HELEN program
Short Term Training Report

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1 Comment on the HELEN network

When I arrived at CERN I knew who was going to be my supervisor there, professor Giacomo Polesello, and where I was going to live, and somehow what to do when I got there. Nevertheless some of the information I had from my advisor at home was confusing, and I ended up acquiring my health insurance in Chile, which was not cheap. It would have been helpful to get a better explanation of how it was going to be done, since one letter stated we should get the insurance at home and another said the program was going to take care of it. I thought that maybe the money could have been refunded, and my first insurance kept.

On my first days at CERN my supervisor was away, but I was assigned temporarily to a workspace for ATLAS visitors in building 40. With that I had a small problem: since it was an open and public space, every time I went for lunch I had to carry all of my things with me (my books and my laptop), and sometimes when I came back, the space was being used by somebody else – which I understood was the purpose of that space. So I asked the secretary how could I get, or who could I ask for, a space of my own (at least for 3 months). It was supposed to be my supervisor's call, so he finally let me use his own office. I think maybe the network could get more involved in that, by letting the departments know that they should provide a propper workspace for the trainees when they arrive.

2 Work Program Development

The first draft on how to start my training, given my supervisor, was not followed strictly, but it helped out a lot on the further collaboration with my colleague Boris Panes:

1. Set the program we used at home to calculate neutrino masses and mixings, to also give out tables of $\widetilde{\chi}_1^0$ decays.

2. Decide on a few sets of parameters, consistent with neutrino physics, giving different final state phenomenology for neutralino decays.

3. Build decay tables for our supergravity benchmark SPS1a, including the $\widetilde{\chi}_1^0$ decay table.

4. Produce events with PYTHIA
5. Analyse the events at:
    - parton level
    - particle level
    - detector level (ATLFAST)

The first item was not done as it appeared. At first I attempted to do it based on the mentioned program, but then that task was assigned to Boris Panes. He created a new program, using some things of the old program too, while I concentrated on understanding the data analysis. The second item was never reached (although it is an important thing to do eventually, but we just did not get to in the period of the training).

The third item was done using Werner Porod's program SPheno, which yielded a file with the masses for sparticles in the SUGRA benchmark SPS1a and R parity conserving decay tables for these particles. We added by hand a decay table of the $\widetilde{\chi}_1^0$, with the branching ratios given in [1], and a total decay width borrowed from the second lightest neutralino. This was done in order to get familiar with items 4 and 5, and as long as we did not have the final results from Boris Panes's program. The detector level analysis was mentioned, I saw some output ntuples from a fortran version of ATLFAST, but I did not learn how to run this program, and for my results I did not get to use it.

Most of my first month was spent learning how to run PYTHIA and how to analyze its output. During my second month at CERN, my supervisor ahd professor John Ellis, who was Boris's supervisor, agreed on coordinating our work programmes, so we met regularly with them to discuss our progress and understand better each other's tasks. Professor Polesello was away almost the entire month of April, but we communicated and he assigned me an exercise that I had trouble completing. Professor Ellis helped me out during our meetings, and I was finally able to finish it. The assignment was to figure out every decay chain that could yield two leptons in the final state, in order to understand the substraction I had to do between the invariant mass distributions of certain lepton pair combinations, to isolate the process in which the leptons come from the same neutralino. When I finally understood this, I got some results that I tried to compare to the selection of lepton pairs coming from the same $\widetilde{\chi}_1^0$, one directly from it and the other from a W boson that came from the neutralino. I show and explain these results in the next section.

3 Event Production and Analysis

We produced 1.25×10^6 SuSy events with PYTHIA, simulated proton-proton collisions with center-of-mass energy of 14 TeV, in the SPS1a benchmark of SUGRA. For each one of these events we have two $\widetilde{\chi}_1^0$. The decay tables used for the production of the events are only those that conserve R parity, for every supersymmetric particle excepting the lightest neutralino $\widetilde{\chi}_1^0$. Since the $\widetilde{\chi}_1^0$ is the lightest supersymmetric particle(LSP), the only way for it to decay through R parity violating processes.

The sparticles masses and decay tables are calculated using SPheno version 2.2.1. We attached by hand a decay table for the $\widetilde{\chi}_1^0$, the branching ratios were given by the paper of Porod and Skands [1], for the bilinear R parity violating parameters (in GeV):

$\epsilon_1 = 0.043$	$\epsilon_2 = 0.1$	$\epsilon_3 = 0.01$
$\Lambda_1 = 0.02$	$\Lambda_2 = 0.062$	$\Lambda_3 = 0.065$

The total decay width of the $\widetilde{\chi}_1^0$ used in the input was that of the second lightest neutralino, since we did not have the correct value for this model, which is much smaller. The effect of this assumption is that the $\widetilde{\chi}_1^0$ decays earlier in our simulation that it would do with the actual number for Γ. This also means closer to the point in which it was produced. If we used the correct total width for the $\widetilde{\chi}_1^0$, we could see some displacement of the vertex of the decay. The largest branching ratios given by [1] are the following:

BR($W^\pm\mu^\mp$)=2.2%	BR($W^\pm\tau^\mp$)=3.2%	BR($\bar{\mathrm{q}}\mathrm{q}'\mu^\pm$)=1.5%
BR($\bar{\mathrm{q}}\mathrm{q}'\tau^\pm$)=2.1%	BR($\mathrm{q}\bar{\mathrm{q}}\nu_i$)=0.47%[1]	BR($\mathrm{b}\bar{\mathrm{b}}\nu_i$) = 15.6%
BR($\tau^\pm\mathrm{e}^\mp\nu_i$)=5.9%	BR($\tau^\pm\mu^\mp\nu_i$)=30.3%	BR($\tau^+\tau^-\nu_i$)=37,3%

The only cuts applied to the sample are those of related to the detector when selecting the particles: for the leptons the pseudorapidity must be

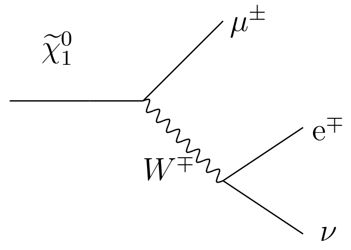

Figure 1: The decay corresponding to the dashed line in figure 3.

$\eta < 2.5$ and the transverse momentum $p_T > 10$ GeV.

3.1 Results

In figure 3 we show the substraction between the invariant mass distributions for a pair of leptons consisting on a muon and an electron with opposite sign (Opposite Sign Different Flavor: OSDF), and the distribution of a muon-electron pair with the same sign (SSDF). The solid line is the number of events where only one OSDF lepton pair was found in the final state; to which we substract the number of events where only one SSDF pair was found, for the same value of invariant mass.

The dashed line belongs to the events in which we find only one lepton pair, and we know it comes from the decay $\widetilde{\chi}_1^0 \rightarrow W^\pm\, l^\mp$ with the W boson decaying into a lepton and a neutrino. This is what we call coming from the truth, or history.

The decay shown in figure 3.1 violates R parity and lepton flavor. The branching ratio of the neutralino decaying into a W boson and an electron is very small, less than 1%, but this is not so for the decay into a W boson and a μ.

When we substract the invariant mass distribution for SSDF pairs from the distribution corresponding to OSDF, we keep only the pairs generated in processes that allow opposite sign lepton pairs exclusively; those pairs that come from the same neutral particle, such as the $\widetilde{\chi}_1^0$ or the $\widetilde{\chi}_2^0$. This does not isolate uniquely the decay we are looking for, depicted in figure 3.1. The solid line in figure 3 also includes the contributions of three body decays of the $\widetilde{\chi}_1^0$, such as $\widetilde{\chi}_1^0 \to \mu^{\pm}\tau^{\mp}\nu$ and $\widetilde{\chi}_1^0 \to \tau^{\pm}\tau^{\mp}\nu$, with the τ decaying into leptons; as well as the decay of the second lightest neutralino $\widetilde{\chi}_2^0 \to \widetilde{\tau_1^{\pm}}\tau^{\mp}$ or $\widetilde{\chi}_2^0 \to \widetilde{\chi}_1^0\tau^{\mp}\tau^{\pm}$ with the τ decaying into different leptons, and the $\widetilde{\chi}_1^0$ into other things (such as quarks and a τ that in turn decays into hadrons). We show all of these possibilities in figure 3.1. These decays, that at first were not considered, would explain the difference found between the dashed and the solid line.

We can see that the dashed line distribution has a triangular shape and a clear endpoint corresponding to what we expected, in analogy to the shape of the decay $\widetilde{\chi}_2^0 \to \widetilde{l^{\pm}}\, l^{\mp}$ with the slepton decaying into a $\widetilde{\chi}_1^0$ and a lepton [5]. The position of that endpoint is given by $m_{ll}^{end} = \sqrt{M^2_{\chi_1^0} - m_W^2} \approx 55$ GeV, according to [3]. The solid line also presents some sort of structure, with an endpoint close but not exactly the same as the distribution we are looking for, but actually close to the mass of the neutralino in this benchmark.

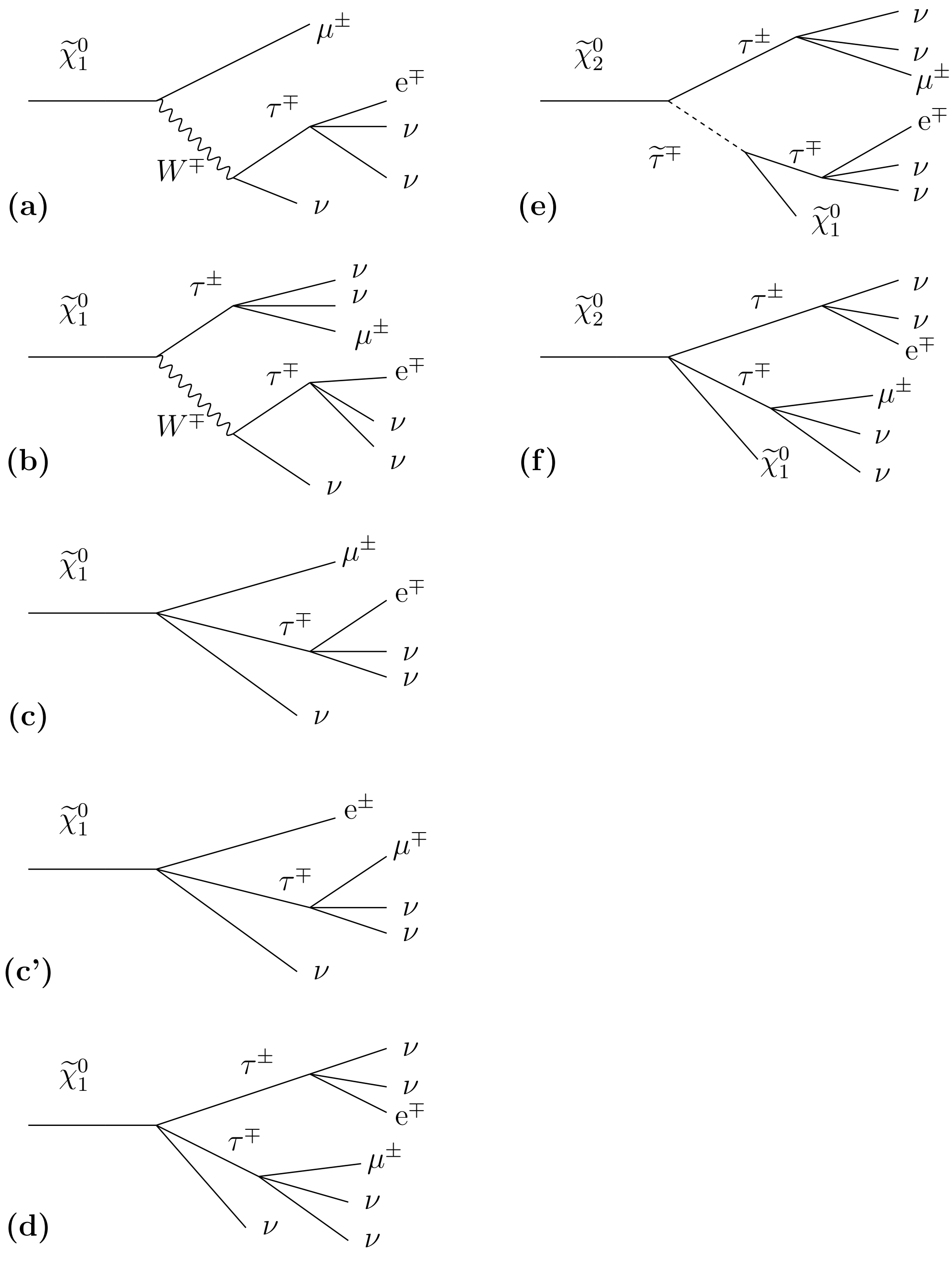

Figure 2: The decays that contribute to the OSDF distribution.The decays on the right are considered when the $\widetilde{\chi}_1^0$ decays into something other than electron and muon, i.e.: quarks and taus, that in turn yield hadrons and jets.

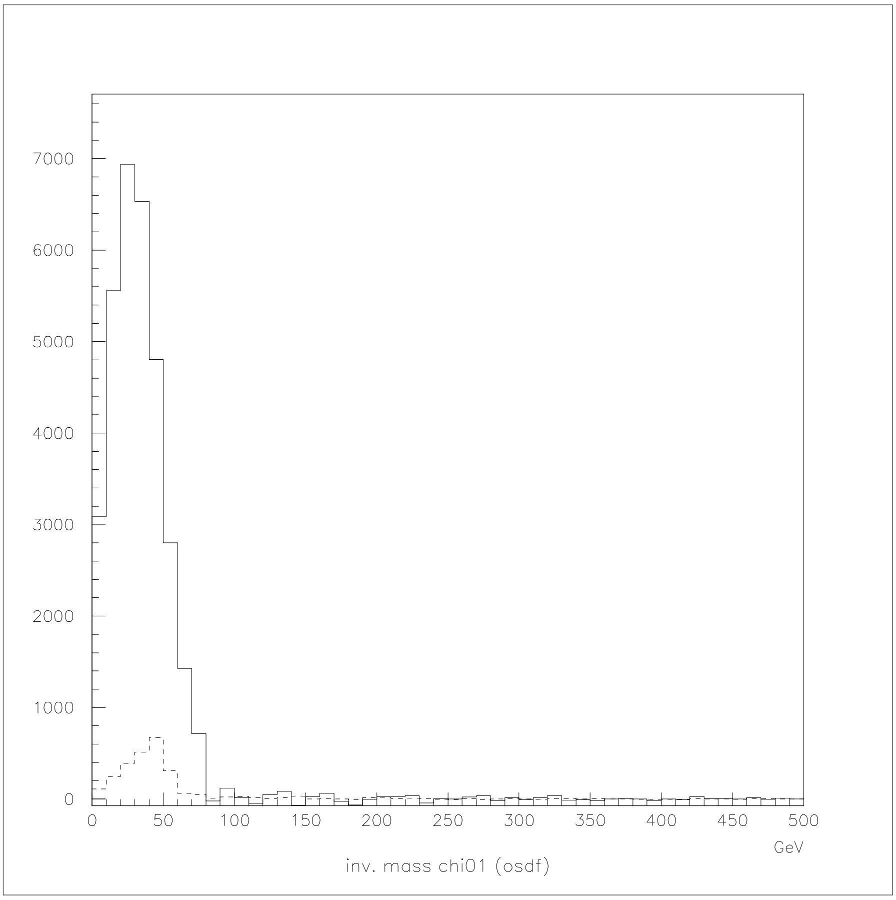

Figure 3: Invariant mass distribution for a pair of leptons with opposite sign and different flavor.

In figure 5 we show the invariant mass distribution of the pair $\mu^+\mu^-$ to which we substract the distribution of the pair of muons with the same sign. At the same time we perform the similar substraction for electrons: the number of events with one pair e^+e^-, minus the number of events with a pair of electrons of the same sign, for the value of invariant mass of the bin. Then we substract the latter from the former, this operation should isolate the decay $\tilde{\chi}_1^0 \to W^\pm\mu^\mp$ in which the W decays into a μ and a ν_μ.

The first operations, substracting SSSF distributions from the ones OSSF, separately for electrons and muons, allows us to keep only those events in which the pair can solely be of opposite sign, when both particles are originated from the same neutral particle. Thus we are left with the decays in figure 3.1 and 3.1 -but replacing the electron for a muon- for the muon pair; and with the decays in figure 3.1 -except the first on the left, and replacing the muon for an electron- for the electron pair. This means we have 7 processes that give SSSF pair of muons and 5 that give SSSF pair of electrons. When we substract the two of them, we don't get to isolate two, but the three processes that do not involve a pair of taus. This because the decay of taus has almost the same branching ratio into muon as into electron. But the direct decay of the $\tilde{\chi}_1^0$ is asymmetric in μ and e,

The second one eliminates the contribution of the two symmetric processes $\chi^\pm \to W^\pm\tilde{\chi}_1^0 \to W^\pm\mu^\pm W^\mp$ with the two W bosons decaying into jets, in this process the signs of the muons do not correlate, we can have same sign as well as opposite sign pairs.

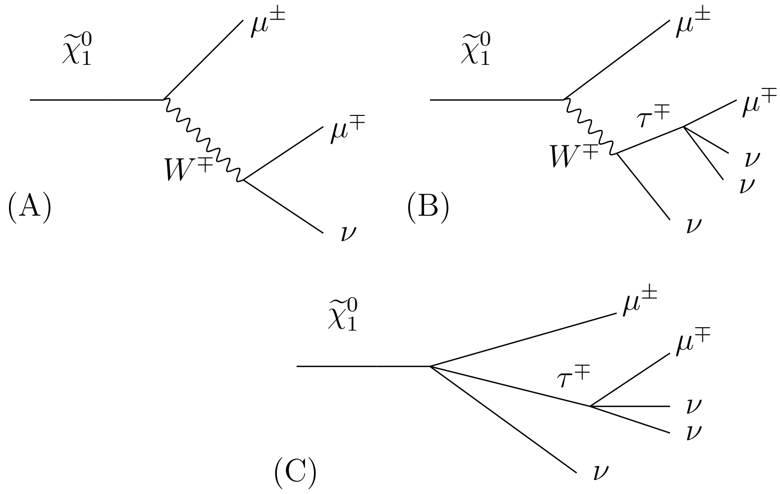

Figure 4: The decays that contribute to the solid line in figure 5, after the substraction $(\#\mu^+\mu^- - \#\mu^\pm\mu^\mp) - (\#\mathrm{e}^+\mathrm{e}^- - \#\mathrm{e}^\pm\mathrm{e}^\mp)$.

Once again the dashed line represents the invariant mass distribution of a pair $\mu^+\mu^-$ that we know comes from the decay $\widetilde{\chi}_1^0 \to W^\pm\mu^\mp$, with the W decaying into a muon and ν_μ. There is the triangular shape and the end point in the same place as before, as expected. The solid line corresponding to the events in which only two leptons were found, making the substraction explained before.

We get a lot more events that do not correspond to the process we want. But since there is also a clear endpoint we can say there must be other lepton flavor violating processes that give a signal. We know the processes (B) and (C) are not completely eliminated with the substraction, so these can explain the difference between the dashed and the solid line in figure 5. In fact, all events that present process (B) are being counted, since the branching ratio of this process but with a pair of electrons is very small, and nothing cancels it. Not all the events that have the (C) process contribute to the plot. Some of them are substracted because the branching ratio for it into an electron pair is not zero, but it is much smaller than the value for the μ pair, and it cannot substract (C) completely.

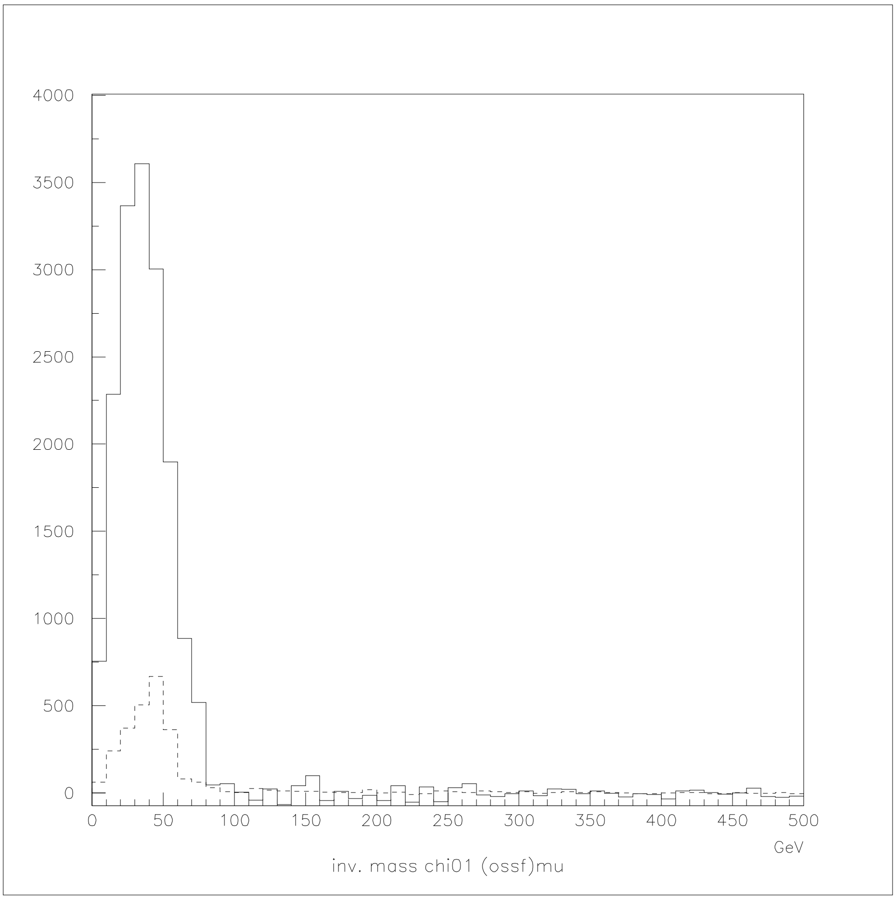

Figure 5: Invariant mass distribution for a pair of leptons with opposite sign and the same flavor.

3.2 Conclusions

We were able to obtain plots that showed us the invariant mass distribution of lepton pairs, isolating processes that gave an endpoint, which is related to the mass of the neutralino. We have not been able yet to isolate exclusively one decay, the one that is shown in the dashed line in the two plots, whose endpoint we know.

We showed two attempts to make the process we want stand out from the simulated data, we try to isolate the distribution of a certain type of decay through substraction. The first one, substracting from OSDF distribution the SSDF distribution, is not too good, we ended up having a lot of extra processes that we did not want, and blurred out the signal we were looking for. The second one, $\mathrm{OSSF}_\mu - \mathrm{SSSF}_\mu - (\mathrm{OSSF}_\mathrm{e}\mathrm{SSSF}_\mathrm{e})$ is better, at least we got rid of the processes involving the $\widetilde{\chi}_2^0$, but we were still counting events we did not wish to count. The processes (B) and (C) shown in figure 3.1 were giving extra events to our count and their invariant mass distribution hid the one from (A) that we were looking for.

To make sure that we are now considering every possibility in our plots, we plan on redoing the plots, but this time including in the dashed line distribution, coming from the simulation truth, the processes the substraction could not cancel. We also want to compare these same plots with a third curve, the theoretical distribution of invariant mass for the lepton pairs for all the processes included in the counts.

Another thing we should do next is to figure out how to measure the branching ratios of the $\widetilde{\chi}_1^0$, because a ratio of branching ratios gives us the value of the atmospheric angle for the neutrinos, which was the original purpose of this work.

References

[1] W. Porod and P. Skands, “Measuring neutrino mixing angles at LHC,” arXiv:hep-ph/0401077.

[2] I. Hinchliffe and F. E. Paige, “Lepton flavor violation at the LHC,” Phys. Rev. D **63**, 115006 (2001) [arXiv:hep-ph/0010086].

[3] A. Mirea and E. Nagy, “Study of the determination of the SUGRA parameters using the ATLAS detector in the case of L-violating R parity breaking,” arXiv:hep-ph/9904354.

[4] ATLAS Collaboration, “ATLAS detector and physics performance. Technical design report. Vol. 2,” CERN-LHCC-99-15

[5] C. G. Lester, “Model independent sparticle mass measurements at ATLAS,” CERN-THESIS-2004-003