Status of a 3D Imaging Calorimeter of DAMPE for Cosmic Ray Physics on Orbit

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Outline

- DAMPE Experiment
- Instrument design
- In-flight calibration and status
  - Pedestal
  - MIPs MPV value
  - Attenuation length
  - Dynode ratio
- Summary
The collaboration of DArk Matter Particle Explorer (DAMPE)

- **CHINA**
  - Purple Mountain Observatory, CAS, Nanjing
  - University of Science and Technology of China, Hefei
  - Institute of High Energy Physics, CAS, Beijing
  - National Space Science Center, CAS, Beijing
  - Institute of Modern Physics, CAS, Lanzhou

- **ITALY**
  - INFN Perugia and University of Perugia
  - INFN Bari and University of Bari
  - INFN Lecce and University of Salento

- **SWITZERLAND**
  - University of Geneva
DAMPE experiment

DAMPE mission

• DAMPE is an orbital experiment for searching dark matter particle indirectly

• Launch: December 17th 2015, CZ-2D rocket
  • Total weight ~1850 kg, power consumption ~640 W
    • Scientific payload ~1400 kg, 400 W
  • Lifetime > 3 years

• Orbit: sun-synchronous
• Altitude: 500 km
• Period: 94 minutes
• 16 GB/day downlink
Instrument design

**DAMPE detector**

- Charge measurement (dE/dx in PSD, STK and BGO)
- Pair production and precise tracking (STK and BGO)
- Precise energy measurement (BGO ECAL)
- Electron/hadron identification (BGO and NUD)
3D Imaging BGO ECAL

- 14 layers of 22 BGO crystals
  - Dimension of BGO bar: $2.5 \times 2.5 \times 60 \, cm^3$
  - Hodoscopic stacking alternating orthogonal layers
  - r.l: $\sim 32 \, X_0$
  - NIL: 1.6 $\lambda_I$
- Two PMTs coupled with each BGO crystal bar in two ends
- Electronics boards attached to each side of module
- Energy range: 5GeV-10TeV (e/γ)
- Energy resolution: 1.5% @800GeV
3D Imaging BGO ECAL

BGO ECAL elements

- 308 BGO bars (Produced by Shanghai Institute of Ceramics)
- 616 PMTs (Hamamatsu R5610A-01)
- 16 FEE boards

2018/7/2

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3D Imaging BGO ECAL

Some tests on ground

(a) Remanence Test

(b) EMC Test

(c) Vibration Test

(d) Thermal Test

 Cosmic ray Test

 Beam Test

Environment Tests
Results of beam test

Energy linearity of electrons

Energy resolution of electrons

1.5%
Launched on 17\textsuperscript{th} Dec. 2015
Jiuquan Satellite Launch Center, Gobi desert
In-flight calibration and status

- Pedestal
- MIPs MPV value
- Attenuation length
- Dynode ratio
In-flight calibration and status

Pedestal calibration

- In order to measure the energy from 5GeV to 10TeV, a multi-dynode readout structure of PMT is designed.
- The pedestal reflects the baseline and noise level of electronics.
In-flight calibration and status

Results of pedestal calibration (From 201601 - 201712)
In-flight calibration and status

The response of BGO units to Minimum-Ionization Particles (MIPs)

Bethe-Bloch curve

Energy spectrum of MIPs
In-flight calibration and status

Stability of MIPs

Before temperature correction

After temperature correction

- Caused by the negative correlation between fluorescent yield and temperature
- The energy of MIPs is about 312 MeV
In-flight calibration and status

Dynode ratio calibration

The ratios between the three dynodes are key parameters for energy reconstruction.

Dy5 vs. Dy2

Dy8 vs. Dy5
Stability of dynode ratio (From 201601 - 201712)
In-flight calibration and status

Attenuation length calibration

- The length of BGO crystal is 60 cm.
- The attenuation of the scintillation light during propagation should be considered.

\[
E_p = E_0 \cdot e^{-\frac{L-x}{\lambda}} \\
E_n = E_0 \cdot e^{-\frac{L+x}{\lambda}}
\]

\[
\ln\left(\frac{E_p}{E_n}\right) = \frac{2x}{\lambda}
\]
In-flight calibration and status

Results of attenuation calibration

The attenuation length of BGO crystal can be used to correct the energy deposition in calorimeter.

\[
\lambda_1 = 1781 \text{ mm} \\
\lambda_2 = 2509 \text{ mm}
\]
In-flight calibration and status

Long time stability of Attenuation (From 201601 - 201712)

\( \lambda_1 \)

\( \lambda_2 \)
In-flight calibration and status

Dataset acquired during two years

Total Entries: \(~5,000,000/\text{Day}\)

\(>10\text{TeV}, \sim 90/\text{Day}\)
In-flight calibration and status

![Diagram of Earth and DAMPE Orbit]

- Summer
- Spring & Autumn
- Winter

Temperature (°C)

Quadrant 1:
- T1:L0_B2_5cm, ThID:48
- T2:L0_B11_5cm, ThID:49
- T3:L0_B19_5cm, ThID:50
- T4_FEE:16

FEE Board

BGO Bar

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In-flight calibration and status

Energy Spectrum during two years on orbit
In-flight calibration and status

Energy measurement

For events with deposit energy of 0.5 – 1.0 TeV

Peak = 1.0025
Sigma = 0.014
In-flight calibration and status

Events selection and reconstruction

LF14: describe the longitudinal development of shower.
TRMS: describe the lateral development of shower.
In-flight calibration and status
In-flight calibration and status

Electron candidate
In-flight calibration and status
Summary

• DArk Matter Particle Explorer (DAMPE) was launched successfully on Dec. 17th, 2015

• DAMPE has been working very well since then.

• Physics goals
  • Search for possible dark matter signals
  • Study the origin and propagation of cosmic ray
  • Study the astronomy of gamma ray

• Status of BGO ECAL is very stable on orbit.
  • Pedestal
  • MIPs MPV value
  • Attenuation length
  • Dynode ratio

Thank you
Backup
In-flight calibration and status

Energy correction by hit position

\[ E_{0,p} = E_p \times e^{\frac{L - x}{\lambda}} \]
\[ E_{0,n} = E_n \times e^{\frac{L + x}{\lambda}} \]

\( \ln\left(\frac{E_{0,p}}{E_{0,n}}\right) = 0 \)

Advantage of correction

- Eliminate the influence of hit position.
- Detect the particle with higher energy.
- Check each other.

After Correction
\[ E_p = E_0 \cdot e^{-\frac{(x_0-x)}{\lambda_1}} \cdot e^{-\frac{(300-x_0)}{\lambda_2}} \cdot R \quad (x < x_0) \]

\[ E_p = E_0 \cdot e^{-\frac{(300-x)}{\lambda_2}} \quad (x \geq x_0) \]
Stability of dynode ratio at different latitude

![Graphs showing the stability of dynode ratio at different latitudes.](image-url)
Results of dynode ratio calibration

Dy5 vs. Dy2

Dy8 vs. Dy5
South Atlantic Anomaly (SAA)
IGRF model