Supersymmetry, Dark Matter, and Dark Energy

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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, arXiv: 0706.2375 [hep-ph]

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: extremely difficult to probe directly at colliders!

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

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

Dark matter: direct collider probes possible

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

Dark matter/Dark energy connection

WIMP cosmological abundance depends on:

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

$$x_F = \frac{T_F}{m_\chi} \sim \frac{1}{20}$$

cosmology

$$\Omega_\chi h^2 \sim \left(\frac{T_{\rm today}}{m_\chi x_F} \right)^3 \left(\frac{m_\chi H_F}{\langle \sigma_A v \rangle} \right)$$

volume dilution factor

particle physics

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

$$\left\{ \begin{array}{ll} \text{radiation} & a^{-4} \\ \text{matter} & a^{-3} \\ \text{inflaton} & a^{0} \\ \text{kination} & a^{-6} \quad \longleftarrow \end{array} \right.$$

(Salati, astro-ph/0207396)

Kination domination and DM abundance

Definition: $$\frac{1}{2}\dot{\Phi}^2 \gg V(\Phi),\ \rho_R,\ \rho_M$$

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

$$\frac{\rho_\Phi}{\rho_\gamma} \propto a^{1-3w_\Phi}$$

e.g. p-wave annihilator:

usual freeze out T

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

$$\eta_\Phi \equiv \left(\frac{\rho_\Phi}{\rho_\gamma}\right)_{T_0}$$

BBN T

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

entropy d.o.f.

k dom freeze out T

Ω_χ increased from standard scenario: $$\frac{T_U}{T_0} \sim 10^3$$

Kination Domination and Neutralino Dark Matter

Scenario implies:

Profumo,Ullio hep-ph/0309220

- 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

- 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, 0706.2375 [hep-ph])

Goal:

Precision to which LHC/ILC can probe kination scenario

Procedure: “recycle” ILC study points of Baltz et al., hep-ph/0602187

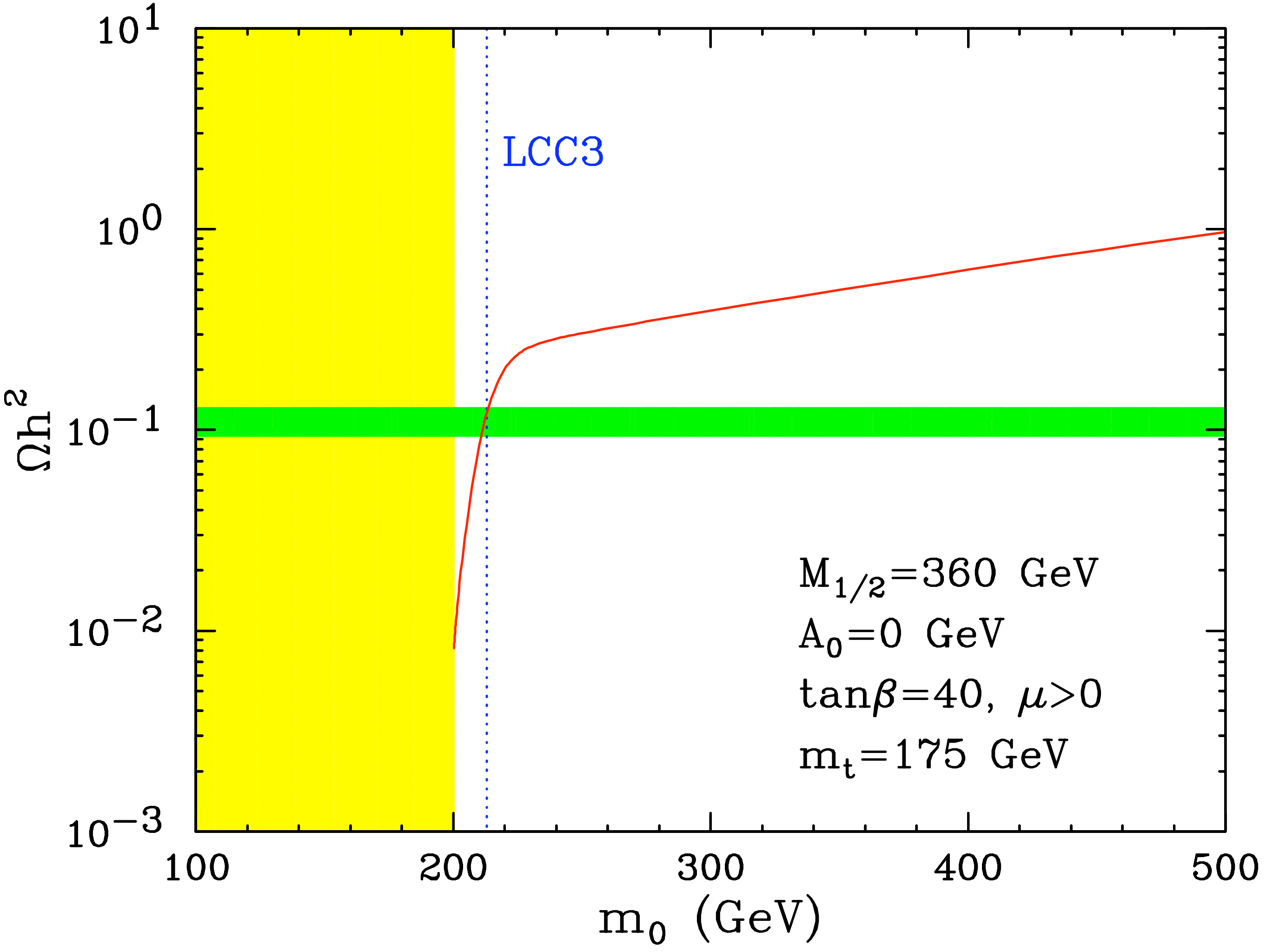
(mSUGRA, masses in GeV)

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

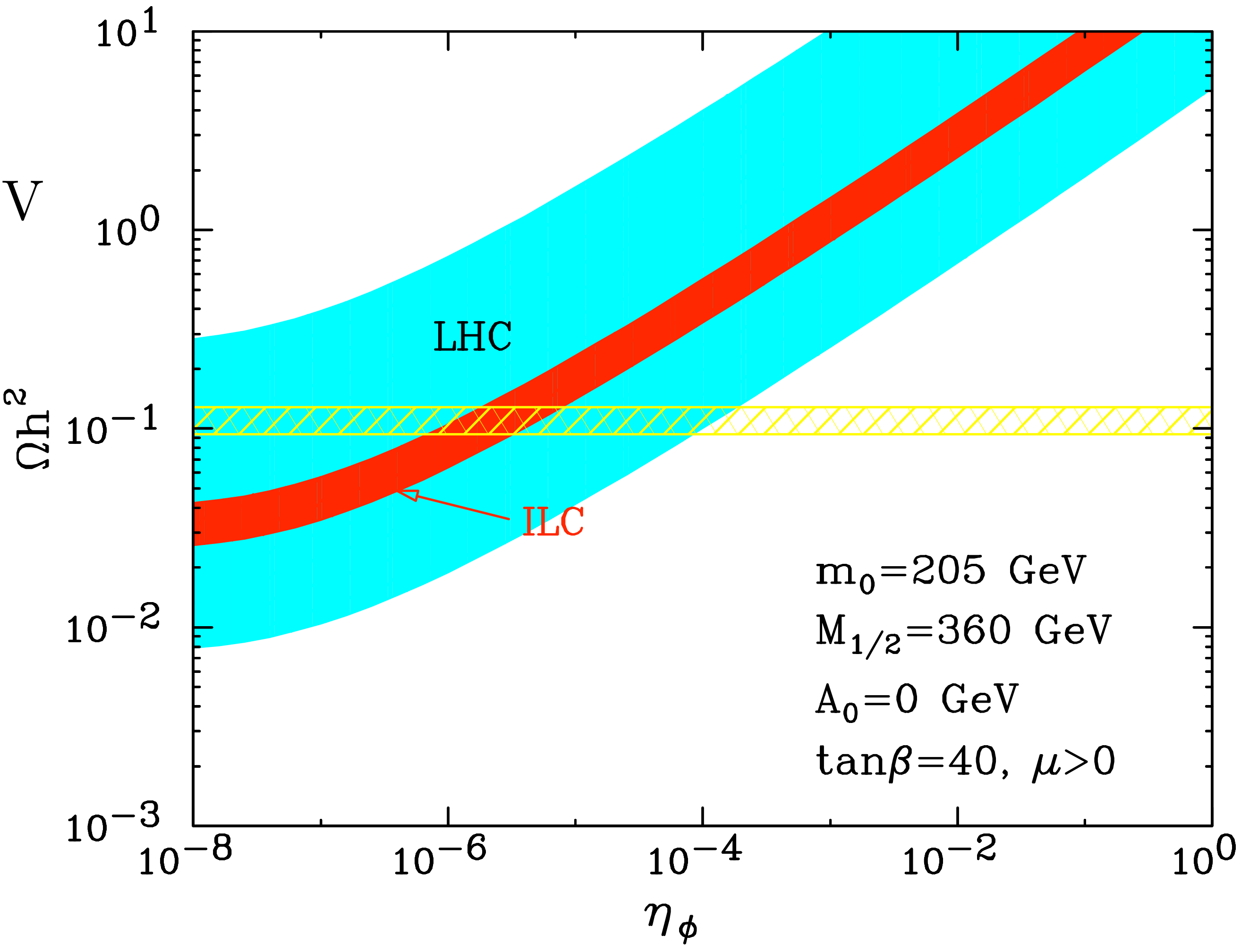


Stau coannihilation region:

mSUGRA LCC3 study point
with adjusted m_0

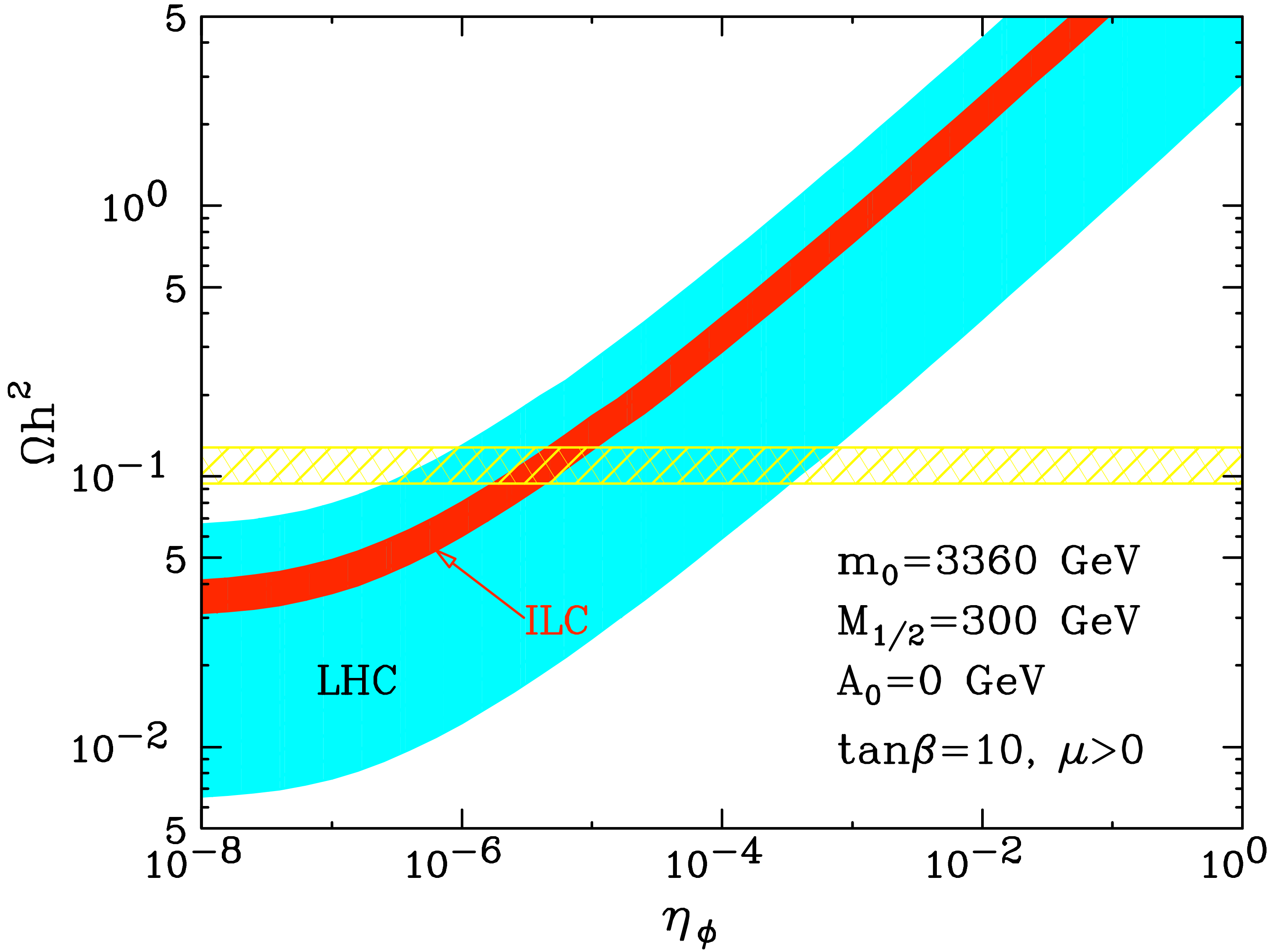
$m_{\tilde{\chi}} \approx 140\,\mathrm{GeV}$

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



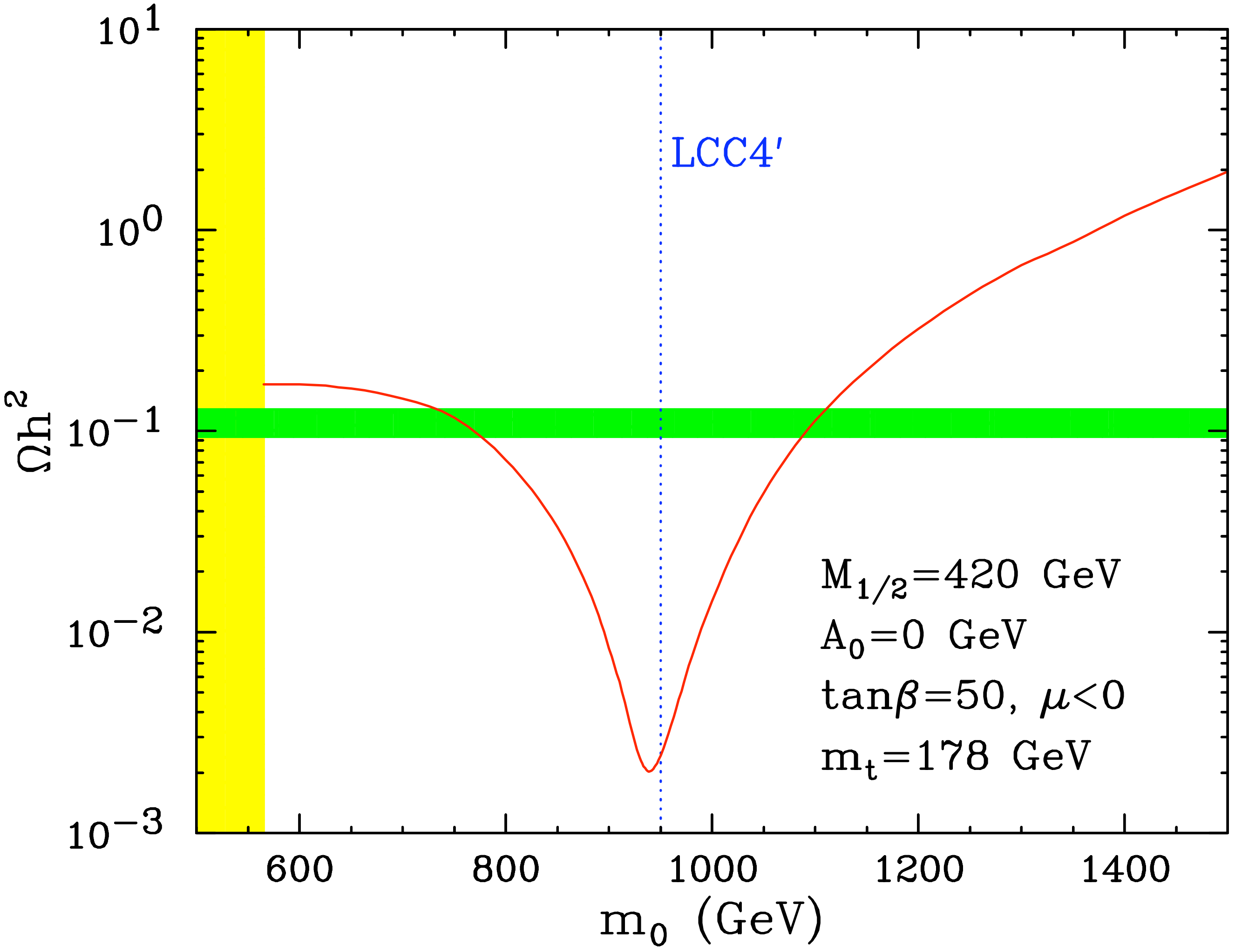
Focus region study point

mSUGRA LCC2 study point
with adjusted m_0



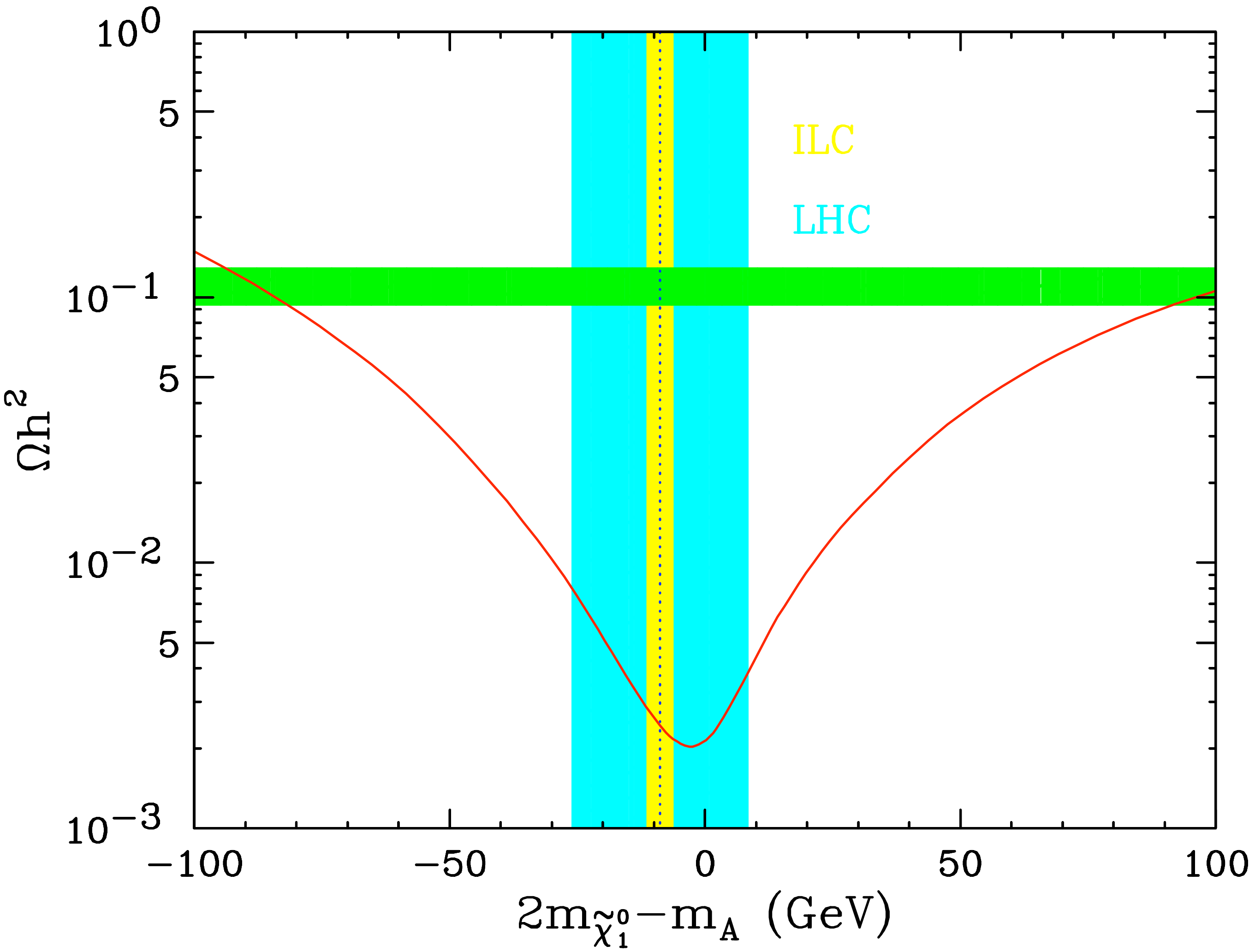
A-funnel study point

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
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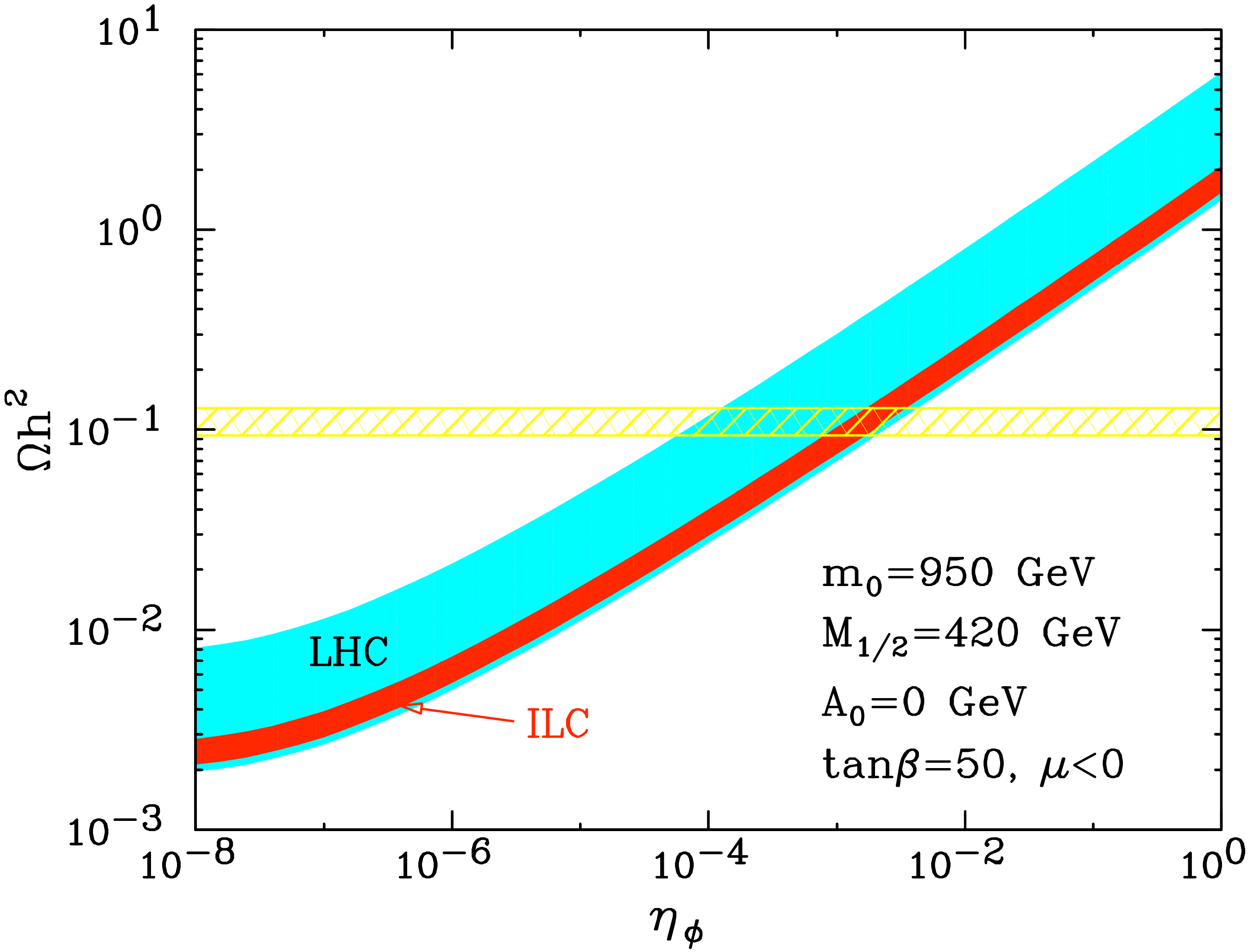
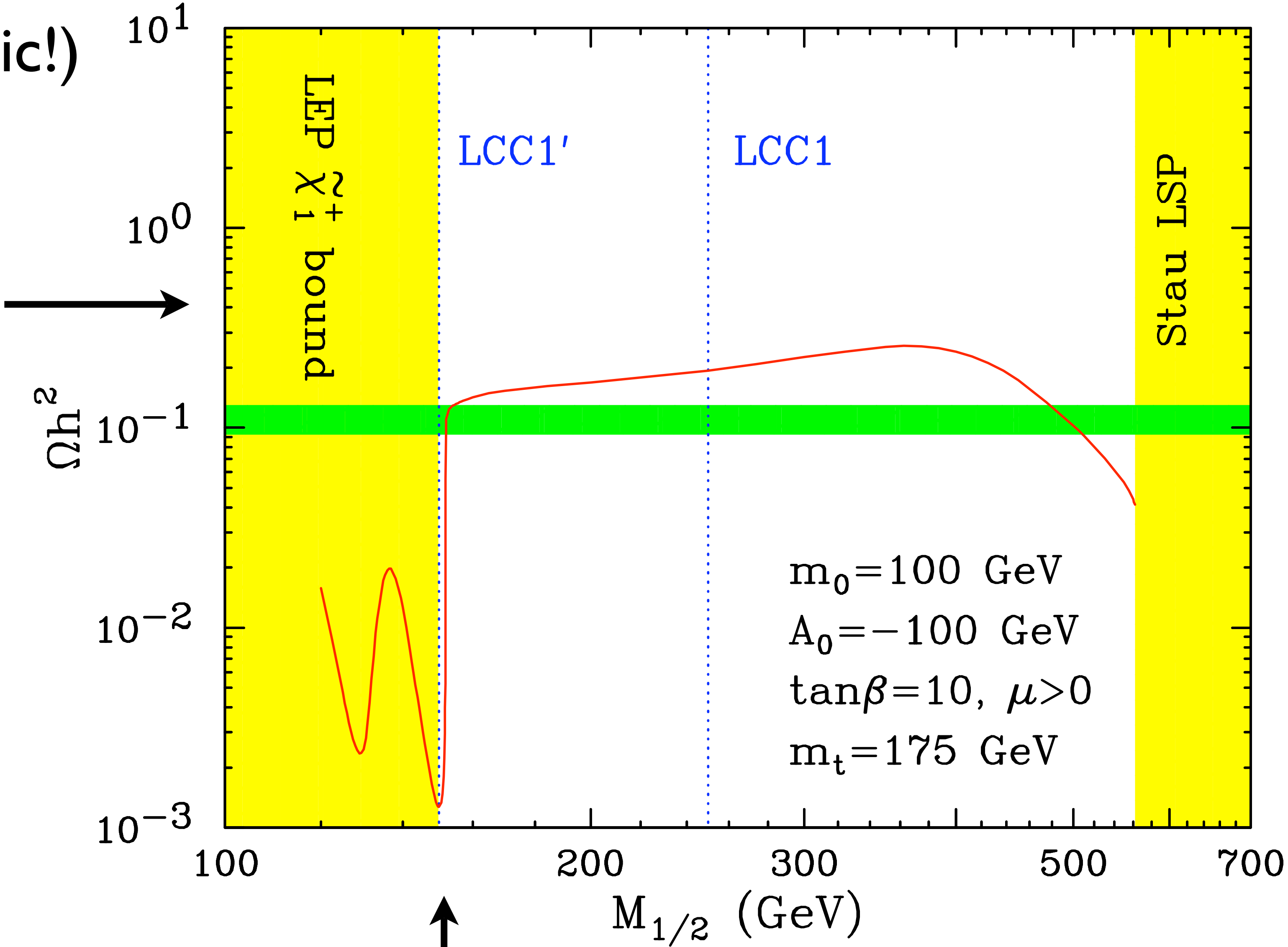


Bulk region study point

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

(more dramatic!)

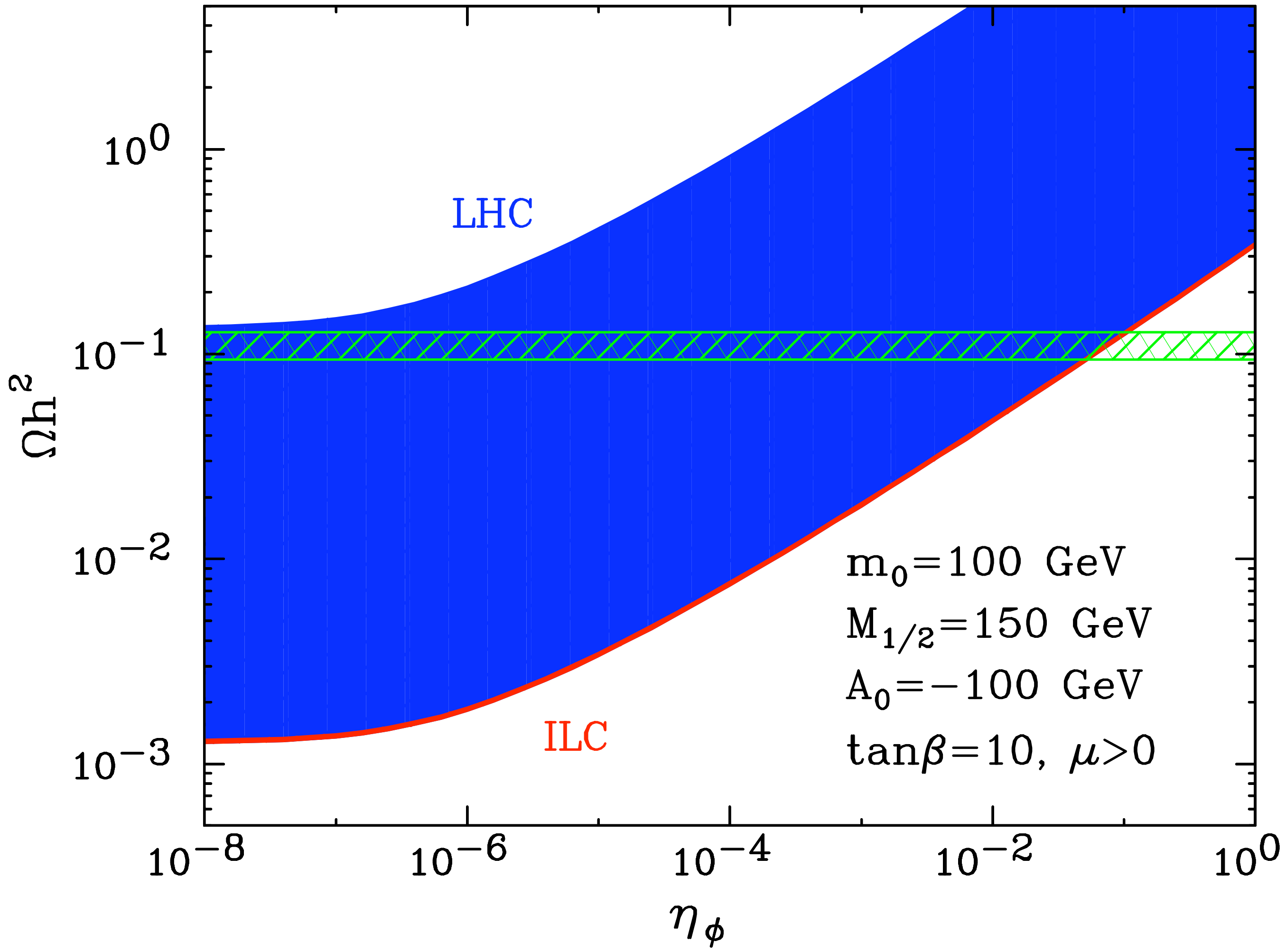
weaker due
to light $\tilde{\nu}$



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

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

Scenario: inflaton = quintessence field

energy dominance
+coherence

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

Example:

quintessence

inflation (ends at Φ_c)

$$V(\Phi) = \Omega_\Lambda \rho_c (1 + b\cosh(\lambda\Phi))^2 + \left(V_0 + \beta \log\frac{(\Phi-\Phi_c)^2}{\Phi_c^2}\right) S(\Phi)$$

$$(V_0 \gg \beta,\ \lambda \sim O(M_P^{-1}),\ b \ll 1)$$

steplike function

$\Phi(t_{\rm end}) \approx \Phi_c$ Planckian (not uncommon in quintessence scenarios)

Inflationary Embedding (II)

Relate $\frac{1}{2}\dot{\Phi}^2$ and ρ_R $\longrightarrow$ predict $\eta_\Phi \equiv \left(\frac{\rho_\Phi}{\rho_\gamma}\right)_{T_0}$

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

upper bound for fixed η_Φ!

Prediction: negligible inflationary tensor perturbations!

(independent of details of potential)

To distinguish kination scenario:

Identify further corroborated cosmological constraints

e.g. gravity wave prod. at EW phase transition, baryo/leptogenesis,...

Conclusions and Outlook

- Seeking collider-cosmology connections:
  important goal in LHC/ILC era!
- Kination-dominated quintessence:
  - enhancement mechanism for DM abundance: option if mismatch of collider+cosmo data
  - further motivation for new SUSY LHC/ILC study points
  - framework for inflationary/quintessence model building, corroborated cosmological constraints
- possibly one of our best hopes for connecting dark energy and collider physics!