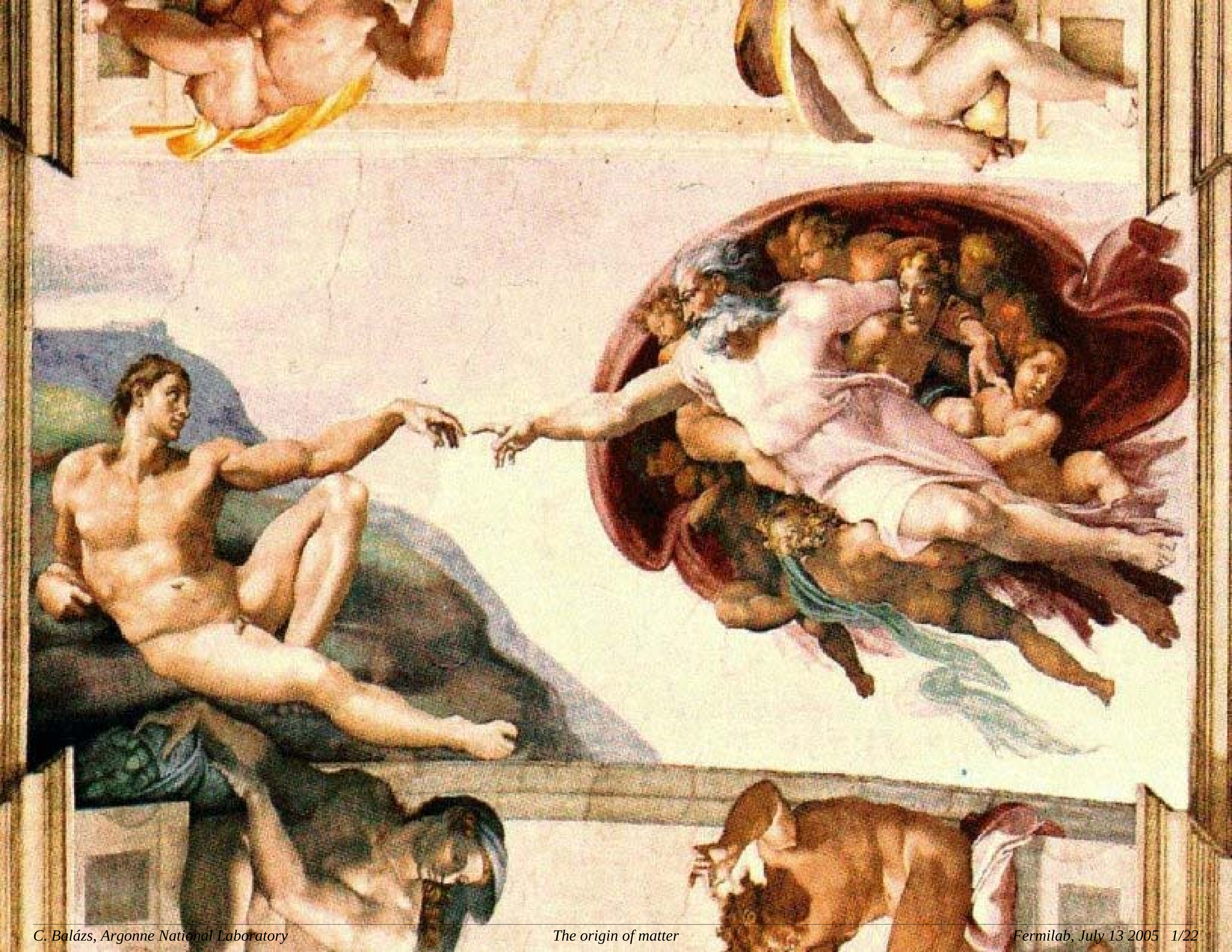


The origin of matter

— Neutralinos as dark matter

— Electroweak baryogenesis

— The supersymmetric origin of matter

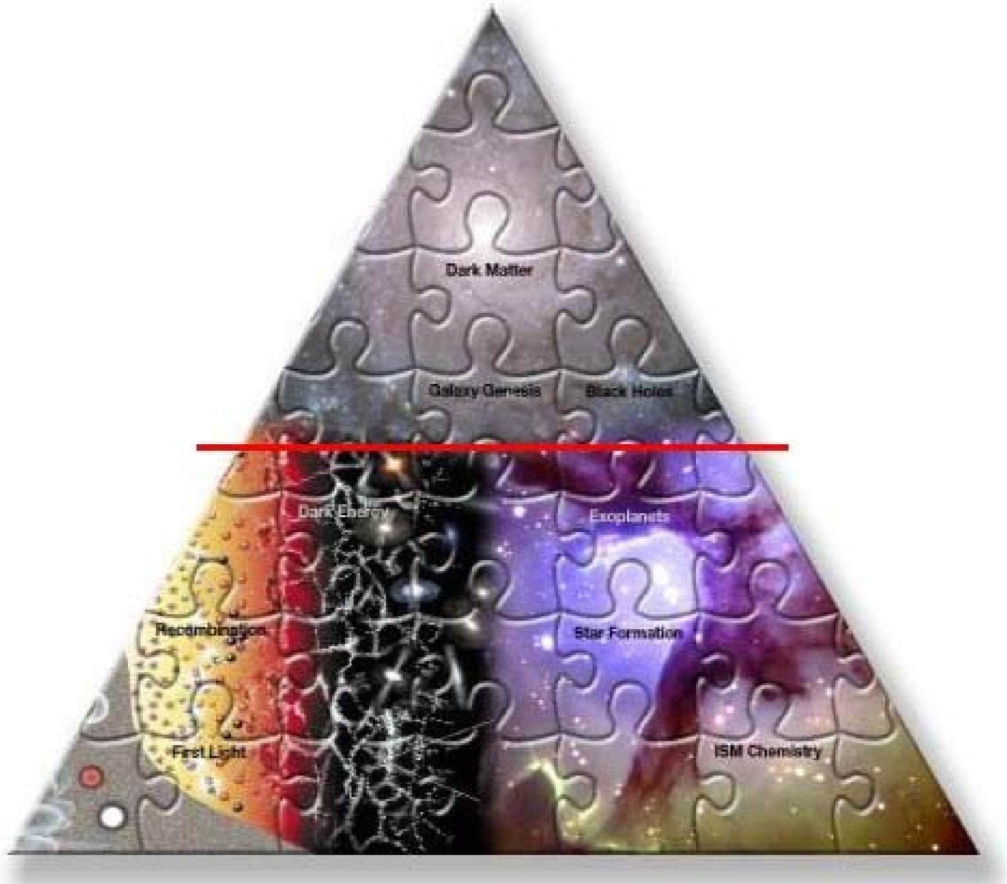
C.Balázs, M.Carena, A. Menon, D.E.Morrissey, C.E.M.Wagner
PRD71 075002 (`05)

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

http://www.hep.anl.gov/balazs/Physics/Talks/2005/07-FNAL

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

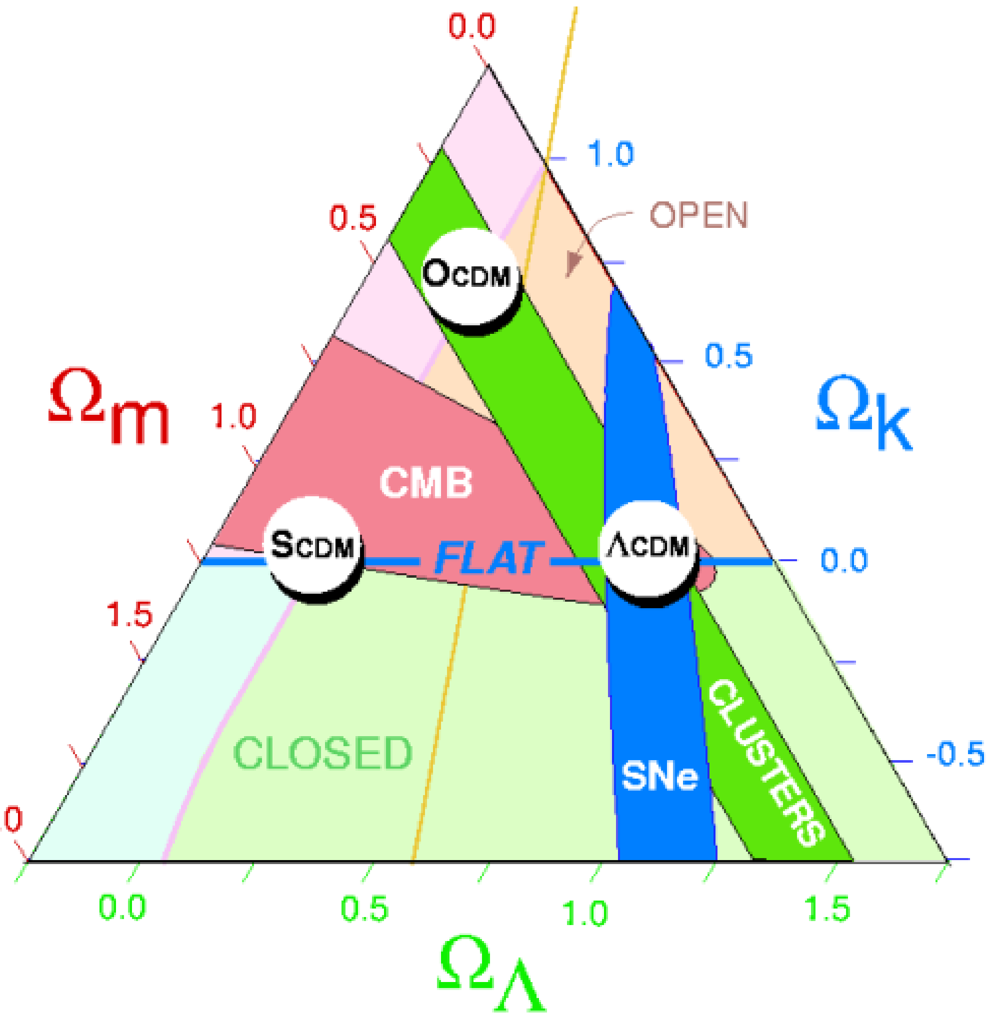


the cosmic puzzle

- SNe,WMAP,SDSS: $\Omega_m \sim 0.25$ $\Omega_\Lambda \sim 0.75$ $\Omega_{tot} \sim 1.0$

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

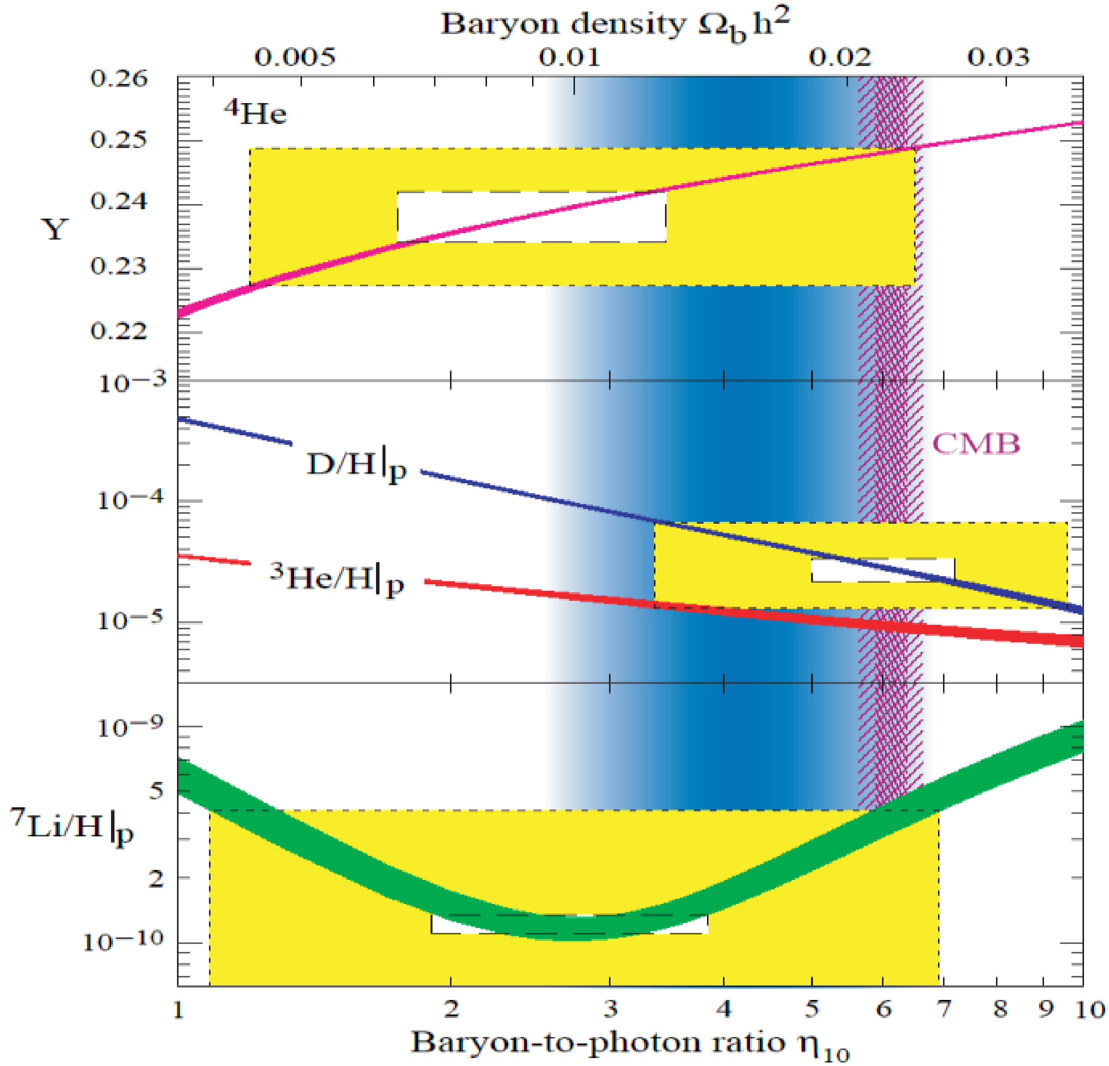


Bahcall et al. 1999

- 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 $\Omega_\nu, \Omega_r < 0.015$



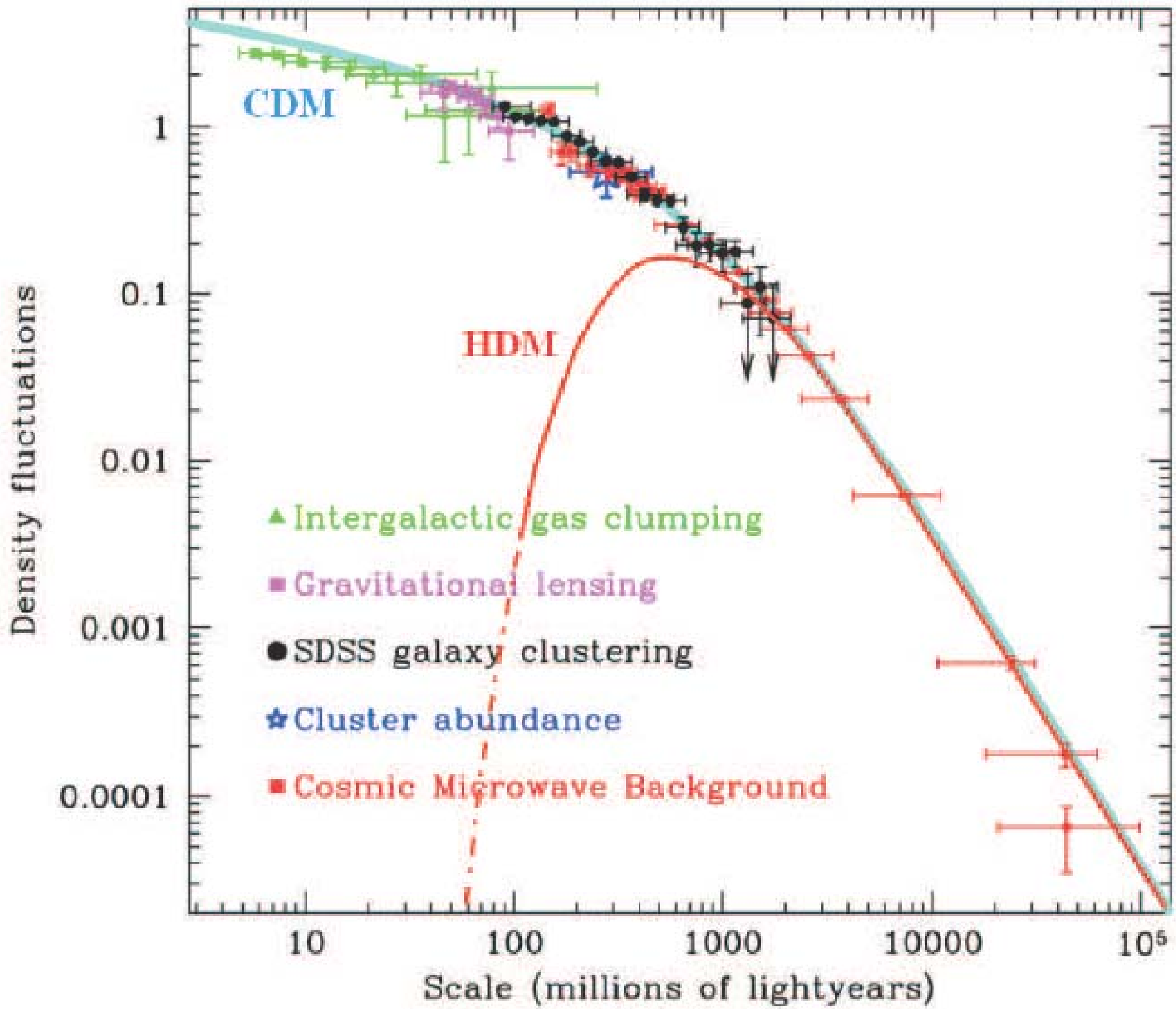
PDB 2004

- 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

– Galactic structure requires cold dark matter

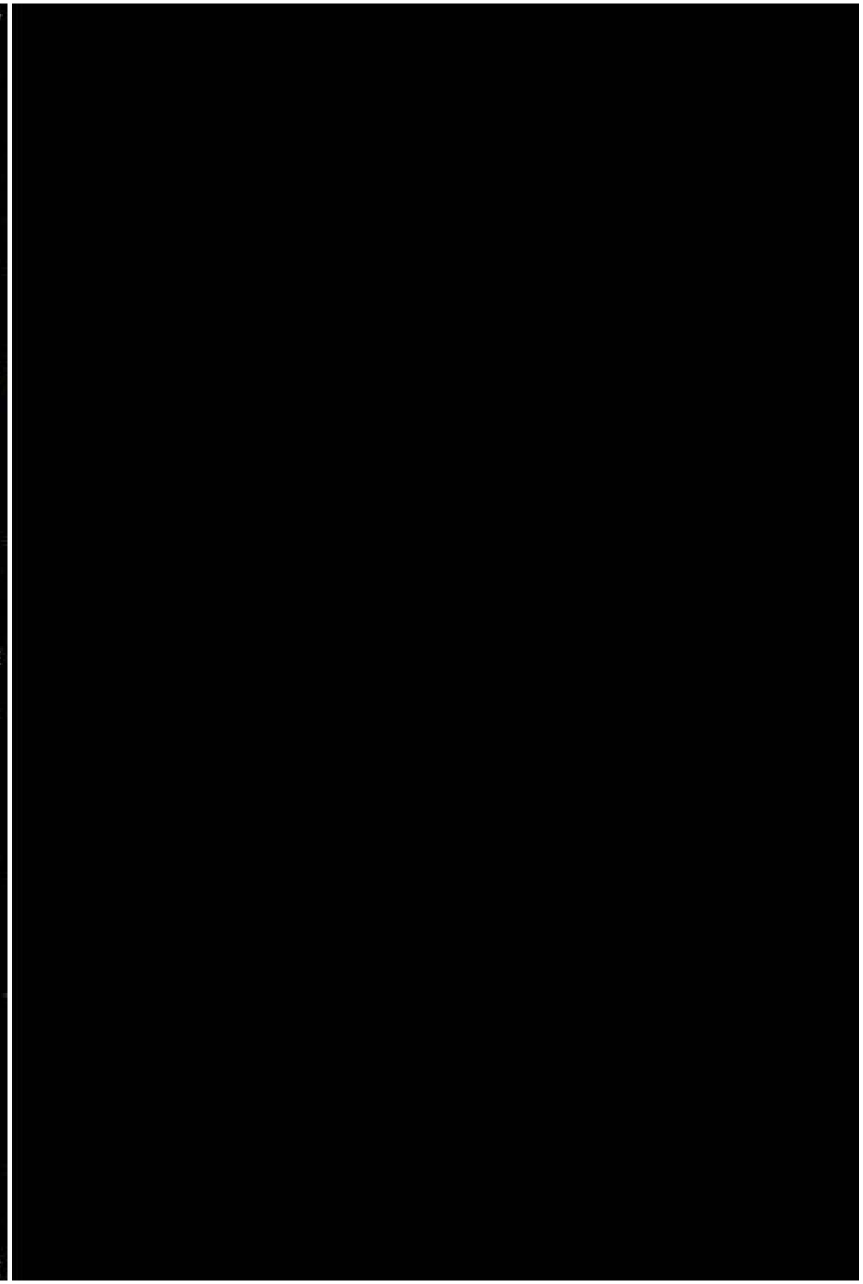
- CDM clumps first, attracting matter later cfcp.uchicago.edu/lss/filaments.htm



Maroto,Ramirez astro-ph/0409280

Cold dark matter? (An astronomer's view)

Luminous matter



Dark matter

Cold dark matter = neutralino

— $\tilde{Z}_1$ properties

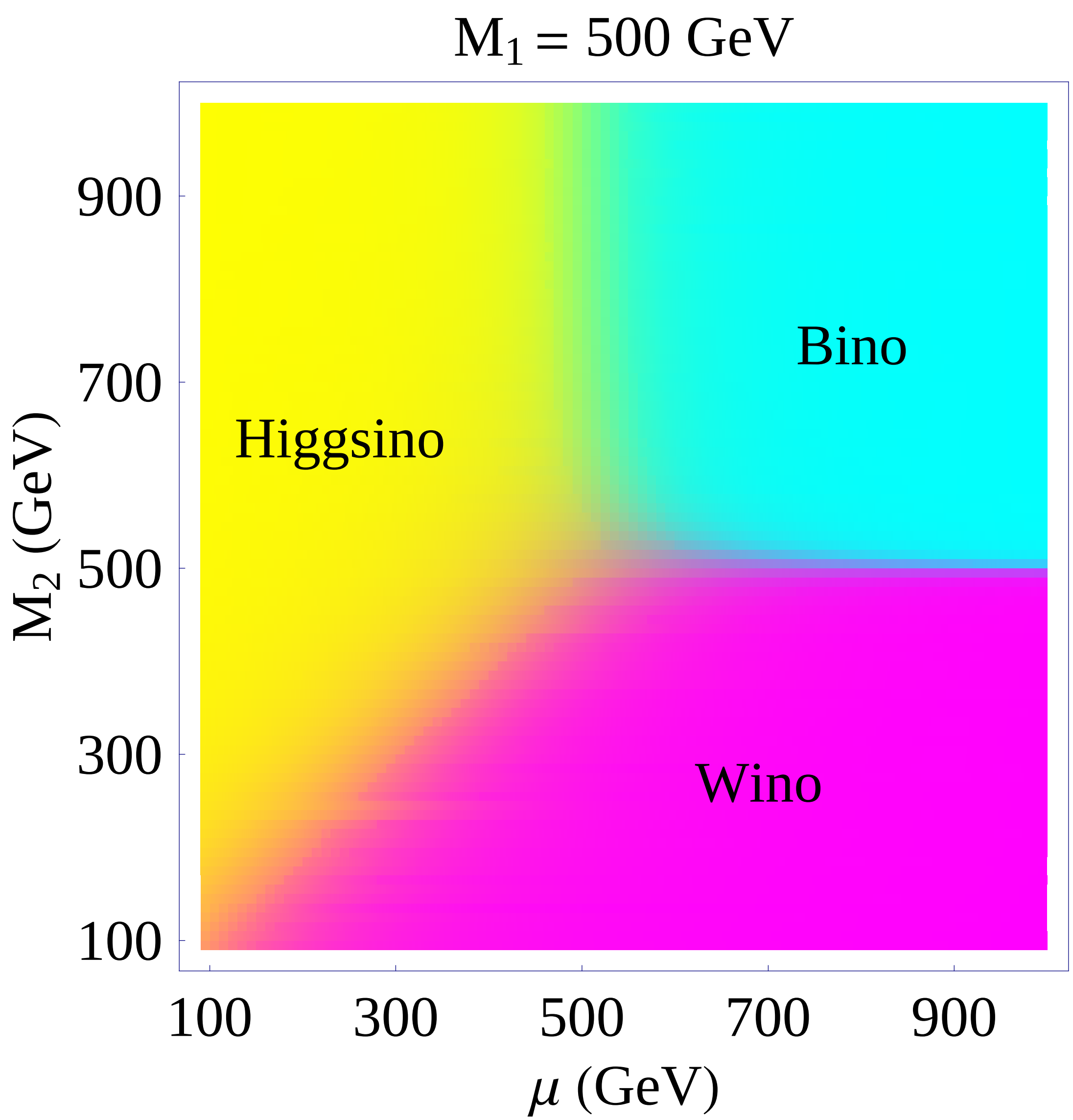
- stable in most models
- neutral, non-baryonic
- mass ~ EW scale

— $\tilde{Z}_1$ admixture

- mass eigenstate

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

- Bino : σ_{eff} small → $\Omega_{\tilde{Z}_1}$ large
- Higgsino : σ_{eff} large → $\Omega_{\tilde{Z}_1}$ small
- Wino : σ_{eff} very large → $\Omega_{\tilde{Z}_1}$ tiny



Balázs 2005

Cold dark matter = neutralino

— $\tilde{Z}_1$ properties

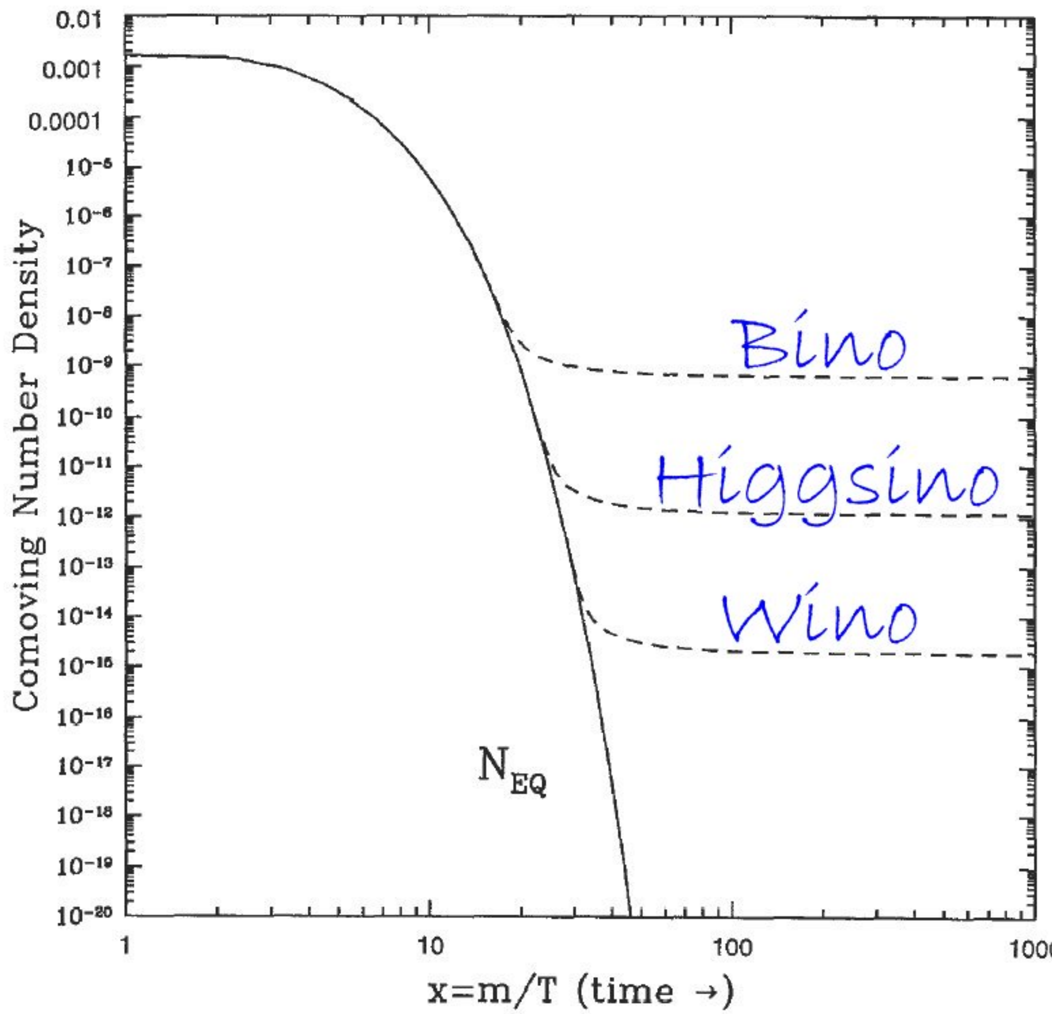
- stable in most models
- neutral, non-baryonic
- mass ~ EW scale

— $\tilde{Z}_1$ admixture

- mass eigenstate

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

- Bino : σ_{eff} small → $\Omega_{\tilde{Z}_1}$ large
- Higgsino : σ_{eff} large → $\Omega_{\tilde{Z}_1}$ small
- Wino : σ_{eff} very large → $\Omega_{\tilde{Z}_1}$ tiny

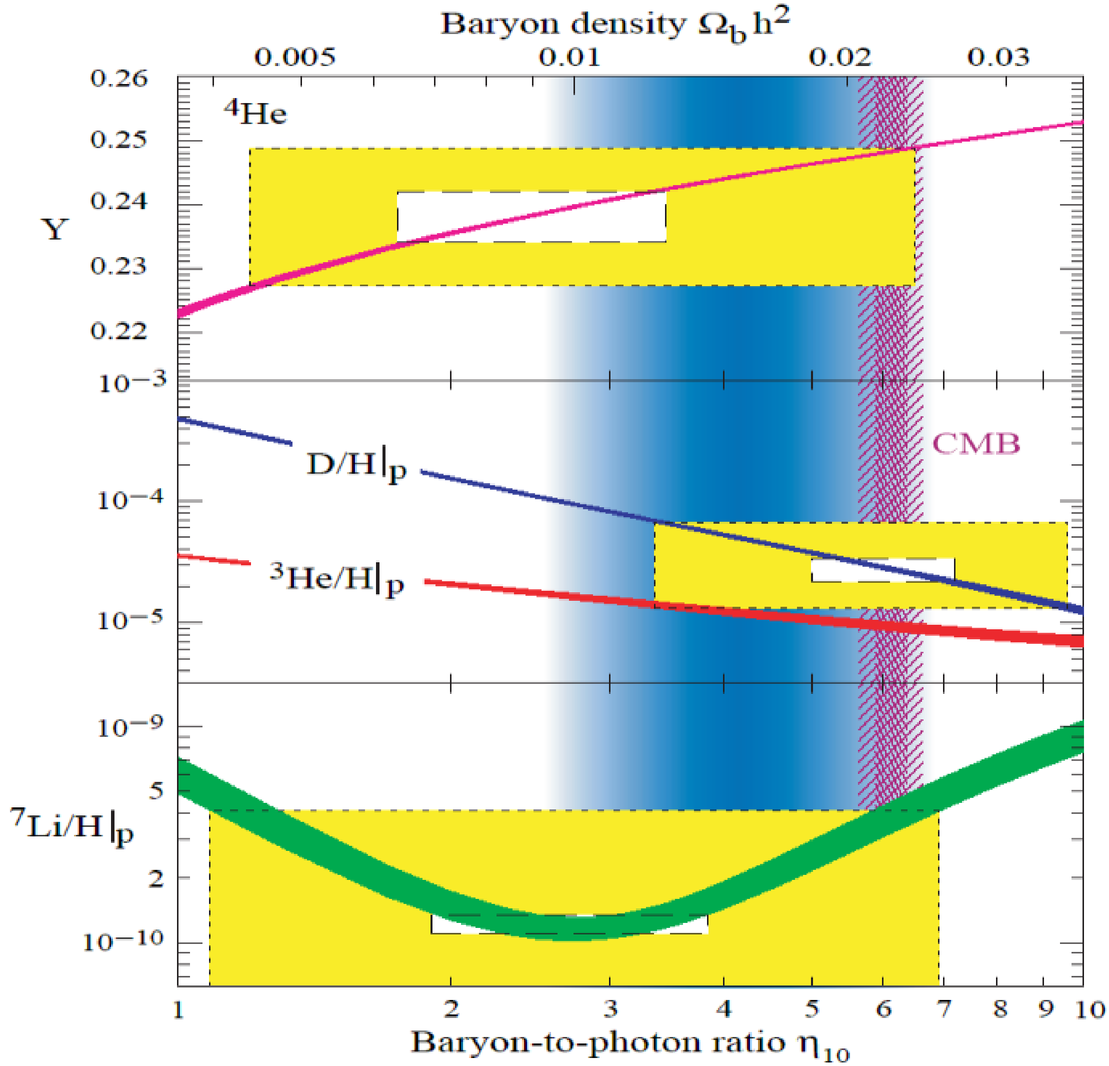


Kolb, Turner 1989

Anti-matter - What's the matter with it?

Anti matter

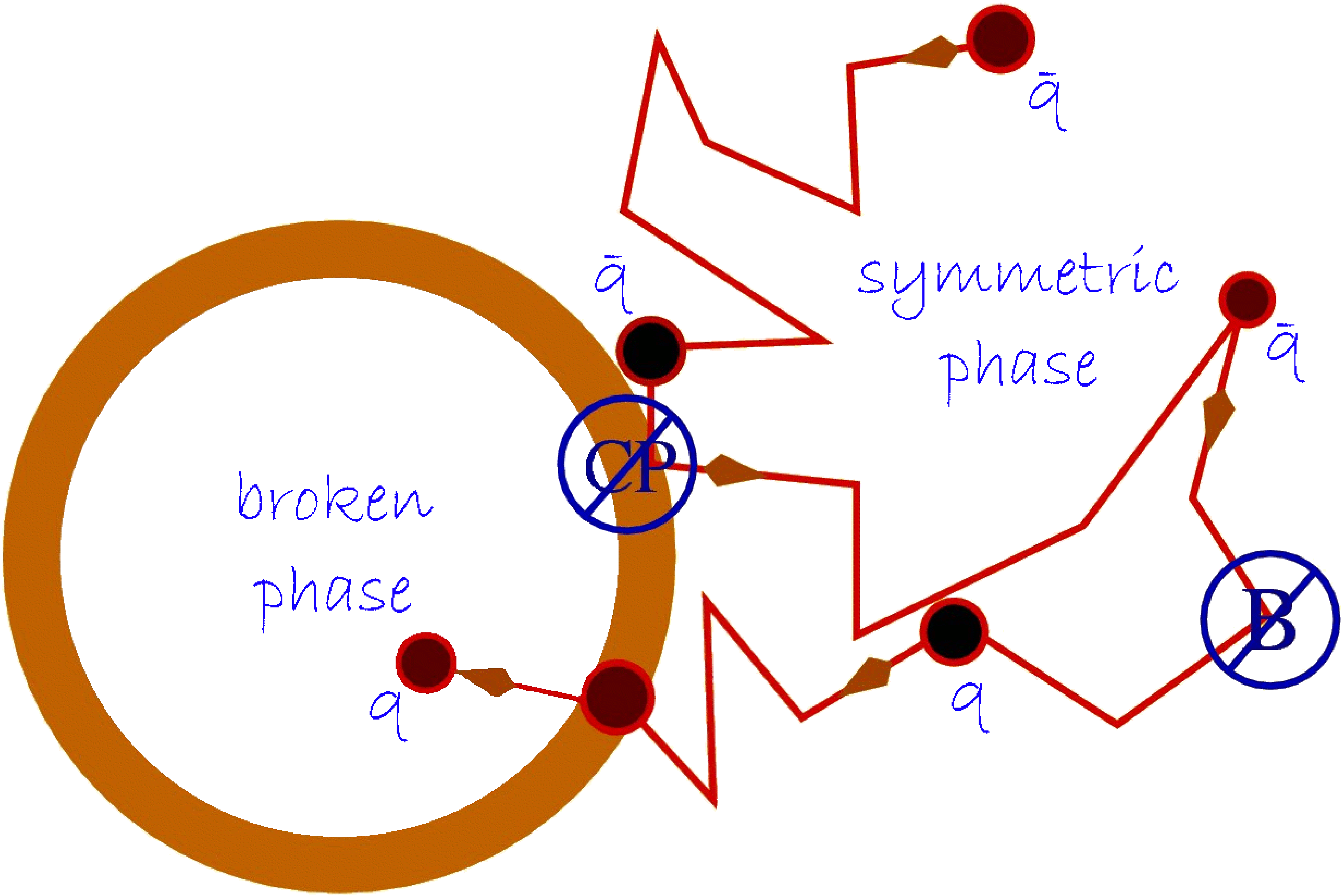
– Matter content: $\Omega_m = \Omega_b + \Omega_r + \Omega_\nu + \Omega_{DM}$ with $\Omega_\nu, \Omega_r < 0.015$



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

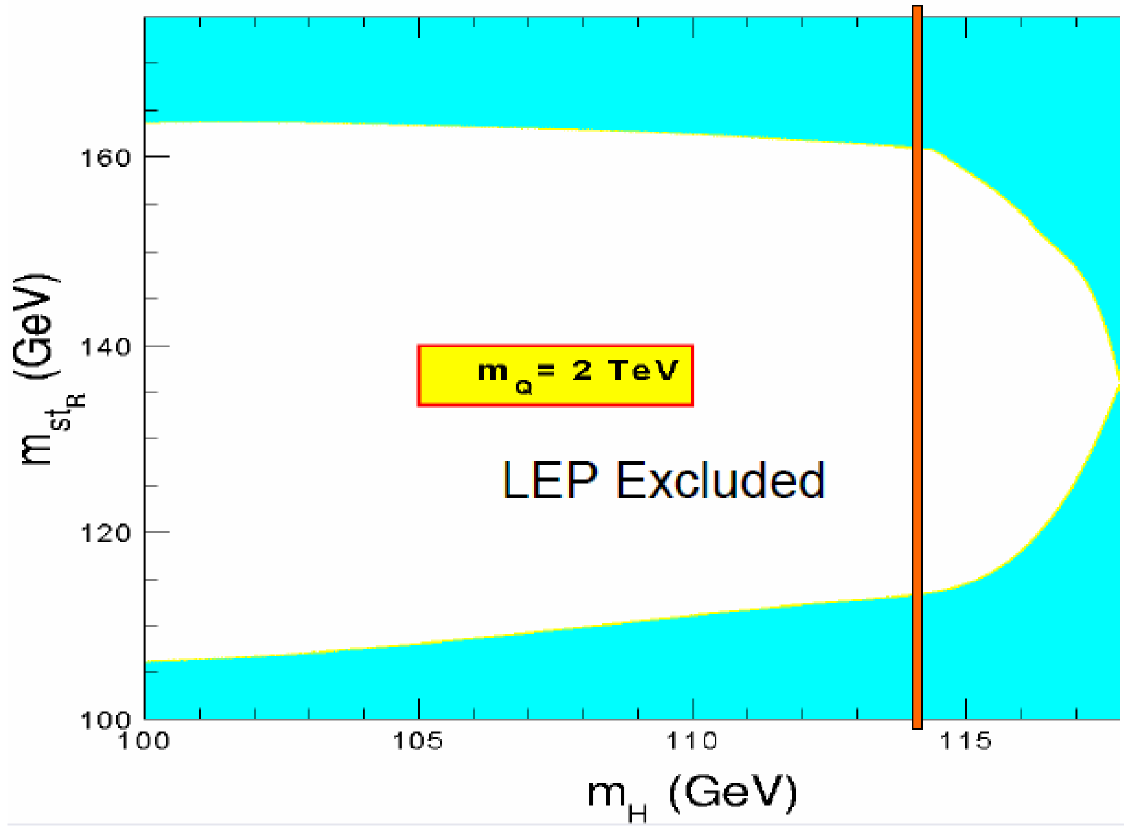
Matter-anti-matter asymmetry



Anti-matter: Electroweak baryogenesis in the MSSM

– Possible if

1. anomalous $\not{B}$ (✓)
2. enough $\not{CP}$ ↔ μ, M_i and/or A_t has (relative) complex phases
3. EW phase transition strongly 1st order → constraints on stop sector $m_{\tilde{t}_1} < m_t$, $m_{\tilde{t}_2} \gtrsim 1$ TeV, $0.3 < |X_t|/m_{\tilde{Q}_3} < 0.5$, constraints on Higgs sector $m_h \lesssim 120$ GeV



Carena, Seco, Quiros, Wagner 2002

- scenario is strongly constrained by LEP 2:

  114.4 GeV < m_h

- Does EWBG survive the stringent WMAP limits?

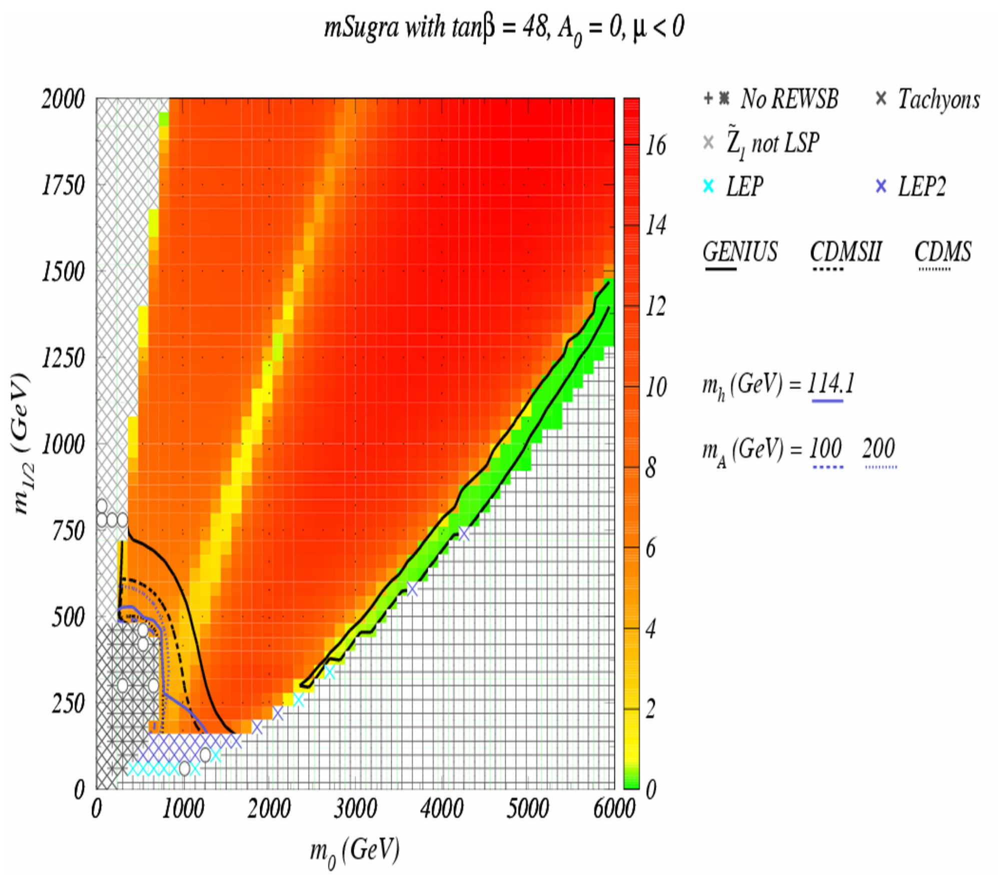
The origin of matter

– Top – down approach

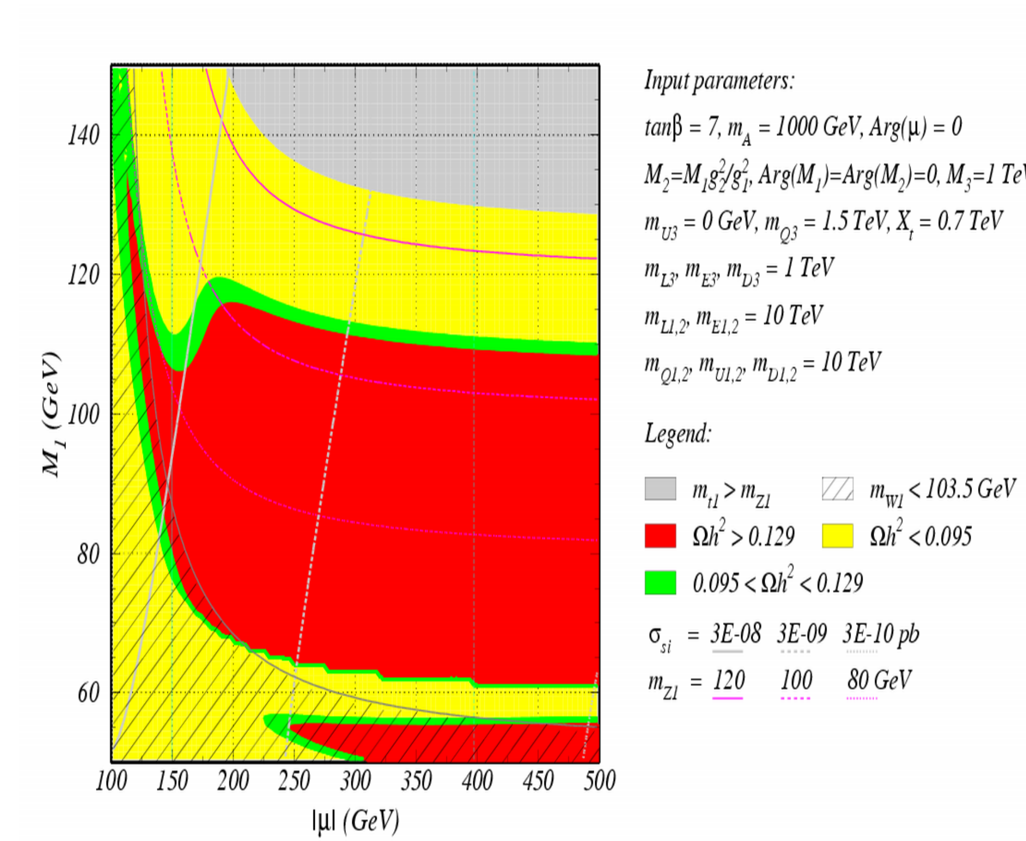
- pick a model → show viabalility
- motivated by aesthetics
- example : mSuGra

– Bottom – up approach

- start from data → narrow theory
- motivated by experimental data
- example : MSSM



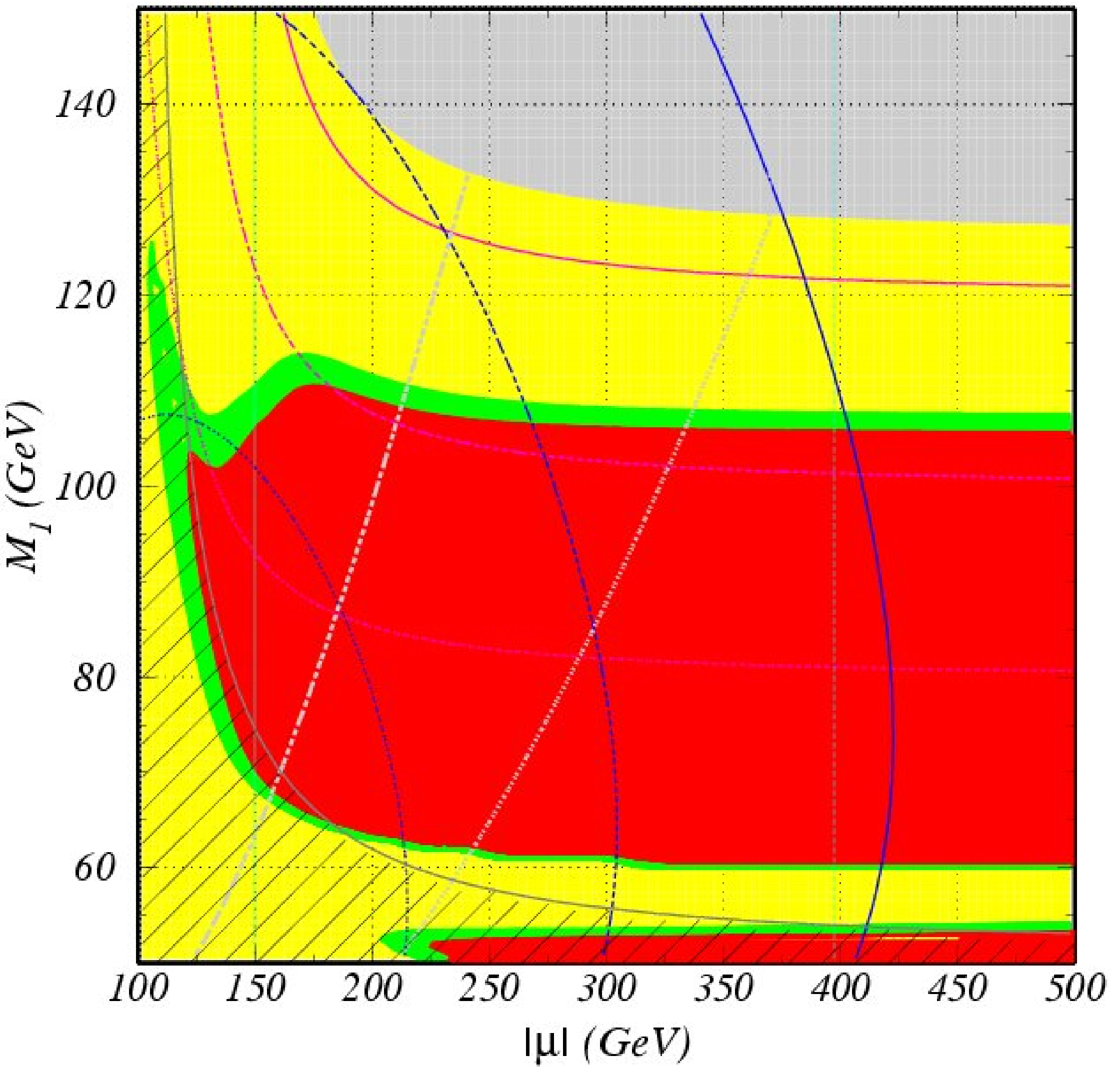
Balázs 2004



Balázs, Carena, Menon, Morrissey, Wagner 2004

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:

$m_{t1} > m_{Z1}$ (grey) $m_{W1} < 103.5$ GeV (hatched)

$\Omega h^2 > 0.129$ (red) $\Omega h^2 < 0.095$ (yellow)

$0.095 < \Omega h^2 < 0.129$ (green)

σ_{si} = 3E-08 3E-09 3E-10 pb

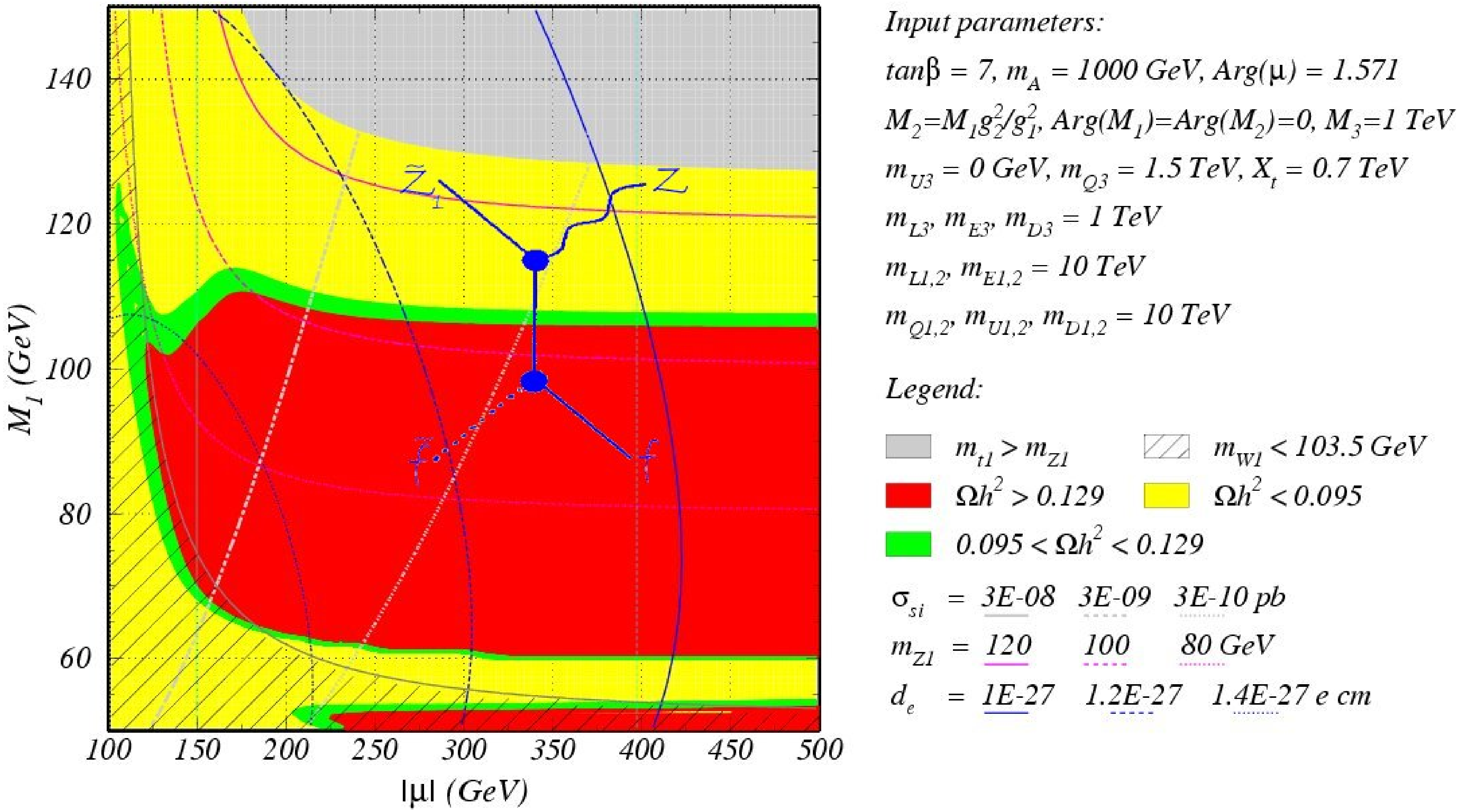
m_{Z1} = 120 100 80 GeV

d_e = 1E-27 1.2E-27 1.4E-27 e cm

Balázs, Carena, Menon, Morrissey, Wagner 2004

The supersymmetric origin of matter

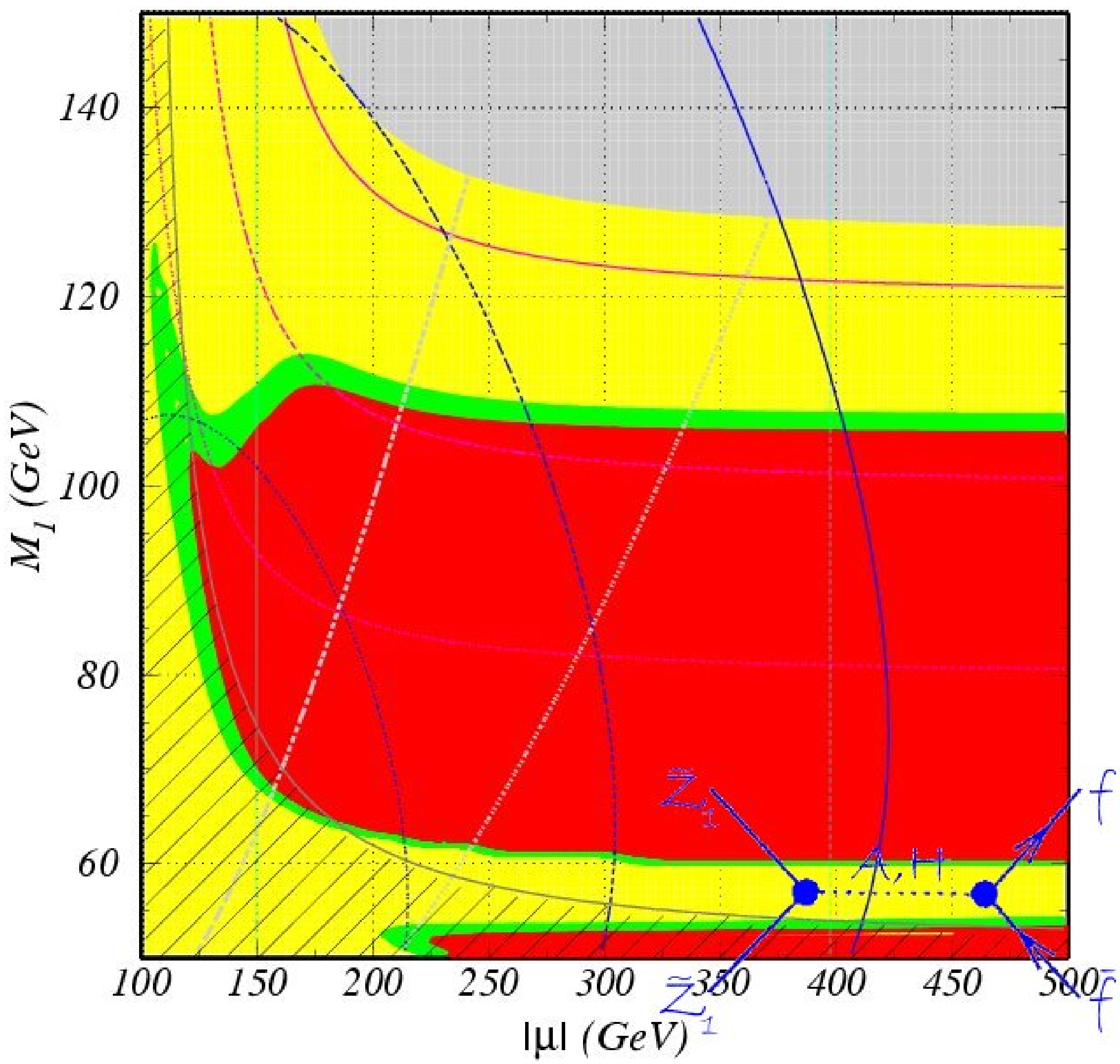
— $\tilde{t}_1$-$\tilde{Z}_1$ coannihilation lowers the neutralino relic density to agree with WMAP where $m_{\tilde{t}_1} \sim m_{\tilde{Z}_1}$



Balázs, Carena, Menon, Morrissey, Wagner 2004

The supersymmetric origin of matter

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



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

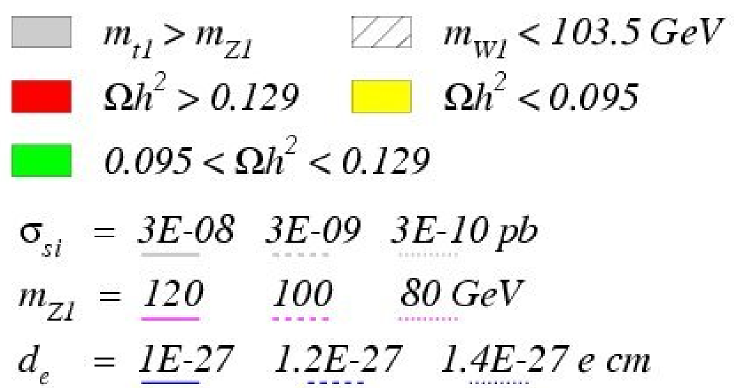
$m_{U3} = 0$ GeV, $m_{Q3} = 1.5$ TeV, $X_t = 0.7$ TeV

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

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

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

Legend:



Balázs, Carena, Menon, Morrissey, Wagner 2004

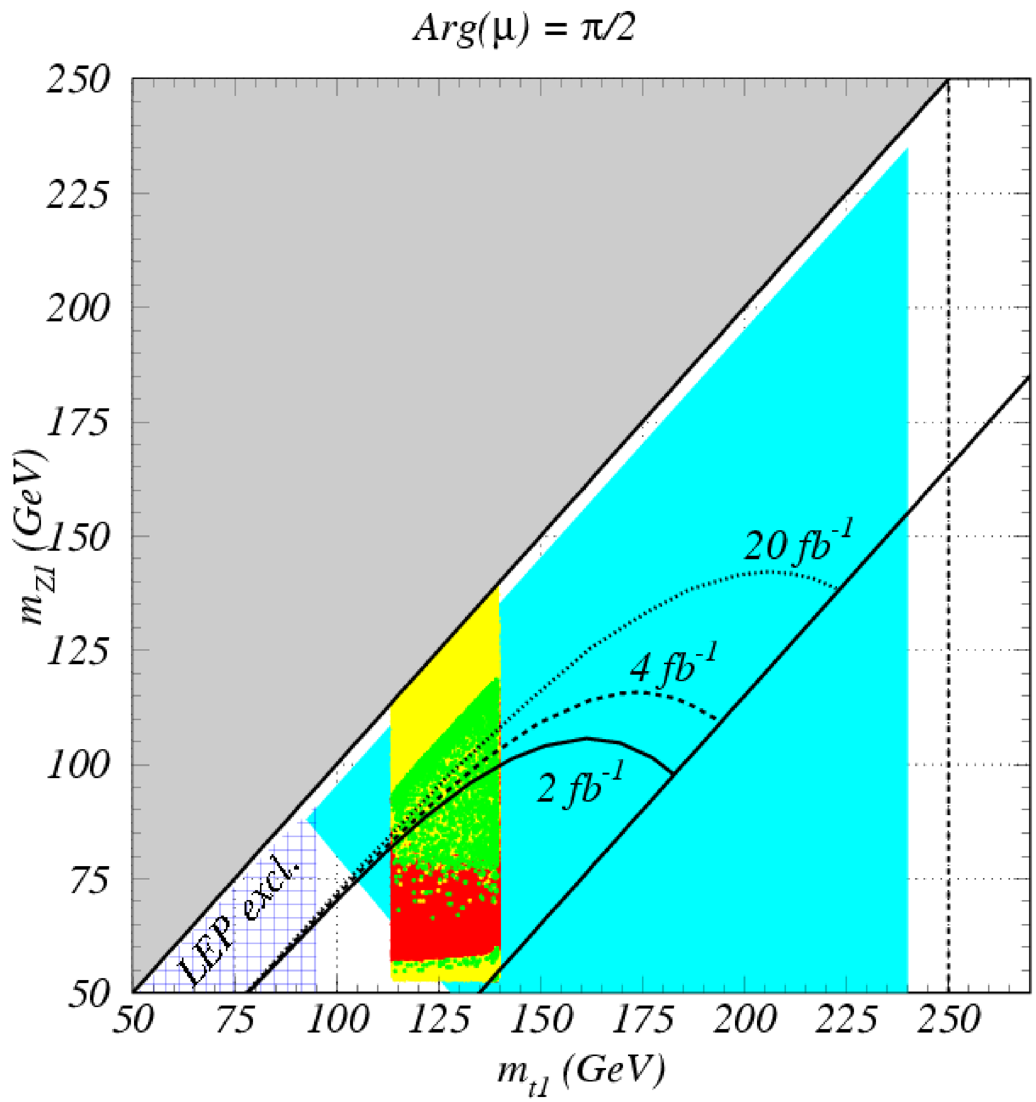
Collider implications → Ayres' talk

— 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

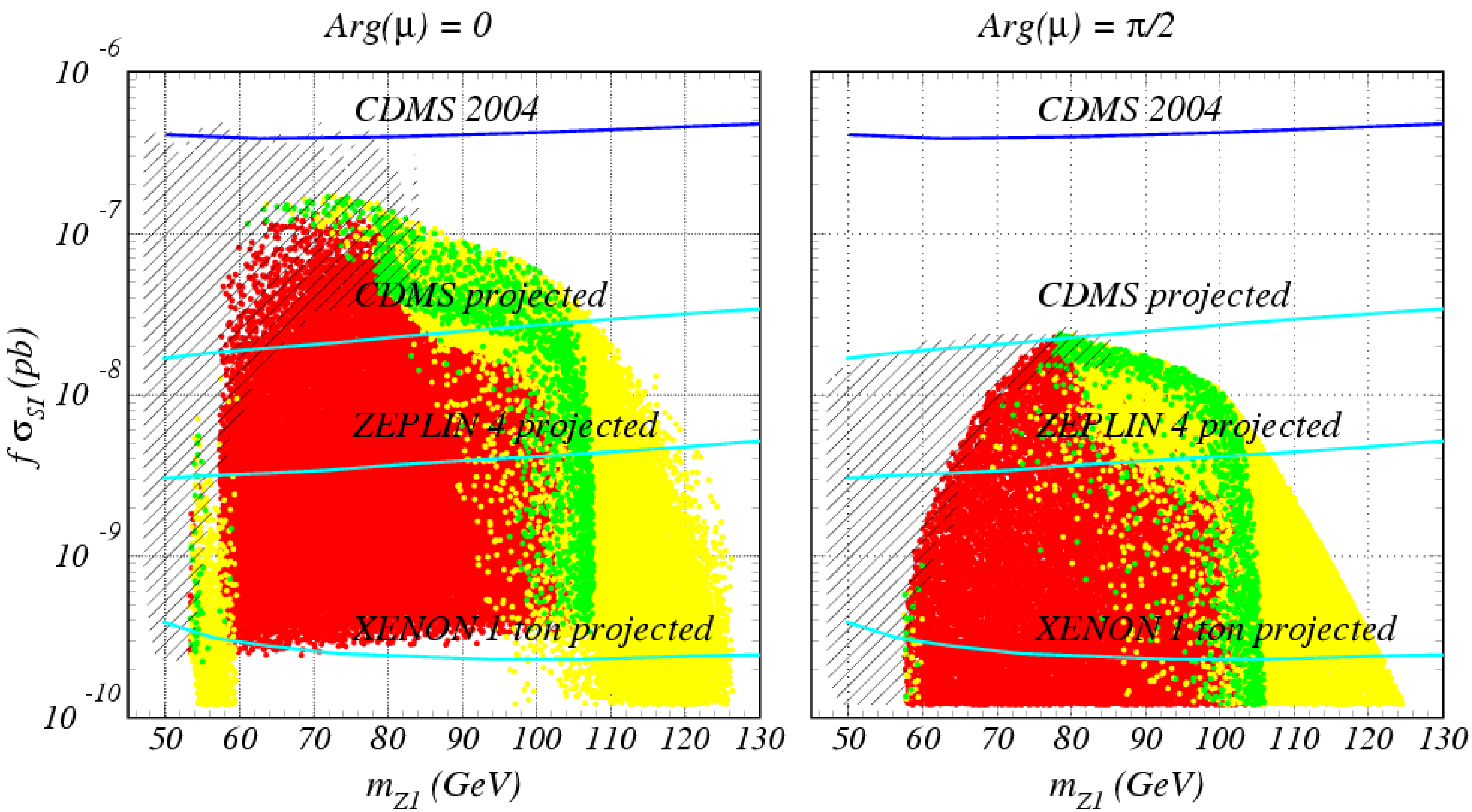
— ILC expected to cover
essentially all regions



Balázs 2005

Direct CDM detection experiments

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

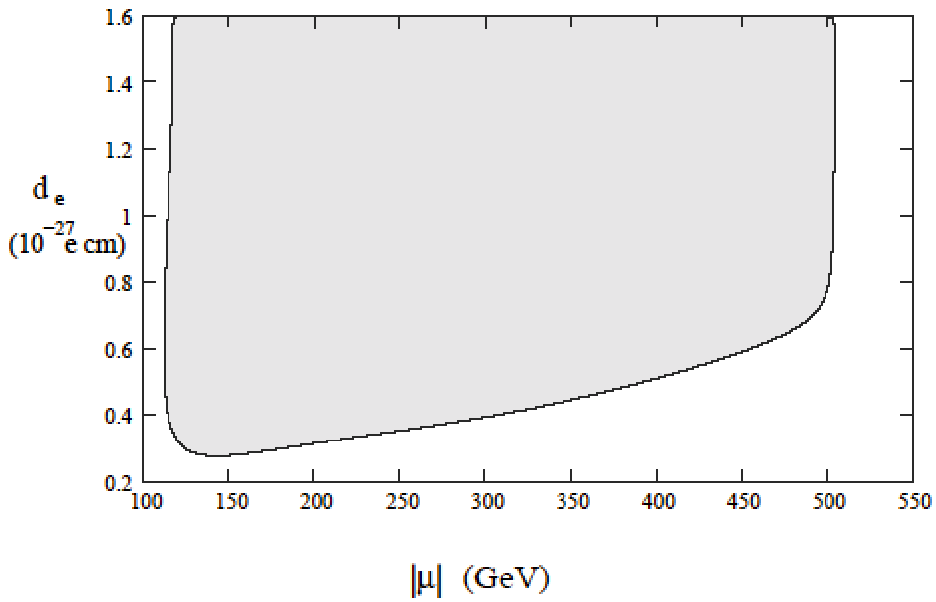


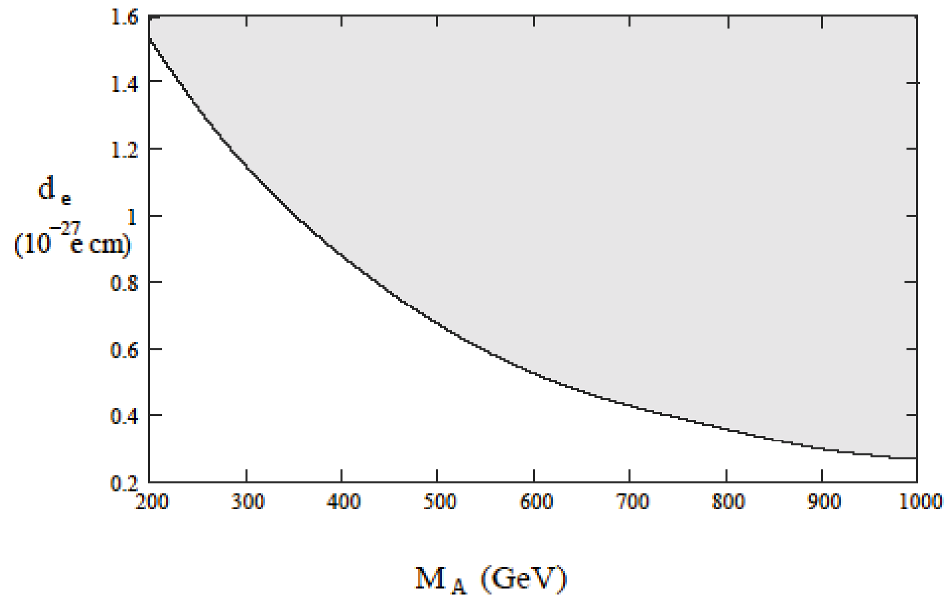
Balázs,Carena,Menon,Morrissey,Wagner 2004

Electron electric dipole moment

– e^- EDM is the most sensitive probe of the model:

- EWBG requires complex phases →← complex phases generate EDM
- EWBG requires: 2×10^{-28} e cm $\lesssim |d_e|$
- Experimental limit: $|d_e| < 1.6 \times 10^{-27}$ e cm





Balázs, Carena, Menon, Morrissey, Wagner 2004

- full parameter space probed if e^- EDM limits improve by factor ~10-100
- 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 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 searches together will uncover...

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 searches together will uncover...

the origin of matter