X-ray detection for accelerator diagnostics

Luciano Malavasi
Dr. David Stuart

Instrumentation for experimental particle physics

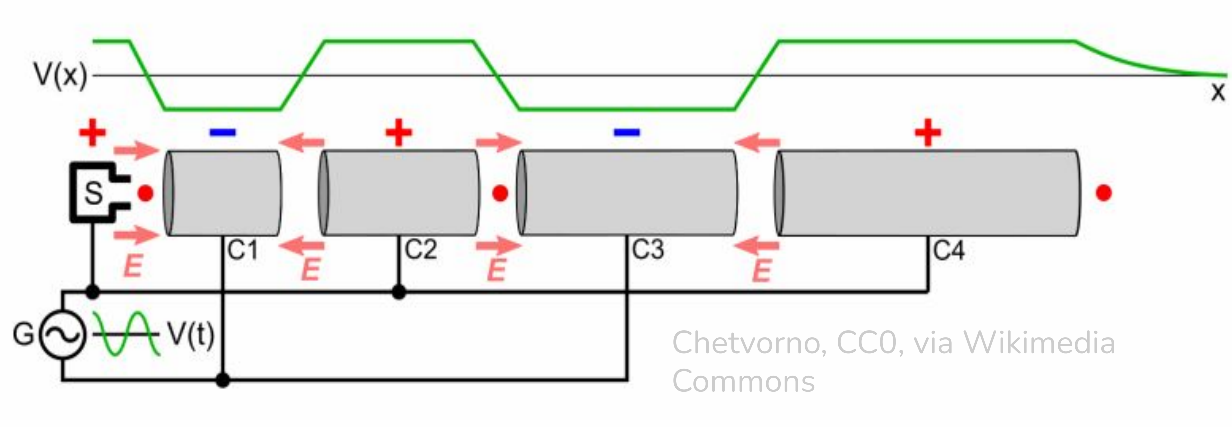
Instrumentation:
Electronic systems for reading accelerator data

Detection systems:
Primary beam target/collision analysis

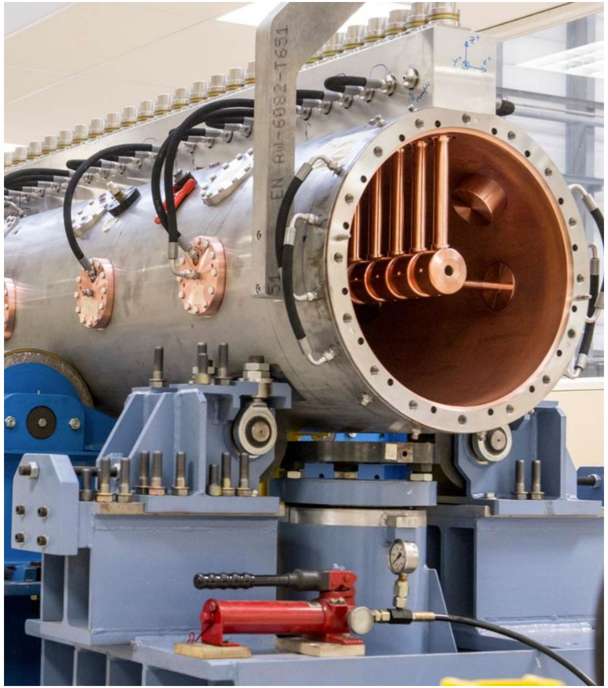
Diagnostic systems:
Monitor, calibrate, and analyze “vital signs”

https://home.cern/news/news/cern/live-lhc-tunnel

Drift tube linear accelerators (DTL)



Chetvorno, CC0, via Wikimedia Commons

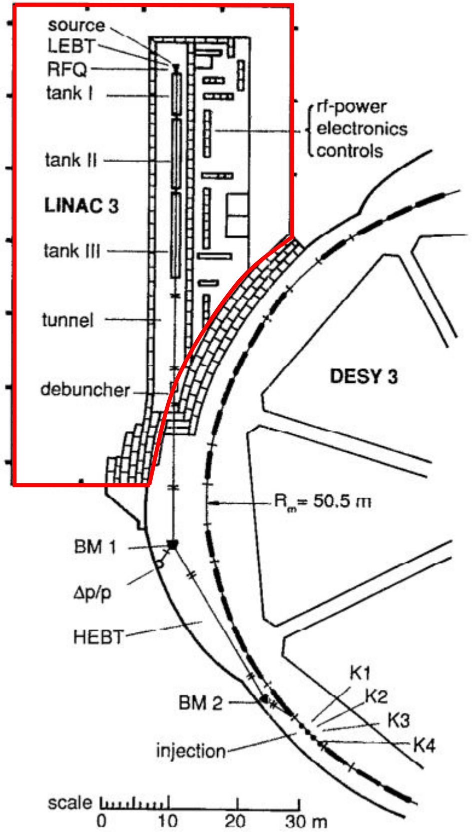


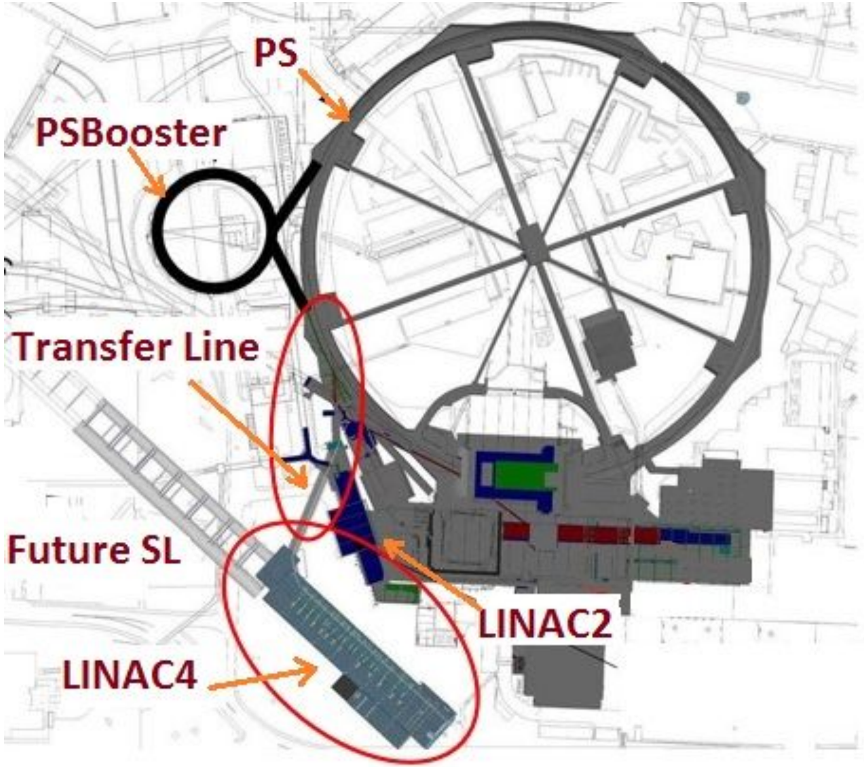
https://home.cern/news/news/accelerators/linac4-drift-tube-linac-under-assembly

DTLs are are installed at many/most accelerators, to produce a beam of charged particles (H^+, H^-, other ions)

DESY LINAC-3 (50 MeV)

CERN LINAC4 (160 MeV)





Review of Scientific Instruments 62, 867 (1991); https://doi.org/10.1063/1.1142023

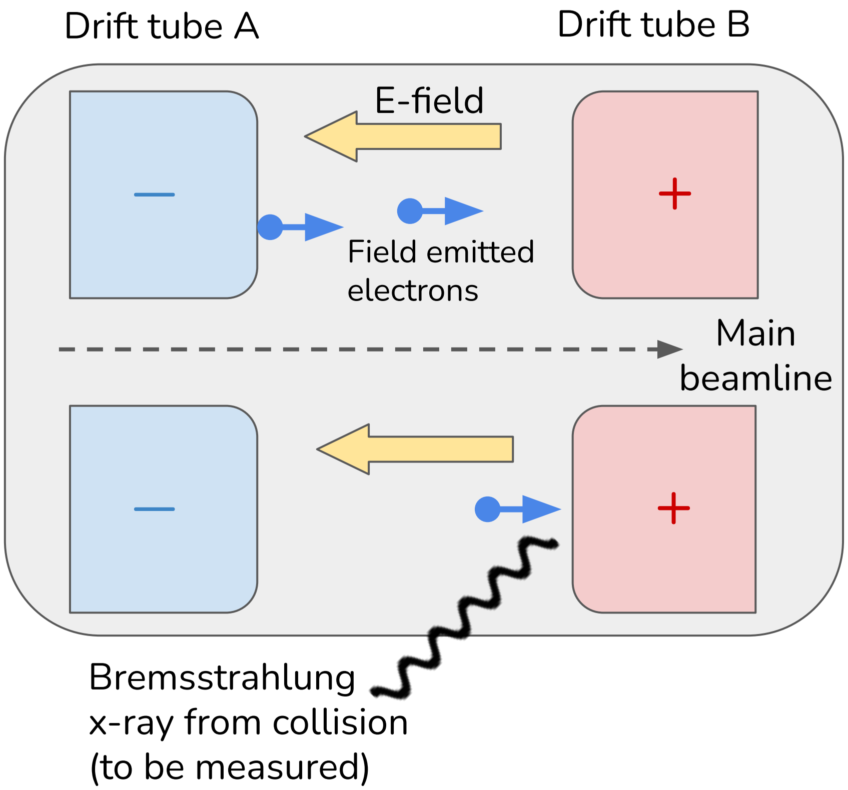
https://www.lhc-closer.es/taking_a_closer_look_at_lhc/0.linac4

Los Alamos Neutron Science Center (LANSCE)

Some facilities & research areas:

- Isotope production for nuclear & health physics, environmental science
- Weapons and fission research
- Probing neutron decay properties (beta-asymmetry) with ultracold neutrons

DTL gap energy diagnostics at LANSCE



Design an x-ray detector for continuous monitoring of drift tube gap energy

1. Perform x-ray spectroscopy in DTL gaps
2. Diagnose beamline issues in real-time
3. Calibrate sensor with known x-ray spectra

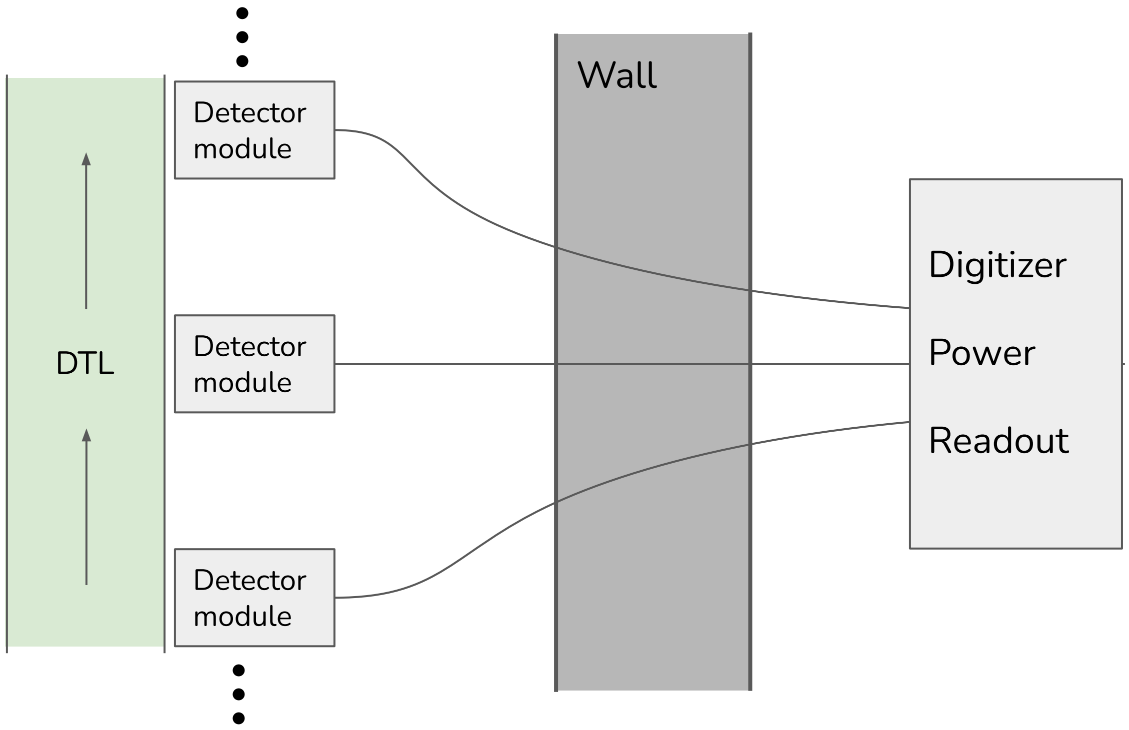
Current solutions are severely limited

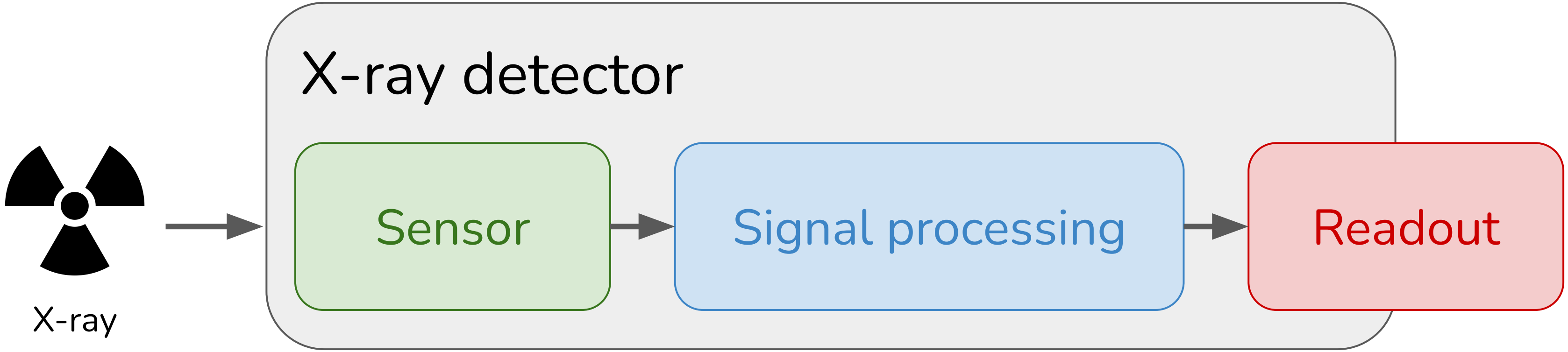
https://www.ortec-online.com/products/radiation-detectors/germanium-hpge-radiation-detectors

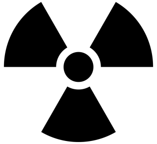
$$$

Bulky

Proposed installation at LANSCE

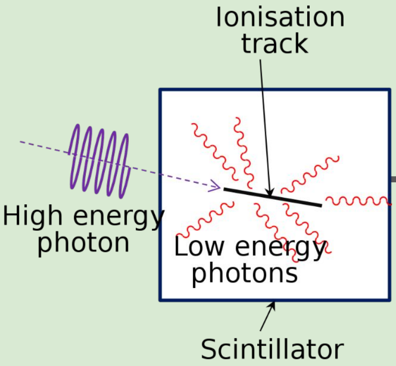



X-ray detector
Sensor
Signal processing
Readout
X-ray

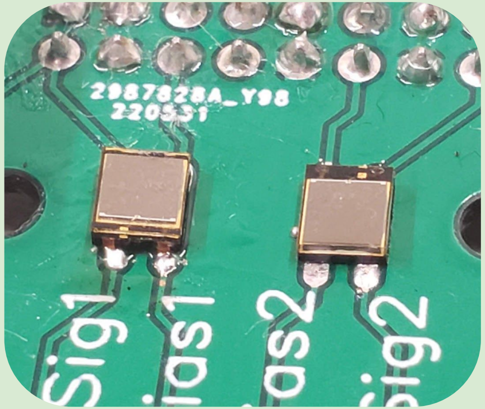


X-ray emission
(beam, source)

Sensor

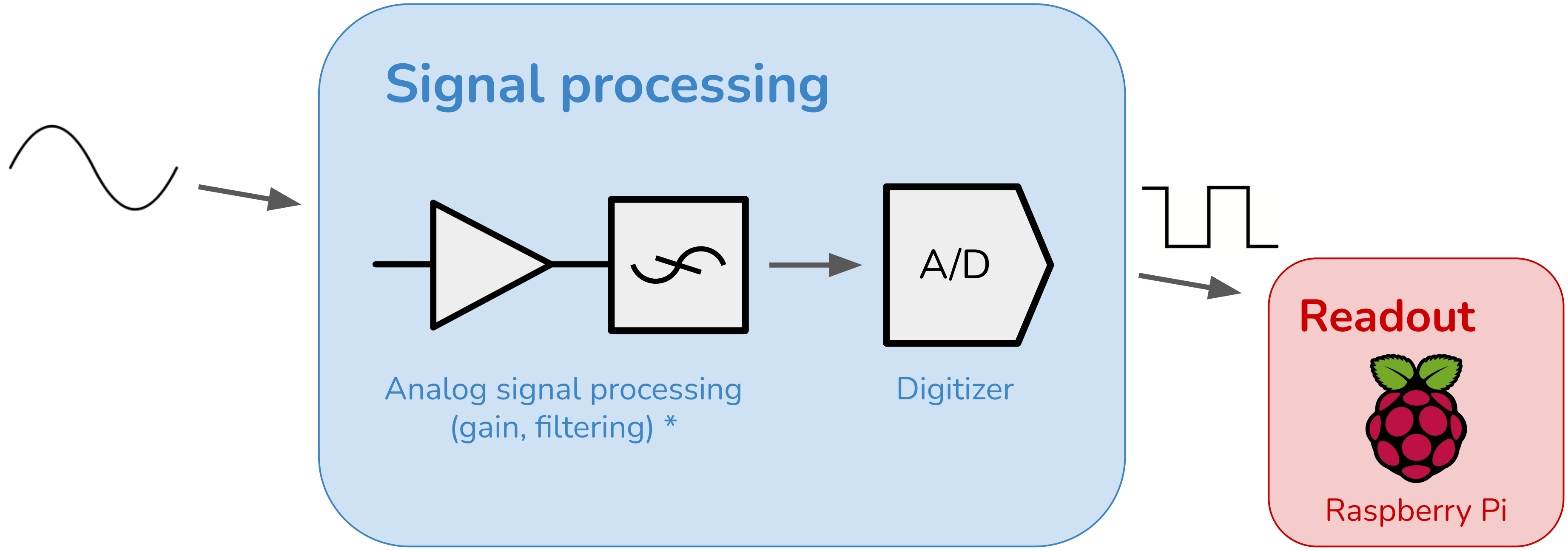


Scintillation
(LYSO)

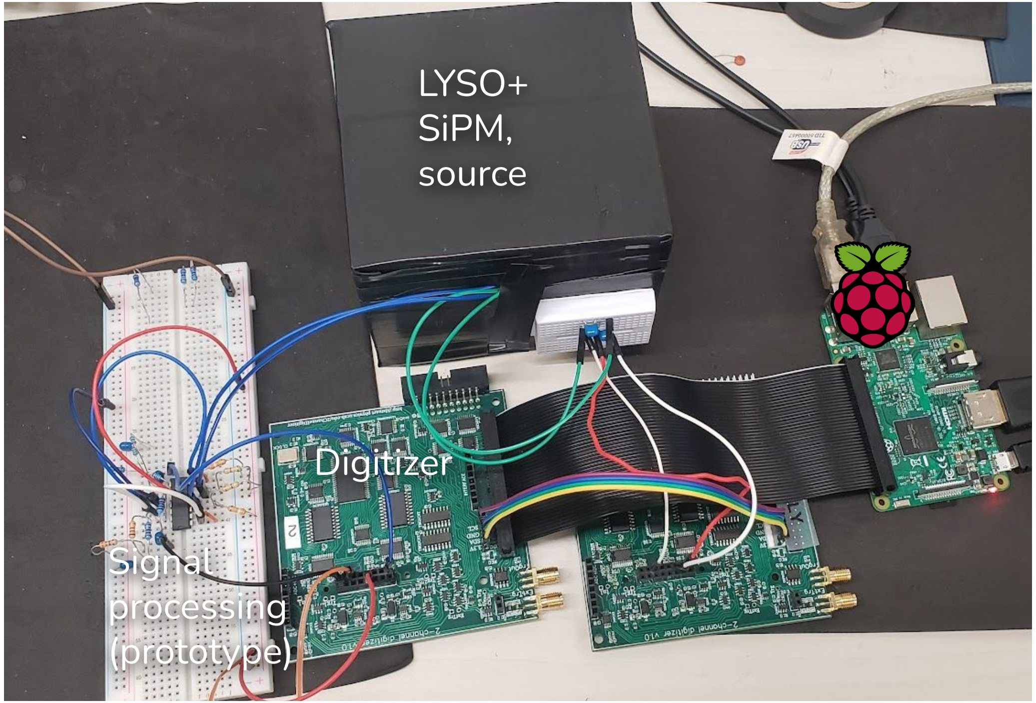


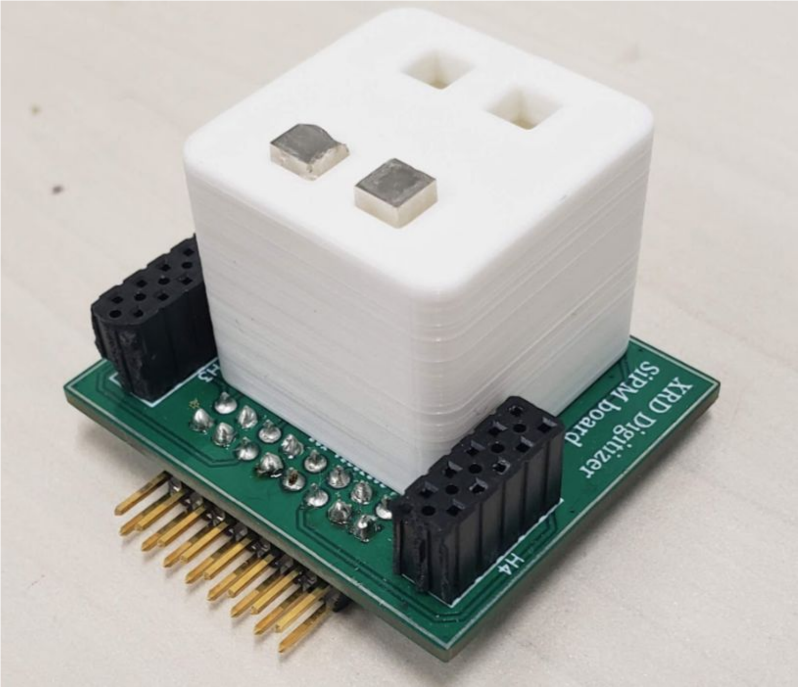
Detection
(Silicon photomultiplier)

Sensors output an electrical signal proportional to incoming energy

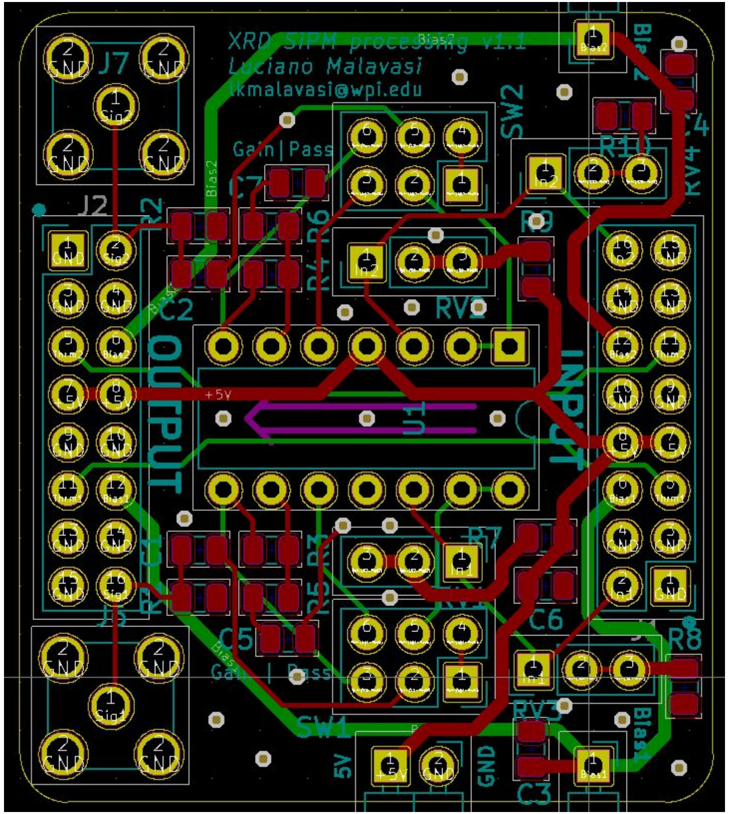

Signal processing
A/D
Analog signal processing
(gain, filtering) *
Digitizer
Readout
Raspberry Pi

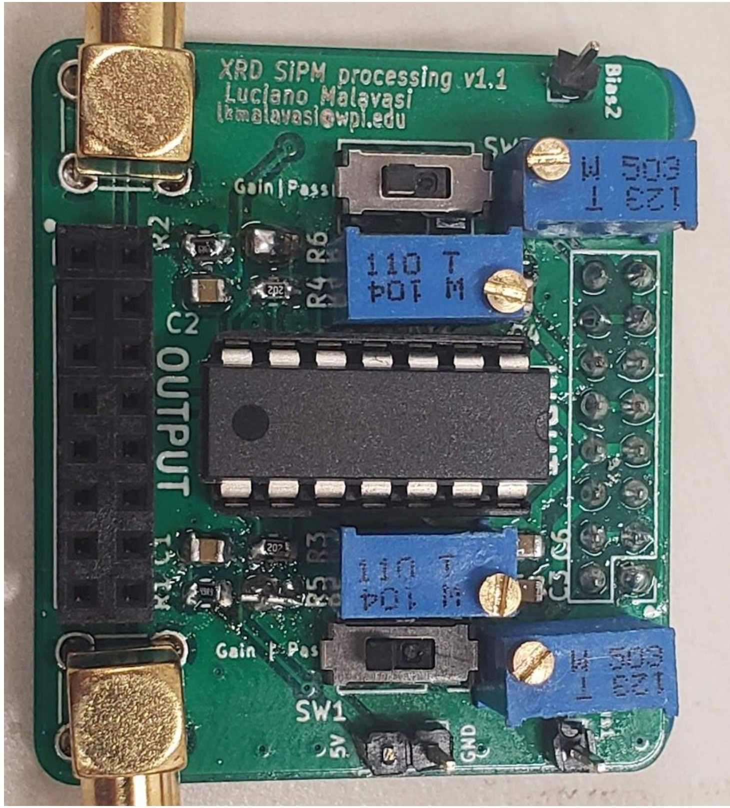
Detector test setup in lab



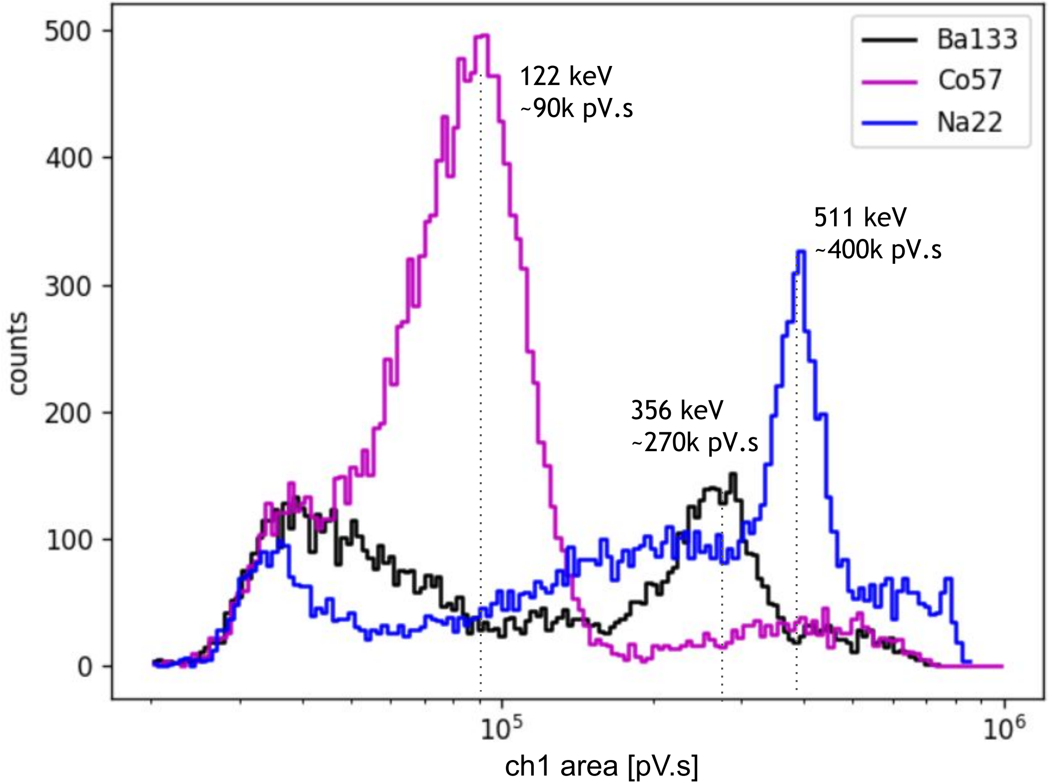


Redesigned analog signal chain

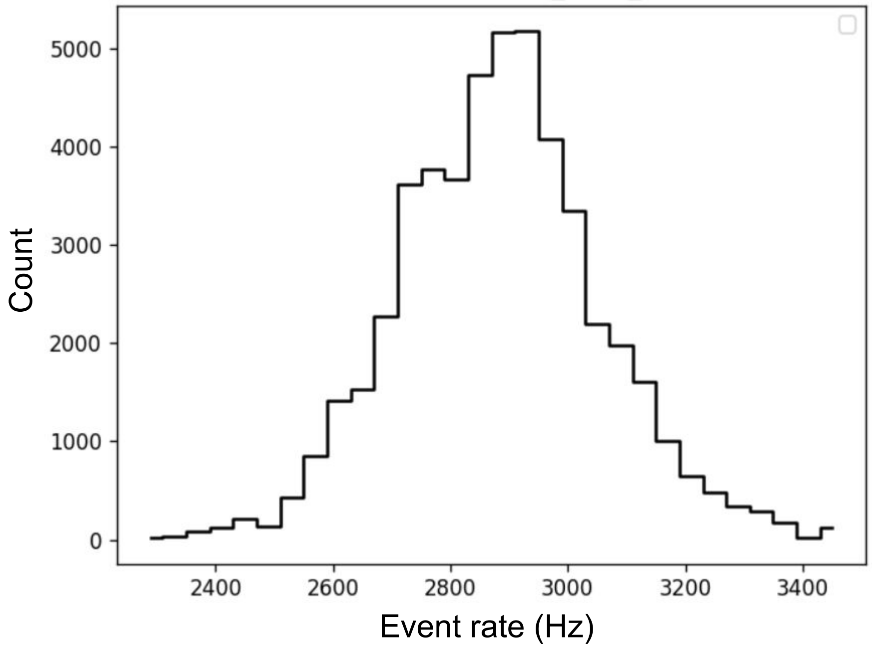


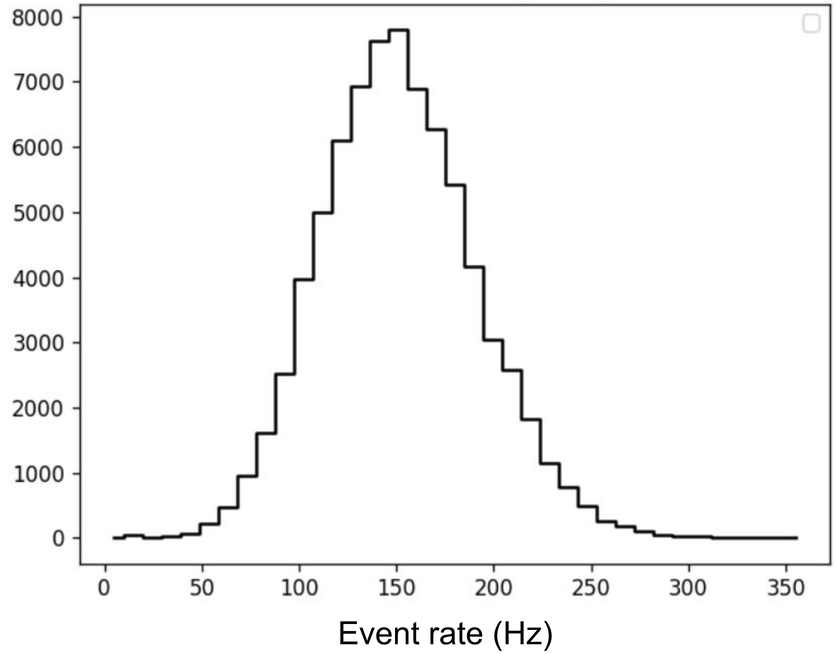


Ex-situ testing: resolving x-ray spectrum peaks



Ex-situ testing: lead tape isolates Ba133 activity

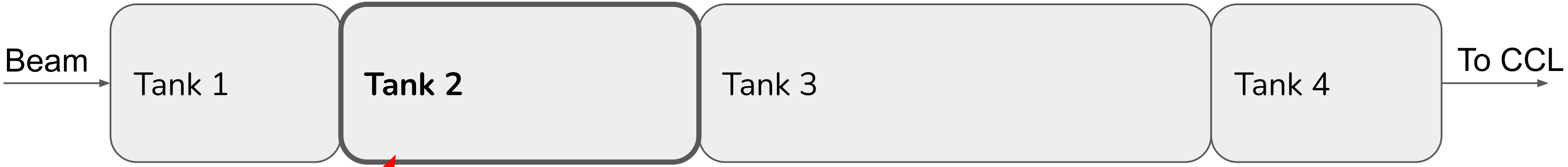


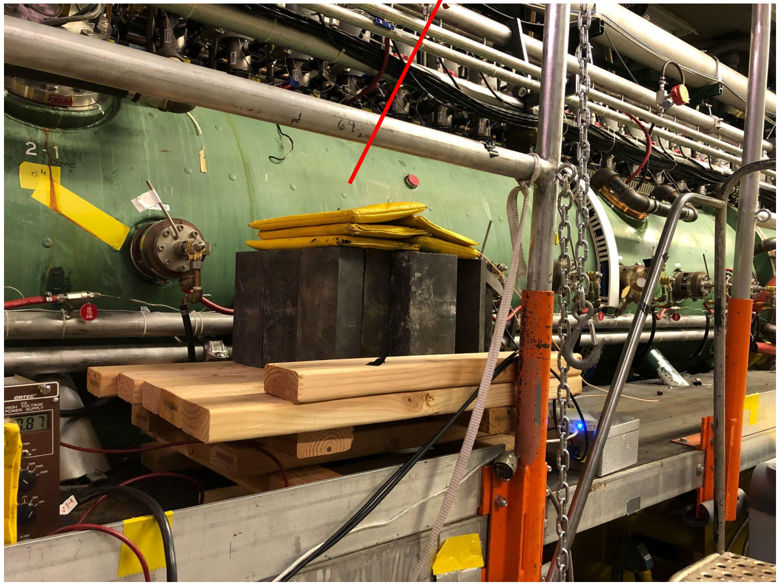


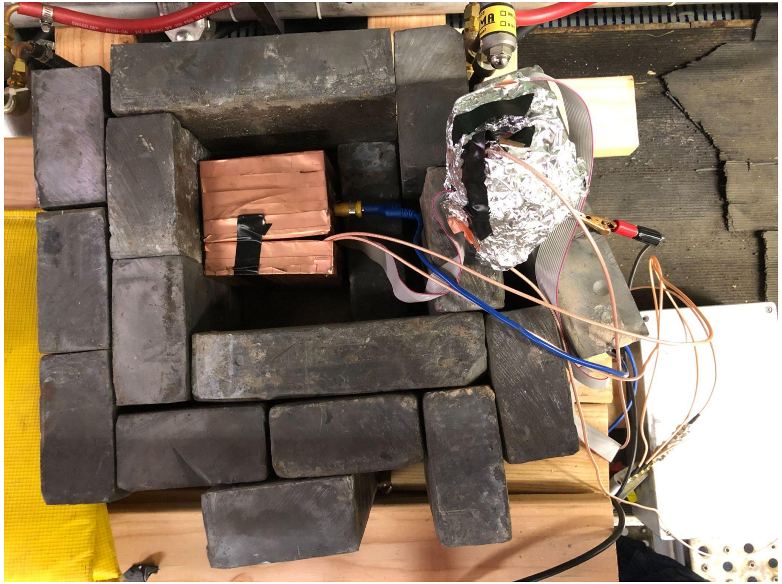
0mm Pb, ~2800 Hz event rate
Mostly Ba133 activity

1.8 mm Pb, ~150 Hz event rate
Mostly LYSO self-activity

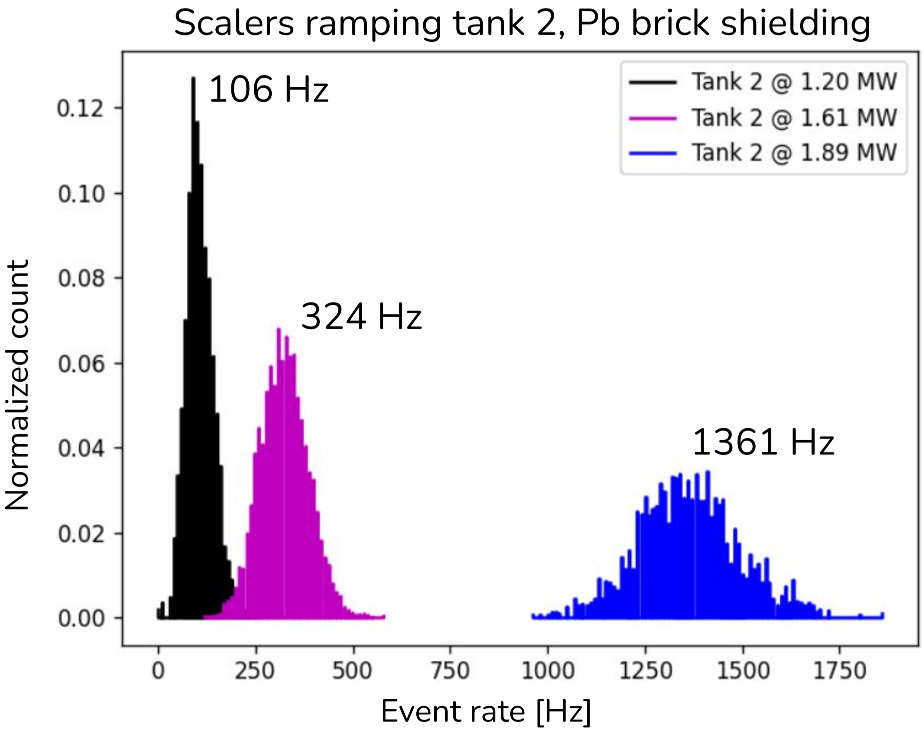
Prototype setup at LANSCE DTL

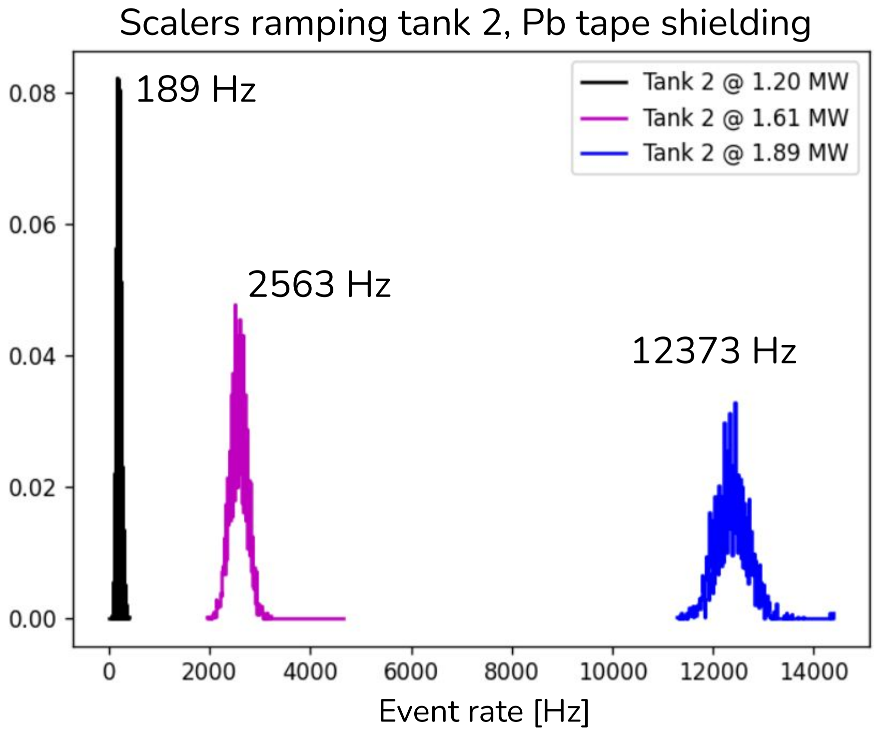






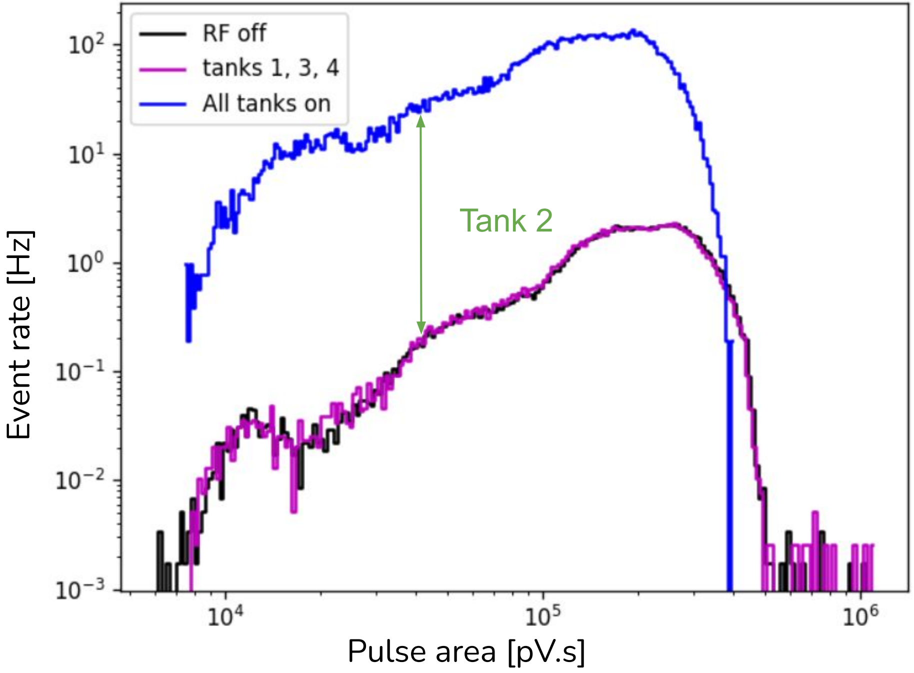
In-situ testing: lead shielding methods at LANL



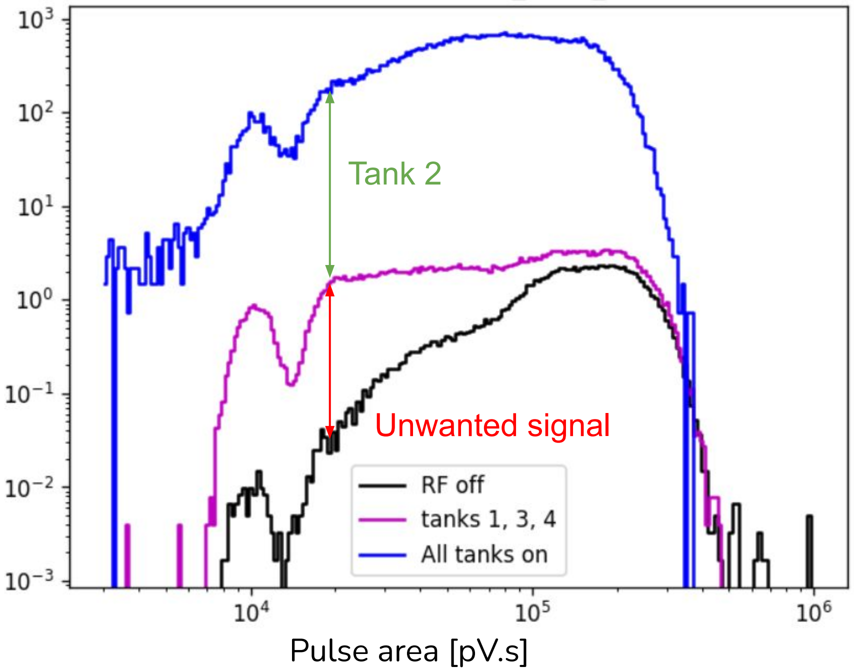


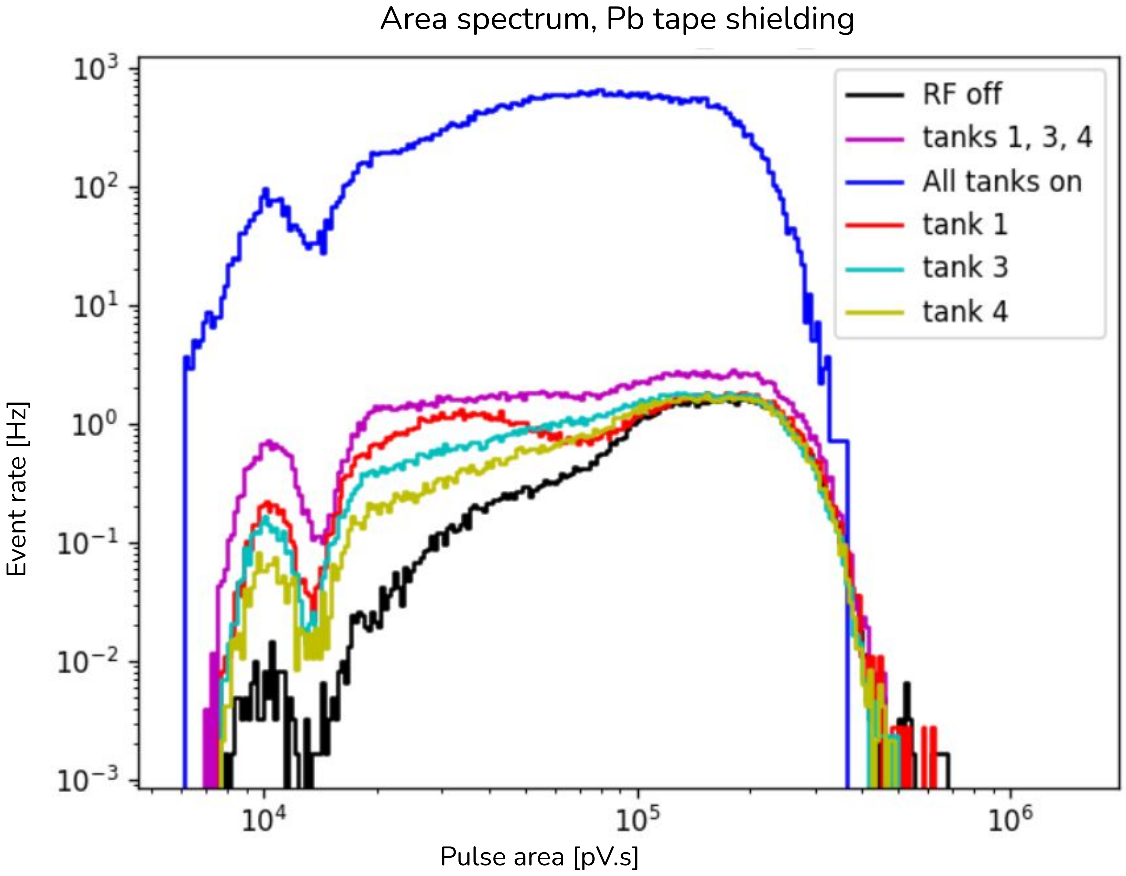
In-situ spectrometry at LANL

Area spectrum, Pb brick shielding



Area spectrum, Pb tape shielding



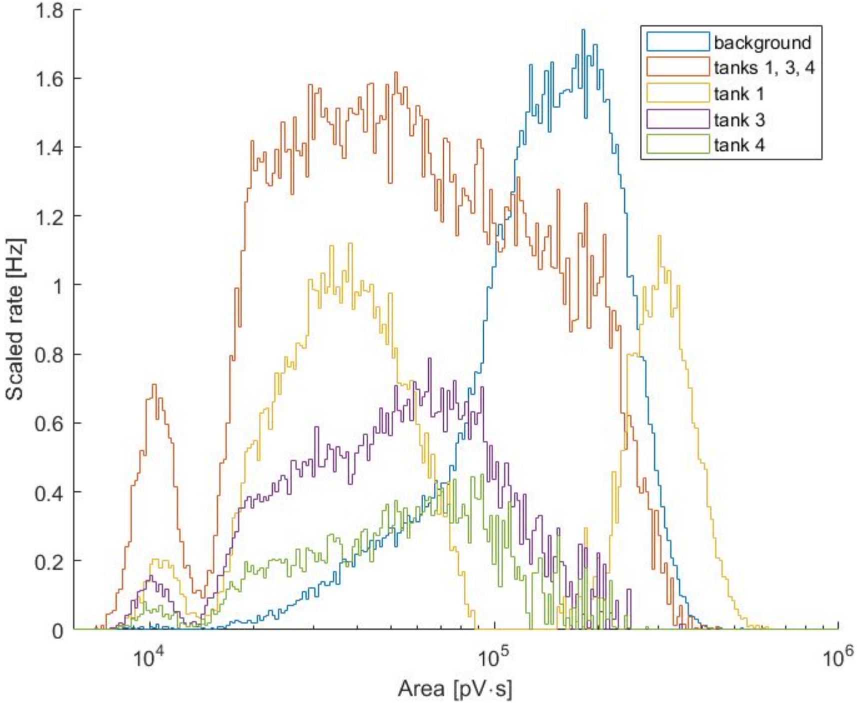


Preliminary conclusions:

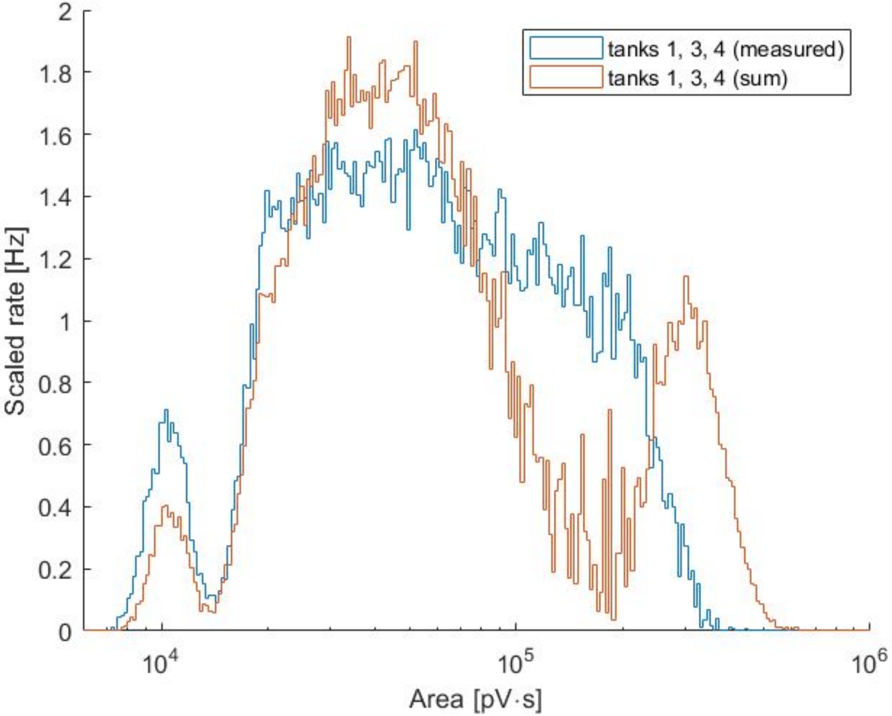
- Lead tape is a decent shielding prototype
- Background contributions are relatively uniform across tanks 1, 3, 4
- Design collimation structure to focus sensor FOV

Isolating tanks with background subtraction

Area spectrum (with background subtraction)



Reconstructing spectra from individual tanks



Project summary

- Designing and testing an inexpensive & modular SiPM-based x-ray detector
    - Characterized by performing spectroscopy on known x-ray sources
    - Redesigned and simplified readout+processing chain
- Installed prototype at LANSCE and collected data during test beam
    - Determined shielding requirements, which inform lower bound on module size
    - Subtract background from signal to isolate each tank
- Future work: improve current module, expanding analysis capabilities
    - Redesign digitizer: self-testing, flexible scaler rate measurement
    - Investigate SiPM energy resolution

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My fellow 2022 Physics REU participants!