Latest results of the Dark Matter Particle Explorer (DAMPE) experiment

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(on behalf of the DAMPE collaboration)
Nov. 27 - 31, 2019, Tsung-Dao Lee Institute, Shanghai
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

\( \Omega_A \)

\( \Omega_{\text{DE}} \)

SNe

BAO

CMB

Flat

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

Dark matter → SM particle → SM particle → Dark matter

(c) Indirect detection

γ → π^0, μ^+, ν_μ, ν_e, e^+, e^−, π^+, π^−, ν_μ, ν_e, e^+, e^−, π^0

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/$\gamma$ detectors
DAMPE ("Wukong") launched on Dec. 17, 2015

Three major scientific goals

Cosmic ray physics

γ-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

*Astropart. Phys., 95, 6 (2017)*
PSD charge detector

- 2 layers (x, y) of 88.4 cm × 2.8 cm × 1 cm
- Active area: 82 cm × 82 cm
- Weight: ~103 kg
- Power: ~8.5 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
On-orbit performance
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

Species | Charge Res.
---|---
P | 0.06
He | 0.10
Li | 0.14
Be | 0.21
B | 0.17
C | 0.18
N | 0.21
O | 0.20
PSF calibrated with bright gamma-ray sources: $\sim 0.5$ degrees @ 5 GeV
BGO energy calibration

MIP: minimum ionizing particle

Counts

Deposited Energy (MeV)

On-Orbit Data
MC-Digi Data

\(-\frac{dE}{dx}\) (MeV g/\(\text{cm}^2\))

\(\beta\gamma - \rho\gamma/\text{Me}\)

Muon momentum (GeV/c)
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](image)
Particle identification

electron

gamma

proton

Z-X View

Z-Y View
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)*
Physical results
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.
Errors of $e^+ + e^-$ spectrum
- Cooling time of TeV electrons $\sim \text{Myr}$, effective propagation range $\sim \text{kpc}$
- Assuming a total SN rate of 0.01 per year, the total number of SNRs within the effective volume and cooling time is $O(10)$


Fang et al. (2017)
Di Mauro et al. (2017)
Manconi et al. (2019)…
Spectral structures of nuclei

PAMELA, 2011, Science

AMS-02, 2017, ICRC

CALET, 2019, PRL


NUCLEON, 2018, JETPL
- Confirms the hundreds GeV hardening
- Detecting a softening at ~14 TeV with high significance

DAMPE proton spectrum


~14 TeV break
Implications: source population(?)
Nearby source(?)

Gaisser et al. (2013)

Liu et al., 1812.09673
DAMPE helium spectrum

\[ E^{2.7} J(E) \times [\text{GeV}/\text{n}]^{1.7} \times \text{s}^{-1} \times \text{m}^{-2} \times \text{sr}^{-1} \]

- DAMPE Preliminary
- AMS02 (2017)
- PAMELA (2011)
- PAMELA-CALO (2006/06-2010/01)
- ATIC-2 (2009)
- CREAM I+III combined (2017)
- NUCLEON (KLEM) (2018)

Energy per nucleon (GeV/n)
Cosmic ray anisotropies

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

- Clear flux decreases after 2017/09/07 flare
- Decreasing behavior of recovery time versus energy
$\gamma$-ray skymap

DAMPE 3 years
$E > 2$ GeV

Preliminary
γ-ray line searches

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>
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<tbody>
<tr>
<td>AGN</td>
<td>100</td>
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<tr>
<td>Pulsar</td>
<td>27</td>
</tr>
<tr>
<td>SNR / PWN</td>
<td>9</td>
</tr>
<tr>
<td>Binary</td>
<td>2</td>
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<td>Globular cluster</td>
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<td>Unassociated</td>
<td>4</td>
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<tr>
<td><strong>Total</strong></td>
<td>143</td>
</tr>
</tbody>
</table>
\(\gamma\)-ray pulsars

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

(d) Crab  
(e) J0007+7303
DAMPE detected outbursts of several AGNs
Consistent with multi-wavelength observations

(Yuan et al. PoS (ICRC2017) 617)
• DAMPE works in a survey mode, its data can be used for MM studies
• No clear variabilities of TXS 0506+056 were detected due to limited statistics
Summary

- DAMPE detector is working extremely stably for nearly 4 years since launch.
- Very precise measurements of the $e^+e^-$ spectrum from $25\,\text{GeV}$ to $4.6\,\text{TeV}$ have been obtained, showing a spectral break at $\sim\text{TeV}$ energies.
- Precise measurements of proton spectrum from $40\,\text{GeV}$ to $100\,\text{TeV}$ have been obtained, revealing interesting softening features at $\sim10\,\text{TeV}$.
- Variable gamma-rays from AGNs are detected. DAMPE is expected to play an important role in the MM campaign!
- More results are coming.

Thank You!
Backup
Raw count spectra
Energy measurement

BGO calorimeter

308 BGO bars

616 PMTs

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

Electrons: 0.5 - 243 GeV

- Raw Energy
- Corrected Energy

Astropart. Phys., 95, 6 (2017)
Absolute energy scale

- 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)

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

\[ \frac{C_{\text{data}}^{lbin1}}{C_{\text{tracer}}^{lbin1}} = 1.0121 \pm 0.0126 \]
Validation of e/p separation

400 GeV proton beam

243 GeV electron beam

γ-rays
For 90% electron efficiency, proton background is ~2% @ TeV, ~5% @ 2 TeV, ~10% @ 5 TeV.
DAMPE IRFs for γ-rays

Acceptance

Effective area

Point spread

Energy response
Three-component $e^+e^-$ model

- Primary $e^-$ accelerated together with ions (in 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, …)