Precise cosmological predictions

from NLO calculations and

measurements at the LC

work in progress

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ECFA LC2013

Intro

and Structure

- Normally $\Omega_\chi h^2$ is used as a *constraint for BSM models*. Can we turn this around and, assuming we find SUSY, use it to see if the relic density predicted for the LSP found at colliders agrees with this measurement?
- Can predictions of $\Omega_\chi h^2$ from colliders reach accuracies comparable to the incredible 0.1196 ± 0.0031 (Planck2013) to learn about cosmology?[1]

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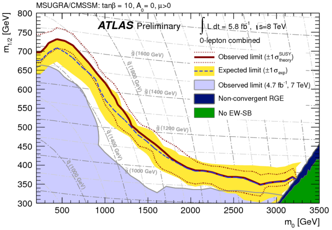

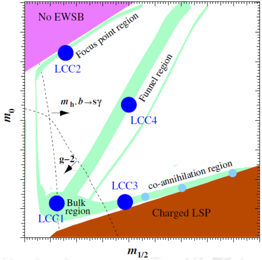

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- These work towards obtaining crucial information about DM in complementary ways: ISR searches, masses from thresholds and endpoints, (polarized) production cross-sections: staus, neutralinos...

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- In pMSSM, $\Delta\Omega_\chi h^2$ requires ΔX_i, $i = 1$ to 19[b]
- Aim: combining our results with $\Delta X_i^{LHC/LC}$, how precisely could we predict $\Omega_\chi h^2$?

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- Discuss errors on two complementary scenarios considered
- Present results of $\Delta\Omega_\chi h^2$ and conclusions

Background

The LC: an ideal machine for predicting $\Omega_\chi h^2$-not a new idea

- Here LC determination of the fundamental parameters M_1, M_2, μ and $\tan\beta$ plays a primary role
- LO analysis showed precise determination of these parameters possible via $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^0\tilde{\chi}_2^0, \tilde{\chi}_2^0\tilde{\chi}_2^0$[3]

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The LHC has given us invaluable insight about the Higgs mass as well as the masses of the squarks and gluinos, motivating redoing these analyses

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Why incorporate loop effects?

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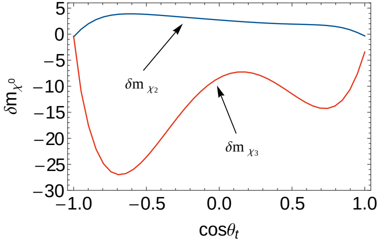

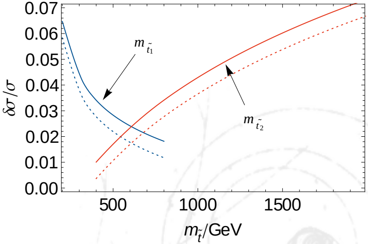

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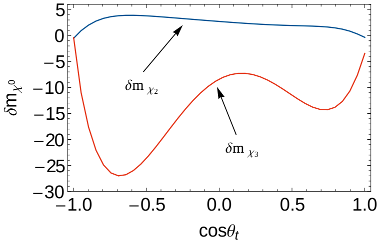

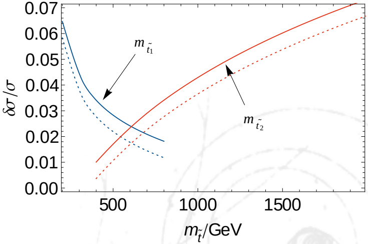

Realistic % level determination of fundamental electroweak parameters possible: interesting to see implications for DM!

Scenarios

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Scenario 1: Focus point region

Heavy sleptons (m_{ν_e} accessible in the fit) and charged Higgs (1 TeV) - inaccessible: creates uncertainty

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Scenario 2: Hybrid (focus point/bulk) region

Light sleptons, accessible at LHC and/or LC(500) and Lighter charged Higgs ($\sim$ 500 GeV). NLSP is $\tilde{\tau}_1$.

Projected errors from the LHC and LC

- Errors from NLO EWino production analysis LC
- Larger errors from continuum measurements at LC
- 10% errors on sfermion masses < 1 TeV from LHC
- Errors on accessible slepton masses from LC

Parameter	Scenario A	Scenario B
M_1	$123 \pm 0.3\,(0.6)$	105 ± 0.3
M_2	$250 \pm 0.6\,(1.6)$	211 ± 0.5
μ	$182 \pm 0.4\,(0.7)$	181 ± 0.4
$\tan\beta$	$10 \pm 0.5\,(1.3)$	11 ± 0.3
m_{A^0}	1000 ± 500	500 ± 150
M_3	1000 ± 100	1500 ± 150
$m_{\tilde{t}_1}$	400 ± 40	430 ± 43
$m_{\tilde{t}_2}$	800 ± 80	1520^{+200}_{-300}
$\cos\theta_t$	0.46 ± 0.15	$0.15^{+0.08}_{-0.06}$
$m_{\tilde{b}_1}$	400 ± 40	450 ± 45
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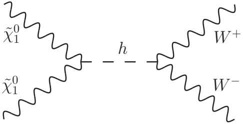
$\tilde{\chi}_1^0 \sim 0.83\tilde{B} - 0.18\tilde{W} + 0.44\tilde{h}_1 - 0.29\tilde{h}_2$
Annihilation channels: W^+W^- (68%), ZZ (12%), hh (7%), Zh (6%) etc



- The most important parameter here is $m_{\tilde{\chi}_1^0}$, determined via endpoints or monojet searches[6]
- Sfermions$\sim$decoupled (except stops via loop corrections to m_h)
- % level precision on fundamental EW parameters critical

[6] C. Bartels, M. Berggren and J. List, Eur. Phys. J. C **72** (2012) 2213 [arXiv:1206.6639 [hep-ex]].

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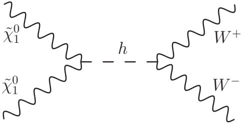

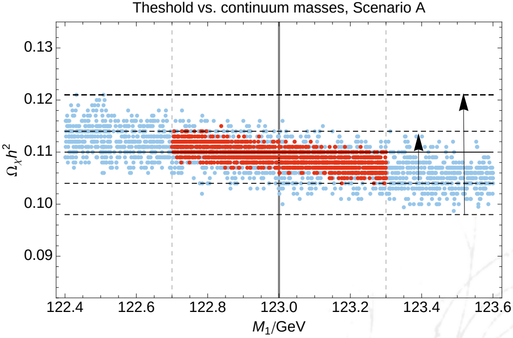

$m_{\tilde{\chi}_1^0}$ from endpoints improved via threshold scans

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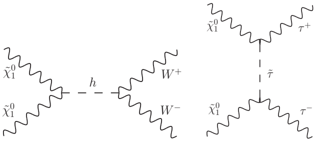
Scenario B

Results I

$\tilde{\chi}_1^0 \sim 0.87\tilde{B} - 0.18\tilde{W} + 0.41\tilde{h}_1 - 0.23\tilde{h}_2$

W^+W^- (24%), $\tau^+\tau^-$ (23%), $\mu^+\mu^-$ (10%), e^+e^- (8%), $b\bar{b}$ (7%)



- Most important parameters are $m_{\tilde{\chi}_1^0}$ and $m_{\tilde{\tau}_1}$.
- The stop, sbottom, selectron and muon sectors will also be influential

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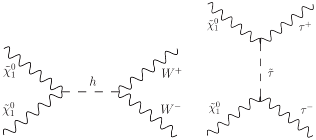

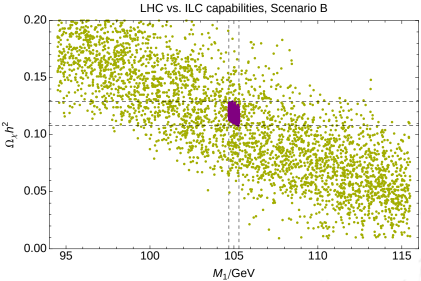

We show how this improves at the LC wrt LHC determinations,[7] and the effect of $\delta m_{\tilde{\tau}}^{\mathrm{LC}}$: stau-coannihilation region ruled out[8]

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Scenario B

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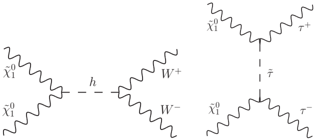
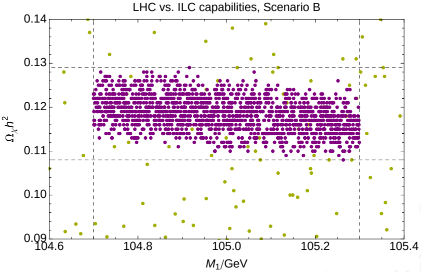
$\tilde{\chi}_1^0 \sim 0.87\tilde{B} - 0.18\tilde{W} + 0.41\tilde{h}_1 - 0.23\tilde{h}_2$

W^+W^- (24%), $\tau^+\tau^-$ (23%), $\mu^+\mu^-$ (10%), e^+e^- (8%), $b\bar{b}$ (7%)





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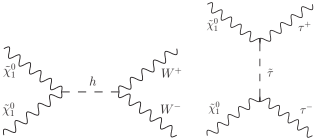

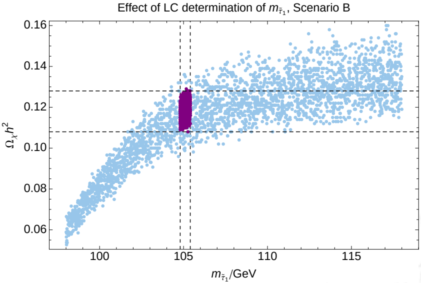

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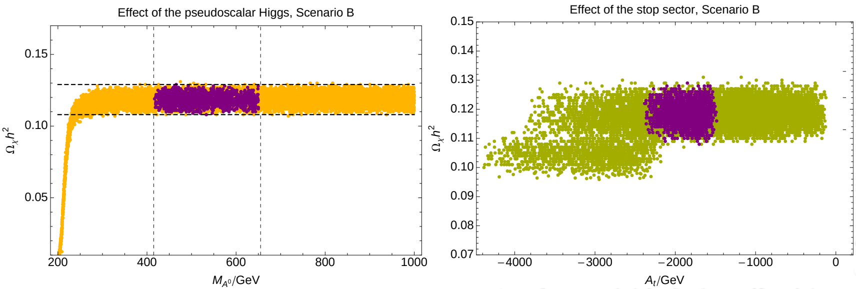
- NLO chargino production analysis gives information about the stop sector and M_A
- Unique info? Bounds on $cos\theta_t$, $m_{\tilde{t}_2}$ and upper bound on M_A



The constraints on M_A could be interesting in the funnel region+ stop constraints for large A_t

The situation would probably somewhat change if loop corrections were included in the relic density calculation

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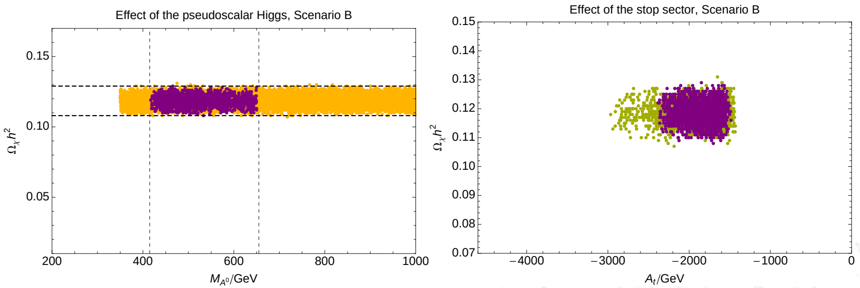

Higgs measurement (annihilation to Higgs ruled out) + $b \to s\gamma$ result in strong constraints on M_A+stops

The situation would probably somewhat change if loop corrections were included in the relic density calculation

What does this mean?

Summary

- Precise predictions $\sim 10\%$ for $\Omega_\chi h^2$ possible via LC measurements
- NLO parameter determination possible up to $\mathcal{O}(\%)$ level at a LC via $\tilde{\chi}^0/\tilde{\chi}^\pm$ production (with only light spectrum)
- Extract parameters $\mathbf{M_1}$, $\mathbf{M_2}$, μ, $\tan\beta$, $\mathbf{m_{\tilde{t}_i}}$ and $\cos\theta_{\mathbf{t}}$ from fit to **NLO** predictions for masses, polarised σs and $A_{\rm fb}$
- Increased sensitivity to larger number of parameters compared to LO analyses $\Rightarrow$ Precise determination of $\Omega_\chi h^2$ possible
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Outlook

- Investigate case when non-zero **CP phases** e.g. $\phi_\mathbf{t}$
- Re-evaluation necessary when full LHC study of error projections available