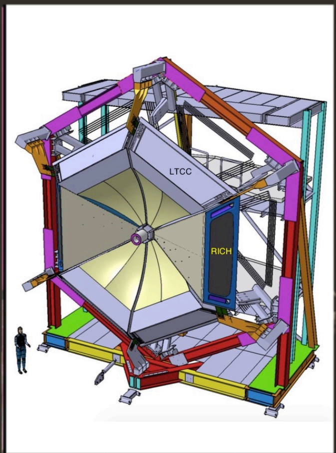
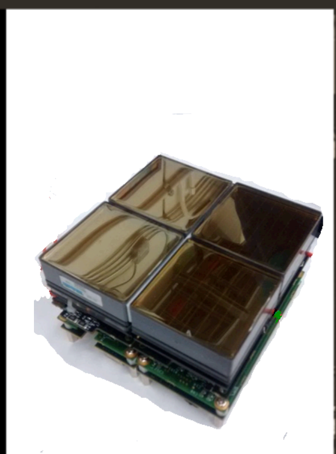
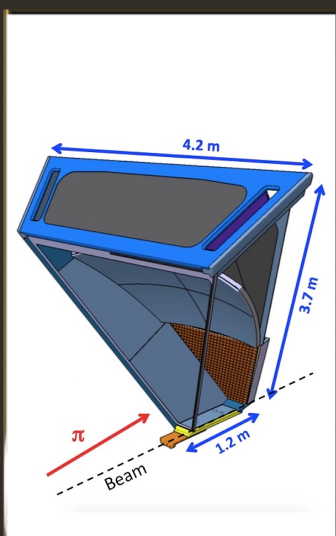






Università degli Studi di Ferrara

DOTTORATO DI RICERCA IN
FISICA

CICLO XXIX

COORDINATORE Prof. Vincenzo Guidi

The CLAS12 RICH readout electronics: design, development and test

Settore Scientifico Disciplinare FIS/04

Dottorando
Dott. Turisini Matteo

Tutore
Dott. Mantovani Fabio

Tutore Aggiunto
Dott. Contalbrigo Marco

Overview

CLAS12 RICH

- Scientific objectives
- Detector layout
- Electronics requirements

The Readout Electronics

- Design
- Performance:
  - Bench test
  - Light Sensor
  - Radiation tolerance
  - Beam test

Conclusion and outlook

- Applications / Spillover

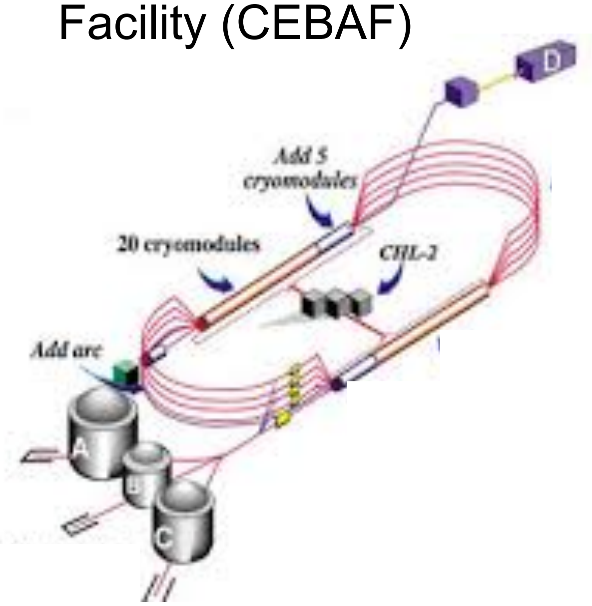
Strategy

1. Satisfy specs from CLAS12
2. Develop for imaging applications
3. Compact, On detector, Easy to use

Scientific Objectives

- Explore the nature of the matter by scattering experiments
- Thomas Jefferson Laboratory (JLAB) Virginia USA
- Ring Imaging Cherenkov (RICH) detector

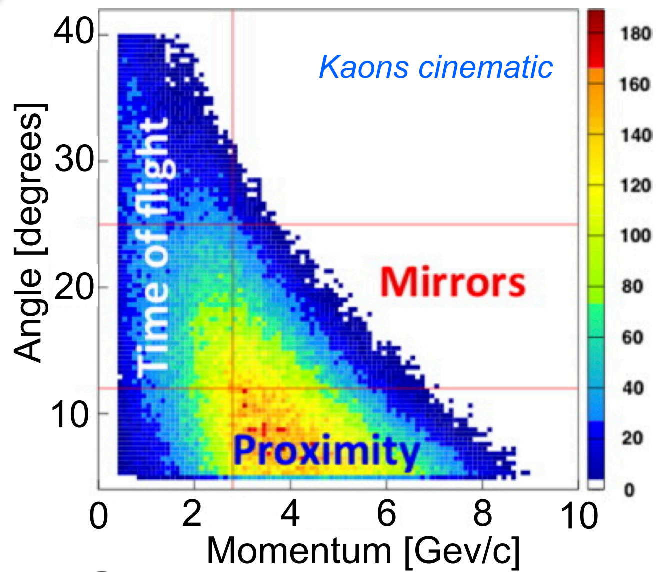
Continuous Electron Beam Accelerator Facility (CEBAF)

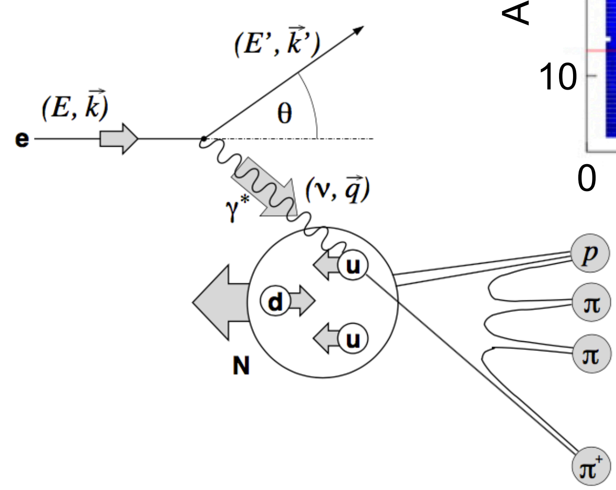


upgraded energy 12 GeV

with RICH

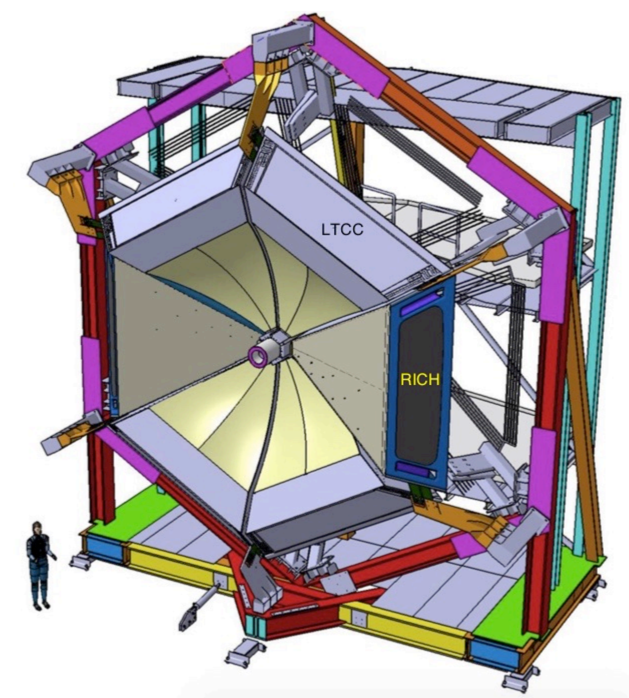
improve hadron identification



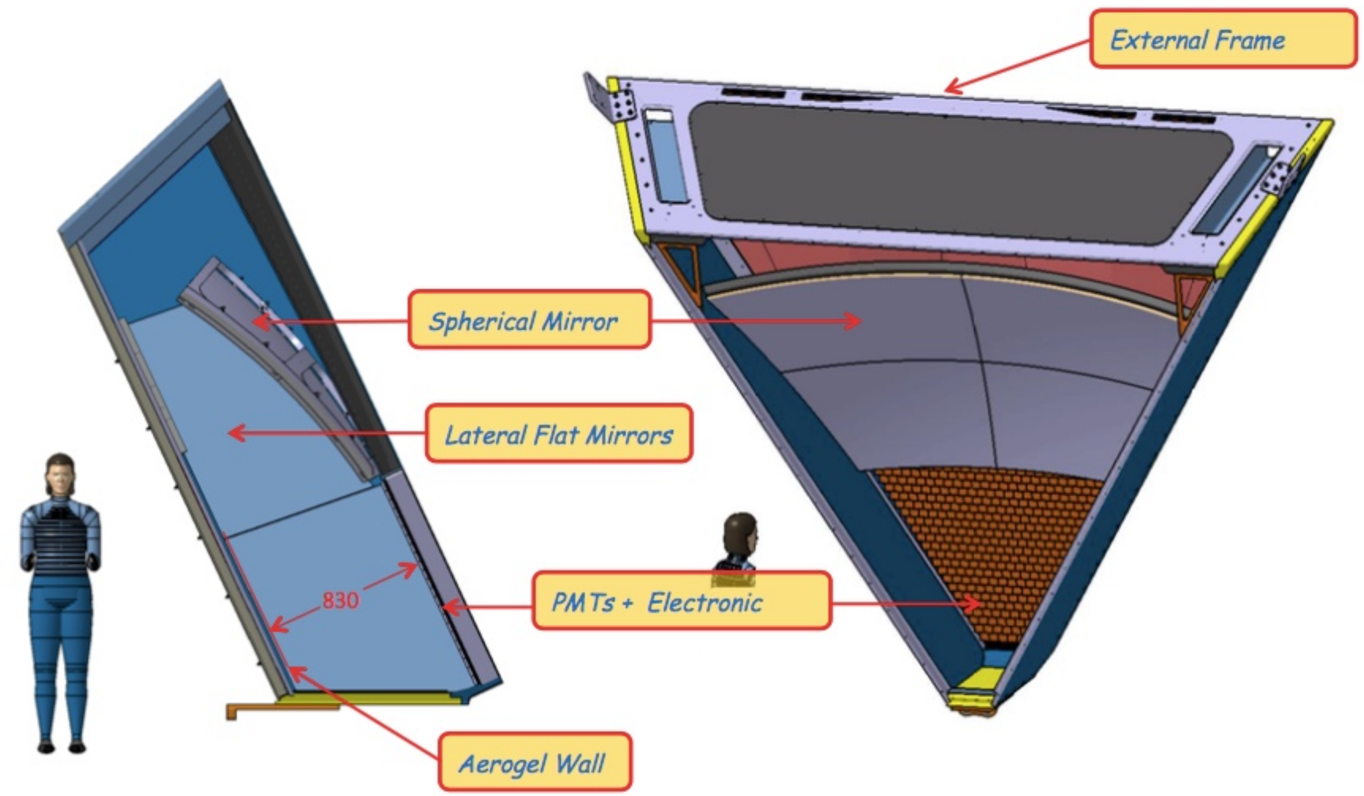


flavor tagging

CEBAF Large Acceptance Spectrometer (CLAS12)



CLAS12 RICH module

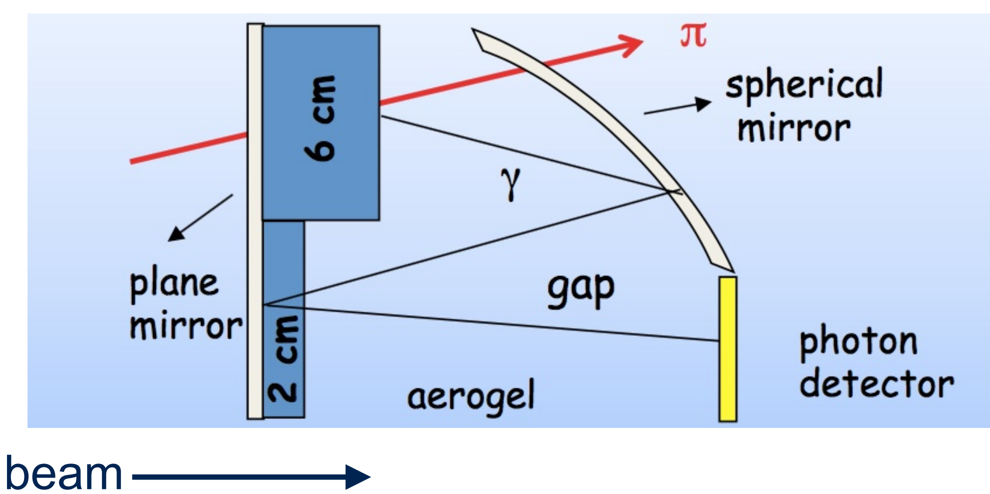


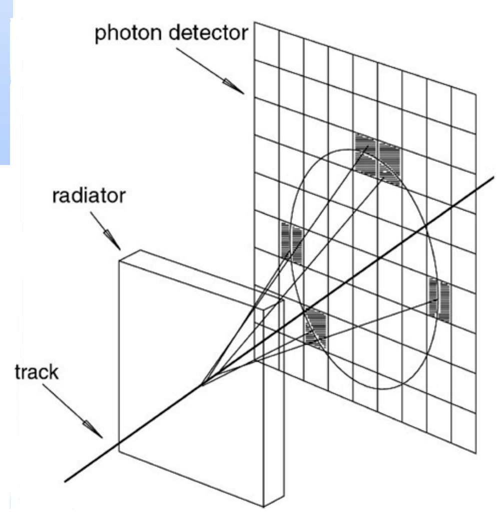
first idea 2009
first run 2017

π,K rejection power 1:500
in 3-8 GeV/c momentum range
up to 25 degrees azimuthal

Aerogel Radiator
New! Hybrid optics
New! Multi Anode Photomultiplier Tubes
single photon

a lot of R&D!





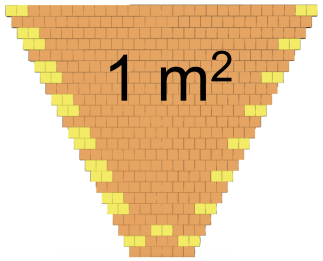
RICH principle
measure Cherenkov angle
using photon hits position

History: *Cherenkov Effect 30s*
RICH idea 70s
fully operative RICH 90s

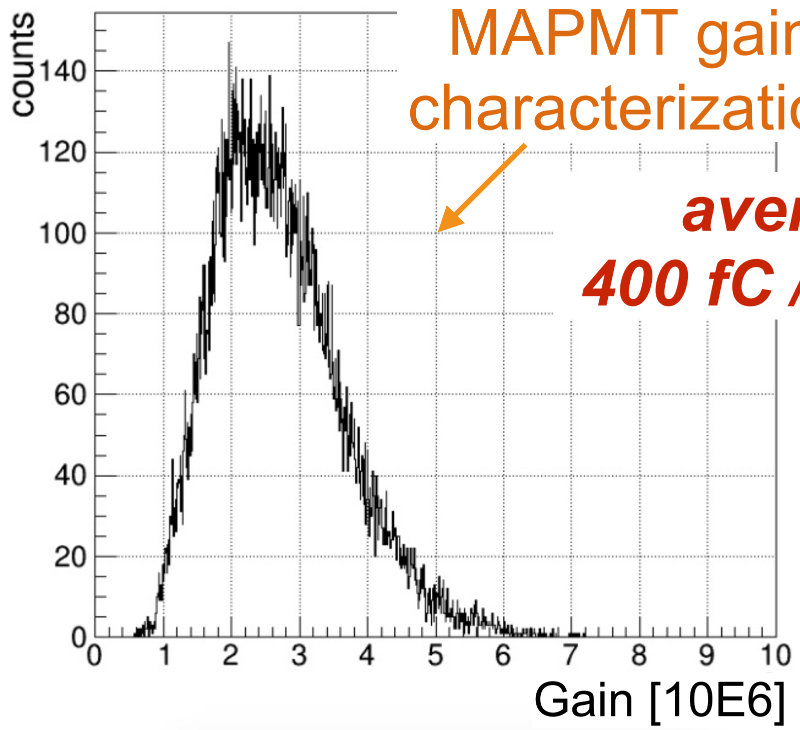
RICH electronics requirements

Single Photo Electron (SPE)

	Requirement	Unit
Efficiency 100%	>50	fC
Time resolution	1	ns
Rate	20	kHz
Latency	8	μs
Crosstalk	3-5	%
Radiation Tolerance	50	10E9 Neq
	137	Rad
Power	30	mW/ch



25k channels



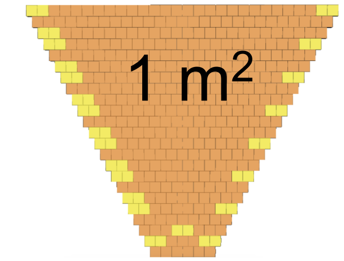
Modularity (scalability)
Equalization (uniformity)
Automation (generic user)
Autonomy (independent)
Slow Control (monitoring)

10 years life cycle →

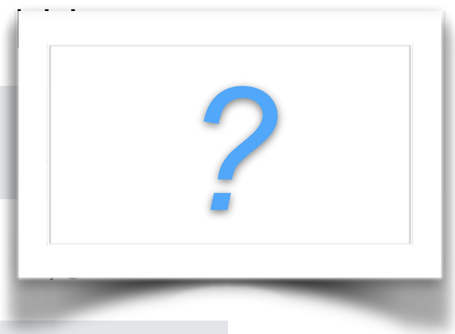
RICH electronics requirements

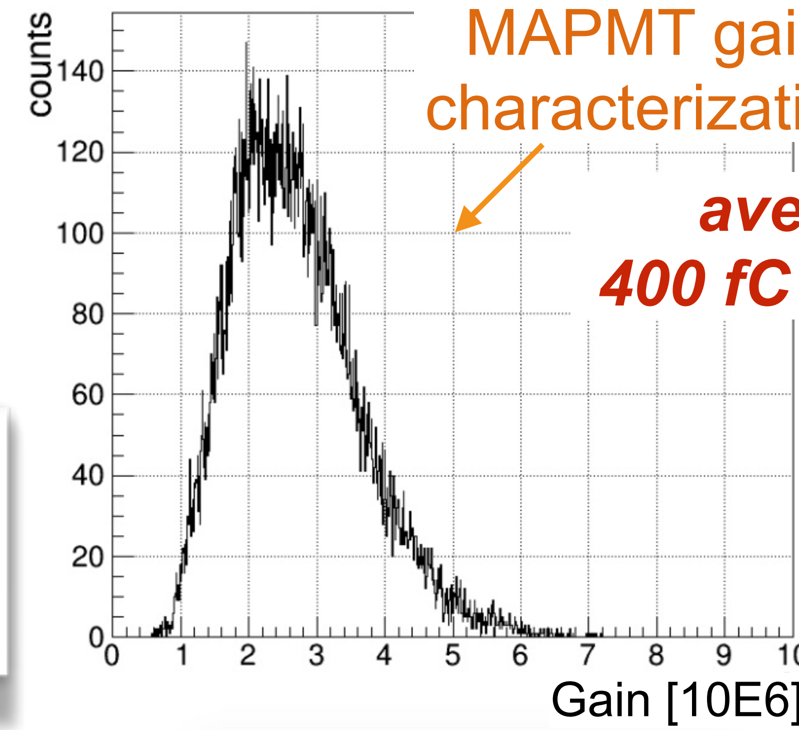
Single Photo Electron (SPE)

25k channels



	Requirement	Unit
Efficiency 100%	>50	fC
Time resolution	1	ns
Rate	20	[illegible]
Latency	8	[illegible]
Crosstalk	3-5	[illegible]
Radiation Tolerance	50	10E9 Neq
	137	Rad
Power	30	mW/ch



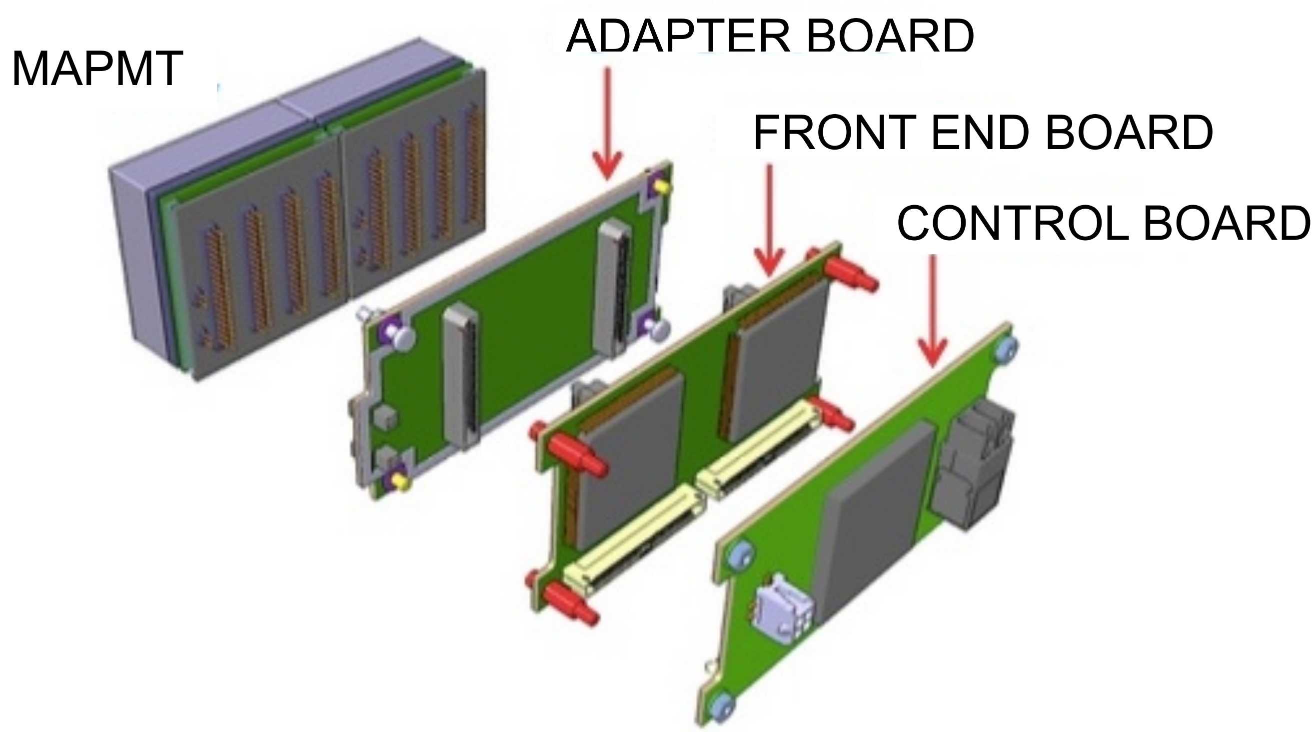


10 years life cycle →

Modularity (scalability)
Equalization (uniformity)
Automation (generic user)
Autonomy (independent)
Slow Control (monitoring)

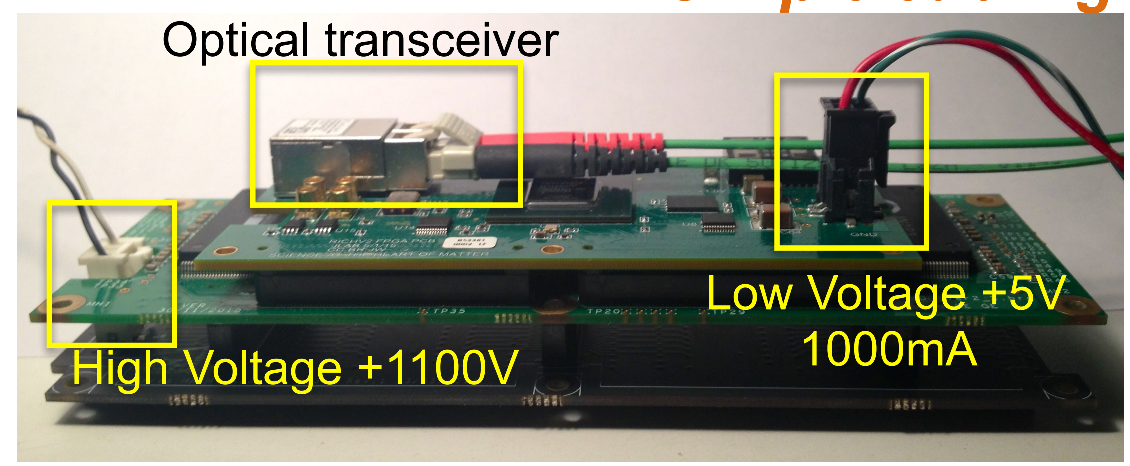
Design

RICH electronics assembly

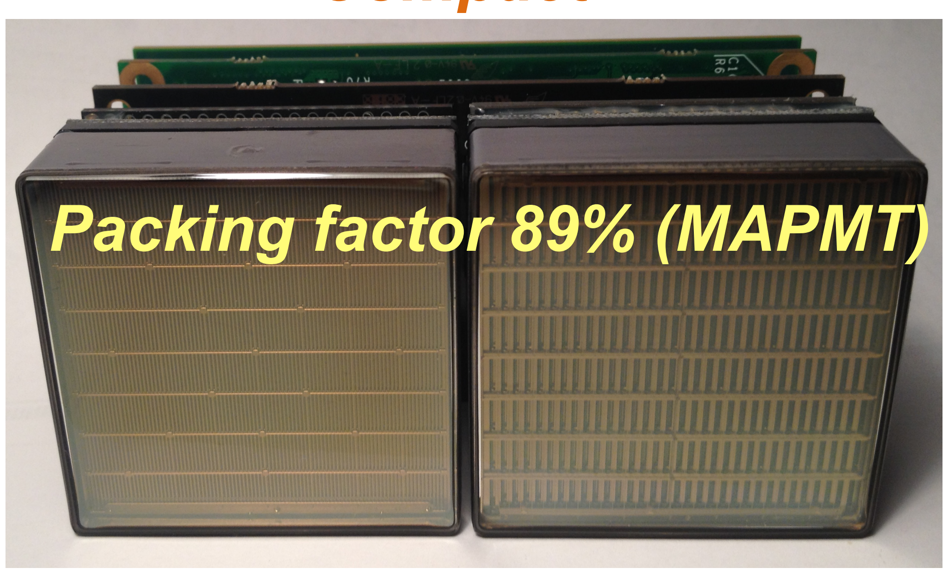


On detector!
Specialized but Flexible

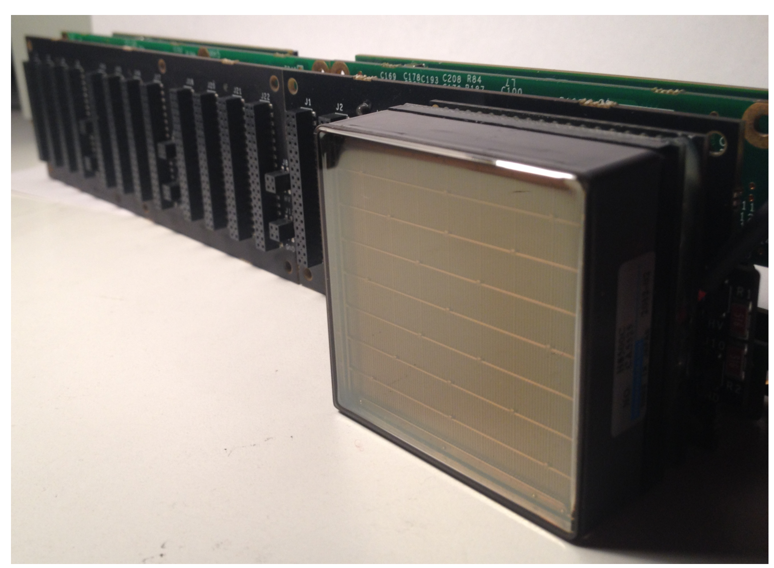
Simple cabling



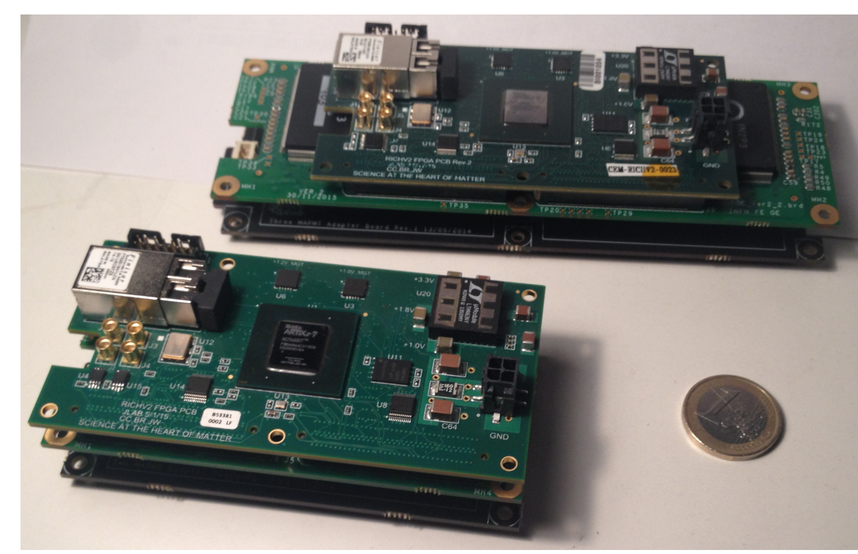
Compact



Modular

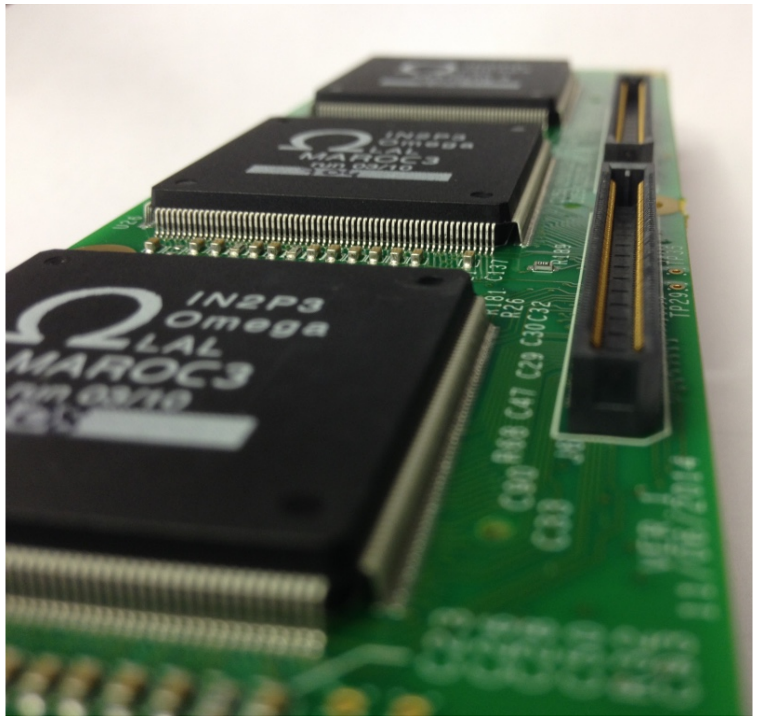


2 variants: 128 / 192 channels



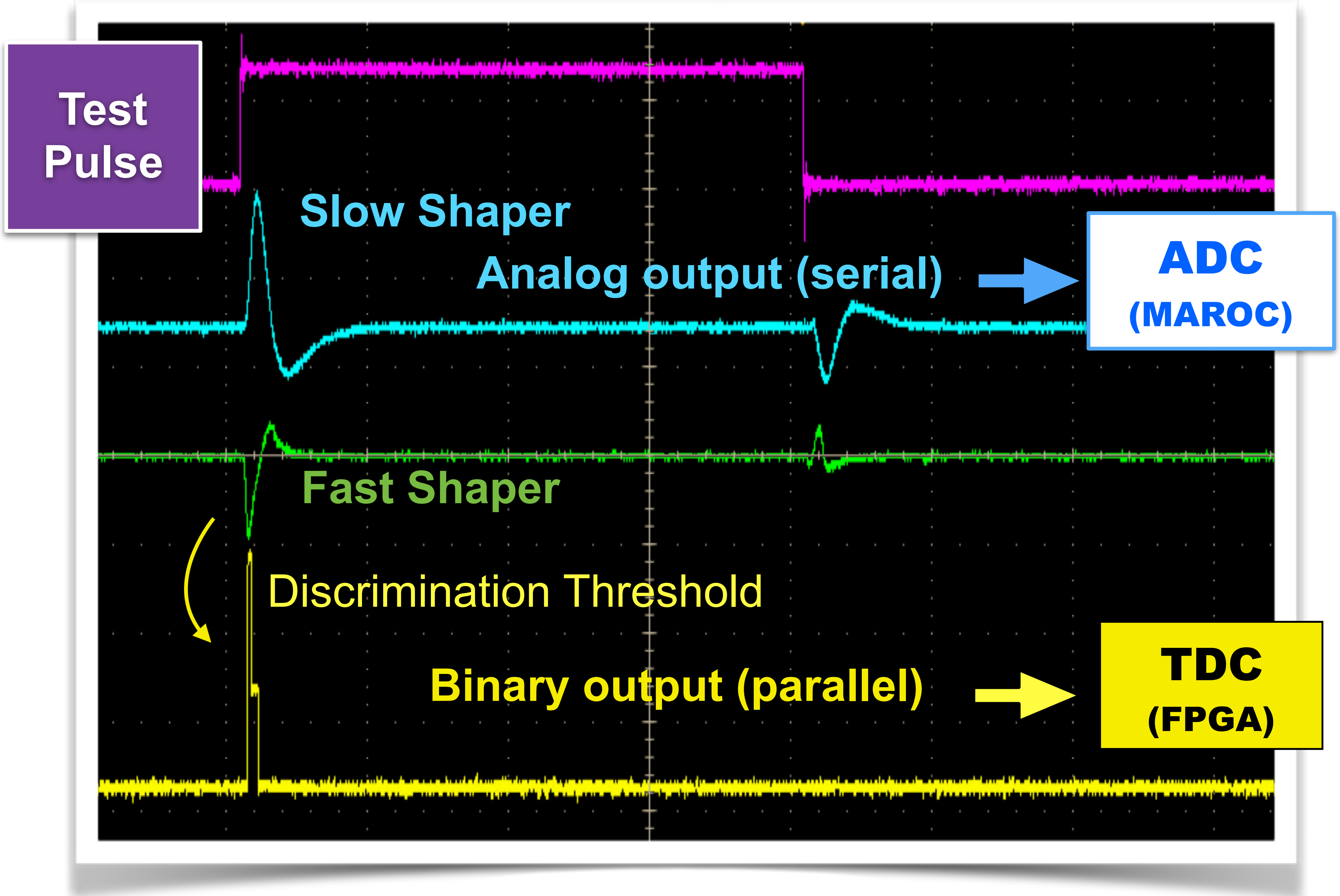
Features

- MAROC (**M**ulti **A**node **R**ead**O**ut **C**hip)
  - 64 input
  - 64 binary output
  - Common threshold 10 bits
  - Charge output (12 bit, **ADC**)
  - Individual preamplifier (8 bit, gain 0 to 4)
  - Highly configurable shaping section
  - Total 829 configuration bits
- Test Pulse (12 bit, 0-5pC)



- FPGA (**F**ield **P**rogrammable **G**ate **A**rray)
  - Reference clock 1 GHz
  - Event builder
  - Stream data
  - Scalers
  - **TDC** and 8 microsecond latency
  - Temperature and voltage monitor
  - Optical Ethernet 2.5 Gbps
- Protocol
  - Custom (Large apparatus)
  - TCP/IP (Small setup)

Signal processing & data acquisition modes



Charge measurement
Small latency (150 ns)

equalization
calibration
monitoring
in CLAS12

Discrimination and timing
Arbitrary latency (8 μs)

physics runs
in CLAS12

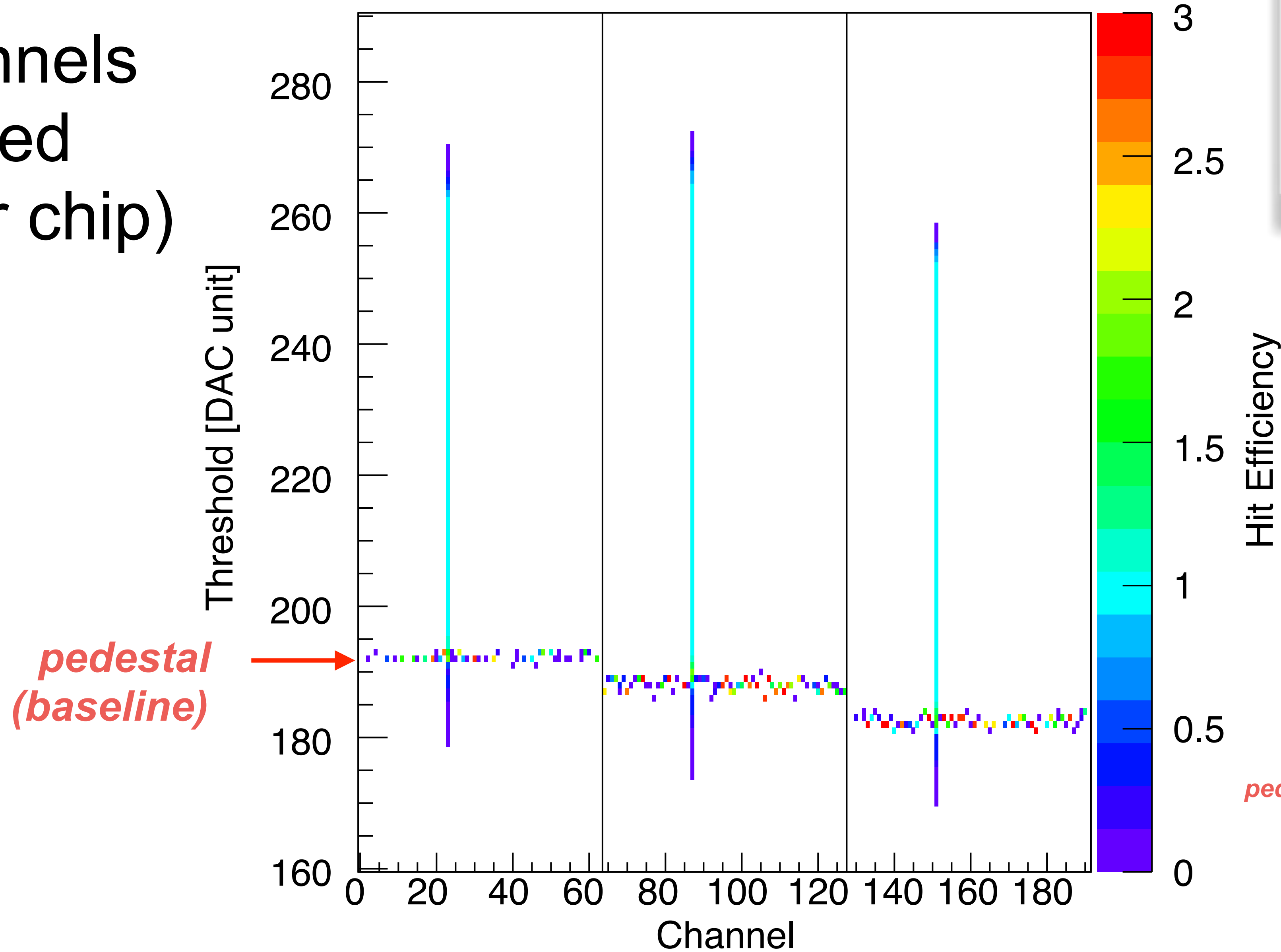
external, internal **+ self triggered** data acquisition

Discrimination Efficiency

On board pulser

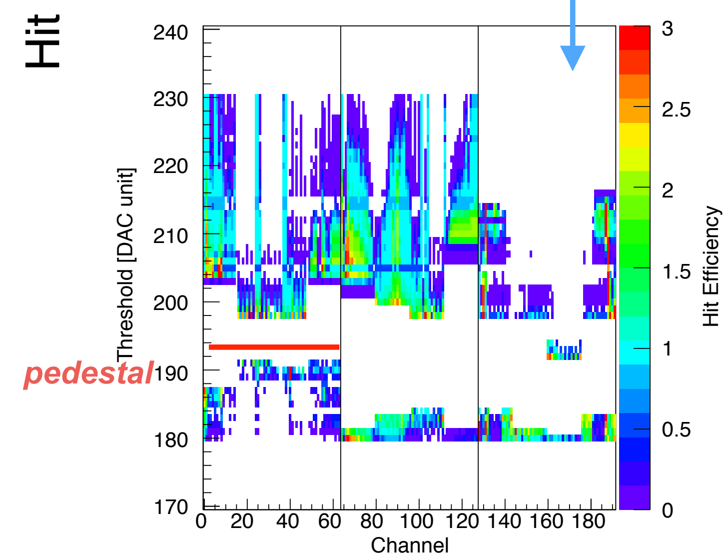
3 channels injected (one per chip)

INPUT: 40 fC = 1/10 SPE



Clean discrimination few DAC above the pedestal
1 DAC ~ 1 fC

same condition but with the very first prototype

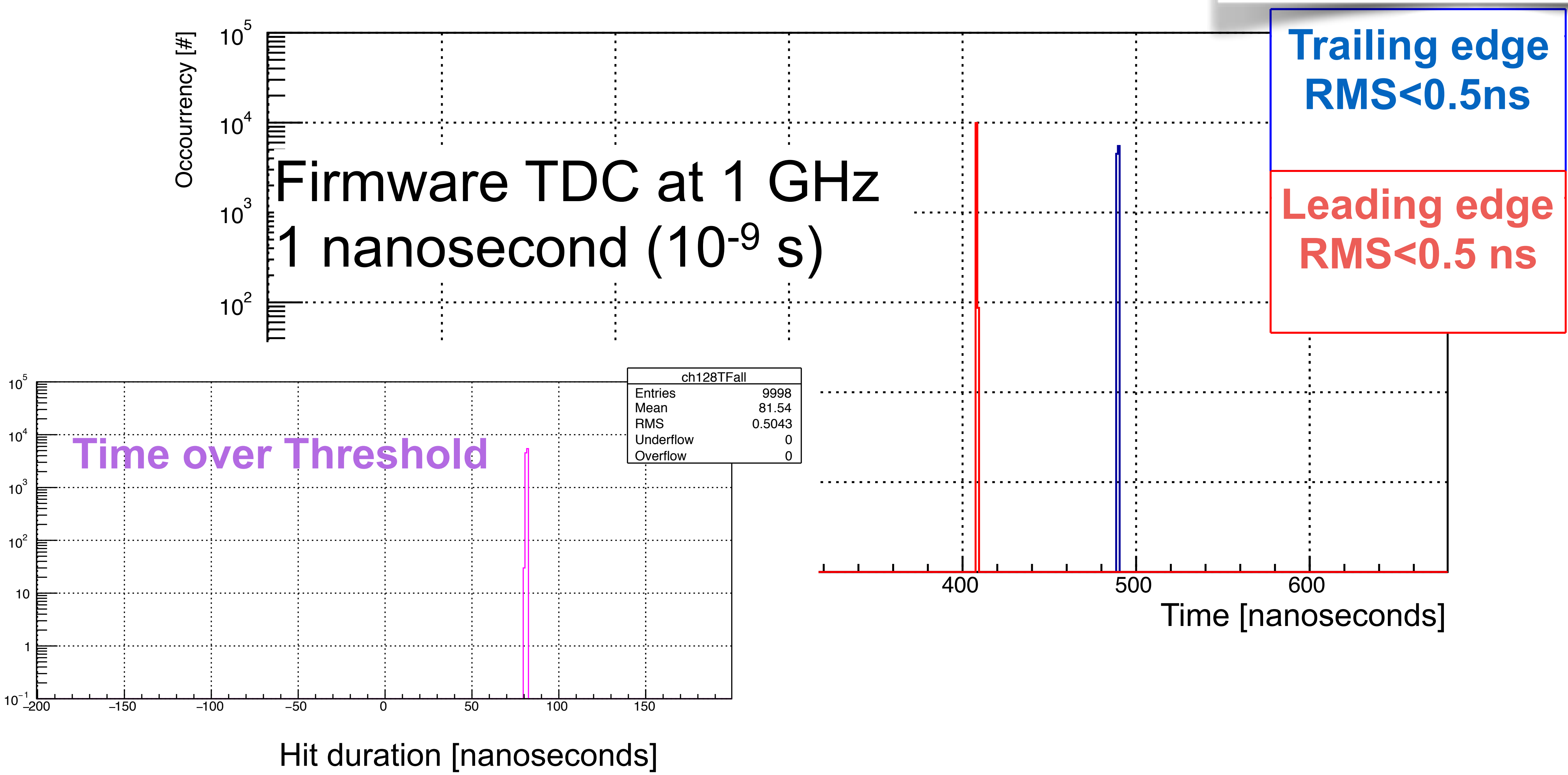


Time Resolution

On board pulser

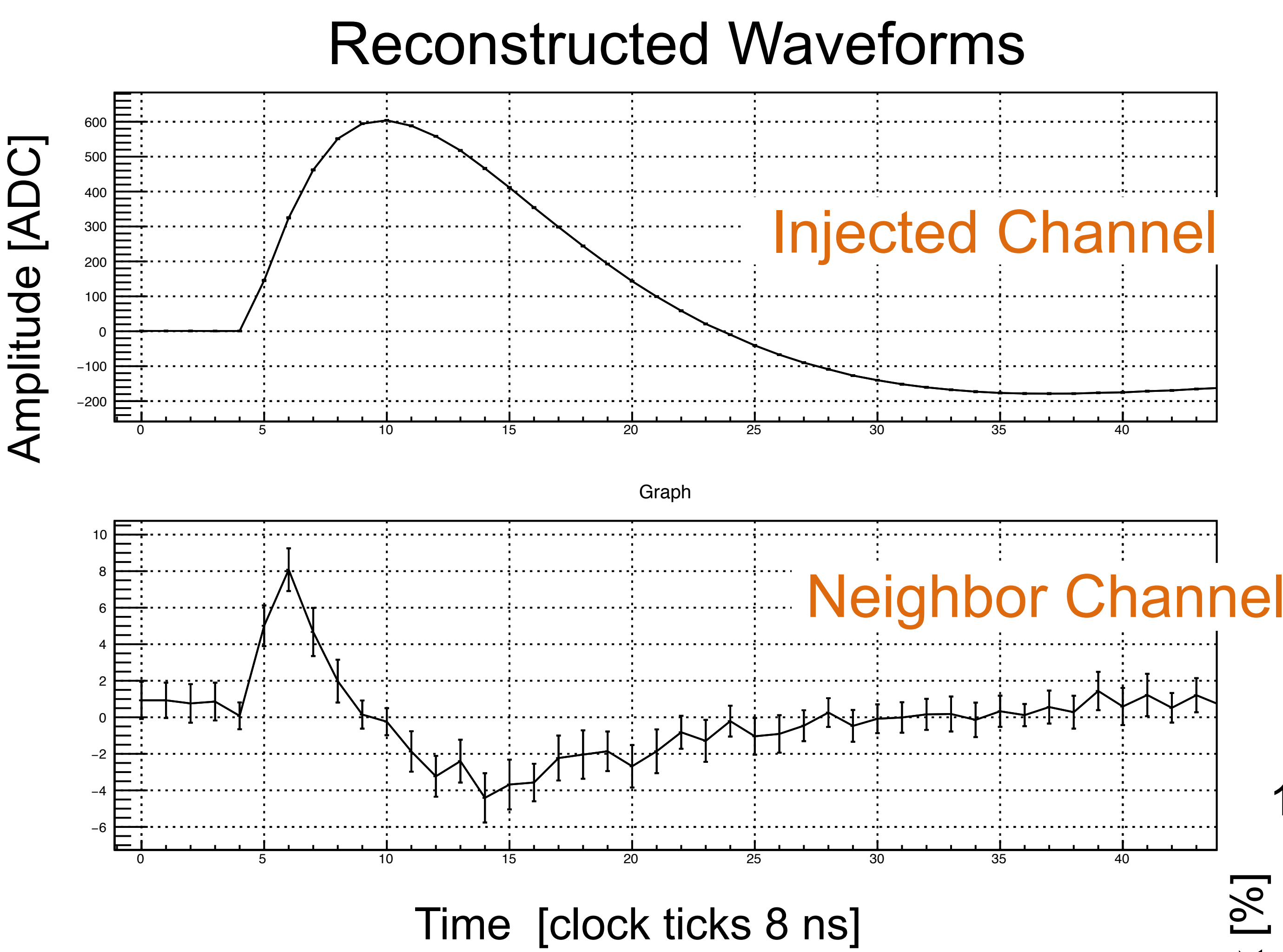
Fluctuation below sensitivity (at fixed charge)

INPUT: 40 fC = 1/10 SPE



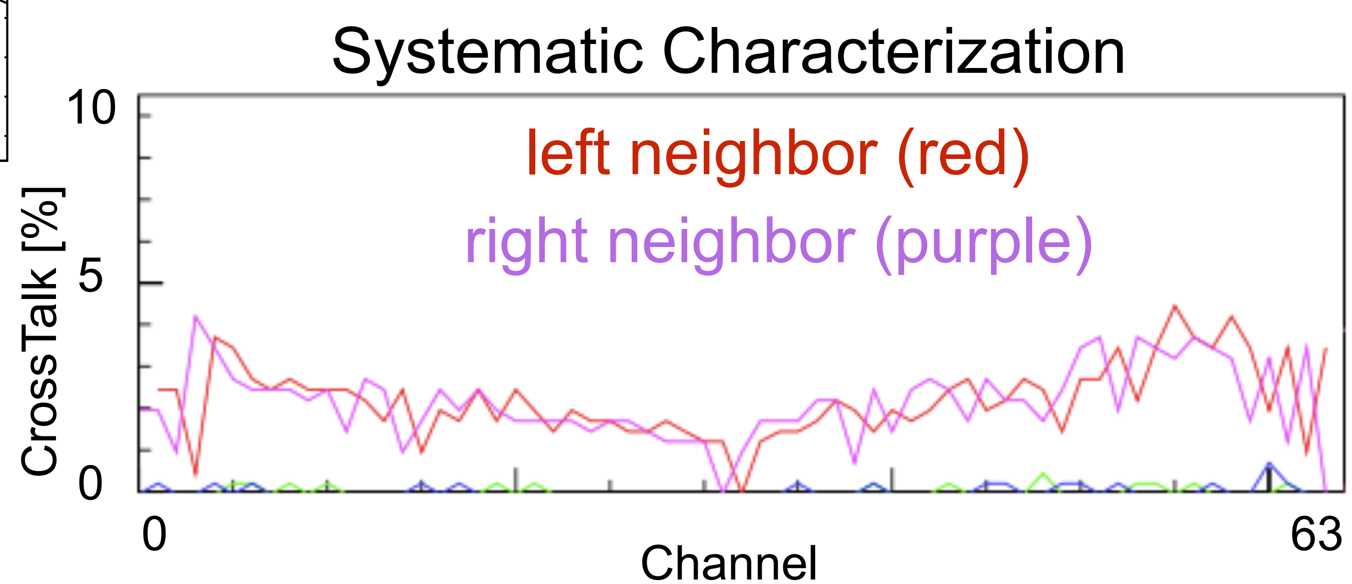
Cross Talk

External Pulse Injector



less than 5%
can be suppressed
offline using TDC data

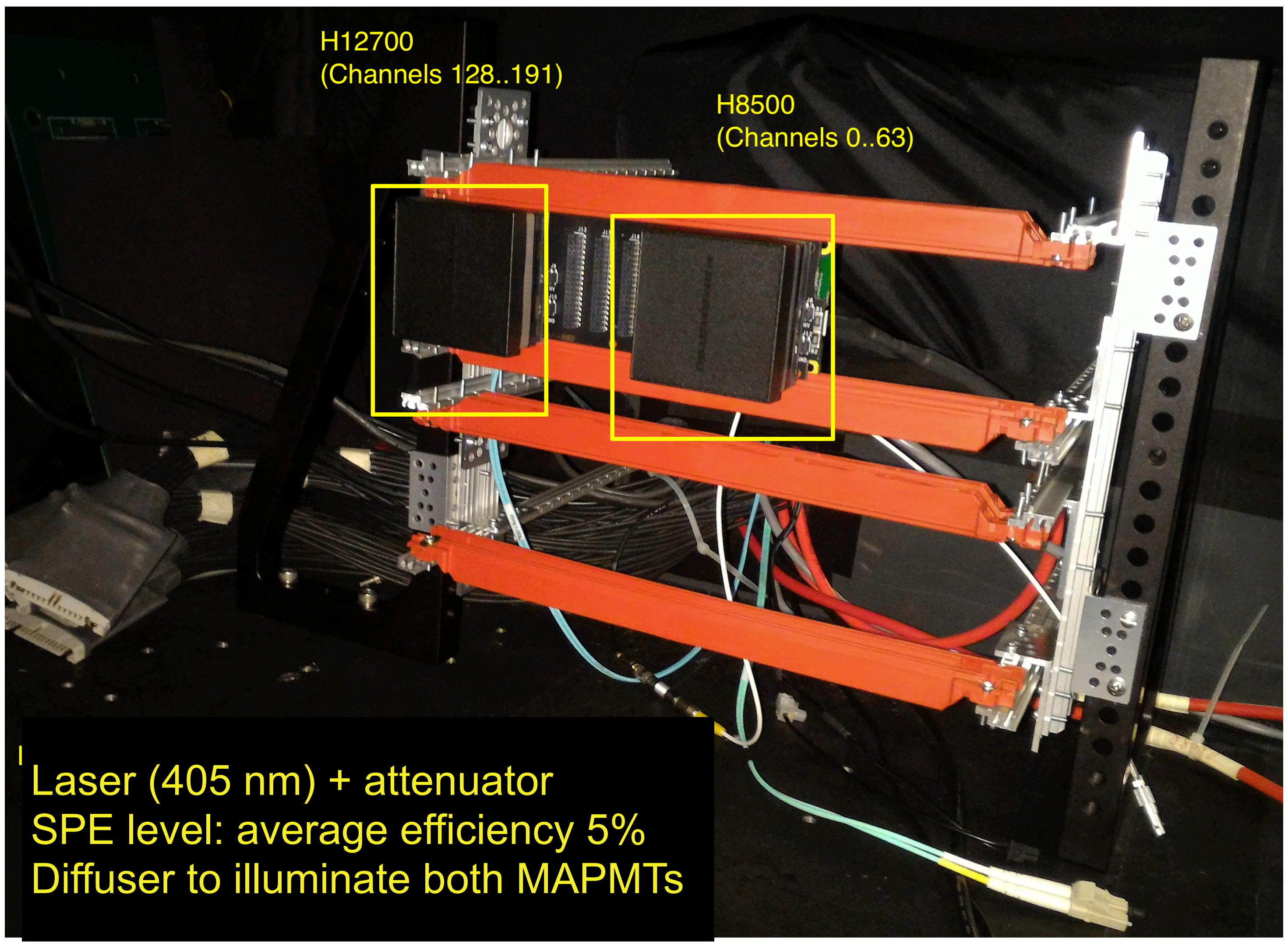
Capacitive coupling between adjacent routing paths



Sensor test with Laser

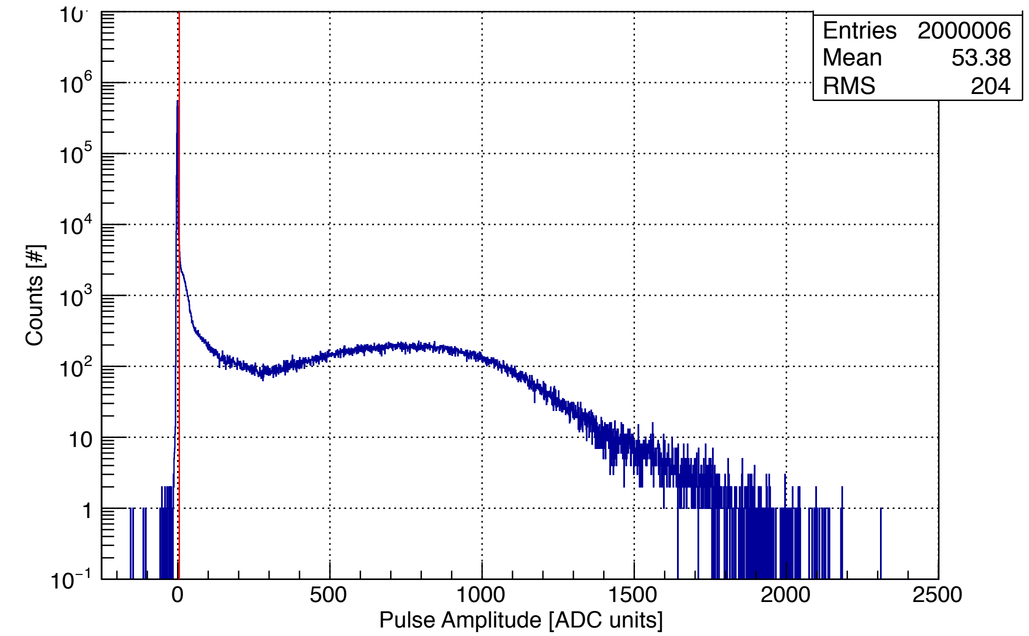
Same signal seen by two different MAPMT

Pedestal 1-2 [ADC]
Single photon signal ~ 600 [ADC]

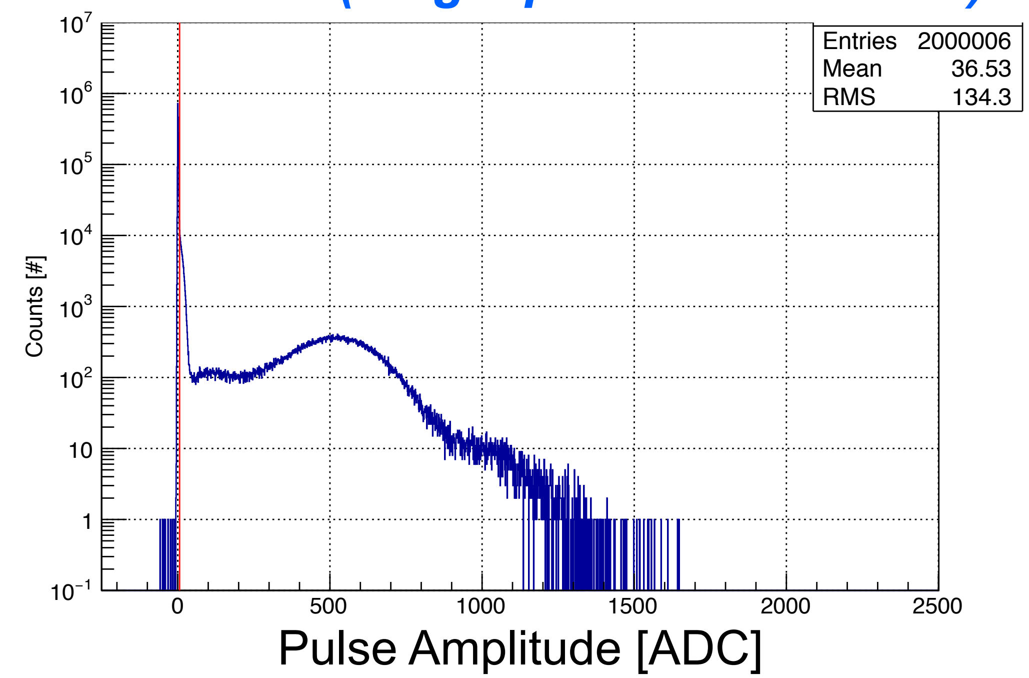


Laser bench at JLab

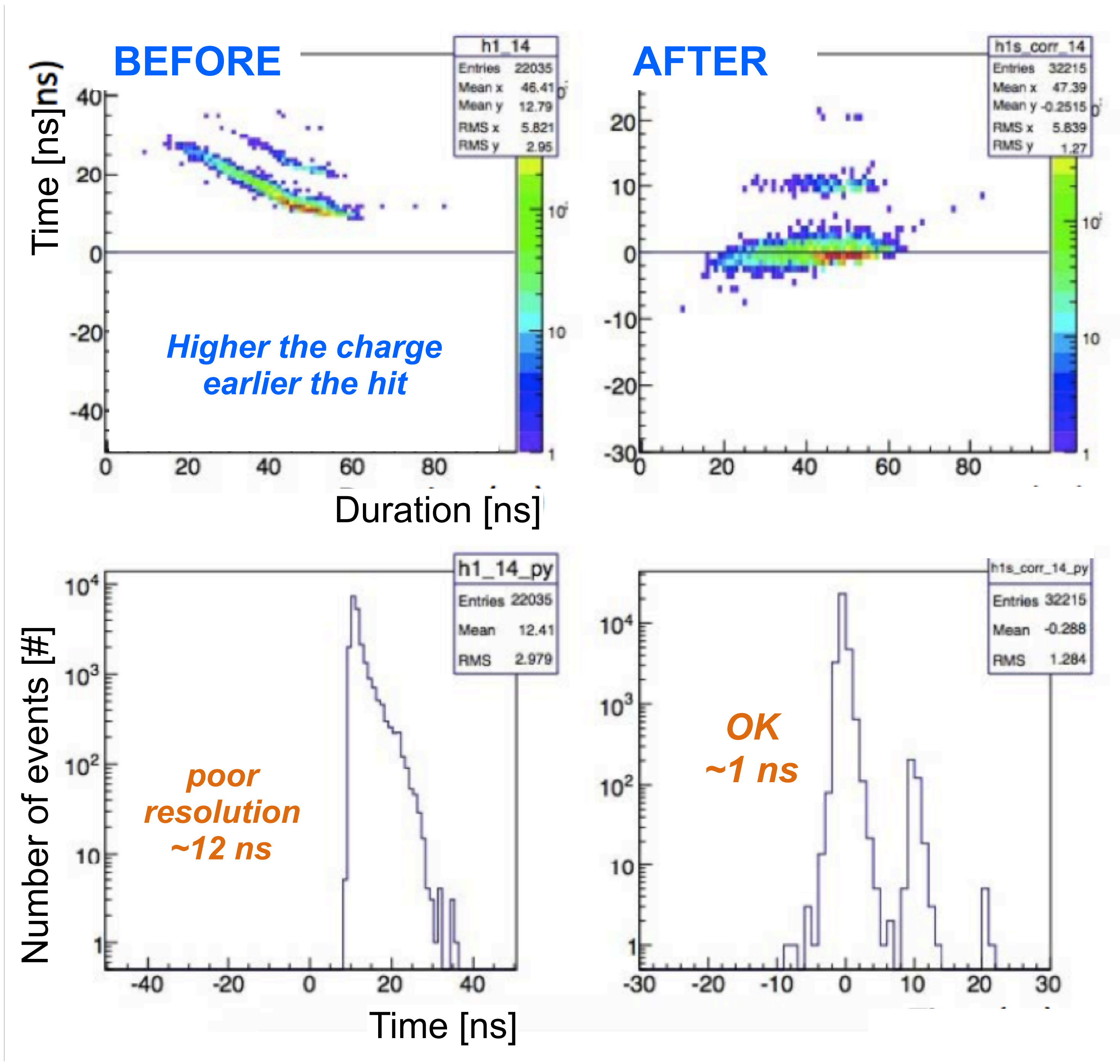
H8500 (generic)



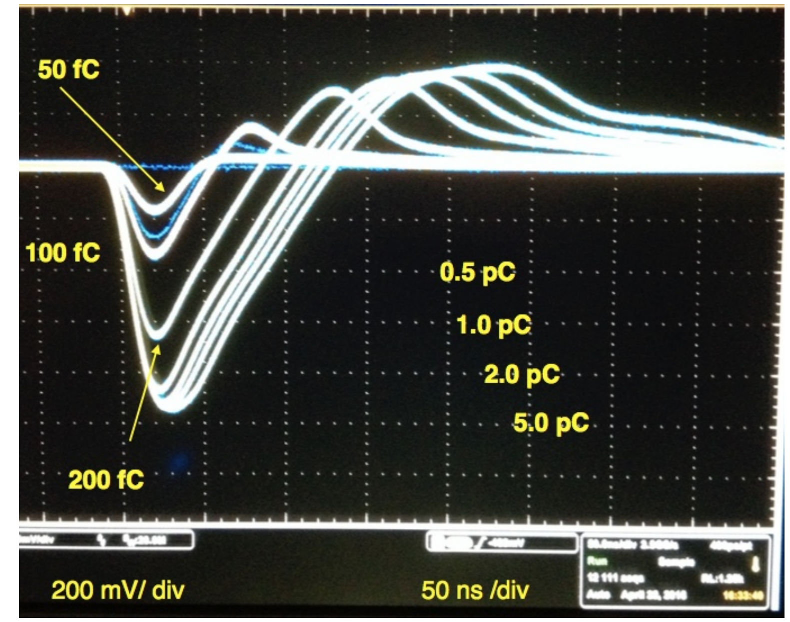
H12700 (single photon dedicated)



Time walk correction



same setup as previous slide



Hit duration information to correct hit arrival time (walk correction)

Ring search 3D (x,y,t)

- background rejection
- direct/reflected separation

Dark rate

Thermal emission produces single photoelectron equivalent signal

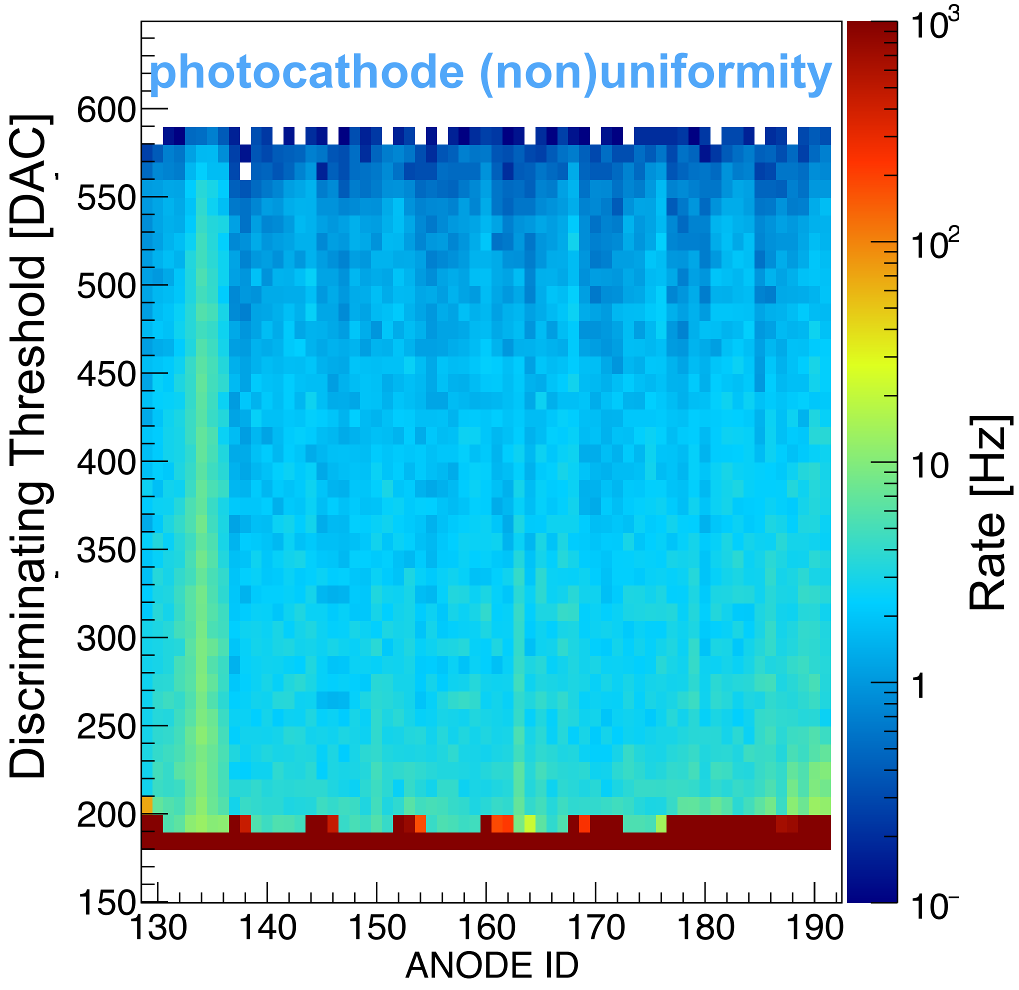
Take advantage from background noise:

- single photoelectron spectra
- gain equalization
- aging monitoring

Manufacturer declare only the total current (e.g 1 kHz)

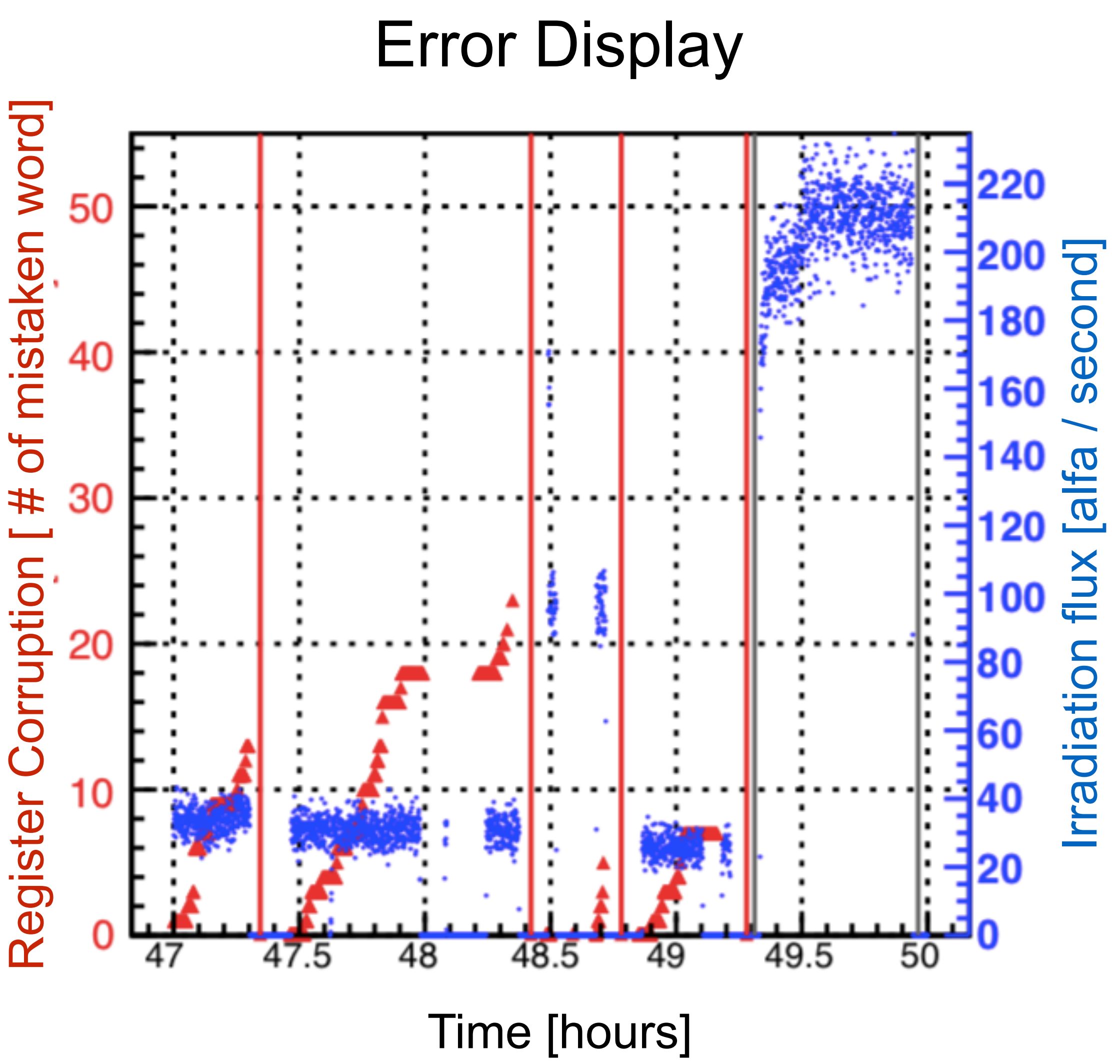
RICH electronics can access individual channel in self triggered (ADC) or trigger-free modes (scaler).

MAPMT at HV 1000 Volts



Radiation tolerance

RICH firmware functionality + additional memory to increase error statistics



Test

- Neutron (14 MeV)
- Gamma (622 keV)

Method

- Alternate irradiation and checks
- Memory or Functional alterations
- Correlate with fluence

Results

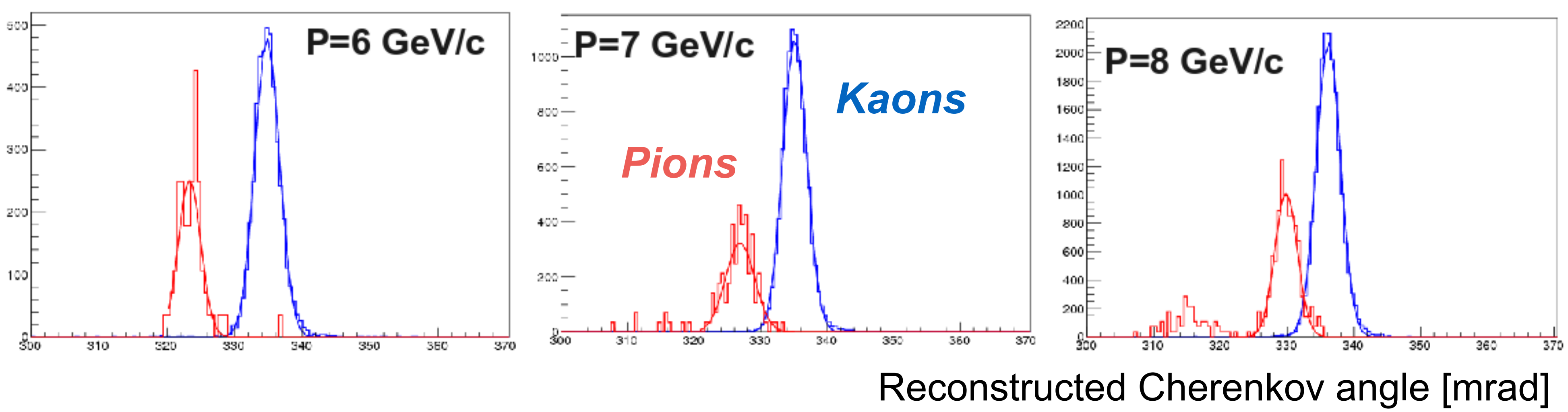
- no permanent damage in 10 years equivalent CLAS12 TIME
- small soft error probability
- no mitigation required (e.g. parity check)
- reconfiguration frequency compatible with CLAS12 operations

Optical transceiver (Finisar) and FPGA (Xilinx Artix7) tested for the first time

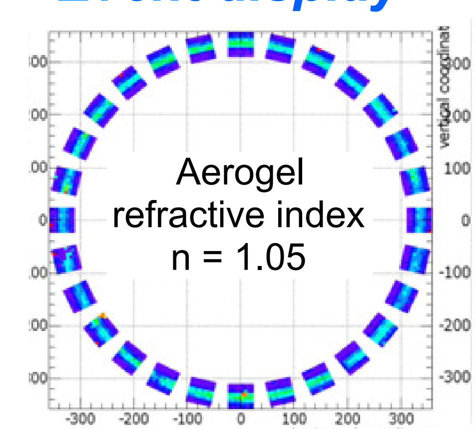
Beam test at CERN T9

Large scale RICH prototype
28 x H8500
1792 channels

- Validation campaign of RICH components
- H8500 and MAROC for single photon
- Analog readout



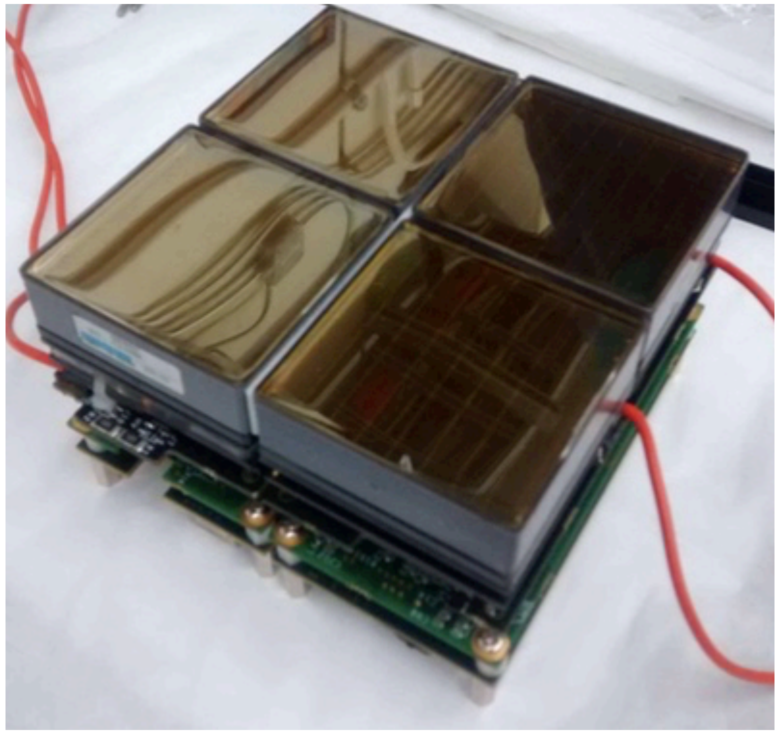
Event display



Beam test at FermiLab

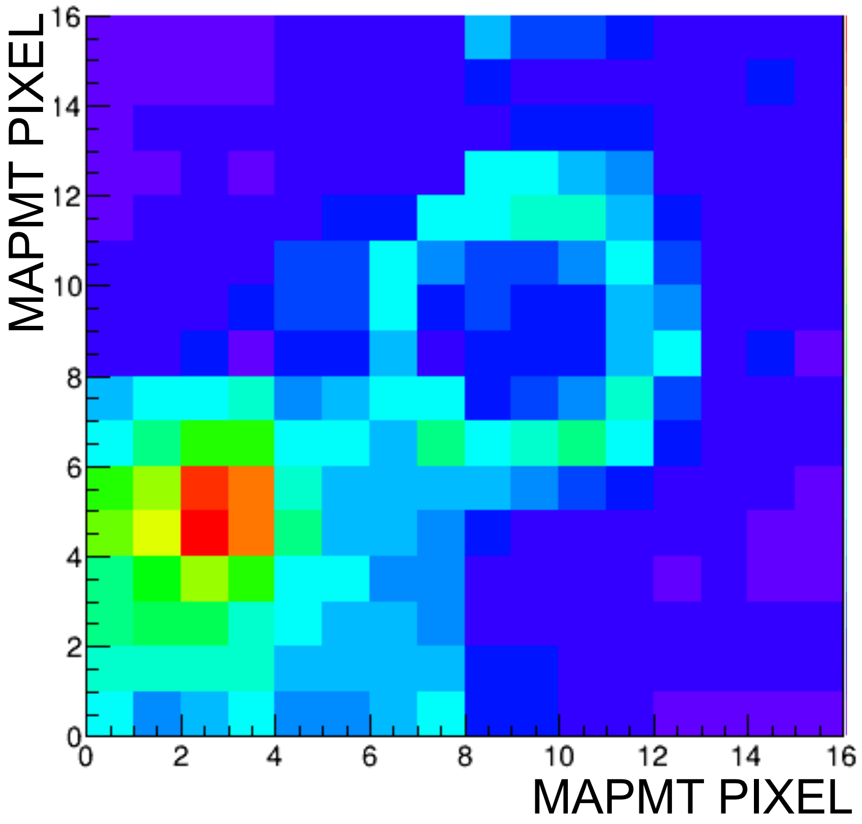
- Small prototype for an EIC project: mRICH → array of compact RICH modules using Fresnel lenses
- Binary readout validation in real condition

2x2 matrix of H12700
256 channels

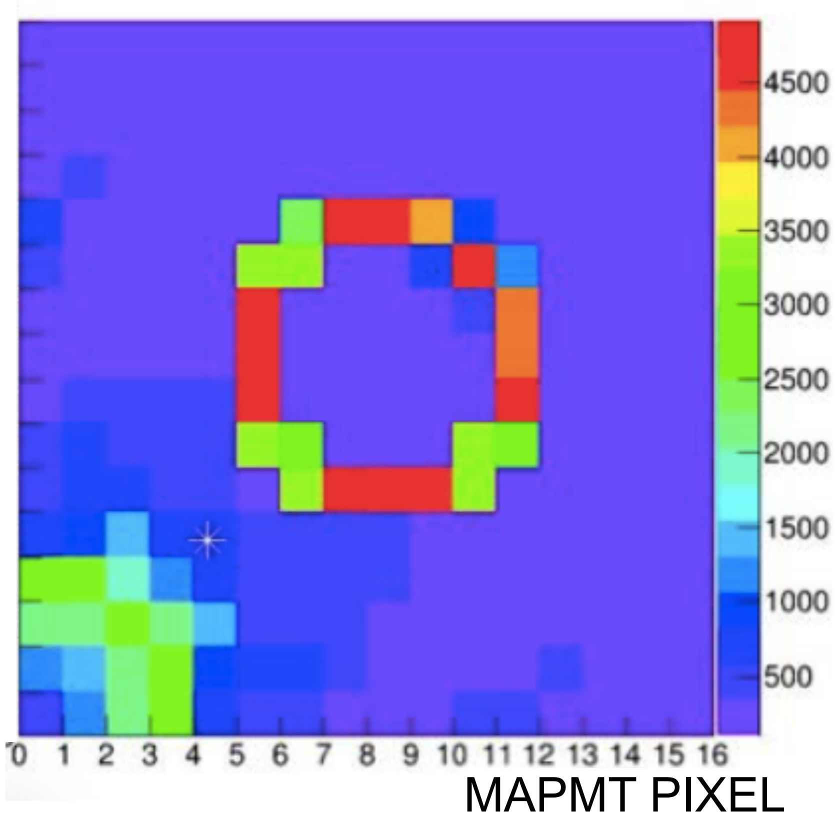


Cherenkov ring produced by 120 GeV/c protons

Experimental data



Simulation



Electron Ion Collider (EIC) 140 GeV

Conclusion

	Requirement	Measured	Unit	Note
Efficiency 100%	>50	>5	fC	threshold calibration
Time resolution	1	1	ns	software correction
Crosstalk	few	<4	%	reduced with re-routing
Radiation Tolerance	50	100	10E9 Neq	Soft Error negligible
	0,137	50	kRad	Soft Error negligible
Power	30	26	mW/ch	voltage regulator optimization
Rate	20	50	kHz	occupancy dependent (tested with TCP/IP)

in-situ monitoring

- charge injector
- dark current
- slow control

software library

- configuration
- logbooking
- automation
- autonomy

validation
characterization
equalization
calibration

Conferences and Publications

1 accepted
1 submitted
3 proceedings

1 invited talk (DIRC 2015)

1 paper in preparation

[1] A. Pereira, M. Turisini, *et al.*, "Test of the CLAS12 RICH large-scale prototype in the direct proximity focusing configuration," *The European Physical Journal A*, vol. 52, no. 2, p. 23, 2016.

[2] C. Wong, M.Turisini, *et al.*, "Modular focusing ring imaging cherenkov detector for electron-ion collider experiments." Preprint submitted to Nuclear Instruments and Methods in Physics Research A, January 2017.

[3] M. Mirazita, M.Turisini, *et al.*, "The large-area hybrid-optics RICH detector for the CLAS12 spectrometer," in *RICH2016 Proceedings of the Ninth International Workshop on Ring Imaging Cherenkov Detectors*, 2017.

[4] M. Contalbrigo, M. Turisini, *et al.*, "Aerogel mass production for the CLAS12 RICH: Novel characterization methods and Optical Performance," in *RICH2016 Proceedings of the Ninth International Workshop on Ring Imaging Cherenkov Detectors*, 2017.

[5] I. Balossino, M. Turisini, *et al.*, "Cherenkov light imaging tests with state-of-the-art solid state photon counter for the CLAS12 RICH detector," in *RICH2016 Proceedings of the Ninth International Workshop on Ring Imaging Cherenkov Detectors*, 2017.

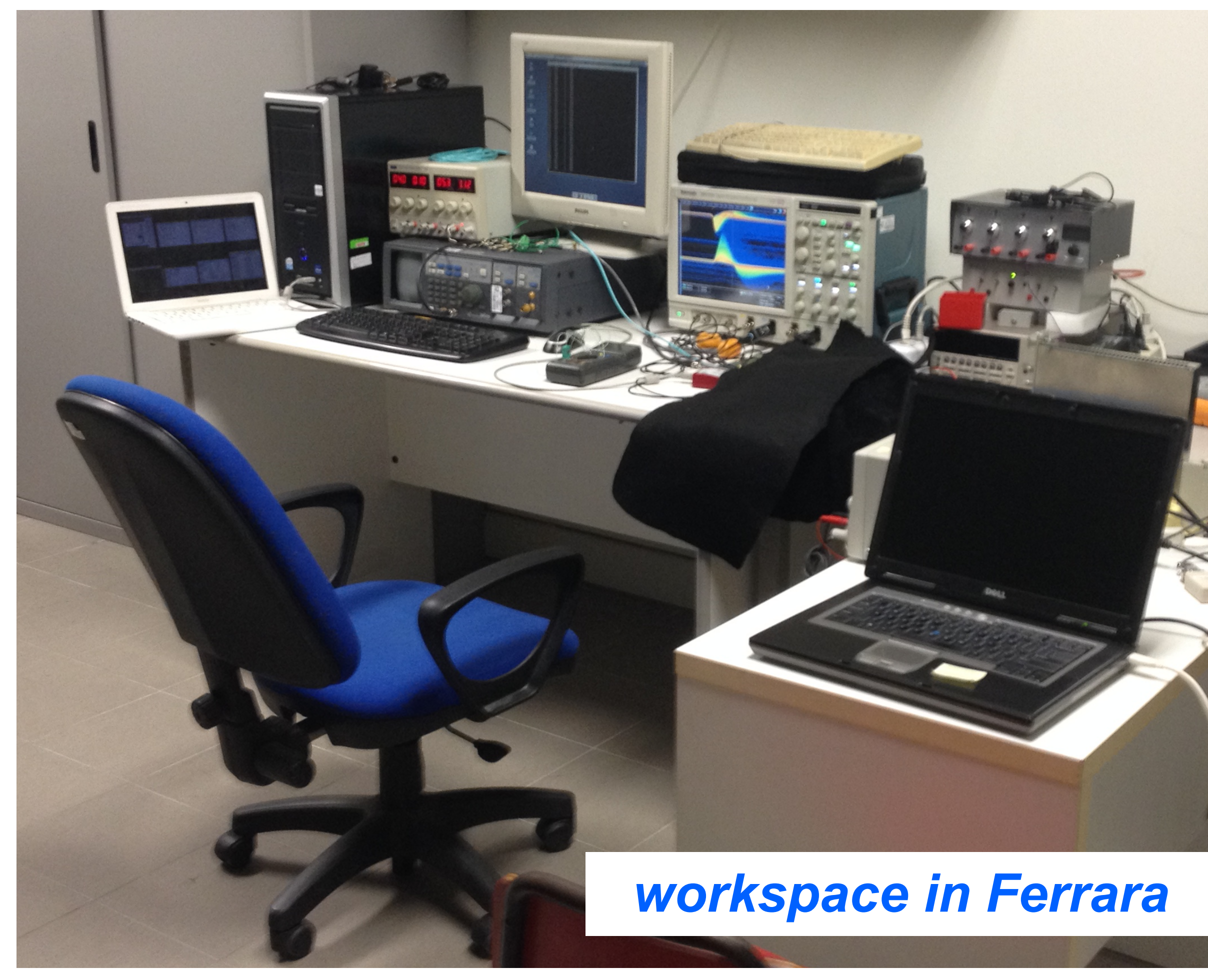
Outlook and Spillover

- RICH electronics mass production in March 2017
- First physics run in September 2017

Being compact, modular, precise and reliable many application can take advantage of it on a short time scale:

- DIRC at JLAB Hall D (mass production this week)
- R&D for other detectors (mRICH, Optotracker-INFN Gruppo 5)
- Molecular Imaging (PET with JLAB, SPECT with ISS)

RICH collaborators close to the RICH module in the clean room at JLAB March 2016

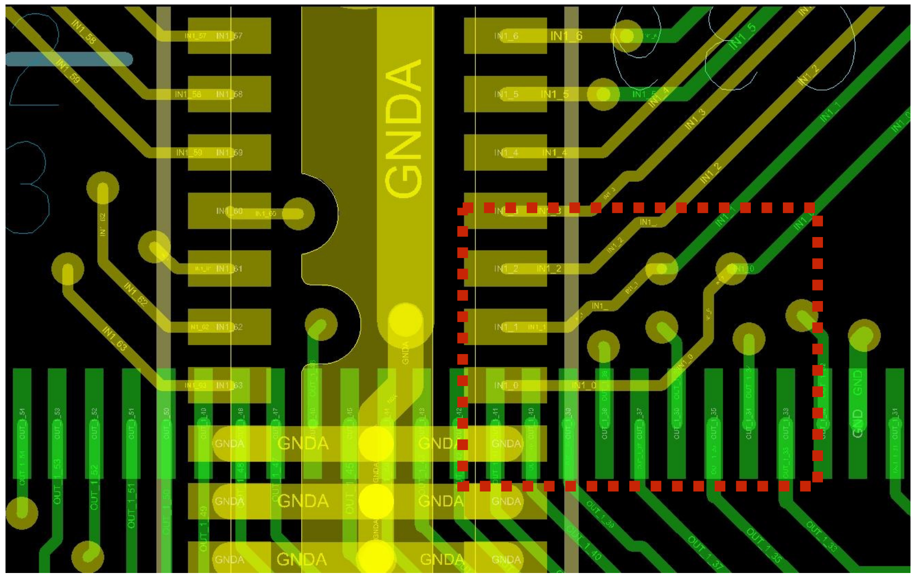


workspace in Ferrara

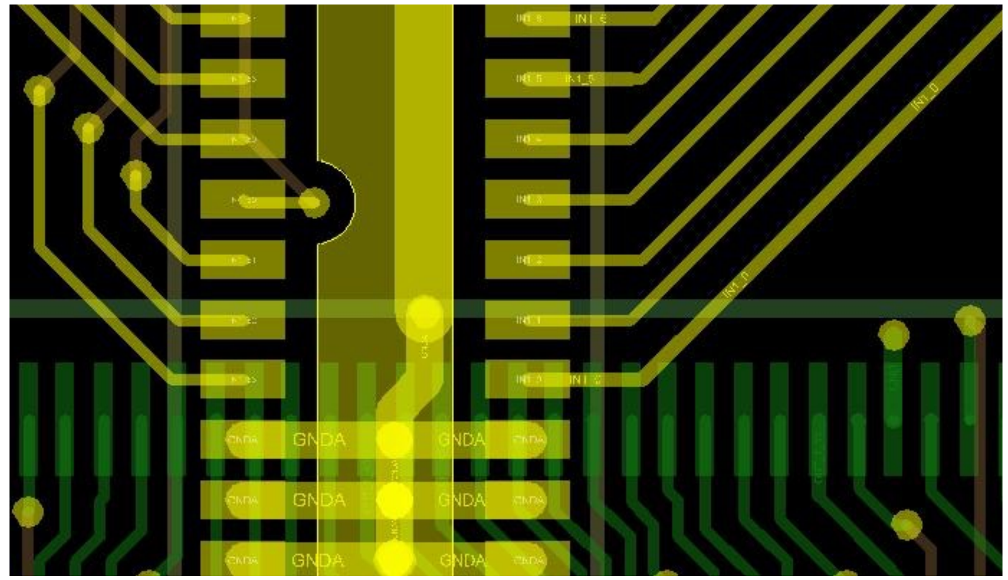
BACK UP

Routing optimization

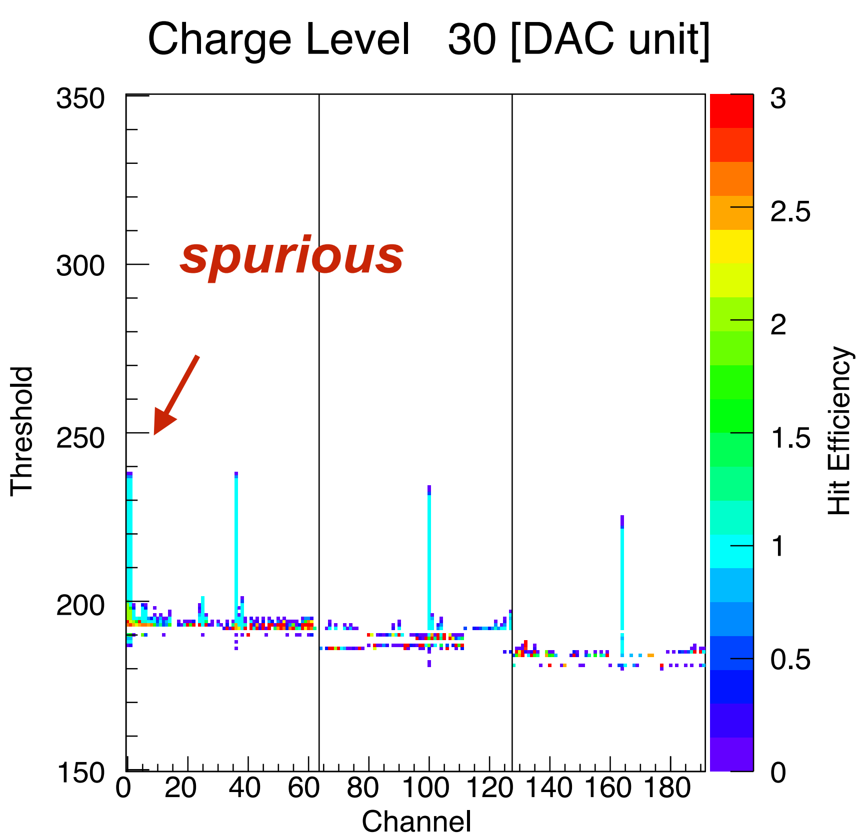
before



after



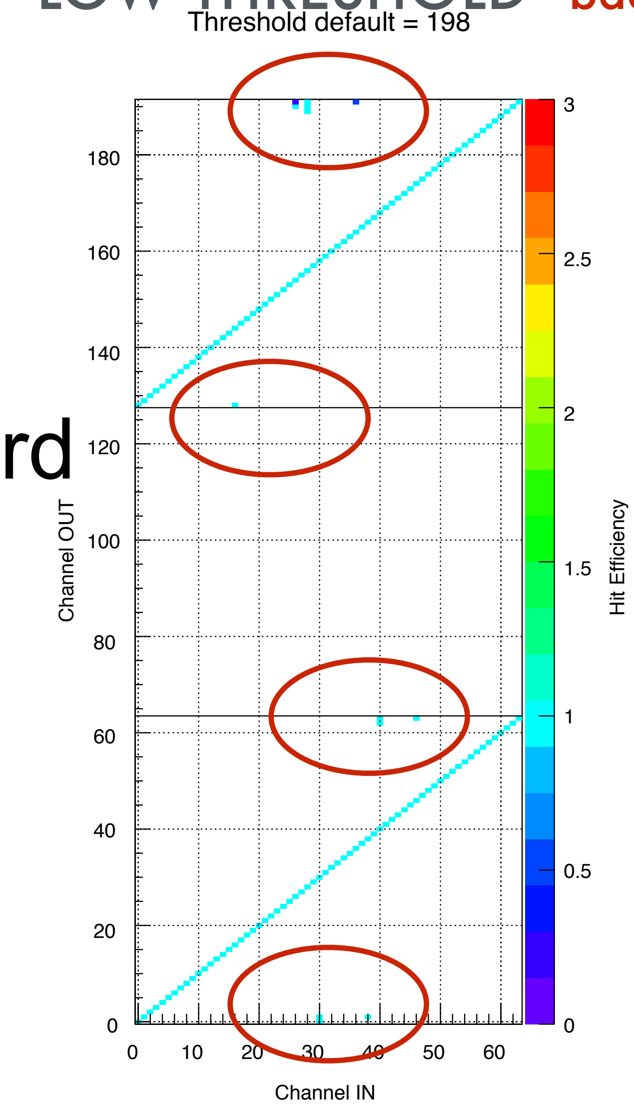
Legend:
YELLOW - Layer BOTTOM
GREEN - Layer TOP
CIRCLES - VIAS between layers



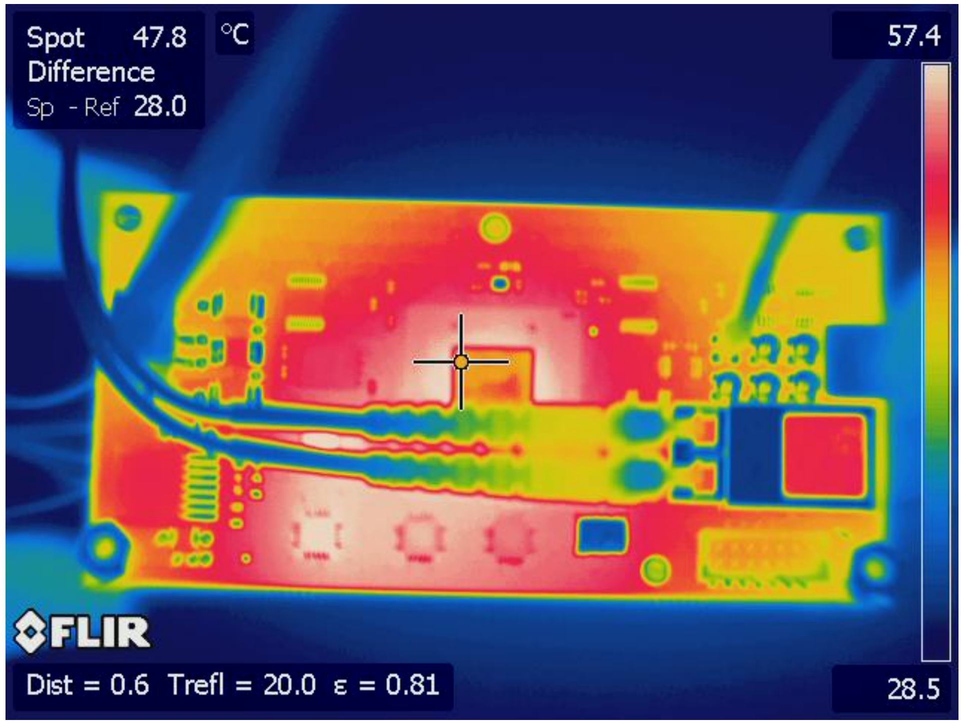
MAROC analog /digital board

limited space for routing

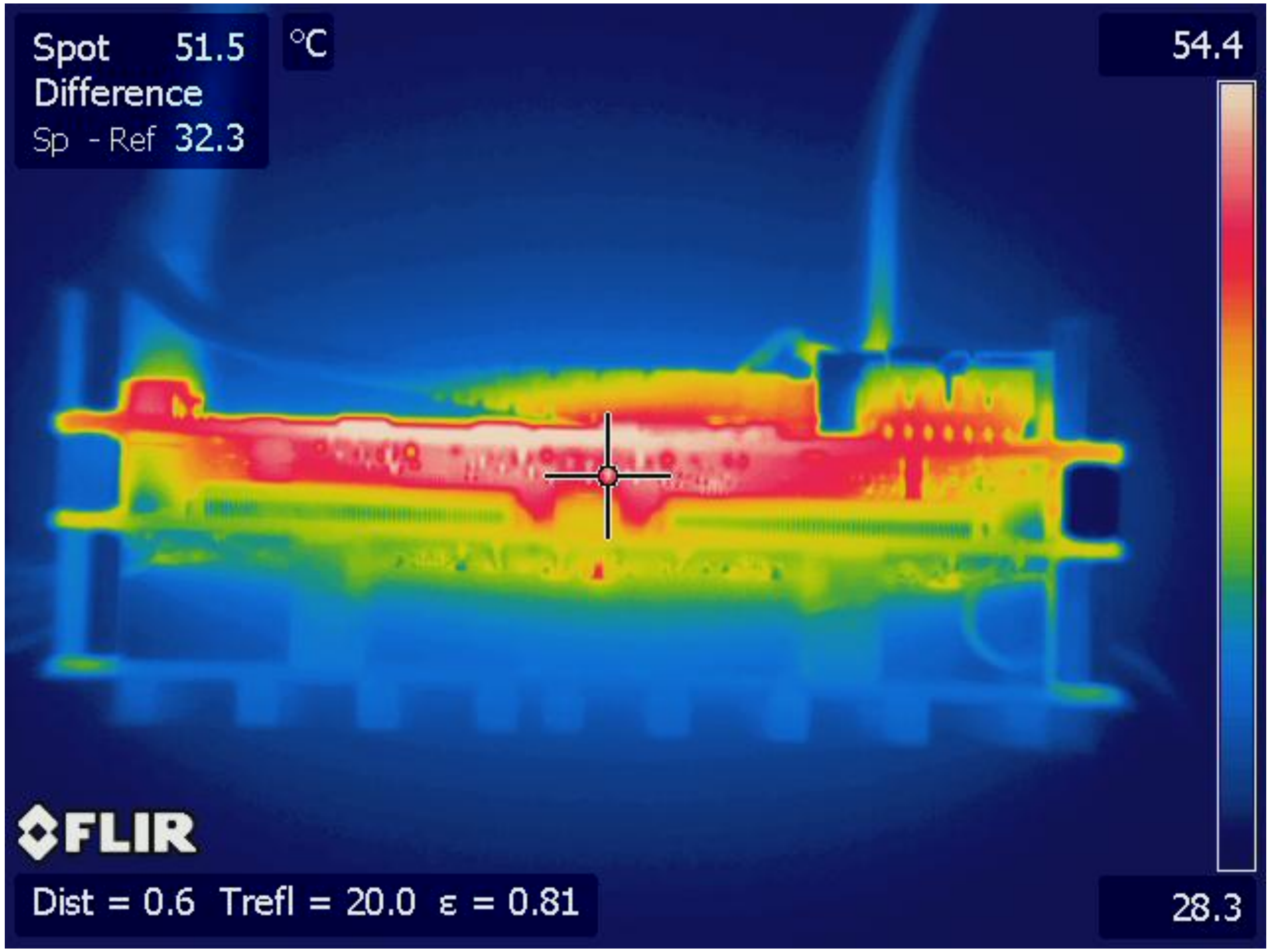
LOW THRESHOLD - **bad**



Thermographic pictures



Majority of the heat is produced by the FPGA board



Air conditioning
100 liters/ minute