Theoretical Aspects of SUSY Studies at ILC

S.Y. Choi (Chonbuk, Korea)

Why SUSY ?

What did we do here?

How to probe SUSY?

Future Tasks

Outlook

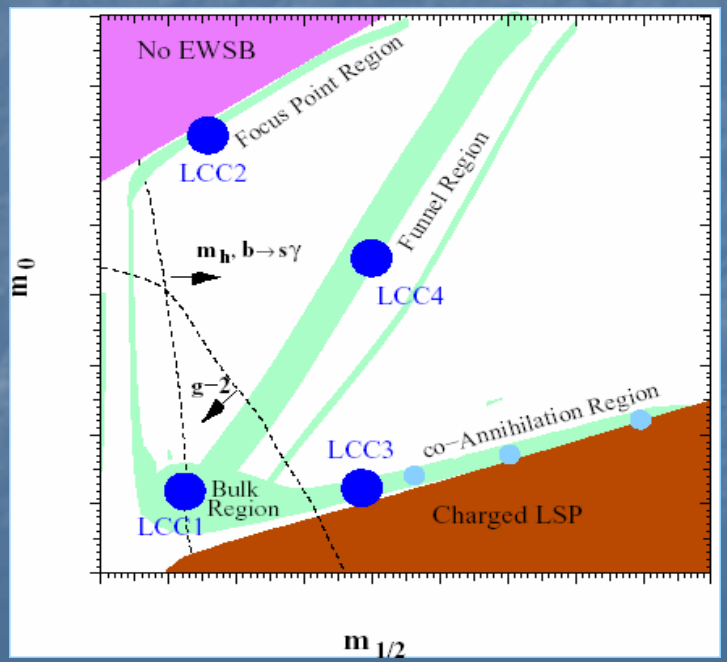
Why SUSY?

Natural extension of 4-dimensional space-time by fermionic coordinates, linking bosons to fermions and vice versa

SUSY breaking unknown but expected to be discovered at the Tera-scale

Resolve a lot of physics issues such as gauge hierarchy, grand unification and cold dark matter

High precision measurements and cosmological observations prefer (slightly) low-scale SUSY



[M. Battaglia]

Why SUSY?

$m_h > 114.4$ GeV for SM-like h

$m_{\chi_1^\pm} > 103.5$ GeV

$m_{\tilde{e}} > 99$ GeV for $m_{\tilde{e}} - m_{\chi_1^0} > 10$ GeV

$B(b \to s\gamma) = (3.25 \pm 0.54) \times 10^{-4}$

$B(B_s \to \mu^+\mu^-) < 1.5 \times 10^{-7}$

$\Delta a_\mu = (27.1 \pm 9.4) \times 10^{-10}$

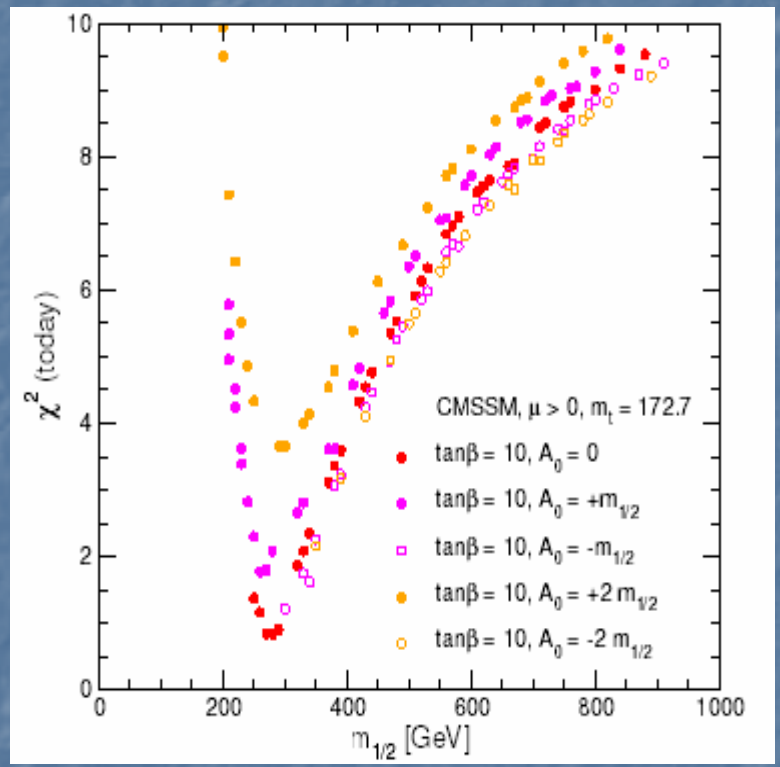
$m_t = 172.7 \pm 2.9$ GeV

$m_W = 80.425 \pm 0.034$ GeV

$\sin^2\theta_{\text{eff}} = 0.23150 \pm 0.00016$

$\eta_B = (6.1 \pm 0.4) \times 10^{-10}$

$0.094 < \Omega_{\text{CDM}} h^2 < 0.129$



[G.Weiglein]

What did we do here?

A. Belyaev	SUSY at ILC
G. Weiglein	Indirect Sensitivities on the Scale of SUSY
J. Kalinowski	SPA Studies
C. Milstene	Analysis of Stop Quark with Small Stop-Neutralino Mass Difference at a Linear Collider
A. Freitas	Studying Light Sneutrinos at the ILC and Physical Implications
J. Proulx	Update on Slepton and Gaugino Mass Resolution Studies
S. Gopalakrishna	B-physics and Linear Collider Signatures of Light Stop and Sbottom
Y.G. Kim	Probing the Majorana Nature and CP Properties of Neutralinos
W. Porod	Correlations between Neutrino Physics and Collider Physis in the Bilinear Model
M. Battaglia	Detector and Simulation Issues of SUSY Searches at ILC
S. Hillert	Physics Potential of Vertex Detector as Function of Beam Pipe Radius
S. Heinemeyer	FeynHiggs
C. Balazs	Electroweak Baryogenesis in the MSSM
J.A.R. Cembranos	Collider Signatures of SuperWIMP Warm Dark Matter"
T. Krupovnickas	The Challenges of Focus Point at the LHC and LC
A. Belyaev	Implications of Non-universal SUGRA Models at ILC
H. Baer	Scenarios for SUSY CDM and the ILC
W. de Boer	Why the EGRET Excess of Diffuse Galactic Gamma Rays Points Towards Heavy Scalars
S. Hesselbach	CP-odd and T-odd Asymmetries in Chargino and Neutralino Production and Decay
G. Moortgat-Pick	The Physics Case for the Polarization of Both Beams at the ILC
G. Moortgat-Pick	Impact of Forward-Backward Asymmetries for Constraining Heavy Virtual Particles
Z. Zhang	Analysis of Two Challenging SUSY DM Scenarios at ILC
A. de Roeck	Non-universal Scalar Masses/Gravitino DM Benchmarks

DISCUSSION ON SUSY BENCHMARK POINTS AT ILC

What did we do here?

A. de Roeck	SUSY and BSM
G. Weiglein	LHC-ILC Interplay
S. Hesselbach	Identifying the NMSSM by Combined LHC-ILC Analyses
D. Zerwas	SUSY Parameter Determination
W. de Boer	Dark Matter Not So Dark Anymore?"
C. Balazs	Supersymmetric Origin of Matter"
A. Freitas	Analyzing the Stop Co-annihilation Region
M. Peskin	LHC and ILC Cosmology Predictions from Scans of the MSSM Parameters"
F. Richard	Dark Matter with Heavy Scalars at the ILC
M. Perelstein	Dark Matter at Colliders: a Model-Independent Approach?
J. Alexander	Dark Matter and Precision Measurements in the Focus Point Region
J. Gunion	Dark Matter from Light Neutralinos and CP-odd Higgs Bosons in the NMSSM and the ILC
J. Reuter	Multi-particle Event Generators for the MSSM
P. Bechtle	SUSY Parameter Measurements with Fittino
W. Porod	Progress Report on SPheno
H. Baer	Progress Report on ISAJET
A. Belyaev	Progress Report on IsaTools
G. Belanger	Progress Report on MicrOmegas
H. Baer	Constraints on SUSY Parameters from Present Data
D. Cline	Direct Dark Matter Detection
M. Battaglia	Can the Relic Density Be Determined at Colliders?
J. Kalinowski	SUSY Benchmarks
A. Belyaev	SUSY at ILC: Sugra Scenarios and Connections
W. Porod	Flavor, CP, RPV, Neutrino Physics at ILC
A. Safonov	SUSY Tools
K. Kawagoe	Detector and Simulation Issues

What did we do here?

5 conveners: A. Belyaev, S.Y. Choi, K. Kawagoe, J. Kalinowski, A. Safonov
3 mini-plenary, 5 parallel, 2 joint and 1 discussion sessions
More than 50 talks in SUSY, ILC/LHC, ILC/Cos, and Loopfest

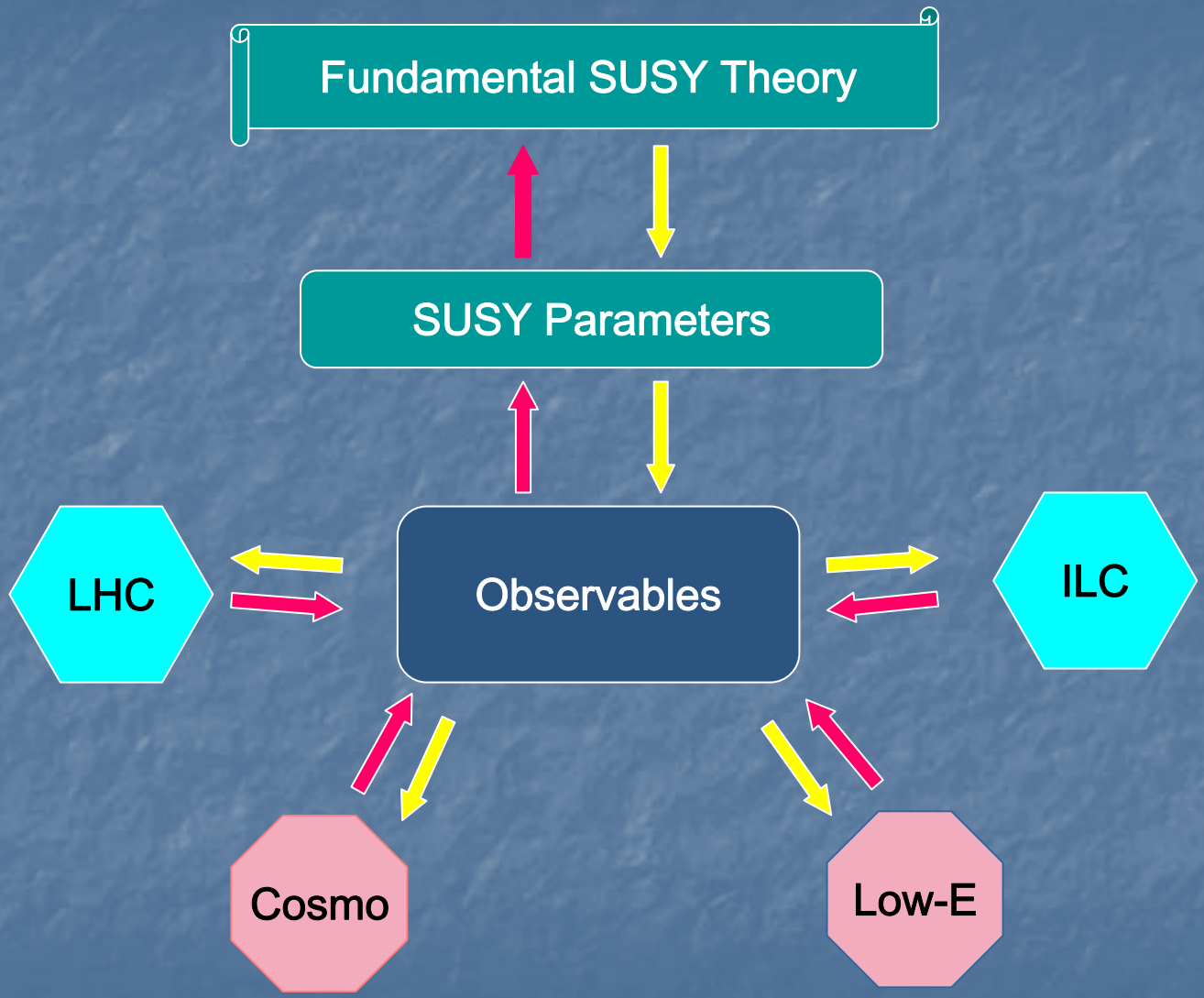
Impossible to give justice to all

More than half of the talks are related to CDM
Most studies are based on mSUGRA
New benchmark points are discussed and proposed
A few new realistic simulations

Here: theoretical aspects of SUSY
SUSY tools and experiments covered by Alexi Safonov

How to Probe SUSY?

Grand SUSY Path



Requirements

Precise and efficient theoretical predictions [A. Belyaev, A. Safonov]
- => Higher-order corrections and automatic calculation tools
- => Consistent RGE programs

Excellent accelerator and detector performance is a must
- => Physics/detector-oriented benchmarks [LCCs by Phy. Bench. Panel]
- => Detector performance evaluations [K. Kawagoe]

Overall (model-independent) combined analyses are urgent?!
- => New benchmarks for Cos/LHC/ILC [J. Kalinowski] under discussion!
- => Perform full simulations for the LHC/ILC/Cos points within three years. Remember that LHC will start running in 2007. [M. Nojiri]

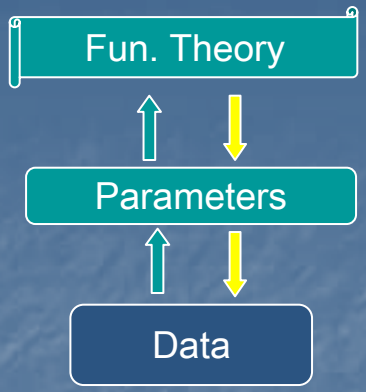
R-parity, CP and flavor violating phenomena [W. Porod]
- => Neutrino and LE flavor physics
- => EW baryogenesis [C. Balazs]
- => Direct CP violation
- => …

In addition: NMSSM, GDM and other SUSY breaking scenarios

Synergy

Constructive Interference/Cooperation ⇔ Quantum Jump in Quality

ILC ⇔ LHC ⇔ Cosmology
Discovery ⇔ Precision
Theory ⇔ Tool ⇔ Experiment



The SPA Project

SPA Convention

renorm. schemes / LE parameters / observables

Program repository

th. /exp. analyses / LHC+ILC tools / SLHA

Theoretical and experimental tasks

short- and long-term sub-projects

Reference point SPS1a'

derivative of SPS1a, consistent with all data

Current and future developments

CP-MSSM, NMSSM, RpV, String effective th. etc

Visit http://spa.desy.de/spa and join the project as an author

Recent Progress: A Few Examples

Recent, interesting and provocative

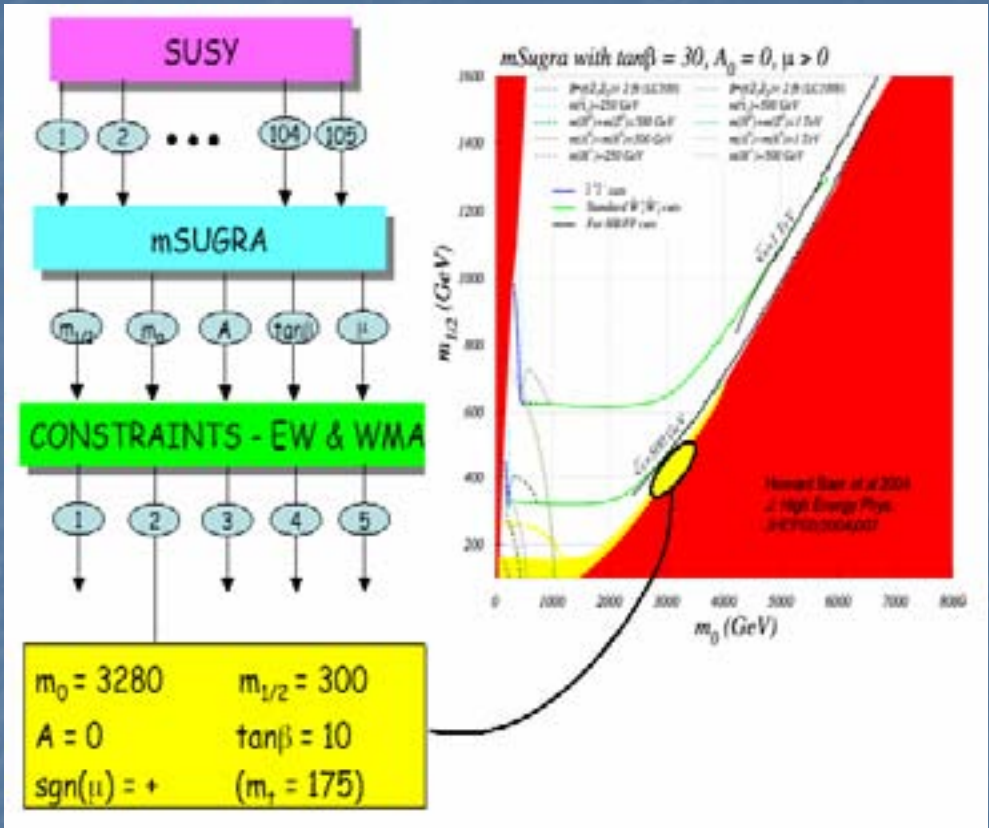
With emphasis on

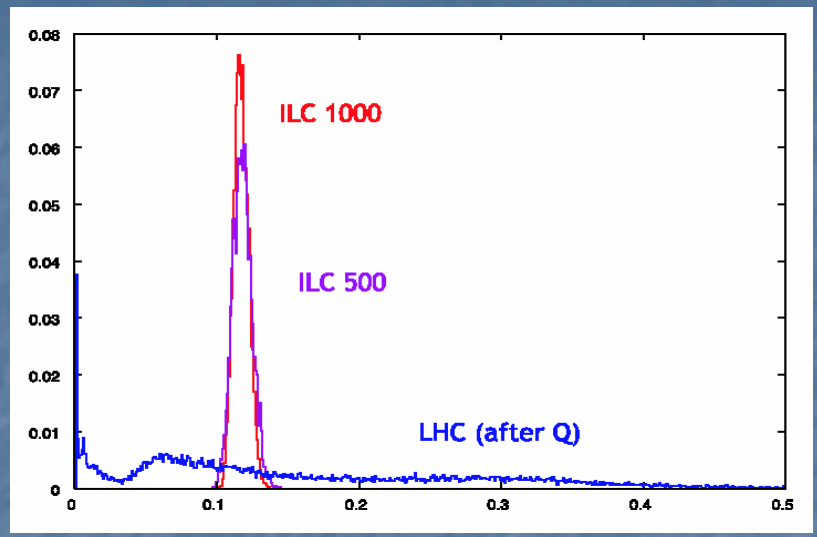
Significant improvements of ILC on LHC measurements

Matching the current and future CDM relic density measurements

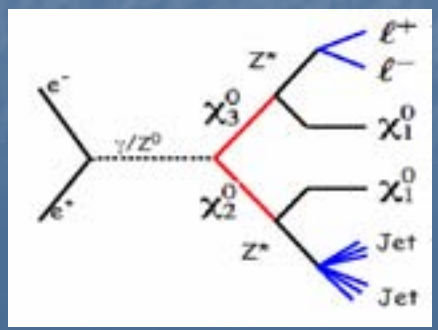
Focus on Focus Points (LCC2)

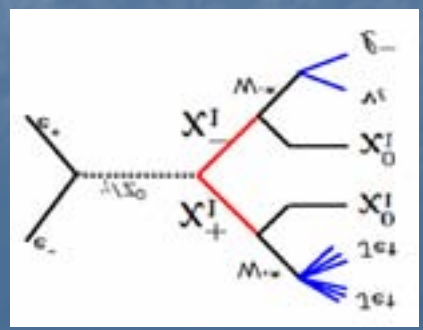
[J. Alexander, M. Peskin, F. Richard, …]

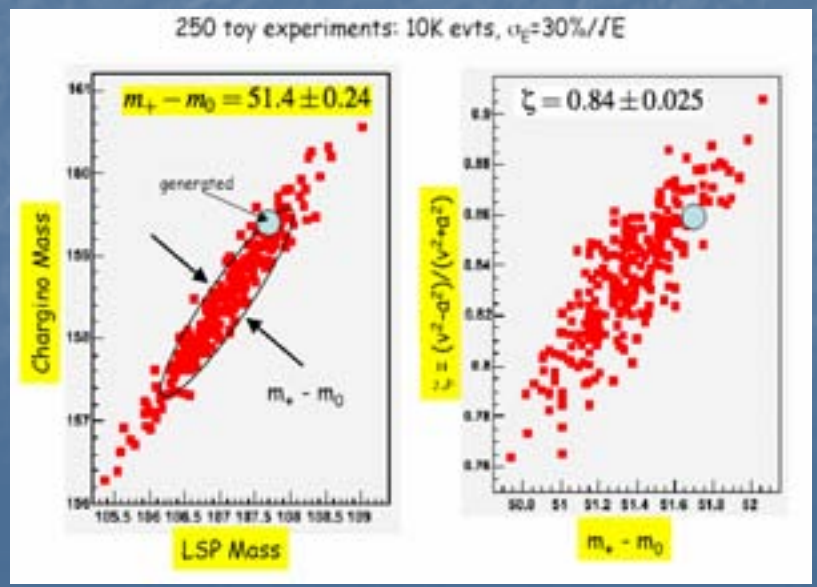




[Markov Chain Scan]





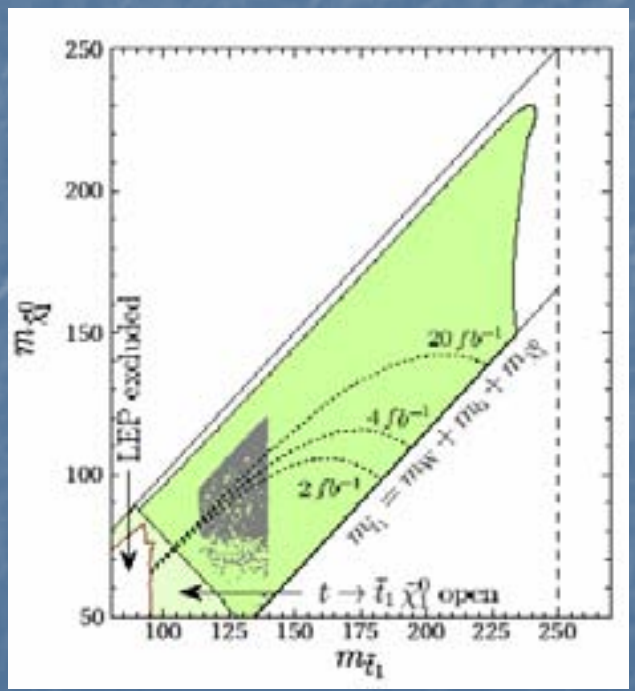


EW Baryogenesis in MSSM

[C. Milestene, C. Balazs. A. Freitas]

Light R-handed stop for 1st order phase transition
New CP phases from μ and tri-linear parameter A

Small stop-LSP mass difference ⇔ Stop co-annihilation

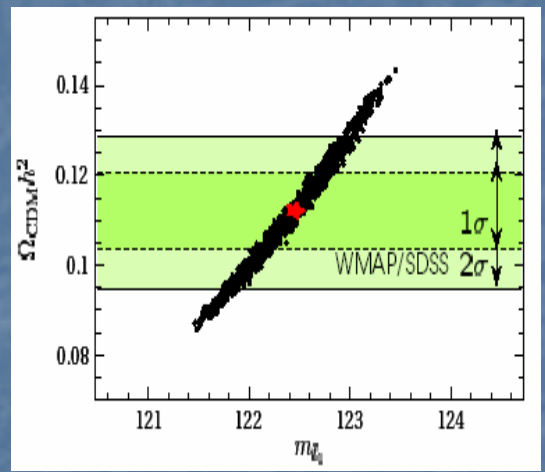


$$e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^-$$
$$e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0$$
$$e^+e^- \to \tilde{\chi}_2^0 \tilde{\chi}_2^0$$

$$M_1 = 112.6 \pm 0.2 \text{ GeV}$$
$$M_2 = 225.0 \pm 0.7 \text{ GeV}$$
$$|\mu| = 320.0 \pm 3.3 \text{ GeV}$$

$$|\phi_\mu| < 1.0$$
$$\tan\beta = 5^{+0.5}_{-2.6}$$

$$e^+e^- \to \tilde{t}_1 \tilde{t}_1^* \to c\bar{c}\,\tilde{\chi}_1^0 \tilde{\chi}_1^0$$



Indirect Searches: Galactic Gamma Spectrum in EGRET

Excess over conventionally expected yield

Candidate: $\chi\chi \to bb \to \pi^0 \to \gamma \Rightarrow m_\chi \sim 50$ to 100 GeV$|M_{\rm scal} \sim 1$ TeV

[W. de Boer]

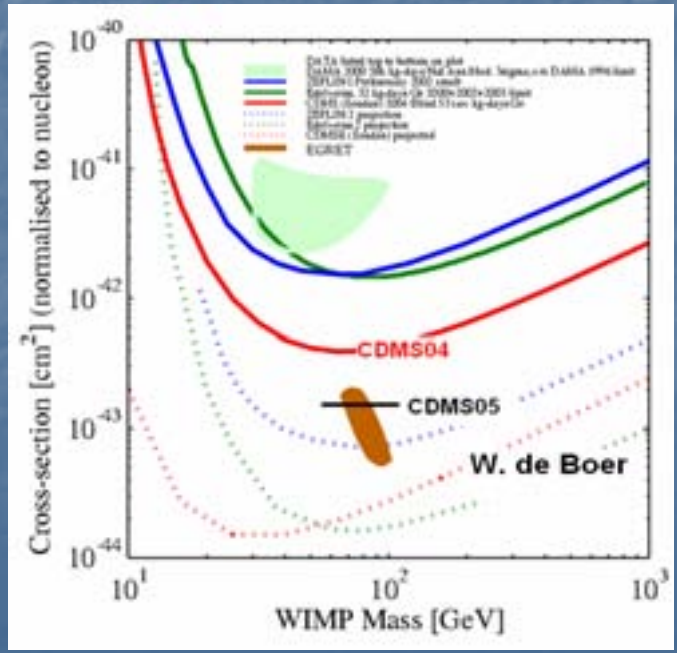
Higgs limit requires then: squarks and sleptons above ≈ TeV
EWSB (and g-2) require: squarks and sleptons ≤ 2 TeV
tanβ ≈ 50-55 preferred

Conclusion dep crucially on conventional bkgd: under sufficient control?

Direct searches

CDMS05 is already sensitive to the proposed parameter range.

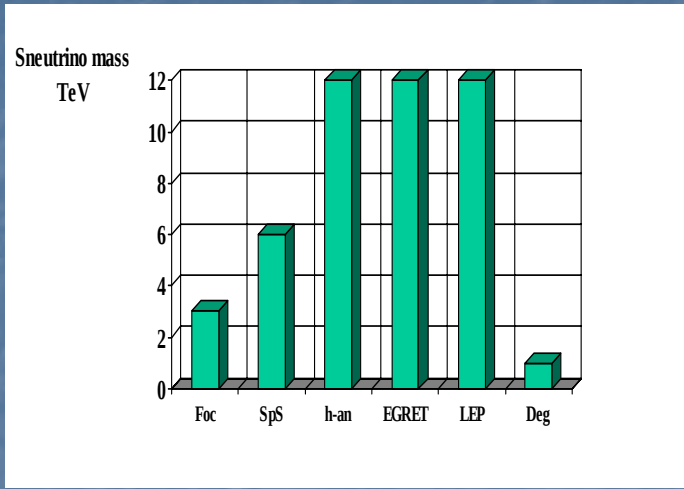
[F. Richard, D. Cline]



High Precision: Exploiting Virtual Effects of High-mass Particles

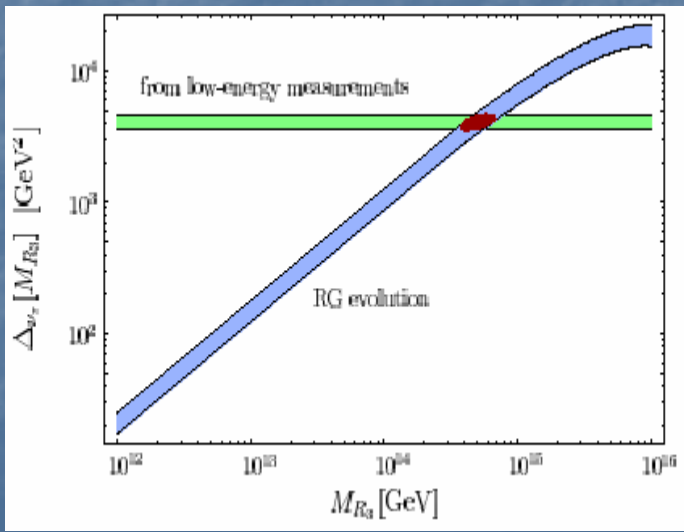
[F. Richard, G. Moortgat-Pick, Z. Zhang]

Chargino production affected by sneutrino t-channel exchanges
Sneutrino mass large in focus-point theories
Indirect sensitivities up to 12 TeV



[A. Freitas]

High precision in slepton/sneutrino sector sensitivie to R-handed neutrino scale around 10^14 GeV



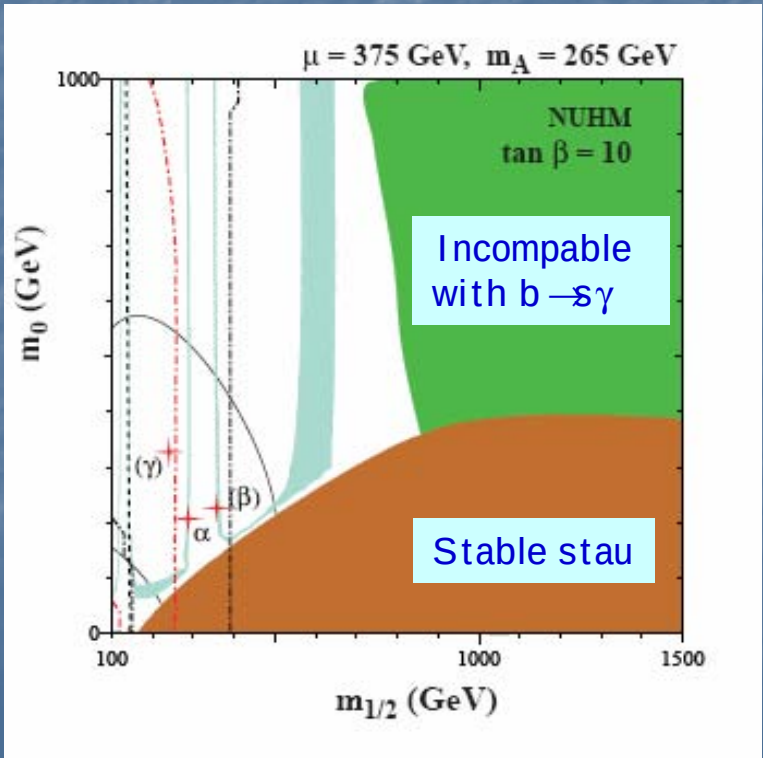
What if

Non-Universal Higgs Masses

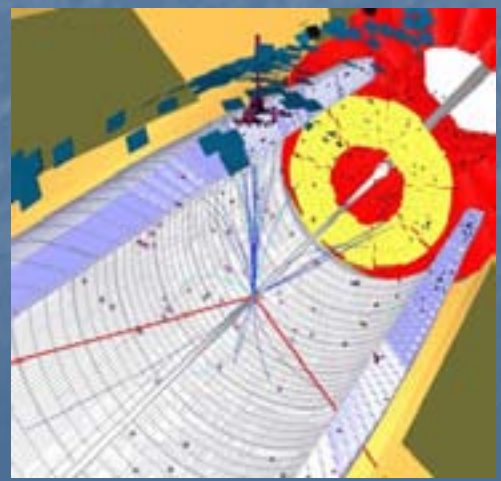
[A. de Roeck, A. Belyaev, H. Baer]

$$m^2_{H_{u,d}} = (1 + \delta_{u,d}) m^2_0$$

EW vacuum conditions no longer fix μ and m_A
Can use this freedom to get new signatures



$\alpha \Rightarrow \chi_2 \rightarrow \chi Z$
$\beta \Rightarrow \chi_2 \rightarrow \chi h$
$\gamma \Rightarrow \chi_2 \rightarrow \chi Z^*$



Simulated SUSY event in the CMS detector for α

What if

CP-violated MSSM

[S. Hesselbach]

CP-odd asymmetries in gaugino/higgsino

Beam polarization important
[G. Moortgat-Pick]

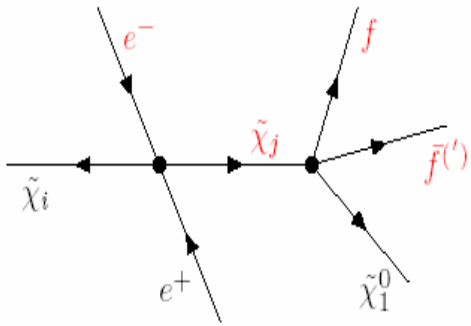
[Y.G. Kim]

$\tilde{\chi}_2^0(\tilde{m}) \to \tilde{\chi}_1^0 l^+ l^-$

in the neutralino rest frame

Majorana nature can beconfirmed by
lepton energy/angular distribution
lepton invariant mass/opening angle

Triple products: $\mathcal{T} = \vec{p}_{e^-} \cdot (\vec{p}_f \times \vec{p}_{\tilde{f}^{(\prime)}})$ or $\mathcal{T} = \vec{p}_{e^-} \cdot (\vec{p}_{\tilde{\chi}_j} \times \vec{p}_f)$



→ T-odd asymmetry: $A_T = \frac{\sigma(\mathcal{T}>0) - \sigma(\mathcal{T}<0)}{\sigma(\mathcal{T}>0) + \sigma(\mathcal{T}<0)} = \frac{\int \text{sign}(\mathcal{T}) |T|^2 d\text{Lips}}{\int |T|^2 d\text{Lips}}$

→ CP-odd, if final state interactions and finite-widths effects can be neglected

What if

R-parity Violation

[W. Porod]

$$\mathrm{MSSM} + \epsilon_i \tilde{L}_i \tilde{H}_u + B_i \epsilon_i \tilde{L}_i H_u$$

$$m_{\nu,eff} = \frac{M_1 g^2 + M_2 g'^2}{4\, det(\mathcal{M}_{\chi^0})} \begin{pmatrix} \Lambda_1^2 & \Lambda_1\Lambda_2 & \Lambda_1\Lambda_3 \\ \Lambda_1\Lambda_2 & \Lambda_2^2 & \Lambda_2\Lambda_3 \\ \Lambda_1\Lambda_3 & \Lambda_2\Lambda_3 & \Lambda_3^2 \end{pmatrix}$$

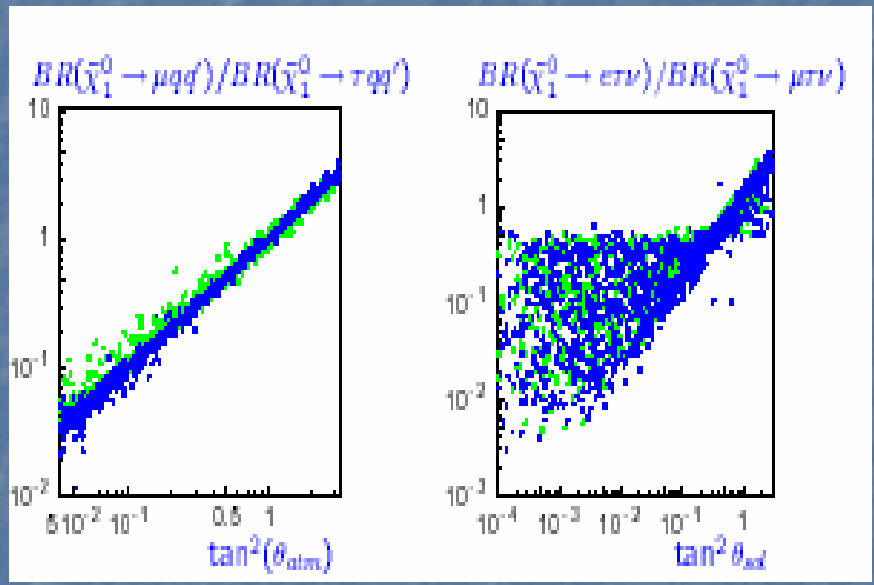
$$\Lambda_i = \mu v_i + v_d \epsilon_i$$

$$\tan^2\theta_{atm} = \left(\frac{\Lambda_2}{\Lambda_3}\right)^2, \; U_{e3}^2 = \frac{\Lambda_1^2}{\Lambda_2^2 + \Lambda_3^2}, \; \tan^2\theta_{sol} = \left(\frac{\bar{\epsilon}_1}{\bar{\epsilon}_2}\right)^2$$

$$\Gamma(\tilde{\chi}_1^0 \to W^{\pm} l_i^{\mp}) \propto \frac{\Lambda_i^2}{\det \mathcal{M}_{\tilde{\chi}^0}}$$

$$\Gamma(\tilde{\chi}_1^0 \to \sum_i Z \nu_i)$$

$$\Gamma(\tilde{\chi}_1^0 \to \nu_\tau + l_i^-) \propto \frac{\epsilon_i^2}{\mu^2}$$



Gravitino could be a warm DM even in this model

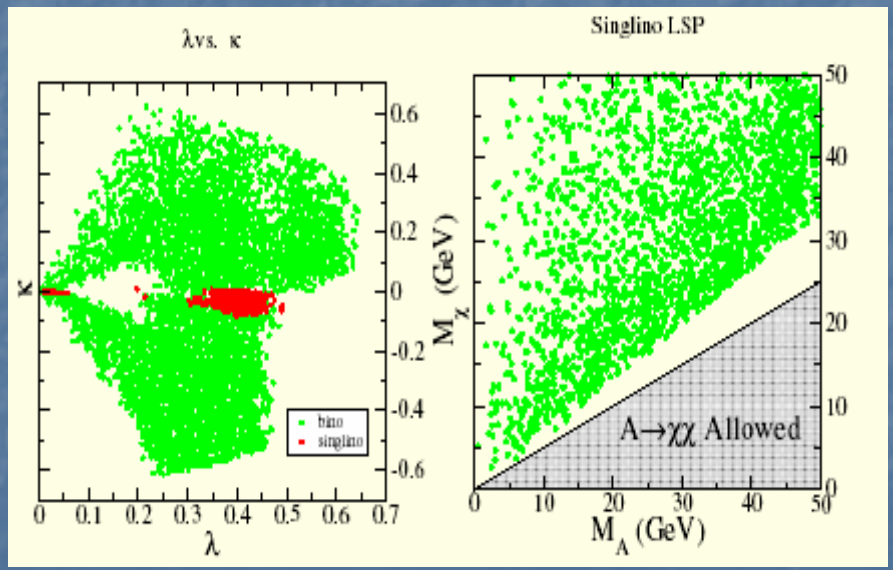
What if

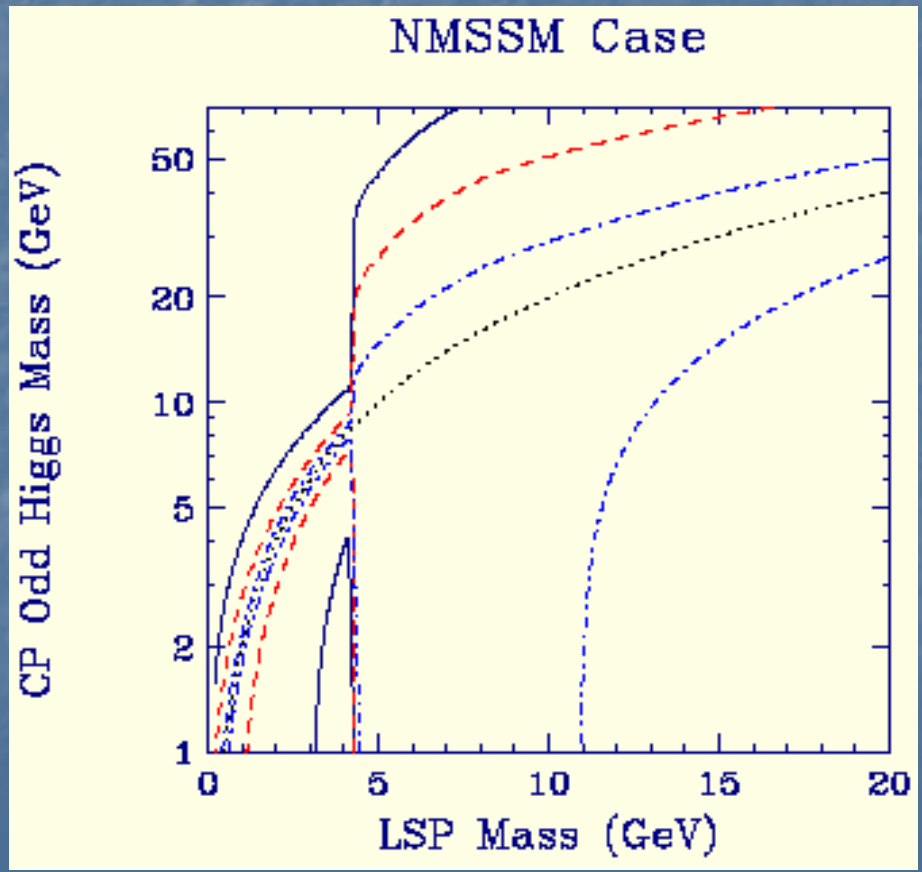
NMSSM

[J. Gunion, S. Hesselbach]

$$\lambda\, \widehat{S}\widehat{H}_u\widehat{H}_d + \frac{\kappa}{3}\,\widehat{S}^3$$

$$\tan\beta = \langle H_u\rangle / \langle H_d\rangle \;,\; \mu_{\rm eff} = \lambda\,\langle S\rangle \equiv \lambda x$$





Future Tasks for SUSY enthusiasts

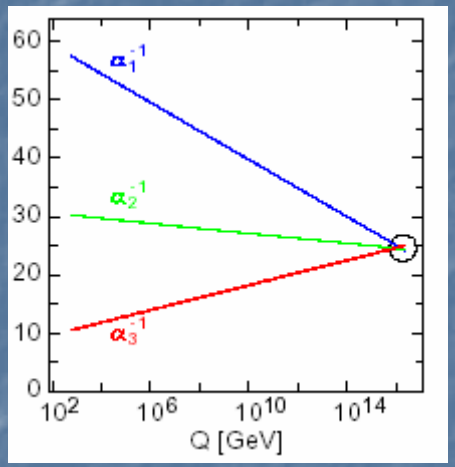
Perform more precise theoretical calculations to match expected experimental precision: factor 10 ~ one more loop

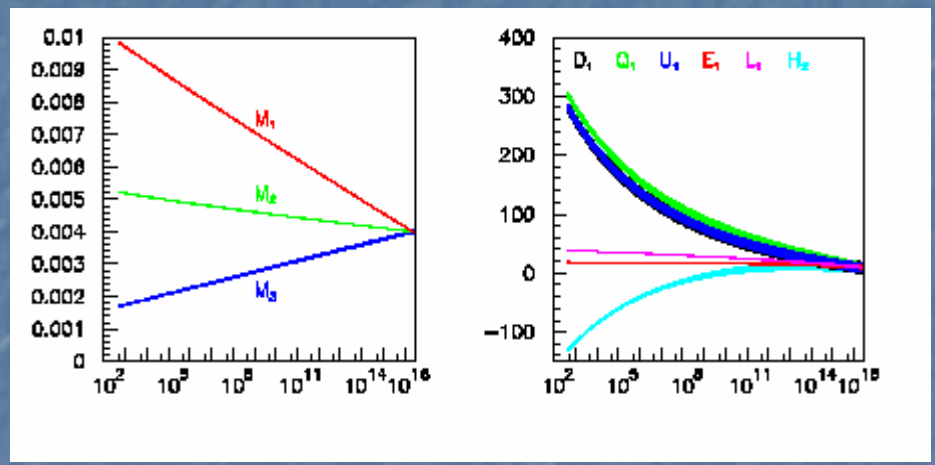
Develop several indep. tools: connection of fund. parameters to observables : predictions for relic density etc

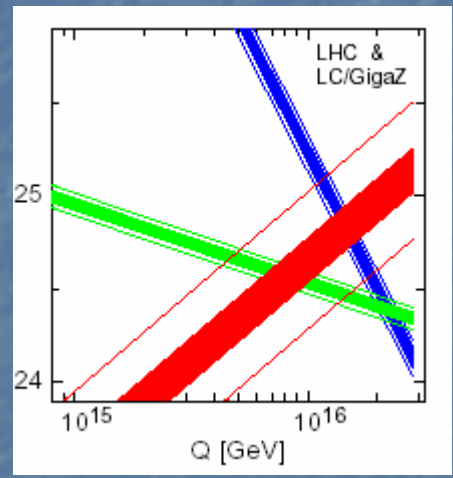
Experimental simulations for many more scenarios and reference points

Outlook

High Precision SUSY Analyses at LHC + ILC + Cos + LE







Telescope to GUT / Planck Scale Physics