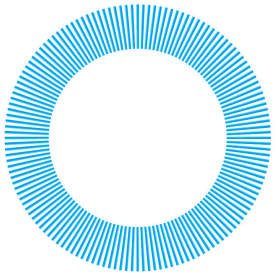
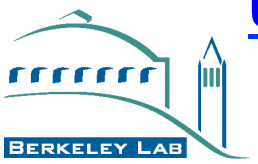


openPET

Second User's Group Meeting

Welcome & Overview	*Bill Moses*
Hardware Status & Plans	*Seng Choong*
Software Status & Plans	*Qiyu Peng*
Event Data Transfer Video	*Leonid Lamwertz*
Source Code Management	*Martin Judenhofer*
U. Manitoba OpenPET Projects	*Andrew Goertzen*
UC Davis OpenPET Projects	*Simon Cherry*



November 1, 2012

openPET Concept

- Nuclear Medicine Research Community Needs "Industrial Strength" Electronics
- Needs Can Be Met By a Single, *Flexible* Design!
  - Heavy Use of FPGAs
  - Highly Programmable Electronics
- By Sharing and Modifying Code, Community Avoids Duplication of Effort

Everybody Wins if We Pool Our Efforts

BERKELEY LAB

OpenPET Vision

Open Source

- Hardware, Firmware, and Software
- Schematics, Gerbers, BOM,…

Standardized Architecture

- Compatible Alternate Hardware
- Software Readily Transportable

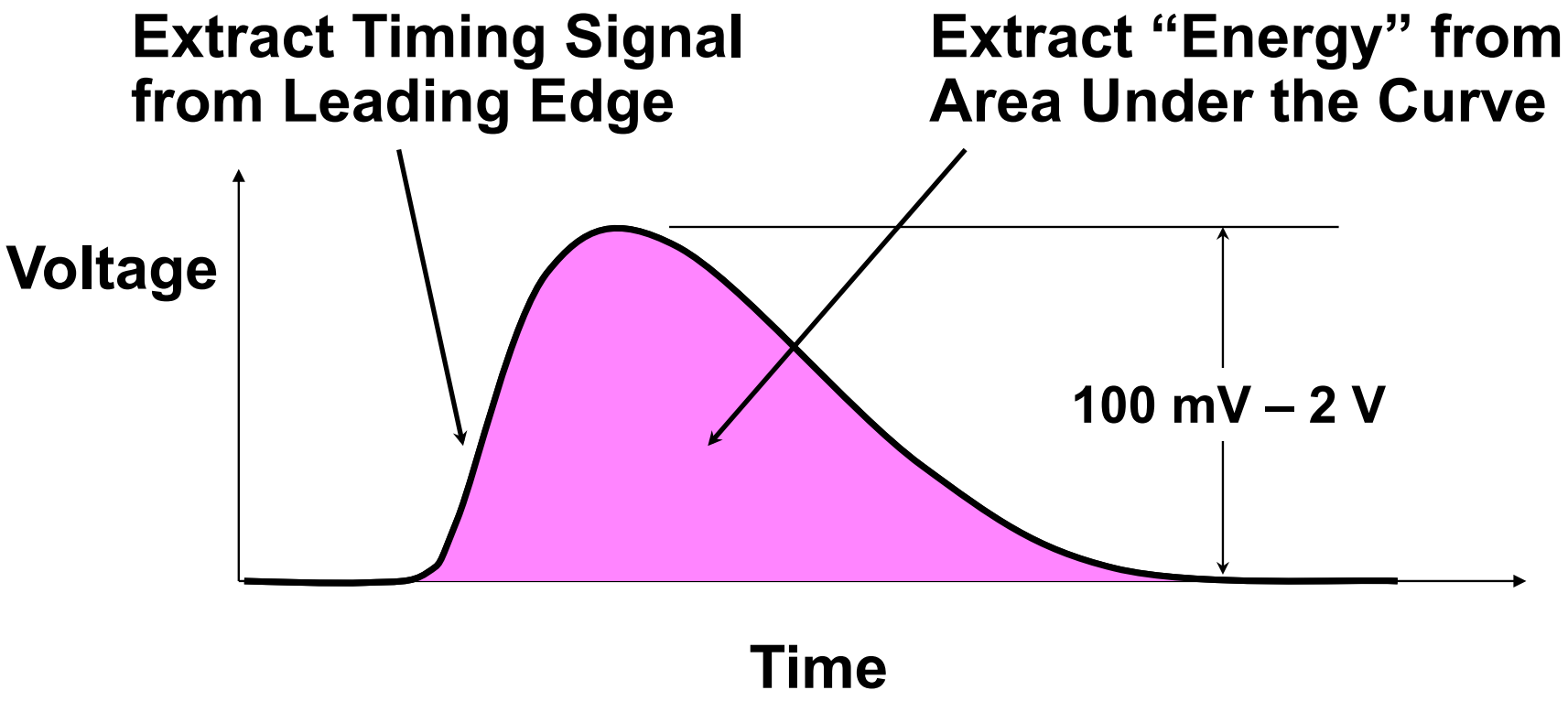
Active User Community

- Share Software and Expertise
- Module, Calibration, DAQ, Display,…

OpenPET is the GATE of Nuclear Medical Imaging Electronics

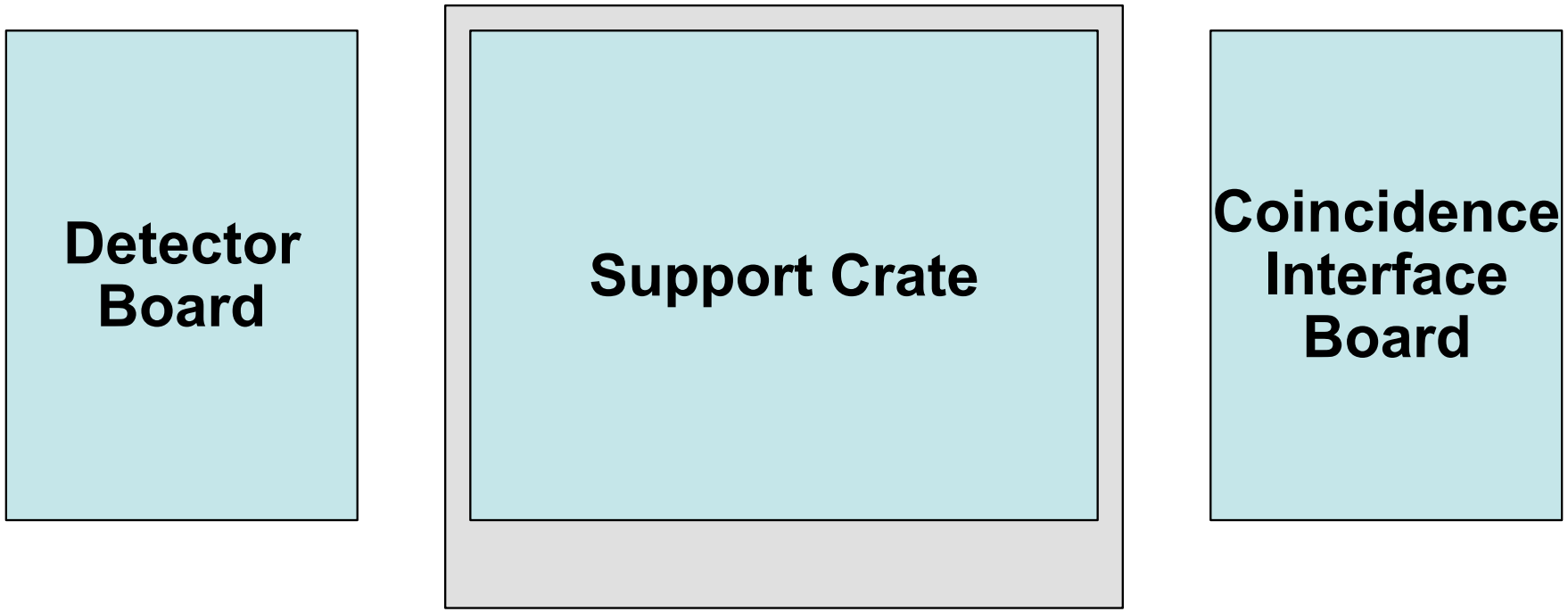
BERKELEY LAB

All Detector Outputs Look the Same

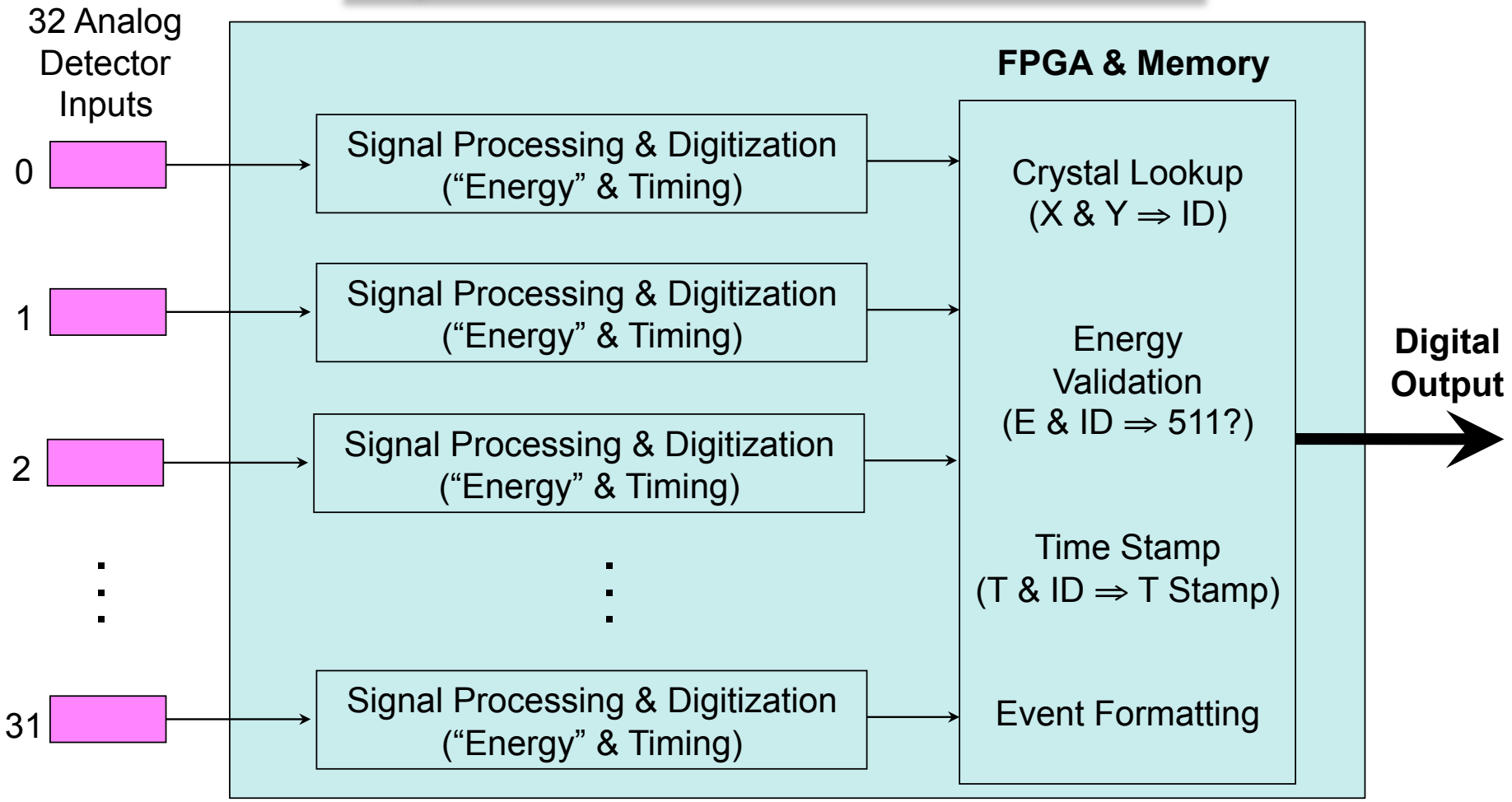


- *Tremendous* Variation in How Outputs Are Combined
  ⇒ Digitize, Then Combine Outputs in Firmware

Needs Met With Three Pieces of Hardware



OpenPET Detector Board

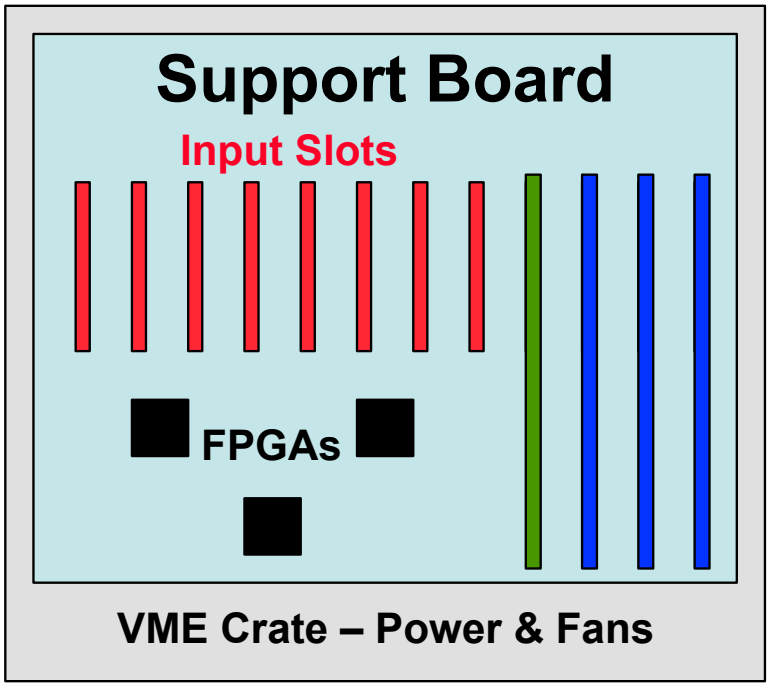


All Inputs Have Individual Signal Processing

OpenPET Support Crate

Support Board
- 3 FPGA's
- Microprocessor
- 8 Input Slots
- 1 Output Slot
- 3 Adapter Slots

"VME" Crate
- Mechanical Support
- Power
- Fans



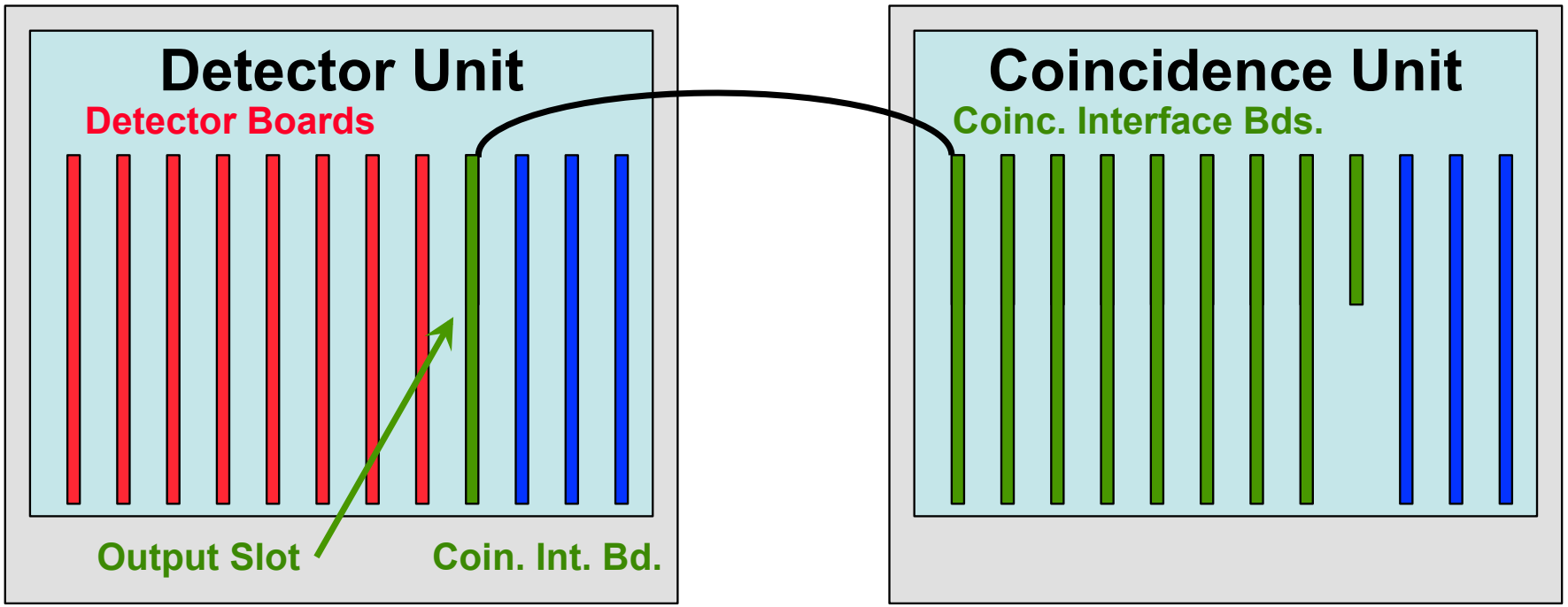
Output & Adapter Slots

Output & Adapter Boards
- Coinc. Interface
- PC Interface
- User IO
- Debugging

Support Crate

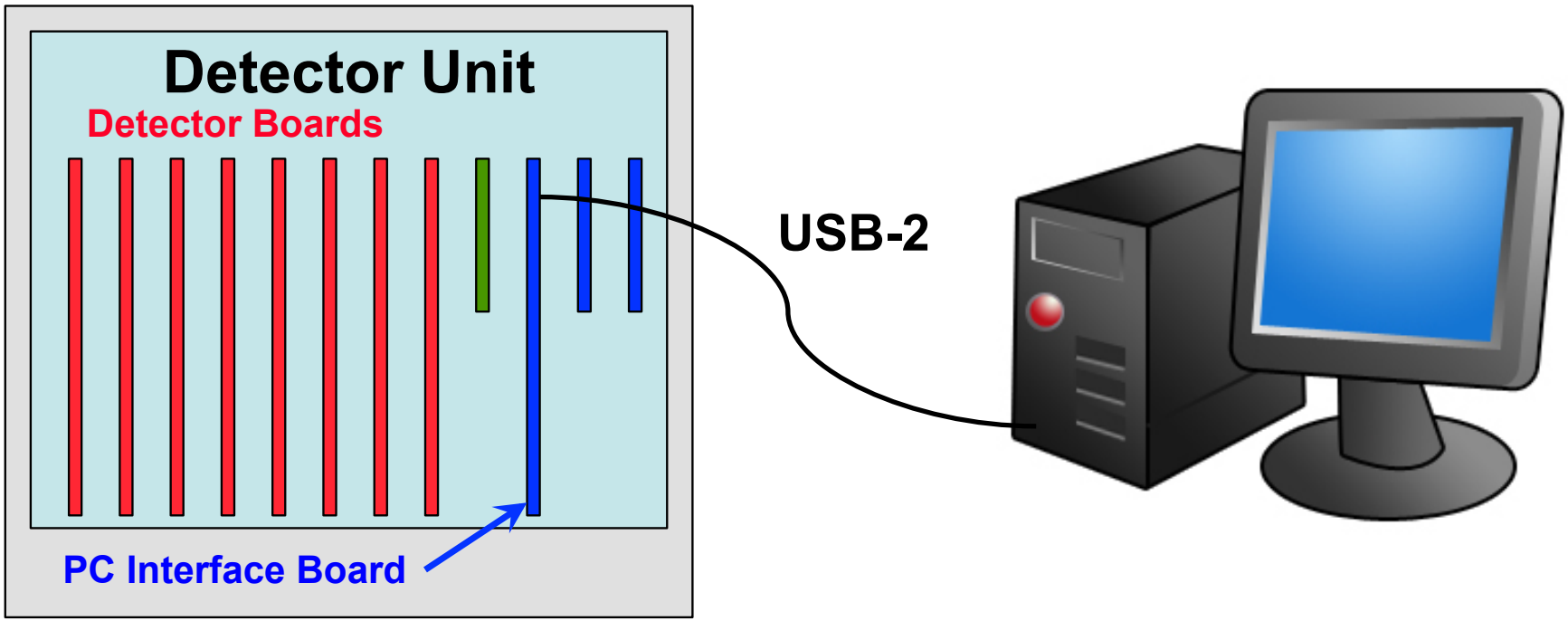
- **Support Board Resembles a PC Motherboard**
- **Support Crate Resembles VME Crate**

OpenPET Coincidence Interface Board



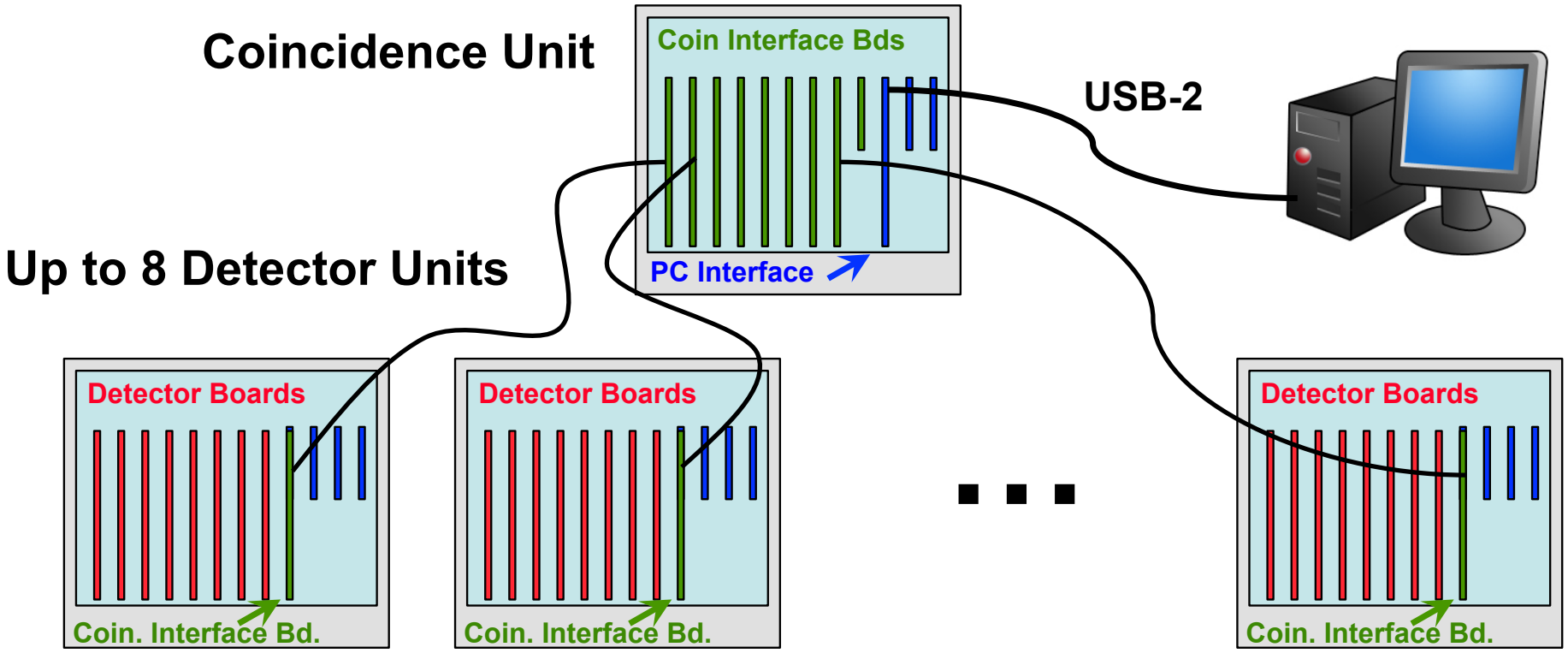
- Detector Unit: Support Crate w/ Detector Boards
- Coinc. Interface Bd.: Adapter from Support Crate to Cable
- Coincidence Unit: Support Crate w/ Coinc. Interface Bds.

Small System



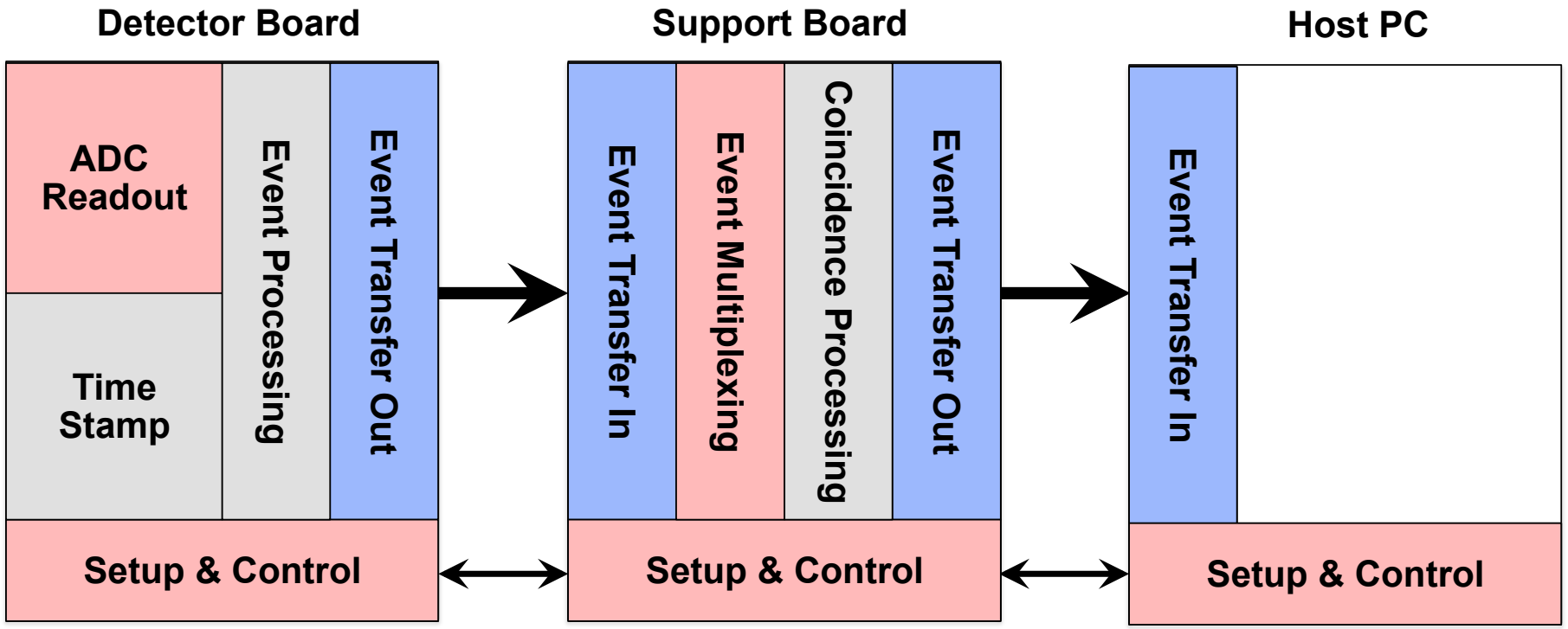
- 1 Support Crate, Up To Eight Detector Boards
- Up to 256 Analog Inputs (64 Block Detectors)
- PC Interface Board Connects to PC

Large System



- Up To Eight Detector Units, 1 Coincidence Unit
- Up to 2048 Analog Inputs (512 Block Detectors)
- PC Interface Board Connects to PC

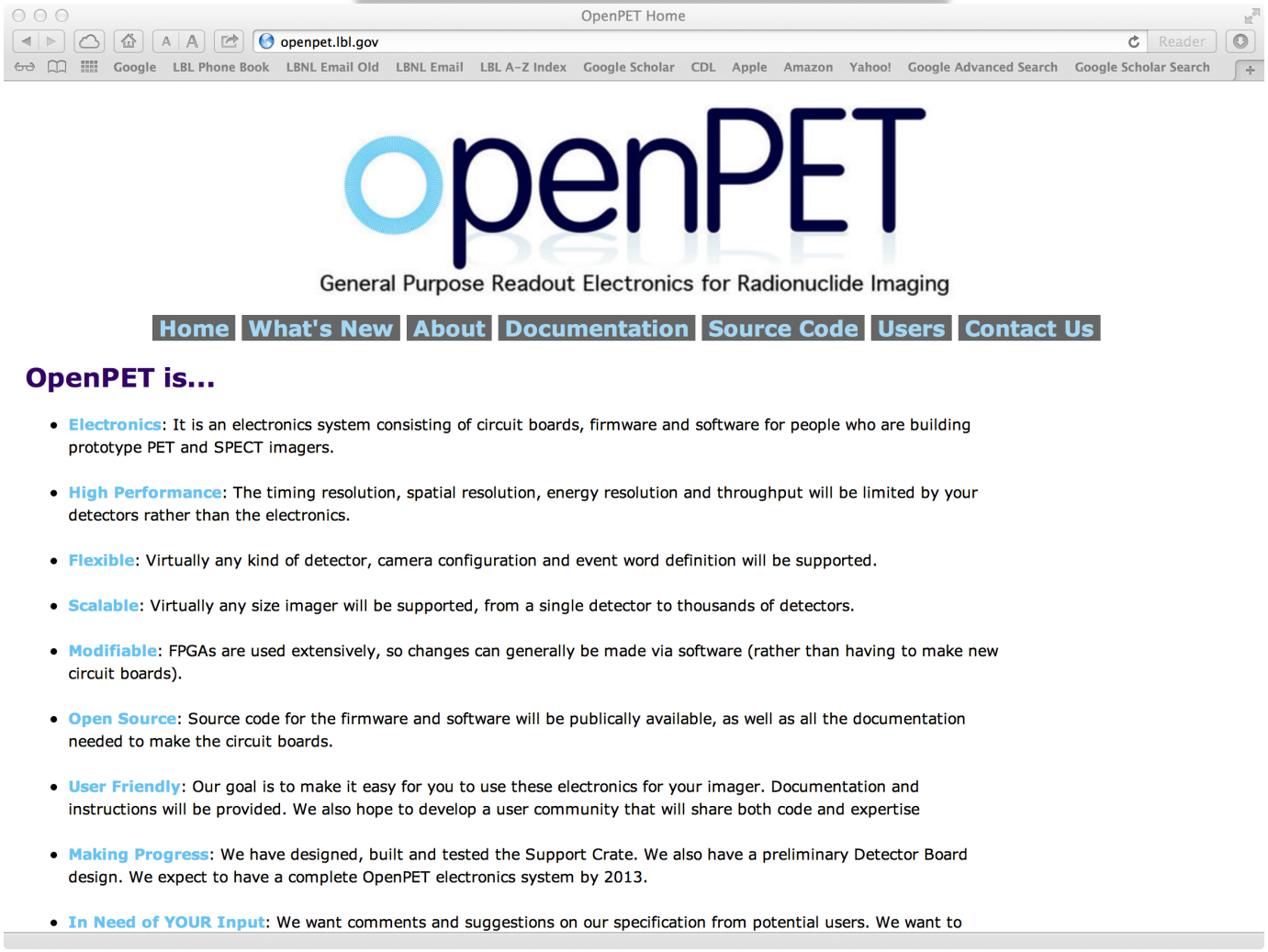
Firmware / Software



Completed | High Priority | Not Needed for Oscilloscope Mode

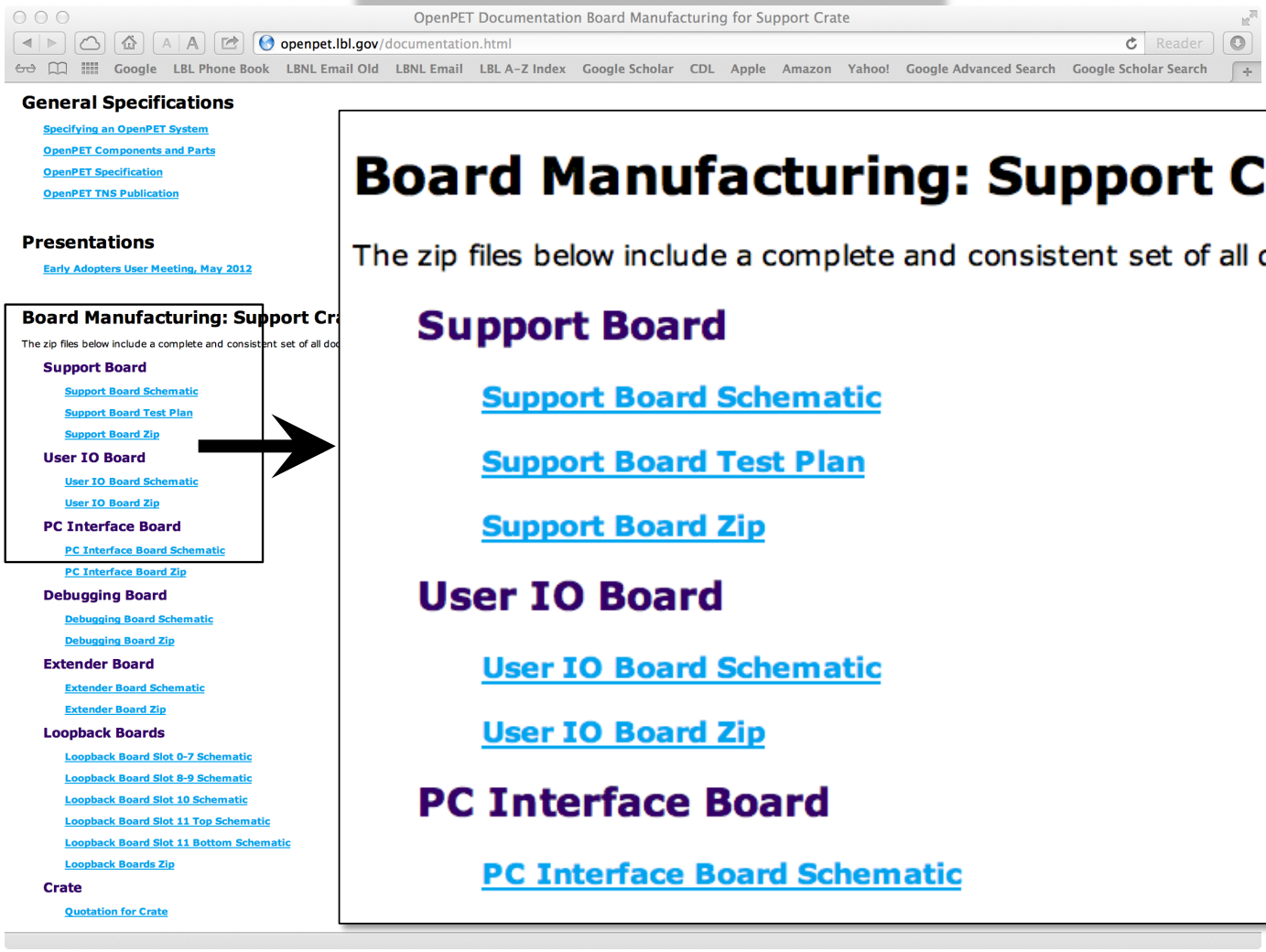
- First Milestone: "Oscilloscope Mode" for Small System
- Two Sets of Data: Events (one way) and Control (two way)

Documentation



http://OpenPET.LBL.gov

Documentation



Documentation Section Significantly Increased

Status

Detector Board

- Behind Schedule—See Seng's Presentation

Support Board

- Completed, Available for Purchase

Coincidence Interface Board

- Not Started, Only Needed for Large System
- Easy, Cable Definition is Main Question

Software / Firmware

- Partially Complete—See Qiyu's Presentation

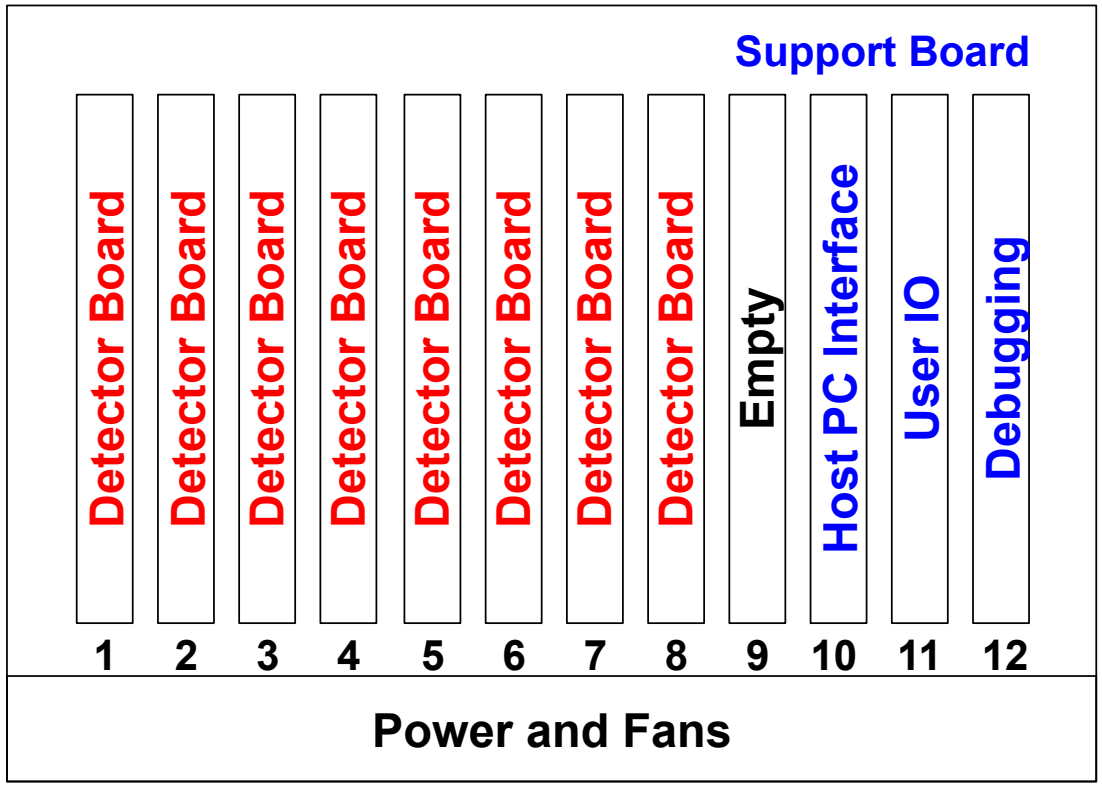
User Community / Support

- Early Stages

- *LOTS* of Progress Since Last Meeting
- Progress Will Be Even Faster If We Get NIH Funding…

OpenPET Hardware

Detector Unit



VME crate, Support Board, Host PC Interface, User IO, Debugging

-Developed using DOE funding

-Tested and functioning

-Currently available through prearranged vendors

-Schematics, layout, and bill of material available on OpenPET website

Detector Board

-Under development

-Seeking funding from NIH

Support Crate

VME Crate

- 12-slot 6U VME 19” rack mountable
- 740W power supply:

+5V@40A

-5V@40A

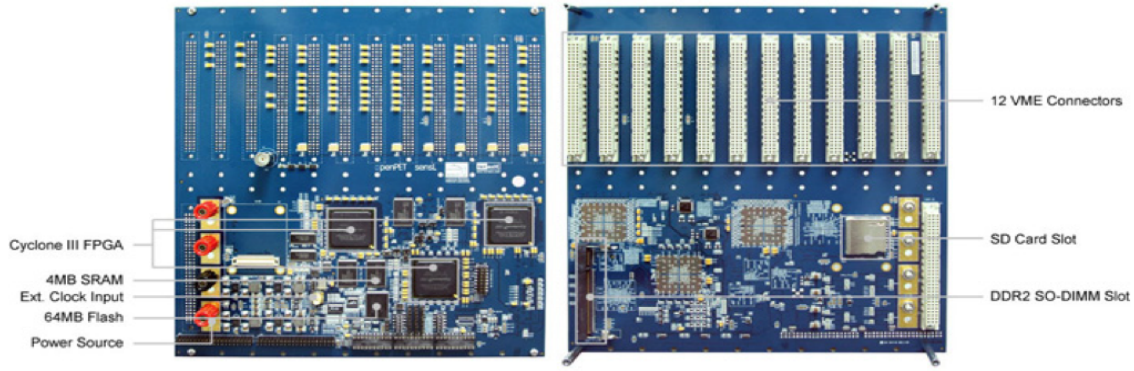
+3.3V@80A

+12V@6A

- 12VDC fans in front and back

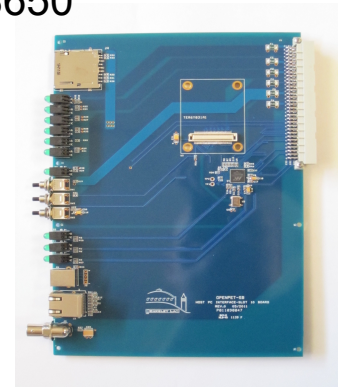
Available from Elma Electronics, Part# 12V12XXX78N2VCGX-LBL (~$3,500)

Support Board and Adapters Board

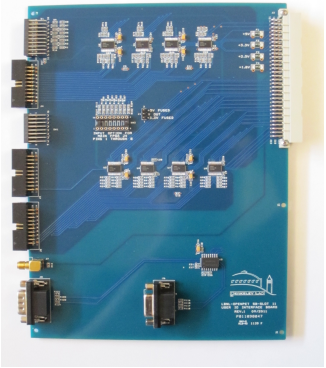


Support Board
(Part# S0139_EN50A)
~$7,500

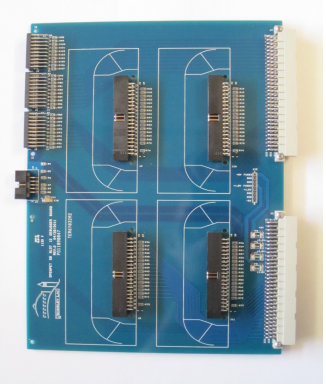
Host PC Interface
(Part# S0174_EN10A)
~$650



User IO
(Part# S0175_EN10A)
~$750



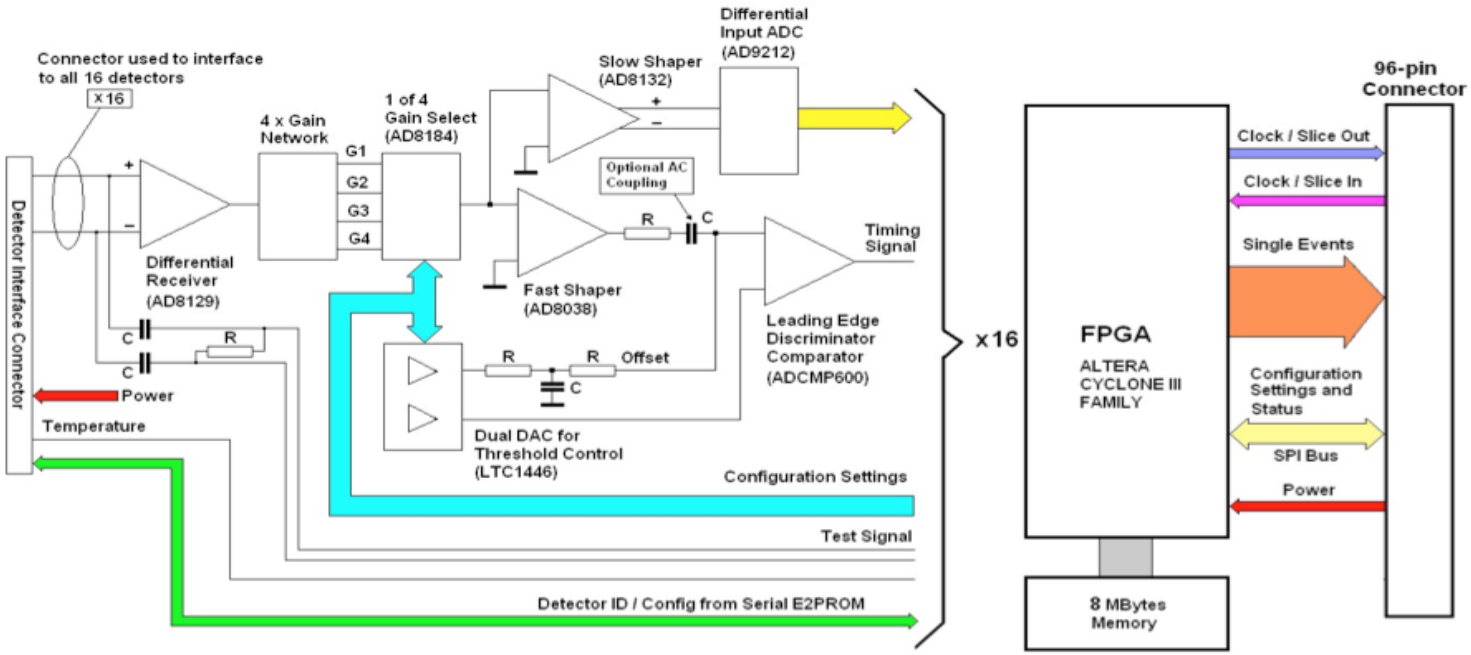
Debugging
(Part# S0176_EN10A)
~$650



Available from Terasic Technologies

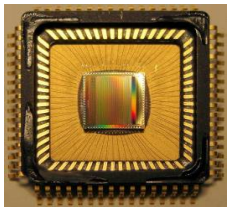
Detector Board

- Two years ago, we started designing a Detector Board in collaboration with SensL
- Design was based on conventional electronics (analog filtering, ADC, TDC, discriminator, etc.)
- Development was put on hold due to limited funding and departure of SensL from OpenPET project



Detector Board (New Design)

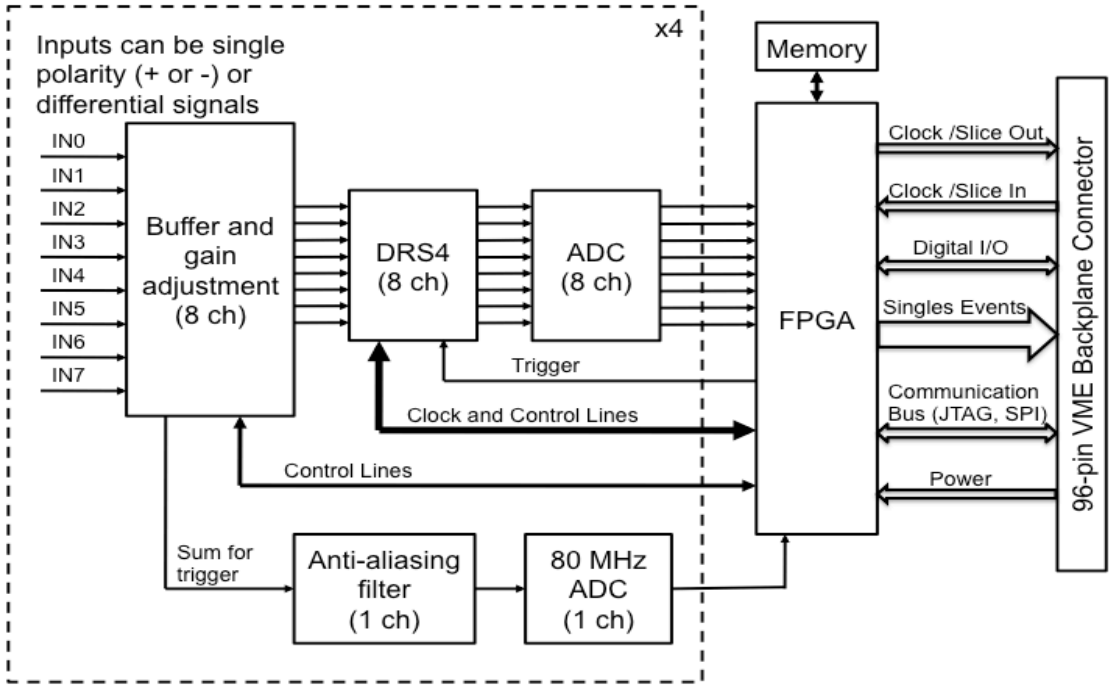
- We propose a more flexible, higher performance design based on waveform sampling (no analog filtering, discriminator, or TDC required)
- Uses high-speed waveform sampling chip from PSI (DRS4)



Parameter	
Number of channels / chip	8
Number of cells / channel	1024
Differential input dynamic range (V)	1
Sampling rate (GSPS)	0.7 to 5
Readout rate (MHz)	33
Input analog bandwidth (MHz)	950
Typical power consumption @ 2GSPS (mW)	140

Detector Board (New Design)

- The Detector Board will be 32 channels utilizing 4 DRS4 chips
- Trigger can be implemented to decrease dead time and improve rate capability
- An NIH RO1 proposal was submitted last February, but received unfunded score
- A resubmission will be submitted in a few days, results expected in February/March



Summary

- The Support Crate (VME crate, Support Board, three Adapter Boards) has been developed and is available for purchase from our prearranged vendors (go to openpet.lbl.gov for more information)
- The remaining board to be developed to complete a Detector Unit is the Detector Board
- A more flexible, higher performance Detector Board based on high-speed waveform sampling (DRS4) is proposed
- An NIH R01 proposal will be submitted in a few days, results expected in February/March
- If funded, the Detector Board will be available in 1 to 2 years
- We will also explore developing a scaled-down version of the Detector Board based on the conventional design contingent on finding other funding sources

We will update you by March 2013

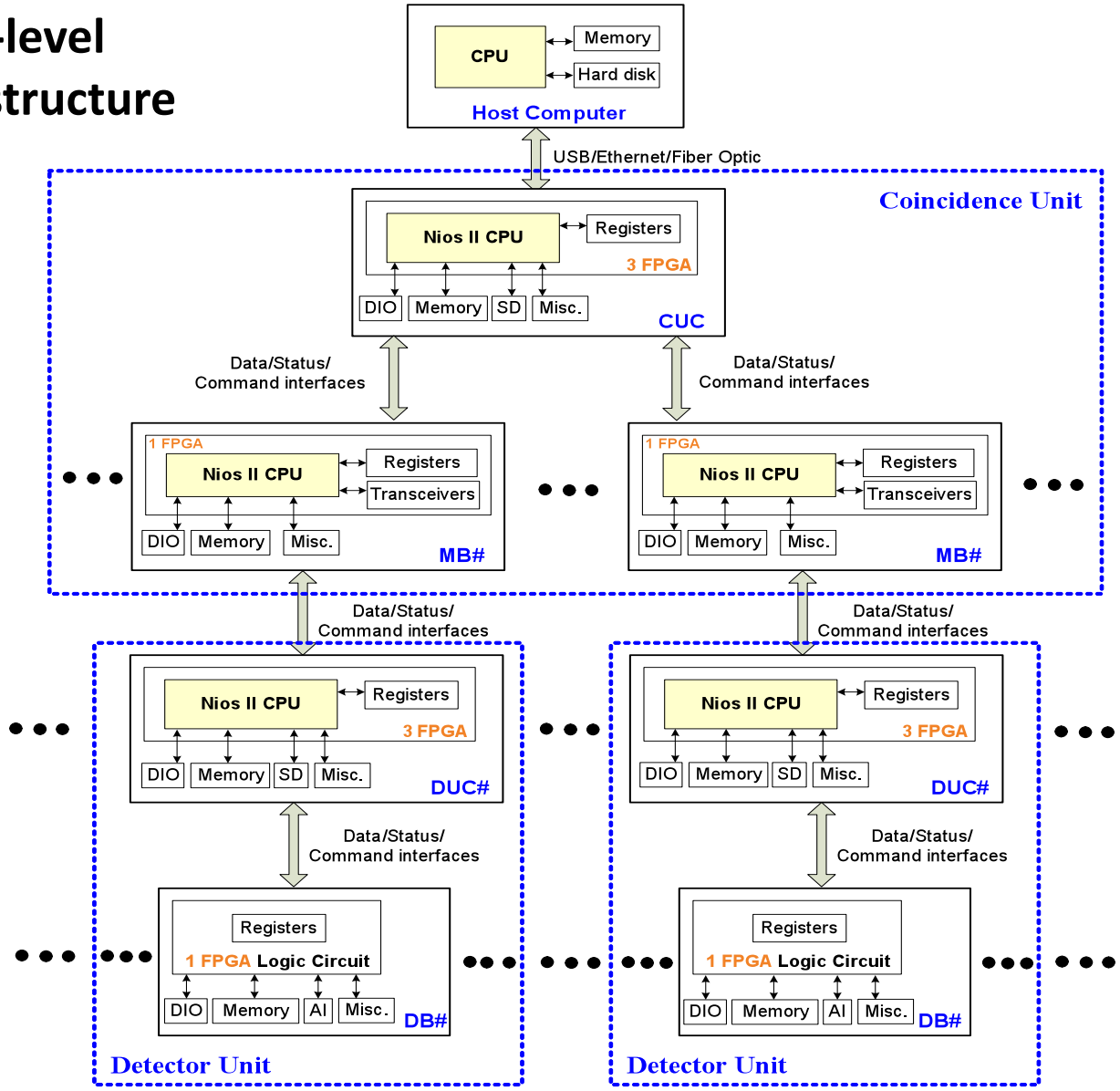
The OpenPET Firmware and Software Framework

Qiyu Peng

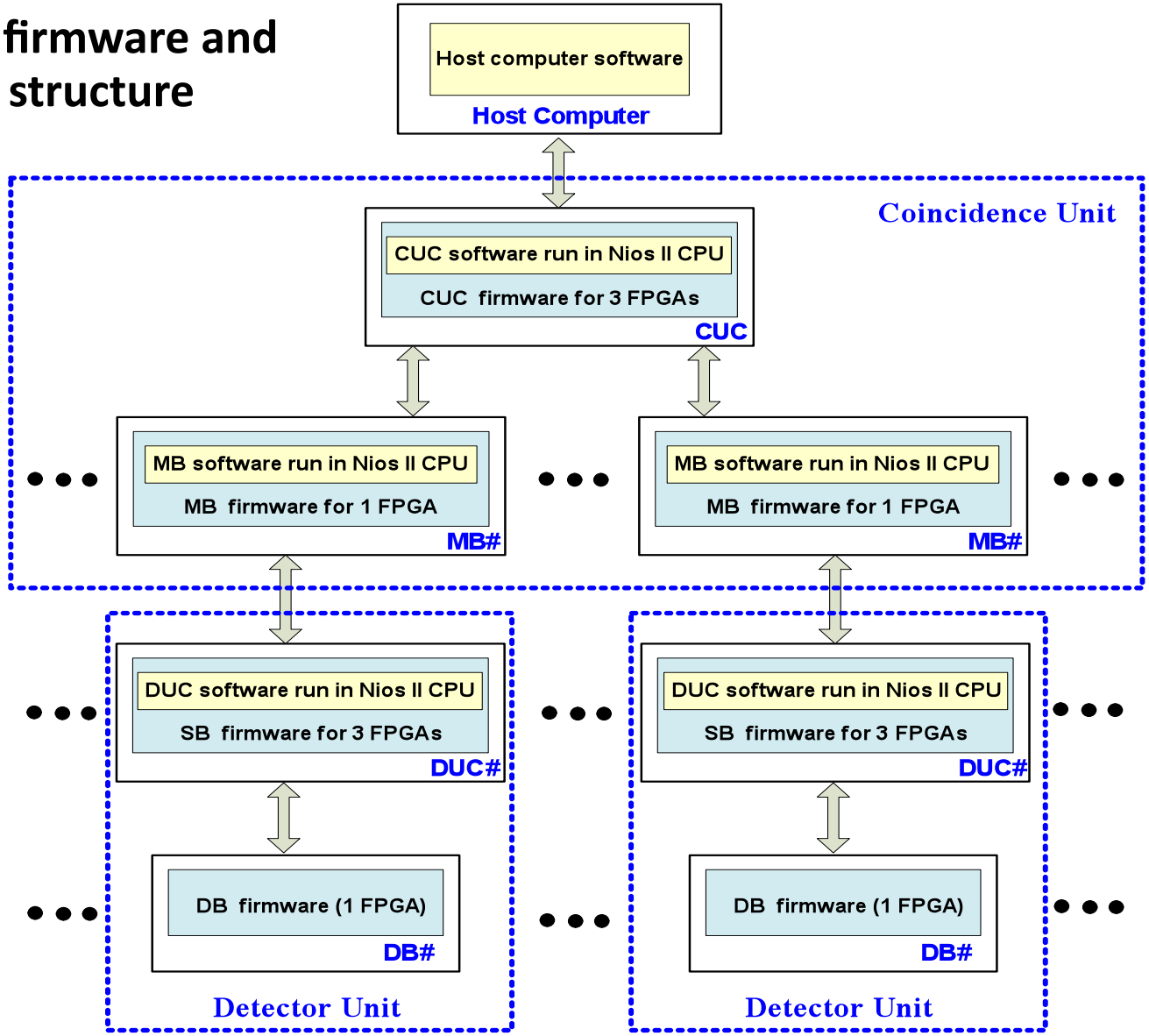
Outlines

- System framework
  - System-level hardware structure
  - System-level firmware and software structure
  - Programming Tools / Environment
- Software function and framework
  - Host PC software
  - Graphical User Interface
  - Nios Software
- Firmware function and framework
  - Firmware (VHDL) coding style
  - List mode data format
- Current status and plan

System-level hardware structure



System-level firmware and software structure



Programming Tools / Environment

	DB	DUC	MB	CUC	Host PC
FPGA Firmware	X	X	X	X	
Embedded MCU Software (NIOS)		X	X	X	
PC Software					X

X: VHDL (Altera Quartus II ver. 12.0)

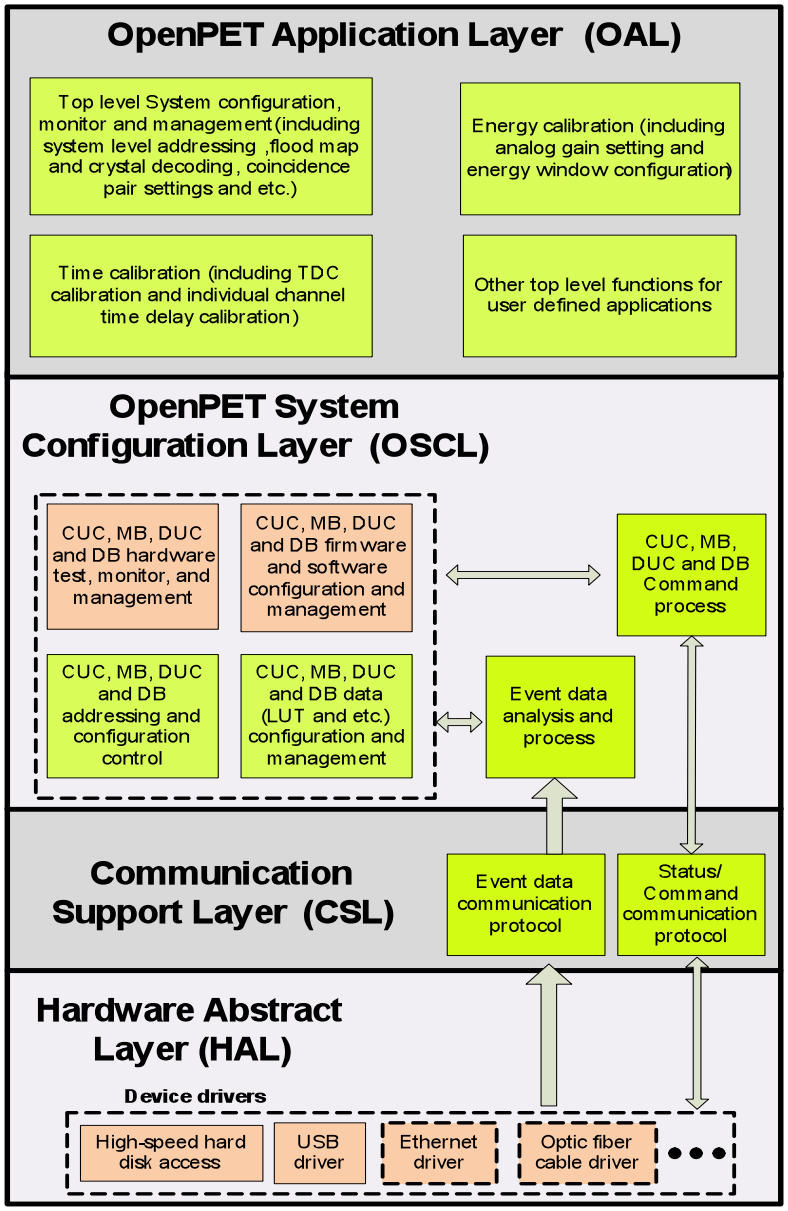
X: C (Altera Nios II EDS ver. 12.0)

X: C (NI LabWindows CVI 2009)

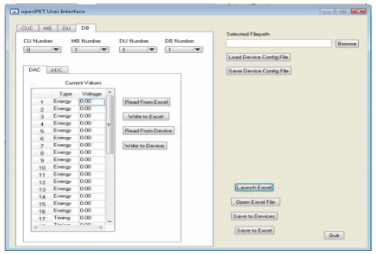
Host PC software

- Main Functions
- System configuration
- System diagnosis
- Data acquisition
- Data analysis

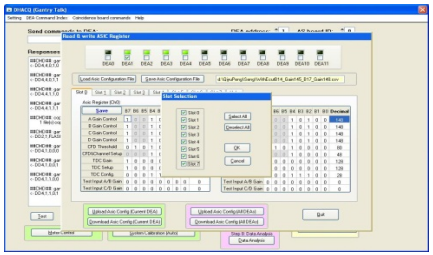
- Modular Design
- Stable and reliable
- Flexible, compatible and scalable
- Upgradable
- Simple and easy to use
- Well-documented



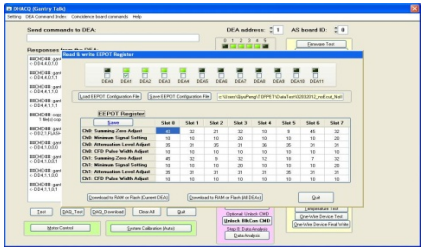
Graphical User Interface (GUI) design



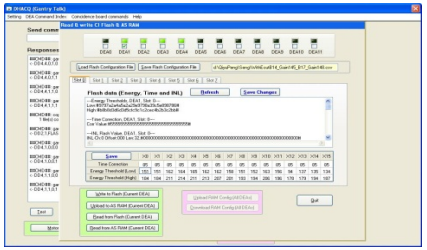
System configuration database management



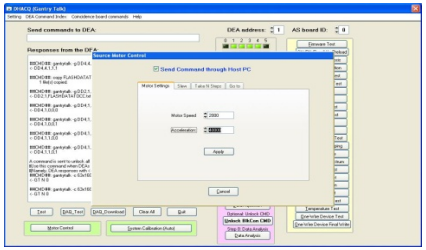
Analog gain settings



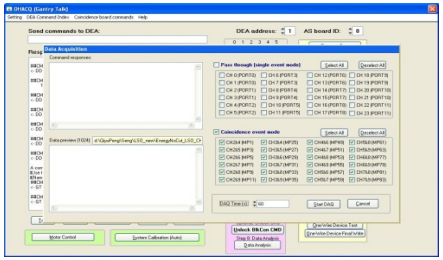
CFD settings



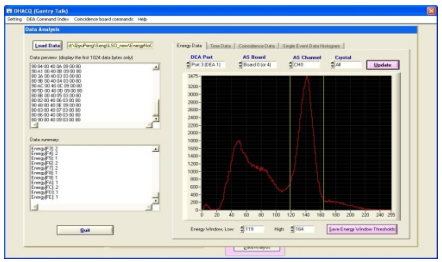
Energy window settings



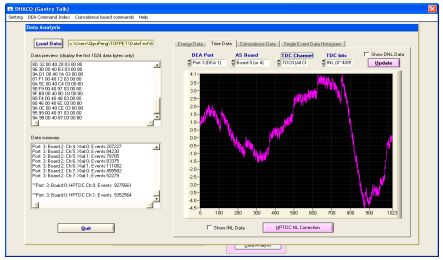
Serial communication



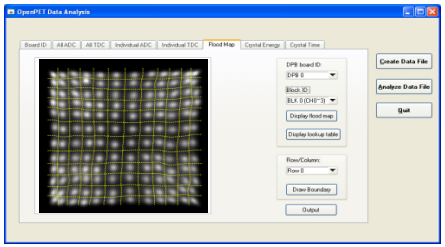
Data acquisition



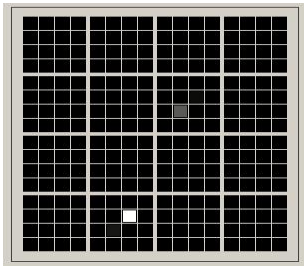
Energy data analysis



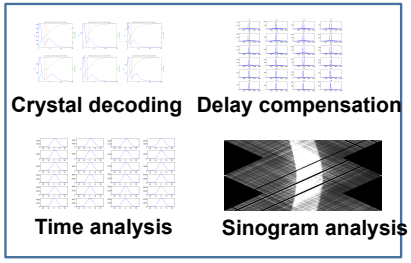
TDC calibration



Flood map display (for block detector)



SSPM event display



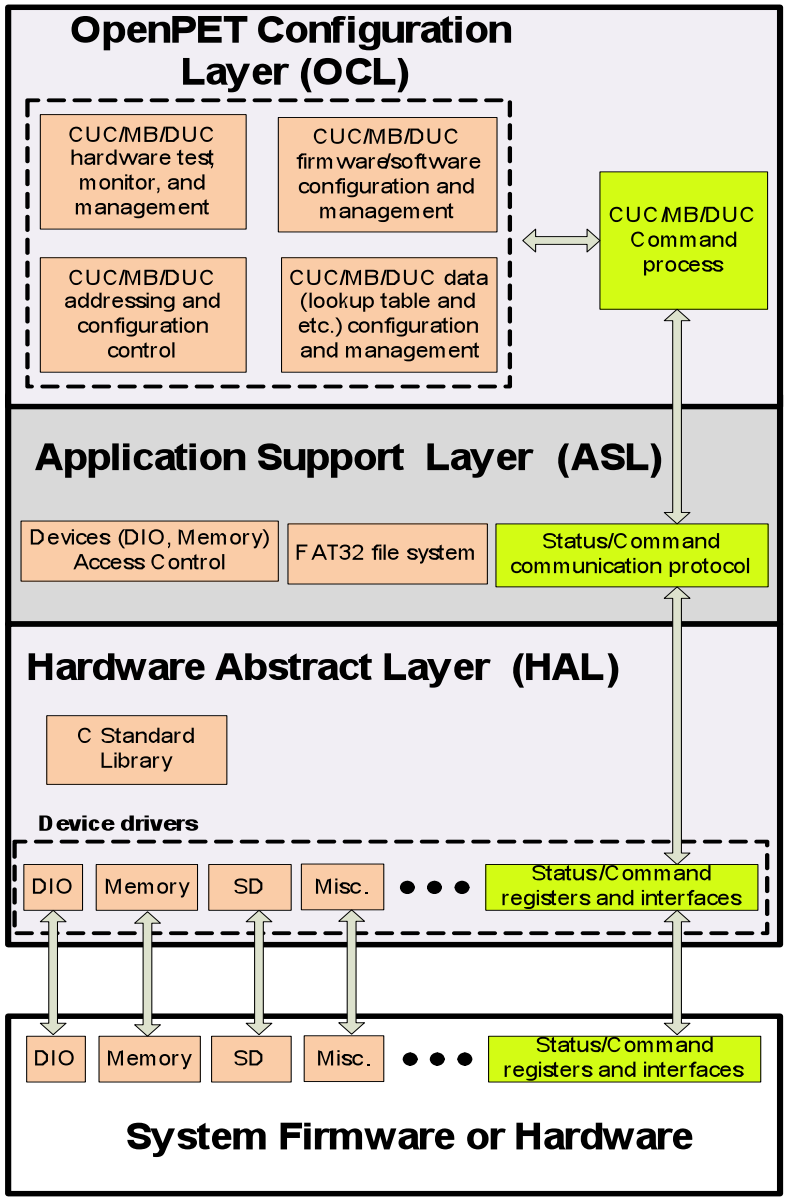
Data analysis SW package (currently in Matlab)

Chinh Vu and Michael Malus also contributed to the GUI design

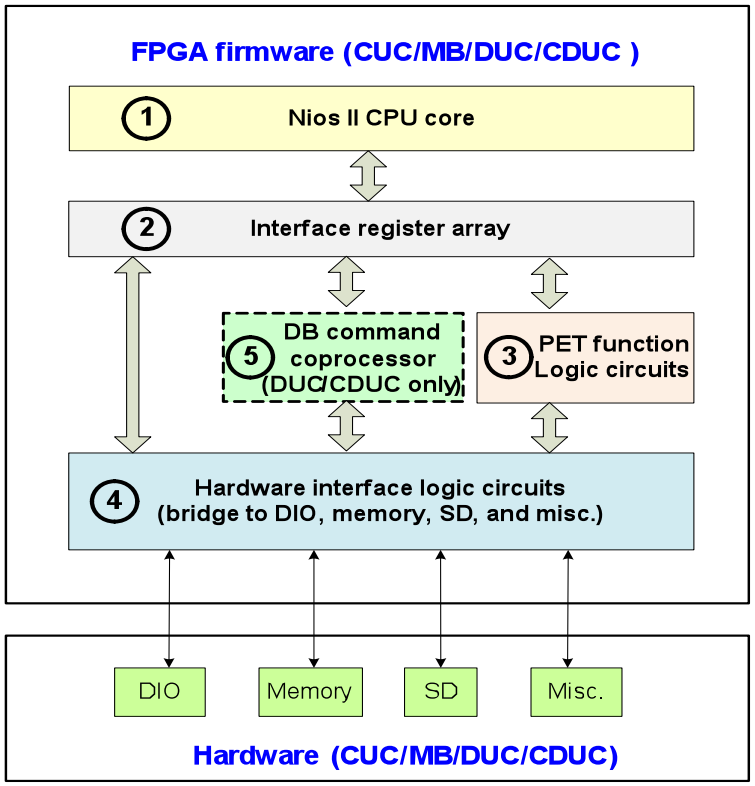
Nios software

- Main Functions
- System configuration
- System monitoring
- System diagnosis

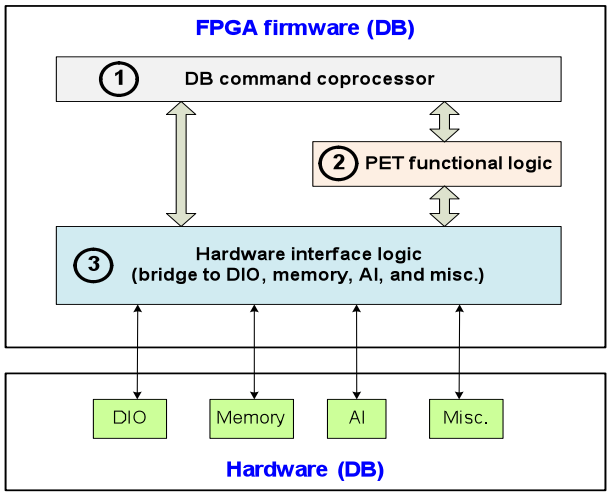
- Modular design
- Stable and reliable
- Flexible, compatible and scalable
- Upgradable
- Simple and easy to use
- Well-documented



Firmware function and framework

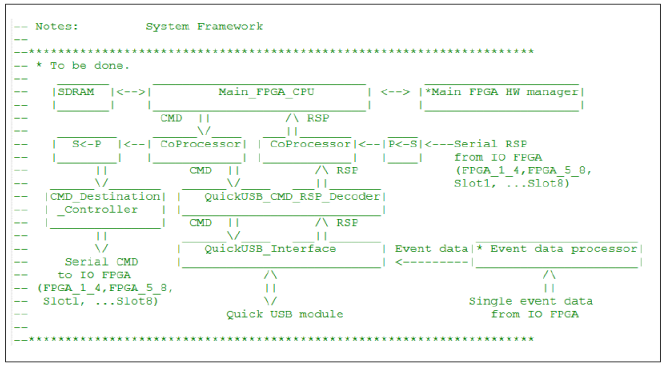


CUC/MB/DUC/CDUC firmware

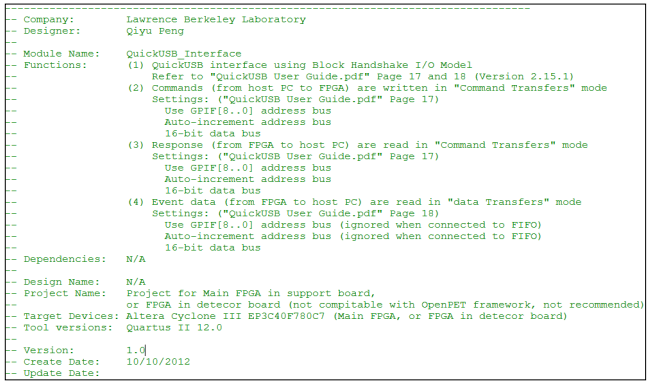


DB firmware

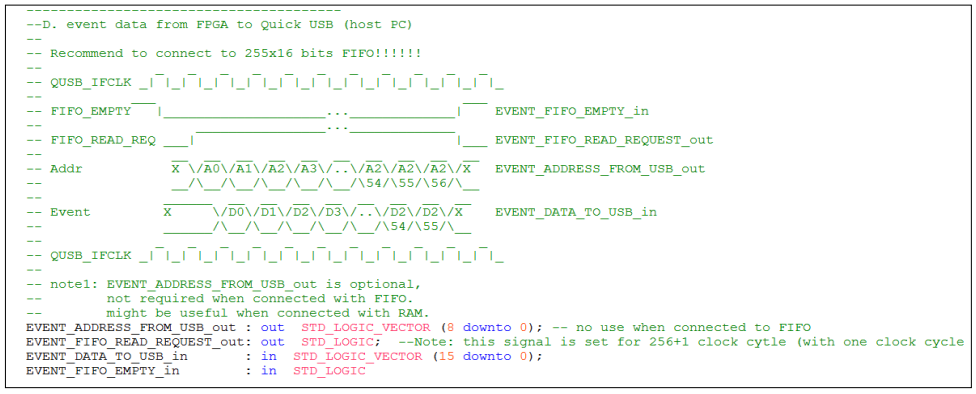
Firmware (VHDL) coding style



Modular design



Professional file head
(for function description and version control)



Detailed timing diagram (input & output)

- 2. List mode data
  - 2.1 Data addressing strategies
    - 2.1.1 Individual channel data addressing mode (00)
    - 2.1.2 Crystal data addressing mode (01)
    - 2.1.3 User-defined addressing mode (10 and 11)
  - 2.2 List mode data format
    - 2.2.1 Coincidence events data format
    - 2.2.2 Single events data format
    - 2.2.2.1 Time mode
    - 2.2.2.2 Energy mode
    - 2.2.2.3 Raw ADC data mode
    - 2.2.2.4 Standard Anger-logic mode
    - 2.2.2.5 Test mode1
    - 2.2.2.6 Test mode2
    - 2.2.2.7 Reserved modes (10 modes)
    - 2.2.2.8 User defined modes (16 modes)
    - 2.2.3 Status words format
    - 2.2.3.1 Time status word
    - 2.2.3.2 Event rate status word
    - 2.2.3.3 Temperature status word (3 digits, range from 0.1°C ~99.9°C)
    - 2.2.3.4 Reserved status words (13 modes)
    - 2.2.3.5 User-defined status word (16 modes)

List mode data format

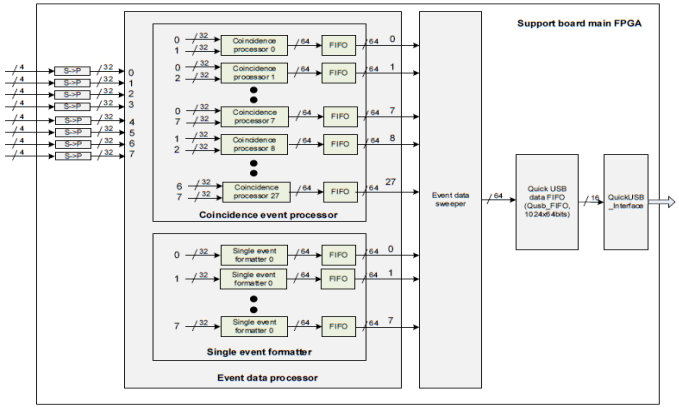


Diagram of data format controller

Summary: current status and plan

- The first version of OpenPET Firmware and Software package will include:
- Detailed documentation of the system framework (50 pages)
- VHDL code and Nios C code for CUC
- C code for host PC (with fundamental functions of system management, configuration, diagnosis, data acquisition and analysis)

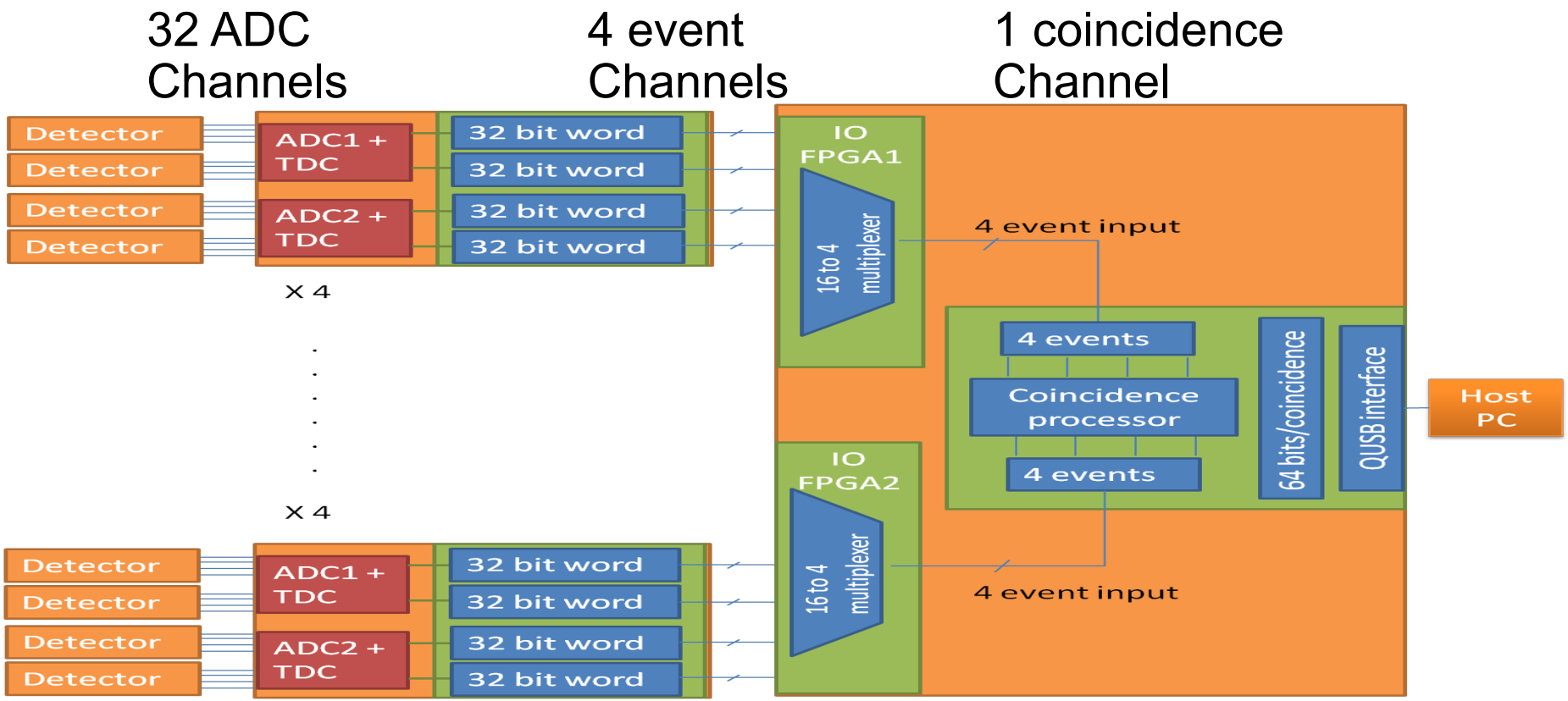
Event Data Transfer

Leonid Lamwertz

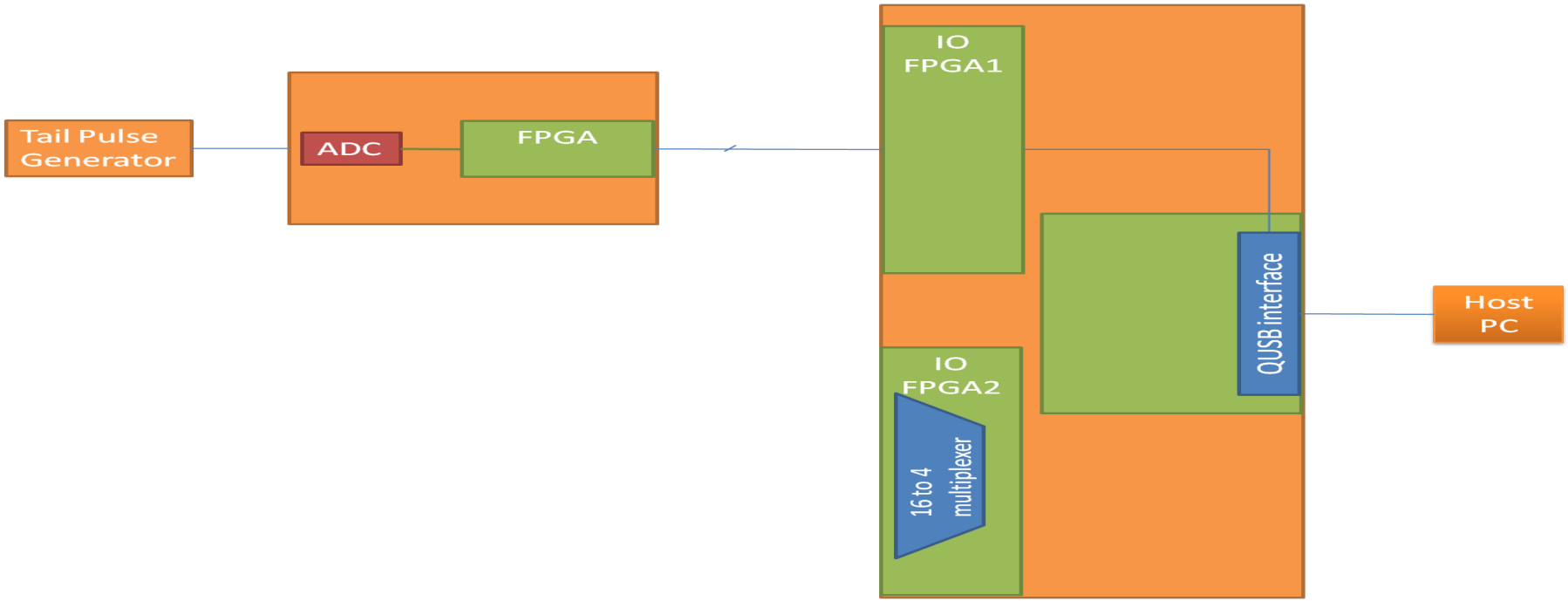
Department of Electrical and Computer Engineering, University of Manitoba

System data flow

Up to 80 M single event/sec processing capability



Simulation data flow



OpenPET Software and Firmware Management

Martin S. Judenhofer, PhD

Department of Biomedical Engineering, University of California-Davis, Davis, CA

OpenPET Meeting, Berkeley, May 11-12, 2012

UC DAVIS
UNIVERSITY OF CALIFORNIA

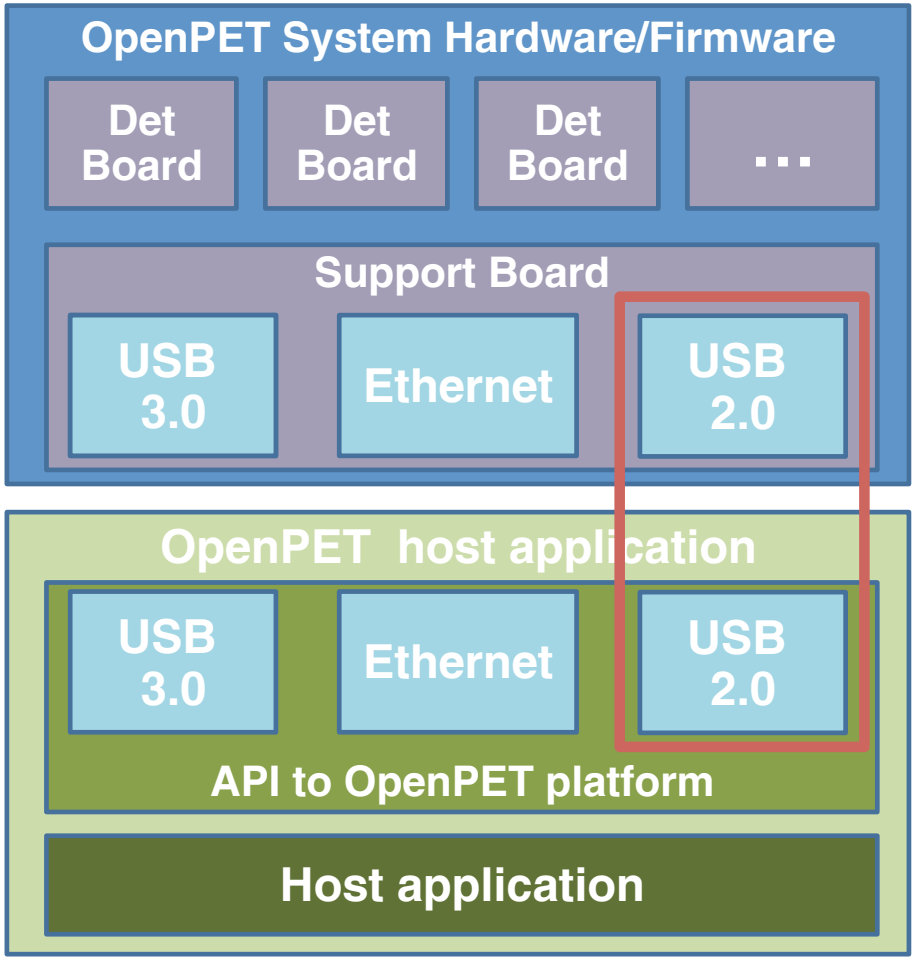
cmg

OpenPET Groups

- Users
  - Want to use the hardware and its framework implementation as is (e.g. block based PET system)
  - May not want to modify firmware or software
- Developers
  - Want to adjust firmware and software for specific applications
  - Build their application on existing framework

OpenPET Software and Firmware

Overview:



OpenPET Software and Firmware

System components/packages:

System component	Firmware (FPGA)	uC source (NIOS II)	Application (GUI - on host)
Support Board	●	●	
API (driver)	●	●	●
Detector Board	●		
Host PC software			●

Probability to modify

Increased Complexity of modifications

OpenPET Package Content

For Users

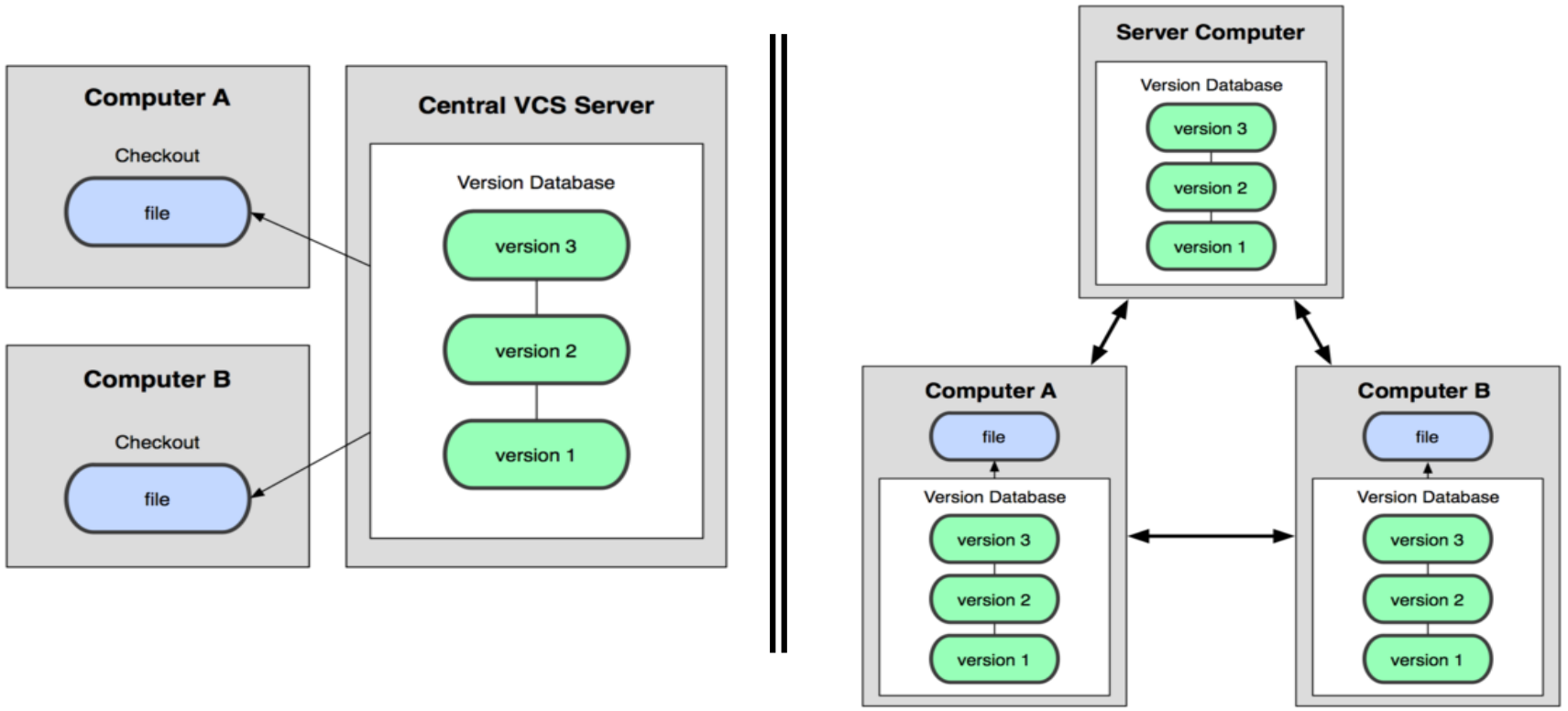
- Binaries and soft/firmware to set up and run system
- Modify system calibration/setup to match users geometry
- Use tested software/firmware to run system

For Developers

- Source code for firmware & software
- Can build upon existing and tested code
- Can add own modifications
- Should perform intensive testing to verify functionality

OpenPET Software and Firmware Management

Centralized version control **vs.** **Distributed version control**



OpenPET Version Control

- Use distributed version control (GitHub, or similar)
- Main repository provides “official” (current and previous) versions (master branch)
- Distributed version control allows small groups to share their work (experimental branch)
- Only code verified by OpenPET will be added to the main repository (master branch)
- Repository will provide “release”, “developer” and archived versions of the source code

Conclusion

Aim of the OpenPET project:

- **Provide complete packages for download (Users)**
- **Provide sources for custom modifications (Developer)**
- **Provide regular updates**
- **Have close tracking of modifications (GitHub)**
- **Provide documentation for framework usage**
- **Have system for bug reporting (GitHub)**

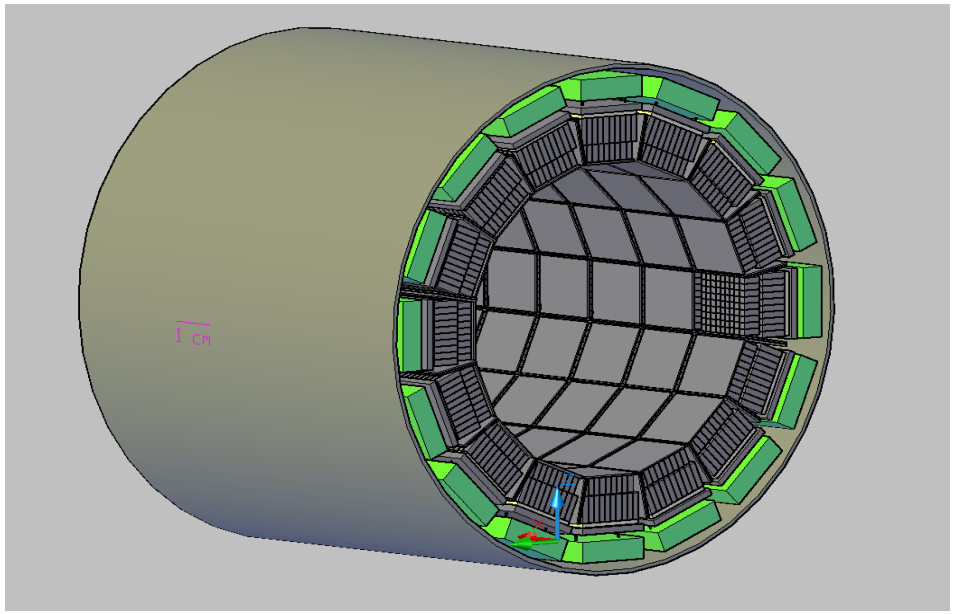
Development of an OpenPET Based MRI Compatible PET Insert

Andrew L. Goertzen, PhD, MCCPM
Department of Radiology
University of Manitoba, Winnipeg, Canada

OpenPET Users Meeting, IEEE MIC 2012, Anaheim, CA

Our Project: High Resolution PET Insert for PET/MR Imaging

- Fit within gradient coil of 7T animal MRI (115 mm diameter) or with low-field open MR system.
- Allow simultaneous PET and MR imaging.
- Dual-layer offset crystal design to give limited depth of interaction (DOI)
- Prototype will be 1 ring, extendable by adding additional detector rings.



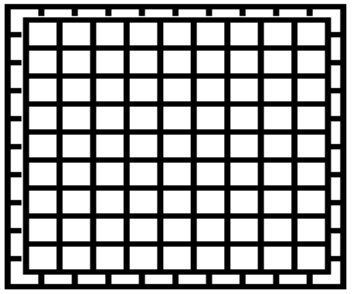
Health Sciences Centre Winnipeg

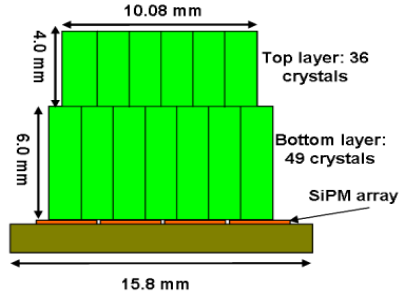
University of Manitoba

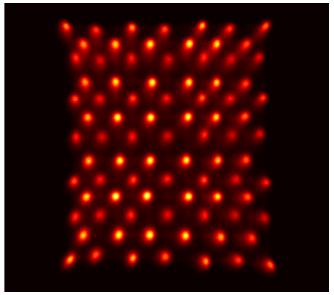
Detector Design

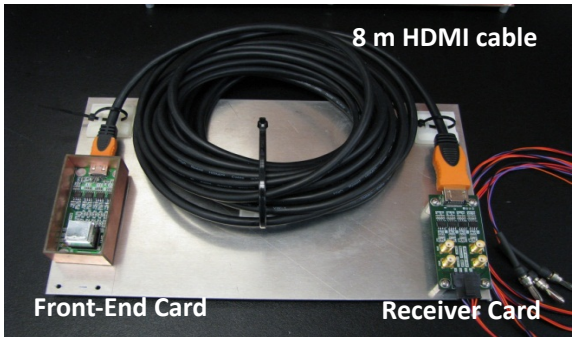
- Dual-layer offset crystal design
  - 4 mm top layer, 6 mm bottom layer, 1.2 mm crystal pitch.
  - See poster M16-23 for details
- SensL SPMArray4 SiPM Array
  - 4 x 4 pixels, 13.4 x 13.4 mm^2 active area
  - 16 outputs multiplexed on front end to 4 channels per detector
- Analog signals brought out using HDMI cables
  - See poster M16-37
- Energy resolution 13-16%
- Timing resolution 2.5 ns

Dual-Layer Offset Crystal Design









Health Sciences Centre Winnipeg

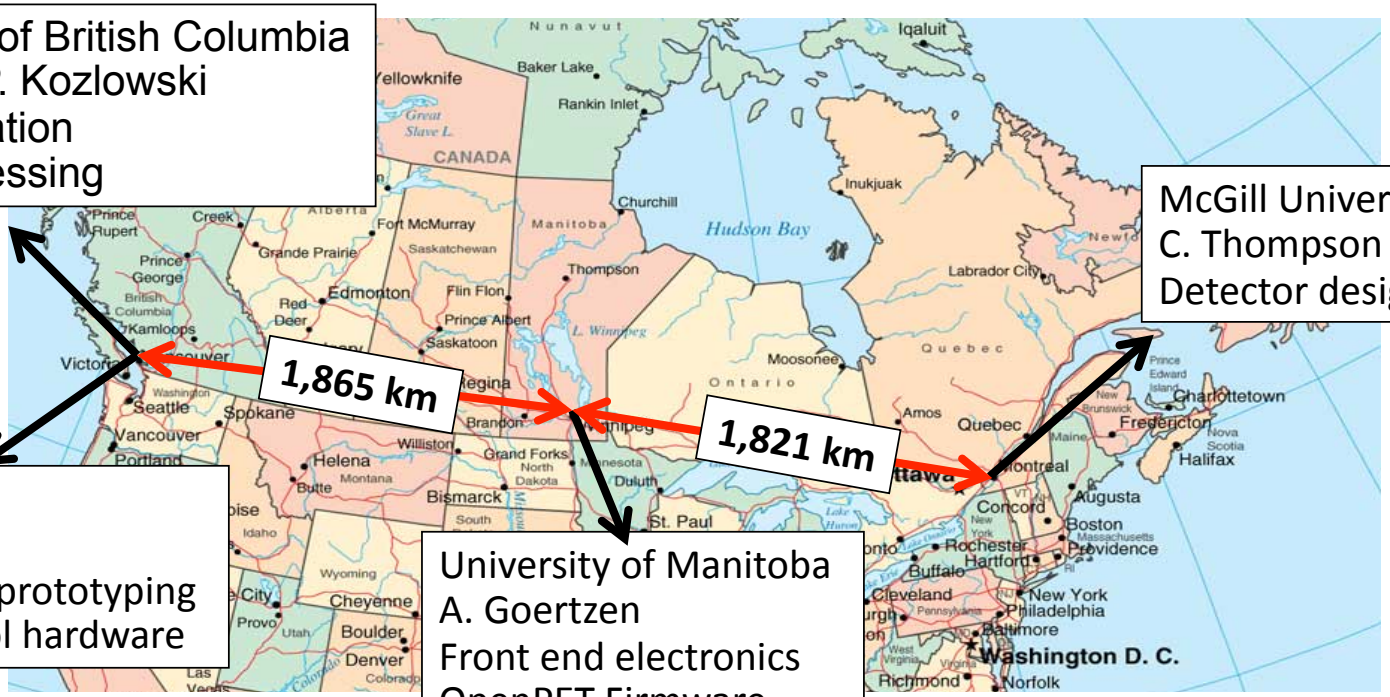
UNIVERSITY OF MANITOBA

Why Use OpenPET Electronics?

- Funding for large research and development projects is increasingly directed to Team or Network Grants.
- This leads to research projects distributed as multicentre collaborations, creating challenges including:
  - Distributing subprojects to member sites with the appropriate expertise.
  - Ensuring that components and subassemblies from each site can integrate well.
  - Standardizing methods and signal interfaces.
  - Scaling new detector technologies developed at R&D member sites to full systems assembled at sites responsible for systems integration.

Our Collaboration Challenge - Geography

University of British Columbia
V. Sossi, P. Kozlowski
MR integration
Data processing



TRIUMF
F. Retiere
Electronics prototyping
Slow control hardware

University of Manitoba
A. Goertzen
Front end electronics
OpenPET Firmware
Systems assembly

McGill University
C. Thompson
Detector design

Health Sciences Centre
Winnipeg

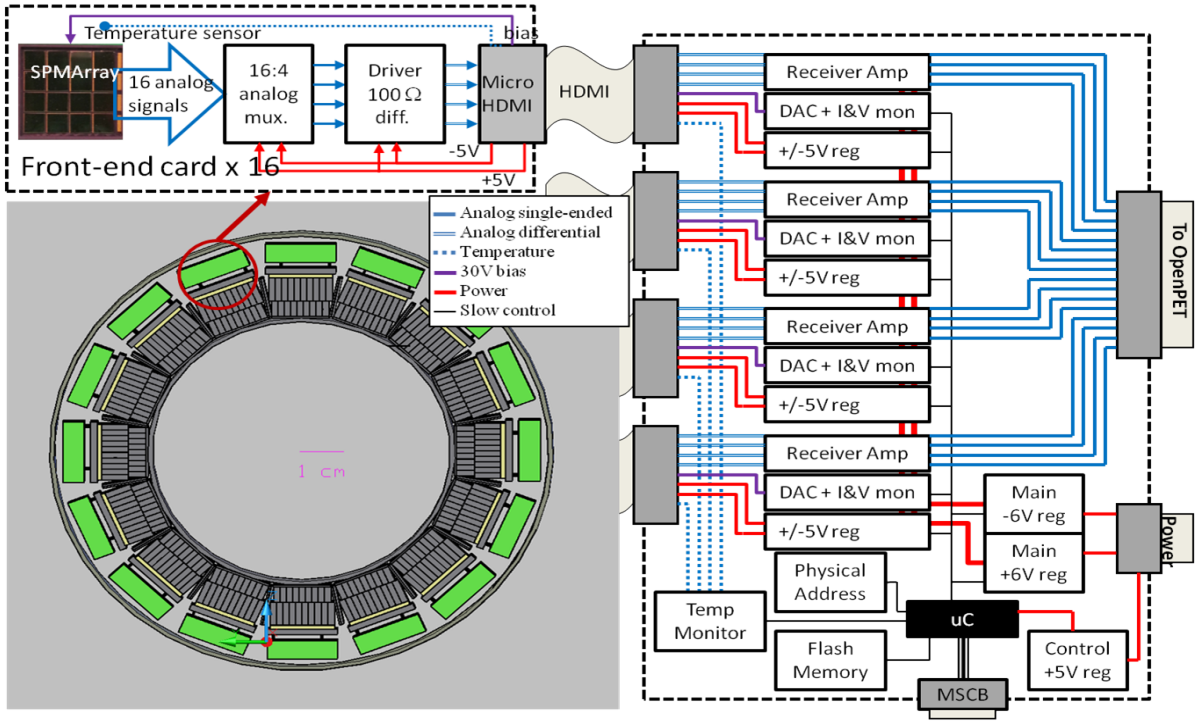
University of Manitoba
EST. 1877

Why Use OpenPET Electronics?

- Benefits of OpenPET for a multicentre collaboration:
  - Scalable design allows deployment of small data acquisition systems at detector / electronic development sites and large system at systems integration site.
  - Standard data acquisition platform facilitates distributing detector development among sites.
  - Ensures that data acquisition protocols are identical among collaboration sites.
  - Avoids duplication of labour since any custom OpenPET configuration only needs to be developed once at the site with relevant expertise and then deployed across the network.

Signal Interface Panel (SIP)

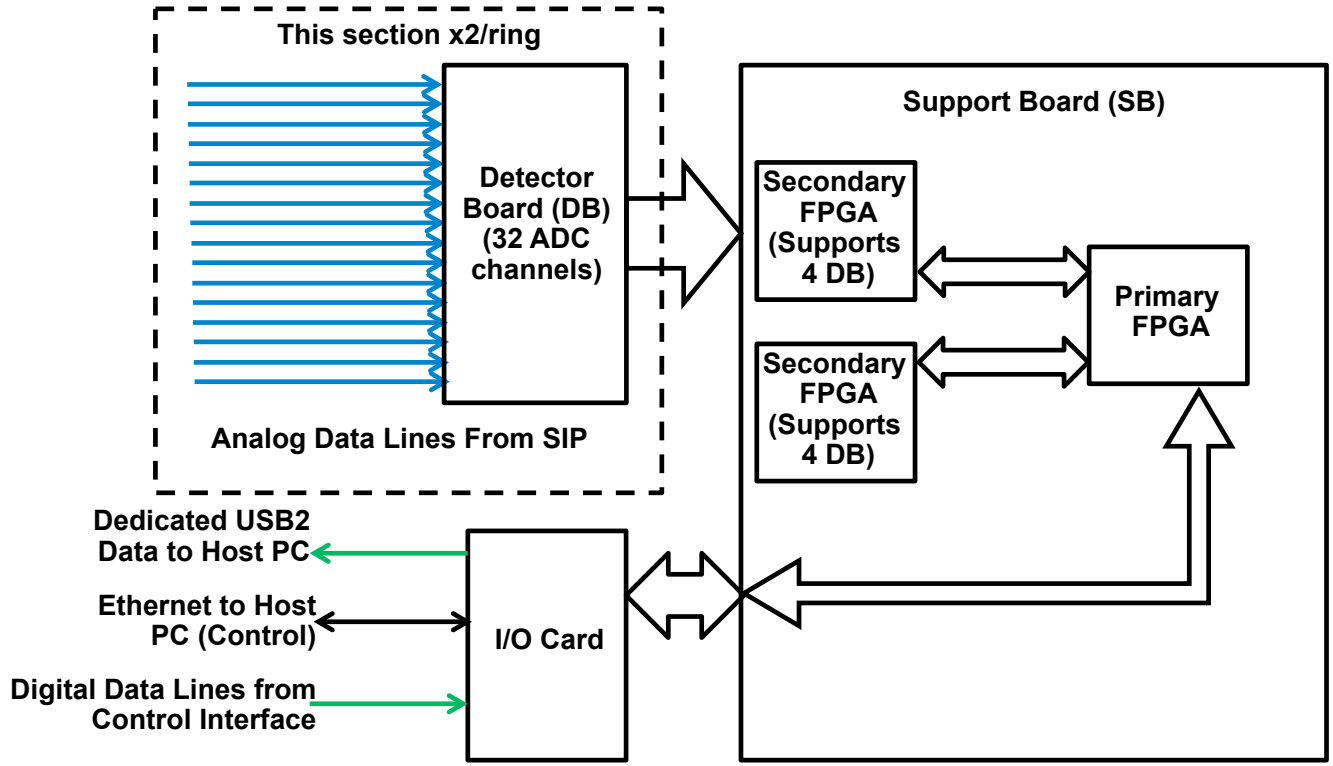
- 32 channel detector board (DB) allows 8 detectors/DB
- 2 DB/ring of 16 detectors
- Easily scalable to up to 4 rings using a 'small' OpenPET system.
- Functions of SIP:
  - System slow control via micro-controller
  - Signal conditioning for input to OpenPET
  - Connector interface to OpenPET



Health Sciences Centre Winnipeg

University of Manitoba

OpenPET Configuration



Health Sciences Centre Winnipeg

University of Manitoba

Summary

- Using OpenPET as a standardized platform in our multicentre collaboration will accelerate our system development by:
  - Allowing reproducible experimental measurements at different sites
  - Facilitating remote debugging and testing of components
  - Simplifying the specification of test conditions and protocols for acceptance testing of components
- The students and post-docs trained on these systems will have sought after skills readily translatable to other research groups, minimizing training time for new hires/recruits.

Health Sciences Centre
Winnipeg

University of Manitoba

OpenPET for High Resolution PET with Dual Ended DOI Readout

Simon R. Cherry, PhD

Department of Biomedical Engineering, University of California-Davis, Davis, CA

OpenPET User Meeting, IEEE MIC 2012, Anaheim

UC DAVIS
UNIVERSITY OF CALIFORNIA

cmg

Why use OpenPET electronics?

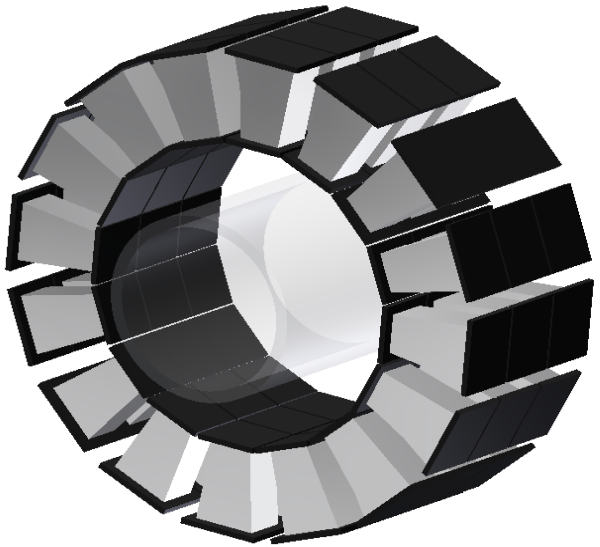
- Most interesting projects often go beyond the test of a two-detector setup
- NIM electronics is expensive and bulky, not scalable
- Alternative “off-the-shelf” acquisition systems may lack some functionality and scaling also often limited
- Existing dedicated PET electronics are typically proprietary and may be difficult to modify and adapt
- Much effort is invested in “reinventing” and “replicating” basic elements of the electronics, data acquisition and software systems for a PET scanner

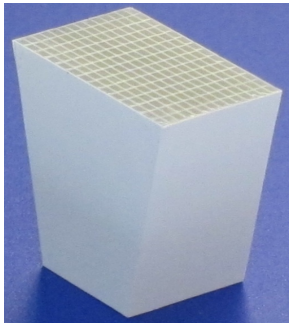
Why use OpenPET electronics?

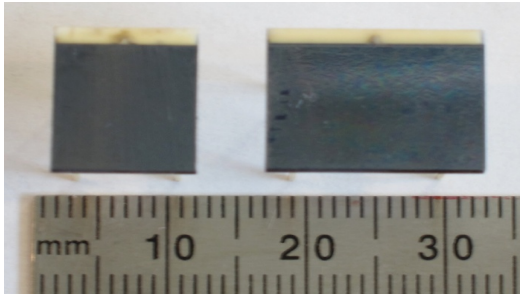
- OpenPET will
  - Allow rapid and lower-cost system-level prototyping of novel detector concepts
  - Allow sharing of data acquisition hardware and software across laboratories
  - Allow custom needs to be met while still working within the OpenPET framework
  - Establish a resource of great value to the field of nuclear medical imaging that will reduce the time and cost of innovative technology development

High Resolution Mouse Brain PET Scanner

- Use very small crystals with tapered geometry (0.5x0.5mm at front, 0.8 mm at back)
- Use dual ended readout to obtain depth of interaction (DOI)
- Currently 1-ring system, 16 blocks
- Extend to 2 or 3 ring system



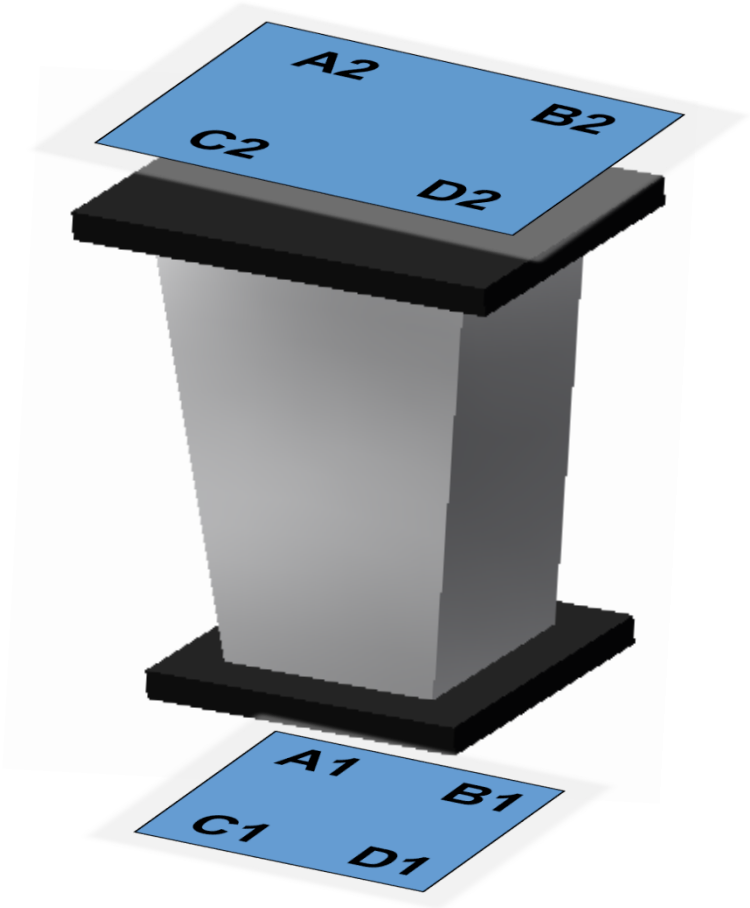




DOI Block Readout Requirements

- Each PSAPD has 4 corner signals
- Sum of all 8 signals is energy (E)
- Ratio of Sum1 to Sum2 is DOI
- X/Y is calculated from ABCD and sum

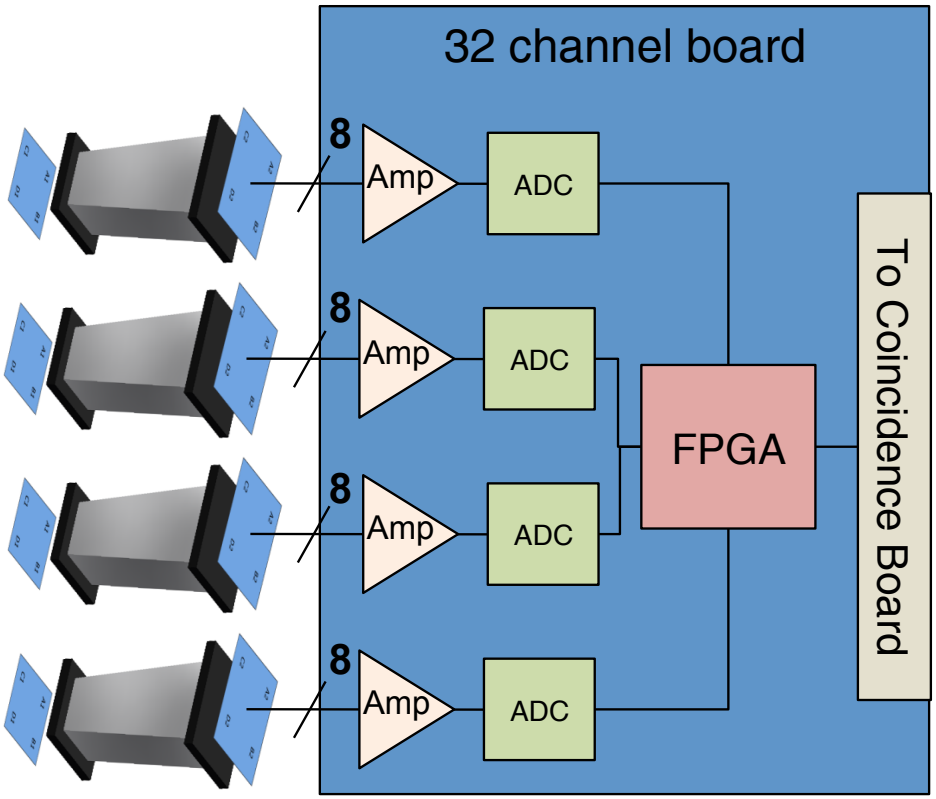
→ 8 channels need to be sampled



OpenPET Configuration

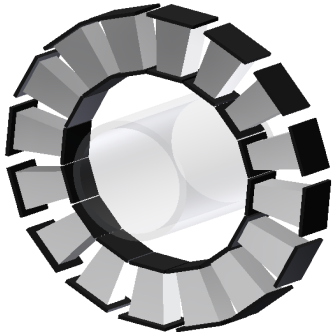
OpenPET Detector board designed to read up to 32 channels

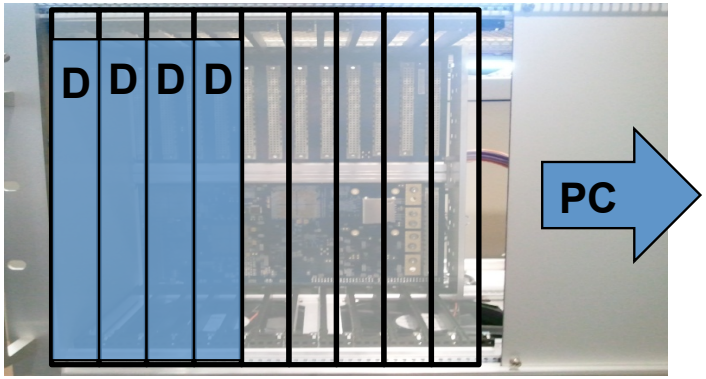
- Per Block 8 channels are required
- Combination of all 8 channels can be used as trigger
- All 8 signals are required to generate X/Y/E/DOI
- Signal duration ~ 200-300 ns
- Rise time 40-60 ns



High Resolution Mouse Brain PET Scanner

32 detectors



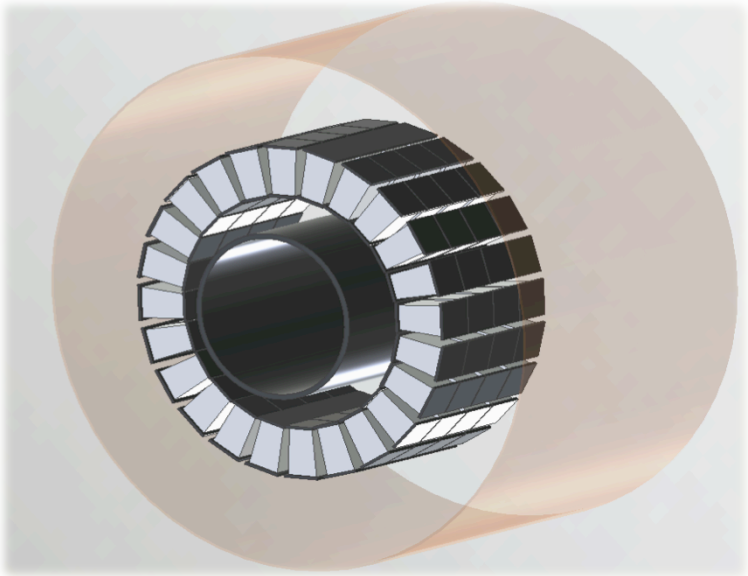


1 OpenPET crate with 8 detector boards

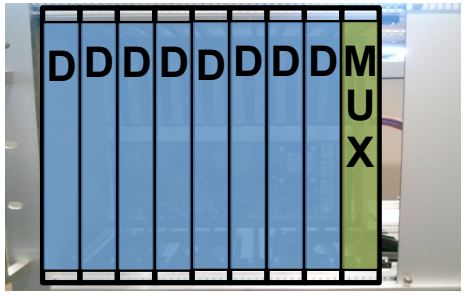
Larger OpenPET Example:

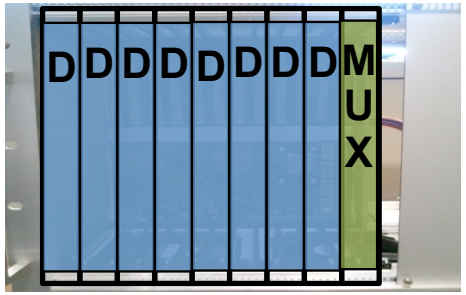
MRI compatible PET system with DOI

- Use dual ended readout to obtain DOI
- 4-ring system, each ring 24 blocks (96 blocks total)



32 blocks





32 blocks

OpenPET…for the community, by the community

- OpenPET provides a great standardized platform to develop PET imaging systems based on novel detector approaches
- OpenPET is scalable and can accommodate a small prototype or full scale system
- OpenPET is flexible, and can be tailored to meet a wide variety of generic and custom needs
- OpenPET is a physical and intellectual resource that can catalyze nuclear medical imaging science