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Search for gluinos with ATLAS at LHC

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Abstract

Prospects for ATLAS observation of a SUSY-like signal from two gluinos $pp \to \tilde{g}\tilde{g}$ are investigated within a certain region of the mSUGRA parameter space, where the cross section of the two gluinos production via gluon-gluon fusion, $gg \to \tilde{g}\tilde{g}$, is estimated at a rather high level of 13 pb. The event selection trigger uses a very clear signature of the process (4 jets + 4 muons + up to 4 secondary vertices topology) when final decay products of each gluino are b–anti-b and muon–anti-muon pairs and the lightest SUSY particle, the neutralino. Rather high transverse missing energy carried away by two neutralinos is an essential signature of the event and also allows the relevant Standard Model background to be reduced significantly. The generation and reconstruction processes are performed by means of the ATLAS common software framework ATHENA.

The minimal supersymmetric version of the Standard Model with universal soft supersymmetry breaking terms induced by supergravity (mSUGRA) [1] has a minimal set of free parameters:

$$m_0,\ m_{1/2},\ \mathrm{sign}\,\mu,\ A_0,\ \tan\beta = v_2/v_1.$$

where m_0 and $m_{1/2}$ are respectively common masses for scalar and spinor superpartners at the unification scale, μ is the Higgs mixing parameter, A_0 is the trilinear soft supersymmetry breaking parameter and $\tan\beta$ is the ratio of vacuum expectation values of two Higgs fields. The allowed values of these parameters are limited by both theoretical and experimental constraints as well as recent astrophysical data [2].

In supersymmetric models with conserved R-parity, superpartners of ordinary particles may be created only in pairs, which leads to the existence of the stable lightest supersymmetric particle (LSP). Usually it is the lightest neutralino – neutral, massive and weakly interactive particle. The mass spectrum of superpartners at some scale in mSUGRA can be calculated by solving renormalization group equations with parameters mentioned above being initial conditions at the unification scale.

In the present analysis the region with large scalar masses m_0 and small fermion masses $m_{1/2}$ was studied. In this case LSP properties are consistent with observed relic density, i.e. they can serve as cold dark matter particles, and, on the other hand, can naturally explain the excess of diffuse galactic gamma rays observed by EGRET [3]. The set of the parameters used in the analysis (let us call it the EGRET point) is the following (Fig.1):

$$m_0 = 1400\ \mathrm{GeV},\ m_{1/2} = 180\ \mathrm{GeV},\ \mathrm{sign}\,\mu = +1,\ A_0 = 0,\ \tan\beta = 50.$$

This region has not been intensively studied yet, though it is within the reach of Tevatron and forthcoming LHC. It appears to be very interesting phenomenologically, because of the mass splitting between light gauginos and heavy squarks and sleptons. The cross-sections for chargino and neutralino production in this case are relatively large not being suppressed by masses and being comparable with squark and gluino production. The latter being enhanced by strong interactions remains suppressed by heaviness of squarks. This means that in the EGRET region leptonic channels are not suppressed and so might give clear leptonic signature for supersymmetry in the upcoming LHC experiments [4].

The detection of a SUSY-like signal at LHC corresponding to the EGRET point of mSUGRA would be a strong indication both for supersymmetry and for solution of the dark matter problem. These parameters (EGRET point) were used as input for the ISAJET code [5] which calculated the superparticle spectrum. Later the PYTHIA generator [6] used the spectrum for event generation. It is worth mentioning that the whole generation process was performed within the ATLAS software ATHENA [7]. Superparticle spectrum and cross-sections of different processes depend on chosen parameters of mSUGRA. The common property of SUSY-like processe in models with conserved R-parity is undetectable LSP in the final state which are rather heavy and thus take away quite high (and undetectable) transverse momentum. The condition for choosing of the certain SUSY channel was not only the large cross-section but also a peculiar signature which would tell it from different Standard Model background events. In the EGRET point the process of pair gluino production and their subsequent decay appeared to be

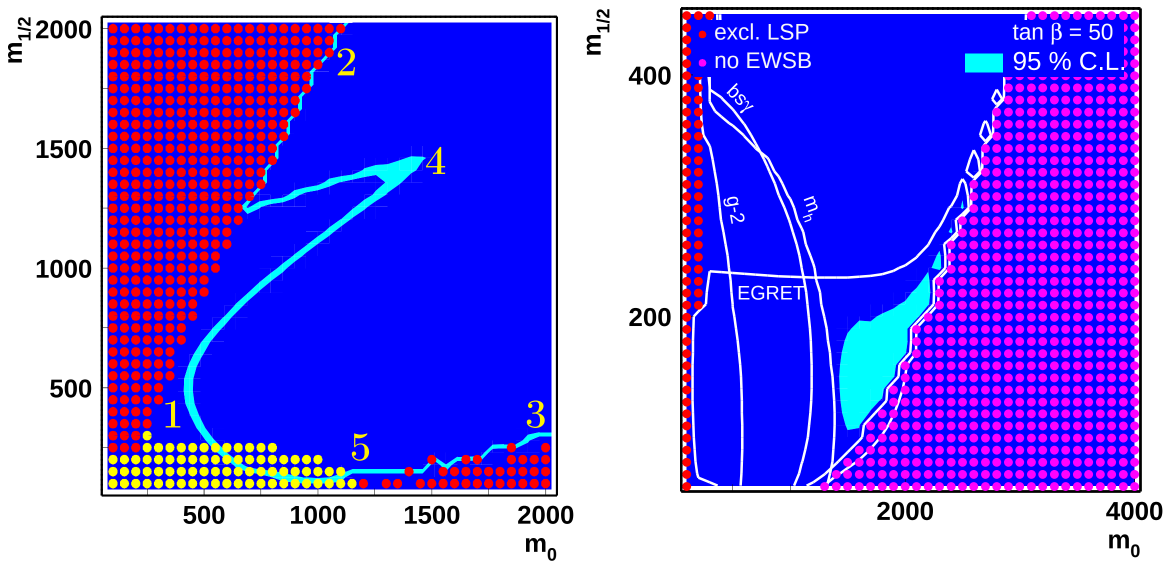

Figure 1: Left: MSSM parameter space. Light blue line corresponds to the region consistent with WMAP data. One can distinguish between different regions marked by digits. 5 – is the EGRET region. Right: The light shaded (blue) area is the enlarged region preferred by EGRET data for $\tan\beta = 50$, $\mu > 0$ and $A_0 = 0$. The excluded regions where the stau would be the LSP, or the electroweak symmetry breaking fails, or the Higgs boson is too light are indicated by the dots.

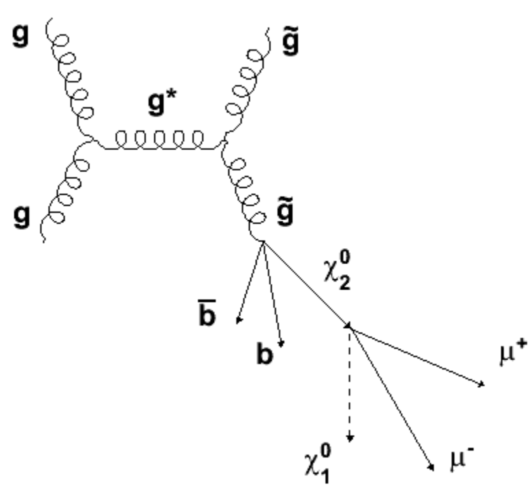

Figure 2: Topology of the "half of the event" under study with 2 b-jets, 2 muons and 2 secondary vertices.

the most interesting:

$$
\begin{array}{llll}
gg \to \tilde{g}\tilde{g} & & & \\
 \downarrow & & & \\
 \bar{b} + b + \tilde{\chi}_2^0 & & & \\
\phantom{gg \to \bar{b} + b +} \downarrow & & & \\
\phantom{gg \to \bar{b} + b +} \mu^- + \mu^+ + \tilde{\chi}_1^0 & & &
\end{array} \qquad (1)
$$

Here we assume that both gluinos decay in the same way. So, in the final state the gluino pair give 4 b-quarks (b-jets), 4 muons and a pair of the lightest stable neutralinos $\tilde{\chi}_1^0$ giving the high missing transverse momentum. There are B-hadrons in these jets, and, in general, the event could have 4 secondary vertices, which allows to reduce the background even at the trigger level (Fig. 2).

Fig. 3 shows the event inside the ATLAS pixel detector in cylindrical first layer ($R \approx 4$ cm). The cross-section of the hard $gg \to \tilde{g}\tilde{g}$ process at $\sqrt{s} = 14$ TeV is quite large. It varies between 5.6–14.2 pb (PYTHIA) at the chosen values of SUSY parameters (EGRET point). The cross-section depends on the parton distribution function (PDF) for the proton and its dependence on Q^2. We chose the independent on Q^2 PDF model GRV94D (DIS) [9] and put $Q^2_{min} = 0.5$ GeV. In this case the cross section is ≈ 13 pb.

The transverse momentum P_t distribution for one gluino decay products (two b-quarks forming 2 b-jets as well as 2 muons and the lightest neutralino) is shown in Fig. 4. One can see that neutralino takes away quite high transverse momentum. It is worth noticing that in the real experiment one can measure only the total missing (undetectable) energy of two neutralinos $\not{E}_t$ Fig. 5 shows the total transverse momentum of two neutralinos. Clearly, that the careful reconstruction will allow to detect such a high loss in the total measure transverse energy.

The b-tagging of all b-jets and the careful reconstruction of their energy are extremely important for the study of the considered processes. B-hadrons with b-quarks inside live rather long time and can move rather far away off the creation point (the cross point of initial proton beams). As a result it allows to observe a secondary vertex of B-hadron decay at a certain distance from the primary beams collision initial vertex. This secondary vertex allows to tag hadronic jets from b-quarks. Fig. 6 shows the distribution of the free path of B-hadrons provided all four B-hadrons have free paths more than 100 μm simultaneously. One can see that 94% of events satisfy this condition.

All above presented distributions were performed for 150 events, which is expected for ATLAS detector after a year of running with total LHC luminosity 10^{34} cm^{-2}s^{-1} for chosen values of SUSY parameters, parton distribution functions and their Q^2 dependence. Other PYTHIA parameters were set to their default values. The process (1) has the very peculiar signature (4 b-jets, 4 muons and high transverse momentum), however there is a mimic background process with only Standard Model particles (top-quarks and gluons) with alike signature:

$$
\begin{array}{l}
gg(q\bar{q}) \to t \quad \bar{t} \quad t \quad \bar{t} \\
\phantom{gg(q\bar{q}) \to} \downarrow \quad \downarrow \\
\phantom{gg(q\bar{q}) \to t \quad} \bar{b} + W^-(\to \mu^- + \nu_\mu) \\
\phantom{gg(q\bar{q}) \to} b + W^+(\to \mu^+ + \bar{\nu}_\mu)
\end{array} \qquad (2)
$$

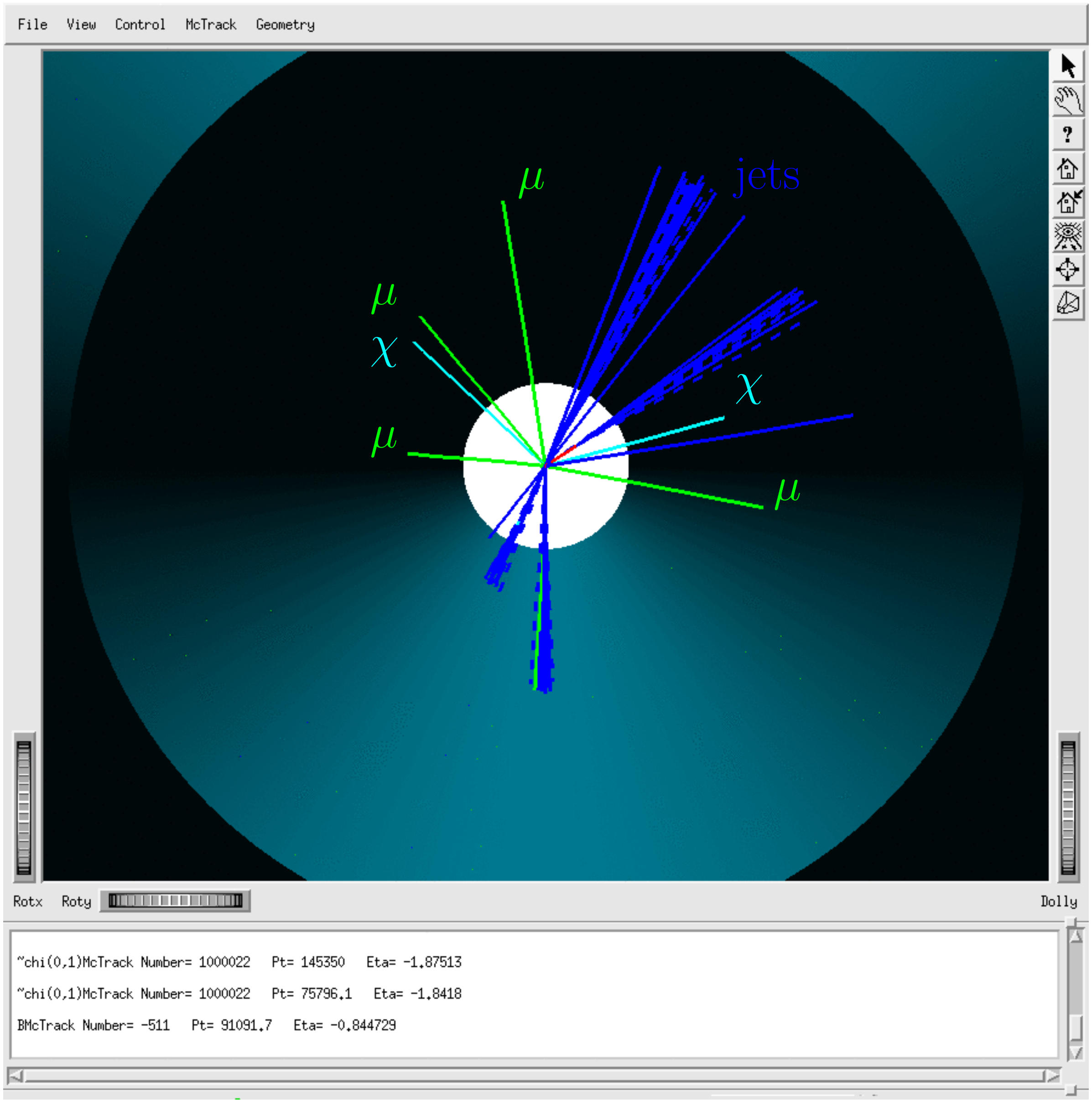

Figure 3: Generation of the process 1 inside the cylindrical (Layer 1) pixel detector in the XY-plane (transversely to the beam). One can see 4 muon tracks (green lines), 2 tracks from neutralino (light blue lines), 4 jets (dark blue lines) and one long-living B-meson (red line). Visualisation has been performed with the help of ATLAS GeoModel HitDisplay [8].

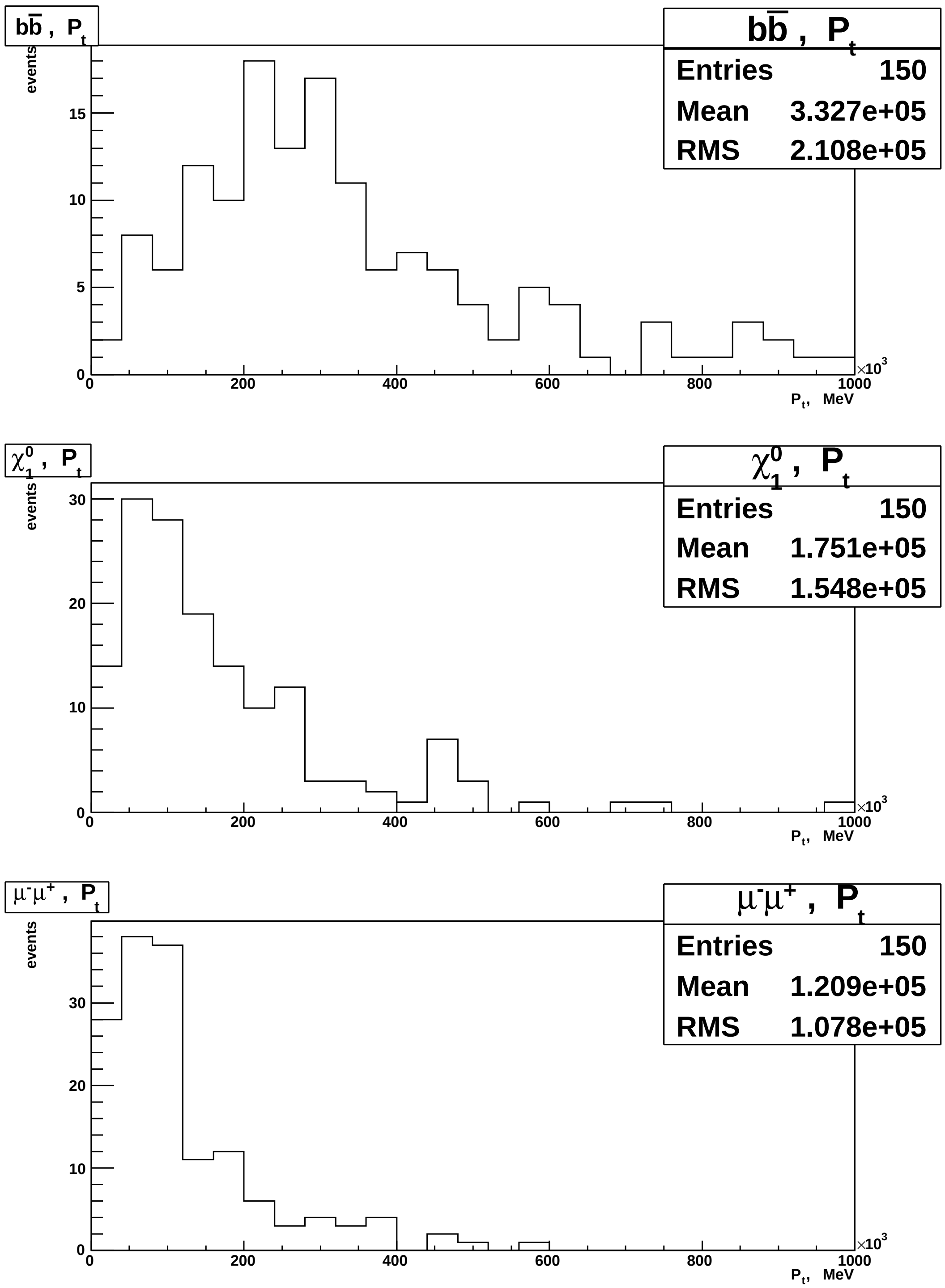

Figure 4: Transverse momentum distributions for the products of one of the gluinos decay. Top: the total P_t for the $b\bar{b}$ pair; Middle: P_t for the lightest stable neutralino $\tilde{\chi}_1^0$ from the heavier neutralino decay; Bottom: total P_t for the muon pair.

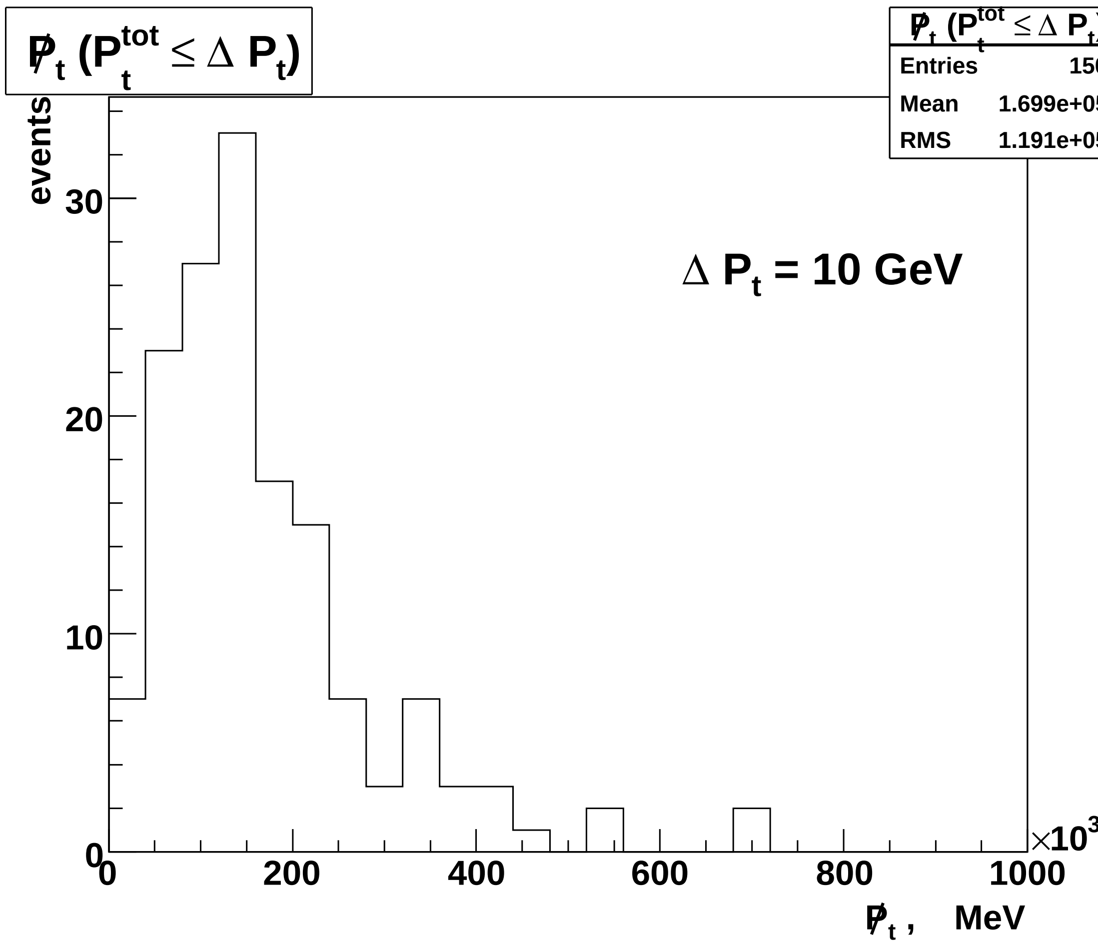

Figure 5: Total missing transverse momentum P_t of two neutralinos. Event selection is made assuming that the total P_t of gluino pair is less than 10 GeV. Since in our study the initial state radiation was not taken into account, all events satisfy this condition.

In this process (2) we again have 4 b-quarks (4 b-jets), 4 muons and the missing transverse momentum, but from 2 neutrinos. Now this background process is under study, however we can make some qualitative conclusions. The cross-section of the processes $gg(q\overline{q}) \rightarrow t\bar{t}t\bar{t}$ varies (depends on choice of Q^2-scale) in the range of 2.6 – 9.4 (0.5 – 1.5) fb (Acer MC-generator [10]). So, at the total LHC luminosity, 10^{34} cm^{-2}s^{-1}, the expected rate of $gg, q\overline{q} \rightarrow t\bar{t}t\bar{t}(W^+bW^-\overline{b}W^+bW^-\overline{b})$ is up to 3500 events per year. We require that all of 4 W-bosons decay into muon–neutrino pair ($BR(W^- \rightarrow \mu^-\nu_\mu \approx 0.1082)$) to give the same signature as one for the SUSY process 1. Then the SM background (process 2) rate is < 0.5 events per year. So, the preliminary estimation of the SM background gives its negligible contribution in the total signal. Moreover, due to the negligible (0 in our analysis) neutrino mass the missing transverse momentum is smaller than in the process (1). That is there is a possibility to distinguish between the background (2) and SUSY-like process (1) by choosing events with the large missing transverse momentum (larger than 50 GeV). Now we perform the full analysis (event simulation and reconstruction) of these processes using ATHENA.

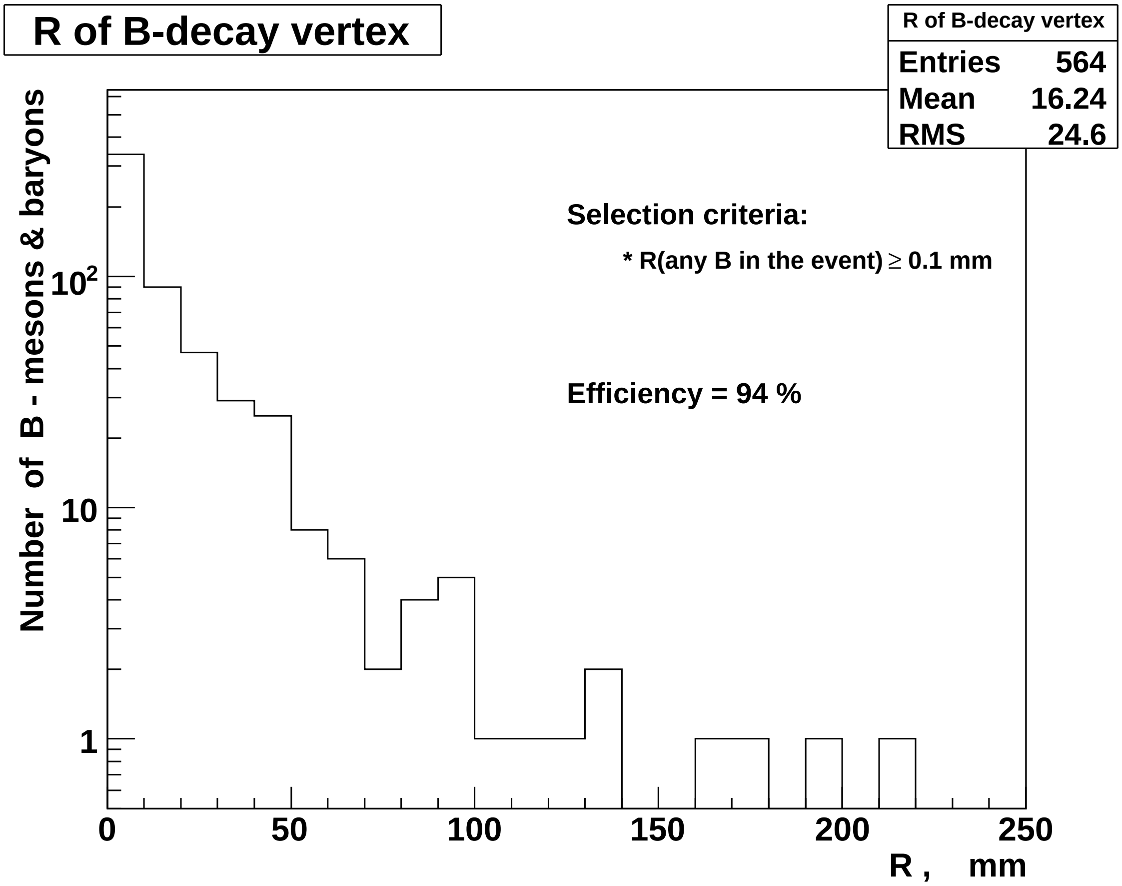

Figure 6: The free path of B-hadrons created in the process (1) before their decay. The criterion for the event selection is that the free path is not less than 100 μm for each of four B-hadrons in the same event. 94% of events satisfy this condition.

To conclude, the prospects for ATLAS observation of a SUSY-like signal from two gluinos are under investigation. The region of the mSUGRA relevant to SUSY dark matter interpretation of the EGRET observation is considered. The cross section of the two gluinos production via gluon-gluon fusion, $gg \to \tilde{g}\tilde{g}$, is rather high in the region. The clear signature of the process is 4 b-jets, 4 muons and rather large missing transverse energy (due to 2 lightest SUSY particles, the neutralinos). This large transverse missing energy carried away by two neutralinos allows the relevant Standard Model background to be reduced significantly. The generation and reconstruction processes are performed within ATHENA ATLAS software.

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