Background environment at Boulby

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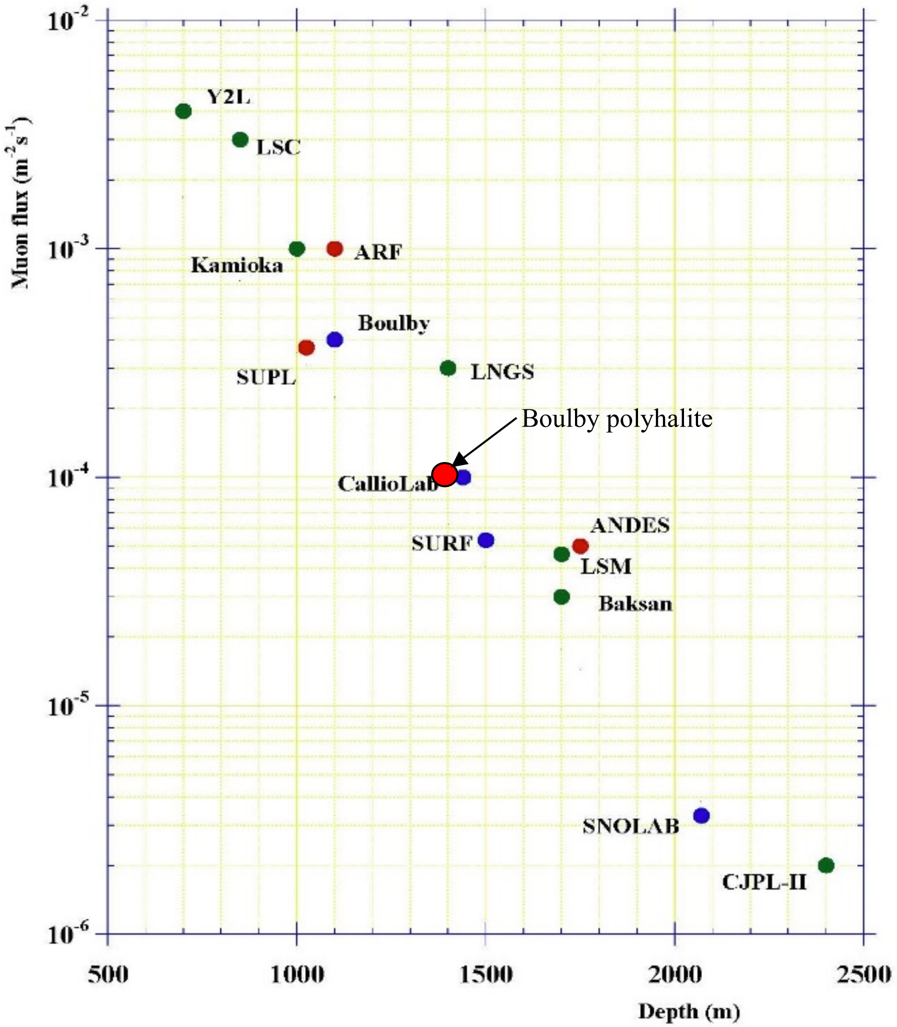
Muon fluxes

- Vertical depth: about 1100 m (current lab).
- ZEPLIN-I veto:
  - $(4.09 \pm 0.15)\times10^{-8}$ cm^{-2} s^{-1},
  - 2805 ± 45 m w. e.,
  - Robinson et al., NIMA **511** (2003), 347.
- ZEPLIN-II veto:
  - $(3.79 \pm 0.15)\times10^{-8}$ cm^{-2} s^{-1},
  - 2850 ± 20 m w. e.,
  - H. M. Araújo et al. Astropart. Phys. **29** (2008) 471–481.
- ZEPLIN-III veto:
  - $(3.75 \pm 0.09) \times 10^{-8}$ cm^{-2} s^{-1}
  - L. Reichhart et al. Astropart. Phys. **47** (2013) 67–76.
- Defined as a flux through a spherical detector with unit cross-section area.
- Expected flux at 1400 m (additional 725 m w. e.): 9.85×10^{-9} cm^{-2} s^{-1}.



Courtesy of N. Smith (SNOLab)

Muon backgrounds

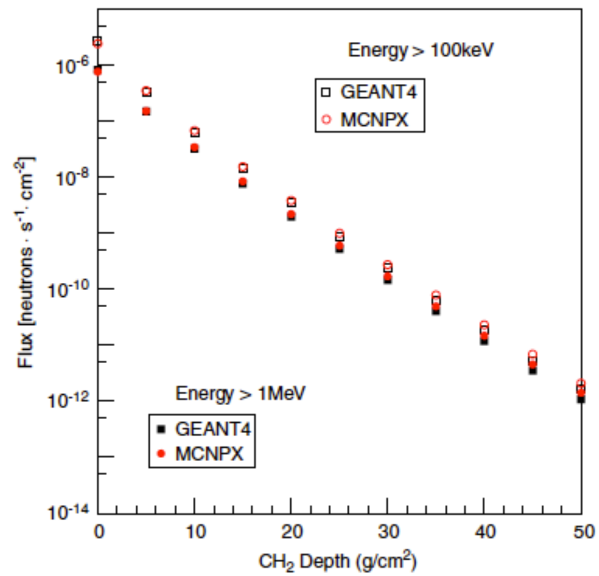
- Mean muon energy:
  - 260 GeV (1100 m, current site)
  - 280 GeV (1400 m, polyhalite)
- Muon model:
  - exists for a flat surface profile and current lab location,
  - known but simplified rock composition,
  - flux normalised to the measurements so the exact profile (change in depth of <50 m) is not critical.
- Muon-induced neutrons:
  - Difficult to predict without experiment's design,
  - Depend largely on the environment: rock composition, in particular water content; specifics of the experimental set-up: shielding, presence of high-Z/A materials etc.
  - some info in:
    - H. M. Araújo et al. Astropart. Phys. **29** (2008) 471–481.
    - Lindote et al. Astroparticle Physics, 31 (2009) 366.
    - L. Reichhart et al. Astropart. Phys. **47** (2013) 67–76.
    - … and many others.
    - Need to be carried out for a specific design.
    - Ongoing as part of Boulby FS.

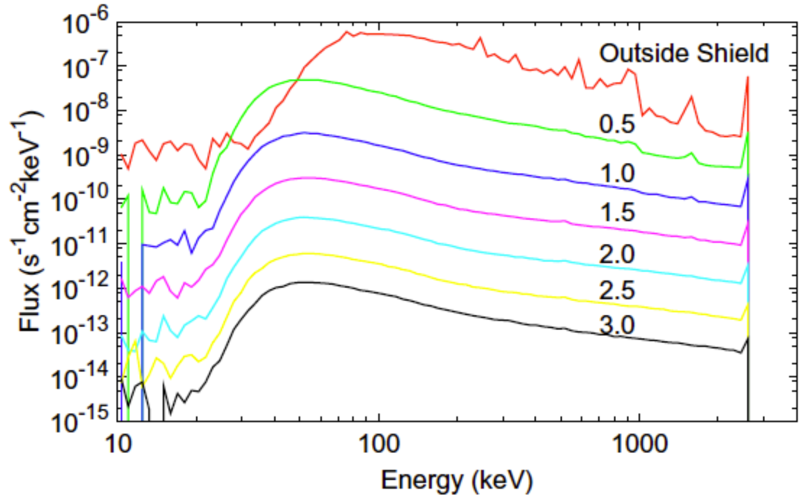
Radioactivity

- Fast neutrons:
  - $(1.72 \pm 0.61(\text{stat.}) \pm 0.38(\text{syst.})) \times 10^{-6}$ cm^{-2} s^{-1} above 0.5 MeV,
  - This corresponds to $127 \pm 45(\text{stat.}) \pm 28(\text{syst.})$ ppb of U/Th if their concentrations are equal,
  - E. Tziaferi et al., Astroparticle Physics **27** (2007) **326**–338.
- U/Th/K contaminations from gamma-ray measurements (non-uniform):
  - gamma flux above a few keV: 0.128 cm^{-2} s^{-1} (outside the lab [1]),
  - 132 ± 5 ppb of ^{238}U [1], 67 ± 6 ppb of ^{238}U [2]
  - 462 ± 15 ppb of ^{232}Th [1], 127 ± 10 ppb of ^{232}Th [2],
  - (0.036 ± 0.06)% of natural potassium [1],
  - Non-uniform contamination; requires measurement at a specific site,
  - [1] Malczewski et al. J. Radioanal. Nucl. Chem. 298 (3) (2013) 1483–1489
  - [2] Smith et al. Astropart. Phys. 22 (2005) 409–420
  - See also Scovell et al. Astroparticle Physics 97 (2018) 160–173.
  - Relatively low in U/Th; significant contribution of gamma-rays from ^{40}K.
- Radon:
  - 2.4 Bq/m^3 from Araújo, et al., Astropart. Phys. 35 (2012) 495–502.
  - About 3 Bq/m^3 from S. Paling.

Reducing background from radioactivity

- Neutrons:
  - 10 cm of CH_2 suppress neutron flux (above 1 keV) by a factor of 10-20
  - suppression depends on the fraction of H in the shielding and neutron spectrum
  - Lemrani et al. NIMA **560** (2006) 454-459.
- Gamma-rays:
  - 0.5 m of water reduces the gamma-ray flux by an order of magnitude,
  - Tomasello et al. Astropart. Phys. **34** (2010) 70-79.
- Usually consider 4 m of water as sufficient to attenuate neutrons and gammas from radioactivity.
- Argon is more efficient for attenuation of gammas but require additional neutron shielding.
- Size of the shielding is one of the parameter that determines the minimum size of the cavern.





Summary

- Muon model supported by measurements predicts the muon flux of about 3.8×10^{-8} cm^{-2} s^{-1} depending on specific location.
- May be sufficient for a dark matter experiment with efficient veto systems; study in progress.
- Moving deeper to 1400 m reduces the muon flux by a factor of 3.5-4.0.
- This may open a window for a neutrinoless double-beta decay search (Ge).
- The radioactivity environment is known in the vicinity of the existing laboratory but new measurements will be required in a specific location.
- Fluxes of gammas and neutrons will also be affected by the cavern wall cover (concrete, paint etc).
- The size of the required shielding and veto affects the design of the new lab.
- I save other details (if required) for the next meeting but happy to answer questions now.