Determining MSSM parameters from higgsino/gaugino sector

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Plan of seminar

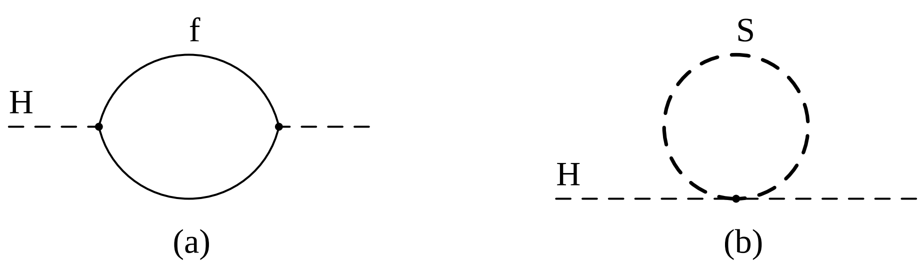
1. MSSM Lagrangian
2. Higgsinos and gauginos mixing
3. Chargino pair production
4. Chargino decays
5. Extraction of MSSM parameters
6. Conclusions

Motivations for supersymmetry

1. Hierarchy problem: quadratically divergent corrections to Higgs boson mass

$$(a)\ \Delta m_H^2 = \frac{|\lambda_f|^2}{8\sqrt{2}\pi^2}\left(-2\Lambda_{UV}^2 + 6m_f^2 \ln(\Lambda_{UV}/m_f) + \ldots\right)$$

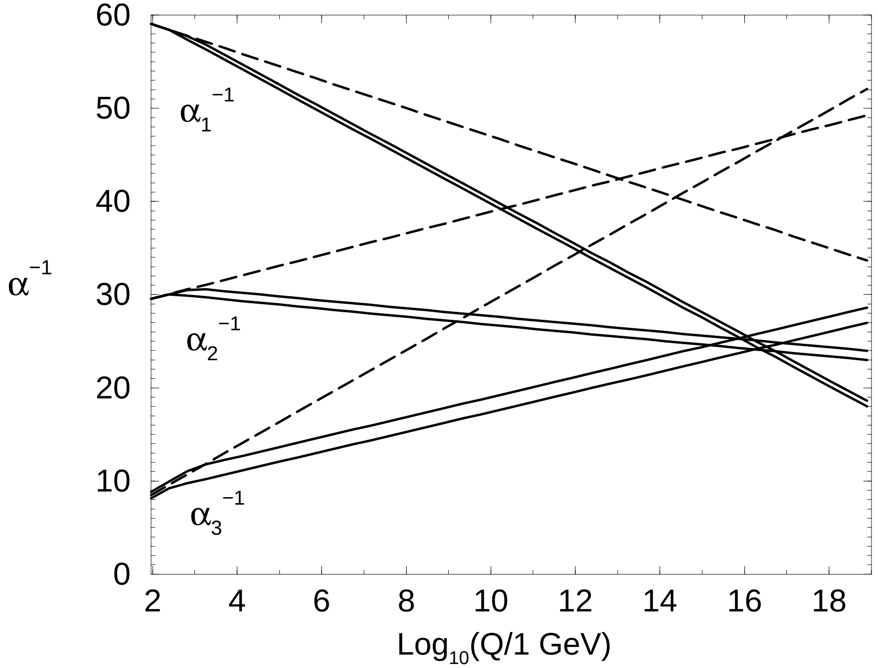
$$(b)\ \Delta m_H^2 = \frac{\lambda_S}{8\sqrt{2}\pi^2}\left(\Lambda_{UV}^2 - 2m_S^2 \ln(\Lambda_{UV}/m_S) + \ldots\right)$$



2. Naturally incorporates spacetime symmetries $\longrightarrow$ supergravity

3. Provides candidate for cold dark matter and CP-odd phases for baryogenesis

4. Gauge couplings unification



Chiral supermultiplets of MSSM

Name		spin 0	spin 1/2	$SU(3)_c, SU(2)_L, U(1)_Y$
squarks & quarks	Q	$\begin{pmatrix} \tilde{u}_L \\ \tilde{d}_L \end{pmatrix}$	$\begin{pmatrix} u \\ d \end{pmatrix}_L$	$(\mathbf{3}, \mathbf{2}, \frac{1}{6})$
(3 generations)	U	$\tilde{u}_R^*$	u_L^c	$(\bar{\mathbf{3}}, \mathbf{1}, -\frac{2}{3})$
	D	$\tilde{d}_R^*$	d_L^c	$(\bar{\mathbf{3}}, \mathbf{1}, \frac{1}{3})$
sleptons & leptons	L	$\begin{pmatrix} \tilde{\nu} \\ \tilde{e}_L \end{pmatrix}$	$\begin{pmatrix} \nu \\ e \end{pmatrix}_L$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$
(3 generations)	E	$\tilde{e}_R^*$	e_L^c	$(\mathbf{1}, \mathbf{1}, 1)$
Higgs bosons &	H_u	$\begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}$	$\begin{pmatrix} \tilde{H}_u^+ \\ \tilde{H}_u^0 \end{pmatrix}$	$(\mathbf{1}, \mathbf{2}, \frac{1}{2})$
higgsinos	H_d	$\begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$	$\begin{pmatrix} \tilde{H}_d^0 \\ \tilde{H}_d^- \end{pmatrix}$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$

Vector supermultiplets of MSSM

Name	spin $\frac{1}{2}$	spin 1	$SU(3)_c, SU(2)_L, U(1)_Y$
gluino & gluon	$\tilde{g}$	g	$(\mathbf{8}, \mathbf{1}, 0)$
winos & W bosons	$\tilde{W}^{\pm}\ \tilde{W}^{0}$	$W^{\pm}\ W^{0}$	$(\mathbf{1}, \mathbf{3}, 0)$
bino & B boson	$\tilde{B}^{0}$	B^{0}	$(\mathbf{1}, \mathbf{1}, 0)$

Soft SUSY breaking terms

$$
\begin{aligned}
\mathcal{L}_{\mathsf{soft}} = & -\frac{1}{2}(M_3\tilde{g}\tilde{g} + M_2\tilde{W}\tilde{W} + M_1\tilde{B}\tilde{B}) + \mathsf{c.c.} \\
& - (\tilde{u}\mathbf{a_u}\tilde{q}H_u - \tilde{d}\mathbf{a_d}\tilde{q}H_d - \tilde{e}\mathbf{a_e}\tilde{l}H_d) + \mathsf{c.c.} \\
& - \mathbf{m^2_{\tilde{q}}}\tilde{q}^*\tilde{q} - \mathbf{m^2_{\tilde{l}}}\tilde{l}^*\tilde{l} - \mathbf{m^2_{\tilde{u}}}\tilde{u}^*\tilde{u} - \mathbf{m^2_{\tilde{d}}}\tilde{d}^*\tilde{d} - \mathbf{m^2_{\tilde{e}}}\tilde{e}^*\tilde{e} \\
& - m^2_{H_u}H_u^*H_u - m^2_{H_d}H_d^*H_d - (bH_uH_d + \mathsf{c.c.})
\end{aligned}
$$

$$
\mathcal{L} = \mathcal{L}_{\mathsf{SUSY}} + \mathcal{L}_{\mathsf{soft}}
$$

SPS1 scenario of MSSM

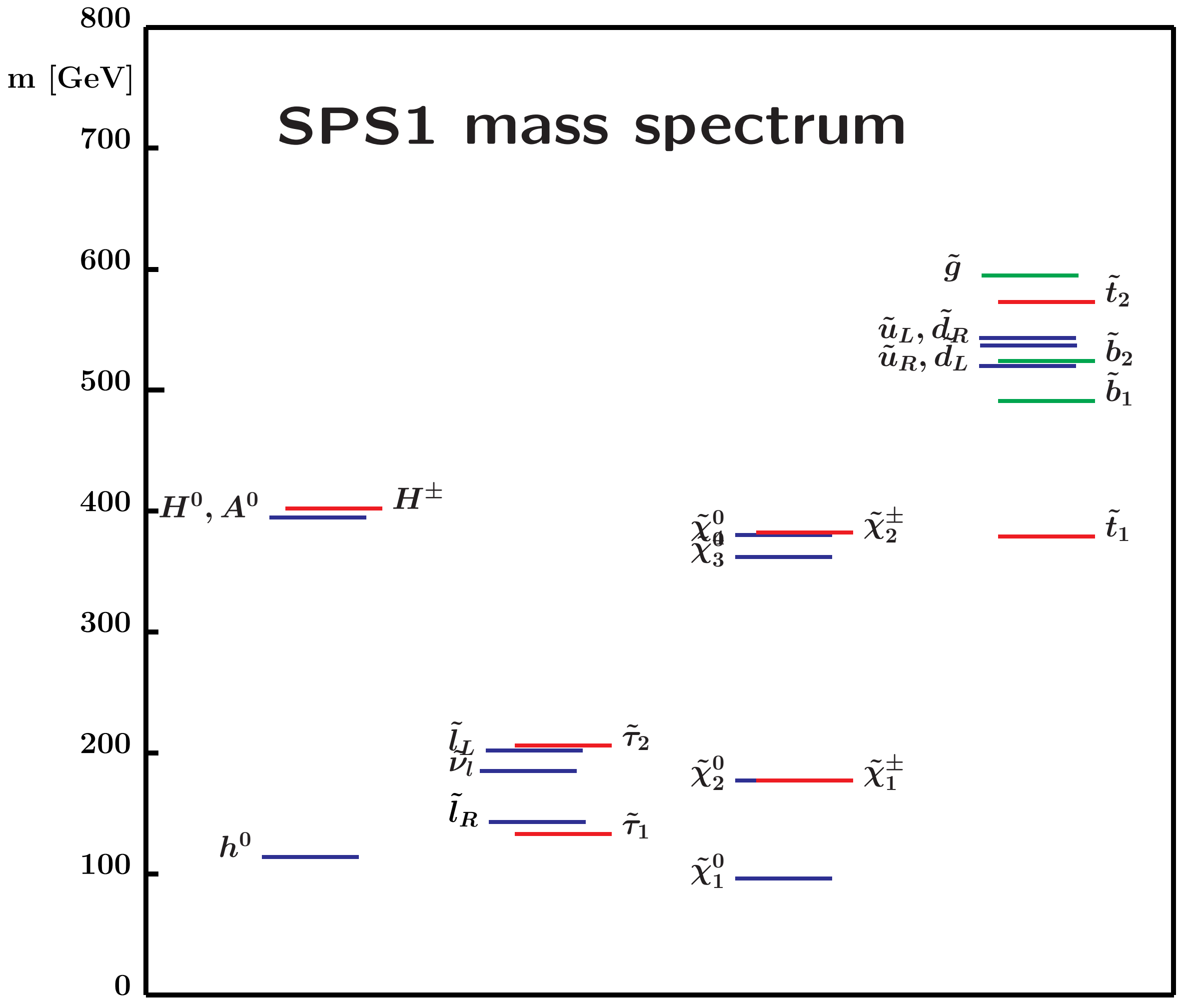
Input parameters at electroweak scale:

$M_1 = 99.13$ GeV, $M_2 = 192.74$ GeV,

$|\mu| = 352.39$ GeV, $m_{\tilde{\nu}} = 186.00$ GeV

Output - masses and mixing angles (tree-level):

SPS1					
	$m_{\tilde{\chi}_1^\pm}$	$m_{\tilde{\chi}_2^\pm}$	$\cos 2\phi_L$	$\cos 2\phi_R$	$m_{\tilde{\chi}_1^0}$
$\Phi_\mu = 0$	176,1	378,5	0,662	0,888	96,1
$\Phi_\mu = \frac{\pi}{2}$	180,5	376,4	0,681	0,914	97,4
$\Phi_\mu = \pi$	184,9	374,3	0,702	0,942	98,6



800
m [GeV]
SPS1 mass spectrum
700
600
500
400
300
200
100
0
H^0, A^0
$H^\pm$
h^0
$\tilde{l}_L$
$\tilde{\nu}_l$
$\tilde{\tau}_2$
$\tilde{l}_R$
$\tilde{\tau}_1$
$\tilde{\chi}_4^0$
$\tilde{\chi}_3^0$
$\tilde{\chi}_2^\pm$
$\tilde{\chi}_2^0$
$\tilde{\chi}_1^\pm$
$\tilde{\chi}_1^0$
$\tilde{g}$
$\tilde{t}_2$
$\tilde{u}_L, \tilde{d}_R$
$\tilde{u}_R, \tilde{d}_L$
$\tilde{b}_2$
$\tilde{b}_1$
$\tilde{t}_1$

Chargino mixing

Chargino mass lagrangian in terms of gauge eigenstates:

$$\mathcal{L} \supset \left(\bar{\tilde{W}}_R^-, \bar{\tilde{H}}_u^{+c}\right) M_{\tilde{\chi}^\pm} \begin{pmatrix} \tilde{W}_L^- \\ \tilde{H}_d^- \end{pmatrix} + \text{h.c.}$$

mass matrix $\Longrightarrow M_{\tilde{\chi}^\pm} = \begin{pmatrix} M_2 & \sqrt{2} m_W \cos\beta \\ \sqrt{2} m_W \sin\beta & \mu \end{pmatrix}$

diagonalization $\Longrightarrow U_R M_{\tilde{\chi}^\pm} U_L^\dagger = \begin{pmatrix} m_{\tilde{\chi}_1^\pm} & 0 \\ 0 & m_{\tilde{\chi}_2^\pm} \end{pmatrix}$

mass eigenstates $\Longrightarrow U_L \begin{pmatrix} \tilde{W}_L^- \\ \tilde{H}_d^- \end{pmatrix} = \begin{pmatrix} \chi_{1L}^- \\ \chi_{2L}^- \end{pmatrix}, \quad U_R \begin{pmatrix} \tilde{W}_R^- \\ \tilde{H}_u^{+c} \end{pmatrix} = \begin{pmatrix} \chi_{1R}^- \\ \chi_{2R}^- \end{pmatrix}$

Neutralino mixing

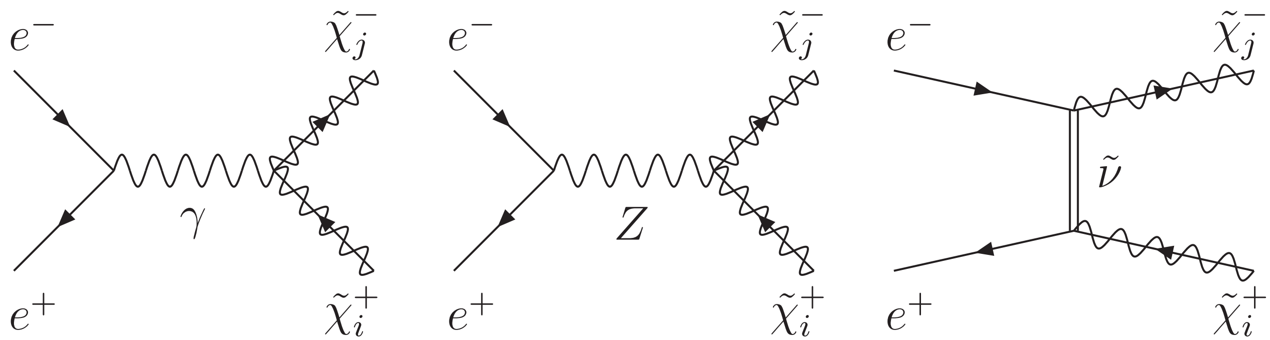
Neutralino mass lagrangian in terms of gauge eigenstates $\psi^0 = (\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0)$:

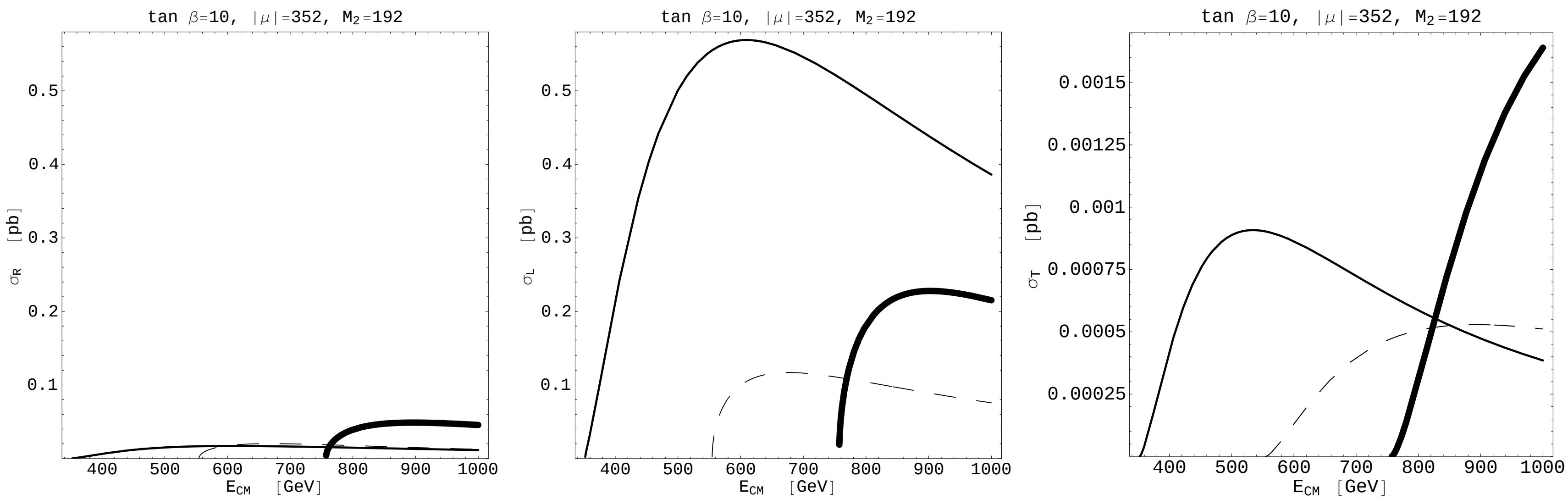
$$\mathcal{L} \supset -\frac{1}{2}(\psi^0)^T M_{\tilde{\chi}^0} \psi^0 + \text{h.c.}$$

mass matrix $\Longrightarrow$
$$M_{\tilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -m_Z c_\beta s_W & m_Z s_\beta s_W \\ 0 & M_2 & m_Z c_\beta c_W & -m_Z s_\beta c_W \\ -m_Z c_\beta s_W & m_Z c_\beta c_W & 0 & -\mu \\ m_Z s_\beta s_W & -m_Z s_\beta c_W & -\mu & 0 \end{pmatrix}$$

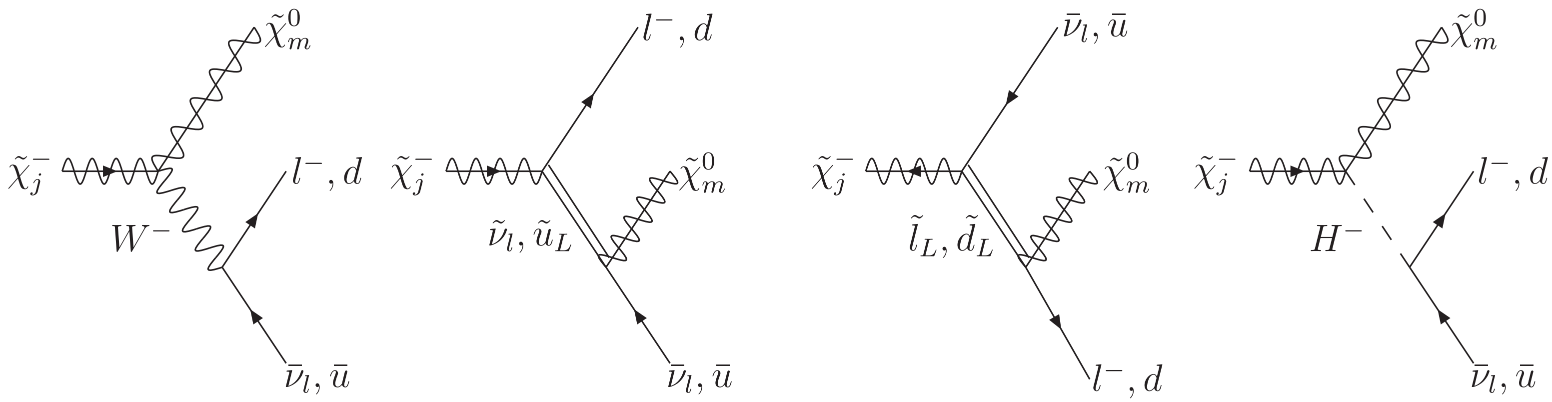
diagonalization $\Longrightarrow$
$$M_{\tilde{\chi}^0}^{\text{diag}} = N^* M_{\tilde{\chi}^0} N^{-1}$$

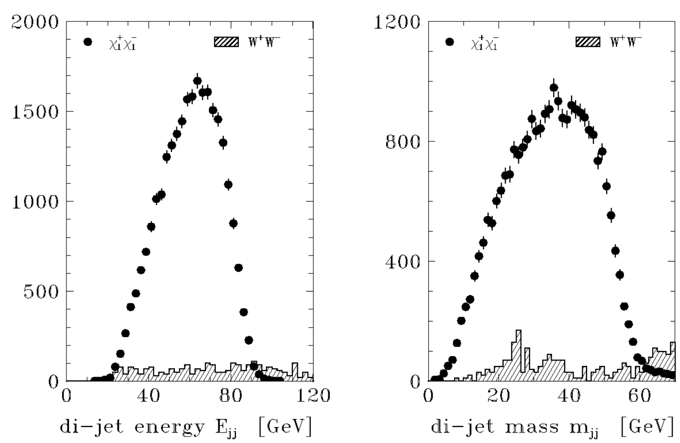
Chargino pair production

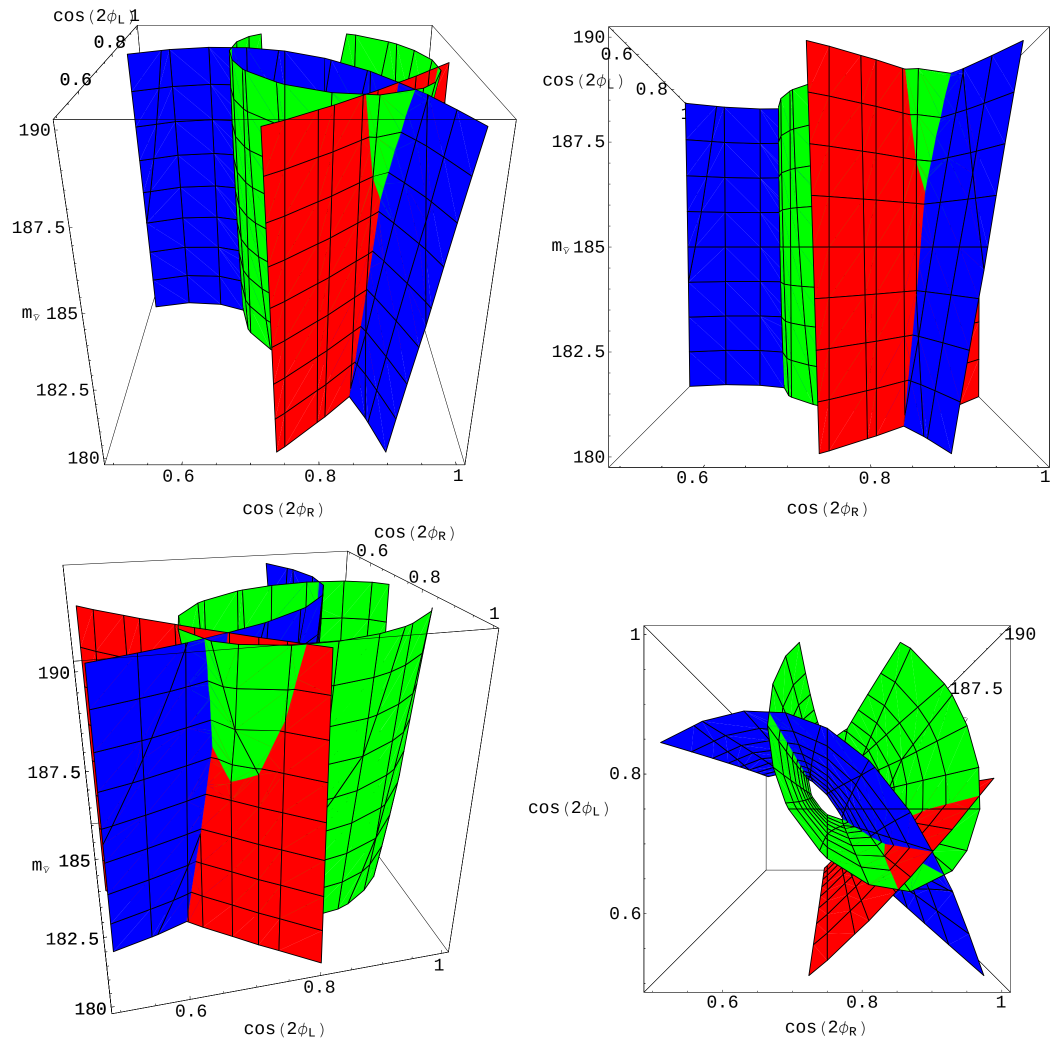




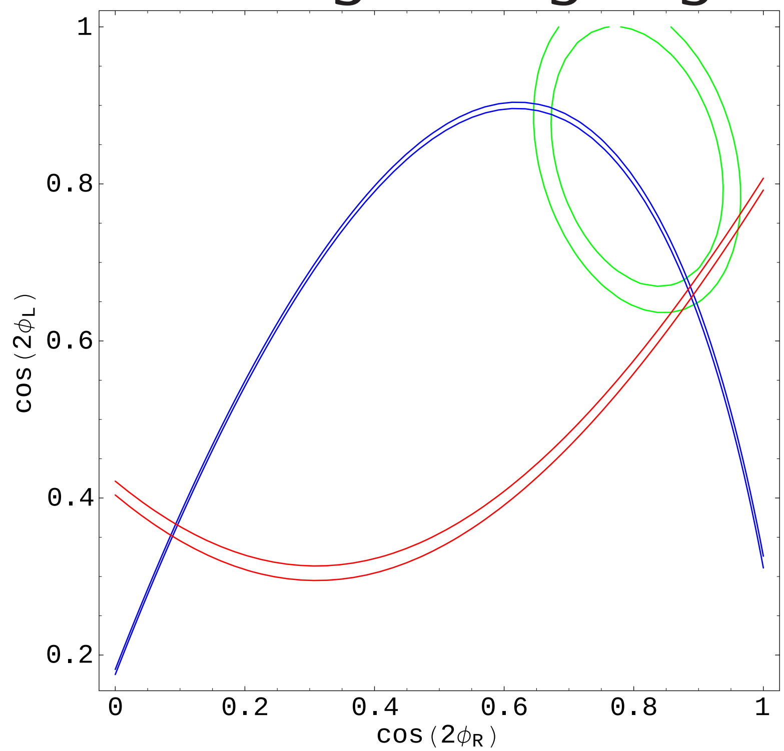
Chargino decays






cos(2ϕL)
1
0.8
0.6
190
187.5
mν̃ 185
182.5
180
0.6
0.8
1
cos(2ϕR)
190
0.6
cos(2ϕL)
0.8
187.5
mν̃ 185
182.5
180
0.6
0.8
1
cos(2ϕR)
cos(2ϕR)
0.6
0.8
1
190
187.5
mν̃ 185
182.5
180
0.6
0.8
1
cos(2ϕL)
1
190
187.5
0.8
cos(2ϕL)
0.6
0.6
0.8
1
cos(2ϕR)

Determining mixing angles



Cross sections @ 500 GeV $\sigma_R\{11\} = 0{,}01506 \pm 0{,}00012$ pb, $\sigma_L\{11\} = 0{,}5007 \pm 0{,}0007$ pb, $\sigma_T\{11\} = 0{,}00089 \pm 0{,}00003$ pb

Extracting μ, M_2 and $\tan\beta$ from masses and mixing angles

$$M_2 = \sqrt{\frac{m^2_{\tilde{\chi}^\pm_2} + m^2_{\tilde{\chi}^\pm_1} - 2m^2_W}{2} - \frac{(m^2_{\tilde{\chi}^\pm_2} - m^2_{\tilde{\chi}^\pm_1})(\cos 2\phi_L + \cos 2\phi_R)}{4}}$$

$$|\mu| = \sqrt{\frac{m^2_{\tilde{\chi}^\pm_2} + m^2_{\tilde{\chi}^\pm_1} - 2m^2_W}{2} + \frac{(m^2_{\tilde{\chi}^\pm_2} - m^2_{\tilde{\chi}^\pm_1})(\cos 2\phi_L + \cos 2\phi_R)}{4}}$$

$$\cos\Phi_\mu = \frac{(m^2_{\tilde{\chi}^\pm_2} - m^2_{\tilde{\chi}^\pm_1})^2(2 - c^2_{2L} - c^2_{2R}) - 8m^2_W(m^2_{\tilde{\chi}^\pm_2} + m^2_{\tilde{\chi}^\pm_1} - 2m^2_W)}{\sqrt{\left(4(m^2_{\tilde{\chi}^\pm_2} + m^2_{\tilde{\chi}^\pm_1} - 2m^2_W)^2 - (m^2_{\tilde{\chi}^\pm_2} - m^2_{\tilde{\chi}^\pm_1})^2(c_{2L} + c_{2R})^2\right)}}$$

$$\times \frac{1}{\left(16m^4_W - (m^2_{\tilde{\chi}^\pm_2} - m_{\tilde{\chi}^\pm_1})^2(c_{2L} - c_{2R})^2\right)}$$

$$\tan\beta = \sqrt{\frac{4m^2_W - (m^2_{\tilde{\chi}^\pm_2} - m^2_{\tilde{\chi}^\pm_1})(\cos 2\phi_L - \cos 2\phi_R)}{4m^2_W + (m^2_{\tilde{\chi}^\pm_2} - m^2_{\tilde{\chi}^\pm_1})(\cos 2\phi_L - \cos 2\phi_R)}}$$

Chargino sector parameters

SPS1				
	$m_{\tilde{\chi}_1^\pm}$ [GeV]	$m_{\tilde{\chi}_2^\pm}$ [GeV]	$\cos 2\phi_L$	$\cos 2\phi_R$
$\Phi_\mu = 0$	$176{,}06 \pm 0{,}04$	$378{,}51 \pm 0{,}25$	$0{,}662 \pm 0{,}003$	$0{,}888 \pm 0{,}004$
$\Phi_\mu = \frac{\pi}{2}$	$180{,}47 \pm 0{,}04$	$376{,}42 \pm 0{,}25$	$0{,}681 \pm 0{,}004$	$0{,}914 \pm 0{,}004$
$\Phi_\mu = \pi$	$184{,}90 \pm 0{,}04$	$374{,}27 \pm 0{,}25$	$0{,}702 \pm 0{,}005$	$0{,}942 \pm 0{,}004$

SUSY Lagrangian parameters

SPS1				
	M_2 [GeV]	$\lvert\mu\rvert$ [GeV]	$\tan\beta$	$\cos\Phi_\mu$
$\Phi_\mu = 0$	$192{,}8 \pm 0{,}4$	$352{,}4 \pm 0{,}3$	10 ± 6	$> 0{,}4$
$\Phi_\mu = \frac{\pi}{2}$	$192{,}8 \pm 0{,}4$	$352{,}4 \pm 0{,}3$	11 ± 8	$0{,}00 \pm 0{,}09$
$\Phi_\mu = \pi$	$192{,}7 \pm 0{,}4$	$352{,}4 \pm 0{,}3$	11 ± 8	$< -0{,}3$

Conclusions

- Charginos might be first discovered SUSY particles
- Importance of polarized beams for determining masses and mixing angles in chargino/neutralino sector
- Joined analysis of chargino/neutralino sector provides precise values of SUSY M_1, M_2, μ parameters
- $\tan\beta$ needs to be determined from Higgs sector
- More detailed analysis needed to resolve CP violating phases
- To be done: full analysis including radiative corrections and CP-odd phases