Precision measurements of $e^+$, $e^-$, $e^+e^-$ fluxes with AMS-02

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Abstract. The Alpha Magnetic Spectrometer (AMS-02) is a large acceptance particle physics detector installed on board the International Space Station (ISS) since May 19th 2011 to search for primordial anti-matter, for indirect signals of dark matter and to perform a high statistic and long duration measurement of the spectra of primary charged cosmic rays. Precise measurements of the electron and positron fluxes and of the total $e^++e^-$ flux are presented. These AMS results provide a deeper understanding of the nature of high energy cosmic rays and can shed more light on the nature of dark matter.

1. Introduction
AMS-02 is a general purpose high energy particle physics detector installed on the ISS to conduct a unique long duration mission. The main goal of this detector is the accurate measurement of the cosmic ray composition and energy spectra up to the TeV scale, to search for the presence of primordial anti-matter and for signatures of cosmic ray exotic sources, like dark matter annihilation.

We present the AMS-02 measurement of the fluxes of cosmic ray electrons and positrons in the first 30 months of data taking: the positron ($e^+$) spectrum in the energy range from 0.5 GeV to 500 GeV, the electron ($e^-$) spectrum from 0.5 GeV to 700 GeV and the total electron plus positrons flux in the energy range 0.5-1000 GeV.

2. The AMS-02 Detector
The AMS-02 detector [1] consists of a permanent magnet, nine planes of double sided silicon microstrip tracker, a transition radiation detector (TRD), four planes of time-of-flight counters, an array of anticoincidence counters, a ring imaging Cherenkov detector, and an electromagnetic calorimeter (ECAL). AMS-02 operates continuously on the ISS and is monitored and operated around the clock from the ground. The timing, location and attitude are determined by a combination of GPS units affixed to AMS-02 and to the ISS. The detector performance is steady over time.

The TRD (above the magnet), the ECAL (below the magnet) and the tracker provide clean and redundant identification of positrons and electrons with independent suppression of the more abundant proton background. The matching of the ECAL energy, $E$, and the momentum measured with the tracker, $p$, greatly improves the proton rejection.
3. The data analysis

Similar analysis strategies have been applied to the \((e^+ + e^-)\) flux measurement and to the individual electron and positron flux measurements. A major experimental advantage of the \((e^+ + e^-)\) combined flux analysis with respect to the individual \(e^+\) and \(e^-\) flux measurement is that the selection does not depend on the charge sign. This allows not only a higher overall efficiency but also an improvement in the measurement systematic uncertainty. Consequently, this measurement is extended to 1 TeV with improved accuracy over the entire range. In this contribution we mainly refer to the total \((e^+ + e^-)\) flux analysis, pointing out differences when needed.

A selection has been applied on the first 30 months of data collected by AMS-02 in order to select charge 1 relativistic, down-going, and not interacting particles and to remove under-cutoff secondaries. The selected sample includes electrons, positrons and protons.

The TRD and ECAL detectors are the key detectors used to distinguish electrons/positrons from the large proton background. The TRD exploits the differences in the energy deposit released in its 20 layers of proportional tubes interleaved with fleece radiator by same momentum light (\(e^\pm\)) and heavier (\(p\)) particles. The measured signals in all TRD layers associated to the reconstructed particle are combined in a TRD Classifier, a discriminating variable based on the log-likelihood for the electron hypothesis, which is then used either to cut or to estimate the proton component in the sample. A different definition for the TRD Classifier, with the same differentiation power, has been used for the electron and positron separate analysis.

The 3D imaging capability of the ECAL detector is exploited to distinguish between hadrons and leptons through the analysis of the shower topologies. A statistical estimator, called ECAL Classifier, based on boosted decision tree algorithm has been developed using the complete ECAL information to identify \(e^+ / e^-\) over the protons.

4. The flux measurement

The isotropic flux \(\Phi\) is measured in each energy bin of width \(\Delta E\) as:

\[
\Phi = \frac{N(E)}{A_{\text{eff}}(E)\epsilon_{\text{trig}}(E)\epsilon_{\text{ECAL}}(E)T(E)\Delta E}
\]

where \(N\) is the number of particles \((e^+, e^-\) or \(e^+ + e^-)\) identified in the detector, \(A_{\text{eff}}\) is the effective detector acceptance, \(\epsilon_{\text{trig}}\) is the trigger efficiency, \(\epsilon_{\text{ECAL}}\) is the signal selection efficiency based on the ECAL estimator and \(T\) is the exposure time.

The detector acceptance has been estimated with a full Geant4 \([2]\) MonteCarlo (MC) simulation of the response of the AMS-02 detector to an isotropic electron spectrum. The effect of each single selection has been evaluated on electron control samples and compared between flight data and MC to validate the simulation and to obtain the acceptance, \(A_{\text{eff}}\). If needed, small corrections (O(\%)) have been applied to the acceptance obtained by MC.

The trigger efficiency is determined from data. The data acquisition system is triggered by the coincidence of all four time-of-flight planes. A pre-scaled sample of events passing a looser trigger condition, three out of four TOF planes, is also recorded. This allows the direct determination of the trigger efficiency, that is 100\% above 3 GeV.

The ECAL estimator efficiency \(\epsilon_{\text{ECAL}}\) is measured using a control sample of electrons.

In each energy bin the exposure time \(T(E)\) is determined by counting the live time weighted number of seconds at each location only when the minimum bin energy exceeds the rigidity cutoff minimum requirement, that is 1.2 times the maximum Størmer cutoff \([3]\) for charge 1 particles in the AMS-02 geometric acceptance. The exposure time excludes periods in which AMS-02 was not in nominal conditions and time spent in the South Atlantic Anomaly. For the energy bins above \(\sim 30\) GeV, where the effects of the geomagnetic cutoff are negligible, the exposure time is constant at \(\sim 6.2 \times 10^7\) seconds.
The flux is evaluated independently each energy bin. The binning is chosen according to the energy resolution and the available statistics such that migration of the signal events to neighbouring bins has a negligible contribution to the systematic errors above 2 GeV. In each energy bin the data are fitted with a standard template-fit approach, using the reference spectra of the TRD Classifier, to determine the numbers of signal (background) events in the total sample (Fig.1). The templates are constructed from the data using pure samples of electrons and protons. These samples are selected using the ECAL estimator, $E/p$ matching, and the charge sign. The templates are evaluated separately in each bin; however, the signal templates show no dependence on the energy above 10 GeV. Therefore, all the $e$ selected in the range 15.1 - 83.4 GeV are taken as a unique signal template up to the highest energies.

In the individual $e^+$ and $e^-$ analysis a two-step fit procedure is performed. First, a template fit is used to find the number of of electrons plus positrons reconstructed with a positive charge sign, then in the second step this number is corrected for the charge confusion to obtain the number of positrons. Charge confusion occurs when an electron is reconstructed as a positron and vice versa. Charge confusion is determined using a dedicated estimator. Similarly is done to determine the number of electrons from the negative charge sign events.

![Figure 1. Left panel: Combined distribution of ECAL Classifier and TRD Classifier for a sample of preselected events: the proton population is well separated from the $(e^+ + e^-)$ signal. Right panel: After a selection on the ECAL Classifier, the template fit is performed on the TRD Classifier.](image)

5. Results and conclusion
The $(e^+ + e^-)$ flux multiplied by $E^3$ is presented in Fig. 2. Below $\sim 10$ GeV, the behavior of $\Phi(e^+ + e^-)$ is affected by solar modulation. However, above 20 GeV the effects of solar modulation are insignificant within the current experimental accuracy. From 10 GeV to 1 TeV the flux is smooth and no structures have been found in the data. Above 30 GeV the flux has been found to be compatible with a single power law.

The electron and positron fluxes multiplied by $E^3$ are presented in Fig. 3 and 4. Neither the electron flux nor the positron flux can be described by single power laws over the entire range. Between 20 and 200 GeV, the positron spectral index is significantly harder than that of electrons. This indicates that high energy positrons have a different origin from that of electrons.

The accuracy of the AMS measurement challenges current knowledge of primary $e^+/e^-$ sources and their secondary production in the interstellar medium. AMS-02 is providing for the first time simultaneous measurements of different cosmic ray species with O(%) accuracy in an extended energy range. The AMS data will allow very deep phenomenological and theoretical
studies. New phenomena are being highlighted by these measurements whose nature will be further clarified as more data will be collected by the experiment.

Figure 2. Flux of (e^+ + e^-) measured by AMS-02 together with previous measurements (references in [4]).

Figure 3. Positron flux measured by AMS-02 compared with previous measurements (references in [6]).

Figure 4. Electron flux measured by AMS-02 compared with previous measurements (references in [6]).

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