The supersymmetric origin of matter

– BMSSM = Baryogenesis + MSSM

– BMSSM → $\Omega_{WIMP} + \eta_B$

– BMSSM benchmarks

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

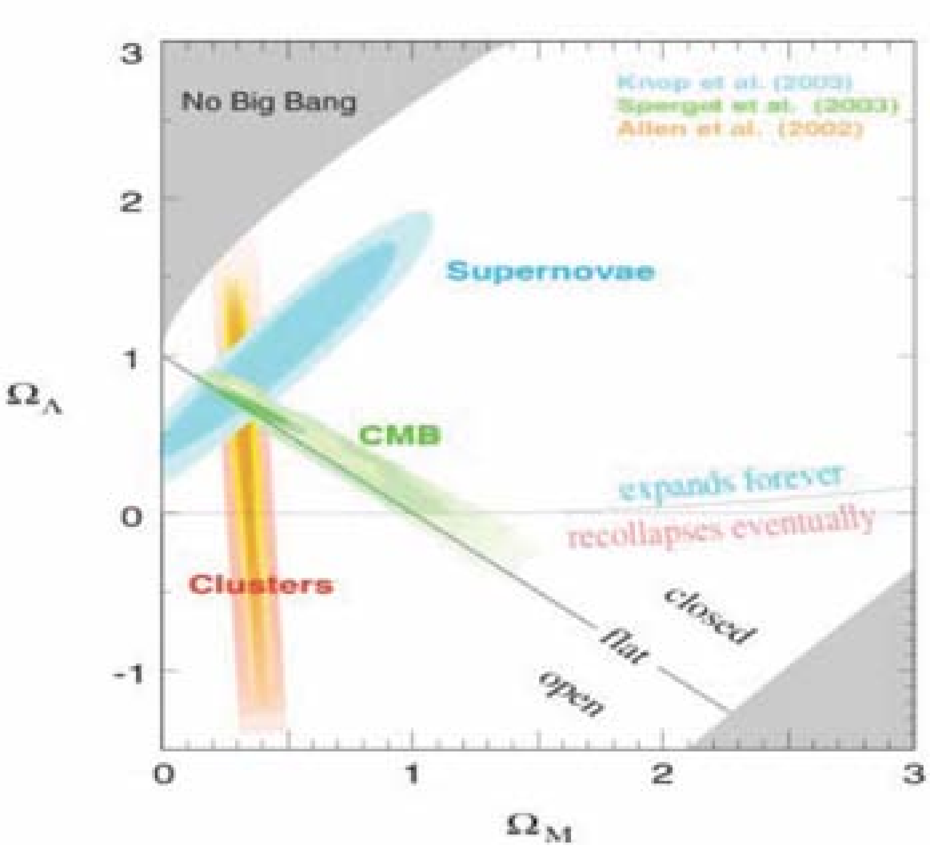
PRD71 075002 (`05)

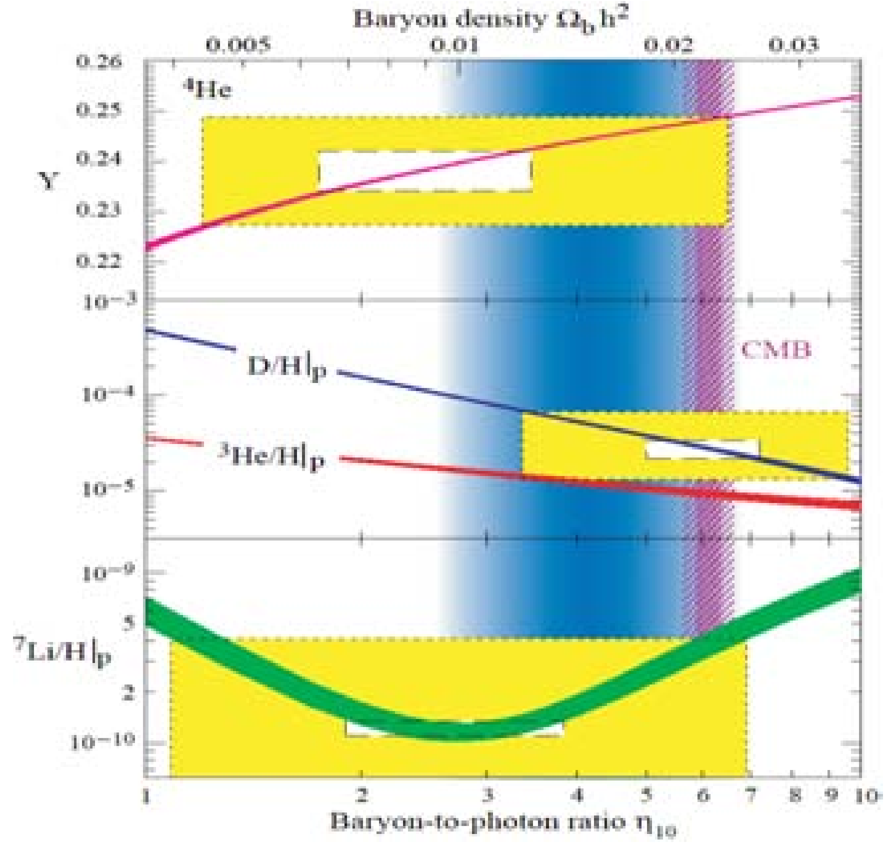
C.Balázs, M.Carena, C.E.M.Wagner PRD70 015007 (`04)

http://www.hep.anl.gov/balazs/Physics/Talks/2005/08-Snowmass

Why do we need an ILC?

— Recent precise, direct, consistent astro observations → robust result





Supernovae, WMAP, SDSS

$\Omega_M = 0.27 \pm 0.04$

$\Omega_\Lambda = 0.73 \pm 0.04$

BBN, CMB

$\Omega_B = 0.044 \pm 0.004 \Rightarrow$

$\Omega_{DM} = 0.22 \pm 0.04$

- new form of matter: stable, non-bary., non-rel., weakly ia. → new physics

Baryon asymmetry

— BBN & WMAP: $\eta_B = \frac{n_B}{n_\gamma} = (6.1 \pm 0.4) \times 10^{-10} > 0 \rightarrow B\overline{B}$ asymmetry

— Baryo- (or lepto-) genesis has to satisfy the Sakharov conditions

0. initial condition: matter-antimatter symmetric phase

   early Universe: existence of a phase transition to asymmetric phase

1. ~~B~~ is efficient before the 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

— Electroweak baryogenesis: dynamical generation of asymmetry from symmetric initial conditions

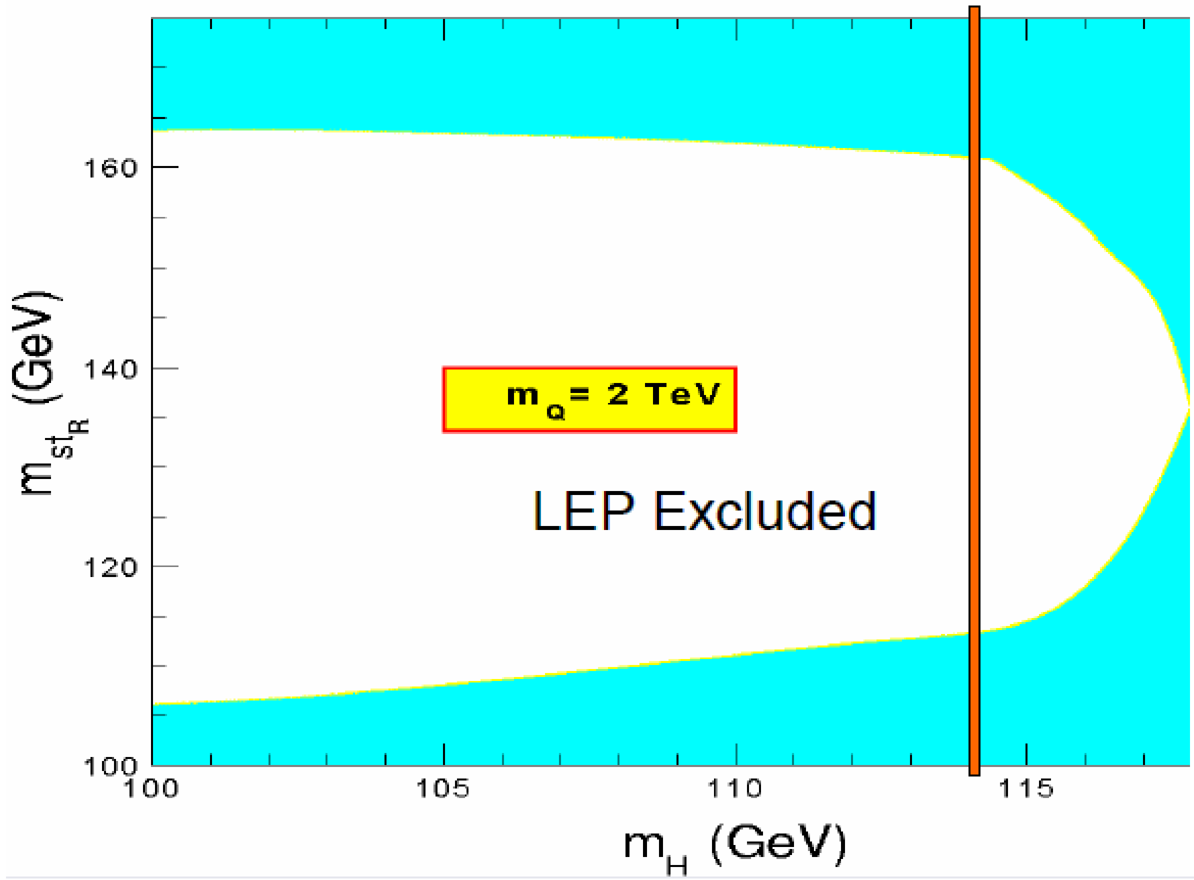
- consistent with particle physics and cosmology (inflation)
- utilizes existing phase transition: EWSB
- connected to weak scale → testable at Tevatron, LHC and ILC

BMSSM: EW Baryogenesis + MSSM

— EW phase transition
strongly 1st order →
constraints on stop sector
$m_{\tilde{t}_1} < m_t$, $m_{\tilde{t}_2} \gtrsim 1$ TeV,
$0.3 < |X_t| / m_{\tilde{Q}_3} < 0.5$,
constraint on h^0
$m_h \lesssim 120$ GeV

— Enough $\not{CP}$ →
constraints on charginos
$M_2, \mu \lesssim 500$ GeV,
$\mathrm{Arg}(M_2\,\mu) \gtrsim 0.1$

Carena, Seco, Quiros, Wagner 2002



— EDM limits → heavy 1 st & 2nd generation scalars

— Scenario is strongly constrained by LEP2: 114 GeV $< m_{h^0}$

- Does EWBG survive the stringent astro (collider & lowE) constraints?

The origin of matter in the BMSSM

— Can SUSY explain the existence of dark matter and lack of anti-matter?

— Top-down: embed EWBG in an existing SSB model

- assume modified mSuGra: m_0, $m_{1/2}$, A_0, $\tan(\beta)$, $\arg(\mu)$
- run (1-loop MSSM) RGE's up, to check unification:

$$m^2_{\tilde{U}_3}(M_{GUT}) \sim \frac{2}{3} m^2_{\tilde{Q}_3} + 2A_t^2 + 11 A_t M_1 - 53 M_1^2 + O(EW)$$
$$m^2_{\tilde{Q}_3}(M_{GUT}) \sim \frac{4}{3} m^2_{\tilde{Q}_3} + A_t^2 + 5 A_t M_1 - 46 M_1^2 + O(EW)$$
$$m^2_{H_1}(M_{GUT}) \sim - \frac{1}{12} M_1^2 + m_A^2 - \mu^2 + m_Z^2$$
$$m^2_{H_2}(M_{GUT}) \sim m^2_{\tilde{Q}_3} + 3A_t^2 + 15 A_t M_1 - 20 M_1^2 + O(EW)$$

- $m^2_{\tilde{Q}_3}$, A_t, M_1, μ constrained by EWBG ⇒ no scalar (or gauge) unification

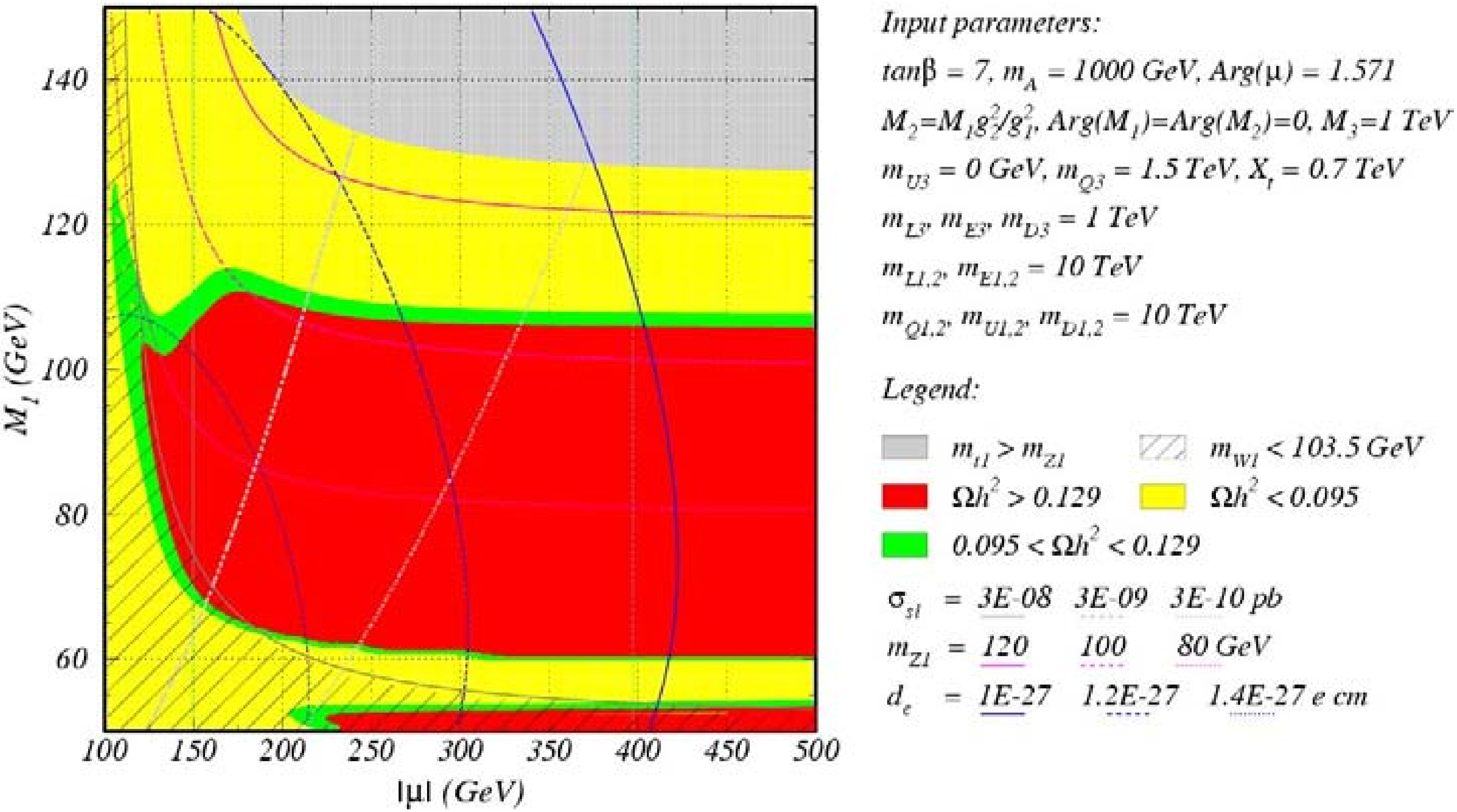
  mSuGra, m$\overset{(\sim)}{\text{G}}$MSB or mAMSB (+phases) inconsistent with EWBG

— Bottom-up: let experimental data determine the low energy parameters

- assume EWBG in (n,N)MSSM (no assumption on SSB): BMSSM
- use data (η_B, Ω_{WIMP}, e^- EDM, $B(b\to s\gamma)$, g_μ-2...) to narrow parameter space
- simplifying assumptions: $\tilde{Z}_1$ is LSP & only μ acquires a complex phase

The supersymmetric origin of matter

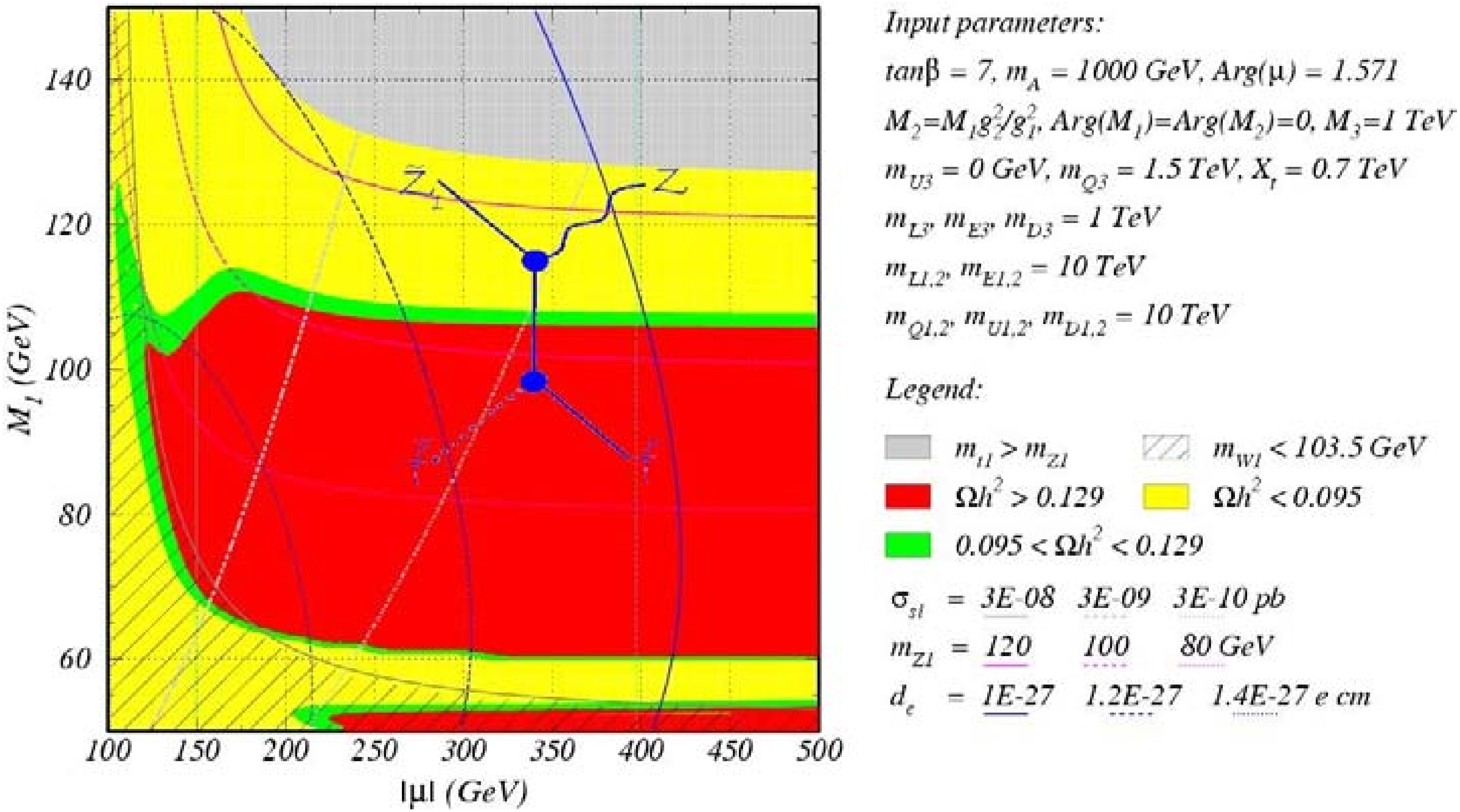
– Can baryon asymmetry & neutralino dark matter be simultaneously generated in the MSSM?



Balázs,Carena,Menon,Morrissey,Wagner 2004

The supersymmetric origin of matter

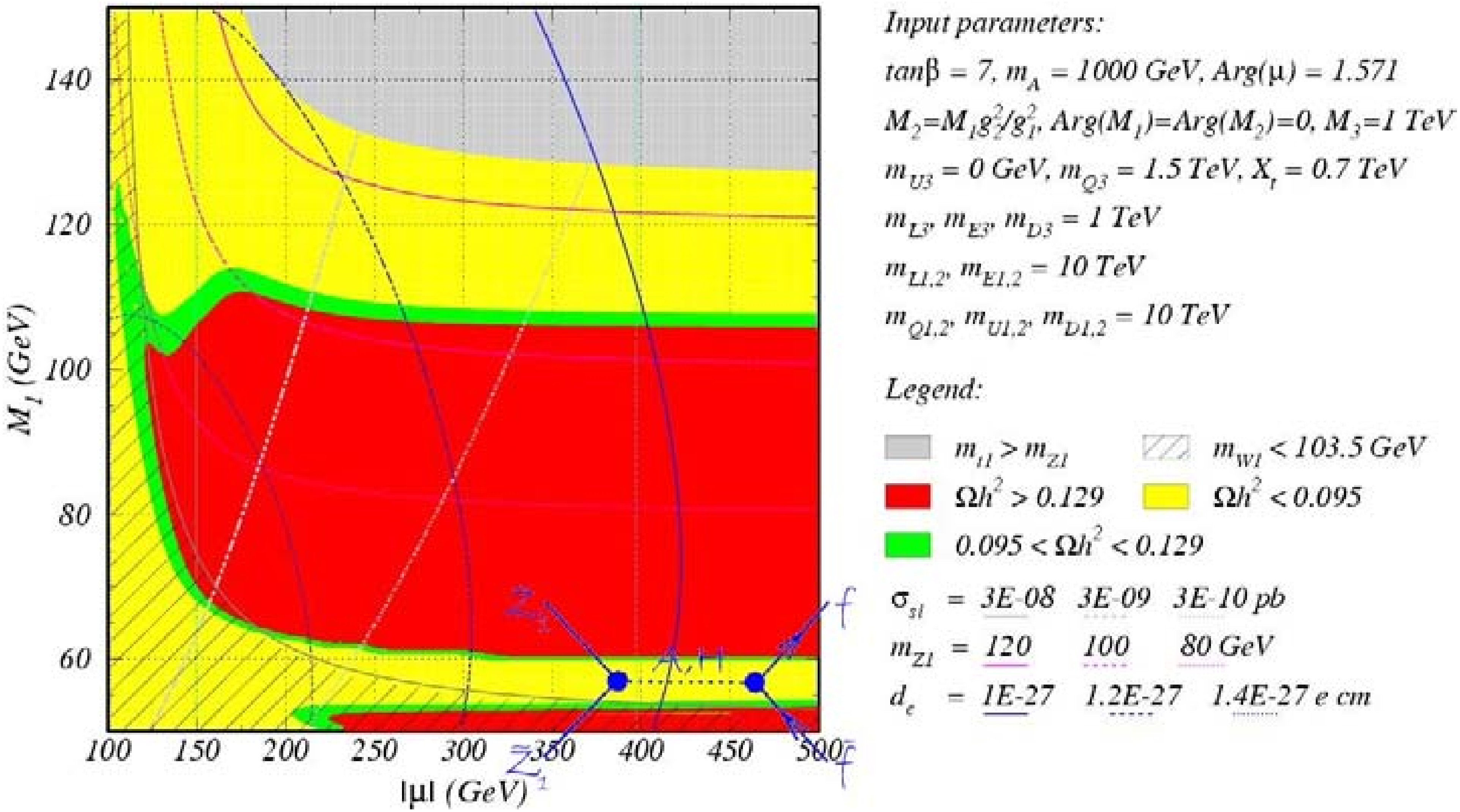
— $\tilde{t}_1$-$\tilde{Z}_1$ coannihilation lowers the neutralino relic density to agree with WMAP where $m_{\tilde{t}_1} \sim m_{\tilde{Z}_1}$



Balázs,Carena,Menon,Morrissey,Wagner 2004

The supersymmetric origin of matter

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



Balázs,Carena,Menon,Morrissey,Wagner 2004

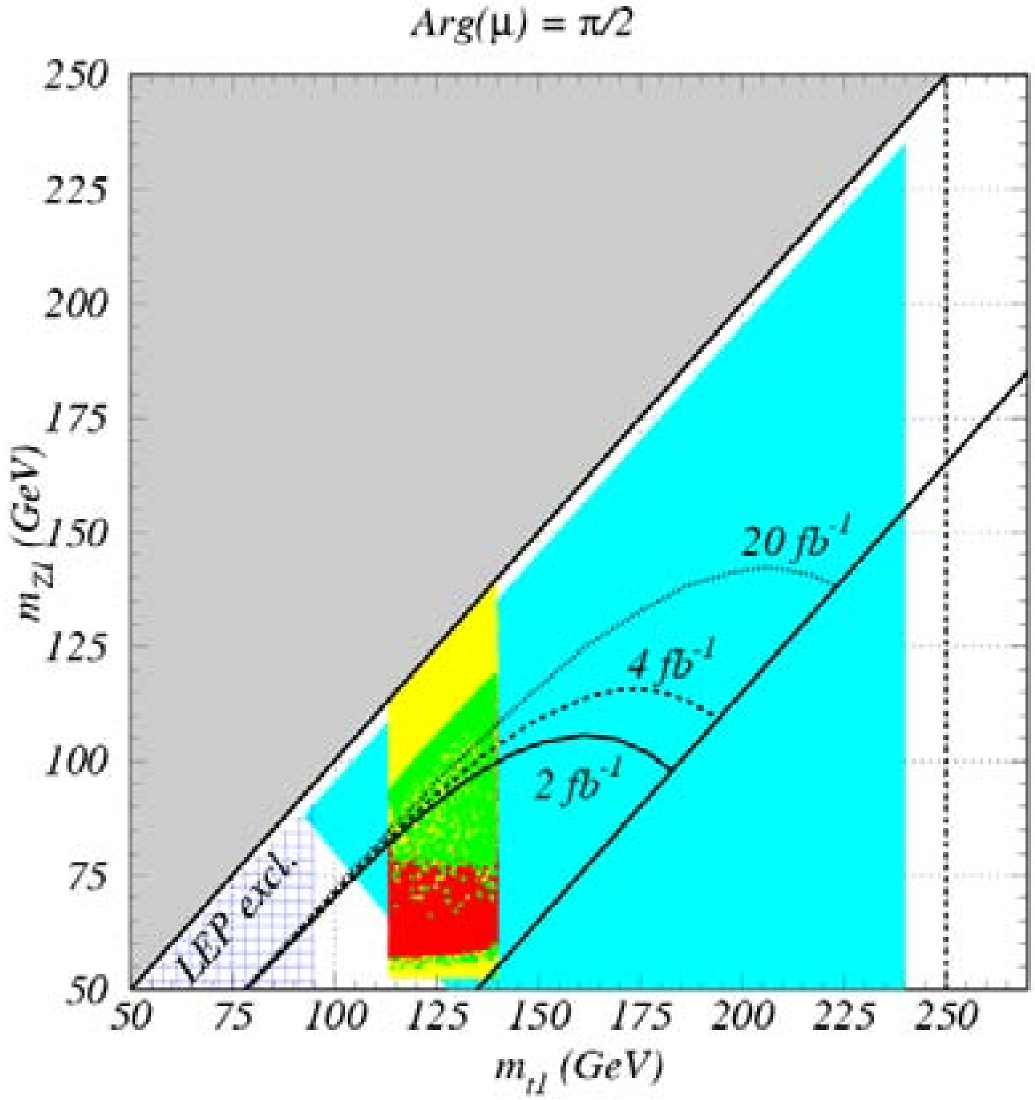
Collider implications → Ayres' & Caroline's talk

— 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

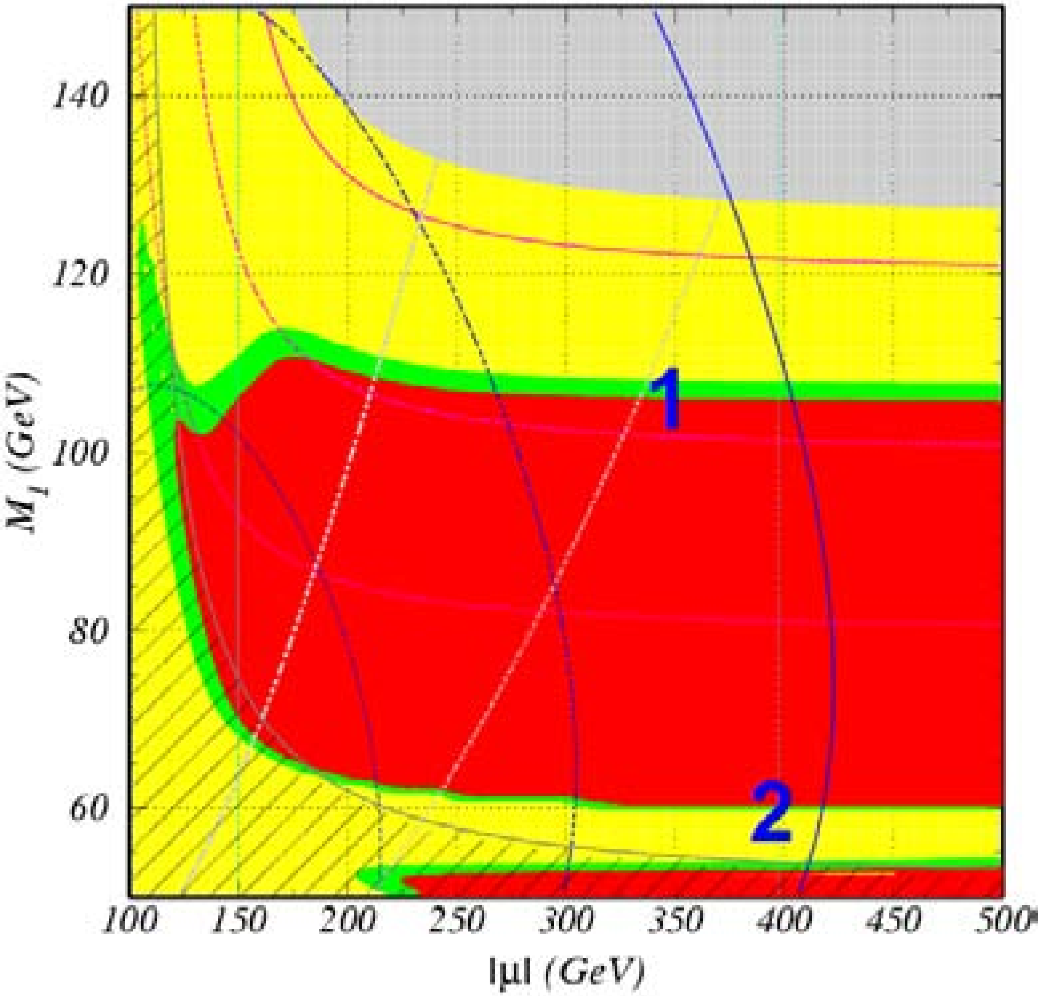
— LHC : similar situation

— ILC expected to cover
essentially all regions



Balázs 2005

BMSSM Benchmarks



1 $\{|\mu|, M_1\} = \{350, 110\}$ GeV

Arg (μ) optional ($\tilde{t}_1 \tilde{Z}_1$ coann. insensitive to it)

2 $\{|\mu|, M_1\} = \{400, 60\}$ GeV

in Tevatron / LHC reach (resonance ann.)

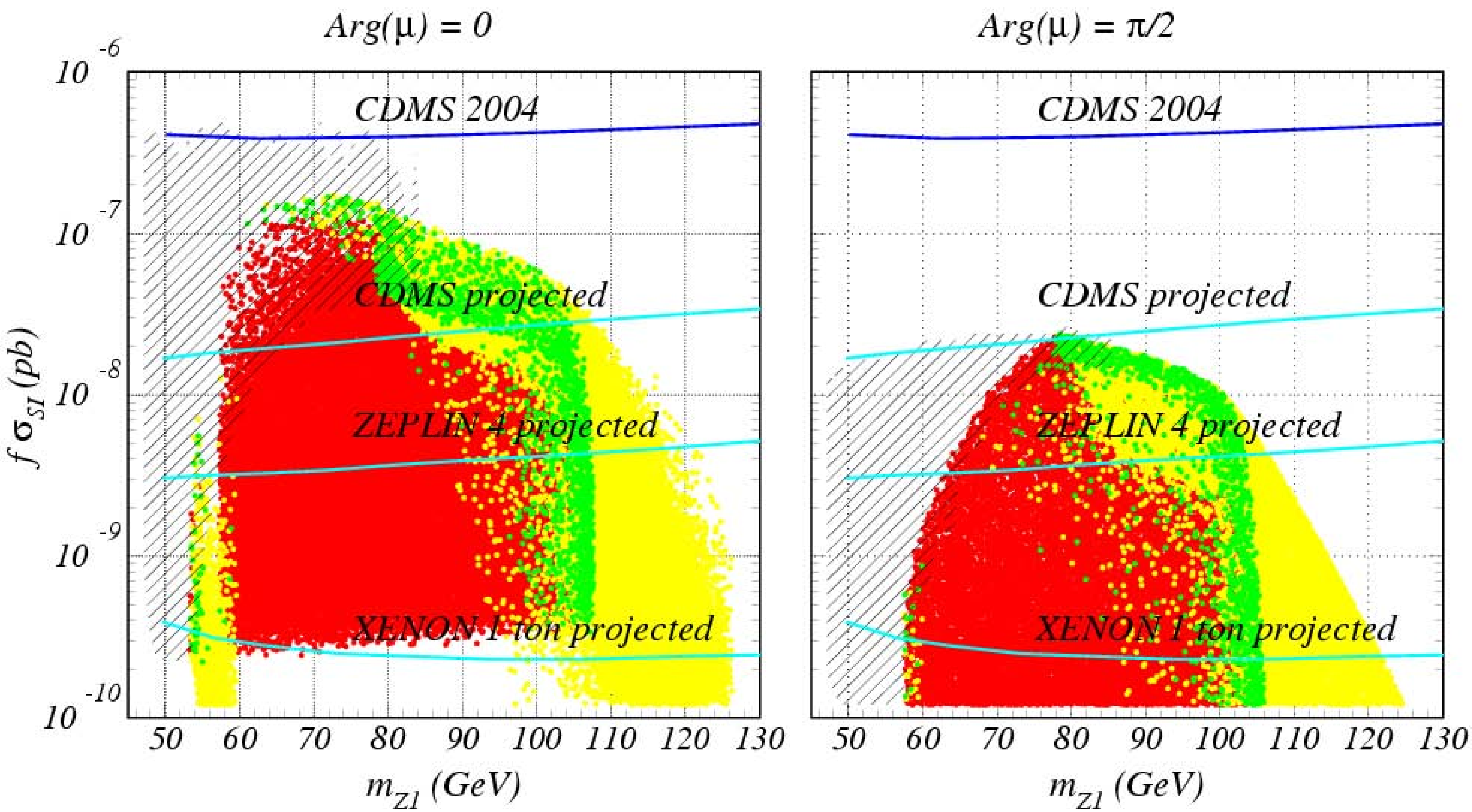
- Strategy to explore collider phenomenology

  Les Houches light $\tilde{t}$ WG

  (Allanach, Balázs, Galanti, Ghosh, Godbole, Guchait, Lari, Schumacher, Shepherd, Sopczak, Zhukovarena ...)
- Benchmark point selection : 1, 2 and modified SPS1a (Ayres)
- Benchmark point analisys
  - BMSSM 1
    - $\tilde{t}_1 \tilde{Z}_1$ mass gap small
    - no Tevatron (LHC) reach
    - ILC reach → Les Houches
  - BMSSM 2
    - Tevatron (LHC) reach ?
  - BMSSM 3
    - No Tevatron (LHC) reach
    - ILC reach → Ayres

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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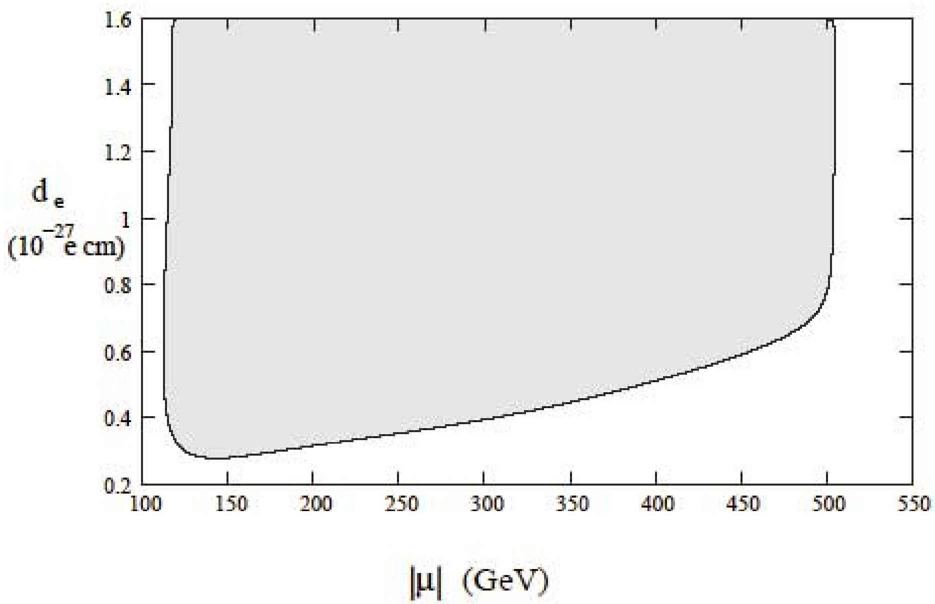
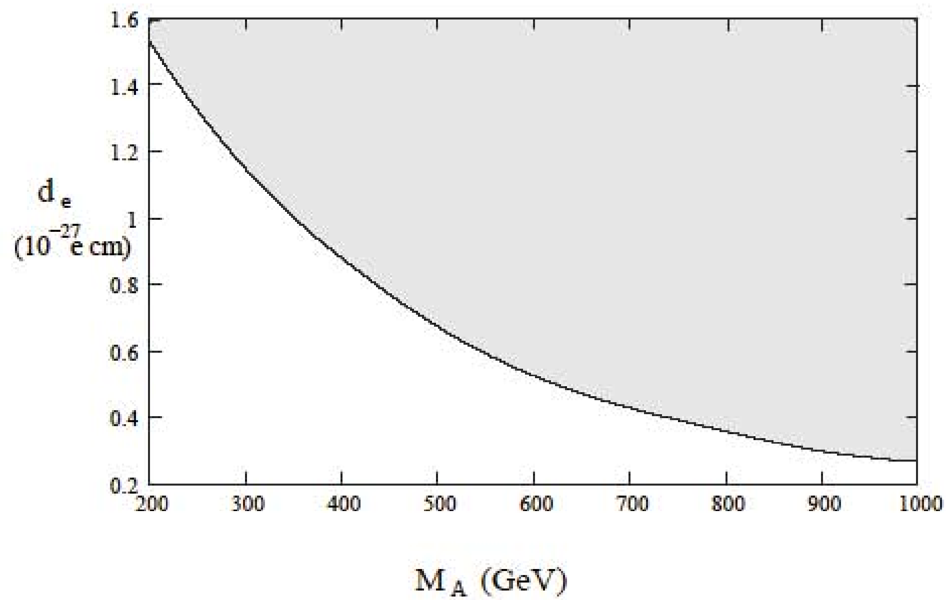
Electron electric dipole moment constraint

– e^- EDM is one of the most sensitive probes of EWBG

- EWBG requires complex phases →← complex phases generate EDM
- EWBG requires Arg(μ) $\gtrsim$ 0.1 → $2\times10^{-28} e$ cm $\lesssim |d_e|$
- experimental limit: $|d_e| < 1.6\times10^{-27} e$ cm





Balázs,Carena,Menon,Morrissey,Wagner 2004

- Minimal model probed if d_e- limits improve by 10-100 (next few years)
- Escape e^- EDM: specific phase arrangements, $m_A >$ 1 TeV, non-min. models

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 will not cover the full para. space
- International Linear Collider covers most of the parameter region
- direct dark matter searches can find the neutralino in this scenario
- complementary collider, dark matter & low energy experiments can uncover..

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