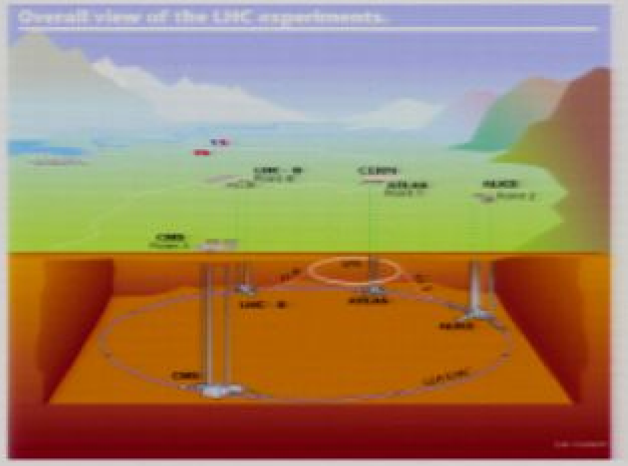
Title: LHC, ILC, and Quintessence

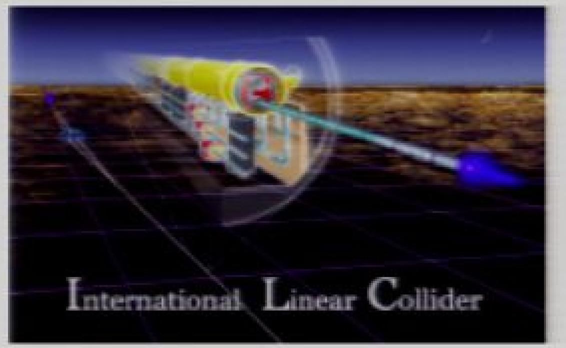
Date: May 25, 2009 04:00 PM

URL: http://pirsa.org/09050074

Abstract: TBA

LHC, ILC, and Quintessence





Lisa L. Everett (U. Wisconsin, Madison)

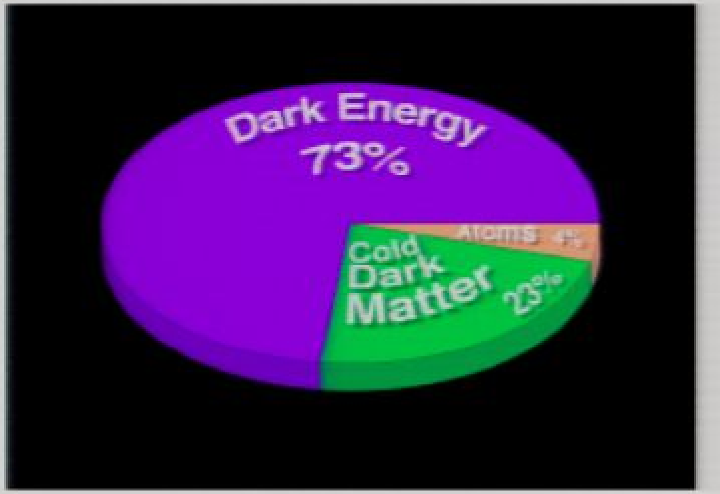
New Prospects for Solving the CC Problem

Perimeter Institute, May 2009

Overview

Focus: dark matter + dark energy connections

("kination-dominated quintessence") at LHC and ILC



in the context of thermal WIMP dark matter

prototype TeV physics: low energy supersymmetry

Connecting Collider Physics and Cosmology

Desired collider connection w/cosmology:

understand dark energy , dark matter

Dark energy (DE):

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

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

$$w_\Phi = \frac{p_\Phi}{\rho_\Phi} = \frac{\frac{1}{2}\dot{\Phi}^2 - V(\Phi)}{\frac{1}{2}\dot{\Phi}^2 + V(\Phi)}$$

Extremely difficult to probe directly at colliders!

Dark matter connection (I)

Many dark matter candidates: WIMPs, axions,...

Focus here on WIMP hypothesis (thermal relic $\widetilde{\chi}$)

(assume: non-gravitational WIMP interactions)

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

← cosmology

particle physics (electroweak/TeV scale)

$x_F \equiv T_F/m_\chi \sim 1/20$ log dependence on $H_F,\ m_\chi,\ \langle \sigma_A v \rangle$

Standard cosmology: mass drops out...

$$\Omega_\chi h^2 \propto \left(\frac{T_{\text{today}}}{m_\chi x_F}\right)^3 \left(\frac{m_\chi (x_F m_\chi)^2/M_P}{\langle \sigma_A v \rangle}\right)$$

Dark matter connection (II)

Attractive features of thermal WIMP scenario:

- Particle physics motivation:

gauge hierarchy problem: extra EW/TeV scale particles

+ proton decay protection: discrete symmetries (stability)

Prototype example: SUSY + conserved R-parity

LSP neutralino $\tilde{\chi}$

- Predictive, simple (assuming standard cosmology)

Collider +direct/indirect DM searches

can in principle <u>overconstrain</u> by data

Relaxing standard cosmology...

Cosmological DM abundance depends on:

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

This talk: indirect dark energy connection:

consider usual thermal WIMP dark matter, but

nonstandard cosmological expansion (quintessence)

Salati (2002): effects can be dramatic!

If it ain’t broke, why fix it??

- should re-evaluate standard cosmological assumptions in ligh of dark energy (DE)
- suppose particle physics model of interest does not yield a standard thermal WIMP freeze out scenario
- What if collider and cosmological measurements conflict?

  i.e. $\{\sigma_A^{\rm min}, \sigma_A^{\rm max}\}$ $\sigma_A^{\rm cosmo}$ but <u>not</u> $\sigma_A^{\rm min} < \sigma_A^{\rm cosmo} < \sigma_A^{\rm max}$
- Wishful thinking: probe physics at scales far above the electroweak to TeV scale
- How many ways do you know to connect colliders and DE?

Collider Measurements $\longrightarrow \longleftarrow$ Cosmological Data

direct/indirect detection
astrophysics

Suppose $\Omega_\chi^{\rm collider} \in \{\Omega_\chi^{\rm lower},\ \Omega_\chi^{\rm upper}\}$ incompatible with $\Omega_\chi^{\rm cosmo}$

Dilution $\Omega_\chi^{\rm collider} > \Omega_\chi^{\rm cosmo}$

entropy release:

late decays, thermal inflation

scalar-tensor gravity

other modifications of gravity

Enhancement $\Omega_\chi^{\rm collider} < \Omega_\chi^{\rm cosmo}$

extra contributions to *H*

more DM candidates
(not measured)

scalar-tensor gravity

other modifications of gravity

Dark matter + Dark Energy connection

Extra contributions to *H* can result from quintessence field Φ

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

but must be small (<20%) by BBN: $T_0 \sim 1\,\mathrm{MeV}$

More precisely: $\eta_\Phi \equiv \left(\frac{\rho_\Phi}{\rho_\gamma}\right)_{T=T_0} \leq 1$

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

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

(Salati, astro-ph/0207396

Collider Measurements → ← Cosmological Data

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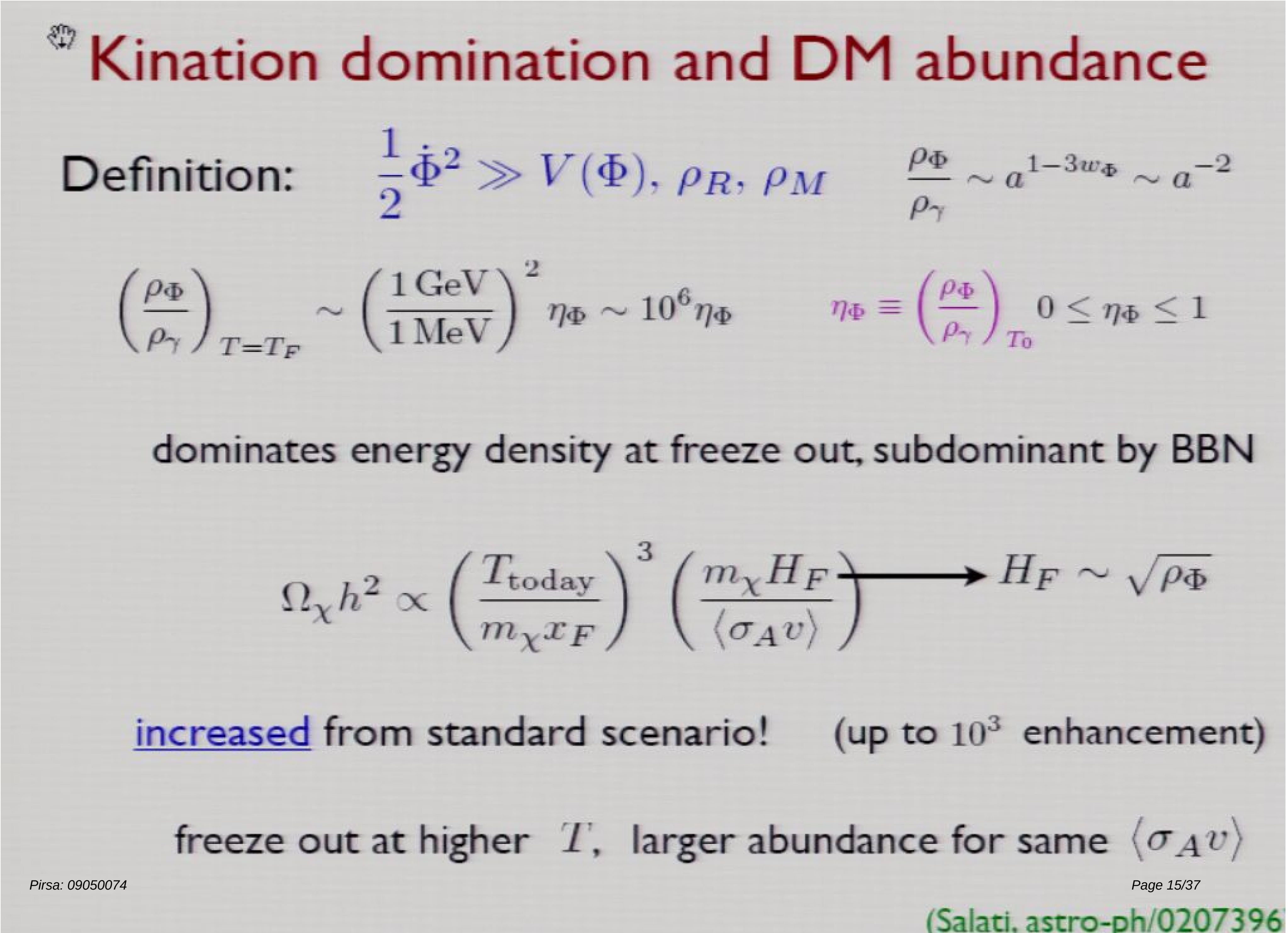

Kination domination and DM abundance

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

$$\left(\frac{\rho_\Phi}{\rho_\gamma}\right)_{T=T_F} \sim \left(\frac{1\,\mathrm{GeV}}{1\,\mathrm{MeV}}\right)^2 \eta_\Phi \sim 10^6 \eta_\Phi \qquad \eta_\Phi \equiv \left(\frac{\rho_\Phi}{\rho_\gamma}\right)_{T_0} \; 0 \le \eta_\Phi \le 1$$

dominates energy density at freeze out, subdominant by BBN

$$\Omega_\chi h^2 \propto \left(\frac{T_{\mathrm{today}}}{m_\chi x_F}\right)^3 \left(\frac{m_\chi H_F}{\langle \sigma_A v\rangle}\right) \longrightarrow H_F \sim \sqrt{\rho_\Phi}$$

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

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

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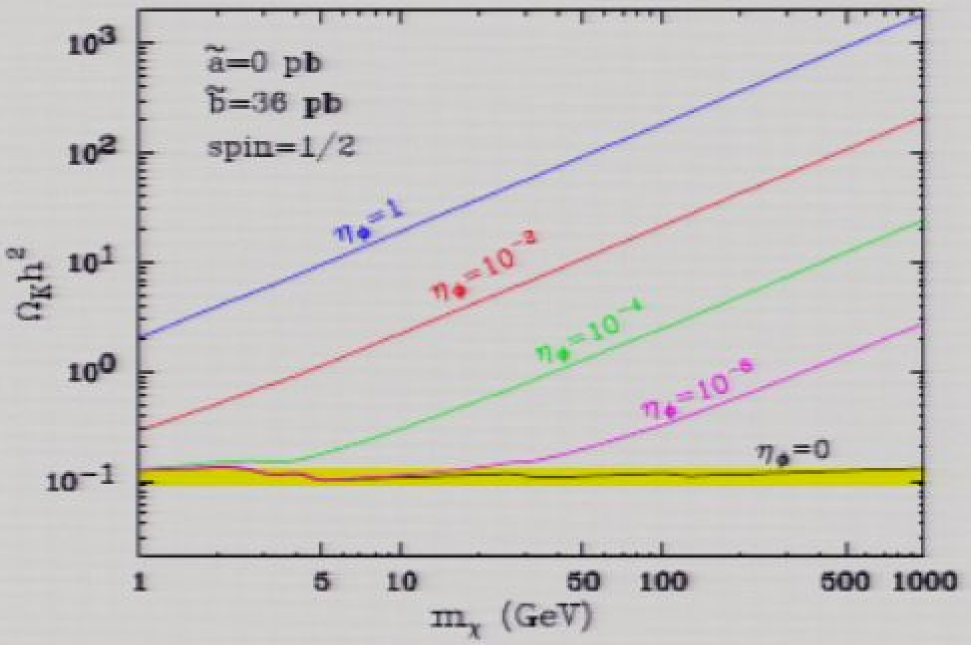

Chung, L.E., Kong, Matchev
0706.2375 [hep-ph]

Figure 2: *The dark matter relic abundance $\Omega_K h^2$ in the kination domination scenario, as a function of the mass m_χ of the dark matter particle, for the case of a pure p-wave annihilator ($\tilde{a} = 0$, $\tilde{b} = 36$ pb) and different values of the kination parameter η_Φ. The horizontal (yellow) shaded band denotes the current 2σ range for the experimental determination of the dark matter relic abundance.*

Kination Domination and Neutralino Dark Matter

Scenario implies:

- Mismatch b/w collider LSP and cosmological data

Implications for favored MSSM parameter space:

low relic abundance regions

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

also coannihilations (not as effective)

Resurrect wino, higgsino dark matter scenarios

Profumo,Ulio
hep-ph/0309220

- Good news for direct/indirect dark matter searches

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

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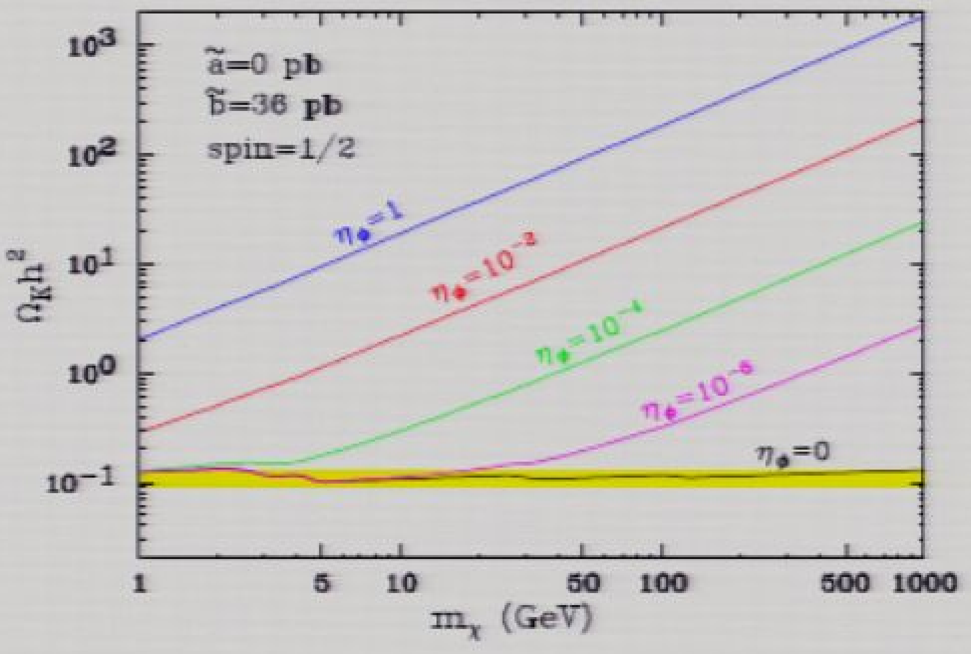

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Kination Domination and Neutralino Dark Matter

Previous studies: LHC probes of kination domination

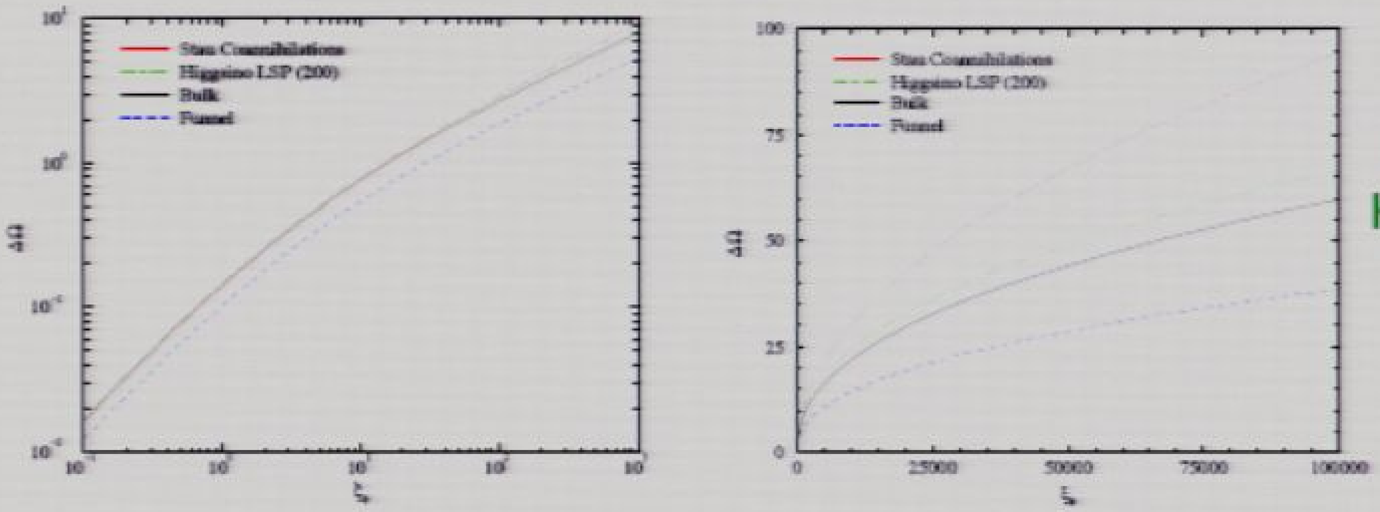

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Figure 6: The quintessential enhancement of the neutralino relic density for the four *benchmark* models of Tab.1 as a function of ξ_ϕ, respectively at large ξ_ϕ in a linear scale (*left*)and at small ξ_ϕ in a logarithmic scale (*right*).

	m_0	$M_{1/2}$	$\tan\beta$	μ	m_χ	Ωh^2	Wino fract.	Higgsino fract.
Bulk	500	500	45.0	>0	204	0.582	$<1\%$	$<0.01\%$
Stau Coan.	327	590	45.0	>0	241	0.022	$<1\%$	$<0.01\%$
Funnel	408	592	45.0	<0	243	0.005	$<1\%$	$<0.01\%$
Higgsino	800	323	45.0	>0	250	0.009	4%	95.5%

also studied nonuniversal gaugino mass models, anomaly mediation

ILC probes of dark matter/dark energy

Chung, L.E., Kong, Matche
0706.2375 [hep-ph]

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)

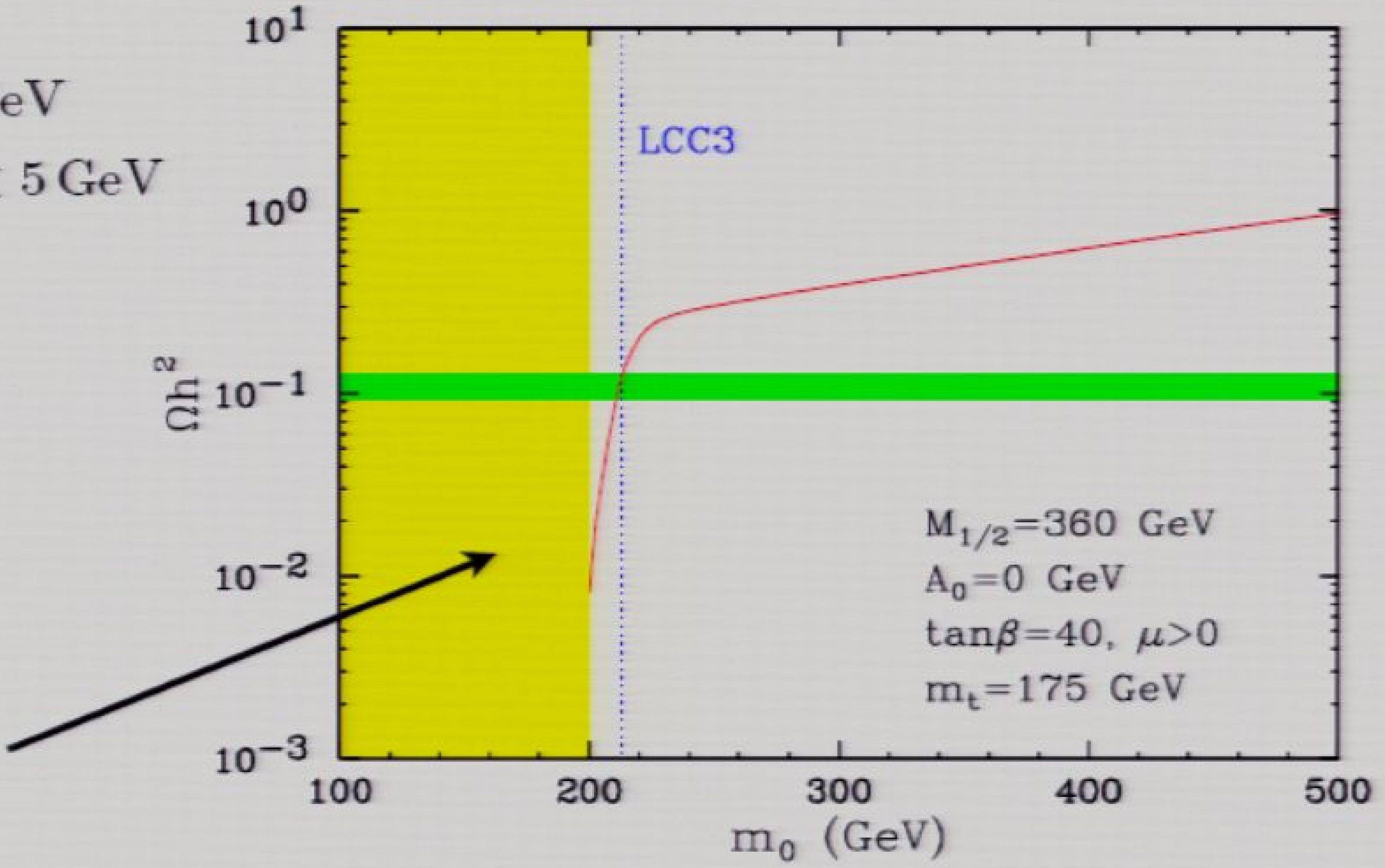
bulk	LCC1	$m_0 = 100, M_{1/2} = 250, \tan\beta = 10, A_0 = -100, \mu > 0$	LCC1'	$M_{1/2} = 150$
focus	LCC2	$m_0 = 3280, M_{1/2} = 300, \tan\beta = 10, A_0 = 0, \mu > 0$	LCC2'	$m_0 = 336$
stau	LCC3	$m_0 = 213, M_{1/2} = 360, \tan\beta = 40, A_0 = 0, \mu > 0$	LCC3'	$m_0 = 205$
A funnel	LCC4	$m_0 = 380, M_{1/2} = 420, \tan\beta = 53, A_0 = 0, \mu > 0$	LCC4'	$m_0 = 950$ $\tan\beta = 50$ $\mu < 0$

Future work: beyond mSUGRA/CMSSM...

Stau coannihilation region: mSUGRA LCC3 study point with adjusted m_0

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

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



stau LSP

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

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funnel	LCC4	$m_0 = 380, M_{1/2} = 420, \tan\beta = 53, A_0 = 0, \mu > 0$	LCC4'	$m_0 = 95$ $\tan\beta = 50$ $\mu < 0$

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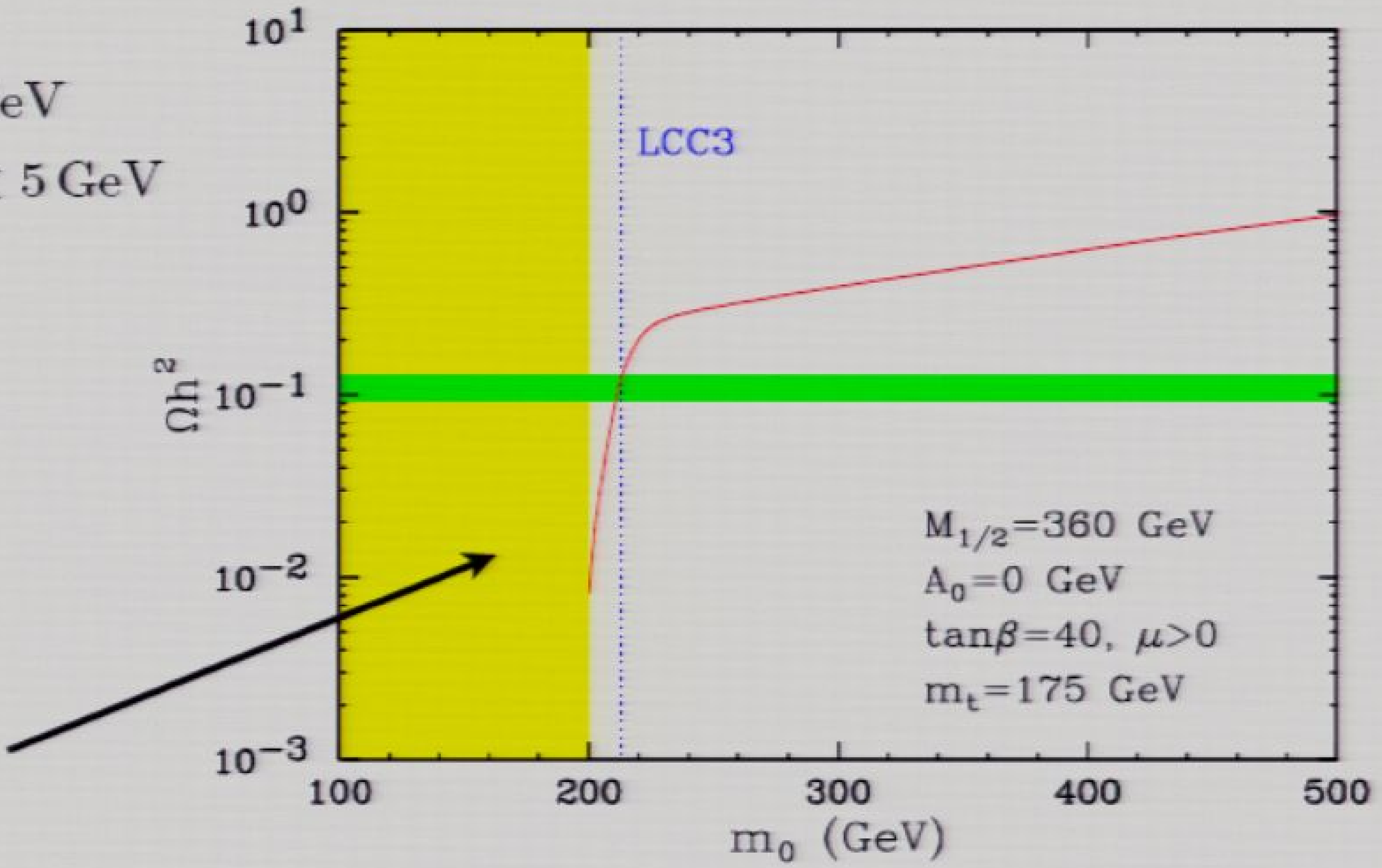

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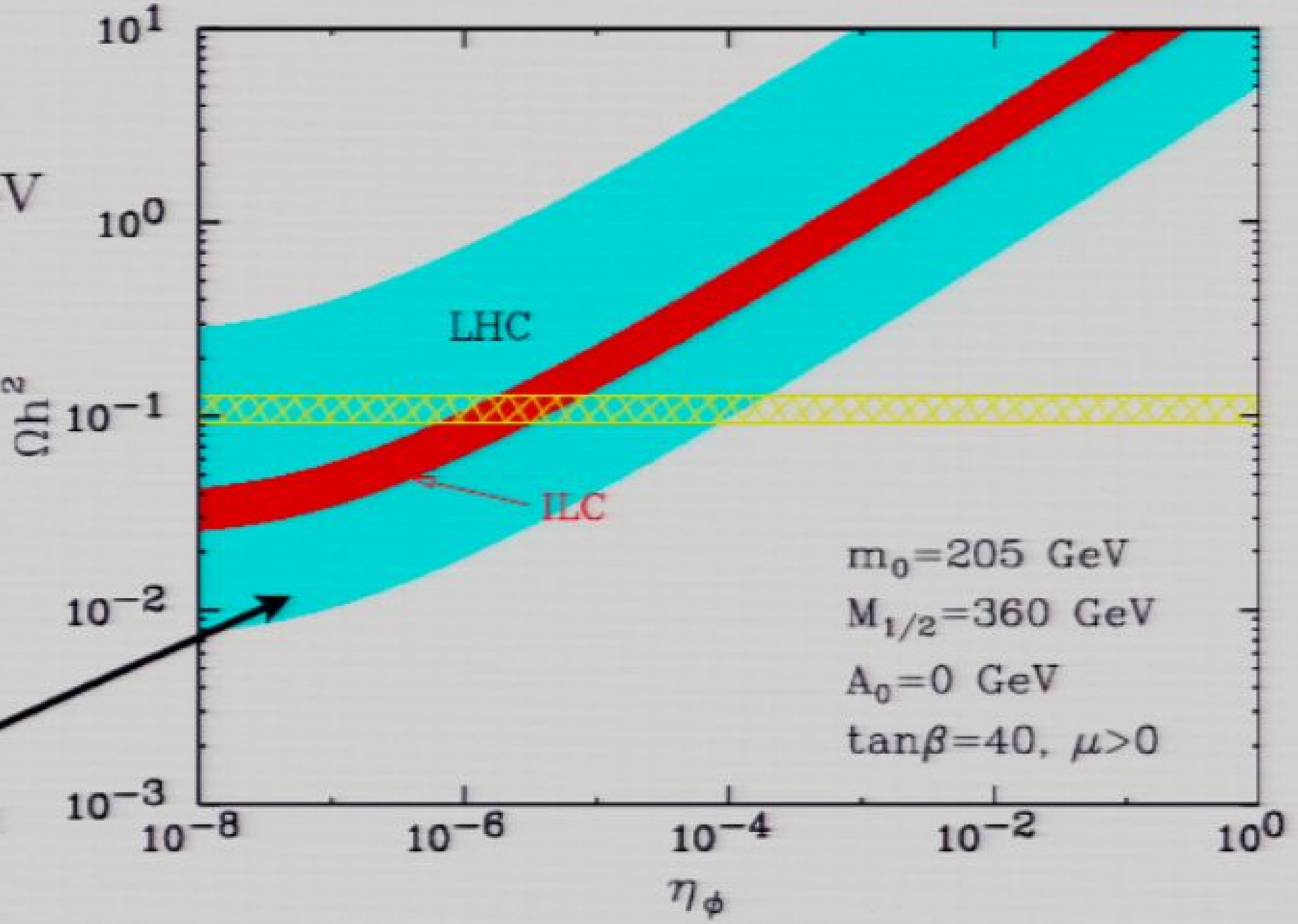


HC consistent with

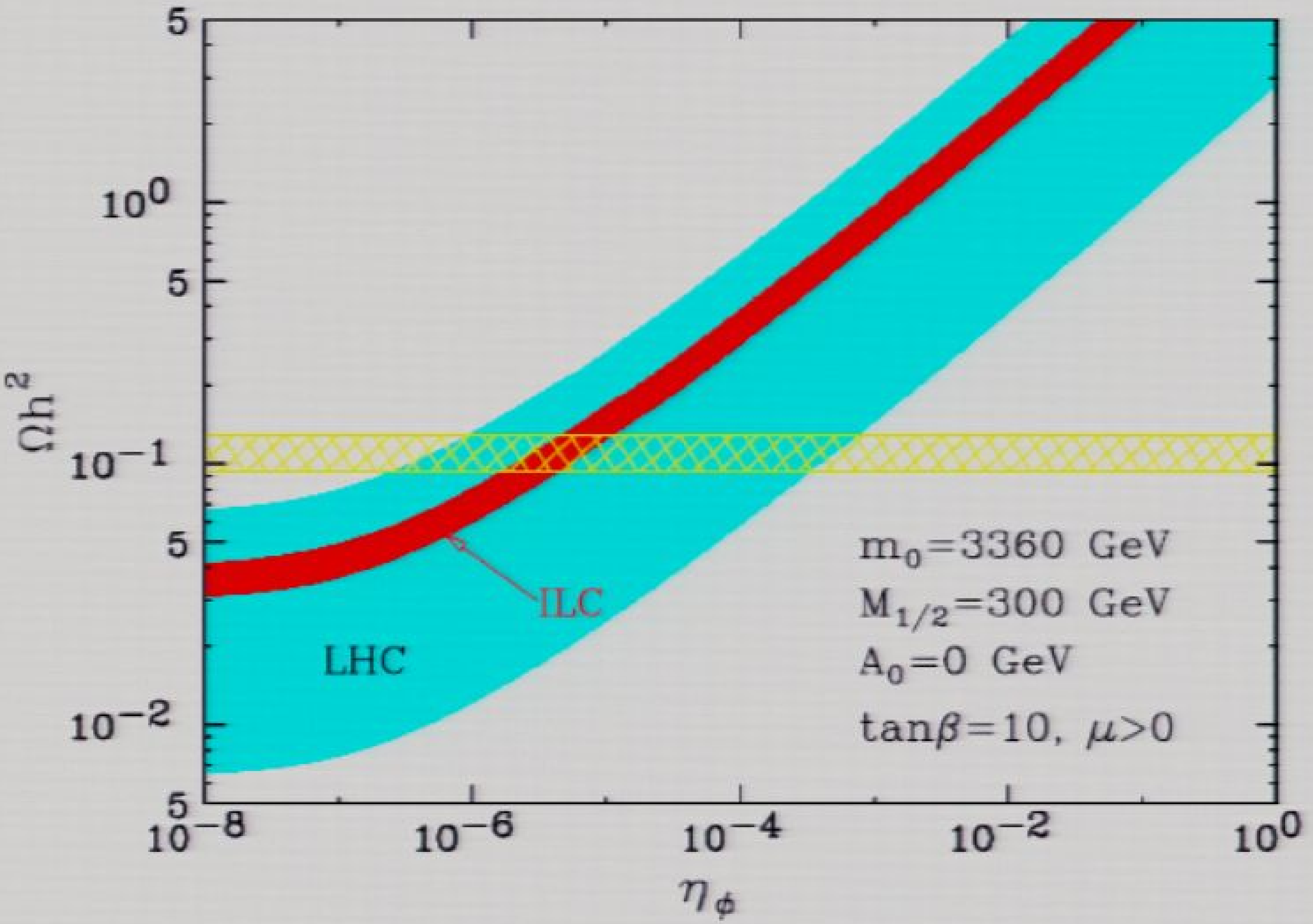
$\eta_\Phi = 0$

ILC inconsistent with

$\eta_\Phi = 0$

Focus region study point

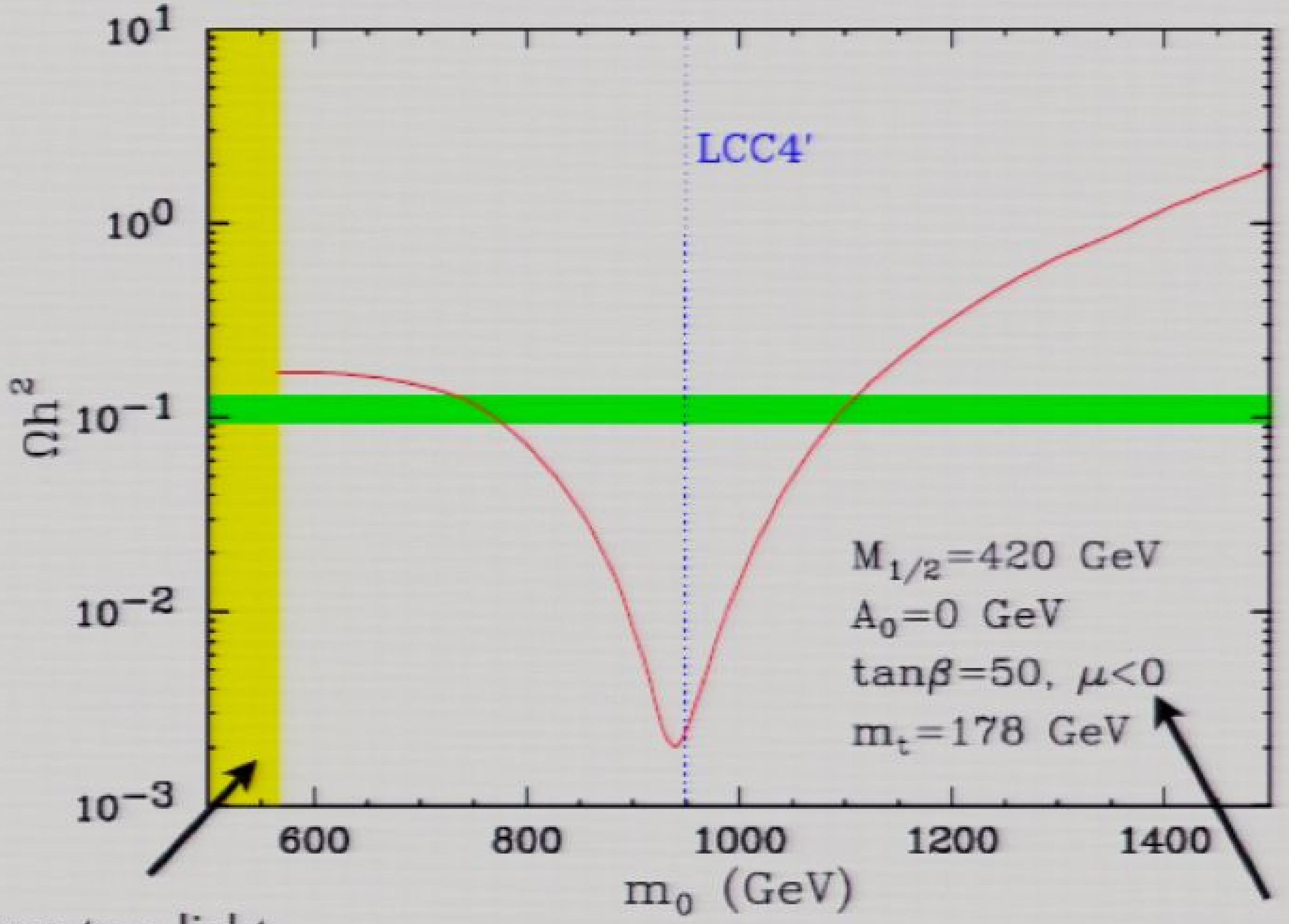
mSUGRA LCC2 study point
with adjusted m_0



both LHC and ILC demonstrate nonzero η_Φ

A-funnel study point

mSUGRA LCC4 study point
with adjusted parameters



Higgs too light

flipped sign from LCC4

A-funnel region study point

mSUGRA LCC4 study point
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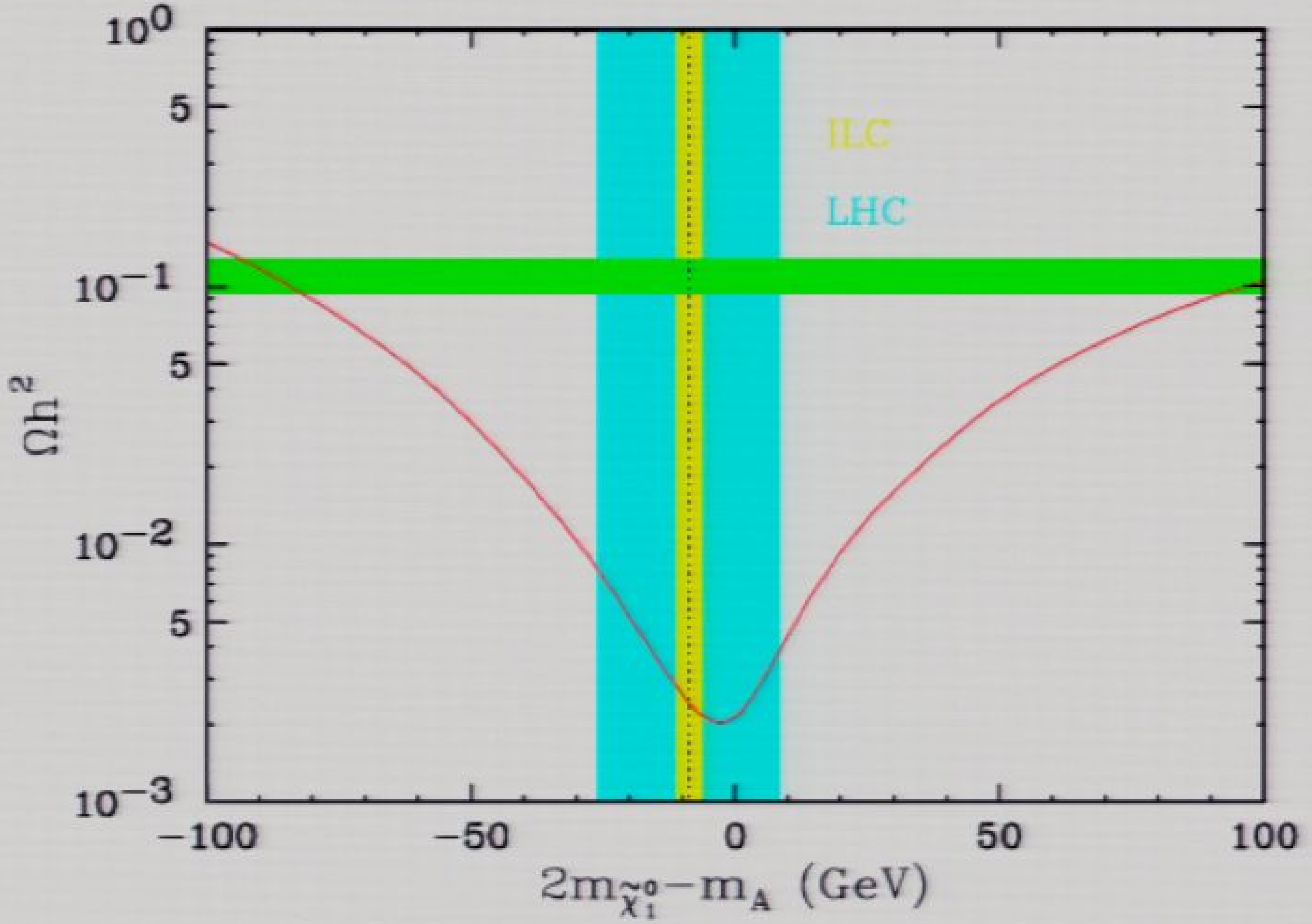
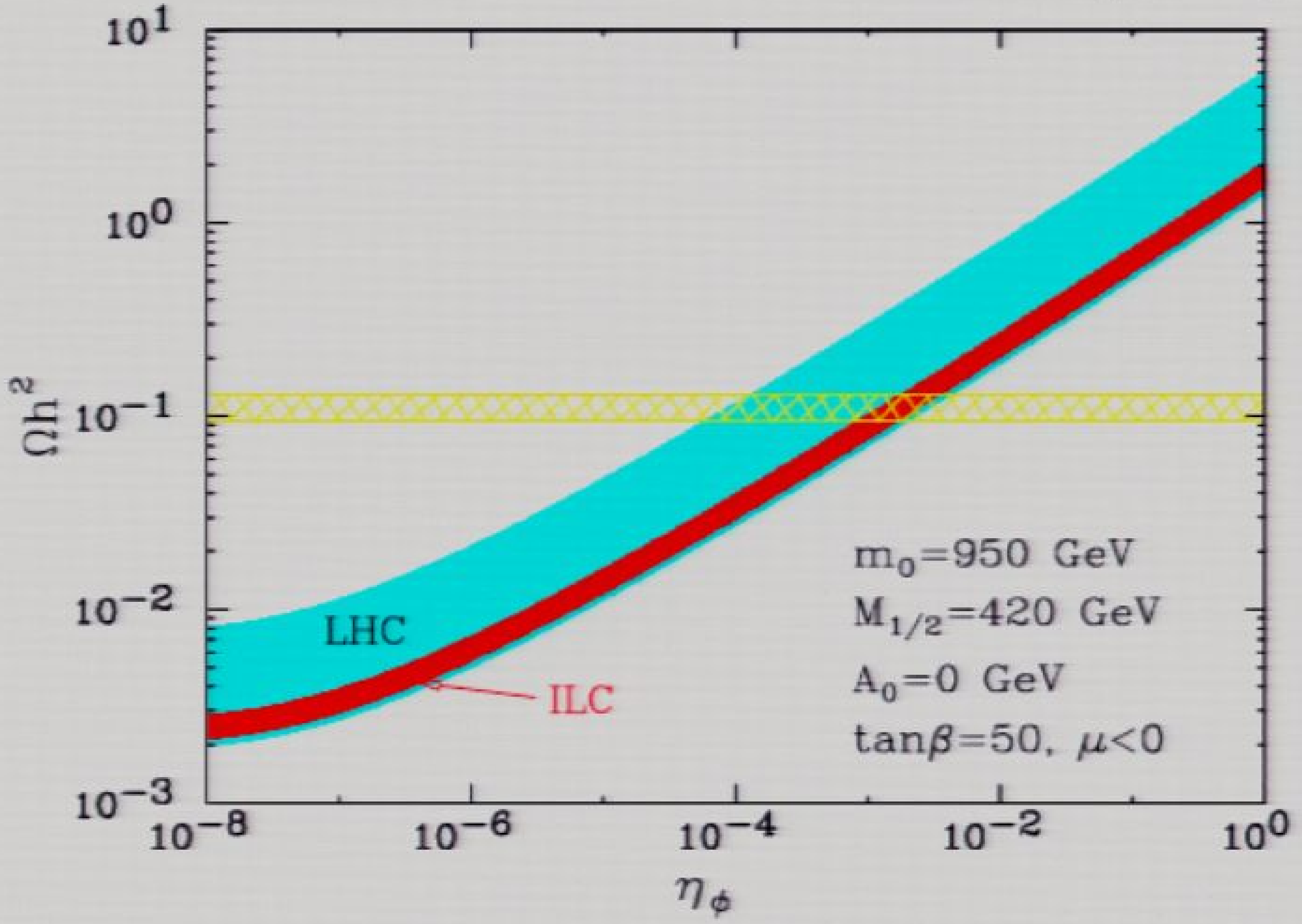


precision to which LHC and ILC-1000 can measure $2m_{\tilde{\chi}_1^0} - m_A$

A-funnel region study point

mSUGRA LCC4 study point
with adjusted parameters



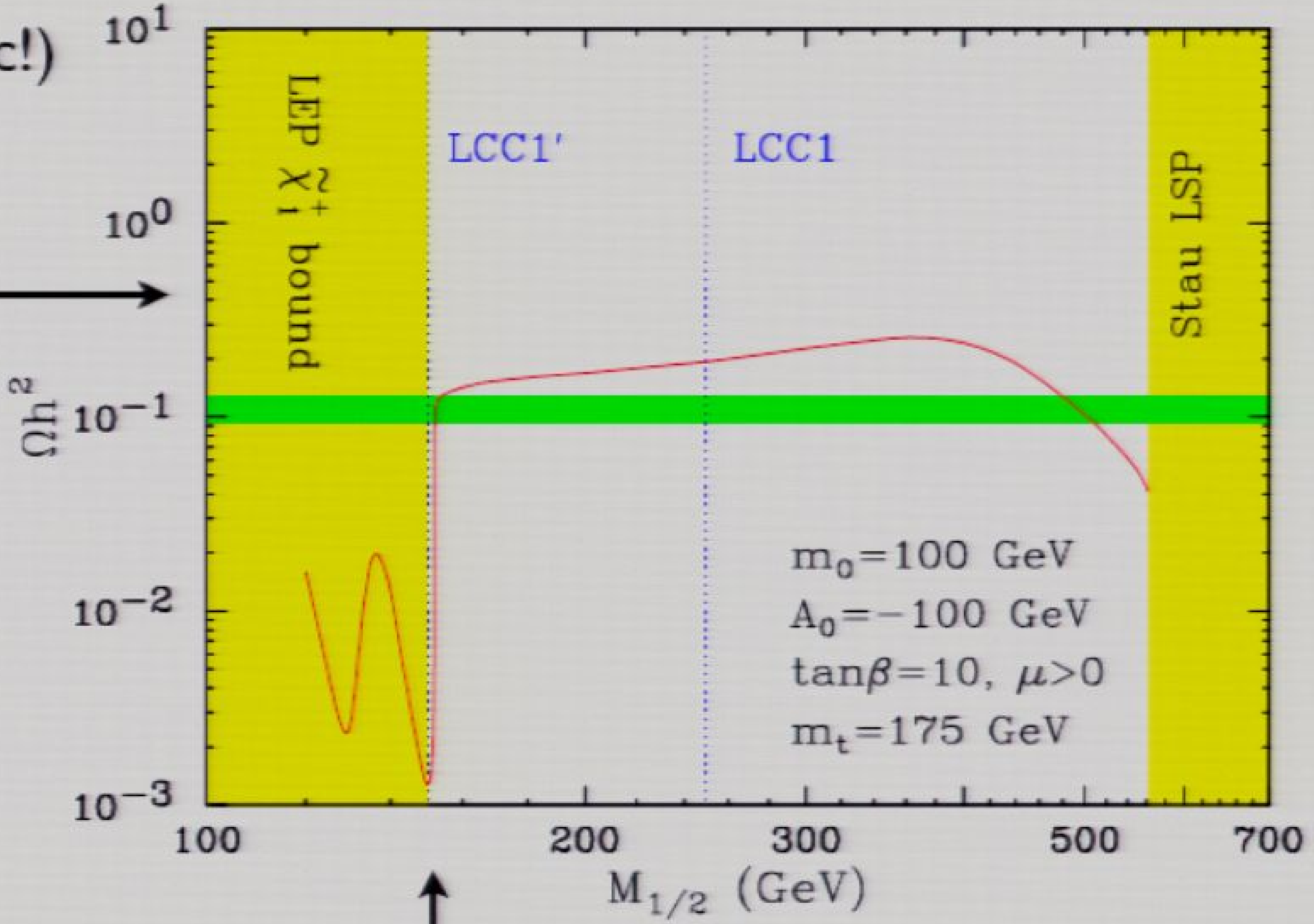
(ILC-1000 needed due to heavy spectrum)

Bulk region study point

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

(more dramatic!)

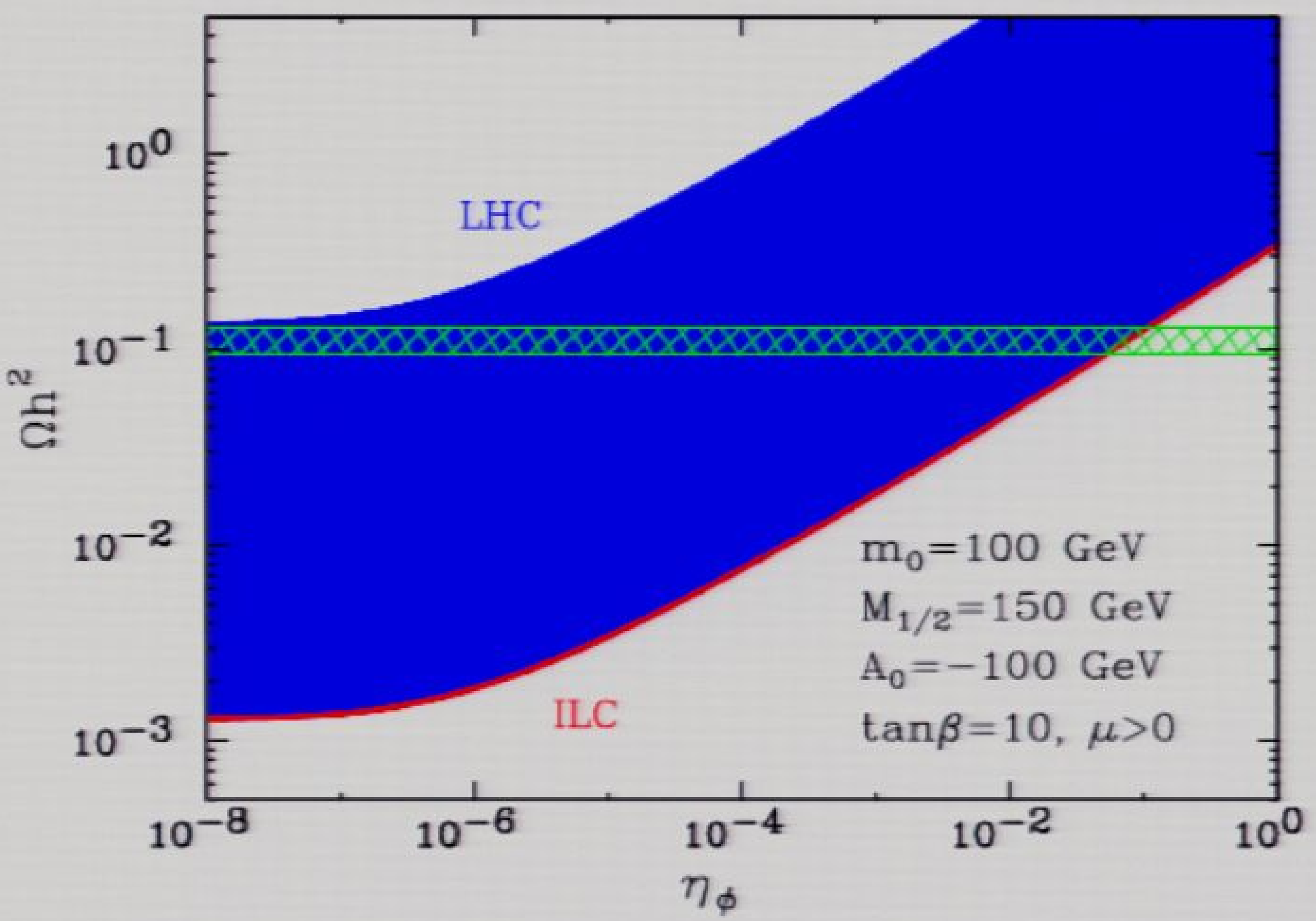
weaker due to light $\tilde{\nu}$ →



↑ 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 much better!

Inflationary Embedding of Kination Domination (I)

Chung, Everett, Matchev, 0704.3285

The scenario:

inflaton = quintessence field

energy dominance
+coherence

kick it at end of inflation:

$$\sqrt{2}M_P\left|\frac{V'}{V}\right|_{T_{\mathrm{end}}} > 6$$

Initial kination behavior transitions to cc'like behavior at late times

(no *generic* equation of state predictions)

note: usual quintessence tuning problems, no obvious particle physics connection

Inflationary Embedding of Kination Domination (II)

Gravitational reheating (minimal scenario):

$$\rho_\Phi \sim V_0 \left(\frac{a_e}{a}\right)^6$$

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

$$\rho_R \sim \frac{V_0^2}{M_P^4}\left(\frac{a_e}{a}\right)^4$$

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

upper bound for fixed η_Φ!

Prediction: negligible inflationary tensor perturbations

Distinguishable from (plausible) case of multiple DM candidates?

- Particle physics: essentially, no
- Cosmology: in principle, yes

tensor perturbations

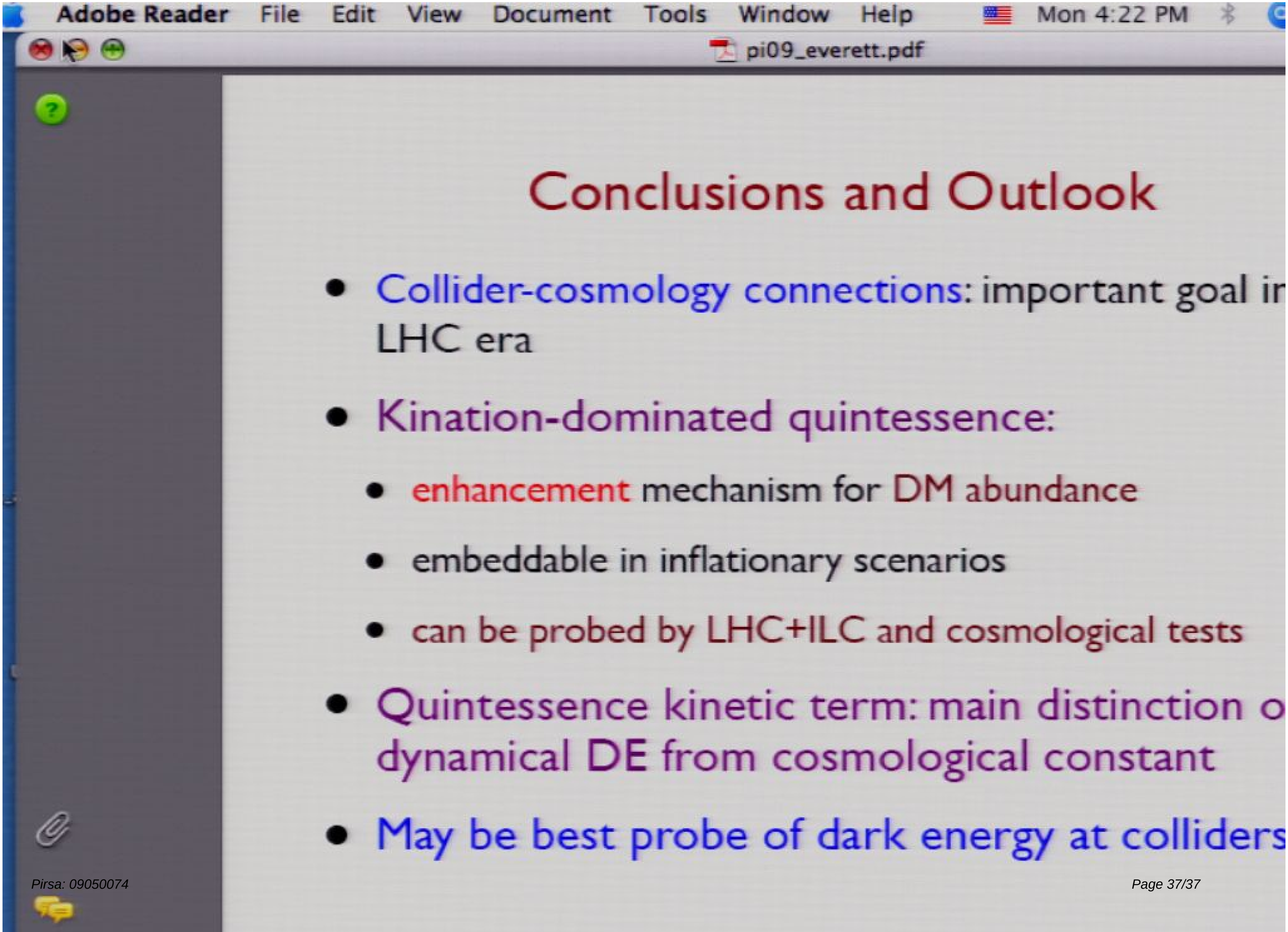
non-standard leptogenesis — Chun and Scopel, 0707.1544,...

shift in gravity wave spectrum — Chung+Zhou, in progress

... (Daniel Chung's talk)

Conclusions and Outlook

- Collider-cosmology connections: important goal in LHC era
- Kination-dominated quintessence:
  - enhancement mechanism for DM abundance
  - embeddable in inflationary scenarios
  - can be probed by LHC+ILC and cosmological tests
- Quintessence kinetic term: main distinction of dynamical DE from cosmological constant
- May be best probe of dark energy at colliders!



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