In-flight second order correction of PAMELA calorimeter characteristics (for simulation in Geant4)

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Abstract. Simulation of the PAMELA spectrometer characteristics is performed with the special program accepted by the PAMELA collaboration based on Geant4 package, which needs a detailed information about geometry, materials etc. of scientific equipment. This data is taken from manufactures or obtained from different ground-based tests including accelerators. We propose a method of in-flight verification of calorimeter characteristics. To calculate them we select relativistic protons passing through all the spectrometer without interactions. We obtain correction values from a comparison of experimental data and simulation in assumption that electromagnetic processes are performed in Geant4 with high precision. As a result, characteristics of silicon detectors (the sensitive part) are verified. Correction factor is $2.0 \pm 0.3\%$ with respect to original value.

1. Introduction

The PAMELA instrument is installed on board of Russian satellite Resurs–DK1 and intended to study fluxes of charged particles in cosmic rays with particular focus on antiparticles. Data acquisition lasted from June 2006 (when the satellite was launched) up to January 2016. The PAMELA instrument consists of following detectors: a time-of-flight system, an anticoincidence system, a magnetic spectrometer, an electromagnetic calorimeter, a neutron detector, a shower tail catcher detector (S4) [1].

The main task of the PAMELA calorimeter is to distinguish positrons/electrons from protons/antiprotons and to measure energy of stopped particles, electrons and positrons [2]. Calorimeter consists of 44 single-sided silicon detector planes (380μm thick) interleaved with 22 plates of tungsten absorber (0.26cm thick). It corresponds to 0.74 radiation lengths and $\sim$0.6 nuclear interaction lengths. Each plane consists of 96 strips. The orientation of the strips of two consecutive planes is orthogonal and therefore provides two-dimensional spatial information.

Thickness of each silicon detector $\mathbf{Dx} = 380\mu$m is known, but it includes non-sensitive parts (see figure 1). PAMELA was constructed mostly for high-energy particles detection, and this

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small thickness difference has very weak influence on measuring results. But now, due to solar flares and solar modulation study, focus of the PAMELA research shifted to low energies. In this energy range, energy releases are not too small with respect to energy of registered particle. For this reason, more accurate knowledge of this characteristic is preferable.

We are intended to determine "relative" thickness of sensitive part of calorimeter detector (shown by hatching on figure 1) using cosmic rays as the calibration data. Precise thickness value is needed for more accurate reproduction of the experimental characteristics in simulation.

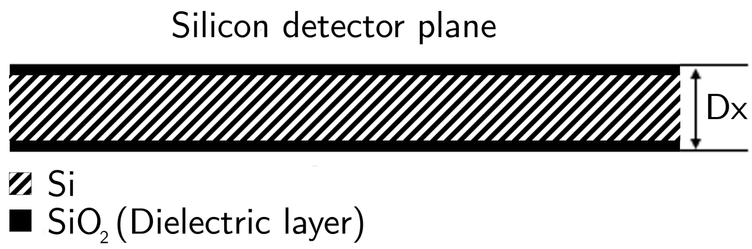

Figure 1. Illustration of a silicon detector. **Dx** value is used in Geant 4 simulation, but thickness of the sensitive part is smaller.

2. Simulation and event selection

Initial experimental dataset was collected from cosmic rays proton events. Initial simulation datasets consist of simulated proton events with spectrum similar to cosmic ray protons and for different silicon detector relative thickness values (it varies in range $0.95 \dots 1.00\mathbf{Dx}$). Simulation was done with accepted in the PAMELA collaboration software based on Geant 4 (FTFP_BERT model with standard electromagnetic physics).

The following selection criteria were applied to initial simulation and experimental data: one hit in each time-of-flight pair of planes (S1, S2, S3), no signal in anticoincidence system, one good track in the tracker, rigidity and energy releases correspond to the single charged particle, exclude data acquired in the radiation belt. These criteria correspond to particles that do not interact with parts of the instrument, and the characteristics of those particles are surely detected.

The following calorimeter selection criteria were also used: one track in the calorimeter with thickness no more than one strip and signal missed in no more than one plane inside the track, no noises outside trajectory (i. e. signals in strips not associated with the trajectory). These criteria correspond to stopped or passing through calorimeter particles produced no shower nor nuclear interactions.

Only relativistic particles (with rigidity > 5GV) were considered. Energy loss in the 1^{st} silicon plane data was used in the following calculations.

3. Method and results

After applying selection criteria, we compare experimental data with simulation data with different silicon plane thickness values. On the figure 2, divergence between simulation and experimental data shown: distribution of energy release for the simulation data shifted to the right by reason of absence of non-sensitive layer. According Landau [3], energy loss distribution approximately admits Landau distribution, which can be determined by the pair (μ, σ) — location and scale parameters. Description of parameters shown on figure 3.

We fit energy loss distribution for simulation and experimental datasets (see figure 3) by the Landau distribution using maximum likelihood estimation method [4]. For each fit, pair (μ, σ) was computed.

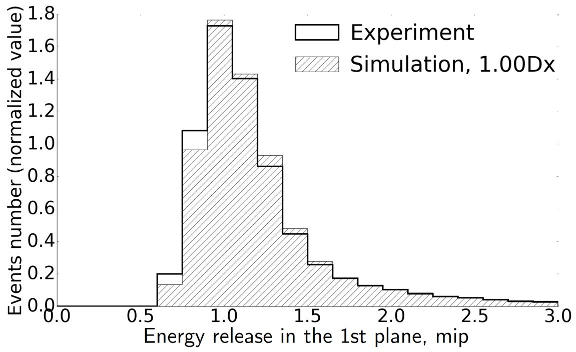

Figure 2. Histograms of energy loss in the 1st calorimeter plane for experimental data and simulation (with silicon plane thickness parameter value set to 1.00**Dx**). Distribution of the simulation data shifted to the right.

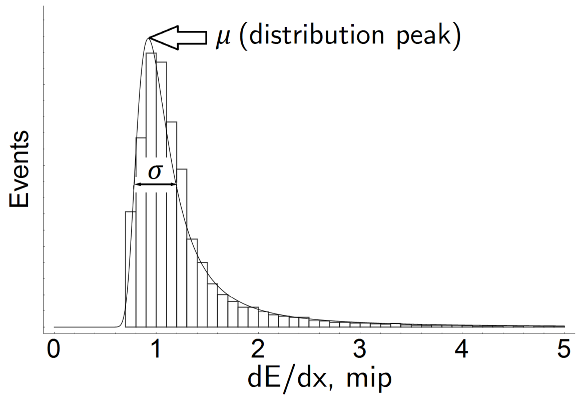

Figure 3. Approximation of 1st plane energy loss distribution by Landau distribution. μ is a location of the distribution peak (the most probable energy loss); σ is a scale parameter — full width at half maximum.

On the figure 4, dependence of the location parameter μ on a correction factor to the detector thickness is shown for the 1st plane of the calorimeter. Each point corresponds to one of simulated relative thickness value. Solid black line is a linear fit of location parameters of different simulation sets. Hashed line shows the location parameter of fit of the experimental data with its standard error. An actual plane thickness value can be found as correspondent to the location parameter of fit of the experimental data.

For actual experimental data, a sensitive layer thickness is $2.0 \pm 0.3\%$ smaller than **Dx**.

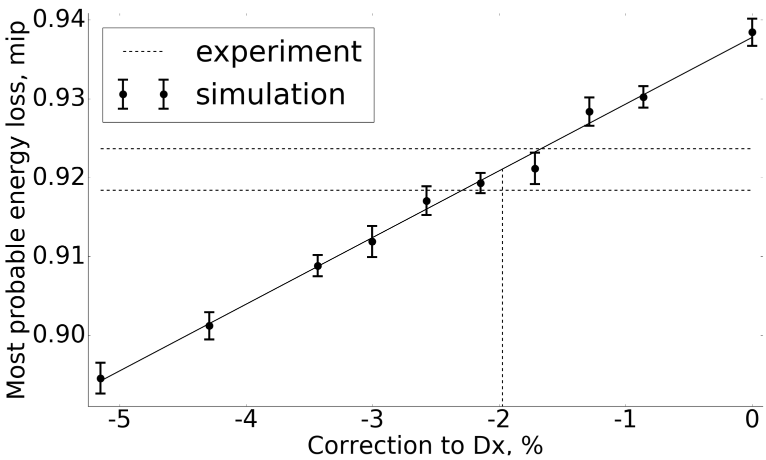

Figure 4. Dependence of the most probable energy loss on correction factor for the 1st plane of the calorimeter. Standard errors for maximum likelihood estimates are shown. Dashed lines are correspondent to the peak of fit of the experimental data (with error).

4. Conclusion

In this work, relativistic proton events were selected from orbital experimental data. Samples of relativistic proton events were simulated with similar to cosmic rays spectrum for different correction factors to the sensitive part of the silicon detector thickness. Distribution of energy loss in the 1st calorimeter plane compared for experiment and different simulation datasets.

As a result, corrections to sensitive part thickness of silicon detectors of PAMELA calorimeter were obtained. The correction factor value is $2.0 \pm 0.3\%$.

Acknowledgments
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