Event by event measurement of (p(T)) of photons in S+Au collisions at 200 A center dot GeV

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Published in:
Physics Letters B

DOI:
10.1016/S0370-2693(97)00567-4

3 July 1997

PHYSICS LETTERS B

ELSEVIER

Physics Letters B 404 (1997) 207–212

Event by event measurement of $\langle p_T \rangle$ of photons in S + Au collisions at 200 A·GeV

WA93 Collaboration

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Received 25 April 1997
Editor: L. Montanet

PII S0370-2693(97)00567-4

Abstract

The mean transverse momentum of photons has been determined on an event by event basis in S + Au collisions at 200 A·GeV from the ratio of the measured electromagnetic transverse energy (E_T^{em}) to the photon multiplicity (N_γ). The average value obtained is similar to that determined for the same system using spectroscopic techniques. The centrality dependence of the measured values are in agreement with the predictions of the VENUS event generator. © 1997 Published by Elsevier Science B.V.

1. Introduction

It has been suggested for quite some time that the study of the variation of the mean transverse momentum $\langle p_T \rangle$ of the produced particles with the global multiplicity could provide a signature for the phase transition from hadronic matter to quark gluon plasma [1]. For a thermalized system at rest undergoing a phase transition, $\langle p_T \rangle$ varies with multiplicity like the temperature with the entropy density, it increases below the transition, then saturates in the transition region and increases again above the transition. Similar behaviour is observed for a system which undergoes hydrodynamical expansion [2,3].

Several experiments have measured the inclusive p_T-spectra of produced particles and derived the $\langle p_T \rangle$ as a function of rapidity density. It has been reported that the $\langle p_T \rangle$ of charged particles increases with increasing rapidity density and saturates at higher rapidity density [4,5]. The WA80 Collaboration has reported a similar behaviour for photons and π^0's [6] in ^{16}O induced reactions. The $\langle p_T \rangle$ values obtained in these cases are averaged over a large number of events. These methods are therefore not suitable for the study of event by event fluctuations. The importance of event by event measurements to study the fluctuations in $\langle p_T \rangle$ and other observables have been emphasized by several authors [7,8]. The study of fluctuations in detail provides yet another way of searching for the onset of a phase transition. In this letter we discuss an approach which allows us to determine $\langle p_T \rangle$ on an event by event basis. Results are presented from the WA93 experiment [9] for S + Au collisions at 200 A·GeV. Preliminary results have been reported earlier [10].

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For photons, transverse momentum and transverse energy are the same. Thus, if the transverse electromagnetic energy E_T^{em} and the number of contributing photons N_γ are measured in the same acceptance, the ratio E_T^{em}/N_γ provides a measure of the $\langle p_T \rangle$ of the detected photons in the event. When the multiplicity in each event is large the result becomes statistically significant on an event by event basis. It should be noted that the detected photons discussed in this article mainly result from the π^0 decay.

2. Experimental details

In the WA93 experiment at the CERN SPS [9] E_T^{em} and N_γ are measured using the Midrapidity Calorimeter (MIRAC) and the Photon Multiplicity Detector (PMD), respectively. The PMD and the MIRAC have a good overlap in pseudorapidity; the region of overlap with complete azimuthal coverage being $3.3 \leqslant \eta \leqslant 4.8$.

The PMD employed in the WA93 experiment is a fine granularity preshower detector consisting of a rectangular matrix of 7500 plastic scintillator pads of size $20 \times 20 \times 3$ mm^3 mounted behind a $3X_0$ thick lead converter plate and divided into four quadrants surrounding the beampipe. The light from the pads is transported via wavelength shifting fibres to image intensifier–CCD readout devices. The principle of photon identification in the PMD makes use of the fact that photons are much more likely to shower in the lead converter and produce a large signal in the scintillator pads, while non-showering hadrons will produce a signal corresponding to a single minimum ionizing particle (MIP). A threshold of 3 MIPs on the preshower signal gave an average photon counting efficiency in the range of 65%–75% depending on centrality, with a 30% contamination of showering hadrons. Although there is some correlation between the incident photon energy and the observed signal, the PMD is used in the present analysis simply to count photons and measure their emission angles. Details of the detector along with methods for extracting photon hit positions, efficiencies and backgrounds have been described in Ref. [11].

The MIRAC in the WA93 setup consists of 144 individual calorimeter modules each of area 20×20 cm^2 arranged in four groups of six stacks (six-packs) in a non-projective geometry [12]. The height of each six-pack is 120 cm, and the width of each sixpack is approximately 132 cm. The six-packs are staggered so that the arrangement forms a central hole of dimension 10.5×10.5 cm^2. Each module, known as tower, has electromagnetic (EM) and hadronic sections, consisting, respectively, of lead-scintillator and iron-scintillator sampling planes readout by photomultipliers coupled to wavelength shifter plates [12]. The depth of the EM section is $15X_0$, which insures essentially complete containment of the electromagnetic energy, with 97.4% and 91.0% containment calculated for 1 and 30 GeV photons, respectively. Hadrons also deposit a sizable fraction of their energy in the EM section. Gain factors for each photomultiplier have been determined from test measurements with electron, pion and muon beams.

In each event one can calculate the transverse electromagnetic energy incident on MIRAC as

$$e_{\mathrm{T}}^{\mathrm{em}} = \sum_{i=1}^{N} \left(E_i^{\mathrm{em}} - \frac{f_{\mathrm{h}} \times f_{\mathrm{bal}}}{1 - f_{\mathrm{h}}} \times E_i^{\mathrm{had}} \right) \sin\theta_i, \qquad (1)$$

where the index i runs over all MIRAC towers, N, E_i^{em} is the energy measured in the EM section of the MIRAC tower, E_i^{had} is the energy measured in the hadronic section of the MIRAC tower, f_{h} is the fraction of the hadronic energy deposited in the EM section, f_{bal} is the balance factor taking account of the different responses for electromagnetic and hadronic particles in the EM section, and θ_i is the polar angle of the ith electromagnetic tower.

The EM signal of MIRAC is reduced due to the presence of the lead converter of the PMD in front of it. Test measurements using electron beams of different energies have been performed to estimate the energy deposition in the PMD absorber. The sum of Eq. (1) is then corrected by the following formula to obtain $E_{\mathrm{T}}^{\mathrm{em}}$ in the η-range of the PMD

$$E_{\mathrm{T}}^{\mathrm{em}} = \frac{e_{\mathrm{T}}^{\mathrm{em}}}{1 - f_{\mathrm{PMD}}} \times f_{\eta}, \qquad (2)$$

where f_{PMD} is the average fraction of the electromagnetic transverse energy deposited in the PMD absorber, and f_{η} is an acceptance correction factor to be applied to $E_{\mathrm{T}}^{\mathrm{em}}$ due to the varying overlap between the two detectors. The various correction factors are described in detail below.

2.1. Hadron fraction f_{h}

Charged hadrons passing through the EM section of MIRAC deposit a finite and fluctuating amount of energy there. Also due to the coarse granularity of MIRAC and the high particle density, several particles deposit their energy in a single tower of MIRAC simultaneously. Therefore, one must make corrections for the hadronic contribution in the EM section based on the average energy deposited.

The hadron fraction f_{h}, the fraction of hadronic energy deposited in the EM section, has been estimated using a combination of test beam measurements and Monte Carlo simulation. f_{h} is obtained from the relation

$$f_{\mathrm{h}} = \frac{\sum r(E) \times n(E)}{\sum n(E)}, \qquad (3)$$

where $r(E)$ is the fraction of hadronic energy deposited in the EM section by hadrons of energy E and $n(E)$ denotes the distribution of hadron energies in S + Au collision at 200 $A\cdot$GeV.

The distribution of hadron energies $n(E)$ has been obtained using the VENUS event generator [13] assuming that the hadron energy spectrum is well reproduced by VENUS. The fraction of energy deposited in the electromagnetic and hadronic sections of MIRAC has been measured using hadrons of different incident energies in a test beam setup. The response of hadrons has also been studied using the GEANT simulation package tuned for the WA93 experimental setup. The cut-off parameters in GEANT have been adjusted in such a way that the Monte Carlo results agree with the test beam measurements. Fig. 1 shows the results of measurement and simulation, as a function of the incident hadron energy.

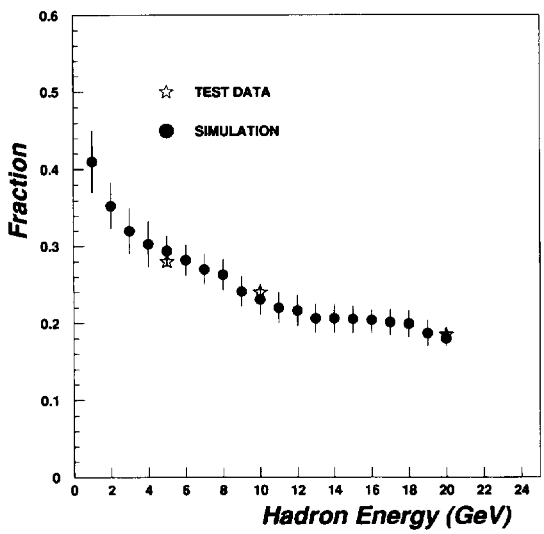

Fig. 1. Fraction of hadronic energy deposited in the EM section of MIRAC as a function of incident hadron energy. The stars represent the experimentally measured values at 5, 10 and 20 GeV and the filled circles are the results of Monte Carlo simulation after adjustment of the parameters affecting the hadronic response.

The energy-averaged value of f_h is found to be 30%. Since the shape of the energy distribution $n(E)$ does not depend strongly on centrality, the factor f_h has little centrality dependence. Similarly, the angular dependence of f_h is small.

2.2. Balance factor f_{bal}

The EM section of MIRAC does not have the same response for a given energy deposition for hadrons as for electromagnetic particles. The ratio of this response, known as the balance factor, is measured in MIRAC as [12], $f_{bal} = R^{had}/R^{em} = 0.8$ where R^{had} is the response to charged hadrons and R^{em} is the response to electromagnetic particles.

2.3. PMD compensation factor f_{PMD}

A fraction of the electromagnetic energy is deposited in the lead converter of the PMD. The energy averaged fraction f_{PMD} is estimated using the formula

$$f_{PMD} = \frac{\sum r(E_\gamma) E_\gamma \sin\theta_\gamma}{\sum E_\gamma \sin\theta_\gamma}, \tag{4}$$

where $r(E_\gamma)$ is the fraction of energy deposited in the PMD absorber by photons of energy E_γ having angle of emission θ_γ. The sum runs over all photons incident on the detectors in the overlapping η-region.

To compute the above factor, the VENUS event generator is again assumed to describe the photon energy spectrum in S + Au collisions. Test beam measurements with electrons of different energies have been used to adjust the parameters in the GEANT simulation for the response of the electromagnetic particles. The WA93 GEANT simulation is then used to calculate the fraction $r(E_\gamma)$. The value of the energy-averaged factor f_{PMD} is found to be 10.5%.

2.4. Acceptance correction factor f_η

The full pseudorapidity coverage of the MIRAC is more than that of the PMD. Because of the coarse granularity of the MIRAC towers, the region of overlap with the η-coverage of the PMD is not sharply defined. A fraction of the energy deposited in the towers on the boundary of the overlap zone actually originates from particles outside the common pseudorapidity region of the detector pair. Therefore a geometrical correction is applied to the estimated E_T^{em} values.

The acceptance correction factor f_η is estimated using the VENUS event generator by taking the ratio of the E_T^{em} value for the particles in the overlap region $3.3 \leqslant \eta \leqslant 4.8$ to the total E_T^{em} for particles in the full η-coverage of MIRAC. The value of f_η is found to have a weak centrality dependence and varies from 60% to 63% [14].

3. Results and discussion

The centrality dependence of the ratio E_T^{em}/N_γ has been studied using E_{ZDC}, the energy deposited in the Zero Degree Calorimeter (ZDC) in the WA93 experiment [15]. The entire ZDC energy range has been divided into 7 bins. The data in the extreme peripheral bin having $E_{ZDC}/E_{beam} \geqslant 0.89$ have not been analysed.

Fig. 2 shows the histogram of the ratio E_T^{em}/N_γ for the most central and the most peripheral event classes in S + Au collisions at 200 A·GeV. A Gaussian fit is used to extract the mean values of E_T^{em}/N_γ for the different centrality classes. The width of the histogram reflects statistical fluctuations due to the finite number

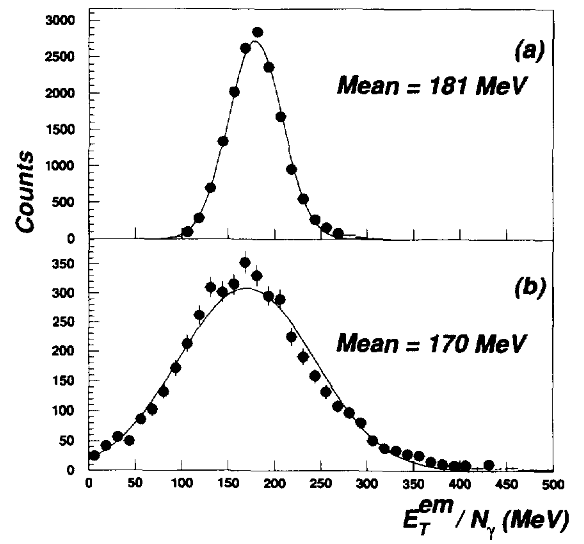

Fig. 2. Histogram of E_T^{em}/N_γ for (a) the most central and (b) peripheral event classes. The solid curve is the Gaussian fit result.

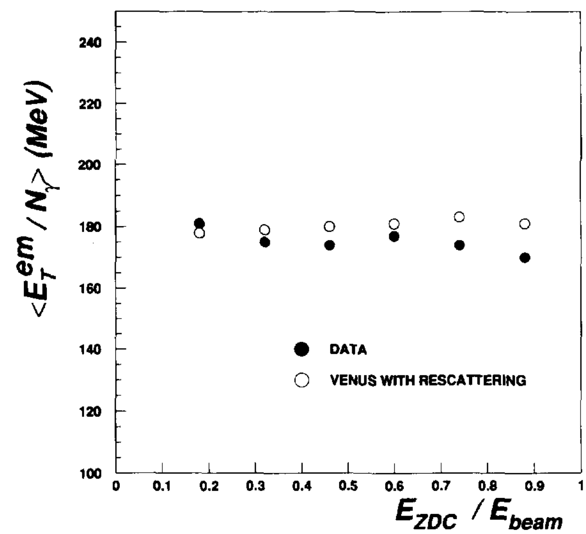

Fig. 3. Variation of $\langle E_T^{em}/N_\gamma \rangle$, shown as filled circles, with E_{ZDC}/E_{beam}. The statistical errors are smaller than the data points shown. The systematic errors are discussed in the text. The results of the VENUS event generator, shown as open circles, are superimposed for comparison.

of particles, which are much larger for the peripheral case than for the central case.

The statistical error on the extracted E_T^{em}/N_γ value is quite small. The systematic error depends on the errors in the estimation of both N_γ and E_T^{em}. The sources of systematic errors on the estimation of N_γ have been discussed in detail in Ref. [16]. The combined effect of contributions due to uncertainty in the estimation of the photon counting efficiency, upstream conversion of photons and the use of average values of subtracting hadronic background leads to a systematic error of about 11% for central events and 9% for peripheral events. The contribution of the systematic error in the estimation of E_T^{em} from MIRAC is estimated to be about 10%. The total systematic error on the E_T^{em}/N_γ scale thus varies from about 13% for the peripheral data sample to about 15% for the central data. The systematic error on the centrality dependence of E_T^{em}/N_γ is estimated to be less than 5%.

Fig. 3 shows the centrality dependence of $\langle E_T^{em}/N_\gamma \rangle$ as a function of E_{ZDC}/E_{beam}. All values lie within a narrow band at around 175 MeV with no marked centrality dependence. The results of Fig. 3 have been compared with the predictions of the VENUS event generator. The total electromagnetic transverse energy and the photon multiplicity have been calculated in the region of overlap of the detectors ($3.3 \leqslant \eta \leqslant 4.8$) for different centrality classes defined by the ZDC energy. The shape of the VENUS minimum bias ZDC energy spectrum for S + Au collisions matches the measured minimum bias ZDC spectrum well. The average value of the ratio E_T^{em}/N_γ for VENUS for different centralities is superimposed in Fig. 3 for comparison. The results of the experiment and VENUS compare well. Since the measured pseudorapidity density of photons increases with increasing centrality [16], the present result may be used to infer that the mean transverse momentum is constant as a function of the pseudorapidity density.

The mean value $\langle E_T^{em}/N_\gamma \rangle$ is only slightly higher for the central events than for the peripheral case, but is consistent with no centrality dependence. This is in contrast to the observation of the WA80 experiment for $^{16}O + Au$ reactions [6] where the truncated $\langle p_T \rangle$ measured with a lead-glass detector varied from 190 MeV/c for peripheral events to 215 MeV/c for central events. A similar variation of from 194 MeV/c (peripheral) to 215 MeV/c (central) was observed by WA80 for $^{32}S + Au$ reactions [17]. This difference is most likely due to the different low p_T cutoffs for the two measurements. While the p_T acceptance for the $\langle E_T^{em}/N_\gamma \rangle$ extends to well below 30 MeV/c, the lead-glass data of WA80 were analyzed with a cutoff of 400 MeV/c [6,17]. Since the photon spectrum is known to increase faster than exponentially at low p_T, the lower p_T cutoff would explain the lower value of $\langle E_T^{em}/N_\gamma \rangle \approx 175$ MeV.

The photon $\langle p_T \rangle$ has also been measured in WA93 using a finely segmented BGO spectrometer. This measurement indicated a photon enhancement in the low-p_T region below 100 MeV/c. A value of 159 ± 15 MeV/c was obtained for central ^{32}S + Au reactions [18]. Neglecting the lowest data point at $p_T = 40$ MeV/c a value of $\langle p_T \rangle = 170 \pm 10$ MeV/c was obtained from the fitted slope for the same data. Alternatively, if the photon p_T spectra measured with the BGO detector [18] is used to determine the PMD integrated photon counting efficiency, instead of the p_T spectra obtained from VENUS, the efficiency is reduced by 4%. This reduction in photon detection efficiency reduces $\langle E_T^{em}/N_\gamma \rangle$ by about 6% to give a value of 169 MeV for central collisions in better agreement with the BGO measurement.

To summarize, the mean transverse momentum of photons in S + Au collisions at 200 A·GeV has been deduced from the measurement of the transverse electromagnetic energy in a coarse granularity calorimeter and the photon multiplicity measured in a finely segmented preshower detector. The various correction factors have been estimated using a combination of test beam measurements with electrons and hadrons of several energies and Monte Carlo simulations tuned to reproduce the test results. The present method provides $\langle p_T \rangle$ on an event by event basis which should be useful for the study of fluctuations and to search for abnormal events as signatures of the phase transition. The value of $\langle E_T^{em}/N_\gamma \rangle$ for central events compares well with the value of the photon $\langle p_T \rangle$ measured for the same system by other detector methods. There is no marked dependence on centrality. This observation is in agreement with the results of the VENUS event generator.

Acknowledgements

We express our sincere gratitude to the CERN SPS crew for providing good sulphur beams during 1991 and 1992. This work was supported jointly by the German BMBF and DFG, the US DOE, the Swedish NFR, the Dutch Stichting FOM, the Humboldt Foundation, the Stiftung für deutsch-polnische Zusammenarbeit, the Department of Atomic Energy, the Department of Science and Technology and the University Grants Commission of the Government of India, the Indo-FRG Exchange Programme, the Swiss National Fund, the PPE division of CERN, the International Science Foundation under Contract N8Y000, the INTAS under Contract INTAS-93-2773 and ORISE. ORNL is managed by Lockheed Martin Energy Research Corporation under contract DE-AC05-96OR22464 with the US Department of Energy.

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