Centrality calibration of the CERES '2000 data

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1 Introduction

Three observables related to the centrality are directly [1] available in the step3c output data: the Multiplicity Counter (MC) amplitude, the track multiplicity in the Silicon Detector (SD) ($0.10 < \Theta < 0.26$), and the track multiplicity in the TPC ($0.12 < \Theta < 0.24$, nhit>13). In the following we will call these three variables "multiplicities". Centrality calibration means finding the relation between a multiplicity on one side and the impact parameter, or, equivalent to it but more commonly used, the percentage of geometrical cross section on the other. For example, a statement like "n_{TPC}=300 corresponds to 5% of σ_{GEOM}" means the total cross section for events with more than 300 TPC tracks is 5% of the geometrical cross section:

$$\sigma(n_{\mathrm{TPC}} > 300) = 0.05\ \sigma_{\mathrm{GEOM}}. \tag{1}$$

For the geometrical cross section of Pb+Au we use

$$\sigma_{\mathrm{GEOM}} = 6.94 \text{ b}, \tag{2}$$

calculated using the overlap model with a Woods-Saxon nucleus density profile and a binary NN collision cross section of σ_{NN}=30 mb.

The calibration is done in two steps, described in the Sections 3 and 4. First, a low beam-intensity minimum bias run (unit 218, run 1424, bursts 0-201) is used to find the calibration tables for the three multiplicities. Second, the run-by-run variation are checked and factors are found which allow to scale multiplicities in all runs such that the high edge is at the same place as the edge in unit 218. Before presenting these two steps, in Section 2 we have a quick look at the systematic dependence of the multiplicities on the running conditions.

2 Dependence of multiplicities on the running conditions

Before comparing multiplicity distributions taken under various conditions one has to normalize them somehow. We chose to normalize to 10^6 incident beam particles:

$$n(m) \quad = \quad \frac{n_0(m)}{\mathrm{N}_0} \cdot \frac{\mathrm{cent}}{\mathrm{beam}} \cdot 10^6 \quad \text{(for cent trigger)} \tag{3}$$

[1] Other variables can be, of course, generated by looping over tracks.

$$n(m) = \frac{n_0(m)}{\mathrm{N}_0} \cdot \frac{\text{minb}}{\text{beam}} \cdot 10^6 \quad \text{(for minb trigger)} \tag{4}$$

$$n(m) = \frac{n_0(m)}{\mathrm{N}_0} \cdot \frac{\text{beam}}{\text{beam}} \cdot 10^6 \quad \text{(for beam trigger)}, \tag{5}$$

where $n_0(m)$ and $n(m)$ are the raw and the normalized multiplicity distributions, respectively; beam, minb, and cent are the numbers of beam, minb, and cent trigger candidates seen in the scalers (no deadtime); and N_0 is the integral of the $n_0(m)$ histogram. This way the DAQ deadtime factor and the losses introduced via event cuts are corrected for, the only assumption being that they do not introduce any centrality bias. The normalized multiplicities obtained with the beam and the minb trigger are shown in Fig. 1. The correlations between the three multiplicities in a minb run are presented in Fig. 2. The beam pile-up within $\pm$ 1 μs, with the exception of a hole of some tenths of ns around zero, was suppressed on the trigger level. The pile-up within the mentioned hole was removed by a cut on the amplitudes of the beam detectors (the variables and functions refering to the output of step3c, version 2):

```
event->GetBC1ADC()**2+event->GetBC2ADC()**2 < 16.
```

Inspecting Figs. 1 and 2 we can see that

- The normalization works: the data obtained with beam (black) and minb trigger (green) coincide.
- The edge of the silicon multiplicity distribution varies depending on the beam intensity (middle panel, green for low; red and blue for high beam intensity).
- The delta electrons produced by a beam particle passing without a nuclear interaction are clearly visible by comparing the beam trigger (black) and MT trigger (red full histogram) events.
- The SD multiplicity is sensitive to noise as can be seen by the presence of high signals in the run without the target. Also, the fact that it increases with centrality faster than the other multiplicities indicates a contribution of random coincidences. Counting only tracks with a good matching between the two SD's might give a more reliable track multiplicity.
- The bump at TPC multiplicities below 50 probably comes from interactions in other than gold materials. According to the overlap model the maximum number of participants in Pb+C should be 7-8 times lower than in Pb+Au. This is consistent with the position of the upper edge of the bump.

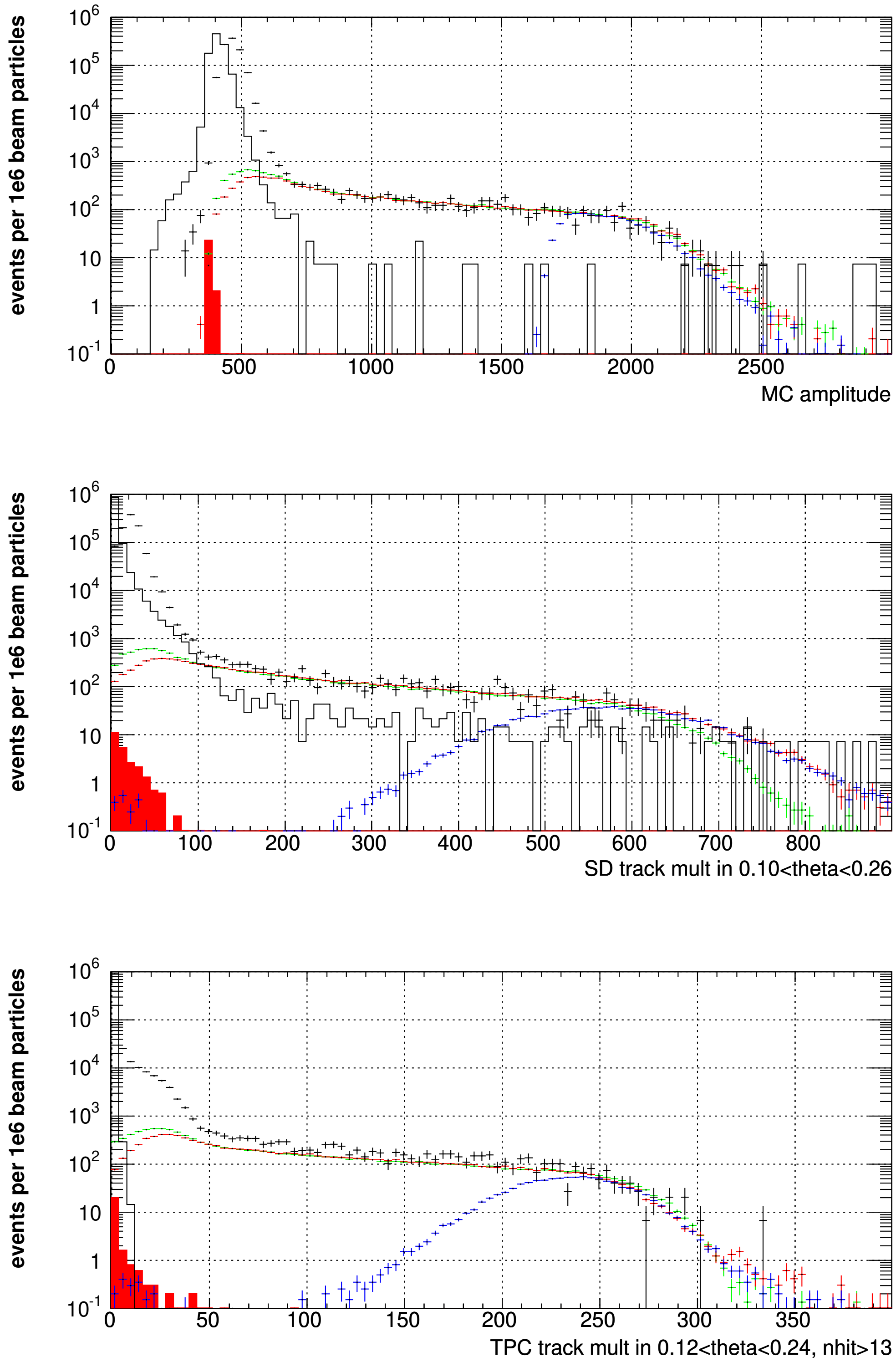

Figure 1: Multiplicity distributions taken under different running conditions: beam (black) and minb (green) triggers at low beam intensity (runs 1423 and 1424); minb (red) and cent (blue) at high (runs 1420 and 1427). The full red histogram represents events taken with the MT (random pulser) trigger during minimum bias run 1424. The solid black histogram represents run 1244: no target, beam trigger, high beam intensity.

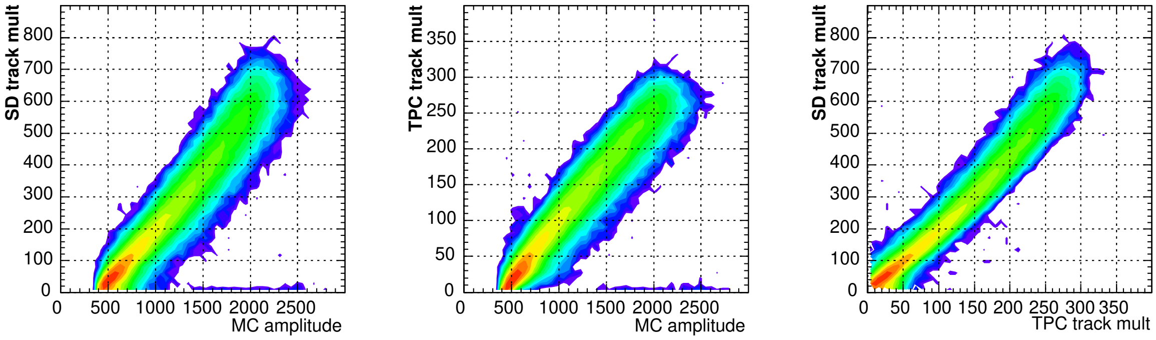

Figure 2: Correlations between the three multiplicities in the low intensity minb run 1424. MC amplitude (above ADC pedestal) and TPC multiplicity are roughly proportional. SD multiplicity increases with centrality faster than the other two.

3 Centrality calibration for the low-intensity minb run

The minimum bias run 1424 was particularly clean since it was taken with a reduced beam intensity. The number of events n per beam particle can be transformed to cross section σ by multiplying it with 521 b:

$$\sigma = n \cdot \frac{m_{\mathrm{Au}}^{\mathrm{mol}}}{N_A \rho d} = n \cdot \frac{196.967 \text{ g}}{6.022 \cdot 10^{23} \; 19.32 \text{ g/cm}^3 \; 325 \mu\text{m}} = n \cdot 521 \text{ b} \tag{6}$$

The normalized distributions from the low intensity minb run, shown in the previous section, are thus multiplied by $521/10^6$ and subsequently integrated from right to left. The integral has the meaning of the cross section for events with the multiplicity above a given value. The vertical lines in Fig. 3 indicate the 1, 2, 3, 4, 5, 10, 20, 30, 40, 50, 60, and 70 percent of the geometrical cross section σ_{GEOM}, with σ_{GEOM}=6.94 b. The centrality vs multiplicities, obtained in this fashion, is saved on ASCII files

```
mc2cent.dat
sd2cent.dat
tpc2cent.dat .
```

For example, `mc2cent.dat` looks like this:

```
   0      88.53
   1      88.53
   2      88.53
   3      88.53
   4      88.53
. . .
 678      51.54
 679      51.43
```

```
 680      51.33
 681      51.23
 682      51.13
. . .
2299       0.21
2300       0.21
2301       0.21
2302       0.21
2303       0.21
```

Integrating the entire multiplicity range triggered on in the central run 1427 gives 7.35%.

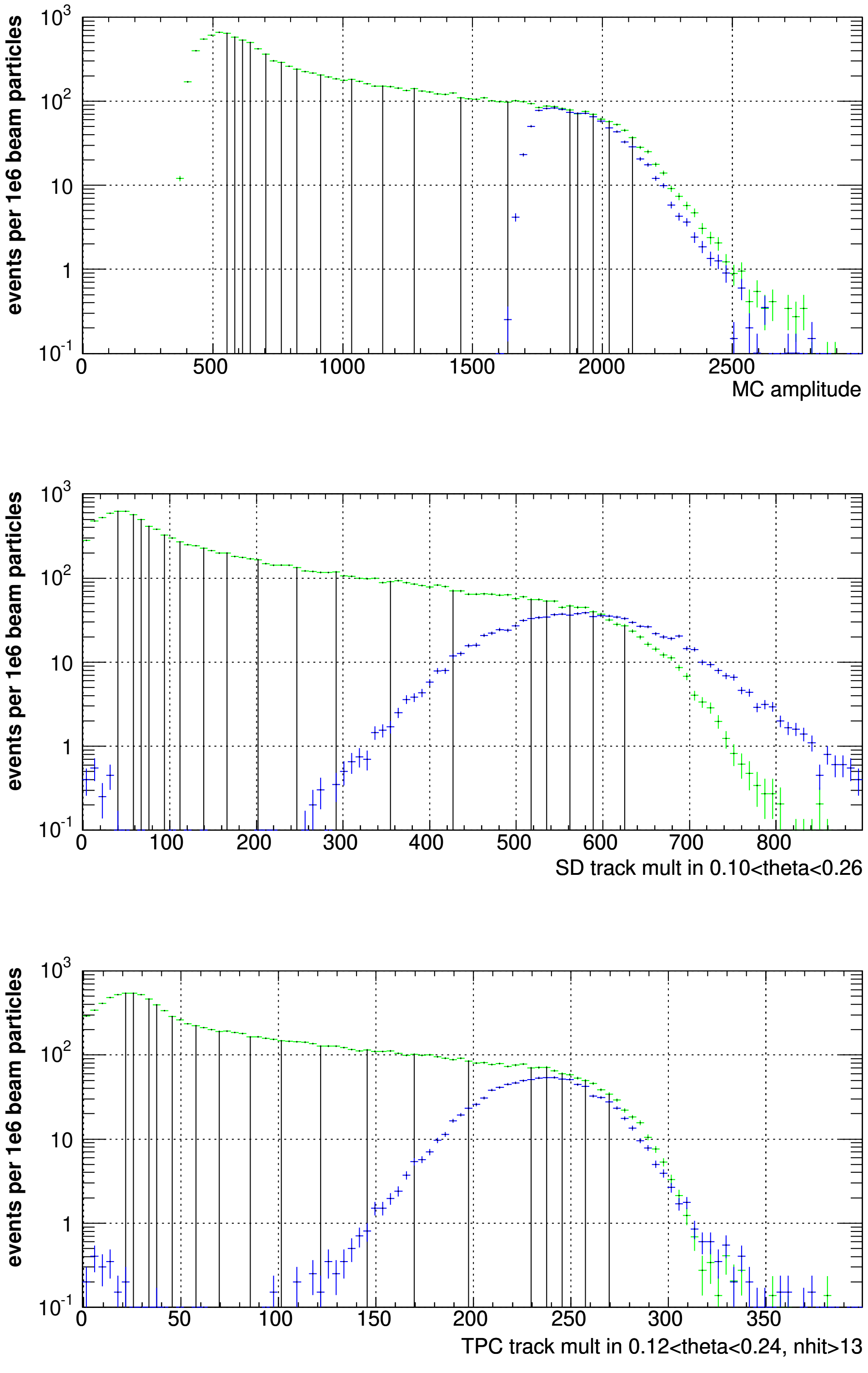

Figure 3: Multiplicity distributions from the minb run at low beam intensity (green), normalized to 10^6 beam particles, with the lines denoting centrality of 1, 2, 3, 4, 5, 10, 15, 20,…, 65, and 70 percent of the geometrical cross section 6.94 b. The centralities above (i.e. less central than) 45% are contaminated by non-target interactions. For comparison, a central run taken at high beam intensity is shown as well (blue).

4 Run-by-run calibration

The position of the upper edge of the multiplicity distributions can vary run-by-run for various technical reasons. In order to monitor these variations and to correct for them the edge position was determined in each unit. This was done in two independent ways: a) by finding such a multiplicity value that the number of events with a multiplicity equal or higher than it corresponds to 200 mb, and b) by taking B of the fit

$$f(x) = \frac{A}{1 + \exp(\frac{x-B}{C})} \tag{7}$$

to the distribution. The results of these two methods of edge determination are shown in Fig. 4 as the blue and black points, respectively. The run-by-run variations were 6% for MC, 5% for SD, and 9% for TPC (peak-to-peak). The green plot represents the blue/black ratio; the two methods agree within 4%. Since the fit method seems more reliable and does not seem to introduce any systematic difference between the minimum bias and central runs we recommend to use its results for the calibration. The numbers are available during the analysis of step3c output data via (see also next Section):

```
Double_t CSCcrp::getEdgeFitMC (int unit) const;
Double_t CSCcrp::getEdgeFitSD (int unit) const;
Double_t CSCcrp::getEdgeFitTPC(int unit) const;
```

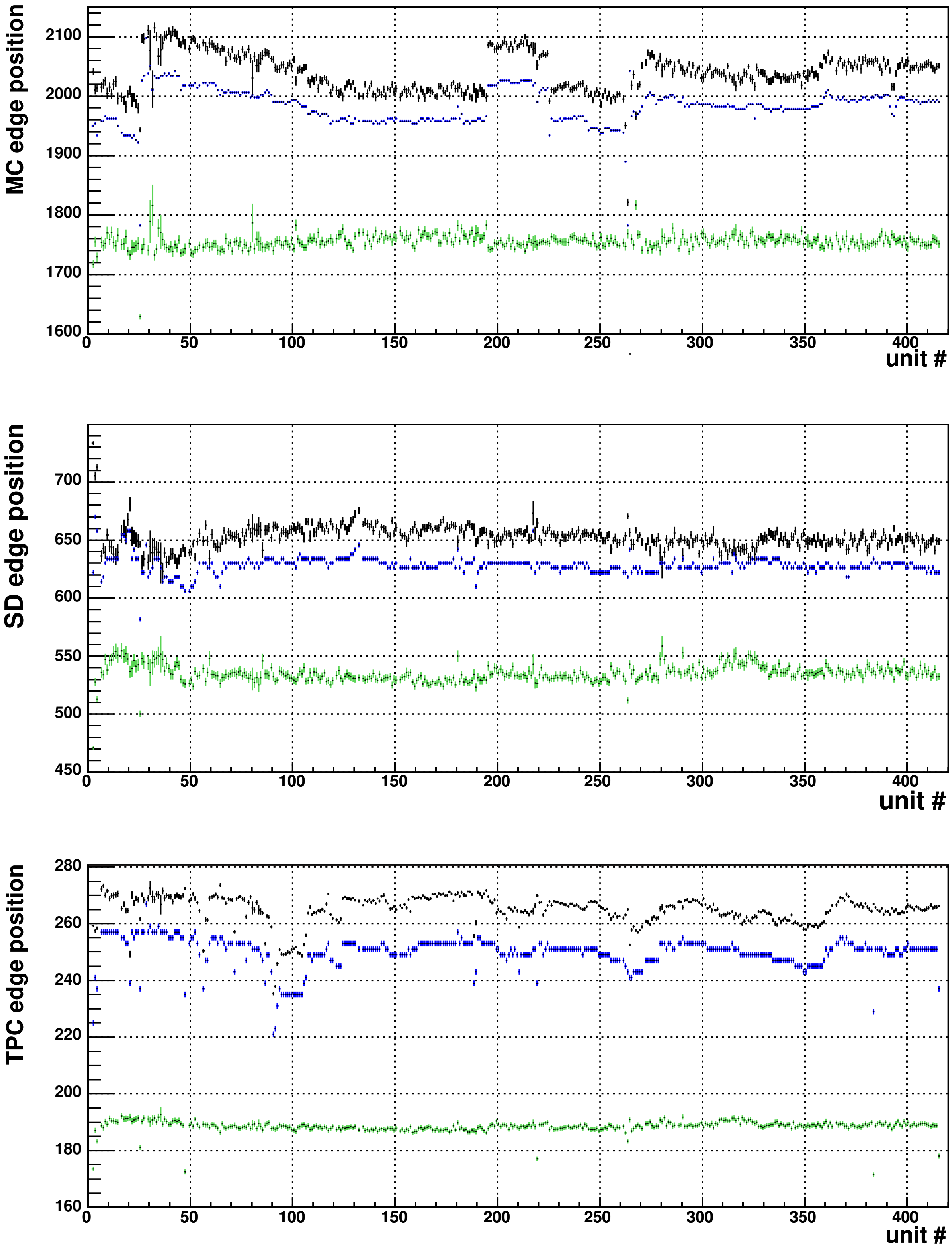

Figure 4: The edge position of multiplicity distributions for each unit, determined via integration (blue) and via fit (black). The green plot shows the (arbitrarily scaled up) ratio of the two methods.

5 How to use it all: centrality for each event

The first step to obtain the calibrated centrality is to create a CSCcrp object which stores the data needed for centrality and reaction plane calibration and provides the corresponding member functions:

```
CSCcrp *cal = new CSCcrp();
cal->InitializeTables("step3c/calib/rp.dat",
                      "step3c/calib/cent.dat",
                      "step3c/calib/mc2cent.dat",
                      "step3c/calib/sd2cent.dat",
                      "step3c/calib/tpc2cent.dat").
```

`step3c` should be a logical link pointing to the directory from the which the step3c library libCSEvent.so was taken.

The multiplicities corrected for the run-by-run variations can be accessed as shown below. The magic number 380 is the ADC pedestal of the MC signal.

```
380+(event->GetCentralityMC()-380) *
              (cal->getEdgeFitMC(218)-380)/(cal->getEdgeFitMC(unit)-380)
event->GetCentralitySD() * cal->getEdgeFitSD(218)/cal->getEdgeFitSD(unit)
event->GetCentralityTPC() * cal->getEdgeFitTPC(218)/cal->getEdgeFitTPC(unit)
```

The centrality in percent of geometrical cross section, including the run-by-run correction, is finally obtained using

```
event->GetCalibCentralityMC(cal, unit)
event->GetCalibCentralitySD(cal, unit)
event->GetCalibCentralityTPC(cal, unit).
```

The distributions of calibrated centrality are shown in the last figure of this note. These distributions ideally should be flat and sharply fall at the trigger edge. The MC central edge is sharp because it was used for triggering. The width of the SD and TPC edges can be used as the upper limit on the respective centrality resolutions. The low-intensity minimum bias run (green) is flat because it was used for calibration. The ugly non-statistical spikes are a binning effect and do not cause any harm.

The impact parameter b can be calculated from centrality fraction c using the relation

$$\pi b^2 = c \cdot 6.94 \text{ b}. \tag{8}$$

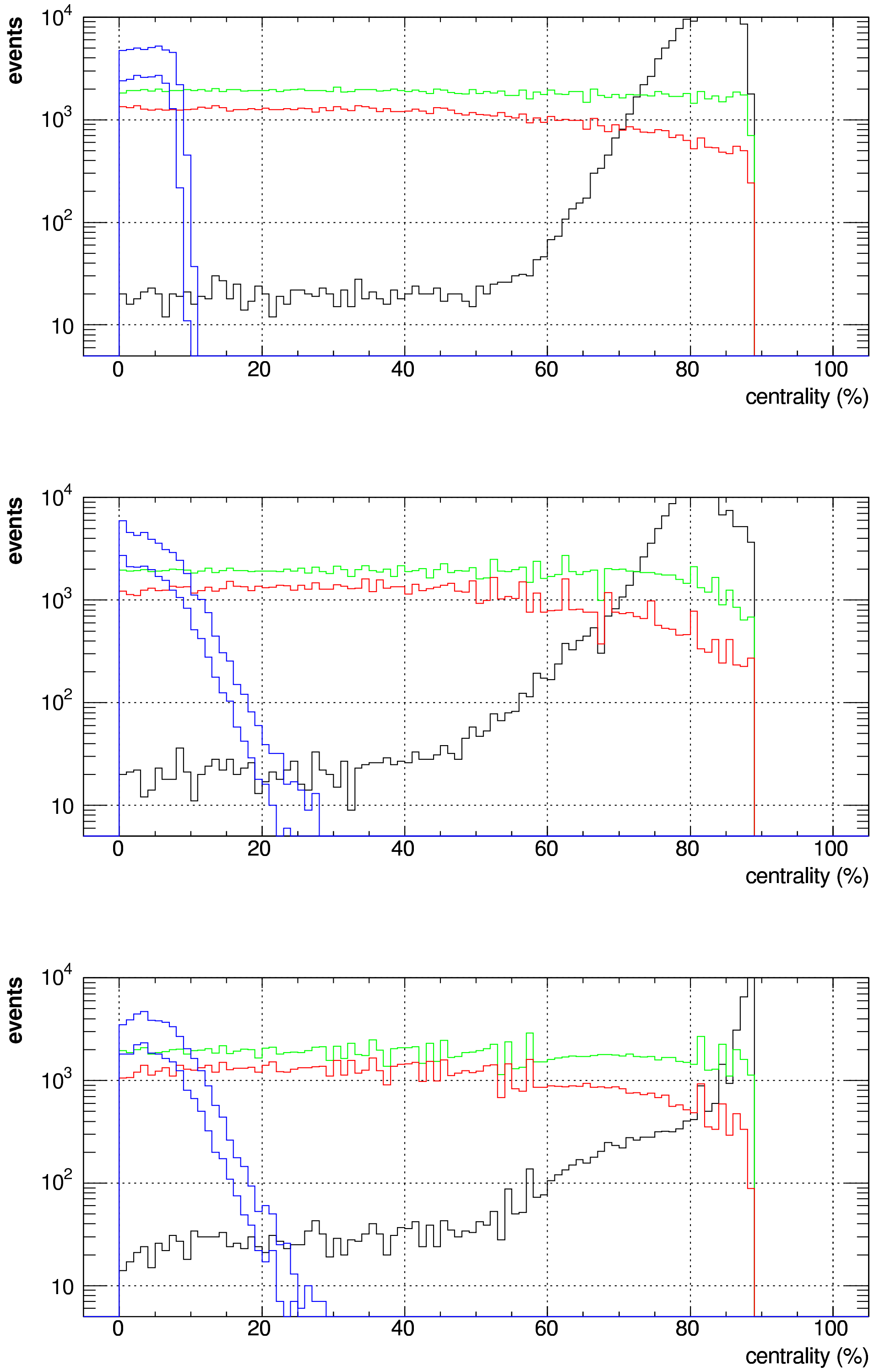

Figure 5: The calibrated centrality in percent of the geometrical cross section. The low intensity minb run (green) was used for calibration and thus is flat by definition. The low intensity beam triggered run (black), which would be best for calibration if we had enough statistics, goes up. This means that our minimum bias cuts into events as central as 50%. Another minimum bias and two central runs are shown in red and blue.