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ATLAS Group
EGamma Studies

journal of activities

Study of EM-calorimeter clustering efficiency using $J\psi \to e^+e^-$

Tag and Probe with electrons

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Abstract: This report gives a summary of my activities during the DESY summerschool 2010. Reconstructing J/ψ from the di-electron channel requires a good efficiency in identifying electron signals. Understanding the efficiencies of the specific reconstruction steps is important. Using tag-and-probe method it was possible to determine the efficiency of the calorimeter clustering in MC and data. The efficiency is well described by the MC. Nevertheless open questions remain.

Abstract: In diesem Protokoll werden die Ergebnisse von meinem Projekt der DESY Summerschool 2010 präsentiert. Um das J/ψ Meson über den Di-Elektron Kanal zu rekonstruieren, braucht man eine gute Effizienz beim Identifizieren von Elektronen. Ein tiefes Verständniss des Detektorverhaltens ist eine wichtige Grundlage für jede weitere Analyse. Die Effizienz der Clustersuche im EM-Kalorimeter wurde untersucht. Wir konnten zeigen, dass die MC-Daten die Effizienz der echten Events gut beschreiben kann. Allerdings verbleiben einige offene Fragen.

Contents

1. Motivation

The ATLAS detector at the LHC accelerator is a multi purpose detector. Its goal is to discover the last missing particle of the Standard Model (SM), the Higgs boson and search for other physics beyond the SM like SUSY. To better understand the detector in the beginning of the experiment the detector is also used to rediscover known physics. With the improved statistics perhaps even new details of known systems can be discovered.

It is very important to understand the different subdetectors and their efficiencies very precise before new physics can be discovered. The report focusses on the detection of electrons, especially the efficiency of the cluster reconstruction in the electro-magnetic (EM) calorimeter. The tag-and-probe method using the electrons from the J/ψ meson was chosen to determine the efficiency of the EM-calorimeter clustering.

2. Basics

All information in this chapter is taken from the PDG. [eaPDG10] The J/ψ particle is a $c\bar{c}$ meson with a mass of 3096.916 ± 0.011 MeV and a width of 92.9 ± 2.8 keV. The most prominent decay is to hadrons $(87.7 \pm 0.5)\%$ followed by the decay to a e^+e^- pair $(5.94 \pm 0.06)\%$, which is used in this analysis, and to $\mu^+\mu^-$ pairs $(5.93 \pm 0.06)\%$.

An electron signature consists of a track in the inner detector and a shower in the EM-calorimeter. Requiring a track rejects neutral particles like photons or neutral pions and kaons. A typical electron looses all its energy inside the EM-calorimeter and therefore does not give a signal in the hadronic calorimeter, so hadrons (pions and kaons) can be rejected. To differentiate an electron shower from other signals in the EM-calorimeter, cuts on specific variables of the shower shape are done, for example on the ratio of energy deposit in the first layer to the total energy deposit. A full list of the different cuts can be found in the ATLAS documentation. [ATL09] In addition to the EM-calorimeter the ATLAS detector has electron identification capability using the Transition Radiation Tracker (TRT). This uses the fact, that particles with high velocity ($\gamma \gtrsim 10^3$) produce more hits passing high thresholds, than slower particles.

3. Tag-and-probe method

To determine the clustering efficiency of the EM-calorimeter we use the tag-and-probe method. We need an unbiased probe track, that very certainly comes from an electron. Then it is possible to determine the efficiency to find a corresponding cluster to this track. This very clear electron signal is provided by the J/ψ to e^+e^- decay. If we can reconstruct the J/ψ mass peak with requiring an electron and only requiring a track for the second decay particle, one can be quite sure to have a track from an electron.

4. J/ψ reconstruction with electron and track

The first step was to show that it is possible to reconstruct the J/ψ peak with requiring an electron and a track. Therefore testing this method with Monte Carlo data is necessary. The MC data used in this study are created with Pythia. One set of data contains direct J/ψ production with on electron above 3 GeV and another set contains minimum bias events as background.

To get the optimal number of reconstructed events the required parameters for the track have to be varied. The first parameter is the p_T cut (ranging from 1 GeV to 5 GeV). The other

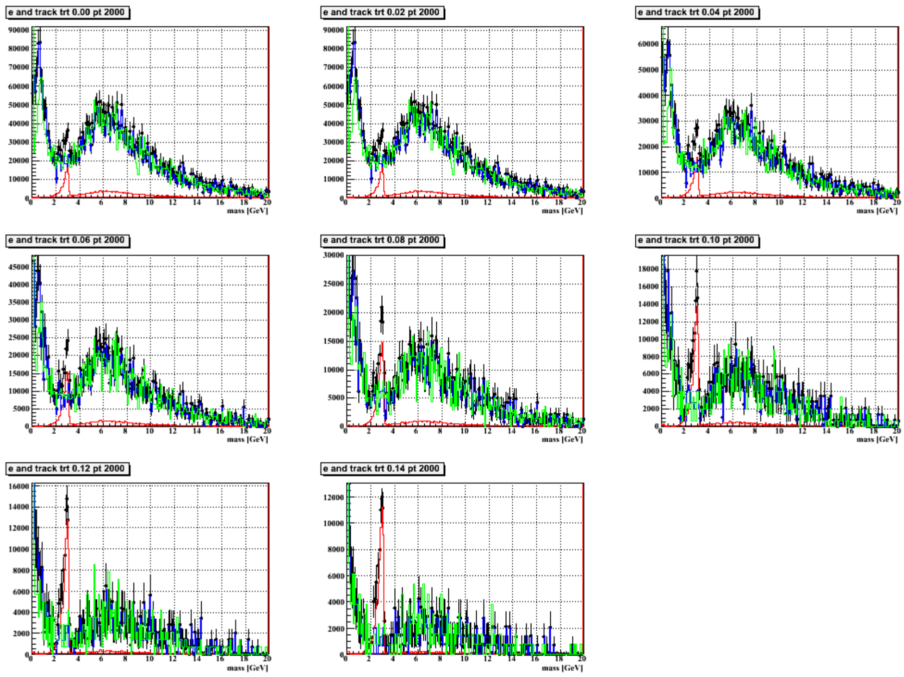


Figure 1: mass spectra for $p_T > 2000MeV$

parameter is the TRT-ratio (ranging from 0.00 to 0.14), this parameter has a big influence on the rejection of false positive signals. This parameter is defined as the ratio of number of TRT hits passing the high threshold to the total number of hits.

The invariant mass of the sum of the electron and every track out of the MC data is calculated and filled into a histogram. The same is done with the minbias events. The reconstruction requires in addition to the cut selections that electron and track have different sign of charge. The result shown in figure 1 is typical for a medium p_T cut. The other plots for values of p_T can be found in the appendix A. The histograms are normalised to $100\,\mathrm{nb}^{-1}$

It can be seen, that it is possible to see the J/ψ peak with the electron plus track method. The height of the peak strongly depends on the value of TRT and the pt-cut. To compare the different sets of these variables, one has to calculate the number of signals (or the rate) and the ratio of signal to noise.

From the sum of minbias and direct J/ψ we subtract the scaled (same integral from 4 GeV to 20 GeV) same-sign events as background. The number of signal and noise events is measured in the interval from 2.5 GeV to 3.2 GeV.

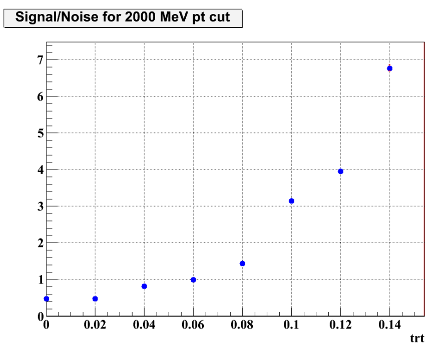


Figure 2: signal to noise for $p_T > 2\,\mathrm{GeV}$

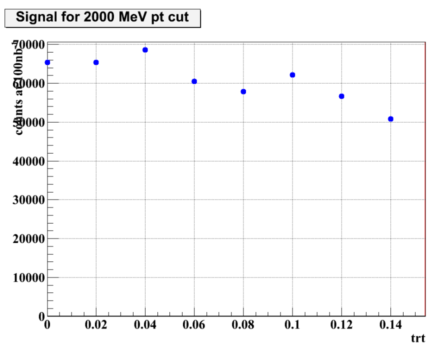
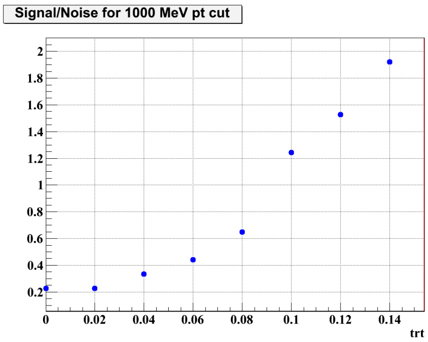
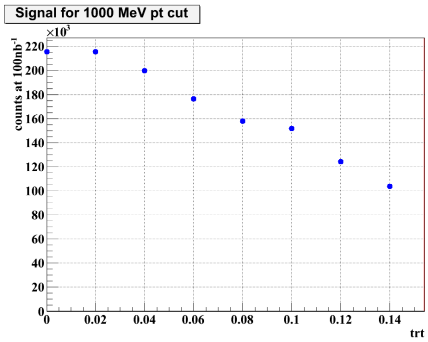


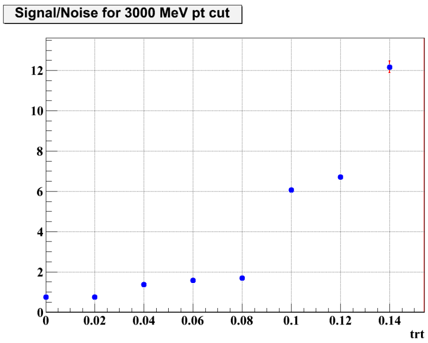
Figure 3: signal for $p_T > 2\,\mathrm{GeV}$



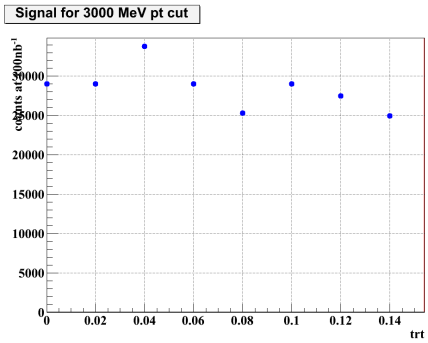
(a) signal to noise for $p_T > 1\,\mathrm{GeV}$



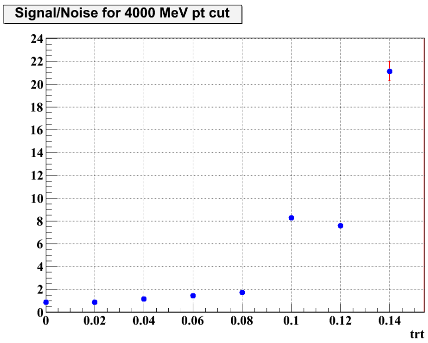
(b) signal for $p_T > 1\,\mathrm{GeV}$



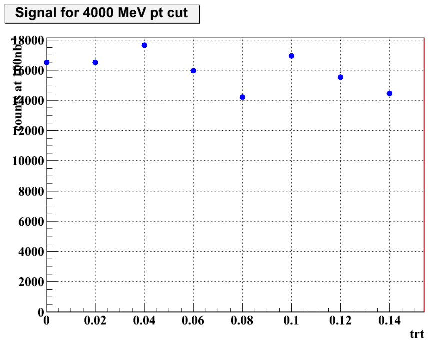
(c) signal to noise for $p_T > 3\,\mathrm{GeV}$



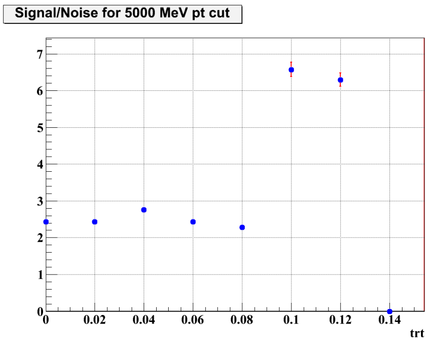
(d) signal for $p_T > 3\,\mathrm{GeV}$



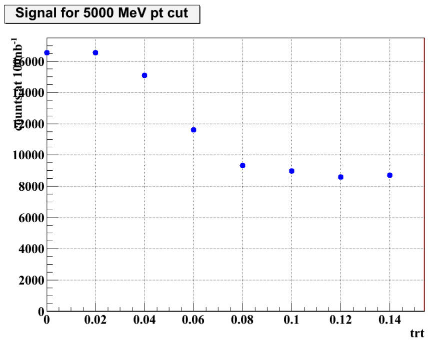
(e) signal to noise for $p_T > 4\,\mathrm{GeV}$



(f) signal for $p_T > 4\,\mathrm{GeV}$



(g) signal to noise for $p_T > 5\,\mathrm{GeV}$



(h) signal for $p_T > 5\,\mathrm{GeV}$

Figure 4: Signal to Noise Plots

We could show, that it is possible to get a reasonable number of J/ψ events with a good separation from the background. For the further analysis we choose $p_T^{min} = 2\,\text{GeV}$ and $trt = 0.12$ so signal to noise is ca. 4 for this combination (see figure 2) with a high number of events (see figure 3).

5. Calorimeter Efficiency

To estimate the efficiency of the calorimeter we try to match the CaloClusters to the tracks manually. We consider a cluster matched to the track if it is within a specific ΔR range.

$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

To exclude double counting only the cluster with the smallest ΔR is taken. One has to find a reasonable maximum value for the ΔR between the track and the cluster. Therefore the spectrum of all ΔR values was used (see figure 5 and 6) and $(\Delta R)_{max} = 0.2$ determined.

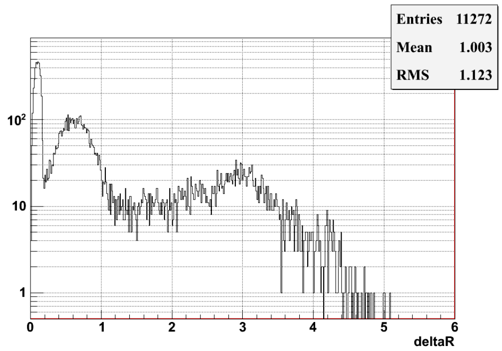


Figure 5: distribution of deltaR

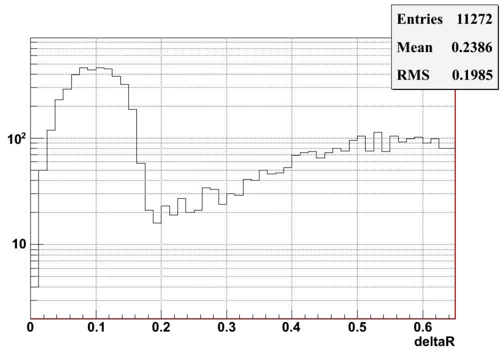


Figure 6: detail view

The peak near zero is the right associated cluster. The second peak could be the cluster corresponding to the other electron. As a cross check to see if the cluster and the track really belong to each other the correlation between E_T in the calorimeter an the p_T of the track is plotted. The result shows (see figure 7), that track and cluster have almost the same transverse energy or momentum, so they are really related.

5.1. Implementation

For the determination of the efficiency as a function of the track-p_T we fill the reconstructed J/ψ into histograms corresponding to track-p_T bins with the function `fillMassHistCalo(pt, electron, track)`. The calculation of events with (electron + track) is done the same way as for the signal-to-noise analysis. So the same-sign background is scaled to the data for the interval from 4 GeV to 20 GeV. The signal region is also the same as before (2.5 GeV to 3.2 GeV). Then we try to find a matching cluster to the track and fill the results into another instance of the p_T separated mass plots.

The first code snippet is called for each event and contains the part where the loop over all candidates of tracks is taken to search for the corresponding clusters. Also storing every pair of electron and track is visible.

```
// electron-track JPsi with cluster analysis
const khep::vectorCA& vclus0 = e->caloClusters();
vector<atr::KCaloCluster*> vclus = vclus0.vop<atr::KCaloCluster>();
vector<pair<atr::KEgamma*, atr::KInDetTrack* > >  v_et;
recJpsi(v_et, ve.vop<atr::KEgamma>(), vtracks.vop<atr::KInDetTrack>(), &
    mSel_electron1, &mSel_track1 );
```

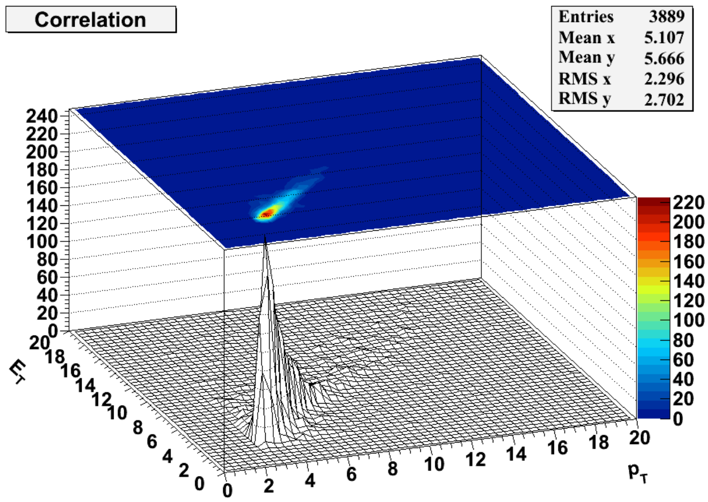


Figure 7: correlation of track and cluster

```
    vector<atr::KCaloCluster*>::const_iterator p_calo;
    vector<pair<atr::KEgamma*, atr::KInDetTrack*> >::const_iterator p_et;
    float deltaR;
    float track_counter = 0;
    float calo_counter = 0;
    // start the loop over the tracks and combine with clusters
    for (p_et = v_et.begin(); p_et!=v_et.end(); ++p_et) {
      float min_deltaR = 0.3;
      atr::KCaloCluster* min_Calo;
      pair<atr::KEgamma*, atr::KInDetTrack*> min_et;
      for (p_calo = vclus.begin(); p_calo!=vclus.end(); ++p_calo) {
        //now inside a cluster / track pair
        //cout << "DEBUG 1" << endl;
        CLHEP::HepLorentzVector v_calo = (*p_calo)->v4();
        CLHEP::HepLorentzVector v_trk = ((*p_et).second)->v4();
        deltaR = v_calo.deltaR(v_trk);
        if (deltaR < min_deltaR) {
          min_Calo = *p_calo;
          min_et = *p_et;
          min_deltaR = deltaR;
        }
      }
        if (min_deltaR < 0.2) {
          mCaloElecHistMgr.fillRec(min_Calo, (min_et).second);
          mElecTrkJpsiHistMgrCalo.fillRec(min_et.first, min_et.second);
          fillMassHistCalo(   ((p_et->second)->tv4()).Pt()*0.001   , p_et->
              first, p_et->second);
        }
    }
    for (p_et = v_et.begin(); p_et!=v_et.end(); ++p_et) {
      mElecTrkJpsiHistMgr.fillRec(p_et->first, p_et->second);
      fillMassHist( ((p_et->second)->tv4()).Pt()*0.001, p_et->first, p_et->
          second);
    }
```

To get the candidates the function `recJpsi()` is called. This function checks the electron and track selection criteria and returns a vector of candidates.

```
//reconstruction function for electron and track
void JpsiHistJob::recJpsi(std::vector<std::pair<atr::KEgamma*, atr::
    KInDetTrack*> >& v,
                          const std::vector<atr::KEgamma*>& v_in1,
                          const std::vector<atr::KInDetTrack*>& v_in2,
                          atr::KEgammaSelection* sel1,
                          atr::KInDetTrackSelection* sel2) {
  unsigned int n1 = v_in1.size();
```

```
  unsigned int n2 = v_in2.size();
  unsigned int i, j;
  bool s, t;
  float q1, q2;

  for (i=0; i<n1; ++i) {
    atr::KEgamma* e = v_in1[i];
    s = false;
    q1 = e->charge();
    if (!sel1 || sel1->apply(e)) s = true;
    if (!s) continue; //check for electron selection
    for (j=0; j<n2; ++j) {
      atr::KInDetTrack* track = v_in2[j];
      q2 = track->charge();
      t = false;
      if(!sel2 || sel2->apply(track)) t = true;
      //check for different sign and track selection
      if (q1*q2 < 0.0 && t) {
        v.push_back(make_pair(e, track));
      }
    }
  }
}
```

5.2. Results on MC

As a first check of the results plots of some properties were produced e.g. the energy spectrum of the caloclusters (see figure 8). The other plots are in the appendix B. One can see, that the spectrum has a very steep rise at 3 GeV and a long tail.

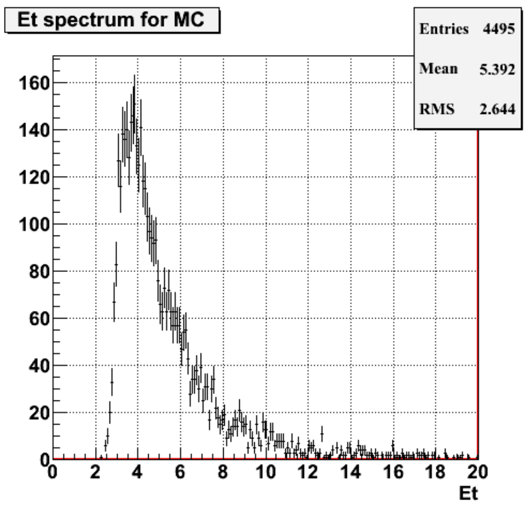


Figure 8: spectrum of E_T

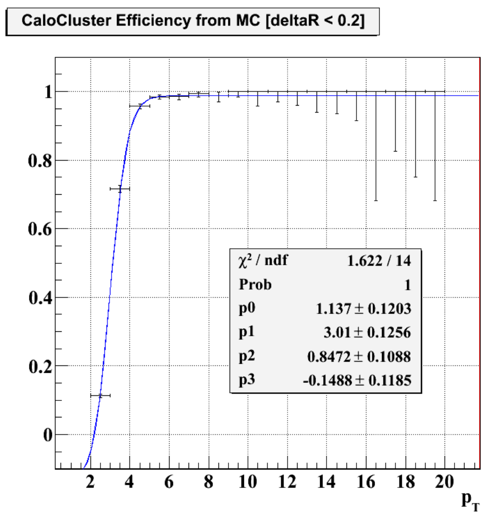


Figure 9: ratio as function of p_T

The calculation of the efficiency uses the root function `TGraphAsymmErrors::BayesDivide` [ROO] that calculates the error with respect to the non physical values above 1. So the errors are asymmetric as seen in figure 9. We divide the number of clusters that matched with a track by the number of the tracks for each bin in p_T of the reconstructed J/ψ.

To compare the efficiency with other measurements and with data, we fit the distribution to the function 1.

$$f\left(x, \vec{p}\right) = p_0 \times 0.5 \times \left(1 + \tanh\left(\frac{x - p_1}{p_2}\right)\right) + p_3 \tag{1}$$

The values of the parameters can be found in figure 9. With this values it is possible to determine the plateau to $\epsilon_{max} = 0.99 \pm 0.16$ and the turnpoint at $p_t = (3.0 \pm 0.1)$ GeV.

5.3. Results on data

To compare the MC results with reality, real data from LHC is analysed. Data was recorded from 2nd to 14th August using a single-electron trigger with an integrated luminosity of 615 nb^{-1}.

Again the spectra are plotted (see appendix B). Some differences can be seen, but there was no time to analyse this behaviour. But the "jumps" in the E_T spectrum seem to originate from different trigger settings at different luminosities, because they coincidence with the cuts of the following triggers: EF e3 medium, EF e5 medium and EF e10 loose.

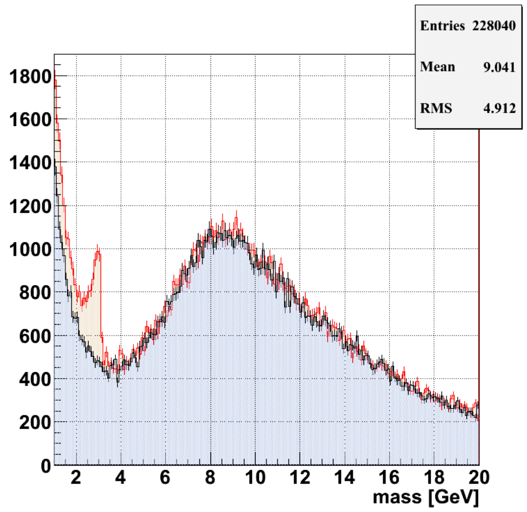


Figure 10: mass spectrum for electron and track

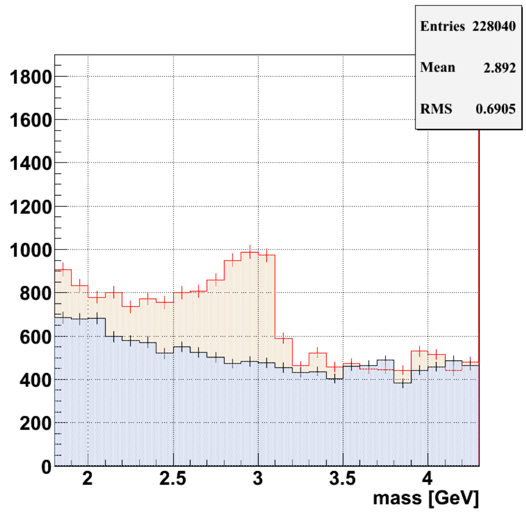


Figure 11: detail view of the signal region

The mass peak of the J/ψ is clearly visible in the data. Same-sign data is a good estimator for background in the region of the mass peak and for higher masses. For masses lower than the signal region the same-sign is no longer the best estimator. The reason why the data is higher there is unclear up to now and requires further analysis, that could not be done at the summerschool.

The determination of the efficiency is the same as for MC and for comparison the efficiency plot from data is plotted with the monte carlo results in shaded yellow as backgrund (see fig. 12). The plateau is calculated to be 1.00 ± 0.10 and 90% is reached at ca. 4 GeV. The datapoints fluctuate and it is not clear if this is systematic or just statistics, but there was no time left to investigate this problem.

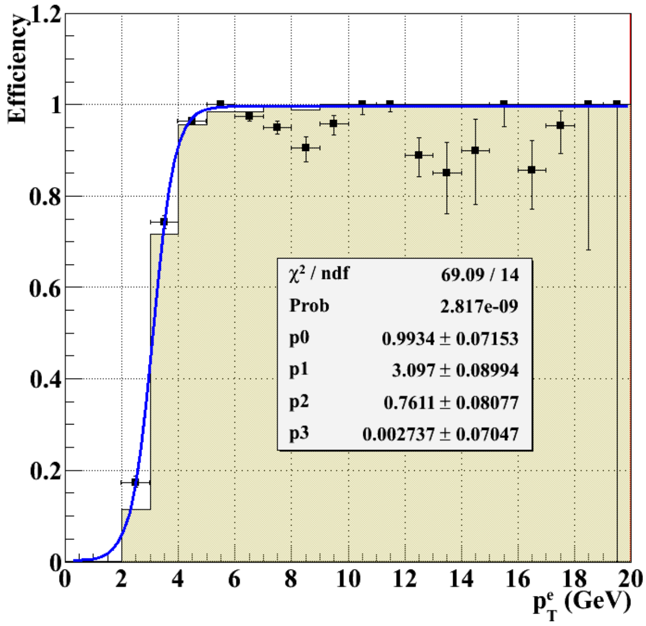


Figure 12: comparison of efficiency in data and MC

6. Conclusion

It was possible to show, that with properly chosen cuts, the J/ψ peak can be reconstructed using only one electron and a track. But the background is not fully understood for low masses. In the η spectrum also big differences are visible, but the plots are not directly compatible because of the included background in the data plots.

The efficiency could be calculated and is quite high for track-p_T above 4 GeV, so the clustering of the EM-calorimeter works fine. Nevertheless there are perhaps deviations from the plateau that are not understood.

7. Acknowledgement

I would like to thank DESY for the kind invitation to the summerschool and T. Kono for supervising me and the help with the analysis.

References and list of figures

References

[ATL09] *Expected performance of the ATLAS experiment: detector, trigger and physics.* CERN, 2009.

[eaPDG10] K. Nakamura et al. (Particle Data Group). J/ψ (1S). *JPG 37*, 075021, 2010. URL: http://pdg.lbl.gov.

[ROO] ROOT documentation, http://root.cern.ch/root/html/TGraphAsymmErrors.html.

List of Figures

Appendix

A. mass spectra

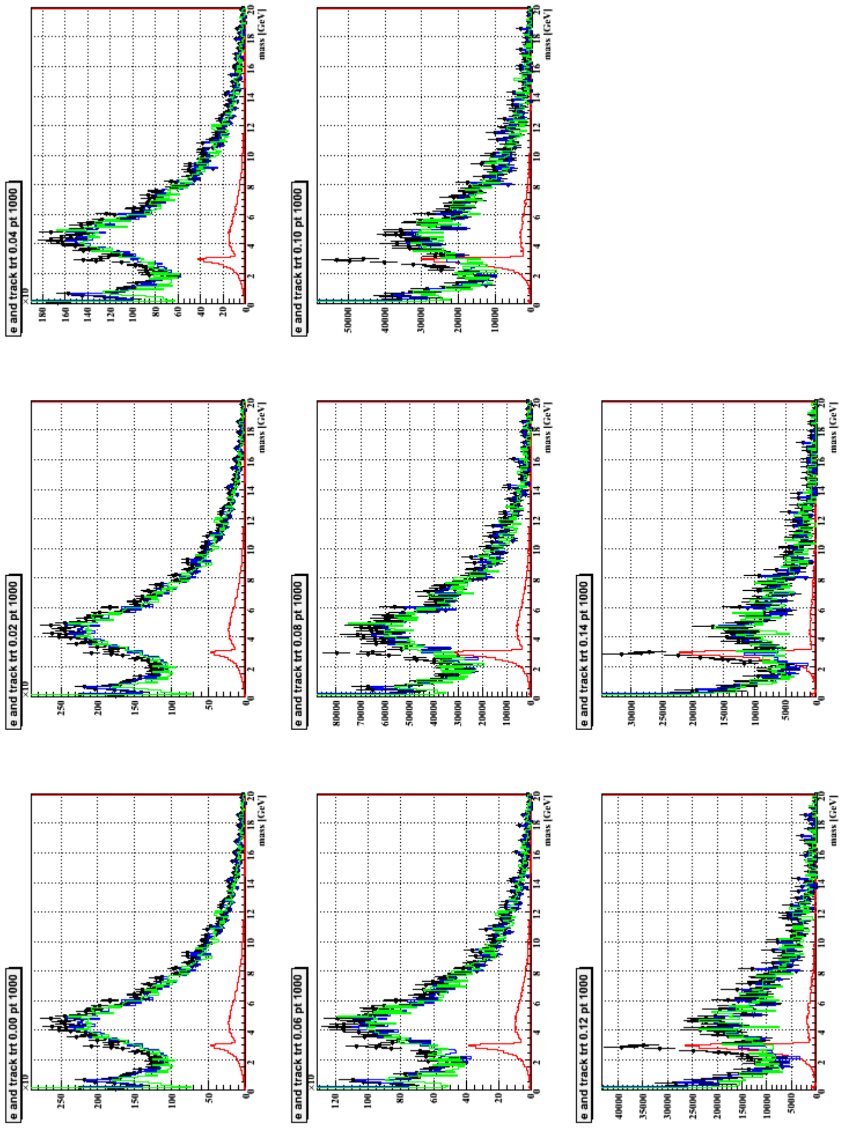


Figure 13: mass spectra for $p_T > 1000MeV$

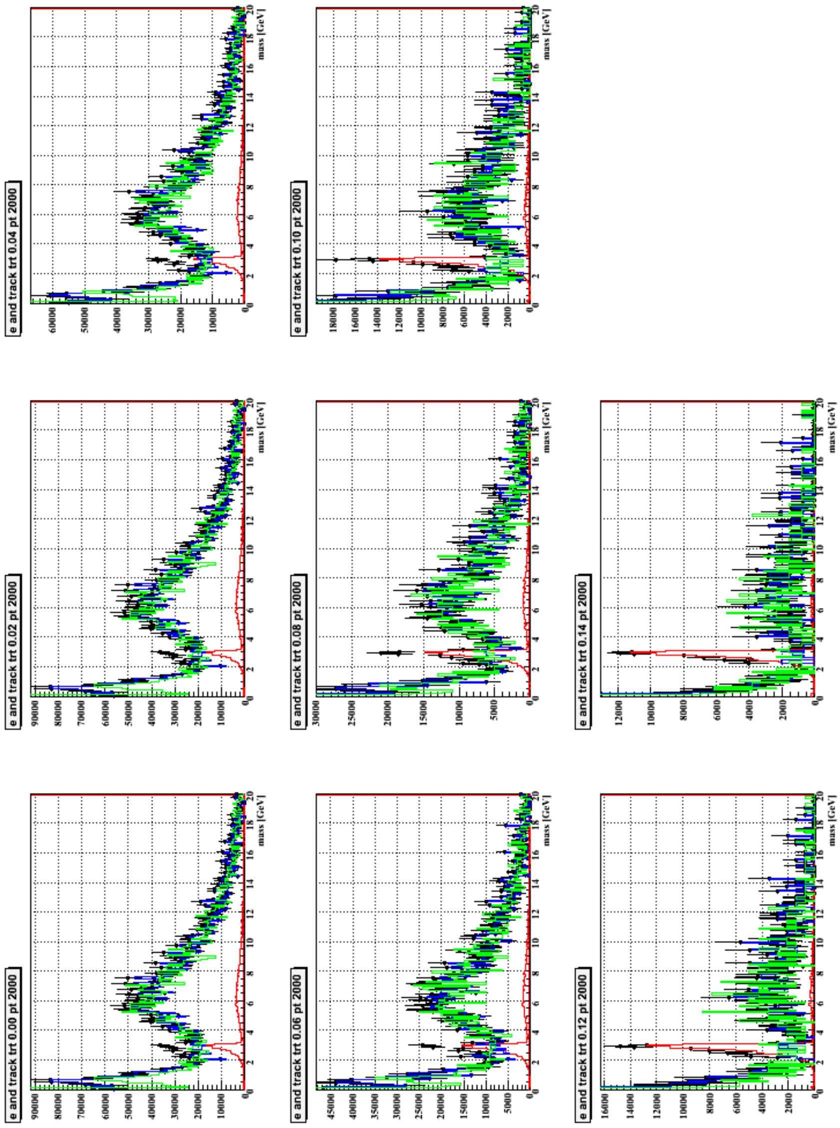


Figure 14: mass spectra for $p_T > 2000MeV$

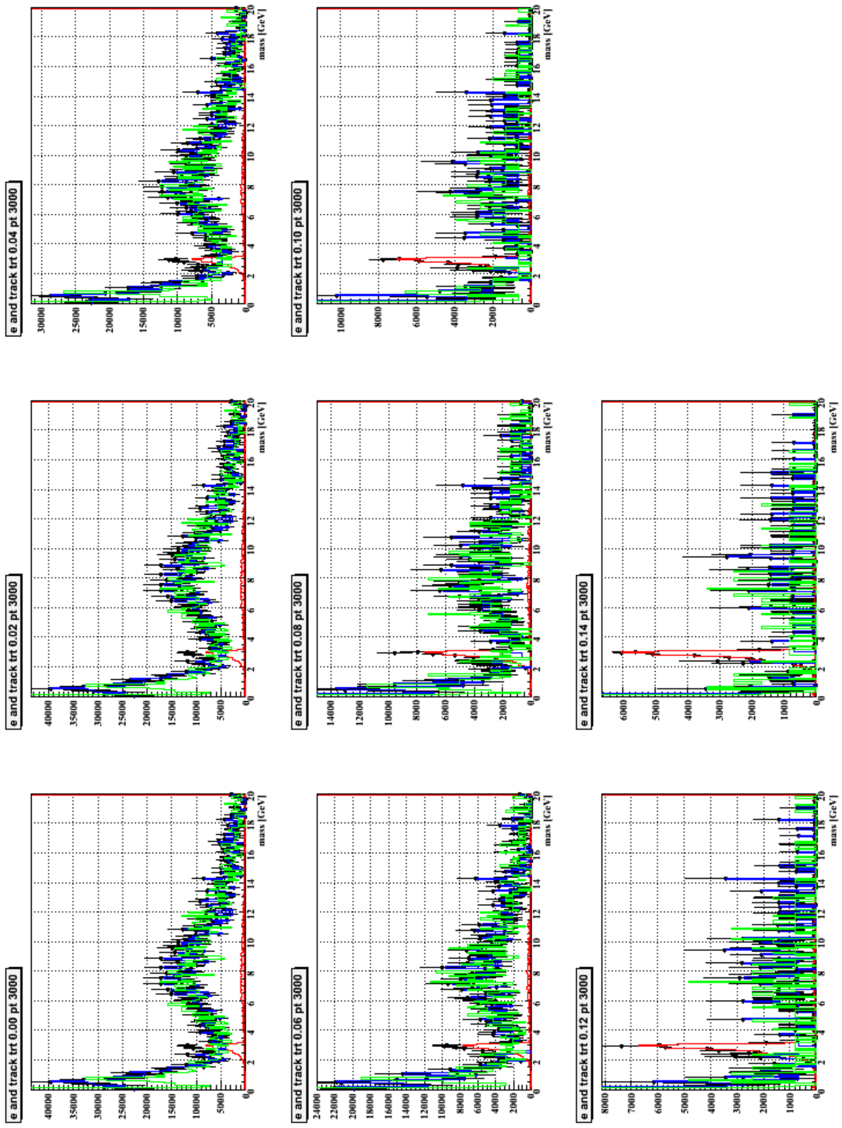


Figure 15: mass spectra for $p_T > 3000 MeV$

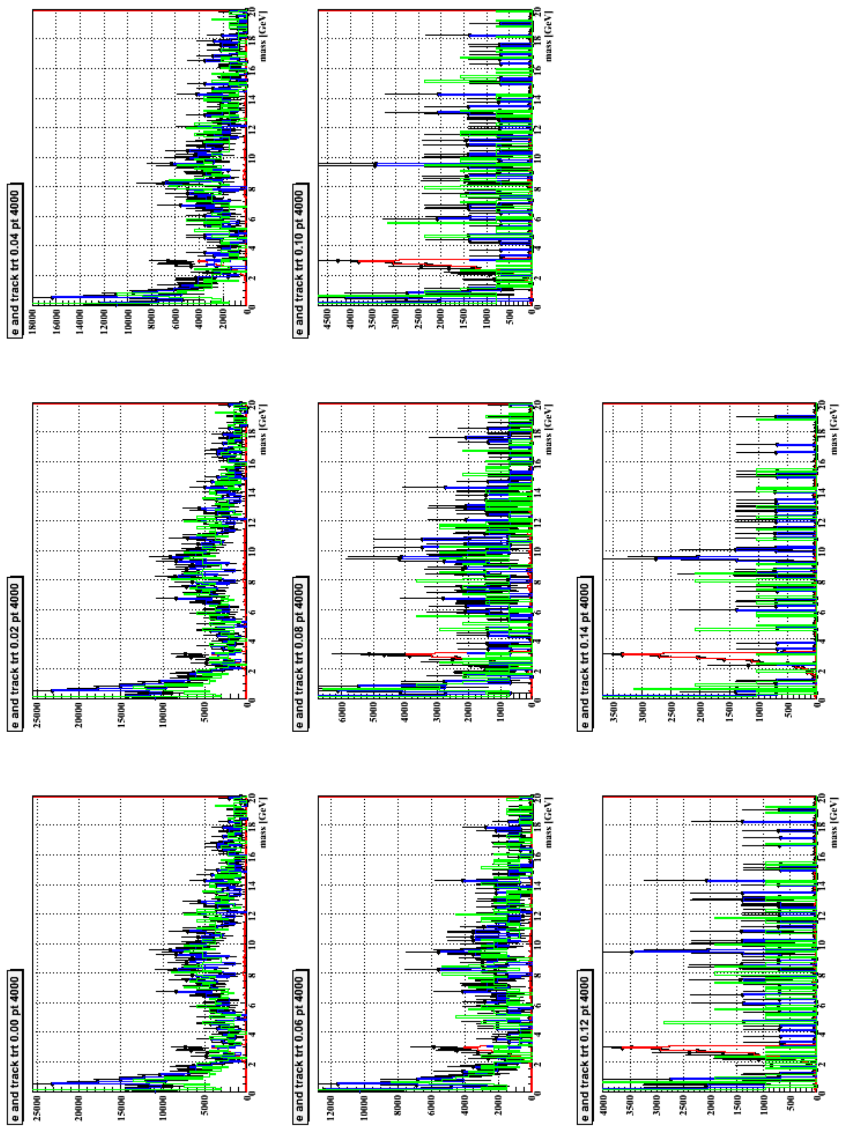


Figure 16: mass spectra for $p_T > 4000MeV$

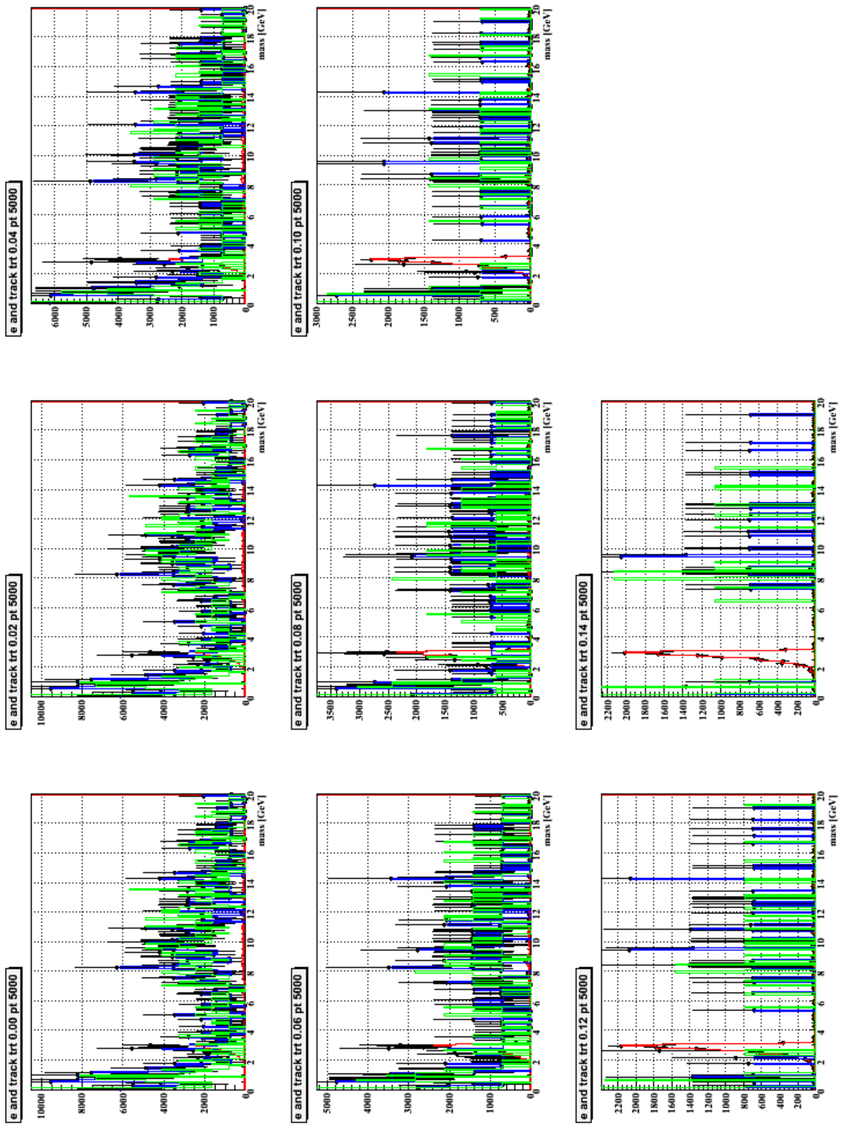


Figure 17: mass spectra for $p_T > 5000MeV$

B. Spektra of caloclusters

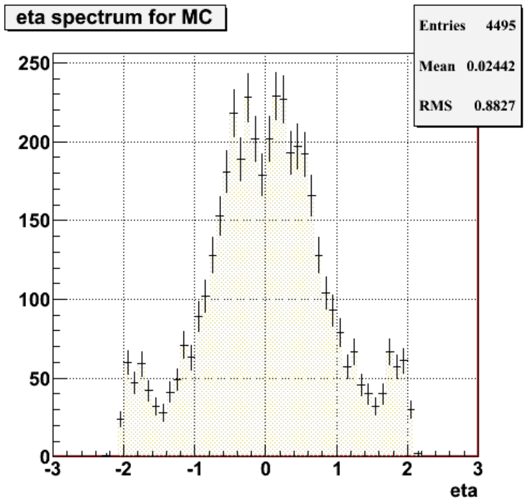


Figure 18: η spectrum from MC

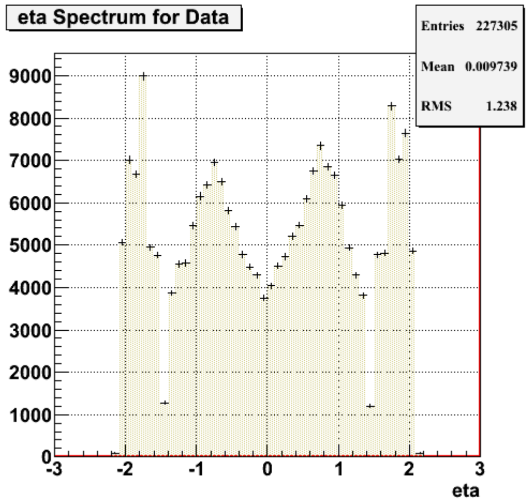


Figure 19: η spectrum from data

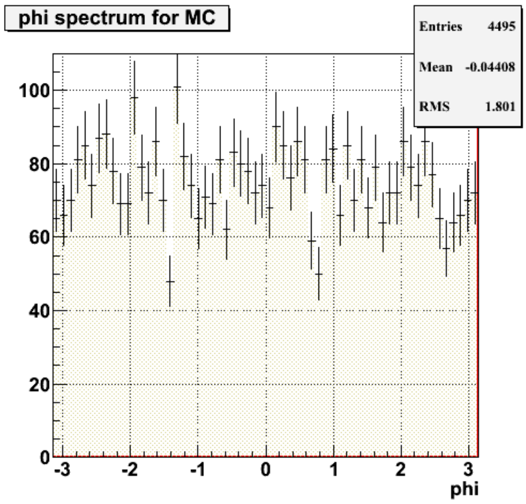


Figure 20: ϕ spectrum from MC

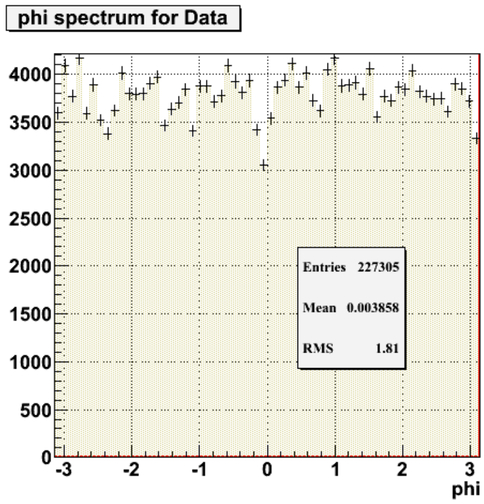


Figure 21: ϕ spectrum from data

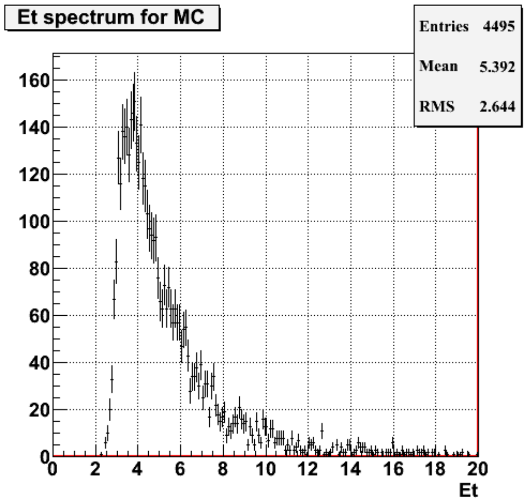


Figure 22: E_T spectrum from MC

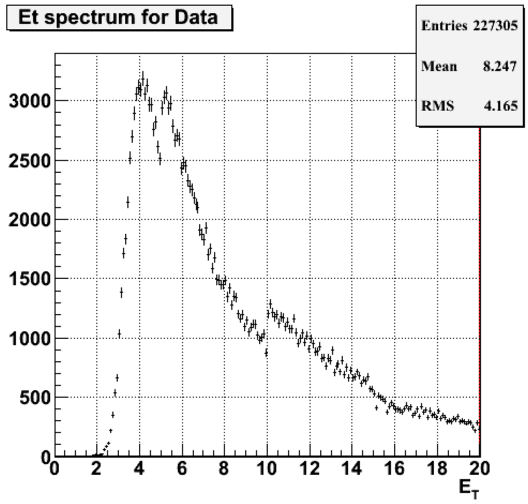


Figure 23: E_T spectrum from data

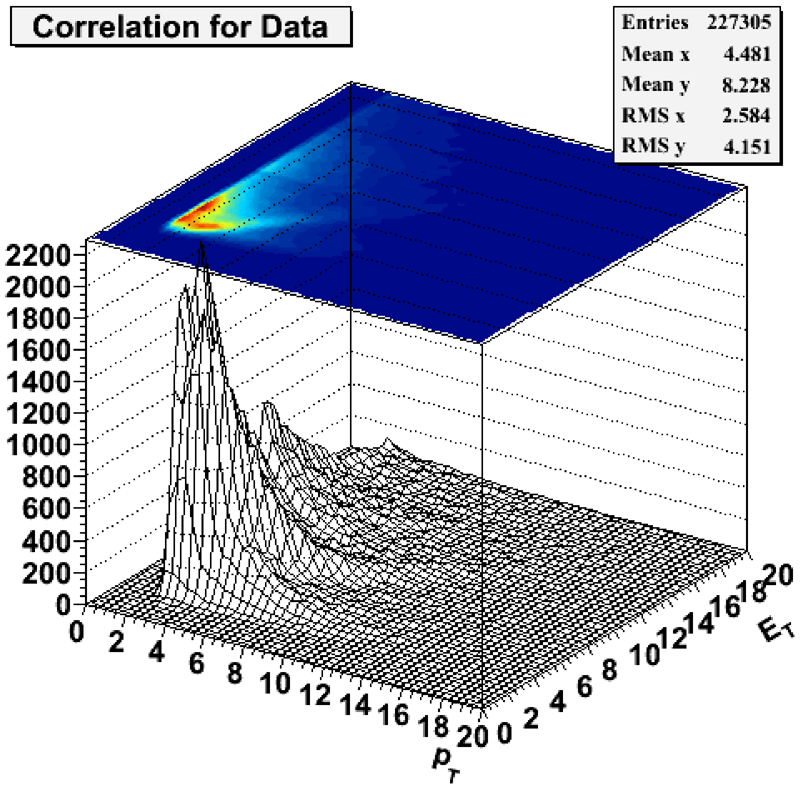


Figure 24: correlation of E_T of calorimeter and p_T of track for data. When comparing this plot with the MC plot in figure 7 one as to take into account, that background is included here.