Online Monitoring System for the PHENIX ZDC and SMD
Technical Note

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4th May 2007

Contents

Abstract

This technical note is supposed to describe the online monitoring software [1] of the ZDC and the SMD. It is part of the framework of the PHENIX Online Monitoring System (POMS) [2]. The plots and the values showed them are explained below. Most of the plots are taken from Run 3.

1 The zero degree calorimeter

The Zero Degree Calorimeter (ZDC) is a neutron detector, which is placed in the line where the two beams of RHIC cross each other (the interaction region). It is present at all four experiment of the Relativistic Heavy Ion Collider and may be considered to be part of RHIC instrumentation also.

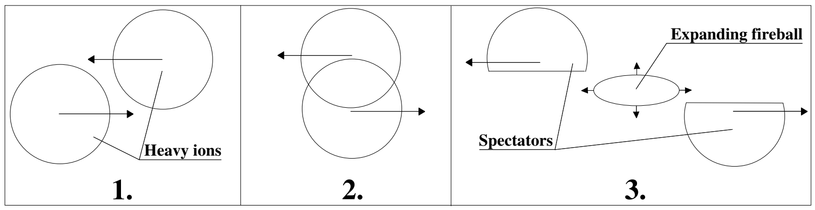

Figure 1: Sketch of a high energy heavy ion collision

In the first part, the two heavy ions are nearing to each other. Lorentz-contraction is neglected here to have a more clear picture. After that, they collide. From the region where they overlap arises an expanding fireball of new particles, and the other parts, the so called spectators continue their way. From these parts, protons and neutrons evaporate.

The ZDC was designed as a detector for luminosity measurement and monitoring, event geometry characterization. In heavy ion collisions it is used for centrality selection (with the Beam Beam Counters), to study Coulomb-dissociation, nuclear fragmentation processes, investigation of γ-γ collisions, etc… In d+Au runs the ZDC (together with the Forward Hadron Calorimeter) is used for p(d)+Au $\rightarrow$ n+X, n(d)+Au $\rightarrow$ p+X , d+Au $\rightarrow$ X event classification [3, 4, 5].

My task at the ZDC was to develop the online monitoring software for this detector component. The online monitoring is a program that has to produce plots from the data that is currently taken.

1.1 Goals of the calorimeter

It measures the energy of the neutrons that are evaporated from the spectators of the collision. These neutrons do not take part in the collision, and if they decouple from the protons, the magnetic field will not guide them to stay in the beampipe, and go straight forward into the zero degree calorimeter.

The energy of these neutrons can be computed from the center of mass energy ($\sqrt{s_{NN}}$). If we use the center of mass frame, where $\mathbf{p}_1$=-$\mathbf{p}_2$=$\mathbf{p}$:

$$s_{NN} = (p_1 + p_2)^2 = 2m^2 + 2(|\mathbf{p}|^2 + E^2) = 4E^2 \tag{1}$$

So, by measuring the energy of the evaporated neutrons, we access the fluctuations of the center of mass energy.

Another purpose of the ZDC is to measure the vertex position, the position, where the collision happened. This is possible, because the evaporated neutrons start their flight with the spectator part of the nucleus at the same time from the collision point. If in one direction, the neutrons reach the ZDC earlier, the vertex was nearer to this side. This is possible, because we read out not only energy, but timing information, too. The velocity of the neutrons equals within error the speed of light.

channel	number
south analog sum	0
south slabs	1-3
north analog sum	4
north slabs	5-7

Table 1: ZDC channels

There are eight ZDC channels, six for the south and north slabs, and two more for the analog sums of these channels.

Expressed with a formula:

$$z_{vertex} = (t_{south} - t_{north})c \tag{2}$$

1.2 Construction of the ZDC

The Zero Degree Calorimeter is a Cherenkov light sampling calorimeter, and there is one at both ends of the interaction region.

Mechanically, each arm of the ZDC is subdivided into 3 identical modules with 2 interaction length each. The active medium is made from clear PMMA fibers interleaved with Tungsten absorber plates. This sandwich structure is tilted at 45 degree to the beam to align the optical fibers with the Cherenkov angle of forward particles in the shower. The energy resolution of the ZDC for 100 GeV neutrons is 21%. Time resolution is around 120 ps for 100 GeV neutrons which may be translated into a vertex position resolution of around 2.5cm.

The three analog signals coming from the slabs are digitalized after some amplifying, as well as their analog sum, and a timing signal for each channel. This information is then stored and analyzed by computers. Channel numbering is shown in table 1.

The energy is calibrated with an LED, which pulses with a low frequency. We take some events where there was no collision only an LED pulse, and we know the energy of the LED sigal, and through this, energy of the detected particles can be calibrated. We monitor the LED energy too.

2 The Shower Max Detector

The Shower Maximum Detector (SMD) is unique to the PHENIX ZDC's. It is useful for a study of transverse momentum distribution of beam fragmentation products, beam steering and beam profile studies due to beam divergence.

SMD is an X-Y scintillator strip detector inserted between 1st and 2nd ZDC modules. This location corresponds (approximately) to hadronic shower maximum position. The horizontal x coordinate is sampled by 7 scintillator strips of 15 mm width each, while the vertical y coordinate is sampled by 8

channel	number
south horizontal strips	8-15
south vertical strips	16-22
south analog sum	23
north horizontal strips	24-31
north vertical strips	32-38
north analog sum	39

Table 2: SMD channels

There are 32 SMD channels, seven and eight for the vertical and horizontal strips respectively, and two more for the analog sums.

strips of 20 mm width each, tilted by 45 degrees. The active area covered by SMD is 105 mm $\times$ 110 mm. The SMD position resolution depends on energy deposited in the scintillator and varies from around 10 mm at small number of charged particles crossing the SMD to values smaller than 3 mm when number of particles exceed 100. For comparison, the spread of neutrons due to of nucleon Fermi motion is about 2.2 cm at 100 GeV.

Digitalized signals are coming from all stripes. Channel numbering is shown in table 2.

As mentioned before, with the SMD we can measure the beam position, if we look at the energy distribution of the shower in the vertical and horizontal strips. I measure the beam position on the following way then:

$$x = \sum_{i=1}^{7} \left(\frac{E_i x_i}{\sum E_i} - \frac{x_i}{7} \right), \tag{3}$$

$$y = \sum_{i=1}^{8} \left(\frac{E_i y_i}{\sum E_i} - \frac{y_i}{8} \right), \tag{4}$$

where E_i is the energy deposited in the ith slab and x_i is it's position. Figure 2 shows a possible energy distribution. In the formulas the average position of the slabs is subtracted to have the $(x, y) = 0$ position at the physical center of the SMD.

Now, we have the beam energy and position at both the north and south side. It is very important to monitor these to see immediately, if there is a change in these basic quantities.

3 The online monitoring

The PHENIX Online Monitoring [2] is a software system, that has the purpose to monitor the data that is taken at the moment. For every detector-component there has to be an online monitor program, because if there won't be one, we

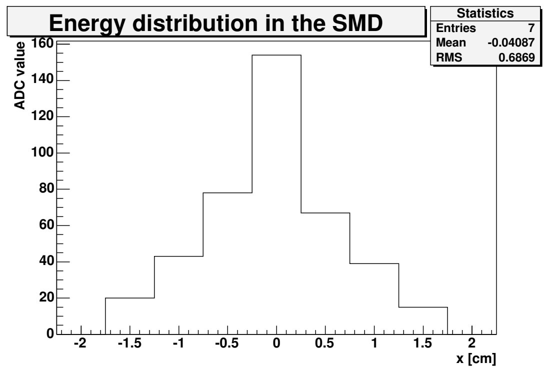

Figure 2: SMD energy distribution

In this figure, we see the energy distribution in the horizontal slabs of the north SMD. If we take the average of the positions weighted with the deposited energy, we get the mean position.

might not notice that that particular component is not working properly, and the data from that detector is unusable.

In this section, I show some plots of the ZDC and SMD online monitor. The code is available in ref. [1].

The code is part of the POMS framework, and as such, `MakeCanvas` functions in `ZdcMonDraw.C` prepare the canvases and `Draw` functions draw the plots themselves. These plots have to be filled/computed in `ZdcMon.C`. Which `Draw` function produces which plot is shown in table 3.

3.1 Beam energy monitoring

We have a monitor for south and north beam energy. The upper panels in figures 3 and 4 show the energy distribution in the north and south ZDC. The red dashed lines show the allowed region for the maximum of the curve. This is around 1700-1900 GeV for gold beam, and at 100 GeV for deuterium beam. In the latter case, we can have only one evaporated neutron, so the energy should be around 100 GeV, and in the former case, we saw, that the most likely number of evaporated neutrons is 17-19, so this energy region should be maintained.

3.2 Vertex position monitoring

We have a monitor for the south and north beam position. The left middle panel in figures 3 and 4 show the vertex position, and the middle right is the same just for the events where the BBC level 1 trigger fired. The latter, corrected distribution has a gaussian shape, because if we have an event, where BBC level 1 trigger did not fire, it is very likely, that this was a fake event. Some timing correction is still missing in figure 4, as the maximum is very far from zero. This

Plot	Drawing function	name
3-4	`Draw1()`	ZDC Main Monitor
5-6	`Draw2()`	SMD Expert Data
12	`Draw3()`	SMD Position Values
7	`Draw4()`	LED Energy Values
8	`Draw5()`	LED Timing Values
13	`Draw6()`	SMD Values South
13	`Draw7()`	SMD Values North
14	`Draw8()`	ZDC Ratio Values
15	`Draw9()`	ZDC BBC Vertex
10	`DrawHistory(,0)`	ZDC PPG History
9	`DrawHistory(,1)`	SMD South Y PPG History
9	`DrawHistory(,2)`	SMD South X PPG History
9	`DrawHistory(,3)`	SMD North Y PPG History
9	`DrawHistory(,4)`	SMD North X PPG History
11	`DrawHistory(,5)`	Position, vertex and energy history

Table 3: Drawing functions

This table shows which plots are generated with which function in the code. In case of figure 13 and 9, several similar plots are generated for different the different SMD's and stripe directions, I only included one of these.

correction was already made for the Au+Au run, so the vertex position is in figure 3 near to zero. ZDC vertex is also compared to BBC vertex on figure 15, the ratio should be near one here.

3.3 Beam position monitoring

There is a monitor for the vertex position. The last two plots in figures 3 and 4 show the north and south SMD position distribution. Scattering is bigger in the deuteron case, the hits for the gold beam are relatively more concentrated. IIn figure 3 there is a circle drawn around the middle, and the maximum of the distribution should be in this circle.

3.4 Main expert plots

If there is something strange in the main monitors, it is more easy to detect the root of the problem, if we have already some special plots which show some useful information. Shifters do not have to understand and monitor these plots, but they are useful for experts.

Main expert plots are in figures 5 and 6. These show in the first line the separate beam centroid distributions in the SMDs. After that, there are plots to see correlations between position and energy. This is very useful, because if a little peak appears in energy, we could possibly see, from which direction this

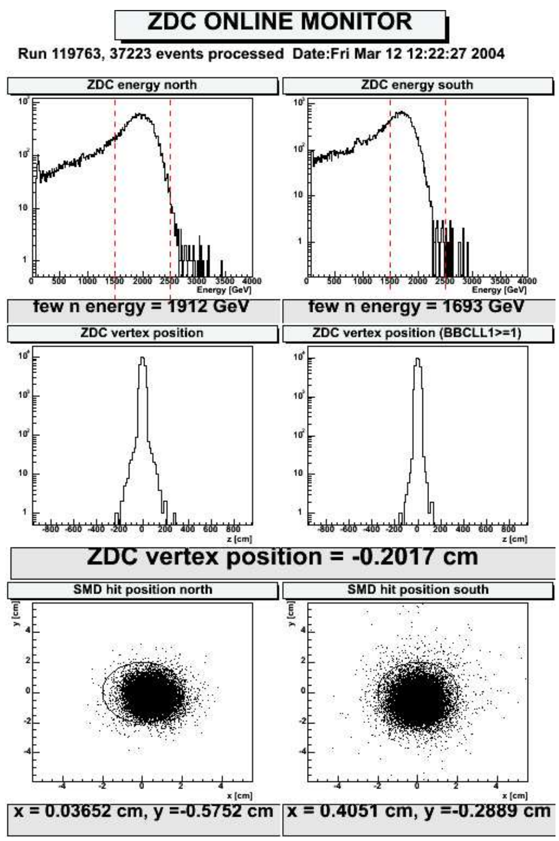

Figure 3: ZDC main online monitor in a Au+Au run

This figure shows the ZDC online monitor in a Au+Au run. In the first row, we see the energy distributions in the north and south side calorimeters. The plots in the second row show the vertex position distribution, on the left hand side with a cut made with help of the BBC. In the last row, we see the transverse position distribution measured via the SMD. All plots show values within the normal ranges.

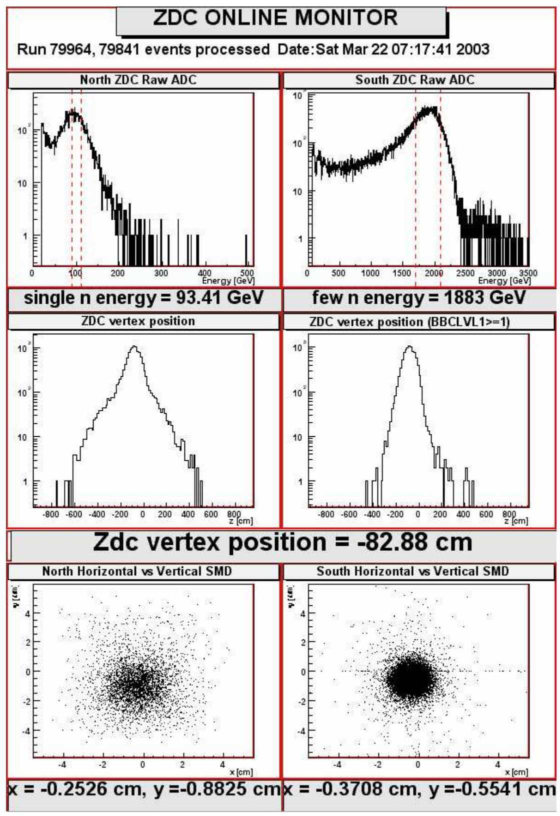

Figure 4: ZDC main online monitor in a d+Au run

The plots shown in this figure are similarly arranged as in figure 3. The nominal value of the energy maximum on the deuteron side is smaller here, and the measured value is in the allowed 100 GeV ± 10 GeV range. An other feature is, that the vertex distribution was broader here and had a maximum shifted towards the south side. Later, the ZDC timing was corrected and then the maximum moved to zero, as in figure 3.

'noise' comes. The other four plots show the raw ADC distributions for the sum of the SMD channels.

3.5 LED signal monitoring

As we saw already, the energy calibration in ZDC is done via an LED signal. There is a plot for the LED energy values in figure 7, where we can see, if the gain of some channels went bad for example, or somehow the energy of the LEDs changed somehow. This would cause the LED energy plots not to be constant. There are green lines on these plots, which show the values of the energy seen a few days ago. The values at the first ZDC slab on the north side deviate from this green line, because gain for that channel was changed in the meantime.

The timing is monitored as we see in figure 8, this is more constant.

History of LED values for every channel is stored in a database and monitored. Some of these plots are shown in figure 9 and 10. Values on the horizontal axis are in units of 10^4 seconds. There were in the monitored interval of a few weeks four changes.

3.6 Other expert plots

It is important to monitor the history of the main values that are measured by the ZDC, to keep track of changes. Because of this I included figure 11 in the online monitoring. On this figure, the first two lines we see the history of the four SMD positions. In the monitored time-interval, there were no big changes, we can just see, that in a short interval of around 80000 seconds we had no beam. The strong deviations on these plots are due to averaging problems. I average 1000 events and put their value to the database, but there can be a short period with lots of bad events, or if a run ends before the completion of 1000 events, averaging goes wrong.

We have two plots for the energy history, what we see here is a constant energy with rare bad values. The explanation for them could be the same as in the previous paragraph. Interesting is here furthermore the small scattering of the energy values.

The vertex position history seems to have a large scattering, but this just due to the lack of strong deviations and small scales. It is nearly constant in the monitored interval.

SMD position history is monitored inside of a run as well, these plots are in figure 12. The green lines are at hard-coded values and represent the value seen a few weeks ago. We see, that the south horizontal position did slightly change, the others are pretty constant. The error bars come from the averaging, which is made for 1000 events here also.

The raw ADC values of the SMD channels are included in the online monitoring also, the north channels are to see in figure 12. The smaller histogram is made with a cut in the ZDC energy (eg. here in Au+Au, $E_{ZDC} < 200 MeV$), and it helps testing that cut. If we see, that these small histograms start to

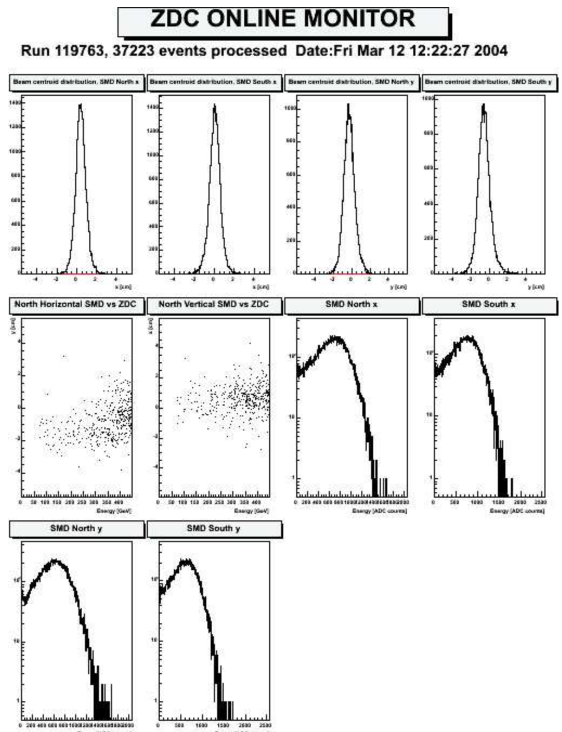

Figure 5: Expert plots in a Au+Au run

The first four plots show the beam position distribution in the four (south and north, horizontal and vertical) SMD sets. The first two plots in the second row show the correlation between energy and position, while the in the last plots we see the distribution of the raw ADC signal from the SMDs.

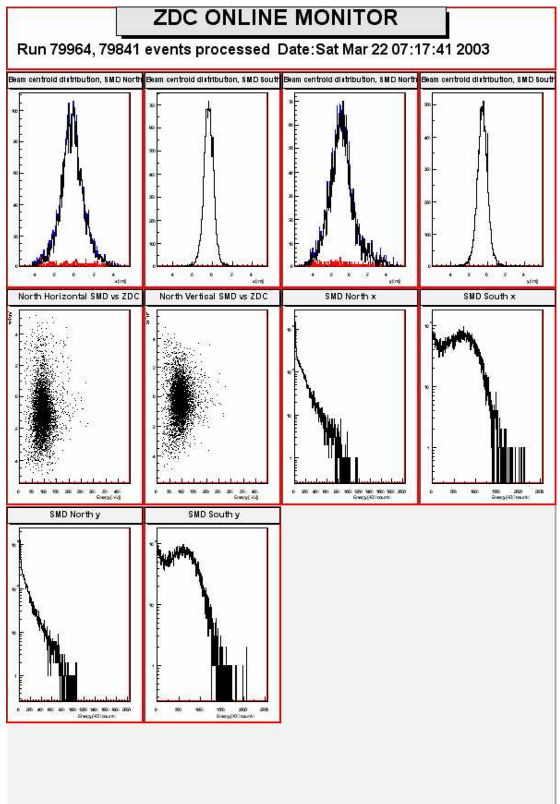

Figure 6: Expert plots in a d+Au run

The plots shown here are the same as in figure 5, just in a d+Au run. The south, Au side plots are very similar, but on the north side the energy is smaller, and the scale of the correlation plots was changed also.

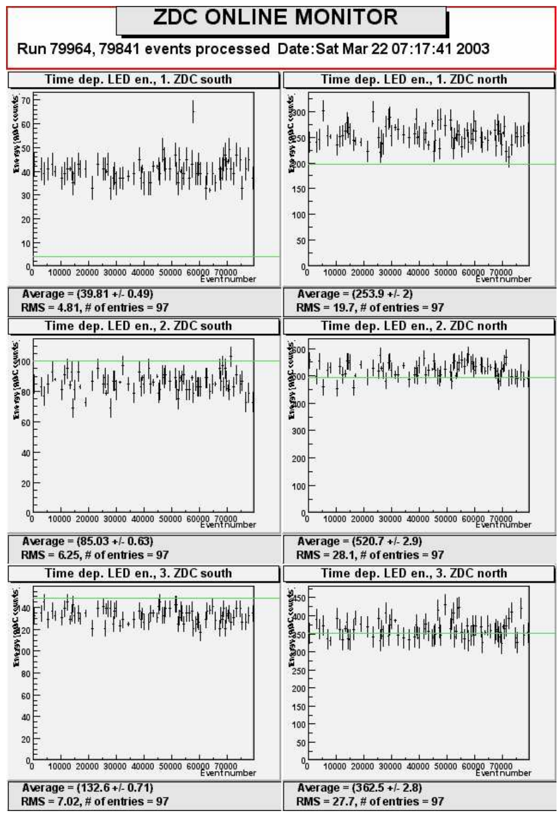

Figure 7: LED energy values versus event number

In this set of plots we see the time (event number) dependence of the LED energy. The south side is shown on the right, the north side on the left. The individual raws correspond to the deposited energy measured in the first, second and third ZDC slab, respectively. Green lines represent the average values measured a few days formerly.

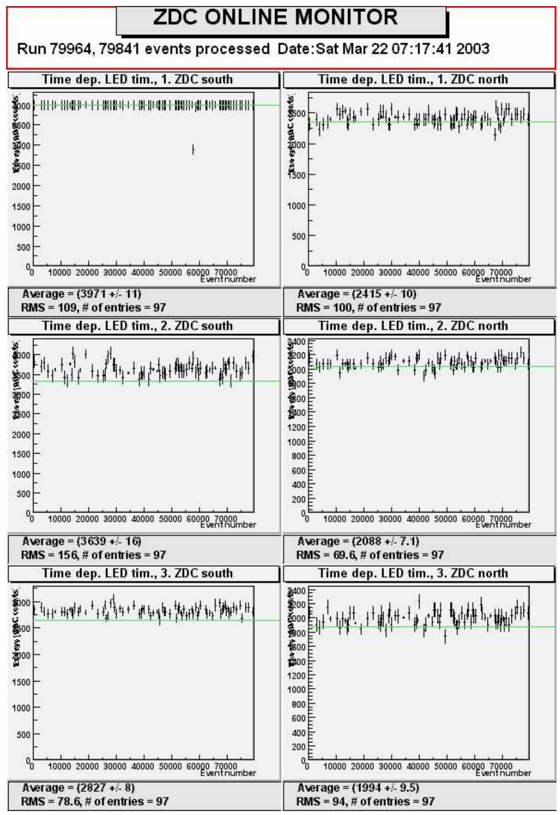

Figure 8: LED timing values versus event number

LED timing values are plotted here versus the event number. Arrangement of the plots is the same as in figure 7. There are acceptable random fluctuations, but in the first slab on the south side, all values are in the last bin. Because of this overflow, some corrections on the timing signal had to be made.

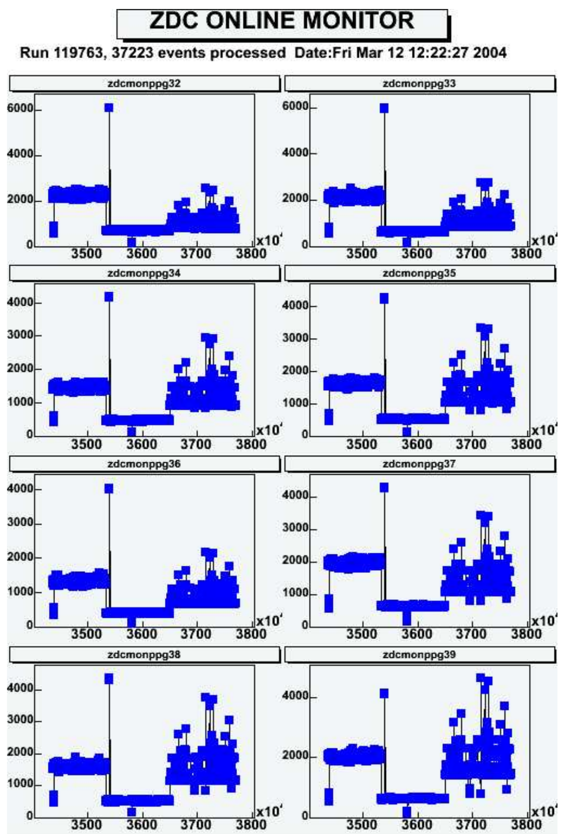

Figure 9: LED energy in the SMD stripes in a Au+Au run

The average LED energy deposited in the north vertical SMD stripes is plotted here versus the time of the run in which it was measured. Two significant changes are noticeable on all eight plots corresponding to the eight strips. Both of the shifts are due to a change in the high voltage setting in our detectors. The covered period of time plotted in these figures is around one and a half month.

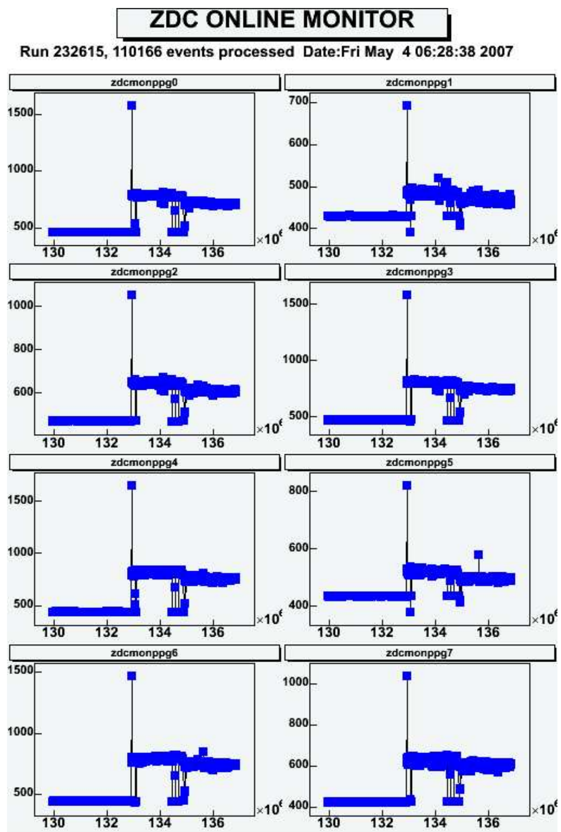

Figure 10: Expert plots in a Au+Au run

The average LED energy deposited in the ZDC's is plotted here versus the time of the run in which it was measured, similarly to figure 9.

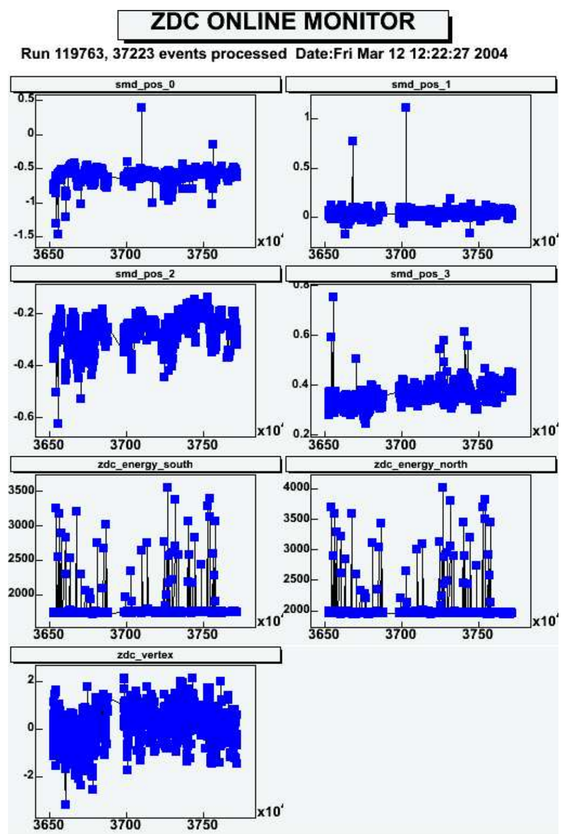

Figure 11: Expert plots in a Au+Au run

In the first four figures the history of the position measured in the SMDs is plotted here. After that the average deposited energy in the south and north ZDC is shown. There is a clearly visible constant line at around 2000 GeV, the higher values are due to a numeric problem in the averaging method. The last plot shows the vertex position history. The covered period of time plotted in these figures is around two weeks.

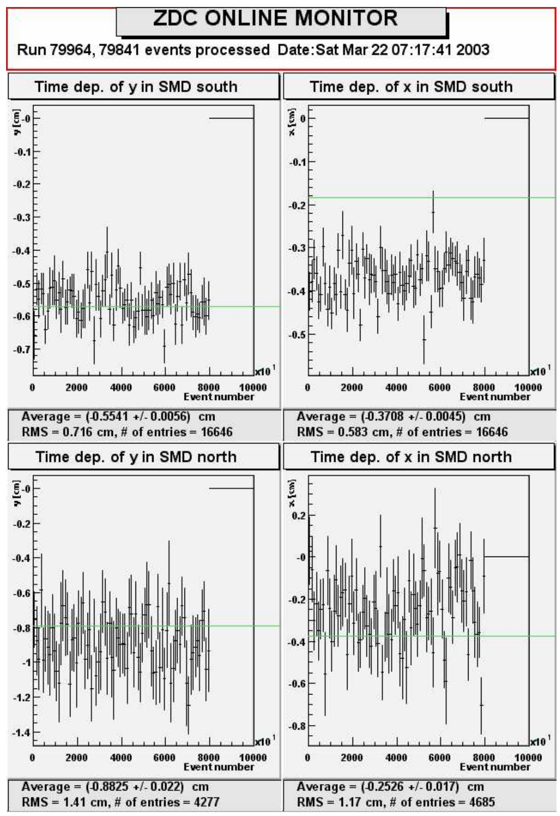

Figure 12: SMD position versus event number

Time – event number – dependence of the beam position is shown in these figures. There are large but acceptable random fluctuations in this run.

increase, the cut limit has to be revised. Furthermore, the location of the peaks in the larger histograms helps to determine gain factors in SMD channels.

It is important to determine gain factors in the ZDC channels, too. With the plots in figure 14 we constantly check, if have correct values for this. If the gains are correct, the ratio deposited energies in the first and second plus third slab should be equal for north and south side, due to same geometry. The bend in the curve is still unexplained, but could be due to different acceptance of the detectors at different energies.

4 The vernier scan

Vernier scans are done from time to time in RHIC to be able to calibrate the SMDs. In a vernier scan, the beam position is changed by the main control room stepwise, and we look at our position values, if the give back the motion. We get the positions from the control room as a function of time, and then compare to the monitored values. This is shown in figure 16.

What we have learned from the plots (back then, in Run 3), is that there is a small synchronization problem still, and the calibration has to be improved, too, but the beam movement is to well monitored.

References

[1] `http://www.phenix.bnl.gov/viewcvs/online/monitoring/Run3/subsystems/zdc/`

[2] `http://www.phenix.bnl.gov/WWW/run/??/online_monitoring/`

[3] C. Adler, A. Denisov, E. Garcia, M. Murray, H. Strobele and S. White Nucl. Instrum. Meth. A **470**, 488 (2001), nucl-ex/0008005

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[5] A. J. Baltz, C. Chasman and S. N. White, Nucl. I. M. A **417**, 1 (1998), nucl-ex/9801002

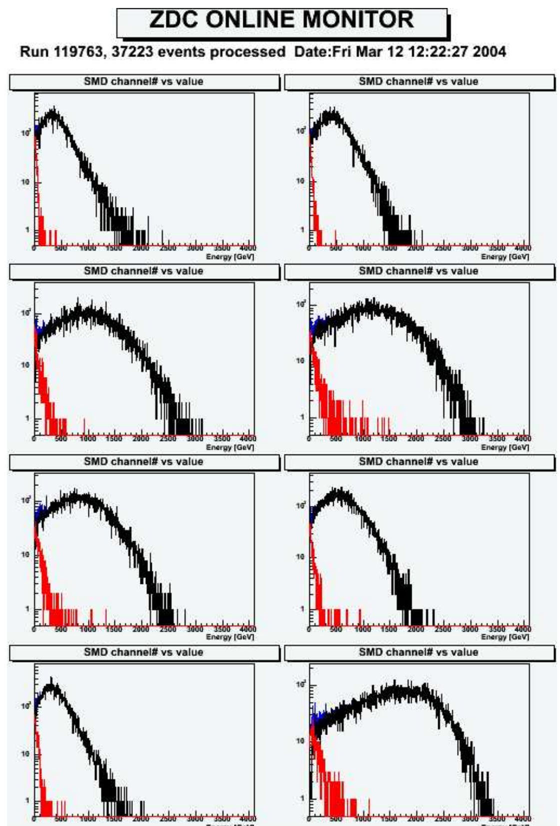

Figure 13: Raw ADC value distributions in the north vertical SMD

Distribution of the raw ADC signal coming from north vertical SMDs is shawn here. The width of the distribution changes from plot to plot, due to different gains in different photomultipliers. Red curves show the ADC signal only for events with $E_{ZDC} < 200 MeV$.

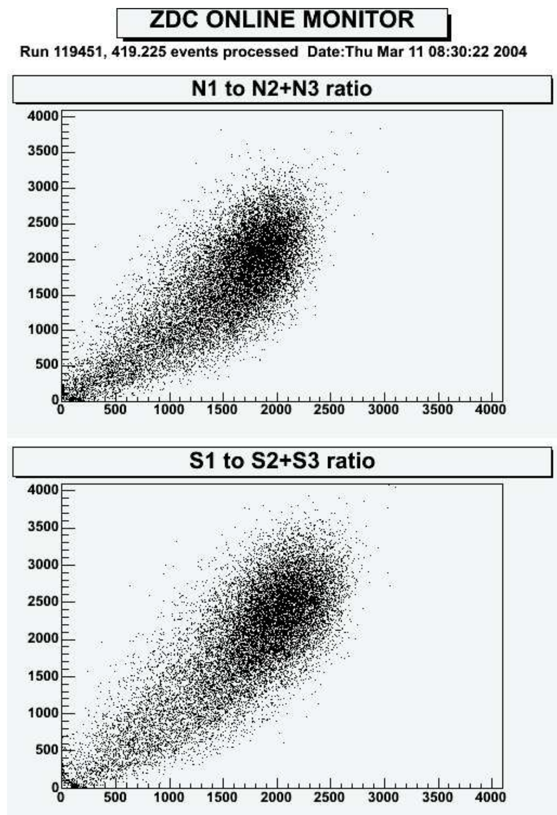

Figure 14: Expert plots in a Au+Au run

In the top panel, the correlation between the deposited energies in the first and the second plus third ZDC slab is plotted. The bottom panel shows the same correlation for the south side. The slope of the distributions should be the same for both sides, as it represents the ratio of the gain factors used in the individual ZDC slabs.

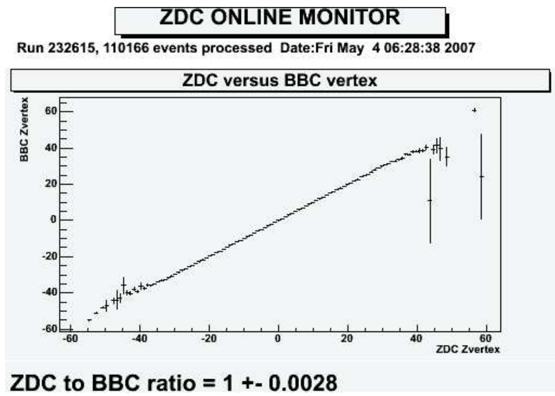

Figure 15: ZDC to BBC vertex in a Au+Au run

Vertex calculated from ZDC versus vertex calculated on BBC is shown on this plot.

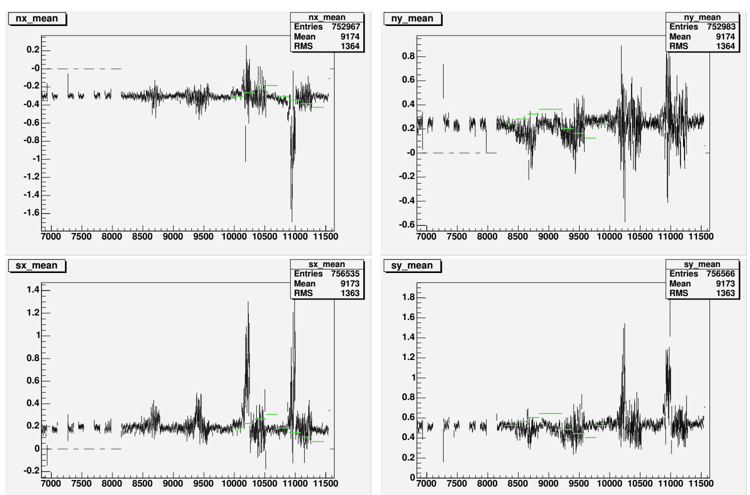

Figure 16: Vernier scan plots

Plots of a Vernier scan. Green straight lines show the desired position, while the values with error bars are the monitored positions. The moving is clearly visible while it does not reproduce the beam positions given by the main control room. Further corrections are necessary and the calibration of the detector has to be improved.