Search for SQM in CRs at high altitudes laboratories

The Collaboration (Bolivia, Canada, Italy, Pakistan)

S.Balestra , S. Cecchini, F. Fabbri , G. Giacomelli, A. Kumar S. Manzoor , J. McDonald , E. Medinaceli, L. Patrizii, J. Pinfold , V. Popa , O. Saavedra, G. Sher , M. Shahzad , M. Spurio, V. Togo, A. Velarde , A. Zanini

O. Saavedra
Dipartimento di
Fisica Generale
Universita di
Torino,

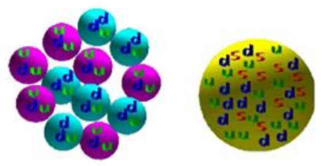
Strange Quark Matter

E. Witten, Phys. Rev. D30 (1984) 272A. De Rujula, S. L. Glashow, Nature 312 (1984) 734

- Aggregates of u, d, s quarks + electrons , $n_e = 2/3\, n_u - 1/3\, n_d - 1/3\, n_s$
- Ground state of QCD; stable for ~300 < A < 10^{57} (neutron star)

$\rho_N \sim 3.5 \times 10^{14}$ g cm^{-3}

$\rho_{nuclei} \sim 10^{14}$ g cm^{-3}



A qualitative picture...

[black points are electrons]

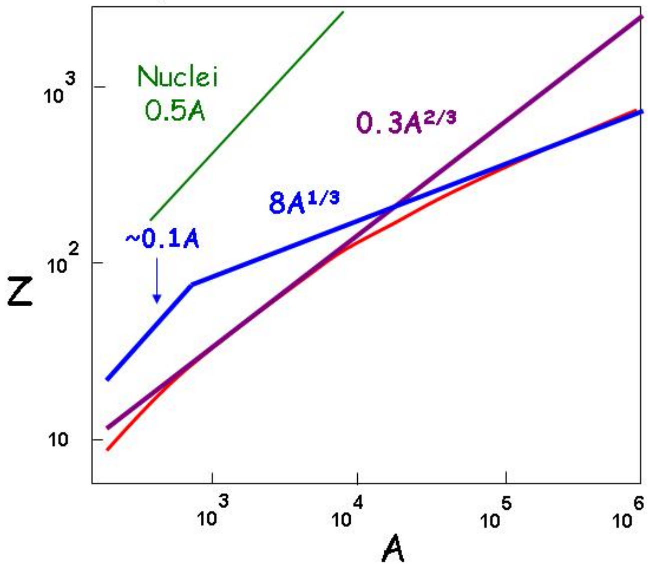
R (fm)	10^2	10^3	10^4	10^5	10^6
M (GeV)	10^6	10^9	10^{12}	10^{15}	10^{18}

strangelets (10^2–10^3 fm) — nuclearites (10^5–10^6 fm)

Produced in Early Universe

Candidates for cold Dark Matter Searched for in CR reaching the Earth

Important feature: $Z/A \ll 1$



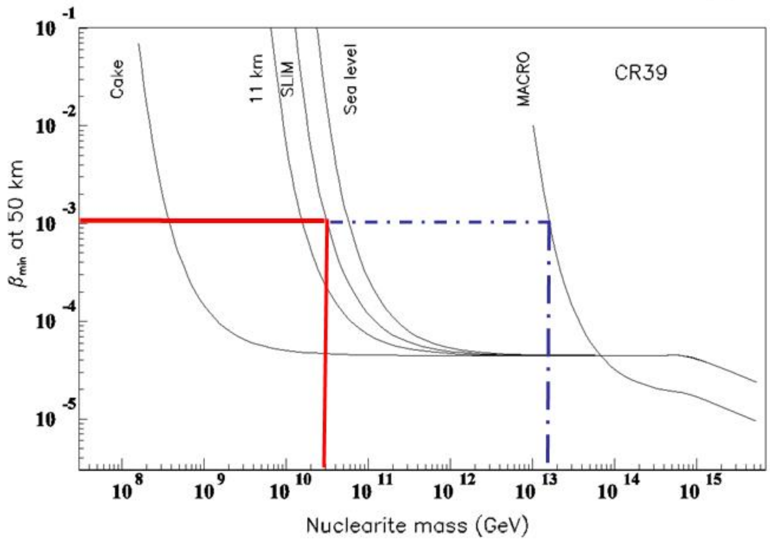
M. Kasuya et al. Phys.Rev.D47(1993)2153
H.Heiselberg, Phys. Rev.D48(1993)1418
J. Madsen Phys. Rev.Lett.87(2001)172003

Nuclearites, i.e. SQM "meteorites": ~neutral, $\beta \sim 10^{-3}$

Main energy loss mechanism by atomic collisions

$$dE/dx = -\,\sigma\,\rho_{medium}\,v^2_N \quad \begin{cases} \sigma \sim \pi\,10^{-16}\,cm^2 & R_N < 1Å \\ \sigma \sim \pi \times R^2_N & R_N > 1Å \end{cases}$$

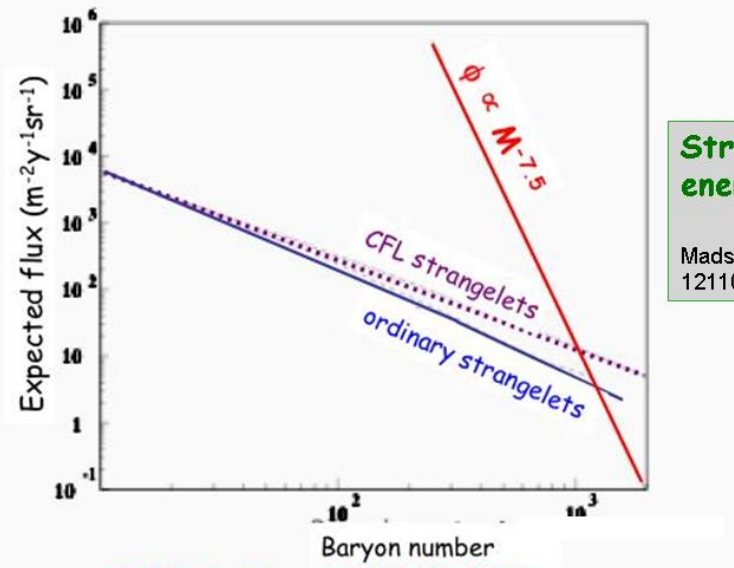
$$v(L) = v(0)\ \exp\left\{-\frac{\sigma}{M}\int_0^L \rho\ dx\right\} \qquad \int_0^L \rho\ dx = \left(M/\sigma\right)\ln\left(v(0)/v_c\right)$$



Accessible (mass,β) regions for nuclearites from above

Strangelets : small lumps of SQM

- ~300 < A < 10^6 — Produced in collisions of strange stars
  R. Klingenberg J. Phys. G27 (2001) 475
- charged — Accelerated as ordinary nuclei



G. Wilk et al. hep-ph/ 0009164 (2000)
J. Madsen et al. Phys.Rev.D71 (2005) 014026

Strangelets as ultra-high energy cosmic rays?

Madsen & Larsen, PRL 90 (2003) 121102

Did we already detect them?

Several "exotic" (= unexplained) events from different CR experiments

[1] HECRO-81 (Japan): CR composition on balloon (9 gr/cm²)

Č + Scintillator counter +Proportional tubes

2 events with: Z ~ 14 A ~ 350 and A ~ 450

[2] "Exotic Track" event : Balloon born emulsion chamber

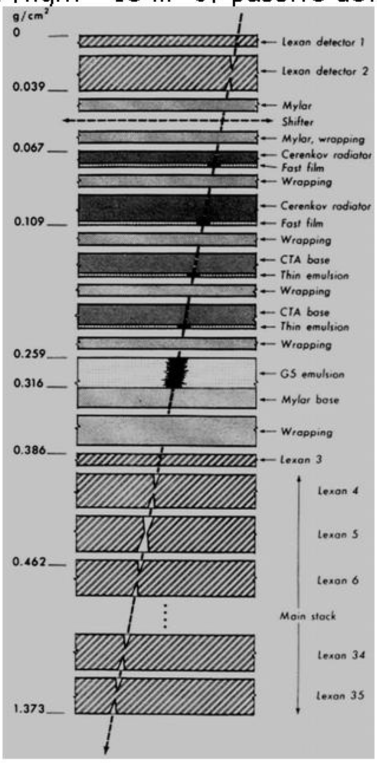
Z ~ 20 and A ~ 460, θ_{zenith}= 87.4° → 200 gr/cm²

[3] Price's "Monopole" re-analysis Z ~ 46 and A > 10^3 - 10^4

[1] T. Saito et al. Phys. Rev.Lett 65 (1990) 2094
[2] M. Ichimura et al., Nuovo Cim. A106 (1993) 843
[3] P. B. Price et al. Phys. Rev. D18 (1978) 1382

The " Price Event":

Balloon flight – 10 m² of passive detectors + emulsions and Č films.



PRL 35 (1975) 0486

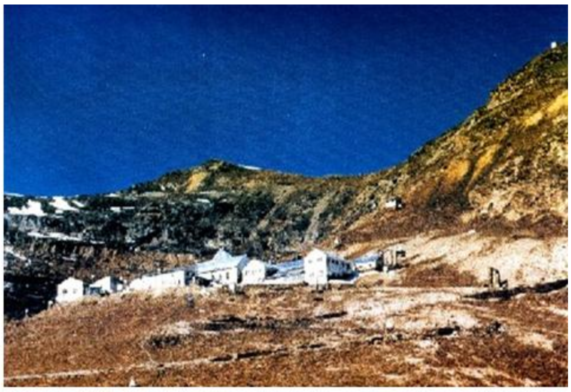
MM with g= 137e   β=0.5

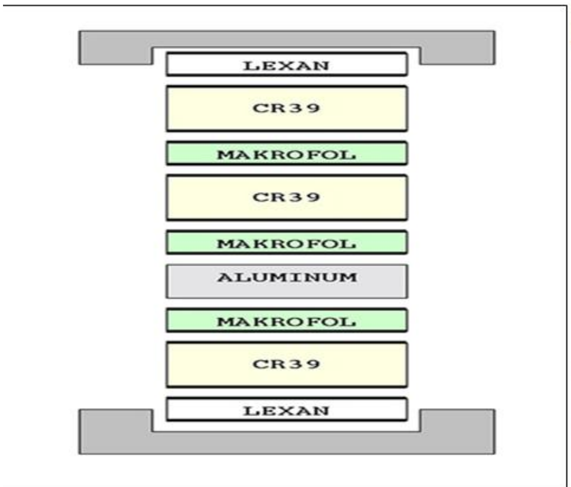
SLIM

Nuclear Track Detector Arrays

440 m² @ Chacaltaya, 5230 m asl

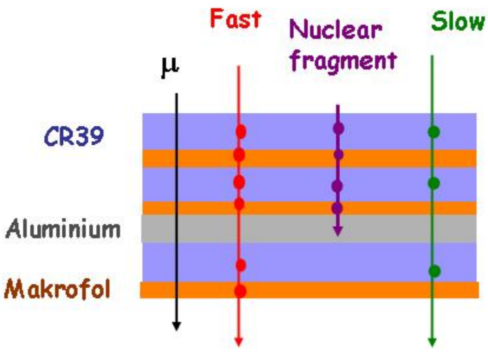
100 m² @ Koksil, Himalaya, 4275 m asl



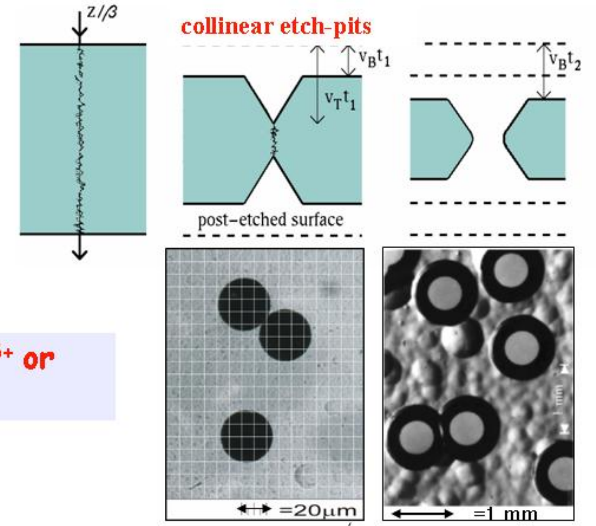


modules 24x 24cm²

Nuclear Track Detectors: CR39 and Makrofol

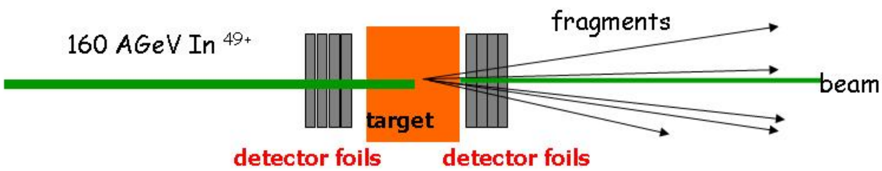


The track-etch technique

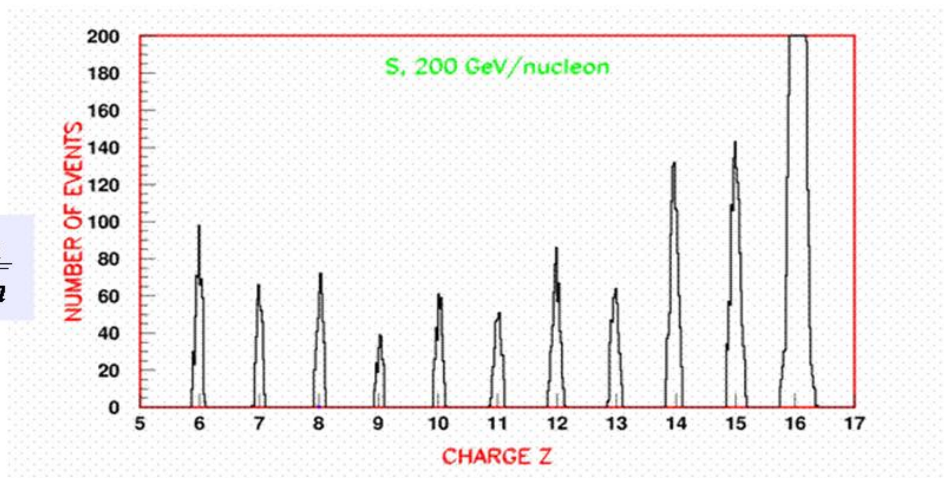


200 A GeV S^{16+} or
$\beta \sim 10^{-2}$

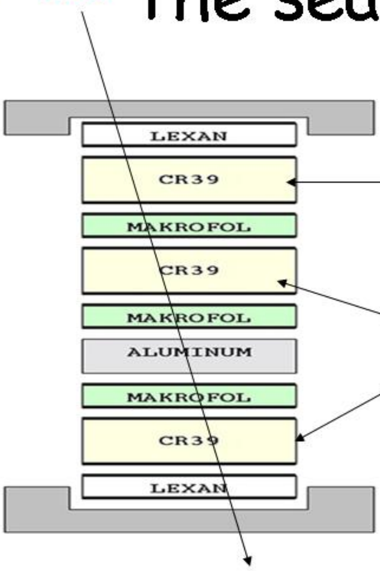
Detector Calibration: ion beams @ CERN, BNL



$$\sigma_n = \frac{\sigma_1}{\sqrt{n}}$$



The search technique



Strong etching (large tracks, easy to detect)

General scan of the surface

If a signal is found in the first sheet...

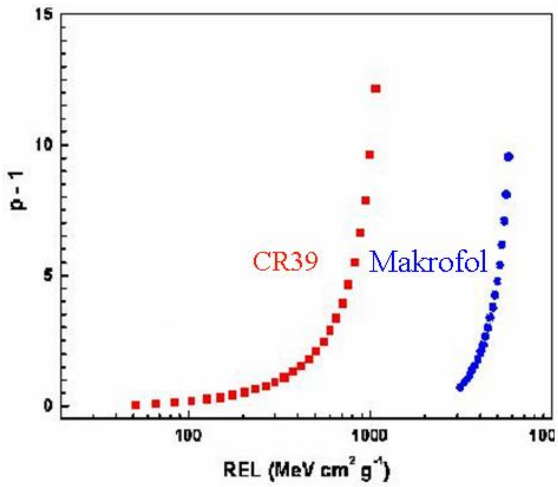
Soft etching

Scan in the predicted position measurement of REL and direction of incident particle.

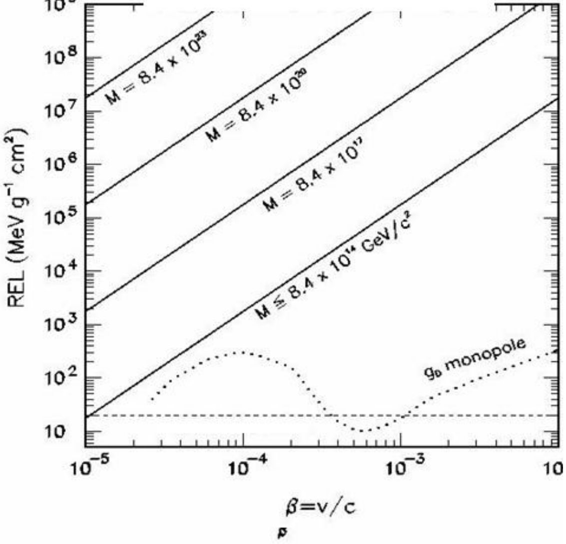
Up to now, no double coincidences found

Calibrations of NTDs

Reduced etch rate vs REL



REL vs ß for nuclearites



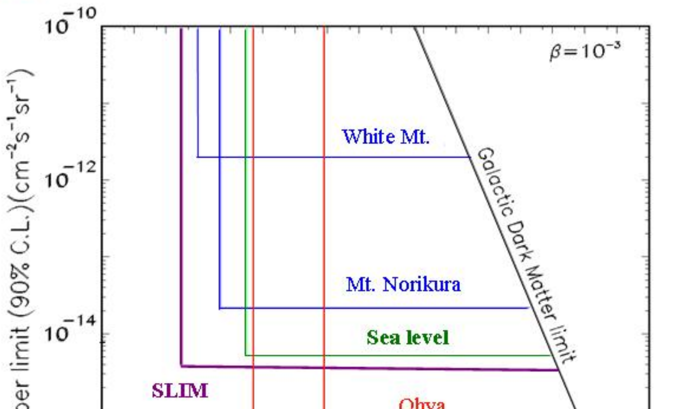
Preliminary results

Analysis of 170 m^2 $\langle t \rangle_{exp}$=3.5 y

No candidate found:

$$\Phi_{SQM} < 3.9 \times 10^{-15} cm^{-2}\ sr^{-1}\ s^{-1} \quad (90\%\ CL)$$

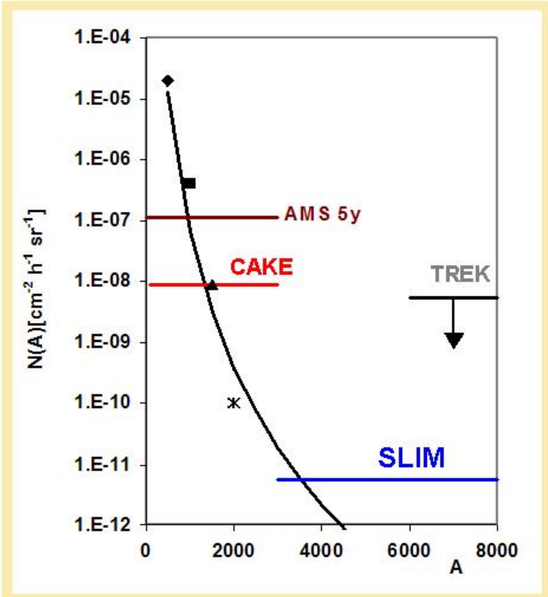
Nuclearites



High altitude: SLIM :5300 m White Mountain: 4800 m Mt. Norikura: 2000 m

Underground Ohya : 100 hg/cm^2 MACRO : 3700 hg/cm^2

Strangelets



If Abundance in CR: $\Phi \propto M^{-7.5}$

Predicted Flux @ Chacaltaya :

7×10^{-6} m^{-2} h^{-1} sr^{-1} for $m_N > 3 \times 10^3$

SLIM: tens of events in 4 y

Model already ruled out…

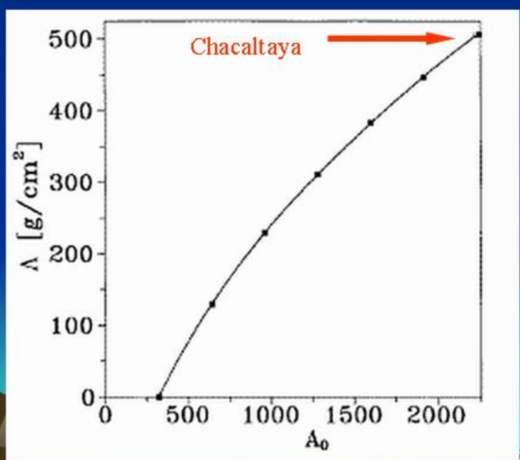
Propagation of strangelets in the atmosphere

1-Mass and size decrease

A_0 at the top of the atmosphere

- Spectator-participant picture: only quarks in the geometrical intersection of colliding nuclei
- mass reduced (at most) to $A_0 - A_t$ until $A = A_{crit}$ (~300) → neutron evaporation → decay into normal matter
- Maximum depth reached before evaporation:

$$\Lambda\left(g/cm^2\right) \approx \frac{4}{3}\lambda_{N-air}\left(\frac{A_0}{A_{air}}\right)^{1/3}$$



Ref. Strangelets at Chacaltaya

G. Wilk et al. hep-ph/0009164

Conclusions

- SLIM: still discovery potential for SQM

or

- Upper flux limits for unexplored masses
- Rejection/confirmation of strangelets propagation models and abundances

Analysis completed by mid 2006