

PRECISE MEASUREMENTS OF THE COSMIC RAY FLUXES WITH AMS-02 AND IMPLICATIONS FOR DARK MATTER SEARCH

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AMS-02: SCIENTIFIC GOALS

- Precise measurements of cosmic rays in the GeV to TeV region
- Study cosmic ray sources and propagation
- Search for primordial antimatter
- Indirect search for dark matter



COSMIC RAYS

Cosmic rays are high energy particles produced outside the solar system



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COSMIC RAYS IN THE MILKY WAY



Primary cosmic rays:

- Produced directly in the source
- Known sources (E< 10¹⁶ eV): SNRs
- Primary cosmic rays include e⁻, p, He, C, ...

Secondary cosmic rays:

- Produced in the interaction of primaries in the interstellar medium
- Secondary cosmic rays include e⁻, e⁺, anti-p, B, ...

$$p + p_{\text{ism}} \to \pi^+ + \dots$$
$$\downarrow \mu^+ + \nu_\mu$$
$$\downarrow e^+ + \nu_e + \overline{\nu}_\mu$$

COSMIC RAYS FLUXES [in the GeV to TeV energy range]



ANTIMATTER

• At the time of the Big Bang, i.e. 14 billion years ago, the Universe was thought to be made of an equivalent mixture of matter and antimatter.



- The Universe seems to be matter-dominated:
 - Is there any antimatter left ?
 - Do anti-stars or anti-galaxies exist ?

DARK MATTER

- Less than 5% of the energy density of the Universe is in the form of baryonic matter.
- Dark matter accounts for ~27% of the energy density of the Universe.

- We do not know what dark matter is made of .
 We only know that:
 - * it has no electric charge
 - * it does not interact via EM interaction
 - * it does interact gravitationally



DARK MATTER CANDIDATES



Let's suppose that DM is made of WIMPs.

WIMPs are predicted by most extensions of the SM:

weakly interacting

- I0 to I000 times heavier than the proton
- no electric charge
- produced during the big-bang at early times

DARK MATTER SEARCH STRATEGIES



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INDIRECT DARK MATTER SEARCH



... in other words: a multi-messenger approach !

THE ALPHA MAGNETIC SPECTROMETER

A particle physics detector operating aboard the International Space Station





- Size: 5m X 4m X 3m
- Weight: 7.5 Tons
- Power consumption: less than 2.5 kW

AMS: A TeV precision, multipurpose spectrometer



THE LAUNCH OF AMS-02



Cap Canaveral: May 16th 2011



THE AMS-02 COLLABORATION



AMS-02: THE EXPERIMENTAL CHALLENGES



- AMS-02 detects 54 million particles/day
- Data taking is running continuously since 4 years:
 - 35 TB/year
 - 60 Billion events detected



AMS Data Flow



AMS Payload Operations Control and Science Operations Centers (POCC, SOC) at CERN





TDRS Satellites

Commanding: 1 Kbit/s Monitoring: 30 Kbit/s



White Sands Ground Terminal, NM

ENERGY MEASUREMENT



MOMENTUM MEASUREMENT

Rigidity=pc/(Z|e|)



REDUNDANT CHARGE IDENTIFICATION

measuring heavier nuclei



AMS-02 RESULTS



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COSMIC RAY PROTON MEASUREMENTS



AMS-02 PROTON FLUX

- Measurement based on 300 million proton events
- Proton flux cannot be described by a single power law
- A transition in the spectral index occurs around 300 GeV NEW!





POSITRON AND ELECTRON COSMIC RAYS

PHYSICAL REVIEW LETTERS

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High Statistics Measurement of the Positron Fraction in Primary Cosmic rays of 0.5–500 GeV with the Alpha Magnetic Spectrometer on the International Space Station

PHYSICAL REVIEW LETTERS

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Electron and Positron Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the International Space Station

SEARCH FOR PRIMARY ANTIMATTER: POSITRONS



Main background: protons (S/B~10⁻⁴) Background is reduced combining complementary detection techniques

LEPTON-HADRON SEPARATION



Proton rejection

TRD

With 90 % e⁺ efficiency



THE POSITRON FRACTION

Defined as : $F = \frac{\Phi_{e^+}}{\Phi_{e^+} + \Phi_{e^-}} = \frac{N_{e^+}}{N_{e^+} + N_{e^-}}$

- Acceptance and efficiencies simplify in the ratio
- A ratio of number of counts

Challenge :

Proton rejection of the order of 10⁶ is required

What we do expect :

 Positrons are secondaries, produced in protons interactions with the Interstellar medium.

• If positrons are ONLY secondaries, the positron fraction is expected to decrease with energy.

LOW ENERGY POSITRON FRACTION

Fraction begins to increase above 10 GeV



POSITRON FRACTION

Based on 10.9 million positron and electron events



• No sharp structure

- With the current sensitivity, the flux is isotropic
- Above 200 GeV the PF is no longer dependent on energy NEW.

ELECTRON AND POSITRON FLUX



The electron flux and the positron flux are different in their magnitude and energy dependence.

SPECTRAL INDEX NEW!



- The spectral indices of electrons and positrons are different
- Both spectra cannot be described by single power laws
- Change of behaviour at ~30GeV

The rise in the positron fraction is actually due to an excess of positrons, not the loss of electrons (the positron flux is harder).

A COSMIC RAY PUZZLE

- The positron fraction is expected to be a decreasing function of energy
- The measured rise is incompatible with the conventional model
- What is the origin of the galactic positrons ?



MINIMAL MODEL TO FIT AMS DATA

$$\begin{array}{ll} \label{eq:point} \textbf{Diffuse Term} & \textbf{Source Term} \\ \Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s} \\ \Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s} \end{array}$$

Positrons:

- Diffuse term: secondary production
- Source term



Electrons:

- Diffuse term: Primary and secondary production
- Source term

POSITRON FRACTION



SEARCH FOR PRIMARY ANTIMATTER: ANTIPROTONS

The antiproton to proton ratio is measured in the range between I to 450 GV using 290.000 antiprotons selected from the data sample of 54 billion events.

Status report

Antiproton/proton separation





ANTIPROTON-TO-PROTON RATIO



Dark matter interpretation of AMS02 AntiProton ratio will require a detailed study of cosmic-ray propagation/interactions. Theoretical parameters need to be re-tuned after the high precision AMS02 results on He,Li,C flux/ratio will be released.

STATUS REPORT ON HELIUM FLUX

- Measurement based on 50 million He events
- He flux cannot be described with a single power law
- A transition in the spectral index occurs around 300 GeV NEW!



STATUS REPORT ON CR NUCLEI

Sensitive to CR propagation parameters



"I think AMS's data is taking the whole analysis of cosmic rays in this energy range to a whole new level. It's revolutionizing the field." John Ellis @ AMS days JOHN EIIIS @ AMS days

SUMMARY

- The AMS-02 experiment operates onboard the ISS since May 2011
 - All the detectors are working as expected
 - More than 60 billions events were recorded so far
 - Data taking up to 2020
- The latest AMS-02 measurements:
 - the positron fraction
 - the fluxes of electrons, positrons, protons
 - Status report on: the antiproton/proton ratio, helium, and other nuclei

provide precise and unexpected information

The accuracy of the data requires a comprehensive model to ascertain if their origin is from dark matter, astrophysical sources, acceleration mechanisms or a combination

Stay tuned for He, anti-p, B/C ... papers!

THANKYOU FORYOUR ATTENTION !

