Abstract: In the Earth’s atmosphere primary cosmic rays interact with the present molecules and atoms. Hence, the radiation environment in the Earth’s atmosphere is affected by the generation of secondary charged and neutral particles i.e. electrons, muons and protons as well as neutrons and gamma rays. At cruising altitude of commercial aircraft, neutrons yield a significant proportion to the dose rate equivalent. The student team MONSTA (Measurement Of Neutrons with Scintillators in The Atmosphere) participated in the BEXUS (Balloon Experiments for University Students) program. The team used the Phoswich Instrument for Neutrons and Gammas (PING) on the stratospheric balloon BEXUS 14 to measure the height dependent flux of the neutral component. In order to determine the contribution of neutrons to the dose, it is essential to measure their altitude-dependent energy deposition spectra. The sensor head of PING consists of two different scintillators: The inner plastic scintillator BC-412 and the surrounding inorganic scintillator CsI(Na). The scintillators are optically coupled and are read out by a common photomultiplier. Neutrons deposit mostly their energy in the hydrogen rich BC-412 plastic scintillator while the heavy inorganic scintillator has a high cross-section for gamma rays. Because of their different decay times, the pulses of the two scintillators have a different pulse shape. Hence, they can be separated by applying pulse shape analysis. This pulse shape analysis, as well as the pulse height and phase reconstruction, will be presented.

Keywords: Phoswich detector, scintillator, neutrons, phase correction, pulse height correction

1 Introduction
The BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Center and the Swedish National Space Board. Each year, two balloons are launched in Esrange near Kiruna, carrying up to 20 experiments designed and built by student teams. Before analysing the BEXUS flight data, the calculation of the phase and pulse height correction (14.8 MeV neutron calibration measurements) was an eligible possibility to study the instrument performance in detail. The instrument as well as the data processing is described in [1].

2 Scientific Background
The cosmic-ray environment in a spacecraft and aircraft differs greatly from the one at sea level. Over the past decades the exposure of the aircraft crew and astronauts to (atmospheric) cosmic radiation has become an important concern. Interaction of cosmic rays with the matter leads to electromagnetic and hadronic cascades in which secondary particles are produced. At aviation altitudes (around 11 km), cosmic-ray neutrons contribute about half of effective dose. Therefore it is important for dosimetry purposes to have a detailed knowledge about all different components that make the radiation. However, it is difficult to measure neutrons with energies greater than 10-20 MeV precisely in a mixed radiation field. The Phoswich Intrument for Neutrons and Gammas (PING) spectrometer is a phoswich-type scintillation detector and was designed to measure the high-energy neutron spectrum from 10 MeV to about 100 MeV, by separating neutral particles well from cosmic-ray protons and other charged particles.

3 Instrument Description
The Phoswich detector PING developed by Esther M. Dönsdorf consists of two different scintillators (see Fig. [1]).
Figure 1: Schematic of the Phoswich Intrument for Neutrons and Gammas [1].

Neutrons deposit mostly their energy in the inner hydrogen rich plastic scintillator made of BC-412 mainly due to elastic scattering. Other particles (e.g. gamma rays, muons, protons) almost certainly give a light signal in the outer antico- incidence made of CsI(Na) due to photo effect, compton effect or pair production.

The light output of the both scintillators are read out by a common photomultiplier tube (PMT) on the top of the detector. With the pulse shape analysis described in 4 the pulses of the two different scintillators can be separated.

4 Electronics

The output of the PMT is fed into the Charge Sensitive Amplifier (CSA) which converts it into a voltage pulse. The voltage pulse is then processed in two different ways:

1. The direct pulse is amplified and then converted by the Analog Digital Converter (ADC).
2. The direct pulse is amplified, shaped, and then converted by the ADC.

The Field Programmable Gate Array (FPGA) reads out the ADC signal and calculates different parameters N, F, S, P every 333 ns by calculation of

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N = \sum n_i \cdot s_i
\]
\[
P = \sum f_i \cdot s_i
\]
\[
S = \sum p_i \cdot s_i
\]
\[
S = \sum S_i \cdot s_i
\]

with \(n_i\) (blue), \(f_i\) (green), \(p_i\) (magenta) and \(S_i\) (red) as the coefficients of the analysis functions and \(s_i\) as the ADC values of the pulse (see Fig. 2).

Due to the fact that the sum over all coefficients of every parameter is zero, the parameters grow with rising pulse height. The coefficients \(f_i\) and \(n_i\) analyse the direct pulse, the coefficients \(p_i\) and \(S_i\) analyse the shaped pulse. When the value \(F\) exceeds a certain threshold, an event triggers. When \(F\) has a maximum, the values \(F\) and of \(N\), \(P\), and \(S\) at the same time are stored.

Parameter N gives a value for the slope of the pulse. By normalising N with F pulses of the two different scintillators can be separated.

Parameter S leads to a value representing the pulse height.

Due to the fact that the samples of a pulse are stored according to the ADC clock (every 333 ns), it is possible that same shaped pulses are

Figure 3: P/S over N/F for all events measured by the detector. The populations are separated by two linear functions.

Figure 2: Analysis functions which are used to calculate the parameter N, F, P and S.
shifted in time and lead to different values for the parameter $S$. For this reason a pulse height correction in dependency of the time shift is required. Parameter $P$ represents this phase shift. By plotting $P/S$ over $N/F$, two populations are visible in Fig. [3]. The two fingers 1 and 2 in the upper right corner represent the events in the BC-412. In the following, the phase and pulse height correction of these events is presented.

5 Phase Correction

Before the pulse height is corrected, a phase correction is required. In Fig. 4 two different direct BC-412 pulses can be seen. One has a negative $P/S$ with its origin in the lower finger, the other has a positive $P/S$ with its origin in the upper finger. The horizontal phase shift between the pulses is visible as well as a vertical difference in the slower part of the pulses due to the normalisation of the ADC values $S$ with the uncorrected pulse height $S$. In the next step a 1D-histogram of $P/S$ is calculated as shown in Fig. 5. To the integration of the curve the following function is fitted:

$$\Phi(P/S) = a \cdot (P/S)^2 + b \cdot P/S + c$$

The samples of a pulse are now shifted from the time $t_0$ to a new time $t$ dependent of $P/S$:

$$t = t_0 + \Phi(P/S) \cdot 333 \text{ ns}$$

The result of the phase correction for the two example pulses can be seen in Fig. 6. The horizontal phase shift is now corrected. For all measured BC-412 pulses (14.8 MeV) one obtains Fig. 7. Zooming into the the slow part of the pulses, the unshifted samples belonging to $\Phi = 0$ are in the upper left corner, samples in the lower right corner ($\Phi = 1$) are shifted 333 ns. If the samples were normalised with the right pulse height $S$, all samples would lie on the same curve.

6 Pulse Height Correction

To the slow part of the pulses ($t > 12 \cdot 333 \text{ ns}$) in Fig. 7 the following 2D-function $F(t, \Phi) = f(t) \cdot b(\Phi)$ is fitted:

$$f(t) = a \cdot (t - 12 \cdot 333 \text{ ns})^2 + b \cdot (t - 12 \cdot 333 \text{ ns}) + c$$

and

$$b(\Phi) = d \cdot (\Phi - 0.5)^2 + e \cdot (\Phi - 0.5)$$

The corrected pulse height $S_{corr}$ is now calculated by $S_{corr} = S/b(\Phi)$. Applying this to all BC-412 pulses, we obtain Fig. 8 and see that the pulses approximately lie on the same curve.

For $\Phi = 0$, one obtains $b(\Phi) = 0.988$, for $\Phi = 1$ one obtains $b(\Phi) = 1.017$. Thus, the correction of the pulse height is less than 2%.

Figure 4: Two direct BC-412 pulses without phase correction.

Figure 5: BC-412 events: 1D histogram of $P/S$.

Figure 6: Two direct BC-412 pulses with phase correction. The blue pulse is shifted $0.93 \cdot 333 \text{ ns}$, the green pulse is shifted $0.03 \cdot 333 \text{ ns}$.

Figure 7: BC-412 events: 1D histogram of $P/S$.

Figure 8: BC-412 events: 1D histogram of $P/S$.
In Fig. 7 the spectrum of the 14.8 MeV calibration measurements can be seen. In black the spectrum with uncorrected parameter $S$ is shown, in red the spectrum with corrected parameter $S$. The slope at the edge ($S/3500 \approx 340$) is not more abrupt for the corrected spectrum than for the uncorrected spectrum. In the next step an error function will be fitted at these spectra to quantify the values of the slope.

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References


Figure 7: All BC-412 events: ADC values over the time.

Figure 8: All BC-412 events phase and pulse height corrected: ADC value over time.

Figure 9: Spectrum of 14.8 MeV calibration measurements.

7 Result of Correction