Ground based quark nugget searches

- cosmic ray detectors
  -fluorescence, surface counts, radio
- radio signal in ice
- visible signal in ice

Flux Through the Earth

- The local dark matter density is on the order of $1 GeV/cm^3$ and carries typical galactic velocities on the order of 200km/s
- In this case DM in the form of TeV WIMPs has a flux on the order of $10^8 m^{-2} s^{-1}$
- Nuggets with $B = 10^{26}$ will have a flux of $10^{-21} m^{-2} s^{-1} \approx 0.1\ km^{-2} yr^{-1}$
- Traditional direct detection experiments have no sensitivity to a flux this small despite the fact that the interactions are very readily observable

Energy Deposited

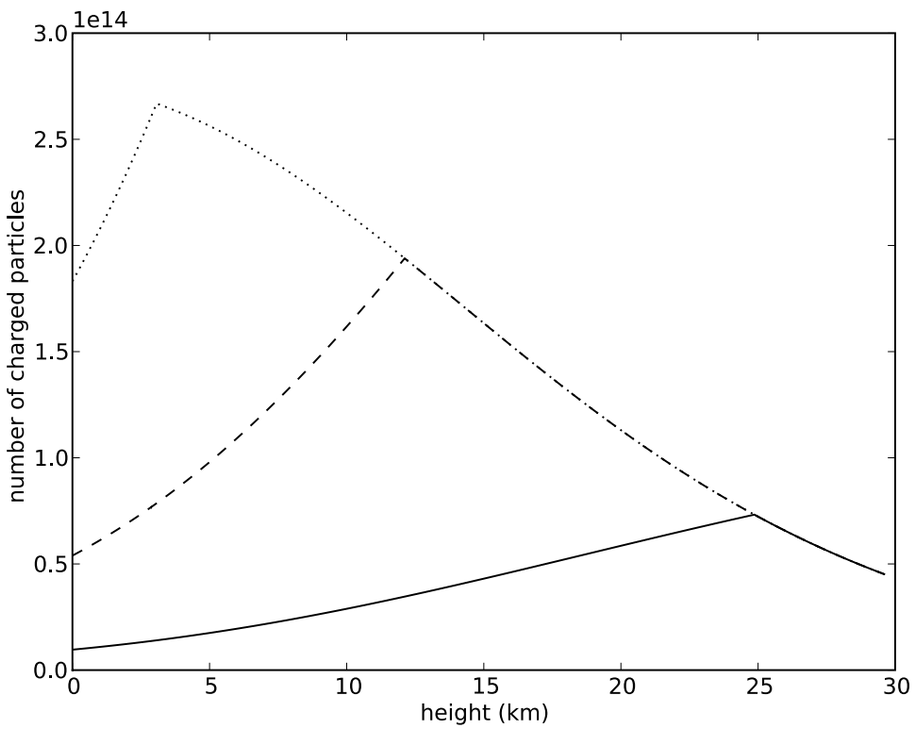
- Nuggets have a physical cross section on the order of $10^{-9}cm^2$ and the integrated atmospheric depth is $1kg/cm^2$ so an incoming nugget will strike roughly a μg of atmospheric matter
- In the case of matter nuggets only a few J of energy is deposited and no readily observed secondary particles are produced.
- If the nugget is composed of antimatter the atmospheric molecules incident on a nugget will be annihilated. In this case the energy produced will be much larger ($E \sim 10^{26}eV$.)
- Much of this will be converted into thermal energy inside the nugget, however some will be transfered to the atmosphere in the form of high energy secondary particles

Quark Matter Induced Extensive Air Showers

- The flux of nuggets near the preferred mass range is similar to that of cosmic rays near the GZK limit
- Nuclear annihilations are capable of producing a significant number of secondary particles with relativistic energies
- The nugget takes ~10ms to cross the atmosphere resulting in an extended duration shower
- Mesons and electrons are unlikely to escape the nugget so the shower consists mainly of muons

Atmospheric Fluorescence

- As the emitted muons move through the surrounding atmosphere they produce nitrogen fluorescence
- The total number of charged particles is generally larger than in a UHECR shower but there are no particles with energies above ~1GeV
- The long duration of the shower means that many CR detectors will cut them from their data



Surface Particle Counts

- Nuclear annihilations and particle production continue all the way to the earth's surface
- On reaching the surface the secondary particles will be distributed over a few km but more tightly centred on the shower core than for an UHECR
- Again arrival times are spread over a ms time scale and peak at late times (CR events peak rapidly then decay on <μs scales)

Radio Emission

- Charged particles emitted by the nugget will be deflected by the earth's magnetic field resulting in the emission of geosynchrotron radiation
- The radio signal is of a comparable intensity to that in an UHECR event
- A nugget passing through the radio transparent antarctic ice may be visible due to the thermal contribution to the radio spectrum
- The thermal spectrum also extends across the visible range and should be observable by cherenkov detectors