Searching for fractionally charged particles with DAMPE

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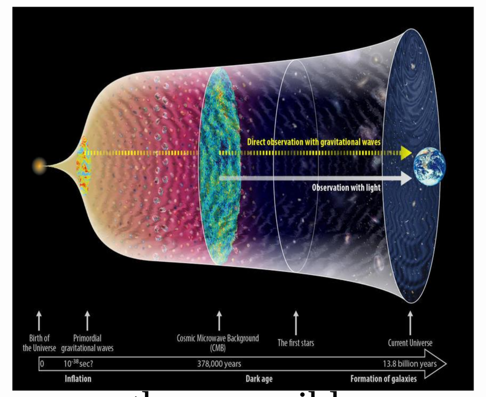
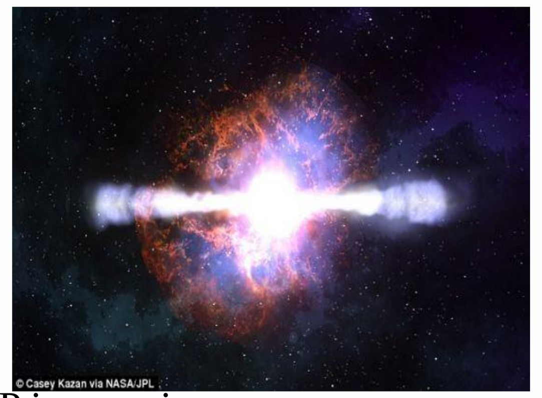
Abstract

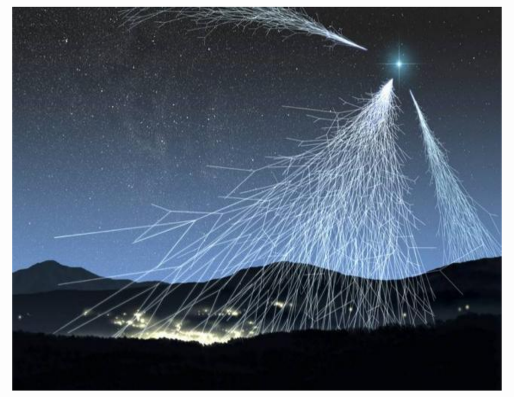
The existence of fractionally charged particles (FCP) is foreseen in some extensions to the Standard Model of particle physics, and their detection would be a significant breakthrough. Most of the previous cosmic-rays (CRs) studies are mainly focused on the secondary CRs from the extensive air shower, but there are a few on-orbit studies to search FCP from primary CRs. The DArk Matter Particle Explorer (DAMPE) was launched into space on the 17th December 2015, and it has been working well in space for more than five years with the purpose of measuring CRs and gamma-rays, and as today a large amount of scientific data has been acquired. The FCP is assumed to be a heavy lepton, as a result, the Minimum Ionized Particles (MIPs) are selected. The Geant4 simulations toolkit is used to investigate the signal region and to evaluate selection efficiency of 2/3 FCP in DAMPE. The detailed selection methods are presented and discussed in this work.

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.







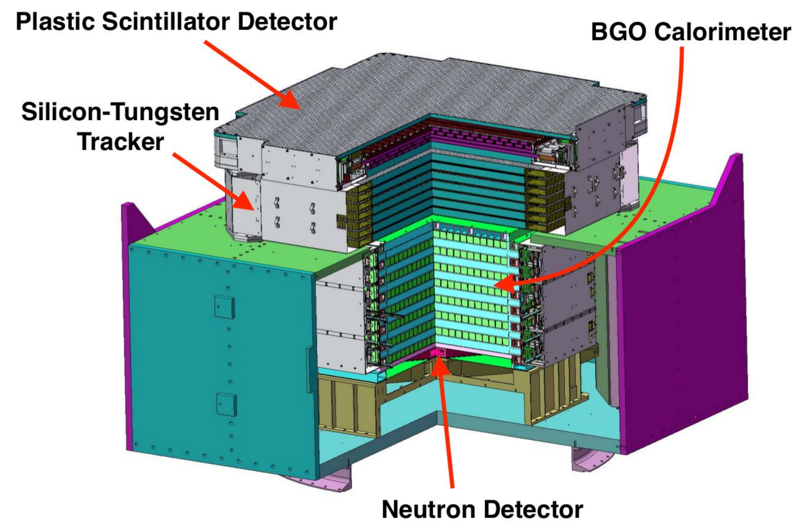
There are three possible sources of FCP in cosmic rays:

- **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}
In-space	AMS01	3.0 x 10^{-7}
	BESS	4.5 x 10^{-7}

DAMPE Instrument



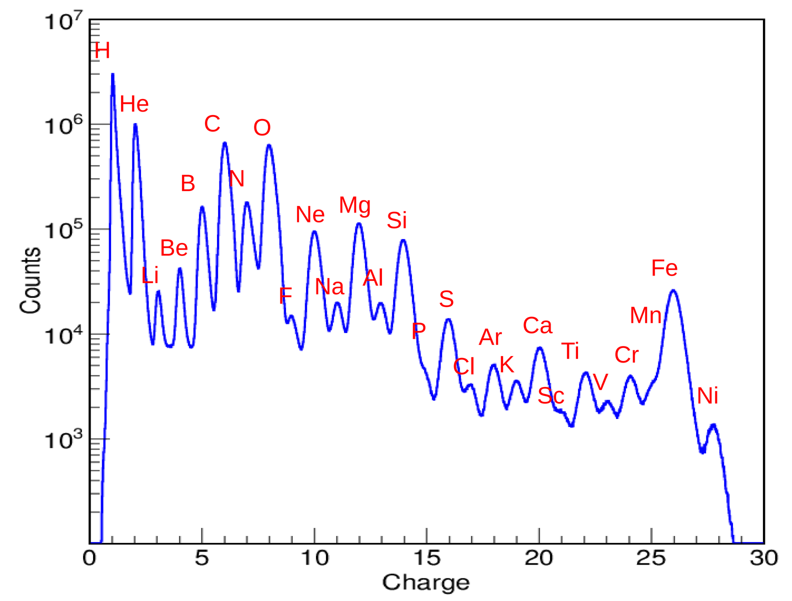
- DAMPE is an orbital experiment for detecting high energy cosmic ray
- DAMPE orbit the earth at an altitude of 500 km.
- Launched on Dec.17th 2015, CZ-2D rocket
- Period: about 90 minutes
- Life time > 5 years

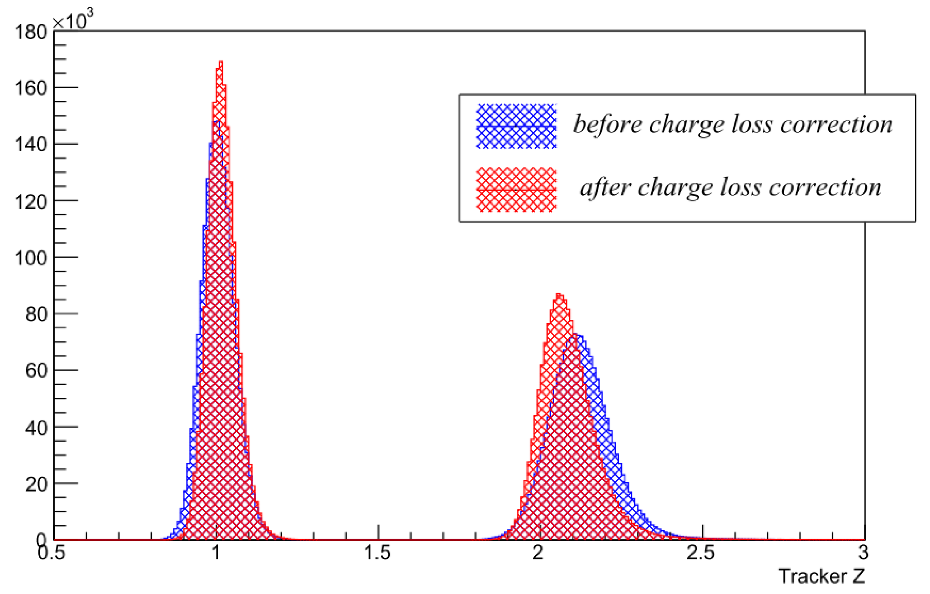
DAMPE consists of four sub-detectors.

- Charge measurement (dE/dx in **PSD, STK**)
- Precise tracking (**STK + BGO**)
- Precise energy measurement (**BGO**)
- Particle identification (**BGO + NUD**)

Charge reconstruction is based on Bethe-Bloch Formula. The energy deposited in the PSD and STK is related to the square of particle charge.

The Figures below show the ability to reconstruct the charges of nuclei (with PSD, left), of proton and helium nuclei (with STK, right).

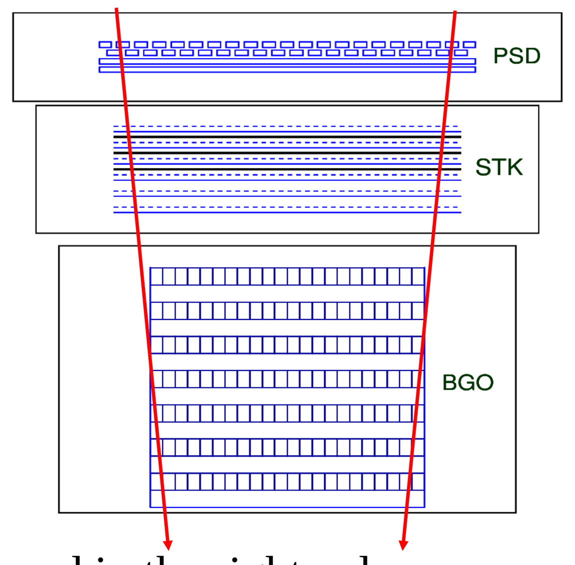




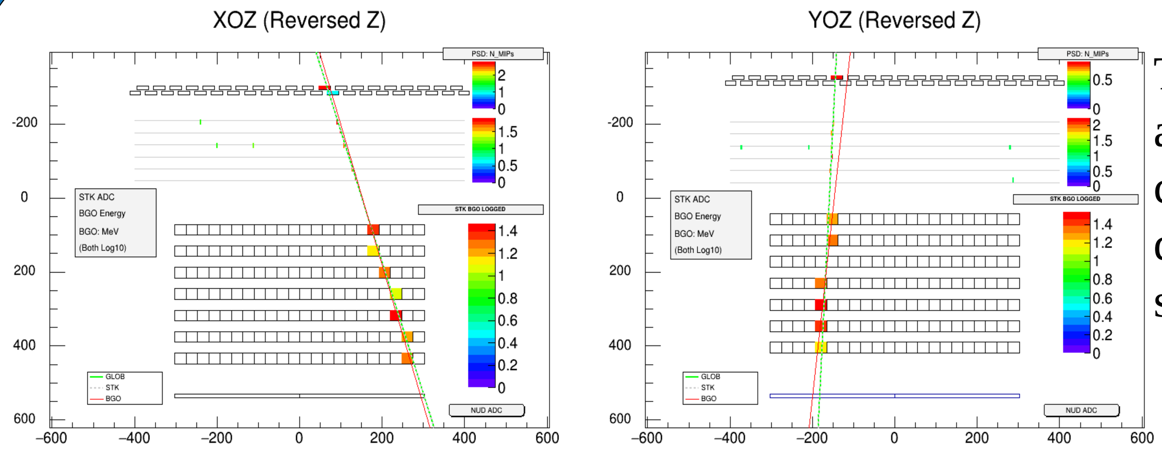
Methods of Searching FCP with DAMPE

Since the designed trigger threshold of MIPs is 0.2 MIPs which is larger than the 1/3 charged particles(1/9 MIPs), this work looks for the 2/3 charged particles with the following criteria:

- **Fiducial:** Geometry angle, latitude restrictions, good track, energy deposition.
- **Angle difference:** Remove the scattered events
- **MIPs selections:**
  - Constrain the fired detector cells in PSD and BGO
  - Require the track going through the PSD strips
  - Require the event penetrate the whole BGO calorimeter
- **PSD end charge ratio:** Maintain the reliability of PSD charge reconstruction
- **STK charge:** Select the good cluster to reconstruct the charge



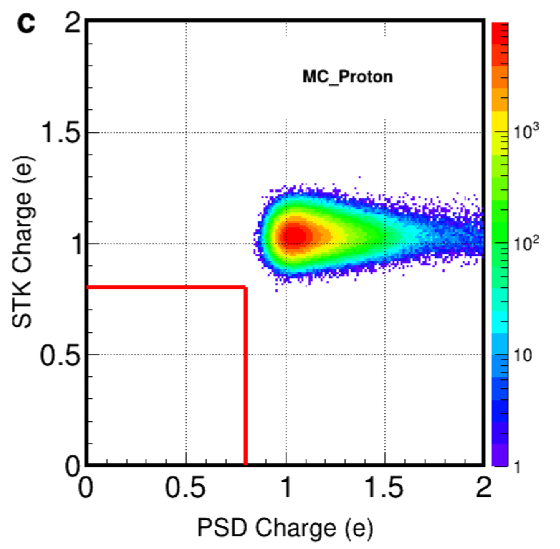
An MIP event is reconstructed under DAMPE framework and displayed in the right column.

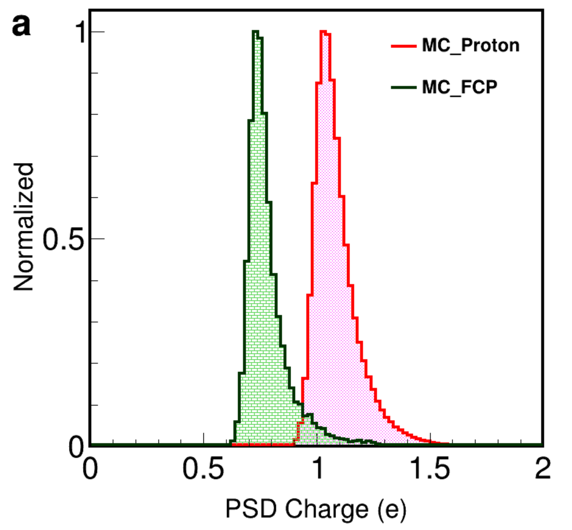


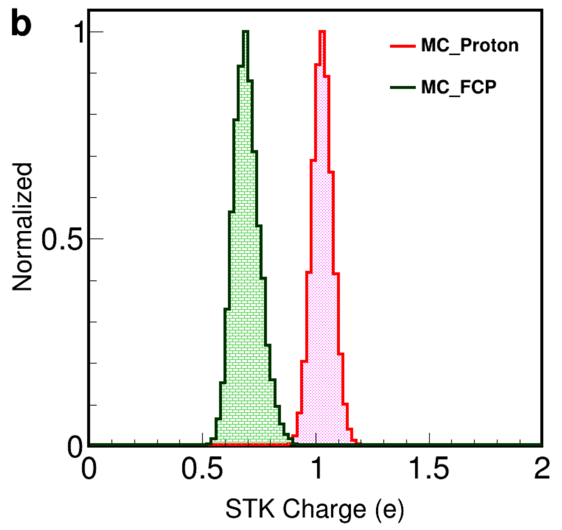
The charges in both the PSD and STK are reconstructed. Thanks to the good charge resolution of DAMPE, a good discrimination between 2/3 FCPs and singly charged particles is possible.

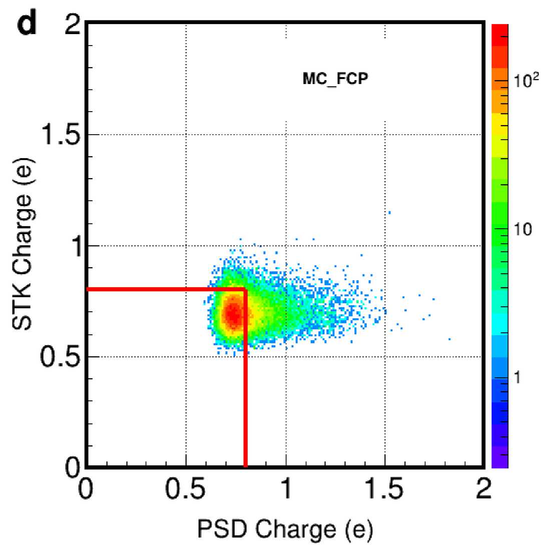
Considering the main background comes from the cosmic ray proton, all the criteria are applied to Proton Monte Carlo(MC) first.

A signal region can be defined by PSD and STK MC as the red lines shows, the charge of two lines are set to 0.8 e which is about 5 sigma value smaller than the mean value of Gaussian fit in Figure a and b. At the same time, the FCP MC is simulated by creating a new particle in DAMPE software. The signal region has a 68% efficiency of covering the FCP as shown in figure d at right.









Summary

The DAMPE instrument has been working stably on-orbit for more than five years. DAMPE has a good charge discrimination based on the PSD and STK sub detectors. , so it can be used to search for Fractionally Charged Particles. The selection criteria to search FCP with DAMPE have been studied, a MC simulation has been performed and an evaluation of the search efficiency has been carried out.

References

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