ミューオン・トモグラフィ用の検出器の開発

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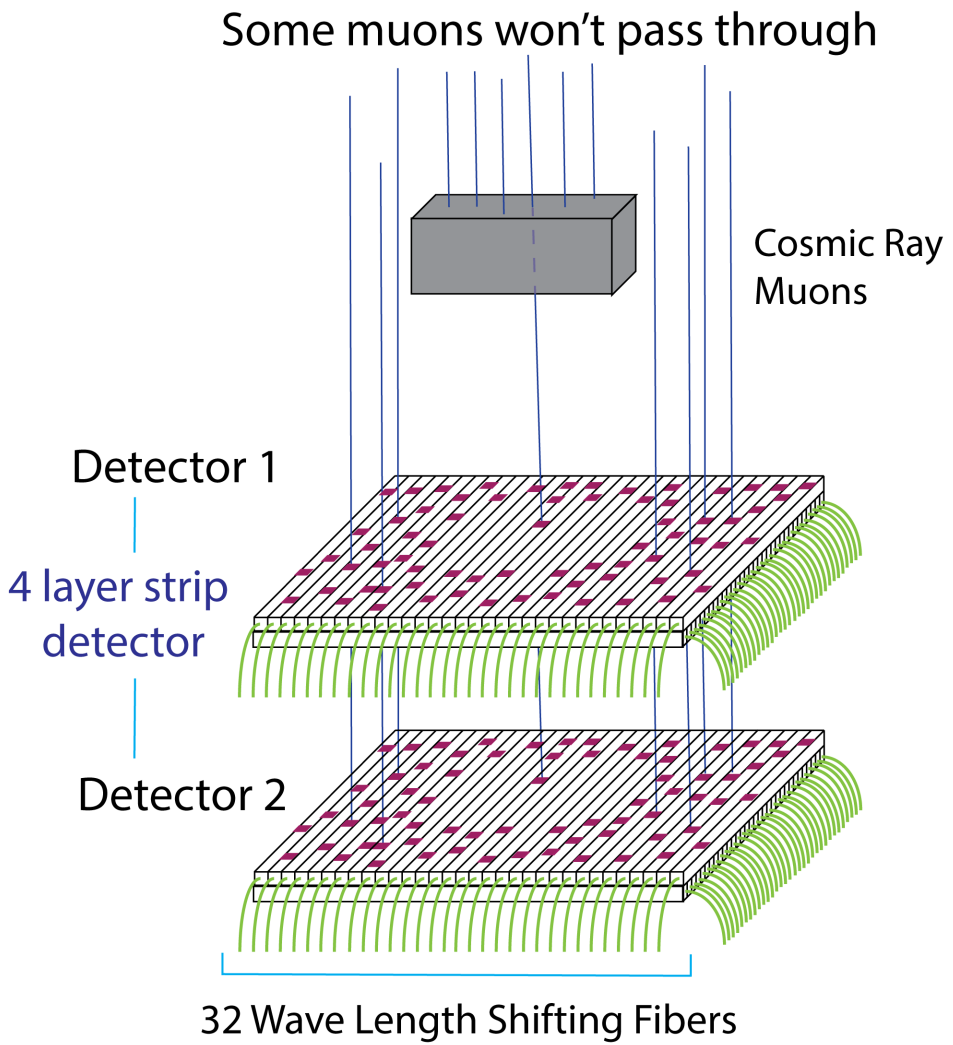
What is Muon Tomography ?

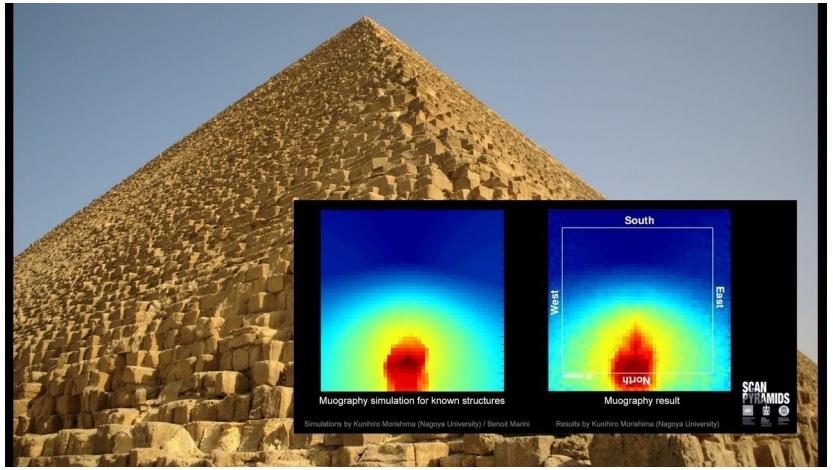


- Cosmic Ray Muons to create 2-D, 3-D images
- Why Muons ? High energy, Penetrate than X-rays, Free

→ Can image large and dense objects

Applications of Muon Tomography

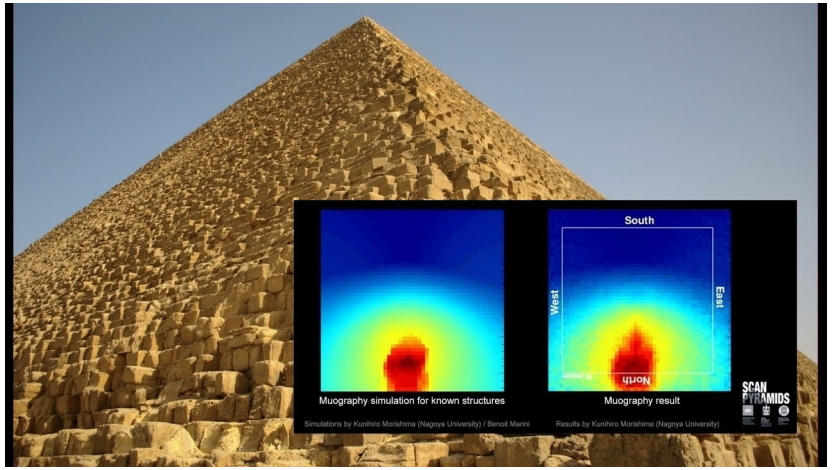
Observing the movement of magma in a volcano



Investigating the hidden chambers in pyramids

Applications of Muon Tomography

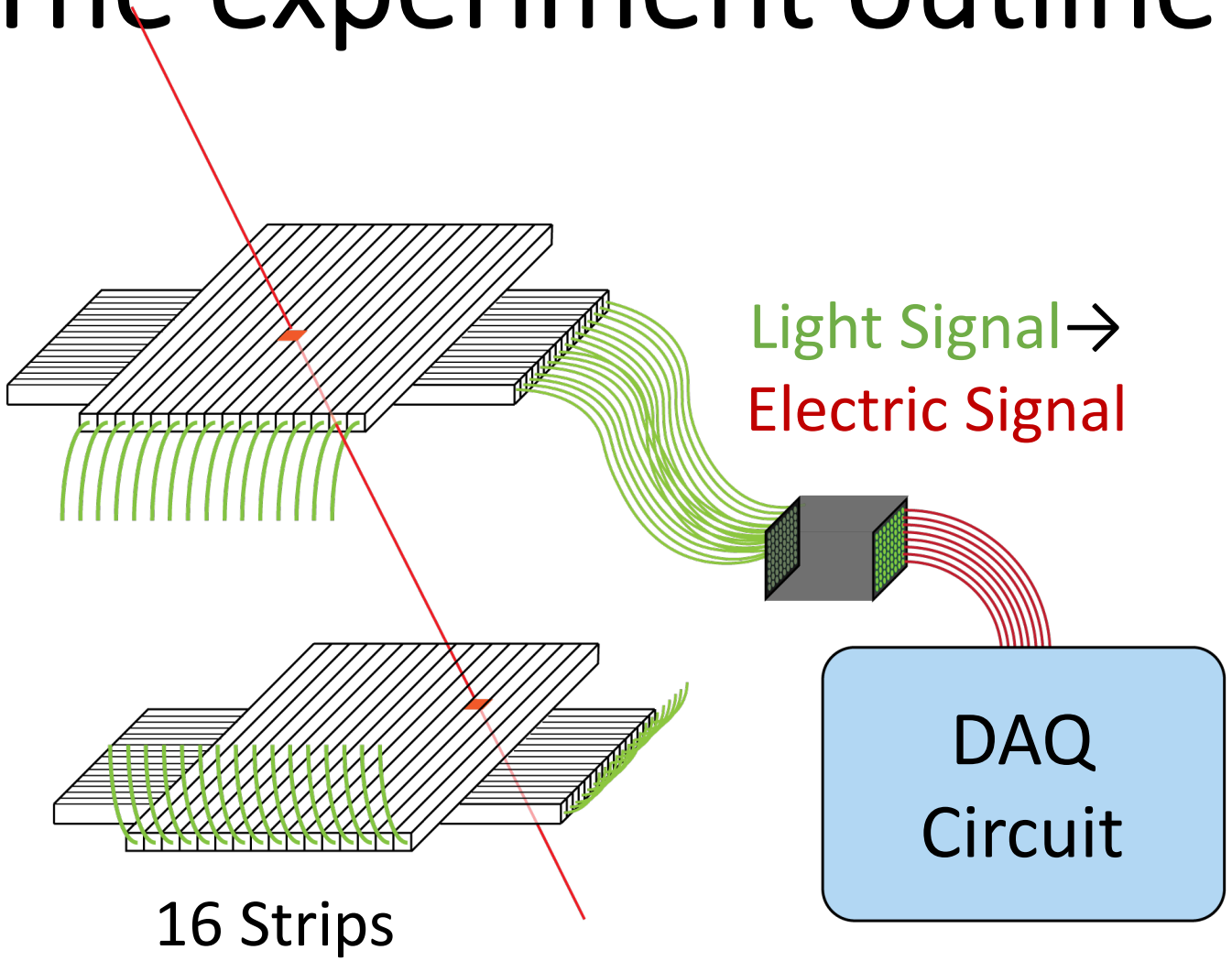
Observing the movement of magma in a volcano



Investigating the hidden chambers in pyramids

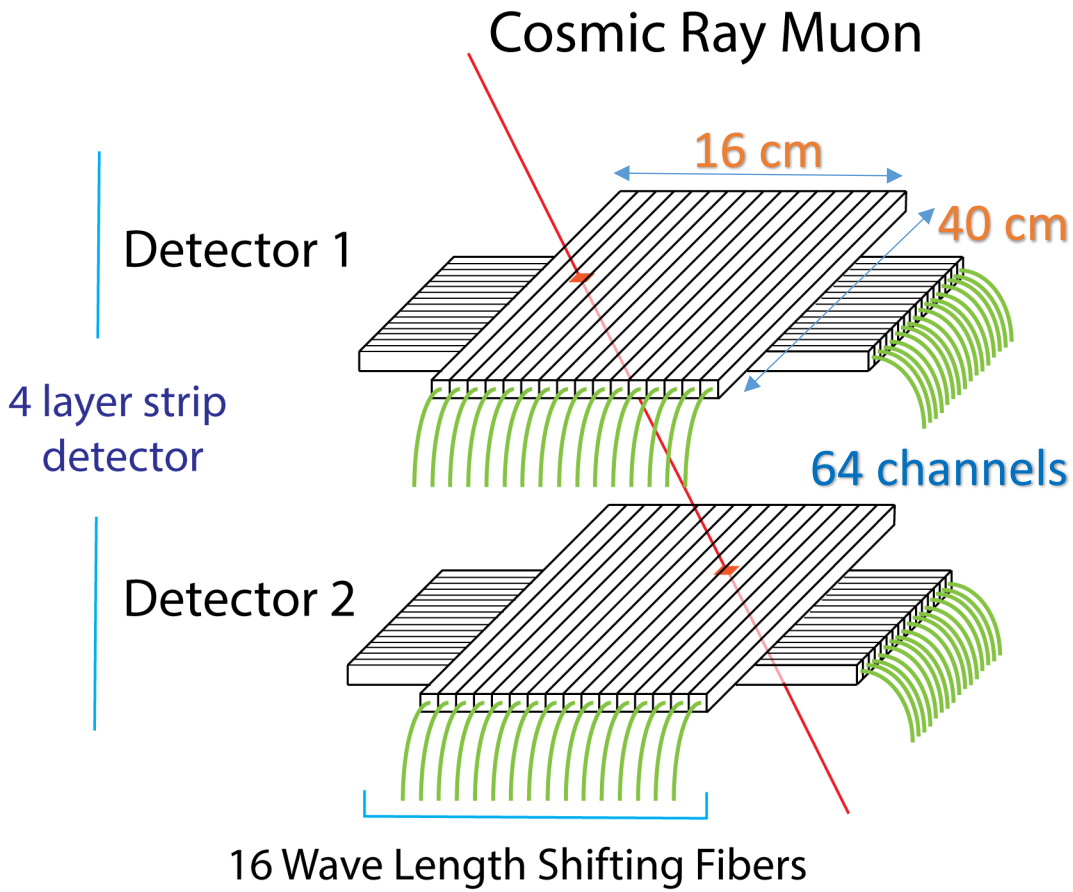
Or what's inside this stone pillar ?

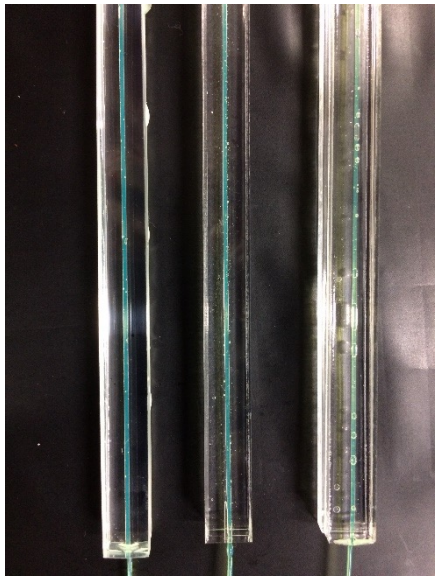
The experiment outline



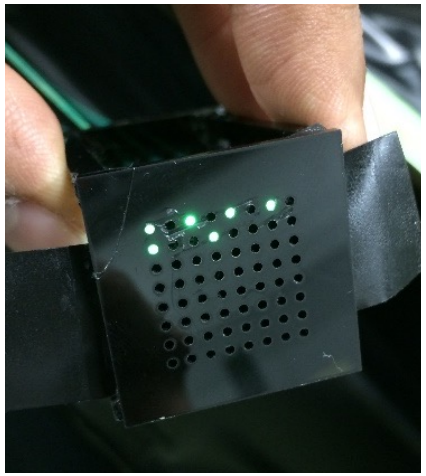
- Tracking Detector → Muon track for image reconstruction
- Data AcQuisition (DAQ) Module for 64 channels

Design of the 4 layer strip detector

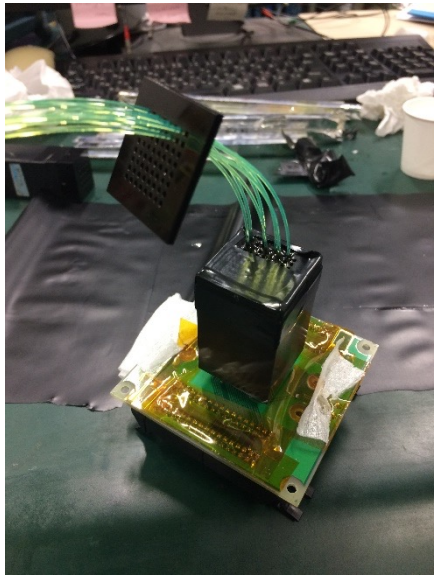




40 cm plastic scintillator strips



Fiber grid



64 channel multi-anode PMT

Production method comparison

Milling Machine

Merits

- Won't damage scintillating material

Demerits

- Slow (more than 1 hour/strip)

Laser Cutter

Merits

- Faster (4 mins/strip)

Demerits

- Heating → Might damage the scintillating material

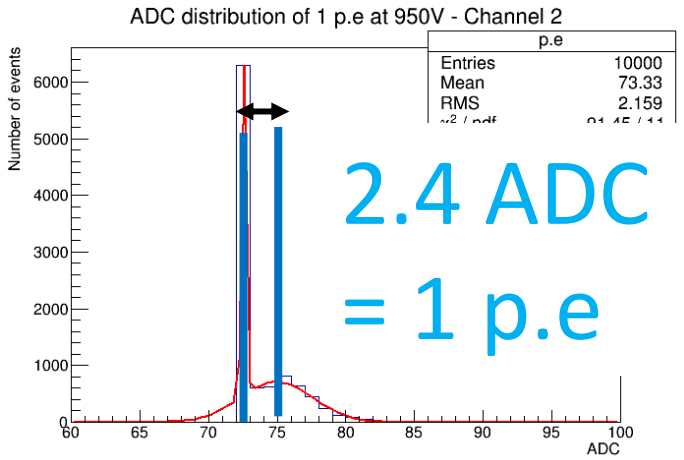
Compared by measuring the number of photo-electrons

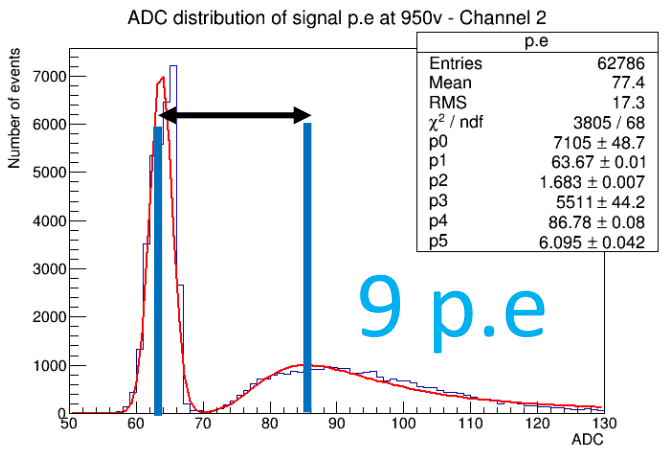
Measurement of photo electrons

LED

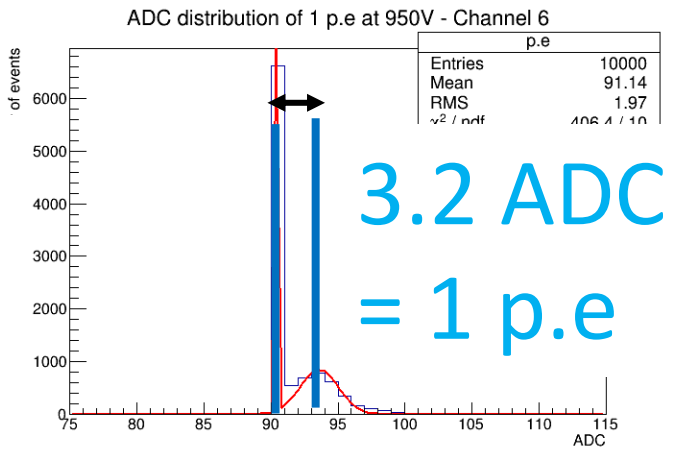
Muon

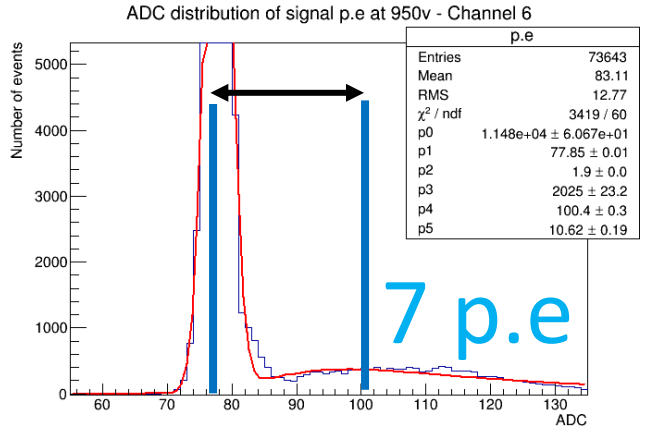
Laser cutter





Milling Machine





No significant difference!

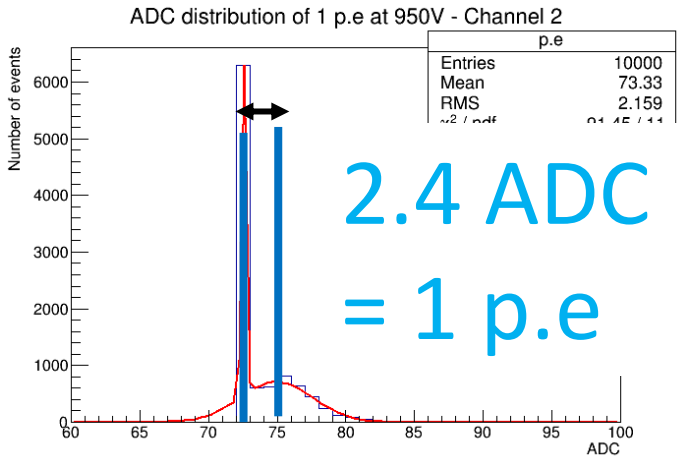
Measurement of photo electrons

Adopted this method!

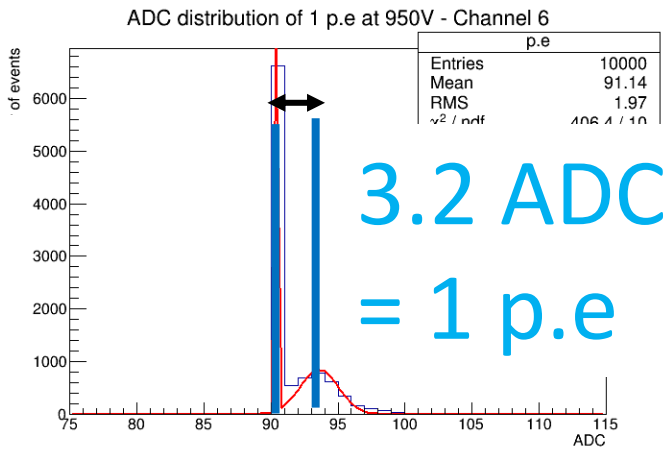
Laser cutter

Milling Machine

LED

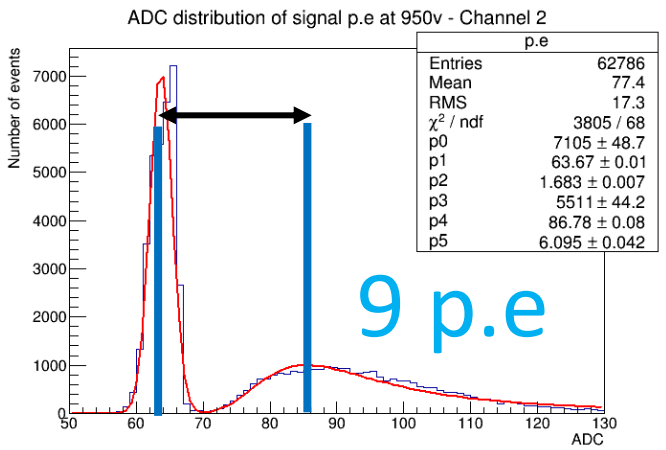


2.4 ADC = 1 p.e

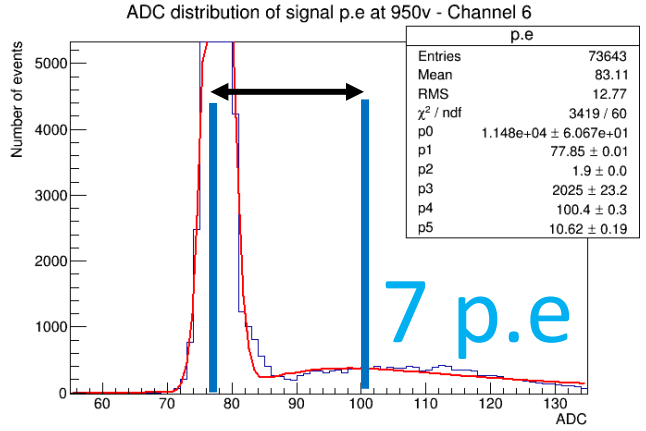


3.2 ADC = 1 p.e

Muon



9 p.e

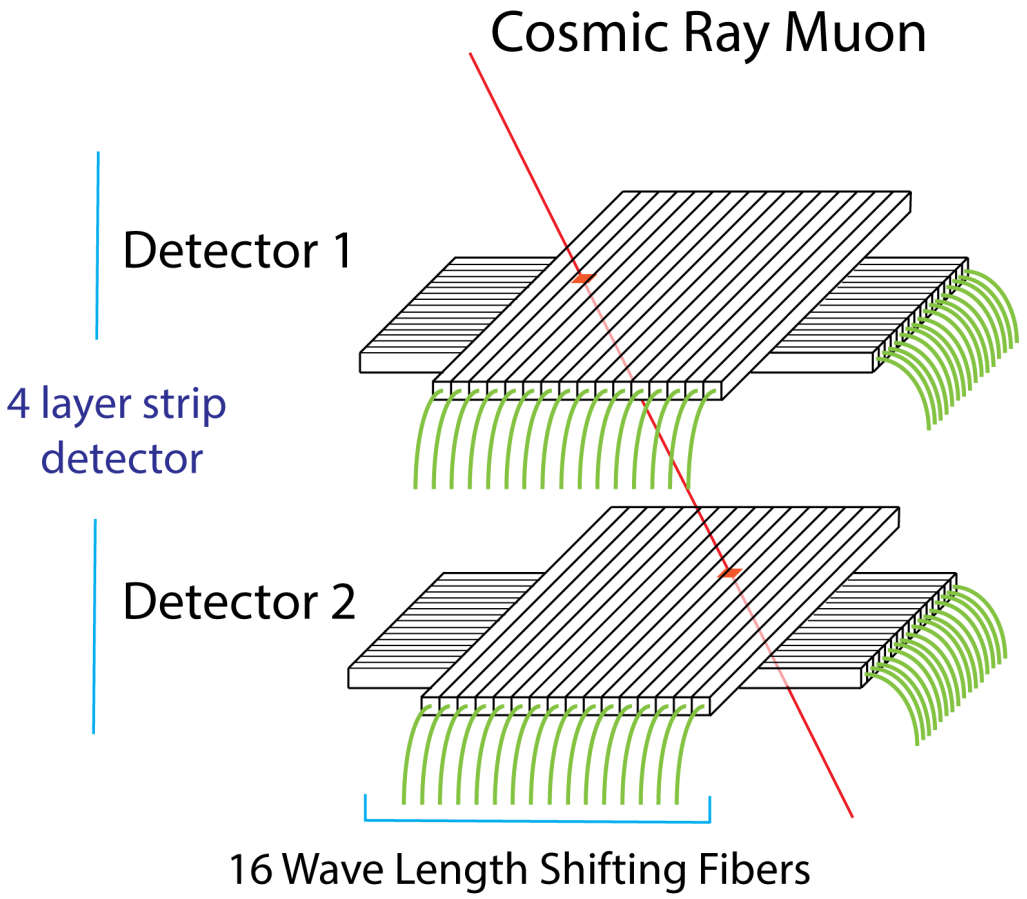


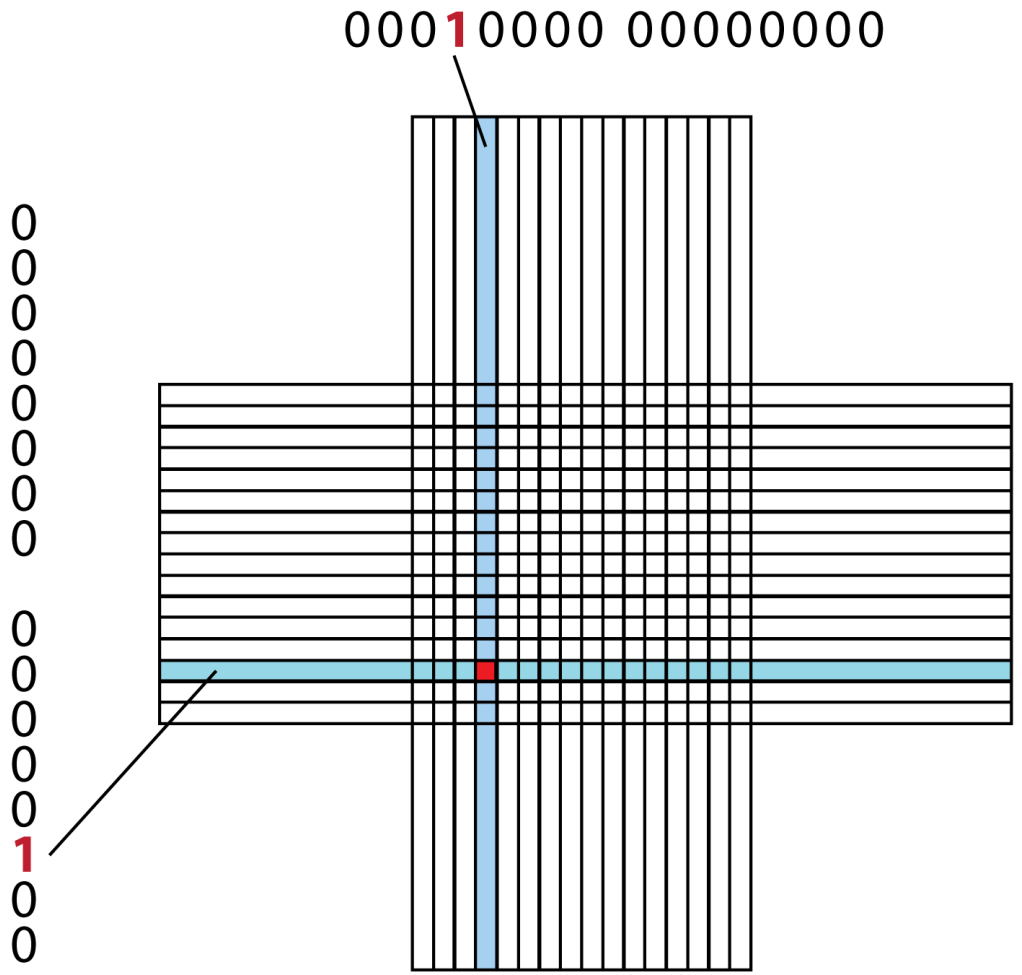
7 p.e

No significant difference!

The Data Acquisition

Hit ➡ 1 No Hit ➡ 0





The Data Acquisition

We need 64 channels of

- Pre-Amps
- Discriminators
- Fan-in
- Coincidence Counters
- Hit Registers

The Data Acquisition

We need 64 channels of

- Pre-Amps
- Discriminators
- Fan-in
- Coincidence Counters
- Hit Registers

We don't have that number !

Problem !

The Data Acquisition

We need 64 channels of

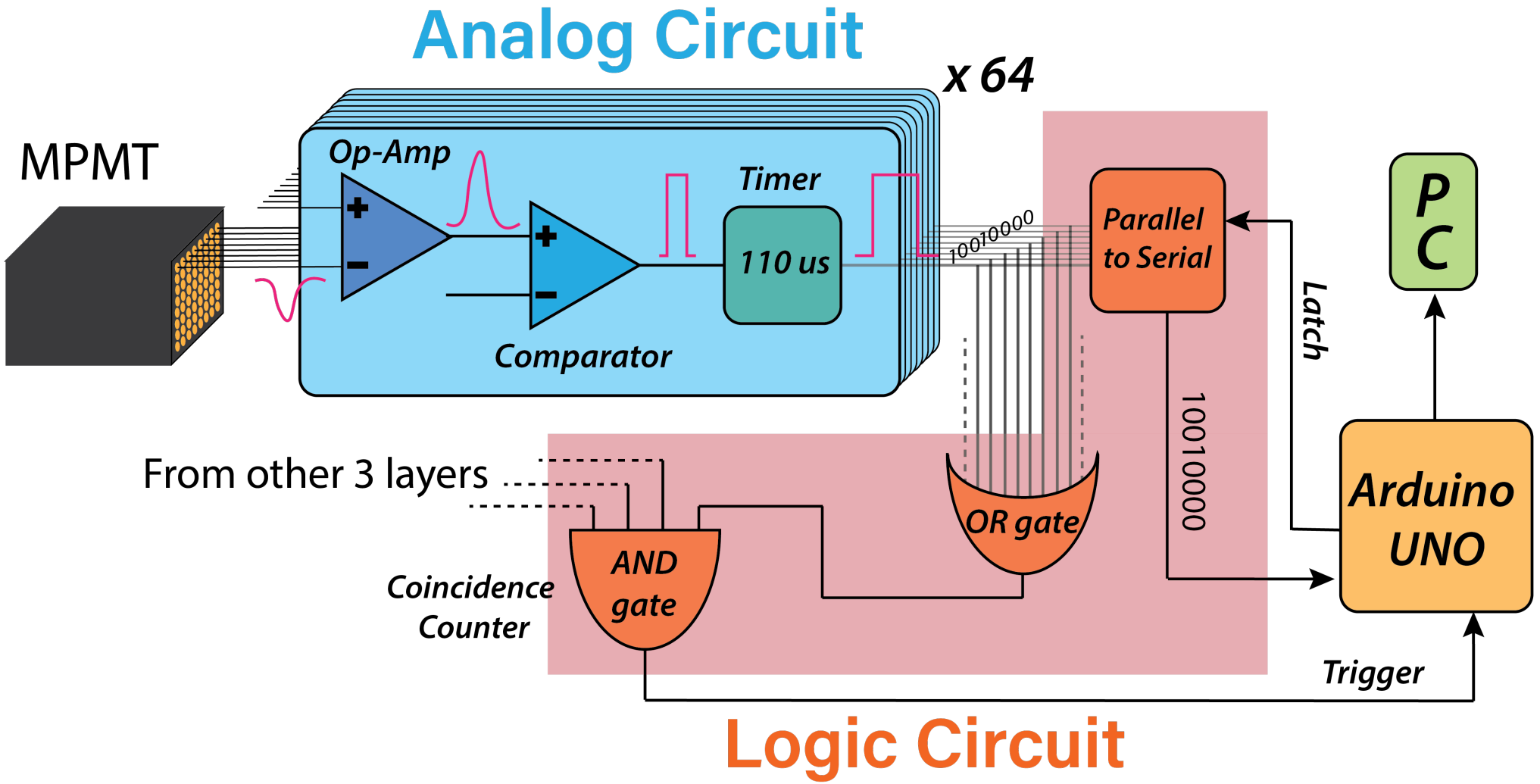
- Pre-Amps
- Discriminators
- Fan-in
- Coincidence Counters
- Hit Registers

We don't have that number !

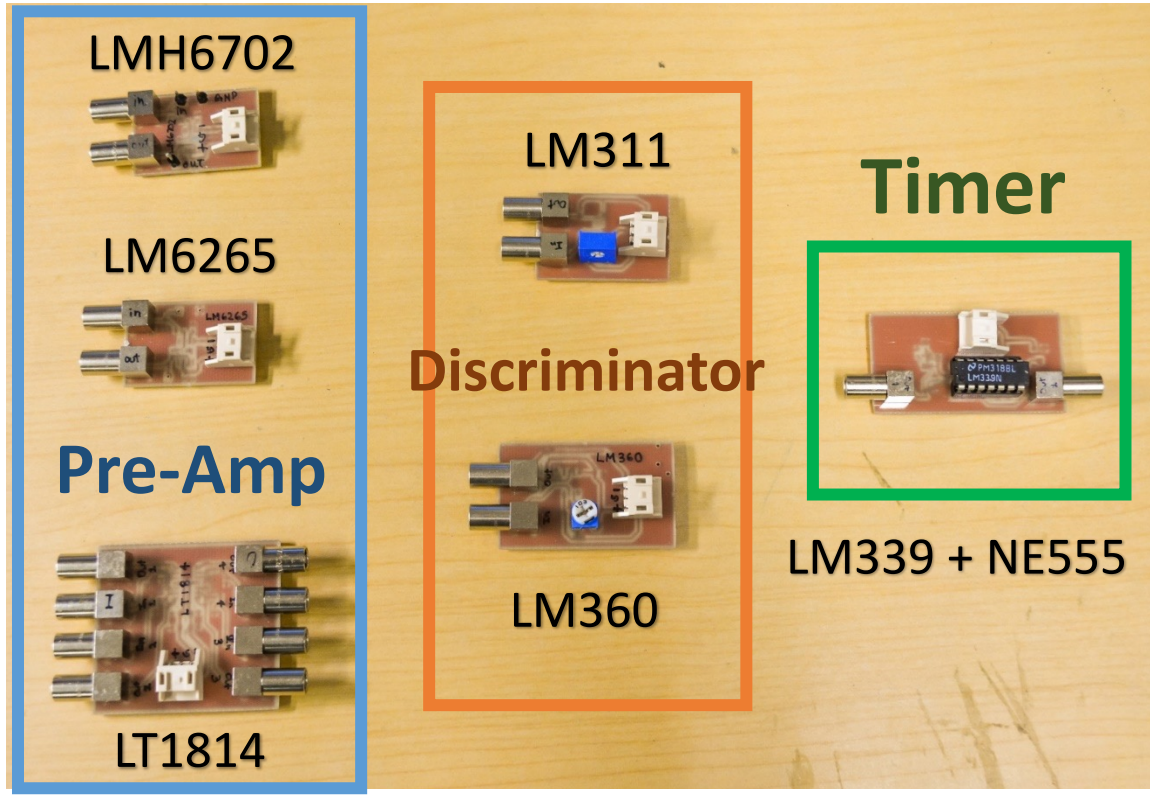
Problem !

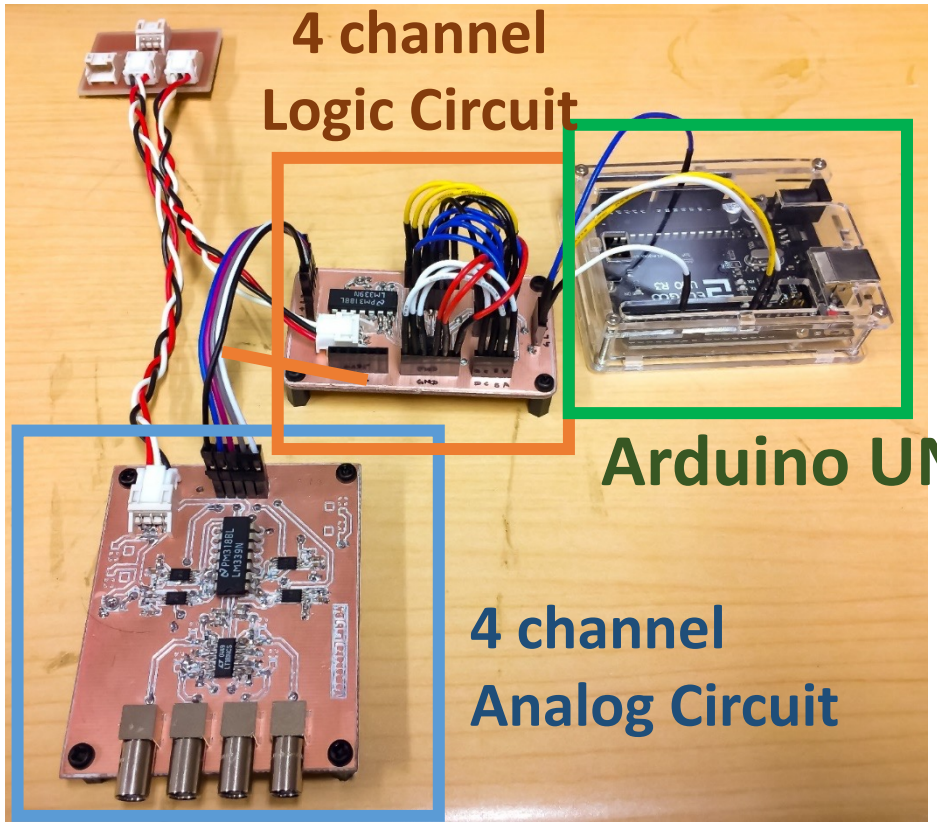
Develop our own DAQ system

Readout circuit for DAQ



Readout Circuit – Prototype

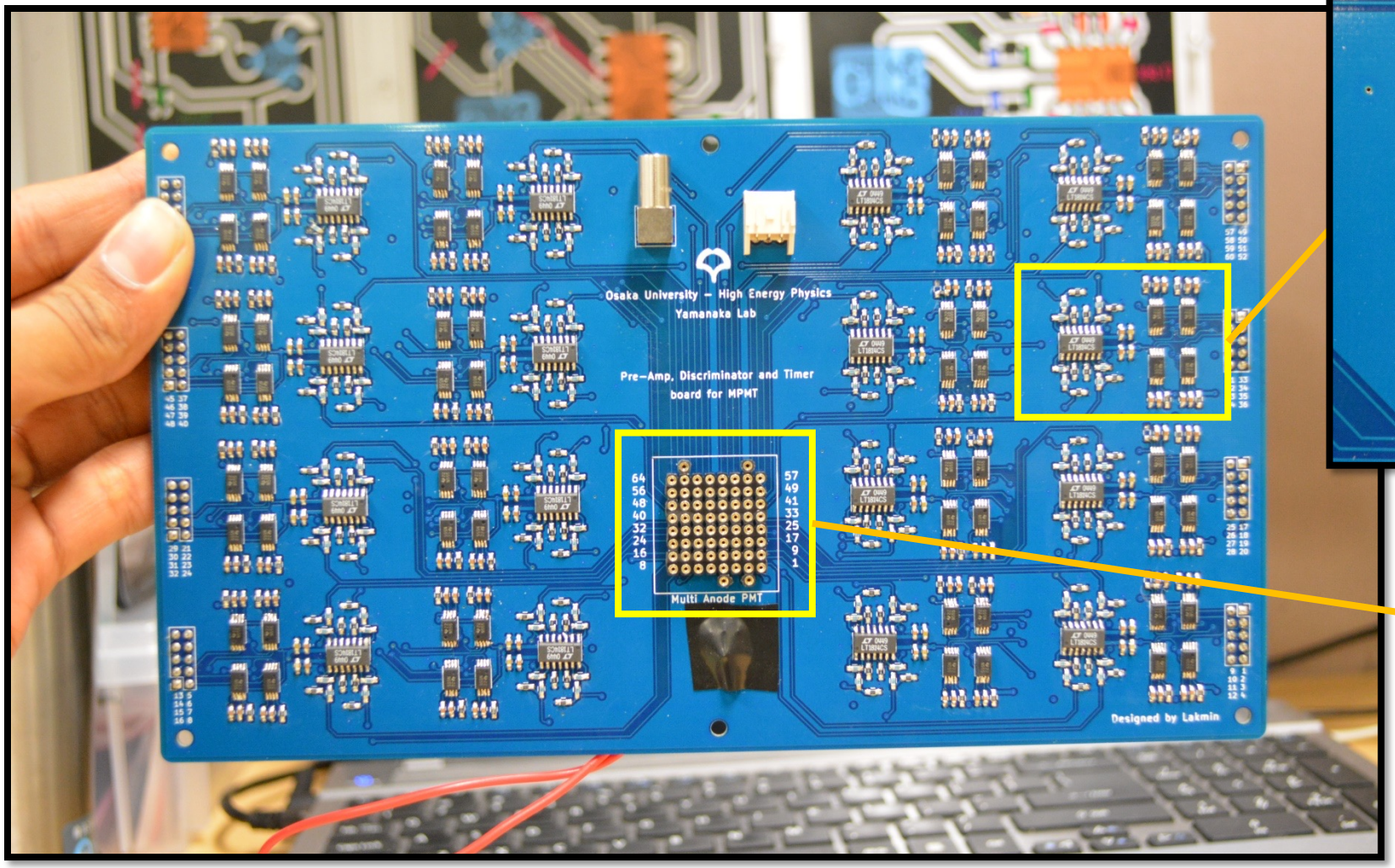




- Cost Efficient
- High Speed
- Fast Turnaround

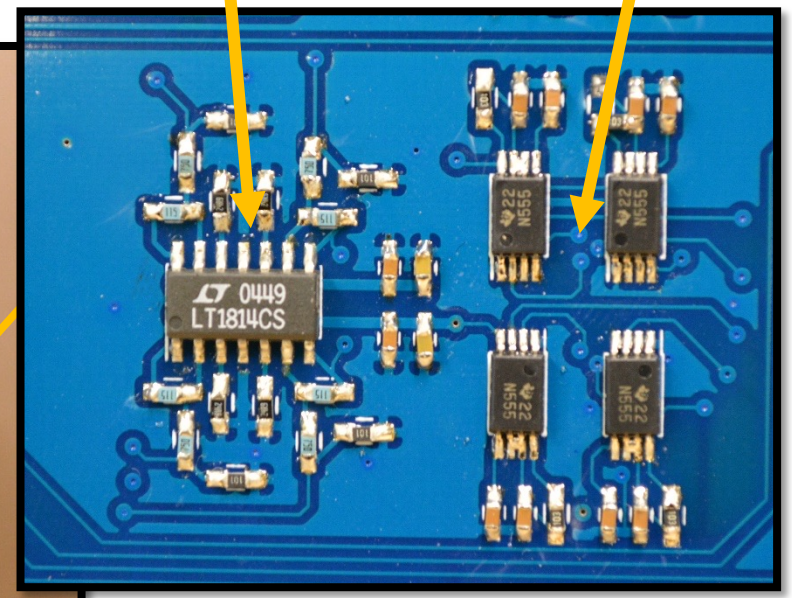
64 channel board

64 ch Analog Circuit - Front



Pre-Amp

Timer

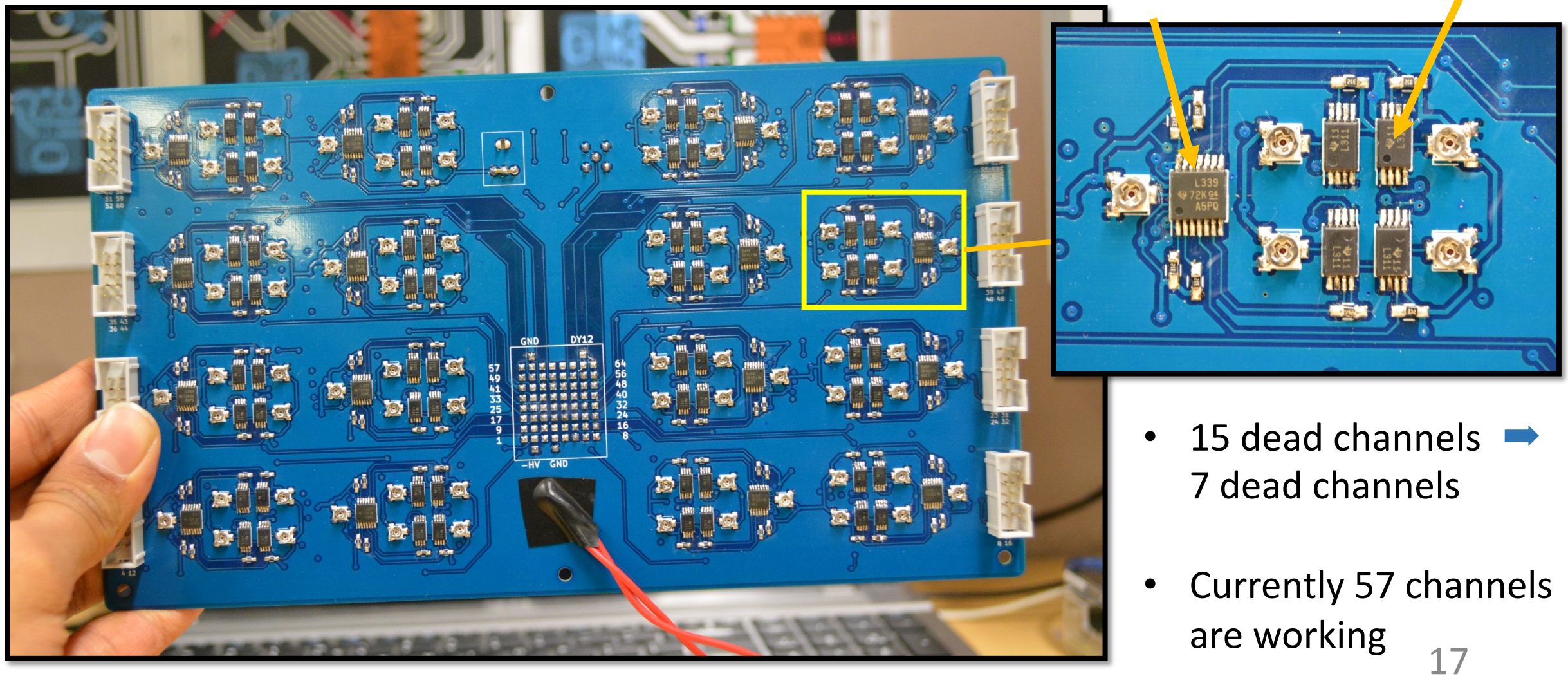


64 channel Multi-Anode Photo Multiplier Tube Socket

64 ch Analog Circuit - Back

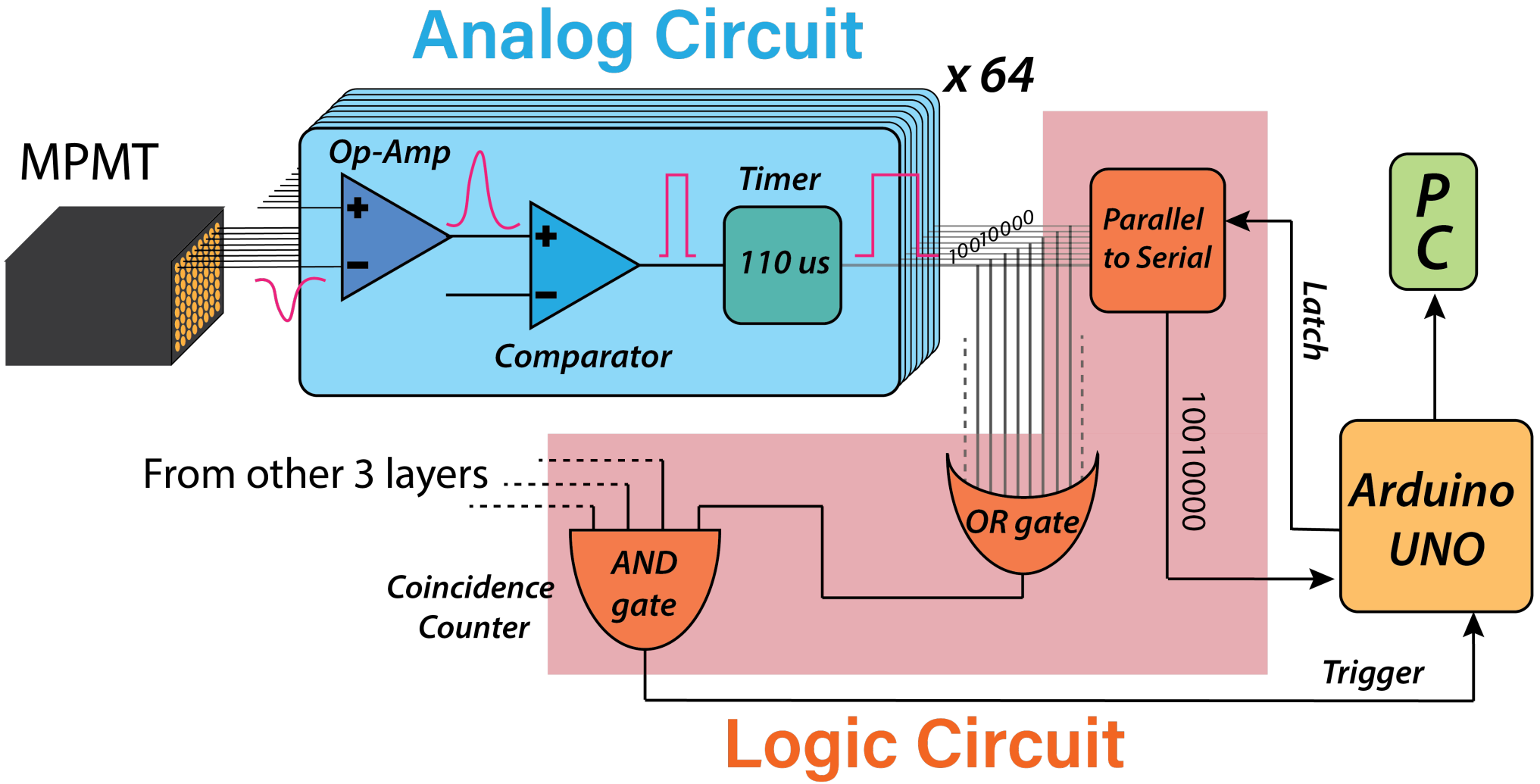
Discriminator 1
(High Speed)

Discriminator 2



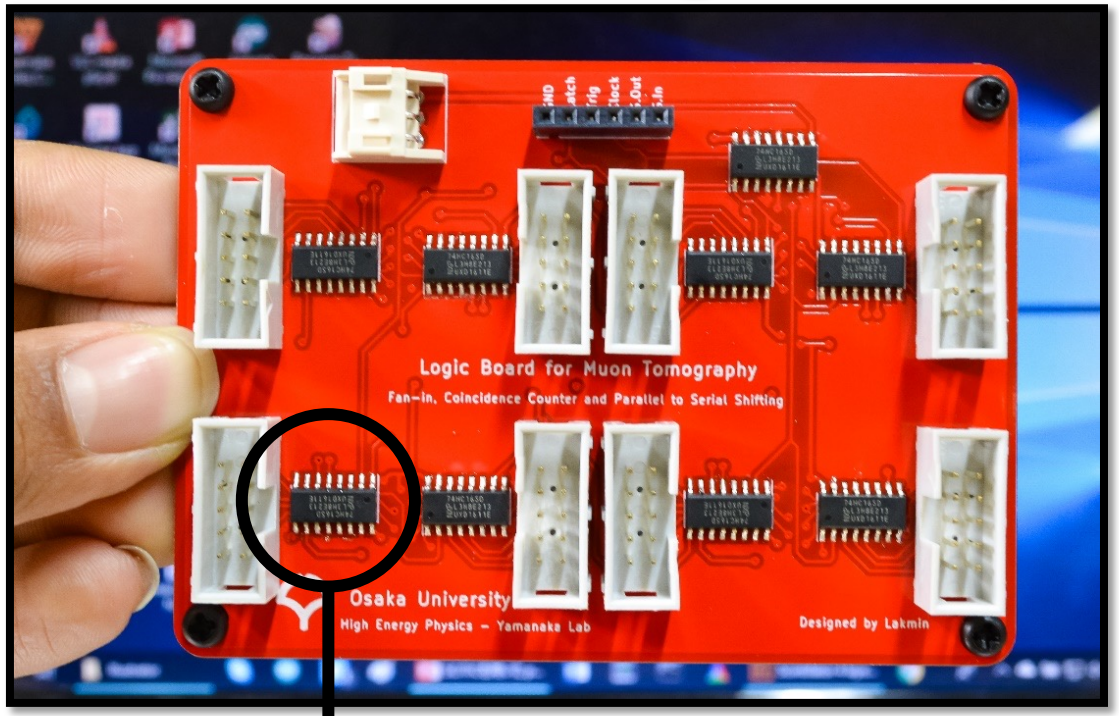
- 15 dead channels ➡
  7 dead channels
- Currently 57 channels are working

Readout circuit for DAQ



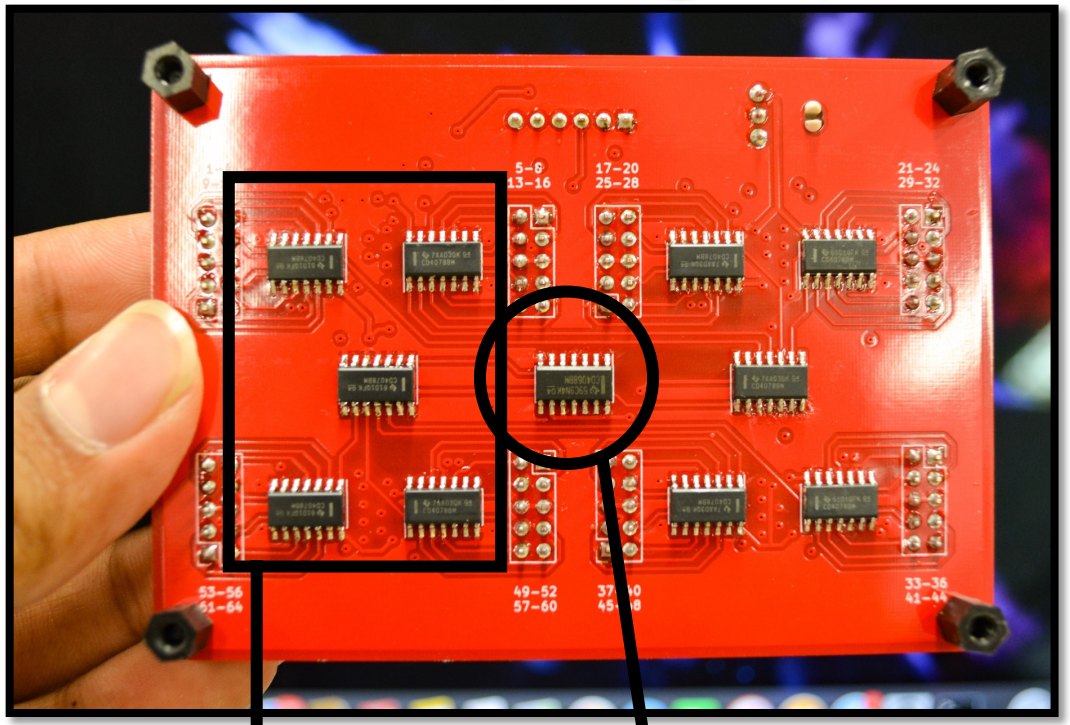
64 ch Logic Circuit

Front(Register)



8 bit parallel to serial shift register

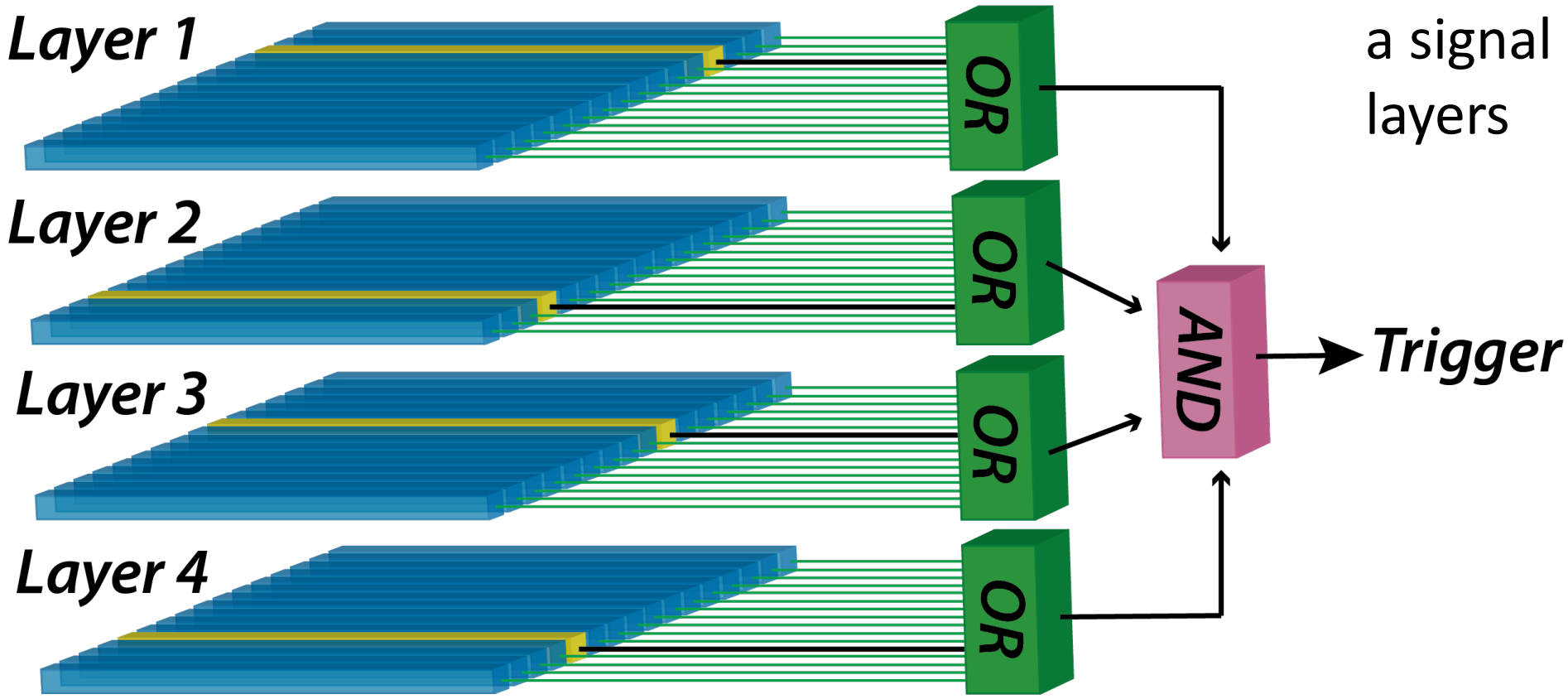
Back(Logic)



Fan-in

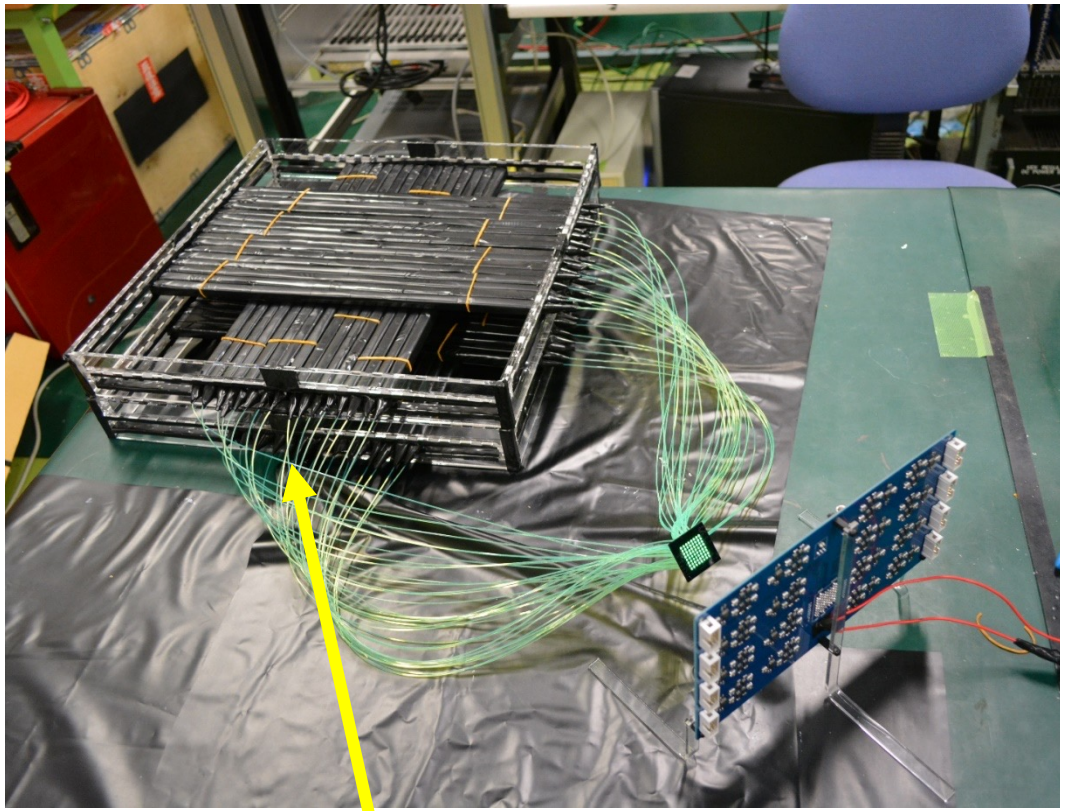
Coincidence Counter

Trigger Logic

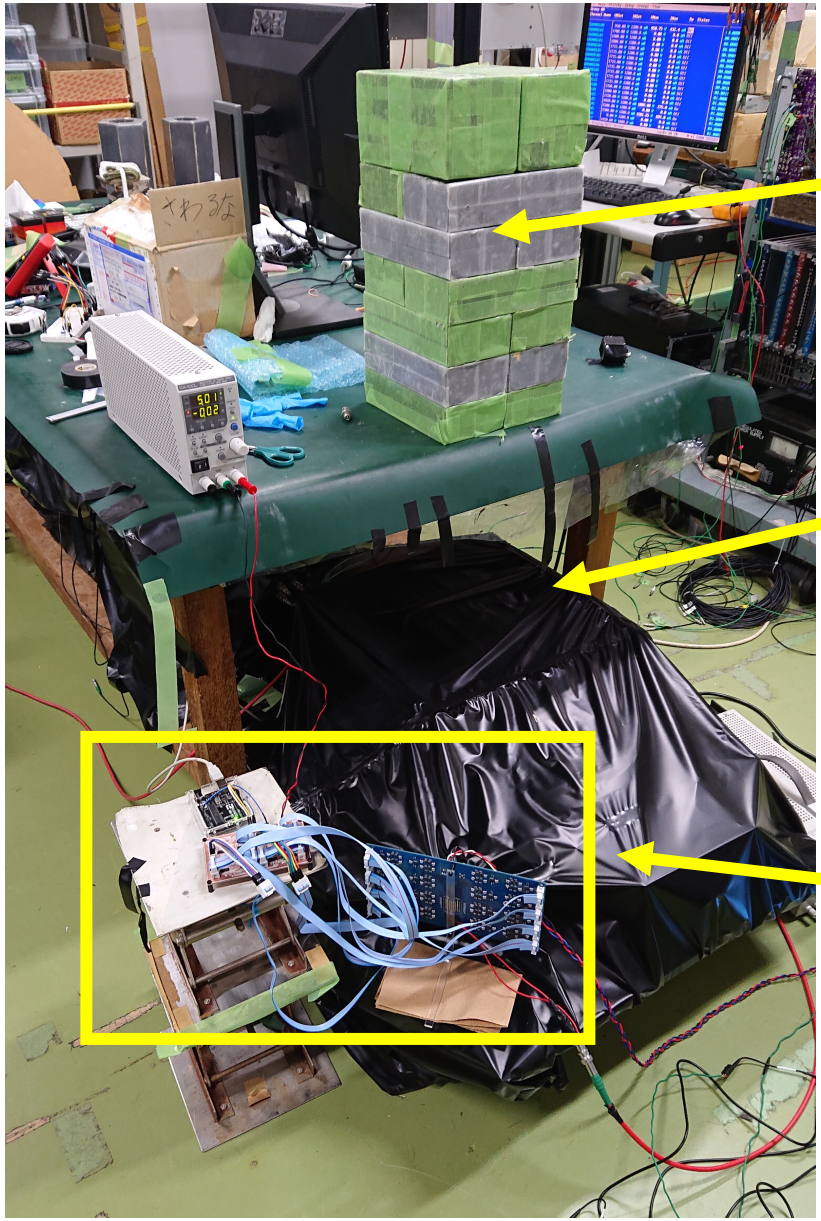


- Trigger will activate only when there is a signal in all 4 layers

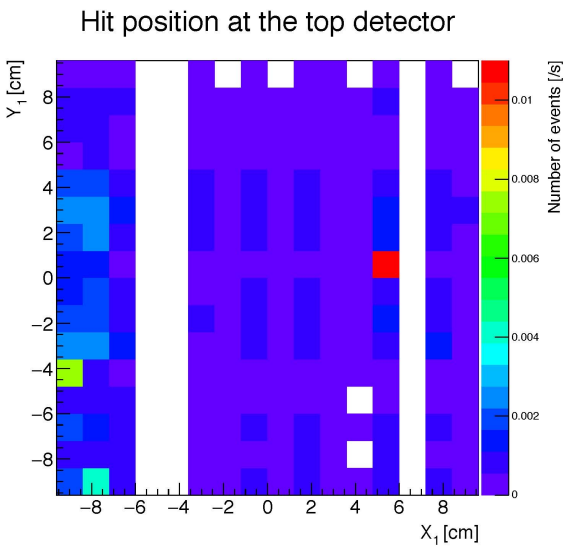
Experiment Set-Up

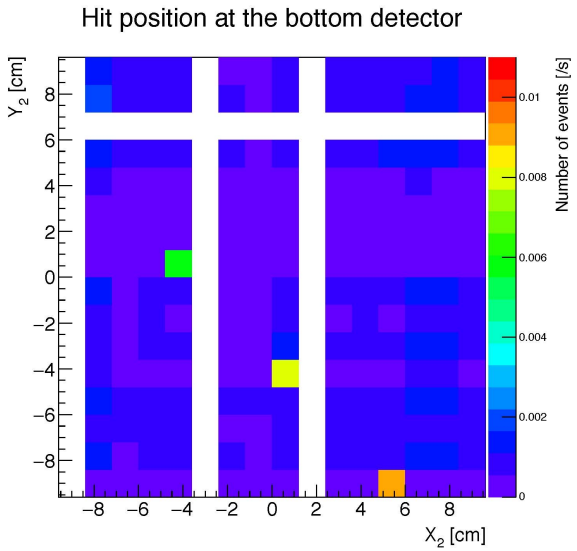


Detector (w/o black sheet)



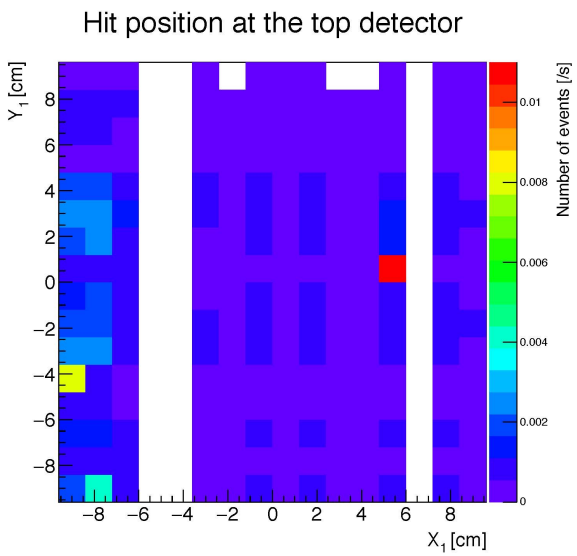
Hit map with Pb & w/o Pb

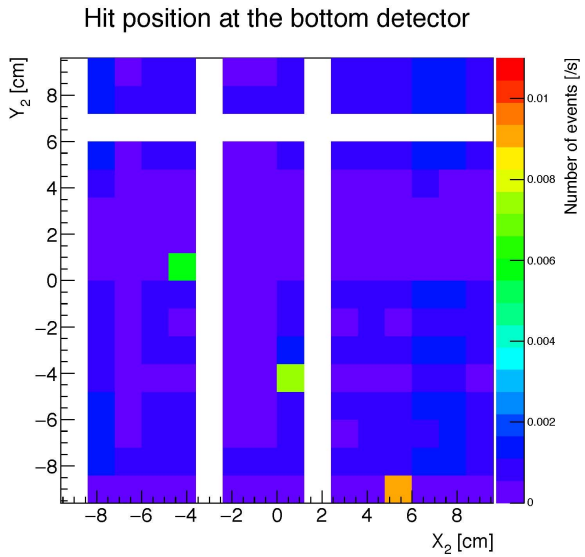




Top Detector

Bottom Detector





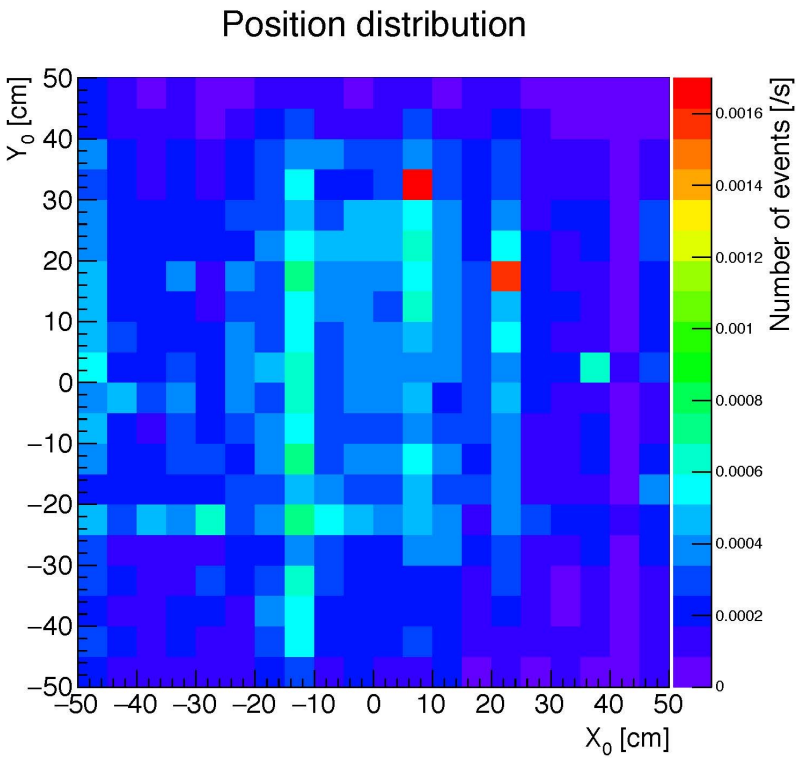
Top Detector

Bottom Detector

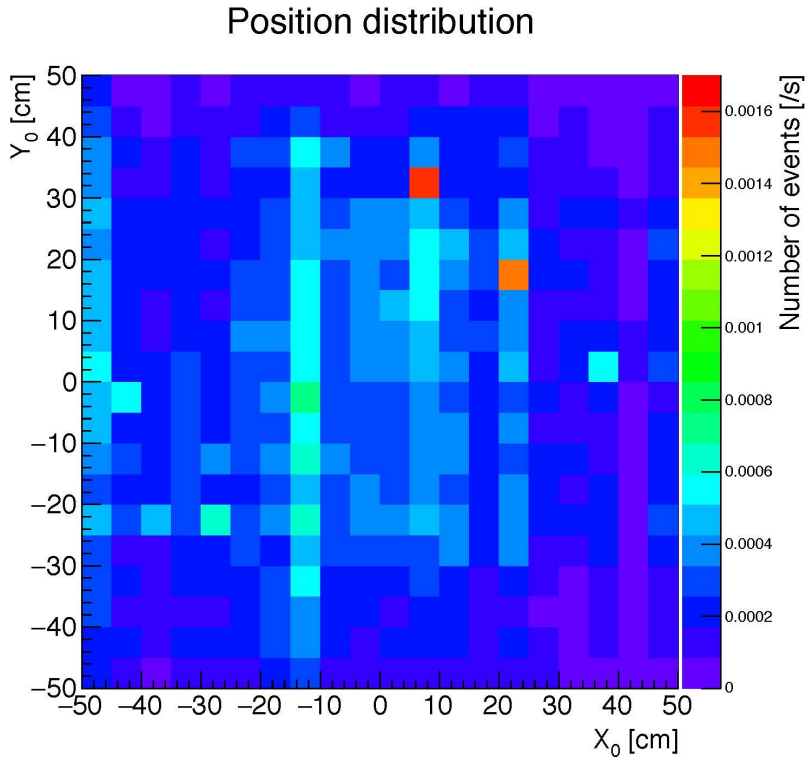
Without Lead (Pb)

With Lead (Pb)

Position Distribution



Without Lead (Pb)



With Lead (Pb)

Conclusion

- Built our own tracking detector for Muon Tomography. Found an efficient way to mass produce scintillation strips.
- Invented our own DAQ system to be used for Muon Tomography.
- DAQ system for 57 channels worked properly, and data was taken for analysis.

Future Plan

- Expand from 64 channels -> 128 Channels to increase acceptance.
- Performance evaluation of the DAQ Circuit.

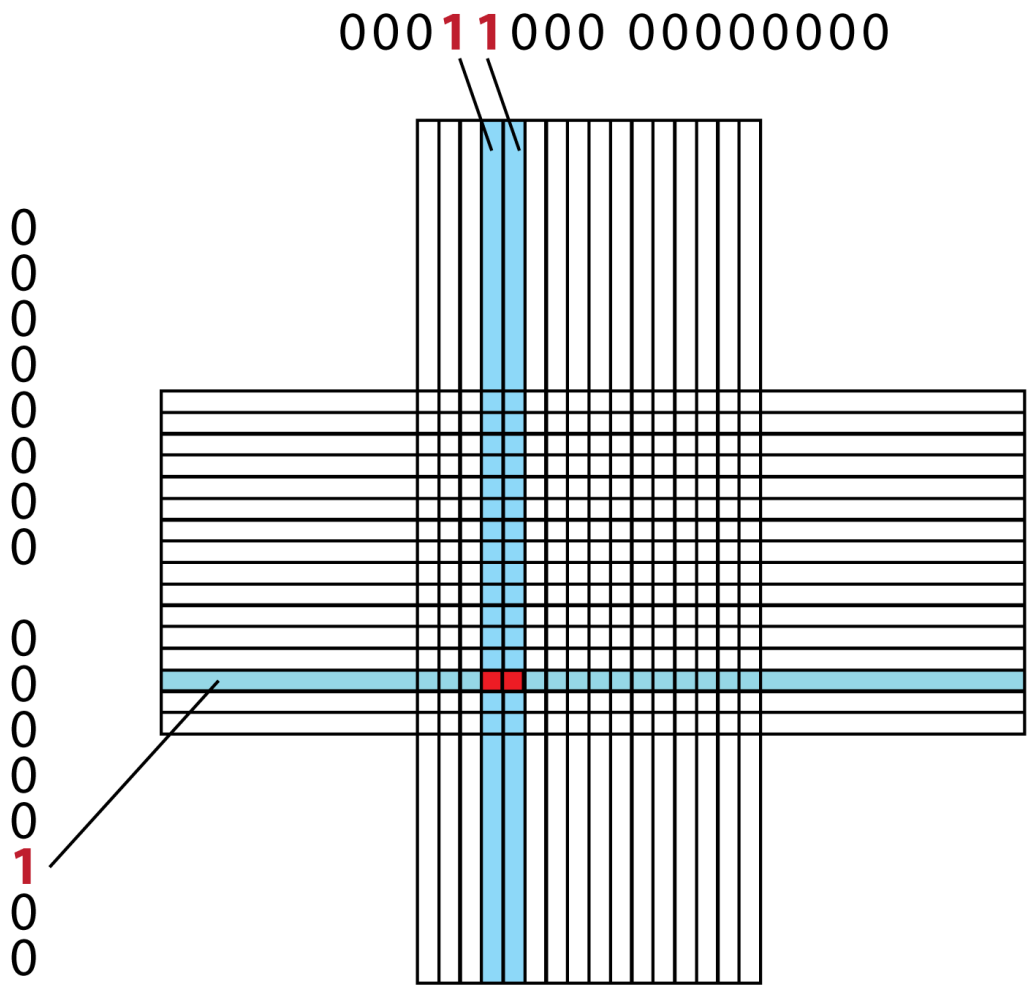
- Making a new version of the DAQ circuit (with upgrades)
  - Set-up a method to control the comparator threshold digitally.
  - Upgrading the Op-Amp circuit/parts to give a much clearer signal.

Back Up

Data Taking

1 set of Data

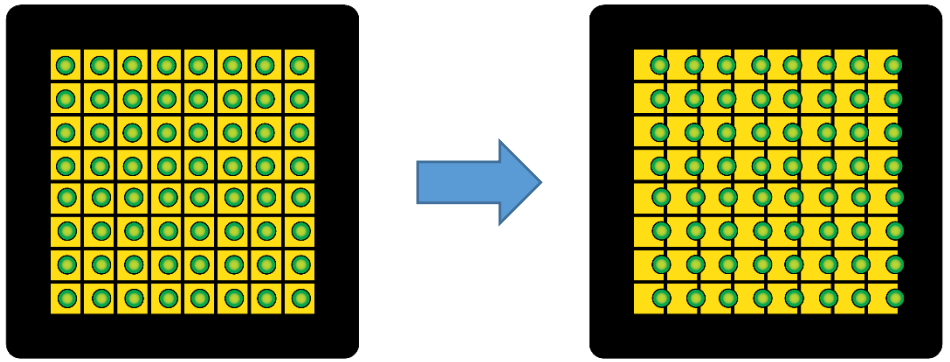
Time :	15 hrs 31 mins
Total Events :	25 779
Used for analysis: 1 hit in all layers :	4713 (18.3 %)
Used for analysis: 2 hits in one layer :	6166 (23.9 %)
2 hits in two layers :	5662 (21.9 %)



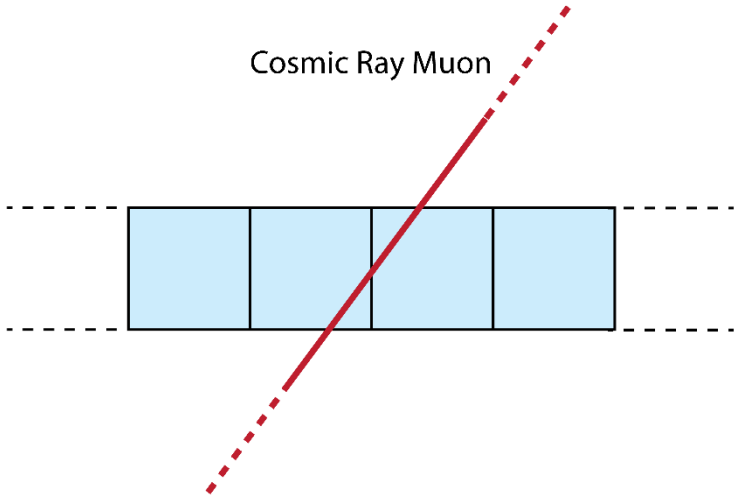
4 Layer Strip Detector – 2 hits

- Fiber Grid and MPMT not aligned properly
- Silicon Cookie

Crosstalk

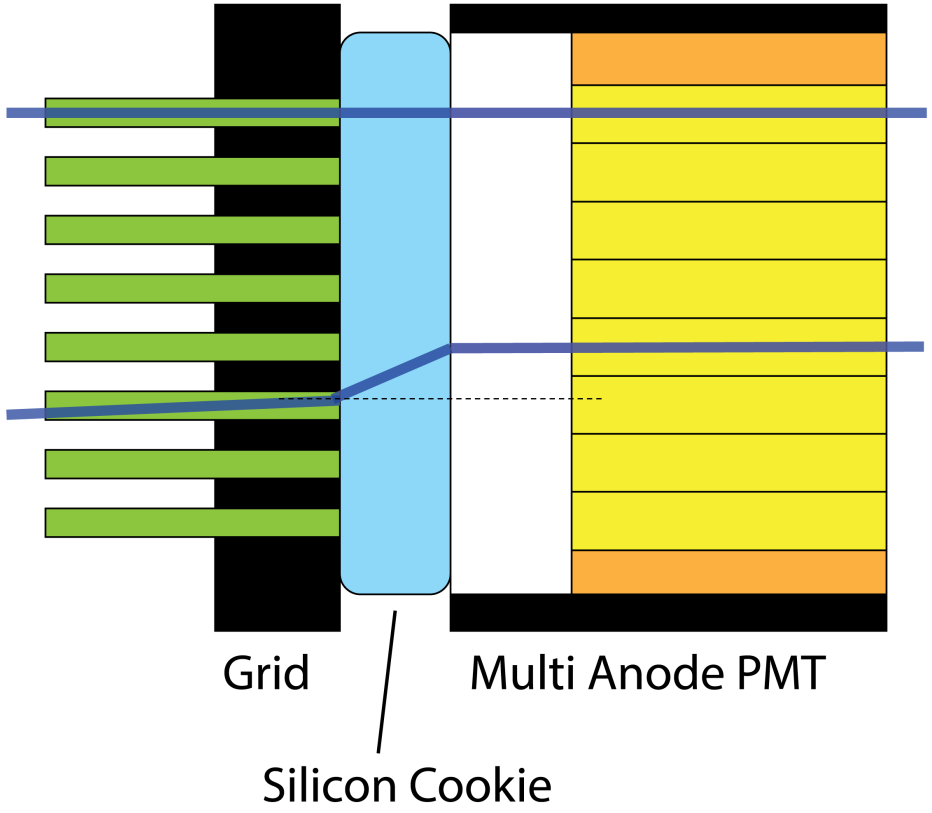


- Muon passing two scintillators
- Two muons passing two scintillators at the same time
- Noise



Crosstalk – Silicon Cookie

Cross section of the connection



Production method comparison

1.

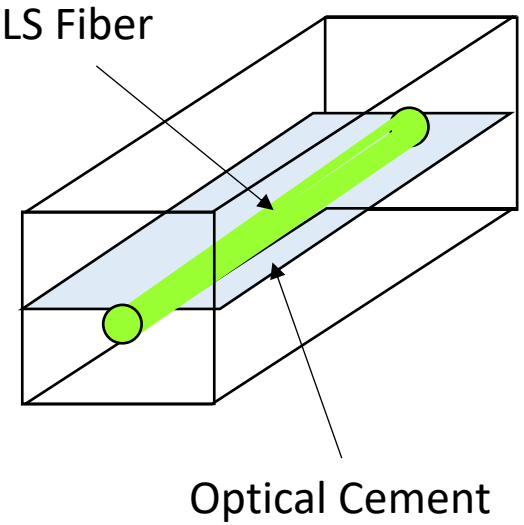
Laser cutter to make scintillation strips

2.

Sanding

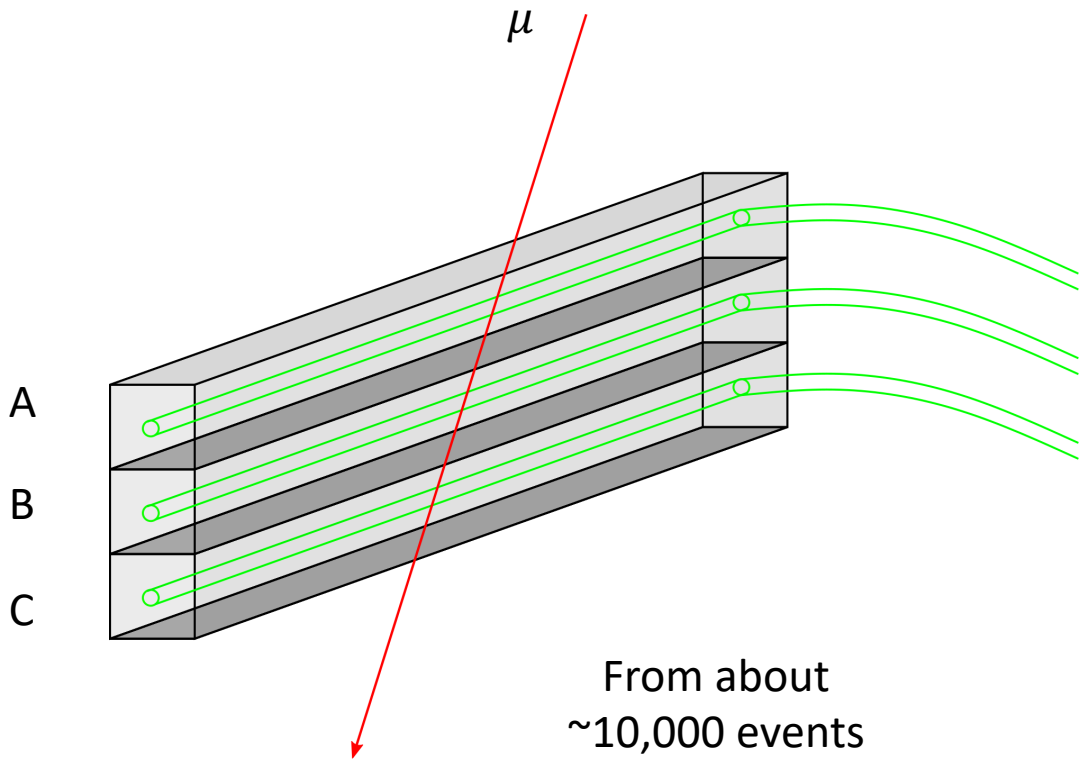
Horizontal milling machine to make scintillation strips

Vertical milling machine to make a groove for the WLS fiber



Efficiency

- $\varepsilon_B = \frac{\#(A \cap B \cap C)}{\#(A \cap C)}$



From about
~10,000 events

Strip Design	Efficiency
2 (Laser)	70 %
4 (Laser)	59 %
6 (Horizontal Milling Machine)	60 %
13 (Horizontal Milling Machine)	63 %

Circuits – Performance Evaluation

- Debugging – More than a week

Analog Circuit

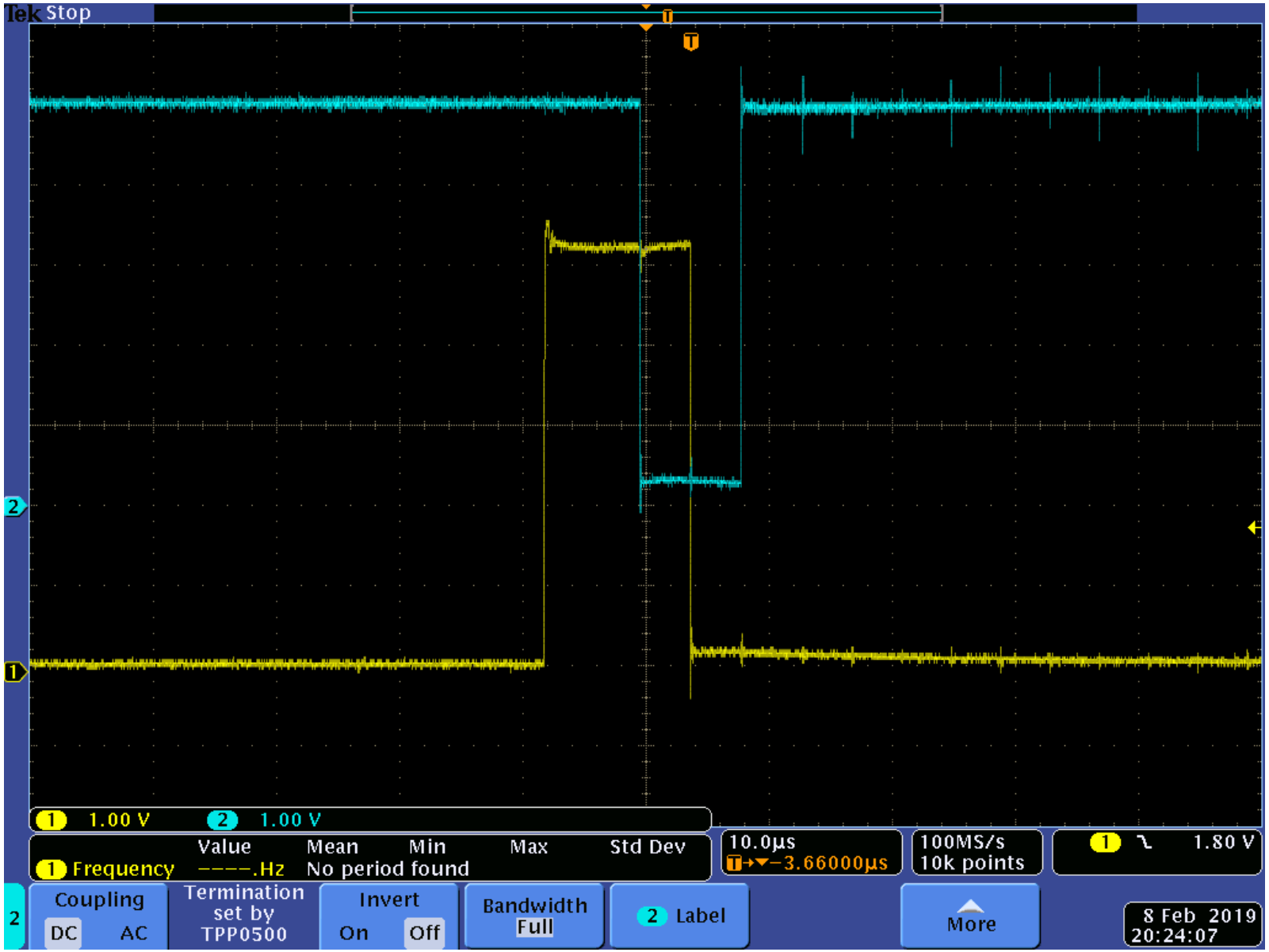
- 15 dead channels ➡ 7 dead channels
- Currently 57 channels are working

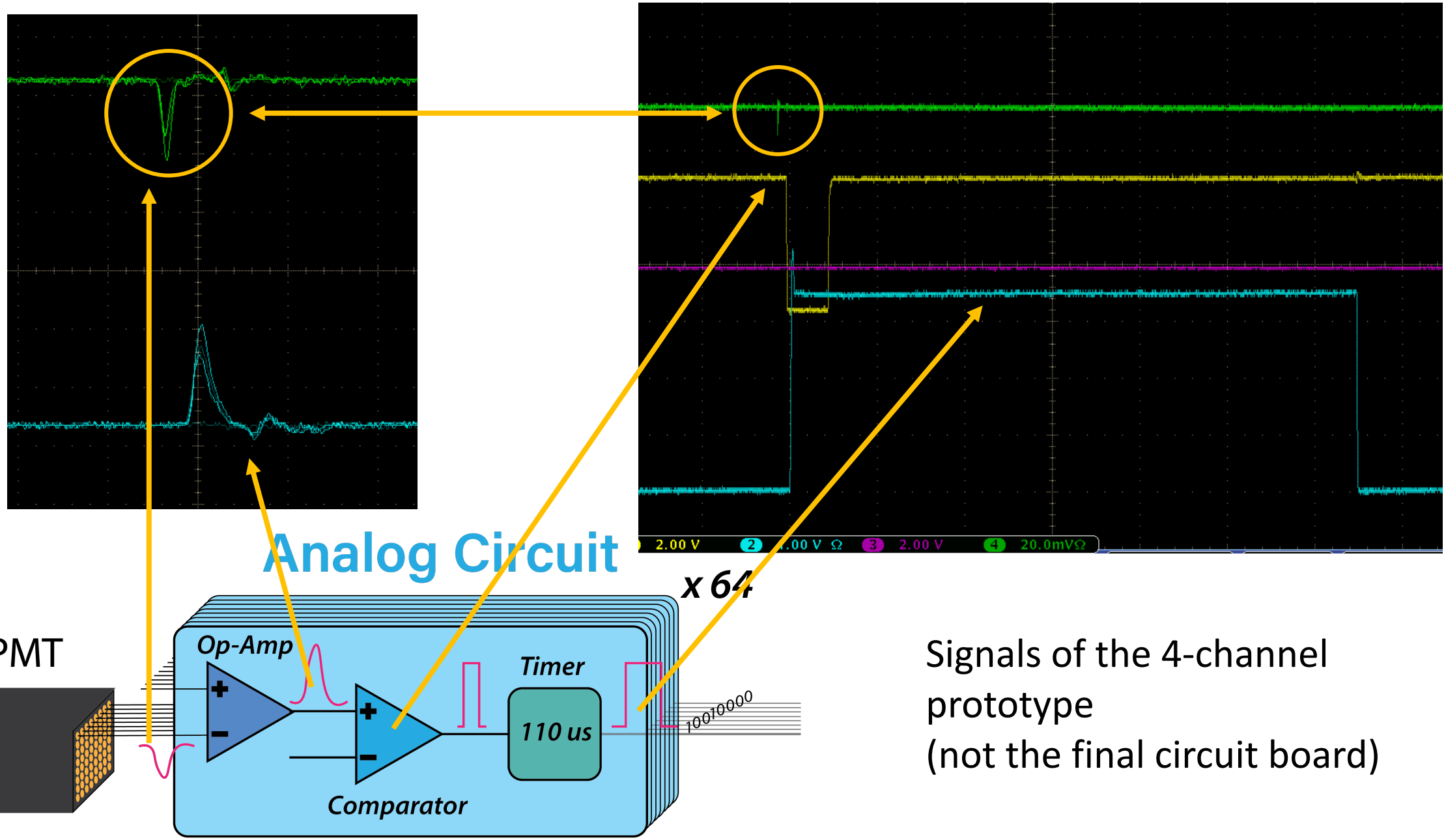
Logic Circuit

- All 64 channels work fine
- Delay of 2-4 μs latch trigger to arrive. So pulse from Timer (Analog Circuit) was 11 μs ➡ 110 μs

The reason for 110 µs signal :

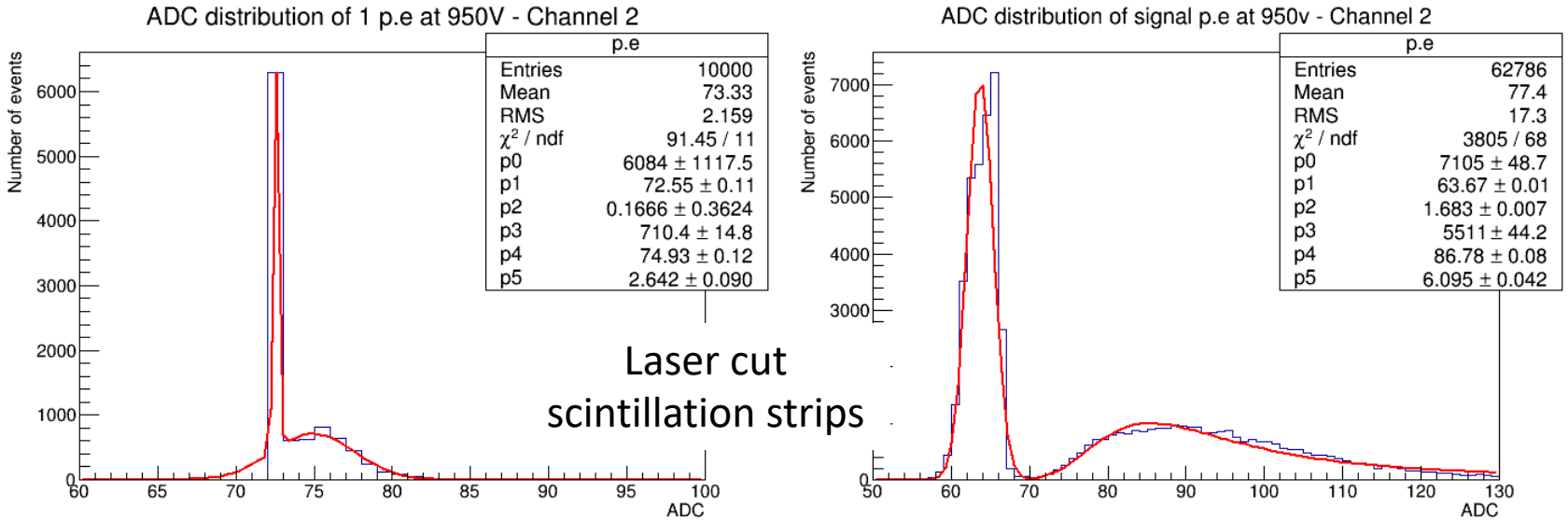
- Delay of 2-4 µs latch trigger to arrive
- Cosmic ray Muon rate is small



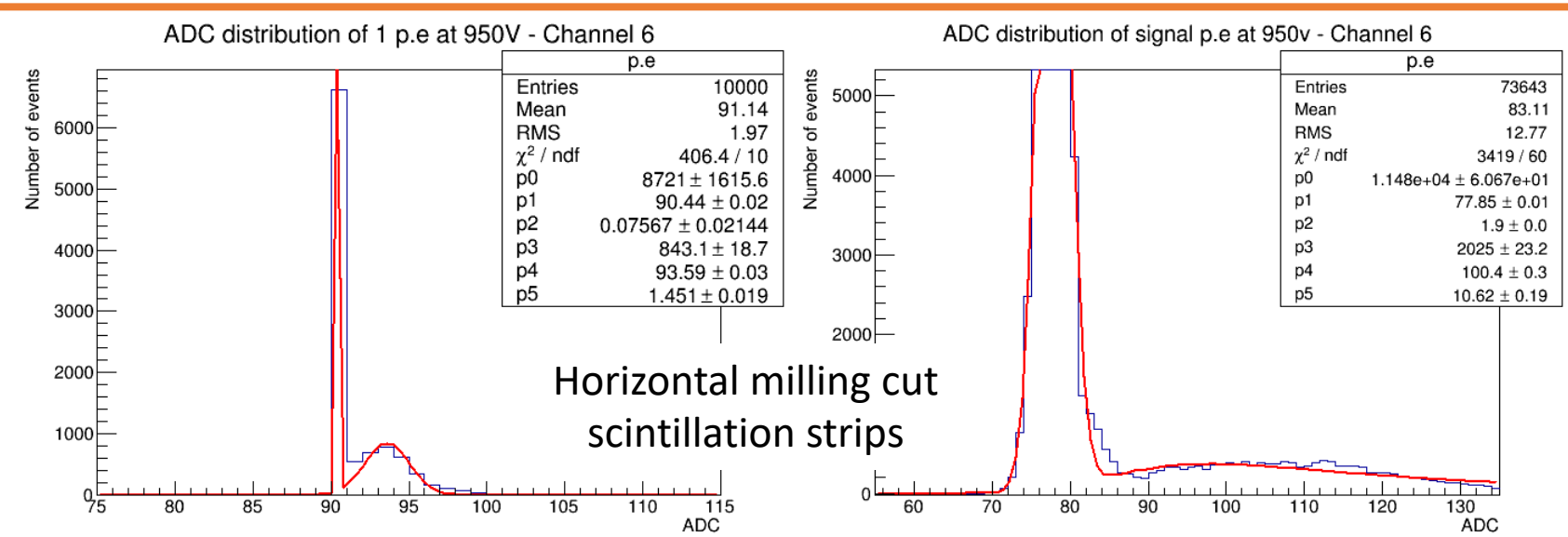


Signals of the 4-channel prototype
(not the final circuit board)

Measurement of photo electrons

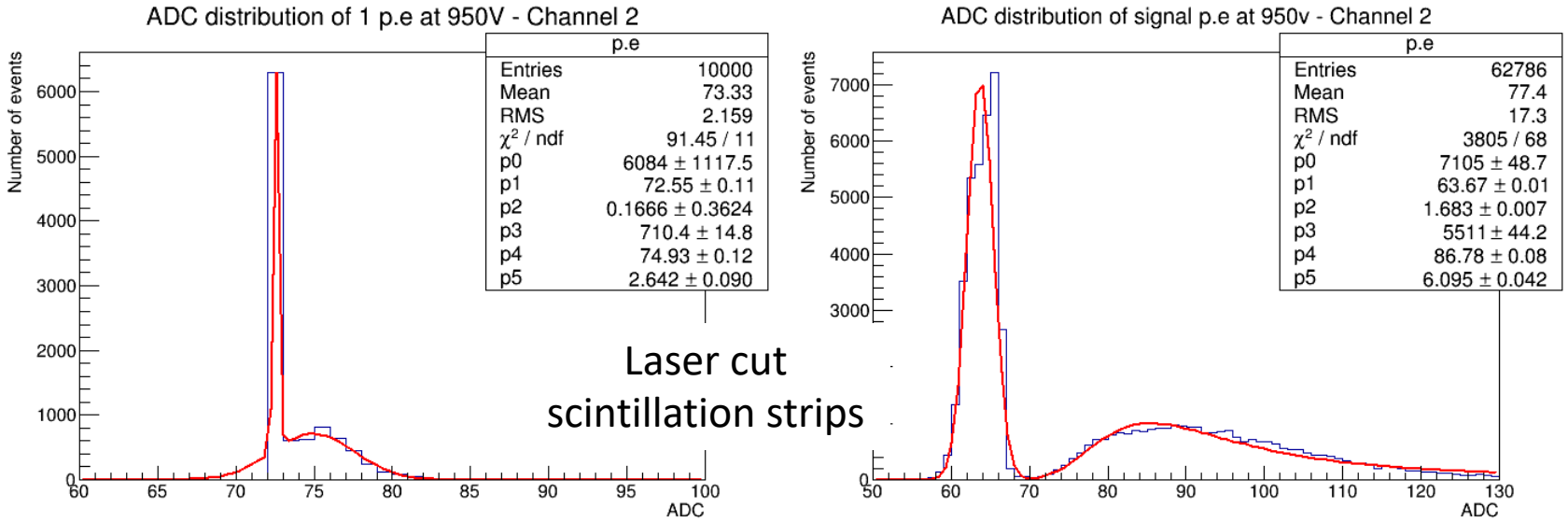


Laser cut scintillation strips

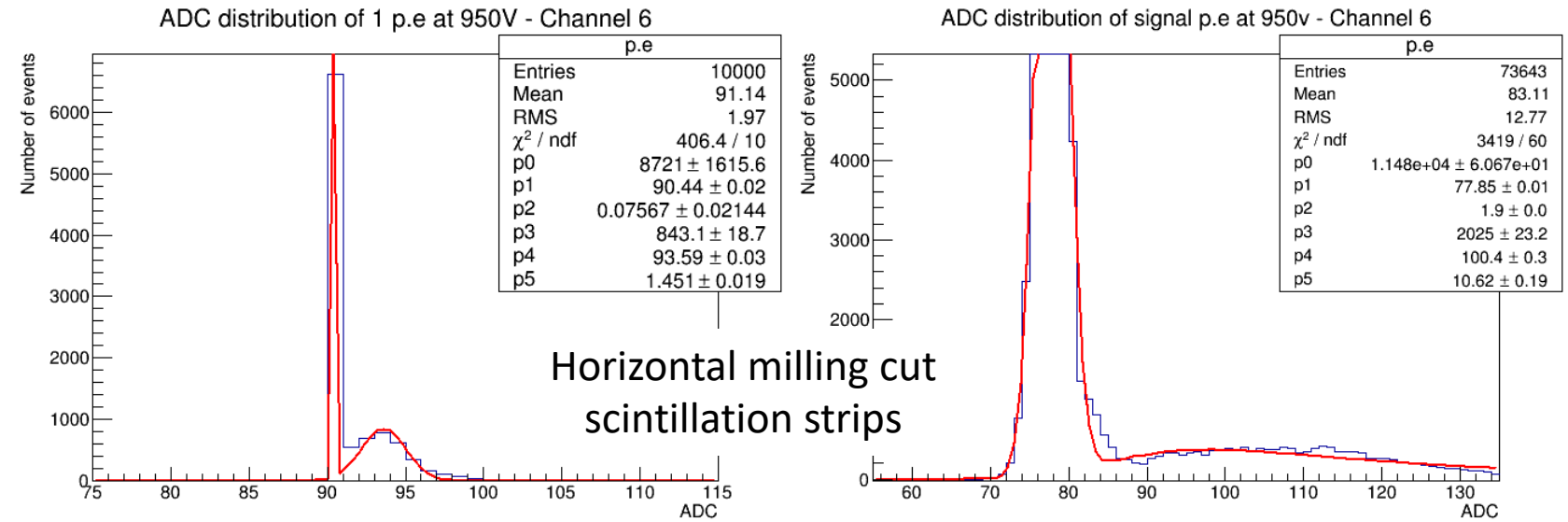


Horizontal milling cut scintillation strips

Measurement of photo electrons



Laser cut scintillation strips



Horizontal milling cut scintillation strips

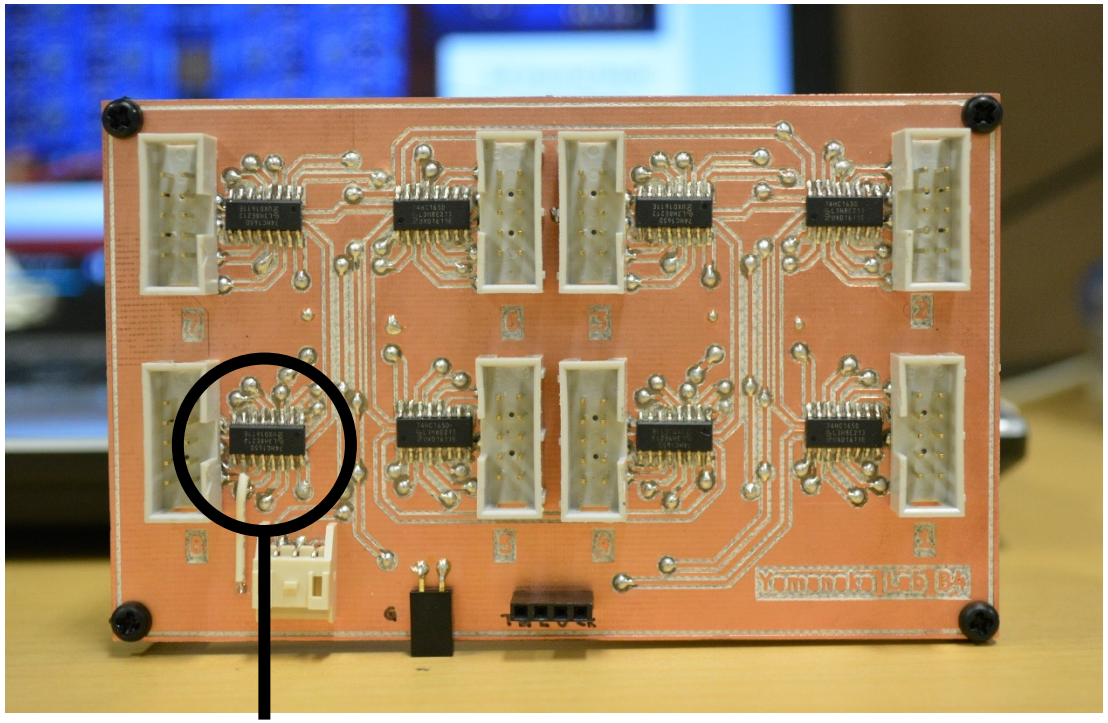
Channel	ADC (counts)	No. of p.e
1 p.e	2.38	1
Signal	23.11	> 9

Channel	ADC (counts)	No. of p.e
1 p.e	3.15	1
Signal	22.55	> 7

64 ch Logic Circuit

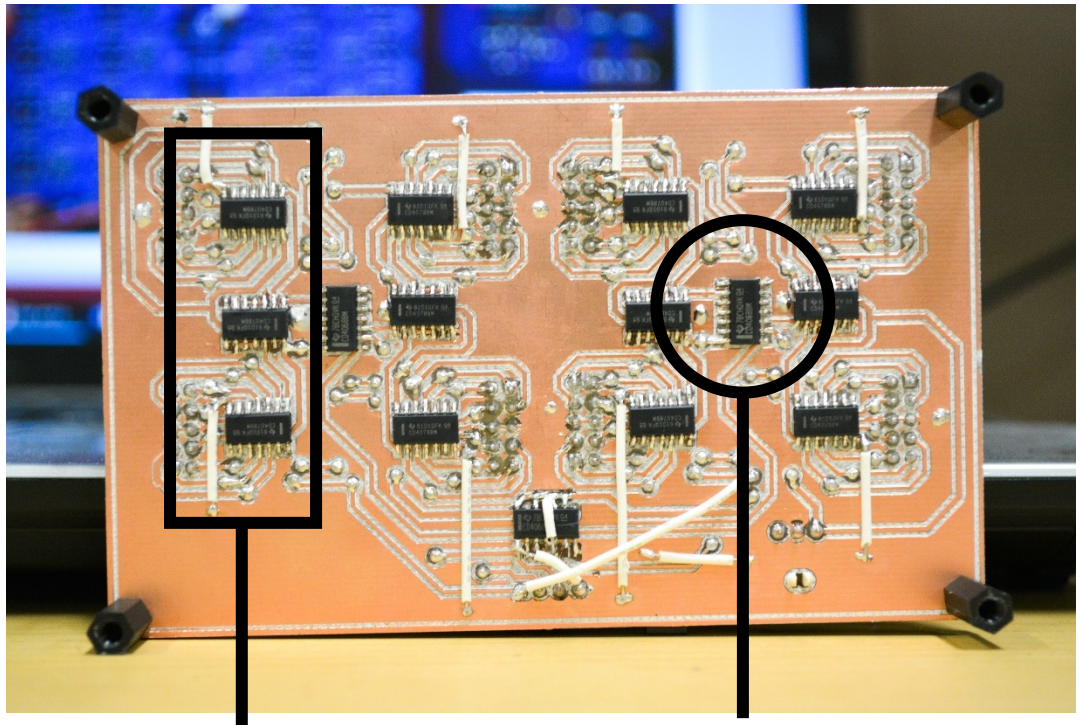
- All 64 channels work fine

Front



8 bit parallel to serial shift register

Back



Fan-in

Coincidence Counter