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Strangelets detection with LAr detectors

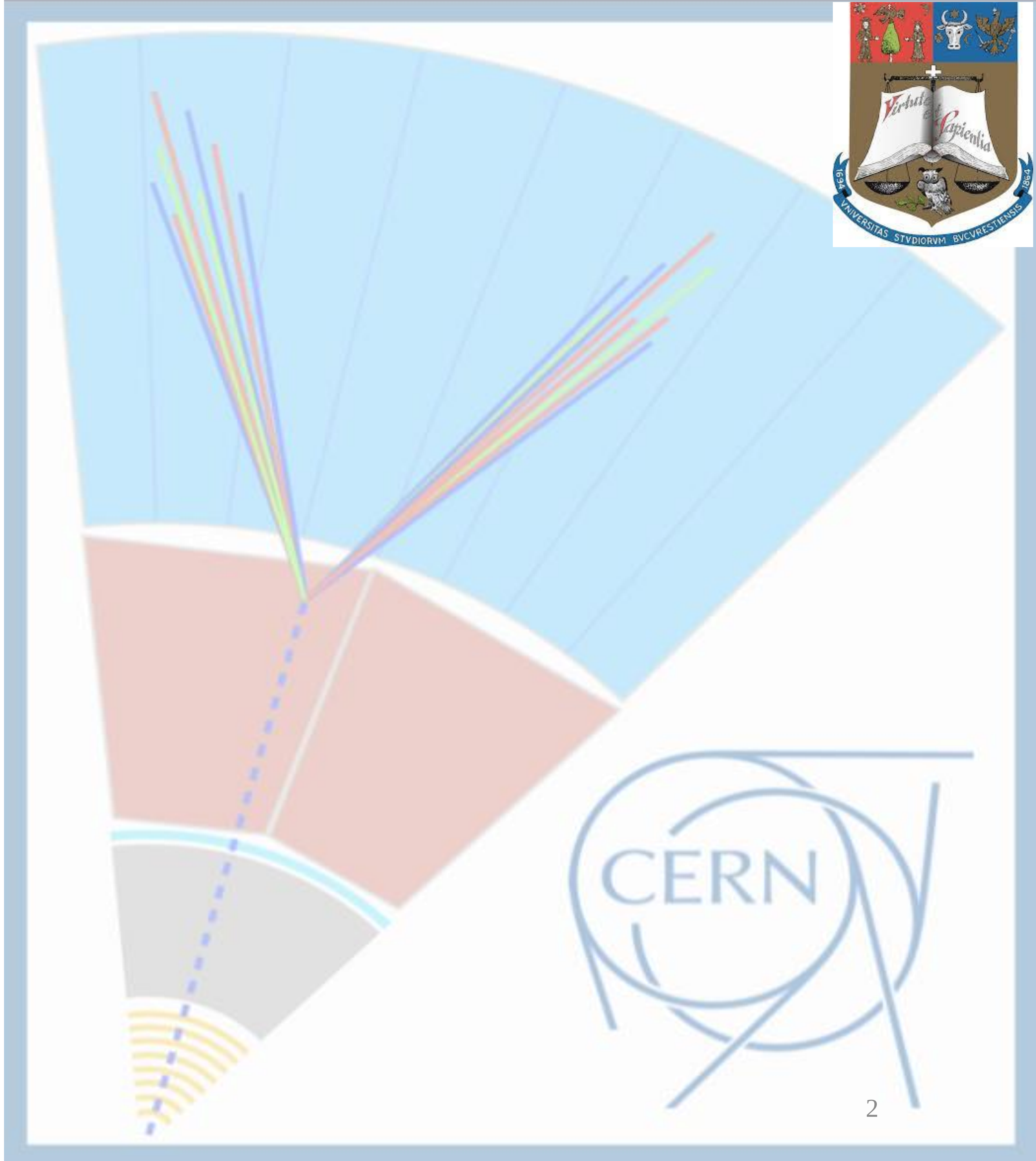
Mihaela PÂRVU, Ionel LAZANU

arXiv:2107.05257

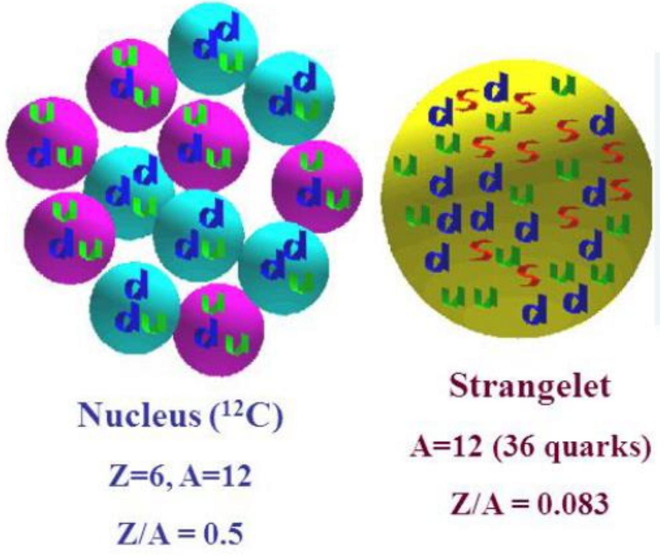
Searching for long-lived particles at the LHC and beyond: 10th workshop of the LLP Community, November 11th 2021

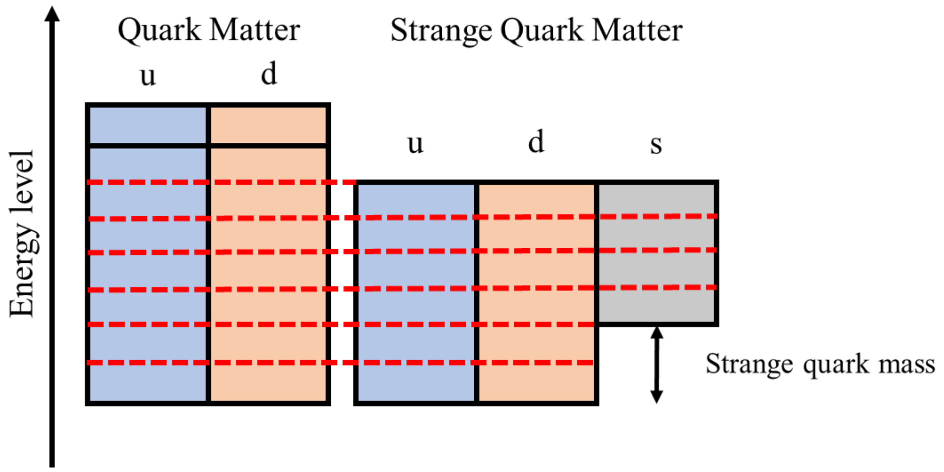
Outline

1. Strangelets
2. LAr used as Detector
3. Signal discrimination
4. Conclusions



Strangelets

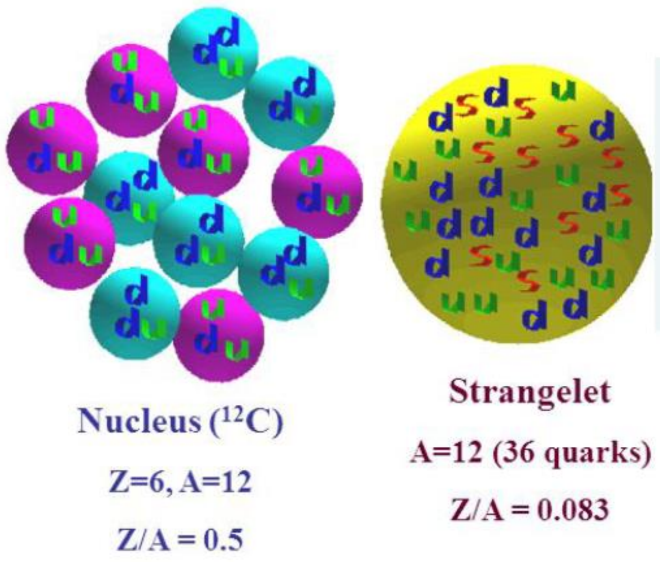


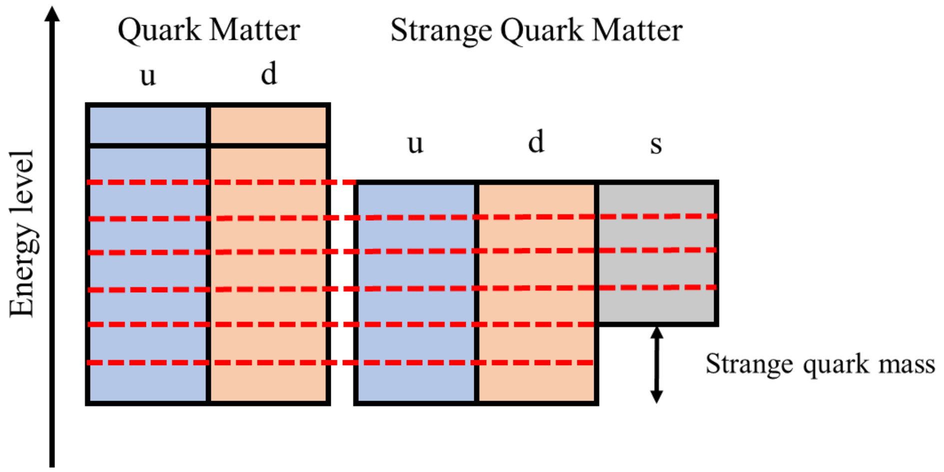


Jes Madsen, Stable quark matter in cosmic rays?, PoS (JHW2005)010, https://doi.org/10.22323/1.022.0010
Jes Madsen, Strangelet propagation and cosmic ray flux, Phys. Rev. D 71, 014026 (2005)

Strangelets

- ➢ They can be produced in high energy nuclear collisions, as a remnant of the hot quark gluon plasma (QGP).
- ➢ They can be produced in heavy ion collisions.
- ➢ Strangelets can be formed in the collision of strange stars and they might be a component of the cosmic ray flux.





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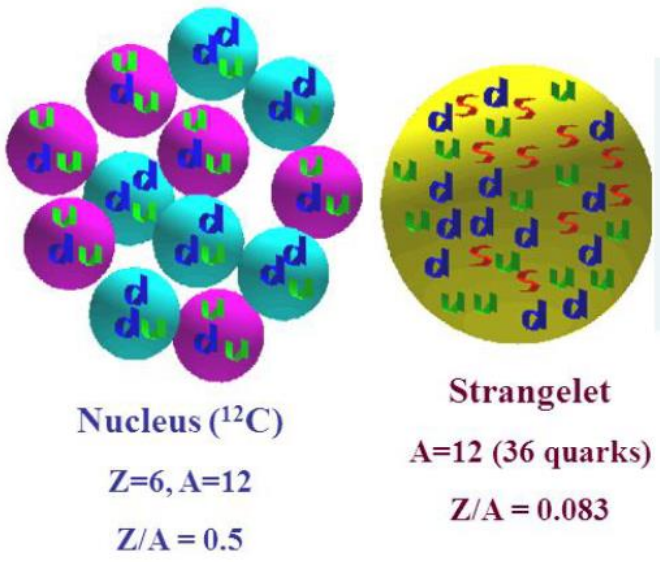
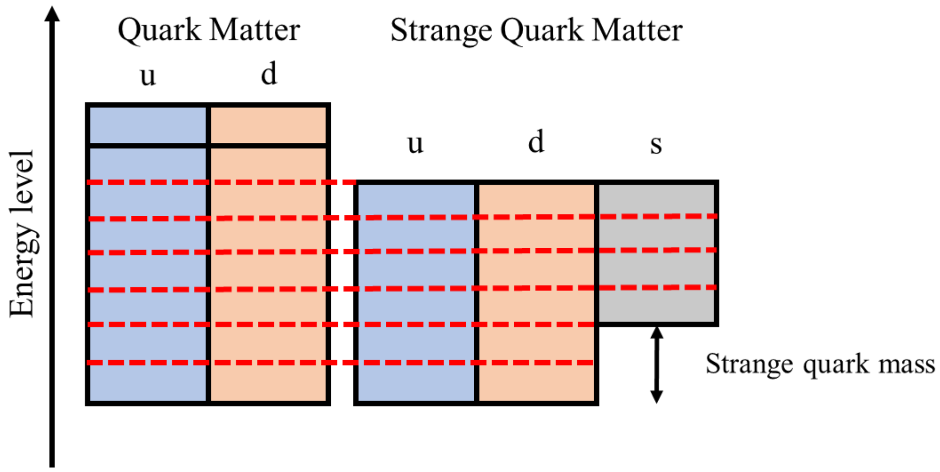
Strangelets

- During flight STS-91 (1998), when the Alpha Magnetic Spectrometer (AMS-01) detector was flown on the Discovery space shuttle at altitudes between 320 and 390 km, two events were identified as possible candidates for SQM. The first candidate with Z/A = 0.114 and a kinetic energy of 2.1 GeV has been assigned to ^{16}He and the second candidate with Z = 8 and A = 54 has been assigned to ^{54}O.

- In 1990 Saito et al. reported two events which correspond to Z = 14 and A = 350.





P. B. Price, E. K. Shirk, R. Hagstrom, and W. Z. Osborne. Further Studies of the Monopole Candidate. Phys. Rev. D, 18:1382-1421, 1978. doi:10.1103/PhysRevD.18.1382.
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M. Ichimura et al. An unusually penetrating particle detected by balloon borne emulsion chamber. Nuovo Cim. A, 106:843-854, 1993. doi:10.1007/BF02771498.
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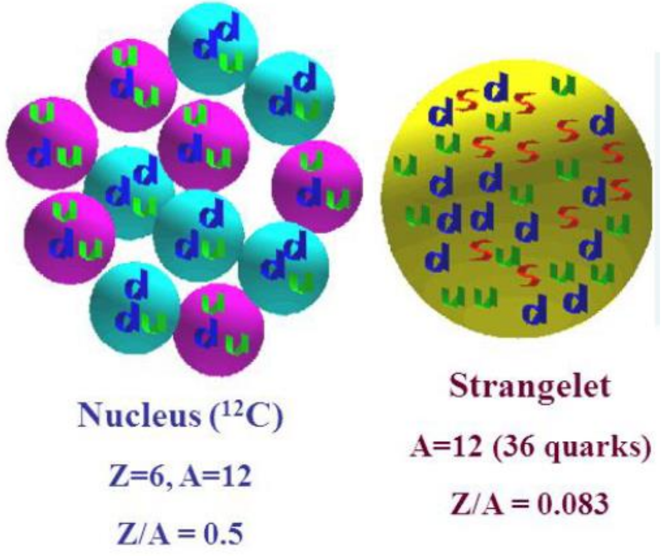
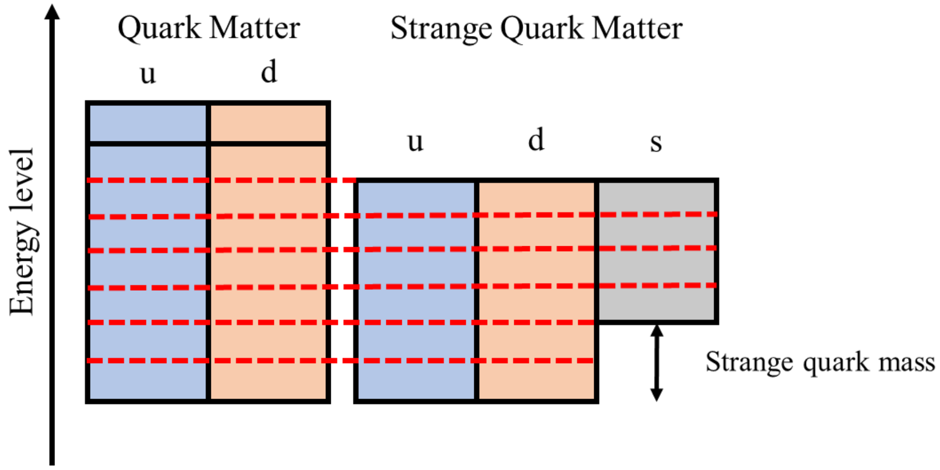
Ke Han et al.. Search for stable Strange Quark Matter in lunar soil. Phys. Rev. Lett., 103:092302, 2009. doi:10.1103/PhysRevLett.103.092302.

Strangelets

- Ichimura et al. reported an unusual event with Z = 20 and A = 460.
- In 1978 Price et al. reported an event with Z = 46 and A > 1000 which is a candidate for SQM considering the Z/A ratio.





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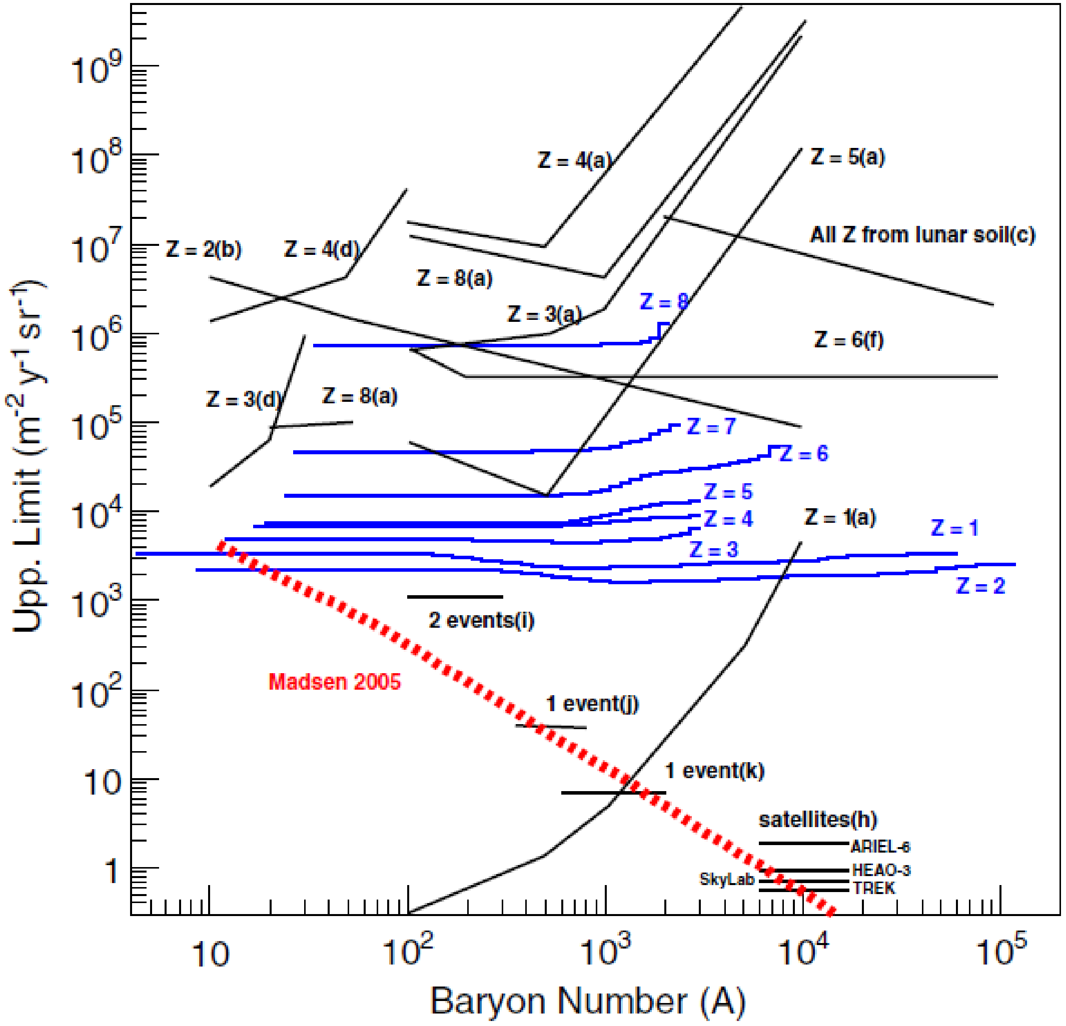
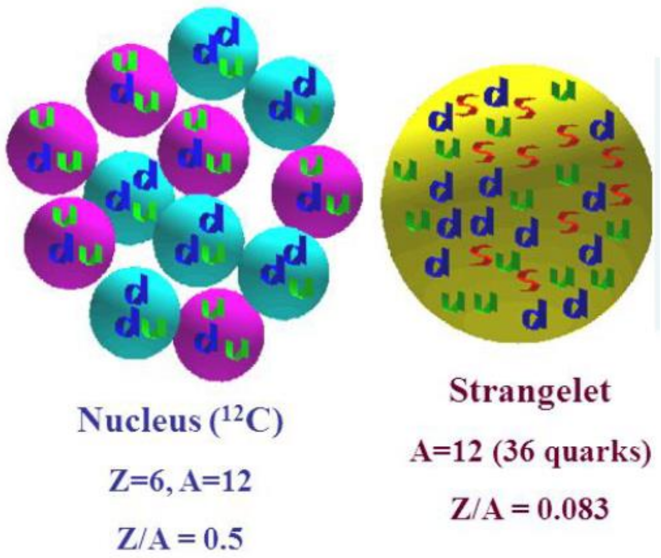
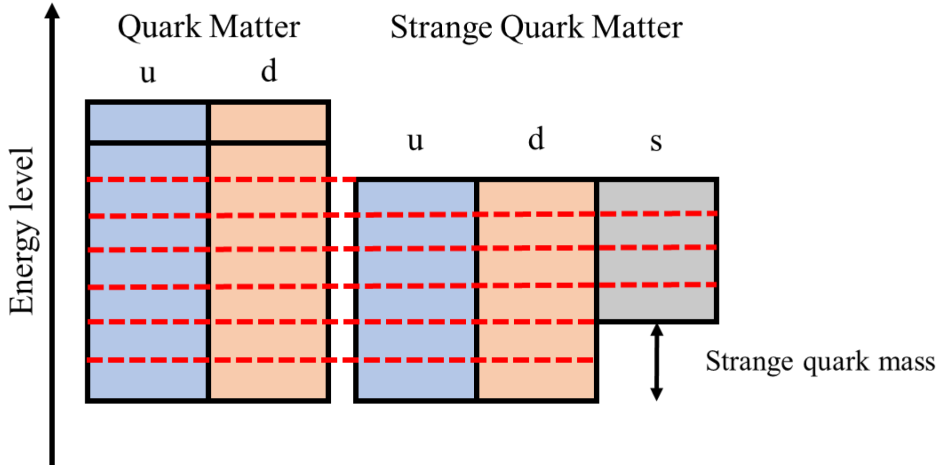
Strangelets

Expected strangelet flux :







New Upper Limit on Strange Quark Matter Abundance in Cosmic Rays with the PAMELA Space Experiment, Phys.Rev.Lett. 115 (2015) 11, 111101, DOI: 10.1103/PhysRevLett.115.111101

Liquid Argon used as detector

Scintillation Mechanism

(i) Excitation

Ar^* :

$Ar^* + Ar + Ar \rightarrow Ar_2^* + Ar$

$Ar_2^* \rightarrow 2Ar + h\nu$

(ii) Ionization

Ar^+ :

$Ar^+ + Ar \rightarrow Ar_2^+$

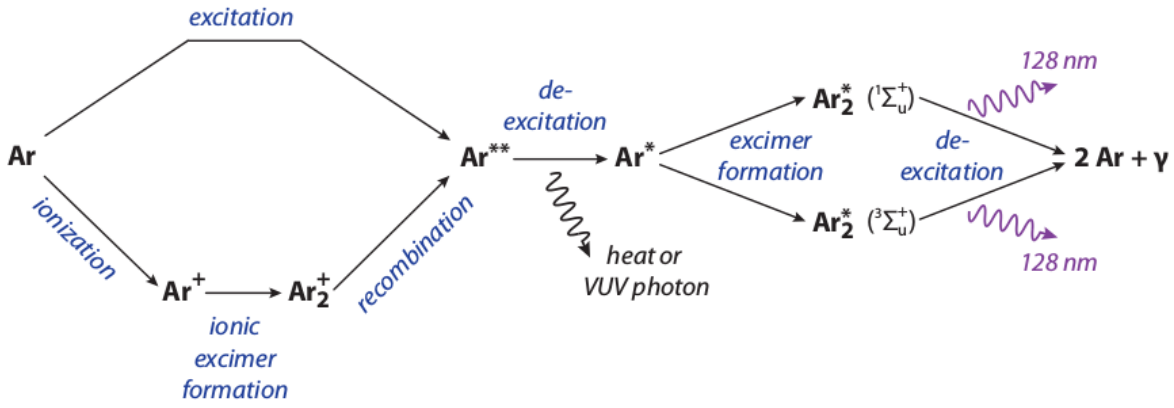
$Ar^+_2 + e^- \rightarrow Ar^{**} + Ar$

$Ar^{**} \rightarrow Ar^* + \text{heat}$

$Ar^* + Ar + Ar \rightarrow Ar_2^* + Ar$

$Ar_2^* \rightarrow 2Ar + h\nu$

Property	Symbol	Value
Density	ρ	$1.396\ \mathrm{g/cm^3}$
Ionization energy	W_{ion}	23.6 eV
Mean excitation energy	W_{ex}	19.5 eV
Scintillation emission peak	λ_{scint}	128 nm
Refractive index at 128 nm	n	1.38



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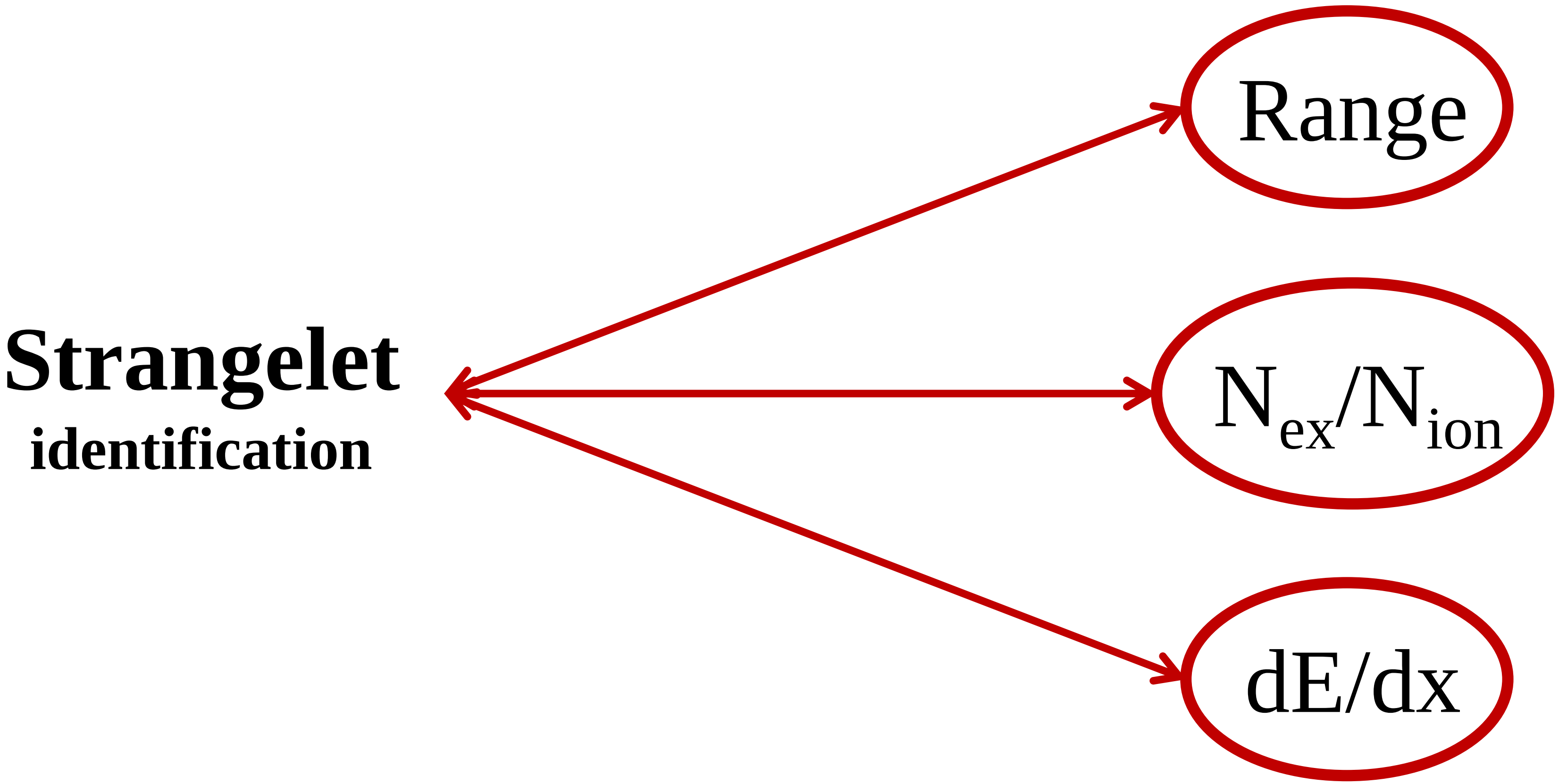
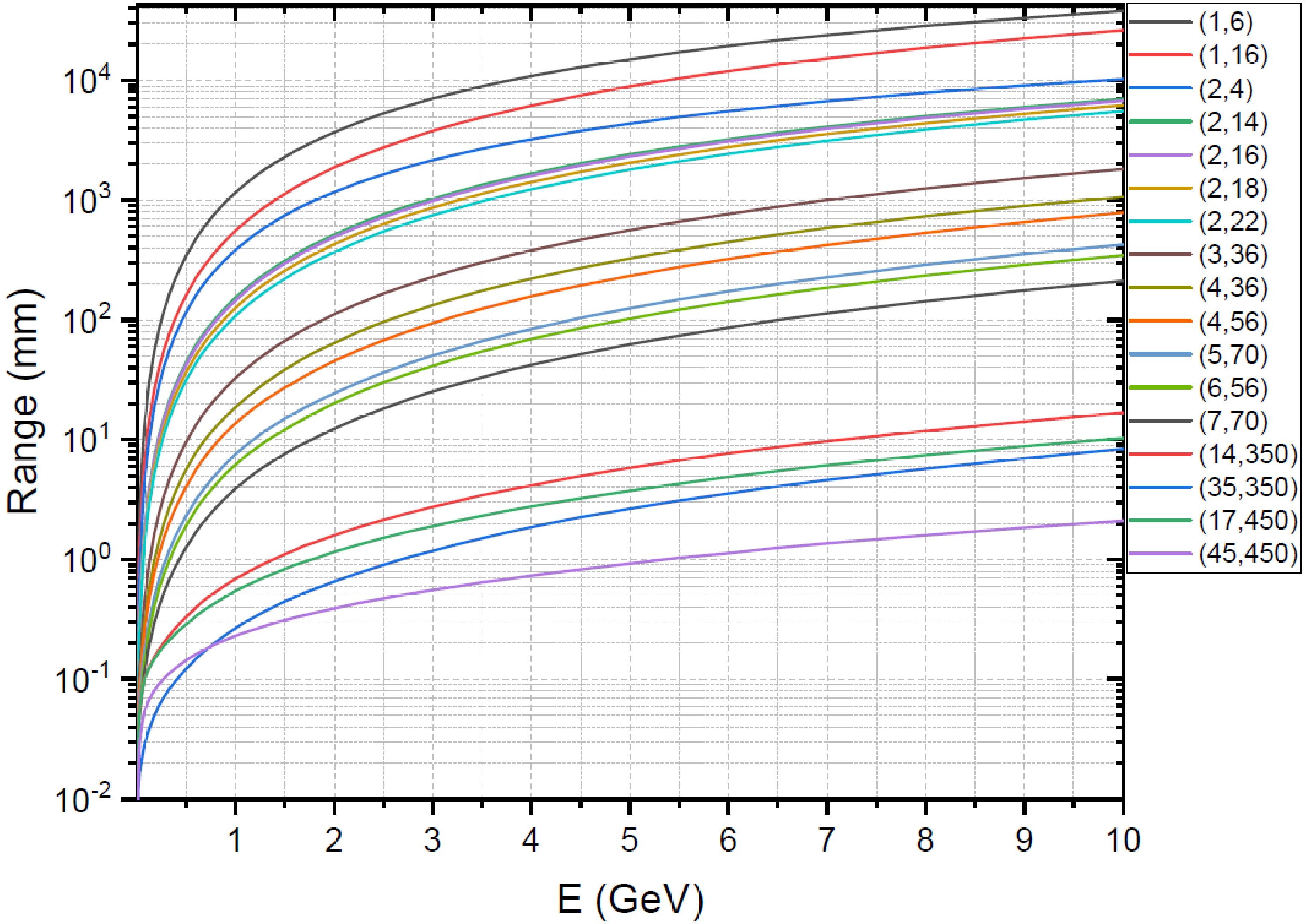


Particle Ranges



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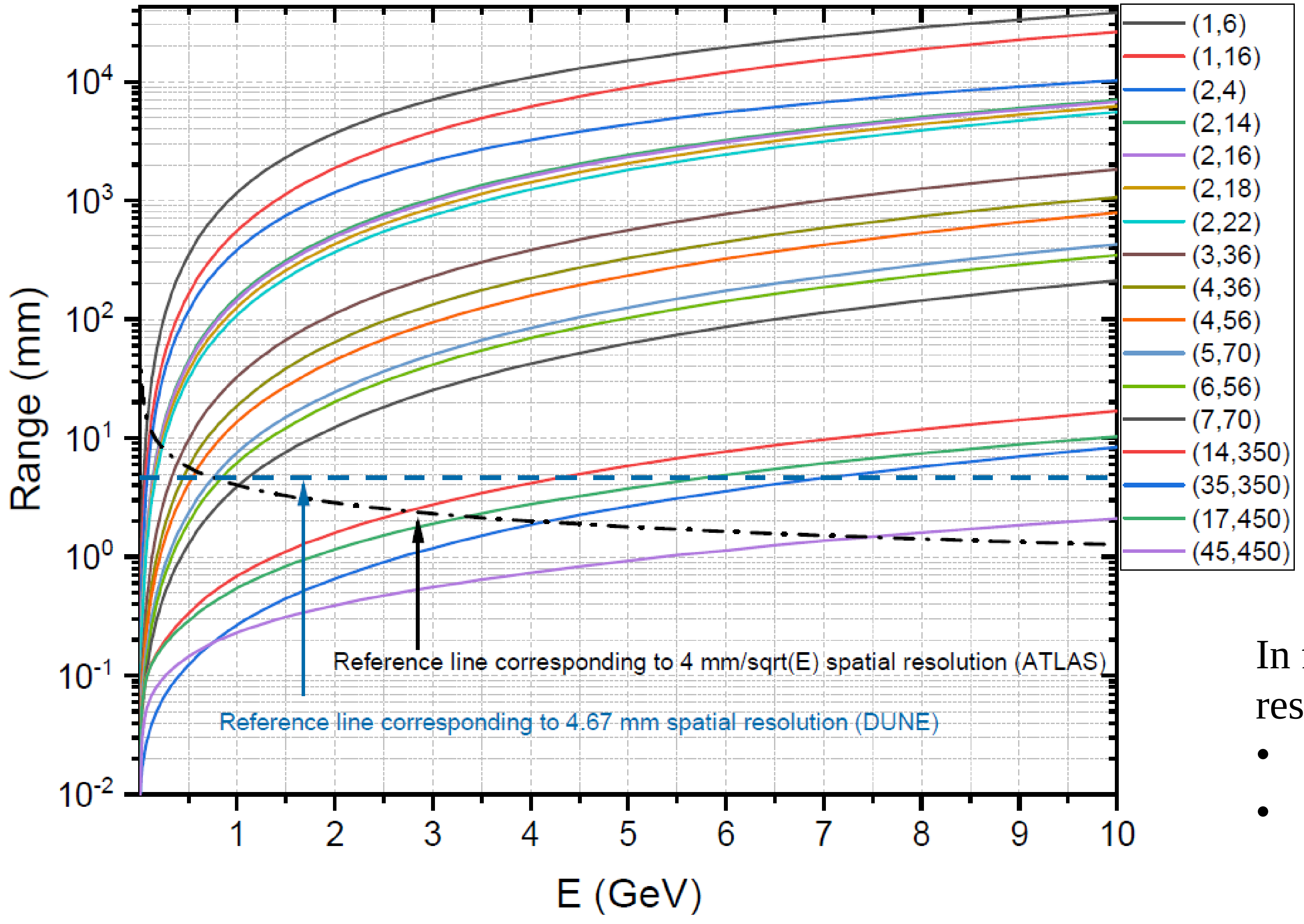

In function of the spatial resolution:

- DUNE 4.67 mm
- ATLAS ~ 4 mm/$\sqrt{E}$ [GeV]

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Scintillations vs. Ionizations

The maximum number of scintillation photons produced for the deposited energy E_0 by an ionizing particle, N_{ph}(max) is:

$$N_{ph}(max) = N_i + N_{ex} = \frac{E_0}{W}\left(1 + \frac{N_{ex}}{N_i}\right)\frac{E_0}{W'}$$

For LAr: $\frac{N_{ex}}{N_{ion}} = 0.21, W_{ion} = 23.6\ eV$ and $W_{ex} = 19.5$

$W'(N_{ion} + N_{ex}) = E_0$

For 1 MeV deposited energy, the maximum number of generated photons is $\mathbf{5.14 \times 10^4}$.

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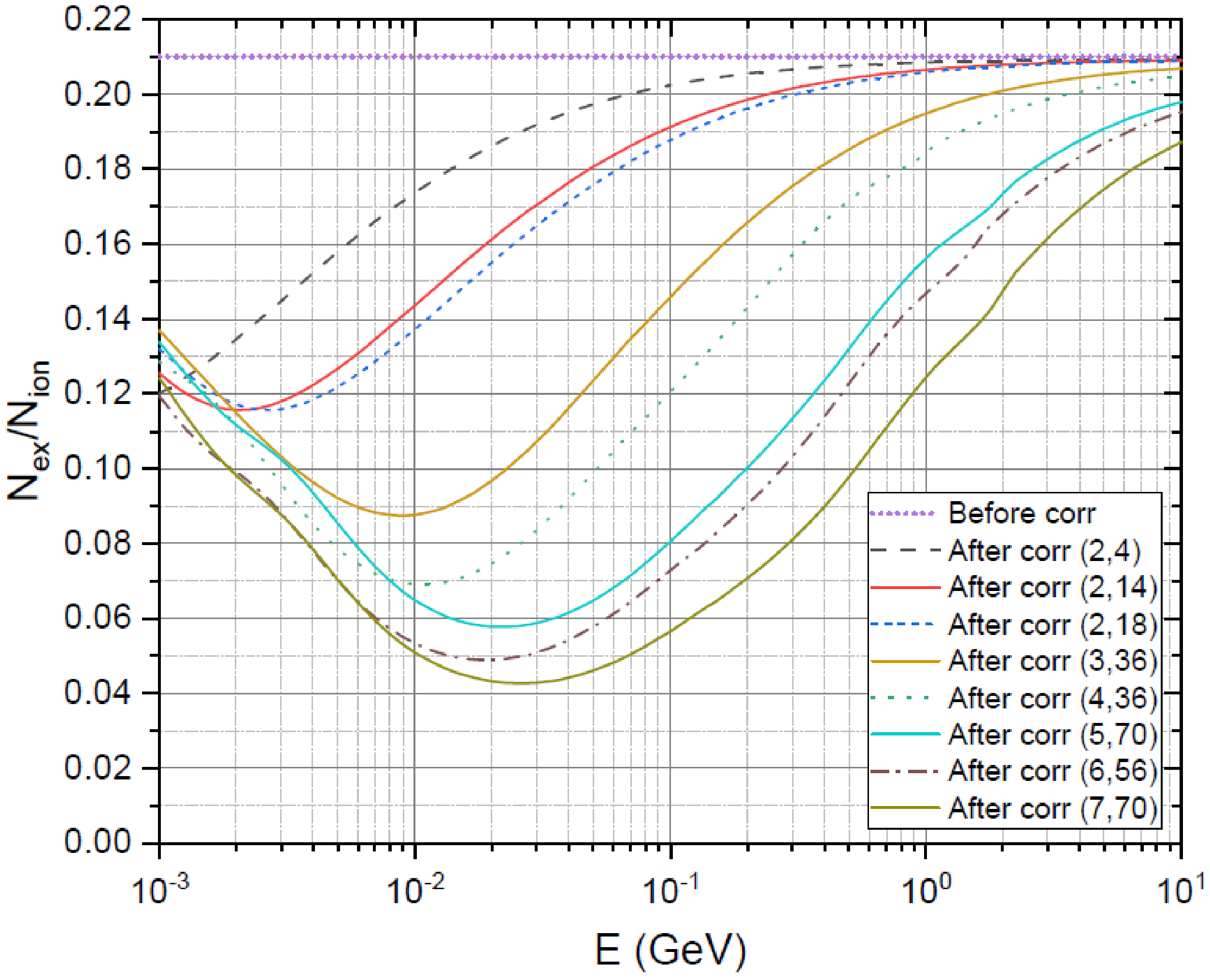
No quenching mechanisms and no detection efficiency taken into account!

Birks' Law

$$f_l = \frac{1}{1 + kB\left(\frac{dE}{dx}\right)_{elec}} + C$$

$kB = 7.4 \times 10^{-4}$ MeV^{-1} g cm^2

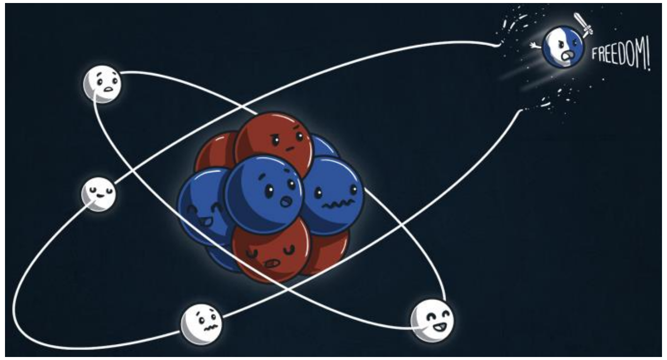


Recombinations and the electric field were not taken into account.

M. PARVU and I. Lazanu, Can strangelets be detected in a large LAr neutrino detector?, arXiv:2107.05257

Recombination mechanism

A part of the electron-ion pairs created in the ionization process in argon are not separated fast enough by the electric field, this leading to their recombination.



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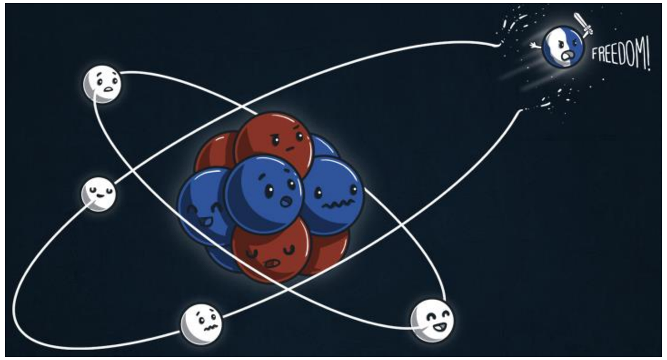

$$r = \frac{A\frac{dE}{dx}}{1 + B\frac{dE}{dx}} + C$$

ICARUS

$A = 0.05 \cdot E_{drift}^{-0.85}$,

$B = 0.06 \cdot E_{drift}^{-0.85}$,

$C = 1/6$

M. Sorel, Expected performance of an ideal liquid argon neutrino detector with enhanced sensitivity to scintillation light Published in: JINST 9 (2014) P10002,e-Print: 1405.0848

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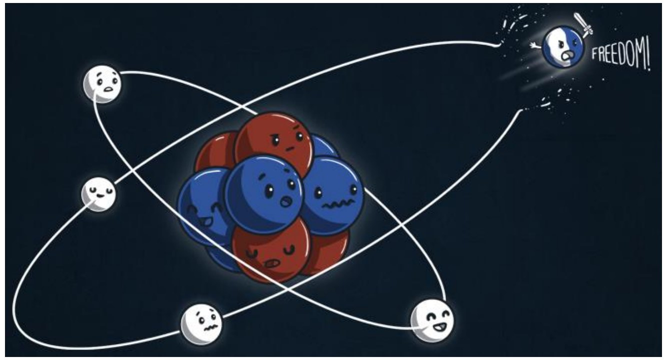

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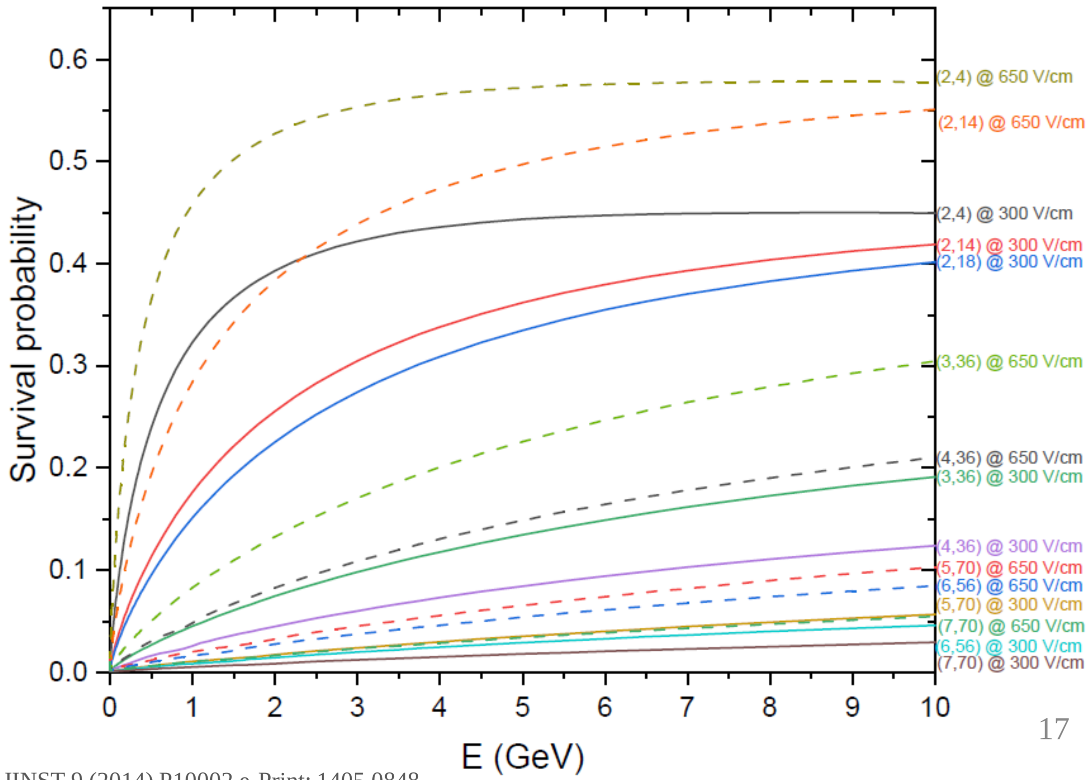

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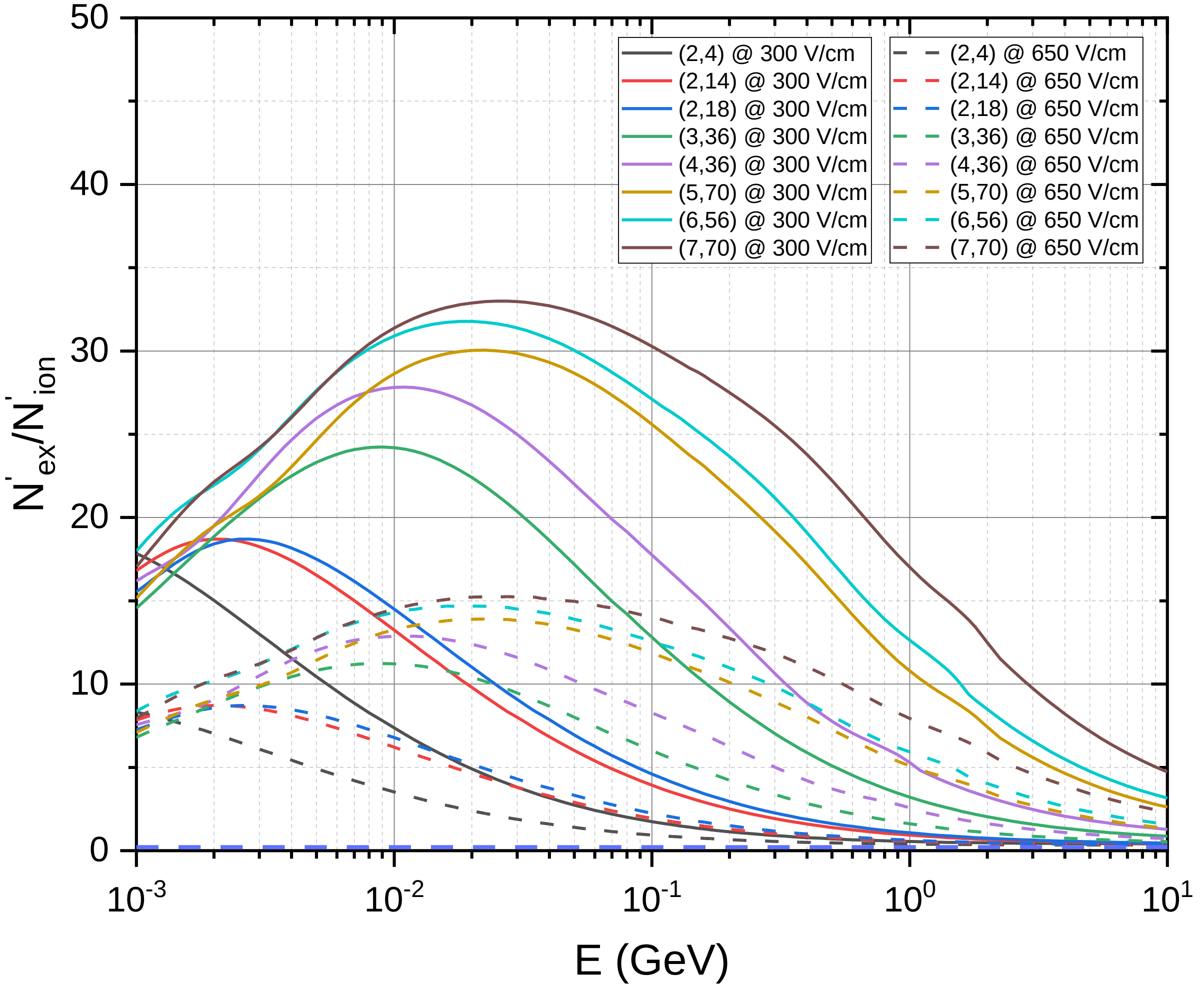
Excitations vs. ionizations

$$\frac{N'_{ex}}{N'_{ion}} = \frac{N_{ex}}{N_{ion}} \frac{f_l}{(1-r)}$$

Electron survival probability



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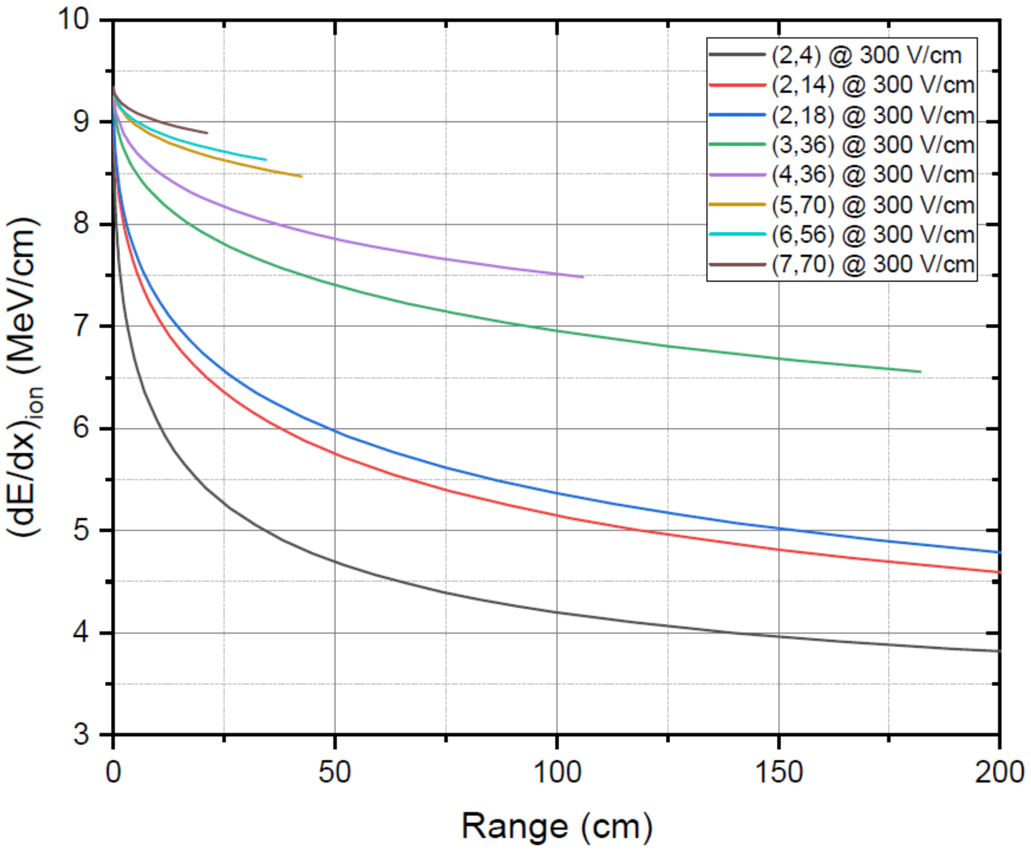
Strangelets discrimination from the background

In accord with Farnese, ICARUS Collaboration has estimated the background value to be around *dE/dx* = 2.1 MeV/cm. Thus, a clear discrimination between the considered strangelets and the background can be done.



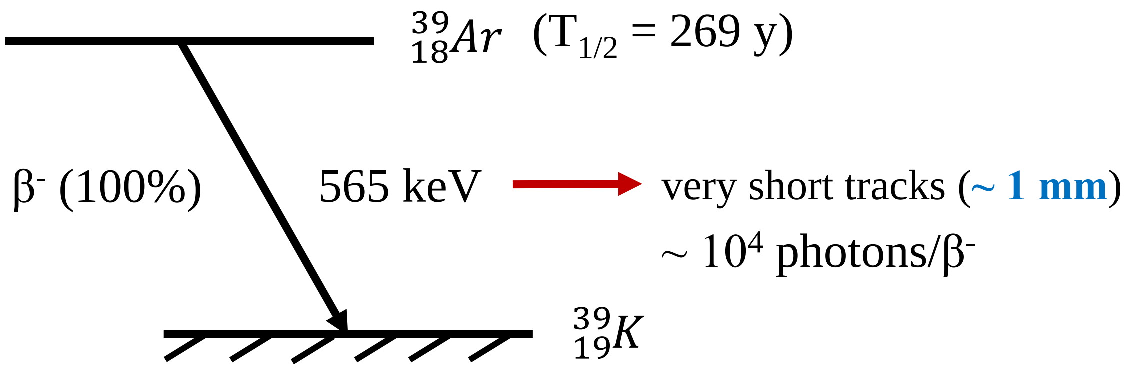
The linear energy loss via ionizations for the considered strangelets with incident energies up to 10 GeV.

C. Farnese [ICARUS], Universe 5 (2019) no.2, 4, doi:10.3390/universe5020049

Strangelets discrimination from the background

^{39}Ar in natural argon

Natural activity of argon (1.01 ± 0.08) Bq/kg



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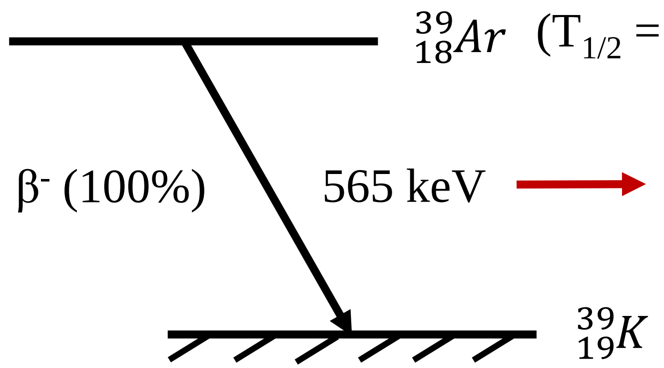

very short tracks (**~ 1 mm**)

~ 10^4 photons/β^-

3 orders of magnitude lower than the no. of photons per unit path length generated by strangelets.

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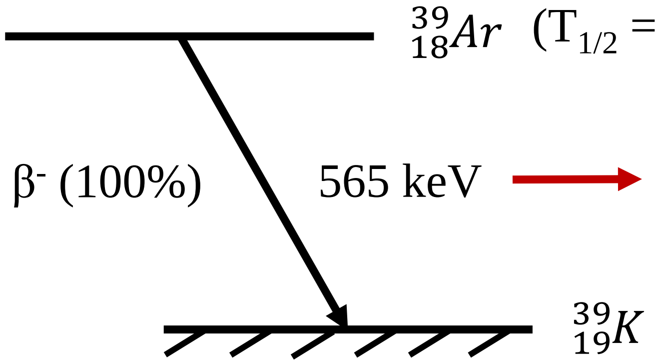

→ very short tracks (**~ 1 mm**)

~ 10^4 photons/β^-

3 orders of magnitude lower than the no. of photons per unit path length generated by strangelets.

In order to improve the signal to noise ratio, the use of underground argon will lower the background due to ^{39}Ar with a factor of 1400.

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Summary

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- The possibility of direct observation of light strangelets with energies up to 10 GeV in large LAr detectors was discussed. Two different types of signals were considered: ionization electrons and scintillations due to atomic excitations.

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- It was showed that for a LArTPC detector, the signals generated by strangelets can be discriminated by the ones produced by heavy ions and the efficiency decreases with the increase of the electric drift field.

Summary

- The possibility of direct observation of light strangelets with energies up to 10 GeV in large LAr detectors was discussed. Two different types of signals were considered: ionization electrons and scintillations due to atomic excitations.

- It was showed that for a LArTPC detector, the signals generated by strangelets can be discriminated by the ones produced by heavy ions and the efficiency decreases with the increase of the electric drift field.

- This study is of interest for all the LAr detectors that are searching for charged long lived particles.

Thank you for your attention!