Connecting LHC, ILC, and Quintessence

K.C. Kong

Fermilab

LCWS08 and ILC08
November 16-20, 2008
University of Illinois at Chicago

Overview

- This talk:

  dark matter+dark energy energy connections at LHC/ILC

  ("kination-dominated quintessence")

  in the context of low energy supersymmetry

- Based on:

  Chung, Everett, Kong, Matchev, JHEP 0710:016,2007

Connecting Collider Physics and Cosmology

- Desired collider connection with cosmology:
  - understand dark energy and dark matter
- Dark Energy
  - cosmological constant: CC problem sensitive to entire spectrum, couplings, SUSY breaking
  - quintessence : scalar field Φ with 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 χ): motivated in SUSY models (LSP), extra dimensions (LKP), little Higgs (LTP), $\cdots$
- Cosmological abundance depends on:
  - couplings and masses (collier 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: $T_U \sim 1$ GeV
  - but must be small ($<$ 20 %) by BBN: $T_0 \sim 10^{-3}$ GeV
  - $\rho_\Phi \sim a^{-3(1+w_\Phi)}$ must dilute faster than $\rho \sim a^{-4}$

$$\Phi \text{ behaves like} \begin{cases} \text{radiation} & a^{-4} \\ \text{matter} & a^{-3} \\ \text{inflation} & a^{-0} \\ \text{kination} & a^{-6} \end{cases}$$

(P. Salati, astro-ph/0207396)

Kination Domination and DM abundance

- Definition: $\frac{1}{2}\dot{\Phi}^2 \gg V(\Phi)$, ρ_R, ρ_M
  - freeze out at higher T, larger abundance for same $\langle \sigma_A v \rangle$
  - e.g. p-wave annihilator:

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

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

$$\eta_\Phi = \left(\frac{\rho_\Phi}{\rho_\gamma}\right)_{T_0} \quad (0 \le \eta_\Phi \le 1)$$

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

Kination Domination and Neutralino DM

- Mismatch b/w collider LSP and direct/indirect search
- Implications for favored MSSM parameter space:
  - near resonances: $2m_\chi = m_{int}$
  - coannihilations (not as effective)
  - resurrect wino, higgsino dark matter scenarios
  - previous studies: LHC probes of kination domination (Profumo, Ulio 2003)
- 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

- Goal:
  precision to which LHC/ILC can probe kination scenario

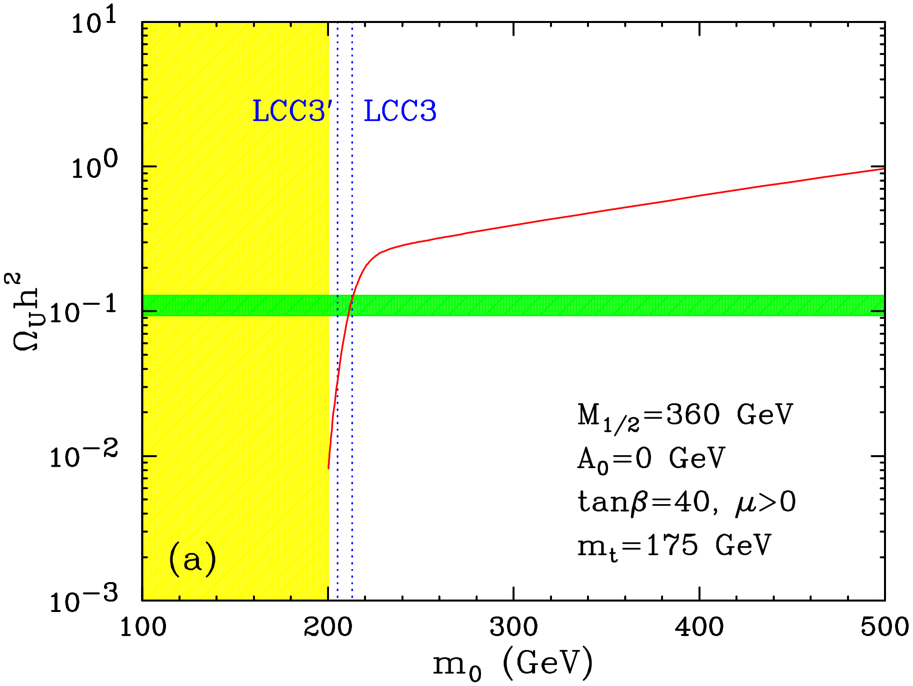
- Procedure:
  "recycle" ILC study points of Baltz, Battaglia, Peskin, Wizansky, hep-ph/0602187

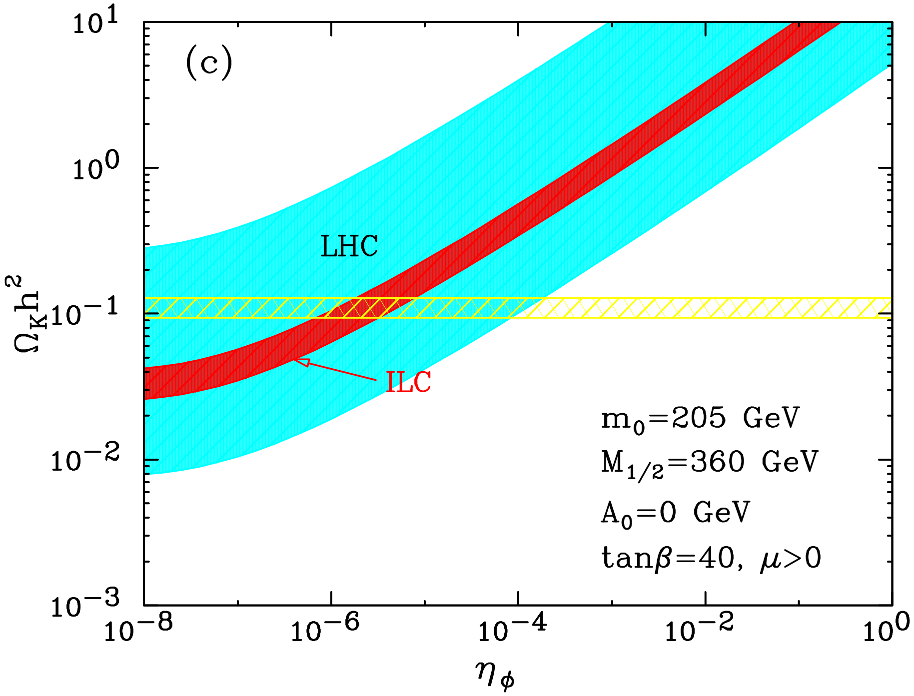
(mSUGRA, masses in GeV)

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'	$m_0 = 205$
funnel	LCC4	$m_0 = 380$, $M_{1/2} = 420$, $\tan\beta = 53$, $A_0 = 0$, $\mu > 0$	LCC4'	$m_0 = 950$ $\tan\beta = 50$ $\mu < 0$

Stau coannihilation region

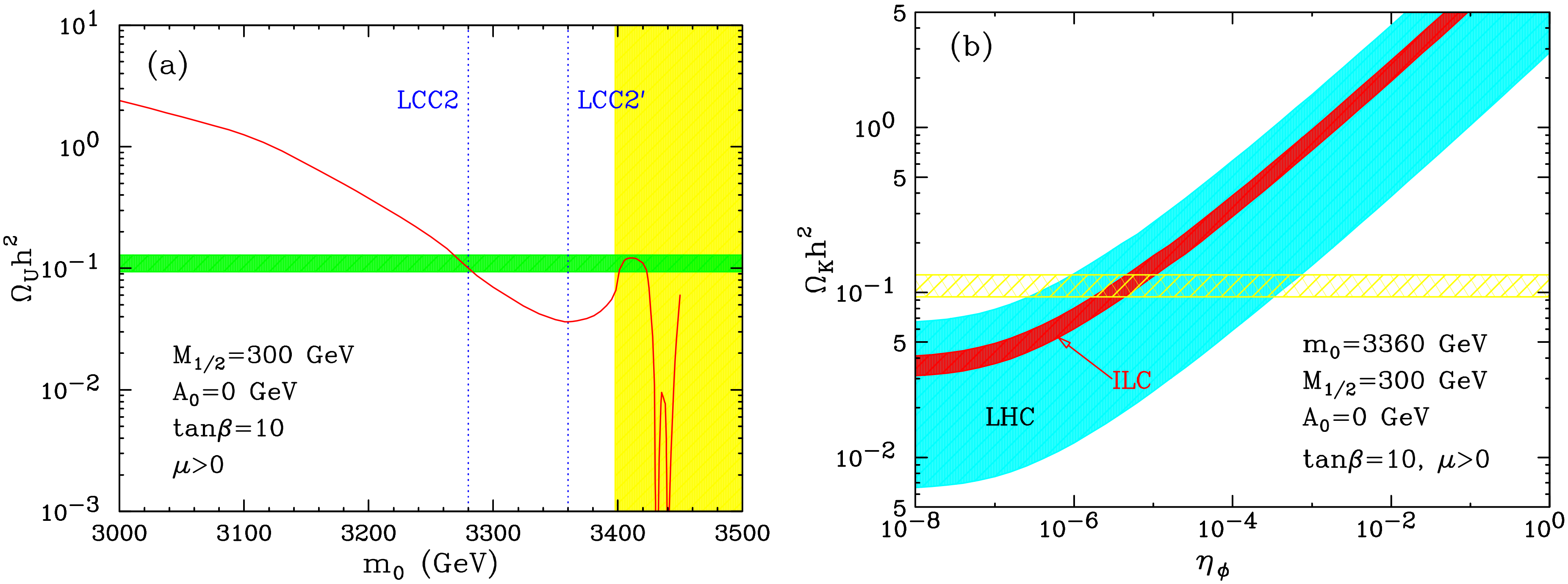
- mSUGRA LCC3 study point with adjusted m_0
- $m_\chi \approx 140$ GeV, dominant decay of χ_2^0: $\chi_2^0 \longrightarrow \tau^+\tau^-\chi_1^0 \longrightarrow$ taus are soft.
- LHC: $m_{\tilde{\tau}} - m_{\tilde{\chi}} \sim 40$ GeV (LHC can only rule out large mass splitting)
- ILC: $m_{\tilde{\tau}} - m_{\tilde{\chi}} \sim 5$ GeV, down to about ± 1 GeV





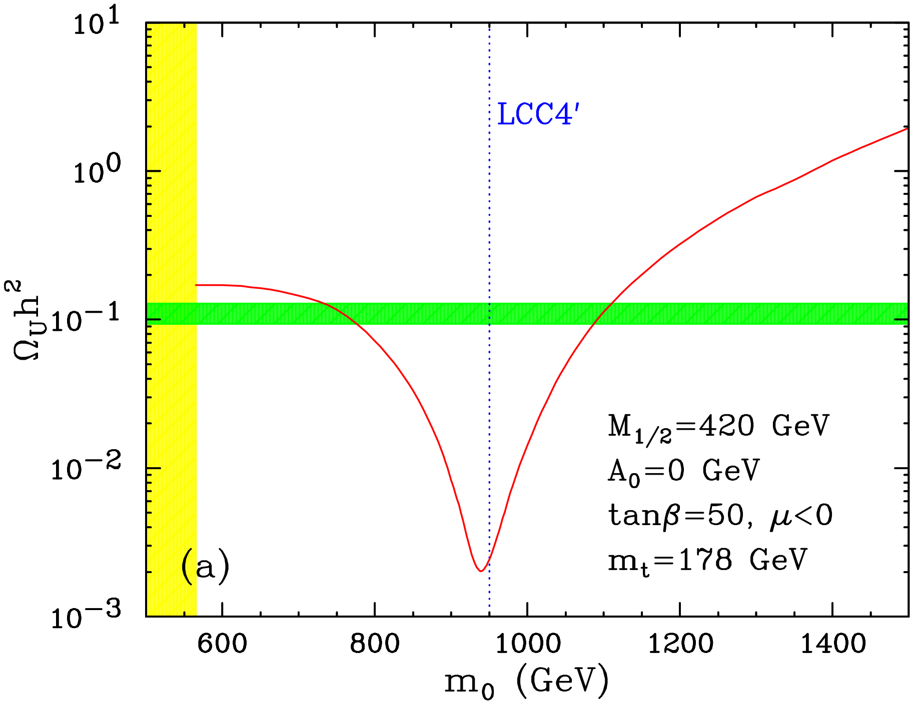
Focus point region

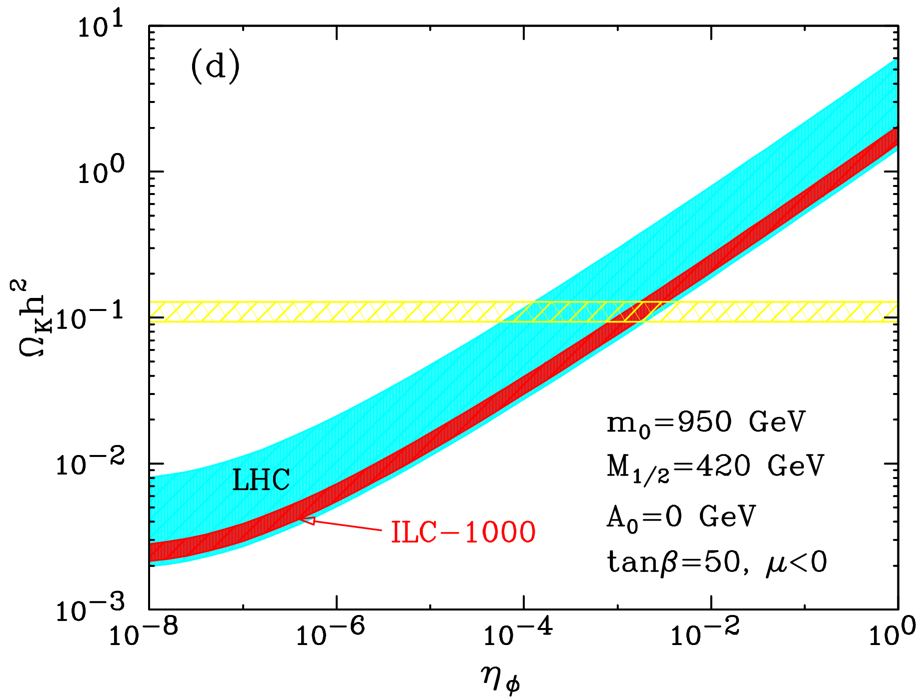
- mSUGRA LCC2 study point with adjusted m_0
- χ_1^0 is predominantly bino but has a non-negligible Higgsino component
- Sfermions are very heavy but the relic density is determined primarily by the neutralino and chargino sector $\longrightarrow$ uncertainty in $\Omega_U h^2$ as 82% at the LHC and 14% at the ILC.



A-funnel study point

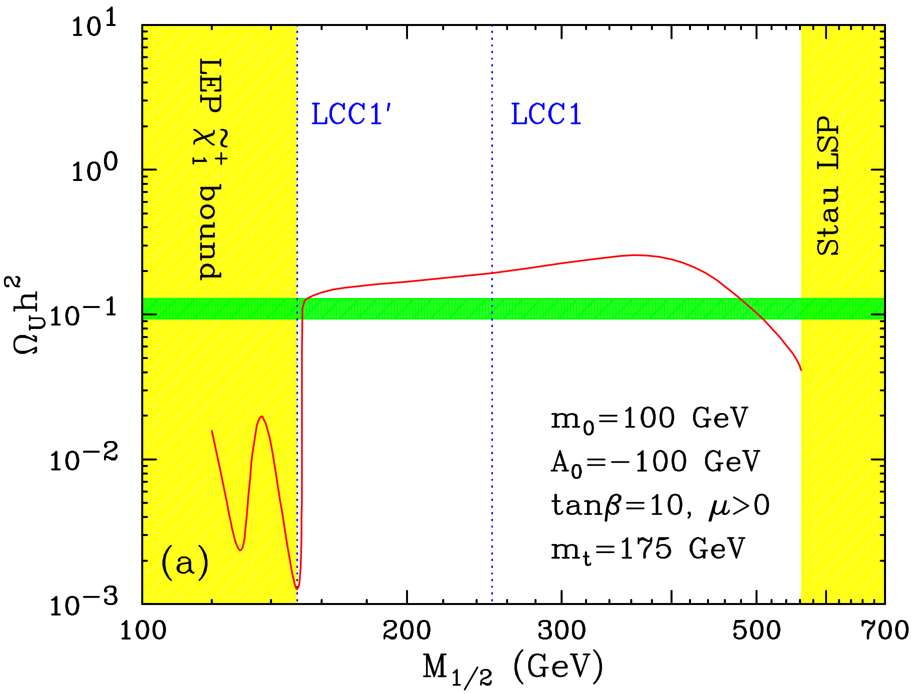
- mSUGRA LCC4 study point with adjusted parameters
- LHC: $m_{\chi_1^0}$ within 17 GeV and m_A within 1.5 GeV
- ILC: $m_{\chi_1^0}$ within 1.4 GeV

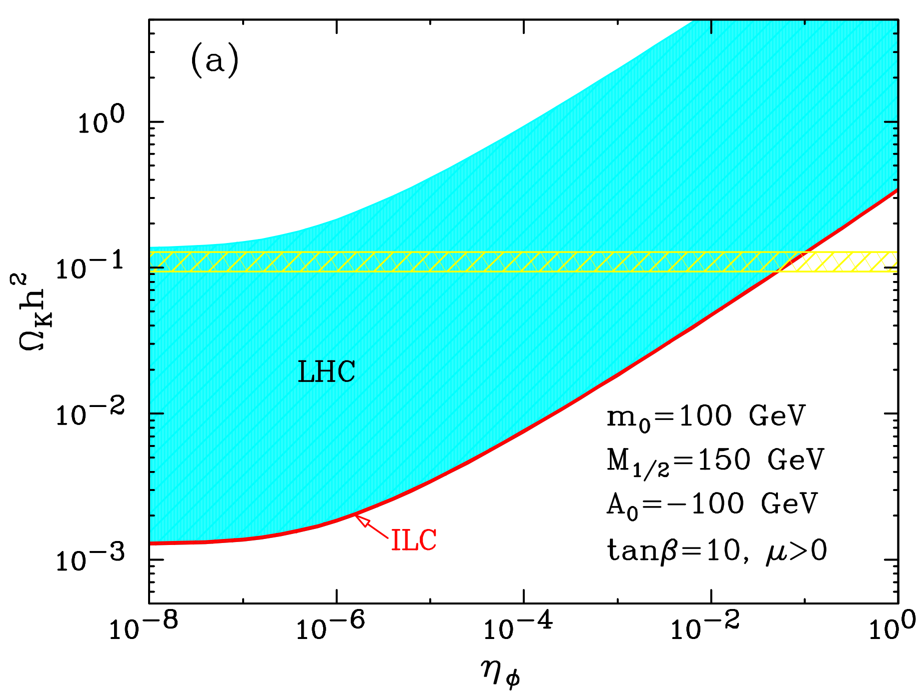




Bulk region

- mSUGRA LCC1 study point with adjusted $M_{1/2}$
- LHC not precise enough to resolve Δm_χ near resonances
- ILC better!





Conclusion 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
  - TeV physics implications, cosmological phenomena
- Option if mismatch of collider + cosmo data
- May be best probe of dark energy at colliders!