COMPET: High Resolution High Sensitivity MRI Compatible Pre-Clinical PET Scanner

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The Research Council of Norway
FNSNF
Swiss National Science Foundation

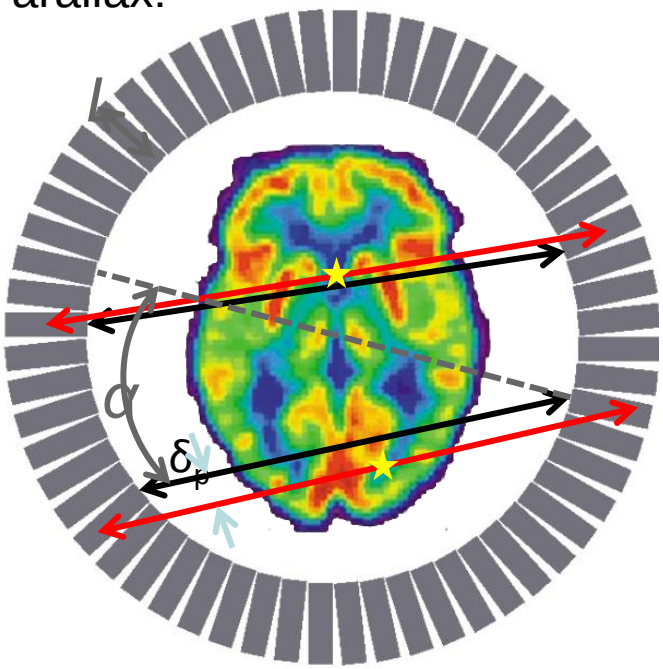
Outline

- COMPET overview
- DAQ system overview
- COMPET status
- Characterization
- Reconstructed images

COMPET

Two (of many) challenges with PET

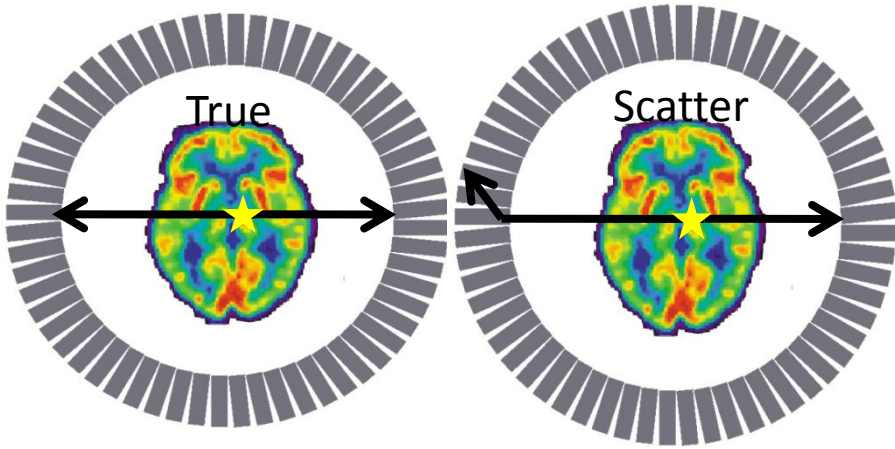
Parallax:



Parallax error: $\delta_p = L \times \sin\alpha$

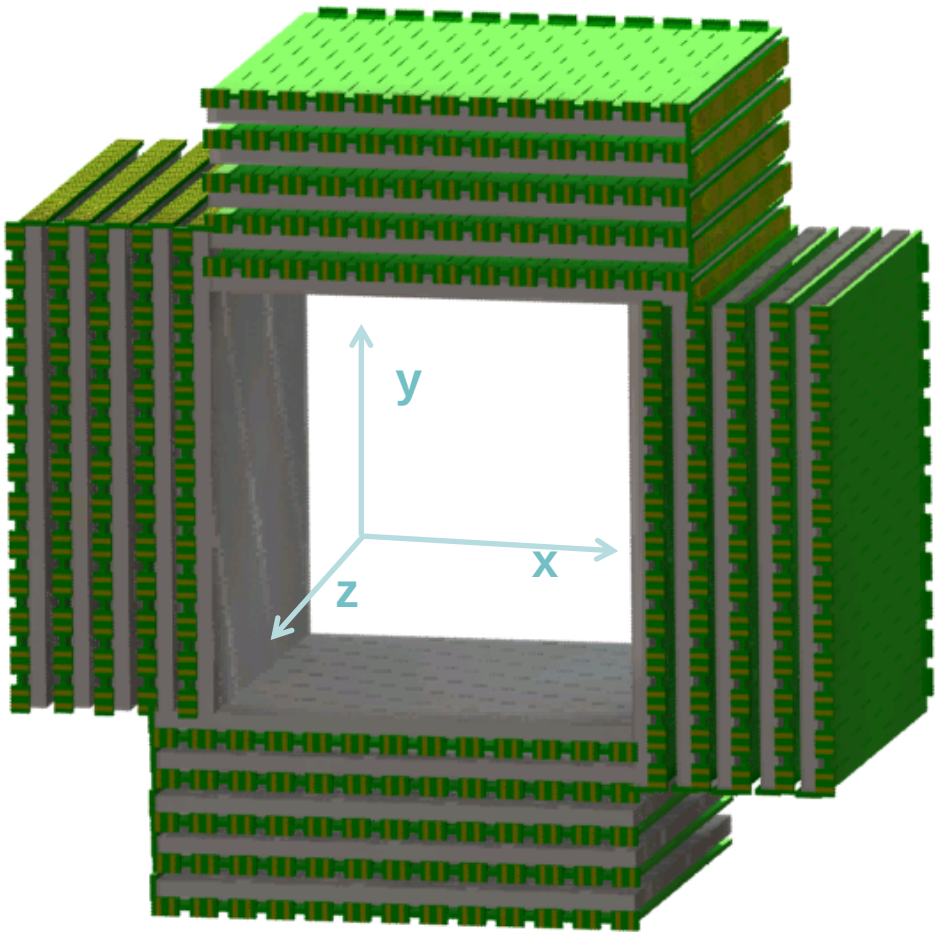
- Increases with distance from center of FOV
- No DOI → Parallax error!
- **Solution**: Measure interaction point in 3 dimensions

Inter-crystal scatters:



- With no DOI inter-crystal scattered events are lost
- Energy+DOI allows for Compton reconstruction
- Fewer discarded events -> higher sensitivity

COMPET – Quick overview



- 4-8 cm adjustable bore opening with 8cm axial view
- very high sensitivity (16%)
- high resolution (~1 mm)
- 3D event reconstruction
- no inter module or inter crystal gap
- High data throughput FPGA/Ethernet readout (~Mevents/sec)
- Back-end computer farm for data acquisition and image reconstruction
- MRI compatibility

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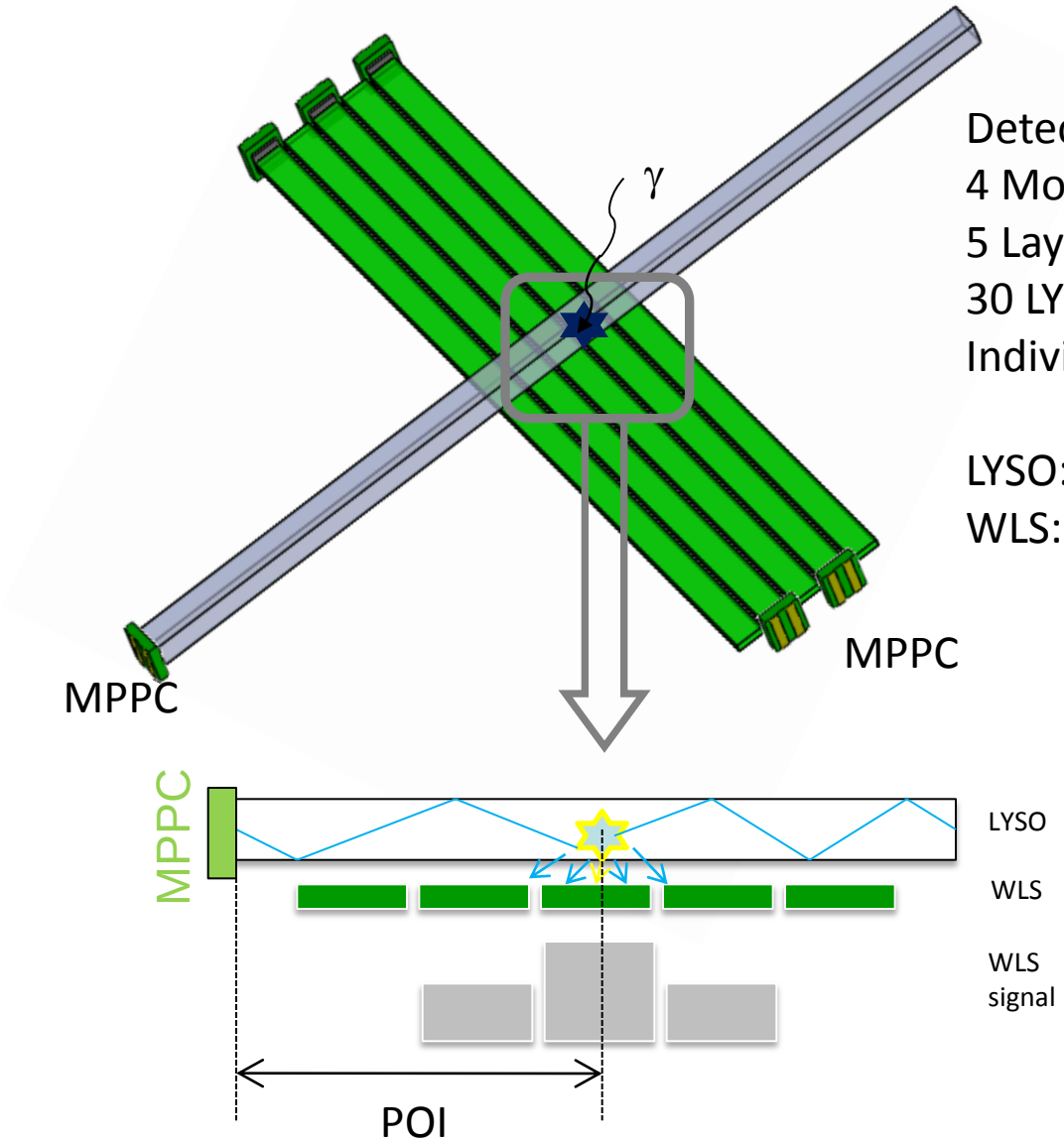
COMPET: POI Measurement Concept

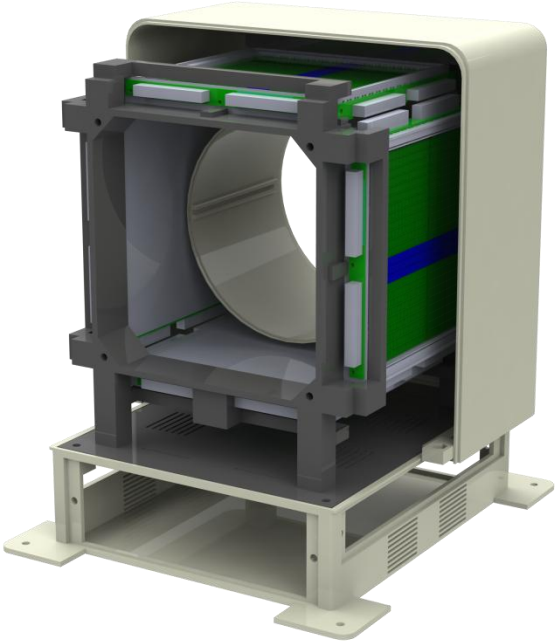


Detector consists of:
4 Modules, where 1 module is
5 Layers, and 1 layer consists
30 LYSO crystals and 24 Wavelength shifters
Individually read out

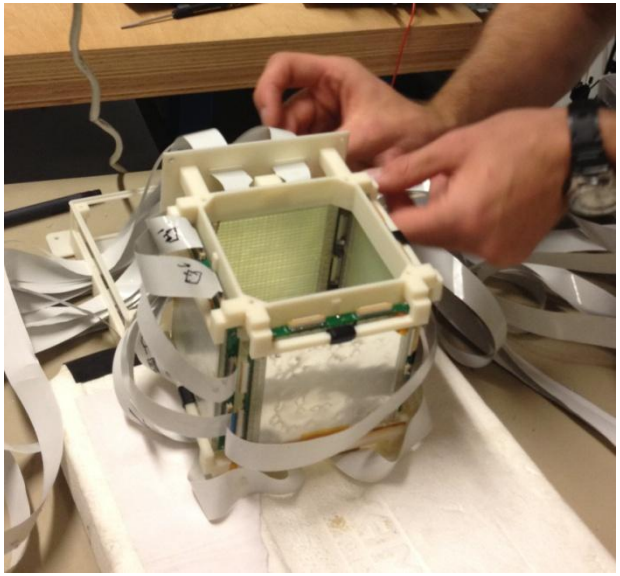
LYSO: 3x2x80 mm
WLS: 1x3x80 mm

First proposed by AxPET.
See: [The AX-PET experiment: A demonstrator for an axial Positron Emission Tomography]

COMPET status



- Four layers assembled and set-up in a square bore
- DAQ system verified
- Preliminary rat and phantom studies performed
- First MRI tests performed
- Image reconstruction program (CUDA based) made and verified



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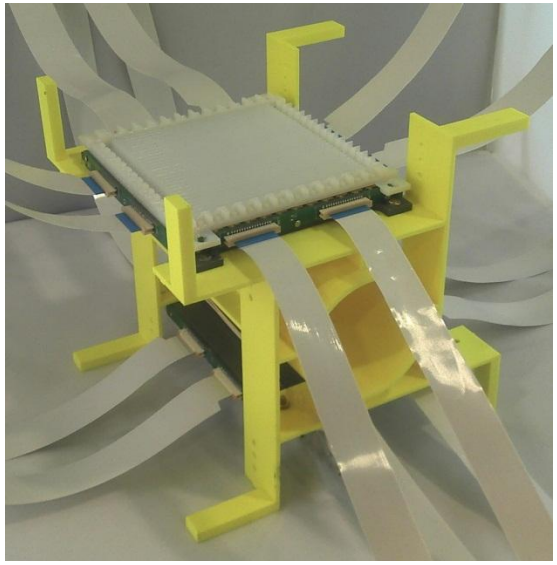
Read-Out System Front-End (1)

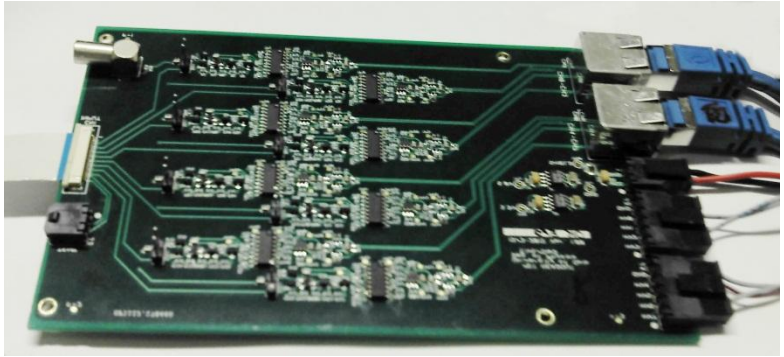
¼ of a LYSO or WLS layer: →

- A flat cable carries HV and signal for 8 SiPMs
- Ground seperation between each channel
- Cable length 1 meter (will be extended)
- Temperature sensor near MPPCs
- 6,7 or 8 channels per FFC



Analog Pre-amplifier: →

- 8 channels per card
- Time-over-Threshold from charge integration and linear decay from constant current source
- Typical ToT value for 511kev=0.3µs
- LVDS output through shielded CAT-5
- 4 channels per CAT-5



Read-Out System Front-End (2)

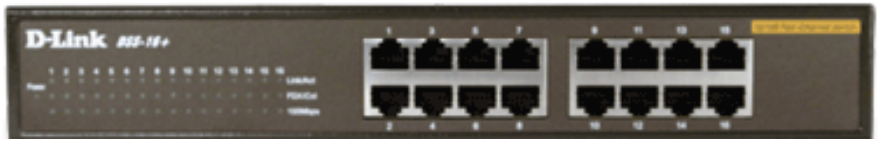
Digitalization:

- A Virtex-5 Dev. Board using 54 deserializers digitizes one full layer (30 LYSO, 24 WLS)
- 20 read-out cards + 1 centralized trigger needed for a full scanner
- Deserializers run at 0.6 Gbps for a timing resolution of 1.667 ns
- Data output as synchronized UDP streams through a switched 1 Gbps network

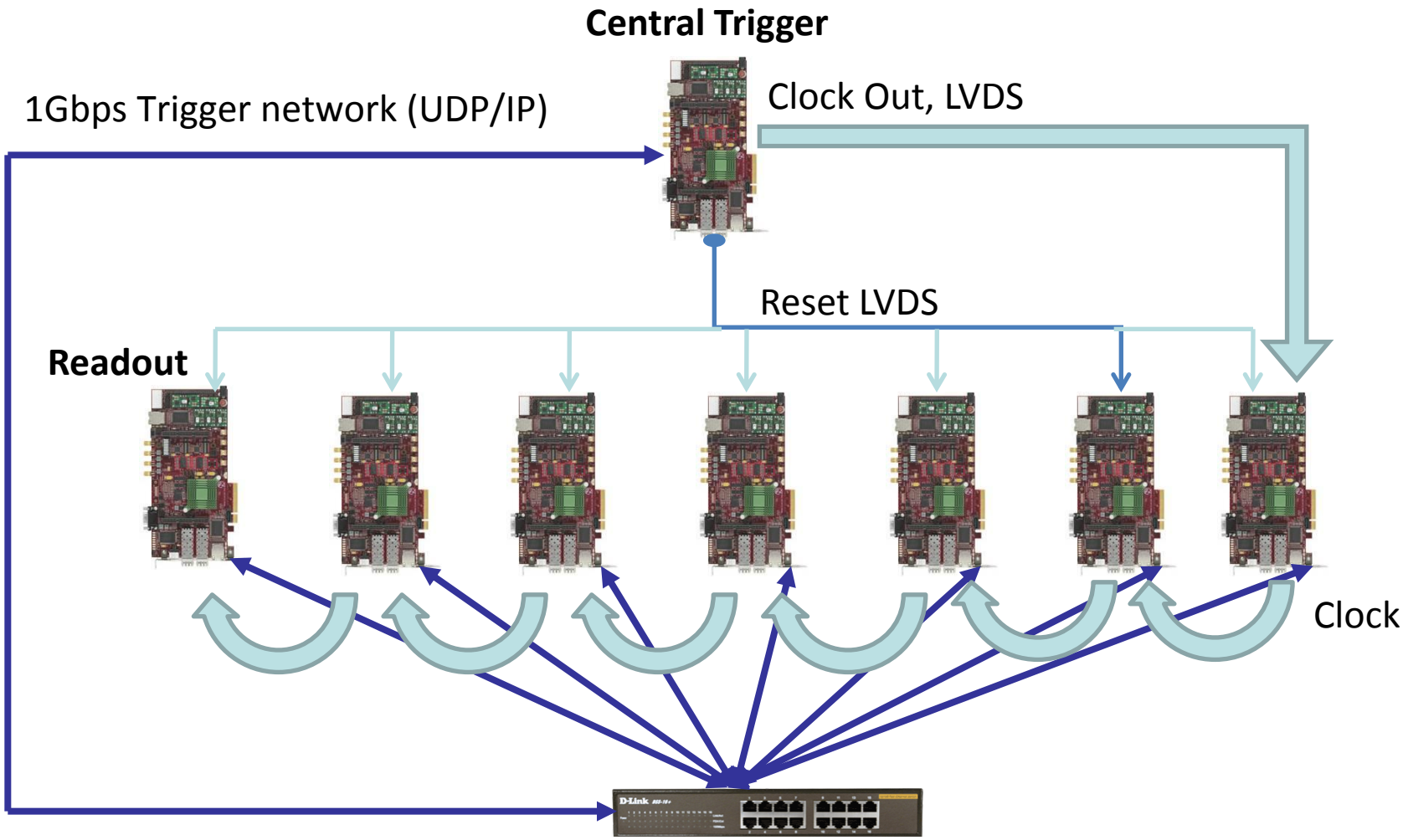
→

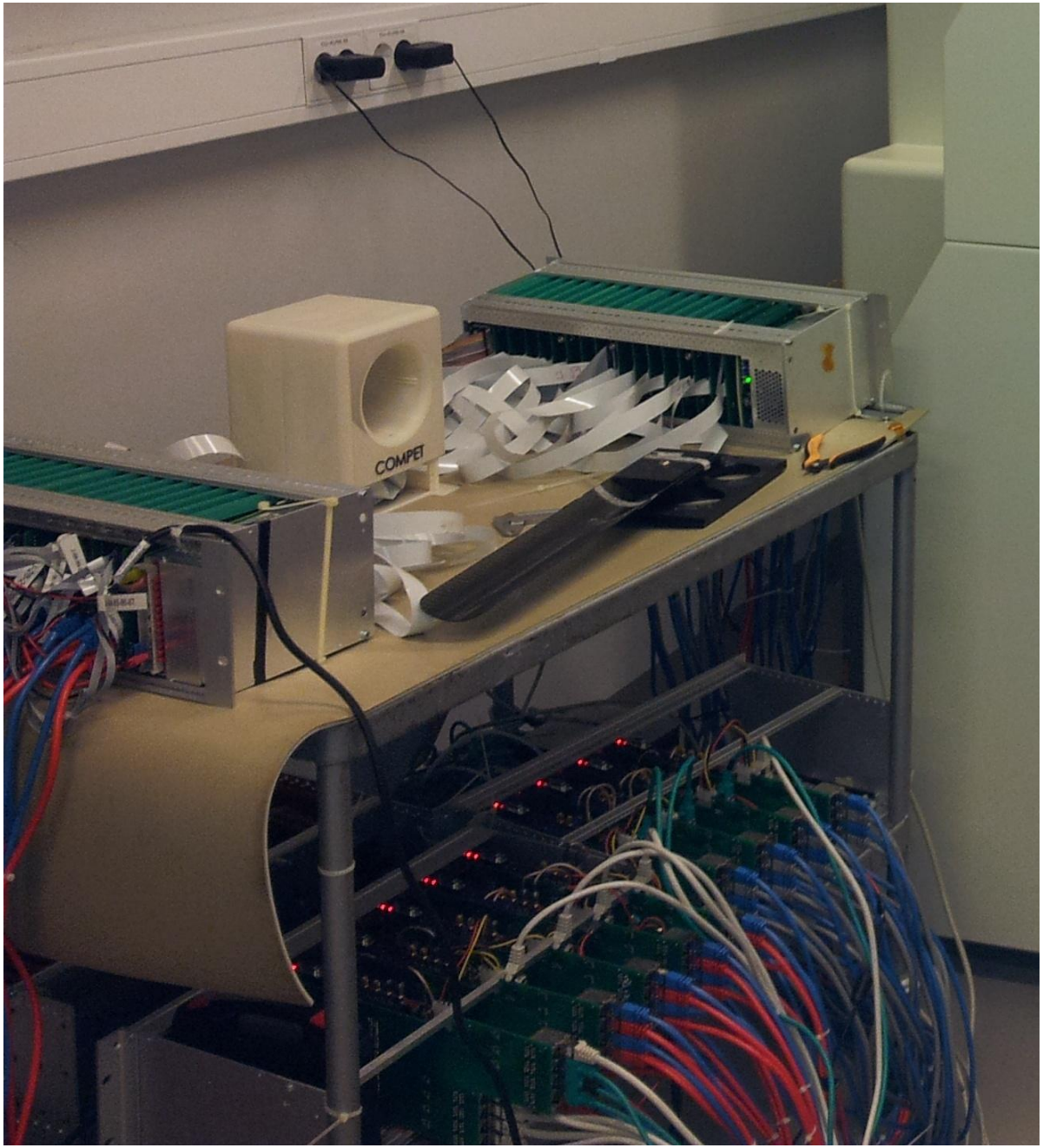
Computer Storage:

- An arbitrary number of multi-core computers can be used
- Events are stored as raw binary

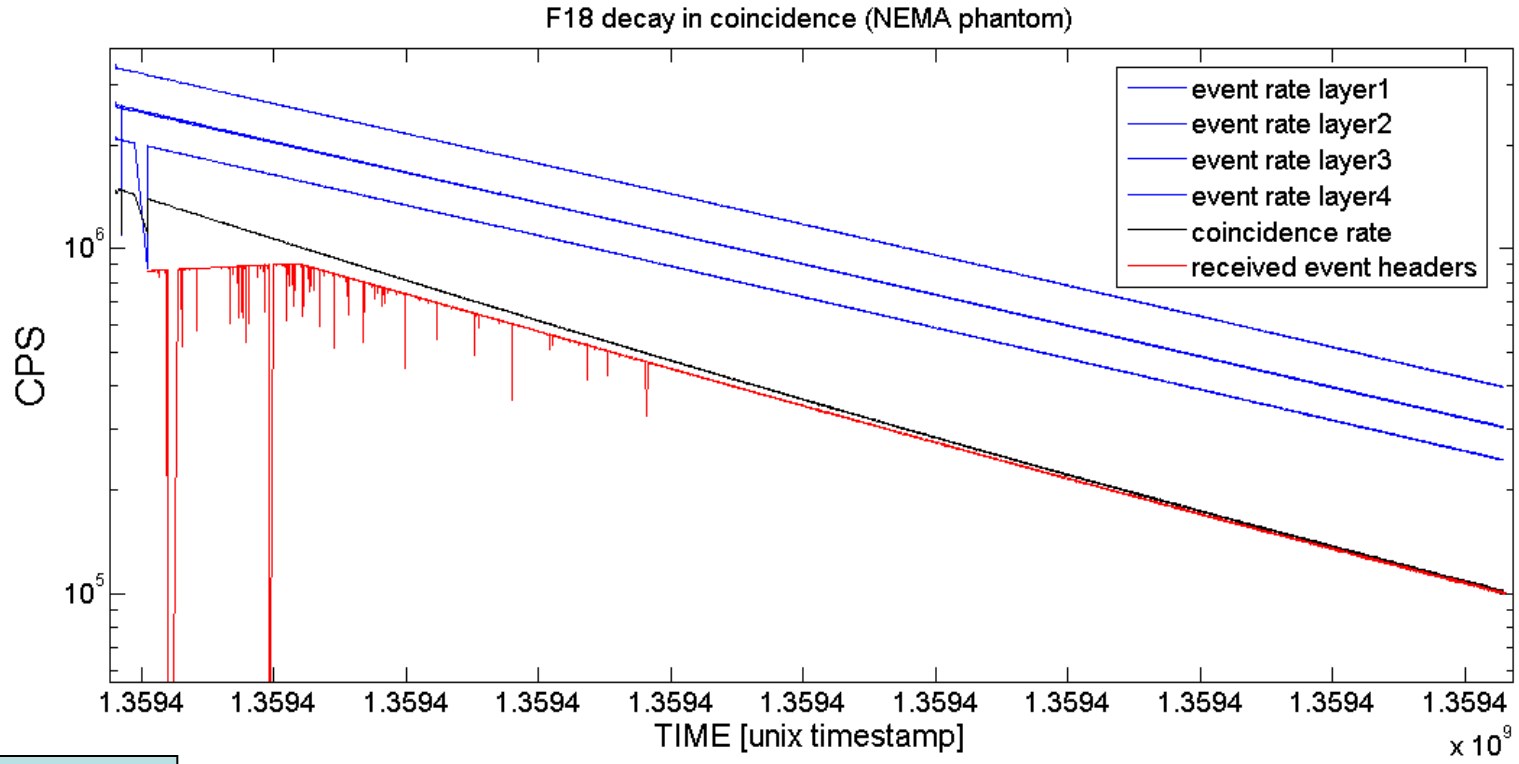


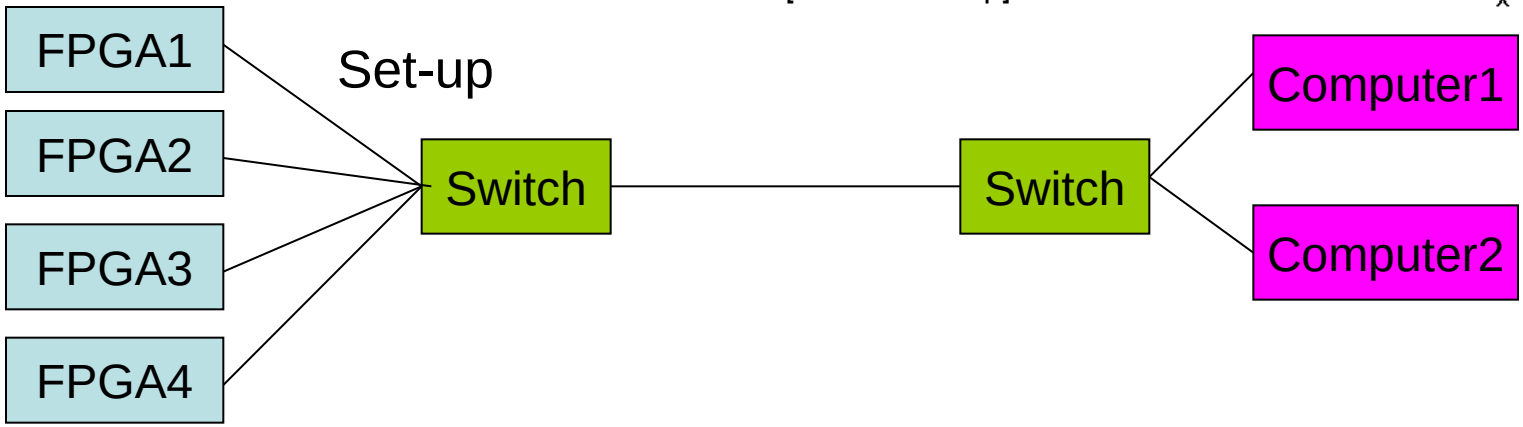
Trigger & Reset system



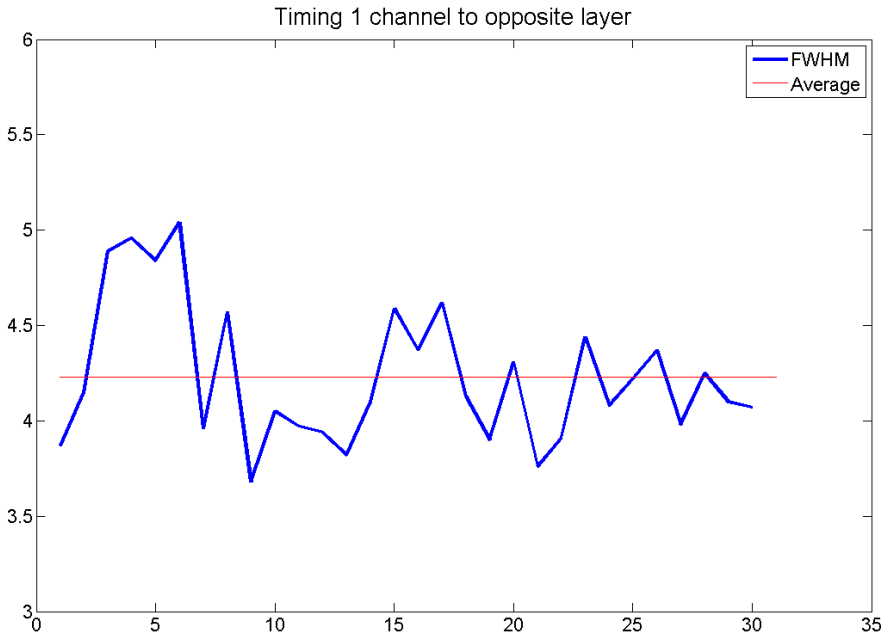

COMPET

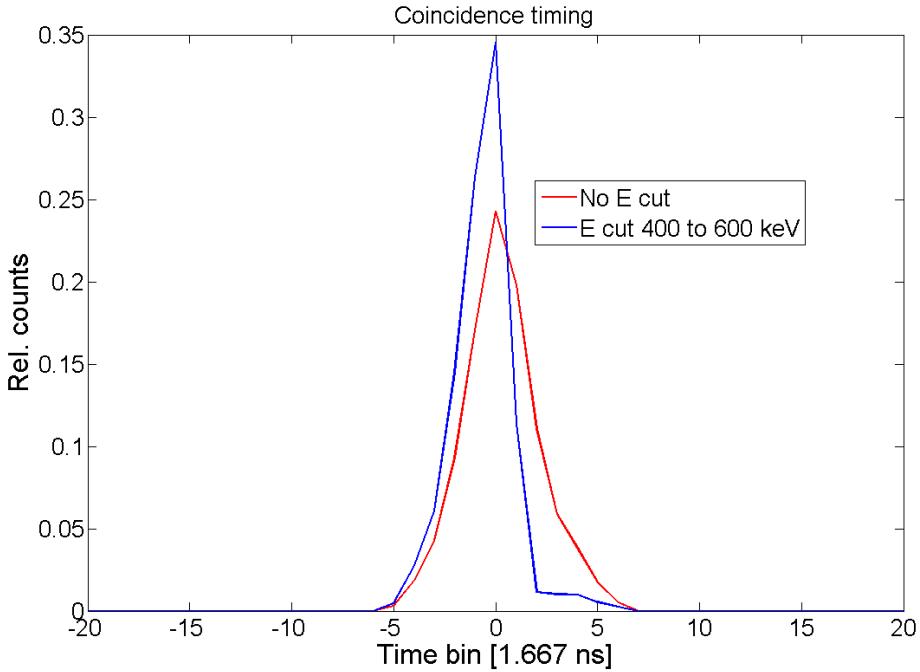
Rate capabilites





Coincidence Timing



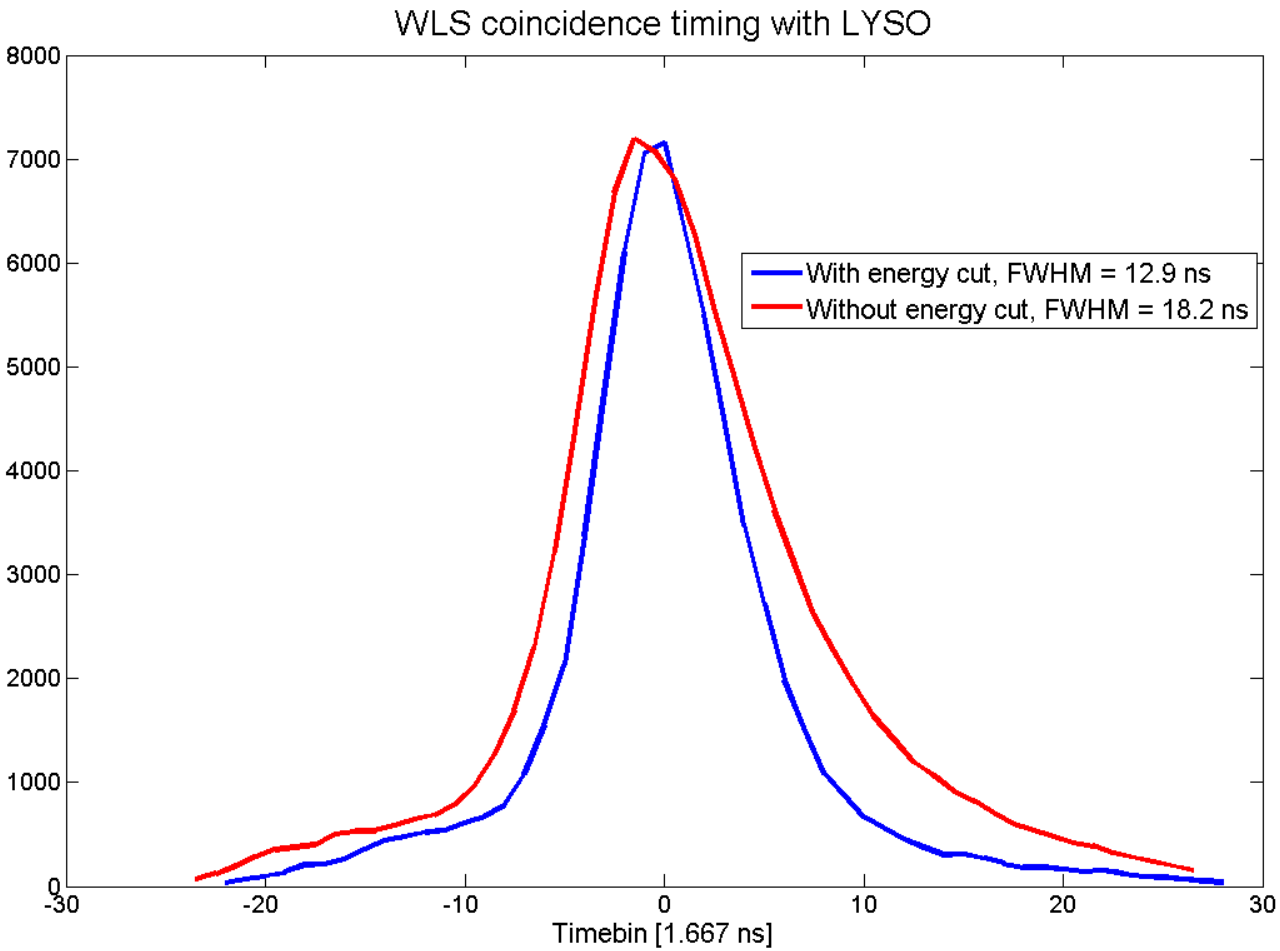


Differences from channel to channel can be explained by non-uniform gain (steepness of rising edge)

FWHM with E-cut = 4.22 ns
FWHM without E-cut = 5.85 ns

Time walk may be a large contributor for timing uncertainties and is not yet accounted for

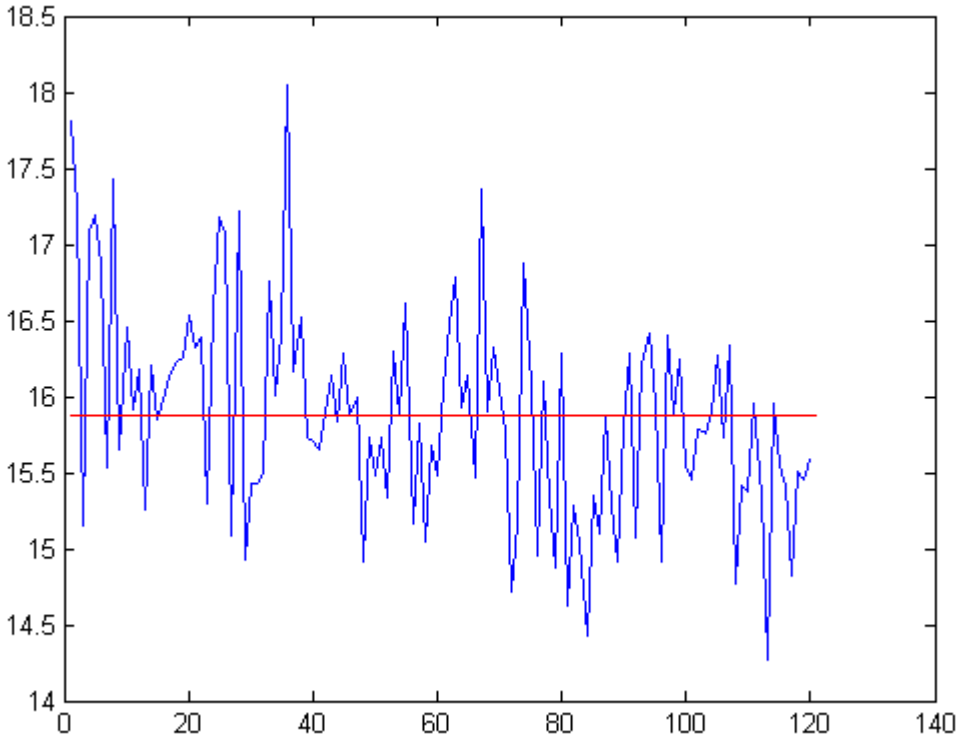
WLS timing

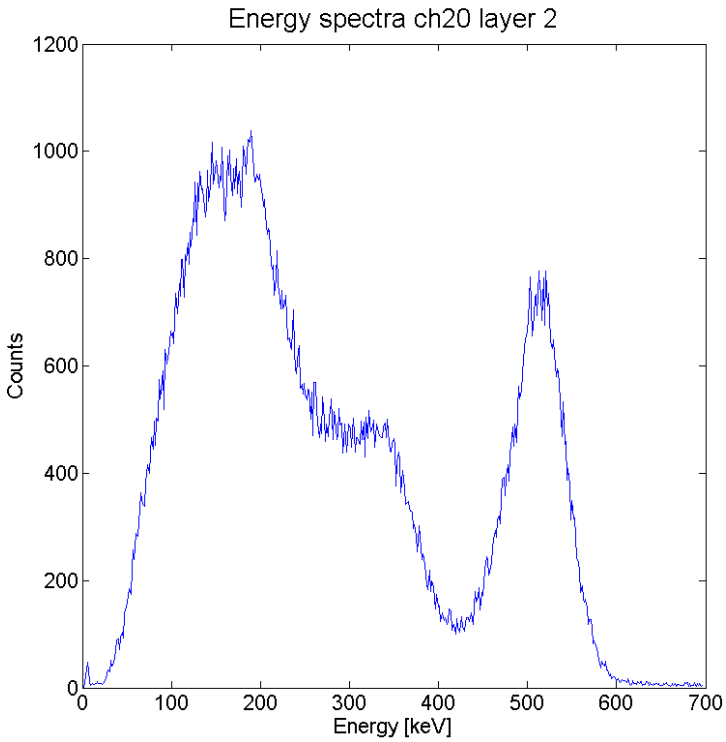


WLS events where LYSO E>400 keV

constant offset from LYSO event start time ~20 ns

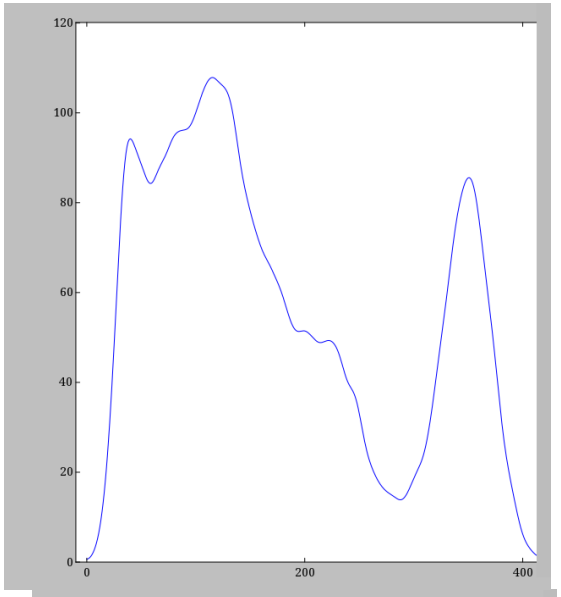
Energy resolution

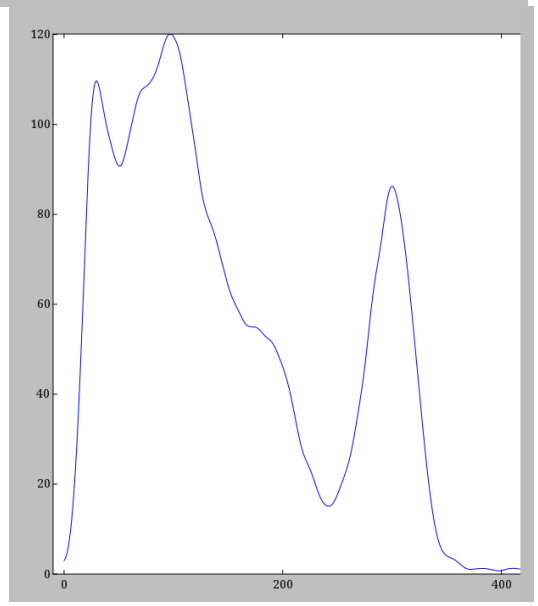




- Average FWHM = 15.8%
- Best = 14.3% Worst =18%

LYSO calibration





Calibrate each channel for time-invariant variance:

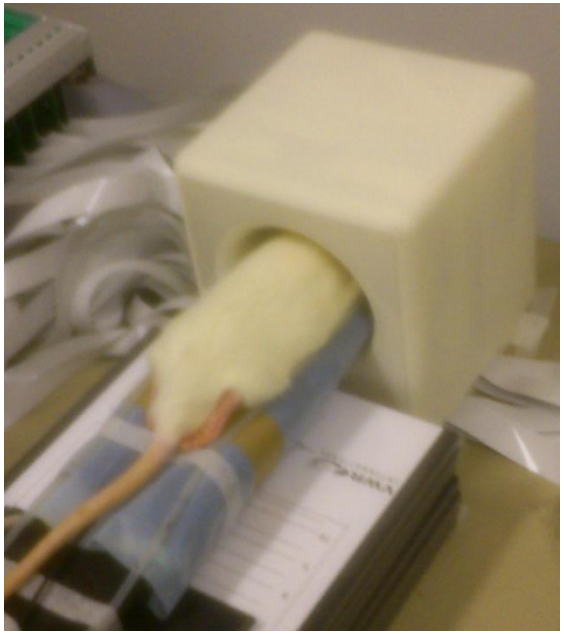
- Optical coupling
- Pre-amplifier gain difference (electronic tolerance)
- HV tolerance

Calibrate each channel for time-variant variance:

- MPPC Temperature (~ 8% pr °C)

Method:

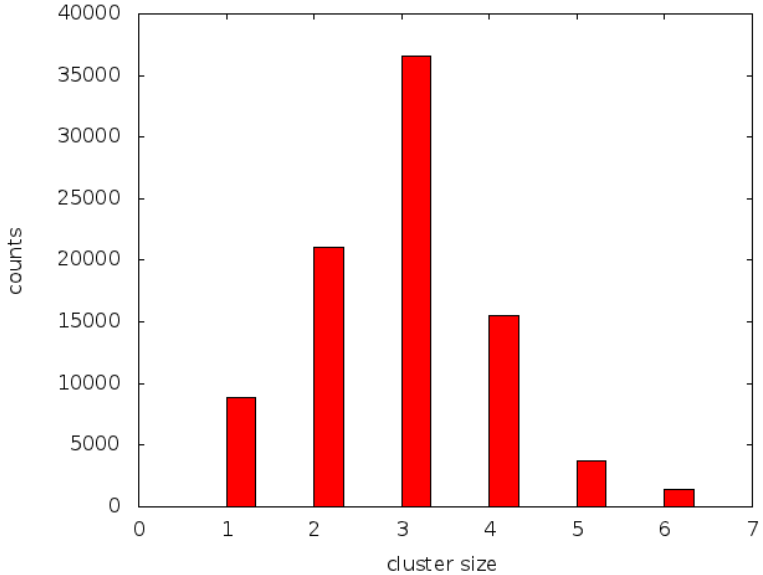
Use 1 minute long snippets of data and calibrate after photo-peak



Multiplicites and WLS calibration

- Multiplicities needed for center of gravity measurement
- Reflective coated lid on top of all layers

multiplicities in WLS for E>400keV



Calibration scheme for energy:

- Use WLS events where associated calibrated LYSO energy is between 400-600 keV
- Filter out WLS events which isn't part of a 3-hit cluster
- Calibration constant: $k = E_{LYSO} / E_{WLS}$

Problems:

WLS channels at the edge is never in the middle of a triplet

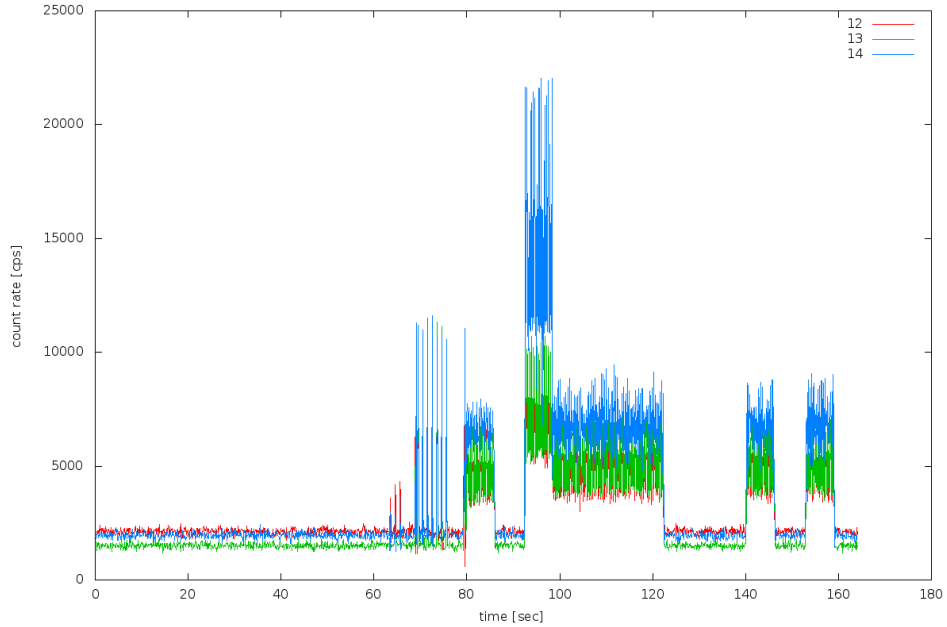
First MRI test

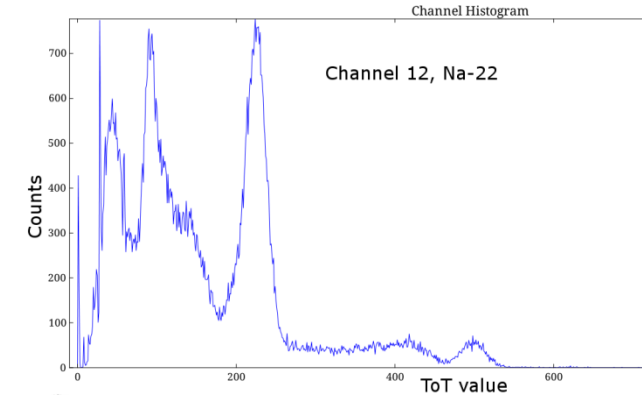
- Test set-up:

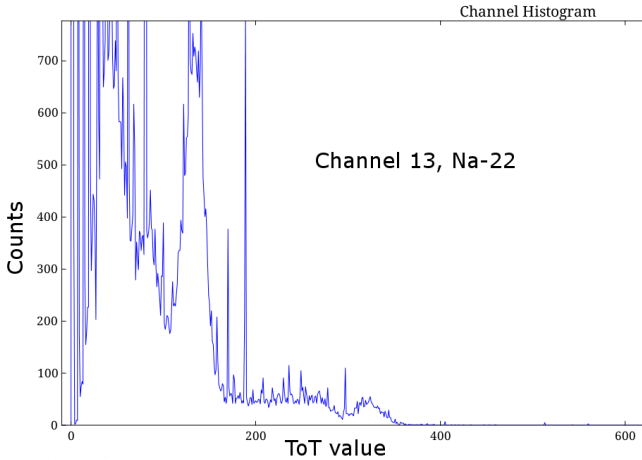
Phillips Sonata 3T

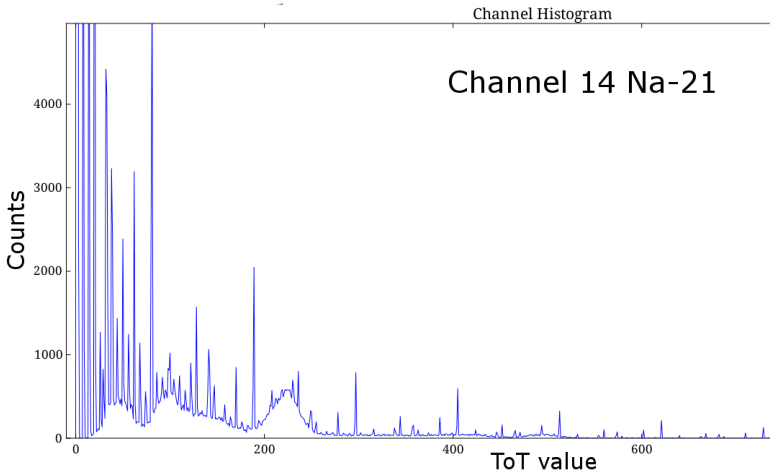
- 3 channels in a semi-assembled layer
- Pre-amplifier placed 1m from the MRI bore
- HV supply (Keithly) and FPGA was placed outside the MRI room
- Na-22 source was placed on top of the 3 channels
- Recorded energy and rate data before and under a “typical” MRI acquisition

First MRI test





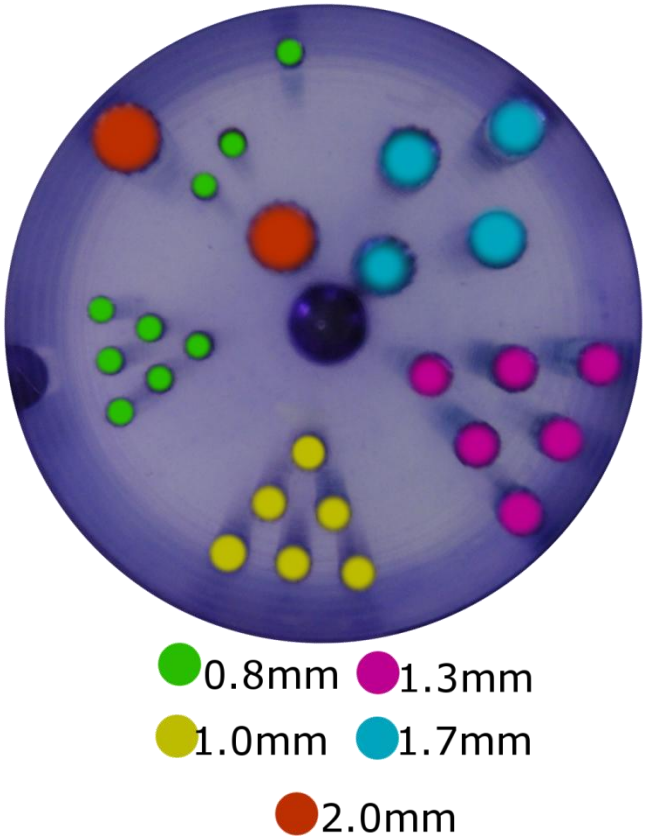


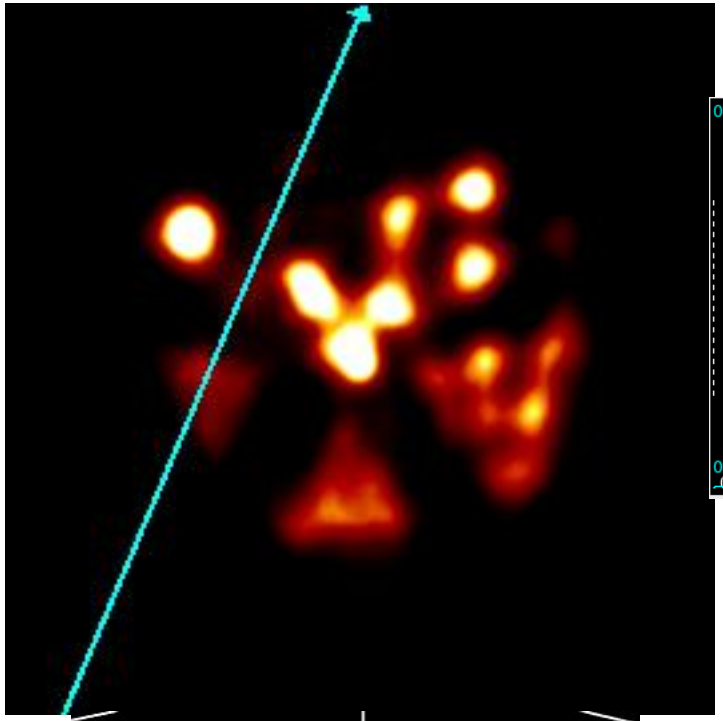


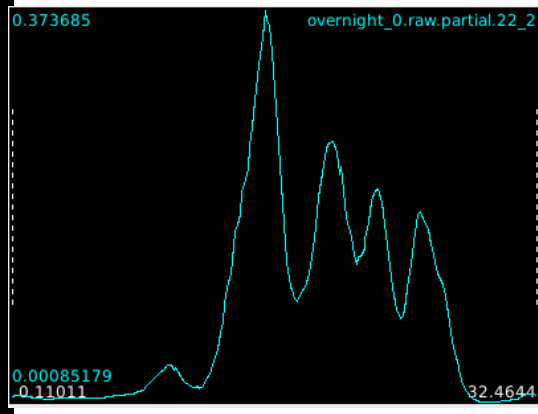
Noise rate depends on the MRi sequence type

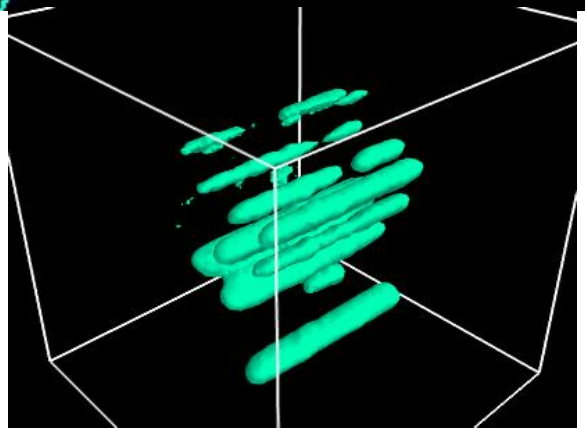
Improvements:
- Shielding (will affect MRi SNR)
- Gating
- Post acquisition filtering

Micro Derenzo

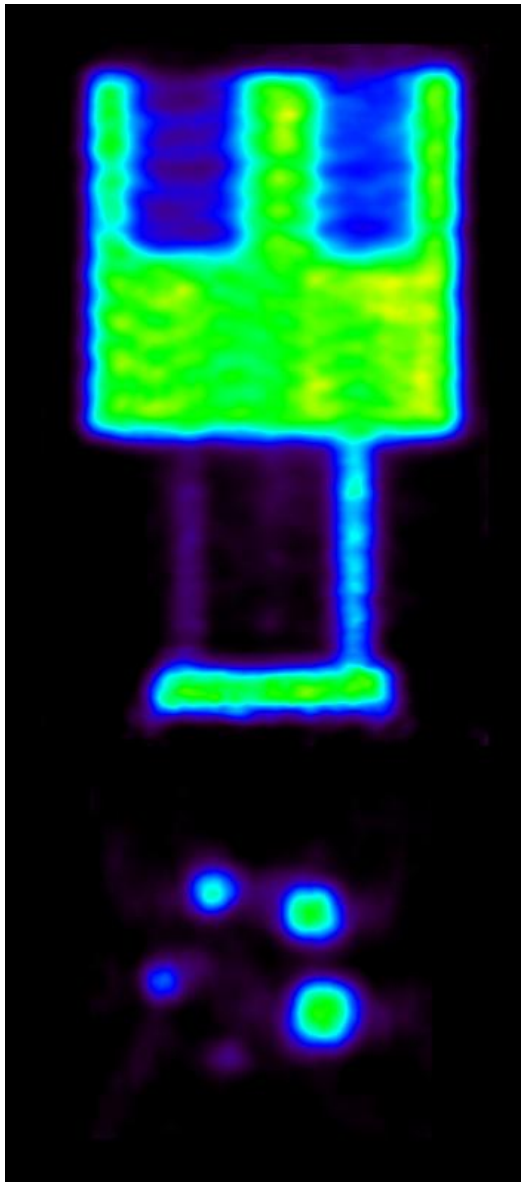




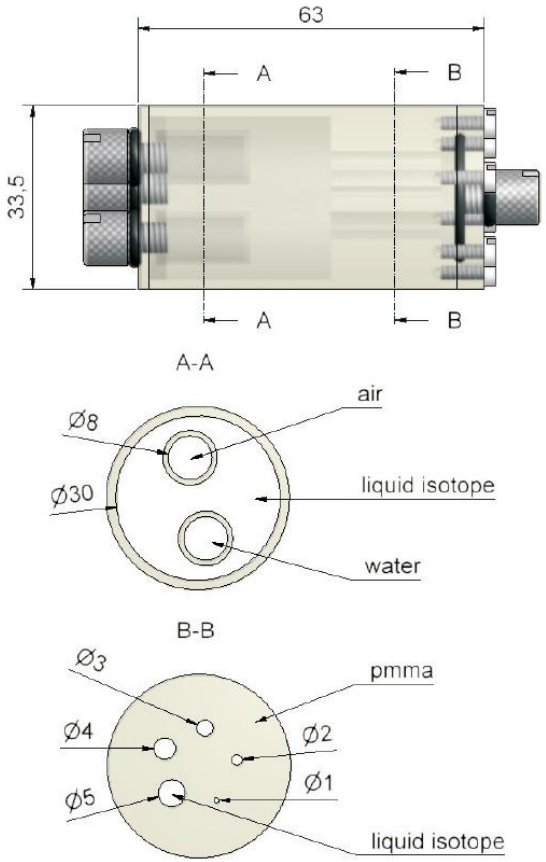




NEMA IQ

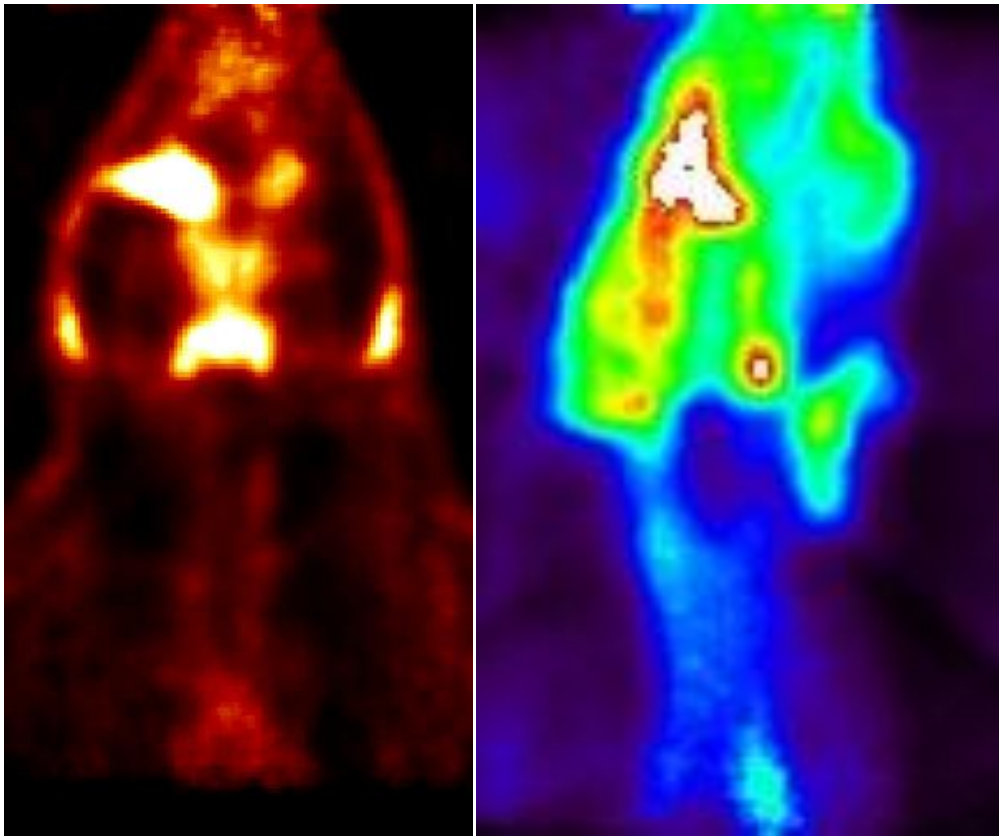


Acquisition was not done according to NEMA standards

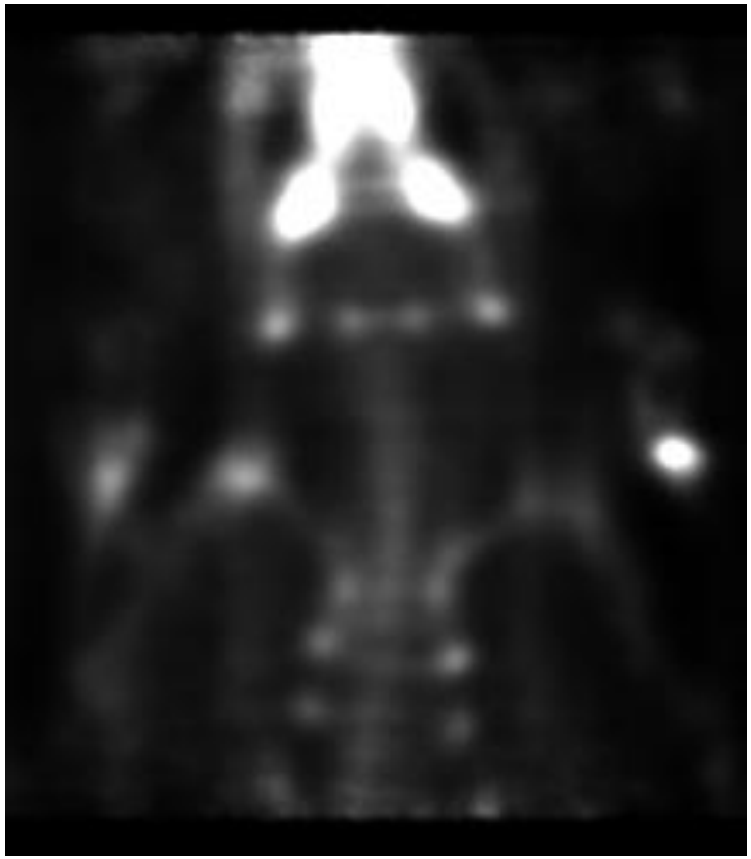


Reconstructed Images

FDG. Sagital and coronal view.

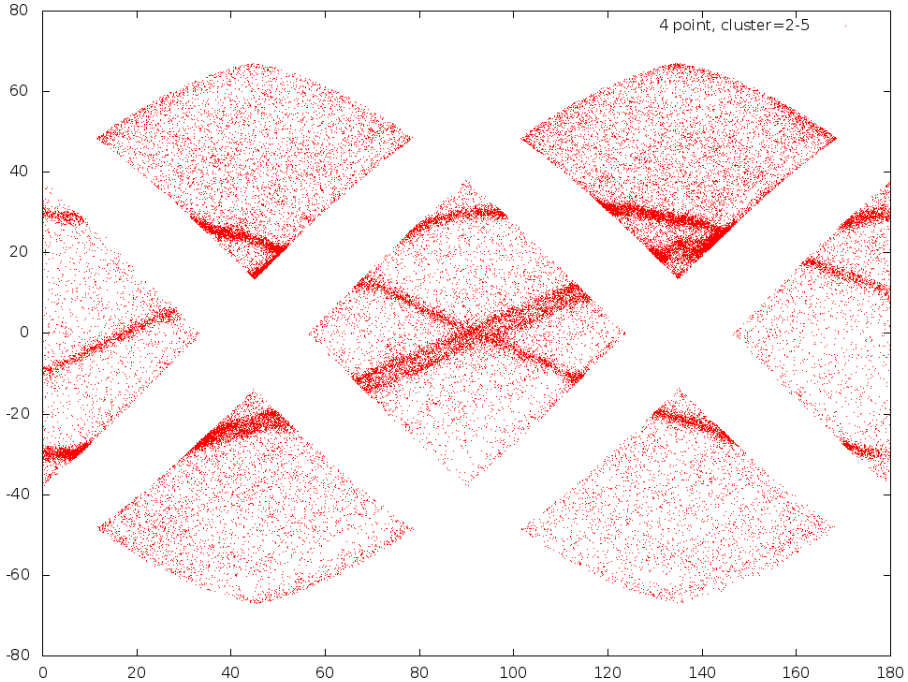


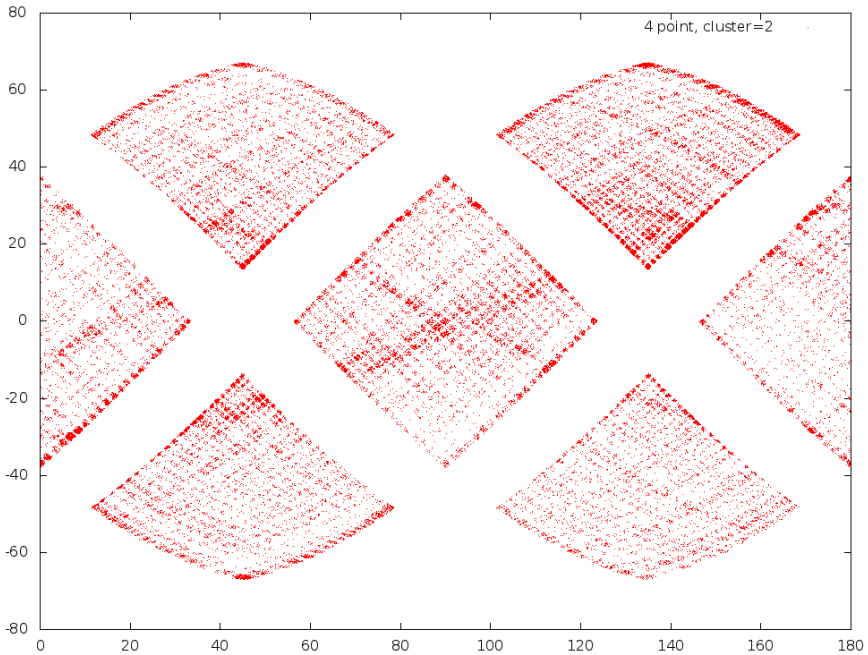
NaF (bone study tracer) Sagital view



Issues with current set-up

Sinogram, 4 point sources

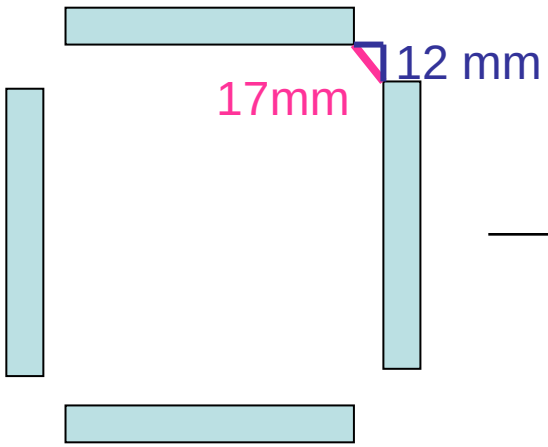




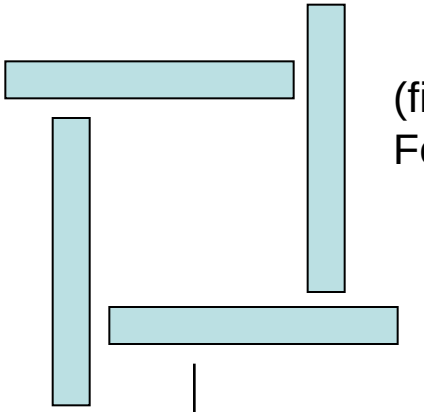
- Inter module gaps are too big!
- Blurring in the edges of module pairs believed to be caused by WLS calibration

Improving image quality

Now:

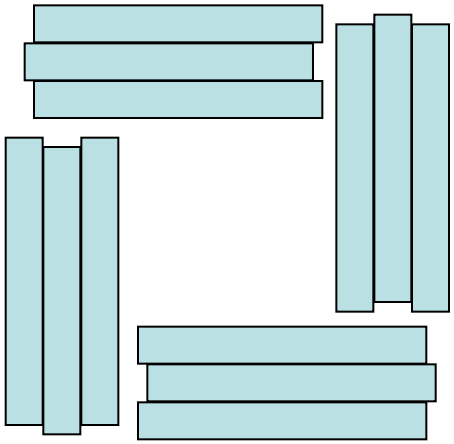


Removing inter-module gaps in FoV:



(finished by end of February)

Removing inter crystal gaps:



- Increase sensitivity
- Increase spatial resolution
- Compton reconstruction

Summary

- Four layers assembled
- DAQ proven to work for rates up to MCPS
- Layer characterization
- First studies carried out

Outlook:

- Continue with MRI testing
- Redo mechanics to eliminate inter-module gaps
- Currently searching for industrial partners

Thanks to:

UNIVERSITAS OSLOENSIS MDCCCXI

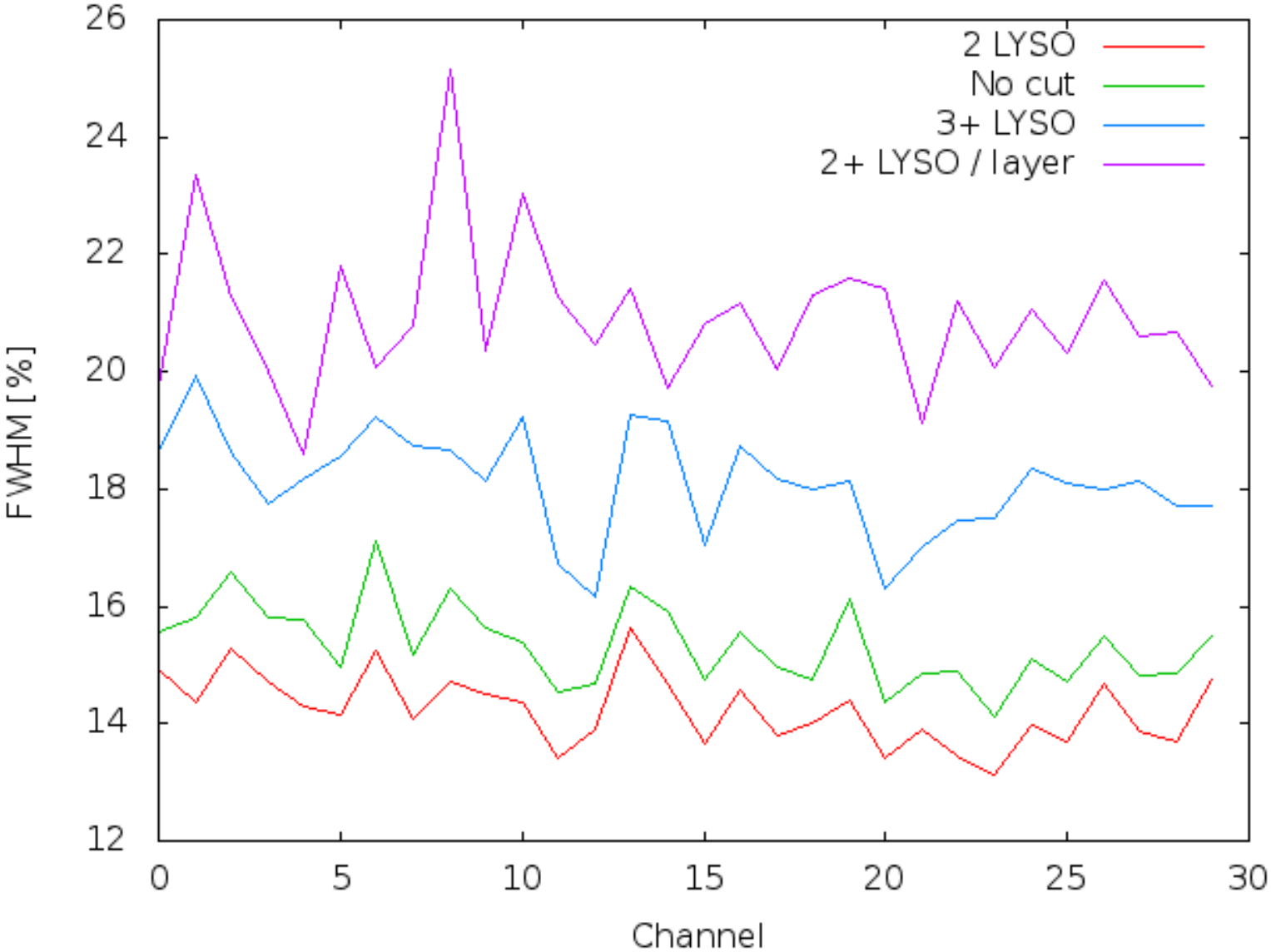
The Research Council of Norway

FNSNF Swiss National Science Foundation

Oslo universitetssykehus

SAFE

E res vs LYSO counts



MPPCs

LYSO:

Hamamatsu 1.8x3mm-40ump

3375 pixels

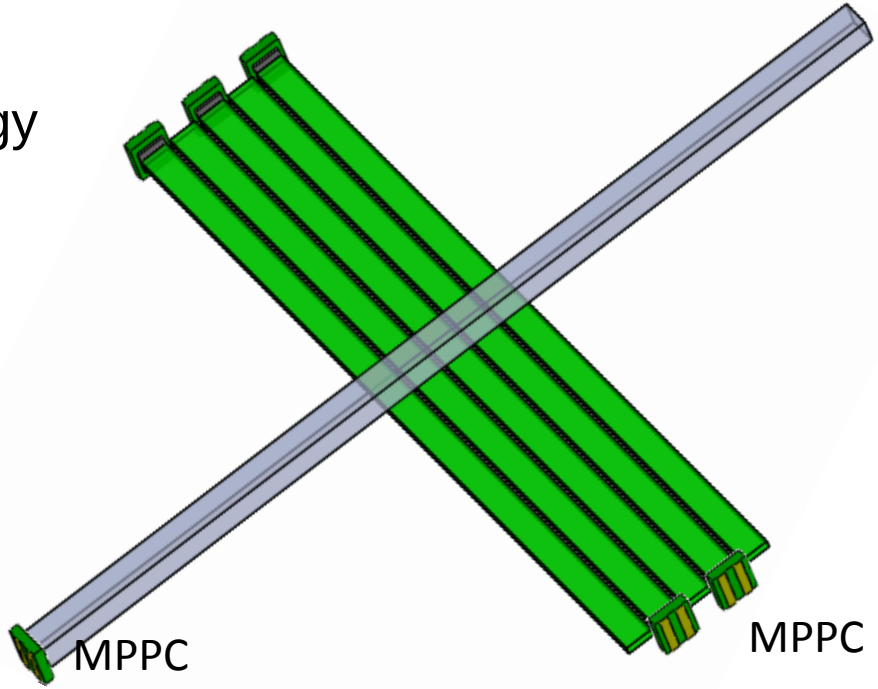
WLS

Hamamatsu 3.22x1.19mm-70ump

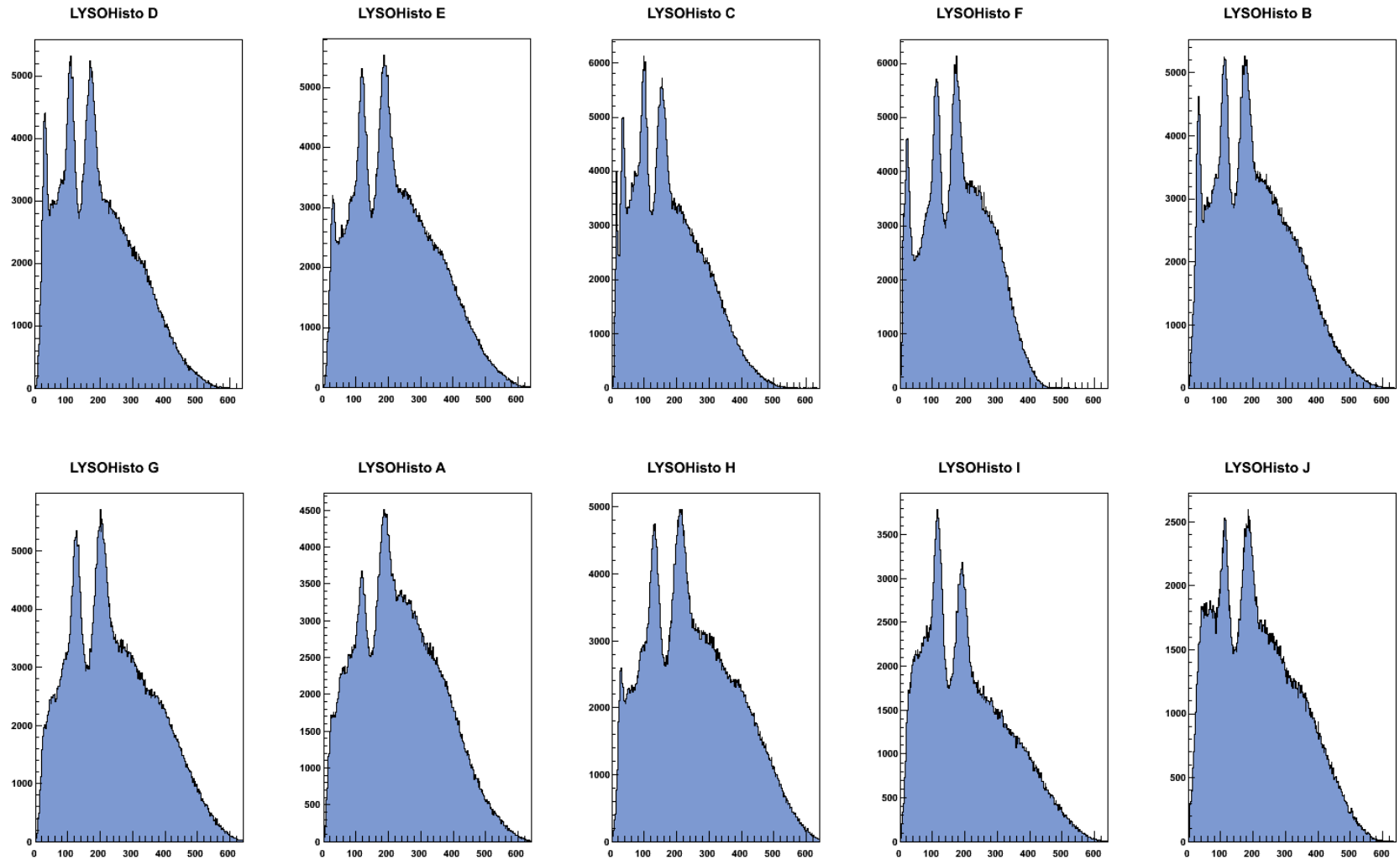
782 pixels

WLS calibration

- Use events from the middle LYSO
- Sum up integrated energy in WLS for different LYSO energy windows
- Pick a “golden wls” and calibrate after this



Intrinsic Spectra (LYSO)



Peaks at: 202keV, 303keV

Na-22 Coincident Spectra (LYSO)