Cryogenic particle detection with regard to BLM application

Christoph Kurfuerst
CryoBLM Project
BE-BI-BL CERN

Outline

- Introduction
- Specifications for CryoBLM
- Existing/investigated detectors:
  - Thermal equilibrium calorimeters (Microcalorimeter as example)
  - Transition-Edge Sensors (superconductors)
  - He3 Ionisation chamber
  - Si used at 1 K
  - Si radiation hardness at 4.2 K
  - He scintillation (see talk from Thijs Wijnands)
  - (Scintillators, Cerenkov fibers)
  - ...
- Detectors currently under investigation

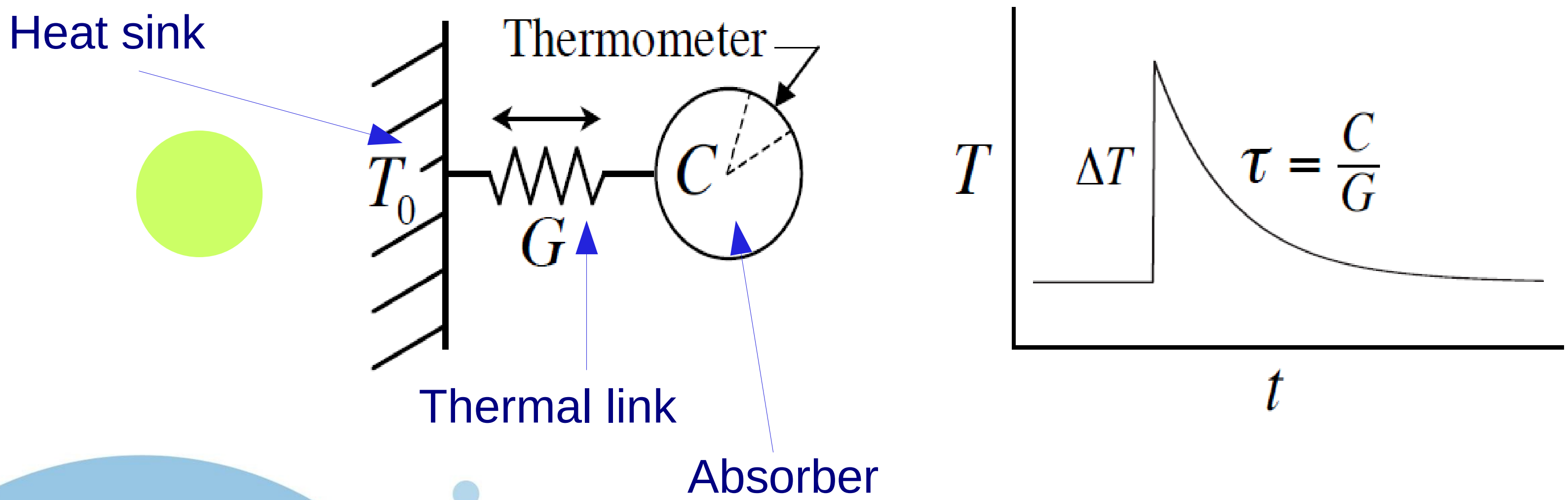
Introduction

- First researches aimed at finding existing technology that satisfy the LHC CryoBLM criteria
- Cryogenic temperatures have the main advantage of extremely low thermal noise level
- Many application use this property for for very precise single particle detection, like it is needed for dark matter analysis and space applications
- This precision is not needed for BLM
- Little detailed information found about radiation hardness at cryogenic temperatures

Specifications for CryoBLM

- Present conditions:
  - low temperature of **1.9 K** (superfluid Helium)
  - radiation of about **1 MGy** in 10 years (see Alessios talk)
  - magnetic field of **2 T**
  - pressure of 1.1 bar, withstanding a fast pressure rise up to about 20 bar
- Main contribution to radiation field comes from:
  - neutrons and
  - photons, but also charged particles are expected.
- Linearity between **0.1 and 10 mGy/s**
- Detector response **faster than 1 ms**
- **Stability, reliability and availability:** after installation no access possible

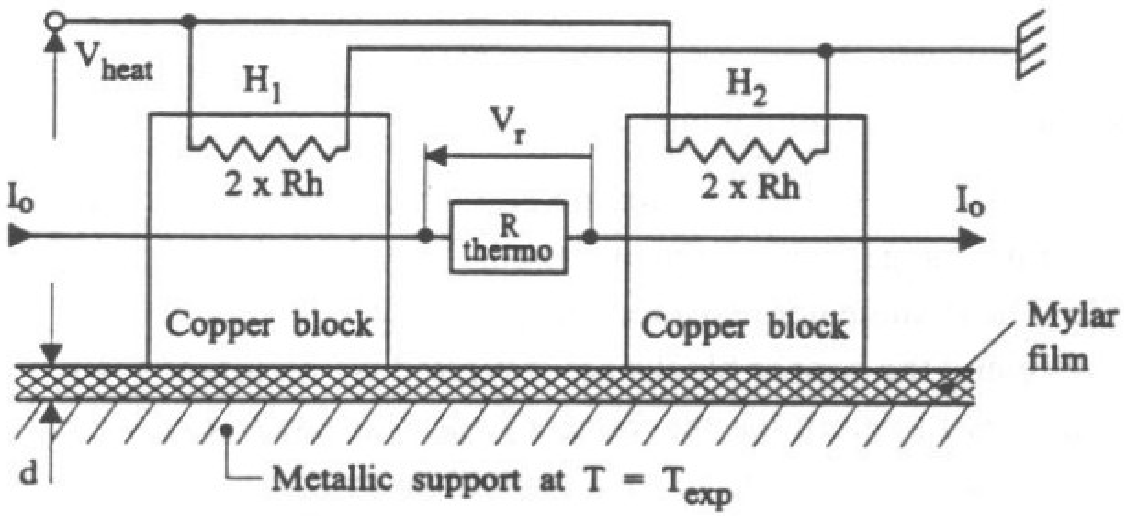
Thermal equilibrium Calorimeters
Reference [1]



- No requirement for efficient charge transport – impurities can be tolerated
- Thermal equilibrium detectors enable very good energy resolution (3 eV FWHM at 6 keV), because almost no fluctuations at low temperatures

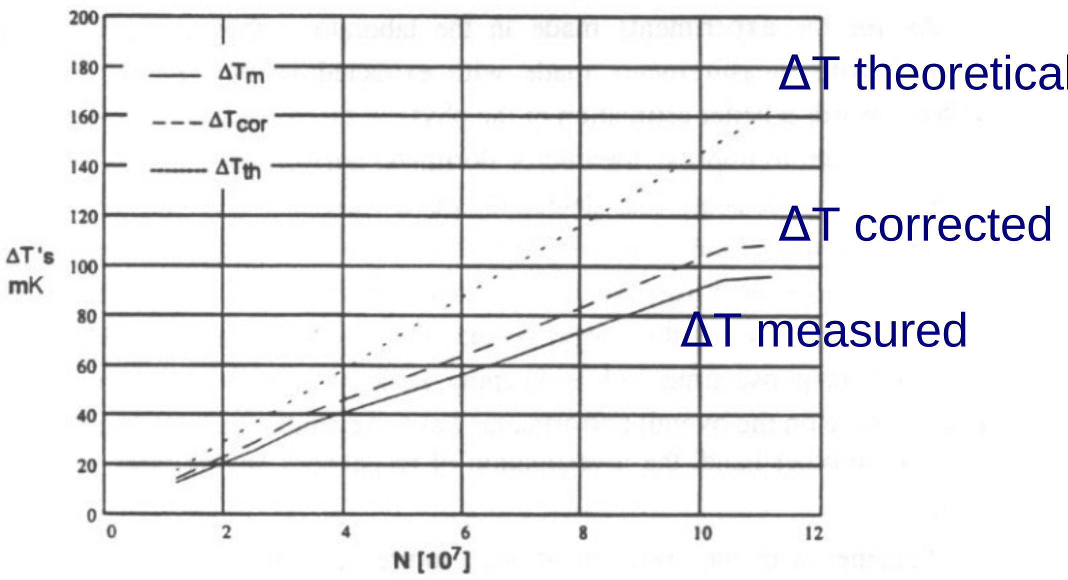
Microcalorimeters as BLM 1996
Reference [2]

- Carbon resistance as thermometer, coupled to copper block
- In case of losses, particle shower deposits heat into copper, leading to resistance decrease



Microcalorimeters as BLM 1996
Reference [2]

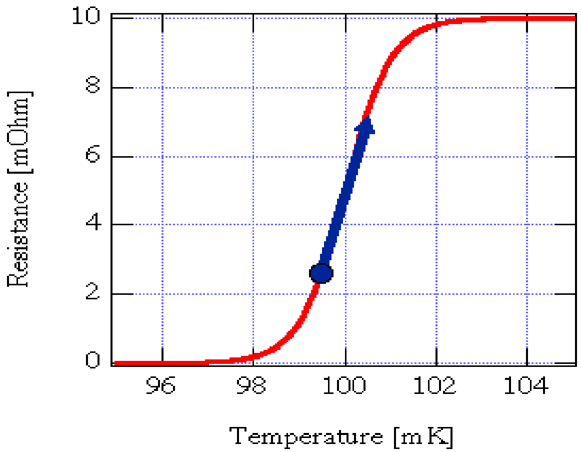
- Possible to correlate resistance decrease with number of particles lost



- In the end not used, because: cooling time constant with 3 s too long (and practical arguments)

Transition Edge Sensors (TES)
Reference [3]

- Superconductor operated in the temperature range between normal and superconducting state



- Extremely sensitive
- Possibility to make bilayers (combination of superconductors to reach required transition temperature)
- Arrays with superconductors of different sensitivity to have higher dynamic range

Transition Edge Sensors as BLM?

- No, because:
  - BLM needs large dynamic range, which would mean arrays with different combination of superconductors -> very complex
  - Low saturation level compared to other detectors
  - Tendency for **instability** (Joule heating, fluctuations in bath temperature)
  - Similar to already existing QPS (quench protection system of the LHC)

He3 Ionisation chamber

- This chambers are often used in nuclear industry because of their **simple and reliable** construction and high **sensitivity to thermal neutron** flux
- From phase diagram of He3 it is possible to have gas in the detector at 1.9 K if the right pressure is applied
- He3 extremely rare, with cost of **3000 €/liter** in gas (February 2011)
- Not the material of the future and it would not be very forward-looking to use it as CryoBLM

Silicon at 1 K
Reference [4]

- Scattering experiment at CERN PS used “frozen spin” polarized target
- Silicon surface barrier diode used to replace scintillators that showed low efficiency
- Pulses generated from 5 GeV/c negative pions traversing target
- Good performance of diodes: no noise and pulse FWHM from 50 ns at RT to 20 ns at 1 K
- No radiation damage observed after 15 weeks with 10^5 particles/s (total about 10^{12} particles)
- No detectable effect on operation of diodes from ~0.1 T magnetic field

Silicon at 1 K
Reference [4]

- Read out: 50 Ω input low noise preamplifier

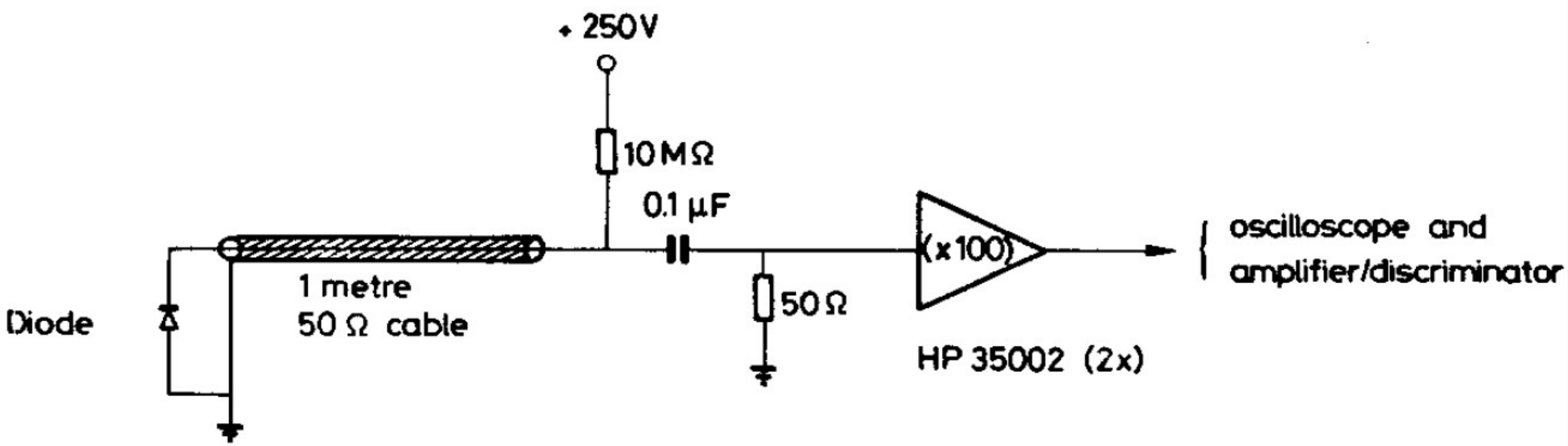


Fig. 12. Electric circuit of semiconductor diodes.

Silicon radiation hardness
Reference [5]

- Silicon detectors at 4.2 K irradiated with $1.2 \cdot 10^{14}$ cm^{-2} 1 MeV neutrons
- Team found reduction of destructive effects compared to RT
- Trap concentration from $5 \cdot 10^{12}$ cm^{-3} to $1 \cdot 10^{14}$ cm^{-3}
- CCE_{max} reaches 100 % at 20 V for irradiated diodes
- Temperatures below 150 K leakage current settle to system noise ~ 1 pA
- Forward current at 4.2 K 1-10 pA for bias voltage smaller 30 V
- Below 50 K detector capacitance achieves geometrical value 7.6 pF

Silicon radiation hardness
Reference [5]

- Charge collection efficiency recovery at low temperatures (without annealing):
  - Detrapping may be considered as negligible at liquid helium temperatures
  - Carriers fill out radiation induced defects and stay there, so that defects can be considered as passivated
- Downside of this effect: Polarisation of the detector and therefore disappearing signal

Silicon radiation hardness
Mail from Erik Heijne

- "Crystals often have been irradiated to quite high dose at 4K or a bit higher, because they wish to have defect concentrations in the order 10^{15} cm^{-3} e.g. for Electron Paramagnetic Resonance (EPR) or Nuclear Magnetic Resonance (NMR) studies"
- "I know that besides Si also diamond has briefly been studied in the team of prof C.A.J. Ammerlaan, who worked at EPR defect characterization"

Detectors currently under investigation (see presentation in the afternoon)

- Silicon planar detectors
- Single crystal diamond
- Ionisation chamber with liquid helium as detection medium
  - Elegant solution
  - No radiation hardness issues
  - - Low charge carrier mobility (0.02 $cm^2/V/s$)

References

(1) Ch. Enss: "*Cryogenic particle detection*", Springer, 2005 .

(2) J. Bosser et al.: "*Preliminary Measurements on Microcalorimeters foreseen to be used as Beam Loss Monitors*", LHC Project Note 71, 1996.

(3) http://web.mit.edu/figueroagroup/ucal/ucal_tes/index.html, 14.10.2011.

(4) T. Niinikoski and F. Udo: "*"Frozen Spin" Polarized Target*", Nuclear Instruments And Methods I34 (1976) 219-233.

(5) V. Palmieri: "*Liquid He cooled silicon for radiation-hard hybrid superconducting pixel detectors*", Nucelar Instruments and Methods in Physics Research A 426 (1999) 56-60.