QGP, HBT and DCC

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April 1999

Abstract

We discuss simple implementation of a quark-gluon plasma source, HBT effects and DCC domain in Monte Carlo generators for the purpose of the PHOBOS experiment.

1 Introduction

Heavy ion collisions are complex processes that involve many nonperturbative effects. Therefore our understanding of nucleus-nucleus interactions at relativistic energies is mainly restricted to phenomenological models. Their MC implementations are valuable tools for the initial design of experiments and further for the analysis of the experimental data.

Although there are at least several MC generators, based on different physical assumptions, at the RHIC energies we expect the appearance of quite new physical effects, which had not been included so far in the codes. Our main goal is to introduce some modifications to MC generators which can help us to understand semi-quantitatively: production of pions from a plasma source, HBT effects and decay of DCC domains. In the following we present results obtained from the HIJING generator. However, our methods are quite general and should work in connection with other MC generators. In fact they can be mostly implemented as separate application programs operating on the output from the original generator.

2 Plasma source

For our purposes we introduced modifications to the HIJING output in order to simulate effects of droplets of plasma, which can appear in the region of collision. For sake of simplicity we assume that plasma source is static i.e. the particles are produced on the hypersurface $t = t_1$. Their spectrum can be estimated with the help of Cooper-Frye formula [1]

$$E\frac{dn}{d^3p} = \int d^4x\delta(t-t_1)f(x,p)p^\mu u_\mu, \tag{1}$$

where p_μ is 4-momentum of the particle and u_μ is a vector orthogonal to the hypersurface where particles are counted (in our case $u_\mu = (1,0,0,0)$). We assume also thermal nature of production by taking the invariant phase-space density in the form $f(x,p) = \exp(-E/T)$. The temperature T is the so called "freezeout" temperature, which we set to be $170MeV$.

Then the momenta of produced particles are distributed according to

$$\frac{dn}{4\pi p^2 dp} \propto \exp\left[-E(p)/T\right], \tag{2}$$

where we have assumed the spherical symmetry of a plasma source. Consequently the particles are produced isotropically in the cofiguration space. In the first approximation we neglect strange and neutral particles and assume that only charged pions are produced.

In the real experiment we expect that only some fraction of pions come from the plasma source. Since we are mainly interested in the leading effect we simply randomly replace, with a certain probability α, charged pions from the HIJING with pions from our source. The limit $\alpha = 0$ corresponds to the unmodified HIJING and $\alpha = 1$ to the pure thermal source.

In Fig.1 we show the effects of plasma. The most significant change is seen in the pseudorapidity distribution which becomes more peaked around $\eta = 0$. The corresponding effects in the P_{tot} and p_t distributions are rather small.

Of course the model described above is very simple and it has many shortcomings. It does not take into account many physical effects like expansion of plasma, production of strange particles etc. To proceed further one can try, for example, to establish more precisely the hypersurface of production and solve the equation of motion for a plasma fluid. This requires extensive numerical calculations and in conjunction with MC programs would be very difficult and might not be useful.

3 Bose-Einstein correlations

Unique features of the PHOBOS apparatus will allow for detailed studies of pion HBT effects especially at small p_t. At present there is no well defined method for incorporating Bose-Einstein correlations into MC generators and e.g. in HIJING these effects are completely neglected. For our purposes we implemented the method which introduces BE correlations as appropriate interactions in the final state [2]. More precisely the two pions with similar momenta are shifted toward each other in such a way as to reproduce the two-particle correlation function, which is usually taken in the Gaussian form $C_2(Q_{inv}) = 1 + \lambda \exp(-Q_{inv}^2 R^2)$ with λ and R being free parameters.

In the calculations it is assumed that in the absence of final state interactions the number of pairs N_p is proportional to the available phase-space. Thus under this assumption the distribution of pairs is given by

$$f(Q_{inv}) \equiv \frac{dN_p}{dQ_{inv}} = \frac{Q_{inv}^2}{(Q_{inv}^2 + 4m^2)^{1/2}} \tag{3}$$

where m is a pion mass.

For each pair of pions with a given Q_{inv}^{old} we calculate the new one, Q_{inv}^{new}, by solving the equation

$$\int_0^{Q_{inv}^{old}} f(Q_{inv}) dQ_{inv} = \int_0^{Q_{inv}^{new}} f(Q_{inv}) C_2(Q_{inv}) dQ_{inv} \tag{4}$$

The latter reflects simply the conservation law for the number of particles provided that only two-particle correlation are taken into account. In the next step we calculate the corresponding momentum shift $\delta\mathbf{p}_{ij}$ from the $\delta Q_{inv} = Q_{inv}^{old} - Q_{inv}^{new}$. $\delta\mathbf{p}_{ij}$ may be regarded as a partial shift caused by the presence of particle j on the momentum of particle i. If we neglect higher order correlations the final momentum of particle

i will be given by

$$\mathbf{p}_i^{new} = \mathbf{p}_i^{old} + \sum_{i \neq j}^{N} \delta \mathbf{p}_{ij} \quad (i = 1, ..., N) \tag{5}$$

In Fig.2 we show the unmodified and modified distribution $f(Q_{inv})$ for pairs of positive pions generated by HIJING (both pions of the pair are taken from the same event). Once the momenta of pions has been shifted one can calculate the correlation function C_2

$$C_2(Q_{inv}) = \frac{N_0}{N} \frac{f(Q_{inv})}{f_0(Q_{inv})}, \tag{6}$$

where f_0 is a "background" distribution obtained by taking both pions of the pair from different events. N and N_0 are the total number of pairs under consideration.

For the central collisions and rather large source $R = 0.02GeV = 10fm$ the corresponding C_2 is well reproduced. For smaller sources e.g. $5fm$ there is a significant probability that in the region, where δQ_{inv} is not close to 0 there will be more than two particles. This situation is not properly treated by the above equations and one should modify the method to take into account also higher order correlations. Unfortunately there is no simple analytical results for 3-particle correlations and we presume that one is left to purely numerical approach. This problem will be investigated in future.

On the other hand one can still use this method with smaller sources in case of smaller density of particles: lower energies or more peripherial events. Currently we are testing situation with $R = 5fm$ and $b > 7fm$ for Au+Au system at $\sqrt{s} = 200GeV$.

4 Decay of DCC

The idea that in the high-energy heavy ion collision a domain of disoriented chiral condensate can appear attracts a lot of interest [3]. From the experimental point of view it can be defined as a cluster of pions with almost identical momenta and with the fraction of neutral to all pions, f, distributed according to

$$P(f) = \frac{1}{2\sqrt{f}}. \tag{7}$$

Our MC model of DCC follows closely the model used in the design of the MiniMax experiment [5]. It is based on the assumption of the coherent radiation of pions. Consequently we may expect that in the CM frame of DCC, pions are nonrelativistic and their momenta are determined mainly by the uncertainty principle. Hence it is natural to assume that they have a Gaussian distribution with dispersion $< \mathbf{pp} >= 3\sigma$. For our purposes we set $\sigma = 100MeV$. In reality, center mass of pions can move in the laboratory frame in the direction given by the pseudrapidity η and with transverse momentum p_t (normalized per one pion). Taking reasonable values of these parameters ($\eta = 3$ and $p_t = 300 MeV$) pions produced from the decay of DCC look like a jet in $\eta - \phi$ space in the laboratory frame. The radius, R_{DCC}, of the jet in $\eta - \phi$ space is approximately given by $R_{DCC} = \sigma / p_t$

The charges of pions are assigned according to Eq. 7 using the transformation method. The charged pions are produced with equal probability as negative or positive. In principle the parameters η and p_t can fluctuate from event to event and one should consider different possibilities. For example, η can be distributed with equal probability over the interval $(-\eta_0, \eta_0)$.

At this moment it is not well known how many pions can be produced from a DCC domain with radius of the order of few fermis. In fact it is an additional free parameter. Crude estimation suggest that it could be about 30-300 pions, the number negligible in comparison with the total multiplicity of the event [4]. Therefore, without any significant violation of energy conservation we simply add the pions produced from DCC to the HIJING output (Fig.4).

References

[1] F. Cooper and G. Frye, Phys. Rev. **D10** (1974) 186

[2] K. Kadija and P. Seyboth Phys. Lett. **B287** (1992) 363

[3] J.D. Bjorken, Acta Phys. Pol. **B28** (1997) 2773

[4] S. Gavin, hep-ph/9407368

[5] M. Convery, hep-ex/9801020

Figure Captions

1. Comparison of pure HIJING (dashed line) and its modification with plasma source (solid line) with $\alpha = 0.3$. Data obtained from 100 central events. Distributions of positive pions in (a) pseudrapidity, (b) total momentum, (c) transverse momentum. The distributions shown in Fig.1b and Fig.1c are only for positive pions with $0 < \eta < 2$.

2. Bose-Einstein effects. Data taken from 3000 HIJING central events.
   (a) unmodified distribution of $\pi^+\pi^+$ pairs
   (b) modified distribution of pairs
   (c) the reproduced correlation function C_2.

3. Distribution of produced pions in $\eta - \phi$ space: (a) in the CM of the domain, (b) in the laboratory frame. A large number of 1000 pions is assumed to originate from the DCC domain.

4. $dn/d\eta$ distribution of π^+ in the (a) normal event and (b) DCC event.

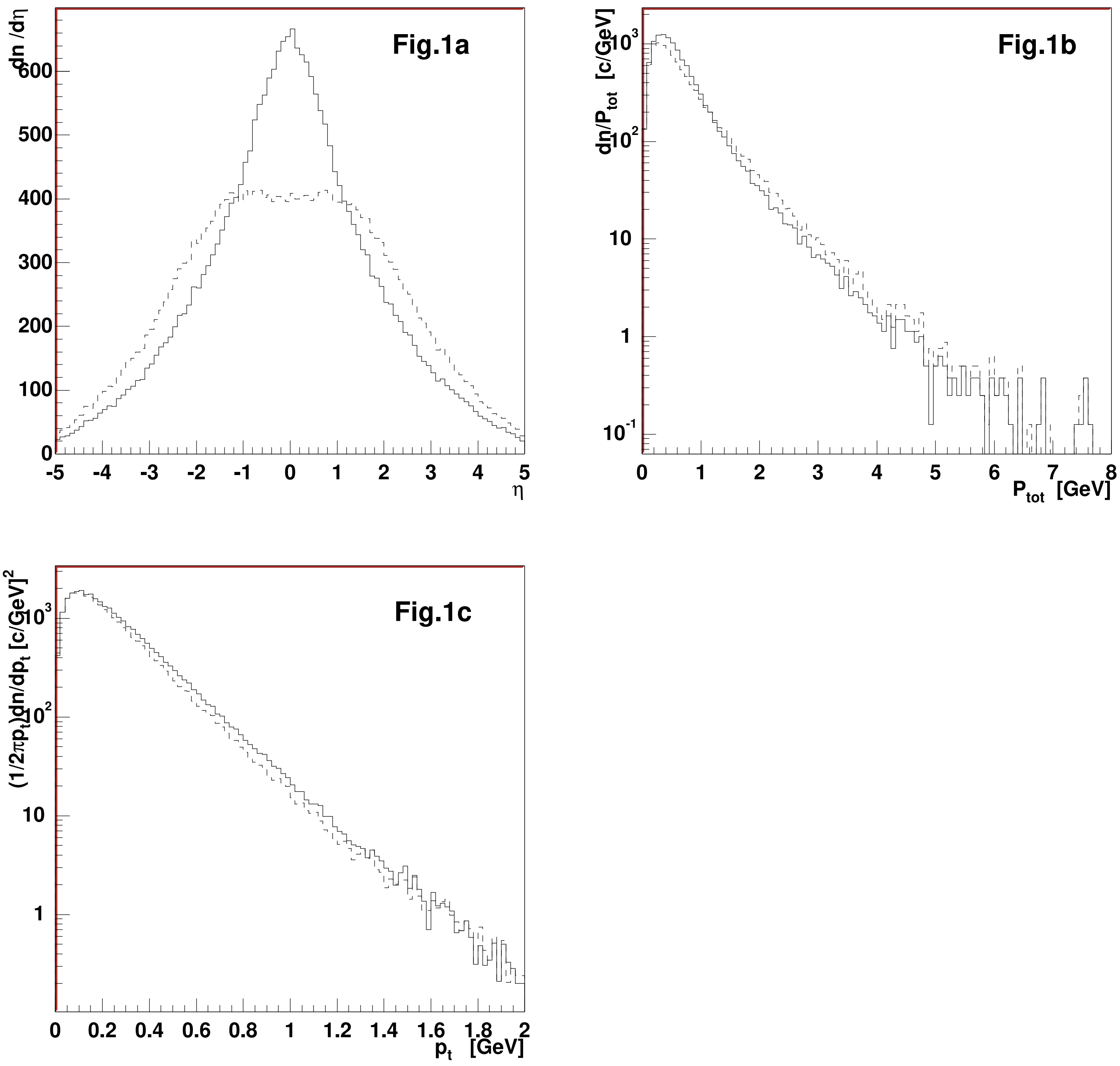
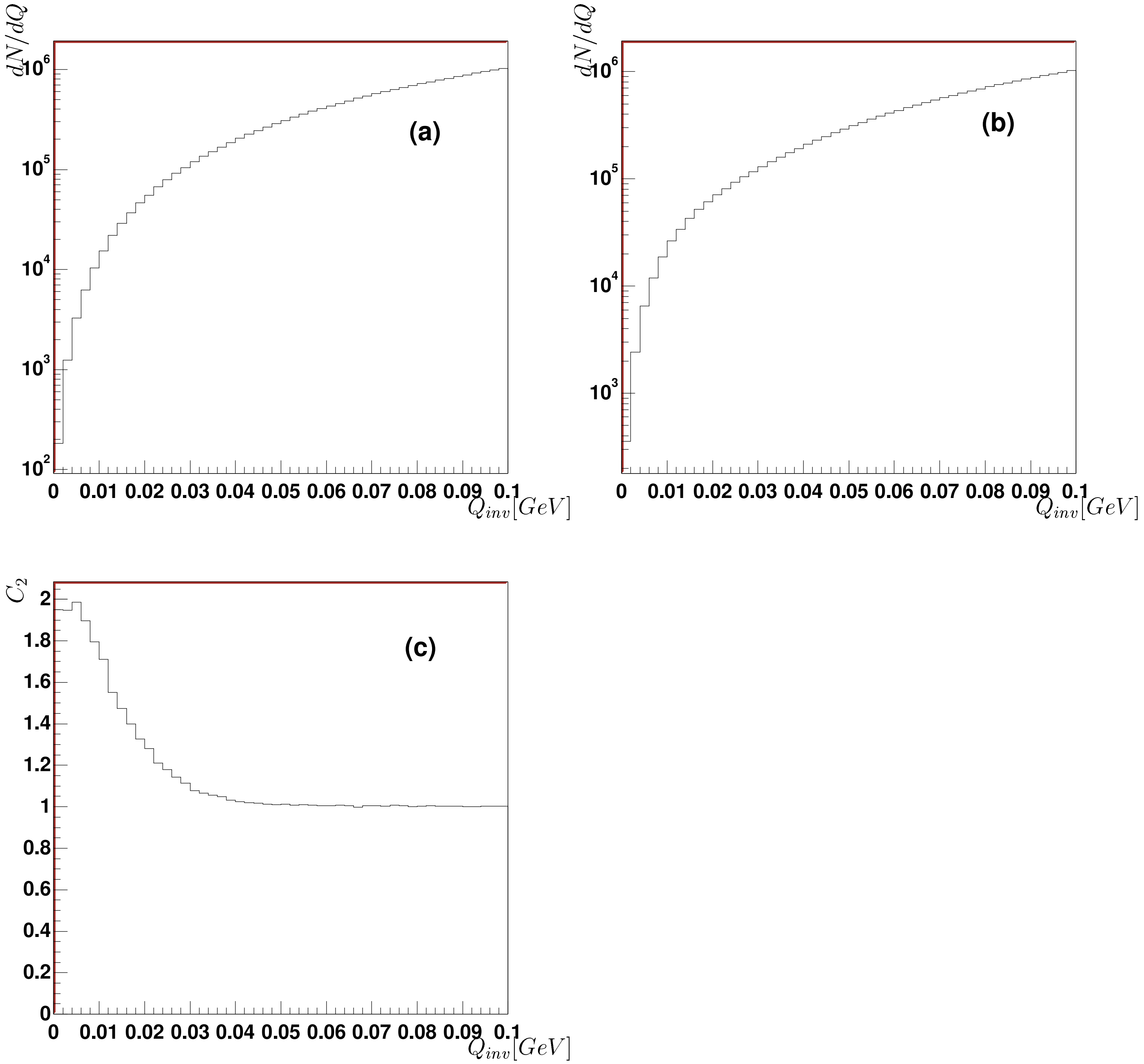


Fig.1a
dn /dη
η
Fig.1b
dn/P_tot [c/GeV]
P_tot [GeV]
Fig.1c
(1/2πp_t)dn/dp_t [c/GeV]^2
p_t [GeV]

Figure 1:



dN/dQ
(a)
10^6
10^5
10^4
10^3
10^2
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1
$Q_{inv}[GeV]$
dN/dQ
(b)
10^6
10^5
10^4
10^3
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1
$Q_{inv}[GeV]$
C_2
(c)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.1
$Q_{inv}[GeV]$

Figure 2:

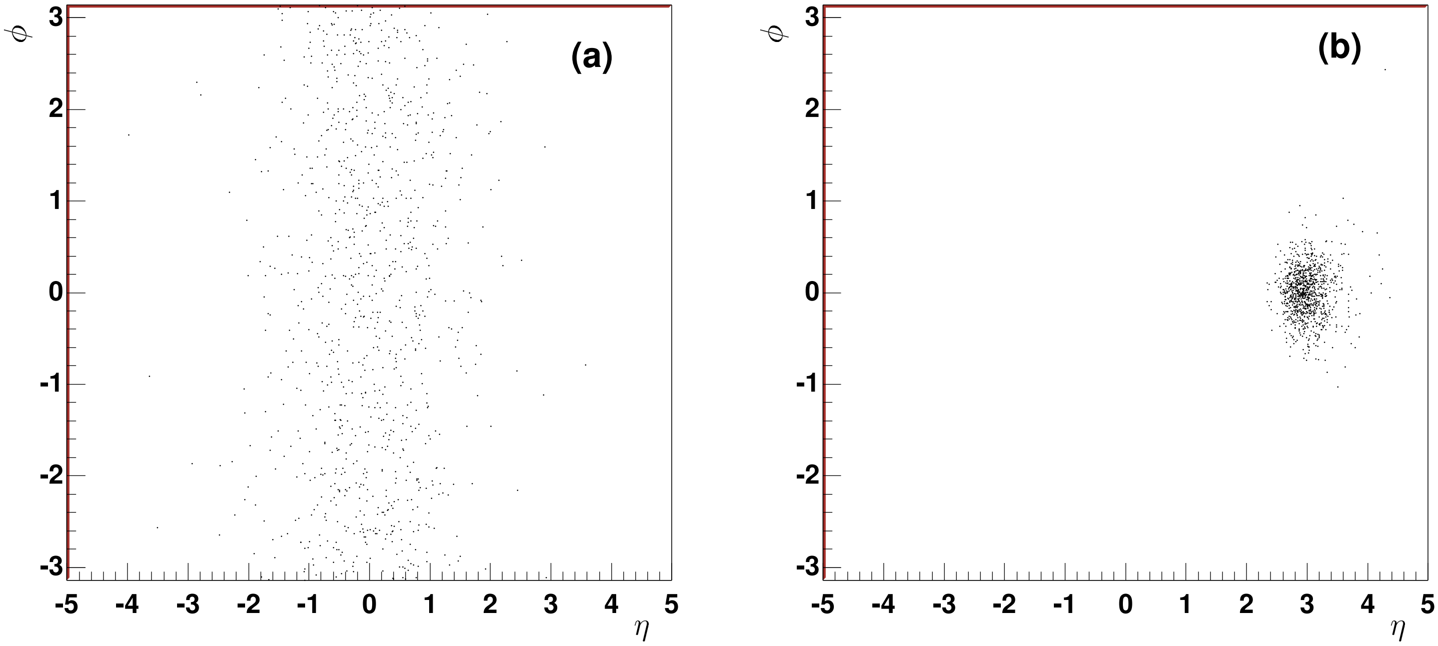


Figure 3:

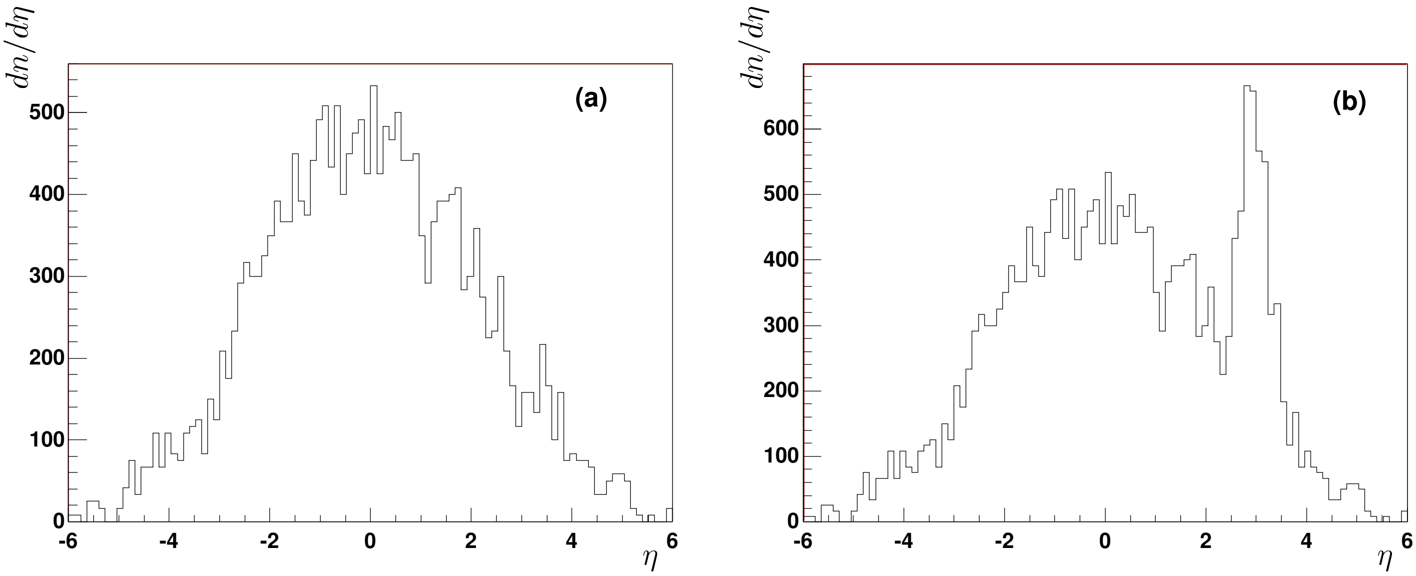


Figure 4: