# Low Cost, High-Density Digital Electronics for Nuclear Physics

Wojtek Skulski

Principal Investigator

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# Outline

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- Customers.
- Products.
- Description of Phase II project.
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  - Example experiment with 1,359 digital DAQ channels.
- Deliverables.
- Schedule.
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- Questions for the NP community.

# The company and its capabilities

We focus on data acquisition (DAQ) for nuclear physics, high energy physics, and particle astrophysics.

Our instruments use digital techniques to acquire and process signals from nuclear radiation detectors.

Our capabilities:

- Electronic design “top to bottom”: from the requirements, through schematic capture and board layout, all the way to prototyping, production, and support.
- Firmware development for Field Programmable Gate Arrays (FPGA).
- Software development for embedded processors, with special focus on Embedded Linux.
- Algorithms for pulse processing.
- Algorithm implementation in the FPGA (VHDL, Verilog) and in embedded processors (python, C).
- Development of nuclear radiation detector readout using vacuum or silicon photomultipliers.

# Our customers

University of Rochester

Houghton College

SFU Simon Fraser University — Engaging the World

The University of Tennessee Knoxville

Los Alamos National Laboratory

Fermilab

Wiener Plein & Baus, Corp. — Worldwide Industrial-electronic Nuclear-electronic Ressources

Albert Einstein Center for Fundamental Physics — Universität Bern

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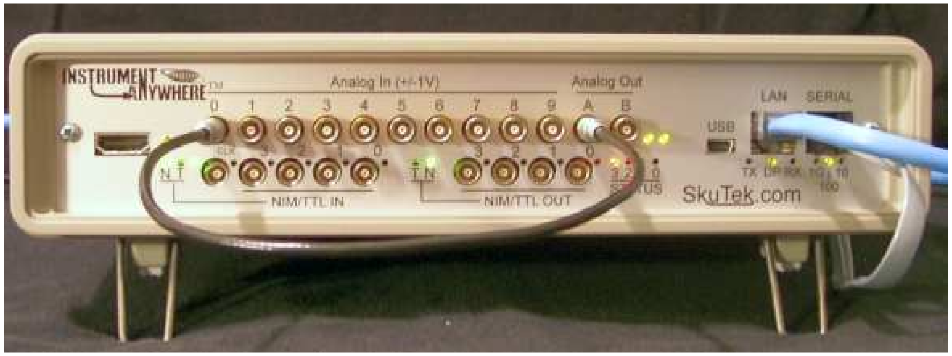
# Products: VME modules and table top DAQ units

Standalone networked digitizer (10 channels)




Low cost networked digitizer (2 channels)


VME digitizer

VME trigger module

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# Description of Phase II project

Problem or situation that is being addressed.

In Nuclear Physics there is need for cost effective, high density data acquisition (DAQ) systems with hundreds or even thousands of channels capable of signal monitoring and analysis.

How this problem or situation is being addressed.

We are developing digital DAQ modules with dozens of channels of waveform digitization, on-board FPGA, Ethernet, USB-2, and VME interfaces, and running Linux on-board.

The deliverables.

- The products will be extremely scalable, from a single-channel table-top units, all the way to systems with thousands of channels.
- The table top units will serve small NP experiments, radiation detector development, or student labs teaching Nuclear Physics.
- Larger systems will serve experiments conducted at DOE facilities, e.g., Facility for Rare Isotope Beams (FRIB), which is a new national user facility for Nuclear Physics.

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# Example detector served by our DAQ electronics

SkuTek collaboration with UofR Physics and Astronomy

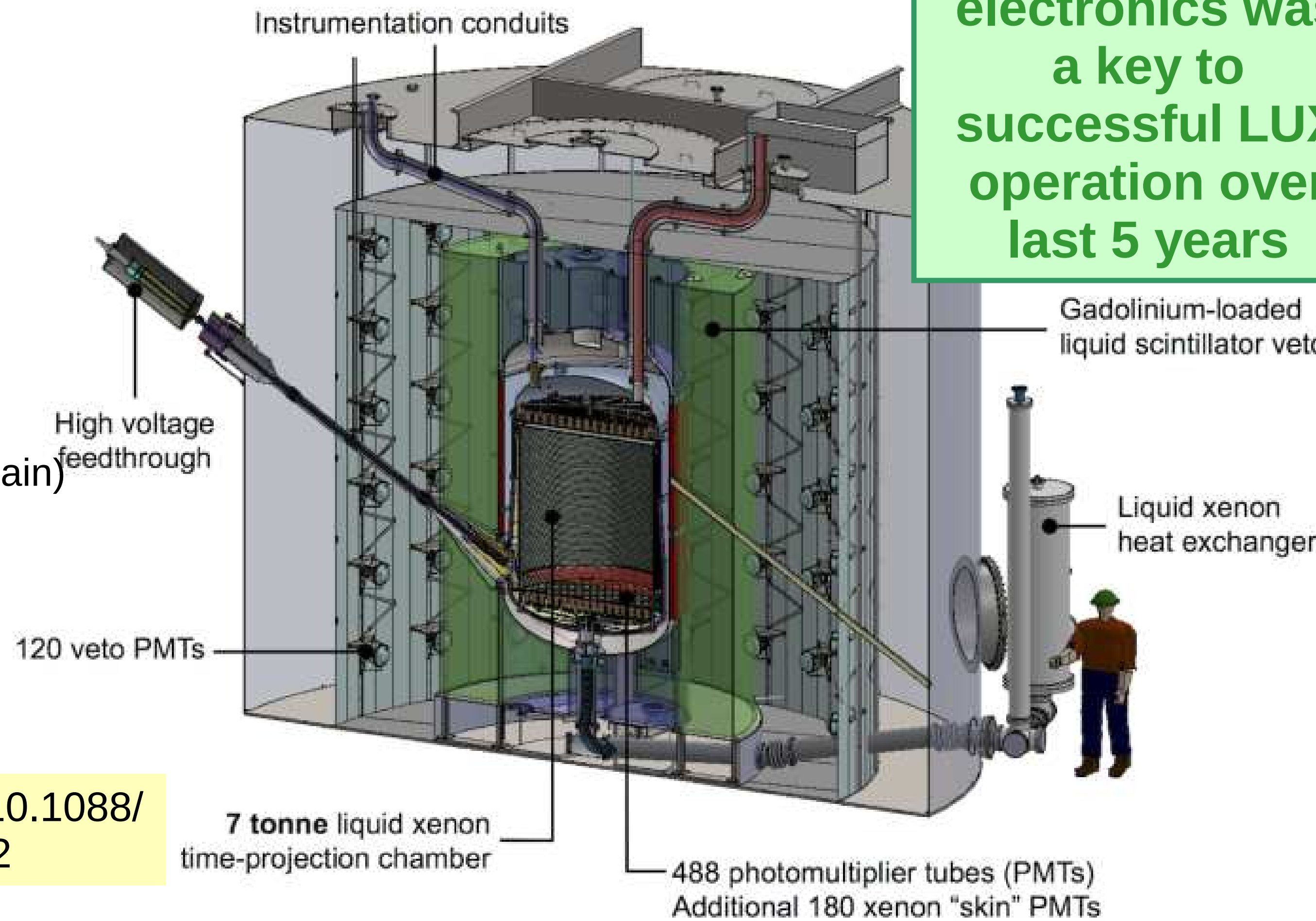
UNIVERSITY of ROCHESTER

LUX-Zepplin is the "ultimate Dark Matter Search Detector" under development by 32 institutions. We are building the digital DAQ for LZ with **1,359** channels.

**SkuTek Digital Trigger electronics was a key to successful LUX operation over last 5 years**

- Amount of Xenon:
  - 5.6 tons fiducial
  - 7 tons in the vessel
  - 10 tons total.
  - Drift time in Xenon: 700 $\mu$s.
- Number of PMTs:
  - 494 main volume (dual gain)
  - 131 "skin"
  - 120 outer detector veto (dual gain)
  - Total **745** PMTs.
- Electronic channels:

  2*494 + 131 + 2*120 = **1,359**.



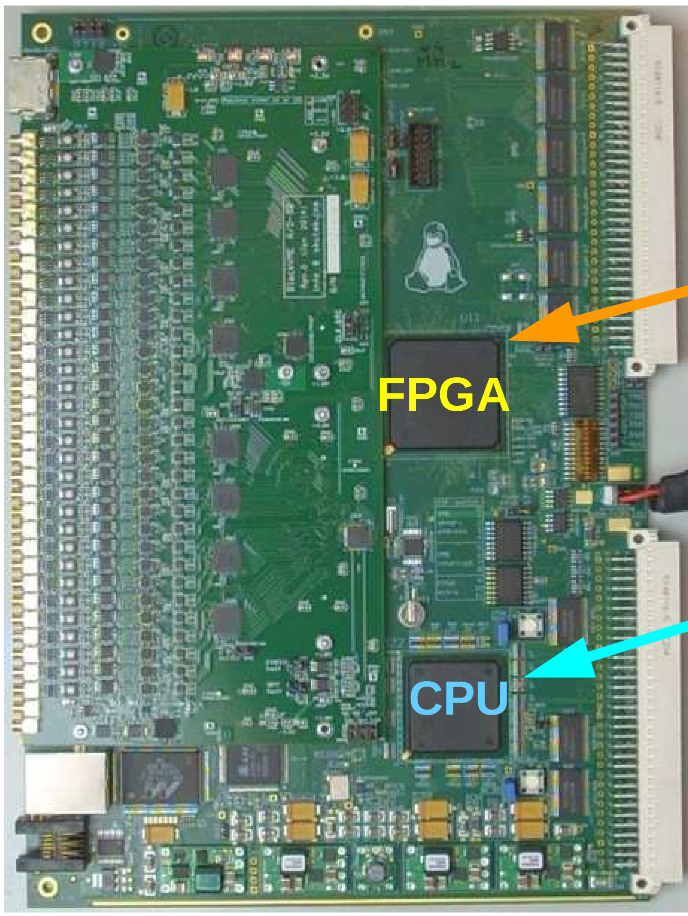

http://iopscience.iop.org/article/10.1088/1748-0221/11/02/C02072

# Electronics for the Data Acquisition System

A modern digital DAQ is composed of digitizers and the Trigger / Logic modules. The current SkuTek designs employ Blackfin processors and Spartan-6 FPGAs. We are upgrading the electronics with **ARM processors** and **Kintex-7 FPGAs** in order to improve the performance.

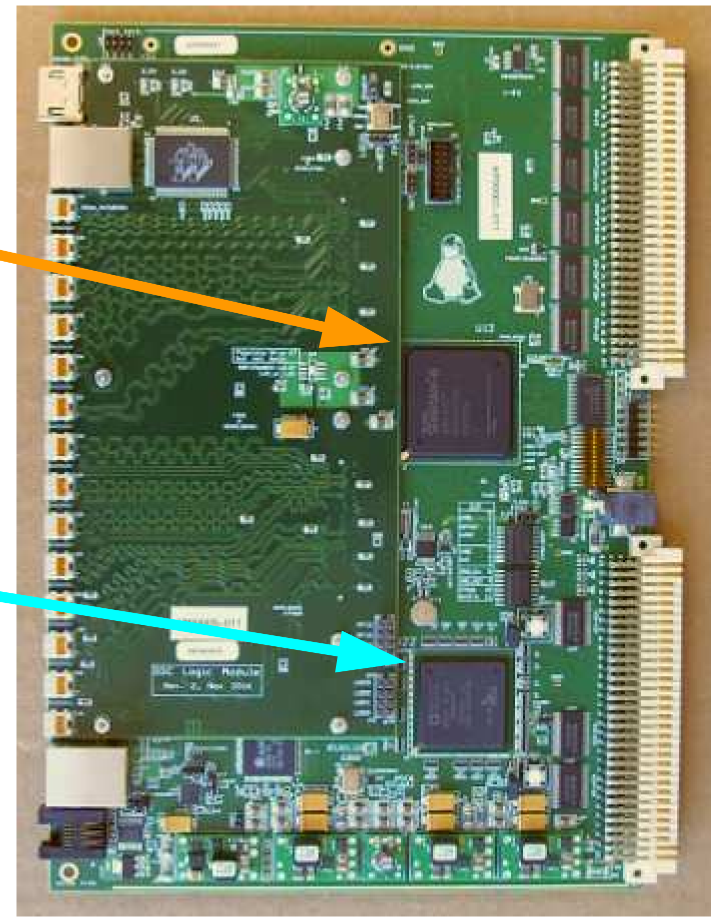
High density digitizer: **32 channels**

Trigger / Logic module: **14 inputs**




FPGA upgrade
Spartan-6 to Kintex-7

CPU upgrade
Blackfin to ARM



# Kintex-7 will improve the performance of our products

Kintex-7: more logic, more memory

- Spartan-6 was the best tradeoff between price and performance circa five years ago.
- The new Series-7 FPGAs now offers more digital resources at a reasonable cost.

| Feature | XC3S5000 Spartan-3 a) | XC6SLX150 Spartan-6 b) | XC7K325T Kintex-7 c) | XC7K410T Kintex-7 c) | Relative to XC3S5000 |
|---|---|---|---|---|---|
| Equivalent logic cells from Data Sheet | 74,880 | 147,443 | 326,080 | 406,720 | 2.0 / 4.4 / **5.4** |
| Multiply-accumulate units | 104 d) | 180 | 840 | 1540 | 1.7 / 8.1 / **14.8** |
| Waveform memory (k samples) e) | 104 k | 268 k | 890 k | 1,590 k | 2.6 / 8.6 / **15.3** |
| Balls per package | 900 | 900 | 900 | 900 | same |
| I/O pins | 633 | 576 | 500 | 500 | 0.9 / 0.8 / 0.8 |
| Price lowest speed grade (900 balls) | $166 | $210 | $1,032 | $1,496 | 1.3 / 6.2 / 9.0 |
| Price “our” speed grade (900 balls) | $191 | $210 | $1,550 | $1,796 | 1.1 / 8.1 / 9.4 |
| $$ per channel for 32+ channels f) | $5 | $5 | $40 | $45 | |

a) XC3S5000 is used in present GRETINA digitizers. It is the community’s performance yardstick.

b) XC6SLX150 is used in our present 10-channel and 32-channel digitizers.

c) These pin compatible Kintex-7 chips will be used in our forthcoming high density digitizers (40 channels).

d) XC3S5000 provides multipliers without the built-in accumulate register.

e) Total number of block RAM bits divided by 18. Parity bits are considered not useful for waveform storage.

f) Approximate FPGA cost per channel for 32+ channels.

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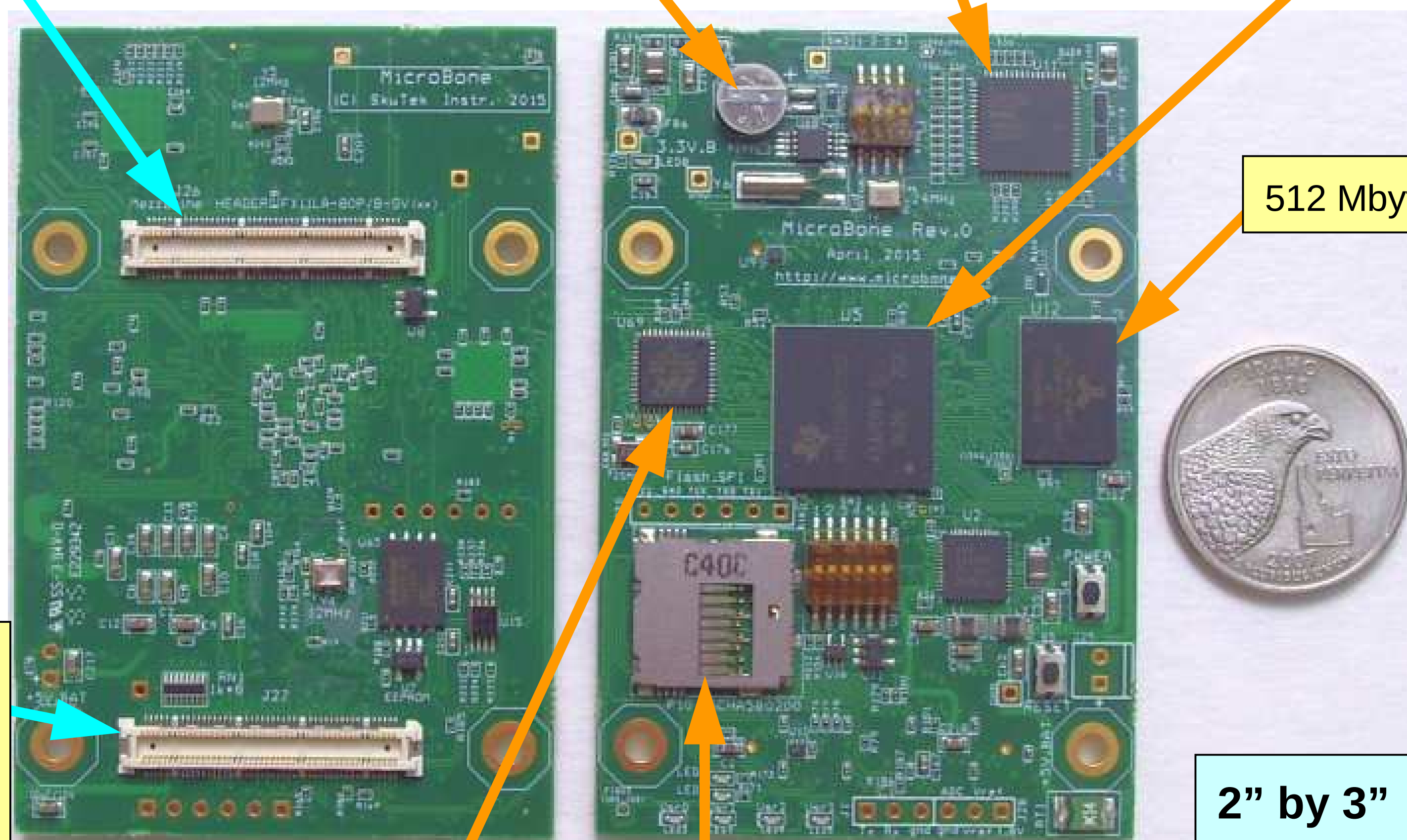
# ARM will save board space and enable more channels

In order to upgrade our electronics, we developed the ARM Linux System on Module (SOM) with a low-power, high-performance 1 GHz ARM processor.

We will use it in our forthcoming electronics. The SOM module itself will also be offered to the community.



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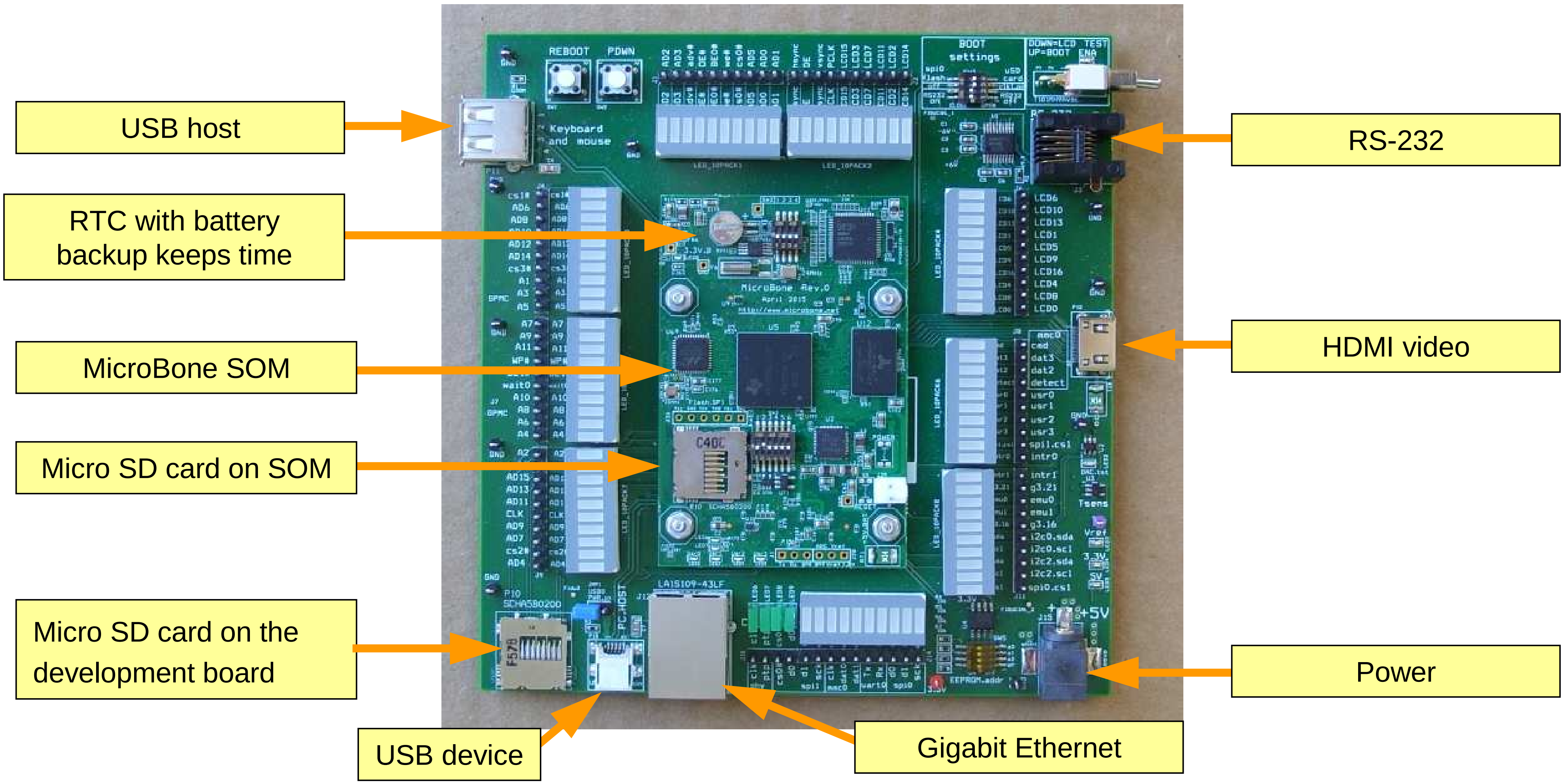
# **SOM** Development Board

- The SOM is hosted by a development board.
- The entire Linux is contained on the MicroSD card. The entire Linux can be upgraded **in 10 seconds**.
- The RTC with battery keeps track of the wall clock. (No need to call NTP…)
- Eight analog pins can be individually configured as 12-bit ADC, 12-bit DAC, or  5V-tolerant logic I/Os.



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# Possible use for the embedded ARM: The Fog

The Industrial Internet of Things transforms isolated programmable devices into intelligent networks of connected machines. The cloud is a component in these systems, but it is hardly primary. The intelligent software that drives these systems must also reside in the field at the "edge." There is no time, bandwidth or reason to send the data from these devices to a data center. Instead, the compute must come to the devices.

**This design is called "fog computing."**

Dr. Stan Schneider, CEO, RTI

- Do we have the bandwidth to **always** send **all** the data from the digitizers to a data center?
- Do we have the reason for always doing so?
- Can we rather use computing power inside the DAQ modules?
- Can we find worthy tasks for embedded processing?
  - In-situ histogramming?
  - Waveform preprocessing?
  - Pulse deconvolution?
  - Local trigger calculations?
  - Signal quality monitoring?

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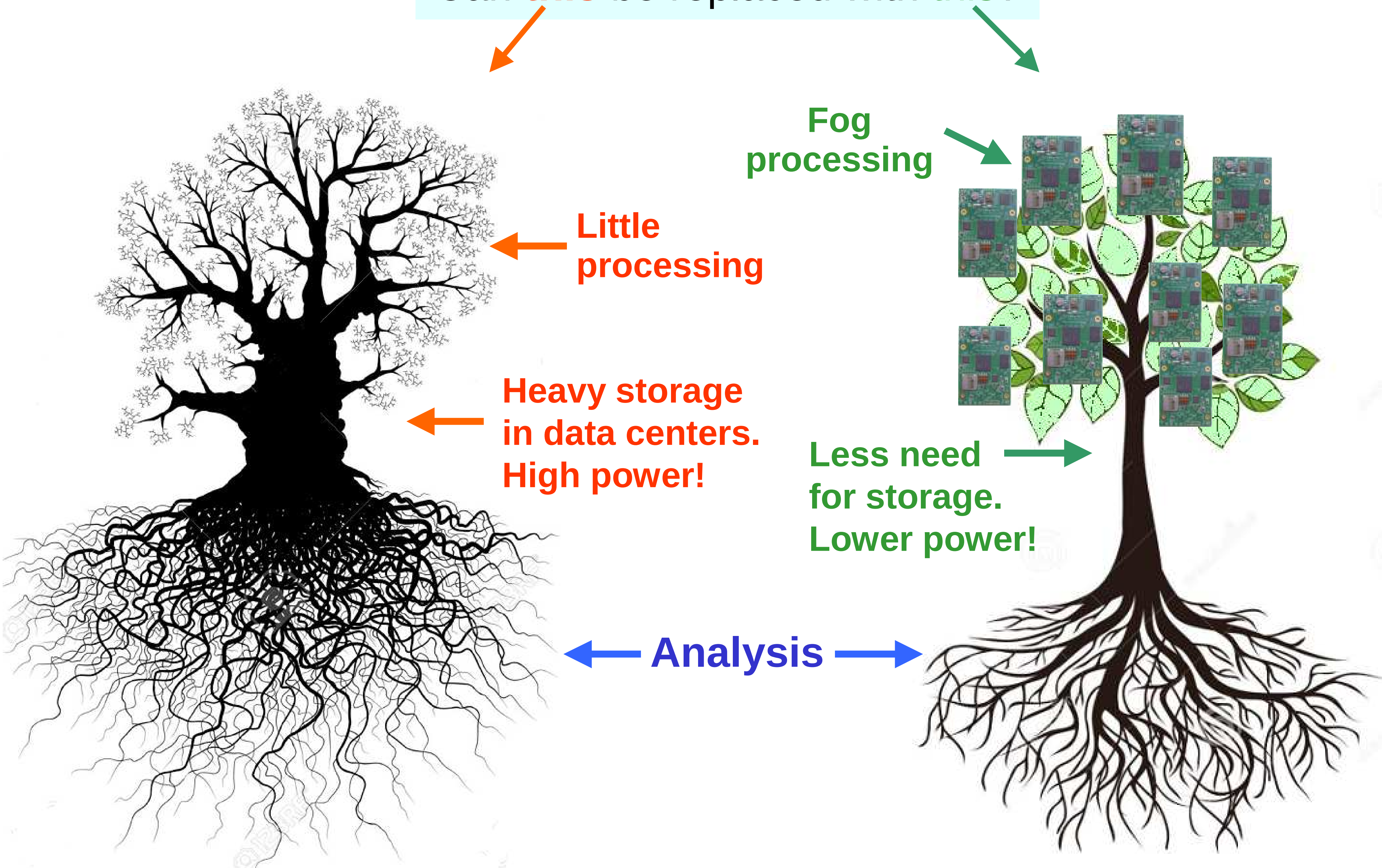
# Can Fog Computing reduce the need for storage?

Can **this** be replaced with this?



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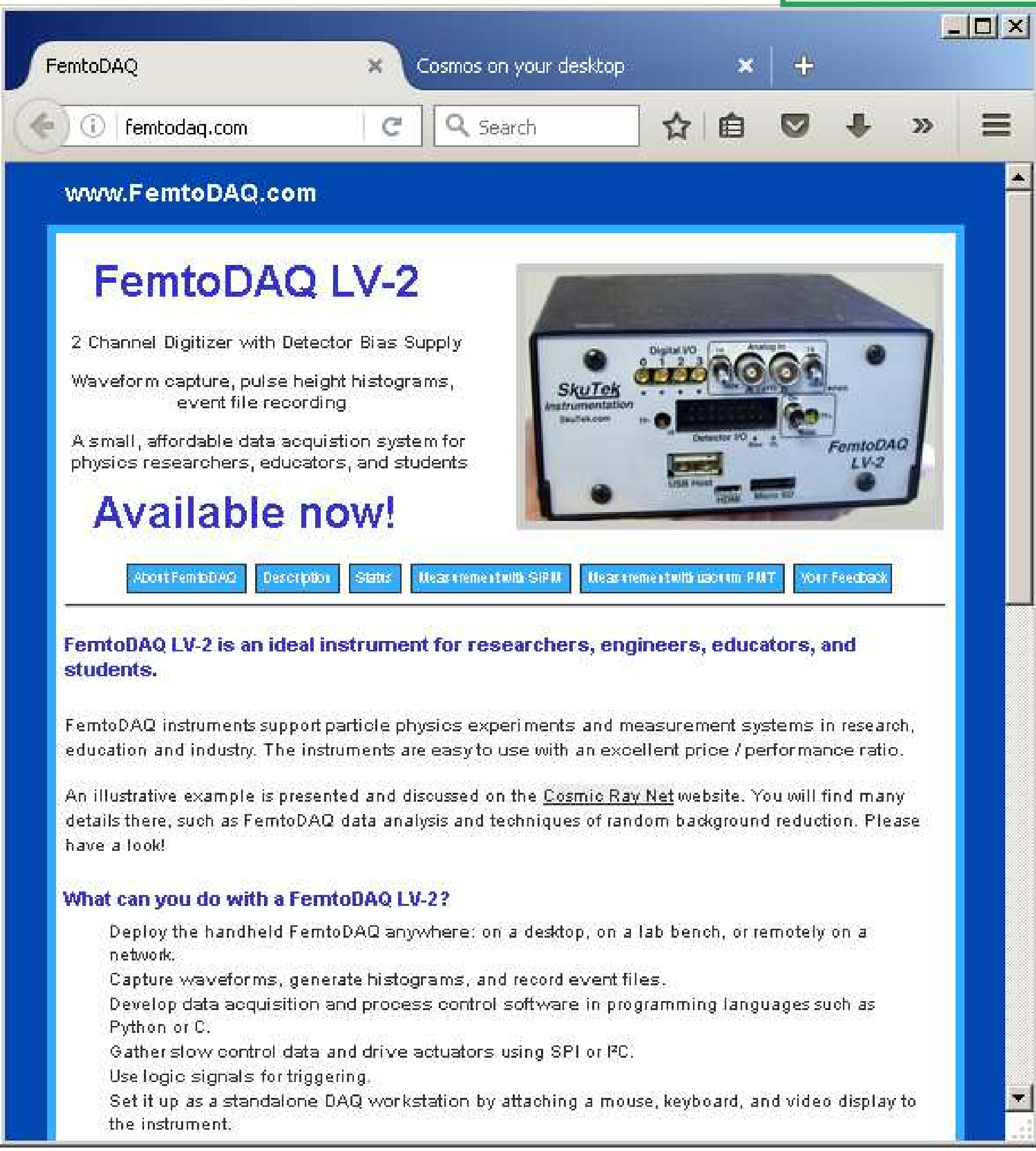
# Low cost, entry-level **Fog** FemtoDAQ with ARM

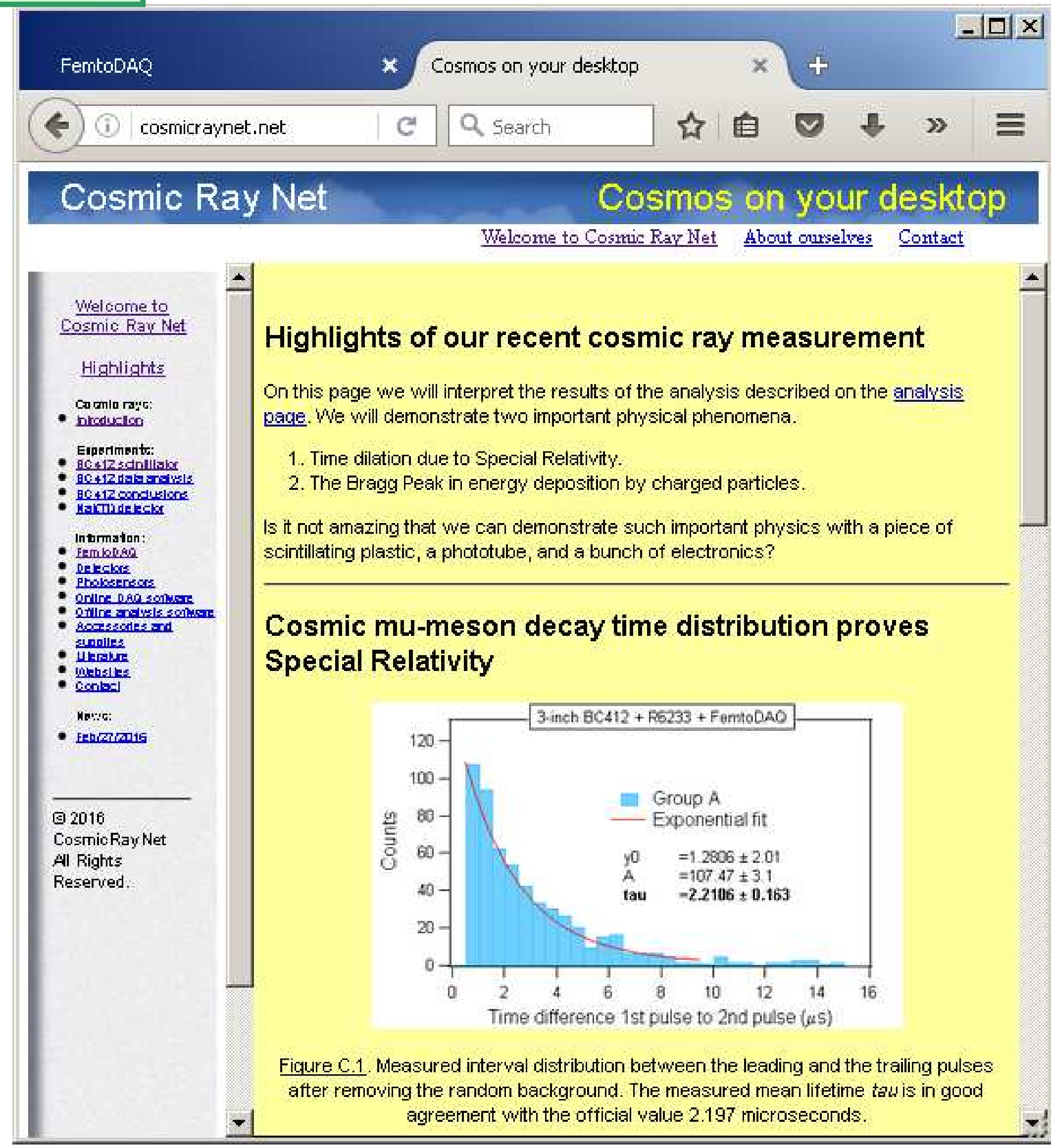
Dual channel FemtoDAQ with Silicon Photomultiplier control: an entry-level, low cost, easy to use DAQ.

Instrument: **FemtoDAQ.com**

**Fog development?**

Example application: **CosmicRayNet.net**



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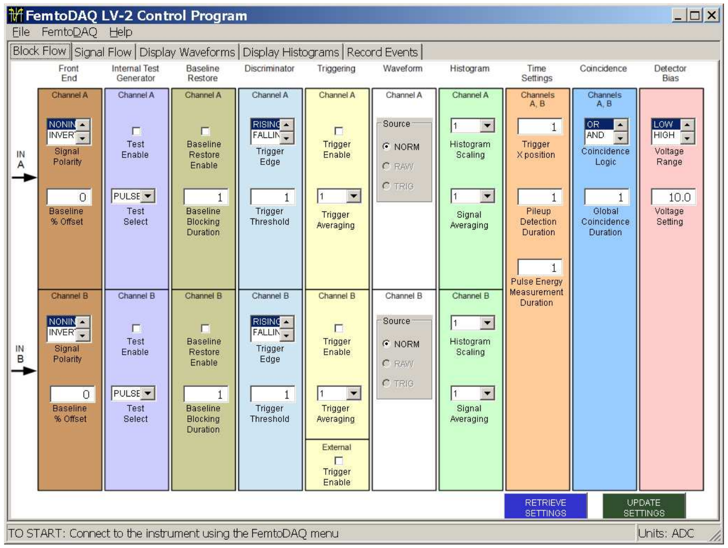
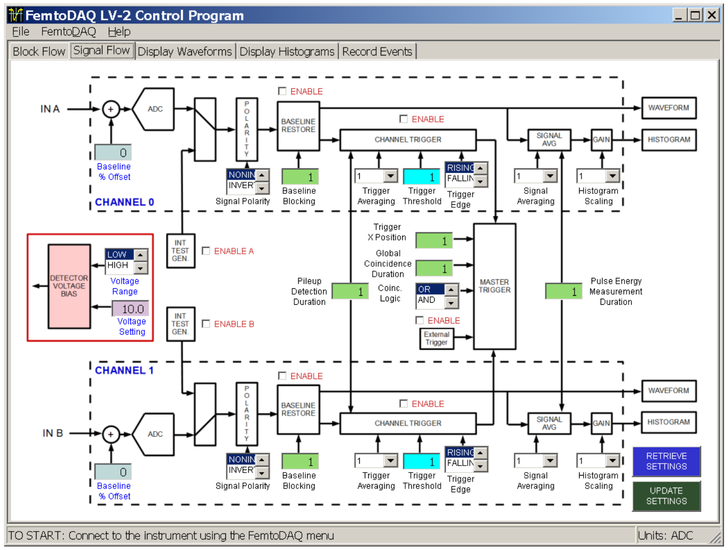
# FemtoDAQ: Easy to use GUI for everyone

Dual channel FemtoDAQ is easy to operate for first-time users.

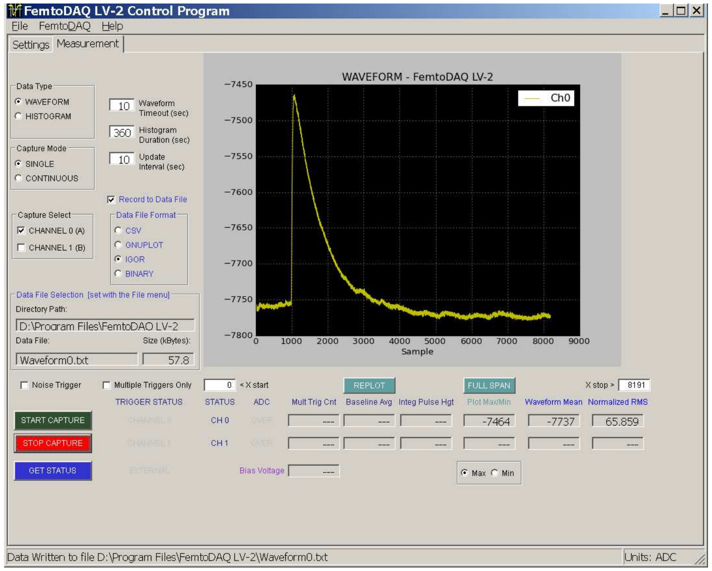
## Traditional setup screen



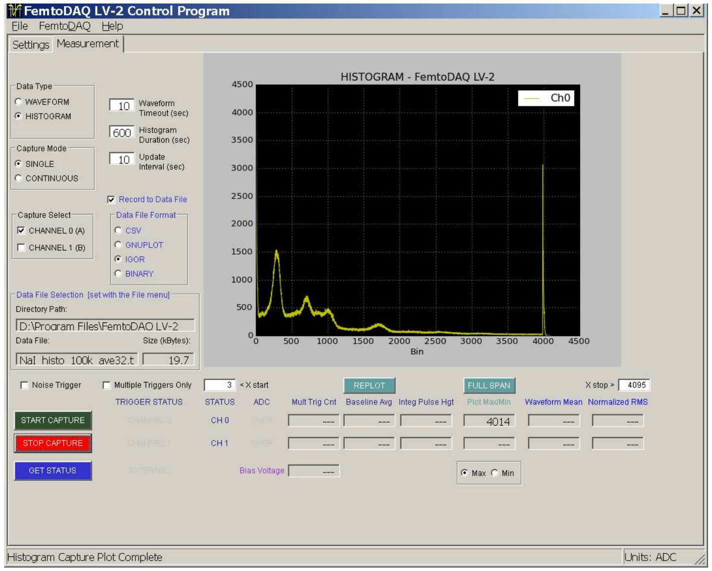

## Data flow setup screen




## Waveform display




## Histogram display



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# Schedule


- Standalone table top DAQ units with ARM running Debian Linux.
  - **FemtoDAQ**: **2** channels, 14 bits @ 100 MSPS, Spartan-6: **AVAILABLE NOW**.
    - We are working with our customers on improving its features.

  - **DDC-10 100 MHz**: **10** channels, 14 bits @ 100 MSPS, Spartan-6: **SENT TO PRODUCTION**.
  - **DDC-10 250 MHz**: **10** channels, 14 bits @ 250 MSPS, Spartan-6: next in line.

- VME DAQ modules with Kintex and optional ARM running Debian Linux: **under development**.
  - **High density 100 MHz**: **32+** channels, 14 bits @ 100 MSPS, Kintex-7.
  - **Logic Unit** for triggering and data streaming, Kintex-7.

- ARM SOM will be offered to customers.
  - ARM SOM can be embedded in third party instruments.
  - Can be used for standalone control applications (it has the 12-bit ADC/DAC).

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# Future plans

"Prediction is very difficult, especially if it's about the future."  -- Niels Bohr

We plan the following:

- Complete the high density digitizer with 32+ channels per unit.
- Complete the 250 MHz versions of our low density modules (2 and 10 channels).
- Develop the ARM SOM into a full featured product of its own.
    - Establish and nurture the SOM user community.
- Keep improving the features of our instruments according to the feedback from customers.
- Add more kinds of modules to our product line.
- Our plans depend on the reception of our work by the community.

# Questions for the NP community

- What difficulties do you have with your current DAQ systems?
- What features should a DAQ system provide to best support your experiments?

**Acknowledgements**:

David Hunter, Joanna Klima, Gregory Kick, William Noonan

Eryk Druszkiewicz, Dev Khaitan, Jun Yin, Frank Wolfs

# Backup slides

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# Improved CPU performance in numbers

- ARM has superior performance thanks to integration of many peripherals on chip.
- ARM will provide 4x more RAM with 3x higher nominal performance.
- NEON vector floating point unit and the Mobile GPU which can be used for event processing.
- Programmable Real Time Units (PRU) can be used for software trigger with deterministic latency.
- ARM will run mainstream Linux (Debian, Ubuntu, etc.) with up to date security features.

| Feature | BF561 (present) | ARM AM335x (new products) | Improvement? |
|---|---|---|---|
| # cores | two | three (1 ARM + 2 PRU) | yes |
| Speed | 2*600 MHz | 1 GHz + 2*200 MHz | ~same |
| Off-chip RAM memory | 128 MB | 512 MB | 4x more |
| Type of RAM memory | SDRAM | DDR3 | |
| Memory bus | 133 MHz * 32 bits | 400 MHz * 16 bits * 2 (DDR) | 3x more |
| Separate SDRAM / SRAM buses | no | yes | yes |
| Floating point | no | yes | yes |
| USB-2 on chip | no | yes | yes |
| Gigabit MAC on chip | no | yes | yes |
| Graphics unit on chip (GPU) | no | yes | yes |
| Resident GUI | no | yes | yes |
| Linux version running on-board | uClinux | full Linux (Debian, Ubuntu, …) | yes |
| Linux community projects | few | many | yes |