GaAs strip detector for high energy X-ray imaging

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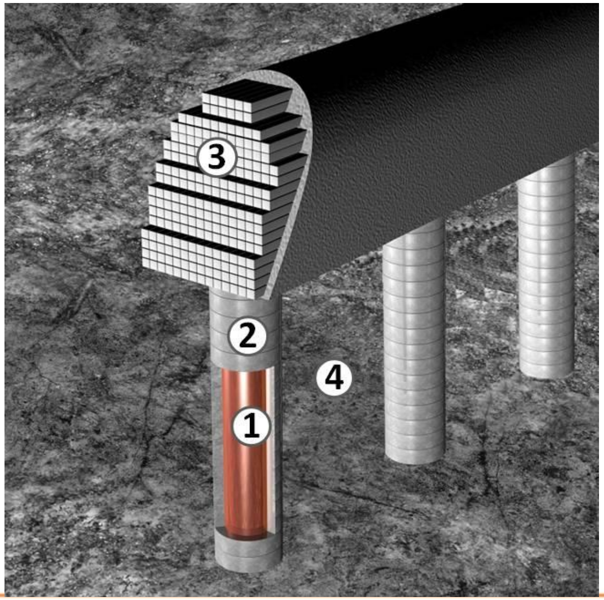
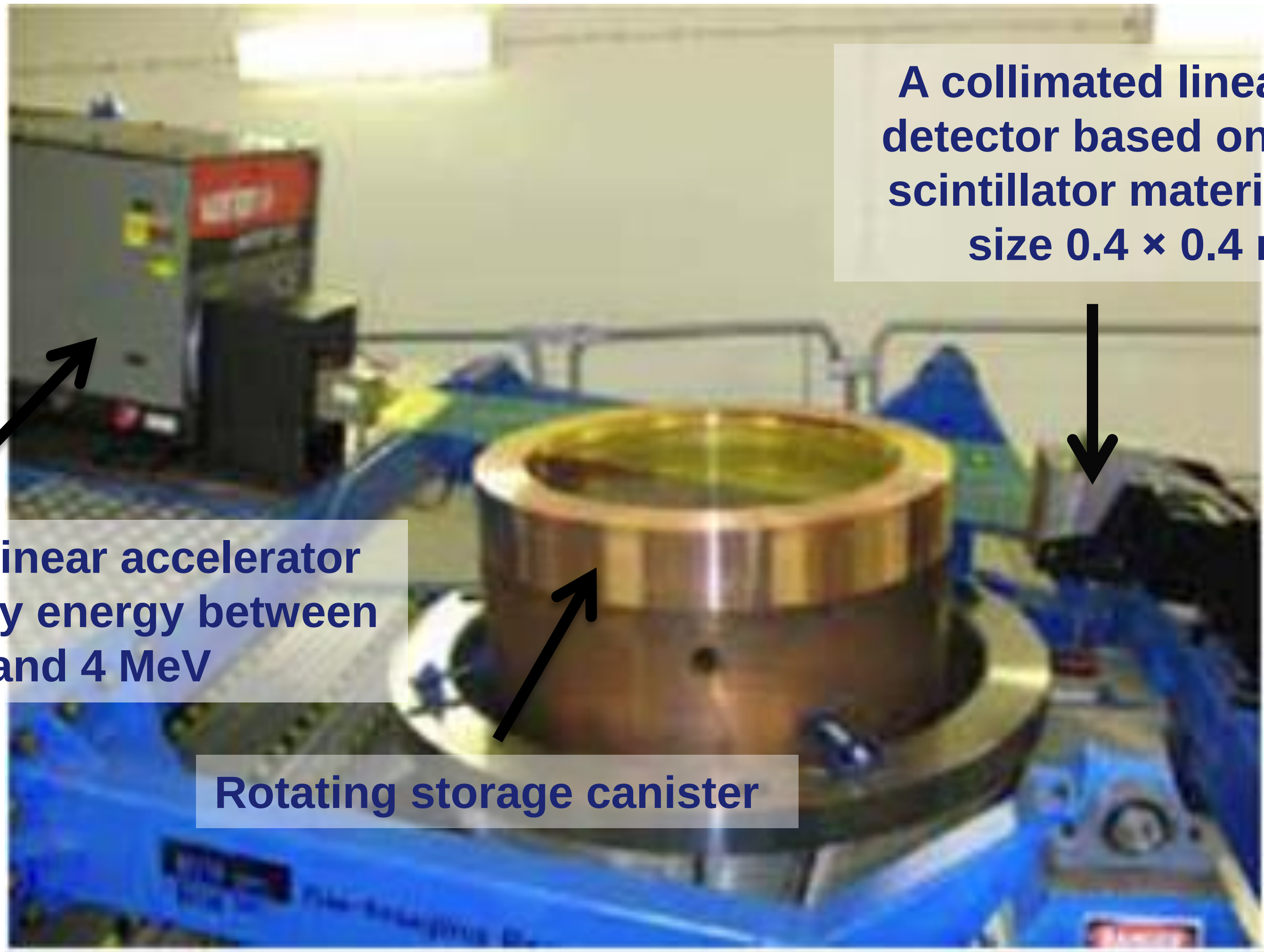
- Imaging system to inspect the welds in spent nuclear fuel storage canisters which are to be used in the final storage facility being built by Posiva Oy in Eurajoki, Finland, at a depth of about 400 m.
- The copper canister acts as a corrosion barrier for a cast iron insert with channels for the spent fuel bundles



1.Final disposal canister
2.Bentonite buffer
3.Tunnel backfill
4.Bedrock

- Canister sealing welds need to be absolutely tight and will be inspected using several NDE methods: ultrasonic testing, eddy current testing, remote visual testing and radiographic testing
- Tests need to be fully automated because the nuclear fuel inside the canisters emits radiation
- The canisters are rotated in front of the detector at an angle. The thickness of copper that the X-rays need to pass through during weld inspection is up to 160 mm, which demands for a 9 MeV radiation source

Current Weld Inspection Setup



Migrating to a GaAs Detector

With a GaAs direct conversion detector

- it is possible to approximately halve the measurement time for one rotation of the canister (currently it takes one hour)
- spatial resolution is improved because there is no optical blurring and a smaller pixel size can be used

Technology used:

- high purity GaAs grown by CVPE method (Chloride Vapour Phase Epitaxy). A PIN structure is grown on n+-type bulk GaAs wafers in a quartz tube, layer thicknesses i (less than $1 \cdot 10^{13}\,cm^{-3}$ free carries): 200μm, p+ : 1-2μm
- Good material homogeneity
- Normal lithographical patterning techniques for the strips

Detector and Readout Frontend Block Diagram

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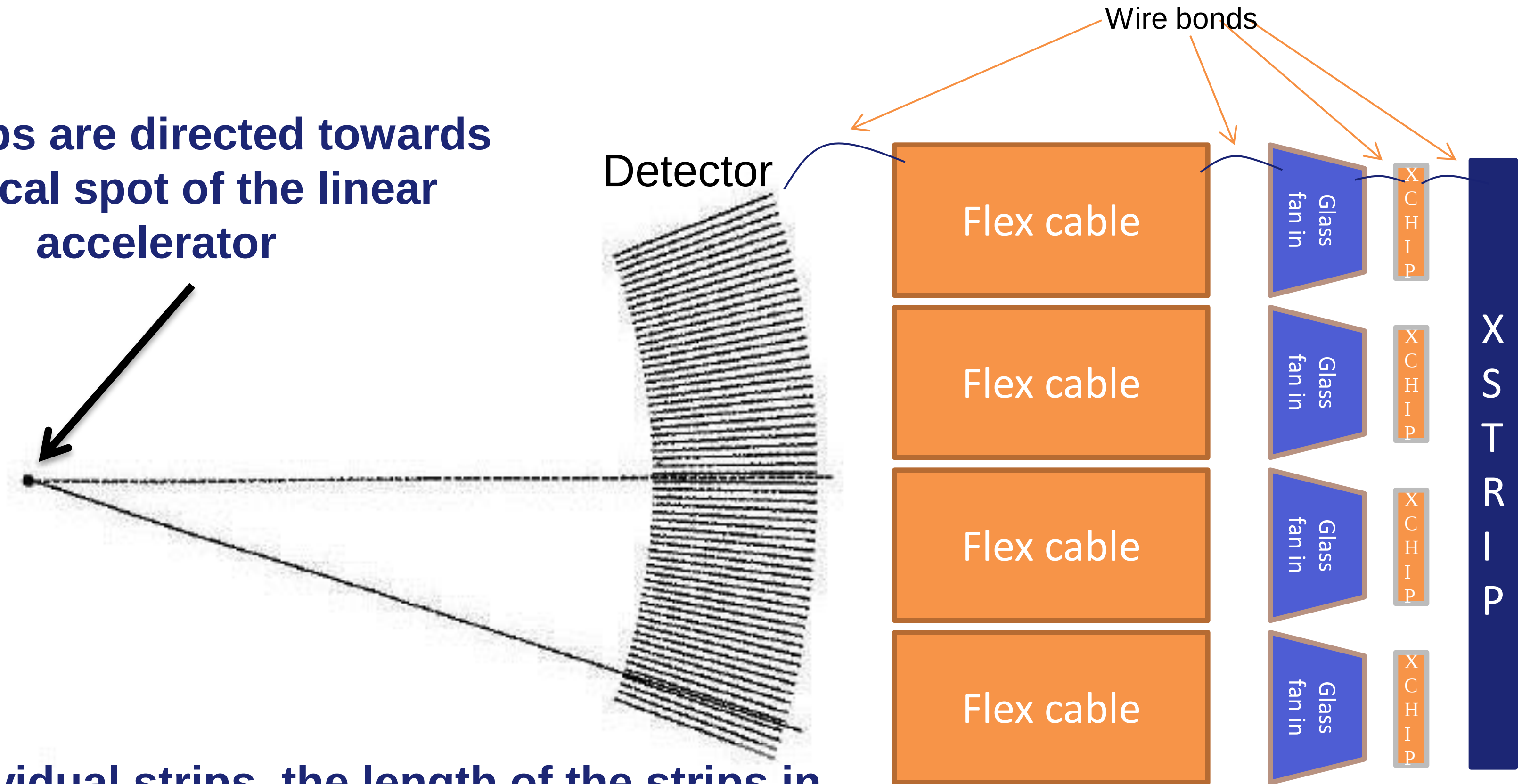
The strips are directed towards the focal spot of the linear accelerator



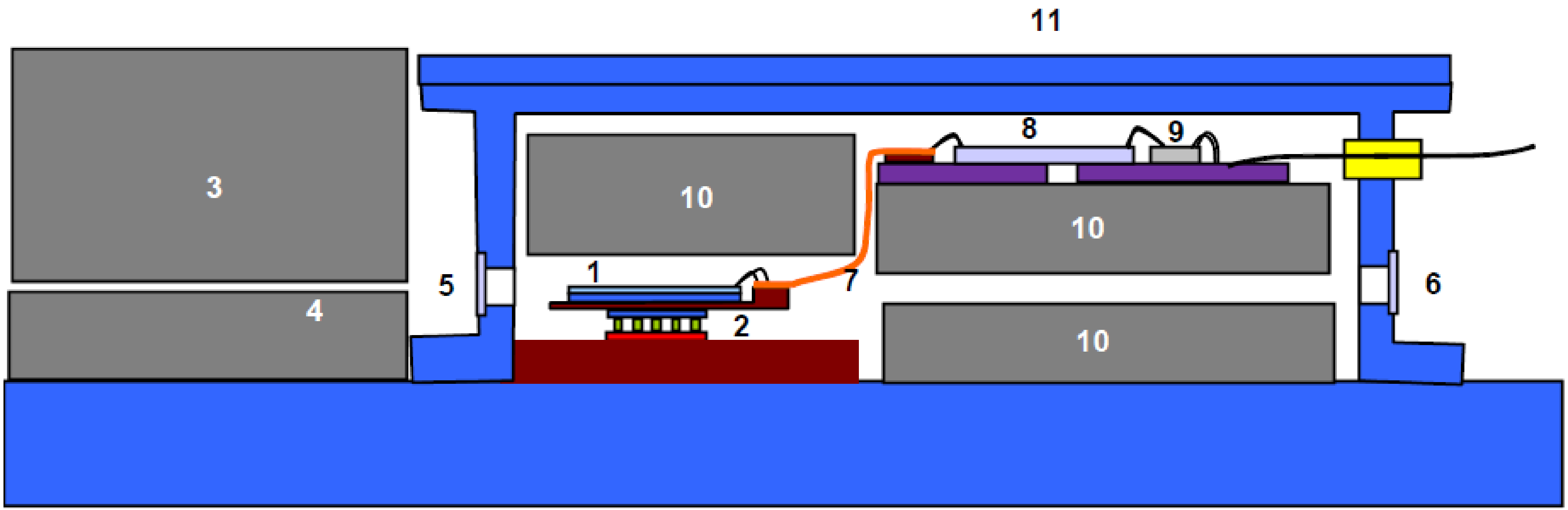
512 individual strips, the length of the strips in the X-ray direction is 25 mm. The pitch is 0.2 mm.

Readout is realised with XCHIP ASICs and XSTRIP modules from RAL, which are controlled and read out by an UltraDaq system from Quantum Detectors

Detector Design

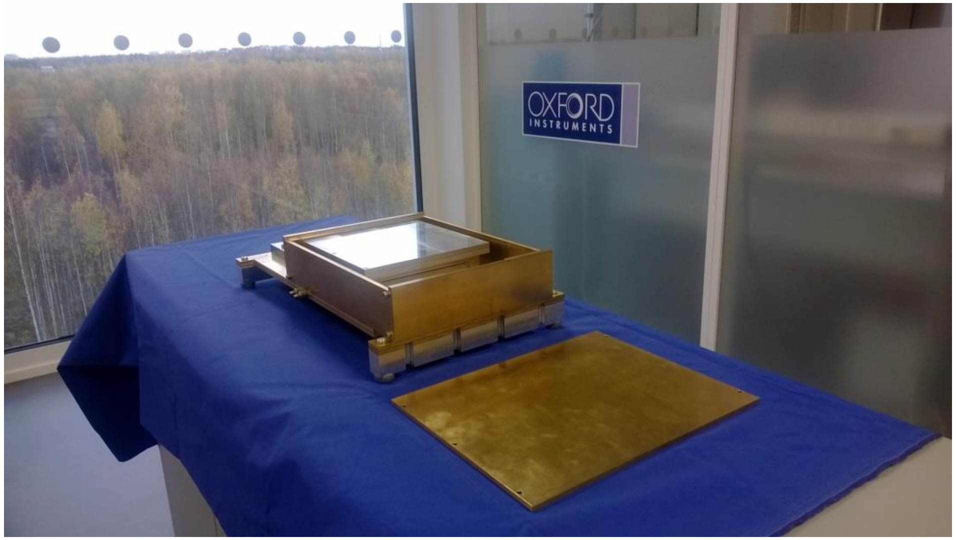
- The X-ray beam is collimated to an area of 100mm x 0.2mm on the edge of the detector by a collimator 150 mm in length, making alignment rather demanding
- The design goal is to be able to see volumetric defects as small as 1 x 1 x 1 mm^3
- The 200 μm strip pitch has been chosen to ensure the required resolution and the strip length of 25 mm to offer enough stopping power for the high-energy X-rays
- The readout chips are protected from the incident X-rays by elevating them from the detector plane so that they are better shielded. This is achieved with a flex cable connection from the detector chip to the readout electronics.

Detector Assembly with Collimator and Enclosure

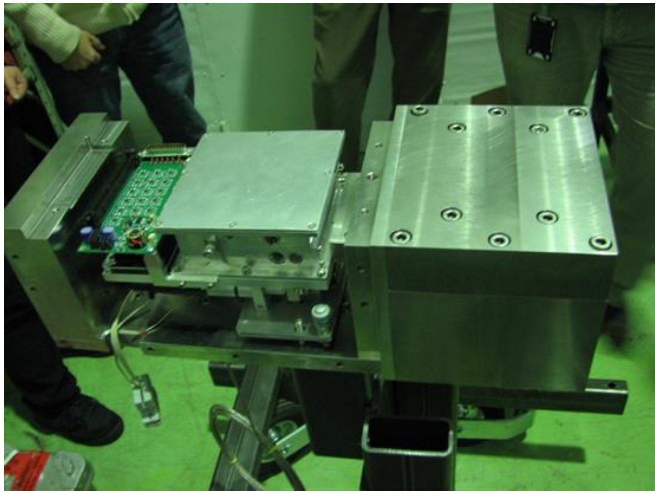


1. GaAs detector with 512 strips
2. Peltier cooler
3. Collimator + detectors shield
4. The slit of the collimator
5. Entrance window
6. Escape window
7. Polyimide flexible cable
8. Fan-in structure on a glass plate
9. XCHIP readout chips
10. Densimet shields
11. Hermetic chamber

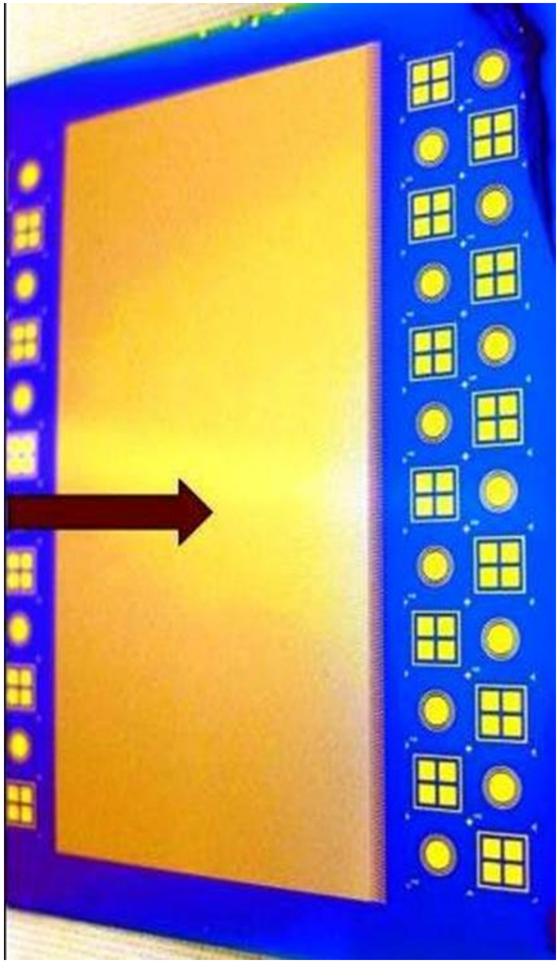
Photos



Detector eclosure parts being inspected and test assembled

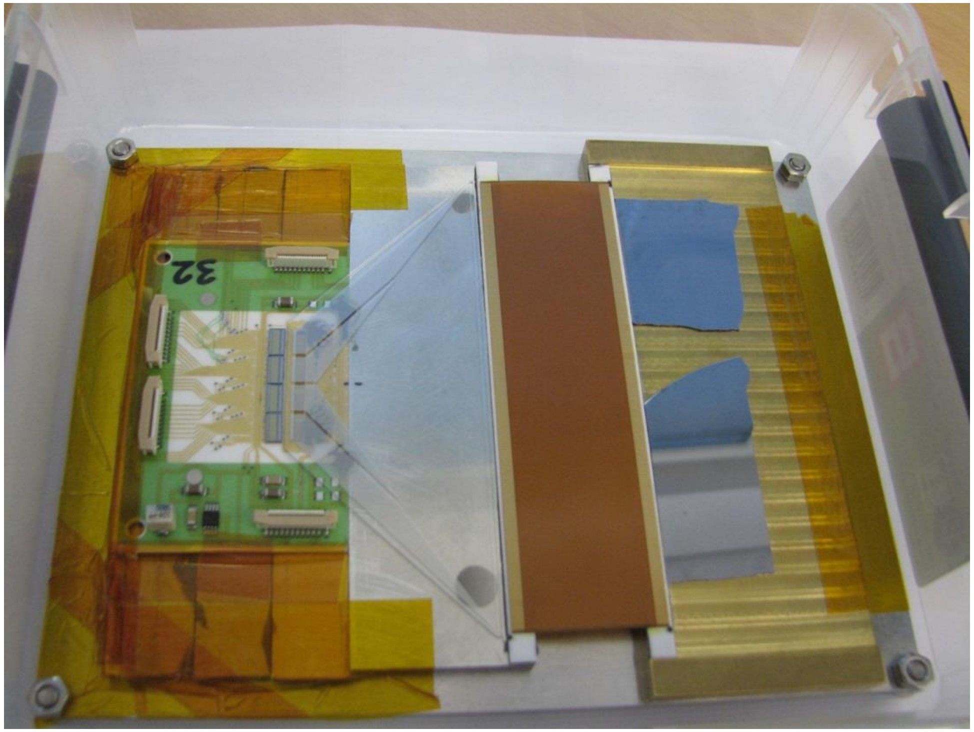


Previous 50um ptich detector system being tested at VTT Betatron

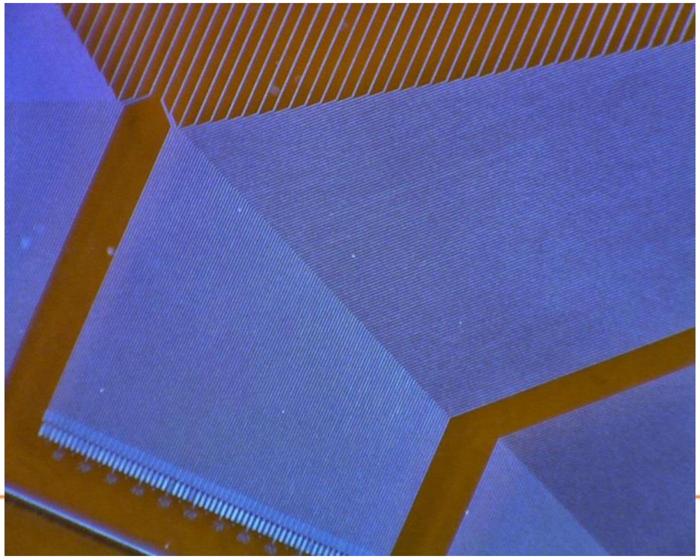


GaAs strip detector with arrow showing the Direction of the X-rays

Wire Bonding

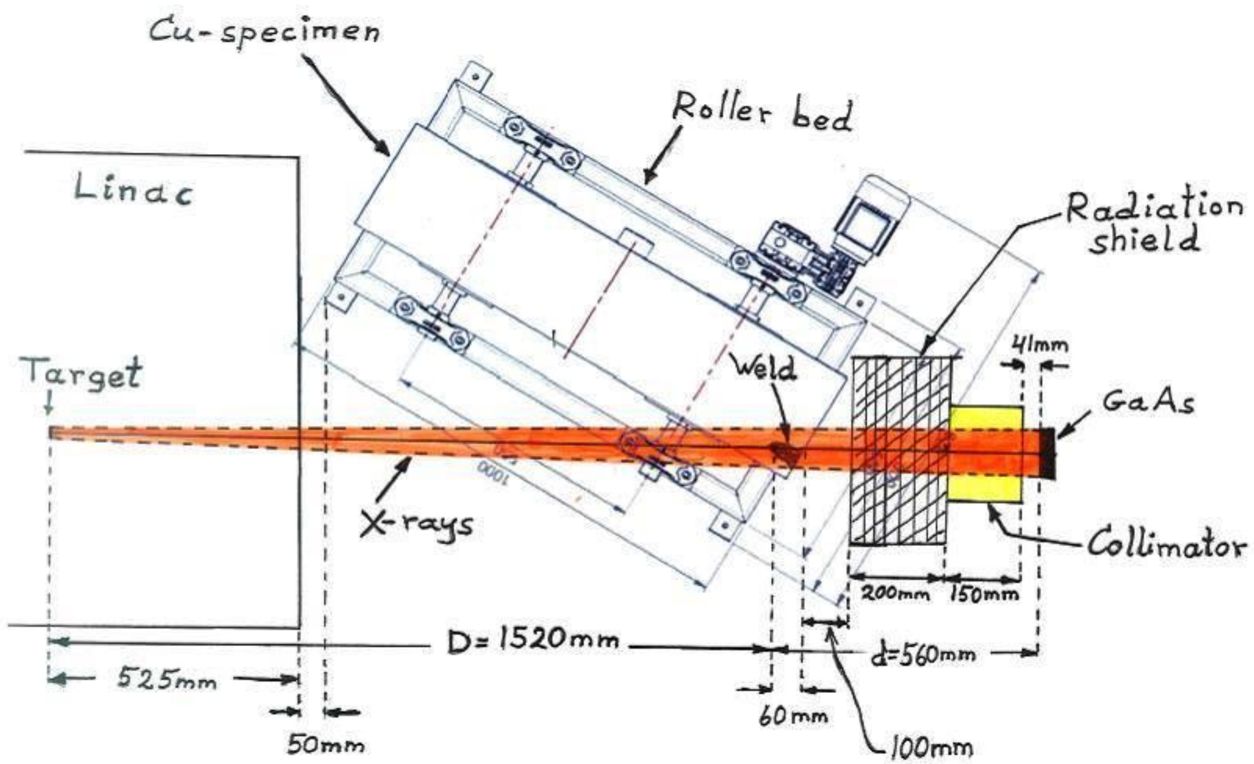


Several bonding tests have been Carried out at RAL. These were Successful on the first try for the Current detector setup, with the test Piece shown here (readout module on the right, mock detector on the left). No yield problems were encountered as opposed to the previous detector prototypes that had a smaller pitch and no fan-in.



Wire bonding test assembly and a close-up of the glass pitch adapter plate

Test Setup at Fraunhofer EZRT



Linac used is Siemens Industrial Linear Accelarator (SILAC)

Specs: energies 4 – 9 MeV at up to 1 kW of average

electron beam power, 16Gy/min max. dose rate at one metre at 9 MeV

tungsten anode

Conclusions

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- Tests have been delayed for administrative reasons and will be carried out only in late 2014 / early 2015
- A similar detector with a 50μm pitch and a different kind of enclosure was tested in summer 2013 at Oskarshamn in Sweden but problems with the detector support mechanism caused severe alignment issues that made much of the data unusable
- The final detector will be composed of two or three detectors similar to this prototype to facilitate stereoscopic radiography