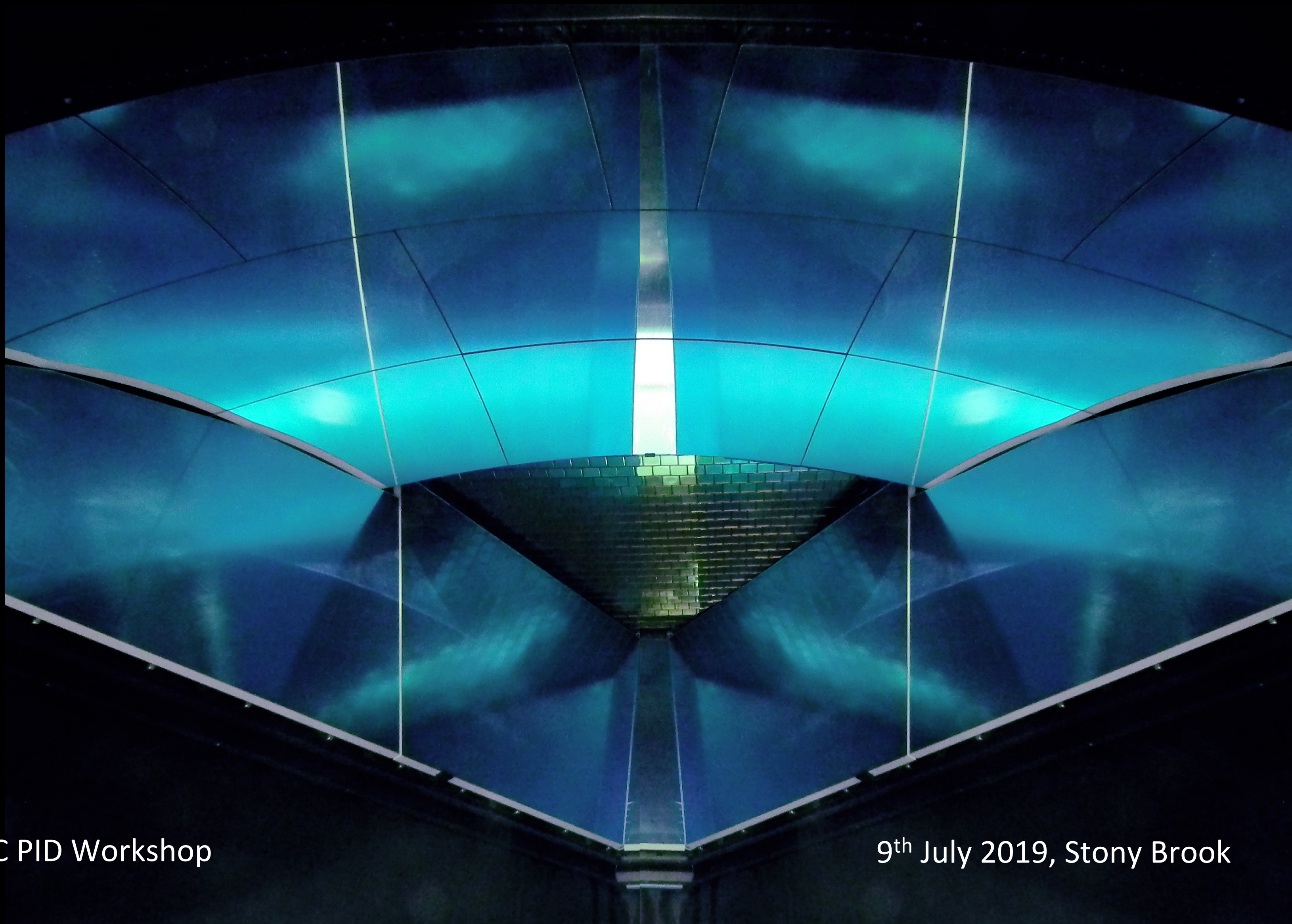
Single Photon Detection with the CLAS12 MAROC Readout

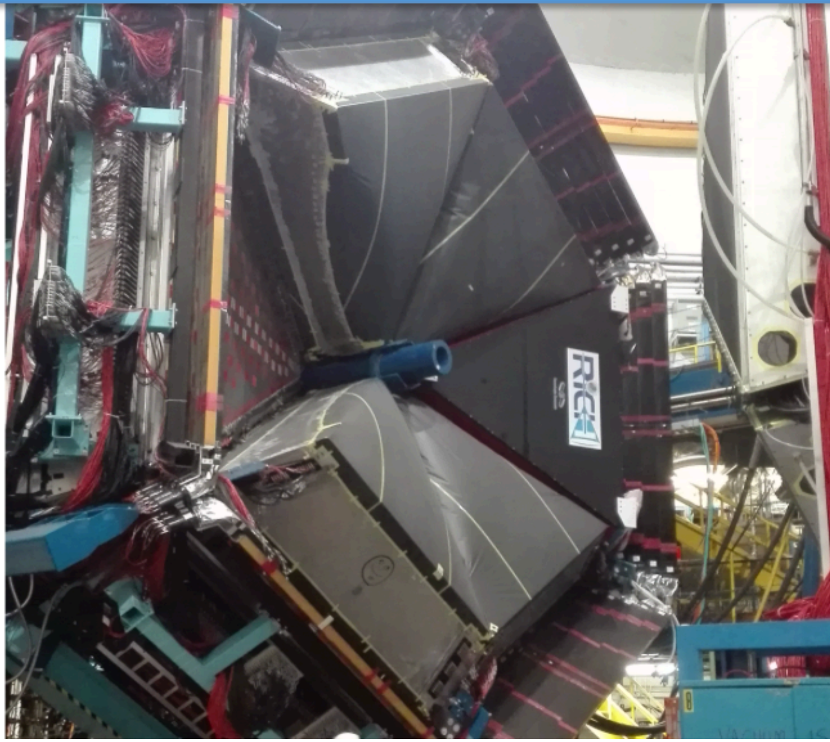
M. Contalbrigo – INFN Ferrara



EIC PID Workshop

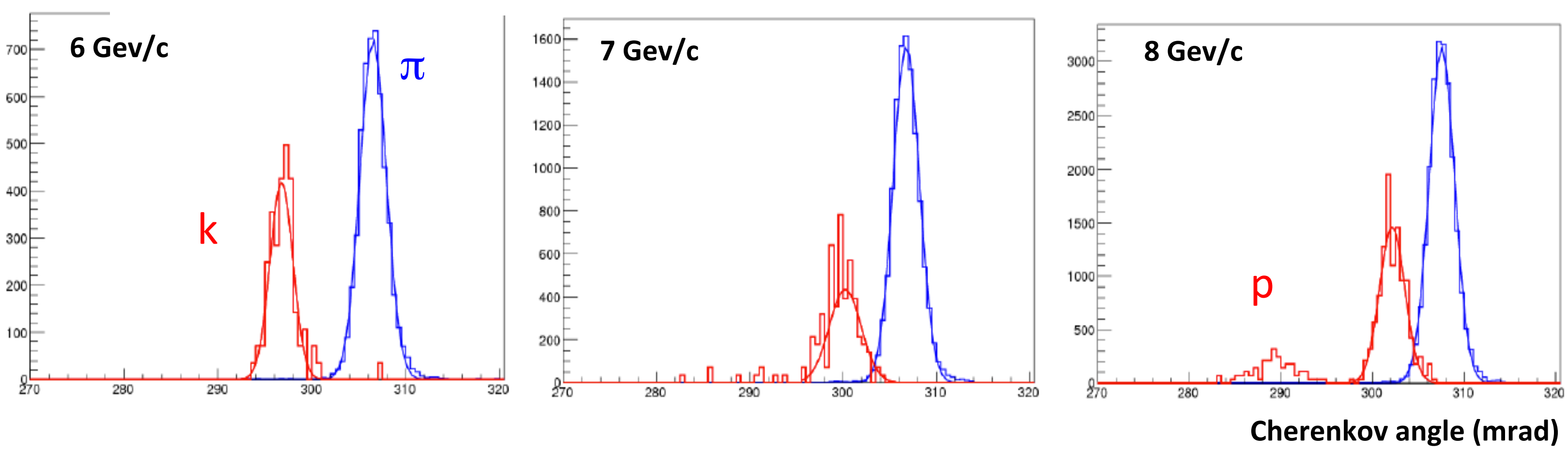
9th July 2019, Stony Brook

CLAS12 RICH



INSTITUTIONS
INFN (Italy) Bari, Ferrara, Genova, L.Frascati, Roma/ISS
Jefferson Lab (Newport News, USA)
Argonne National Lab (Argonne, USA)
Duquesne University (Pittsburgh, USA)
George Washington University (USA)
Glasgow University (Glasgow, UK)
Kyungpook National University, (Daegu, Korea)
University of Connecticut (Storrs, USA)
UTFSM (Valparaiso, Chile)

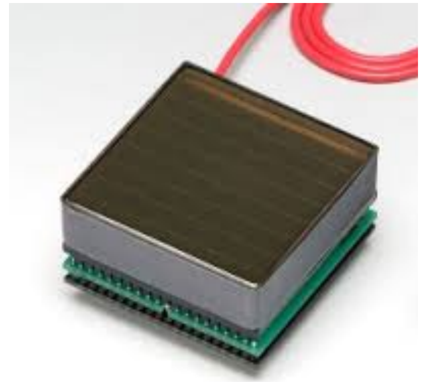
Goal kaon-pion separation up to 8 GeV/c (prototype results):



MA-PMT

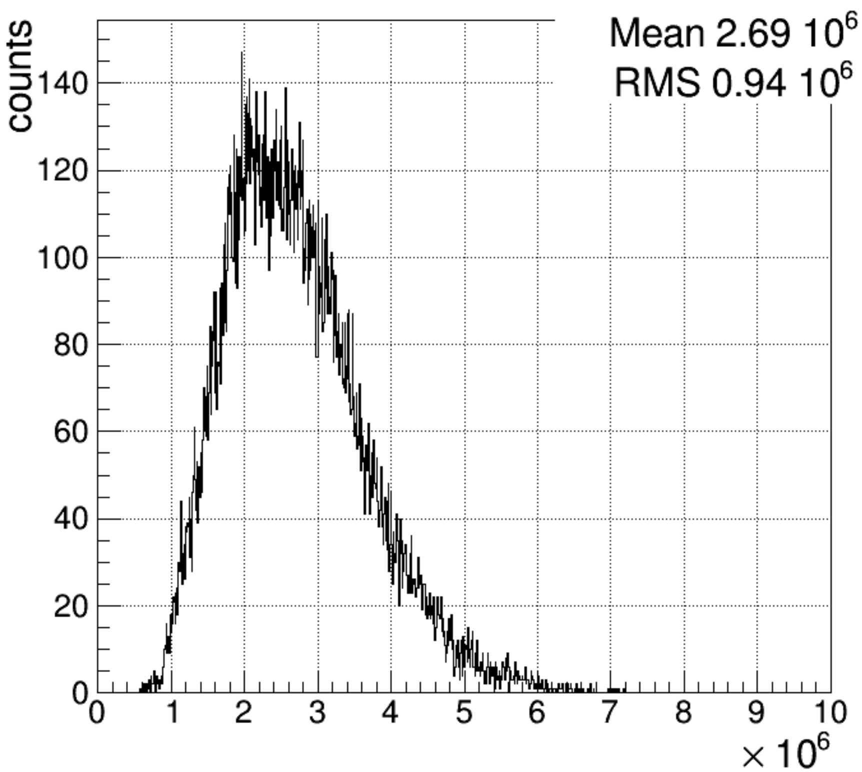
< 1 cm spatial resolution
< 1 ns time resolution
Compatible with the low torus fringe field

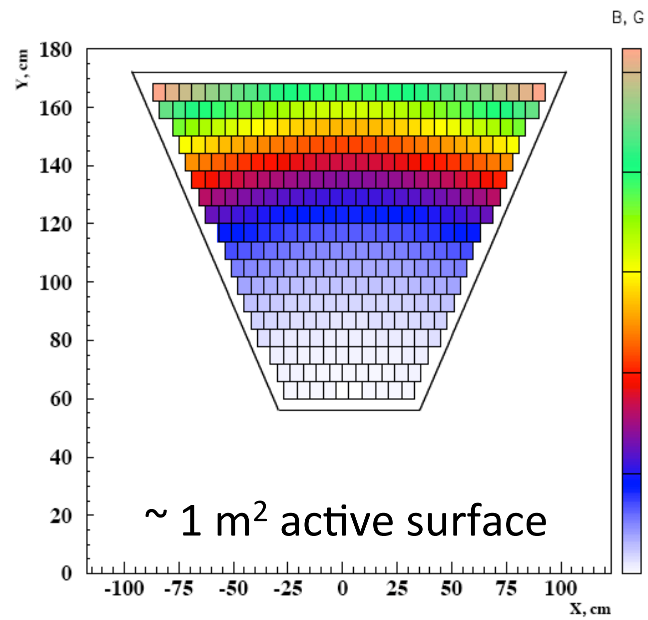
Average MA-PMT gain ~ 2.7 10^6
Corresponds to SPE ~ 400 fC



- ✓ 64 6x6 mm^2 pixels cost effective device
- ✓ High sensitivity on VIS towards UV light
- ✓ Mature and reliable technology
- ✓ Large Area (5x5 cm^2)
- ✓ High packing density (89 %)
- ✓ Fast response

- ✗ Expensive technology

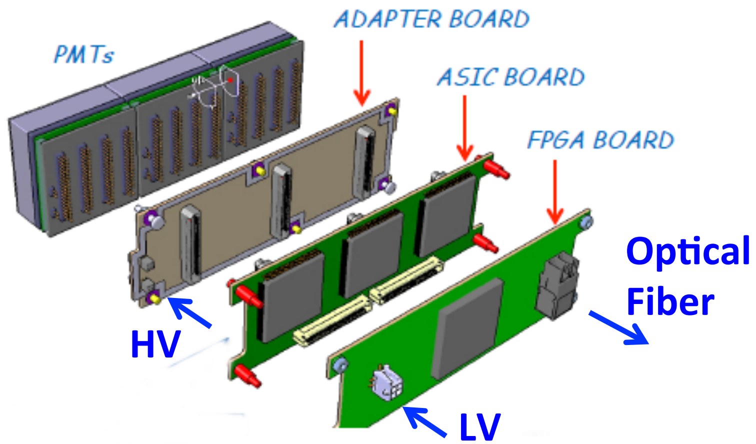




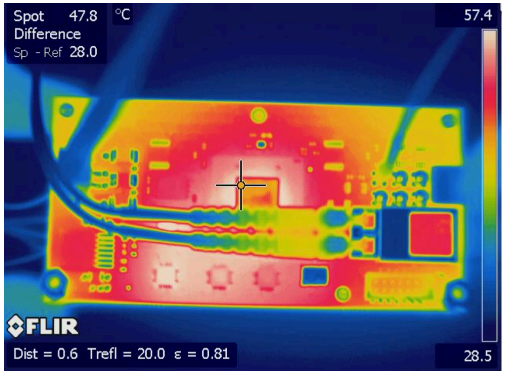
RICH Readout Electronics

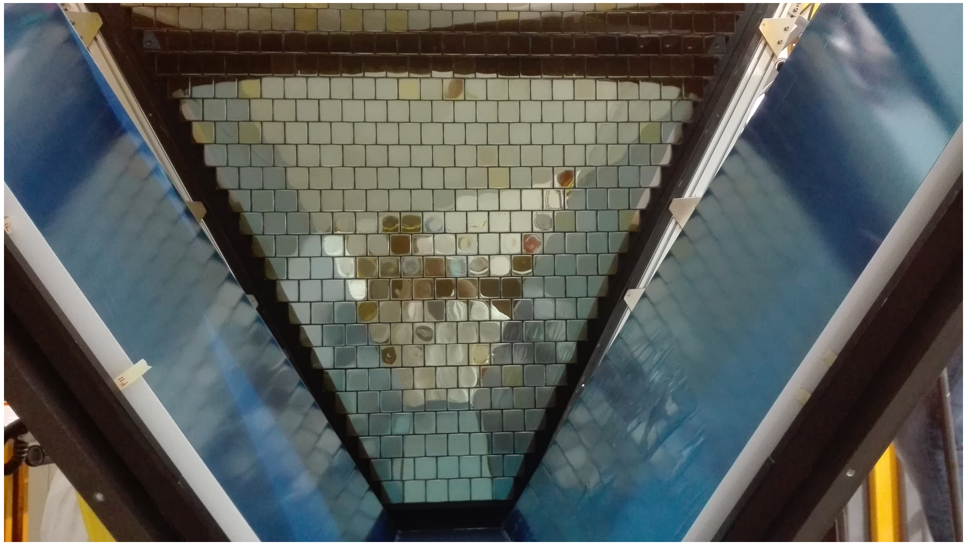
Readout Electronics

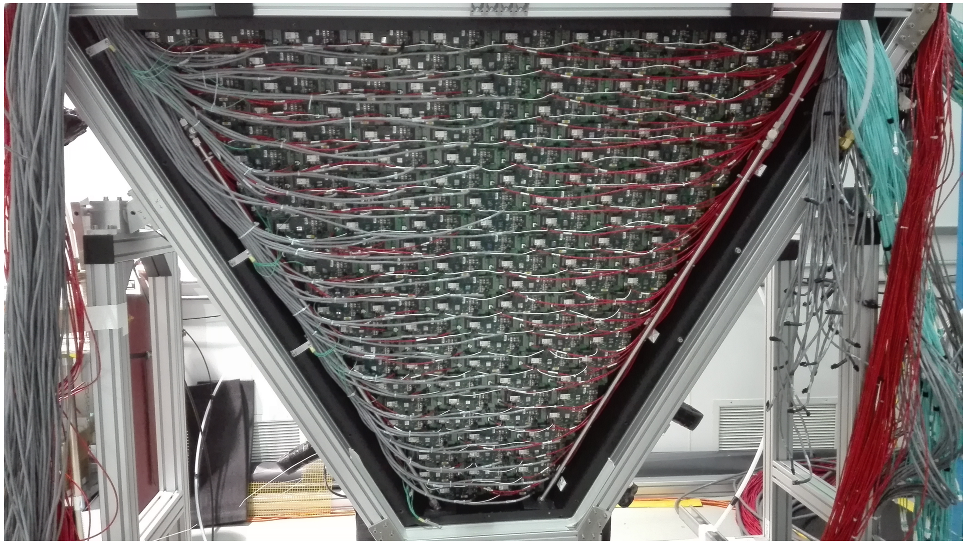
Compact (matches sensor area)
Modular Front-End (Mechanical adapter, ASIC, FPGA)
Scalable fiber optic DAQ (TCP/IP or SSP)
Tessellated (common HV, LV and optical fiber)



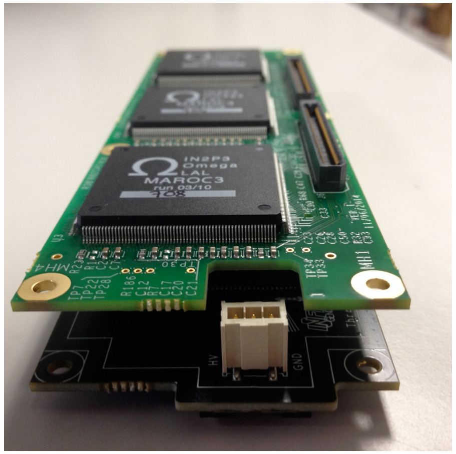
Tile power dissipation ~ 3.5 W

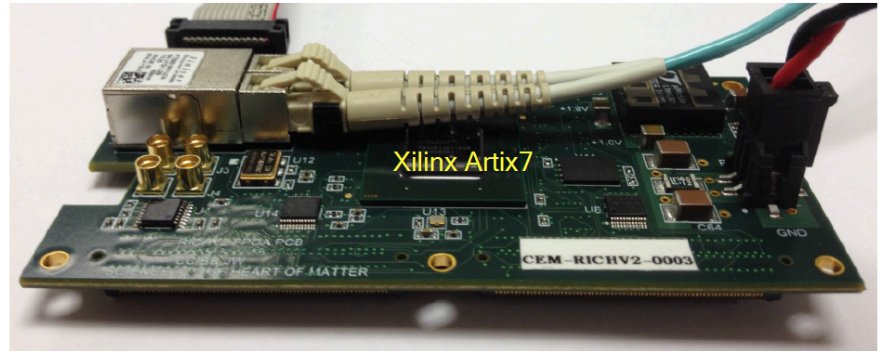






RICH Front-End Electronics





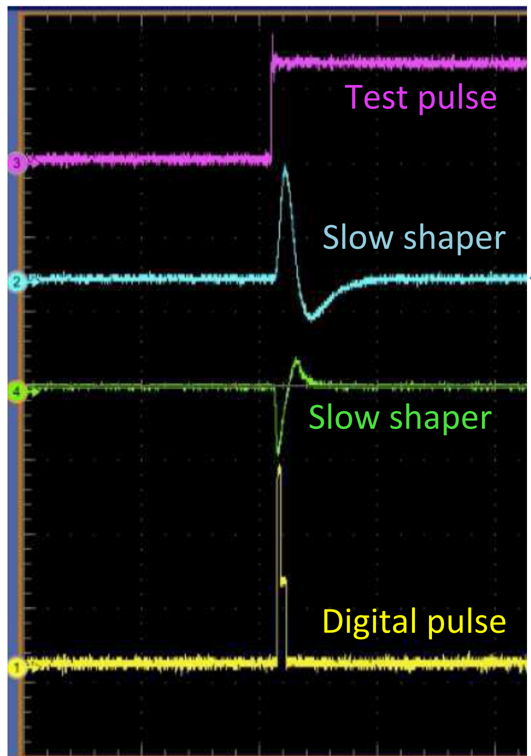
Analog: Charge (1 fC)
Digital: Time (1 ns)

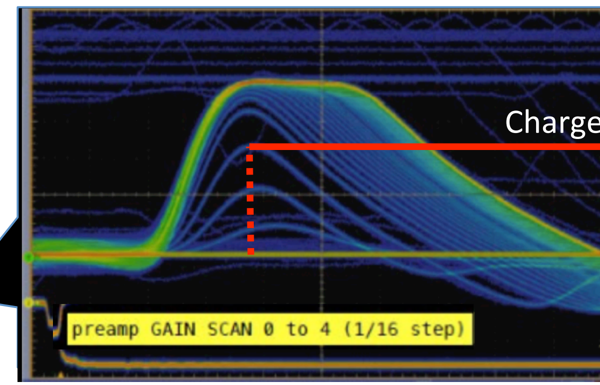
Trigger latency (8 μs)

Optical ethernet (2.5 Gbps)

Trigger: external
internal
self

On-board pulser





Linear response

Multiplexed readout
Limited holding time delays

Used for calibrations

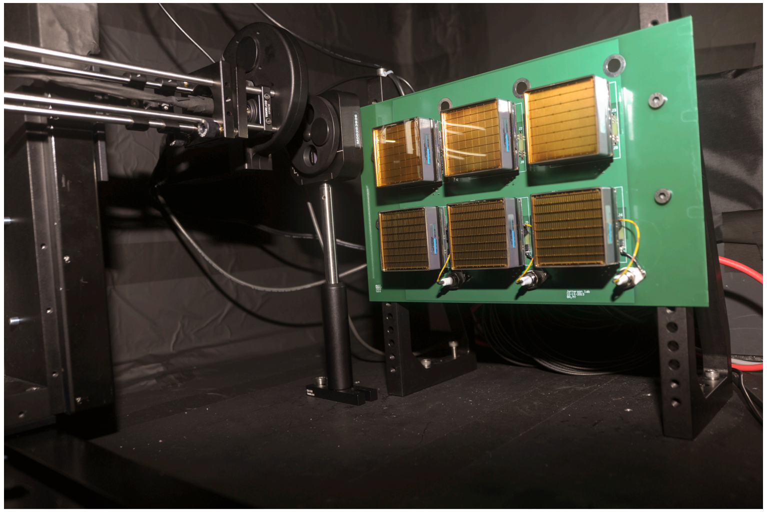
ADC Charge Measurement

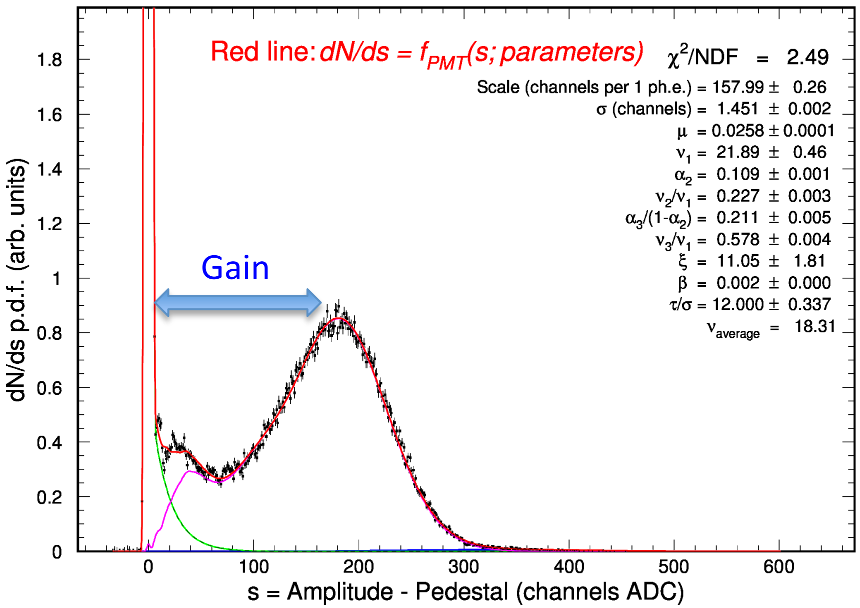
Multiplexed readout up to 50 kHz

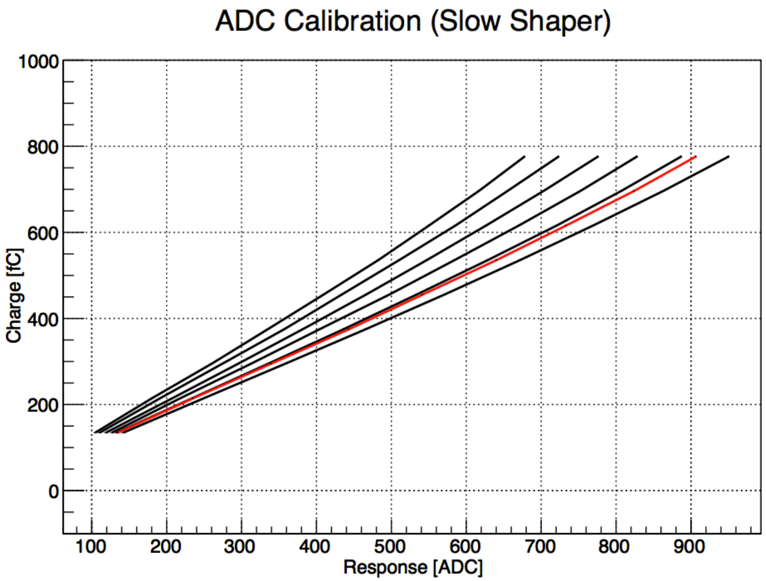
High resolution SPE spectrum

Viable for efficiency and gain monitors

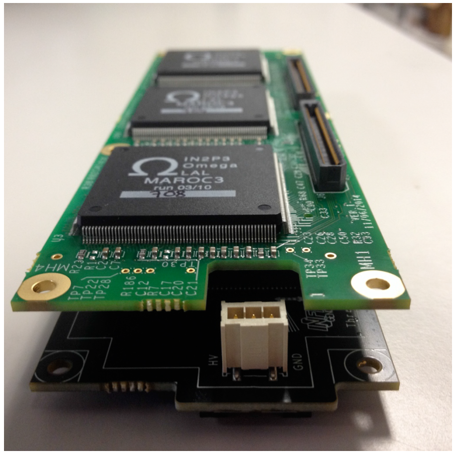
In conjunction with timing, allows the study of PMT discharge and cross-talk

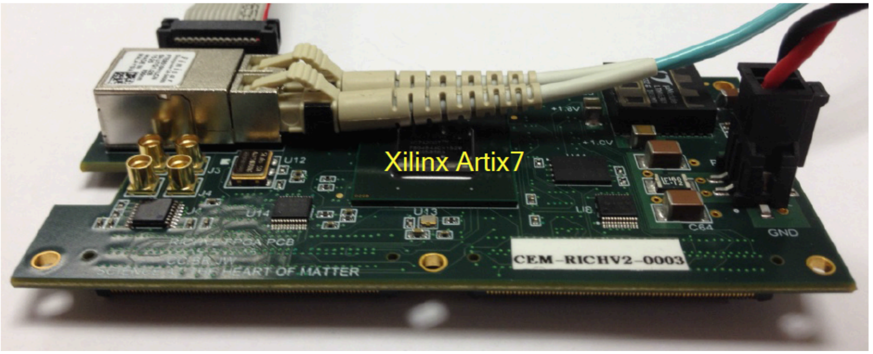






RICH Front-End Electronics





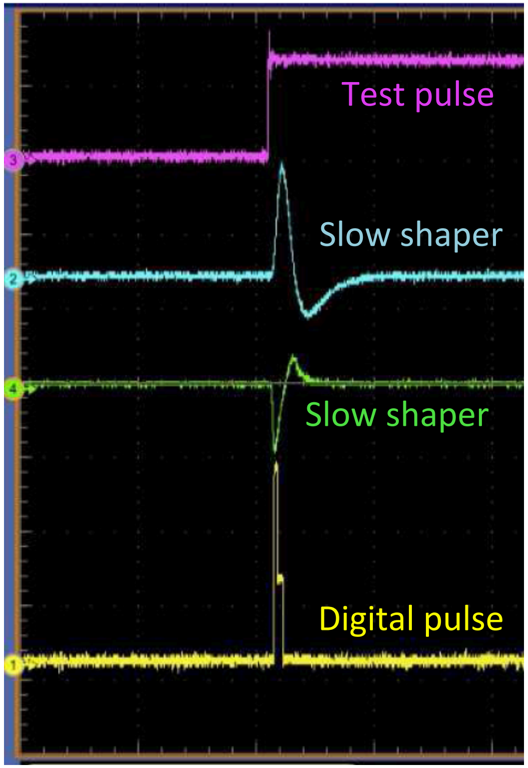
Analog: Charge (1 fC)
Digital: Time (1 ns)

Trigger latency (8 μs)

Optical ethernet (2.5 Gbps)

Trigger: external
internal
self

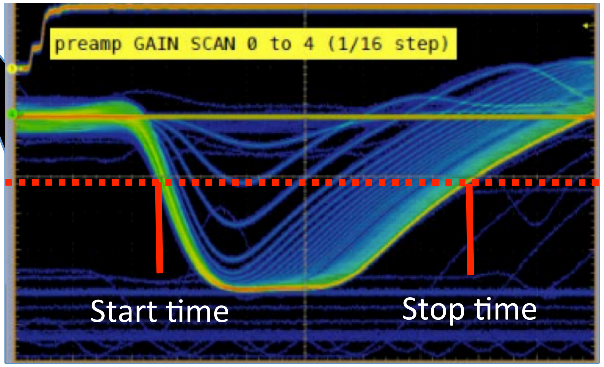
On-board pulser



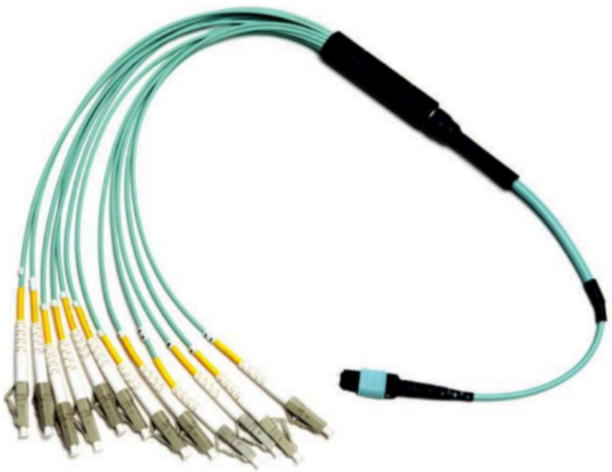
Digital response
Working in saturated regime

64 parallel channel readout

8 μs FIFO and delays
1 ns time resolution



RICH Back-End Electronics



Optical bridge / PC Desktop
Few FPGA units ~ 500 channels

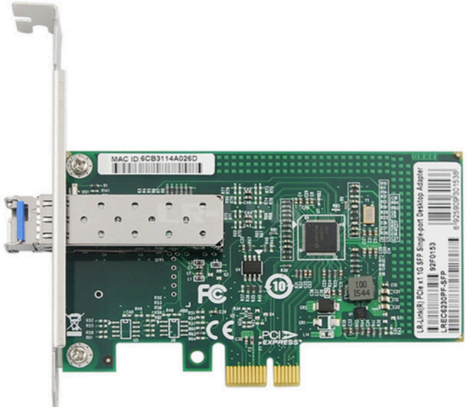
SSP board / VSX crate
2 RICH sectors ~ 50 k channels

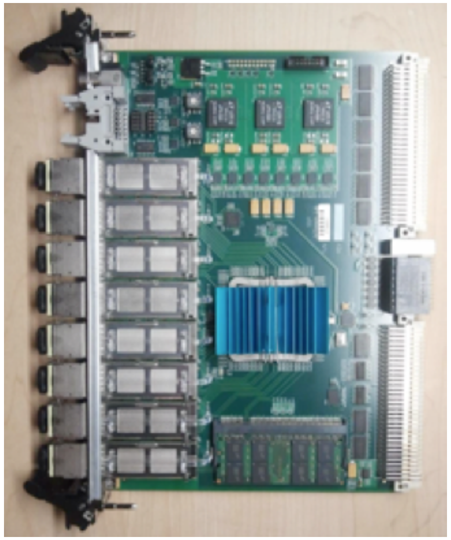
Optical ethernet (2.5 Gbps)

Small setups:
TCP/IP
Optical bridge / PC Desktop

Full experiment:
SSP protocol
SSP board / VSX crate

Next:
Ethernet Switches

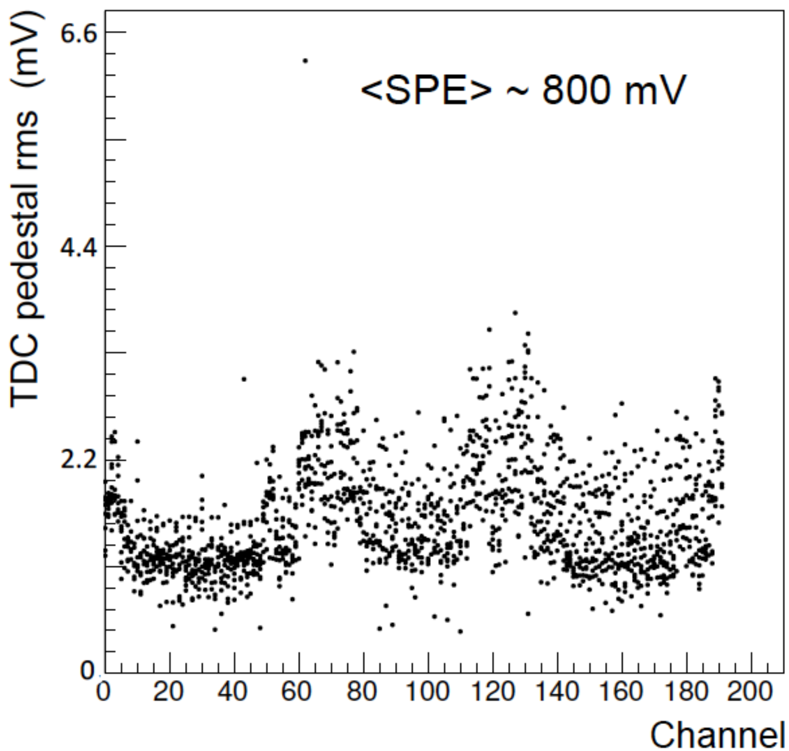




TDC Digital Readout

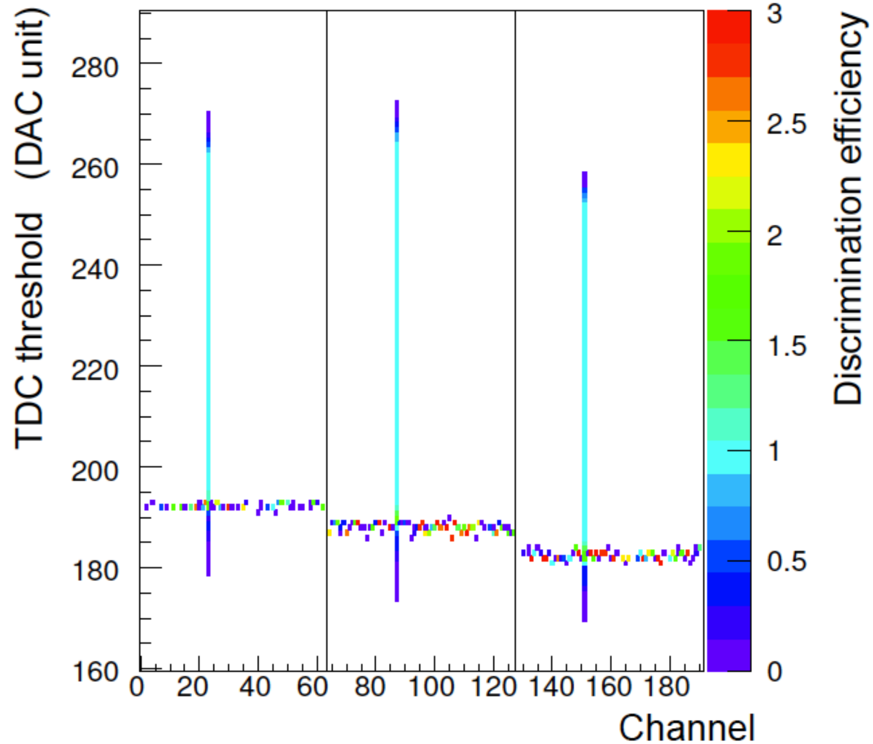
During Acceptance tests

Pedestal rms as seen by a test-point



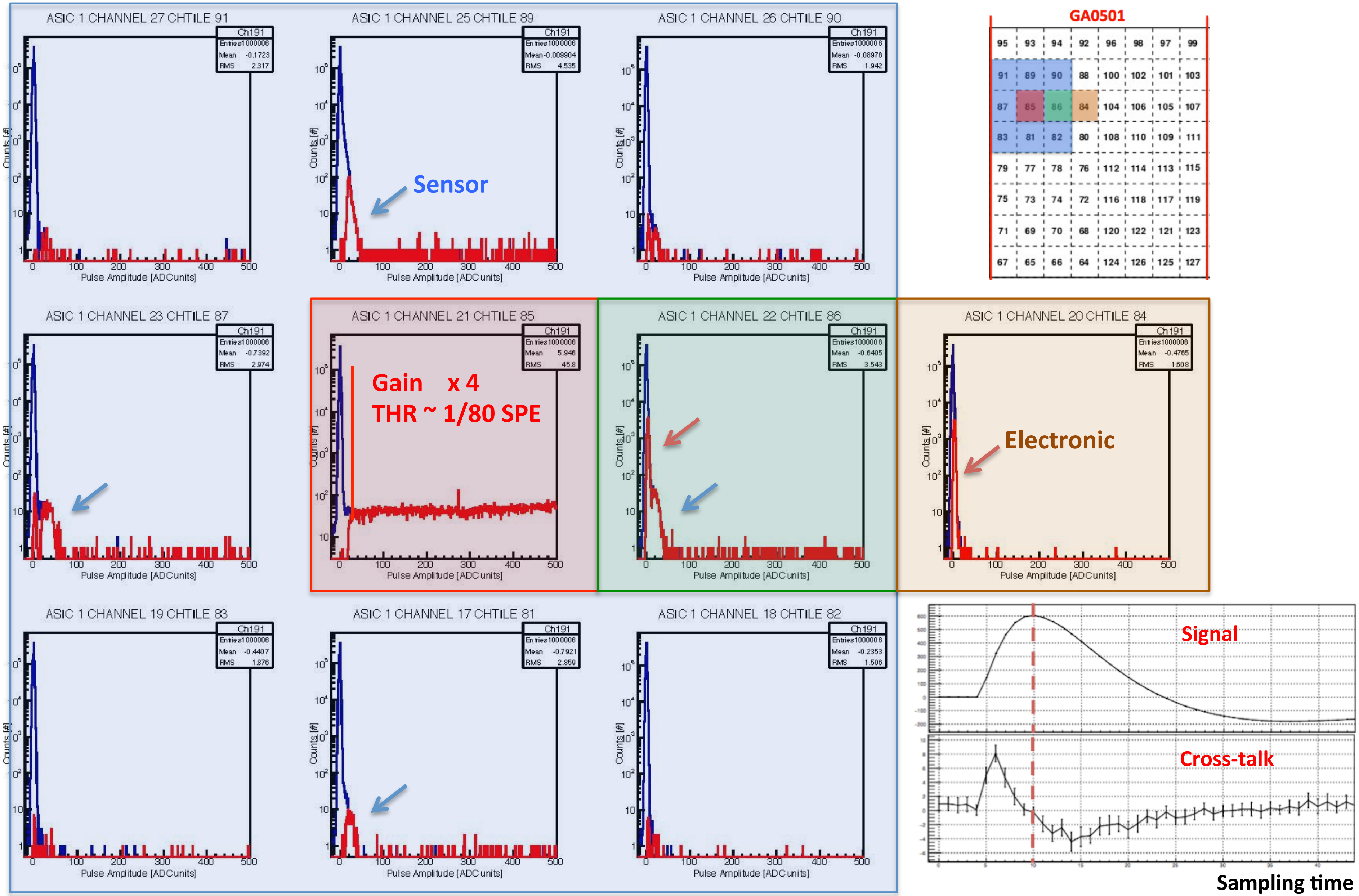
During Internal Pulser Calibration

As seen by RICH readout



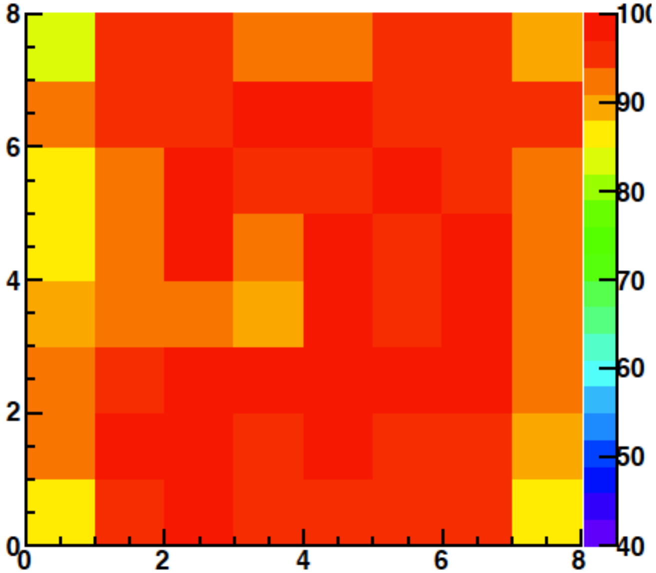
Discrimination down to 20 fC, i.e. few % of SPE, allows sensor characterization

Optical and Electronic Cross-talk

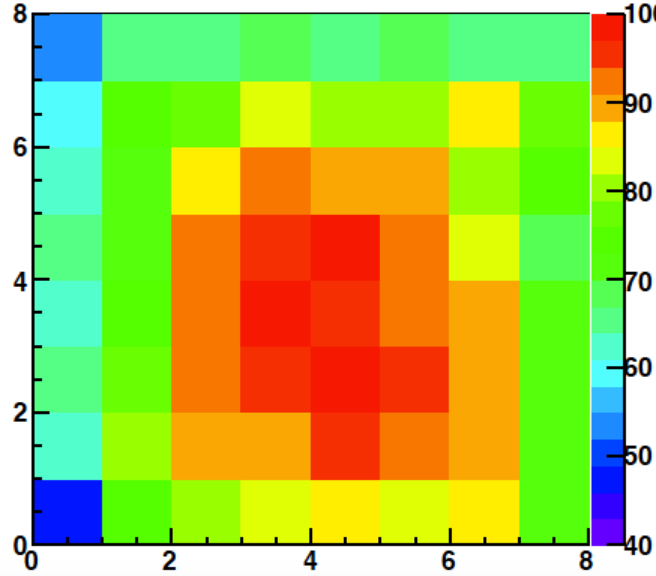


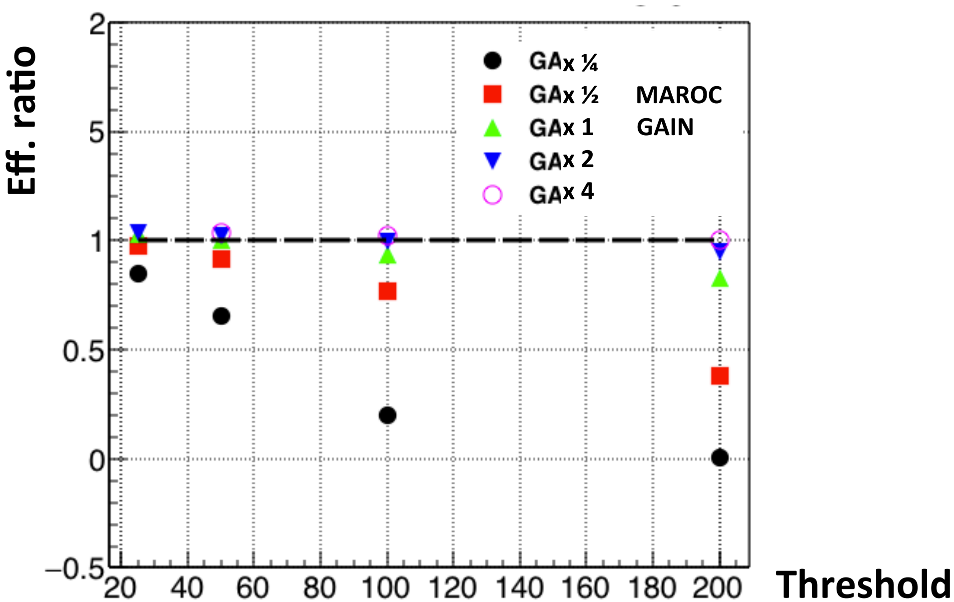
Single-photon Discrimination

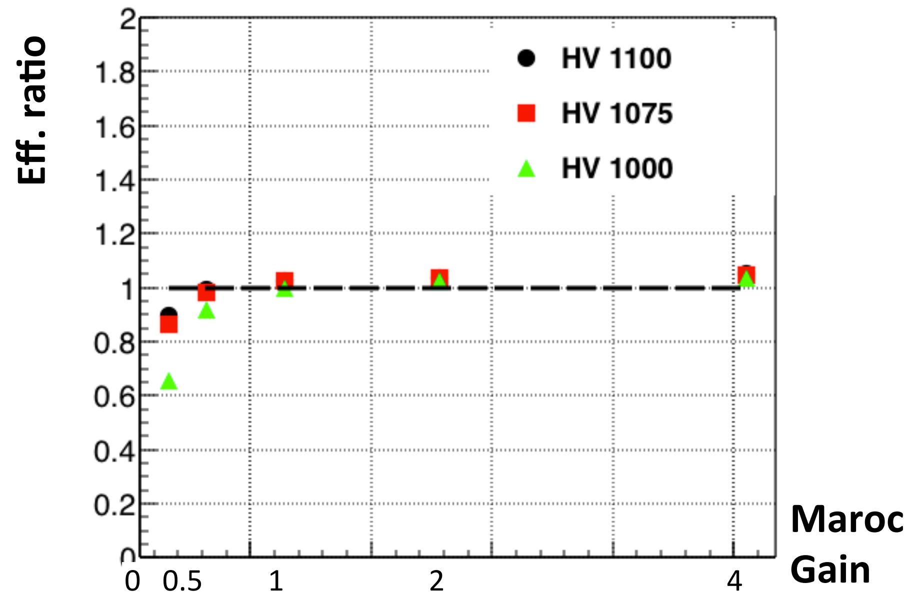
Relative efficiency map



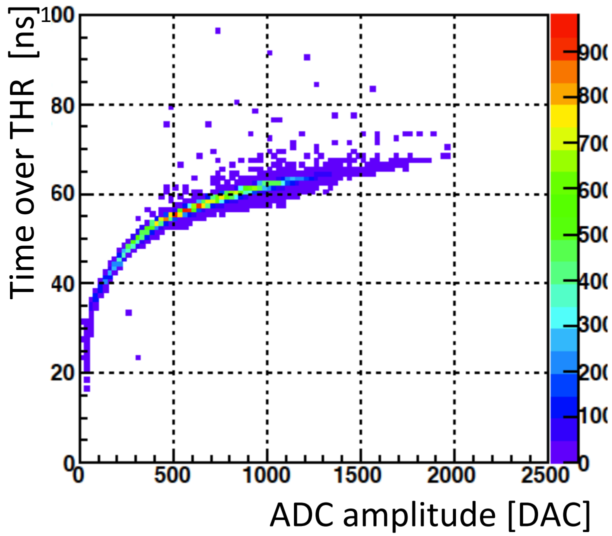
Relative gain map



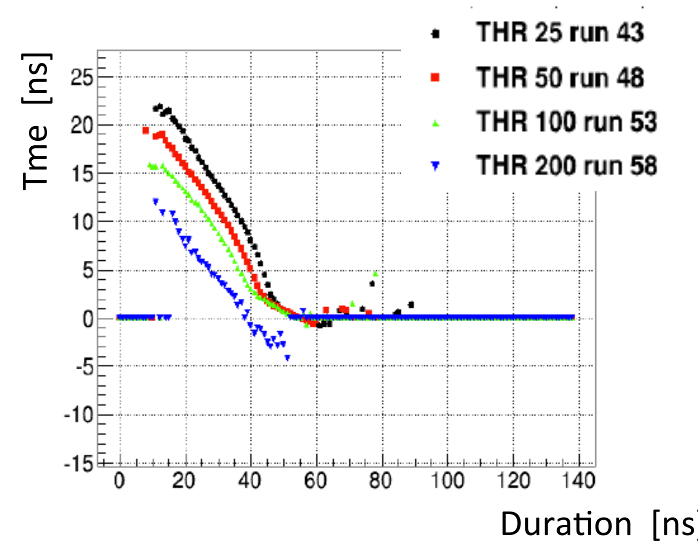




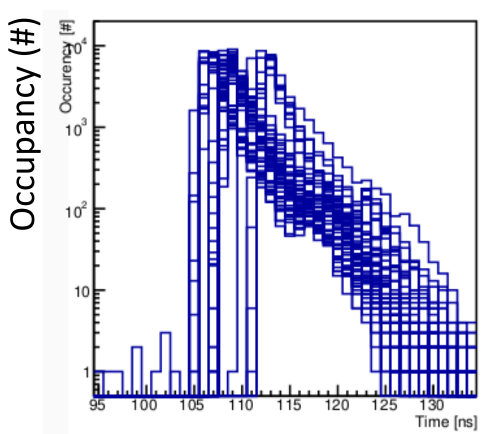
Time over threshold relates to charge

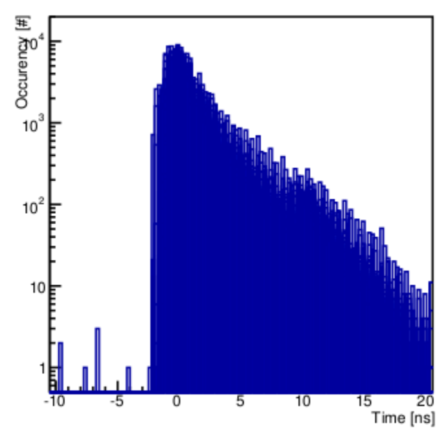


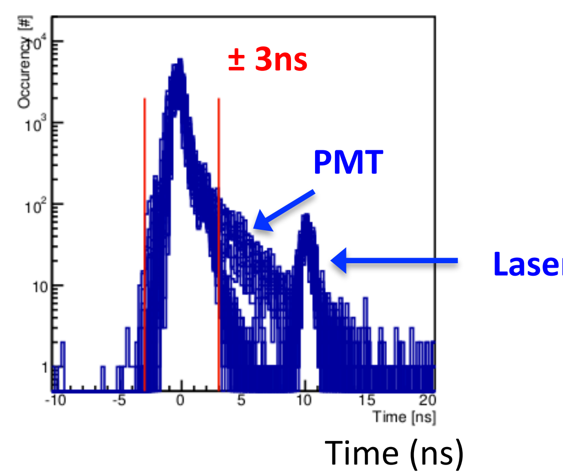
Typical time-walk with charge



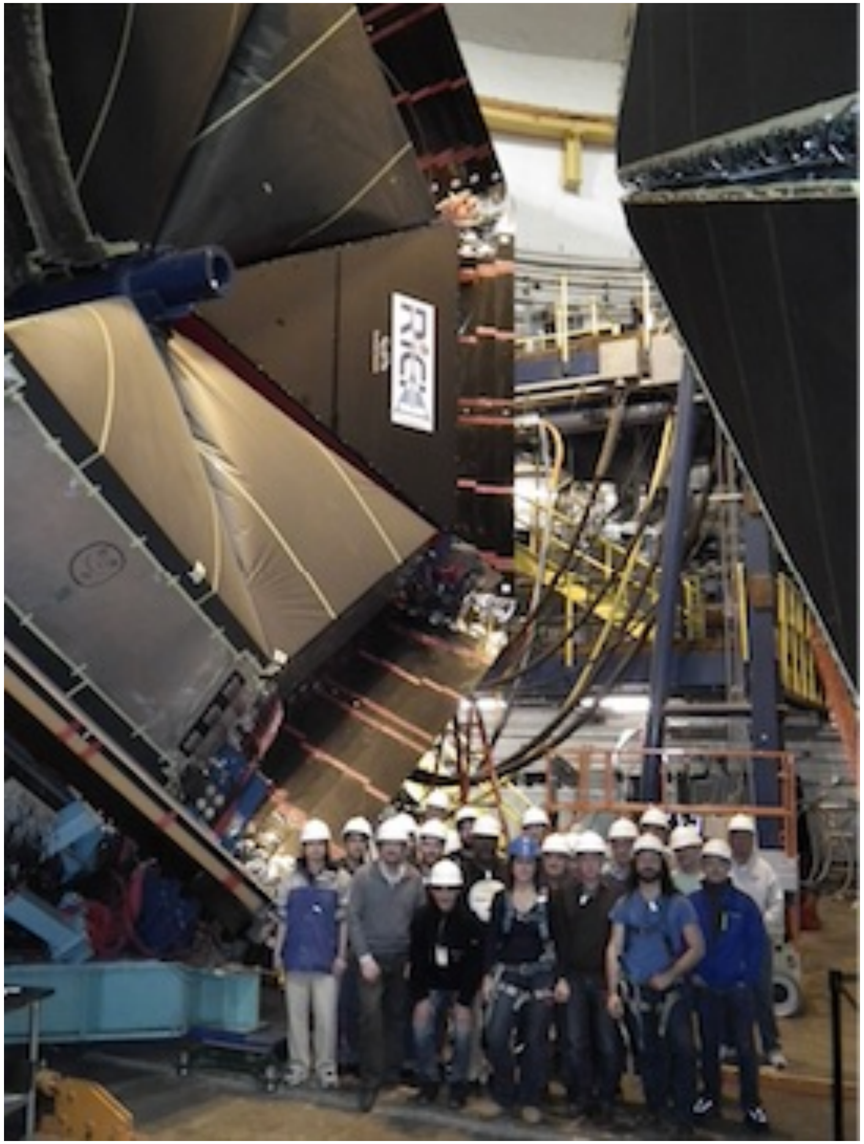
Channel by channel time calibration: no offsets no walk



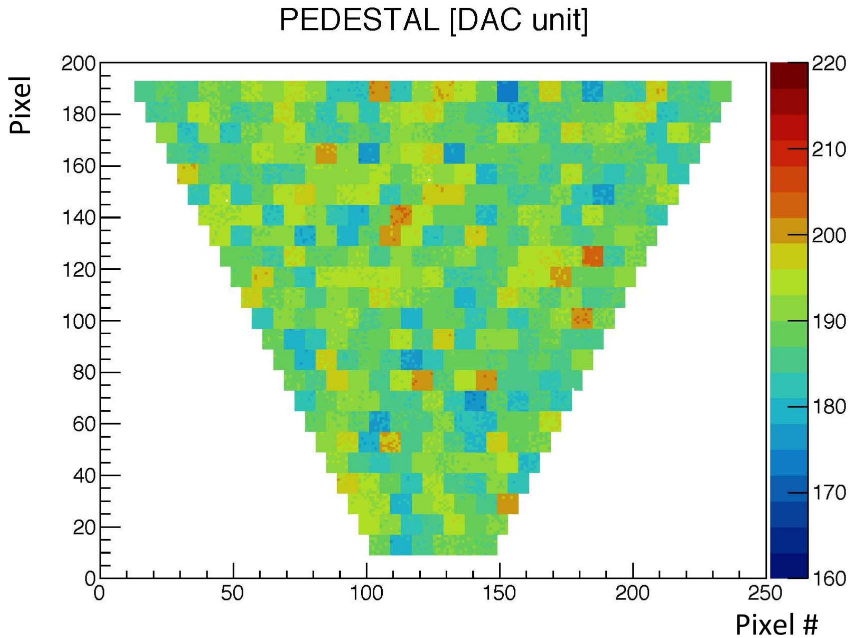


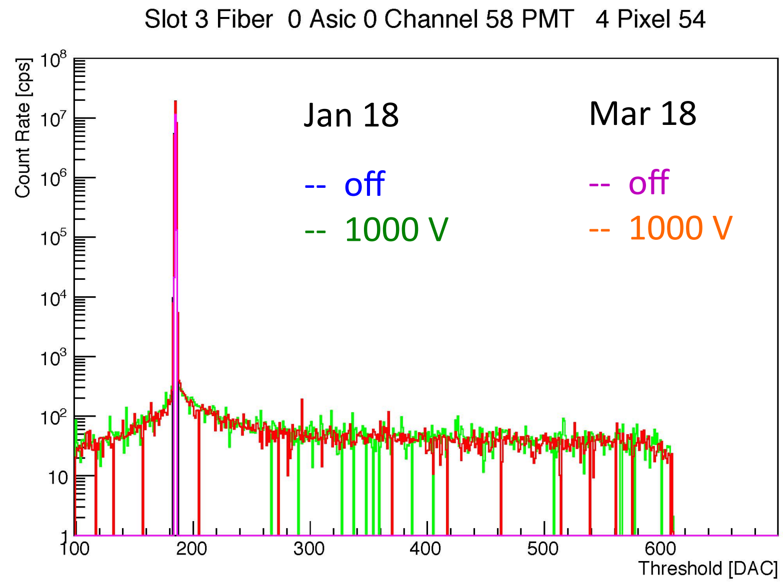


RICH Installation

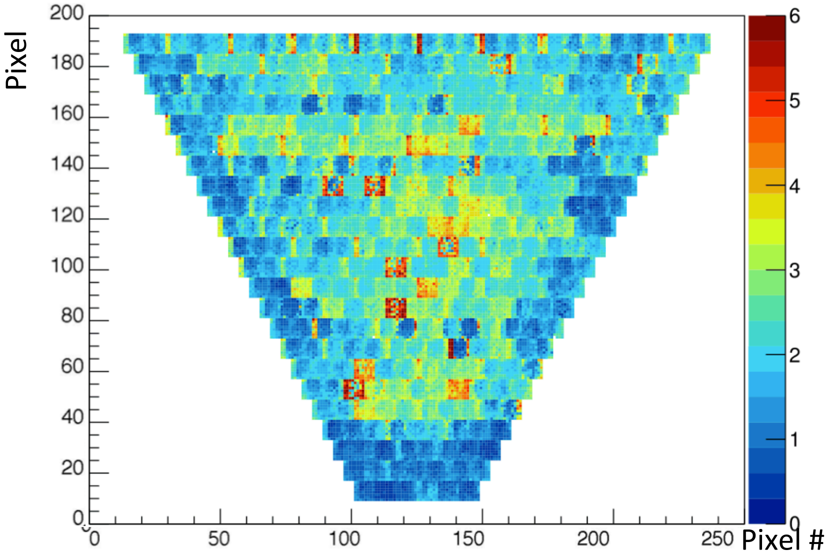


Electronic Pedestals

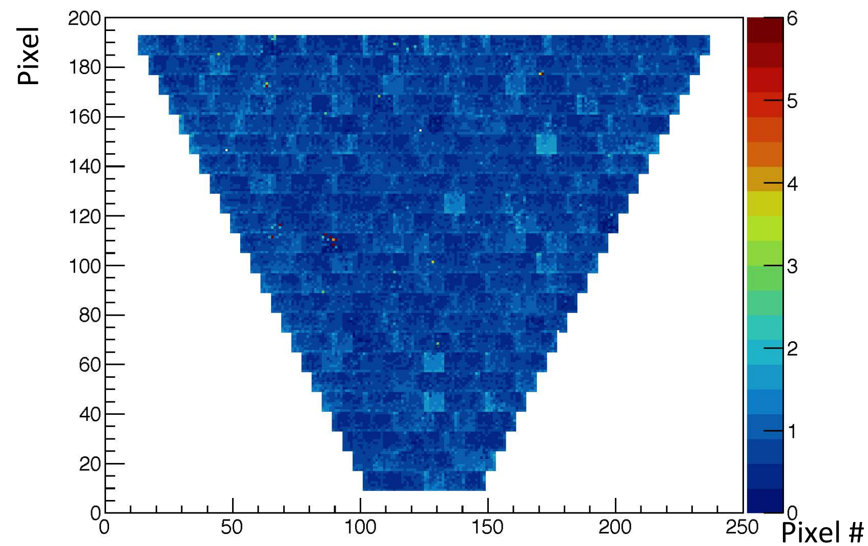




Pedestal rms [DAC unit]: without

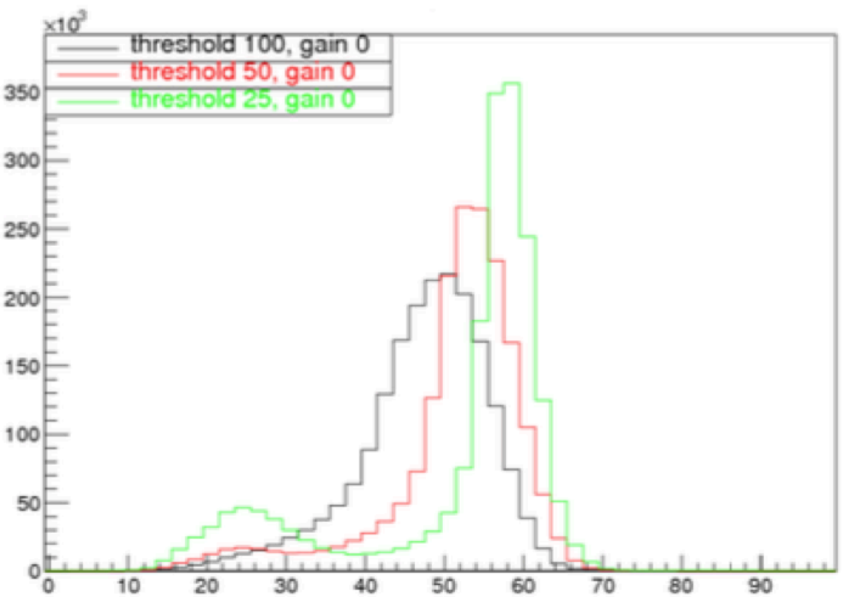


and with grounding grid

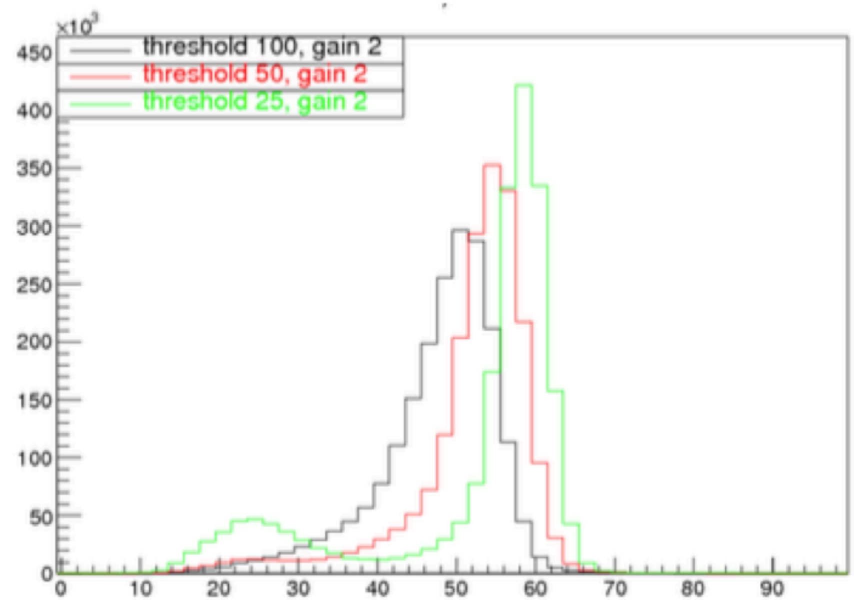


After equalization: distributions narrower and less sensitive to the common threshold
saturate signals and cross-talk well separate

Before equalization

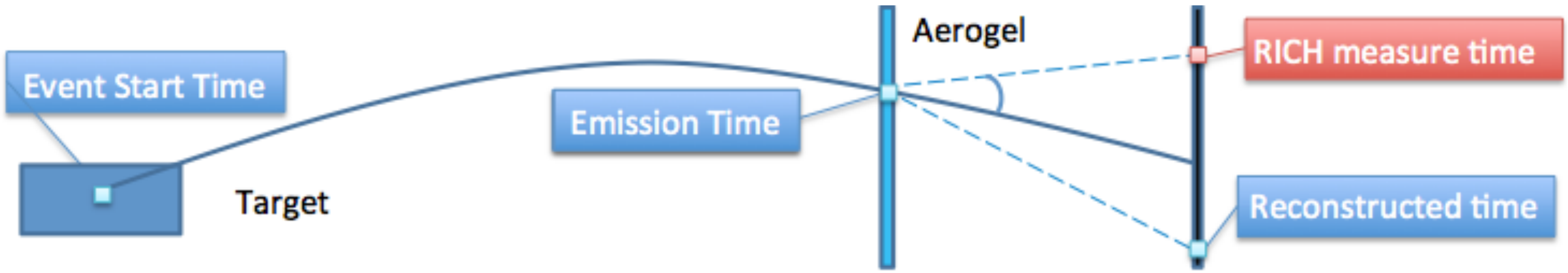


After equalization



black: high threshold **red: intermediate threshold** **green: low threshold**

Single Photon Time Analysis

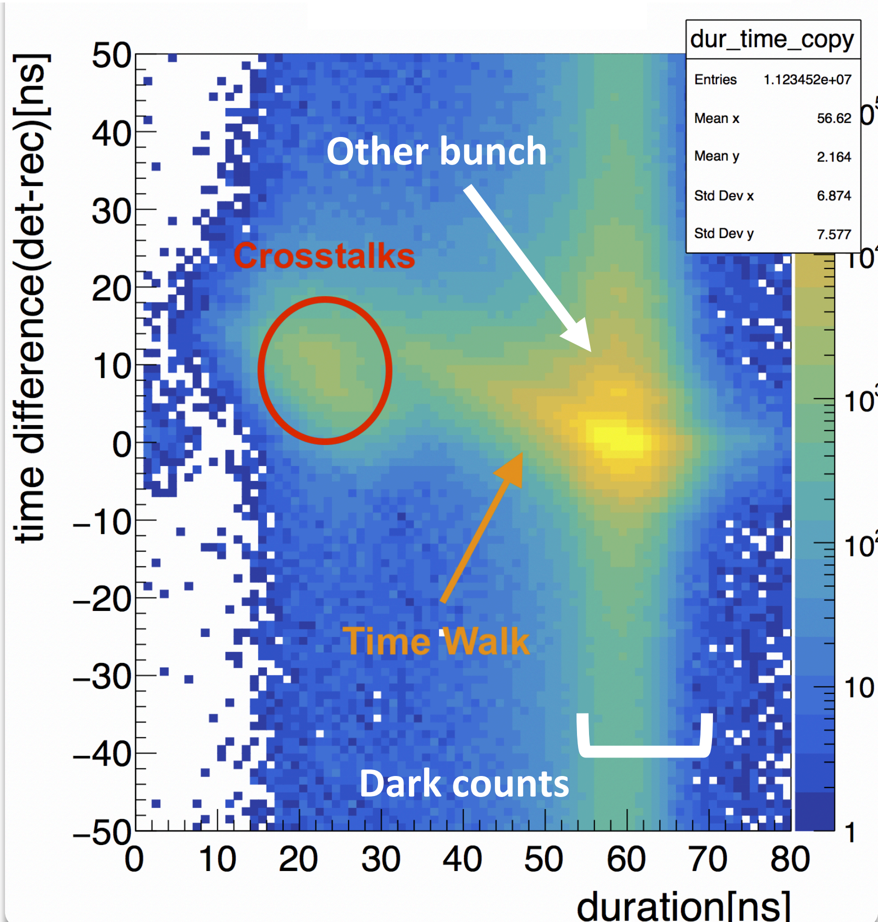


CLAS12 Reconstructed Time and Position:
Photons are traced using information from other CLAS12 detectors

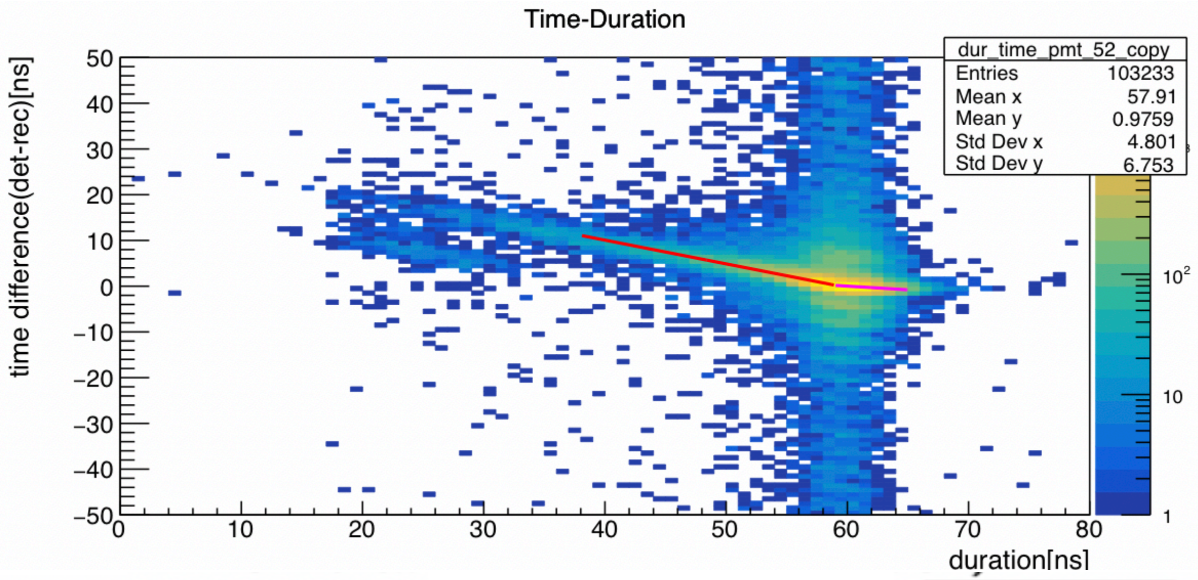
RICH Measured Time and Position:
Defined by the RICH DAQ

Good photons should match in time and space

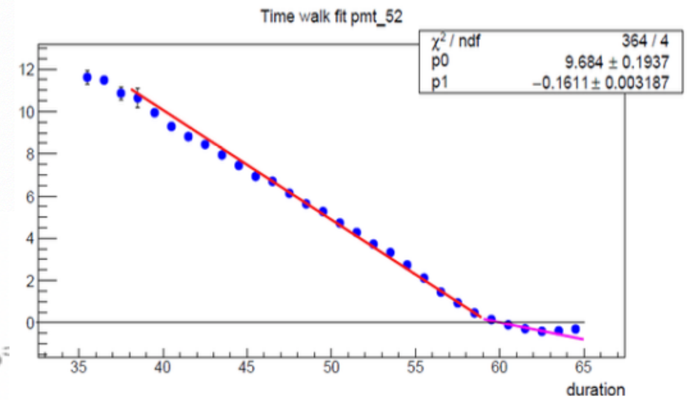
Time analysis allows to separate spurious signals

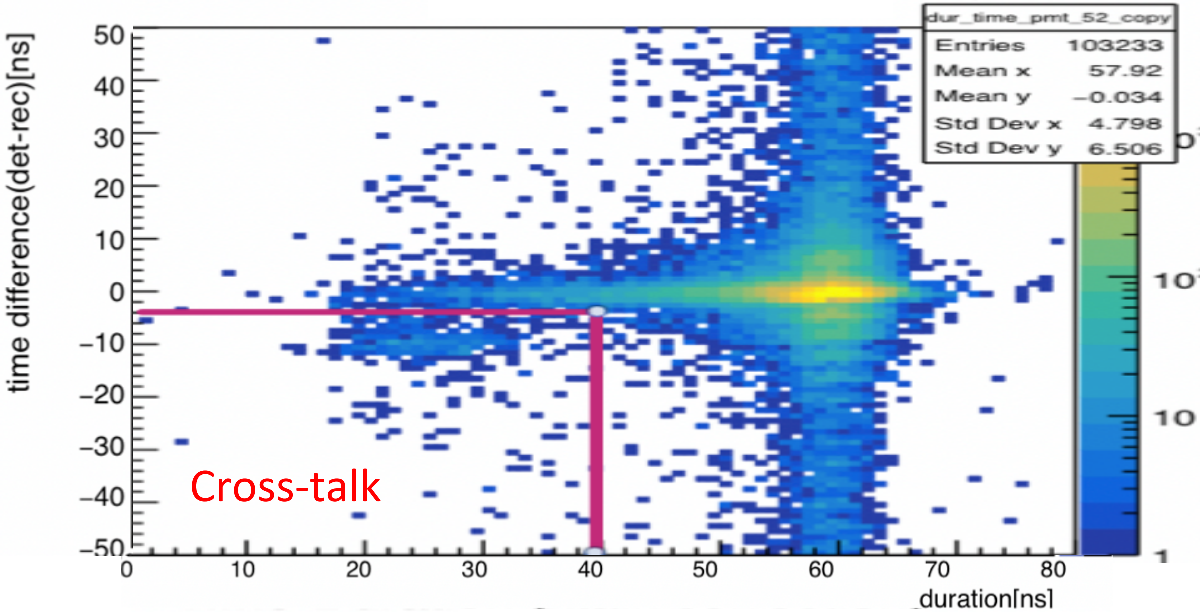


Time Calibration



Time vs Duration
after offset correction

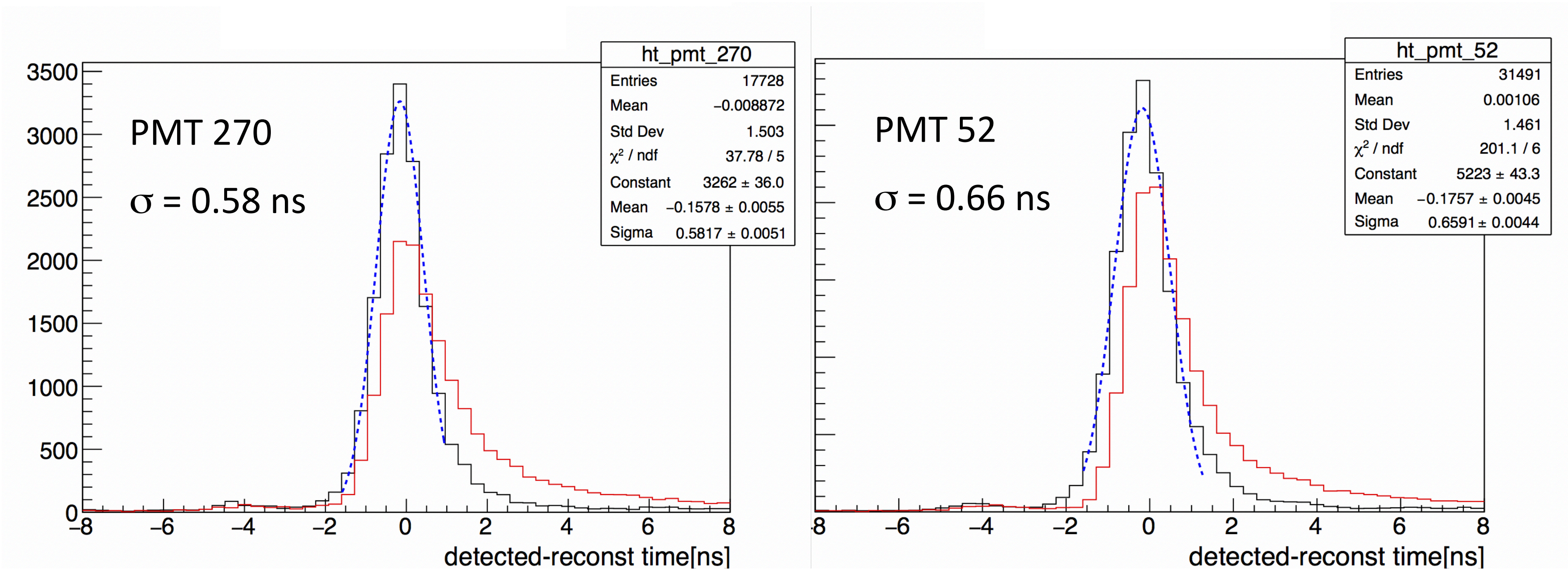




Time vs Duration
after walk correction

Single-photon Time Resolution

Single-photon time resolution better than the 1 ns specification

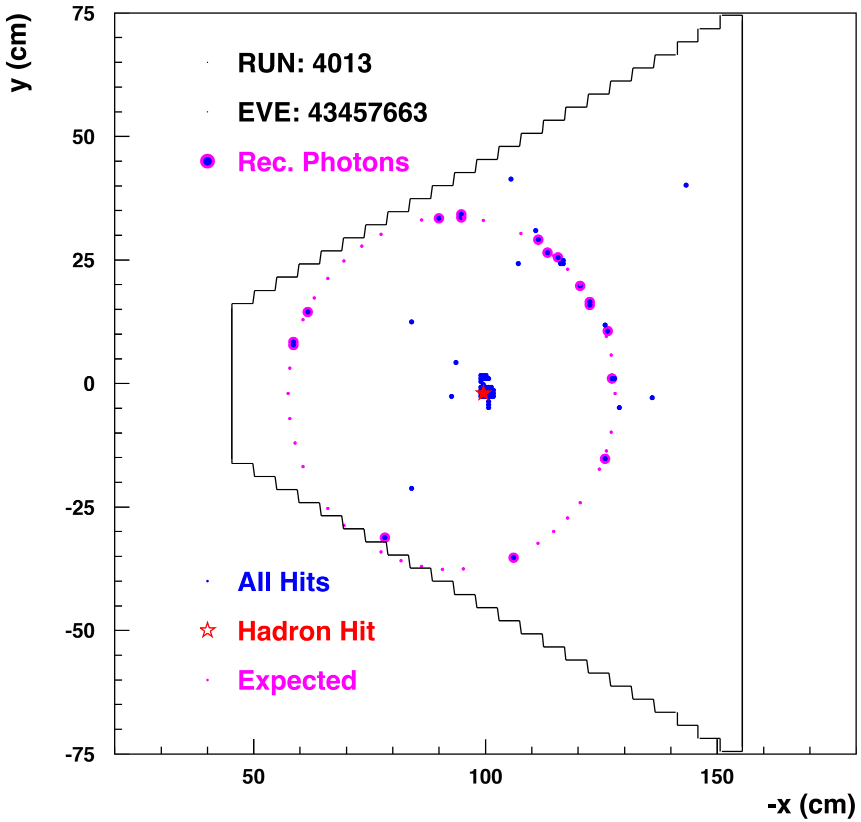


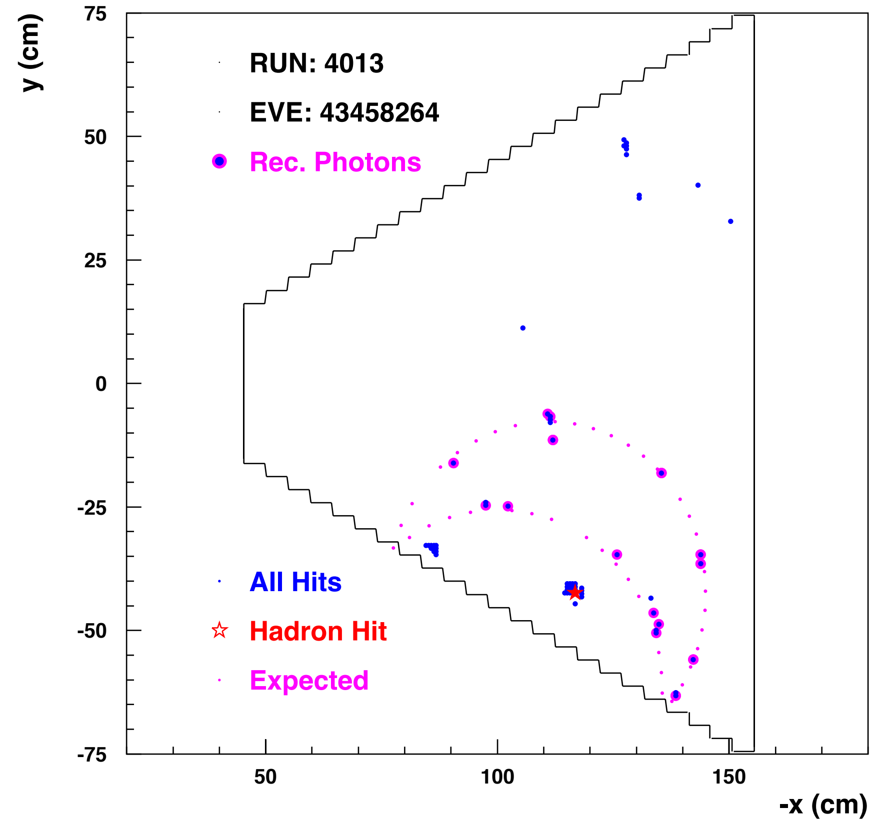
— before time-walk correction

— after time-walk correction

Cherenkov Photon Reconstruction

Example of signal hits identified by time consistent with CLAS12 reconstruction





Direct ring

Half recflected ring

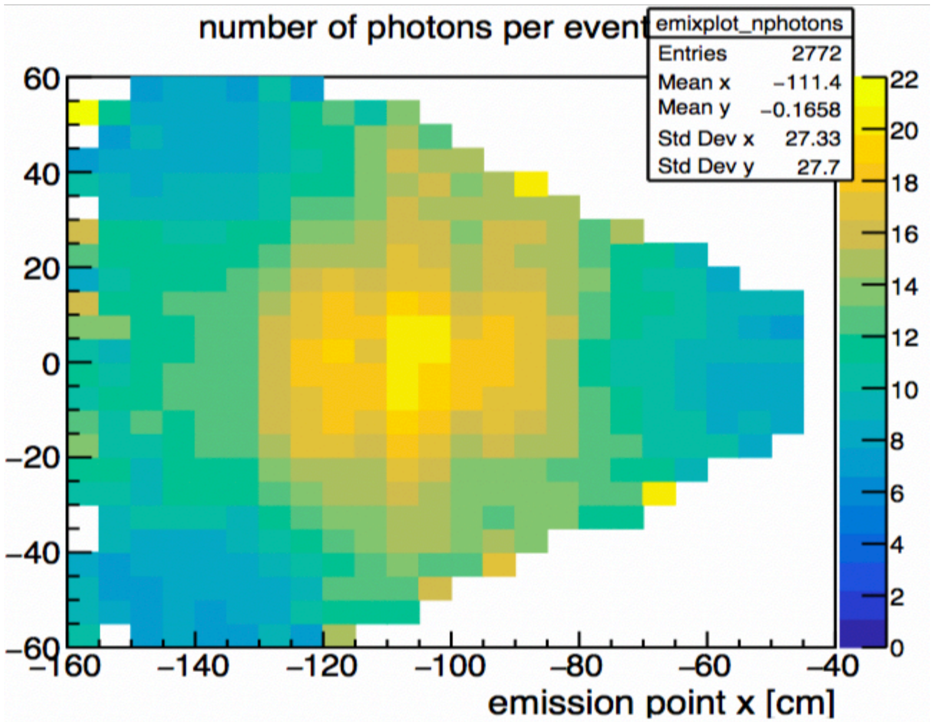
Direct Cherenkov Photons

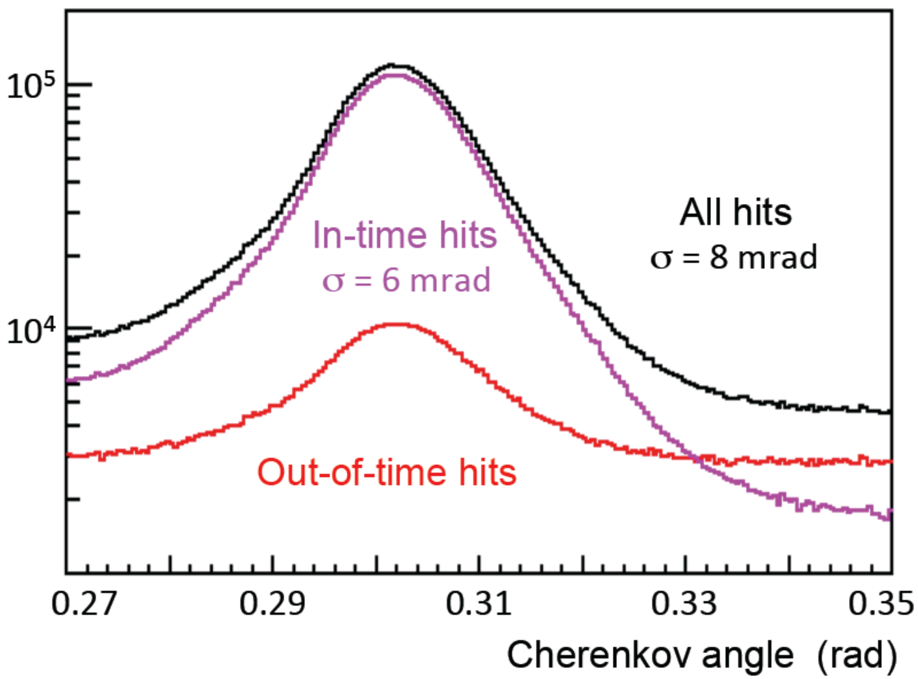
About 18 photons for a center ring (no reflection accounted for)

Consistent with the TDR projection

Preliminary single photon Cherenkov angle resolution = 6 mrad

Close to the 4.5 mrad goal despite
- No alignment
- Nominal (no real) optical property

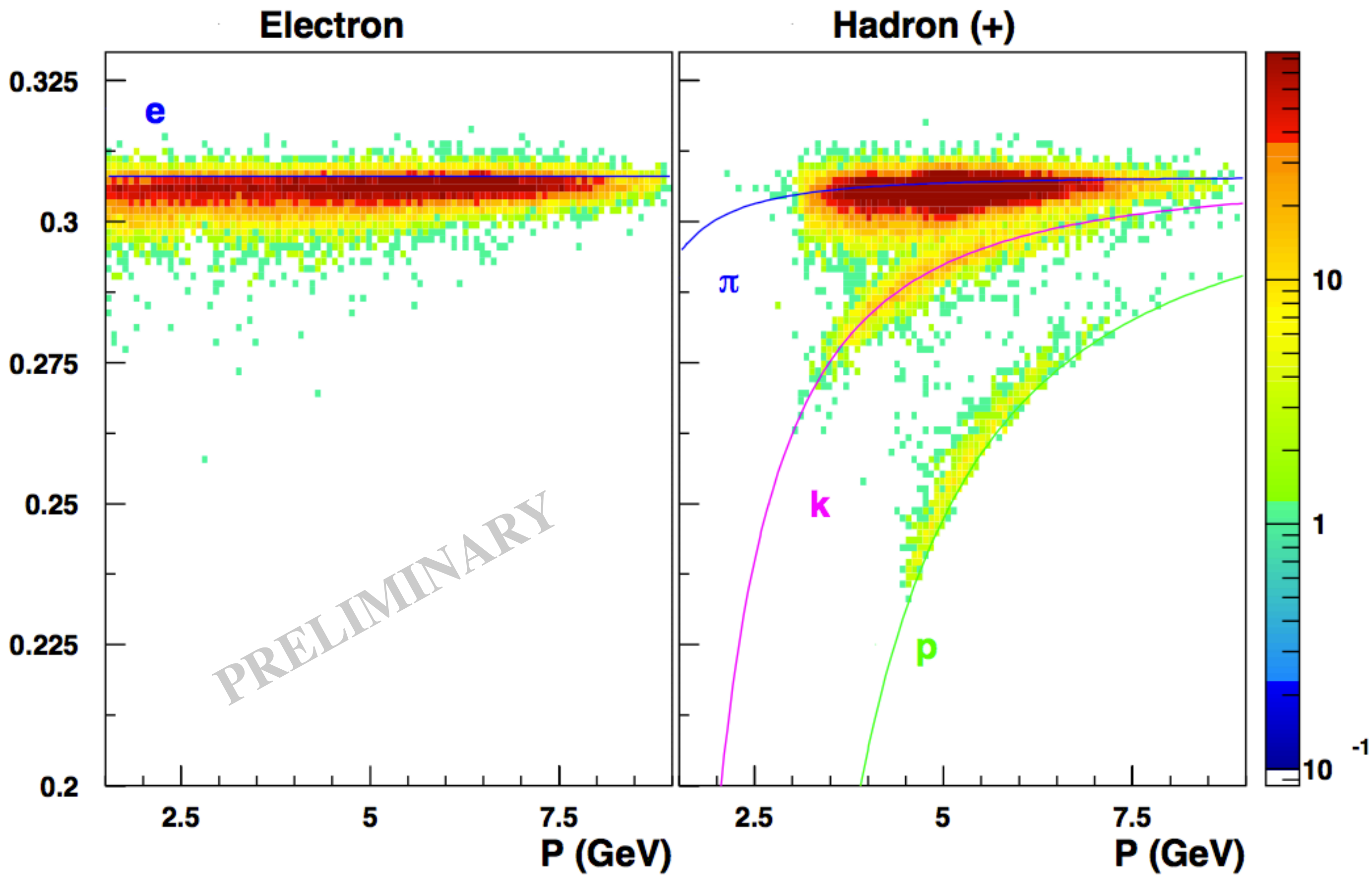




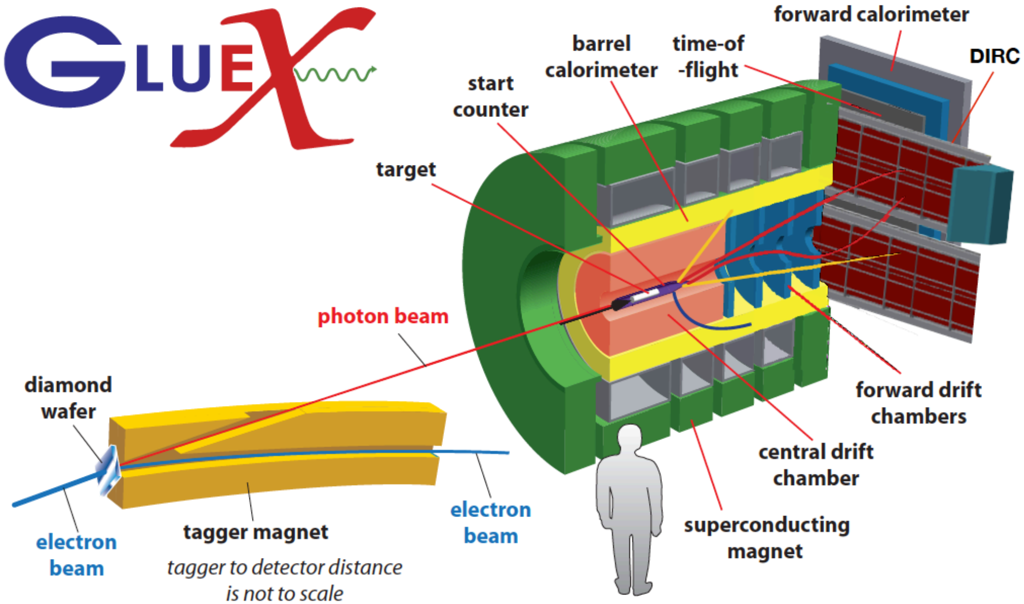
Enough for a Cherenkov resolution at track level of $\sigma = \sigma_1/\sqrt{N} \sim 1.5$ mrad

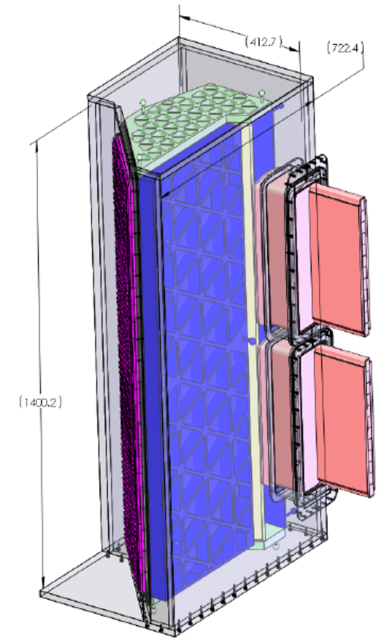
Hadron ID

Hadron separation, direct photon, RGA data

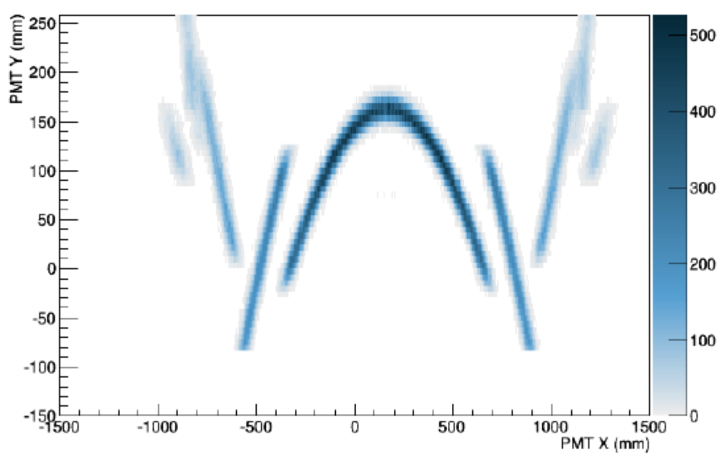


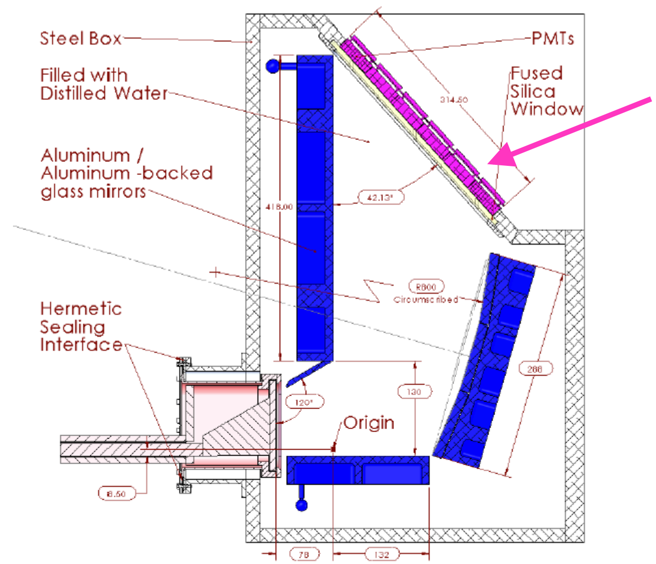
Application: DIRC @ GlueX





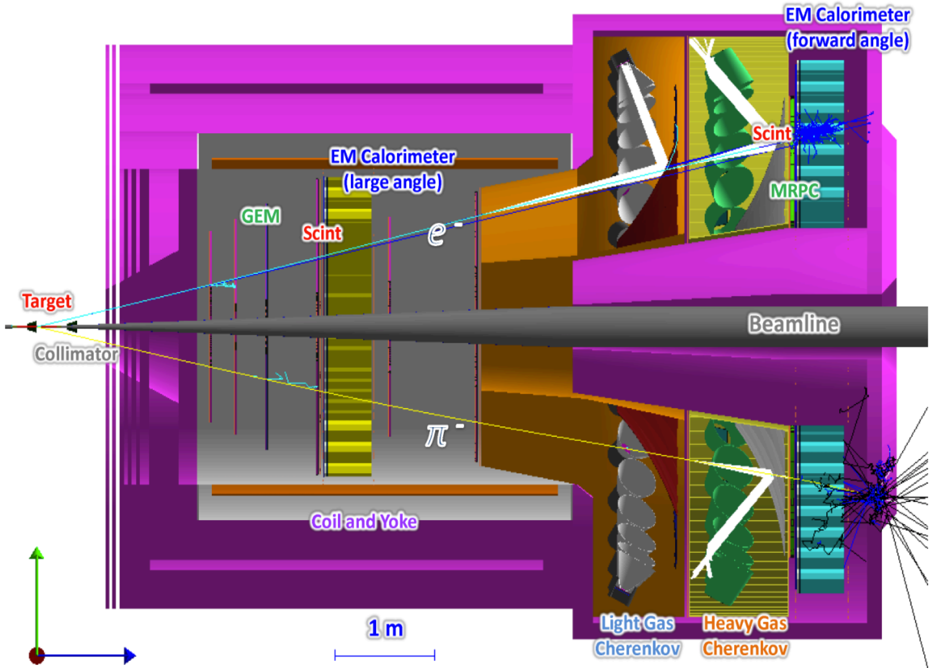
Hadron discrimination up to 4 GeV/c





H12700 + CLAS12 readout

Application: Gas Cherenkov @ SOLID



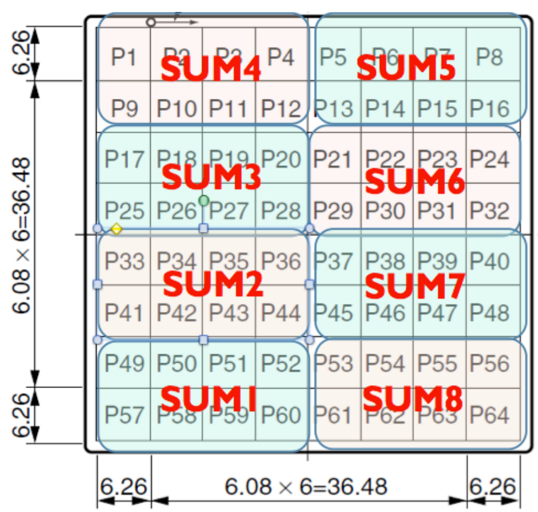
Light Gas Cherenkov

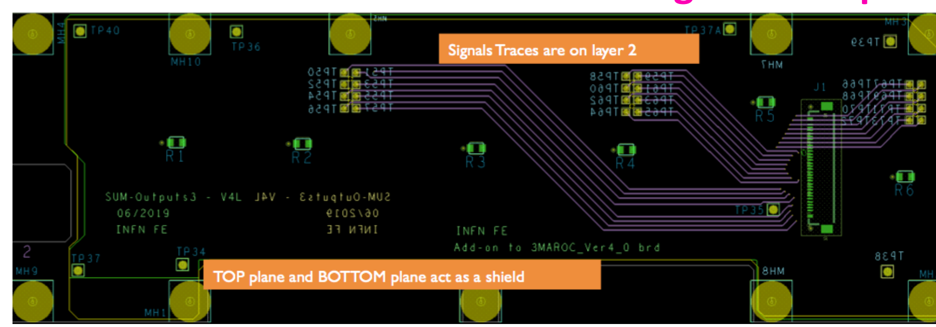
Momentum range 1-5 GeV/c
Cover 7^o to 15^o angular range
Pion contamination goal < 1%

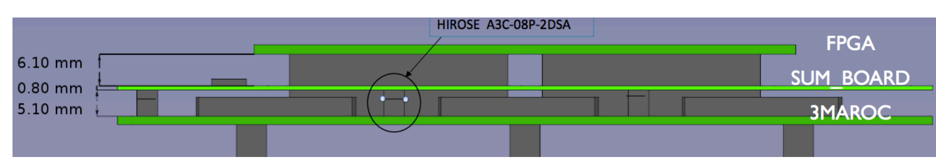
Heavy Gas Cherenkov

Momentum range 2.5-7.6 GeV/c
Cover 8^o to 15^o angular range
Kaon contamination goal < 1%

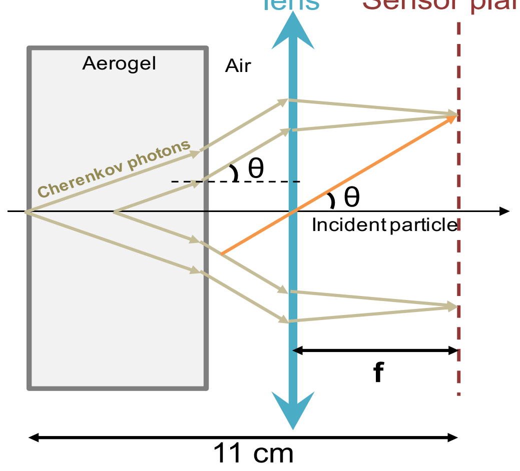
H8500 + CLAS12 readout with analog SUM output

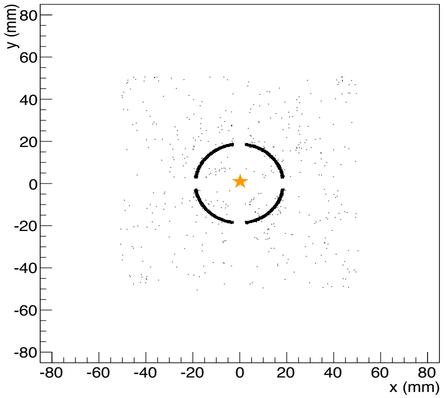


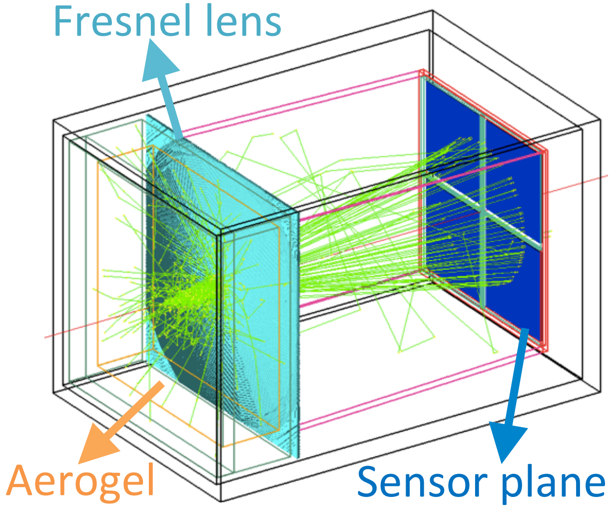




Compact and modular RICH indipendent elements



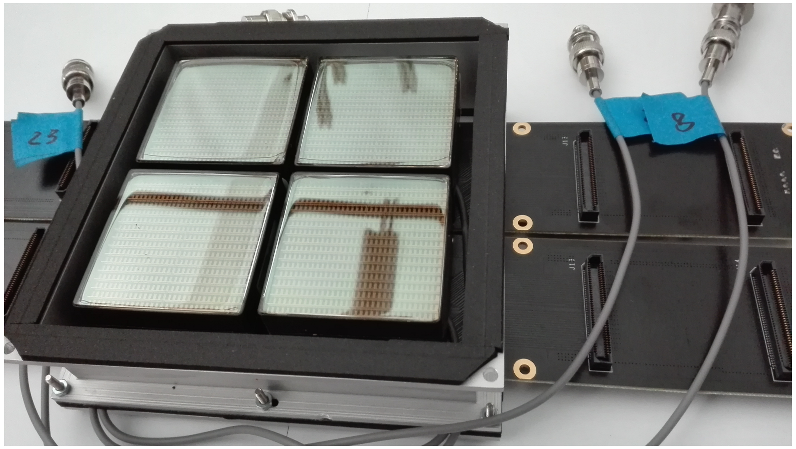


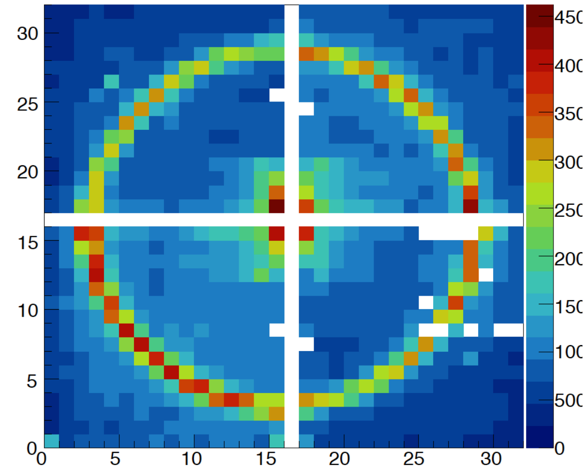


See Xiaochun He talk

H13700 to reach the 3 mm spatial resolution

Two completed mRICH prototypes

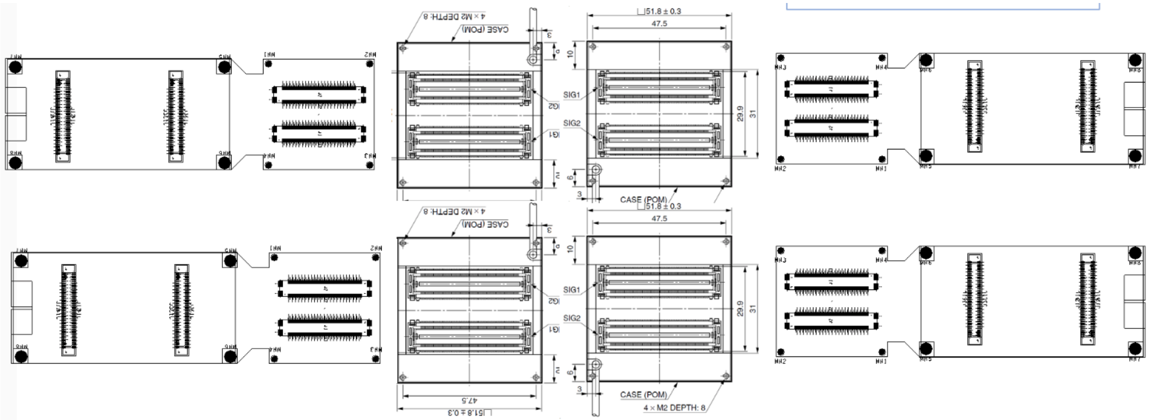




Application: H13700 Readout

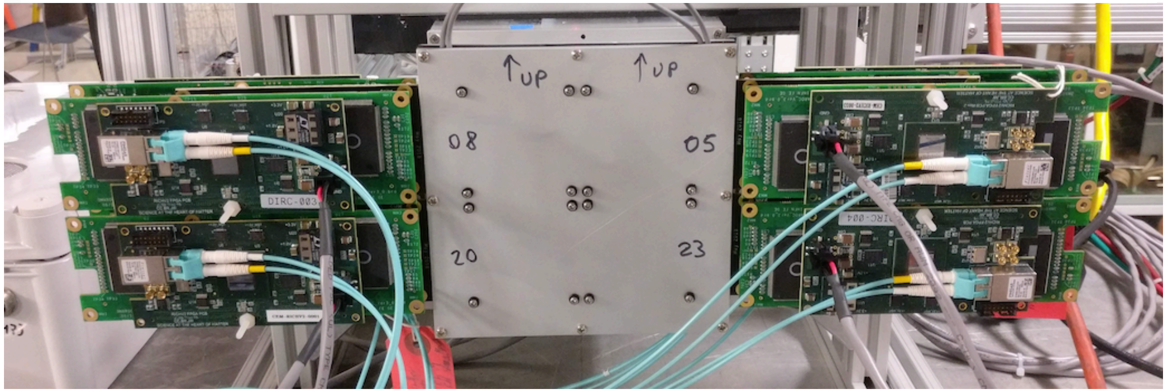
Derived from CLAS12 RICH readout:

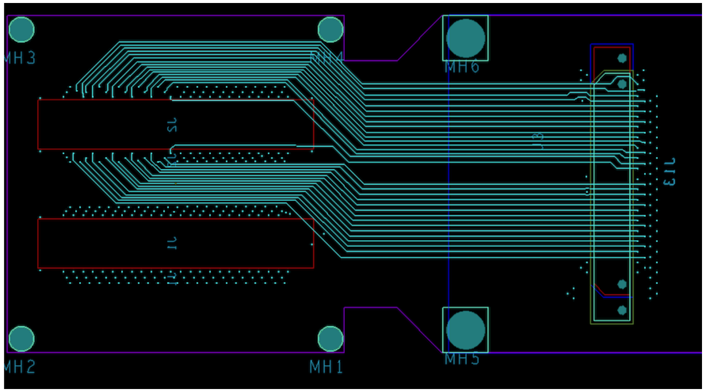
- 1024 channels
- MAROC 64 channel parallel digitalization
- FPGA generated 1 ns timestamp
- DAQ protocol based on VME/VSX SSP



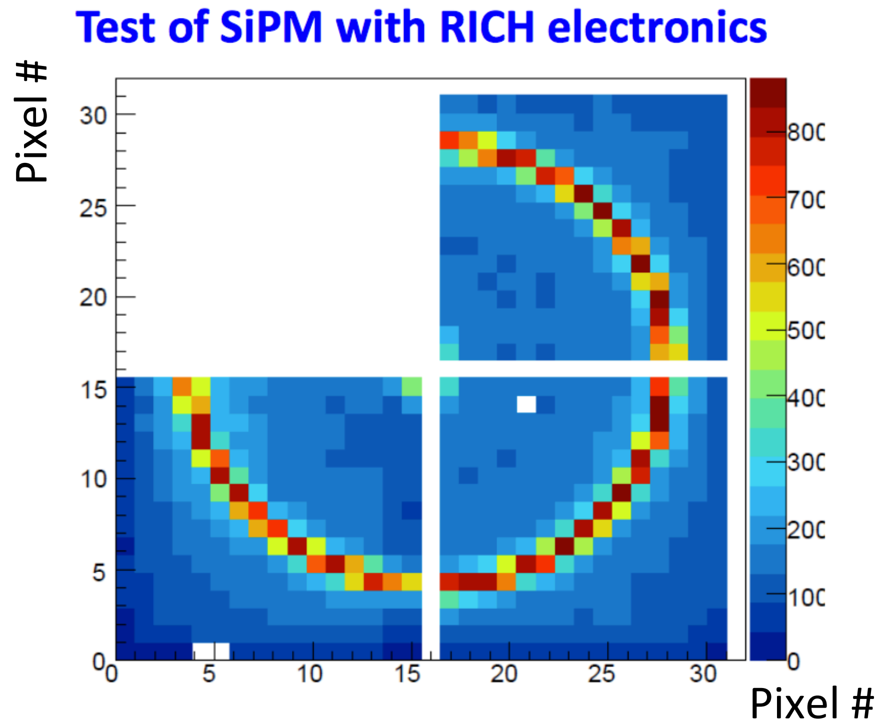
Custom adapter boards

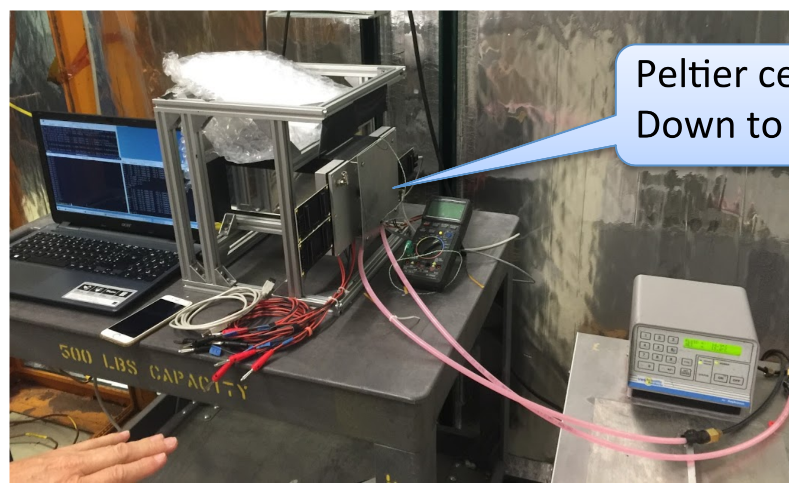
- Compact distribution
- Use of existing MAROC boards
- Light and gas tightness





Application: SiPM Arrays





Peltier cell cooling
Down to -30° in N_2

Conclusions

CLAS12 RICH designed to provide hadron identification in the 3 to 8 GeV/c momentum range
A hybrid-optic design has been adopted to minimize the instrumented area to about 1 m^2

The MAROC readout electronics is designed to offer

Discrimination down to few % of SPE
Time resolution of 1 ns
Negligible dead time at 30 KHz
Trigger latency up to 8 μs

Featuring:

Compatibility with various sensors and applications
Modular Front-End (Mechanical adapter, ASIC, FPGA)
Scalable fiber optic DAQ (TCP/IP or SSP)
Compact and tessellated geometry (common HV, LV and optical fiber)
Flexible trigger logic (external, auto, self)
Charge measurement (multiplexed ADC or time-over-threshold)

Multi purpose electronics: in use also for GlueX DIRC and available for EIC R&D