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"Experimental Particle Physics Group" scientific activities

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Alexandru Mihul
(on the behalf of the group)

Abstract. The working program of the "Experimental Particle Physics Group" (EPPG) will be presented. The group's program contains the experimental verification of the Standard Model for the elementary particles interactions. The participation of the EPPG in different collaborations is discussed. It began with the contributions to the L3 collaboration on the tracker construction as well as to the MC simulation of different reactions in the electron-positron interactions at LEP with CMS energy of 190-209 GeV. The participation in the strange particle electroproduction experiment in electron-nucleus interactions at Thomas Jefferson Laboratory Accelerator in interactions of an electron beam with nuclei will be mentioned. The group activities in the construction of the CMS detector at CERN LHC (p-p 14 TeV interaction) machine, by manufacturing in Romania a series of dummy detectors for different tests as well as the contributions to the radiation hardness studies of the silicon detector are mentioned. Finally, the participation in the AMS 1-2 cosmic is presented. The results obtained in the prototype AMS 1 flight are discussed from the physical as well as technical point of view. As a principal physical result, an upper limit of $1.1\ 10^{-6}$ of the ratio Antiheliu/Heliu in cosmic rays was found. Technically, a series of improvements in comparison with the flown prototype were considered. The change in magnet from a permanent to a superconducting one was decided and the change and modification of the detection systems was proposed. At the end some considerations are made about the construction and schedule of the AMS 2 detector complex to be installed on the ISS space station in 2005.

Aims

The publication of the UBPub. EPPG/Phys series is in the first a mirror of the activities of the Experimental Particle Physics Group (EPPG) of the Bucharest University and of related groups. The publication report on research and progress in the field of Physics and Instrumentation related to the EPPG activities and those of connected groups. Publications of outside groups are strongly encouraged

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«Experimental Particle Physics Group» scientific activities

ALEXANDRU MIHUL on behalf of the group
Bucharest University, Romania

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I. INTRODUCTION

Experimental Particle Physics research, especially the one involving high-energy particles, is a hard business. This comes, from the complexity of the physics processes at these energies that pushes the involved technologies (of particle detection, of data recording, storage and processing) toward their present limits. And all of these must be done with limited financial resources. These characteristics force even the big laboratories to join their resources and to work in large collaborations. A collaboration work allows not only to compensate for the insufficient financial resources available to one group or laboratory but also to satisfy the needs for a very diverse profile of the researchers and technical staff.

These characteristics of the high-energy physics research influenced the activity and the evolution of the Experimental Particle Physics Group (EPPG) from Bucharest University.
The basis of the group were put by few physicists from the Department of Atomic and Nuclear Physics, Faculty of Physics of this university, in 1991.

The group intended to participate in internal (Romanian) and external research collaborations. In Romania, the group collaborated with scientists, many Ph. D. students, undergraduate students, and technicians from the Institute for Microtechnology, the Institute for Physics and Nuclear Engineering Horia Hulubei, Microelectronica S.A. and later from the Institute for Space Science. The group participated in several internationals experiments contributing to more research areas, from the detector design and construction up to experimental data processing and their physics interpretation. The general research goal of the group was "The verification of the Standard Model (SM) of the elementary particle interactions". The studies were performed on different type of physical interactions: electron-positron (LEP experiments at CERN, Switzerland), electron-nucleus (experiments at TJNAF, USA), proton-proton (LHC

experiments at CERN), and on cosmic rays (AMS 1,2) experiments. These activities were done in the frame of international collaborations because this was the only way for our group to do successful research in this domain of Physics.

2. ELECTRON-POSITRON INTERACTIONS AT LEP. THE L3 EXPERIMENT

Between 1991 and 2003 EPPG participated to the L3 collaboration that allowed us to do research on SM in the e^-e^+ interactions in the energy range 180-209 GeV.

The main goal was to observe the Higgs particle in the energies available at LEP and to analyse the properties of Z and W particles.

The L3 experiment used the particles beams provided by LEP accelerator from CERN, Switzerland and a complex detection system [2.1] embedded in a large volume, low field, conventional solenoid magnet (Figure 2.1). In short, the detection system contained a small central silicon tracking system with very high spatial resolution (SMD), a multi-wire drift chamber system, a high-resolution BGO electromagnetic calorimeter (ECAL) surrounding the central detector and a hadron calorimeter (HCAL). All of these were introduced in a large support tube. Eight three-layer high precision muon-tracking chambers were attached externally to the tube. The external boundary of the detector was given by the iron return-yoke of the magnet.

The detection system was designed to measure the energy and the position of leptons with the precision allowing a mass resolution ($\Delta m/m$) smaller than 2% in dilepton final states. The hadronic energy flux was detected by the HCAL, which also served as a muon filter and a tracking device. The magnetic field was 0.5 T over a length of 12 m. This large volume allowed a high precision muon momentum measurement, performed by the drift chambers in the central detector region.

Using multiple measurements of the coordinate in the bending plane a momentum resolution of 2.5% for 45 GeV muons was obtained. A forward-backward muon detection system extended the polar angle coverage to 22 degrees. This system was made out of three layers of trapezoidal multi-wire drift chambers for the reconstruction of trajectories, two layers of Resistive Plate Chambers (RPC) providing a fast trigger, and aluminum coils surrounding the main magnet doors to create a toroidal field which provided additional bending power. Going radially inwards, the combined hadron calorimeter and muon absorber consisted of wire chambers operating in the proportional mode, sandwiched with U-plates as energy converter. A subdivision into 3000 space elements covering the full solid angle (except the beam pipe) allowed localization and determination of the hadronic energy flow with about 11% energy resolution at the Z pole energy. Approximately 11000 crystals of BGO (Be4Ge3O12), a transparent scintillator with 1.1 cm radiation length determined the electromagnetic energy flow. An energy resolution of about 1.4% and a spatial resolution better than 2 mm was obtained for photon energies larger than 1GeV, with a rejection against hadrons of better than 1000.

Surrounding the 10 cm diameter beam pipe, a high precision Silicon Microstrip Detector (SMD) and a small drift chamber operating in the time expansion mode (TEC) acted as charged particle vertex detectors. The SMD consisted of two layers double-faced silicon microstrip detectors, each providing readout of the R-and Z coordinates with an intrinsic resolution of about 7 μm and 15 μm, respectively. The polar angle of the micro vertex detector extended from 22 degrees to 158° degrees. The drift chamber achieved a space resolution down to 45 μm. The combination of TEC and SMD allowed a good momentum and charge determination for particles with the energy of 45 GeV, an efficient electron-photon separation and a measurement of the impact parameter of the tracks of long-lived charged particles.

EPPG contributed to the design and mounting of elements of the SMD as well as to t software development for the analysis of data (mainly Monte Carlo simulation).

The physics program of the L3 experiment was very vast and the results were published approximately 250 papers and presented at about 500 conferences. I will mention here only tv of them.

A) Search for the Standard Model Higgs.

Within the SM [2.2] the Higgs mechanism is invoked to break the electroweak symmetry, implies the existence of a single scalar particle, the Higgs boson. The mass is not specified b indirect experimental limits are obtained from precision measurements of electroweak paramete that depend logarithmically on the Higgs boson mass through radiative corrections. The da taken prior to year 2000 gave no indication of the production of SM Higgs and allowed only lower bound of 107.9 GeV/c^2 to be set. During the last year of running LEP, (2000), the da samples collected at a center-of-mass energy exceeding 206 GeV extended the search sensitivi to masses about 115 GeV/c2 through the $e^-e^+ \to HZ$ (higgsstrahlung process). Differe experiments from LEP observed an excess of events consistent with the production of a S Higgs with a mass of 115 GeV/c2 (Figure 2.2). The data obtained by the LEP experimen (Aleph, Delphi L3 and Opal) scan the energy from 189 to 209 GeV with an integrated luminosi of, respectively, 2461 and 536 pb^{-1} [2.3]. Combining the final results from the four experiments lower bound of 114.4 GeV/c^2 is set on the mass of the SM Higgs at a 95% confidence level whi the median expected limit is 115.3 GeV/c^2. The combined LEP data are also used to set a 95' confidence level upper bound on the HZZ coupling in non-SM.

B) The determination of the number of light neutrino types

The most precise measurements of the number of light neutrino types, N_ν, come from studi of Z production in e^-e^+ collision. The invisible partial width, Γ_{inv}, is determined by subtractir the measured visible $\Gamma_{partial}$ widths, corresponding to Z decays into quarks and charged lepton from the total Z width. The invisible width is assumed to be due to N_ν light neutrino species ea contributing the neutrino partial width Γ_ν as given by the Standard Model. In order to reduce t model dependence, the Standard Model value for the ratio of the neutrino to charged lepton partial widths, $(\Gamma_\nu/\Gamma_l)_{SM}$, is used instead of $(\Gamma_\nu)_{SM}$ to determine the number of light neutrino types

$$N_\nu = (\Gamma_{inv}/\Gamma_l)(\Gamma_\nu/\Gamma_l)_{SM} \quad (2$$

The combined result from the four LEP experiments (Figure 2.3) (ALEPH, DELPHI, L3, ar OPAL experiments) is $N_\nu = 2.994 \pm 0.012$ [2.4]

In 2000 the running of the L3 experiment was ended and the detector dismounted but tl analysis of data continued till in 2003 by the CERN L3 collaboration. The further analysis of tl obtained experimental material remained to be done by different universities and institutes fro the collaboration.

Our group organized itself to continue the analysis of the data at Bucharest University collaboration with Perugia University, named "post L3". The approached subject is the no conservation of lepton numbers by families

3. ELECTRON-NUCLEUS INTERACTION AT 2-4 GEV AT TJNAF. HYPERNUCLEI STUDIES

Hypernuclei studies at Thomas Jefferson Laboratory.

The collaboration of the EPP Group with Hampton University and Thomas Jefferson National Accelerator Facility (TJNAF), started in 1995 with the study of strange particle electroproduction on protons. The main results have been summarized in [3.1]: longitudinal and transverse cross section separation in Λ and Σ electroproduction, induced hyperon polarization, kaon form factor evaluation. In 1999 the HNSS (Hypernuclei spectroscopic studies group) collaboration began the first study of light hypernuclei produced in (e,e' K⁺) reactions.
We present here the first results and the perspective of our collaboration in this group.

Λ is the lightest hyperon. Its mean lifetime in free space is $2.63\ 10^{-10}$ seconds before it decays through weak interaction into a nucleon and a pion. Since, when Λ is embedded in the nuclear matter the momentum of the outgoing nucleon is below the Fermi momentum, the Pauli principle inhibits its decay process. Therefore when Λ is attached to a nucleus it experiences "non mesonic decays". These processes are weak interactions between Λ and a nucleon: $\Lambda + N \rightarrow N + N$ in which the final nucleons have a relatively high momentum.
These reactions are interesting because they allow us to explore the four-fermion strangeness changing weak interaction. It gives a possibility to study Λ N interaction in the absence of Λ beams.

In order to determine the Λ nucleon effective interaction a variety of spectroscopic data, particularly sensitive to the effective spin-dependent potential parameters is needed for determining the parameters of the Λ N potential. The reaction (e,e' K⁺) has a large spin-flip component producing states of non-natural parity and substituting Λ for a proton in the target nucleus. This produces hypernuclei charge symmetric to the reactions (K⁻, π⁻) or (π⁺, K⁺) employed previously. The cross section for electroproduction can be written by separating the virtual photon flux, Γ, in one virtual photon approximation. The virtual photon cross section can be approximated by the real photoproduction cross section at forward angles. The factor Γ is very forward peaked. On the other side, working at forward angles implies electron bremsstrahlung in the target and a high electron background from Dalitz pair production. The TJNAF beam of about 2 GeV has a momentum spread of 10^{-5} which introduces a very small error in the missing mass.

The experimental setup is given in figure 3.1. An electron beam of 1.8 GeV and 1 μA current hits a thin target (20 mg /cm²) just before a splitting dipole magnet. K⁺ are analyzed in kaon spectrometer (SOS) and electrons in the magnetic spectrometer (ENGE). The beam is directed into the beam dump. The resolution in missing mass is about 600 – 1000 keV due to the poor resolution of the kaon spectrometer. Two targets have been investigated (^{12}C and ^{7}Li) [3.2] and a target of CH_x was used to observe Λ and Σ production from hydrogen. The reaction of interest has been: ^{12}C (e,e' K⁺) $_{\Lambda}{}^{12}B$ and the bound levels of $_{\Lambda}{}^{12}B$ have been measured by missing mass method. A high positron (10^5) and pion ($1.4\ 10^3$) background have been removed by the SOS detector package.
A silicon strip detector designed for this experiment to detect the position in the focal plane of the ENGE spectrometer has detected the scattered electrons.

The p (e, e' K⁺) Λ/Σ reaction has been used to calibrate the missing mass spectrum in the S detector system. The resolution has been determined by using the Dalitz pairs detected in reaction in the target: A(e,e'|e⁺ e⁻|)A (e⁺ detected in SOS and e⁻ in ENGE –SSD)

The value of 890 keV is consistent with the observed resolution in the hypernucl spectrum and is the best resolution obtained in the binding energy of light hypernuclei. The Λ spectrum is shown in Figure 3.2. For Λ inserted in the s and p shells, peaks are seen (1⁻,: respectively (2⁺ ,3⁺) The two doublets are not resolved. The spectrum is similar to that predic by Motoba [3.3] the curves are superimposed as gaussians with 900 keV resolution or polynomial background.

The binding Λ energy has been found to be 11.4 ± 0.5 MeV in good agreement with t obtained in emulsion experiments. A cross section value computed as in photoproduct experiments was found: 140 ± 17 (stat) ±18(syst.) nb/sr consistent with the theoretical value the ground state

The two important characteristics of this study at TJNAF are the fact that in hyper electroproduction both spin-flip and non-spin-flip states are available and the spectrometers us can reach a high resolution (better than the magnitude of l-s splitting).
The value of the spin–orbit splitting is highly controversial in different models of Λ N interact (boson exchange and quark models). The weak feature of the electroproduction experiment is low statistics. In order to keep the background from bremsstrahlung and Dalitz pair product low, the intensity of the beam is less than 1 μA. In this way the integrated intensity on the fo plane is $2\ 10^8$ e/sec. For a long time exposure the most important requirement is that the be should be kept stable at the level of 10^{-4}.

Studies of possible radiation damage of silicon detectors at this rate ($2.8\ 10^8$ e/sec) ha been done by Bucharest University group [3.4].We analyzed the signal/electronic noise ratio a the charge collection efficiency as a function on the detector thickness and electron angle incidence on the detector .The effect of a dose of 10-30 kGy for 600 hours of beam time on leakage and bulk damage current of the detector is of about 200nA/pitch. At the end of exposure the signal/electronic noise ratio could decrease from 20 to 10 and the detect efficiency is close to 100%.

According to these evaluations, a change in the SSD geometry has been done segmenting the detector in such a way that at any momentum electrons hit the detector a perpendicular incidence. In this way the bulk current will have the same value all over the fo plane

A problem which arise in using silicon strip detectors is the electron multiple scattering a relatively thick solid material which results in a worse resolution. For a further experimen drift chamber with very thin walls would replace the silicon detector.

The program of spectroscopic study of Λ hypernuclei at TJNAF continues with the goal to determine the spin orbit potential of $_{\Lambda}{}^{28}Al$ and $_{\Lambda}{}^{51}Ti$ beyond the p shell by achieving a better resolution (600 keV).

4. PROTON-PROTON INTERACTIONS AT LHC. THE CMS EXPERIMENT

The search for the Higgs boson and other research is foreseen to be done at CERN by f experiments in four intersections regions of LHC. One of them is CMS (Central Magn Solenoid) (Figure 4.1). As the LHC is expected to provide beam in 2006, the experiments

now in the preparation stage. The EPPG is involved mostly in studying, designing and the construction of the tracker system of the CMS experiment.

The tracker is mostly constructed from elements of silicon microstrip detectors. The total area of the silicon detector is ~ 200 m^2 (Figure 4.2). One of the specific situations of this silicon system is that it must work long time without major interventions in a high radiation field. As it is located in the middle of the CMS detection system every intervention will require the shut down of the whole complex for about 3-5 month which is costly and time consuming. So the detector, during its running (10 year), has to support fluences around 10^{15} particles per cm^2 without major change in detection properties.

Special studies were performed to find the best conditions to be fulfilled and to optimize the system. The main results were that: in order to avoid the radiation effects on the detector elements, the bias voltage must be greater than usual (~400 V) [4.1], the silicon wafers have to be cut from a medium resistivity (1-2 kohm. cm) material [4.2] with the crystallographic orientation <100> [4.3]. Also field plates and guard rings have to be introduced for avoiding the regions with a high potential gradient. (Figure 4.3) [4.4].

Our team participated to the design and the construction of silicon detectors at INFN Pisa and INFN Perugia, Italy. In addition, IMT Bucharest produced all dummy detectors elements used for mechanical and thermal tests. Now the activities are continuing for the full construction of the tracking system.

5. STUDIES IN COSMIC RAYS WITH ALPHA MAGNETIC SPECTROMETER (AMS EXPERIMENT)

Studies connected with SM were done also in Cosmic Rays (CR). The main goal of the AMS experiment was the detection of primordial antimatter. The apparent absence of antimatter in universe is one of the major puzzles in physics. All theories conceive that at the beginning of our universe, at the Big Bang, equal amount of matter and antimatter was produced. The present extreme preponderance of matter over the antimatter raises the problem of the fate of the primordial antimatter. The absence of the annihilation gamma ray peaks excludes the presence of significant quantities of antimatter within distance of the order of several Mpc from the solar system.

Different scenarios were conceived in order to explain the present local unbalance.

Some ideas are based on the CP violation and baryon number non-conservation, which determines the disappearance of the antimatter so that only the matter remains. Other ideas claim that the two worlds, one of matter and other of antimatter, still exist but are separated by big distances so that they have no possibilities to contact and therefore no significant annihilation exists. In this second case, it is conceivable that some very few elements of antimatter can be present in CR. The detection of antimatter in CR will enforce this second hypothesis.

The antimatter discussed is especially hadronic one. This means antiprotons and antinuclei. The presence of antiprotons was already observed but these antiparticles were of secondary origin appearing in the interactions of the primary cosmic particles with the terrestrial and extraterrestrial matter. The cross section of pair (proton-antiproton) production is sufficiently large so that a detectable amount of antiprotons should exist in CR. In these conditions we need to study the presence of antinuclei in primary CR because the probability of their production, as the results of secondary interactions, is extremely small so that the detection of at least one nuclei of antihelium or anticarbon will be sufficient to demonstrate, with a great probability, the existence of anti world.

The AMS experiment proposes to use a complex detection system containing a wi angle spectrometer with a microstrip silicon tracker detector surrounded by a series of oth detectors. The system will fly on the International Space Station (Figure 5.1) for three years.

The approved experiment was foreseen to take place in two stages. In a first stage prototype was constructed (Figure 5.2) and flew successfully for a rather short time (10 days) the Discovery 91 shuttle (Figure 5.3). The first stage of the experiment had several goals:

--to prove that such an experiment is achievable,

--to show the way to improve the installation and

--to obtain data for a preliminary physical analysis.

These goals were achieved and the analysis of the performance shows that the experime can successfully be done and that some improvements in the detection system are suitable. T most important change was in the used magnet. If the prototype (AMS 1) had a permane magnet, for the second stage of the experiment (AMS 2) (Figure 5.4) it was decided to use superconducting magnet. Such a magnet will provide a bending power of $BL^2 = 0.86\ TM^2$ and will raise at least one order of magnitude the spectrometer magnetic field. It was also decided improve the existing detectors or to add some new detectors in order to improve the partic identification capability.

The new tracker will be made from eight layers (6.45 m^2) of double-sided silic microstrip detectors, which will provide a coordinate resolution of 10 μm in the bending pla and 30 μm in the non-bending plane (Figure 5.5).

A transition Radiation Detector (TRD) will be added to identify positrons against hadro in the range 1.5 – 300 GeV with a rejection factor of 100-1000.

Also there will be added or redesigned a synchrotron radiation detector (SRD), a Ri Imaging Cherenkov Counter (RICH) to measure the charge of particles and the velocity wi 0.1% accuracy and an Electromagnetic calorimeter (ECAL) made out of 15 X_0 of lead and plast fibers. Veto counters surrounding the active area will allow being accepted only particle passi through the magnet aperture. A time of flight hodoscopes (TOF) will provide time of flig measurements with a good precision (~120 ps), dE/dx measurements and will provide t primary trigger.

The design and construction of the second stage detection system AMS 2 began in 199 and has to be finished in 2004 and mounted on ISS in 2005. Its mission is scheduled to last for 5 years.

Our group played an important role in the design, testing and the construction of t tracker system, for both stages of the experiment.

AMS on the STS-91 flight

During the period 2-12 June 1998 the Discovery STS-19 shuttle performed 154 orbits an inclination of 51.7° at an altitude between 320 and 390 km. During 184 hours time the AMS 1 collected about 10^8 events, which were analyzed searching for electrons, protons, nuclei an their antiparticles.

A comparison of the results obtained by AMS in 10 days flight, with all other existin data (Figure 5.6) show that even in such a short flight our result compete with all the existing.

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5.4. Cosmic protons AMS Collaboration Phys. Lett B 490 (2000) 27-35.

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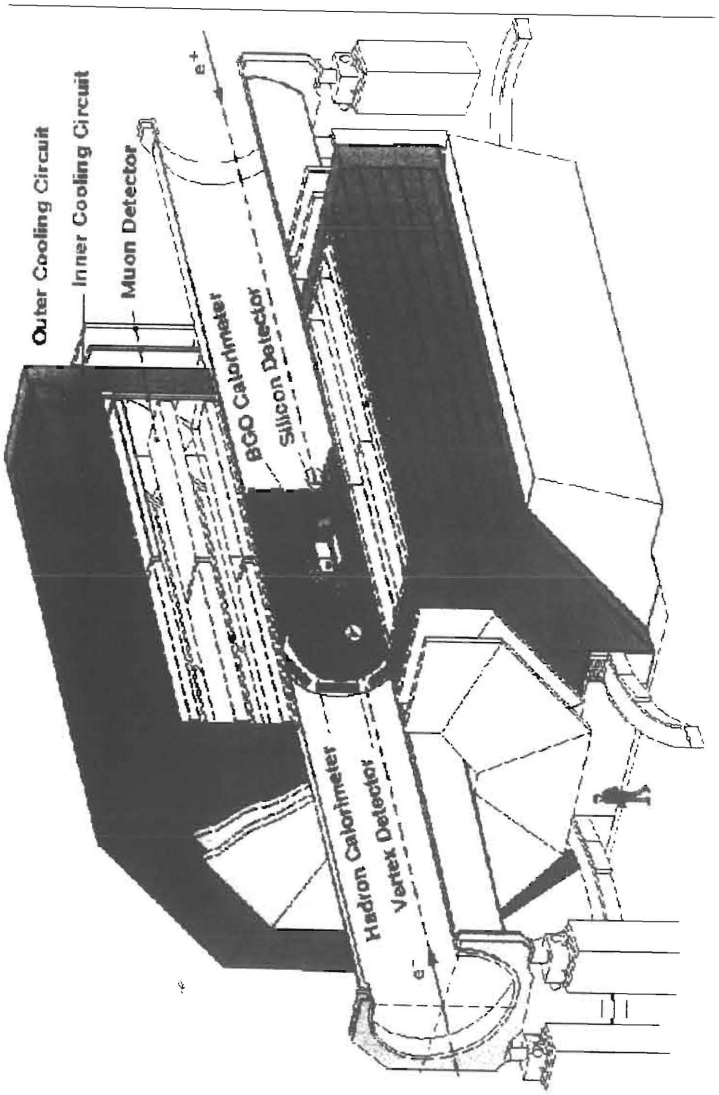
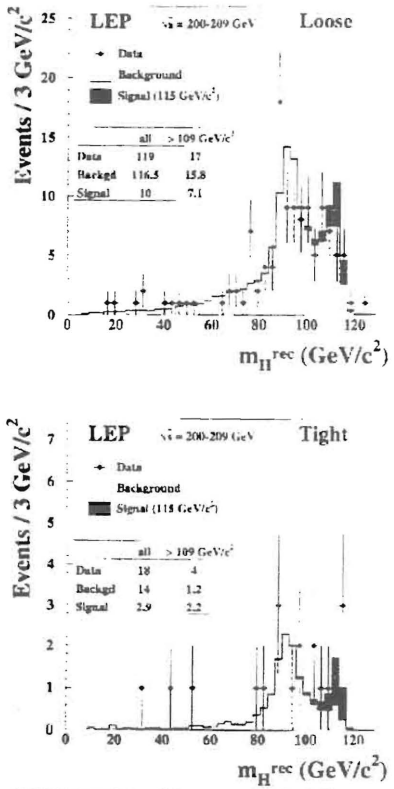
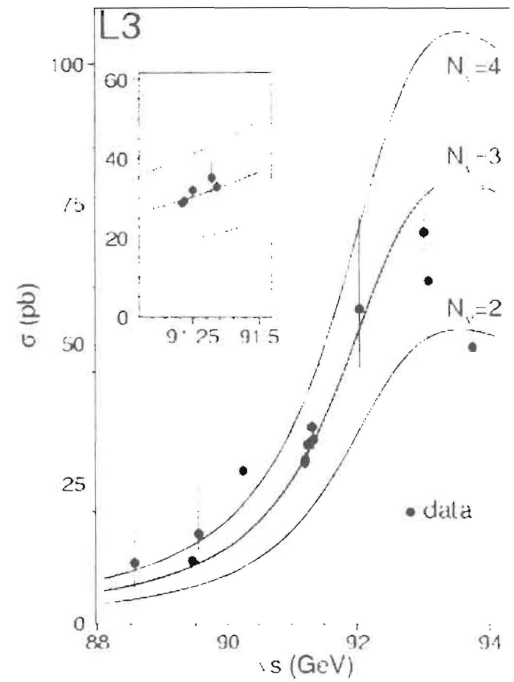
5.7. The Alpha Magnetic Spectrometer (AMS) on the International Space Station: Part I AMS Collaboration Physics Reports 366 (2002) 331-405.



2.1 Artist view of the L3 detection system



2.2 Distributions of the reconstructed Higgs Mass obtained from two selections with different signal purities. The histograms show Monte Carlo predictions. Background lightly shaded and with a SM Higgs boson of 115 GeV/c2 mass heavy shaded



2.3 The Corrected single photon Cross Section as a function of $\sqrt{s}$, compared with predictions.

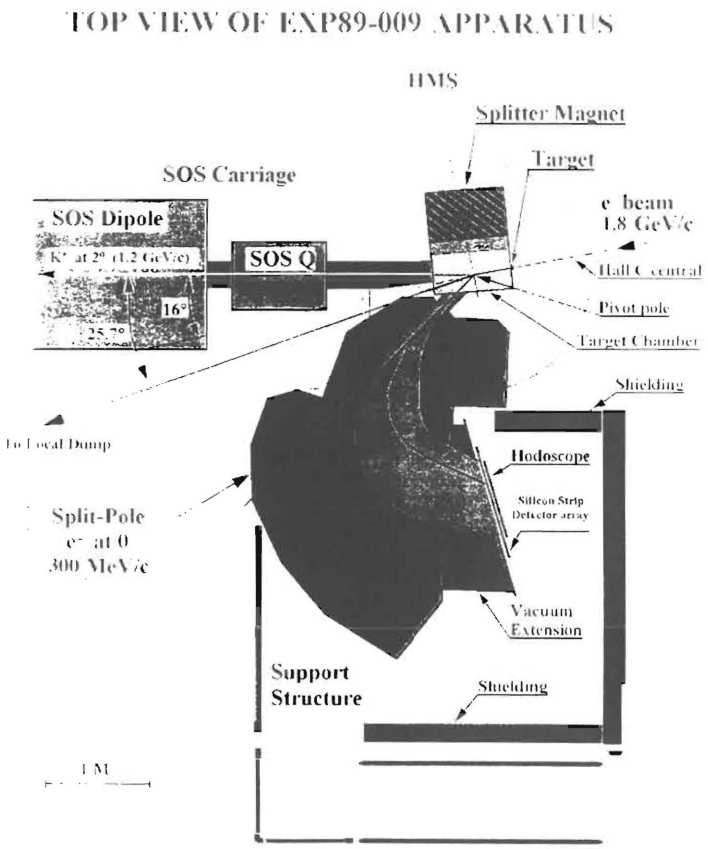

TOP VIEW OF EXP89-009 APPARATUS
HMS
Splitter Magnet
Target
SOS Carriage
SOS Dipole
SOS Q
e beam
1.8 GeV/c
Hall C central
Pivot pole
Target Chamber
Shielding
To Local Dump
Hodoscope
Silicon Strip
Detector array
Split-Pole
Vacuum
Extension
Support
Structure
Shielding
1 M

Fig 3.1

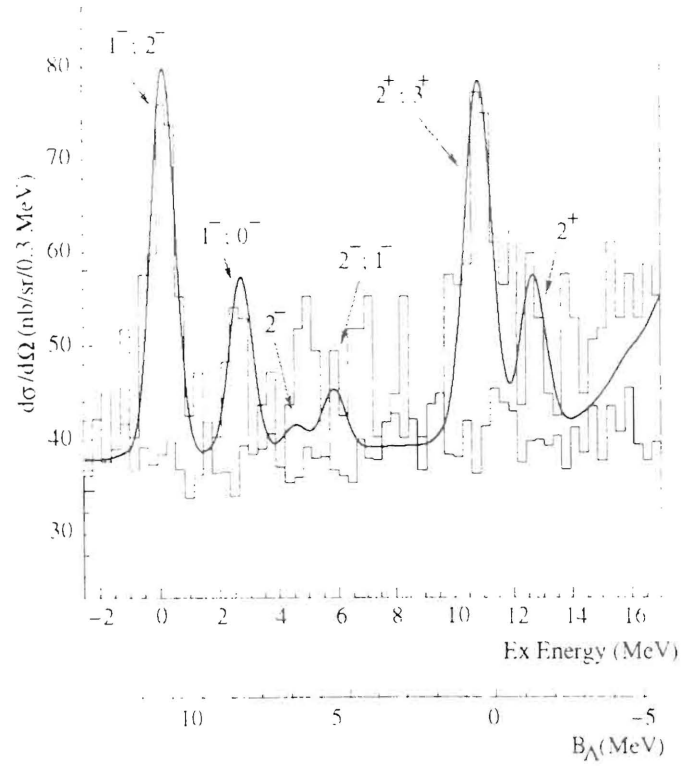
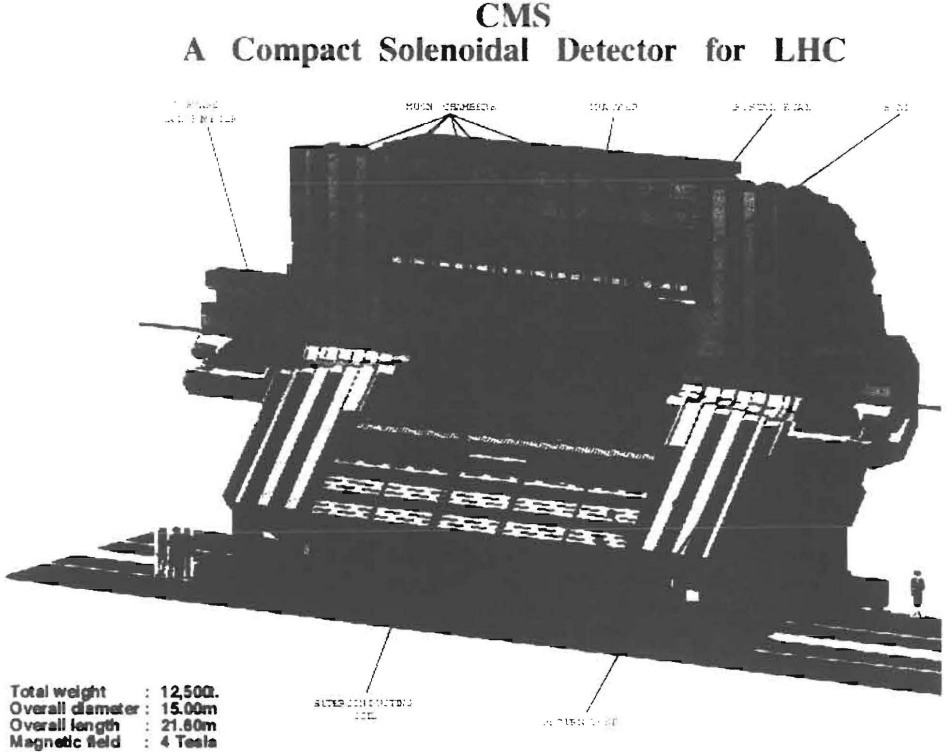
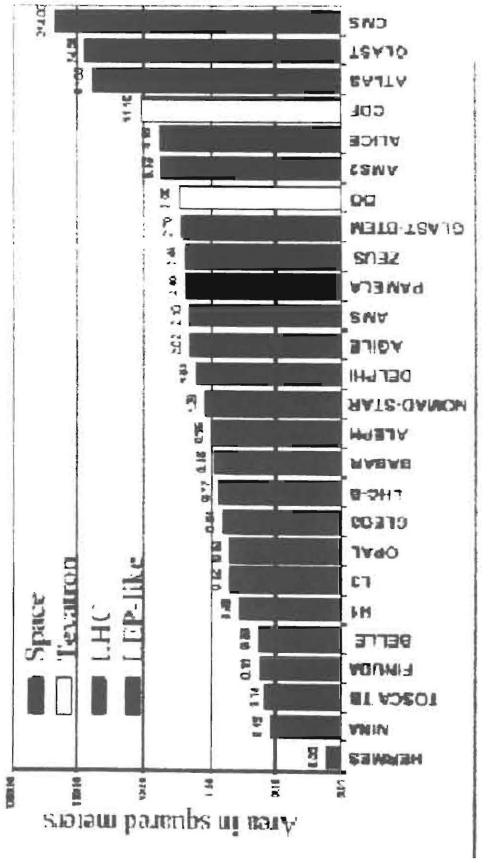

dσ/dΩ (nb/sr/0.3 MeV)
Ex Energy (MeV)
B_Λ(MeV)

Fig 3.2



4.1 Artist view of the CMS detection complex

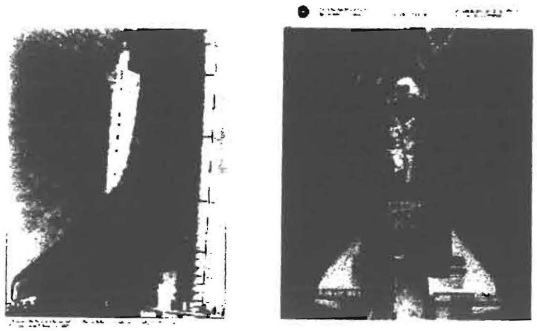


4.2 Area of silicon microstrip detectors in main present detectors

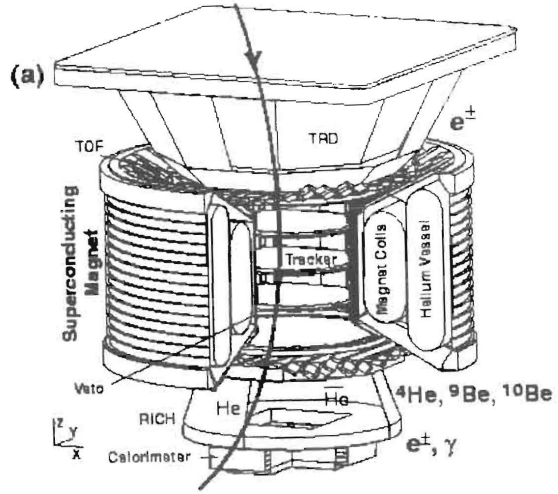
51 The position of AMS 2 to be flown for three year on the International Space Station

5.2 Schematically view of the AMS 1 prototype

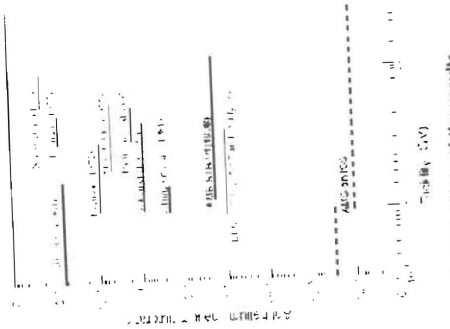
4.3 The influence of field plates on the potential gradient modeled for a CMS silicon microstrip detector element



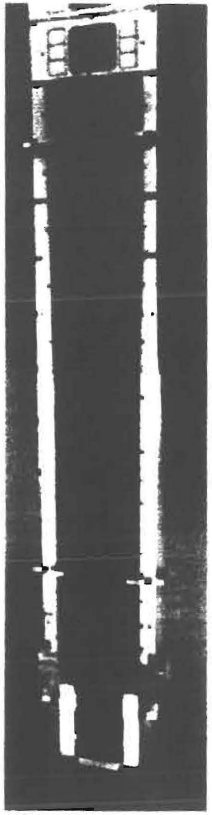
5.3 The shuttle Discovery STS 91 close to Launch Pad and in flight (photo taken from the Mir station)

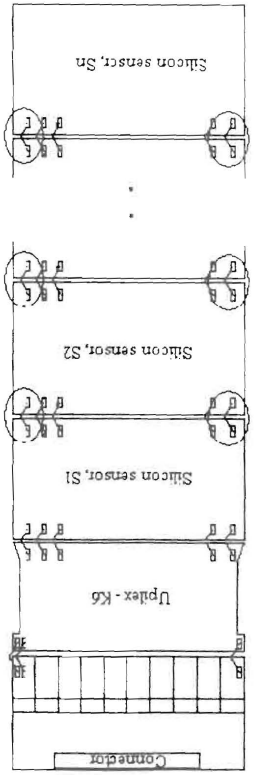


5.4 Schematic view of the AMS 2 detector complex.



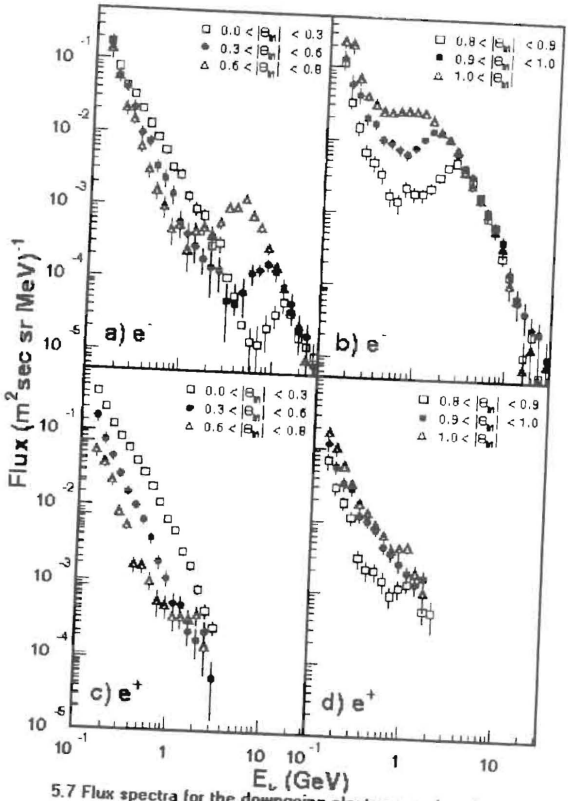
5p A comparison, of the results obtained by AMS 1 in 10 days flight, with all other existing data



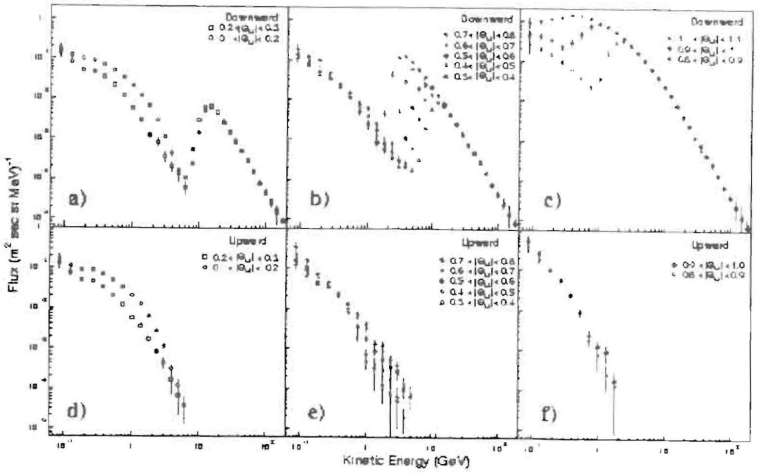


Schematic view of a ladder. Sensor to sensor connection on S-side

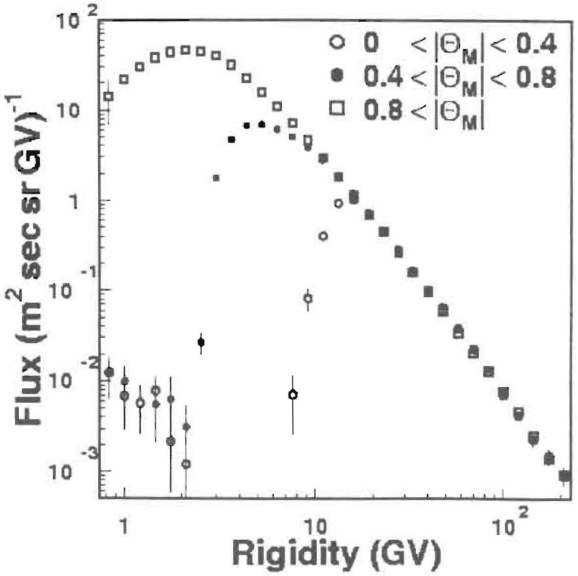
5.5Wiev of an AMS ladder



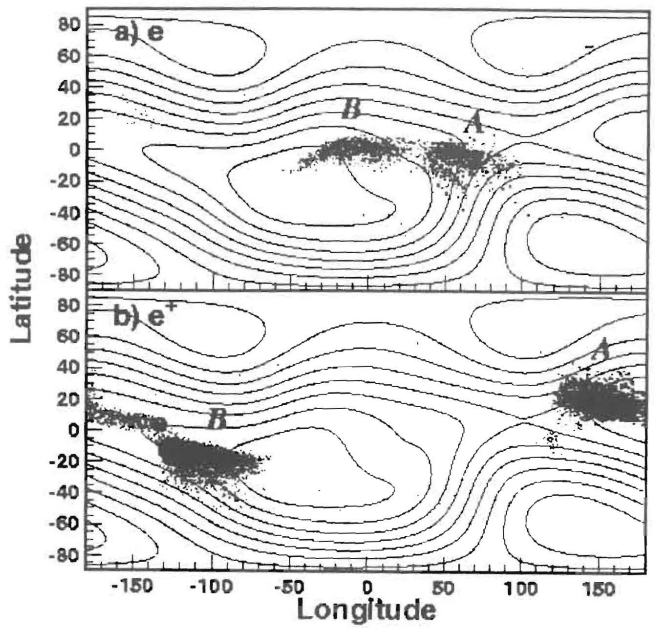
5.7 Flux spectra for the downgoing electrons and positrons separated according to the geomagnetic latitude |ΘM| at which they were detected.[5.7]



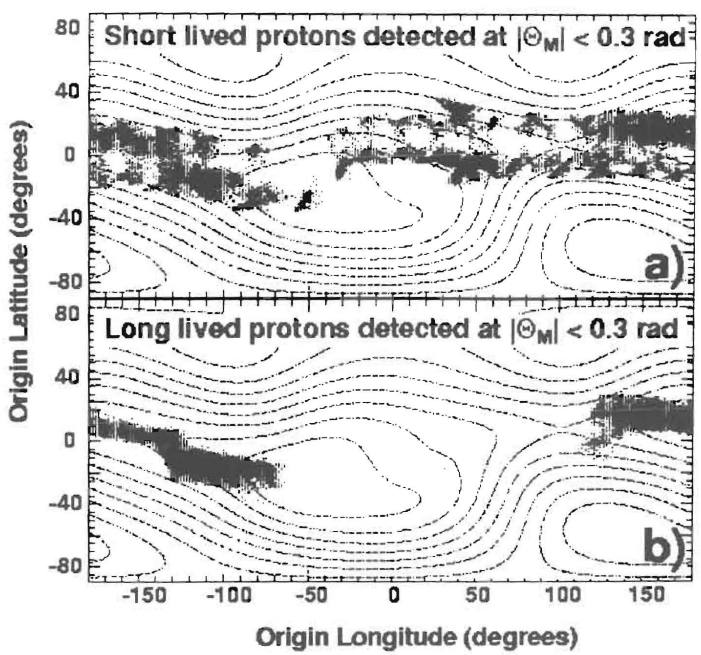
5.8 Fux spectra for downward and upward going protons, according to the geomagnetic latitude |ΘM| [5.7]



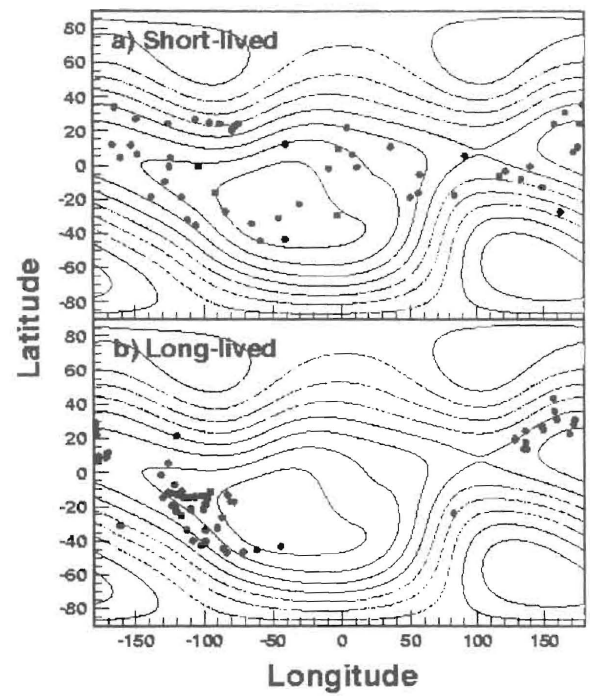
5.9 Helium flux spectra for the zenith pointing data according to the geomagnetic latitude |ΘM| [5.7]



I



II



III

5.10 The geographical origin of I) longlived leptons (e^- e^+ II) protons and III) helium nuclei. The dashed lines indicates the geomagnetic field contours at 380 km [5.7]