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Space Experiments with Silicon Strip Detectors*

E. do Couto e Silva

Stanford Linear Accelerator Center, 2575 Sand Hill Rd., Menlo Park, CA, 94025, USA

Abstract

This paper briefly describes some of the scientific goals of the experiments using silicon strip detectors in space and highlights interesting features of their silicon detectors.

1 Introduction

The new generation of experiments in space benefits from the developments in the High Energy Physics (HEP) community. The lifetime of space missions can be increased by replacing gaseous detectors with silicon strip detectors. In addition, deadtimes can be reduced from ms to μs allowing a better study of astronomical sources with transient behavior. Silicon detectors became a robust and mature technology and in the last 10 years their cost has gone down by a factor of 10. Therefore, large area detectors are currently being considered for space applications.

Figure 1 summarizes the area of silicon used for different experiments. From this figure one also sees that space experiments such as AMS and GLAST are of comparable size to the LHC experiments.

The purpose of this paper is to summarize the experiments in space that use or plan to use silicon strip detectors (see Table 1). We will highlight the interesting aspects of their silicon detectors and also provide an overview of their scientific goals.

Since this conference focuses on High Energy Physics experiments, we feel appropriate to start with a brief overview on the requirements for space applications. After that we describe the experiments according to the primary objects of their scientific goals, namely, gamma-rays, radiation induced effects, antimatter and cosmic rays.

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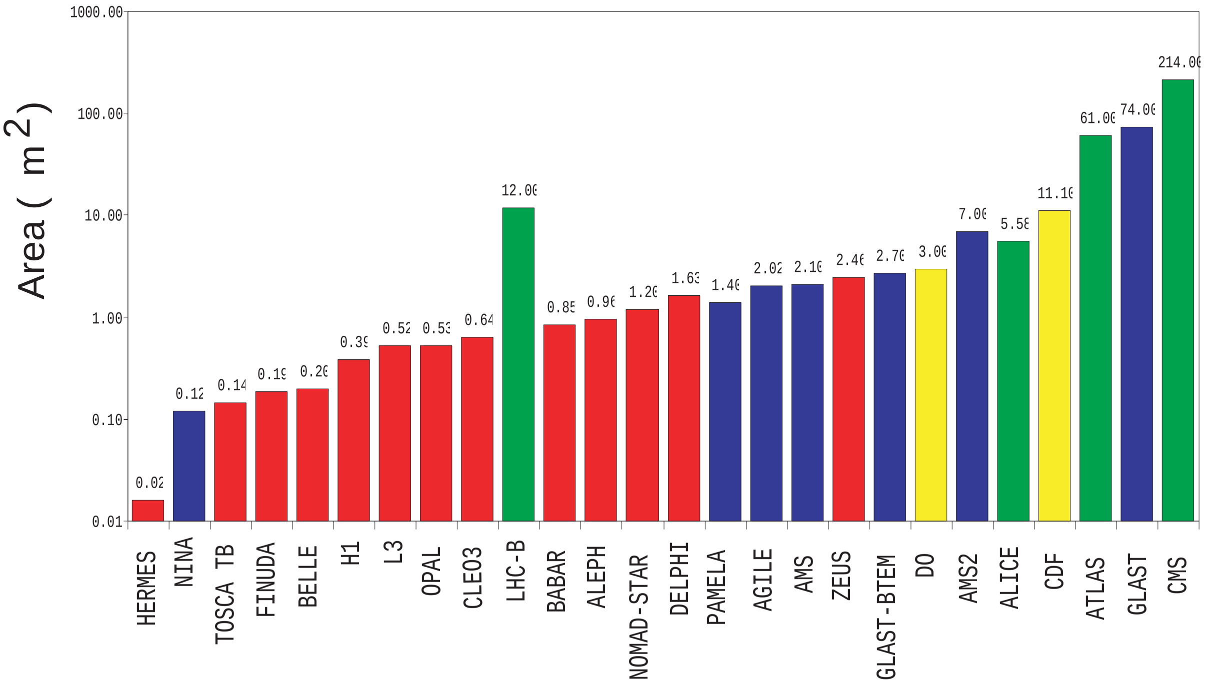

Figure 1: Area for most of the experiments using silicon strip detectors.

2 Requirements in Space

One of the limitations for space experiments is the amount of power available from solar panels or batteries. This constrains the total number of readout channels in the system and pushes the power used by the readout electronics to be as low as possible (hundreds of μW/channel). The power budget also limits the number of cycles allowed for computer operations for the on-board software. Therefore Digital Signal Processors (DSP) commonly used for coherent noise subtraction may not always be a viable option. Radiation damage on silicon detectors or on readout chips is not a concern as it is in the Tevatron or in the LHC environments. For instance, typical radiation levels expected for 5 years of GLAST operation is about 10 krads. However particle rates can saturate the electronics in a region known as the South Atlantic Anomaly (SAA). Because the center and the poles of the Earth and its magnetic field are not aligned, off the coast of Brazil there is a factor of 20 to 30 higher flux of low energy protons than that observed at the equator. Ideally one should always launch from the equator to reduce backgrounds. Nevertheless there are experiments (e.g. NINA) interested in studying the composition of the cosmic ray spectra at the SAA. Additional difficulty is imposed by the required redundancy schemes in the detector layout to ensure reliability in space. Critical power and control lines may have to be duplicated. Launch requirements dictate the need for vibration tests. Wirebonds are not usually damaged by vibrations, but their encapsulation may be needed to prevent conductive material floating in the detector volume from short circuiting the electronics. Thermal excursions are also a concern due to difficulties from heat dissipation in vacuum.

Experiment	Launch Date	Expected Lifetime (yr)
Si-eye1	1995	2
Si-eye2	1997	2
NINA1 (A New Instrument for Nuclear Analysis)	1998	3
AMS1 (Alpha Magnetic Spectrometer)	1998	STS-91 flight
NINA2	2000	3
ALTEA (Anomalous Long Term Effects in Astronauts)	2000	3
PAMELA	2002	> 3
AGILE(Astro-rivelatore Gamma ad Immagini LEggero)	2002	3
AMS2	2003	3
GLAST (Gamma-ray Large Area Space Telescope)	2005	> 5

Table 1: Status of present and future silicon strip detectors in space. During the space shuttle flight (STS-91) AMS1 collected about 135 hours of data.

Usually space experiments build one or more engineering models to test the functionality and the technology choices before the final instrument is built. The difference from the prototyping phase in HEP is that for space applications, whenever possible, the engineering models are flown in a balloon or sent into space.

Table 2 describes some of the features of the space experiments using silicon detectors. BTEM corresponds to the GLAST Beam Test Engineering Model, which will go through some modifications for a balloon flight in 2001. AMS, NINA and Si-eye were designed in two versions. AMS1 is the engineering model flown into the space shuttle and Si-eye 1 and NINA1 were the engineering models aboard the MIR space station.

3 Gamma Rays

Since gamma–rays of < 100 GeV are very difficult to be observed in the ground, detectors have to be placed into balloons or satellites. For higher energy gammas (order of > 100 GeV), showers of particles produced in the atmosphere can be detected via Cerenkov radiation by large detector arrays on the ground. Gamma ray astronomy started in the 60's and the first all–sky survey above 50 MeV was performed in the 90's by the CGRO–EGRET instrument [6]. Among the near 300 sources of gamma-rays discovered by EGRET, about 170 have not yet been associated with known astrophysical objects. The understanding of the diffuse and extragalactic emission remain open questions. When one compares the sources detected by EGRET in the energy range from 100 MeV to 30 GeV with that from high energy gamma-ray emissions (TeV) measured by Cerenkov detectors one finds a discrepancy. The number of sources found by ground based detectors is less than expected if one assumes that the flux of gamma rays decreases as $\frac{1}{E^2}$. Some cosmological arguments may be invoked to solve the problem. Future studies on gamma-ray emissions from active galactic nuclei will shed light into this question. GLAST in particular will provide substantial energy overlap with ground–based gamma–ray telescopes to explore together a greatly expanded dynamic

	GLAST		AMS		PAMELA	AGILE	NINA	Si-eye
	Flight	BTEM	2	1				
detectors	9216	550	2286	778	36 (198)	224	32	6
ladders	2304	130	192	62	18 (66)		32	6
readout channels	737280	41600	196608	63488	18432 (4416)	92160	512	96
readout pitch (μm)	238	194	110,208	110,208	50	242		
strip pitch (μm)	238	194	27.5,26	27.5,26	25,67	121		
strip width (mm)					(2.4)		2.6	3.6
technology	SS	SS	DS	DS	DS	SS	SS	SS
wafer size (inch)	6	4,6	6	4	4 and 6	4	4	4
area (m^2)	74	2.7	7.0	2.1	1.65	2.02	0.42	0.02

Table 2: Summary of present and future strip detectors in Space. BTEM corresponds to the Beam Test Engineering Model for GLAST. The row labelled as *strip width (mm)* is only filled for detectors with mm wide strips and for theses cases every strip is read out, SS = single sided and DS = double sided. The values in parenthesis in the PAMELA column correspond to the silicon detectors used in the imaging calorimeter. Values separated by commas correspond to the pitch on the p and n side, respectively.

range compared to EGRET with well–matched capabilities. Many astrophysical objects have luminosities that vary over periods of seconds to days, e.g. gamma-ray bursts, active galactic nuclei. To understand the mechanism of emission of these objects it is therefore crucial to correlate observations at different wavelengths.

3.1 Detectors

GLAST and AGILE are pair conversion telescopes. After photons are converted in a passive material the silicon strip detectors are used to track their original directions by reconstructing the electron and positron tracks and by measuring their corresponding energy with a calorimeter. Charged particle backgrounds are the order of 10^5 to 10^6 higher than the weakest gamma ray signal and detectors are usually surrounded by veto counters (e.g. scintillators). The tracker usually involves many planes (> 15)and there is no need for small strip pitches (see Table 2), typical values range from 100 to 250 μm. Both trackers employ self–triggering electronics. GLAST with the total number of channels of almost a factor of 10 greater that of AGILE requires very low power electronics ($\simeq 200$ μW/channel). GLAST has shown that single sided 6–inch technology is becoming more reliable with dead channel rates well below the 1% level (single sided) commonly required in HEP applications [1]. In addition, leakage currents of the order of < 10 nA/cm^2 are easily achieved [1]. AGILE incorporates additional silicon layers on the top of the detector. These are instrumented with the XA family of readout chips to allow detection of X–rays [7] at the expense of more material in front of the telescope. The silicon detectors used for AGILE are the largest to date from a single wafer(9.5×9.5 cm^2).

AMS2 is not designed to be a gamma-ray detector, rather a spectrometer with a permanent (or superconducting) magnet to be placed on the International Space Station (ISS) to search for antimatter. The AMS collaboration is currently investigating the possibility of adding converter foils or using the material in front of the detector as a passive element for gamma-ray conversions [8]. The main difficulty is to ensure that the charged particles from photon conversions does not increase the background to $\bar{\mathrm{He}}/\mathrm{He}$ searches whose target sensitivity is the order of 10^{-9}.

4 Radiation Induced Effects

Since the Apollo missions, astronauts have been experiencing brief flashes of light after a period of dark adaptation [9]. This effect has been predicted long before these flights and could be due to ionizing radiation [10]. In addition, fast heavy ions can cause higher tissue damages than protons and electrons releasing the same amount of energy. Therefore monitoring of the radiation environment inside space stations is important for the astronaut's safety. A comprehensive review on radiobiological experiments in space is given in [11].

4.1 Detectors

Two experiments aboard the space station MIR used silicon strips to study light flashes (Si-eye 1 and Si-eye 2 [16]) while an improved version is being planned for the International Space Station (ALTEA [17]).

All experiments rely on the same detection technique, a special hat is made with silicon planes that are placed in front (and sometimes on the sides) of the astronaut's head (as close as possible to the eyes). Three silicon detector planes[†] are used to measure the direction of the incoming particles. Si-eye2 has Fe absorbers in between silicon planes so that energy losses could be measured in the range of 40 to 200 MeV/n. An adjustable trigger is provided by requiring an excess of charge above a certain threshold in any given plane and by an electrical response from a joystick button (or PC keyboard) that is pressed when the astronaut sees a light flash. One of the important systematic uncertainties is the astronaut's response ($\simeq$ 300 ms), which can vary significantly if the astronaut is tired.

The ALTEA experiment is designed to enhance the capabilities of the Si-eye experiments by correlating light flashes with brain activities. To this end an electroencephalograph is coupled to the design. The detector design also involves 18 single sided detectors glued back to back to provide simultaneous measurements of two spatial coordinates. These planes will be placed in front of the astronaut's eye (3), in the temporal (3) and occipital(3) regions. Despite being of small scale, the Si-eye and ALTEA experiments still push the technology towards high resistivity substrates. To reduce the bias voltage needed for operation these (will) use resistivities from 4 to 16 kΩ/cm, which are slightly higher than those normally used for HEP detectors.

Results from both Si-eye experiments indicated that protons may be ruled out as a most probable cause for light flashes. In order to verify whether heavy nuclei are responsible

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[†] Each plane corresponds to one view in x and one view in y.

for that one awaits more statistics. First data from Si-eye2 have shown that the measured abundance ratio of nuclei to protons as a function of the atomic number (Z) of the nuclei is different from the expected cosmic ray distribution. This can be ascribed to the abundance of recoil nuclei from the body of the Space Station. NINA was located in a satellite surrounded by a 3 mm thick Al container, while Si-eye2 is inside the MIR space station. Comparison of both data indicates an increase of nuclei below Nitrogen due to interactions with the hull of the Space Station.

5 Cosmic Rays and Antimatter

Satellite experiments are more appropriate for antimatter studies in cosmic ray because the residual Earth's atmosphere and the short duration of balloon flights limit the measurement of cosmic ray spectra to energies of about few tens of GeV‡. Because of that, the flux of antiprotons as a function of their kinetic energy is statistics limited. Balloon flight data indicates that the number of antiprotons in the kinetic energy range from 5 to 15 GeV is higher than that predicted by interactions of cosmic rays (CR) with the interstellar medium (ISM) [12]. Secondary production from CR/ISM interactions are kinematically limited to rigidities less than 1 GV/c. In addition, this limit is the only strong energy dependent process in CR. These are both part of the scientific goals of PAMELA.

Cosmic rays in the energy range from 10-100 MeV/n can be classified as Galactic (GCR), Anomalous (ACR) and Solar (SCR). Studies of their nuclear component including effects due to solar activity are of paramount importance. Solar modulation of cosmic ray flux that follows the 11 yr period of solar maxima can also be monitored by PAMELA and NINA.

According to the Big Bang Theory, antinuclei heavier than Helium can only be produced by nucleosynthesis processes in antimatter stars. Therefore detecting the abundance of antimatter is important to understand matter dominance in our present universe. PAMELA and AMS will be able to search for antimatter, while the latter with higher sensitivity and over a large range of rigidities. Their increased sensitivity for measuring the cosmic antimatter flux , has led to focus on searches for cosmic antiprotons as a signature for dark matter via neutralino annihilation in the galactic halo [18].

5.1 Detectors

Most of the experiments using silicon strip detectors to study cosmic rays and antimatter are satellite–borne (NINA1 and NINA2, PAMELA, AMS1) while AMS2 is designed for the International Space Station.

The NINA detectors consist of 16 planes of silicon stacked in a tower configuration. Contrary to GLAST or AGILE they are not interleaved with passive absorbers. They were designed to study the anomalous, galactic and solar components of cosmic rays at low energy (10 to 200 MeV/n) and measured charge of cosmic ray particles and isotopes up to oxygen via dE/dx. The main difference between NINA1 and NINA2 is that the former has a

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‡ Note that flux of particles decreases as $\frac{1}{E^2}$.

transmission bandwidth that is only 20% of latter. An interesting approach used by the NINA experiments is to use the lateral strips of silicon detectors as anticoincidence counters. To understand mechanisms of emission and acceleration in the sun, one wants to study solar energetic particles and their interaction with the ISM.

PAMELA is a magnetic spectrometer to study the antimatter component of cosmic rays. It consists of 6 planes of double sided silicon read out by VA1 chips and an imaging calorimeter with 22 planes of silicon with custom designed electronics, since the dynamic range of the VA1 is not adequate. The PAMELA experiment will study the spectra (0.1 to 100 GeV) of electrons, protons and their corresponding antiparticles (galactic and extragalactic) and search for antihelium with a sensitivity of the order of 10^{-7}, which is better by 2 orders of magnitude than that of balloon experiments. Its orbit is also adequate to study low energy cosmic rays because the satellite spends most of the time at higher latitudes and polar regions where the cut-off due to the Earth's magnetic field is very small. These cosmic rays (50 MeV e± and 80 MeV $\bar{p}$) are not easily accessible by the AMS experiments.

The AMS experiment is a magnetic spectrometer and has been described in these proceedings [3]. AMS2 will reach unprecedented sensitivities (2 order of magnitude better than that of PAMELA) in the search for antimatter in cosmic rays. It will also search for dark matter by doing precision measurements of photons, positrons, electrons and antiprotons. AMS2 will perform precision measurements of light elements to understand propagation and confinement of galactic CR. Despite the complexity of double sided trackers (e.g CDF, D0 [2]), it is worthwhile to note that double sided detectors are considered an option for AMS [3]. Nevertheless, one should note that dead channel rates for double sided detectors after assembly are usually greater than 3% [3, 4].

6 Summary

We have described experiments using silicon strip detectors according to the primary objects of their scientific goals, namely, gamma-rays, radiation induced effects, antimatter and cosmic rays.

The High Energy Astrophysics community has benefited from the developments of the High Energy Physics detectors. Silicon detectors a are mature, reliable and robust technology. They can replace gaseous detectors and increase lifetime of missions in space and reduce the deadtime of detectors. Recent developments on 6 inch technology with very low leakage current and a factor of 10 reduction in price in the last 10 years has favored the integration of large scale silicon strip experiments. Since typical contingencies for single sided is about 10% while for double sided can be as high as 30% [3], we feel that only in cases where the physics can not be done with single sided (AMS), shall double sided be considered.

The interplay between HEA and HEP communities will increase, especially with the construction of the LHC detectors, AMS and GLAST. These and other technological developments will certainly improve our powerful tools to continue probing fundamental physics.

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