

New physics searches with the ILD detector at the ILC

Mikael Berggren¹
on behalf of the ILD concept group

¹DESY, Hamburg

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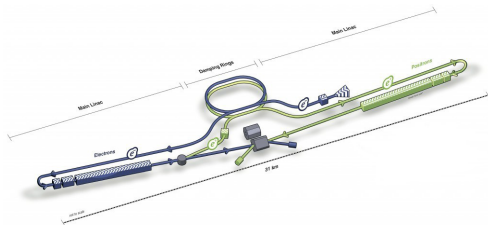


CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE



The ILC strong points for searches

- e^+e^- collider with $E_{CMS} = 250 - 500$ (- 1000) GeV, and **polarised beams**
- e^+e^- means EW-production \Rightarrow **Low background.**
 - Detectors w/ $\sim 4\pi$ **coverage.**
 - Rad. hardness not needed: only **few % X_0** in front of calorimeters.
 - **No trigger**
- e^+e^- means colliding point-like objects \Rightarrow **initial state known**
- 20 year running $\rightarrow 2 \text{ ab}^{-1}$ @ 250 GeV, **4 ab^{-1} @ 500 GeV.**
- Construction under **political consideration** in Japan.



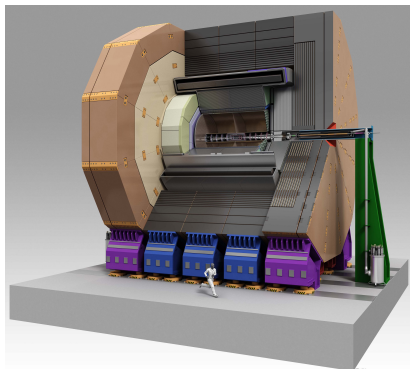
The ILD concept (arXiv:2003.01116)

Physics requirements, SM and BSM:

- $\sigma(1/p_{\perp}) = 2 \times 10^{-5} \text{ GeV}^{-1}$
- JER $\sim 3\text{-}4\%$
- $\sigma(d_0) < 5\mu$
- particle Id (PID)
- hermeticity down to 5 mrad
- triggerless operation.

Leads to key features of the detector:

- low mass tracker with PID:
 - Main device: TPC
 - Enhanced by silicon
- High granularity calorimeters optimised for particle flow
- Power-pulsing.



BSM at ILC

In this talk: Concentrating on

- **SUSY:**

- *The most complete theory of BSM.*
- Serves as a boiler-plate for BSM: almost any new topology can be obtained in SUSY...
- Most studied model with serious simulation: In most cases, full simulation of ILD, with all SM backgrounds, all beam-induced backgrounds included.
- Under some stress(?) by LHC. However, ILC offers
 - Loop-hole free searches.
 - Complete coverage of Compressed spectra - the most interesting case.

- + A few slides on non-SUSY BSMs...

- Won't mention Dark Matter: Listen to Filip Zarnecki's talk after the break !

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SUSY: What *do* we know ?

Naturalness, hierarchy, DM, g-2 all prefer **light electroweak** sector.

- Except for 3rd gen. squarks, **the coloured sector doesn't enter the game**.
- Many models and the global set of constraints from observation points to a **compressed spectrum**.
- So, most sparticle-decays are via cascades, with **small $\Delta(M)$** at the end.
- For this, current LHC limits are for specific models. LEP2 sets the scene.

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Why compressed spectra ?

- Higgsino or Wino LSP:

- If the LSP is Higgsino or a Wino, several other bosinos *must* be close to the LSP.

- \Rightarrow **Compressed spectrum.**

- In addition: if the LSP is higgsino:

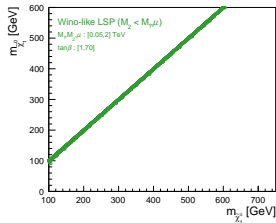
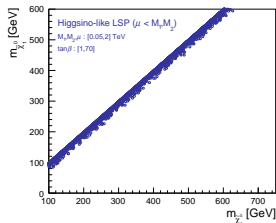
Natural SUSY:

- $m_Z^2 = 2 \frac{m_{H_u}^2 \tan^2 \beta - m_{H_d}^2}{1 - \tan^2 \beta} - 2 |\mu|^2$

- Low fine-tuning $\Rightarrow \mu = \mathcal{O}(m_Z)$

- Bino LSP: Overabundance of DM.

- Need balance between early universe production and decay.
- One compelling option is $\tilde{\tau}$ Co-annihilation. For this to contribute: Early universe density of $\tilde{\tau}$ and $\tilde{\chi}_1^0$ similar \Rightarrow **Compressed spectrum.**

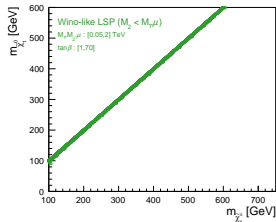
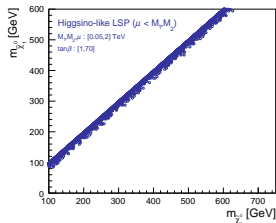


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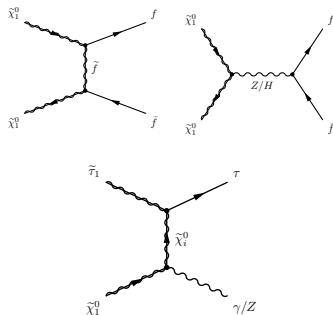


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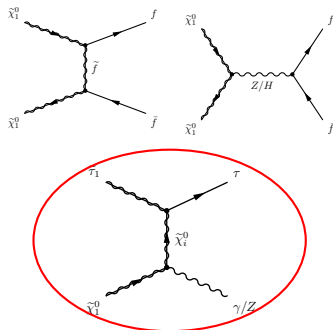
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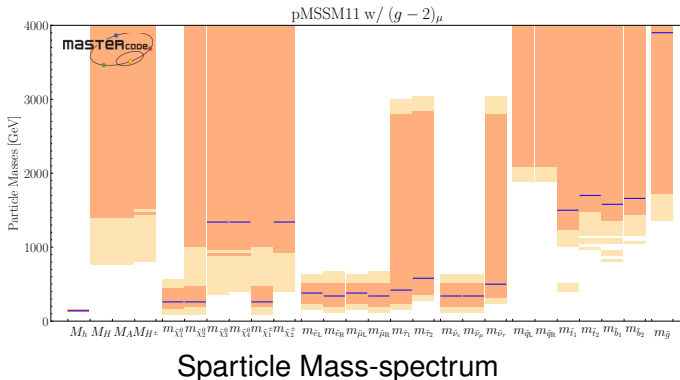
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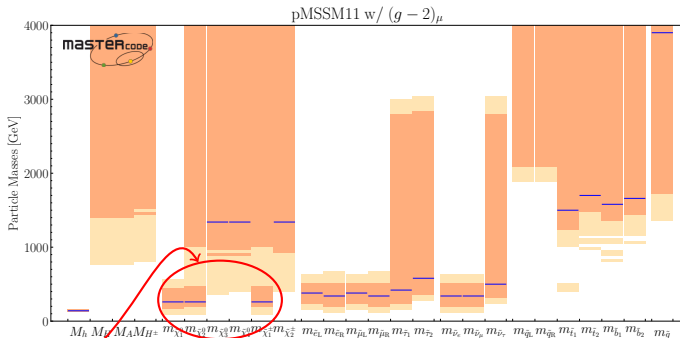
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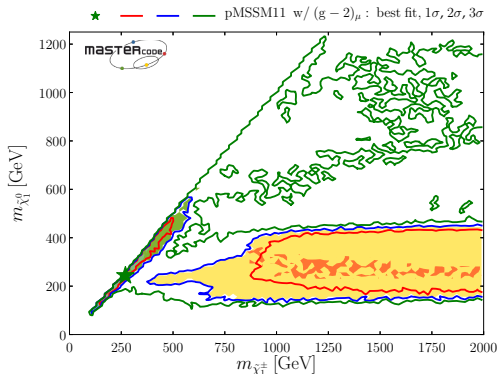


Low $\Delta(M)$!

Particle Mass-spectrum

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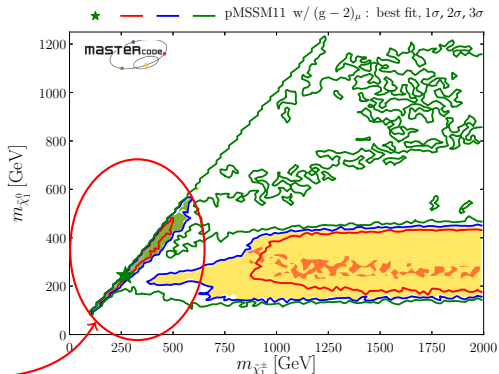
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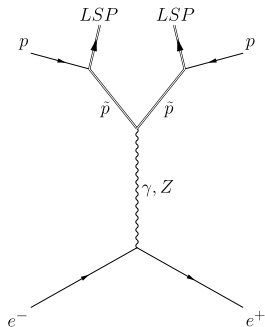
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- All is **known** for given masses, due to SUSY-principle: “sparticles couples as particles”.
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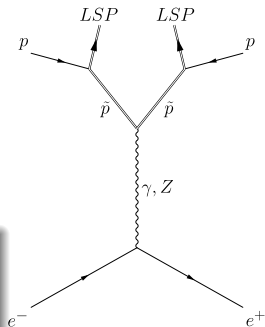


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- Model **independent** exclusion/ discovery reach in $M_{NLSP} - M_{LSP}$ plane.
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- Cover entire parameter-space in a few plots
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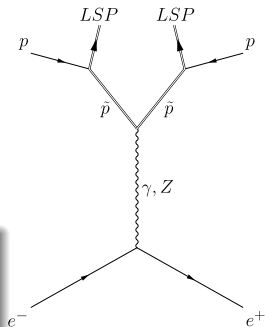


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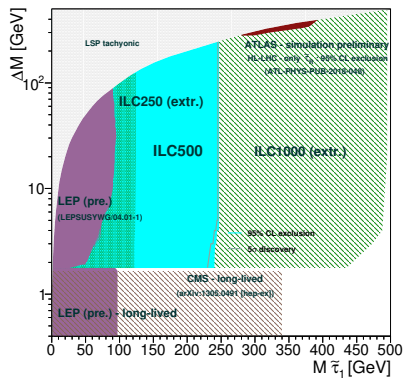
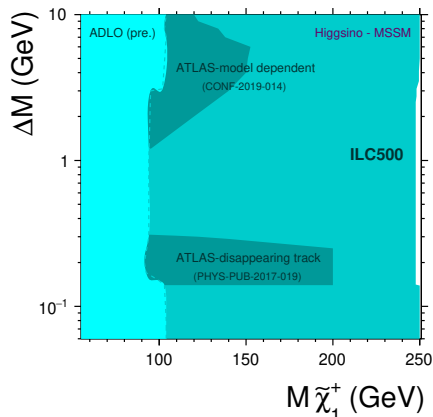
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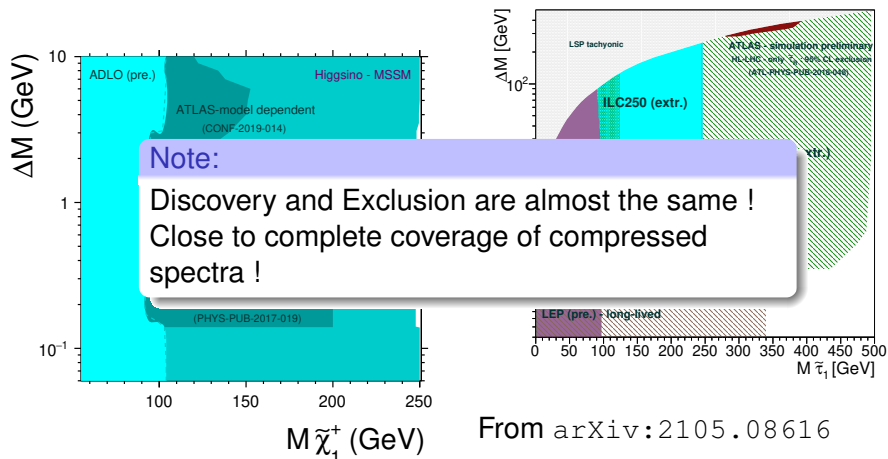
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At ILC: discovery in a week...

ILD fast detector simulation studies: Selectrons in a co-annihilation model (EPJC 76,183 (2016)), after:

- $5 \text{ fb}^{-1} \approx 1 \text{ week}$

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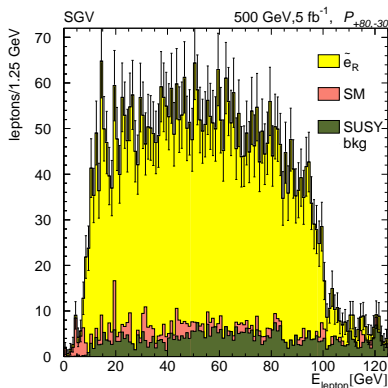
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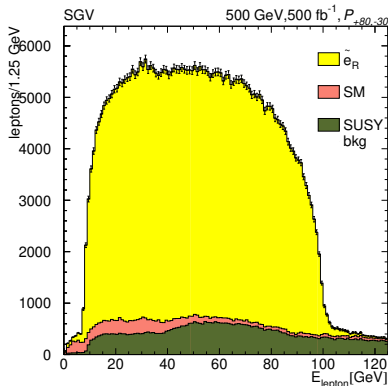
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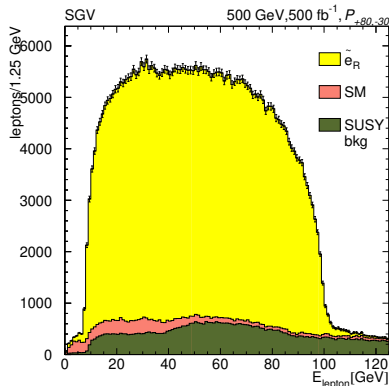
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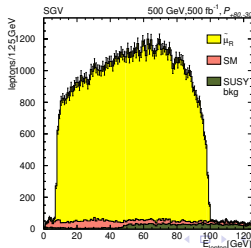
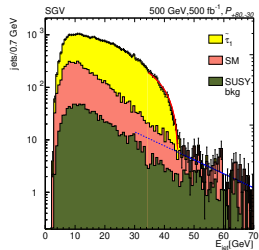
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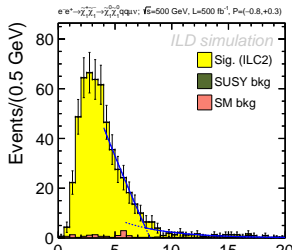
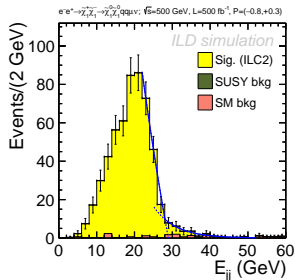
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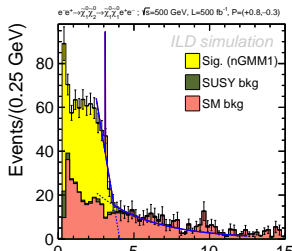
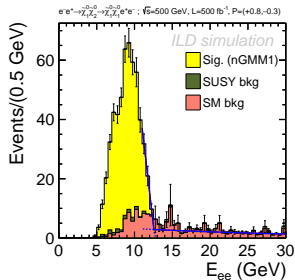
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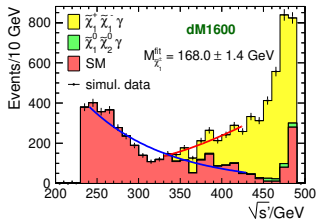
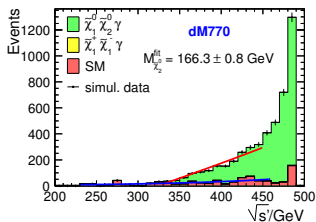
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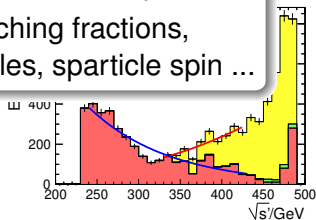
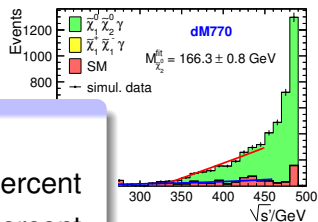
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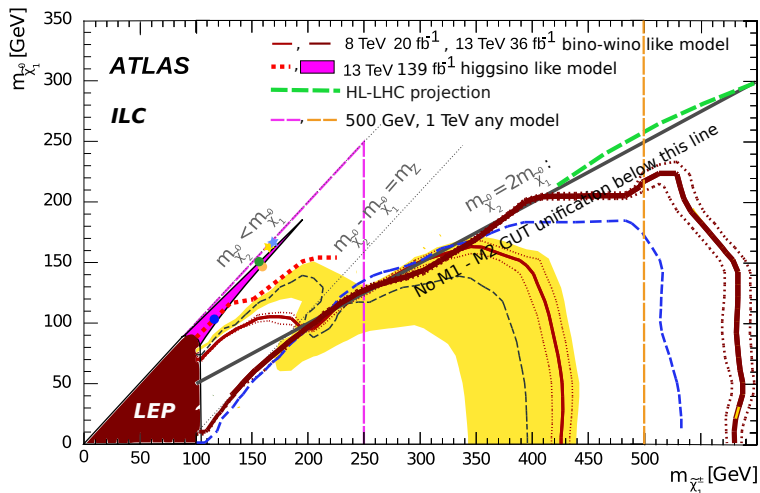
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In all cases:

- SUSY masses to sub-percent
- Cross-sections to few percent
- Also: Branching fractions, mixing angles, sparticle spin ...



SUSY bosinos - All-in-one

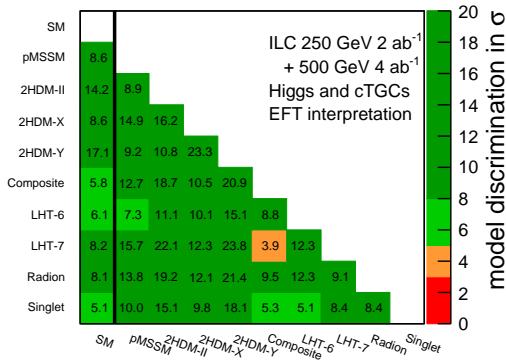


ATLAS Eur Phys J C 78,995 (2018), Phys Rev D 101,052002 (2020), arXiv:2106.01676;

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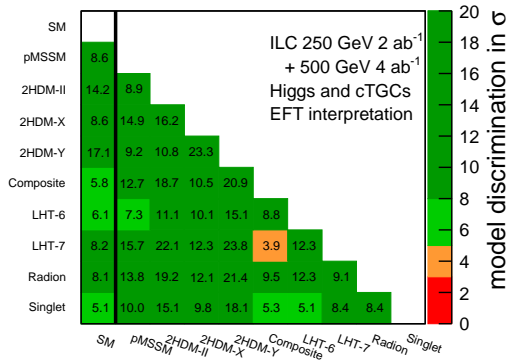
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- BSM discovery and model separation from **indirect** searches.
- SMEFT study using ILC results on **Higgs** properties and **TGCs**
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- At ILC: Both separate at 5σ **from the SM**, but also **from each other** !



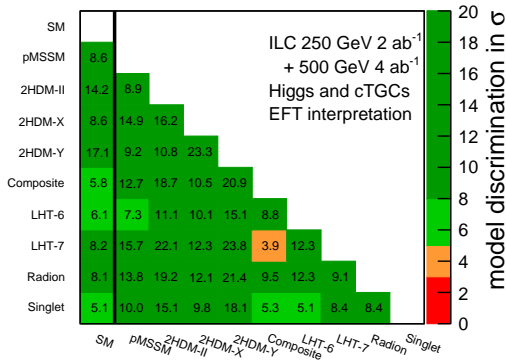
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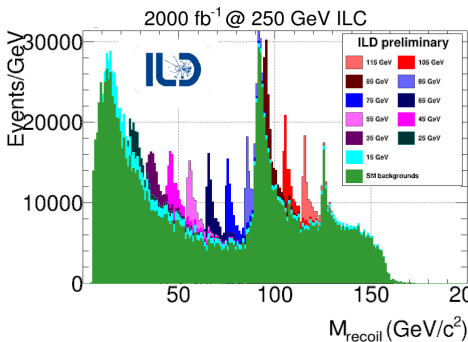


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- Search for it in a decay-mode insensitive way: The recoil-mass, i.e. the mass of the system recoiling against the measured Z .
- Example peaks for a coupling equal to the an SM-Higgs at the same mass. (arXiv:2005.06265)
- \Rightarrow exclude couplings down to a few percent of the SM-Higgs equivalent.
- Note importance of FullSim !

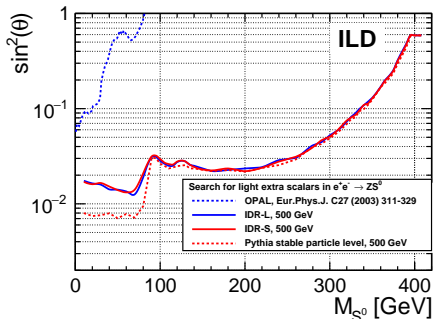
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- \Rightarrow exclude couplings down to a few percent of the SM-Higgs equivalent.
- Note importance of FullSim !



Other BSM: a gallery

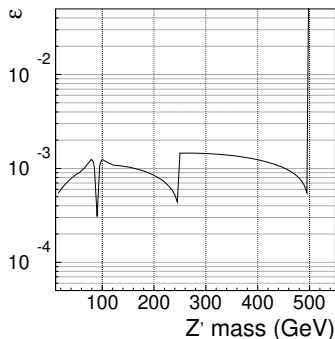
- Dark photon/ Z' :

$$-\frac{\epsilon}{2 \cos \theta_W} F'_{\mu\nu} B^{\mu\nu}$$
- A **tiny, narrow resonance**, but still wide enough to make decays **prompt**.
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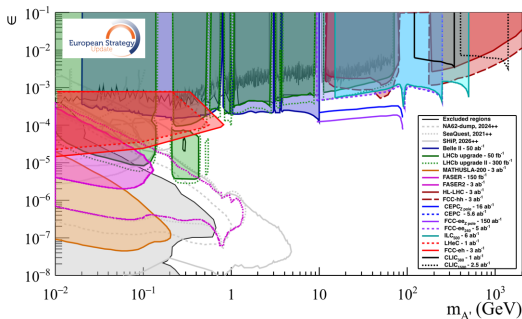
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compared to others
(from EPPSU).

Conclusions

- Sometimes, the capabilities for the **direct discovery** of new particles at the ILC **exceed** those of the LHC, since ILC provides
 - Well-defined **initial state**
 - **Clean environment** without QCD backgrounds
 - **Extendability** in energy and **polarised beams**
 - Detectors like **ILD**, factors more precise, **hermetic**, and with **no need** for triggering
- Many **ILC - LHC synergies** from energy-reach vs. sensitivity.
 - SUSY: High mass vs. Low $\Delta(M)$. If SUSY is reachable at ILC, it means 5σ discovery, and precision measurements. This input might be just what is needed for LHC to transform a 3σ excess to a discovery of states beyond the reach of ILC.
 - Dark matter, FIPS, ...: Leptophilic vs. Leptophobic - Higher mass and higher coupling vs. lower mass and lower coupling.
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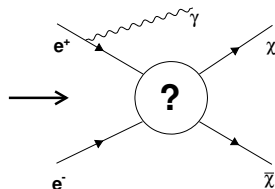
Thank You !

Backup

BACKUP SLIDES

Only WIMPs

- 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” \Rightarrow **Mono-X** search.
 - At ILC: $e^+e^- \rightarrow \chi\chi\gamma$, ie. **X** is a γ



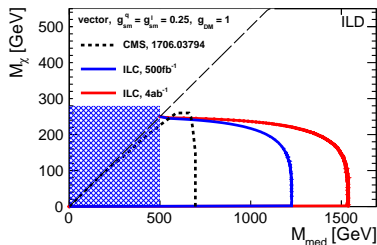
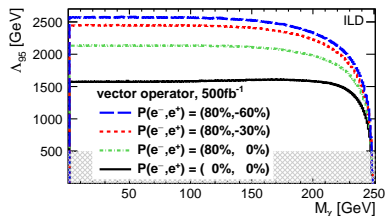
- ILC simulation studies: arXiv:1206.6639v1, A. Chaus, Thesis, M. Habermehl, Thesis, in preparation.
- Model-independent **Effective operator approach** to “?”
 - Analyse as an effective four-point interaction. Strength = Λ .
 - Allowable if direct observation the mediator is beyond reach. Mostly true at ILC, but not at LHC !
 - Write down all possible Lorentz-structures of the operators.
 - Exclusion regions in M_χ/Λ plane, for each operator.

ILC and LHC exclusion

- Examples:
 - Vector operator (“spin independent”), Note how useful **beam-polarisation** is!
- At LHC, EffOp can't be used \Rightarrow use “simplified models”
- Need to translate Λ to M_{med} :
$$M_{med} = \sqrt{g_{SM}g_{DM}}\Lambda$$

ILC/LHC complementarity

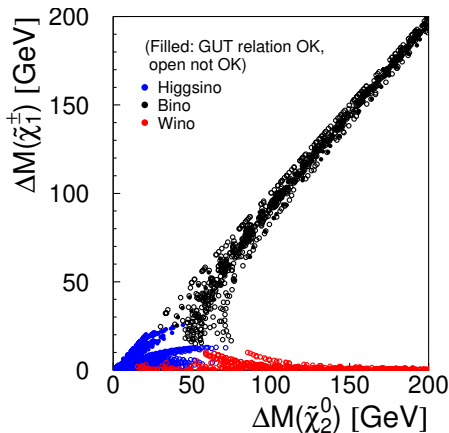
- LHC: coupling to **hadrons**,
ILC: coupling to **leptons**.
- LHC has best M_χ reach, ILC best M_{med} reach



Aspects of the spectrum

Another angle: $\Delta(M)$ for $\tilde{\chi}_1^\pm$ vs. that of $\tilde{\chi}_2^0$: Important experimentally

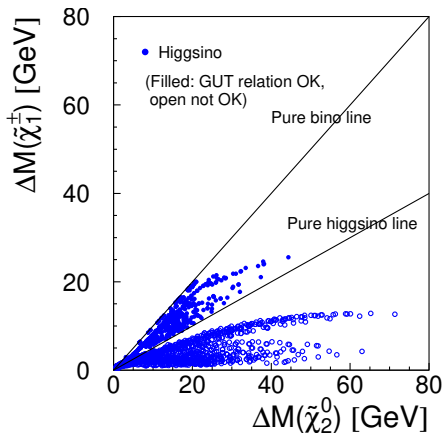
- Three regions:
 - Bino: Both the same, but can be anything.
 - Wino: $\Delta_{\tilde{\chi}_1^\pm}$ small, while $\Delta_{\tilde{\chi}_2^0}$ can be anything.
 - Higgsino: Both often small
- But note, seldom on the “Higgsino line”, ie. when the chargino is *exactly* in the middle of mass-gap between the first and second neutralino.



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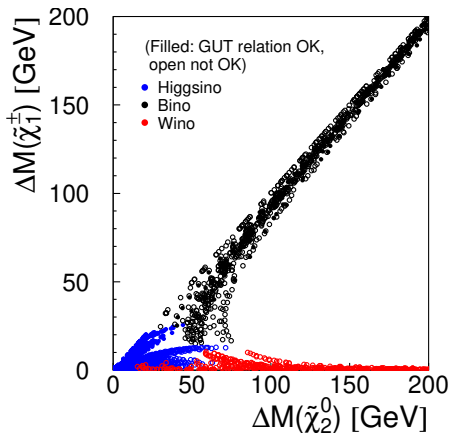
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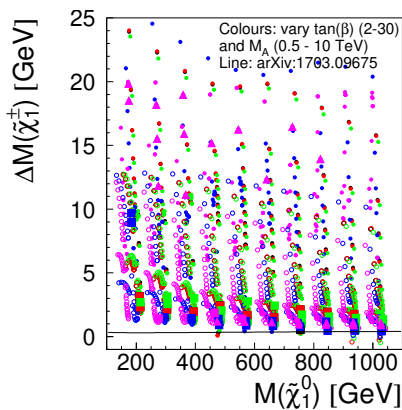
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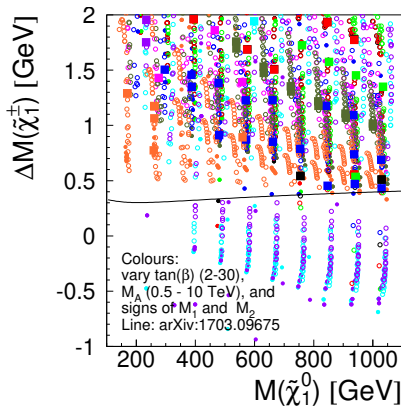
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- Higgsino LSP.
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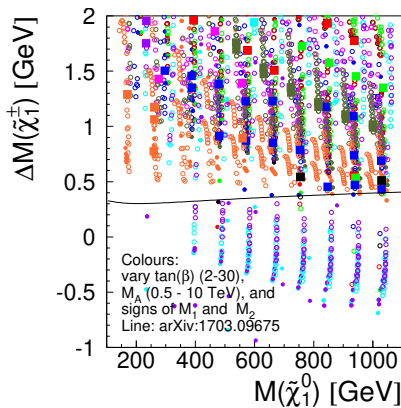
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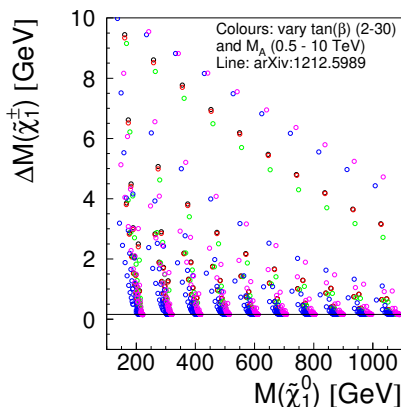
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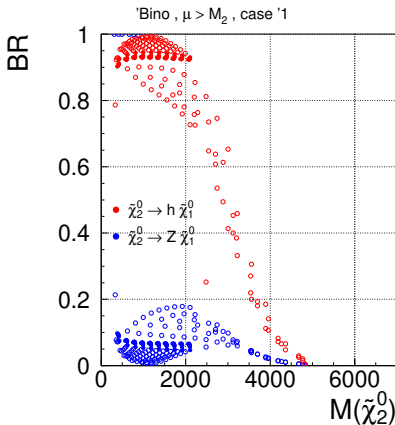
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Bino LSP: BRs

Why is the decay-mode an issue? Here's why :

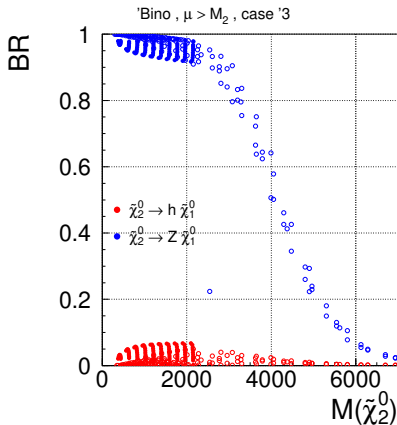
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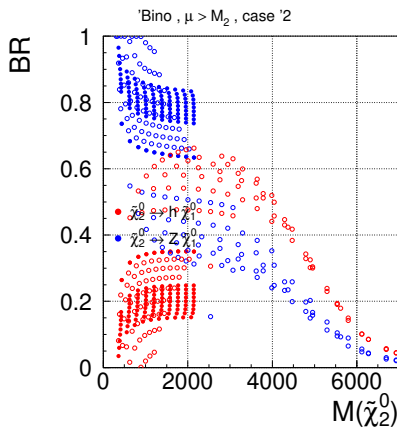
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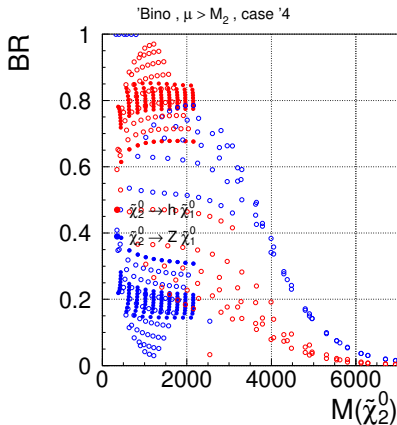
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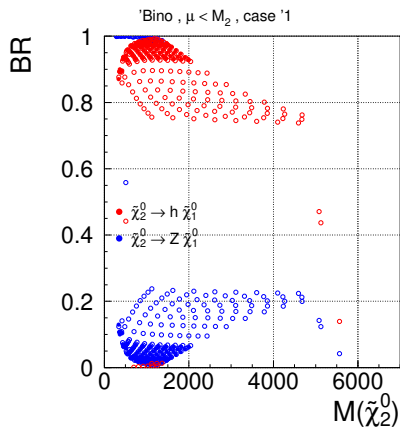
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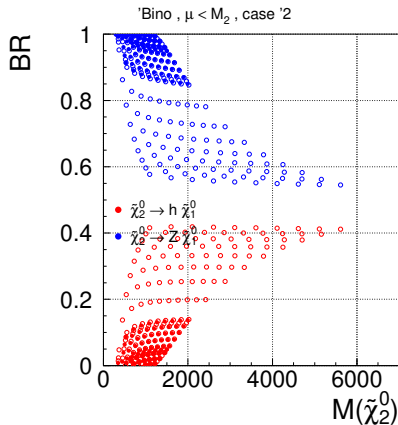
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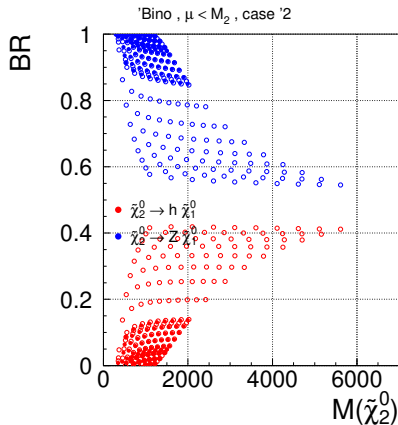
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