The DAMPE experiment and its latest results

Piergiorgio Fusco
University and INFN Bari - Italy
on behalf of the DAMPE Collaboration
The DAMPE Collaboration

- **CHINA**
  - Purple Mountain Observatory, CAS, Nanjing, *Prof. Jin Chang*
  - 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
Scientific goals

- DAMPE – DArk Matter Particle Explorer – is a **space particle detector** aimed to:
  - study *cosmic electrons* spectra
  - study *cosmic protons + nuclei* spectrum and composition
  - astronomy with high-energy cosmic *gamma-rays*
  - search for *dark matter* signatures in lepton spectra
  - search for *e.m. counterparts* of gravitational waves or neutrinos
  - quest for *exotic* particles and phenomena

- **Excellent performance:**
  - detection of 5 GeV – 10 TeV e/$\gamma$, 50 GeV – 100 TeV p and nuclei
  - energy resolution < 1.5% for 100 GeV e/$\gamma$, < 40% for 800 GeV p
  - angular resolution < 0.2° for 100 GeV $\gamma$
  - field of view ~1 sr
The DAMPE instrument

**PSD:** Plastic Scintillator Detector
Anti-coincidence, ion identification

**STK:** Silicon Tracker/converter
(6 Si double layers + 3 1 mm W plates)
Photon conversion, particle tracking

**CALO:** Calorimeter
(14x22 hodoscopic BGO bars, 32 r.l.)
Energy deposition and profile, trigger

**NUD:** Neutron detector
(4 B-doped plastic scintillators)
Neutron showers measurement
## DAMPE, AMS-02, Fermi LAT

<table>
<thead>
<tr>
<th>Performance</th>
<th>DAMPE</th>
<th>AMS-02</th>
<th>Fermi LAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>e/γ Energy resol. @100 GeV (%)</td>
<td>&lt;1.5</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>e/γ Angular resol. @100 GeV (deg.)</td>
<td>&lt;0.2</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>e/p discrimination</td>
<td>&gt;$10^5$</td>
<td>$10^5$ - $10^6$</td>
<td>$10^3$</td>
</tr>
<tr>
<td>Calorimeter thickness ($X_0$)</td>
<td>32</td>
<td>17</td>
<td>8.6</td>
</tr>
<tr>
<td>Geometrical acceptance (m²sr)</td>
<td>0.3</td>
<td>0.09</td>
<td>1</td>
</tr>
</tbody>
</table>

### DAMPE facts

- **Mass**: 1400 kg
- **Power consumption**: 400 W
- **Readout channels**: > 75k
- **Data transfer**: 16 Gbyte/day
- **Lifetime**: 5 years
The launch

- DAMPE was launched on Dec. 17th 2015
  - Launch site: Jiuquan Satellite Launch Center, Gobi desert, China
  - Orbit: 500 km altitude, Sun synchronous
Trigger rate and data transfer

### Acquisition rate
- **High Energy (physics) trigger rate**: up to 50 Hz
- **Raw data plus control data download**: 15 GB/day
- **Reconstructed data in ROOT format**: 85 GB/day
- **Total data per year**: 35 TB

### Graphs
- **Total trigger rate**
  - MIP Calibration
  - Different prescale factor for lower latitudes
  - SAA
- **2.5 years exposure map**
  - Trigger rate range: 20 Hz to 200 Hz
  - Exposure range: 80k to 220k
The geomagnetic rigidity cut-off of cosmic-ray electrons (CRE) spectrum provides a reference for absolute energy calibration.

- Low energy CRE flux is measured in the range $8 \text{ GeV} < E < 100 \text{ GeV}$.
- Flight data and Monte Carlo data (with back-tracing in Earth magnetic field model IGRF12) are compared.
- Expected cut-off: 13.0 GeV; DAMPE measured cut-off 13.2 GeV.
- Stable with time - slight decrease due to solar modulation of primary electrons.

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

$C_{\text{bin}}^\text{data} / C_{\text{bin}}^\text{tracer} = 1.0121 \pm 0.0126$

1.2% difference
Particle identification

- Several different PID methods used (Shape parameters; Boosted Decision Trees; Random Forest + Convolutional Neural Network)
An electron candidate (\(\sim 5\) TeV)
The "ζ shower parameter" was computed from the lateral shower development in BGO plus the energy deposition in the last layer:

- The cut ζ > 8.5 was adopted to discriminate e− (and e+) from p.
- For 90% e± efficiency, p background ~2% @ 1 TeV, ~5% @ 2 TeV, ~10% @ 5 TeV.
Validation of $\zeta$ parameter

- The $\zeta$ parameter was validated with beam tests and with photons
  - Different PID methods give consistent results
- Cosmic-rays electrons and positrons from 20 GeV to ~5 TeV [Nature 552, 64 (2017)]
- Direct detection of a spectral break at 0.9 TeV (6.6 $\sigma$ c.l.)
- A smoothly broken power law fits data ($\gamma = 3.1 \rightarrow 3.9$)
- Next step: search for structures and anisotropies (nearby sources, pulsars, DM?)

![Graph showing the energy spectrum of cosmic-ray electrons and positrons](image-url)
Identifying protons and nuclei with PSD and STK

- charge measurement tested with ion beam tests at CERN
- PSD: up to Argon; STK: up to Oxygen
- charge resolution is dependent on Z and ranges from 0.2 to 0.4
- more details in Astropart. Phys. 95, 6 (2017)

**PSD** – Argon beam 40 GeV/n

**STK** – Lead beam 40 GeV/n
Protons and nuclei: flight data

- Identifying protons and nuclei with PSD and STK

[Image: PSD and STK data showing charge distributions and particle identification]

[Text citation: Astropart. Phys. 105, 31 (2019)]
Protons and Helium spectra

- Agreement with other experiments
- Protons: hardening at $E > 300$ GeV, softening at $E > 10$ TeV
- Helium: hardening at 200 GeV
- Analysis is being extended to higher energies
Photons: background

- Charged particles are a massive background for photons

- Protons vs $\gamma$:
  - $10^5$ factor @ $E > 100$ GeV
  - mainly rejected using the shower profile and the onboard trigger

- Electrons vs $\gamma$:
  - $10^3$ factor @ $E > 100$ GeV
  - mainly rejected using the PSD and the 1st layer of STK
  - key problem is the back scattering at high energy
Event topology

Random Forest + Convolutional Neural Networks

PSD + BGO profile + NUD: rejection $> 10^7$ for hadrons

PSD + STK: rejection up to $10^3$ for electrons
Photons: counts maps

\text{~150 photons/day}

\text{Angular resolution: } \sim 1^\circ \text{ @ 1 GeV, } \sim 0.1^\circ \text{ @ 100 GeV, } \sim 0.05^\circ \text{ @ 1 TeV}
The DAMPE gamma-ray sky and major gamma-ray sources
Algorithms to resolve gamma-rays from charged cosmic rays

[Res. Astron. Astrophys. 18, 27 (2018)]

- Geminga, IC443 and Crab pulsars

- Geminga pulsar phase profile (T $\sim$237 ms)
DAMPE detection of gamma-ray variability of some blazars:

- CTA 102
- 3C 454.3
- 3C 279
- ...

![Graph showing variability in gamma-ray flux from CTA 102 over time.](image)

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**DAMPE detection of variable GeV gamma-ray emission from blazar CTA 102**

ATel #9901: Zun-Lei Xu (PMO), Micaela Caragiulo (Bari), Jin Chang (PMO), Kai-Kai Duan (PMO), Yi-Zhong Fan (PMO), Fabio Gargano (Bari), Shi-Jun Lei (PMO), Xiang Li (PMO), Yun-Feng Liang (PMO), M. Nicola Mazzotta (Bari), Zhao-Qiang Shen (PMO), Meng Su (HKU/PMO), Andrii Tykhonov (Geneva), Qiang Yuan (PMO), Stephan Zimmer (Geneva), on behalf of the DAMPE collaboration, and Bin Li (PMO) and Hai-Bin Zhao (PMO) on behalf of the CNEOST group.

on 27 Dec 2016; 01:02 UT

Credential Certification: Zun-Lei Xu (xuzl@pmo.ac.cn)
Participation to multi-messenger searches

- DAMPE participates to multi-messenger search of $\gamma$ counterparts
- Detection of gamma-ray source TXS 0506+056 (possibly associated with the neutrino event IceCube-170922A)
  - no clear variability detected due to limited statistics
  - ongoing monitoring of the source
Summary

- DAMPE is working extremely well since ~3 years
- $e^{-}+e^{+}$ spectrum precisely measured up to TeV energies
  - a clear spectral break has been directly measured at ~1 TeV
  - improved precision of the $e^{-}+e^{+}$ spectrum behavior and structures may shed light on nearby sources, anisotropies, DM
- Proton, Helium and nuclei measurements are ongoing
- Photon detection capability assessed
  - accumulating more statistics to profit the excellent energy resolution at high energy
Thank you
Backup
The Silicon TracKer (STK)

- 48 μm wide Si strips - 121 μm pitch
- 95×95×0.32 mm³ Silicon Strip Detectors (SSD) - 768 strips
- 1 ladder composed by 4 SSDs
- 16 ladders per layer (76×76 cm²)
- 12 layers (6x + 6y)

Analog Readout of each second strip:
384 channels / SSD- Ladder
Charge sharing
The CALOrimeter

- 14 alternate orthogonal layers, each of 22 BGO bars
  - Total 308 bars
  - Dimensions of a bar: 2.5×2.5×60 cm³
  - Total depth ~32 $X_0$, ~1.6 $\lambda$

- One PMT at each BGO bar end
  - Two PMTs per bar, total 616 PMTs

- Electronics boards attached to each side of the module

- Deposited energy ranges: 2 MeV – 2 TeV and 10 MeV – 5 TeV
The PSD and the NUD

- **PSD**
  - 2 layers (x and y), each is $82 \times 82 \text{ cm}^2$
  - $88 \times 2.8 \times 1 \text{ cm}^3$ scintillator bars
  - Staggered by 0.8 cm in each layer

- **NUD**
  - 4 large area boron-doped plastic scintillators, $30 \times 30 \times 1 \text{ cm}^3$ each
  - Wrapped in Al for photon reflection
Beam tests at CERN

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

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

- **17 days @ SPS, 16/03-10/04 2015**
  - Fragments @ 66.67, 88.89, 166.67 GeV/c
  - Argon @ 30A, 40A, 75A GeV/c
  - p @ 30, 40 GeV/c

- **21 days @ SPS, 10/06-01/07 2015**
  - p @ 400 GeV/c (SPS primary beam)
  - e @ 20, 100, 150 GeV/c
  - $\gamma$ @ 50, 75, 150 GeV/c
  - $\mu$ @ 150 GeV/c
  - $\pi^+$ @ 10, 20, 50, 100 GeV/c

- **6 days @ SPS, 20/11-25/11 2015**
  - Pb @ 30A GeV/c (and fragments)
## The DAMPE triggers

<table>
<thead>
<tr>
<th>Trigger Type</th>
<th>Logic</th>
<th>Energy Threshold</th>
<th>Pre-scale factor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HE</strong></td>
<td>L1_P_dy5 &amp; L2_P_dy5 &amp; L3_P_dy5 &amp; L4_N_dy8</td>
<td>~10 MIPs</td>
<td>1</td>
</tr>
<tr>
<td>MIPs (Type I)</td>
<td>L3_P_dy8 &amp; L11_P_dy8 &amp; L13_P_dy8</td>
<td>~0.4 MIPs</td>
<td>4 (low latitude(±20°))</td>
</tr>
<tr>
<td>MIPs (Type II)</td>
<td>L4_P_dy8 &amp; L12_P_dy8 &amp; L14_P_dy8</td>
<td>~0.4 MIPs</td>
<td>4 (low latitude(±20°))</td>
</tr>
<tr>
<td>LE</td>
<td>L1_N_dy8 &amp; L2_N_dy8 &amp; L3_N_dy8 &amp; L4_N_dy8</td>
<td>~0.4 MIPs</td>
<td>8 (low latitude(±20°))</td>
</tr>
<tr>
<td><strong>Unbiased</strong></td>
<td>(L1_P_dy8 &amp; L1_N_dy8)</td>
<td>~0.4 MIPs ~0.4 MIPs</td>
<td>512 (low latitude(±20°))</td>
</tr>
<tr>
<td></td>
<td>(L2_P_dy8 &amp; L2_N_dy8)</td>
<td>~0.4 MIPs ~0.4 MIPs</td>
<td>2048 (other region)</td>
</tr>
</tbody>
</table>
STK alignment

- STK alignment is performed once every two weeks
  - MIPs (non-showering particles) are used to correct the alignment
  - A spatial resolution < 40 μm on central STK planes is achieved
Stability of detectors

PSD stability: 0.5%

STK stability: 0.7%

BGO stability: 0.5%

NUD stability: 0.9%
MIP calibration

- Energy calibration with MIPs

![Graph showing counts vs. deposited energy for On-Orbit Data and MC-Digi Data.](image)
Selection based on Convolutional Neural Networks + Random Forest

Other PID algorithms are under study to decrease the contamination from electrons at a level below the Extra Galactic Background emission.