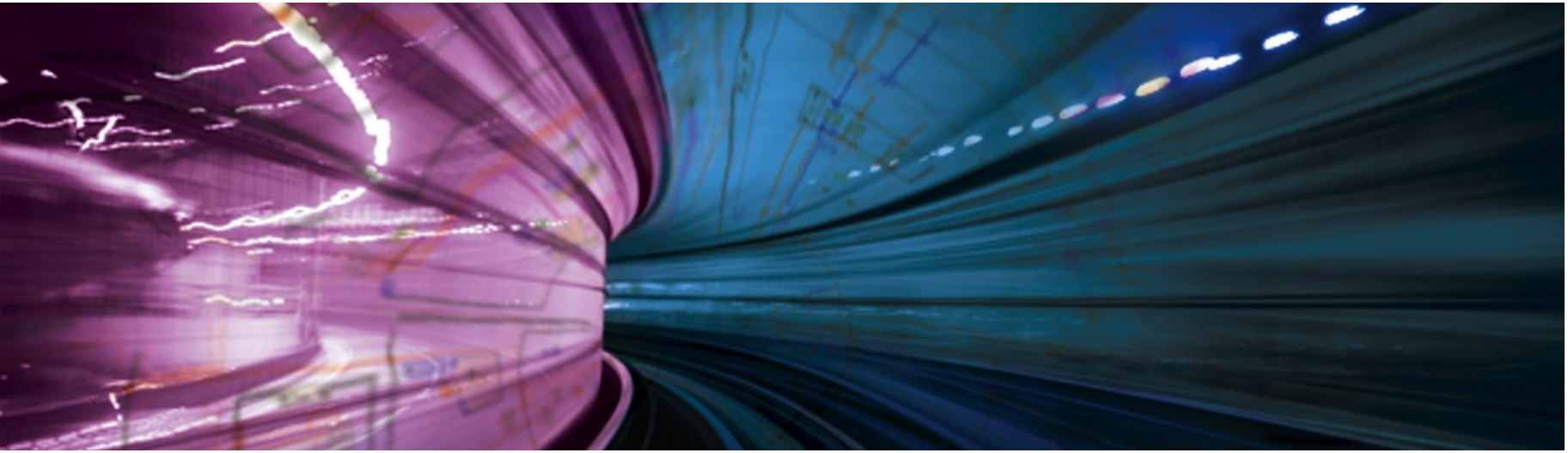
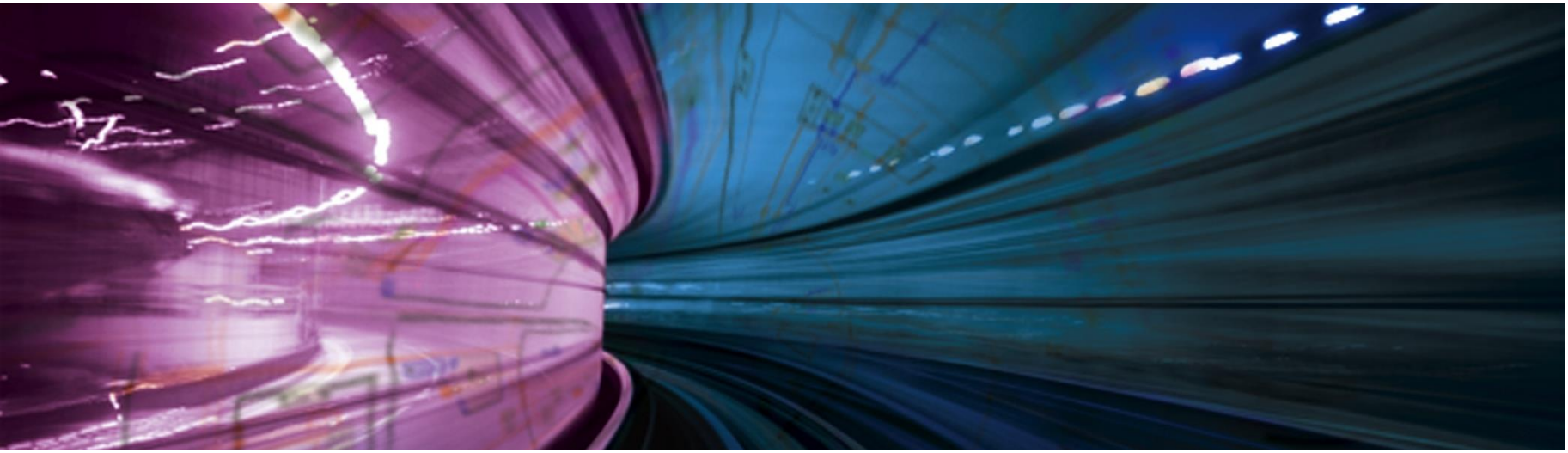


# How NI is Investing in new Technologies for Measurement and Control

Robert Canik
Vice-President of R&D, PXI Platform Products
National Instruments

# Agenda

- NI's Involvement in Physics Research
- Technology Trends and NI's Investment in New Technologies for Measurement and Control
  - Data Convertors
  - High Performance Processing
  - Network Communication
- Platform-Based System Development

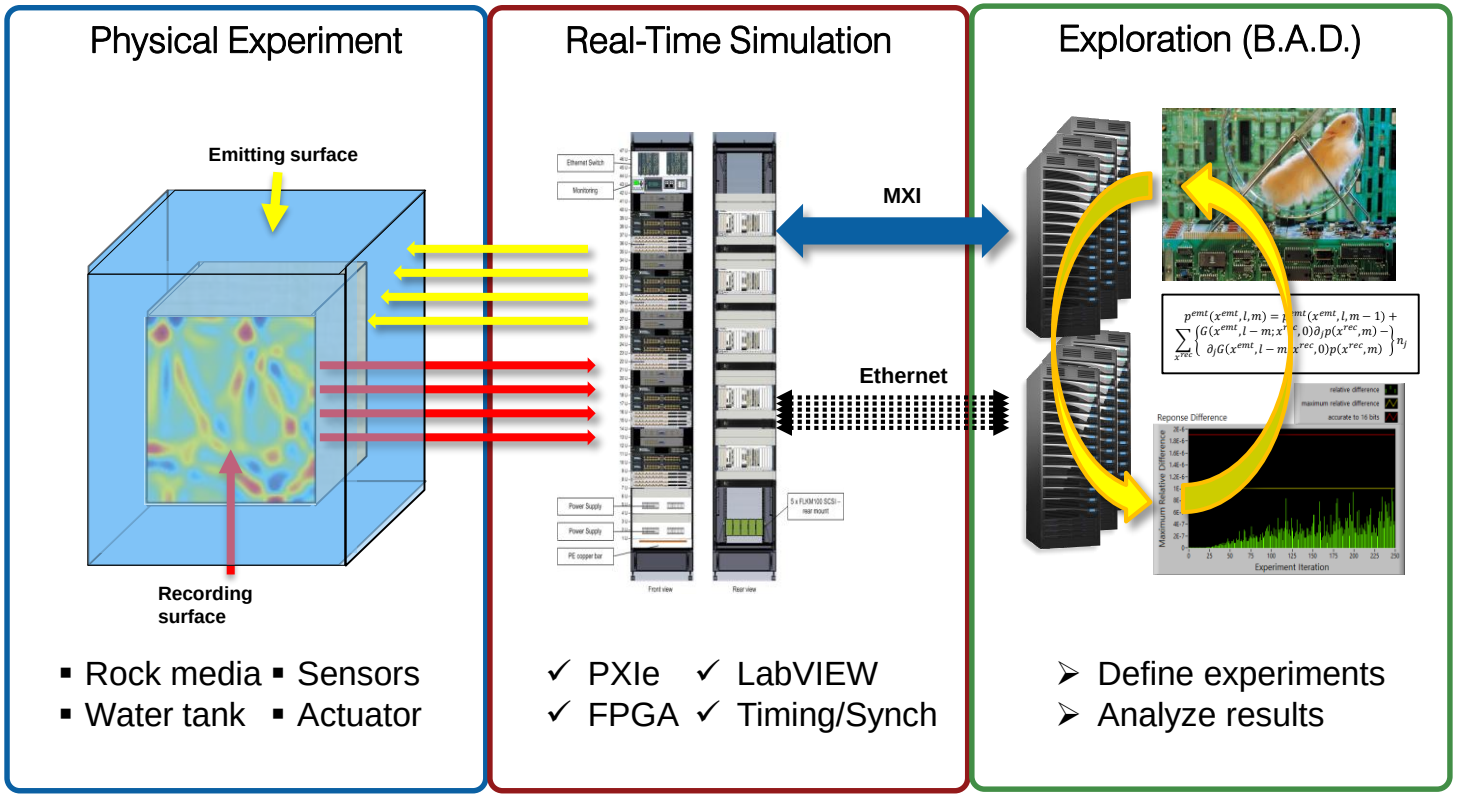


# NI's Involvement in Physics Research

# Worldwide Collaboration

# Central Europe Collaboration

# Wavelab Project: Closed Loop Control with Massive Computation



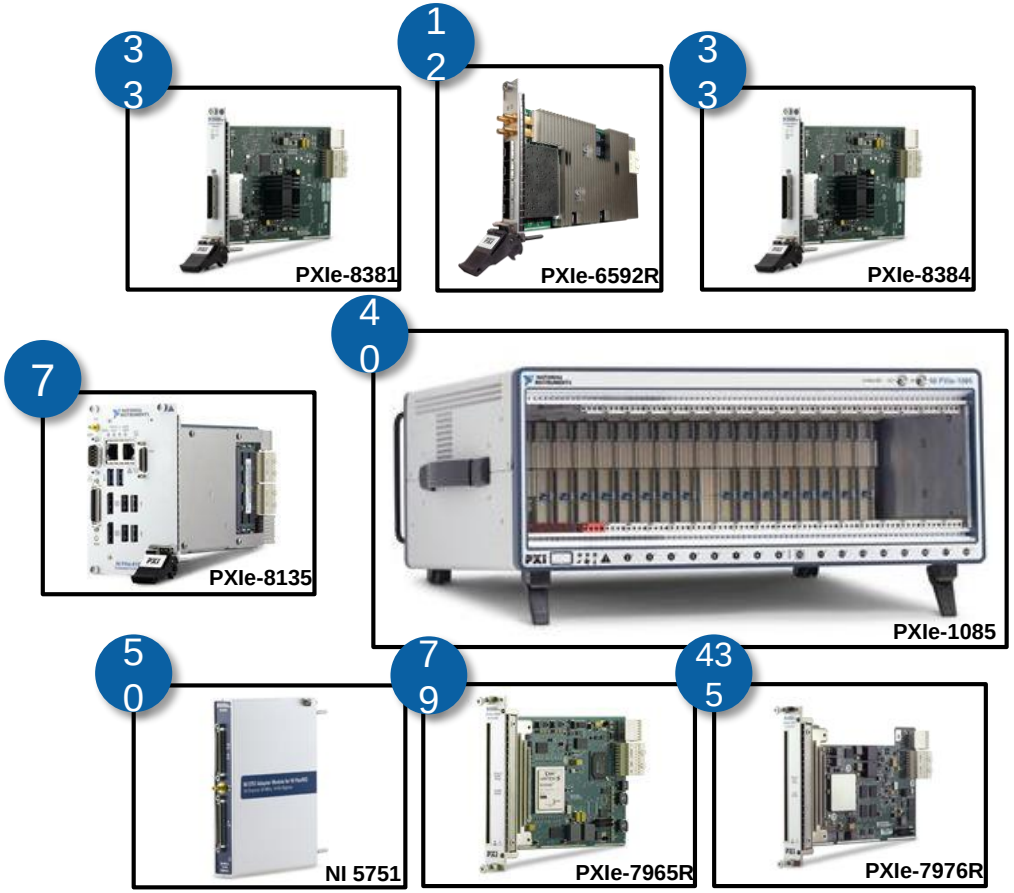

- Rock media
- Sensors
- Water tank
- Actuator

- ✓ PXIe
- ✓ LabVIEW
- ✓ FPGA
- ✓ Timing/Synch

- ➢ Define experiments
- ➢ Analyze results

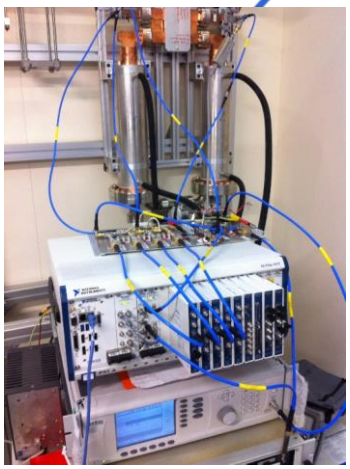
# NI Platform: I/O, Timing and Data Distribution

- Chassis and Controllers
  - PXIe-1085
  - PXIe-8135
  - PXIe-8381/8384
- I/O with FPGA
  - PXIe-7965R(FlexRIO)
  - PXIe-7976R (FlexRIO)
  - NI 5751 (analog input)
  - NI 5742 (analog output)
- Data distribution and routing
  - PXIe-6592R



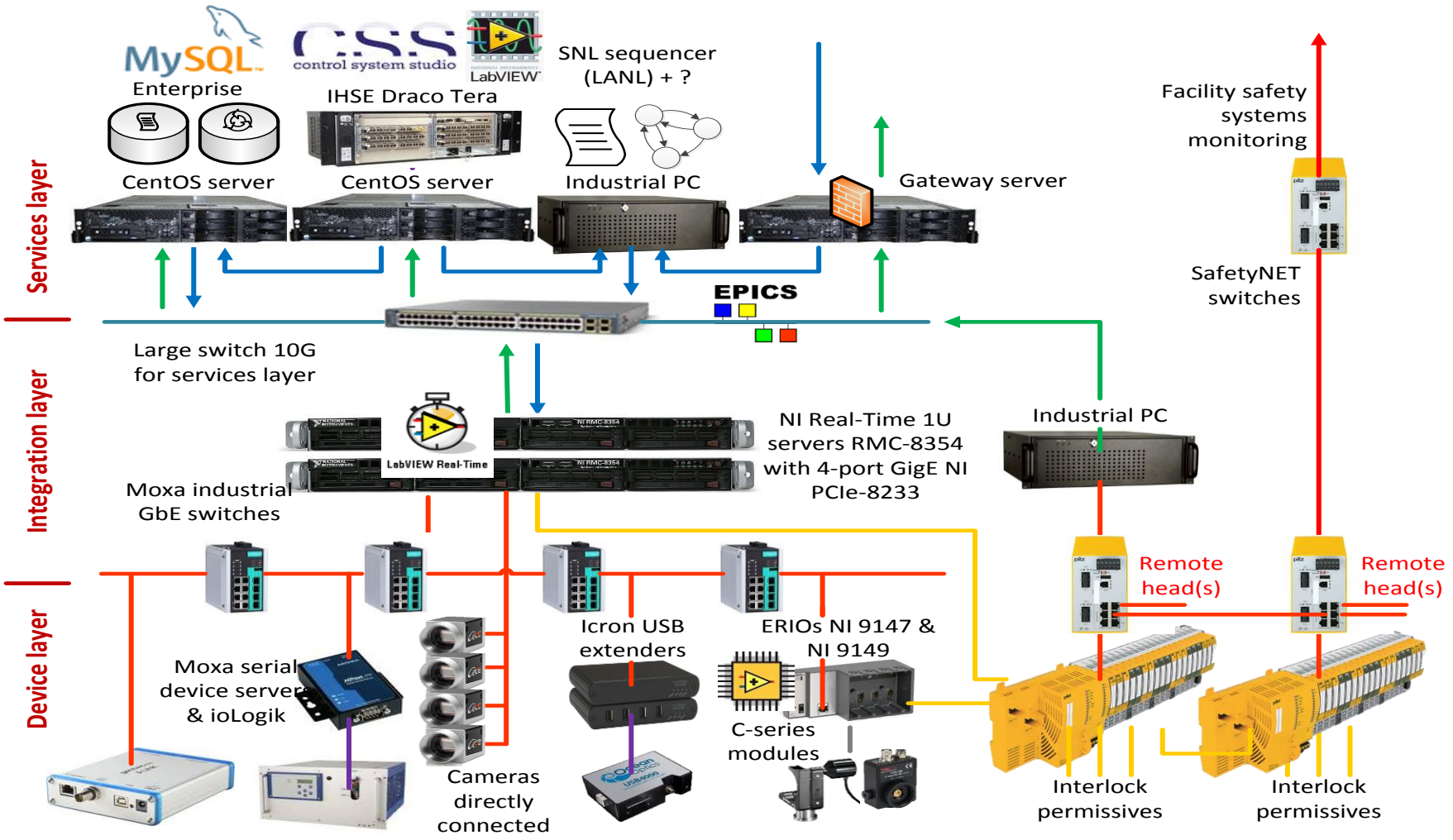
# CERN – XBOX Control and Test System

- High-gradient cavity conditioning and testing systems for the CLIC
- Three phase project
  - XBOX 1 - PXIe control with mixture of NI and external instrumentation
  - XBOX 2 - Fully PXIe-based control and instrumentation
  - XBOX 3 - Same as 2, but can test multiple structures simultaneously
- NI Hardware
  - PXIe-1075, PXIe-8135
  - FlexRIO 5761R, 5772R, 6583R, 5793R
- XBOX 1 & 2 are fully functional and have delivered thousands of hours of data. XBOX 3 is currently being assembled and tested.
- Project has received worldwide attention and systems implemented at:
  - SLAC, Uppsala University, University of Valencia



# ELI Control System Architecture

Slide courtesy: Dr. Jack Naylon, ELI Czech Republic



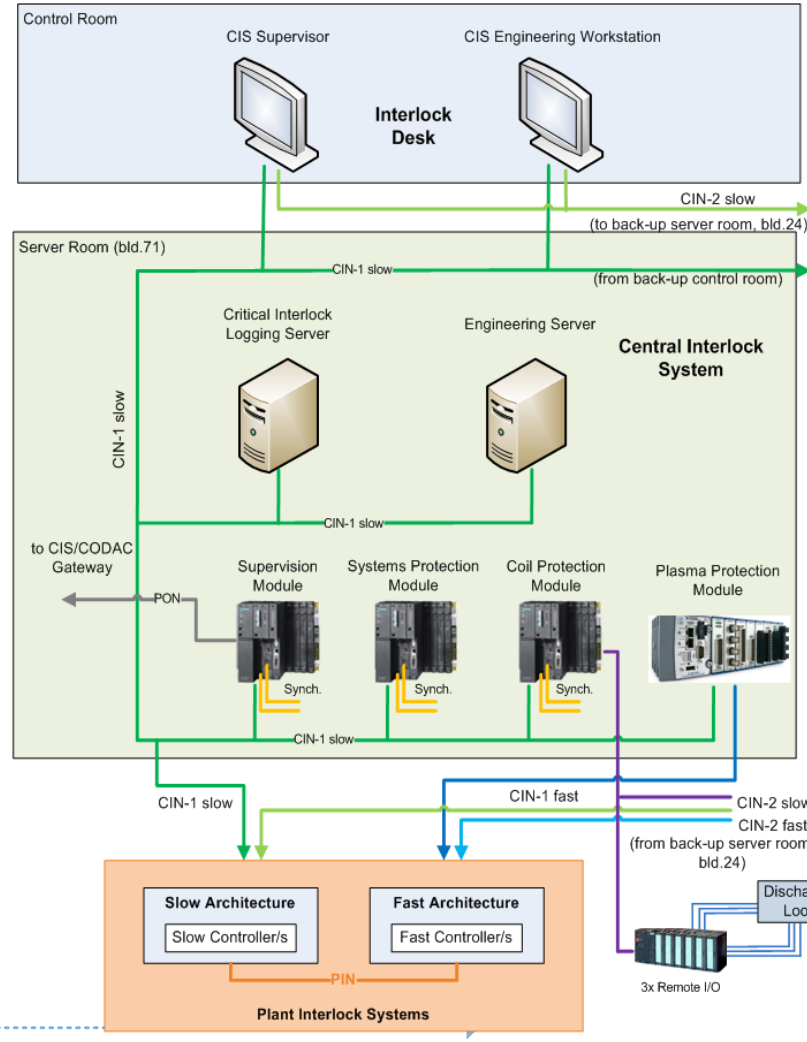
# ITER Interlock Systems

ITER Interlocks (Plant and Central) are implemented using different technologies

- Critical Interlocks: Hardwired current loops
- Slow (and human safety) interlocks: High Integrity Siemens PLC
- Fast interlocks (plant systems): FPGA redundant technologies using cRIO

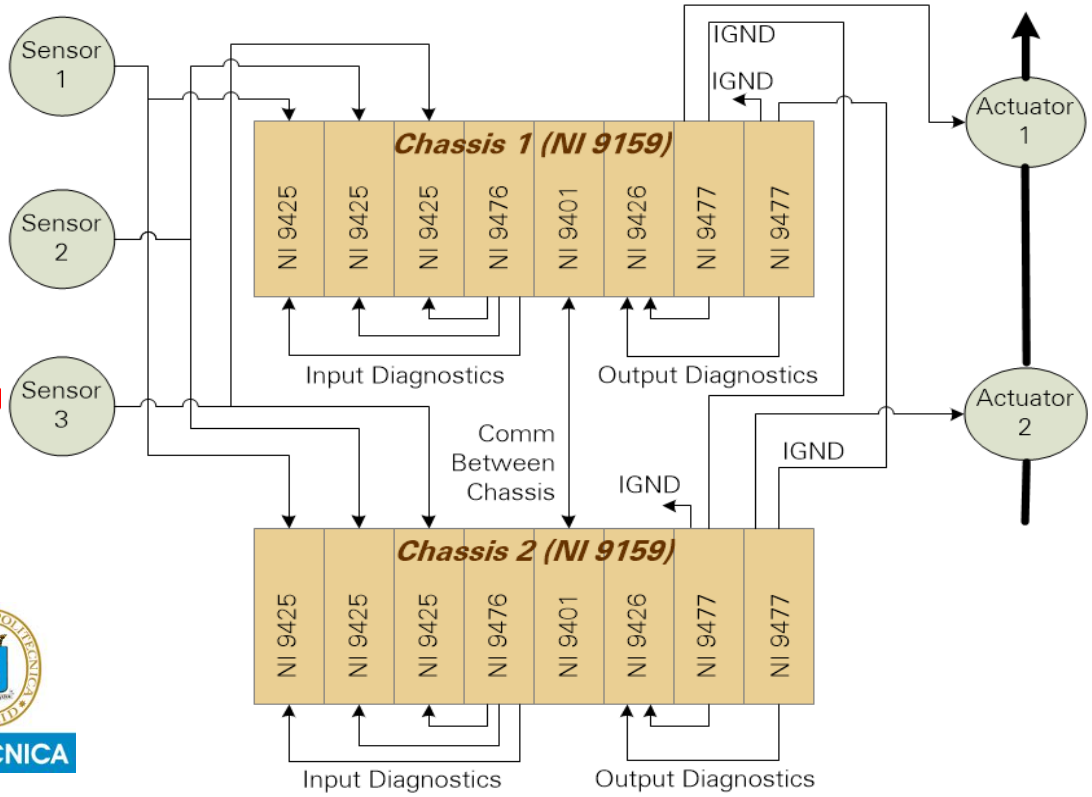
ITER awarded a contract to CIEMAT, UPM and NI for review of cRIO platform involving:

- FMEDA Analysis
- Fast ICS Architecture Study and Performance Analysis



# Fast Interlock with cRIO

- Availability > 99.9%
- Reliability > 99.6%
- HFT (HW fault tolerance) = 1
- SFF (safe failure fraction) = 85%
- PFH = 1.32 E-08
- *SIL 2 type numbers* *(NOT CERTIFIED*



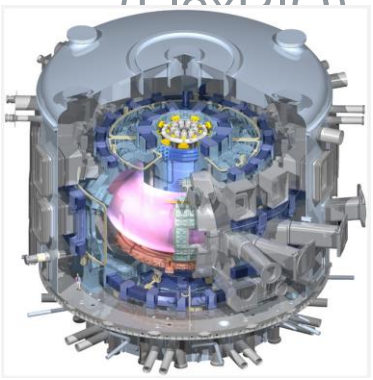

GOBIERNO DE ESPAÑA MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

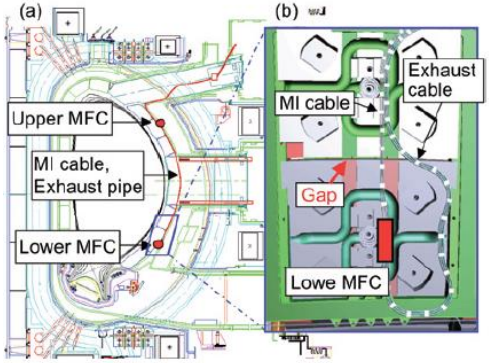
POLITÉCNICA

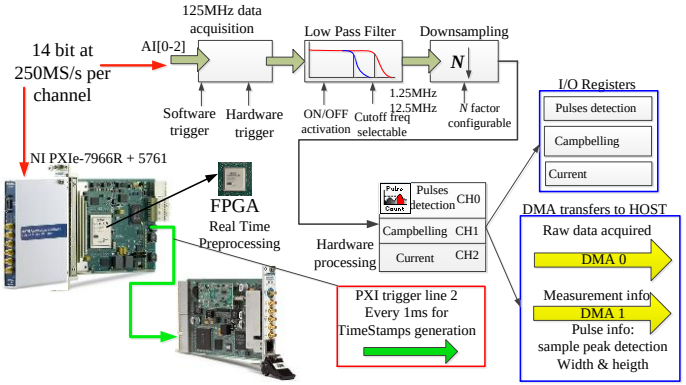
# ITER Diagnostics: High Performance Data Acquisition

**Micro Fission Chamber**: Measures neutron flux in the tokamak

- 4 fission chambers with 3 detectors
- Neutron flux measurements, in counting, campbelling and current modes
- Tested NI PXIe platform for radiation (Neutrón and Gamma) tolerance
- Data acquisition: 250MS/s, 14 bit, 3 channels. Filtering on FPGA (FlexRIO)





# NI's Investment in New Technologies for Measurement & Control


- **Data Converters**

- High Performance Processing

- Network Communication

# Trends in High Resolution ADC

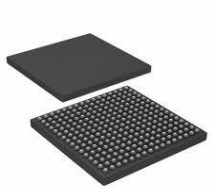
(most bits and most speed)

1990 | 1998 | 2006 | 2016


**8 bit 3MS/s Pipeline**

**16 bit 1MS/s SAR Hybrid**

**16 bit 50kS/s Σ-Δ**



**8 bit 50MS/S Pipeline**

**16 bit 1MS/s SAR monolithic**

**20 bit 10kS/s Σ-Δ**


**16 bit 250MS/s Pipeline**

**16 bit 3MS/s SAR monolithic**

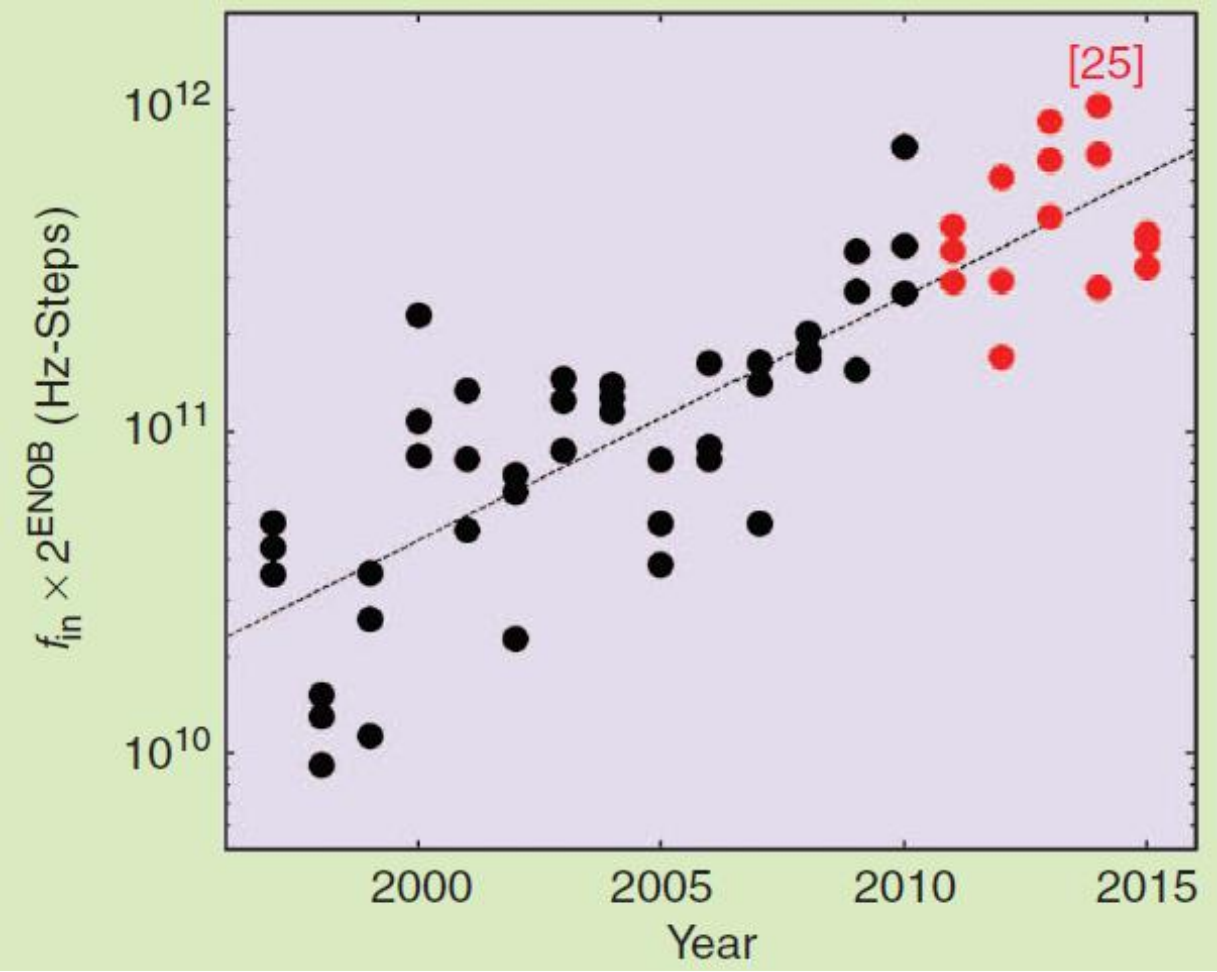
**24 bit 105kS/s Σ-Δ**

**12 bit 4S/s**
**16 bit 1GS/s Pipeline**

**18 bit 15MS/s SAR**

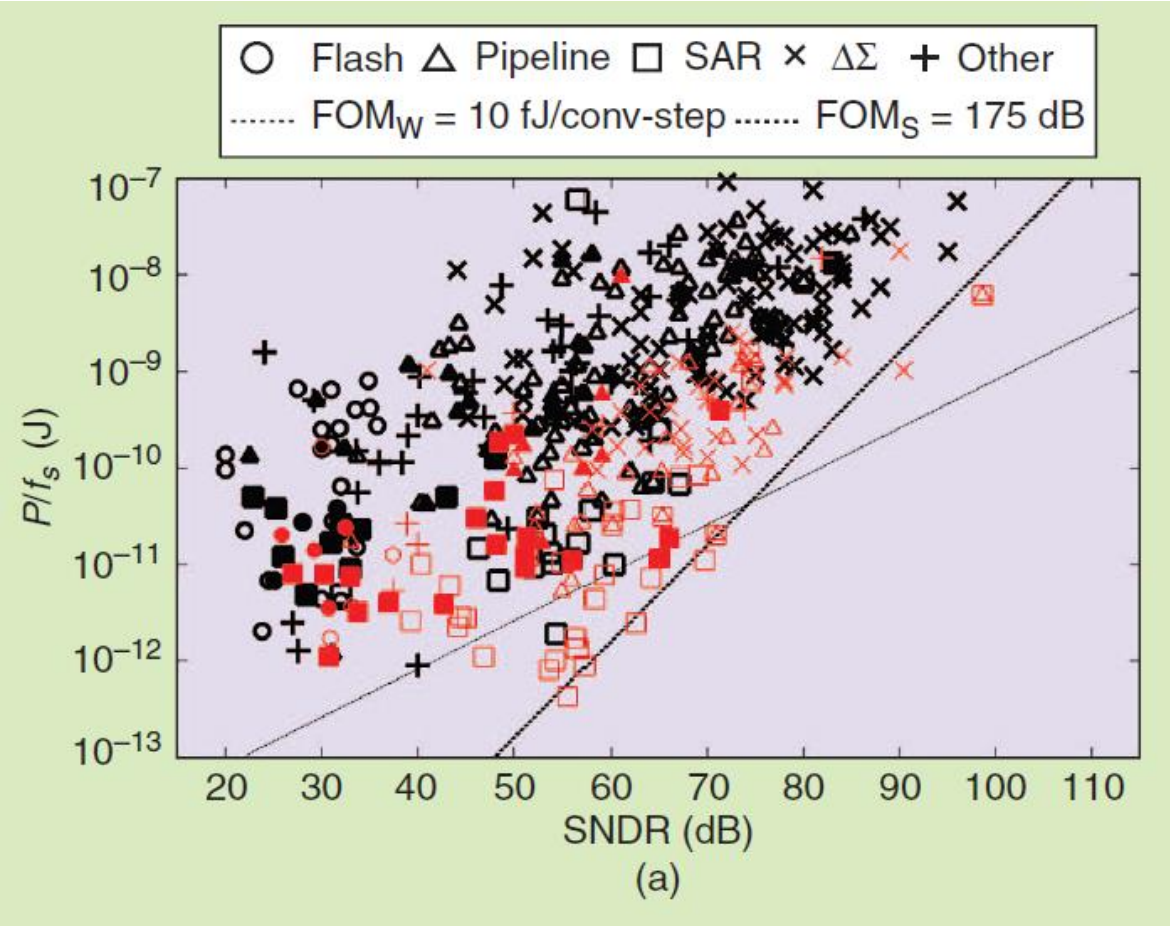
**24 bit 500kS/s Σ-Δ**

# Speed/Resolution Landscape




Source : B. Murmann, "ADC Performance Survey 1997-2015"

# Energy Efficiency

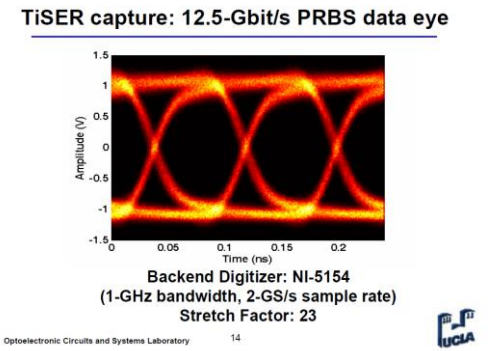


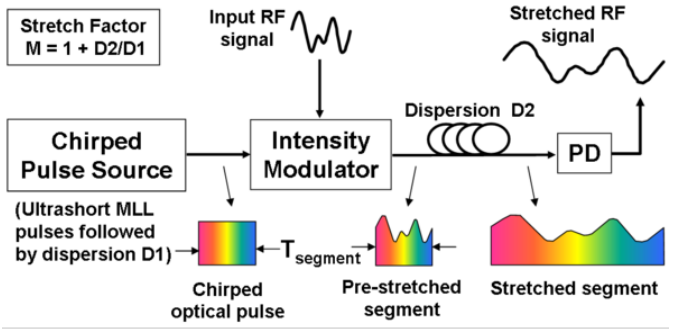

Source : B. Murmann, "ADC Performance Survey 1997-2015

# 2016 and Beyond

- Process Scaling continues to enable Integration and performance
  - Mass interleaved ADCs (up to and beyond 8b/90GSps) in small geometry CMOS
  - Increased Digital Signal Processing for Calibration/Correction/Noise Shaping
  - “Hybrid” Converters such as SAR-Assisted Pipelines

- Experimental Time Stretch Photonic ADCs
  - TiSER (Time Stretch Enhanced Recorder)
  - “Fits in a single room”
  - 10 Terasamples/sec transient ADC



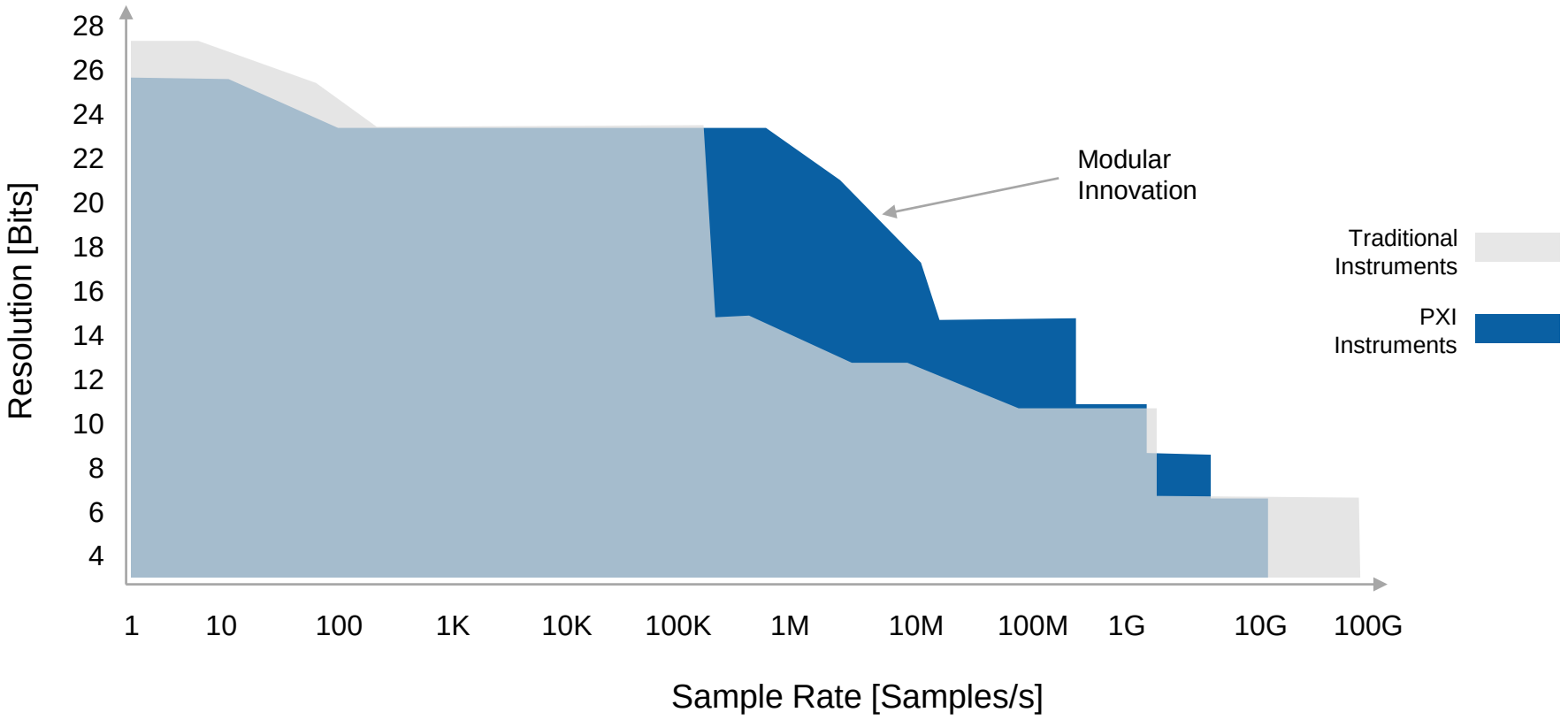




- Evolution of Serial Data Standards (JESD204)
  - Flexibility over Resolution/Speed/Channel Density
  - JESD204B has been well accepted in industry (up to 12.5Gbps/lane)
  - JESD204C in development for bandwidth progression (>12.5Gbps/lane)

A. Fard, S. Gupta, and B. Jalali, "Photonic time-stretch digitizer and its extension to real-time spectroscopy and imaging," *Laser & Photonics Reviews* vol. 7, no. 2, pp. 207-263, March 2013.

# Trusted Measurement Quality

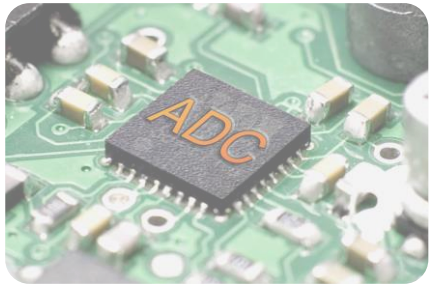
*Year: 2014*



# PXI Instruments Released in 2015

| | | | |
|---|---|---|---|
|  |  |  |  |
| **PXIe-4139**<br>Precision System SMU | **PXIe-5162**<br>4ch, 1.5GHz, 10-bit Digitizer | **PXIe-4112**<br>2ch, 60V, 1A DC Power Supply | **PXIe-5646R**<br>6GHz Vector Signal Transceiver |
|  |  |  |  |
| **PXIe-5451**<br>2ch, 400MS/s, 16-bit AWG | **PXI-4071**<br>7½-digit, 1000V Precision DMM | **PXIe-6556**<br>24ch, 200MHz, PPMU Digital | **PXIe-2543**<br>6GHz, 8ch, Solid-State Mux |

# Technology Trends

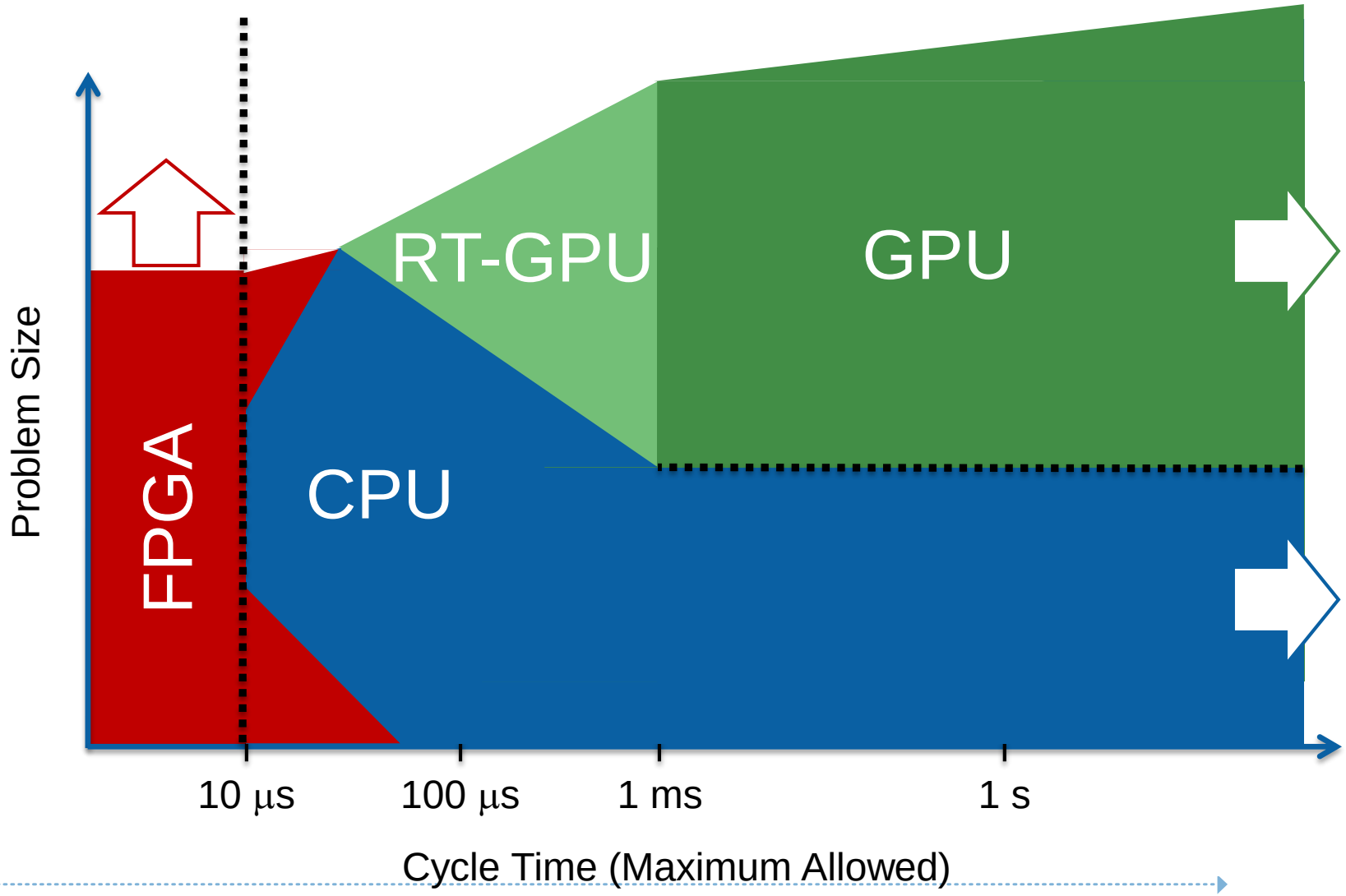



- Data Converters

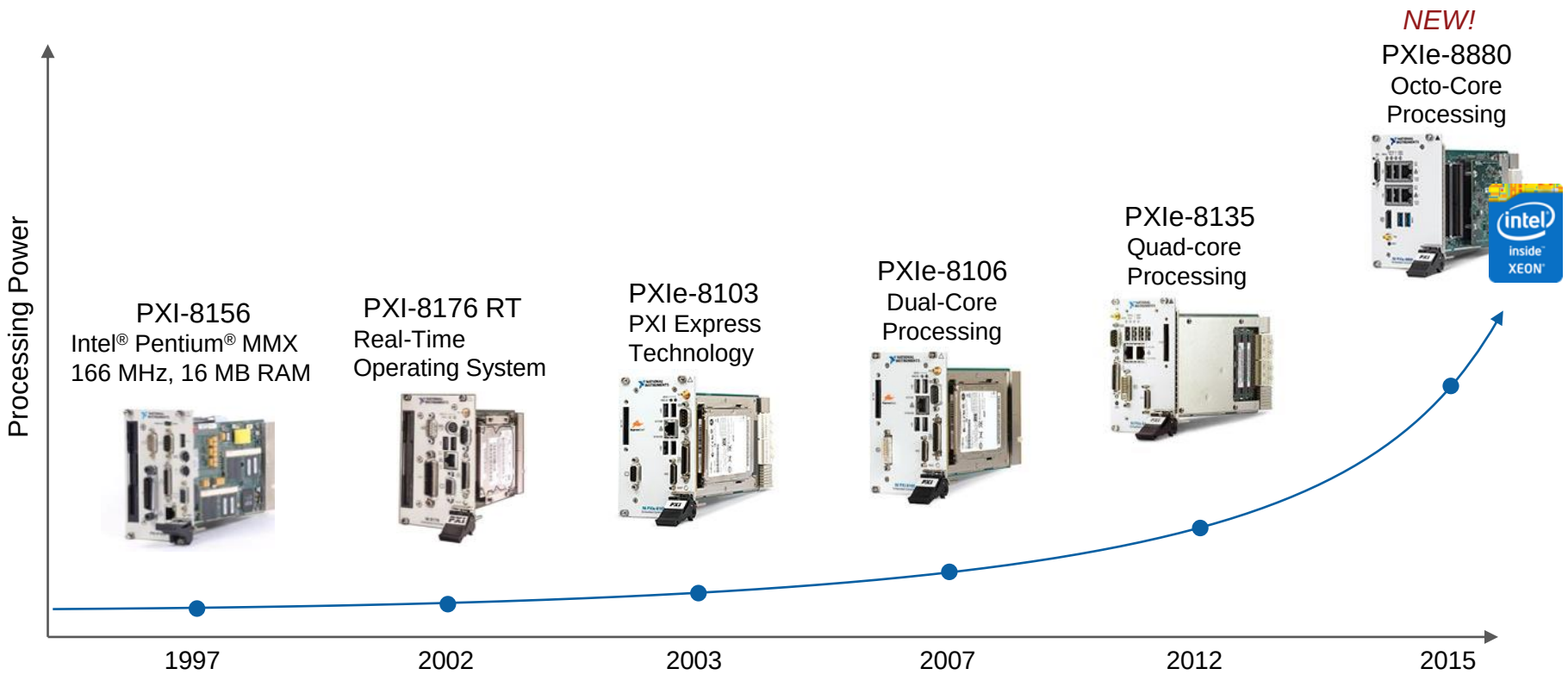
- **High Performance Processing**

- Network Communication

# Processing Landscape for Real-time Computation

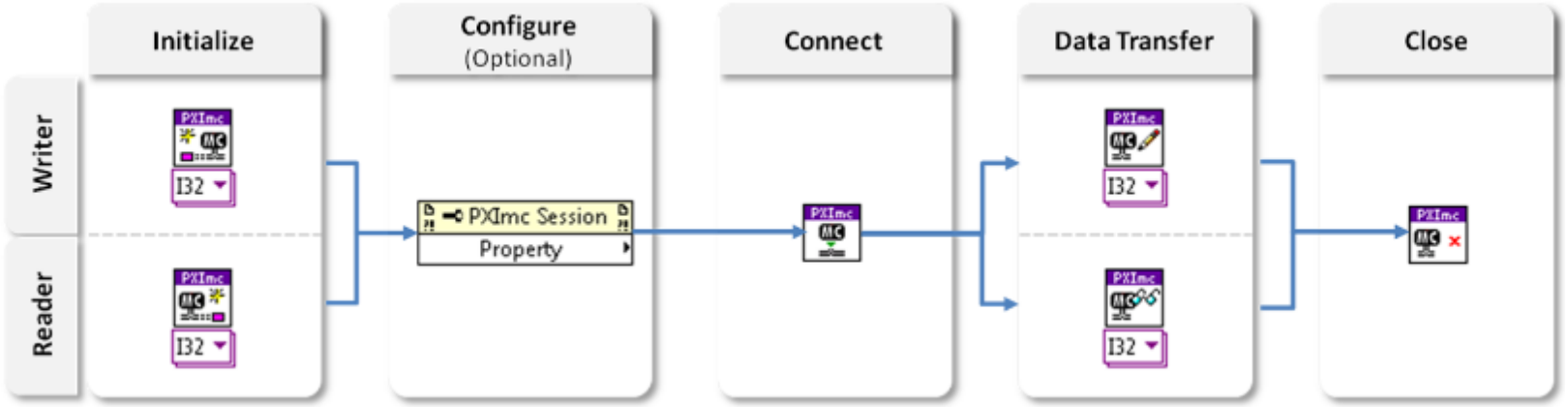


# Industry-Leading NI PXI Controller Portfolio

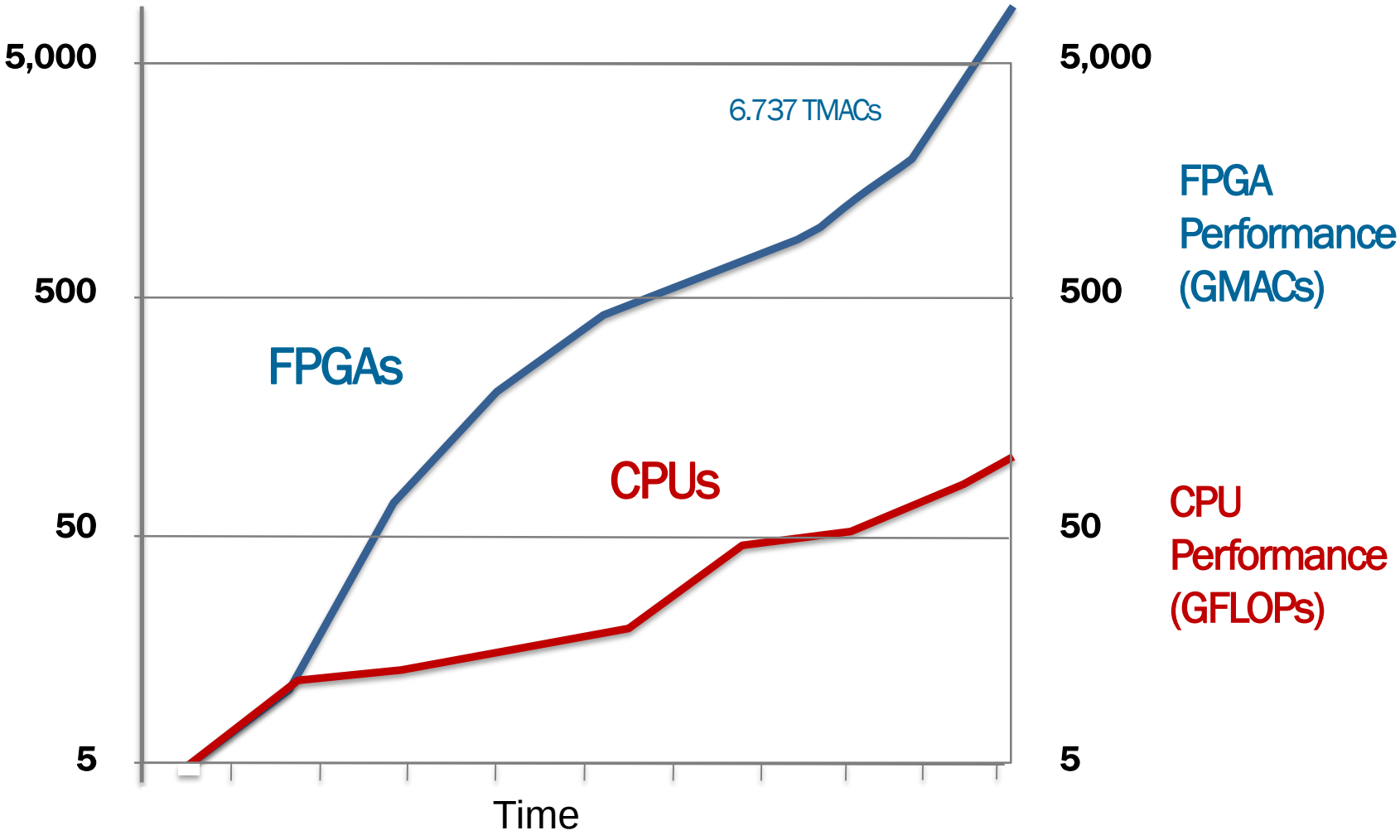


# PXImc: Remote & Embedded Co-processors

- Industry's first PXImc product
- PXIe-8383mc Specifications:
  - x8 PCI Express 2.0 Interface → 2.7GB/s
  - 5us of one-way app-to-app latency
  - 3m Copper Cable & up to 300m FO Cable
- **PXIe-8830mc Specifications**
  - **Intel Quad Core i7 Embedded Co-processor**
  - **Up to 2.7 GB/s of bandwidth**
  - **5us of one-way app-to-app latency**
- High-Level Driver API
- Allow multiple Controller in a chassis like VMEbus



# Parallel Architectures Drive Performance



# Why FPGAs for Instruments?


## High-Throughput Processing

- Inherently parallel
- High clock rate
- Algorithm-specific pipelining

## Low-Latency Decision Making

- Custom logic in a single clock cycle

## Complete Determinism

- Design implemented in a custom circuit

## Re-programmable

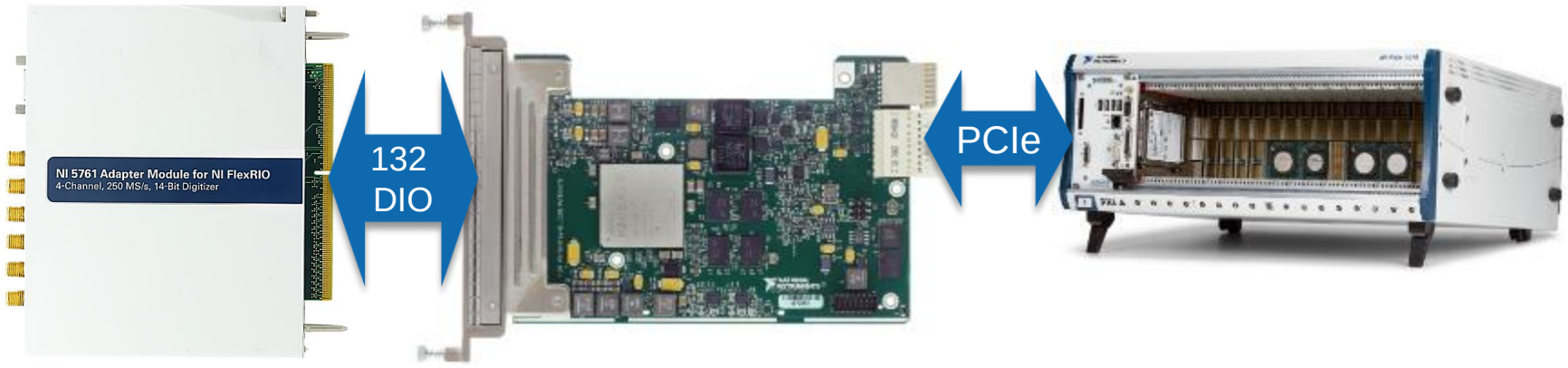
Higher Measurement Throughput

Hardware Re-Use and Future-Proofing

New, Innovative Measurements

***Lower Total Cost of Measurement***

# FlexRIO System Architecture




FlexRIO Adapter Module

- Interchangeable I/O
- Analog or digital
- FlexRIO Adapter Module Development Kit (MDK)

FlexRIO FPGA Module

- Kintex-7 FPGA
- 132 digital I/O lines
- Up to 2 GB of DRAM

PXI Platform

- Synchronization
- Clocking/triggers
- Power/cooling
- Data streaming

# NI's FlexRIO Adapter Module Offerings

## Digital


100 Mbps
SE DIO


300 Mbps
LVDS DIO


300 Mbps
SE/LVDS DIO


1 Gbps
LVDS DIO


Camera Link


RS-485/422

## Digitizers


2 ch. 3 GS/s
8-bit AI


4 ch. 250 MS/s
14-bit AI


2 ch. 1.6 GS/s
12-bit AI


2 ch. 250 MS/s
16-bit AI


4 ch. 120 MS/s
16-bit AI


32 ch.  50 MS/s
12-bit AI


2 ch. 80 MS/s
14-bit AI


2 ch. 120 MS/s
16-bit AI


2 ch. 40 MS/s
12-bit AI


16 ch. 50 MS/s
14-bit AI

## RF


100MHz BW
4.4 GHz RF I/O


200MHz BW
4.4 GHz RF
Tx


200MHz BW
4.4 GHz RF Rx

## Transceivers


2 ch. 100 MS/s
14-bit AI
16-bit AO


2 ch. 250 MS/s
14-bit AI
16-bit AO

## Signal Generators


2 ch. 1.25 GS/s
14-bit AO


1 ch. 2 GS/s
14-bit AO

Plus many more from our partne

# Software-Designed Instruments

PXIe-5668R
26.5 GHz, >765MHz BW
RTBW Vector Signal
Analyzer

PXIe-5646R
6GHz, 200MHz BW
Vector Signal Transceiver

PXIe-5624R
2 GS/s, 12-bit
IF Digitizer

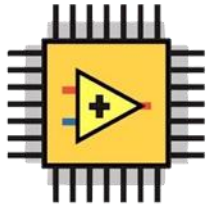
NI PXIe-6591/92R
12.5 Gbps, 4-8 ch.
High Speed Serial

PXIe-5070/71R
250 MS/s, 14-bit, 4-8 ch.
Oscilloscope

PXIe-7976R
3.5GB/s Streaming
K410T K7 FlexRIO

"Fully-functional instrument out-of-the box"

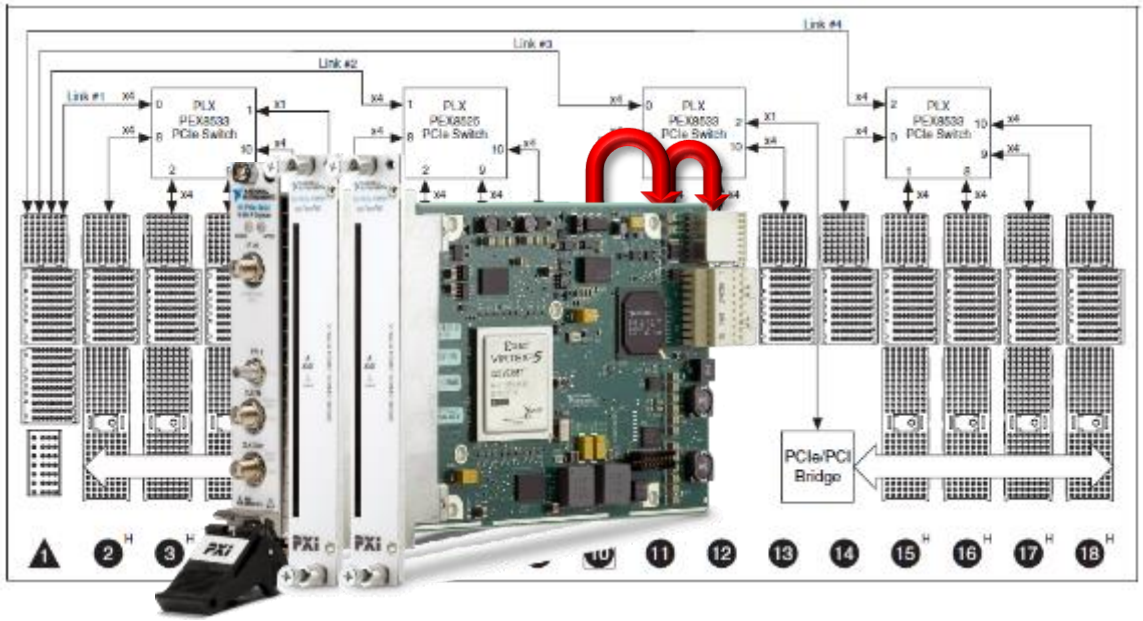
Customize functionality with



LabVIEW FPGA

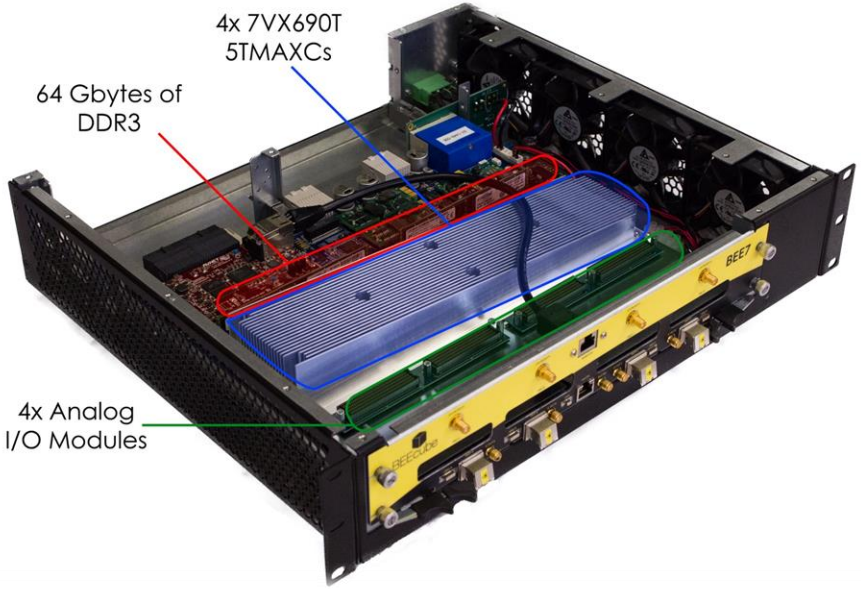
# FlexRIO Peer-to-Peer Architecture

- ~3.2 GB/s one-way
- ~2.4 GB/s both ways
- ~10 us latency
- Up to 16 streams per FPGA




Supported Hardware
Arbitrary Waveform Generators
Scopes/Digitizers
VSA
VSG
VST
FlexRIO FPGA Modules

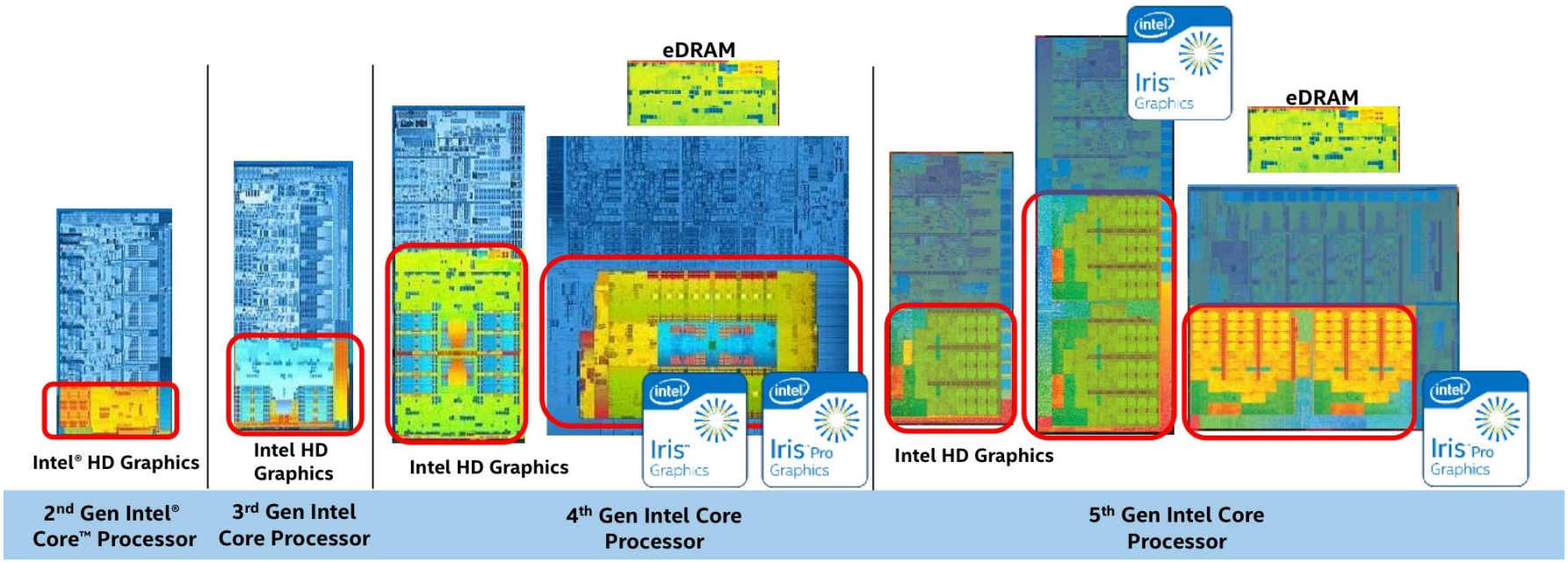
# BEE7 ATCA Blade – "For Big Jobs"




- Aggregate Sensor Data
  - Up to 144x 10Gbps optical links
  - ~100ns latency per connection
- DSP Processing
  - 5TMACs (4x 690T FPGAs)
  - 64GB DDR (1333MHz)
  - Full mesh connect between FPGAs
- 24/7 Reliability
  - ATCA supports redundancy
- Easy to Customize
  - 4x FMC connector per blade
  - 80LVDS per FMC @ ~10ns latency
- Toolflow: VHDL, MATLAB, Vivado

- 6x blades per 13U chassis

# GPU transistor count increasing even faster!

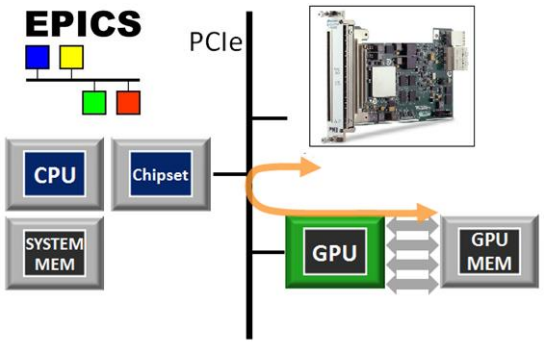



slide from Intel

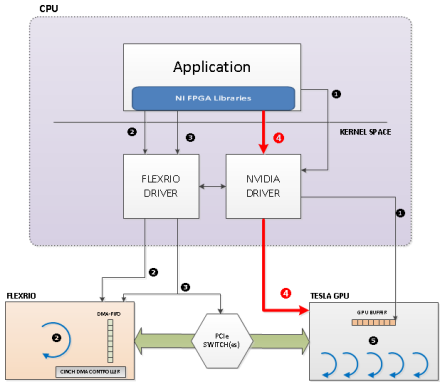
# Interfacing NI Flex RIO with GPUs

Content curtesy: Dr. Mariano Ruiz, UPM, Madrid

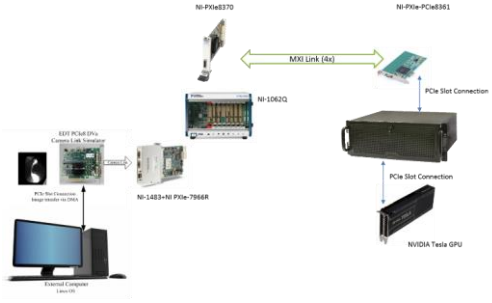
- Peer to peer data communication using the same PCI Express bus to implement continuous real time DAQ & processing with minimum CPU intervention
- Software environment
  - RHEL 64 bit Linux (no MRG extension), NI RIO driver, nvidia SDK (Kepler)
- Hardware
  - NI PXIe, NI FlexRIO, MXI4 link, nvidiaTesla GPU, ITER CPU




System Overview

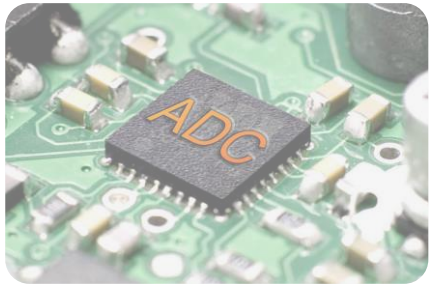



Software Architecture




Hardware

# Technology Trends




- Data Converters

- High Performance Processing

- **Network Communication**

# IEEE 802 Ethernet Standards Activity

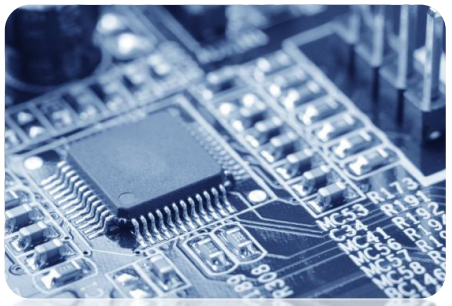
- Efforts driven by 802.x (bridges/switches/cabling) to enable reliable, high performance control applications over standard and shared Ethernet

- Representatives involved from multiple industries


Industrial

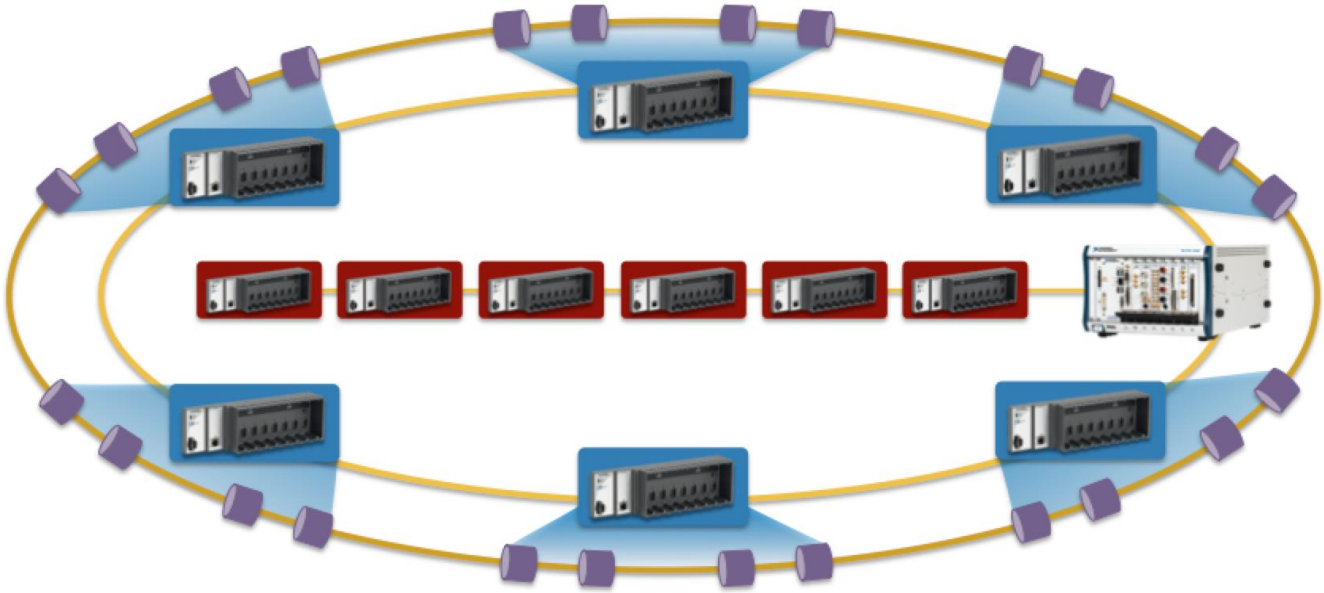

Automotive


Scientific


Semiconductor

# Key Technical Goals of Standards Activity

- Converged network (control, streaming, "normal" traffic)
- <uS synchronization between all nodes
- Low latency (end-to-end latency of  <30uS)
- Network redundancy with 0 fail over time
- Scaling with Ethernet evolution



BPM + Steering Magnets  EtherCAT CompactRIO (AI)  Steering Magnets Power Supplies + CompactRIO (AI AO DIO)

# Standards Efforts

- Standards effort through IEEE 802 to improve latency and performance while maintaining interoperability and openness

- Time Sensitive Networking (TSN) will provide:
  - Time synchronization
  - Bandwidth reservation and path redundancy for reliability
  - Guaranteed bounded latency
  - Low latency (cut-though and preemption)
  - Bandwidth (Gb+)
  - Routable to support complex networks and wireless

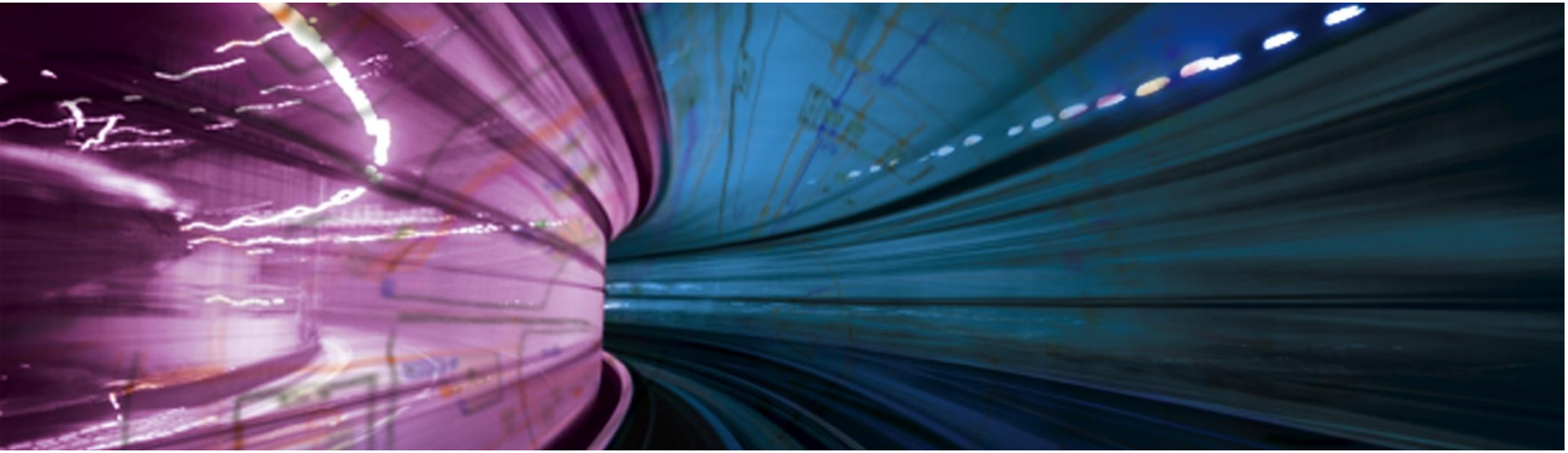
# Background: AVnu Alliance


## Members of the Industrial Working Group

- Silicon and network infrastructure representation from key suppliers
- End device representation primarily from Pro A/V, Automotive (for now)
- Formation of Industrial Group announced Dec 2014

# High-Channel-Count Expansion for RIO

| MXI-Express (915x) | EtherCAT (9144) | Ethernet (9148) |
| --- | --- | --- |
| • Highest Performance<br>• Data streaming<br>• Local control | • Distributed<br>• Synchronized<br>• Single Point | • Flexible<br>• Expansion for existing networks |



# Platform-Based System Development

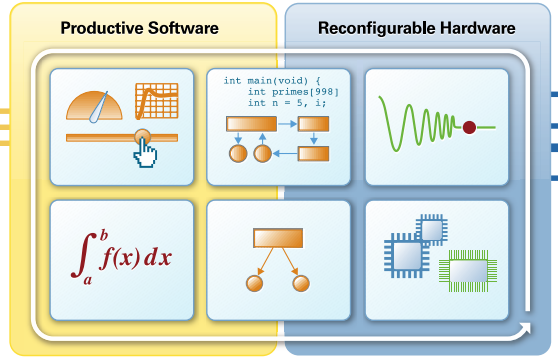
# Platform-Based System Development

## Software

COMMUNITY
140,000+ online members
250+ registered user groups
1000+ job postings online
400K+ children through LEGO

CONNECTIVITY
9000+ instrument drivers
8000+ example programs
1000+ motion drives
1000+ smart sensors
1000+ Third-party PAC devices

COLLABORATION
280+ third-party add-ons
400+ Solution partners
1000+ value added resellers
35+ training courses




## Hardware

PROCESSOR
Intel, Microsoft, Freescale, Wind River
Multi-core and real-time technology

FPGA
Xilinx Virtex & Spartan
Reconfigurable hardware

IP
Control & signal processing IP & I/O drivers
Built-in graphical IP, integrate user IP

I/O
Analog Devices, Texas Instruments
Connect to any sensor & actuator

BUS
PCI/PCIe, Enet, USB, wireless, deterministic Enet, Open architecture

# Graphical System Design

## A platform-based approach to measurement and control

Measurement

Test

Monitor

Embedded

Control

NATIONAL INSTRUMENTS LabVIEW™

Desktops and PC-Based DAQ

PXI and Modular Instruments

CompactRIO and Custom Designs

NI Single-Board RIO

# Graphical System Design

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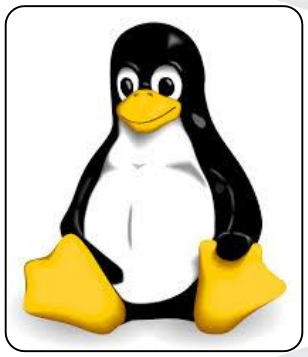


NATIONAL INSTRUMENTS LabVIEW™

Linux Pres.
4:15PM today
Jason Hobbs

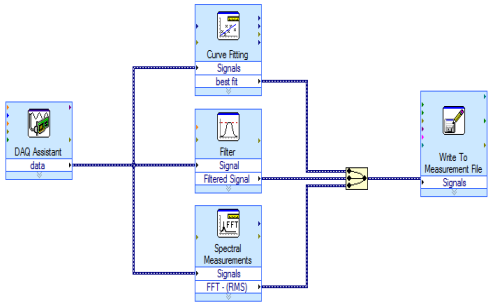
Desktops and PC-Based DAQ

PXI and Modular Instruments

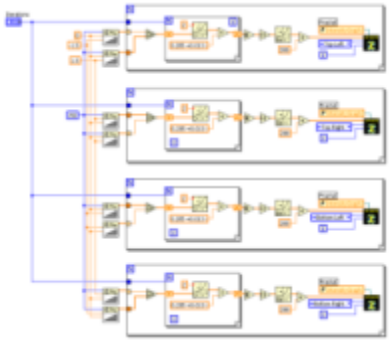
CompactRIO and Custom Designs

NI Single-Board RIO

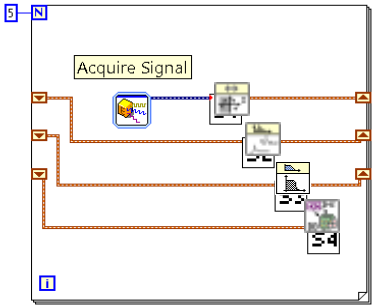
# Common System-Level Design Software




Signal Processing



Parallel Execution




Pipelining


# Characteristics of the Stable PXI Platform

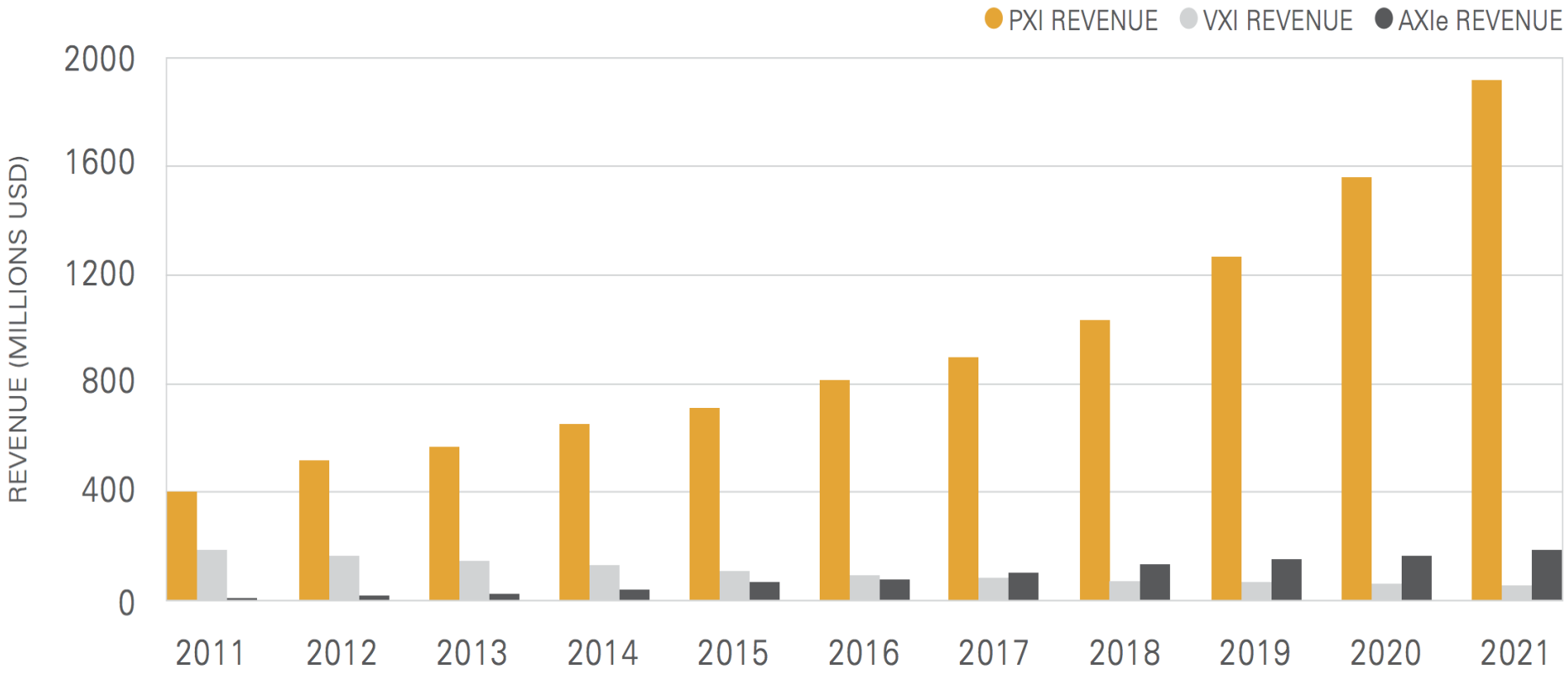
PXI

*Systems Alliance*

- Founded in 1997
- 60+ Vendors
- 2000+ Modules
- Latest Technology
- Growing Market Share

# PXI Revenue Forecast for Test Applications

## INNOVATION AND STABILITY MAKE PXI THE STANDARD PLATFORM FOR AUTOMATED TEST




Source: Frost & Sullivan

# Complete PXI Instrumentation Portfolio

## NI Offers 600+ PXI Products and 2000+ on the market

### DAQ and Control

- Multifunction I/O
- FPGA / Reconfigurable I/O
- Digital I/O
- Analog Input / Output
- Vision and Motion
- Counter / Timer / Clock

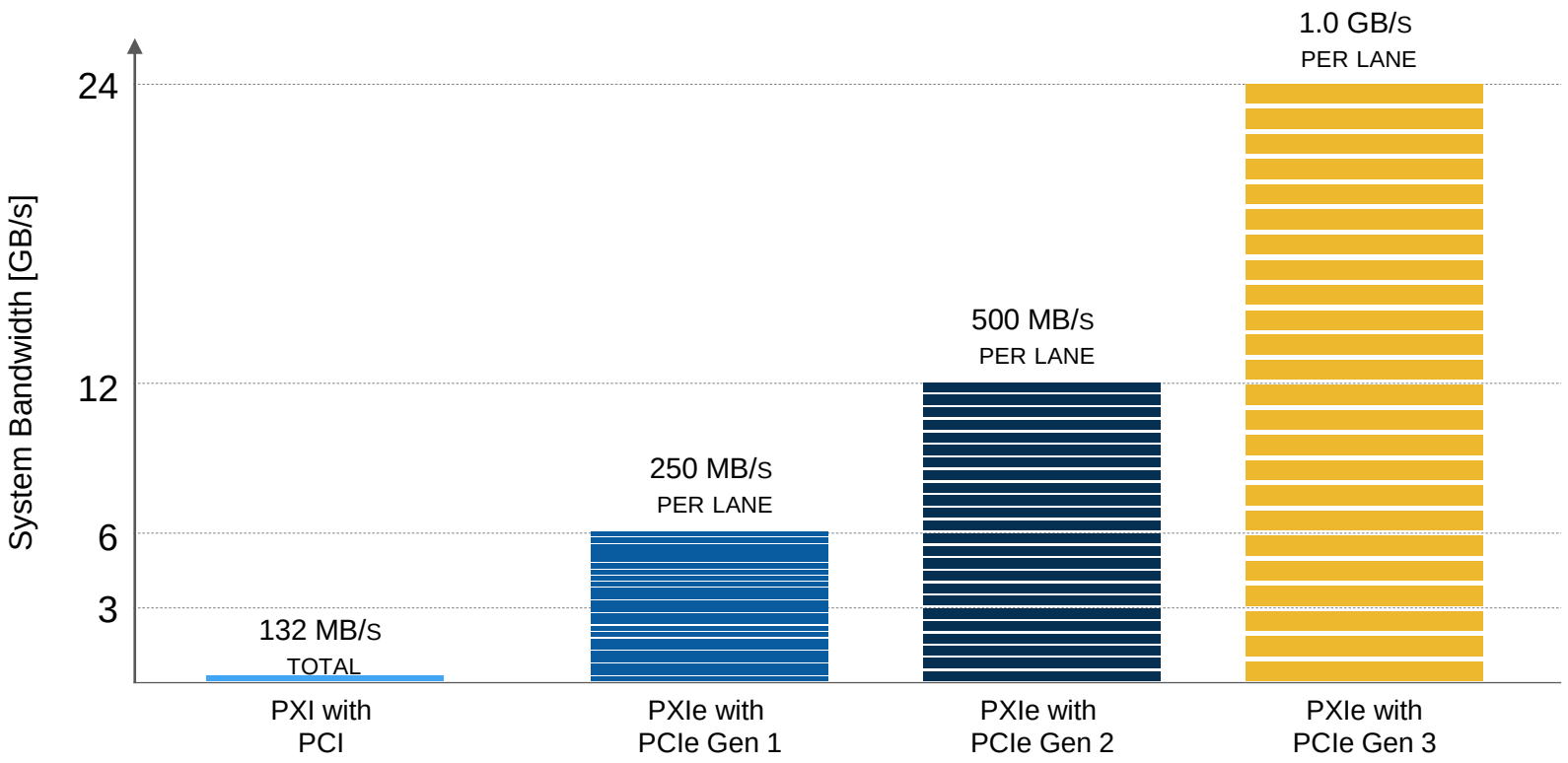
### Instruments

- Oscilloscopes
- High-Speed Digital I/O
- Digital Multimeters
- Signal Generators
- Switching
- RF Analyzers & Generators

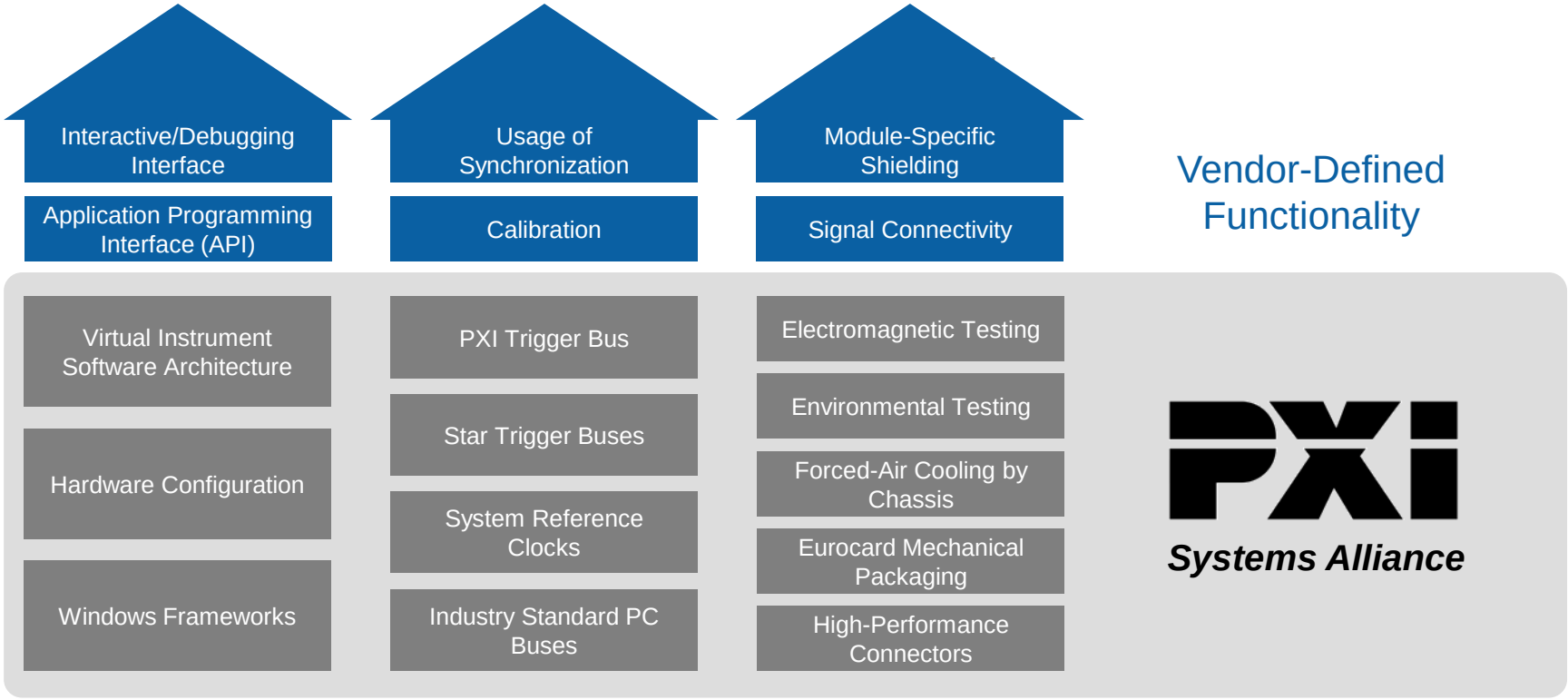
### Interfaces

- GPIB, USB, LAN
- RS232 / RS485
- CAN, LIN, DeviceNet
- SCSI, Ethernet
- VXI - VME
- Boundary Scan / JTAG

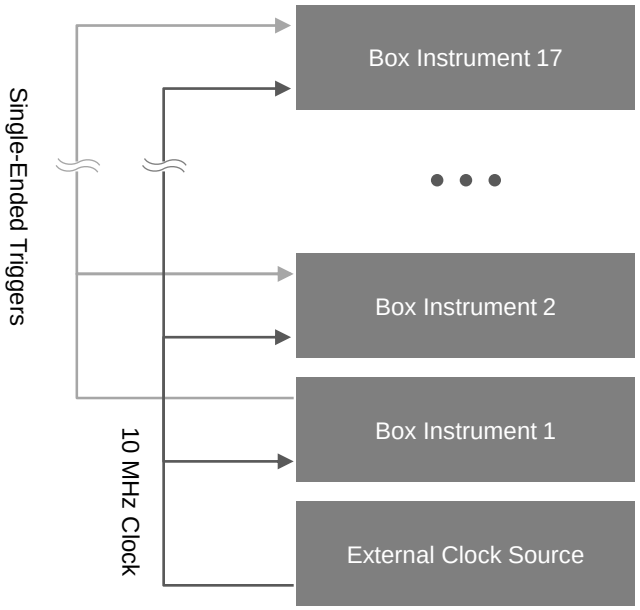
# Continually Increasing System Bandwidth



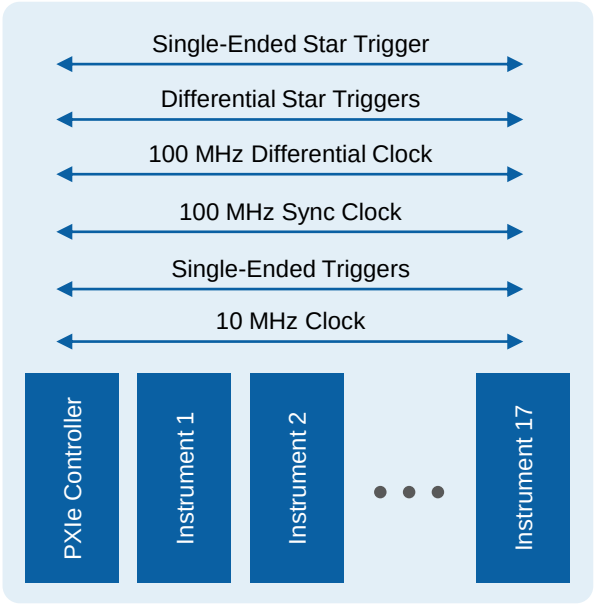
# PXI Balances Standardization and Innovation



# Advanced Timing and Synchronization with PXI

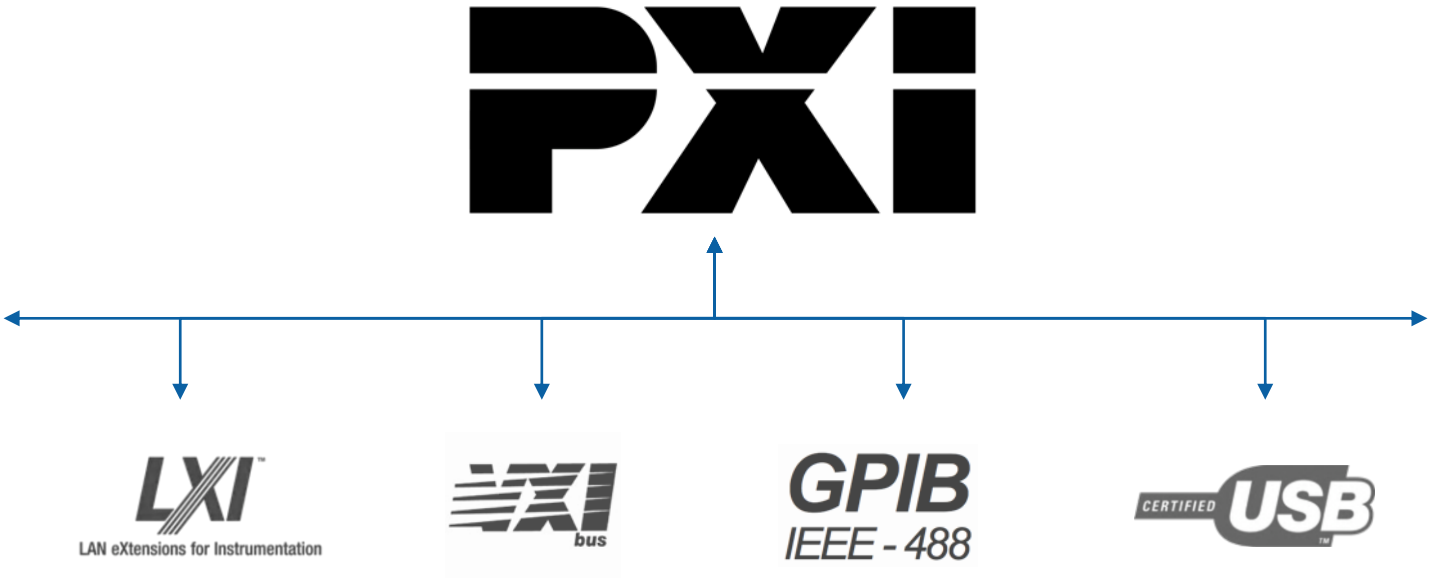



Box Instruments




PXI

# PXI Integrates All Instrumentation Protocols



# Delivering a World-Class Deployment Platform

## Reliability

*A system operates as intended, without failure or down time, and satisfies the desired performance requirements.*

## Availability

*The measure of how often a systems is able to perform its intended function, even in the midst of failures.*

## Serviceability

*Features and aspects of the system design contributing to ease of diagnosis and repair.*

## Manageability

*The extent to which a system can be controlled, supervised and monitored.*

ni.com/RASM

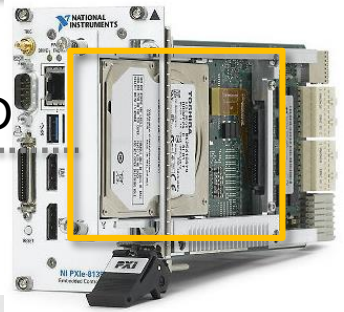
# Maximizing Hardware Availability & Serviceability

PXIe-1066DC Chassis

NI RMC-8355 Rackmount Controller

Removable / Redundant Hard-Drives

PXIe 8135 RHDD



Redundant & Hot-Swappable Fans & Power Supplies

***Downtime Planning***

Spares (managed by you or NI)

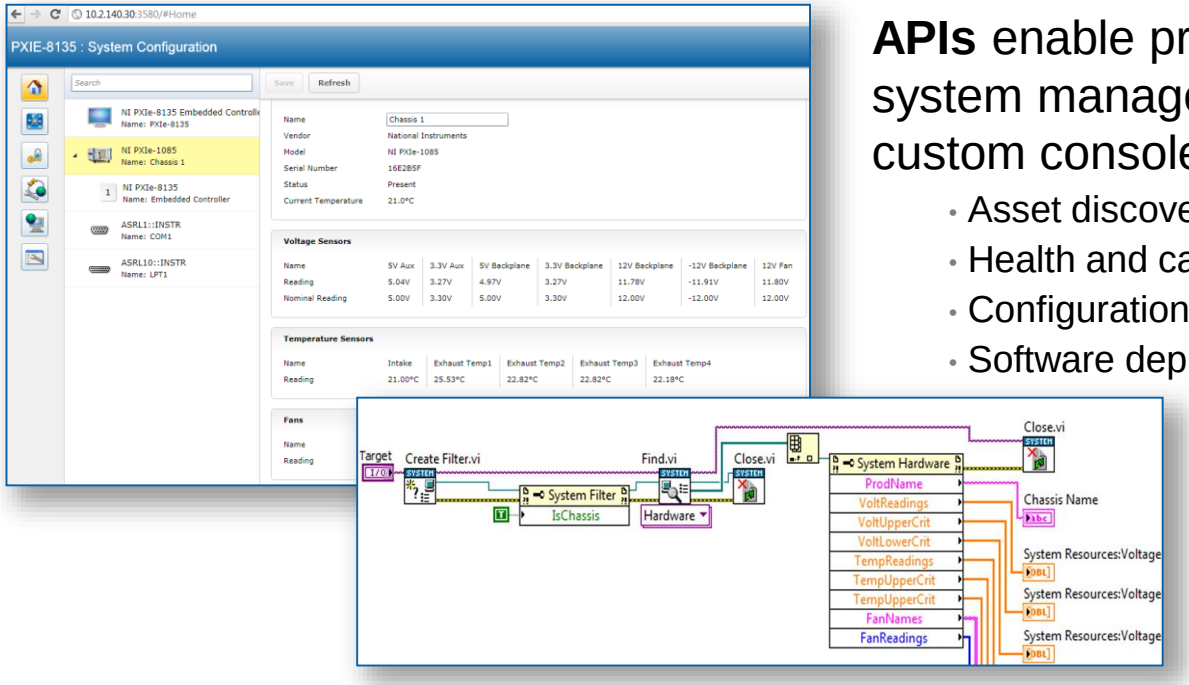
Redundancy

RMA (Expedited & Standard)

minutes | hours | 1 day | >1 week

# Improved Manageability of Deployed Systems

## **Asset** Management, **Data** Management, and **Software** Management




**APIs** enable programmatic access to system management functions for custom consoles and applications

- Asset discovery and identification
- Health and calibration monitoring
- Configuration and control
- Software deployment

Deployment Presentation 3:45PM tomorrow by Jaidev Amrite

**Management Consoles** are software tools for enabling local or remote system management across the system life cycle

# Product EOL Management

- Critical for large scale, long term applications
- Manageability for highly customizable COTS solutions

# Summary

- Physics research applications are extremely demanding for measurement and control systems
- Many unique needs can be met with off-the-shelf technology
- A platform-based approach enables use of standard technology in a way that supports
  - Efficient development of highly-customized solutions
  - Extensive collaboration with commercial vendors
  - Long-term support and evolution of systems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