Dark Matter Particle Explorer: The First Chinese Astronomical Satellite

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Purple Mountain Observatory
(on behalf of the DAMPE collaboration)
The collaboration

• **CHINA**
  – Purple Mountain Observatory, CAS, Nanjing
  – Institute of High Energy Physics, CAS, Beijing
  – National Space Science Center, CAS, Beijing
  – University of Science and Technology of China, Hefei
  – 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
Outline

• Scientific Objectives
• Instrument Design
• Expected Performance
• Beam Test
• In-flight calibration and performance
• First Results
Scientific Objectives

Cosmic ray origin & propagation

Gamma-ray astronomy

Particle dark matter
Instrument Design

- Plastic Scintillator Detector (PSD)
- Silicon-Tungsten Tracker (STK)
- BGO Calorimeter (BGO)
- Neutron Detector (NUD)

- Charge measurement (dE/dx in PSD, STK and BGO)
- Pair production and precise tracking (STK and BGO)
- Precise energy measurement (BGO bars)
- Particle identification (BGO and NUD)
Instrument development: PSD

- Active area: 82 cm x 82 cm
- Number of layers: 2
- 41 modules each layer
- A PMT at each end of plastic scintillator bar
- Each PMT provides two signals (from Dy5 and Dy8 for large dynamic range)
- Charge resolution: 0.13 for $Z = 1$

Charge measurement
Anti-coincidence for photons

(see arXiv:1703.00098)
Instrument development: STK

- 12 layers (6x, 6y) of single-sided Si strip detector mounted on 7 support trays
- Tungsten plates (1mm thick) integrated in trays 2, 3, 4 (from the top)
  - Total 0.85 X₀ for photon conversion

768 silicon sensors
95 x 95 x 0.32 mm³

1,152 ASICs

73,728 channels

Charge and track measurement
Instrument development: BGO

• 14 layers of 22 BGO crystals
  • Dimension of BGO bar: $2.5 \times 2.5 \times 60\text{cm}^3$
  • Hodoscopic stacking alternating orthogonal layers
  • r.l.: $32X_0$, NIL: 1.6

• Two PMTs coupled with each BGO crystal bar in two ends

• Electronics boards attached to each side of module

308 BGO bars  616 PMTs  FEE Boards

Charge, track, energy, and PID
Instrument development: NUD

\[ n + ^{10}B \rightarrow \alpha + ^7Li + \gamma \]

4 large area boron-doped plastic scintillators (30 cm × 30 cm × 1 cm)

PID (hadron/lepton)

Table 5: NUD designed parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>4 Plastic Scintillators ($^{10}$B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active area</td>
<td>61 cm × 61 cm</td>
</tr>
<tr>
<td>Energy range</td>
<td>2 – 60 MeV for single detector</td>
</tr>
<tr>
<td>Energy resolution(^a)</td>
<td>≤10% at 30 MeV</td>
</tr>
<tr>
<td>Power</td>
<td>0.5 W</td>
</tr>
<tr>
<td>Mass</td>
<td>12 kg</td>
</tr>
</tbody>
</table>
Signals for different particles

- electron
- gamma
- proton
Signals for different particles

- electron
- gamma
- proton
## Expected performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy range of gamma-rays/electrons</td>
<td>5 GeV to 10 TeV</td>
</tr>
<tr>
<td>Energy resolution (electron and gamma)</td>
<td>&lt;1.5% at 800 GeV</td>
</tr>
<tr>
<td>Energy range of protons/heavy nuclei</td>
<td>50 GeV to 100 TeV</td>
</tr>
<tr>
<td>Energy resolution of protons</td>
<td>&lt;40% at 800 GeV</td>
</tr>
<tr>
<td>Eff. area at normal incidence (gamma)</td>
<td>1100 cm² at 100 GeV</td>
</tr>
<tr>
<td>Geometric factor for electrons</td>
<td>0.3 m² sr above 30 GeV</td>
</tr>
<tr>
<td>Photon angular resolution</td>
<td>&lt;0.2 degree at 100 GeV</td>
</tr>
<tr>
<td>Field of View</td>
<td>1.0 sr</td>
</tr>
</tbody>
</table>

(see arXiv:1706.08453)
## Comparison with other missions

<table>
<thead>
<tr>
<th></th>
<th>DAMPE</th>
<th>AMS-02</th>
<th>Fermi LAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>e/γ Energy res.@100 GeV (%)</td>
<td>1.2</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>e/γ Angular res.@100 GeV (deg)</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>e/p discrimination</td>
<td>10⁵</td>
<td>10⁵ - 10⁶</td>
<td>10⁵</td>
</tr>
<tr>
<td>Calorimeter thickness (X₀)</td>
<td>32</td>
<td>17</td>
<td>8.6</td>
</tr>
<tr>
<td>Geometrical accep. (m²sr)</td>
<td>0.3</td>
<td>0.06</td>
<td>2</td>
</tr>
</tbody>
</table>

![Diagram](image1.png)

![Image](image2.png)
Expected performance

gamma-ray

proton

helium

electrons
Expected performance

Electron: 3 yr

Proton: 3 yr
Simulation based on AMS-02 fit

Helium: 3 yr
Simulation based on AMS-02 fit

DM anni. into Gamma-ray line

Expected performance
Beam test @ CERN

- **14days@PS, 29/10-11/11 2014**
  - $e$ @ 0.5GeV/c, 1GeV/c, 2GeV/c, 3GeV/c, 4GeV/c, 5GeV/c
  - $p$ @ 3.5GeV/c, 4GeV/c, 5GeV/c, 6GeV/c, 8GeV/c, 10GeV/c
  - $\pi$- @ 3GeV/c, 10GeV/c
  - $\gamma$ @ 0.5-3GeV/c

- **8days@SPS, 12/11-19/11 2014**
  - $e$ @ 5GeV/c, 10GeV/c, 20GeV/c, 50GeV/c, 100GeV/c, 150GeV/c, 200GeV/c, 250GeV/c
  - $p$ @ 400GeV/c (SPS primary beam)
  - $\gamma$ @ 3-20GeV/c
  - $\mu$ @ 150GeV/c

- **17days@SPS, 16/3-1/4 2015**
  - Fragments: 66.67-88.89-166.67GeV/c
  - Argon: 30A- 40A- 75AGeV/c
  - Proton: 30GeV/c, 40GeV/c

- **21days@SPS, 10/6-1/7 2015**
  - Primary Proton: 400GeV/c
  - Electrons @ 20, 100, 150 GeV/c
  - g @ 50, 75, 150 GeV/c
  - m @ 150 GeV /c
  - p+ @10, 20, 50, 100 GeV/c
Beam test @ CERN

Energy linearity of electrons

Energy resolution of electrons
Energy resolution of protons

Beam test @ CERN
Beam test @ CERN

Charge measurement with Argon beam

Charge by PSD

Charge by STK
Flight Model: four detectors

PSD: IMP

BGO: USTC & PMO

STK: IHEP, UG, INFN Perugia

NUD: PMO
Flight Model: cosmic ray test
Flight Model: environmental tests

- **vibration**
- **TC**
- **TVT**
- **EMC**
DAMPE mission

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

- Altitude: 500 km
- Inclination: 97.4065°
- Period: 95 minutes
- Orbit: sun-synchronous
- 16 GB/day downlink

Wukong
Launch on 17th Dec. 2015

Jiuquan Satellite Launch Center, Gobi desert
On-orbit trigger rate

~50 Hz average trigger rate
\[ \rightarrow 100 \text{ GB (H.L.)/day on ground (about 5 M events)} \]
Event: ~1 TeV electron candidate
Event: ~5 TeV electron candidate
PSD on-orbit calibration

Pedestal distribution

Pedestal comparison

Pedestal variation

Dy5 and Dy8 correlation

Light attenuation calibration

Single layer efficiency

$\sim 0.995$
On-orbit STK noise: very stable

- **Noisy channels stabilized to lower noise values**
  - Very small temperature effect
    - ~0.01 ADC per 2°C

- **Bulk of noise correlated with temperature**
  - Very small temperature coefficient

- **Simplification for operation**
  - Data compression thresholds updated only once on Feb. 22, using average noise of Feb. 13-17

**Average noise 2.84-2.87 ADC**

**Number of noisy channels <0.3%**

18 months since launch

(See Xin Wu’s talk DM030)
STK on-orbit alignment

- Achieved ~40 μm intrinsic position resolution after on-orbit alignment
  - Good agreement with perfect aligned MC
  - Resolution stability ~2% over time

Bi-weekly update of alignment is sufficient!
BGO on-orbit calibration: MIPs

(See Yunlong Zhang’s poster DM045)
BGO on-orbit calibration: stability
BGO on-orbit calibration: high energy stability

Carbon Peak  Iron Peak

Stability of Carbon MIPs  Stability of Fe MIPs

(See Sicheng Wen’s poster DM044)
On-orbit performance: charge measurement

Charge Res.: \( \sim 0.13e \) for H and 0.32e for Fe

(See Yapeng Zhang’s poster CRD098)
On-orbit performance: absolute energy scale

(See Jingjing Zang’s talk CRD051)
For events with deposit energy of 0.5–1.0 TeV

On-orbit performance: energy measurement

Peak=1.0025
Sigma=0.014
For events with deposit energy of 0.5-1.0 TeV. For >90% efficiency, the proton contamination is found to be ~2% below 1TeV, ~5% @2TeV, and ~10%@5TeV.

(See Zhiyong Zhang’s poster DM041)
On-orbit performance: NUD response

Proton candidates

Electron candidates

Neutron Energy (ADC)
First results: gamma-ray sky map

(See Shijun Lei’s talk GA206)
First results: bright gamma-ray sources

(See Shijun Lei’s talk GA206, Yunfeng Liang’s poster GA271)
First results: variable CTA 102

(PRELIMINARY)

CTA 102

observed average

Flux \( \times 10^{-7} \text{ cm}^2 \text{s}^{-1} \)

Time since 2016-01-01 (day)

(See Shijun Lei’s talk GA206, Qiang Yuan’s poster GA204)
First results: p and He
First results: proton flux

(See Chuan Yue’s talk CRD082)
First results: Helium flux

(See Paolo Bernardini’s talk CRD096)
First results: $e^+e^-$ (upcoming)
First results: $e^+e^-$ (upcoming)

DAMPE will publish the spectrum from 20 GeV to 5 TeV
Summary

The detector
- Large geometric factor instrument (0.3 m² sr for electrons)
- Precision Si-W tracker (40 um, 0.2°)
- Thick calorimeter (32 $X_0$, energy res. ~1% for e/g, (20~35)% for hadrons)
- Multiple charge measurements (0.2-0.3 e resolution)
- e/p rejection power > $10^5$ (higher with neutron detector)

Launch and performances
- Successful launch on Dec. 17th, 2015
- On orbit operation steady and with high efficiencies
- Absolute energy calibration by using the geomagnetic cut-off
- Absolute pointing cross check by use of the photon map

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

Expect at least 3 times more data with 5 years’ lifetime
Contributions in ICRC2017

Oral talks:
• [CRD051] Measurement of absolute energy scale of ECAL of DAMPE with geomagnetic rigidity cutoff (Jingjing ZANG)
• [CRD082] Studies on cosmic-ray proton flux with DAMPE (Chuan YUE)
• [CRD096] Studies on Helium flux with DAMPE (Paolo BERNARDINI)
• [CRD117] The On-orbit Performance of DAMPE Trigger System (Yang LIU)
• [DM030] In-orbit Performance of the Silicon-Tungsten Tracker of the DAMPE Mission (Xin WU)
• [GA206] Gamma-ray Astronomy with DAMPE (Shijun LEI)

Posters:
• [CRD097] Measurement of cosmic ray charge with DAMPE Silicon-Tungsten Tracker (Xin WU)
• [CRD098] PSD performance and charge reconstruction with DAMPE (Yapeng ZHANG)
• [CRD124] Determination of the South Atlantic Anomaly from DAMPE data (Wei JIANG)
• [DM032] Readout Electronics of DAMPE BGO Calorimeter and the Status during the First Year In Orbit (Changqing FENG)
• [DM041] Study of E/P separation for the DAMPE experiment with the TMVA BDT method (Zhiyong ZHANG)
• [DM042] Validation of GEANT4 Monte Carlo Models with a three dimensional BGO Calorimeter of DAMPE (Libo WU)
Contributions in ICRC2017

Posters:

- [DM043] Acceptance research and electron/proton characteristic investigation in the DAMPE experiment (Yifeng WEI)
- [DM044] Energy calibration of DAMPE in space (Sicheng WEN)
- [DM045] The Performance of a 3D Imaging Calorimeter of DAMPE for Cosmic Ray Physics in Orbit (Yunlong ZHANG)
- [GA183] First observations of Pulsars with the DArk Matter Particle Explorer (Maria Fernanda MUÑOZ SALINAS)
- [GA184] Gamma-ray selection of DAMPE (Zunlei XU)
- [GA204] The variable sky of DAMPE (Qiang YUAN)
- [GA248] The performance of DAMPE for gamma-ray detection (Kaikai DUAN)
- [GA271] Bright gamma-ray sources observed by DArk Matter Particle Explorer (Yunfeng LIANG)
- [GA282] A Machine Learning classifier for photon selection with the DAMPE detector (Simone GARRAPPA)
Some members and partners
Some members and partners

Thanks for your attention!