Instruments that Advance the Art

Distributed Digital Data Acquisition System with Network Time Synchronization

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Motivation

NP community => DOE => SBIR Solicitation for

“Software-Driven Network Architectures for Data Acquisition”

- Design for a distributed DAQ system
- Eliminate clock and trigger distribution networks
- Synchronize DAQ units via data network

Requirements for timing precision depends on experiment

• Background reduction by coincidence:	Hundreds of nanoseconds
• Event building for detector arrays:	Tens of nanoseconds
• Time of flight measurements:	Sub-nanosecond

Approach

Existing Technologies

❖ **IEEE 1588 Precision Time Protocol (PTP)**

Time Stamping Units (TSU) built into several Ethernet MACs, physical layers (PHY); also into a few routers

Open source software for managing time synchronization (LinuxPTP, ptpd)

Reported time resolutions:	milliseconds	(software TSU)
	low nanoseconds	(hardware TSU)

❖ **CERN's White Rabbit (WR)**

Extension of PTP standard with synchronized Ethernet

Open hardware project

Reported time resolution: sub-nanosecond, even tens of picoseconds

XIA SBIR Project

⇒ Adapt existing solutions (PTP and/or WR) to detector DAQ modules (Sounds simple, but has not been done before)

⇒ Stay within standards, use open HW/SW environment, no "black box" for purchase

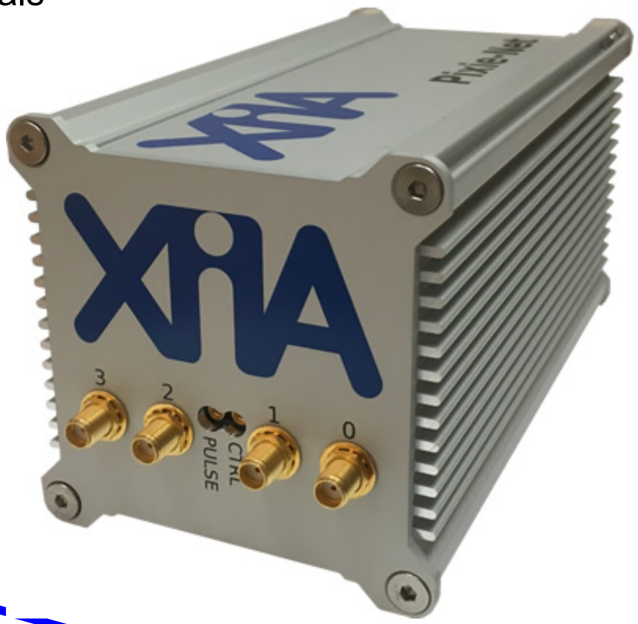
⇒ Collaborate with scientists, open for new ideas

XIA SBIR Project Timeline

- **Phase I (now)**
  - Implement PTP
  - Test performance
  - Explore WR
- **Phase II (2018)**
  - Integrate WR
  - Software trigger scheme
  - Whatever **you** want

R&D Platform: Pixie-Net

- **Latest in a family of DAQ electronics for nuclear physics**
  - **~2000: DGF-4C**
    Developed with GRETA related SBIR
    Patented technology for processing segmented HPGe signals
    Still used in Miniball, AGATA detector testing
  - **~ 2003: Pixie-4, 2014: Pixie-4e**
    100/500 MB/s data bandwidth with PCI/PCIe
    Used in many smaller lab systems <10 channels
  - **~ 2005: Pixie-16, 2016: Pixie-32**
    Low cost, high density, extensive clock/trigger capabilities
    Used in SeGA, VANDLE, CANDOR …



- **Based on Zynq SoC: FPGA + ARM**

FPGA → pulse processing → pulse heights, waveforms

ARM → Linux OS → USB, SD, Ethernet, webserver

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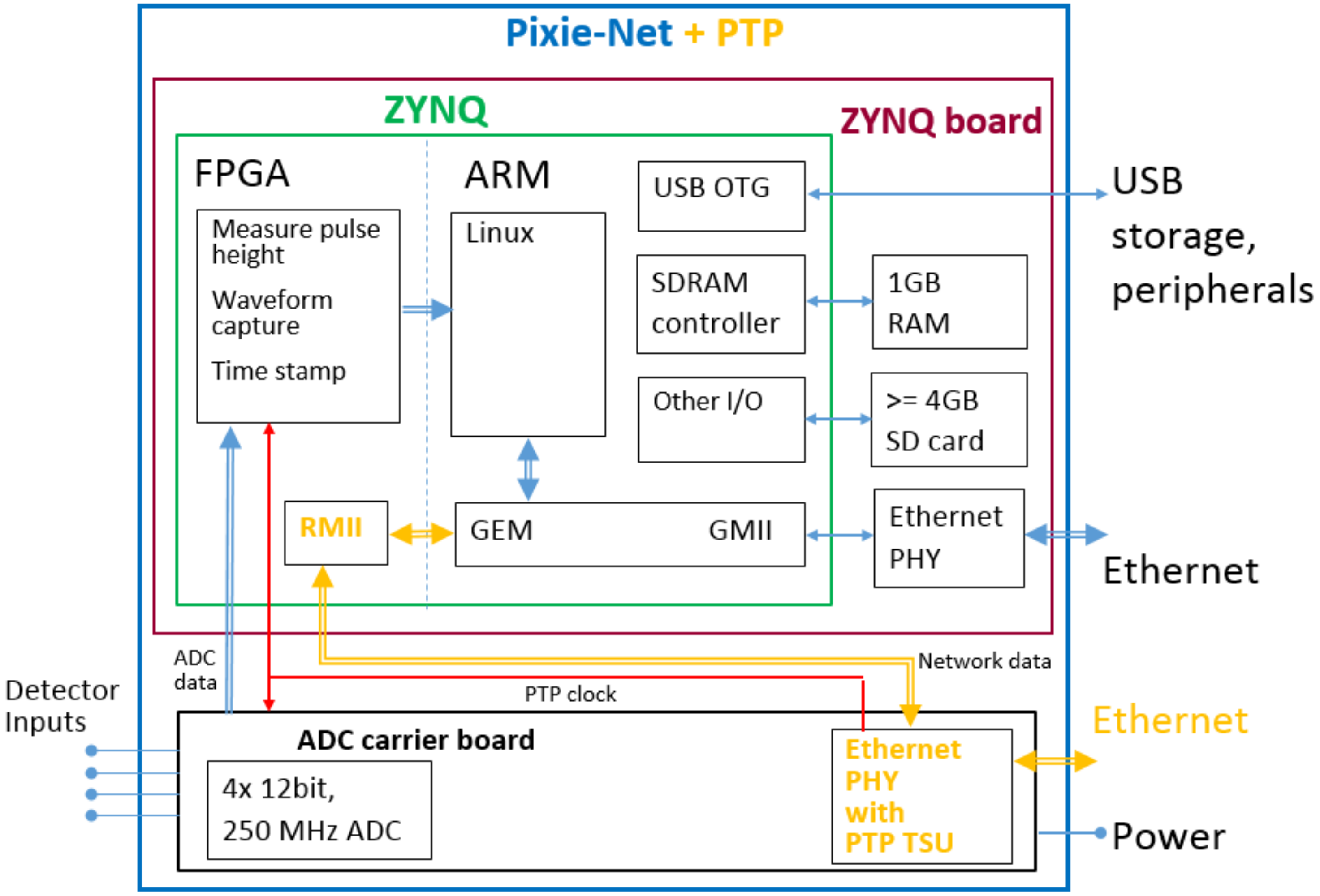
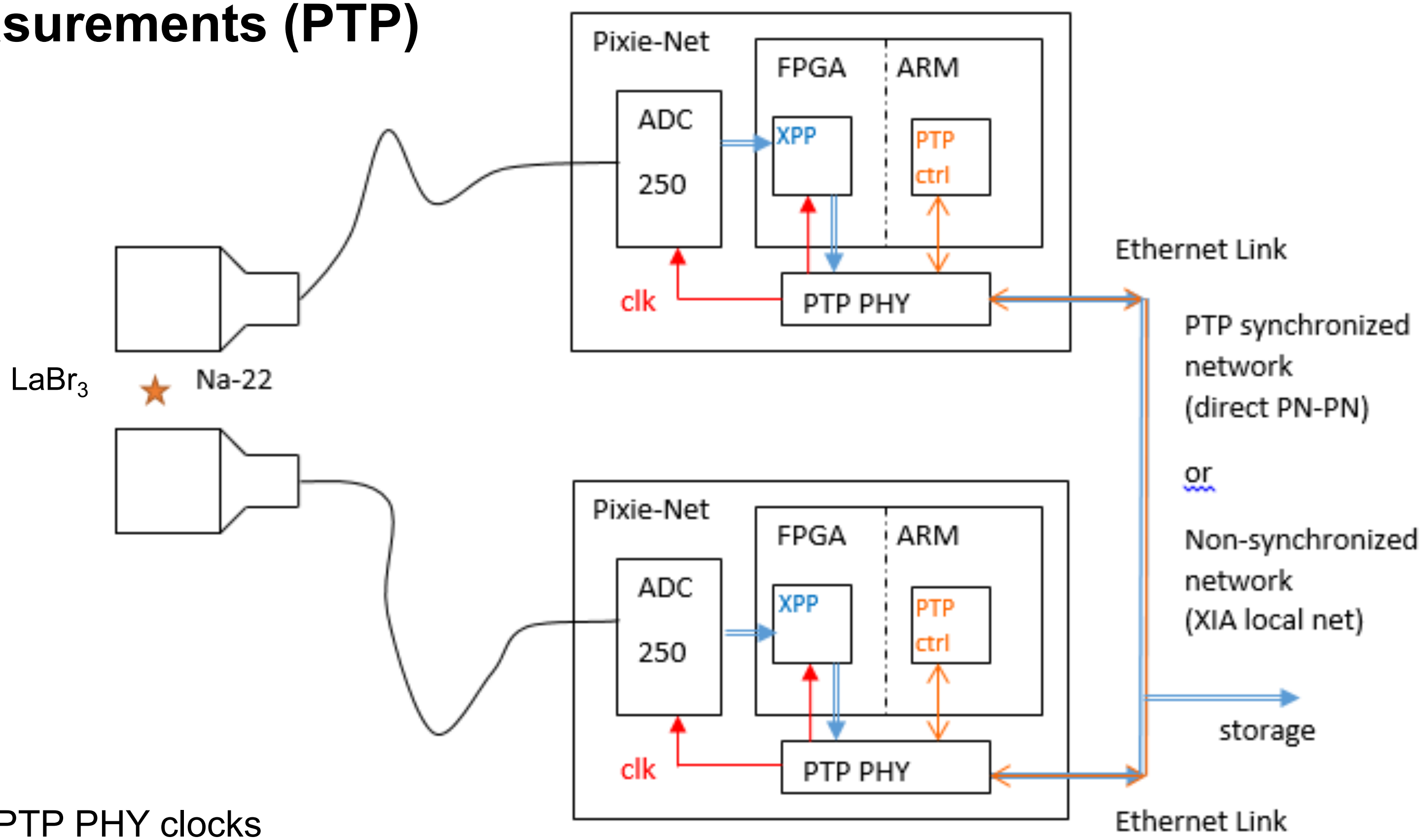


- COTS Zynq board
- ARM runs Ubuntu 15
- SSH login to control DAQ
- Webserver displays results
- Data stored to USB drive, SD card, or network drive
- **New for SBIR: Ethernet PHY with PTP TSU and clock output**

Measurements (PTP)



The PTP PHY clocks
- ADCs capturing coincident scintillator pulses
- FPGA logic for time stamping pulses

If perfectly synchronized clock => zero variation in arrival time difference of coincident 511 keV gammas
If not => time difference varies over time
But also broadened by clock jitter, light collection variations, PMT transit time, noise, etc.

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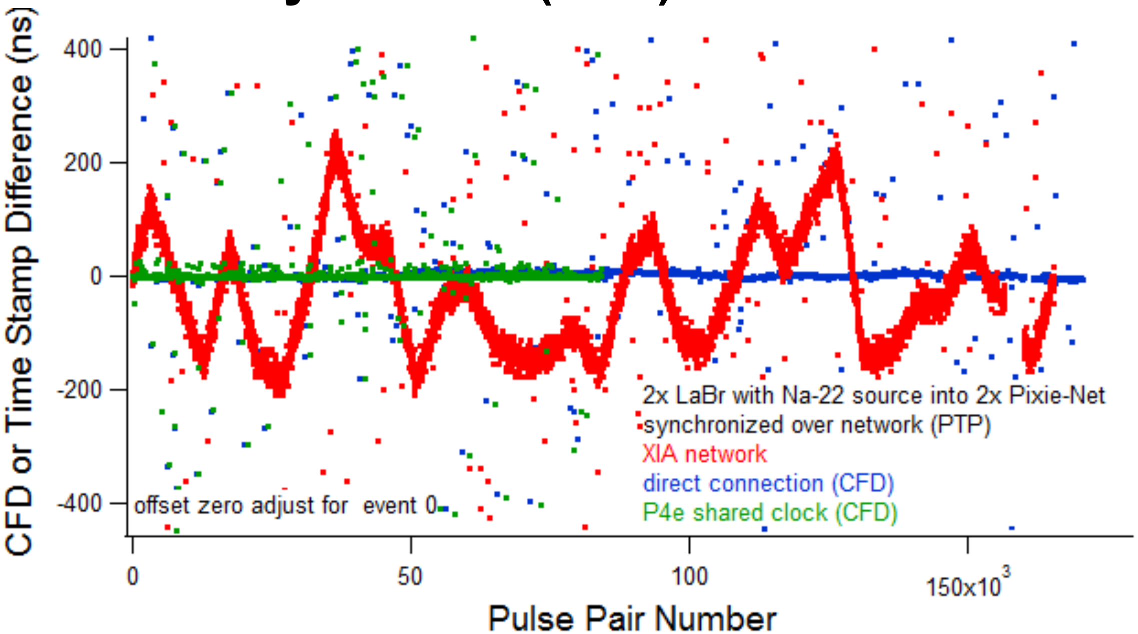
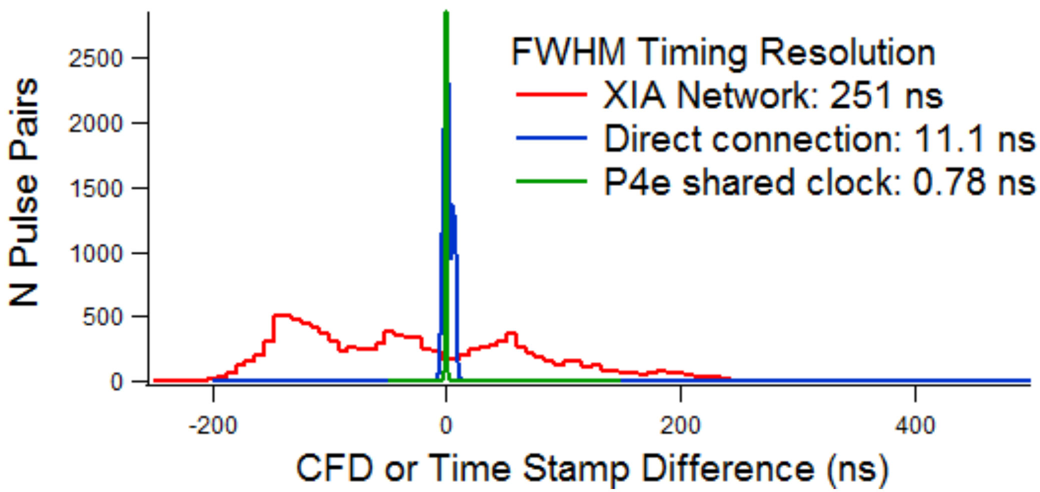
Preliminary Results (PTP)

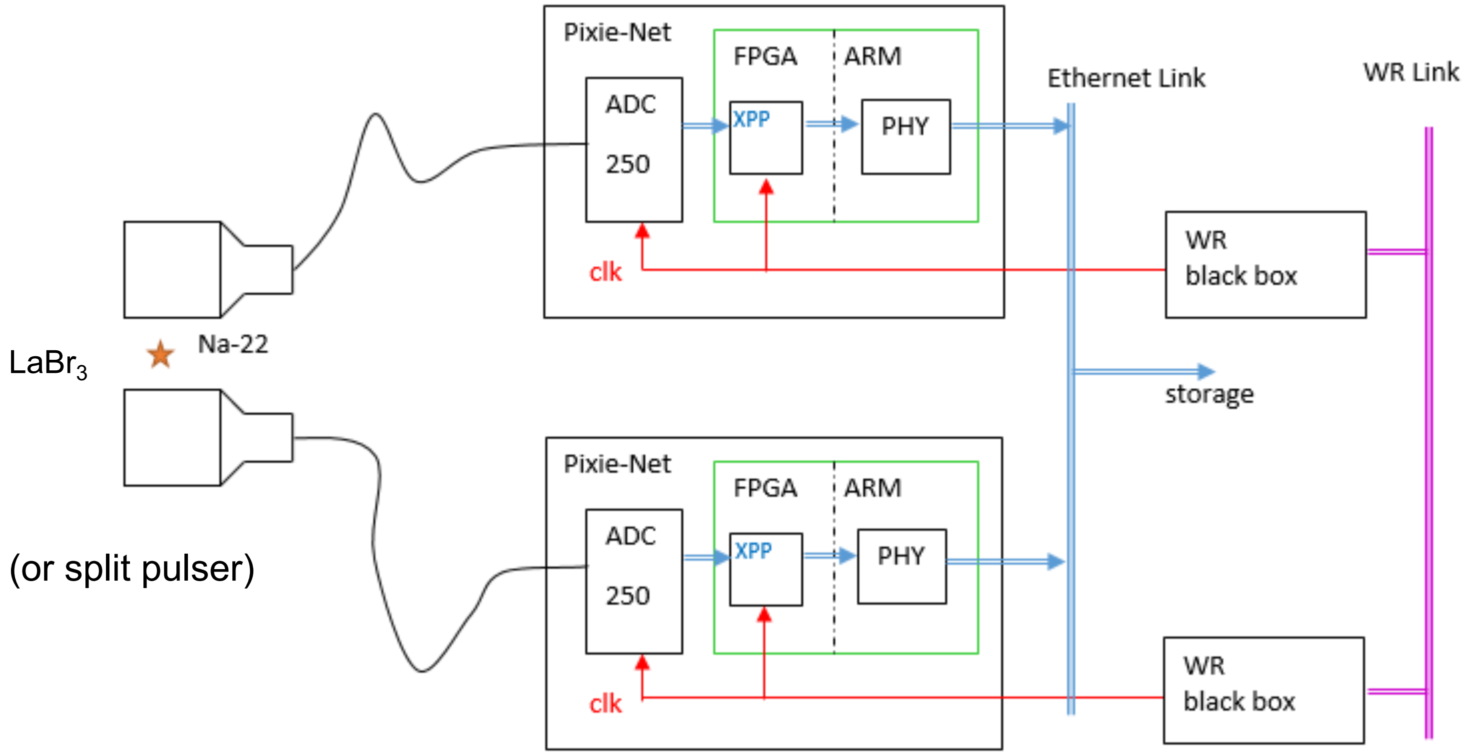


Not a SW report on network delay, or jitter of PPS reference signals; but measured time difference between coincident gammas

PTP
LaBr pair



Measurements (WR)



Using commercial WR "black box" for time synchronization, standard Ethernet for data.

(Phase II: integrate WR into Pixie-Net, use the WR data link instead of ARM controlled Ethernet)

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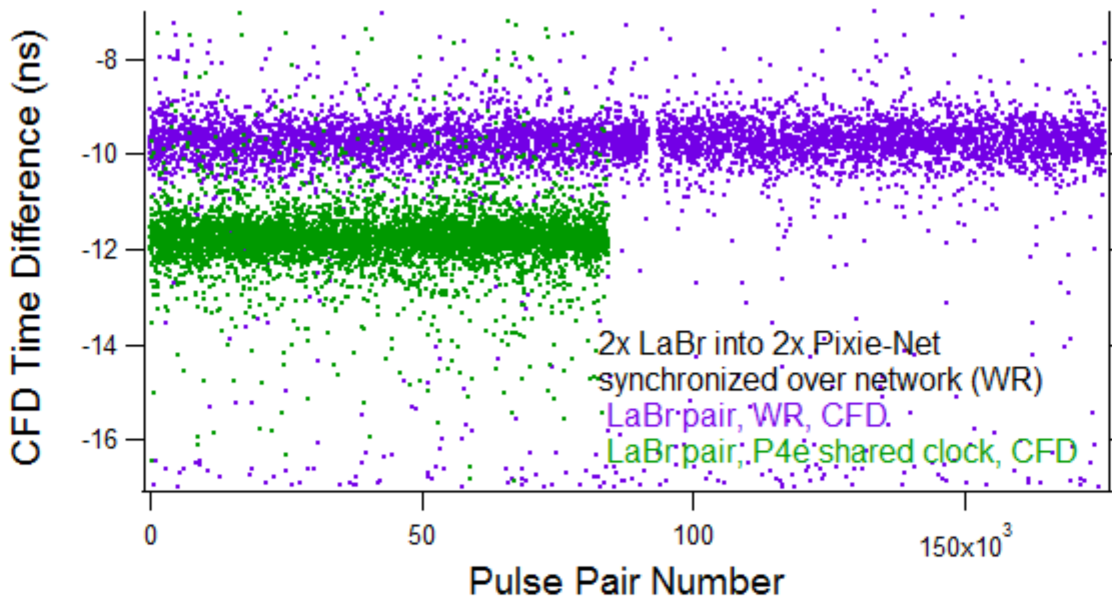
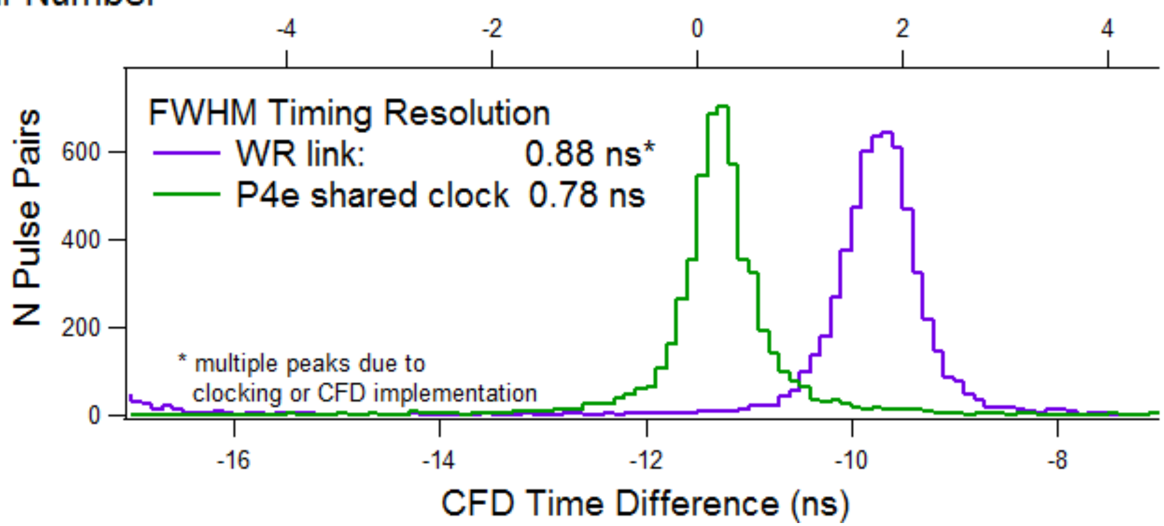
Preliminary Results: WR (with $LaBr_3$)



For LaBr, the WR synchronization matches timing resolution of P4e shared clock

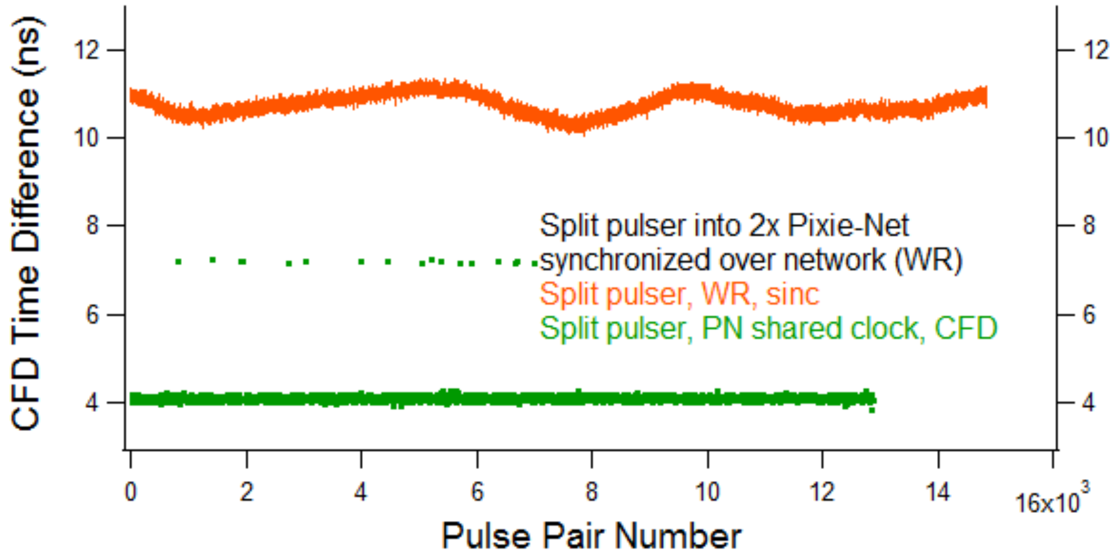
(But need to improve detector, past P4e measurements were better)



WR
LaBr

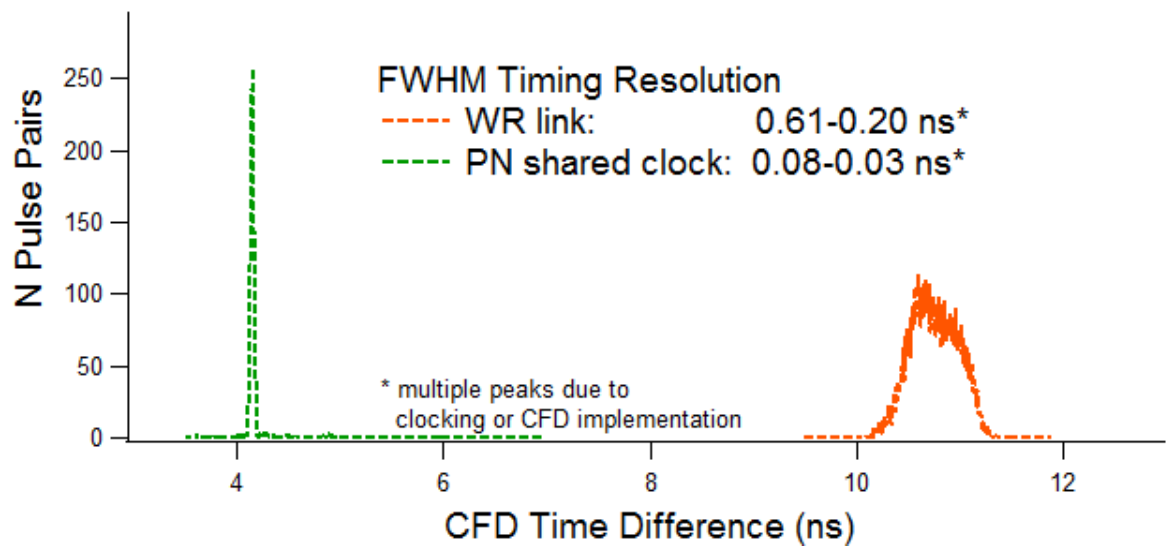
Distributed digital data acquisition system with network time synchronization

Preliminary Results: WR (with Pulser)



For split pulser, timing resolution improves but WR not quite matching PN shared clock

=> Signal source matters !

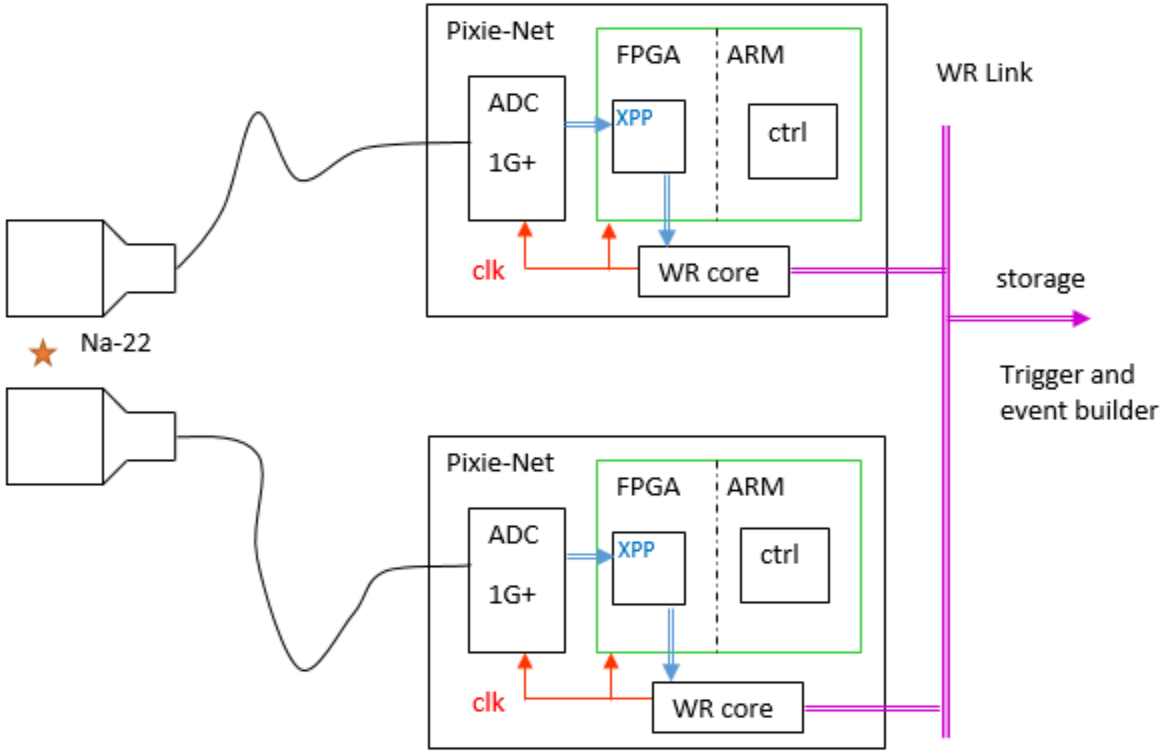


WR pulser

Phase II Project

Phase I will result in a demo system with standard IEEE 1588 PTP, ~10ns resolution, White Rabbit compatible. Available with existing Pixie-Net. Suitable for less demanding applications.

In Phase II, aim for 10-100ps resolution by integrating White Rabbit into an upgraded Pixie-Net.
Work with scientists to be compatible with HW and SW infrastructure developed locally.
Collaborate in “open hardware” projects rather than trying to sell “black box” proprietary electronics.



Summary

Explored PTP and WR network time synchronization for detector data acquisition electronics

Phase I is work in progress

-	February	ptpd software time stamping	17,966,000 ps
-	March	Zynq PTP hardware time stamping	1,310,000 ps
-	April	PHY PTP hardware time stamping, XIA network	398,000 ps
-	June	PHY PTP hardware time stamping, XIA network, LaBr	251,000 ps
		PHY PTP hardware time stamping, PN-PN, CFD, LaBr	11,000 ps
-	July	WR clocking, CFD*, LaBr	900 ps*
		WR clocking, sinc* pulser	600 ps*
		…	
	goal	shared clock equivalent	10 ps

Phase II plans

- Integrate WR
- Develop software for triggering and event building
- Collaborate with interested scientists

The ultimate goal is to reach the timing resolution of an optimized shared clock system (e.g. Pixie-500e: 7ps [1]) or what was reported for WR PPS measurements (6 ps [2]). Signal sources and timing algorithms need to be improved as well.

[1] WK Warburton et al, to be published
[2] M. Lipinski et al, 2011 ISPCS conference

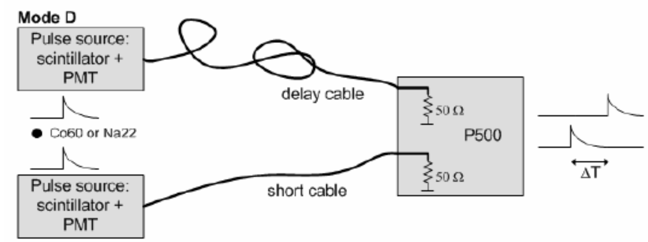
Questions?

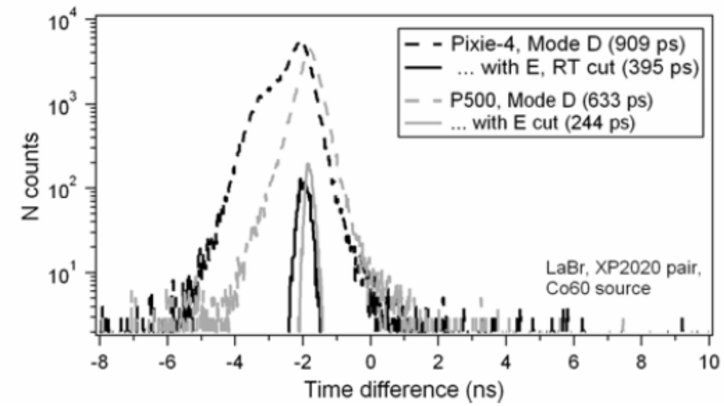
Distributed digital data acquisition system with network time synchronization

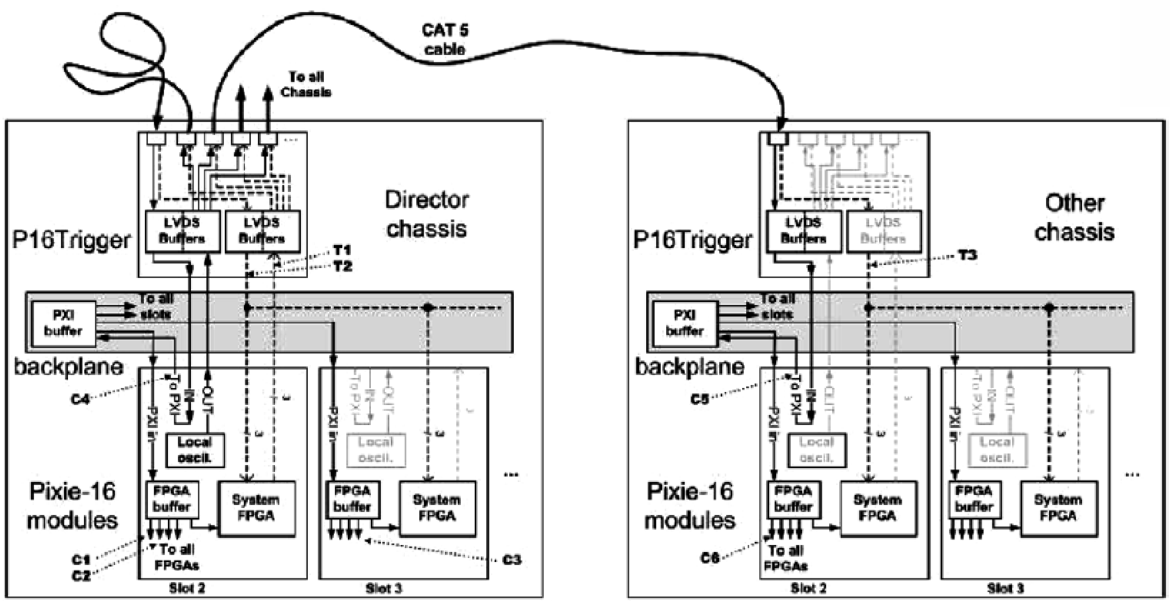
Traditional Synchronization

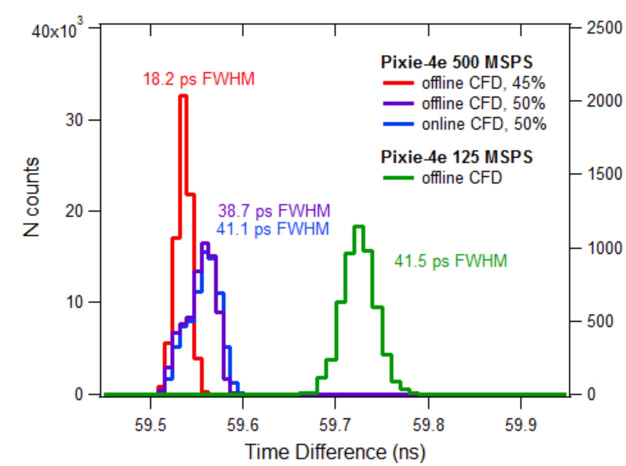
Traditionally, time synchronization between multiple channels of digital data acquisition is accomplished by sharing clocks, clock reset signals, and triggers.

With suitable algorithms (CFD), timing resolutions can be ~20 ps for idealized signals and a few hundred ps for detector signals digitized with 100-5000 MSPS.









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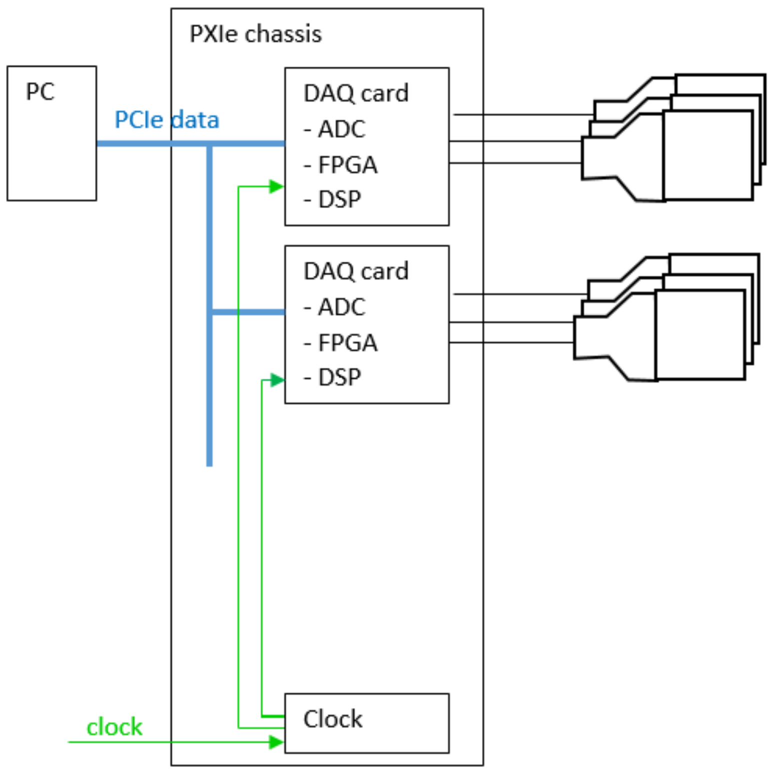
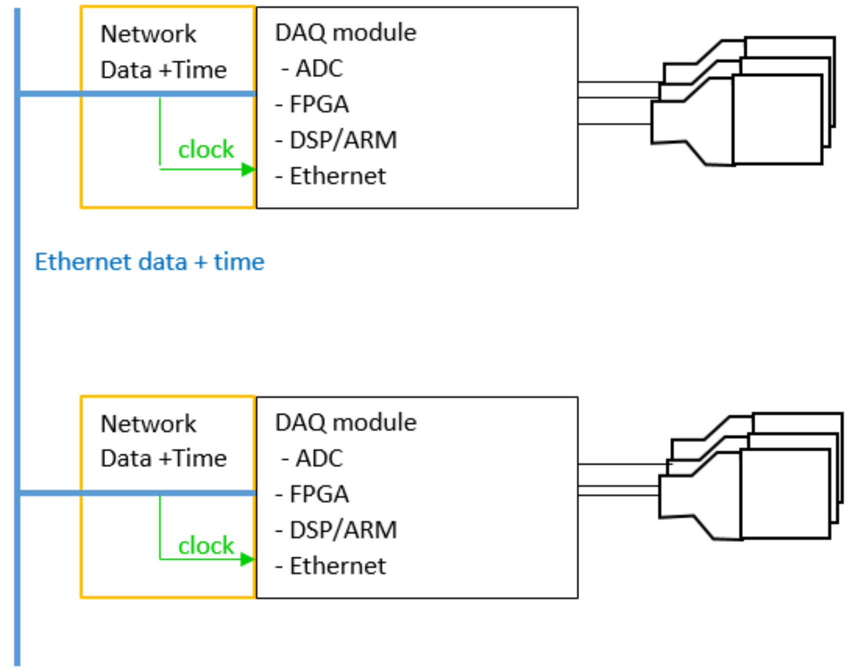


Traditional

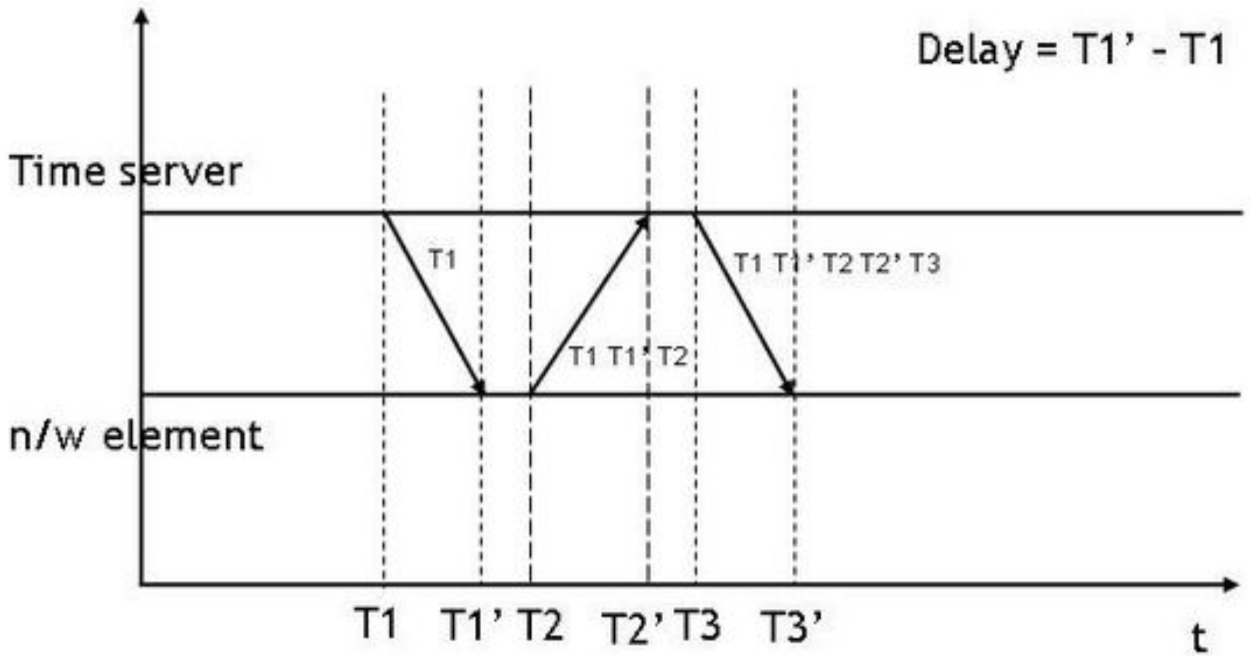
Crate with data I/O to host PC and local clock distribution



This Project

Independent modules with network data and derived clock

PTP synchronization



If d is the transit time for the *Sync* message, and $\tilde{o}$ is the constant offset between master and slave clocks, then

$$T1' - T1 = \tilde{o} + d \text{ and } T2' - T2 = -\tilde{o} + d$$

Combining the above two equations, we find that

$$\tilde{o} = (T1' - T1 - T2' + T2)/2$$