Phenomenology of the chargino and neutralino systems

LCWS 2000
Fermilab

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Question: How to determine fundamental SUSY parameters in a model independent way in the chargino and neutralino systems.

Answer based on:

- Choi, Djouadi, Dreiner, J.K, Song, Zerwas
  EPJC7, C8, C14, PLB 478
- Moortgat-Pick, Fraas, Bartl, Majerotto
  EPJC 7, C9, PRD59
- Kneur, Moultaka
  PRD 59, D61
- Choi, JK, Moortgat-Pick, Zerwas, in prep.

(earlier work Bartl et al '86, '89
Tsukamoto et al. '95
Feng et al. '95)

Analysis in unconstrained MSSM including CP phases with R_p-conserving, at e^+e^- collider.

See also Diaz, Blöchinger, Plehn

1. The goal

- in MSSM many new fundamental parameters
  - gauge ~ $g_{q\tilde{g}\tilde{q}}$, $g_{\tilde{g}\tilde{g}g}$, ...
  - ~~SUSY~~ ~ M_i, A_i, $m_{\tilde{Q}}$, $m_{\tilde{L}}$, ... μ
- after SUSY discovered, measure parameters in a <u>model-independent</u> way
  - verify SUSY relations
  - check for any relations among them
    $\Rightarrow$ learn about ~~SUSY~~ mechanism
- two-step procedure

$$\begin{pmatrix} M_i \\ \mu \\ \tan\beta \\ A_i \\ \vdots \end{pmatrix} \Longleftrightarrow \begin{pmatrix} m_{\tilde{\chi}_i} \\ \phi_L, \phi_R \\ m_{\tilde{q}} \\ \vdots \\ \phi_{\tilde{t}} \\ \vdots \end{pmatrix} \Longleftrightarrow \begin{pmatrix} \sigma_{tot} \\ \sigma_L, \sigma_R \\ \frac{d\sigma}{d\cos\theta} \\ \vdots \end{pmatrix}$$

fundamental   physical   observables

- need strategy

-inos	charginos	M_2, μ, $\tan\beta$
	neutralinos	" $+ M_1$
	sleptons	$+ \ldots$
	$\vdots$	

Kneur, Moultaka '99

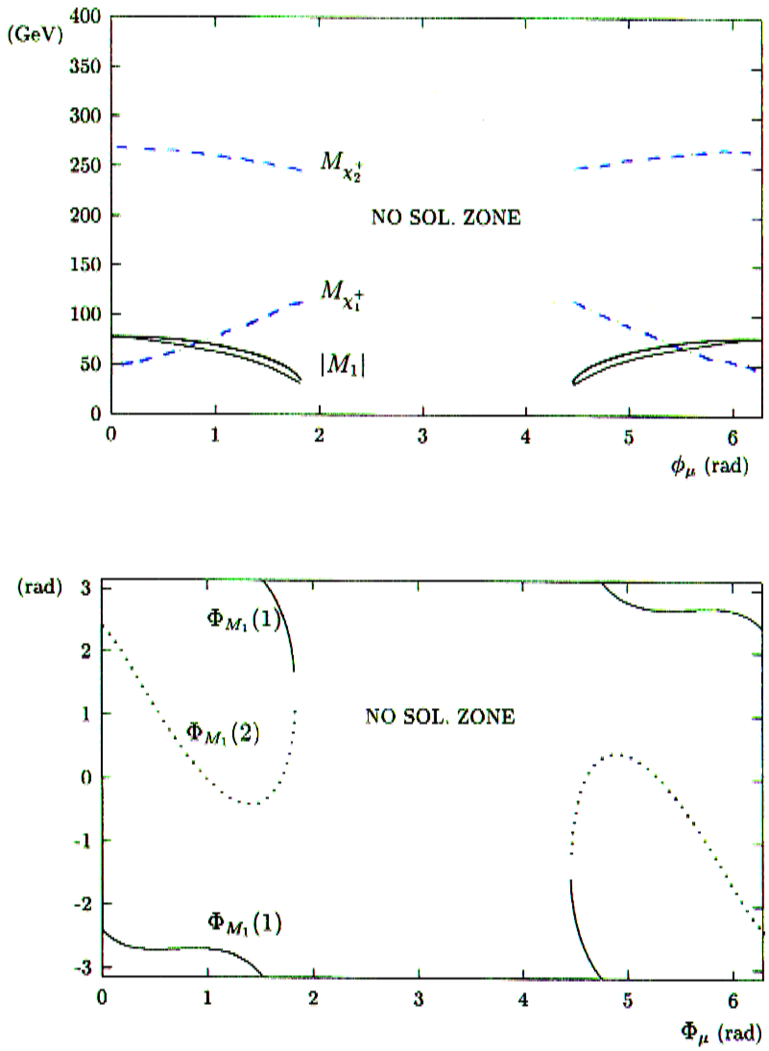
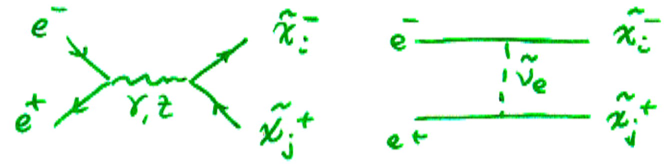


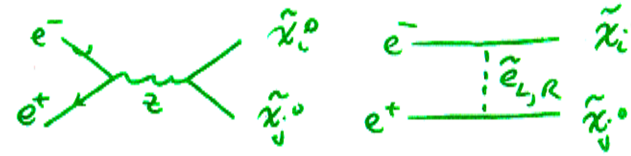
Figure 1: the twofold $|M_1|$ (top figure) and Φ_{M_1} (bottom figure) reconstruction with input choice $|\mu| = 100$ GeV, $M_2 = 120$ GeV, $M_{N_1} = 40$, $M_{N_2} = 80$; $\tan\beta = 2$. Also shown are the corresponding chargino mass values.

3. -Ino pair-production processes

chargino:



neutralinos:



$+ \; i \leftrightarrow j$

After Fierz-ing t- and u-channel exchanges

$$\mathcal{A}^{ij} = \frac{e^2}{s} Q^{ij}_{\alpha\beta} \left[\bar v(e^+)\gamma^\mu P_\alpha u(e^-)\right]\cdot\left[\bar u(\tilde\chi_i)\gamma_\mu P_\beta v(\tilde\chi_j)\right]$$

$$\alpha, \beta = L, R$$

where, for example:

chargino $\tilde\chi_1^+\tilde\chi_1^-$ $\quad Q^{11}_{LL} = D_L - F_L \cos 2\phi_L$

for neutralinos $\tilde\chi_i^0\tilde\chi_j^0$ $\quad Q^{ij}_{LL} = \alpha Z_{ij} - \beta g^L_{ij}$

$$Z_{ij} = \frac{1}{2}\left(N_{i3}N_{j3}^* - N_{i4}N_{j4}^*\right)$$

$$g^L_{ij} = \frac{1}{4 s_W^2 c_W^2}\left(N_{i2}\, s_W + N_{i1}\, s_W\right)\left(N_{j2}^* c_W + N_{j1}^* s_W\right)$$

Note:

(a) for charginos: $Q_{\alpha\beta}$ linear in $\cos 2\phi_L$, $\cos 2\phi_R$
$\tilde\nu_e$ only in the LR amplitude

(b) for neutralinos: more complicated dep. on mixing
$\tilde e_{L,R}$ in all amplitudes.

Measuring chargino masses and mixing angles

masses : a) from energy scan

b) $e^+e^- \to \tilde{\chi}_i^+ \tilde{\chi}_j^-$

$\hookrightarrow \chi_1^0 jj, \ \chi_1^0 \ell \nu$

di-jet energy or mass distribution

error $\sim$ 0.05 – 0.2 GeV (Blair, Martyn '99)
also $m_{\tilde{\chi}_1^0}$ determined.

mixing angles

a) if only $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ produced

- exploit $\tilde{\chi}^\pm$ – polarization or
- use transverse beam polarization

b) if all $\tilde{\chi}_i^+ \tilde{\chi}_j^-$

σ_L, σ_R sufficient

$\Rightarrow$ unique solution for $\cos 2\phi_L, \cos 2\phi_R$

note: $\tilde{\nu}_e$ contribution essential

here we assume $m_{\tilde{\nu}_e}$ known from other processes (Peskin)

or $\chi_1^+ \tilde{\chi}_1^- \to \tilde{\chi}^0 e \tilde{\nu}_e$ (Moortgat-Pick, Fraas)

mSUGRA	RR1	RR2
$\tan\beta$	3	30
m_0	100	160
$m_{1/2}$	200	200
$m_{\tilde{\chi}_1^\pm}$	128	132
$m_{\tilde{\chi}_2^\pm}$	346	295
$m_{\tilde{\nu}}$	166	206
$m_{\tilde{\chi}_1^0}$	70	72

Choi et al.

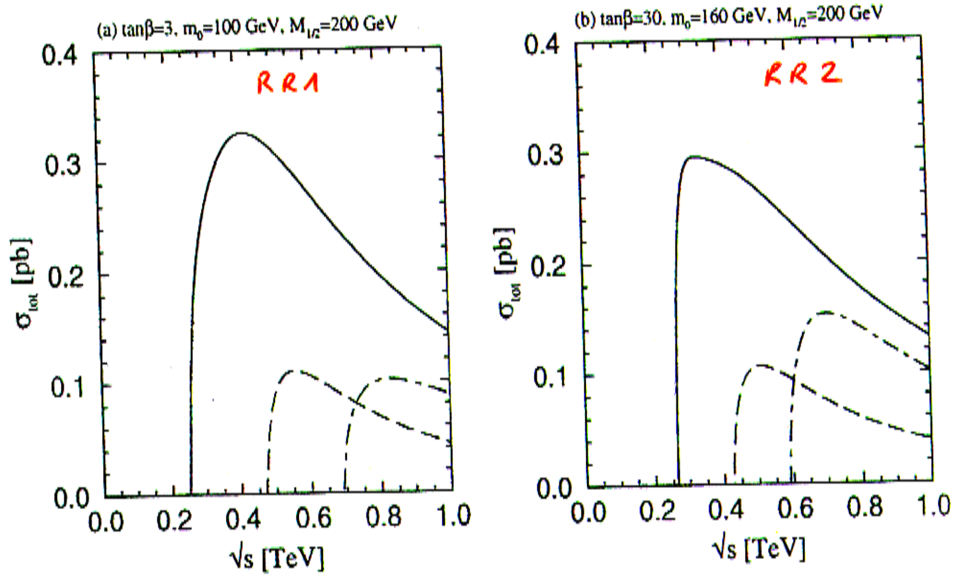


Figure 2: *The cross sections for the production of charginos as a function of the c.m. energy (a) with the set* [$\tan\beta = 3, m_0 = 100\,\mathrm{GeV}, M_{1/2} = 200\,\mathrm{GeV}$] *and (b) with the set* [$\tan\beta = 30, m_0 = 160\,\mathrm{GeV}, M_{1/2} = 200\,\mathrm{GeV}$]*: solid line for $\tilde{\chi}_1^-\tilde{\chi}_1^+$ production, dashed line for $\tilde{\chi}_1^-\tilde{\chi}_2^+$ production, and dot-dashed line for $\tilde{\chi}_2^-\tilde{\chi}_2^+$ production.*

M_2	152	150
μ	316	263

Chargino Production

$\boxed{e^+e^- \to \chi_1^+\chi_1^-}$

H.U. Martyn
G. Blair

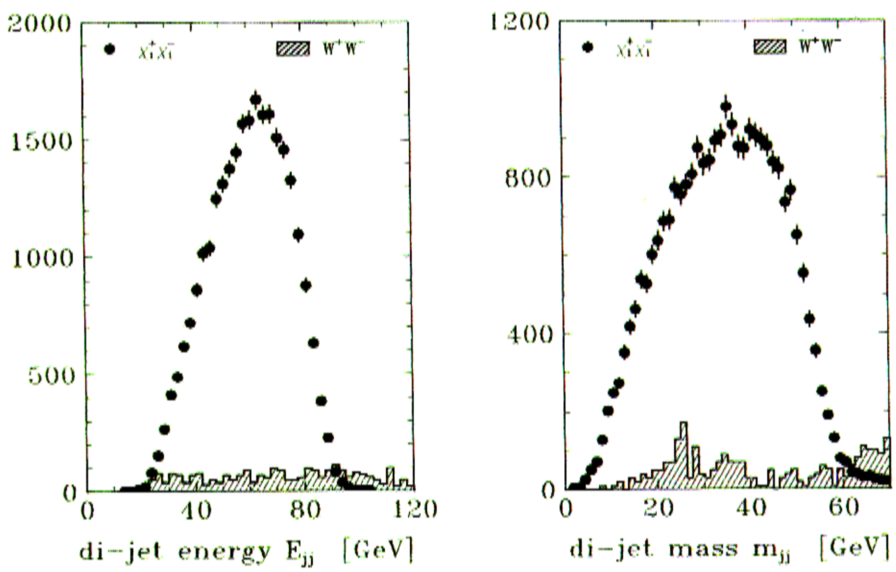
$$e^+e^- \to \chi_1^+\chi_1^-$$
$$\to l^\pm \nu \chi_1^0 \, q\bar{q}'\chi_1^0 \qquad Br = 2 \cdot 0.45 \cdot 0.55$$

background:

$W^+W^- \quad < 10\%$

$\Rightarrow m_{\chi_1^\pm}$ **and** $m_{\chi_1^0}$ **from di-jet energy and mass spectra**

$\sqrt{s} = 320$ GeV



$m_{\chi_1^\pm} = 127.7 \pm 0.2$ GeV $\qquad \Delta m(\chi_1^\pm - \chi_1^0) = 55.8 \pm 0.15$ GeV

$\sigma(e_L^- e_R^+)\,\mathcal{B} = 330 \pm 1.5$ fb

Scan at threshold, 10 fb^{-1}/point $\Rightarrow$ $\Delta m = 0.04$ GeV

Moortgat-Pick, Fraas '99

[7] G. Moortgat-Pick, H. Fraas, A. Bartl, W. Majerotto, Eur. Phys. J. **C 7** (1999) 113.

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[10] S. Ambrosanio, G.A. Blair, P. Zerwas, ECFA-DESY LC-Workshop, 1998.

[11] S.P. Martin, P. Ramond, Phys. Rev. **D 48** (1993) 5365.

[12] A. Bartl, H. Fraas, W. Majerotto, B. Mösslacher, Z. Phys. **C 55** (1992) 257.

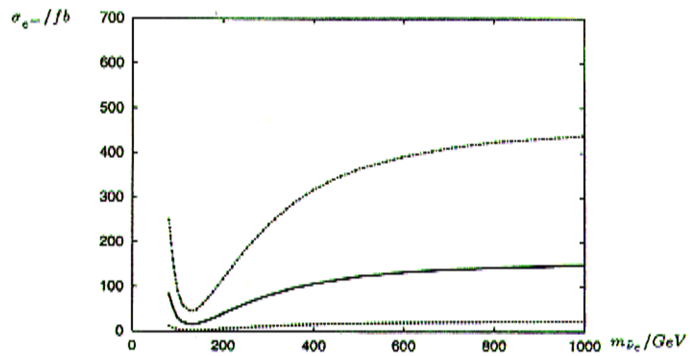
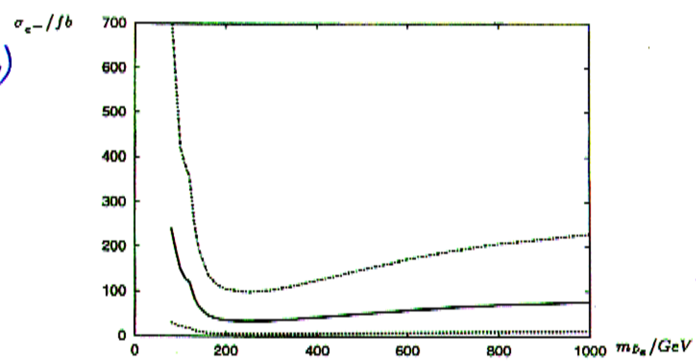


Fig. 1: Cross section σ_{e^-} (see eq. (1)) for $\sqrt{s} = 270$ GeV in scenario A for unpolarized beams (solid line), with only e^- beam polarized $P_- = +85\%$ (dotted line) and with both beams polarized $P_- = -85\%$, $P_+ = +60\%$ (dash-dotted line).

σ_{e^-} (fb)



$m_{\tilde\nu_e}$

10

Fig. 2: Cross section σ_{e^-} (see eq. (1)) for $\sqrt{s} = 500$ GeV in scenario A for unpolarized beams (solid line), with only e^- beam polarized $P_- = +85\%$ (dotted line) and with both beams polarized $P_- = -85\%$, $P_+ = +60\%$ (dash-dotted line).

Mixing angles in the neutralino sector:

in general 6 angles + 10 phases

for $|M_1|, |M_2| \gg |\mu|$ or $\ll |\mu|$

approximate analytical expressions can be found

CKMZ, in prep

$$N^* \mathcal{M}_N N = \mathcal{M}_{diag}$$

$$N^* = \begin{pmatrix} e^{-i\alpha_1} & & & \\ & e^{-i\alpha_2} & & \\ & & e^{-i\alpha_3} & \\ & & & e^{-i\alpha_4} \end{pmatrix} \begin{pmatrix} 1 & & & \\ & 1 & & \\ & & c_{34} & s_{34} \\ & & -s_{34}^* & c_{34} \end{pmatrix} \begin{pmatrix} c_{13}c_{14} & s_{12} & s_{13} & s_{14} \\ -\tilde{s}_{12} & c_{23}c_{24} & s_{23} & s_{24} \\ -s_{13}^* & -s_{24}^* & -s_{12}s_{14}^* - s_{23}s_{24}^* & c_{14}c_{24} \end{pmatrix}$$

$c_{ij} = \cos\theta_{ij}$, $s_{ij} = \sin\theta_{ij}\, e^{i\delta_{ij}}$

e.g. $s_{13} = -\dfrac{m_Z s_W}{|M_1|^2 - |\mu|^2}\left(M_1 e^{i\Phi_1} c_\beta + \mu e^{-i\Phi_\mu} s_\beta\right)$

$\vdots$

very complicated

<u>However,</u> use unitarity of diagonalization matrices to check completeness of $(\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm)$ and $(\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0)$ systems

$\Rightarrow$ first check the completeness of $(\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm)$

* sum rules from 2×2 mixing

for couplings: $\sum_{i,j=1,2} |Q^{ij}_{\alpha\beta}|^2 = 2\left(|D_\alpha|^2 + |F_\alpha|^2\right)$

$\alpha\beta = LL,\ RL,\ RR$

does not depend on ANY SUSY param!

for cross sections: (for $\sqrt{s} \gg m_\chi, m_{\tilde{\nu}}$)

$$\sum_{i,j=1,2} (\sigma_L^{ij} + \sigma_R^{ij}) = \frac{347\ \mathrm{fb}}{s/(\mathrm{TeV})^2}\left(1 + O\left(\frac{m^2}{s}\right)\right)$$

$\to F$

at finite energy: $\sigma_L^{ij}, \sigma_R^{ij}$ quadratic function of $x = \cos 2\phi_L$, $y = \cos 2\phi_R$

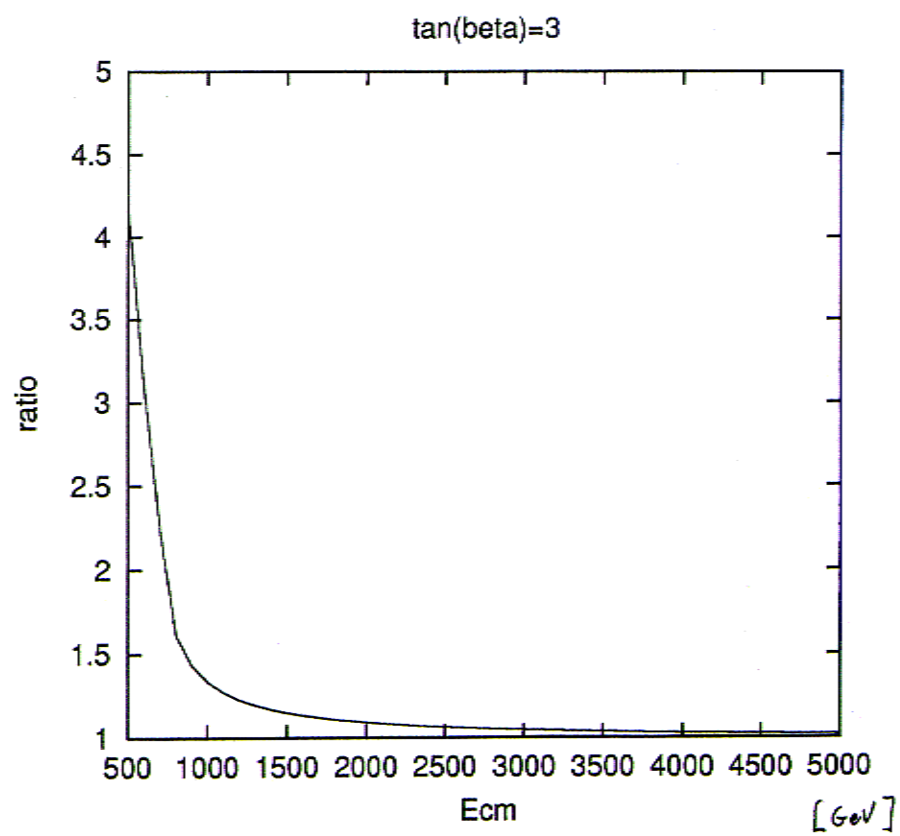
$\Rightarrow$ nontrivial consistency conditions for measured cross sections

* for neutralinos 4×4 mixing

$$\sum_{i,j=1,\ldots,4} (\sigma_L^{ij} + \sigma_R^{ij}) = \frac{325\ \mathrm{fb}}{s/(\mathrm{TeV})^2}\left(1 + O\left(\frac{m^2}{s}\right)\right)$$

$\to F$

charginos

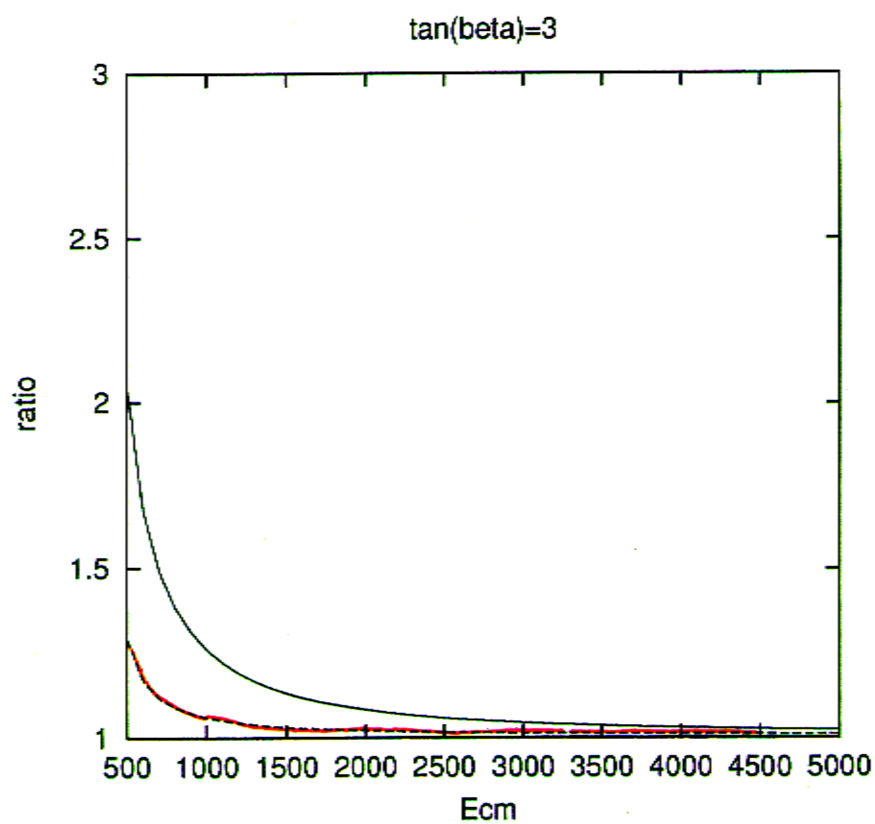


$\frac{\text{asymptotic}}{\text{exact}}$

CKMZ

neutrinos

$$\sum_{ij} \sigma_{ij}^{as} = \frac{\pi\alpha^2}{8s}\left[\frac{8}{3}\left(\frac{s_w^2-\frac{1}{2}}{s_w^2 c_w^2}\right)^2 + \frac{8}{3}\frac{1}{c_w^4} + \frac{16}{c_w^4} + \frac{1}{s_w^4 c_w^4}\right]$$



$\frac{\text{asymptotic}}{\text{exact}}$

$\frac{\text{including } m^2/s \text{ corrections}}{\text{exact}}$

Conclusions

- charginos + neutralinos = overconstrained system
- $\sigma_{L,R}$ + masses $\Rightarrow$ couplings $\Rightarrow$ complete determination
- analytic algorithms $\Rightarrow$ M_2, $M_1 e^{i\Phi_1}$, $\mu e^{i\Phi_\mu}$, $\tan\beta$
  (→ Plehn)
- expected errors under control
  except for large $\tan\beta$
- sum rules for completeness checks
  (consistency)
- radiative corrections
  - other parameters enter
  - global analyses needed
  (→ Diaz
  also T. Blank + W. Hollik)
- other LC modes
  $e\gamma$, $\gamma\gamma$ → Blöchinger