Dark matter relic density from observations of supersymmetry at the ILC

Suvi-Leena Lehtinen

DESY

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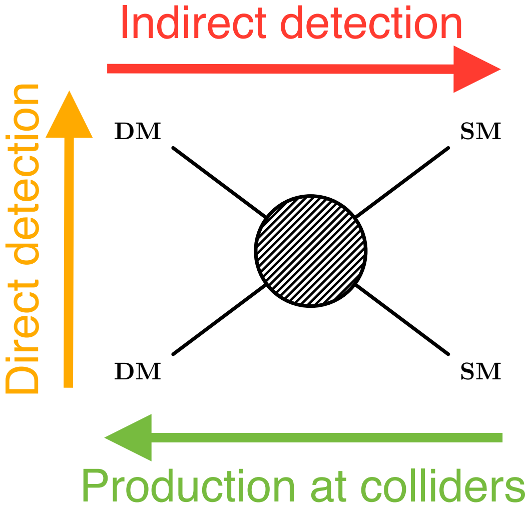
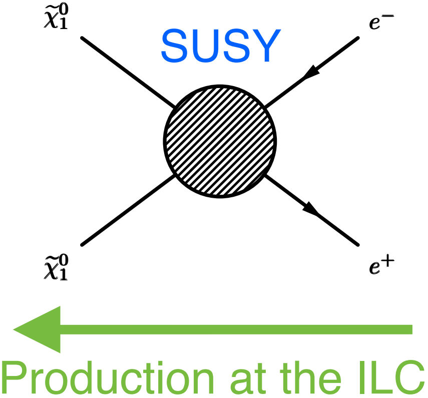
Dark matter experiments



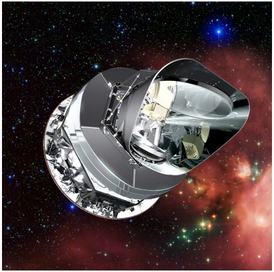
Measurements at the ILC



Cosmological vs. collider precision

- $\Omega_{CDM} h^2 = 0.1197 \pm 0.0022$

$$\Longrightarrow \quad \Delta = 2\%$$



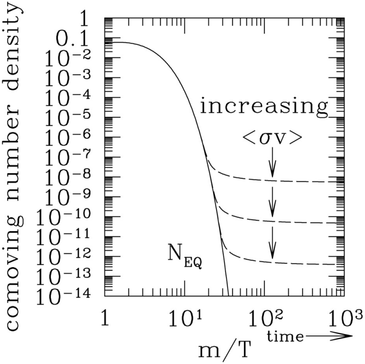
- $\Omega_{CDM} h^2 = ? \pm ?$

$$\Longrightarrow \quad \Delta = ?\%$$

e^+e^- at 500 GeV (1 TeV)
$P(e^-, e^+) = (\pm 80, \pm 30)$

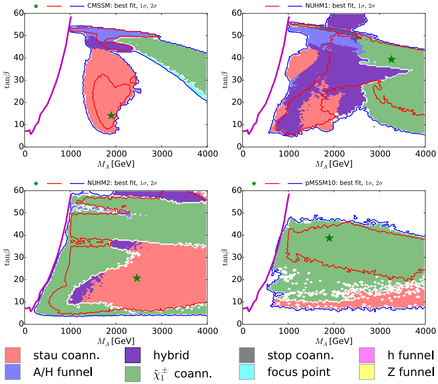
How is DM relic density determined

- relic density $\propto$ present day abundance $Y(T_0)$
- $\frac{dY}{ds} \propto \langle \sigma v \rangle (Y^2 - Y_{eq}(T)^2)$
- Full model $\Longrightarrow$ prediction for relic density
- micrOMEGAs a code to calculate relic density arXiv:1305.0237



Dark matter mechanisms in SUSY

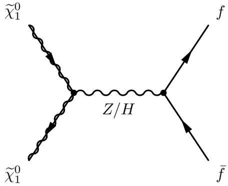
➤ Stau coannihilation is one of the preferred mechanisms to explain dark matter in SUSY

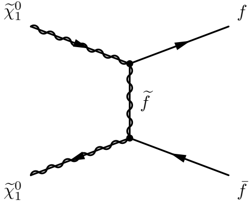


Mastercode arXiv:1508.01173v1

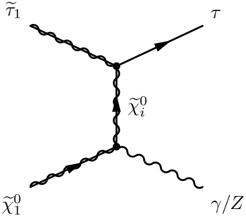
Processes in stau coannihilation

- Pair annihilation depends on LSP mixing and sfermion mass





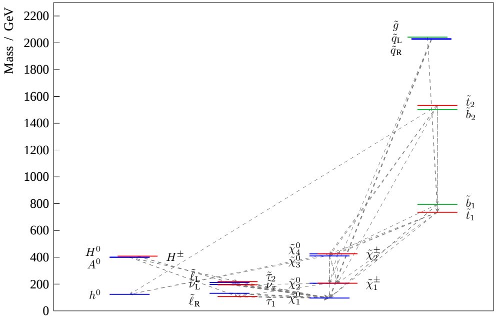
- Coannihilation depends strongly on the stau-LSP mass difference



- Need to measure LSP and stau1 masses and mixings precisely

Stau coannihilation observable at the ILC

- pMSSM point with 12 parameters "STC8" (arXiv:1307.0782)
- $m_{\tilde{\chi}_1^0} = 96$ GeV (bino), $m_{\tilde{\tau}_1} = 107$ GeV ($\theta_{\tilde{\tau}} = 71°$)
- True relic density value 0.113



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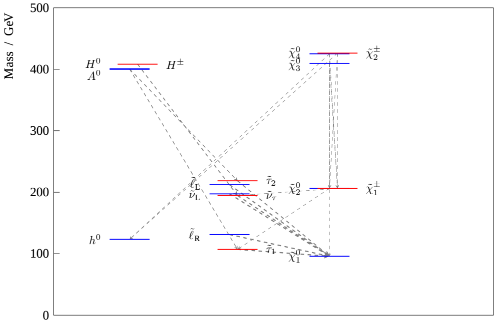
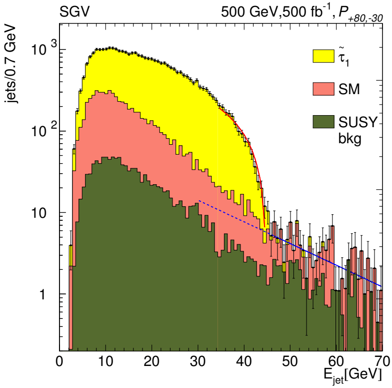


500GeV measurements

- Analysis of STC8 done by Berggren (arXiv:1508.04383v1)
- $\widetilde{\tau}_1 \to \widetilde{\chi}_1^0 \tau$ endpoint $\implies$ $\Delta m_{\widetilde{\tau}_1} = 0.15\%$



500GeV measurements

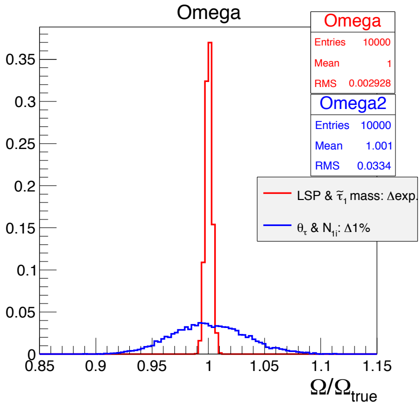
- Can discover of all sleptons, sneutrinos, $\widetilde{\chi}_1^0, \widetilde{\chi}_2^0$ and $\widetilde{\chi}_1^{\pm}$
- Precisions on masses and mixings:

black=estimate, blue=analysis (arXiv:1508.04383v1)

$m_{\widetilde{\chi}_1^0}$	0.15%	$m_{\widetilde{\chi}_2^0}$	0.5%
$m_{\widetilde{\tau}_1}$	0.16%	$m_{\widetilde{\tau}_2}$	2.5%
$m_{\widetilde{e}_R}$	0.17%	$m_{\widetilde{\mu}_R}$	0.40%
$m_{\widetilde{e}_L}$	1%	$m_{\widetilde{\mu}_L}$	1%
$m_{\widetilde{\nu}_e,\widetilde{\nu}_\mu,\widetilde{\nu}_\tau}$	1%	$m_{\widetilde{\chi}_1^{\pm}}$	1%
θ_τ	1%	A_τ	20%
$N_{11,12,13,14}$	1% each	$Umix$, $Vmix$	20% each

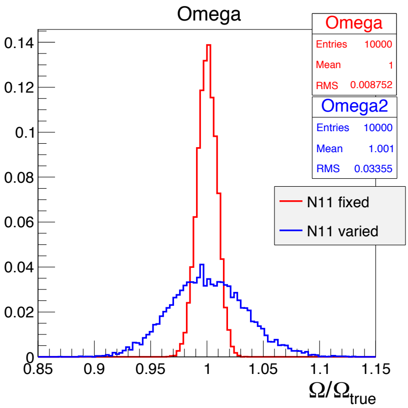
Stau1 and LSP mass vs mixings

- Red: LSP mass and stau1 mass varied 0.15%
- Blue: LSP mixings and stau1 mixing varied 1%
- With these assumptions, mixings dominate uncertainty on relic density Ω



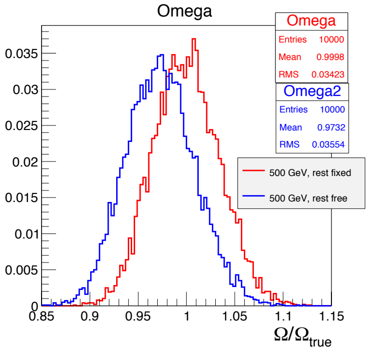
Important to measure: binoness of LSP

- Blue: LSP and stau1 mass 0.15%, LSP, stau1 mixings 1%
- Red: same but N11 (binoness) fixed



500GeV measurements

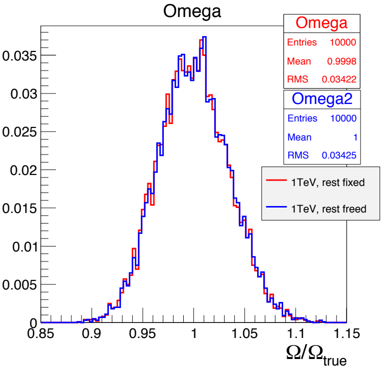
- Red: all sleptons, sneutrinos, $\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_1^\pm$ varied, rest fixed. $\Delta\Omega = 3.5\%$ (fix N11 $\implies$ $\Delta\Omega = 2\%$)
- Blue: same but squarks uniformly varied 1 - 50 TeV, higgses 0.4 - 2 TeV and $\tilde{\chi}_3^0, \tilde{\chi}_4^0, \tilde{\chi}_2^\pm$ 0.25 - 2 TeV
- Unobserved sector $\implies$ $\sim 1\sigma$ shift of the mean, width similar



Assumptions for 1TeV measurements

- Assume no further improvement on light sparticle measurements (over-conservative)
- Extended Higgs masses: $\Delta = 1\%$
- $\widetilde{\chi}_3^0, \widetilde{\chi}_4^0, \widetilde{\chi}_2^\pm$: $\Delta = 1\%$

- Red: unobservables fixed
- Blue: unobservables free
- No shift from unobservables, width same



Not considered

- MicrOMEGAs $\implies$ tree-level SUSY cross-sections
- SUSY loop corrections can give $\sim$ 10%
  (e.g. arXiv:0710.1821v3)
- This probably just a shift of the mean predicted Ω
  (for other coannihilation scenarios arXiv:1510.0629v1)

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- $h_0 - H_0$ mixing angle ignored
- Related to couplings of light Higgs

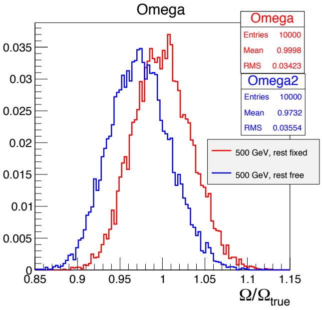
Summary

- In stau-coannihilation: if measure slepton, sneutrino and light gaugino masses with ILC precision and mixings to 1%

  $\Longrightarrow$ ILC precision on relic density $\sim 2 \times$ Planck precision

- With current assumptions, uncertainties on mixing properties dominate over mass uncertainties
- Need a more reliable estimate of the ILC capabilities e.g. from tau polarisation and polarised cross sections
- With real discoveries would need to consider loop corrections

Backup: 500 GeV assumptions



500GeV discoveries
black=estimate, blue=analysis
(arXiv:1508.04383v1)

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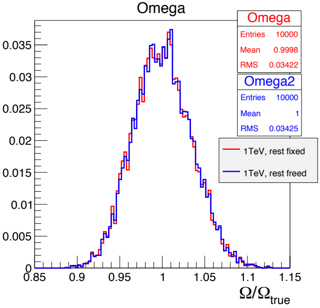
$m_{\tilde{e}_L}$	1%	$m_{\tilde{\mu}_L}$	1%
$m_{\tilde{\nu}_e,\tilde{\nu}_\mu,\tilde{\nu}_\tau}$	1%	$m_{\tilde{\chi}_1^\pm}$	1%
θ_τ	1%	A_τ	20%
$N_{11,12,13,14}$	1% each	$Umix, Vmix$	20% each

Unobservables at 500GeV - uniform variations

$m_{\tilde{\chi}_3^0,\tilde{\chi}_4^0}$	0.25 – 2 TeV	$m_{\tilde{\chi}_2^\pm}$	0.25 – 2 TeV
$m_{H_0,A_0,H^\pm}$	0.4 – 2 TeV		
$m_{\tilde{d}_L,\tilde{u}_L,\tilde{s}_L,\tilde{c}_L}$ all equal	1 – 50 TeV	$m_{\tilde{d}_R,\tilde{u}_R,\tilde{s}_R,\tilde{c}_R}$	$= m_{\tilde{d}_L} - 100$ GeV
$m_{\tilde{t}_1,\tilde{t}_2,\tilde{b}_1,\tilde{b}_2}$ independent	0.6 – 50 TeV	$m_{\tilde{g}}$	1 – 50 TeV
$\theta_{t,b}$	$-\pi/2 \to \pi/2$	$A_{t,b}$	$-5000 \to 5000$

Backup: 1 TeV assumptions



1 TeV observations

$m_{\tilde{e}_R}$	0.17%	$m_{\tilde{\mu}_R}$	0.40%
$m_{\tilde{e}_L}$	1%	$m_{\tilde{\mu}_L}$	1%
$m_{\tilde{\tau}_1}$	0.16%	$m_{\tilde{\tau}_2}$	2.5%
θ_τ	1%	A_τ	20%
$m_{\tilde{\nu}_e,\tilde{\nu}_\mu,\tilde{\nu}_\tau}$	1%	$m_{\tilde{\chi}_1^\pm}$	1%
$m_{\tilde{\chi}_1^0}$	0.15%	$m_{\tilde{\chi}_2^0}$	0.5%
$N_{12,13,14}$	1% each	$Umix, Vmix$	20% each
$m_{\tilde{\chi}_3^0,\tilde{\chi}_4^0}$	1%	$m_{\tilde{\chi}_2^\pm}$	1%
$m_{H_0,A_0,H^\pm}$	1%		

Unobserved at 1 TeV

$m_{\tilde{d}_L,\tilde{u}_L,\tilde{s}_L,\tilde{c}_L}$	all equal	$1 - 50$ TeV	$m_{\tilde{d}_R,\tilde{u}_R,\tilde{s}_R,\tilde{c}_R}$	$= m_{\tilde{d}_L} - 100$ GeV
$m_{\tilde{t}_1,\tilde{t}_2,\tilde{b}_1,\tilde{b}_2}$	independent	$0.6 - 50$ TeV	$m_{\tilde{g}}$	$1 - 50$ TeV
$\theta_{t,b}$		$0 \to \pi/2$	$A_{t,b}$	$0 \to -5000$

Backup: Variation of dark matter with masses

- In STC8 with many light sparticles

Observable	$\pm$ variation	$\pm$ change in Ω
$m_{\tilde{\chi}_1^0}$	1%	5%
$m_{\tilde{\tau}_1}$	1%	5%
$m_{\tilde{l}_R}$	1%	$< 0.5\%$
$m_{\tilde{l}_L}$	1%	$< 0.01\%$
$m_{\tilde{\nu}}$	10%	$< 0.1\%$
m_{H,A_0}	10%	$< 0.1\%$
$m_{\tilde{\chi}_i}$	10%	$< 0.1\%$
$m_{\tilde{q}}$	10%	$< 0.01\%$

- LSP and stau1 mass crucial, others much less important

Backup: Variation of dark matter with mixings

- In STC8 with many light sparticles

"observable"	± variation	± change in Ω
stau mixing angle θ_τ	1%	1%
binoness of LSP N_{11}	1%	3.5%
other neutralino mixings	100%	$\sim 1-4\%$
Higgs mixing	50%	2%
other mixings	50%	$< 0.1\%$

- Stau and LSP mixing also crucial, Higgs and other neutralino mixings needed to $\sim 10\%$