

SUSY parameters from higgsino measurements

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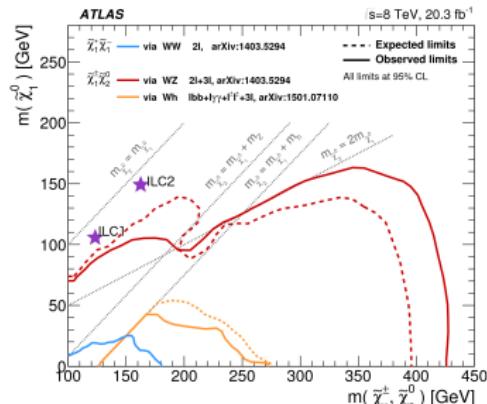
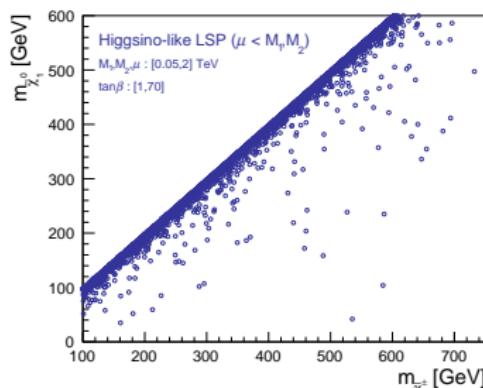
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Why study light higgsinos

- Naturalness and small fine tuning require μ parameter at the EW scale:

$$m_Z^2 = 2 \frac{m_{H_d}^2 + \Sigma_d^d - (m_{H_u}^2 + \Sigma_u^u) \tan^2 \beta}{\tan^2 \beta - 1} - 2\mu^2$$

- μ small \implies light higgsinos
- Typical mass difference 10 - 20 GeV
 \implies challenging for LHC if other sparticles are heavy



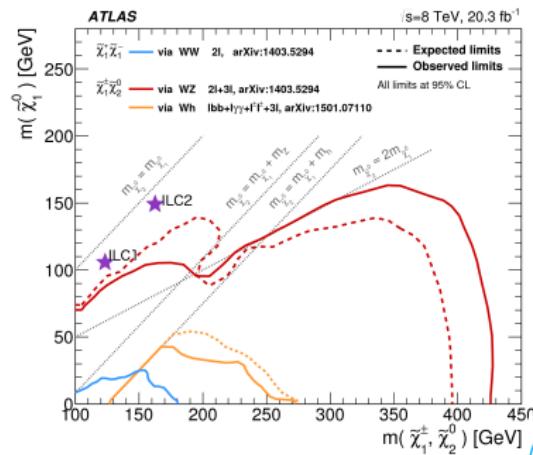
Benchmarks studied (analysis by Jacqueline Yan)

- $\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_1^\pm$ observable, $\tilde{\chi}_3^0$ accessible with a small cross section
- Other sparticles heavy
- Mass gaps $\sim 10 - 20$ GeV \implies higgsinos decay via a virtual Z/W

Two specific benchmarks

mass	ILC1	ILC2
$\tilde{\chi}_1^0$	103 GeV	148 GeV
$\tilde{\chi}_1^\pm$	117 GeV	157.8 GeV
$\tilde{\chi}_2^0$	124 GeV	158.3 GeV
$\tilde{\chi}_3^0$	267 GeV	539 GeV
\tilde{g}	1560 GeV	2830 GeV

Cross sections for production in e^+e^- at $\sqrt{s} = 500$ GeV several hundred fb



Summary: Preliminary analysis results for ILC1

- ▶ After 500 fb^{-1} for both $\mathcal{P}(+0.8, -0.3)$ and $\mathcal{P}(-0.8, +0.3)$:
- ▶ Higgsino mass measurements with $\sim 0.4\%$ precision
- ▶ Cross section measurements $\sim 1\%$ precision depending on beam polarisation and decay channel
 - ▶ $e^+ e^- \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_1^\mp \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 q\bar{q}'/\nu_l$ ($l=e, \mu$)
 - ▶ $e^+ e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 //$ ($l=e, \mu$)
- ▶ Details e.g. in Jackie's LCWS16 talk
<https://agenda.linearcollider.org/event/7371/contributions/37853/>
- ▶ Fit input: The above, scaled to H20 + Higgs mass and BR measurements from H20
(also gluino mass measurement from HL-LHC, however main results do not depend on this)



Parameter fitting

- What can we say about SUSY parameters based on these observables?
- Which parameters are determined and how accurately?
- Can we test the SUSY model type?
- Can we make predictions about the unobserved part of the spectrum?



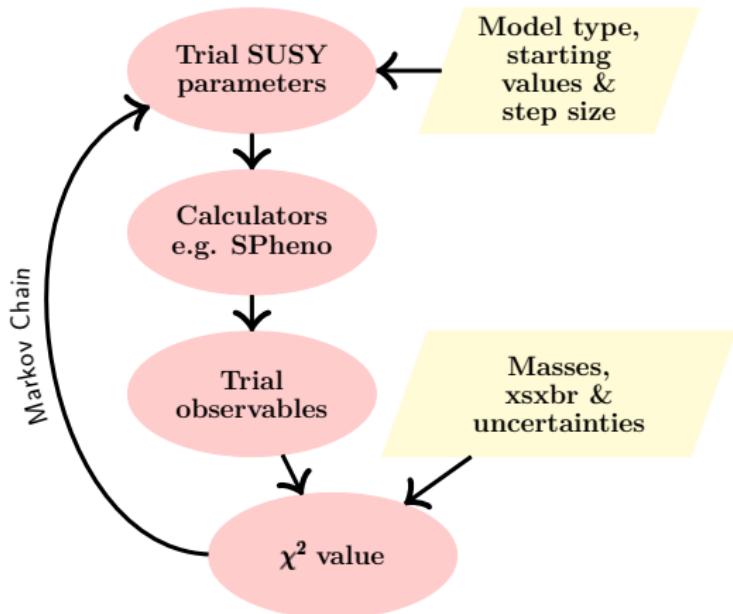
Fitting parameters to observables with Fittino

Fittino minimises

$$\chi^2 = \left(\frac{\mathcal{O}(ILC) - \mathcal{O}(theory)}{\Delta\mathcal{O}(ILC)} \right)^2$$

(arXiv:hep-ph/0412012)

SPheno 3.3.9beta,
Higgs mass and BRs
FeynHiggs2.10.2



Parameters of ILC1

- Underlying theory is a 6-parameter GUT model (NUHM2)
- Can try to fit even more constrained models but then $\chi^2_{min}/d.o.f.$ gets large
- A priori do not know it is a GUT model so fit weak scale pMSSM-10 (at 1 TeV)

parameter	ILC1 pMSSM-10	Fitted values
μ	115	[115, 122] GeV
M_1	250	247 ± 4 GeV
M_2	463	452 ± 11 GeV
M_3	1270	1280 ± 130 GeV
$\tan \beta$	10	[8, 18]
$M_{\tilde{t}_L}$	4820	[4500, 8000] GeV
$M_{\tilde{t}_R}$	1670	[1500, 2000] GeV
$M_{\text{other sfermions}}$	7150	[5500, 8500] GeV
$A_{t=b=\tau}$	-4400	[-6600, -4200] GeV
m_A	1000	1110 ± 116 GeV



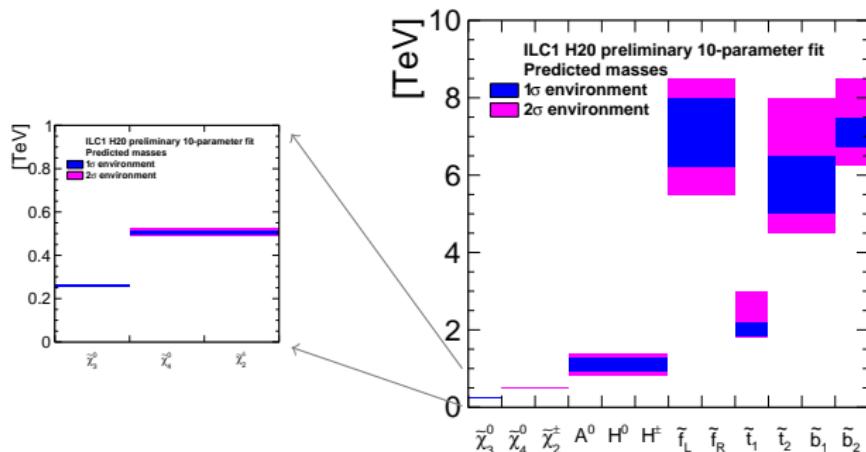
Predicted masses of heavier sparticles from 10-param. fit

► Heavier neutralino/chargino masses

- $m_{\tilde{\chi}_3^0} = 263 \pm 4$ GeV
- $m_{\tilde{\chi}_4^0} = 509 \pm 10$ GeV, $m_{\tilde{\chi}_2^\pm} = 509 \pm 10$ GeV

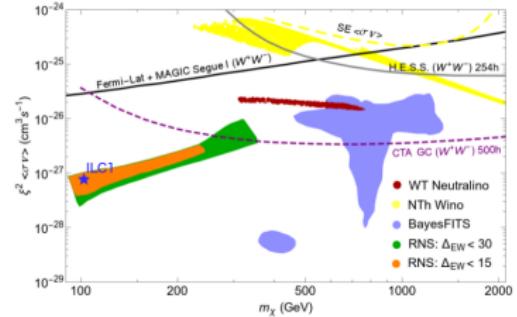
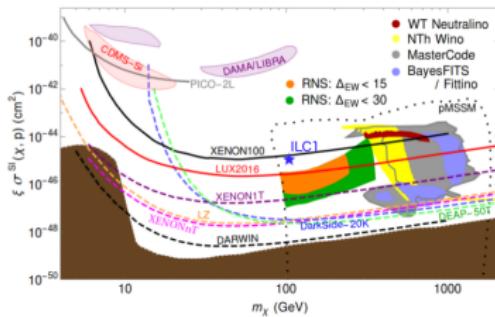
⇒ Motivation for ILC energy upgrade e.g. to $\sqrt{s} = 1$ TeV

► Rough ranges for all other masses



Dark matter predictions

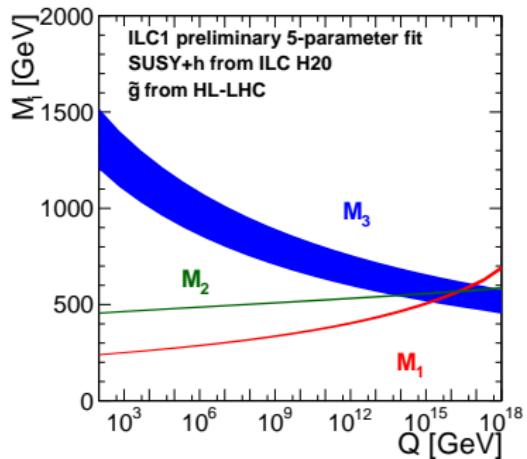
- Dark matter relic density $\Omega_{ILC1}/\Omega_{Planck} = 0.054 \pm 0.001$
⇒ Strong hint that non-SUSY DM or non-thermal production of higgsinos exists
- Spin-independent WIMP-nucleon scattering cross section $\sigma^{SI} = 1.5 \times 10^{-8}$ pb
- WIMP annihilation cross section $\langle \sigma v \rangle = 2.6 \times 10^{-25} \text{ cm}^3 \text{s}^{-1}$



Figures from 1609.06735

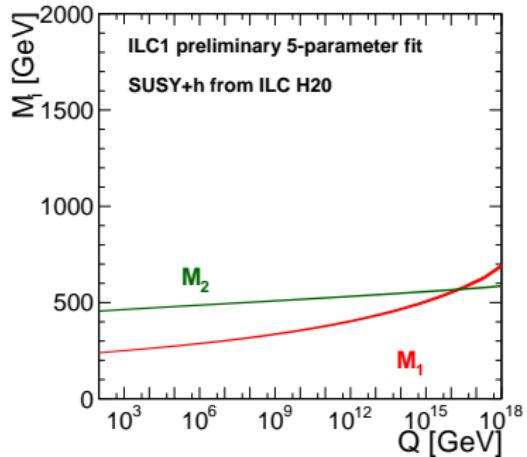
Test of gaugino mass unification

- Take determined parameters at 1 TeV
- Run up to GUT scale with two-loop RGEs, but fix other parameters to model values
- Underlying theory is NUHM2 and indeed find unification of M_i at 10^{16} GeV



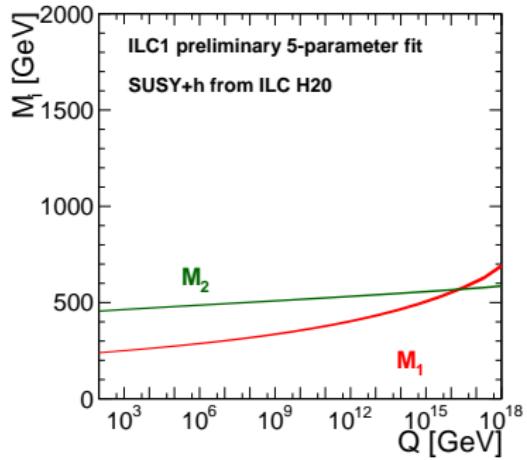
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- Take determined parameters at 1 TeV
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- Underlying theory is NUHM2 and indeed find unification of M_i at 10^{16} GeV
- Can relax assumption about observing gluino



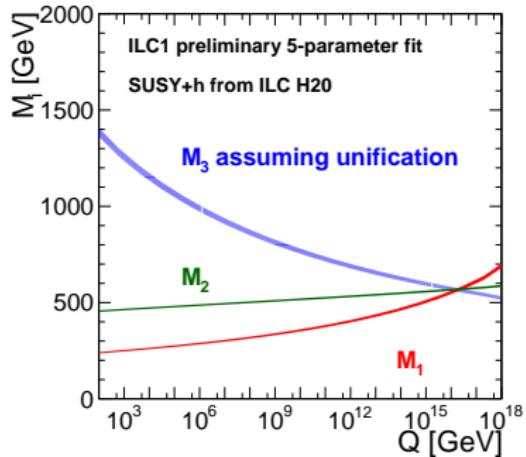
Extrapolation of M_3 assuming unification

- Find $M_1 = M_2$ at
 $Q = 1.9 \times 10^{16}$ GeV,
65% CL from
 $1.0 - 3.6 \times 10^{16}$ GeV



Extrapolation of M_3 assuming unification

- Find $M_1 = M_2$ at
 $Q = 1.9 \times 10^{16}$ GeV,
65% CL from
 $1.0 - 3.6 \times 10^{16}$ GeV
- If assume $M_{1/2} = M_3$ and
take NUHM2
- Then $M_3 = 1256 \pm 21$ GeV at
1 TeV
- And prediction for gluino
mass $m_{\tilde{g}} = 1510 \pm 23$ GeV

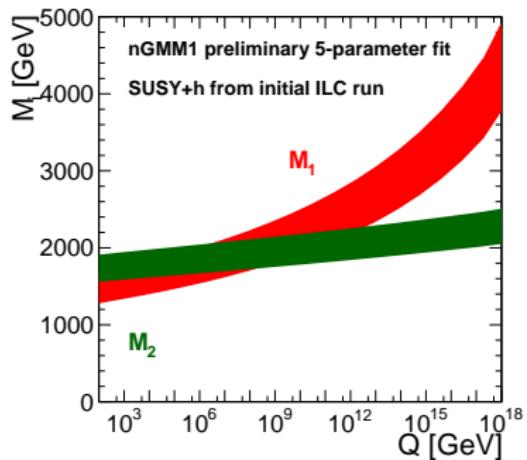


A different type of scenario: "mirage mediation"

- Some theories can have a gaugino mass (M_i) unification at lower energy scale
- In our model case has higgsino mass gaps ~ 5 GeV and M_i unification at $\sim 10^7$ GeV, analysis ongoing
- Motivation for mirage breaking scenarios (Baer et al 1610.06205)

Preliminary results for mirage

- Here: expected initial ILC run precisions, clear difference to ILC1 scenario
- Prediction for gluino mass is possible, some computational issues to be solved first



Summary

- ILC would measure properties of higgsinos to percent-level precision, with full ILC run / threshold scans to sub-% precision in the ILC1 benchmark
- These precise measurements allow for extracting some weak scale parameters, in particular the bino and wino mass parameters with 1-2% uncertainty after H₂₀
- Masses of heavier gauginos can be predicted, motivating an upgrade of the \sqrt{s} of the ILC
- Would get a strong hint of the existence of non-SUSY DM
- Can have sensitivity to different GUT unification hypotheses

