Searching for fractionally charged particles in space with DAMPE

Chengming Liu

on behalf of DAMPE collaboration

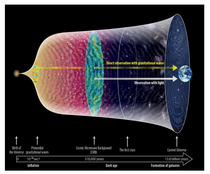
State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei

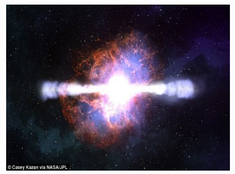
Abstract

The existence of fractionally charged particles(FCP) is foreseen in some extensions to the Standard Model of particle physics, and their detection would be a significant breakthrough. Most of the previous cosmic-rays (CRs) studies are mainly focused on the secondary CRs from the extensive air shower, but there are a few on-orbit studies to search FCP from primary CRs. This study reports a search for 2/3e FCPs in primary cosmic rays based on five-year on-orbit data acquired by DArk Matter Particle Explorer (DAMPE). No FCP candidate is observed. Therefore, a flux upper limit is determined to be $\Phi < 6.2\times10^{-10}$ cm^{-2}sr^{-1}s^{-1} at the 90% C. L.. Our results demonstrate that DAMPE exhibits higher sensitivity than experiments of similar type by three orders of magnitude, which also more stringently restricts the conditions for the existence of FCP in primary cosmic rays.

Introduction

In early 19th century, the Millikan Oil's drop experiment showed that all charged particles have multiple charge of electron charge. Then the Quark Model by Gell-Mann and Zweig proposed in 1964 that quarks have fractional charge of one third and two third. With the help of accelerators, many searches for free quarks have been studied. But due to the color confinement of QCD theory, the FCP will not exist freely. The current research in this field looks for any free fractional charge particles.





There are three possible sources of FCP in cosmic rays:
- **First,** it may be produced at the early Universe after the Big Bang and remains in some bulk matter.
- **Second,** it may be produced through high-energy astrophysical processes.
- **Third,** it may be produced in the extensive air shower of cosmic-rays.

Here are some typical experiments for searching FCP from CRs:

	Experiment	*Upper limits($cm^{-2}sr^{1}s^{-1}$)*
Underground	LSD	2.7 x 10^{-13}
	Kamiokande II	2.1 x 10^{-15}
	MACRO	6.0 x 10^{-16}
Space	AMS01	3.0 x 10^{-7}
	BESS	4.5 x 10^{-7}

DAMPE Instrument

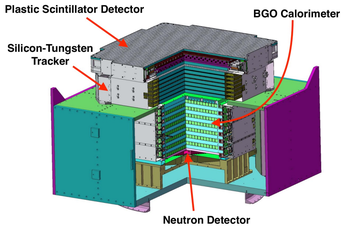


Fig.1 The structure of the DAMPE detector

- DAMPE is an orbital experiment for detecting high energy cosmic ray
- DAMPE orbit the earth at an altitude of 500 km.
- Launched on Dec.17th 2015, CZ-2D rocket
- Period: about 90 minutes
- Life time > 5 years

DAMPE consists of four sub-detectors.
- Charge measurement (dE/dx in **PSD, STK**)
- Precise tracking (**STK + BGO**)
- Precise energy measurement (**BGO**)
- Particle identification (**BGO + NUD**)

Sub-detectors PSD and STK are capable of achieving good charge measurements.		
Resolution	PSD (charge unit, c. u.)	STK (charge unit, c. u.)
For proton	0.06	0.04
For Helium	0.10	0.07

Target FCPs

■In this study, FCPs are assumed to be a type of heavy leptons.

■FCPs are expected to exhibit high penetrating ability and be free from high energy cascade effects, except ionization and weak interaction (or saying, MIP-like events).

■This work searches for 2/3e FCPs since the designed trigger threshold is 0.2 MIPs (0.45e) which is higher than the 1/3e FCPs' signals.

■A MIP-like FCP with 2/3e is created within the GEANT4 toolkit.

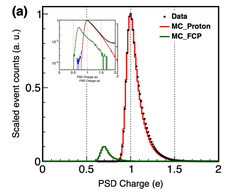
Methods

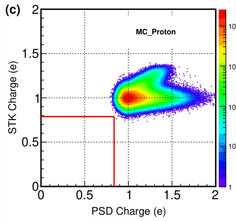
■Event selection

- **Trigger selection**: events should pass the MIPs Trigger (MIPT).
- **Track selection**: a good track reconstruction is required, and maintained in the geometric volume.
- **MIP requirement**: at most two fired strips are allowed in each layer for both PSD and BGO.

■Charge reconstruction

- The average values of PSD layers and STK layers are taken as the PSD charge and STK charge, respectively.
- The distributions of charges measured by the PSD and STK are shown in Fig. 2 .
- The signal region: The MC FCP charge peaks adding 3σ, which correspond to 0.84e and 0.79e for PSD and STK, respectively (red line in Fig. 3).





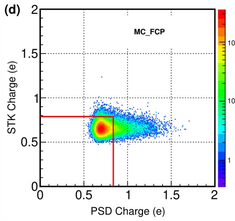
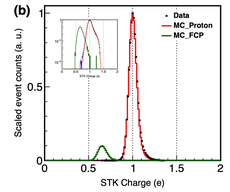


Fig.2 The distributions of charges measured by the PSD (a) and STK (b)



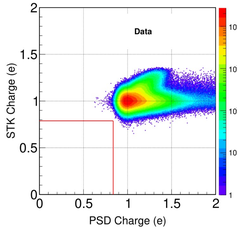


Fig.3 The two-dimensional distributions of the PSD-STK charges for (a) MC protons, (b) MC FCPs, (c) data. The red lines indicate the signal region

Result

TABLE I. The comparison between DAMPE and other similar types experiments.

Experiments	Geometric acceptance(cm^{2}sr)	Exposure time (s)	Upper limit (cm^{-2}sr^{-1}s^{-1})
AMS-01	3000	3.6×10^4	3.0×10^{-7} (95% C. L.)
BESS	1500	3.2×10^5	4.5×10^{-7} (90% C. L.)
DAMPE	3000	2.3×10^7	6.2×10^{-10} (90% C. L.)

- Underground experiments assume that FCPs would exhibit long penetration paths, which, in turn, requires them to have energy exceeding a few hundred GeV.
- Given the effective energy threshold arising from the geomagnetic cut-off, experiments in space can detect FCPs with energy as low as a few GeV.
- With DAMPE, a flux upper limit of 2/3e FCP is derived to be $\Phi < 6.2\times10^{-10}$ cm^{-2}sr^{-1}s^{-1} , which improves the previous precision of space experiment by three orders of magnitude

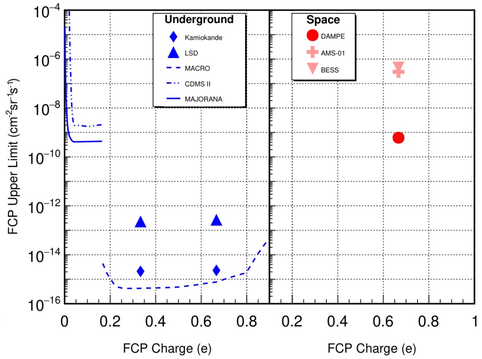


Fig.4 The FCP flux upper limit versus electric charge from different cosmic rays experiments.

References

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