A Distributed Data Acquisition System for Nuclear Detectors

European H2020 C-BORD project

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Overview

- C-BORD Project
- C-BORD Electronics and DAQ Requirements
- Distributed Data Acquisition System
- Conclusions and Prospects

C-BORD Project

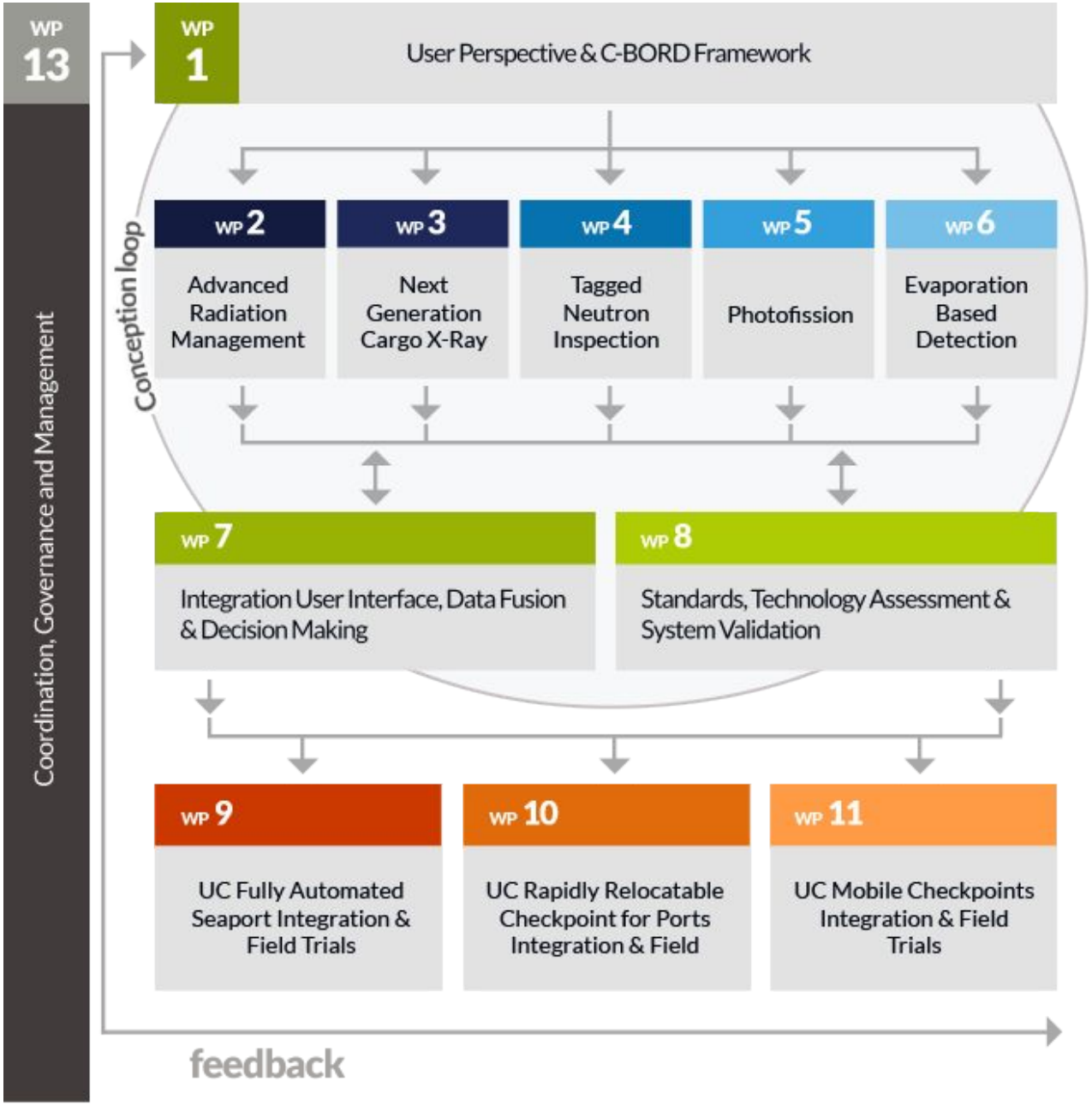
effective Container inspection at BORDer control points

C-BORD Project

- Container security is an important factor in overall EU border security, and efficient NII (non-intrusive inspection) of containerised freight is critical to trade and society.
- The most effective array of screening technologies should be selected: the C-BORD Toolbox.
- The best results are expected when (at least) two independent technologies are employed in conjunction: the C-BORD Framework.
- C-BORD develops five technologies to enable next generation container NII at EU sea and land borders:

  Advanced Radiation Management / Next Generation Cargo X-Ray / Tagged Neutron Inspection / Photofission / Evaporation Based Detection

- Live field trials will show proof of capabilities: three use cases under real conditions at different border control points.

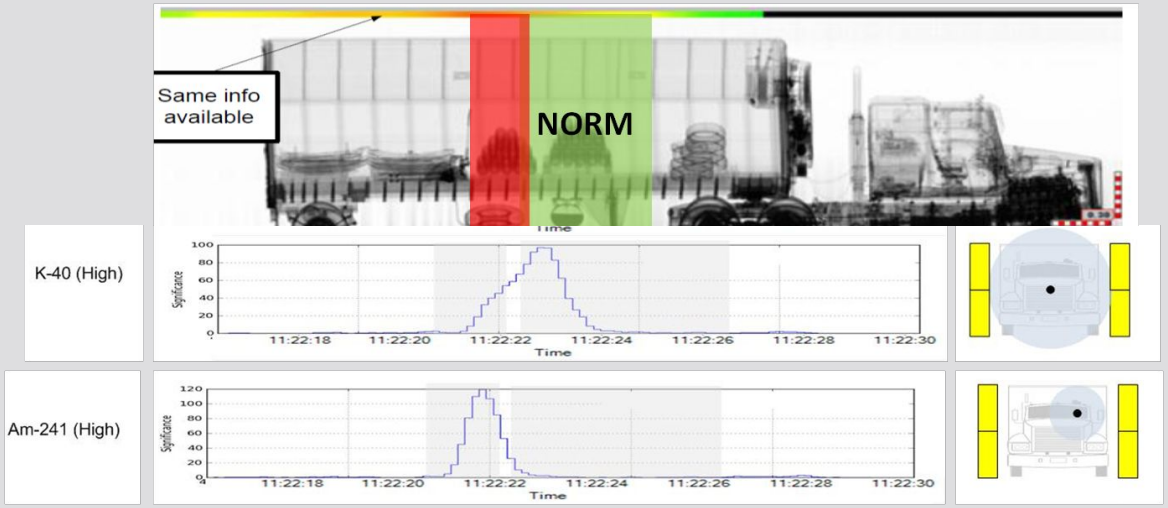


Work packages

The C-BORD project is divided in 13 work packages. Each one of them is handling an aspect of the project.

Advanced Radiation Management

Passive Neutron and Gamma Detection Sub-systems

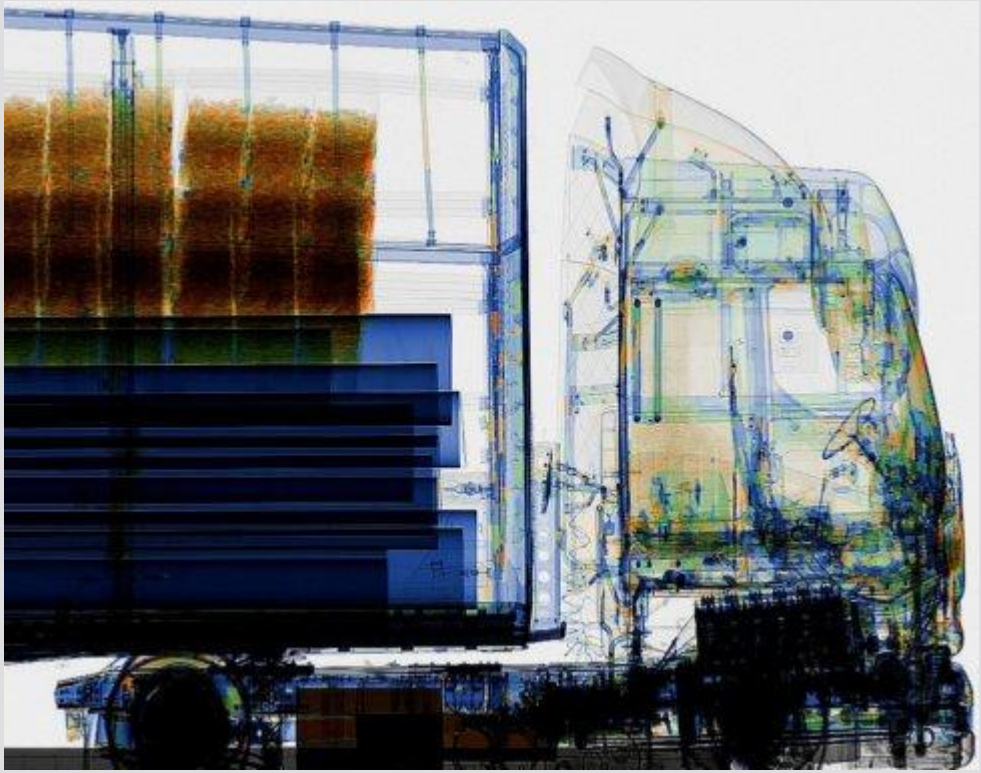


- Spectrometers for low false alarm rates on Naturally Occurring Radioactive Materials (NORMs)
- Detection system adapted for non-stop, higher speed lorry transits with SNM specific and material discrimination capabilities.

Mobile systems

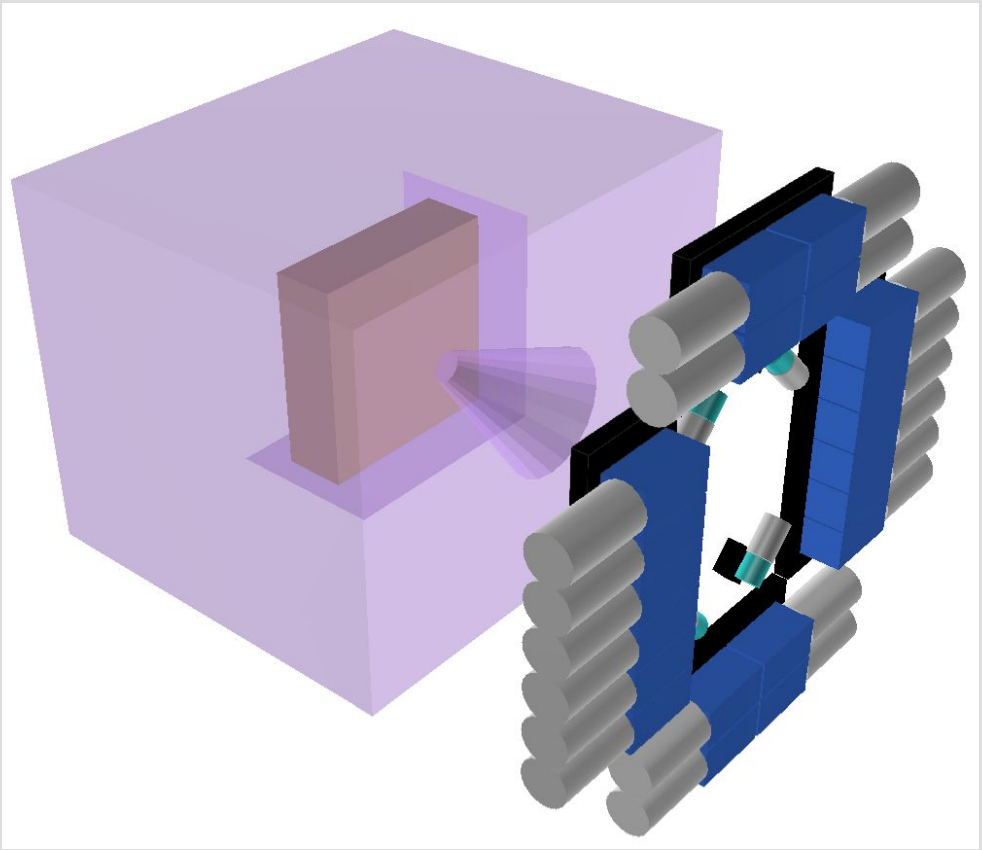
Fixed and relocatable portals

Next Generation Cargo X-Ray



- Global X-ray image improvements, corrections from:
  - the effects of the scattered radiation
  - the effects of the variation of the dose and energy of the incident beam
- Chemical separation of overlapping objects.
- Improved material classification in the organic range: solution to the problem of overlays.

Tagged Neutron Inspection System

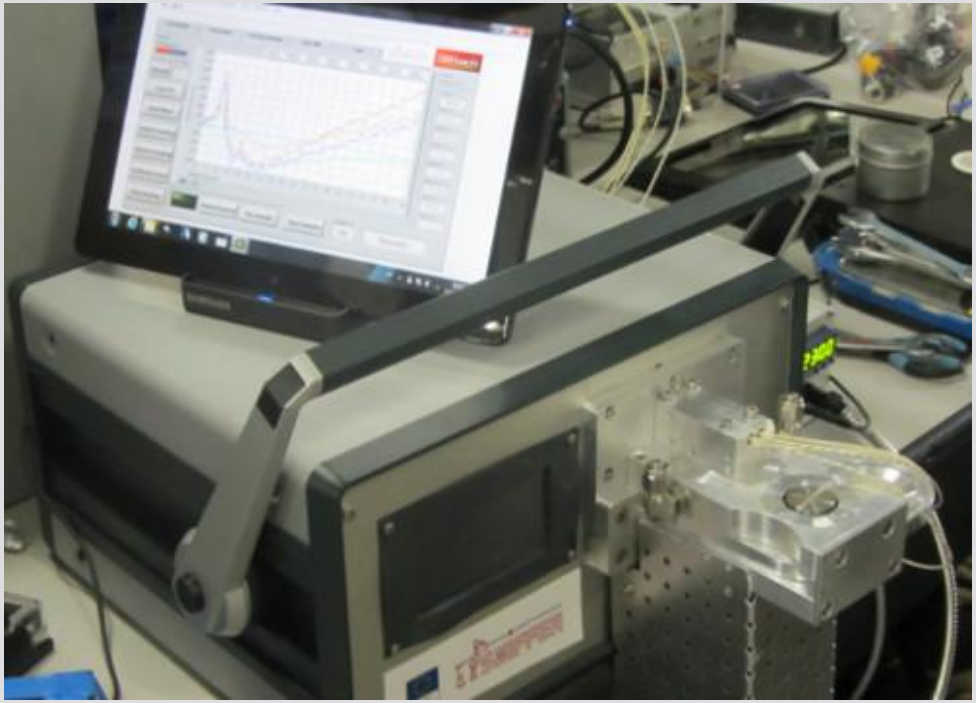


- Uses an associated-particle neutron generator to detect explosives or other threat materials.
- The neutron generator is used to produce a 14 MeV neutron and an alpha particle through the fusion reaction:
  $D + T \rightarrow \alpha + n$
- Gamma rays induced by neutron inelastic scattering on the elements of the cargo material are detected.

Photofission

- Fission reactions are induced by 9 MeV X-rays delivered by a linear electron accelerator (LINAC)
- Detectors dedicated to the measurement of
  - Prompt and delayed particles emitted by fission products,
  - Delayed neutrons,
  - Prompt neutrons,
  - Delayed gamma-rays.

Evaporation Based Detection

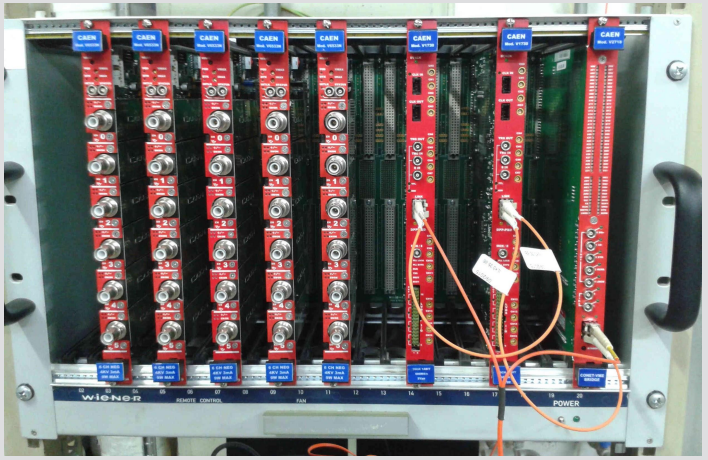


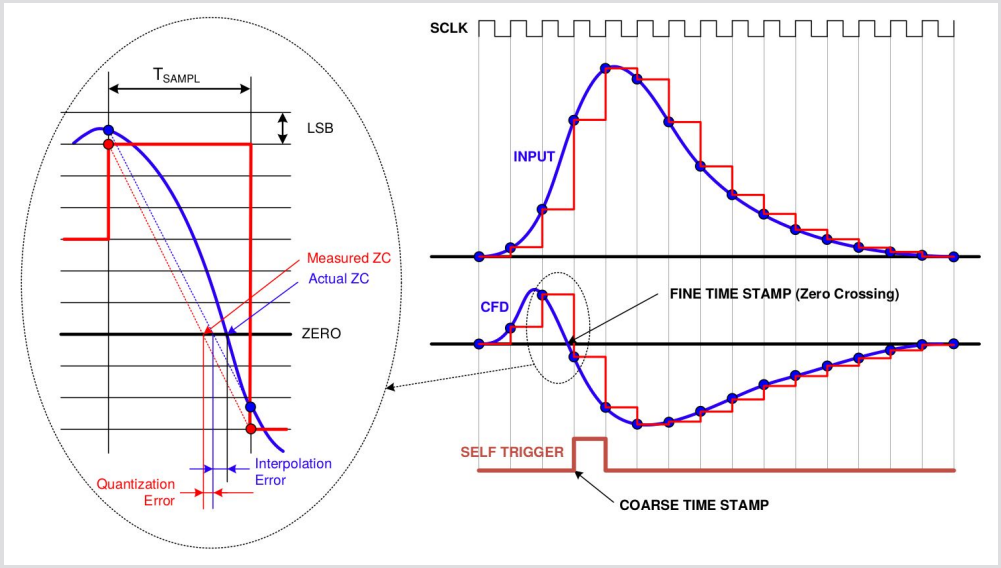
- Selective binding elements from biological systems are coupled with highly sensitive diamond microcantilever detectors.
- Machine learning algorithms enhance the detection capabilities by comparing the results with a database of materials.

C-BORD Electronics & DAQ Requirements

DAQ Electronics

- Two CAEN V1730 digitizers,
  16 ch, 14 bit, 500 MS/s.
- Five CAEN V6533 HV Power Supply,
  6 Channel 4 kV/3 mA.
- CAEN V2718 optical bridge





- A new firmware for the V1730 was developed with an embedded Constant Fraction Discriminator

Ref. CAEN Application Note AN5111
BaF2 and LaBr3 Time Measurements with a 500 MS/s Digitizers

Project Requirements for DAQ

The project's book of requirements listed the specifications for the new DAQ:

- Read data from CAEN V1730 signal digitizers;
- Control CAEN V6533 high-voltages modules;
- Able to read data rates of 200 kevt/s per digitizer channel;
- Must interface with the project's data framework;
- Easy interoperability with modules developed by other groups of the project;
- On-line analysis capabilities;
- Reliable and fault-tolerant.

Distributed Data Acquisition System:

ABCD

Acquisition and Broadcast of Collected Data

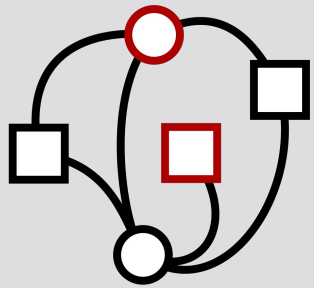
Proposed Solution: ABCD

Acquisition and Broadcast of Collected Data

A new DAQ was developed according to the following paradigms:

- Each task related to the DAQ runs in a different process;
- Communication is obtained through network sockets;

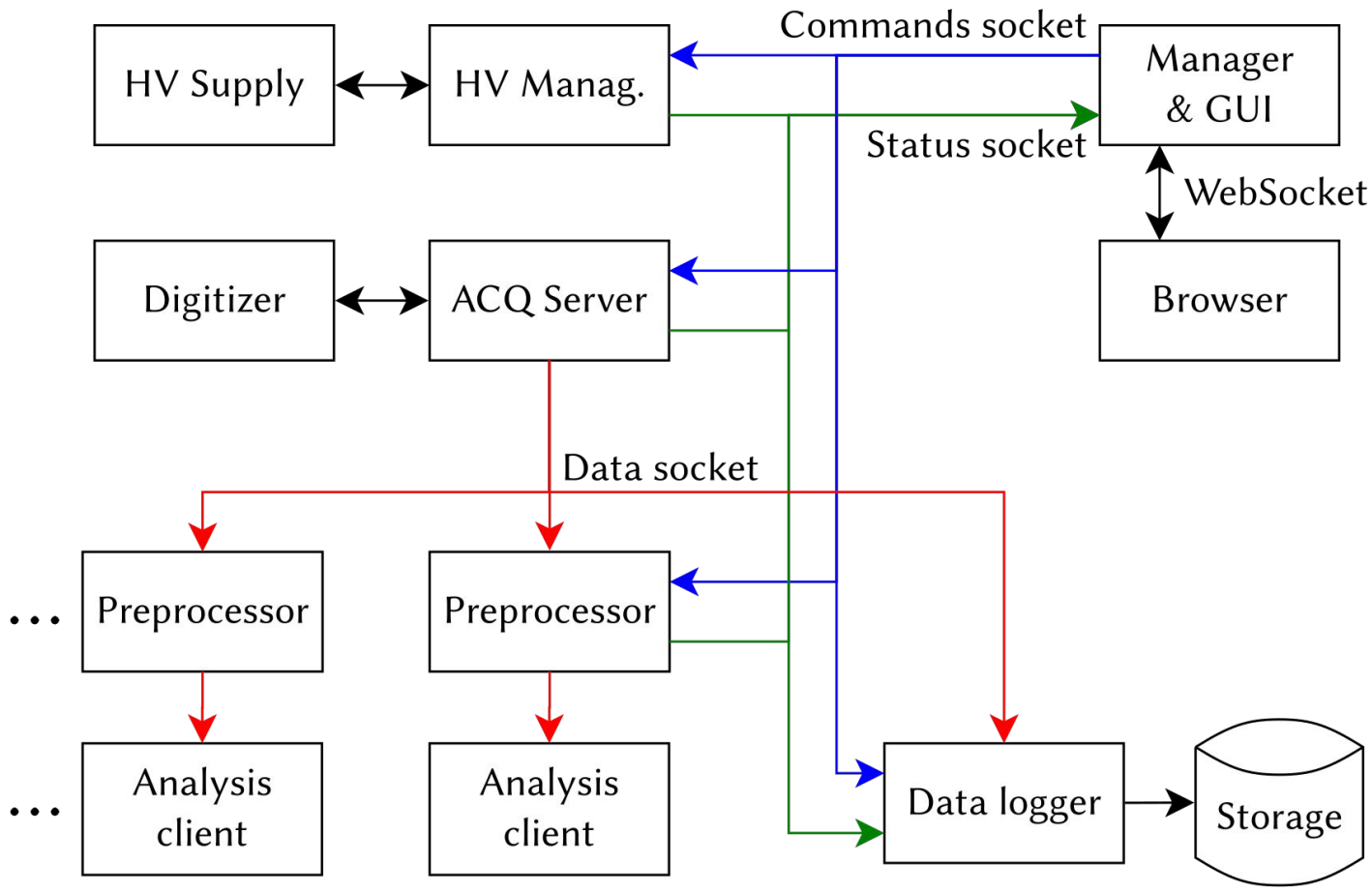
Distributed system



- The single processes are designed to be as simple as possible: easier development phase;
- Implemented following the finite state machines paradigm.

Reliable and fault tolerant

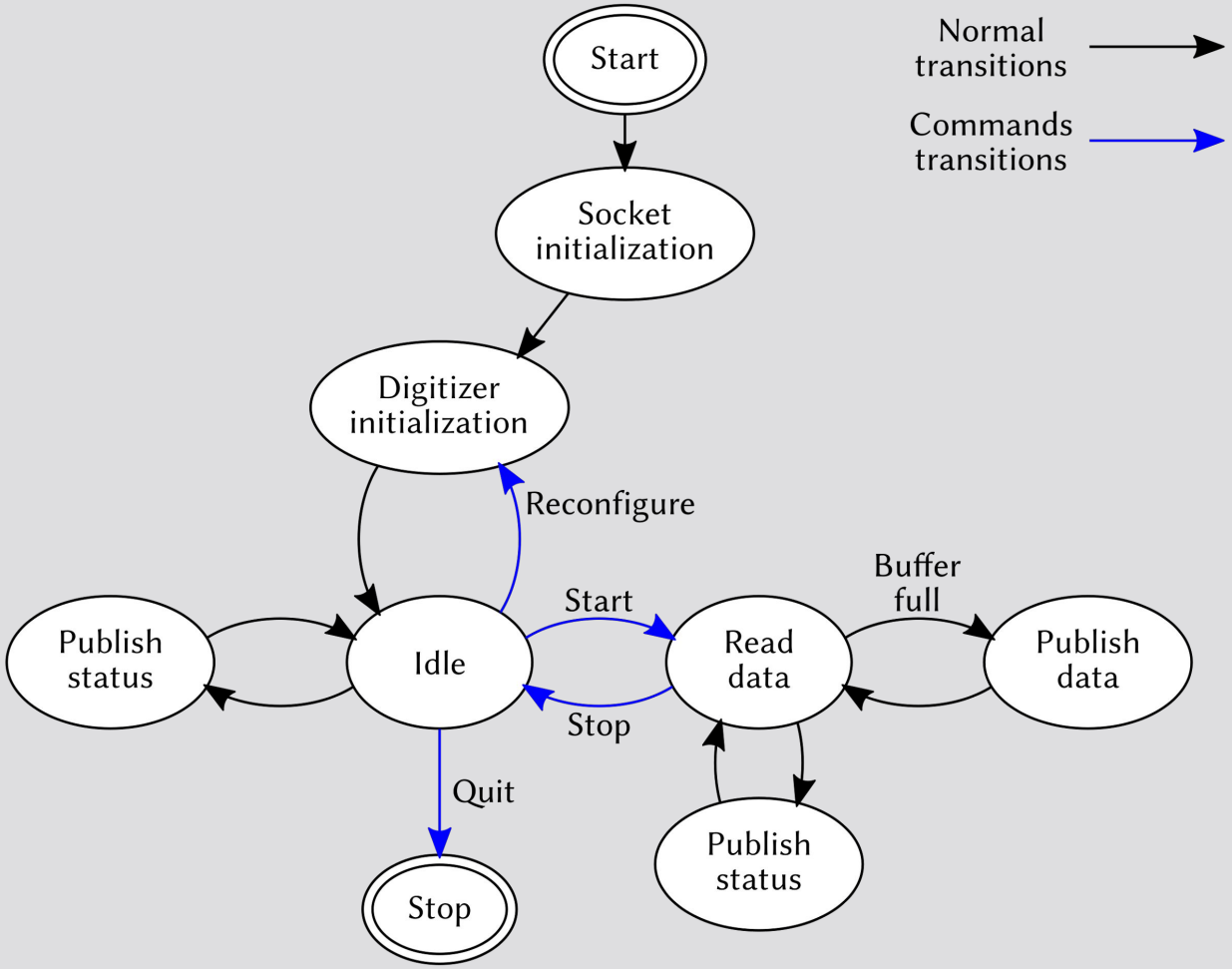
DAQ System Diagram



Boxes: separate processes

Arrows: Communication channels over the network

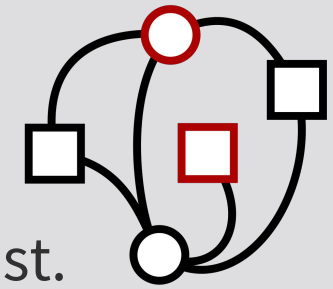
Hardware Interfacing Processes



- Implemented following the finite state machines paradigm.
- Single threaded to simplify development and therefore improve stability and reliability.

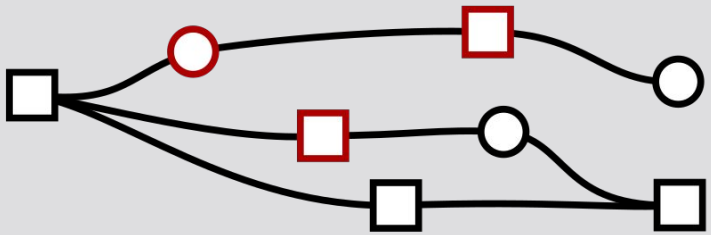
Communications

- Communication between processes is implemented through the ZeroMQ messaging library. http://zeromq.org/
- Data is delivered through a *publish* socket, that allows several processes to read all the messages at the same time.
- High performance data-streams are *serialized* in a custom binary format.
- High-level data streams (statuses, commands...) are serialized as JSON objects.
- Simplified collaboration: each process can be independently developed and then attached to the network.
- On-the-fly changes of network structure are permitted, making the system versatile.
- Heterogeneous programming languages can coexist.



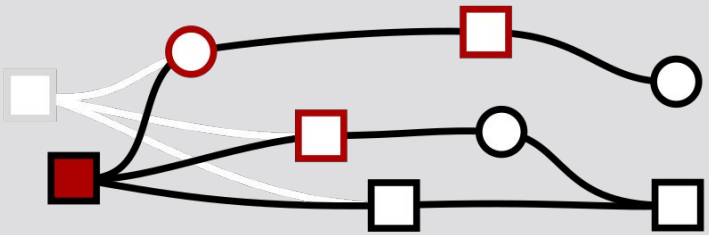
On-line data processing

- The distribution of data-streams over several processes allows to have different types of analyses to run in parallel on-line, on the same data.
- Data is distributed with an uniform protocol of communication: the data processors can be dynamically connected to each other.
- The distributed nature of the system allows to share the computational load over different computers.

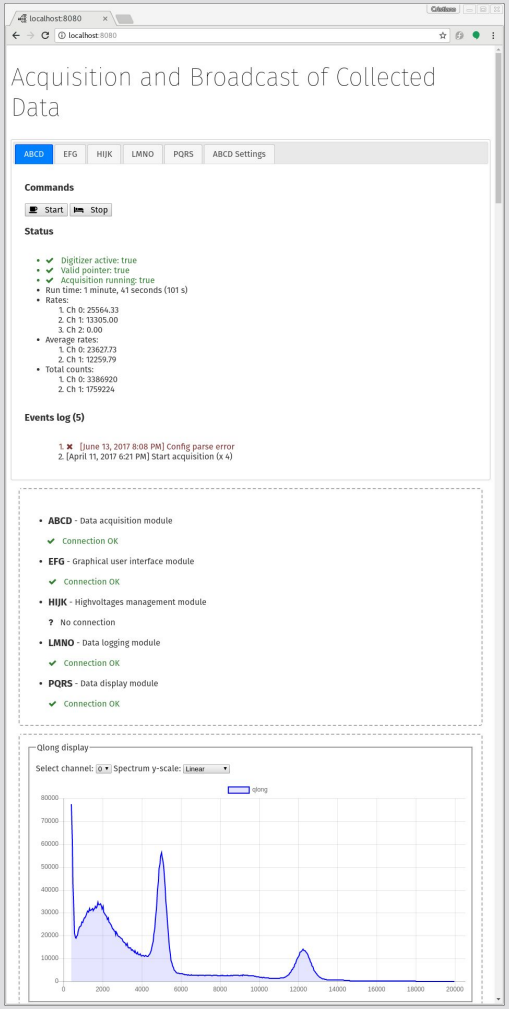


Data logging and simulation

- Obviously, data-streams can be saved.
- Most importantly, they can be “replayed” simulating a full working system.
- The simulator greatly simplifies the development of on-line data analysis software.



ABCD Graphical User Interface



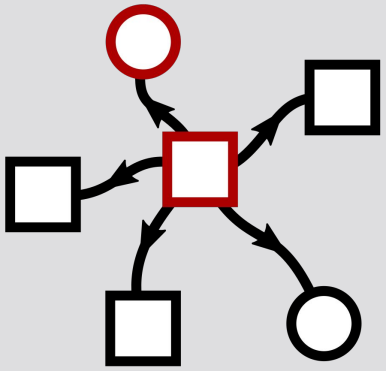
- In order to simplify interoperation, the user interface was implemented as a web-service.
- Any user can connect to the DAQ computer with a web-browser and remotely control the DAQ.
- Websockets ensure scalable and fast communication between the browser and the GUI process.

- For C-BORD, another GUI is being developed in the project's framework.

System Manager

- Each experiment has different peculiarities and control logic.
- All the processes can be used as they are in most situations.
- A manager may be implemented tailored to the experiment.
- The manager could operate the DAQ: checking its environmental conditions and interfacing with a more complex network.

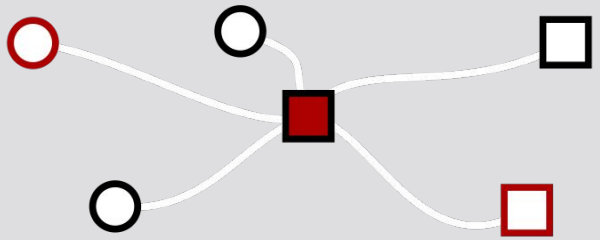
- In the case of C-BORD, the manager is provided by the project's framework.



Performances

- The system has been installed at UniPD (Italy), Laboratori nazionali di Legnaro (INFN, Italy) and CEA Cadarache (France) and is currently being used in the C-BORD's daily activities.

- Stability: We have an ongoing acquisition that was started few months ago, that is still running.
- Acquisition rate: The system was proved to be able to sustain the required rate.



Conclusions & Prospects

- A new DAQ system was developed for the C-BORD project.
- The system was developed to be versatile and adapted to other experiments.
- The distributed architecture of the new system has been showing great results in terms of stability and performance.
- Could be easily controlled remotely, using only a web-browser.

- The system was also adapted to be used in the laboratory for Physics students at UniPD.
- We are releasing soon the sources as an open-source project, in order to allow to other groups to use it.

Thank You!

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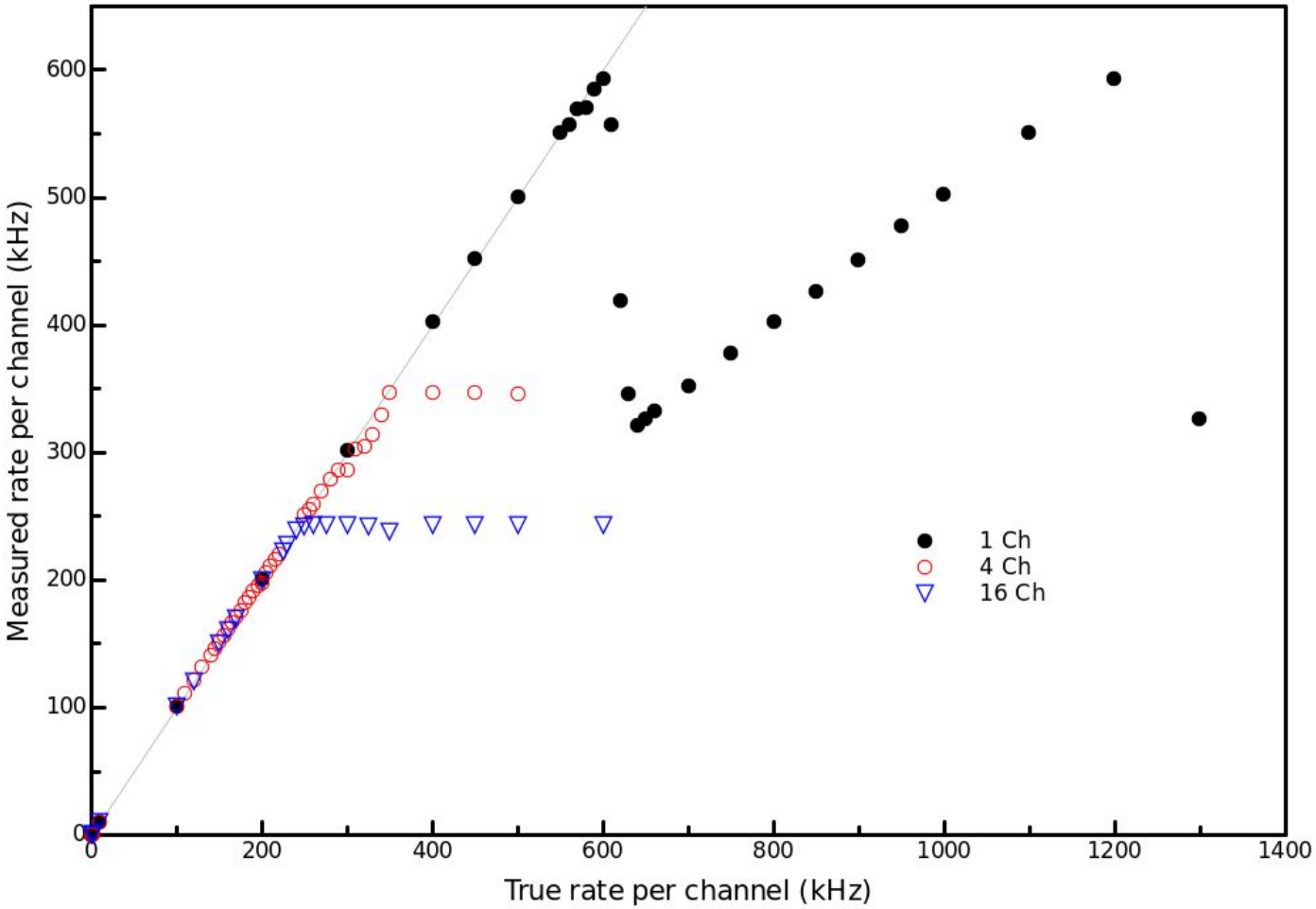
Back-up slides



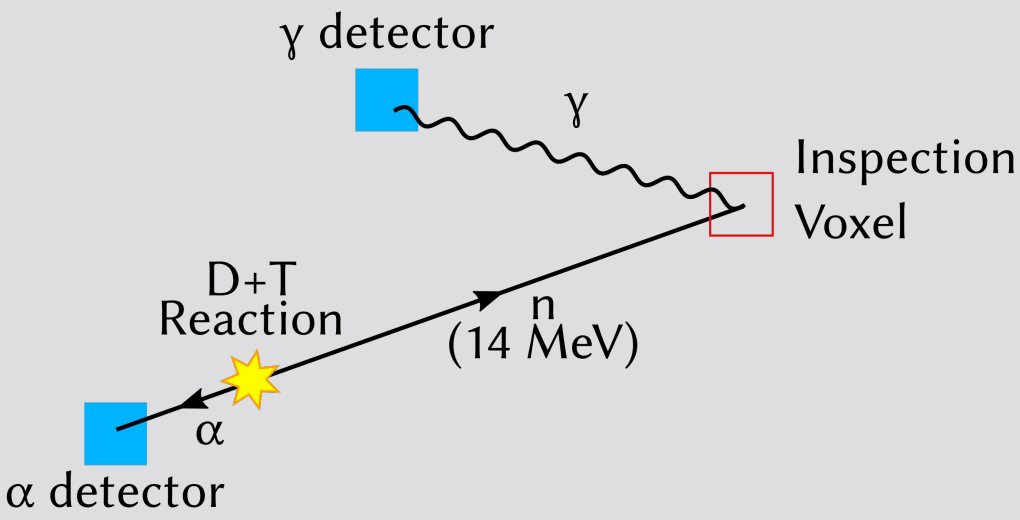
DAQ Performance measurements

A pulser simulated the incoming signals with a known rate per channel.

RRTNIS

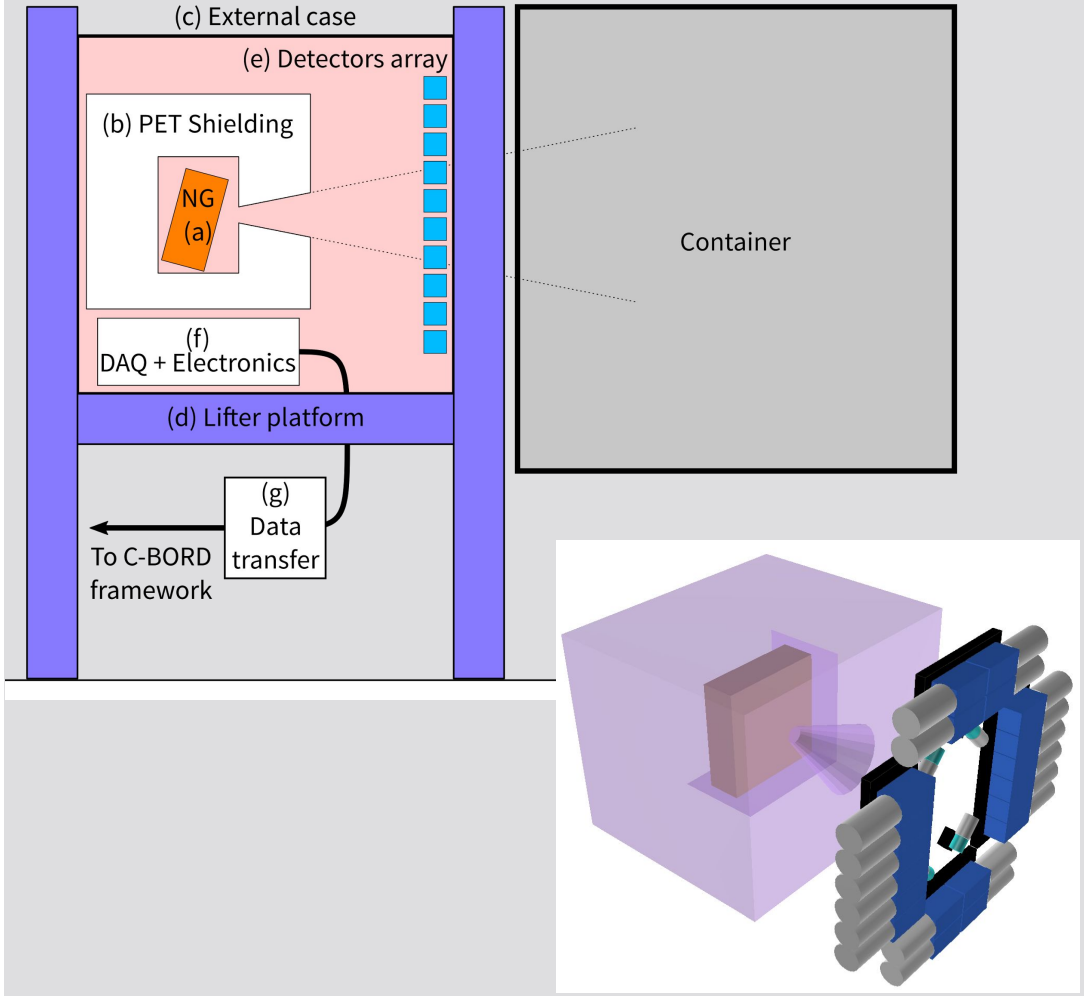
Rapidly Relocatable Tagged Neutron Inspection System

Tagged Neutron Inspection Technique



- Fast neutrons (14 MeV) from:
  D + T → α + n
- The collinear α tags the n.
- Voxel selection is given by time-of-flight (ToF) measurement and α direction.
- The γ spectrum at selected ToF depends on the voxel material.

RRTNIS Design



- RRTNIS is fully contained in a movable casing.
- γ detectors are in a back-scattering configuration.
- The whole system is moved to be aimed at the inspection voxel.
- 20 large (5” x 5” x 10”) NaI + 4 $LaBr_3$ (3” x 3”) detectors