Future balloon experiments for the measurement of electron spectra at high energy

P. S. Marrocchesi
Univ. di Siena
INFN-Pisa
Gruppo Collegato di Siena

Outline of the talk

- Physics goals

- Magnetic spectrometer: - PEBS

- Calorimetric experiment: - CALET-POLAR

- Electron Synchrotron experiment: - CREST
PEBS - Positron Electron Balloon Spectrometer

Stefan Schael
RWTH Aachen
• A dedicated balloon experiment to provide a competitive measurement of the cosmic ray positron flux.

• The spectrometer is based on a scintillating fiber tracker with SiPM readout.

• Proton rejection achieved by a combination of ToF, TRD, ECAL and Tracker.

• R&D Phase: 2006 - 2009

• PEBS-1 with permanent magnet (First Flight: Summer 2012 from Kiruna, Sweden)

• PEBS-2 with superconducting coil (proposed for an Antarctic flight in 2014)
PEBS-1 Experiment

Focused on the measurement of the positron fraction below 20 GeV
Positron fraction

PEBS-1: +/- separation up to 20 GeV
PEBS-1 Permanent Magnet

Weight 250 kg, B-Field = **0.34 Tesla**, 
\( R_{\text{Inner}} = 0.31 \text{ m}, \quad R_{\text{Outer}} = 0.43 \text{ m}, \quad \text{Height} = 12.5 \text{ cm} \)
PEBS-1 Experiment

2012 / 2013

\[ \frac{\sigma_p}{p} = 0.011 \cdot p \oplus 0.07 \]

Spectrometer:
± separation up to 20 GeV

Fiber tracker:
250 μm closely packed fibers readout by SiPM array
- 2 x 8 layer of straw modules and 10μm fiber fleece radiator.
- TR x-ray photons absorbed by Xe/CO₂ mixture (80:20) in 6 mm straw tubes with 30μm tungsten wire.
- Proportional mode with a gas-gain of 3000.
- The signals are readout by VA chips.

- SAME DESIGN AS THE AMS-02 TRD

- Detection possible with Lorentz boosts > 300.
- Discriminate e+ (TR) against p (no TR)
Launch Sides for PEBS-1: Kiruna => Alaska
Geomagnetic-Cutoff

North Pole

Kiruna, SWE

AMS-02 orbit

Ft. Sumner, NM

South Pole

Cut-off [GV]

10^2

10

1

0

10^{-2}

10^{-1}

10^{-2}

10^{-3}

10^{-4}

10^{-5}

10^{-6}

10^{-7}

10^{-8}

10^{-9}

10^{-10}

10^{-11}

efficiency [%]

100

90

80

70

60

50

40

30

20

10

0

10^{-1}

1

10

10^2

rigidity [GV]

Polar Balloon Experiment

AMS-2
PEBS-2

- A dedicated balloon experiment to provide a competitive measurement of the cosmic ray positron flux up to 2 TeV.

- The spectrometer is based on a scintillating fiber tracker with SiPM readout in a superconducting magnet with $BL^2 = 0.8Tm^2$.

- The proton rejection of $\sim 10^6$ can be achieved by a combination of ToF, TRD, ECAL and Tracker.

- Key parameters:
  Acceptance: $\sim 3000 \text{ cm}^2 \text{ sr}$
  Weight: $\sim 2000 \text{ kg}$
  Power: $\sim 900 \text{ Watt}$

- R&D Phase:
  2006 - 2009

- Construction Phase:
  2010 - 2012

- First Flight (from McMurdo): December 2014?
\[ \frac{\sigma_p}{p} = 1.8 \cdot 10^{-4} \cdot p + 0.008 \]
PEBS

TRD Proton Rejection

AMS2 20 Layers  PEBS 16 Layers  PEBS 24 Layers

Rejection vs. p [GeV]

- A log-log plot showing the rejection of protons as a function of momentum (p) for different layer configurations in a TRD (Time-Projection Chamber) detector.
- The graph compares three different setups: AMS2 with 20 layers, PEBS with 16 layers, and PEBS with 24 layers.
- The rejection decreases significantly with increasing momentum, and the effectiveness varies between the configurations.
Proton Rejection TRD+ECAL

- AMS2
- PEBS

Rejection vs. $p$ [GeV]
Spectra corrected for solar modulation

Positron fraction up to 2 TeV

\[
e^+/(e^+ + e^-)
\]

\[10^{-1}
\]

\[10^{-2}
\]

\[10^{-3}
\]

\[P \text{ [GeV]}
\]

- PAMELA 2008
- weighted mean HEAT, AMS-1, TS-93, CAPRICE
- Galprop
- Galprop + Pulsar
- Galprop + 500 GeV Kaluza-Klein Dark Matter
- PEBS-2 40 days, 3000 cm² sr

Stefan Schael
RWTH Aachen
positron & electron fluxes up to 2 TeV

Stefan Schael
RWTH Aachen
Proposal for PEBS-1 & PEBS-2 submitted to NASA in March 2009 by:

- Prof. J. Beatty, Ohiho State University, USA  
  ToF, Gondola

- Prof. G. Dissertori, ETH Zuerich, Switzerland  
  ECAL

- Prof. Dr. T. Nakada, EPF Lausanne, Switzerland  
  ECAL

- Prof. Dr. S. Schael, RWTH Aachen, Germany  
  Co-PI for PEBS  
  Magnet, TRD, Tracker

- Prof. Dr. S. Swordy, University Chicago, USA  
  Co-PI for PEBS  
  RICH, ToF
CALET - POLAR

- Balloon flights of the CALET collaboration
- Collaboration with Japanese National Ballooning (ISAS)
CALET on a balloon

- **bCALET-1** (1/64 scale of CALET)
  - was flown in 2006 from Sanriku balloon center

- **bCALET-2** (1/16 scale of CALET)
  - in preparation
  - approved for short (test) flight in the Summer 2009 from Japan

- **bCALET-3** (1/4 scale of CALET)
  - approved for test flight in 2010 from Brazil or Australia

- **CALET-POLAR**
  - proposed for Long Duration Flight in 2011 from Svalbard

Technical flights:
- Prototype tests
- System tests
- Science LDB flight
GF $\sim 7300$ cm$^2$ sr total of 26 $X_0$

- inclusive electrons + positrons BELOW 1 TeV: investigate ATIC structure with NO Carbon target

CALET- POLAR concept

<table>
<thead>
<tr>
<th>Detector</th>
<th>Dimensions</th>
<th>Weight</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIA</td>
<td>810 x 810 x 50</td>
<td>50</td>
<td>170</td>
</tr>
<tr>
<td>IMC</td>
<td>640 x 640 x 60</td>
<td>70</td>
<td>84</td>
</tr>
<tr>
<td>WCAL</td>
<td>500 x 500 x 120</td>
<td>450</td>
<td>162</td>
</tr>
<tr>
<td>NEUCAL</td>
<td>680 x 680 x 100</td>
<td>168</td>
<td>50</td>
</tr>
<tr>
<td>Trig+DAQ</td>
<td></td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>TOT</td>
<td></td>
<td>738</td>
<td>501</td>
</tr>
</tbody>
</table>
Full containment of the electromagnetic shower in 26 $X_0$.

**WCAL**

**IMC**

**Longitudinal Profile**

Shower start: 3 $X_0$

$\alpha$: 4.86, $T_{max}$: 9 $X_0$

$E_d$ [GeV]

$t$ [X$_0$]

**Longitudinal profile in IMC**

$E_d$ [GeV]

$t$ [X$_0$]

Event #6

$E_0 = 589.269$ GeV

IMC Ed = 0.26 GeV

WCAL Ed = 12 GeV

Chi2ndf = 2.46; p = 0.1

100.00 kkeV

Number of neutrons: 87±87±0
Large longitudinal leakage of the hadronic shower in 26 $X_0$
Example of early interacting proton generating an “electron-like” shower

WCAL

IMC

neutrons

Longitudinal profile in IMC

Longitudinal profile in WCAL
Detector Development

Lower half of the Silicon Array (SIA)

Pair of Si sensors (64 pixels each) developed in Italy for the SIA

SciFi Belts

MAPMT

FEC

SciFi Belt

64-anode PMT

BGO

FEC (VA32, TA, 16bits ADC, FPGA)

FEC-unit

MAPMT
CALET on the ISS
- 2013

CALET-POLAR balloon flight
- 2011
2006 LAUNCH - 17 DAYS – PEGASO (Italian Space Agency - ASI)

COMPLETE CIRCUMPOLAR TRAJECTORY
Detect synchrotron radiation of primary electron as it passes through Earth’s magnetic field

- Advantage: Effective area of instrument greatly increased.
  - Area determined by $R_s$, not physical size.

Antarctic long duration balloon flights

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**the CREST collaboration:**

Penn State Univ.
Indiana Univ.
Univ. of Chicago
Northern Kentucky Univ.
Univ. of Michigan
**Signal and Background**

- **Signal:** Electron events appear as a line of photons arriving nearly simultaneously;

- CREST will extend the TeV electron flux measurements from ~2 TeV to ~50 TeV (depending on length of flight);
  - Mean photon energy related to primary electron energy:  
    \[ \varepsilon = 12 \text{ keV for 2.5 TeV electron; 5 MeV for 50 TeV electron;} \]
  - Strong atmospheric absorption below ~30 keV;

- **Backgrounds:**
  - Random singles coincidences (cosmic and CR shower x-ray photons and large charged particle flux);
  - Interactions in the detector and frame;
  - Requires \(4\pi\), efficient discrimination against charged particles.
Surviving synchrotron photons at 4 g/cm²: 75°S & 135°E

Interaction between electron and magnetic field

9.4 TeV electron released at 400 km above the ground at \( \cos(\theta) = -0.32 \). 416 photons are generated and **115 photons survive through the atmosphere**.
Basic detector: 1024 BaF$_2$ crystals (2 cm thick, $\phi = 5$ cm) read by 2” PMTs:

- ⇒ segmented system to identify line of photons;
- ⇒ photon energies 20 keV to 50 MeV;

Hermetic plastic scintillator veto paddles (2.6 m) with waveshifting fiber readout:

- ⇒ ability to veto charged particles at as close to 100% efficiency as possible;
- ⇒ fast (~1 ns) timing ensures photons are synchrotron, not random background;

Antarctic flight expected in 2010/2011

Second flight in 2011/2012

Detector area
- ~5.8 m$^2$
- ~2.0 m$^2$ in crystals only
For 4-fold or greater coincidences, co-linear, 6 ns time window;

Goal: Keep rate < 1% of expected event rates;

~1 in 30 day flight with 40 keV threshold.

<table>
<thead>
<tr>
<th>Electron Energy [TeV]</th>
<th>Number of Electrons for a 28 day flight</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 - 5</td>
<td>31</td>
</tr>
<tr>
<td>5 - 10</td>
<td>11.2</td>
</tr>
<tr>
<td>10 - 20</td>
<td>5.6</td>
</tr>
<tr>
<td>20 - 50</td>
<td>2.8</td>
</tr>
<tr>
<td>&gt; 50</td>
<td>2.2</td>
</tr>
</tbody>
</table>

LOW signal rate:

About 2 events/day above 2 TeV;
Assumes $E^{-3.3}$ spectrum with no cutoff.