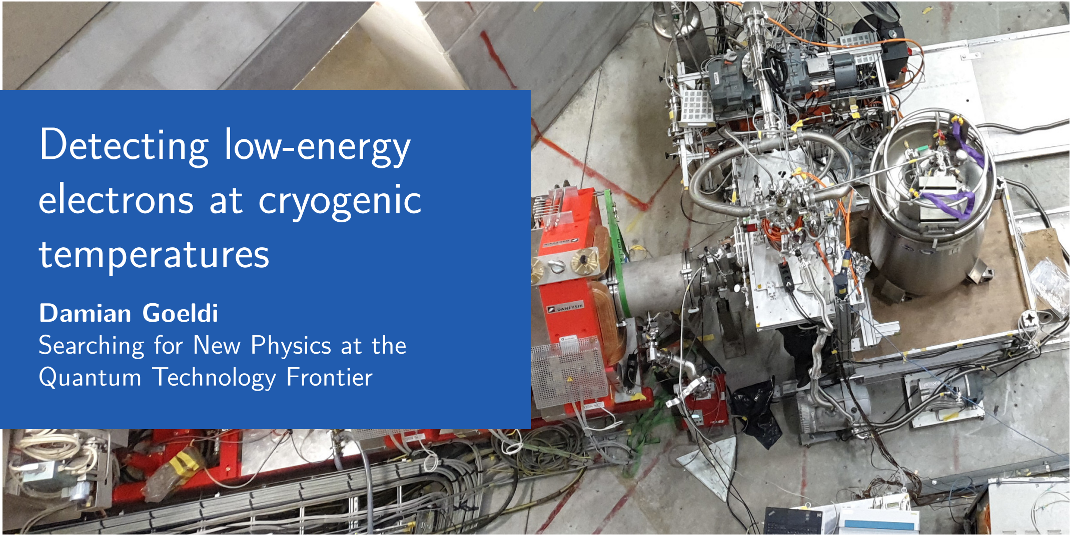
ETH zürich

Low Energy Particle Physics Group
IPA, ETH Zürich



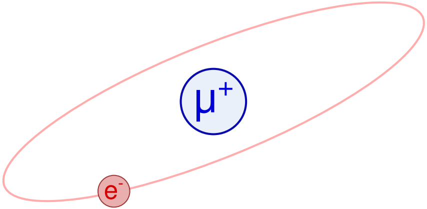
Detecting low-energy electrons at cryogenic temperatures

Damian Goeldi

Searching for New Physics at the Quantum Technology Frontier

Muonium gravity experiment

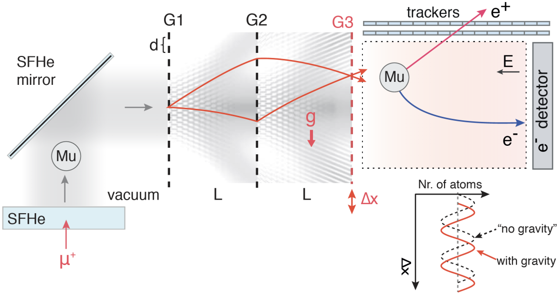
See Anna Soter's talk from yesterday



By LZiegler13—Own work, CC BY-SA 4.0, URL

$\Downarrow$?

test weak equivalence principle using second-generation leptonic antimatter



M beam

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

Interferometry

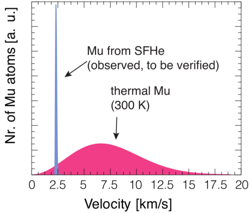
- 3-grating interferometer
- g shifts interference pattern

Detection

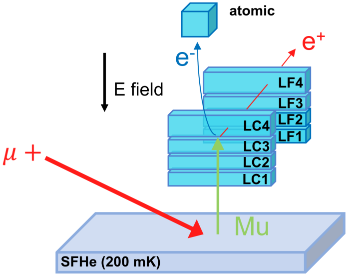
- coincidence signal of e^+ from μ^+ decay and atomic e^-

Novel atomic M beam from SFHe

- M source based on SFHe
  - M gravity experiment requires novel M beam with low emittance and narrow momentum distribution



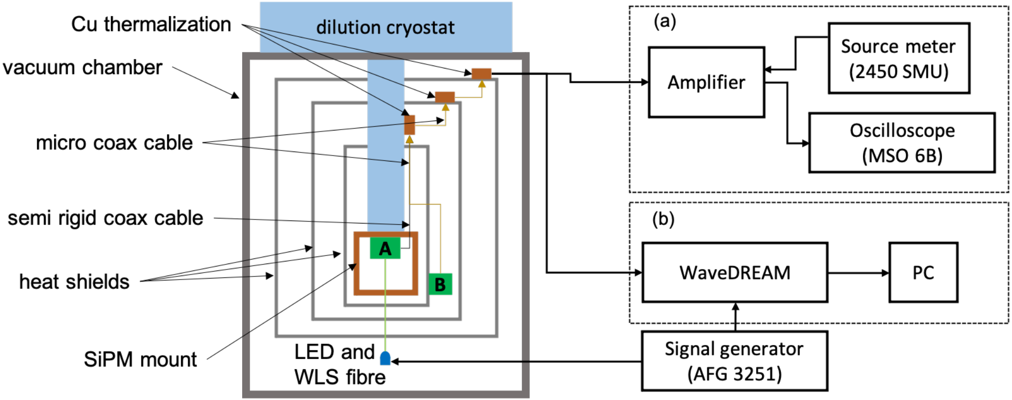
- M detection
  - triple coincidence of horizontally emitted e^+ in two e^+ detectors plus signal in atomic e^- detector
  - e.g. LC4 $\wedge$ LF4 $\wedge$ atomic



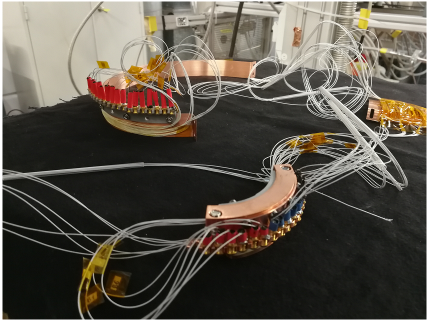
Detector requirements

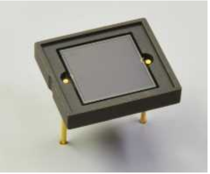
- fast timing
- high efficiency
- high background rejection
- **operation at $T < 200\,\mathrm{mK}$**

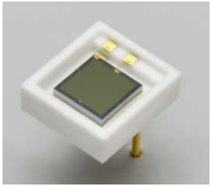
Cryogenic SiPMs
Setup in dilution cryostat



Cryogenic SiPMs
Wiring



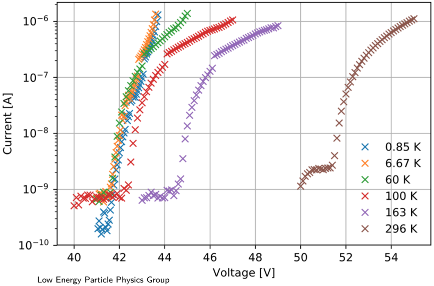


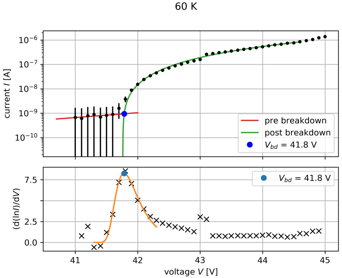


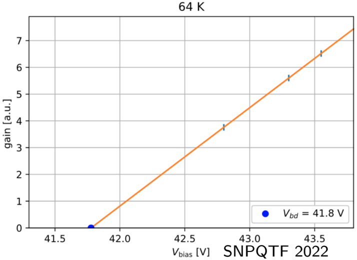
- SiPM: Hamamatsu S13370-3075CN/6075CN
  - pixel pitch: 75 µm, active area: 3 mm × 3 mm / 6 mm × 6 mm
  - designed for LAr / LXe VUV scintillation light
  - no window
- wiring with ≈7 m micro coax cables
  - 38 AWG, ⌀0.4 mm, 50 Ω
  - compromise between heat load and signal quality
  - 3-stage thermalisation
  - 40 dB preamplifier
  - DRS4 digitiser

Cryogenic SiPMs
Electrical characterisation

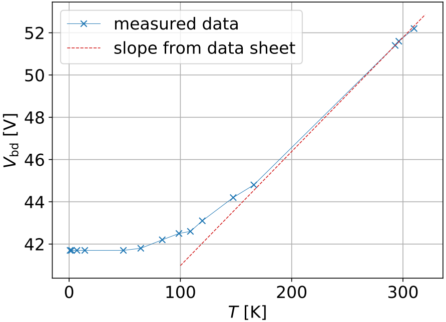
- measure reverse IV curve under low-light condition
  - linear increase up to V_{bd}, then quadratic increase
  - steeper increase after V_{bd} at low temperature
- determine V_{bd} from
  - logarithmic derivative with Landau fit
  - gain vs. bias with linear fit

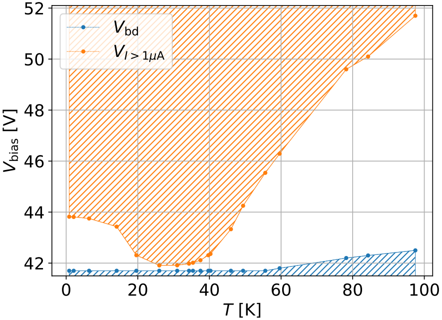






Cryogenic SiPMs
Operating range



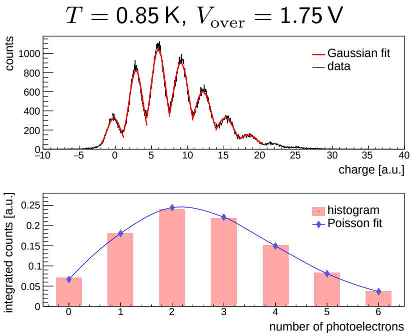


- non-linear V_{bd} at cryogenic temperatures
- explained by Baraff's model (10.1063/1.1754731 ↗)

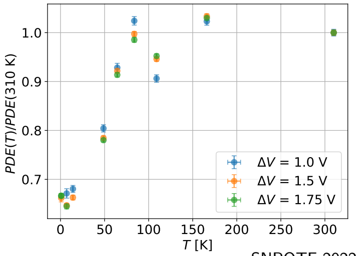
- no proper operation from 20 K to 40 K
- V_{over} limited to ≈2 V at ultra low temperatures

Cryogenic SiPMs

Single photon detection



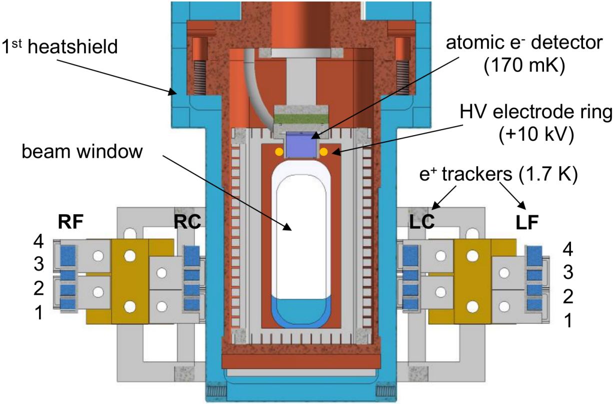
- measure charge spectrum under low-light condition
  - photons from WLS fibre coupled to pulsed LED
- Poisson fit to estimate detected photons
- compare low-temperature measurement to room-temperature measurement

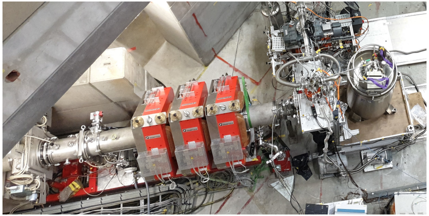


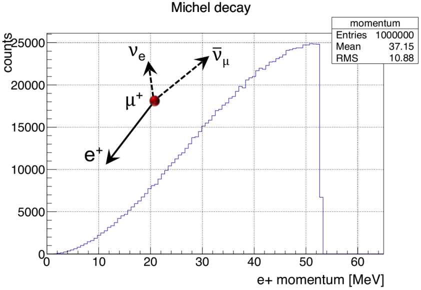
Single photon counting possible at ultra low temperatures

Commissioning with μ^+ beam

- test detectors with μ^+ beam at PSI
- e^+ energy follows Michel spectrum

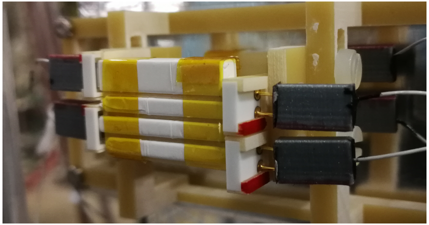


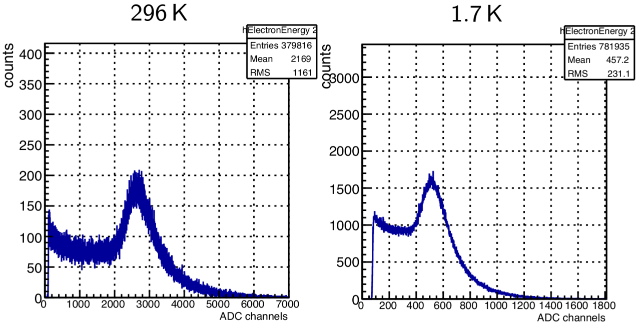




e^+ detectors

- plastic scintillator bars
- Eljen EJ-204, 20 mm × 3 mm × (2 mm to 4 mm)
- wrapped in PTFE
- no optical cement (thermal stress)
- 3D-printed acrylic sleeves

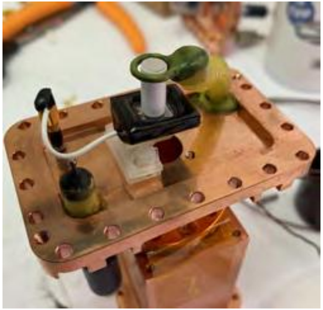


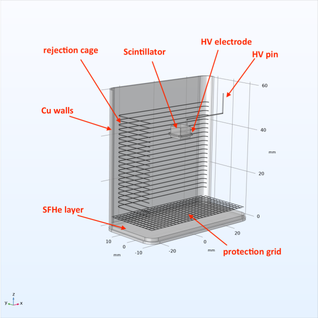


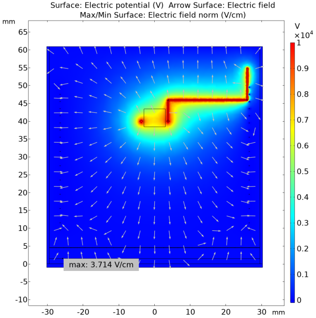
- energy deposition in thin absorber ⇒ Landau distribution
- lower gain at cryogenic temperatures, but full peak resolved

Atomic e^- detector
Design

- Goal
  - remove μ^+ background in e^+ detectors
  - coincidence detection of e^+ from μ^+ decay and atomic e^-
- Method
  - HV electrode to accelerate e^- towards scintillator pill
  - detect low-energy (<10 keV) electrons

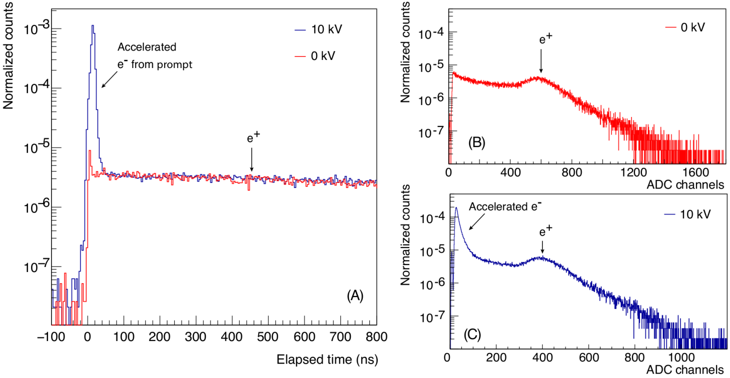






Atomic e^- detector

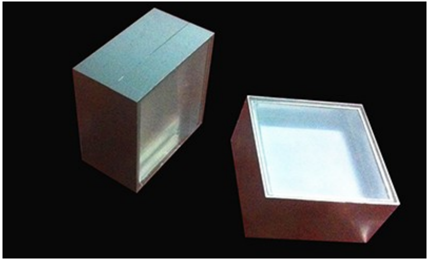
Energy and time spectrum



- operate with HV off and on
- high-energy Michel e^+ from μ^+ decay (always)
- accelerated e^- from μ^+ hitting Cu walls (only with HV on)

- Success at ultra low temperatures in vacuum
- **Not (yet) in SFHe**

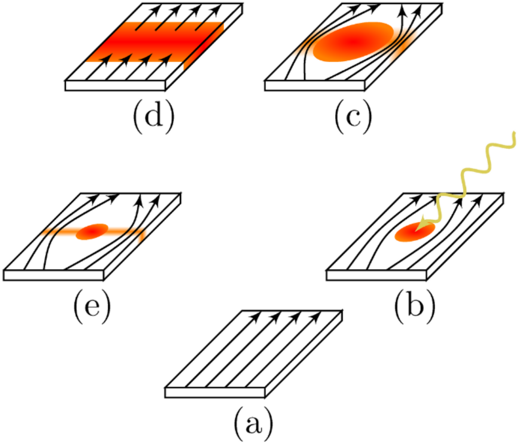
$CeBr_3$ scintillator



https://www.epic-crystal.com

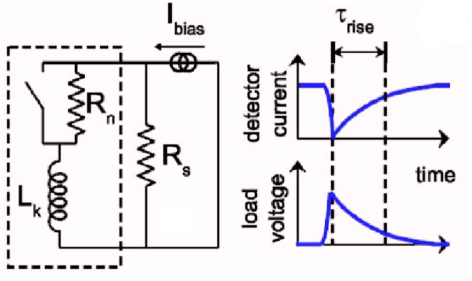
- short decay time: 20 ns
- high light yield: 6×10^4 ph/MeV
- peak emission wavelength: 380 nm
- very good energy resolution: $<4.5\,\%$
- might allow for lower electric field

Superconducting nanowire single-photon detectors
Operating principle



10.3390/nano10061198

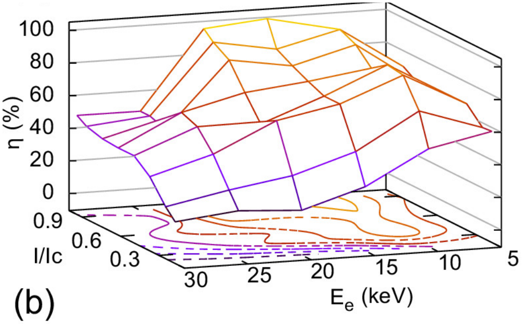
- incoming particle produces local hotspot
- hotspot confines bias current
- nanowire becomes normally conducting above critical current density
- bias current quench produces voltage pulse



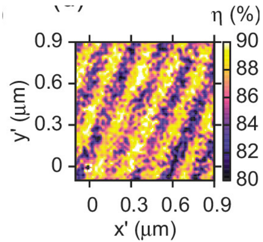
10.1063/1.2183810

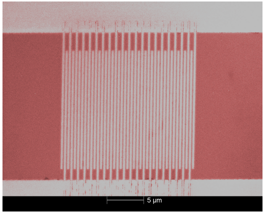
Superconducting nanowire single-photon detectors
Electron detection

- well established for photon detection
- very high efficiency (>0.9)



- proofs of concept for e^- detection
- efficiency drops at low energies (charge build-up suspected)
- not clear what happens if e^- hits between meanders





10.1063/1.3506692

Conclusion and outlook

- successfully operated Hamamatsu VUV4 SiPMs at $T < 20\,\mathrm{K}$
- achieved single photon counting at $T < 1\,\mathrm{K}$
- detected low-energy e^- at $T < 0.2\,\mathrm{K}$ in vacuum
- not yet in SFHe
- investigating low-threshold scintillators and superconducting nanowire single-photon detectors as alternatives
- constructing a field emission e^- gun for tests without μ beam

Low Energy Particle Physics Group

- Anna Soter
- Damian Goeldi
- Robert Waddy
- Jesse Zhang
- Paul Wegmann