Particle Discovery Opportunities at the International Linear Collider

EPS-HEP 2019, Ghent

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on behalf of the LCC Physics Working Group

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

CLUSTER OF EXCELLENCE QUANTUM UNIVERSE

The International Linear Collider

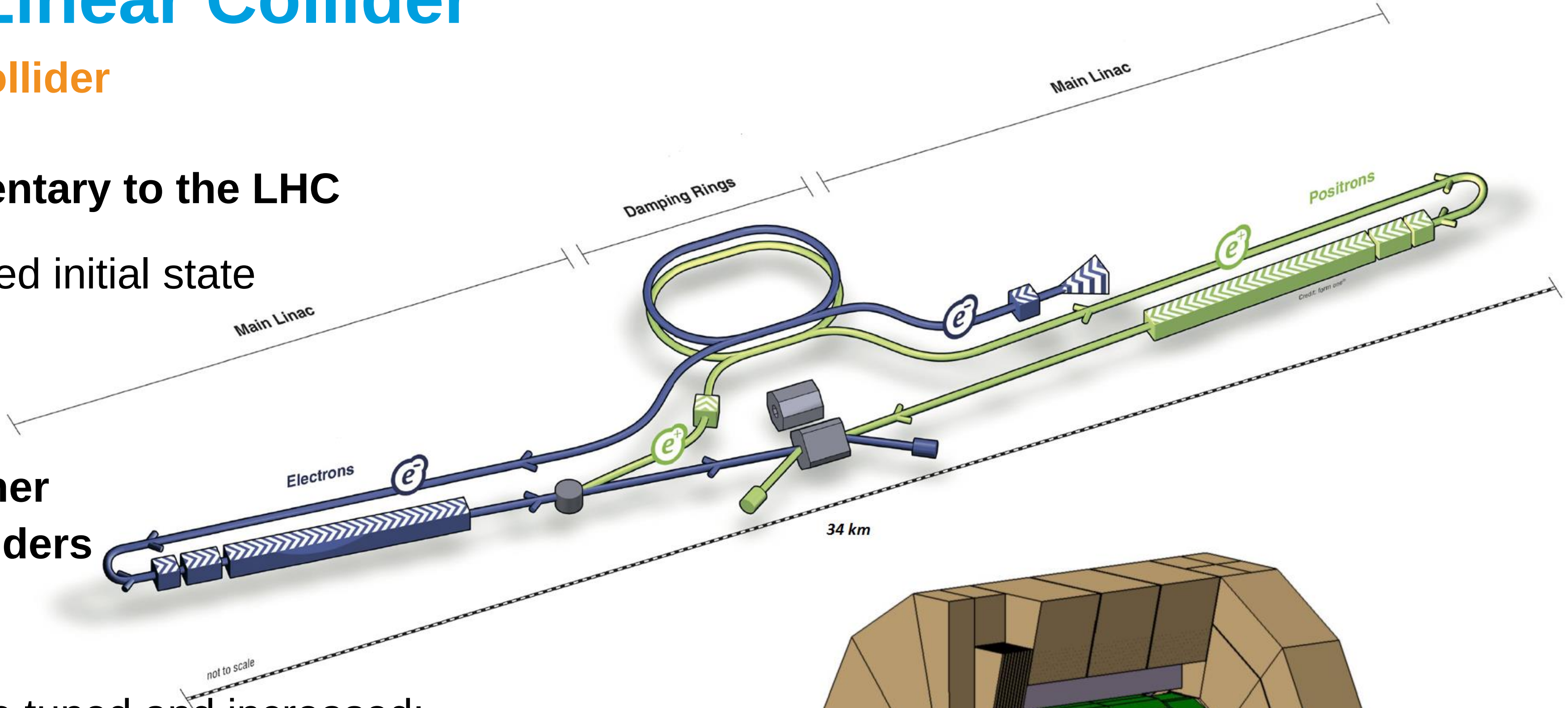
A planned electron-positron collider

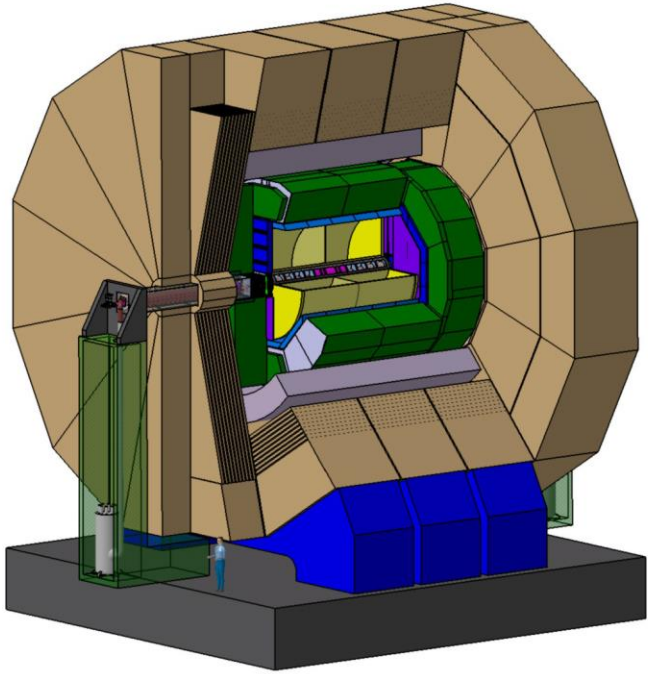
Lepton colliders are complementary to the LHC

- cleaner environment, controlled initial state
- coupling to leptons is tested

Advantages of the ILC over other planned electron-positron colliders

- mature technology
- centre-of-mass energy can be tuned and increased:
  250 GeV in initial stage, upgrades to 500 GeV and 1 TeV
- polarisation of both beams: *P(e-)*=±80%, *P(e+)*=∓30%
- triggerless operation
- hermeticity of detector down to lowest angles





ILD

The BSM Physics Programme of the ILC

Large range of detailed studies

arxiv:1702.05333 **The Potential of the ILC for Discovering new Particles** → focus on 500 GeV

arxiv:1903.01629 **The International Linear Collider: A Global Project** → focus on 250 GeV

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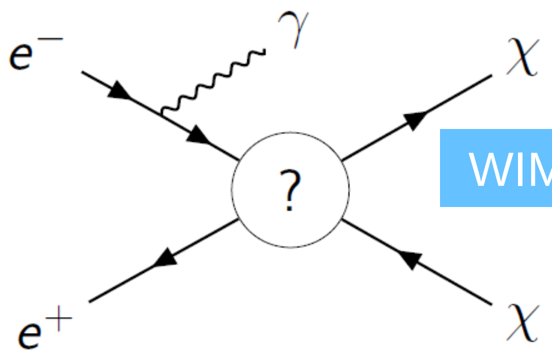
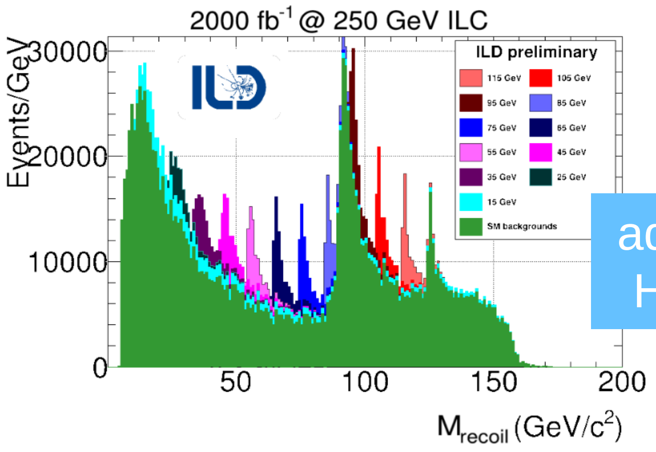


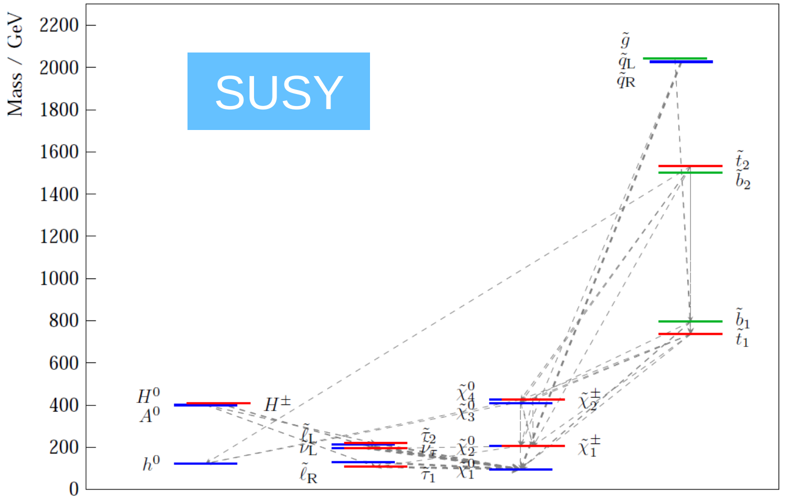
WIMPs



additional Higgses

… to studies of

complete BSM models



SUSY

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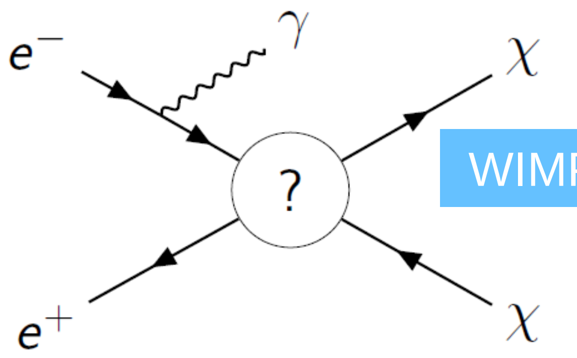

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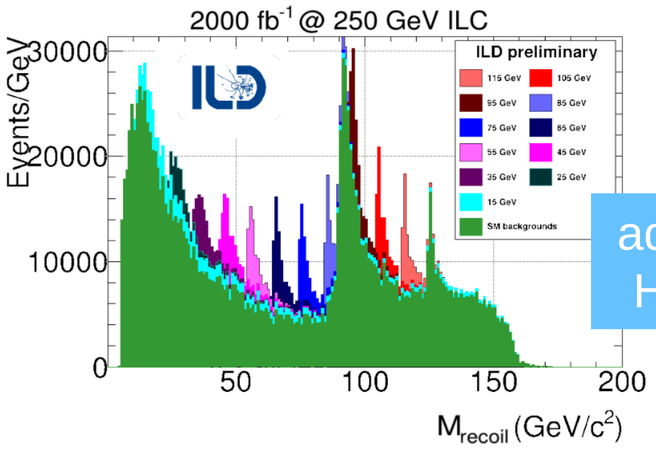

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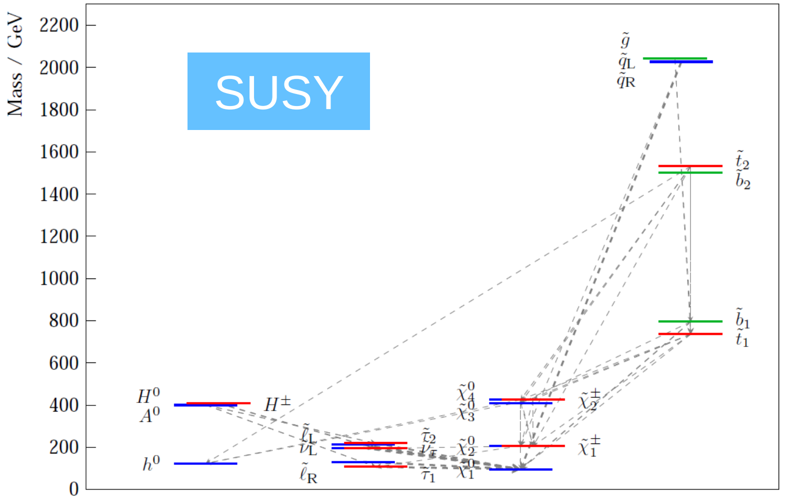


SUSY

In addition: indirect constraints

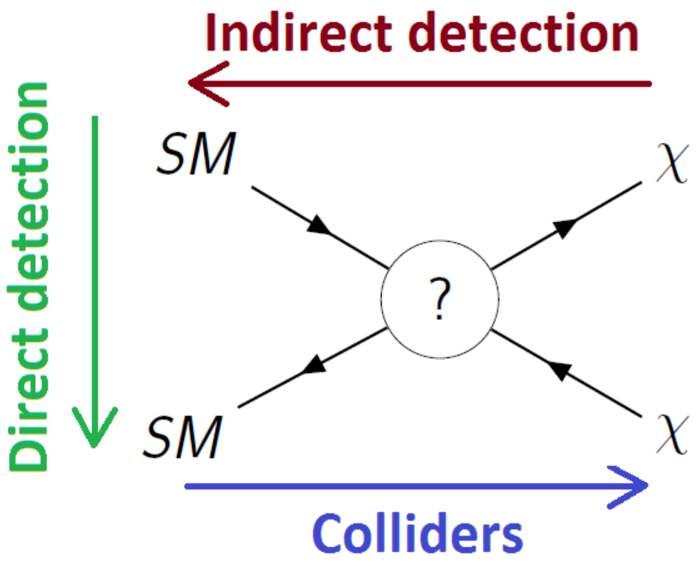
- Higgs precision measurements **talk by S. Kawada**
- Standard Model precision measurements

Searches for WIMP Dark Matter

WIMPs = Weakly Interacting Massive Particles

Interplay between search channels

- direct and indirect detection
- collider searches



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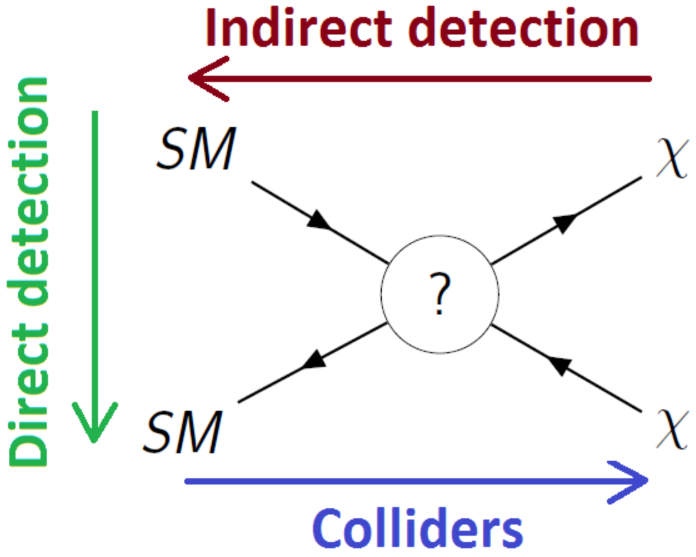
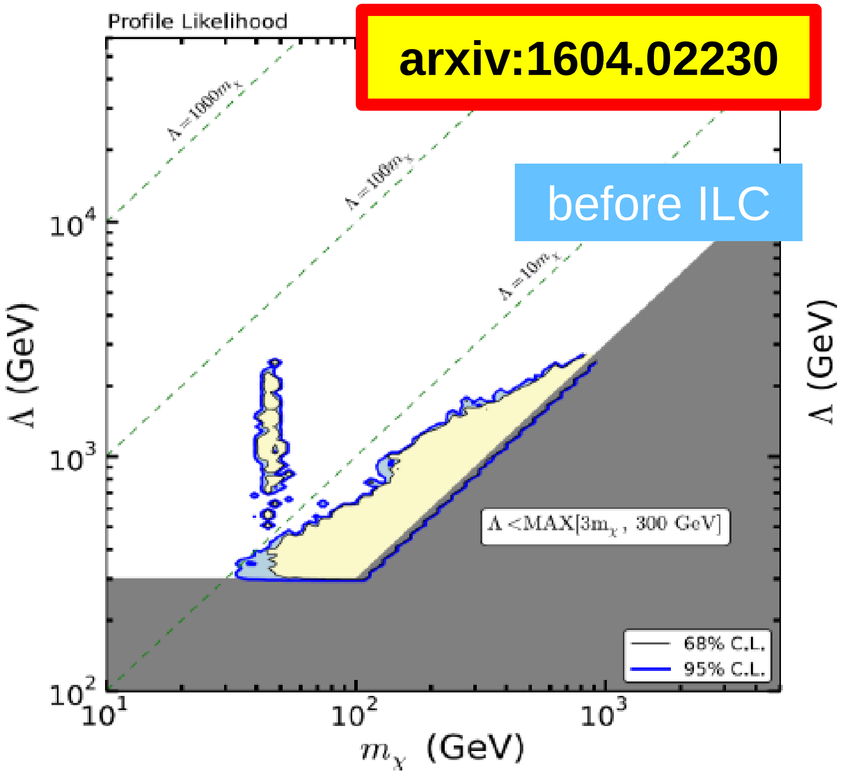


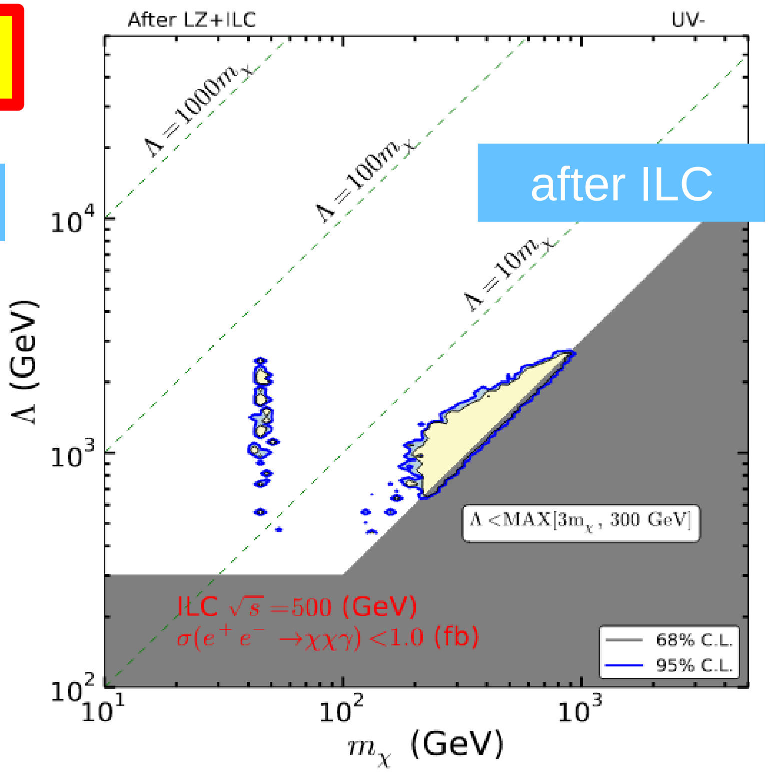
Interplay between search channels

- direct and indirect detection
- collider searches

Example: singlet-like fermion WIMP

- likelihood analysis of Planck, PICO-2L, LUX, XENON100, LEP, LHC, plus LZ, PICO250 projections
- surviving region assuming no WIMP signals are detected → can be tested at the ILC
- framework: effective operators
  - Λ – energy scale of new physics
  - valid: testable energies $\gg \sqrt{s}$

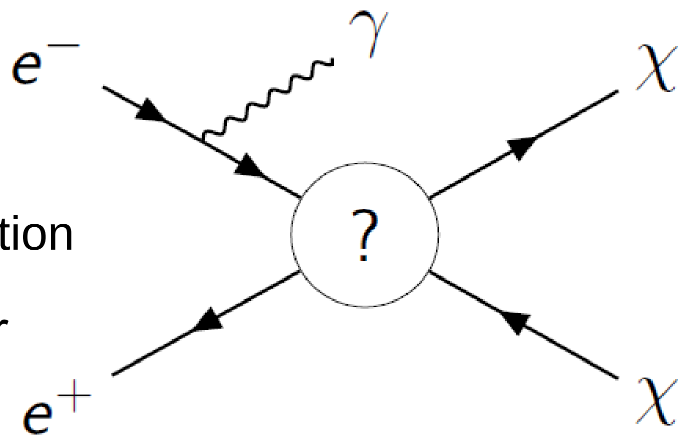




WIMPs in the Mono-Photon Channel

Generic collider search

- WIMP pair production
- with a photon from initial state radiation
- single photon in an "empty" detector



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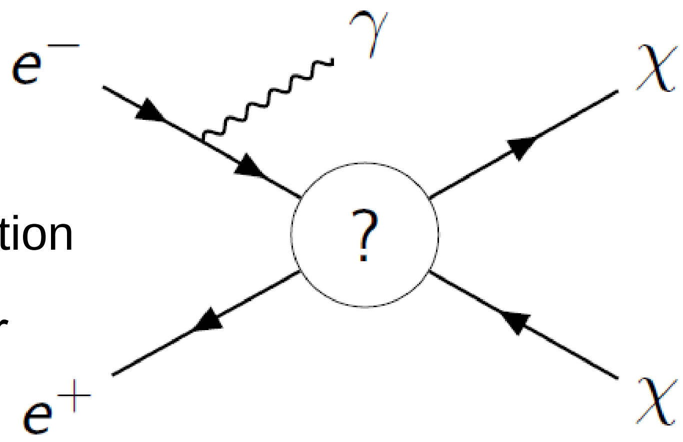


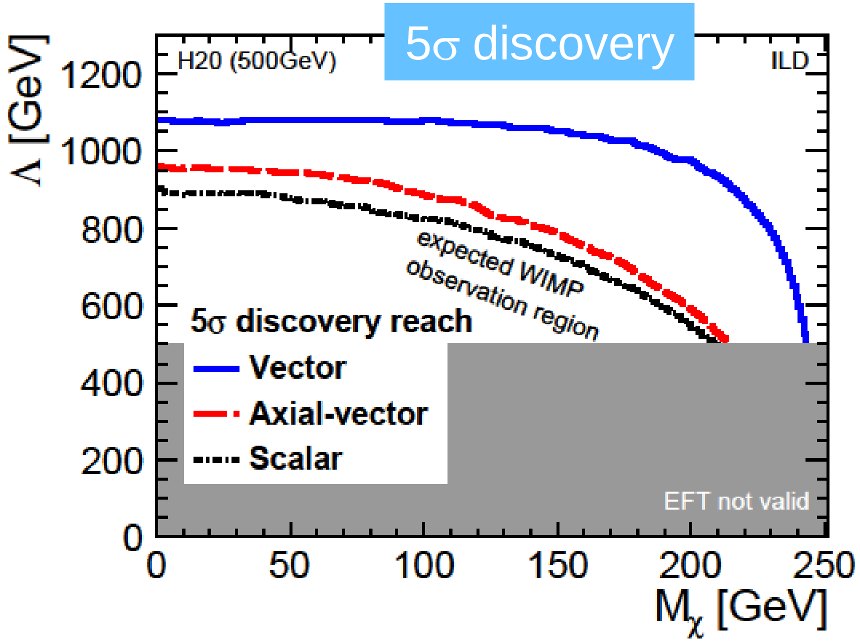
Example: vector-like fermion WIMP

full detector study at 500 GeV

- carefull ISR modelling
  - several photons possible
  - double-counting avoided
- ILC accelerator environment
  - luminosity spectrum
  - beam-induced background

effective operators

- vector
- axial-vector
- scalar



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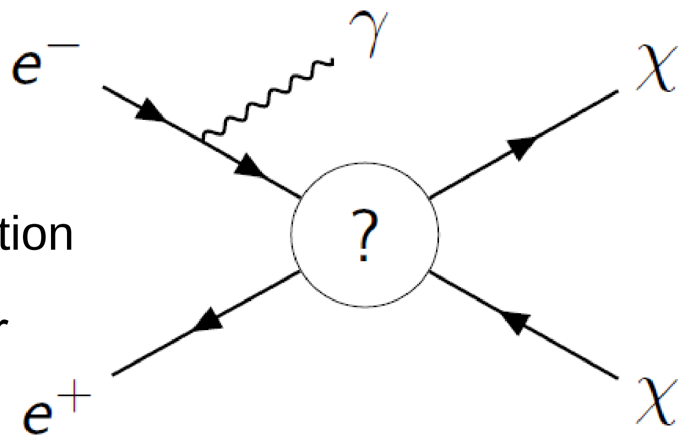

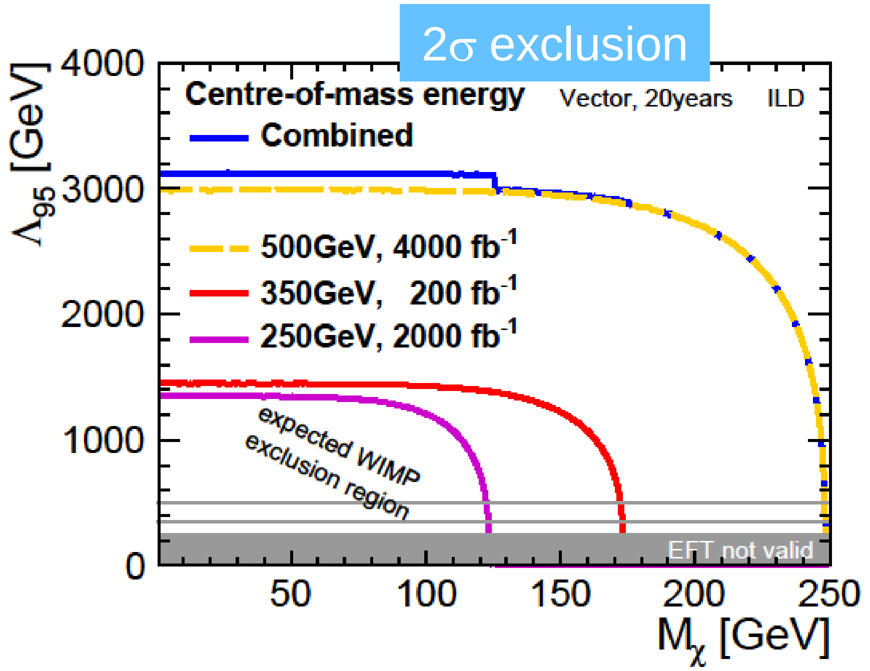

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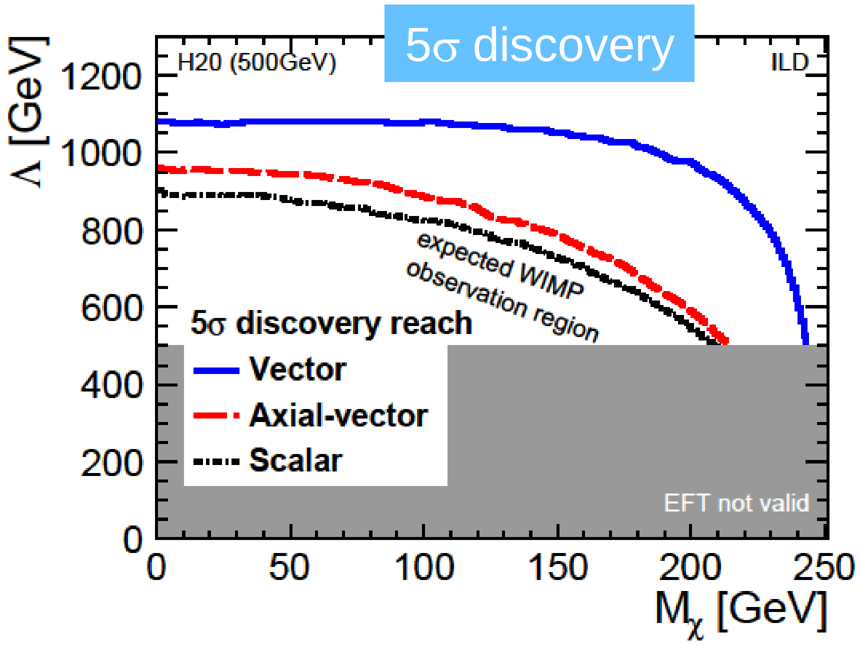
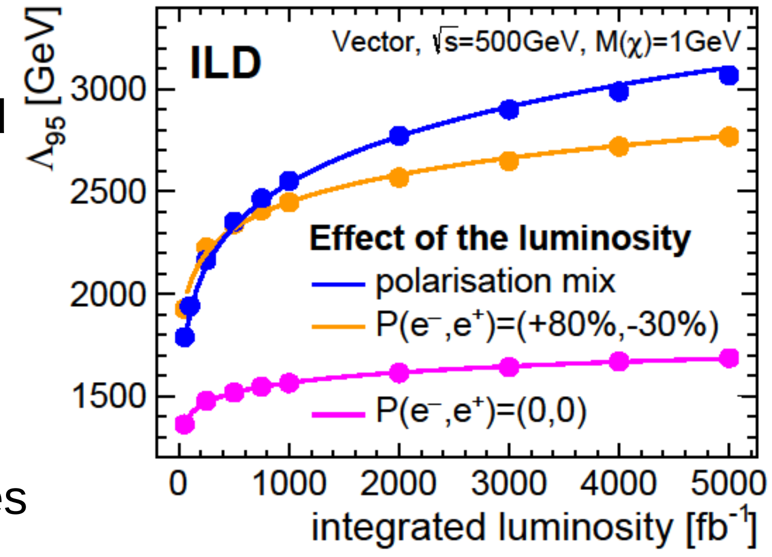


Sensitivity to WIMP Dark Matter: Operation Scenarios

Role of $\sqrt{s}$, luminosity and polarisation

Polarisation is crucial

- suppression of neutrino background
- enhancement of signal
- provides statistically independent data sets with different polarisation configuraitons
  → control of systematic uncertainties



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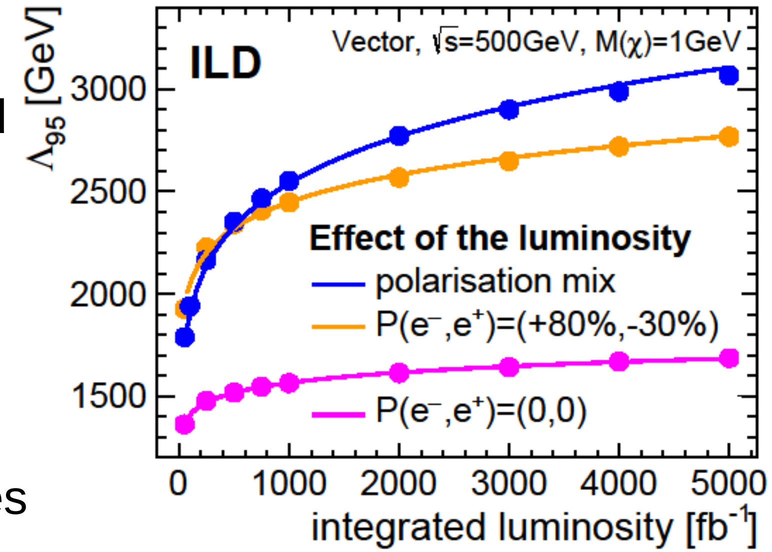

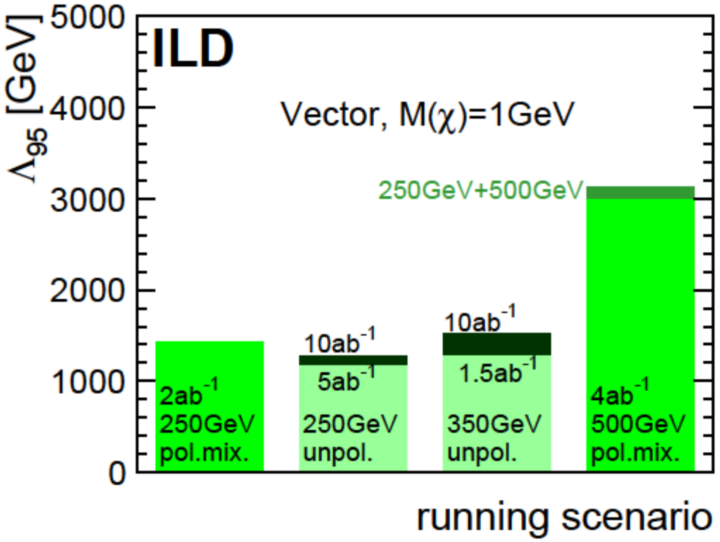

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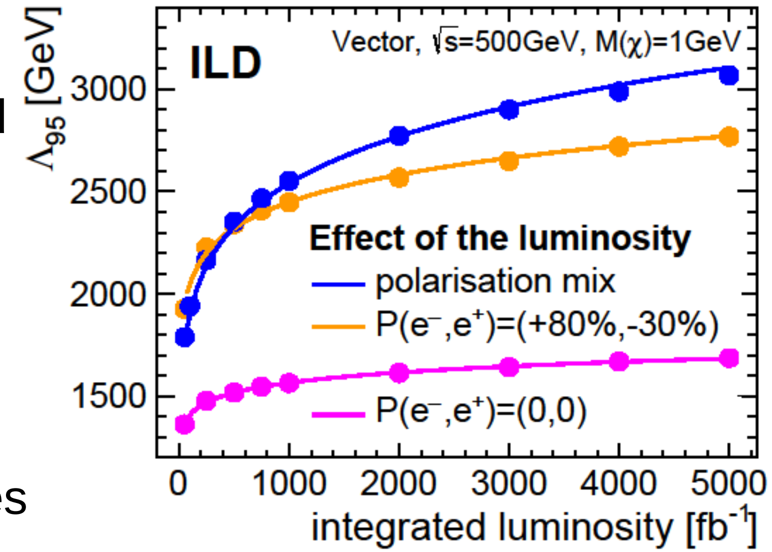
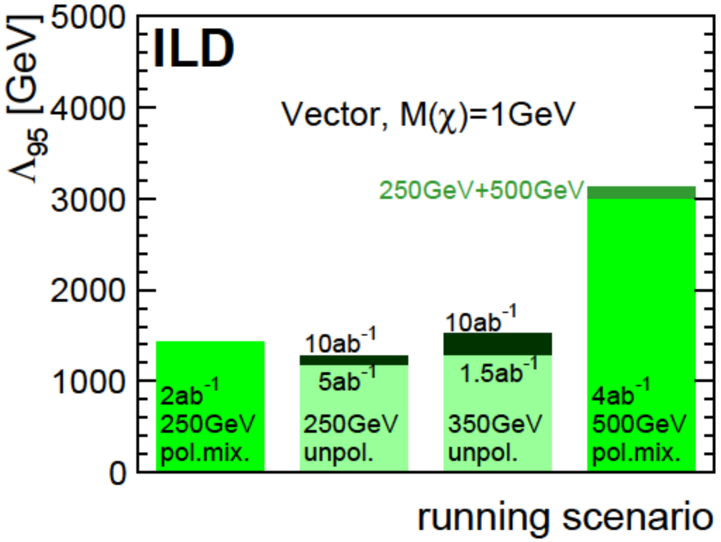
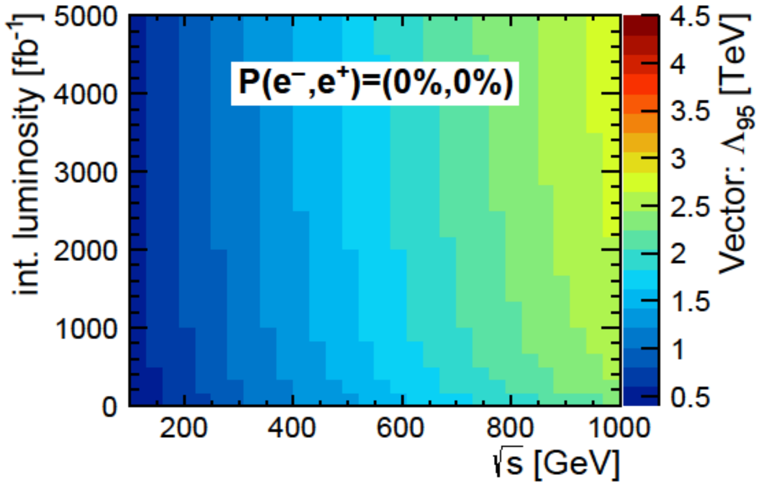
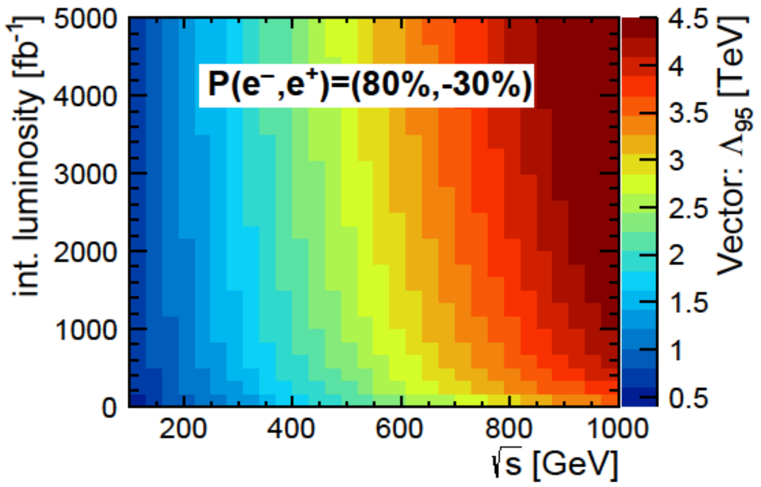
Higher centre-of-mass energies are favored

- signal cross-section rises with energy
- collecting data for decades at a moderate energy is worse than running at higher energies and collect a smaller data set









Detector Hermeticity

Background suppression crucial for BSM studies

Bhabha scattering: background for WIMPs

- huge cross-section
- particles mainly in forward region
  → challenging reconstruction
  → mono-photon signal can be mimicked

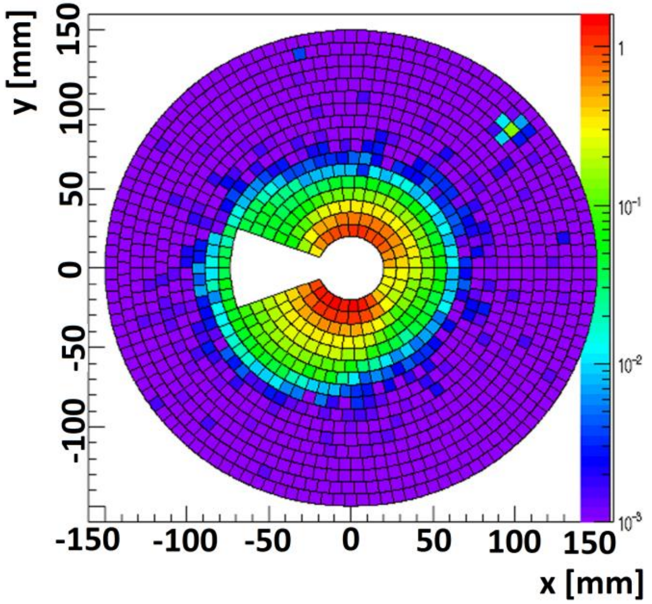
Overlay

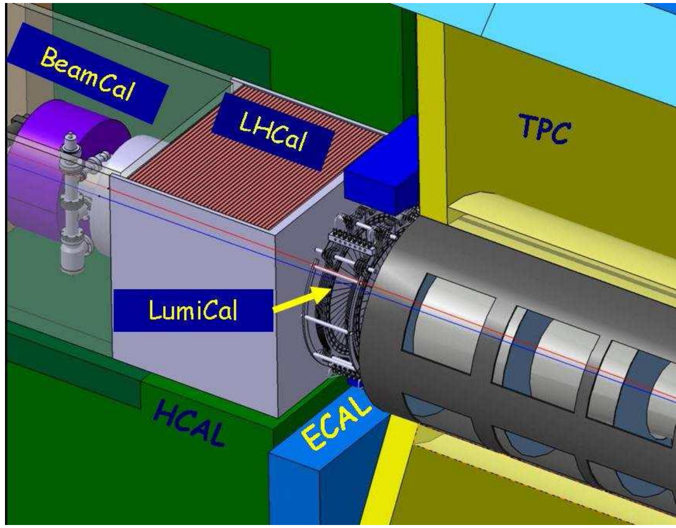
- pairs produced from beamstrahlung photons
- forward region is polluted

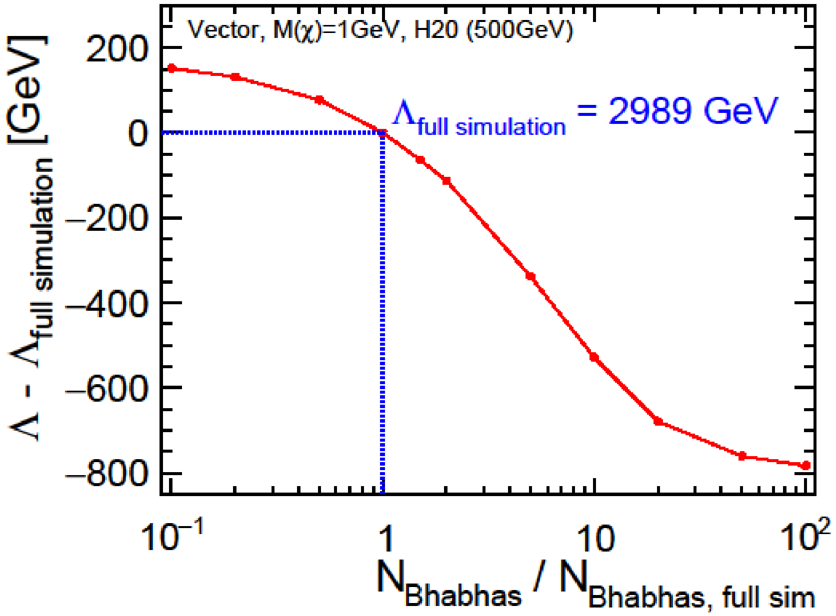
Hermeticity study: WIMPs as example

- sensitivity depends on number of reconstructed Bhabha scattering events
- with a larger "blind region" around beam pipes: testable energy reach is significantly reduced

forward detector BeamCal at 3.6 m to IP





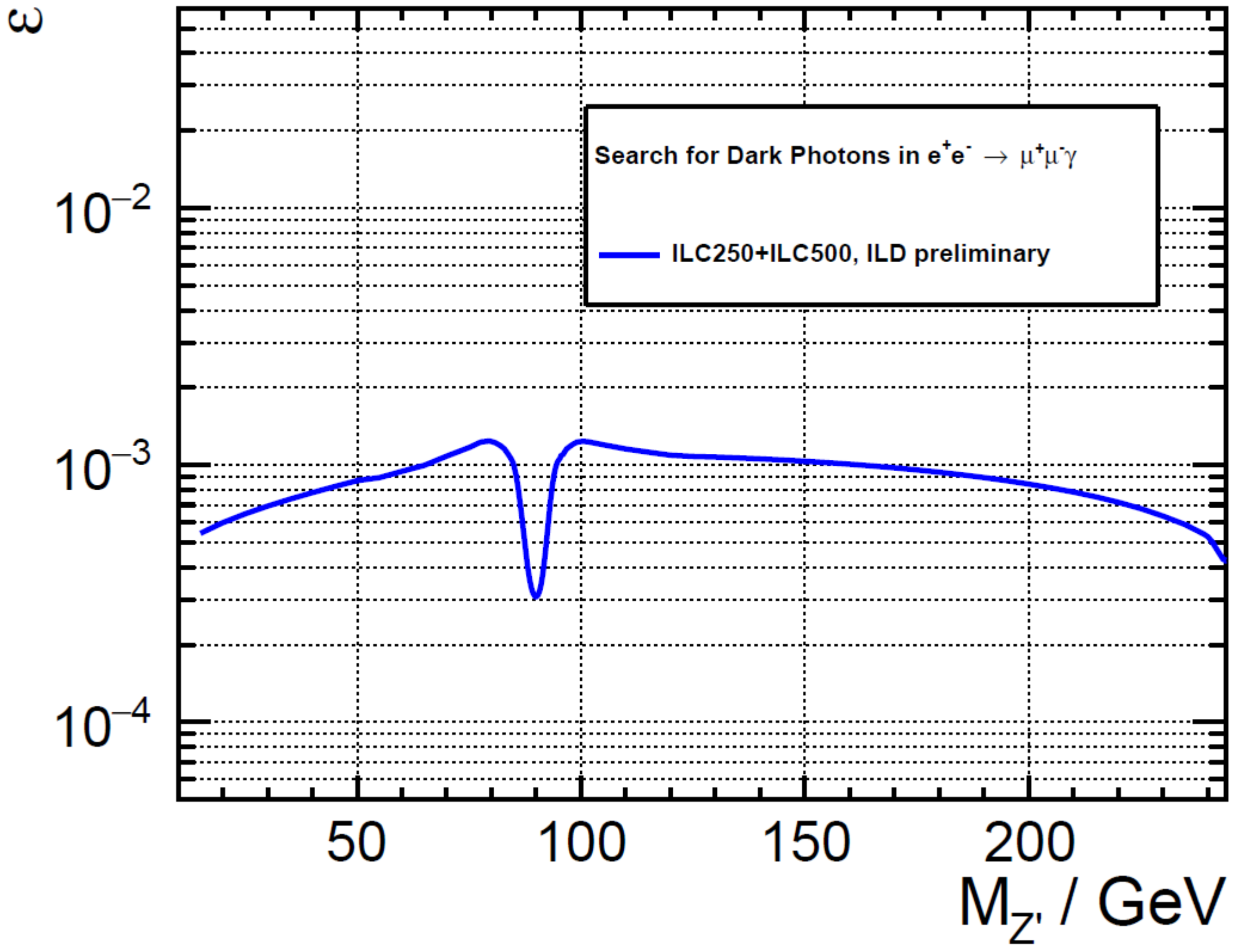


Dark photon search

e+e- → γA'→ γμ+μ-

95% exclusion limit (no deviation from SM observed)

- amplitute ε: mixing of dark photon with hypercharge gauge boson
- assumes full ILC programme
  → shown mass range dominated by run at 250 GeV



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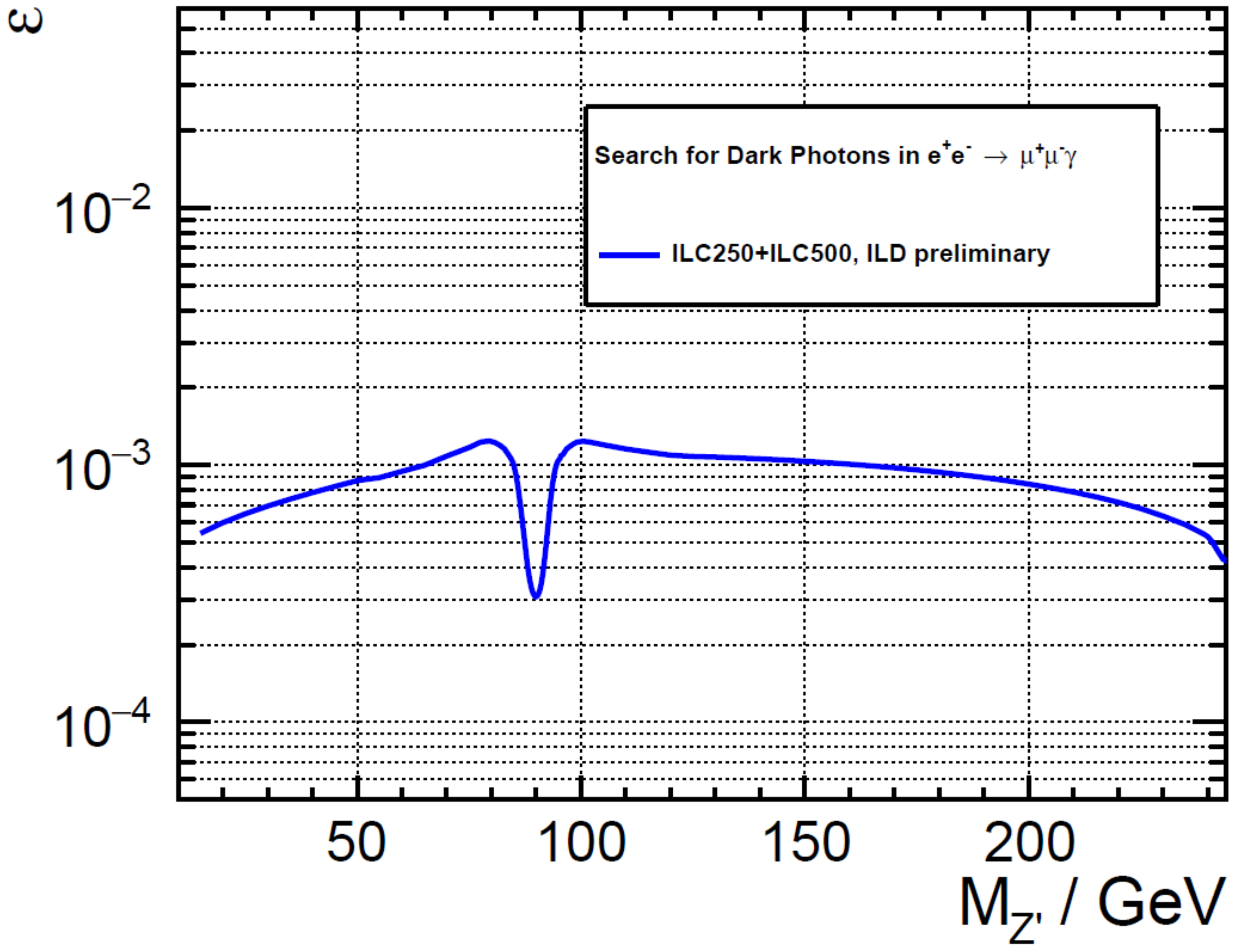
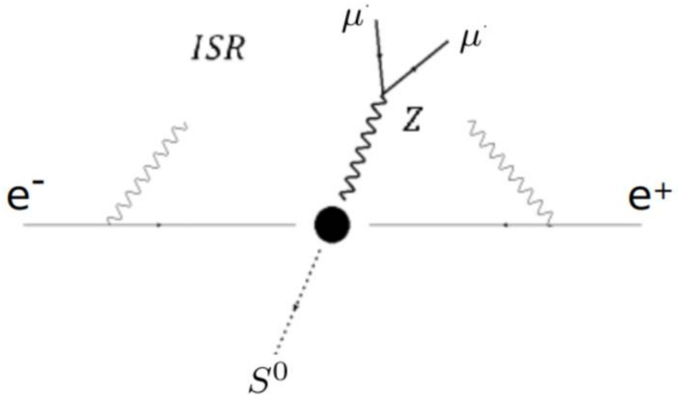
Role of polarisation

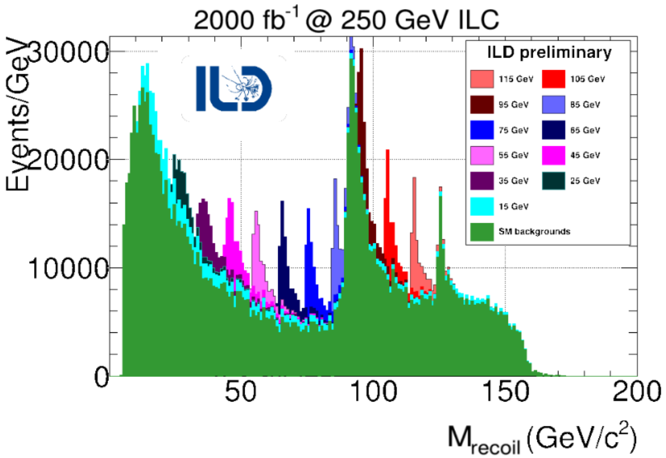
- polarisation not considered in study
  → sensitivity around *Z* mass could improve
- for invisible decay products: polarisation crucial to suppress SM neutrino background



Additional Higgs Bosons

Search for extra light scalars



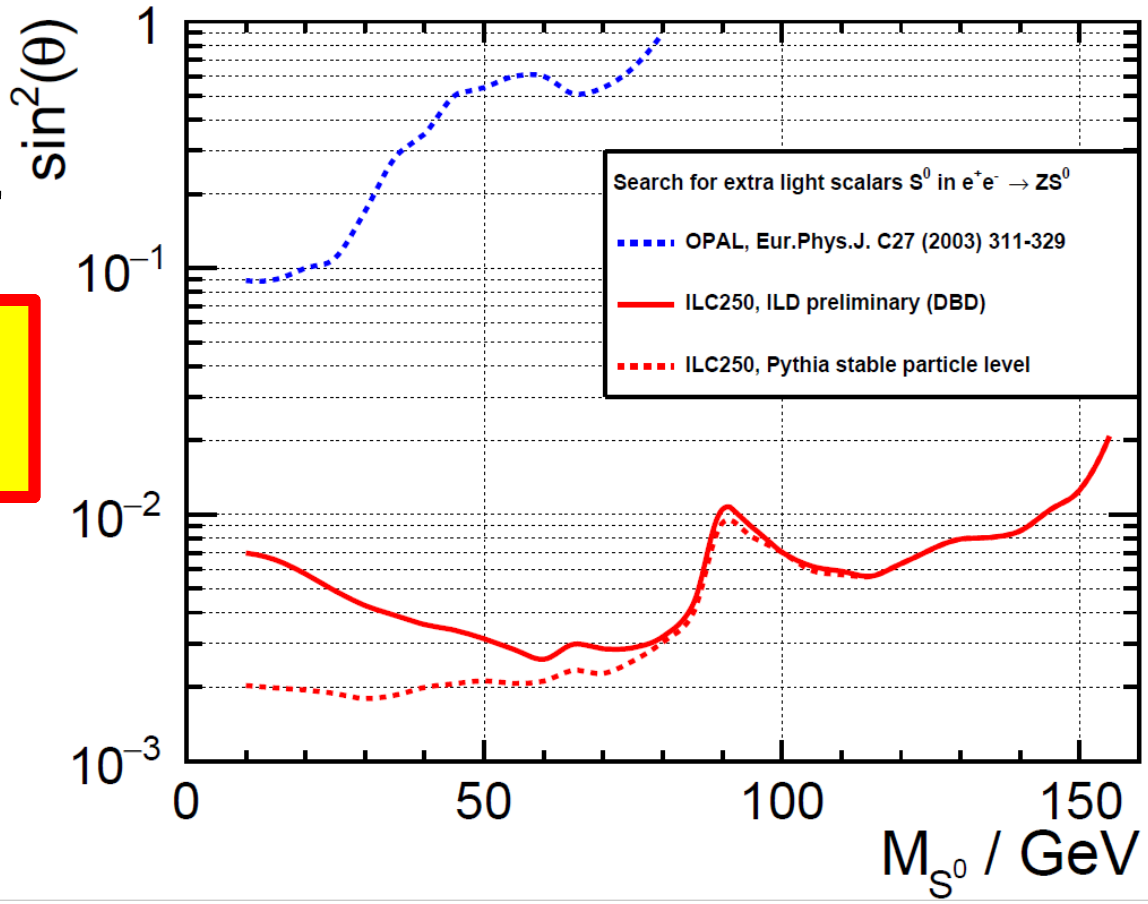


Recoil against *Z*

- lepton collider: initial state 4-mom. is known
- *Z* reconstructed from its decay products
  → scalar can be reconstructed as the missing 4-mom.
- reconstruction of the scalar without "looking at the scalar"
  → highly model-independent

arxiv:1902.06118,

arxiv:1801.08164

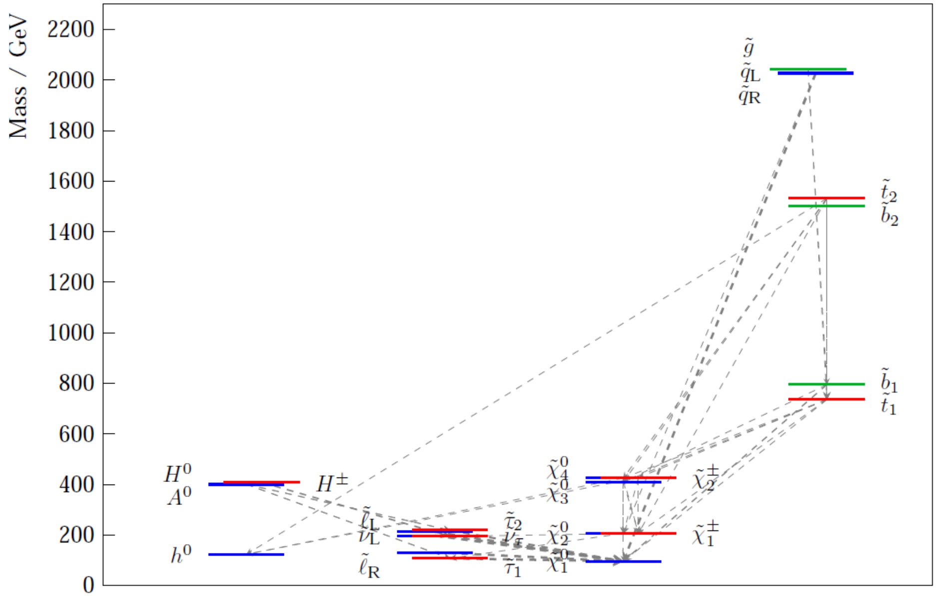


Exclusion limit

- $\sin^2(\theta)$: cross-section relative to a SM Higgs with correspoding mass
- full detector simulation
  → for low masses: detector effects play a role

Supersymmetry

UV-complete BSM models



Assumption: discovery of several new particles

- nature of new physics can be tested
- conclusions about underlying parameters

Detector simulations of the complete model

- complete particle spectrum
- model branching ratios (instead of just assuming 100% for dominant channel)

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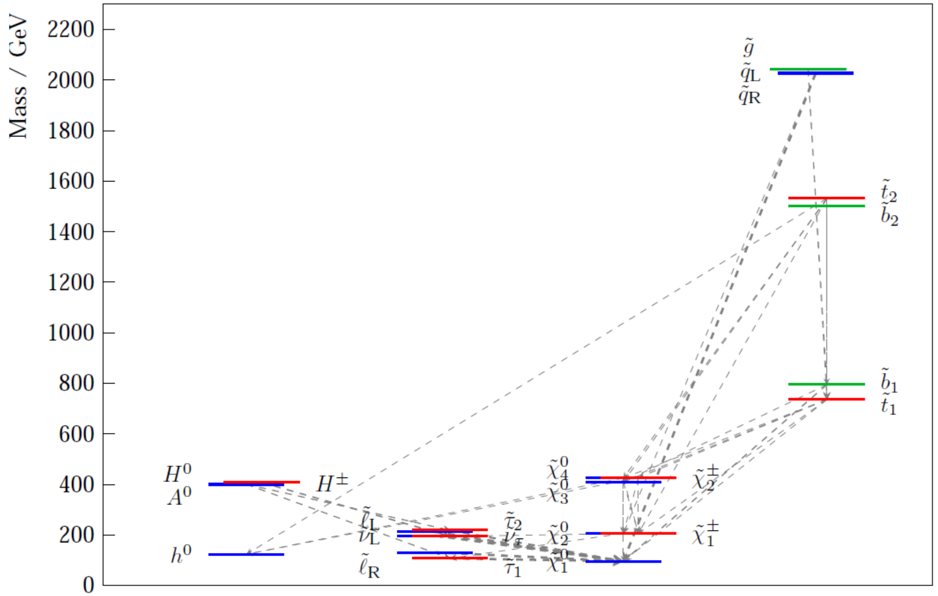
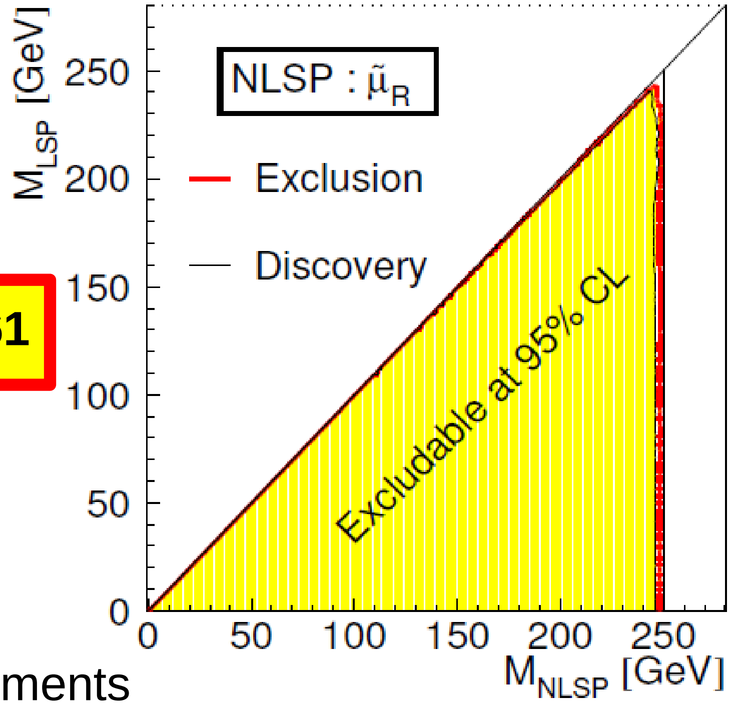
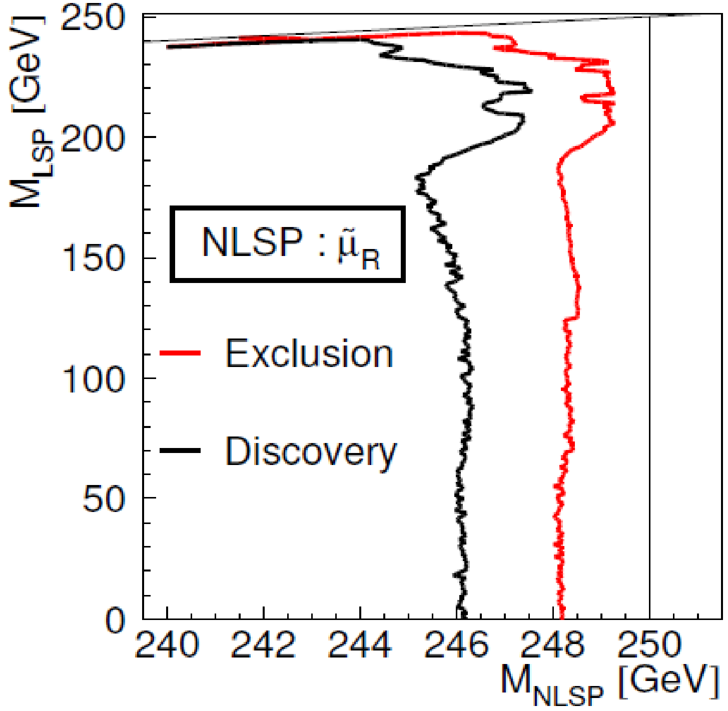
Loop-hole free searches

arxiv:1308.1461

- next-to-lightest SUSY particle searches
- in kinematic reach:
  discovery guaranteed or immutable limits
- in case of a discovery: accurate measurements





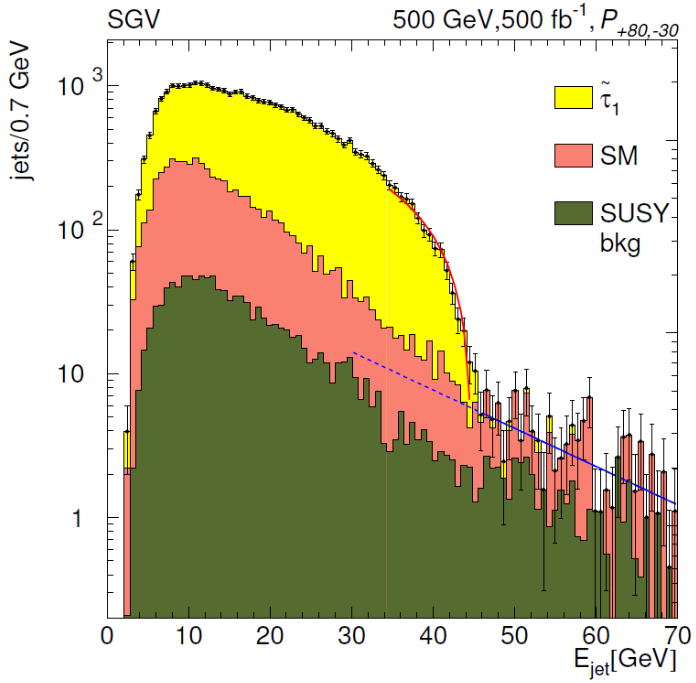


SUSY: Precision Measurements

Fitting the dark matter relic density *Ω*

Stau coannihilation scenario

- lightest supersymmetric particle (LSP) is *the* dark matter
- study at 500 GeV **arxiv:1508.04383**
- $\tilde{\tau}_1 \rightarrow \tau\, \tilde{\chi}_1^0$ endpoint → stau mass precision 0.15%



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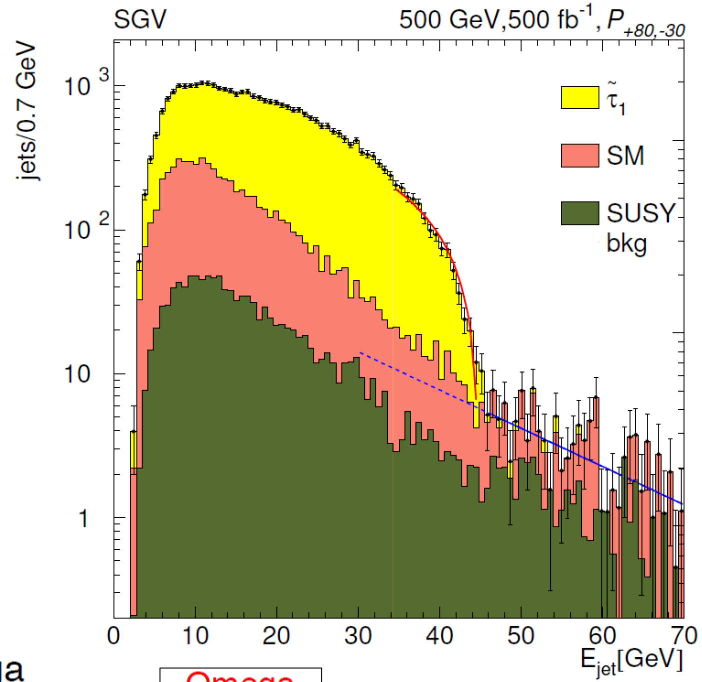
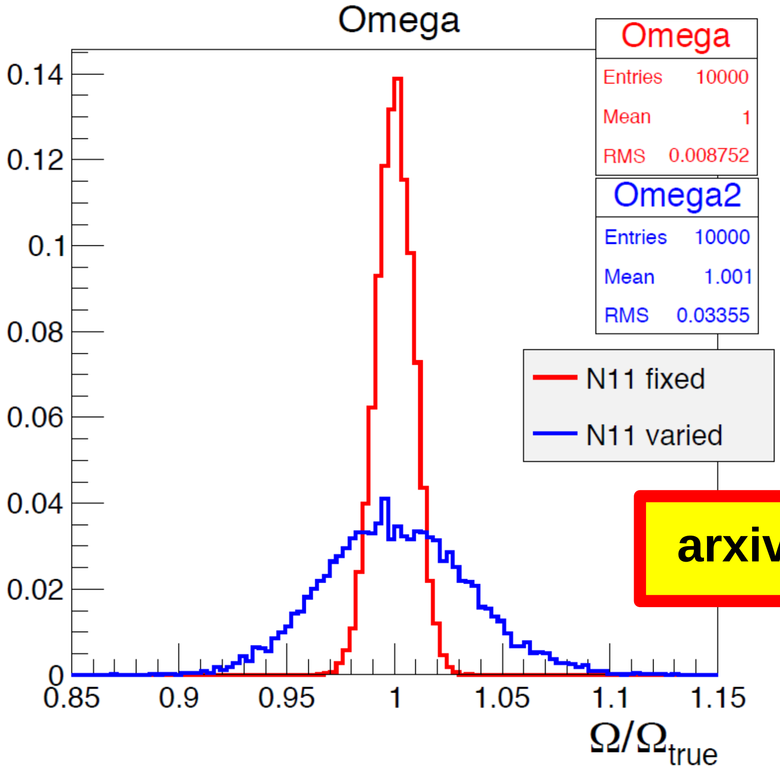
With SUSY observables as input
dark matter relic density Ω can be fitted

- using micrOMEGAs (arxiv:1305.0237)
- input: discovery of all sleptons, sneutrinos, $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{\chi}_1^\pm$ with permille mass precision
- fit precision 2% → same precision as Planck
- clear identification of LSP as dark matter constituent





arxiv:1602.08439

SUSY: Precision Measurements II

Testing gaugino mass unification

talk by S. Sasikumar

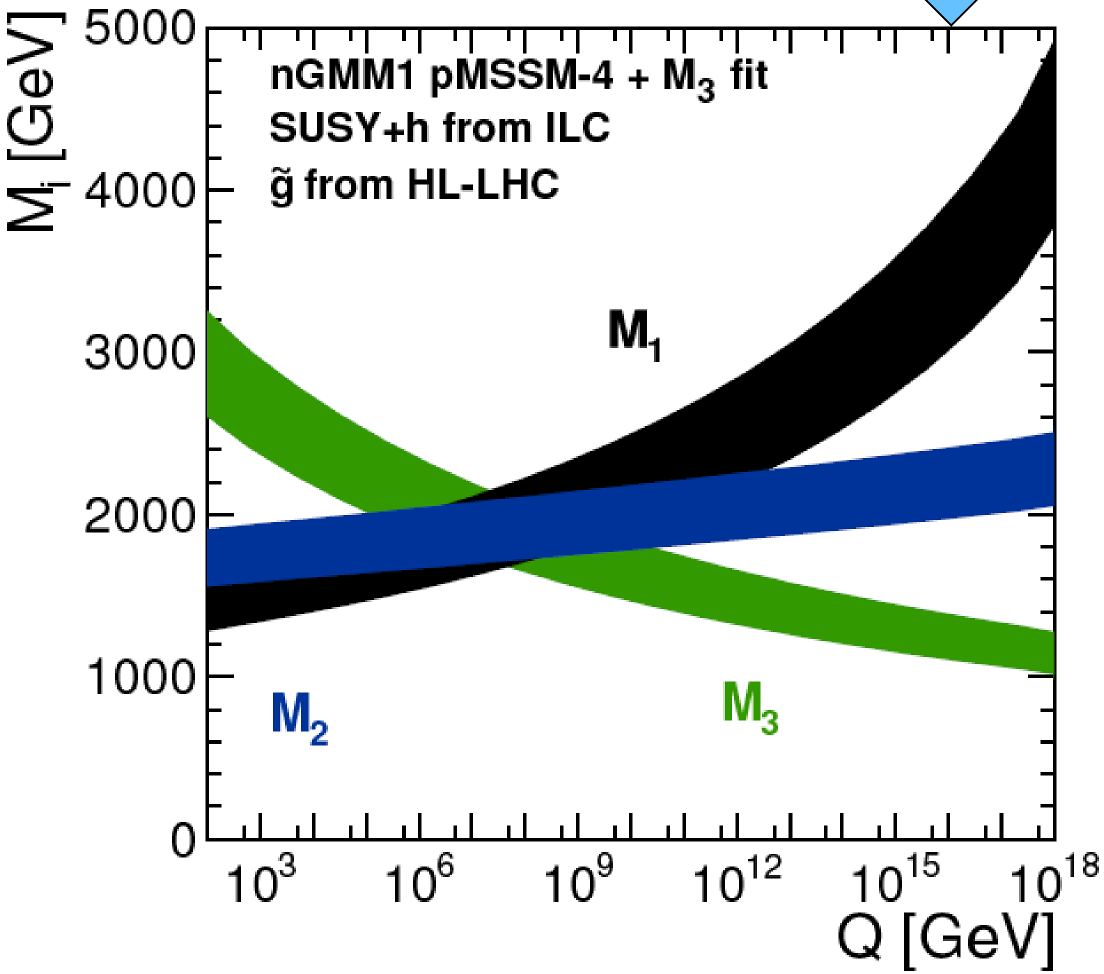
GUT scale

Natural SUSY with light Higgsinos

- not excluded natural SUSY model
- mirage mediated breaking model
  → unification below GUT scale

Running gaugino masses

- gaugino masses are fitted (at 1 TeV)
  - using Fittino (arxiv:hep-ph/0412012)
  - input: Higgsino masses and polarised cross-sections
- evolving gaugino masses to higher scales
  - using renormalization group equations
  - bands show 1σ confidence levels
- unification at GUT scale can be excluded from fit

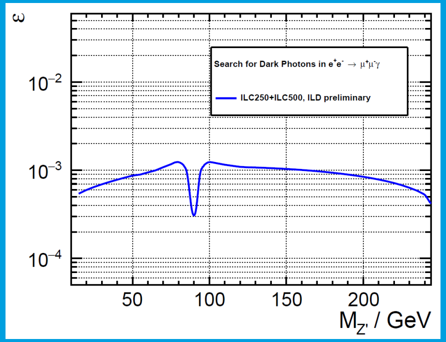


Conclusion

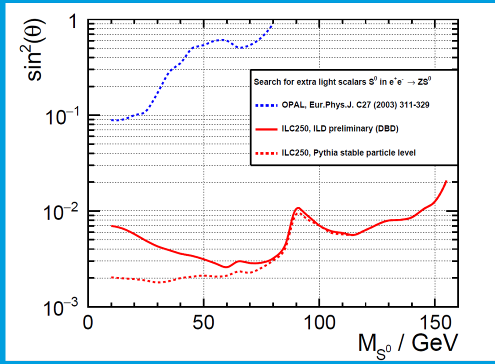
new particle that couple prefentially to leptons

polarisation of both beams
→ chirality of new process can be tested

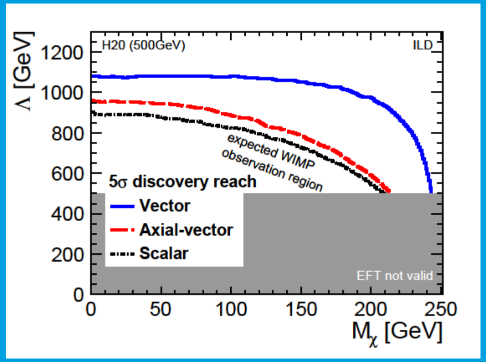
The ILC has the potential to find …



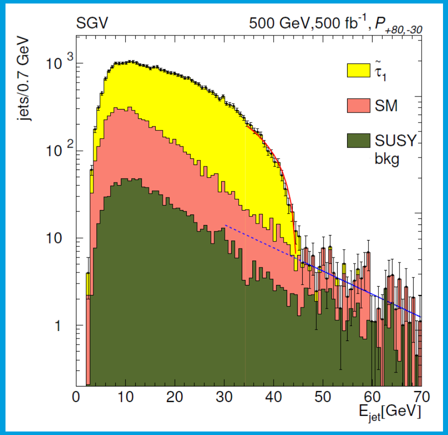
exclusion limits

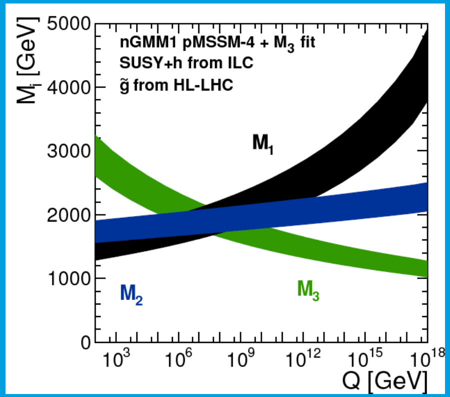


precision measurements



new particles





new physics

loophole-free searches

polarisation: control of systematics

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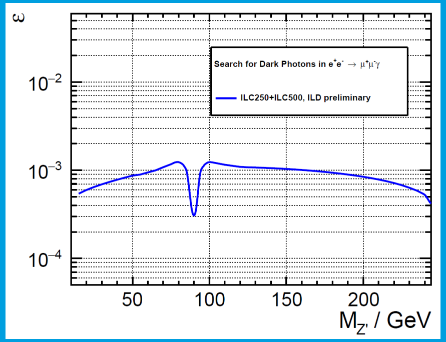

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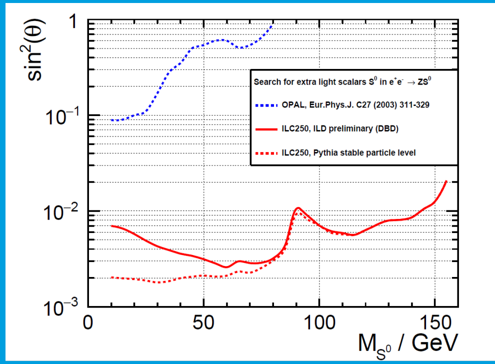

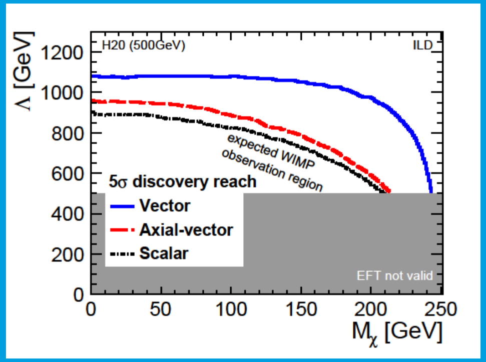

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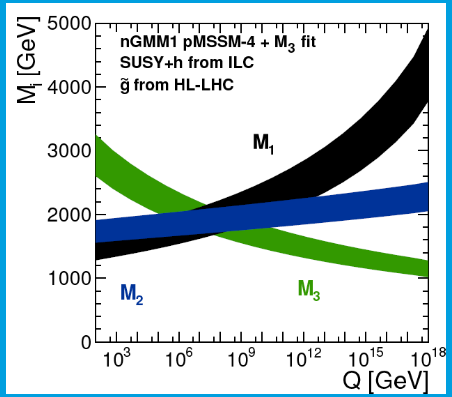

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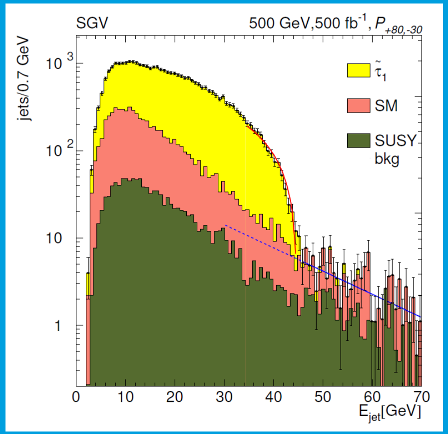

loophole-free searches

polarisation: control of systematics

Lepton colliders cover unique parameter space ➔ complementary to the LHC

Polarisation of both beams is crucial for many searches ➔ ILC

Contact

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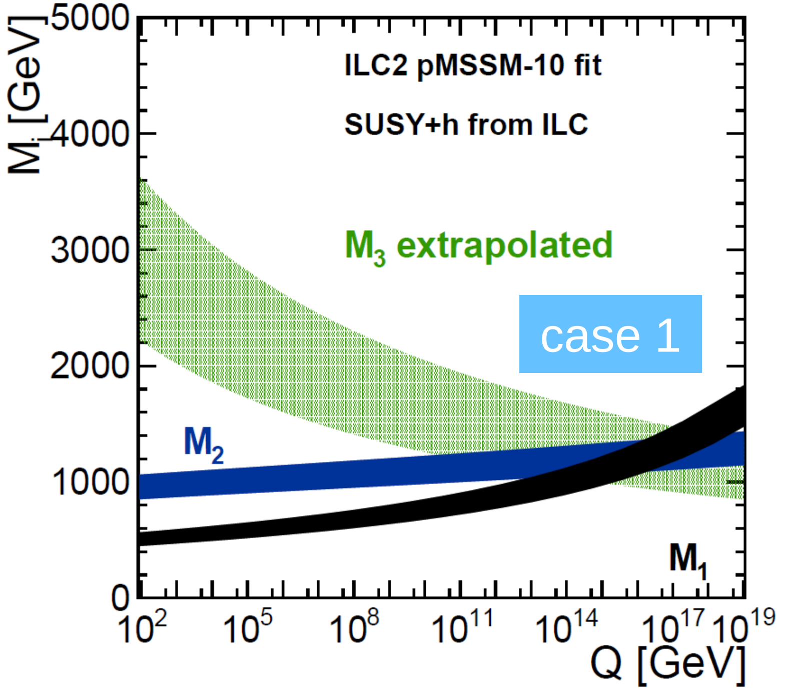
SUSY: Testing Gaugino Mass Unification

Natural SUSY with light Higgsinos

talk by S. Sasikumar



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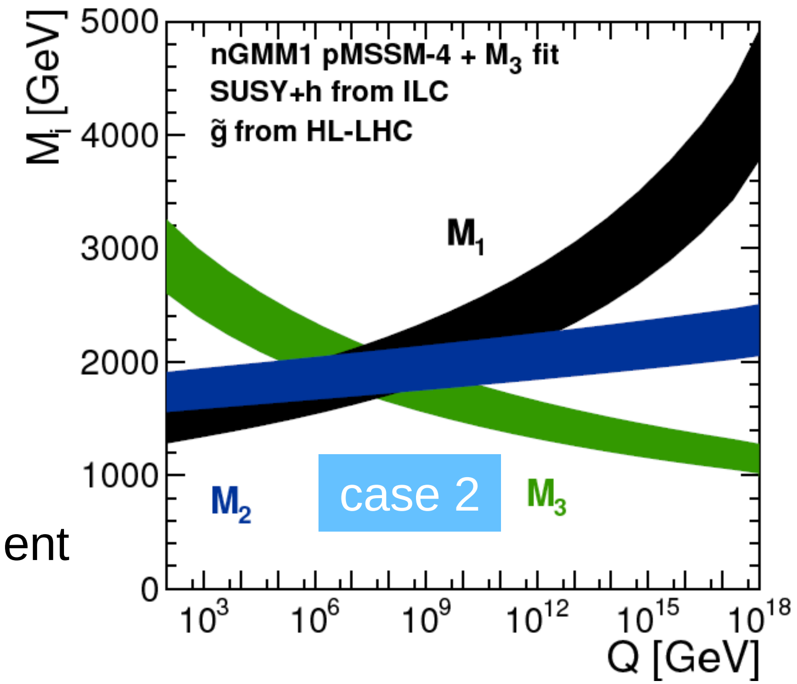
- gaugino masses are fitted (at 1 TeV)
  - using Fittino (arxiv:hep-ph/0412012)
  - with Higgsino masses and polarised cross-sections as input
- evolving gaugino masses to higher scales
  - using renormalisation group equations
  - bands show 1σ confidence levels



Case 1: unification at GUT scale

- running of M1 and M2
- unification at GUT scale can be fitted
- running of M3 from unification to lower energies
  - matches model point at 1 TeV
  - could be cross-checked with LHC results

Case 2: unification below GUT scale

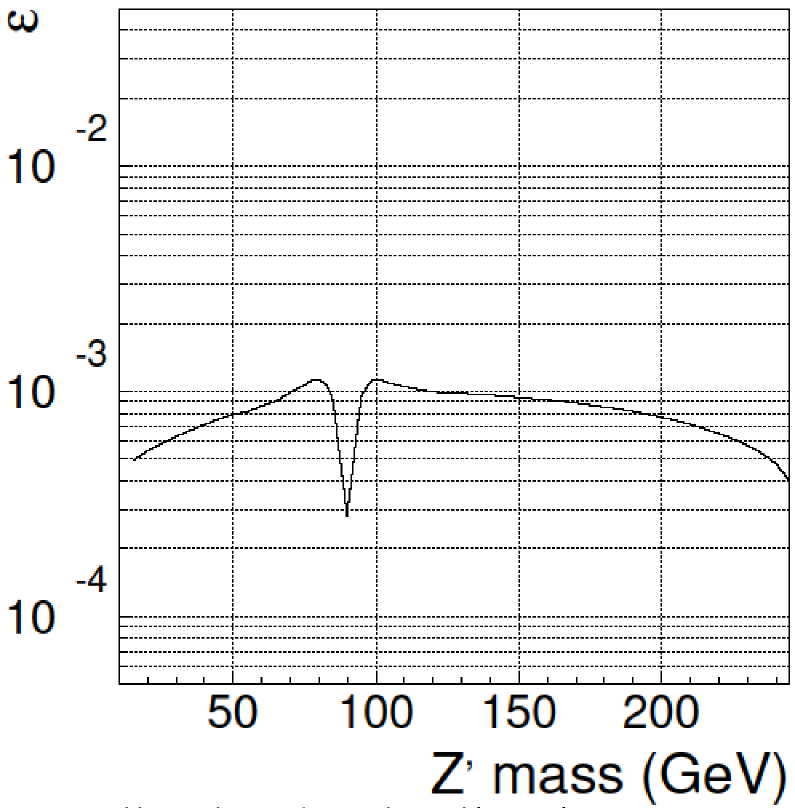
- unification at GUT scale can be excluded from fit
- good precision with 10% measurement of gluino mass from HL-LHC

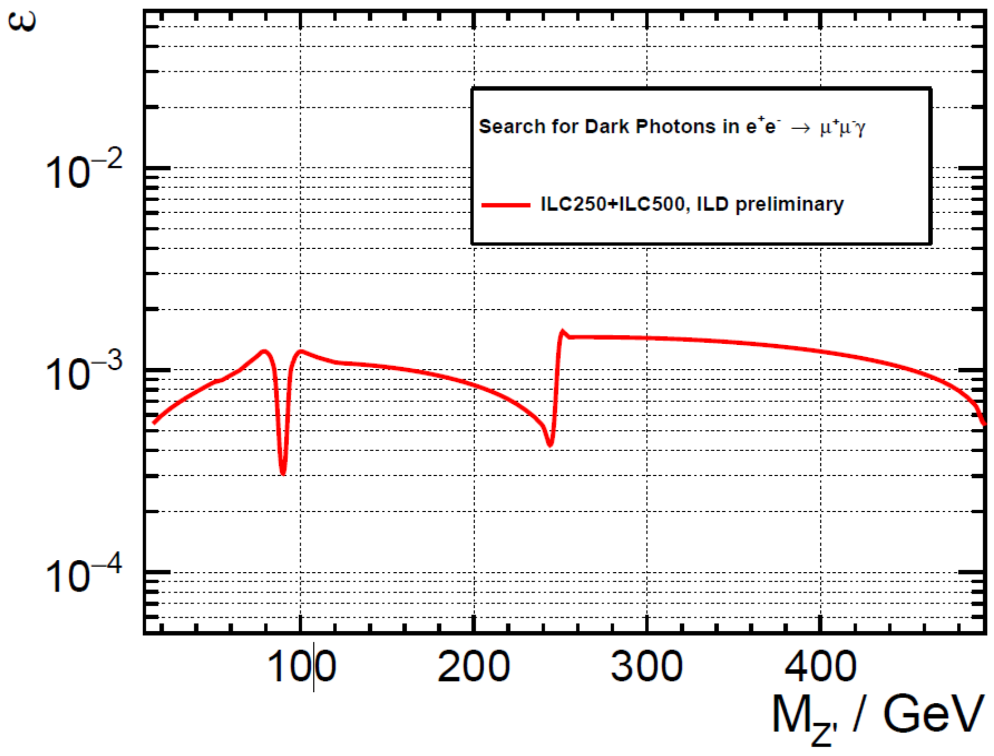
BACKUP: Dark photon search I

Limits below 250 GeV dominated by 250 GeV run

approach

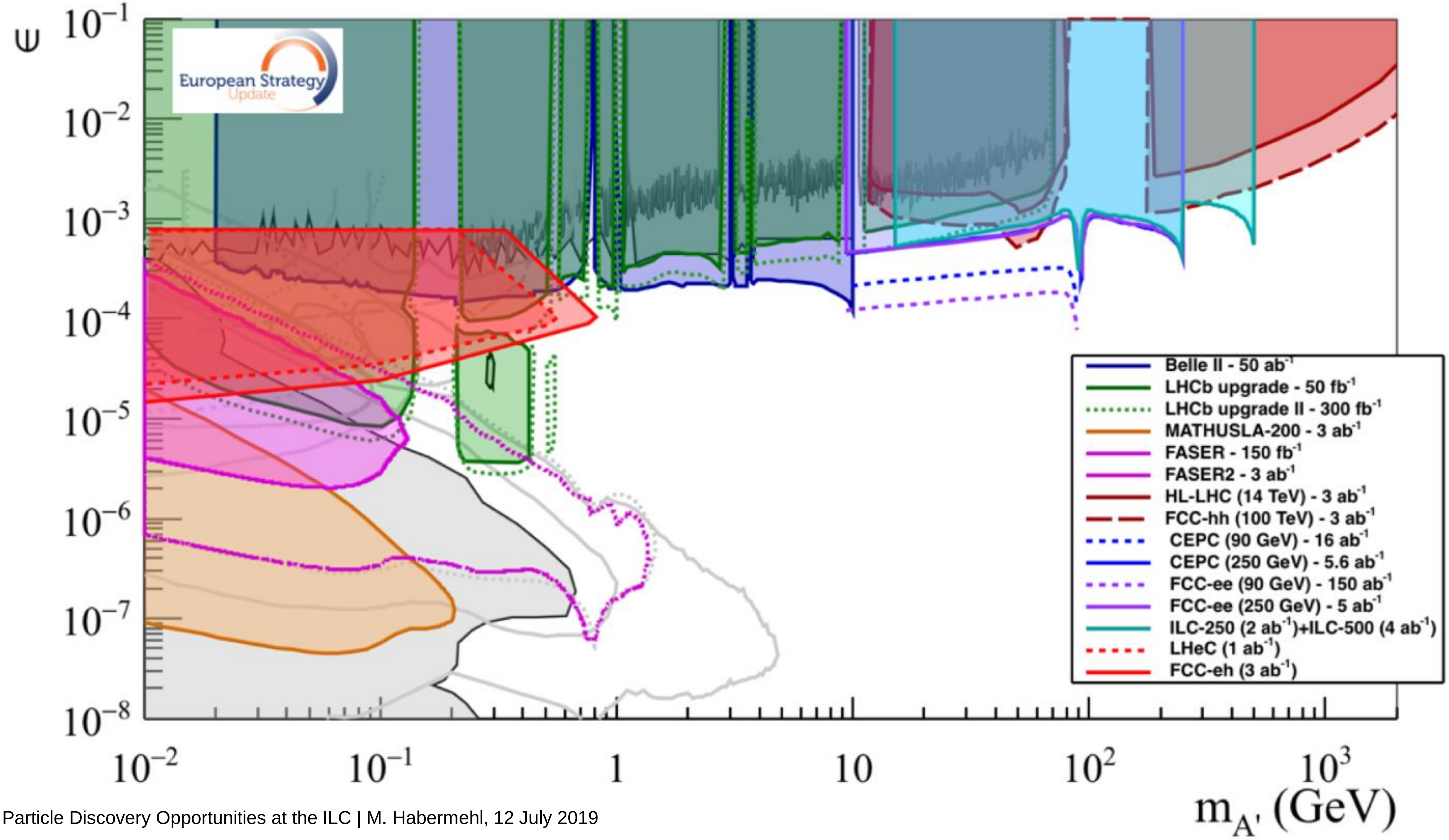
- muon momentum resolution taken from full detector simulation → propagated to mass peak width
- energy dep. BG cross-section from generator level
- around *Z* mass
  - shape taken from CEPC study (arxiv:1503.07209)
  - more background, but interference of *Z* and dark photon





BACKUP: Dark photon search II

Comparison to other experiments

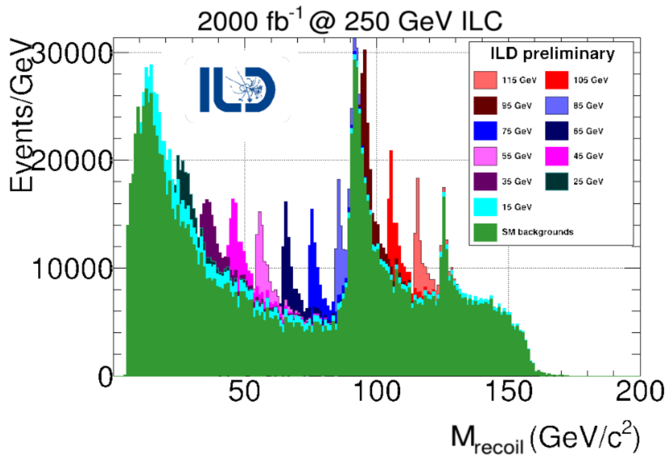


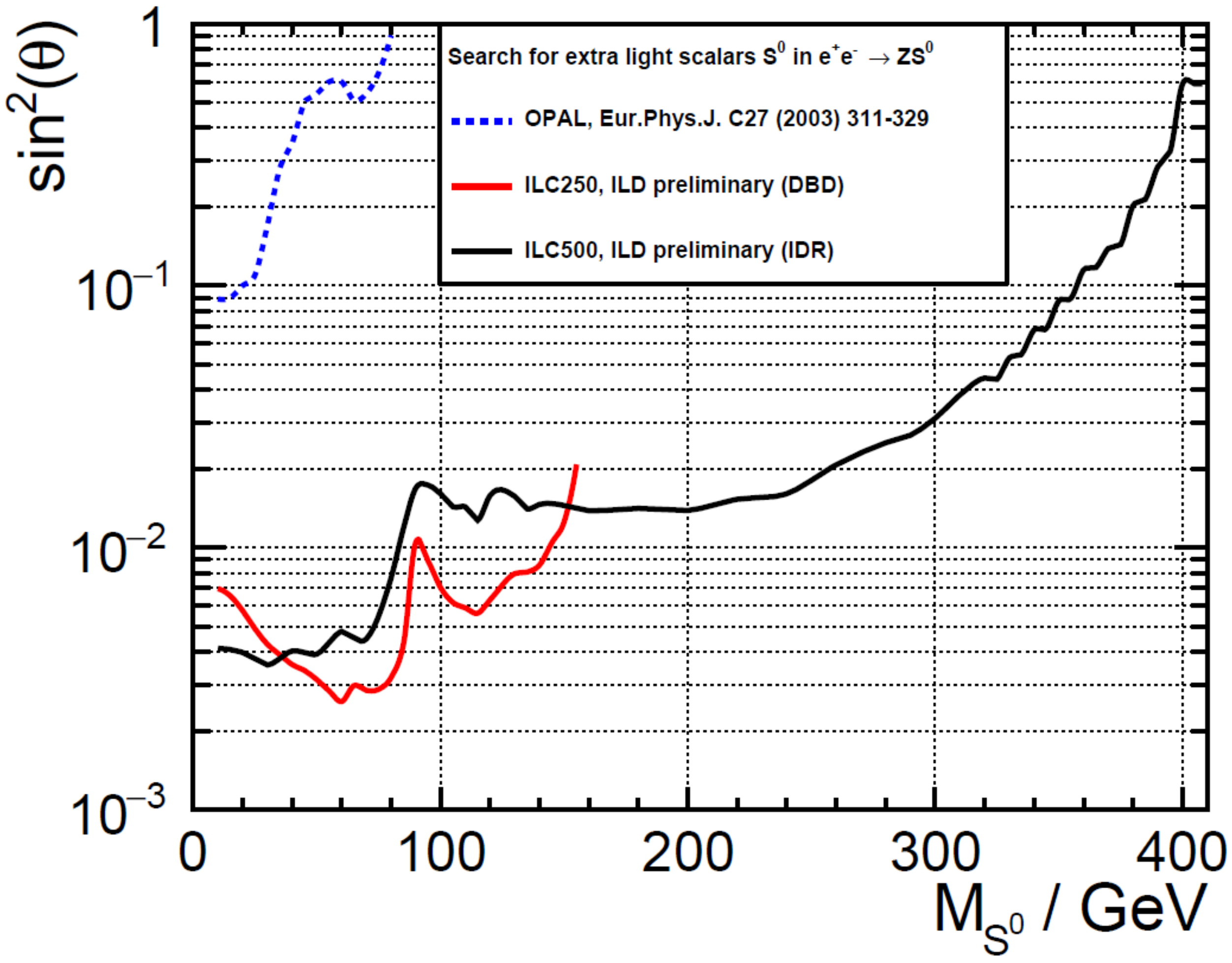
BACKUP: Additional Higgs Bosons

Search for extra light scalars

arxiv:1902.06118, arxiv:1801.08164

- black curve: update with 500 GeV and IDR detector model





BACKUP: Supersymmetry

UV-complete BSM models

Assumption: discovery of several new particles

- nature of new physics can be tested
- conclusions about underlying parameters

Detector simulations of the complete model

- complete particle spectrum
- model branching ratios (instead of just assuming 100% for dominant channel)

Loop-hole free searches **arxiv:1308.1461**

- next-to-lightest SUSY particle searches
- in kinematic reach:
  discovery guaranteed or immutable limits
- in case of a discovery: accurate measurements