Study of Cosmic Ray Proton and Helium at small atmospheric depths by BESS spectrometer

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BESS Collaboration

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Balloon-borne Experiment with a BESS Superconducting Spectrometer

- **Antiparticle/Antimatter**
  - $\bar{p}, \bar{D}$
    - CR Propagation
    - CR Origin studies
  - $\bar{He}$
    - Baryon Asymmetry

- **Cosmic-ray Data**
  - $p, He$
    - Propagation
    - Solar Modulation,
    - Interactions in the atmosphere
  - $\mu$
    - CR proton (0.5 – 100 GeV) and helium (0.2 – 50 GeV/n) spectra.
    - Improved upper limit on antihelium search.
    - Atmospheric muon spectra at various altitudes (1 – 10 GeV/c).
    - CR electron spectra in 0.1 – 10 GeV.

9 annual flights from 1993 – 2002. Results Published on:

- ~950 Antiproton events detected. (spectrum, solar cycle studies, …)
BESS-99 Flight

- Balloon ascended from ground level to a height of 36 Km in 3 hours.
  
  (Top Of the Atmosphere)

  Around $5g/cm^2$ of air above

- It remained at 36 Km height for 32 hours

- 1999 flight launched from Lynn Lake, Canada
  
  $56^\circ 48' N, 101^\circ 25' W$

- Geomagnetic cut off ~ 0.4GV

- Data collected while balloon ascend was analyzed at NSU.
BESS-99 Spectrometer

- Superconducting Solenoid (~1 Tesla)
- JET/IDC for Rigidity (pc/Ze) measurement
- TOF for velocity and energy loss measurement
- Aerogel Cherenkov detector for particle id
- Shower Counter for electron/positron detection.
Measurements and particle identification

• **Rigidity** $R$  By reconstructing particle trajectory using JET and IDC data.

• **The transverse momentum resolution** is,

\[ \frac{\Delta p_t}{p_t} \approx 0.5 \, p_t \quad \text{in (\%)}, \quad \text{where } p \text{ is in (GeV/c)} \]

(eg., 0.5% at 1 GeV/c, 5% resolution at 10 GeV/c).

• **Velocity** $\beta$  is derived from: TOF between upper and lower scintillators and path length of particle trajectory in chambers.

• For a timing resolution of 100 ps in TOF, $\frac{\Delta \beta}{\beta} \sim 0.024$ for a single charged particle with $\beta \sim 1$

• $\frac{dE}{dx}$ is measured with a resolution of 6% for all counters for MIP’s.
• **The charge** $z$ of the particle is identified using,

$$\frac{dE}{dx} \propto \frac{z^2}{\beta^2} R$$

A scatter plot of $dE/dx$ against $R$ separates various charges.

• **Mass** $m$ of the particle can be reconstructed using,

$$m = zeR\sqrt{\left(\frac{1}{\beta^2} - 1\right)}$$

For a given charge $z$, a scatter plot of $\frac{1}{\beta}$ against $R$ separates isotopes.

• **Sign of the charge** is determined from track curvature.

• **Up/Down direction** is provided by TOF measurement.

• **Cherenkov data** provides good separation between electrons and protons up to 3 GV rigidity. Also helps separating muons and pions
Data Analysis

• Choose the Trigger

  T0 Low Countdown trigger: 1/3 MIP in upper and lower TOF with a Count Down of 1/60

  Low energy proton trigger: TT trigger + Aerogel ADC less than a threshold value with a Count Down of 1/2

• Select clean, single track events

• Particle Identification and separation

• Flux and Background estimation
Select single track events

Select Events with

- Only one TOF hit in top and bottom layer.
- Only one track in JET/IDC
- Consistency between track and TOF hit position
- Track quality cuts (number of JET hits, quality of fit etc)
- TOF quality cuts (by studying the location of extrapolated track)

- Accept Events with clean single track
- Reject Particles interacted in the detector to produce secondaries.

Instrument material: \(18g/cm^2\) along vertical
Particle Identification

- To Low Count Down Trigger

- Low energy proton Trigger

- Proton

- Helium

- Muon

(Charts showing particle identification based on dE/dx in upper and lower TOF against Rigidity (GV).)
Selection cuts

After selecting single track events, further selection cuts were applied for particle identification.

\[ 1.0 \leq \left( \frac{dE}{dx} \right) < 4.0 \]

in upper TOF \textit{ (proton component) }

\[ 4.0 \leq \left( \frac{dE}{dx} \right) < 14.0 \]

in upper TOF \textit{ (helium component) }

\[ R > 0.3 \]

for all components

\[ 0.6 \leq m^2 \leq 1.6 \]

(proton component)

\[ 1.6 \leq m^2 \]

(helium component)

\[ m^2 = R^2 \left( \frac{1}{\beta^2} - 1 \right) \]

determined from velocity and rigidity measurements
Particle identification…
Flux Estimation

For a given trigger, Flux at the detector location

\[ F_{\text{det}} = \frac{N \cdot C_d}{S\Omega \cdot T_{\text{live}} \cdot \Delta E \cdot \varepsilon_{\text{tr}} \cdot \varepsilon_{\text{nuc}} \cdot \varepsilon_{\text{dat}}} \]

- \( N \) Number of observed events
- \( C_d \) Count down rate for trigger (60(T4), 2(T15))
- \( S\Omega \) Geometrical acceptance (0.18 \( m^2 \) Sr)
- \( T_{\text{live}} \) Live time of data collection (0.87 \( \times \) \( T \))
- \( \Delta E \) Kinetic energy range in the bin (0.82 GeV/n)
- \( \varepsilon_{\text{tr}} \) Efficiency of trigger(1(T4), 0.144 \( \pm \) 0.021(T15))
- \( \varepsilon_{\text{nuc}} \) Efficiency of nuclear interaction in detector (0.8)
- \( \varepsilon_{\text{dat}} \) Efficiency of data selection cuts (0.9)
Helium flux

K.E = 0.18 - 1 GeV/n

Helium Flux (m⁻¹g⁻¹sr⁻¹(GeV/nucleon)⁻¹)

Atmospheric depth (gm cm⁻²)
Proton, Helium measurement in BESS-95 experiment

Cosmic-ray spectra near the LISA orbit

C Grimani et.al., Class. Quantum Grav. 21(2004) S629 – S633
These are very preliminary results.

Corrections Needed for:
- Interactions in the detector
- Interactions of primary in the small atmosphere above
- Secondary helium production in the atmosphere
BESS-2001 measurements

CAPRICE-98 measurements

- Atmospheric shower simulations are necessary for neutrino background estimations.
- Air shower simulations are compared with observed muon spectra in the atmosphere.
- \( P, He \) spectra can be used for fine tuning the models.
- Very few direct measurements in the past.
- BESS can provide information at few GeV energies.

E. Mocchiutti et al., 28th ICRC proc.
Conclusions

• BESS 1999 flight gave a good sample of proton and helium events at various atmospheric depths.

• Preliminary results from He data (<1 GeV/n) are encouraging.

• A very large sample of proton data in the whole atmospheric depth is separated.

• Accurate estimation of \( p, \)He flux and background estimations will be done in the coming months.
Time Of Flight system

- 10 plastic scintillators in upper layer, 12 in lower layer
- Each scint. $950 \times 100 \times 20$ mm
- Bicron BC-404, $n = 1.56$
- One 2.5 inch PMT per scintillator, connected with a light guide.
- Magnetic field at PMT location was 0.2 T
- Beam tests with 1 – 4 GeV/c proton, pion beams at KEK, Japan.
- From the test, timing resolution of each scintillator was found to be 50ps over entire length.
Cherenkov counter

- Sensitive area: 0.6\(m^2\)
- Silica aerogel radiator blocks, \(n = 1.032\)
- Thickness of block 8 cm
- Blocks in diffusion box, viewed by 46 PMT’s fixed to the side. (2.5 inch PMT).
- For cosmic muons in 2 – 10 GeV/c, 11.5 mean photoelectrons reaching PMT.
- Distribution obtained by summing up all 46 ADC’s for proton and muon is shown here. (muons 2-10 GeV/c, protons 1.5 to 2.5 GeV/c from balloon flight).
- For ADC combined threshold at 20 counts, muon rejection factor was \(1.7 \times 10^4\) while keeping proton detection efficiency at 99%.

Y. Shikaze et.al., NIM A 455 (2000) 596-606
The JET chamber

- A cylindrical chamber inside magnet. 0.85m diameter, 1.34m in length
- 1T uniform, axial magnetic field
- Ar + CO2 Gas Mixture
- Subdivided into 4 sections along length by 3 cathode planes, with wire separation 6.7mm.
- At the center of each of the four sections, there is a signal wire plane.
- Signal plane has sense wires equally spaced at 13.4mm intervals alternated with potential wires in staggered arrangement.
- 2 central sections have 52 sense wires, left and right section 32 wires.
- Maximum drift distance in one section is 95mm

- Particle trajectory in \((r, \Phi)\) plane by drift time measurement.
- Trajectory in Z-direction by charge division readout
- Spatial resolution of chamber is 175mm (X,Y plane), 2.0cm (Z).
- Max.detectable Rigidity = 200 GV
Inner Drift Chamber

- IDC is a cell type, arc shaped drift chamber inside magnet
- 1.06m long, at radii 384mm, 420mm
- $Ar + CO_2$ gas mixture
- Divided into 2 layers in radial
- In each layer, sense and field wires are alternately arranged.
- Hit position in $(r, \Phi)$ plane is determined by measuring drift time.
- Hit position along Z-direction is determined using the signal induced on two vernier pads above and below the sense wires.
- Absolute Z-position of hit can be estimated with a precision of 350 microns.
- (A coarse estimate of Z-location of hit is given by JET-chamber).
- Spatial resolution is $220\, \mu m$ in $(r, \Phi)$

![Diagram of Inner Drift Chamber](image)
BESS Trigger Scheme

**T0 Trigger**

Based on certain number of MIPs in the upper and lower TOF scintillators hit by the charged particle.

4 bits

**TT Trigger**

IDC hit pattern selection.

(By comparing the observed IDC cell hit patterns with the stored hit patterns simulated for various types of events (particles...))

**IDC rigidity selection**

By making an on-line estimate of deflection using a look-up table of IDC cells hit.

8 bits

**Master Trigger (T1)**

Count Down (prescale) Circuit.

(Unbiased Events)

Logic Circuit generating "Biased" events.

Using information from Cerenkov Detector and other signals.

12 bit output

**T0 Low Count Down trigger**

Low energy proton trigger