The origin of matter

EWBG, NCDM & light stops

— Neutralino dark matter

— Electroweak baryogenesis

— The supersymmetric origin of matter

C.Balázs, M.Carena, A. Menon, D.E.Morrissey, C.E.M.Wagner

PRD71 075002 (`05)

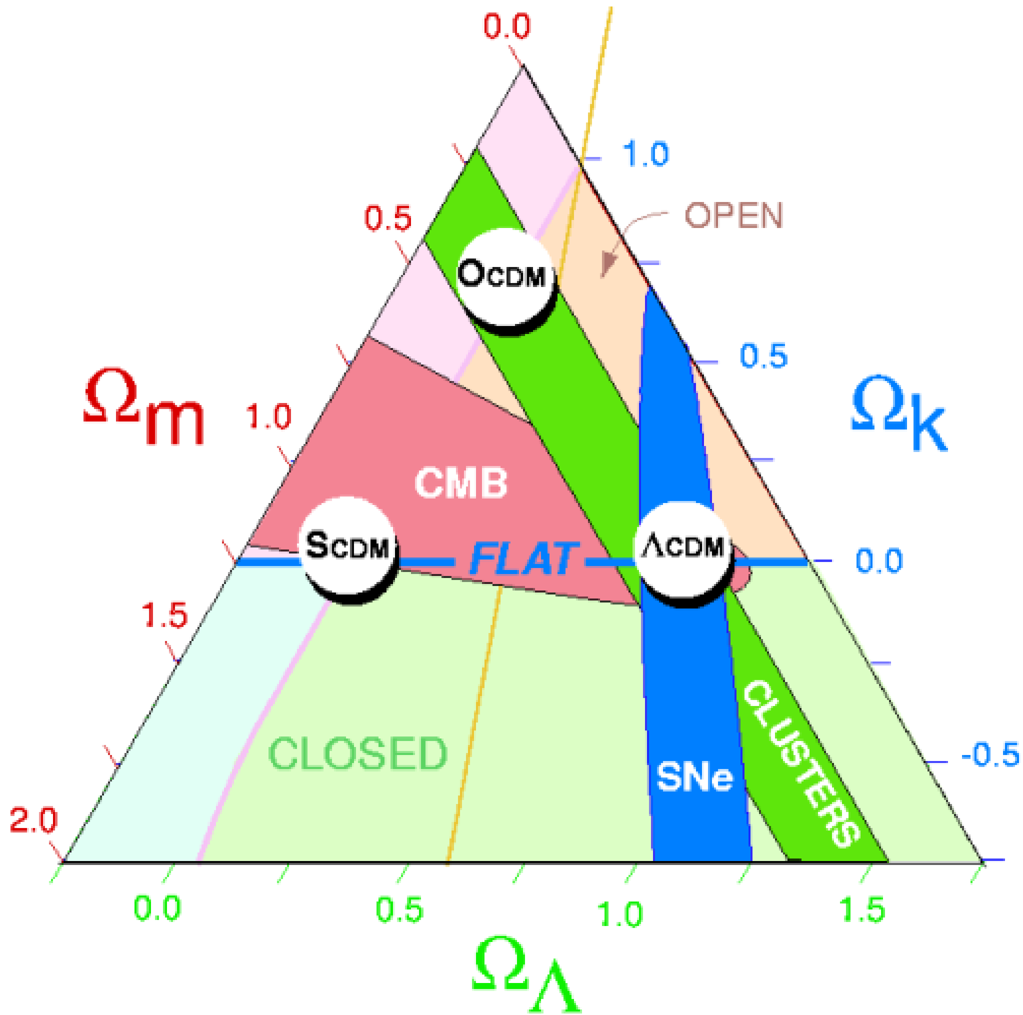
C.Balázs, M.Carena, C.E.M.Wagner PRD70 015007 (`04)

H.Baer, C.Balázs JCAP0305 006

http://www.hep.anl.gov/balazs/Physics/Talks/2005/05-Les-Houches

Matter

— E balance a 'la FRW: $\frac{\rho}{\rho_c} = \Omega_m + \Omega_\Lambda + \Omega_k$ $\rho_c = 3H_0^2/8\pi G_N$, $H_0 = 71 \pm 4$km/s/Mpc

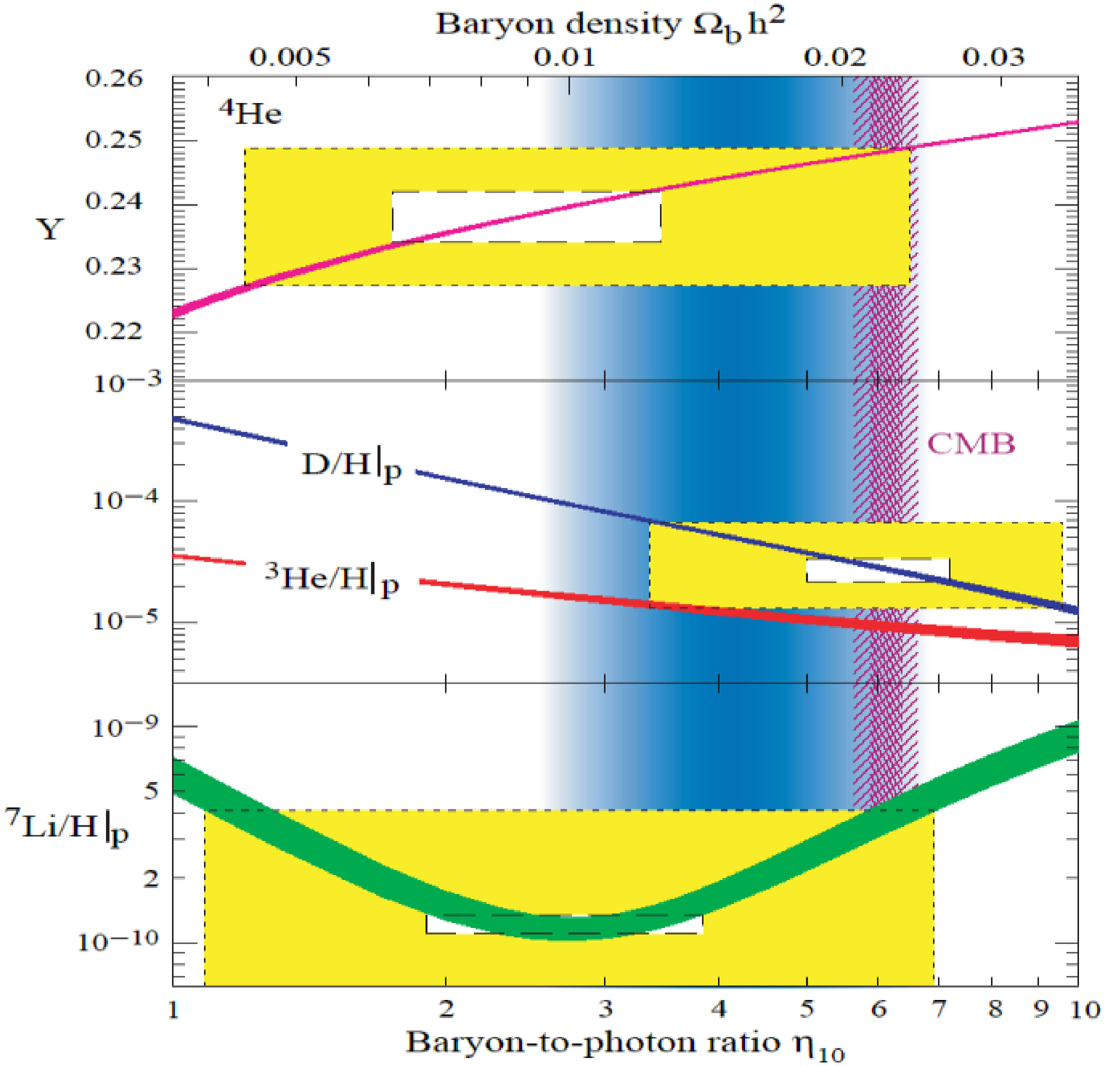


Bahcall et al. 1999

- SNe,WMAP,SDSS: $\Omega_m = 0.27 \pm 0.04$ $\Omega_\Lambda = 0.73 \pm 0.04$ $\Omega_{tot} = 1.02 \pm 0.02$
- direct, independent, precise, consistent observations → robust result

Dark matter

– Matter content: $\Omega_m = \Omega_b + \Omega_r + \Omega_\nu + \Omega_{DM}$ with $\Omega_\nu, \Omega_r < 0.015$

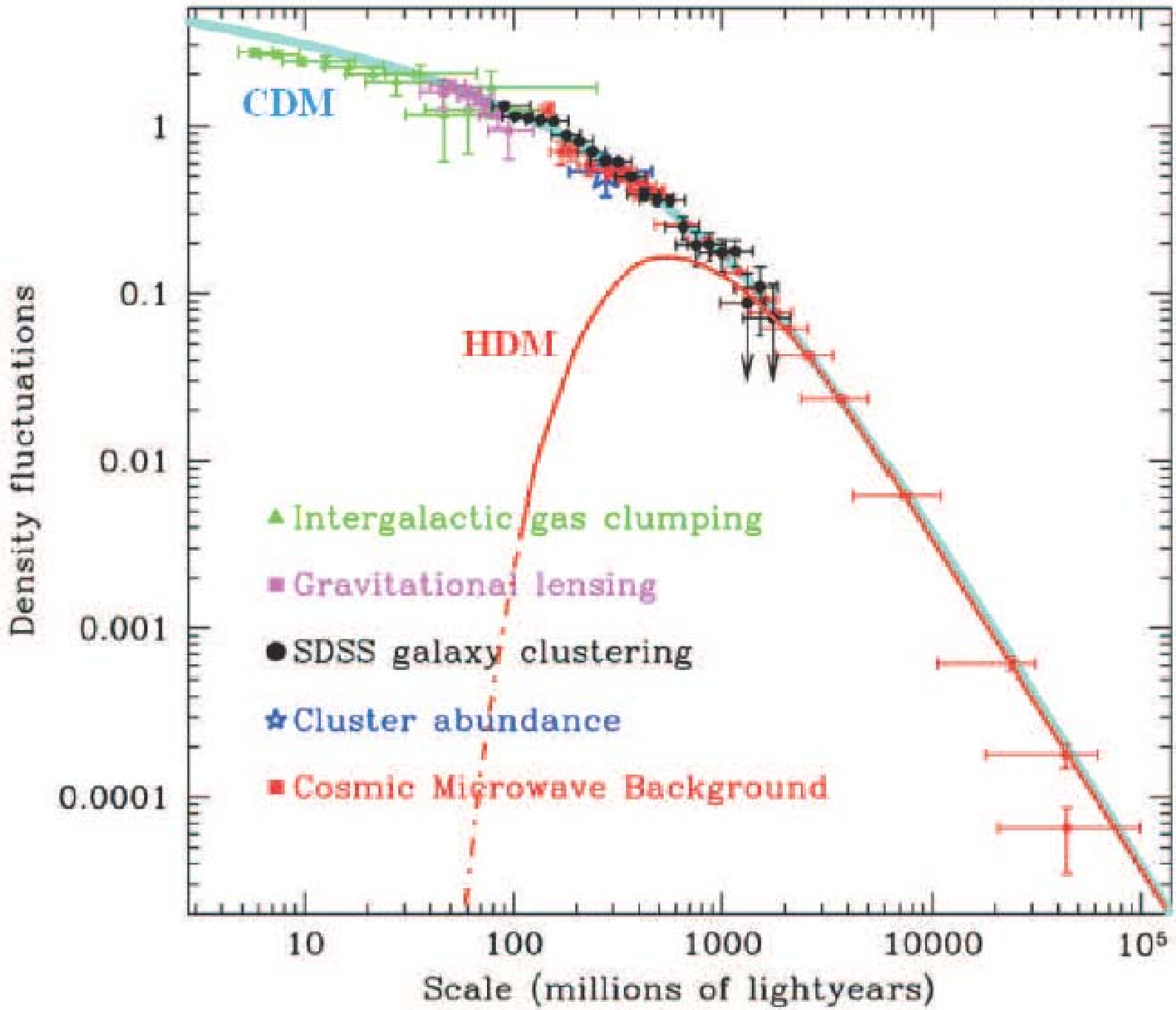


PDB 2004

- BBN&CMB, cosmic concordance: $\Omega_b = 0.044 \pm 0.004 \Rightarrow \Omega_{DM} = 0.22 \pm 0.04$
- Stable, non-baryonic, non-relativistic matter → new physics

Cold dark matter

— Inter galactic structure is due to cold dark matter



Maroto,Ramírez astro-ph/0409280

Cold dark matter? (A particle physicist's view)

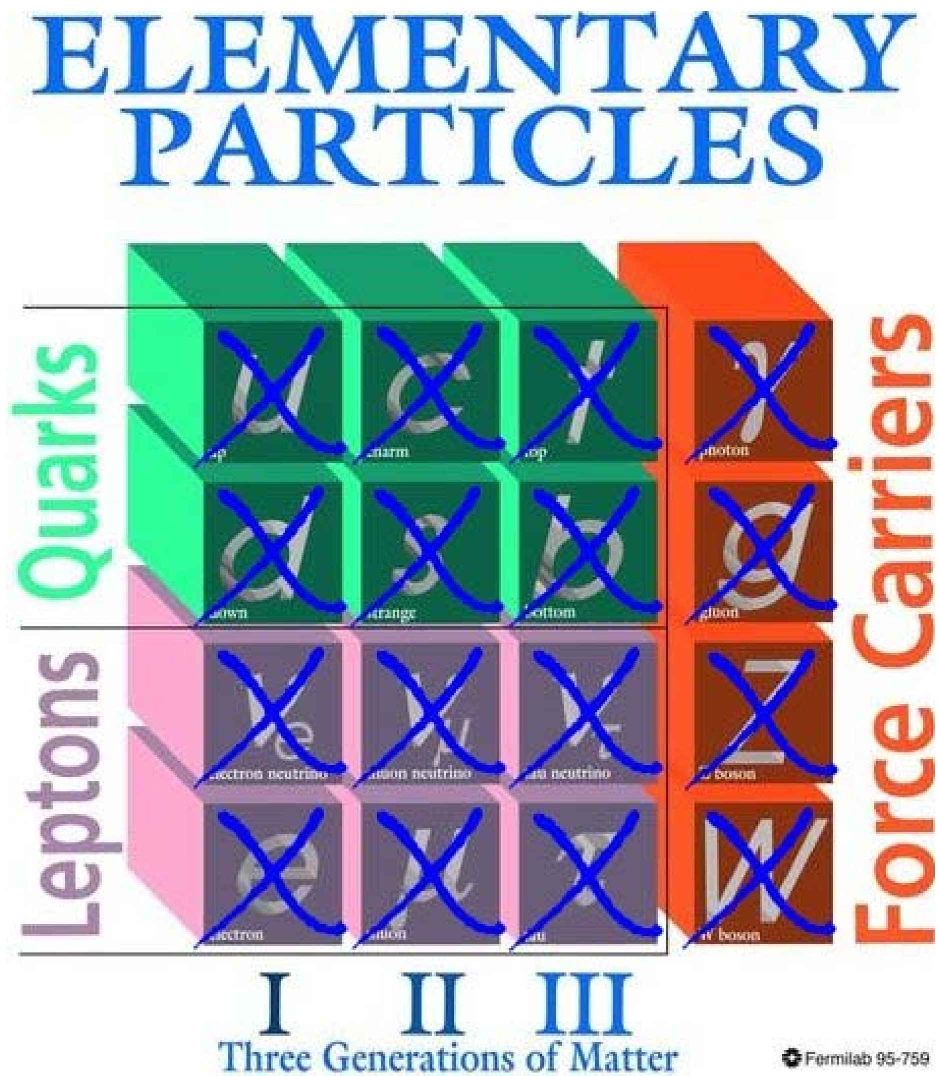
— Known properties

- stable
- non-baryonic
- non-relativistic
- weakly interacting

New physics !

— New matter originates from

- supersymmetry → LSP
- new space dimensions → LKP
- little Higgs + T parity → LTP
- ← ... *your idea here* ... → LXP
- ...



The lightest neutralino as CDM candidate

— $\tilde{Z}_1$ properties

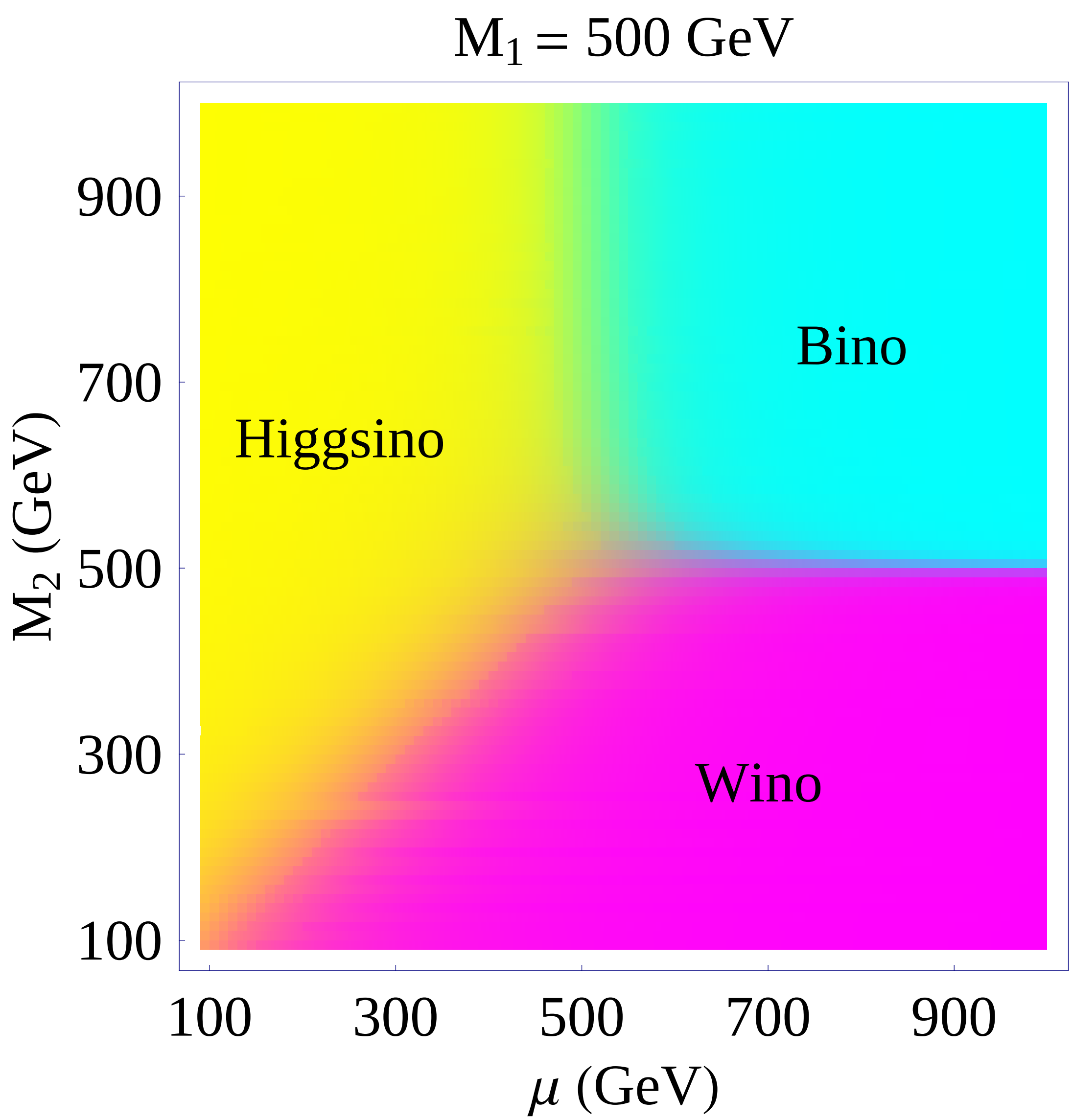
- stable in most models
- neutral, non-baryonic
- mass ~ EW scale

— $\tilde{Z}_1$ admixture

- mass eigenstate

$$\tilde{Z}_1 = n_{11}\,\tilde{B} + n_{1i}\,\tilde{H}_i + n_{13}\,\tilde{W}_3$$

- Bino : σ_{eff} small
- Higgsino : σ_{eff} large
- Wino : σ_{eff} very large



Balázs 2005

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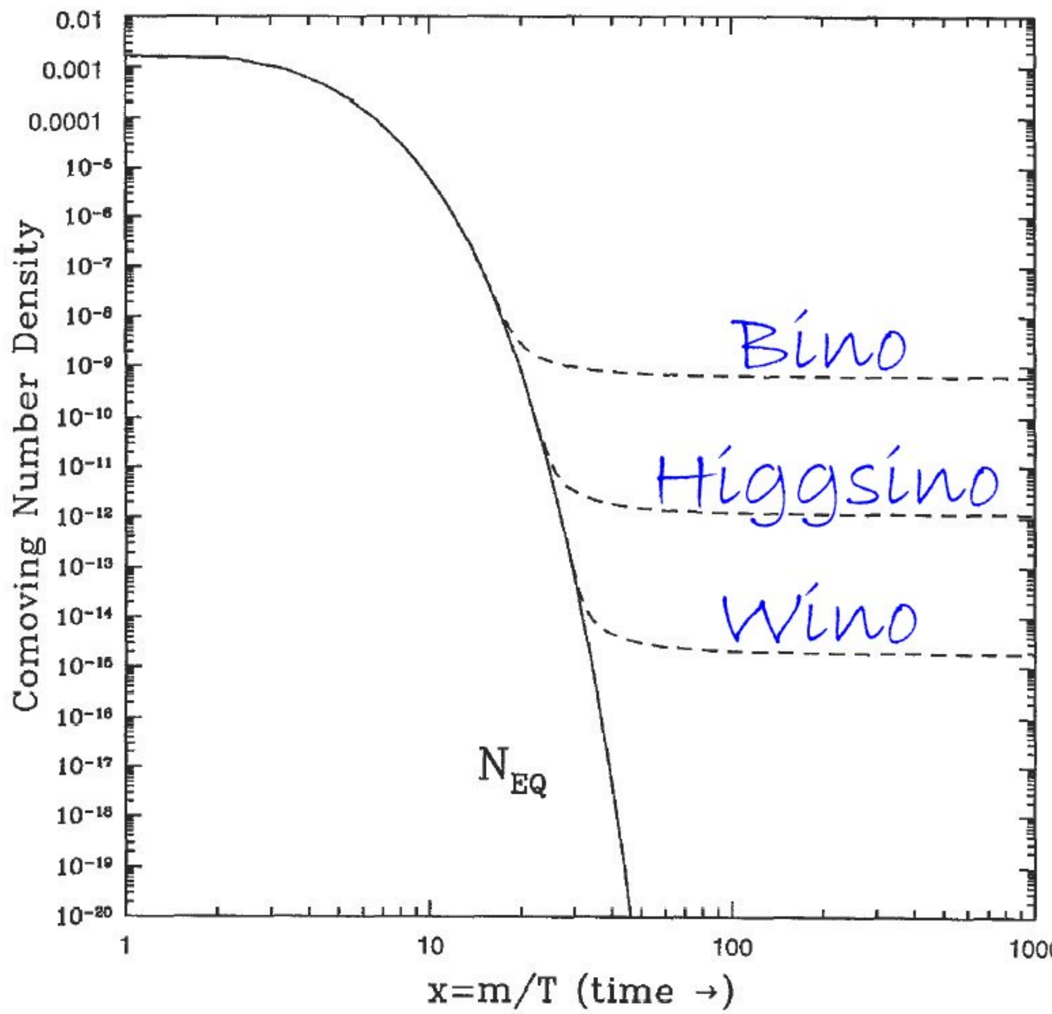
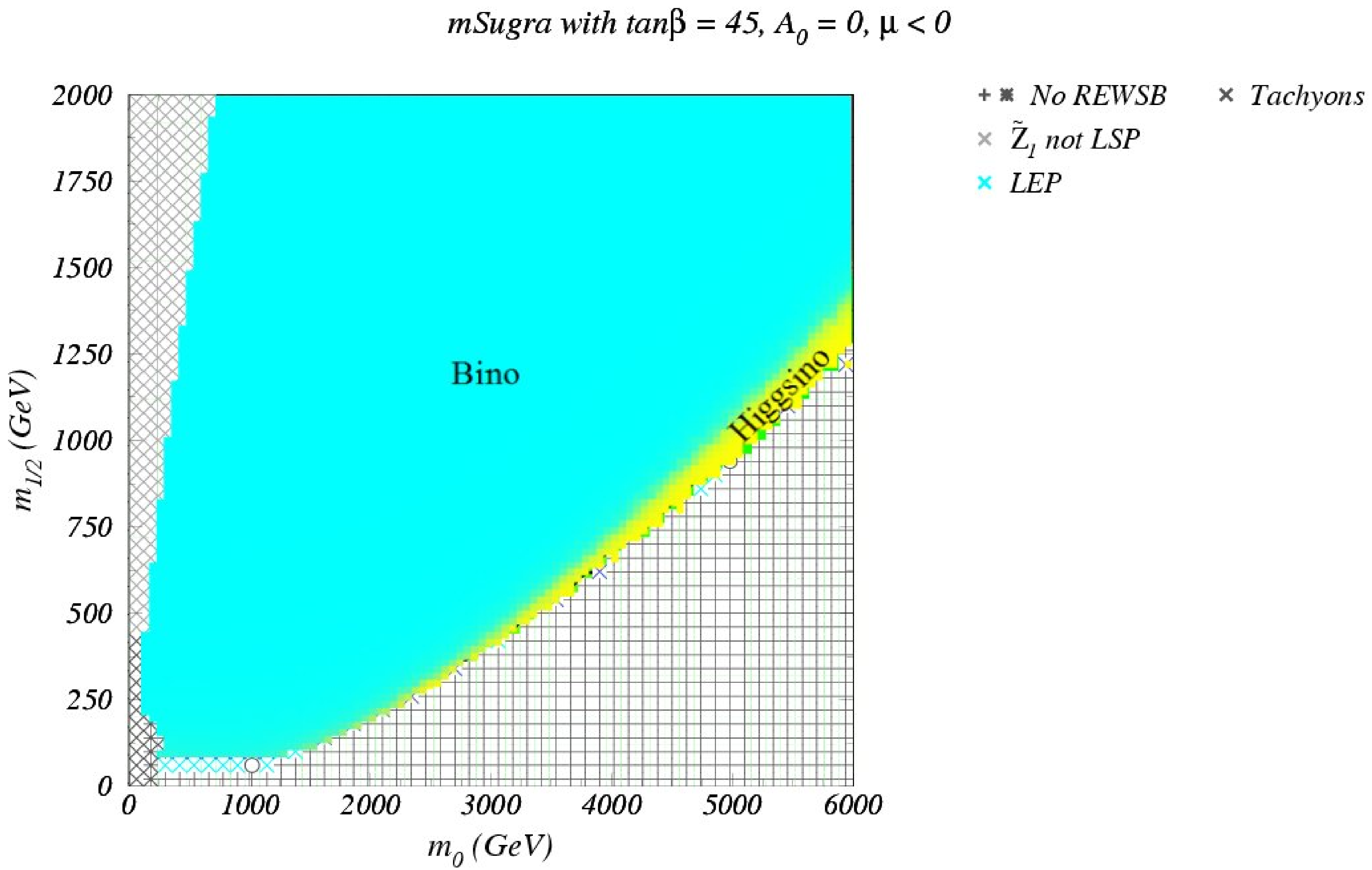


Kolb, Turner 1989

mSUGRA, neutralino relic abundance



Baer,Balázs JCAP0305(2003)

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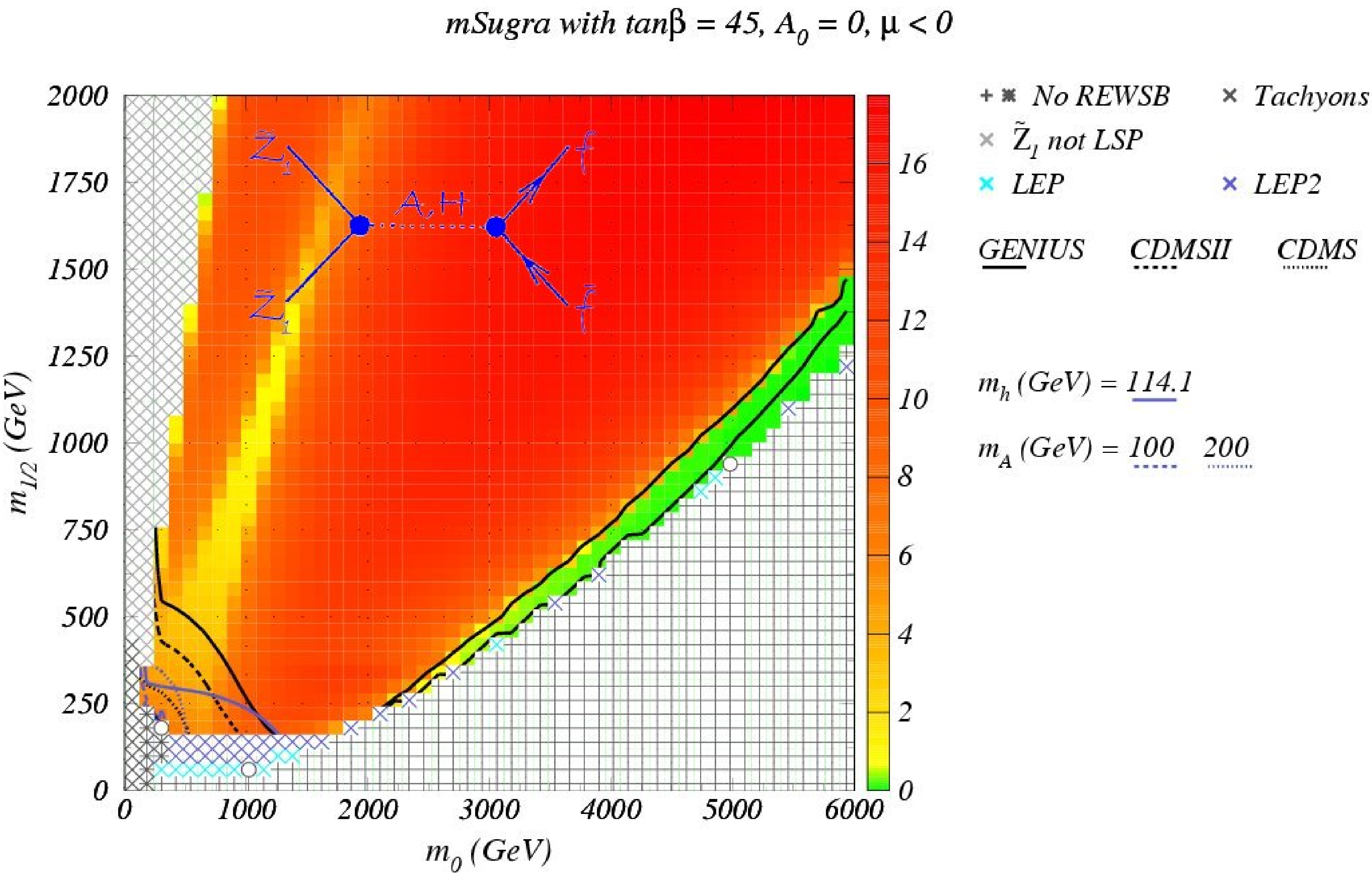

Baer,Balázs JCAP0305(2003)

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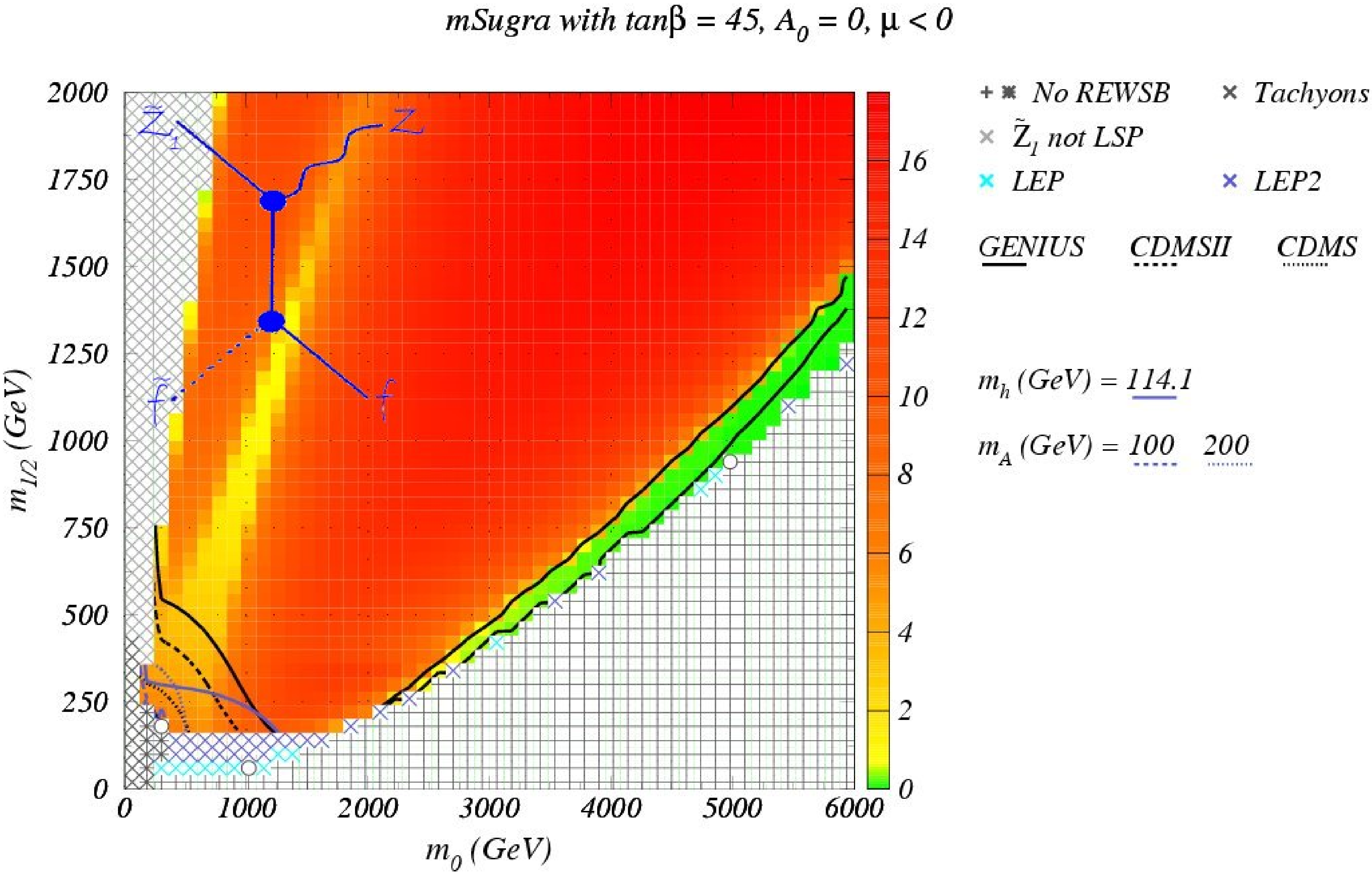


Baer,Balázs JCAP0305(2003)

Matter-anti-matter asymmetry

— BBN&WMAP: $\frac{n_B}{n_\gamma} = (6.1 \pm 0.4) \mathrm{x} 10^{-10}$ & $n_{\bar{B}} \sim 0$ (2^{nd}ary production) →

(baryon-anti-baryon or) matter-anti-matter asymmetry

- no experimental (or theory) indication of large amounts of anti-matter
- preexisting asymmetry →← inflation

— Baryogenesis:

- dynamical generation of asymmetry from symmetric initial conditions

0. early universe: matter-antimatter symmetric phase

1. ~~B~~ is efficient before a thermodynamic phase transition

2. ~~C~~ & ~~CP~~ interactions allow to generate asymmetry

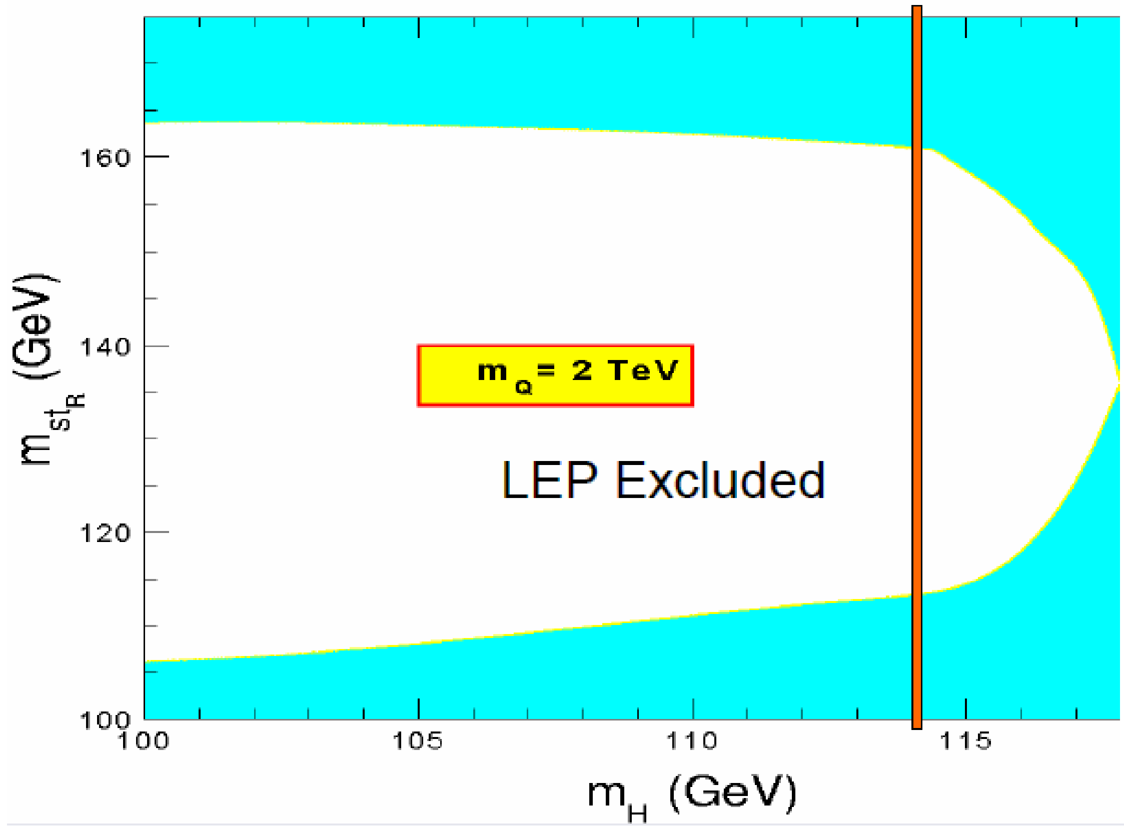
3. ~~T~~ preserves asym.: at phase transition universe falls out equilibrium, and new vacuum B conserving (Sakharov conditions)

- electroweak baryogenesis: connected to weak scale → testable at colliders

Electroweak baryogenesis in the MSSM

— Possible if

1. anomalies violate B (✓)
2. there's enough ~~CP~~ ↔
   μ, M_i and/or A_t has
   (relative) complex phases
3. EW phase transition
   strongly 1st order →
   constraints on stop sector
   $120\ \text{GeV} \lesssim m_{\tilde{t}_1} < m_t$,
   $0.3 < |X_t| / m_{\tilde{Q}_3} < 0.5$,
   constraints on Higgs sector
   $m_h \lesssim 120\ \text{GeV}$



Carena, Seco, Quiros, Wagner 2002

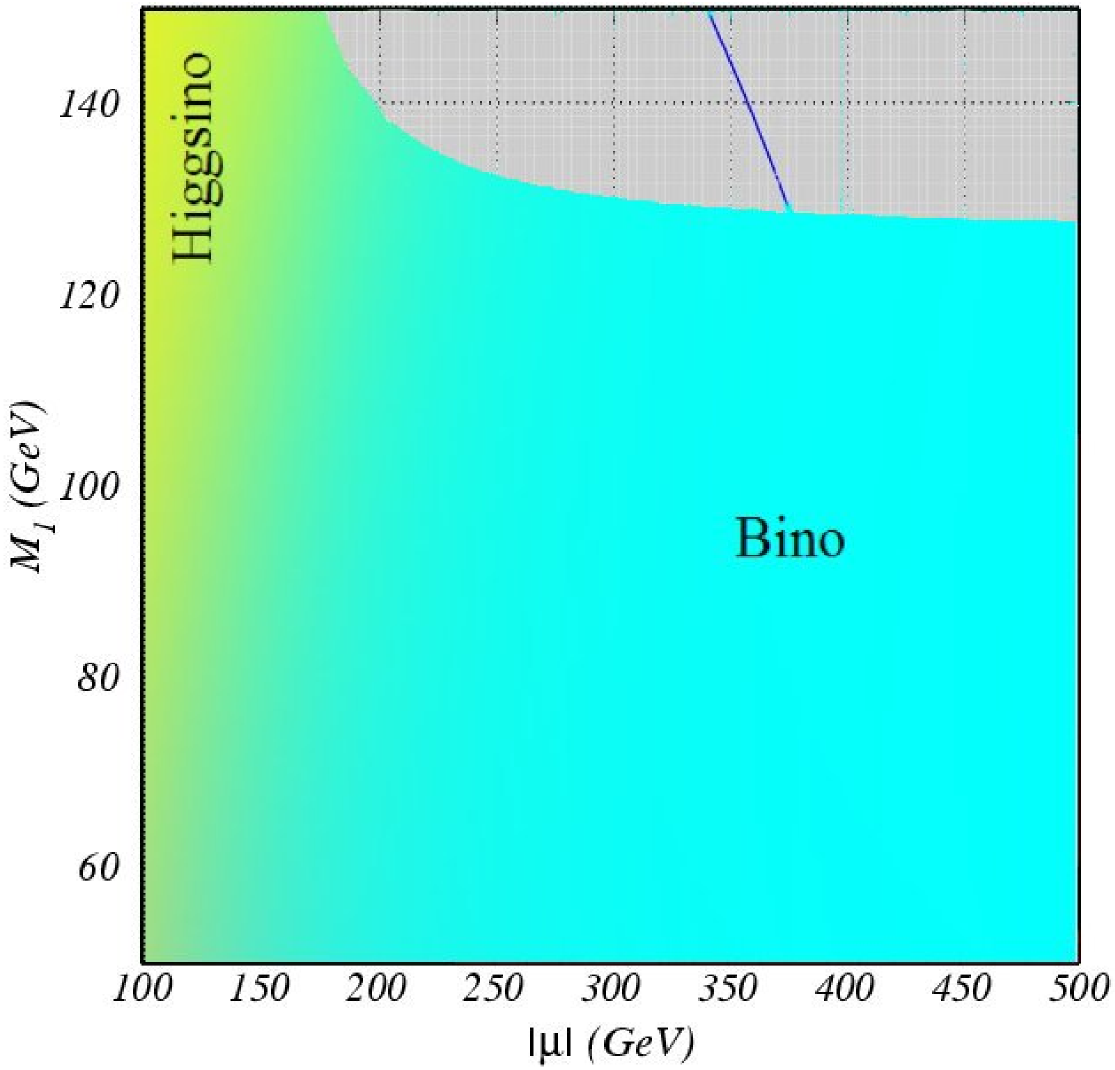
- scenario is already strongly constrained by LEP 2:

  $114.4\ \text{GeV} < m_h$

- EWBG not accommodated by mSuGra, CMSSM, GMSB, $\tilde{g}$MSB, AMSB
- Does electroweak baryogenesis survive the stringent WMAP limits?

The supersymmetric origin of matter

– Can the baryon asymmetry & right amount of neutralino dark matter be simultaneously generated in the MSSM? Davidson et al., Boehm et al. 1999



Input parameters:

$\tan\beta = 7$, $m_A = 1000$ GeV, $Arg(\mu) = 1.571$

$M_2 = M_1 g_2^2/g_1^2$, $Arg(M_1) = Arg(M_2) = 0$, $M_3 = 1$ TeV

$m_{U3} = 0$ GeV, $m_{Q3} = 1.5$ TeV, $X_t = 0.7$ TeV

m_{L3}, m_{E3}, $m_{D3} = 1$ TeV

$m_{L1,2}$, $m_{E1,2} = 10$ TeV

$m_{Q1,2}$, $m_{U1,2}$, $m_{D1,2} = 10$ TeV

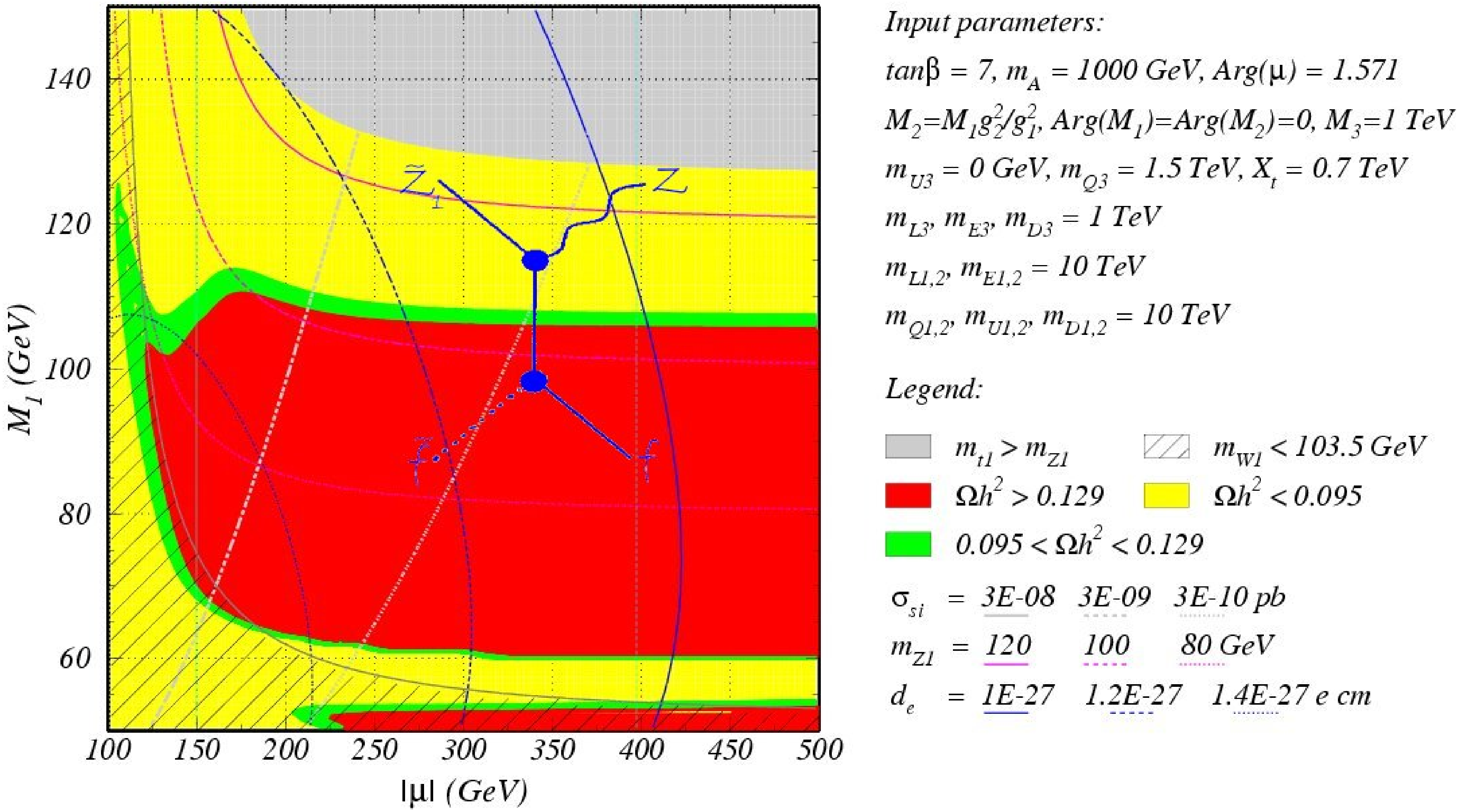
Legend:

(grey) $m_{t1} > m_{Z1}$

Balázs,Carena,Menon,Morrissey,Wagner 2005

The supersymmetric origin of matter

— $\tilde{t}_1$-$\tilde{Z}_1$ coannihilation lowers the neutralino relic density to agree with WMAP where $m_{\tilde{t}_1} \sim m_{\tilde{Z}_1}$



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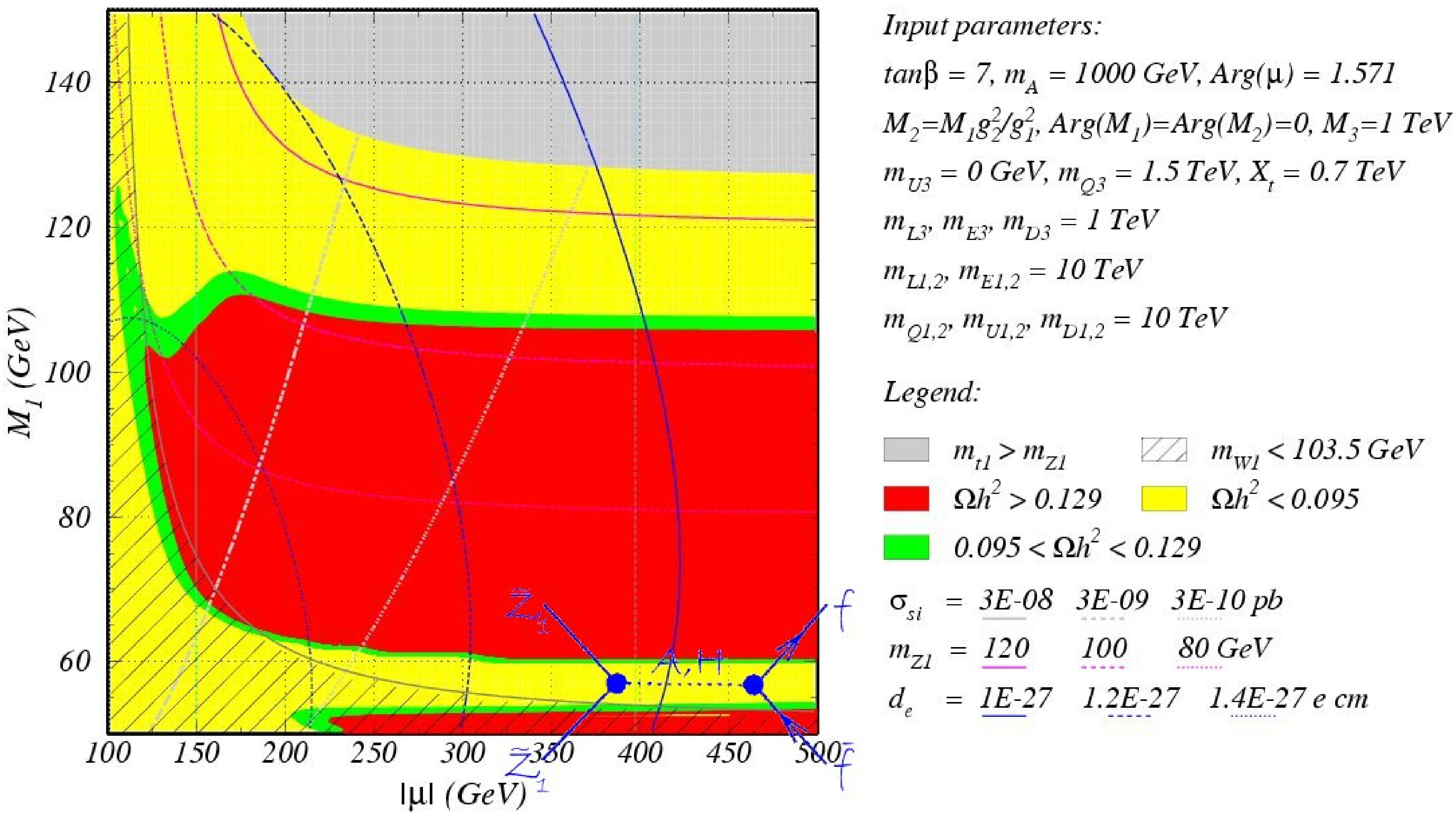
The supersymmetric origin of matter

– Annihilation via the h^0 (A^0) resonance lowers the neutralino relic density to agree with WMAP where $2m_{\tilde{Z}_1} \sim m_{h^0(A^0)}$



Balázs, Carena, Menon, Morrissey, Wagner 2005

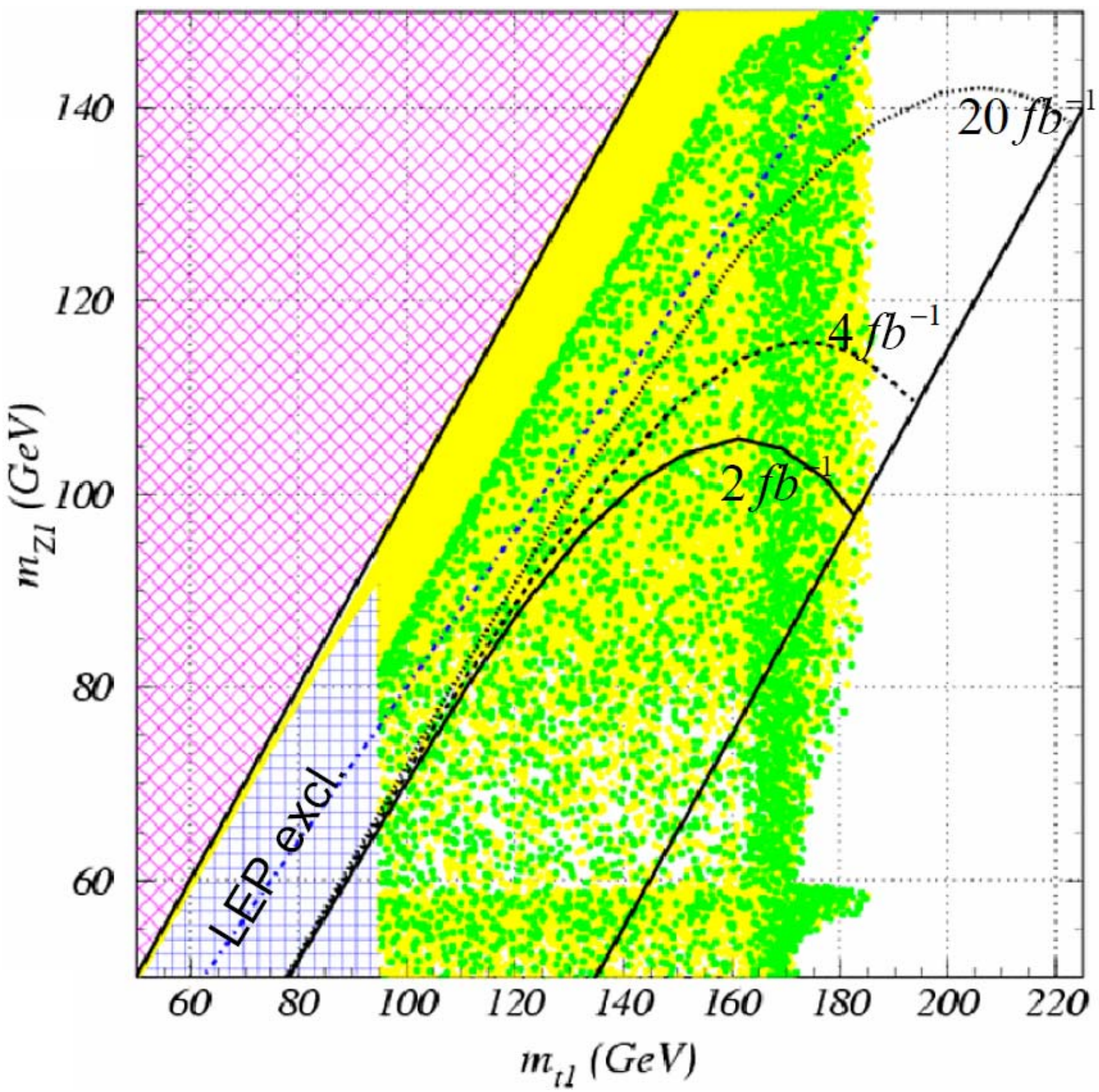
Collider implications

- If $\tilde{t}_1 \to c\,\tilde{Z}_1$ dominant
  considerable part of
  para. space observable
  at Tevatron depending on L

- If $\tilde{t}_1 \to b\,\tilde{Z}_1\,W$ or
  $m_{\tilde{t}_1} \lesssim 1.25\, m_{\tilde{Z}_1}$
  (Higgs resonance or
  $\tilde{t}_1$ - $\tilde{Z}_1$ coannihilation**)**
  difficult at Tevatron

- LHC : similar situation

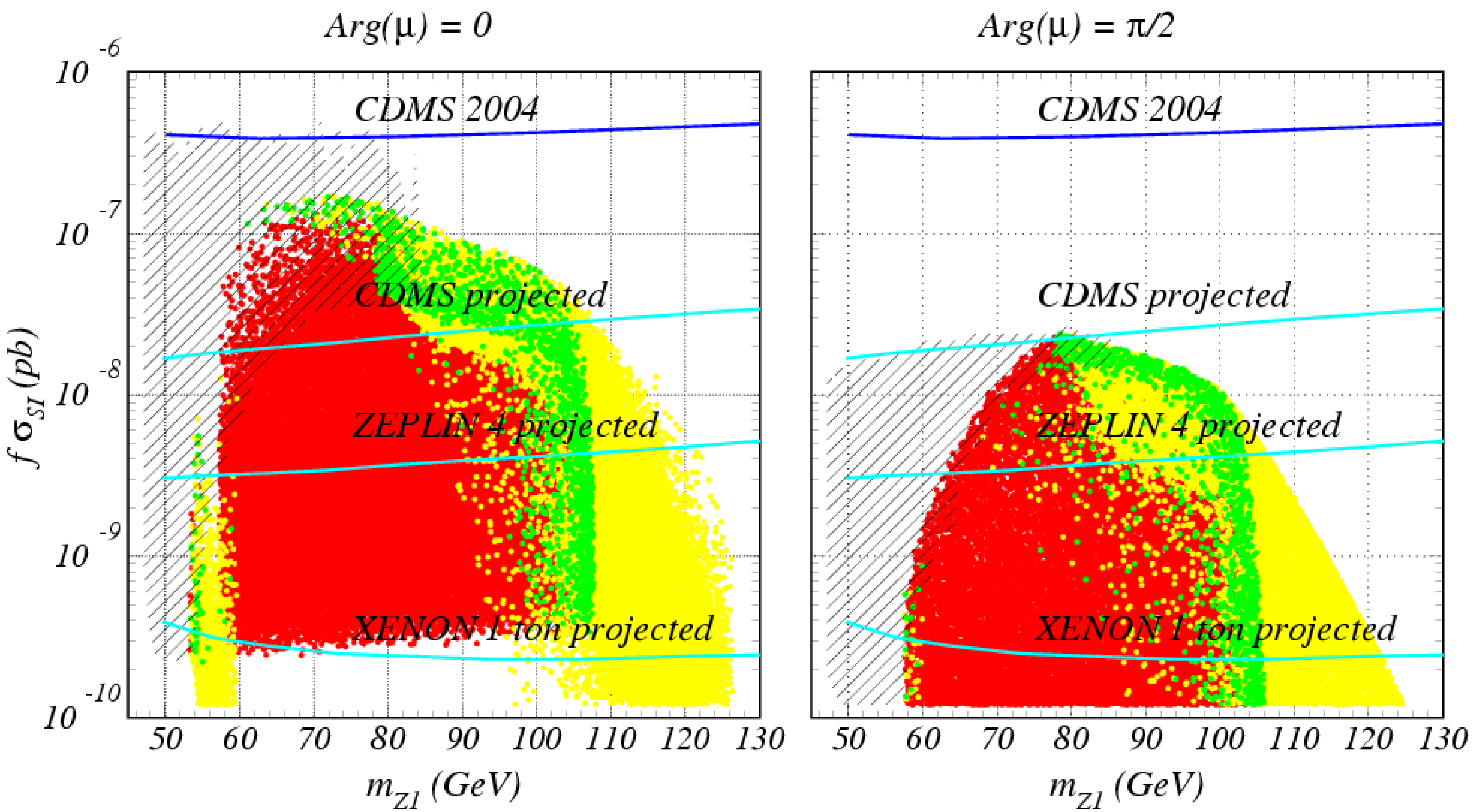
- ILC expected to cover
  essentially all regions



Balázs, Carena, Wagner 2004

Direct CDM detection experiments

— Future nucleon-WIMP detection experiments will probe considerable part of all regions (including $\tilde{t}_1$-$\tilde{Z}_1$ coannihilation)



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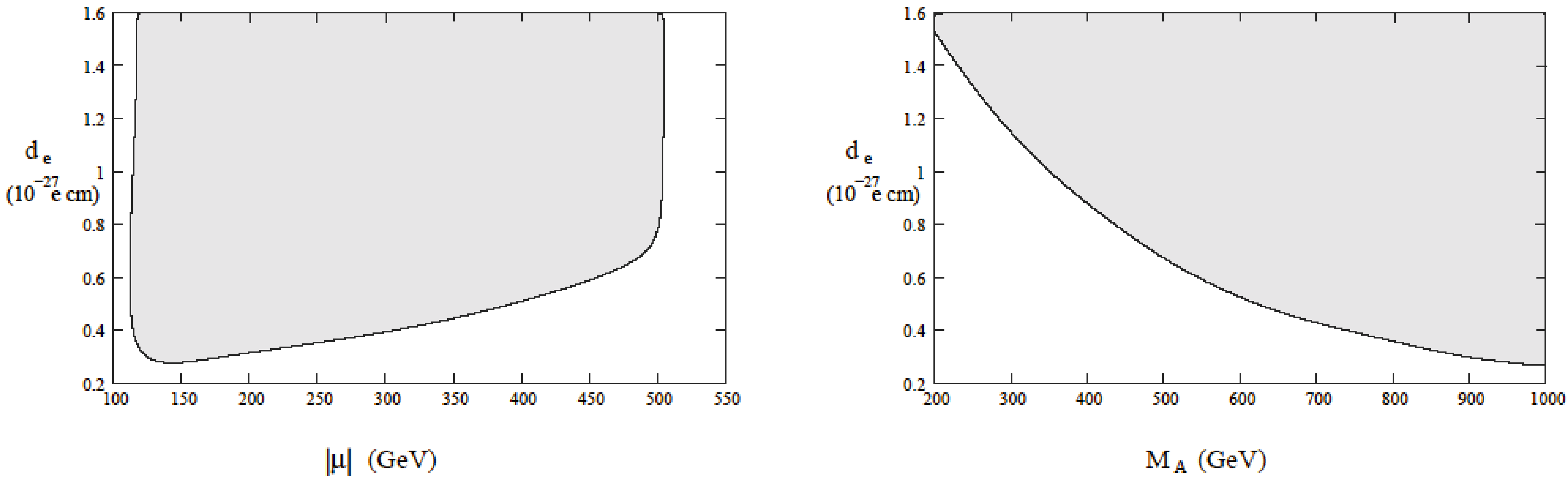
Electron electric dipole moment

— e^- EDM is the most sensitive probe of the model

- EWBG requires complex phases →← complex phases generate EDM



Balázs,Carena,Menon,Morrissey,Wagner 2004

- full parameter space is probed if e^- EDM measurements improve by about an order of magnitude!
- except... if: accidental cancellations, $m_A > 1$ TeV, or nMSSM ...

Summary

— Cold dark matter seems to be out there and

neutralinos are excellent candidates for it

— Baryogenesis explains the baryon asymmetry based on the

electroweak phase transition in the MSSM

- simultaneous electroweak baryogenesis and neutralino cold dark matter

  is viable in the MSSM ⇒ all matter might just originate from SUSY!

— Does matter have a supersymmetric origin?

- e^- EDM measurements are the most sensitive probes of this model
- Tevatron has a good chance to find the light stop, but even the
- Large Hadron Collider could find the light top in the full para. space
- International Linear Collider will covers most of the parameter region
- direct dark matter searches can find the neutralino in this scenario
- complementary collider & dark matter searches together will uncover...

the origin of matter