Search for Higgs production in supersymmetric decay cascades with ATLAS detector

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Introduction

The multipurpose detectors ATLAS and CMS at the CERN Large Hadron Collider confirmed in March 2013 the discovery of the Higgs boson. Yet there is strong evidence that the Standard Model of particle physics is incomplete. Theoretical problems such as the hierarchy of energy scales, the fine tuning of the Higgs mass and the large number of postulated parameters need to be addressed. Additionally, there is the enigmatic dark matter, an invisible mass revealed through astronomical data.

Supersymmetry (SUSY) is the leading theoretical extension of the Standard Model.
SUSY associates to each fermion a bosonic shadow-particle, and symmetrically to each boson a fermionic equivalent. Those new partners are labeled "**sparticles**".

This theory possesses good features:

- **Stabilization of energy scales**
  $\Rightarrow$ naturally addresses gauge hierarchy problem (no more Higgs fine tuning)
- **Unification of gauge couplings**
- **Good dark matter candidate**
  in the Lightest SUSY Particle (LSP) for R-Parity conserving scenarios.

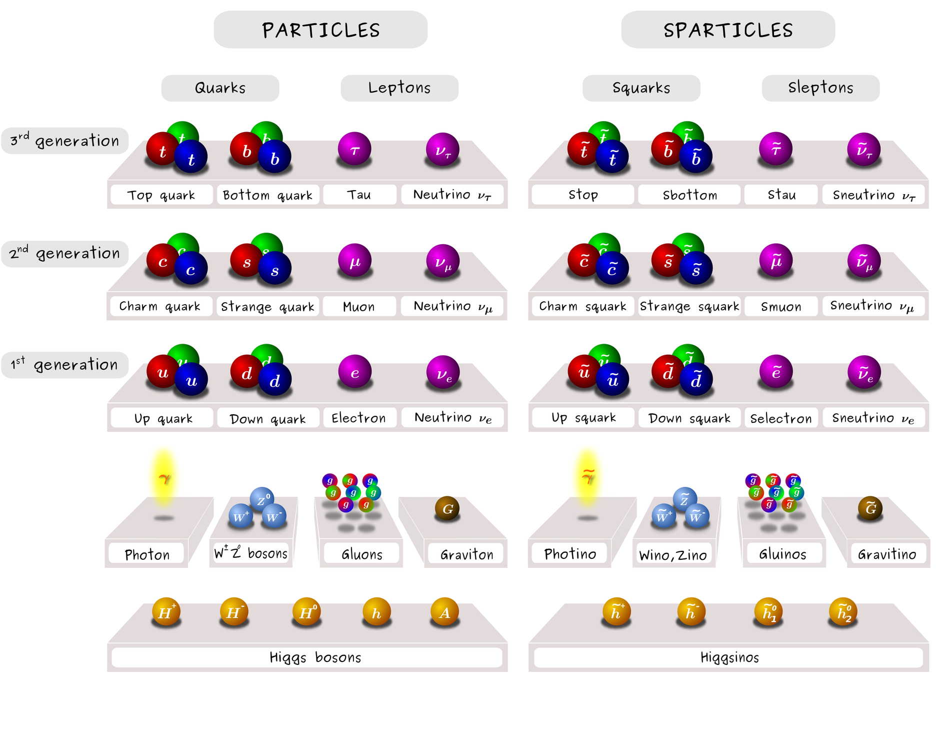
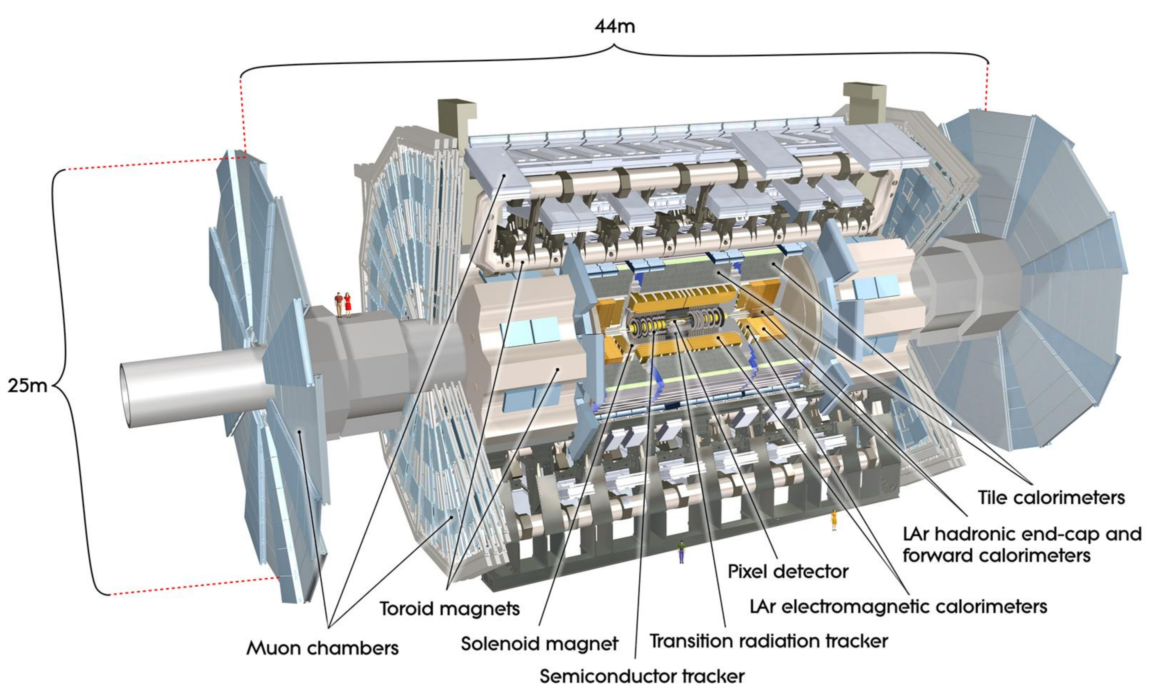


Figure: A representation of the SUSY spectrum.

Supersymmetry searches are among the primary tasks of the Large Hadron Collider's program.

Observing SUSY with the ATLAS detector

- **Context**
  ATLAS is one of two multipurpose detectors at the LHC, the world's largest particle accelerator.
- **Weight**
  7000 tons
  (100 Boeing 747s)
- **Rate**
  40 million collisions per second



- **Composition**
  - **Inner tracker and muon spectrometer**: precise reconstruction of particle track patterns
  - **Magnets system**: bends trajectories of charged particles $\Rightarrow$ better identification
  - **Calorimeters**: measure deposited energy (creation of electromagnetic and hadronic showers)

Seeing SUSY: clear signature in detector as the LSP leaves the readout material undetected
$\Rightarrow$ SUSY events exhibit significant missing transverse energy (E_T^{miss}).

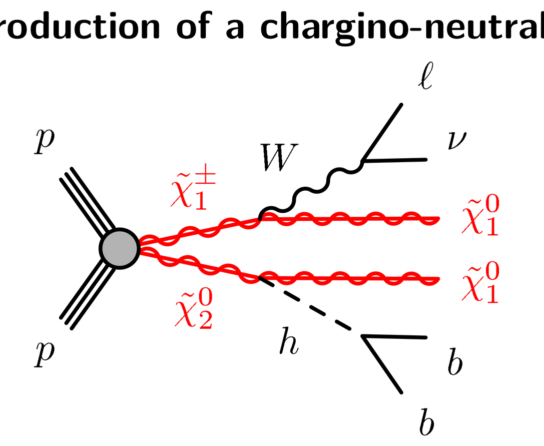
SUSY Model - Direct gaugino production

Gauginos are the mass eigenstates formed from linear superpositions of SUSY partners of Higgs and electroweak gauge bosons.
Gauginos are split into two types:

- Charginos: $\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2^{\pm}$
- Neutralinos: $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{\chi}_3^0$, $\tilde{\chi}_4^0$

Naturalness arguments $\Rightarrow$ gaugino masses $\sim$ hundreds of GeV.

Direct production of a chargino-neutralino pair

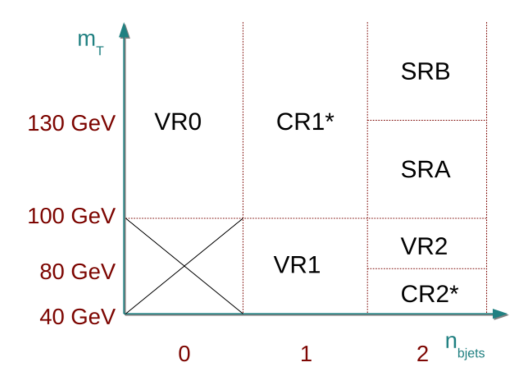


This search targets the process $pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$, where:

- Lightest neutralino $\tilde{\chi}_1^0$ considered to be LSP
- Simplified model: $m_{\tilde{\chi}_1^{\pm}} = m_{\tilde{\chi}_2^0}$
- **Higgs in decay chain**: complementary scenario of $pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ searches exploiting presence of a Higgs boson (for the first time at the LHC).
- **Final states**: 1 lepton (e or μ), 2 b-tagged jets, E_T^{miss}

Event selection and regions

- **Object definition**:
  - **Electron**: isolated `tight++` electron, $p_T > 25$ GeV, $|\eta| < 2.4$
  - **Muon**: matched & isolated muon, $p_T > 25$ GeV, $|\eta| < 2.47$
  - **Jets**: using anti-k_T jet clustering algorithm with $R = 0.4$
    Central jets ($p_T > 25$ GeV, $|\eta| < 2.4$) are baseline for b-tagging at 70% efficiency operating point.
  - E_T^{miss}: based on transverse momenta of lepton candidates, jets and calorimeter energy clusters not associated with objects.
- **Event quality**: all standard SUSY cleaning cuts applied
- **Overlaps**: event rejected if $\Delta R(e,\mu) < 0.1$ or $\Delta R(\mu,\mu) < 0.05$
- **Discriminating variables**
  Contransverse mass
  $$m_{CT}(v_1, v_2) = \sqrt{[E_T(v_1) + E_T(v_2)]^2 - [\mathbf{p}_T(v_1) - \mathbf{p}_T(v_2)]^2}$$
  Measures mass of pair-produced particles decaying semi-invisibly.
  Transverse mass
  $$m_T = \sqrt{2 p_T^{\text{lep}} E_T^{\text{miss}} - 2\mathbf{p}_T^{\text{lep}} \cdot \mathbf{p}_T^{\text{miss}}}$$



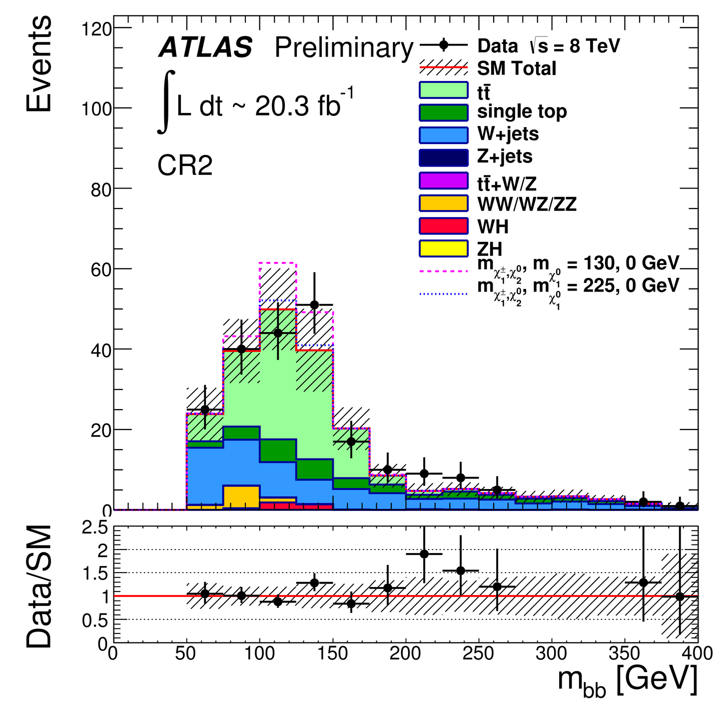
- **Signal regions**: SRA (SRB) most sensitive at low (high) $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ masses.

Control Regions (CR) and Validation Regions (VR) are defined to model SM background contributions. These are orthogonal to Signal Regions (SR) but kinematically close.

Background estimation

Backgrounds are evaluated from Monte Carlo (MC) simulations. Main ones are reduced using m_{CT} and m_T kinematic end-points.

- **Dominant background processes**
  - **QCD** $\Rightarrow$ killed through $E_T^{\text{miss}} > 100$ GeV
  - $t\bar{t}$ $\Rightarrow$ removed with $m_{CT} > 160$ GeV
  - **W** + jets $\Rightarrow$ decreased $m_T > 100$ (SRA) 130 (SRB) GeV
- **Higgs resonance mass peak**
  - Invariant mass of the 2 b-jets $m_{bb} > 50$ GeV (all regions)
  - CR1 and CR2 defined with m_{bb} outside "Higgs window" [105, 135] GeV to avoid signal contamination



Results

- **Signal significance of the data**: characterized by calculating the probability of observing an excess at least as signal-like as the one observed in data, assuming that signal is absent (p-value).
- Results based both on pseudo-experiments and asymptotic formulae for a **profile-log-likelihood test statistic** are given.

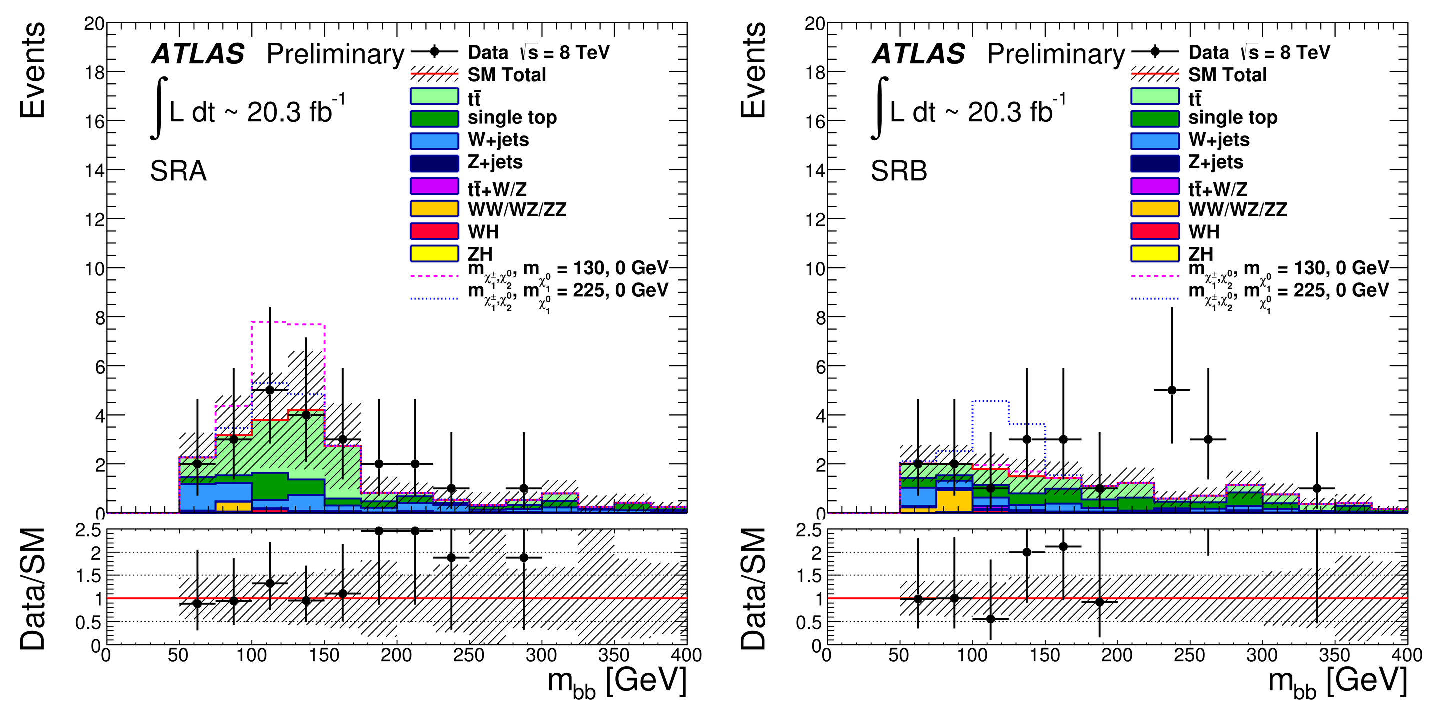


Figure: Distributions of m_{bb} for (left) SRA and (right) SRB for data and MC events. Dotted and dashed lines are two representative signal models, added on top of the background predictions. The simulated backgrounds are normalized to the results from the background-only likelihood fit. Shaded bands around the expectations include statistical and systematic uncertainties.

Model-independent limits in the signal region for the m_{bb} signal bin ($105 < m_{bb} < 135$ GeV)

	SRA	SRB
Asymptotic		
Observed σ_{vis}^{95}	0.32 fb	0.21 fb
Observed S_{obs}^{95}	6.5	4.4
Expected S_{exp}^{95}	$7.0^{+3.1}_{-1.9}$	$4.4^{+2.5}_{-1.5}$
Pseudo-experiments		
Observed σ_{vis}^{95}	0.34 fb	0.21 fb
Observed S_{obs}^{95}	6.9	4.4
Expected S_{exp}^{95}	$7.0^{+2.8}_{-1.6}$	$4.4^{+1.8}_{-0.8}$

Table: Shown are the observed 95% CL upper limits on the visible cross section, σ_{vis}^{95}, for non-SM events, and on the expected number of signal events, S_{exp}^{95}, for both the pseudo-experiment and asymptotic-formulae approaches.

Conclusion

The **search for chargino and neutralino pair-production** decaying into final states with one charged lepton, missing transverse momentum, and two b-jets consistent **with a Higgs boson** has been performed using **20.3 fb^{-1} of proton-proton collision data** at $\sqrt{s} = 8$ TeV with the ATLAS detector.

No significant excess is observed with respect to SM predictions.

Limits set on $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ mass (for $m_{\tilde{\chi}_1^0} = 0$). Ranges:

- $125 < m_{\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0} < 141$ GeV
- $166 < m_{\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0} < 287$ GeV

excluded at 95% CL, determined at -1σ signal theoretical uncertainty.

Expected exclusion range:

- $225 < m_{\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0} < 235$ GeV

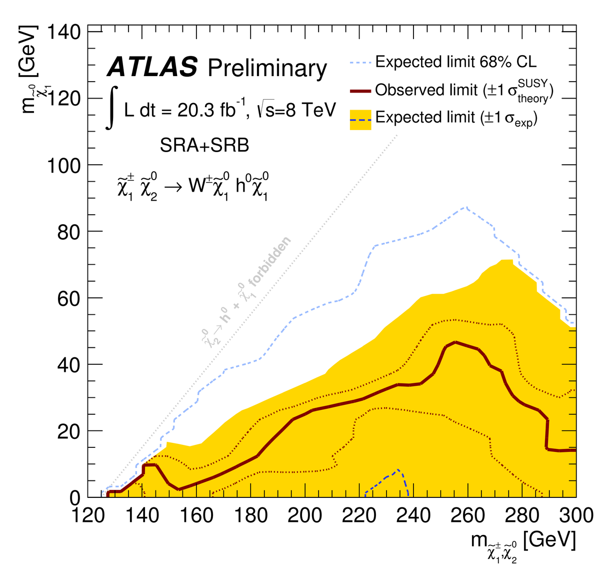


Figure: Exclusion limits in the $m_{\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0}$-$m_{\tilde{\chi}_1^0}$ plane. The dashed and solid lines show the 95% CL expected and observed limits, respectively, including all uncertainties except for the theoretical signal cross section uncertainty (PDF and scale). The solid band around the expected limit shows the $\pm1\sigma$ result where all uncertainties are considered except those on the signal cross sections. The $\pm1\sigma$ lines around the observed limit represent the results obtained when moving the nominal signal cross section up or down by the $\pm1\sigma$ theoretical uncertainty.

Ref: ATLAS Collaboration, ATLAS-CONF-2013-093, https://cdsweb.cern.ch/record/1595756 (2013)