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Soft photon registration at Nuclotron

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First results of a soft photon yield in nucleus-nuclear interactions at 3.5 GeV per nucleon are presented. These photons have been registered at Nuclotron (LHEP, JINR) by an electromagnetic calorimeter built in the SVD Collaboration. The obtained spectra confirm the excess yield in the energy region less than 50 MeV in comparison with theoretical predictions and agree with previous experiments at high-energy interactions.

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1. Introduction

The experiments with relativistic heavy ions point to the manifestation of a quark-gluon matter. The understanding of the nature of the deconfinement (the transition of hadrons to quarks and gluons) is important for the formulation of the nuclear substance of the state equation. Physicists consider that at their interactions with proton and deuteron beams are formed a cold nuclear matter. These researches permit to compare properties of hot quark-gluon matter formed in collisions of heavy ions and a cold nuclear matter producing in pp or $p(d)$A interactions [1]. The SVD Collaboration carries out studies of pp, pA and AA interactions. Experiments with 50 GeV-proton beams are fulfilled at U-70 in IHEP, Protvino [2]. The SVD-2 Collaboration also works at Nuclotron of JINR (Dubna) with 3.5A GeV/c nuclear beams.

The SVD Collaboration has carried out studies in the unique region of high multiplicity where the collective behaviour of secondary particles is observed. One of the most important results obtained in these studies is the rapid growth of the scaled variance, $\omega = D/ < N_0 >$, with increasing of total pion multiplicity [3]. Here D is the variance of a number of neutral mesons at the fixed total multiplicity, $< N_0 >$ – their mean multiplicity. The growth of the experimental value ω as compared to the Monte Carlo predictions has been confirmed at the level of 7 standard deviations. This result is one of the evidences of the Bose-Einstein condensate (BEC) formation [4].

The theoretical description of this phenomenon has been developed by Begun and Gorenstein [4] at the specific conditions of the SVD-2 experiment. S. Barshay predicts [5] that the pion condensation may be accompanied by an increased yield of soft photons (SP). The anomalous SP have being studied experimentally during more than 30 years [6, 7, 8, 9]. There are some theoretical models worked out for explanation of SP yield [10, 11, 12]. Unfortunately, an incompleteness of data does not permit disclosing of the physical essence of this phenomenon completely.

To understand the mechanism of the SP formation more comprehensive and in particular to test a connection between their excess yield and the BEC formation, a SP electromagnetic calorimeter (SPEC) has been manufactured and tested by the SVD Collaboration at U-70 [13]. This calorimeter is a stand-alone device and it differs from many similar ones by its extremely low threshold of gamma-quantum registration – of order of 2 MeV. The SPEC technique permits an execution of the unique research program of pp, pA and AA interactions with registration of SP.

2. Review of experimental data on the soft photon yield

The experimental and theoretical studies of the direct photon production in hadron and nuclear collisions essentially expand our knowledge of the multi-particle production mechanisms. These photons are useful probes to investigate nuclear matter at all stages of the interaction. SP play the particular role in these studies. Until now we do not have a comprehensive explanation for the experimentally observed excess of the SP yield. These photons have low transverse momentum p_T < 0.1 GeV/c and the Feynman variable |x| < 0.01. In this domain their yield exceeds the theoretical estimates by $3 \div 8$ times.

This anomalous phenomenon has been discovered at the end of 1970s with the Big Europe Bubble Chamber at the SPS accelerator (CERN) in the experiment with the 70 GeV/c K^+-meson and antiproton beams [6]. The SP yield had exceeded the theoretical predictions by 4.5 $\pm$ 0.9. The following electronic experiments such as [7, 8, 9] have confirmed an anomalous behaviour of SP.

The WA83 Collaboration studied the direct SP yield at OMEGA spectrometer in $\pi^- + p$ interactions at a hydrogen target with 280 GeV/c π^--mesons. The increased yield of SP turned out to be equal to 7.9 $\pm$ 1.4 [7]. The last experimental study of SP had been carried out at the LEP accelerator with the DELPHI setup in CERN [9]. The investigated processes were: $e^+ + e^- \to Z^0 \to$ jet + γ and $e^+ + e^- \to \mu^+ + \mu^-$. In processes with the formation of jets the DELPHI Collaboration had revealed the excess of the SP yield over of Monte Carlo estimations at the level 4.0 $\pm$ 0.3 $\pm$ 1.0 times. For the first time the SP yield at maximum number of neutral pions (7-8) had amounted to about 17-fold exceeding [9] in comparison with bremsstrahlung of charged particles. On the contrary, in the lepton processes without the formation of the hadron jets the yield of SP turned out to agree well with the theoretical predictions.

Modern theoretical models attempt to explain the anomalous yield of SP. The SVD Collaboration has developed a gluon dominance model [12] explained the increased SP yield by the production of soft gluons in the quark-gluon system. These gluons do not have enough energy to fragment into hadrons, so they are scattered on the valency quarks of secondary particles and form SP [12]. This model gives two(three)fold exceeding of common accepted of strong interaction area in accordance with estimations of the region of their emission.

3. Design, manufacture and testing of SPEC. SP spectra

The SPEC has been manufactured on the base of the BGO scintillators (bismuthortogermanate) [13]. The BGO crystals have a small radiation length X_0 = 1.12 cm, that permits to reduce considerably the volume of the device. At manufacturing of such calorimeter the problems of uniform distributions of an activator in the crystal volume do not appear. While many of inorganic scintillators have the long-term of emission. BGO crystals shows relative small afterglow.

The SPEC scheme is shown in Fig. 2, a left panel. It is a square matrix composed of 49 ($3\times3\times18$ cm^3) counters [13]. The front side is covered by the high-reflective film VM2000. The PMT 9106SB are used (ET Enterprises). They have 8 dynodes and a high quantum efficiency in the green part of spectrum. The photocathode diameter is equal to 25 mm. The tube has the permalloy magnetic protection. PMT is glued to the crystal by the optic EPO-TEK 301 glue.

The plastic veto-detector of charged particles ($23\times23\times1$ cm^3) is placed before the crystals. Behind it an assembly of 4 plastics of a pre-shower ($18\times4.5\times1$ cm^3) is shown. Lead 2mm-convertor is put between the front-veto and plastics. In Fig. 1, right panel, the target and counters of a trigger system are shown. A trigger is produced at the signal from any 2 of 4 pre-shower counters. In front of the target, there are two large veto-counters to forbid a response from the beam halo. Time-stamp is given by the $4.5\times4.5\times0.1$ cm^3 beam counter (not shown), also upstream from the target.

SPEC is set at an angle of 16°, the front plane of crystals is away from a target at the distance 203 cm. The digitization of the plastic scintillators is realised with a CAMAC ADCs (Lecroy 2249A) and TDCs (LeCroy 2228A), the digitization of the analog signals of the calorimeter - by ADC CC-008.

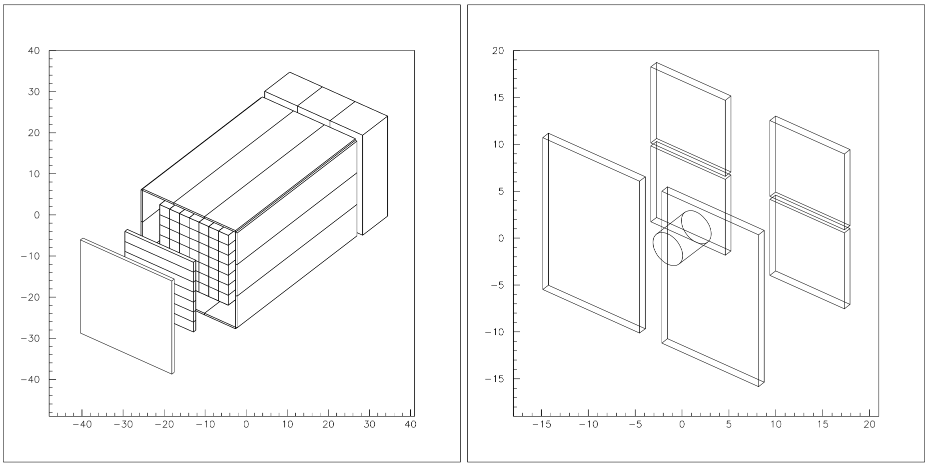

Figure 1: Left panel: the simplified scheme of SPEC. Right panel: the carbon target (2.5 g/cm^3) and counters of the trigger system.

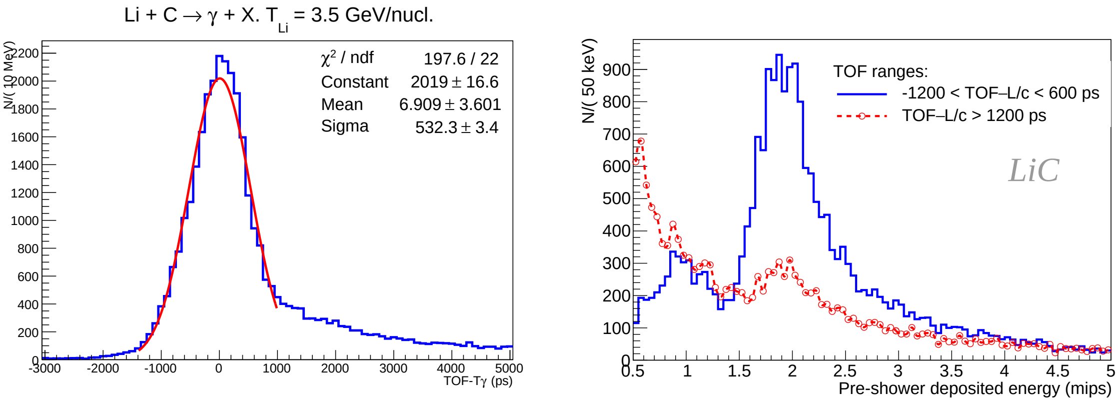

Figure 2: Left panel: the time resolution in the pre-shower for Li+C interactions. Right panel: the time of flight between the beam counter and the pre-shower for neutral particles.

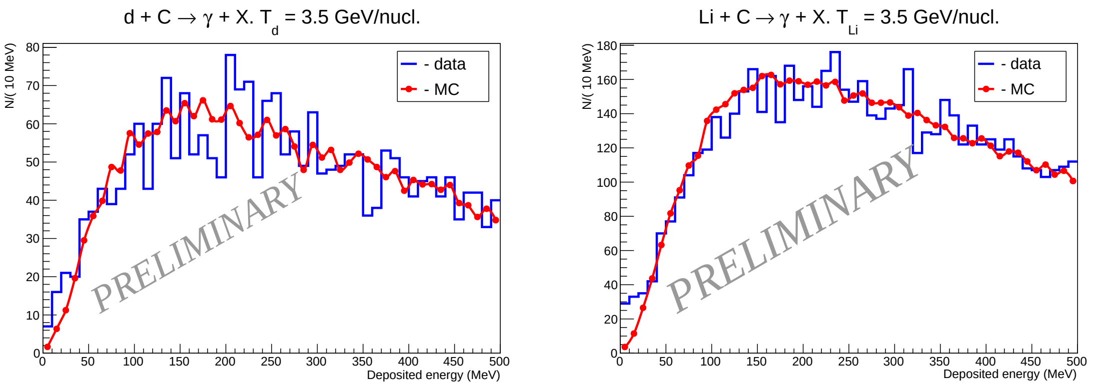

Figure 3: the energy release registered in SPEC with the pre-shower (blue line) and the simulation (red line) for (left panel) d+C and (right panel): Li+C interactions at Nuclotron.

We used CAMAC and a LE-88K crate-controller with input for a trigger signal. The crate-controller has been connected to PC with the PCI-QBUS interface. Data acquisition software has been developed in the MIDAS framework (http://midas.psi.ch). The time of flight between the beam counter and the pre-shower for neutral particles (no signal in the front-veto) gives time resolutions 632 ps for d+C and 532 ps for Li+C (Fig.2, left panel) interactions. In Fig.2, right panel spectrum of γ quanta deposited in pre-shower plastic with the time selection for neutral particles is presented for Li+C interactions. A solid line shows a Compton peak at 1 MIP energy and more intensive peak of the gamma quanta conversion at 2 MIP. In this Fig. with dotted line this structure is almost unnoticeable.

Selection criterions of events were as the following: 1) energy in the front veto-counter smaller than 0.3 MIPs; 2) energy in pre-shower $0.5 < E < 4$ MIPs; 3) time of flight - 1200 < t - t_γ < 600 ps; 4) more than 2 MeV is registered in one of BGO crystals; 5) location of shower in BGO crystal must overlay throughout vertical with the triggered pre-shower counter; 6) energy deposition in the outer BGO layer should be no more than 1/3 of a total to prevent significant leakages.

In 2014 two experimental runs have been carried out at Nuclotron in LHEP JINR with 3.5A GeV/c deuterium and lithium beams. SPEC was installed at the location of the NIS-GIBS setup. After data processing we have obtained the SP spectra of the energy release in the deuterium-carbon (Fig. 3, left panel) and lithium-carbon (Fig. 3, right panel) interactions. A discrepancy between the experimental data and the Monte-Carlo simulation (uRQMD+Geant-3.21) has been observed at energies below 50 MeV.

References

[1] A. Andronic et al. e-Print: arXiv:1506.03981 [nucl-ex].

[2] V. V. Avdeichikov et al., Proposal "*Termalization*" (in Russian), JINR-P1-2004-190 (2005).

[3] E. S. Kokoulina (On behalf of the SVD-2 Collaboration). Progr. Theor. Phys., **193** (2012) 306; V. N. Ryadovikov (On behalf of the SVD-2 Collaboration). Phys. Atom. Nucl., **75** (2012) 989.

[4] V. V. Begun and M. I. Gorenstein. Phys. Lett. **B**653 (2007) 190; V. V. Begun and M. I. Gorenstein. Phys. Rev. **C**77 (2008) 064903.

[5] S. Barshay. Phys. Lett. **B**227 (1989) 279.

[6] P. V. Chliapnikov et al., Phys. Let. **B**141 (1984) 276.

[7] S. Banerjee et al. SOPHIE/WA83. **B** 305 (1993) 182.

[8] J. Schukraft. HELIOS Collaboration. Nucl.Phys. **A** 498 (1989) 79.

[9] J. Abdallah et al. DELPHI Collaboration. Eur. Phys. J. **C** 47 (2006) 273.

[10] L. Van Hove . Ann.of Phys. (NY), **192** (1989) 66; P. Lichard and L. Van Hove. Phys.Lett. **B** 245 (1990) 605.

[11] Wong Cheuk-Yin. Phys.Rev. Lett. **C** 81(2010) 064903.

[12] E. Kokoulina. Acta Phys. Polon. **B**35 (2004) 295; M. K. Volkov, E. Kokoulina, and E. A. Kuraev. Pepan Letters. N **5** (2004) 16.

[13] E. .N. Ardashev et al. Instr. Exp. Tech. **58** (2015) 18.

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