PEBS: Positron Electron Balloon Spectrometer

- Physics Goals
- Detector Design
- Current Status

Cosmic ray backgrounds in dark matter searches
25 January 2010, AlbaNova, Stockholm

Fabien Zehr
EPFL, Lausanne, Switzerland
Interesting feature seen in electron+positron spectrum...

![Graph showing cosmic ray backgrounds in dark matter searches with an inset highlighting an interesting feature.]

---

Cosmic ray backgrounds in dark matter searches
25 January 2010
Fabien Zehr
PEBS
... and in positron fraction $\frac{e^+}{e^+ + e^-}$
... and in positron fraction $\frac{e^+}{e^+ + e^-}$

Not seen in antiproton fraction $\frac{\bar{p}}{\bar{p} + p}$
PEBS: Balloon-borne experiment

Weight ~2000 kg
PEBS: Balloon-borne experiment

- Cheaper than space detectors
- Multiple flights
- Reoptimization between flights
- Short time data taking (max 40 days)
PEBS Goals

PEBS I

*North pole: 5 days flights in Summer 2012/2013*

- Electron + positron up to ~1 TeV
- Positron fraction up to ~30 GeV

PEBS II

*South pole: 40 days flights in Winter 2014/2015*

- Positron fraction up to 1.8 TeV

Challenges:

- Proton rejection (at 100 GeV p/e = $10^4$, at 1 TeV $10^5$)
- Charge separation requires very strong magnetic fields.
Why at the poles?
I) Full sky coverage in conjunction with AMS-2
Why at the poles?
II) Geomagnetic Cutoff

AMS-2 Low Energy Threshold: ~2GeV
PEBS-1 Experiment

$\frac{\sigma_p}{p} = 0.011 \cdot p \oplus 0.07$

Acceptance:
Spectrometer: 1000 cm$^2$ sr
ECAL+TRD: 7500 cm$^2$ sr

Weight $\sim2000$ kg  Power Consumption $\sim900$ W

Cosmic ray backgrounds in dark matter searches
25 January 2010

Fabien Zehr
PEBS
Cosmic ray backgrounds in dark matter searches
25 January 2010

Fabien Zehr
PEBS

PEBS-2 Experiment

Antarctica, 2014/2015

\[ \frac{\sigma_p}{p} = 1.8 \cdot 10^{-4} \cdot p \oplus 0.008 \]

\[ B = 2T \]
The PEBS ScFi Tracker

PEBS-1: 36 modules, l= 86cm, 80 km fibers, 576 MPPC arrays
PEBS-2: 60 modules, l=2000cm, 310 km fibers, 960 MPPC arrays

scintillating fibers

\( \lambda_p = 440 \text{nm} \)

SiPM arrays

\( \varnothing 250 \mu \text{m} \)

frontend electronics

~20 photons/MIP
The PEBS ECAL

≈ 840 mm

≈ 108x7.5 mm

W or Pb absorber

W or Pb absorber

W or Pb absorber

Superlayer

Total: 7 superlayers

≈ 16 \times X_0

SiPM readout

Scintillating bars with embedded fibres
ECAL Projected Performance

Good performance up to 1 TeV electrons

Shower contained within the ECAL

Energy resolution

Cosmic ray backgrounds in dark matter searches
25 January 2010
Electron and proton distributions from TRD 20-layer prototype testbeam data.

Analysis of TRD prototype testbeam data, using first 16 layers.

Proton rejection factor for positron measurement.

Proton rejection ~1000.

2009 test beam:
PS accelerator:

- Secondary beam with protons, pions and electrons up to 10 GeV
- 2 weeks beam
- New electronics
ECAL Prototype Results

ECAL results coming soon...
Will be presented at

THE 12TH VIENNA CONFERENCE ON INSTRUMENTATION
FEB 15-20, 2010

Next beamtime: September 2010
SPS secondary beam
protons, pions, electrons up to 450 GeV.
Tracker Prototype Results (2008)

- MIP Signal 10 Photons
- Tracking Efficiency ≥ 99%
- Position resolution 0.07 mm (2008) ⇒ 0.05 mm (2009)

Signal Plot Hamamatsu MPPC 5883 + Kuraray Fiber
(central region => complete cluster amplitude contained)

σ = 70 μm

Cosmic ray backgrounds in dark matter searches
25 January 2010

Fabien Zehr
PEBS
PERDAix: Proton Electron Radiation Detector Aix-la-Chapelle “Mini PEBS”

Measure Proton and electron fluxes up to 5 GeV.

Two independent fittings of the solar modulation parameter $\Phi$.

Simple experiment. Can be launched each year to monitor the solar constant over long periods.

Gain experience for PEBS

First flight scheduled for autumn 2010, Kiruna, Sweden
PEBS projected performance: PEBS I positron fraction

Positron fraction

- Weight Mean AMS-1, HEAT, Caprice
- $e^+/(e^+ + e^-)$ PEBS-1
- Galprop Phi=500 MV Phi=2 MV
- Galprop Phi=500 MV Phi=1000 MV

PEGS-1, 5 days flight
1000 cm$^2$ sr (Spectrometer + ECAL + TRD)
PEBS projected performance: PEBS I electron + positron flux

**Electron+Positron Flux**

- **Galprop Electrons+Positrons**
- **Galprop+DM**
- **Galprop+Pulsar**
- **Electrons+Positrons PEBS**
- **Electrons ATIC-2**

**PEBS-1, 5 days flight**

7500 cm² sr (ECAL + TRD)
A dedicated balloon experiment could provide a competitive measurement of the cosmic ray electron & positron flux.

A novel scintillating fiber tracker with SiPM readout allows the construction of large area, high resolution (0.05 mm), low power and low weight tracking detectors.

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

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

R&D Phase:
2006 – 2009
Construction Phase:
2010 - 2012

First Flight: Summer 2012 from Kiruna, Sweden
Backup Transparencies
Proposal for PEBS-1 & PEBS-2 submitted to NASA in March 2009 by:

- Prof. J. Beatty, Ohio State University  PEBS ToF, Gondula
- Prof. G. Dissertori, ETH Zuerich, Switzerland  PEBS ECAL
- Prof. Dr. T. Nakada, EPF Lausanne, Switzerland  PEBS ECAL
- Prof. Dr. S. Schael, RWTH Aachen, Germany  PEBS Magnet, TRD, Tracker
- Prof. Dr. S. Swordy, University Chicago, USA  PEBS Trigger, DAQ, RICH
Dark Matter Searches

Charged particles

\(\bar{e}^+, \bar{p}, \bar{D}, \ldots\)

\(\gamma, \nu\)

Cryogenic detectors

~20% energy ionization

~100% energy

FNAL, LHC, ILC

AMS

2626

Liquid Xe

NaI, Xe

Al2O3, LiF

CaWo4, BGO

Antares, Km3,

Amanda, Icecube

GLAST

Dama, CDMS,

GENIUS,

CREST,

Edelweiss,

CANGAROO,

HESS,

MAGIC,

Veritas,

...
Dominant
\[ X + X \rightarrow A \rightarrow b \overline{b} \text{ quark pair} \]

B-Fragmentation known!
Hence Spectra of Positrons, Gammas and Antiprotons known!

\[ \text{Galaxy} = \text{Super B-Fabrik with rate } 10^{40} \times \text{B-Factory} \]
Cosmic Ray Spectra

Proton Flux: \[ F_p : E^{-2.74} \]

Electron Flux: \[ \Phi_e : E^{-3.43} \]

Proton/Positron Ratio:

\[
\begin{align*}
\rho &= \frac{E}{1\, Te\xi}^{-1} \\
\tau_{\text{positron}} &= 2.1 \times 10^5 \gamma \rho \left( \frac{E}{1\, Te\xi} \right)^{-1}
\end{align*}
\]
\[ F_a : E^{-\gamma_{\alpha}} \varepsilon^{-E/E_{\chi\nu\tau}} \]
Antarctic LDB Facilities (new)
Jan. 16th 2005
Previous record of 31 days and 20 hrs broken.

Dec. 16th 2004
Launch from McMurdo.

Jan. 27th 2005
Landing.

Figure 1. Balloon trajectory of the CREAM flight. CREAM broke both distance (~14,000 nautical miles) and duration (41 days 21 hrs 36 mins) records for a LDB flight.
Figure 2. Altitude and latitude of the balloon.
Cosmic-ray flux at 3g/cm² (40km)
BESS
An Instrument of Some Complexity
PEBS-1 Permanent Magnet

Weight 250 kg, B-Field 0.3 Tesla,
rInner=0.31 m, rOuter = 0.43 m, Height = 12.5 cm
Silicon Photomultipliers
(Geiger-mode APD)

- avalanche photo diodes (APD) operated in Geiger mode
- internal gain $\sim 10^6$, compact in dimension, insensitive to magnetic fields, low bias voltage ($<100$ V)
- noise is an issue
Photon detection efficiency

@ 440nm

PDE

0.6

0.5

0.4

0.3

0.2

0.1

0

mean overvoltage / V

0

1

2

3

4

5

MPPC 5883

FBK-irst 2008

FBK-irst 2007
optical glue layer on top of Hamamatsu MPPC 5883 defines fiber-SiPM-gap
Expected Resolution

over voltage 2.4 V

over voltage 1.5 V

beamtest 2007 (35% xtalk)
simulation 35% xtalk
simulation 15% xtalk

spatial resolution [mm]

thickness of glue layer [mm]
TRD design

2 x 8 layers of fleece radiator,
TR x-ray photons absorbed by Xe/CO2 mixture (80:20),
in 6mm straw tubes with
30 µm tungsten wire

Design equivalent to
AMS02 space experiment

AMS02 TRD octagon
integrated at RWTH Aachen workshop
Analysis of TRD prototype testbeam data, using first 16 layers

Proton rejection for positron measurement

proton rejection ~1000
ECAL dynamic range

SiPM is pixellated device

photons at fibre end

pixel array

560 photons on 560 pixels

Entries 50000
Mean 354.7
RMS 7.387

partially reflective foil $R \approx 90\%$

SiPM 1
embedded fibre

840 mm

scintillator bar with groove

7.75 mm

SiPM 2

Henning Gast • Bad Honnef – September 2008
building up the ECAL out of 5 super layers with a 5mm Ti support plate below
complete super layer exploded view
Zoom on the other corner.

SiPM – FE-board

Polycarbonate endpiece

tungsten - scintillator sandwich with wavelength shifting fibers
$$\frac{\sigma_p}{p} = 1.8 \times 10^{-4} \quad p = 0.008$$
Spectra corrected for solar modulation

\[ \frac{e^+/e^+-e^-}{e^+} \]

- **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**

\[ P [\text{GeV}] \]
## Cosmic Ray Experiments

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Acceptance [cm² sr]</th>
<th>Duration [days]</th>
<th>Electron Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAMELA</td>
<td>20</td>
<td>1000</td>
<td>Spectrometer + ECAL</td>
</tr>
<tr>
<td>AMS-2:</td>
<td>850</td>
<td>1000</td>
<td>Spectrometer + ECAL + TRD</td>
</tr>
<tr>
<td>PEBS-1</td>
<td>1000</td>
<td>10</td>
<td>Spectrometer + ECAL + TRD</td>
</tr>
<tr>
<td>ATIC-2:</td>
<td>1500</td>
<td>20</td>
<td>ECAL</td>
</tr>
<tr>
<td>PEBS-2</td>
<td>3000</td>
<td>40</td>
<td>Spectrometer + ECAL + TRD</td>
</tr>
<tr>
<td>PEBS-1</td>
<td>7500</td>
<td>10</td>
<td>ECAL + TRD</td>
</tr>
<tr>
<td>FERMI</td>
<td>25000</td>
<td>2000</td>
<td>ECAL</td>
</tr>
</tbody>
</table>
Analysis of TRD prototype testbeam data, using first 16 layers

TRD Performance

proton rejection for positron measurement

proton rejection ~1000