PROCEEDINGS OF SCIENCE
ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
37th International Cosmic Ray Conference
12–23 July 2021

Application of Desensitized Nuclear Emulsion films for Chemical Composition Study of Cosmic-ray Nuclei in GRAINE 2018 balloon-borne experiment

Atsushi Iyono,[a,*] Saya Yamamoto,[a,b] Shigeki Aoki,[c] Hiroki Rokujo [b] and Satoru Takahashi[c] on behalf of the GRAINE Collaboration
(a complete list of authors can be found at the end of the proceedings)

[a] *Okayama University of Science,*
1-1 Ridai-cho, Okayama,Okayama 700-0005,Japan
[b] *Nagoya University, Department of Physics,*
Furo-cho, Chikusa-ku, Nagoya, 464-8602, Japan
[c] *Kobe University,Faculty of Human Development,*
3-11, Tsurukabuto, Nada-ku, Kobe-shi, Hyogo 657-8501, Japan
E-mail: iyono@das.ous.ac.jp

We have developed the desensitized nuclear emulsion films suitable for the detection of heavy cosmic ray nuclei in the high speed image processing systems (HTS) which was utilized at Nagoya University. And we have carried out our balloon flight of nuclear emulsion telescope for high resolution gamma-ray imaging of Vela Pulsar in April, 2018. We have deployed the emulsion chamber which consisted of several sensitivity type of desensitized nuclear emulsion films in this balloon flight. We are going to report the results of this pilot studies of the application of desensitized films for the detection of cosmic ray nuclei, and the potential of sensitivity control of nuclear emulsion films suitable for image analysis.

37th International Cosmic Ray Conference (ICRC 2021)
July 12th – 23rd, 2021
Online – Berlin, Germany

*Presenter

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License (CC BY-NC-ND 4.0).

https://pos.sissa.it/

PoS(ICRC2021)075

1. Introduction

Current progresses in nuclear emulsion technology have provided to precise and huge scale experiments in high energy cosmic ray physics. Various grain sizes and various types of silver-halide weight-content have been developed for nuclear emulsion gels. Nuclear emulsion films made with these nuclear emulsion gels can record charged tracks from minimum ionized particles to heavy nuclei with sub-micrometer spatial resolution. The OPERA experiment[1] , the NINJA experiments[2], the GRAINE experiments[3], and muon tomographic imaging have successfully utilized those nuclear emulsion technology. On the other hand, the high-speed charged track-recognition system used to analyze nuclear emulsion films such as Hyper-Track Selector (HTS) instruments [4], has been innovated at Nuclear emulsion facility of Nagoya University. Consequently, high performance track analyses have been carried out for minimum ionized tracks in these experiments, whereas signals by high atomic-number (Z) particles like heavy nuclei would be saturated and could not distinguish their charge number (Z) solely.

To apply nuclear emulsion technology for the cosmic ray nuclei (CRN) detection with high performance image analysis system(HTS), we have decided to develop desensitized nuclear emulsion gels by controlling the chemical compounds added [5]. The tracks of heavy cosmic ray nuclei in desensitized nuclear emulsion films behave like MIP tracks in HTS analysis.

We have deployed the emulsion chambers which consist of some desensitized nuclear emulsion films on the balloon flight of the GRAINE experiments carried out in 2018 at Alice Springs, Australia in order to examine the performance of desensitized films. We report the results of these test experiment in this paper.

2. GRAINE 2018 balloon flight and desensitized nuclear emulsion films

In April 2018, we have carried out a balloon-borne experiment with a 0.38 m^2 aperture and 17.4 hour flight duration shown in figure 1 and in Australia to demonstrate the performance to detect know gamma-ray source, Vela Pulsar.The total flight duration was 17.4 hour with 15 hour level flight at 35-38 km altitude. Because the pressure vessel [6] was worked during the flight, the stable operation of GRAINE nuclear emulsion telescope was made and finally the gondola was recovered. We deployed two sets of the CRN chambers with desensitized nuclear emulsion films in the gondola shown in figure 2. The size of chamber was 10×10 cm^2 and 8mm thickness with 15 nuclear emulsion films of various sensitivities and one CR-39 plate per one chamber shown in figure 3

When desensitizing the nuclear emulsion film, sodium hexachlororhodate (III) 5-hydrate (rhodium compound, Na_3 $RhCl_6{\cdot}5H_2$ O) was added when producing the nuclear emulsion gel. The sensitivity can be controlled by adjusting the total amount of each additive. We prepared two type of desensitized emulsion films for testing. We added rhodium compound into the no ripening samples to achieve a rhodium concentration of 2.5 μmol/Ag mol (abbreviated as RH25 in the following section) and 5.0 μmol/Ag mol (abbreviated as RH50),respectively.

A nuclear emulsion gel consisting mainly of silver bromide has been applied to both surfaces of a plastic film base to make samples of nuclear emulsion film. The thickness of the nuclear emulsion layer was designed to be 60 μm on both sides of the plastic films, whose thickness was

PoS(ICRC2021)075

Figure 1: The Gondola of GRAINE2018 balloon borne telescope.

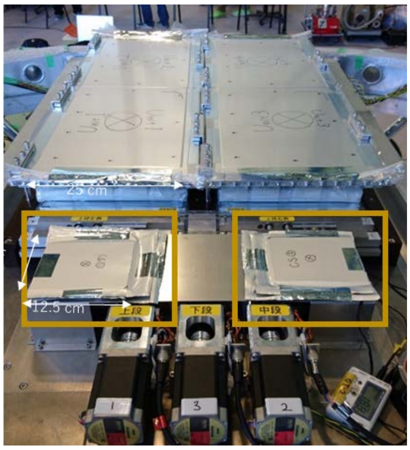

Figure 2: The two set of test chamber for cosmic ray nuclei detection were deployed on the main telescope system, which were indicated with brown color rectangles.

180 μm. Therefore, the total thickness of each nuclear emulsion film was nominally 300 μm. These emulsion films were prepared at Nagoya University in Japan.

CR-39 plate (Sun9 produced by Sunlux Co. ltd.) was also deployed at the furthest downstream side of the test chamber. CR-39 is a well-known solid-state nuclear track detector which allows to determine energy loss of charged beam by measuring the size of the pits formed on the detector due to incident ions.

We summarized the type of material used in the CRN chamber in figure 4. The order of the table tuple was equivalent to the layer order of chamber structure shown in firure 3.

3. Analyses and Results

After scanning emulsion films described above by using HTS, we selected three nuclear emulsion films(non-ripening RH25) from the 15 films, because some error films occurred by some biological damages. HTS provide the position, direction and PHV(pulse height volume) information of each track in the films. The PHV value was defined in HTS system as the total darkness of track along the trajectory in each film. The position extrapolated by using the direction in the neighbor films were calculated and their difference of position, direction and PHV were limited in some criteria in order to make the connection candidates in the three emulsion films. In this analysis, we restricted the differences of position and direction to less than 5μm and less than 0.02$radian$, respectively.

The PHV distributions for each zenith angle $\tan\theta$ region were shown in the figure 5 in the different zenith angle regions. Since the zenith angle dependency of PHV value has already been reported, we restricted the angle regions shown in the same figure. These PHV distributions show the two peak structure which came from cosmic ray charge Z differences.

PoS(ICRC2021)075

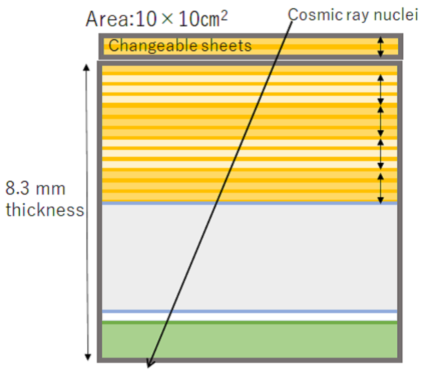

Figure 3: The CRN chamber structure. The area of top side is 10×10 cm^2 and its thickness was 8.3mm. At the furtherest downstream, CR-39 plates was allocated for the calibration of various sensitivity of emulsion films.

Gel type of emulsion gel ① to ④	plates	Thickness mm
①ripening	2	0.3
②non ripening	1	0.3
①ripening	3	0.3
③non ripening Rh25	3	0.3
④non ripening Rh50	3	0.3
①ripening	3	0.3
Acrylic block	1	3
Glassine Paper	1	-
CR39	1	1
Laminate film	1	0.18

Figure 4: Various sensitivity type of nuclear emulsion films were used in this flight. Ripening type and non-ripening type were also used as well as desensitized nuclear emulsion films.

For the zenith angle less tan θ less than 0.25, we furthermore restrict the coincidence of tracks in the downstream RH50 film for detected tracks in the three RH25 films. When comparing these differences of these figure shwon in figure 6, the lower side peak of RH25 PHV distribution was diminished clearly.

The averaged PHV values in the RH25 films of which tracks were trigged by RH50 desensitized emulsion film, were compared with CR-39 etch pit size in order to confirm the correlation between PHV values and etch pit size.

The CR-39 plates were scanned with the microscope to obtain the etch pit size such as the length of minor axis and their location in micrometer resolution. We used the position and direction information obtained by HTS system in order to extrapolate expected positions and angles of tracks on the furthermost downstream CR-39 layer. Finally, we could connect HTS tracks in RH25 and R50 films to CR-39 etch pits, and the total amount of them were 97 tracks. Figure 7shows the correlation between the PHV values in RH25 and minor axis length of etch pit in CR39 for the same cosmic ray nuclei.

4. Discussion

The desensitized nuclear emulsion gel by using Rh compounds such as RH25 and RH50 could be suppressed the production of delta rays and provide suitable PHV values in HTS analysis systems. The HTS image processing system enable to extend the exposure area of nuclear emulsion film and to search cosmic ray heavier nuclei of which frequencies are very low. By controlling the desensitization levels of nuclear emulsion gel, we can study the abundance of cosmic ray nuclei.

The linearity of PHV were exmined by comparing PHV values with etch pit size. Though in figure 7, data points were scatterd to heigher values of PHV region due to zenith angle dependency, data point showed the linear relation in lower PHV values in each etch pit size.

PoS(ICRC2021)075

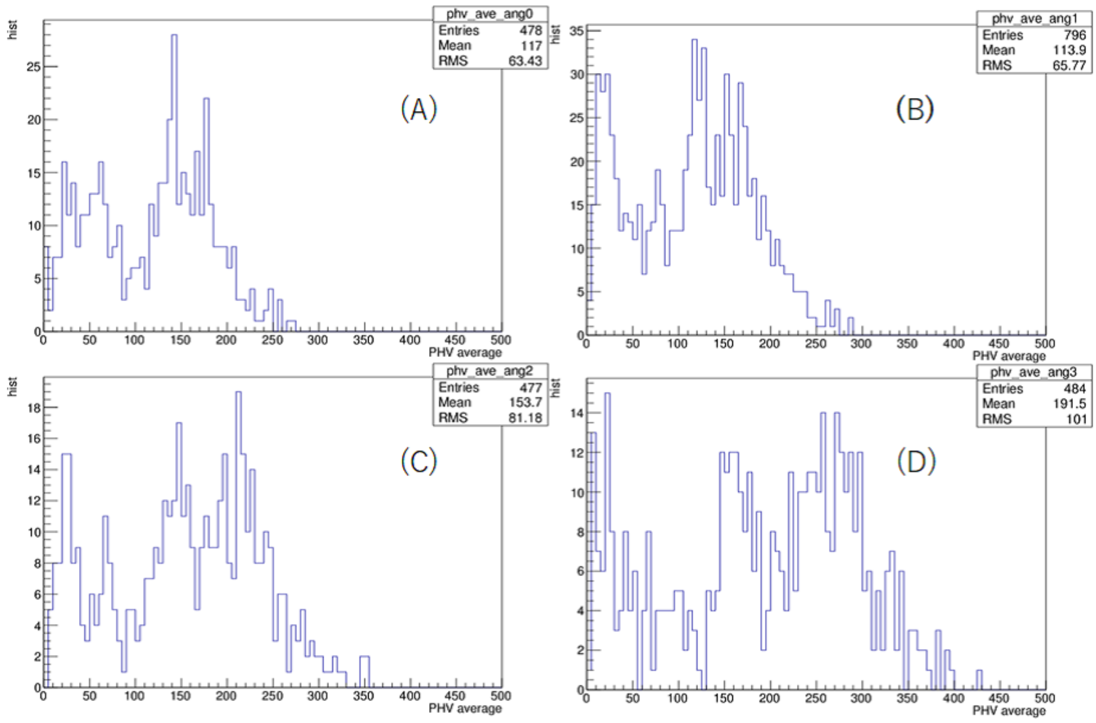

Figure 5: The PHV distribution for each zenith angle region : $\tan\theta < 0.25$ in (A), $0.25 \geq \tan\theta < 0.5$ in (B), $0.5 \geq \tan\theta < 0.75$ in (C) and $0.75 \geq \tan\theta$ in (D) respectively. The horizontal axes represent the mean PHV values obtained from three RH25 emulsion films.

5. Conclusions

The desensitized nuclear emulsion gels adding Rh compounds were applied on the a film base, various sensitivity of nuclear emulsion films were produced. And we exposed the emulsion chambers which consists of ordinal sensitivity and desensitized ones to the cosmic ray nuclei in GRAINE balloon flight experiment for astronomical gamma-ray search at Australia, in April 2018. We have obtained PHV signals in both RH25 and RH50 desensitized films for cosmic ray nuclei, and can select heavier nuclei by triggering RH50 film coincidence. Finally, these desensitized PHV signals were well correlated with the CR-39 etch pit size(minor axis length).

In 2023, GRAINE experiments are going to carry out the astronomical gamma ray study with 10 times larger statistics by using several ten times large area emulsion chambers, and their multiple flights. This will provide the direct measurement of cosmic ray nuclei abundance by optimizing the desensitization degree of nuclear emulsions for high speed image analysis system HTS.

Acknowledgments

This work was carried out by the joint usage / research program of the Institute of Materials and Systems for Sustainability(IMaSS), Nagoya University.

PoS(ICRC2021)075

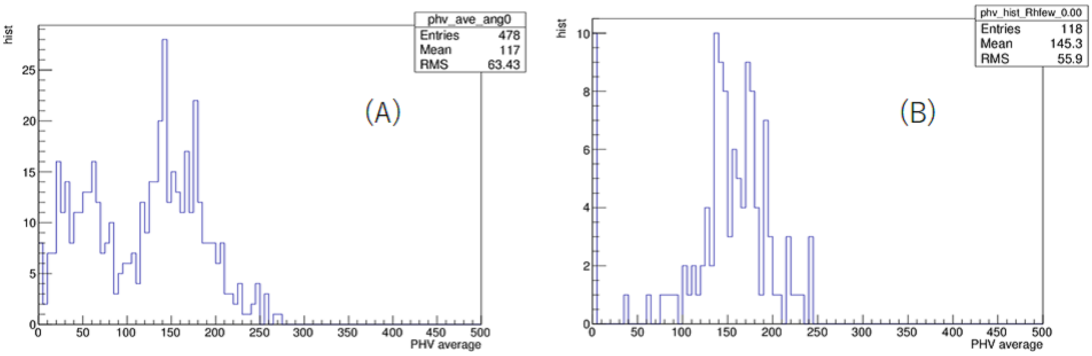

Figure 6: The PHV distribution for each zenith angle region : $\tan\theta < 0.25$. (A):RH25 films solely and (B): RH25 and RH50 films coincidence required. The horizontal axes still represent the mean PHV values obtained from three RH25 emulsion films.

References

[1] R. Acquafredda et al., *The OPERA experiment in the CERN to Gran Sasso neutrino beam JINST* **4**(2009)P04018

[2] T. Fukuda et al., *Neutrino research program with Nuclear Emulsion at J-PARC PoS* **12**(2017)294

[3] K. Ozaki et al., *Development of new-type nuclear emulsion for a balloon-borne emulsion gamma-ray telescope experiment*, *J. Instrum.,* **10**(2015)P12018.

[4] M. Yoshimoto et al., *Hyper-track selector nuclear emulsion readout system aimed at scanning an area of one thousand square meters* , *Prog. Theor.Exp. Phys.* **2017**(2017)103H01.

[5] Saya Yamamoto et al., *Desensitized Nuclear Emulsion Films for Measuring the Chemical Composition of Cosmic-ray Nuclei*, *Bull. Soc. Photogr. Imag. Japan.* **29**(2019)No.2:20-26.

[6] H. Rokujo et al., *Development of a balloon-style pressure vessel gondola for balloon-borne emulsion gamma-ray telescopes* , *JINST* **14**(2019)P09009

PoS(ICRC2021)075

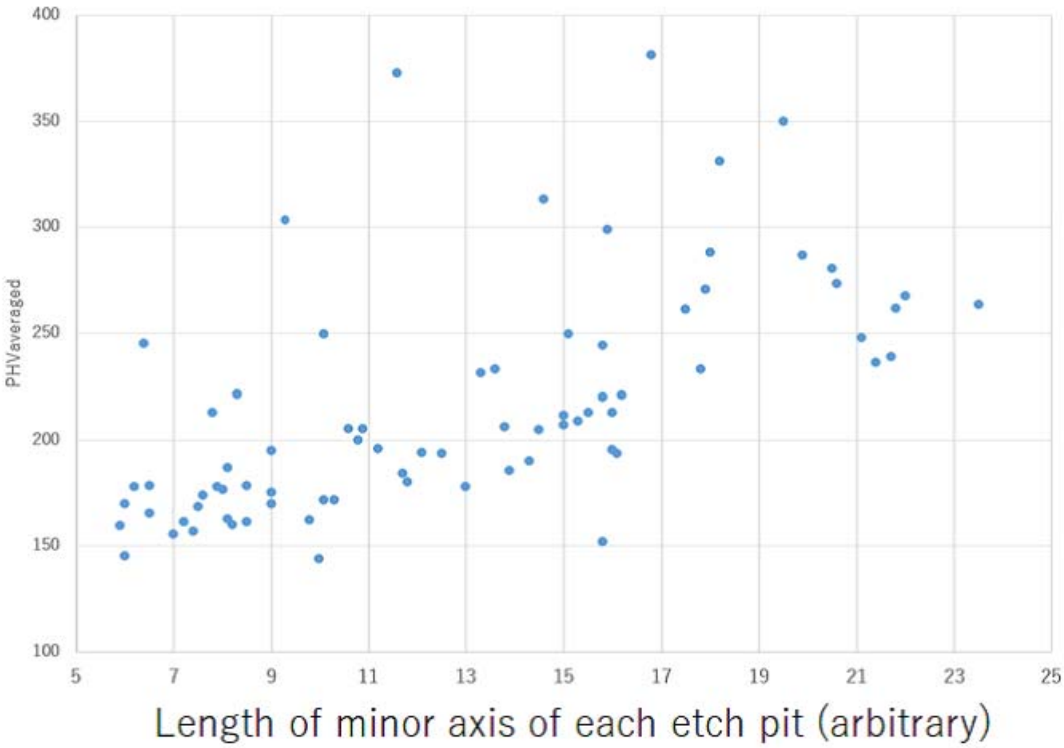

Figure 7: The PHV distribution for each zenith angle region : $\tan\theta < 0.25$. (A):RH25 films solely and (B): RH25 and RH50 films coincidence required. The horizontal axes still represent the mean PHV values obtained from three RH25 emulsion films.

PoS(ICRC2021)075

Full Authors List: GRAINE Collaboration

Shigeki Aoki[1], Satoru Takahashi[1], Atsushi Iyono[2], Ayaka Karasuno[1], Kohichi Kodama[3], Ryosuke Komatani[4], Masahiro Komatsu[4], Masahiro Komiyama[4], Kenji Kuretsubo[1], Toshitsugu Marushima[1], Syota Matsuda[1], Kunihiro Morishima[4], Misaki Morishita[4], Naotaka Naganawa[4], Mitsuhiro Nakamura[4], Motoya Nakamura[1], Takafumi Nakamura[1], Yuya Nakamura[4], Noboru Nakano[4], Toshiyuki Nakano[4], Kazuma Nakazawa[5], Akira Nishio[4], Miyuki Oda[1], Hiroki Rokujo[4], Osamu Sato[4], Kou Sugimura[4], Atsumu Suzuki[1], Mayu Torii[4], Saya Yamamoto[2,4] and Masahiro Yoshimoto[5]

[1]Kobe University, Kobe 657-8501, Japan. [2]Okayama University of Science, Okayama 700-0005, Japan. [3]Aichi University of Education, Kariya 448-8542, Japan. [4]Nagoya University, Nagoya 464-8602, Japan. [5]Gifu University, Gifu 501-1193, Japan.

PoS(ICRC2021)075