Dilepton SUSY studies at ATLAS

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1 Introduction

This review describes a few features of supersymmetry and the way in which supersymmetric particles can be produced at the Large Hadron Collider at CERN. Supersymmetry is able to solve the hierarchy problem by cancellation of the quantum loop corections to the Higgs mass. Above this, supersymmetry is an important part of grand unification theories. In this abstract, special attention is payed to the neutralino χ_1^0, which is supposed to be the lightest supersymmetric particle LSP. As the neutralino χ_1^0 is suspected to be a good candidate for cold dark matter, the features of this sparticle are also interesting for astro particle physics. Unfortunately indirect measurements must be used to aquire information about this particle since it eludes direct detection in the detector. This paper analyzes the decay chain of a χ_2^0 to the χ_1^0 via a slepton acompanied by two leptons as the detectable signal. This decay chain provides information about the mass difference between χ_2^0 and χ_1^0. In the second part generator data are used to observe this decay and the mass.

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2.1 The features of Supersymmetry

Although the Standard Model SM is a good theory to describe most of the known phenomena, there are still a few observations with cannot be explained by this model. The Standard Model does not provide a reason for the amount of observed particles. Why are there so many different lepton and quark flavours? Above this, the three coupling constants of the three SM interactions do not unify at high energies. Due to this near miss, Grand Unified Theories GUT which unify all SM interactions in one group do not work.

But the most interesting point why one believes that the Standard Model has to be extended is the so called *hierarchy problem*. This problem deals with the question why the electroweak mass scale m_W is so much smaller than the Planck scale

$$m_W \ll m_P \approx 10^{19} GeV$$

This is also familiar as the problem with the quantum loop *corrections to the higgs mass*. As the higgs field has to be introduced to explain the origin of particle masses, the higgs boson has to be part of a theory describing the nature of particles. Due to quantum mechanics there are loop corrections concerning the higgs mass itself. As these corrections are quadratic in the considered mass scale, they can become larger than the actual value of the mass itself. If one suggest the Standard Model to be valid up to the Planck scale, the corrections to the higgs mass would be about 36 orders of magnitude higher than the value for the mass.

In the case that the corrections were caused by a fermion an interaction of the same kind but with opposite sign is needed to annihilate the dangerous terms. One solution to this problem is a boson. Therefore doublets consisting of a fermion and a boson have to be created.

This turns out to be a problem as none of the known fermions could be grouped together with a known boson due to its internal quantum numbers. Considering the fact that the lepton number can not be conserved by pairing a boson and a fermion together, new particles have to be introduced. In this way every particle gets its own partner, which

has the same quantum number but different spin. As in this theory a fermion has to be turned into a boson and vice versa the spin of the particle must be changed by half a unit.
As a theory based on particles with spin $\frac{3}{2}$ would not be renormalizable, the spin must be changed such that gauginos get spin $\frac{1}{2}$ and sfermions get spin 0.
The theory that connects a fermion to a boson with the same quantum numbers is called *supersymmetry* (SUSY). To distinguish between "normal" particles and their supersymmetric partners, the supersymmetric partner of a particle is called sparticle. The sparticle associated to a fermion is labeled sfermion and the gauge bosons change their endings to "ino". In this way selectrons and higgsinos are invented.

Another advantage of SUSY is that it plays an important role in the so called *Grand Unification Theories* (GUT), which try to consolidate all existing interactions in one theory. Within the framework of SUSY the three coupling constants of the three standard model interactions actually meet at an energy scale of about 10^{16} GeV. Therefore SUSY already contains a unification. In contrast to this unification without supersymmetry does not work.

2.1.1 How to create sparticles?

Although this theory can break the conservation of lepton and baryon number, there is still another quantity which has to be conserved

$$R = (-1)^{3B+L+2S}$$

known as R parity.
Depending on the baryon number B, the lepton number L and the spin S, the R parity turns out to have the value 1 for the 'original' particles. For the corresponding sparticle, which only differs in the spin S by half a unit, there is an additional factor $(-1)^{-1}$ which turns R into -1. A pair of a particle and a sparticle has the value $R = 0$.
Corresponding to the conservation of lepton and baryon number in the SM, R parity is assumed to be conserved in SUSY. As a result of this, supersymmetric particles can only be produced in pairs, just like leptons. Another Consequence of this conservation law is, that supersymmetric particles can only decay into other supersymmetric particles. The so called *lightest supersymmetric particle* LSP can not decay into another sparticle because of its small mass. Conserving R parity, it can neither decay into a standard model particle, so the LSP has to be stable. As a charged or strong interacting particle dissipates its energy and is likely to condensate, the LSP has to be a neutral weakly interacting particle. Candidates for this type of LSP are a sneutrino, a neutralino, which is a mixture of a photino, a higgsino and a zino , or the gravitino. In the SUSY model investigated here the lightest neutralino is assumed to be the LSP. This is of great interest for astroparticle physics because the neutralino density fits to the expected density for *cold dark matter*. Therefore supersymmetry provides a hint that the neutralino is a candidate for dark matter just by requiring the conservation of R parity. In this theory

the Higgs boson is supposed to have spin 0. But instead of one higgs boson, supersymmetry provides 4 higgs particles, which are grouped in 2 dublets H_u (for up type quarks) and H_d (for down type quarks).
There are a few models describing supersymmetry, the one this abstract concentrates on is the so called *minimal supersymmetric standard model* MSSM. As its name implies this model contains the minimal possible number of sparticles and particles, which are grouped together in multipletts. One multiplett containing the gauge bosons and gauginos and one multiplett which contains the other particles.
Supersymmetry must be broken. If supersymmetry is not broken a spin 0 selectron has the same mass as an electron, thus it would have been seen before. But as none of the experiments has discovered it yet, it can be concluded that the supersymmetric partners of the normal particles are heavier than the particles itself, if SUSY really exists.
This leads to different theories about the way in which the symmetry between fermions and bosons is broken. One way would be the gauge mediated symmetry breaking GMSB. In this theory one assumes that there is a part which can not be observed in which the symmetry breaking takes place. Outside of this sector only the consequences which were mediated by particles from the first sector, can be seen.
The other important model is the *minimal super gravity* mSUGRA, in which the symmetry is broken by the gravitino. The gravitino couples to a massless particle creating a massive form of the gravitino. In this model one assumes that all scalar particles have the same mass m_0 and all gauginos have the mass $m_{\frac{1}{2}}$ at high energies. By using m_0 for all scalar particles and $m_{\frac{1}{2}}$ for all gauge particles most of the parameters are eliminated, so that only 5 parameters are left in the end. Two of the parameters for mSUGRA are the masses m_0 and $m_{\frac{1}{2}}$. Another parameter is given by the proportion of the vacuum expectation values of the two Higgs dubletts H_u and H_d, which are needed to provide masses for the particles. This parameter is referred to as $tan(\beta)$. The fourth parameter is the coupling constant between sfermion, sfermion, and higgs particle A_0. The last parameter needed to characterize the model is the sign of the mixing parameter μ.
As long as the mSugra model is used the whole model can be described by these 5 parameters. In the following discussion a point in the parameter space characterized by

$$\begin{aligned} m_0 &= 100GeV \\ m_{\frac{1}{2}} &= 300GeV \\ A_0 &= -300GeV \\ tan(\beta) &= 6 \\ sgn(\mu) &= 1 \end{aligned}$$

is used
The simulated data for this point corresponds to an integrated luminosity of about $672,40pb^{-1}$.
Trying to observe sparticles, which have much higher masses than the SM particles, high center of mass energies are needed to reach the mass scale at which we achieve

the borders between the standard model and supersymmetry. The LHC (large hadron collider) is build to raise the center of mass energy to this scale. The Atlas detector as one of the two multipurpose detectors seems to be the adequate tool to search for supersymmetry.

2.1.2 The Atlas Detector

As the detector is described in more detail in several papers ([1]) here are only a few aspects mentioned. The detector itself is divided into several parts each developed to measure a special property of the emerging particles. As you can see in Fig. 1 the

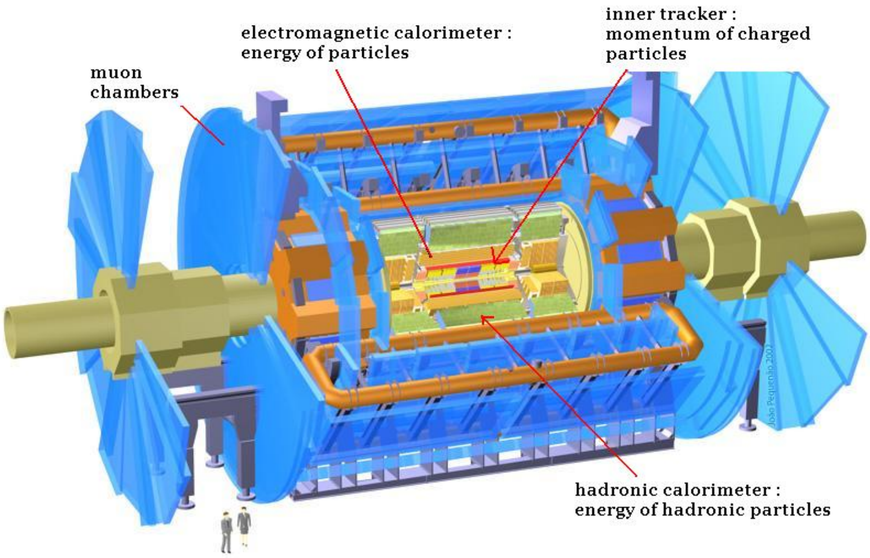

Figure 1: design layout of the Atlas detector [4]

detector is divided into four main parts. The inner part of the detector, the tracker is build to measure the momentum of charged particles. The part nearest to the beam is a silicon vertex pixel detector, which is followed by a silicon strip detector. They are both build to measure the momentum of the passing particles. The third detector ment to measure momenta is the transition radiation tracker (TRT). The TRT is based on straw tubes, which provide a high precision due to the small diameter of the straws. When an electron passes this detector, photons are emitted. These photons can then be detected in the straws and thus, electrons can be identified.
These components are surrounded by the electromagnetic and the hadronic calorimeters. In the calorimeters the energy of charged and neutral particles is measured. The calorimeter consists of metal plates which absorb parts of the energy and create showers. These showers are then detected by the use of liquid Argon. If a shower passes

the Argon electrons are emitted, which then can be measured. In this way the energy of the original particle can be determined. The outer region of the calorimeter consists of a certain form of plastic which emitts light, when a shower passes. This light can then be used to measure the energy of the original particle. Around these calorimeters there are magnets which provide a measurement of the momentum of the particles. The outermost part of the detector is the muon system. The muon system contain chambers consisting of straw tubes which detect charged particles. The chambers of this system are only passed by muons and neutrinos. The neutrinos do not interact with the detetor, which allows to identify muons easily. This feature will be important later on.
In addition to its track in the muon chambers, a passing muon leaves tracks in all parts of the detector. Therefore the reconstruction of muons is quite reliable.
Electrons cause tracks in the tracker and energy deposits in the electromagnetic calorimeter.
As one needs to leave space fo the beam pipe, charged particles can only be measured up to a polar angle of 9.4. In other words the absolute value of the pseudorapidity must not be larger than 2.5.

$$|\eta| < 2.5$$

2.1.3 Simulating the detector

As the Atlas detector is still under construction one has to be content with simulations of the detector. But even when the detector is complete the simulation will be used to analyze the data. Usually Monte Carlo generators are used to generate the decaying particles. In the first step these generators generate all decays corresponding to their branching ratio, which is based on the theory. Then simulation software is used to create the answer of the detector to these particles. After this step you get the information you would get from the detector itself.
All results presented in this abstract are achieved using a combination of Jimmy, IsaJet and Herwig for the Monte Carlo generation and GEANT4 fo the detector simulation. The data is then analyzed with ROOT, a common analysis software tool in high energy physics.

2.1.4 The truth information

The programm provides a list of all generated particles, their mother particles and the particles in which they decay. Above this you can receive information concerning what particle is generated and which momentum and energy it has. The information which particle is created is provided in form of the Particle Data Group identification number (PDG). In the PDG number scheme every type of particle gets its own number. It should be emphasized that all this information is information about the generated particles, so one gets the information what particle it really is and will not have to care about the reliability of the results. In the following chapter the results of these studies are summarized.

2.2 The production of SUSY particles

Let us first have a brief look at the production of supersymmetric particles. As mentioned before supersymmetric particles can only be produced in pairs. In Fig. 2 the supersymmetric particles that first occured in an event, labeled as *primary particles*, are shown, grouped together in the pairs in which they occured. The numbers in the boxes present the percentage. As a consequence of R parity, the lightest supersymmetic

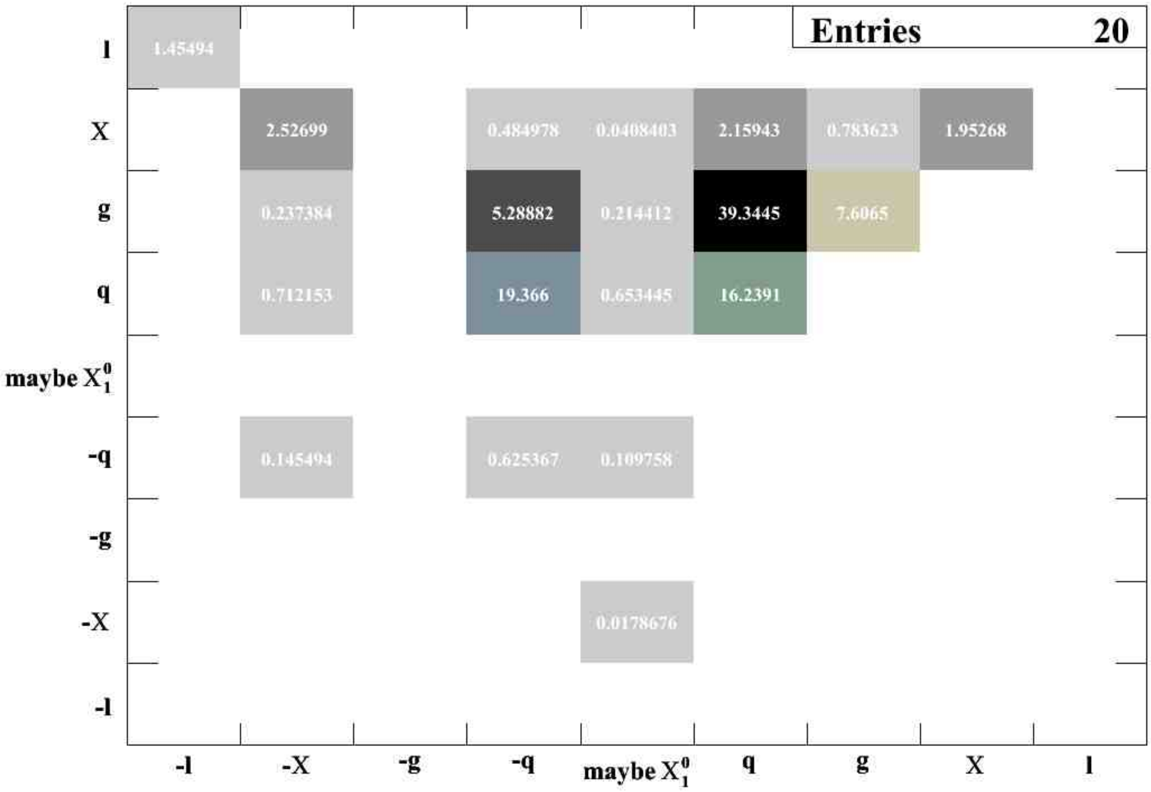

Figure 2: primary particles paired, the numbers give the percentage of all primary particles

particle, neutralino 1 labeled as χ_1^0, has to be stable. It can neither decay into another sparticle because the masses of the other particles are higher nor into a standard model particle, because this would violate R parity. Being neutral, stable and not strongly or electromagnetic interacting, the neutralino 1 escapes detection. Indirect measurements must be used to get information about this particle. In this diagram it is assumed that there must be a neutralino 1 everytime only one primary particle is found in an event. This assumption was made to conserve the R parity and was necessary since the information about the χ_1^0 was not saved.

As can be seen clearly the majority of the emerging particles are grouped either in a gluino-squark pair or in squark-antisquark respectively squark-squark pairs. Considering the fact that the LHC is a proton proton collider, it seems rather obviuos that the squarks come from collisions of the valence and sea quarks and gluons in the proton. If one distinguishes the squark/antisquark and the squark/squark pairs it can be observed that most of them are up and down squarks, which concludes that they come from the valence quarks. The gluinos come from the same source.

To prove this hypothesis the mother of these primary particles is shown in Fig. 3.

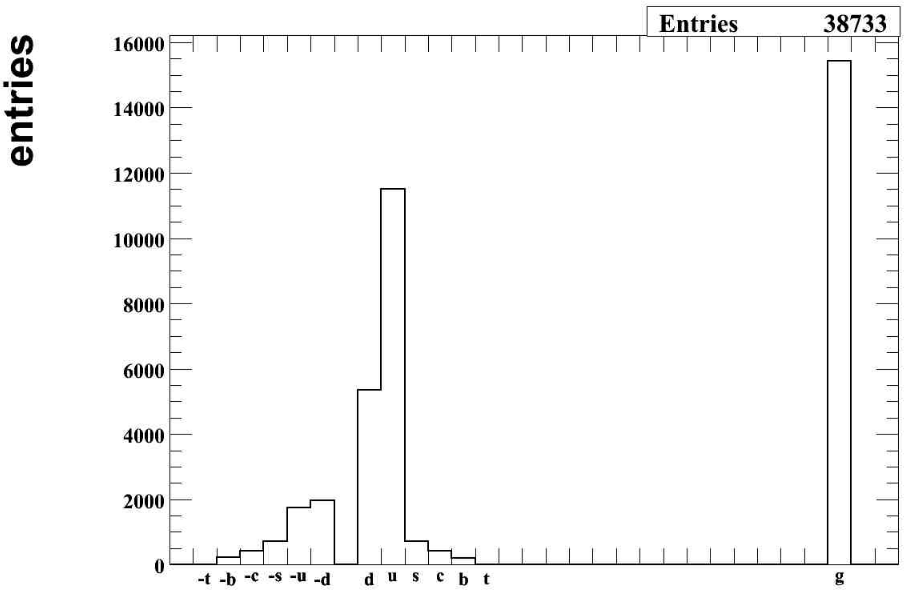

Figure 3: Mother of primary particles

Fortunately most of the primary particles come from gluons, up and down quarks, which are the valence quarks of the proton. Like the proportion of the valence quarks in a proton, there are twice more up quarks than down quarks. In the shown distribution the parton distribution function (Fig. 4) is reflected.
This function describes the distribution of quarks and gluons in a proton, which depend on the fraction of the proton momentum which is carried away by a certain particle. Hence one gets the proportion between up and down quarks and gluons in the colliding protons.

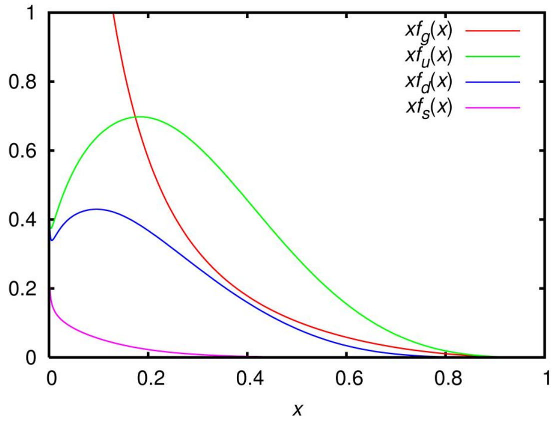

Figure 4: Parton distribution function [3] Xf_u, Xf_d, Xf_s refer to the fraction of the proton momentum carried away by up, down and strange quarks, g refers to gluons

2.3 The mass of neutralinos

Since the neutralino 1 can not be measured directly, the mass can only be determined by using decay chains containing this particle. To conserve R parity the decay chain has to contain another sparticle, which is assumed to be the neutralino 2. The whole decay may look like it is shown in Fig. 5.

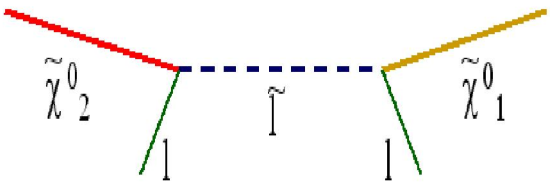

Figure 5: Feynman diagram for the slepton lepton decay

The reason why this decay chain is of special interest is the fact, that there are two leptons in the final state, which can be used to reconstruct the chain.
As leptons depose traces in the tracker, the calorimeter and in case of a muon the muon chambers, these particles can be identified easily. But there is one exception, the tau. Due to its short lifetime the tau decays within the detector. Therefore only the traces of its decay products can be measured. And at least one neutrino is escaping detection. The reconstruction of a tau is very difficult, which is the reason why only electrons and

muons are considered in this study.

2.4 The slepton lepton decay

As shown before this decay consists of a neutralino 2 decaying into a lepton and a slepton, which then decays into the neutralino 1 and another lepton. To reconstruct this decay a slepton and a lepton of opposite sign is required to conserve the charge. In this specific mSUGRA model, the slepton is right handed. In addition to this, the outgoing lepton has to be of the same type like the slepton to conserve lepton number. The second lepton is required to have the same sign as the slepton because it has to carry the charge of the slepton away. Lepton pairs fullfilling these conditions are called *opposite sign same flavour* (OSSF) leptons. There is one additional demand for the slepton. As the neutralino 1 can not be seen the slepton has to decay into one single visible particle, which is the lepton mentioned before. Taking into account all these requirements the following results can be produced.

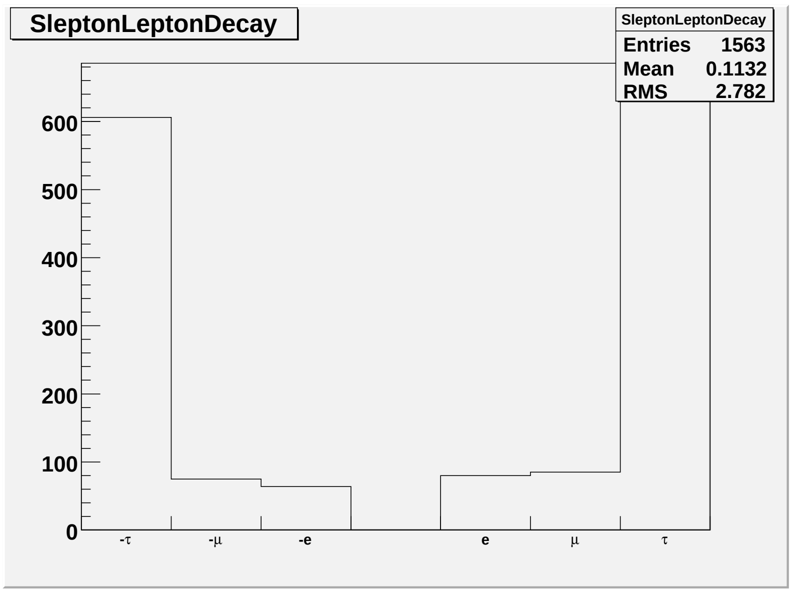

Figure 6: Leptons from slepton lepton decay

The histogram in Fig.6 shows the amount of slepton lepton decays, depending on the leptons which are produced. Even though there are much more slepton lepton decays with taus than with electrons and muons, this abstract concentrates on the cases with electrons and muons as it was mentioned before. There could also be other neutral sparticles decaying in the same cascade. But as it is shown in Fig. 7 most of the slepton lepton decays come from the neutralino 2. Referring to Fig. 7 one can conclude that there are about ten times more taus coming from such a decay than electrons or muons. This agrees with the calculated branching ratio for the decay of a neutralino 2. The values for the branching ratio are

$$BR(\chi_2^0 \to l_R^{\mp} l^{\pm}) = \begin{cases} 2.8\% & \text{for } e, \mu \\ 24\% & \text{for } \tau. \end{cases}$$

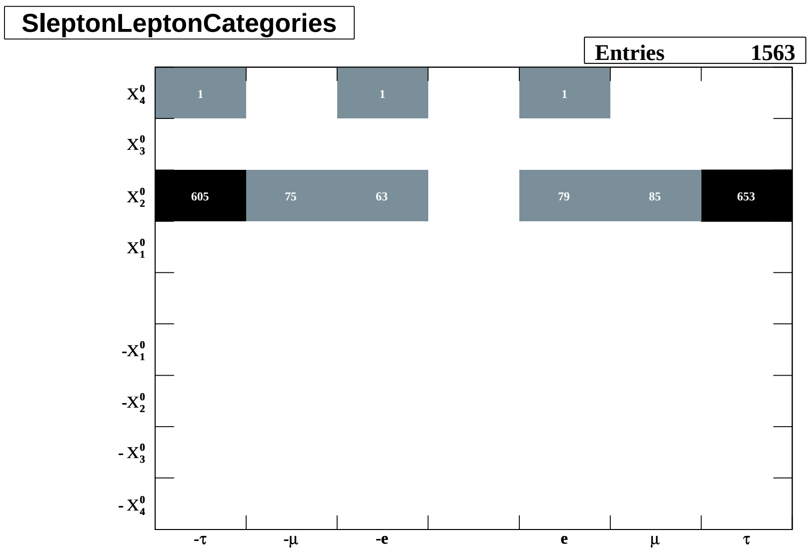

Figure 7: Leptons from slepton- lepton decay grouped after their mother particle

2.4.1 Neutralino masses with truth data

For kinematic reasons the invariant mass of the two leptons rises, until it reaches a certain value. At this value the leptons carry away the energy belonging to the mass difference between the neutralino 1 and the neutralino 2. A triangular shape can be observed. The mass difference between the two neutralinos can be determined from the edge of this triangular shape. As discussed in [2] the edge of this shape can be calculated as

$$m_{ll}^2 = \frac{\left(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{l_R}}^2\right)\left(m_{\tilde{l_R}}^2 - m_{\tilde{\chi}_1^0}^2\right)}{m_{\tilde{l_R}}}.$$

Depending on the masses of the slepton $\tilde{l}_R$ and the neuralinos at the considered parameter point, which can be received from the used Monte Carlo generator, the edge can be calculated and compared to the observed shape. In the parameter point mentioned above the value for the edge is about $m_{ll} \approx 100 GeV$.
It mus tbe emphasized that there are still errors on this calculated value. These errors have their origin in the fact, that the slepton and the neutralino 2 are unstable particles

and that the χ_1^0 is an invisible particle. As a result of this, they do not have a fixed mass. Instead the generator creates a gaussian distribution for the mass. The mean value of this distribution should agree with the mass of the particle.
If the truth data is used to identify the leptons belonging to this decay, the invariant mass of these particles can be calculated. The observed triangular shape is shown in Fig. 8. In this figure, the edge is compared to the calculated mass, which is presented by the blue line.

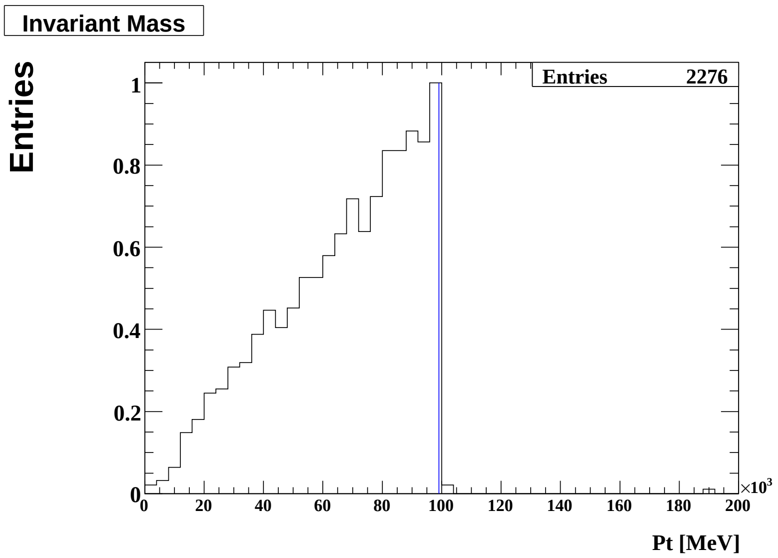

Figure 8: invariant mass shape for the slepton lepton decay compared to calculated value (blue line)

Now the observed edge can be fitted. For this an unbinned maximum likelihood fit is used to avoid dependence of the values on the bin size. The fit was done using two linear fits, which cross each other at the edge. A variable fitting range for the single linear fits must be used to obtain the value for the edge. The edge is then presented by the value for the fittig range. The received plot is show in Fig.9 The value for the edge is about $m_{ll/\text{fit}fit} \approx 99.00\text{GeV}$.

2.4.2 Leptons wanted - Reconstructing the decay

Of course one will not have the truth information concerning the mother of a particle or the particles in which it decays in real data. Therefore we will have to reconstruct the decay using data the detector provides like the momentum of a particle or its pseudorapidity η or the type of lepton it is. To find all requirements which can be made to isolate the decay chain the truth data are used to compare the real slepton lepton decays and the faked ones.
As a first attempt the transverse momentum p_T of a particle is used to isolate the chain.

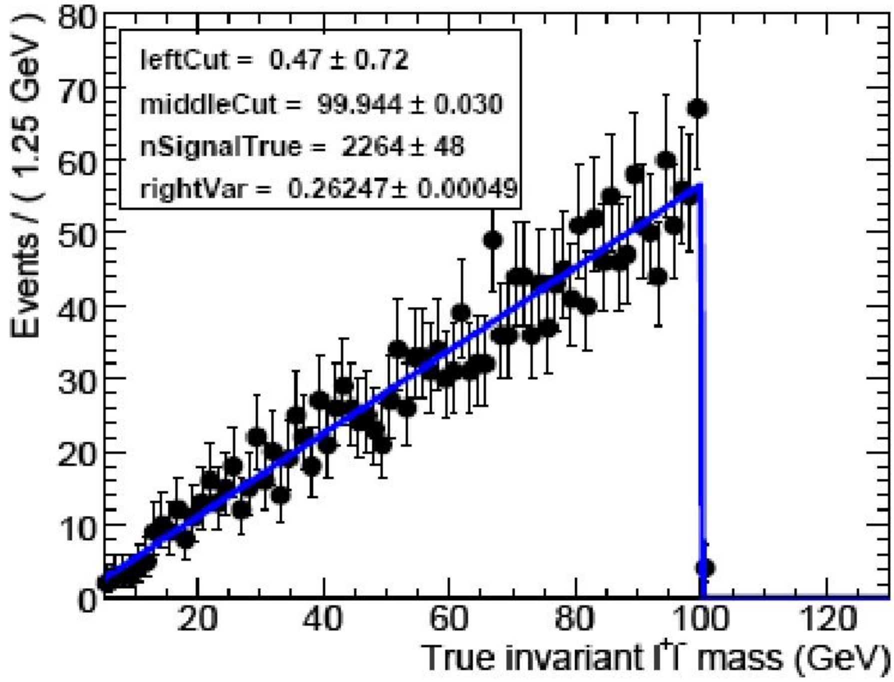

Figure 9: Invariant mass shape for the slepton lepton decay with triangular fit

To isolate the leptons coming from the slepton lepton chain a p_T value above a certain threshold is required. On the one hand this threshold has to be high enough to suppress the majority of standard model processes. But on the other hand this threshold should not be too high, so that it will not change the distribution of the invariant mass. Finding this threshold is not easy, therefore the leptons from the slepton lepton decay and from other leptons are identified by the truth information. Then their p_T distributions are compared. The result is shown in Fig. 10.

The leptons from the slepton lepton decay seem to have a much higher transverse momentum than the other leptons. Now the question arises where all the low energetic electrons come from. Following the path back one finds that about 90% of these electrons come from a pion decaying into a photon which then decays into the electron. Obviously this decay is forbidden in each single step. Neither it conserves the lepton number, nor the charge. So where does this decay chain come from?

This is a consequence of the attempt to keep the storage as small as possible. The whole process is divided into five main parts. In the first stpe the generator creates all particles according to the branching ratios. Then GEANT4 simulates the interactions of these particles. In the next step the signals are digitized and then the reconsrtuction takes place. After this step the answer of the detector to a special particle is available. But these data still contain all the truth information. Thus a lot of storage is needed. Therefore the amount of storage is minimized in the next part. As the truth information

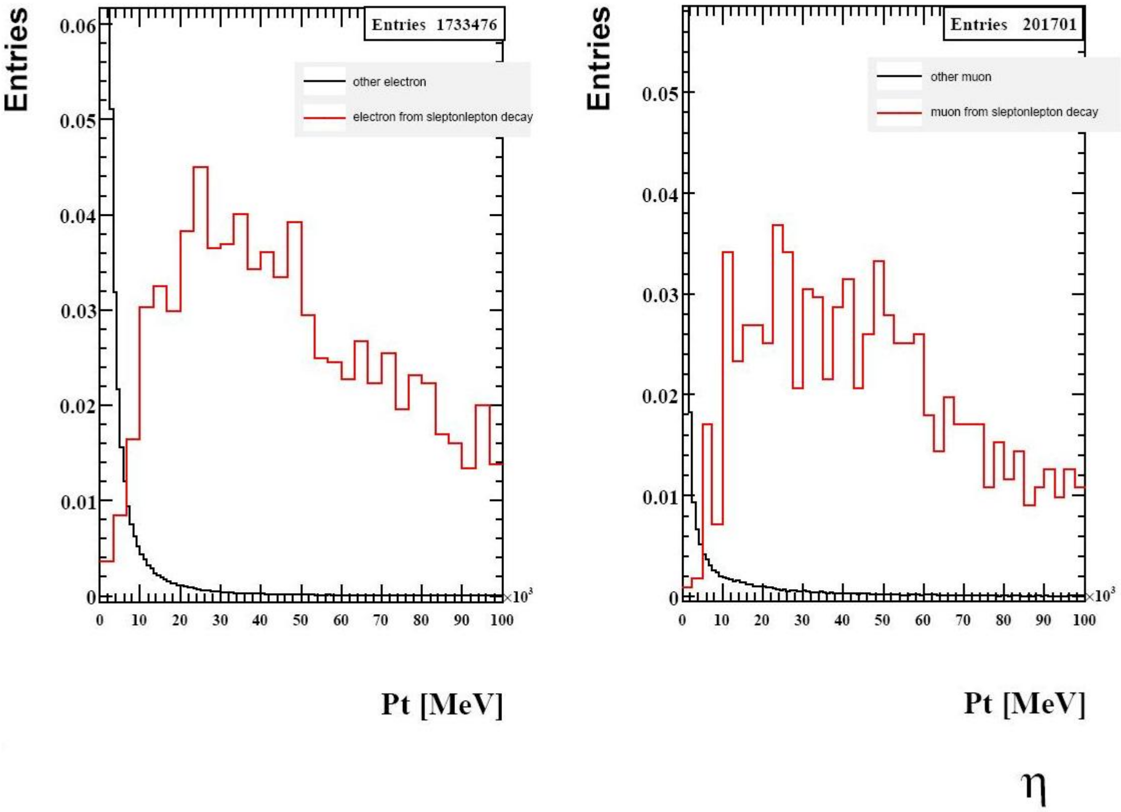

Figure 10: Transverse momentum of all leptons and leptons from slepton lepton decay scaled to compare the distributions

needs a lot of space this information is also cuted. All values corresponding to particles which can not be detected are no longer saved. This may be the reason why there are some particles missing in this decay chain.
Based on this assumption the low energetic electrons are supposed to come from pair productions, where a photon produces an electron and a positron.
It can be deduced from the figure that a threshold for p_T of 10 or 20 GeV would suppress the majority of background processes. But at the same time this cut suppresses some of the wanted leptons, which has influence on the invariant mass distribution. This influence for some typical thresholds up to $25GeV$ can be seen in Fig. 11 and 12 .
Fortunately a p_T cut up to 25 GeV just changes the height of the triangle but not the shape. Hence a p_T cut in this region can be used to isolate the wanted leptons.
Unfortunately some ‘wrong‘ leptons survive this cut, so another cut is needed. Another possible parameter for a cut is the pseudorapidity η. This parameter povides a natural cut as the detector can measure leptons up to a pseudorapidity of $\eta < 2.5$, due to the architecture of the muon and electron trackers.

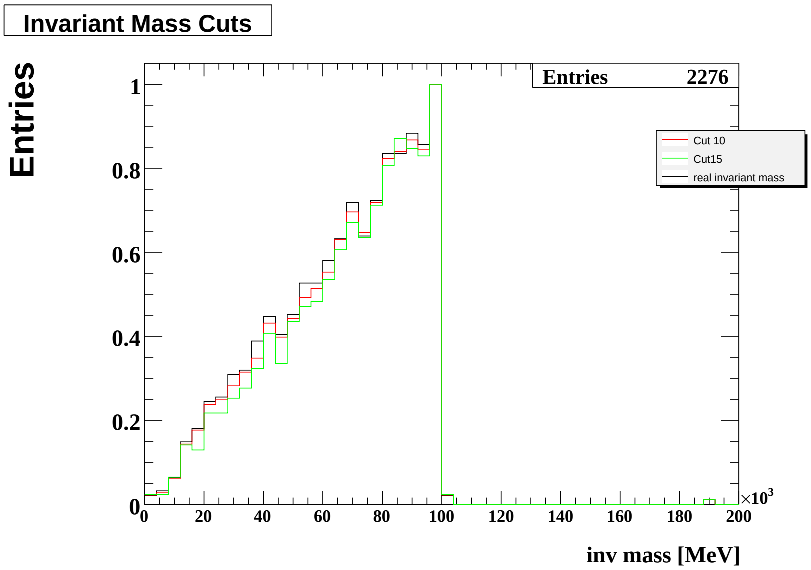

Figure 11: invariant mass (scaled) with different p_T cuts

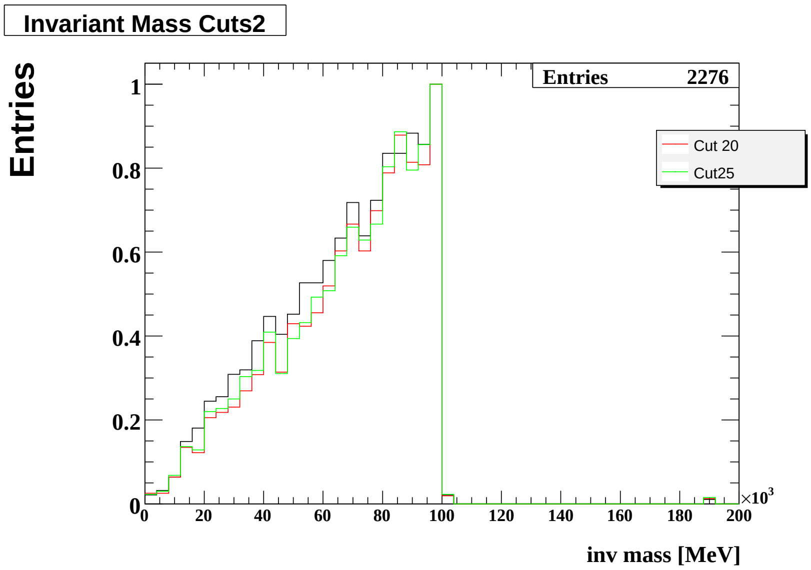

Figure 12: Invariant mass (scaled) with different p_T cuts

This cut should supress ‘fake‘ electrons. In Fig. 13 the η distribution for the "strange decay" and the wanted slepton lepton decay is shown. Unfortunately the data disagrees with the hope to supress the strange decay mentioned before. Unless the distributions differ from each other in the range of small values for $|\eta|$, it is not possible to isolate the strange decay with this cut.

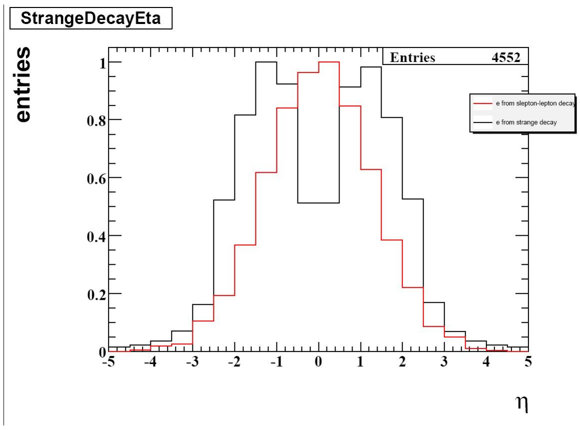

Figure 13: η distribution for strange decay and slepton lepton decay

2.4.3 Trying the method on truth data

At a first aproach we try this method with the truth data, which means all particles labeled as leptons really are leptons. In Fig. 14 the invariant mass of two leptons with opposite sign, same flavour and highest values for the transverse momentum p_T is presented.
In this diagramm we distinguish between electron/positron and antimuon/muon pairs. In addition the invariant mass for opposite sign opposite flavour leptons, which contain electron/antimuon and muon/positron pairs, is shown.

The invariant mass seems to have an edge at the expected value of about 100 GeV. But the shape does not really look like a triangle. It can be concluded that there are still some background processes which have an influence on the shape of the invariant mass distribution. Assuming that these are leptons from standard model processes these should be indepedent of each other. Hence the same amount of standard model background processes in the distribution for OS-SF and OS-OF leptons are expected. As there is no slepton lepton decay with two leptons of opposite flavour in the final state, the distribution for the OS-OF leptons fortunately only consists of background. This provides a good method to identify the background in the OS-SF distribution. So one has to calculate both distributions and subract the OS-OF distribution from the OS-SF distribution. The result is shown in Fig. 14.

2.5 Reconstructing the decay by using this method with reconstructed data

While truth data was used before, we now change to reconstructed data.
Unlike to the truth data, the reconstructed data does not contain information about the mother or the particles in which a certain particle decays. Both data sets have in

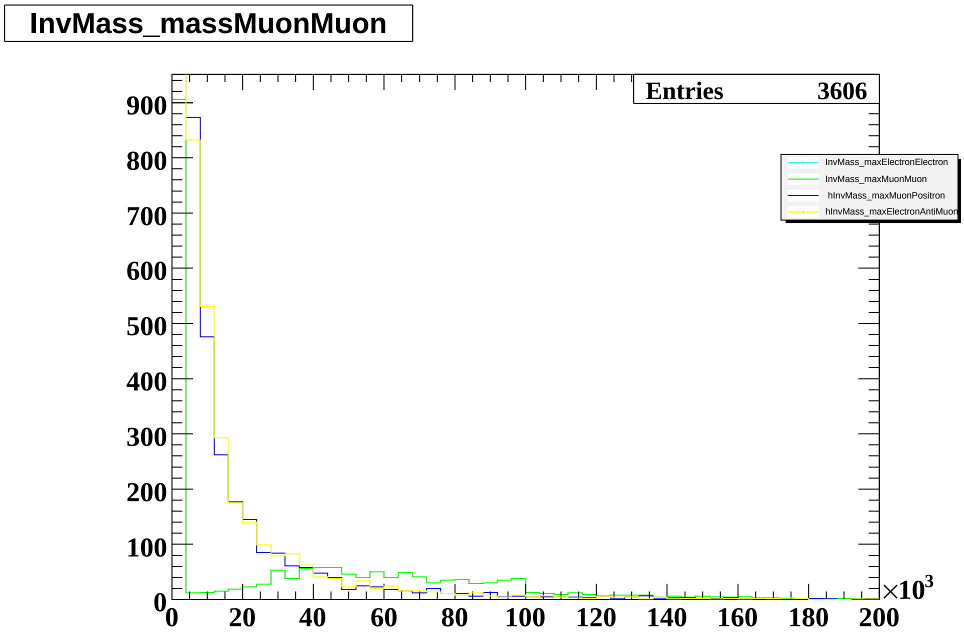

Figure 14: Invariant mass of OSSF - invariant mass of OSOF leptons

common that they provide the momentum, pseudorapidity η, angle φ and the energy of a particle. But instead of storing information about the real type of a particle, the reconstructed data set can only supply information about the type of particle, which a observed track matches to. This means that a particle reconstructed as an electron, does not neccesarily have to be a real electron. Instead it could be any other particle faking the signature of an electron. So one always has to care about the reliability of this information.
As mentioned before the method of following the path of a certain decay can not be used anymore. Hence one has to be content with the demands that were developed before. Recapitulating these results the requirements used are listed

(1) there have to be 2 leptons with opposite signs in charge but the same flavour, which are called *Opposite sign same flavour* (OSSF) leptons,

(2) the highest leptons is required to have a p_T above 20 GeV, whereas the other lepton has to have a $p_T > 10GeV$,

(3) the pseudorapidity should be below $|\eta| = 2,5$.

With these requirements the invariant mass of corresponding leptons can be calculated. As there is more than one electron respectively muon of the required type in one event, they have to be grouped into pairs of two. But which one should be chosen? The p_T of the leptons can be used to select two leptons from all leptons with the required attributes. As seen before the leptons coming from the wanted slepton lepton chain have high p_T. Hence we choose the two leptons with the highest p_T. In addition these two leptons have to be of opposite sign in charge. The p_T distribution of these electrons and the invariant mass received on the basis of this selection is shown in Fig. 15. In this

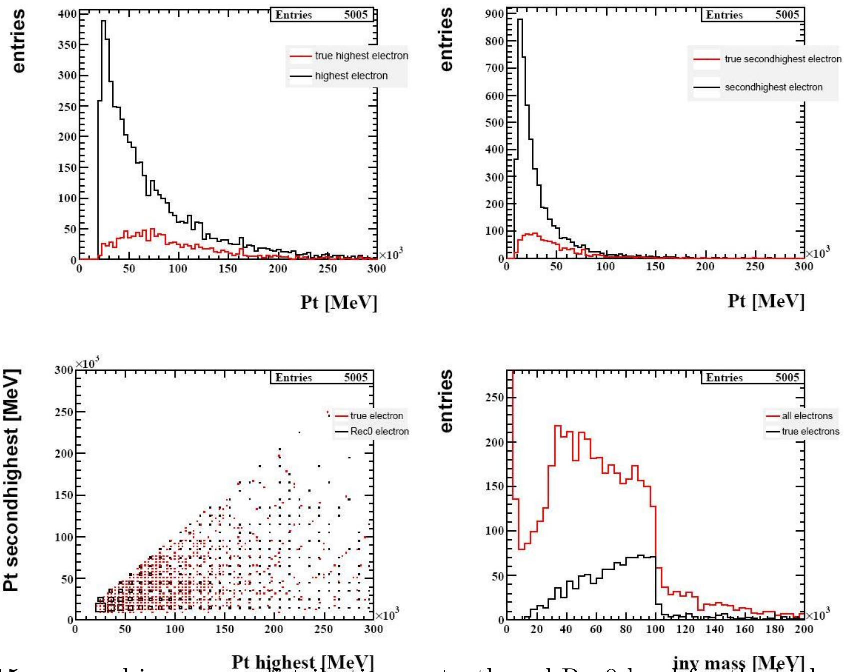

Figure 15: p_T and inv. mass distribution on truth and Rec0 level for the highest electrons

figure the distributions for 'real' electrons can also be seen. As the reconstructed data still contains the truth data, the information if an electron is really an electron can be achieved by matching the truth and the reconstructed data to each other.
There are a lot of faked electrons in the histograms. As you can see there are a lot of wrong electron pairs which have a very small invariant mass. Using the truth information which is still available in the reconstructed data, one finds that about 65% of these electrons come from photons. So the origin of these leptons seems to be pair production. The same plot is also prepared for muons. The results are shown in Fig. 16.
In this diagram the curves for real muons and particles reconstructed as muons are very similar. This is due to the fact, that muons are registered in the muon chambers of the detector. As only muons and neutrinos, which do not interact with the detector pass this section, the reconstructing of muons is easier than the reconstruction of electrons. Therefore faking a muon track is more difficult and thus less frequent.
In Fig. 17 the resulting invariant mass for electrons and muons can be seen. In this figure the edge can already be seen but the shape does not look like a triangle. This

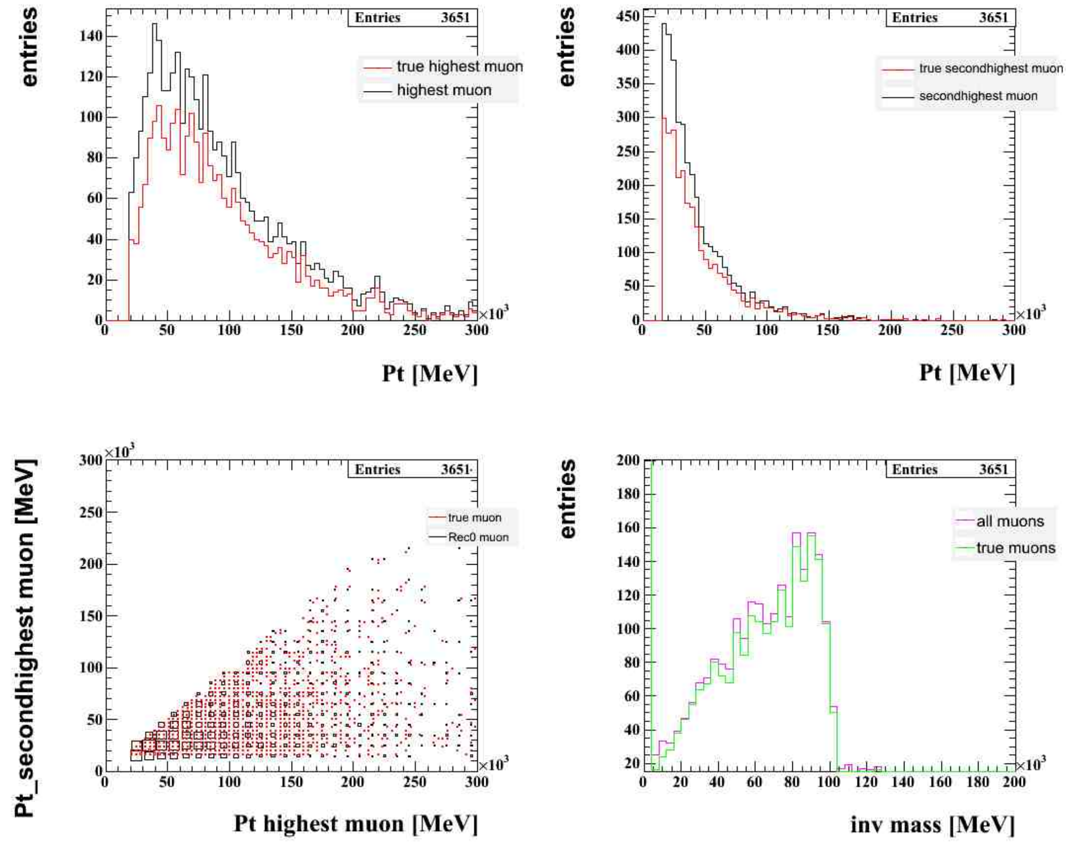

Figure 16: p_T and inv. mass distribution on truth and Rec0 level for the highest muons

deviation from the expected shape comes from the faked electrons, which can be verified by comparing the shape for the invariant mass for electrons and muons.
So how can 'real' and 'faked' leptons be identified? Can another cut on the transverse momentum solve the problem? The transverse momentum for the 'real' and the 'faked' electrons are shown in Fig. 15. As expected there are more 'faked' electrons in the range of low p_T but the range for the 'fake' electrons and the 'true' electrons is the same, so the values mentioned before seem to be the best values for the p_T cut. Again the results for muons are the same. Comparing the invariant mass distributions of electrons and muons to each other, it can be seen that there seem to be more "real" muons than electrons. As the generator produces them in the same amount, there must be a method in the reconstruction causing this effect. In the reconstruction there a more requirements for particles to be identified as electrons, like spacial isolation from jet. These internal cuts seem to dismiss a lot of 'real' electrons.
To find out if the 'faked' electrons could be supressed by changing the values for the η cut, the η distribution of all electrons matching to our requirements and the electrons which really are electrons (based on the truth information) are compared. The results for the highest and the second highest electrons are shown in Fig. 18. Unfortunately the

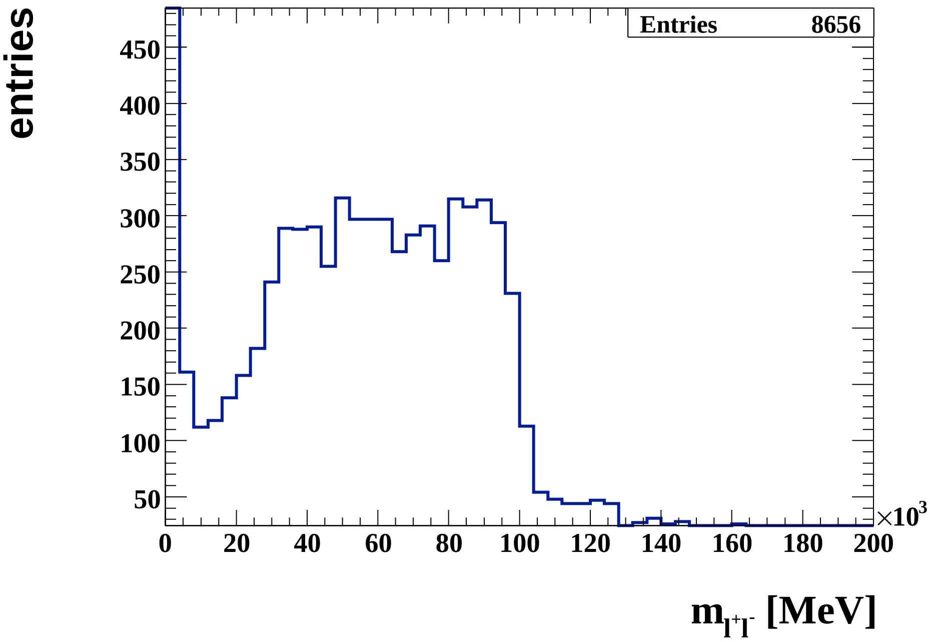

Figure 17: Invariant mass of OSSF leptons

values for the 'real' and the 'faked' electrons are in the same range. Therefore a change in the values for the η cut can not improve the invariant mass shape. The same result is achieved for muons, as can be seen in Fig. 19.

As expected the η distribution for the highest and the second highest leptons are correlated with each other. A high η for one lepton also indicates a high value for the other one. This effect has its origin in the production of the leptons. As the neutralino χ_2^0 which decays in these leptons is moving, the leptons are boosted, too. According to the momentum of the neutralino both leptons have a small or high value for the pseudorapidity η.
So no more cuts can be made to avoid 'faked' leptons. But the distribution for the invariant mass for reconstructed muons already takes the triangular shape.
As a result of this, only muons are considered in the remainder of this analysis.
Although the shape looks already like a triangle, there is still background superimposing this shape.
The distribution for the invariant mass of these background processes is shown in Fig. 20. In this case the OS-OF distribution and therefore the main part of the background seems to be quite small, so that the subtraction has nearly no influence on the resulting shape. This is due to the fact that the data comes from a so called SUSY sample. In

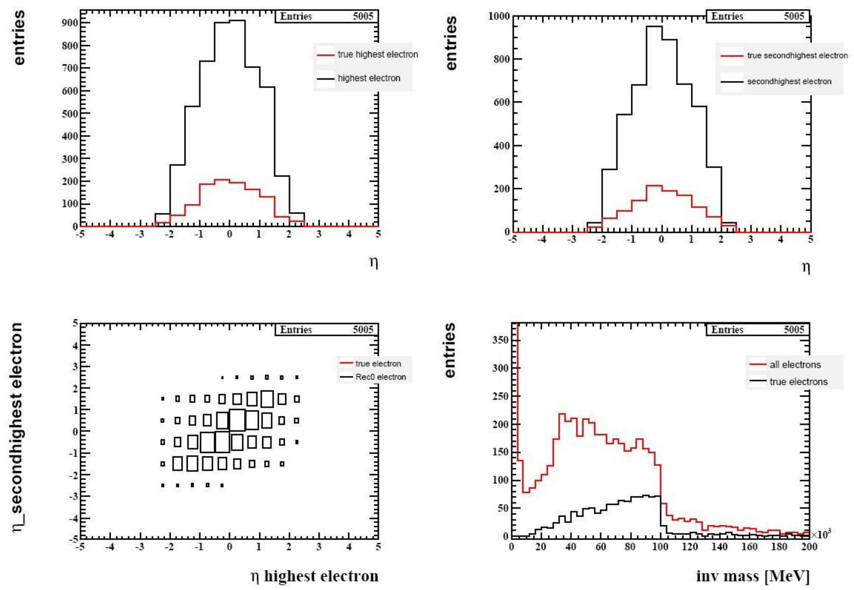

Figure 18: η and invariant mass distribution on truth and reconstruction level for the highest electrons

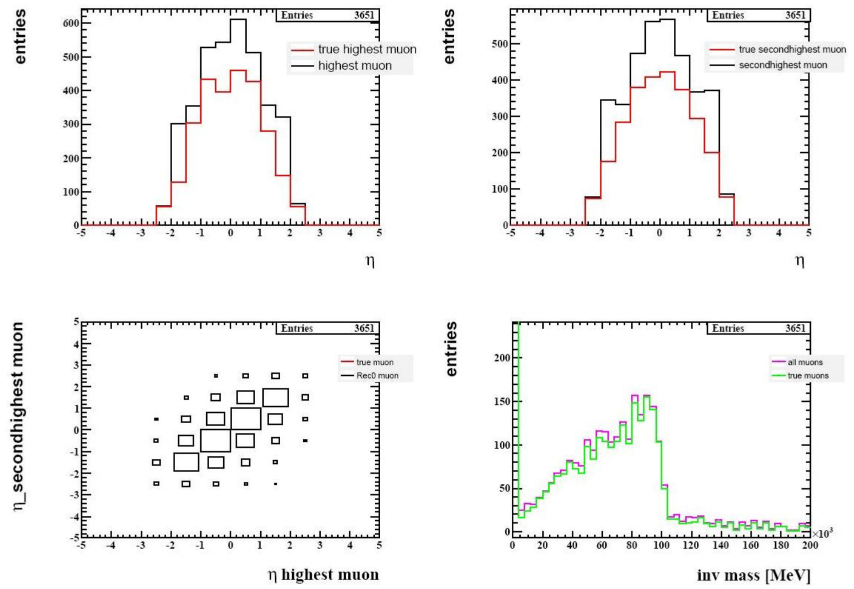

Figure 19: η and inv. mass distribution on truth and Rec0 level for the highest muons

these data only supersymmetric processes are generated. So it is not surprising that there are no standard model processes in the data.
The background can now be considered by fitting a gaussian function to these distributions. The obtained probability density functions (PDF)can than be substracted from the OS-SF distribution. But the detector resolution has also influence on the invariant

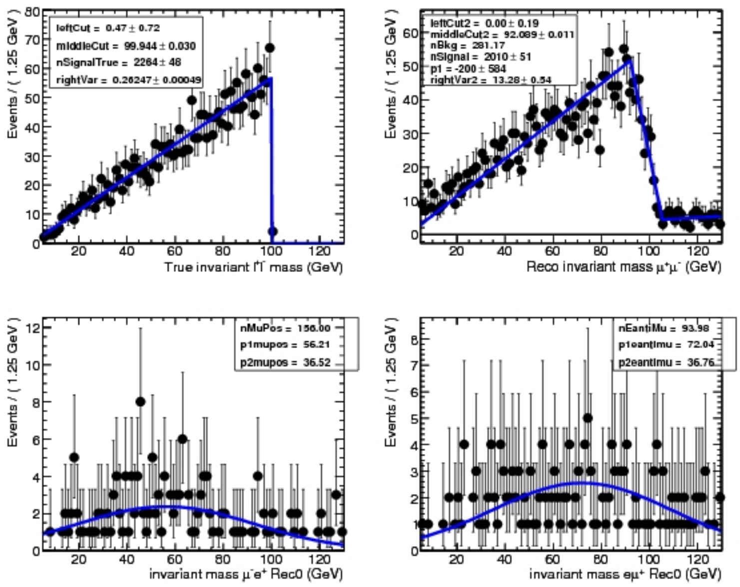

Figure 20: First row: Invariant mass with true (left) and reconstructed (right) data second row:Invariant mass for background processes fitted with gaussian functions, $\mu^- e^+$ (left) and $e^- \mu^+$ (right)

mass shape.

This has to be considered by fitting a convolution of the triangle and a gaussian function to the distribution. To set the value for the gaussian function the width of the function is needed. Therefore the resolution of the detector must be considered. The resolution is given by the difference between the invariant mass, which was calculated on the basis of the reconstructed momenta and the invariant mass, which was calculated using the true momenta. The true momenta are obtained from the truth data. For every event the difference between these two invariant masses is calculated. The result concerning electrons is shown in Fig. 21. If the detector would always measure the right momentum this difference would be zero for every lepton pair. But instead of this a gaussian distribution is observed. For muons the result is shown in Fig. 22 A gaussian width of about 1.34 GeV is obtained for muons.
With these results the distribution can be fitted again, considering the background and the statistical effects. The result is shown in Fig. 23.

The shape looks like a triangle but the edge does not have an angle of 90 degrees anymore. As a consequence of the gaussian smearing the data points move with the same probability to the right and to the left. But there are more points in the upper part of the triangle than next to it (with $m_{l^+l^-} > 100$). Therefore more data points will move down to the right than up on the edge. The vertical line assumes a finite slope. Thus the value for the mass difference $m_{l^+l^-}$ is expected to be in the middle of this line. On the basis of the errors given by the fit algortihm a value for the error of the mass

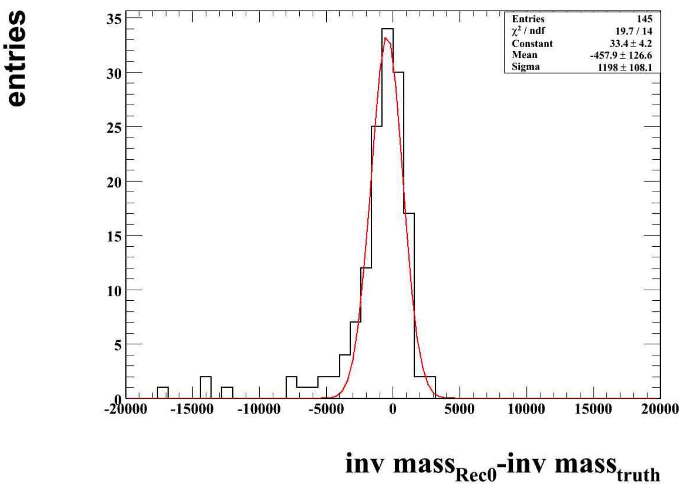

Figure 21: Resolution for the invariant mass for electrons

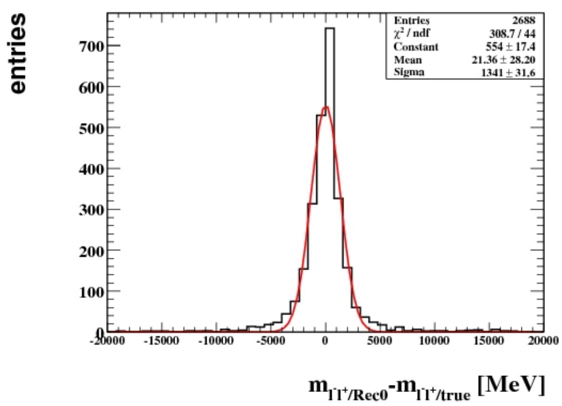

Figure 22: Resolution for the invariant mass for muons

difference is calculated.
The mass difference is obtained from the shown figure by calculating the value for the middle of the slope from the middle cut and rightVar2. The results are summarized in table 1.

middle cut [GeV]	rightVar2 [GeV]	$m_{l^+l^-/fit}$ [GeV]	$m_{l^+l^-/calc.}$ [GeV]
94.02 ± 0.32	10.25 ± 0.67	99.15 ± 0.46	100

Tabelle 1: Results for the mass difference

2.6 Conclusion

The shape of the dilepton invariant mass in the slepton lepton decay can be used to

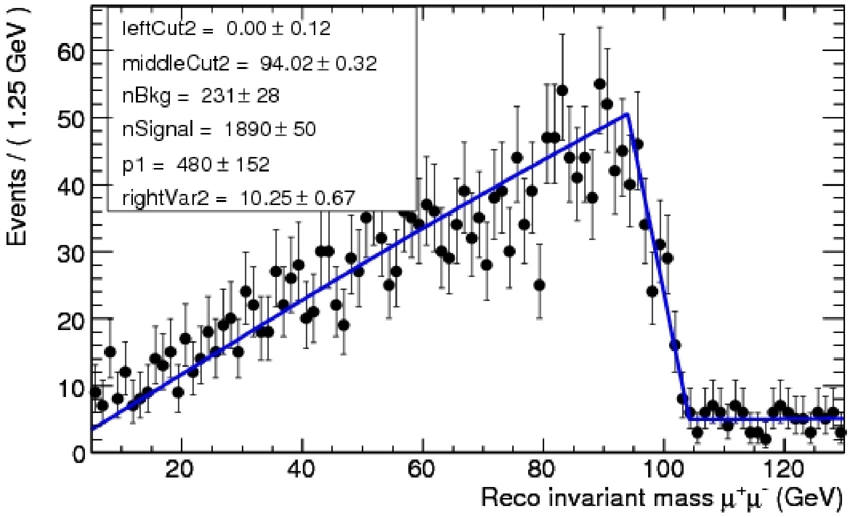

Figure 23: Invariant mass distribution for OS-SF leptons and fitted function considering the SM background and the gaussian smearing

obtain the mass difference between the two neutralinos χ_2^0 and χ_1^0. For this only electrons and muons are used, as the reconstruction of taus is more difficult. The shape for muons resembles a triangle better than the shape for electrons. This is due to the fact, that the fake rate for electrons is higher than for, due to the detector design. With muon data a good result can be achieved using a cut on the transverse momentum and the pseudorapidity η. From the obtained shape of the m_{ll} distribution, a value of (99.15±0.46) GeV is obtained for the mass difference between χ_2^0 and χ_1^0, to be compared with an expected mass difference of about 100 GeV.

A Appendix

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