Neutralino relic density from ILC measurements in the CPV MSSM

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Based on arXiv:0803.2584 (PRD78)

with G. Bélanger, O. Kittel, H.U. Martyn and A. Pukhov

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Motivation

- Cosmol. obs. → amount of DM: $\Omega h^2=0.11$ ±6% (!) most attractive candidate: WIMP from BSM physics.

WMAP
SDSS

- Aim at colliders (after discovery) is to do precision measurements of BSM particles, incl DM candidate
- Hope to determine properties of BSM DM at LHC/ILC
  → make a "collider postdiction" of its Ωh^2
  → test standard cosmological model
- In general, expected precision is O(10%) at LHC and few % at ILC → could match WMAP/PLANCK

Nojiri, Polesello, Tovey; Arnowitt et al.; Bambade, Berggren, Richard, Zhang; Martyn; Baltz, Battaglia, Peskin, Wizansky; Berger, Gainer, Hewett, Lillie, Rizzo.

- Need precise measurements of masses and *couplings* …

MSSM with CP violation

- In the general MSSM, gaugino and higgsino mass parameters and trilinear couplings can be complex:

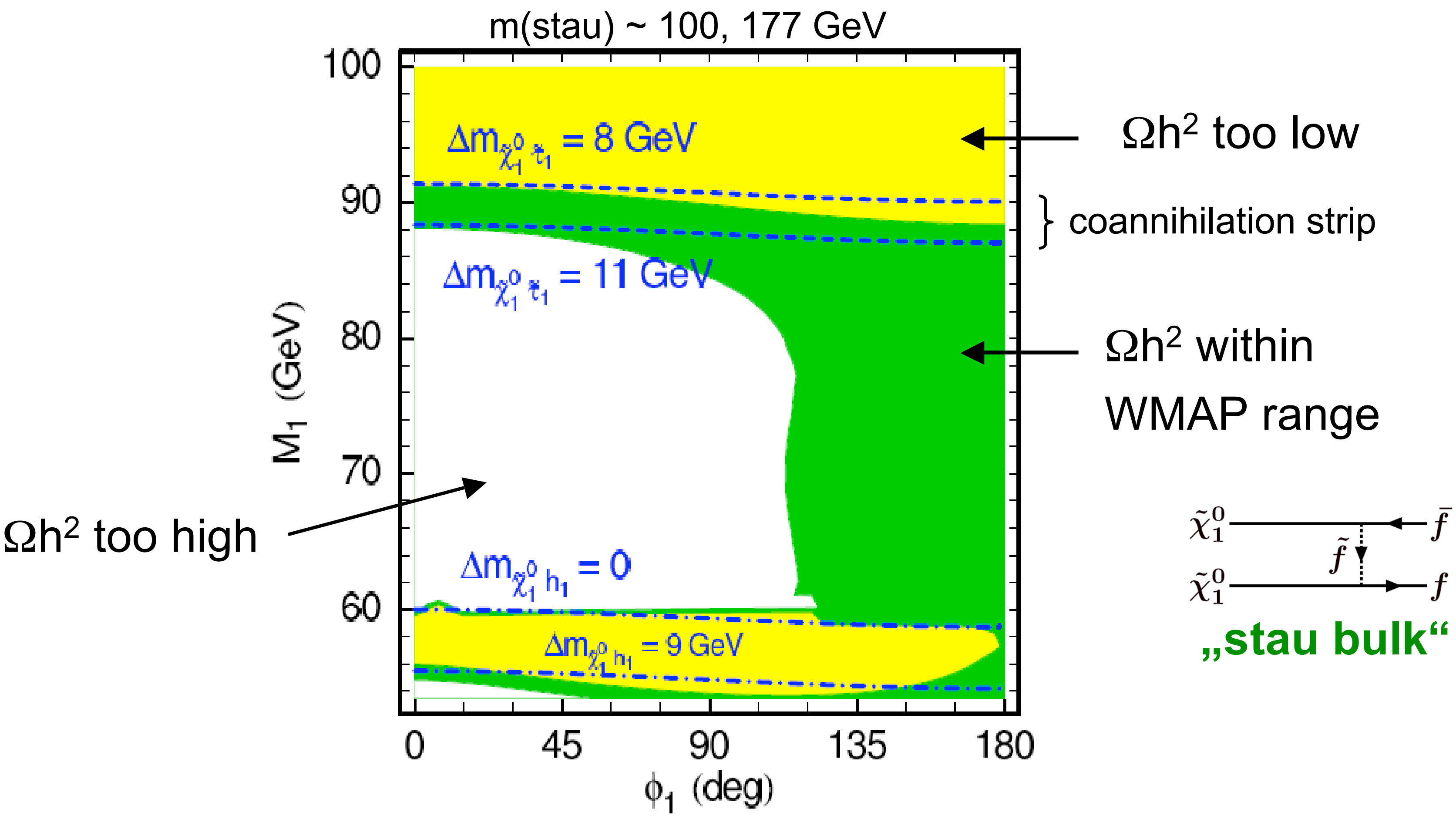
$$M_1 = |M_1| e^{i\phi_1}, \; \mu = |\mu| e^{i\phi_\mu}, \; A_f = |A_f| e^{i\phi_f}$$

- Well known that sparticle and Higgs phenomenology at colliders depends sensitively on CP phases; important variations in production and decay rates.

- In hep-ph/0604150* we analysed all χ^0 annihilation channels and showed that CP phases can also have dramatic effects on the relic density (due to modif's in couplings!)

*) Belanger, Boudjema, SK, Pukhov, Semenov, hep-ph/0604150 (PRD73)

Example: light stau, t-channel



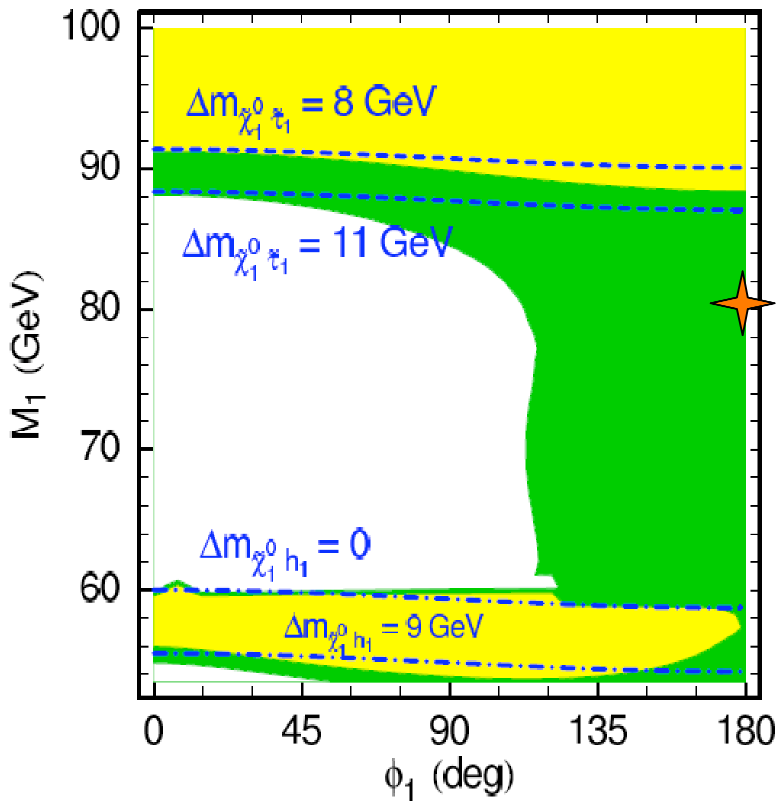
„stau bulk"

Belanger, Boudjema, SK, Pukhov, Semenov, hep-ph/0604150 (PRD73)

How well could ILC resolve this?

- Pick a point for case study

	$\tilde{\chi}_1^0$	$\tilde{\chi}_2^0$ $\tilde{\chi}_1^+$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$
	80.7	164.9	604.8	610.5
	$\tilde{\tau}$	$\tilde{\nu}_\tau$	$\tilde{e}$	$\tilde{\nu}_e$
R(1)	100.9	–	1000.9	–
L(2)	177.2	123.1	1001.1	998.0



- For $\phi_1 > 110^\circ$, $\Omega h^2 < 0.136$

- For ϕ_1=0, relic density would be too large:
  Ωh^2=0.167

Stau-bulk benchmark point

Input parameters

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

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

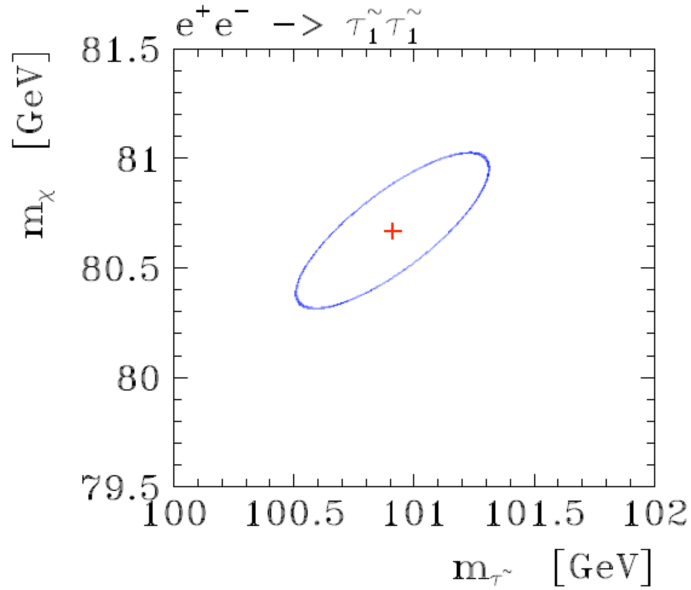
- Light gauginos and staus, staus are strongly mixed
- LSP annihilates into tau pairs via stau exchange in t-channel
  efficient if staus are mixed – no coannihilation

ILC measurements

MC simulation by H.U. Martin

- Threshold scans
- Kinematic endpoints
- Polarized cross sections
- Tau polarization

Difficulty: all channels lead to same signature: $\tau^+\tau^-\ E^{miss}$

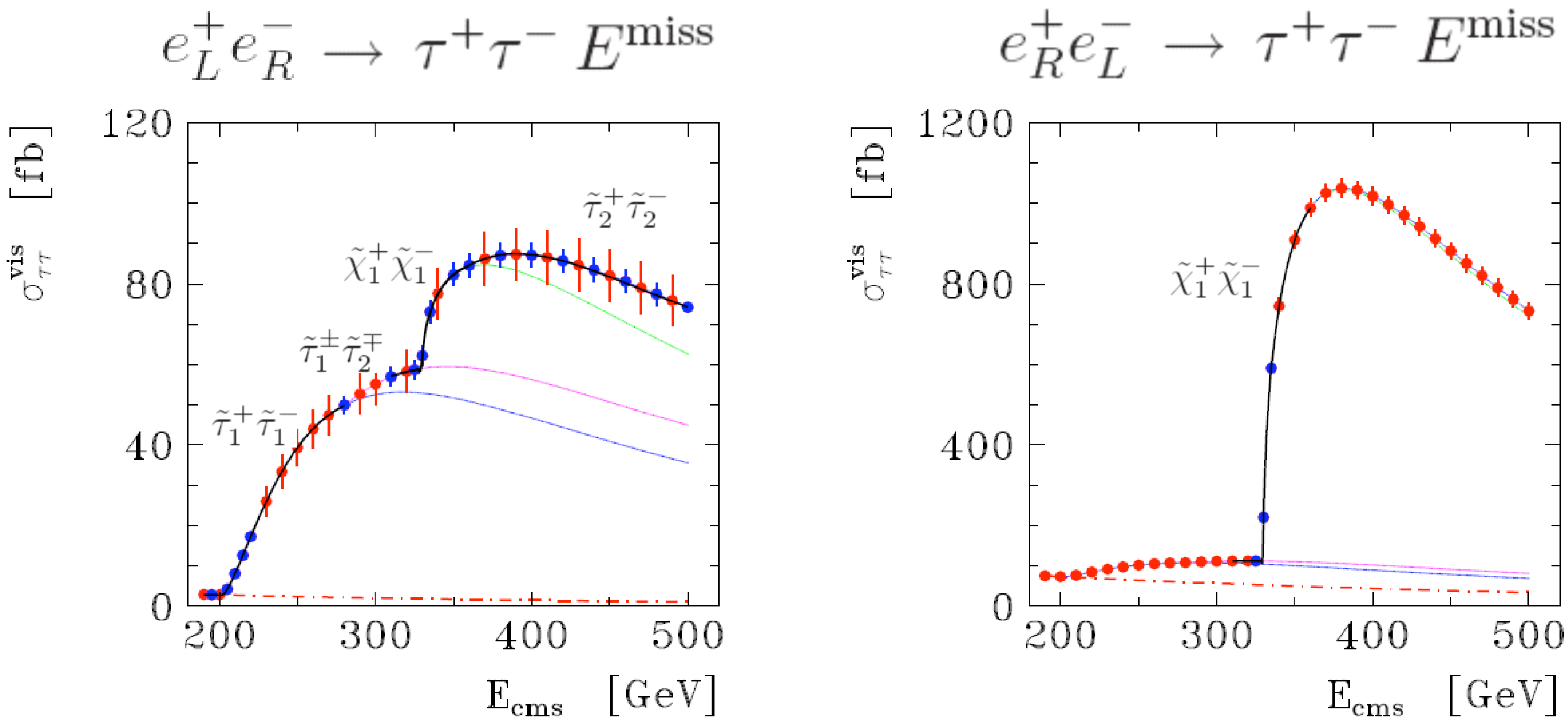


channel	observables	
$\tilde{\tau}_1^+\tilde{\tau}_1^-$	$m_{\tilde{\tau}_1} = 100.92 \pm 0.40$ GeV	$m_{\tilde{\chi}_1^0} = 80.67 \pm 0.35$ GeV
	$\cos 2\theta_{\tilde{\tau}} = -0.065 \pm 0.028$	$\mathcal{P}_\tau = 0.64 \pm 0.035$
$\tilde{\tau}_2^+\tilde{\tau}_2^-$	$m_{\tilde{\tau}_2} = 176.9 \pm 9.1$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

per-mil level !

ILC cross sections

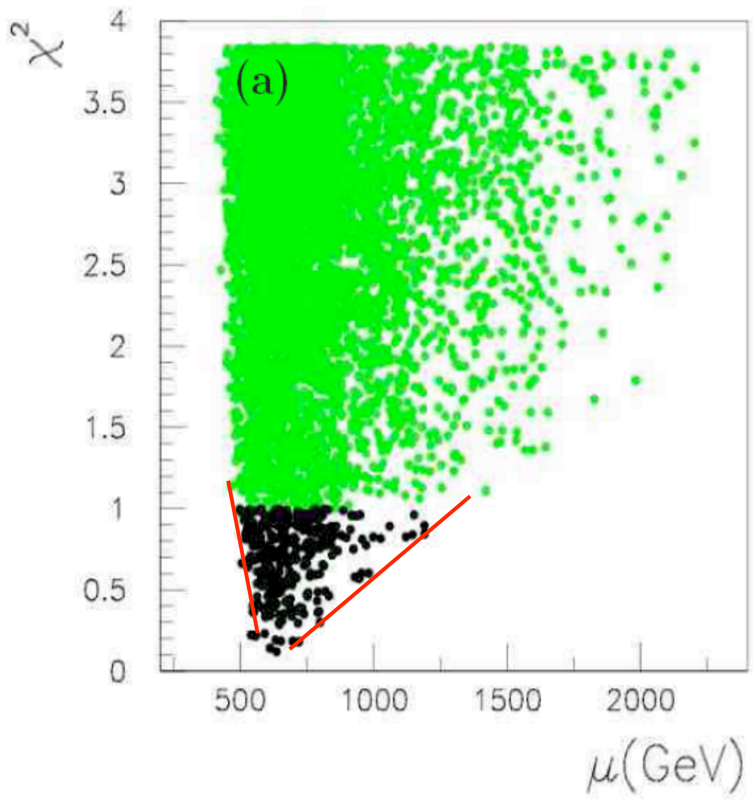
red (blue) points
$\mathcal{L} = 2\,\mathrm{fb}^{-1}(10\,\mathrm{fb}^{-1})$



N.B. heavy selectrons to avoid EDM constraints; suppresses neutralino production

Parameter fit with Markov Chain MC

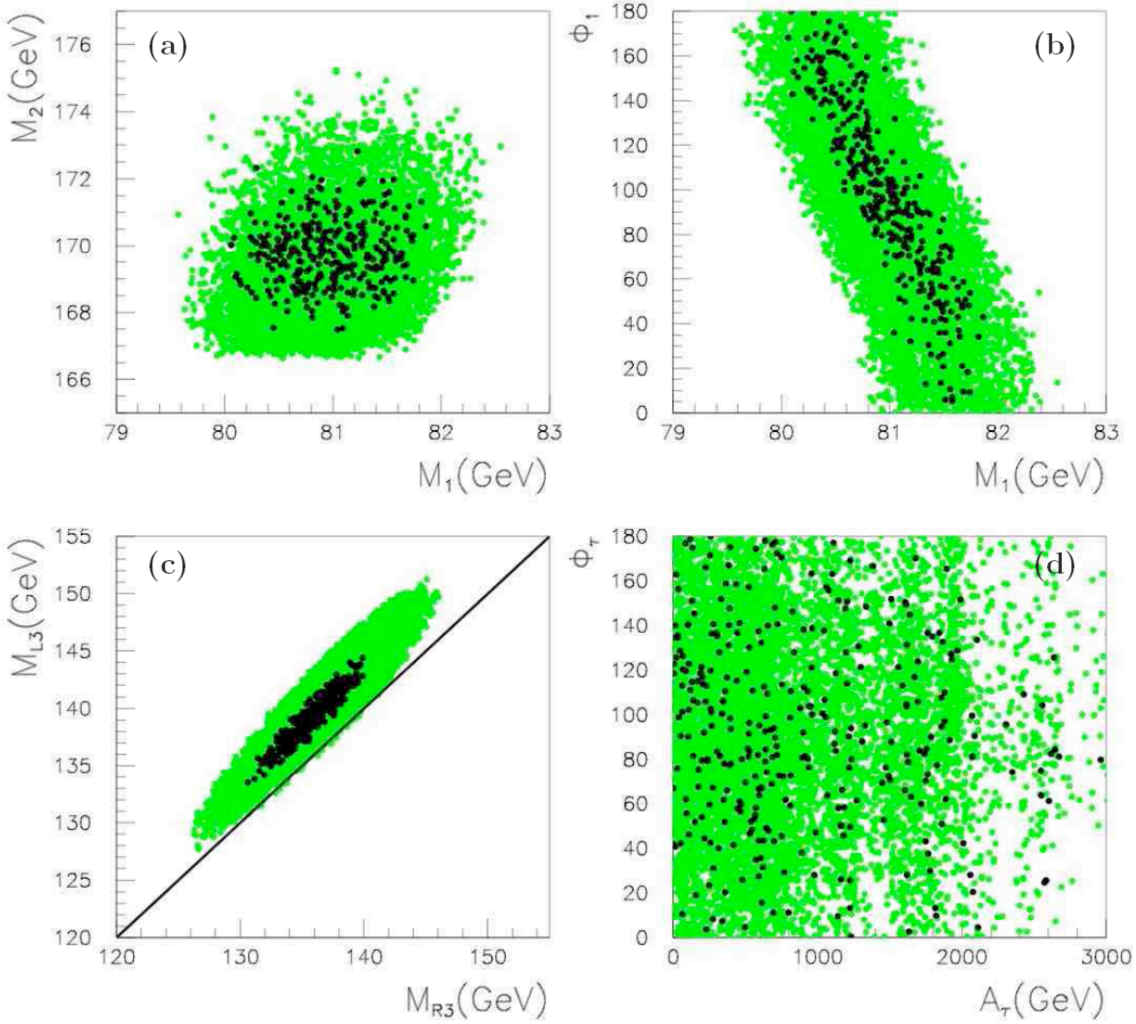
- Perform a fit to the six measurements and $\tau\tau$ total Xsect at 400 GeV
- Free parameters: M_1, μ, $\tan\beta$, M_{L3},M_{R3}, A_τ, ϕ_1, ϕ_τ
- Use Markov Chain Monte Carlo (MCMC) to explore parameter space



Lagrangian parameters

black: $\chi^2<1$

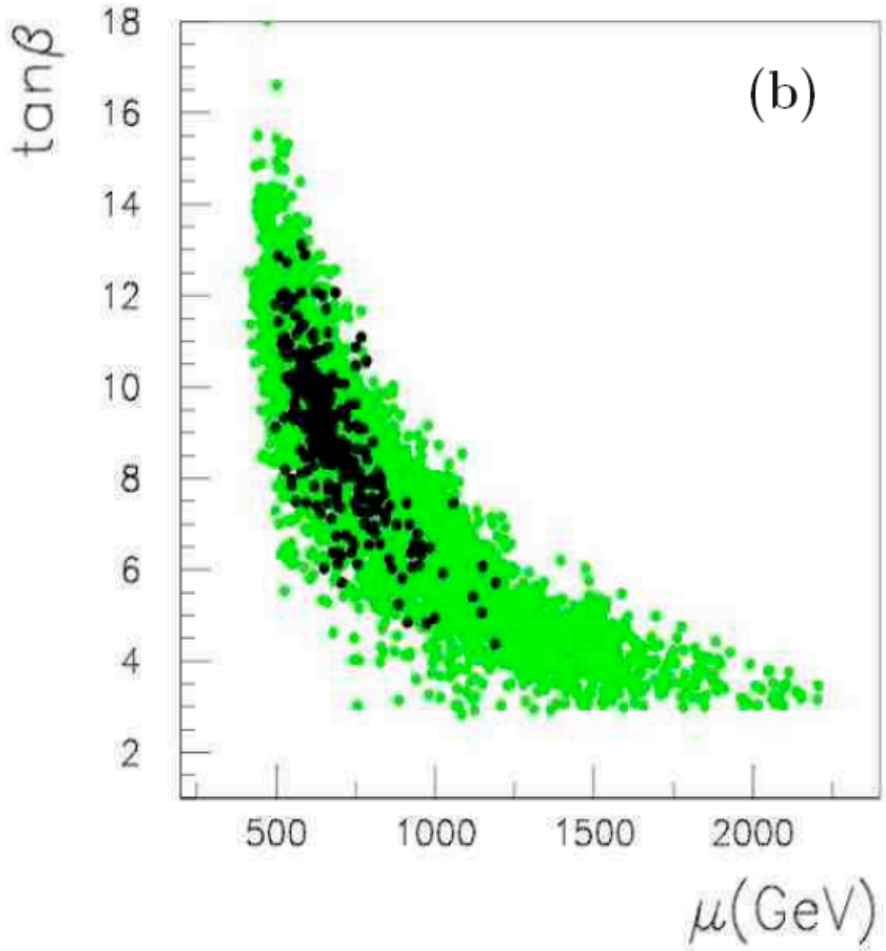
green: $\chi^2<3.84$



NB: Gaugino & slepton mass parameters well determined;

trilinear A_τ and phases of M_1 and A_τ undetermined

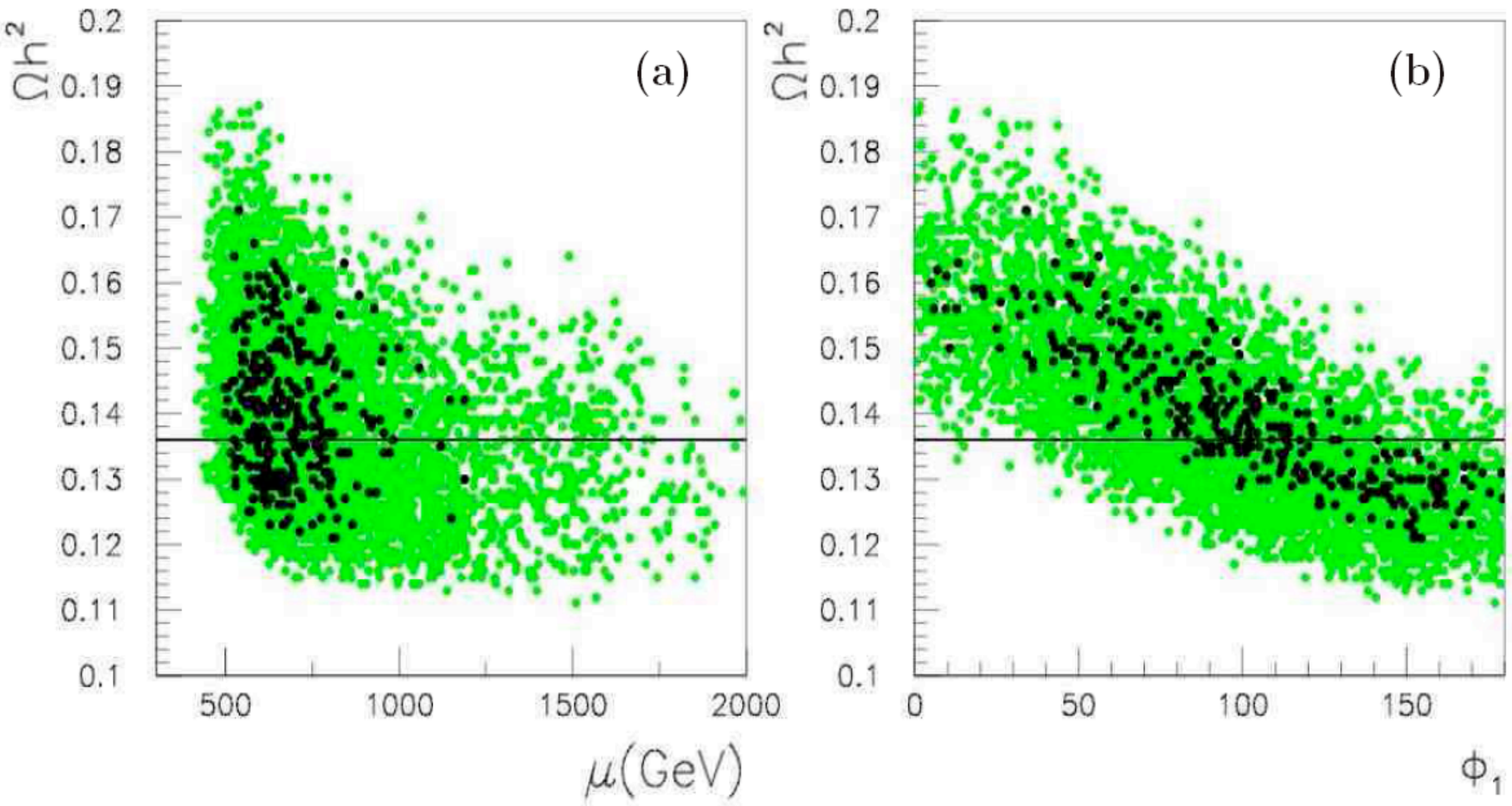
μ – tanβ correlation



black: $\chi^2<1$

green: $\chi^2<3.84$

Impact on relic density



infered range: $0.11 < \Omega h^2 < 0.19$ at 95% CL

Use CP-odd observables?

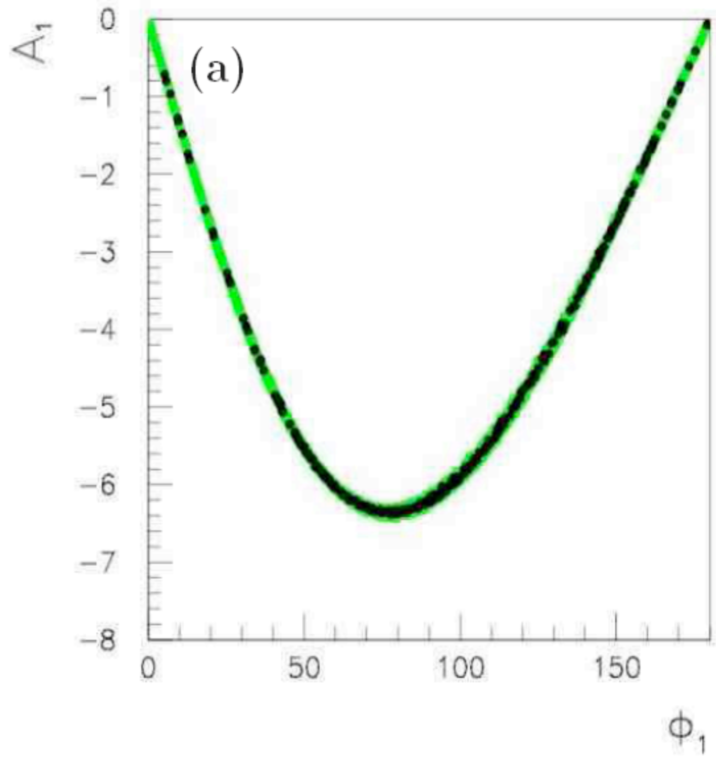
- Consider $e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0$

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

- define T-odd asymmetry

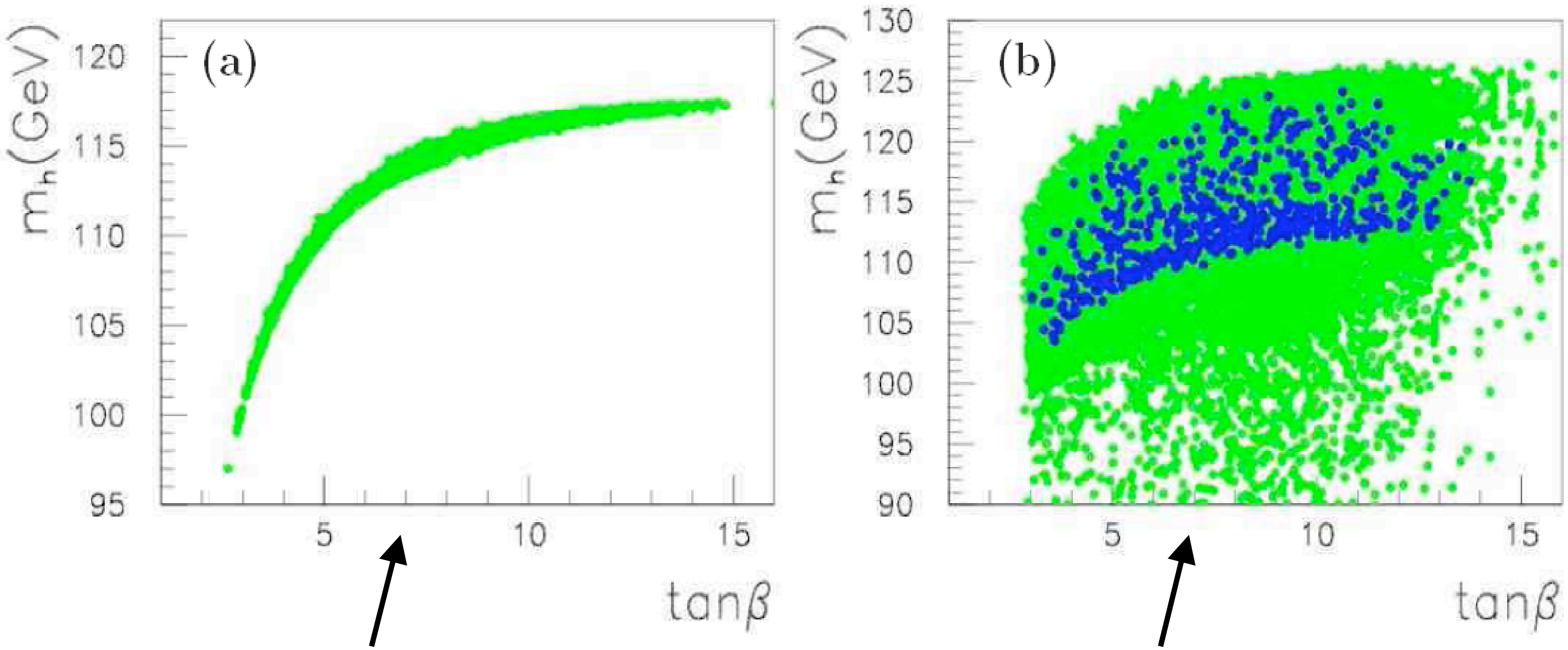
$$A_1 = \frac{\sigma(\mathcal{T} > 0) - \sigma(\mathcal{T} < 0)}{\sigma(\mathcal{T} > 0) + \sigma(\mathcal{T} < 0)},$$

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



$A_1 \neq 0$ would be signal of CP violation. But does not help to constrain Ωh^2 because A_1 symmetric around $\phi_1 = 90°$ ☹

Include Higgs mass in fit? → No

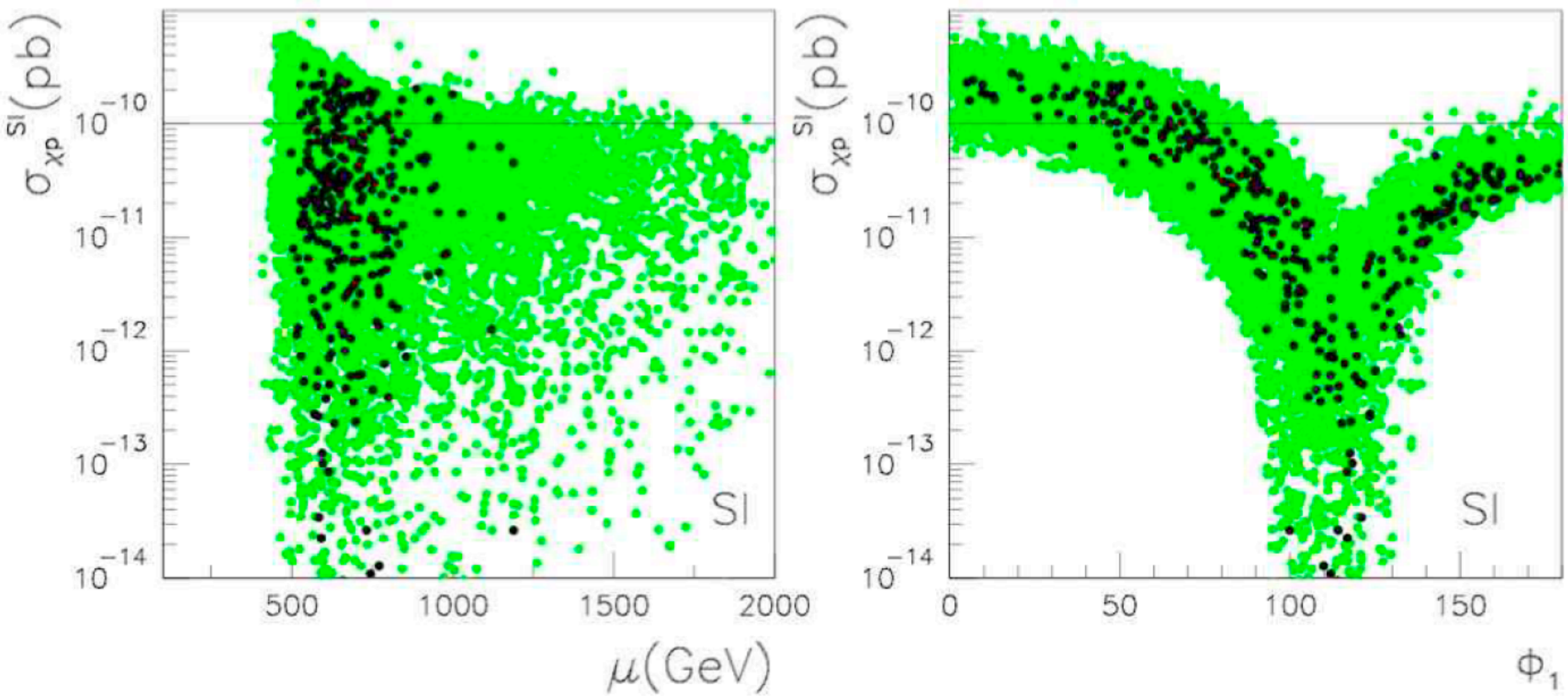


Stop parameters fixed to their nominal values

green: stop sector undetermined;
blue: stop masses known to 10%

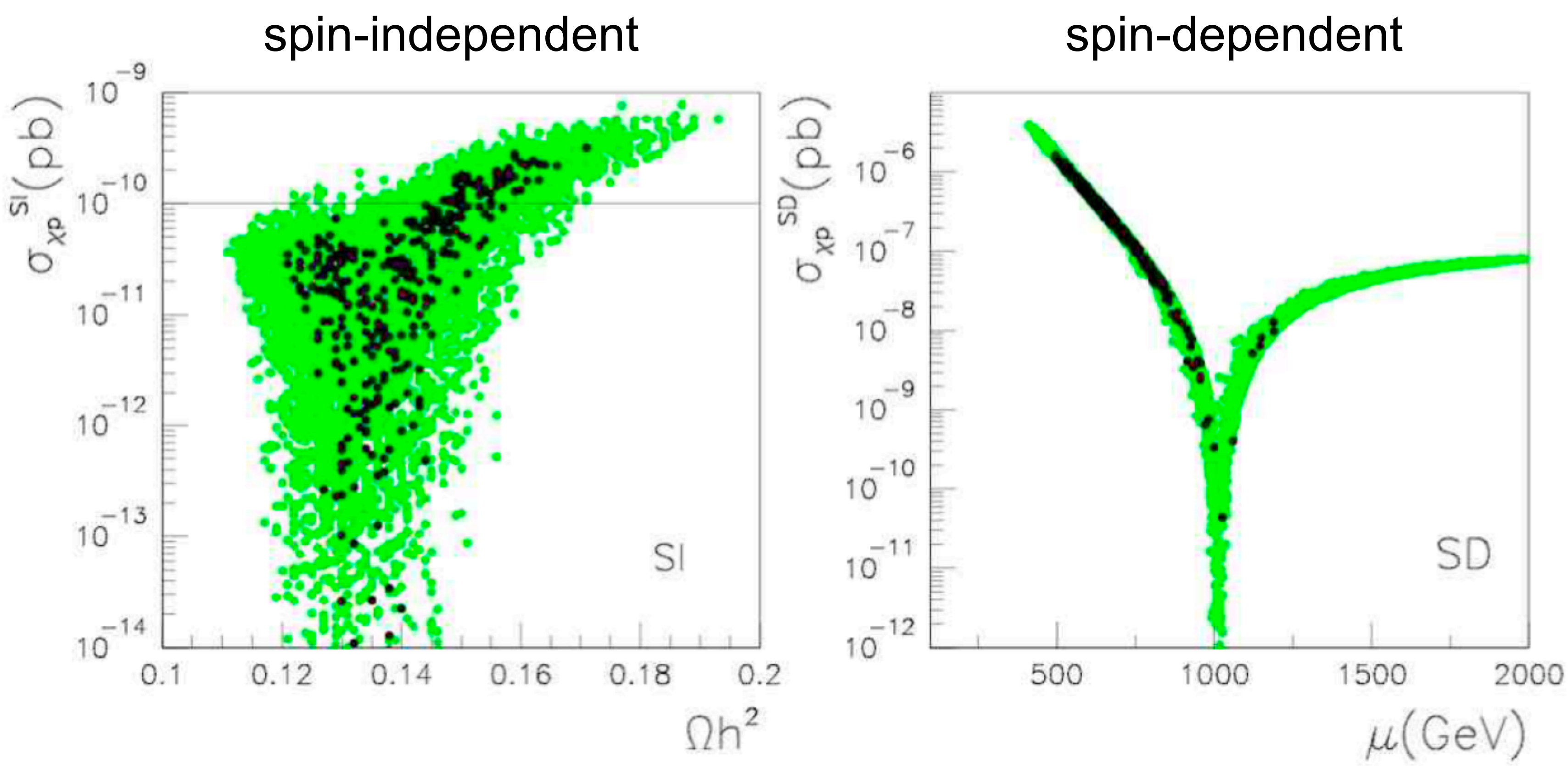
Interplay with direct DM detection

spin-independent neutralino-proton cross sections

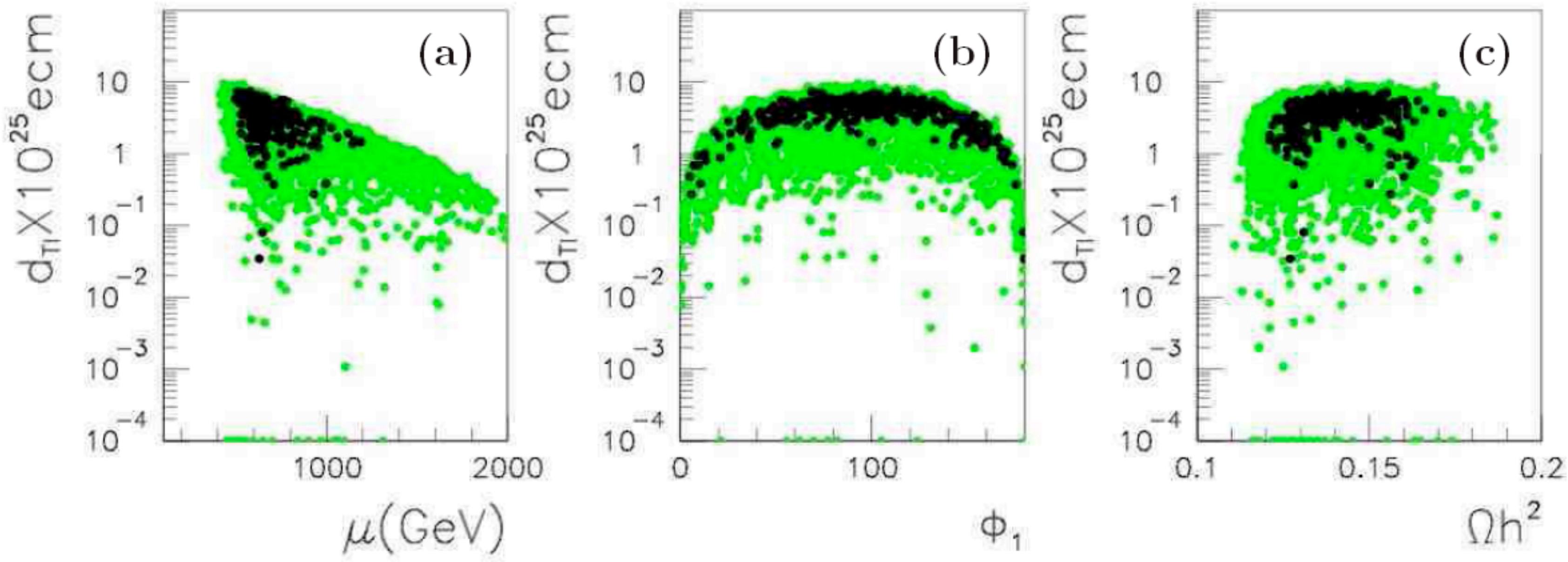


Heavy squarks; χp interaction dominated by Higgs exchange

Interplay with direct DM detection -cont-



Interplay with EDM measurements (Tl)



Present limit: $d_{Tl} < 9*10^{-25}$ e cm. Future improvement by 2 orders of magnitude would probe most of the parameter space of this scenario; however not much impact on Ωh^2

Conclusions

- Collider determination of Ωh^2 needs precise measurements of masses *and* couplings → CP phases
- Investigated „stau bulk" scenario in CPV-MSSM: only neutralino1, chargino1, stau1+2 detectable at ILC.
- Very good precision on masses and stau mixing ☺ however poor parameter determination ☹ [NB μ-tanβ]
- Parameter fit gives $0.11 < \Omega h^2 < 0.19$ at 95% CL
- Direct DM detection and EDM experiments could somewhat help resolve the scenario.
- Would need complete –ino system at LC $\sqrt{s}$~1-2 TeV;