A Compact SiPM-Based Neutron Anger Camera with Sub-Millimeter Spatial Resolution and Time-of-Flight Imaging Capability

Y. Venturini[1] · A. Abba[2] · F. Caponio[2] · M. Bleuel[3] · G. Schneider[3]

[1] CAEN S.p.A., Viareggio, Italy [2] Nuclear Instruments S.r.l., Lambrugo (CO), Italy [3] Louisiana State University, Baton Rouge, USA

PSD14 · Plenary Talk — Detectors for Neutron Facilities

Peston Lecture Theatre · 2 September 2026

Motivation & Context

1 Spatial

Sub-millimeter position resolution

2 Temporal

Nanosecond timing → Time-of-Flight

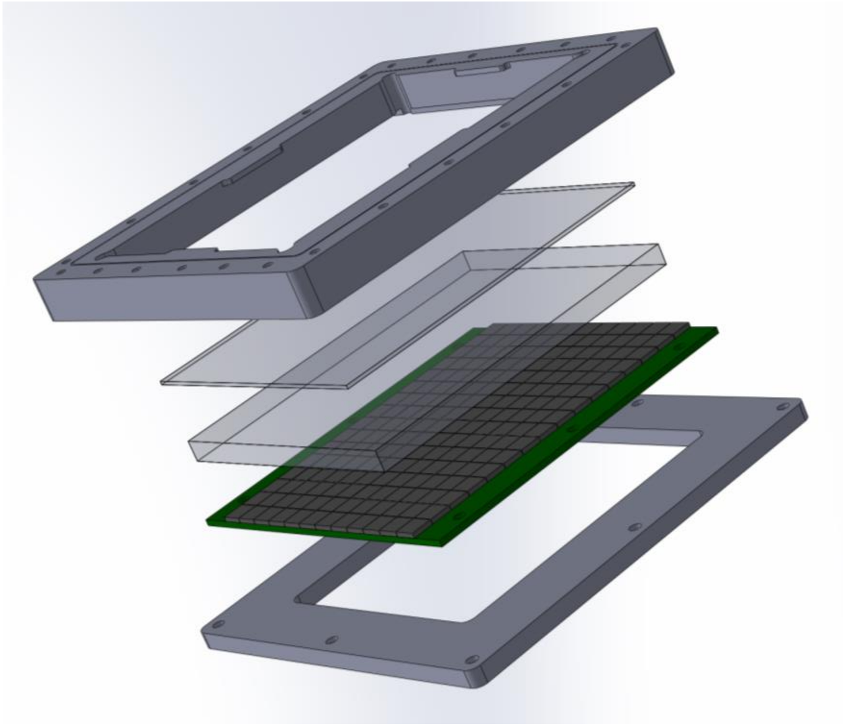
3 Spectroscopic

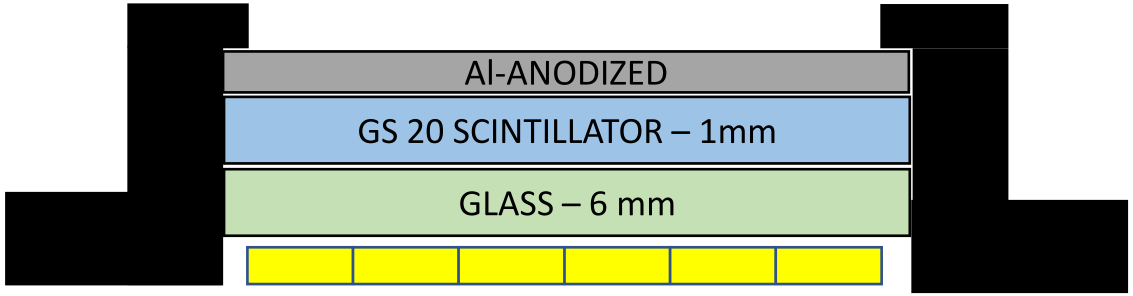
Energy-resolved neutron imaging

- Neutron scattering and time-of-flight (ToF) beamlines increasingly require position-sensitive detectors that combine spatial, temporal, and spectroscopic capability in a single instrument
- Large-area scintillation-based imaging is a scalable route to high-channel-count, position-sensitive neutron detection
- This work: a compact neutron Anger camera, developed as a proof-of-concept for large-area systems, built on CAEN's FERS-5200 SiPM readout platform

Detector Concept

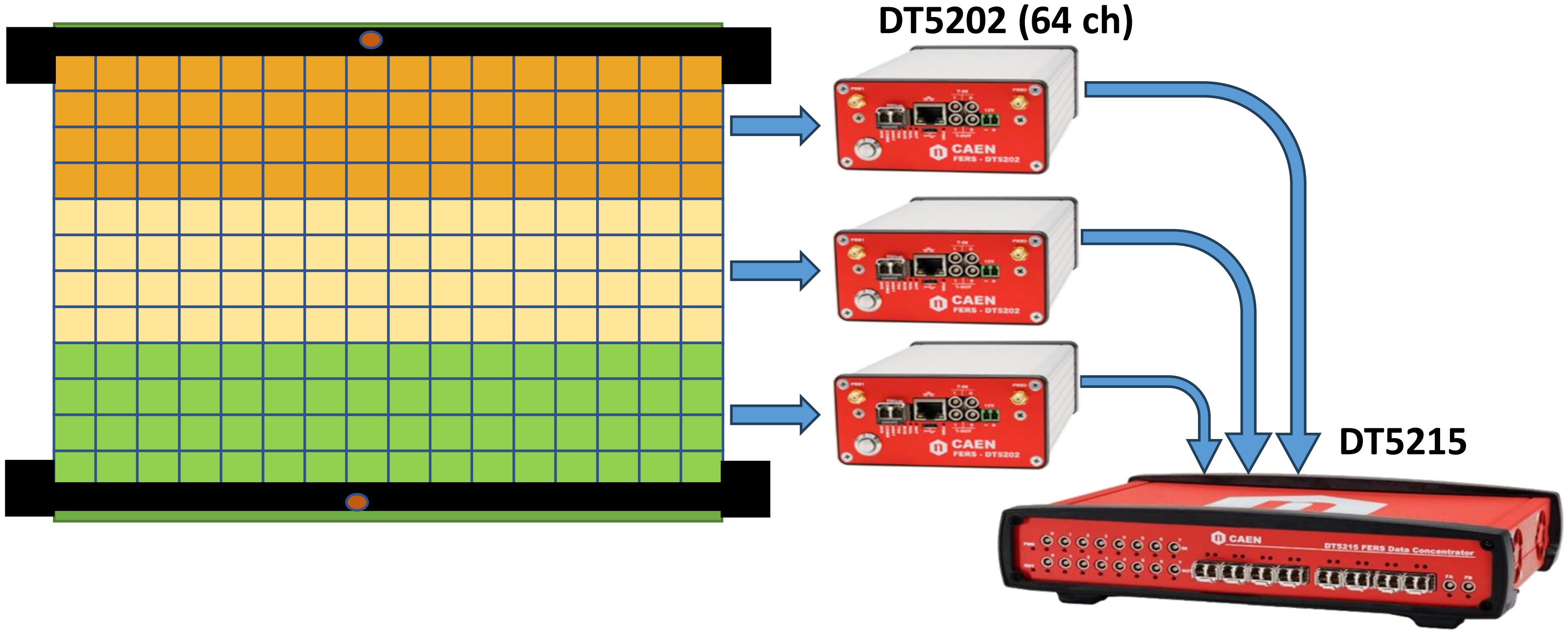
- 1 mm thick GS20 lithium-glass scintillator (^{6}Li neutron converter)
- 6 mm thick, boron-free quartz light spreader
- Reflective coatings maximize light collection onto the photosensor plane
- Scintillation light spreads across an array of SiPMs → classic Anger-camera position encoding





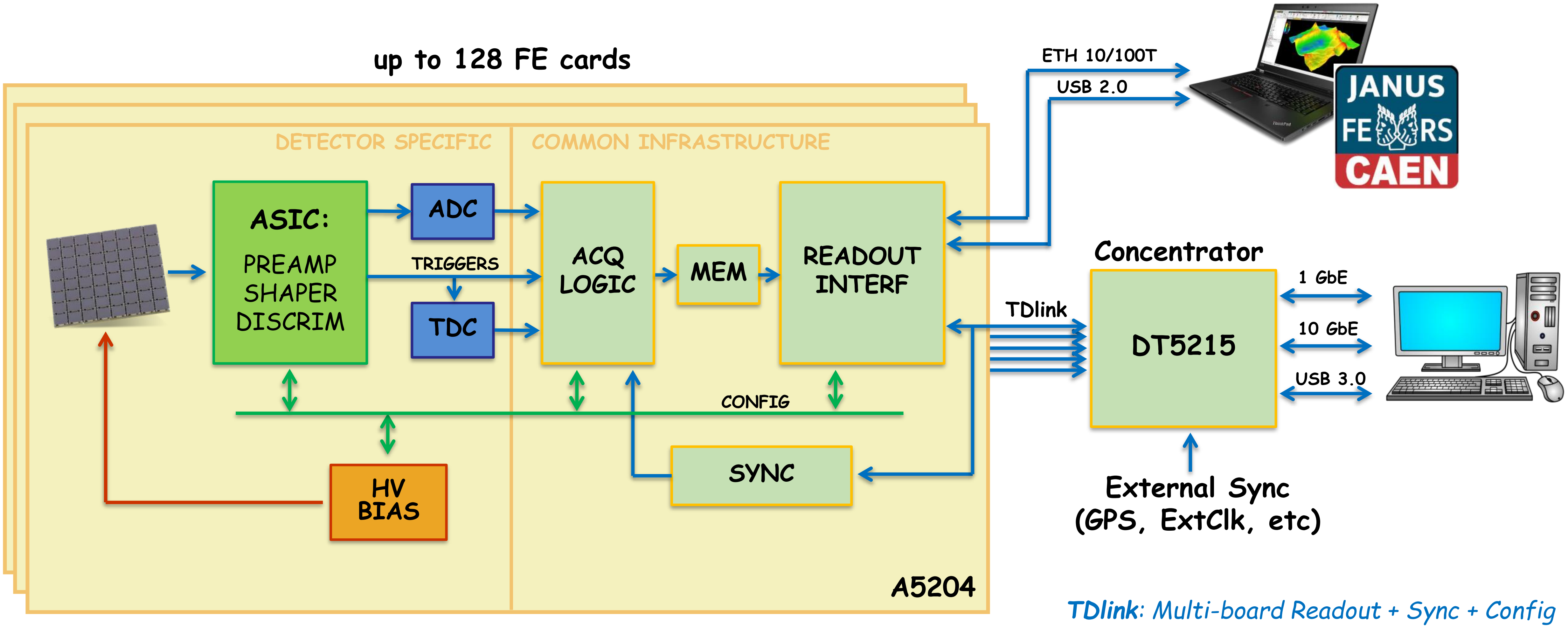
SiPM Matrix & FERS Readout Chain

- Custom SiPM matrix: 192 Hamamatsu devices in a 16×12 array
- 6×6 mm² active area per SiPM, 0.1 mm gap → 6.1 mm pitch → 96×72 mm² total active area
- Readout via 3 CAEN FERS DT5202 units (64-channel SiPM front-end each)
- Event-by-event digitization, sync and timestamping via optical link to a DT5215 data concentrator



FERS-5200: generic block diagram

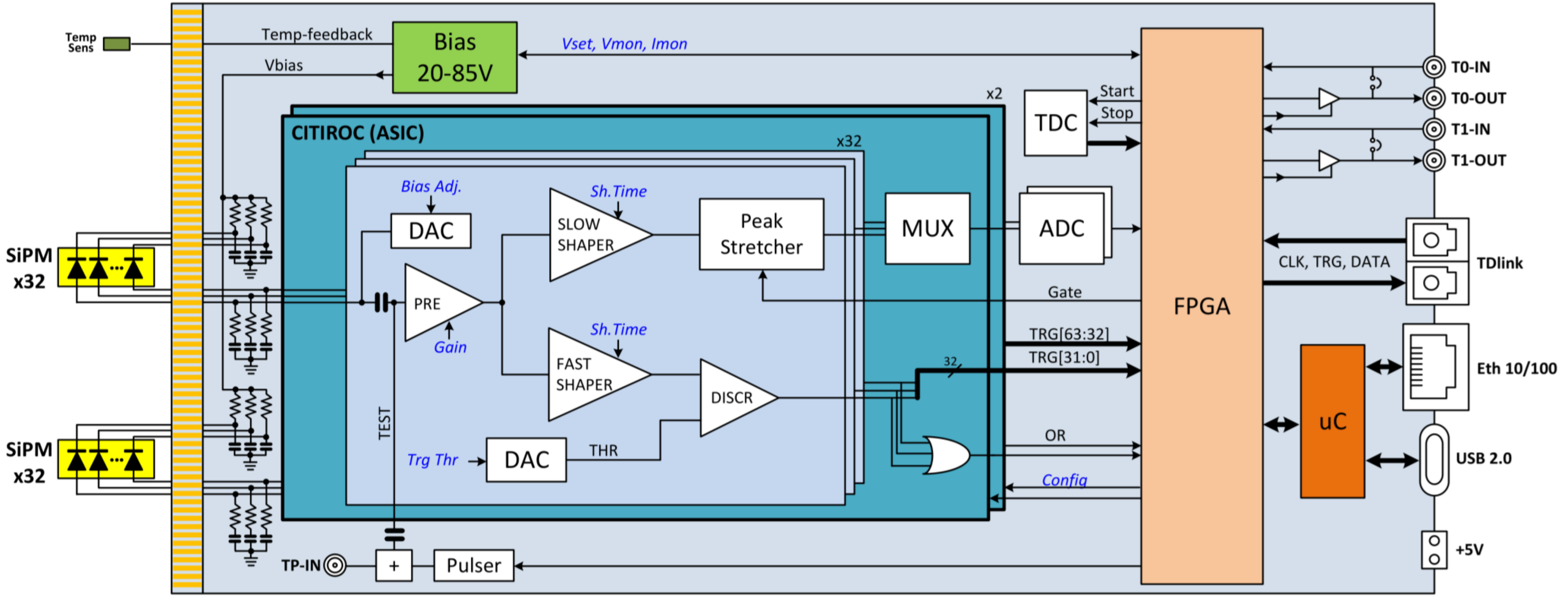
Direct Connect: easy but slow (~2 MB/s)



TDlink: Multi-board Readout + Sync + Config
Up to 300 MB/s

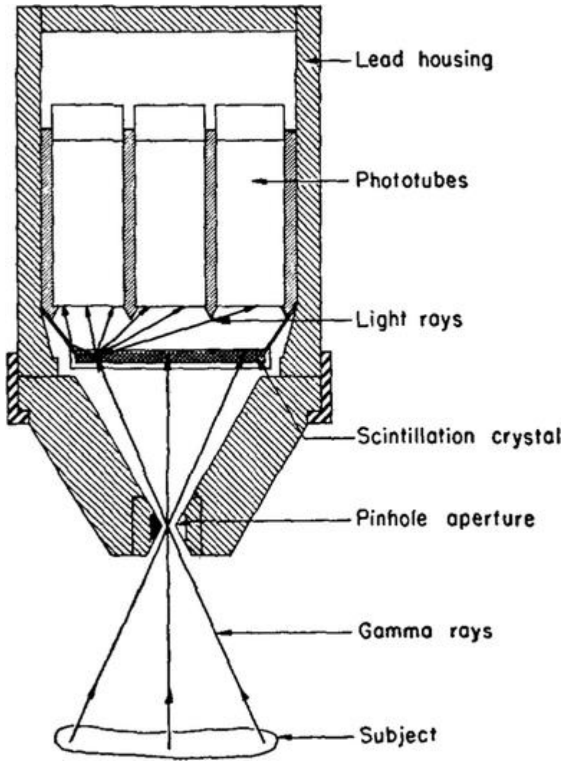
FERS Front-End Electronics

- 5202 card based on two Weeroc CITIROC ASICs (32 channels each): 64-channel charge-sensitive front-end with dual shaping per channel
- On-board TDC and 12-bit ADC per channel; FPGA manages acquisition, triggering, and TDlink readout
- Same modular ASIC-based platform is reused across HEP, muon tomography, PET, ... and now neutron imaging



Event Reconstruction

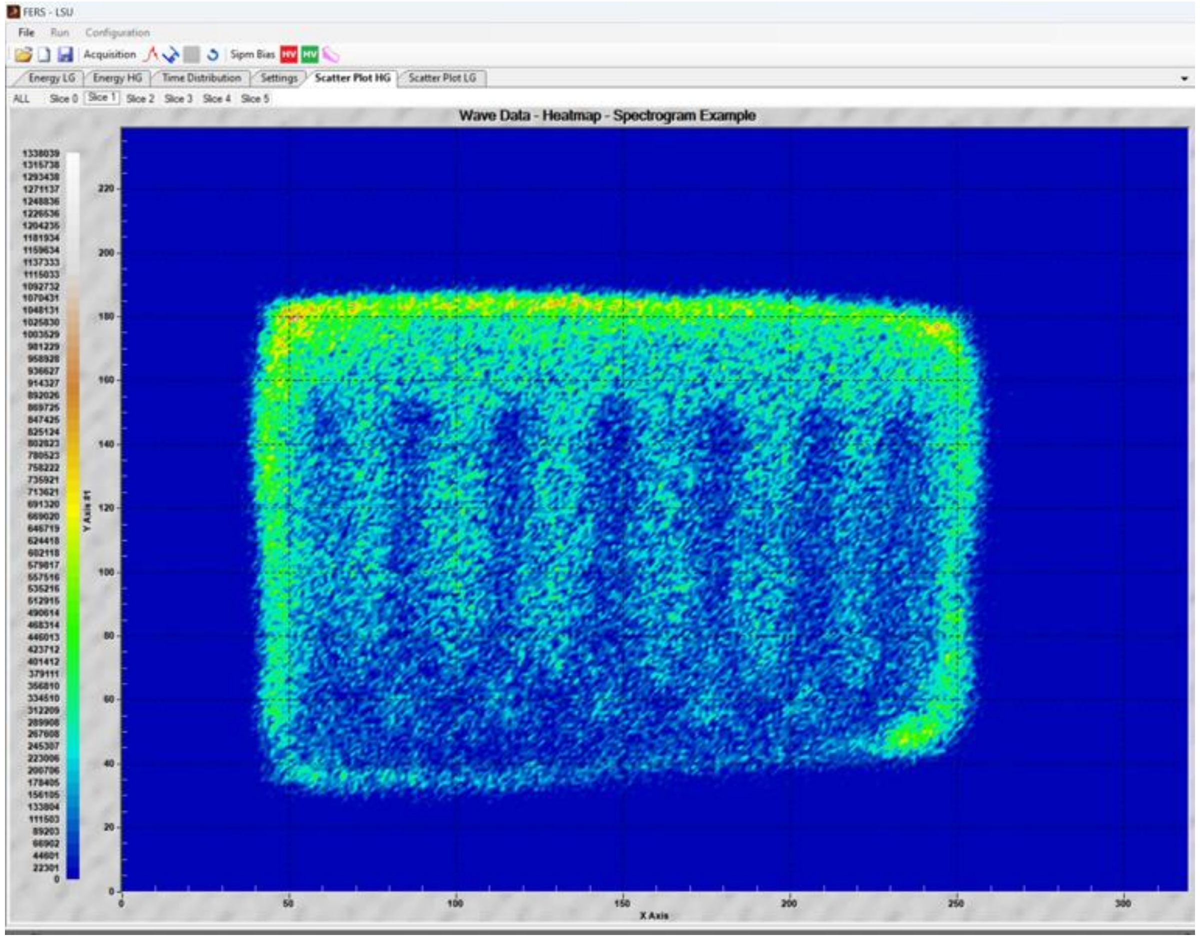
192-channel SiPM light distribution → Center-of-mass algorithm → Sub-pixel interpolation → **320 × 240 virtual pixel image**



- Anger-camera style reconstruction: the position of each event is computed from the centroid of light spread across neighboring SiPMs
- Interpolation between channels achieves sub-pixel resolution, well beyond the physical 6.1 mm SiPM pitch
- Reconstruction runs online during acquisition (Janus-based FERS software)

Spatial Resolution Results

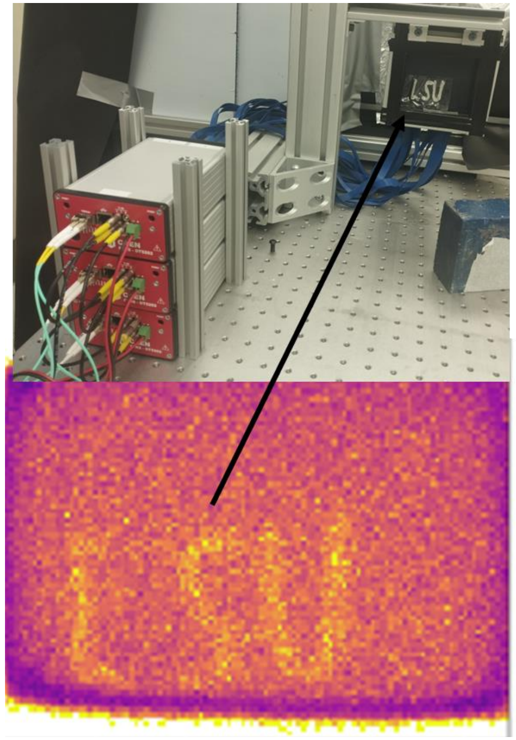
- Characterization performed with a deuterium–tritium (D-T) neutron source
- Edge-spread function (ESF) analysis on sharp-edge and slit-mask phantoms
- **Effective spatial resolution ≈ 0.3 mm**
- well below the 6.1 mm physical SiPM pitch — confirms the effectiveness of the Anger reconstruction
- Good linearity and uniformity across the full 96 × 72 mm^2 active area

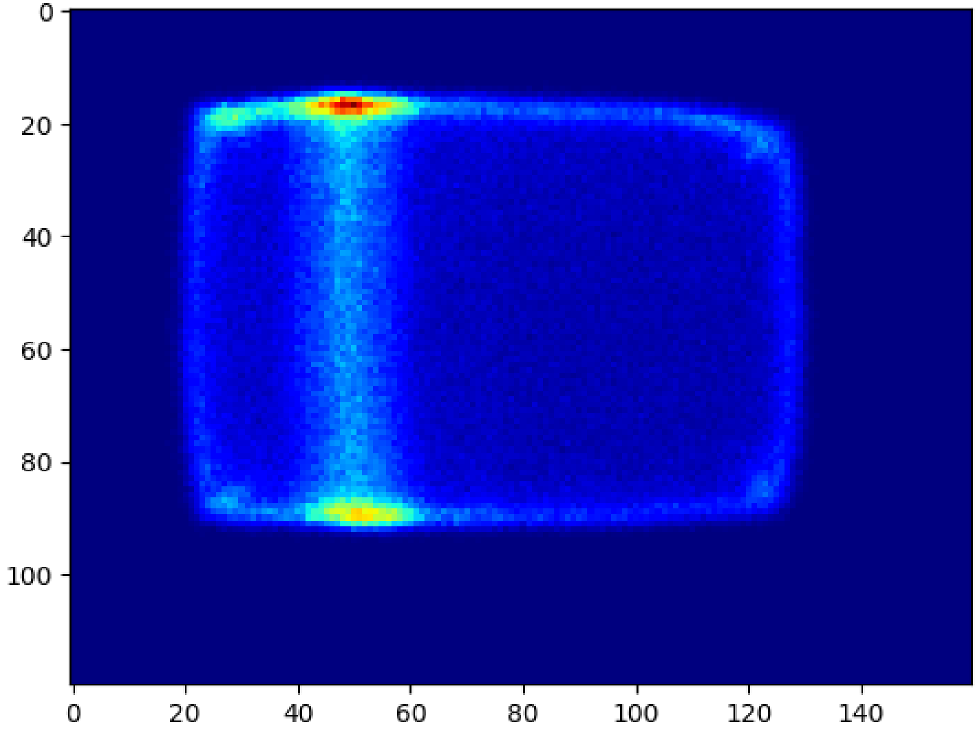


Slit-mask phantom image — FERS-LSU acquisition software

Real-Object Radiography

- Radiographic imaging of test objects at Louisiana State University
- Steel spring and “LSU” letters cut from lithiated resin, imaged in the collimated neutron beam
- Fine structures clearly resolved — consistent with the sub-mm ESF measurement





Courtesy M. Bleuel, G. Schneider (Louisiana State University)

Timing Resolution & Time-of-Flight

- Each FERS channel provides a Time-of-Arrival stamp from an on-board TDC
- Preliminary timing measurements demonstrate a resolution of approximately 1 ns
- Enables Time-of-Flight (ToF) based, energy-resolved neutron imaging at pulsed sources
- Two acquisition modes: integrated (fast, no timing) and frame-based / list-mode (event-by-event, ToF-tagged) with online reconstruction

~ 1 ns

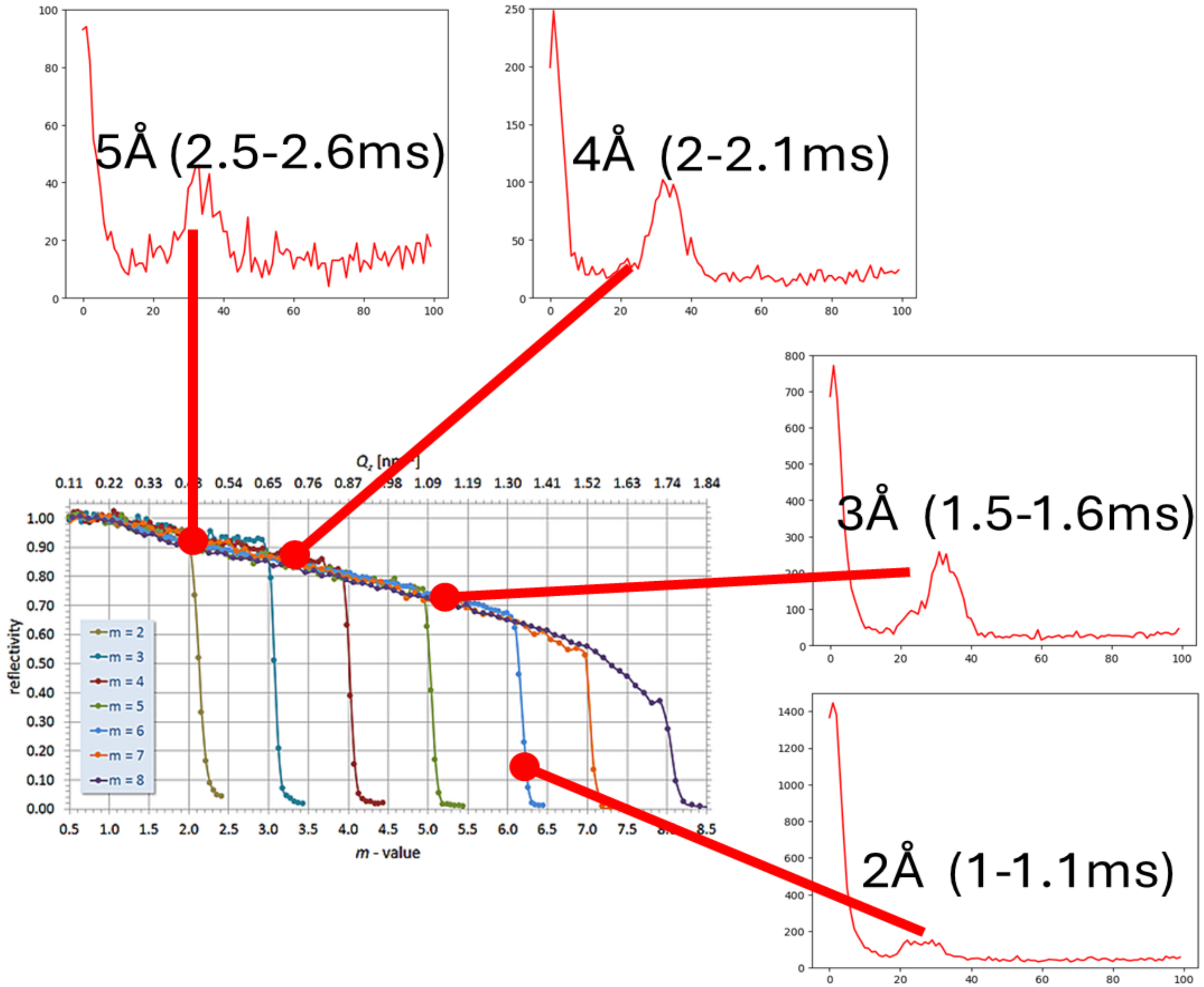
RMS timing resolution per channel

Neutron wavelength from ToF:

$\lambda\ [\text{Å}] = 3.956 \times ToF\ [ms] / L\ [m]$

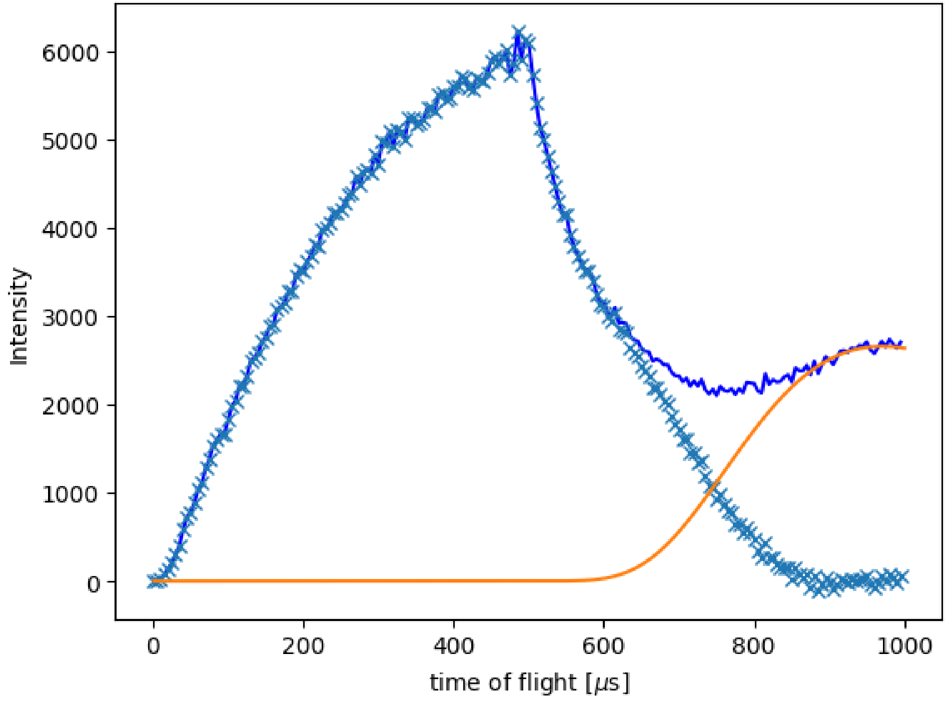
Application: SANS & Reflectivity at Pulsed Sources

- Reflectivity of a Swiss Neutronics supermirror: direct and reflected beams recorded in the same frame
- Intensity ratio vs wavelength gives the reflectivity curve R(Q) directly
  - $Q = (4\pi/\lambda)\cdot\sin\theta$ — θ from the event position, λ from time of flight: one fixed geometry covers the whole Q range, no goniometer scan (white-beam method)
- **SANS and reflectometry with one detector, in a single exposure**
  - Steps at m = 2–8 are the successive critical edges of the Ni/Ti multilayer: $Q_c \approx m \times 0.0217$ Å^{-1}
  - The same ToF slicing gives SANS maps over Q ≈ 0.001–0.3 Å^{-1}

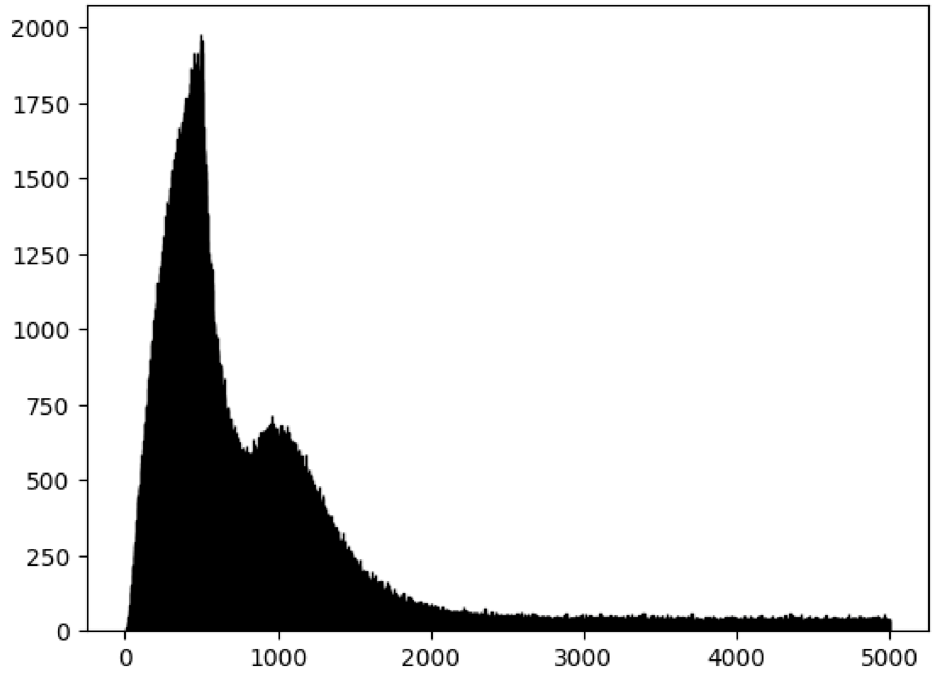


Application: Pulsed-Source Time Structure

- Nanosecond-level timestamping resolves the full pulse time structure at the detector
- Prompt gamma / fast-neutron flash clearly separated from the delayed, moderated thermal-neutron peak
- Enables direct diagnostics of moderator performance at pulsed neutron sources



Direct-beam intensity vs. time-of-flight



Pulse-height spectrum: gamma + neutron components

Conclusions

- A compact SiPM-based neutron Anger camera has been demonstrated as a proof-of-concept for large-area imaging systems
- **Sub-millimeter spatial resolution (≈ 0.3 mm) achieved via Anger-style center-of-mass reconstruction**
- **≈ 1 ns timing resolution enables ToF-based, energy-resolved neutron imaging**
- Validated on real applications: radiography, SANS/reflectivity, and pulsed-source moderator diagnostics
- **Establishes SiPM-based Anger cameras as a scalable architecture for next-generation neutron instrumentation**

Thank you for your attention

Visit us at CAEN booth to see the FERS system

Acquisition Modes & Online Reconstruction

Integrated mode

Fast frame acquisition — ideal for high-flux imaging, alignment, and real-time monitoring

Frame-based / list mode

Event-by-event, ToF-tagged acquisition — enables energy-resolved and time-resolved imaging

- Janus acquisition software: open-source, Python GUI with C/C++ readout engine
- Live spectra, imaging, and statistics displays during acquisition
- Up to 300 MB/s throughput via the DT5215 concentrator (10 GbE or USB 3.0)