# LArIAT Firmware Trigger Upgrades

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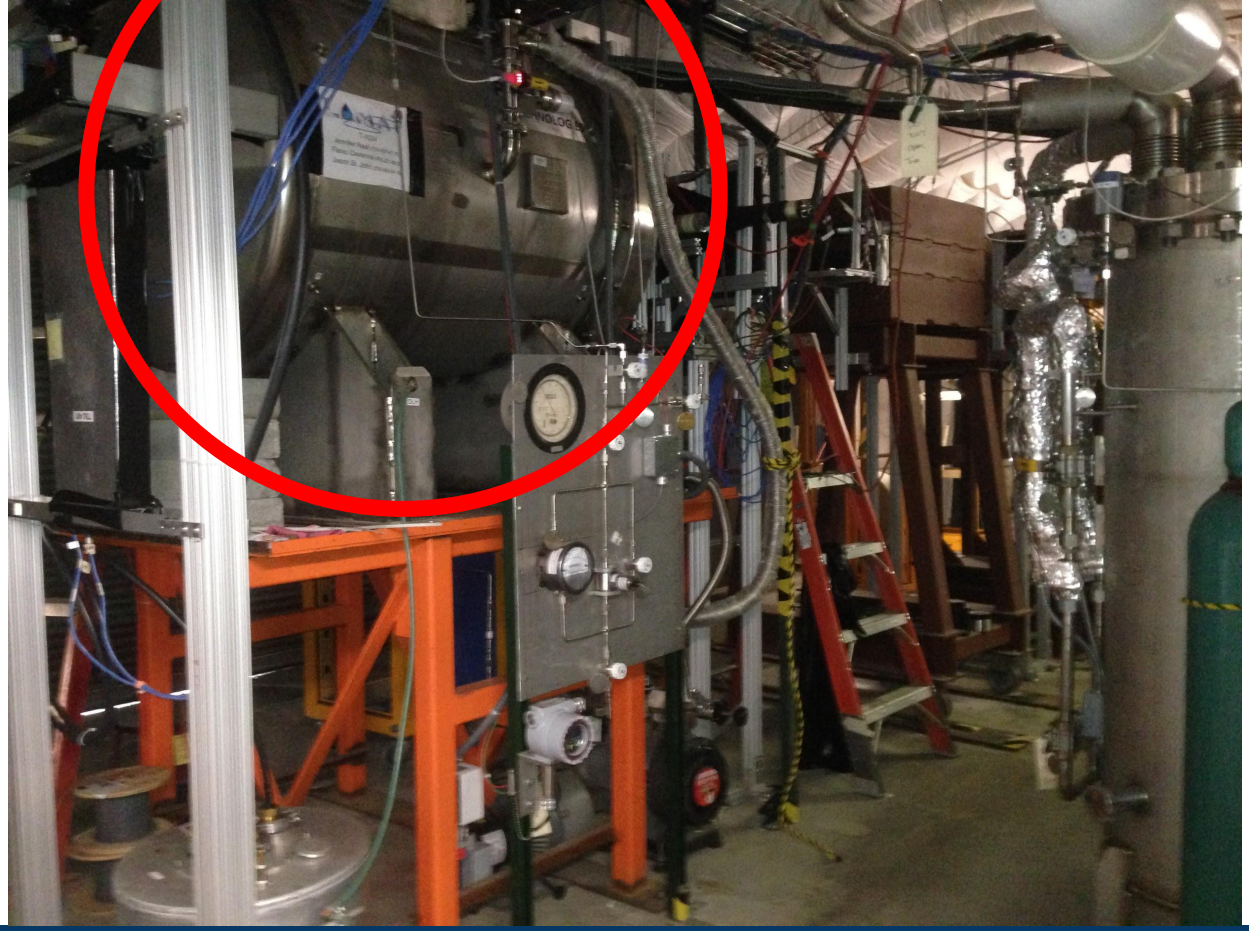
**Mentor: Will Flanagan**

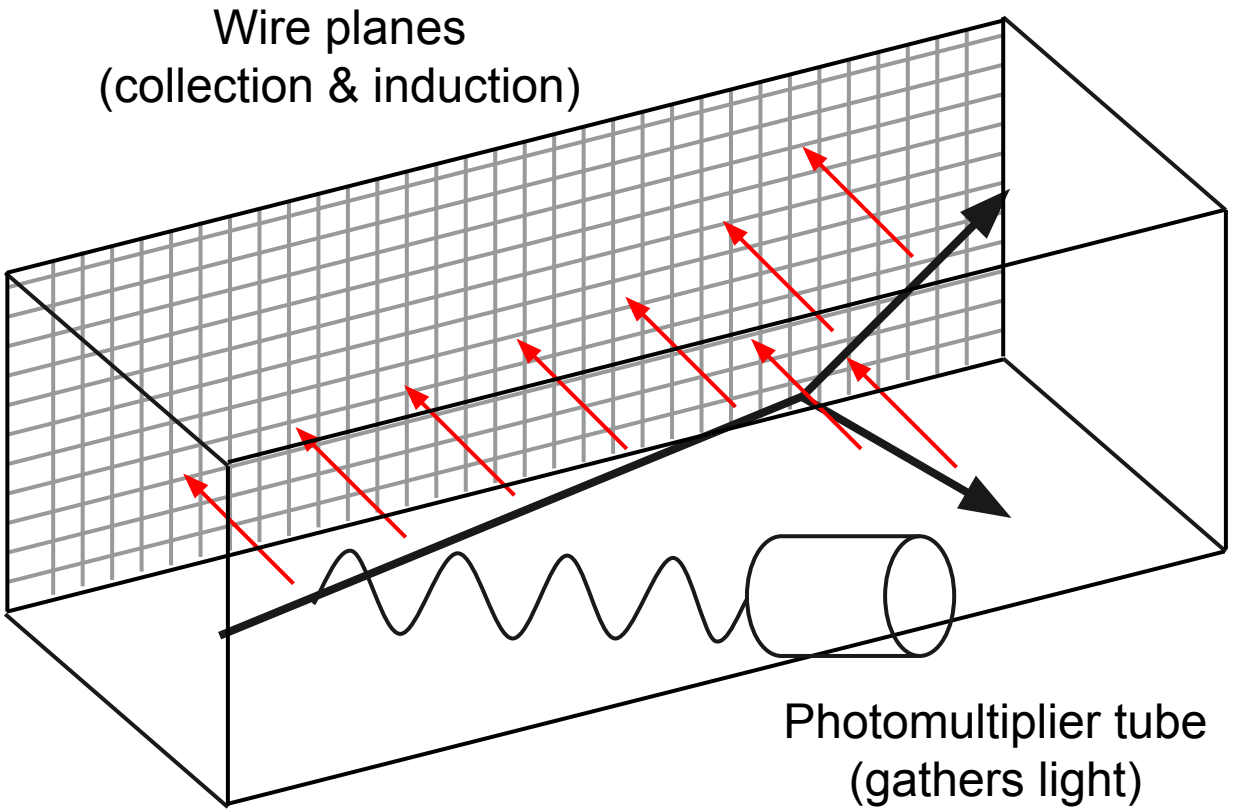

(Liquid Argon In A Test-beam)

- Calibrate liquid argon time projection chambers
  - i.e. observe particles' behavior in new detector tech to prepare for bigger neutrino experiments

## What is LArIAT?

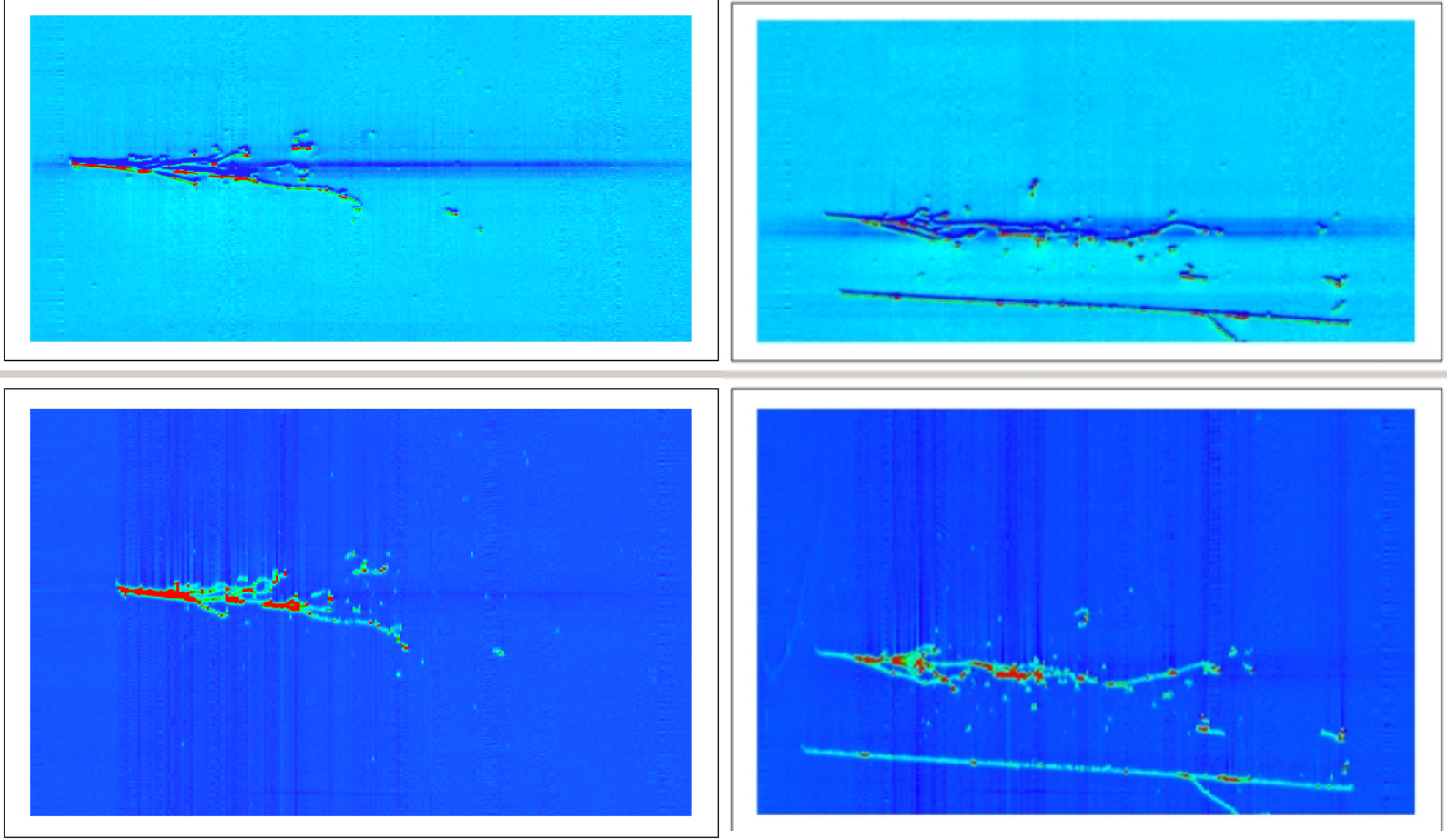


# The LArTPC (liquid argon time projection chamber)

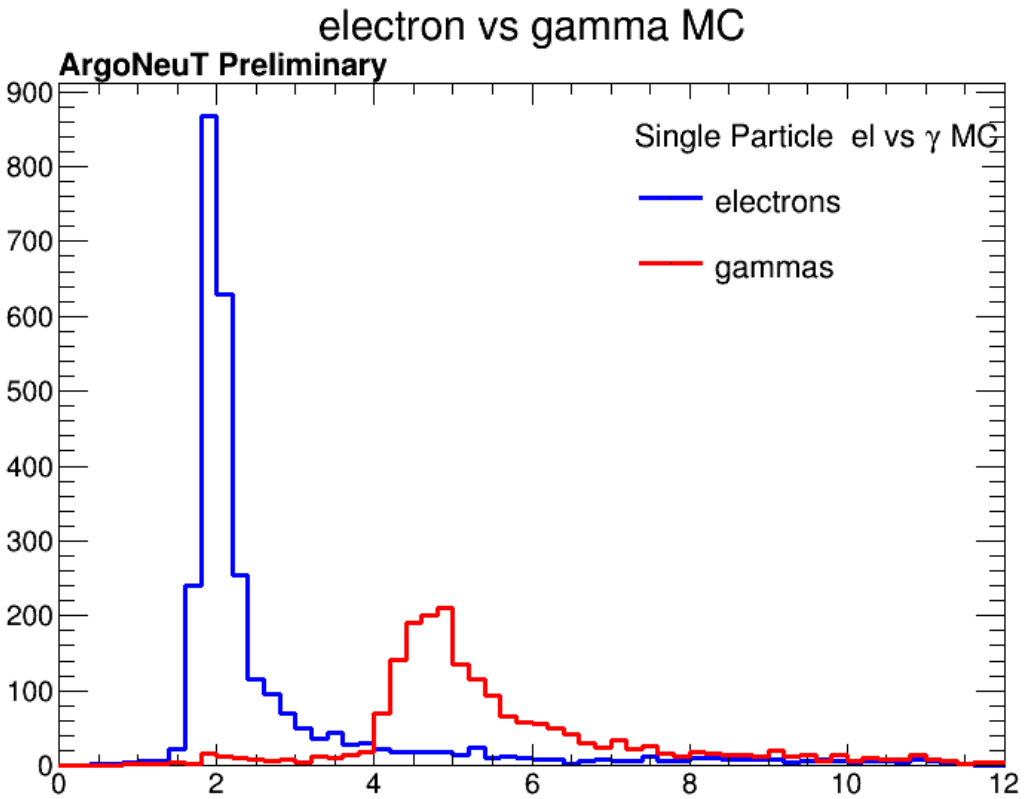



- Charged particle ionizes argon
- Free electrons drift in electric field (constant velocity)
- Y, Z found from position on wire planes
- X calculated from drift time

# LArTPC schematic

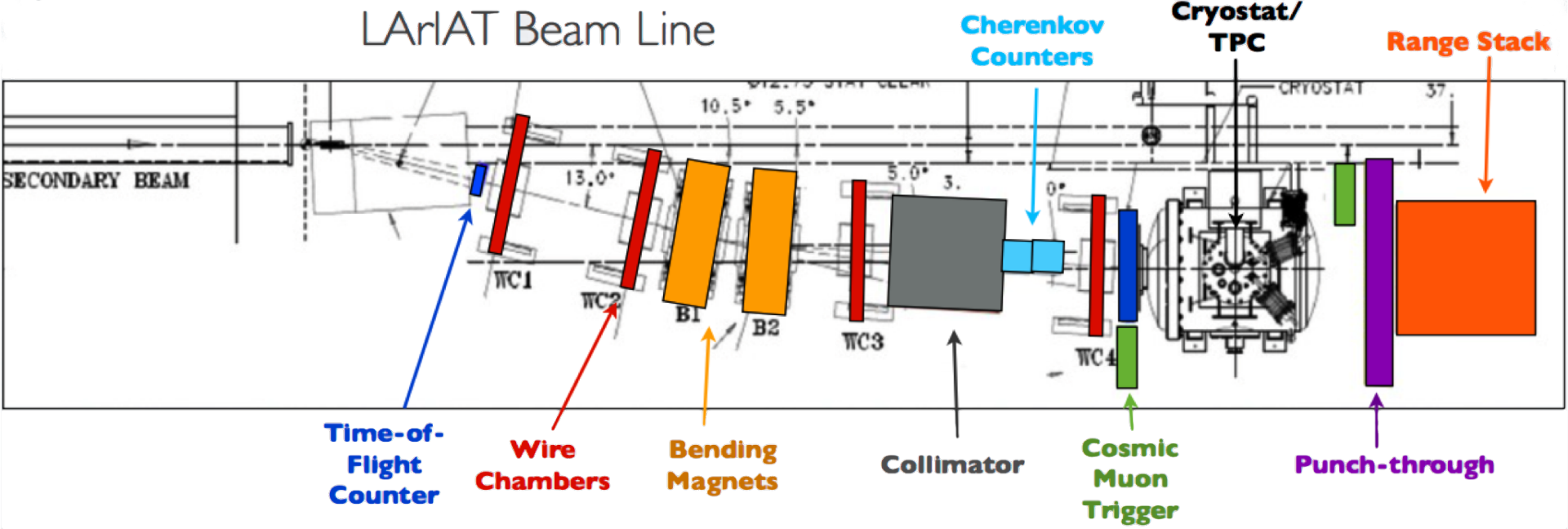


# $\gamma$ vs. e showers - raison d'être (Borrowed from Acciarri Roberto)




# dE/dx of *γ* vs. *e*

**(borrowed from Andrzej Szelc)**

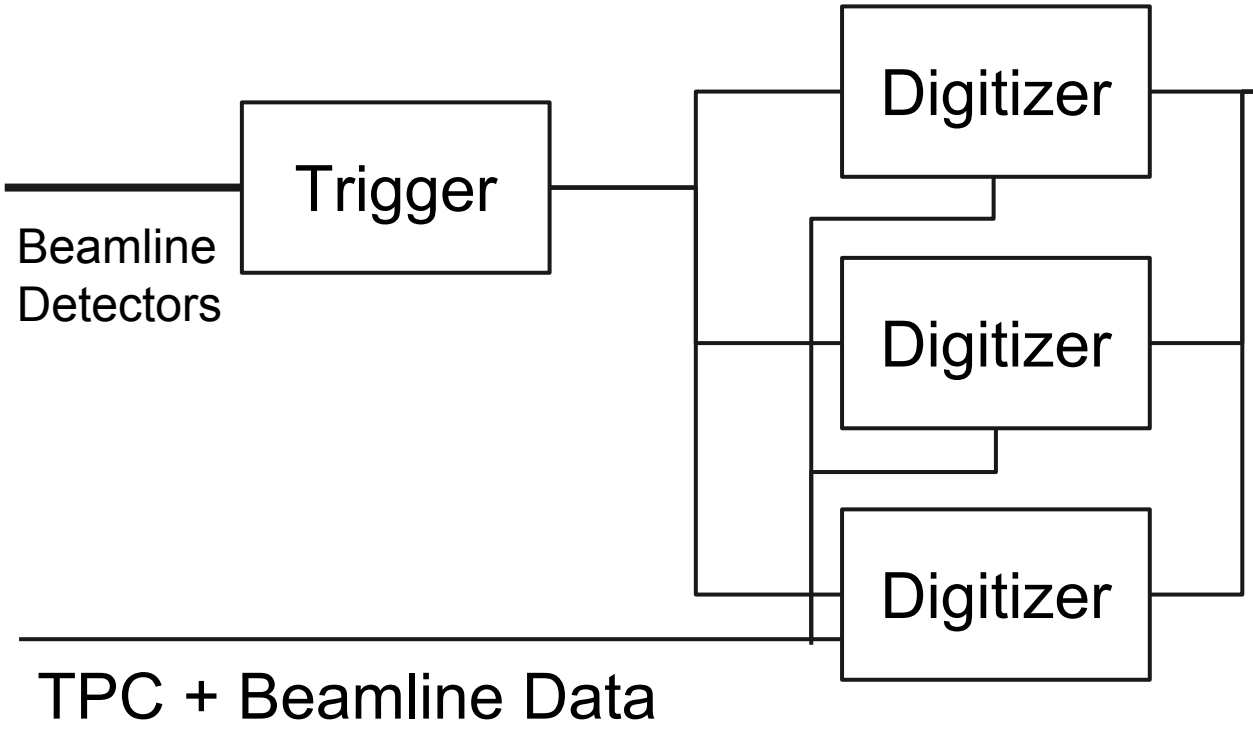



Primary ⟶ Secondary ⟶ <u>Tertiary</u>

$p$ (120 GeV) ⟶ $\pi$ (8 - 80 GeV) ⟶ <u>$\pi$, $p$, [$K$, $e$, $\mu$] (0.2 -2 GeV)</u>

## LArIAT setup in MCenter

# LArIAT Data Flow

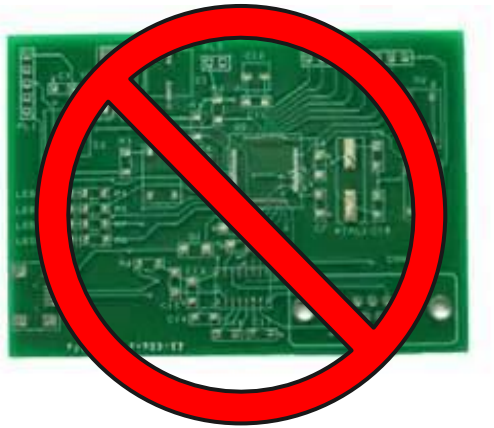



- **152 Mb / min**
- **ns resolution**

# Separating the good, the bad, and the ugly


**CPU**
Too slow

**FPGA**
Fast, configurable



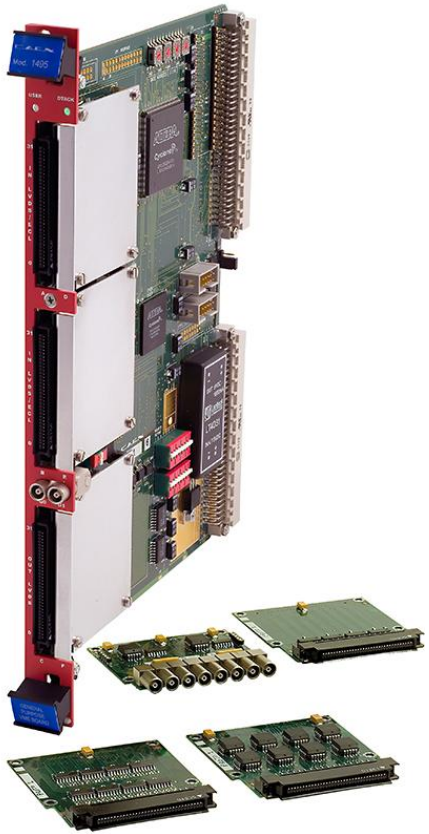
**Board**
Immutable

# Firmware changes

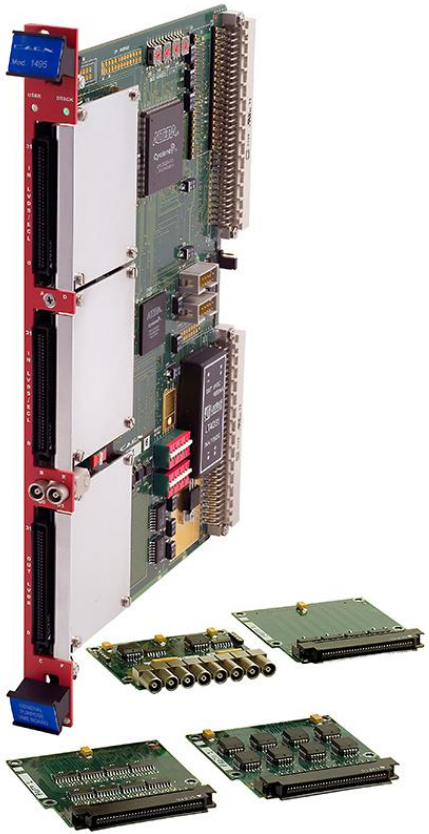
- CAEN V1495 - Altera Cyclone FPGA
- 3 layers of abstraction:
  - Hardware limitations, clocks
  - Firmware
  - Software - config + register reading

Original firmware: Matt Stephen (undergraduate thesis)

+ Mike Kordosky (College of William and Mary)



# Initiate learning sequence



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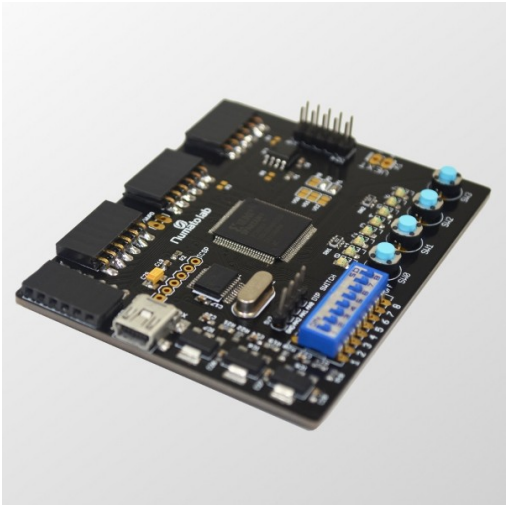
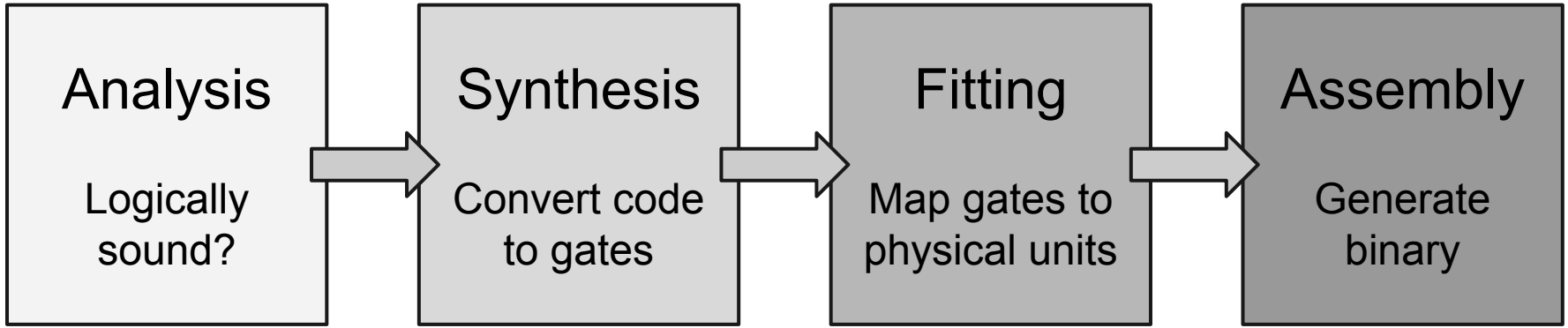
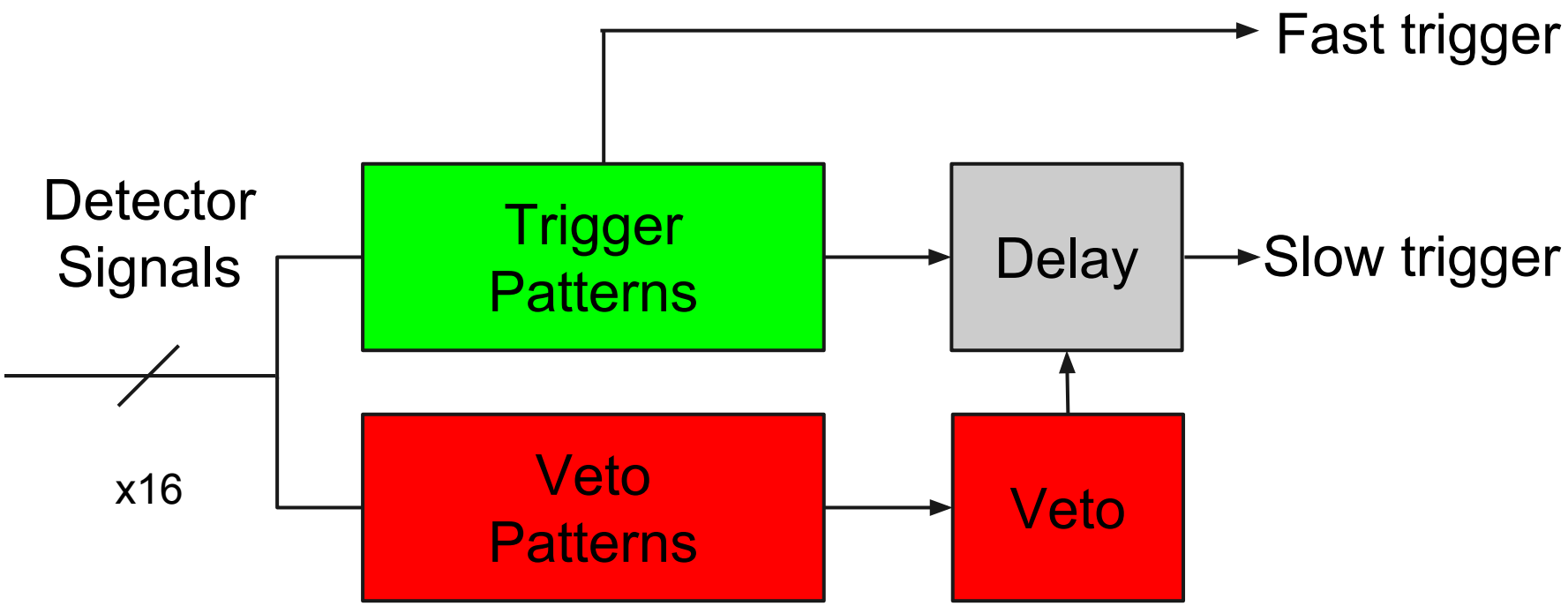


# How to program an FPGA?

- VHDL (VHSIC Hardware Description Language)
  - C++ (entities) + LabVIEW (dataflow, registers)
  - Directly maps hardware pins to firmware signals



# V1495 trigger mechanics

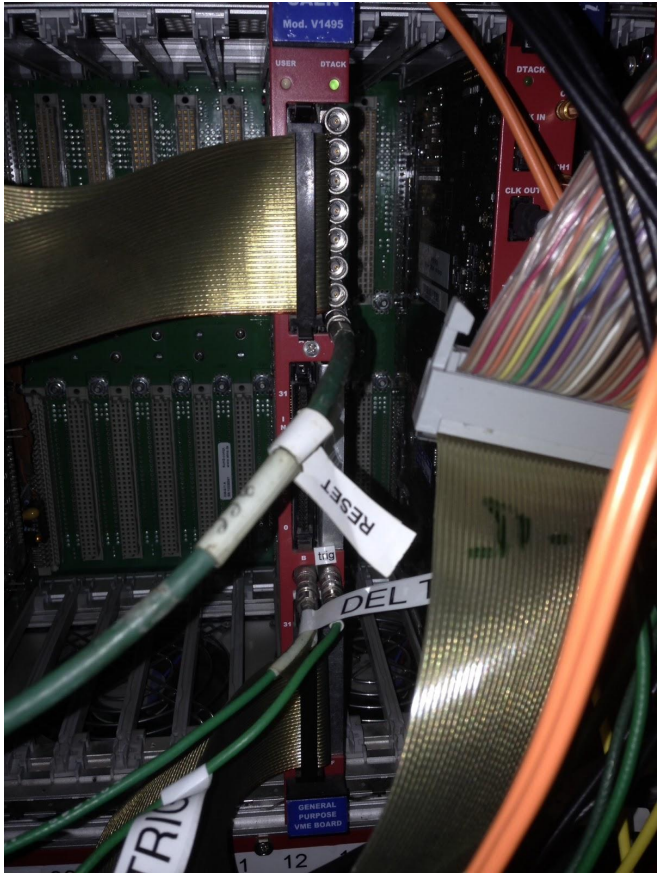


# The Todo List

- Output trigger input data
  - Offline debugging
- Expanding input bus from 16 to 32 bits
  - Read 16 more detectors!
- Internal prescaler
  - Replace pulser input
  - XML-configurable timing
  - Verify external pulser

# 32-bit expansion

- Expand pattern matching to 32-bit patterns, masks
- Remap most registers
- Add mask register addresses to DAQ C++
- Add 16 inputs in XML config



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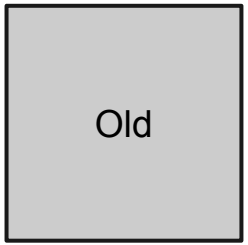


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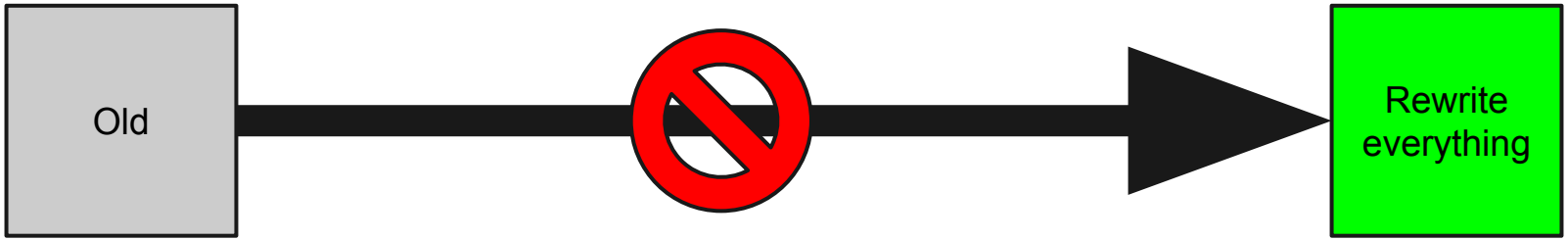

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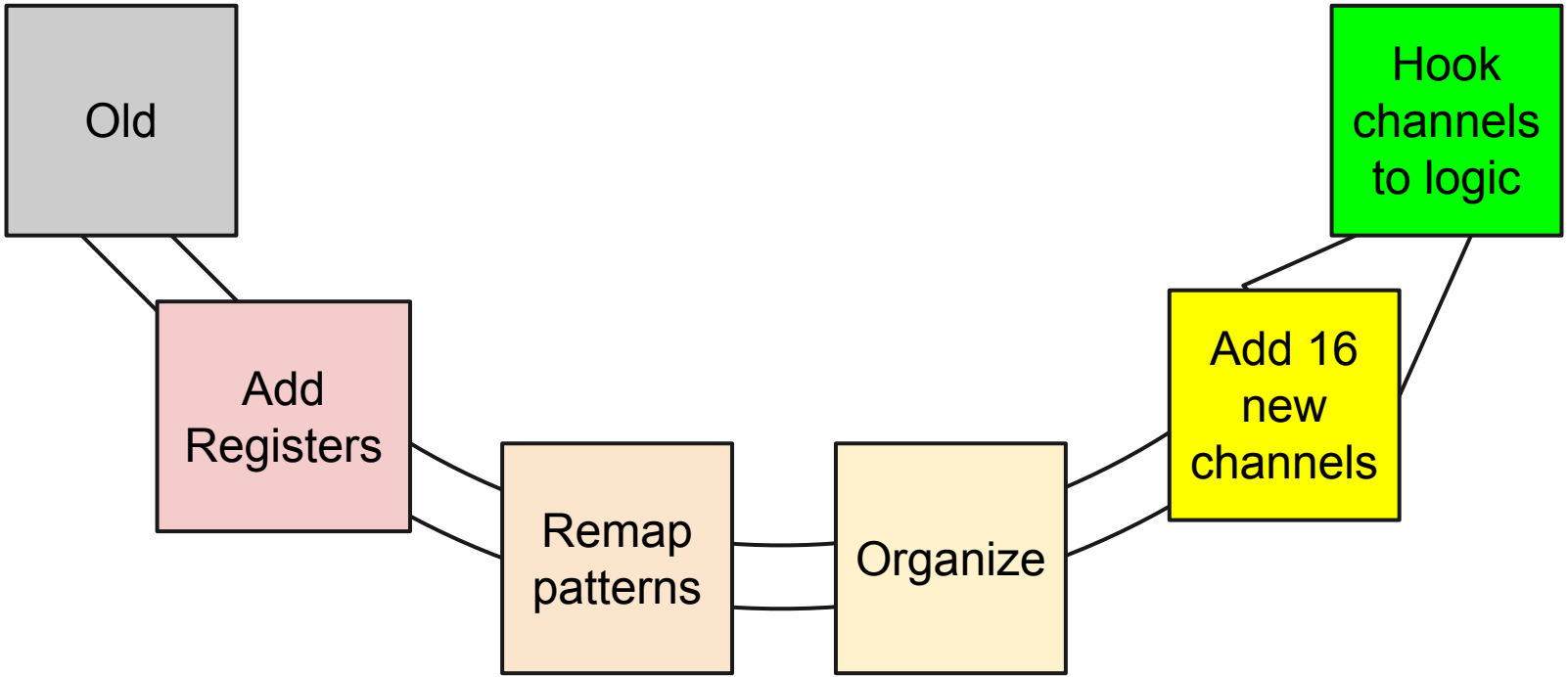
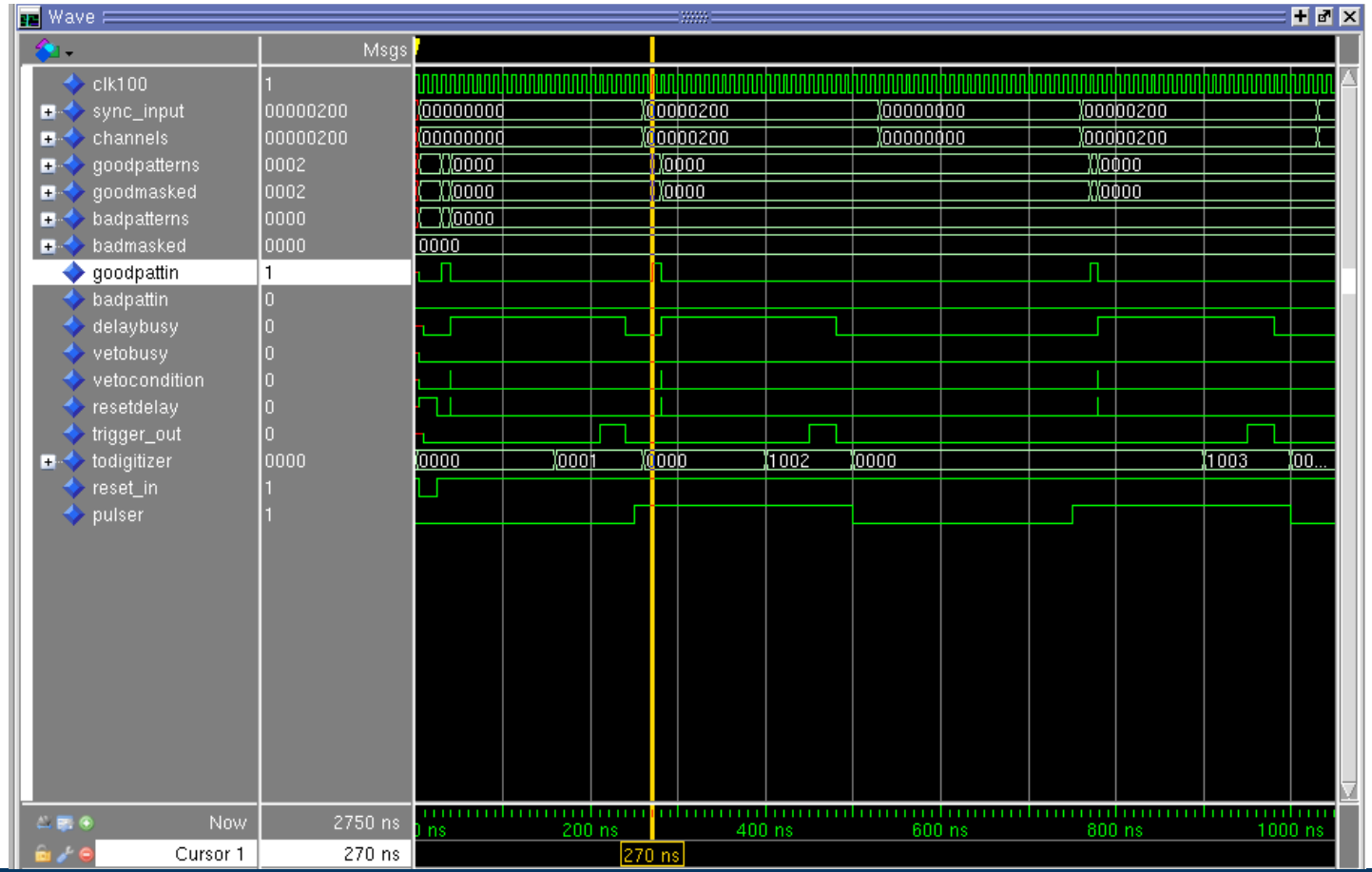





# Simulation with testbenches in ModelSim-Altera

0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60

| | | | |
|---|---|---|---|
| **Run** | 6626 | **Spill** | 3 |
| **V1740 Run Triggers** | 306 | **V1740 Spill Triggers** | 265 |
| **V1740B Run Triggers** | 306 | **V1740B Spill Triggers** | 265 |
| **V1751 Run Triggers** | 305 | **V1751 Spill Triggers** | 265 |
| **SpillActive** | 0 | **RunActive** | 1 |
| **MCenter Energy** | -0.108 GeV | **MCenter Intensity** | 0 ppp |
| **MC7SC1** | 0 Cnts | **MC7 Magnet** | -0.031 amps [100 amps] |
| **DiskSpaceUsed, %** | 26.4 | **SuperCycle Time** | 28.2 SEC |
| **LAr Temperature** | 283.8 degK | **LAr Level** | 0.661 InAr |
| **Time** | 2015.07.30-16:43:18 | **Complete Files Waiting** | 1 |
| **Components** | V1740 V1740B V1751 V2781 V1495 WUT | | |
| **Missing** | TDC LARASIC | | |

**Trigger Inputs**

| | | | |
|---|---|---|---|
| **WC1IGNOREME** | 0 | **WC2IGNOREME** | 0 |
| **WC3IGNOREME** | 0 | **WCCOINC3OF4** | 0 |
| **COSMICAGCOIN** | 0 | **USTOF** | 199 |
| **DSTOF** | 104 | **PUNCH** | 977 |
| **HALO** | 0 | **PULSER** | 265 |
| **COSMICON** | 1 | **COSMIC** | 1 |
| **LARRY** | 0 | **MICHEL** | 0 |
| **DETECTOR_16** | 0 | **DETECTOR_17** | 0 |
| **DETECTOR_18** | 0 | **DETECTOR_19** | 0 |
| **DETECTOR_20** | 0 | **DETECTOR_21** | 0 |
| **DETECTOR_22** | 0 | **DETECTOR_23** | 0 |
| **DETECTOR_24** | 0 | **DETECTOR_25** | 0 |
| **DETECTOR_26** | 0 | **DETECTOR_27** | 0 |
| **DETECTOR_28** | 0 | **DETECTOR_29** | 0 |
| **DETECTOR_30** | 239 | **DETECTOR_31** | 265 |

**Trigger Output Paths**

| | | | |
|---|---|---|---|
| **COSMICAGCOIN** | 0 | **DETECTOR_31** | 265 |

# What's left?

- ~~Output trigger input data~~
  - ~~Offline debugging~~
- ~~Expanding input bus from 16 to 32 bits~~
  - ~~Read 16 more detectors!~~
- Internal prescaler
  - Replace pulser input
  - XML-configurable timing
  - Verify external pulser

# Acknowledgements

The entire LArIAT team, but specifically

- Dr. Will Flanagan
- Dung Phan
- Brandon Soubasis
- Dr. William Badgett, Jr.
- Dr. Mike Kordosky
- Dr. Jin-Yuan Wu
- Dr. Kurt Biery

Quarknet mentors

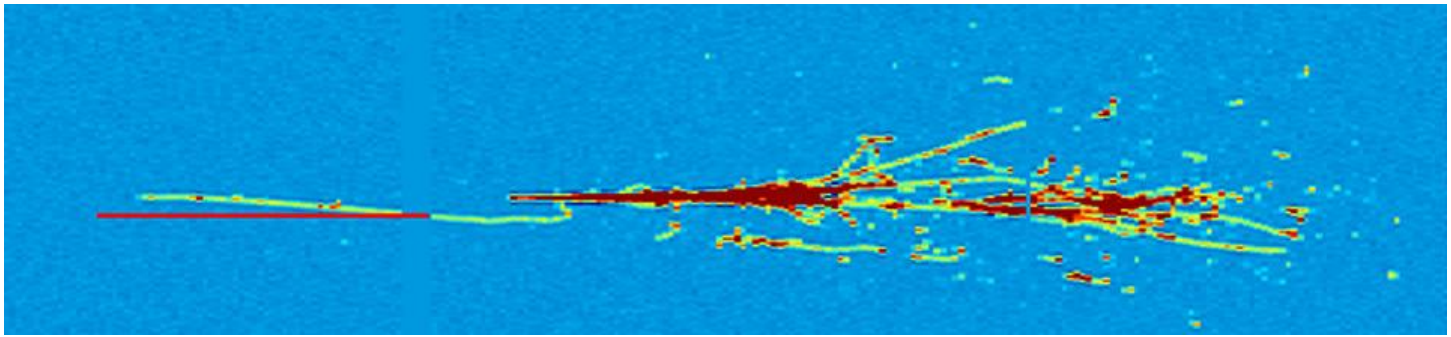
- Dr. Stoughton
- Ben Sawyer
- George Dzuricsko

Quarknet students!

# Backup Slides

# Why liquid argon?

- Scintillation
- Inert (filled outer octet)
- Dense (1.4 g/cm^3)
- Low-cost - $150 - $400 / ton
- Liquifyible with liquid nitrogen



# Use cases?

Neutrino detectors:

- Large volume
- Fine resolution
- Cheap

Examples:

- μBooNE
- DUNE