Progresses of the Dark Matter Particle Explorer (DAMPE) experiment

Qiang Yuan (袁强)
Purple Mountain Observatory
(on behalf of the DAMPE collaboration)
Jul. 24 - Aug. 1, 2019, Madison, Wisconsin
The DAMPE 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
  • INFN LNGS and Gran Sasso Science Institute

• SWITZERLAND
  • University of Geneva
Outline

- Introduction
- DAMPE instrument
- On-orbit performance
- Physical Results
- Summary
Composition of the Universe

Supernova Cosmology Project

No Big Bang

Union2.1 SN Ia Compilation

SNe

BAO

CMB

Flat

Ω_A

Ω_m

26.8% Dark Matter

68.3% Dark Energy

4.9% Ordinary Matter

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Detection of dark matter

(a) Direct detection

(b) Collider detection

(c) Indirect detection

arXiv:0806.2911
Precision measurements of cosmic ray spectra: cosmic ray origin, acceleration, and propagation

The spectra above TeV are not well measured due to limited statistics of direct detection experiments
Recent space particle/γ detectors

- **Fermi**
- **PAMELA**
- **CALET**
- **NUCLEON**
- **ISS-CREAM**
DAMPE (“Wukong”) launched on Dec. 17, 2015

Three major scientific goals

- Cosmic ray physics
- \( \gamma \)-ray astronomy
- Dark matter indirect detection
DAMPE instrument
Instrument design

- **PSD**: charge measurement via dE/dx and ACD for photons
- **STK**: track, charge, and photon converter
- **BGO**: energy measurement, particle (e-p) identification
- **NUD**: Particle identification
PSD charge detector

- 2 layers (x,y) of $88.4 \text{ cm} \times 2.8 \text{ cm} \times 1 \text{ cm}$
- Active area: $82 \text{ cm} \times 82 \text{ cm}$
- Weight: $\sim 103 \text{ kg}$
- Power: $\sim 8.5 \text{ W}$

Silicon tracker

- Detection area: 76 cm x 76 cm
- Total weight: ~154 kg
- Total power consumption: ~ 82W
- Three 1 mm tungsten plates for photon conversion (0.86 $X_0$)
BGO calorimeter

- Outer envelop: 100 cm x 100 cm x 50 cm
- Detection area: 60 cm x 60 cm
- Total weight: ~1052 kg
- Total power consumption: ~ 41.6 W
NUD neutron detector

- $n + ^{10}\text{B} \rightarrow \alpha + ^{7}\text{Li} + \gamma$
- 4 plastic scintillators
- Active area: 60 cm x 60 cm
- Total weight: ~12 kg
- Total power: ~ 0.5 W
Particle identification

electron

gamma

proton
Energy measurement

BGO calorimeter

308 BGO bars

616 PMTs

- Thick calorimeter (32 $X_0$): high-resolution
- Two-side readouts
- Three dynode outputs enable a $>10^6$ dynamic range
Test beam validation

Electrons: 0.5 - 243 GeV

- Raw Energy
- Corrected Energy

Astropart. Phys., 95, 6 (2017)
On-orbit performance

See Y. L. Zhang CRD7e
Observation overview

DAMPE 3.5 year counts map

7 full scans of the sky

5M events/day
6.6 billion in total
Detector stability

PSD pedestal < 0.5%

STK pedestal < 0.7%

BGO pedestal < 0.9%

NUD pedestal < 0.6%
PSD charge measurement

![Graph showing PSD charge measurement with a table of species and their charge resolutions.

<table>
<thead>
<tr>
<th>Species</th>
<th>Charge Res.</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>0.06</td>
</tr>
<tr>
<td>He</td>
<td>0.10</td>
</tr>
<tr>
<td>Li</td>
<td>0.14</td>
</tr>
<tr>
<td>Be</td>
<td>0.21</td>
</tr>
<tr>
<td>B</td>
<td>0.17</td>
</tr>
<tr>
<td>C</td>
<td>0.18</td>
</tr>
<tr>
<td>Ni</td>
<td>0.21</td>
</tr>
<tr>
<td>O</td>
<td>0.20</td>
</tr>
</tbody>
</table>
STK direction measurement

Geminga

PSF calibrated with bright gamma-ray sources: ~0.5 degrees @ 5 GeV
DAMPE IRFs for $\gamma$-rays


Astropart. Phys., 95, 6 (2017)

Acceptance

Effective area

Point spread

Energy response

See X. Li GAD3a and also 1904.13098
BGO energy calibration

Counts

MIP: minimum ionizing particle

- $-dE/dx$ vs. $p/\gamma > 1 M e V$
- $H_2$ liquid, He gas, Sn, $\gamma$, C

Deposited Energy (MeV)

[Graph showing energy deposition vs. momentum for different materials]
BGO energy linearity

P vs. N-side

N-side Energy (GeV)

P-side Energy (GeV)
BGO energy linearity

P vs. N-side

$1.005 \pm 0.016$
BGO energy linearity

Total vs. Max bar energy

![Graph showing Total vs. Max bar energy for BGO energy linearity](image)
- An energy scale higher by (1.2+/−1.3)% from the geomagnetic cutoff
- Cutoff energy is stable with time (a slight decrease due to solar modulation)

$$C_{\text{data}}^{\text{lbin1}} = 13.0123 \pm 0.1640 \text{GeV}$$

$$\frac{C_{\text{data}}^{\text{lbin1}}}{C_{\text{tracer}}^{\text{lbin1}}} = 1.0121 \pm 0.0126$$
We use the lateral (SumRMS) and longitudinal (energy ratio in last layer) developments of the showers to discriminate electrons from protons.

For 90% electron efficiency, proton background is ~2% @ TeV, ~5% @ 2 TeV, ~10% @ 5 TeV.

Nature, 552, 63 (2017)
Validation of e/p separation

- 400 GeV proton beam
- 243 GeV electron beam

- Electron beam
- Protons
- γ -rays

- Normalized entries
- Normalized counts
- Number of events
- Gamma Counts

- Shower Spread [mm]
- ζ
Physical results
γ-ray skymap

DAMPE 3 years
E > 2 GeV

Preliminary
γ-ray line searches

See Z. Q. Shen PS1-256

DAMPE 3 yrs compared with Fermi 5.8 yrs
γ-ray point sources

143 sources with TS > 20
Most are AGNs and pulsars

<table>
<thead>
<tr>
<th>Source Type</th>
<th>Number</th>
</tr>
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<tbody>
<tr>
<td>AGN</td>
<td>100</td>
</tr>
<tr>
<td>Pulsar</td>
<td>27</td>
</tr>
<tr>
<td>SNR / PWN</td>
<td>9</td>
</tr>
<tr>
<td>Binary</td>
<td>2</td>
</tr>
<tr>
<td>Globular cluster</td>
<td>1</td>
</tr>
<tr>
<td>Unassociated</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>143</strong></td>
</tr>
</tbody>
</table>

See X. Li GAD3a
\( \gamma \)-ray pulsars

(a) Vela  
(b) Geminga  
(c) J1709-4229

(d) Crab  
(e) J0007+7303

See M. Munoz GAD2d
Three different PID methods give very consistent results on event-by-event level.

Direct detection of a spectral break at ~1 TeV with 6.6σ confidence level.

Analysis with new data is on-going.

Nature, 552, 63 (2017)
Errors of $e^+e^-$ spectrum

- Syst: background subtraction
- Syst: geometrical acceptance
- Syst: trigger efficiency
- Syst: $\zeta$ selection
- Statistic

![Graph showing uncertainties in energy spectrum](image)
Cooling time of TeV electrons $\sim$ Myr, effective propagation range $\sim$ kpc

Assuming a total SN rate of 0.01 per year, the total number of SNRs within the effective volume and cooling time is $O(10)$
Spectral structures of nuclei
- Confirms the hundreds GeV hardening
- Detecting a softening at ~13 TeV with high significance
Implications: source population(?)
Nearby source(?)

Gaisser et al. (2013)

Liu et al., 1812.09673
DAMPE helium spectrum

See M. Di Santo CRD8h
Cosmic ray anisotropies

95% UL of dipole amplitude for 1-yr data (>~300 GeV): \(6.7 \times 10^{-3}\)

See M. Munoz CRD4e
Solar modulation of $e^+ + e^-$

- Anti-correlation with sunspot numbers
- Monthly variation may be related to occasional solar activities
- Possible time delay between sunspot numbers and CR modulation

See J. J. Zang CRD2e
Clear flux decreases after 2017/09/07 flare
Decreasing behavior of recovery time versus energy

See J. J. Zang CRD2e
DAMPE contributions at ICRC2019

- H16: Progresses of the Dark Matter Particle Explorer
- CRD2e: Observation of time evolution of cosmic ray electron and positron flux with Dark Matter Particle Explorer
- CRD4e: Anisotropy Searches with DAMPE
- CRD7b: Elemental analysis of Cosmic Ray flux with DAMPE
- CRD7e: The Status of DAMPE Satellite in Space
- CRD8g: Measurement of cosmic ray proton spectrum with the Dark Matter Particle Explorer
- CRD8h: Helium spectrum in the cosmic rays measured by the DAMPE detector
- GAD3a: Recent Gamma ray Results from DAMPE
- GAD2d: Gamma ray Pulsars with DAMPE

- PS1-2: Checking the Reconstructed Energy of the DAMPE Experiment with Geomagnetic Cutoff CR-Nuclei
- PS1-5: Charge Measurement of Cosmic Ray Nuclei with DAMPE - Tiekuang Dong
- PS1-6: Neural Networks for Electron Identification with DAMPE
- PS1-7: TeV—PeV hadronic simulations with DAMPE
- PS1-17: First Look on Fractional Charged Particles in Space Based on DAMPE Orbit Data
- PS1-19: A Method of Alignment for Plastic Scintillator Detector of DAMPE
DAMPE contributions at ICRC2019

- PS1-36: Measurement of the Cosmic-ray Proton + Helium Spectrum with DAMPE
- PS1-37: Hadronic cross section validation in the DAMPE experiment
- PS1-42: The selection and energy validation of heavy ions based on DAMPE orbit data
- PS1-44: Ultra-heavy cosmic rays measurements with DAMPE
- PS1-248: Boresight Alignment with DAMPE
- PS1-256: Search for a gamma-ray line feature with DAMPE
DAMPE detector is working extremely well since launch.

Very precise measurements of the $\text{e}^+\text{e}^-$ spectrum from 25 GeV to 4.6 TeV have been obtained, showing a spectral break at ~TeV energies and possible new spectral features.

Precise measurements of proton spectrum from 40 GeV to 100 TeV have been obtained, revealing interesting softening features at ~10 TeV.

More results are coming.

Thank You!
For 90% electron efficiency, proton background is \(~2\% @ 1\text{ TeV}, ~5\% @ 2\text{ TeV}, ~10\% @ 5\text{ TeV}\).
Raw count spectra
Laser experiment
Three-component $e^+e^-$ model

- Primary $e^-$ accelerated together with ions (e.g., supernova remnants)
- Secondary $e^-$ and $e^+$ from hadronic interaction of cosmic ray nuclei
- Additional $e^-$ and $e^+$ from extra sources (e.g., pulsars, ...)

![Graph showing electron and positron spectra](graph.png)