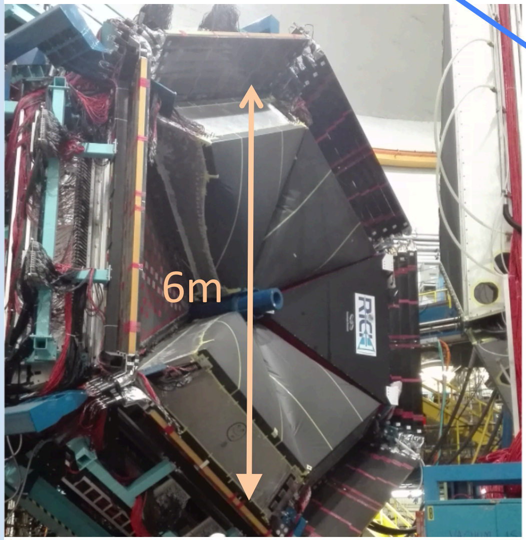
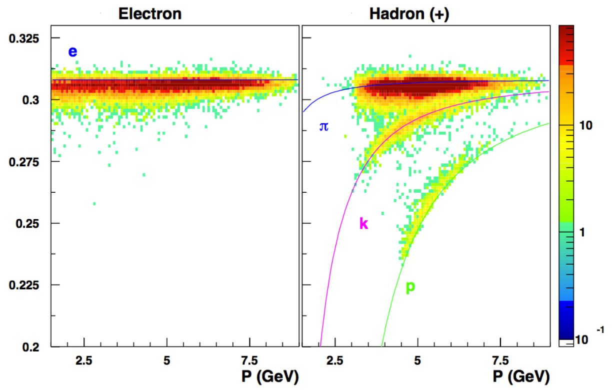
INFN Groups and eRD14

INFN within eRD14 Consortium

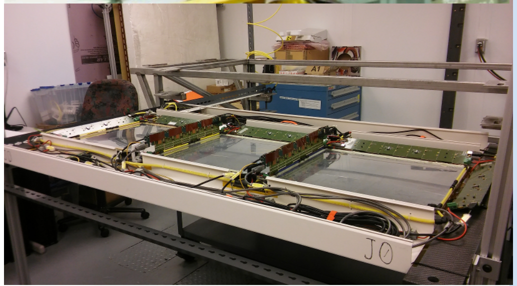
INFN-FE
CLAS12 RICH



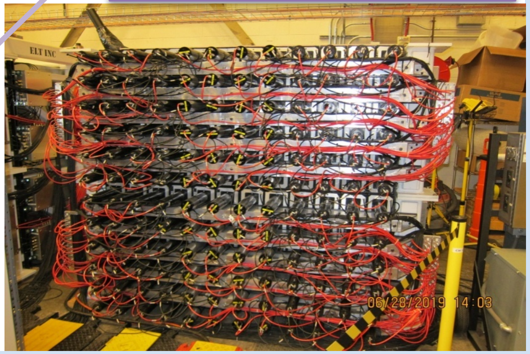
INFN-LNF
CLAS12 RICH



INFN-RM1
HERMES RICH
Hall-A Tracking

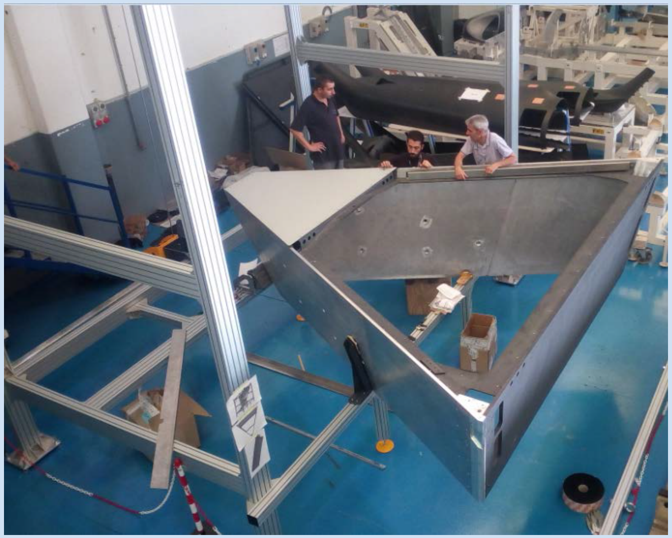


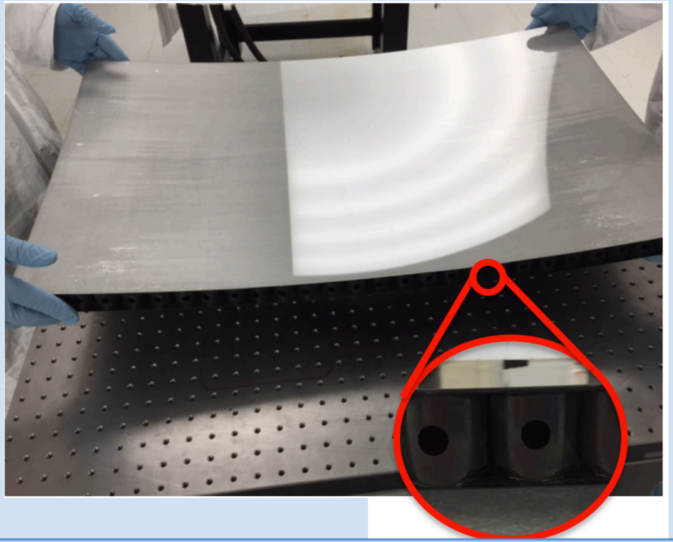
INFN-CT
Hall-A HCAL



RICH Components

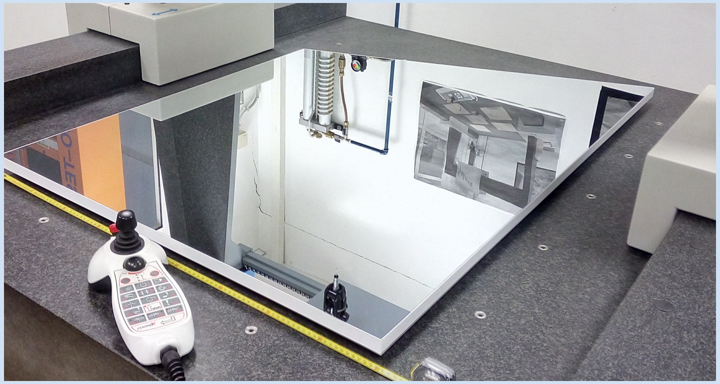
Aeronautic technology for structure
to maximize lightness and stiffness. Trapezoid of composite materials: CFRP inside acceptance, Aluminum outside





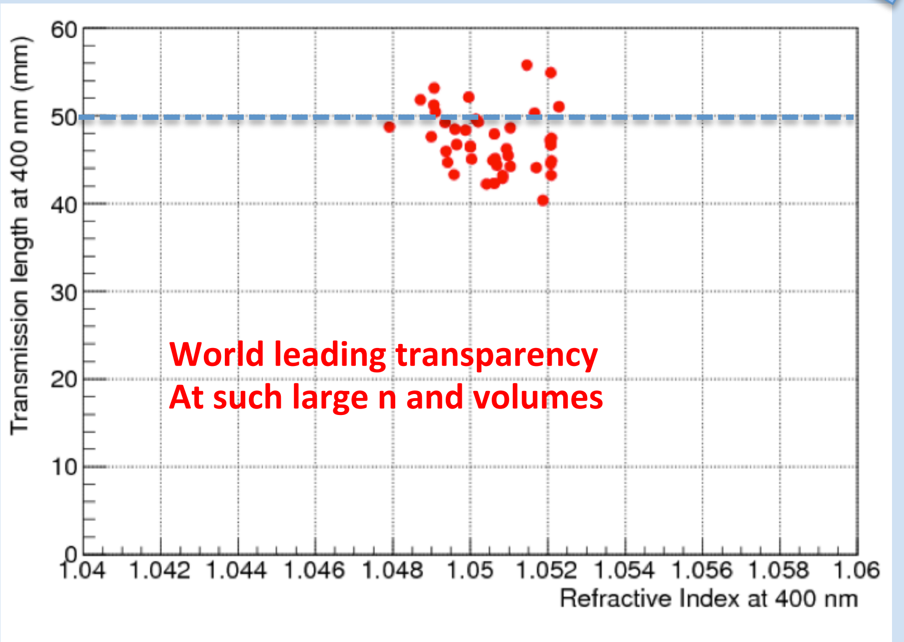
Carbon Fiber Mirrors (spherical)
to maximize lightness and stiffness. Consolidate technology (HERMES, AMS, LHCb) but ~ 30 % material budget reduction

RICH Components



Glass-Skin Mirrors (planar)
Innovative technology never used in nuclear experiments.
1.5 mm outside, 0.7 mm inside acceptance
~ 1/5 cost for squared meter vs CFRP

Large refractive index aerogel radiator
Tiles up to 20x20x3 cm^2 at n=1.05.



World leading transparency
At such large n and volumes

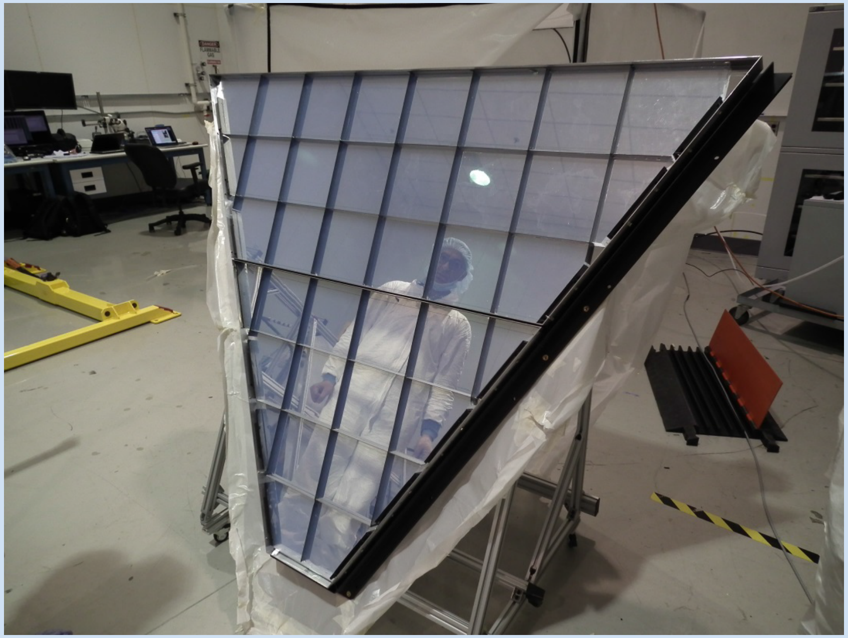
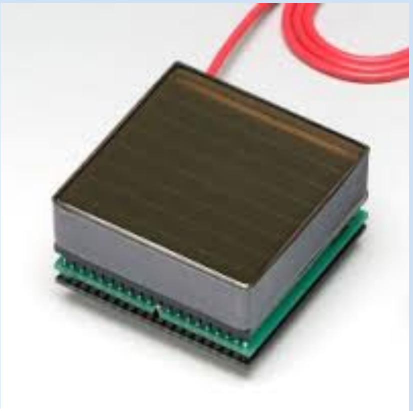


Photo-sensor: MA-PMT

80 H8500 + 350 H12700

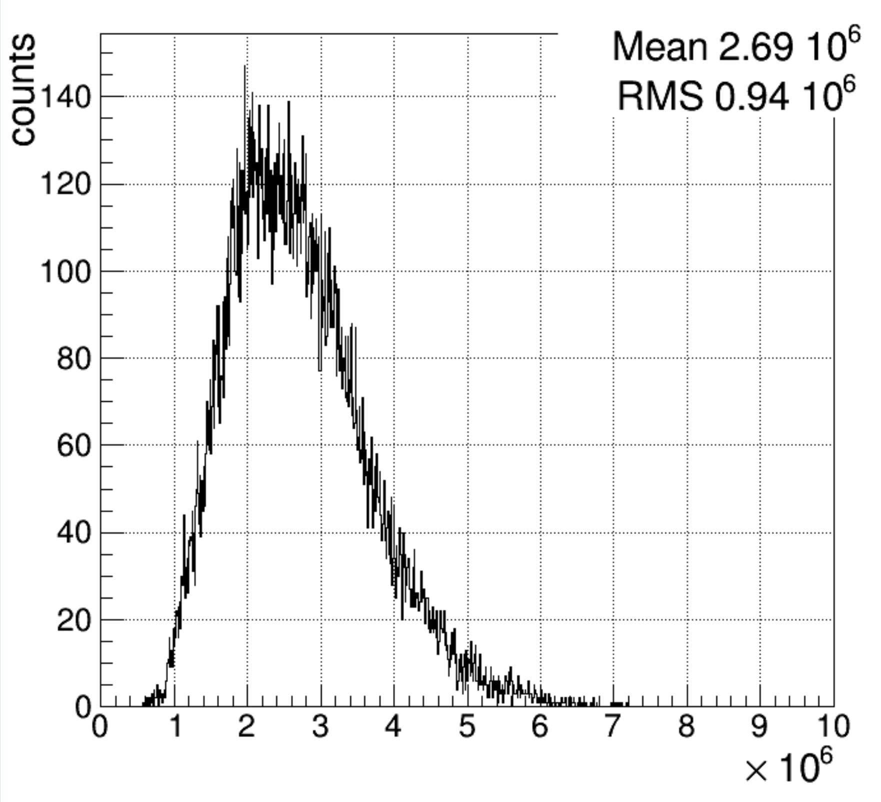
< 1 cm spatial resolution
< 1 ns time resolution
Compatible with the low torus fringe field

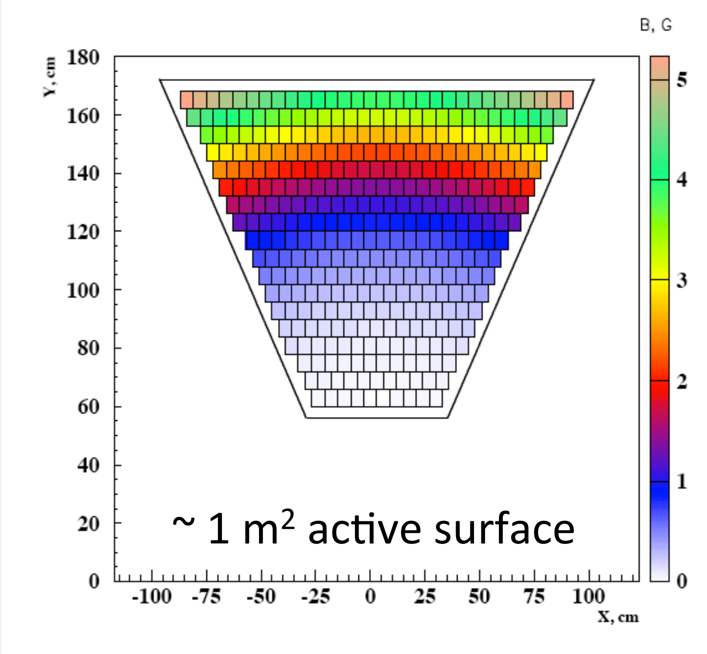
Average MA-PMT gain ~ 2.7 10^6
Corresponds to SPE ~ 400 fC



- ✓ 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

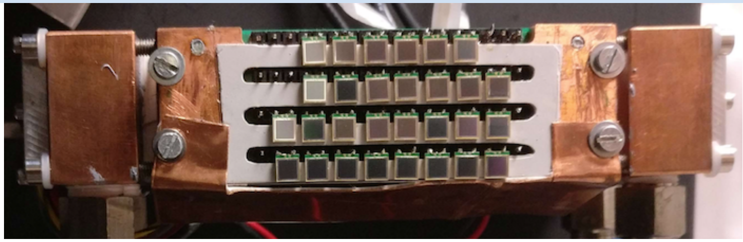
- ✓ Expensive technology

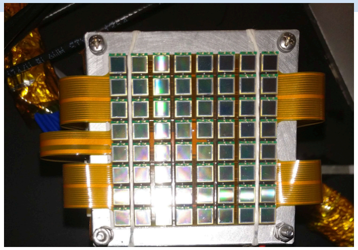


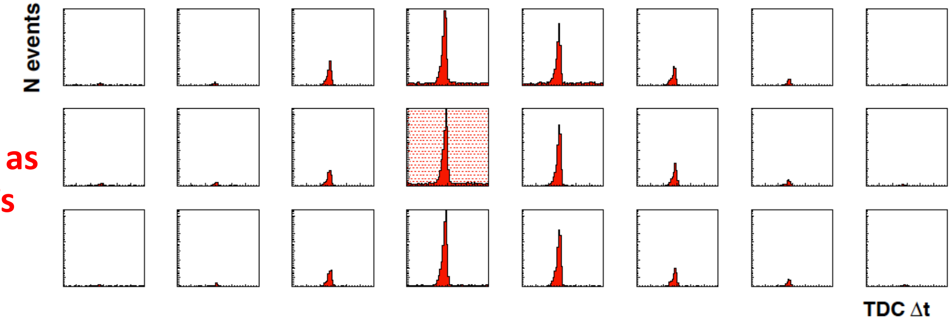


~ 1 m^2 active surface

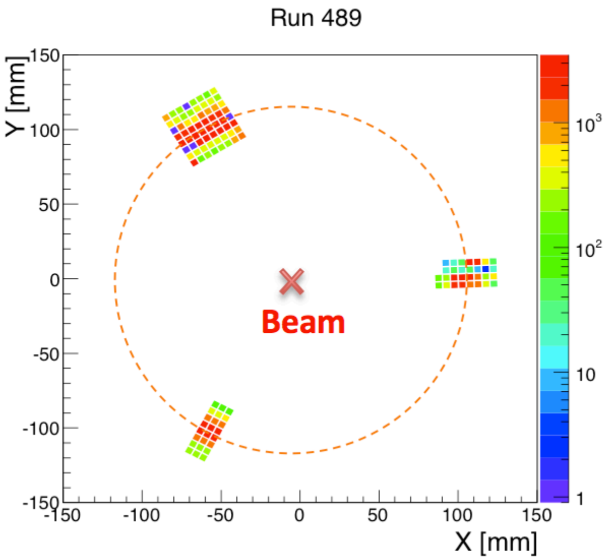
Photo-sensor: SiPM







Cooled SiPM as good as PMTs



SiPMs

- ✓ Mass production technology
- ✓ Photon counting
- ✓ Excellent time resolution
- ✓ Compatible with magnetic field

- ✗ High dark rate
- ✗ Low radiation tolerance

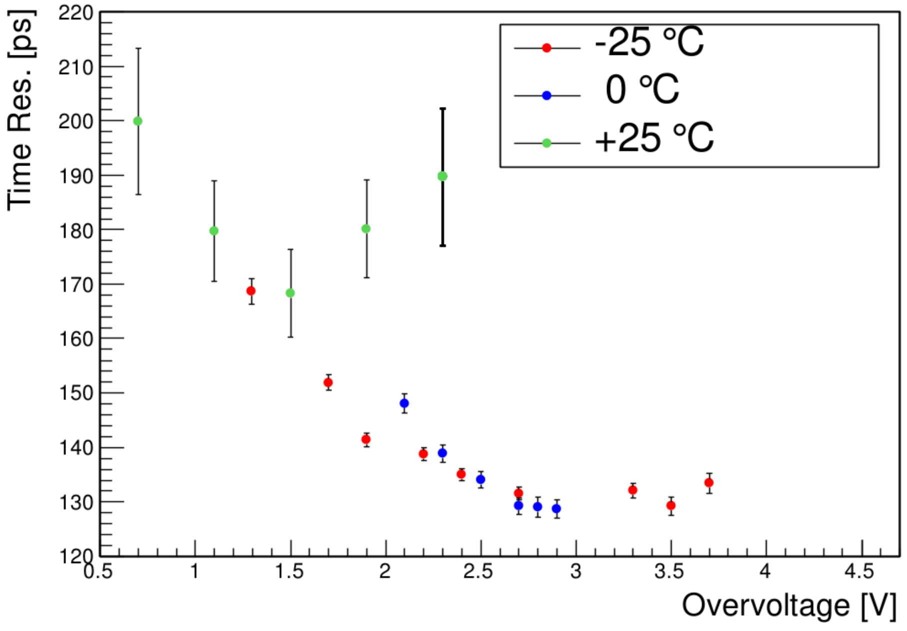


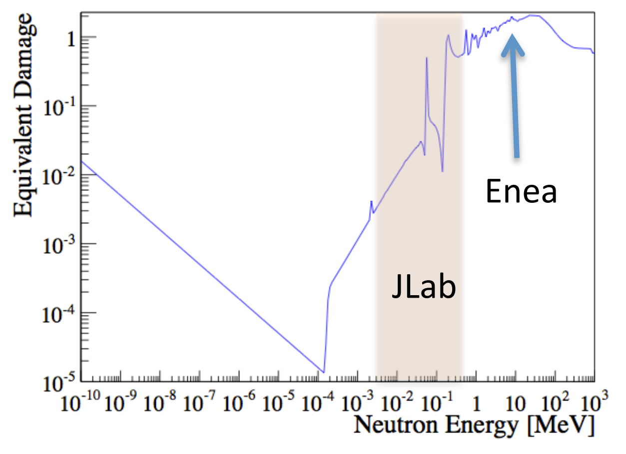
Photo-sensor: SiPM

Neutrons produced isotropically through

d(230keV) t → n α

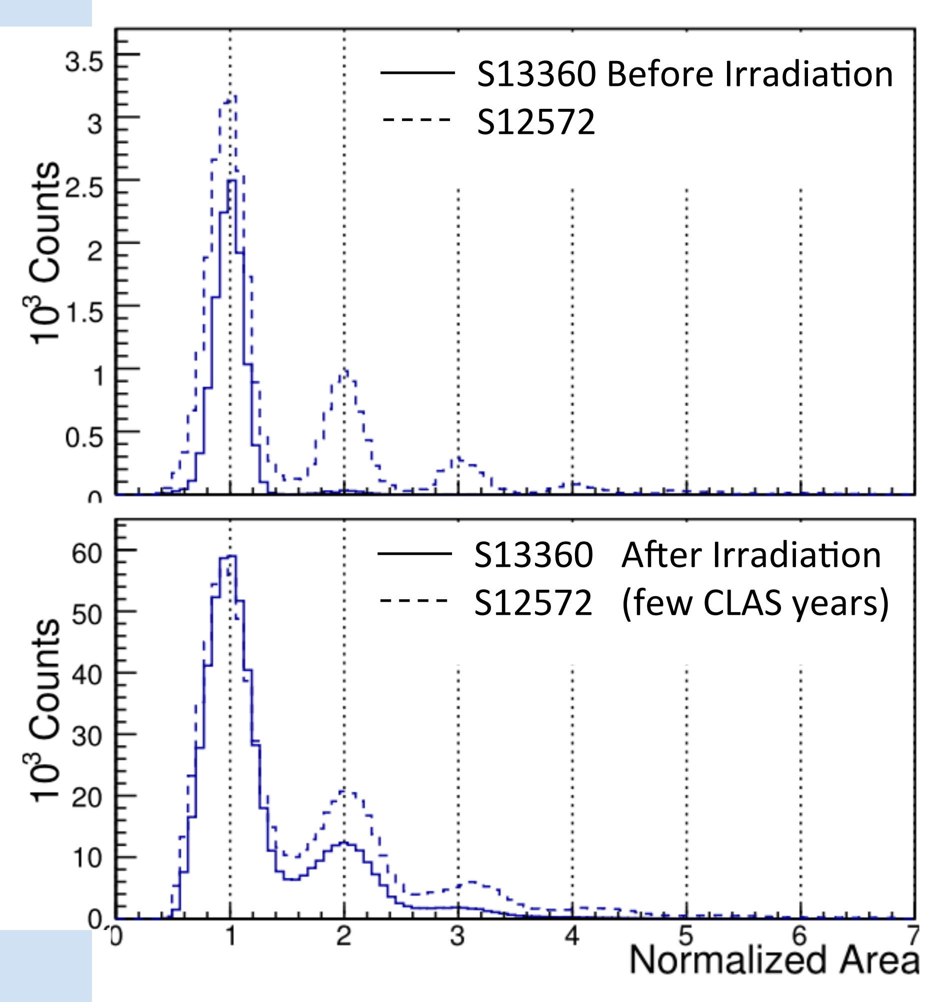
α particles measured to monitor the intensity

- max flux 10^{11} s^{-1} in 4π
- max neutron energy 14.6 MeV



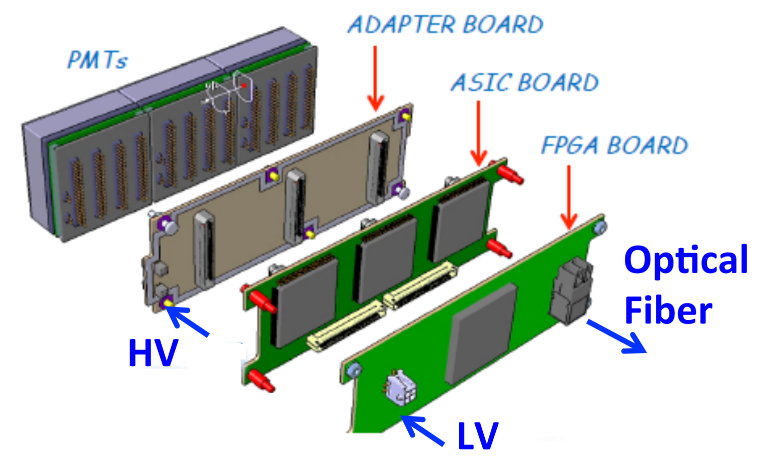
Single-photon capability after irradiation ?

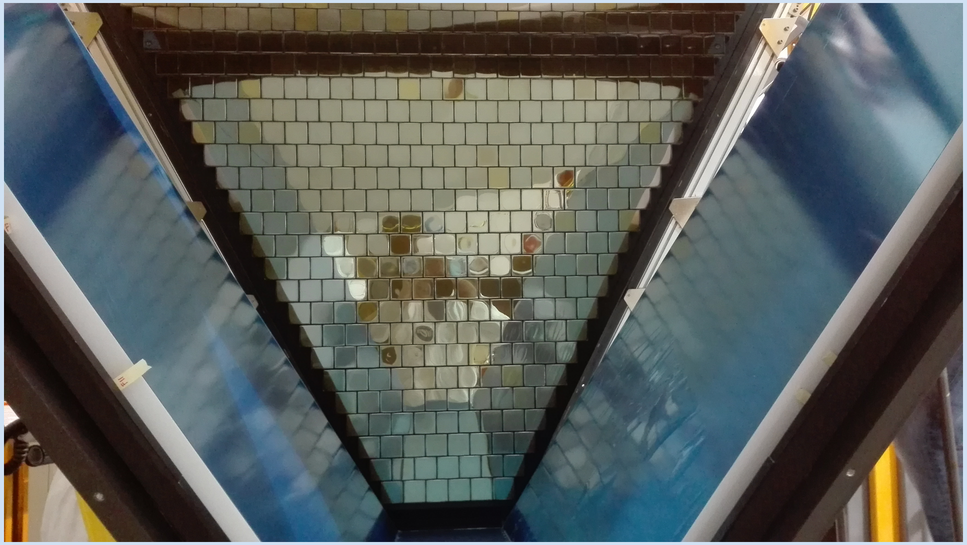
S12572 standard technology
S13360 trench technology



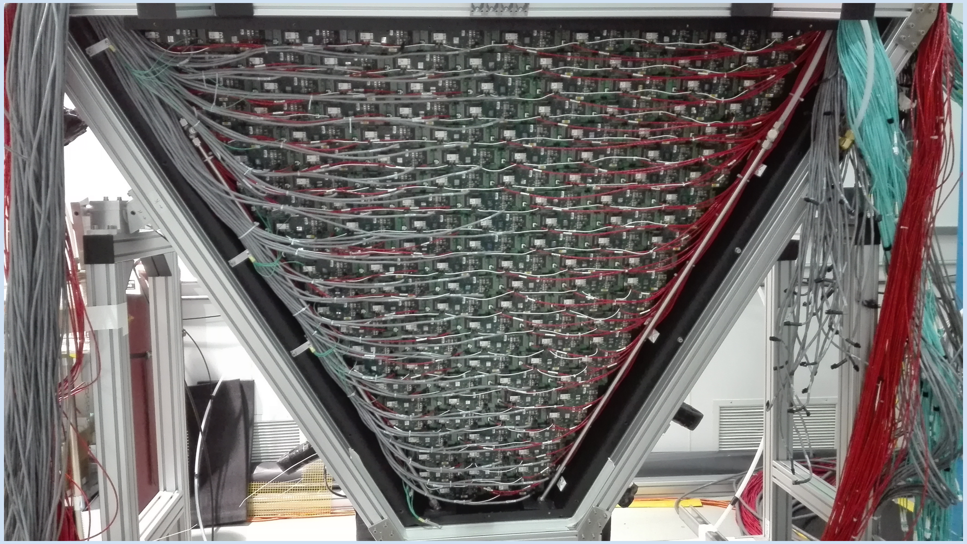
Modular Readout Electronics

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)



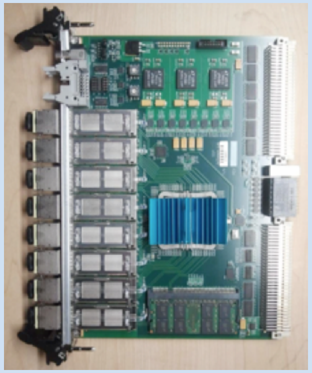


Constant threshold discrimination
1 ns FPGA timestamp (clock distribution driven)



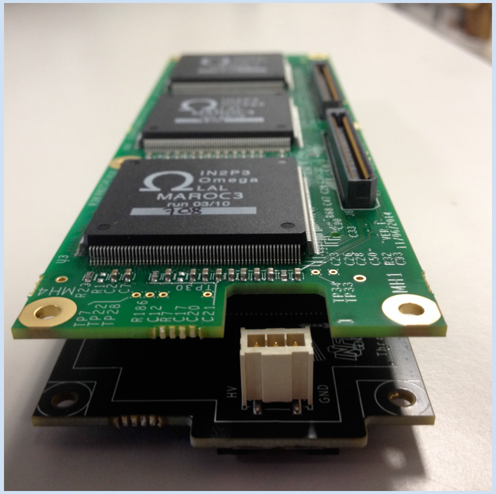
Applications:

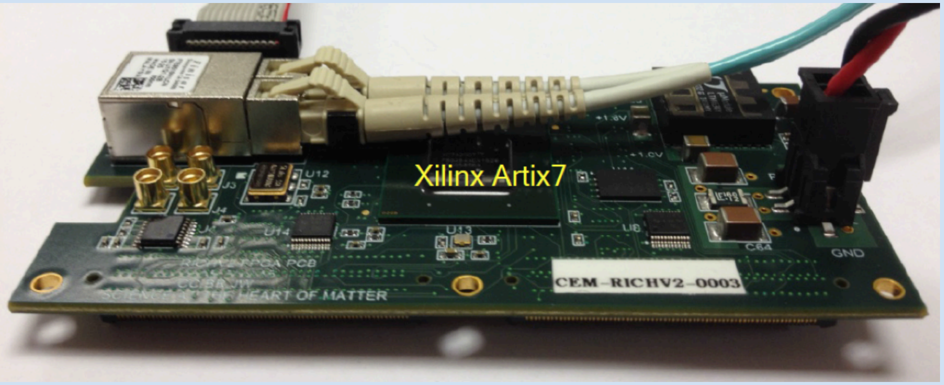
- CLAS12 RICH
- **EIC R&D**
- Gluex DIRC
- SOLID
- Medical Imaging
- Homeland Security



SSP Back-end

Front-End Electronics





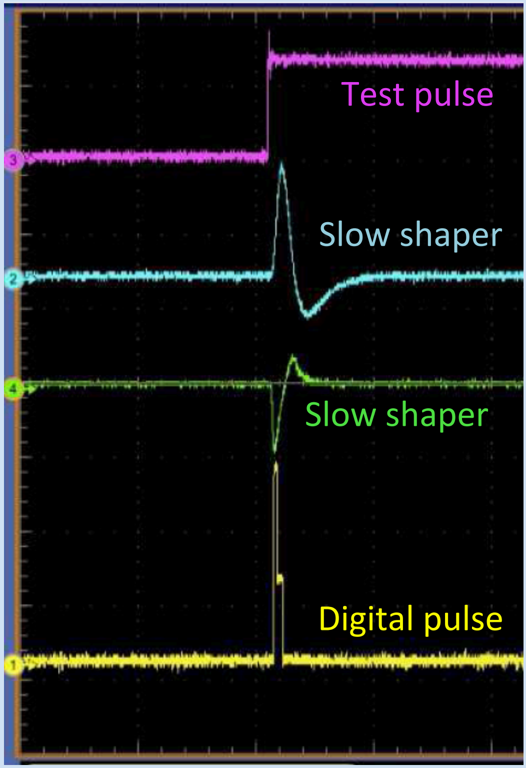
Analog: Charge (1 fC)
Digital: Time (1 ns)

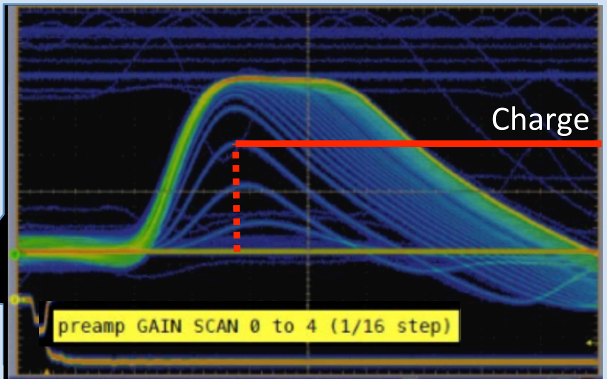
Trigger latency (8 μs)

Optical ethernet (2.5 Gbps)

Trigger: external
internal
self

On-board pulser





Linear response

Multiplexed readout
Limited holding time delays

Used for calibrations

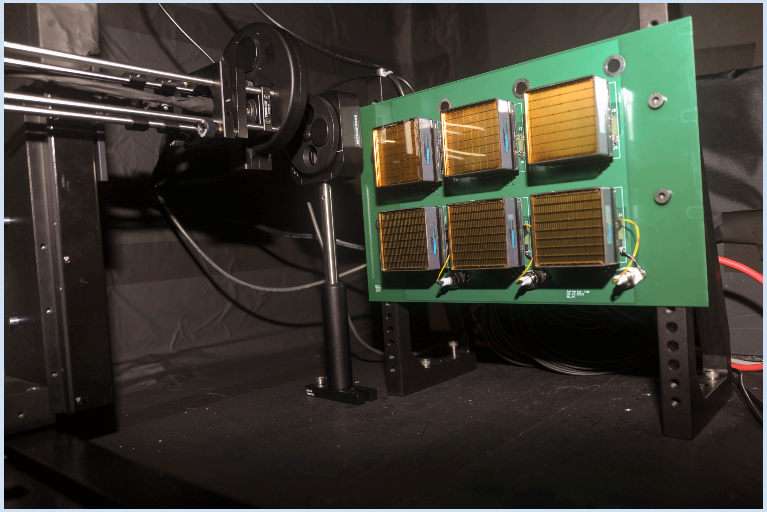
ADC Charge Measurement

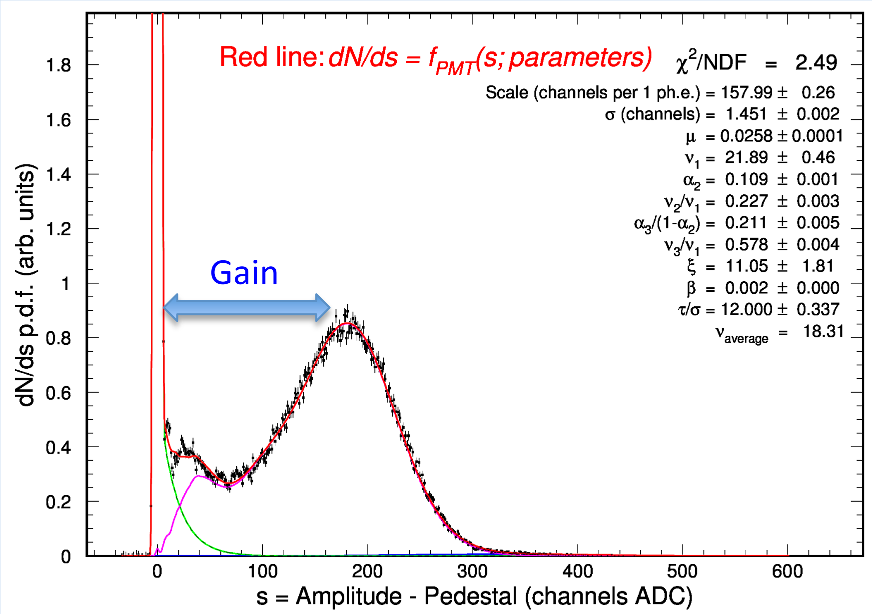
Multiplexed readout up to 50 kHz

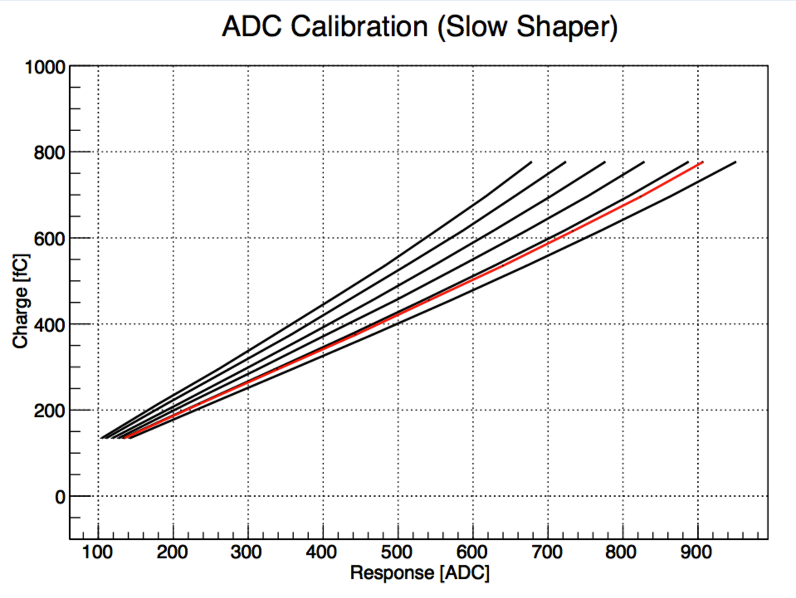
High resolution SPE spectrum

Viable for efficiency and gain monitors

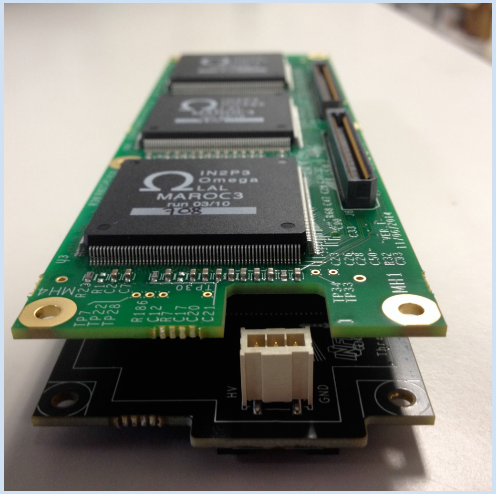
In conjunction with timing, allows the study of PMT discharge and cross-talk

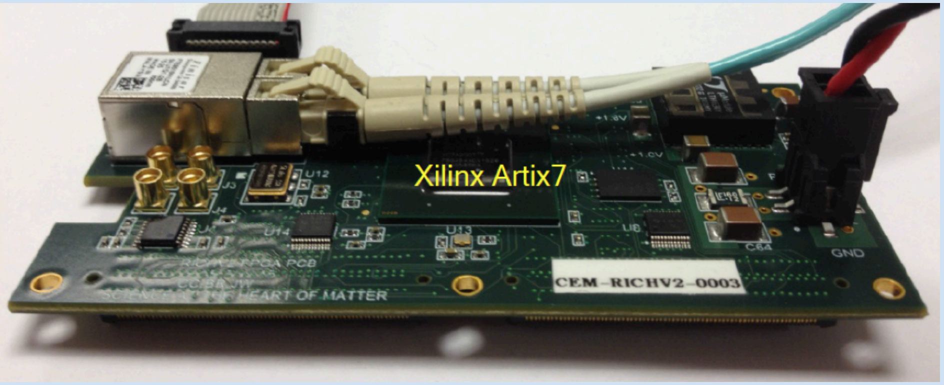






Front-End Electronics





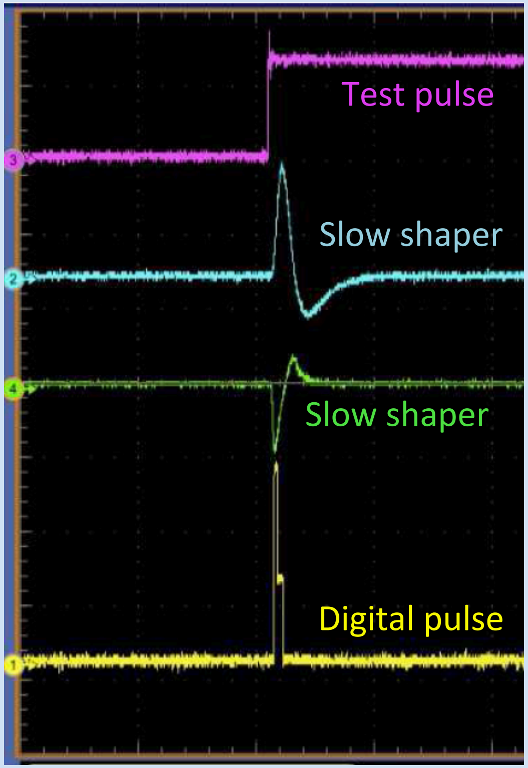
Analog: Charge (1 fC)
Digital: Time (1 ns)

Trigger latency (8 μs)

Optical ethernet (2.5 Gbps)

Trigger: external
internal
self

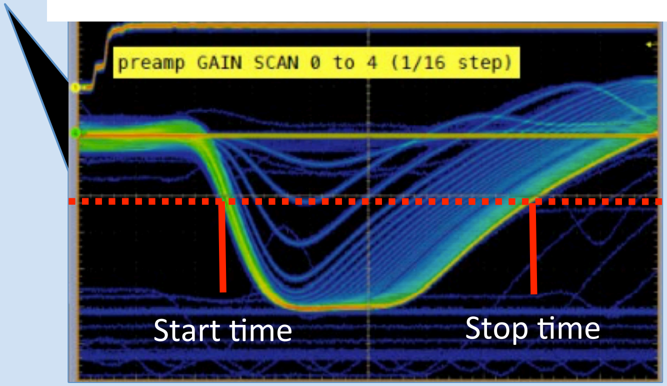
On-board pulser



Digital response
Working in saturated regime

64 parallel channel readout

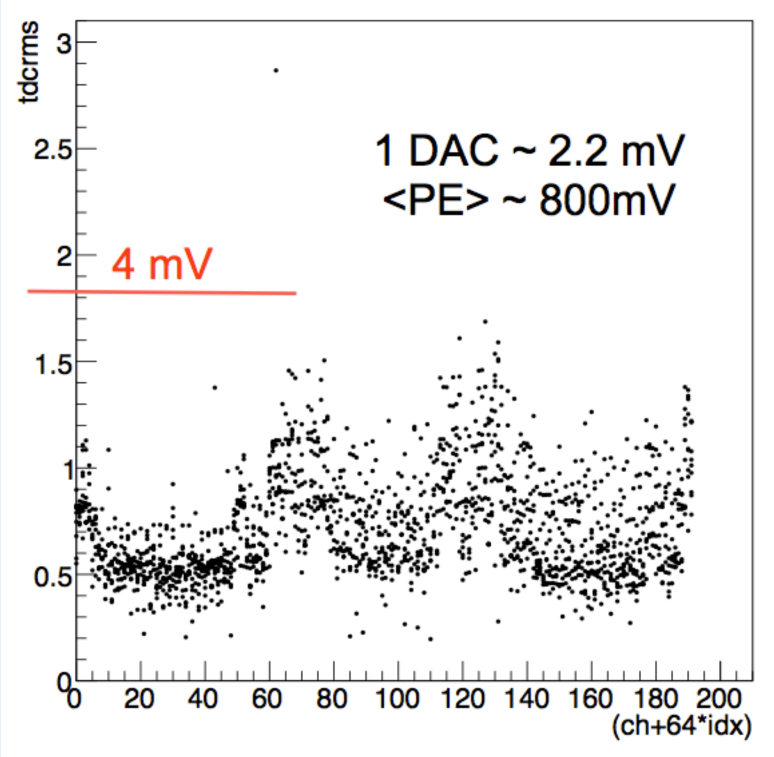
8 μs FIFO and delays
1 ns time resolution



TDC Digital Readout

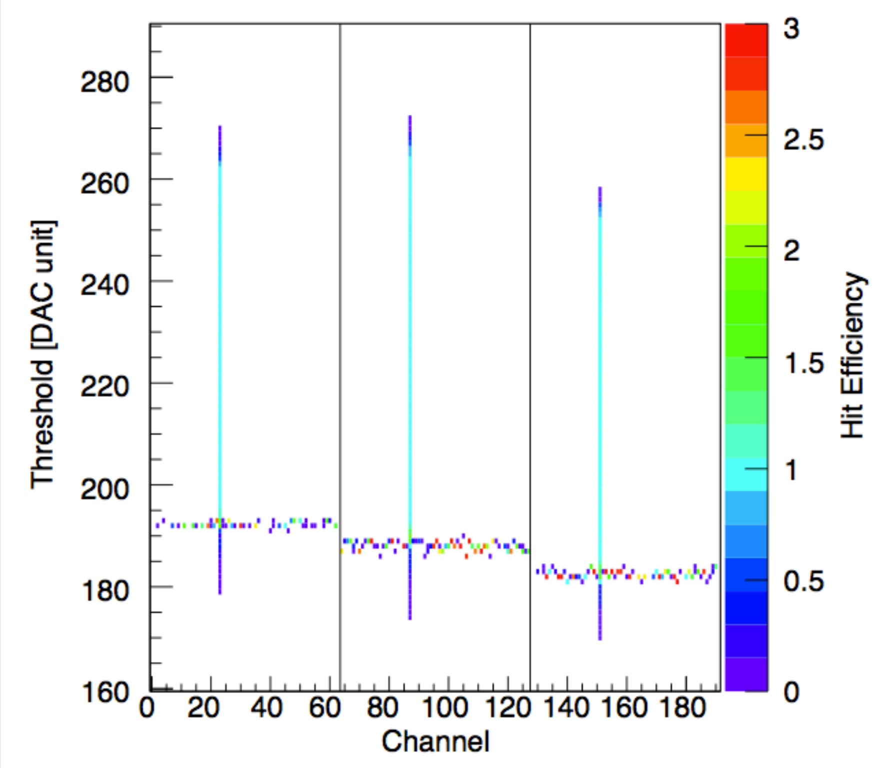
During Acceptance tests

Pedestal rms as seen by a test-point



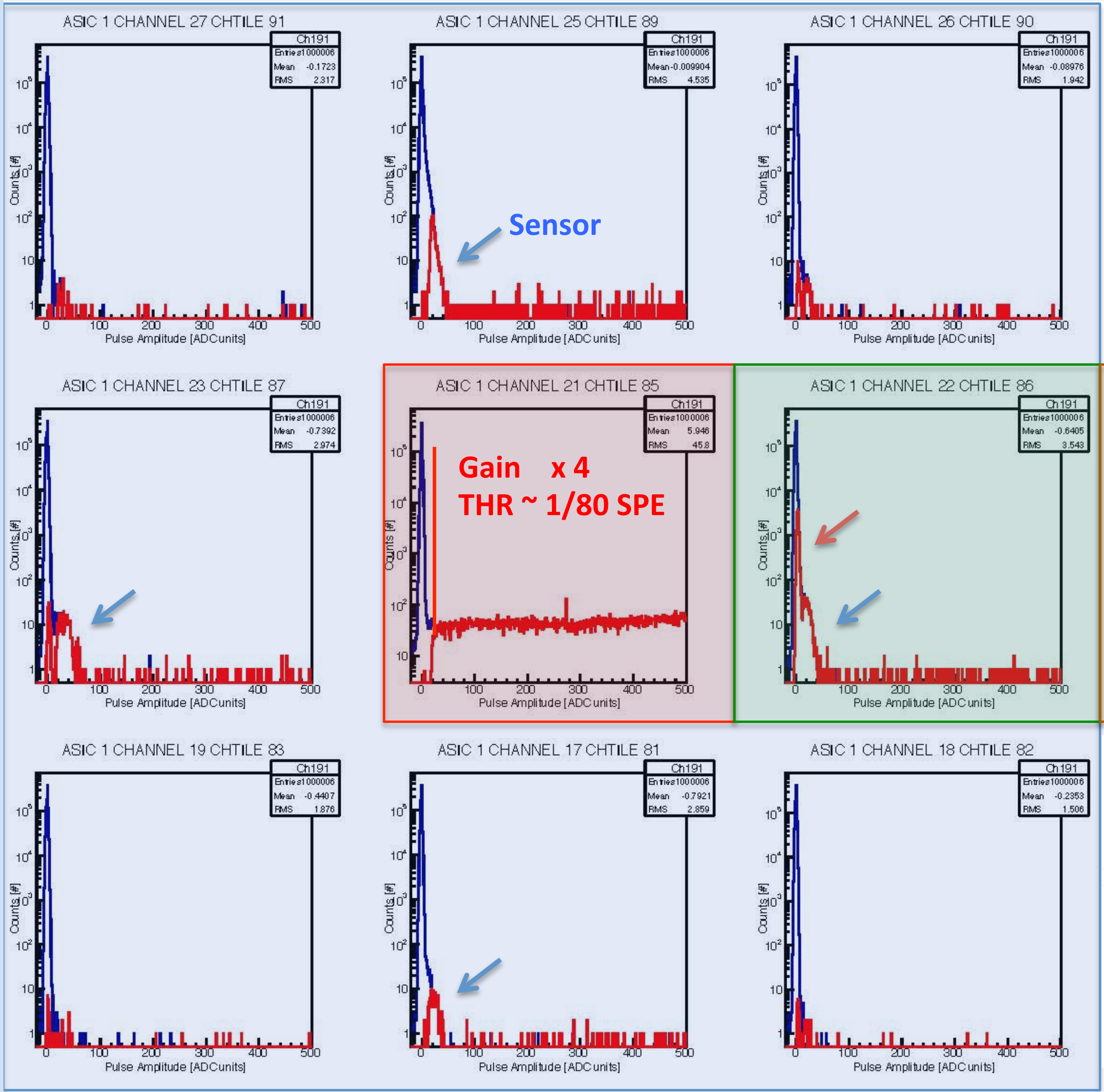
During Internal Pulser Calibration

As seen by RICH readout



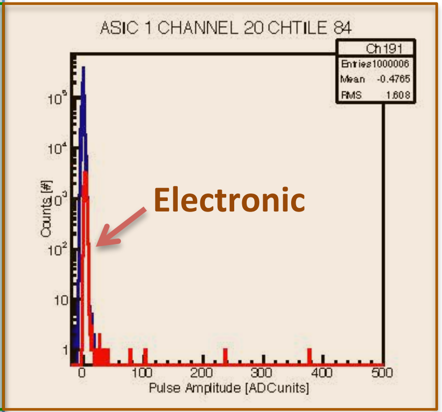
Discrimination down to 20 fC, i.e. few % of SPE, allows sensor characterization

Optical and Electronics Cross-Talk

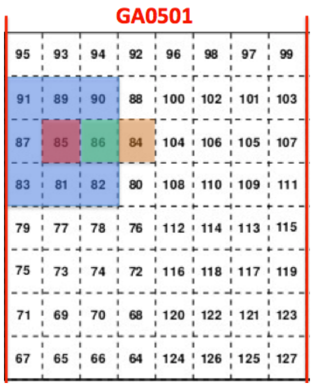


Sensor

Gain x 4
THR ~ 1/80 SPE

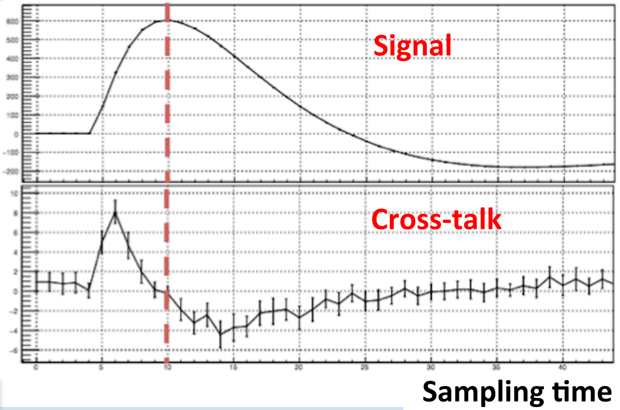


Electronic



GA0501

95	93	94	92	96	98	97	99
91	89	90	88	100	102	101	103
87	85	86	84	104	106	105	107
83	81	82	80	108	110	109	111
79	77	78	76	112	114	113	115
75	73	74	72	116	118	117	119
71	69	70	68	120	122	121	123
67	65	66	64	124	126	125	127



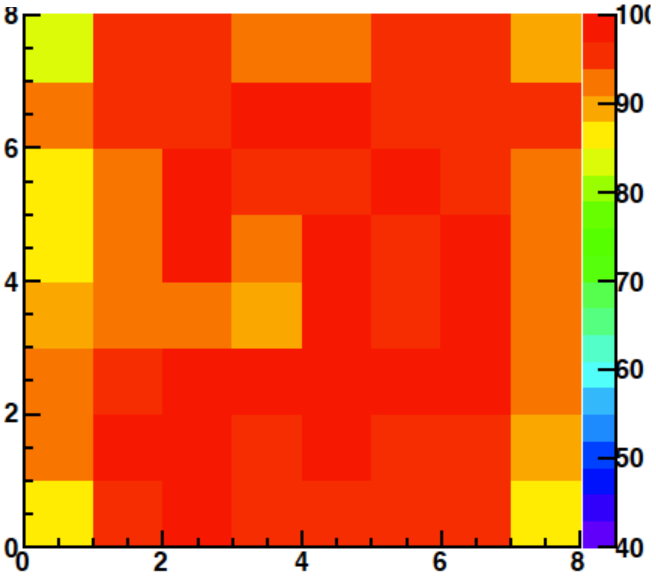
Signal

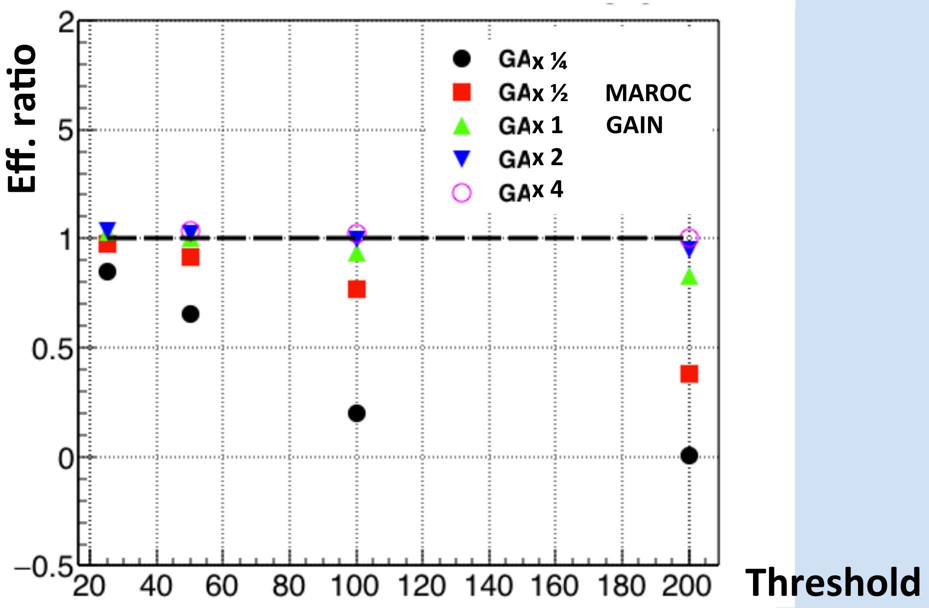
Cross-talk

Sampling time

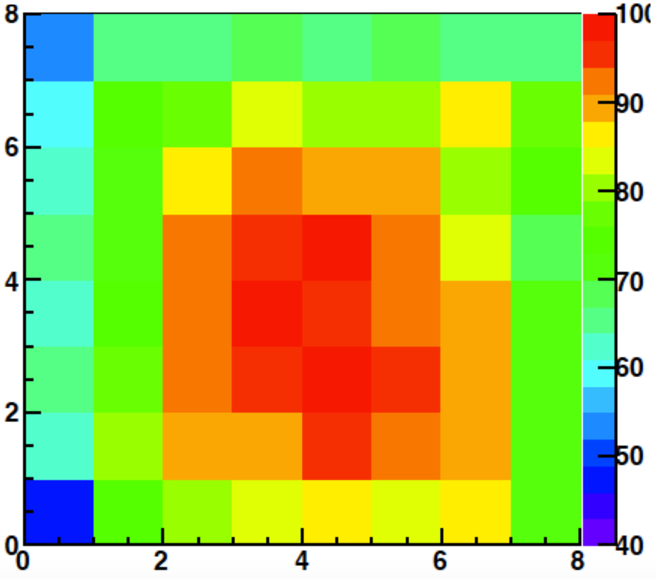
Single Photon Discrimination

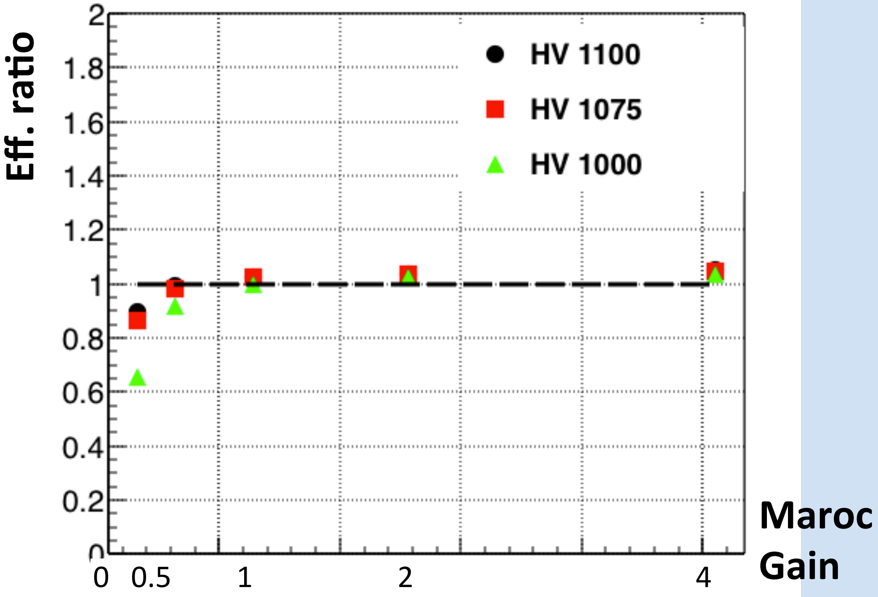
Relative efficiency map



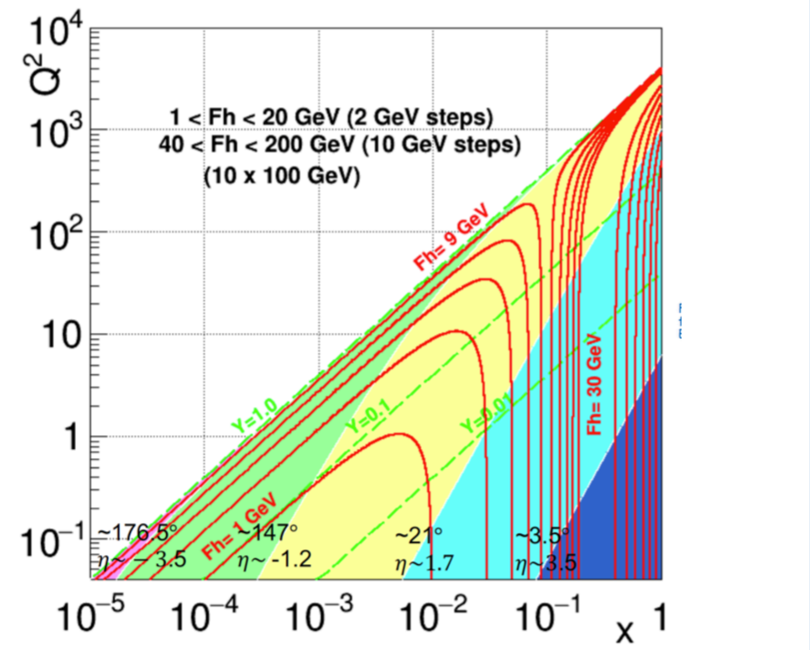


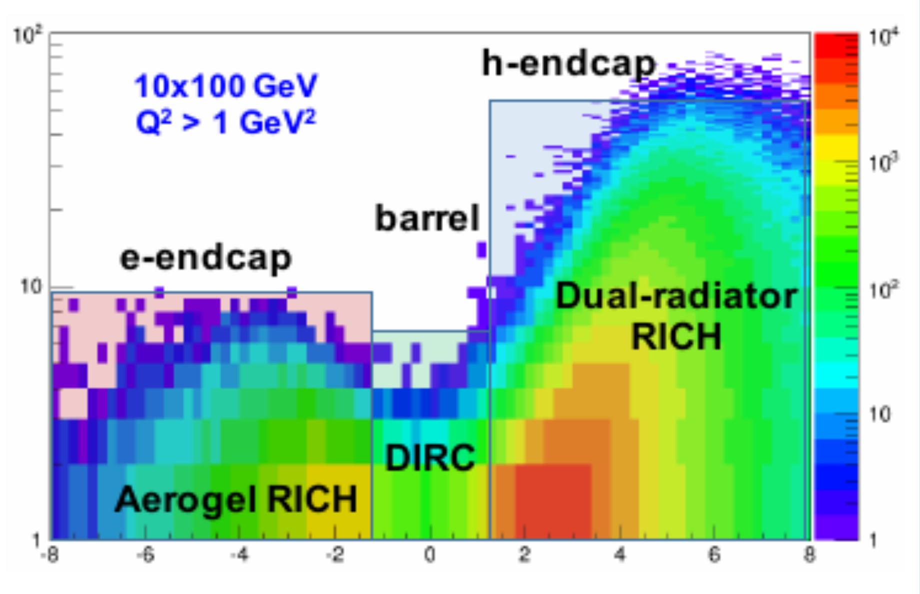
Relative gain map





Hadron Identification @ EIC





eRD14 Consortium: An integrated program for particle identification at a future EIC detector

barrel: A high-performance DIRC

p/k separation up to ~ 6 GeV/c **DIRC**

h-endcap: A RICH with two radiators (gas+aerogel)

p/k separation up to ~ 50 GeV/c **dRICH**

e-endcap: A compact and projective aerogel RICH

p/k separation up to ~ 10 GeV/c **mRICH**

TOF: possible to cover lower momenta

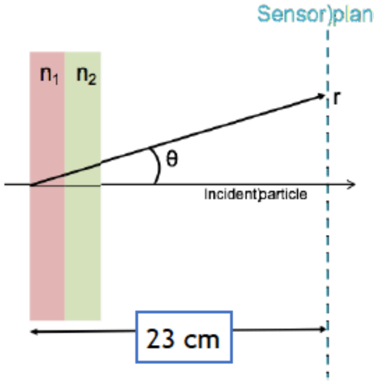
Photosensors & electronics: parallel development to match the needs of the next generation devices

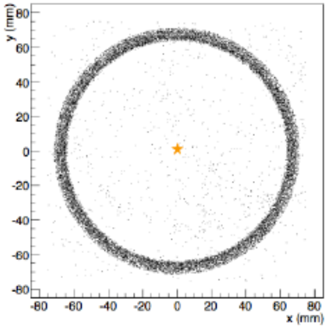
E-endcap mRICH @ EIC

Fresnel lens focusing aerogel detector concept

9 GeV/c pion beam launched at the center of xy plane in simulation

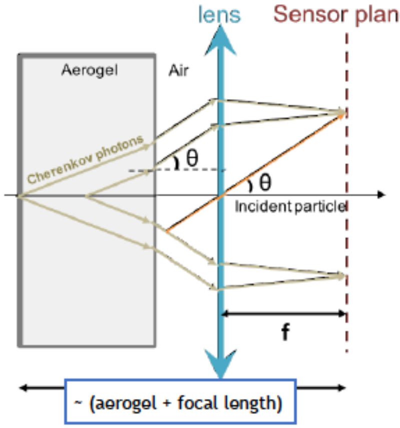
Two-Layer Proximity Focusing Design (BELLE-2 ARICH)

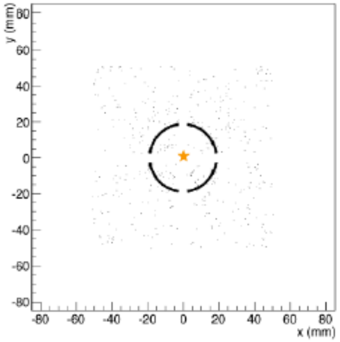




- EIC mRICH designed for K/pi ID up to 9 GeV/c
- BELLE-2 ARICH aims to separate pion and kaon up to 4 GeV/c

Lens-Based mRICH Design





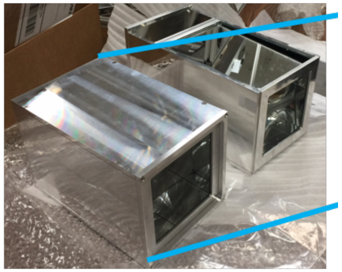
- 9 GeV/c pion beam launched at the center of xy plane in simulation
- **Smaller and thinner ring image**

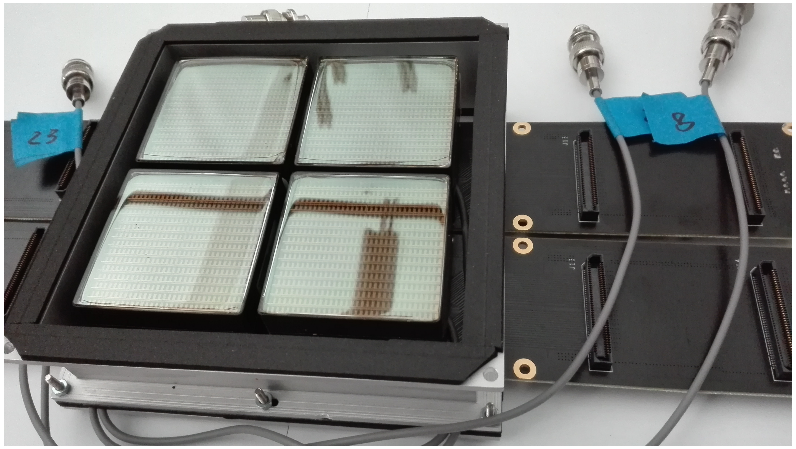
E-endcap mRICH @ EIC

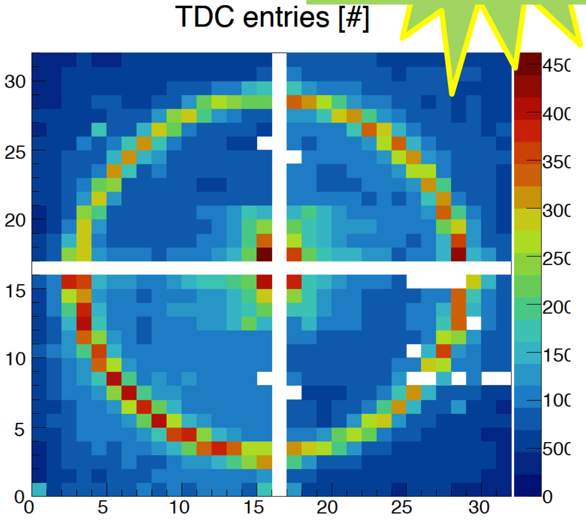
≥3σ π/k separation
~ 2 ÷ 10 GeV/c

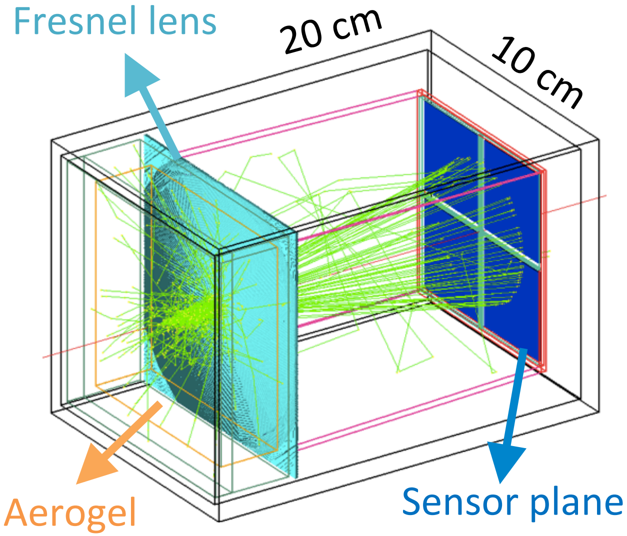
Compact and modular RICH independent elements

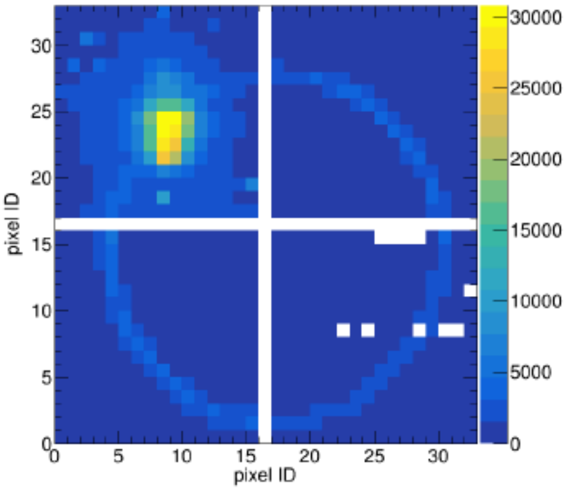
Two completed mRICH prototypes

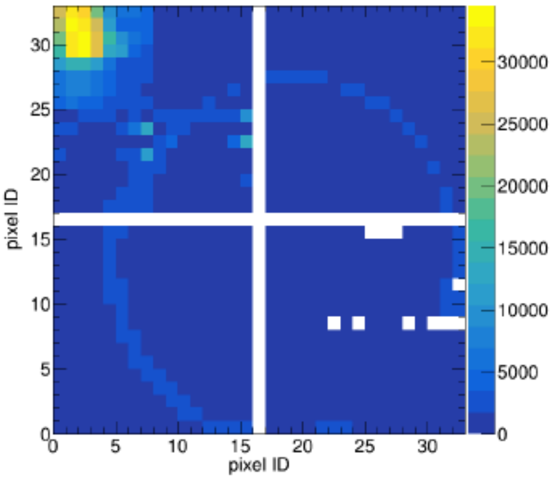












H-endcap dRICH @ EIC

Extended momentum range

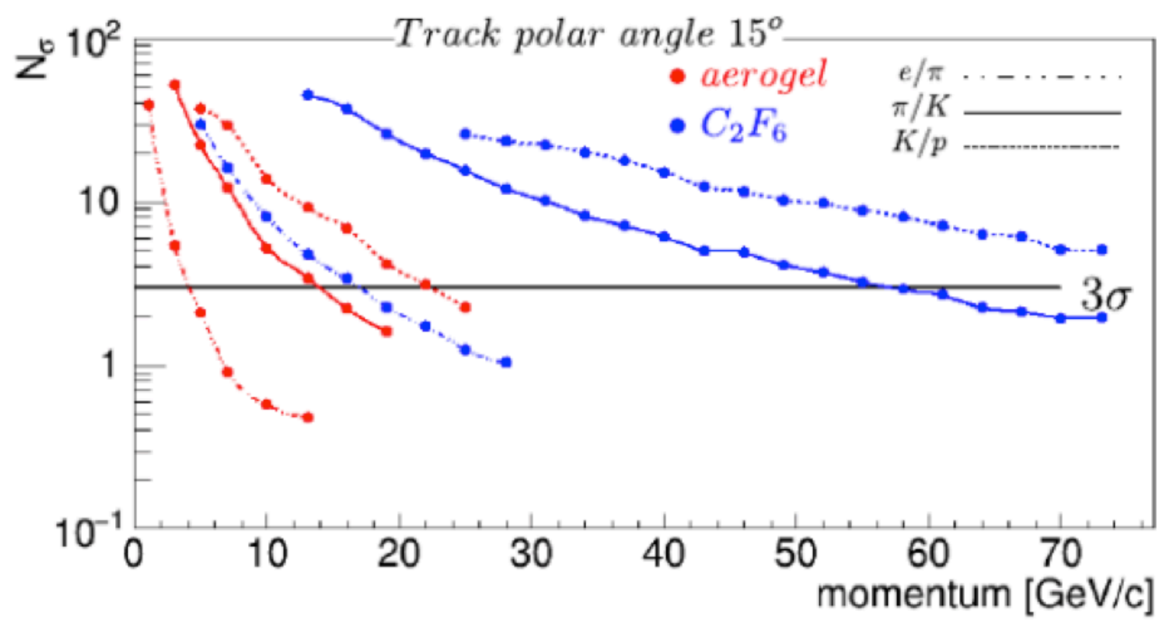
Proposed configuration fitting the spectrometer constraints (evaluated by detailed GEANT4 simulations)

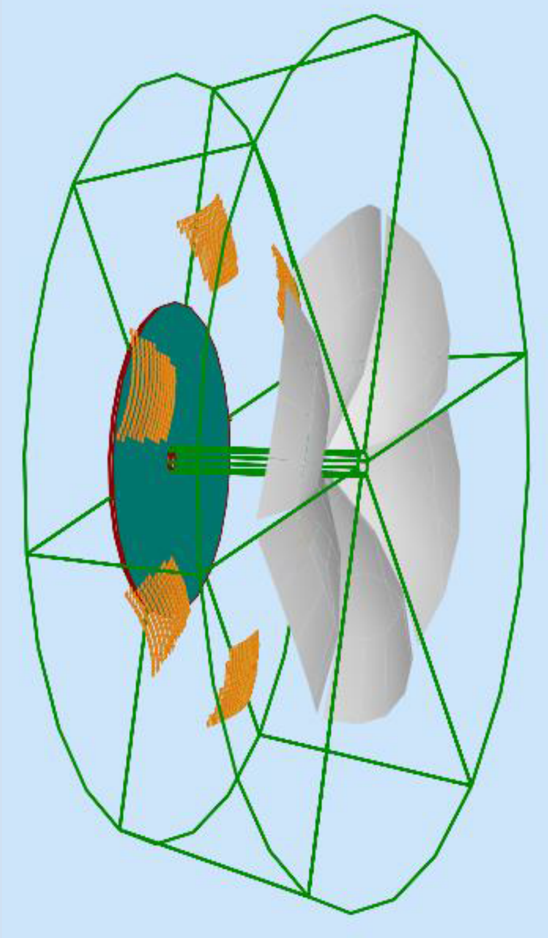
-- dual radiator RICH: aerogel and C_xF_y gas

-- focusing mirror

-- 6 open sectors

-- curved detector surface



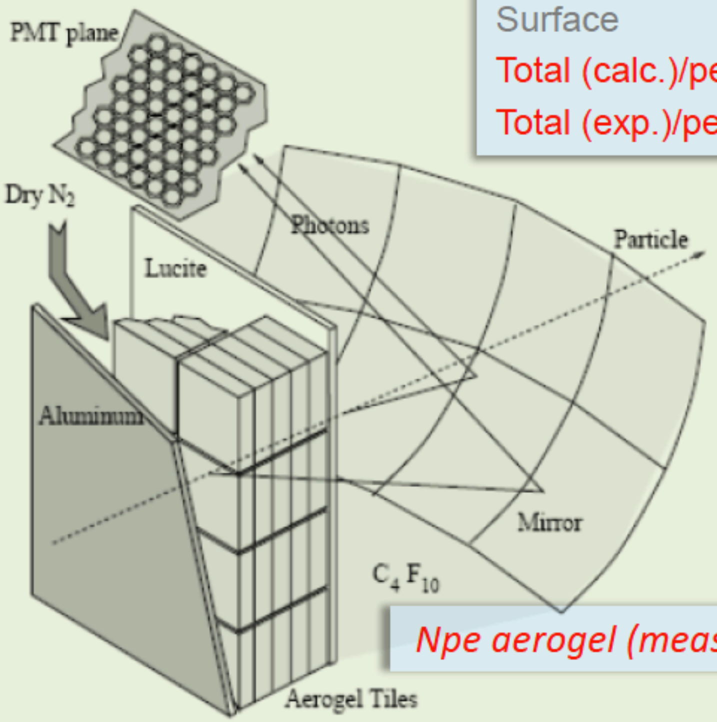


≥3σ π/k separation
~ 2 ÷ 50 GeV/c

Dual Radiator RICHes

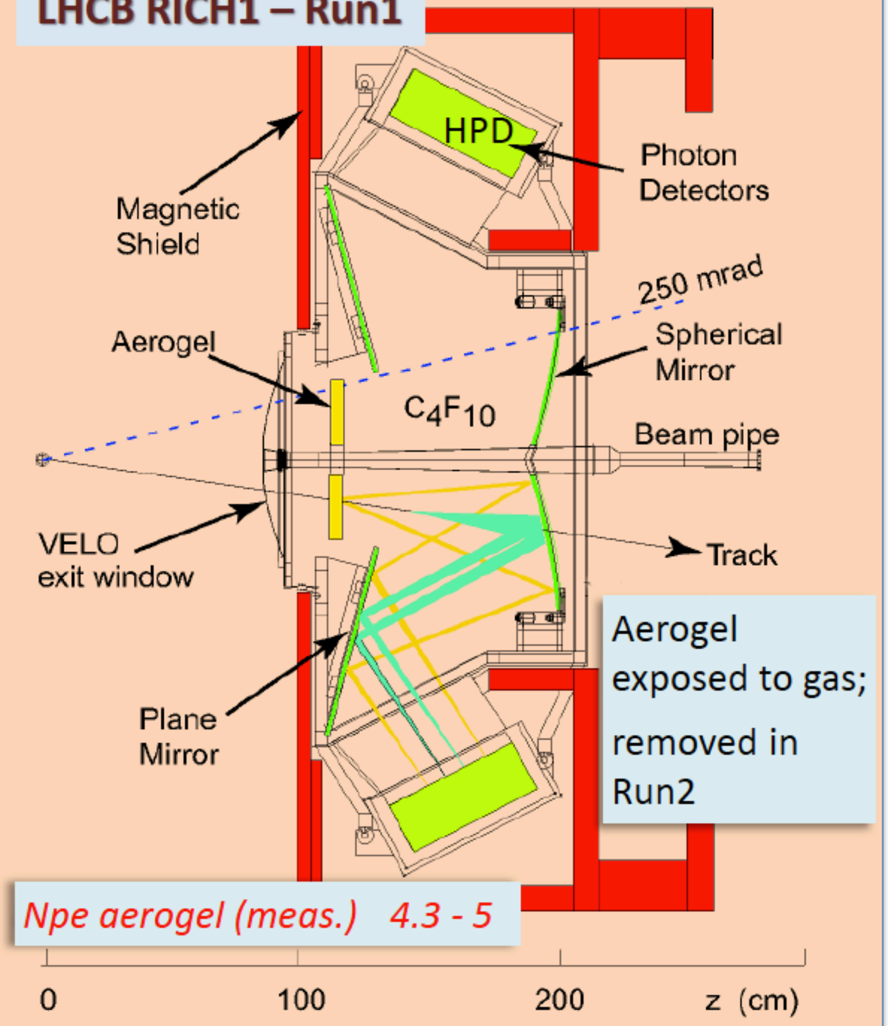
HERMES RICH

Angular resolution	
Pixel	**2.3**
Chromatic	**1.3**
Point emiss.	0.7
Mirror	0.6
n spatial disp.	0.5
Forw. scatt.	0.4
Surface	0.4
Total (calc.)/pe	2.9
Total (exp.)/pe	3.3



Npe aerogel (meas.) ~10

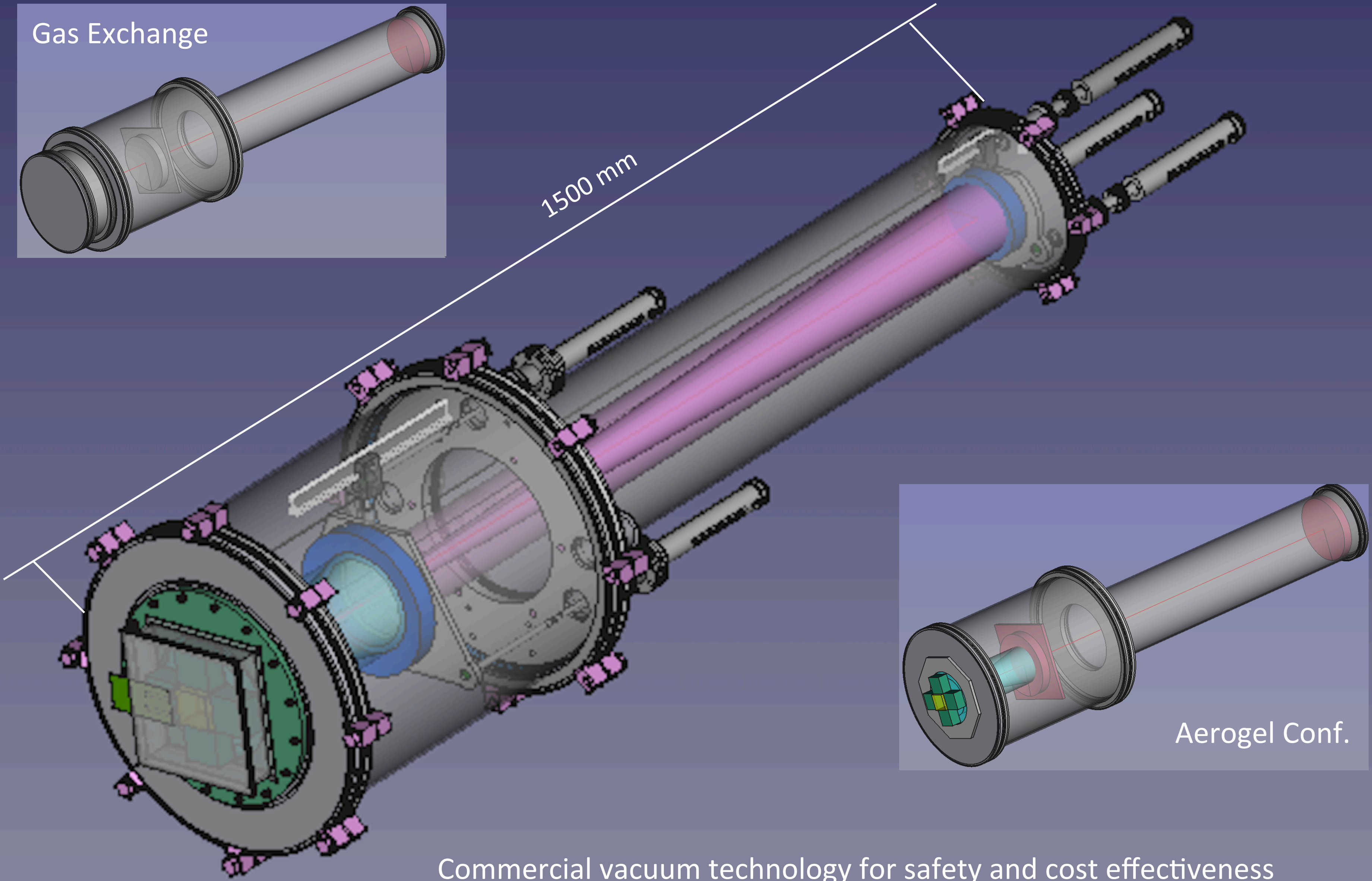
LHCB RICH1 – Run1



Aerogel exposed to gas; removed in Run2

Npe aerogel (meas.) 4.3 - 5

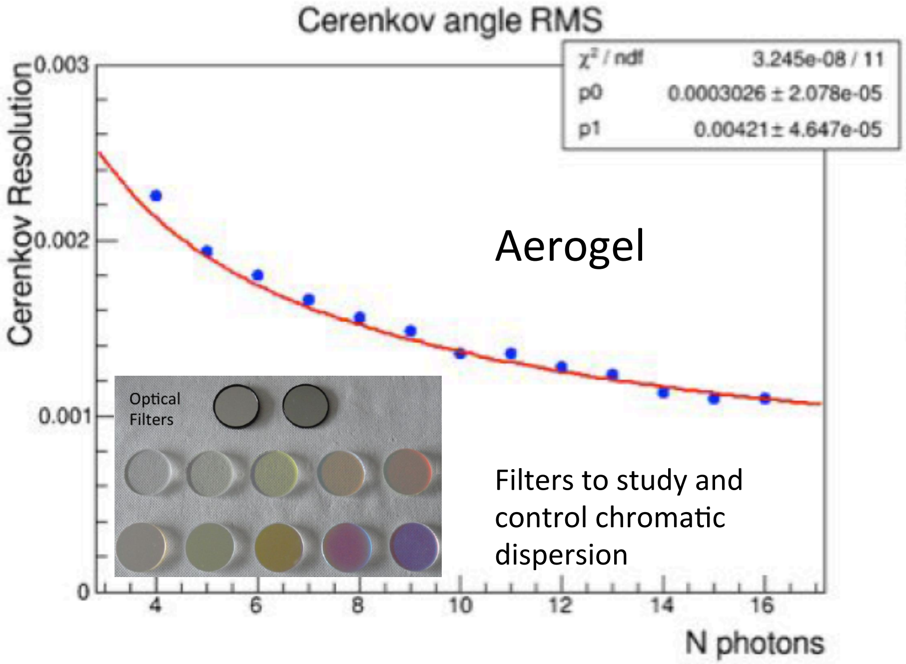
dRICH Prototype Design



Commercial vacuum technology for safety and cost effectiveness
Overlapping rings for parallel beam particles

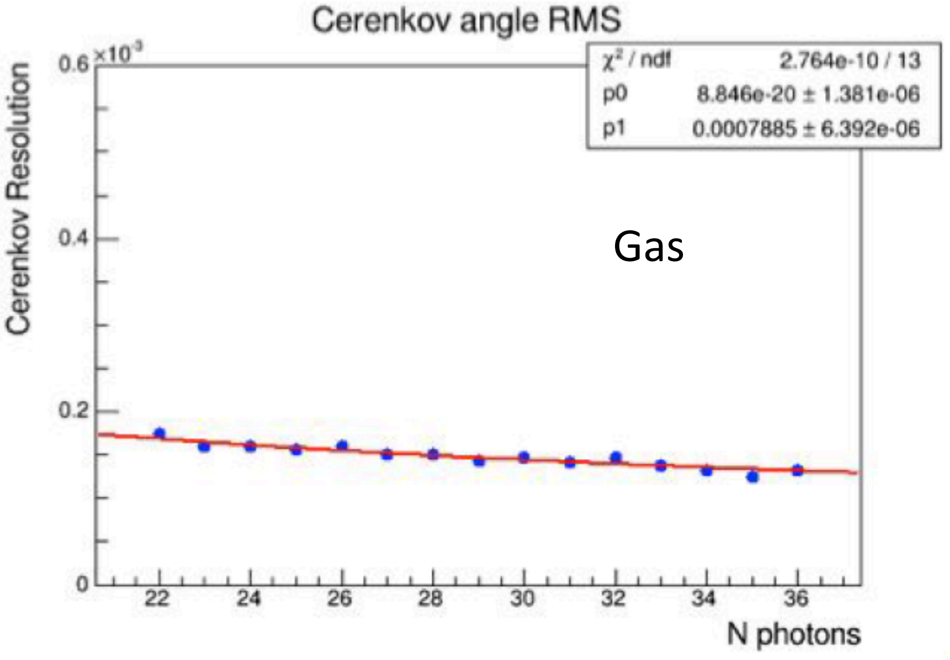
dRICH Prototype Performance

Montecarlo simulation



Aerogel

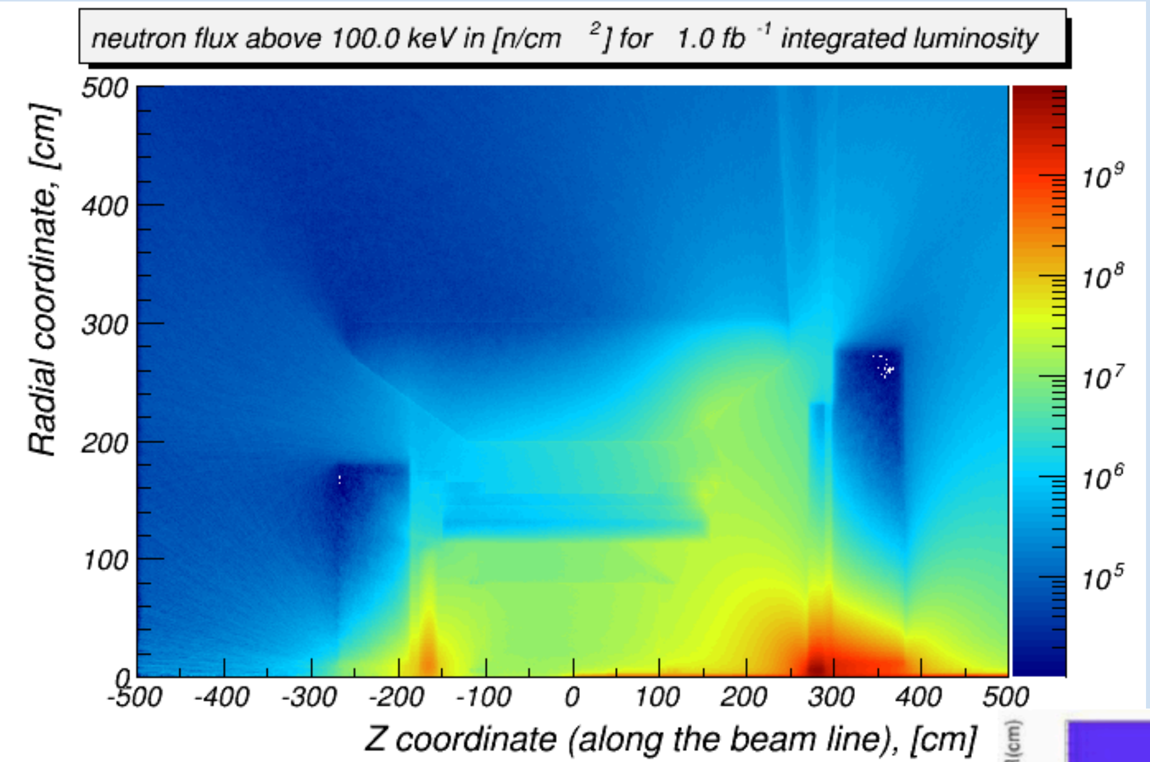
Filters to study and control chromatic dispersion



Gas

1 p.e. Error (mrad)	Aerogel	@EIC	C_2F_6 Gas	@EIC
Chromatic error	3.2	(2.9)	0.51	(0.8)
Emission	0.5	(0.5)	0.5	(1.2)
Pixel	2.5	(0.5)	0.42	(0.5)

EIC Detector Environment



Neutron Fluence
(courtesy of A. Kiselev)

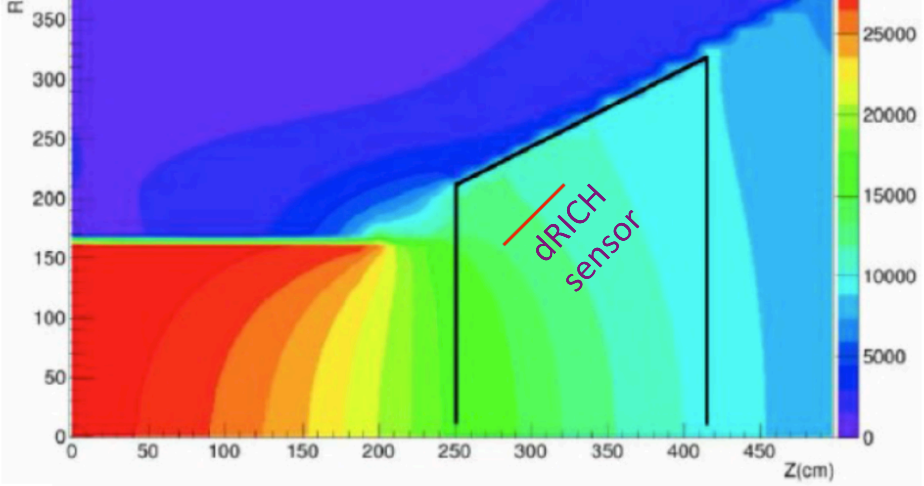
Moderate except for
very forward regions

Reference value ~ 10 ^{11} n_{eq}/cm^2
for several years at max lumi (10^{34})

Magnetic Field

~ 1 T order of magnitude
Detector orientation to be tuned

SiPM: PET study up to 7 T
10.1109/NSSMIC.2008.4774097

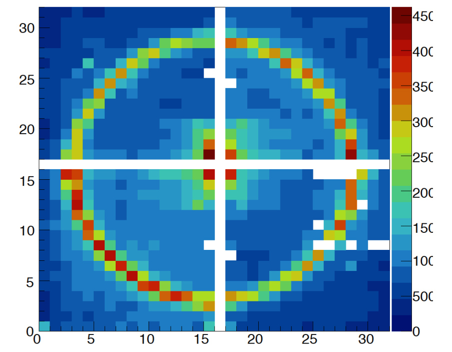


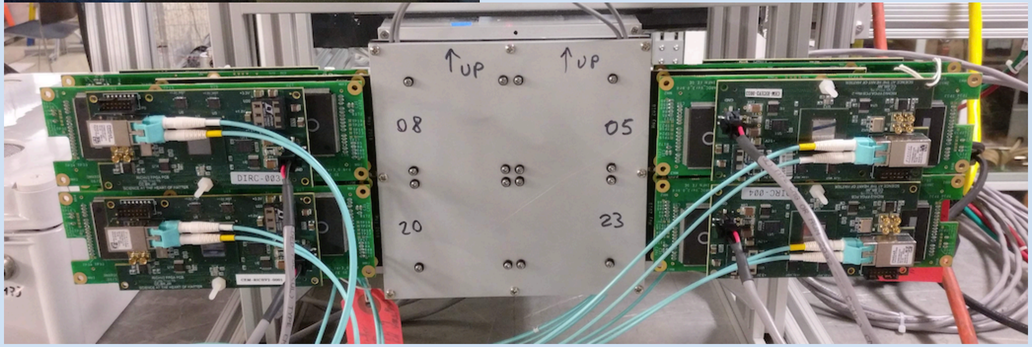
Sensor and Readout

Readout Independent element for flexibility: supports various detectors with possible integrated cooling and streaming readout

Reference:
MAROC (Discriminator) + SSP/VSX (VME)

Dedicated:
SiREAD (Sampling) + SSP/Ethernet

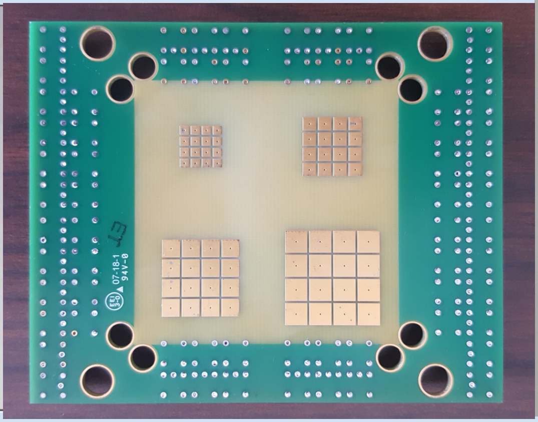


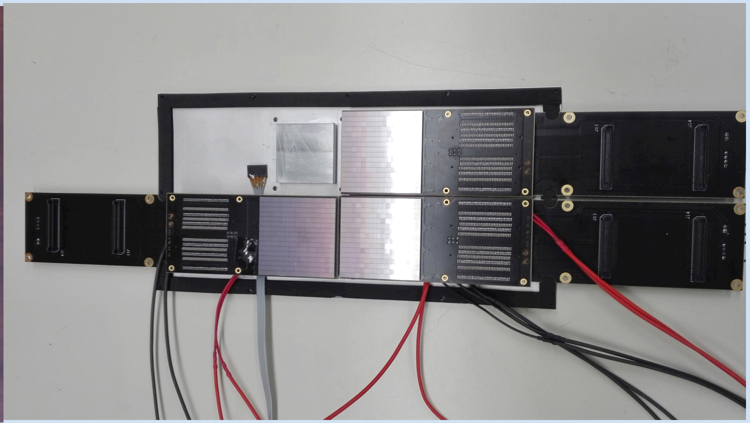


Sensors Reference MA-PMTs

B-field tolerant MCP-PMTs (LAPPDs)

+ Robust/Compact/Cost-effective: SiPMs



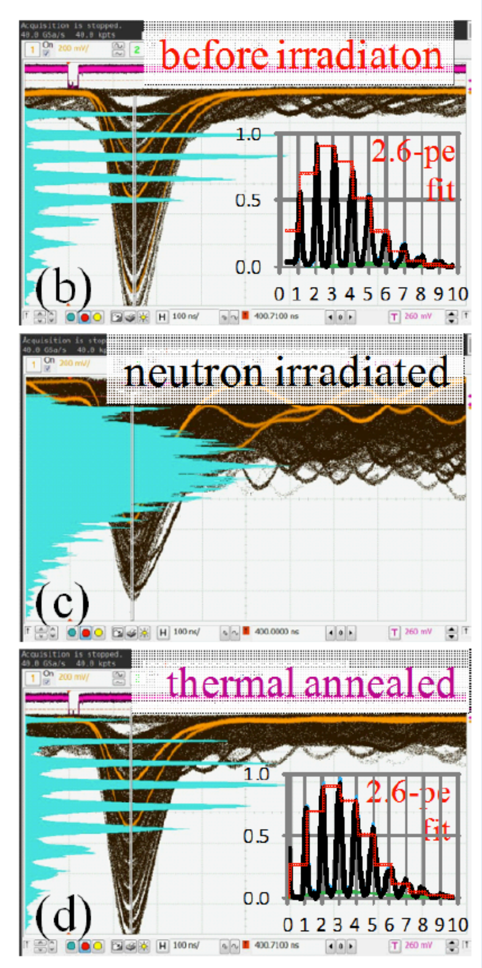


SiPM Radiation Tolerance

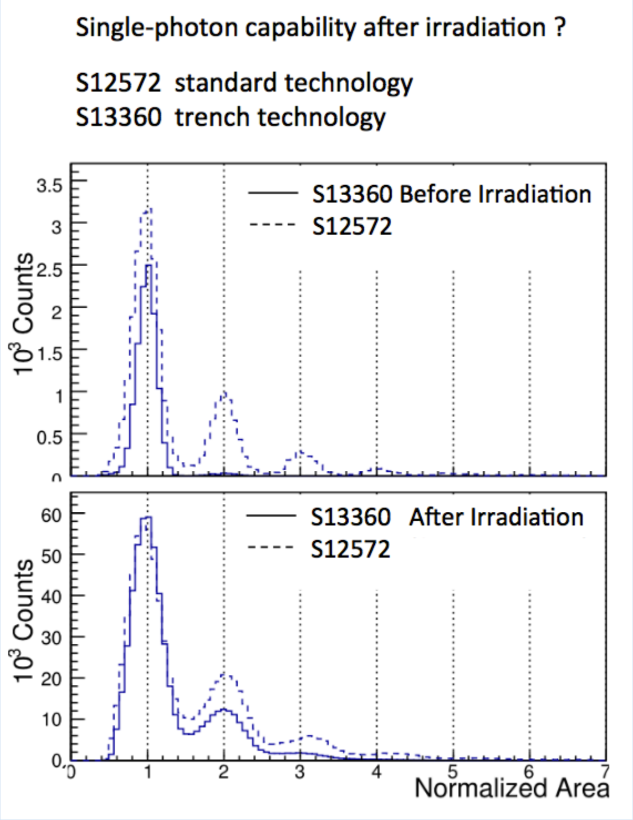
T. Tsang et al.
JINST 11 (2016) P12002

I. Balossino et al.
NIMA 876 (2017) 89

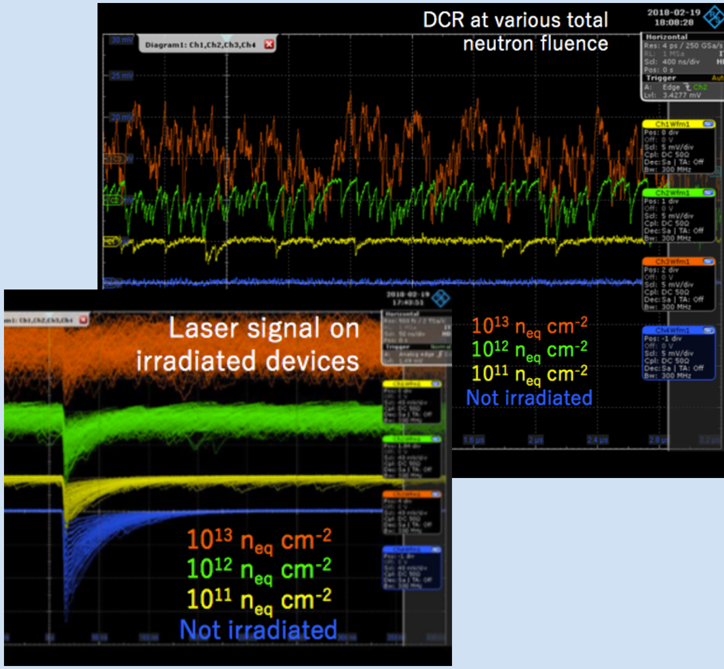
M. Calvi et al.
NIMA 922 (2019) 243



T= 25 C
10^9 n_{eq} cm^2
Annealing at 250 °C



T= 0 C
few 10^9 n_{eq} cm^2



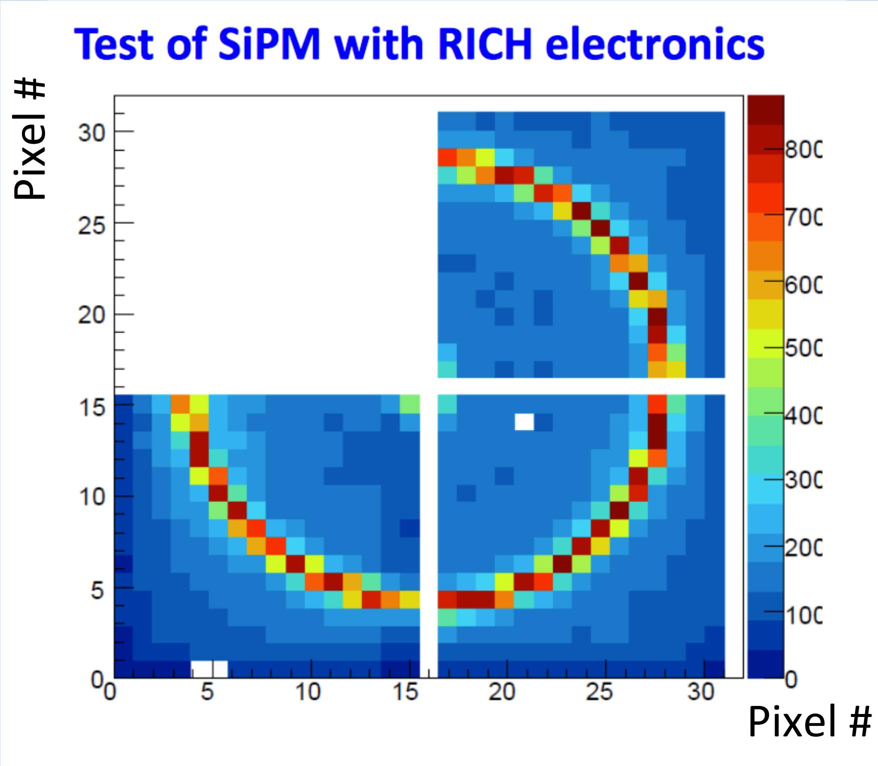
SiPM: Hamamatsu S13360-1350CS (50 µm cells)

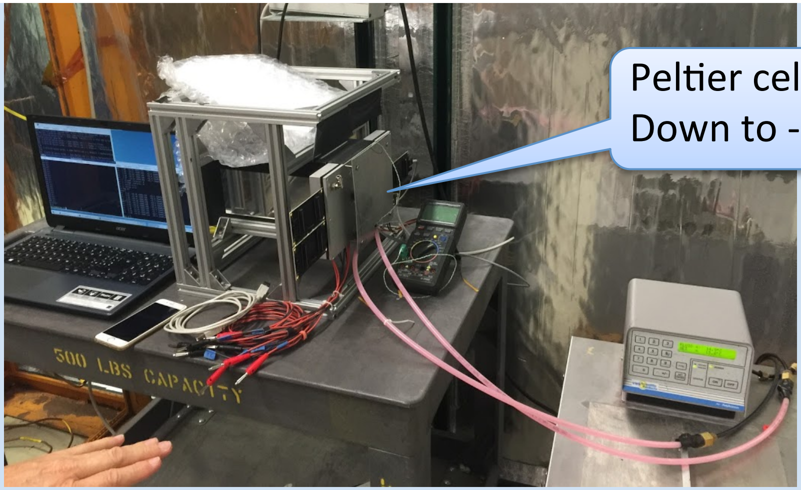
Temperature: –30 °C

≥ 10^{11} n_{eq} cm^2

SiPM Option

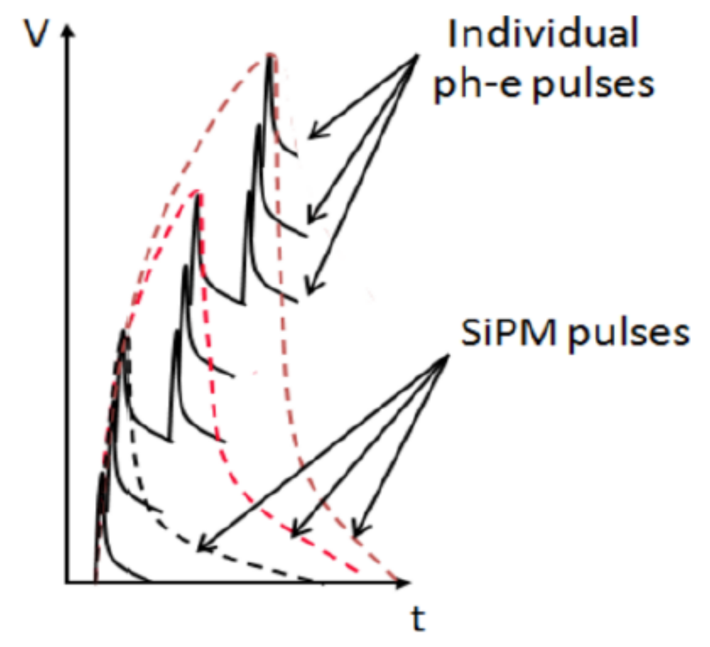
Viable solution with cooling

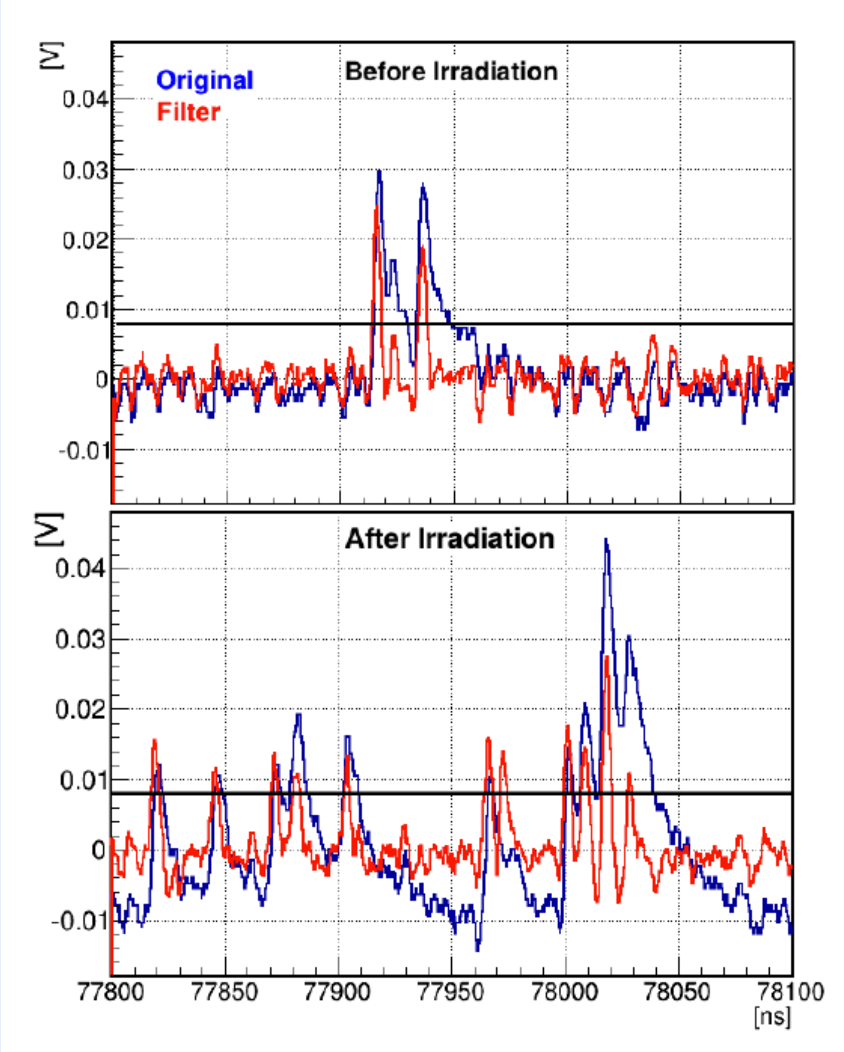




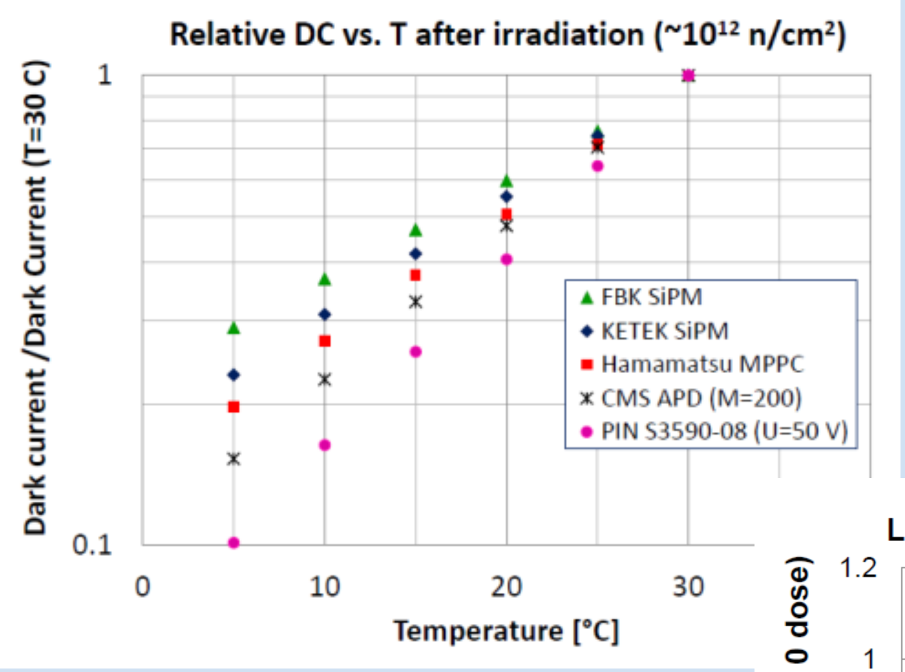
Peltier cell cooling
Down to -30° in N_2

SiPM Signal Discrimination



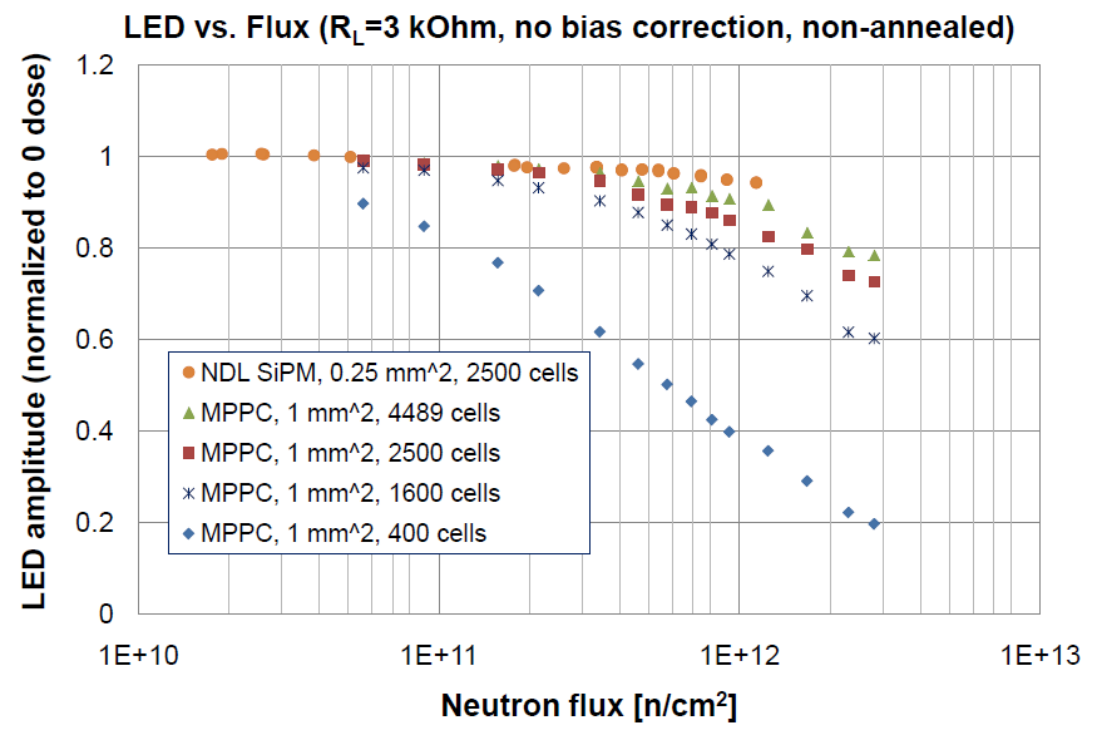


SiPM Radiation Tolerance Investigation



General trend is that SiPMs with high VB value have faster dark current reduction with the temperature

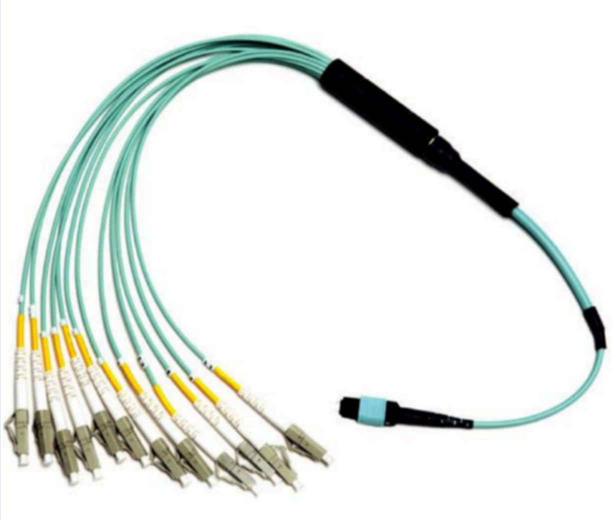
Yu. Musienko @ DIRC2019



SiPMs with high cell density and fast recovery time can operate up to 3*10^{12} neutrons/cm^2 (gain change is< 25%).

- \+ Low/uniform field
- \+ Entrance window (annealing)
- \+ Packaging (ΔT, cooling)
- \+ ……

RICH Back-End Electronics



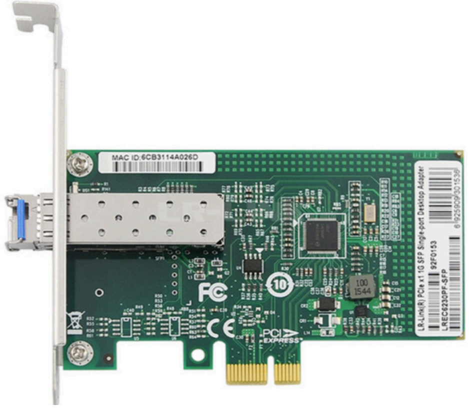
Optical ethernet (2.5 Gbps)

Small setups:
TCP/IP
Optical bridge / PC Desktop

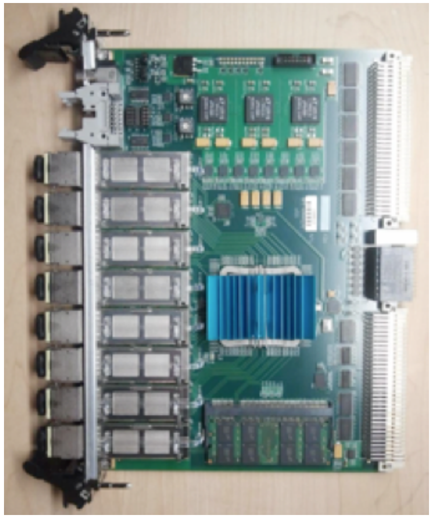
Full experiment:
SSP protocol
SSP board / VSX crate

Next:
Ethernet Switches

Optical bridge / PC Desktop
Few FPGA units ~ 500 channels

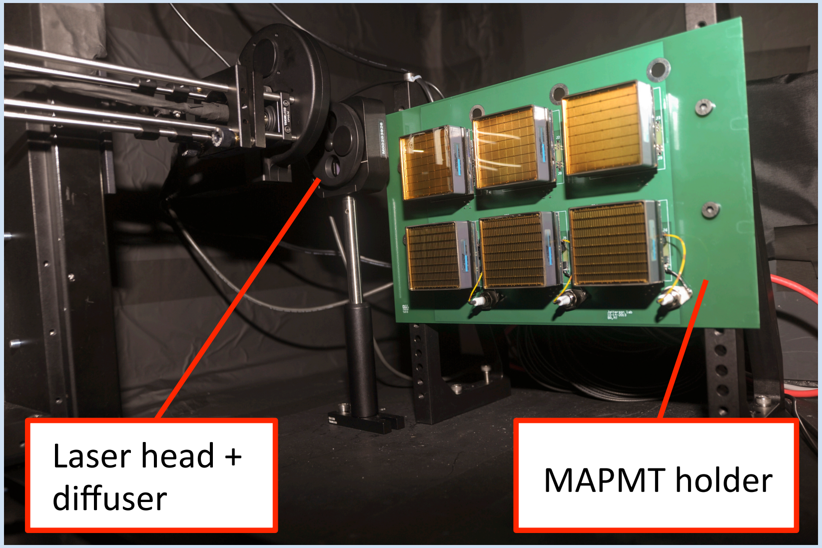


SSP board / VSX crate
2 RICH sectors ~ 50 k channels



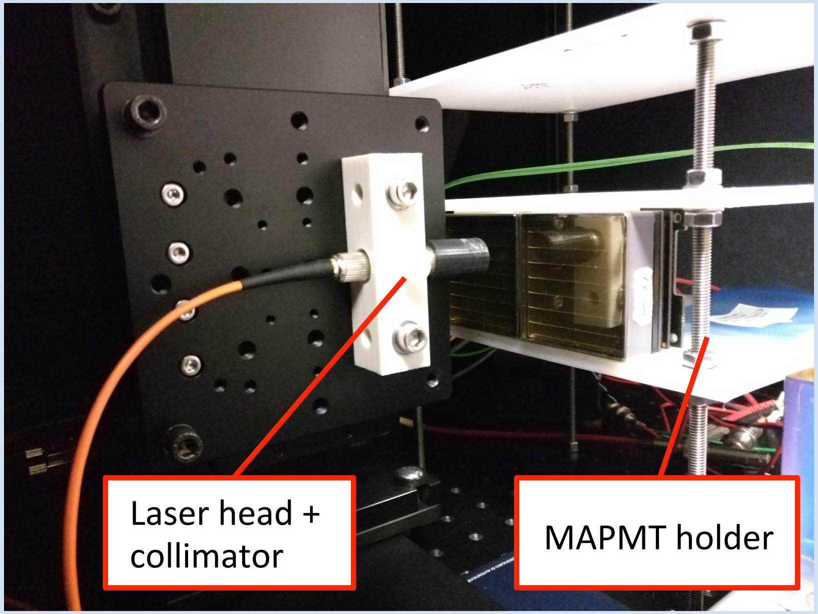
Pulsed Laser Test Benches

Detailed characterization
Sensors: gain, efficiency, cross-talk, radiation tolerance
Electronics: gain, cross-talk, thresholds, time resolution



JLab

632 nm picosecond pulsed laser light
Light diffuser to illuminate the whole MAPMT surface
Standardized system with CLAS12 electronics
H8500 6x6 mm^2 pixel sensor so far



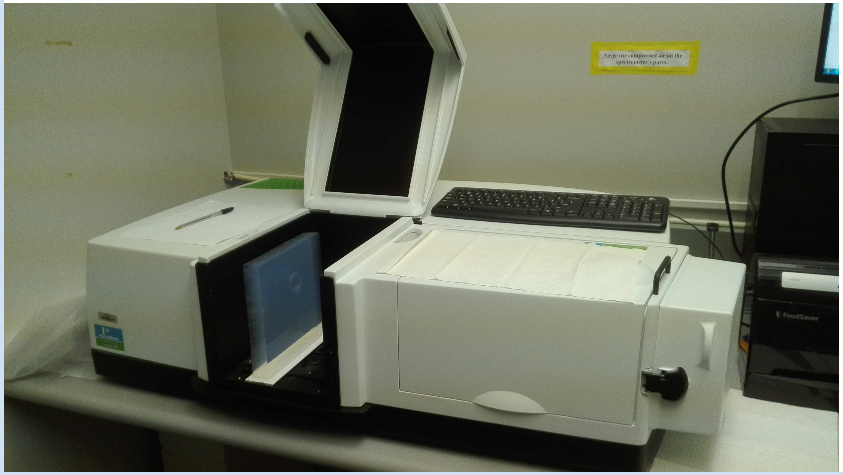
INFN

632 nm and 407 nm picosecond pulsed laser light
Light concentrator to scan the sensor surface
Flexible layout supporting various sensors and
Front-End electronics

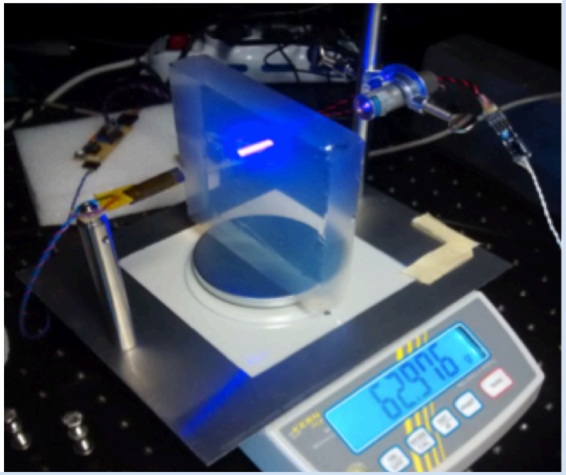
Aerogel Test Laboratory

Existing facility to study detailed aerogel optical properties
(refractive index, surface planarity, forward scattering)
safe handling and Interplay with gas radiator

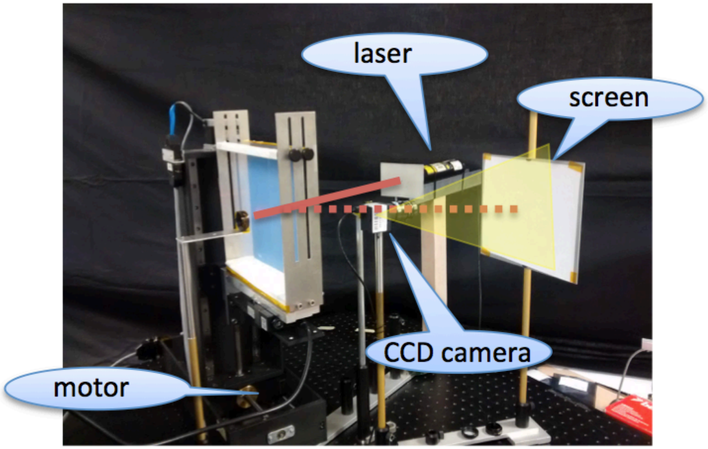
Spectrophotometer



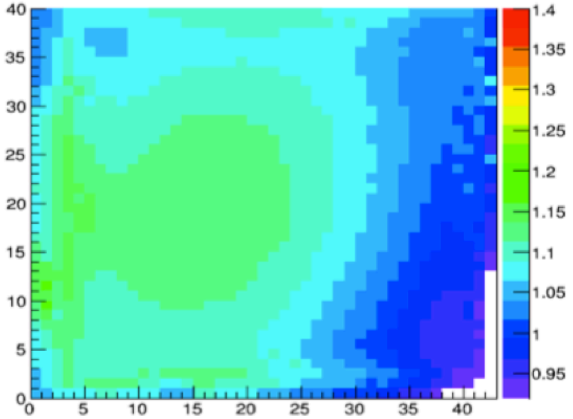
Characterization station

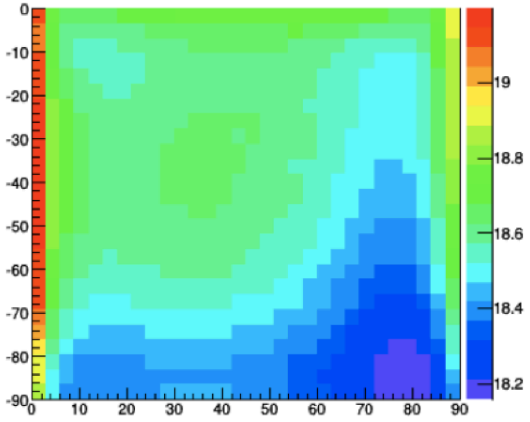


Controlled storage



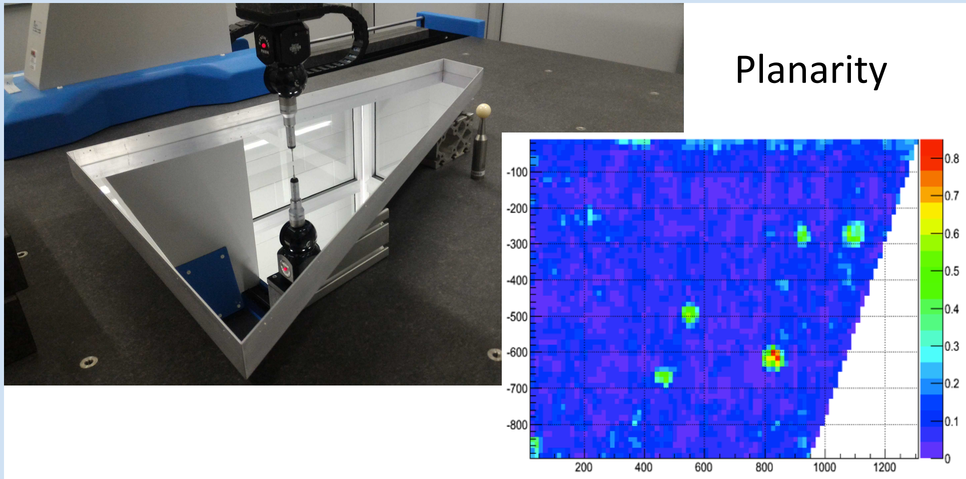
Surface map by laser setup vs touch machine



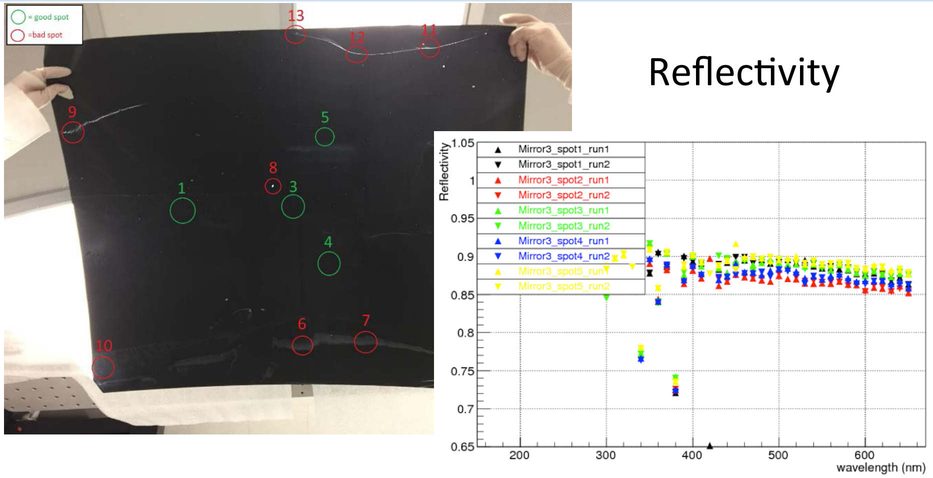


Mirror Test Laboratory

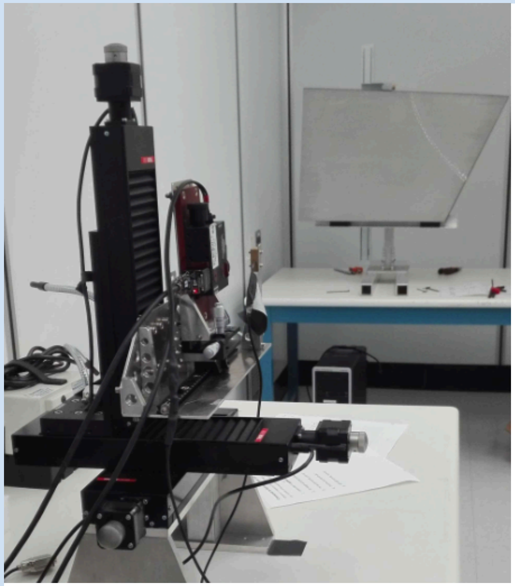
Existing facility to study detailed mirror optical properties
(surface map, radius of curvature, reflectivity)



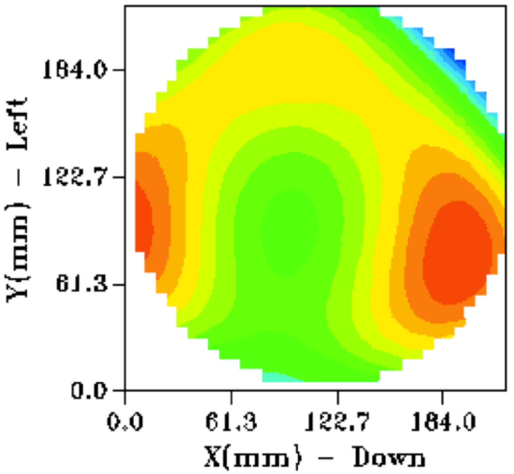
Planarity

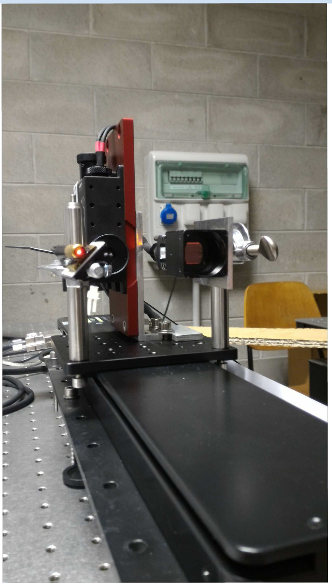


Reflectivity

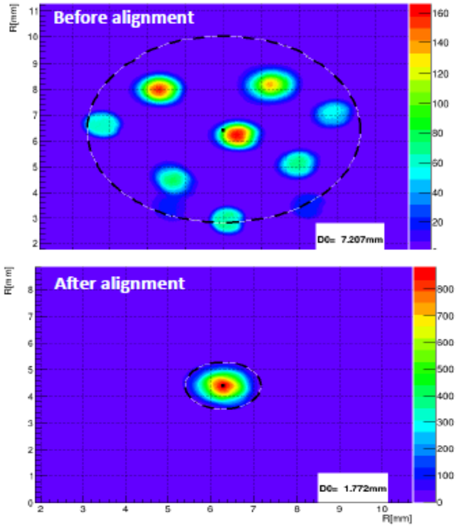


Shack-Hartmann: Aberrations



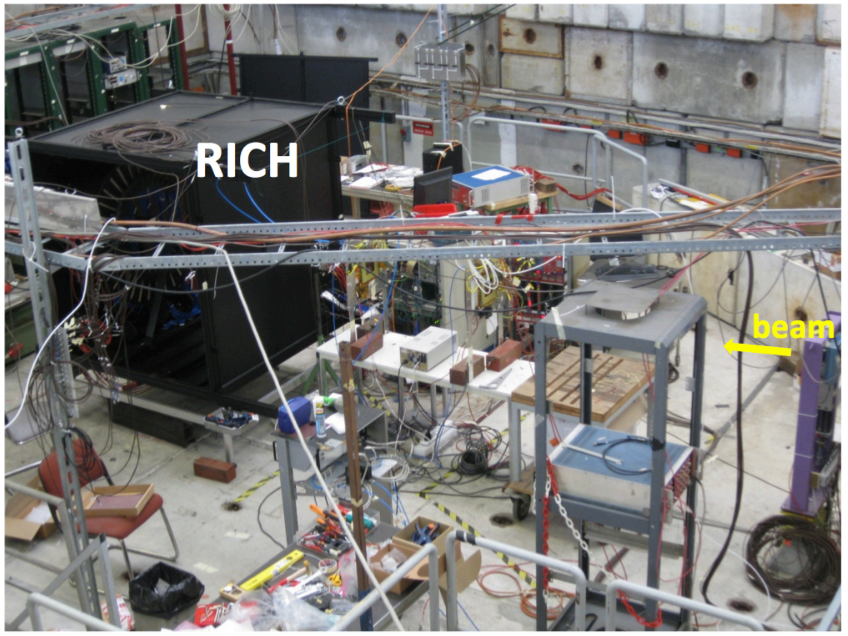


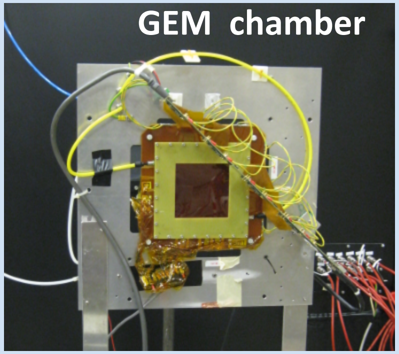
Point Image: Alignment

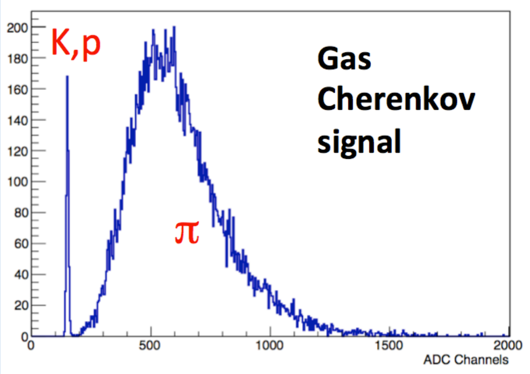


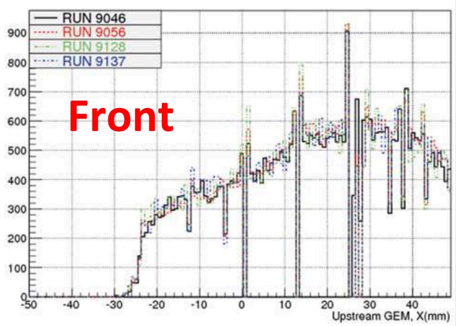
CLAS12 RICH Prototype @ CERN T9

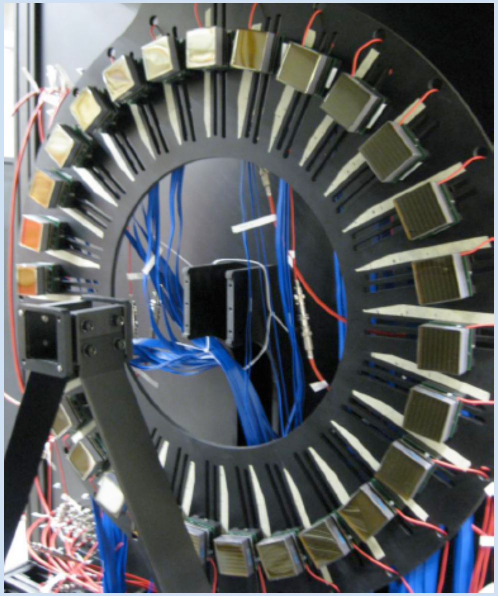
S.A.Pereira et al, Eur. Phys. J. A (2016) 52: 23

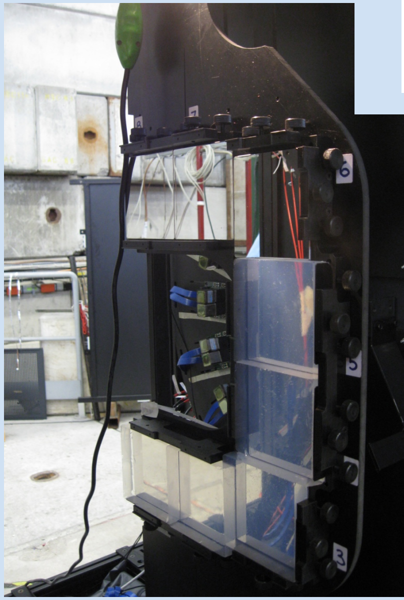




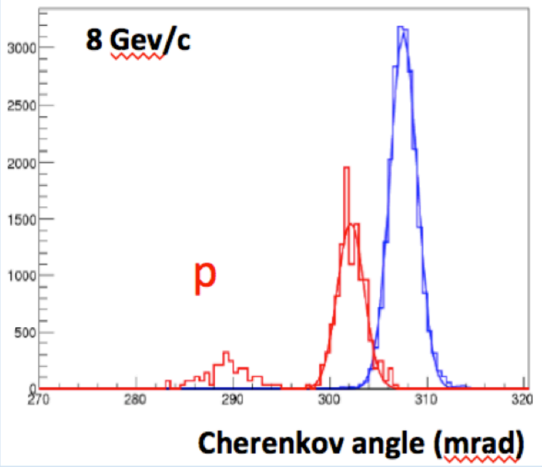




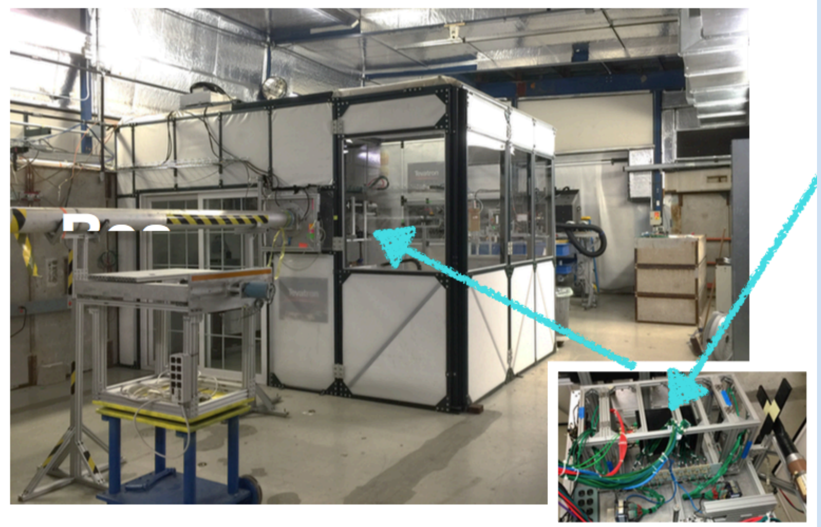


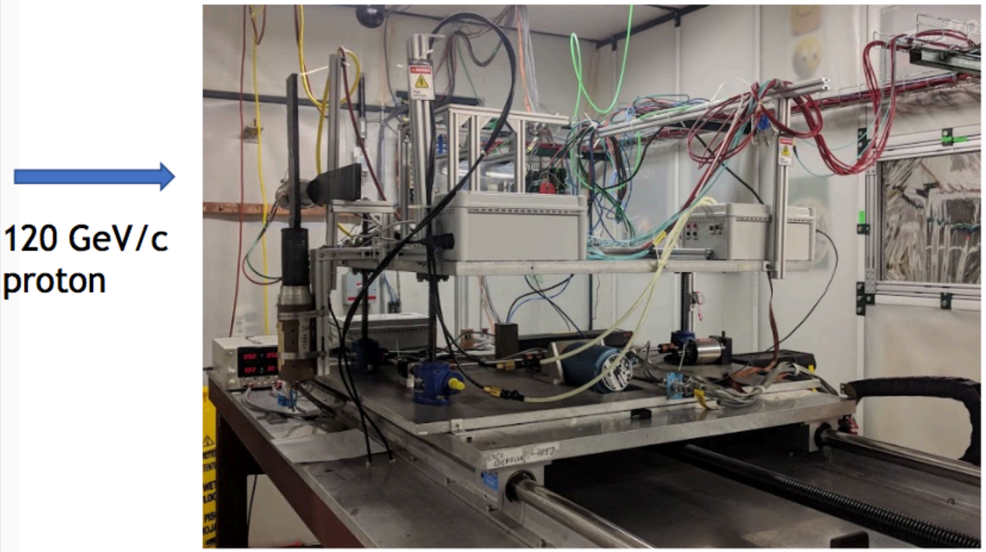


Goal:
Separation
up to 8 GeV/c



mRICH Prototype @ Fermilab BTF




120 GeV/c
proton

120 GeV proton pencil beam

1-100 GeV hadron wide beam

2016 and 2018 test beams


Team members from the 2nd mRICH beam test

eRD14 Electronics

Readout Electronics Development

Goal:

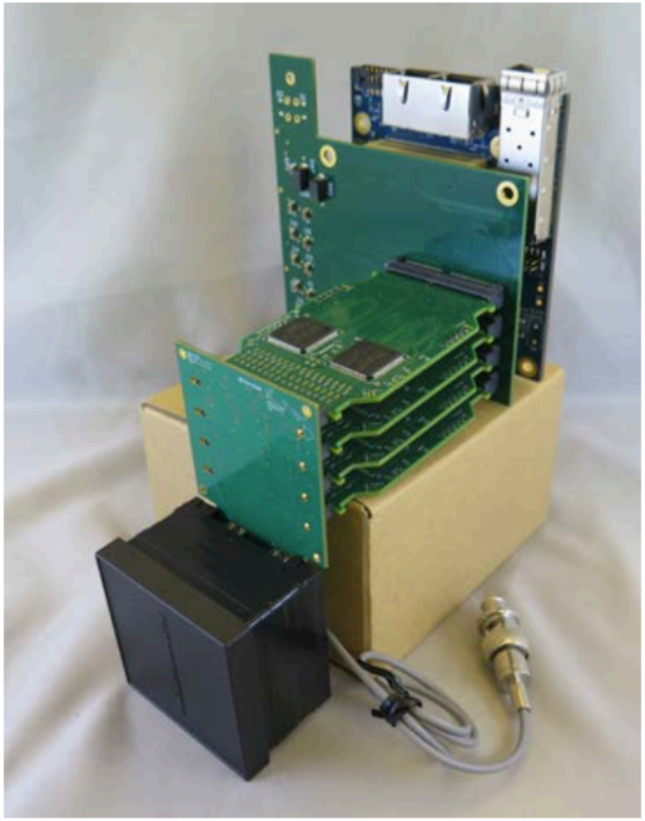
- Develop an integrated suite of readout electronics for the different photosensors used for all the Cherenkov detectors and prototypes.
- Provide a reference readout system for prototypes performance assessment
- Developed a generic DAQ system compatible with the Consortium needs
- Test applications with various sensors (including SiPMs)

FY 20 Activities:

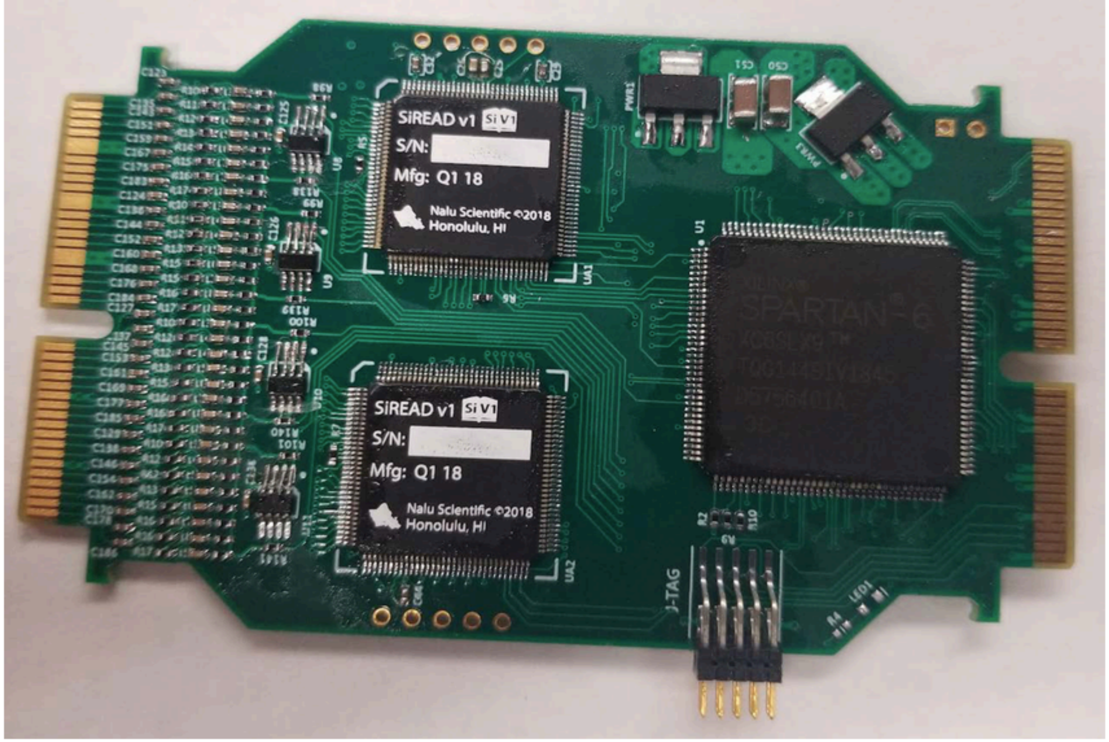
- Moving from the TARGETX (Belle-II) to the new SiREAD chip
- Development of pulsed laser test benches for detailed characterization

SiREAD

MA PMT Readout

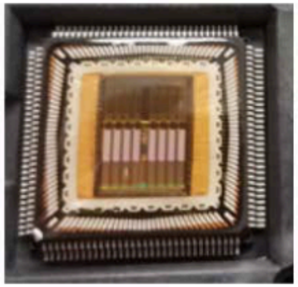


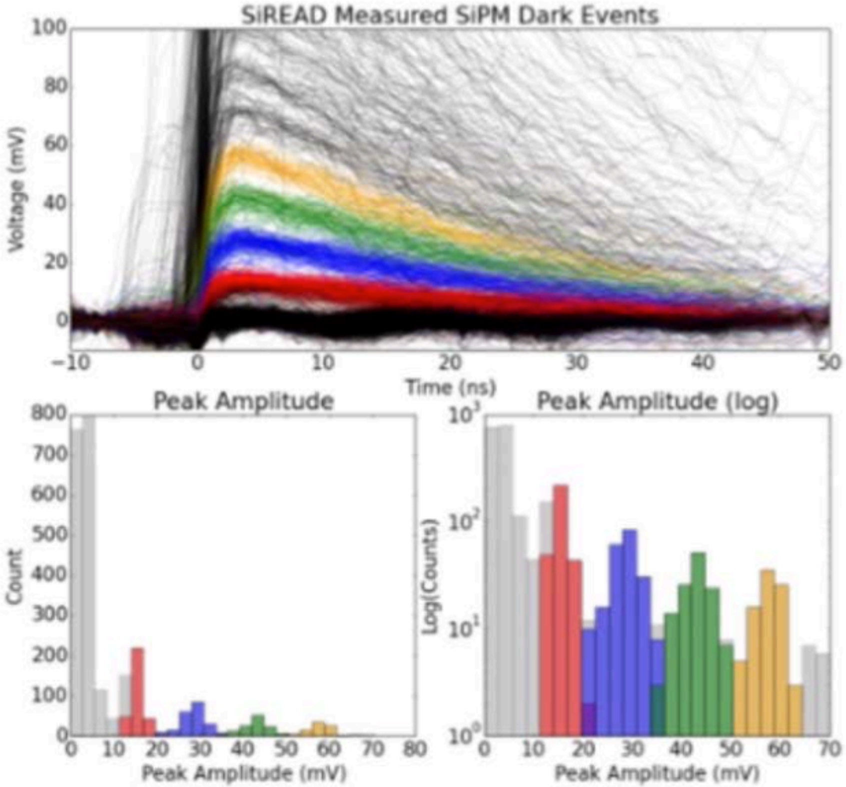
Photograph of the first generation of 256-anode 2" PMT readout for use with mRICH prototype in the Fermilab beam test facility.

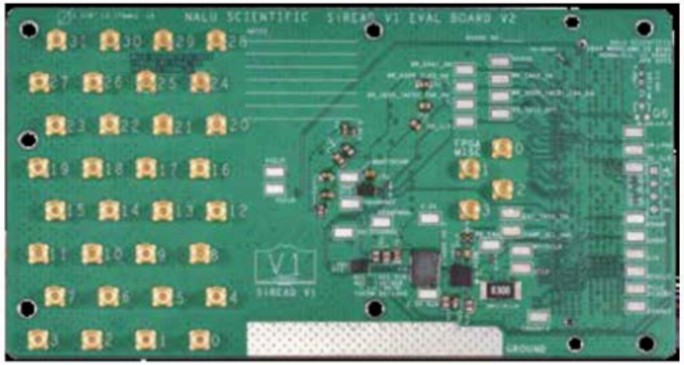


Photograph of the 64 channel SiREAD based (2x SiREAD rev.1) readout card as a building block for the 256 MA-PMT readout.

SiREAD Performance







- Micrograph of the fabricated prototype SiREAD (**top left**). Prototype SiREAD on the evaluation PCB (**top middle**). Superimposed dark count waveforms recorded from a SiPM using the SiREAD operating at 1 Gsa/s (**right**). High channel count evaluation PCB for SiREAD with 32 dedicated MMCX connectors (**bottom left**).

Spares

New Radiator Materials (eRD6-SBU)

Aim: find radiator medium that combines
properties of gas and aerogel

सत्यमेव जयते

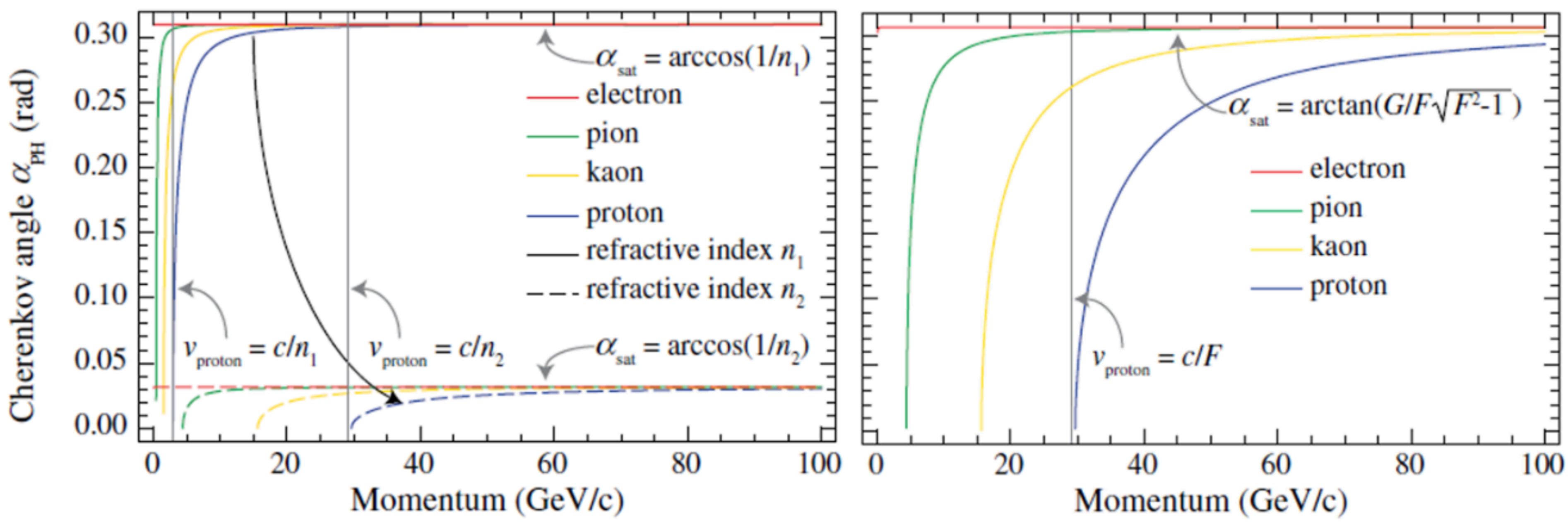
National Coordinator

SPARC
Scheme for Promotion of Academic and Research Collaboration

Method: use anisotropic media (meta-materials) to produce
small forward F=1.0005 and large transverse G=10 optical stretch factors

Transformation optics yield:

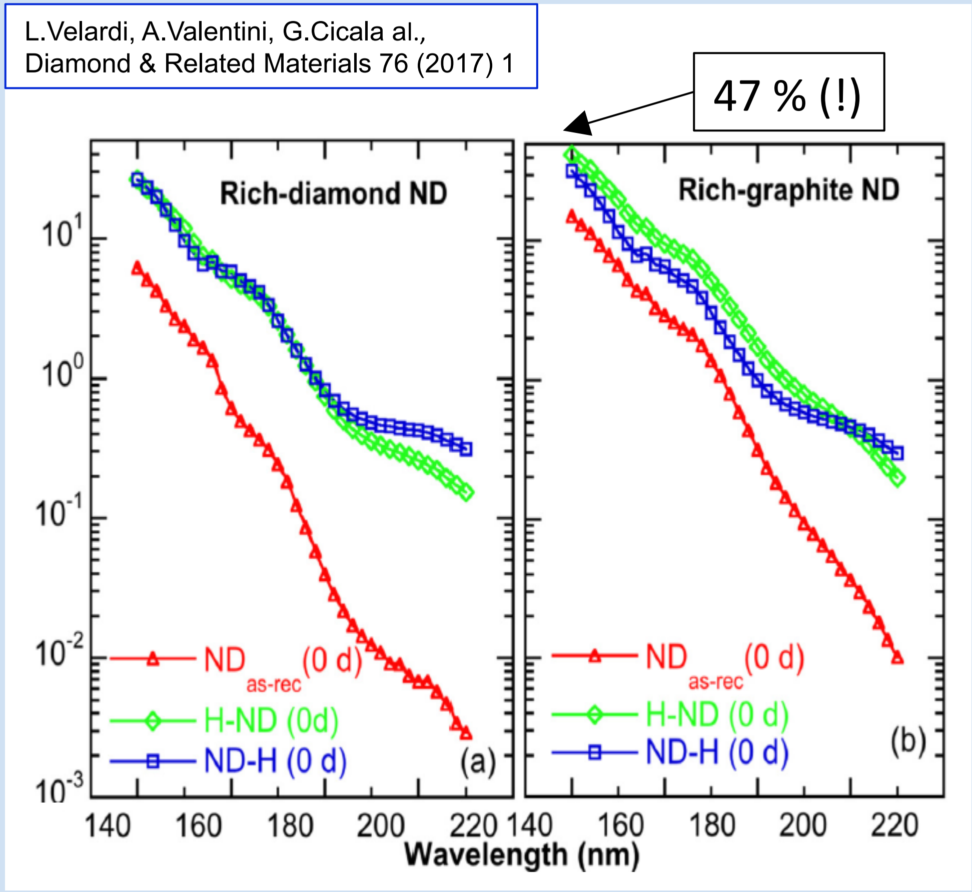
$$\tan(\alpha_{\mathrm{PH}}) = \frac{k_y}{k_x} = \frac{G}{F}\frac{\sqrt{F^2\epsilon_b\omega^2/c^2 - k_x^2}}{k_x} = \frac{G}{F}\tan(\alpha^*)$$



New Photocathode Materials (eRD6-INFN)

Aim: robust alternative to CsI for gaseous detectors

Method: Hydrogenate diamond film obtained with spray technique using nano powders


L.Velardi, A.Valentini, G.Cicala al., Diamond & Related Materials 76 (2017) 1

47 % (!)

To be matched with a

windowless thick GEM-MicroMegas
hybrid gaseous detector
with miniaturized pad size