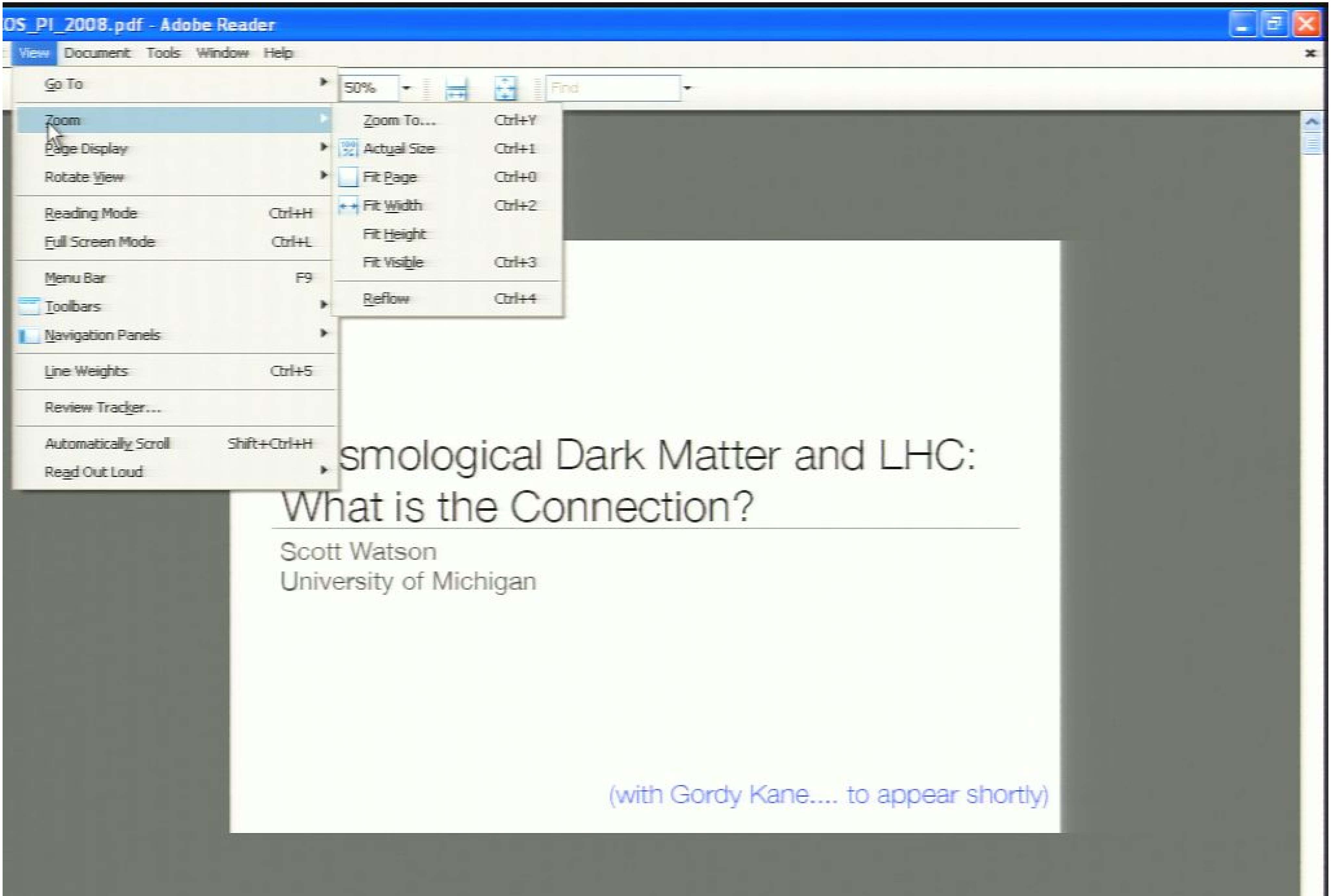
Title: CDM / LHC: How Robust is the Connection?

Date: Jun 06, 2008 09:30 AM

URL: http://pirsa.org/08060173

Abstract: One of the most compelling hints for physics beyond the standard model is the cosmological observation that nearly a quarter of our universe consists of cold dark matter. In the next few years, LHC shows the promise of producing these elusive particles and possibly measuring their microscopic properties. This will be challenging, per se, and using LHC observations to reconstruct a complete theory of cosmological dark matter could prove quite challenging. In this talk I will discuss the prospects and many challenges facing such a program. In particular, we will consider complications that can arise rather generically from supersymmetry breaking or gravitational effects in the early universe. Although this will make synthesis much more difficult, many of these effects could lead to insights into the baryon asymmetry and its relation to the dark matter abundance.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…smological Dark Matter and LHC:
What is the Connection?
Scott Watson
University of Michigan
(with Gordy Kane.... to appear shortly)

Cosmological Dark Matter and LHC: What is the Connection?

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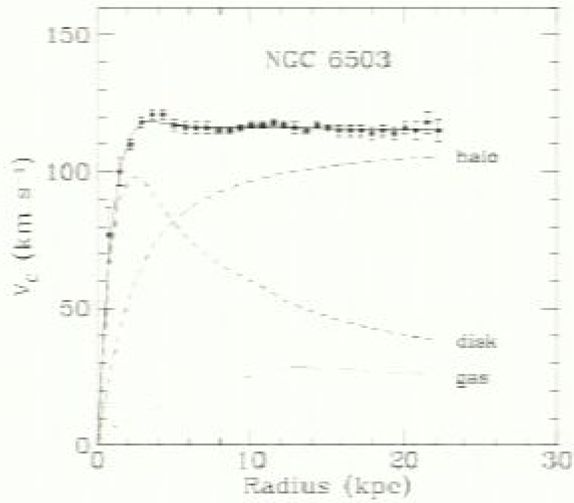
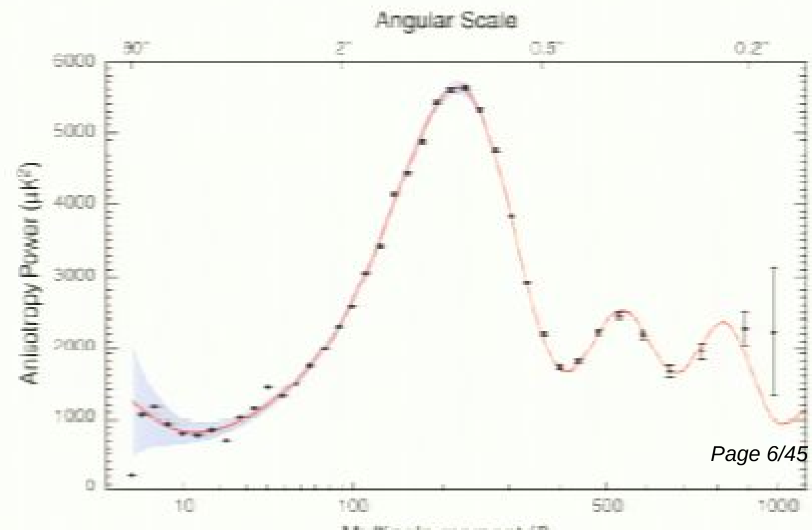
Connection between CDM and LHC?

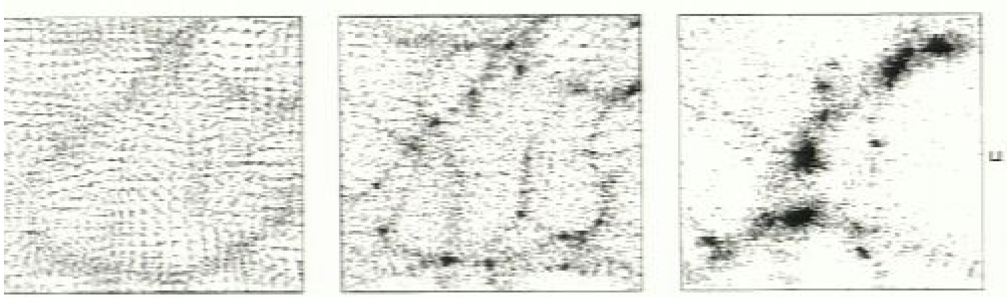
$$\Omega_{dm}^{cosmo} \overset{?}{=} \Omega_{dm}^{LHC}$$

Precision Cosmology

- Rotation curves
- CMB / LSS / Supernovae
- Evolution of LSS
- Gravitational Lensing







t_{age}=1.6 Gyr t_{age}=4.6 Gyr t_{age}=13 Gyr

Cosmological Dark Matter

Cosmological Properties (WMAP3+BBN+LSS+Lensing)

- Cold (Non-relativistic when structure forms)
- Dark (electrically neutral)
- Stable (or very long-lived)

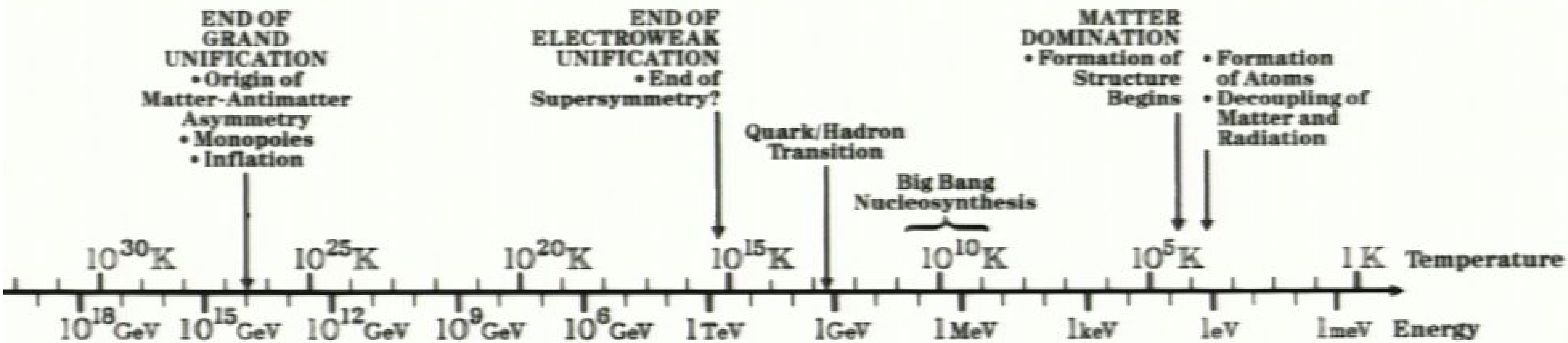
"WIMPs"

$$\Omega_{cdm}h^2 = 0.1143 \pm 0.0034$$

How is dark matter produced?

Bottom-up approach -- Thermal WIMPs

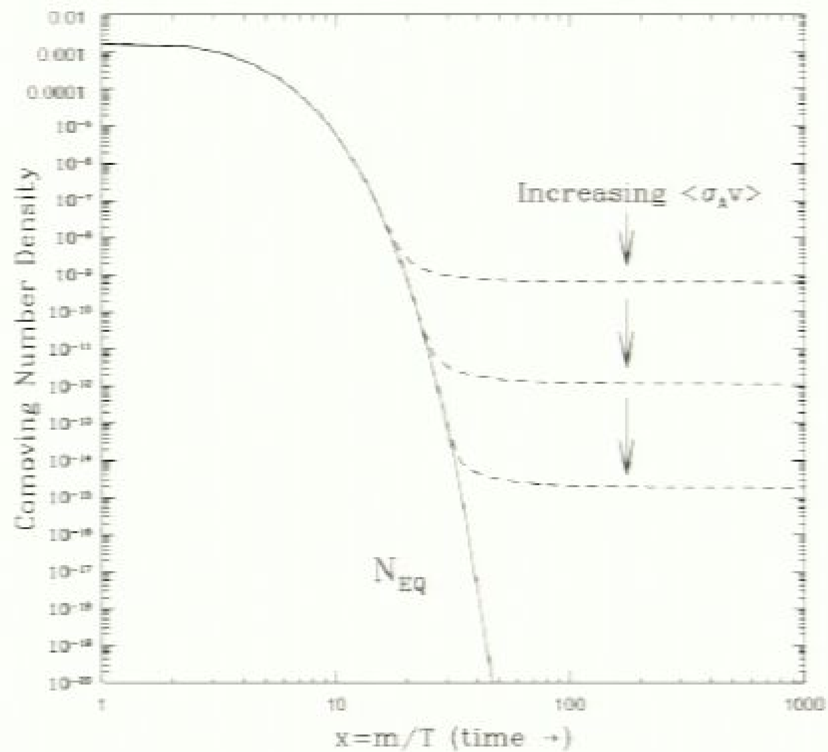
Dark Matter Creation



As the universe expands it cools.

At early times expect temperature exceeds mass.

Thermal Dark Matter



Relativistic

$$T > m_x \quad XX \leftrightarrow \gamma\gamma$$

Non-Relativistic

$$T < m_x \quad XX \rightarrow \gamma\gamma \qquad N_x \sim e^{-m_x/T}$$

Freeze-out

$$H > \Gamma_{ann}$$

$$N_x = \left. \frac{3H}{T^3 \langle \sigma v \rangle} \right|_{T=T_f}$$

Thermal Dark Matter

$$N_x = \frac{3H}{T^3 \langle \sigma v \rangle}\bigg|_{T=T_f}$$

Assumed equilibrium was reached
Assume radiation dominated universe at freeze-out
Assume no significant entropy production after freeze-out

$$\Omega_X h^2 = \frac{10^{-10}\ GeV^{-2}}{\langle \sigma v \rangle}$$

Connection between CDM and LHC?

$$\Omega_{\text{dm}}^{\text{cosmo}} \overset{?}{=} \Omega_{\text{dm}}^{\text{LHC}}$$

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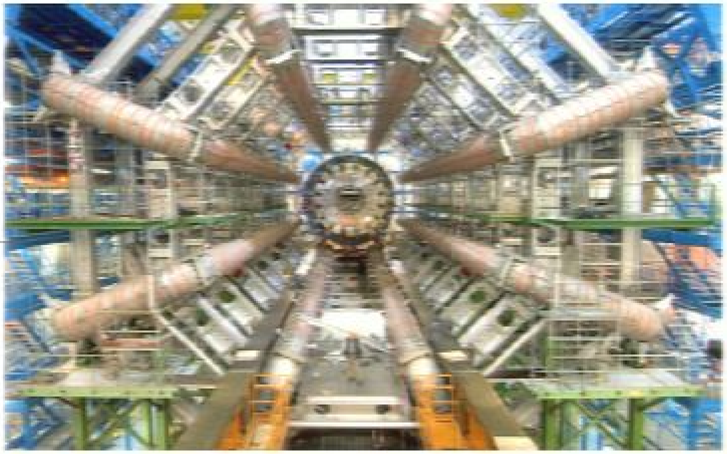
New Physics at Weak Scale

$$\langle \sigma v \rangle \sim 1\ \text{pb}$$

LHC and Dark Matter



LHC will probe our theories of EWSB.

$$\Omega_X h^2 = \frac{10^{-10}\ GeV^{-2}}{\langle \sigma v \rangle}$$

Measure dark matter mass/interaction

--> End game?

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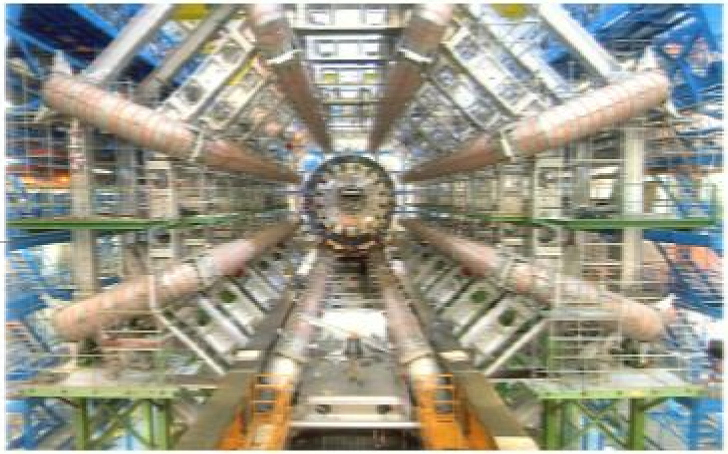

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LHC and the CDM Inverse Problem

(with Gordy Kane.... to appear shortly)

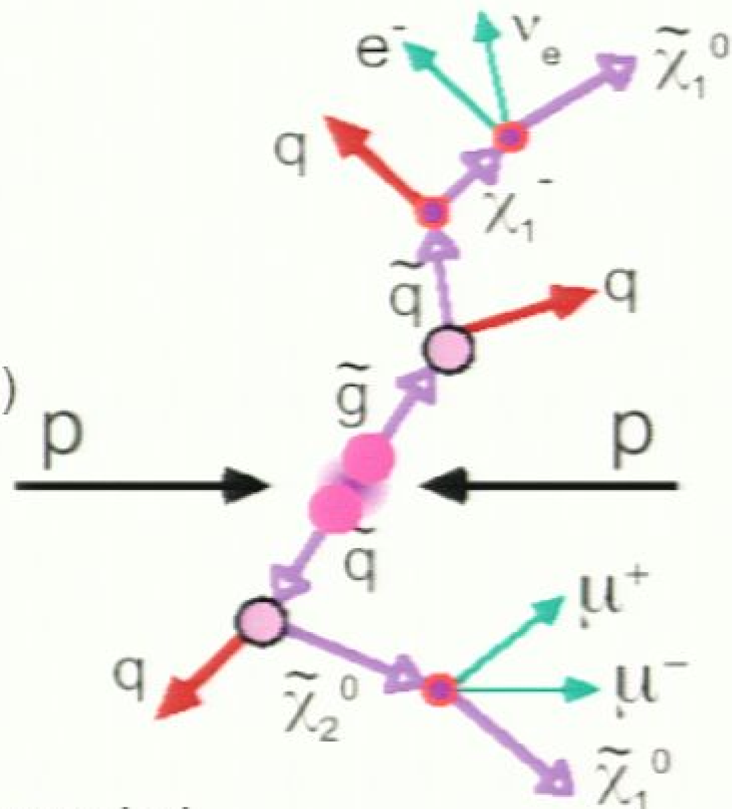
Challenges for CDM Reconstruction at LHC

LHC is proton-proton collider
constituent velocities uncertain

CDM is weakly interacting = missing energy
(Measure other particles -> deduce WIMP properties)

Particle lifetime in detector ~10^{-8} s
CDM lifetime > 10^{17} s

Matching signatures to theory will be challenging:
Many degeneracies - model independent approaches needed.



Other aspects of the CDM Inverse Problem

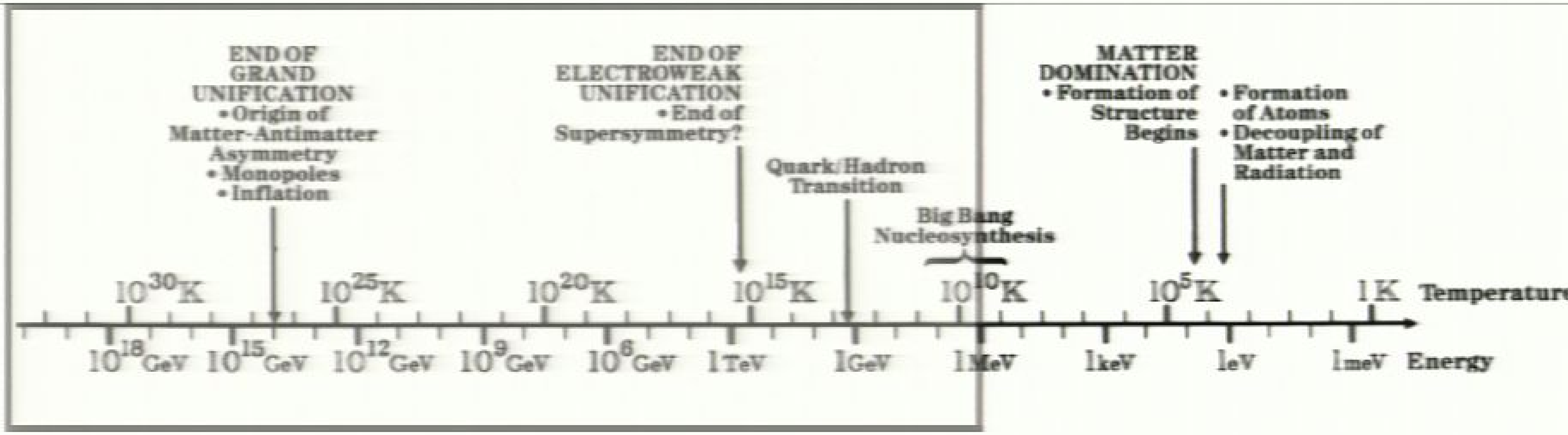
Even if we measure WIMP mass/cross-section, still many challenges:

- Coannihilations can lower relic density
- Many additional dark matter particles - (e.g. neutrinos / axions)

$$\Omega_{cdm}^{Total} = \sum_i \Omega_{cdm}^{(i)}$$

- Many assumptions go into thermal calculation

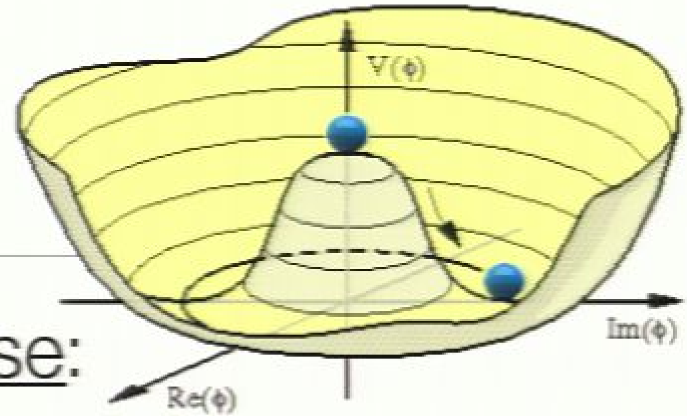
Cosmological Dark Matter



*Assumed equilibrium was reached
*Assumed radiation dominated universe at freeze-out
*Assumed no entropy production after freeze-out
*Assumed no other sources of cdm (e.g. late decays)

Top-Down Approach to Dark Matter

Light Scalars in the Early Universe

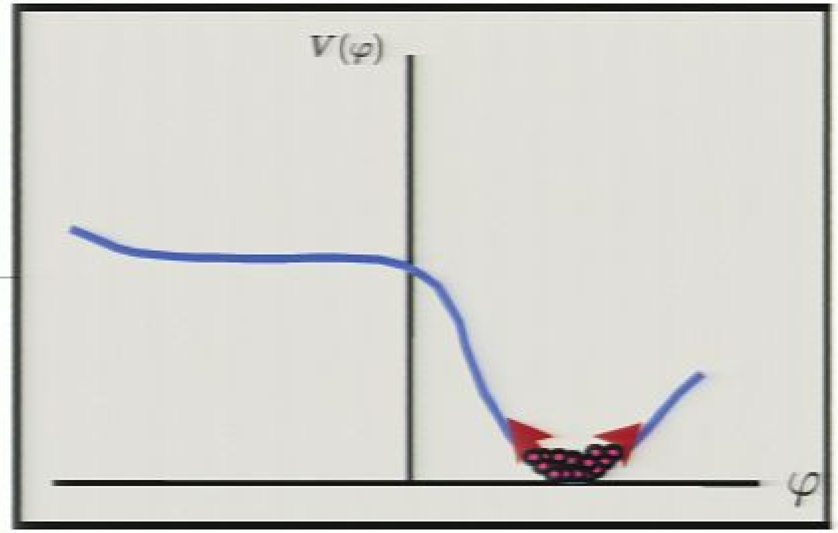


Expect many light scalars in early universe:

- Higgs / Inflatons
- Size and shape of extra dimensions
- Locations of branes and strings
- MSSM flat directions

Beyond Standard Model
--> New Symmetries --> Degeneracies

Scalar Condensates



Coherent Oscillations

$$V(\Phi) \sim \Phi^\gamma \qquad p = \left(\frac{2\gamma}{2+\gamma} - 1\right)\rho.$$

Scalar Condensate forms

$$\Delta\Phi \to \Delta E$$

$\gamma = 0$	$p = -\rho,$	Λ
$\gamma = 1$	$p = -\frac{1}{3}\rho,$	tadpole
$\gamma = 2$	$p = 0,$	matter
$\gamma = 4$	$p = \frac{1}{3}\rho,$	radiation
$\gamma = \pm\infty$	$p = \rho,$	stiff fluid

Density may grow relative to radiation
--> Danger for BBN!

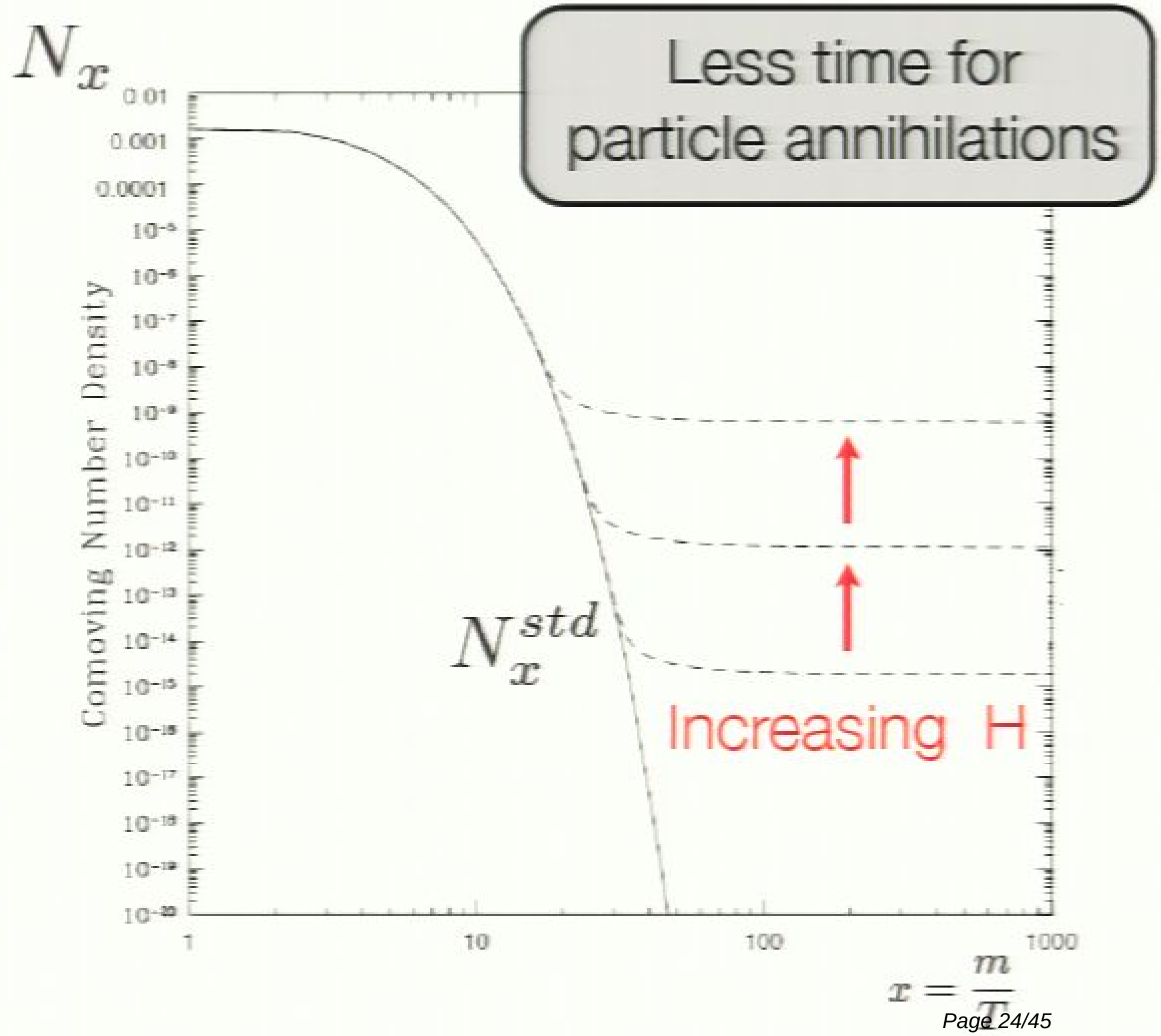
1 Modified Expansion History

Scalars may increase expansion rate

$$\rho_r \to \rho_r + \rho_\phi$$

Increase: H

Increase: $\langle \sigma v \rangle$



2 CDM Dilution from Scalar Decay

Condensate can decay after CDM freeze-out

$$\varphi \longrightarrow \gamma\gamma$$

$$T_r \approx \left(\frac{m_\varphi}{10\,TeV}\right)^{3/2} MeV \qquad T_f = \frac{m_x}{25} \simeq \mathrm{GeV}$$

Relic density diluted

$$\Omega_{cdm} \to \Omega_{cdm}\left(\frac{T_r}{T_f}\right)^3$$

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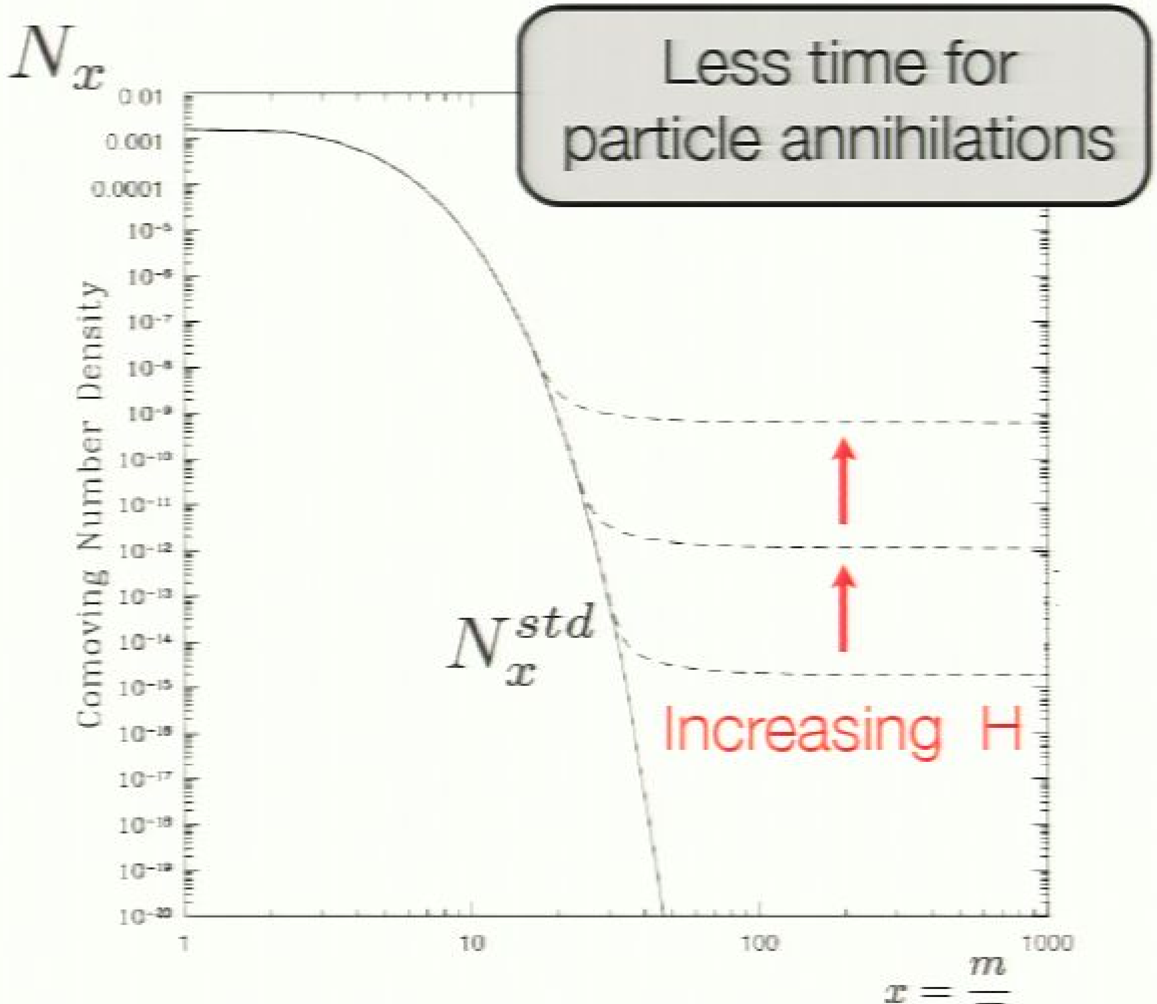

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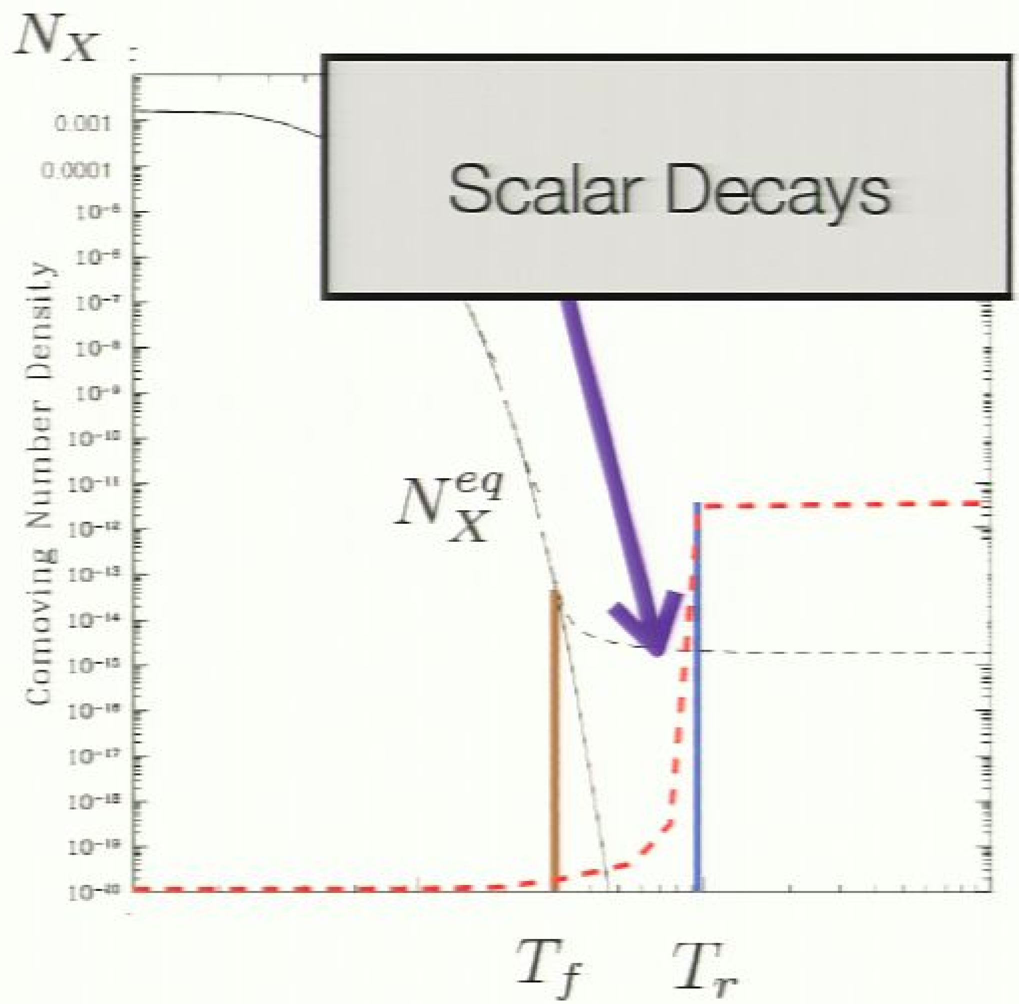
3 Late-time Production of Dark Matter

New dark matter from decay

$$\varphi \rightarrow XX$$



$T_r < T_f$ → **No Annihilation !!!**

Effect of Moduli on CDM

hermal Relic Density

$$\Omega_X h^2 = \frac{10^{-10}\ GeV^{-2}}{\langle \sigma v \rangle} \qquad T_f \approx \frac{m_X}{25}$$

Modified expansion

$$\Omega_x = \frac{10^{-10}\ \mathrm{GeV}^{-2}}{\langle \sigma v \rangle} \left(1 + \frac{\rho_\varphi}{\rho_r}\right)^{1/2}$$

Entropy Production

$$\Omega_x = \frac{10^{-10}\ \mathrm{GeV}^{-2}}{\langle \sigma v \rangle} \left(\frac{T_f}{T_r}\right)^{3}$$

Non-thermal Production

$$\Omega_x = \frac{10^{-10}\ \mathrm{GeV}^{-2}}{\langle \sigma v \rangle} \left(\frac{T_f}{T_r}\right)$$

* Larger cross-sections
* Sensitive to underlying parameters of fundamental theory

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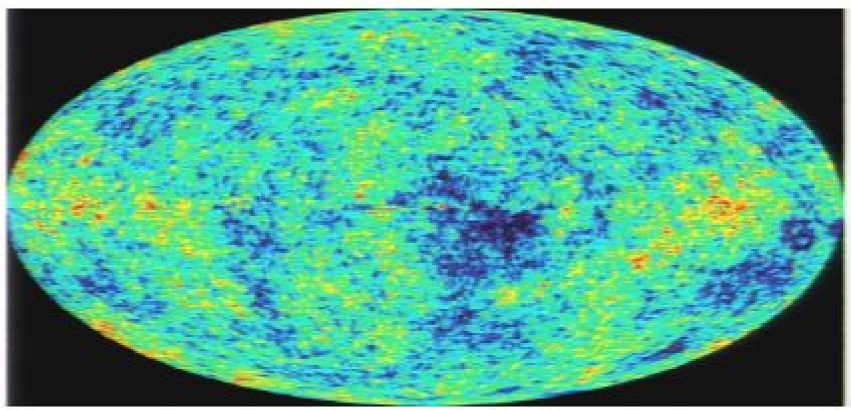
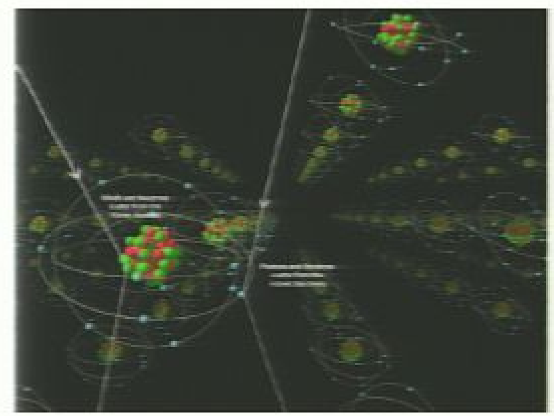
Combine LHC data with other experiments....





Example: Dark matter in the MSSM

leutralino WIMPs (light, stable, neutral)

$$\tilde{\chi} = N_{i1}\tilde{B} + N_{i2}\tilde{W}^3 + N_{i3}\tilde{H}_1^0 + N_{i4}\tilde{H}_2^0$$

Thermal Relic Density

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WMAP Result

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?

Bino-like cross-section (P-wave suppression)

$$\langle \sigma v \rangle \sim 10^{-9}\ GeV^{-2} \qquad \Omega_{lsp}\, h^2 \sim 0.1$$

Example: The Wino-like Neutralino as a WIMP

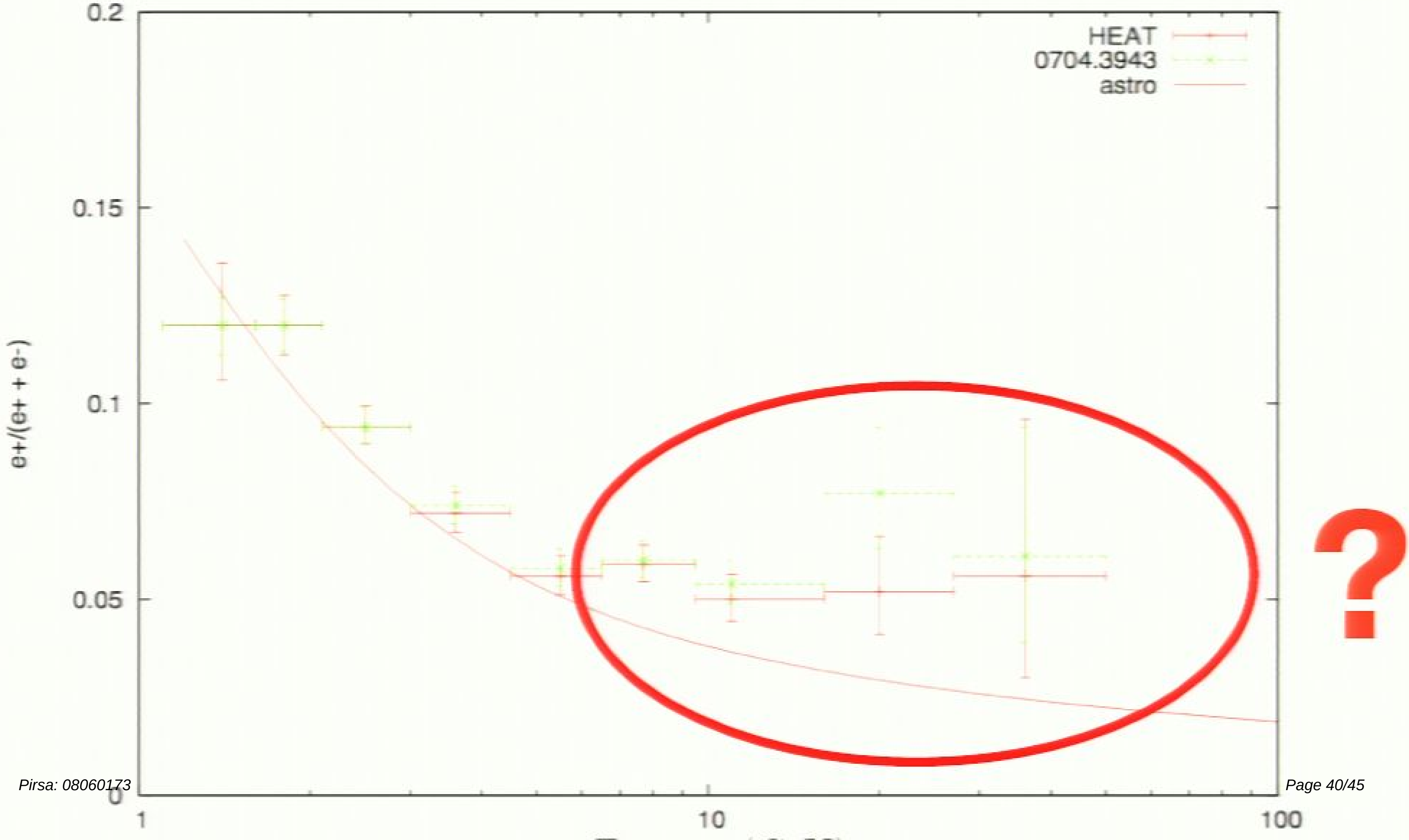
"Non-thermal Dark Matter and the Moduli Problem in String Frameworks"
- arXiv:0804.0863 (Accepted JHEP)
B. Acharya, K. Bobkov, G. Kane, P. Kumar, J. Shao and S.W.

- Stabilize moduli in way that:
  - Preserves the electroweak hierarchy
  - Provides nearly Minkowski or dS vacuum
- Typically modulus with m ~ 10 TeV
- Reheat temperature near MeV
- Wino-like neutralino has freezeout temperature near GeV

ndirect Detection:

.g. Dark matter annihilations giving positron spectrum

Positron Excess -- Annihilating Dark Matter?



Wino-like Neutralinos - Positron Excess

Could excess be due to annihilating dark matter?

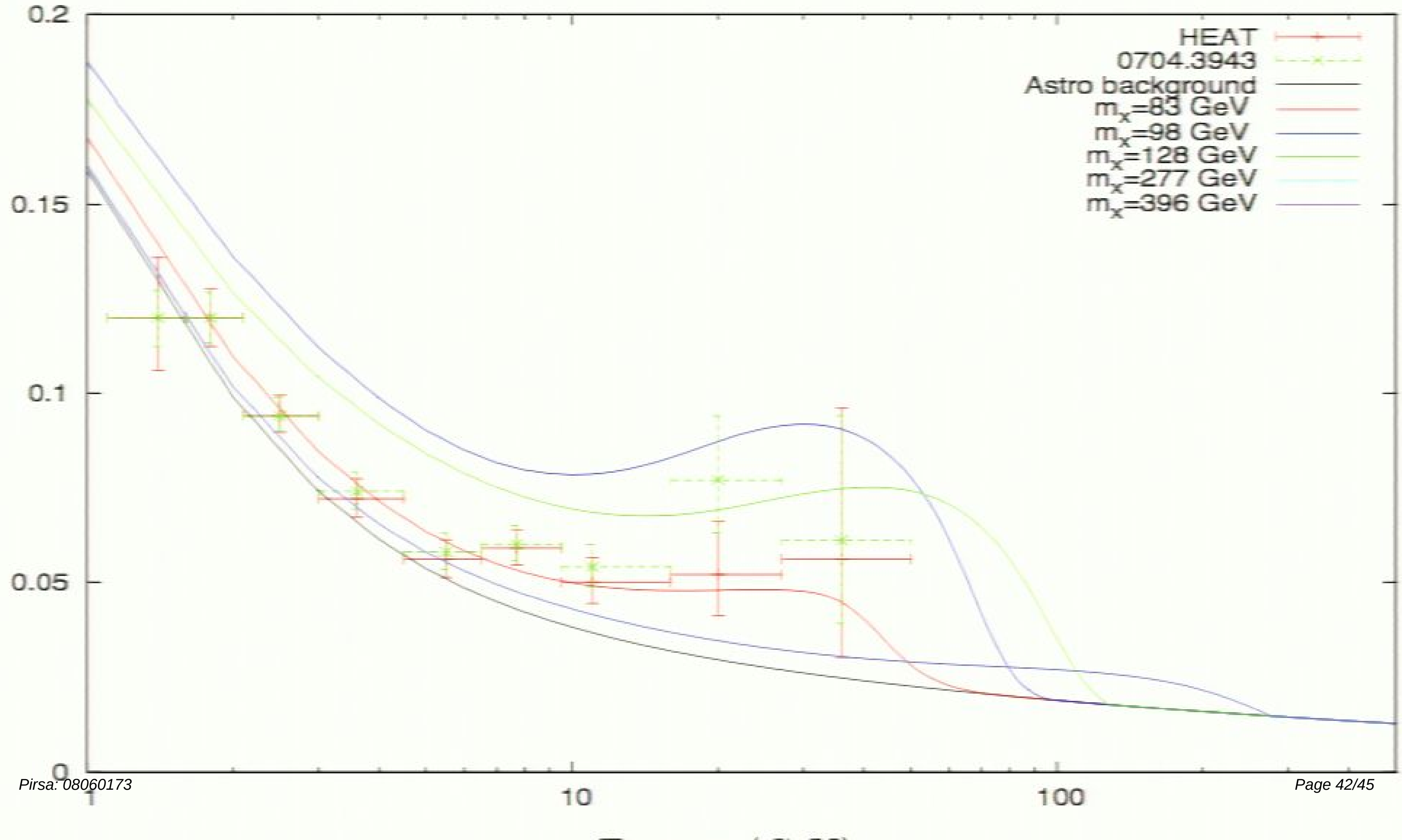
Bino-like requires large "boost" factor (Recent simulations say small)

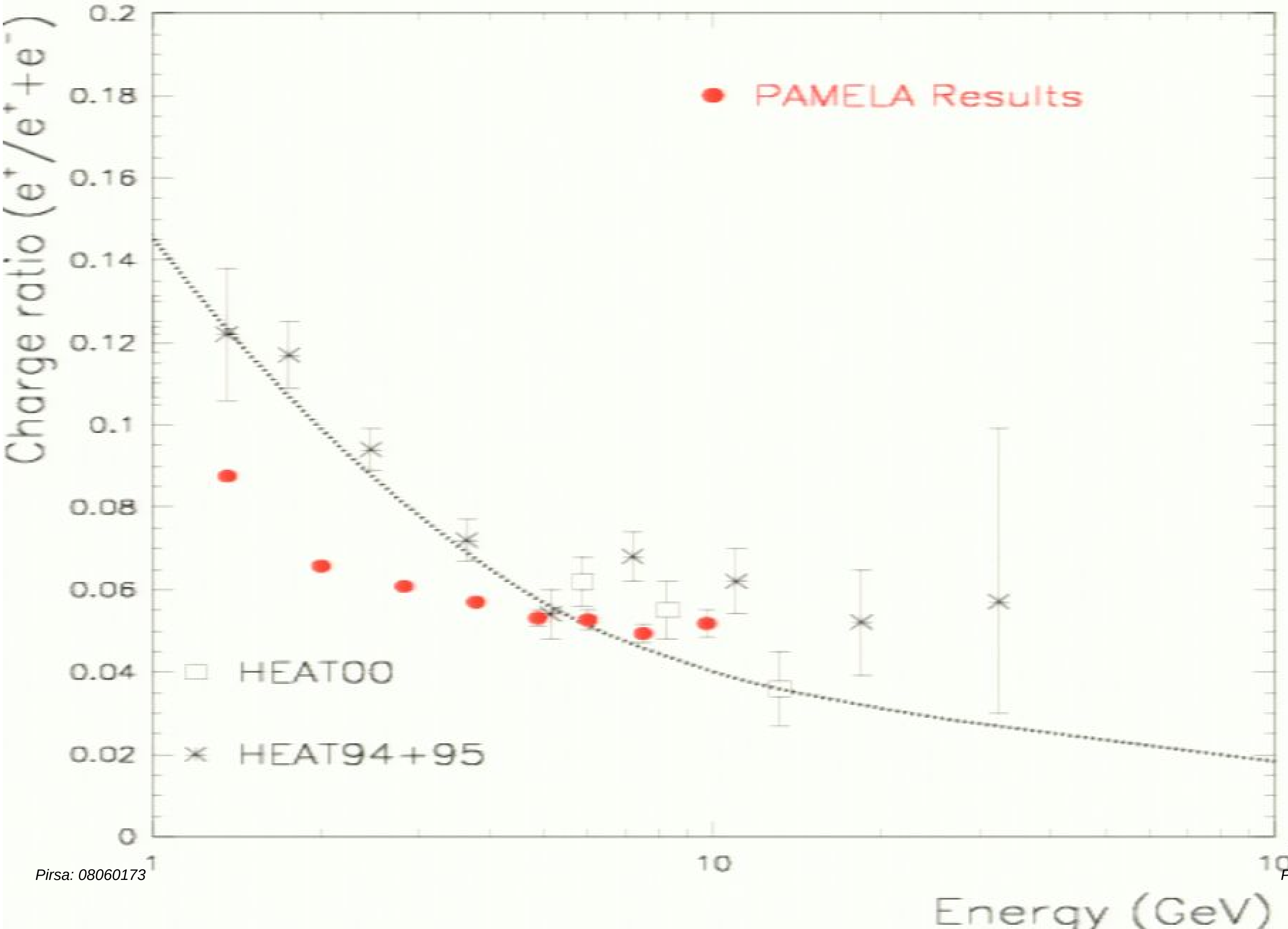
$$Flux \sim \langle \sigma v \rangle \times \left(\frac{\rho_\chi^{halo}}{m_\chi} \right)^2$$

Wino leading decay channel:

$$\chi + \chi \rightarrow W + W \rightarrow e^+ + X$$

Positron Excess -- Annihilating Dark Matter?




PAMELA Results
HEAT00
HEAT94+95
Charge ratio $(e^+/e^+ + e^-)$
Energy (GeV)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1
10
10^2

Conclusions

- We can not obtain a complete understanding of dark matter from LHC data alone

- UV physics and/or early universe evolution may play an essential role in determining the dark matter abundance

- Complete understanding of dark matter requires an interplay: Astrophysics, cosmology, particle experiment, and fundamental theory.

- We can not “calculate” the relic density, we must measure it.


think this is the beginning of a beautiful friendship.