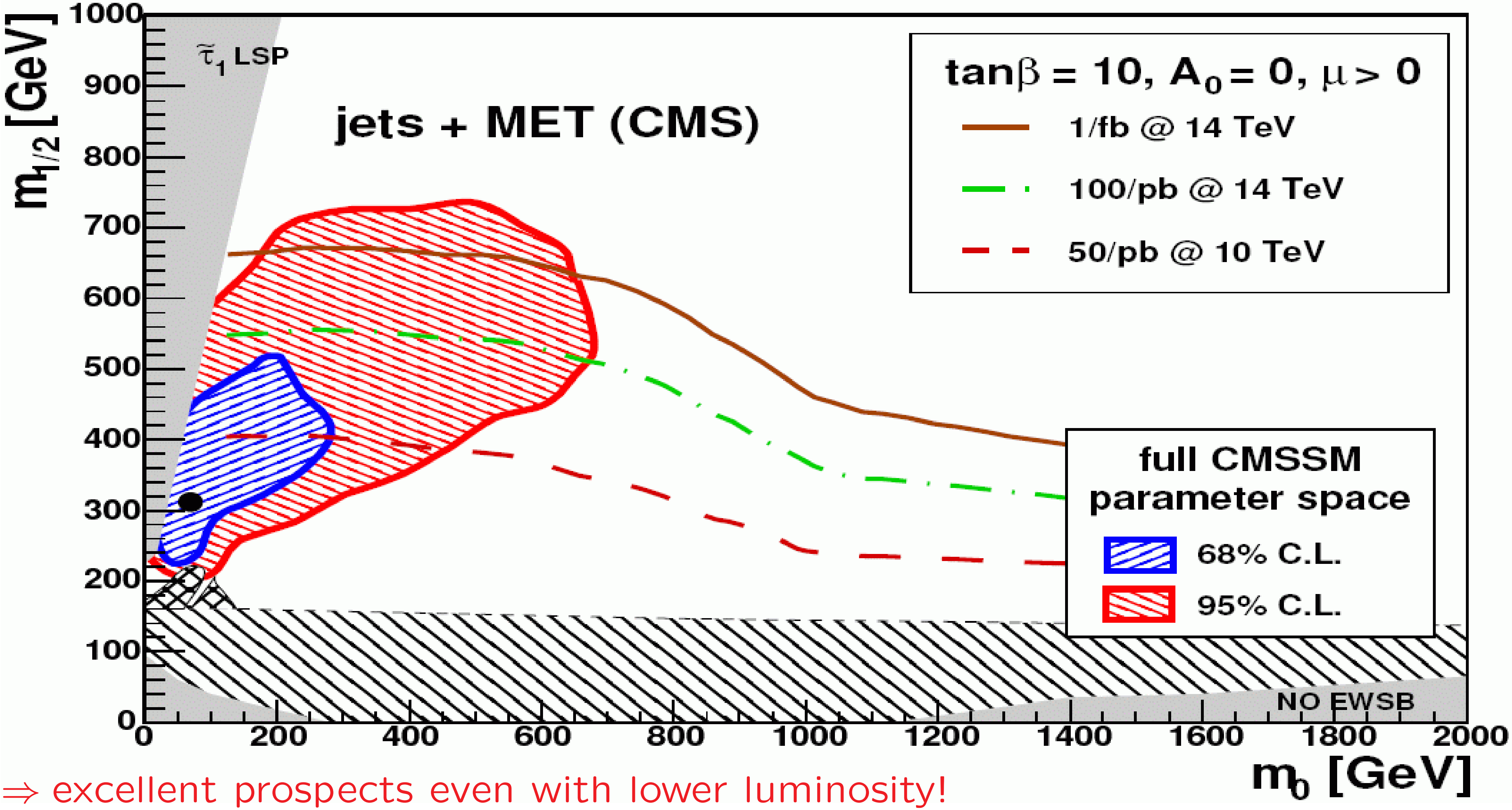


⇒ excellent prospects even with lower luminosity!

# LHC (CMS) reach with 1 $fb^{-1}$: NUHM1 analysis

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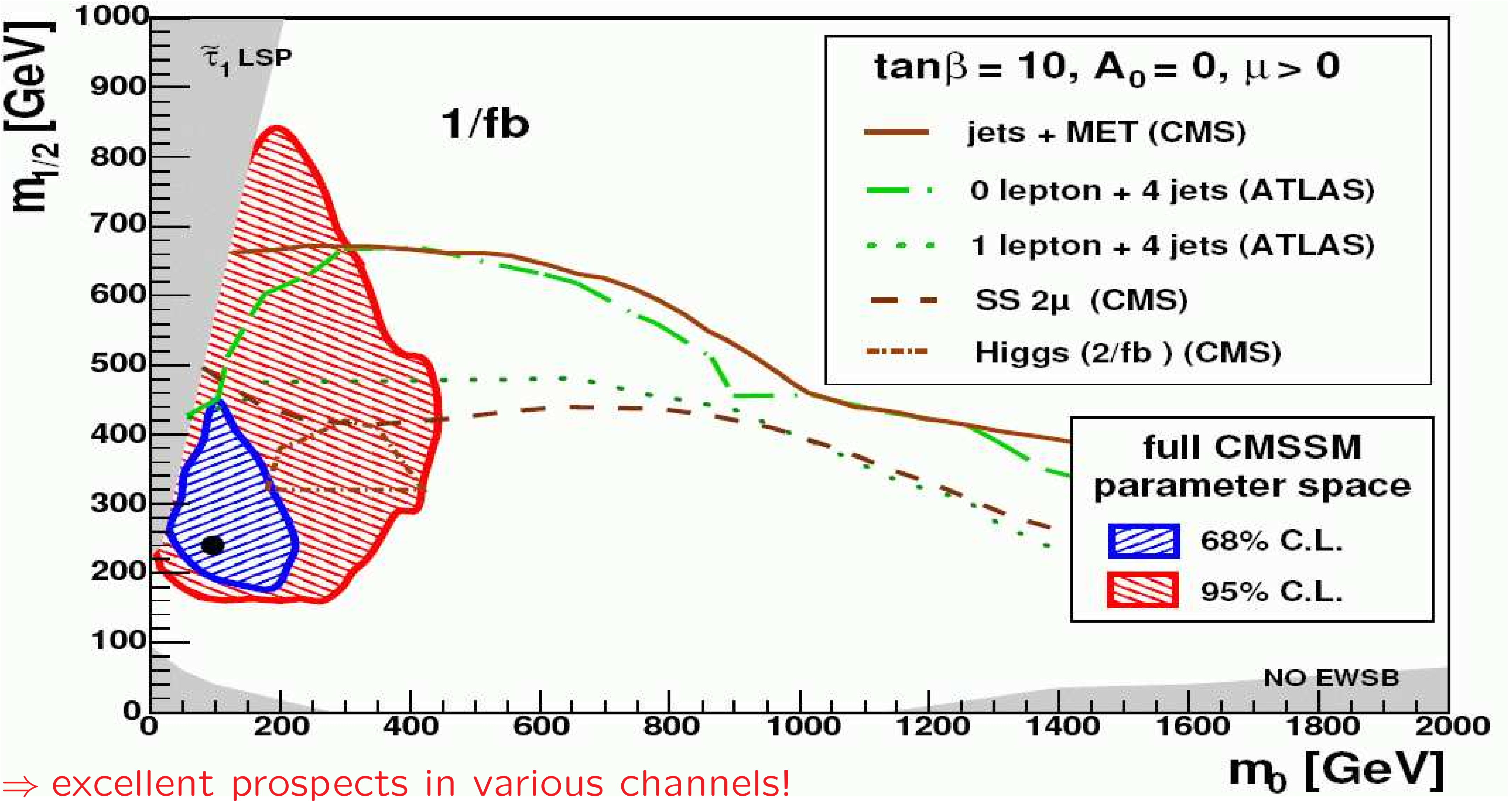


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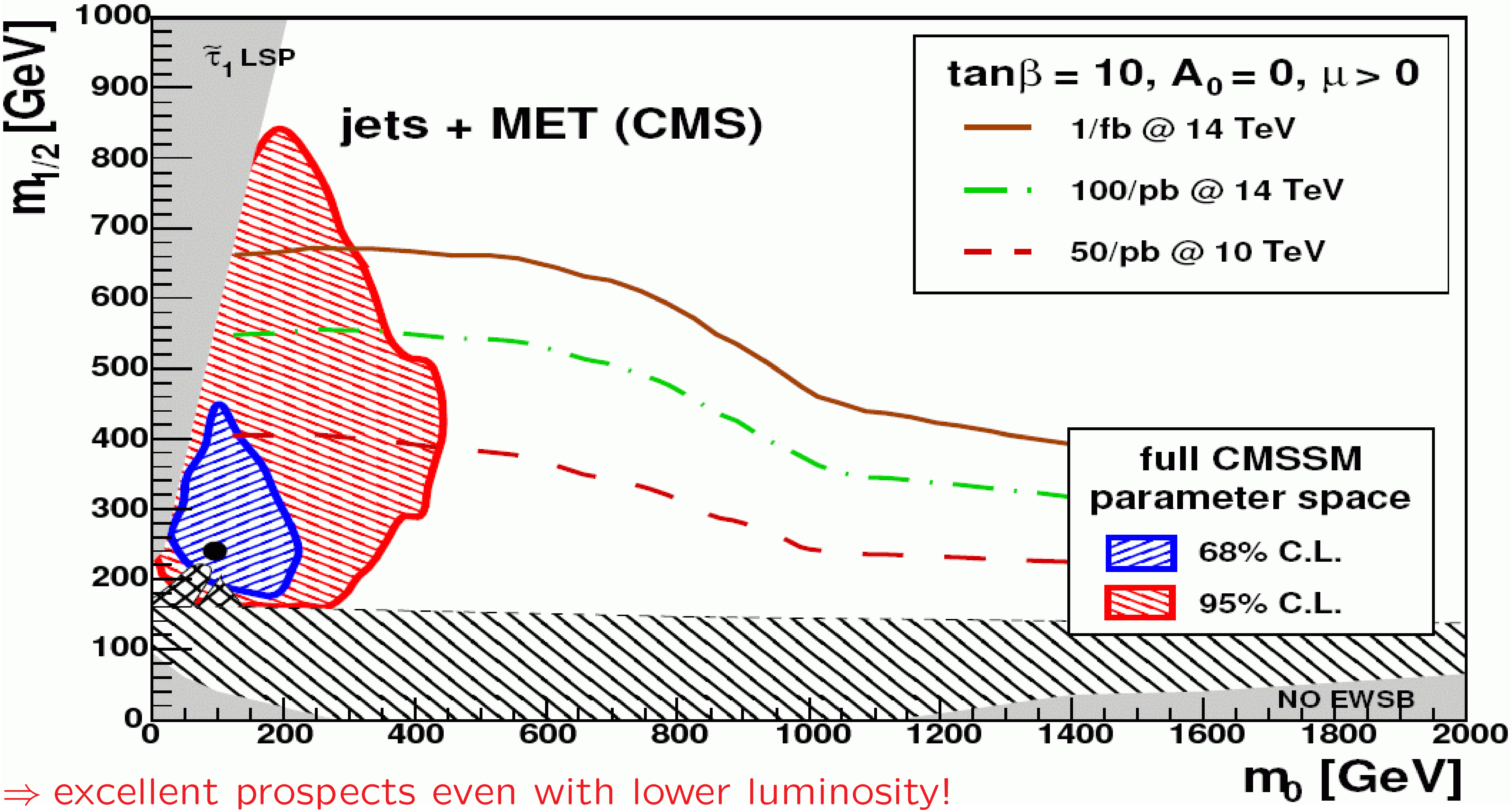
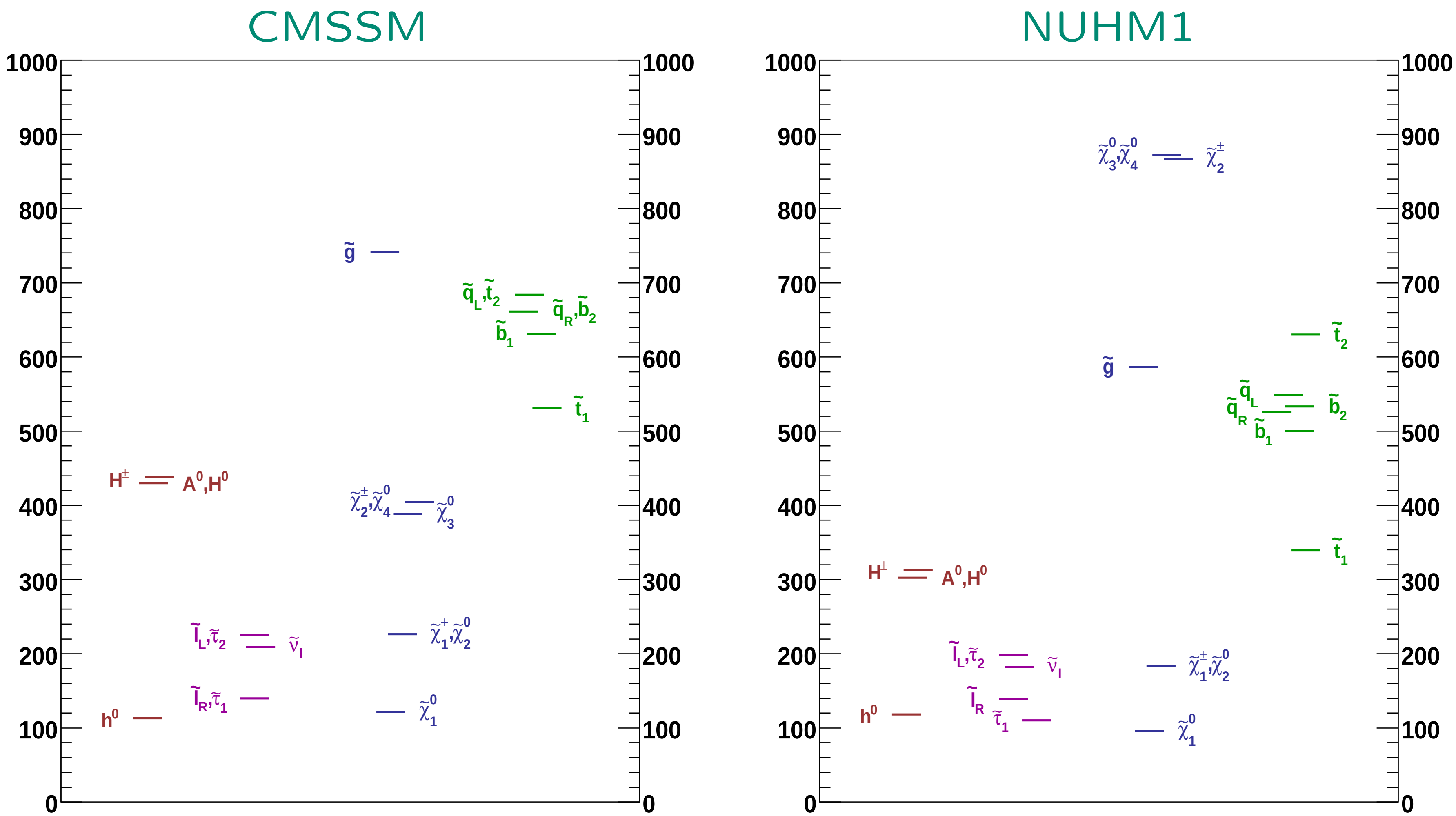



⇒ excellent prospects even with lower luminosity!

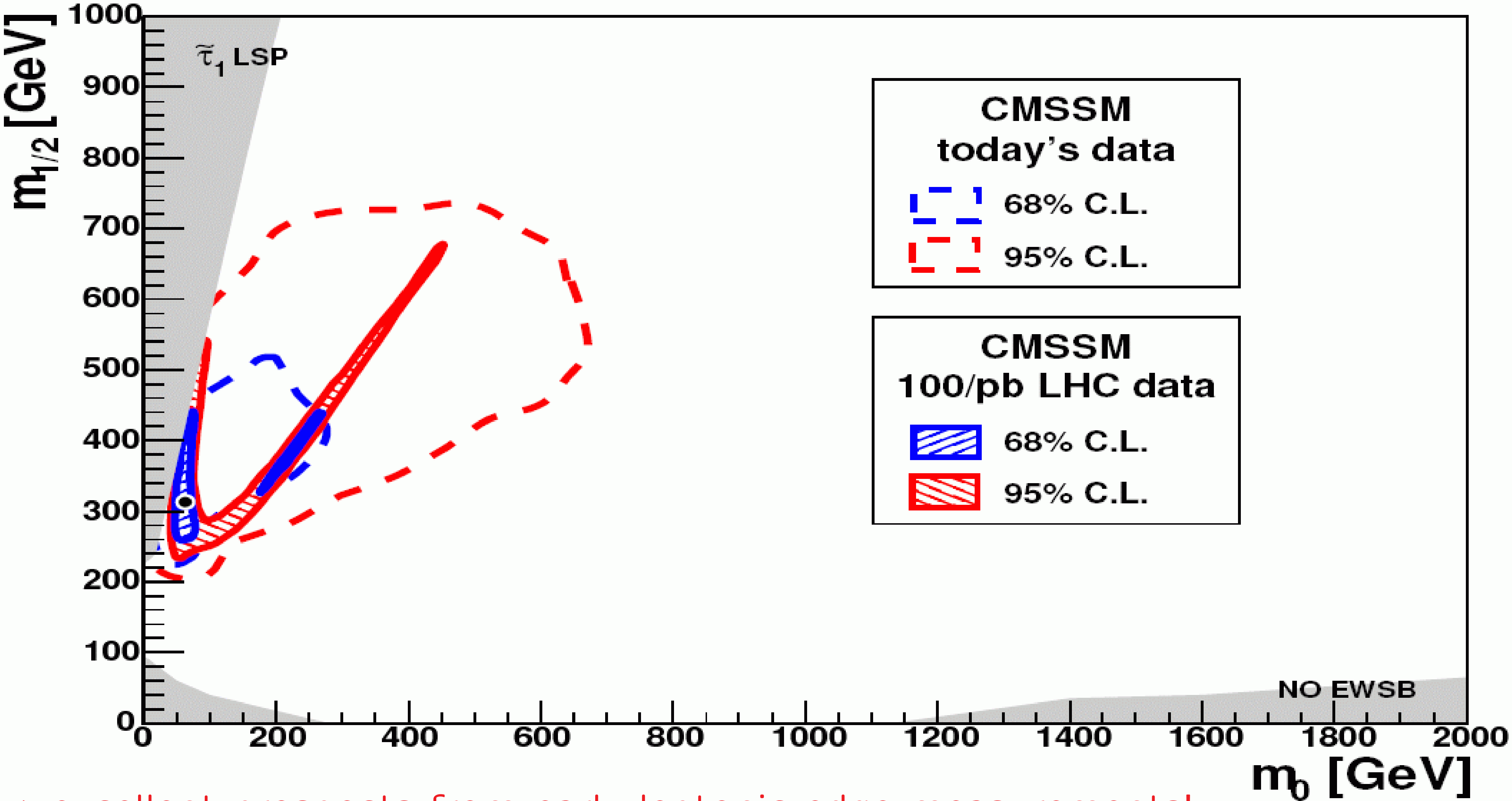
# Masses for best-fit points:




⇒ largely accessible spectrum for LHC and ILC

## LHC (CMS) reach with 1 $fb^{-1}$:

[CMS '07] including leptonic edge measurements




⇒ excellent prospects from early leptonic edge measurements!

# 3. Conclusinos

- Idea: Predict most probable MSSM parameter regions
  using existing data: EWPO, BPO, CDM, . . .

- Models: CMSSM, NUHM1

- statistical measure: $\chi^2$ function (Frequentist, no priors)
  $\sim 2.5\ 10^7$ points samples with MCMC
  $\Delta\chi^2$: 68, 95% C.L. contours

- Best-fit points:
  CMSSM: $m_{1/2} = 310$ GeV, $m_0 = 60$ GeV, $A_0 = 240$ GeV,
  $\tan\beta = 11$, $\mu = 380$ GeV, $M_A = 410$ GeV
  $\Rightarrow$ very similar to SPS 1a :-)
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  $\tan\beta = 7$, $\mu = 870$ GeV, $M_A = 300$ GeV

- 95% C.L. areas: mostly covered with $\sim 1\ \text{fb}^{-1}$ (u.d.!)
  $\Rightarrow$ early LHC data could be very conclusive!