Photodiodes for Field Emission Radiation?

Testing photodiodes in a wide range of energies and at cryogenic conditions

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES
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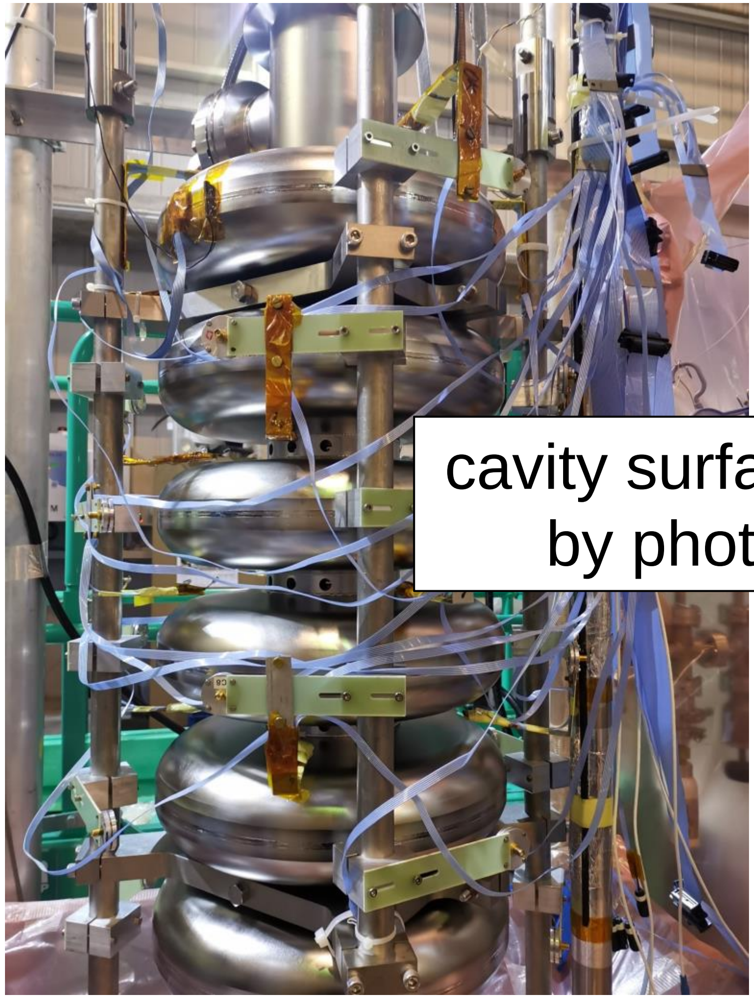
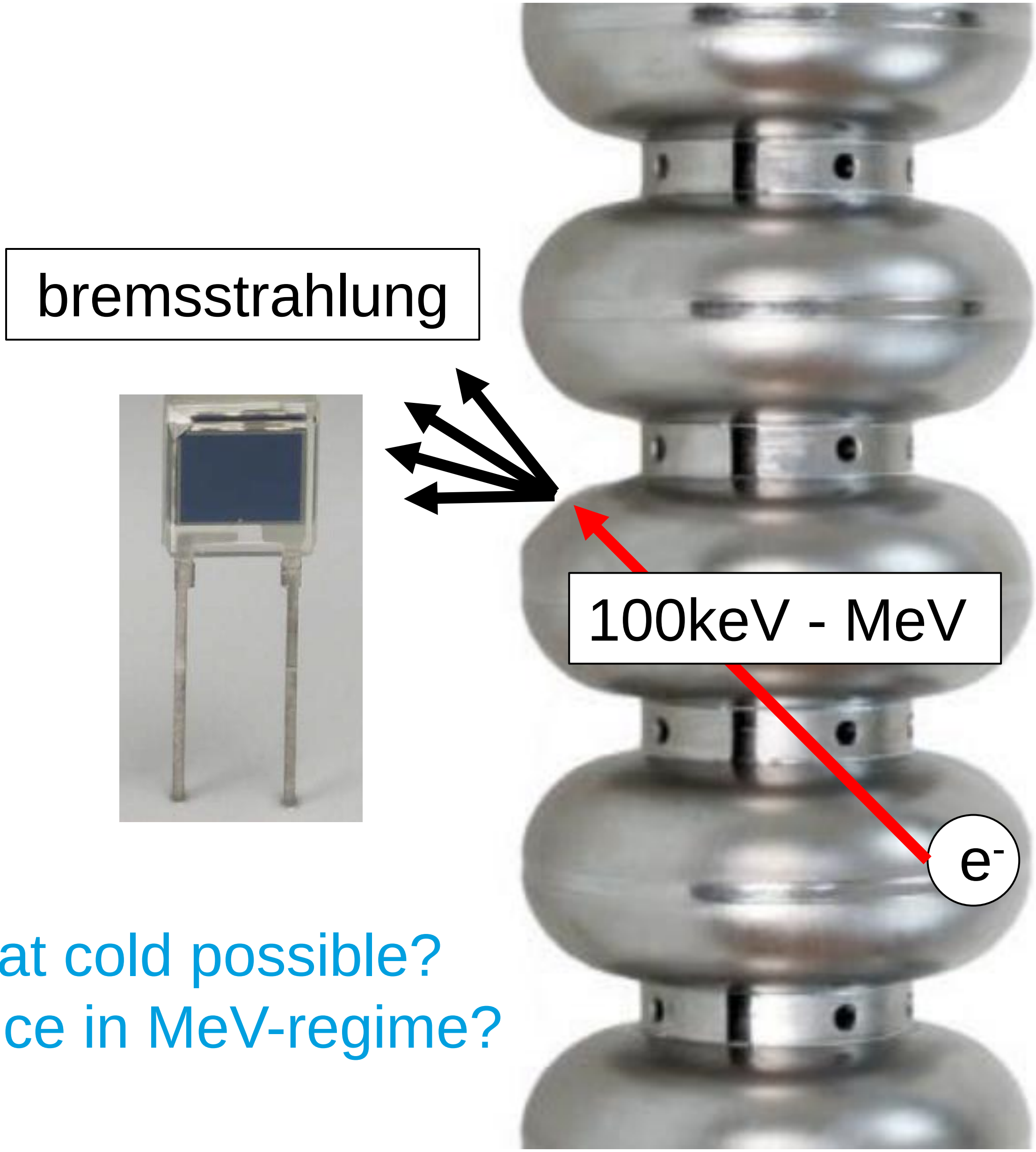
Motivation

How to measure field emission?





⇒ operation at cold possible?
⇒ performance in MeV-regime?

Photodiode Circuits

Photodiodes with or without OPAMP?

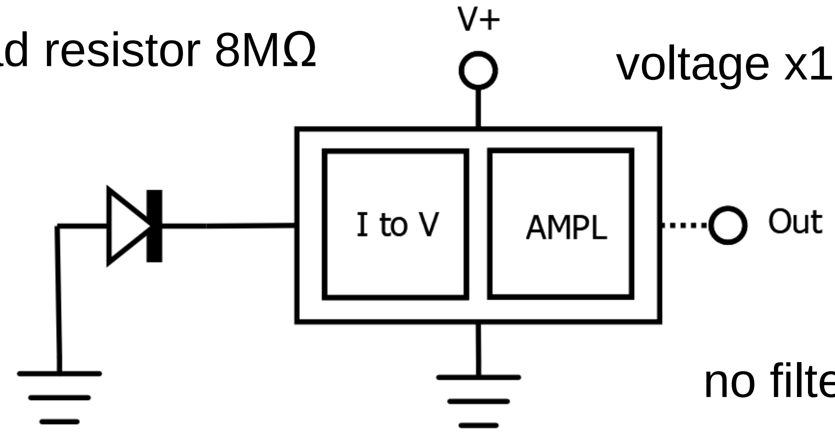
3 options

- simple: photodiode + load resistor + low pass filter
- single: photodiode + single supply amplifier
- dual: diode + dual supply amplifier + low pass

single

load resistor 8MΩ

voltage x10

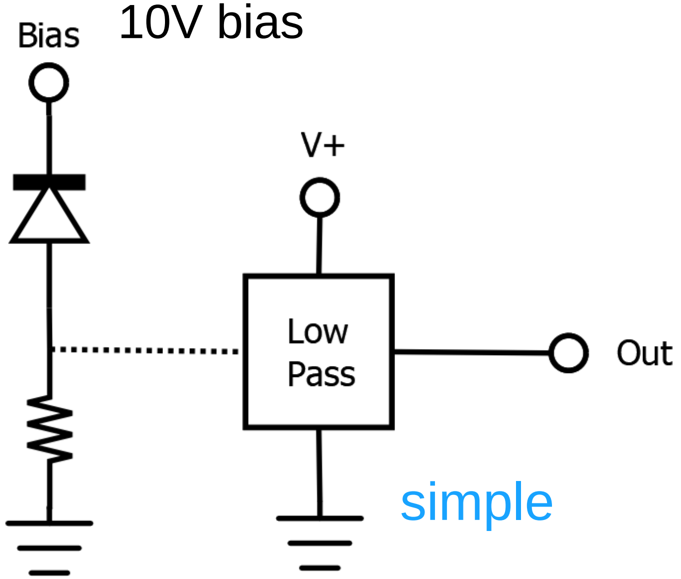


no filter

10V bias

photodiode

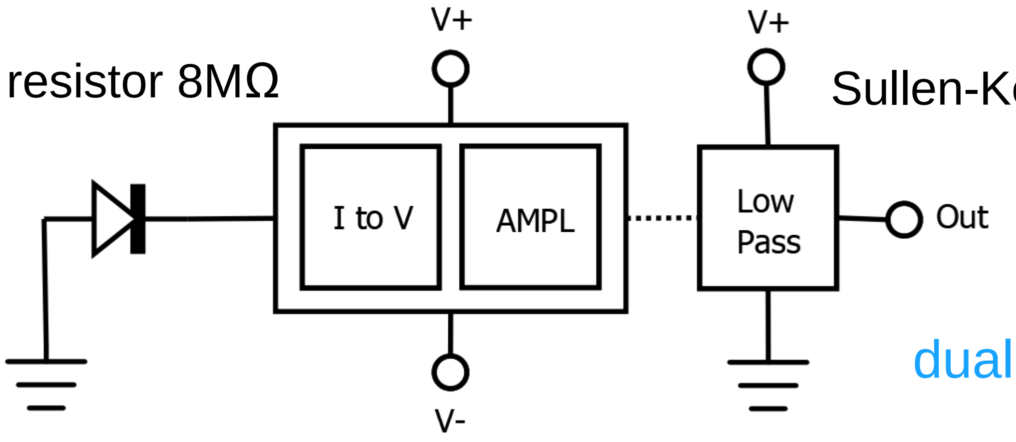
load resistor 1MΩ



simple

load resistor 8MΩ

Sullen-Key filter



dual

Operation at Cold

Performance test with LED light

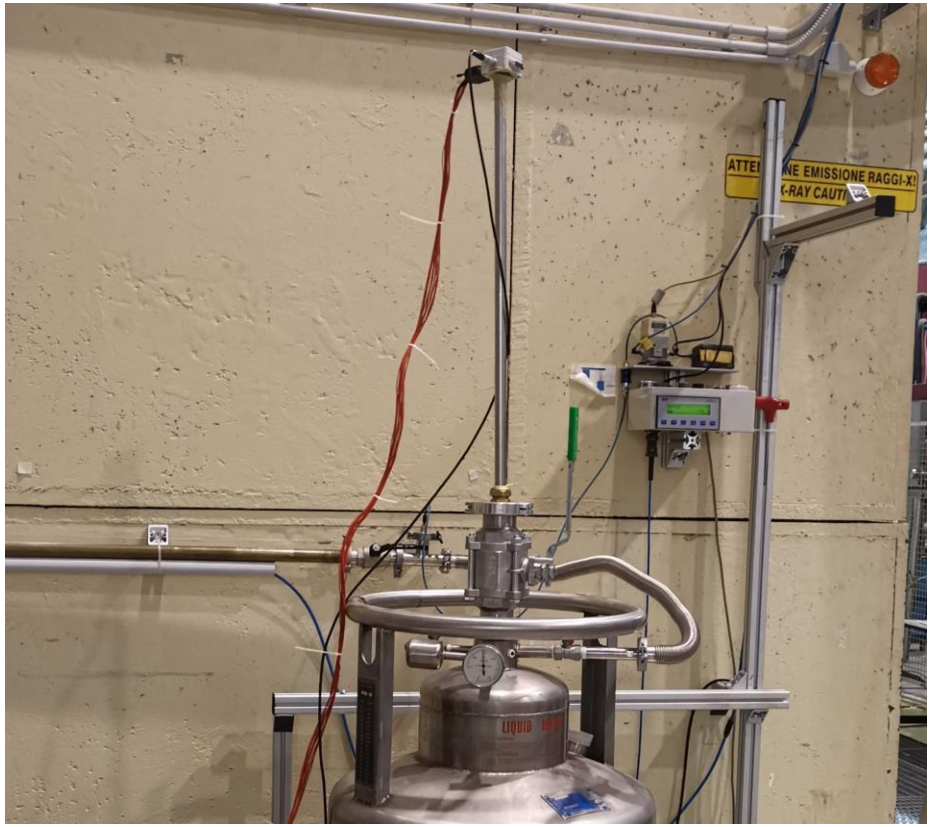
eV

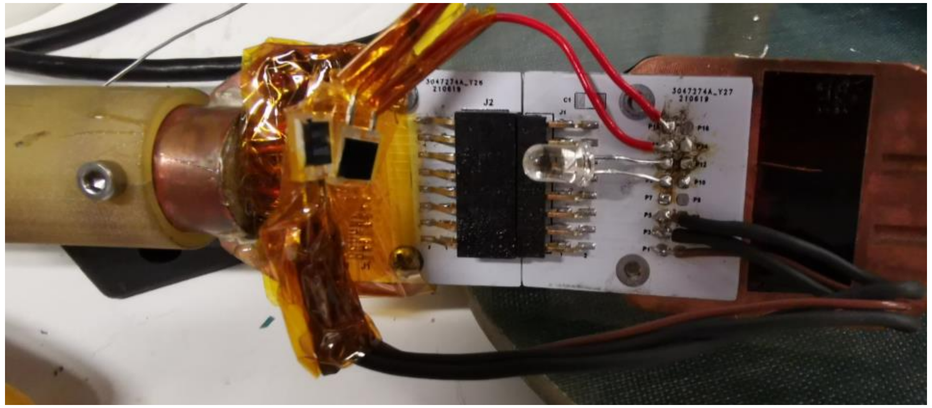
setup

- LED + diodes + temperature sensor on metal rod
- diodes in two different configurations
- dewar with liquid helium

measurement

- rod stepwise immerged → temperature decreases
- increase of LED current
- measurement of diode output
- expectation: $I_{out} \sim$ Intensity $\sim I_{led}$





Performance at 4.2K

Successful operation at cold

results

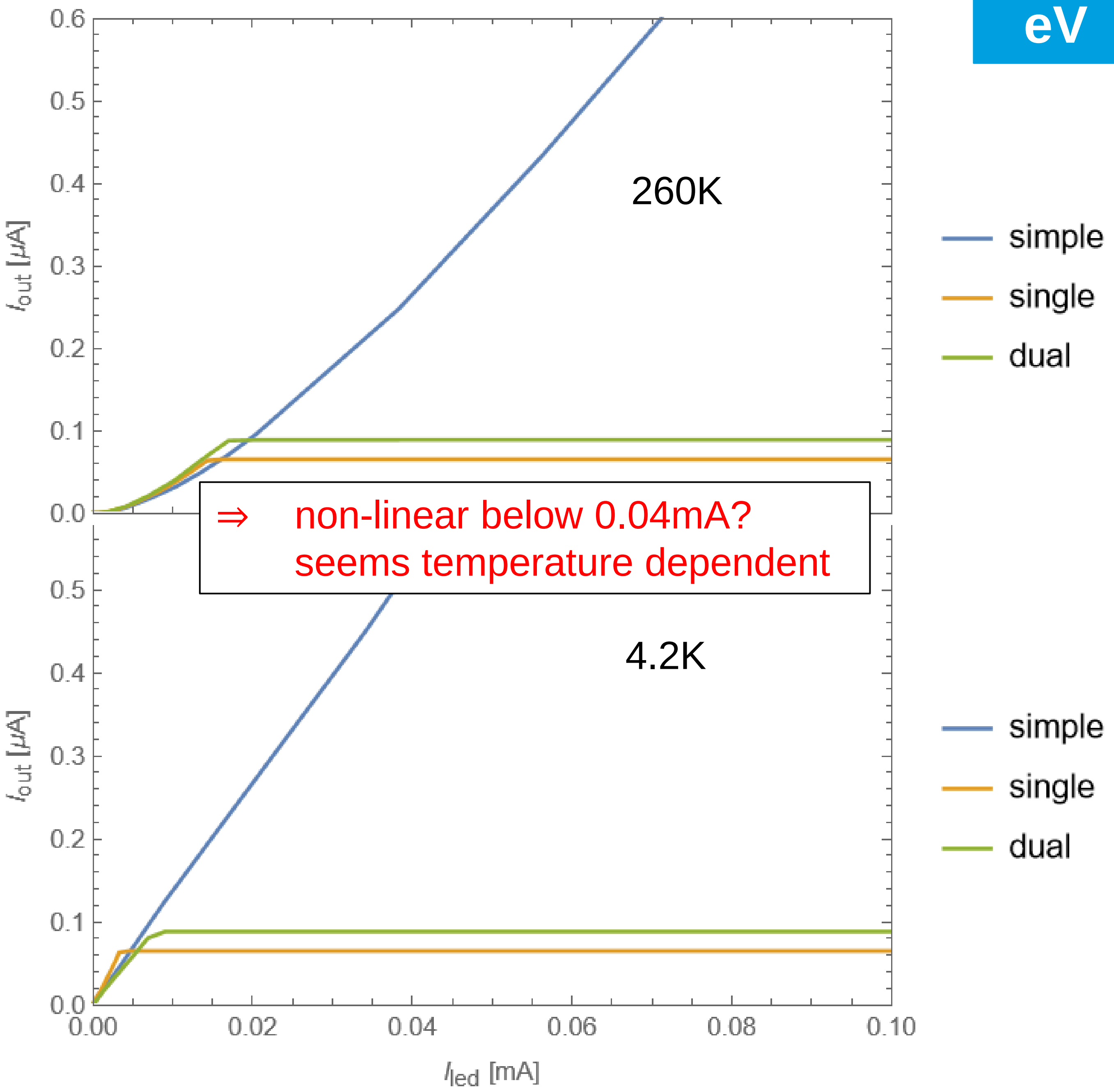
- output rises linearly (in first order)
- early saturation of amplifiers
- comparable results

⇒ successful operation at cold

non-linearity

- diode blindfolded while operating at higher LED currents
- R^2 from 96.7% to 99.9%

⇒ LED likely responsible



eV

External Quantum Efficiency

Quantifying the Performance

$$QE = \frac{\dot{N}_e}{\dot{N}_\gamma} = \frac{I_{out}/e}{P_{in}/h\nu} \sim \frac{I_{out}}{I_{led}}$$

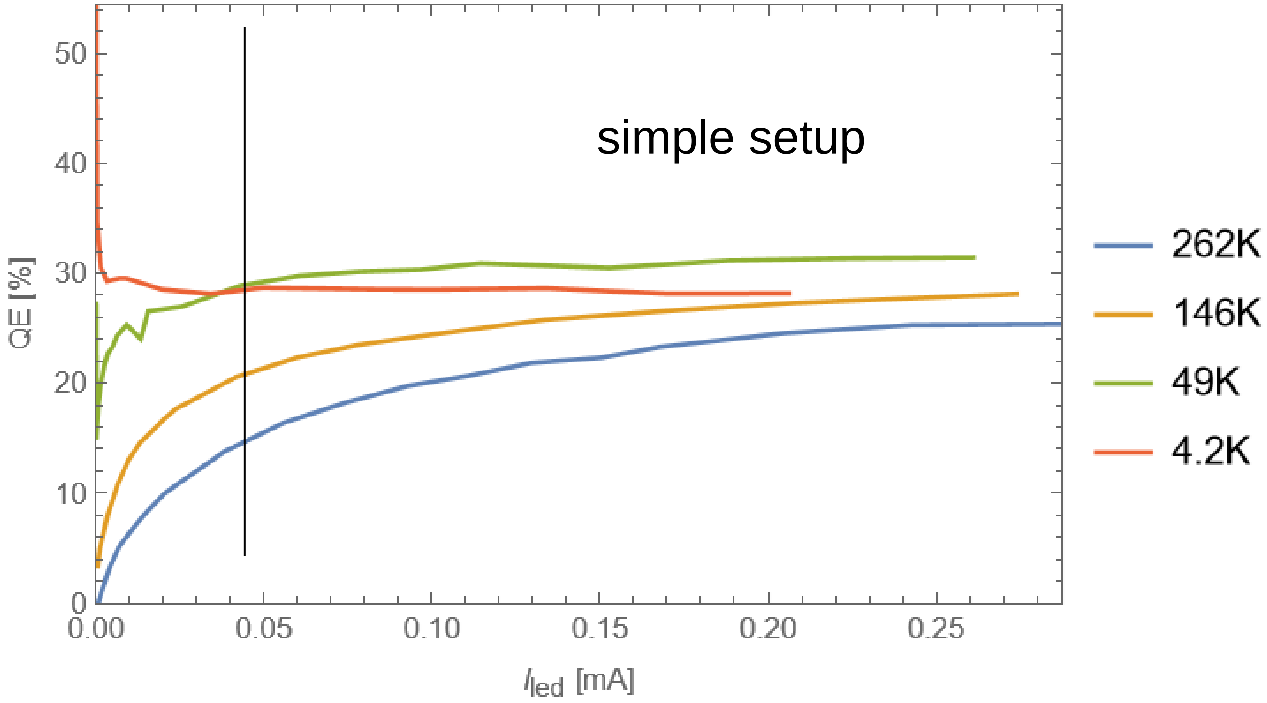
calculation

- generated electrons / incident photons
- max intensity at 470nm → $\mathrm{h\nu} \approx 2.7\mathrm{eV}$
- luminosity at 20mA = 35lm/sr → ?W/sr

datasheet vs measurement

- datasheet → 70%
- approaches constant value of 20-30%
- slight increase at lower temperatures

⇒ prove of order of magnitude



Approaching High Energies

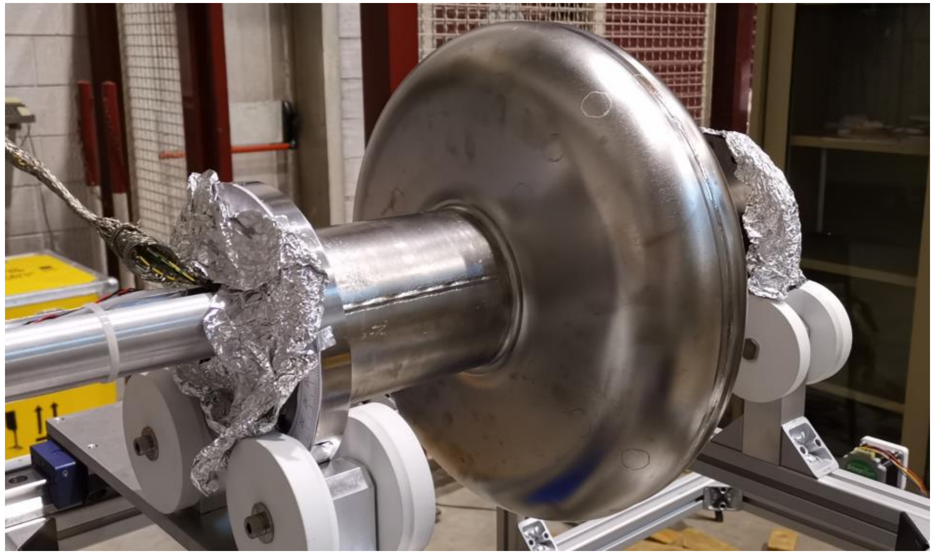
Performance test with XRAY source

setup

- diodes directly mounted on molybdenum-anode
- zirconium-filter (0.25mm) to avoid saturation
- cavity used to shield ambient light

measurement

- accelerating voltage up to 30kV → max energy of continuous spectrum
- current of hot cathode up to 4mA → intensity
- measurement of diode output



Performance at 30keV

keV

Efficiencies up to 5600!

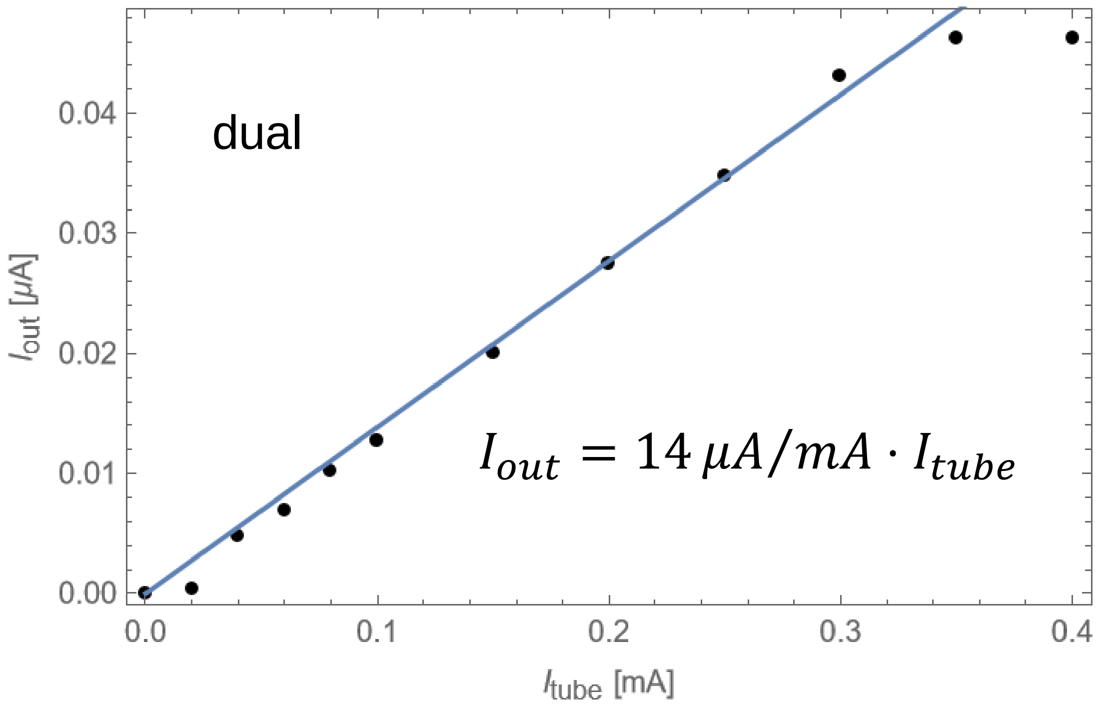
results

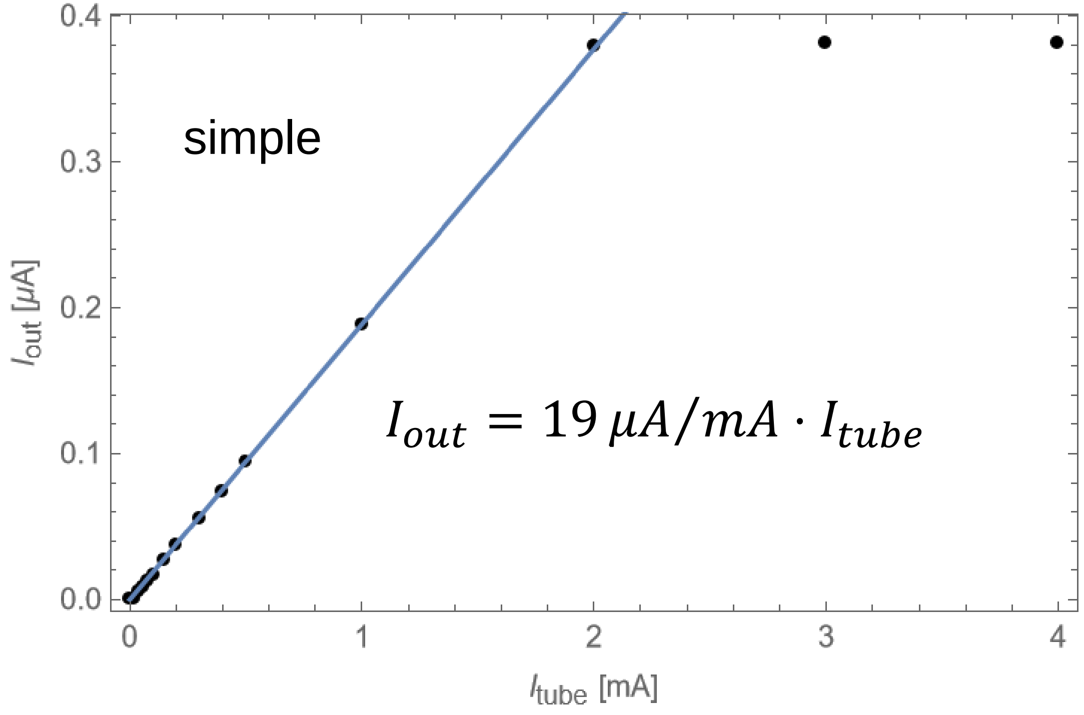
- output rises linearly up to saturation
- comparable results
- linear fit → I_{out}/I_{tube}

$$\boxed{QE = \frac{\dot{N}_e}{\dot{N}_\gamma} = \frac{I_{out}/e}{\dot{N}_{\gamma,1\mu A} \cdot I_{tube}}}$$

simulated using FLUKA: $2 \cdot 10^5$ photons per second per uA

⇒ external quantum efficiency of 4200 (dual) and 5600 (single) respectively





Performance in the keV range

Linearly rising quantum efficiency

keV

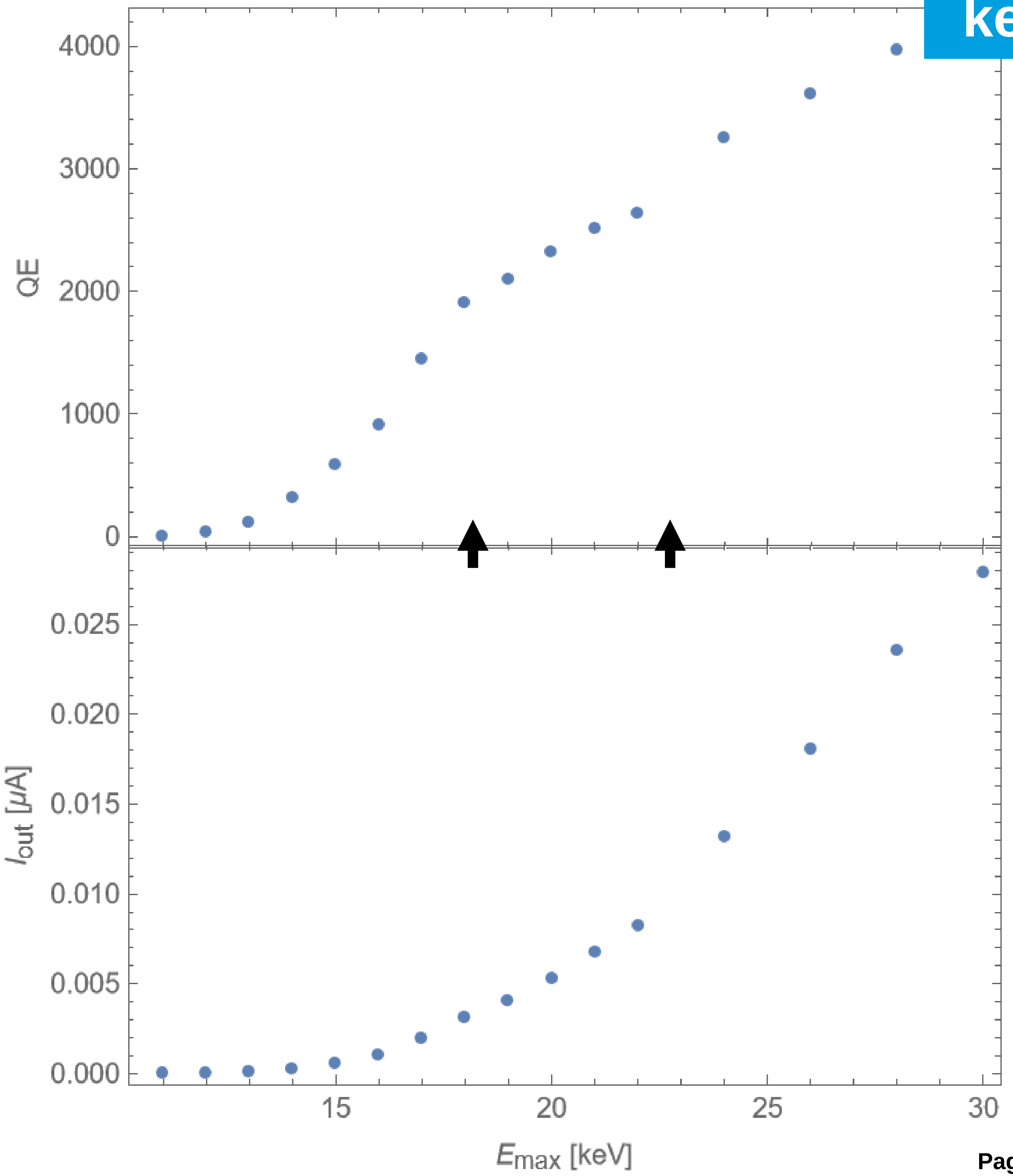
parameters

- dual supply configuration
- hot cathode current of 200uA
- tube voltages between 10kV and 30 kV

results

- photon flux based on FLUKA
- quadratic trend linear → rise of quantum efficiency
- several thousand electron-hole-pairs per absorbed photon

⇒ looks promising?



Kramer’s Law

Attenuation model for quantum efficiency

electron flux

$$\dot{N}_e = P_{abs}/3.6eV$$

$\longrightarrow$

power spectrum

$$P_{abs} = \int_0^\infty \frac{dP}{d\omega} \cdot [1 - exp(-\mu d)] d\omega$$

attenuation of silicon

photon flux $\dot{N}_\gamma = \int_0^\infty \frac{dP}{d\omega} \frac{1}{\hbar\omega} d\omega$

radiation power / energy per photon

$$dP = K\delta(\hbar\omega_0 - \hbar\omega)d\omega$$

simple case: monochromatic

$\longrightarrow$

$$QE = \frac{\hbar\omega_0}{3.6eV} \cdot [1 - exp(-\mu(\omega_0)d)]$$

Performance in the MeV range

MeV

Photodiodes inefficient

MeV radio sources

- so far: rising efficiency up to 5600
- but: cobalt60 (1.1MeV) → no signal at 1uCi (37kBq)

generated electron-hole-pairs per absorbed photon

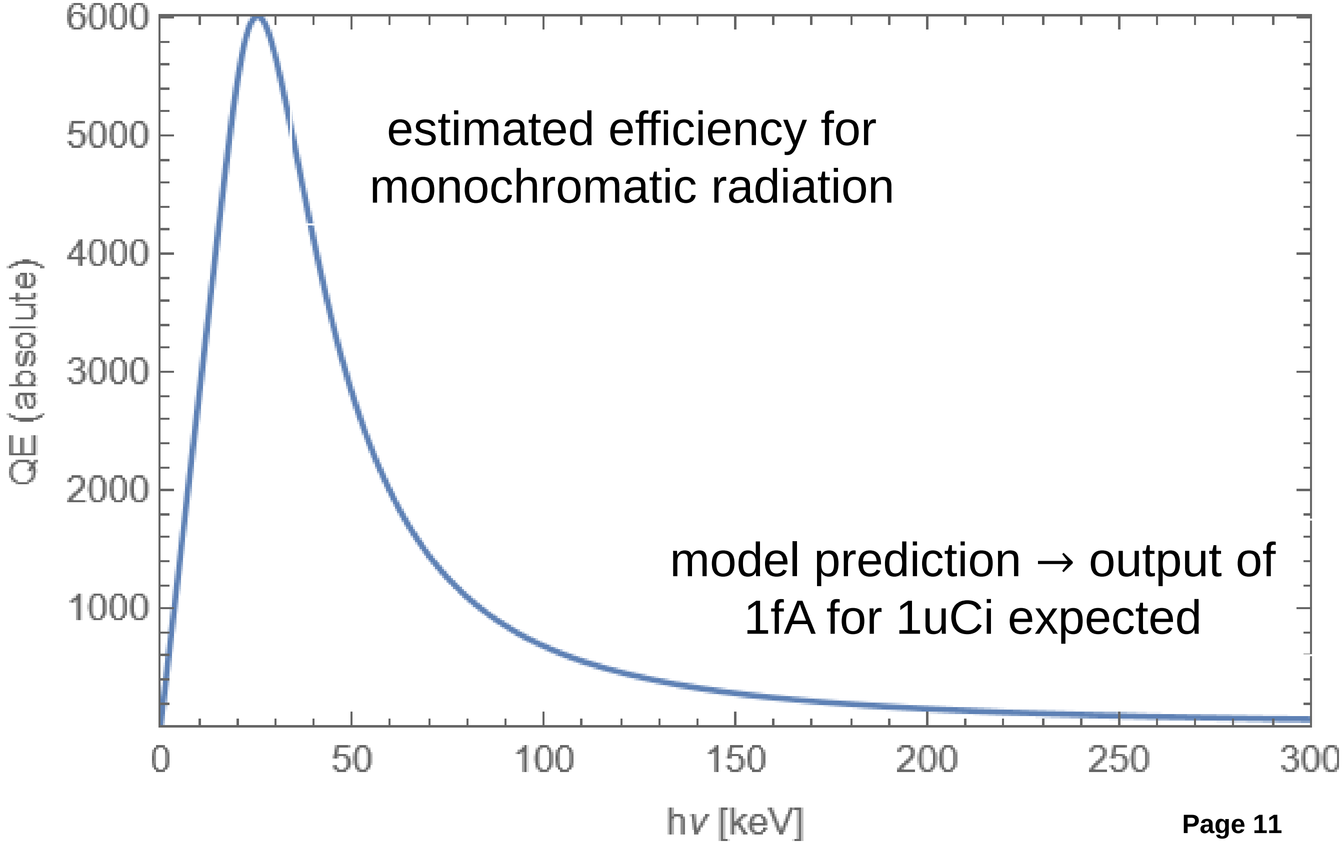
$$QE(h\nu) = \hbar\omega/3.6eV \cdot (1 - e^{-\mu(\omega)\cdot d})$$

absorption rate based on photoelectric attenuation

estimated efficiency

- estimation based on photoelectric attenuation → sharp drop after 30keV
- photodiode more and more transparent
- in addition: high energy electrons likely escape

⇒ greatly reduced efficiency

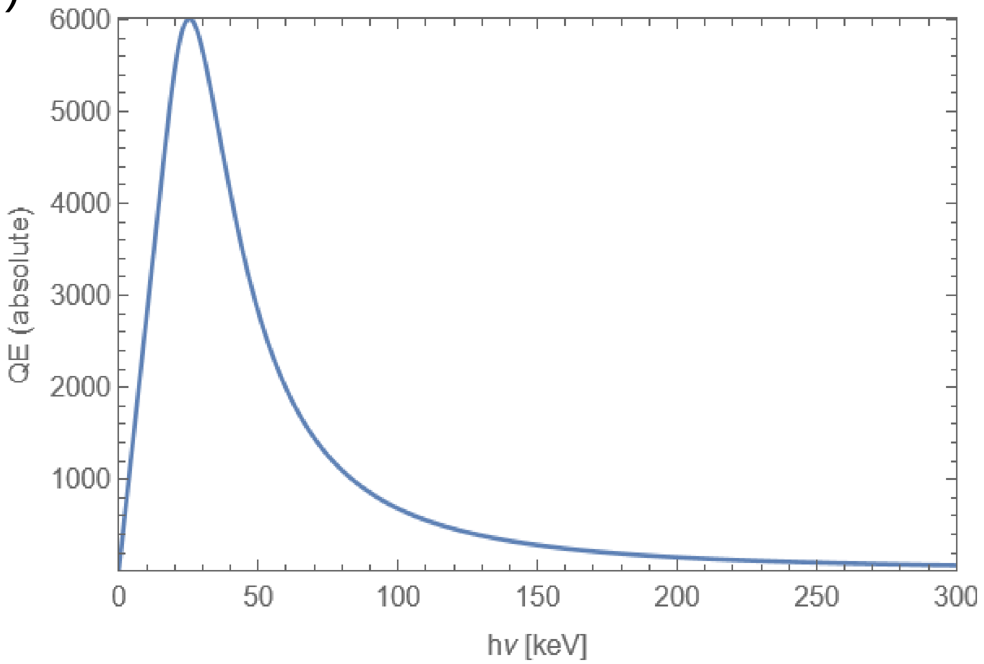


Drawing Conclusions

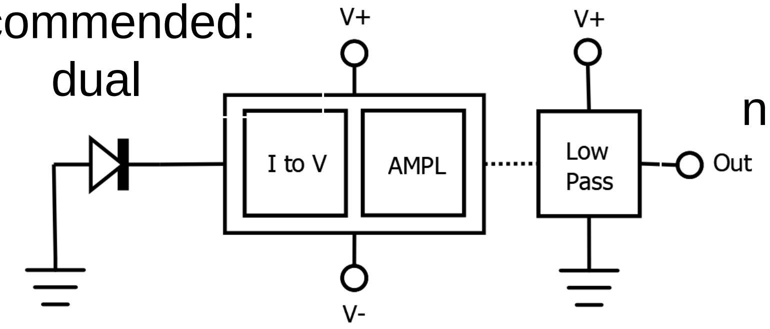
Suited for low energy part of field emission radiation

$$QE = \frac{\dot{N}_e}{\dot{N}_\gamma} \sim \frac{I_{out}}{I_{led}}$$

1. response to visible light → QE ~ 30% (right order of magnitude)
2. operation at cold → almost no change in quantum efficiency
3. response to XRAY radiation → rising QE up to 5000 at 30keV
4. response to weak radio sources → no signal
5. QE prediction → sharp drop of efficiency above 30keV



recommended:
dual

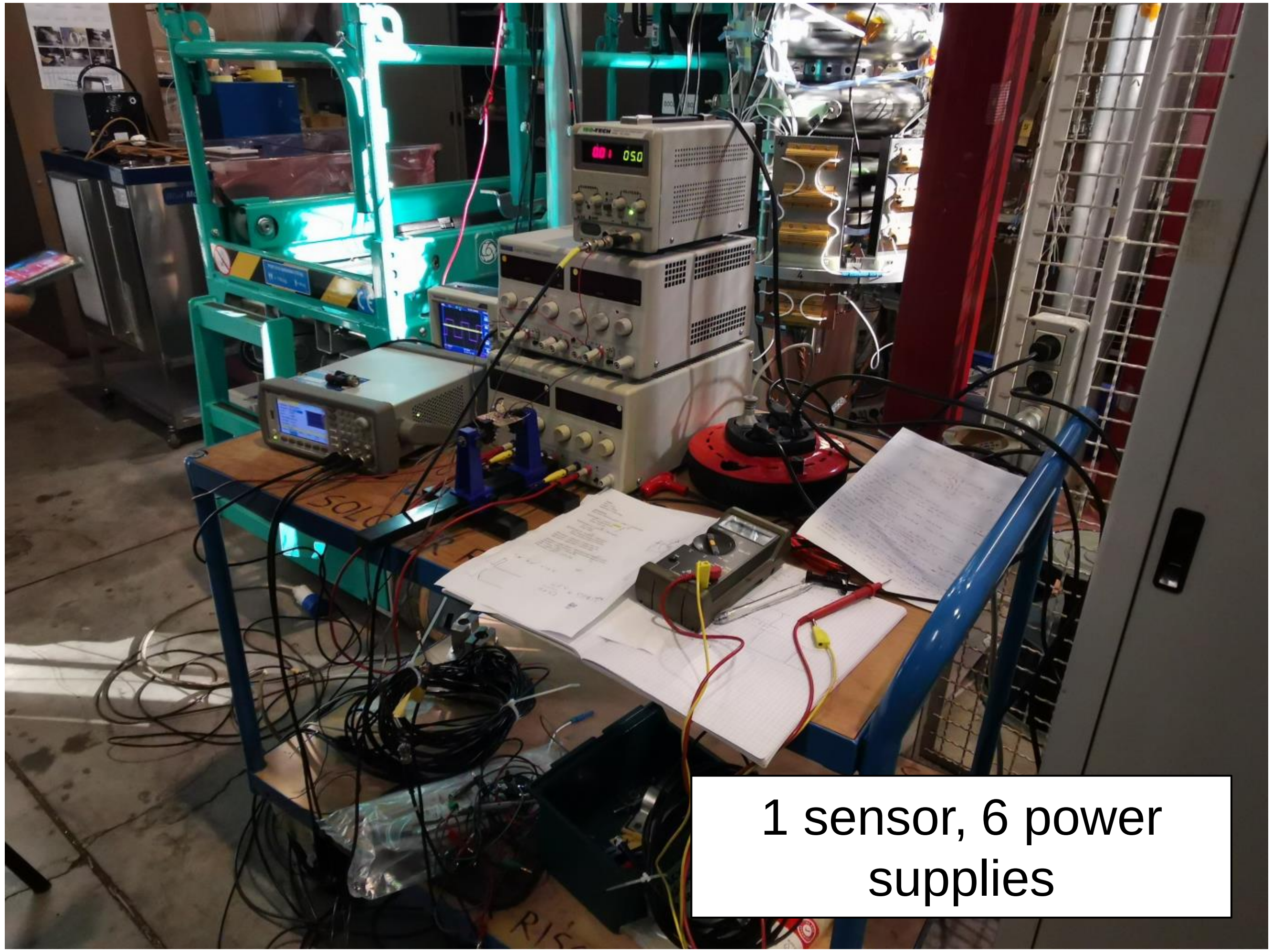


noise filtering + amplification

⇒ photodiodes: powerful (and cheap) detectors for field emission radiation at keV range

Other Activities

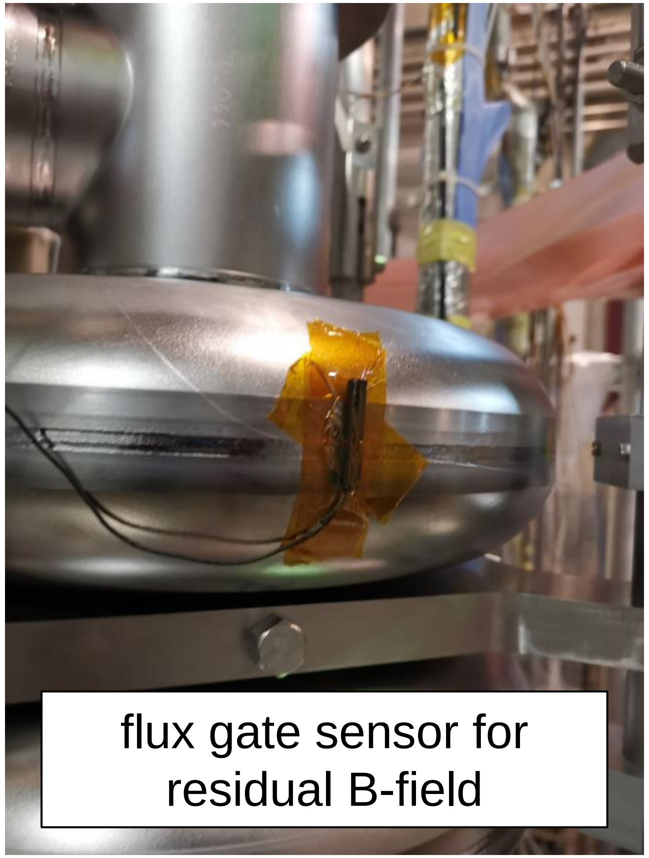
Testing magneto-resistive sensors

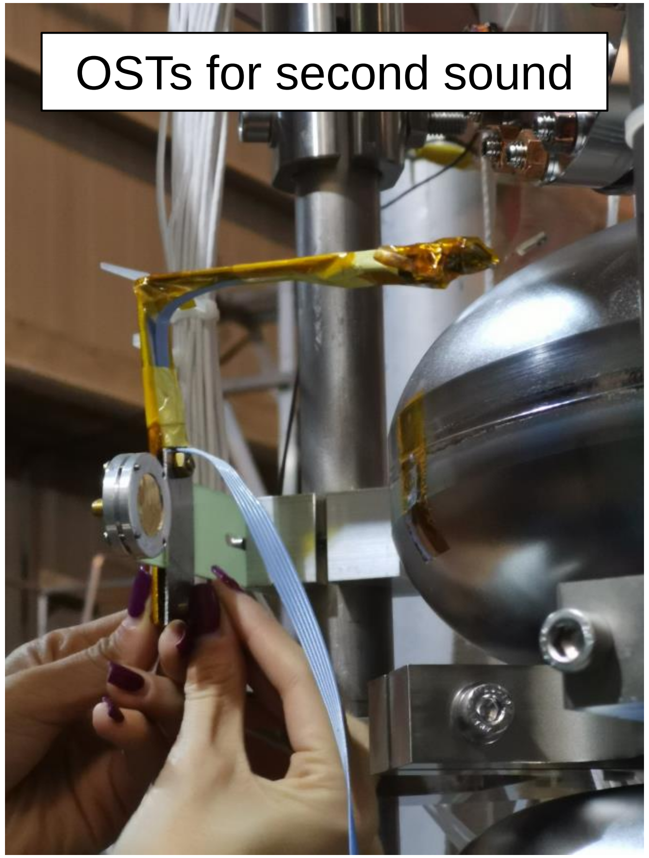


- powering the sensor
- weak residual field → dual supply amplifier
- sensor response → test coil
- unknown magnetization (offset) → flip coil
- noise in flip circuit → transistor setup

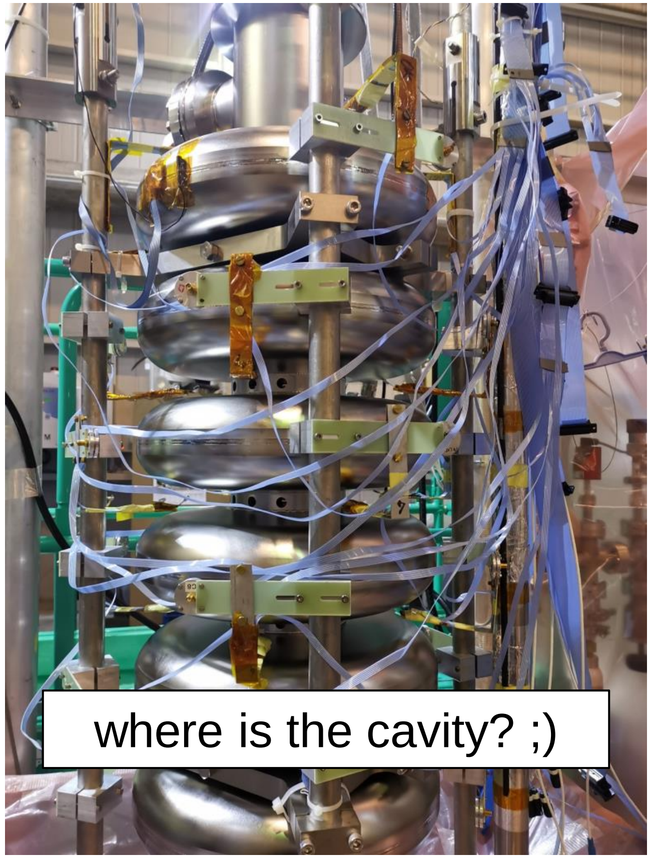
Other Activities

Preparing vertical tests



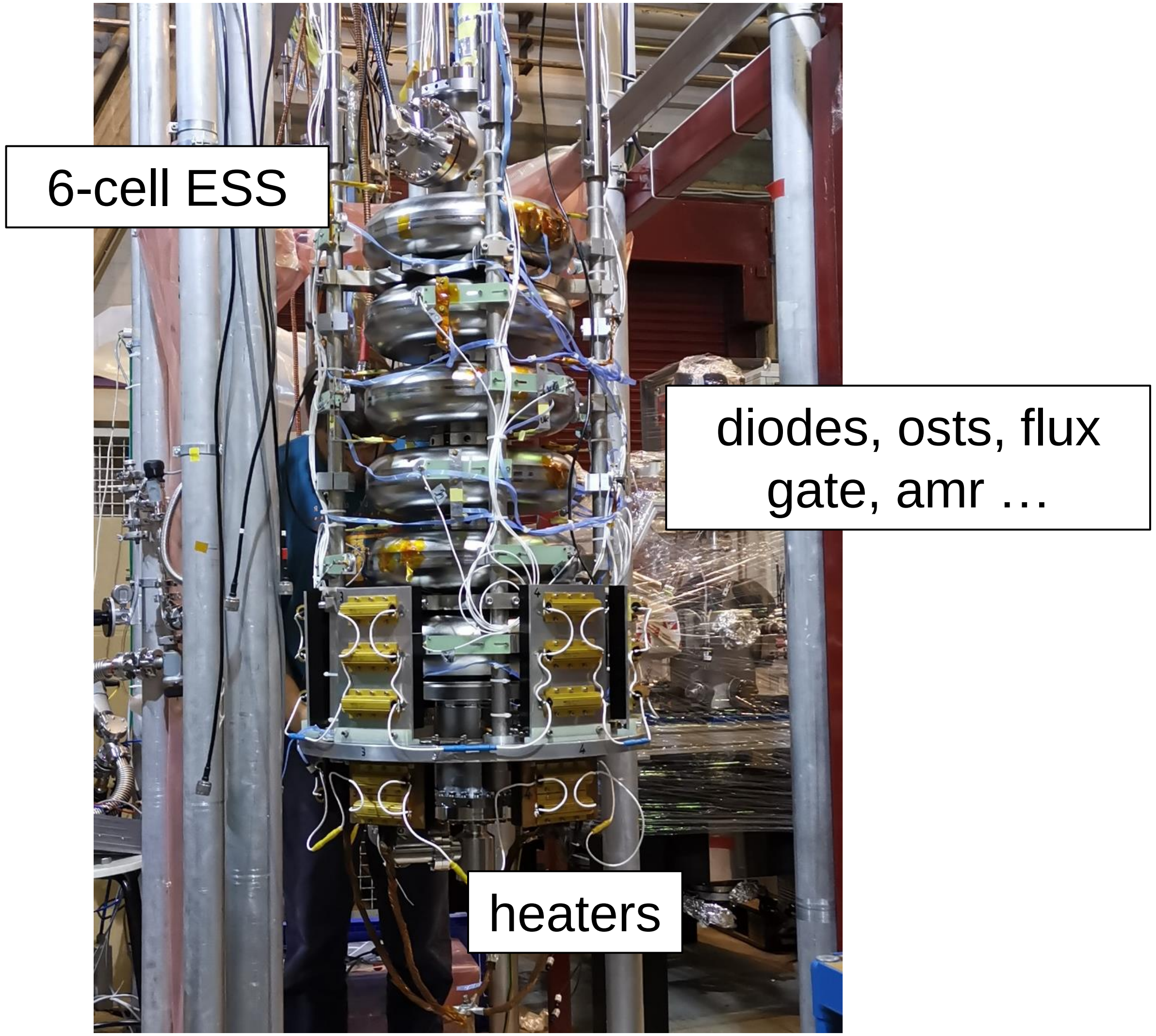


⇒



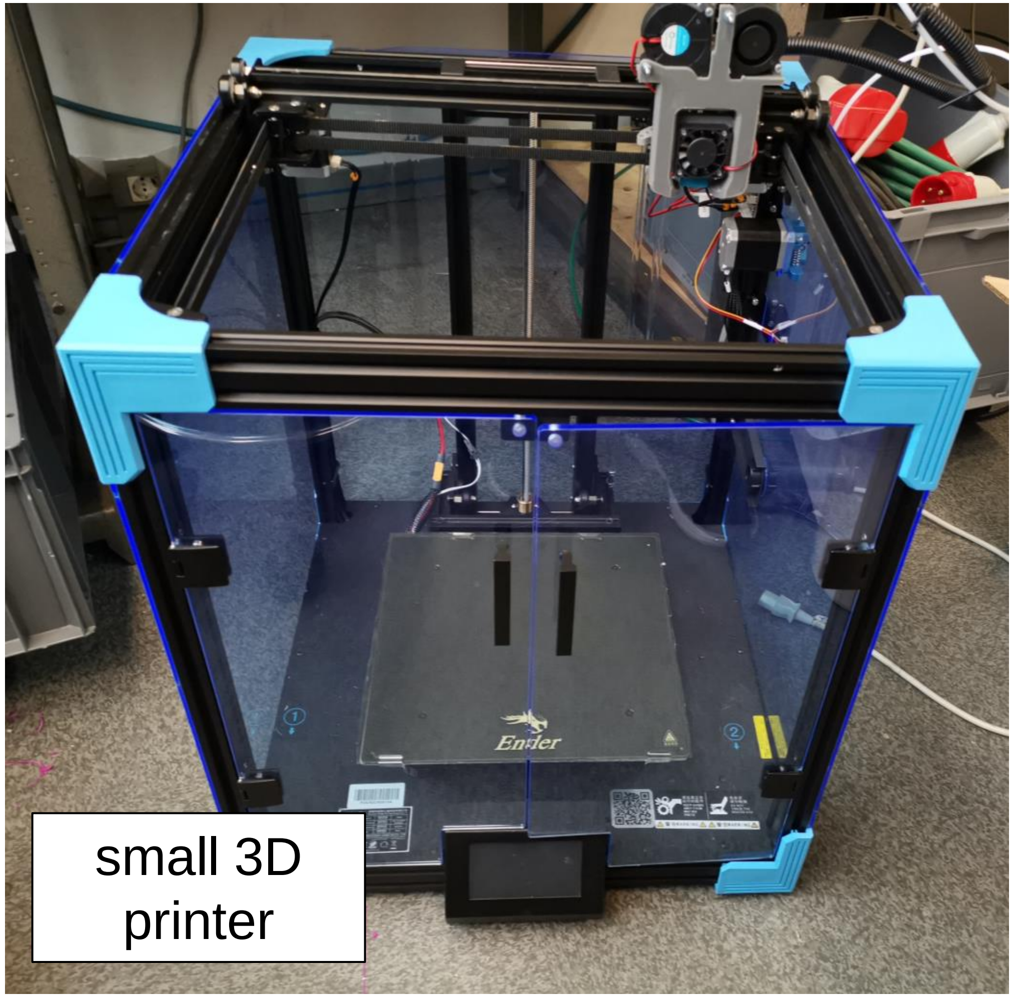
Other Activities

Preparing vertical tests



Other Activities

Printing flange caps with 3D printers



X-Ray Fluorescence

Opportunity for cooperation

setup

- x-ray tube with molybdenum-anode + sensor
- max setting: 4mA, 30keV
- cavity rotatably mounted

measurement

- cavity material locally excited by x-ray tube
- secondary emission → lines of niobium (or iron)
- cavity rotated or shifted

Thermal Imaging

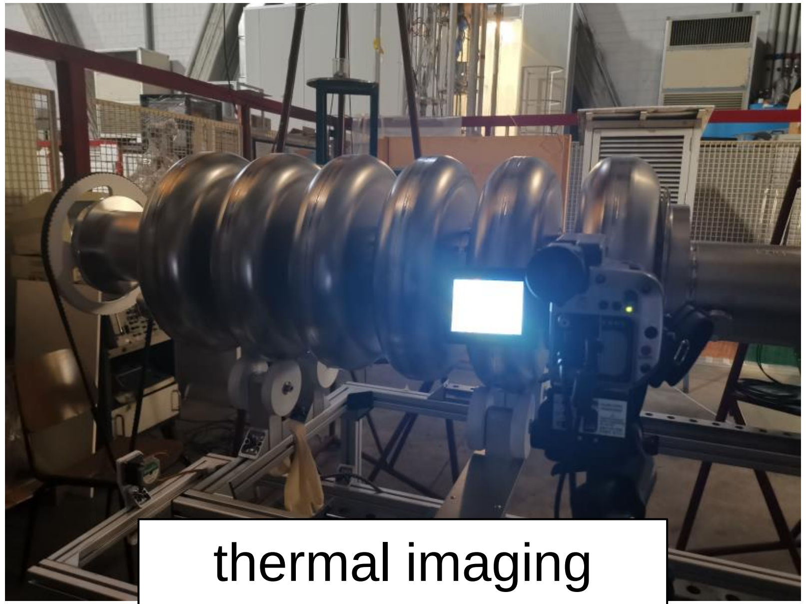
We could do it, too

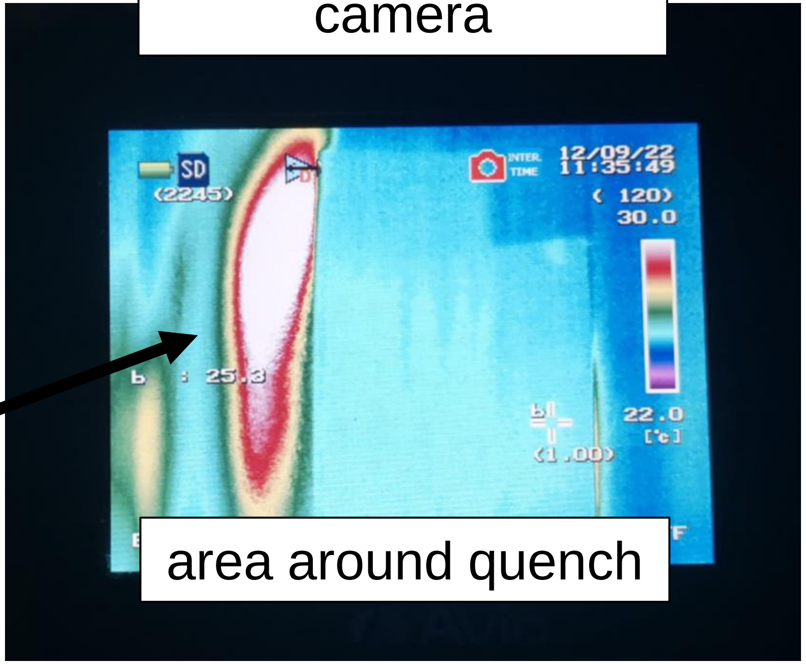
setup

- quench already localized
- cavity locally heated with spotlight

measurement

- heat dissipation observed with thermal camera
- allows conclusions about extraneous materials





slower heat dissipation than surrounding niobium

Thank you

and kind regards from LASA ☺

Contact

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