List-mode Data Acquisition – a New IEC Standard

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ERNCIP Thematic Group on Radiological and Nuclear Threats to Critical Infrastructure

Coordinator: Harri Toivonen

ERNCIP fosters the emergence of innovative and efficient security solutions, through the networking of European experimental capabilities.

Analyzed topics:

1. List-mode data acquisition based on digital electronics
2. Robotics - radiation measurements with unmanned systems
3. Reachback - expert support to field teams

Solutions are needed to mitigate the threat to critical infrastructure from radiological attacks and contamination.

https://erncip-project.jrc.ec.europa.eu/

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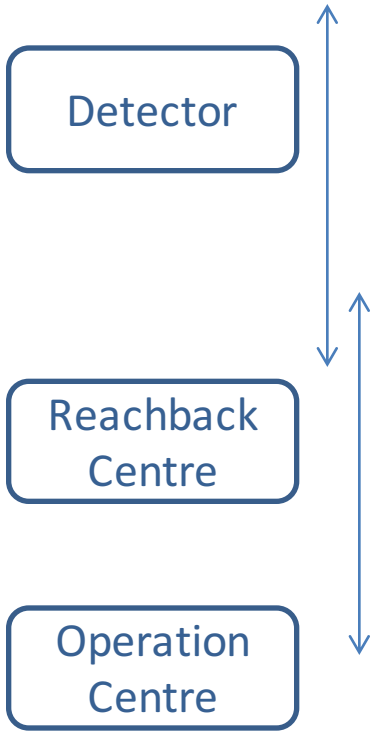
1. **Introduction - Detection Architectures**
2. **Detection Systems Today**
3. **Detection Systems Tomorrow**
4. **Example of List-mode Data Acquisition**
5. **Benefits of List-mode**

Part 2

Jan Paepen (EC) and John Keightley (NPL): A standard format for list-mode data, Project IEC 63047

Categorization of Terms for Nuclear Measurements and Related Information Products



1	**Raw data**	Time stamped events detected by instruments
2	**Data**	Spectra generated from raw data at certain intervals
3	**Information**	Messages in compact format (metadata, data, raw data, initial analysis results)
4	**Knowledge**	Verified information consisting of nuclide identification, activity estimation, …
5	**Wisdom**	Appropriate decision-making based on the attained knowledge. A message which is useful for the frontline officers to interdict.

COTS

Information Sharing Challenges

- Different needs by different users
- Message platforms vary (email, telephone,…)
- Vendor-specific data formats
- Detection architectures have large amount of sensors deployed for CBRNE detection

Formats and protocols for information sharing

Finnish LINSSI

NATO MAJIIC

US NIEM

EU/ERNCIP Initiative

- Use common interfaces for data exchange
- Upload data to a shared data server
- Give services to all relevant partners

The users exchange data through the server, not directly with each other

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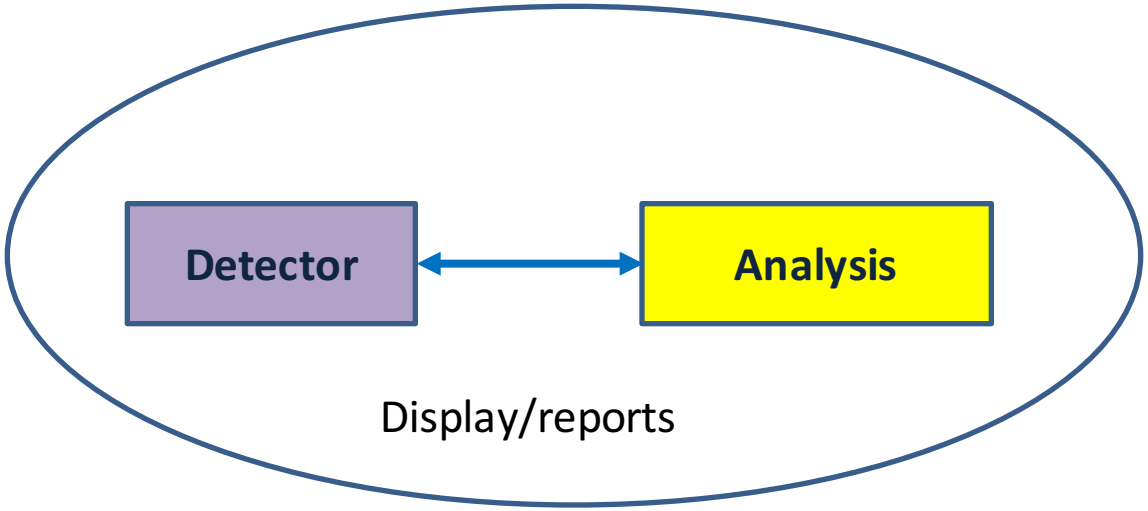
Part 1

Commercial RN Product Today – Lab Approach!

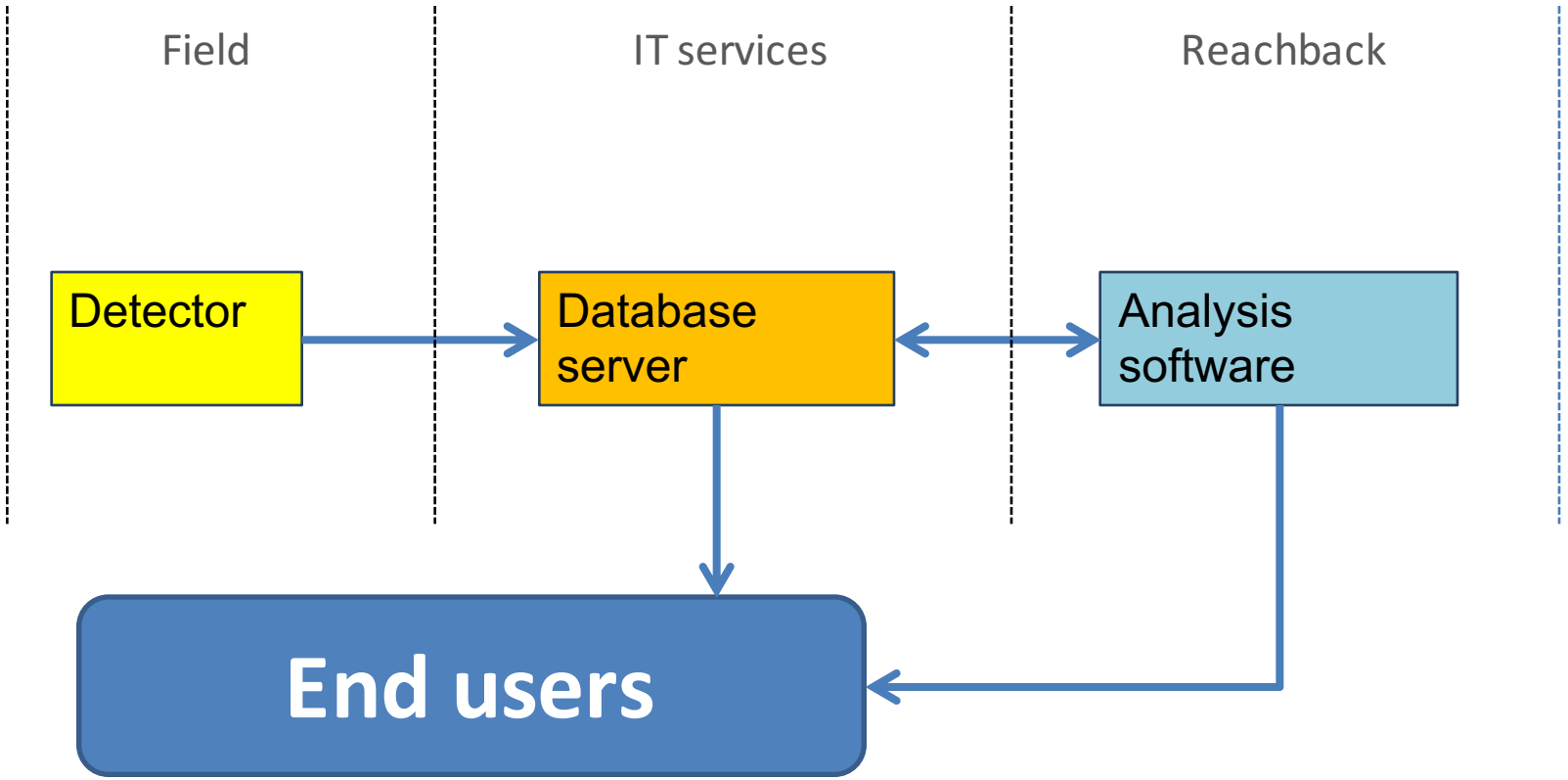


Problems in field applications:

- Handling of alarms: /false/innocent/true
- Information – not knowledge or wisdom

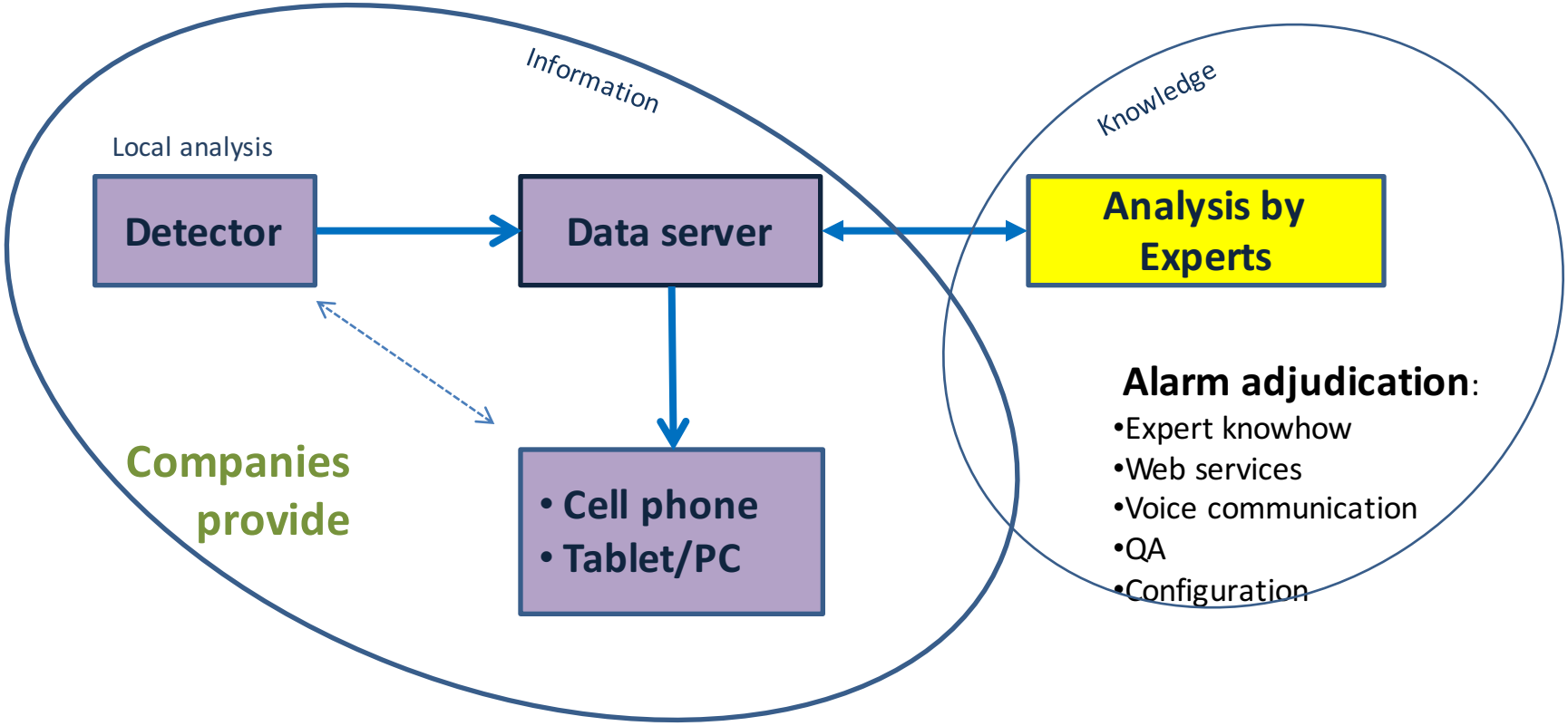
Separating Measurement and Analysis

Centralized Alarm Adjudication for Nuclear Security



Nuclear Security Detection Architecture

Finnish REPO Concept



Technical reachback needs robust data transfer:

1. **Prioritization of alarms**
2. **Recovery from breaks (no data lost)**
3. **Large amount of spectra (1 spectrum per second)**
   - **Clever data transfer algorithm (adapt to bandwidth, zip)**
4. **Encryption**

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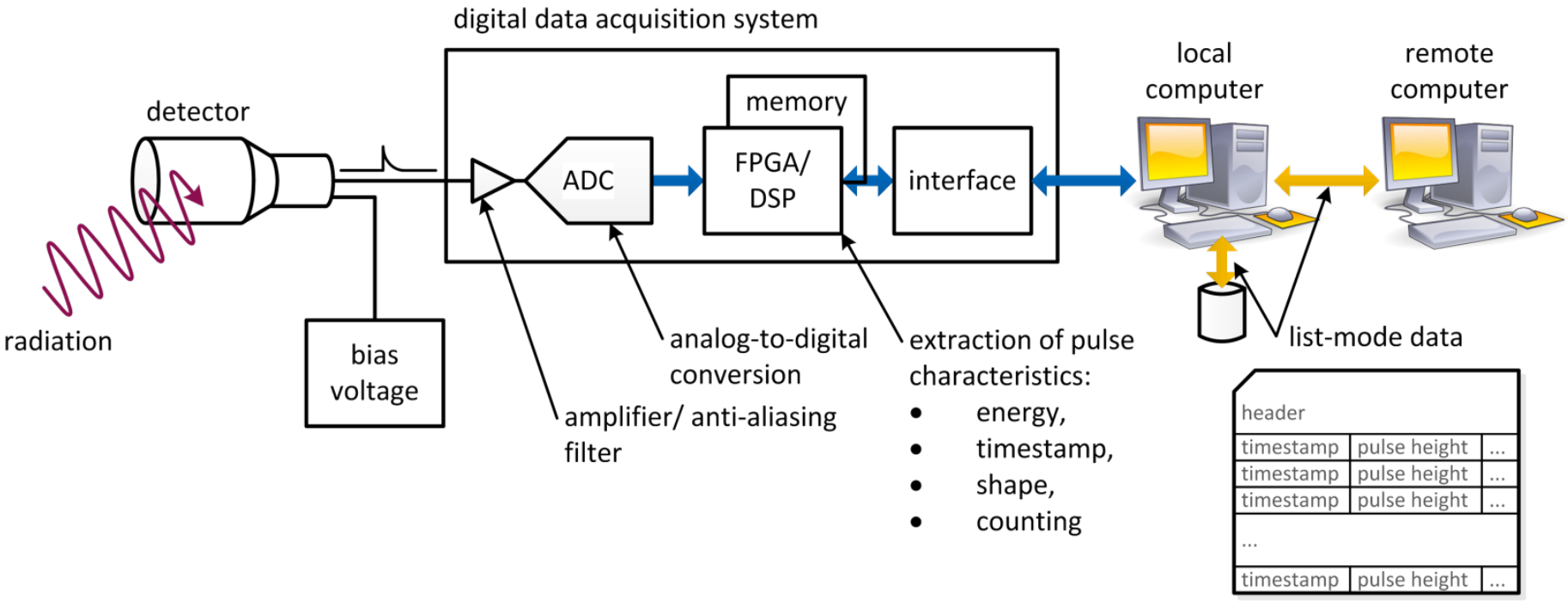
Digital Data Acquisition in List-mode



Main differences with conventional acquisition

- Analog-to-digital conversion at the beginning of the electronics chain
- Signal processing and logic in software/firmware

- # Conventional spectrometry

  (a) COTS equipment with MCA →

  Initial product: ***Spectrum***

  (b) Fixed data acquisition time

  Problems:
  1.[Vendor-specific formats]
  2.Optimization of data acquisition time
  3.Complexity of building detector arrays

- # List-mode spectrometry

  (A) COTS equipment in list mode →

  Initial product: ***List of events with time stamp***

  (B) Optimized data acquisition time decided during analysis
  (C) Straightforward to assemble detector arrays (time stamp)

  Problems:
  1.[Vendor-specific formats]
  2.Speed of data processing
  3.Synchronization of clocks
  4.Complexity of data analysis

Listmode Data Acquisition Standard (1/2)

ERNCIP 2013 – 2015

1. Pre-normative R&D → first elements for the standard → preliminary draft
   - two reports, one survey by ERNCIP RN Thematic group
2. Task launched by DG-HOME
   - based on EC report M/487 Phase II, executed by CEN/TC 391) : highest priority among 300 standardization proposals

R&D programme 2015 →

3. EC Horizon 2020: EMPIR 14SIP07
   - consortium: NPL, STUK, ENEA, CEA, JRC
   - objectives
     - draft listmode standard
     - development of software tools
       - manufacturers of security equipment
       - analysis support

Listmode Data Acquisition Standard (2/2)

IEC/TC45

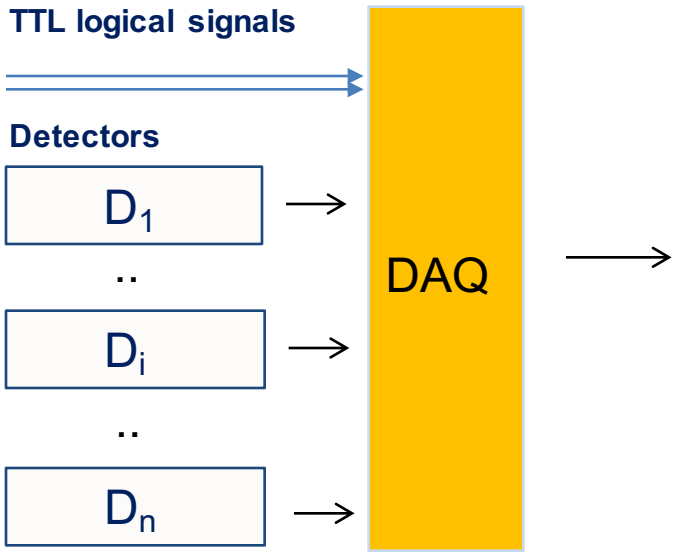
4. OCT 2015. JRC submitted a New Work Item Proposal (NWIP) to IEC/TC45 for the development of a new international standard. The NWIP was accompanied by a preliminary draft, developed by JRC in collaboration and agreement with the consortium partners.

5. FEB 2016. The NWIP was accepted by the IEC/TC45 National Committees.Firther dicussion in IEC/TC45/W9 meeting.

6. 2019. Expected date of publication.

JRC has lauched Call for Expression
- companies given opportunity to test the draft standard
- call open still for 2 years (2015/S 222-403785)

Efficient data acquisition is based on detector systems



Raw data

File or continuous stream

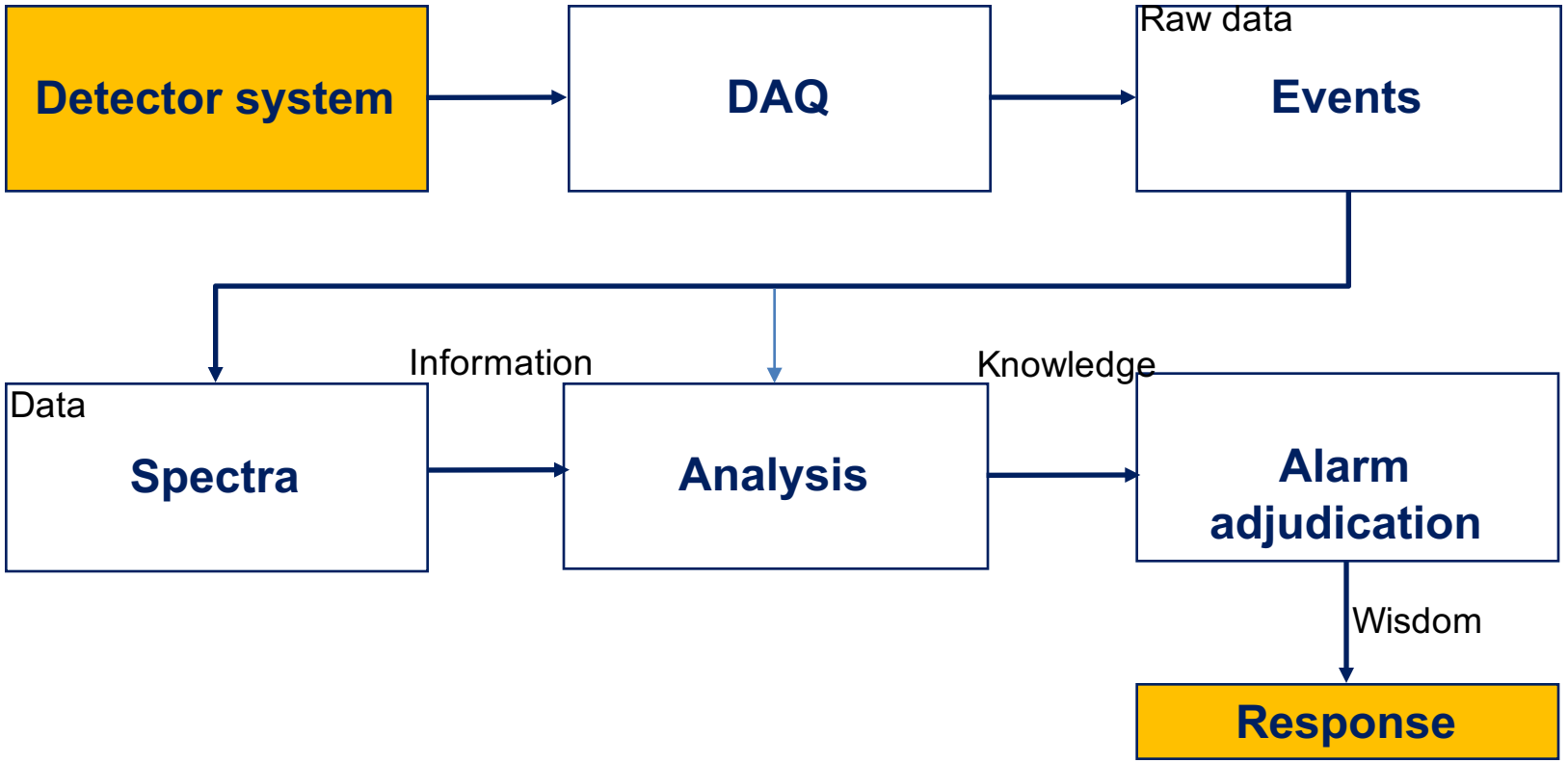
Events time stamped with resolution of Δt (typically 1-100 ns)

TTL

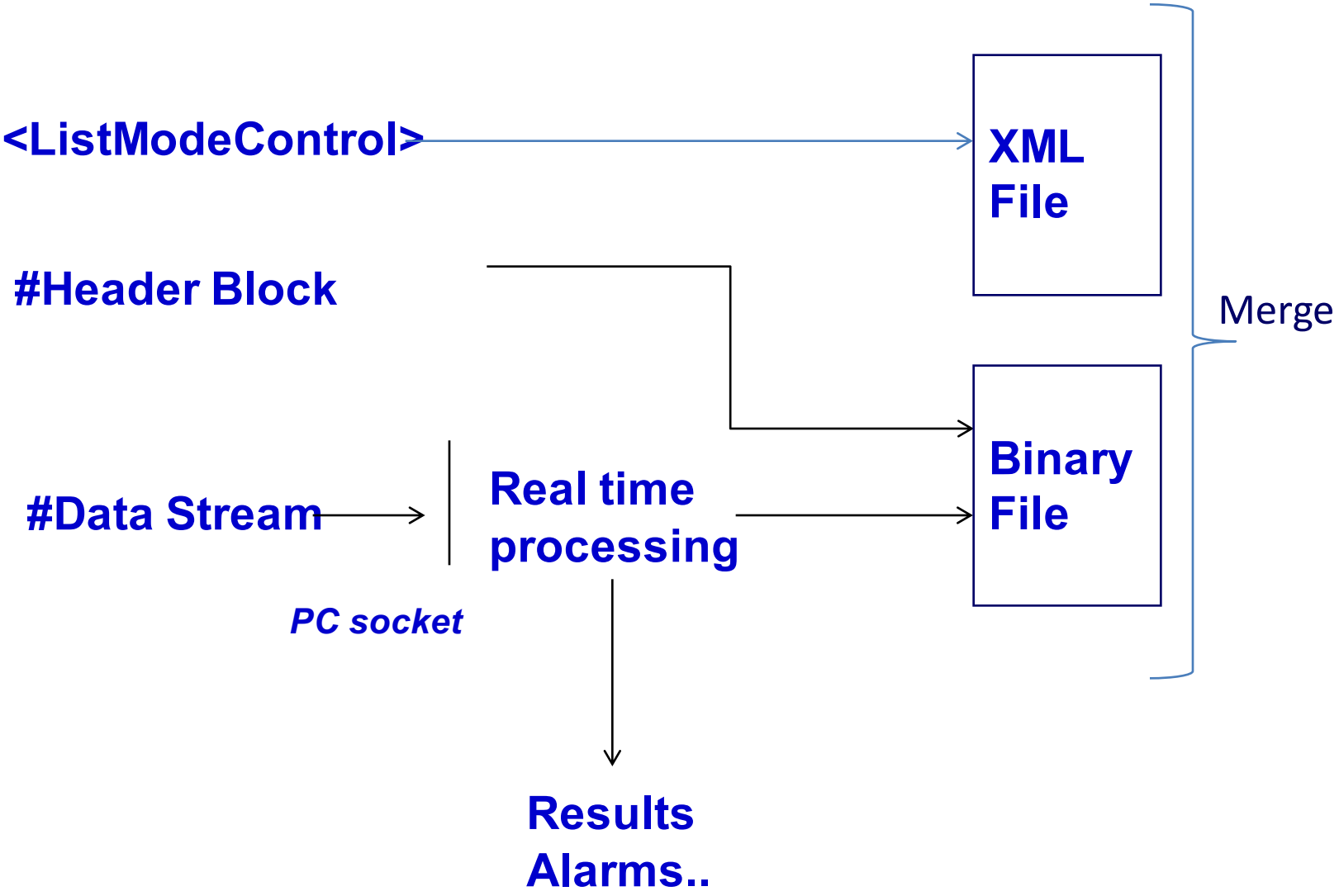
- Occupancy sensor
- Beam on/off
- Any 1/0 signal

- Spectrum is not any more the fundamental element of observation.
- Spectrum is a first analysis result, albeit pretty primitive.

From Detection to Response



List-mode Data Structures



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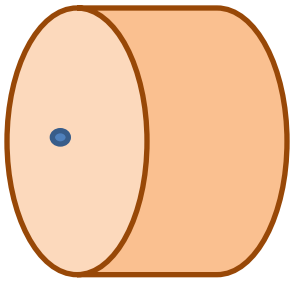
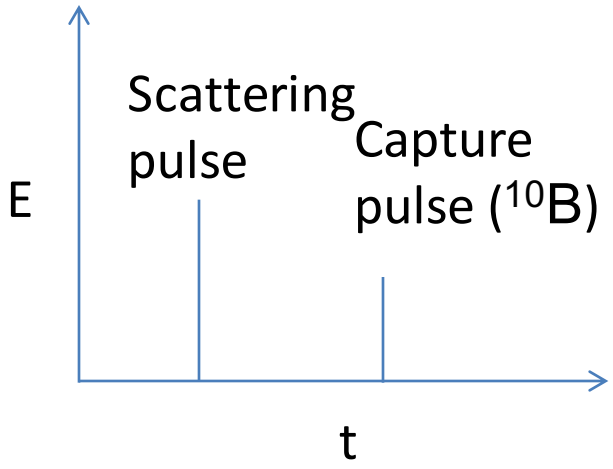
Part 1

Fast neutron measurement in listmode

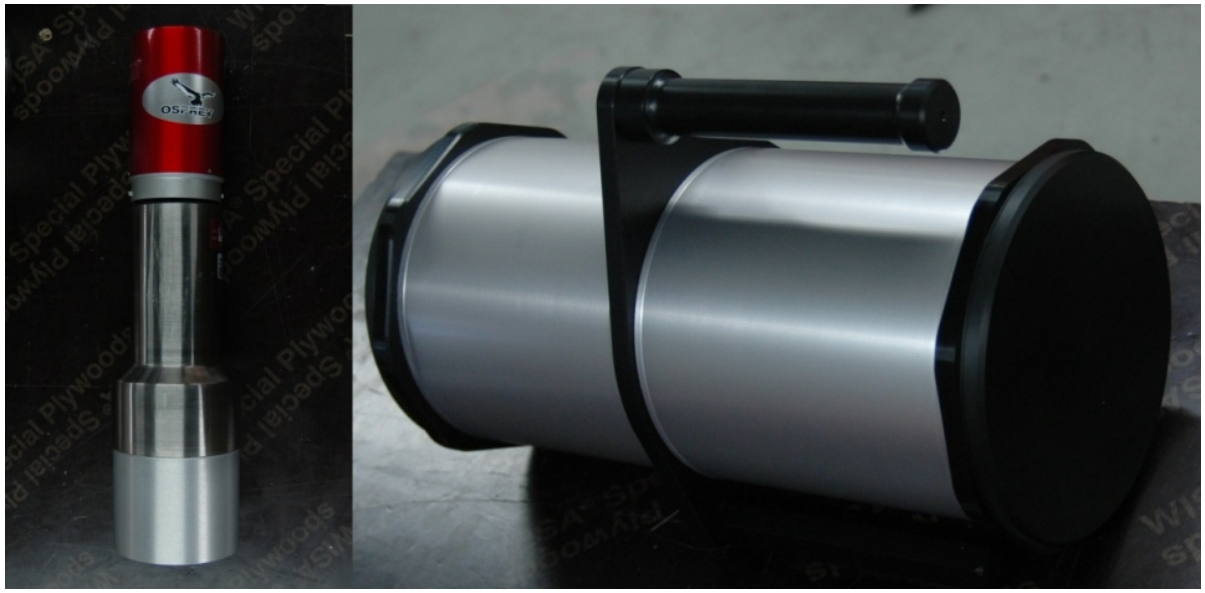
- Borated plastic scintillator
- Fast neutrons lose their energy in scattering reactions with hydrogen
  - Pulse height proportional to the energy of the neutron
  - The neutron is thermalized
- ^{10}B captures the thermalized neutron: $^{10}B(n,\alpha\gamma)^{7}Li$
  - Pulse with fixed height (76 keVee)





Portable capture-gated neutron spectrometer

- Cylindrical 3” x 3” borated plastic scintillator - EJ254 with 5% natural boron by weight, Eljen Technology.
- Coupled to a photomultiplier and a Canberra Osprey digital MCA.

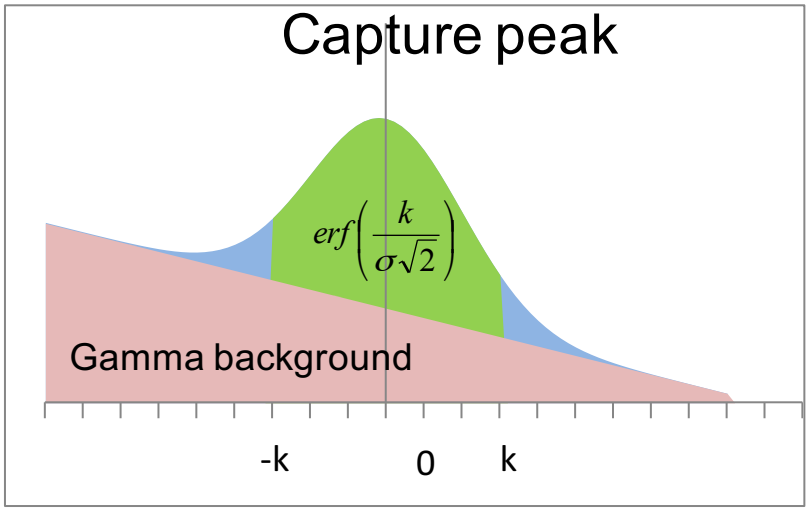


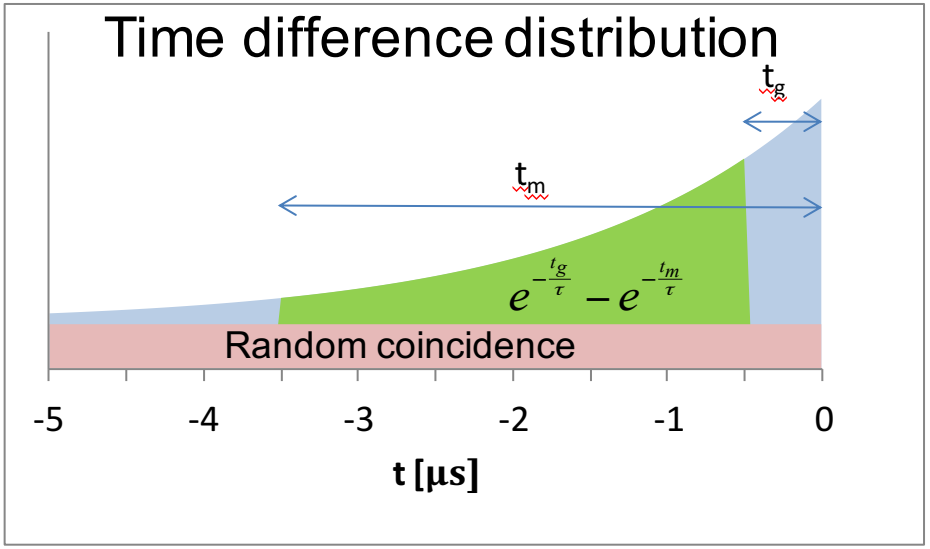
List-mode data acquisition is the only solution.

Analyzing both the singles spectrum and the capture-gated spectrum gives information from the source and the source shield.

ANALYSIS

• Trigger window for the coincidence analysis is optimized to the background count rate



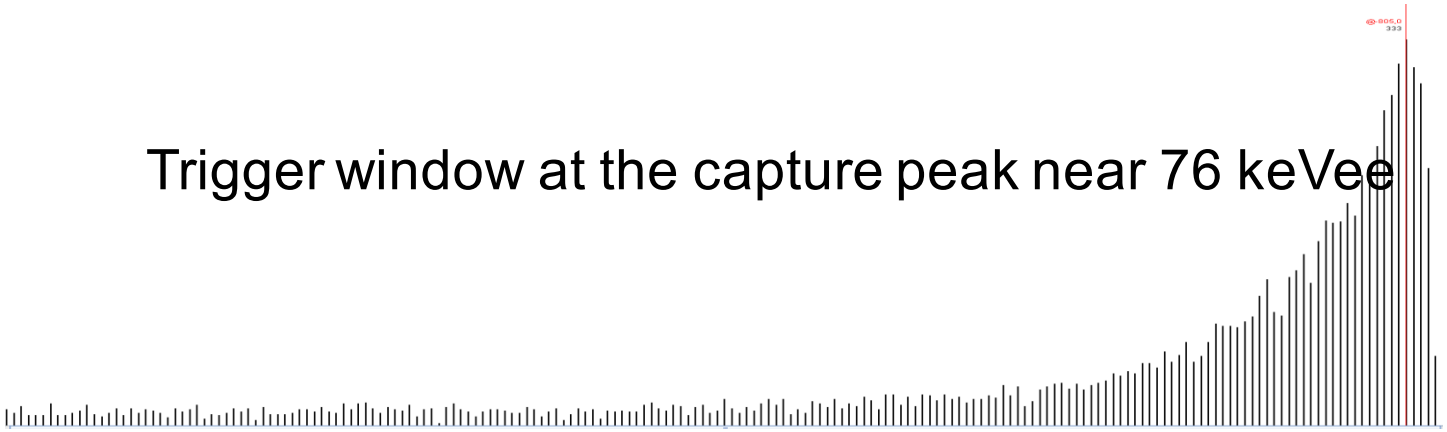


Efficiency of trigger window:

$$\eta = erf\left(\frac{k}{\sigma\sqrt{2}}\right)\left(e^{-\frac{t_g}{\tau}} - e^{-\frac{t_m}{\tau}}\right)$$

Time distribution of the events (- 20,000 ns, 0)

Trigger window at the capture peak near 76 keVee



Trigger window near 478 keV Compton edge

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Part 1

Benefits of List-mode Standard

1. Novel detection systems can be designed (interdisciplinary applications)
2. Detection capability can be optimized (start/stop) – Data acquisition time issue is solved!
3. Freedom to select hardware because they all obey same data structures
4. Data quality is improved: skip false data; prevent spoofing,..
   Field:
5. Source localization becomes possible from fast moving vehicles
6. Ship effect is eliminated (many neutron counts in short time, spallation reaction)

Who

- Radionuclide laboratories (activity determination)
- Basic research laboratories (complex measurement setups)
- Homeland security (field units → Reachback)
- Safeguard agencies (IAEA,…)
- IAEA, CTBTO and other international agencies, including arms control efforts

New technologies are required for more efficient measurement systems in lab and in field.

List-mode data acquisition is a key step forward

- **to standardized data acquisition and**
- **to improve RN detection quality and timeliness.**

Integration of CBRNE detection systems becomes possible.