DAMPE (and HERD)

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(on behalf of DAMPE and HERD collaborations)

The Future Research on Cosmic Gamma Rays
August 26-29, 2015
La Palma
The DAMPE Collaboration

- China
  - Purple Mountain Observatory, CAS, Nanjing
    - Chief Scientist: 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

- Switzerland
  - University of Geneva

- Italy
  - INFN and University of Perugia
  - INFN and University of Bari
  - INFN and University of Lecce
The DAMPE physics goals

• High energy particle detection in space
  – Study of the cosmic e, γ spectra and Search for DM signatures
  – Study of cosmic ray (nuclei) spectrum and composition
  – High energy gamma ray astronomy

Detection of 10 GeV - 10 TeV e/γ, 100 GeV - 500 TeV CR
  Excellent energy resolution and tracking precision
  Complementary to Fermi, AMS-02, CALET, ISS-CREAM, ...

• Follow-up mission to both Fermi/LAT and AMS-02
  – Extend the energy reach to the TeV region, providing better resolution
  – Overlap with Fermi on gamma ray astronomy
  – Run in parallel for some time
The beam!
(charged particles)

A few years-old scenario
The beam!
(charged particles)

Now measurements by:
PAMELA
CREAM
ATIC
FERMI
AMS-02
The beam!
(charged particles)

PAMELA
CREAM
ATIC
FERMI
AMS-02
DAMPE
The beam!
(charged particles)

- PAMELA
- CREAM
- ATIC
- FERMI
- AMS-02
- DAMPE
- HERD
Electrons: Dark Matter vs Nearby Sources

Need a detector in space that can detect electrons well above 1 TeV with very good energy resolution.
Nuclei: CR Spectra & Composition toward the knee(s)

Proton spectrum to \( \approx 900 \) TeV
He spectrum to \( \approx 400 \) TeV/n
Spectra of C, O, Ne, Mg, Si to \( \approx 20 \) TeV/n
B/C ratio to \( \approx 4-6 \) TeV/n
Fe spectrum to \( \approx 10 \) TeV/n

(Depending on the assumed single primary spectra)
Photons: spectral features (DM) and astronomy

DAMPE 1 year all sky above 1 GeV
DAMPE in space

- One of the 5 satellite missions of the Strategic Priority Research Program in Space Science of CAS
  - Approved for construction (phase C/D) in Dec. 2011
  - Scheduled launch date **December 18, 2015**

- Satellite < 1900 kg, payload ~1340kg
- Power consumption 640W (400 W)
- Lifetime > 3 years
- Launched by CZ-2D rockets

- Altitude 500 km
- Period 90 minutes
The DAMPE Detector

Plastic Scintillator Detector

Silicon-Tungsten Tracker

BGO Calorimeter

W converter + thick calorimeter (total 33 $X_0$) + precise tracking + charge measurement ➔ high energy $\gamma$-ray, electron and CR telescope
The STK detector

Each ladder is composed by 4 95 × 95 × 0.320 mm³ Silicon Strips Detectors (SSD).

- Each SSD has 768 strips (width 48 μm);
- distance between two strips 121 μm;
- 1 over 2 strips is readout (384 channels): a correction on the signal collected must be applied ⇒ charge sharing.
3D Imaging BGO Calorimeter

- 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
  - depth $\sim 32X_0$
- Two PMTs coupled with each BGO crystal bar in two ends
- Electronics boards attached to each side of module
3D Imaging BGO Calorimeter

308 BGO bars

616 PMTs

Light transmission (%) vs wavelength (nm)

Overlapping dynamic ranges

1 MIPs

1.08 \times 10^5 \text{ MIPs}
3D Imaging BGO Calorimeter Assembly

Carbon Fiber Structure
BGO crystal installation
PMT installation
Cable arranging
Cable connector
BGO Cal
Comparison with AMS-02 and FERMI

<table>
<thead>
<tr>
<th></th>
<th>DAMPE</th>
<th>AMS-02</th>
<th>Fermi LAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e/\gamma$ Energy res.@100 GeV (%)</td>
<td>1.5</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>$e/\gamma$ Angular res.@100 GeV (°)</td>
<td>0.1</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>$e/p$ discrimination</td>
<td>$10^5$</td>
<td>$10^5 - 10^6$</td>
<td>$10^3$</td>
</tr>
<tr>
<td>Calorimeter thickness ($X_0$)</td>
<td>31</td>
<td>17</td>
<td>8.6</td>
</tr>
<tr>
<td>Geometrical accep. (m²sr)</td>
<td>0.29</td>
<td>0.09</td>
<td>1</td>
</tr>
</tbody>
</table>

- Geometrical acceptance with BGO alone: 0.36 m²sr
  - BGO+STK+PSD: 0.29 m²sr
  - First 10 layers of BGO ($22 \, X_0$) +STK+PSD: 0.36 m²sr
Test beam activity at CERN (nov ‘14 - nov’15)

• 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
  – π-@ 3GeV/c, 10GeV/c
  – γ @ 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)
  – γ @ 3-20GeV/c
  – μ @ 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
  – γ @ 50, 75 , 150 GeV/c
  – μ @ 150 GeV /c
  – π+ @10, 20, 50, 100 GeV/c

• 10days@SPS, 11/11-20/11 2015
  -- Pb 30AGeV/c (and fragments) (HERD)

• 6days@SPS, 20/11-25/11 2015
  -- Pb 030 AGeV/c (and fragments)
CERN recognized experiment
RE29 : DAMPE
9 Institutions, 55 Participants
Electron Energy Reconstruction

0.5, 1, 1.5, 2, 3, 4, 5 GeV @ PS
5, 10, 20, 50, 100, 149, 197, 243 GeV @ SPS

225 GeV Electron Longitudinal profile
Electron Energy Reconstruction

5 GeV electron (simulation & test beam data)

Energy spectra (5GeV)

Energy longitudinal distribution
Electron Energy and Angle Reconstruction
(linearity and resolutions)

\[ \frac{\sigma_E}{E} = \frac{0.0606}{\sqrt{E/\text{GeV}}} \pm 0.0082 \]

\[ \frac{\sigma_E}{E} = \frac{0.0611}{\sqrt{E/\text{GeV}}} \pm 0.0147 \pm 0.0088 \]
Photon tagging

Photon energy measured by BGO
\[ \text{vs} \]
Beam moment –Tagged electron

Electron bending angle
\[ \text{vs} \]
\[ \frac{1}{\text{Electron Moment}} \]

PRELIMINARY
Protons @5 GeV

Longitudinal profile

Deposited energy

Normalized counts

DAMPE BGO Event Display

Longitudinal profile

Depth ($X/L$)
Ions in the BGO calorimeter

First Layer MiPS or Bar

He, Li, Be, B, C, N, O, F, Ne, Na, Al, P, S, Cl, Ar

Total Energy in the BGO (MeV)

@ 40 GeV/n

Charge Z

PRELIMINARY
PSD
(Plastic Scintillator Detector)

PRELIMINARY
STK preliminary performance evaluation

PRELIMINARY
NUD: NeUtron Detector
(Boron doped scintillators)

\[ n + ^{10}\text{B} \rightarrow \alpha + ^{7}\text{Li} + \gamma \]
China’s Space Station Program

**Phase -I**
- 2003
- 2011
- 10 astronauts in 5 flights ➔ space walk

**Phase -II**
- 2016
- Space lab: no living cabin

**Phase -II**
- 2020
- Space Station
  - 3 large modules
  - ~60 tons
  - ~10-year lifetime

10 astronauts in 5 flights ➔ space walk

Space lab: no living cabin
High Energy Radiation Detector

- Top tungsten + silicon strip charge detection
- Cosmic ray (CR) composition
- Gamma ray tracking

- Side silicon strip charge detection
- CR composition

- LYSO calorimeter e/γ energy detection
- CR nuclei energy detection
- E/p separation
The HERD Proto-Collaboration Team

• Chinese institutions (more welcome!)
  – Institute of High Energy Physics, Purple Mountain Observatory, Xi’an Institute of Optical and Precision Mechanics, University of Science and Technology of China, Nanjing University, Peking University, Yunnan University, China University of Geosciences, Ningbo University, Guangxi University

• International institutions (more welcome!)
  – Switzerland: University of Geneva
  – Italy: Università di Pisa/INFN, IAPS/INAF, University of Florence/INFN, University of Perugia/INFN, University of Trento/INFN, University of Bari/INFN, University of Salento/INFN-Lecce
  – Sweden: KTH
  – USA: MIT/Harvard
**HERD: High Energy cosmic-Radiation Detector**

<table>
<thead>
<tr>
<th>Science goals</th>
<th>Mission requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark matter search</td>
<td>Better statistical measurements of $e/\gamma$ between 100 GeV to 10 TeV</td>
</tr>
<tr>
<td>Origin of Galactic Cosmic rays</td>
<td>Better spectral and composition measurements of CRs between 300 GeV to PeV with a large geometrical factor</td>
</tr>
</tbody>
</table>

Other science goals:
- Monitoring of GRBs,
- Microquasars
- Blazars and other transients.
## Characteristics of HERD components

<table>
<thead>
<tr>
<th>Type</th>
<th>Size</th>
<th>(X_0, \lambda)</th>
<th>Unit</th>
<th>Main Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tracker (top)</strong></td>
<td>Si strips</td>
<td>70 cm × 70 cm</td>
<td>2 (X_0)</td>
<td>Charge Early shower Tracks</td>
</tr>
<tr>
<td><strong>Tracker 4 sides</strong></td>
<td>Si strips</td>
<td>65 cm × 50 cm</td>
<td>2 (X_0)</td>
<td>Charge Early shower Tracks</td>
</tr>
<tr>
<td><strong>CALO</strong></td>
<td>~10K LYSO cubes</td>
<td>63 cm × 63 cm × 63 cm</td>
<td>55 (X_0), 3 (\lambda)</td>
<td>e/y energy nucleon energy e/p separation</td>
</tr>
</tbody>
</table>

Total detector weight: \(~2000\) kg
## Expected performance of HERD

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma/e$ energy range (CALO)</td>
<td>tens of GeV-10TeV</td>
</tr>
<tr>
<td>Nuclei energy range (CALO)</td>
<td>up to PeV</td>
</tr>
<tr>
<td>$\gamma/e$ angular resol. (top Si-strips)</td>
<td>0.1°</td>
</tr>
<tr>
<td>Nuclei charge resol. (all Si-strips)</td>
<td>0.1-0.15 c.u</td>
</tr>
<tr>
<td>$\gamma/e$ energy resolution (CALO)</td>
<td>&lt;1%@200GeV</td>
</tr>
<tr>
<td>Proton energy resolution (CALO)</td>
<td>20%</td>
</tr>
<tr>
<td>$e/p$ separation power (CALO)</td>
<td>&lt;10$^{-5}$</td>
</tr>
<tr>
<td>Electron eff. geometrical factor (CALO)</td>
<td>3.7 m$^2$sr@600 GeV</td>
</tr>
<tr>
<td>Proton eff. geometrical factor (CALO)</td>
<td>2.6 m$^2$sr@400 TeV</td>
</tr>
</tbody>
</table>
One example: HERD Proton and He Spectra

Hoerandel model as HERD input
Only statistical error

Protons

He
Summary

- **DAMPE** is among CAS funded projects for space
- Better/extended performance than existing detectors for e/\(\gamma\)/CR towards larger energies
- Systematic activity on assembly, qualification, test beam and simulation on schedule
- Preparation for mission data analysis is ongoing
- Launch foreseen on December 18, 2015

- HERD: an opportunity to further increase the energy range and the detection reach in galactic CR measurements
- Novel calorimetric concept
More Stuff
(SNR) Maximum CR energy (for protons)

\[ \varepsilon \approx 230 n_e^{1/2} u_7^2 R_{pc} \text{ TeV} \]

\[ \varepsilon \approx 160 \text{ TeV} \quad \text{shock vel} \sim 5,000 \text{ km s}^{-1} \]

\[ \varepsilon \approx 20 E_{44}^{1/3} n_e^{1/6} u_6^{4/3} \text{ TeV} \]

Blast wave energy in \(10^{44} \text{J}\)

SN expansion into circumstellar wind

wind mass loss in \(10^{-5}\) solar masses yr\(^{-1}\)

\[ \varepsilon = 800 u_7^2 \sqrt{\frac{M_5}{u_4}} \text{ TeV} \]

wind vel in 10 km s\(^{-1}\)

T. Bell
GSSI workshop
Sep. 2014
Fundamental issue also for any precision measurement on atmospheric neutrinos.

Fig. 11. The all-particle spectrum (black solid curve) obtained by summing up CREAM elemental spectra from p to Fe (filled symbols) is compared with previous measurements (open symbols): ATIC-1 [35], black squares; JACEE, blue downward triangles; RUNJOB, black crosses; Ichimura et al. [71], green upward triangles; SOKOL [72], pink circles. The gray shaded area indicates ground based indirect measurements. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Direct measurements

Requirements:
Calorimetry vs Spectrometry
Large acceptances
<30% resolutions

Output:
Fully explore the sub-PeV region

Limitations:
Surface/weight limited
Hard to reach the all-particle knee
Need high technology

Indirect measurements

Requirements:
Multi-Hybrid approach
Operate at (not too) high altitude
Large surfaces / samplings

Output:
Reach the highest energies

Limitations:
Very poor mass resolution
Intrinsically limited by systematics
Give many hints but few answers
What is needed

• Focus on the 100TeV-10 PeV energy region
• Measure the “knees” of each species

Together with high energy gamma and neutrinos astronomies

• Identify galactic sources
• Understand acceleration and diffusion mechanisms
• Better understand the transition to extragalactic
Current and Future projects (space)

CALET

ISS_CREAM

DAMPE

Gamma-400

HERD

AMS-03