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The Status of the PAMELA Experiment

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The PAMELA experiment will be launched on-board of a polar orbiting Resurs DK1 satellite in mid-2003. The primary objective of PAMELA is to measure the flux of antiprotons (80 MeV - 190 GeV) and positrons (50 MeV - 270 GeV) in the cosmic radiation. The wide energy range and large statistics (O(10^4) antiprotons and O(10^5) positrons) will allow sensitive tests of cosmic ray propagation models and searches for exotic sources of antiparticles, such as cold dark matter neutralino annihilations. PAMELA is built around a permanent magnet spectrometer equipped with double-sided silicon detectors and surrounded by an active veto shield. This is complemented by a proportional straw tube / carbon fibre radiator transition radiation detector and a silicon-tungsten imaging calorimeter which is augmented by a scintillator shower tail catcher. A time-of-flight system provides the primary experimental trigger. The status of PAMELA is presented along with main results from simulations and test-beam studies.

1. INTRODUCTION

The PAMELA[2] spectrometer [1] will be launched into space by a Soyuz TM2 rocket in mid-2003. PAMELA will be mounted in a pressurised vessel attached to a Resurs DK1 earth-observation satellite, as shown in figure 1. During launch and orbital manoeuvres the pressure vessel is secured against the satellite's body. During data-taking the pressure vessel is swung up to give PAMELA a clear view into space (shaded position in the figure). The satellite will execute a semi-polar (70.4° inclination) elliptical orbit with an altitude varying between 300 km and 600 km. Three years of data-taking are expected. An overview of the experiment is given in figure 2. PAMELA is built around a 0.4 T permanent magnet spectrometer ('tracker') equipped with double-sided silicon detectors which will be used to measure the sign, absolute value of charge and momentum of particles. The tracker is surrounded by a scintillator veto shield ('anticounters') which is used to reject particles which do not pass cleanly through the acceptance of the tracker. Above the tracker is a transition radiation detector based around proportional straw tubes and carbon fibre radiators. This allows electron-hadron separation through threshold velocity measurements. Mounted below the tracker is a silicon-tungsten calorimeter. This measures the energies of incident electrons and allows topological discrimination between electromagnetic and hadronic showers (or non-interacting particles). A scintillator is mounted beneath the calorimeter to provide an additional trigger for high energy electrons (>100 GeV). A scintillator telescope system provides the primary experimental trigger and time-of-flight particle identification. PAMELA stands approximately 1.2 m high, has an overall mass of approximately 450 kg and a power consumption of approximately 350 W.

PAMELA is a natural progression from the WiZard balloon flights [2] and forms part of the RIM (Russian Italian Mission) framework, which has also generated the successful Si-eye [3] and NINA [4] space experiments.

2. SCIENTIFIC GOALS

The primary objective of PAMELA is to measure the energy spectrum of antiprotons and positrons in the cosmic radiation. Per year, at least 10^5 positrons and 10^4 antiprotons are expected. Figures 3 and 4 summarise the current experimental situation for antiproton and

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[2]Payload for AntiMatter Exploration and Light-nuclei Astrophysics.

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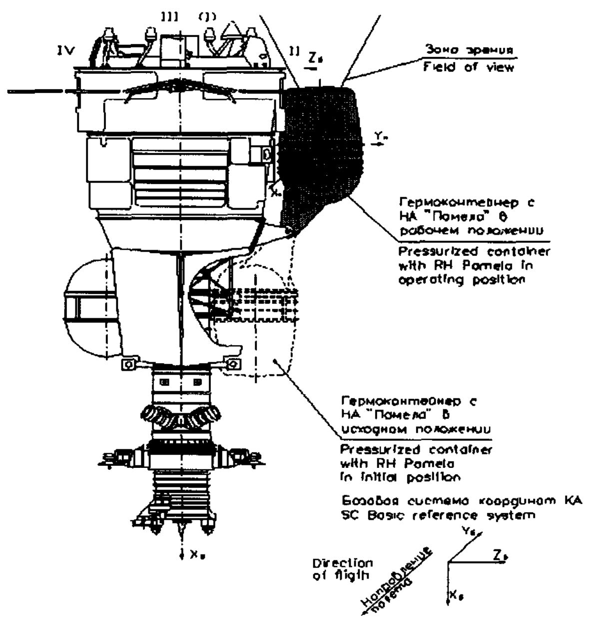

Figure 1. A schematic view of the Resurs DK1 satellite on which PAMELA will be located inside a pressure vessel. The pressure vessel is shown in both the 'parked' and 'data-taking' (shaded) orientations.

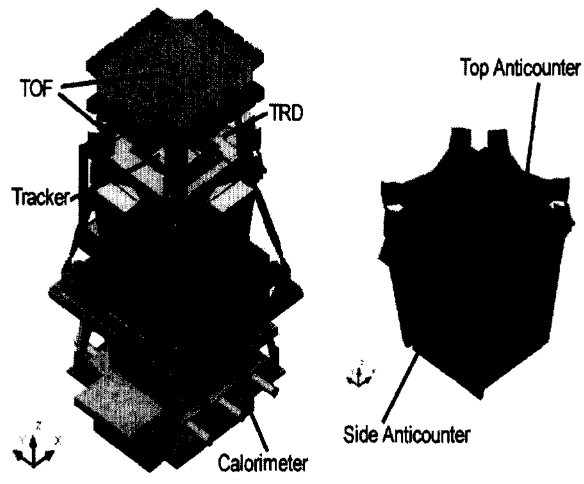

Figure 2. A stylised overview of the PAMELA experiment. The insert to the right shows the anticoincidence system in more detail. The TRD is not shown so that the entrance to the tracker is visible.

positron energy spectrum measurements, respectively. All of these measurements originate from balloon-borne experiments (apart from the AMS positron fraction measurement) operating at altitudes around 40 km for approximately 24 hours. There is still a residual amount of the earth's atmosphere above the detecting apparatus at this altitude ($\sim$5 g/cm^2) with which cosmic rays can interact. A satellite-borne experiment benefits from a lack of atmospheric overburden and a longer data-taking time. On each figure, the PAMELA expectation after three years of data taking is indicated. These data sets exceed what is available today by several orders of magnitude and will allow significant comparisons between competing models of antimatter production in our galaxy. Distortions to the energy spectra are very interesting because of possible contributions from exotic sources, such as the annihilation of supersymmetric neutralino particles - candidates for the dark matter in the universe [6]. Sensitivity to the low energy part of the spectrum is a unique capability of PAMELA and arises because the semi-polar Resurs orbit overcomes the earth's geomagnetic cut-off. Another PAMELA goal is to measure the antihelium/helium ratio with a sensitivity of at least 10^{-7}, ie: a factor of 50 improvement on the current limits [7]. Although optimised for the detection of antimatter, PAMELA will also study protons, electrons and light nuclei up to Z=6. Since PAMELA will carry out its observations during the transition to the minimum of the 23rd solar cycle, and will stay in orbit for at least three years, the effects of long and short term solar modulation on the fluxes of electrons, positrons, protons and nuclei can also be studied. The expected particle samples after three years of operation are summarised in table 1.

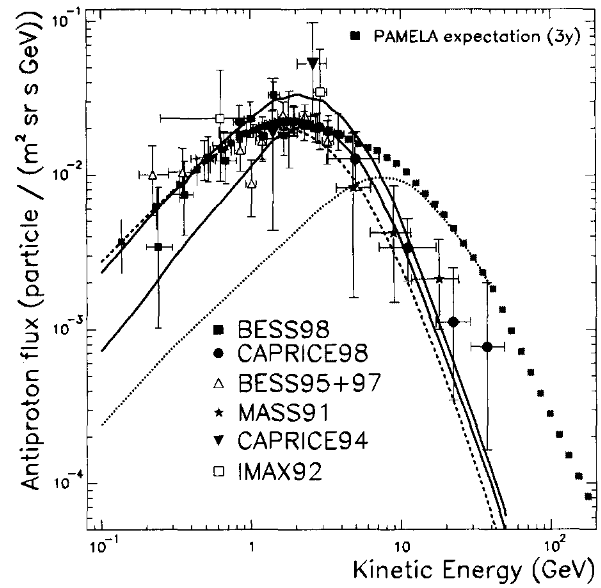

Figure 3. A summary of the current status of antiproton flux measurements. All data comes from balloon-borne experiments. The dotted line shows a possible distortion to the spectrum expected from neutralino annihilations. The other lines indicate expectations from secondary production models [5].

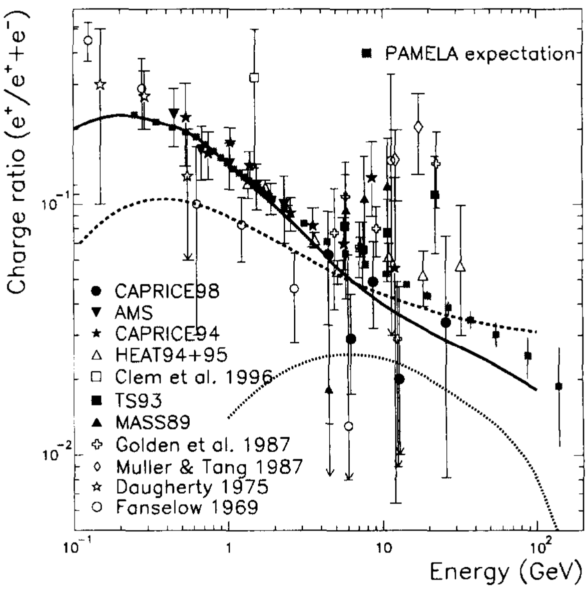

Figure 4. A summary of the current status of positron fraction measurements. All data comes from balloon-borne experiments and the AMS experiment flown on-board the Space Shuttle in 1998. The dotted line shows a possible distortion to the spectrum expected from neutralino annihilations. The other lines indicate expectations from secondary production models [5].

3. DETECTOR PERFORMANCE

In this section a more detailed overview of each PAMELA subdetector and the expected performance is given. The transition radiation detector is presented in detail elsewhere in these proceedings [8] and is not discussed further here.

3.1. Anticounters

The anticounter system [9] consists of four lateral detectors covering the sides of the tracker and one top detector placed above the tracker, as shown in figure 2. Each detector is made from a sheet of plastic scintillator read out by multiple compact photomultiplier tubes for redundancy. Each anticounter can be tested in-flight using a LED based system. The efficiency for detecting minimum ionising particles has been measured using cosmic ray muons and determined to exceed the required 99.9% per detector. The main purpose of the anticounter system is to detect particles which do not pass cleanly through the tracking system but still give rise to coincidental energy deposits in the time-of-flight scintillators and therefore generate a trigger. An example event is shown in figure 5 where a particle enters PAMELA from the side and interacts in the magnet, producing secondaries which hit the time-of-flight scintillators. The anticounter system surrounding the tracker can be used to reject such false triggers. The ratio between good and false triggers is 0.3 Hz : 2.8 Hz (7.2 Hz : 17.0 Hz) in equatorial (polar) regions. A problem arises at high energies, since particles backscattered from the calorimeter can enter the anticounters even though the trigger particle passes cleanly through PAMELA's acceptance - so-called self-veto. The backscattering of particles from the calorimeter was studied using a CERN SpS testbeam in order to understand how the anticounter system could be used to reject false triggers either off-line or in a second level trigger. Figure 6 shows that there is good agreement between the measured and simulated backscattering ratio for electrons and reasonable agreement for pions. A second level trigger would be enabled through uplinked commands if the PAMELA data volume is significantly larger than expected. This trigger could be formed by asking for coincidental energy deposits in the time-of-flight scintillator telescope (the standard trigger) and also that there is no activity in the anticounter system. The inclusion of calorimeter information in the second level trigger will ensure that the effect of self-veto is reduced.

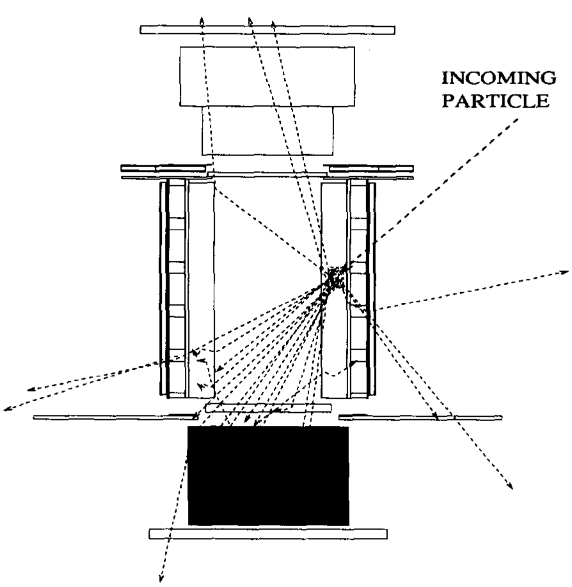

Figure 5. A simulation of a false trigger. A particle enters PAMELA from the side and interacts in the magnet producing secondaries which give coincidental energy deposits in the time-of-flight scintillators producing a trigger. Such false triggers can be suppressed with the anticounter system.

3.2. Calorimeter

The sampling calorimeter [10] is made from 44 planes (24×24 cm^2) of single-sided silicon sensors interleaved with 22 layers of tungsten absorbers. The strips in the silicon are arranged in a Si-x/W/Si-y fashion to allow topological shower reconstruction. The total depth of the calorimeter is therefore 16.3 X_0 (0.6 λ). The performance of the calorimeter has been extensively studied with simulations tuned with data from earlier balloon flights of a similar calorimeter and more recent testbeam studies at CERN of PAMELA prototypes. For example, figure 7 shows data taken at the SpS at a momentum of 100 GeV/c with only 5 views of the calorimeter equipped. Despite this incomplete set up, a clean division can still be drawn between electrons and pions. Figure 8 shows that an energy resolution of 5.5% across the range 20 GeV - 200 GeV is achieved (filled symbols). Furthermore, a rejection factor of 10^4 for protons and electrons (at 95% selection efficiency) in antiproton and positron measurements has been demonstrated. A novel feature of the calorimeter is the self-trigger mode. This hardware feature allows the stand-alone registration of electrons up to an energy of 2 TeV with an acceptance of 470 cm^2sr. The simulated self-triggering efficiency for electrons with an energy greater than 300 GeV exceeds 99%. As shown in figure 8 (open symbols), an energy resolution of approximately 12% is possible between 200 GeV and 700 GeV. At 1 TeV, the energy resolution climbs to approximately 16% - a simple consequence of incomplete shower containment.

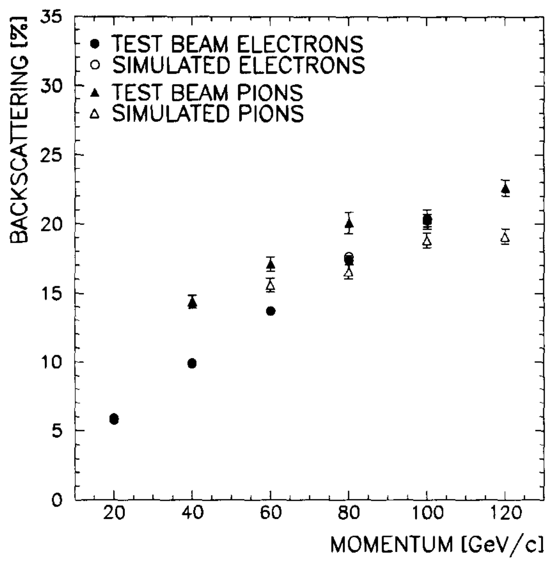

Figure 6. The fraction of particles backscattered from the calorimeter for different test beam momenta. Data points and simulation results for both electron and pion beams are shown.

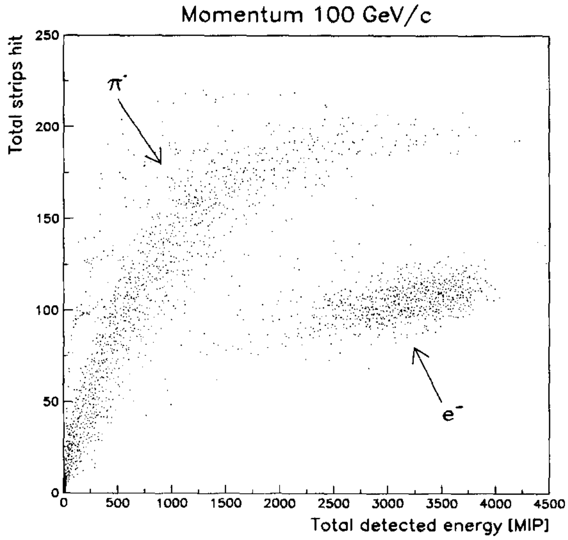

Figure 7. The electron-pion separation at a momentum of 100 GeV/c in a testbeam version of the PAMELA calorimeter. The vertical axis indicates the total number of silicon strips activated in the calorimeter.

3.3. Silicon Tracker

The magnetic spectrometer or 'tracker' [11] consists of 5 modules of Nd-B-Fe alloy interleaved with 6 planes of 300 μm thick doubled-sided silicon detectors. The tracking cavity is 445 mm tall and has a cross-section of 131×161 mm^2, defining the overall acceptance of PAMELA to be 20.5 cm^{2}sr. The mean bending field inside the tracking cavity is 0.4 T. In the bending view, the implantation pitch is 25 μm and the read-out pitch is 50 μm. Capacitive coupling between adjacent strips is used to improve the spatial resolution. Using testbeam data, the spatial resolution in the bending view has been measured as (3.0±0.1) μm as shown in figure 9. The spatial resolution in the non-bending view is (11.5±0.6) μm. The bending view resolution implies a maximum detectable rigidity of 740 GV/c. In practice, simulations have shown that 'spillover' effects will limit the maximum detectable antiproton (positron) momentum to ~200 GeV/c (~300 GeV/c). Each tracker plane contains 6144 electronic channels. In order to give a manageable read-out time, data from the tracker planes are compressed using a Zero Order Predictor ('ZOP') algorithm. The compression factor is estimated at 95% per plane. Since the algorithm is non-reversible it is important to verify that there is no effect on the detector performance. Figures 10 and 11 show the signal to noise ratio and spatial resolution for detectors in the bending view, respectively, derived from compressed and non-compressed data. In both cases, there are no significant differences between the compressed and non-compressed distributions.

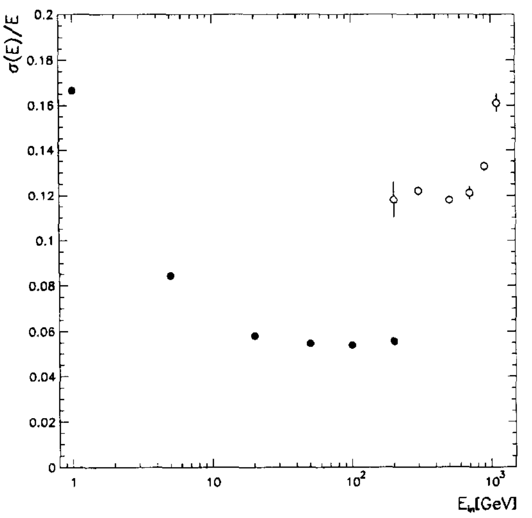

Figure 8. The energy dependence of the energy resolution of the electromagnetic calorimeter. The filled symbols are for normal operation and the open symbols are for the self-trigger mode.

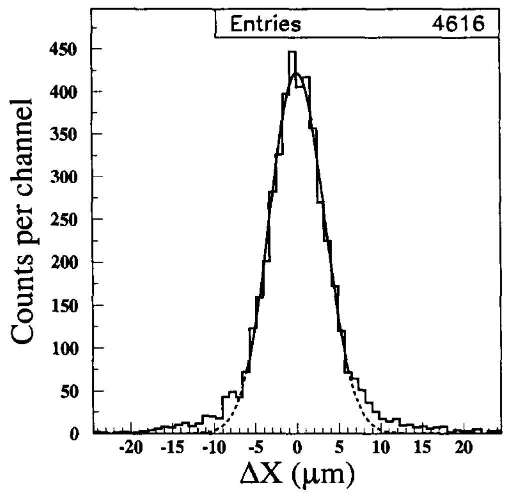

Figure 9. The spatial resolution of the tracker in the bending view.

3.4. Time-of-Flight

The time-of-flight system is made up from 3 planes of scintillator detectors. The first plane is located above the TRD, the second plane between the TRD and the tracker and the final plane beneath the tracker. Each detection layer actually consists of two independent and segmented layers of plastic scintillator for redundancy. The accuracy for time-of-flight measurements is demonstrated by the width of the distribution shown in figure 12. The difference in impact point (subsequently converted to a time) reconstructed by the time-of-flight layer is compared to the position derived from an external drift chamber. With no timewalk correction applied, the timing resolution is 109 ps [3]. This can be compared to a flight time of 2.7 ns (3.7 ns) for a 1 GeV/c electron (proton). A stand-alone separation between (anti-) protons and (positrons) electrons using time-of-flight information is expected up to 1.5 GeV.

[3]The application of a timewalk correction is expected to improve the time resolution by approximately 10%.

4. DATA ACQUISITION SYSTEM AND DATA DOWNLINK

Each PAMELA subdetector has its own data acquisition board which is read out through redundant data links by the central DAQ processor. Here, the subdetector data are packed for storage in the Resurs hard-disk array prior to downlinking to earth. Two downlink stations are currently foreseen for PAMELA: one near Moscow (where there is also a command uplink) and one in the south of Sweden.

5. OVERALL STATUS

During 2000 and 2001, engineering models of the PAMELA subdetectors were qualified during vibration, thermal, irradiation, testbeam and laboratory studies. Integration of the flight

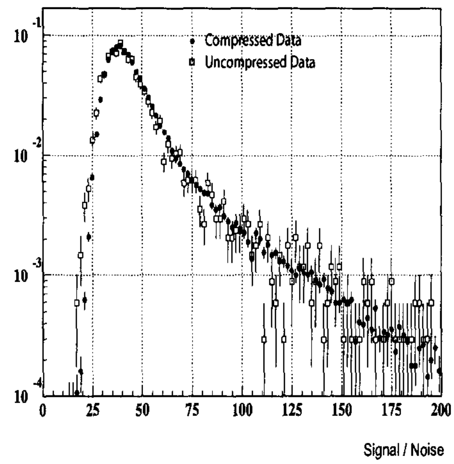

Figure 10. The signal to noise ratio for bending view tracker detectors derived from raw data (open symbols) and compressed data (closed symbols).

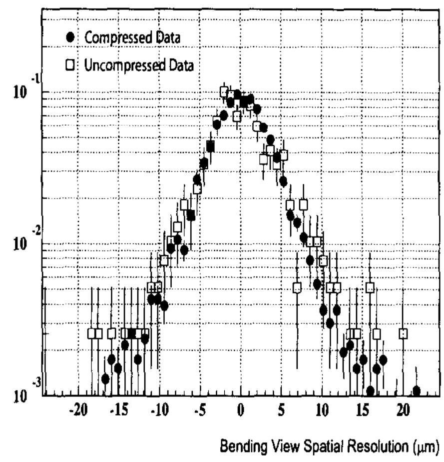

Figure 11. The tracker spatial resolution in the bending view derived from raw data (open symbols) and compressed data (closed symbols).

model versions of all subdetectors is now underway. A preliminary integrated flight model set-up consisting of the tracker and anticounter systems and calorimeter was exposed to protons (200 GeV - 300 GeV) and electrons (40 GeV - 300 GeV) at the CERN SpS in June 2002. A stand-alone version of the TRD was also tested. Further testbeam studies of a completely integrated PAMELA are planned for later in the year. PAMELA will be shipped to the TsSKB-Progress factory in Samara, Russia for integration with the Resurs DK1 satellite towards the end of this year. Once integration tests are complete and the functionality of PAMELA is verified, the satellite will be moved to the Baikonur launch site (Kazakhstan) for launch preparations. The launch is scheduled for mid-2003.

6. CONCLUSIONS

PAMELA will start to make precision measurements of antimatter in the cosmic radiation, soon after launch in mid-2003. The performance of the subdetectors has been rigorously checked with simulations and particle beams during the last few years and the expected performance is confirmed.

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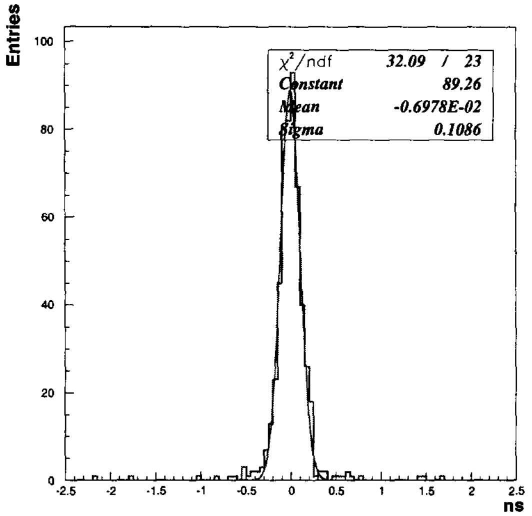

Figure 12. The difference in impact point reconstructed by the time-of-flight paddle compared to the position derived from an external drift chamber.

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Particle	Number (3 years)	Energy Range
p	3×10^8	80 MeV - 700 GeV
$\bar{p}$	$>3\times10^4$	80 MeV - 190 GeV
e^-	6×10^6	50 MeV - 2TeV
e^+	$>3\times10^5$	50 MeV - 270 GeV
He	4×10^7	80 MeV/n - 700 GeV/n
Be	4×10^4	80 MeV/n - 700 GeV/n
C	5×10^5	80 MeV/n - 700 GeV/n
$\bar{He}$ limit (90% C.L.)	7×10^{-8}	80 MeV/n - 30 GeV/n

Table 1: Expected particle samples after a three year PAMELA mission.