Study of neutralino spin measurements with the ATLAS detector

M.Bianco[1 2] I.Borjanovic[1], G.Cataldi[1], G.Chiodini[1], R.Crupi[1,2], E.Gorini[1,2], F.Grancagnolo[1], S.Grancagnolo[1,2], A.Guida[1,2], R.Perrino[1], M.Primavera[1], G.Siragusa[1,2], S.Spagnolo[1,2], A.Ventura[1,2] and the ATLAS Collaboration [1]

[1]Istituto Nazionale di Fisica Nucleare, sezione di Lecce, Italy

[2]Dipartimento di Fisica, Università del Salento, Italy

1. Introduction

The Minimal Supersymmetric extension of the Standard Model (MSSM) [2] is a promising candidate to describe the physics beyond the Standard Model. The minimal Supergravity (mSUGRA) breaking mechanism is assumed here. After a possible discovery of physics beyond the Standard Model (SM) with the ATLAS experiment [3] at the LHC, it will be fundamental to measure properties of new particles, like spin, in order to prove that they are indeed SUSY partners. The present study is based on a method [4] which allows to choose between different hypotheses for spin assignment, and to discriminate SUSY from an Universal Extra Dimensions (UED) model mimicking low energy SUSY [5, 6].

The cascade decay of the $\tilde{q}_L$ to $\tilde{\chi}_2^0$ which further decays to slepton:

$$\tilde{q}_L \rightarrow \tilde{\chi}_2^0 \, q \rightarrow \tilde{l}_{L,R}^{\pm} \, l^{\mp} \, q \rightarrow l^+ \, l^- \, q \;\; \tilde{\chi}_1^0 \qquad (1)$$

gives an excellent opportunity for measuring SUSY particles' spin [4]. In the following, the first lepton (from $\tilde{\chi}_2^0$ decay) is called *near*, and the one from slepton decay is called *far*.

In the MSSM, squarks and sleptons are spin-0 particles and their decays are spherically symmetric, differently from the $\tilde{\chi}_2^0$ which has spin 1/2.

A charge asymmetry is expected in the invariant masses $m(ql^{near(\pm)})$ formed by the quark and the near lepton. Also $m(ql^{far})$ shows some small charge asymmetry [5, 6], but it is not always possible to distinguish experimentally near from far lepton, thus leading to dilution effects when measuring $m(ql^{near(\pm)})$ charge asymmetry.

In the cascade decay (1), the asymmetry in the corresponding $m(\bar{q}l)$ charge distributions is the same as the asymmetry in $m(ql)$ from $\tilde{q}_L$ decay, but with opposite sign [7]. Though it is not possible to distinguish q from $\bar{q}$ at a *pp* collider like the LHC more squarks than anti-squarks will be produced. In this work only electrons and muons are considered for analysis.

Two mSUGRA points were selected for analysis: SU1 point, in the stau-coannihilation region (m_0= 70 GeV, $m_{1/2}$= 350 GeV, A_0=0 GeV, $tan\beta$=10, $sgn\mu$=+) and SU3 point, in the bulk region (m_0= 100 GeV, $m_{1/2}$= 300 GeV, A_0=-300 GeV, $tan\beta$=6, $sgn\mu$=+). In SU1 (SU3) LO cross section for all SUSY is 7.8 pb (19.3 pb), and observability of charge asymmetry is enhanced by $\sim$5 ($\sim$2.5) in $\tilde{q}/\bar{\tilde{q}}$ production yield.

In SU1 point, owing to the small mass difference between $\tilde{\chi}_2^0$ and $\tilde{l}_L$ (264 GeV and 255 GeV, respectively), the near lepton has low p_T in the $\tilde{\chi}_2^0 \rightarrow \tilde{l}_L \, l$ decay, while the small mass difference between $\tilde{l}_R$ and $\tilde{\chi}_1^0$ (155 GeV and 137 GeV, respectively), implies low values for far lepton's p_T in $\tilde{\chi}_2^0 \rightarrow \tilde{l}_R \, l$ decay. As a consequence, near and far leptons are distinguishable. Decay (1) represents $\sim$ 1.6% of all SUSY production. From the three detectable particles l^+, l^-, q (where quark hadronizes to jet) in the final state of the $\tilde{q}_L$ decay (1) four invariant masses are formed: $m(ll)$, $m(qll)$, $m(ql^{near})$ and $m(ql^{far})$. Their kinematic maxima are given by: $m(ll)^{max}$ = 56 GeV ($\tilde{l}_L$), 98 GeV ($\tilde{l}_R$), $m(qll)^{max}$ = 614 GeV ($\tilde{l}_L$, $\tilde{l}_R$), $m(ql^{near})^{max}$ = 181 GeV ($\tilde{l}_L$), 583 GeV ($\tilde{l}_R$) and $m(ql^{far})^{max}$ = 329 GeV ($\tilde{l}_R$), 606 GeV ($\tilde{l}_L$). In the SU3 point, only the decay $\tilde{\chi}_2^0 \rightarrow \tilde{l}_R^{\pm} \, l^{\mp}$ is allowed (3.8% of all SUSY production). The endpoints for $m(ll)$, $m(qll)$, $m(ql^{near})$ and $m(ql^{far})$ are 100, 503, 420 and 389 GeV, respectively.

Also the most relevant SM processes have been also studied, i.e. $t\bar{t}$ + jets, W + jets, Z + jets produced with Alpgen 2.0.5 [8]. Events were passed through a parametrized simulation of ATLAS detector, ATLFAST [9].

2. Analysis

In order to separate SUSY signal from SM background these *preselection* cuts were applied:

- missing transverse energy E_T^{miss} > 100 GeV,
- 4 or more jets with transverse momentum $p_T(j_1)$ > 100 GeV and $p_T(j_2, j_3, j_4)$ > 50

GeV.

- exactly two SFOS leptons ($p_T^{lepton} > 6$ GeV for SU1, and $p_T^{lepton} > 10$ GeV for SU3).

At this selection stage, few invariant masses are formed: the dilepton invariant mass $m(ll)$, the lepton-lepton-jet invariant mass $m(jll)$, and the lepton-jet invariant masses $m(jl^+)$ and $m(jl^-)$, where $l^\pm$ are the leptons and j is one of the two most energetic jets in the event. Subsequently

- $m(ll) < 100$GeV, $m(jll) < 615$ GeV (for SU1) or $m(jll) < 500$ GeV (for SU3)

is required. In SU1, the decays (1) with $\tilde{l}_L$ or $\tilde{l}_R$ are distinguished asking for $m(ll) < 57$ GeV or 57 GeV $< m(ll) < 100$ GeV, respectively. For SU1, in the decay (1) with $\tilde{l}_L$, the near (far) lepton is identified as the one with lower (higher) p_T, and vice versa for the decay (1) with $\tilde{l}_R$. Efficiencies and signal/background ratios after all the cuts described so far, when applied on SUSY and SM events, are shown in Table 1. Further background reduction is applied subtracting statistically in invariant mass distributions events with two opposite flavor opposite sign (OFOS) leptons: This reduces SUSY background by about ~ 2 and makes SM events with uncorrelated leptons compatible with 0.

	ε (SU1)	S/B	ε (SU3)	S/B
Signal	17.0(3)%	/	20.0(3)%	/
SUSY bkg	0.94(1)%	0.33	0.75(1)%	1
$t\bar{t}$	2.69(2) 10^{-4}	0.18	3.14(2) 10^{-4}	0.9
W	1.4(9) 10^{-5}	$\sim$16	0.4(4) 10^{-5}	300
Z	1.1(3) 10^{-5}	$\sim$12	0.9(2) 10^{-5}	100

Table 1
Efficiencies and S/B ratios for SUSY signal and background (SU1, SU3) and for SM background.

3. Results

Charge asymmetries of $m(jl)$ distributions have been computed after SFOS-OFOS subtraction in the ranges $[0, 220]$ GeV for SU1 (only for the decay (1) with $\tilde{l}_L$ and near lepton) and $[0, 420]$ GeV for SU3. Two methods have been applied to detect a non-zero charge asymmetry:

- a non parametric χ^2 test with respect to the null function, with confidence level CL_{χ^2},
- a *Run Test* method [10] with a confidence level CL_{RT} for the hypothesis of symmetry.

The two methods are independent and are not influenced by the actual shape of charge asymmetry. Their probabilities can be combined [10] providing a final confidence level CL_{comb}.

In Fig. 1 the charge asymmetry is reported for $m(jl)$ in the case of the SU3 point.

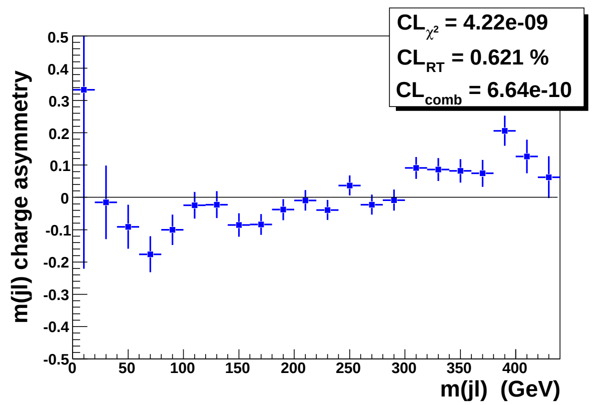

Figure 1. Charge asymmetry for lepton-jet invariant masses after SFOS-OFOS subtraction using both near and far leptons in SU3 point.

With 100 fb^{-1}, in SU1 CL_{comb} is well below 1%, while for SU3 30 fb^{-1} are enough to get a $\mathrm{CL}_{comb} \sim 10^{-9}$.

It is observed that the evidence with a 99% confidence level for a charge asymmetry needs at least 100 fb^{-1} in the case of SU1, while even less than 10 fb^{-1} would be needed for SU3.

4. Conclusions

The decay chain $\tilde{q}_L \rightarrow \tilde{\chi}_2^0 q \rightarrow \tilde{l}^\pm_{L,R} l^\mp q \rightarrow l^+ l^- q \tilde{\chi}_1^0$ has been studied in two selected mSUGRA points to verify the hypothesis of the spin-0 slepton and spin-1/2 neutralino, by looking for charge asymmetry in invariant mass distributions. Two independent statistical methods have been used to detect the presence of charge asymmetry. Results show that at least 100 fb^{-1} is needed in the case of the SU1 point to observe a non-zero charge asymmetry with a confidence level of 99%, while in the case of the SU3 point 10 fb^{-1} would be sufficient.

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Brazil, Canada, Chile, China, Colombia, Czech Republic, Denmark, France, Georgia, Germany, Greece, Israel, Italy, Japan, Morocco, Netherlands, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Taiwan, Turkey, UK, USA, CERN, JINR.

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