Prospects for SUSY Discovery and Measurements with the ATLAS Detector at the LHC

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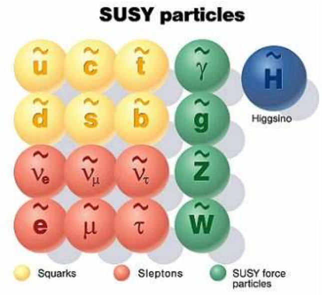
Outline

Supersymmetry

- Symmetry: bosons $\longleftrightarrow$ fermions
- Consider minimal extension of SM
- At LHC: production of strongly interacting SUSY particles
- Cross-section mostly dependent on particle masses
- Decay chains model dependent



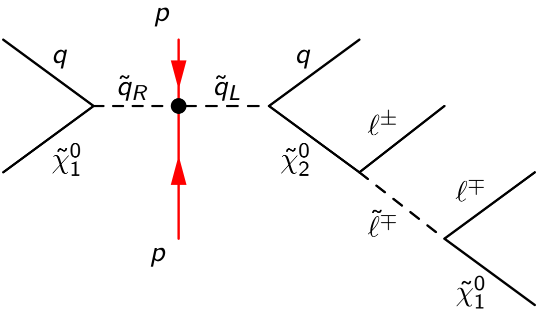
Topics covered:

- R-parity conserving scenarios only
- E_T^{miss} signatures
- Long-lived heavy particles

Benchmark models:

- mSUGRA
- NUHM
- GMSB

SUSY signatures



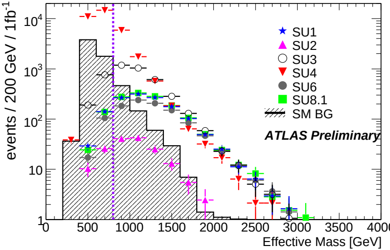
- Emission of hard jets and leptons
- If the lightest SUSY particle is neutral and weakly interacting

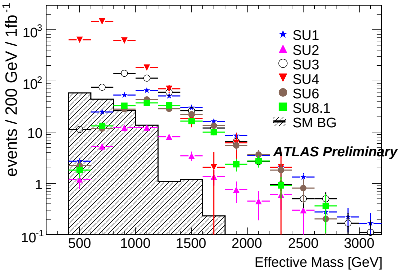
⇒ Missing energy in the detector

Main backgrounds:

- Z/W + jets
- $t\bar{t}$
- QCD events

E_T^{miss} signatures: zero- and one-lepton modes





- $E_T^{miss} > 100$ GeV + 4 jets + 0 (left) or 1 (right) lepton
- Effective Mass $= \sum_{\text{jets},\ell} p_T + E_T^{miss}$
- Lepton requirement to bring background down to manageable levels

E_T^{miss} signatures: other modes

- Broad spectrum of E_T^{miss} signatures (not covered here):
  - Two and three leptons + jets
  - τ-jets + jets
  - b-jets + jets
  - Multi leptons (No requirements on the number of jets)

    $\Longrightarrow$ Direct production of $\tilde{\chi}^0$ and $\tilde{\chi}^{\pm}$
  - Photons + jets

    $\Longrightarrow$ $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$

- All signals and backgrounds studied with fully detailed `Geant 4` simulations

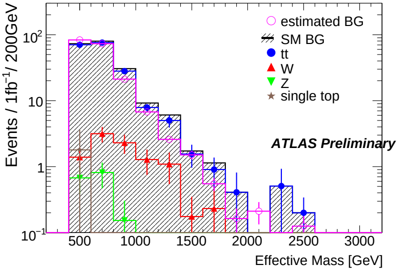
Background estimation from data

- Precise estimate of background relies on both MC and data
- Control samples needed for data driven estimates

Example: reverse one selection cut

Signal region $M_T \equiv \vec{p}_{T,\ell} \cdot \vec{E}_T^{miss} > 100$ GeV

Control region $M_T \equiv \vec{p}_{T,\ell} \cdot \vec{E}_T^{miss} < 100$ GeV

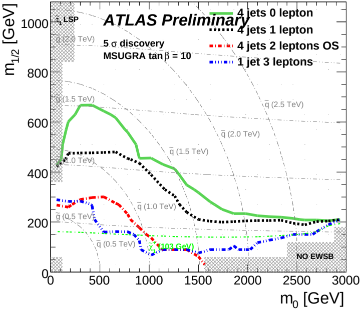


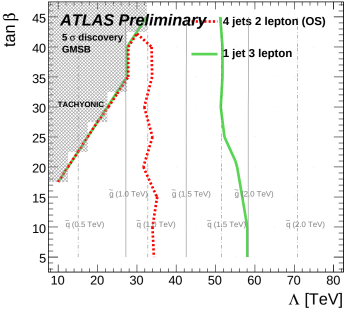
- Background shape from control sample
- Normalize to number of events in signal sample in a region where SUSY contribution is small ($E_T^{miss} < 200$ GeV)

Systematic effects

- Detector response challenges
  - Lepton identification efficiency
  - Jet energy scale and jet response tails
  - Missing E_T shape
- Theoretical uncertainties
  - Parton Density Functions
  - Normalization of background
  - EW and QCD corrections at NLO
- SUSY contamination in control samples

Discovery reach





- mSUGRA and GMSB scan
- 1 $fb^{-1} \sim$ 1 year of LHC operation
- Reach up to gluino and squark masses $\sim O(1 \text{ TeV})$
- Stat. and syst. uncertainty on background included

Endpoint measurements

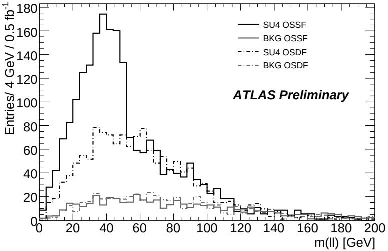
- Mass spectrum informations from cascade kinematic

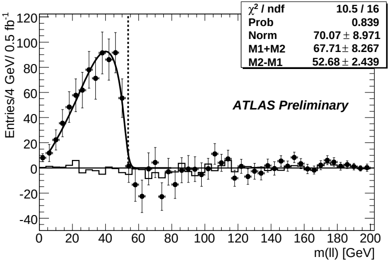
$$\tilde{q}_L \to \tilde{\chi}_2^0 q \to (\tilde{\ell}^{\mp}\ell^{\pm} q) \to \tilde{\chi}_1^0 \ell^- \ell^+ q$$

- Endpoints in invariant mass distributions
  - $\ell^+ + \ell^-$
  - $\ell^+ + \ell^- + q$
  - $\ell^{\pm} + q$
- For instance

$$M_{\ell\ell}^{\mathrm{edge}} = m_{\tilde{\chi}_2^0} \sqrt{1 - \frac{m_{\tilde{\ell}}^2}{m_{\tilde{\chi}_2^0}^2}} \sqrt{1 - \frac{m_{\tilde{\chi}_1^0}^2}{m_{\tilde{\ell}}^2}}$$

Leptonic signatures

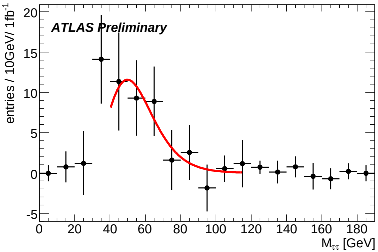




- Background significantly reduced by subtracting $e^{\pm}\mu^{\mp}$
- $M_{\ell\ell}^{\text{edge}} = 52.7 \pm 2.4\ (\text{stat}) \pm 0.2\ (\text{syst})$ GeV
- Consistent with true value 53.6 GeV

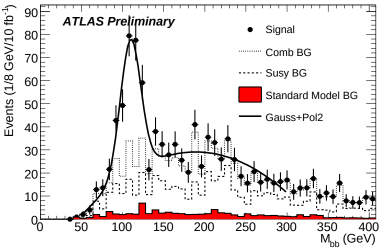
Other signatures

$\tau^+\tau^-$ invariant mass



- $L - R$ mixing may enhance $\tau^+\tau^-$ with respect to $\ell^+\ell^-$
- No sharp edge because of neutrino presence

Higgs to $b\bar{b}$ in SUSY events



- E_T^{miss} requirement suppresses QCD background
- Competitive with SM channels

Long-lived heavy particles: trigger issues

- Assume the lightest SUSY particle is charged or strongly interacting
- Penetrating charged track $\Longleftrightarrow$ "heavy slow muons"
- For $\beta \sim 0.8 \Rightarrow$ Time of flight 15 ns longer than muons

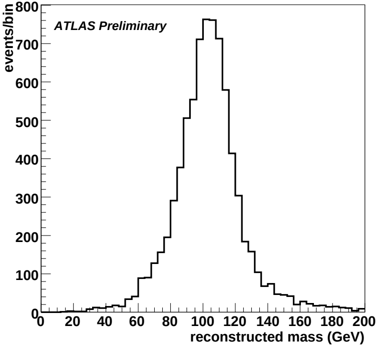
- ATLAS muon system provides excellent time of flight resolution (0.7 ns)

$\Rightarrow$ Precise mass reconstruction and muon rejection

- But very high LHC bunch-crossing rate (25 ns)
  - Particle could be assigned to the wrong bunch crossing and not read out
  - Appropriate triggering scheme is critical

Long-lived heavy particles: discovery reach

Stable sleptons



- Example: 100 GeV slepton
- Discovery largely independent of the model characteristics

R-hadrons

Sample	Events/fb^{-1}
300 GeV gluino	6.4×10^3
1 TeV gluino	10.7
1.6 TeV gluino	0.1
300 GeV stop	70.0
600 GeV stop	3.9
1 TeV stop	0.1
QCD events	$\lesssim 1$
$Z \to \mu\mu$	$\lesssim 1$

- Characteristic "heavy slow muon" signature
- May also undergo charge flipping in the calorimeter

Conclusions

- New physics expected to appear at the TeV scale
- *R*-parity conserving SUSY scenarios are well motivated
- Extensive studies of signatures:
  - With E_T^{miss}
  - With long-lived heavy particles

$\Rightarrow$ Reach up to gluino and squark masses $\sim O(1\ \text{TeV})$ for 1 fb^{-1}

- Discovery relies on good knowledge of backgrounds
  - Interplay between MC and data-driven estimations