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Analysis of $Z' \rightarrow ee$ with the ATLAS-Detector

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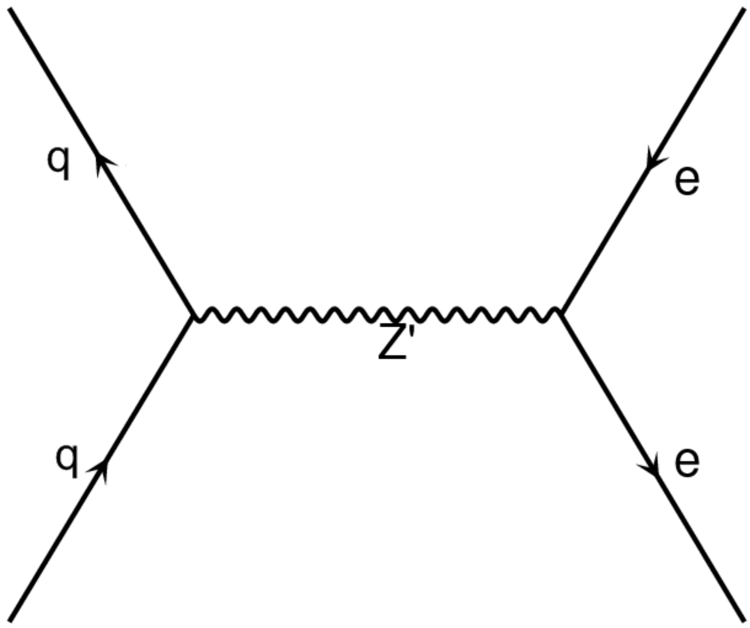

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1 Introduction

The current theory in particle physics is the so-called *Standard Model*. This theory has been confirmed by many experiments and describes three of the four fundamental forces. Gravity, the fourth force in nature, is neglected. The Standard Model groups the electroweak [1]- and the strong force in one $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$ gauge group [2]. Although it seems to be a good theory, one knows that this cannot be the final one, due to the fact that gravity is not included. In addition the *coupling constants* do not meet at higher scales. So other theories, so called *Grand Unified Theories (GUT)*, try to unify the three forces in bigger gauge groups like $SU(3)^3$, $SU(5)$, $SO(10)$ or the Lie-groups E_6 or E_8. But one cannot observe such a symmetrie in nature yet, so the higher symmetrie must be broken. In these mechanisms a massive neutral gauge boson occurs, the Z', named in analogy to the Standard-Model Z boson, the neutral elektroweak force carrier. Many other theories like string theories or extra dimensions predict a Z' as well.
In this analysis a Z' is considered, that has the same couplings as the Z boson, but a mass of 1 *TeV* (as pictured in Fig. 1). In this paper, natural units are used, such that $c = \hbar = 1$.

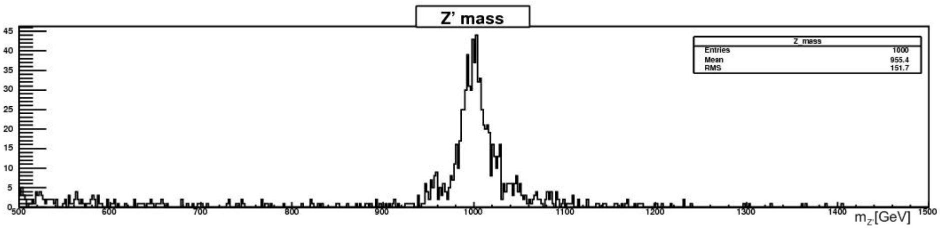

Figure 1: Z' mass on true-level

2 Analysis

In Monte Carlo data there are mainly two sets of data, the *truth* and the *reconstructed* parameters. The truth-level describes the physical process and there the decay-chain can be investigated, because to every particle a parent-particle is present, whereas the reconstructed-level contains the detector output and there it is not as easy to get information about the parents as on truth-level. I tried to investigate in the Monte Carlo data, using parent-trees, which processes lead to a Z' production, but some problems occur within the data structure. There one must have a closer look, if one writes a diploma thesis (or something equal) about this topic, but I only have a couple of weeks.
The analysis is subdivided into two parts, the first will handle the truth-level data and the second one the reconstructed electrons.

2.1 Monte Carlo Truth Level

In *pp* colliders like the LHC, the transverse momentum is a very important variable, because it is conserved, while the momentum in z-direction (in beam direction) is not known apriori.

[1] a unification of electromagnetism $U(1)_{el}$ and the weak force $SU(2)_L$ to a $SU(2)_L \otimes U(1)_Y$ symmetry
[2] where C indicates *color*, L the *left-handed* particles and Y the *hypercharge*

On truth level, it is possible to get the transverse momentum of the Z' directly. As Fig. 2 (first one) shows, the transverse momentum of the Z' is expected to be mainly below $200GeV$. When one looks at the electrons coming from a Z' decay, it is expected that the transverse momentum decreases rapidly at $500GeV$. Figure 2 reflects this behavior.

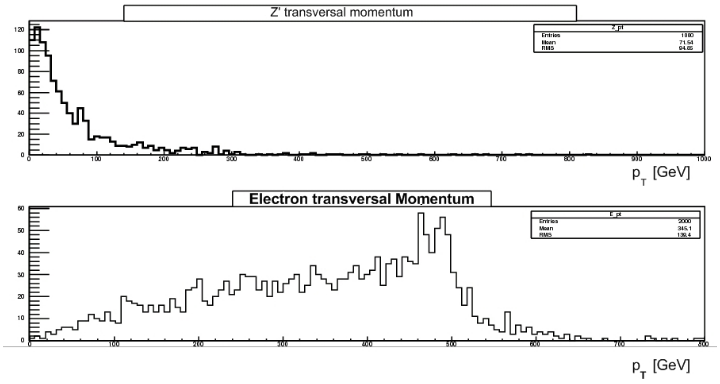

Figure 2: Z' transversal momentum and electron transversal momentum

To get the mass of the particle the electrons came from, one can calculate the invariant mass of the two electron system. This is shown in Fig. 3.

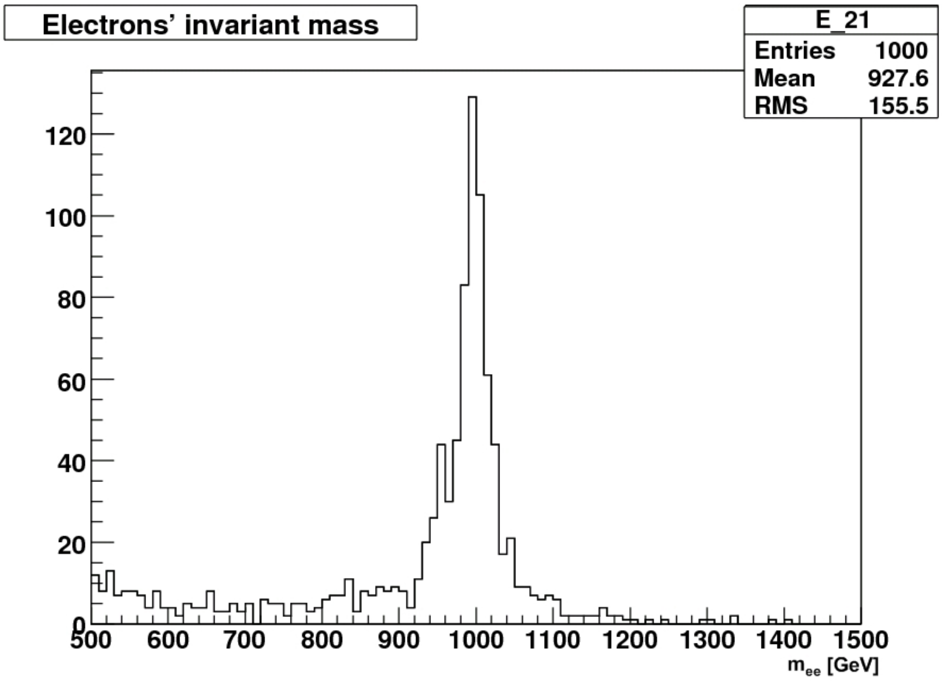

Figure 3: e^+e^- system's invariant mass

One observes a peak at $1TeV$, because this is the mass of the parent particle, the Z'.

Another important parameter is the so called *pseudorapidity* $\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$.

One can see in Fig. 4 that $\eta = 0$ means a scattering with $\theta = 90°$. The ATLAS detector is sensitive for electrons in a region of $|\eta| < 2.5$, in addition electrons in the interval of $|\eta| \in [1.37, 1.52]$ are neglected, because there, the detector is not that accurate due to the transition of the barel to the end-cap calorimeter.
It is of importance that one knows how many particles cannot be seen in the detector due to geometric reasons. The percentage of the seen electrons is called *geometric acceptance*.
Figure 5 shows the η distributions of all electrons without any restrictions and the distributions of all electrons with geometrical cuts and a p_T greater than $100GeV$. In addition it is illustrated how the p_T spectrum of the Z' changes when only the electrons with these cuts are taken into account (see Fig. 6).

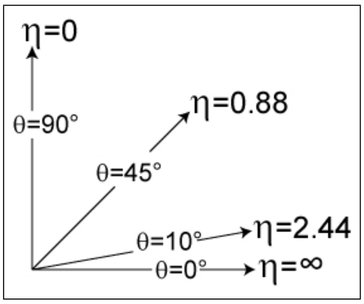

Figure 4: Pseudorapidity

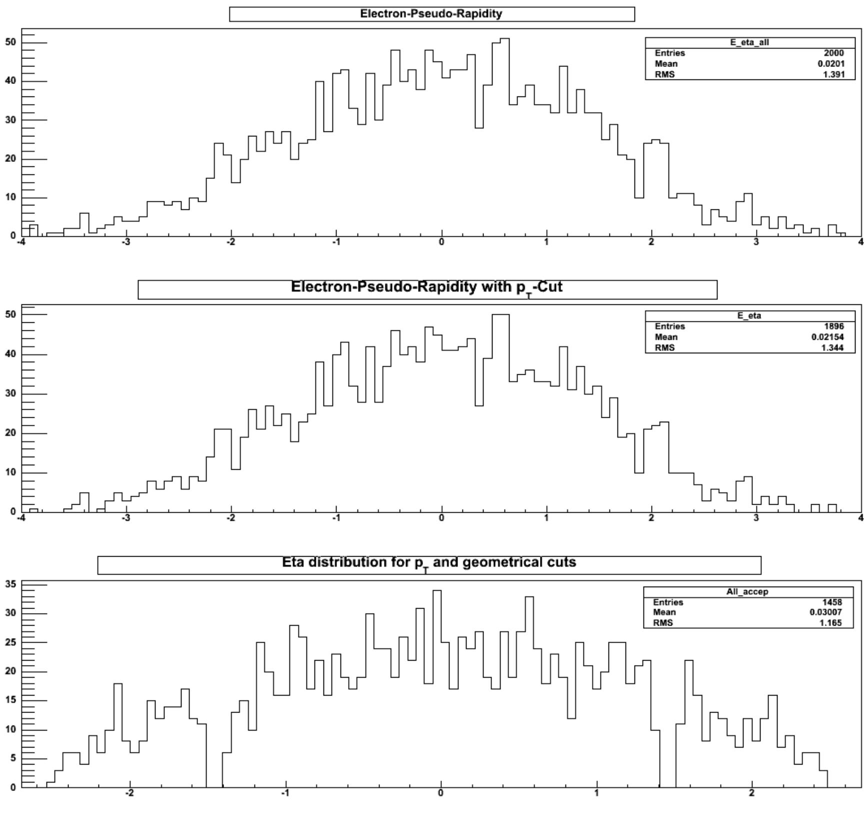

Figure 5: η distributions with different cuts

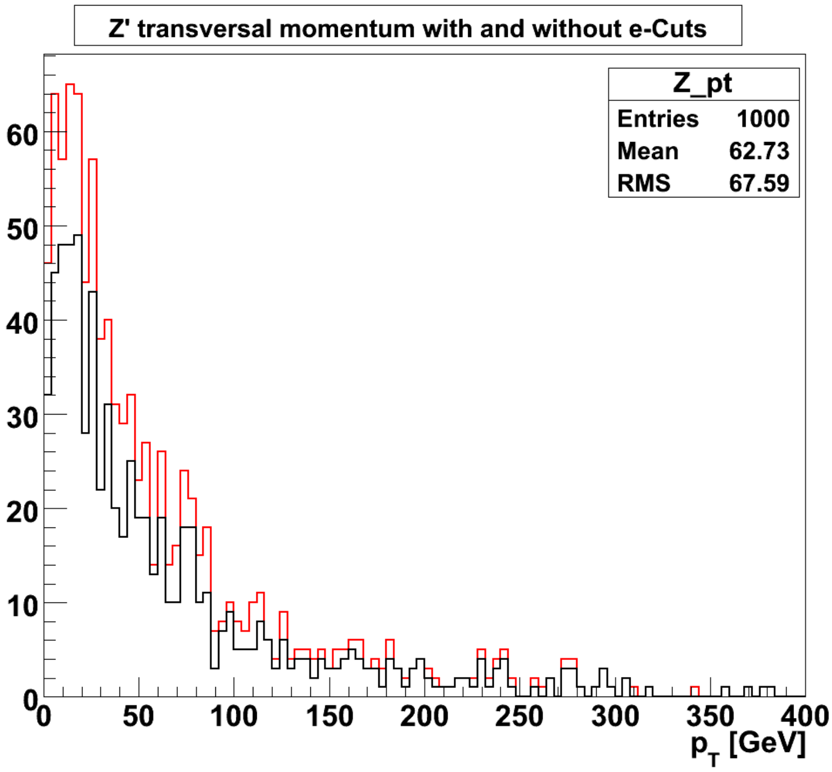

Figure 6: Z' p_T spectrum, red spektrum is without, black one with cuts

One can see that with a cut on $p_T > 100\ GeV$ there are still 94.80% of the electrons left. If one adds the geometrical boundaries, one ends up with 76.90% of the "cutted" electrons and 72.90% of all electrons. This is, of course, the acceptance of the Z', too.

Another interesting point are the η distributions of the Z' depending on whether it is coming from a $u\overline{u}$- or $d\overline{d}$ reaction, just to check if there is a difference between them. The result is pictured in the figure 7.

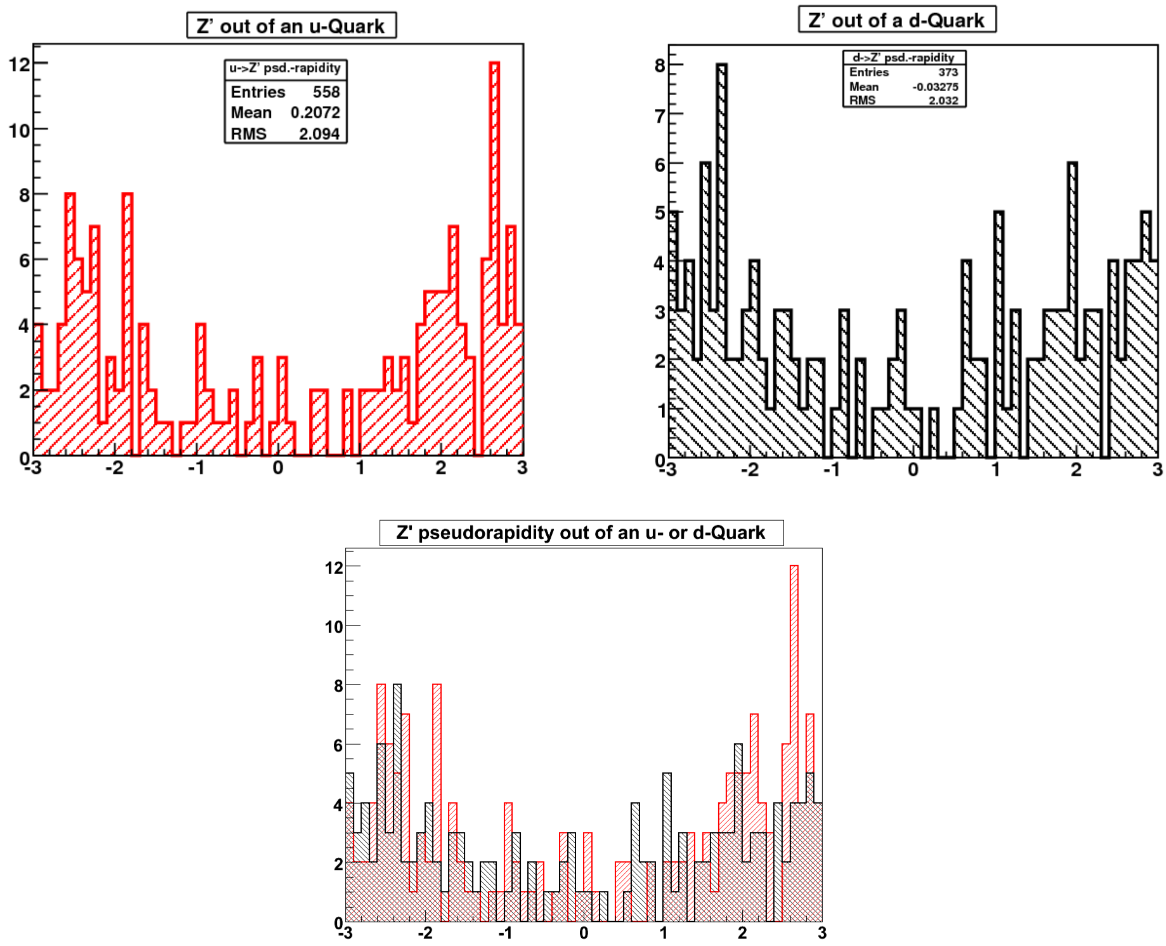

Figure 7: Z' p_T depending on parent-quark

As it can be seen, there is no significant difference between the distribution for up and down-quarks. Besides there are more Z's coming from an u-quark, than from a d-quark (as expected, because the proton has two valence up-quarks), there are only statistical fluctuations.

2.2 Reconstructed Level

On reconstructed level, detector details are taken into account and QCD background was included into the dataset. In addition all histogramms are normalized to an integrated luminosity of $\int \mathscr{L} \mathrm{d}t = 100pb^{-1}$. But due to the fact that in the interesting energy regime there are no electrons[3] in the background anymore, one calculates a "fakerate"-factor ζ. This factor is the percentage of jets falsely identified as electrons. Theoreticaly this should be $E-$ or p_T-dependent, but there was not enough background for this calculation (see Fig. 8).

[3] these electrons are faked electrons, this means jets falsely identified as electrons in the detector

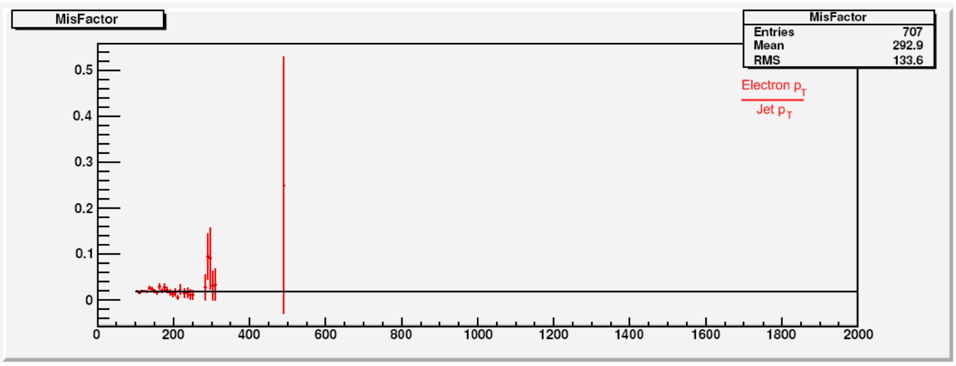

Figure 8: Electron p_T spektrum divided by jet p_T

The electron p_T spektrum is divided by the jet p_T (in red) and one can see, that between $400 - 800GeV$ there are not enough electrons for a good p_T dependent fakerate-factor.
So, in this case, the fakerate-factor is a constant, calculated by dividing the number of electrons and the number of jets in the background-sample.

$$\zeta = \frac{\#electrons}{\#jets}$$

One distinguishes between loose, medium and tight electrons, these are special kinds of electron selections, which suppresses the background by a factor of around 10 each. Here only loose and medium electrons are considered. For loose electrons the fakerate-factor is

$$\zeta = \frac{105}{31099}$$

and for medium ones

$$\zeta = \frac{24}{31099}.$$

Now one takes all the jets and handle them as background, but weighted with ζ (and luminosity of course). The results are shown in the Fig. 9 for loose and Fig. 10 for medium electrons, where the background- and signal samples are added.

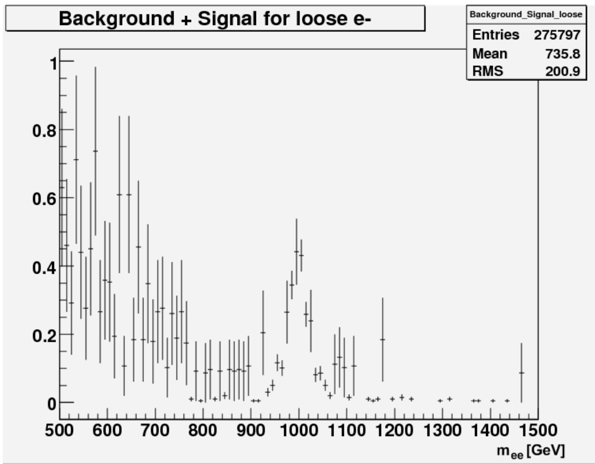

Figure 9: Background and Signal (loose) electrons invariant mass

As one can see (in Fig. 9), the background is quite dominant, especially the errors are big and a lot of bins in the histogramm are not filled with background, this again indicates, that the number background events is too small.

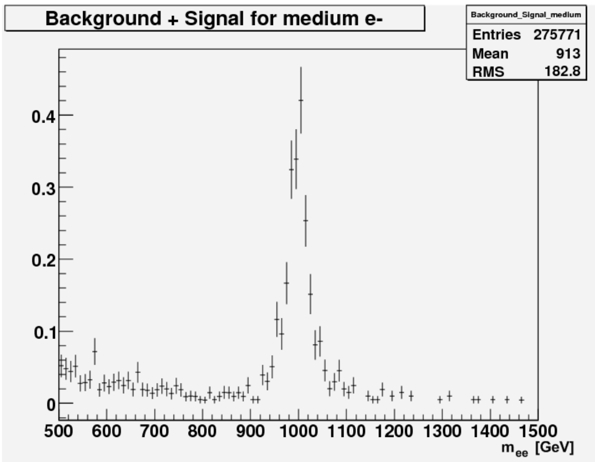

Figure 10: Background and Signal (medium) electrons invariant mass

Now, taking medium electrons, the background is suppressed in a good way (see figure 10).
For the physical process a Breit-Wigner function is expected, but as the detector is not perfect, one should take detector uncertainties into account. This leads to a so called *Voigtian* function, which is the convolution of a Breit-Wigner and a Gaussian function. For the background a simple exponential function is assumed. The results of the fit are shown in the Fig. 11 and 12.

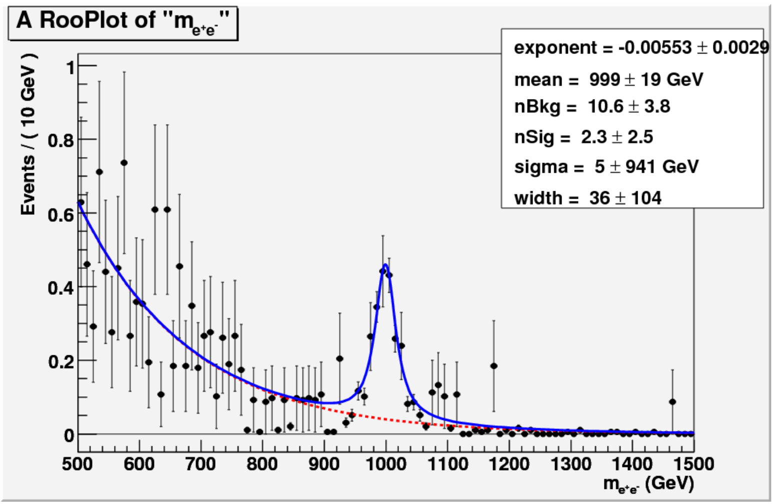

Figure 11: Fit of the invariant mass for loose electrons

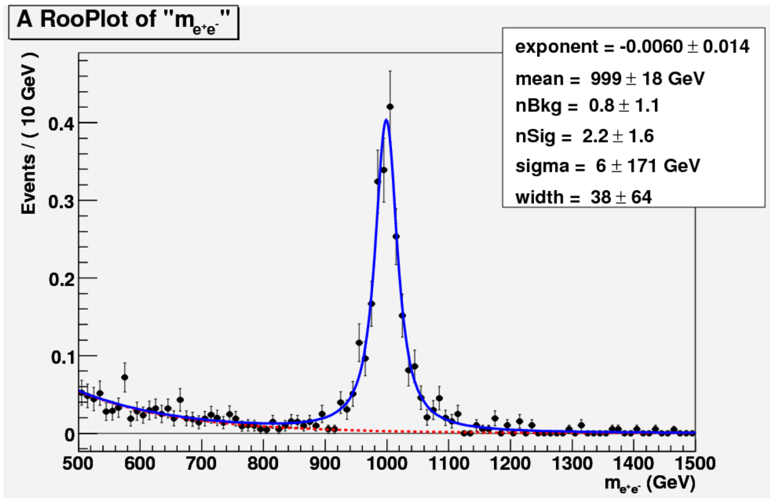

Figure 12: Fit of the invariant mass for medium electrons

It seems that the function describes the data well. In both cases the calculated parameters are more or less the same and the mean, which represents the mass, is quite accurate with around 2% error. Also, one can see that with taking the medium electrons the background is suppressed, as expected. But a crucial point are the errors on *sigma* and the *width*, but it is hard to tell, if they are meaningful, because on the one hand the background has no significant statistic in the interesting energy-region and on the other hand the plots are dependent on the binning of the histogramms. But reducing the number of bins do not lower the errors in a satisfying way, because one loses accuracy on signal events. It seems that the interpretation of the background and handling the weights produces high errors.
In the end one can calculate a cross-section (here for medium electrons) as

$$\sigma_{pp\to Z'} \otimes BF(Z' \to ee) = \frac{nSig}{(acceptance \otimes efficiency) \cdot \int \mathscr{L} \mathrm{d}t}$$

where $nSig = 2.2$ is taken from Fig. 12, $(acceptance \otimes efficiency) = 57.1\%$, knowing that 571 Z's are still present after all cuts and $\int \mathscr{L}\mathrm{d}t = 100pb^{-1}$. One ends up with

$$\sigma_{pp\to Z'} \otimes BF(Z' \to ee) = 0.04pb^{-1}$$

The nominal Pythia-generator value for this cross-section was $\sigma_{pp\to Z'} \otimes BF(Z' \to ee) = 0.5126pb^{-1}$, so a factor of 10 is missing.

3 Summary and Outlook

For the truth level analysis part everything is fine. There one can see, that the ATLAS detector should have a high geometrical acceptance for the Z'. Aboud 73% of the $Z's$ can be seen in the ATLAS detector. Although the statistic is not so good, there was no difference in the η-distributions of the Z' found depending on the parent-quark.
The analysis with reconstructed electrons is problematic, because there was not enough background in the interesting energy region. Adding enormous (luminosity-) weights might result in very large errors. This can be a reason for the big uncertainties on the fit parameters. To improve the fitting algorithm, one can use datasets instead of histogramms. The big advantage is, that then the fits are independent of the histogramm binning. This may also result in lower errors. There would be a few methods to improve the fits, but time is running out.
The calculated cross-section is wrong, but a recent check shows, that in the input files of the analysis a missing factor of 10 in the normalization could lead to the wrong cross-section. But this of course has to be examined in more detail.

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