

Connecting LHC, ILC, and Quintessence



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Overview

Focus: dark matter + dark energy connections
 (“kination-dominated quintessence”)

at LHC and ILC

in the context of low energy supersymmetry

Based on:

Chung, Everett, Kong, Matchev, 0706.2375 [hep-ph]

Chung, Everett, Matchev, 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 $\tilde{\chi}$): 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: $T_U \sim 1 \text{ GeV}$

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

$\rho_\Phi \propto a^{-3(1+w_\Phi)}$ 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}	←

Kination domination and DM abundance

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

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

e.g. p-wave annihilator:

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

$$0 \leq \eta_\Phi \leq 1$$

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

usual freeze out T
BBN T

entropy d.o.f.
k dom freeze out T

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: $2m_\chi = m_{\text{int}}$

also **coannihilations** (not as effective)

Resurrect wino, higgsino dark matter scenarios

previous studies: LHC probes of kination domination

Profumo, Ulio
hep-ph/0309220

- **Good news** for **direct/indirect dark matter searches**

larger $\langle \sigma_{Av} \rangle$ 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

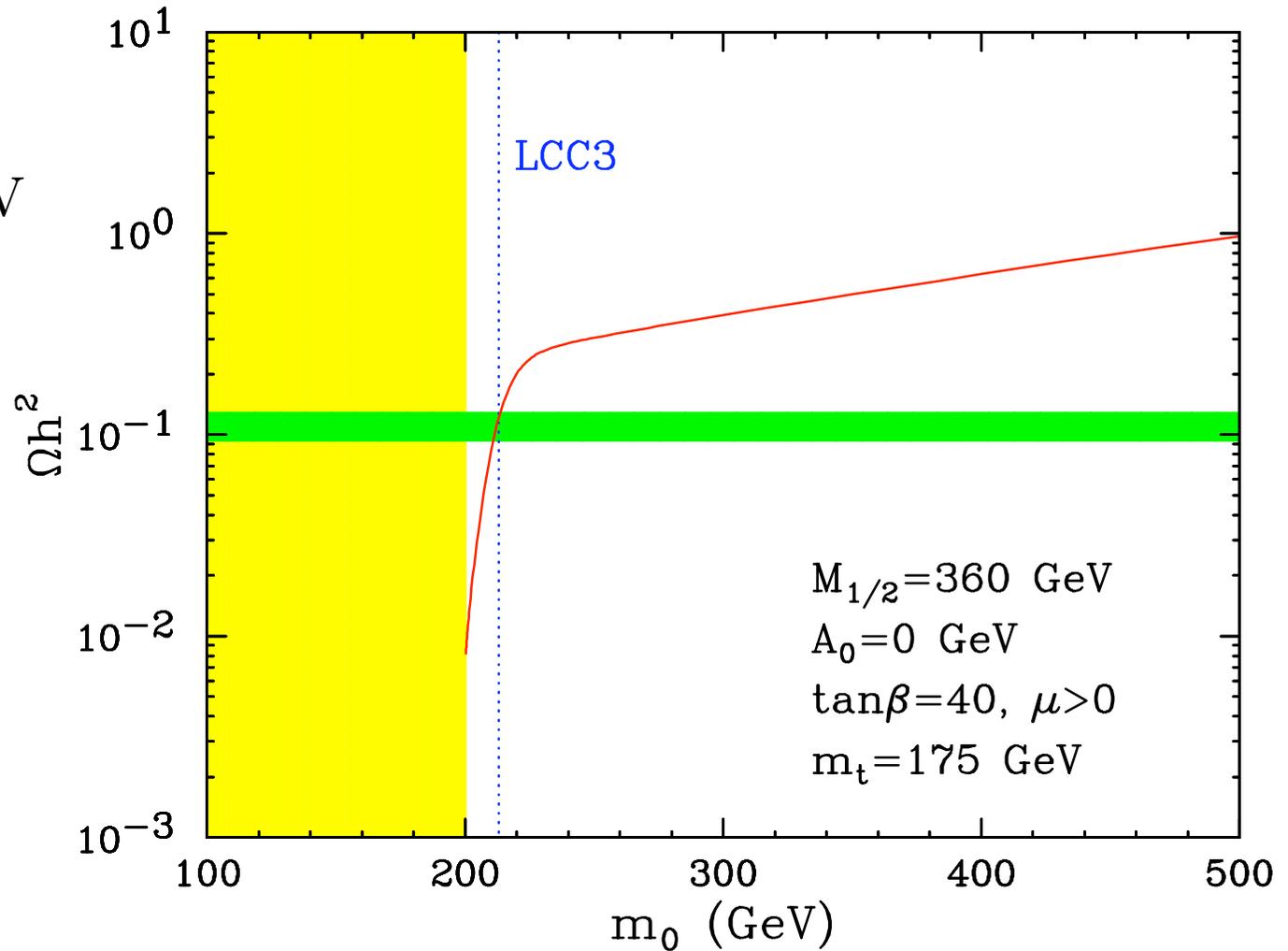
(mSUGRA, masses in GeV)

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

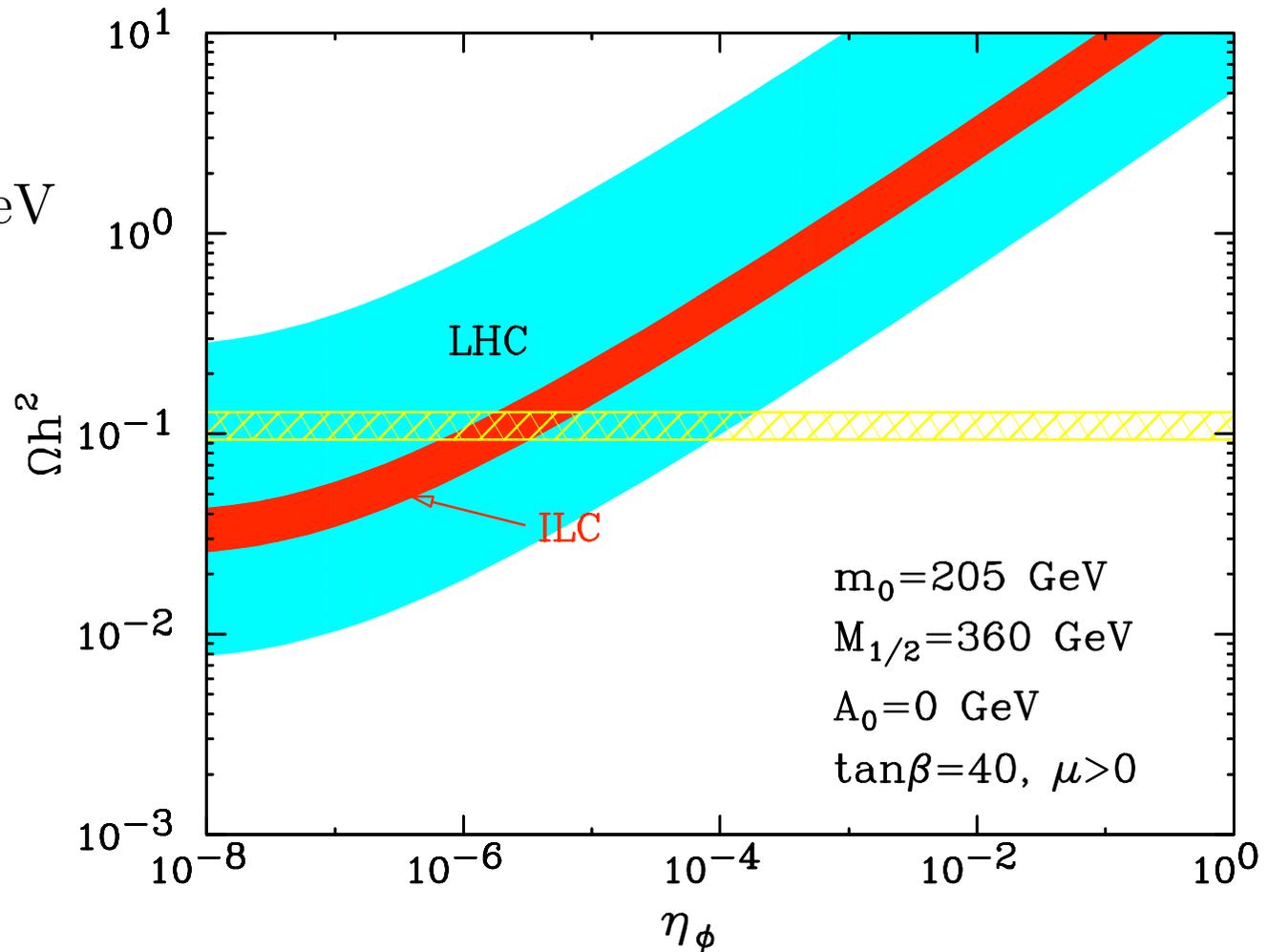
$$m_{\tilde{\chi}} \approx 140 \text{ GeV}$$
$$|m_{\tilde{\chi}} - m_{\tilde{\tau}}| < 5 \text{ GeV}$$



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

Stau coannihilation region: mSUGRA LCC3 study point with adjusted m_0

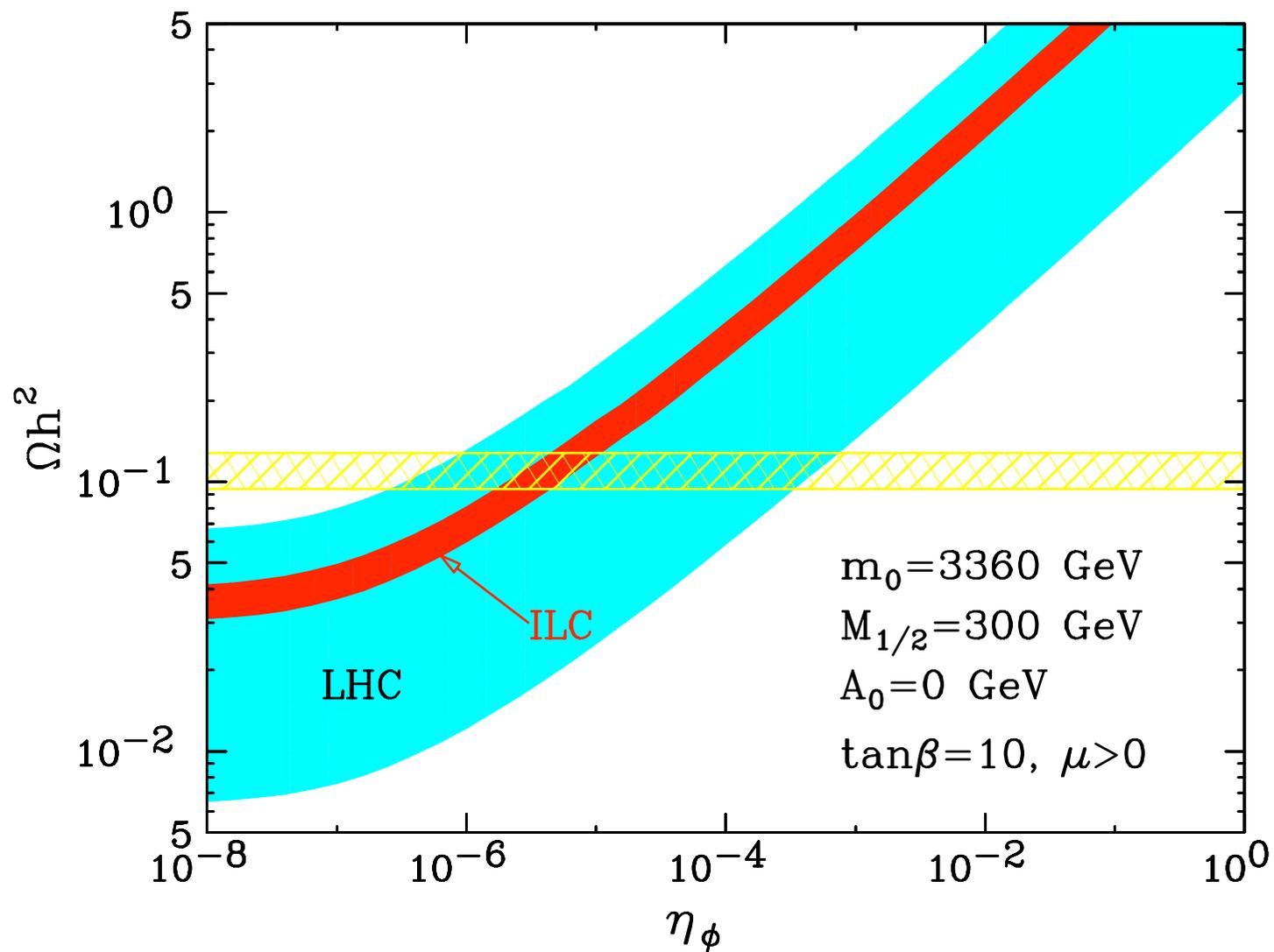
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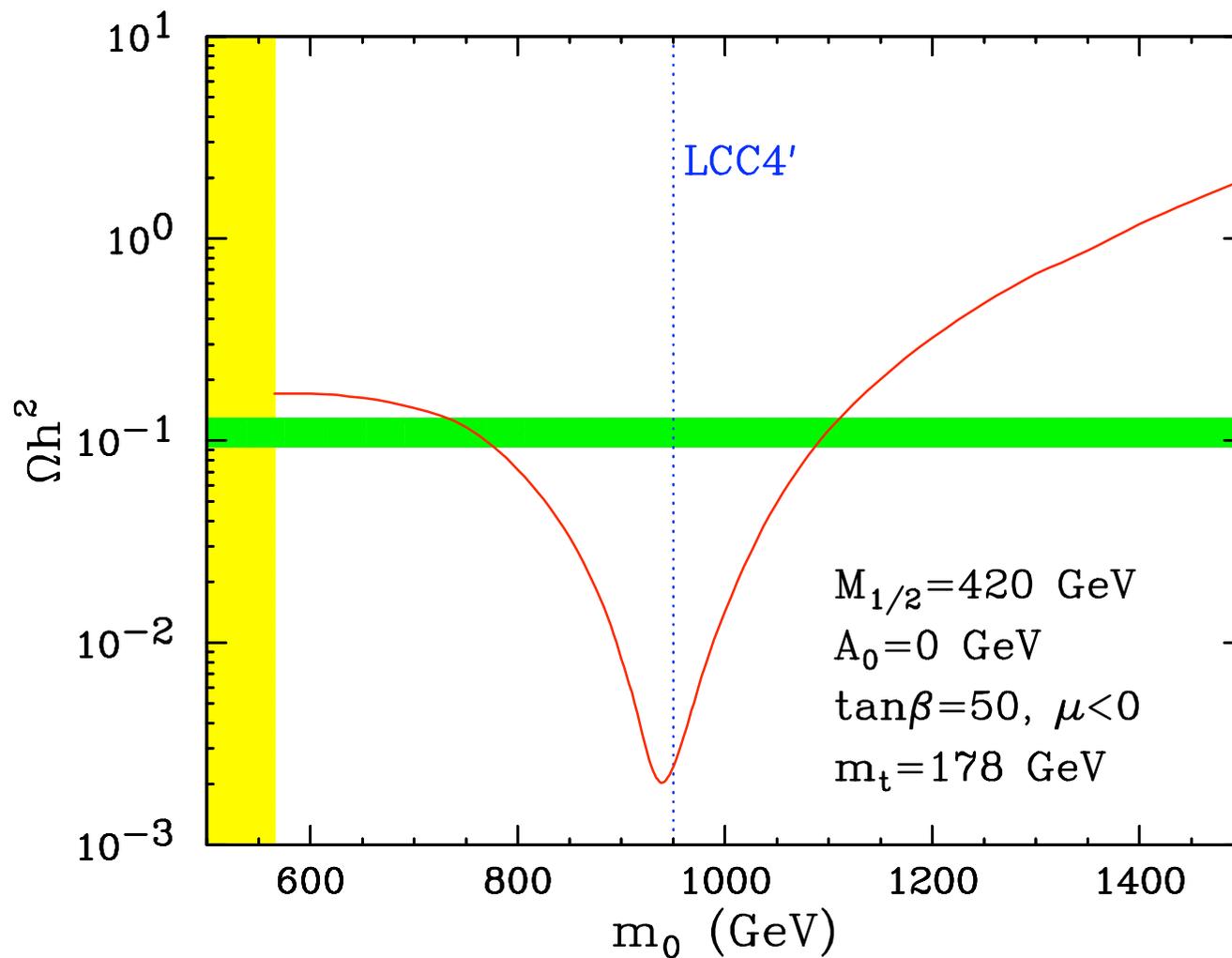
Focus region study point

mSUGRA LCC2 study point
with adjusted m_0



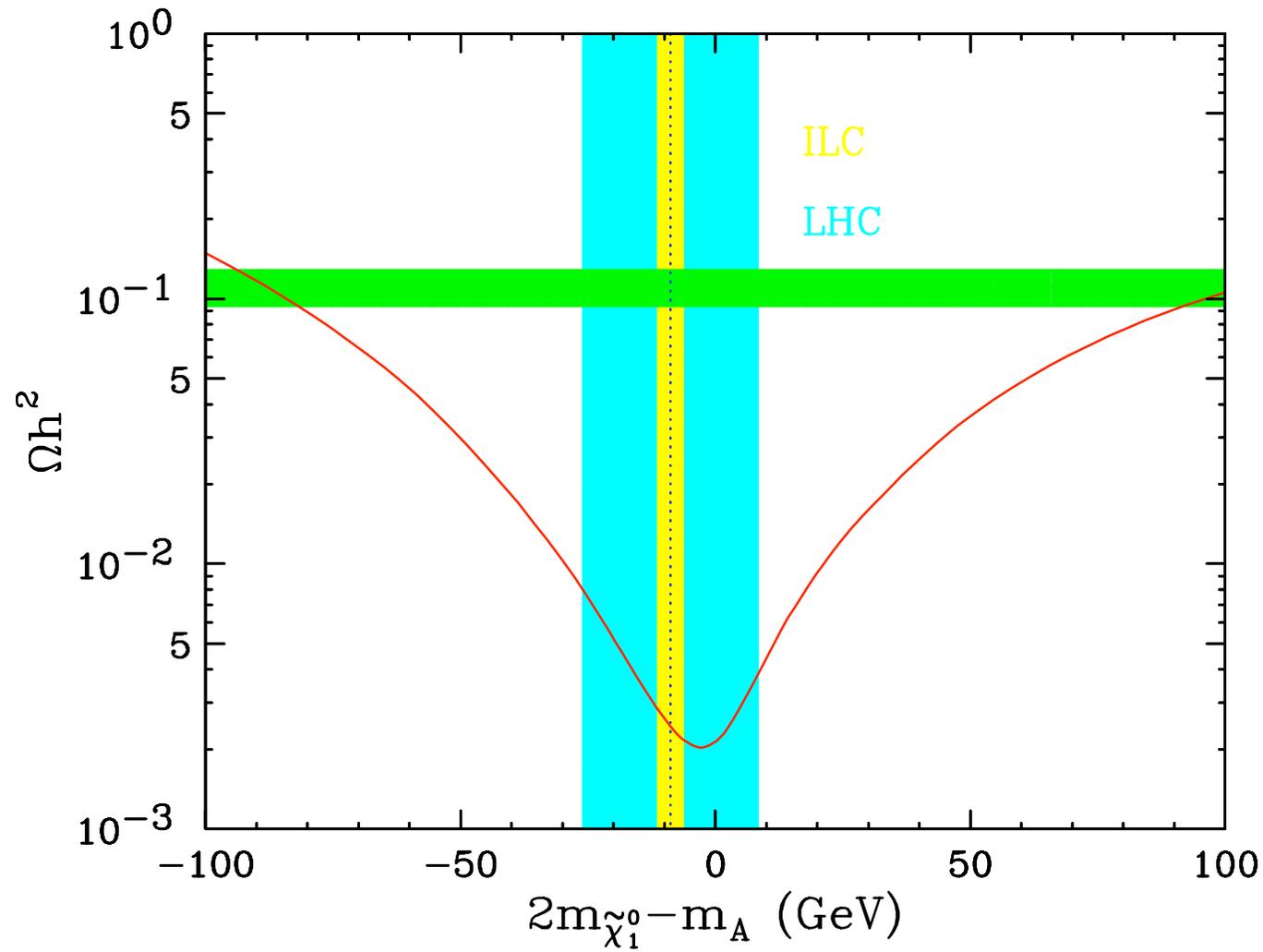
A-funnel study point

mSUGRA LCC4 study point
with adjusted parameters



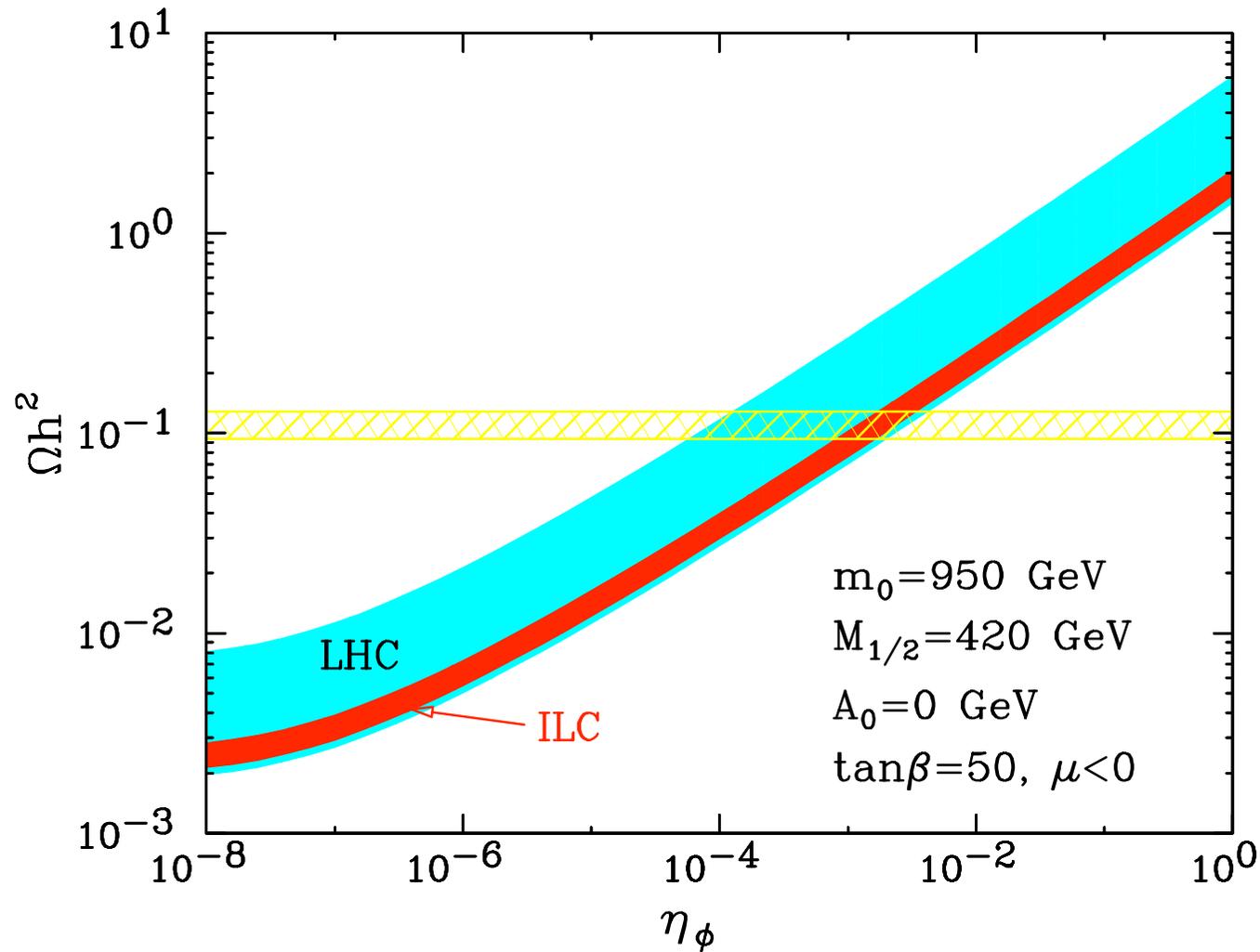
A-funnel region study point

mSUGRA LCC4 study point
with adjusted parameters



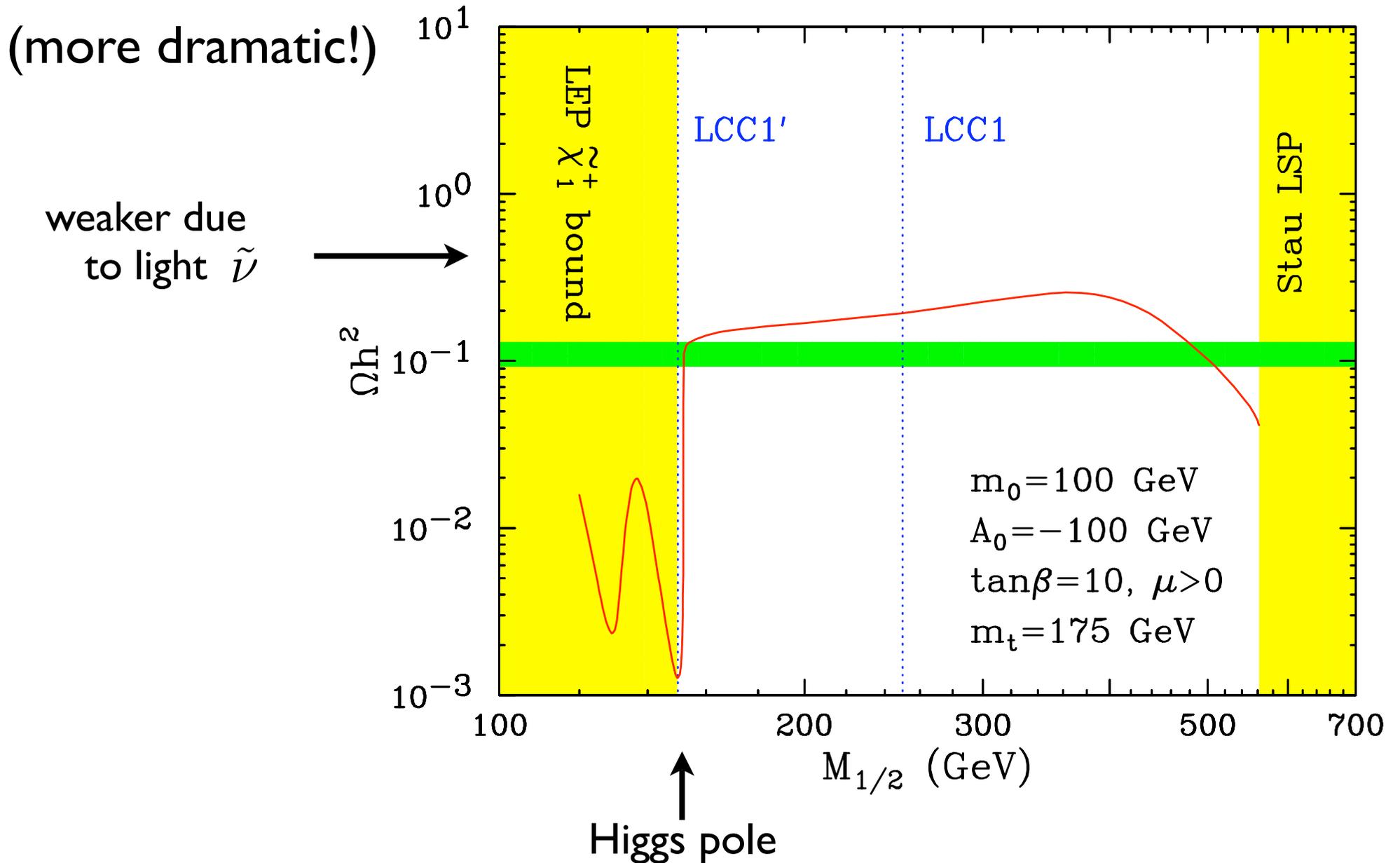
A-funnel region study point

mSUGRA LCC4 study point
with adjusted parameters



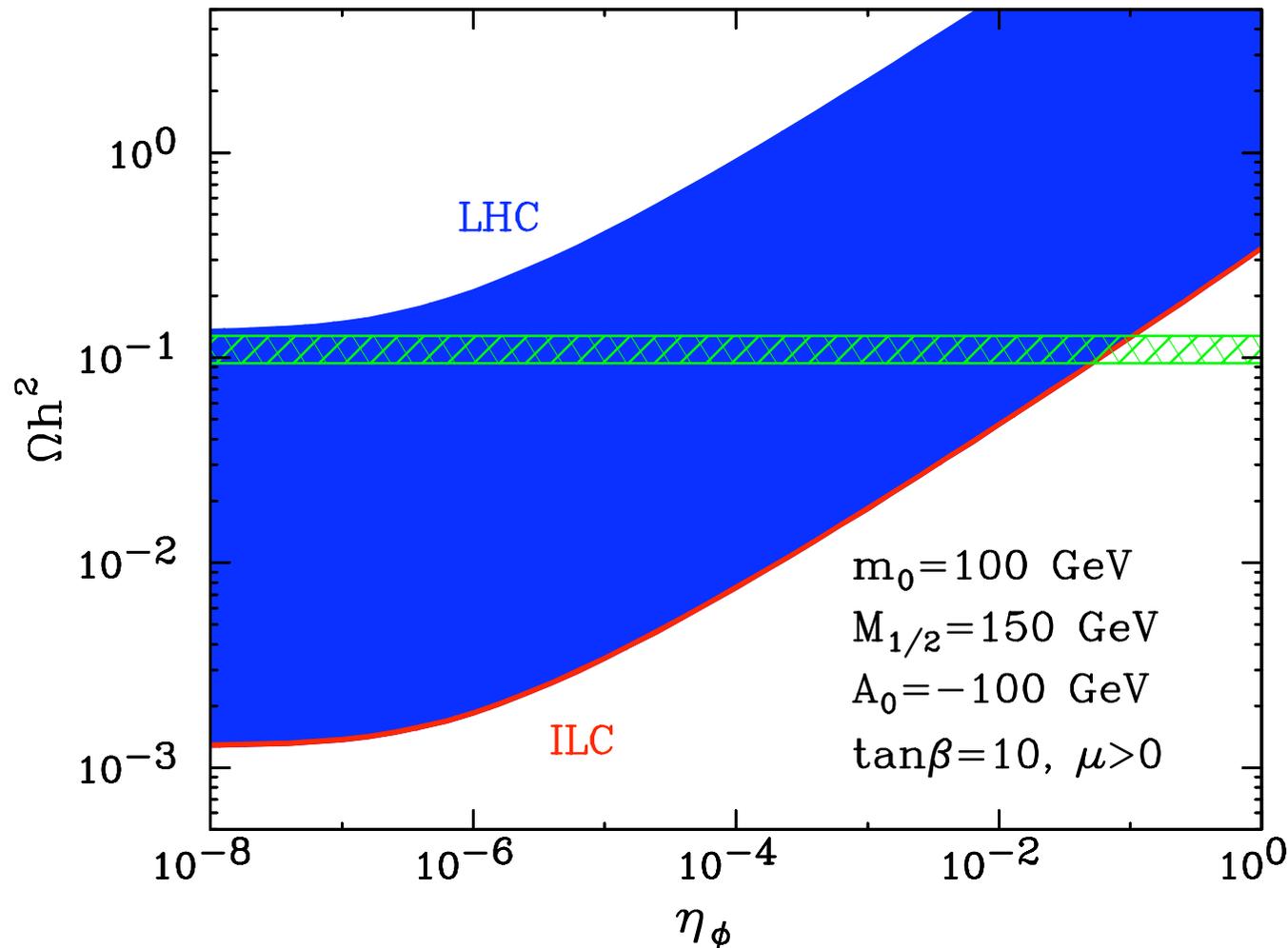
Bulk region study point

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



Bulk region study point

mSUGRA LCCL 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, '07

Our scenario: inflaton = quintessence field

energy dominance
+coherence

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

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

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

upper bound for fixed η_{Φ} !

Prediction: negligible inflationary tensor perturbations

can devise other cosmological tests

Conclusions and Outlook

- Seeking **collider-cosmology connections**: important goal in LHC/ILC era!
- **Kination-dominated quintessence**:
 - **enhancement** mechanism for **DM** abundance
 - **ILC** a crucial probe of such scenarios
- **Many issues** to be explored: cosmological tests, collider physics of new study points
- **May be best probe of dark energy at colliders!**