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Proposal for a German - Italian research program to measure charged cosmic rays with Long Duration Balloons

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Abstract. We present a research program to be implemented between the Italian Space Agency (ASI) and the German Space Agency (DLR) to launch stratospheric balloons from launch sites near the North Pole to perform high precision measurement of the cosmic radiation. The proposing groups have been working together successfully on space borne detectors during the past 10 years, in particular on the Alpha-Magnetic-Spectrometer (AMS) project, developing state of the art particle detectors for space experiments. AMS will be launched in 2010 while the smaller Pamela spectrometer is already operating in space since 2006; in order to be able first to cross-check scientific results from these space experiments and then to extend the scientific reach in certain well defined areas, we propose a program of dedicated balloon experiments, optimized for specific physics questions. We present here a list of four experiments being studied, which, in our opinion, would address most relevant questions in the field of Cosmic Rays and which would be the first to be performed on a LDB program which could last over a period of ten years. The experiments discussed in the following have become technically feasible due to recent new developments led by our groups in particle detection concepts and allow today for the design and construction of large scale light weight particle detectors with low power consumption and very high resolution at a fraction of the cost of a space mission.

Key words. Cosmic Ray: antimatter – Cosmic Ray: dark matter – Supersymmetry – Long Duration Balloons

1. Introduction

Astro-particle physics started in 1907 with the balloon measurements done by Victor Hess near Vienna. In the following 40 years almost all discoveries which gave birth to particle physics, like the muon and the positron, were done using cosmic rays, until at least 1953, when experiments at accelerators started to systematically discover new elementary particles and Cosmic Rays experiments suddenly stopped finding new particles. Indeed, in the 1950 we have started to build particle accelerators for a better understanding of the fundamental interactions between elementary particles.

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In 2008 we will switch on the LHC at CERN in Geneva and we will very likely explore new physics at the TeV energy scale. We know that new physics has to show up also from important astro-physics observations over the past 10 years.

This was the justification for the AMS (Aguilar et al. 2002) as well for the PAMELA programs (Picozza et al. 2006), timely started in 1994, and consisting in state of the art detectors to study particle physics in space. Without dedicated new experiments we will not be able to connect the new findings that we expect with cosmological observations on dark matter and dark energy. As we do not know what we will find at LHC it is important to develop a flexible platform that can be adapted fast and effectively to react to new developments in our understanding of fundamental particles and allows us also to exploit new particle detection techniques in a continuous upgrade process.

1.1. Dark matter

Among the most intriguing open questions in modern physics is the nature of the dark matter, that has been shown to contribute around 23% to the total energy density of the universe (Spergel et al. 2007). Certain models, such as super-symmetric extensions (Aitchison et al. 2005; de Austri et al. 2006) of the Standard Model of particle physics, predict a new particle, the neutralino, which has all the properties required by a dark matter candidate. It would form halos around galaxies and annihilate pairwise into known particles. There are over 20 current and planned underground experiments that hope to directly detect dark matter; however, none of them cover a large portion of the available parameter space.

Detecting annihilation signals of neutralinos in the cosmos provides an alternative way of indirect dark matter search. It takes an advantage of the fact that dark matter particles could annihilate in pairs producing a variety of indirect signals in cosmic rays such as gamma-rays, neutrinos, and anti-particles. Rare cosmic anti-particles like positrons, anti-protons and anti-deuterons are sensitive probes for new phenomena as there are no known primary sources of anti-particles in the Galaxy (Barrau et al. 2005; Donato et al. 2008; Hooper & Silk 2004; Hooper & Taylor 2006). The observation of an excess in the positron spectrum over the expected secondary flux by the HEAT (DuVernois et al. 2001; Beatty et al. 2004) and AMS-01 (Aguilar et al. 2007) experiments has sparked some excitement (see Figure 1) but it needs to be confirmed by a precise measurement.

Anti-deuterons would also provide a particularly sensitive indirect signature for supersymmetric dark matter, as first pointed out in (Donato et al. 2000). The relative astrophysical backgrounds for anti-deuteron are significantly suppressed especially in the energy region below 1 GeV/n because of the small probability of its secondary production. The search for indirect dark matter signals requires very sensitive, optimized experiments, since the expected signal from dark matter annihilation is at the level of $1/10^{10}$(see Figure 1).

1.2. Sources of high energy electrons

The direct detection of nearby electron sources by observing the energy spectrum in the TeV region is a well known, challenging goal of Cosmic Rays physics. High-energy electrons lose their energy (per unit time) in proportion to the square of their energy by synchrotron radiation in the galactic magnetic field and inverse-Compton scattering with background photons. Therefore, in the TeV region, only the electrons from sources at a distance within 1 kpc and with an age less than 10^5 years, can reach the Earth. Since the number of such possible sources should be very limited, the energy spectrum of electrons might have a characteristic structure (Nishimura et al. 1980), and the arrival directions are expected to show a detectable anisotropy (Shen & Mao 1971; Putsukin & Ormes 1995). The diffusion process in the Galaxy also significantly modulates the electron flux. The electron energy spectrum could, therefore, give direct knowledges of the nearby sources and the diffusion characteristics. Among some source candidates, Vela is

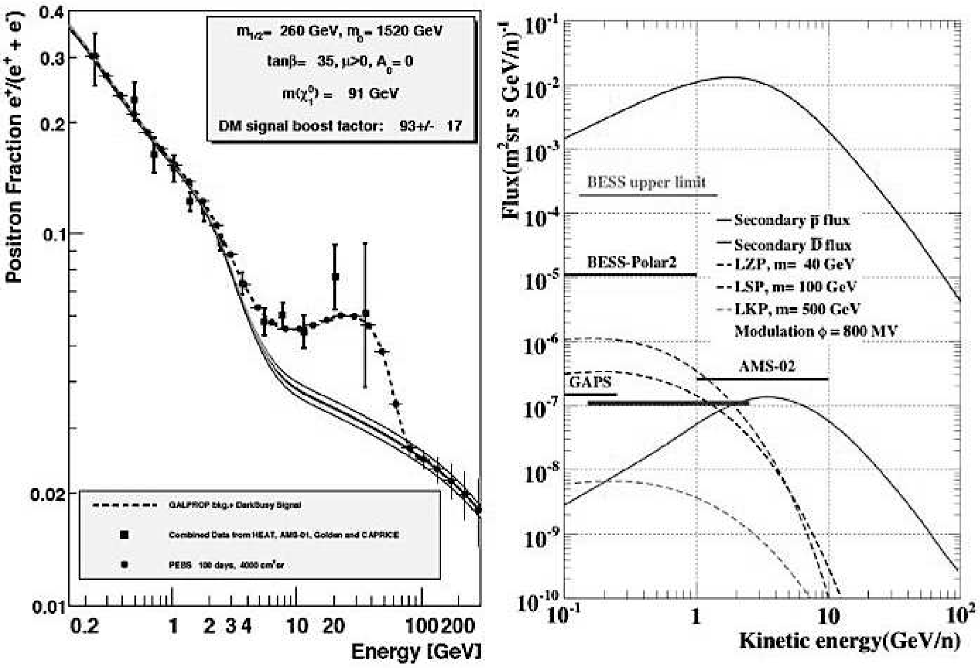


Fig. 1. (left): Combined data for the cosmic-ray positron fraction from TS93 (Goldenet al. 1994), HEAT (DuVernois et al. 2001; Beatty et al. 2004) and AMS-01 (Aguilar et al. 2007) together with the projected PEBS data (this proposal). Model predictions have been estimated using DarkSusy (Gondolo et al. 2004). The shown signal process is based on a mSugra model calculation (Djouadi et al. 2006) with neutralino dark matter. (right): Combined data for the anti-deuteron fraction from BESS (Fuke et al. 2005), BESS-Polar2 (Yoshimura 2007)) together with the predictons for AMS-02 (Aguilar et al. 2007), GAPS (Fuke et al. 2007) and the DbarSUSY (this proposal) sensitivity. Model predictions have been estimated using DarkSusy (Gondolo et al. 2004).

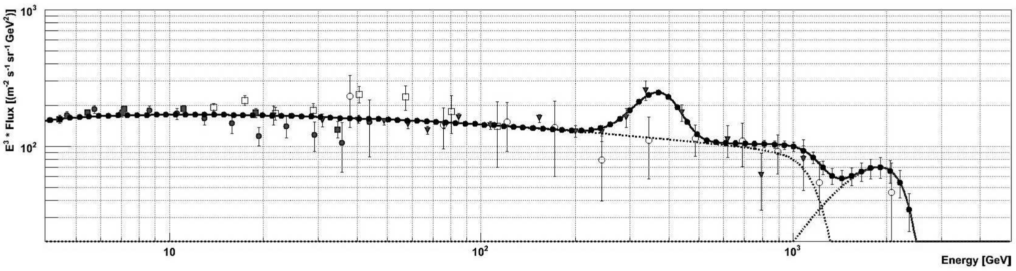


Fig. 2. Measured cosmic ray electron data from (Moiseev et al. 2007). The expected precision for the eTeV measurement is indicated by the full black circles. A possible feature in the spectrum at 500 GeV as observed by Chang (Chang et al. 2005) is also indicated.

the most promising nearby source since both the distance, $0.25kpc$, and the age, 10^4 years, are very suitable for an observation. Other possible candidates which contribute in the TeV region are Cygnus loop and Monogem, in order of strength.

1.3. VHCR composition

The CR spectrum follows a broken power law. The two power laws are separated by a feature christened the *knee*, located around $10^{15}eV$. Circumstantial evidence exists that cosmic rays up to energies of 10^{16} – $10^{17}eV$ originate in galactic Supernova remnants. The transition from galactic to extragalactic cosmic rays is important in understanding acceleration mechanisms in our Galaxy. Our knowledge about the compositon around the knee region is rudimentary, and it has attracted the interest of a generation of CR physicists. The extension of existing direct balloons measurements to PeV ($10^{15}eV$) energies requires experiments with apertures exceeding $20m^2sr$ and long exposure times. Although these exposure values are challenging, these experiments could be performed on balloons exploiting the new detector technologies which will be developed by our groups in the framework of this proposal. Exploring the composition around the knee would be a tremendous step forward in the improvement of high-energy interaction models mandatory to interpret air showers at higher energies.

2. Stratospheric balloons

Earth's atmosphere prohibits a measurement of GeV-range cosmic rays on ground. As an interesting alternative to space-based measurements, high-altitude long duration balloon (LDB) flights can be chosen. Mission durations of around 40 days (Ahn et al. 2007) can be reached by traveling with the circular arctic winds around the Pole at an altitude of 40 km and leaving 99.7% of the Earth's atmosphere behind. We know that balloons for LDB flights can be ordered at AeroStar Inc., U.S. for 250,000 Dollar. While the details still have to be worked out, NASA estimates the total cost of an LDB flight to be 1.5 Million US$, including the balloon, Helium, man power, transportation to Antarctica and recovery of the experiment. We then assume that a cost estimate of 1 Million Euro for each LDB ballon flight (excluding the payload) would be a reasonable figure.

2.1. Launch sites

Regular launch of LDB's can only be managed by Space Agencies, as it is done for example by NASA for LDB flights from Antarctica.

The optimal launch side for European experiments would be Svalbard (see Fig. 3), if the problem with the overflight permission over Russia could be solved. The access to Svalbard is much easier than to Antarctica, as it can be reached from major European airports within a day. Operations and infrastructure are consequentlly simpler. In addition, launching experiments from McMurdo Station requires, as of today, a principal investigator from the U.S. and is therefore no viable option for European led experiments.

Due to the geomagnetic cutoff (see Fig. 3) a launch from Svalbard would be required for DbarSUSY and preferable for PEBS to allow also a measurement of low energetic antiprotons. The eTeV experiment is designed to measure high energy cosmic ray electrons and can therefore also be launched from Kiruna, Sweden. A similar consideration holds for the experiment to study the composition of CR in the region approaching the knee.

The AMS project is an excellent role model for the collaboration between Space Agencies and scientific communities. If adapted to the proposed German-Italian research program for stratospheric balloon flights the responsibility of the university groups would be the construction of the scientific instruments. The responsibility of the space agencies would be to fly the experiments. For DLR the missions would be managed by DLR Oberpfaffenhofen, for ASI a collaboration between CIRA and ASI Milo could be considered.

The decision from where to launch the proposed experiments has to be taken one year before the launch, i.e. for the first experiment

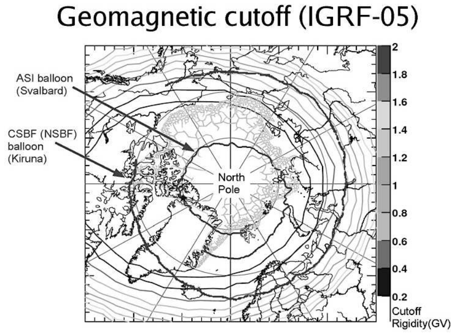


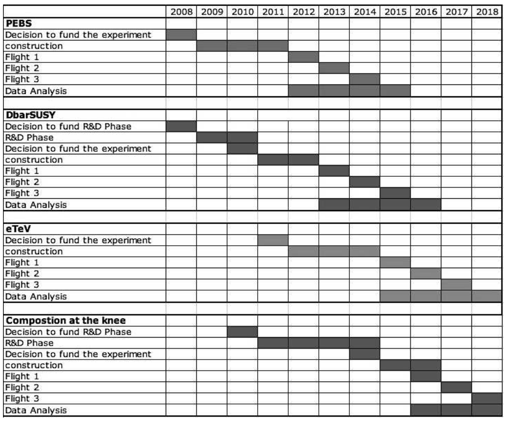
Fig. 3. The two possible European launch sites, Svalbard, Norway and Kiruna, Sweden close to the North Pole.

in this series, PEBS, in 2011. If we had to take the decision today we would propose a first launch from Kiruna to minimize the risk, since large payload have not been launched form the Svalbard, yet. As of 2011 we expect that OLIMPO and Boomerang will have been launched by ASI from Svalbard. If these two missions are successful, one will also launch all other experiments from Svalbard. If launching large balloons from Svalbard turns out not to be feasible or the problem with the overflight permission over Russia cannot be solved we will have to try to implement an agreement between ASI, DLR and NASA on how to launch European experiments from Antarctica.

3. Cosmic ray balloon experiments

Motivated by the scientific and technical challenges described above and by the opportunity offered by the LDB flights from the Swalbard base operated under the ASI-Norway agreement, we propose a multiyear program deploying a series of balloon borne experiments to study charged cosmic rays. We have identified four such experiments, the first two of them having an higher degree of maturity than the following two. In the following we briefly describe them.

- **PEBS**: The Positron Electron Balloon Spectrometer (PEBS) (Doetinchem et al. 2007) is designed to measure positrons and electrons in the energy range from 0.5 GeV to 200 GeV. The main purpose is to verify the anomaly in the cosmic ray positron flux above 10 GeV and to extend the precision measurement reach up to 200 GeV. The experiment consists of a superconducting magnet, a scintillating fiber tracker, a transition radiation detector and an electromagnetic calorimeter. It has a geometrical acceptance of 4000 cm^2 sr.
- **DbarSUSY**: Anti-deuteron in the energy range from 0.1 GeV to 2.5 GeV could be a very sensitive probe for dark matter annihilation. The predicted anti-deuterons are very low energetic and due to the low flux their measurement requires a detector with a large geometrical acceptance. The DbarSUSY experiment consists of a permanent magnet, a scintillating fiber tracker, a time of flight system and a solide state ring image Cherenkov counter (Haino & Battiston 2000). It has a geometrical acceptance of $18,000$ cm^2 sr.
- **eTeV**: The measurement of electrons in cosmic rays with TeV energies would allow to test directly cosmic ray acceleration mechanisms. Electrons lose their energy very fast by synchrotron radiation in the galactic magnetic field. Therefore only electrons from nearby supernova remnants are expected to populate the spectrum in the TeV range. The eTeV detector consists of a large TRD, an electromagnetic calorimeter and a neutron detector. It has a geometrical acceptance of $25,000$ cm^2 sr.
- **Composition at the knee**: The knowledge of the composition of CR in the region around the knee is a classical, unsolved problem, which can be solved only by direct measurements. Experiments with an acceptance in excess of $200,000$ cm^2 sr are necessary to tackle this challenge. New techniques like TRD or Cerenkov solid state detectors read by fast photomultipliers (DIRC, TOP) could allow, after a suitable *R&D* phase, the construction of LDB payloads having the necessary exposure. The proposed program would provide an unique framework for these developments.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
PEBS											
Decision to fund the experiment	■										
construction		■	■	■							
Flight 1					■						
Flight 2						■					
Flight 3							■				
Data Analysis					■	■	■	■			
DbarSUSY											
Decision to fund R&D Phase	■										
R&D Phase		■	■								
Decision to fund the experiment			■								
construction				■	■						
Flight 1						■					
Flight 2							■				
Flight 3								■			
Data Analysis						■	■	■	■		
eTeV											
Decision to fund the experiment				■							
construction					■	■	■				
Flight 1								■			
Flight 2									■		
Flight 3										■	
Data Analysis								■	■	■	■
Compostion at the knee											
Decision to fund R&D Phase			■								
R&D Phase				■	■	■	■				
Decision to fund the experiment							■				
construction								■	■		
Flight 1									■		
Flight 2										■	
Flight 3											■
Data Analysis									■	■	■

Fig. 4. The schedule for the proposed program of LDB experiments.

3.1. Schedule

The main advantage of balloon borne experiments is that they can be realized on much shorter time scales and at a modest cost if compared to space experiments. In addition they can be repeated several times with continuous detector upgrades and beamtest calibrations. Therefore PEBS, DbarSUSY, eTeV and the related *R&D* could be the European pathfinder projects to develop the know-how, the techniques and the infrastructure for a midterm program to study charged cosmic rays at the North Pole, in preparation for the next large space mission. The anticipated overall schedule is shown in Fig. 4.

3.2. International collaboration

The proposing groups at the University of Perugia and RWTH Aachen have a lasting tradition of collaboration at international level, which is required by the complexity of the instruments needed to study particle phyiscs in space as well as at accelerators. Once approved by the two space agencies the participation to this program will be open to the European and international communities following the standard rules used within international scientific collaborations. Initial expression of interests for participating to the development of PEBS and DbarSUSY have been issued by groups in Switzerland (Lausanne University), Russia (ITEP, MSU) and by the large INFN community (Italy) interested in astroparticle physics with CR.

4. Summary

The proposed balloon experiments would strengthen the up to now weak link between astrophysics and collider physics addressing fundamental questions about dark matter, high energy cosmic ray composition and sources. These experiments have a signficant discovery potential and they represents the intermediate developement of future ambitious astroparticle mission to space or to other planets, since the *R&D* development they foster will maintain and improve the European leadership on space based particle physics detection technologies, as the AMS and PAMELA programs did during the last decade.

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