Collider Signatures of SuperWIMP Warm Dark Matter

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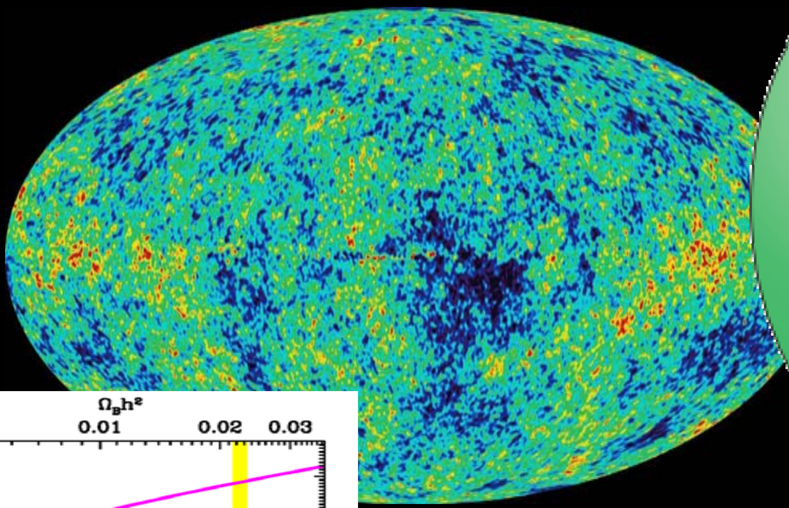
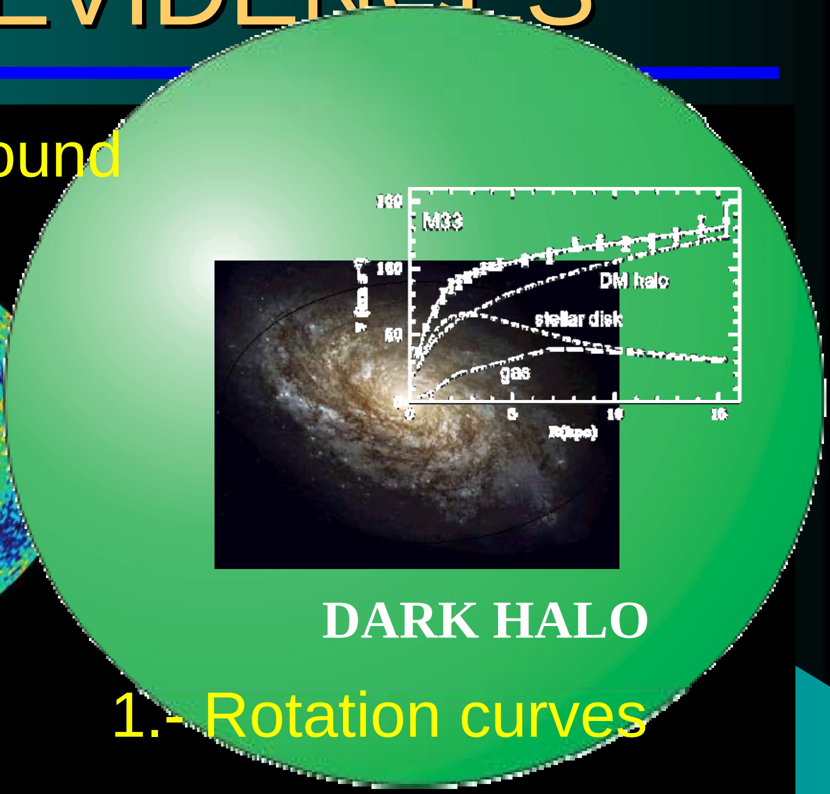
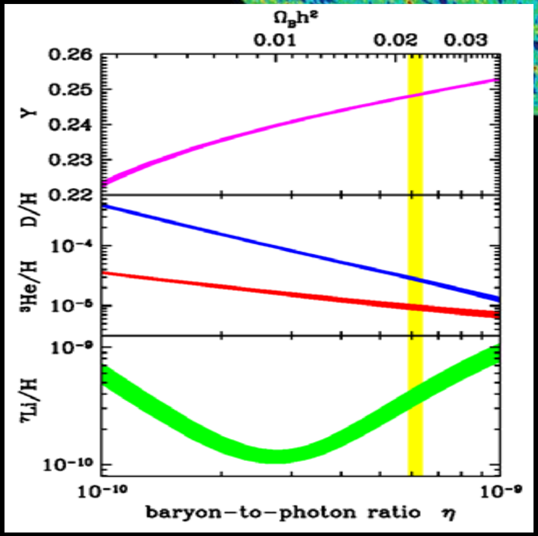
DARK MATTER EVIDENCES

2.- Cosmic Microwave Background



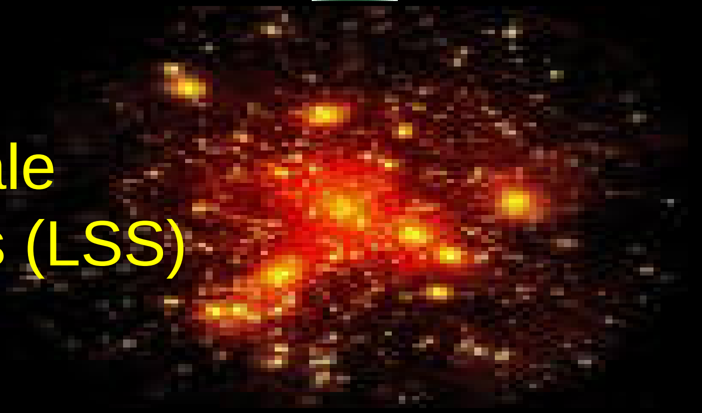


1.- Rotation curves

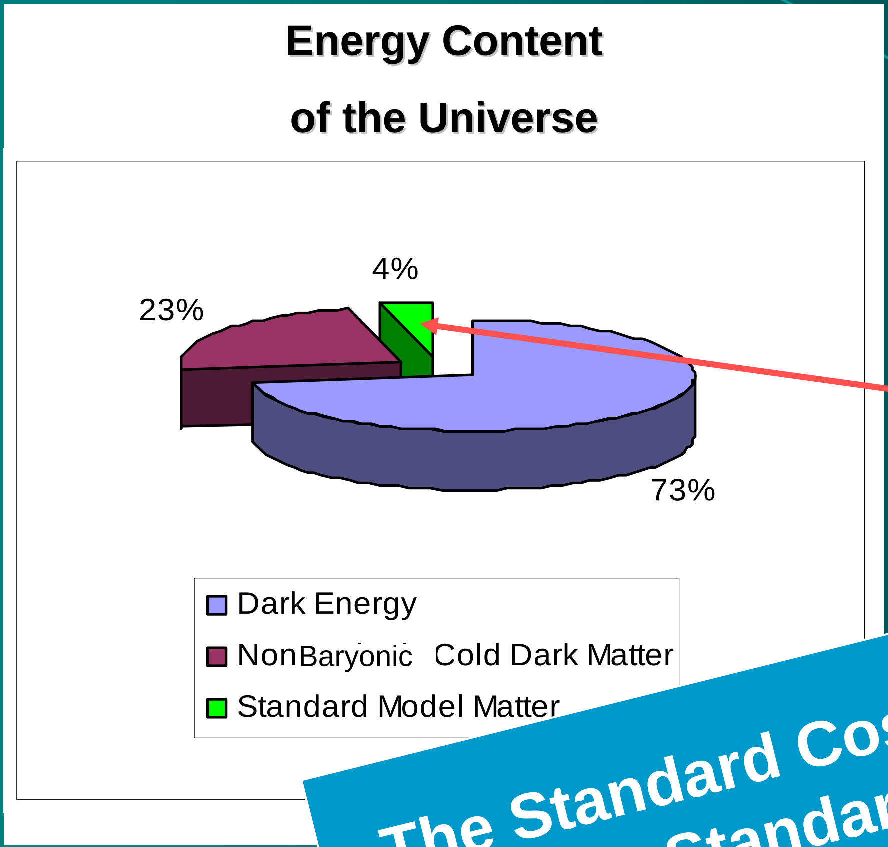


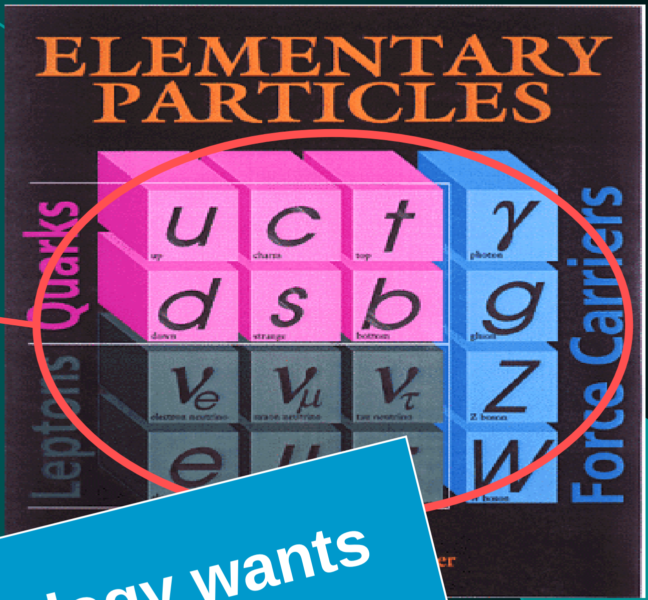
4.- Nucleosynthesis

3.- Large Scale
Structures (LSS)



COSMOLOGICAL MODEL





The Standard Cosmology wants non Standard Particles

Search of DM candidates beyond the SM.

DARK MATTER CANDIDATES

Among the most well-motivated candidates are the weakly-interacting massive particles (WIMPs) with masses of the order of the weak scale M ~ 100 GeV:

1.- Supersymmetric (SUSY) models :

Lightest supersymmetric particle (LSP): Neutralinos,…

2.- Universal Extra Dimensions (UED):

Lightest KK mode (LKKM): B^1,…

3.- Brane-World Scenarios (WBS):

Branons,…

WIMPS behave as cold DM (CDM) and are remarkably successful in explaining the observed large scale structure down to length scales of ~ 1 Mpc.

SUPERWIMP MODELS

Superweakly-interacting massive particles (SWIMPs) appear naturally in the same well motivated scenarios:

1.- Supersymmetric (SUSY) models :

Lightest supersymmetric particle (LSP): gravitinos, axinos, quintessinos…

2.- Universal Extra Dimensions (UED):

Lightest KK mode particle (LKKM): G^1,…

The relic density of SuperWIMPS also yields to the observed dark matter abundance since they are produced by the decay of a typical WIMP.

WIMPs vs. SuperWIMPs

The evolution of the WIMP number density follows the Boltzmann equation: $dn_{WIMP}/dt = -3Hn_{WIMP} - \langle \sigma_A v \rangle [(n_{WIMP})^2 - (n_{WIMP}^{eq})^2]$

Thermal equilibrium density:

$$n_{WIMP}^{eq} = g/(2\pi)^3 \int f(p)\, d^3p$$

When $\Gamma = \langle\sigma_A v\rangle\, n_{WIMP} < H$, the DM is frozen out.

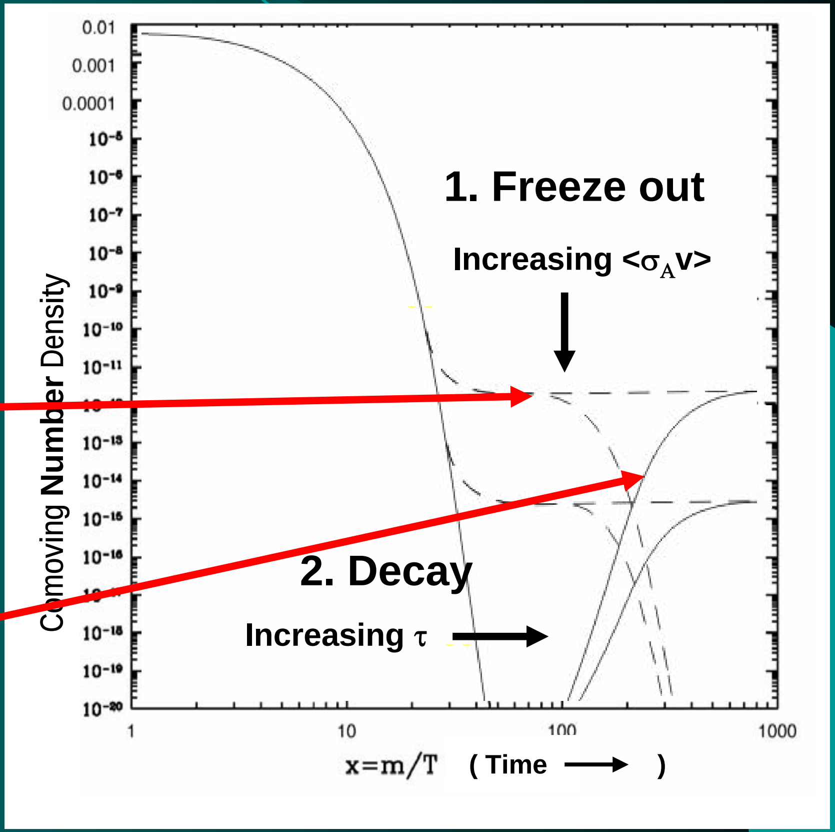
WIMP relic density:

$$\Omega_{WIMP}\, h^2 \propto m_{WIMP} / \langle \sigma_A v_{WIMP} \rangle$$

$$T_{Freeze\ out} \sim m_{WIMP} / 20$$

SWIMP relic density:

$$\Omega_{SWIMP}\, h^2 = \Omega_{WIMP}\, h^2\, m_{SWIMP} / m_{WIMP} \propto m_{SWIMP} / \langle \sigma_A v_{WIMP} \rangle$$



MSUGRA PARAMETER SPACE

For example, mSUGRA have 6 free parameters:

$$\{ m_0, M_{1/2}, A_0, \tan\beta, \mathrm{sgn}(\mu) , m_{3/2} \}$$

1.- WIMP scenario:

1.a. $\tilde{\tau}$ LSP excluded

1.b. χ LSP favored

1.c. $\Omega_{LSP}h^2 > 0.13$ excluded

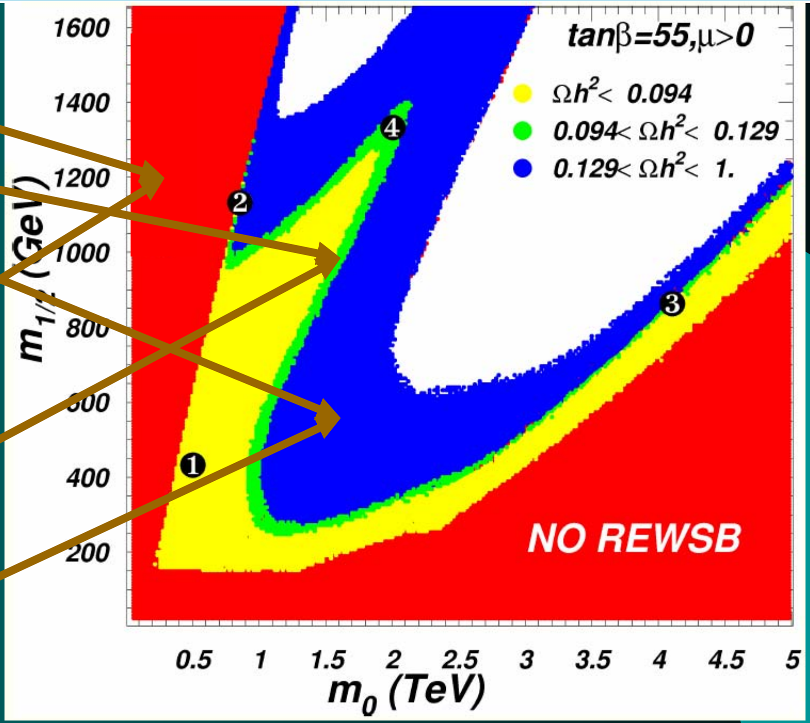
2.- SuperWIMP scenario:

2.a. $\tilde{\tau}$ NLSP favored

2.b. χ NLSP disfavored

2.c. $\Omega_{NLSP}h^2 > 0.13$ favored

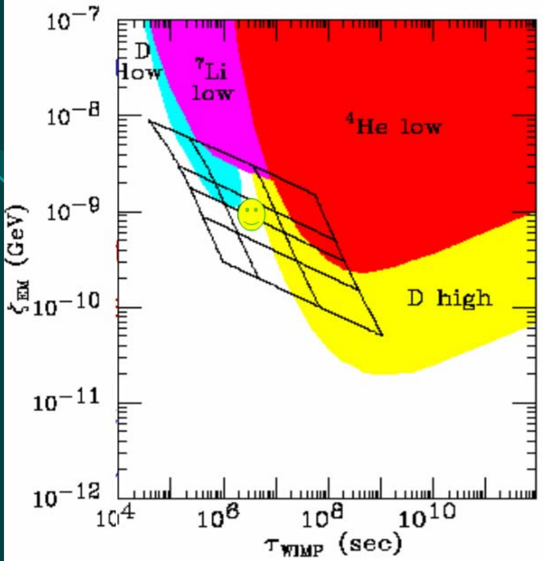
A. Belyaev, ALCPG, Snowmass (2005)



Complementary scenarios

SIGNALS AND COSTRAINTS

The superWIMP signatures are completely different to the typical WIMP signals:



Feng *et al.*, PRD 68, 063504 (2003)

Cyburt *et al.*, PRD 67, 103521 (2002)

Feng *et al.*, PRD 70, 063514 (2004)

1.- Big Bang nucleosynthesis

Late decays modify late elements abundances.
They can reduce the ^{7}Li and explain the present inconsistent measurements (☺).
The same analyses constraint superWIMP models: χ NLSP disfavored.

2.- Cosmic microwave background

Late decays may also distort the CMB spectrum, from the Planck spectrum (μ=0) to a general Bose-Einstein one.

$$\frac{1}{e^{E/(kT)+\mu} - 1}$$

3.- Cosmic rays

Sleptons NLSP are produced in cosmic rays and could be detected:

1.- With high energy neutrino telescopes (IceCube,…)

Albuquerque *et al.*, PRL 92, 221802 (2003) | X. Bi *et al.*, PRD 70, 123512 (2004)

Cembranos *et al.*, in progress

2.- With sea water analyses since the staus are trapped in Earth.

SMALL SCALE PROBLEMS

CDM appears to face difficulty in explaining the observed structure on length scales < 1 Mpc.

1.- Overdense cores in galactic halos

2.- Too many dwarf galaxies in the local Group

3.- Disk galaxies with angular momentum loss.

Superweakly-interacting massive particles (SuperWIMPs or SWIMPs) can resolve these problems since they are produced with large velocities at late times. Consequently:

A.- Reduce the phase space density smoothing out cusps in DM halos.

B.- Damp the linear power spectrum reducing power on small scales.

STRUCTURE FORMATION

1.- The velocity or angular momentum of DM halos can be increased in the SWIMP scenario

1.a. Reducing the phase space density

$$Q \equiv \rho / \langle v^2 \rangle^{3/2}$$

$$Q \simeq Q_0 \, u_X^{-3} \left[\frac{10^6 \text{ s}}{\tau_X}\right]^{\frac{3}{2}} \left[\frac{\Omega_{\text{SWIMP}} h^2}{0.11}\right]$$

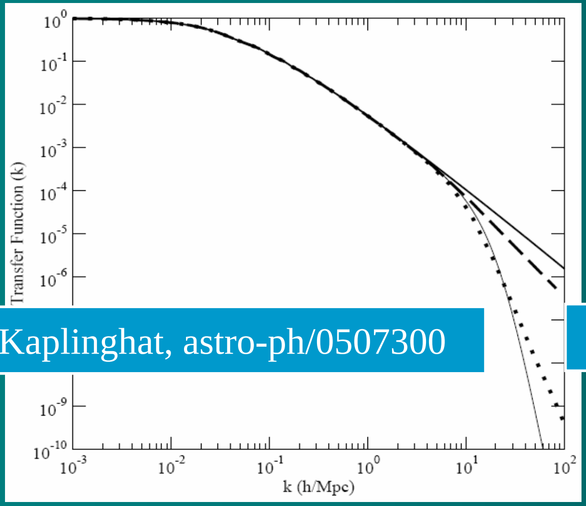
$$Q_0 \equiv 1.0 \times 10^{-27} \text{ GeV}^4$$

Cembranos *et al.* hep-ph/0507150

2.- Small scales in the linear Power Spectrum are damped:

2.a Free-streaming scale

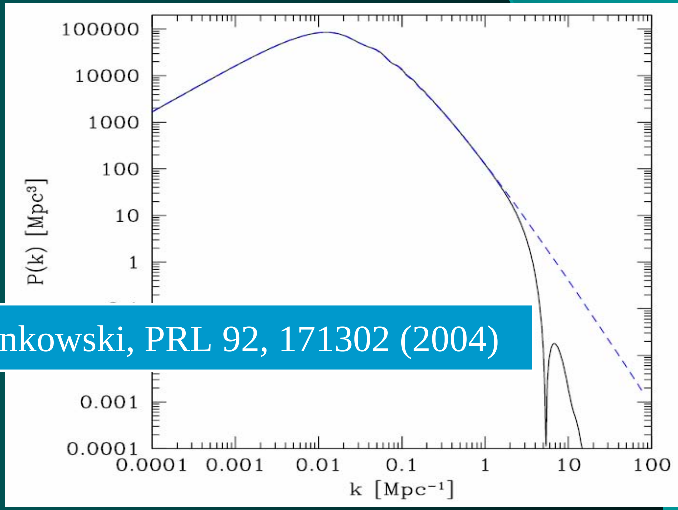
$$\lambda_{\text{FS}} \simeq 1.0 \text{ Mpc } u_X \left[\frac{\tau_X}{10^6 \text{ s}}\right]^{\frac{1}{2}}$$



M. Kaplinghat, astro-ph/0507300

2.b. Acoustic damping scale

$$\lambda_{\text{A}} \simeq 7.2 \times 10^{-2} \text{ Mpc} \times \left[\frac{\tau_X}{10^6 \text{ s}}\right]^{\frac{1}{2}}$$

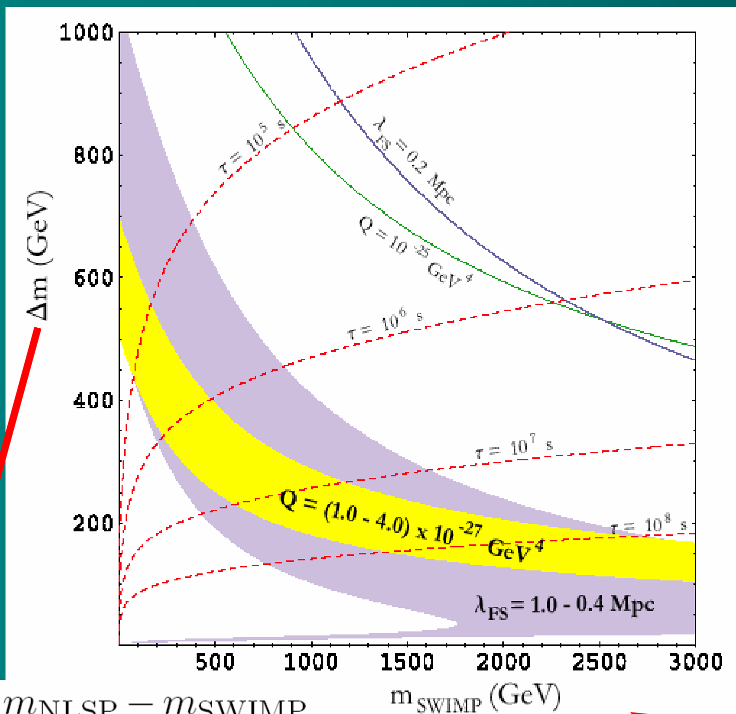


Sigurdson and Kamionkowski, PRL 92, 171302 (2004)

GRAVITINO AND AXINO STUDIES

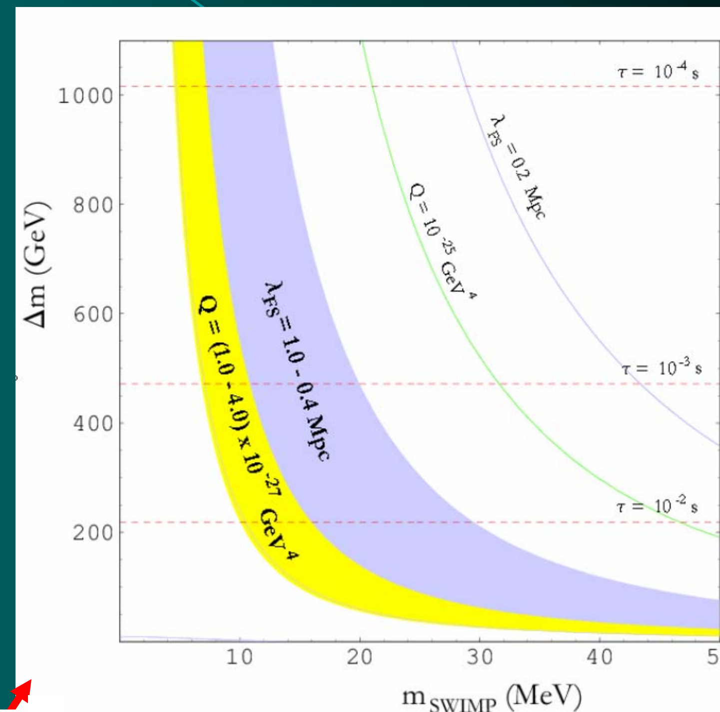
Preferred regions for Q and λ_{FS} with a slepton as NLSP

A. Gravitino



$\Delta m \equiv m_{\rm NLSP} - m_{\rm SWIMP}$

B. Axino



$f_a = 10^{11}$ GeV

$$\tau_{NLP} = \frac{f_*^2}{m_{\rm NLP}^3}$$

LP	NLP	f_*^2
$\tilde{G}$	$\tilde{l}$	$48\pi M_{\rm Pl}^2 \frac{m_{\tilde{G}}^2}{m_{\tilde{l}}^2}\left[1-\frac{m_{\tilde{G}}^2}{m_{\tilde{l}}^2}\right]^{-4}$
$\tilde{a}$	$\tilde{l}$	$\frac{512\pi^5 \cos^8\theta_W}{9\,\alpha^4 C_{\rm aYY}^2} f_a^2 \frac{m_{\tilde{l}}^2}{m_{\tilde{B}}^2}\left[1-\frac{m_{\tilde{a}}^2}{m_{\tilde{l}}^2}\right]^{-2} \xi^{-2} \log^{-2}\left[\frac{f_a}{m}\right]$

Feng *et al.*, PRL 91, 011302 (2003)

Brandenburg *et al.*, PLB 617, 99 (2005)

COLLIDER SIGNATURES

1.- CHARGED NLSP

Hamaguchi *et al.*, PRD 70, 115007 (2004)

Feng and Smith, PRD 71, 015004 (2005)

Production of two metastable sleptons
Highly ionizing charged tracks

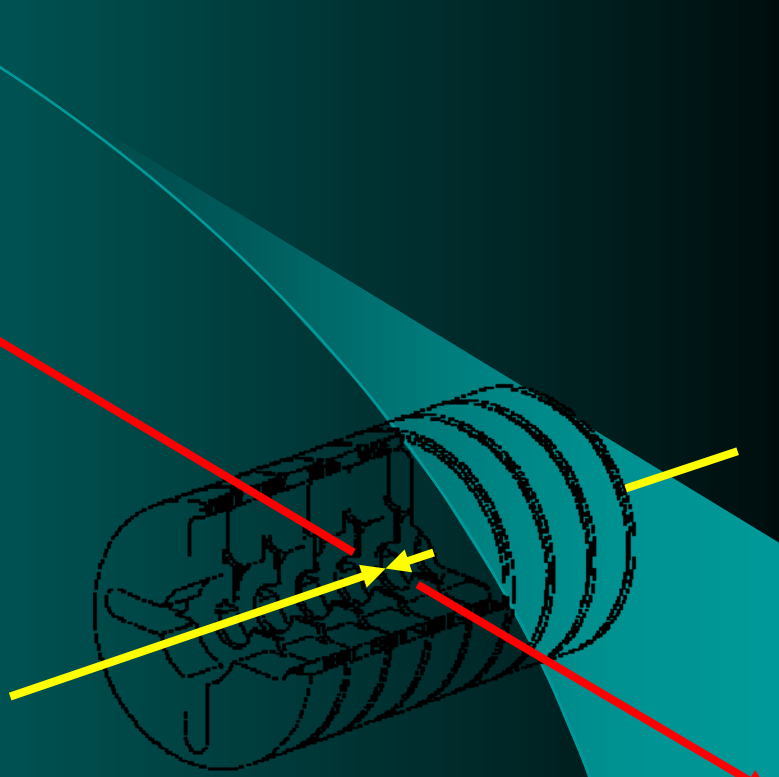
Experiment	$\sqrt{s}$ (TeV)	$\mathcal{L}$ (pb^{-1})	$m_{\tilde{l}}(GeV)$
LEP-II	0.2	700	100
Tevatron Run II	2.0	10^3	150
ILC	0.5	10^5	250
ILC	1.0	10^5	500
LHC	14	10^5	700
CLIC	5.0	10^6	2500

2.- Neutral NLSP

New motivations to distinguish between the neutralino and sneutrino NLSP models

TRAPPING SLEPTONS

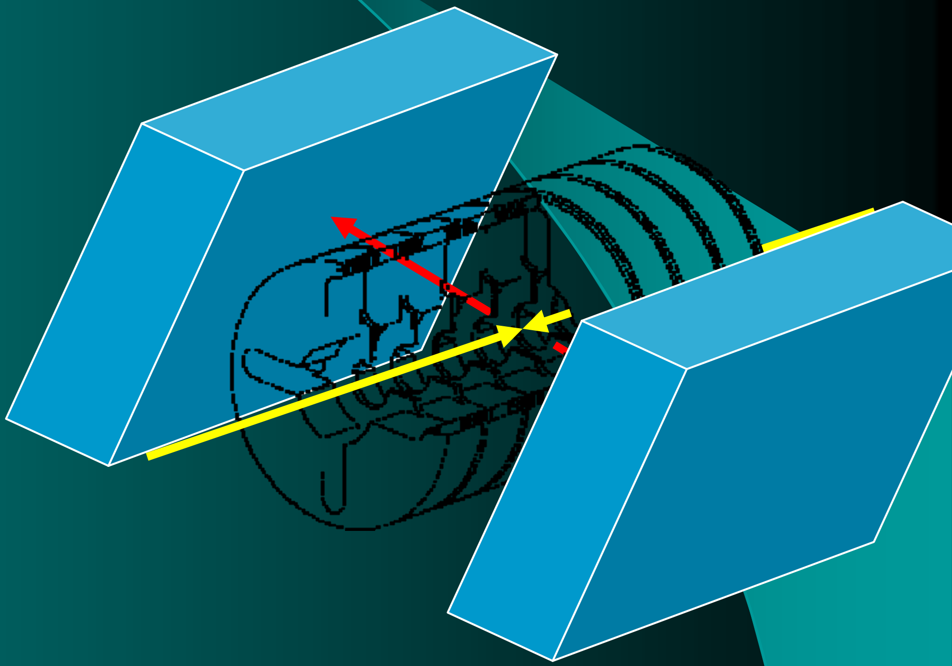
- 1.- Sleptons are missed in the environment of the detector.



Feng and Smith, PRD 71, 015004 (2005)

TRAPPING SLEPTONS

- 1.- Sleptons are missed in the environment of the detector.
- 2.- Slepton are trapped in tanks of water.



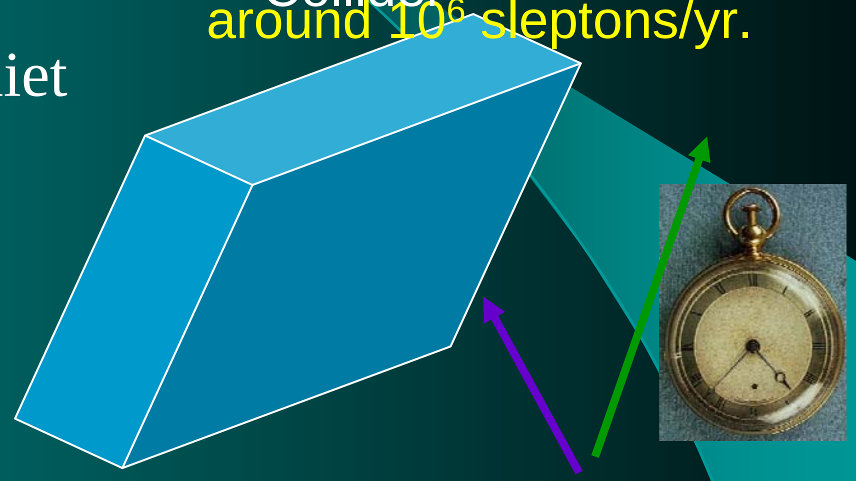
Feng and Smith, PRD 71, 015004 (2005)

TRAPPING SLEPTONS

- 1.- Sleptons are missed in the environment of the detector.
- 2.- Slepton are trapped in tanks of water.
- 3.- The water is moved to a quiet environment.
- 4.- We wait for detecting the decays.

A.- In the LHC, the trap can catch ~100/yr in 100 m^3we. If it produces around 10^6 sleptons/yr.

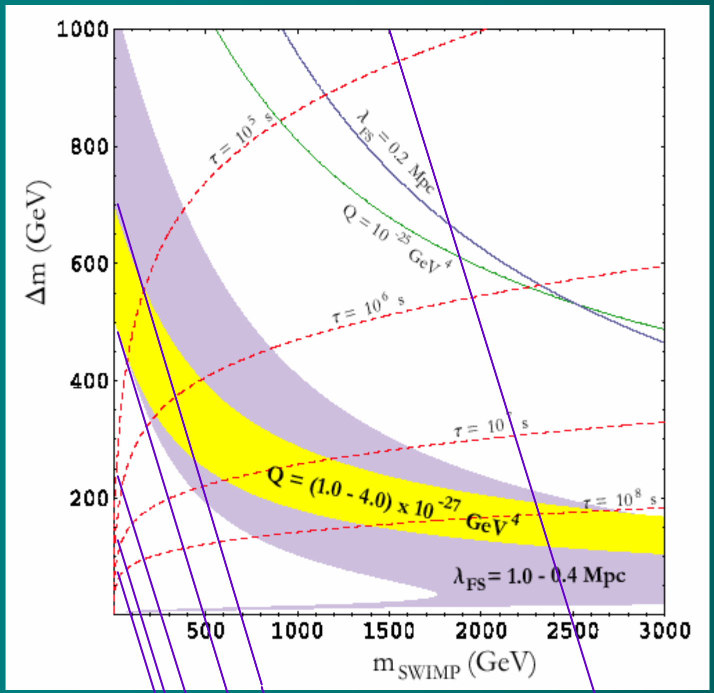
B.- By tuning the beam energy in the ILC to produce slow sleptons, it is possible to trap ~100/yr in 100 m^3we.



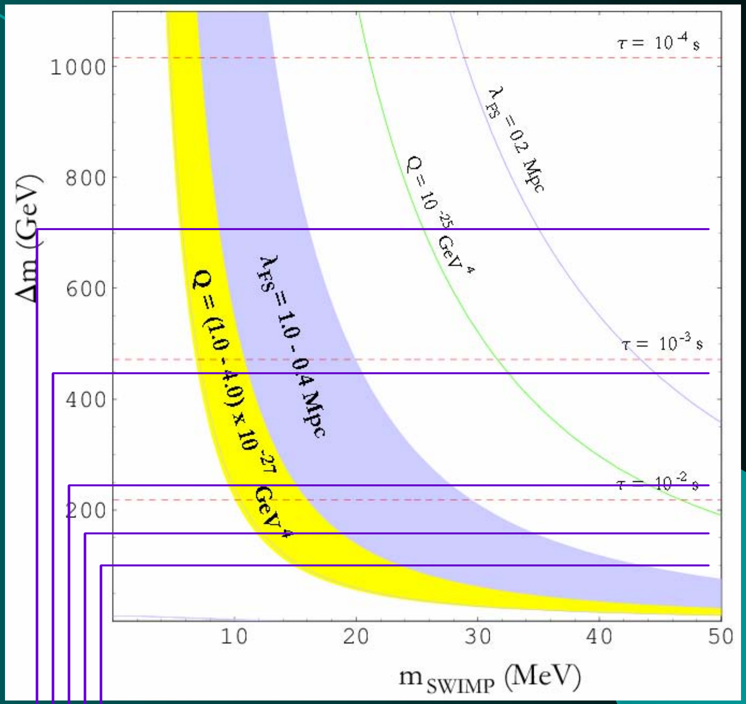
Feng and Smith, PRD 71, 015004 (2005)

COLLIDER SENSITIVITIES

A. Gravitino



B. Axino



The lower areas are accessible at future collider experiments (LEP-II fixes the present exclusion region) .

Experiment	$\sqrt{s}$ (TeV)	$\mathcal{L}$ (pb^{-1})	$m_{\tilde{l}}(GeV)$
LEP II	0.2	700	100
Tevatron Run II	2.0	10^3	150
ILC	0.5	10^5	250
ILC	1.0	10^5	500
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CONCLUSIONS

1.- We have examined the implications of superWIMP (SWIMP) dark matter (DM) for small scale structures.

2.- Because SWIMPs are produced with large velocity in late decays, their behavior in relation with structure formation can differ very much of cold DM.

3.- These analyses could be interpreted as a new SWIMP signal or as a new SWIMP constraint depending of future astrophysical observations.

4.- We have analyzed the consequences for collider experiments supposing pure SWIMP DM scenarios:

4.a. In the gravitino SWIMP case, no signal is expected in the ILC. The LHC only will be sensitivity to a small preferred region.

4.b. The situation is opposite for the axino SWIMP scenario, whose signals can be found not only for the warm DM case but also for the cold DM one.