Further developments on Data communication related to FE processing in Medical Imaging

Georgios Konstantinou

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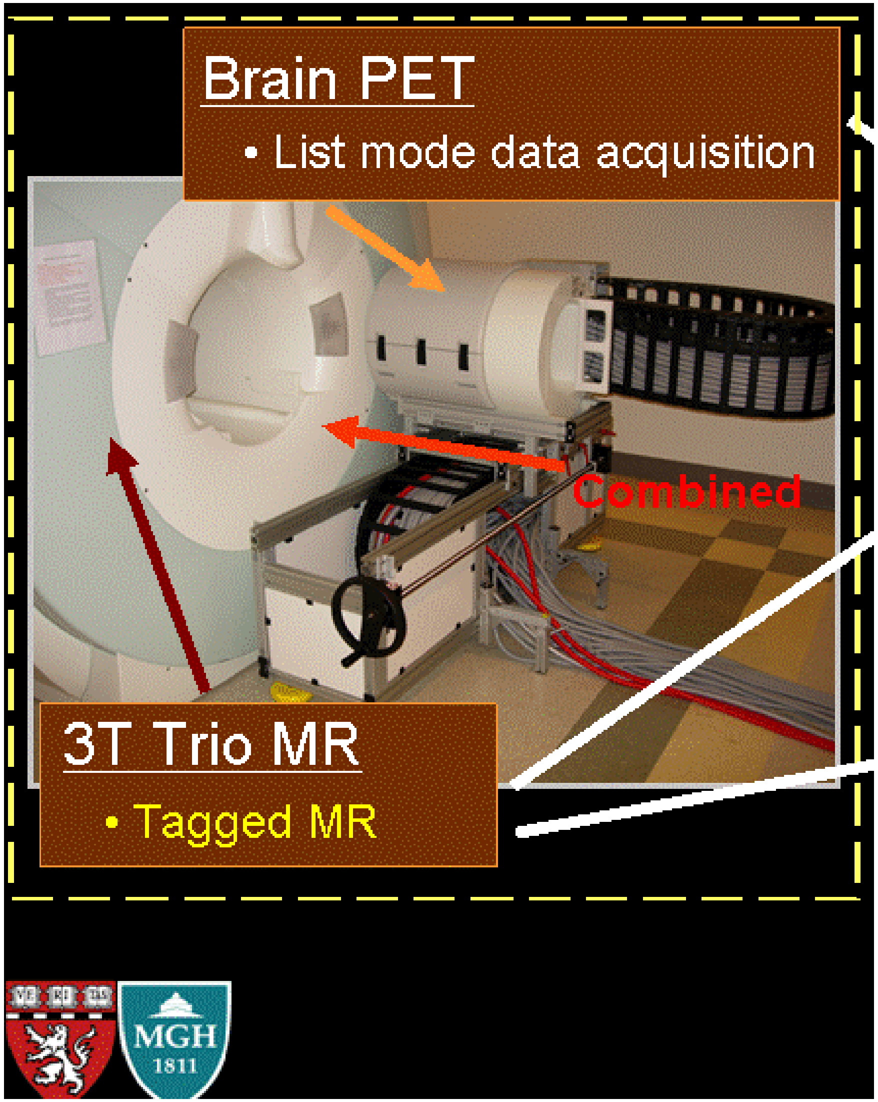
Outline

- Introduction
- Event rate expected
- Readout of single event
- Firmware architecture
- Data throughput
- Workplan



G. El Fakhri, MGH-Harvard

Issues:

Detectors size
Connections to the DAQ

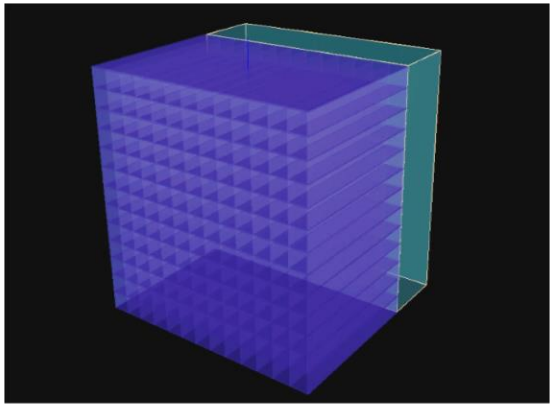
Detectors size: SiPM + SSLE

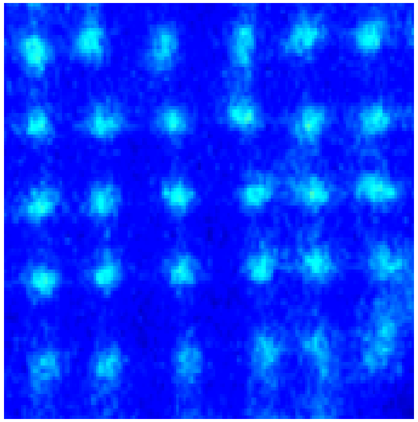
Sub-Surface Laser Engraving for scintillators

- **SSLE Nd:YAG laser and GAMOS simulations**
- **Scintillator pixelation without external reflectors**
- **Depth of interaction have been achieved.**

Advantages:

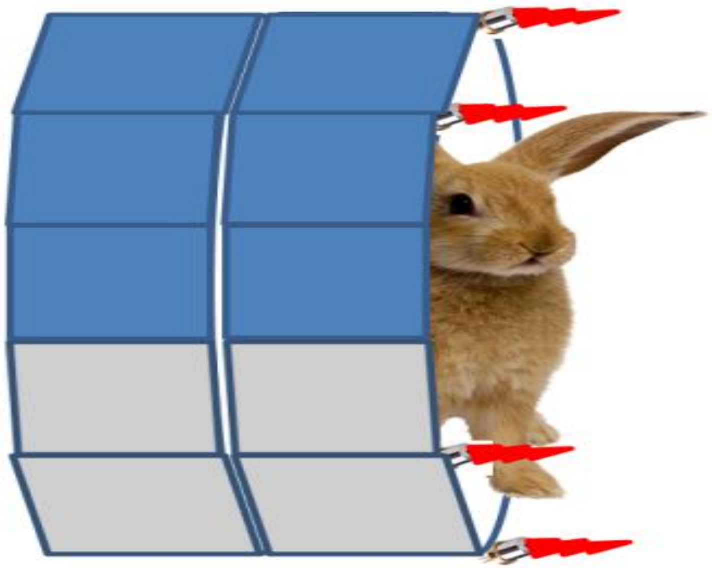
-Design flexibility
-Higher packing fraction and sensitivity
-Light sharing necessary for Anger logic
-Cost effectiveness.



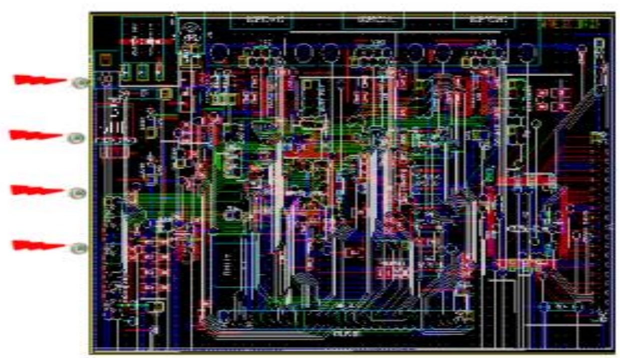


Connections: wireless detector

- How far out of the MRI is far enough?
- What wavelength could do the trick?
- How much electronics can we keep outside?
- What are the drawbacks?



Can this be wireless?

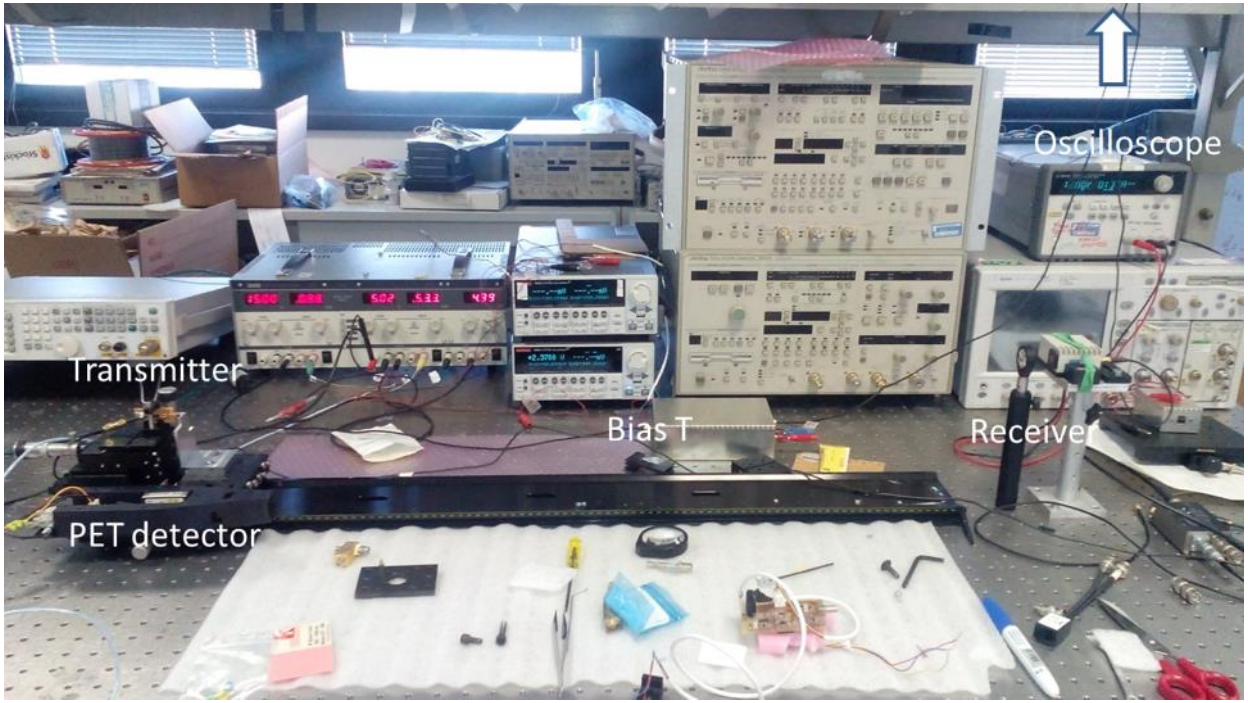


Insert

base station

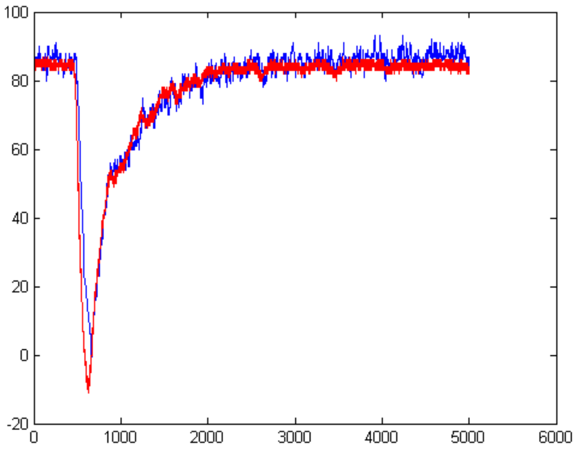
Initial experimental setting

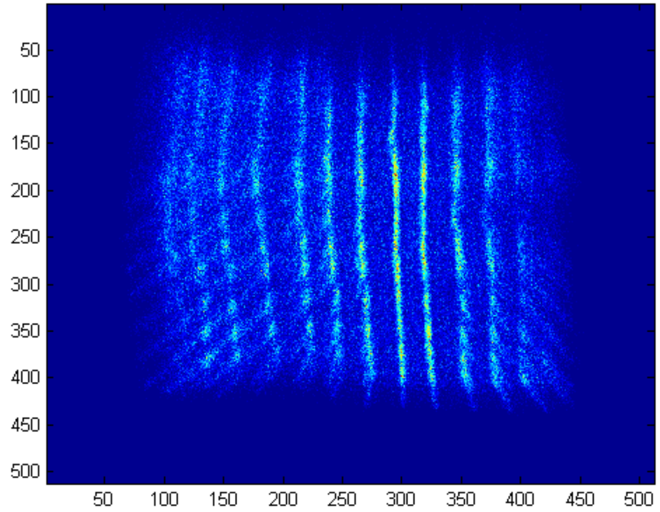
- Necessary measurements for PET:
  - Transmission jitter → ~80 ps, within specifications
  - Transmission bandwidth → higher than 250 MHz (sufficient)

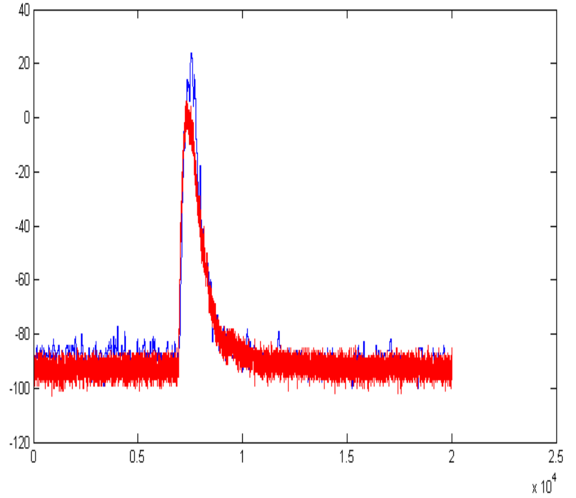


Testing

- Amplified output (red Tx, blue Rx)
- SiPM output (red Rx, blue Tx)
- Profile with conventional and OWC channels







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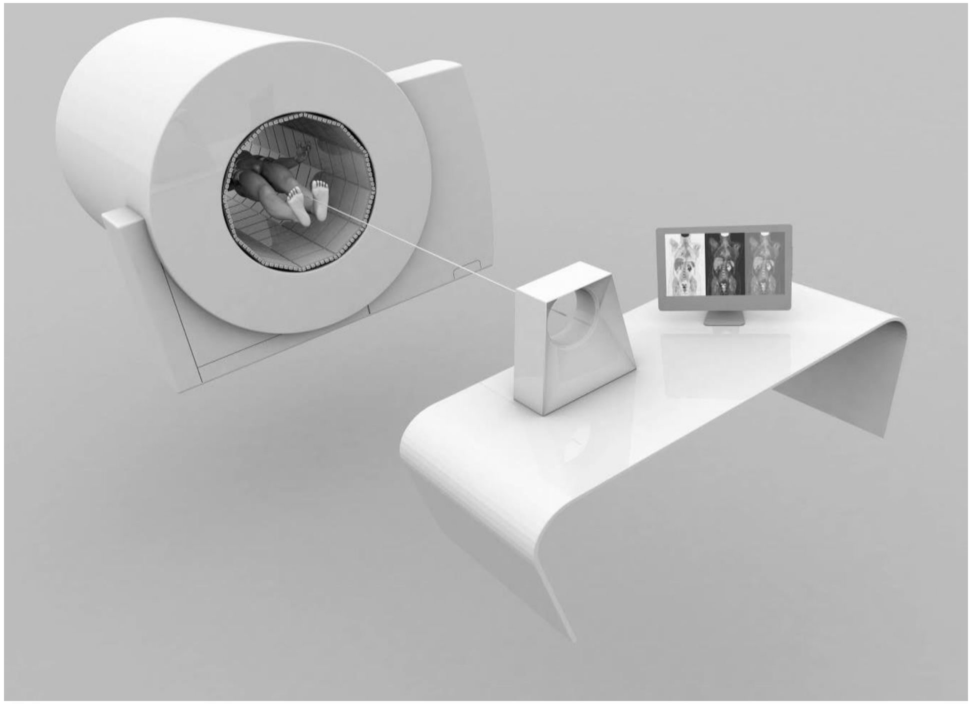
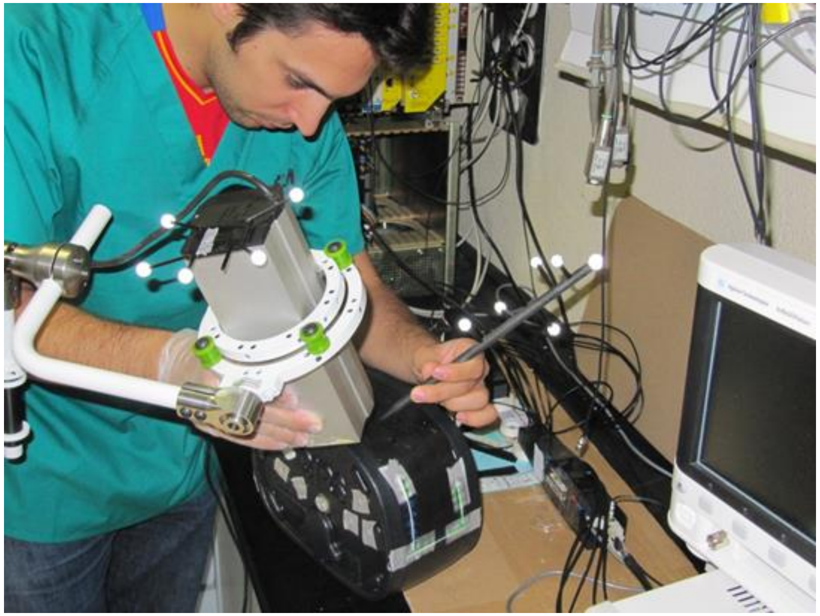
First ideas

- Innovative, cost-effective, miniaturized, versatile MR-compatible front-end scintillation detector.
- Handheld gamma camera



Wireless analog front-end



Gamma camera

Current status

- ✓ Studies on the application of shorter scintillator crystal treated with SSLE techniques
- ✓ Prototyping with SiPM
- ✓ Studies on feasibility of analog OWC

What about data processing?

Nutaq PicoDigitizer-125

Key Features:

-Up to 64 channels coupled to a large Virtex-6 FPGA

-125 MSPS ADCs, 14 bit resolution
-Phase aligned channels and phase coherent sampling

- GigE and PCIe 4x high speed interfaces

-AC-DC coupling options, single-ended or differentia
-l
-Model-based design integration

-Optional DACs, 1000 MSPS (Int. Modes), 16-bit

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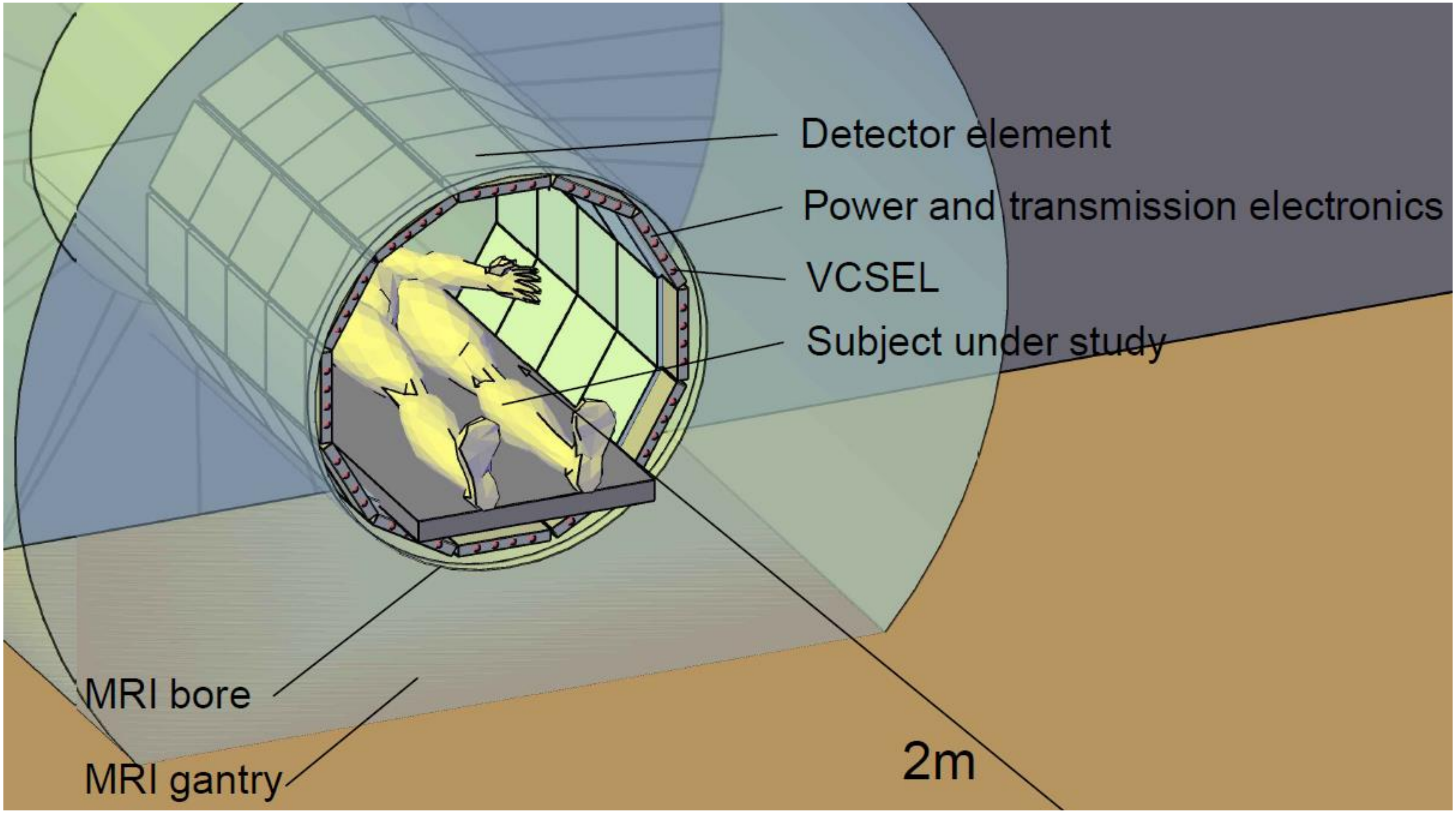
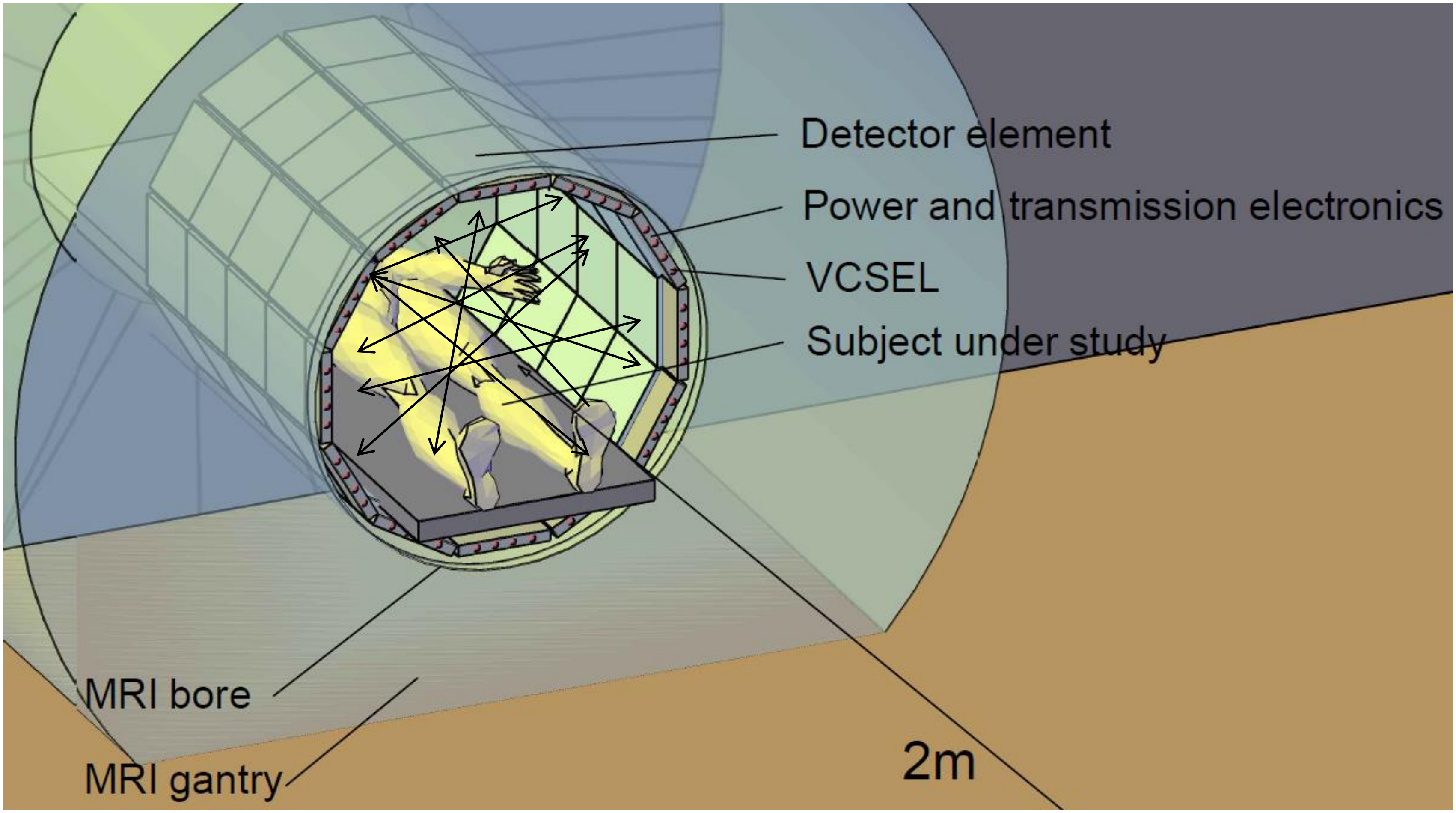
Event rate calculation

- Focusing on the subject under study:



Event rate calculation

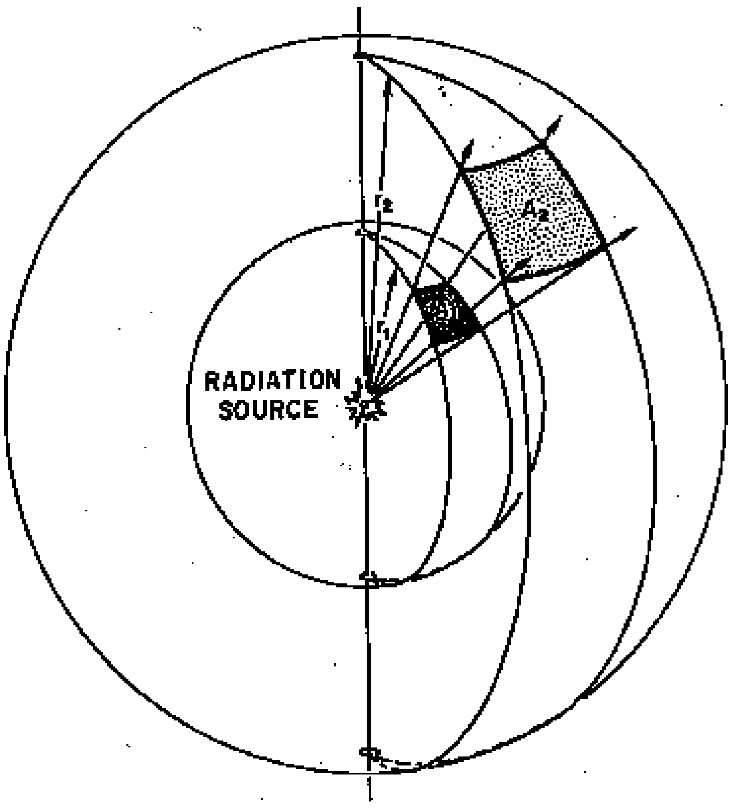
- Focusing on the subject under study:



Event rate calculation

Theoretical model:

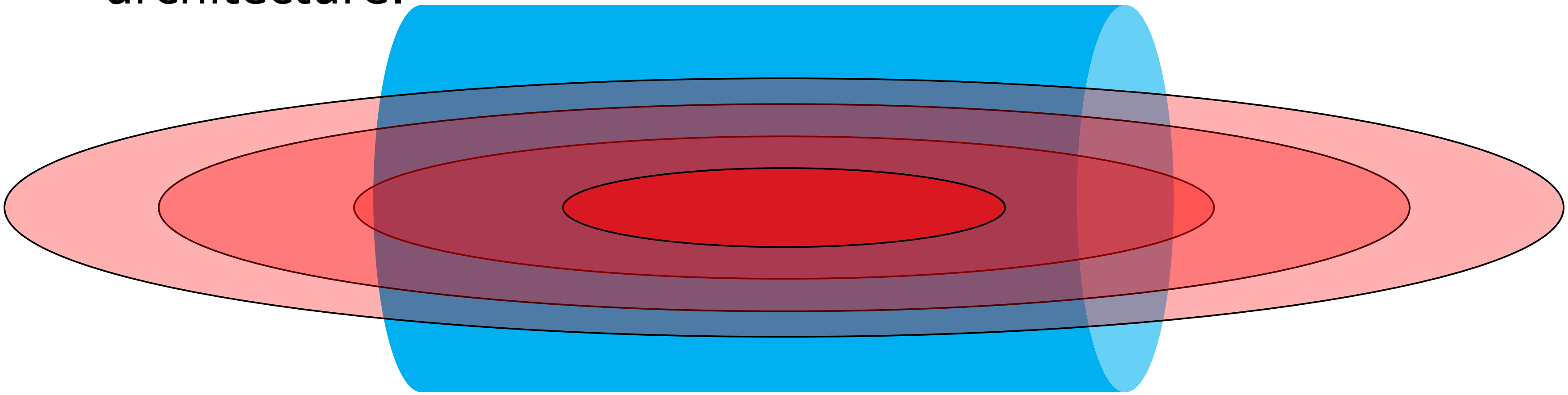
- Radioactive source with spatial distribution of spherical (or spheroid, depending on the considered shape of source) field.
- The intensity of the field is a function of the radiotracer dose.
- The detector (square of area a^2) has a given distance h from the center, thus a solid angle of $\Omega = \frac{a^2}{h^2}$ maximum.
- The radiant intensity equals $I_E = \frac{\partial \Phi}{\partial \Omega}$



Event rate calculation

Theoretical model:

- Taking into account the dead time in order **to avoid pile-up for 95%** of events (also cosmic, singles) we choose the **Maximum Accquired Rate** (MAR) from expected radiant intensity.
- **MAR<1Mhz** limits I_E and Ω, thus $\alpha^2<6cm^2$, for each independent readout.
- With this modular dimension, we build our detector architecture.



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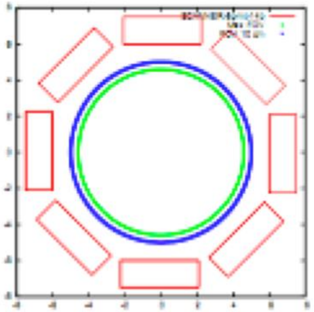
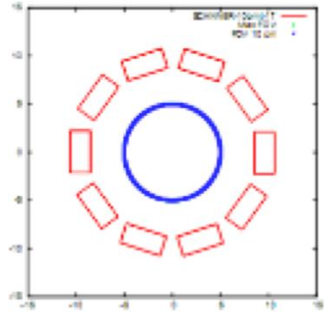
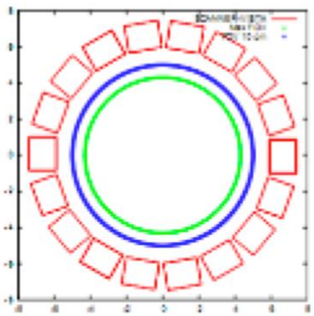
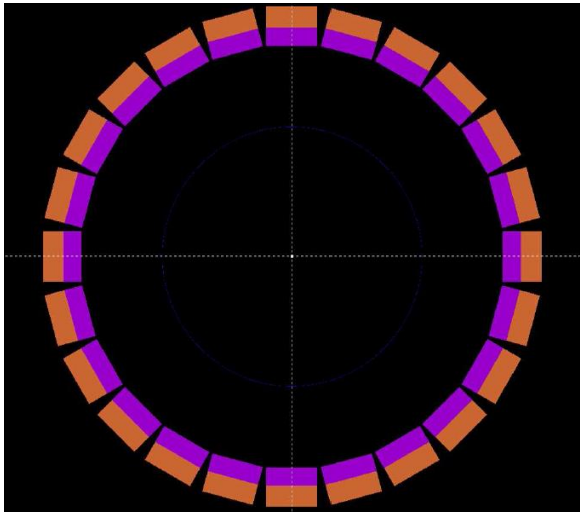
Existing systems

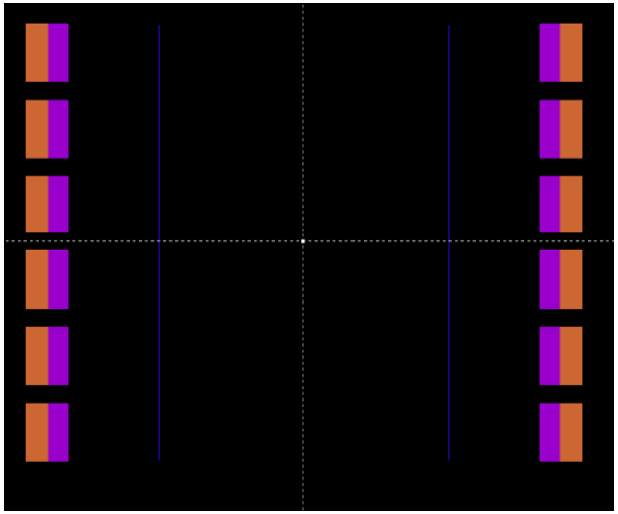


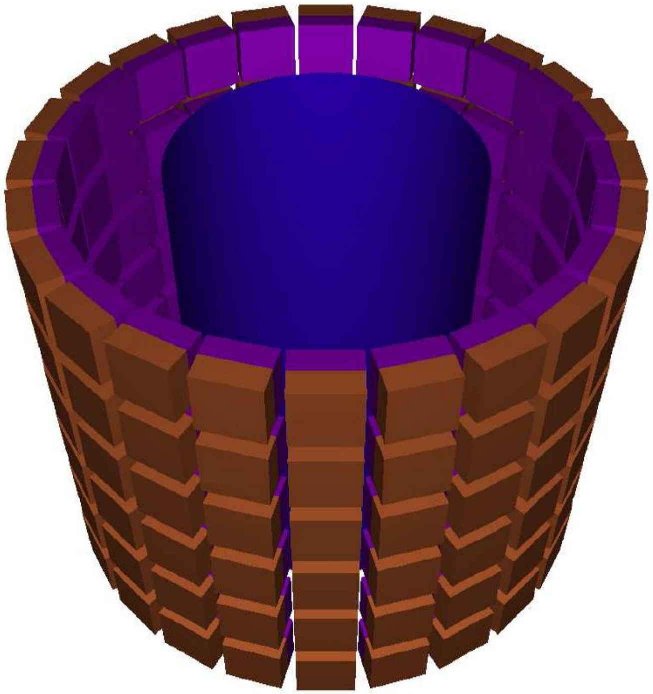




Scanner								FOV Trans-axial (cm)	FOV Axial (cm)	CPSS 250-700 KeV (%)	FWHM (Intirnsic, mm)
Rings	# LORs (millions)	Name	Gap Size (mm)	Diam (cm)	Detec/R	# Det. In coinc.	Crystal Length and pitch (mm)				
2	28	Vista	7.8	11.8	18	7	7(LYSO)+ 8(GSO) 1.55	8.6 (7.0-8.0)	4.8	4.0	1.5
4	143	Inveon	0.1	16.1	16	9	10 (LSO) 1.60	12. (10.0-11.0)	12.8	10.9	1.7
6	543		6.0	16.2	24	11	7(LYSO)+ 8(GSO) 1.55	12.5 (10.5-11.5)	15.0	10.1	<1.6
5	377		6.0	16.2	24	11	7(LYSO)+ 8(GSO) 1.55	12.5 (10.5-11.5)	12.5	8.6	<1.6







Geometry calculation

- To build a cylindrical insert, the diameter D of which is dictated by the dimensions of the MRI bore and the thickness of the module h_{module}. To evaluate the number of modules per ring we follow the equation:

$$\mathrm{N}_{\text{detectors}} = \left\lfloor \frac{2\pi}{\arcsin\left(\frac{a}{D - 2 * h_{\text{module}}}\right)} \right\rfloor$$

- For the height of the cylinder, since not the whole length of the bore is necessary, we take the dimensions of the desired field of view

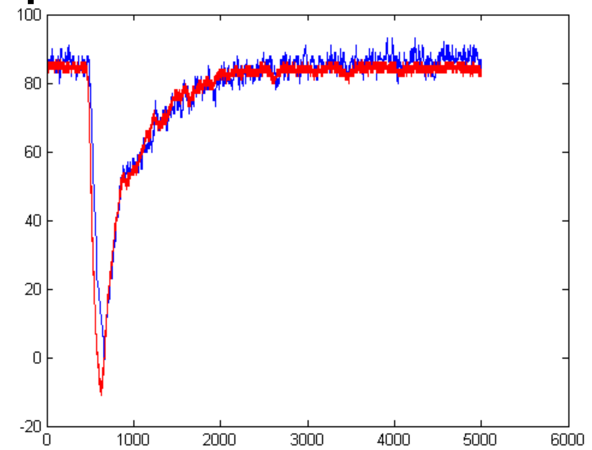
$$\mathrm{N}_{\text{rings}} = \left\lceil \frac{h_{\text{FOV}}}{a} \right\rceil$$

- Realistic example:
  - D=20 cm,
  - h_{FOV}=20cm
  - a=5.8cm,
  - h_{module}=2.2cm

$\mathrm{N}_{\text{detectors}}$= 16 and $\mathrm{N}_{\text{rings}}$= 4→ 64 modules

Readout of detector element: pulse model

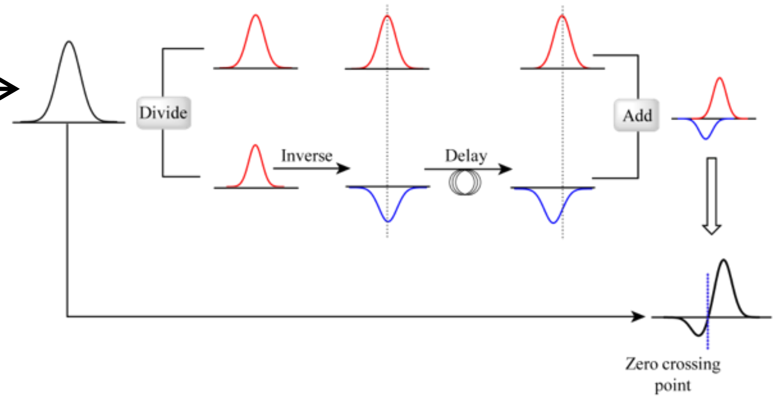
- Scintillation event:
    - Described by bi-exponential model: $e^{-t/0.72} - e^{-t/43}$
    - Duration ~200 ns
- Spectrum: Depends on the bandwidth of electronics (theory→ infinite, practice changes the model)
- **Digitalization Rate** of ~200 Mhz possible and sufficient (~5 ns step)
- Digital pulse duration: ~40 words
- Digitalization in 12bits/word
- Pulse digital size: 16 bits.

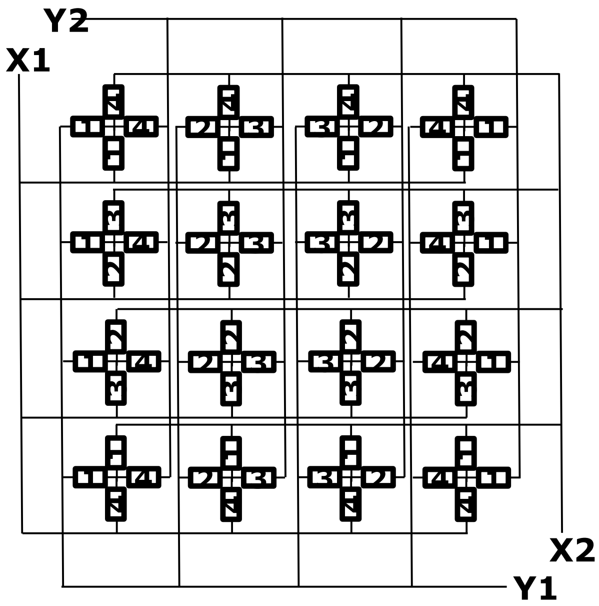


Deterioration of fast element due to high frequency filtering

Readout of detector element

- Event information:
  - Timing
  - Fine position (pixel ID), X and Y)
  - Event Energy





- Constant fraction discriminator
  - This is not relevant for the Gamma camera
- Charge addition network (Anger logic) codifying position and energy from the integrals of pulses:

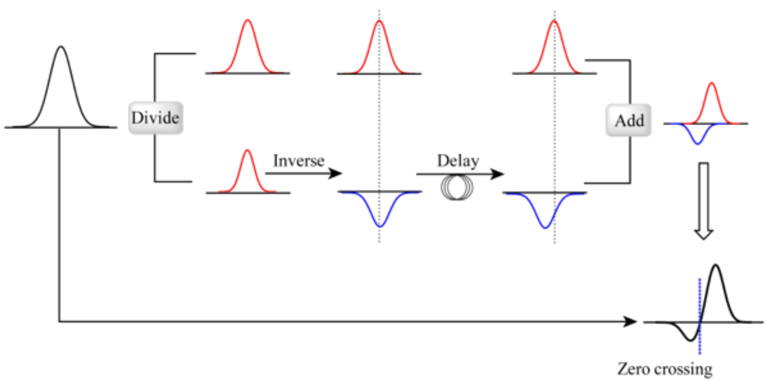
$$X = \frac{X_1 - X_2}{X_1 + X_2}$$

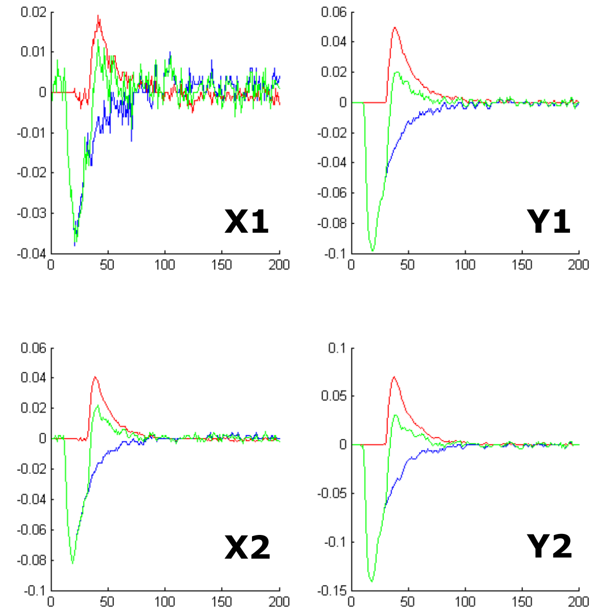
$$Y = \frac{Y_1 - Y_2}{Y_1 + Y_2}$$

$$E = X_1 + X_2 + Y_1 + Y_2$$

Readout of detector element- timing (CFD)

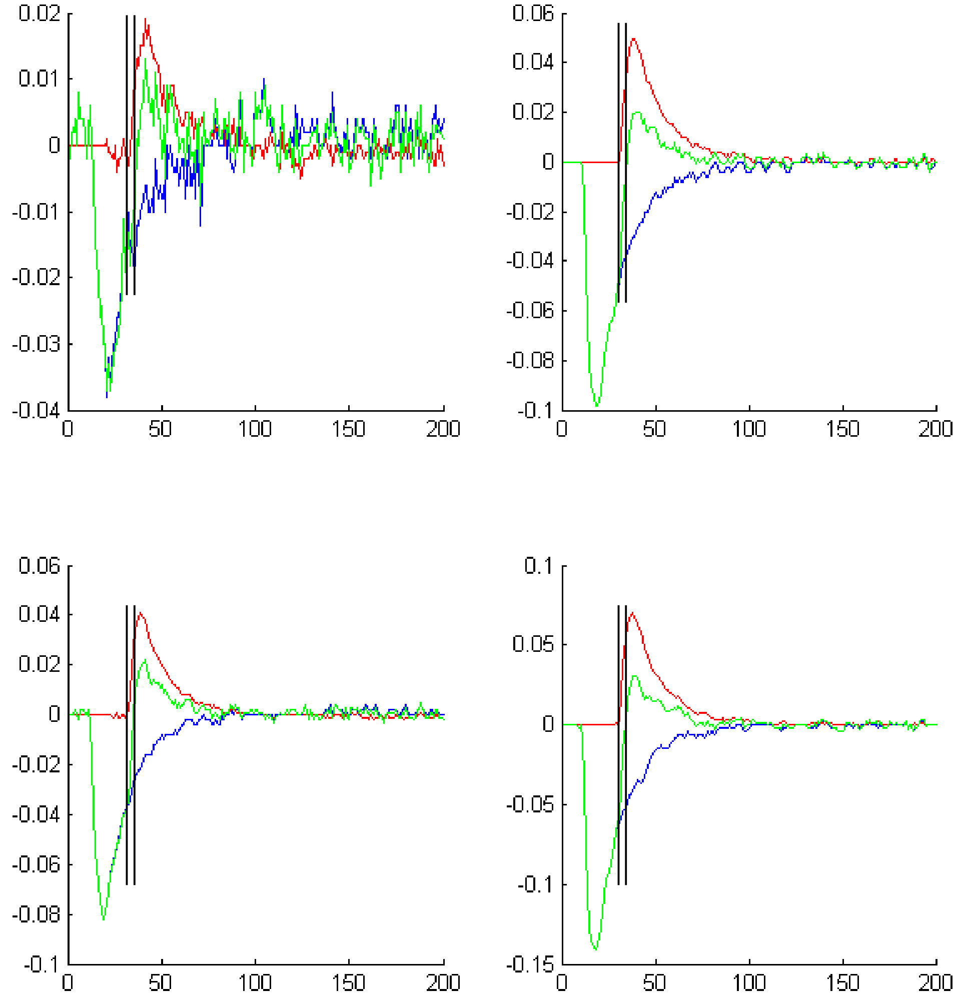
- Since anyway four pulses are recorded for energy measurement, **why not evaluate all four and take a mean**?
- Another idea, take a weighted mean, depending on predominant channel (more energy, event closer to the given channel pair, timing more accurate)





Readout of detector element- timing

- Zero crossing point results from **linear interpolation** between bigger negative and smaller positive value.
- By scaling the values to the MSB a small look up table can be created to avoid the division necessary for interpolation
- 2^6 values → fine time <100ps.



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Readout of detector element-energy/position

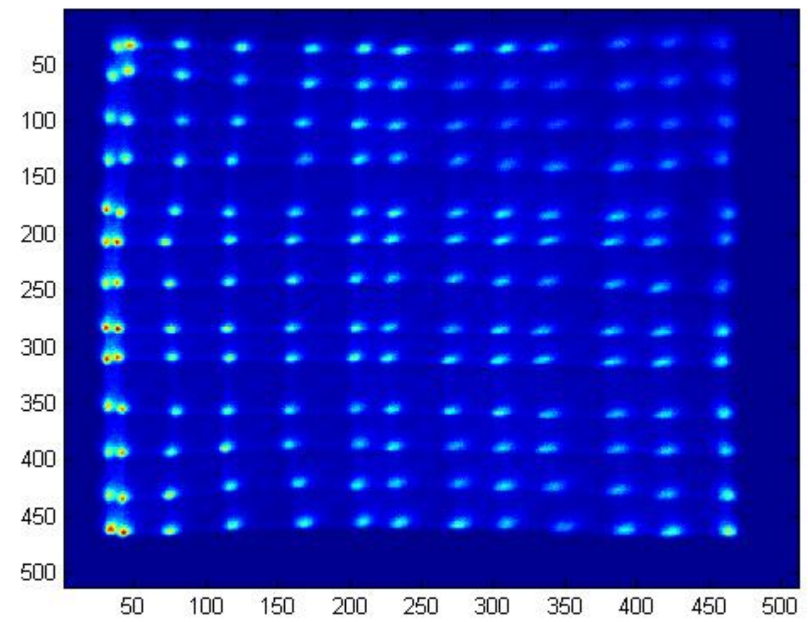
Integration by addition of words of pulse duration: Can be rounded (no need for 2^{16} different values).

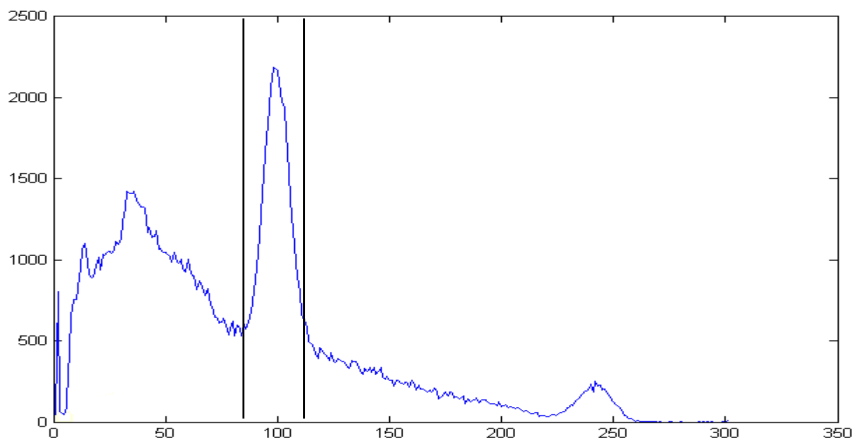
How many bits are necessary for the results (generously)?

512 values for X, Y

256 values for Energy

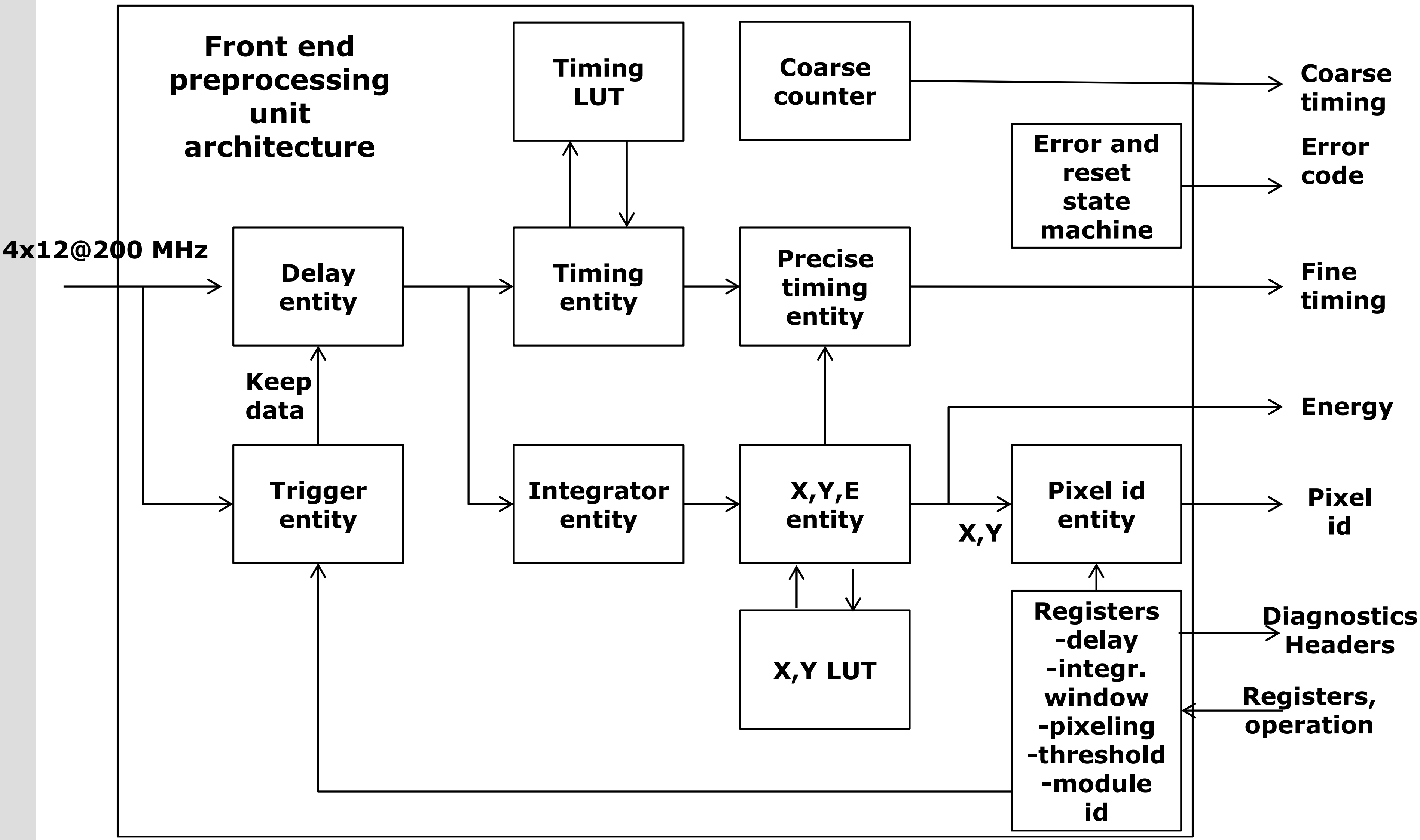
Thus $2^{16} \rightarrow 2^{9}$



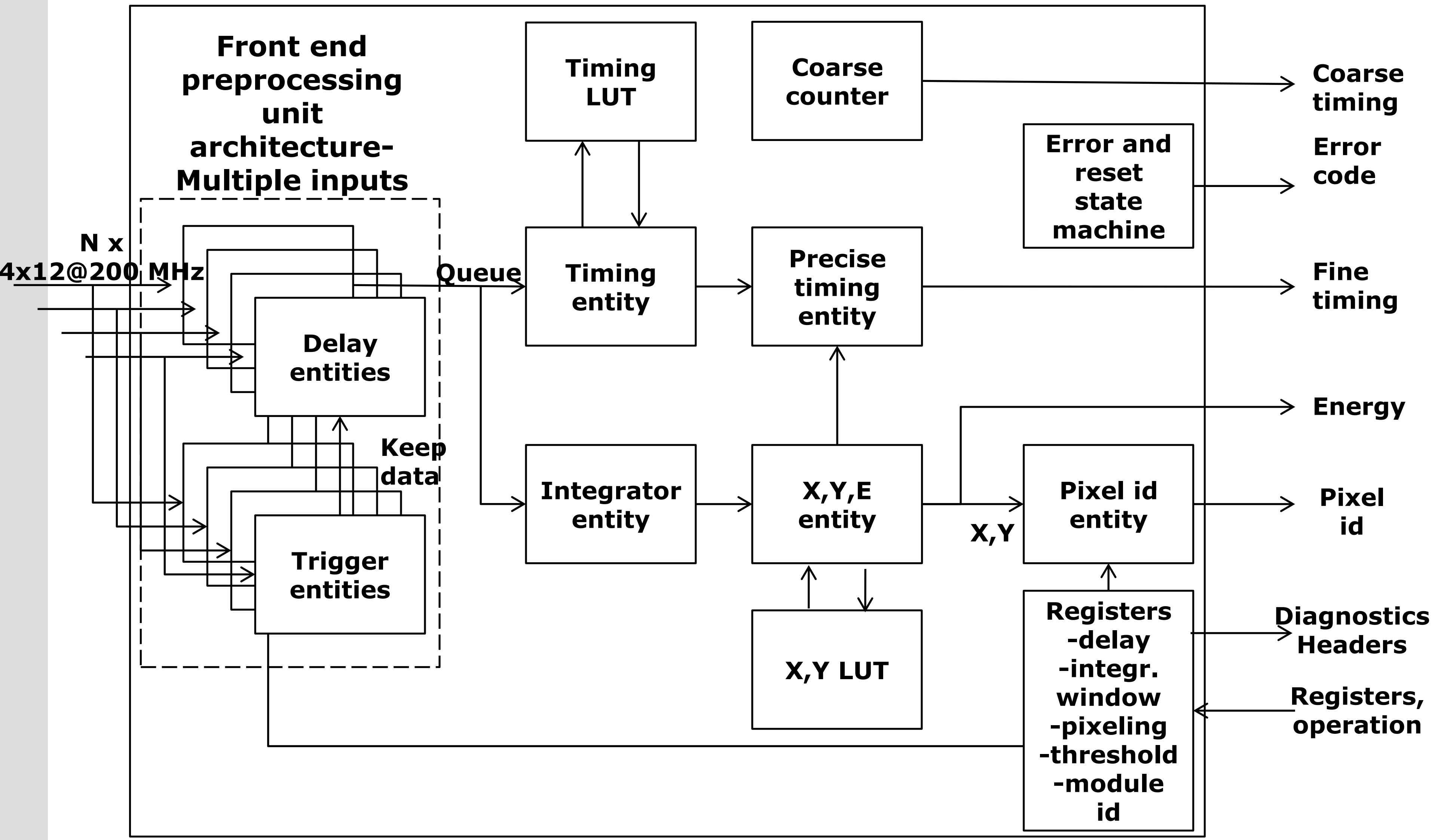


- X,Y can be calculated through a LUT, to avoid digital division…
- Furthermore, once a detector image has been analyzed, X,Y can be given directly in pixel ID, needing 11 bits (pixel size ~1 mm)…

Firmware architecture



Firmware architecture-multiple detectors



Workplan

- We need to evaluate the size of the architecture, but initial goal is a small FPGA (Artix, Zynq PL, Cyclone).
- The possibility of more than one front-end modules connected to one FPGA will be also evaluated.
- Most of the independent entities have been algorithmically developed.
- A big number of pre-recorded pulses exist and will be used for test benching.
- Secondment will be undertaken in INFN Pisa in November, supervised by Giancarlo Sportelli as an FPGA specialist.

The end

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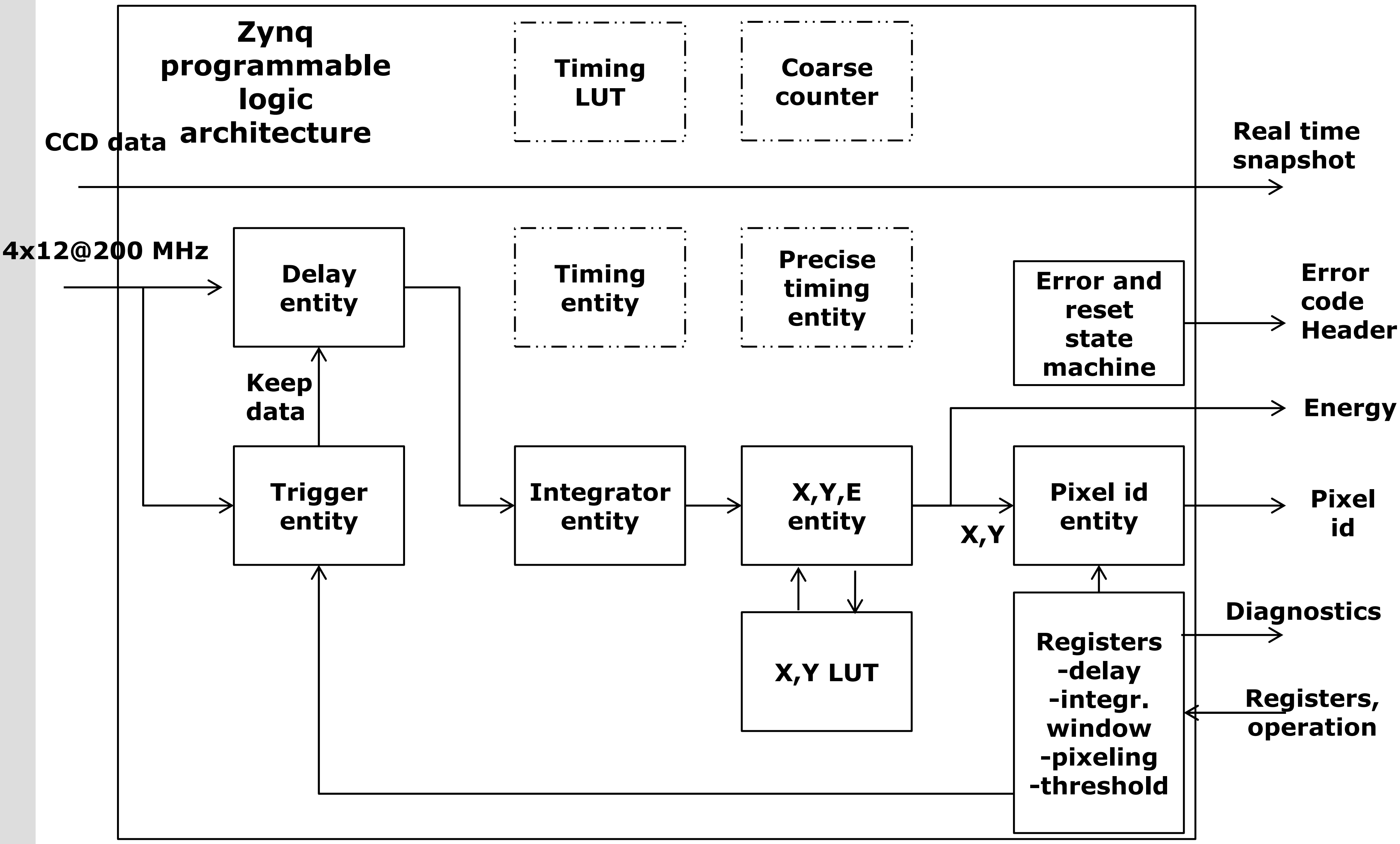
Firmware architecture- Gamma camera



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