EPJ Web of Conferences will be set by the publisher
DOI: will be set by the publisher

SOFT PHOTON YIELD IN NUCLEAR INTERACTIONS

On behalf of the SVD-2 Collaboration

E. Kokoulina[1,a]

[1] *JINR, Dubna, Russia and GSTU, Gomel, Belarus*

Abstract. First results of study of a soft photon yield at Nuclotron (LHEP, JINR) in nucleus-nucleus collisions at 3.5 GeV per nucleon are presented. These photons are registered by an BGO electromagnetic calorimeter built by SVD-2 Collaboration. The obtained spectra confirm the excessive yield in the energy region less than 50 MeV in comparison with theoretical estimations and agree with previous experiments at high-energy interactions.

1 Introduction

Physicists consider that at interactions of nuclei with proton and deuteron beams are formed cold nuclear matter [1]. These researches permit to compare properties of hot quark-gluon medium formed in collisions of relativistic heavy ions and cold nuclear matter producing in pp or $p(d)$A interactions. The SVD Collaboration carries out studies of pp, pA and AA interactions. These experiments are fulfilled at U-70 in IHEP, Protvino with 50 GeV-proton beams [2] and at Nuclotron (JINR) with 3.5 GeV/nucleon nucleus beams.

The SVD-2 Collaboration investigates the unique region of high multiplicity in which a number of phenomena of collective phenomena of secondary particles is predicted. It has been received the following results [2, 3]:

∗ the topological cross sections in the region up to charged multiplicity $N_{ch} = 24$ that had permitted to advance in them down on three orders of magnitude;

∗ the average multiplicity and variance of number of charged particles;

∗ distributions on the number of neutral pions at fixed total pion multiplicity, $N_{tot} = N_{ch} + N_0$ (N_0 – number of π^0-mesons);

∗ the rapid growth of the scaled variance, $\omega = D/\overline{N}_0$, with the increasing of total pion multiplicity (D – a variance of the neutral meson number at the fixed total multiplicity, $\overline{N}_0$ – their mean multiplicity).

The growth of the experimental value ω gets 7 standard deviations in respect of Monte Carlo predictions. This result is one of the evidences of Bose-Einstein condensate (BEC) formation [4].

The theoretical description of this collective phenomenon has been developed by Begun and Gorenstein [4] at the specific conditions of the SVD-2 experiment at U-70 in pp interactions. They have estimated the total pion multiplicity at which BEC can start to form. The German physicist S. Barshay predicts [5] that the pion condensation may be accompanied by an increased yield of soft photons (SP) with energy smaller than 50 MeV. The anomalous SP have being studied experimentally during more than 30 years [6–9]. There are some theoretical models worked out for an explanation of the SP yield [10–12]. Unfortunately, an incompleteness of data does not permit disclosing of the physical essence of this phenomenon completely.

To understand nature 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 SVD Collaboration at U-70 [13] accelerator. This calorimeter is a stand-alone device and it differs from many similar ones by its extremely low energy threshold of gamma-quantum registration – of order of 2 MeV. The SPEC technique permits to execute the unique research program of pp, pA and AA interactions with registration of SP.

The report is organised in the following way. The previous SP experiments are reviewed in section 2. In section 3 the description and technical characteristics of electromagnetic calorimeter manufactured by SVD Collaboration are given. The first preliminary spectra of SP obtained with the deuterium and lithium beams on a carbon target at Nuclotron are also presented in this section.

2 Review of experimental data on the soft photon yield

Experimental and theoretical studies of direct photon production in hadron and nuclear collisions essentially expand our knowledge about multi-particle production mechanisms. These photons are useful probes for an investigation of nuclear matter at all stages of the interaction.

[a] e-mail: kokoulin@sunse.jinr.ru

SP play a particular role in these studies. Until now we do not have total explanation for the experimentally observed excess of SP yield. These photons have low transverse momenta $p_T < 0.1$ GeV/c and Feynman variable |x| < 0.01. In this domain their yield exceeds the theoretical estimates by 3 ÷ 8 times [6–9].

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

WA83 Collaboration studied the direct SP yield at OMEGA spectrometer in $\pi^- + p$ interactions at hydrogen target with 280 GeV/c π^--mesons. Excess yield of SP turned out to be equal to 7.9 ± 1.4 [7]. Last experimental study of SP had been carried out at the LEP accelerator with DELPHI setup in CERN [9].

Two kinds of processes were investigated: $e^+ + e^- \rightarrow Z^0 \rightarrow$ jet $+ \gamma$ and $e^+ + e^- \rightarrow \mu^+ + \mu^-$. In processes with formation of hadron jets the DELPHI Collaboration had revealed excess of SP yield over of Monte Carlo estimations at the level 4.0 ± 0.3 ± 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 formation of hadron jets the yield of SP turned out to agree well with theoretical predictions.

The theoretical models try to explain anomalous yield of SP. The SVD-2 Collaboration has developed a gluon dominance model [12] explained an excessive SP yield by the production of soft gluons in 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 over common accepted area of strong interactions in accordance with estimations of the region of SP emission.

3 Design, manufacture and testing of SPEC. SP spectra

SPEC has been manufactured on the base of the BGO scintillators (bismuth ortogermanate) [13]. The BGO crystals have a small radiation length X_0 = 1.12 cm (for comparison, crystals NaI(Tl) have X_0 = 2.59 cm), that permits reducing considerably the volume of the device. Moreover, this scintillator has small sensibility to neutrons. It is important at the measurement of a gamma-radiation. At manufacturing of such calorimeter the problems of uniform distributions of 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 scheme of SPEC is shown in Fig. 1 (from a top). It is a square matrix composed of 49 (7×7) counters. The counter with a demultiplier and a preliminary amplifier are placed directly on the panel PMT as shown in Fig. 1 (from below) [13]. Every crystal has the parallelepiped form, 30×30×180 mm^3. 180 mm correspond to 16 radiation lengths. Its front side is covered by the high-reflective film VM2000. The lateral facets of crystals are wrapping up of Tyvic for increasing of light gathering (the thickness 120 mkm). The PMT 9106SB are used (ET Enterprises). They have 8 dynodes and 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.

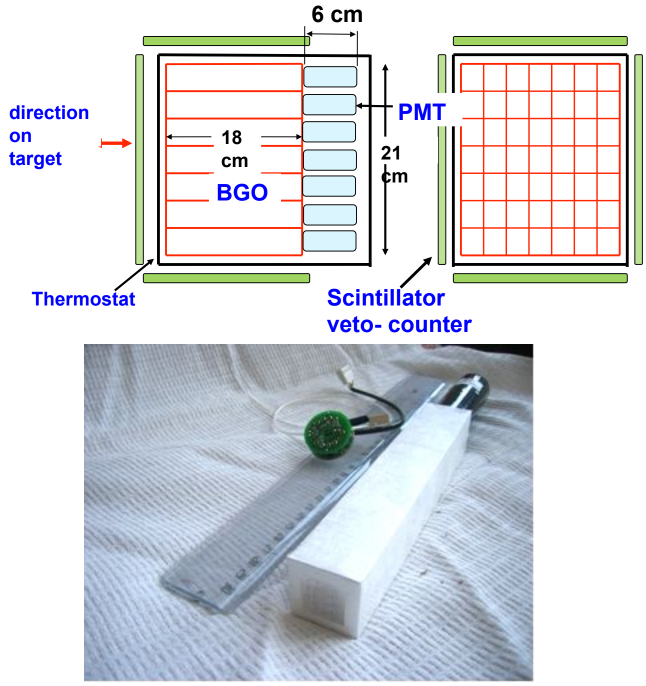

Figure 1. Top panel: scheme of SPEC. Bottom panel: BGO crystal with PMT.

The box with counters is surrounded by the scintillator detectors of a guard veto-system. SPEC is placed inside of the thermostat (the top panel of Fig. 1). The thermo stabilisation is realised by cooling system Huber 006B. The temperature of liquid in thermostat can change in the diapason from -20° up to +40° C. After few testings the temperature has been chosen +18° C.

The plastic veto-detector of charged particles (23×23×1 cm^3) is placed before the crystals. Behind it an assembly of 4 plastics of a pre-shower (18×4.5×1 cm^3) is shown. A lead 2 mm-convertor is put between the front-veto and plastics. In Fig. 2 (from the top), the target and counters of a trigger system are shown. The trigger is produced at the signal from any 2 of 4 pre-shower counters. There are two large veto-counters in front of the target. They are necessary to forbid a response from the beam halo. SPEC with veto-detectors has been laid near the NIS-GIBS setup (Fig. 2, bottom panel).

The maximum of the signal-noise ratio is provided by input capacitance minimisation. It is determined by

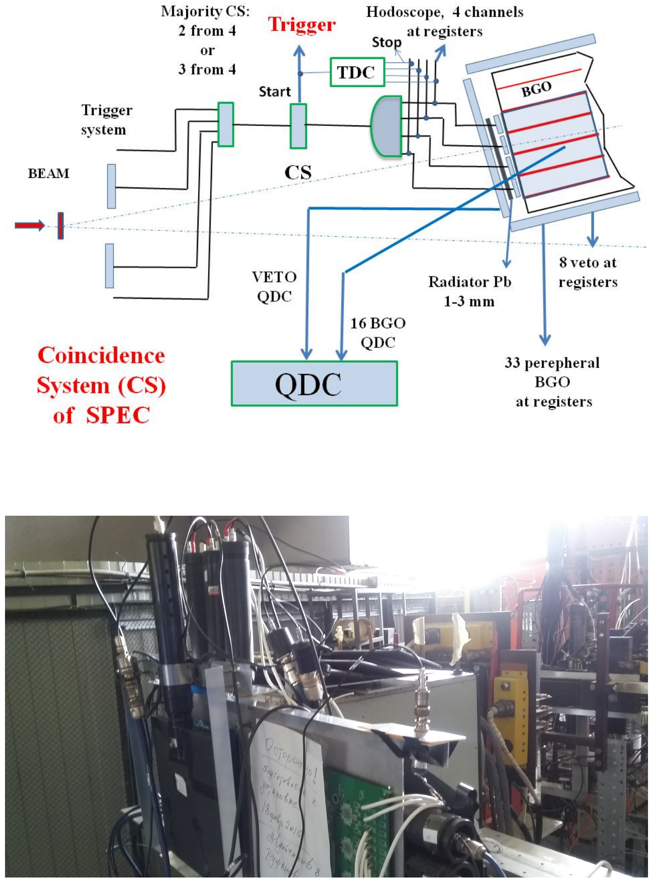

Figure 2. Top panel: the reductive working scheme of SPEC at the Nuclotron. Bottom panel: view of SPEC with veto-detectors at NIS-GIBS setup.

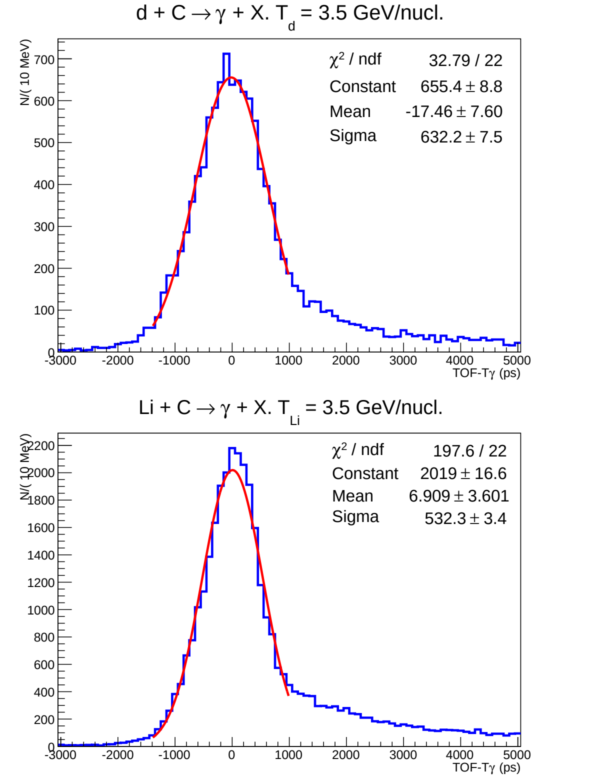

Figure 3. Top panel: time resolution in pre-shower for d+C interactions. Bottom panel: same as above for Li+C interactions.

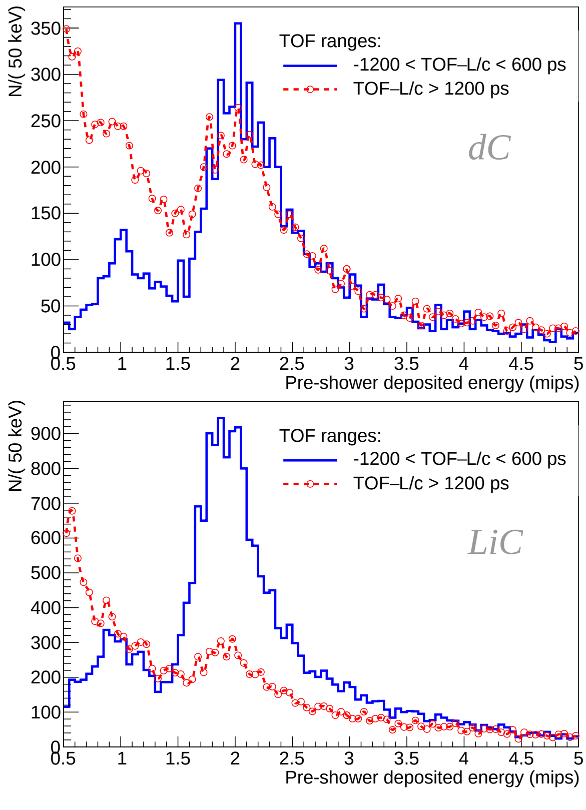

Figure 4. Top panel: time of flight of neutral particles between the beam counter and the pre-shower for d+C interactions. Bottom panel: same as above for Li+C interactions.

the dynode-anode gap and capacitance of assembly that amounts to ~ 6 pF. The noise in the spectrometric channels does not exceed 100 keV that permits for the first time measuring of SP spectrum in the range 0.6 ÷ 600 MeV. The dynamic diapason of signals amounts to more than 66 dB. Time-stamp is given by the $4.5{\times}4.5{\times}0.1$ cm^3 beam counter (not shown). It is also placed in front of the target.

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

We used CAMAC and a LE-88K crate-controller with input for a trigger signal. The crate-controller has been connected to PC with PCI-QBUS interface. Data acquisition software has been developed in MIDAS framework (http://midas.psi.ch). 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 interactions (Fig. 3).

In 2014 and 2015 two experimental runs (40th and 50th, correspondingly) have been carried out at Nuclotron

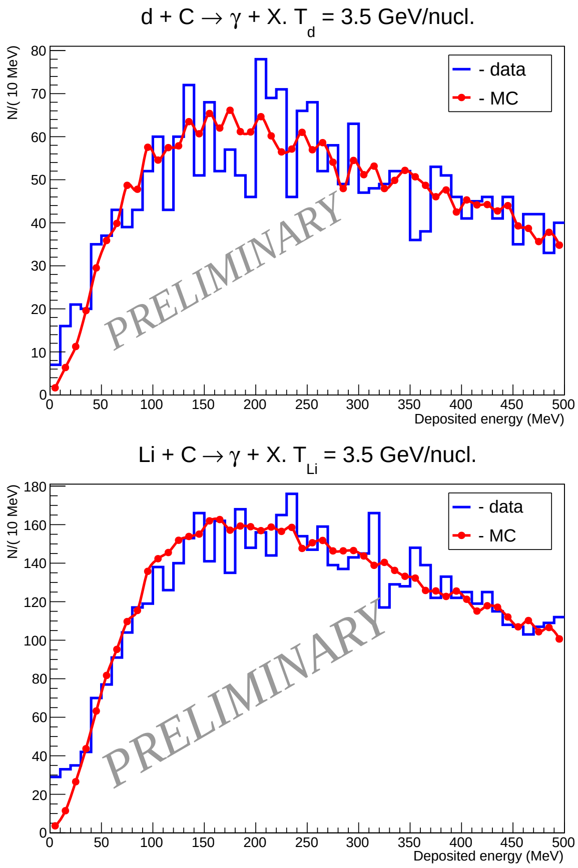

Figure 5. Entire energy spectra in SPEC with pre-shower and simulation in d+C (a top panel) and in Li+C (a bottom panel) interactions at Nuclotron.

in LHEP JINR with 3.5 A GeV deuterium (18 hours) and lithium (14 hours) beams. SPEC has been installed at the location of NIS-GIBS setup.

Criterions of selection 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 - $1200 < t - t_\gamma < 600$ 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 Fig. 4 spectra of γ quanta deposited in pre-shower plastic with time selection for neutral particles is presented for d+C (top) and Li+C (bottom) interactions. A solid line shows Compton peak at 1 MIP energy and more intensive peak of gamma quanta conversion at 2 MIP. In this Fig. with dotted line this structure is almost unnoticeable.

Monte Carlo simulation of the SPEC setup has been carried out at the conditions of the last assembly and the beam energy – 3.5 A GeV. Monte-Carlo simulation (uRQMD+Geant-3.21) is used. Geant-4 has shown the same result.

After data processing we have obtained SP spectra of energy release in deuterium-carbon (Fig. 5, a top panel) and lithium-carbon (Fig. 5, a bottom panel) interactions. In the region of energy below than 50 MeV, a noticeable excess over Monte-Carlo simulation has been observed. It agrees well to other SP experiments [7].

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**, 306 (2012); V. N. Ryadovikov (On behalf of the SVD-2 Collaboration). Phys. Atom. Nucl., **75**, 989 (2012).

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

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

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

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

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

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

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

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

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

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