The KATRIN Forward Beam Monitor Detector

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Overview

- Motivation
- Mounting position and mechanical integration
- Detector technology
- Test setup & first results
- Summary & Outlook

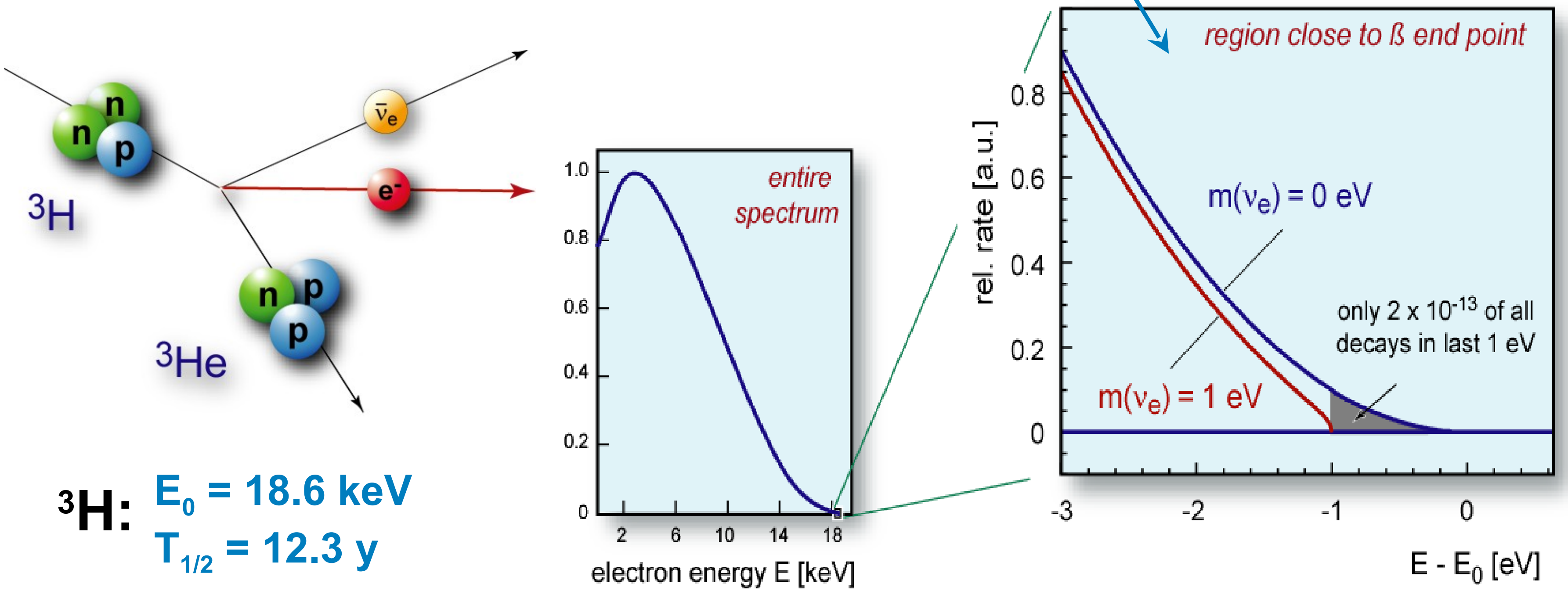
Introduction: KATRIN objective

Model independent neutrino mass from tritium β-decay kinematics

Sensitivity on m_ν: 0.2 eV

Only assumption: relativistic energy-momentum relation

$$\frac{d\Gamma_i}{dE} = C\, p\,(E+m_e)\,(E_0-E)\,\sqrt{(E_0-E)^2 - m_i^2}\,F(E)\,\theta(E_0-E-m_i)$$

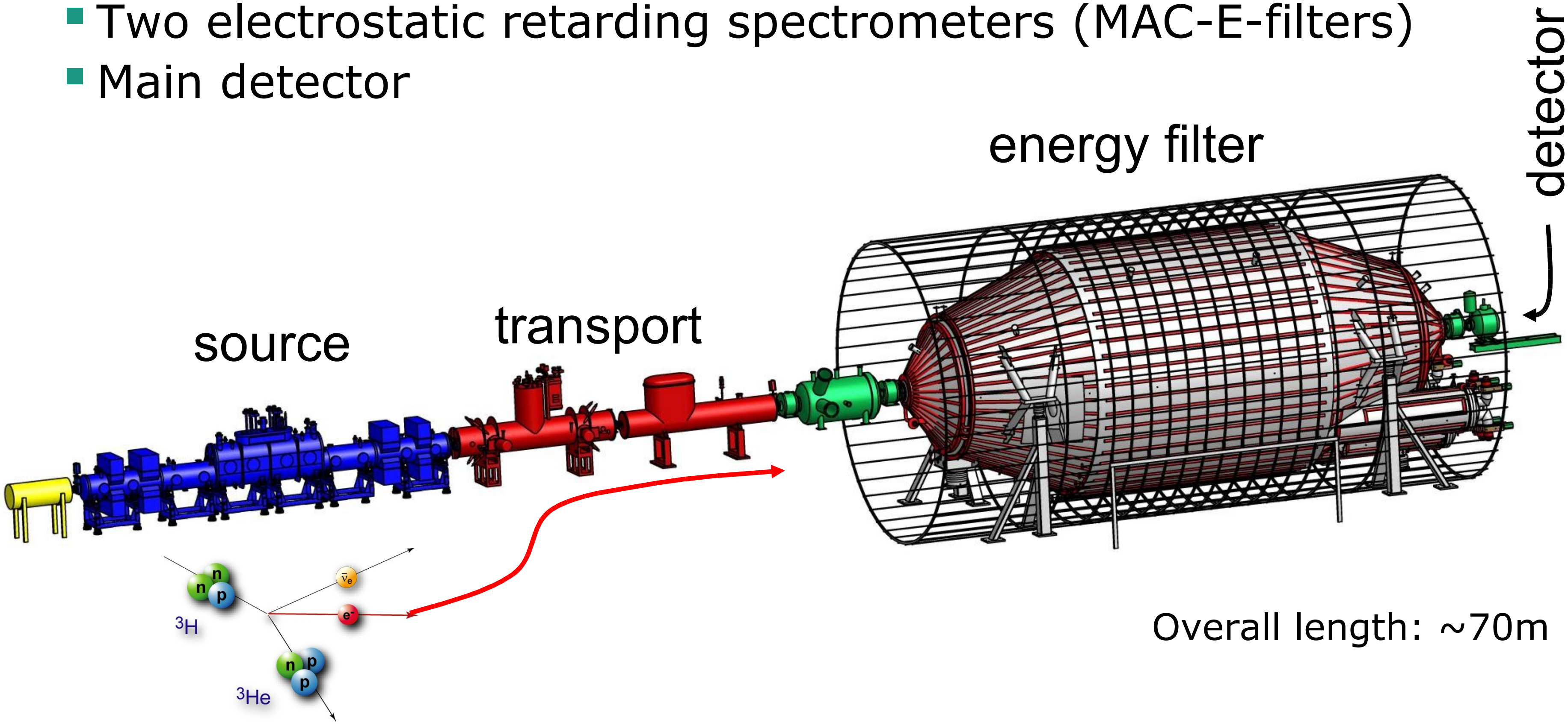


^{3}H: E_0 = 18.6 keV
$T_{1/2}$ = 12.3 y

Introduction: KATRIN experimental setup

Main components:

- High-luminosity gaseous tritium source (1.7×10^{11} Bq)
- Two electrostatic retarding spectrometers (MAC-E-filters)
- Main detector



Overall length: ~70m

Motivation: Source design & properties

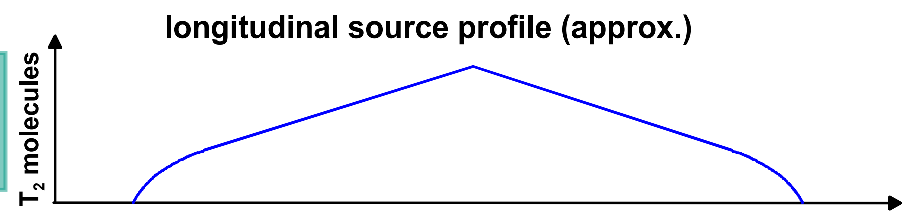
Source strength $N(T_2) = A_S * \rho d * \varepsilon_T$

A_S = source area
ρd = column density
ε_T = tritium purity

Optimized source design parameters:

- $\rho d = 5*10^{17}$ cm^{-2} (= 86% of maximum count rate of non-scattered electrons)
- A_S = 53 cm^2, B = 3.6 T
- ε_T = 95%

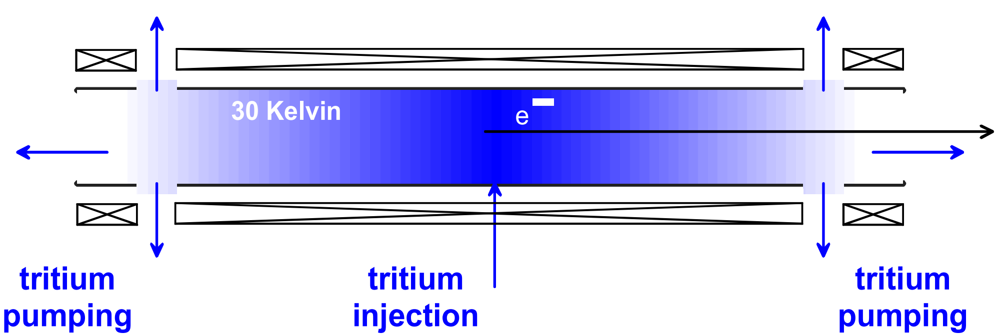
➔ required tritium gas injection:
1.8 mbar l/s = 160 l/day



Source stability requirements:

ρd needs to be stable ➔

- $\Delta\varepsilon_T/\varepsilon_T < 0.002$
- $\Delta T/T < 0.002$
- $\Delta p_{inj}/p_{inj}$, $\Delta p_{ex}/p_{ex} < 0.002$



Source parameters and their monitoring

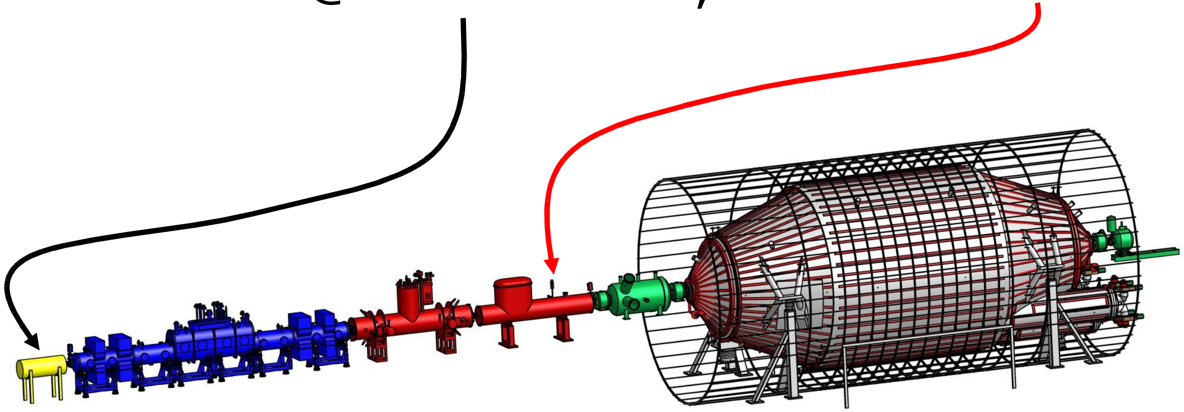
- Source stability @ 0.1% level is very challenging
- Critical parameter: column density ρd, mainly defined by
  - Source temperature (27-30 K) +/- 30 mK
  - Tritium inlet rate
  - Tritium purity (isotopic mixture)

inelastic scattering
→ modified spectrum

Monitoring concepts:

- Tritium purity: Laser Raman spectroscopy
- Column density: rear E-gun
- Tritium activity: reduced spectrometer voltage, monitor detector @ rear section, monitor detector @ CPS

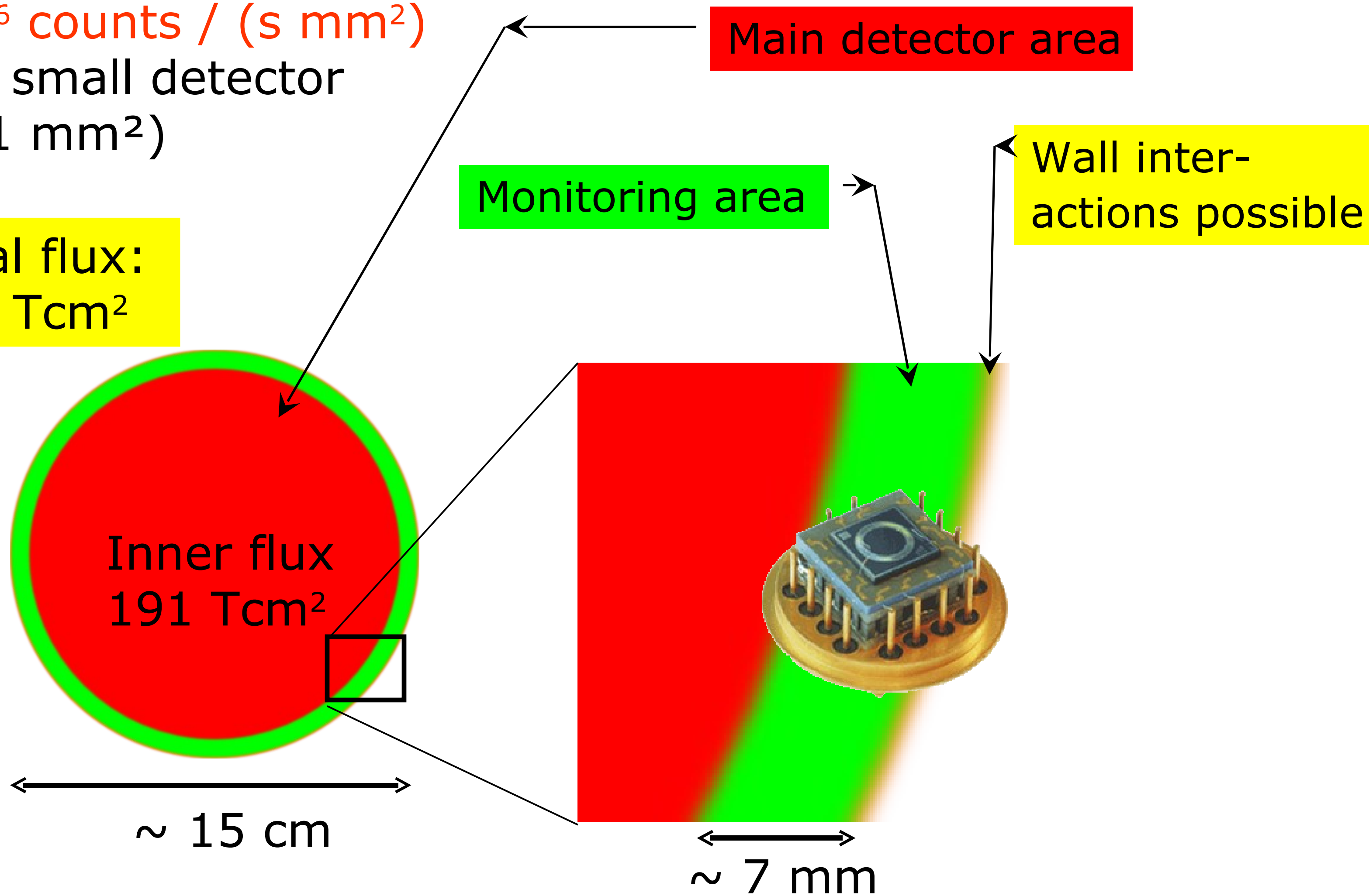
not real-time



Beam dimensions @ mounting place

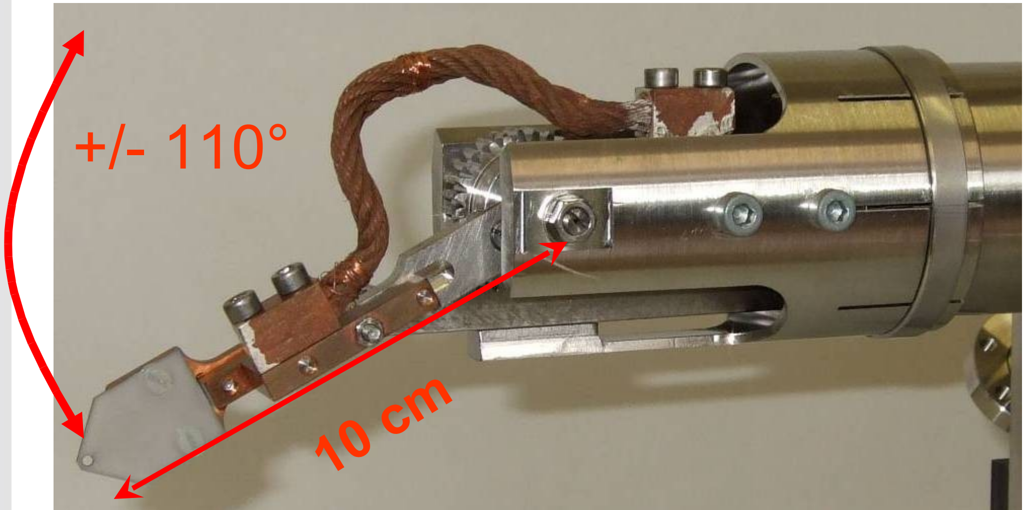
Expected count rate:
$1.3*10^6$ counts / (s mm^2)
→ very small detector
(< 1 mm^2)

Total flux:
229 Tcm^2



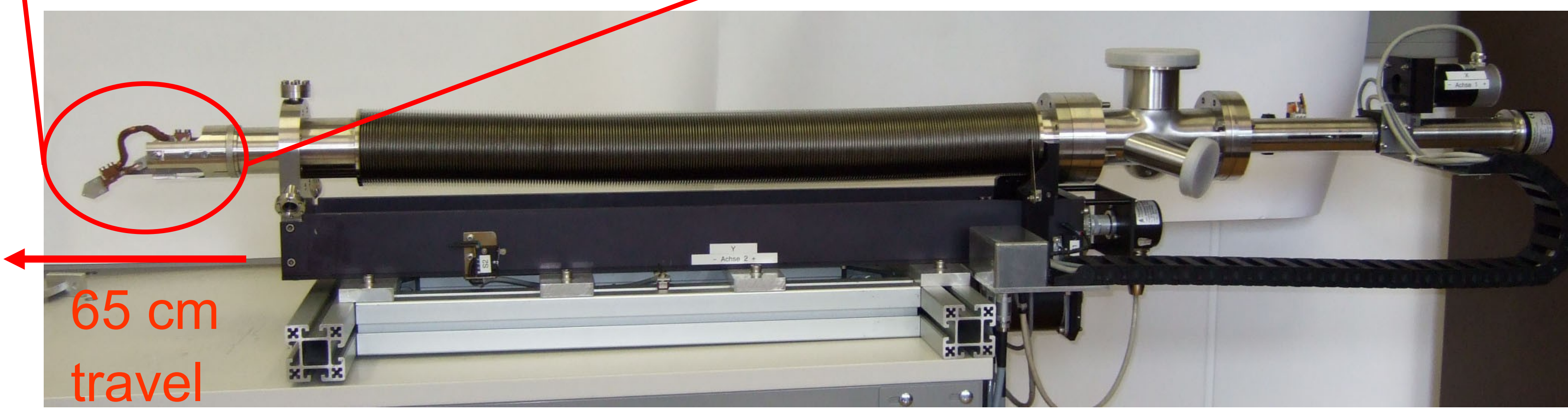
B_{av} ~ 1.1 T

Mechanical integration



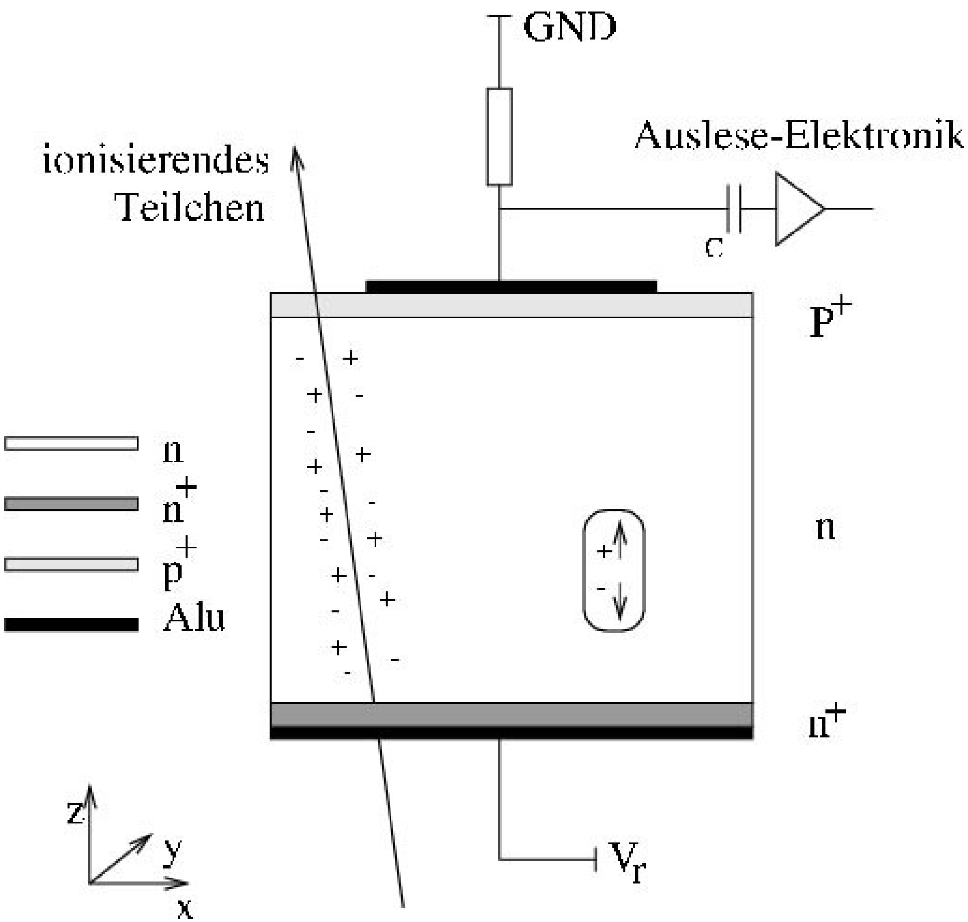
2-D manipulator:

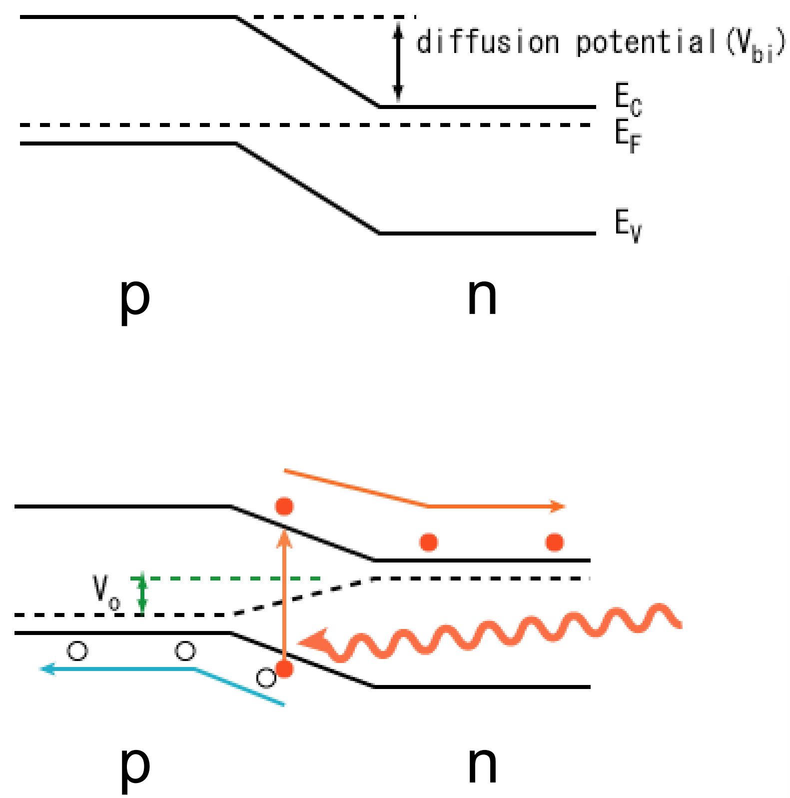
- Two linear motions combined via gear mechanism
- Motorized positioning
- Flexible cooling braid
- Platform for detector element & preamp
- Rotary encoders measuring position



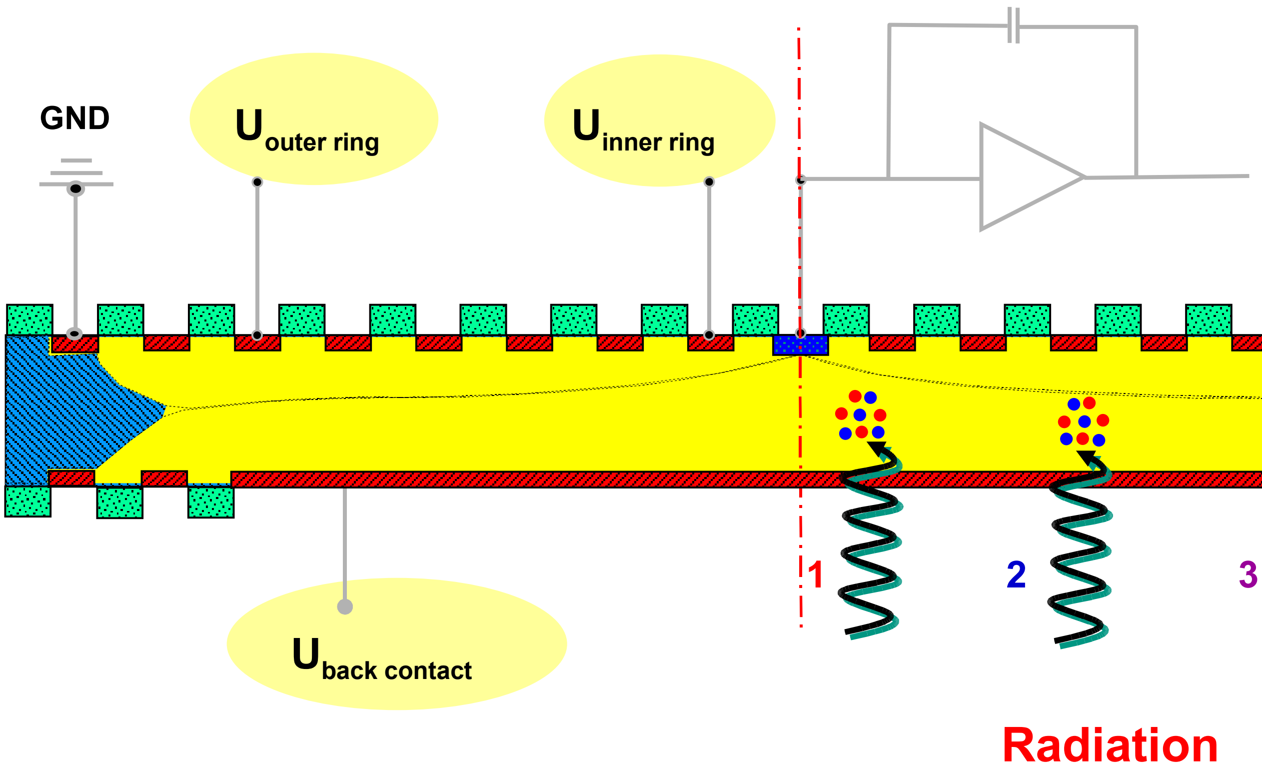
Detector technology

Reverse biased p-n junction (diode)



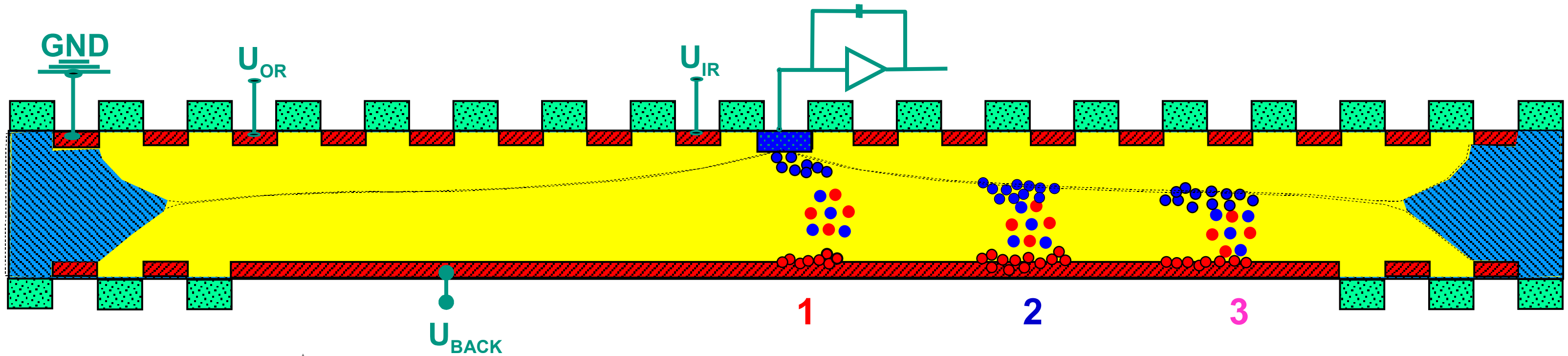


Silicon drift detector (SDD)



Animation: KETEK

Silicon drift detector (SDD)

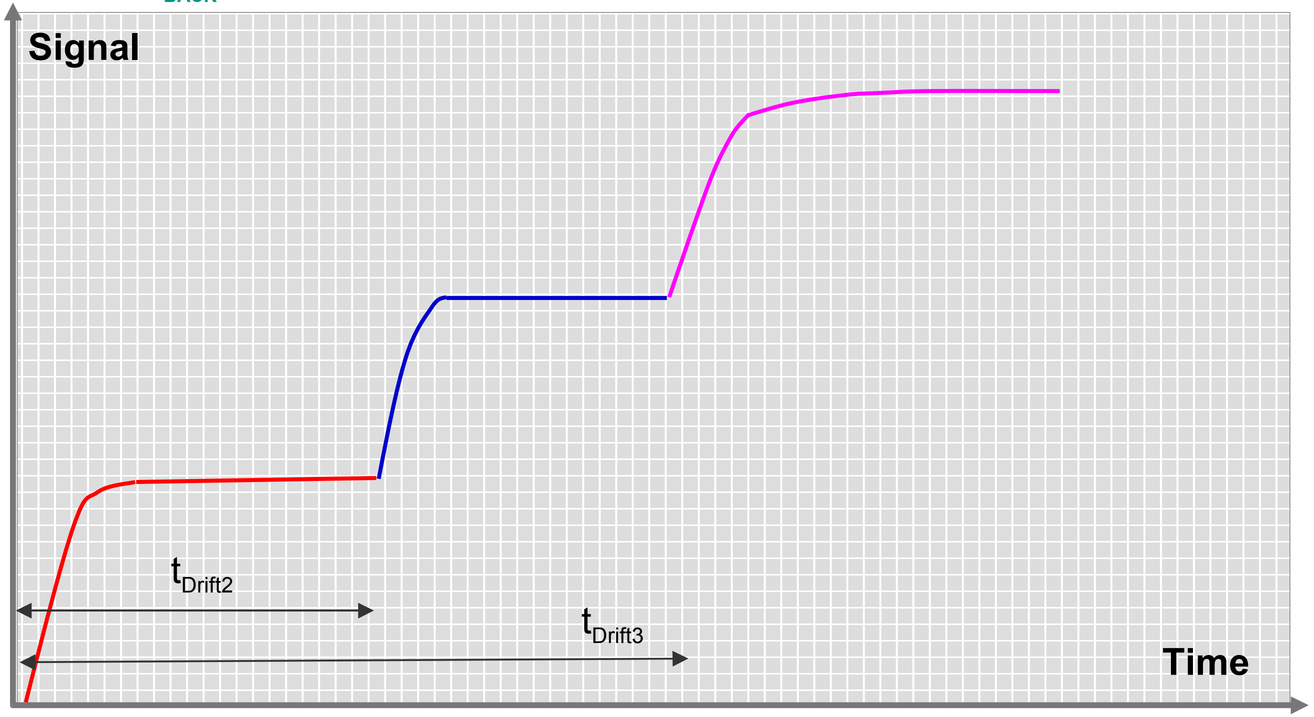


Charge Collection:

Event 1 signal 1

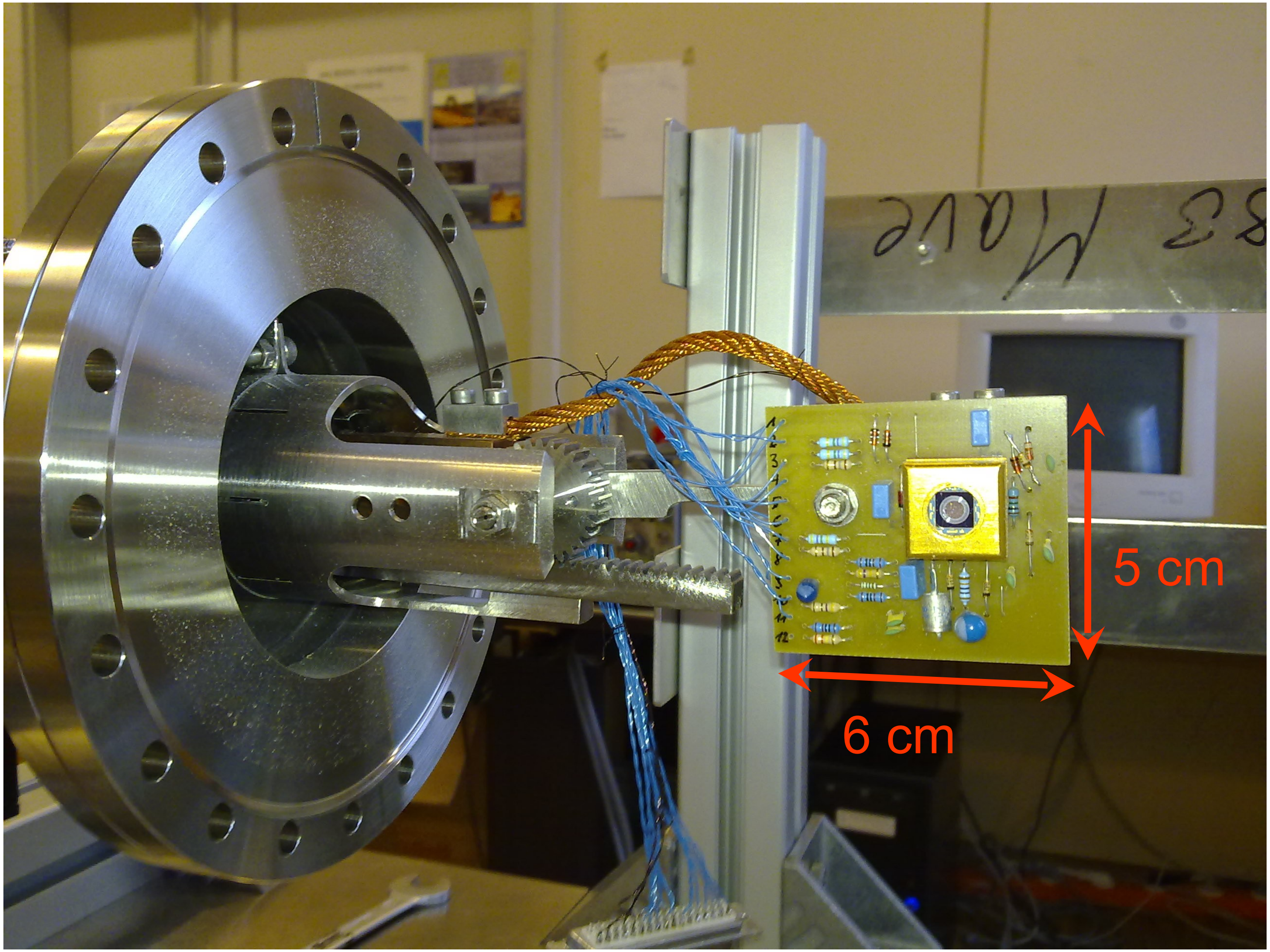
Event 2 signal 2

Event 3 signal 3

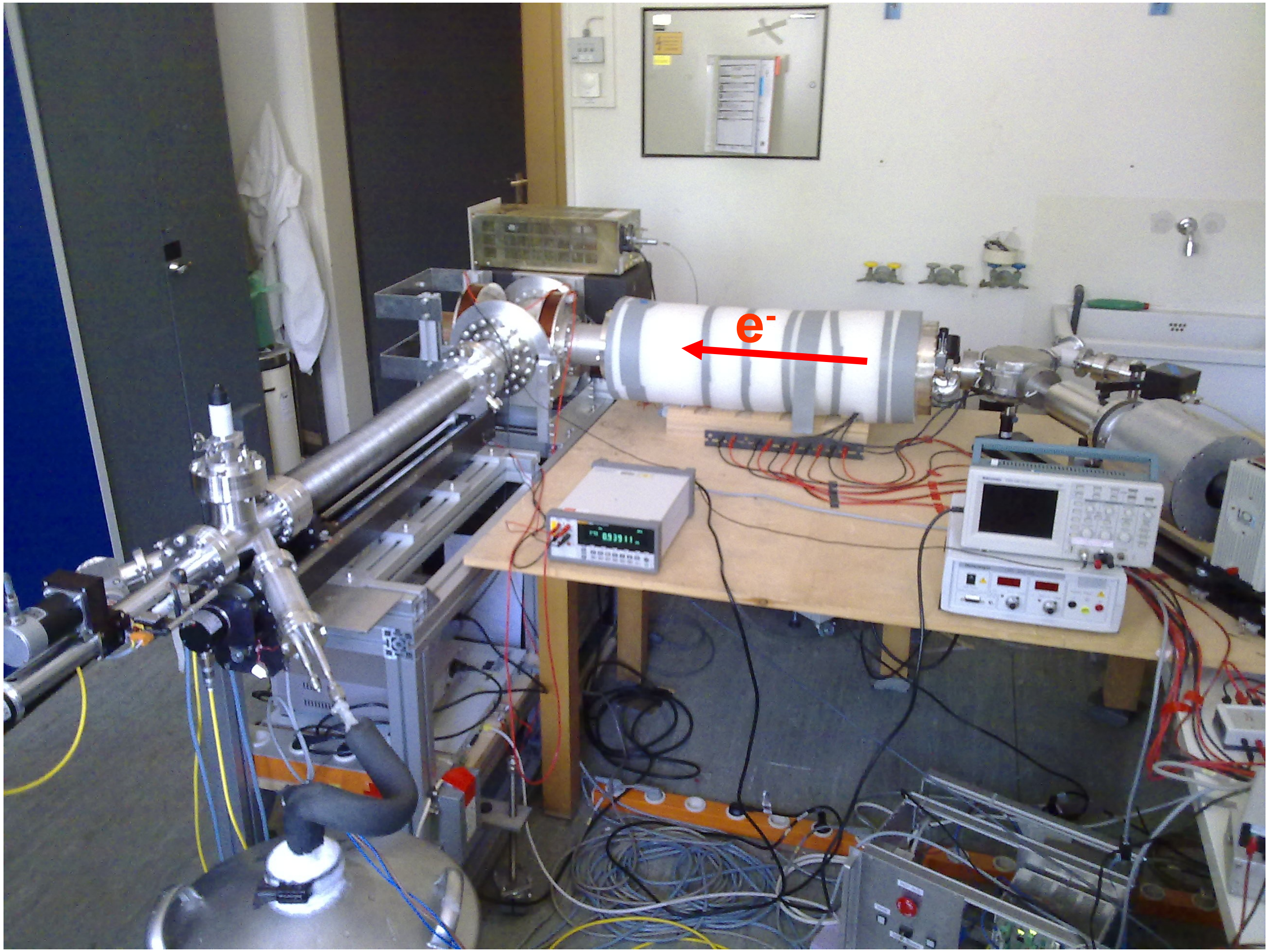


Animation: KETEK

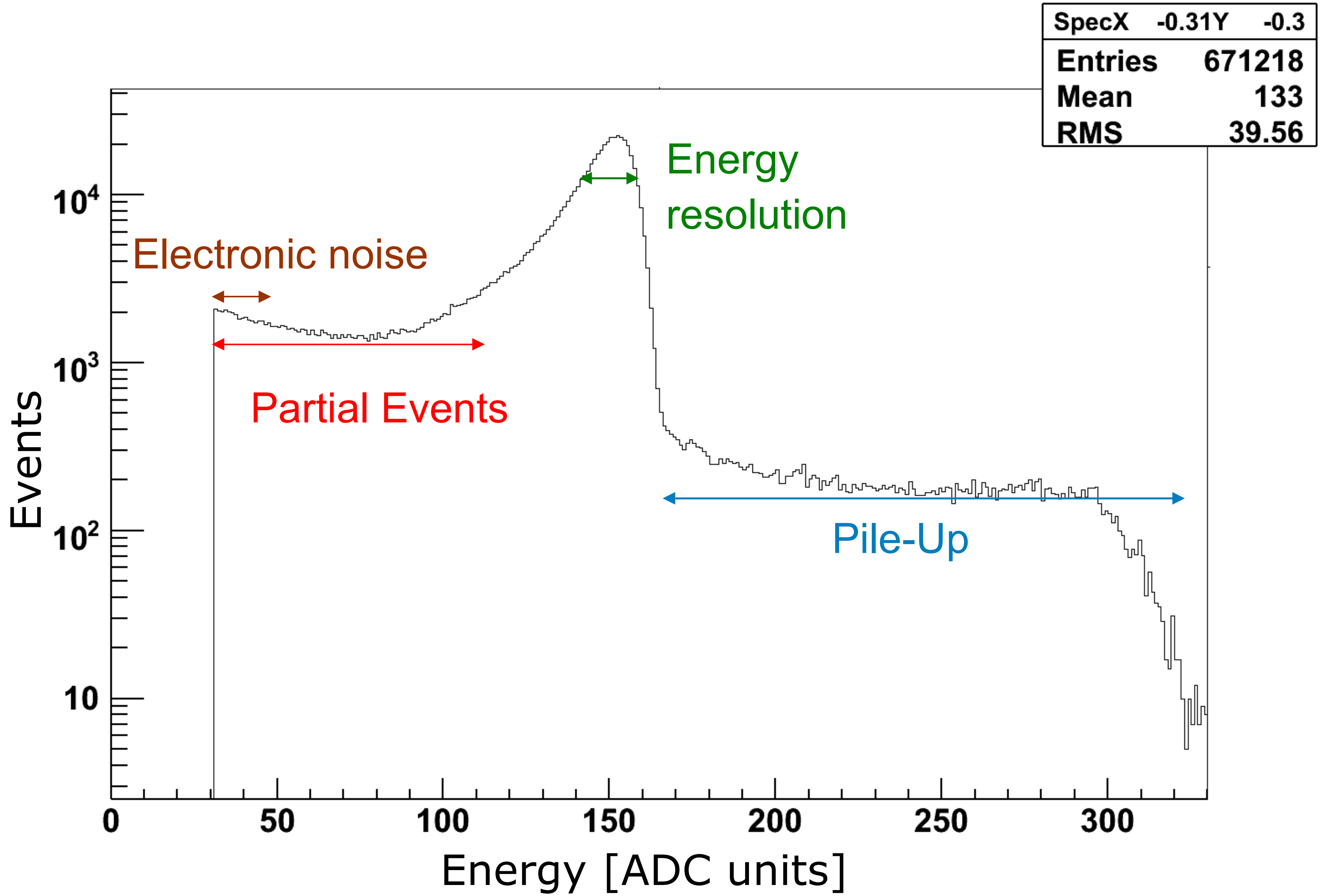
SDD Detector prototype



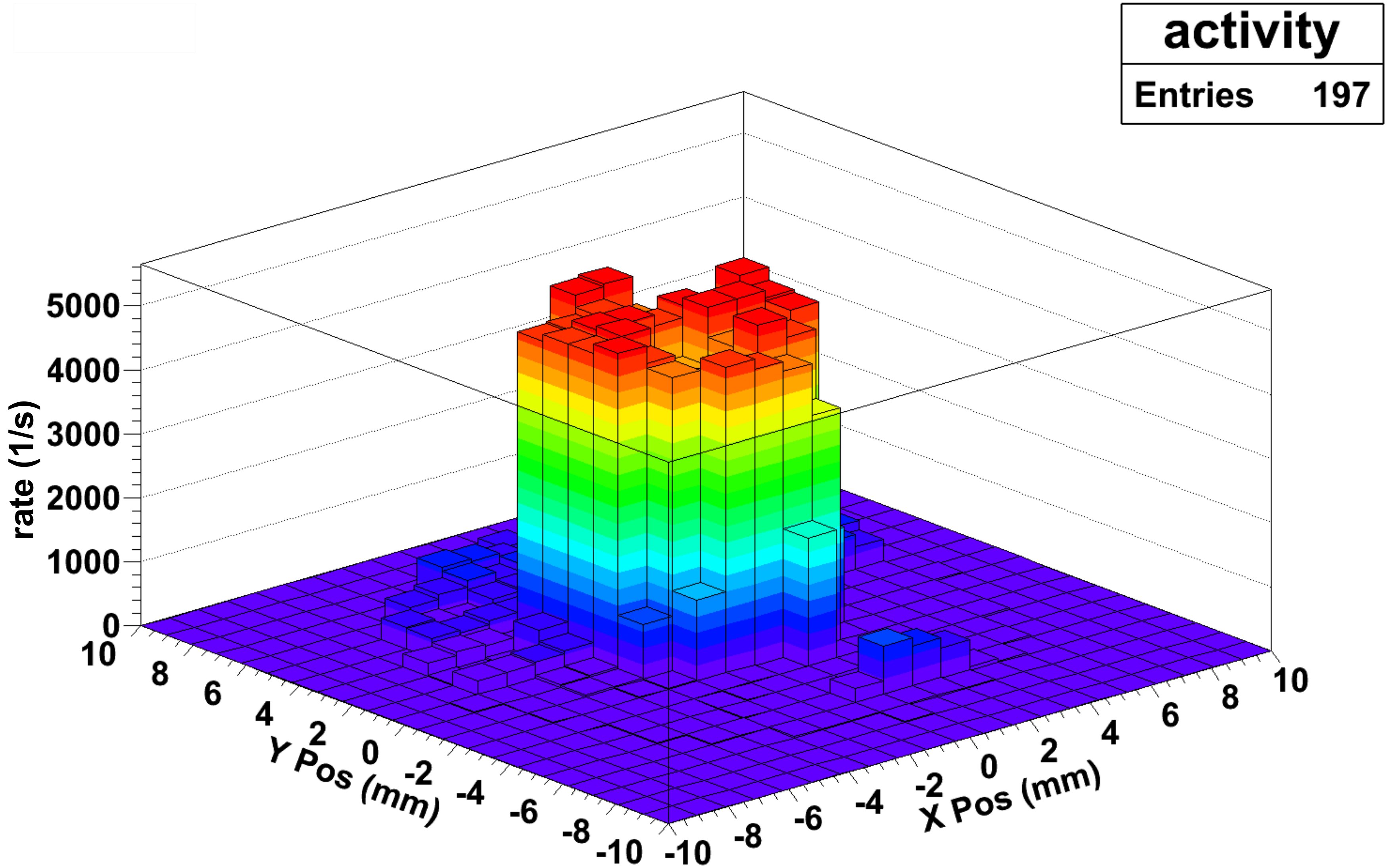
Electron-gun testing environment



Example spectrum: 7 keV Electrons on SDD

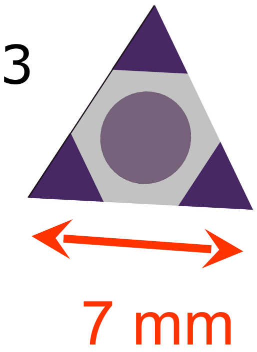


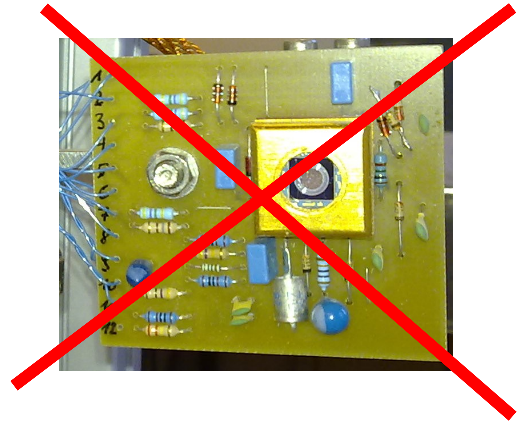
E-Gun results – 2D beam scan



Next steps: PIN diode

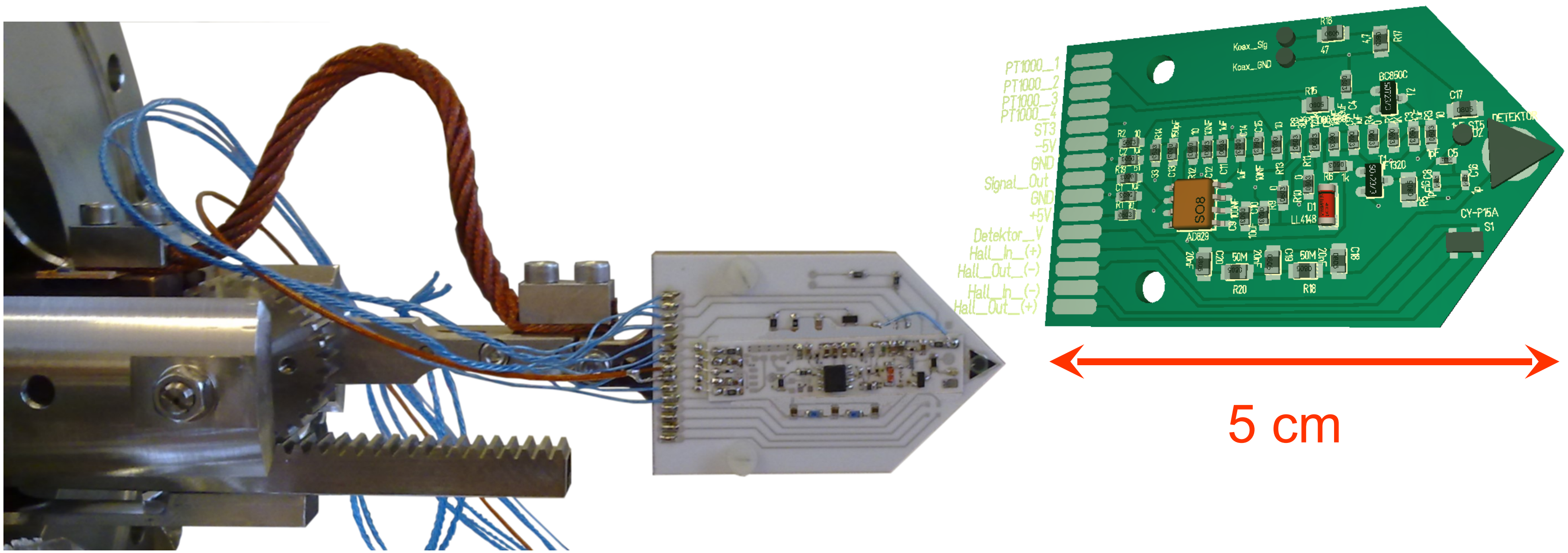
Test structure:
Micron Semiconductor MSD0013





Properties:

- 140 µm thickness
- 3 mm² active area, ~3.5 pF
- 100 nm dead layer



Summary & Outlook

Summary:

- Detector design concept approved
- Full beam cross section can be probed
- Detector prototypes tested, proved to measure electrons with energies down to 2 keV and rates of ~40000 events/s

Outlook:

- Selection SDD / PIN diode
- Preamplifier optimization
- Approval of ultrahigh vacuum compatibility
- Tests at count rates ~100 kHz
- DAQ upgrade

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