Neutralino relic density in the CPVMSSM and the ILC

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LAPTH

G. B, O. Kittel, S. Kraml, H. Martyn, A. Pukhov, hep-ph/08032584, Phys.Rev.D

Motivation

ILC measurements

DM properties: fit to observables

Other constraints

Motivation

- WMAP and SDSS gives precise information on the amount of dark matter
- Most attractive explanation for dark matter: new weakly interacting particle - for example neutralino in SUSY models
- One challenge at colliders after discovery of new particles, measurement of their properties and "collider prediction" of relic density of DM
  - Check whether matches what has been measured in the sky
  - Confront standard cosmological picture
- Precision measurements at colliders are needed
- How difficult strongly depends on the details of the new physics model – which SUSY scenario, what is the dominant DM annihilation process
- Studies exist for both LHC and ILC in CMSSM and MSSM – bulk scenario, stau coannihilation- focus point scenario
  - Polesello, Tovey, Nojiri, Martyn, Bambade et al, Baltz et al,

Collider prediction of relic density in a CPVMSSM scenario

- MSSM generically has phases, although constrained from edm ..
- CPVMSSM could explain baryogenesis

- What needs to be measured?
  - Masses : LSP, NLSP + other particles that contribute to dominant process
  - Couplings of LSP: modification of coupling, for example due to a phase, can impact value of Ωh^2 by one order of magnitude - G.B. et al. hep-ph/0604150

Stau-bulk scenario

Input parameters

$$
\begin{aligned}
M_1 &= 80.47\mathrm{GeV} \quad M_2 = 170.35\mathrm{GeV} \quad M_3 = 700\mathrm{GeV} \quad \phi_1 = 180 \\
\mu &= 600\mathrm{GeV} \quad \tan\beta = 10 \quad \phi_\mu = 0 \\
M_{\tilde{\tau}_L} &= 138.7\mathrm{GeV} \quad M_{\tilde{\tau}_R} = 135.2\mathrm{GeV} \quad A_\tau = 60\mathrm{GeV} \quad \phi_\tau = 0
\end{aligned}
$$

Mass spectrum

	$\tilde{\chi}_1^0$	$\tilde{\chi}_2^0$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$	$\tilde{\chi}_1^+$	$\tilde{\chi}_2^+$	h_1	$h_{2,3}$
	80.7	164.9	604.8	610.5	164.9	612.1	116.1	997.

	$\tilde{\tau}$	$\tilde{\nu}_\tau$	$\tilde{e}$	$\tilde{\nu}_e$	$\tilde{u}$	$\tilde{d}$	$\tilde{t}$	$\tilde{b}$
R(1)	100.9	–	1000.9	–	999.4	1000.3	939.1	995.6
L(2)	177.2	123.1	1001.1	998.0	998.6	1001.7	1075.6	1006.4

Light gauginos and staus, staus are strongly mixed

LSP annihilates into tau pairs via stau exchange in t-channel – efficient if staus are mixed -- no coannihilation

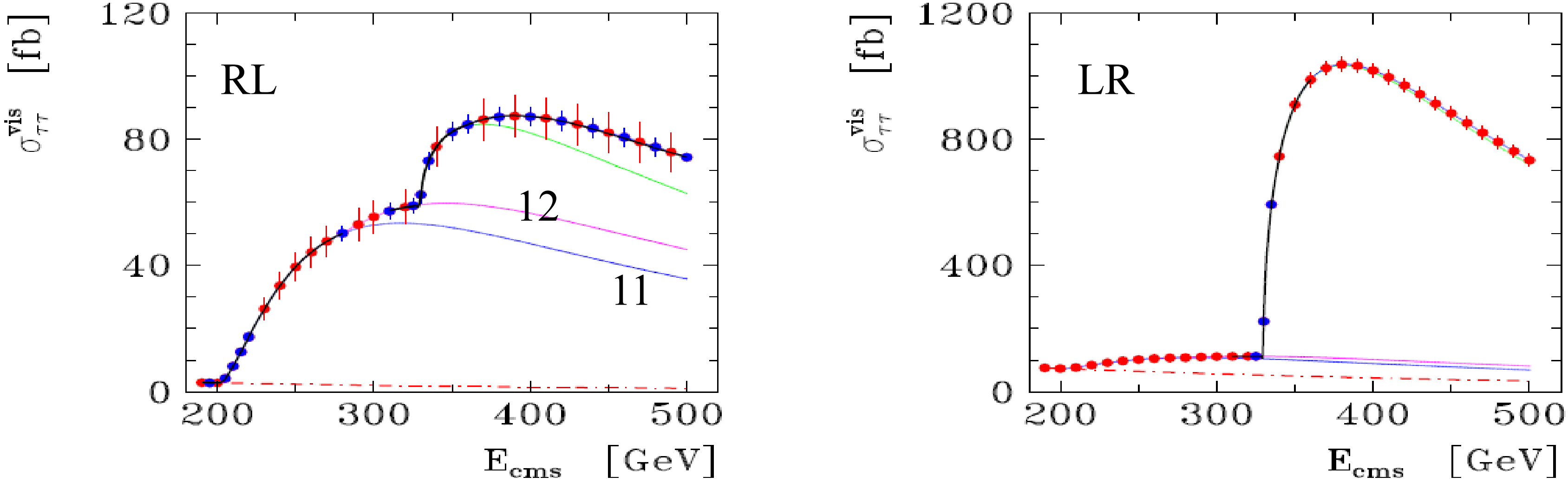
ILC - measurements

- All signals in $\tau\tau E_{miss}$ - disentangle sources – determine parameters
  - Threshold scans
  - LSP mass from stau decays (endpoint energy spectrum in τ-- $\pi\nu$, $\rho\nu$,$3\pi\nu$)
  - Stau mixing angle from polarised cross section
  - Tau polarisation

Event generation

- SIMDET4.02 acceptance 125mrad
- e,γ veto >4.6mrad
- PYTHIA 6.2 with beam polarisation (0.8,0.6)
- QED radiation beamstrahlung –CIRCE
- τ decays –Tauola
- SM backgrounds: W pair
- SM ee->ττ and ee->ee ττ – negligible
- Selection for signal : two acoplanar jet in central region (|cosθ|<0.75)
- Efficiency ~0.32

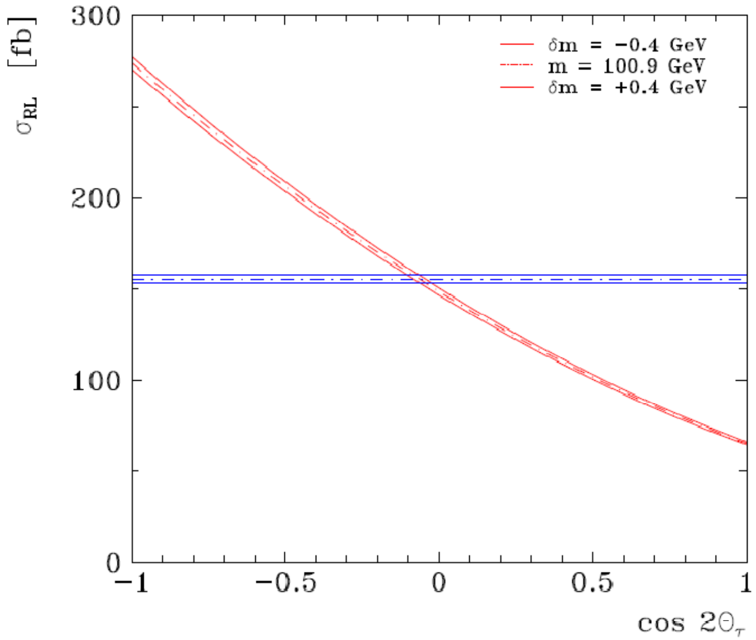
Mass from threshold scans



- $e^-_R e^+_L$ for staus, LR for chargino
- Excitation curve: β^3 for stau, β for chargino, use $2fb^{-1}$ at each energy
- Mass of τ_1 τ_2 χ^+

Stau mixing angle

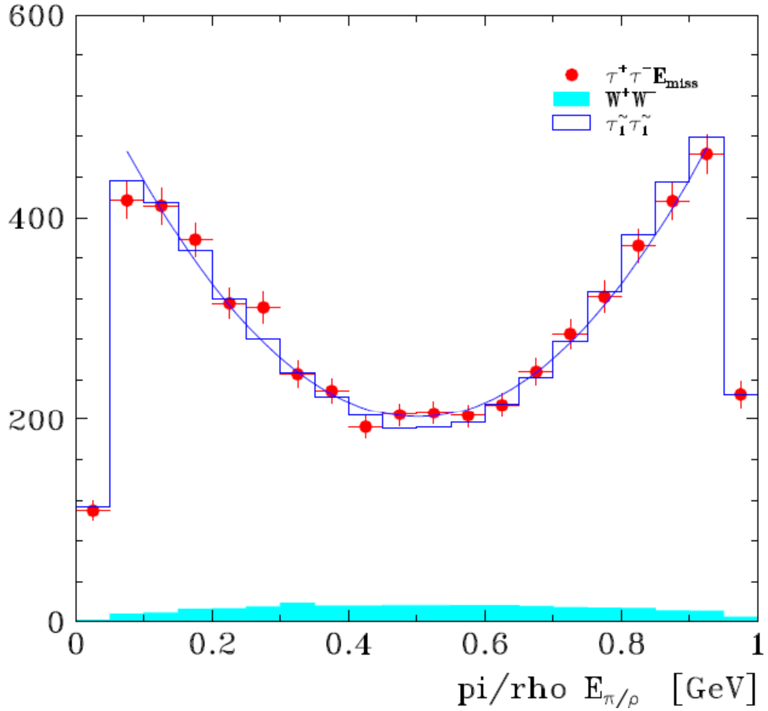
- Polarised cross section (RL) at 280 GeV (below threshold for other sparticles)
- σ_{RL} depend on mixing angle
- To improve accuracy combine with σ_{LR}
- Δm_{τ}=0.35GeV; $\delta\cos 2\theta$=0.017



•Integrated luminosity 200fb^{-1}

Tau polarisation

- P_τ from stau decay depends on stau and neutralino mixing
  - τ mixing from polarized σ_{RL}
  - P_τ - gaugino-Higgsino component of LSP
- $\tau \to \rho\nu \to \pi\pi\nu$
- E_π / E_ρ – sensitive to P_τ
  - τ_R - ρ longitudinal E_ρ peak z=0,1
  - τ_L - ρ transverse- E_ρ peak at z=0.5

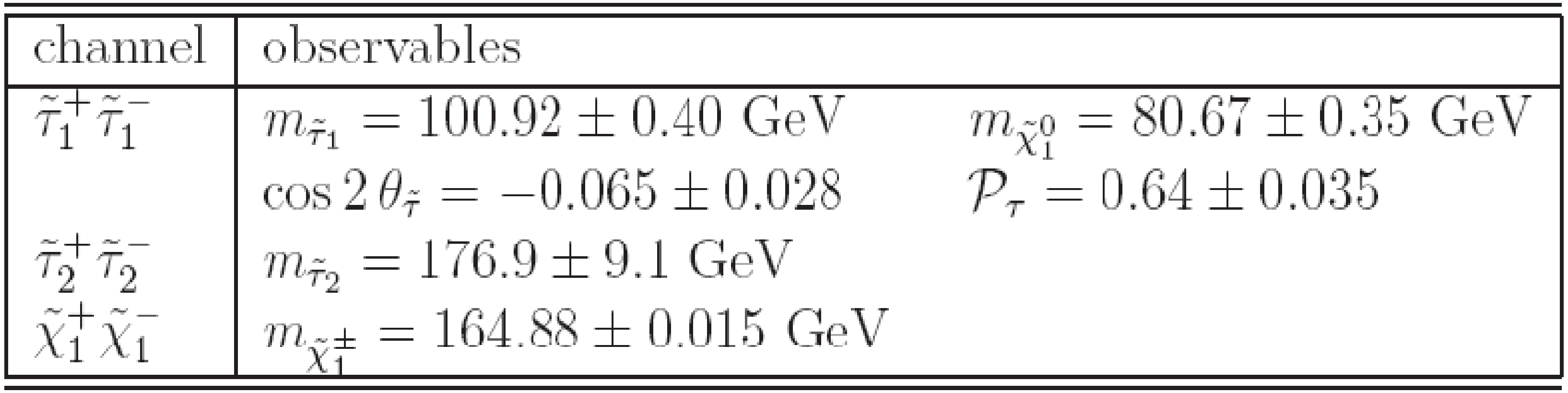


•Integrated luminosity 200fb^{-1}

$$\mathcal{P}_\tau = 0.64 \pm 0.035$$

ILC measurements-summary

- Mass from threshold scans
- LSP mass from stau decays
- Stau mixing angle from polarised cross section
- Tau polarisation

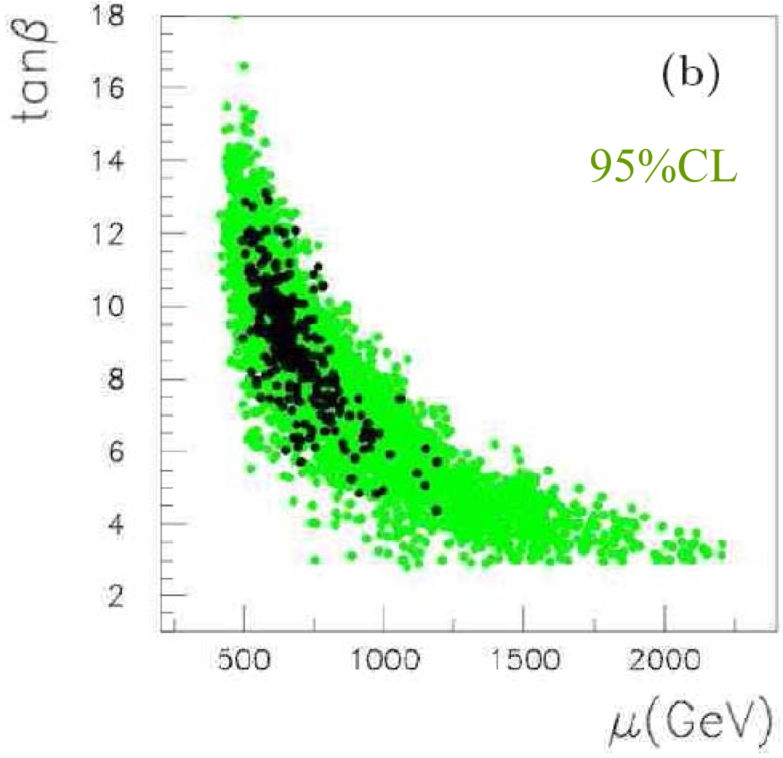


channel	observables	
$\tilde{\tau}_1^+\tilde{\tau}_1^-$	$m_{\tilde{\tau}_1} = 100.92 \pm 0.40$ GeV	$m_{\tilde{\chi}_1^0} = 80.67 \pm 0.35$ GeV
	$\cos 2\,\theta_{\tilde{\tau}} = -0.065 \pm 0.028$	$\mathcal{P}_\tau = 0.64 \pm 0.035$
$\tilde{\tau}_2^+\tilde{\tau}_2^-$	$m_{\tilde{\tau}_2} = 176.9 \pm 9.1$ GeV	
$\tilde{\chi}_1^+\tilde{\chi}_1^-$	$m_{\tilde{\chi}_1^\pm} = 164.88 \pm 0.015$ GeV	

DM properties : fit to ILC observables

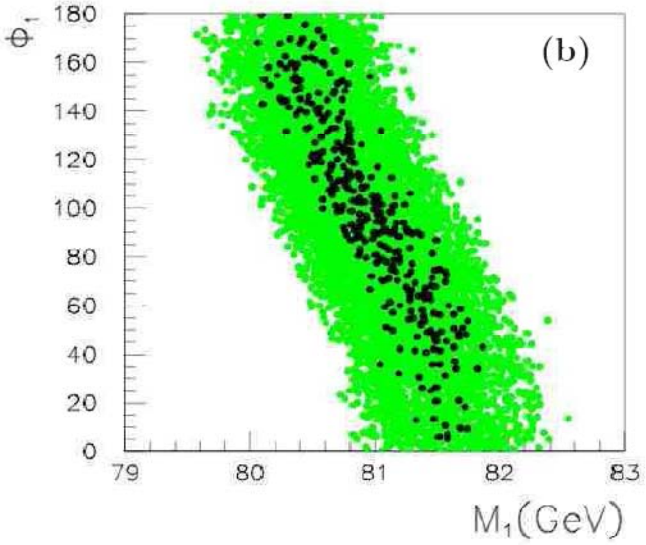
- Fit to $m_{\tau 1,} m_{\tau 2}\ m_{\chi,}\ m_{\chi +,}\ \cos\theta_{\tau}, P_{\tau}$
- Total σ(ττ) @400GeV
- Free parameters:

  M_1, μ, tanβ, M_{L3}, M_{R3},A_{τ}, Φ_1,Φ_{τ}
- Check a posteriori that M_A, M_e small influence on Ωh^2 if M > 250 GeV
- MCMC method for efficient probing of parameter space

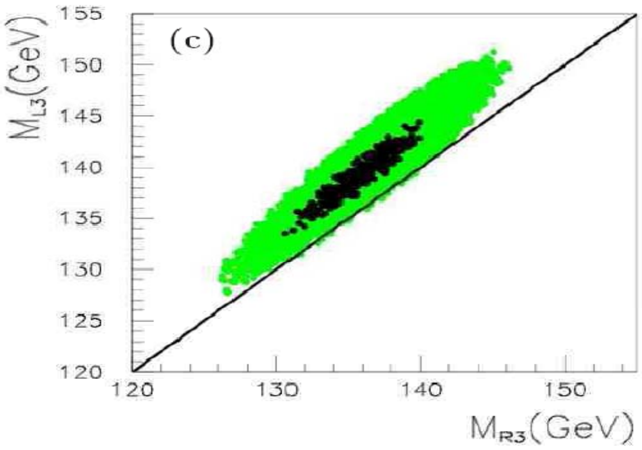


Large allowed parameter space for μ-tanβ
– strongly correlated because stau mixin

…fit to ILC observables



- M_1 (1-2GeV) and M_2(~4GeV) well determined
- φ_1 arbitrary but correlated with M_1
- About 10GeV on M_{L3},M_{R3} and $M_{R3} < M_{L3}$ only
- A_τ,φ_τ undetermined



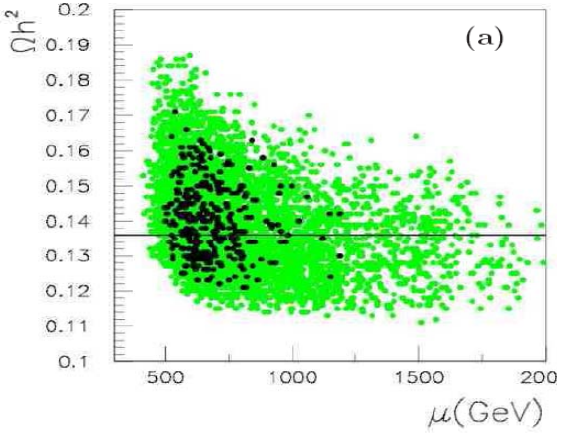
Impact on relic density

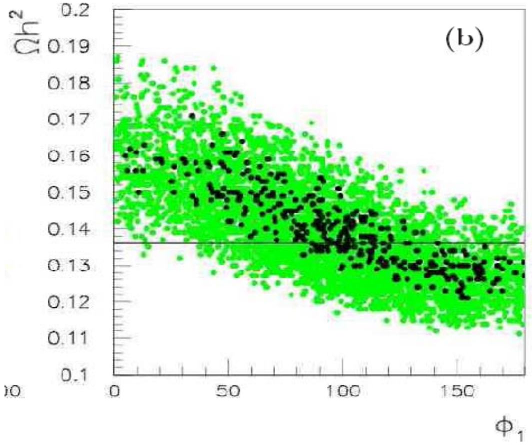
- Allowed region
  $0.116 < \Omega h^2 < 0.19$

- WMAP: $0.094 < \Omega h^2 < 0.136$

- Ωh^2 large only for small μ– more Higgsino component
- Need large phase to be below WMAP upper bound

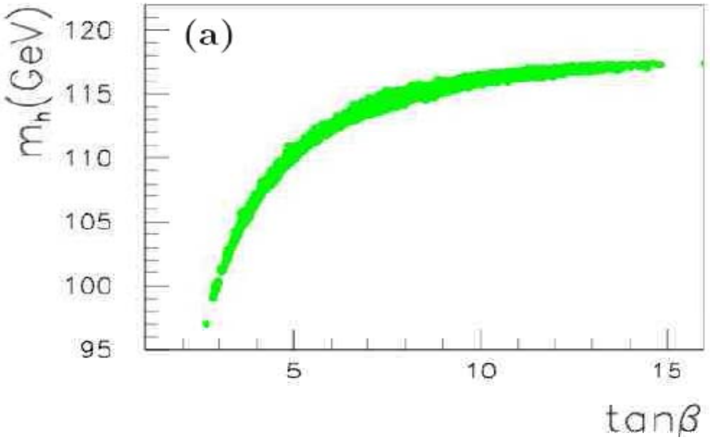
- Within real MSSM $M_1 > 0$ would conclude that Ωh^2 too large



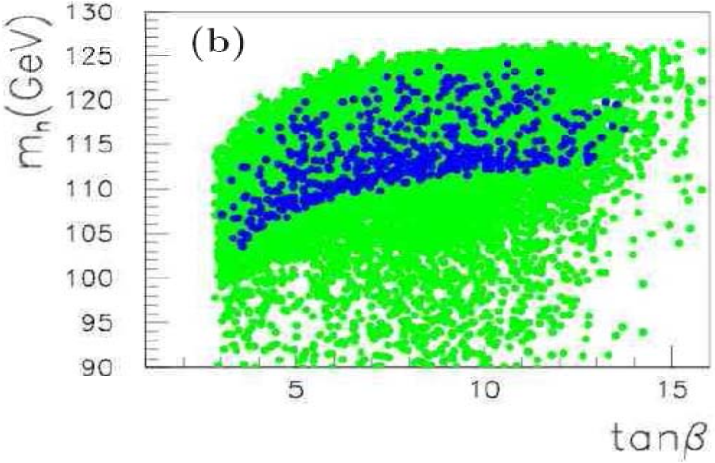


Higgs mass

- M_h is measured precisely but large parametric uncertainty - - masses of stops unknown



- Even if 10% accuracy on stop mass from LHC large range of tanβ allowed



CP-odd observables

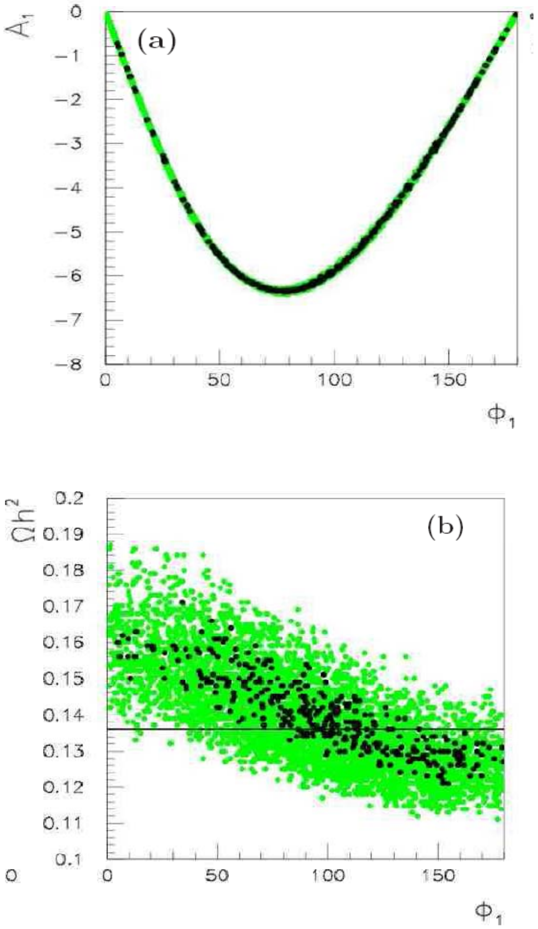
- T-odd asymmetry in ee--$\chi_1\chi_2$ with 2body decays

$$\tilde{\chi}_2^0 \to \tilde{\tau}_1^{\pm}\tau^{\mp},\ \tilde{\bar{\tau}}_1^{\pm} \to \tilde{\chi}_1^0\tau^{\perp}$$

$$A_1 = \frac{\sigma(\mathcal{T}>0)-\sigma(\mathcal{T}<0)}{\sigma(\mathcal{T}>0)+\sigma(\mathcal{T}<0)},$$

$$\mathcal{T} \quad = \quad (\mathbf{p}_{e^-} \times \mathbf{p}_{\tau^-}) \cdot \mathbf{p}_{\tau^+},$$

- Clear signal of CP violation
- No constraint on Ωh^2 – two-fold ambiguity



Stau-bulk scenario

- In addition to precise determination of parameters at ILC need also some information on the rest of the spectrum
- LHC: scale of squarks and gluino, maybe whether Higgs (H/A) is heavy – whether sleptons are heavy – gauginos
- Small influence on Ωh^2 from sleptons if heavier than 250GeV
- No nearby Higgs resonance- otherwise strong influence on Ωh^2
- If only lower limit on Higgs/sleptons – $\delta\Omega/\Omega < 7\%$

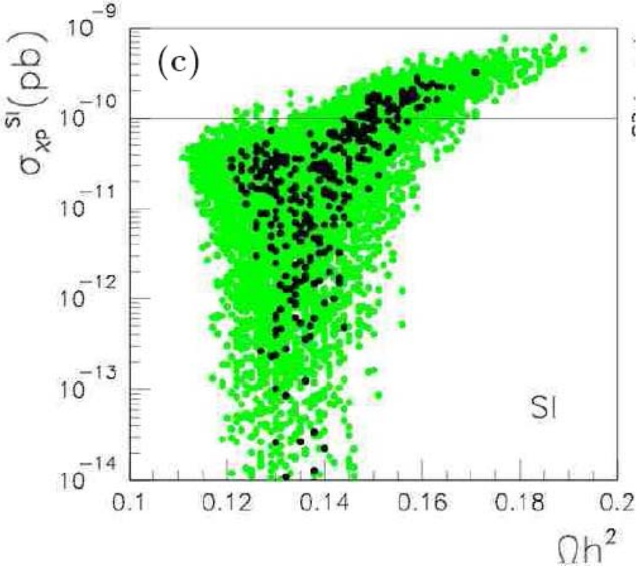
Other observables

- edm
  - Depend on selectron mass
  - Improving the sensitivity by 2 orders of magnitude probe most of parameter space of the model.
  - No direct impact on Ωh^2

- Heavy particles at colliders
  - Search for heavy Higgs at LHC (would only confirm that Higgs is irrelevant for DM annihilation – not in the favourite channel bb-$\tau\tau$)
  - Stop mass – for mh
  - Heavy chargino/neutralino – μ, tanβ : LHC cross sections are small would need LC >1.5TeV to produce some of the heavy Higgsinos
- Direct detection DM
- Indirect detection DM

Direct detection

- Direct detection – new experimental limits every year Xenon/CDMS- 4x10^{-8}pb
- SI: goal 10^{-10}pb before 2018



- Dominated by Higgs exchange because squarks are heavy - for bino LSP σ^{SI} small

- Detectable rate only for μ small
  - No signal $0.116 < \Omega h^2 < 0.17$

Conclusion

- The stau-bulk in the CPV-MSSM is example of a scenario where determination of masses AND couplings matter - challenging for ILC
- Collider prediction $0.116 < \Omega h^2 < 0.19$
- Phases are important – with mass measurement at ILC in real MSSM would conclude that relic density is too large : also search for CP violating signal in asymmetries or edm.