International school of subnuclear physics
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electrons flux measurement with AMS-02

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1. The AMS-02 experiment

2. electrons and positrons analysis
   2.1 $e^+e^-$ flux
   2.2 $e^+, e^-$ fluxes in time

3. Conclusion
AMS-02: Alpha Magnetic Spectrometer

PHYSICS GOALS

- Measurement of the *composition of charged cosmic rays up to TeV*
- *Direct search for primordial antimatter* (anti-nuclei)
- *Indirect search for dark matter* (matter/antimatter spectra)
- Gamma ray astrophysics
- Exotic physics (strangelets...)

ISS - May 19, 2011
AMS installation completed

measurements of *cosmic rays* (O(GeV) – O(TeV))

\[ p \sim 90\% \]
\[ e^- \sim 1\% \]
\[ e^+ \sim 0.1\% \]

He (~8%)
Be, C, Fe, ... (~1%)
Why electrons?

1. Information about the origin and the propagation of cosmic rays complementary to the hadronic component ($m_e \ll m_p \rightarrow$ very different energy losses in the interaction with ISM);

2. possible indirect detection of dark matter.

Very challenging measurement:

\[
\begin{align*}
e^-/p & \sim 10^{-2} - 10^{-3} \\
e^+/p & \sim 10^{-3} - 10^{-4}
\end{align*}
\]

high e/p rejection power is needed
AMS: A TeV precision, multipurpose spectrometer

**TRD, Transition Radiation Detector**
Identify e+, e-

**TOF, “Time of Flight”**
Z, E

**Silicon Tracker**
Z, R(=p/q)

**ECAL, Electromagnetic Calorimeter**
E of e+, e-, γ

**RICH, Ring Imaging Cherenkov**
Z, E
(σ_β/β ~ 0.1%)

**Permanent Magnet**
±Z

**Anti-Coincidence Counters (ACC)**

**Z, P are measured independently by the Tracker, RICH, TOF and ECAL**

see S. Schael talk “Highlights from AMS” for more details
Minimum requirements on the event

**TRD:**
- Minimum 8 hits used for e/p identification
- $|Z| = 1$

**TOF:**
- Relativistic down-going particle ($\beta > 0.83$)

**TRACKER:**
- $|Z| = 1$
- Track/ECAL matching to define fiducial volume

**ECAL:**
- Shower axis within the fiducial volume
- Not MIP in the first $5X_0$

Signals released by e and p have different distributions in the TRD and ECAL:

- Signals from the different TRD layers are combined with a likelihood method to define the **TRD classifier**
- Signals in the ECAL are combined in with a Boost Decision Tree technique to define the **ECAL classifier**
TRD and ECAL are the key instruments for e/p separation:

![Image showing a scatter plot with two clusters representing electrons and positrons, along with spillover protons.](image)
The flux ingredients

**Flux definition in energy interval \( \Delta E \)**

\[
\Phi(\Delta E) = \frac{N(\Delta E)}{\epsilon_{\text{trigg}}(\Delta E) \cdot T_{\text{exp}}(\Delta E) \cdot \Delta E \cdot A_{\text{MC}}(\Delta E) \cdot (1 + \delta(\Delta E))}
\]

1. \( N(\Delta E) \) = number of events in \( \Delta E \)
2. \( \epsilon_{\text{trigg}}(\Delta E) \) = trigger efficiency in \( \Delta E \)
3. \( \Delta T_{\text{exp}}(\Delta E) \) = exposure time (s) in \( \Delta E \)
4. \( A_{\text{MC}}(\Delta E) \) = Detector acceptances in \( \Delta E \) (on MC data)
5. \( (1 + \delta(\Delta E)) \) = data/MC correction
1. N(ΔE): number of events in ΔE

Sample to fit:

- **clean unitary charge** sample of downgoing relativistic particle selected from data. Protons background suppressed by mean of ECAL estimator.

Reference distribution for background:

- protons sample obtained from data using ECAL+TRD+charge sign

Reference distribution for signal:

- electrons sample obtained from data using ECAL+TRD+charge sign

Data

Fit to data

(e^+ + e^-): signal

Protons background

E = 73.51 - 141.31 GeV
All-electrons (e^+e^-) flux results

It is consistent with a single power law above 30 GeV.

The flux is smooth and reveals new and distinct information.

No structures were observed.
All-electrons ($e^+ + e^-$) flux results

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Motivations

• The energy spectra of galactic cosmic rays carry fundamental information regarding their origin and propagation.

• These spectra, when measured near Earth, are significantly affected by the solar magnetic field. A comprehensive description of the cosmic radiation must therefore include the transport and modulation of cosmic rays inside the heliosphere.

• AMS can provide the most accurate measurements of the time dependence of electron and positron fluxes since 2011 thanks to its high acceptance and the excellent performances of the detector.

Analysis method:

• same approach for \((e^+e^-)\) fluxes + Tracker for charge sign

• time binning: 27 days
Solar modulation of CR

http://neutronm.bartol.udel.edu/

http://www.sidc.be/silso/datafiles

sunspot number

 AMS start to taking data

neutron monitor counts

11 years

cycle 20
cycle 21
cycle 22
cycle 23
cycle 24


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Erice, 27.06.2015
Solar modulation, comparison with neutron monitor

$E = 4.12-4.54$ (GeV)

$\Phi_+ \text{ normalized}$

$\Phi_- \text{ normalized}$

neutron monitor norm
Solar modulation of CR – $e^-$ flux result

$E^3 \times \Phi_e$ (GeV$^2$ m$^{-2}$ sr$^{-1}$ s$^{-1}$)

Energy (GeV)

each color $\rightarrow$ $\Delta t=27$ days

PRL

Jun 2011

Dec 2011

Jun 2012

Dec 2012

Jun 2012

Nov 2013
Solar modulation of CR – e\(^+\) flux result

\[ E^3 \times \Phi_{e^+} \text{ (GeV}^2 \text{ m}^{-2} \text{ sr}^{-1} \text{ s}^{-1}) \]

Energy (GeV)

Each color \( \Delta t = 27 \text{ days} \)

PRL

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Erice, 27.06.2015
Conclusions

1. \((e^++e^-)\) flux

- 10.5 million electrons and positrons collected by AMS-02 have been analyzed to measure the \(e^++e^-\) spectrum up to 1 TeV.
- Electron plus positron spectrum measured with unprecedented precision up to 1 TeV.
- Measurement systematics within few percent in a wide energy range.
- No evidence of prominent features observed.

2. \(e^+, e^-\) fluxes in time

- same approach for \((e^++e^-)\) flux
- preliminary results \(\rightarrow\) to be finalized
- this work will be useful in the understanding of solar modulation
THANKS FOR YOUR ATTENTION
The Physics: Primordial Antimatter

- Fundamental physics & Antimatter:
  - Primordial origin (Signal: anti-nuclei)

Dirac’s Nobel speech

“We must regard it rather as an accident that the Earth [...] contains a preponderance of negative electrons and positive protons. It is quite possible that for some stars it is the other way about.”
The Physics: The quest for Dark Matter

Annihilation

\[ \chi + \chi \rightarrow p, \bar{p}, e^-, e^+, \gamma \]

Production

\[ \chi + \chi \leftarrow p + p \]

Scattering

\[ \chi + p \rightarrow \chi + p \]
The Physics: The quest for Dark Matter

Annihilation
\[ \chi + \chi \rightarrow p, \bar{p}, e^-, e^+, \gamma \]

Production
\[ \chi + \chi \leftarrow p + p \]
The Physics: Anti-Matter & Dark Matter

WIMP as the responsible of Dark Matter (?)

Direct Searches

Indirect DM search → search for (RARE IN CR) products from their annihilation….

But you should know what you expect in the ISM!!

Cosmic Rays Flux


Direct Searches

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Precise measurement of the energy spectra of B, C ... provides information on Cosmic Ray Interactions and Propagation

Interactions with the Interstellar Medium:

\[ C + (p, \text{He}) \rightarrow B + ... \]
The Physics: DM/exotic sources

The electron bump?

No bump in Fermi / PAMELA data

No fresh source of anti-p!

A confirmed positron "excess"
The Physics: DM/exotic sources

**The electron bump?**

No fresh source of anti-p!

A confirmed positron “excess”

No bump in Fermi / PAMELA data
Origin of the excess

**Astrophysical objects**

**Dark Matter**
Kopp hep-ph/1304.1184

Different energy behavior of the positron fraction:

- **Pulsars predictions:**
  - slow fall at high energies
  - anisotropic positron flux

- **Dark Matter prediction:**
  - steeper fall at high energies
  - isotropic positron flux
**e/p separation with TRD**

**Combined Probability to be electron:**

\[
P_e = \prod_{i=1}^{n} P_e^{(i)}(A)
\]

**TRD-Classifier** = \(-\log_{10}(P_e) - 2\)
e/p separation with ECAL

electrons and protons behave differently when entering the ECAL

Two complementary techniques can exploit electron/proton differences in ECAL

1) Matching measured momentum in tracker with the deposited energy in ECAL [not used for event selection, but to select control samples]

2) 3D imaging of the energy shower allows to discriminate electron or proton initiated showers [ECAL classifier, used to preselect events for further analysis]
Exposure time: geomagnetic effects

Effect on data taking:

- **Reduced livetime**: in South Atlantic Anomaly region and close to geomagnetic poles.
Exposure time : geomagnetic effects

The exposure time to a given energy along the orbit is performed only considering the time spent in the regions where the rigidity cutoff used in the event selection is lower than the energy.
2. Exposure Time

- Data taking period: **19 May 2011 – 19 May 2013**
- Average detector live-time fraction $T_{\text{exp}}/2\text{years} = 81.6\%$

3. Trigger Efficiency

Trigger efficiency 100% for Energy $>4$ GeV
Systematic errors: stability of the signal

- Dominating systematic uncertainties on $N_{e^+e^-}$
  - Knowledge of the TRD reference distributions
  - Stability of the fit result for different background levels, e.g. ECAL classifier cuts

The analysis was repeated 2000 times in each energy bin varying the ECAL classifier cut and different values of selection cuts used to construct the templates and the stability of the results verified within a 5% window in ECAL classifier cut efficiency.
Systematic errors: stability of the signal

The RMS of the $N_e$ as been used as systematics uncertainty, the effect of purely statistical contributions were taken into account and subtracted estimated from a dedicated simulation.

Negligible contribution to the measurement error below $\approx 200$ GeV

Dominant source of systematic error at higher energies ($> 500$ GeV)
4. Acceptance

\[ A_{\text{eff}}(\Delta E, \Delta t) = A_{\text{geom}} \cdot \epsilon_{\text{sel}} \cdot (1 + \delta) \]

evaluated from MC:

\[ A_{MC}(\Delta E) = \frac{N_{\text{sel}}(\Delta E)}{N_{\text{gen}}(\Delta E)} \pi l^2 \]
4. Acceptance correction $1+\delta$

$A_{\text{eff}}(\Delta E) = A_{\text{geom}} \cdot \epsilon_{\text{sel}} \cdot (1 + \delta)$

Evaluated via the disagreement in the selection efficiency between data and MC for each analysis cut.

Example: TRD reconstruction quality

\[ \frac{\epsilon_{\text{MC}}}{\epsilon_{\text{ISS}}} \]
Measurement error

Dominated by acceptance systematics below ≈100 GeV

Dominated by statistics above 130 GeV. Finite Statistics of reference distributions in the fit are the major source of systematics. With more data both errors will decrease.
Solar modulation of CR – $e^-$ flux result

Each color $\rightarrow \Delta t=27$ days

$\Phi_{e^-}(\Delta t) / \Phi_{e^-}$ vs. Energy GeV

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Solar modulation of CR – e⁻ flux result

\[ \frac{\Phi_{\text{e}^{-}}(\Delta t)}{\Phi_{\text{e}^{-}}} \]

Energy: GeV

Entries E>20 GeV

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Solar modulation of CR – e⁻ flux result

\[ \frac{\Phi_{e^+}(\Delta t)}{\Phi_{e^+}} \]

Energy GeV

each color → Δt=27 days

Jun 2011
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Solar modulation of CR – $e^-$ flux result

\[
\frac{\Phi_{e^+}(\Delta t)}{\Phi_{e^+}}
\]

Each color $\rightarrow \Delta t = 27$ days

Entries

E$>20$ GeV

- Entries: 396
- Mean: $-2.464 \times 10^{-5}$
- Constant: $25.36 \pm 1.77$
- Mean: $-0.00082 \pm 0.06802$
- Sigma: $1.134 \pm 0.055$