

Neutralino relic density in the CPVMSSM and the ILC

G. Bélanger
LAPTH

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

Neutralino relic density in the CPVMSSM and the ILC

G. Bélanger
LAPTH

**G. B, O. Kittel, S. Kraml, H. Martyn, A. Pukhov, hep-ph/08032584,
to appear in 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
- “Doing cosmology at colliders” : discovery of new particles and measurement of their properties →
 - “collider prediction” for the relic density of DM
 - 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,

Cosmology at colliders in a CPVMSSM scenario

- MSSM generically has phases, although constrained from edm .. CPVMSSM could explain baryogenesis
- Relic density depends strongly on masses of LSP, NLSP but also on couplings, in particular CP phases can impact value of Ωh^2 by one order of magnitude - G.B. et al. hep-ph/0604150
- Specific CPVMSSM scenario, the stau-bulk scenario
 - Light gauginos and staus, staus are strongly mixed
 - LSP annihilates into tau pairs – stau exchange in t-channel – no coannihilation
 - In MSSM this scenario is possible if $M_1 < 0$
 - Other fermions are heavy (TeV scale) to satisfy easily edm constraints

Stau-bulk scenario

Input parameters

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

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}	d	\tilde{t}	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

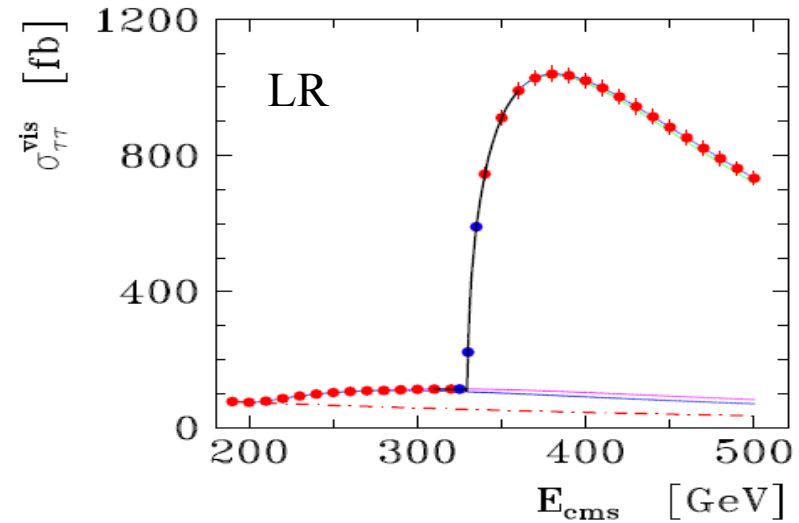
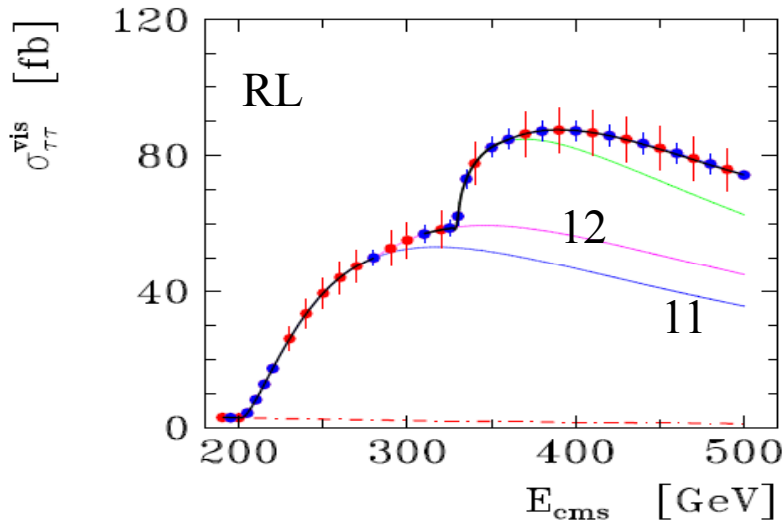
ILC - measurements

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

Event generation

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

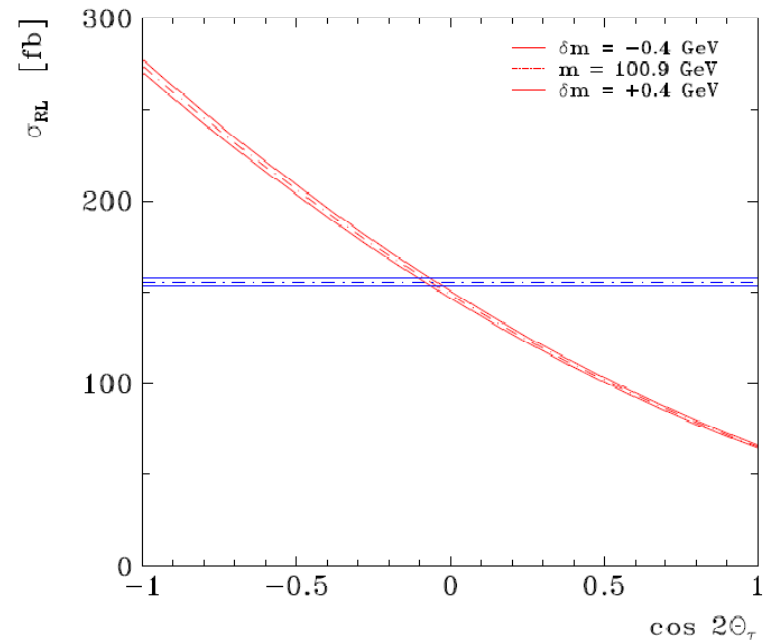
Mass from threshold scans



- $e^-_R e^+_L$ for staus, LR for chargino
- Excitation curve: β^3 for stau, β for chargino, use 2fb^{-1} at each energy
- Mass of $\tau_1 \tau_2 \chi^+$

Stau mixing angle

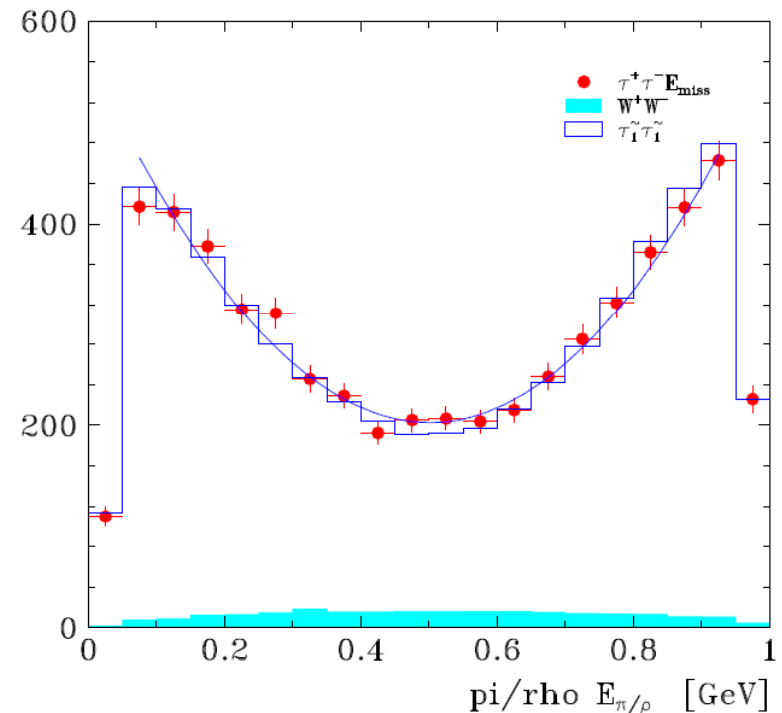
- Polarised cross section (RL) at 280 GeV (below threshold for other sparticles)
- σ_{RL} depend on mixing angle
- To improve accuracy combine with σ_{LR}
- $\Delta m_{\tau} = 0.35 \text{ GeV}$; $\delta \cos 2\theta = 0.017$



• Integrated luminosity 200 fb^{-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
- $\tau \rightarrow \rho \nu \rightarrow \pi \pi \nu$
- 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}

$$P_\tau = 0.64 \pm 0.035$$

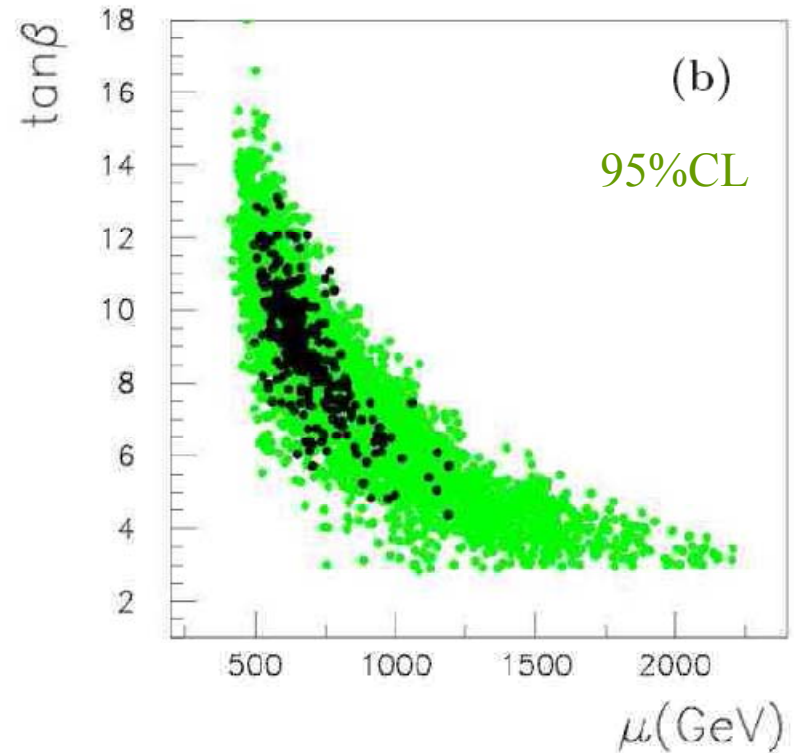
ILC measurements-summary

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

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

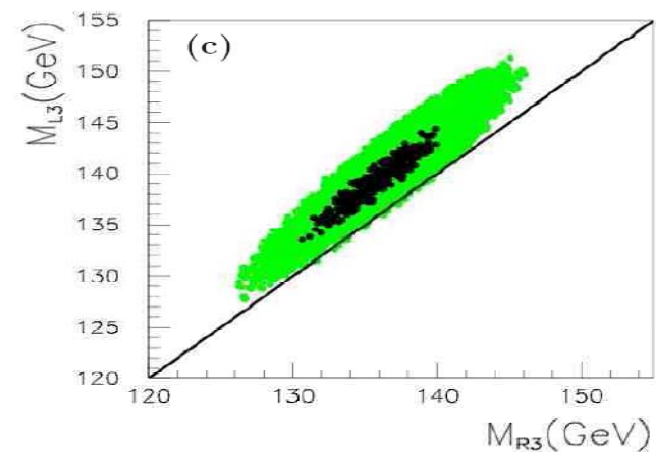
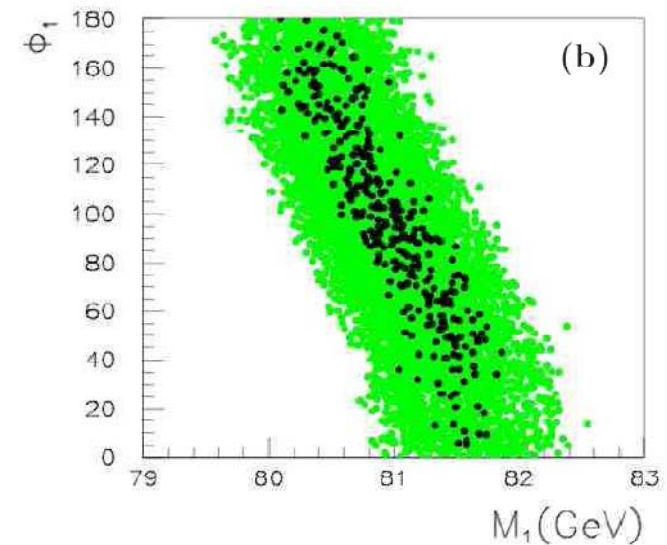
DM properties : fit to ILC observables

- Fit to $m_{\tau 1}, m_{\tau 2}, m_{\chi}, m_{\chi^+}, \cos\theta_{\tau}, P_{\tau}$
- Total $\sigma(\tau\tau)$ @400GeV
- Free parameters:
 $M_1, \mu, \tan\beta, M_{L3}, M_{R3}, A_{\tau}, \Phi_1, \Phi_{\tau}$
- MCMC method for efficient probing of parameter space
- Large allowed parameter space for μ - $\tan\beta$
 - strongly correlated because stau mixing



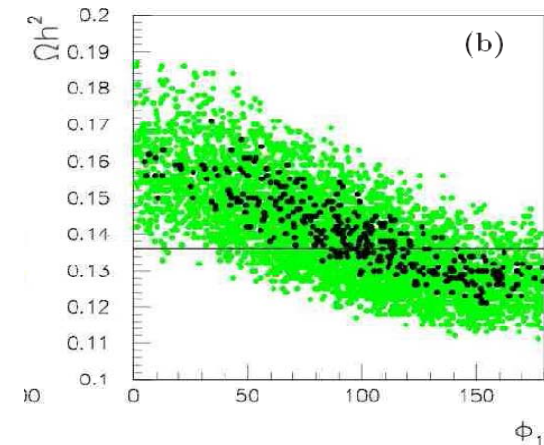
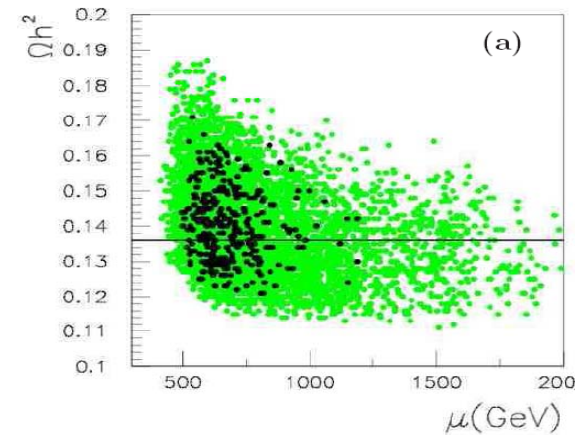
...fit to ILC observables

- 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

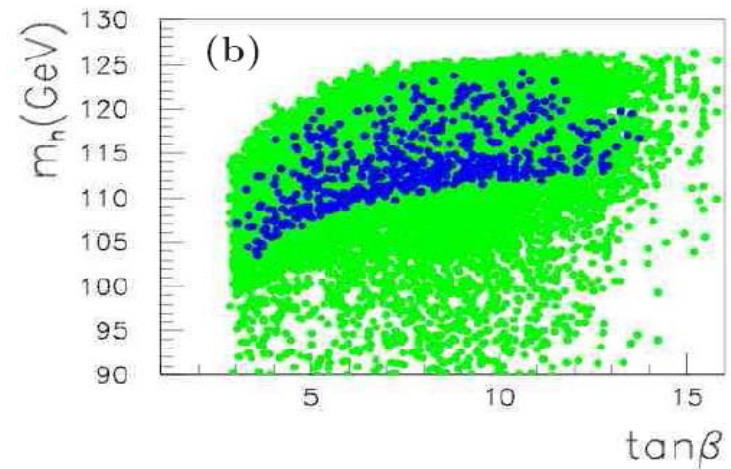
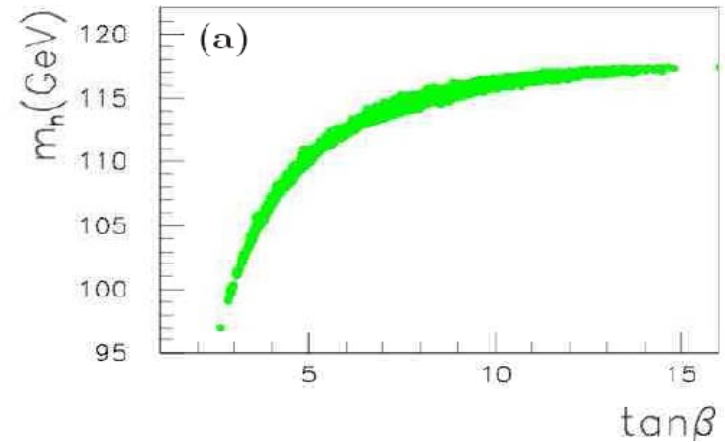


Stau-bulk scenario

- 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 – $\delta\Omega/\Omega < 7\%$

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 $\tan\beta$ allowed



CP-odd observables

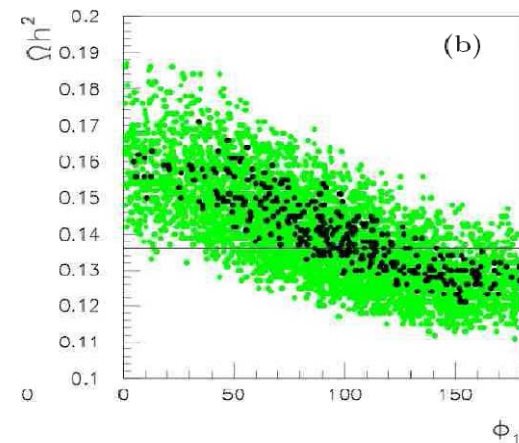
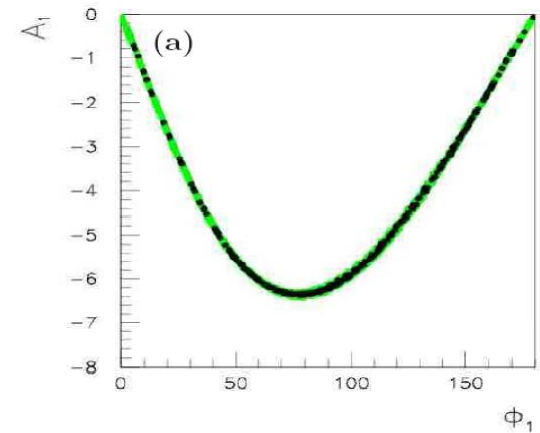
- T-odd asymmetry in $ee \rightarrow \chi_1 \chi_2$ with 2body decays

$$\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1^\pm \tau^\mp, \tilde{\tau}_1^\pm \rightarrow \tilde{\chi}_1^0 \tau^\pm$$

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

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

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

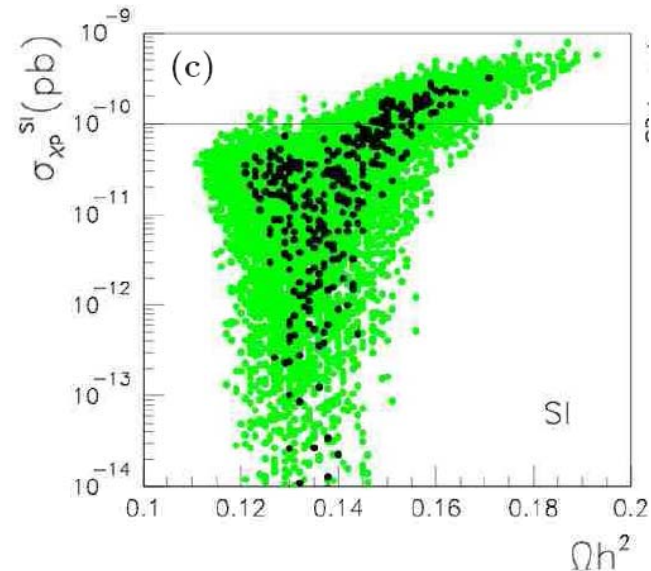


Other constraints

- 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
 - Stop mass
 - Heavy chargino/neutralino – $\mu, \tan\beta$
- Direct detection DM
- Indirect detection DM

Direct detection

- Direct detection – new experimental limits every year
Xenon/CDMS- $4 \times 10^{-8} \text{pb}$
- 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

- A precise determination of the SUSY parameters in the stau-bulk scenario in the CPV-MSSM is challenging for ILC
- Example of a scenario where determination of masses AND couplings matter
- 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
- CP violating signal in asymmetries or edm