Experimental techniques for Higgsinos with $\Delta(M) \sim 1$ GeV DRAFT

Mikael Berggren[1], S. Sasikumar[1], J. List[1], & al.
on behalf ILD

[1]DESY, Hamburg

ALCW, Fukuoka, May, 2018

Outline

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 ($\Delta M \leq 1$ GeV)
  - Ex. of UV model giving this:
    Hybrid gauge-gravity mediation.
    F. Brümmer and W. Buchmüller, JHEP 1107 (2011) 010 [arXiv:1105.0802[hep-ph]] & JHEP 1205 ('12) 006 [arXiv:1201.4338[hep-ph]]

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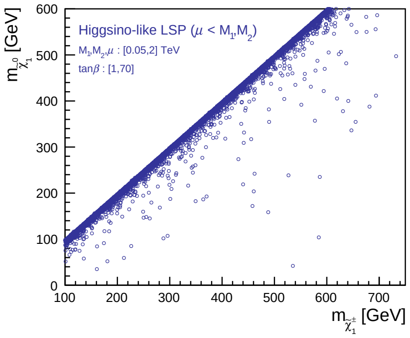
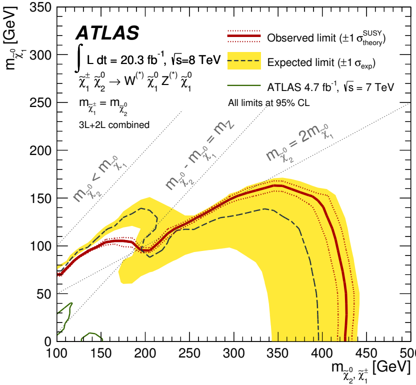
But quite generic:
Parameter-scan by T. Tanabe:



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



Detailed simulation study of such a model at DBD:

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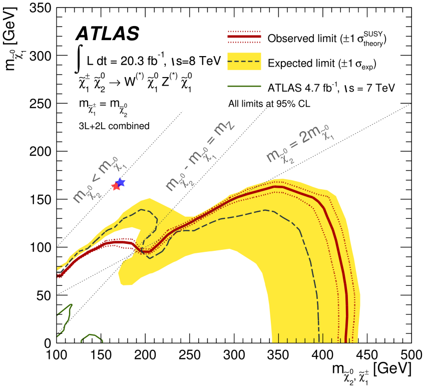

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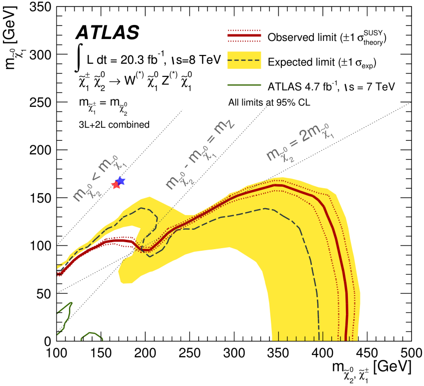

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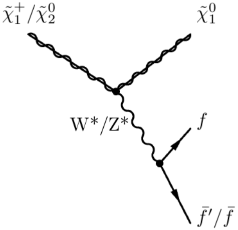
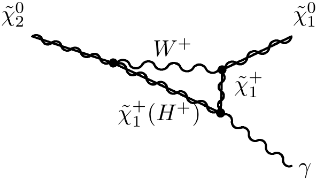
Light, degenerate higgsinos: Signal Characteristics

- Few-body decays and radiative decays (for $\tilde{\chi}_2^0$) (calculated with Herwig).
- Few particle F.S. Here: BR:s of $\tilde{\chi}_1^\pm$ vs. $\Delta(M)$
- Separate $\tilde{\chi}_1^\pm$ from $\tilde{\chi}_2^0$: Either semi-leptonic f.s.: Only $\tilde{\chi}_1^\pm$, or γ: only $\tilde{\chi}_2^0$.
- Low $p_\perp$ particles only visible signal.





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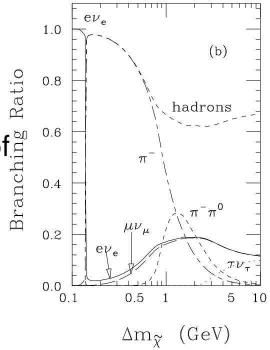

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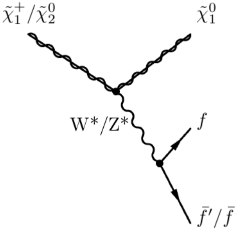

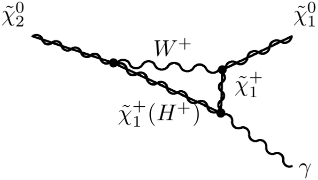

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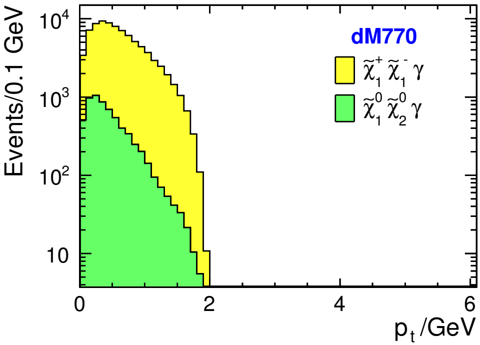

Light, degenerate higgsinos: $\gamma\gamma$...

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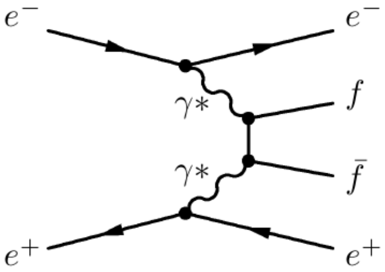

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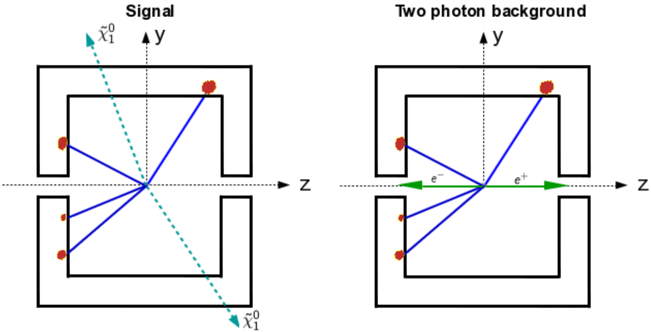

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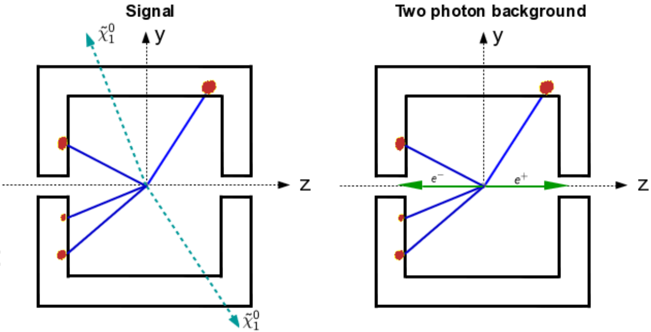

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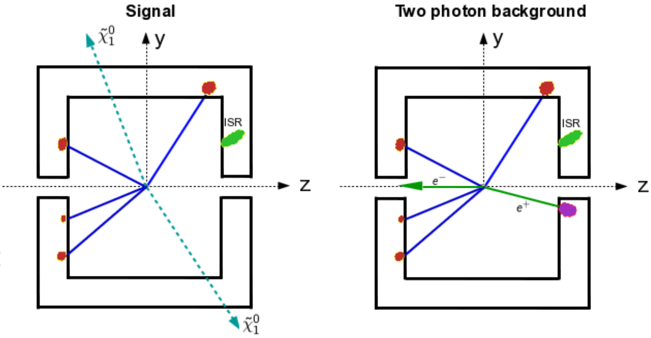


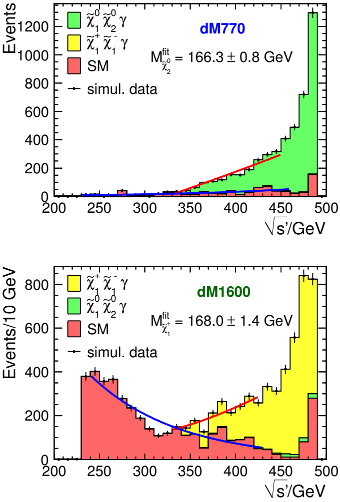
Light, degenerate higgsinos: Selections

- No seen beam-remnant: No activity in BeamCal.
- Low multiplicity: $N_{\text{Reconstructed P}} < 15$.
- Require ISR: Exactly one reconstructed γ with $E_{\text{ISR}} > 10\,\text{GeV}$ and a $|\cos\theta_{\text{ISR}}| < 0.993$.
- Central production: Any other reconstructed particle $> 20^\circ$ away from the beam axis.
- Large fraction of E_{cms} in the LSPs: $E_{\text{miss}} > 300\,\text{GeV}$.
- Sizeable missing $p_\perp$: $|\cos\theta_{\text{miss}}| < 0.992$.

- For $\tilde{\chi}^+_1\tilde{\chi}^-_1$: Semi-leptonic decay.
- For $\tilde{\chi}^0_1\tilde{\chi}^0_2$: Radiative decay.

Light, degenerate higgsinos: Mass and $\Delta(M)$

- 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.



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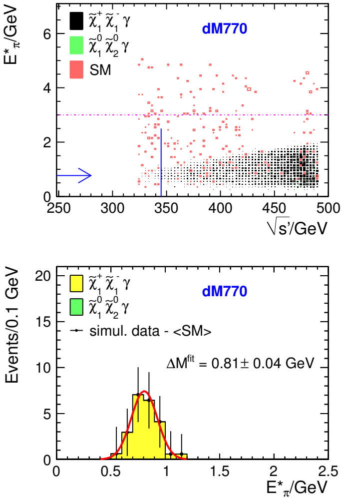

Light, degenerate higgsinos: Model parameters

- Use to extract the model-parameters μ, M_1 and M_2 (little tan β dependence).
- μ can be determined to $\pm$ 4 %.
- Limits on M_1 and M_2 after $\int \mathcal{L} = 2\text{ab}^{-1}$.
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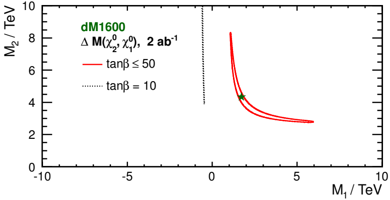

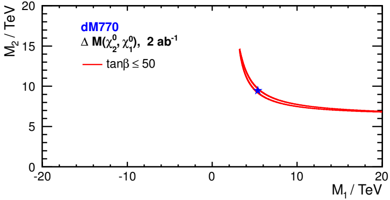

Experimental issues

Experimental issues: The beam-spot

- The ILC beam-spot:
  - To achieve the very high ILC luminosity, the beam-beam crossover region (the "beam-spot") is *extremely* small and dense.
  - 5 nm $\times$ 150 nm $\times$ 200 μm
  - $\Rightarrow$ *very* high E- and B-fields.
  - $\Rightarrow$ synchrotron radiation (= X-rays) and e^+e^- pairs.
  - Who says "photons meets electrons", says "Compton back-scattering"
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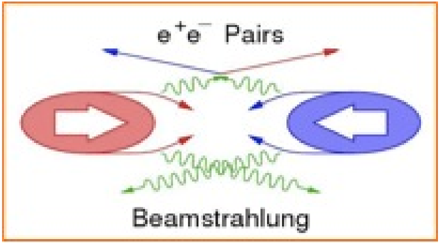

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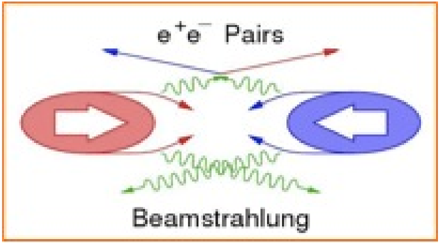

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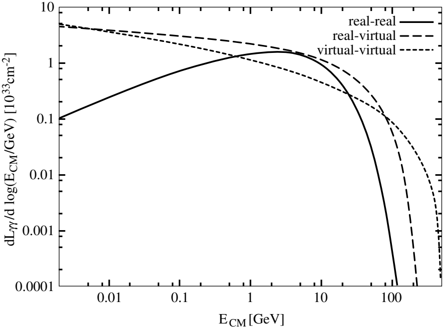

Experimental issues: Photons sometimes are hadrons

- Inclusive cross-section for $\gamma\gamma \rightarrow$ hadrons : “In $\frac{1}{400}$ of the cases, a γ is a vector-meson”
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- High $m_{\gamma\gamma}$: Multi-peripheral dominates.
- At low $m_{\gamma\gamma}$: vector-meson scattering dominates.
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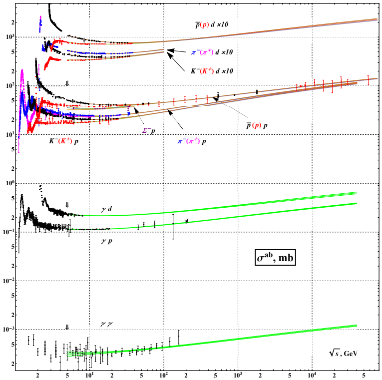

(PDG)

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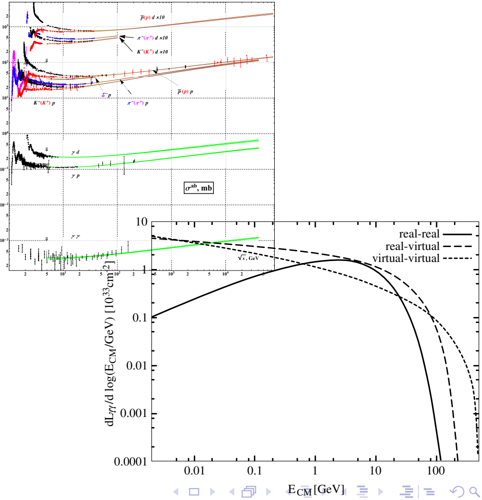

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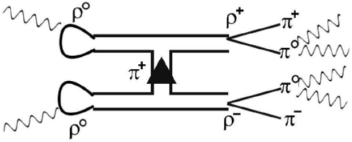

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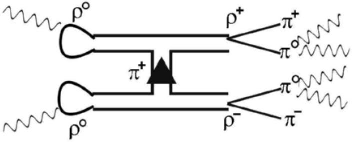
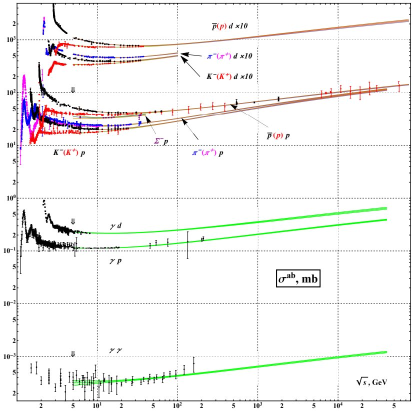


Experimental issues: ILC “pile-up”

- Previous study: Multi-peripheral $\gamma\gamma$ considered (ISR trick, see above).
- However, overlay low-$p_\perp$ hadrons and pairs wasn’t. Overlay was not well described at the time.
- Little phase-space ⇒ exclusive modes ⇒ codes like PYTHIA inadequate.
- Theory shaky, need data!
- Dedicated, data-driven, generator (Barklow, Peskin, Chen).



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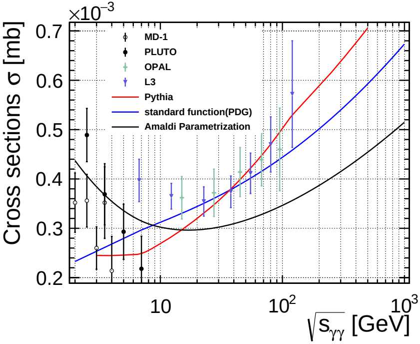

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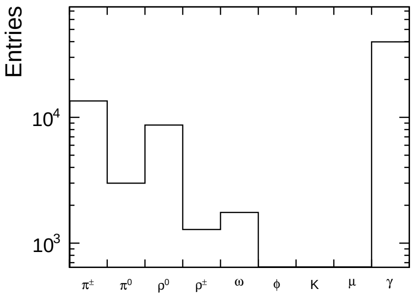
Final state particles when $M_{\gamma\gamma} < 2\mathrm{GeV}$



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  - $\Rightarrow$ Solved by ISR trick.
- Overlay:
  - Confuses signal: extra signal-like tracks in selected events, but will not alone pass signal criteria.
  - Often distinct signature, identifiable by direct reconstruction of vector mesons.
  - Different production point.

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- Multi-peripheral:
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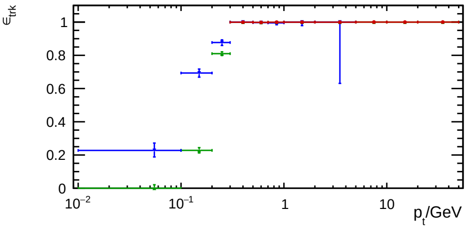
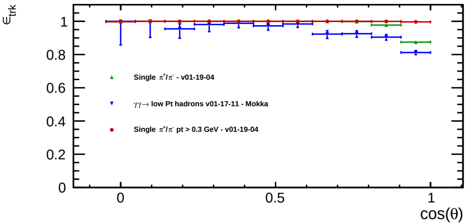
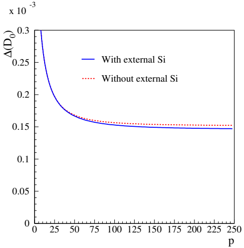
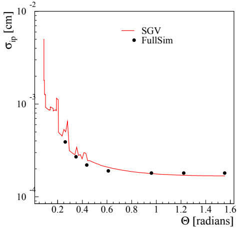




Experimental issues: Separate vertex?

- Remember: beam-spot in x-y plane is at nano-metre scale.
- Even with the excellent vertex-detectors of ILD and SiD ($\sigma_{ip} \sim 1\ \mu m$), this is a point
- $\Rightarrow$ vertex-finding is a 1D-problem (unlike LEP or LHC).
- Create groups of tracks w/ low ip_{x-y} (ie. from the beam-spot), and compatible ip_z.
- Promising...





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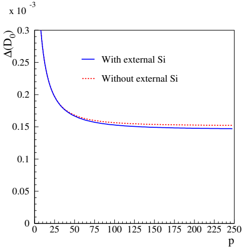

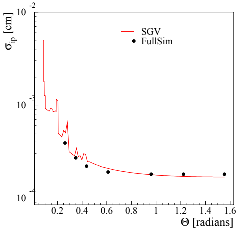

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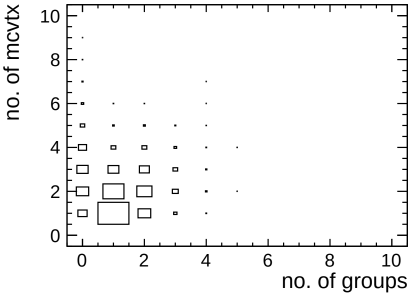

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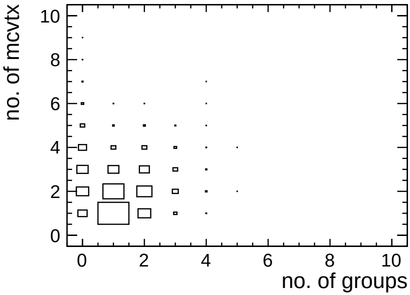

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So, we can often separate tracks from different vertices.

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  2. Particle ID: To separate channels, a semi-leptonic signature is requested for the $\tilde{\chi}_1^{\pm}$ channel. The background never has that.
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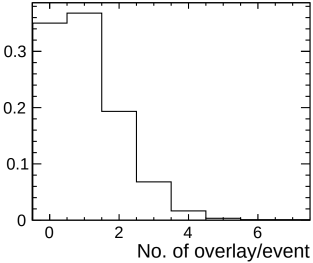

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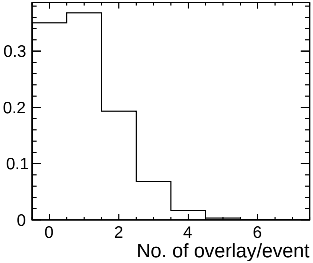

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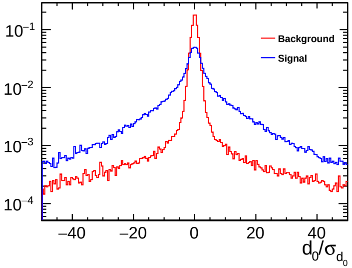

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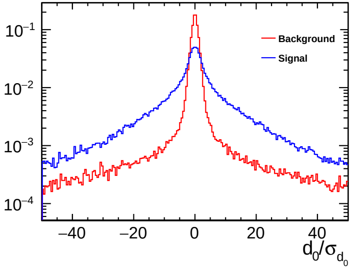

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Conclusions

At ILC:

- 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.
- This is being re-visited, including important experimental features not modelled at DBD-times, or not used:
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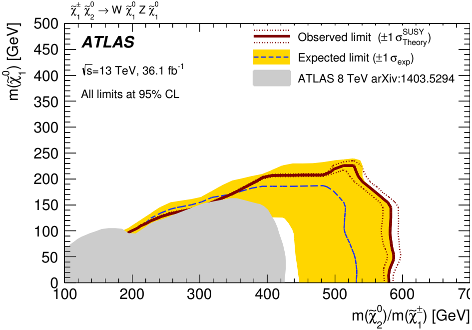
Thank You !

BACKUP

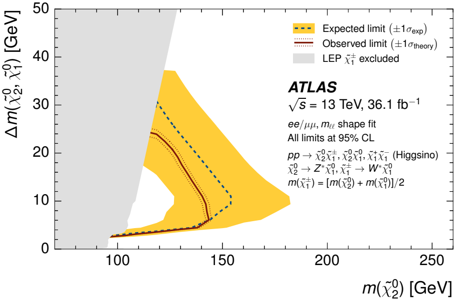
BACKUP SLIDES

Latest Atlas (13 TeV, 36 fb^{-1})

arXiv:1712.08119



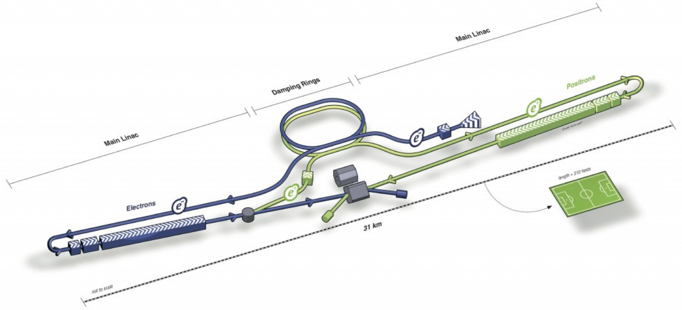
arXiv:1803.02762



$\sim$ same analysis as shown in talk. Only extends below the $M_{\tilde{\chi}_2^0}$ (or $M_{\tilde{\chi}_1^{\pm}}) > 2M_{\tilde{\chi}_2^0}$ line

Same channel as in this talk. Look at $\Delta(M) \sim 1\,\mathrm{GeV}$ and $M_{\tilde{\chi}_2^0} \sim 160\,\mathrm{GeV}$. The actual limit is the LEP one.

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 !

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