Summary on Cosmological Connections Session

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1. Introduction

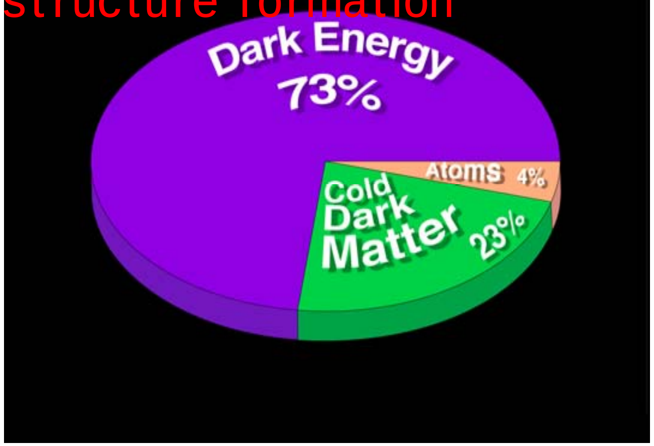
Observations of the present Universe

after WMAP

Dark energy: 73%
Dark matter: 23%
Baryon: 4%

$$\Omega_{CDM}h^2 = 0.1126 \pm 0.009$$

From CMB + SN1a +
structure formation



What is DM? ← **non-baryonic, stable, neutral**

→ **No candidates in the Standard Model !**

→ **New Physics!**

Well discussed DM is WIMPs & SuperWIMPs

appear in particle physics models independently motivated by attempts to understand the weak scale

the relic densities are determined by the weak scale or the Planck scale and are naturally near the observed values

Natural candidates for WIMPs:

neutralino **in SUSY model, LKP in UED model etc. with mass of** $\mathcal{O}(\mathcal{M}_W)$

SuperWIMPs: gravitino, axino, KK gravitons with mass $\leq \mathcal{O}(\mathcal{M}_W)$

→ **The mass range is accessible at the future colliders**

Baryon asymmetry in the present Universe $Y_B = \frac{n_B - n_{\bar{B}}}{n_\gamma} \sim 10^{-10}$

What is the origin of the present baryon asymmetry?

→ **Baryogenesis**

EW baryogenesis → **SM cannot produce enough BAU**

with CP-phase in CKM-matrix and $m_h \geq 114\mathrm{G}eV$

→ **New Pysics at the EW scale**

← **accessible at the future clliders**

Cosmological connections to ILC is important and interesting subjects!

2. Talks in Cosmology session

Lots of interesting ideas, results of detailed analysis have been reported

Direct and indirect detections of neutralino dark matter in mSUGRA

H. Baer: Neutralino dark matter and the ILC

W. de Boer: Dark matter interplitation og EGRET excess of diffuse gamma rays

Y. Mambrini: Indirect ditection of dark matter in non-minimal SUGRA scenarii

(Model independent) signatures of WIMPS and SuperWIMPs at ILC

M. Perelstein: Model independent signature for WIMPS at the ILC

S. Su: Guaranteed rates for dark matter production at colliders

F. Steffen: Signatures of axinos and gravitinos at the ILC

Repots from ALCPG on cosmology connections (neutralino DM in mSUGRA)

M. Peskin: Dark matter studies at the ILC

A. Birkedal: Testing Focus Point cosmology at the NLC

R. Gray: Measuring mass and cross section parameters at a Focus Point region

M. Battaglia: determining the dark matter density with the ILC data

B. Dutta: SUSY co-annihilation region at ILC

Higgs physics and cosmology interface through EW baryogenesis scenario

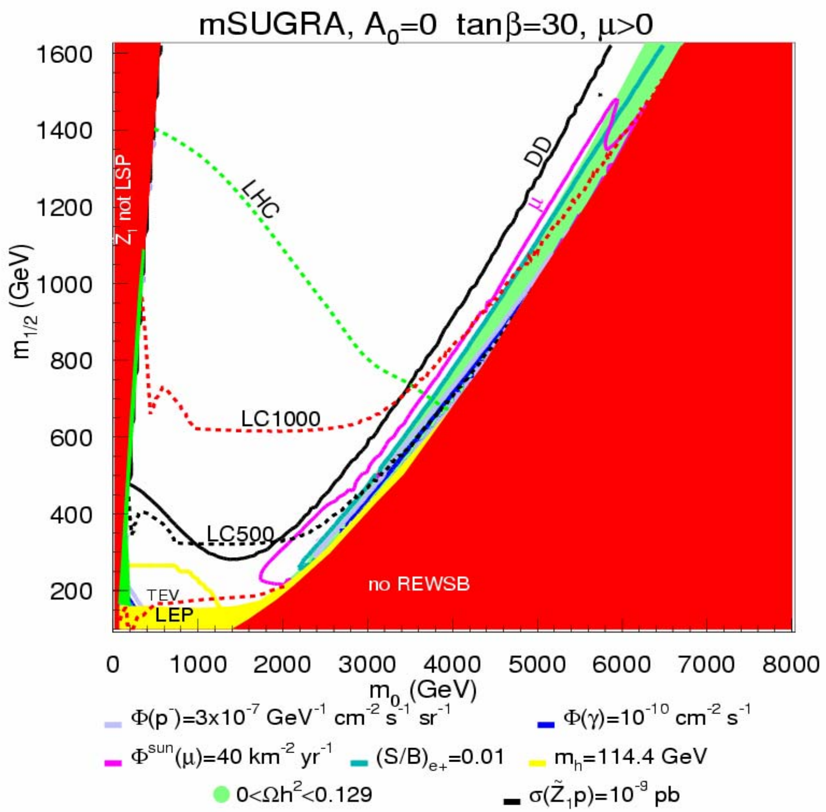
E. Senaha, Electroweak baryogenesis and triple Higgs boson coupling

3. Brief summary on each talks

Direct and indirect detections of neutralino dark matter in mSUGRA

Neutralino DM in m SUGRA model

5 free parameters: $m_0, m_{1/2}, A_0, \tan\beta, sign(\mu)$



Talk by H. Baer

1.In FP region, ILC reach exceeds LHCs!

2.Direct DM detectors (GENIUS etc.) can explore all FP region

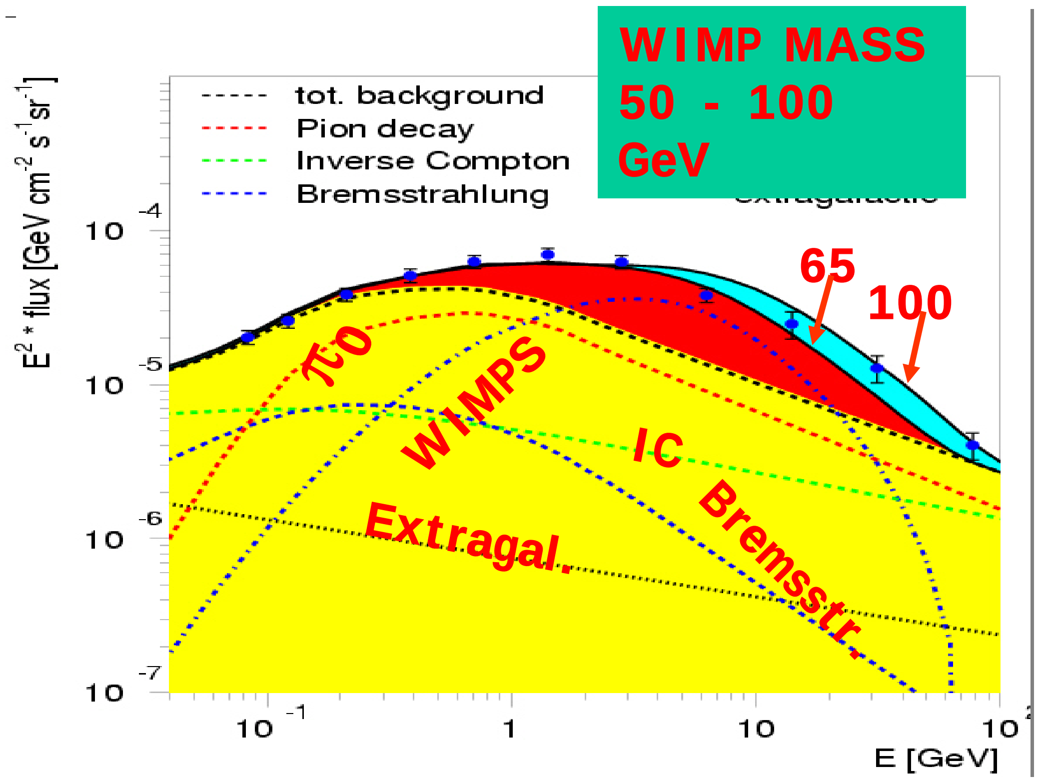
3. Ice Cube neutrino telescope (km^3 scale) can rule in/out FP region

Dark matter interpretation of EGRET excess of diffuse gamma rays

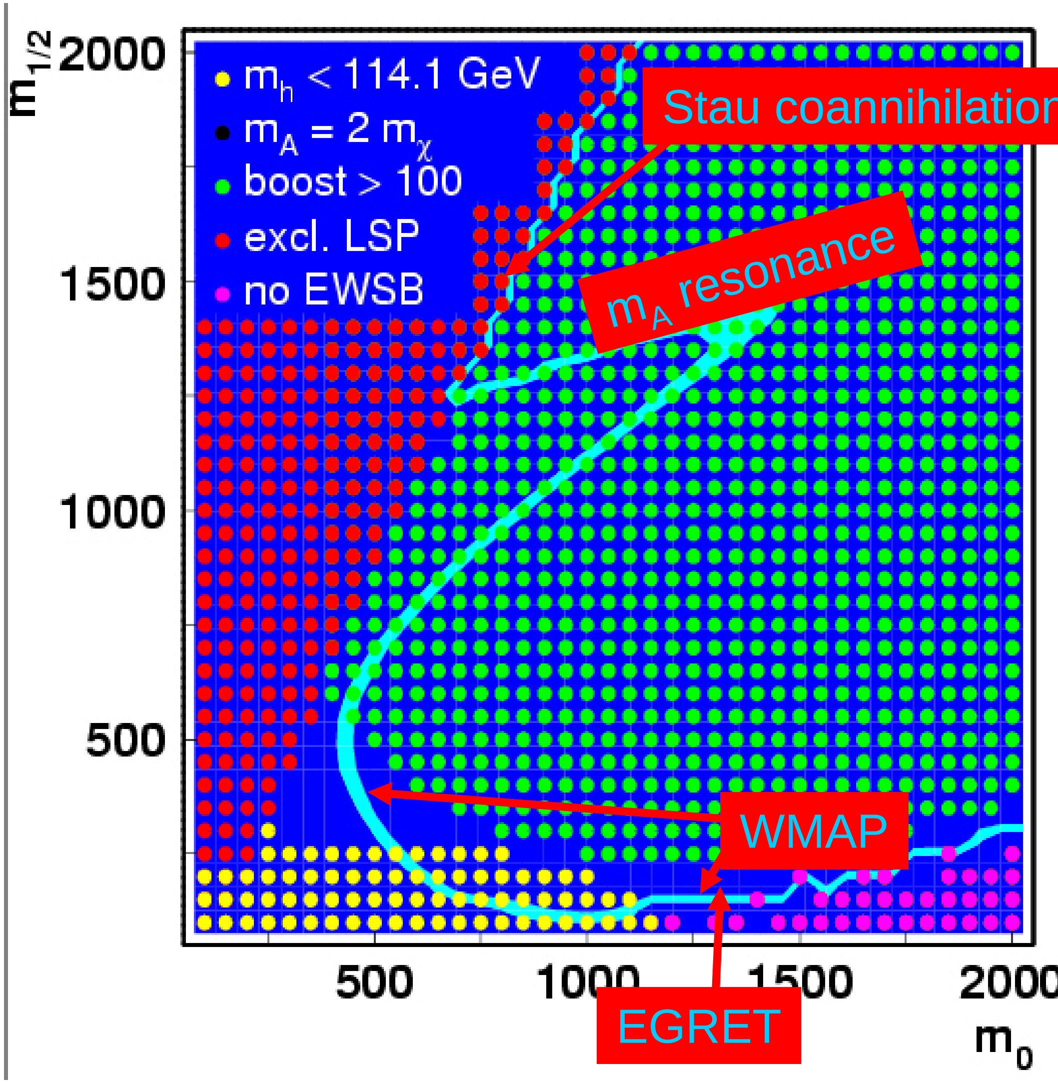
<u>Talk by W. de Boer</u>

EGRET excess can be fitted by DM annihilation at the galactic center with mass 50-100GeV

appropriate DM density profile in halo



Interpret EGRET excess and WMAP constraint into mSUGRA



$$
\begin{aligned}
m_0 &= 1400\text{GeV} \\
m_{1/2} &= 180\text{GeV} \\
\tan\beta &= 51 \\
A_0 &= 0.5 m_0 \\
\mu &> 0
\end{aligned}
$$

Predicted SUSY spectrum is favorable for ILC

← Higgs, charged Higgs

charginos are all light

Indirect detection of DM in non-minimal SUGRA models

Talk by Y. Mambrini

Non minimal SUGRA

ex) dilaton dominated scenario

$W(S) \propto e^{-3S/b_+}$ **for dilaton stabilization**

Non minimal SUGRA parameterized by $m_{3/2}, b_+, \ldots$

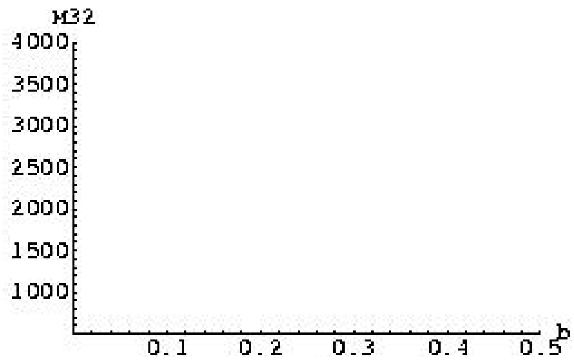
Various constraints by the current experiments

+ ILC + future cosmic ray experiment (GLAST)

will reach all the parameter space in SUGRA

Indirect detection from Galactic Center

M3/2



b+

Model independent signature for WIMP at the ILC

Talk by M. Perelstein

1)WIMP DM → WMAP data constrains its annihilation cross section

$$\sigma_i^{(J_0)} : \quad \chi + \chi \to X_i + \bar{X}_i; \quad X_i : \text{SM particles}$$

$$\sigma_{an} = \sum_i \sigma_i^{(J_0)} \qquad J_0 : \text{ angular momentum of partial wave}$$

σ_{an} **is determined as a function of WIMP mass**

2) Detailed balancing equation

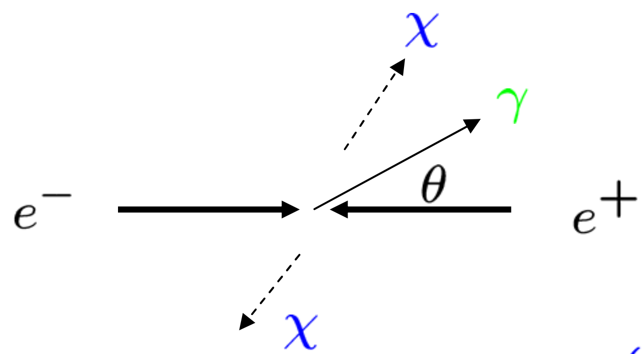
$$\frac{\sigma(\chi + \chi \to X_i + \bar{X}_i)}{\sigma(X_i + \bar{X}_i \to \chi + \chi)} = 2\frac{v_X^2(2S_X+1)^2}{v_\chi^2(2S_\chi+1)^2}$$

Production cross section for non-relativistic WIMP at colliders is expressed by that of WIMP annihilation cross section

Search for WIMPS at ILC

See the collinear photon process $e^+e^- \to 2\chi + \gamma$

$$\frac{d\sigma(e^+e- \to 2\chi + \gamma)}{dx\ d\cos\theta} \sim \mathcal{F}(x, \cos\theta)\sigma(e^+e^- \to 2\chi)$$



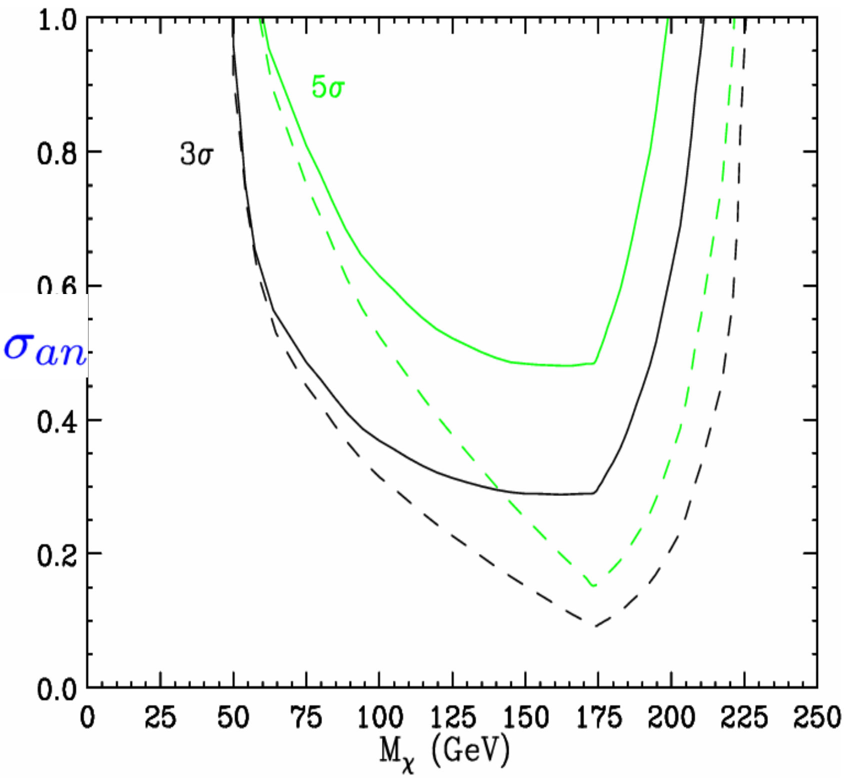
$$\kappa_e = \sigma_i^{(J_0)}/\sigma_{an}$$

Bkg: $e^+e^- \to \nu\bar{\nu}\gamma$

With cuts: $\sin\theta > 0.1$

$P_{T,\gamma} > 7.5\text{GeV}$

$$1 - \frac{8M_\chi^2}{s} \leq \frac{2E_\gamma}{\sqrt{s}} \leq 1 - \frac{4M_\chi^2}{s}$$



0.3 % systematic uncertainty

Guaranteed rates for dark matter production at colliders
Talk by S. Su

SuperWIMP scenario with charged WIMP NLSP

WIMP → freeze out → decay into SuperWIMP + SM matters

(gravitino, KK-graviton)

Gravitational coupling → long life time $10^4 s < \tau_{SWIMP} < 10^8 s$

Apply the same strategy for charged WIMP

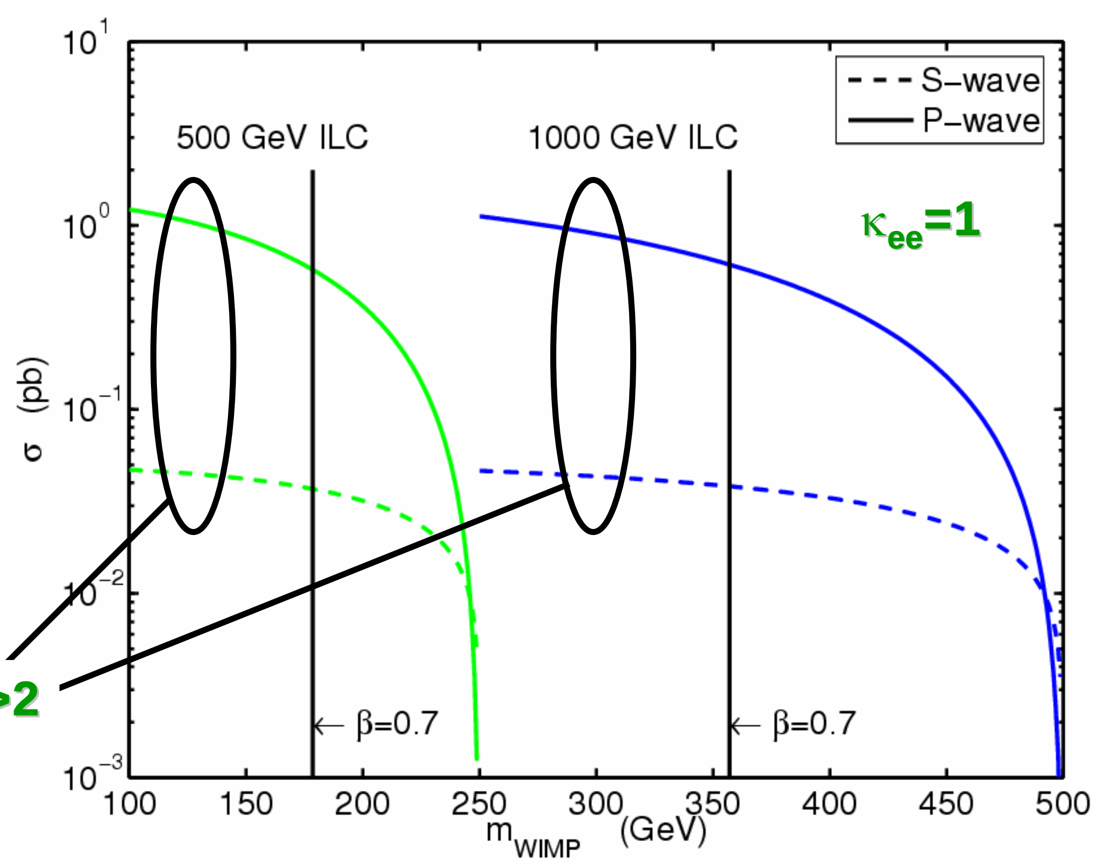
→ WMAP data gives lower bound on annihilation cross section

Pair production of non-relativistic charged WIMP at ILC

→ two isolated charged tracks in detector

→ clean signal if $|\eta| < 2.5, \beta < 0.7$

SuperWIMP with charged WIMP at ILC



$\beta > 0.7$, $V_X^2 > 2$
unreliable

Signatures of axinos and gravitinos at the ILC

Talk by F. Steffen

SuperWIMP scenarios

1) SM+PQ sym. +SUSY → axino as LSP

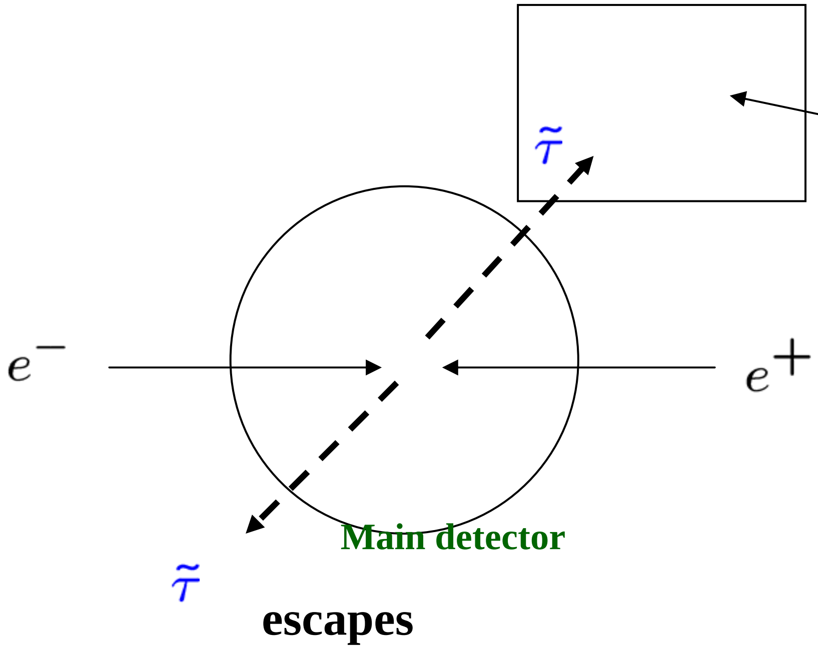
2) SM+SUGRA → light gravitino as LSP

Interaction is suppressed by

PQ scale > 10^{10} GeV

Planck scale

See implication to the ILC, assuming stau NLSP



Place 1-10 ktons of massive additional material to stop stau

Stau decays inside the material

Two body decay: $\tilde{\tau} \to \tau + \tilde{a}/\tilde{G}$

Measurements of mass and PQ-scale/Planck scale

Three body decay: $\tilde{\tau} \to \tau + \gamma + \tilde{a}/\tilde{G}$

Measurements of Br

differential distribution w.r.t. gamma energy

tau, gamma polarizations → SWIMP spin

Repots from ALCPG on cosmology connections (neutralino DM in mSUGRA)

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Concentrate on neutralino DM in mSUGRA model

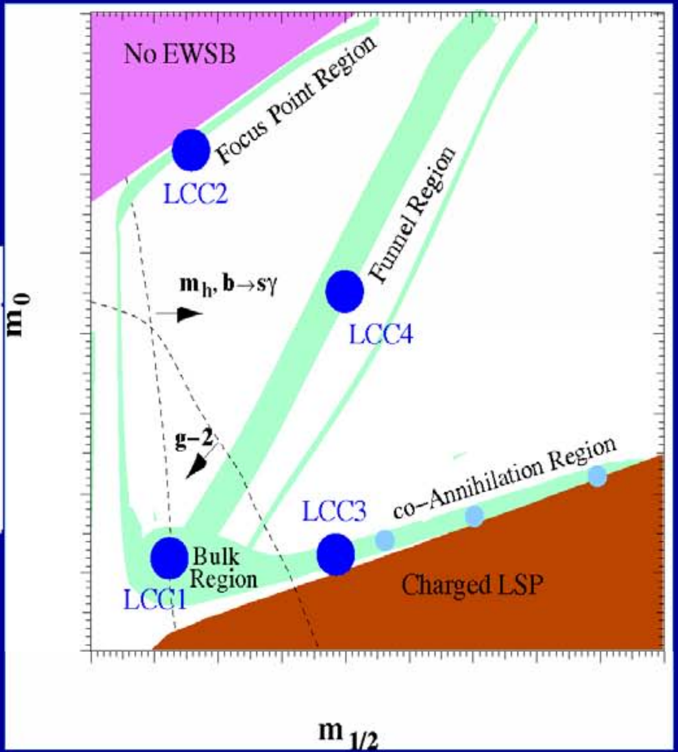
Detailed numerical analysis for each benchmark points

LCC Benchmark Points

✧ Choice of four representative benchmark points from MSUGRA parameters for detailed analyses of ILC reach in determining SUSY parameters relevant to Ωh^2 estimation;
✧ SUSY spectra obtained with `ISASUGRA 7.69`:

Point	m_0	$m_{1/2}$	$\tan\beta$	A_0	$M(t)$	$M(\chi_1^0)$
LCC 1	100	250	10	-100	178.	96.1
LCC 2	3280	300	10	0	175.	107.7
LCC 3	210	360	40	0	178.	142.5
LCC 4	380	420	53	0	178.	169

Point	DarkSUSY 4.0	MicroMEGAS 1.3
LCC 1	0.193	0.193
LCC 2	0.108	0.110
LCC 3	0.059	0.057
LCC 4	0.113	0.106



The physics of the WIMP annihilation cross section is different at each point:

LCC1: 'bulk region'

annihilation through slepton exchange
σ_{NN} depends on the light slepton masses and couplings

LCC2: 'focus point region'
annihilation to WW, ZZ
σ_{NN} depends on $m_1, m_2, \mu, \tan\beta$

LCC3: 'coannihilation region'
annihilation of $\widetilde{\tau}$ is actually dominant
σ_{NN} depends on $m(\widetilde{\chi}_1^0), m(\widetilde{\tau}), \theta_\tau$

LCC4: 'A funnel region'
annihilation through A resonance
σ_{NN} depends on $m(\widetilde{\chi}_1^0), m(A), \Gamma(A), \tan\beta$

Bulk Region: LCC 1

✧ LCC 1 = SPS1a to profit of extensive LHC and ILC analyses performed after Snowmass 2001;

✧ Point does not strictly satisfy WMAP Ωh^2 constraint but is good examplification of phenomenology in bulk region;

	value	Δ(LHC)	Δ(ILC)	Sensit.
$M(\tilde{\chi}_1)$	96.1	$\pm$ 4.8	$\pm$ 0.05	strong
$M(\tilde{e}_R)$	143.0	$\pm$ 4.8	$\pm$ 0.05	strong
$M(\tilde{\mu}_R)$	143.0	$\pm$ 4.8	$\pm$ 0.2	strong
$M(\tilde{\tau}_R)$	133.2	$\pm$ 5-8	$\pm$ 0.3	strong
$M(\tilde{e}_L)$	202.1	$\pm$ 5.0	$\pm$ 0.2	medium
$M(\tilde{\mu}_L)$	202.1	$\pm$ 5.0	$\pm$ 0.5	medium
$M(\tilde{\tau}_L)$	206.1	?	$\pm$ 1.1	medium
$M(\tilde{\chi}_2) - m(\tilde{\chi}_1)$	80.3	$\pm$ 0.08	$\pm$ 2	weak if $M(\tilde{\chi}_2) \sim 2m(\tilde{\chi}_1)$
$M(A)$	393.6	not seen (?)	$(m(A) > 220)$ (?)	weak if $m(A) > 200$

Focus Point Region: LCC 2

✧ LCC 2 in Focus Point Region with strongly interacting sparticles beyond LHC reach and just four SUSY processes accessible at 0.5 TeV at ILC;

✧ Detailed analysis by J. Alexander *et al.* being finalised:

	value	Δ(LHC)	Δ(ILC)	Sensit.
$M(\tilde{\chi}_1)$	107.7	–	$\pm$ 0.7	strong
$M(\tilde{\chi}_2) - M(\tilde{\chi}_1)$	58.6	–	$^{+0.5}_{-0.2}$	strong
$M(\tilde{\chi}_3) - M(\tilde{\chi}_1)$	82.3	–	$^{+0.3}_{-0.4}$	strong
$M(\tilde{\chi}_1^+) - M(\tilde{\chi}_1)$	143.0	–	$\pm$ 0.3	strong
$\sigma(e_R^- e^+ \to \tilde{\chi}_1^+ \chi_1^-)$	119 fb		$\pm$ 12.5 fb	strong
$M(\tilde{\ell})$	3270			weak if $m(\ell) > 300$ GeV
$M(\tilde{q})$	3300	5.0		weak if $m(\ell) > 300$ GeV
$M(A)$	3242.2	not seen (?)	$(m(A) > 220)$	weak if $m(A) > 250$

co-Annihilation Region: LCC 3

✧ LCC 3 in co-Annihilation Region with only $\tau\tau + E_{missing}$ final state accessible at 0.5 TeV at ILC;

✧ Detailed analysis by B. Dutta *et al.* recently submitted arXiv:hep-ph/0503165;

✧ * improved determination of $M(\chi_1^0)$ can be obtained operating at 0.6 TeV at and above $\tilde{\mu}_R\tilde{\mu}_R$;

	value	Δ(LHC)	Δ(ILC)	Sensit.
$M(\tilde{\chi}_1)$	142		± 0.5*	strong
$M(\tilde{\tau}_1) - M(\tilde{\chi}_1)$	9.5	–	± 1.0	very strong
θ_τ				medium
$M(\tilde{e}_R)$, $M(\mu_R)$	252			small if $m(\tilde{\ell}) - m(\tilde{\tau}_1) > 100$
$M(\tilde{\chi}_2) - M(\tilde{\chi}_1)$	80.3	0.08	± 2	weak if $M(\tilde{\chi}_2) \sim 2M(\tilde{\chi}_1)$
$M(A)$		1.0	$(m(A) > 220)$ (?)	weak if $M(A) > 300$

Rapid Annihilation Funnel: LCC 4

✧ LCC 4 in A annihilation funnel with $M(A)$ possibly beyond LHC reach in $A \to \mu\mu$;

✧ Interesting ILC program from 0.35 TeV to 1.0 TeV to determine $M(\chi_1^0)$, $M(\chi_2^0)$, $M(A)$ and $\Gamma(A)$

Parameter	ΔX	$\Delta\Omega/\Omega$ DarkSUSY	$\Delta\Omega/\Omega$ microMEGAS
M_{top}	$\pm$ 0.1 GeV	$\pm$ 0.019	$\pm$ 0.019
M_b	$\pm$ 0.1 GeV		$\mp$ 0.048
$\alpha_s(M_Z)$	$\pm$ 0.01		$\pm$ 0.01
$2M_\chi/M_A$	$\pm$ 0.02	$\mp$ 0.11	$\mp$ 0.13
A_0	$\pm$ 100 GeV	$\mp$ 0.076	$\mp$ 0.074
Γ_A	$\pm$ 9 GeV	$\mp$ 0.33	-

	value	Δ(LHC)	Δ(LC)	Sensit.
$M(\tilde{\chi}_1^0)$	169	–	$\pm$ 1.4	strong
$M(\tilde{\tau}_R)$	195	–	$\pm$ 1.0	strong
$M(\chi_2^0) - M(\chi_1^0)$	158.		$\pm$ 1.8	medium
$M(A^0)$	419	$\pm$ 6. (?)	$\pm$ 1.0	very strong
$\tan\beta$	53			medium
$\Gamma(A^0)$	18		1.5	strong

Electroweak baryogenesis and triple Higgs boson coupling

Talk by E. Senaha

Higgs physics at LC

Higgs boson ← EW symmetry breaking

mass generation mechanism

Measurement of Higgs boson mass and self coupling

→ structure of EW symmetry breaking

New physics if $\lambda \neq \lambda_{SM}$

Precision measurement at (TeV) ILC

$$\Delta^{Exp} g_{hVV}/g_{hVV} \sim 1\%$$
$$\Delta^{Exp} \lambda_{hhh}/\lambda_{hhh} \sim 10-20\%$$

EW Baryogenesis

Strongly 1st order phase transition is required

→ Spharelon condition should be satisfied

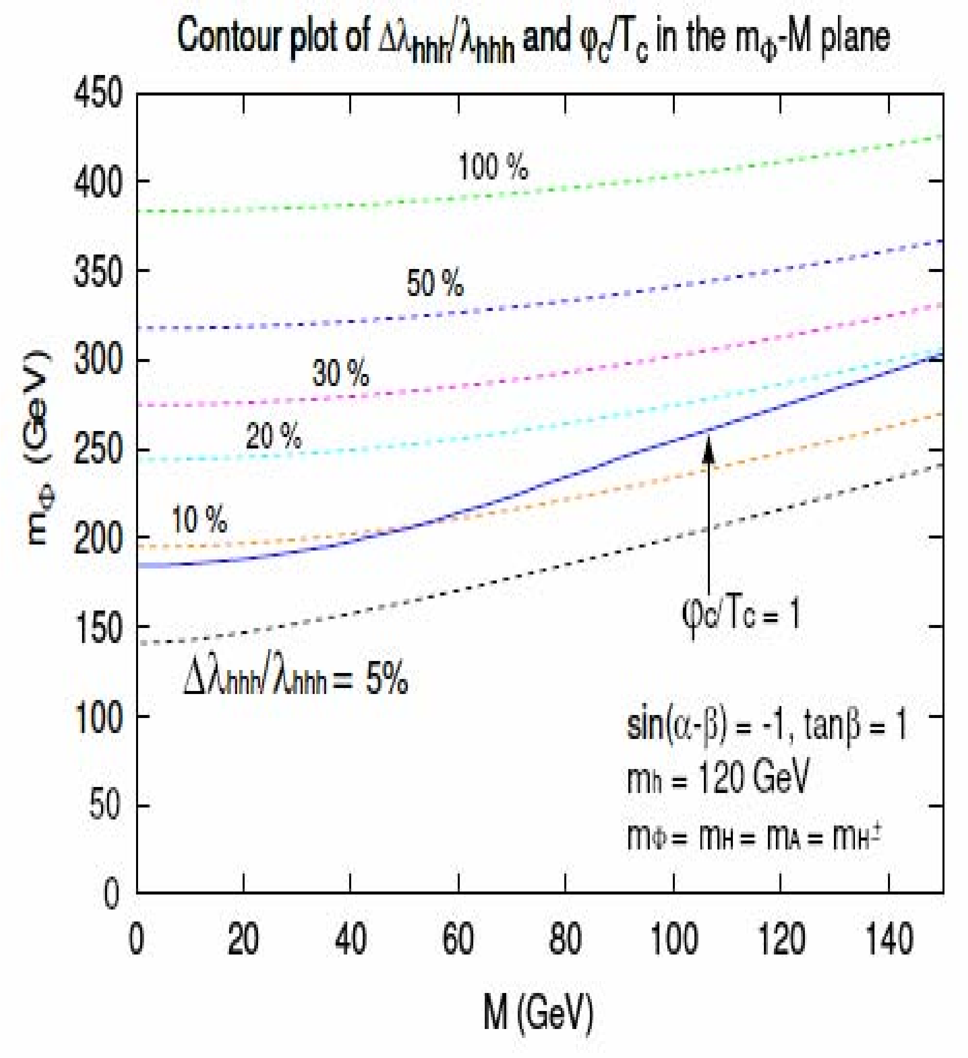
BUT SM with only CP-phase in KM-matrix and $m_h \geq 114\text{GeV}$

cannot satisfy the condition

→ New physics

Two Higgs doublet model are considered

Correlation between Spharelon condition and deviations of the Higgs triple coupling from that of SM are examined



Strongly 1st order phase transition occurs for $m_\Phi^2 \gg m_h^2, M^2$

Large deviation of O(10%) for Higgs triple coupling from SM one

Compare:

MSSM with light stop

O(1%) deviation

4. Conclusions

Cosmology (and astrophysics may) strongly implies the existence of New Physics beyond the Standard Model

Well-motivated New Physics would be around 100 GeV -1 TeV scale

This range is accessible at future colliders: ILC and LHC

New Physics model parameters are (sometimes) greatly restricted by cosmology and observations of the cosmological parameters give independent information of New Physics and is complementary to collider physics

Therefore, ILC studies on cosmological connections is very important area, and is worth investigating further