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

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Outline

• COMPET overview
• DAQ system overview
• COMPET status
• Characterization
• Reconstructed images
Two (of many) challenges with PET

Parallax:

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

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

Inter-crystral scatters:

- With no DOI inter-crystral scattered events are lost
- Energy+DOI allows for Compton reconstruction
- Fewer discarded events $\rightarrow$ 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
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
Read-Out System Front-End (1)

¼ of a LYSO or WLS layer:
- A flat cable carries HV and signal for 8 SiPMs
- Ground separation between each channel
- Cable length 1 meter (will be extended)
- Temperature sensor near MPPCs
- 6, 7 or 8 channels per FFC

Analogue 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
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

1Gbps Trigger network (UDP/IP) → Central Trigger → Clock Out, LVDS → Reset LVDS → Readout → Clock

1Gbps Trigger network (UDP/IP)
Rate capabilities

F18 decay in coincidence (NEMA phantom)
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 $\sim 20$ 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

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: $k = \frac{E_{LYSO}}{E_{WLS}}$

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

- 0.8mm
- 1.3mm
- 1.0mm
- 1.7mm
- 2.0mm
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:

17 mm → 12 mm

(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:
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)