Sub-kelvin electron detectors for the LEMING muonium gravity experiment

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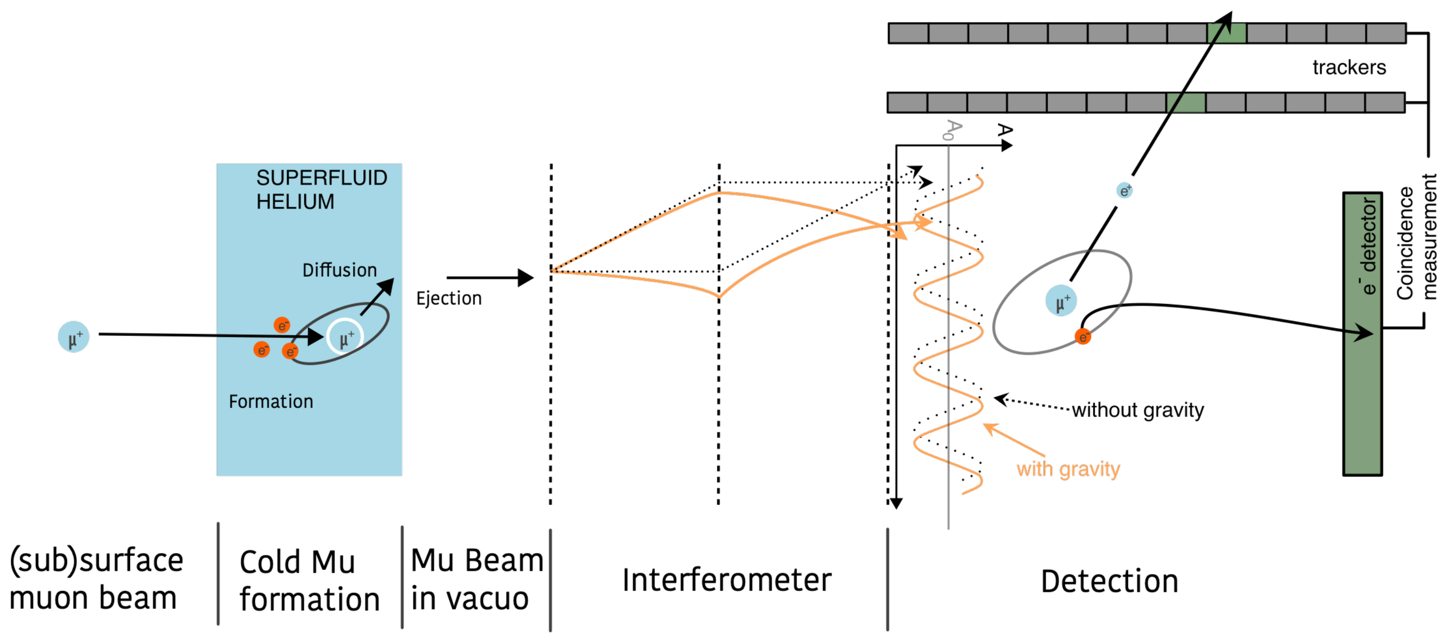
I. Motivation

Testing **weak equivalence**: Does **second-generation leptonic antimatter** fall the same way as regular matter? We plan to drop muonium ($M = \mu^+ + e^-$), which is purely **leptonic**, and mostly made of **second-generation antimatter**, with a lifetime of $\tau = 2.2\ \mu s$, and measure its free-fall acceleration.

II. The LEMING experiment



III. Sensitivity

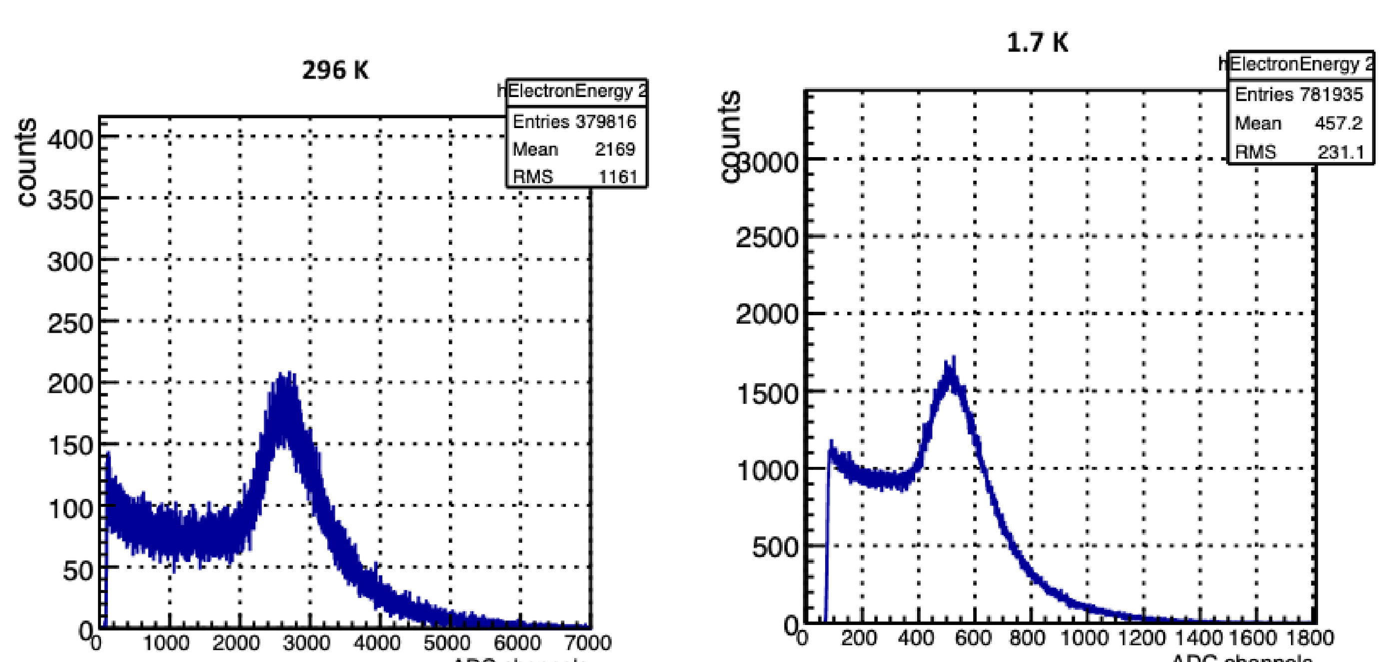
Our projected sensitivity on g depends directly on the detection efficiency ϵ.

$$\Delta g \approx \frac{d}{2\pi T^2 C \sqrt{N_0 \epsilon \eta^3 \exp\left(-\frac{t_0+2T}{\tau}\right)}} \quad (1)$$

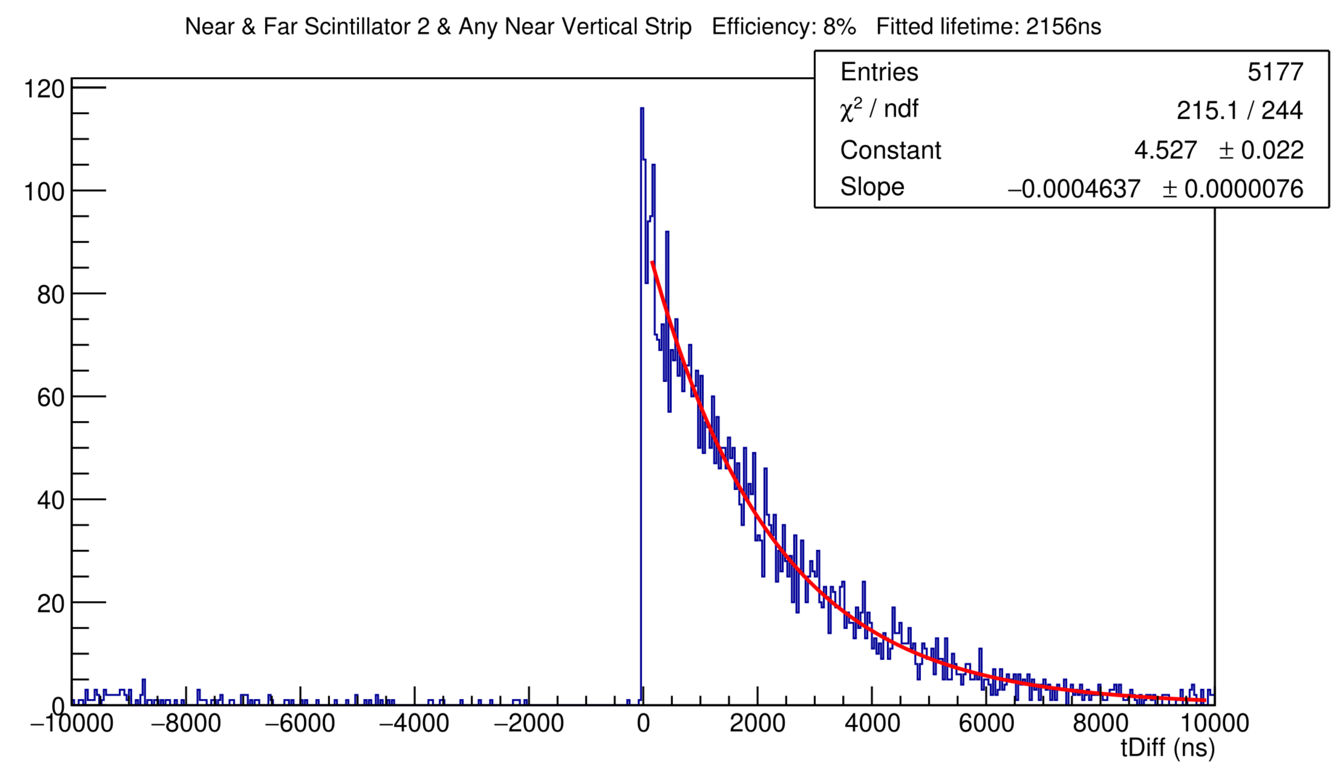
- Grating period $d \approx 100$ nm
- Interaction time $T \approx 2\tau = 4.4\ \mu s$
- Contrast $C \approx 0.3$
- Atoms from source $N_0 \approx 1 \times 10^6$ /s $\times\ t_{\text{measure}}$
- Loss factor $\eta = 0.3$, $\epsilon = 0.5$, $t_0 < \frac{\tau}{2}$

IV. Positron tracking detector

With a tracking detector we can **reject μ^+ decays outside of the target volume** via the direction of the produced Michel e^+ with an energy of $E_{e^+} \approx 10$ M eV– 50 M eV. To minimise the influence of scattering, these detectors will be placed close to the target chamber, containing the superfluid helium, at a temperature $T \approx 1$ K.



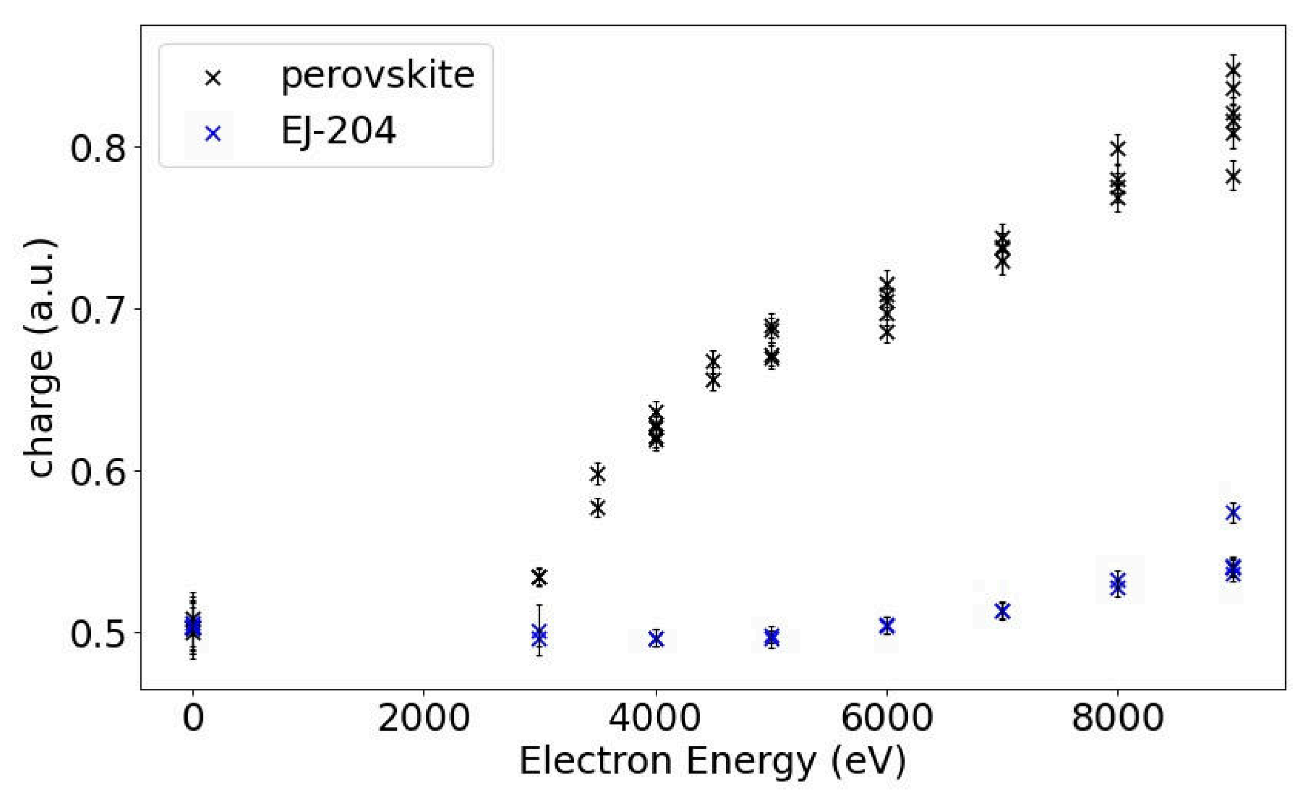
We achieved **sub-kelvin operation of commercial off-the-shelf scintillators** (Eljen EJ-204) and **silicon photomultipliers** (Hamamatsu S13370 VUV4), including single photon detection: DOI:10.1088/1748-0221/17/06/P06024.



To improve the spatial resolution we are currently evaluating the operation of commercial 1 mm silicon strip detectors at **temperatures** $T \approx 100$ mK. Our initial setup suffered from a low signal-to-noise ratio (SNR), limiting the detection efficiency to < 10 %. We **successfully detected** M eV **Michel** e^+ as evidenced by the characteristic exponential decay spectrum of the time difference to the μ^+ entering the target chamber, notwithstanding.

V. Atomic electron detector

Rejecting the entire μ^+ background from the beam using the tracker is expected to be extremely challenging. Detecting the remaining e^- **in coincidence with the Michel** e^+ from the μ^+ decay could provide a **very clean signature**, drastically improving **background rejection**. However, these electrons possess essentially no energy, and we need a **very-low-threshold** detector with **fast** time resolution to form the coincidence. In order to improve instead of jeopardise our sensitivity, it also needs to be **very efficient**. Electrical acceleration of the e^- is very limited due to **dielectric breakdowns in the presence of a superfluid helium film**. Tests with an electron gun show that **novel perovskite ($CsPbBr_3$) scintillators** might provide a **significant improvement** over the aforementioned commercial EJ-204 scintillator at a **temperature of** $T = 4$ K.



In addition, we are evaluating **superconducting nanowire single-photon detectors (SNSPDs)** as an alternative solution. While a detailed characterisation is ongoing, we have **successfully recorded pulses originating from** k eV **electrons**.