The Potential of the ILC for Discovering New Particles

Mikael Berggren[1]
on behalf of the LCC Physics Working group

(based on arXiv:1702.05333)

[1] DESY, Hamburg

ICHEP, Seoul, July, 2018

Direct BSM at ILC

- Several talks in this conference have already shown that ILC has a great potential for *indirect* discovery of BSM (Jeans (411), Ogawa (755), Bilokin (420), and Reuter (912) in Higgs and EW sessions).
- But: Can ILC still *directly* discover BSM, in view of the current LHC results?

Concentrating on

- Dark Matter (DM): Because it's there - but anywhere.
- SUSY: *The* most complete theory of BSM - but under stress (?) by LHC. ILC strenghts:
  - Loop-hole free searches.
  - Compressed spectra.

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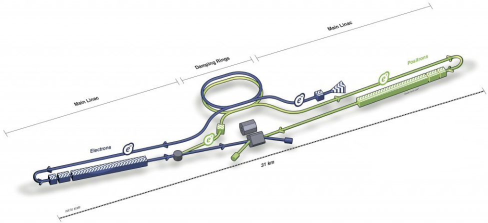
The ILC strong points for searches

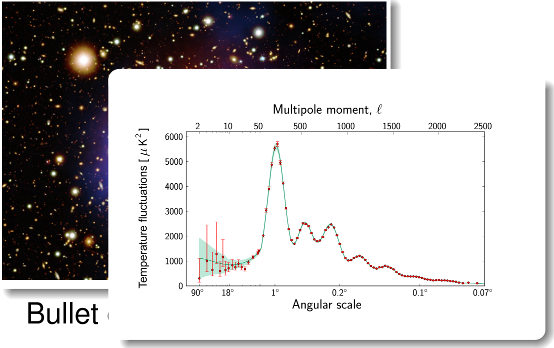
- e^+e^- collider with E_{CMS} = 250 - 500 (- 1000) GeV, and polarised beams
- e^+e^- means EW-production $\Rightarrow$ Low background.
  - Detectors w/ $\sim 4\pi$ coverage.
  - Rad. hardness not needed: only few % X_0 in front of calorimters.
  - No trigger
- e^+e^- means colliding point-like objects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



Dark Matter

Bullet cluster

Dark Matter



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Plank CMB

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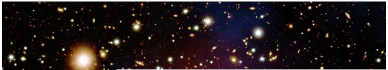

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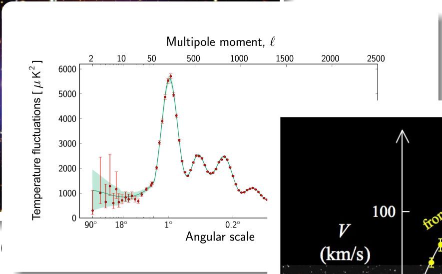

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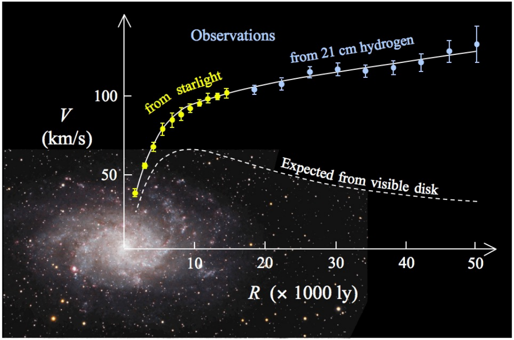

M33 rotation curve

Dark Matter

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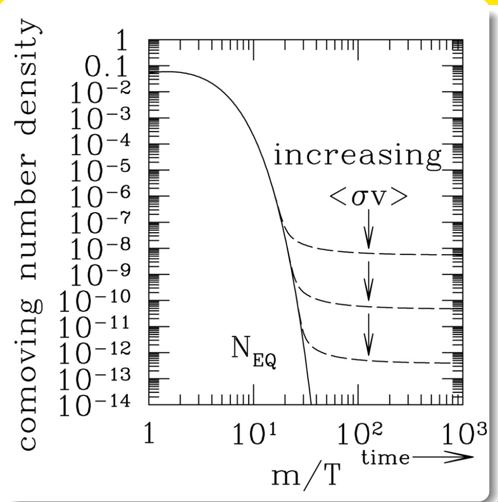
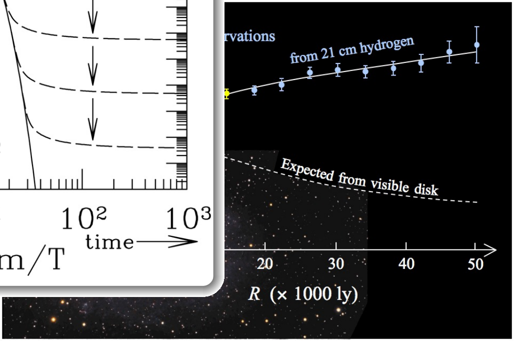


The WIMP miracle !



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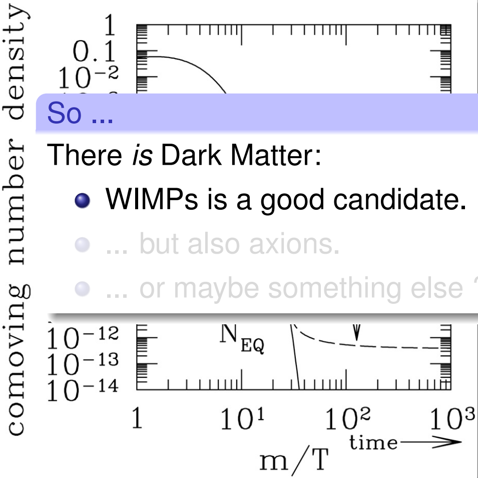

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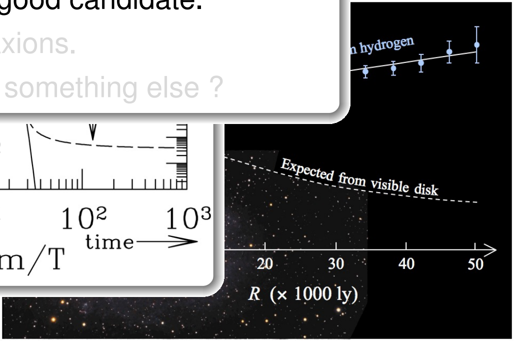
So ...

There *is* Dark Matter:

- WIMPs is a good candidate.
- ... but also axions.
- ... or maybe something else ?



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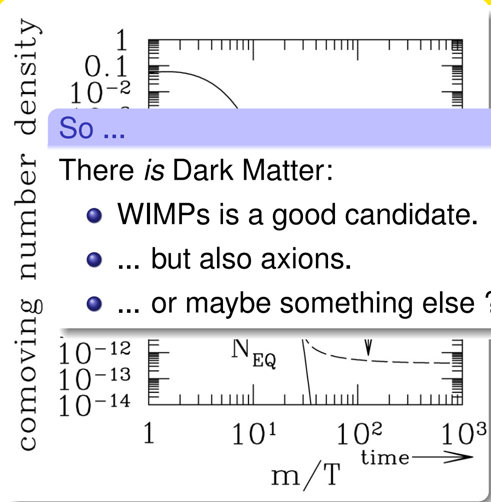

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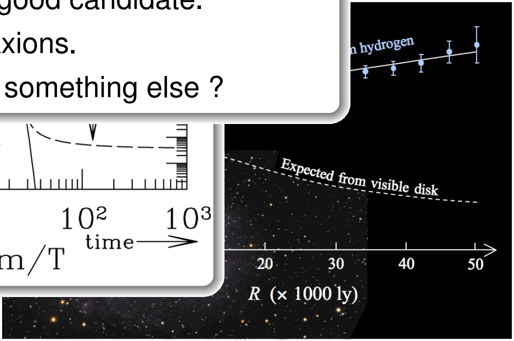

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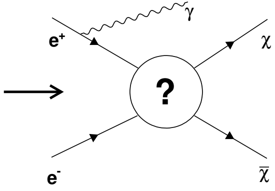
Only WIMPs

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



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- 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.

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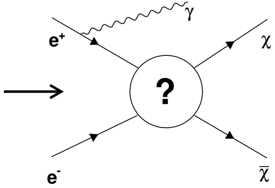

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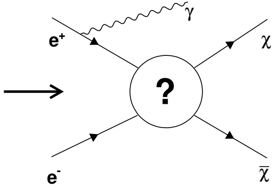

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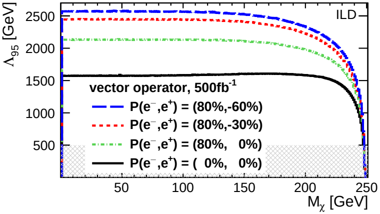
ILC and LHC exclusion

- 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

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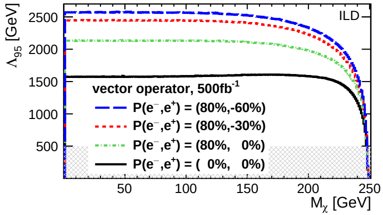

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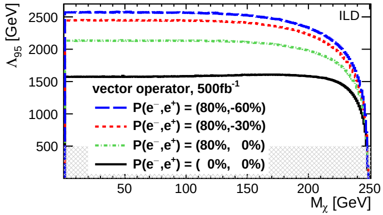

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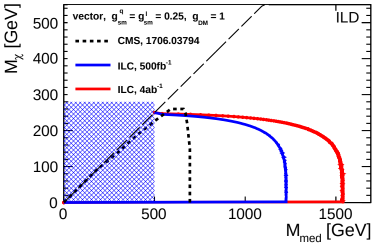

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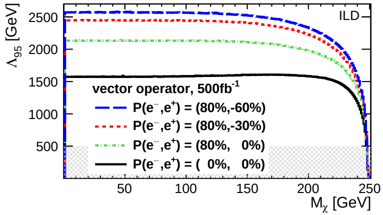

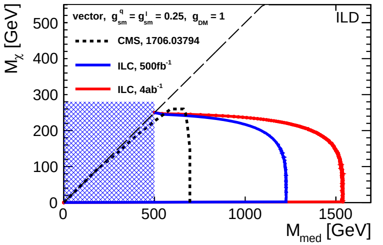

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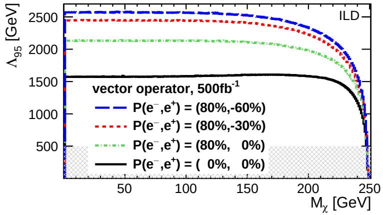
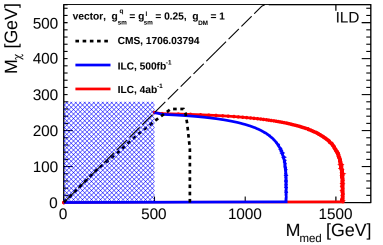
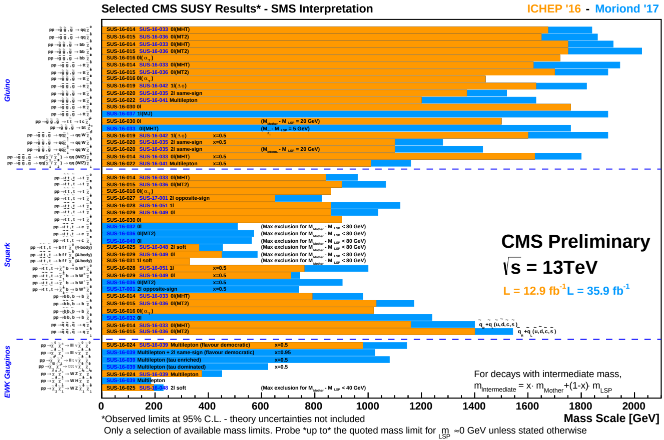
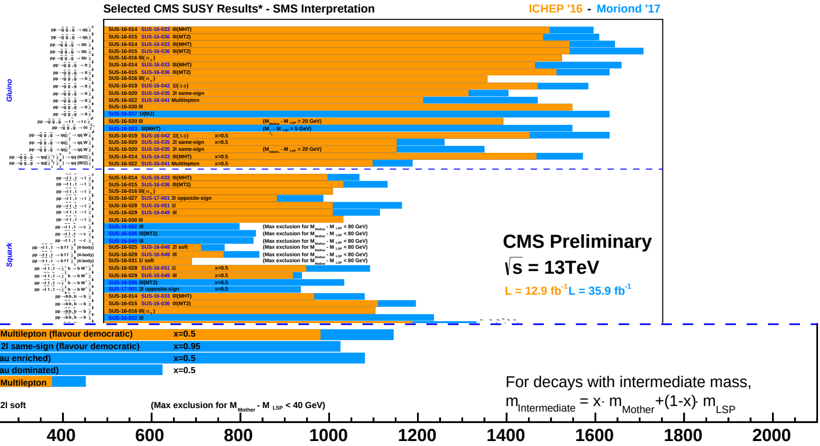




SUSY@LHC: Does this make us depressed ?



SUSY@LHC: No! Read the fine-print !



Mass Scale [GeV]

*Observed limits at 95% C.L. - theory uncertainties not included

Only a selection of available mass limits. Probe *up to* the quoted mass limit for $m_{LSP} \approx 0$ GeV unless stated otherwise

SUSY: What *do* we know ?

Naturalness, hierarchy, DM, g-2 all prefers light electro-weak sector.

- Except for 3d gen. squarks, the coloured sector - LHC:s *tour de force* - doesn't enter the game.
- Both if the LSP is mainly higgsino or mainly wino, electro-weak sector is "compressed".
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- All is known for given masses, due to SUSY-principle: “sparticles couples as particles”.
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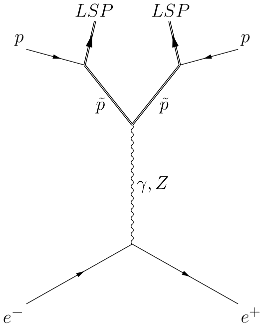
- Obviously: There is one NLSP, and it must have 100 % BR to it’s SM-partner and the LSP.



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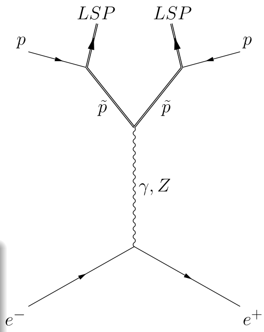

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- Model independent exclusion/ discovery reach in $M_{NLSP} - M_{LSP}$ plane.
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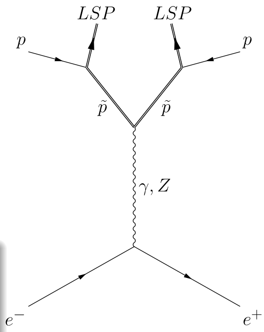

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- “Simplified model” = *assume* sparticle has 100 % BR to particle+LSP ⇒ model-dependent
- NLSP search = sparticle *must have* 100 % BR to particle+LSP.. ⇒ model-independent
- A worst-case example for ILC: $\tilde{\tau}_1$ NLSP (minimal σ)
  - Typical signal (arXiv:1508.04383)
  - Scan over mass-plane (arXiv:1308.1461)

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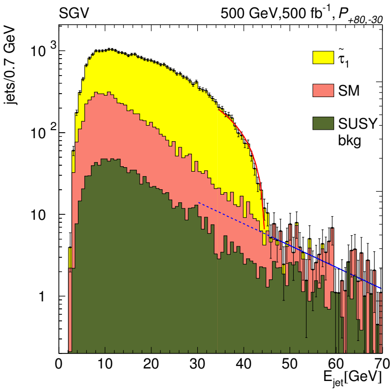

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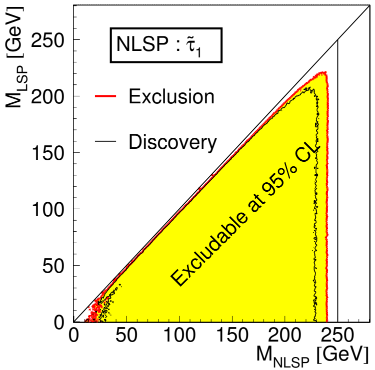

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At ILC

Either discover or exclude NLSPs up to some GeV:s from the kinematic limit, whatever the NLSP is, and whatever the rest of the spectrum is!

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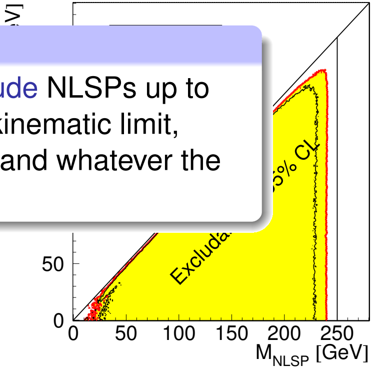

Why compressed spectra ?

Why would one expect the spectrum to be compressed ?

- Natural SUSY:
  - $m_Z^2 = 2\frac{m_{H_u}^2 \tan^2\beta - m_{H_d}^2}{1-\tan^2\beta} - 2|\mu|^2$
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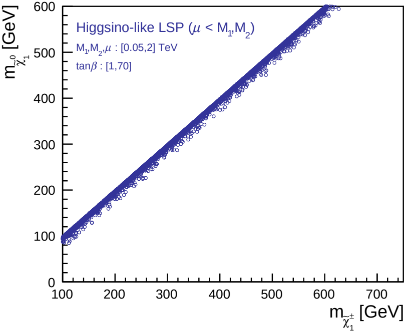
Parameter-scan by T. Tanabe:



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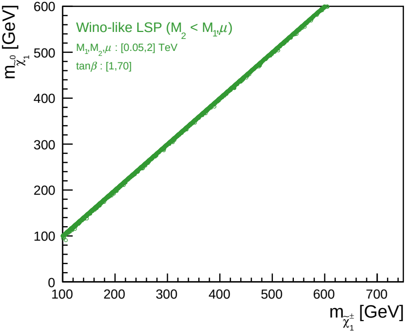

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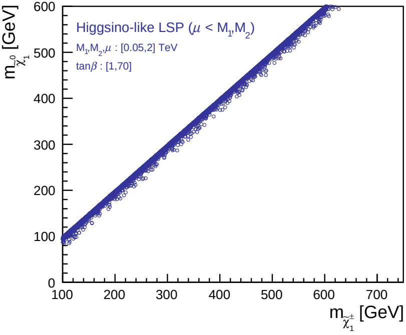
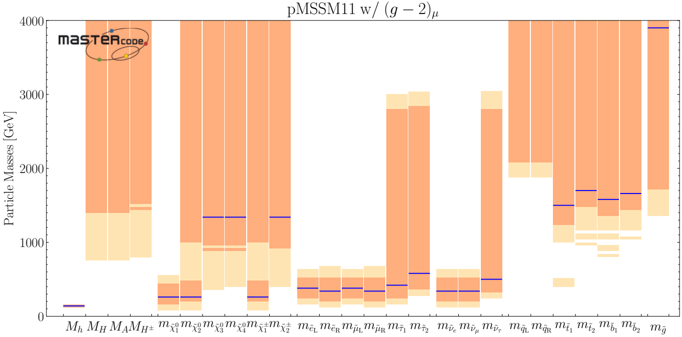


Why compressed spectra ? Global fits

pMSSM11 fit by Mastercode to
LHC13/LEP/g-2/DM(=100% LSP)/presision observables
(arXiv:1710.11091):



Sparticle Mass-spectrum

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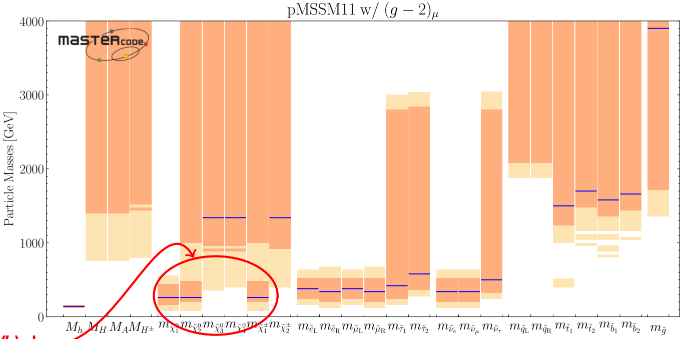
(arXiv:1710.11091):



Low $\Delta(M)$!

Sparticle Mass-spectrum

Why compressed spectra ? Global fits

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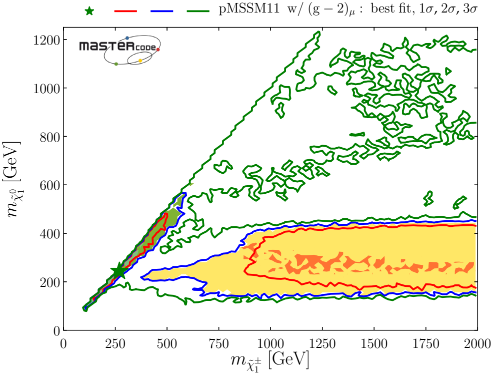

$M_{\tilde\chi^\pm_1}$ - $M_{\tilde\chi^0_1}$ plane

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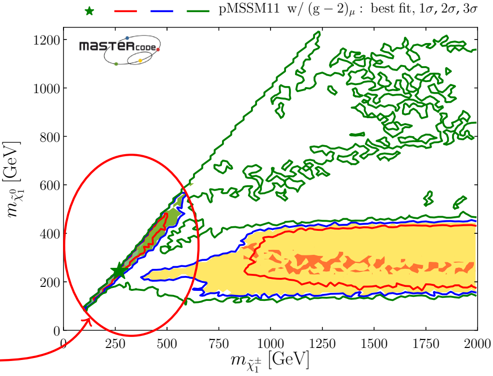

Low $\Delta(M)$!

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Compare LHC (Atlas) & ILC

- Di- and tri-lepton, $M_{\tilde{\chi}_2^0} = M_{\tilde{\chi}_1^\pm}$, only Z or W decays. 7 TeV, 4.7 fb^{-1} (in grey) and 13 TeV, 36 fb^{-1} arXiv:1803.02762. No progress at low $\Delta(M)$.
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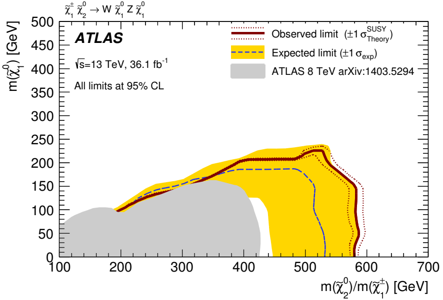

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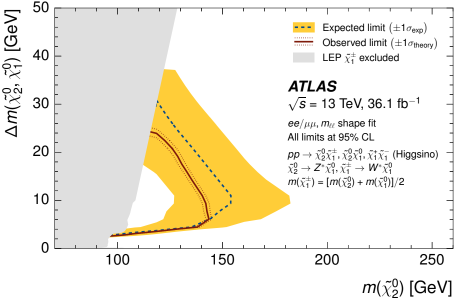

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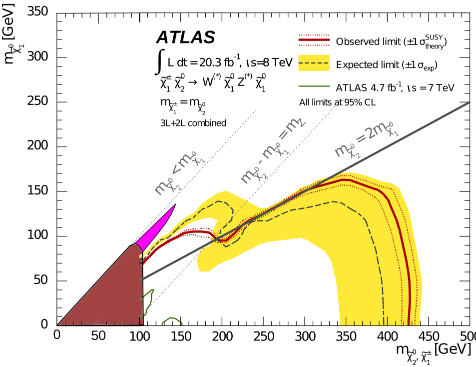
ILC/LHC complementarity



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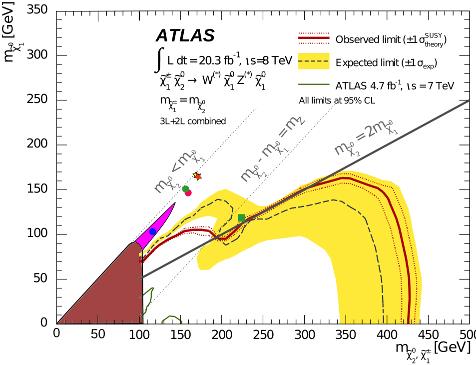

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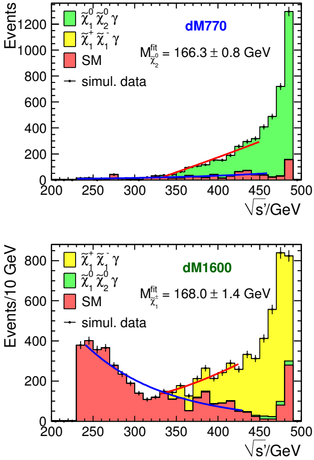
The "stars"



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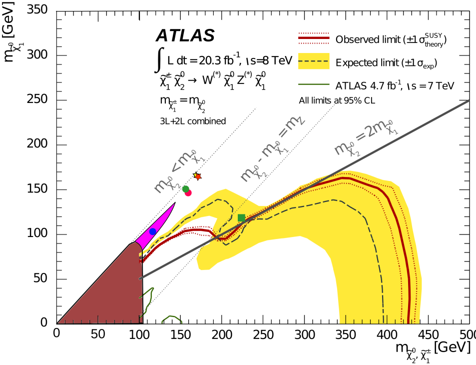

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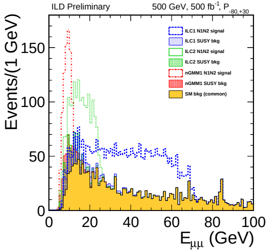
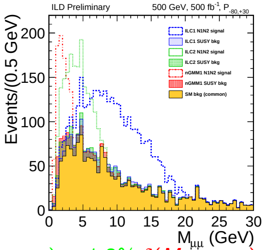
The “circles”





$\delta(M_{higgsinos}) = 1.3\%$, $\delta(M_{higgsinos}) = 1.7\%$

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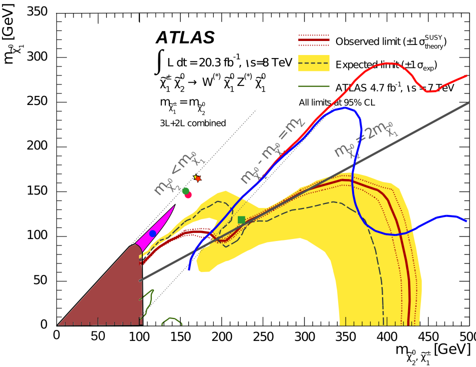

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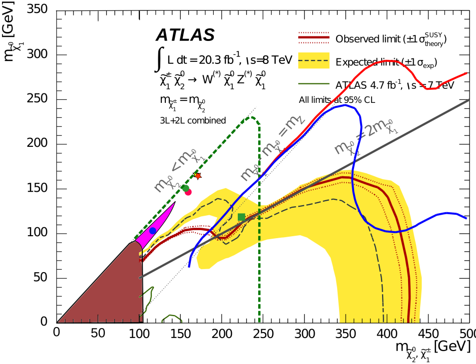

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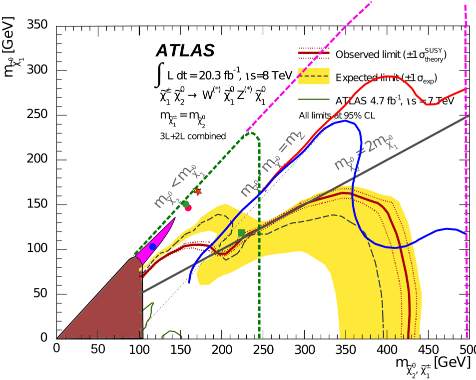

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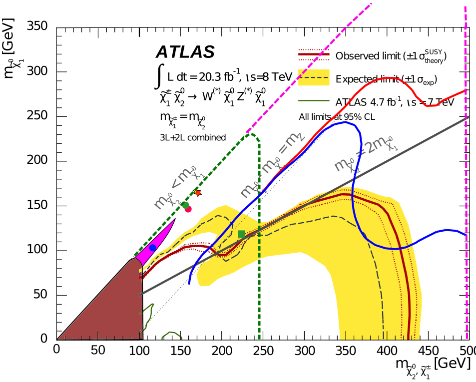

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Conclusions

- 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
  - Hermetic detectors, with no need for triggering.
  - Extendability in energy and polarised beams.
- Many ILC - LHC synergies from energy-reach vs. sensitivity.
  - Dark matter: Leptophilic vs. Leptophobic - Higher mass and higher coupling vs. lower mass and lower coupling
  - SUSY: High mass vs. Low $\Delta(M)$
  - If both ILC and LHC observes SUSY, the (sub)percent level measurements from ILC of the lower states will profit LHC to disentangle long decay-chains of higher states.
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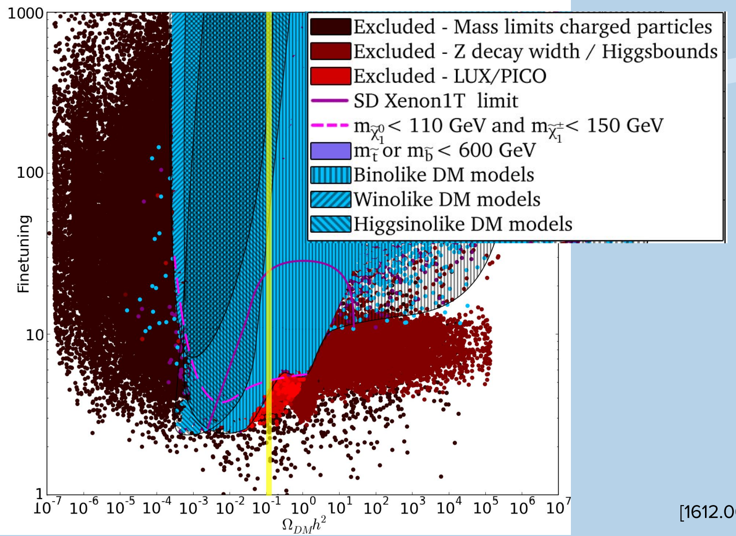
Backup

BACKUP SLIDES

Why compressed spectra ? pMSSM scans



[1612.06333]

More loop-hole free plots