

Overview of the software architecture and data flow for the J-PET tomography device



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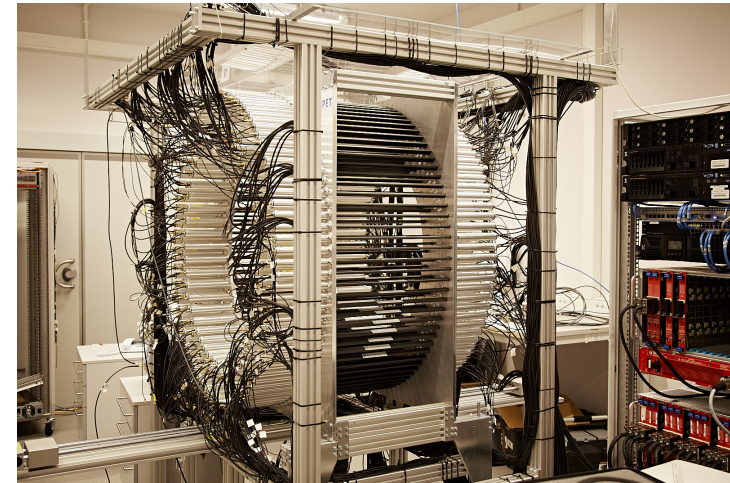
Taras Shevchenko National University of Kyiv

01.09.2016

J-PET scanner project

TOF-PET detector prototype based on:

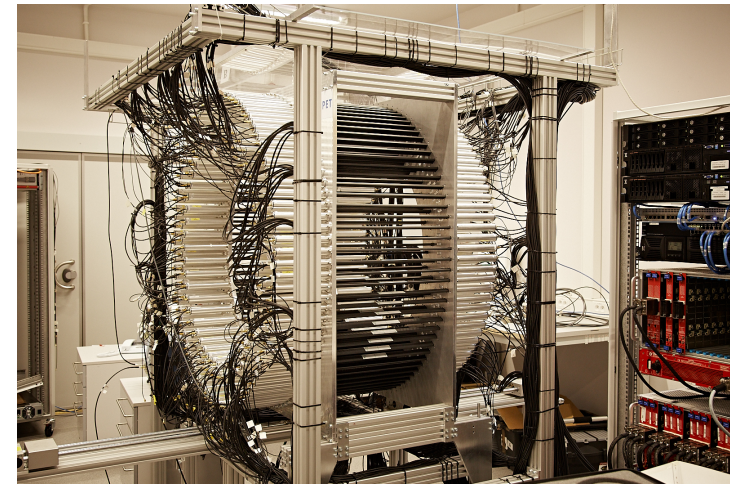
- polymer scintillators,
- large blocks of materials (high acceptance),
- reconstruction of hit position in a scintillator,
- fully 3-D image reconstruction,
- Novel ultra-fast electronics (FPGA),
- Excellent time resolution.



J-PET scanner project

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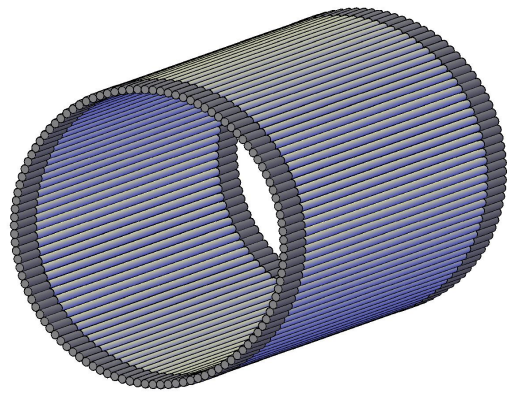


- Advanced PET imaging
- Studies of discrete symmetries violation (positronium)

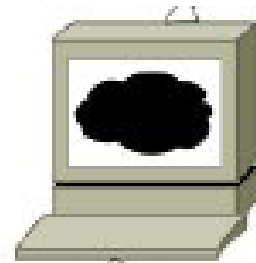
J-PET software

- Data Acquisition System
- Data Reconstruction
- Image reconstruction
- Simulations (GATE) – see P. Kowalski talk
- Special-purpose application (e.g. calibrations, HV steering)

Computing and data flow



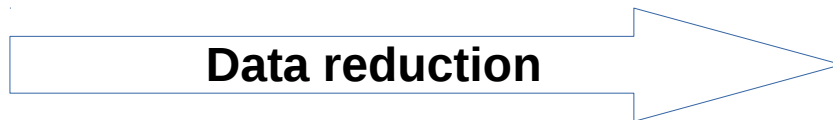
PET detector



Image



Physician



Data reduction

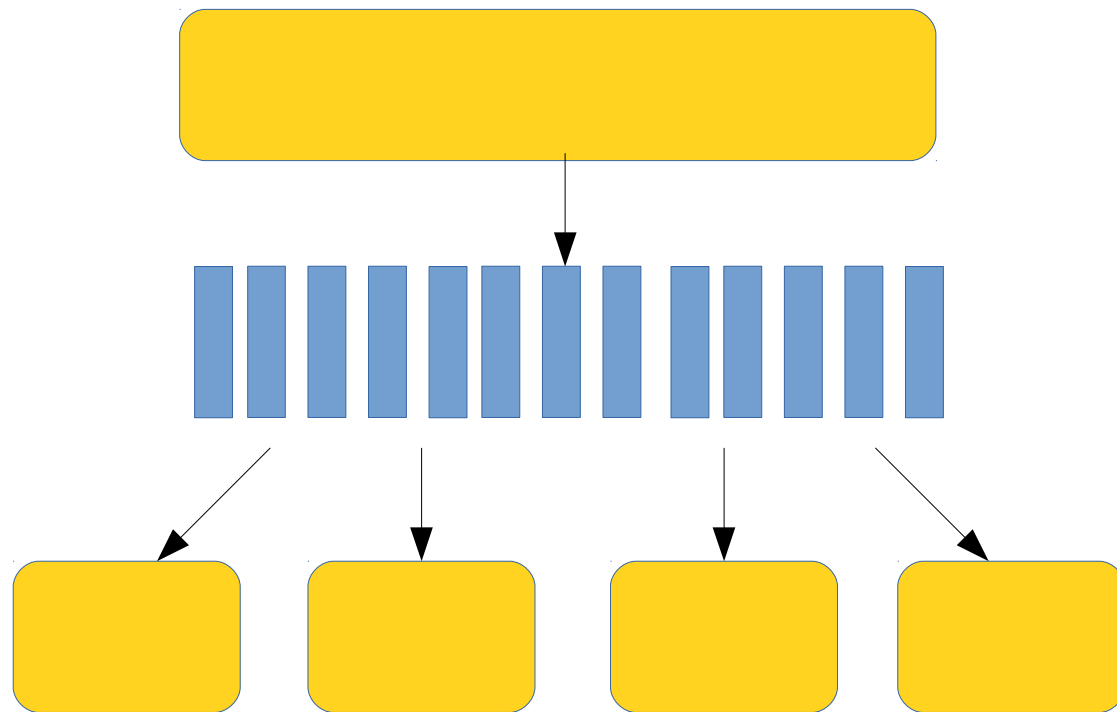
Requirements

PET image reconstruction is highly time- and resource-consuming process

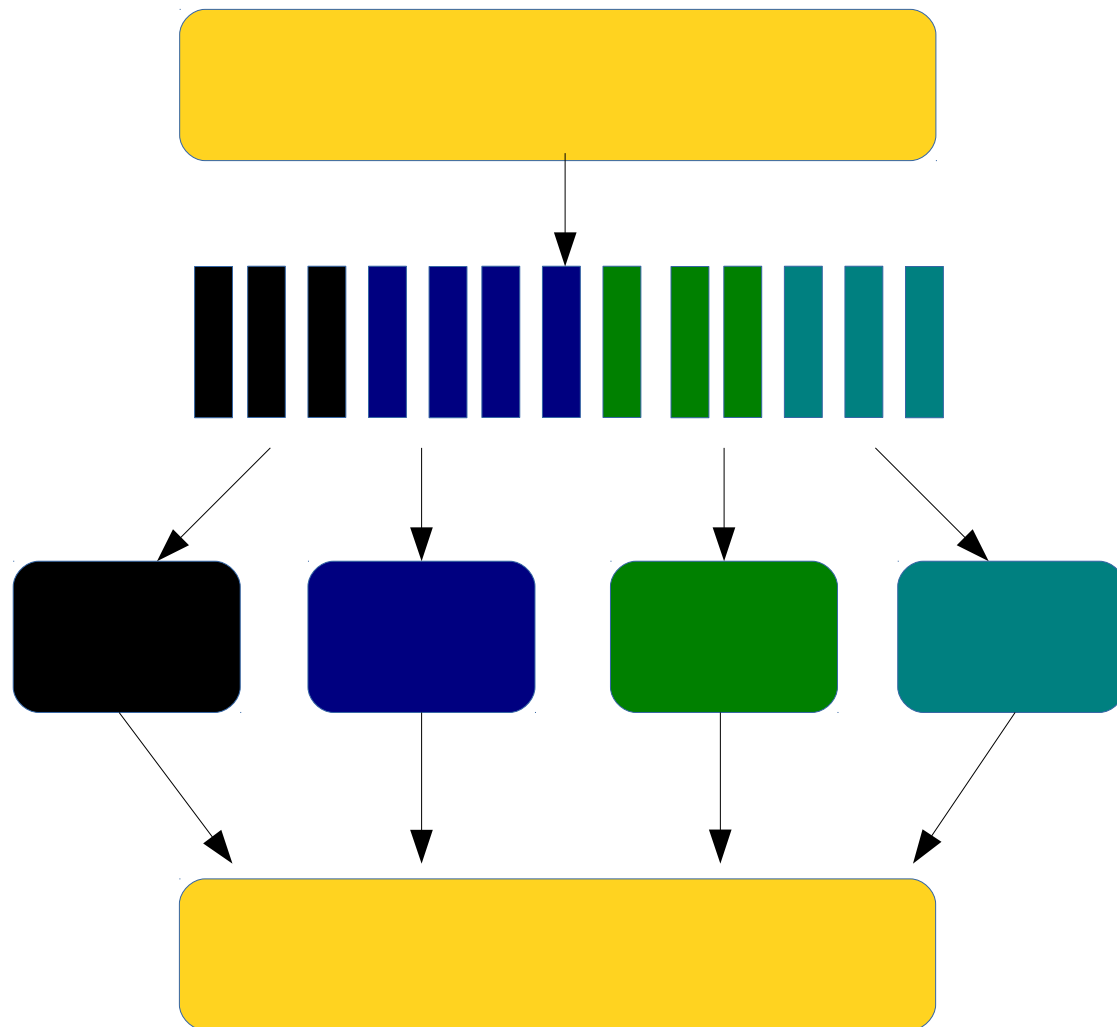
We need:

- data storage,
- dedicated computing resources,
- High-bandwidth transfer links,
- efficient algorithms (**parallelization**).

Parallelization



Parallelization

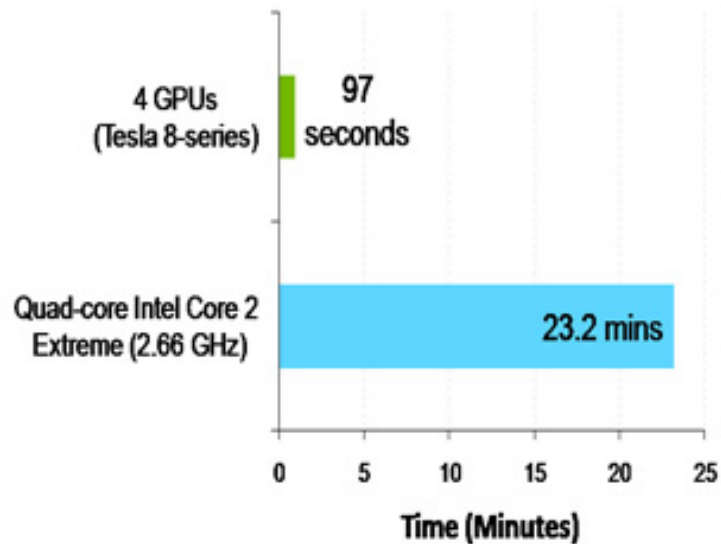


Parallelization

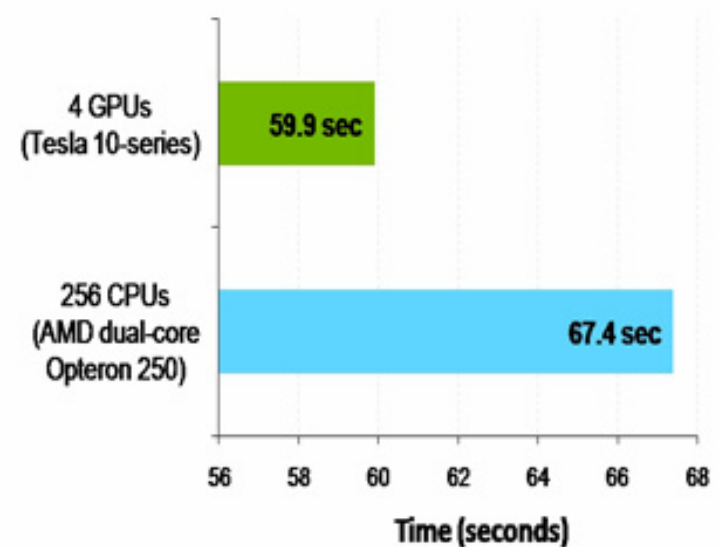
- CPU (Central Processing Unit)
- GPU (Graphics Processing Unit)
- FPGA(Field Programmable Gate Array)

Some benchmarks

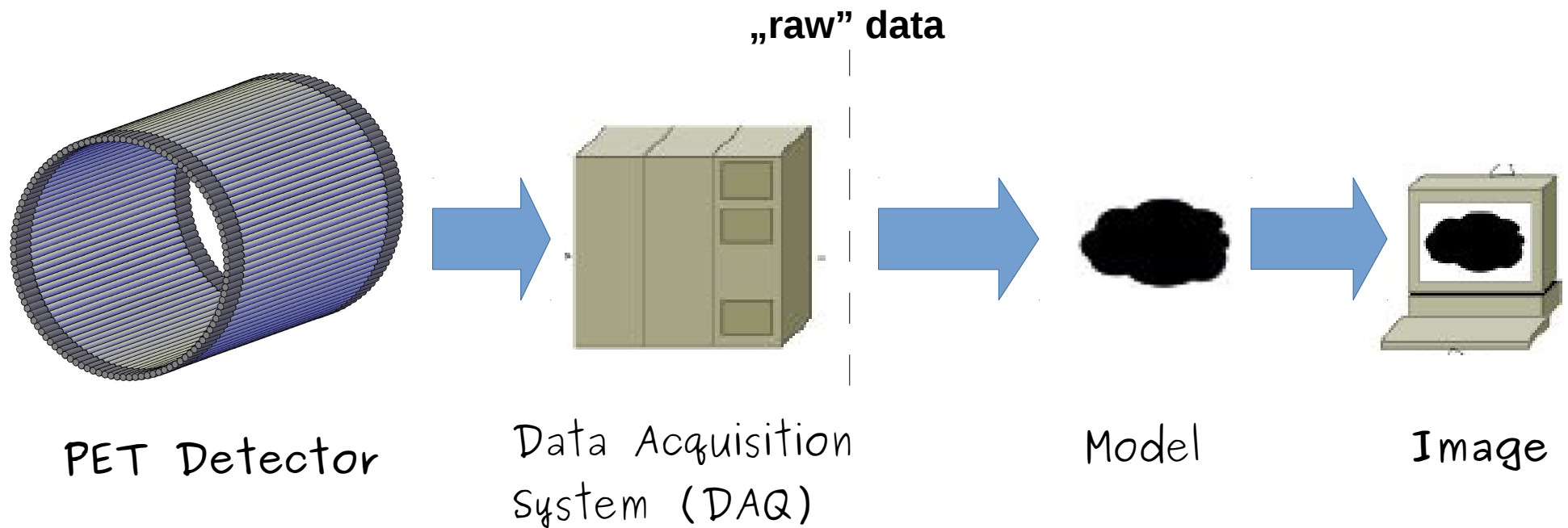
**Advanced MRI
Reconstruction Time**



**Computed Tomography (CT)
Reconstruction Time**



Computing and data flow II



Field Programmable Gate Arrays (FPGA)

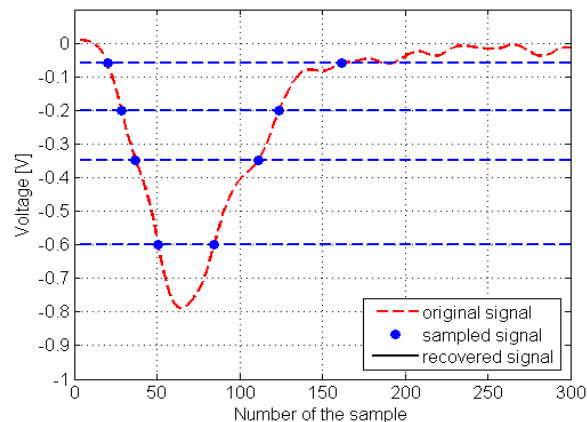
- silicon chip that can be used to implement any digital design,
- consists of millions of logical arrays, but programmable in high-level language (VHDL or Verilog),
- Cost-effective,
- Combines two main advantages:
 - reprogrammable (like a general-purpose processor),
 - hardware-timed speed (like ASIC).

real hardware parallelization



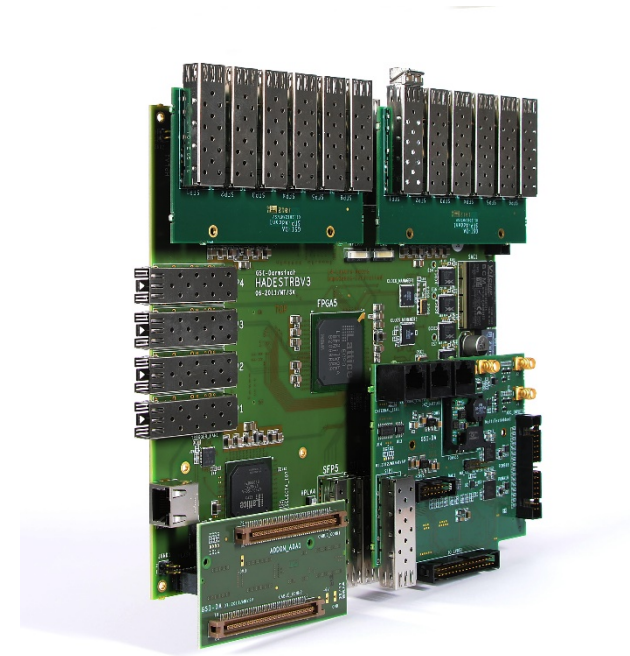
Front-end electronics

- Multi-threshold signal sampling designs:
 - Low-cost purely digital implementation, based solely on a **FPGA** device and few satellite discrete electronic components,
- Can be used to probe extremely **fast** signals, (typically: raising time of **~ 1 ns**)
- Excellent time measurement parameters (resolution **$\sigma \sim 20$ ps**)

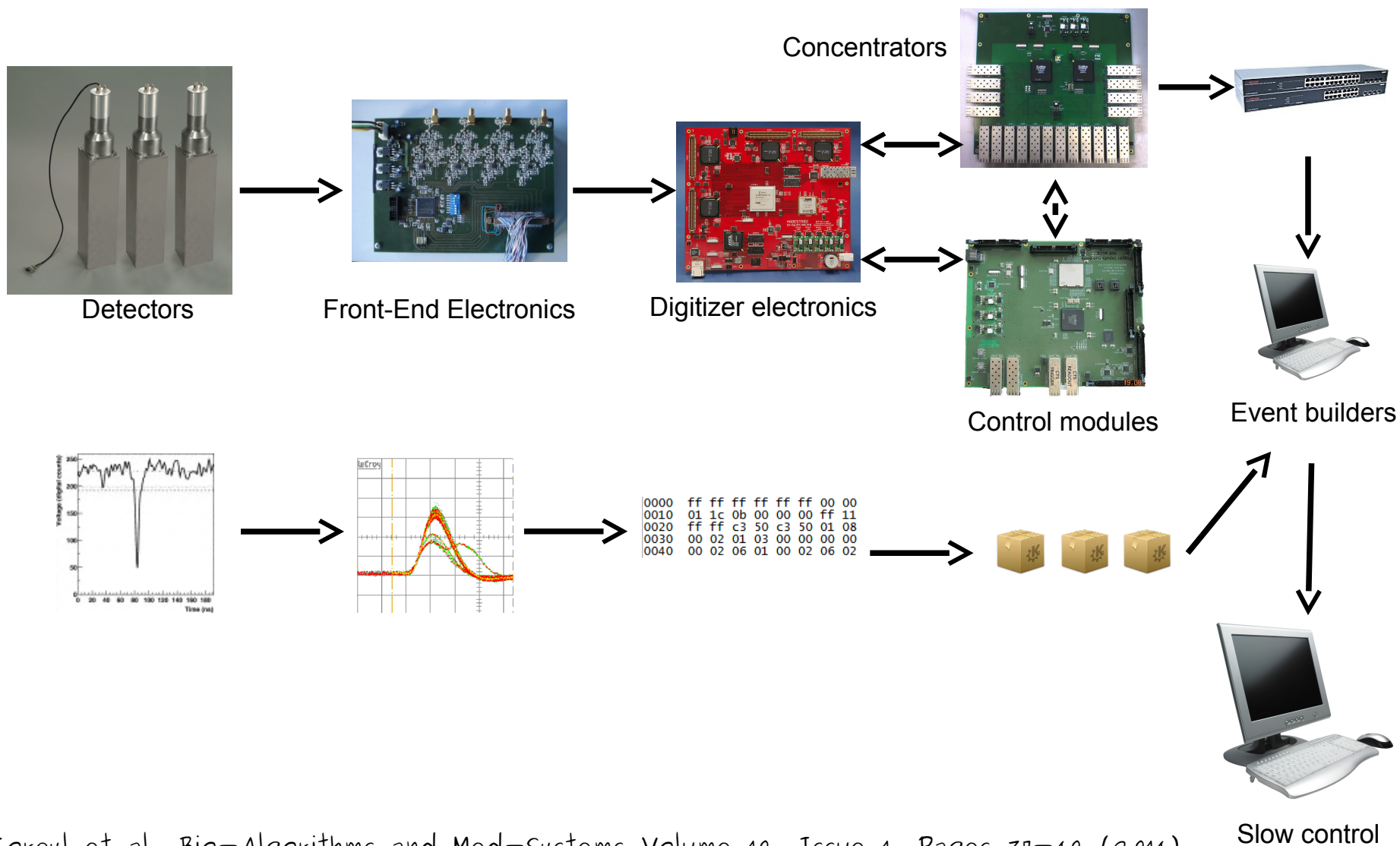


Trigger board (TRBV3)

- Electronic board with 4 x configurable FPGA chips
- Time-to-digital converter firmware:
 - resolution $\sigma \sim 20\text{ps}$,
 - up to 48 single edge input channels each
- Central FPGA chip:
 - data collector
 - interface to the system



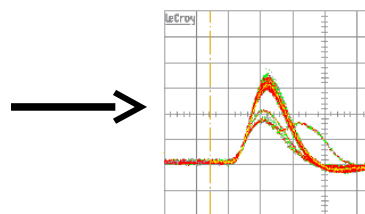
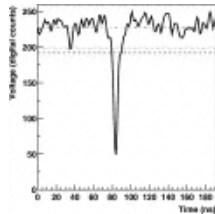
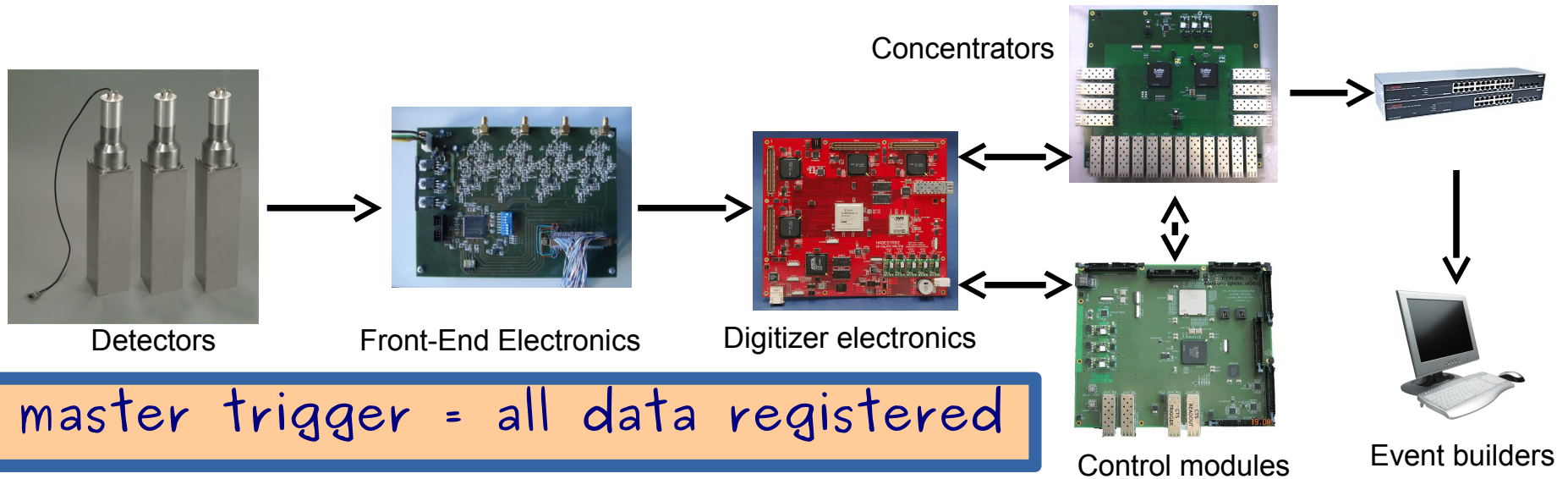
Triggerless DAQ system



G. Korcyl et al. Bio-Algorithms and Med-Systems Volume 10, Issue 1, Pages 37-40 (2014)

Picture taken from G. Korcyl's presentation

Triggerless DAQ system



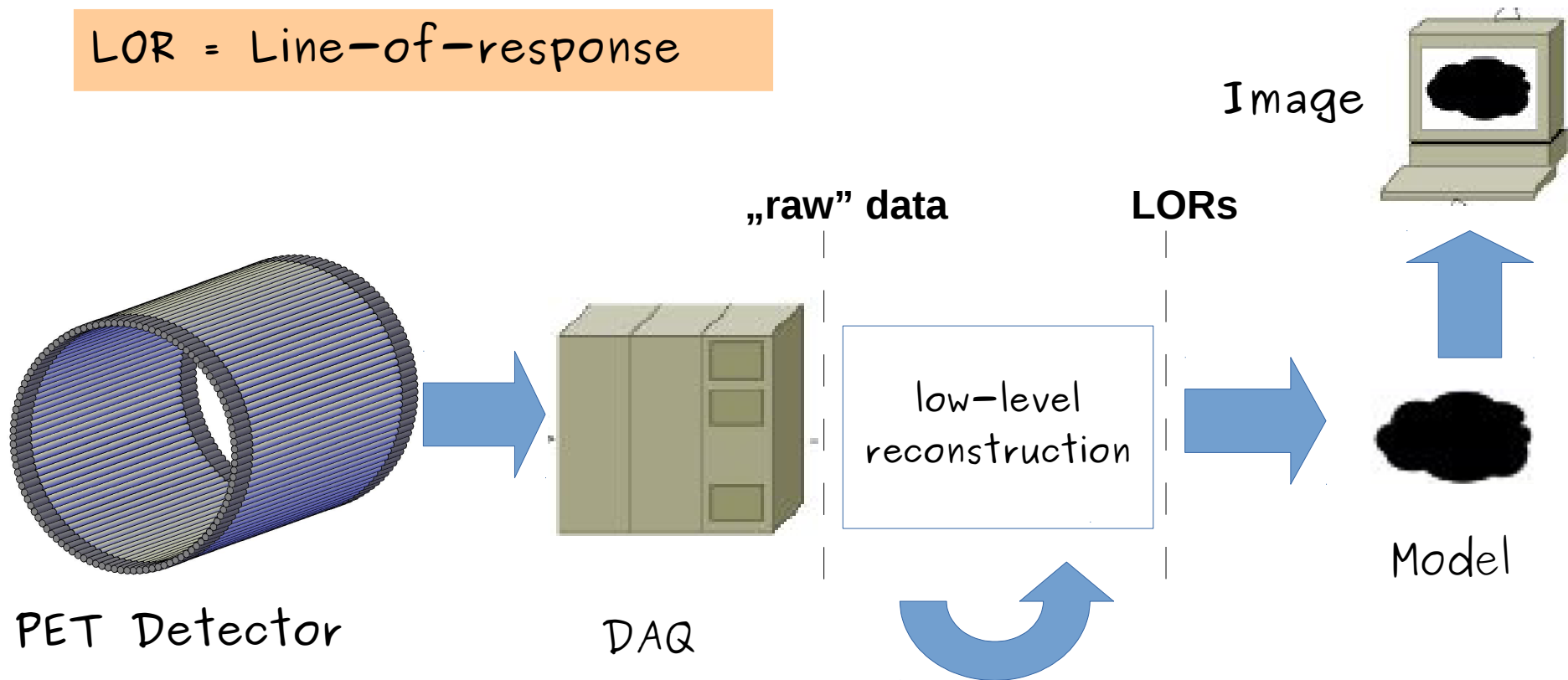
```

0000 ff ff ff ff ff ff 00 00
0010 01 1c 0b 00 00 00 ff 11
0020 ff ff c3 50 c3 50 01 08
0030 00 02 01 03 00 00 00 00
0040 00 02 06 01 00 02 06 02
    
```



Computing and data flow III

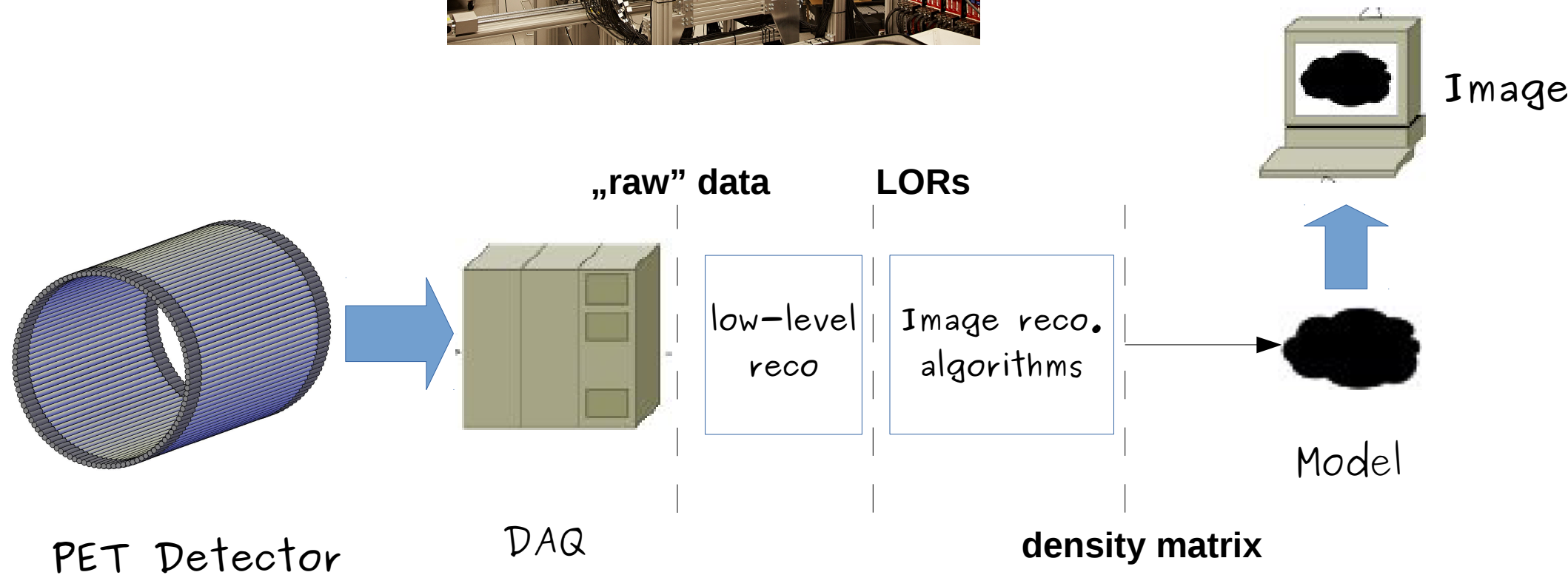
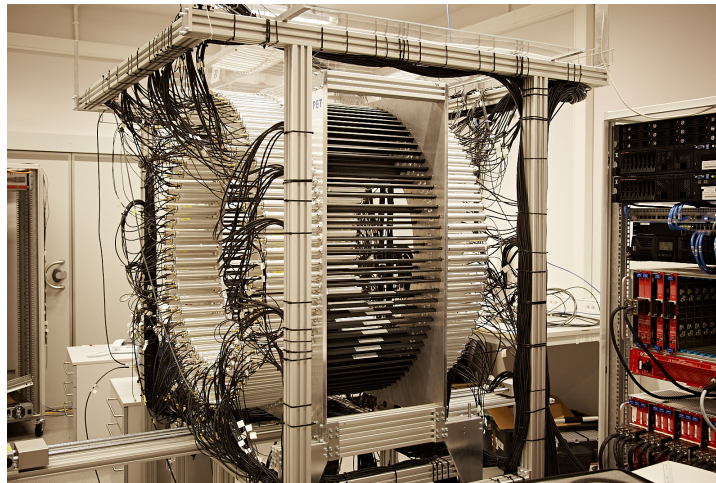
LOR = Line-of-response



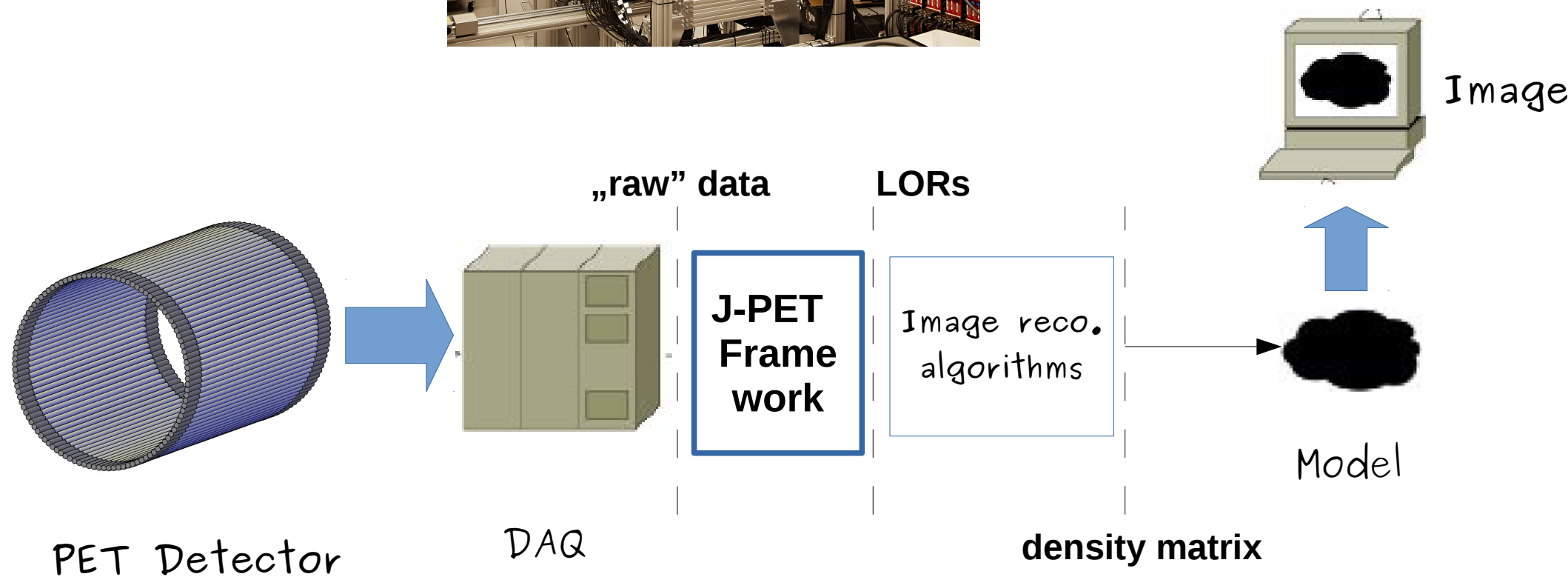
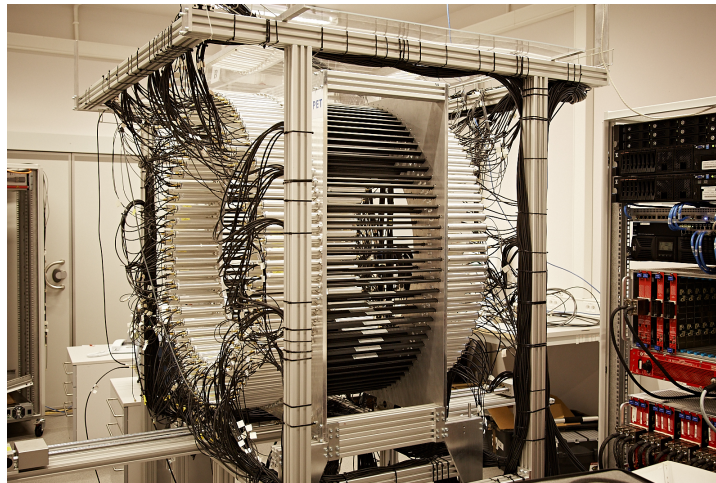
Low level reconstruction e.g.:

- hit position reconstruction,
- line-of-response reconstruction,
- but also some calibration procedures.

J-PET software

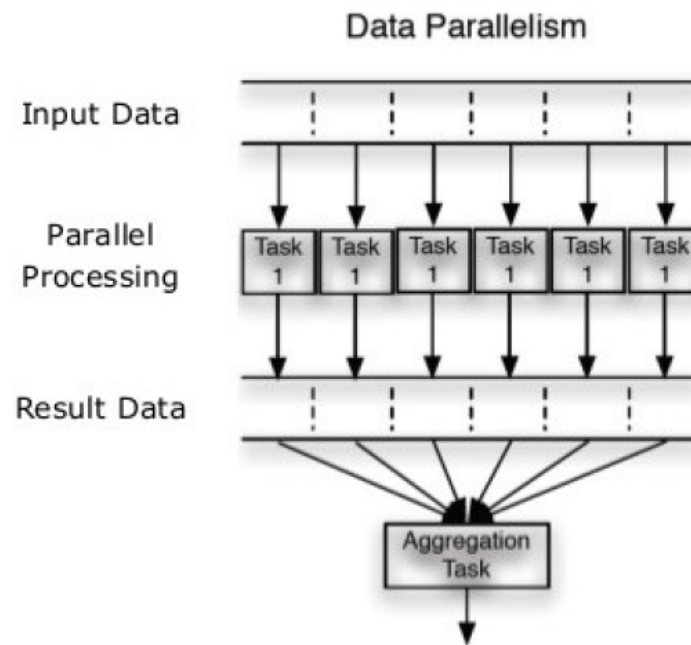


J-PET software



J-PET Analysis Framework

- Mainly developed in C++ (some Python, SQL)
- ROOT-based data structure,
- Heavy usage of BOOST library,
- Parallelization mechanisms included



W. Krzemień et al. Bio-Algorithms and Med-Systems. Volume 10, Issue 1, Pages 33–36 (2014)

20

W. Krzemień et al. Acta Phys Polonica A, Volume 127, Number 5, Page 1491 (2015)

J-PET Analysis Framework

key ideas

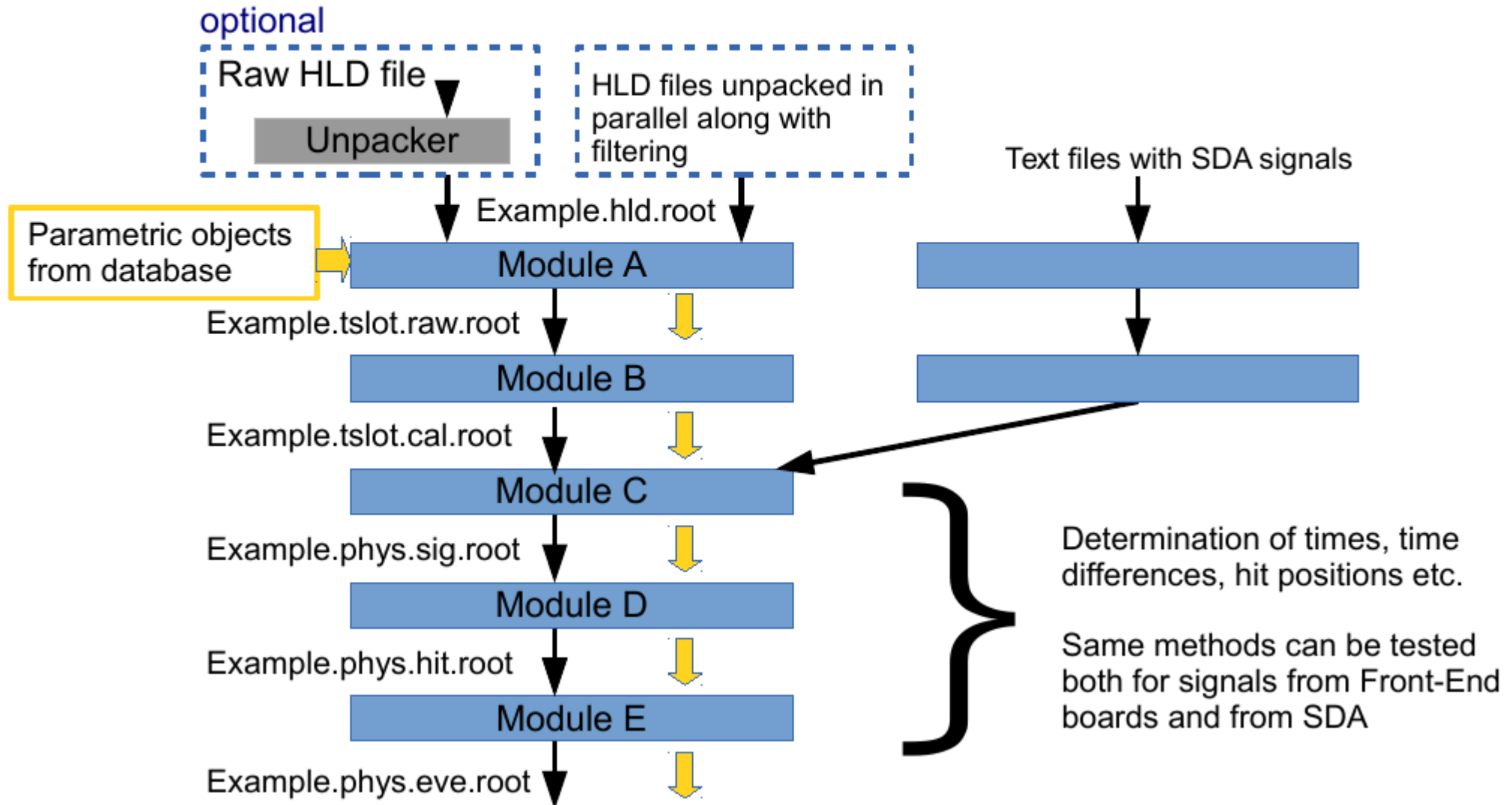
- Hide unnecessary details from the user,
- Reflect reality (use familiar „language“),
- Standardize common tools and operations,
- One task = interexchangeable block

J-PET Analysis Framework

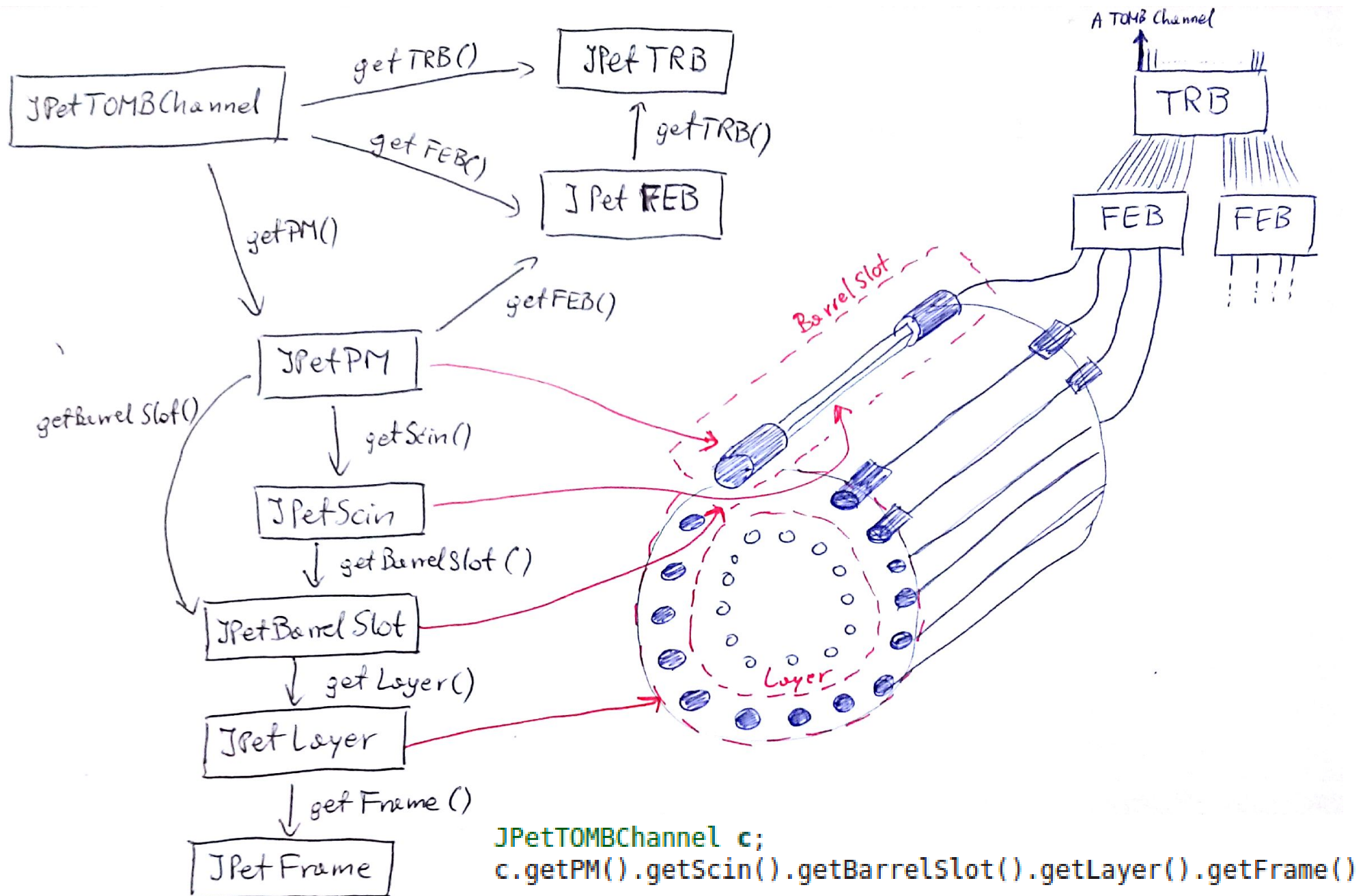
- Provides tools for saving and reading data from files (**standardize tools**)
- Provides read-only access to the J-PET configuration database (**hide details**)
- Handles the detector mapping transparently for the user (**hide details**),
- The same chain of procedures for data from the oscilloscope and from the standard detector (**standardize tools**),
- Allows for creation of modular data analysis programs (**modularity**),

Scheme of the analysis with J-Pet framework

Each analysis module is a separate C++ class.

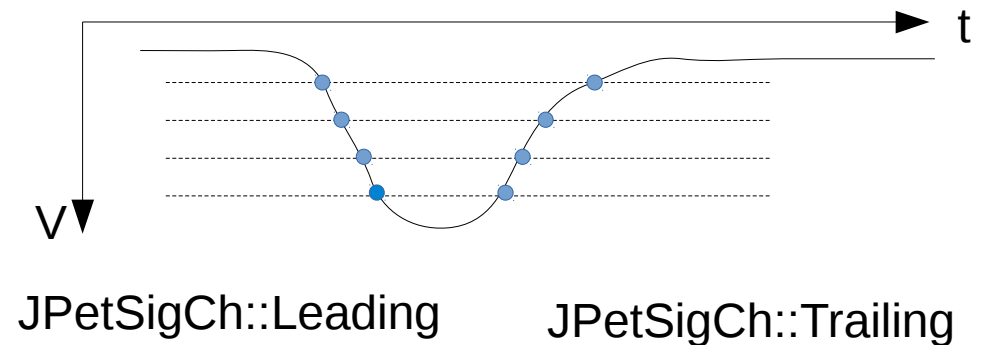


Parametric objects



Data objects

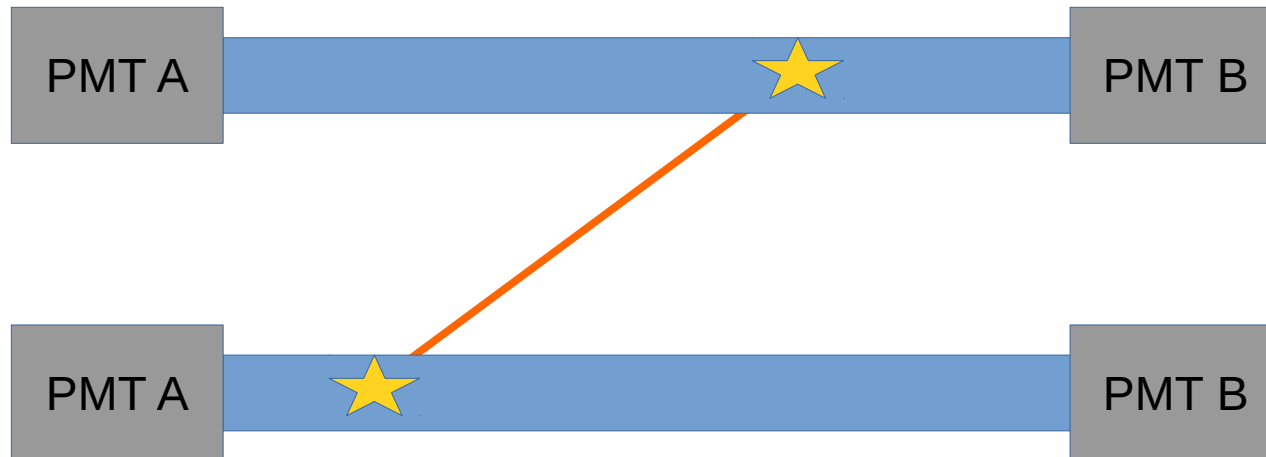
- Represent „events” starting from single TDC signals up to Lines Of Response
 - JPetTimeWindow
 - JPetSigCh
 - JPetRawSignal
 - JPetRecoSignal
 - JPetPhysSignal
 - JPetHit
 - JPetLOR



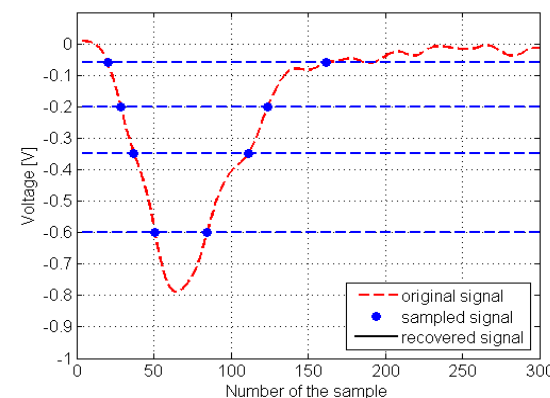
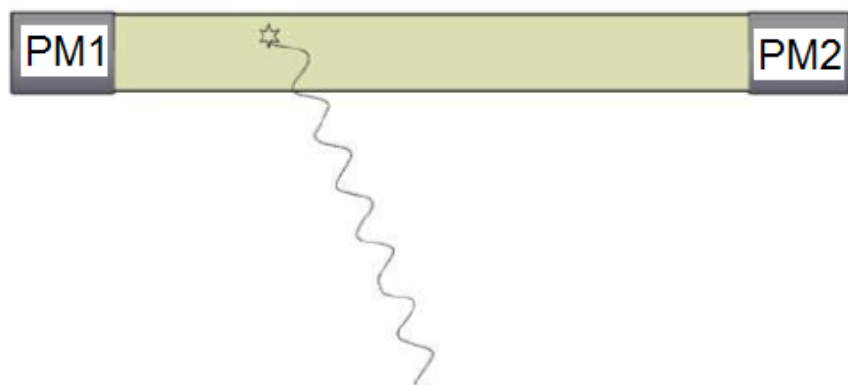
JPetHit



JPetLOR



Precise hit reconstruction in the scintillator



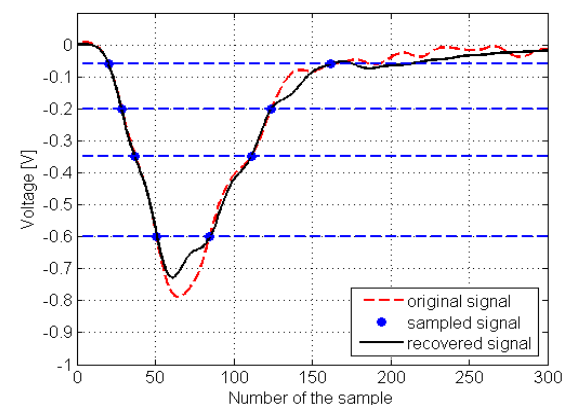
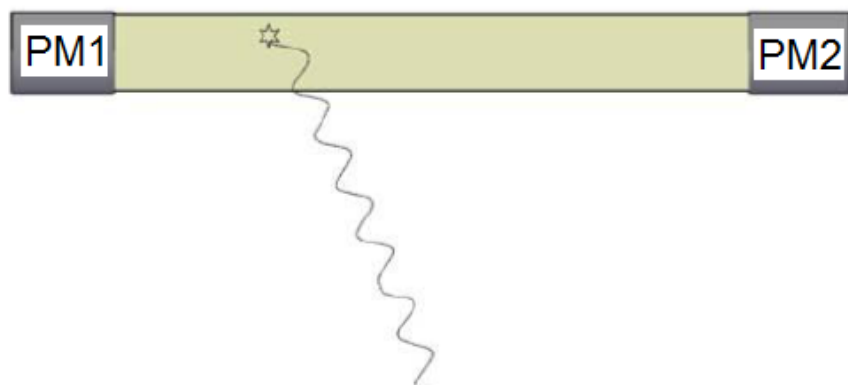
- 1) J-PET front end electronics permits to sample the signal at **several levels**,
- 2) **Compressing sensing theory** provides the mathematical tools to **recover** the signal shape based on limited points,
- 3) The recovered shapes can be used for the **precise** determination of the **hit position** of gamma quanta.

L. Raczyński et al. Nucl. Instr. and Meth. A 786 (2015) 105–112

L. Raczyński et al. Nucl. Instr. and Meth. A 764 (2014) 186–192

P. Moskal, et al., Nucl. Instr. and Meth. A 775 (2015) 54 (another hit reconstruction method)

Precise hit reconstruction in the scintillator



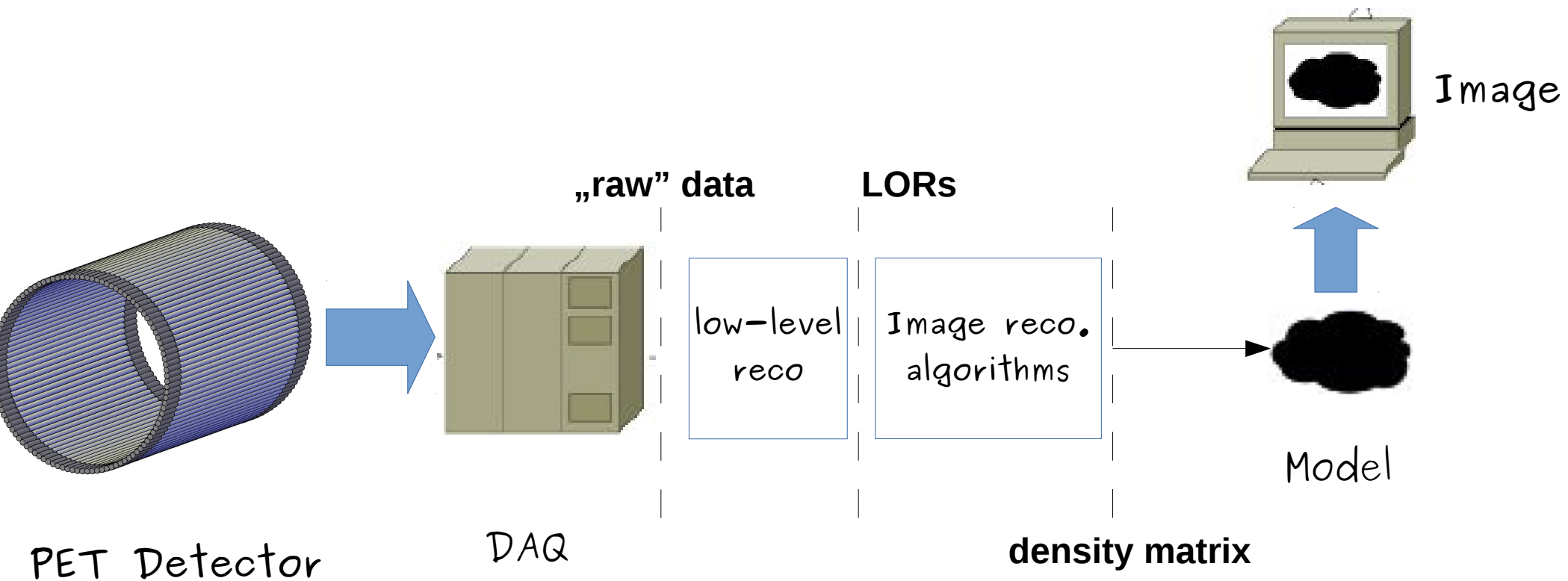
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Computing and data flow IV



MLEM & OSEM

- Maximum-Likelihood Estimation Maximization algorithm
- Common PET model derived by Shepp and Vardi in 1985 (Journal of the American Statistical Association, Vol. 80, No. 389 (Mar., 1985), pp. 8-20)
- Assumption: gamma emission described by the Poisson distribution
- Iterative approach
- Nice feature → OSEM, parallelizable algorithm

$$\lambda_j^{k+1} = \frac{\lambda_j^k}{\sum_i^m C_{ij}} \sum_i^m \frac{C_{ij}}{\sum_j^m C_{ij} \lambda_j^k}$$

Image reconstruction algorithms in J-PET

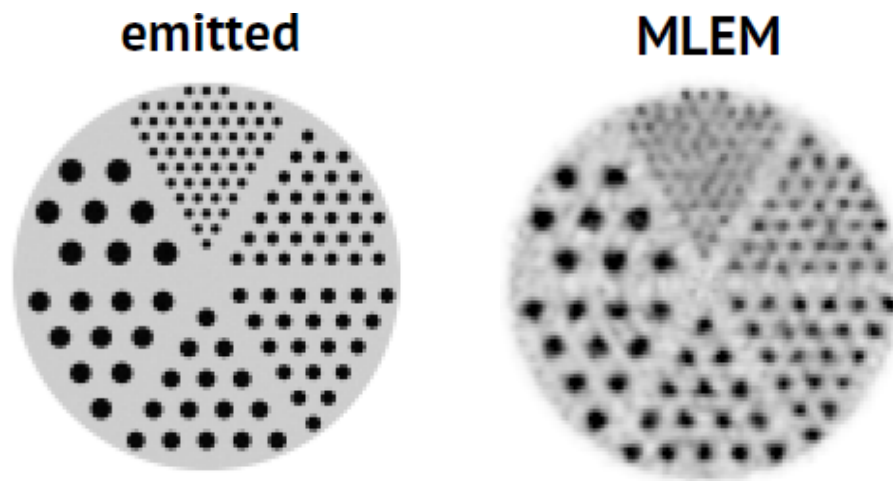
Two types of implementations:

- multi-CPU 3-D MLEM:

e.g. A. Slomski et al. Bio-Algorithms and Med-Systems. Volume 10, Issue 2, Pages 1–7 (2014)

- GPU accelerated 2-D and 3-D MLEM

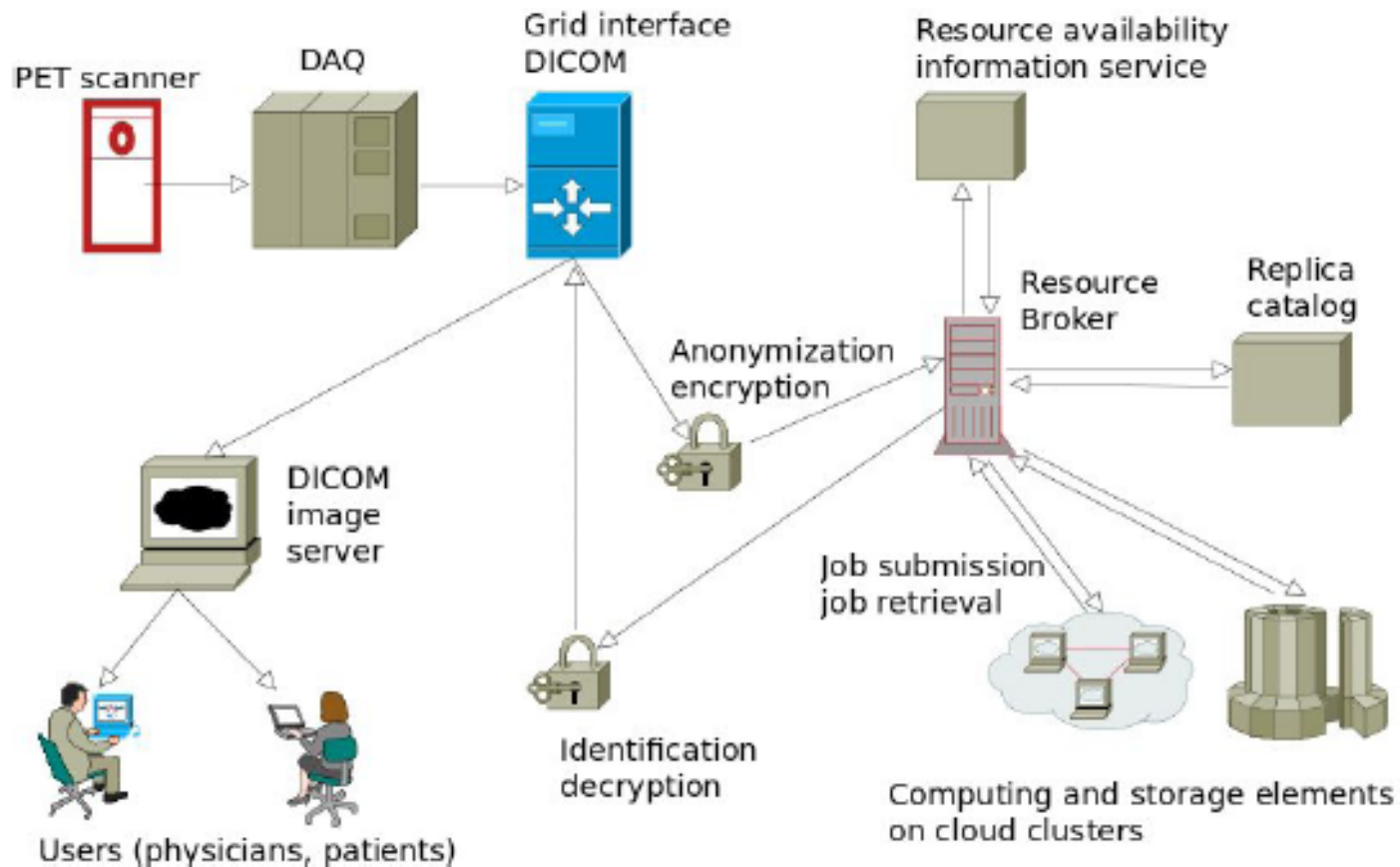
e.g.: P. Białas et al. Acta Phys Polonica A, Volume 127, Number 5, Page 1500 (2015)



Jaszczak Deluxe phantom

$10 * 10^6$ events, $x - y$ cut

GRID-based computing architecture



Picture taken from W. Wiślicki et al. Bio-Algorithms and Med-Systems 10(2014)

J-PET Software@GitHub

<https://github.com/JPETTomography>

Repositories

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Teams 0

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New repository

j-pet-framework

J-PET Analysis Framework

Updated 21 minutes ago

C++ ★ 1 4

ThresholdSync

Updated a day ago

C++ ★ 0 0

j-pet-framework-examples

Example analyses based on the J-PET Analysis Framework

Updated a day ago

C++ ★ 0 3

JPet-HV-GUI-tool

Updated 2 days ago

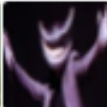
C++ ★ 1 0

JPET-HV-adjust

Updated 2 days ago

C++ ★ 1 1

People 9 >



Invite someone

Continuous integration and testing

- Jenkins server with the automatic set of unit tests
- We are testing also Travis CI



Travis CI

- Project management and issue tracking system,



Google Chrome

Krzen J-PET YouT Fwd: le 18 le 17 J-PET Prof. Prof. musis musis musis musis Over New Tab Redm J-PET D X Travi

jenkins.koza.if.uj.edu.pl

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Jenkins

WŁĄCZ AUTOMATYCZNE ODŚWIEŻANIE

Historia zadań
Manage Jenkins
My Views
Credentials

Kolejka Budowania

Nie ma buildów w kolejce

Stan Wykonawcy Zadań

1 Bezczynny
2 Bezczynny

S	W	Name ↓	Ostatni Sukces	Ostatni Błąd	Ostatni Czas Trwania
		buildTest	5 mo 25 days - #6	6 mo 25 days - #3	3 min 11 sec
		cppTest	5 mo 25 days - #21	4 mo 16 days - #30	7 min 5 sec
		Develop_build	8 hr 50 min - #352	26 days - #278	2 min 4 sec
		Develop_cppcheck_short	8 hr 22 min - #648	2 days 12 hr - #628	23 min
		Develop_examples_build	—	26 days - #2	7.3 sec
		Develop_unit_tests	1 mo 3 days - #280	14 days - #283	5 min 7 sec
		Develop_unit_tests_withTestDataDownload	8 hr 48 min - #115	5 days 8 hr - #103	3 min 39 sec
		J-PET_Build_develop	4 mo 0 days - #911	4 mo 18 days - #863	2 min 22 sec
		J-PET_Build_master	7 hr 57 min - #1245	10 mo - #359	2 min 58 sec
		J-PET_Cppcheck_develop	4 mo 0 days - #900	5 mo 10 days - #790	1 min 13 sec
		J-PET_Cppcheck_master	7 hr 58 min - #1243	1 yr 2 mo - #14	1 min 43 sec
		J-PET_NewDevelopTests	—	—	nd.
		J-PET_UTs_develop	4 mo 0 days - #908	4 mo 18 days - #859	4 min 28 sec
		J-PET_UTs_master	8 hr 38 min - #1242	2 mo 26 days - #992	29 min
		J-PET_Workdir_develop	4 mo 0 days - #910	5 mo 3 days - #820	2 min 56 sec
		J-PET_Workdir_master	8 hr 25 min - #1242	10 mo - #360	3 min 14 sec
		unitTests	6 mo 4 days - #10	4 mo 16 days - #16	1 min 30 sec

Ikona: [S](#) [M](#) [L](#)

Legenda [RSS Dla wszystkich](#) [RSS Tylko niepowodzenia](#) [RSS Tylko dla najnowszych](#)

Outlook

- Novel PET detector with excellent timing resolution,
- Dedicated parallelizable computing architecture developed,
- Novel ultrafast front-end electronics and the triggerless DAQ system,
- Several computing schemes including grid and cloud architecture are considered.

Дякуємо Вам за увагу

Outlook

Most of the articles and materials are available at our website: <http://koza.if.uj.edu.pl/>