

# Procedure for event characterization in Pb-Pb collisions at 40AGeV in the NA49 experiment at the CERN SPS

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**Abstract.** The time evolution of the strongly interacting matter created in a heavy-ion collision depends on the initial geometry and the centrality of the collision. Thus an experimental determination of the collision geometry is required. This paper discusses a procedure for event classification and estimation of the geometrical parameters in inelastic Pb+Pb collisions at a beam energy of 40A GeV recorded with the fixed target experiment NA49 at the CERN SPS. In the NA49 experiment, event classes can be defined using the measured multiplicity of particles in the Time Projection Chambers (TPC) or the energy of projectile spectators deposited in the forward Veto or Ring calorimeters. Using the Monte-Carlo Glauber model, these event classes can be related to average values of the geometric quantities such as impact parameter or number of nucleon-nucleon collisions. The implementation of this procedure within a software framework of the future CBM experiment was adopted for event classification in the NA49 experiment. In future, this procedure will be used for analysis of the new Pb+Pb data collected by the NA61/SHINE experiment and for comparison with the results previously obtained by STAR at RHIC and NA49 at the CERN SPS.

## 1 Introduction

In relativistic heavy ion collisions geometrical properties of initial state cannot be measured directly. Numbers of collision participants and spectators refer to overlap region of colliding nucleons which directly depends on impact parameter of event. In central events the overlap region area has maximal value, thus the number of participants is expected to be maximal as well. Number of spectators vice versa should reach its minimum. In case of peripheral event the conclusions will be the opposite. Experiment observables include event multiplicity and spectator energy instead of collision participants and spectators, respectively. In present work the centrality analysis was performed on 40 AGeV Pb-Pb data collected by the NA49 experiment at CERN SPS. Tracking system of NA49 briefly described in the next section provides information on event multiplicity whereas VETO calorimeter located at the beamline downstream the primary vertex provides spectators energy. In order to associate these quantities with impact parameter of collision, Glauber Monte-Carlo model was used together with mapping procedure which was designed to associate number of participants and wounded nucleons

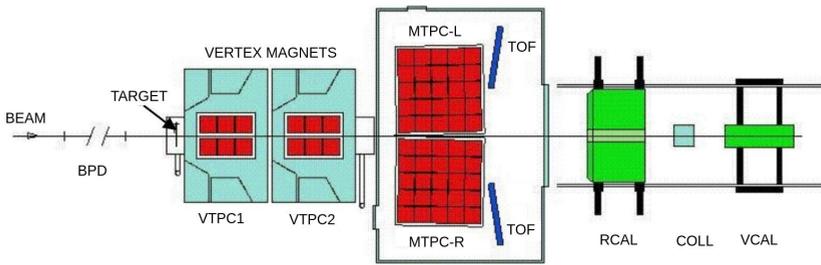
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provided by MC-Glauber with multiplicity and VETO-energy. More detailed description presented in Section 4.

## 2 NA49 experimental setup

The NA49 experimental setup [1] is shown in Fig. 1. Its main components are four large-volume time projection chambers (TPC). The vertex TPCs VTPC-1 and VTPC-2, are placed in the magnetic field of two superconducting dipole magnets VTX-1 and VTX-2. The other two TPCs (MTPC-L and MTPC-R) are positioned downstream of the magnets. The TPCs serve to measure momenta and multiplicity of produced charged particles. A Veto Calorimeter placed about 20 m downstream of the target behind a collimator measures the energy carried by projectile spectators.

The data on Pb+Pb collisions at 40A GeV were collected within the NA49 energy scan program at the CERN SPS. After event selection 120K events remain for further analysis. To ensure good fit quality tracks are required to have a fit  $\chi^2$  in the range  $0 \leq \chi^2 \leq 10$ . It is further required that tracks contain at least 55% of the maximum possible number of points to avoid double-counting of split tracks. Tracks are further required to have distances of closest approach at the interaction vertex of  $|b_x| < 1\text{cm}$ ,  $|b_y| < 2\text{cm}$ . The number of hits should exceed 20 in the VTPCs and 30 in the MTPC. Kinematic cuts select particle pseudorapidity in  $1.4 \leq \eta \leq 5$  and transverse momentum  $p_t < 2.5\text{GeV}$ .

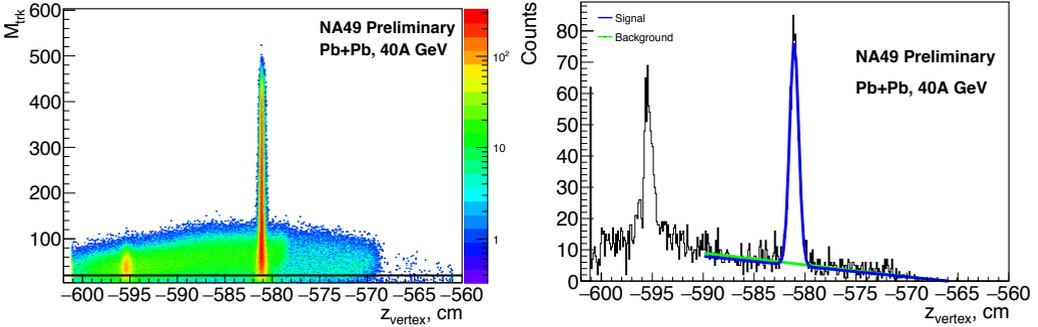


**Figure 1.** NA49 experimental setup [1]

## 3 Subtraction of background events from the multiplicity distribution

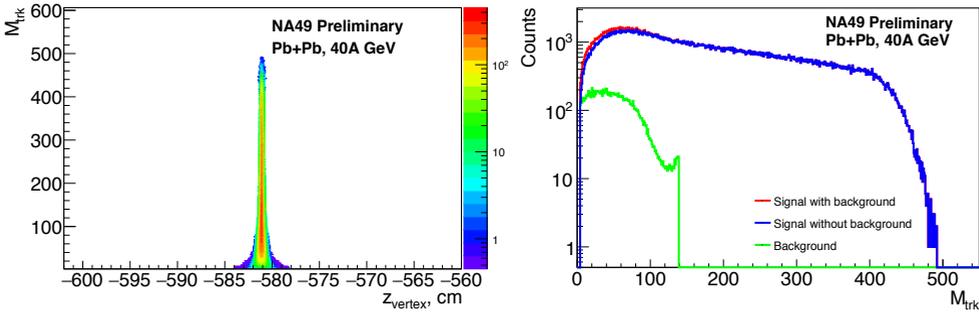
The correlation between multiplicity  $M_{trk}$  of produced particles and z-coordinate of the interaction vertex are shown in Fig. 2 (left). At small multiplicities, vertex reconstruction is not reliable and therefore collisions with multiplicity less than 5 were discarded. In order to subtract background events, the two-dimensional distribution shown in Fig. 2 (left) for each multiplicity value was projected onto the X-axis.

The resulting one-dimensional distribution, which is shown on Fig. 2 (right) for  $M_{trk} \leq 20$ , contains a signal from the Pb target, which is described by the Gaussian function, and for peripheral collisions a background, which is described by a polynomial of the first degree. Using these functions, the signal function is fitted within 3 standard deviations from the peak value and the background function in the region near the collision vertex. After that the background contribution was subtracted from the signal function. In the projection for large multiplicity values there are no background events, so the



**Figure 2.** Left: Correlation between multiplicity  $M_{trk}$  obtained from TPCs and z-coordinate of the interaction vertex before subtraction of background events. Right: Distribution of z-coordinate of the interaction vertex at  $M_{trk} \leq 20$ .

described procedure was carried out only for a multiplicity of less than 130. The multiplicity distribution after subtraction of the background contribution can be used to determine event classes. The two-dimensional distribution after background subtraction is shown in the Fig. 3 (left). The projected multiplicity distribution before and after subtracting the background is plotted in Fig. 3 (right).



**Figure 3.** Left: Correlation between multiplicity  $M_{trk}$  obtained from the TPCs and z-coordinate of the interaction vertex after subtraction of background. Right: Track multiplicity distribution before and after background subtraction. Also shown is the distribution of the subtracted background.

## 4 Centrality determination procedure

Geometric quantities of the collisions are associated with experimentally measured quantities by means of a Modified Wounded Nucleon model (MWN, aka. MC-Glauber) [2]. According to the MWN in any collision with a given number of participants and number of nucleon-nucleon collisions emitted particles are produced by a set of ancestors with negative binomial distribution (NBD). The distribution of track multiplicity  $M_{trk}$  from the TPCs is fitted with the following function:

$$\frac{dN_{ev}}{dM_{trk}}(f_M, \mu, \sigma) = P(\mu, \sigma) \times N_a = P(\mu, \sigma)[f_M N_{part} + (1 - f_M) N_{coll}], \quad (1)$$

where  $N_{part}$  is the number of participants,  $N_{coll}$  is the number of binary collisions.  $f_M, \mu, \sigma$  are parameters of the fit function distribution,  $\mu$  is the mean multiplicity per emitting particle source and  $\sigma$  controls the width of the negative binomial distribution  $P(\mu, \sigma)$ .

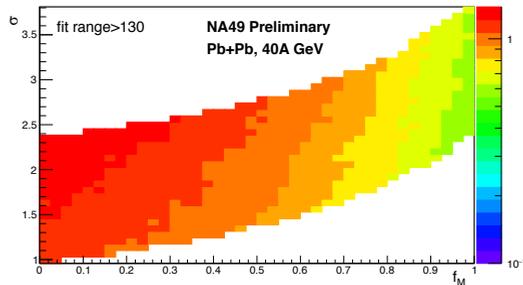
Similarly the distribution of energy  $E_{veto}$  deposited in the Veto calorimeter (mostly from projectile spectators) is parameterized using the following form:

$$\frac{dN_{ev}}{dE_{spec}}(f_E, \mu, \sigma) = P(\mu, \sigma)[f_E N_{part} + (1 - f_E) N_{specA}], \quad (2)$$

where  $N_{specA}$  is the number of projectile spectators.

Experimental distributions for multiplicity and spectator energy were fitted with the functions in Eqs. (1),(2). The fit range for spectator energy was  $E_{veto} < 4500$  and for multiplicity  $M_{trk} > 130$ .

The parameters  $f_M, \mu, \sigma$  were determined by comparing the experimental distribution to the MC generated distribution and finding the parameter values which provide the best match. A 2-dimensional plot of the matching quality is shown in Fig. 4.



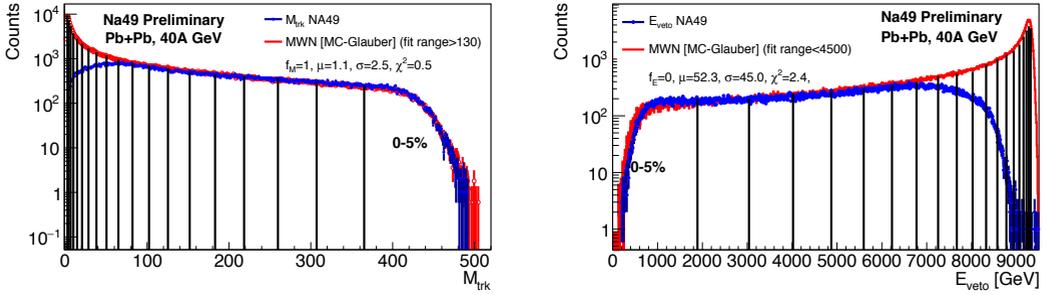
**Figure 4.** Quality of MW fit for different values of NBD parameters  $\sigma$  and  $f_M$

Events were divided into 5% centrality classes as indicated in Fig. 5. The trigger system was set to exclude beams. Due to the the finite energy resolution of the Veto calorimeter there is no sharp onset of the triggering efficiency. Therefore simulation results deviate from the experimental data in the region of the most peripheral collisions. The point where the deviation starts is called the anchor point AP. It is at 40% for the multiplicity distribution and at 25% for the spectator energy distribution.

The total number of events obtained from the fit of the TPC multiplicity distribution was 300K and of the distribution of  $E_{veto}$  was 400K. When  $f_M = 1$  (no hard interactions) soft interactions produce particles with an average multiplicity proportional to  $N_{part}$ . The probability of hard interactions is related to  $N_{specA}$  at  $f_E = 0$ .

Event classes were determined from a correlation plot of spectator energy versus multiplicity of produced particles, shown by Fig. 6 (left), with the following steps [3]:

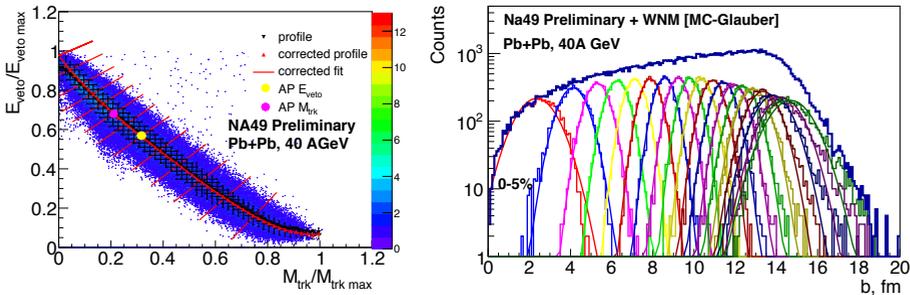
- Scaling the number of tracks and energy in the Veto-calorimeter to their maximum value ( $M_{trk}$  and  $E_{veto}$ ).



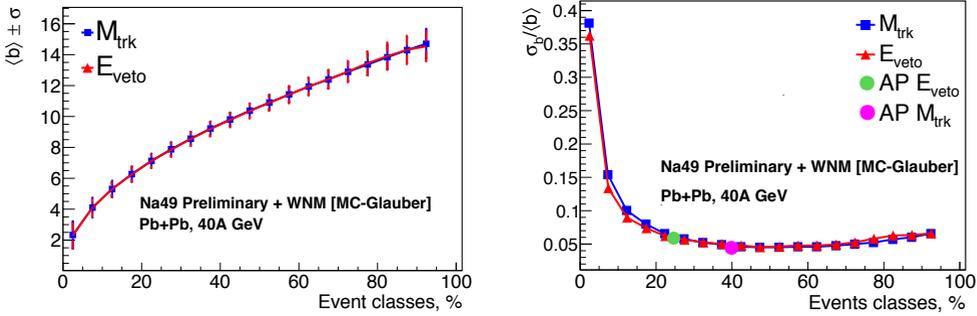
**Figure 5.** Left: Track multiplicity distribution obtained with the TPCs compared to the fitted distribution using the MWN model. Right: Spectator energy distribution obtained with the Veto calorimeter compared to the fitted distribution using the MWN model.

- Parametrization of the distributions of spectator energy and multiplicity of particles [3]

After this mapping procedure one can use the MWN model to estimate the geometrical parameters of the initial state of event classes. Figure 6 (right) shows the impact parameter distributions for events in specific centrality classes, where track multiplicity simulated using the MWN model. For each centrality class the mean value and width was obtained. The resulting dependence of  $b$  and  $\sigma_b / \langle b \rangle$  on centrality are shown in Fig. 7 (left). The dependence of the resolution of  $b$  on centrality is shown in Fig. 7 (right).



**Figure 6.** Left: Correlation between the energy deposited in the Veto calorimeter and track multiplicity obtained from data. Right: Distribution of impact parameter in different centrality classes based on the TPC track multiplicity  $M_{trk}$ . Colored lines and histograms are for consecutive 5% classes.



**Figure 7.** Left: Distribution of mean value of impact parameter in different centrality classes. Right: Distribution of impact parameter resolution in different centrality classes.

## 5 Summary

The procedure for determining the geometric parameters of the collisions developed within the software framework of the future CBM experiment was adopted for event classification in the NA49 experiment. Event classes in the experiment and parameters of the MWN model in event classes were determined. Impact parameter resolution is similar for centrality determination via spectator energy and track multiplicity. In future, the procedure will be used for analysis of the new Pb-Pb data collected by the NA61/SHINE experiment and for comparison with the results previously obtained by STAR at RHIC and NA49 at the CERN SPS.

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