Supersymmetry, Dark Matter, and Dark Energy

Lisa L. Everett (U. Wisconsin, Madison)
BNL, May 31, 2007

Overview

This talk: dark matter + dark energy connections

("kination-dominated quintessence")

at LHC/ILC

in the context of low energy supersymmetry

Based on:

Chung, Everett, Kong, Matchev, to appear

Chung, Everett, Matchev, arXiv:0704.3285 [hep-ph]

Connecting Collider Physics and Cosmology

Desired collider connection w/cosmology:

understand dark energy , dark matter

Dark energy:

cosmological constant: CC problem sensitive to *entire* spectrum, couplings, SUSY breaking

quintessence: scalar field Φ w/ at most gravitational strength couplings to SM

Extremely difficult to probe directly at colliders!

Dark matter connection

Contrast: direct collider probes of dark matter

WIMP hypothesis (thermal relic $\widetilde{\chi}$): motivated in SUSY models (LSP), extra dim's (LKP), ...

Cosmological abundance depends on:

- couplings and masses (collider measurements)
- freeze out $\Gamma_A < H$ (cosmology)

Indirect dark energy connection:

consider usual thermal WIMP dark matter, but nonstandard cosmological expansion (quintessence)

Dark matter and Dark Energy connection

If dark energy is quintessence:

freeze out process can be affected!

Φ energy density can dominate at freeze out: $T_U \sim 1\,\mathrm{GeV}$

but must be small (<20%) by BBN: $T_0 \sim 10^{-3}\,\mathrm{GeV}$

$\rho_\Phi \propto a^{-3(1+w_\Phi)}$ must dilute faster than $\rho_R \sim a^{-4}$

if Φ behaves like

radiation	a^{-4}
matter	a^{-3}
inflaton	a^{0}
kination	a^{-6} ←

(Salati, astro-ph/0207396)

Kination domination and DM abundance

Definition: $\frac{1}{2}\dot{\Phi}^2 \gg V(\Phi),\ \rho_R,\ \rho_M$ $\quad\frac{\rho_\Phi}{\rho_\gamma} \propto a^{1-3w_\Phi}$

freeze out at higher T, larger abundance for same $\langle \sigma_A v \rangle$

e.g. p-wave annihilator: $\quad\eta_\Phi \equiv \left(\frac{\rho_\Phi}{\rho_\gamma}\right)_{T_0}$

$0 \le \eta_\Phi \le 1$

$$\frac{\Omega_\chi^{(K)}}{\Omega_\chi^{(U)}} \sim \frac{g_{*S}(T_U)}{g_{*S}(T_0)} \frac{T_U^2}{T_K T_0} \frac{\sqrt{\eta_\Phi}}{\sqrt{g_{*S}(T_U)/2}}$$

usual freeze out T (→ T_U)

entropy d.o.f. (→ g_{*S})

k dom freeze out T (→ T_K)

BBN T (→ T_0)

Ω_χ increased from standard scenario! (up to 10^3 enhancement)

Kination Domination and Neutralino Dark Matter

Scenario implies:

- Mismatch b/w collider LSP and direct/indirect search data

  Implications for favored MSSM parameter space:

  near resonances: $2m_\chi = m_{\rm int}$

  also coannihilations (not as effective)

  Resurrect wino, higgsino dark matter scenarios

  previous studies: LHC probes of kination domination Profumo, Ulio '03

- Good news for direct/indirect dark matter searches

  larger $\langle \sigma_A v \rangle$ for fixed $\Omega_\chi h^2$

Current study: ILC probes of dark energy

(w/Chung, Kong, Matchev, to appear)

Goal:

precision to which LHC/ILC can probe kination scenario

Procedure:

“recycle” ILC study points of Baltz, Battaglia, Peskin, Wizansky

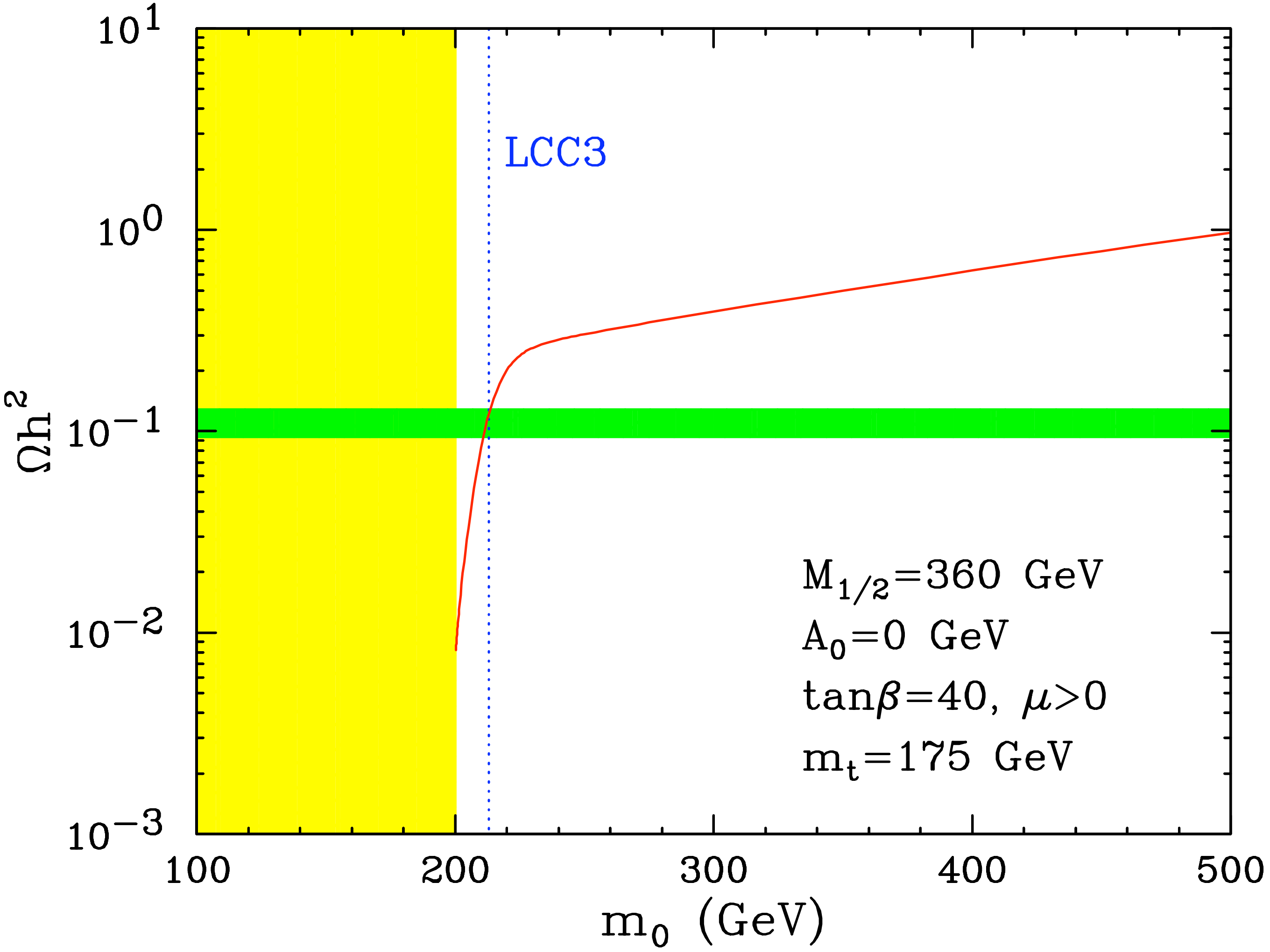
hep-ph/0602187

(mSUGRA, masses in GeV)

bulk	LCC1	$m_0 = 100, M_{1/2} = 250, \tan\beta = 10, A_0 = -100, \mu > 0$	LCC1’	$M_{1/2} = 150$
focus	LCC2	$m_0 = 3280, M_{1/2} = 300, \tan\beta = 10, A_0 = 0, \mu > 0$	LCC2’	$m_0 = 3360$
stau	LCC3	$m_0 = 213, M_{1/2} = 360, \tan\beta = 40, A_0 = 0, \mu > 0$	LCC3’	$m_0 = 205$
A funnel	LCC4	$m_0 = 380, M_{1/2} = 420, \tan\beta = 53, A_0 = 0, \mu > 0$	LCC4’	$m_0 = 950$ $\tan\beta = 50$ $\mu < 0$

Future work: beyond mSUGRA, other scenarios...

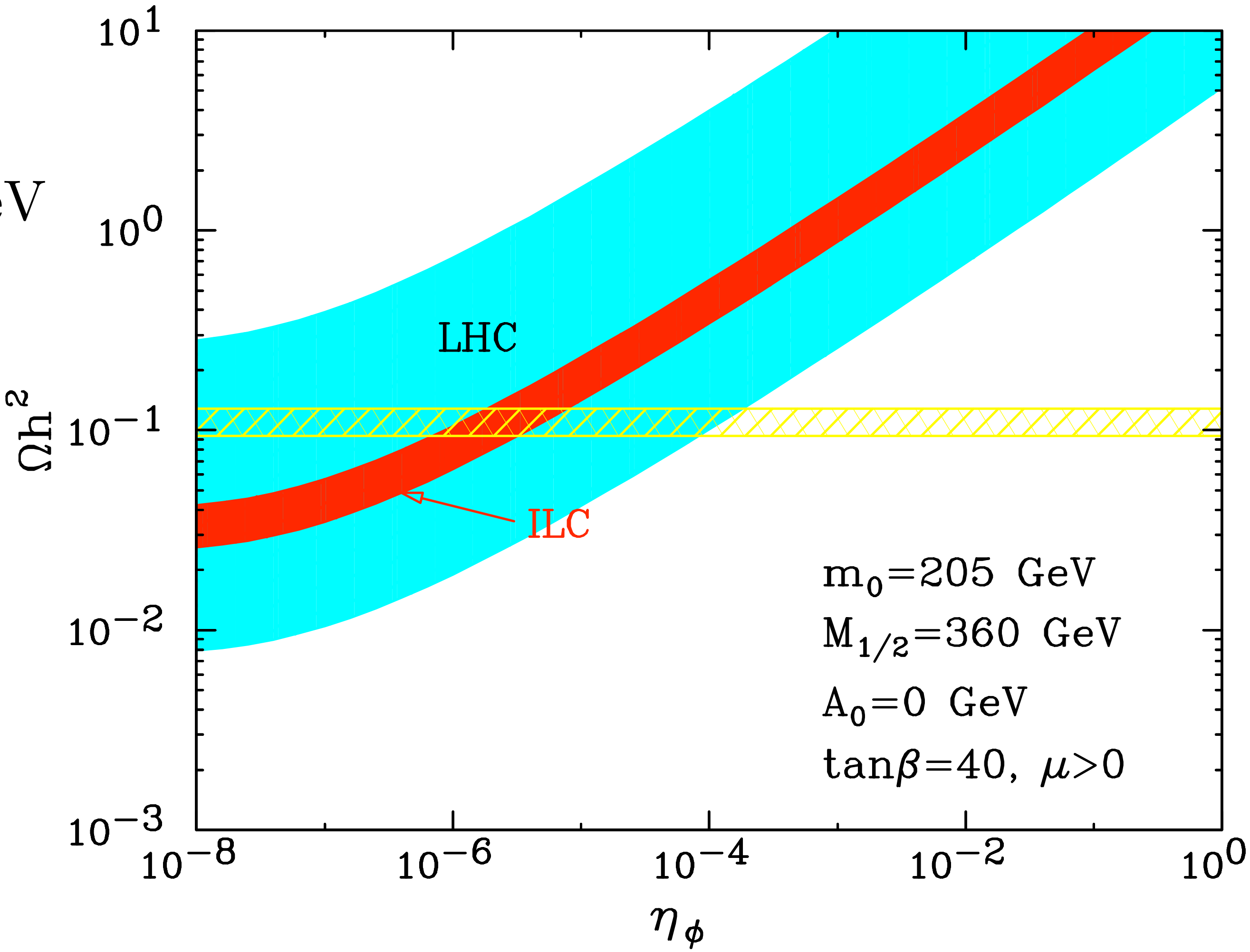
Stau coannihilation region: mSUGRA LCC3 study point with adjusted m_0



Stau coannihilation region: mSUGRA LCC3 study point with adjusted m_0

$m_{\tilde{\chi}} \approx 140\,\mathrm{GeV}$

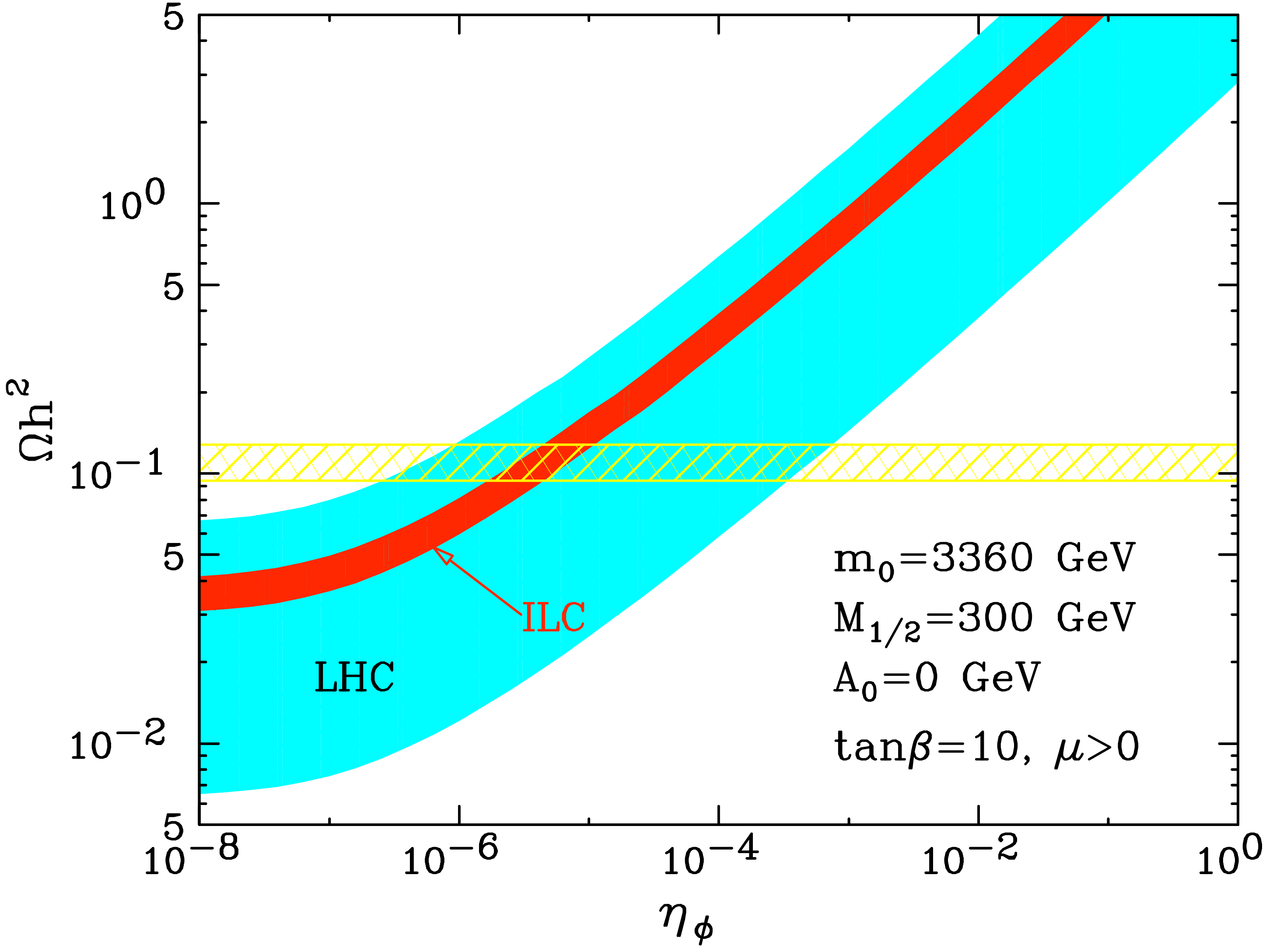
$|m_{\tilde{\chi}} - m_{\tilde{\tau}}| < 5\,\mathrm{GeV}$



(Chung, L.E., Kong, Matchev, preliminary)

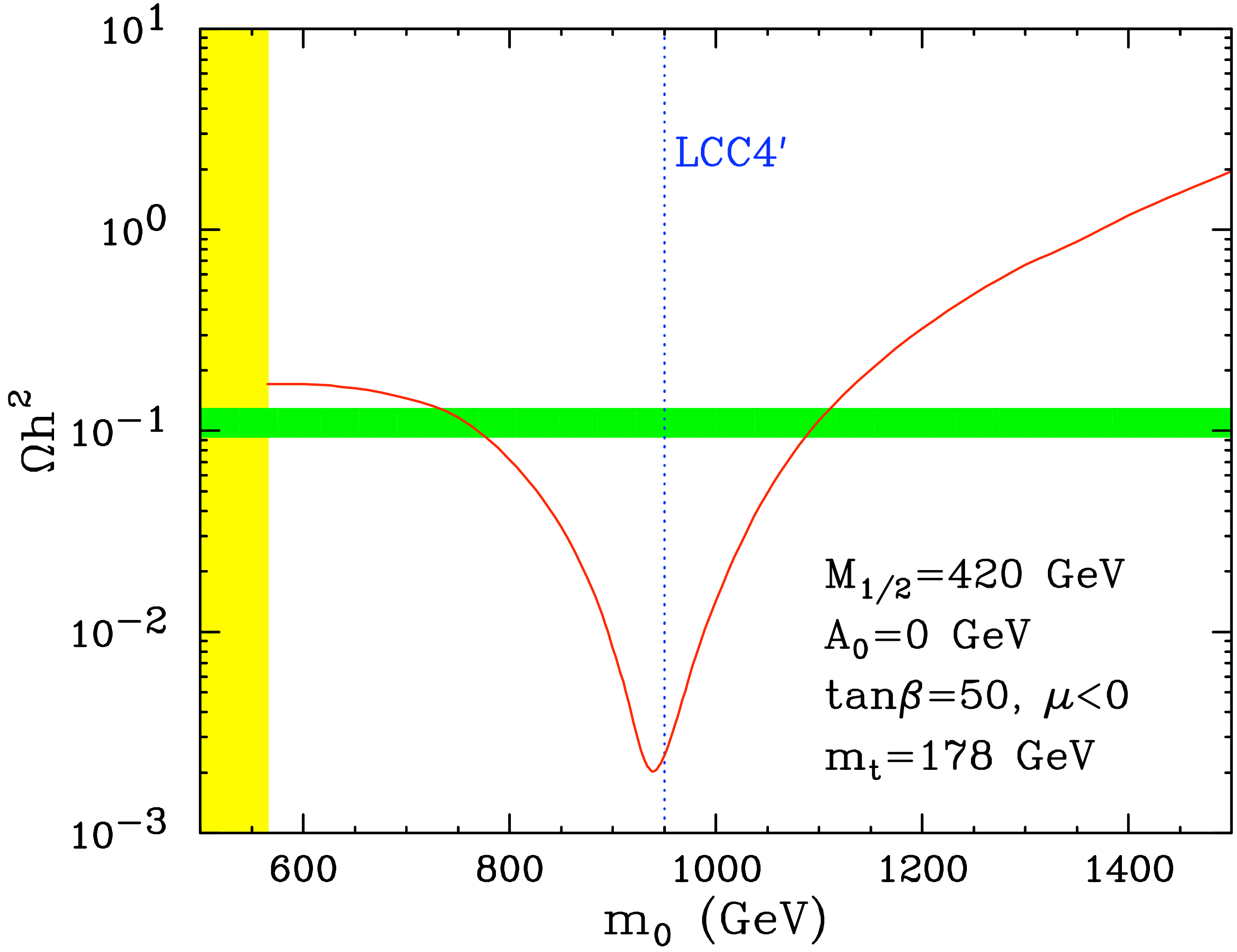
Focus region study point

mSUGRA LCC2 study point
with adjusted m_0



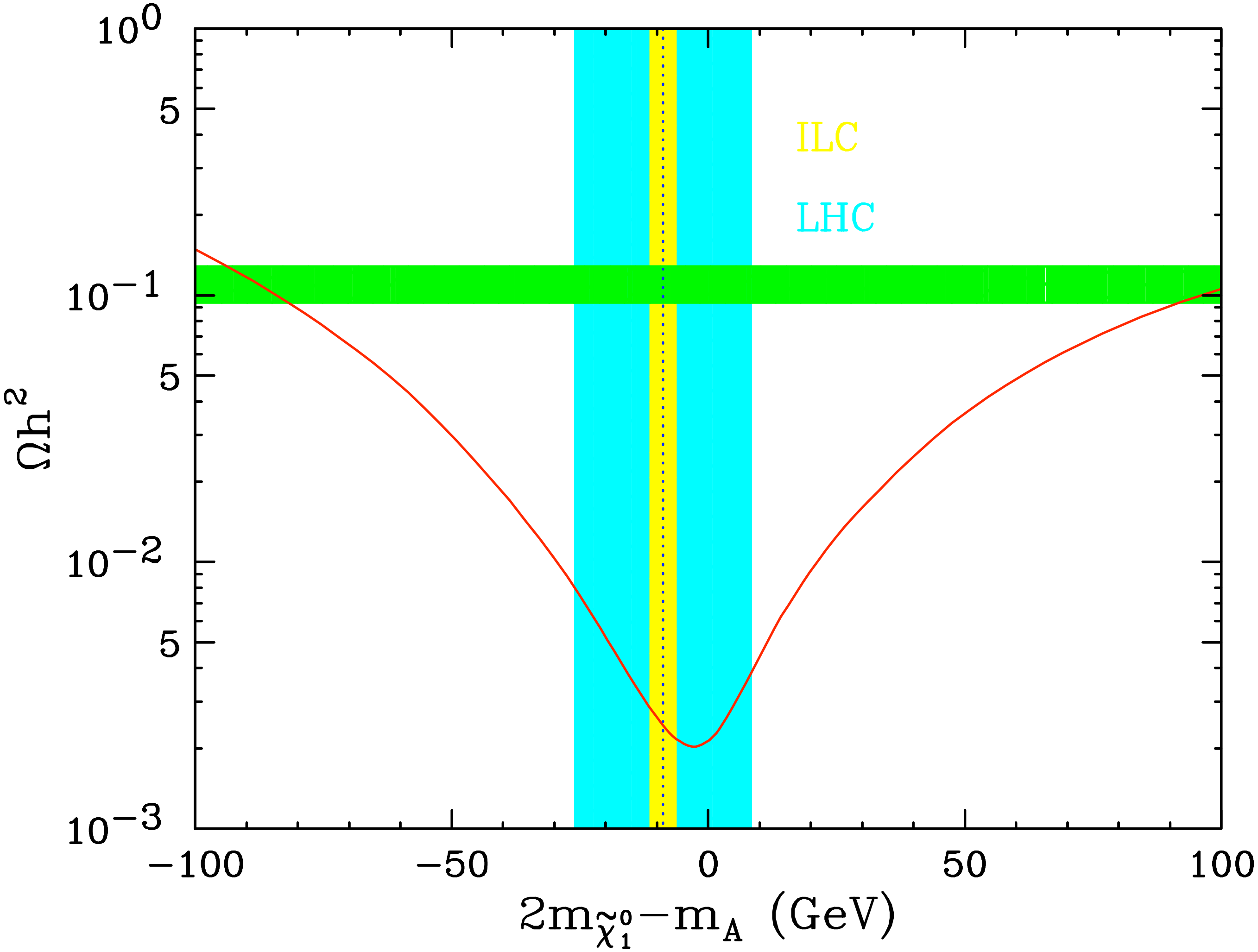
A-funnel study point

mSUGRA LCC4 study point with adjusted parameters



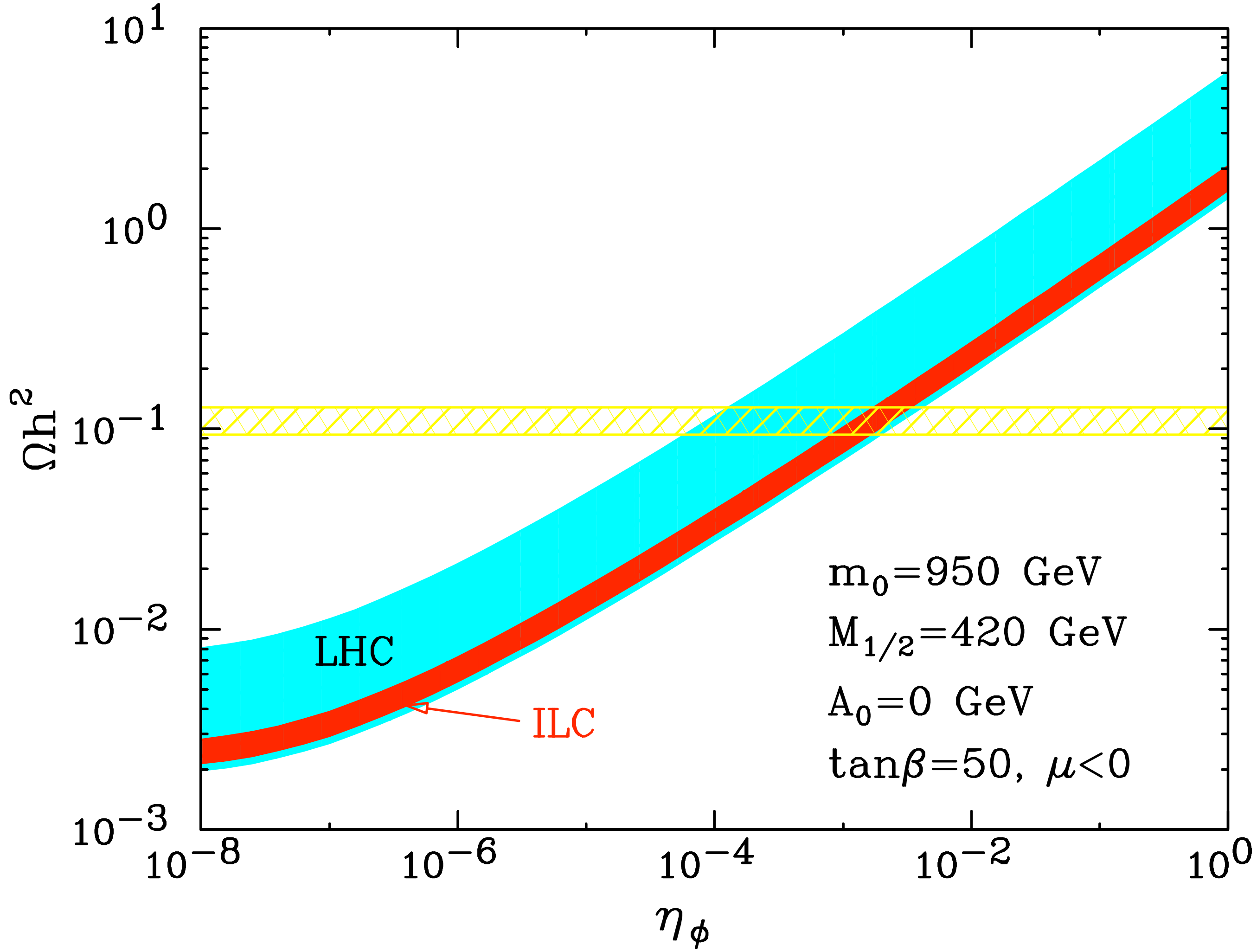
A-funnel region study point

mSUGRA LCC4 study point
with adjusted parameters



A-funnel region study point

mSUGRA LCC4 study point
with adjusted parameters

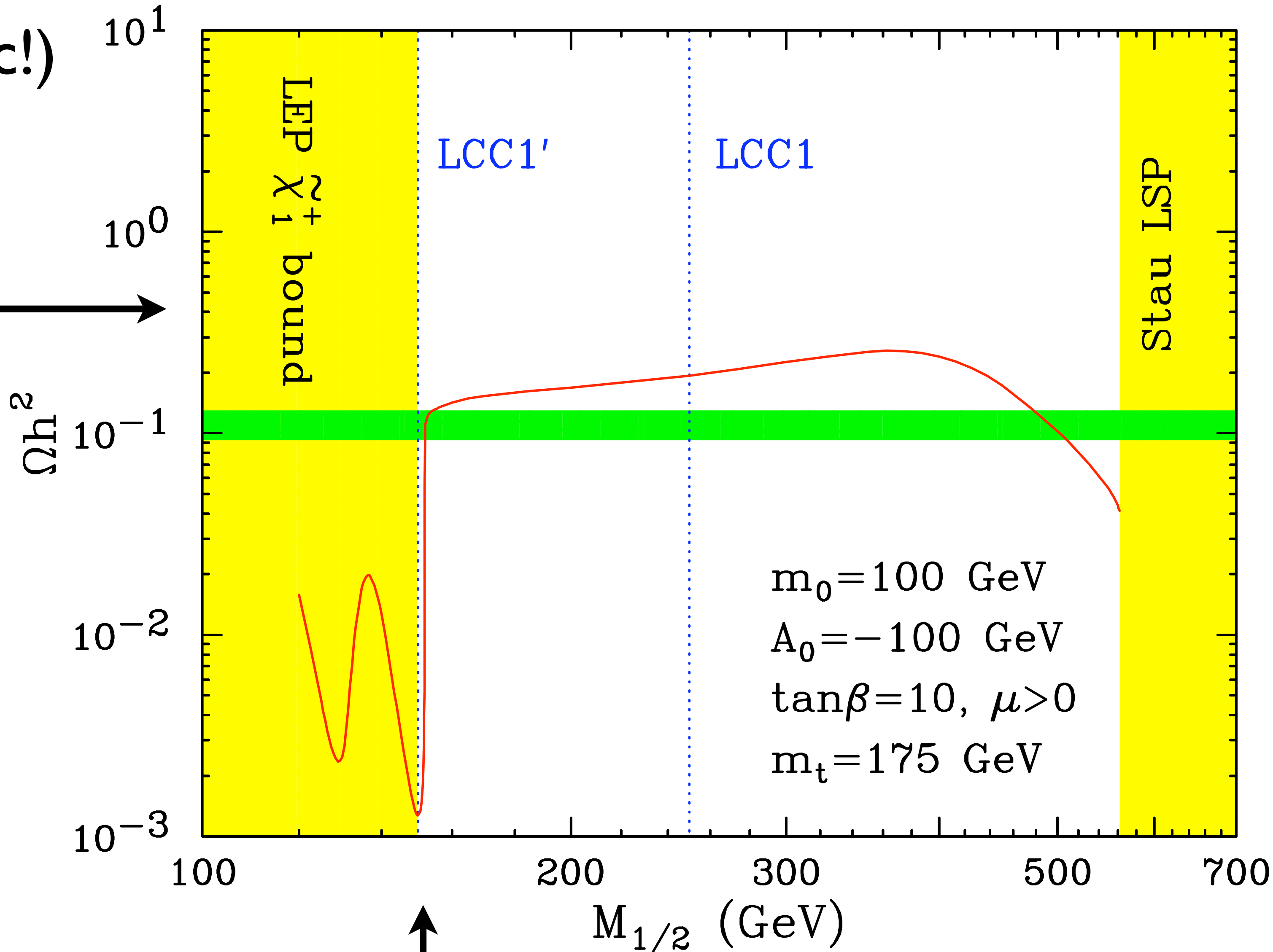


Bulk region study point

mSUGRA LCC1 study point
with adjusted $M_{1/2}$

(more dramatic!)

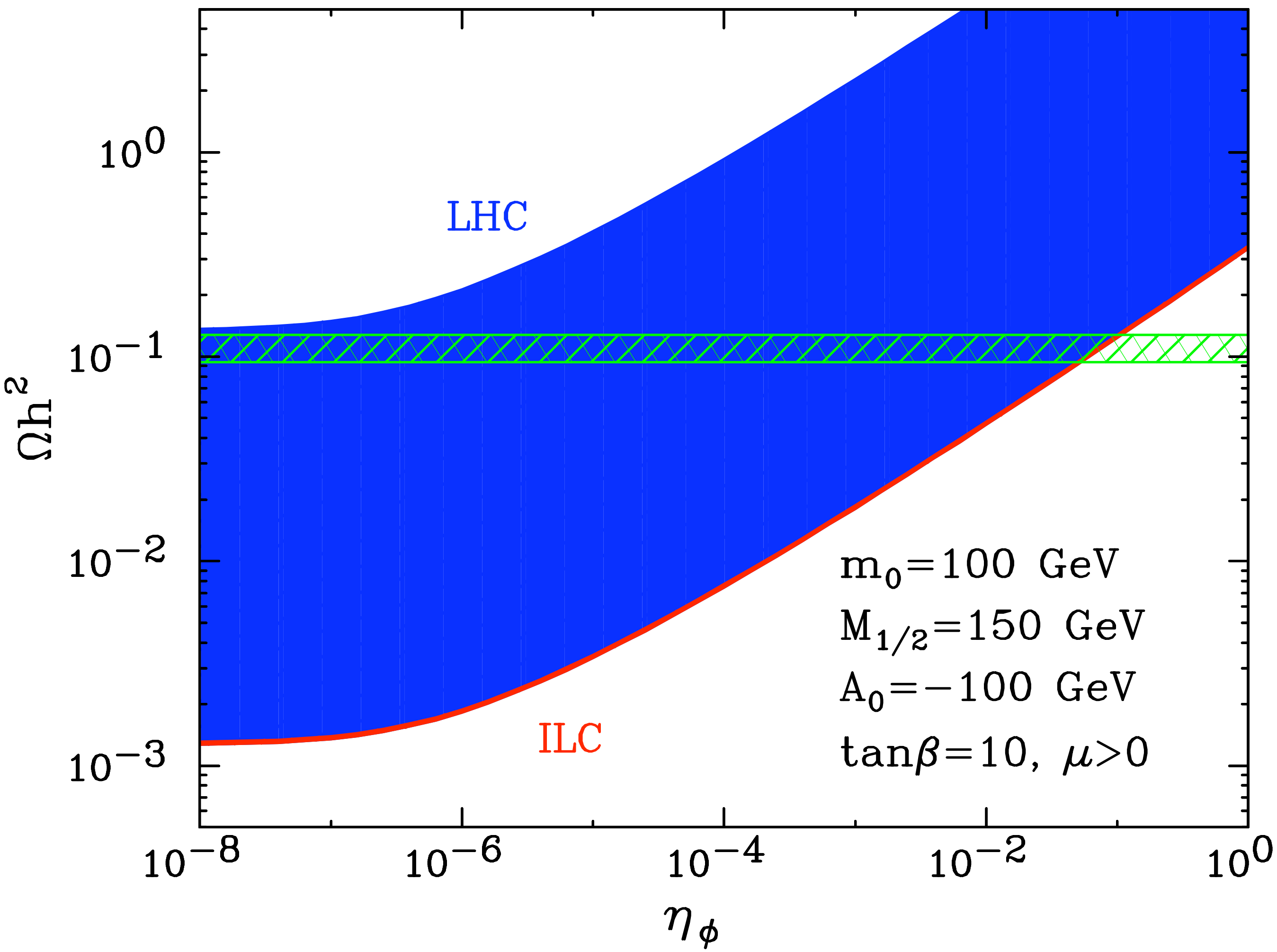
weaker due to light $\tilde{\nu}$



Higgs pole

Bulk region study point

mSUGRA LCC1 study point with adjusted $M_{1/2}$



LHC not precise enough to resolve Δm_χ near resonances

ILC better!

Inflationary Embedding of Kination Domination Scenarios

(Chung, Everett, Matchev, 0704.3285 [hep-ph]

Our scenario: inflaton = quintessence field

energy dominance
+coherence

kick it at end of inflation $\sqrt{2}M_P \left|\frac{V'}{V}\right|_{T_{\rm end}} > 6$, gravitational reheating

Obtain relation between $\frac{1}{2}\dot{\Phi}^2$ and ρ_R

$$V_0 \sim (4 \times 10^{13} GeV)^4 \eta_\Phi^{-1/2} \left(\frac{g_*}{100}\right)^{-1/2}$$

upper bound for fixed η_Φ !

Prediction: negligible inflationary tensor perturbations

many issues yet to explore! (Dan's talk)

Conclusions and Outlook

- Seeking collider-cosmology connections:
  important goal in LHC/ILC era!
- Kination-dominated quintessence:
  - enhancement mechanism for DM abundance
  - ILC significant probe of such cosmological scenarios
- Many issues yet to be explored: (Dan's talk)
  - TeV physics implications, cosmological phenomena
- Option if mismatch of collider+cosmo data
- May be best probe of dark energy at colliders!