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RELATIVISTIC HADRONIC CASCADE ANALYSIS OF TWO-PION BOSE-EINSTEIN CORRELATION FOR Si + Au COLLISIONS AT AGS ENERGY

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Abstract

The proposed relativistic hadronic cascade model has been used to analyse two- pion Bose-Einstein correlation in central collision of Si + Au at AGS energy. The $\pi^-\pi^-$ correlation function calculated according to the space-time and four momentum distributions of π^- at freeze-out agrees quite well with that of E802 experimental onse. We also have calculated the root mean squared length of the π^- source above and compared it with the conventional fitted radius of π^- source. It is mentioned that due to the non-Gaussian features in position and momentum distributions of the source and the dependence of the location upon the momentum especially,to regard the conventional fitted radius as the spatial extent of the source is dangerous. Instead,it might be more reliable to predict the spatial extent of the source with the root mean squared length.

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1 INTRODUCTION

Bose-Einstein correlation between two identical particles was firstly applied in astronomy to the end of extracting stellar radii via the photons they emit[1] and known as Hanbury-Brown-Twiss(HBT) method. Later on this technique has been found to be a powerful diagnostic tool in relativistic nucleus-nucleus collisions[2-7],since in principle correlation function can provide quite detailed information about the space-time evolution history of the collision.

[1] mailing adress.

The primary motivation of the ultrarelativistic nucleus-nucleus collisions is to investigate the possibility of the formation of Quark-Gluon-Plasma (QGP) ,a new phase of matter. If there is really QGP formed in ultrarelativistic nucleus-nucleus collisions, the plasma would subsequently cool,expand and eventually hadronize. The hadronic system might then be cooling and expanding further until the constituents cease to collide each other, i.e. approaching the phase space distribution of the hadrons at freeze-out. It is crucial importance to have the messages about the size of the reaction system at freeze-out and the time spanning from beginning of the collision until approaching the freeze-out. Both of size and time above are expected to be extracted from the two identical particle correlation functions,which seems to be relevant to the QGP formation.

The correlation function is defined[2,8,9] as the ratio of the two-particle probability $P(p_1,p_2)$ to the product of the single-particle probability P(p):

$$C_2(p_1,p_2) = \frac{P(p_1,p_2)}{P(p_1)P(p_2)} \tag{1}$$

where p refers to the four momentum. For a chaotic boson source the Bose-Einstein correlation can be calculated approximately from the boson source function $\rho(x,p)$ describing the production of a boson at phase space point (x,p),here x is the space-time four vector,as follows[2]:

$$C_2(p_1,p_2) = \frac{\int d^4x_1 d^4x_2 \rho(x_1,p_1)\rho(x_2,p_2) \mid \varphi^s_{p_1p_2}(x_1,x_2)\mid^2}{\int d^4x_1 d^4x_2 \rho(x_1,p_1)\rho(x_2,p_2)}, \tag{2}$$

where $\varphi^s_{p_1p_2}(x_1,x_2)$ is the symmetric two boson wave function. In the absence of any other interactions among bosons (i.e. plane wave approximation) the Bose-Einstein correlation function simply reads:

$$C_2(p_1,p_2) = \frac{\int d^4x_1 d^4x_2 \rho(x_1,p_1)\rho(x_2,p_2)\cos[(p_1-p_2)(x_1-x_2)]}{\int d^4x_1 d^4x_2 \rho(x_1,p_1)\rho(x_2,p_2)}. \tag{3}$$

Meanwhile,the Bose-Einstein correlation function can also be expressed,via the Fourier transform of the source function,as follows[3,6]

$$C_2(p_1,p_2) = 1 + \mid \tilde{\rho}(p_1-p_2)\mid^2 \tag{4}$$

Quite a lot of experimental results of the two boson correlation function in relativistic nucleus-nucleus collision at AGS or CERN energy have been published [10-14]. In order to extract the Bose-Einstein correlation from raw (measured) correlation function several corrections should be taken. The corrections for the experimental acceptance and for the Coulomb interaction, via Gamow factor, are taken most popularly. If the experiment was not devised perfectly to limit the effects of the final state hadronic interaction and the resonance, both of them may distort the correlation function[3] as well. Fully corrected correlation functions are commonly fitted with several kind of parametrized correlation function (Gaussian,exponential,etc.)[11,13] deduced under the assumptions of chaotic,non-interacting and momentum independent source. The source size and lifetime parameters are then extracted this way,although it has been questioned recently[9,14]. In Ref.14 it has been pointed out that if the boson source has any correlation between position and momentum,an experiment will only "see" part of the source in the correlated dimension due to the experimental acceptance.

Several theoretical models (event generators),RQMD[15],VENUS[16],ARC[17], etc., have been confronted with above experiments. Using event generator a list of space-time points and four momenta of bosons at freeze-out is created under the same centrality and acceptance cuts as in experiment. The two boson correlation function is predicted according to Eq.(2) by using the symmetric Coulomb scattering wave function[8,9,14]. After the same corrections of Gamow factor and acceptance as that in experment,this simulated Bose-Einstein correlation function is then compared with corresponding fully corrected experimental onse.

In this paper we have used a Relativistic Hadronic Cascade Model (RHCM, which is similar to ARC in spirit) to generate the list of space-time points and four momenta of π^- at freeze-out in central collision of (14.6 A GeV/c)Si + Au . The model parameters were fixed first via reproducing reasonably the experimental data[18-20] of the rapidity and the transverse mass distributions of proton and pion. Although using Coulomb wave function might be better for the correlation function at region of small relative momentum[9],it is sure that in the complex environment of energetic heavy ion collision the practical distorted two pion relative wave function not really be conventional Coulomb scattering wave function. Thus for clearly and simplicity, we have calculated two π^- Bose-Einstein correlation function according to Eq.(3) instead of (2),as did in Ref.5 and 21. Such simulated two π^- correlation function agrees very well with the fully corrected experimental correlation function[11] . We also have compared the conventional fitted source size parameters with the root mean squared length calculated from the list of space-time points and four momenta of π^- at freeze-out and concluded that the root mean squared length might be more reliable to be identified as the spatial extent of the π^- source.

2 INGREDIENTS OF THE RELATIVISTIC HADRONIC CASCADE MODEL

The accurate description of the dynamic processes of the energetic nucleus- nucleus collision is very difficult since it is an extremely complex quantum many body problem. In the past years there are many phenomenological models (event generators) have been proposed such as Fritiof[22],VENUS[16],RQMD[15], ARC[17] etc. in the field of relativistic nucleus-nucleus collisions.

We have proposed a Relativistic Hadronic Cascade Model (RHCM) based on the elementary hadron-hadron collisions. RHCM is quite similar to the ARC in spirit and the early version of RHCM has already been given elsewhere[23],we just depict here the ingredients of it in brief.

In RHCM the colliding nucleus is considered as sphere with radius $1.14A^{1/3}$ (where A refers to the mass number of projectile or target nucleus) in its respective rest frame. The spatial distribution of nucleons in rest frame of respective nucleus is sampled due to the Woode-Saxon distribution. The moment at which the distance between the centers of projectile and target nuclei is equal to the sum of their radius,is defined as the initial time. The Fermi motion of nucleons in nucleus and the mean field of nuclear system are neglected due the interest of high energy in question. Particle trajectory in between two successive collisions or after a decay is described classically.

The collision time is calculated according to that the minimum approaching distance of the colliding pair should be less or equal to the value of $\sqrt{\sigma_{tot}/\pi}$ (σ_{tot} is the total cross section of colliding pair). The probability of particle collision, elastic or inelastic, is given by the corresponding total, elastic and inelastic cross section randomly. The particles included explicitly in the transport processes are the nucleon (N), delta (Δ) and pion (π) presently. Δ is allowed to decay at any time due to lifetime randomly but imposed to decay at the end of event history. All relevant cross sections (total,elastic and inelastic) of binary collision are using the parametrization formulas[24] according to the CERN-HERA data compilation[25].

The particle list is composed of the position,momentum,energy and mass of the particles included. Then We construct the collision (time) list due to the collision criterion above and the decay (time) list according to the lifetime of Δ particle,i.e.

$$t_d = -\frac{0.197E}{m\Gamma}\ln(1-\xi)+t, \tag{5}$$

where m, Σ,and Γ refer to the mass,energy and total decay width of the Δ particle, respectively, ξ stands for the random number and t is the system time.

Comparing the least collision time t_c found out from collision list with the least decay time t_d from decay list.if $t_c < t_d$, the corresponding collision is then executed.the relevant decay process is executed otherwise. For the elastic scattering it is treated conventionally[26-27],do not need to repeat here. The elastic processes considered are: NN,NΔ,$\Delta\Delta$, Nπ,$\Delta\pi$ and $\pi\pi$. In the inelastic scattering (can be NN,Nπ or NΔ,the final state can be more than two body composed of N,Δ and π) the momenta of scattered and produced particles are decided by the momentum phase space factor. Here we firstly sample the transverse momentum of scattered or produced particle according to the exponential distribution. The longitudinal momentum of scattered particle is given by the 'stopping-law'[28] randomly. As for the longitudinal momentum of produced particle it is sampled from the remaining factor in the multidimensional integrals over Lorentz invariant momentum phase-space[29].

The particle list,collision list and decay list are updated after each collision or decay. As long as there are remains in the collision list return back to find out next least collision time or decay time and repeat above calculations. The history of an event is end at the empty of collision list. At the moment of last collision of π^- the corresponding space-time point and four momentum are recorded.

Above recorded phase space distribution of π^- source at freeze-out is then used to calculate $\pi^-\pi^-$ Bose-Einstein correlation function according to the Monte-Carlo estimating expression[8] of Eq.(3):

$$C_2(q) = \sum_{i=1}^{N(q)} A_{(12)_i}/N(q) \qquad (6)$$

where N(c) refers to the total number of π^- pairs in each $q = p_1 - p_2$ bin and $A_{(12)_i}$ stands for the coherent factor of i-th π^- pairs

$$A_{12} = 1 + \cos[(p_1 - p_2)(x_1 - x_2)]. \qquad (7)$$

Such calculated Bose-Einstein correlation function is refereed to the results of full simulation in distinguishing with the results calculated via Fourier transform (i.e. due to the Eq.(4)).

3 RESULTS AND DISCUSSIONS

In Figure.1 the calculated results (full circles in figure) of rapidity and transverse mass distributions for proton (the top frame) and π^- (the bottom frame) are compared with corresponding experimental data of E802-90[18] (open circles), E802-94[20] (open squares) and E810[19] (open rhombus). Reasonably good agreement between model calculation and experiment was required here to fix the model parameters .

Fig.2 gives the $\pi^-\pi^-$ Bose-Einstein correlation function objected on the q_T dimension and the slice $5 < q_L < 15$ MeV in the participant center-of- momentum frame. In this figure the error bars,the full circles and the solid curve refer to the fully corrected experimental results of E802[11],the results of full simulation and the results of calculation via Fourier transform, respectively. Very well agreement among them can be seen (do not need to multiply an extra scale of sixty percent on the calculated results,as did in Ref.9). The results of Fourier transform is a little bit narrow than the full simulation but it is not as strong as that shown in Ref.8,since both calculations here were matched each other (same assumption of plane wave) better than that in Ref.8 .

The above two-dimensional Bose-Einstein correlation function is then fitted to the conventional Gaussian correlation function

$$C_2(q_L, q_T) = N[1 + \lambda \exp(-q_L^2 R_L^2 - q_T^2 R_T^2)]. \qquad (8)$$

In Table.1 the fitted π^- source radii are compared to the corresponding results of E802[11]. The results of RHCM with rescattering meet results of E802 fairly and the importance of the rescattering effects is really seen.

In order to inspect the meaning of fitted source radii,it is necessary to check the assumptions of the chaotic,non-interacting and momentum independent source,involved in the method of conventional Gaussian fit. Fig.3 shows the distributions of π^- in one spatial dimension x (perpendicular to the beam ,the distribution in another perpendicular component looks similar),in the corresponding momentum p_x and in the time,for the RHCM events in the nucleon -nucleon center-of-momentum frame (following Ref.14). On the bottom left part of this figure is given the correlation between x and p_x. One learns from this figure that not only the spatial and the momentum distributions of π^- source exhibit non-Gaussian tails but also both are correlated each other. Therefore it is dangerous to identify the fitted radii as the spatial extent of source,as pointed in Ref.14 .

We propose to calculate the Root Mean Squared Length (RMSL) of source due to the four space-time and momentum records of corresponding particles at freeze- out from the event generator (RHCM here). The results of RMSL in laboratory system for π^- source from RHCM are: $\sqrt{<x^2>}$=3.11 fm,$\sqrt{<y^2>}$ =3.11 fm,$\sqrt{<z^2>}$=7.81 fm and R_{rms}=8.9 fm. If the data of elementary distributions of prime particles (such as rapidity and transverse mass distributions of proton and pion here) and the two boson correlation function have first been reproduced reasonably it might be reliable to regard the RMSL as the prediction of the spatial extent of the source.

4 CONCLUSIONS

In this paper,the proposed Relativistic Hadronic Cascade Model has been tested to analyse the $\pi^-\pi^-$ Bose-Einstein correlation function in the Si + Au collision at AGS energy. The full simulated $\pi^-\pi^-$ Bose-Einstein correlation function and that calculated via Fourier transform are close each other as they should be. Both of them reproduce the fully corrected experimental results[11] reasonably,the conventional fitted source radii from them and from experiment are fairly met together as well.

Both the spatial and momentum distributions of π^- source at freeze-out from the RHCM events exhibit the non-Gaussian features and even the correlation between π^- location and direction of emission. Therefore it might be questionable to regard the conventional fitted radii as the practical spatial extent of corresponding source. Instead,the Root Mean Squared Length calculated according to the space-time and the momentum four vectors of π^- at freeze-out is more reliable to be regarded as the prediction of the spatial extent of the source.

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References

1. R. Hanbury-Brown and R. Q. Twiss, Philos. Mag.,**45**,663(1954).
2. F. B. Yano and S. E. Koonin,Phys. Lett.,**B78**,556(1978).
3. M. Gyulassy,S. K. Kauffmann and L. W. Wilson, Phys. Rev.**C20**, 2267(1979).
4. S. Pratt, Phys. Rev. Lett.,**53**,1219(1984).
5. G. Bertsch, M. Gong and M. Tohyama, Phys. Rev.**C37**,1896(1988).
6. D. H. Boal, C.-K. Gelbke and B. K. Jennings, Rev. Mod. Phys.,**62**, 553(1990).
7. W. Bauer, C.-K. Gelbke and S. Pratt, Annu. ReV. Nucl. Part. Sci. ,**42**,77(1992).
8. J. P. Sullivan, M. Berenguer, B. V. Jacak, S. Pratt, M. Sarabura, J. Simon-Gillo, H. Sorge and H. Van Hecke, Phys. Rev. Lett.,**70**, 3000(1993).
9. S. Pratt, J. Sullivan, H. Sorge,Y. Pang, Nu Xu and S. Panipkin, Nucl. Phys.,**A566**,103c(1994).
10. NA35 Colla.,T. J. Humanic et al.,Z. Physik **C38**,79(1988); Phys. Lett.,**B203**,320(1988).
11. E802 Collab.,T. Abbott, et al., Phys. Rev. lett.,**69**,1030(1992).
12. E802 Collab.,Y. Akiba et al., Phys. Rev. Lett.,**70**,1057(1993).
13. NA44 Colla., H. Bøggild et al., Phys. Lett.,**B302**,510(1993).
14. E814 Collab., J. Barrette et al., Phys. Lett.,**B333**,33(1994).
15. H. Sorge, H. Stöcker, and W. Greiner, Ann. Phys. **192**, 266(1989); A. Jahns, H. Sorge, H. Stöcker, and W. Greiner, Z. Physik ,**A341**,243(1992).
16. K. Werner, Z. Physik, **C42**,85(1989).
17. Y. Pang,T. J. Schlagel and S. H. Kahana, Phys. Rev. Lett., **68**, 2743(1992).
18. E802 Colla.,T. Abbott et al.,Phys. Rev. lett.,**64**,847(1990).
19. E810 Colla.,S. E. Eisemam et al., Phys. lett.,**B292**,10(1992).
20. E802 Colla.,H. Hamagaki et al.,Nucl. Phys.,**A566**,27c(1994).
21. W. Q. Chao,C. S. Gao and Q. H. Zhang, Nucl. Phys.,**A573**,641(1994).
22. B. Andersson, G. Gustafson and H. Pi, Z. Physik,**C57**,485(1993).

23. Wang Zhong-Qi, Sa Ben-Hao, Lu Zhong-Dao, Zhang Xiao-Ze, Song Guang and Zheng Yu-Ming, Chinese Phys. Lett.,**10**,468(1993);
Song Guang, Sa Ben-Hao, Wang Zhong-Qi, Lu Zhong-Dao, Zhang Xiao-Ze and Zheng Yu-Ming, High Energy Phys. and Nucl. Phys.,**19**,172(1995).

24. Feng Zhong-Han, Trends in Nucl. Phys.,**12**,15(1995).

25. CERN-HERA reports: 83-01 (1983),83-02 (1983) and 84-01 (1984),here we thanks Y. Pang for providing those data.

26. J. Cugnon, T. Mizutani and J. Vandermeulen, Nucl. Phys.,**A352**, 505(1981).

27. G. F. Bertsch and S. Das Gupta, Phys. Rep.,**160**,189(1988).

28. Cheuk-Yin Wong and Z.-D Lu, Phys. Rev.**D39**,2606(1989).

29. S. Jadach, Comp. Phys. Commun.,9,297(1975).

Figure Captions

Fig.1 The rapidity and transverse mass distrbutions of proton and π^- in collisions Si + Au at AGS energy. Full circles: the results of RHCM; open circles: data of E802[18]; open squares: data of E802[20]; open rhombus: data of E810[19].

Fig.2 The $\pi^-\pi^-$ Bose-Einstein correlation function $C_2(q_L, q_T)$ in collision of Si + Au at AGS energy. Error bars: the experimental results of E802[11]; full circles: the results of full simulation in RHCM; solid curve: the results of Fourier transform in RHCM.

Fig.3 The distribution of π^- at freeze-out from RHCM. Top left and right: the spatial and momentum distributions of π^- in direction perpendicular to the beam with Gaussian fits (solid line),respectively. Bottom right: time of π^- emission relative to the initial time. Bottom left: correlation between position and direction of emission of π^-.

Table Captions

Table.1 The fitted source paramters from RHCM calculation and E802 experiment

		R_T(fm)	R_L(fm)	λ
E802 Exp.		3.42±0.26	2.33±0.35	0.65±0.07
RHCM	with rescatering	3.32	3.08	0.95
	without rescatering	2.22	2.60	1.08

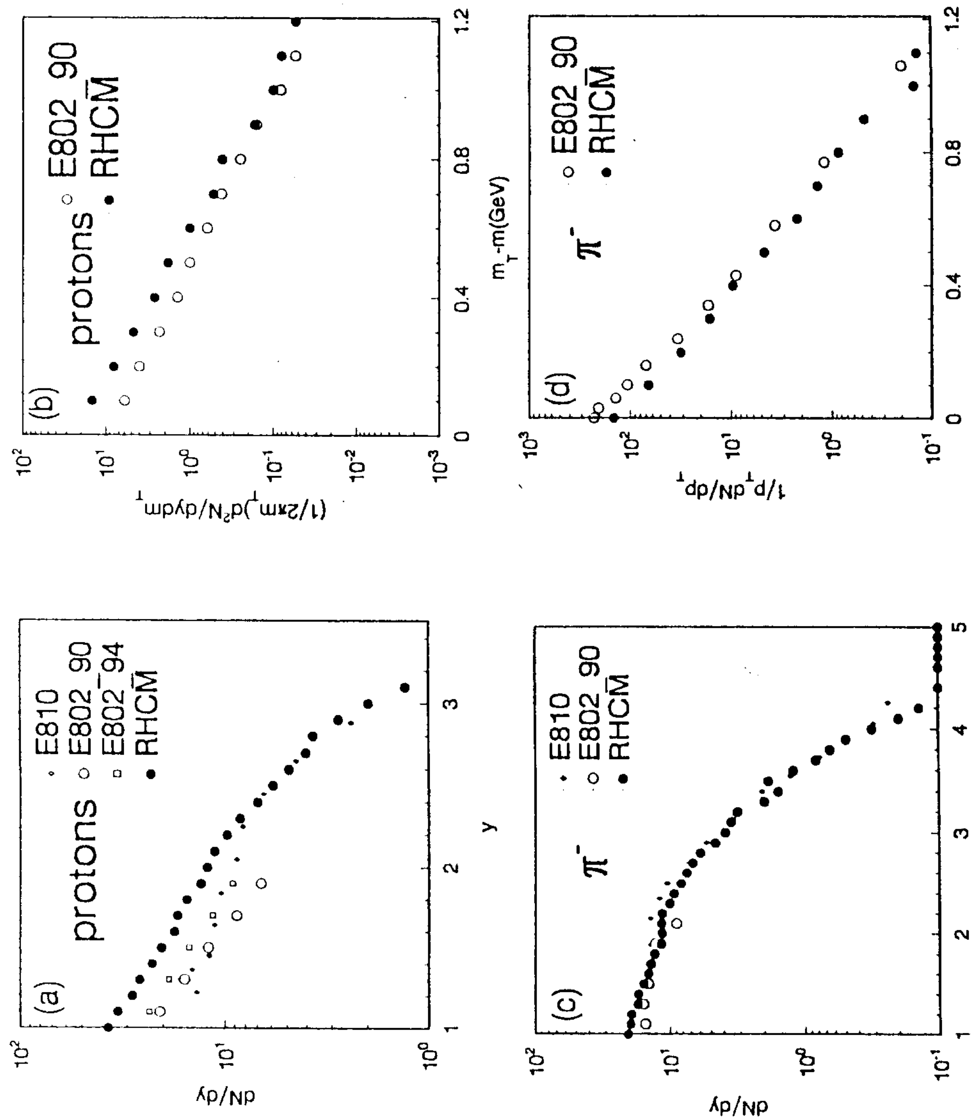

Fig.1

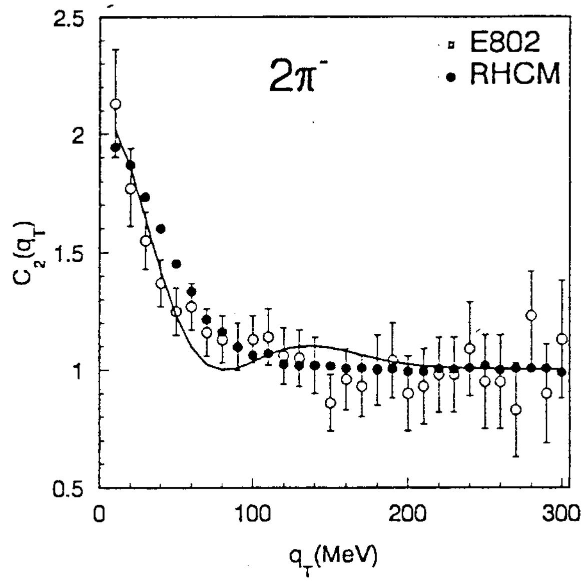

Fig. 2

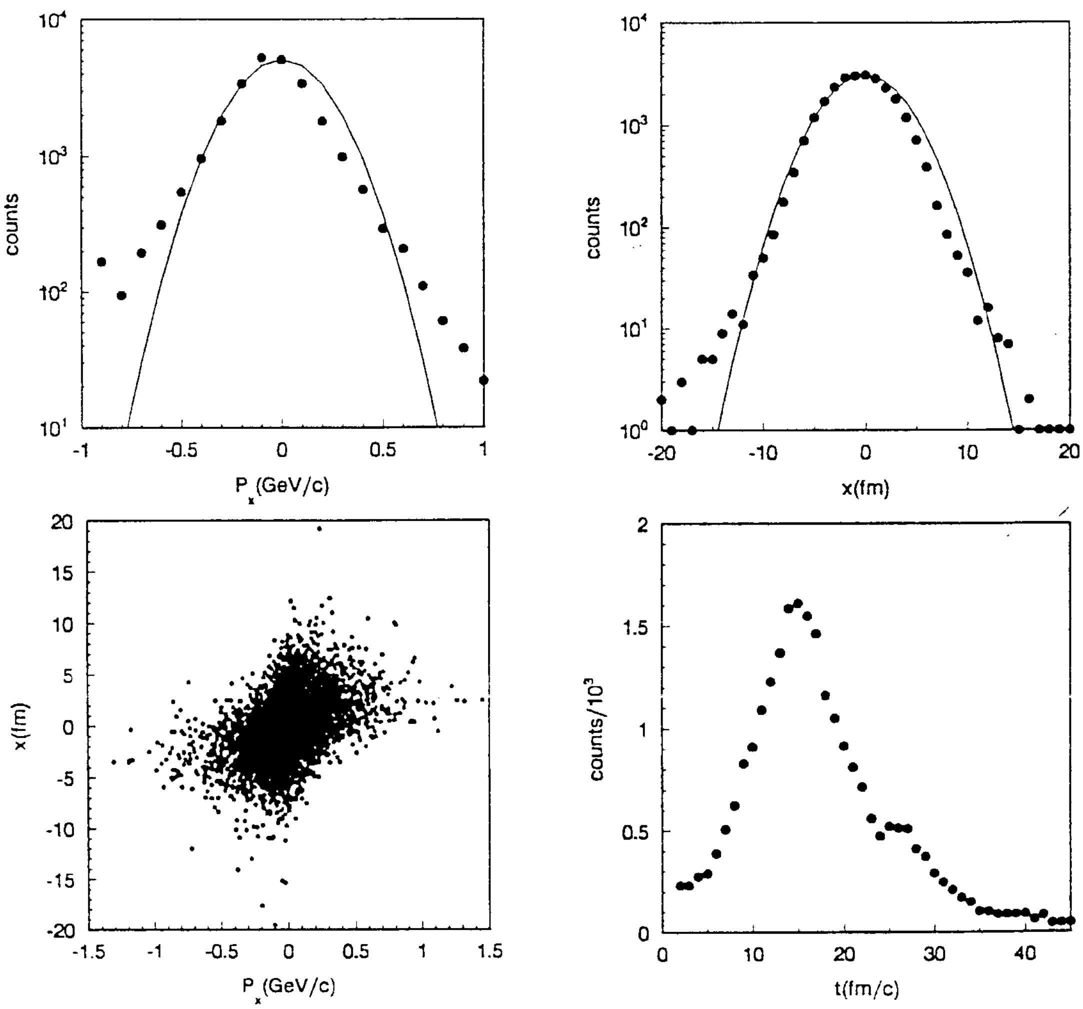

Fig. 3