$\tilde{\tau}$ searches at the ILC

Teresa Núñez - DESY

- SUSY and SUSY searches
- Motivation of $\tilde{\tau}$ studies
- Limits at LHC and LEP
- Current ILC studies
- Outlook and conclusions

HELMHOLTZ GEMEINSCHAFT

CLUSTER OF EXCELLENCE QUANTUM UNIVERSE

DESY.

Supersymmetry

One of the promising candidates for new Physics

Explanation or hints to current SM limitations:

- gauge hierarchy problem,
- Dark Matter composition,
- current excess of matter over antimatter,
- …

Symmetry of spacetime relating fermions and bosons

- Introduces a superpartner for each SM particle
- SM particle and SUSY partner with same quantum numbers except for the spin (1/2 difference)
- Defines R-parity: +1 SM particles, -1 SUSY particles
- SUSY particles couples as SM particles

Supersymmetry searches

Considerable effort searching for SUSY at LHC and LEP

LHC

- Mainly sensitive to production of coloured particles, gluino and squarks, most probably the heaviest ones
- Small cross sections and high background for colour-neutral states, such as sleptons, charginos and neutralinos
- Limits only valid if many dependencies between the model parameters are full filled

LEP

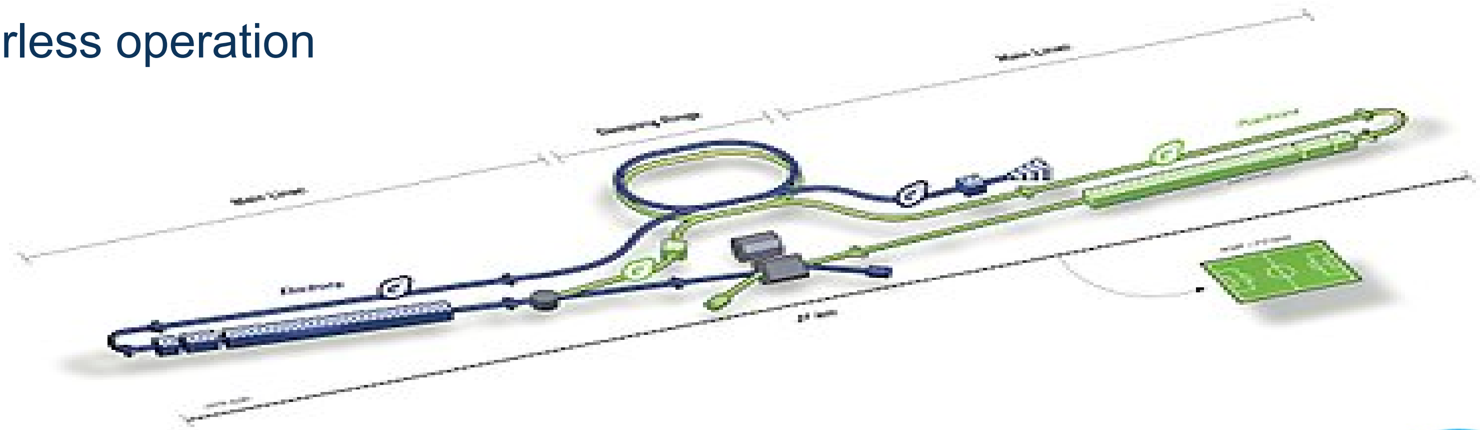
- High sensitivity for production of colour-neutral states, but limited by the energy
- Limits are valid for any value of the model parameters not shown in the exclusion plots

Not evidence of SUSY up to now, exclusion/discovery limits set

Supersymmetry searches

ILC ideal environment for SUSY studies

- Electron-Positron collider at $\sqrt{s}$ = 250-500 GeV with energy upgradability (1TeV)
- Electrons (80%) and positrons (30%) polarisations
- Well defined initial state: 4-Momentum and spin configuration
- Clean and reconstructable final state (near absence of pile-up)
- Hermetic detectors (almost 4π coverage)
- Triggerless operation



Triggerless operation -> huge advantage for precision measurements and unexpected signatures

Motivation for $\tilde{\tau}$ searches

Searching SUSY focused on best motivated NLSP candidates and most difficult scenarios

$\tilde{\tau}$ satisfies both conditions

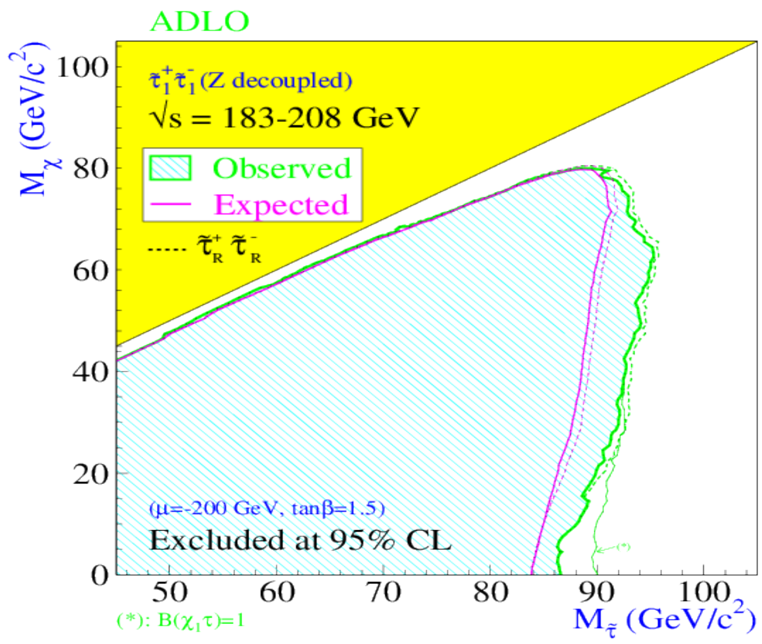
Scalar superpartner of τ-lepton

- Two weak hypercharge eigenstates ($\tilde{\tau}_R$, $\tilde{\tau}_L$) not mass degenerate
- Mixing yields to the physical states ($\tilde{\tau}_1$, $\tilde{\tau}_2$), being the lightest one with high probability the lightest sfermion (stronger trilinear couplings)
- With assumed R-parity conservation:
  - pair produced (s-channel via Z^0/γ exchange, lowest σ with no coupling to Z^0)
  - decay to LSP and τ, implying more difficult signal identification than the other sfermions

SUSY models with a light $\tilde{\tau}$ can accommodate the observed relic density ($\tilde{\tau}$ - neutralino coannihilation)

Limits at LHC and LEP

$\tilde{\tau}$ searches at LEP



- $\sqrt{s}$ = 183-208 GeV
- Combined four LEP experiments data

LEPSUSYWG/04-01.1

Valid for any mixing and any values of the not shown parameters

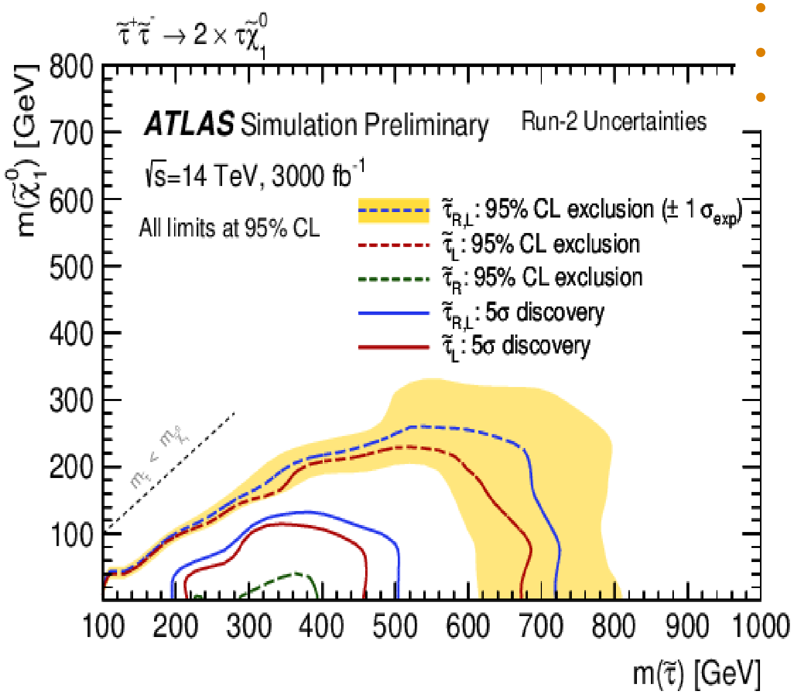
HELMHOLTZ GEMEINSCHAFT

DESY.

Limits at LHC and LEP

$\tilde{\tau}$ prospects at HL-LHC

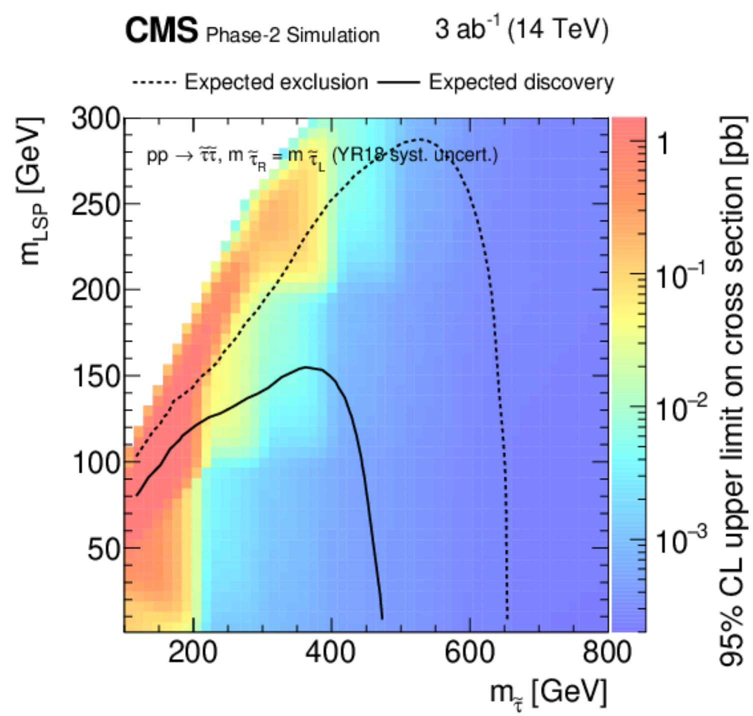
Expected gain in sensitivity to direct $\tilde{\tau}$ production



ATL-PHYS-PUB-2018-048

- **Two models: $\tilde{\tau}_R$ and $\tilde{\tau}_L$**
- **Not mixing**
- **M $\tilde{\tau}$ - MLSP > 120 GeV**

- **Two $\tilde{\tau}$ assumed to be mass-degenerate**
- **Not mixing**



CMS PAS FTR-18-010

Not discovery potential for $\tilde{\tau}$ coannihilation scenarios or $\tilde{\tau}_R$ pair production

ILC Study: conditions and tools

$\tilde{\tau}$ searches in worst scenario using SGV fast simulation

- Mixing angle set to 53 degrees (lowest cross sections)
- Focused on small mass differences (ΔM < 11 GeV)
- Cross-check larger mass differences

Previous preliminary study

ILC experimental conditions

- Polarization $P(e^-,e^+)=(+80\%,-30\%)$
- $\sqrt{s}$ = 500 GeV with 1.6 ab^{-1} integrated luminosity (H-20, I-20 ILC500)

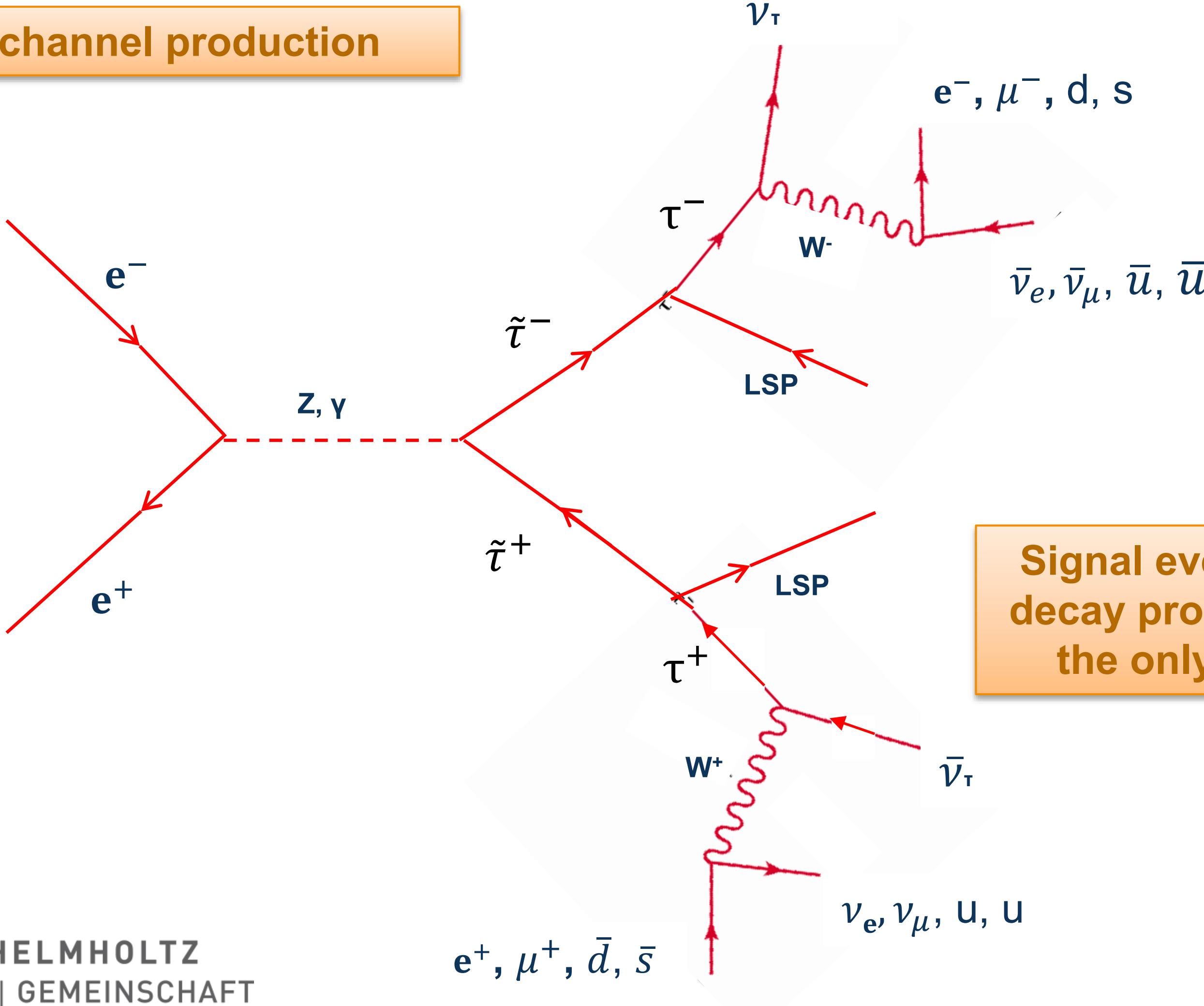
Event reconstruction using SGV adapted to the ILD detector concept at ILC

- Signal: Phytia 6.422
- Background: Whizard 1.95 (standard “DBD” background samples)
- Not signal in the calorimeter closest to the beam pipe (the BeamCal)

Root ntuples for analysis

Signal characterization

s-channel production



Signal events with the (visible) decay products of two τ's being the only detectable activity

Signal characterization (ctd.)

Signature:

- large missing energy and momentum
- high acollinearity, with little correlation to the energy of the decay products
- large fraction of detected activity in central detector (isotropic production of scalar particles)
- unbalanced transverse momentum
- no forward-backward asymmetry

Background

SM processes with real or fake missing energy

Irreducible

4-fermion production with two of the fermions being neutrinos and two leptons

- ZZ -> ννττ, WW -> τν τν

Almost irreducible

2-τ production partially escaping detection

- ee -> ττ, ZZ -> ννll, WW -> lν lν (l = e or μ)
- ee -> ττ + ISR, ee -> ττ ee, γγ -> ττ

γγ interactions

HELMHOLTZ GEMEINSCHAFT

DESY.

General cuts

Properties $\tilde{\tau}$ -events “must” have

Well known initial state
Hermeticity

- Missing energy (E_{miss}). E_{miss} > 2*MLSP GeV
- Visible mass (mvis). mvis < 2*(M$\tilde{\tau}$ - MLSP) GeV
- Momentum of all jets (pjet). pjet < 70% Beam Momentum (or M$\tilde{\tau}$/MLSP dependent)

- Two well identified τ's and little other activity

Clean final state
(‘no’ pile-up)

Above 95 % signal efficiency for each of these cuts (excluding for the τ-identification)

- Maximum jet momentum:

$$P_{max} = \frac{\sqrt{s}}{4}(1 - (\mathrm{MLSP} - \mathrm{M}\tilde{\tau})^2)(1 + \sqrt{1 - \frac{4\mathrm{M}\tilde{\tau}^2}{s}})$$

HELMHOLTZ GEMEINSCHAFT

CLUSTER OF EXCELLENCE QUANTUM UNIVERSE

DESY.

General cuts (ctd.)

Properties $\tilde{\tau}$ -events "might" have but background "rarely" has

- Missing transverse momentum (ptmiss). ptmiss limit depending on mass difference
- Large acoplanarity (thetaacop). 0.2 rad < thetaacop < 2. rad
- Large transverse momentum wrt. thrust-axis (rho). rho limit depending on mass difference
- High angles to beam (thetaptot). 0.79 rad < thetaptot < 2.84 rad

Cuts against properties of irreducible sources of background

- Charge asymmetry (cha_asym: $\Sigma charge * \cos(polar\_angle)$). char_asym > -1
- Difference between visible mass and Z mass (Z_peak). Z_peak > 4 GeV

Properties that the background often "does not" have

- Low energy in small angles. Therefore, demand energy in 30 degrees cone around the beam axis to be below a limit depending on mass difference
- Low energy of isolated neutral clusters. Therefore, demand maximum momentum of isolated neutral clusters to be below 10% beam momentum

General cuts (ctd.)

Main sources remaining background:

- WW going to ττνν
- γγ going to 4 fermions

Beam polarisation dependence

M_T=247GeV, ΔM=10GeV

Polarisation	Signal	ee -> ττνν	aa->ττll	aa->llll
$P(e^-,e^+)$=(+80%,-30%)	7.4	1.7	0.2	0.02
$P(e^-,e^+)$=(-80%,+30%)	5.7	28	0.2	0.02
Unpolarised	6	12	0.2	0.02

$P(e^-,e^+)$=(+80%,-30%) clearly enhance Signa/Background ratio

95%CL exclusion defined as $S > 2\sqrt{S+B}$

HELMHOLTZ GEMEINSCHAFT

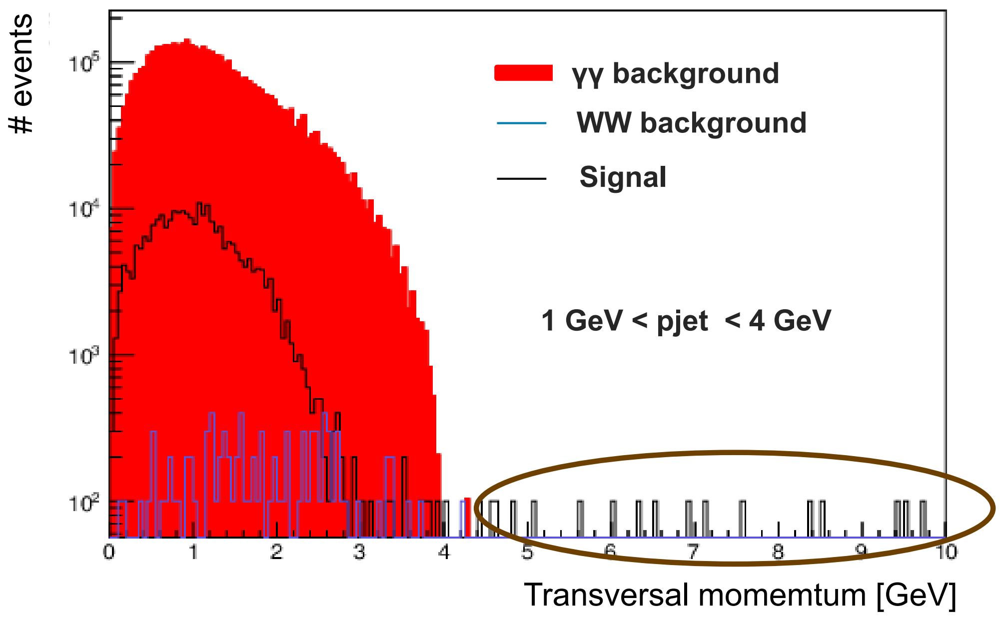
Polarisation also crucial for parameter determination

DESY.

Detailed study ΔM = 2 (3) GeV region

Analysis of ISR photons

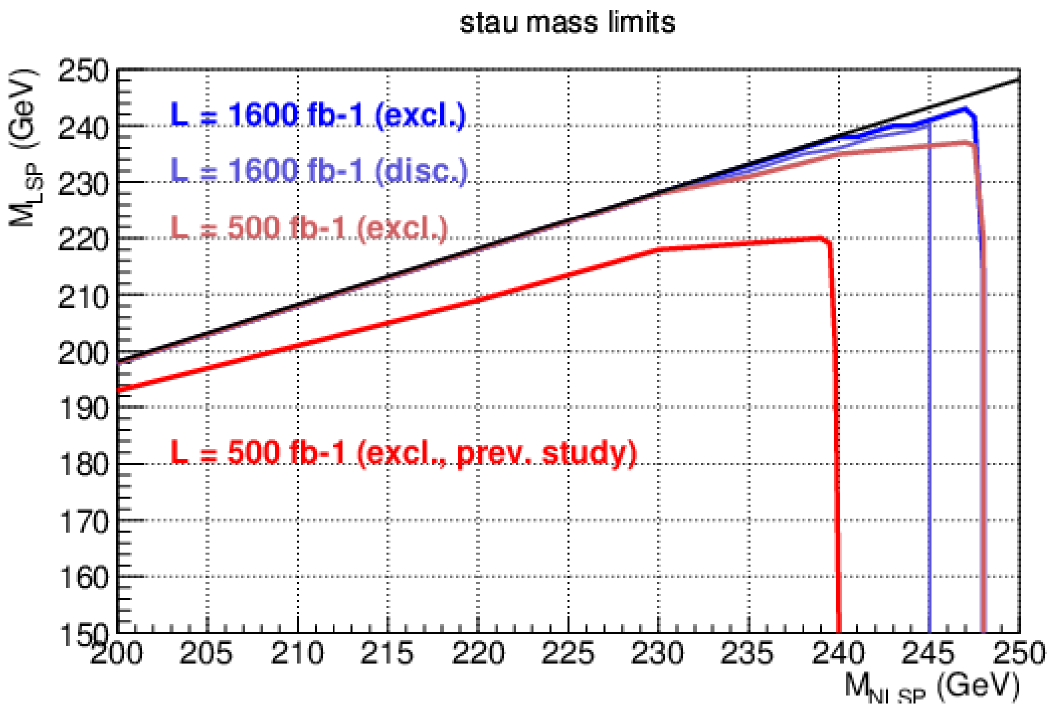
Select events with high transversal momentum due to isolated photons



pjet:
sum of momentum of jets

Transvesal momentum (pt):
sum of pt of all particles

Current status



$\tilde{\tau}_1$NLSP

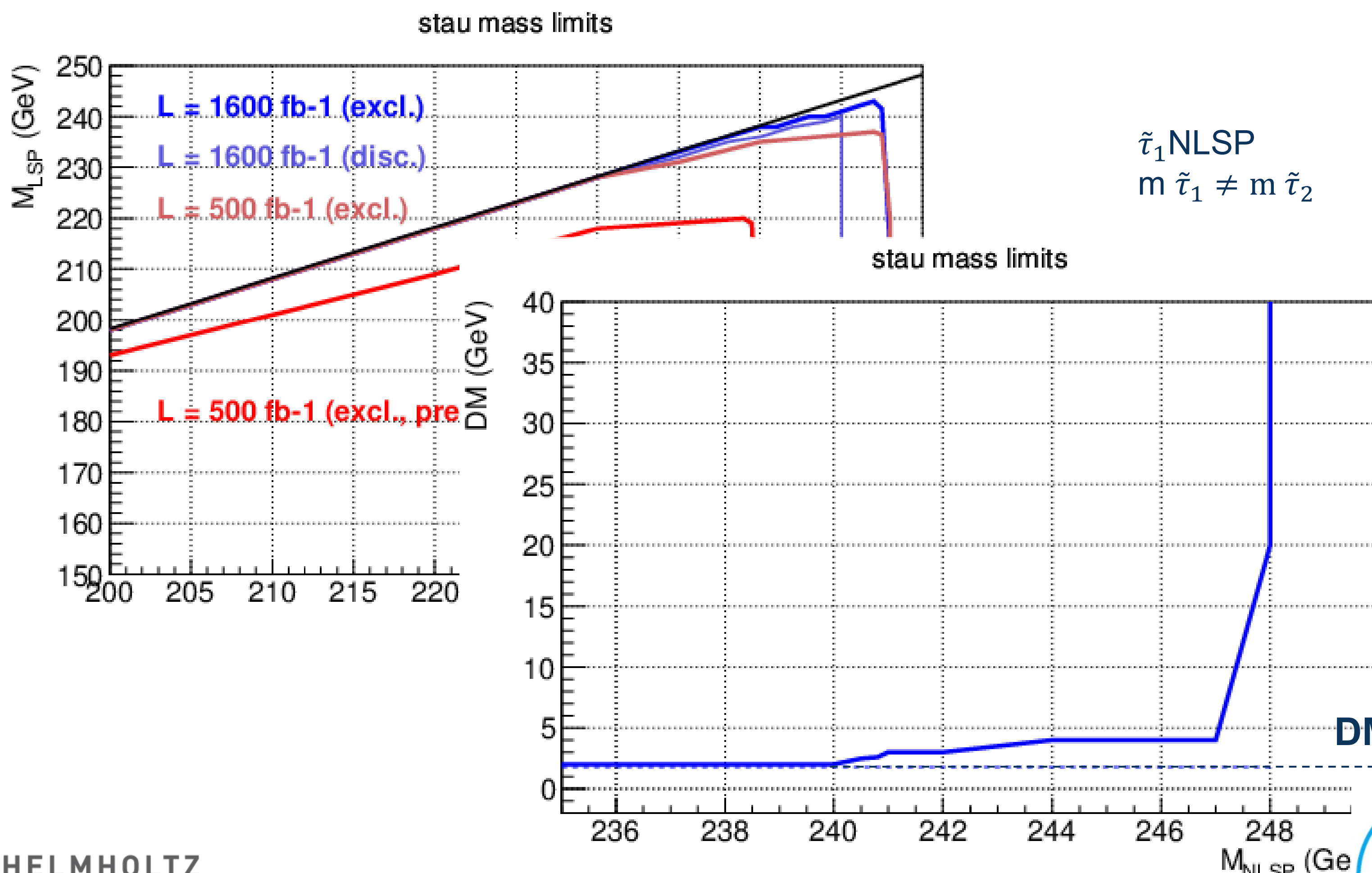
m $\tilde{\tau}_1 \neq$ m $\tilde{\tau}_2$

Limits valid for any mixing

HELMHOLTZ GEMEINSCHAFT

DESY.

Current status



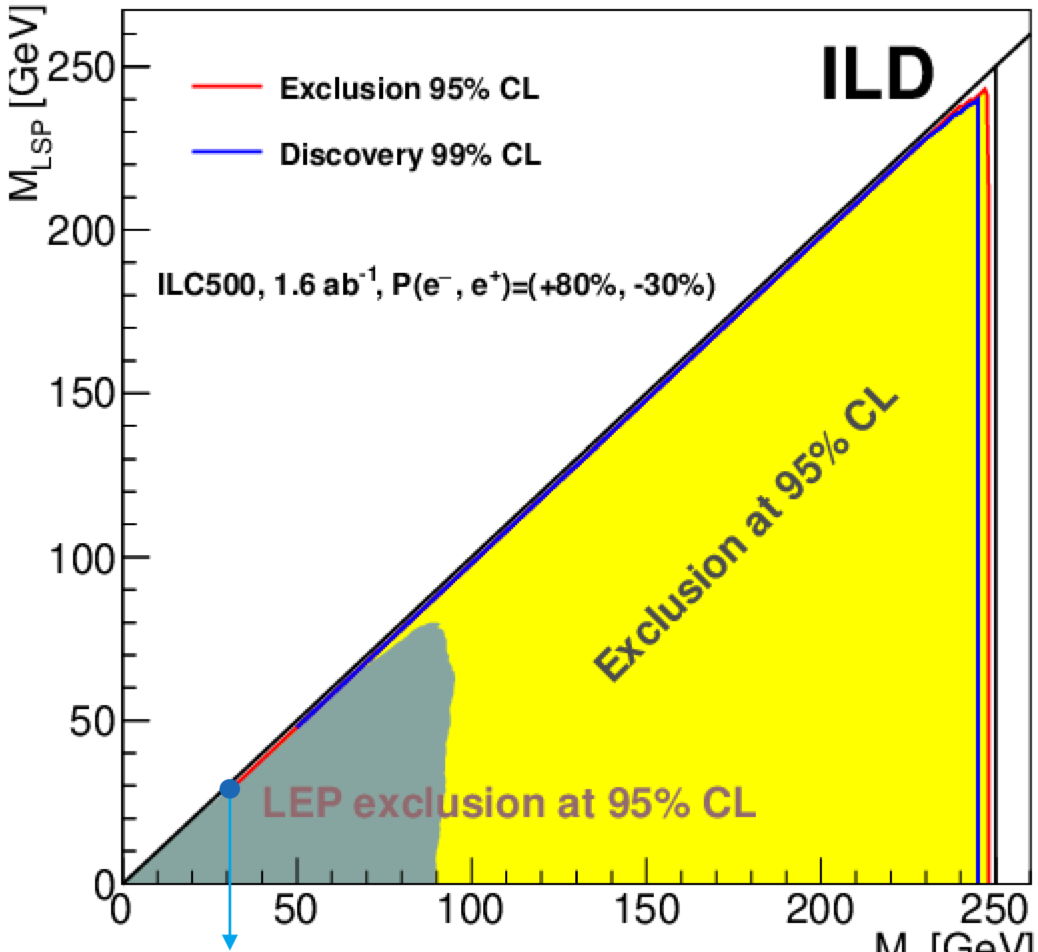
$\tilde{\tau}_1$NLSP
m $\tilde{\tau}_1 \neq$ m $\tilde{\tau}_2$

DM = m_τ

Region with DM < mτ easily excluded due to the long $\tilde{\tau}$ lifetime expected

Current status

Valid for all values of the not shown model parameters

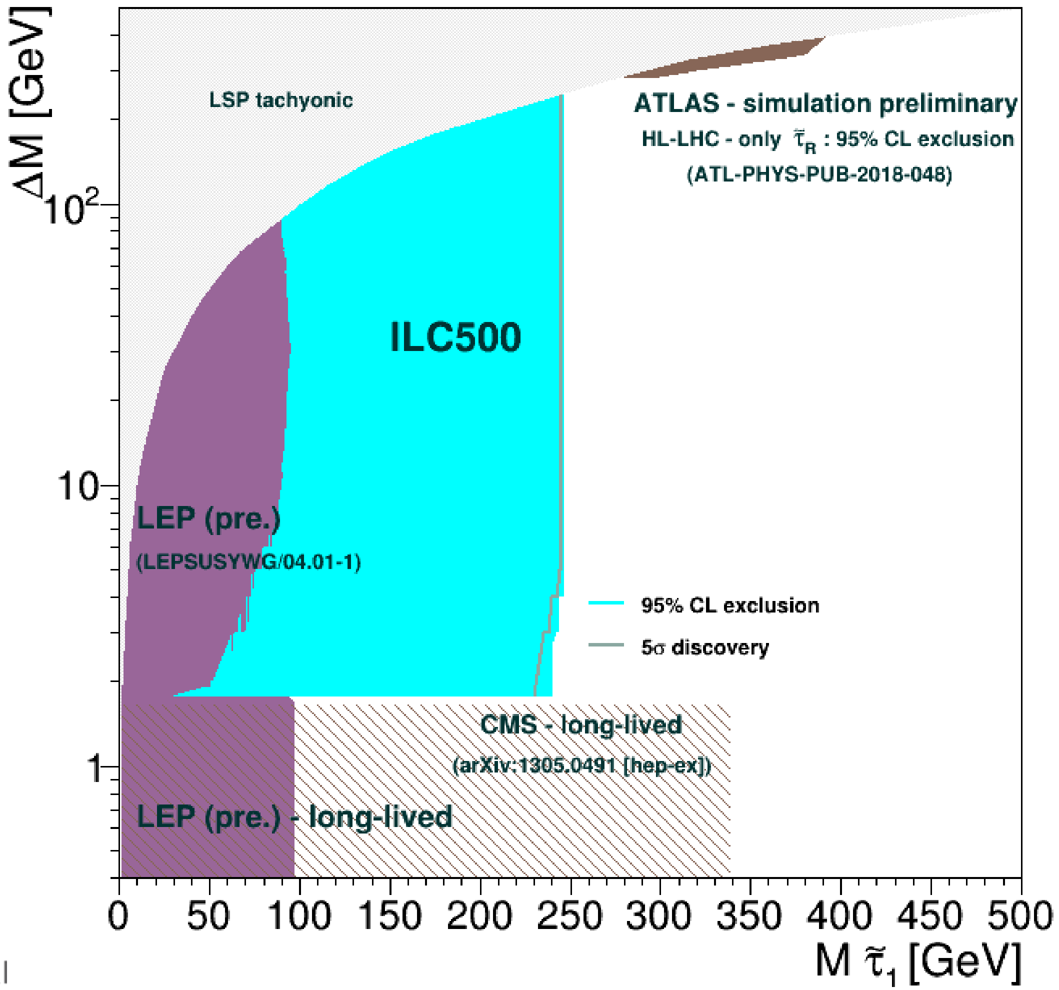


$\tilde{\tau}_1$NLSP

m $\tilde{\tau}_1 \neq$ m $\tilde{\tau}_2$

26.3 GeV: limit for any mixing angle and any mass difference above τ mass

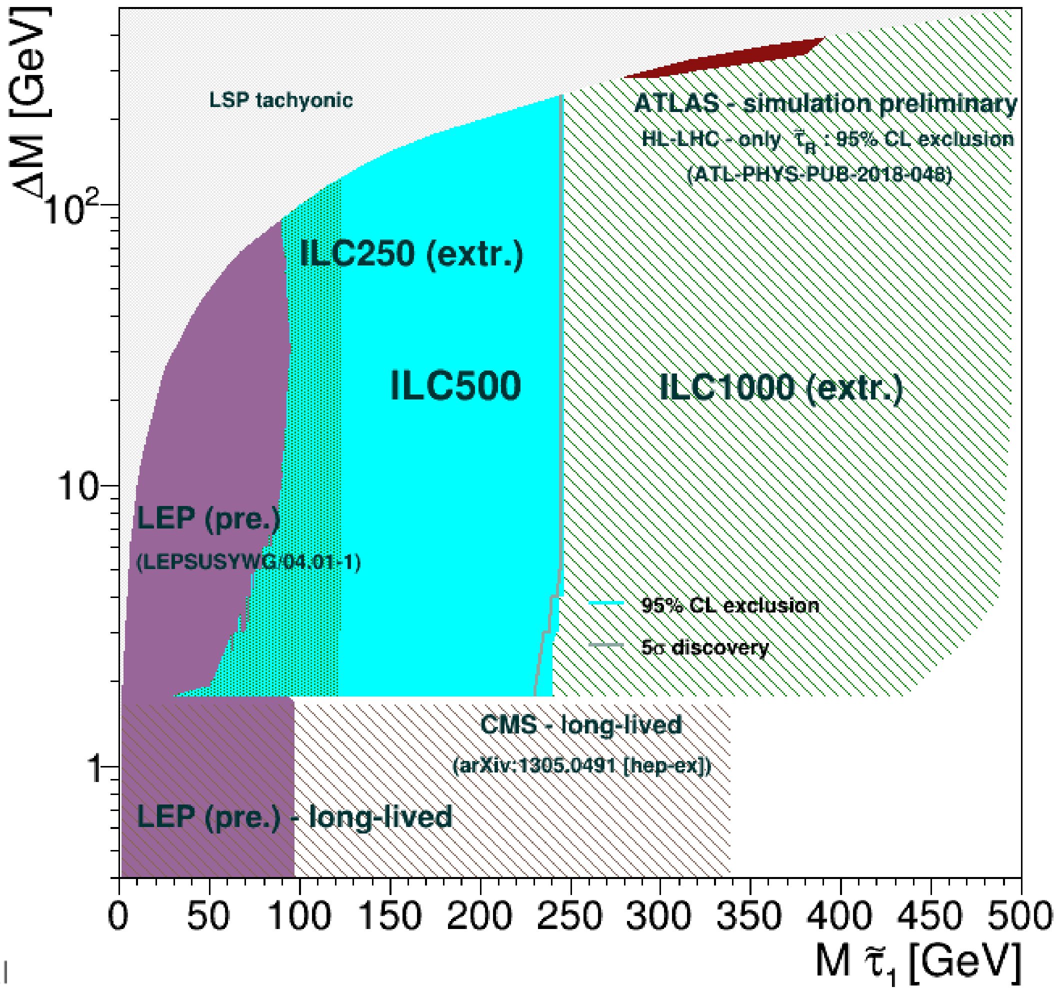
Current status



HELMHOLTZ GEMEINSCHAFT

DESY.

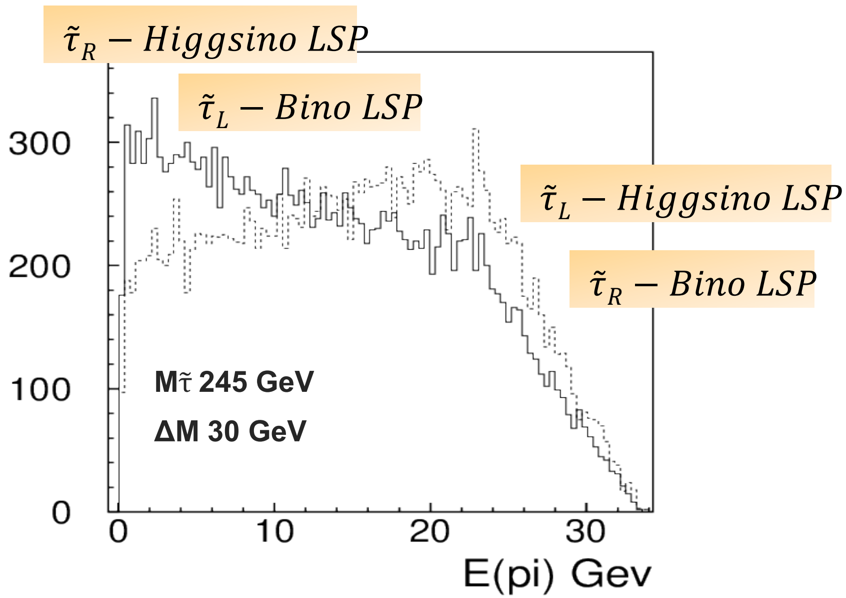
Current status



Outlook and conclusions

Next steps

- Use contribution of both polarisations: P(e^-,e^+)=(+80%,-30%) and (-80%,+30%)
- Study the region with ΔM < Mτ (on going)
  - signal samples created with Whizard
  - vertex displaced by hand based on decay width
- Use full reconstructed background samples
- Increase statistics



- Effect of τ polarisation from $\tilde{\tau}$ decay

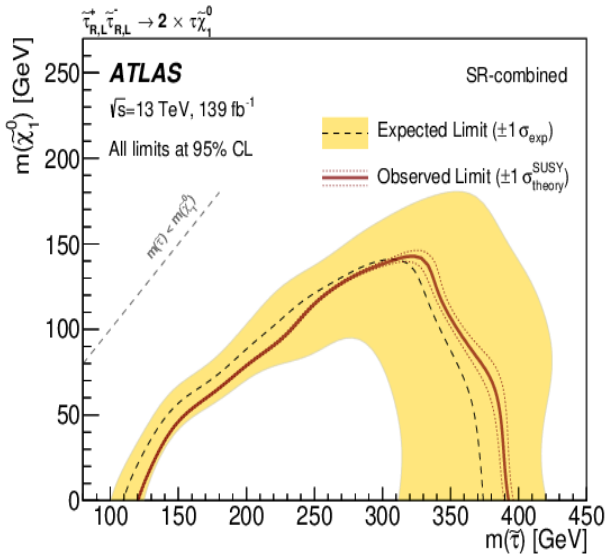
- Exclusion and discovery limits for $\tilde{\tau}$ pair production at the ILC have been computed
- No dependence on hidden SUSY parameters have been imposed for the validity of the limits
- Capability of the ILC for discovering/excluding $\tilde{\tau}$'s close to the kinematic limit, even in the worst scenario, has been shown

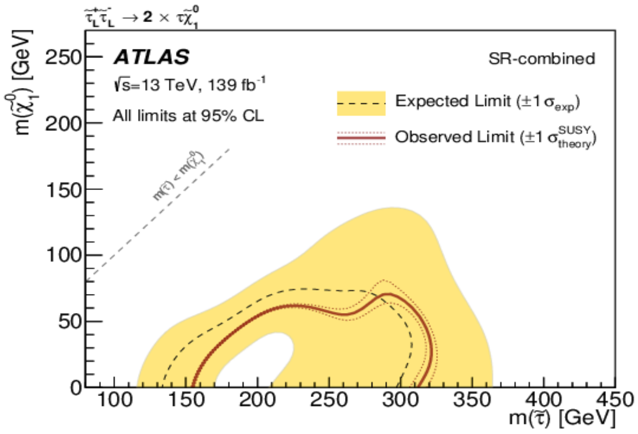
Backup slides

Limits at LHC and LEP

ATLAS

- **Dataset: 139 fb^{-1} @ $\sqrt{s}$ = 13 TeV pp**
- **Two $\tilde{\tau}$ assumed to be mass-degenerate**
- **Not mixing**
- **100% decay into a bino-like neutralino and τ-lepton**





arXiv:1911.06660v1 [hep-ex]

CMS

- **Dataset: 77.2 fb^{-1} @ $\sqrt{s}$ = 13 TeV**
- **Two models: $\tilde{\tau}$ assumed to be mass-degenerate or purely $\tilde{\tau}_L$**
- **Not mixing**
- **For purely $\tilde{\tau}_L$ model, strongest limit set at 125 GeV**
- **Mass-degenerate (more optimistic) limit between 90 (closing gap with LEP) and 150 GeV for nearly massless neutralino**

arXiv:1907.13179v2 [hep-ex]

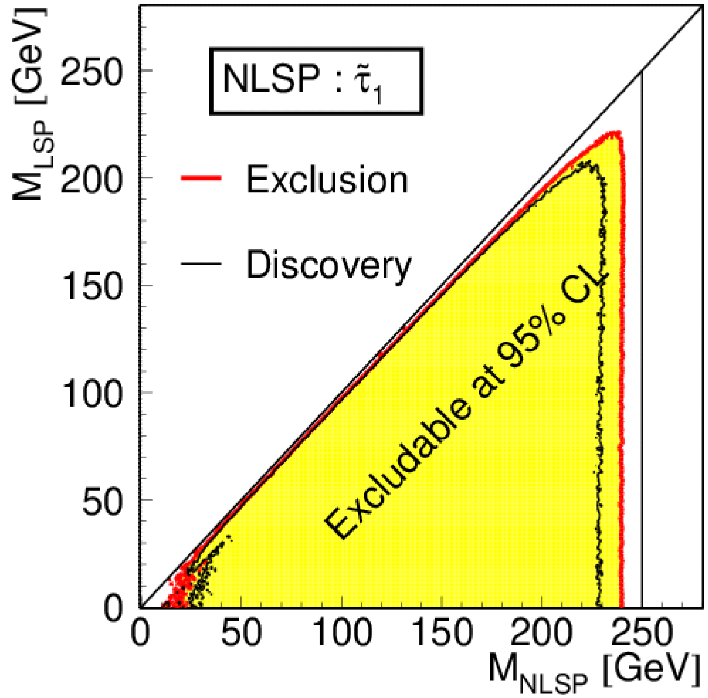
ILC studies

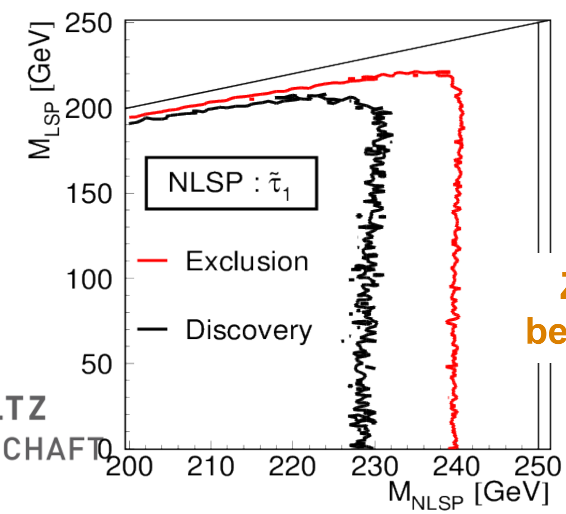
Previous ILC searches

Does not cover small ΔM = (M$\tilde{\tau}$ - MLSP)

500 fb^{-1} at $\sqrt{s}$ = 500 GeV
P(e^-,e^+)=(+80%,-30%)

Limits only valid up to ΔM 3-4 GeV
(no dedicate low ΔM analysis)





Zoom last 50 GeV before kinematic limit

HELMHOLTZ GEMEINSCHAFT

arXiv:1308.1461 [hep-ph]

DESY.

General cuts (ctd.)

Two well identified τ's and little other activity

- Number of charged particles (ncha). 1< ncha < 6
- Number of clusters identified as τ (nclu). nclu = 2 or 3
- τ-indentification
- Total charge (totcharge). totcharge = 0, +/- 1

Tau identification

- Pattern of charged tracks from τ-decay:
  - Exactly two jets with charged particles
  - 1 or 3 charged particles in each charged jet, with total charge +/-1
  - Two jets with opposite charge
- Reduction of background from sources with leptons not from τ-decays
  - Two charged jets not made by single leptons with same flavour
  - None of the jets made by single positron (RL beam polarization)
  - Most energetic jet should not be a single electron

HELMHOLTZ | GEMEINSCHAFT

CLUSTER OF EXCELLENCE

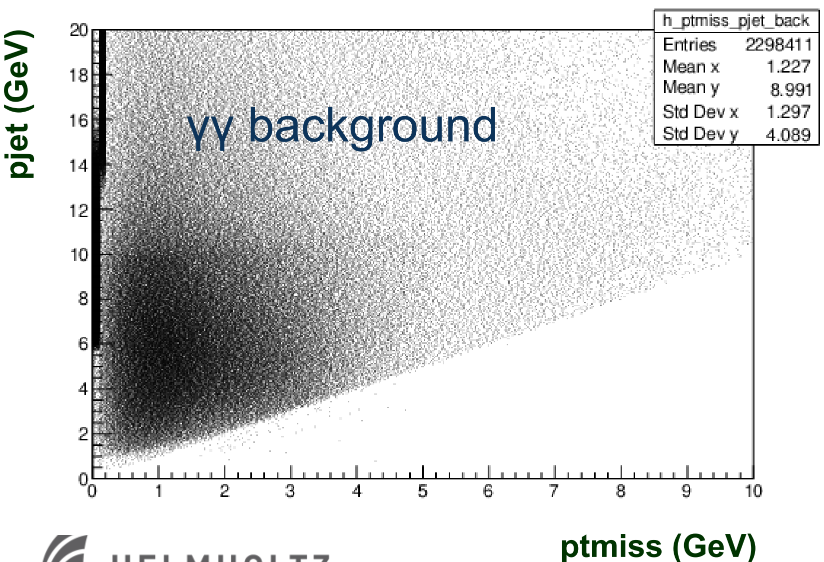
Signal efficiency ~ 40% but reduce the background by ~ 94 %

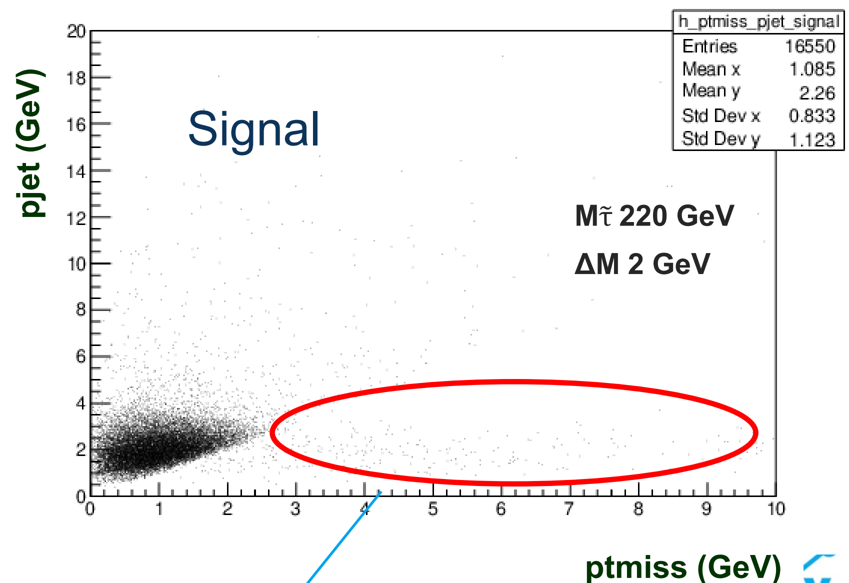
DESY.

Detailed study ΔM = 2 (3) GeV region

Analysis of ISR photons

Improves limits by selecting events with high transversal momentum and isolated photons



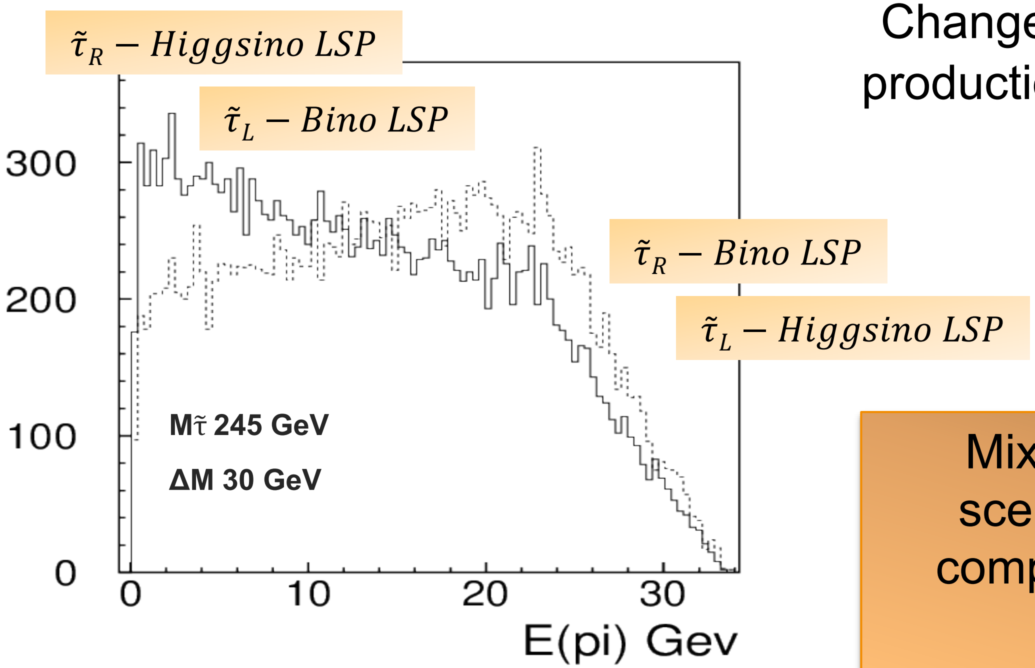


Contribution to pt from isolated photons

HELMHOLTZ GEMEINSCHAFT

Effect of τ polarisation from $\tilde{\tau}$ decay

Energy distribution of products from decays depends on τ polarisation



Changes in $\tilde{\tau}$ and neutralino mixing affects production cross section and signal efficiency

Mixing angle 53 degrees still worst scenario: softening of the spectrum compensated by higher cross section (preliminary)

τ production and decay simulated using TAUOLA

HELMHOLTZ GEMEINSCHAFT