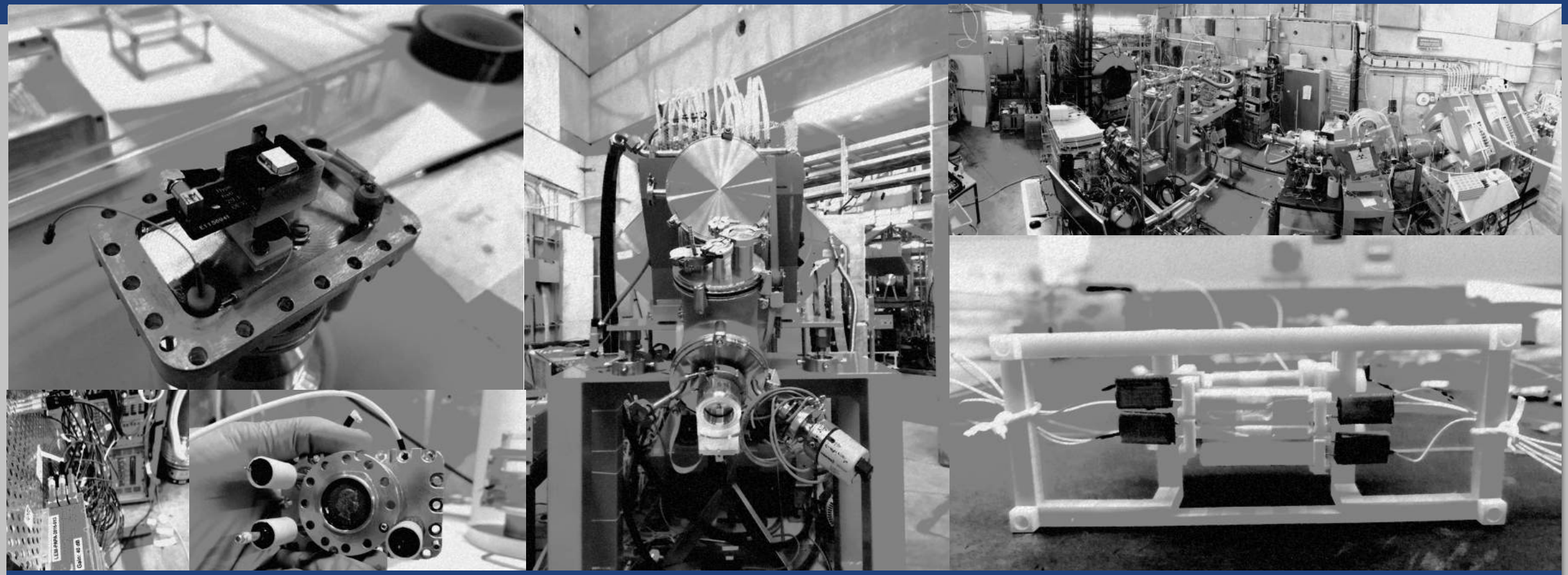
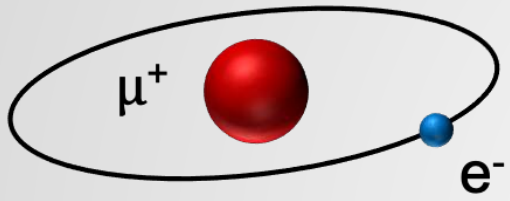
ETH zürich



Development of a novel cryogenic Muonium beam

Jesse Zhang, Low Energy Particle Physics Group, ETH Zürich

Next generation Muonium experiments



- Why Muonium?
  - **Mu** is a Hydrogen like exotic atom
  - $\tau \sim 2.2\,\mu s$
  - Purely leptonic system, no finite size and nuclear effect

- Precision-spectroscopy
  - test bound-state QED
  - fundamental constants: m_μ , R_∞, q_μ/q_e

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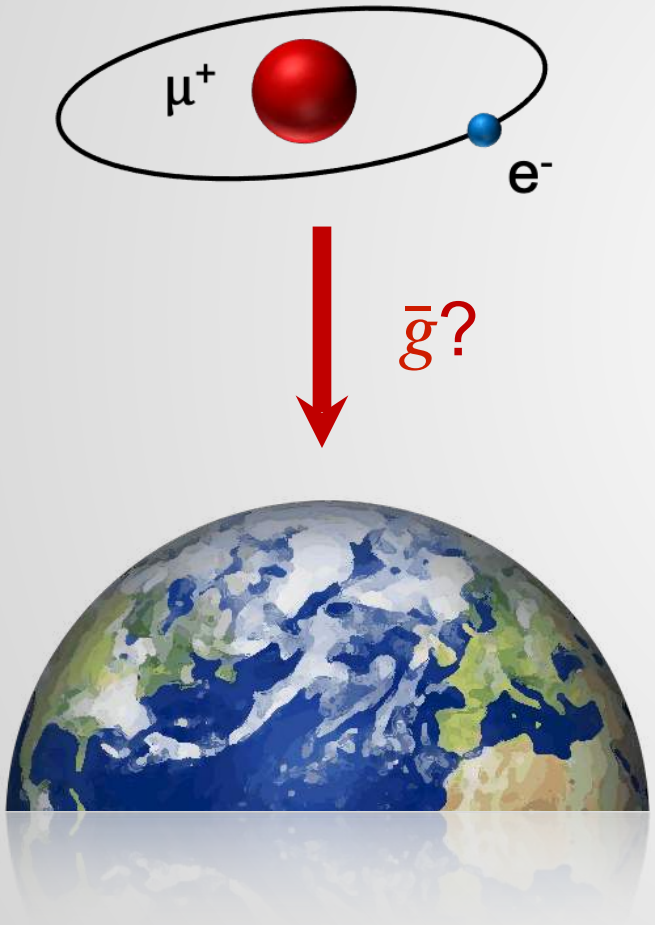

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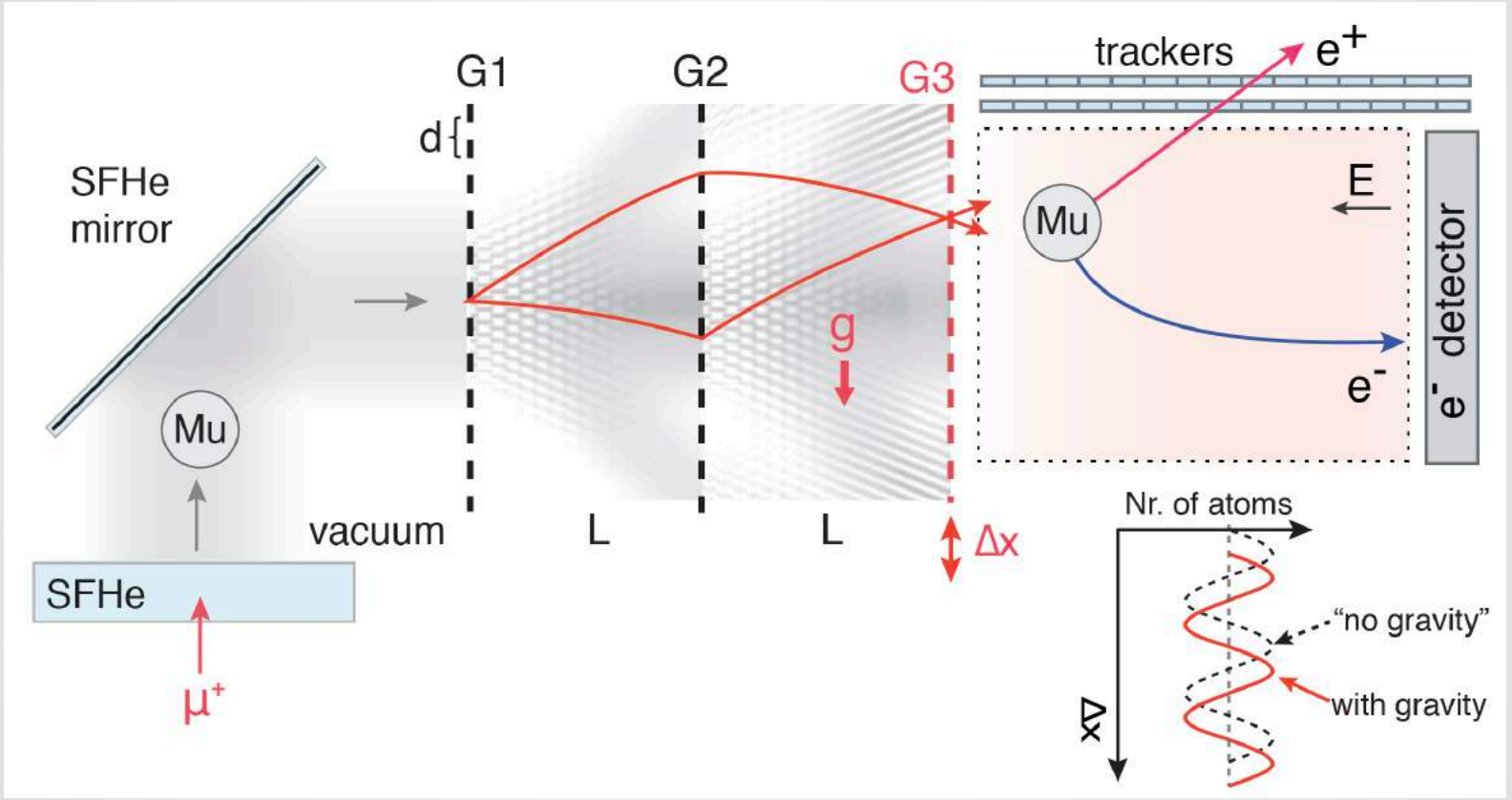
- **Second generation, antimatter gravity** with Mu
  - test **weak equivalence principle** on μ^+
  - elementary **antiparticle**
  - **second generation** lepton

Muonium gravity experiment

Mu beam

- μ^+ to vacuum Mu conversion
- low emittance
- narrow momentum distribution



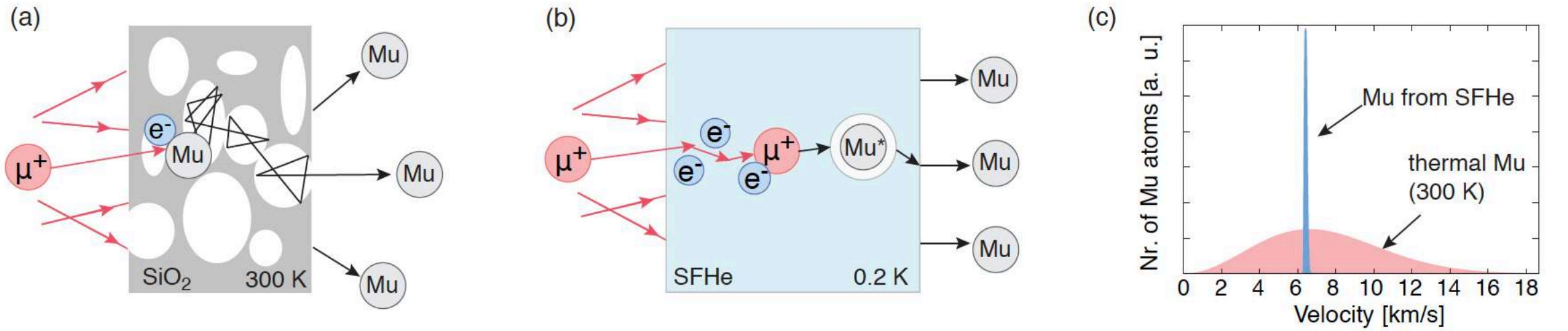
Detection

- coincidence signal of e^+ from μ^+ decay and atomic e^-

Interferometry

- 3-grating interferometer
- gravitational interaction shifts interference pattern

Cryogenic Mu source based on SFHe



present Mu source

- porous SiO_2 structures
- **thermal beam**
  - large momentum distribution
  - wide angular distribution

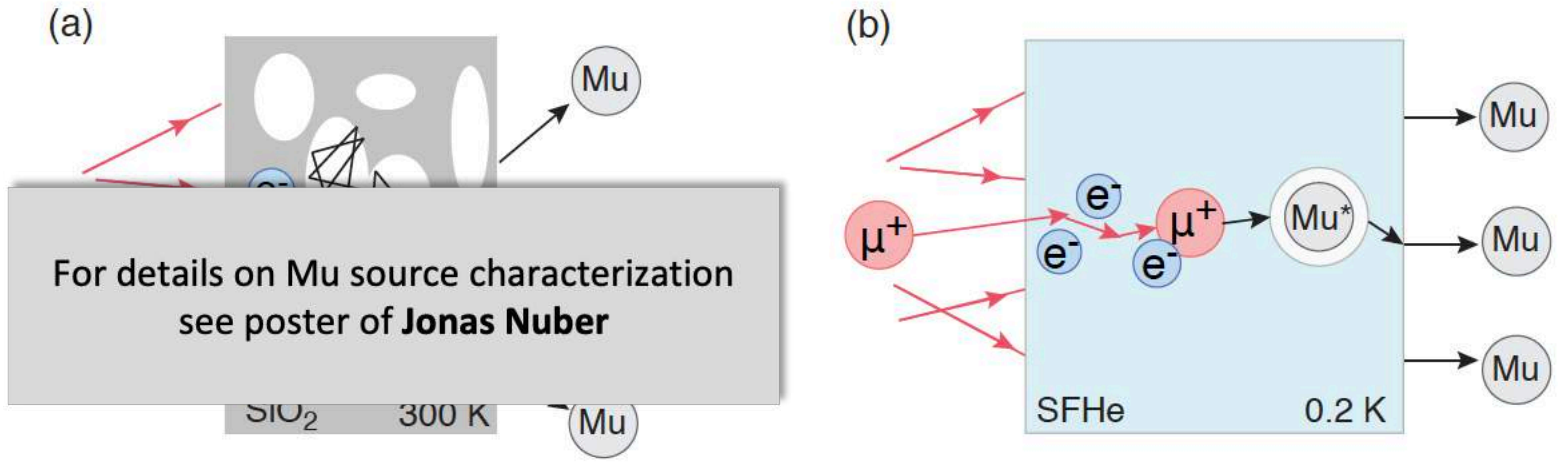
proposed SFHe Mu source

- **superfluid ^{4}He** target
- Mu experience positive **chemical potential** inside SFHe, $E / k_B \sim 270$ K
- Mu ejected with 6 mm/μs perpendicular to SFHe surface

high quality Mu beam

- with SFHe source: fast atomic beam with defined direction and energy

Cryogenic Mu source based on SFHe



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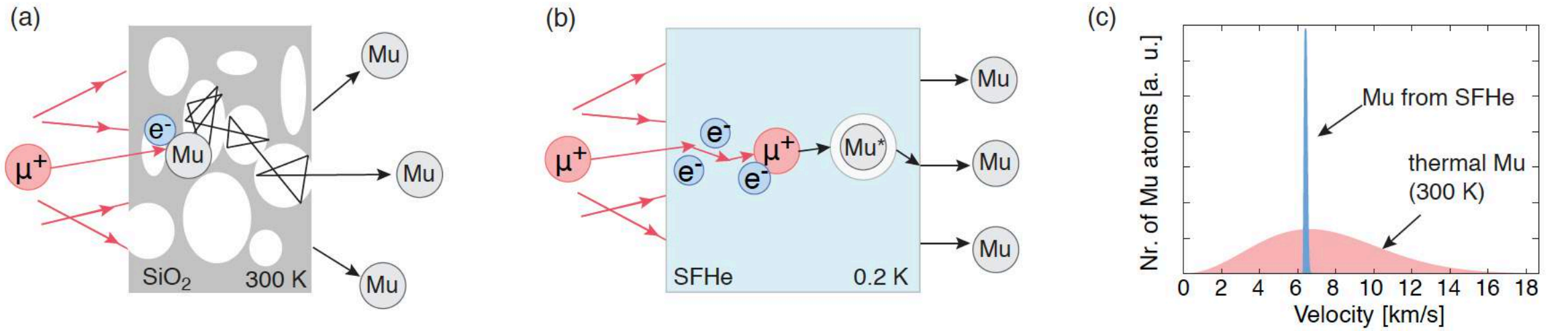

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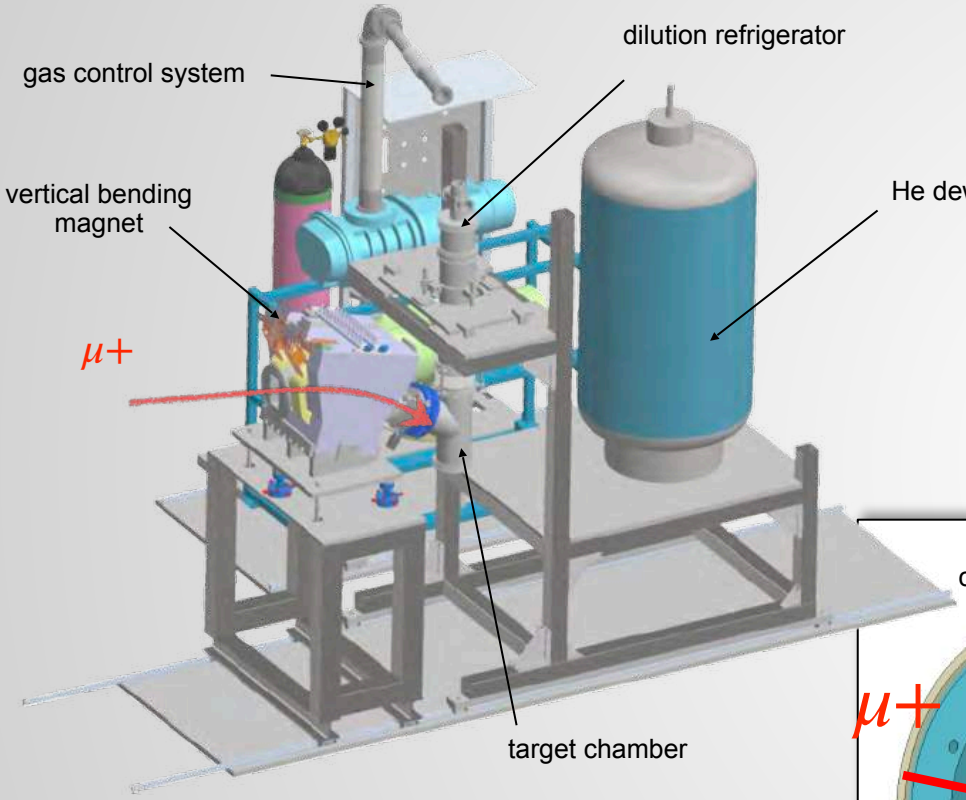
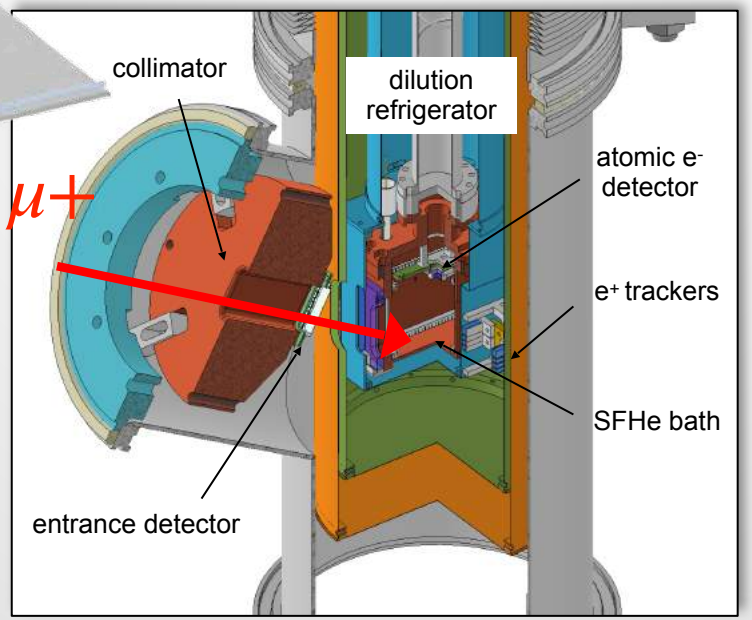
Experimental setup





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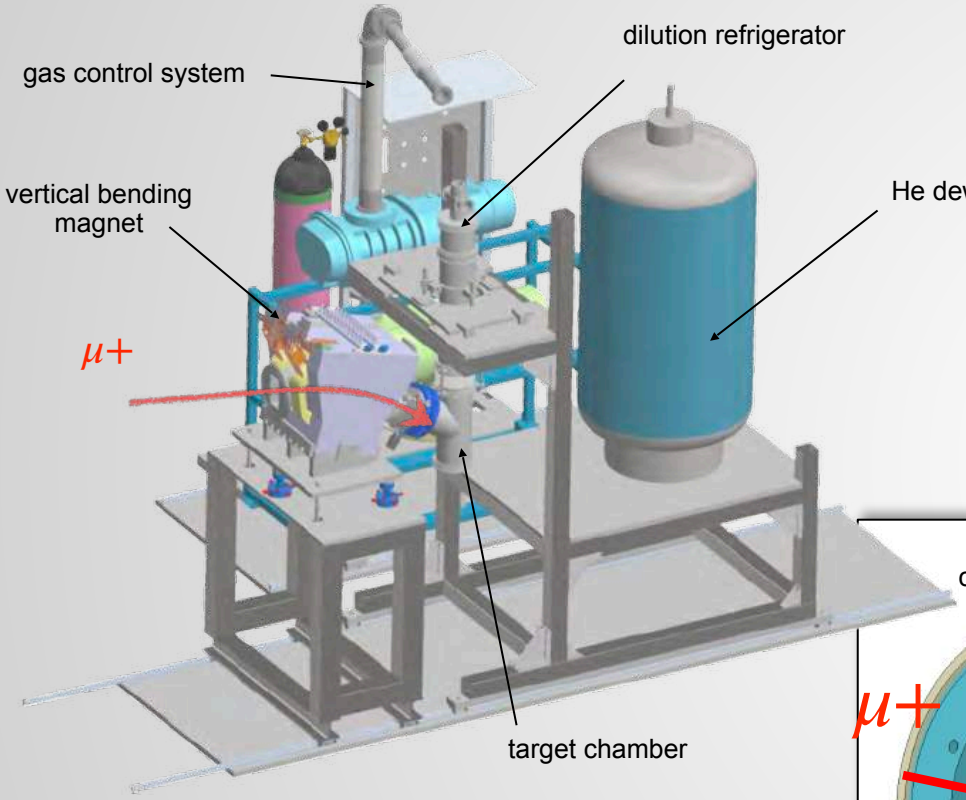
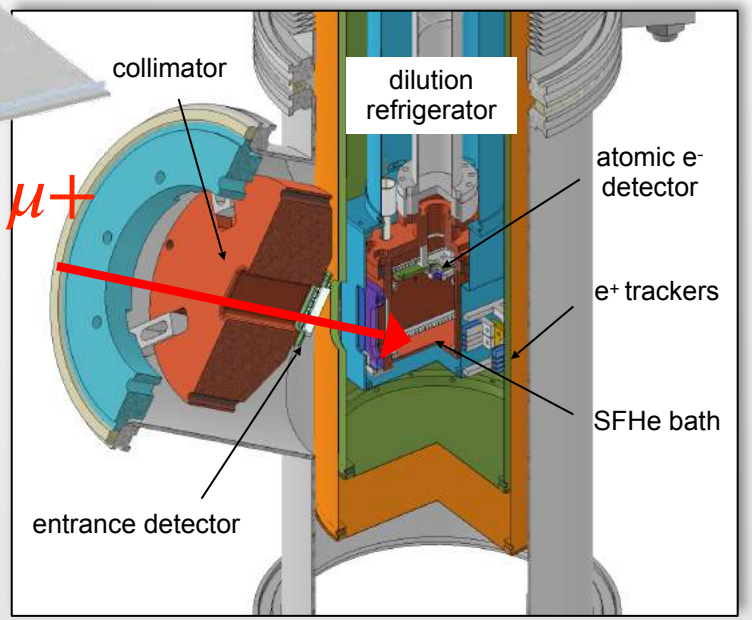
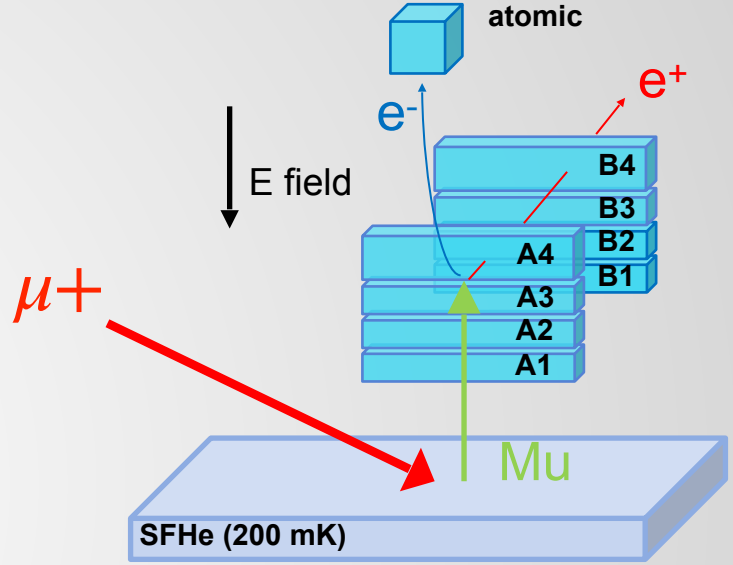


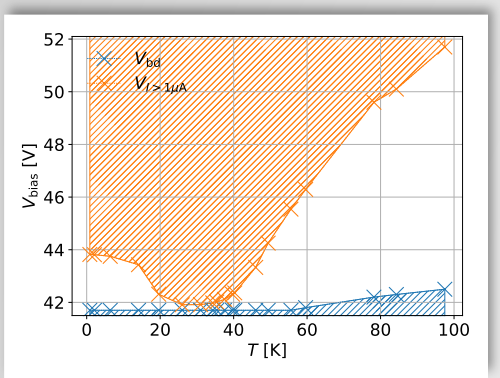


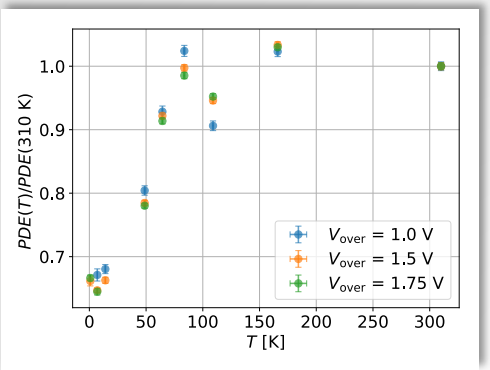


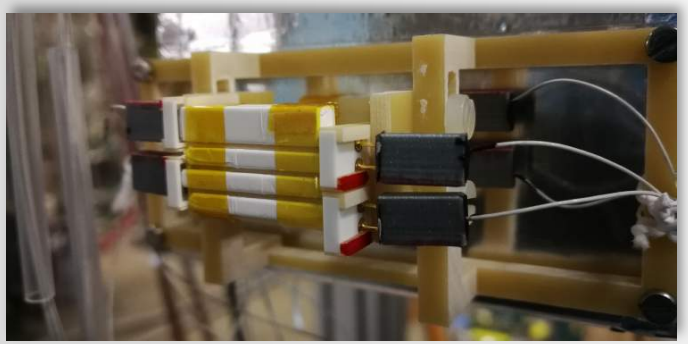
Detection scheme

- select horizontally emitted e^+ in positron tracker
- simultaneous coincidence in atomic e^- detector
- ~ 1 % vacuum Mu emission sensitivity

Cryogenic detectors



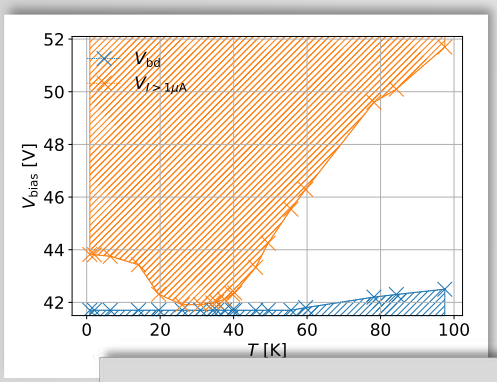


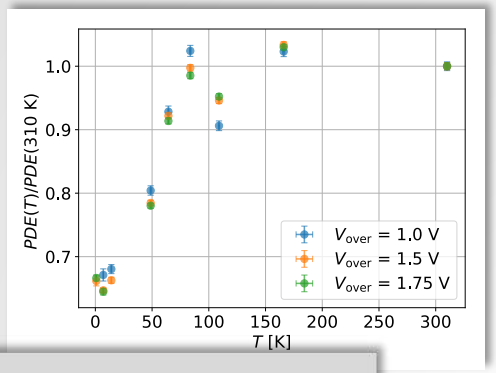


Detector characterization:

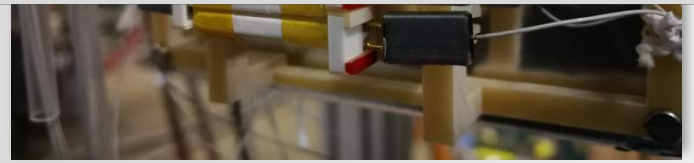
- **plastic scintillator** coupled to **SiPM**
- shown to be operational at **T < 200 mK**
- can detect low energy charged particles
- capable of single photon detection

Cryogenic detectors





For details on instrumentation see poster of **Damian Göldi**



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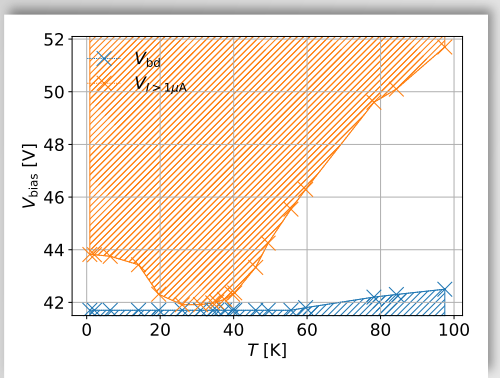

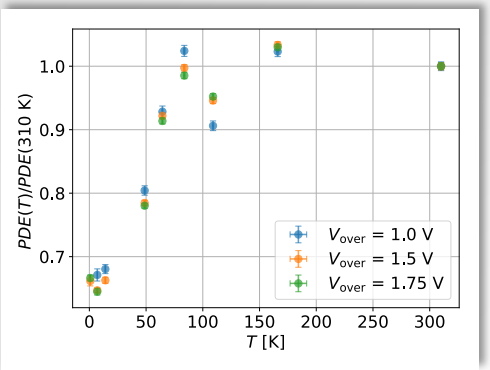

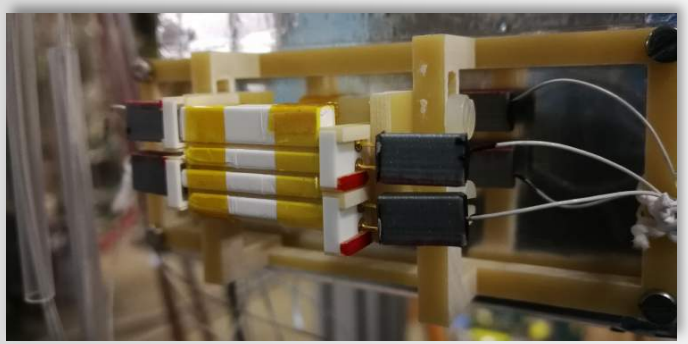

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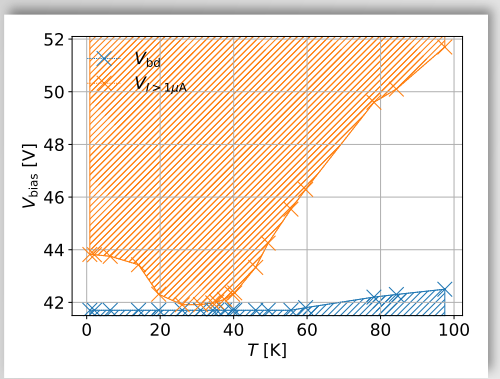

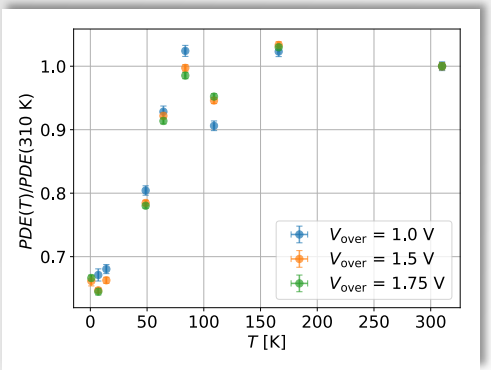

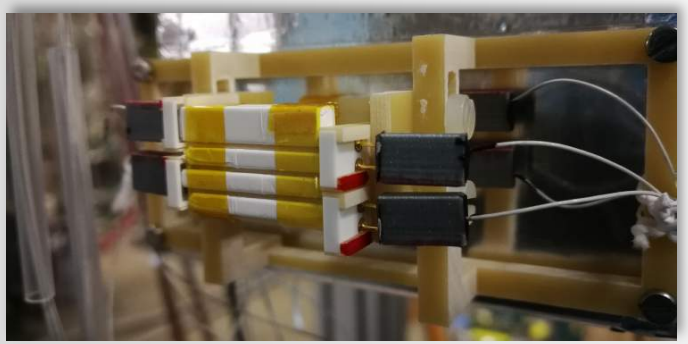

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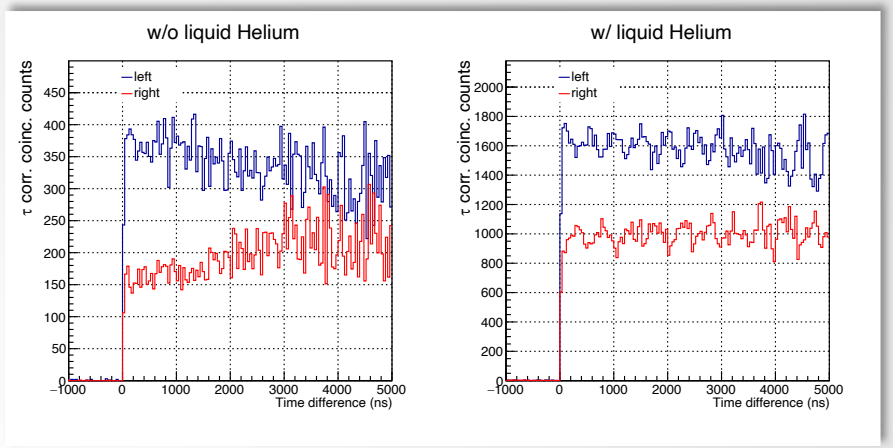
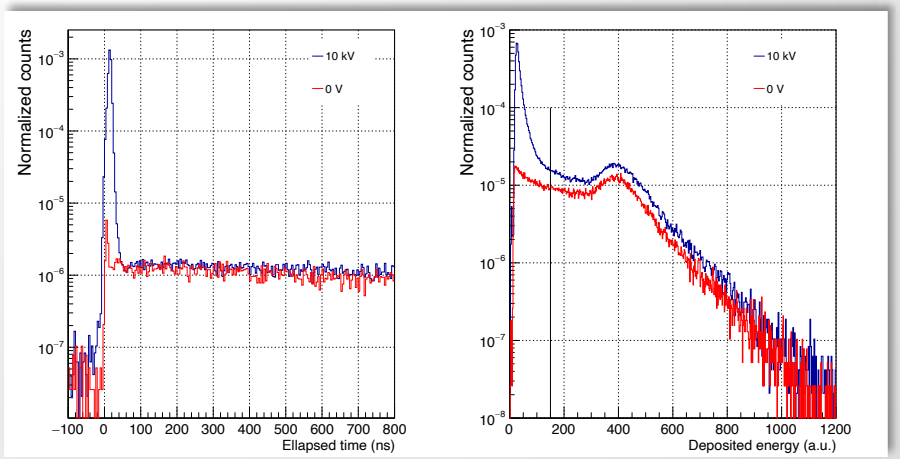
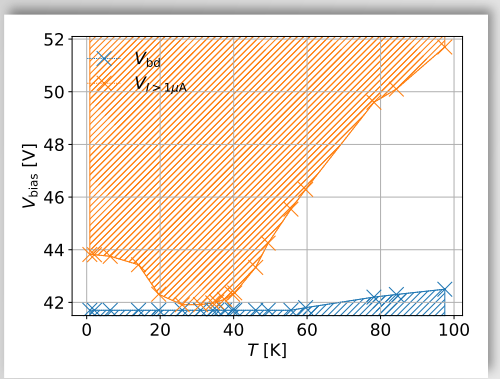


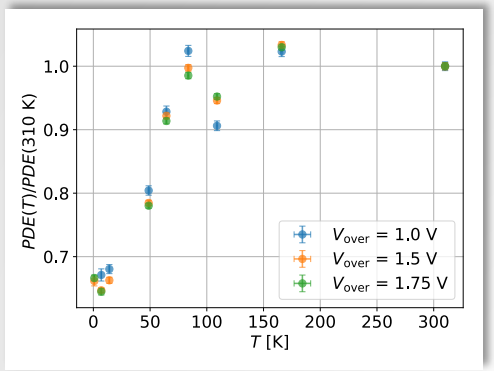


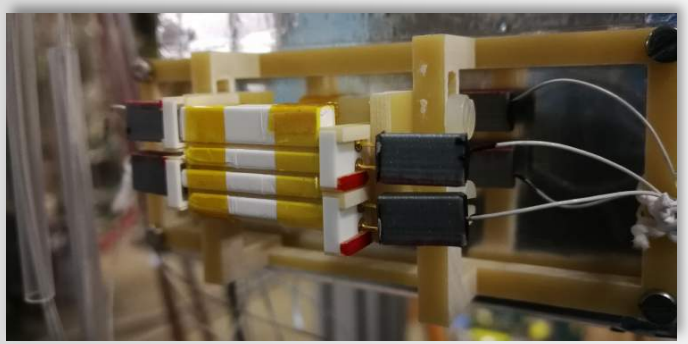
Detector commissioning:

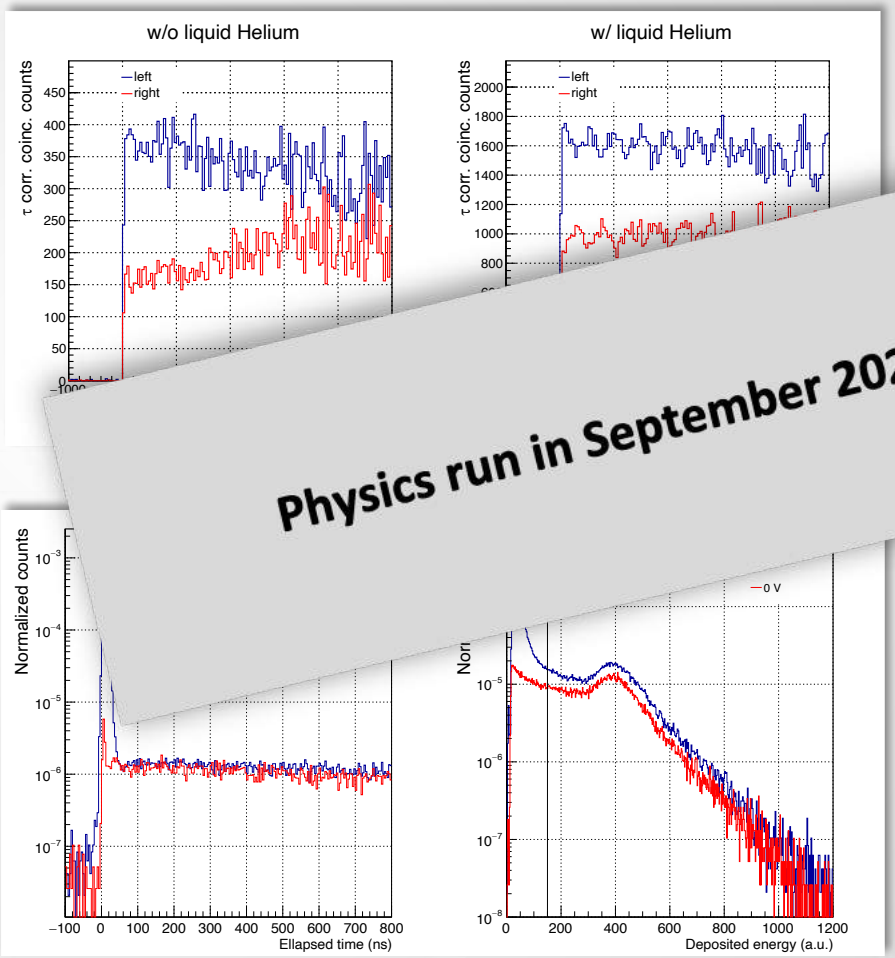
- e^+ detector used to observe **Mu formation in SFHe**
- atomic e^- detector capable of detection low energy e^-

Cryogenic detectors









Physics run in September 2021!

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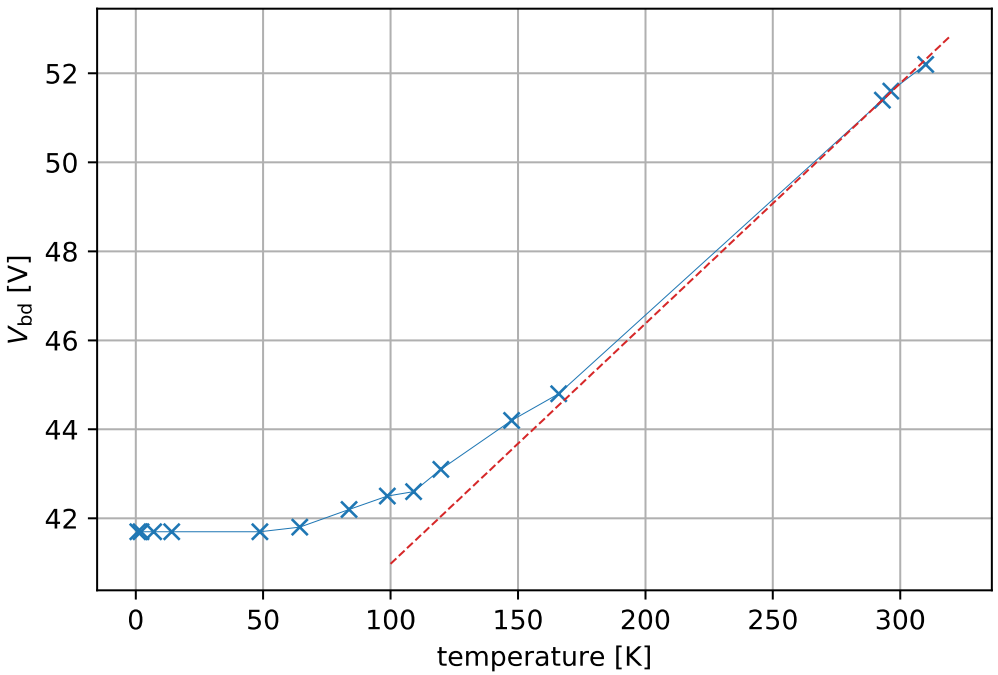
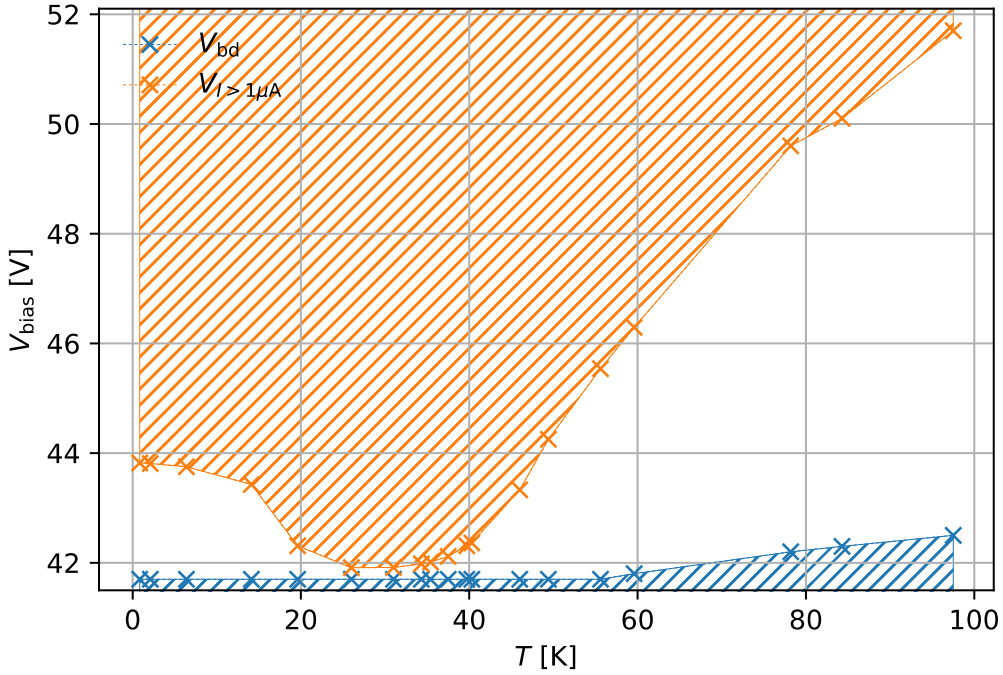
Backup

Cryogenic SiPM: Operating range

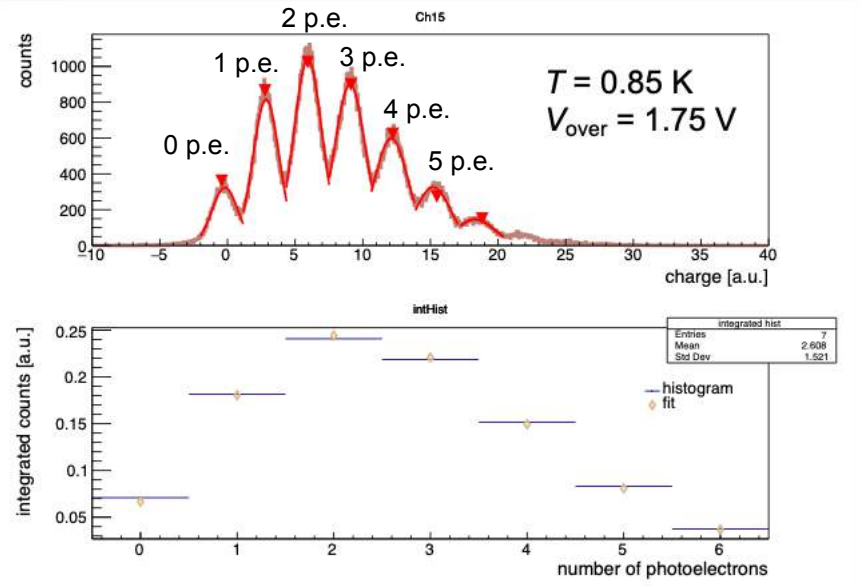




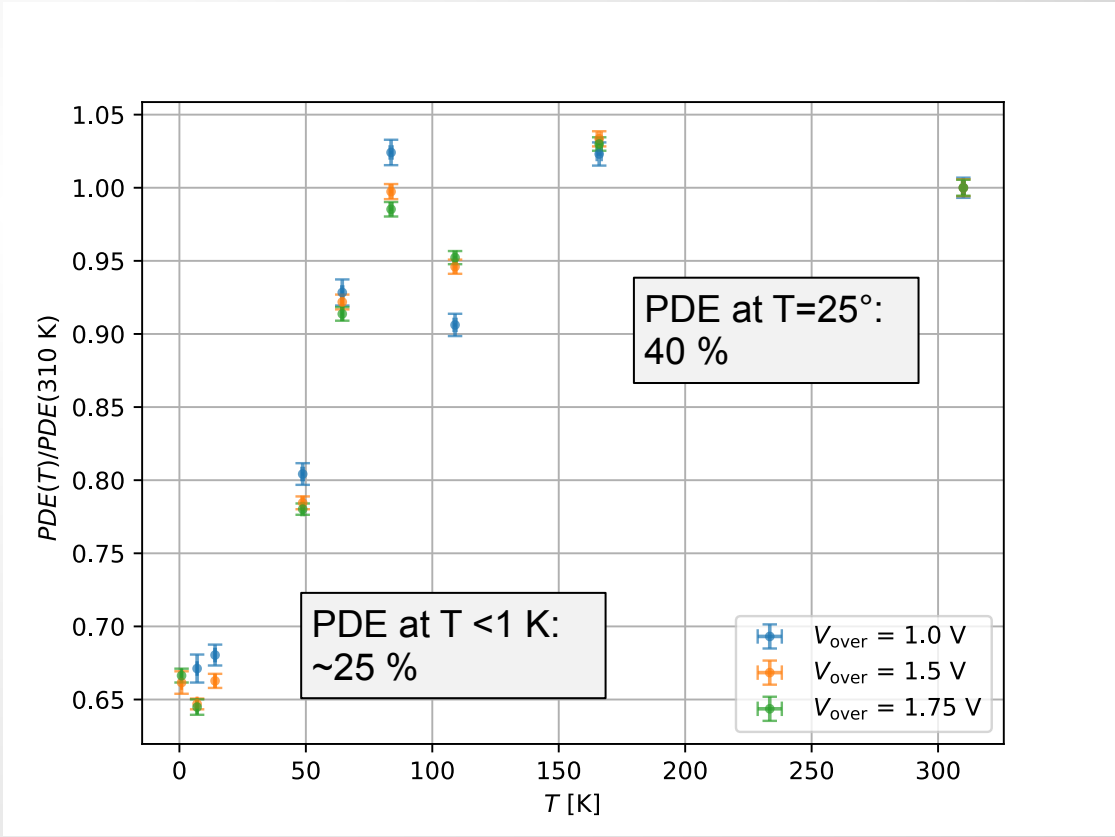
- Non-linear V_{bd} at cryogenic temperatures
- explained by Baraff's model:
  - see C. R. Crowell et al., Appl. Phys. Lett. 9, (1966)

- No proper operation between 20 K and 40 K
- V_{over} limited to ~ 2 V at ultra low temperatures

Cryogenic SiPM: Single photon detection

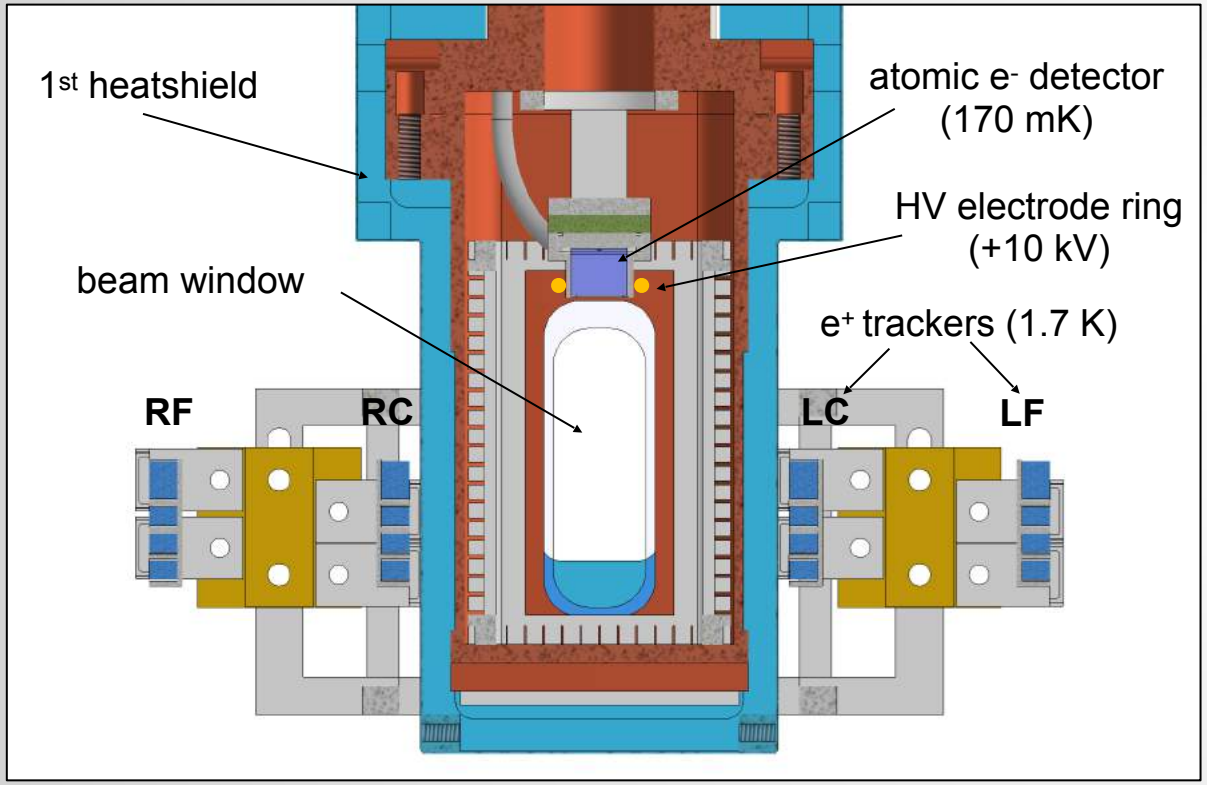


- Measure charge spectrum under low light condition
  - Photon from WLS fibre coupled to pulsed LED
- Poisson fit to estimate detected of photons
- Compare low temperature measurement to room temperature measurement

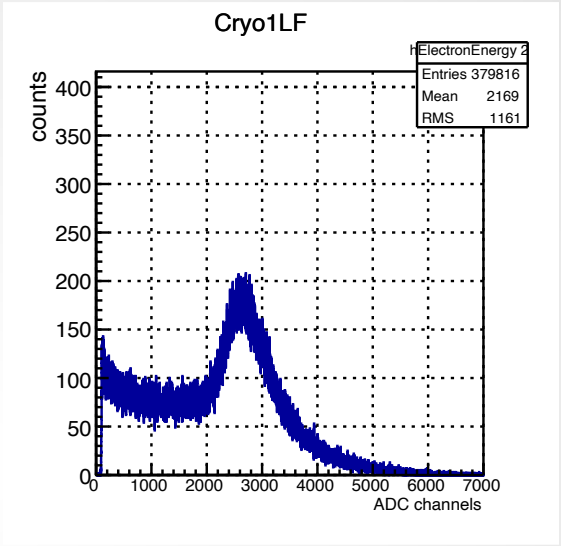


Single photon counting possible at ultra low temperatures

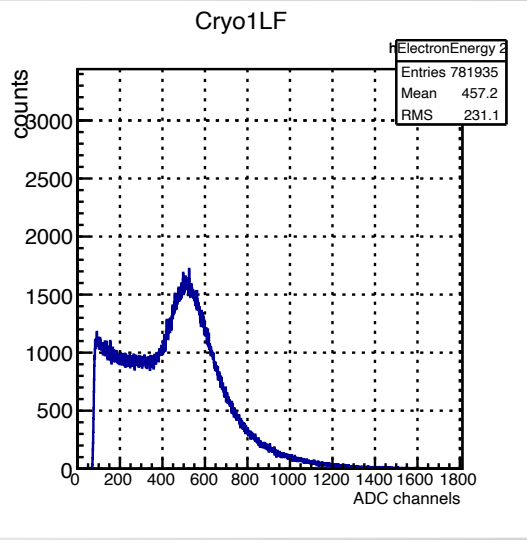
Positron detectors

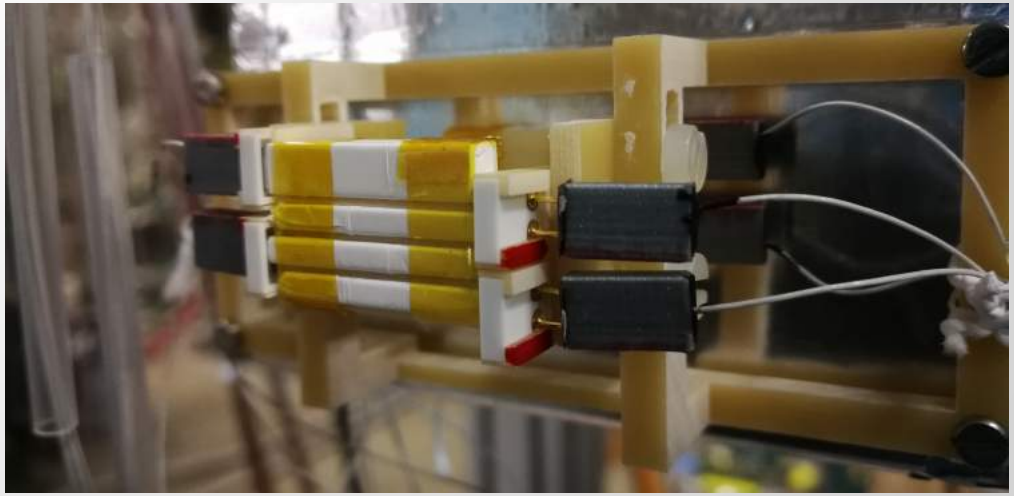


296 K



1.7 K





Atomic e⁻ detector: Energy and time spectrum