Search for anomalous Z/A particles in cosmic radiation with Pamela experiment

M. Casolino*, **C. De Santis***, **N. De Simone***, **F. Guescini***, **N. Nikonov***, **P. Picozza***,
on behalf of the PAMELA collaboration
corr author: casolino@roma2.infn.it
* *INFN and physics Department of University of Rome "Tor Vergata" Italy*

***Abstract*. In this work we will describe the search for particles with anomalous Charge / Mass (Z/A) ratio with Pamela experiment. Pamela is a multi-purpose device composed of a permanent magnet spectrometer to provide particle charge, rigidity (with 10% resolution) and incoming angle information. A series of six segmented scintillator counters arranged at its extremities provides redundant Time-of-Flight and charge information. Lepton/hadron identification is performed by a Silicon-Tungsten calorimeter and a Neutron detector placed at the bottom of the device. The redundant nature of the detector makes it particularly suited to search for heavy mass, light charge particles. These kind of events would look as a slow particle (with low speed from the Time of Flight) and high rigidity in the tracker. We will discuss the analysis technique and future perspectives.**

***Keywords*: Cosmic Ray, Strangelets, Strange QUark matter**

I. INTRODUCTION

We discuss the observational capabilities of PAMELA experiment to look for particles with anomalous charge / mass (Z/A) ratio in cosmic rays. PAMELA consists of a Time of flight, magnetic spectrometer and silicon tungsten calorimeter used to precisely measure the particle and antiparticle component in cosmic rays. Detector redundancy and independent measurement makes PAMELA especially suited to search for up-to-now unobserved particles such as antihelium or exotic matter such as strangelets. In this work we describe the apparatus and its observational capabilities for these searches.

II. STRANGE QUARK MATTER

It has been speculated that quark matter could exist in stable or meta-stable form in cosmic rays. These objects - often named strangelets for their hypothesized strange quark content - could be produced in the Big Bang or more probably be ejected in the stellar collapse, producing quark stars. Several papers have studied the conditions required to have stability for these objects: most of them use the MIT bag model approximation, resulting in heavier objects being more stable. Other calculations take into account shell models[1]. In the current models these particles would not be bounded in A number, ranging from the mass of an hypothetical quark star to chunks of quark matter of $A \sim 10^7$. The negative charges of the strange and down quark can cancel out the positive charge of the up quark producing neutral (if $N_u = N_d = N_s$) or slightly charged nuclei in case of a small excess of u or d quarks. If this model is correct, these particles would have a very high value of A and a low value of Z. Under the additional hypothesis of Colour Flavor Locking, where couples of quarks are joined in Cooper pairs with $\simeq 100MeV$ binding energy, the following relation would apply:

$$Z \approx 0.3 m_{s150}^2 A^{2/3} \quad (1)$$

If CFL is not present the relation would be

$$Z \approx 0.1 m_{s150}^2 A \quad A \ll 10^3 \quad (2)$$

$$Z \approx 8 m_{s150}^2 A^{1/3} \quad A \gg 10^3 \quad (3)$$

See, for instance, [2] and [3] for a review on strangelet search and models.

III. EXPERIMENTAL EVIDENCE

Several experiments have looked for strange quark matter using accelerators (with heavy ion beams) and from space. A particle with an equal number of u, d and s quarks would be electrically neutral, with a low electric charge due a slight excess of u and d quarks, which would tend to fill the Fermi levels before the s quarks due to their lighter mass. Cosmic ray experiments have thus looked for heavy particles with small electric charge. The balloon experiment HECRO-81 has reported the observation of two events with $Z \sim 14$ wich would be below the local magnetic cutoff under the hypothesis of a normal nucleus with rigidity corresponding to the measured speed. The corresponding mass for this events was estimated[4] to be $A \sim 350$. More recently, searches with BESS balloon spectrometer have yielded no candidates for $5 \leq Z \leq 26$ for $Z/A < 0.2$. AMS-01 has reported the observation of one $Z = 2$ $A = 18$ event[5]. A different analysis of AMS data[3], finds two events: $Z = 2, A = 33.00, 13.35GV$ and $Z = 2, A = 64.83, 31.68GV$. The same reference reports of an unpublished analysis giving two events: $Z = 8, A = 20, 3.93GV$ and $Z = 4, A = 50, 5.13GV$. There are no common candidates to the various AMS analysis, even though the methods where sligtly different.

IV. PAMELA DETECTOR

The device is constituted by a number of highly redundant detectors capable of identifying particles providing charge, mass, rigidity and beta over a very wide energy range. A more detailed description of the device and the data handling can be found in [6], [7], [8]. The instrument is built around a permanent magnet with a silicon microstrip tracker, providing charge and track deflection information. A scintillator system provides trigger, time of flight and additional charge information. A silicon-tungsten calorimeter is used to perform hadron/lepton separation in the measurement of antimatter component. A shower tail catcher and a neutron detector at the bottom of the apparatus increase this separation. In this analysis, given the dominant proton flux in cosmic rays, it was not necessary to use information from these subsystems. An anticounter system is used to reject spurious events in the off-line phase. Around the detectors are housed the readout electronics, the interfaces with the CPU and all primary and secondary power supplies. All systems (power supply, readout boards etc.) are redundant with the exception of the CPU which is more tolerant to failures. The system is enclosed in a pressurized container located on one side of the Resurs-DK1 satellite. Total weight of PAMELA is 470 kg; power consumption is 355 W, geometrical factor is 21.6 $cm^2 sr$.

A. Scintillator / Time of Flight

The scintillator system [9] provides trigger for the particles and time of flight information for incoming particles below $\simeq 2GeV/n$, rejecting particles coming from the bottom of the detector. There are three scintillators layers, each composed by two orthogonal planes divided in various bars (8 for S11, 6 for S12, 2 for S21 and S22 and 3 for S32 and S33) for a total of 6 planes and 48 phototubes (each bar is read by two phototubes). S1 and S3 bars are 7 mm thick and S2 bars are 5 mm. Interplanar distance between S1-S3 of 77.3 cm results in a TOF determination of 250 ps precision for protons and 70 ps for C nuclei (determined with beam tests in GSI), allowing separation of electrons from antiprotons up to $\simeq$ 1 GeV and albedo rejection. The scintillator system is also capable of providing charge information up to $Z = 8$.

B. Magnetic Spectrometer

The permanent magnet [10] is composed of 5 blocks, each divided in 12 segments of Nd-Fe-B alloy with a residual magnetization of 1.3 T arranged to provide an almost uniform magnetic field along the y direction. The size of the cavity is $13.1 \times 16.1 \times 44.5\ cm^3$, with a mean magnetic field of 0.43 T. Six layers of 300 μm thick double-sided microstrip silicon detectors are used to measure particle deflection with $3.0 \pm 0.1 \mu m$ and $11.5 \pm 0.6\ \mu m$ precision in the bending and non-bending views. Each layer is made by three ladders, each composed by two $5.33 \times 7.00\, cm^2$ sensors coupled to a VA1 front-end hybrid circuit. Maximum Detectable Rigidity (MDR) was measured on CERN proton beam to be $\simeq 1\, TV$.

C. Silicon Tungsten Calorimeter, tail scintillator,Neutron detector

Lepton/Hadron discrimination is performed by the Silicon Tungsten sampling calorimeter [11] located on the bottom of PAMELA in the measurement of the antiparticle component. It is composed of 44 silicon layers interleaved by 22 0.26 cm thick Tungsten plates. Each silicon layer is composed arranging 3×3 wafers, each of $80 \times 80 \times .380\, mm^3$ and segmented in 32 strips, for a total of 96 strips/plane. 22 planes are used for the X view and 22 for the Y view in order to provide topological and energetic information of the shower development in the calorimeter. Tungsten was chosen in order to maximize electromagnetic radiation lengths (16.3 X_o) minimizing hadronic interaction length (0.6 λ). The CR1.4P ASIC chip is used for front end electronics, providing a dynamic range of 1200 mips (minimum ionizing particles). Below the calorimeter is located a shower tail scintillator ($1 \times 48 \times 48\, cm^3$) and a neutron detector (ND). The ND is used to improve lepton/hadron identification by detecting the number of neutrons produced in the hadronic and electromagnetic cascades.

D. Anticoincidence System

To reject spurious triggers due to interaction with the main body of the satellite, PAMELA is shielded by a number of scintillators used with anticoincidence functions [12]. CARD anticoincidence system is composed of four 8 mm thick scintillators located in the area between S1 and S2. CAT scintillator is placed on top of the magnet: it is composed by a single piece with a central hole where the magnet cavity is located and read out by 8 phototubes. Four scintillators, arranged on the sides of the magnet, make the CAS lateral anticoincidence system.

V. PAMELA PARAMETER SEARCH FOR ANOMALOUS Z/A NUCLEI

As seen in the previous section, for an incoming particle of mass $m_p A$ (m_p proton mass) PAMELA is capable to measure charge Z, beta (β and rigidity R of the incoming particles. We have:

$$\frac{m_p \cdot A \cdot \beta}{\sqrt{1-\beta^2}} = Z \cdot R \qquad (4)$$

and therefore:

$$\frac{Z}{A} = \frac{m_p \cdot \beta\gamma}{R} \qquad (5)$$

stable nuclei have values of $0.33 < Z/A \leq 1$, with average value of Z/A=0.5, corresponding to an equal number of protons and neutrons. Unstable nuclei -which can be produced in hadronic interactions in the detector - can have a lower ratio, for instance ^8He, with a decay

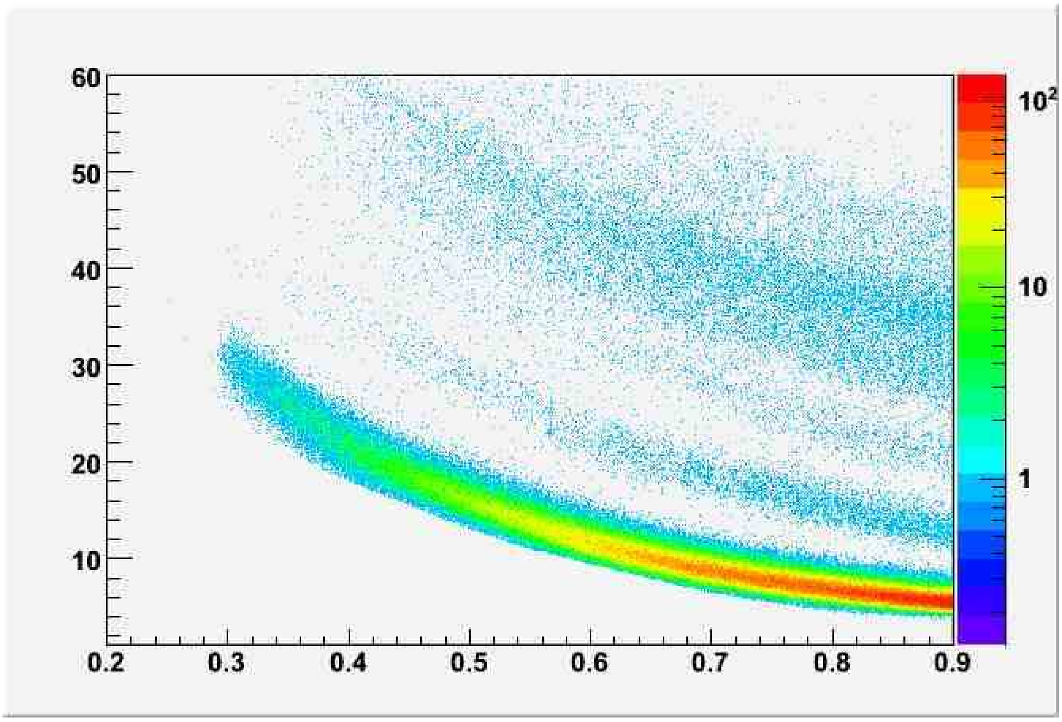

Fig. 1: Energy loss in the tracker (MIP) planes vs beta of the particle for nuclei with $Z > 2$. The various bands correspond - from bottom to top - to nuclei of He, Li, Be, B, C, N with saturation in the tracker beginning to occur around 50 MIPs.

time of 119 ms has Z/A=0.25. PAMELA would therefore look for $Z/A < 0.2$. For rigidities above 3 GV TOF signal is saturated, so an unambiguous signal for a heavy particle would be for $\beta < 0.8$, $R < 2GV$. Charge range is from $1 \leq Z \leq 8$ for Z identification and $Z < 20$ with saturation in the charge deposition.

The advantage of PAMELA is the redundancy of its measurements: for instance TOF is completely redunded, providing two independent measurements for β. In addition, multiple dE/dx measurements in the tracker and in the scintillators provide an independent check of the β of the particle, since slow particles have an higher energy loss according to the Bethe Bloch formula. Deflection is measured in the tracker with up to 6 planes in the bending view allowing different checks of the measured rigidity. An independent check comes from the energy loss measurement in the calorimeter, possibly following the particle up to its Bragg peak, and thus determining initial kinetic energy. In case of hadronic interactions this additional information is not available, but it might be possible to look for specific decay patterns.

References

[1] E. P. Gilson, R. L. Jaffe, Stability of very small strangelets, Physical Review Letters 71 (1993) 332–335.
[2] E. Finch, Strangelets: who is looking and how?, Journal of Physics G Nuclear Physics 32 (2006) 251–+.
[3] D. Baldassarri, Ricerca di strangelets nei raggi cosmici rivelati dall'esperimento AMS-01, Tesi di Laurea in Fisicca.
[4] T. Saito, Y. Hatano, Y. Fukada, H. Oda, Is there strange-quark matter in Galactic cosmic rays?, Physical Review Letters 65 (1990) 2094–2097.
[5] V. Choutko, AMS-01 Collaboration, Search for Doubly Charged Anomalously Heavy Nuclei with AMS Detector in Space, in: International Cosmic Ray Conference, Vol. 4 of International Cosmic Ray Conference, 2003, pp. 1765–+.
[6] P. Picozza, A. M. Galper, G. Castellini, et al., PAMELA - A payload for antimatter matter exploration and light-nuclei astrophysics, Astroparticle Physics 27 (2007) 296–315.
[7] M. Casolino, F. Altamura, A. Basili, M. P. de Pascale, M. Minori, M. Nagni, P. Picozza, O. Adriani, P. Papini, P. Spillantini, G. Castellini, M. Boscherini, M. Boezio, G. Alfarano, F. Sebastiani, S. Tassa, The PAMELA Storage and Control Unit, Advances in Space Research 37 (2006) 1857–1861.
[8] M. Casolino, M. P. de Pascale, M. Nagni, P. Picozza, YODA++: A proposal for a semi-automatic space mission control, Advances in Space Research 37 (2006) 1884–1888.
[9] G. Barbarino, M. Boscherini, D. Campana, W. Filrnkranz, W. Menn, M. Orazi, G. Osteria, M. Simon, E. Webera, The PAMELA time-of-flight system: status report, Nuclear Physics B Proceedings Supplements 125 (2003) 298–302.
[10] O. Adriani, L. Bonechi, M. Bongi, G. Castellini, R. D'Alessandro, A. Gabbanini, M. Grandi, P. Papini, S. B. Ricciarini, P. Spillantini, S. Straulino, F. Taccetti, M. Tesi, E. Vannuccini, The magnetic spectrometer of the PAMELA satellite experiment, Nuclear Instruments and Methods in Physics Research A 511 (2003) 72–75.
[11] M. Boezio, V. Bonvicini, E. Mocchiutti, et al., A high granularity imaging calorimeter for cosmic-ray physics, Nuclear Instruments and Methods in Physics Research A 487 (2002) 407–422.
[12] M. Pearce, P. Carlson, J. Lund, J. Lundquist, S. Orsi, Rydstroem, The Anticounter System of the PAMELA Space Experiment, in: International Cosmic Ray Conference, Vol. 4 of International Cosmic Ray Conference, 2003, pp. 2125–+.

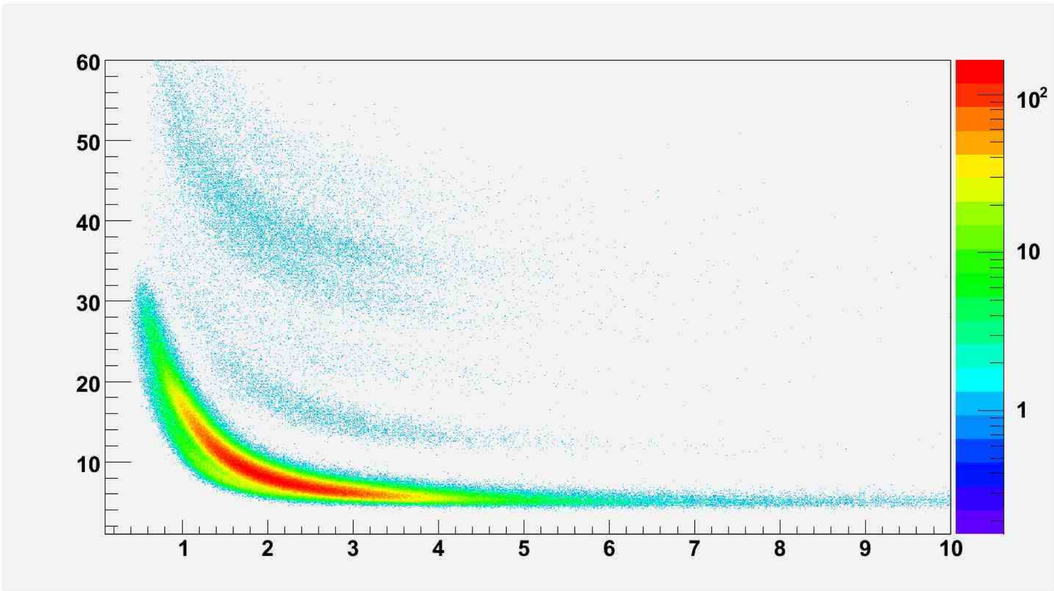

Fig. 2: Plot of energy loss in the scintillators vs rigidity R for Z¿1 nuclei in PAMELA . The bands correspond (from bottom to top) to He, Li, Be, B, CNO

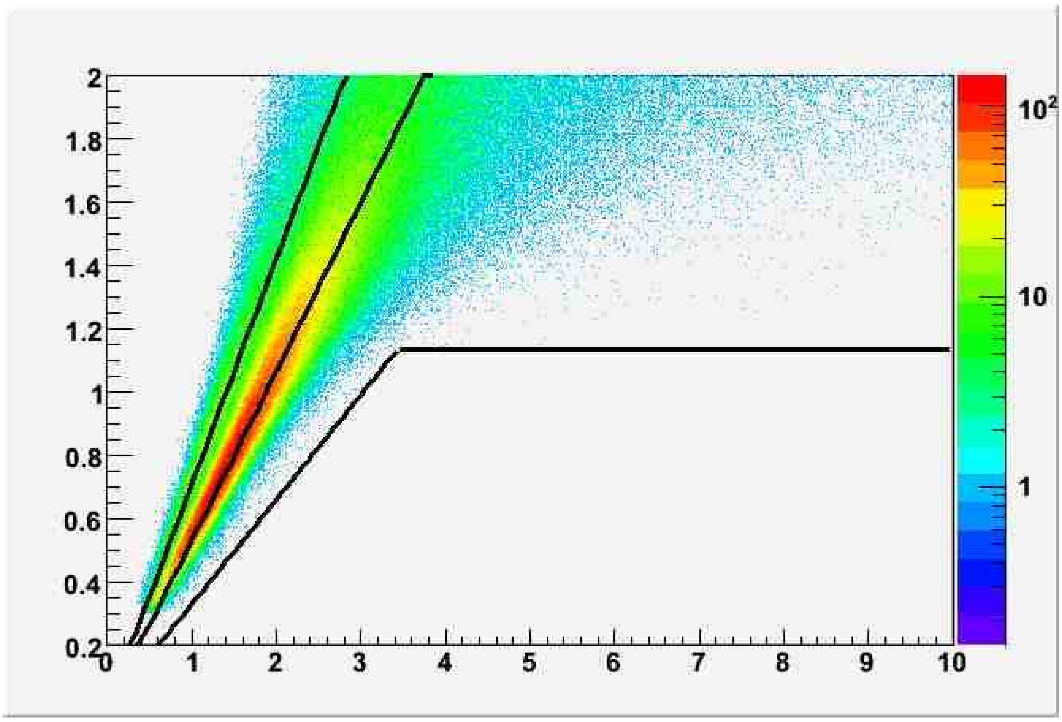

Fig. 3: Plot of $\beta\gamma$ vs rigidity R for $Z > 1$ nuclei in PAMELA . The lines correspond (from left to right) to ^3He, ^4He, $Z/A = 0.3$, $\beta = 0.75$. The search parameter space for PAMELA corresponds to the low right region ($Z/A < .3$, $\beta < 0.75$))