Discovering Supersymmetry and Dark Matter at the International Linear Collider

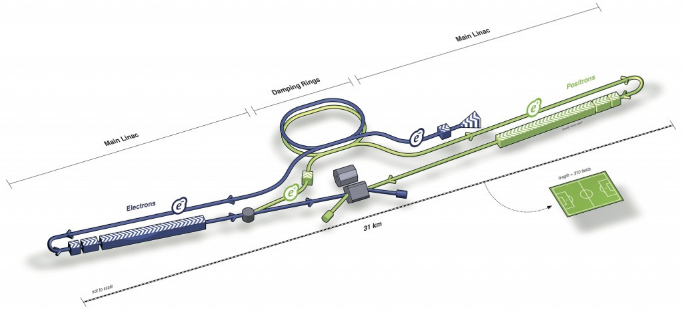
Mikael Berggren[1]
on behalf of the ILC Physics and Detector Study

[1]DESY, Hamburg

ICHEP, Valencia, July, 2014

Outline

The ILC



- A linear e^+e^- collider.
- Total length 31 km
- E_{CMS} tunable between 200 and 500 GeV, upgradable to 1 TeV.
- Polarisation e^-: 80% (e^+: $\geq$ 30%)
- $\int \mathcal{L} \sim$ 250 fb^{-1}/year
- 2 experiments, sharing one interaction region.
- Concurrent running with the LHC

The ILC is not LHC

- Lepton-collider: Initial state is known.
- Production is EW $\Rightarrow$
  - Small theoretical uncertainties.
  - No “underlaying event”.
  - Low cross-sections wrt. LHC, also for background.
  - $\Rightarrow$ Trigger-less operation.
  - High precision (sub-%) measurements needed, to extend our knowledge beyond LEP, Tevatron, LHC.

$\Rightarrow$ for detectors:

- Low background $\Rightarrow$ detectors can be:
  - Thin : few % X_0 in front of calorimeters.
  - Very close to IP: first layer of VXD at 1.5 cm.
  - Close to 4π: holes for beam-pipe only few cm = 0.2msr un-covered = Area of Suisse Romande (or Schleswig-Holstein, or Connecticut) relative to earth.
- Importance of hermeticity for the searches: $\gamma\gamma$ rejection !

The ILC is not LHC

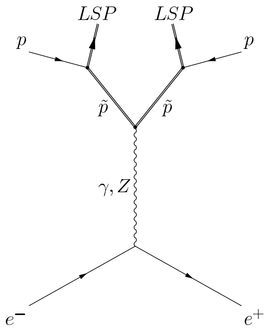
- Lepton-collider: Initial state is known.
- Production is EW $\Rightarrow$
  - Small theoretical uncertainties.
  - No "underlaying event".
  - Low cross-sections wrt. LHC, also for background.
  - $\Rightarrow$ Trigger-less operation.
  - High precision (sub-%) measurements needed, to extend our knowledge beyond LEP, Tevatron, LHC.

$\Rightarrow$ for detectors:

- Low background $\Rightarrow$ detectors can be:
  - Thin : few % X_0 in front of calorimeters
  - Very close to IP: first layer of VXD at 1.5 cm.
  - Close to 4π: holes for beam-pipe only few cm = 0.2 msr un-covered = Area of Suisse Romande (or Schleswig-Holstein, or Conneticut) relative to earth.
- Importance of hermeticity for the searches: $\gamma\gamma$ rejection !

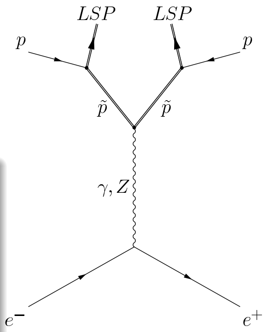
Loop-hole free SUSY searches

- All is known for given masses, due to SUSY-principle: “sparticles couples as particles”.
- This doesn’t depend on the SUSY breaking mechanism !
- Obviously: There is one NLSP.



Loop-hole free SUSY searches

- All is known for given masses, due to SUSY-principle: "sparticles couples as particles".
- This doesn't depend on the SUSY breaking mechanism !
- Obviously: There is one NLSP.



So, at ILC :

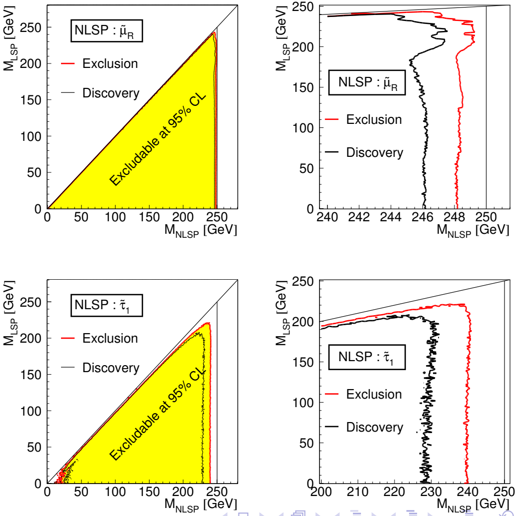
- Model independent exclusion/ discovery reach in $M_{NLSP} - M_{LSP}$ plane.
- Repeat for all NLSP:s.
- Cover entire parameter-space in a hand-full of plots
- NLSP search $\leftrightarrow$ "simplified models" @ LHC!

Simplified models

- Simplified methods at hadron and lepton machines are different beasts.
- At lepton machines they are quite model independent, at LHC model dependent.
- A few examples (M.B. arXiv:1308.1461)
  - $\tilde{\mu}_R$ NLSP
  - $\tilde{\tau}_1$ NLSP (minimal σ).

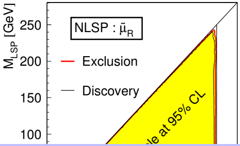
Simplified models

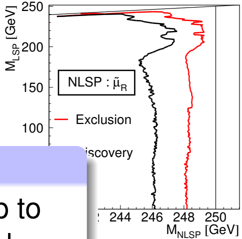
- Simplified methods at hadron and lepton machines are different beasts.
- At lepton machines they are quite model independent, at LHC model dependent.
- A few examples (M.B. arXiv:1308.1461)
  - $\tilde{\mu}_R$ NLSP
  - $\tilde{\tau}_1$ NLSP (minimal σ).



Simplified models

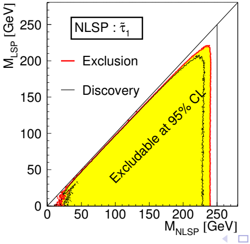
- Simplified methods at hadron and lepton machines are different beasts.
- At lepton machines they are c independ model de
- A few examples (M.B. arXiv:1308.1461)
  - $\tilde{\mu}_R$ NLSP
  - $\tilde{\tau}_1$ NLSP (minimal σ).

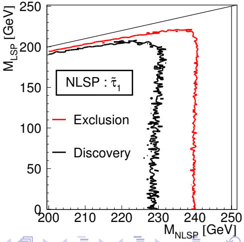




At ILC

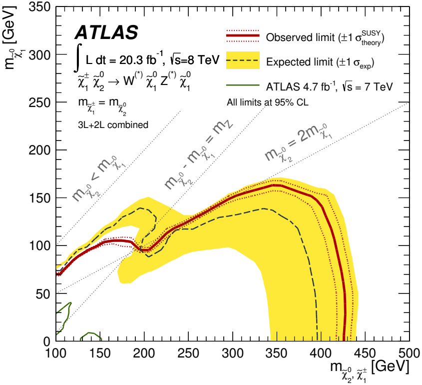
Both discover and exclude NLSPs up to some GeV:s from the kinematic limit !





No loop-holes

- Compare with LHC, here Atlas (arXiv:1403.5294v1):
  - Di- and tri-lepton searches, $M_{\tilde{\chi}_2^0} = M_{\tilde{\chi}_1^\pm}$, Br($\chi \rightarrow W^{(*)}/Z^{(*)}\tilde{\chi}_1^0$)=1.
- Note cut x-axis! Here is LEP, $\tilde{\chi}_1^\pm$ only, any decay-mode!
- Below thick line: Can't fulfil gaugino-mass GUT-relation.
- Discovery projections to 14 TeV 300/3000 fb^{-1} (arXiv:1307.7292v2).

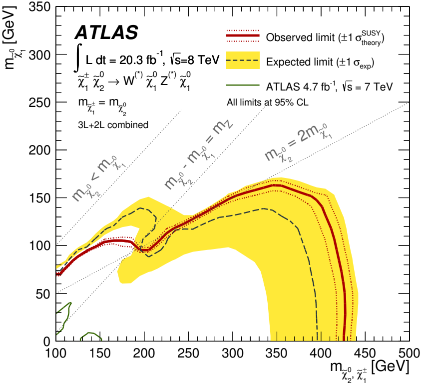


... and now the ILC

at 500 GeV...and 1 TeV⇒ Lots of plain vanilla SUSY to explore at ILC!

No loop-holes

- Compare with LHC, here Atlas (arXiv:1403.5294v1):
  - Di- and tri-lepton searches, $M_{\tilde{\chi}_2^0} = M_{\tilde{\chi}_1^\pm}$, Br($\chi \to W^{(*)}/Z^{(*)}\tilde{\chi}_1^0$)=1.
- Note cut x-axis! Here is LEP, $\tilde{\chi}_1^\pm$ only, any decay-mode!
- Below thick line: Can't fulfil gaugino-mass GUT-relation.
- Discovery projections to 14 TeV 300/3000 fb^{-1} (arXiv:1307.7292v2).

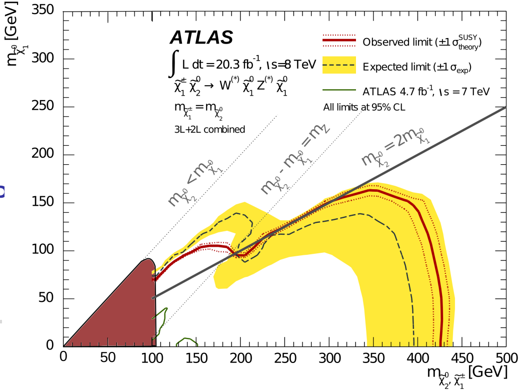


... and now the ILC

at 500 GeV...and 1 TeV ⇒ Lots of plain vanilla SUSY to explore at ILC!

No loop-holes

- Compare with LHC, here Atlas (arXiv:1403.5294v1):
  - Di- and tri-lepton searches, $M_{\tilde{\chi}_2^0} = M_{\tilde{\chi}_1^\pm}$, Br($\chi \to W^{(*)}/Z^{(*)}\tilde{\chi}_1^0$)=1.
- Note cut x-axis! Here is LEP $\tilde{\chi}_1^\pm$ only, any decay-mode!
- Below thick line: Can't fulfil gaugino-mass GUT-relation.
- Discovery projections to 14 TeV 300/3000 fb^{-1} (arXiv:1307.7292v2).

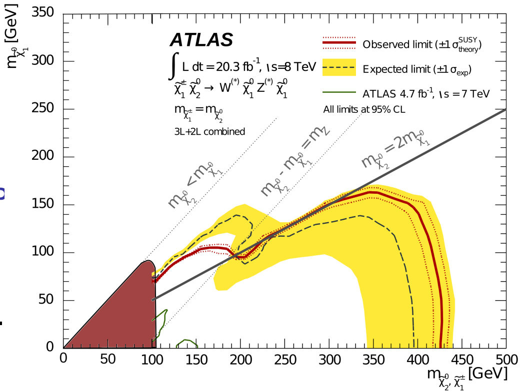


... and now the ILC

at 500 GeV...and 1 TeV⇒ Lots of plain vanilla SUSY to explore at ILC!

No loop-holes

- Compare with LHC, here Atlas (arXiv:1403.5294v1):
  - Di- and tri-lepton searches, $M_{\tilde{\chi}_2^0} = M_{\tilde{\chi}_1^\pm}$, Br($\chi \rightarrow W^{(*)}/Z^{(*)}\tilde{\chi}_1^0$)=1.
- Note cut x-axis! Here is LEP $\tilde{\chi}_1^\pm$ only, any decay-mode!
- Below thick line: Can't fulfil gaugino-mass GUT-relation.
- Discovery projections to 14 TeV 300/3000 fb^{-1} (arXiv:1307.7292v2).

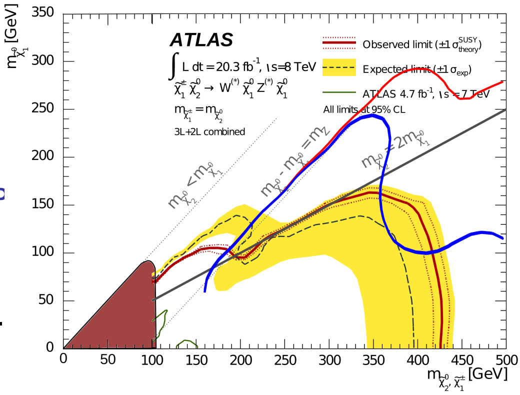


... and now the ILC

at 500 GeV...and 1 TeV⇒ Lots of plain vanilla SUSY to explore at ILC!

No loop-holes

- Compare with LHC, here Atlas (arXiv:1403.5294v1):
  - Di- and tri-lepton searches, $M_{\tilde{\chi}^0_2} = M_{\tilde{\chi}^\pm_1}$, Br($\chi \rightarrow W^{(*)}/Z^{(*)}\tilde{\chi}^0_1$)=1.
- Note cut x-axis! Here is LEP $\tilde{\chi}^\pm_1$ only, any decay-mode!
- Below thick line: Can't fulfil gaugino-mass GUT-relation.
- Discovery projections to 14 TeV 300/3000 fb^{-1} (arXiv:1307.7292v2).

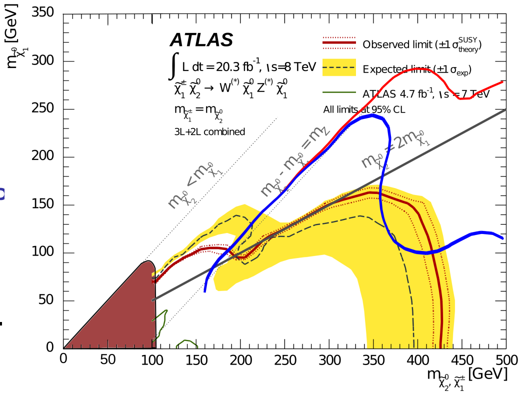


... and now the ILC

at 500 GeV...and 1 TeV⇒ Lots of plain vanilla SUSY to explore at ILC!

No loop-holes

- Compare with LHC, here Atlas (arXiv:1403.5294v1):
  - Di- and tri-lepton searches, $M_{\tilde{\chi}_2^0} = M_{\tilde{\chi}_1^\pm}$, Br($\chi \rightarrow W^{(*)}/Z^{(*)}\tilde{\chi}_1^0$)=1.
- Note cut x-axis! Here is LEP $\tilde{\chi}_1^\pm$ only, any decay-mode!
- Below thick line: Can't fulfil gaugino-mass GUT-relation.
- Discovery projections to 14 TeV 300/3000 fb^{-1} (arXiv:1307.7292v2).

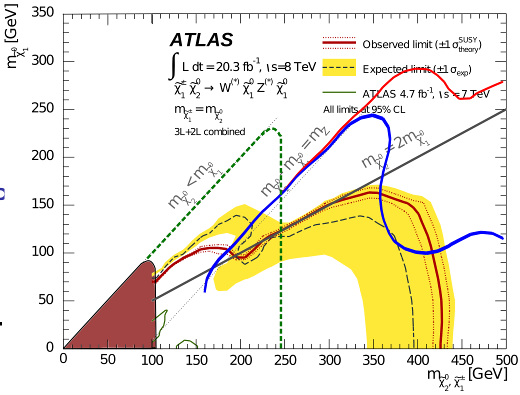


... and now the ILC

at 500 GeV...and 1 TeV ⇒ Lots of plain vanilla SUSY to explore at ILC!

No loop-holes

- Compare with LHC, here Atlas (arXiv:1403.5294v1):
  - Di- and tri-lepton searches, $M_{\tilde{\chi}_2^0} = M_{\tilde{\chi}_1^\pm}$, Br($\chi \rightarrow W^{(*)}/Z^{(*)}\tilde{\chi}_1^0$)=1.
- Note cut x-axis! Here is LEP $\tilde{\chi}_1^\pm$ only, any decay-mode!
- Below thick line: Can't fulfil gaugino-mass GUT-relation.
- Discovery projections to 14 TeV 300/3000 fb^{-1} (arXiv:1307.7292v2).

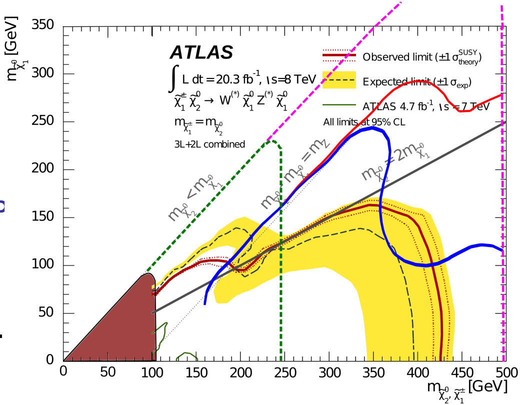


... and now the ILC

at 500 GeV...and 1 TeV⇒ Lots of plain vanilla SUSY to explore at ILC!

No loop-holes

- Compare with LHC, here Atlas (arXiv:1403.5294v1):
  - Di- and tri-lepton searches, $M_{\tilde{\chi}_2^0} = M_{\tilde{\chi}_1^\pm}$, Br($\chi \to W^{(*)}/Z^{(*)}\tilde{\chi}_1^0$)=1.
- Note cut x-axis! Here is LEP $\tilde{\chi}_1^\pm$ only, any decay-mode!
- Below thick line: Can't fulfil gaugino-mass GUT-relation.
- Discovery projections to 14 TeV 300/3000 fb^{-1} (arXiv:1307.7292v2).

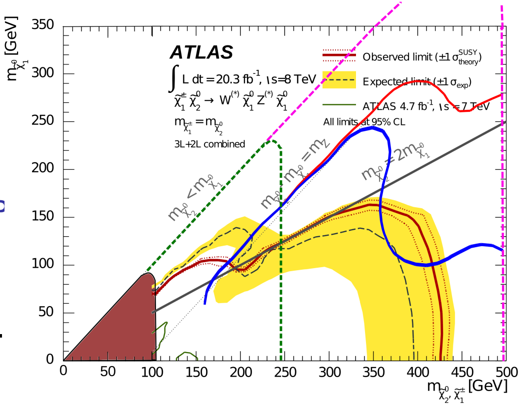


... and now the ILC

at 500 GeV...and 1 TeV⇒ Lots of plain vanilla SUSY to explore at ILC!

No loop-holes

- Compare with LHC, here Atlas (arXiv:1403.5294v1):
  - Di- and tri-lepton searches, $M_{\tilde{\chi}^0_2} = M_{\tilde{\chi}^\pm_1}$, Br($\chi \rightarrow W^{(*)}/Z^{(*)}\tilde{\chi}^0_1$)=1.
- Note cut x-axis! Here is LEP $\tilde{\chi}^\pm_1$ only, any decay-mode!
- Below thick line: Can't fulfil gaugino-mass GUT-relation.
- Discovery projections to 14 TeV 300/3000 fb^{-1} (arXiv:1307.7292v2).



... and now the ILC

at 500 GeV...and 1 TeV$\Rightarrow$ Lots of plain vanilla SUSY to explore at ILC!

Natural SUSY: Light, degenerate higgsinos

- Natural SUSY:
  - $m_Z^2 = 2\frac{m_{H_u}^2 \tan^2\beta - m_{H_d}^2}{1-\tan^2\beta} - 2\,|\mu|^2$
  - $\Rightarrow$ Low fine-tuning $\Rightarrow$ $\mu = \mathcal{O}$(weak scale).
  - If multi-TeV gaugino masses:
    - $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$ pure higgsino. Rest of SUSY at multi-TeV.
    - $M_{\tilde{\chi}_{1,2}^0}, M_{\tilde{\chi}_1^\pm} \approx \mu$
    - Degenerate (ΔM is 1 GeV or less)
- To detect: Tag using ISR photon, then look at rest of event:

SUSY signal and $\gamma\gamma$ background ... and with an ISR photon in addition

Natural SUSY: Light, degenerate higgsinos

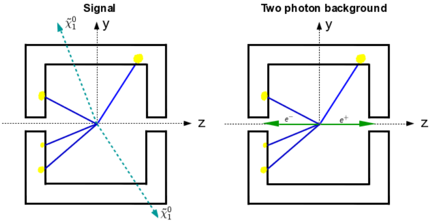
- Natural SUSY:
  - $m_Z^2 = 2\frac{m_{H_u}^2 \tan^2\beta - m_{H_d}^2}{1-\tan^2\beta} - 2|\mu|^2$
  - $\Rightarrow$ Low fine-tuning $\Rightarrow$ $\mu = \mathcal{O}$(weak scale).
  - If multi-TeV gaugino masses:
    - $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$ pure higgsino. Rest of SUSY at multi-TeV.
    - $M_{\tilde{\chi}_{1,2}^0}, M_{\tilde{\chi}_1^\pm} \approx \mu$
    - Degenerate (ΔM is 1 GeV or less)
- To detect: Tag using ISR photon, then look at rest of event:

SUSY signal and $\gamma\gamma$ background ... and with an ISR photon in addition

Natural SUSY: Light, degenerate higgsinos

- Natural SUSY:
  - $m_Z^2 = 2\frac{m_{H_u}^2 \tan^2\beta - m_{H_d}^2}{1-\tan^2\beta} - 2|\mu|^2$
  - $\Rightarrow$ Low fine-tuning $\Rightarrow \mu = \mathcal{O}$(weak scale).
  - If multi-TeV gaugino masses:
    - $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$ pure higgsino. Rest of SUSY at multi-TeV.
    - $M_{\tilde{\chi}_{1,2}^0}, M_{\tilde{\chi}_1^\pm} \approx \mu$
    - Degenerate (ΔM is 1 GeV or less)
- To detect: Tag using ISR photon, then look at rest of event:

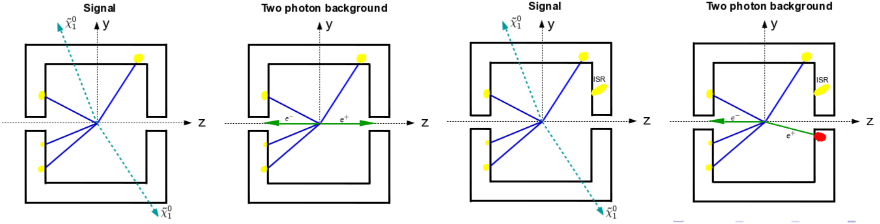
SUSY signal and $\gamma\gamma$ background ... and with an ISR photon in addition



Natural SUSY: Light, degenerate higgsinos

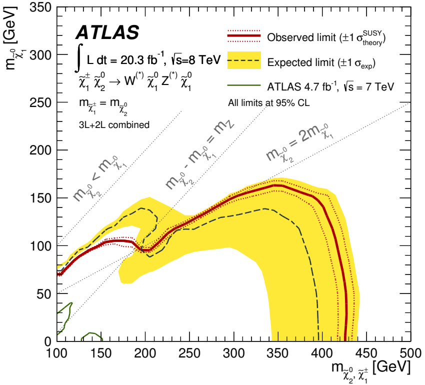
- Natural SUSY:
  - $m_Z^2 = 2\frac{m_{H_u}^2 \tan^2\beta - m_{H_d}^2}{1-\tan^2\beta} - 2|\mu|^2$
  - $\Rightarrow$ Low fine-tuning $\Rightarrow$ $\mu = \mathcal{O}$(weak scale).
  - If multi-TeV gaugino masses:
    - $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$ pure higgsino. Rest of SUSY at multi-TeV.
    - $M_{\tilde{\chi}_{1,2}^0}, M_{\tilde{\chi}_1^\pm} \approx \mu$
    - Degenerate (ΔM is 1 GeV or less)
- To detect: Tag using ISR photon, then look at rest of event:

SUSY signal and $\gamma\gamma$ background ... and with an ISR photon in addition



Natural SUSY: Light, degenerate higgsinos

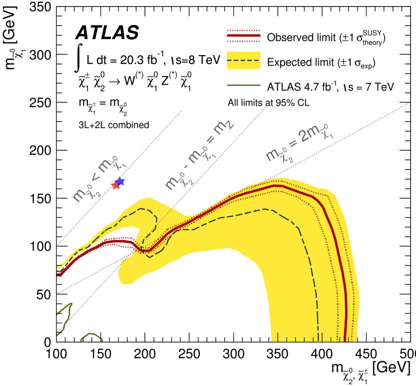
- Studied model points:
  - dm1600: $\Delta(M)$=1.6 GeV, m_h=124 GeV, $M_{\tilde{\chi}^0_1}$=164.2 GeV.
  - dm770: $\Delta(M)$=0.77 GeV, m_h=127 GeV, $M_{\tilde{\chi}^0_1}$=166.6 GeV.
- Very hard for LHC.
- Channels: Only $e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_2$ or $\tilde{\chi}^\pm_1\tilde{\chi}^\pm_1$ in s-channel (no $\tilde{\chi}^0_i\tilde{\chi}^0_i$ due to weak isospin, no t-channel due to higgsino nature)



H. Sert, F. Brümmer, J. List, G. Moortgat-Pick, T. Robens, K. Rolbiecki, M.B., EPJC (2013) 73:2660 [arXiv:1307.3566v2]

Natural SUSY: Light, degenerate higgsinos

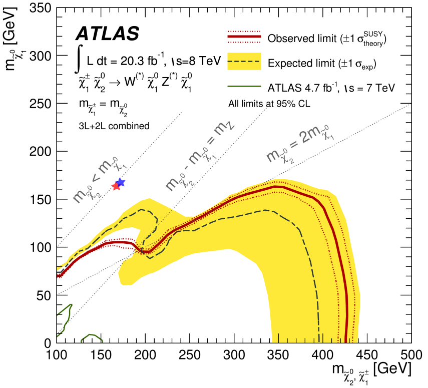
- Studied model points:
  - dm1600: $\Delta(M)$=1.6 GeV, m_h=124 GeV, $M_{\tilde{\chi}^0_1}$=164.2 GeV.
  - dm770: $\Delta(M)$=0.77 GeV, m_h=127 GeV, $M_{\tilde{\chi}^0_1}$=166.6 GeV.
- Very hard for LHC.
- Channels: Only $e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_2$ or $\tilde{\chi}^\pm_1\tilde{\chi}^\pm_1$ in s-channel (no $\tilde{\chi}^0_i\tilde{\chi}^0_i$ due to weak isospin, no t-channel due to higgsino nature)



H. Sert, F. Brümmer, J. List, G. Moortgat-Pick, T. Robens, K. Rolbiecki, M.B., EPJC (2013) 73:2660 [arXiv:1307.3566v2]

Natural SUSY: Light, degenerate higgsinos

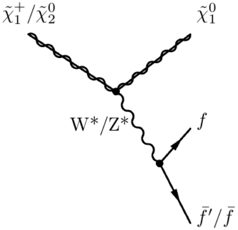
- Studied model points:
  - dm1600: $\Delta(M)$=1.6 GeV, m_h=124 GeV, $M_{\tilde{\chi}^0_1}$=164.2 GeV.
  - dm770: $\Delta(M)$=0.77 GeV, m_h=127 GeV, $M_{\tilde{\chi}^0_1}$=166.6 GeV.
- Very hard for LHC.
- Channels: Only $e^+e^- \rightarrow \tilde{\chi}^0_1 \tilde{\chi}^0_2$ or $\tilde{\chi}^\pm_1 \tilde{\chi}^\pm_1$ in s-channel (no $\tilde{\chi}^0_i \tilde{\chi}^0_i$ due to weak isospin, no t-channel due to higgsino nature)

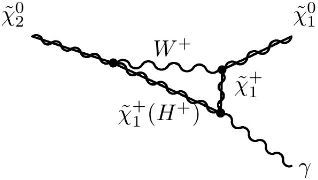


H. Sert, F. Brümmer, J. List, G. Moortgat-Pick, T. Robens, K. Rolbiecki, M.B., EPJC (2013) 73:2660 [arXiv:1307.3566v2]

Natural SUSY: Light, degenerate higgsinos

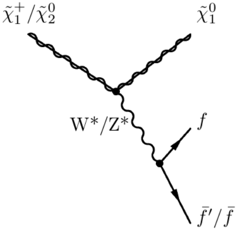
- Few-body decays and radiative decays (for $\tilde{\chi}^0_2$) (calculated with Herwig).
- Separate $\tilde{\chi}^\pm_1$ from $\tilde{\chi}^0_2$: Either semi-leptonic f.s.: Only $\tilde{\chi}^\pm_1$, or γ: only $\tilde{\chi}^0_2$.
- E_{ISR} gives reduced $\sqrt{s'}$: "auto-scan". End-point gives masses to $\sim$ 1 GeV.
- Close to end-point, E_π gives $\Delta(M_{\tilde{\chi}^0_1}, M_{\tilde{\chi}^\pm_1})$ to $\sim$ 100 MeV.

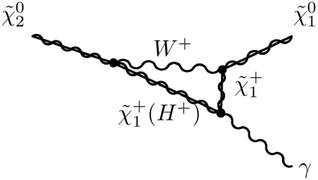




Natural SUSY: Light, degenerate higgsinos

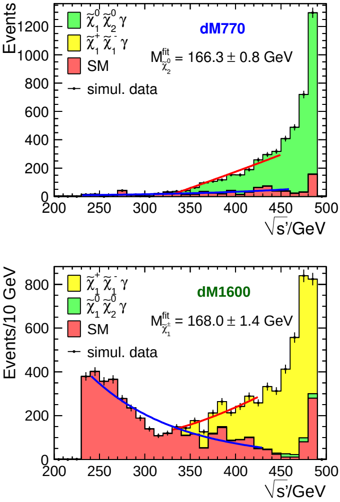
- Few-body decays and radiative decays (for $\tilde{\chi}_2^0$) (calculated with Herwig).
- Separate $\tilde{\chi}_1^{\pm}$ from $\tilde{\chi}_2^0$: Either semi-leptonic f.s.: Only $\tilde{\chi}_1^{\pm}$, or γ: only $\tilde{\chi}_2^0$.
- E_{ISR} gives reduced $\sqrt{s'}$: "auto-scan". End-point gives masses to $\sim$ 1 GeV.
- Close to end-point, E_{π} gives $\Delta(M_{\tilde{\chi}_1^0}, M_{\tilde{\chi}_1^{\pm}})$ to $\sim$ 100 MeV.





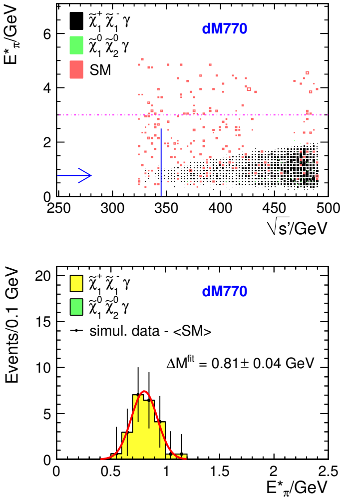
Natural SUSY: Light, degenerate higgsinos

- Few-body decays and radiative decays (for $\tilde{\chi}^0_2$) (calculated with Herwig).
- Separate $\tilde{\chi}^\pm_1$ from $\tilde{\chi}^0_2$: Either semi-leptonic f.s.: Only $\tilde{\chi}^\pm_1$, or γ: only $\tilde{\chi}^0_2$.
- E_{ISR} gives reduced $\sqrt{s'}$: "auto-scan". End-point gives masses to $\sim$ 1 GeV.
- Close to end-point, E_π gives $\Delta(M_{\tilde{\chi}^0_1}, M_{\tilde{\chi}^\pm_1})$ to $\sim$ 100 MeV.



Natural SUSY: Light, degenerate higgsinos

- Few-body decays and radiative decays (for $\tilde{\chi}^0_2$) (calculated with Herwig).
- Separate $\tilde{\chi}^\pm_1$ from $\tilde{\chi}^0_2$: Either semi-leptonic f.s.: Only $\tilde{\chi}^\pm_1$, or γ: only $\tilde{\chi}^0_2$.
- E_{ISR} gives reduced $\sqrt{s'}$: "auto-scan". End-point gives masses to $\sim$ 1 GeV.
- Close to end-point, E_π gives $\Delta(M_{\tilde{\chi}^0_1}, M_{\tilde{\chi}^\pm_1})$ to $\sim$ 100 MeV.

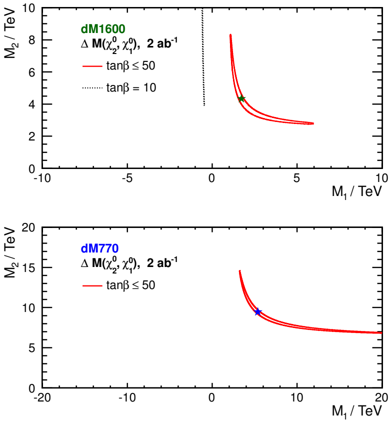


Natural SUSY: Light, degenerate higgsinos

- Use to extract the model-parameters μ, M_1 and M_2 (little $\tan\beta$ dependence).
- μ can be determined to $\pm$ 4 %.
- Limits on M_1 and M_2 after $\int \mathcal{L} = 2ab^{-1}$.
- For both models: Sign determined, allowed lower and upper limits on M_2 (for dm1600 also for M_1).

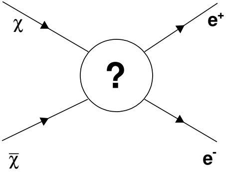
Natural SUSY: Light, degenerate higgsinos

- Use to extract the model-parameters μ, M_1 and M_2 (little $\tan\beta$ dependence).
- μ can be determined to $\pm$ 4 %.
- Limits on M_1 and M_2 after $\int \mathcal{L} = 2\text{ab}^{-1}$.
- For both models: Sign determined, allowed lower and upper limits on M_2 (for dm1600 also for M_1).



Only WIMPs

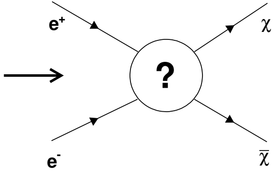
- Cosmology ⇒ 25% of universe = Dark Matter
- One possibility: WIMPs (χ). What if this is the only accessible NP ?



- Search for direct WIMP pair-production at collider : Need to make the invisible visible:
  - Require initial state radiation which will recoil against "nothing"
  - LHC: $pp \to \chi\chi g$ or $\chi\chi\gamma$
  - ILC: $e^+e^- \to \chi\chi\gamma$ (Full simulation study. C. Bartels, J. List, M.B. arXiv:1206.6639v1, and A. Chaus, Thesis,in preparation.)
- Model-independent Effective operator approach to "?"
  - Exclusion regions in M_χ/Λ plane, for each operator.

Only WIMPs

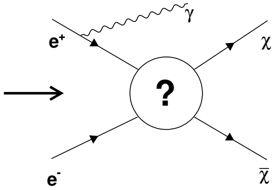
- Cosmology $\Rightarrow$ 25% of universe = Dark Matter
- One possibility: WIMPs (χ). What if this is the only accessible NP ?



- Search for direct WIMP pair-production at collider : Need to make the invisible visible:
  - Require initial state radiation which will recoil against "nothing"
  - LHC: *pp* $\rightarrow \chi\chi g$ or $\chi\chi\gamma$
  - ILC: $\mathrm{e}^+\mathrm{e}^- \rightarrow \chi\chi\gamma$ (Full simulation study. C. Bartels, J. List, M.B. arXiv:1206.6639v1, and A. Chaus, Thesis,in preparation.)
- Model-independent Effective operator approach to "?"
  - Exclusion regions in M_χ/Λ plane, for each operator.

Only WIMPs

- Cosmology $\Rightarrow$ 25% of universe = Dark Matter
- One possibility: WIMPs (χ). What if this is the only accessible NP ?

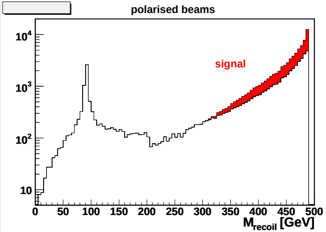


- Search for direct WIMP pair-production at collider : Need to make the invisible visible:
  - Require initial state radiation which will recoil against "nothing"
  - LHC: $pp \rightarrow \chi\chi g$ or $\chi\chi\gamma$
  - ILC: $\mathrm{e}^+\mathrm{e}^- \rightarrow \chi\chi\gamma$ (Full simulation study. C. Bartels, J. List, M.B. arXiv:1206.6639v1, and A. Chaus, Thesis,in preparation.)
- Model-independent Effective operator approach to "?"
  - Exclusion regions in M_χ/Λ plane, for each operator.

Backgrounds and Signal extraction

Irreducible Backgrounds

- $ee \to \nu\nu\gamma$
  - Recoil-mass peaks at M_Z
  - "switched off" by $P(e^-)$=1.
- $e^+e^- \to e^+e^-\gamma$
  - mimics signal if e^+e^- undetected
  - crucial to apply veto from low angle calorimeter



$P(e^-, e^+)$	$\nu\bar{\nu}\gamma$	$e^+e^-\gamma$
$(0\%, 0\%)$	67%	23%
$(+80\%, -60\%)$	25%	75%

Mass & σ from spectrum shape

- fractional event counting: Weight events by $S_{bin}/\sqrt{B_{bin}}$
- Include systematic errors.

Comparison with current LHC Results

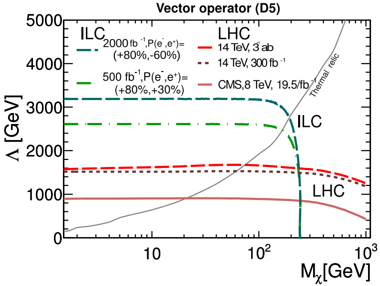
- Examples:
  - Vector operator (“spin independent”), $S_\chi = 1/2$
  - Axial-vector operator (“spin dependent”), $S_\chi = 1/2$

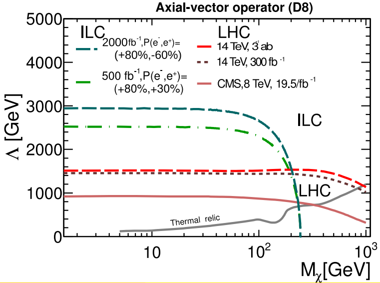
LHC data: CMS PAS EXO-12-048,projections: arXiv:1307.5327

- LHC reaches higher masses, ILC smaller cross-section.

Note:

- LHC curves assume pure coupling to hadrons, while
- ILC curves assume pure coupling to leptons
- Not a priori comparable, rather complementary





Comparison with current LHC Results

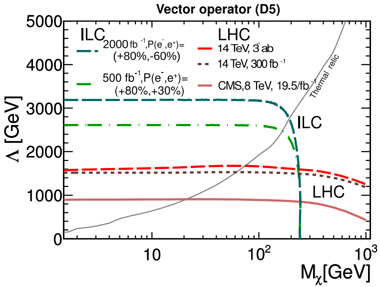
- Examples:
  - Vector operator (“spin independent”), $S_\chi = 1/2$
  - Axial-vector operator (“spin dependent”), $S_\chi = 1/2$

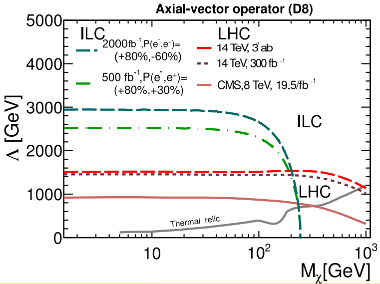
LHC data: CMS PAS EXO-12-048,projections: arXiv:1307.5327

- LHC reaches higher masses, ILC smaller cross-section.

Note:

- LHC curves assume pure coupling to hadrons, while
- ILC curves assume pure coupling to leptons.
- Not a priori comparable; rather complementary!



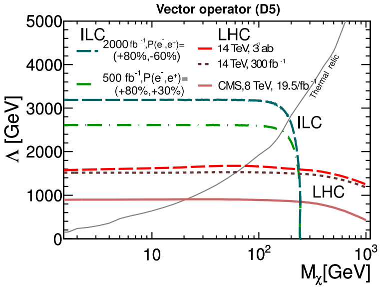


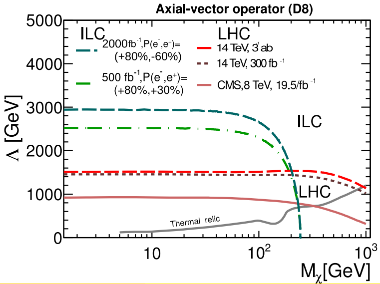
Comparison with current LHC Results

- Examples:
  - Vector operator ("spin independent"), $S_\chi = 1/2$
  - Axial-vector operator ("spin dependent"), $S_\chi = 1/2$

LHC data: CMS PAS EXO-12-048,projections: arXiv:1307.5327

- LHC reaches higher masses, ILC smaller cross-section.





Note:

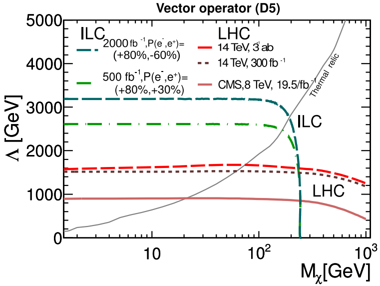
- LHC curves assume pure coupling to hadrons, while
- ILC curves assume pure coupling to leptons.
- Not a priori comparable; rather complementary!

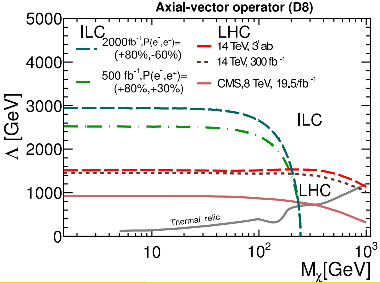
Comparison with current LHC Results

- Examples:
  - Vector operator ("spin independent"), $S_\chi = 1/2$
  - Axial-vector operator ("spin dependent"), $S_\chi = 1/2$

LHC data: CMS PAS EXO-12-048,projections: arXiv:1307.5327

- LHC reaches higher masses, ILC smaller cross-section.





Note:

- LHC curves assume pure coupling to hadrons, while
- ILC curves assume pure coupling to leptons.
- Not a priori comparable; rather complementary!

Conclusions

At ILC:

- Loop-hole free discovery potential for SUSY, up to the kinematic limit.
- Includes a vast region of moderate-to-small LSP-NLSP mass-differences, not explorable by hi-lumi LHC.
- Even in natural SUSY scenarios where the only sparticles below the multi TeV range are almost mass-degenerate higgsinos: ILC can discover, and determine model-parameters, high-mass sector ones included.
- In searches for dark matter, ILC yields orthogonal information to LHC and direct searches.
- Tests contact interaction scales up to 3-4 TeV.
- In addition: WIMP property determination (mass: 1-2%, helicity structure, spin of mediator) ⇒ model discrimination

Conclusions

At ILC:

- Loop-hole free discovery potential for SUSY, up to the kinematic limit.
- Includes a vast region of moderate-to-small LSP-NLSP mass-differences, not explorable by hi-lumi LHC.
- Even in natural SUSY scenarios where the only sparticles below the multi TeV range are almost mass-degenerate higgsinos: ILC can discover, and determine model-parameters, high-mass sector ones included.
- In searches for dark matter, ILC yields orthogonal information to LHC and direct searches.
- Tests contact interaction scales up to 3-4 TeV.
- In addition: WIMP property determination (mass: 1-2%, helicity structure, spin of mediator) $\Rightarrow$ model discrimination

Conclusions

At ILC:

- Loop-hole free discovery potential for SUSY, up to the kinematic limit.
- Includes a vast region of moderate-to-small LSP-NLSP mass-differences, not explorable by hi-lumi LHC.
- Even in natural SUSY scenarios where the only sparticles below the multi TeV range are almost mass-degenerate higgsinos: ILC can discover, and determine model-parameters, high-mass sector ones included.
- In searches for dark matter, ILC yields orthogonal information to LHC and direct searches.
- Tests contact interaction scales up to 3-4 TeV.
- In addition: WIMP property determination (mass: 1-2%, helicity structure, spin of mediator) $\Rightarrow$ model discrimination

Conclusions

At ILC:

- Loop-hole free discovery potential for SUSY, up to the kinematic limit.
- Includes a vast region of moderate-to-small LSP-NLSP mass-differences, not explorable by hi-lumi LHC.
- Even in natural SUSY scenarios where the only sparticles below the multi TeV range are almost mass-degenerate higgsinos: ILC

See also: The other side of SUSY at the ILC

Poster **Precision measurement of SUSY at the ILC**, presented by J. List

LHC and direct searches.

- Tests contact interaction scales up to 3-4 TeV.
- In addition: WIMP property determination (mass: 1-2%, helicity structure, spin of mediator) $\Rightarrow$ model discrimination

Thank You !