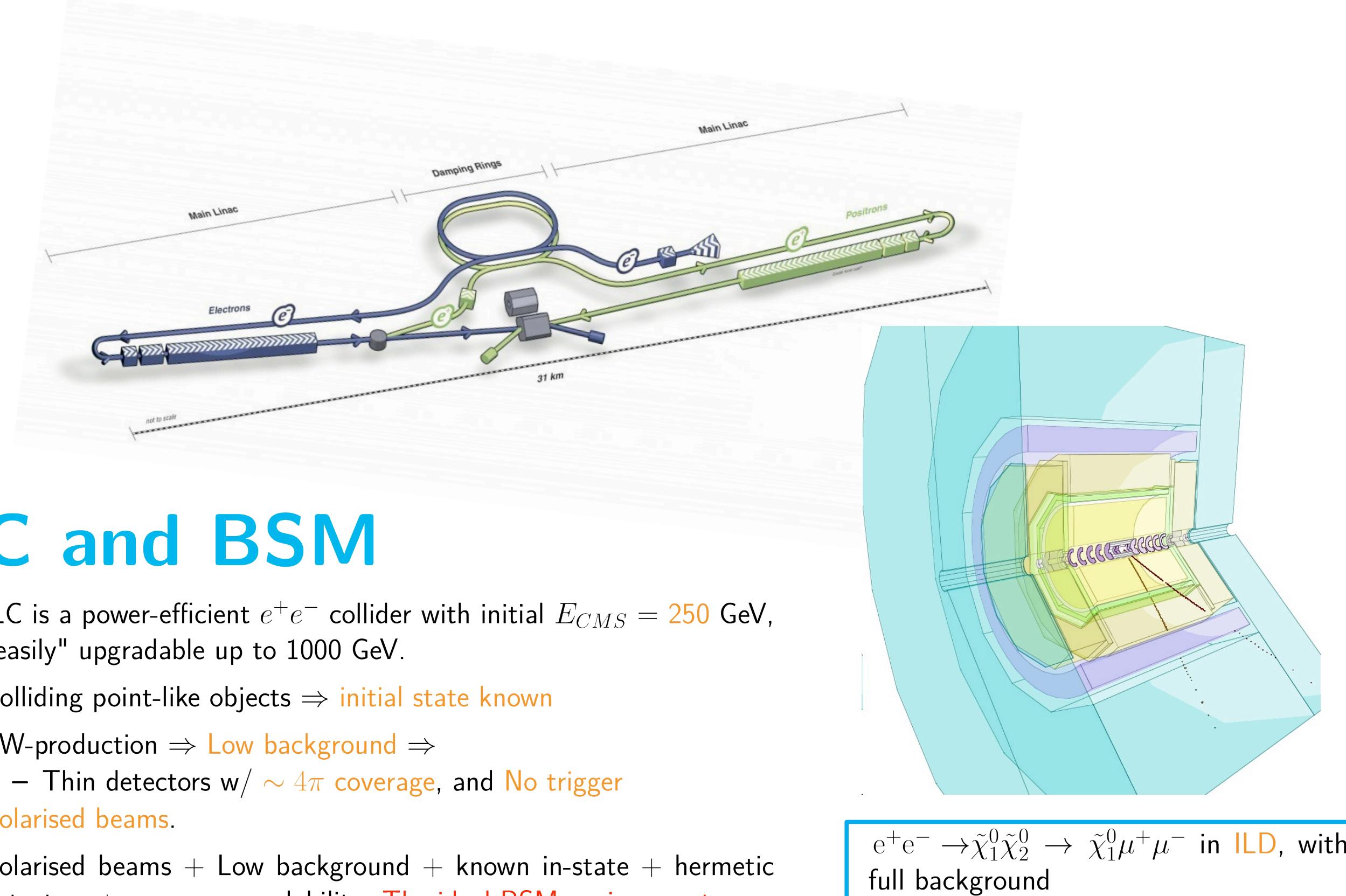


# New physics searches with the ILD detector at the ILC



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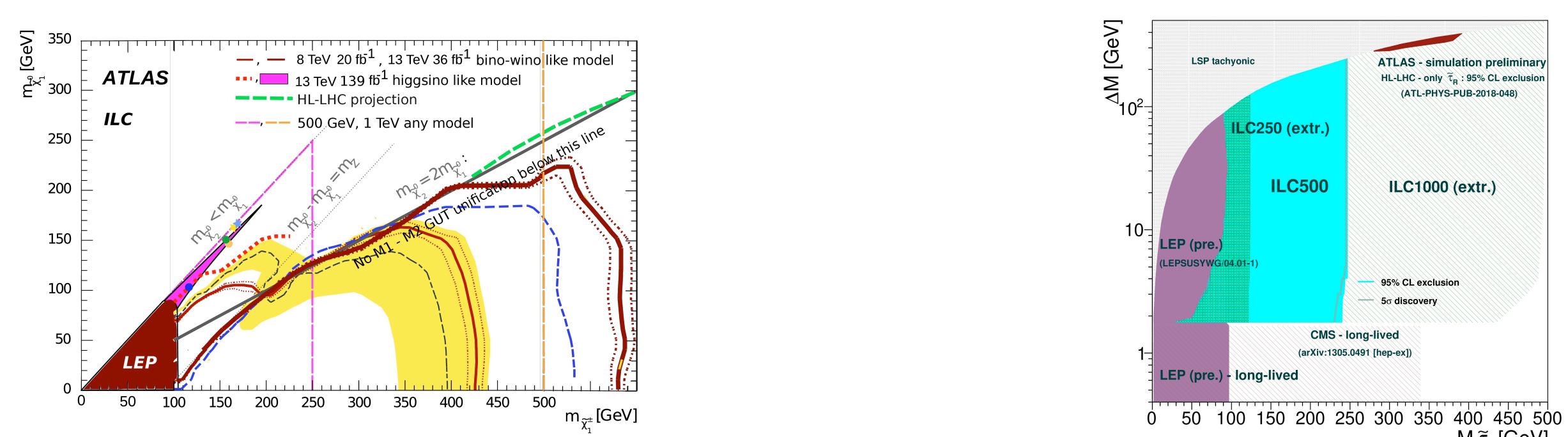


## BSM at ILC: the SUSY case

- 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.
- Although the LHC experiments have searched for and excluded many proposed new particles up to masses close to 1 TeV, there are many scenarios that are difficult to address at a hadron collider.

### Loop-hole free searches, even for low mass-differences

In SUSY, 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, and it must have 100 % BR to its SM-partner and the LSP. So, one can perform model independent exclusion/ discovery reach in  $M_{NLSP} - M_{LSP}$  plane - with no fine-print! One can do this for any possible NLSP, and concentrate on the "worst" cases - the ones with lowest cross-section and most difficult signatures. These are on one hand the bosinos, and on the other  $\tilde{\tau}$ s -

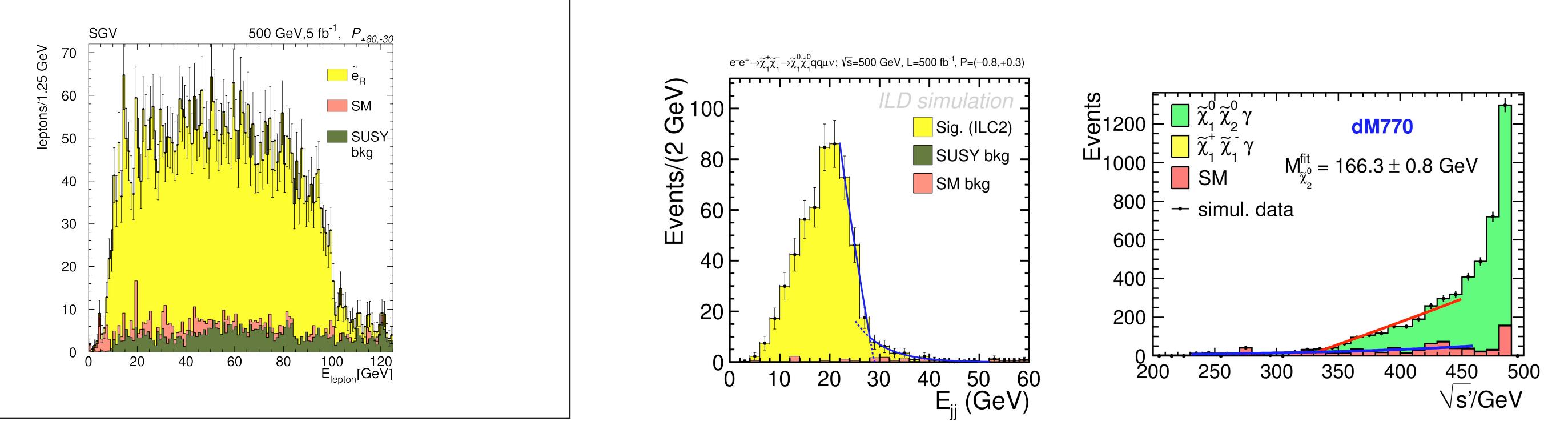


## ILD SUSY measurements

Since Discovery  $\approx$  Exclusion at the ILC, after a possible discovery, one will enter the realm of precision measurements quite quickly.

### Bosinos

Here typical chargino (left) and neutralino signals (right) are shown. Both models are higgsino-LSP ones. The one to the left is one of several studied natural SUSY models with moderate mass differences (15-20 GeV), while the one to the right is a cosmology-motivated model, and has a sub-GeV difference.

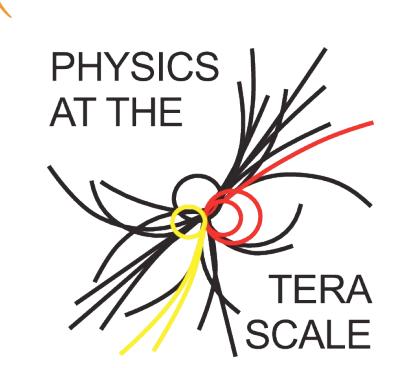


### Sleptons

The end-points of the spectra of the slepton decay-products, enables to measure the slepton and LSP masses to percent level accuracy. Left are examples of  $\tilde{\tau}_1$  and  $\tilde{\mu}_R$  signals, in a  $\tilde{\tau}$  co-annihilation model. To the right, the signal that could be obtained from evaluating the decay-kinematics in a model with cascade decays.

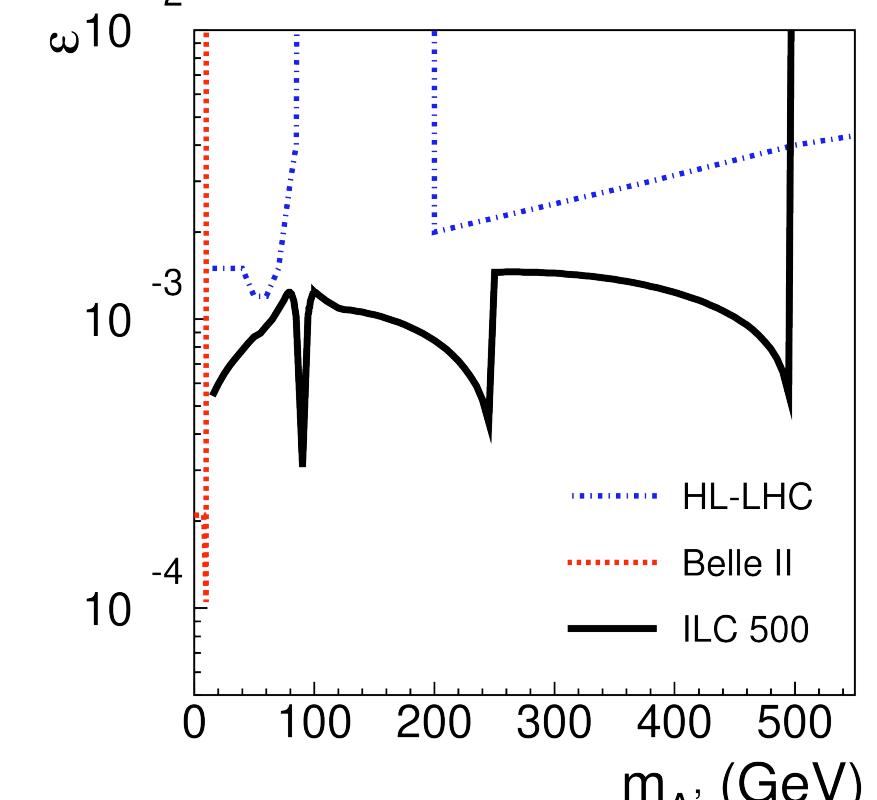
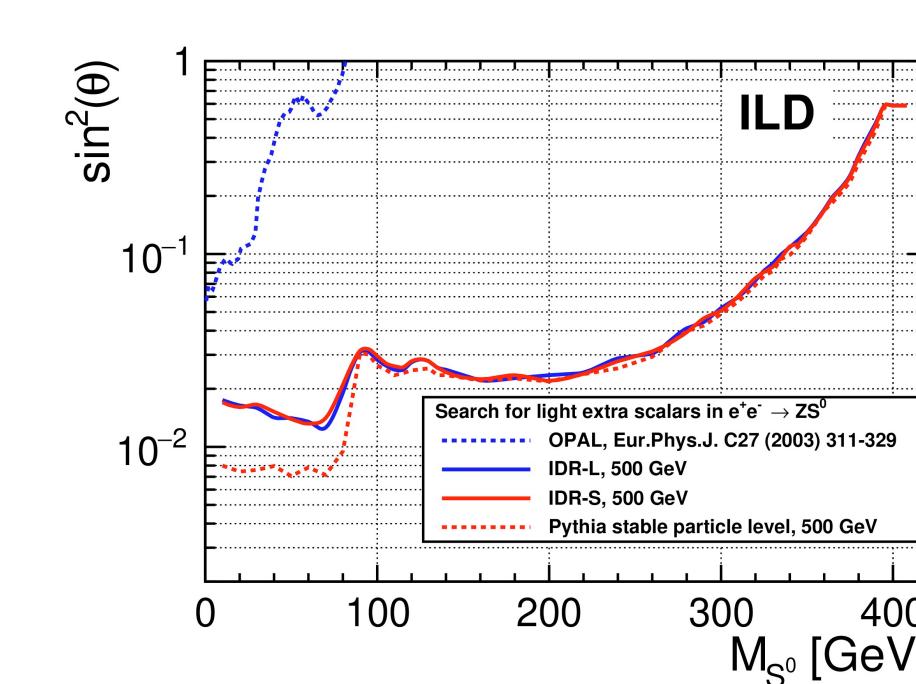
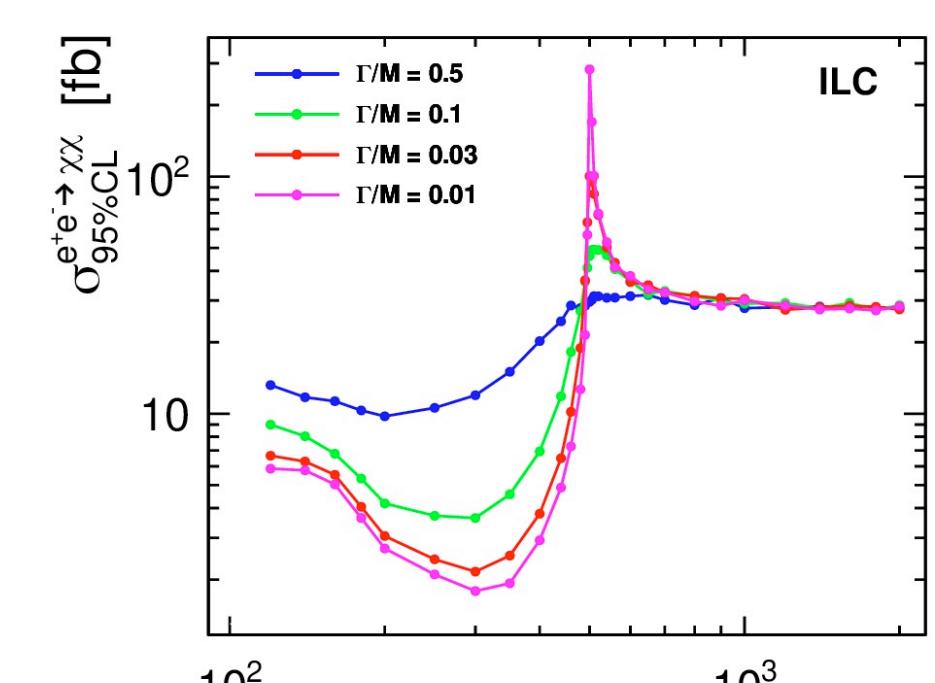
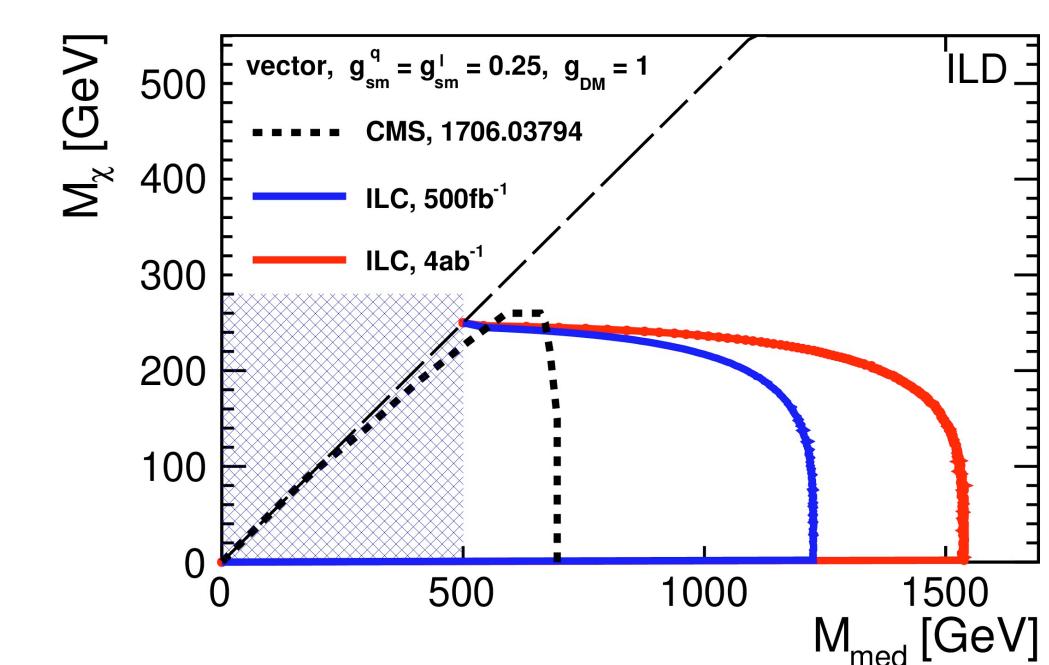
After the full ILC program, and depending on model, channel, and polarisation, we find experimentally that

$$\text{measured } \delta(\text{masses}) = 0.5\text{-}1\%, \delta(\sigma \times \text{BR}) = 1\text{-}6\%$$



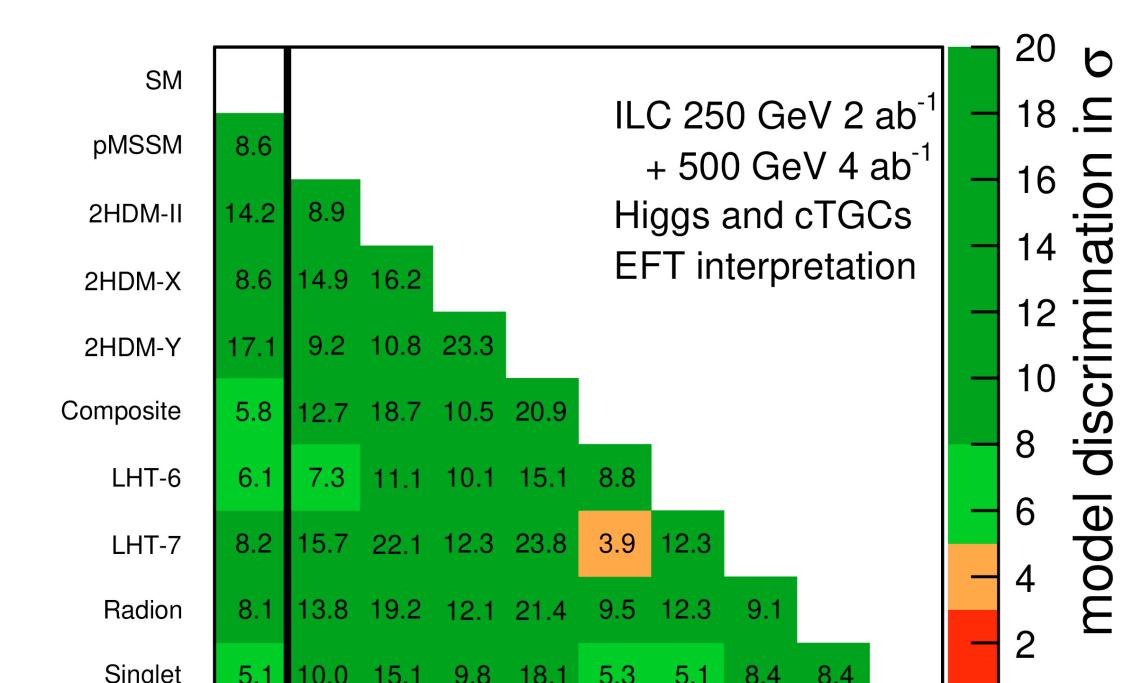
## BSM at ILC: not only SUSY.

- Dark matter in  $e^+e^- \rightarrow (DM)(DM) + \text{ISR}\gamma$ : Mono-photon searches, shown to the right. Searches done either with an EFT approach with heavy mediator (Full simulation), or for arbitrary mediators (fast simulation).
- Search for a new Higgs-like scalar (S), shown below. produced in  $e^+e^- \rightarrow Z^* \rightarrow S\bar{S}$  with unknown decays. Search for it in a decay-mode insensitive way: The recoil-mass, i.e. the mass of the system recoiling against the measured  $Z$ . Couplings down to a few percent of the SM-Higgs equivalent can be excluded.
- Dark photon/ $Z'$ : Kinetic mixing term  $\frac{e}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$  in the Lagrangian leads to a tiny, narrow resonance, but still wide enough to make decays prompt. One can search for it as a  $\mu\mu$  resonance above background in  $e^+e^- \rightarrow Z' + \text{ISR} \rightarrow \mu^+\mu^- + \text{ISR}$ . Results (from EPPSU) shown below, right.

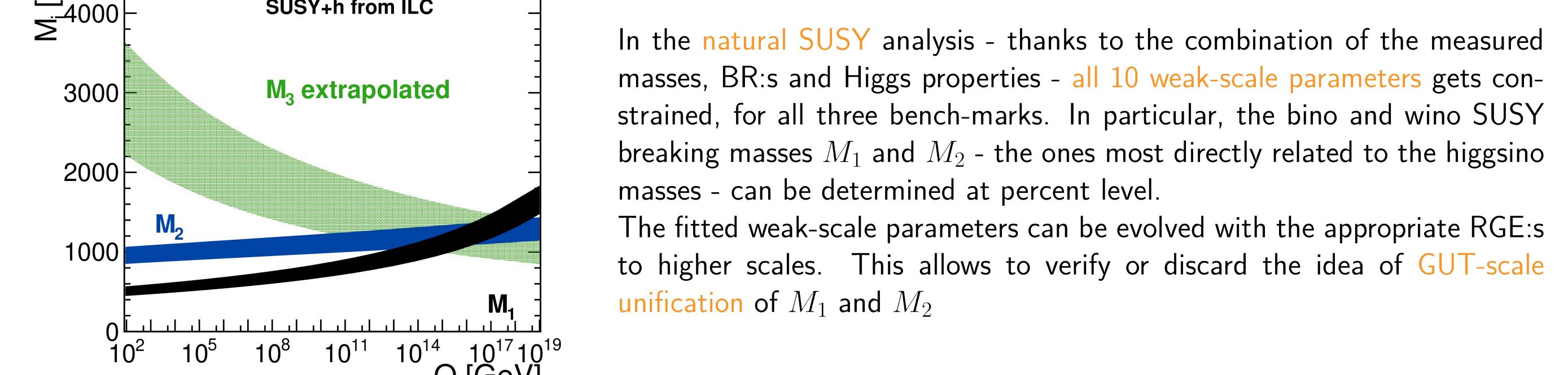


## Indirect BSM: discovery and model separation

- SM effective field theory study, using ILC results on Higgs properties and TGCs
- Select models that are not discoverable at HL-LHC.
- At ILC: Both separate at 5  $\sigma$  from the SM, but also from each other!



## Hints of the GUT scale



## Take-home message

- 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 5  $\sigma$  discovery, and precision measurements. This input might be just what is needed for LHC to transform a 3  $\sigma$  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.

## More info:

- ILC: P. Bambade et al. "The International Linear Collider: A Global Project" (2019), arXiv:1903.01629 [hep-ex] and T. Behnke et al. "The International Linear Collider Technical Design Report - Volume 1: Executive Summary" (2013), arXiv:1306.6327 [physics.acc-ph].
- ILD: T. Behnke et al. "International Large Detector: Interim Design Report" arXiv:2003.01116 [physics.ins-det].
- BSM at ILC and LHC: K. Fujii et al. "The Potential of the ILC for Discovering New Particles" (2017), arXiv:1702.05333 [hep-ph] and M. Berggren "What pp SUSY limits mean for future  $e^+e^-$  colliders" arXiv:2003.12391 [hep-ph].
- Sleptons: M. Berggren et al. "Non-Simplified SUSY: Stau-Coannihilation at LHC and ILC" Eur. Phys. J. C 76, (2016) 183 arXiv:1508.04383 [hep-ph], M.T. Núñez Pardo de Vera et al. "F<sub>z</sub>- searches at the ILC" arXiv:2105.08616 [hep-ph] and M. Berggren "Reconstructing sleptons in cascade-decays at the linear collider" arXiv:hep-ph/0508247
- Bosinos: H. Baer et al. "The ILC as a natural SUSY discovery machine and precision microscope: from light higgsinos to tests of unification" Phys. Rev. D 101, 095026 arXiv:1912.06643 [hep-ex], M. Berggren et al. "Tackling light higgsinos at the ILC" Eur. Phys. J. C 73, 2660 (2013) arXiv:1307.3566 [hep-ph] and M.T. Núñez Pardo de Vera et al. "Chargino production at the ILC" arXiv:2002.01239 [hep-ph].
- WIMPs: M. Habermehl et al. "WIMP Dark Matter at the International Linear Collider" Phys. Rev. D 101, 075053 (2020) arXiv:2001.03011 [hep-ex] and J. Kalinowski et al. "Sensitivity of future linear  $e^+e^-$  colliders to processes of dark matter production with light mediator exchange" Eur. Phys. J. C 81, 95 (2021) arXiv:2107.11194 [hep-ph].
- New scalars: Y. Wang et al. "ILD Benchmark: Search for Extra Scalars Produced in Association with a Z boson at  $\sqrt{s}=500$  GeV" arXiv:2005.06265 [hep-ex].
- Indirect BSM: T. Barklow et al. "Improved Formalism for Precision Higgs Coupling Fits" Phys. Rev. D 97, 053003 (2018) arXiv:1708.08912 [hep-ph].