29th International Cosmic Ray Conference Pune (2005) **9**, 183-186

A Search for Low Velocity Exotic Particles with the L3+C Spectrometer

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Time of flight and velocity of particles can be determined with the timing scintillators and the drift chambers in L3+C. The feasibility to search for low velocity exotic particles, e.g., magnetic monopoles or nuclearites is studied.

1. Introduction

Low velocity exotic particles (LVP) are predicted by theories but have not been observed by experiments. Proposed candidates are nuclearites or stranglets, composed of strange quark matter (SQM) [1]. They consist of almost equal numbers of up, down and strange quarks. Due to their stability, the large mass range, low Z/A, and low velocity, SQM is considered as one of the ultra high energy cosmic rays beyond the GZK cut-off. In particular, color-flavor locked (CFL) SQM [2], in which Quarks form Cooper pairs with very large binding energy, is significantly more stable than ordinary SQM. Another possible candidate for LVP are magnetic monopoles (MM) deduced from the Great Unified Theory (GUT) [3], and assumed having magnetic charge, large mass (about 10^{16}GeV), and very low velocity β=v/c($\sim10^{-3}$). At present, intermediate mass Monopoles (IMM) [4] might be the main part of MM, which should have lower mass and be able to be accelerated in the galactic magnetic field to higher velocity. The third possibility are neutralinos, assumed to collide with high energy cosmic rays and create secondary particles which might be charged, massive and moving with low velocity. Both the Yunnan event and the Kolar events [5] are possibly such large massive particles with $\beta\sim0.95$.

Several experiments designed to search for such events were performed underground or in space. Many deep underground experiments gave search results for SQM and MM, and up to now MACRO obtained the lowest MM and SQM upper flux limits [6]. A five-fold coincident event of an earthquake was recorded by several seismographic stations [7]. The explanation given was that a 'quark nugget' passed the Earth. To avoid large energy losses in matter and to detect lower mass particles, some experiments, e.g., TL [8] and SLIM [9], are installed on the ground or at mountain altitude. In space, since 1970s, four balloon experiments (reviewed in [10]) and AMS-01 [11] observed one or two particles respectively, which exhibit features close to the ones of nuclearites. There are other various SQM detection methods in cosmic rays, e.g., fossil tracks in meteorites [12], and in heavy-ion targets, or even collider experiments, as reviewed in [1, 13].

2. Methodology

The L3 detector at the CERN electron–positron collider (LEP) was employed for the study of cosmic rays from 1999 to 2000, collecting 1.2×10^{10} triggers in 312 days [14]. The L3 muon spectrometer lied underground, including muon chambers installed inside a huge magnet. The detector was installed below 7500g/cm^2 of molasse. The magnet yoke and the coil totalized 1300g/cm^2. The shallow cover on the muon chambers made it possible for L3+C to detect particles with low mass. The muon chambers were assembled into 8 octants, each of which was composed of three layers of detection planes.

The L3 muon spectrometer were able to measure the rigidity (or momentum if Z=1) of charged particles by means of the curvature of the tracks in the magnetic field. Without a time of flight detector, L3+C could measure the event arrival time in two ways under certain conditions:

1. t_{SCNT}: time recorded by the scintillation counters on the top of the spectrometer;
2. t_{WPC}: time for particles crossing a wire plane (WPC) in a given drift chamber cell.

If a segment of a particle track does not cross the wire plane, then the whole hit points of the segment will be shifted parallel to the real track, and the shift is uncertain. On the contrary, if the segment does cross the wire plane (Figure 1), then the hit points will be separated into two parts on each side of the wire plane and shifted from the real track in opposite direction. A time correction can be applied as to obtain the optimal linear fit to the hits. The time correction corresponds then to the particle arrival time. With two times t_1 and t_2, which may be t_{SCNT} or t_{WPC}, the time of flight is t_2-t_1, and the velocity can be calculated with the estimated flight path length. The average time resolution of t_{SCNT} and t_{WPC} is 1.8ns and 5.2ns respectively [14, 15]. To test the WPC method, Monte Carlo simulations have been done. Figure 1 is a Monte Carlo event with input β=0.2, reconstructed using light velocity, and it is obvious that the segment separations from top to bottom become larger and larger.

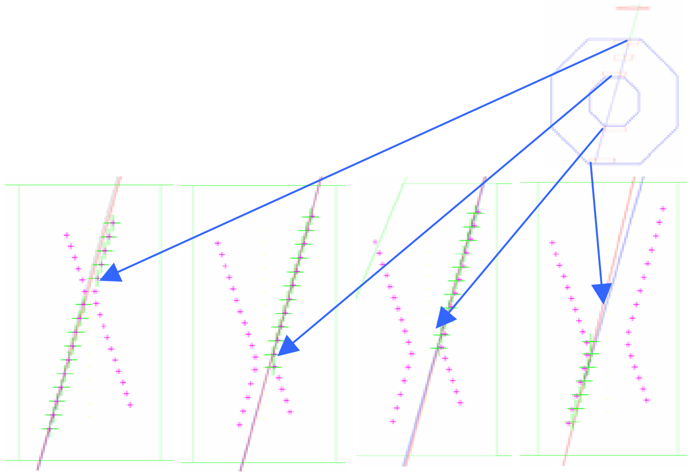

Figure 1. A Monte Carlo event with input β=0.2, and reconstructed assuming light velocity. From top to bottom the segment separations become larger and larger. Smaller crosses are hits before the event reconstruction, and larger crosses are hits after the event reconstruction. Due to the ambiguity of the position measurement, there is a fake one accompanying each true hit.

In consequence, the L3 muon spectrometer can measure particle rigidity R=p/Z (or momentum p if Z=1, e.g., muon), velocity β, and the charge-to-mass ratio Z/A from

$$\frac{Z}{A}=\frac{\beta\gamma m_p}{R} \tag{1}$$

where γ is the Lorentz factor and m_p is mass of proton.

3. Data Analysis

Only single-track events are interesting for the LVP search. As an approach, events having 3 WPC segments are selected. About 10% of the total data sample is analyzed. In each event, the following analysis procedure has been applied:

step 1. t_{WPC} is worked out from the raw data, and β is calculated approximately between every two WPC segments without event reconstruction. The weighted mean value of βs from 3 WPC segments is taken as β_{pro}, the initial value of β.

step 2. Events selected from step 1 are reconstructed with β:

1. If $-1<\beta_{pro}<1$, then $\beta=\beta_{pro}$;
2. If $\beta_{pro}\geq 1$, then $\beta=1$;
3. If $\beta_{pro}\leq -1$, then $\beta=-1$.

Events with one track only are kept.

step 3. β is calculated precisely from the track. Most of multi-muon events, events with noise and events with secondary interactions are removed by following selections:

1. The maximum of three distances from the WPC segments to the track had to be less than 0.4m;
2. The number of cells crossed by the track had to be less than 11.

After these selections, 40 events remained with $\beta<0.5$.

step 4. The remaining 40 events were scanned by eye, and were classified as follows:

1. Multi-muon events: 14
2. Events with noise: 2
3. Events with secondary interaction: 4
4. One WPC was misinterpreted by the program, because it was a binding segment with large curvature, and not really crossing the wire plane: 6
5. Three βs were much different with each other due to a bad quality of WPC: 1
6. Three βs were close to the weighted mean value of β, which is about 0.4~0.5, so these events belong to a fluctuation of β measurement: 13

Therefore the remaining events were not real LVP.

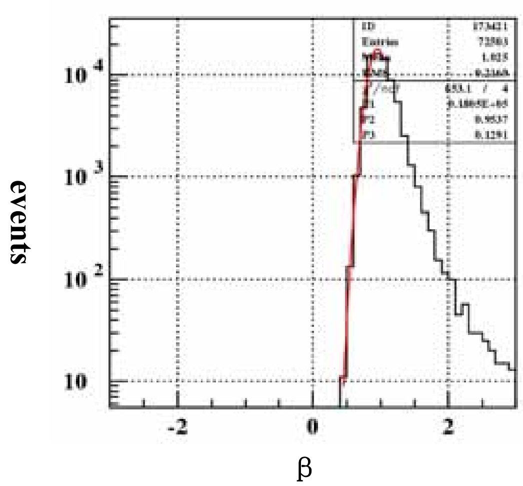

Figure 2. β distribution of a real data sample with Gaussian fitting.

The β distribution is shown in figure 2, after the removal of events of the first 5 classes. The mean value of the distribution is 1.025, and the left Gaussian $\sigma=0.129$. The selection ratio of step 1 to analyzed data is 0.86×10^{-4} because of the very strong event selection, which should be released and extended in the future. The selection ratio of step 2 and 3 to step 1 is 85.3%.

4. Summary

A feasibility study for the search of LVP with the L3+C spectrometer has been performed. L3+C can indeed contribute to the LVP search for $\beta<0.5$.

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