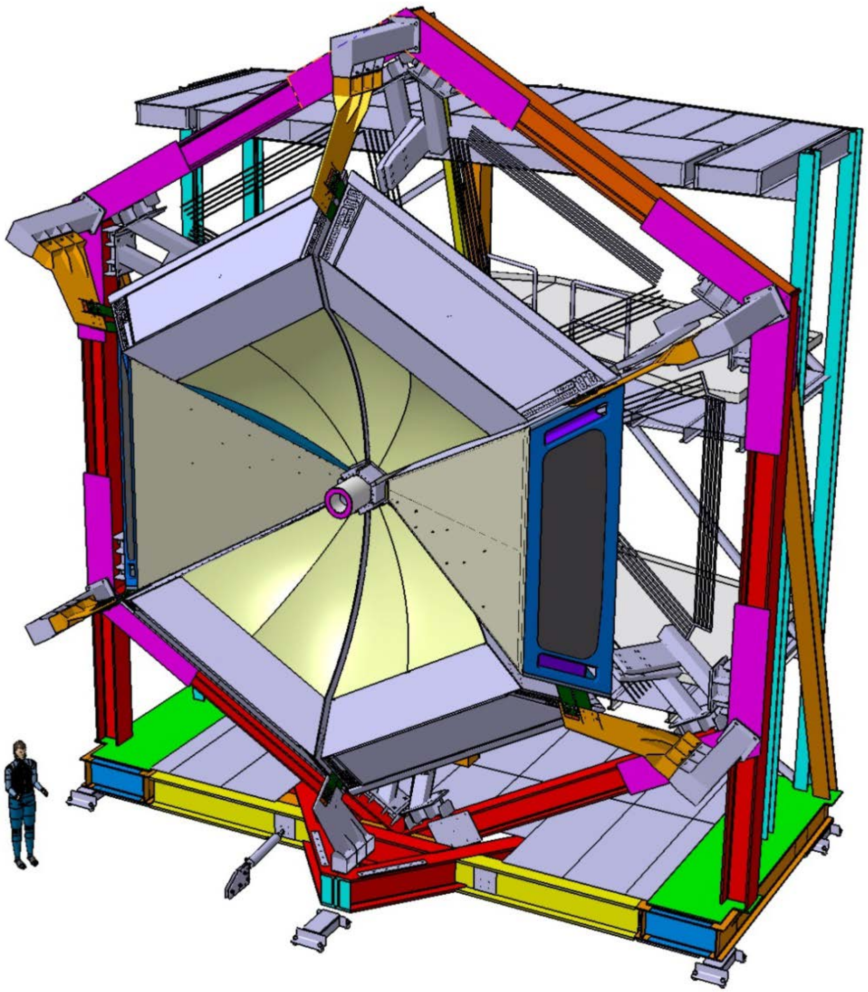


The CLAS12 RICH

Marco Mirazita

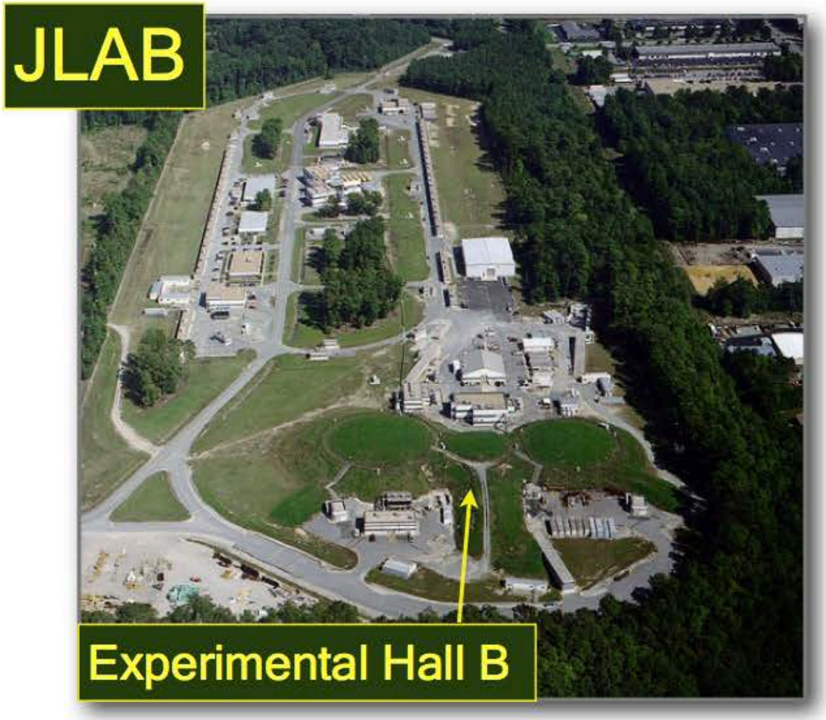
G. Fuga, V. Lucherini, D. Orecchini, A. Orlandi, P. Rossi, S. Tomassini, A. Viticchie'

G. Angelini, R. Montgomery, S. Pisano, M. Turisini

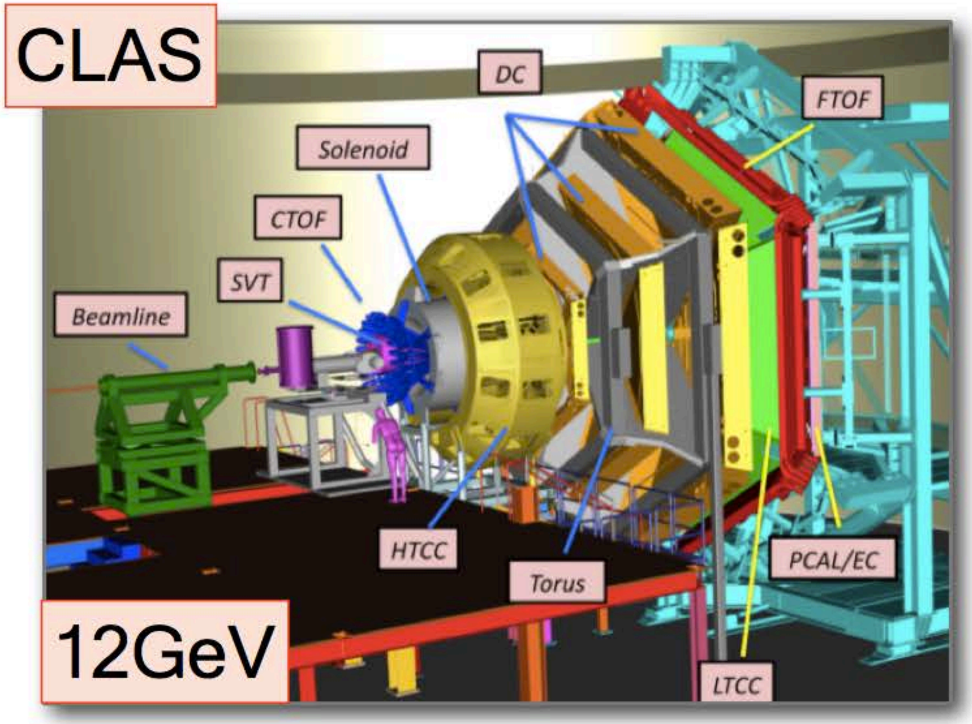
55th Scientific Committee Meeting – LNF, May 14, 2018

The CLAS12 RICH

at Thomas Jefferson National Accelerator Facility, Newport News, Virginia, USA



Continuos Electron Beam Accelerator Facility (CEBAF)



CEBAF Large Acceptance Spectrometer (CLAS)

Why the RICH

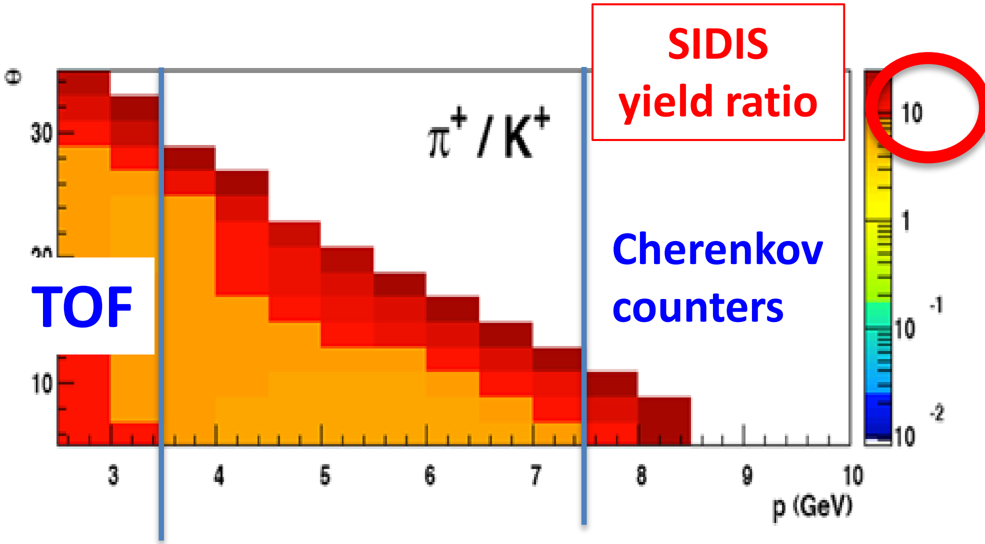
Kaon program at CLAS12

A large fraction of the approved CLAS12 physics program requires good kaon identification

- **flavor separation in SIDIS**
- **hard exclusive meson production**
- **exotic hybrid meson spectroscopy**

CLAS12 provides good kaon ID only at low and high momentum regions

- **pion production rate is one order of magnitude higher than kaon**



RICH goal: **π/K/p identification from 3 up to 8 GeV/c and 25 degrees**

~4σ pion-kaon separation for a pion rejection factor ~ 1:500

The RICH project

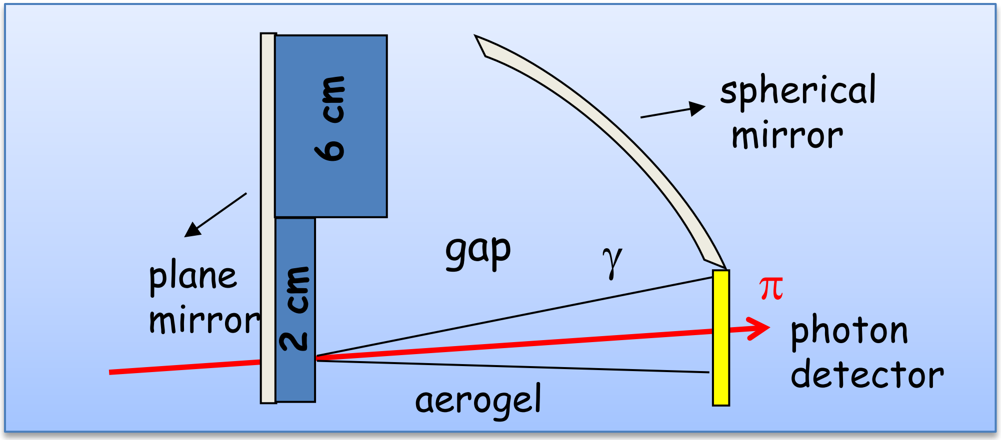
- The construction of the RICH was proposed by Frascati, then involved many other INFN sections and foreign Institutions
- LNF was responsible for many aspects of the construction, from the design of the detector to test of the components, the assembly and the installation.

2011	Beginning of the R&D
2013	Winner of "Premiale" funding from Italian MIUR
2014	Construction of the first module started
March 2017	Beginning of assembly at JLab
Nov. 2017	Assembly completed, starting commissioning
Jan. 2018	Installation in CLAS12 and beginning of data taking
2018	Starting construction of the second module
≥ 2020	Installation of the second module

INSTITUTIONS
INFN Ba, Fe, Ge, LNF, RM/ISS
Jefferson Lab (USA)
Argonne National Lab (USA)
Duquesne University (USA)
Glasgow University (UK)
George Washington University (USA)
Kyungpook National University (Korea)
University of Connecticut (USA)
Universita' Tecnica F. Santa Maria (Chile)

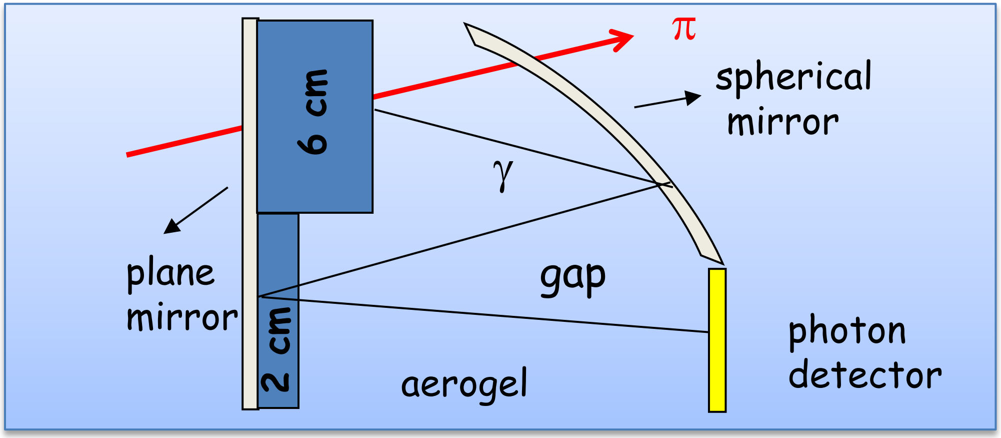
The hybrid optics design

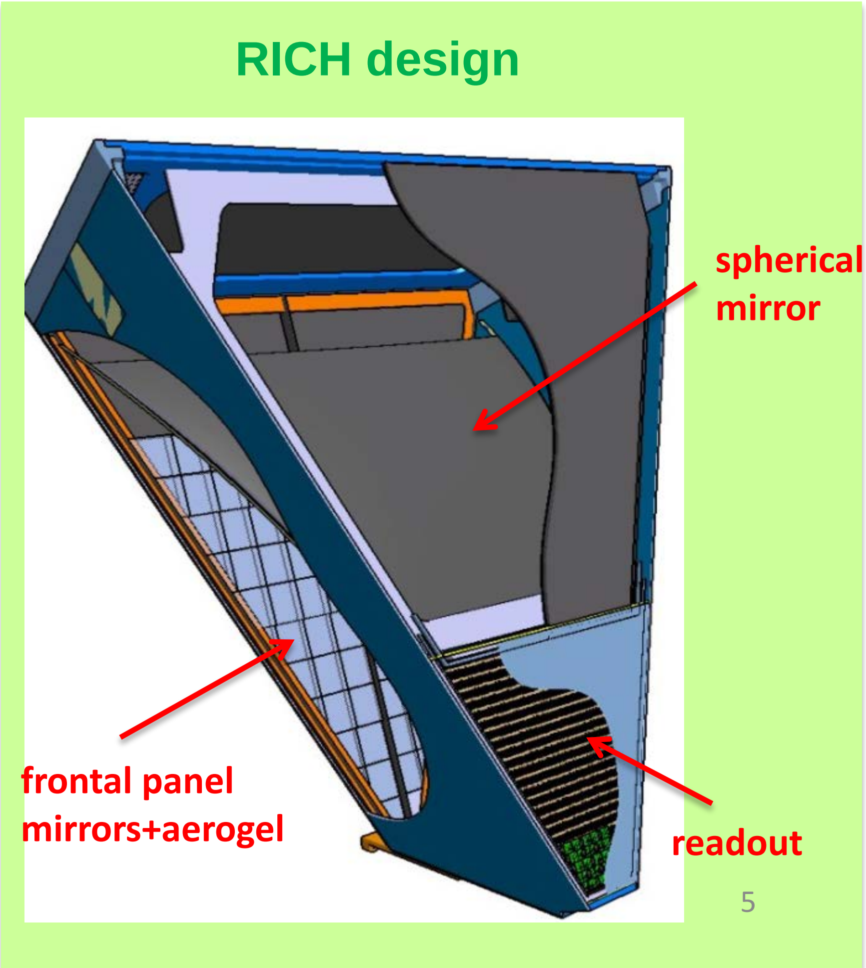
Direct photon detection:
best performance for high momentum particles



Configurations tested with a large scale prototype in test beams at CERN and LNF

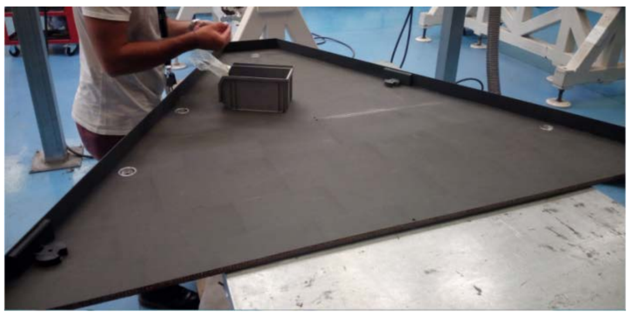
Photon detection after reflections:
less demanding for low momentum particles

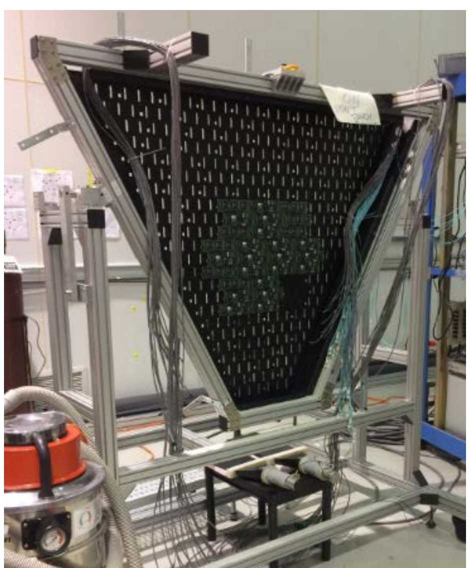


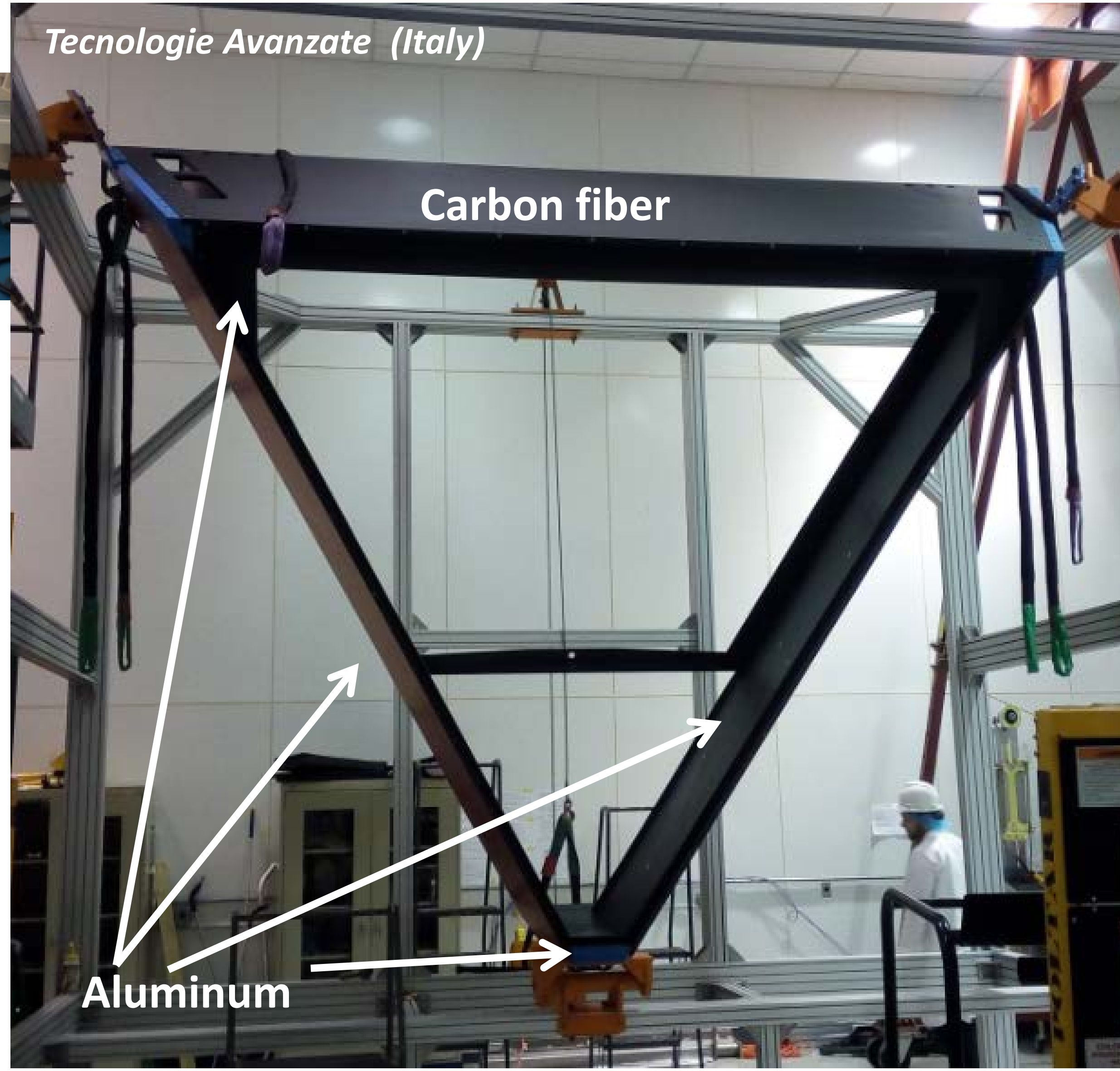


The RICH detector

Carbon fiber



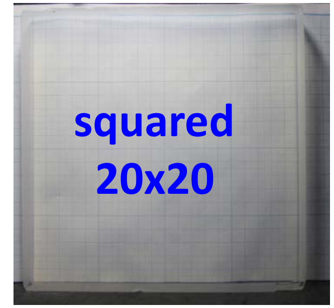




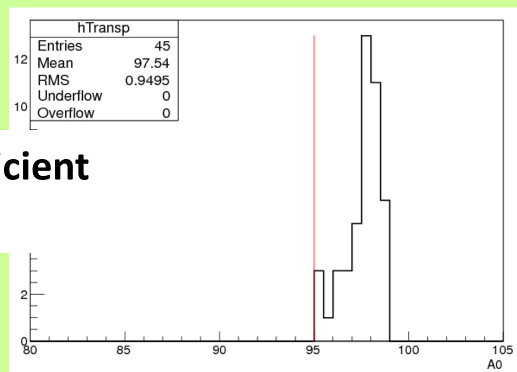
Aerogel radiator

Large tiles produced by the Budker and Boreskov Institutes of Nuclear Physics (Novosibirsk, Russia)

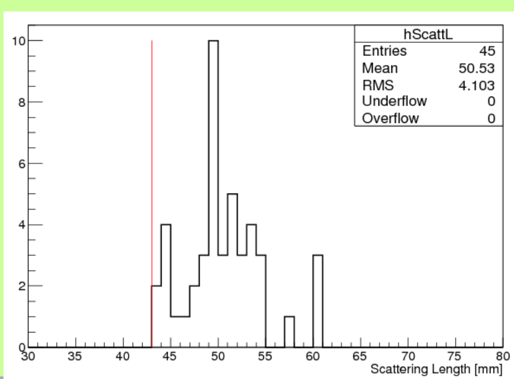
- **Optical quality comparable with the ones produced for Belle but at higher refractive index and larger size**
- **thickness 2 or 3 cm**
- **refractive index 1.05**



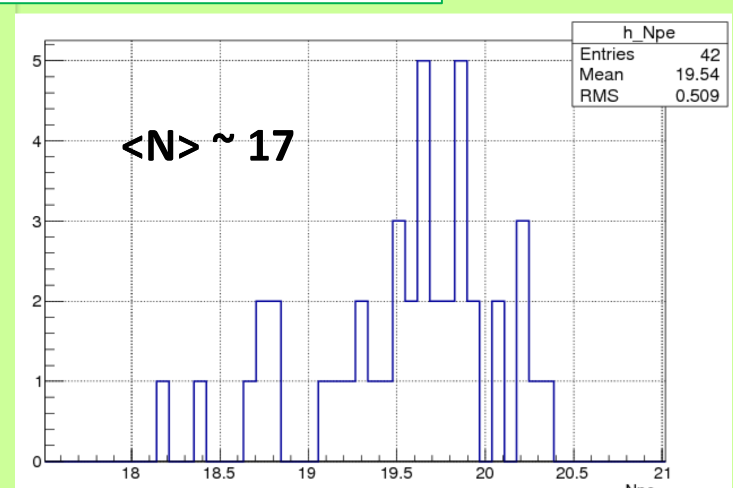
transparency coefficient
A0 > 95 %



scattering length
L > 43 mm

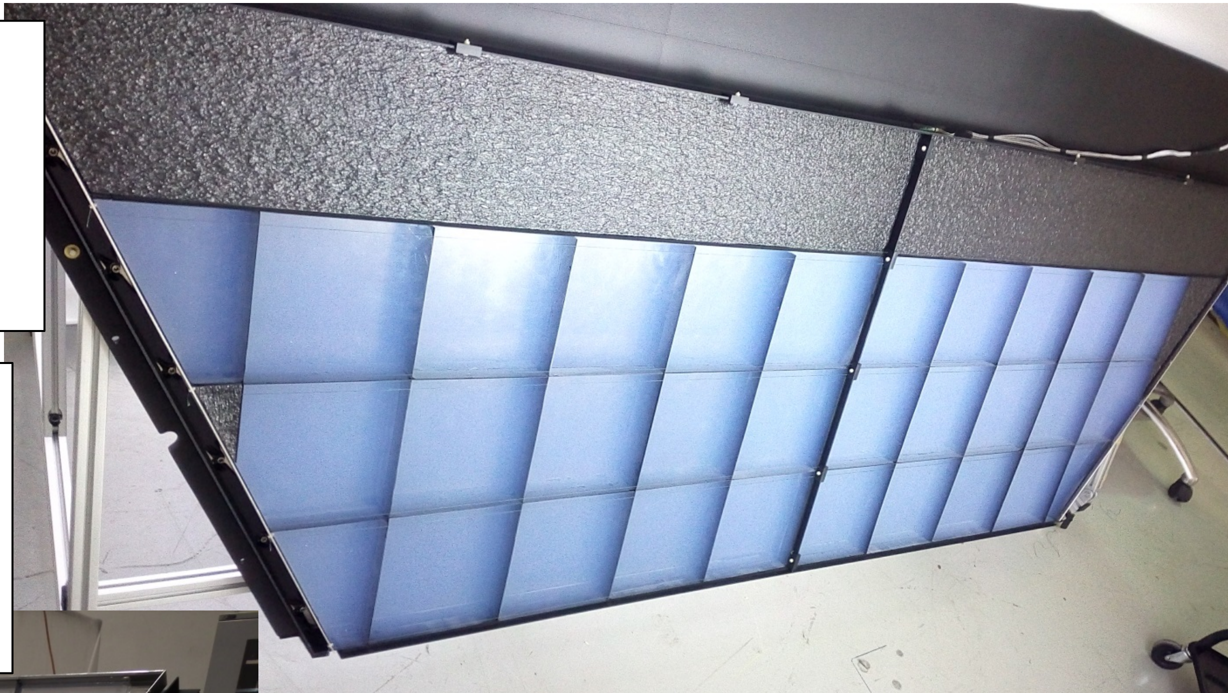


Analysis of optical characteristics

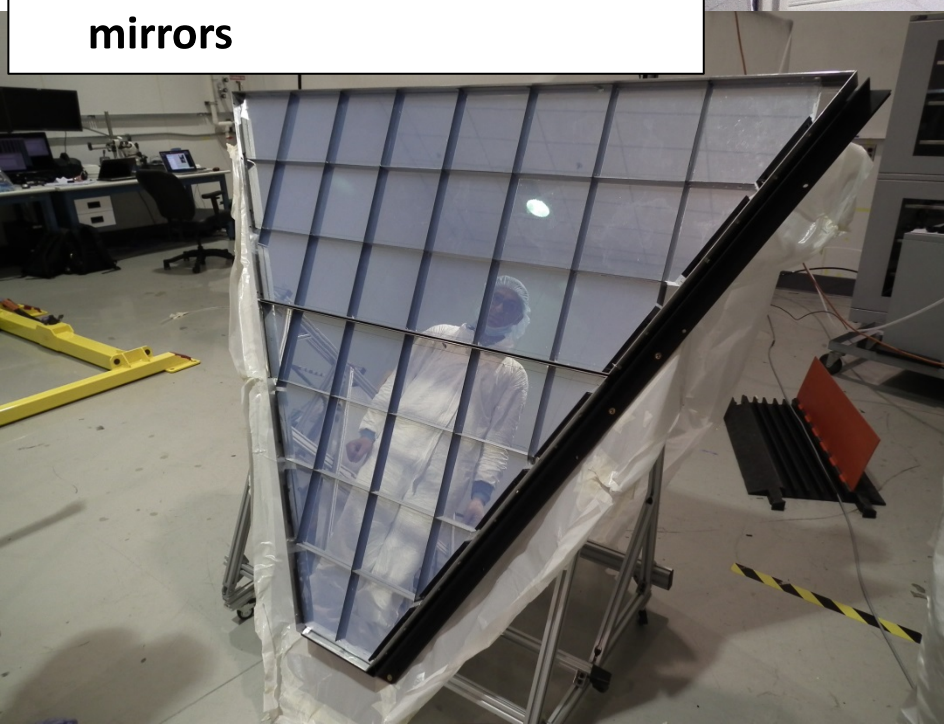


Aerogel assembly

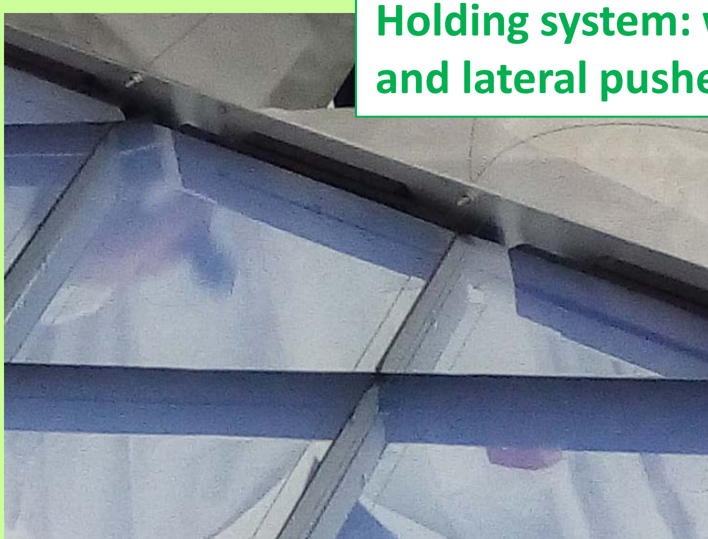
Top section
- **2 layers 3+3 cm thickness**
- **64 tiles**
- **mounted on the frontal closing panel**



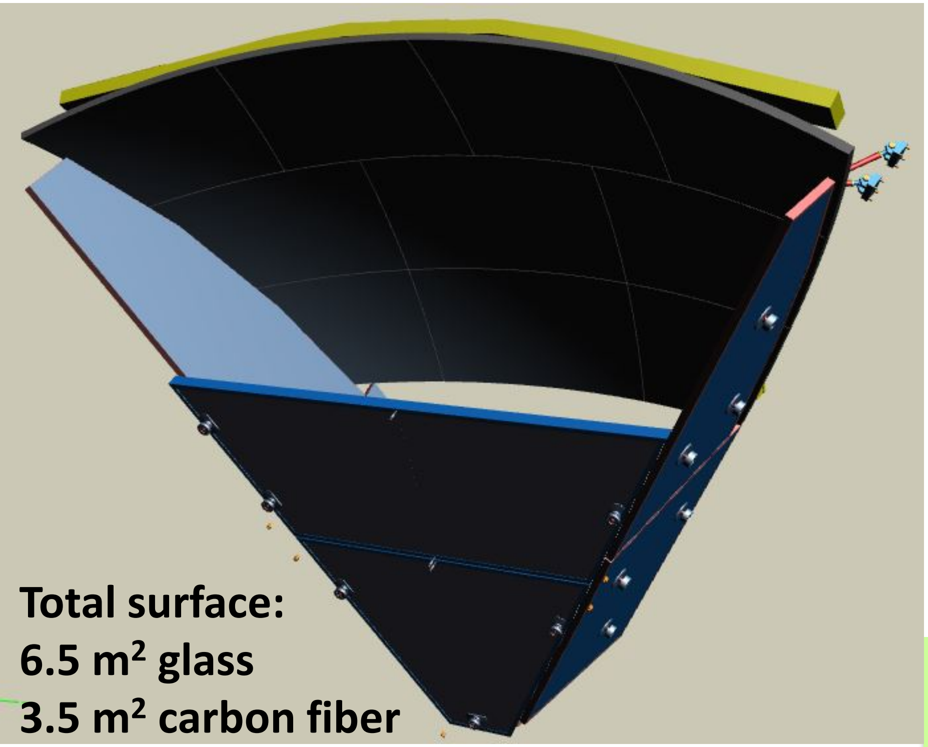
Bottom section
- **1 layer 2 cm thickness**
- **38 tiles**
- **mounted on the two frontal mirrors**



Holding system: wires and lateral pushers



The mirror system

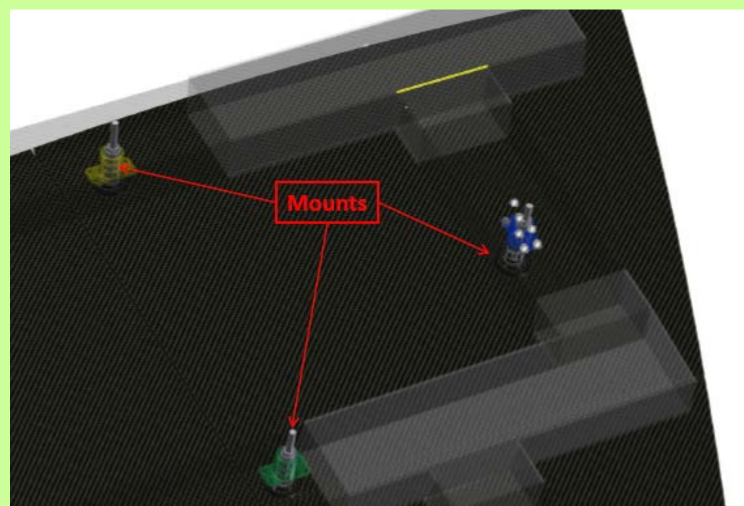


Total surface:
6.5 m^2 glass
3.5 m^2 carbon fiber

Sandwich technique: two layers of material plus honeycomb core

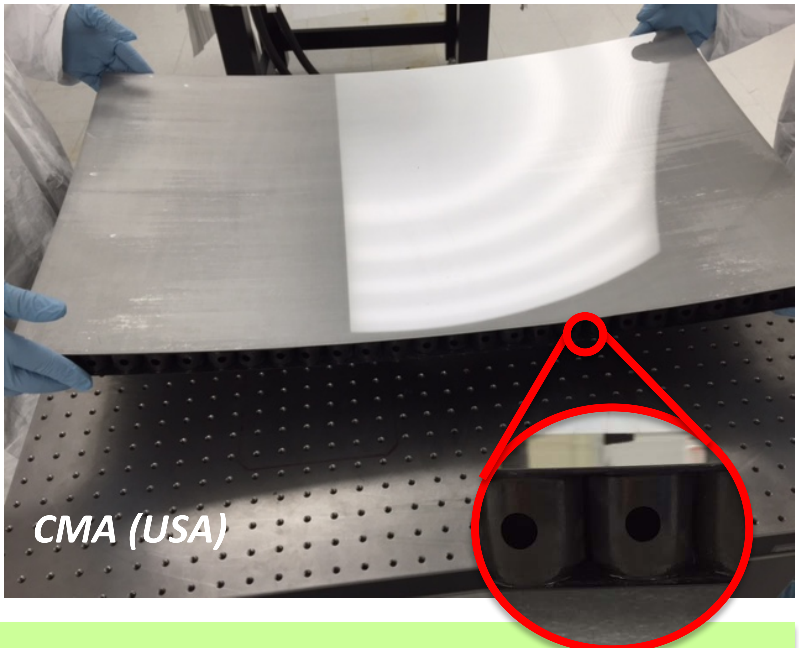
- Mirrors in the acceptance
  - 10 spherical mirrors
    - carbon fiber
  - 2 frontal mirrors
    - thin glass layers
- Mirrors out of the acceptance
  - 4 lateral and 1 bottom mirrors
    - thicker glass layers

System entirely responsibility of LNF from initial studies to select the best technology, to the design, the test and alignment tools, up to the final assembly



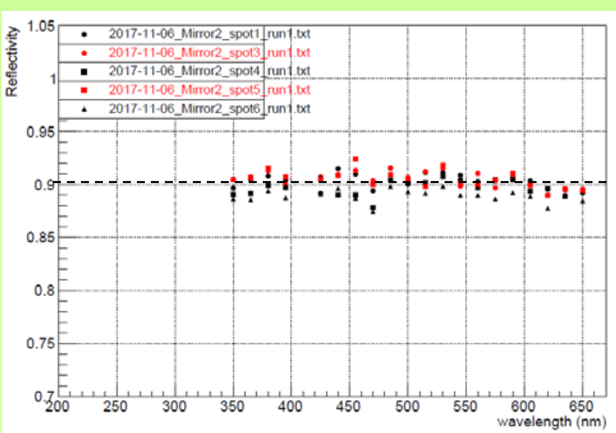
Spherical Mirrors

Same technology as LHCb mirrors, but 30% improvement in the material budget

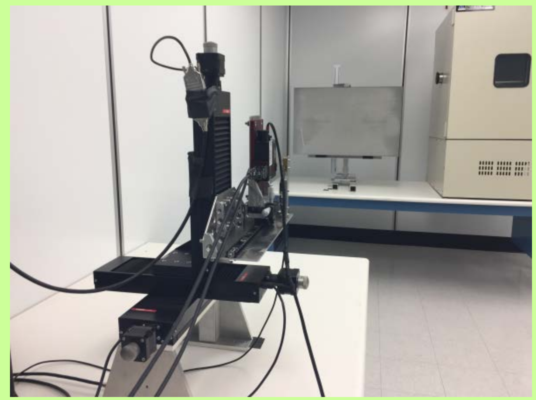


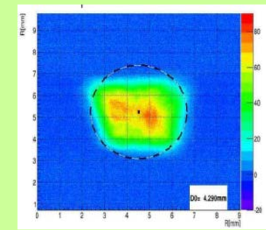
Characterization measurements
- reflectivity

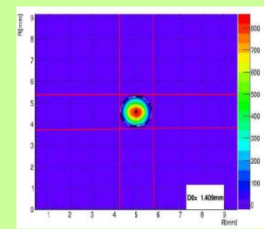
90%

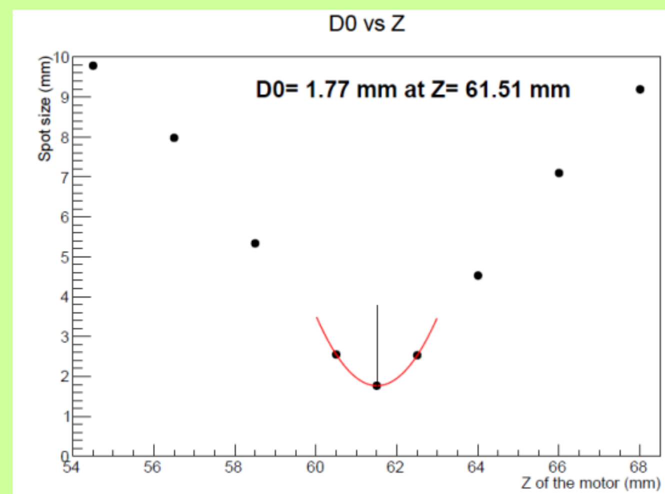


Characterization measurements
- surface accuracy → angular resolution
- radius

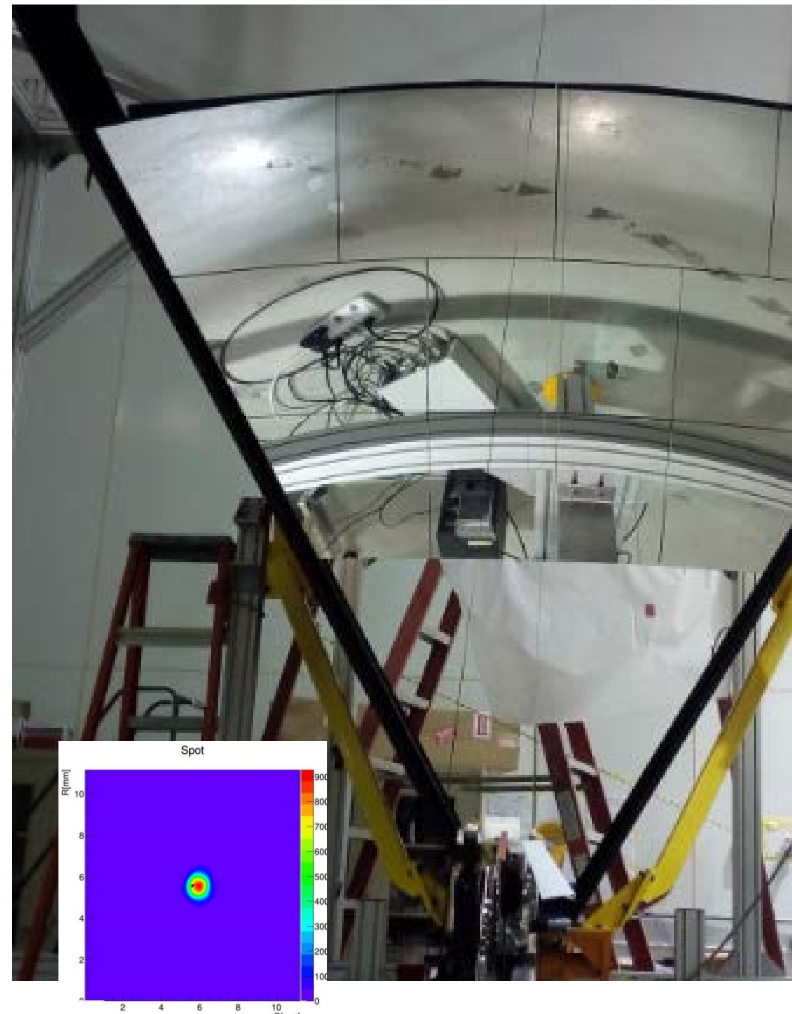








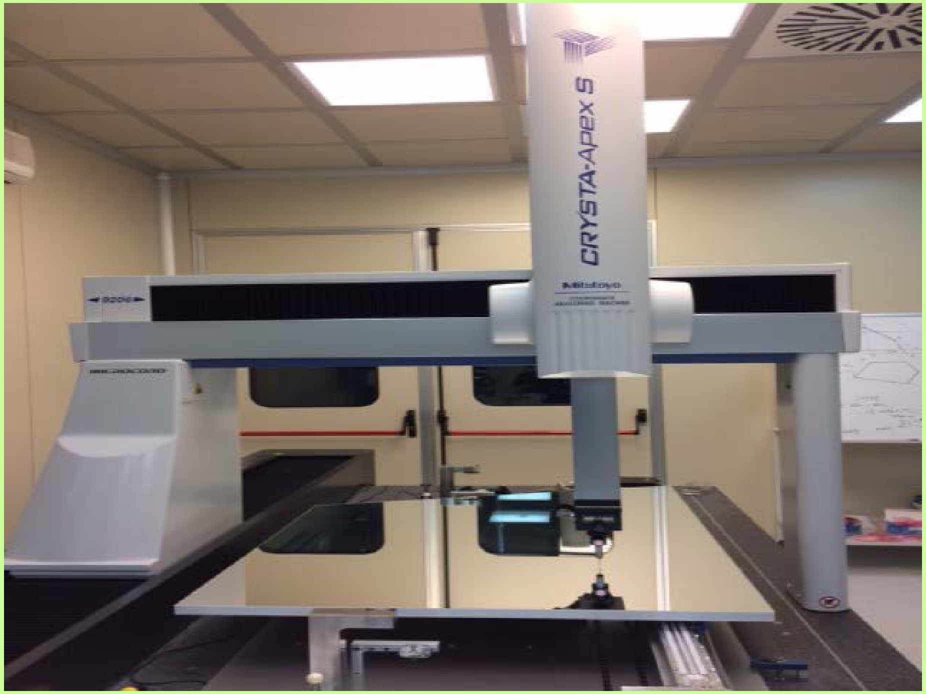
Assembly and alignment



Planar Mirrors

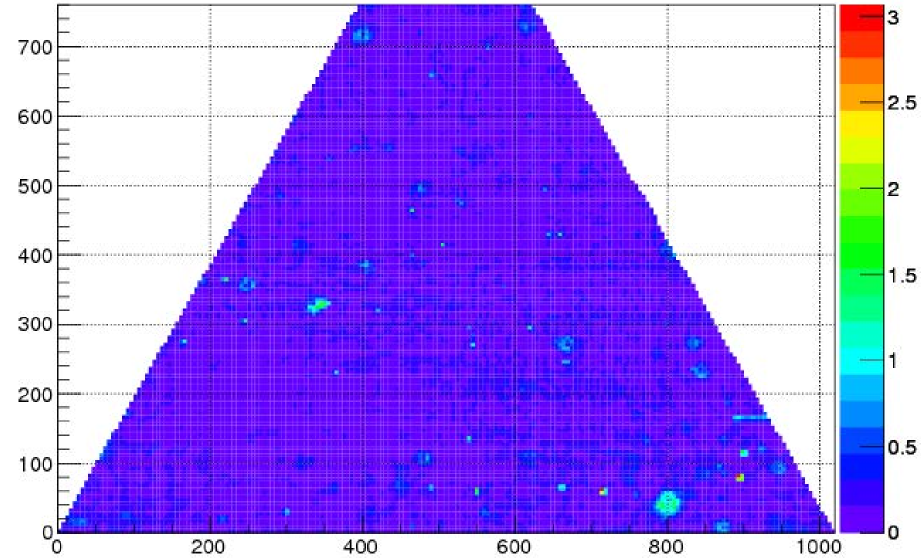
- Two thin layers of glass with Al honeycomb core: technology used in telescopes
  - 2x1.6 mm lateral and bottom: standard
  - 2x0.7 mm frontal: specifically developed for CLAS12
- Radiation length comparable with carbon fiber at much lower costs

Characterization measurements
- surface planarity at LNF



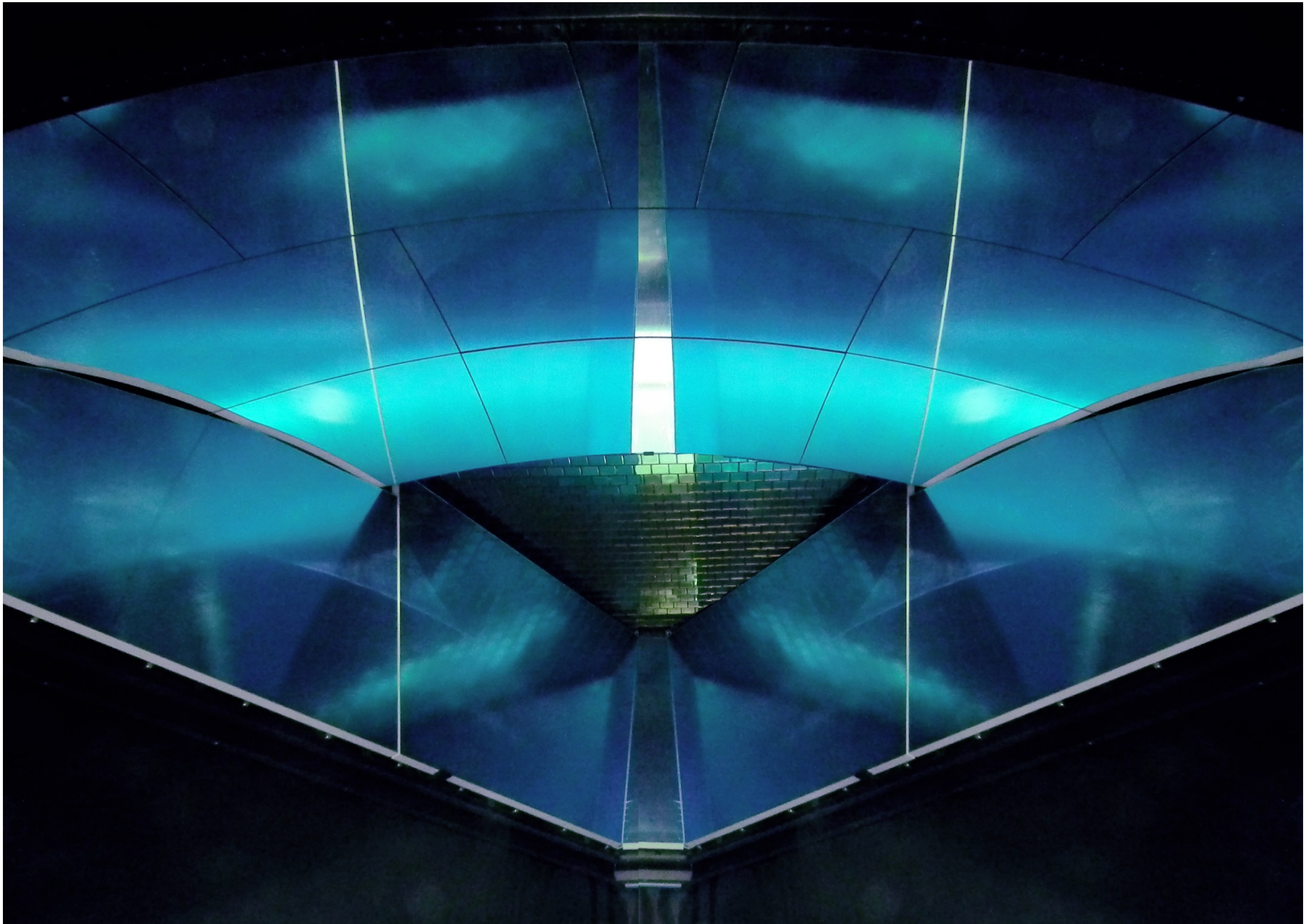
MediaLario (Italy)

Surface slope profile reconstructed from CMM measurements



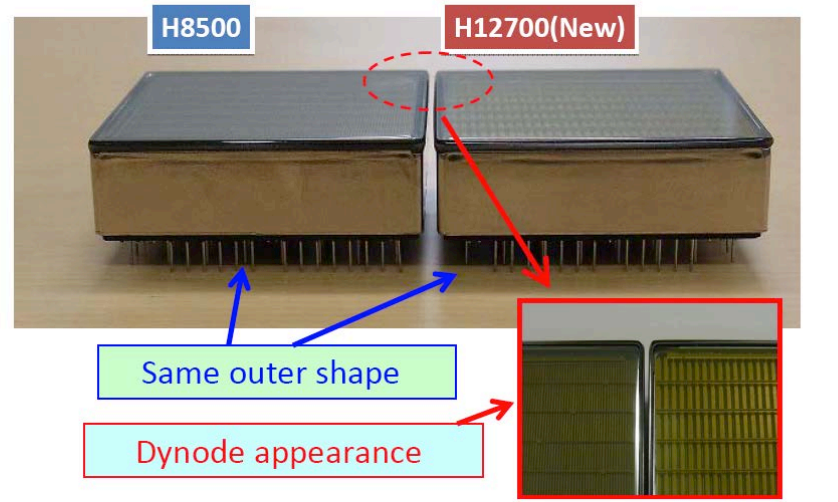
Production process improved after prototype mirror studies
- imperfections level lowered to few % of the total surface

The mirror system assembled



Photodetectors

Photomultipliers only available option for visible light detection

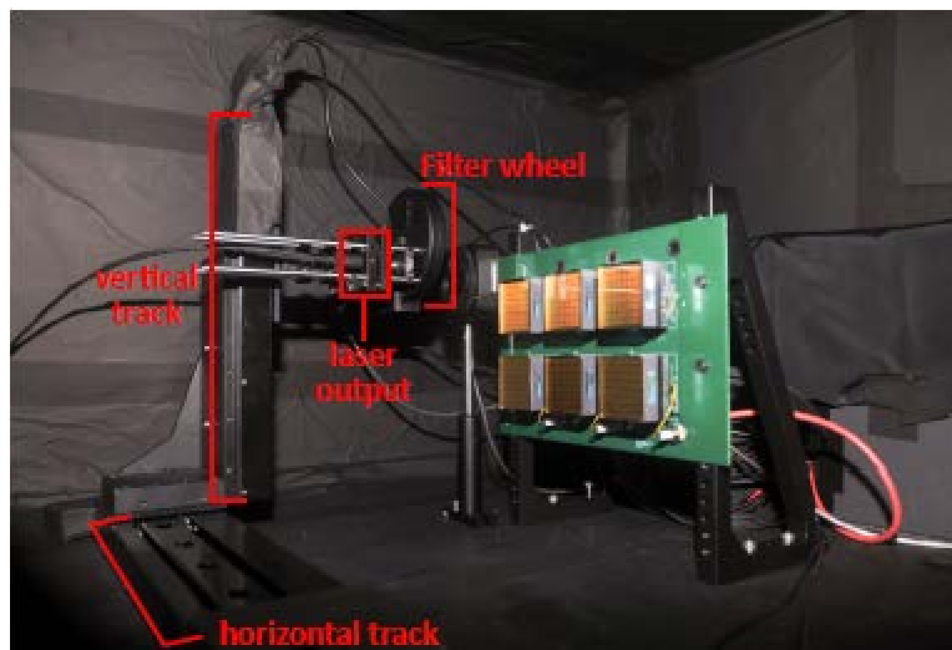


Several Multi-Anode PMT tested during R&D in laboratory and in test beams
Selected device: Hamamatsu H8500/H12700

- large area (5.2x5.2 cm^2)
- high packing fraction (89%)
- matrix of 64 6x6 mm^2 pixels
- high visible to near UV light detection efficiency
- fast response
- gain > 10^6

First massive production of H12700 MAPMTs

- 400 MAPMT tested in Single p.e. regime
- Gain, spe resolution, efficiency extracted for 25024 channels

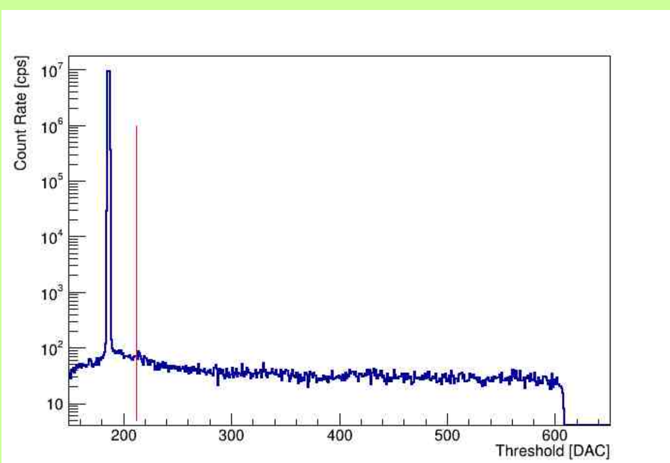


Readout Electronics

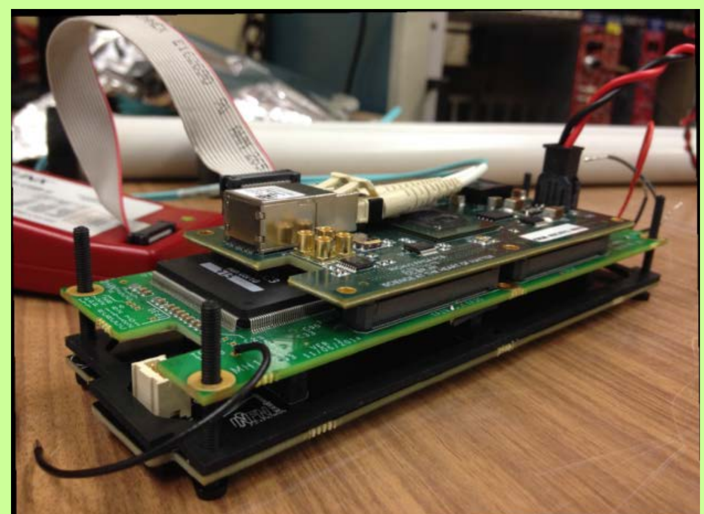
The RICH readout is based on the 64 channel MAROC front end chip

- **single channel adjustable preamp**
- **highly configurable signal shaping**
- **binary output after fast shaping with adjustable threshold**
- **leading and trailing edge time**

SPE spectrum reconstructed by scanning the threshold value
- typical dark current rate is 10 to 100 Hz

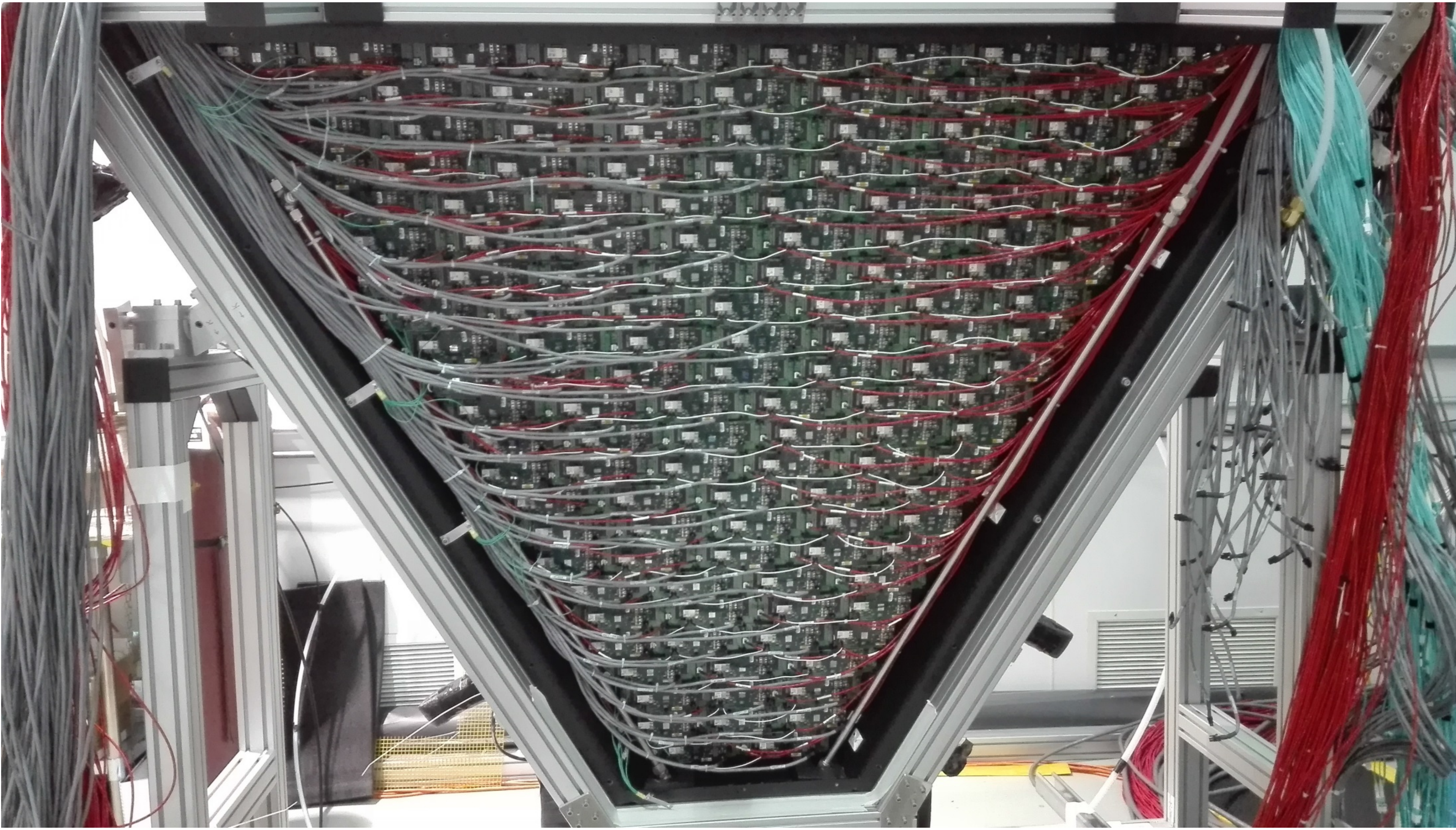


Compact system based on 2x and 3x tiles with adapter, ASIC and FPGA boards



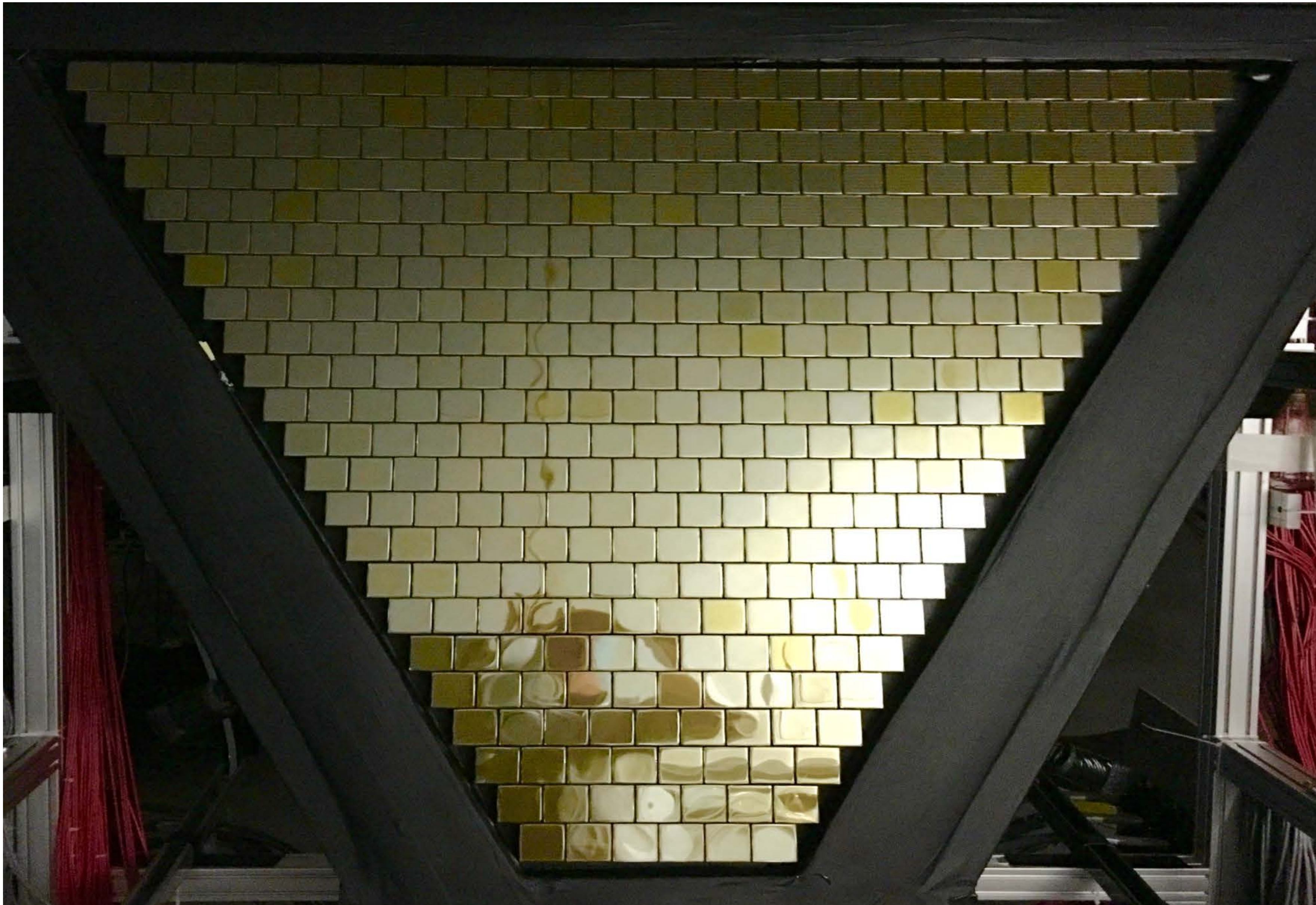
Assembly of the electronics

FE electronics view



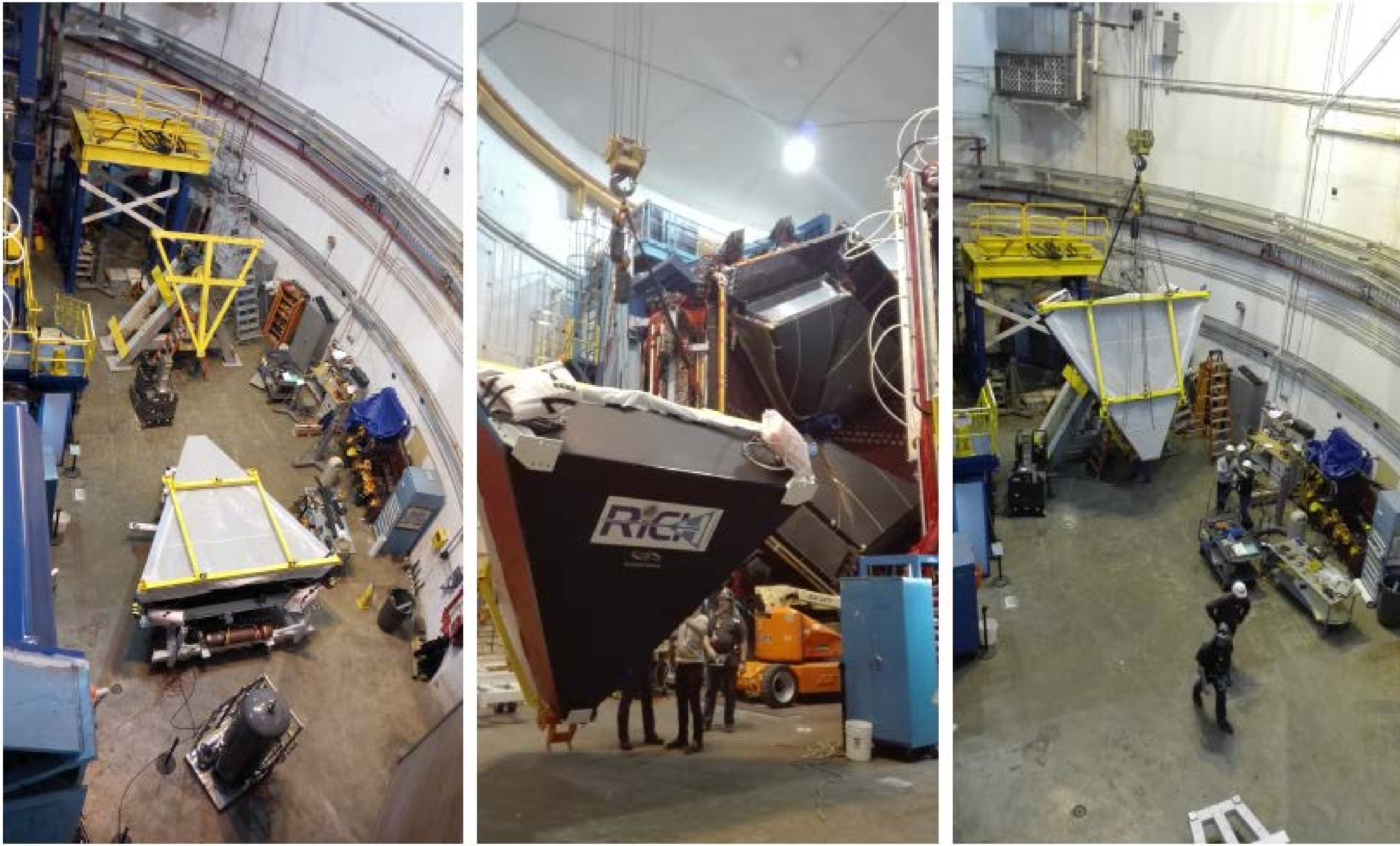
Assembly of the electronics

MAPMT view

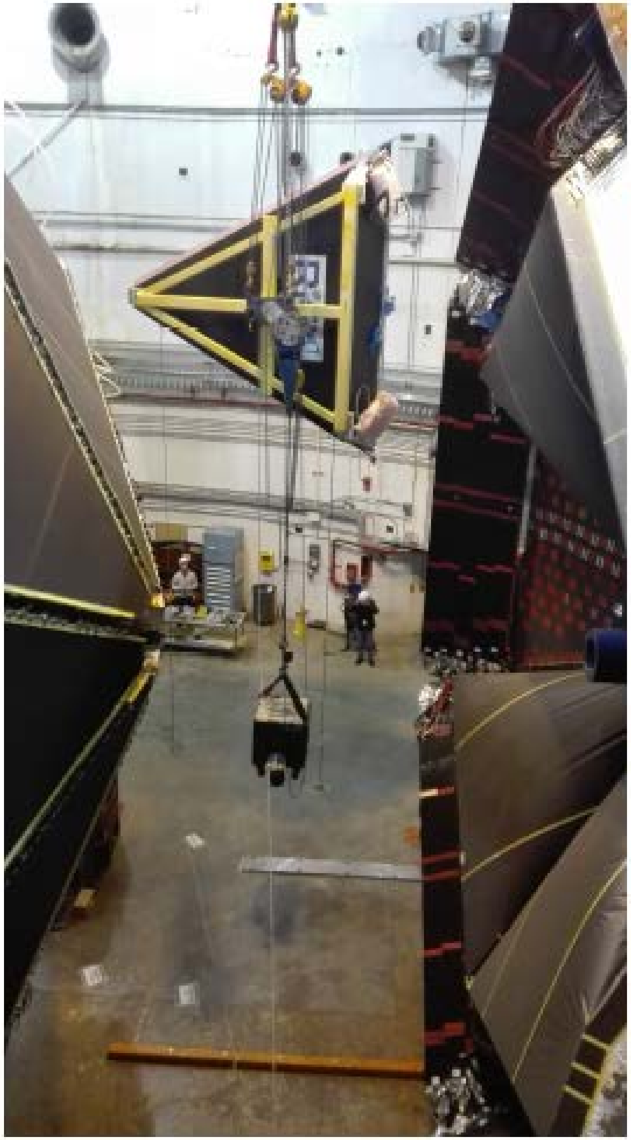


Installation in CLAS12

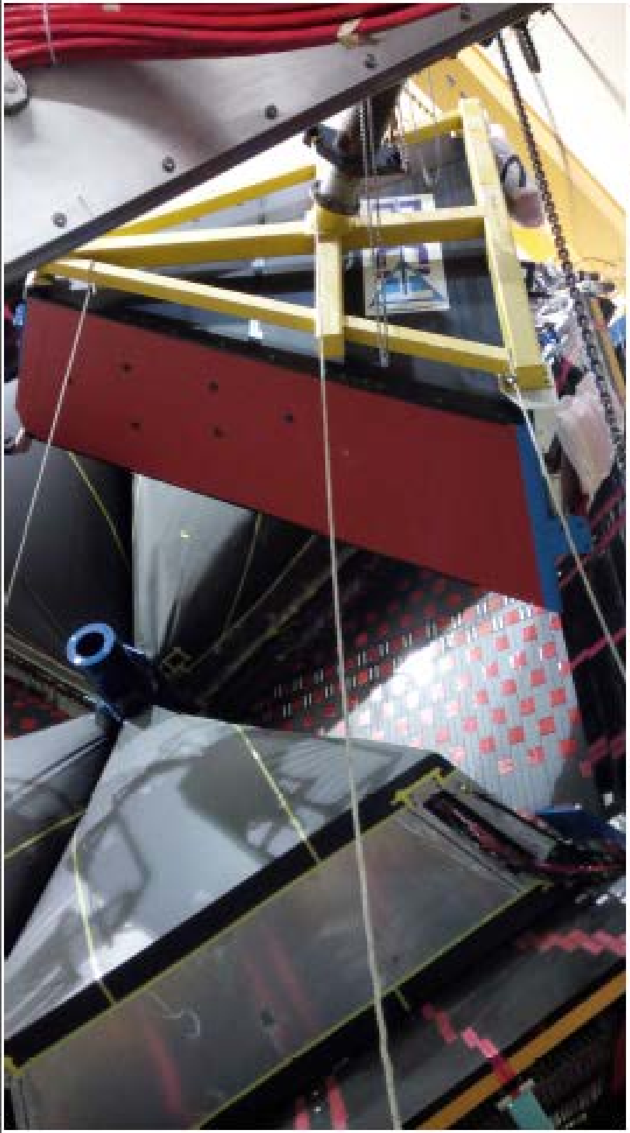
Installation in CLAS12



Installation in CLAS12

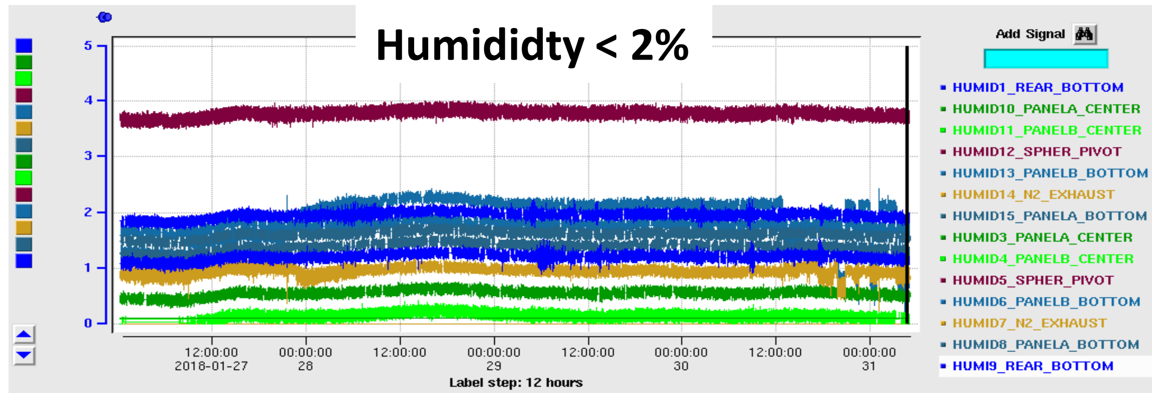



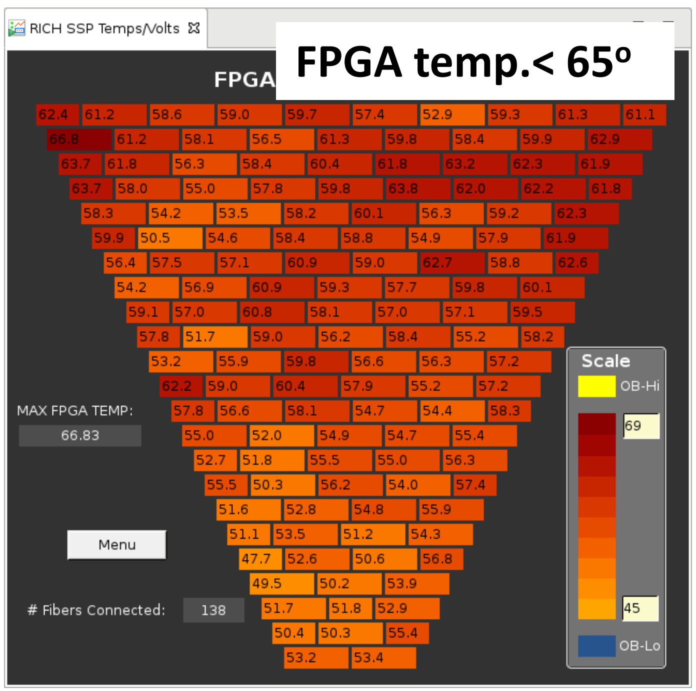

Installation in CLAS12

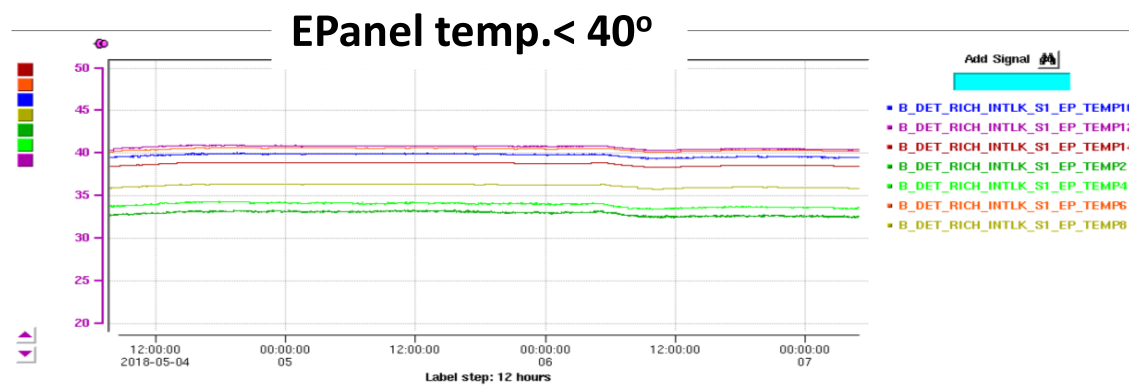


Slow controls

- Several parameters are monitored and sent to interlocks and alarms
  - FPGA chip temperature
  - Electronic panel internal temperatures
  - Cooling air flow
  - RICH internal humidity
  - Nitrogen flow

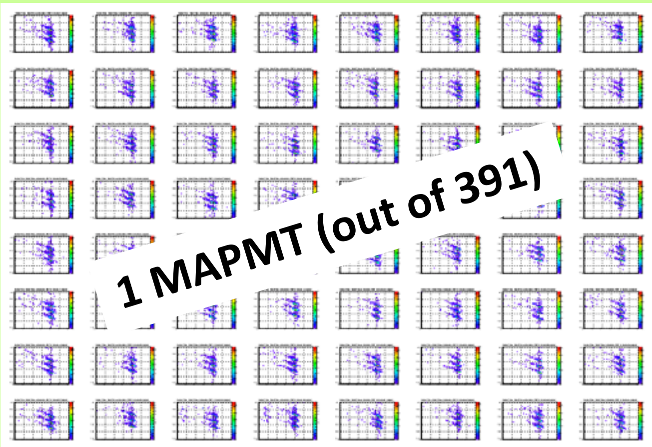




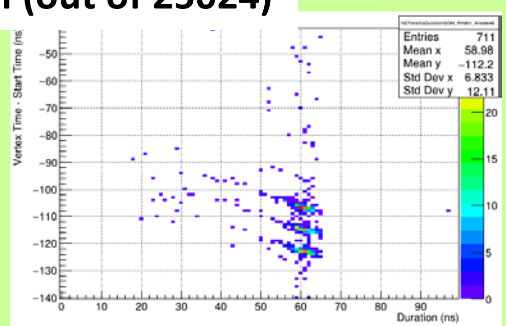


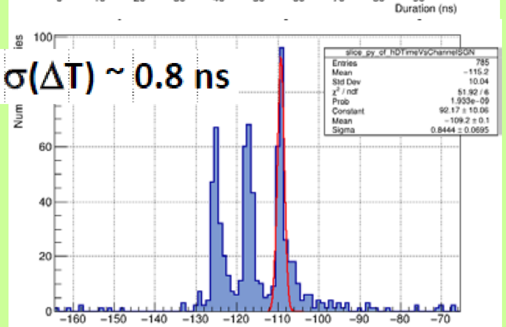
Physics data analysis

Timing analysis
Leading time vs duration (i.e. charge)

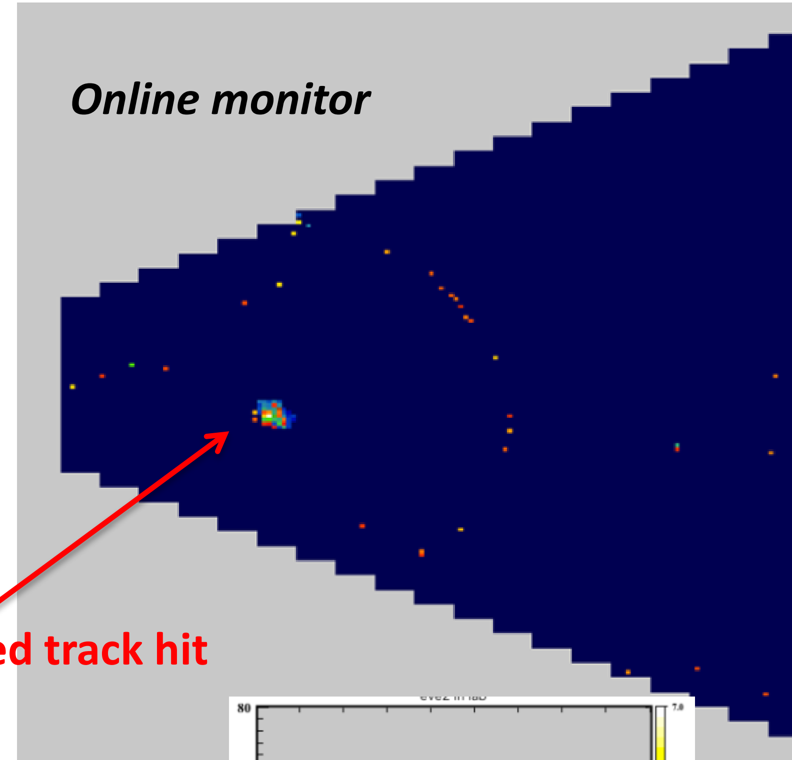


1 channel (out of 25024)

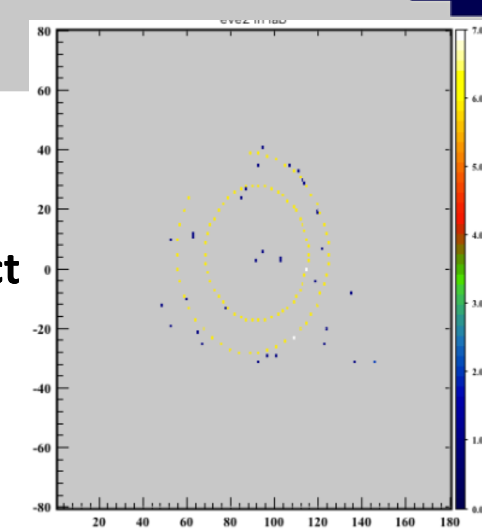




Event reconstruction



Yellow: expected photon hits (Direct Ray Tracing)

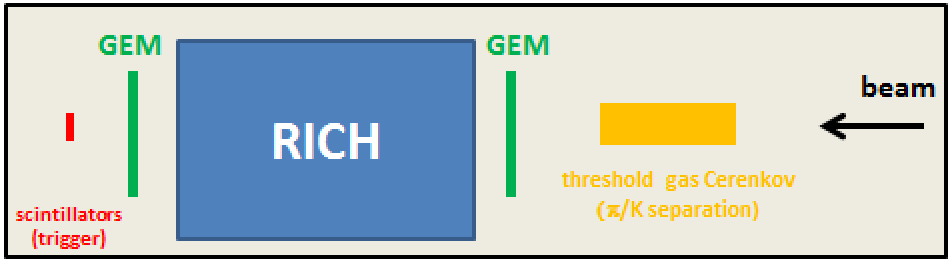


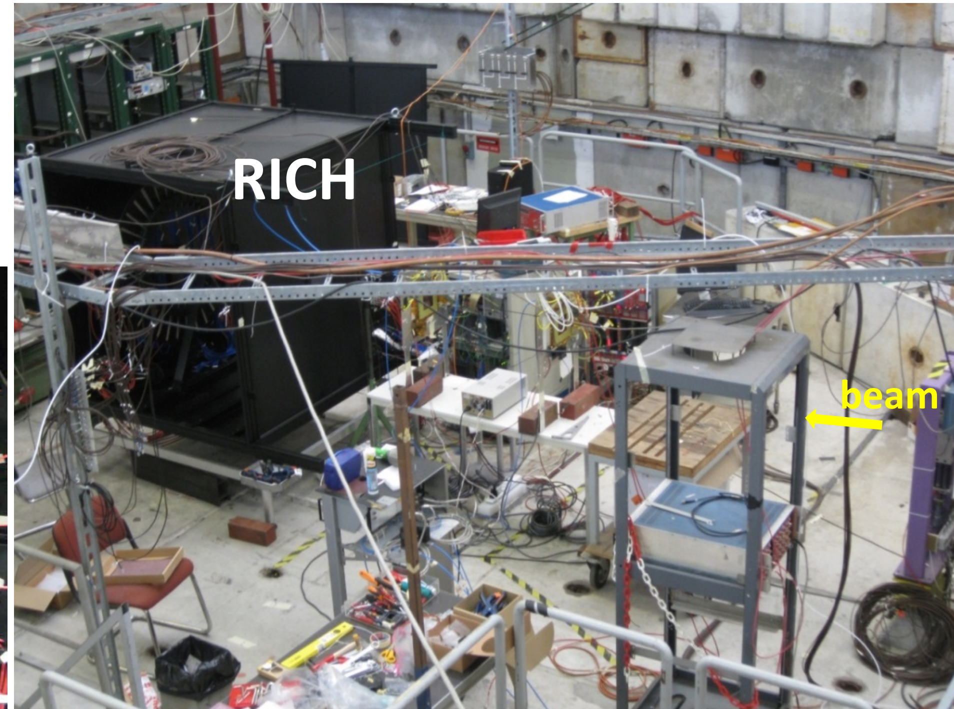
Conclusion

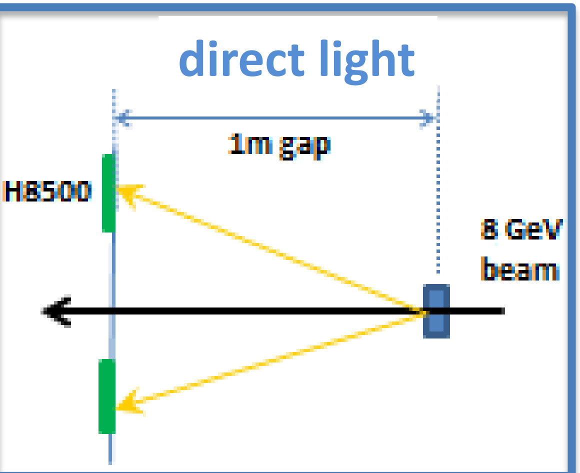
- After many years of work, the first RICH module has been installed in CLAS12 in January 2018
- No major failures have been reported after 1 month of tests in clean room and 4 months of physics data taking
- The analysis of the real and simulated data is underway to extract the detector performance
- The construction of the second module has started, installation in CLAS12 is foreseen by 2020

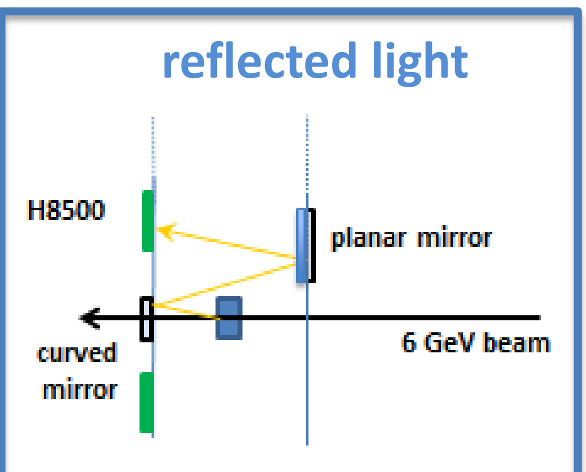
backup

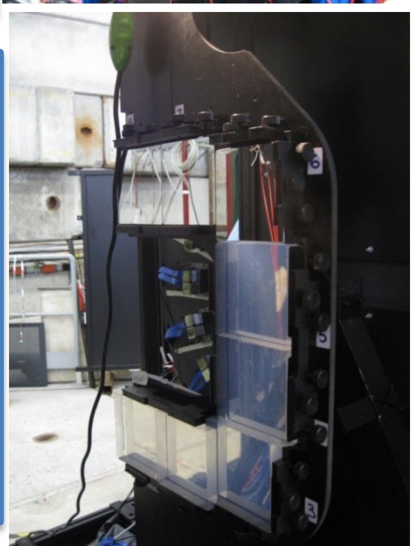
RICH prototype studies at CERN

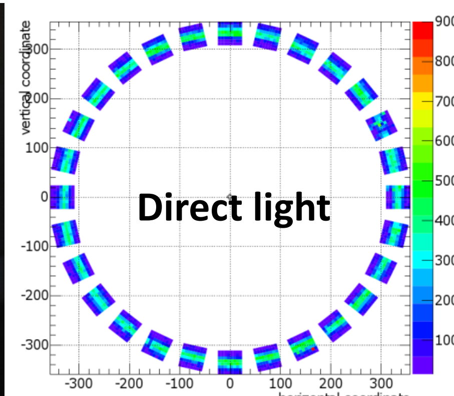


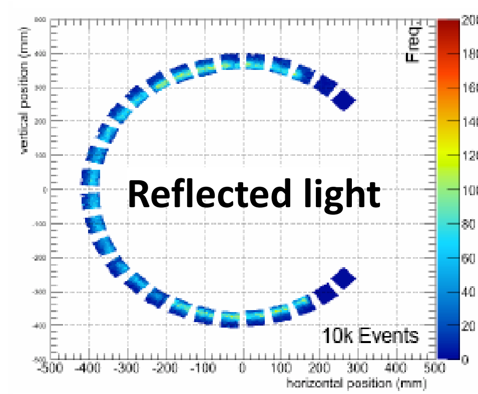






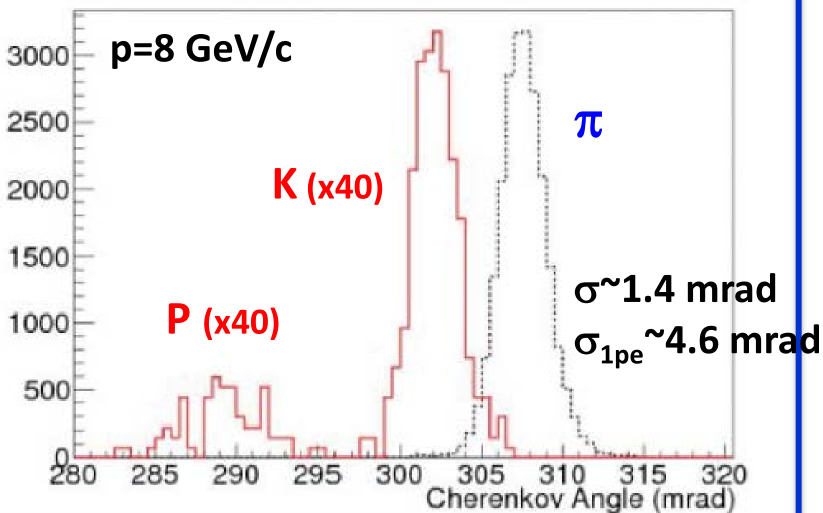


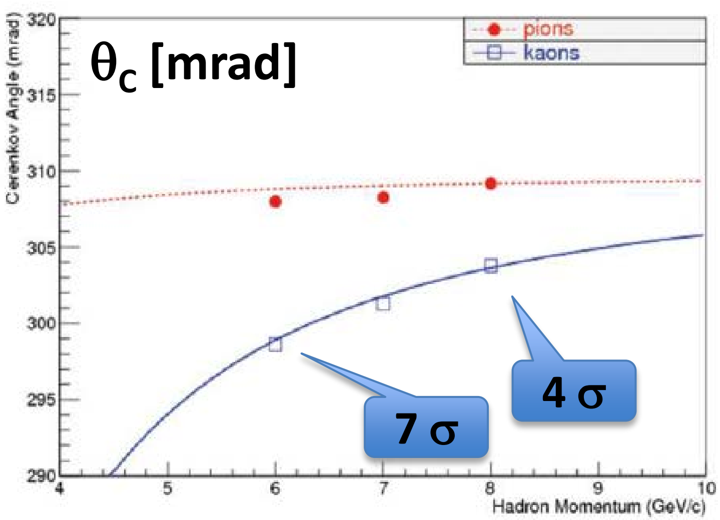




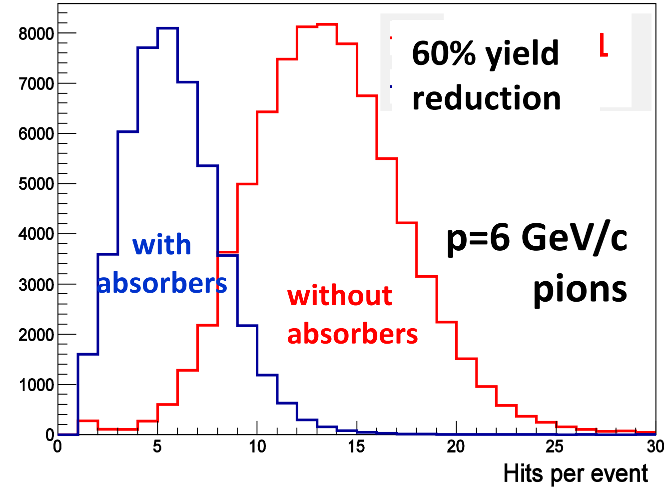
RICH prototype results

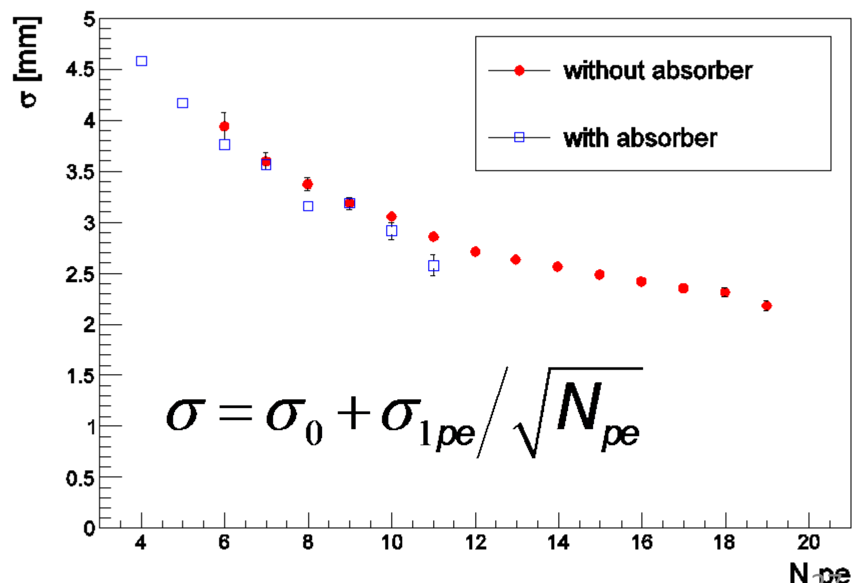
Direct light



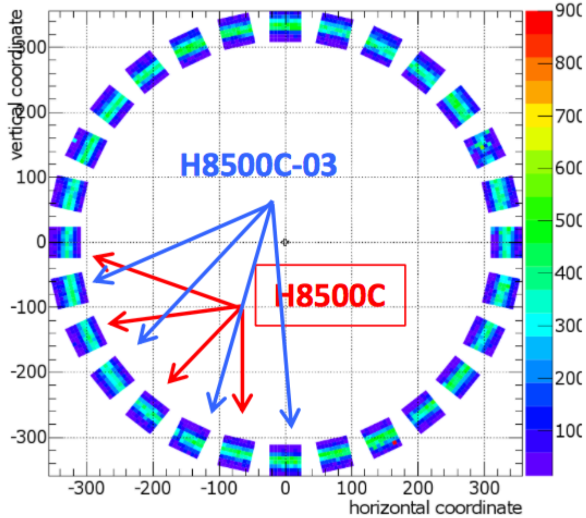


Reflected light



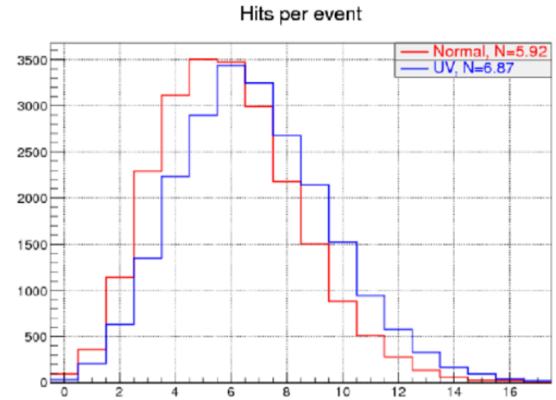


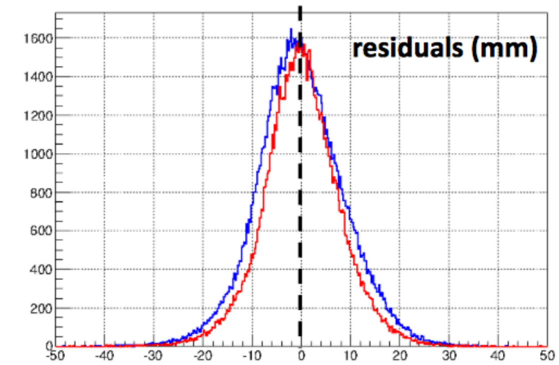
UV photons



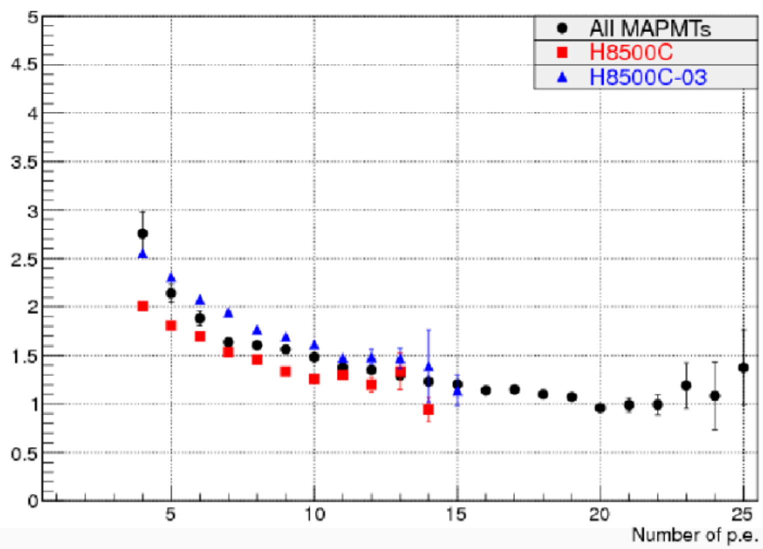
14+14 MAPMT with normal/UV glass in alternated positions

Compare ring reconstruction





Cerenkov Angle sigma (mrad)



Single photon resolution

	σ_{1pe} (mrad)
14 H8500C	3.96±0.16
14 H8500C-03	5.09±0.03
All 28	4.55±0.17

normal glass MAPMTs produce 1 photon less but 30% better resolution than UV glass MAPMTs

CLAS12 RICH Resolution

Requirements	Direct	Reflected
Max Momentum	8 GeV/c	6 GeV/c
σ_ϑ (4σ separation)	1.4 mrad	2.5 mrad
Np.e. Yield	≥ 10	≥ 3

Resolution	Direct (mrad)	Reflected (mrad)
Emission Point	1.7	1.7
Redout Accuracy	2.1	1.0
Chromatic Dispertion	3.0	2.5
Aerogel Optical Prop.	≤ 1	≤ 2
Mirror system		≤ 1
σ_ϑ (1p.e.)	4.2	3.9

$$\sigma_\theta = \sqrt{\frac{\sum_{\mathbf{i}} (\sigma_\theta^{\mathbf{i}})^{\mathbf{2}}}{\mathbf{N_{p.e.}}}}$$

Minimum required number of p.e.

Validated with prototype data

From Lab. studies

Similar single photon resolutions for the direct and reflected case

A factor of ~3 less yield in the reflected case but larger angular separation

➔ comparable π/K rejection power

Photon detection requirements

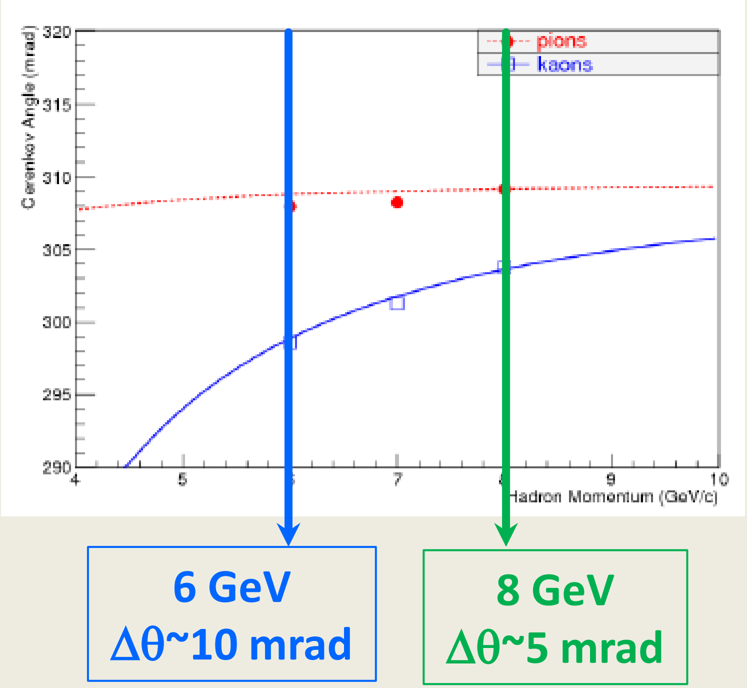
The RICH particle ID capabilities are determined by

- the number of detected photons: N_{pe}
- the angular resolution of each photon: σ_{1pe}

$$\sigma_\theta = \frac{\sigma_{1pe}}{\sqrt{N_{pe}}} \quad \text{vs} \quad \Delta\vartheta = \vartheta_C(\pi) - \vartheta_C(K)$$

→ more photons, better resolution

→ linear with the resolution, square root with N_{pe}



•Direct configuration: 8 GeV
Npe ≥10 Δθ~5 mrad

•Reflected configuration: 6 GeV
Npe≥3 Δθ~10 mrad

lower number of p.e. , larger separation

Same rejection power provided that

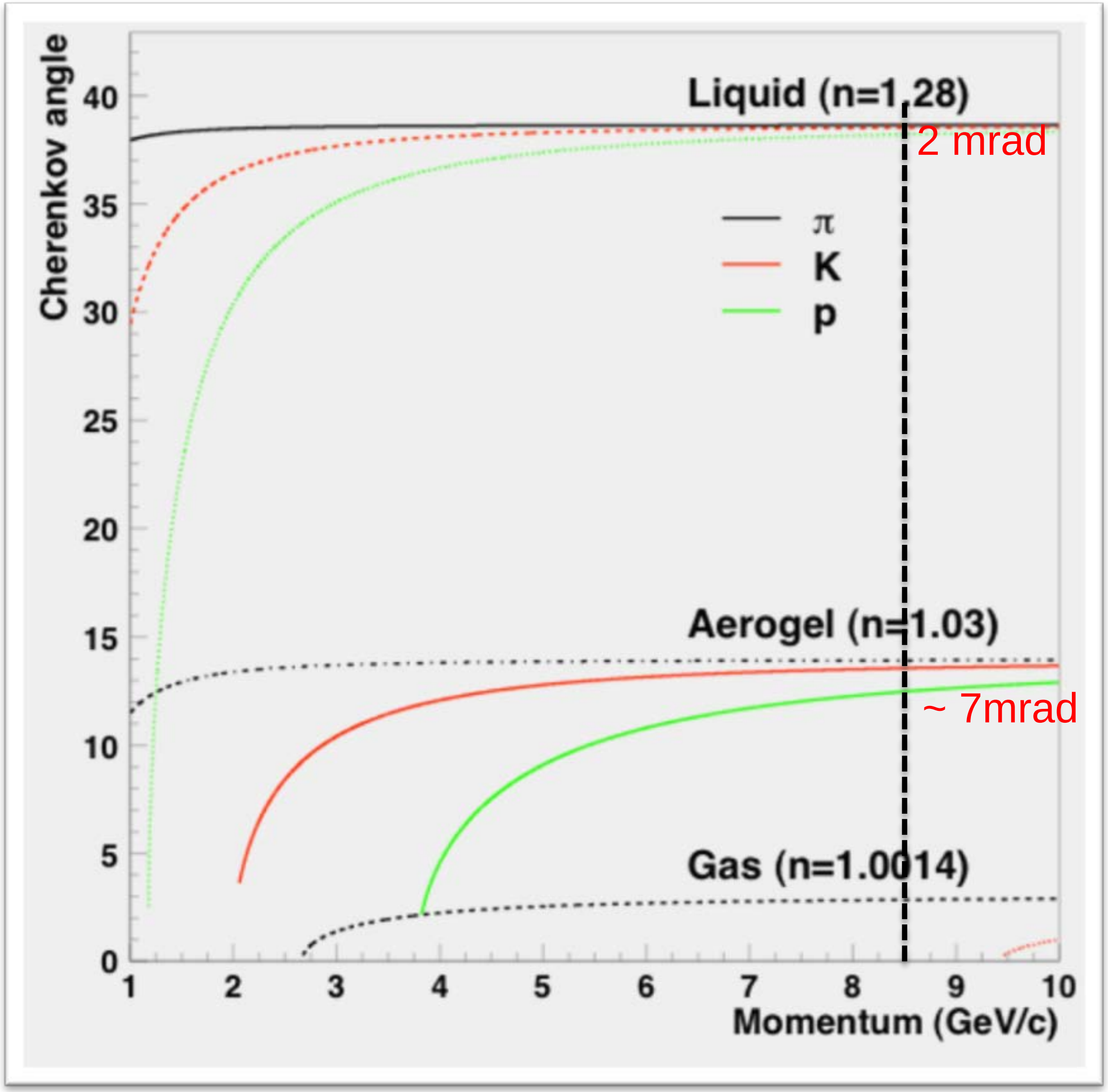
$$\sigma_{1pe}(dir) \approx \sigma_{1pe}(refl)$$

→Mirror system requirement:

σ_{tot} < 2 mrad

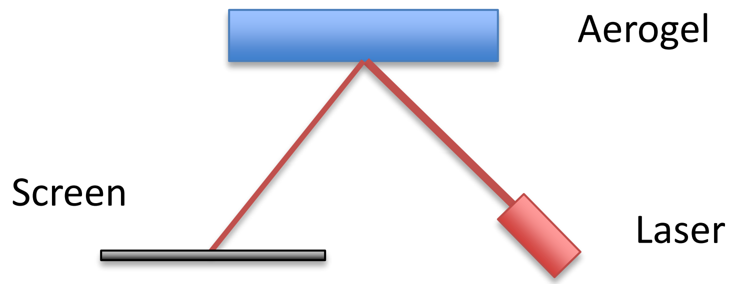
σ_m < 0.5 mrad

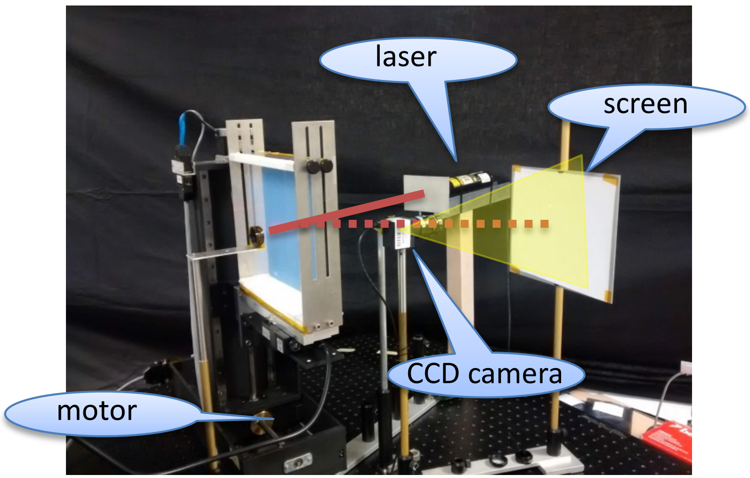
Radiator



- Aerogel mandatory to separate hadrons in the 2-8 GeV/c momentum range
- Solid, very light and transparent material consisting essentially of silica (SiO2)
- Very low density typically ~ 0.1-0.2 g/cm^3 → n (refr. index) close to unity
- Rayleigh scattering dominant cause of aerogel image degradation
- Rayleigh scattering increases as λ^{-4} → collection of visible Cherenkov light → PMT

Aerogel Surface Scan

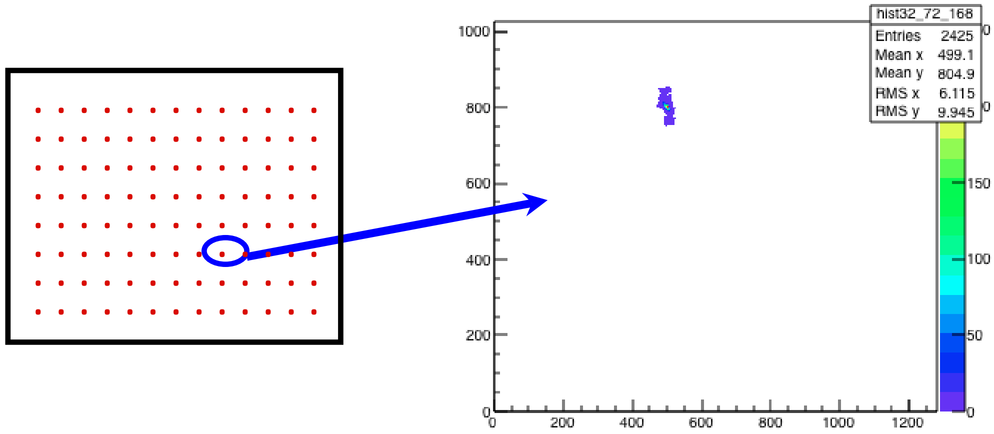




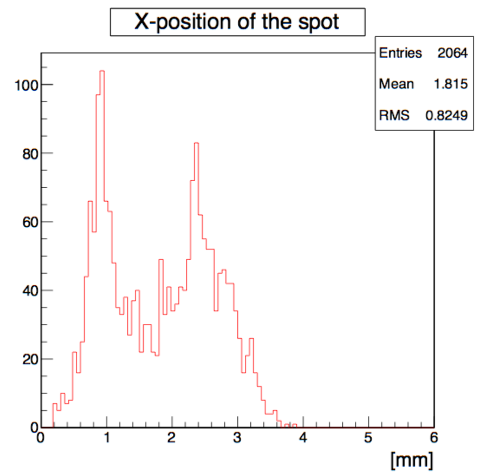
x-y axis movable table

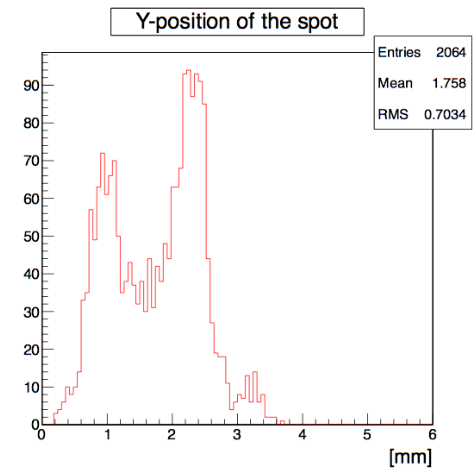
CCD camera [ThorLabs DCU 224c]
- sensitive area [5.95-4.76 mm]
- resolution [1280-1024 pixels]
- pixel size 4.65 μm

Scan of aerogel surface



Distributions of X & Y positions of the spot





Aerogel Surface Planarity

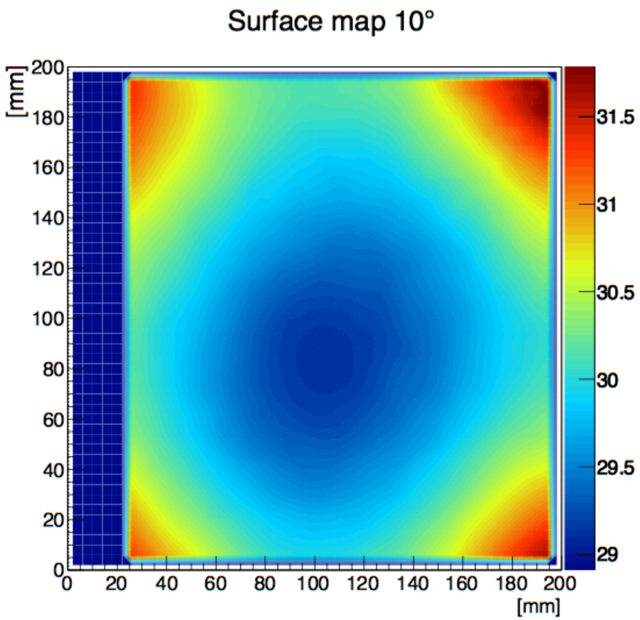
From laser spot shits to surface gradients

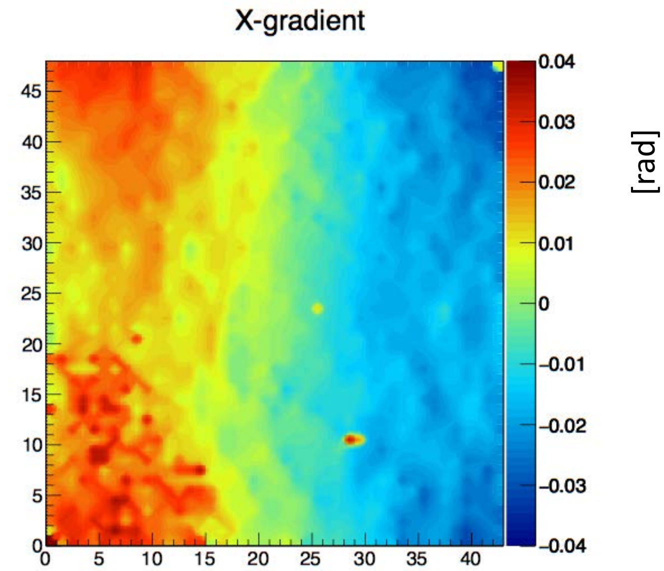
$$\nabla_x = \frac{(x - x_{mean})c_l}{2L}\cos(\theta)$$

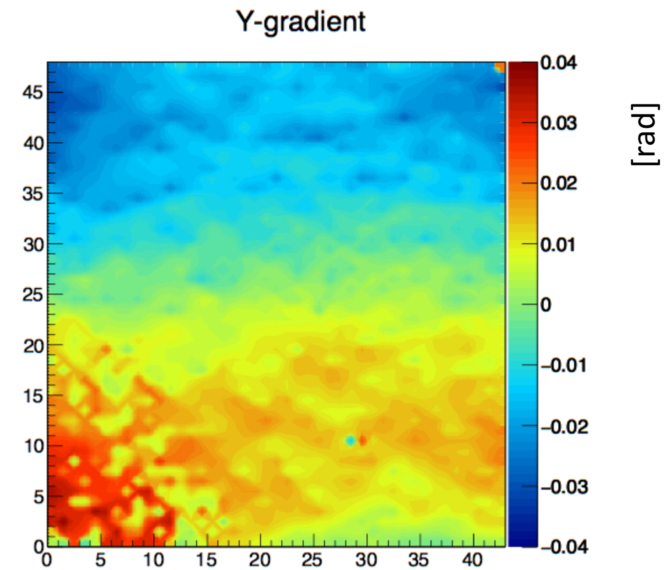
$$\nabla_y = \frac{(y - y_{mean})c_l}{2L}$$

$$L = R/cos(\theta)$$

From surface gradients to surface map by linear regression







Consistent with Russian vendor planarity evaluation

Validated with touch machine measurements

Mirror reflectivity

Higher reflectivity → more photons

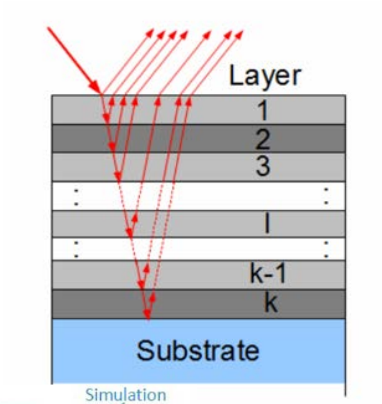
Surface roughness: is measured at the nm scale

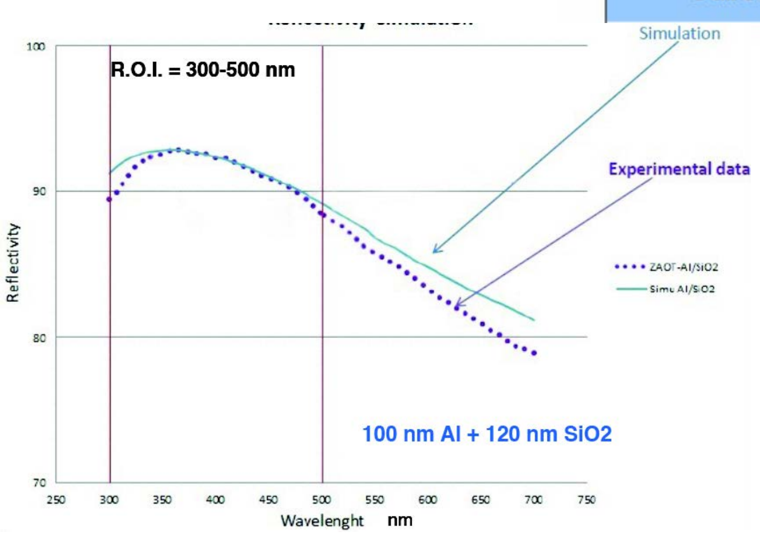
$$R \propto \exp\left[-\left(\frac{4\pi\sigma_r \cos\vartheta_i}{\lambda}\right)^2\right]$$

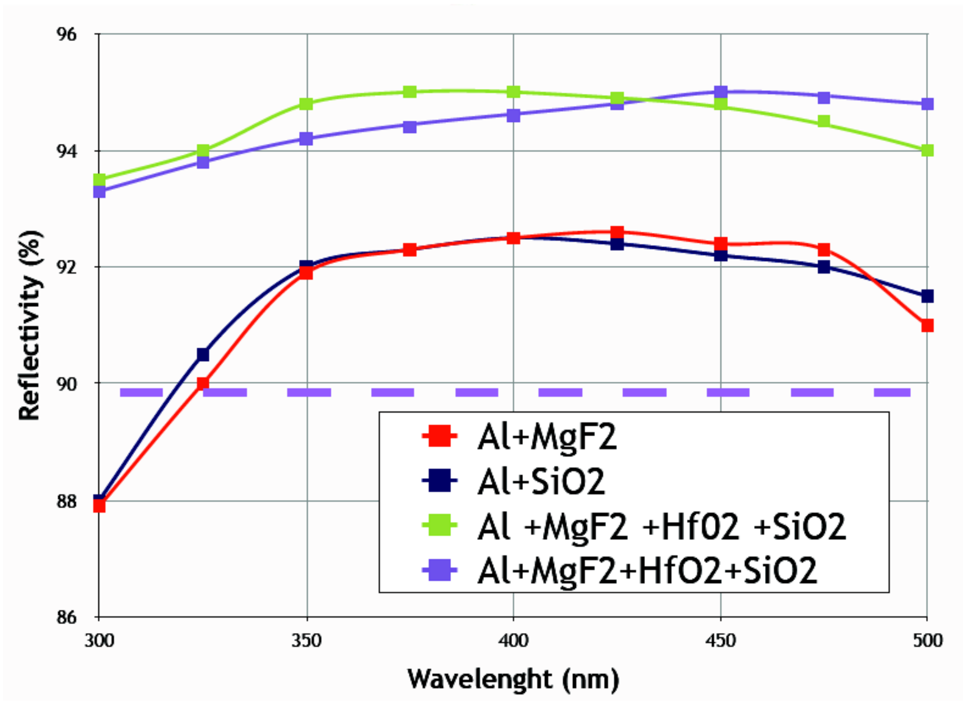
To have R>0.99 at λ=400 nm (aerogel)
σ_r <3 nm

Coating material

Simulation of the propagation of the em field across the layers

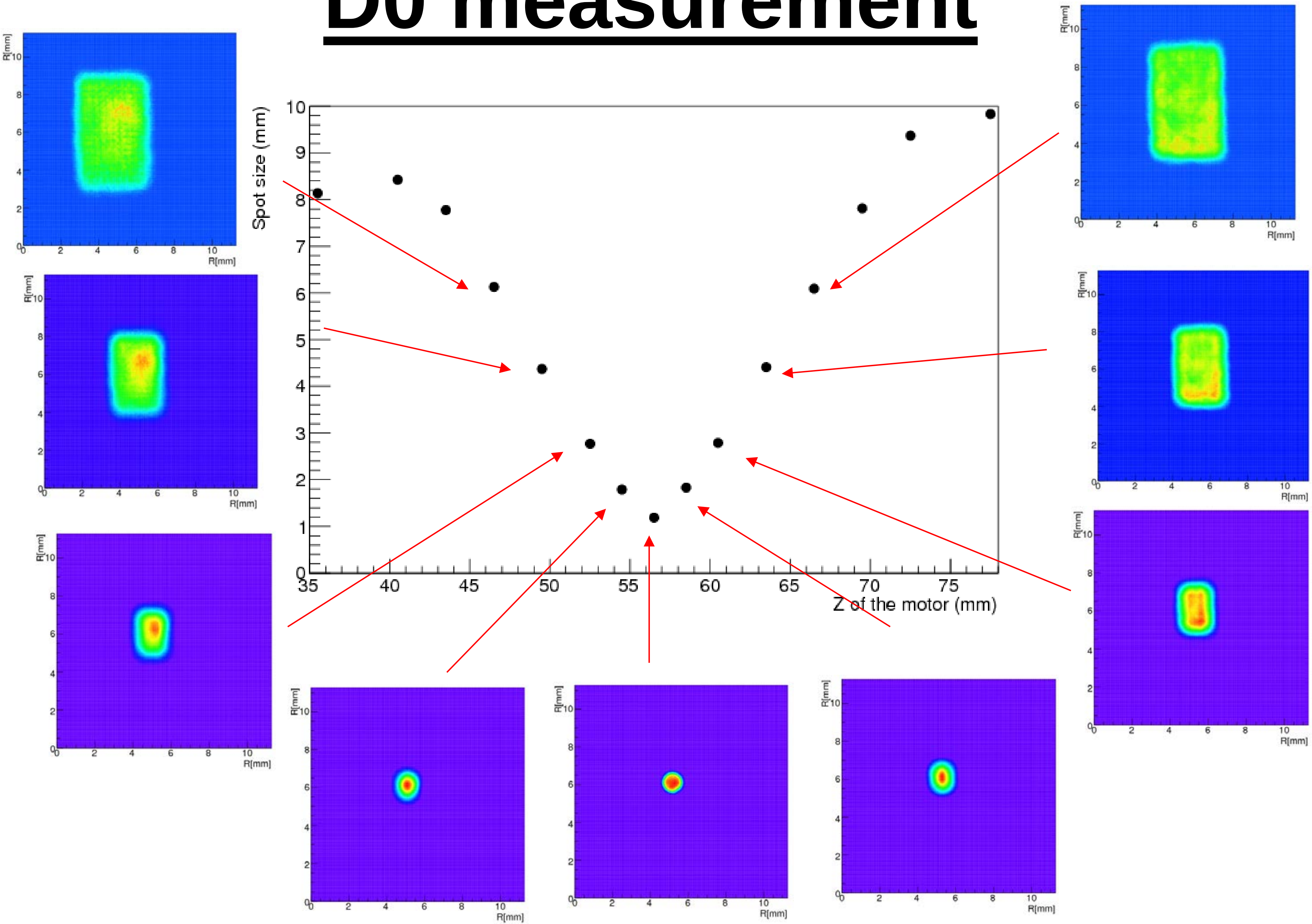




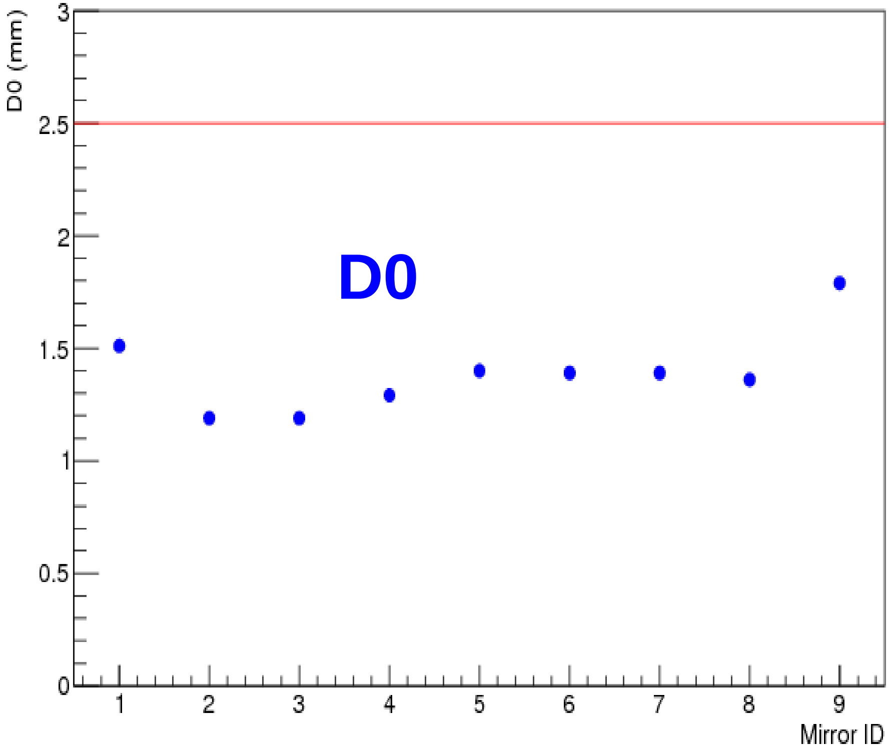


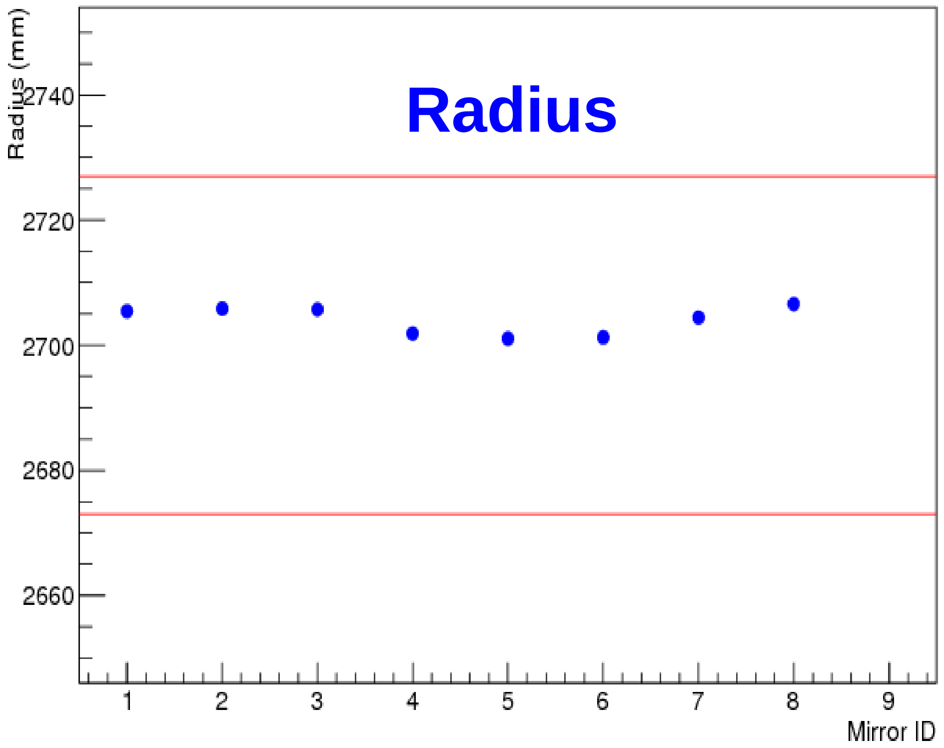
Good coating process usually preserves the roughness of the substrate

D0 measurement



Mirror Results

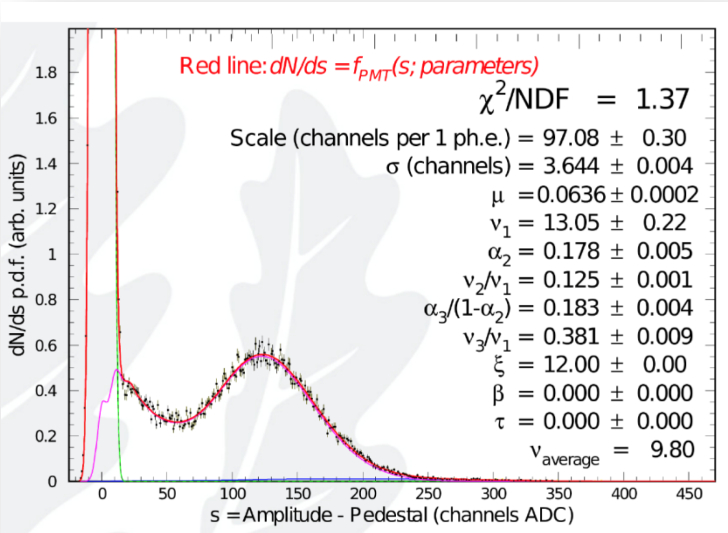


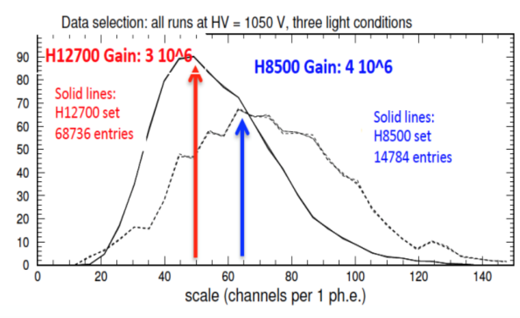


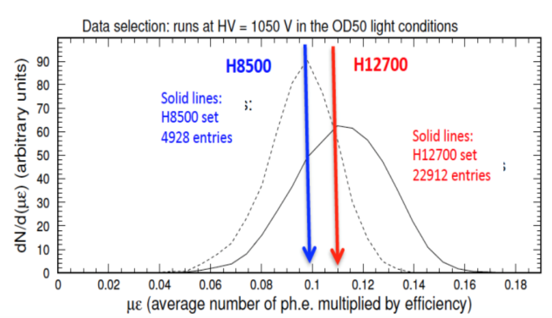
All the 10 mirrors well within the specifications

Photodetectors

Photomultipliers only available option for visible light detection







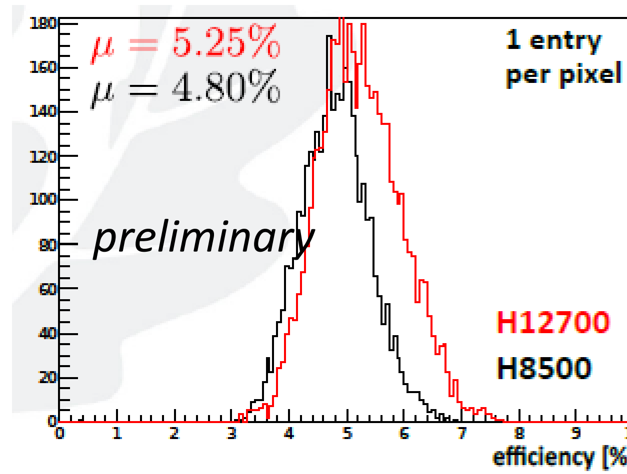
On average, H12700 has superior s.p.e. response

- better efficiency
- improved resolution

But also less uniform response due to the dynode structure

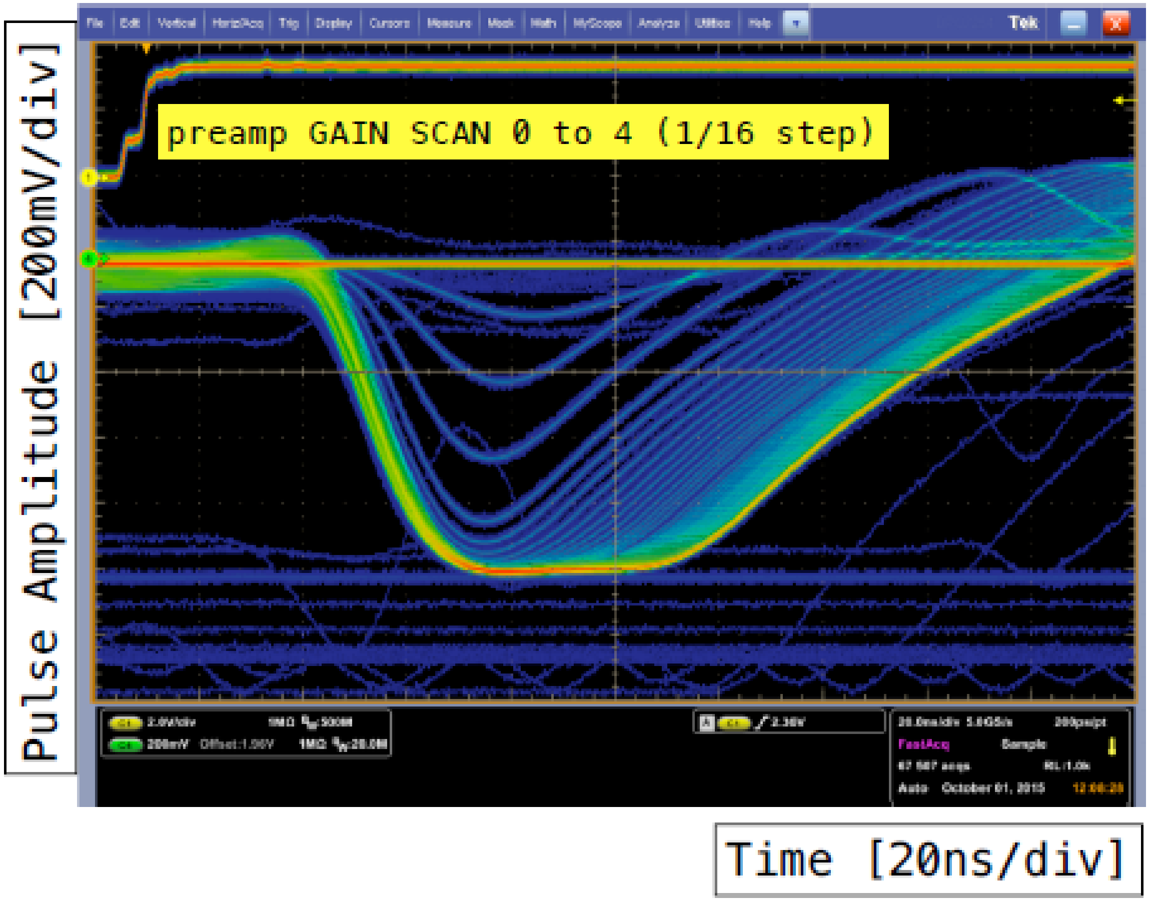
Global efficiency

$$\mu = \frac{N_{5\sigma}}{N_0}$$



RICH assembly completed

Gain Scan

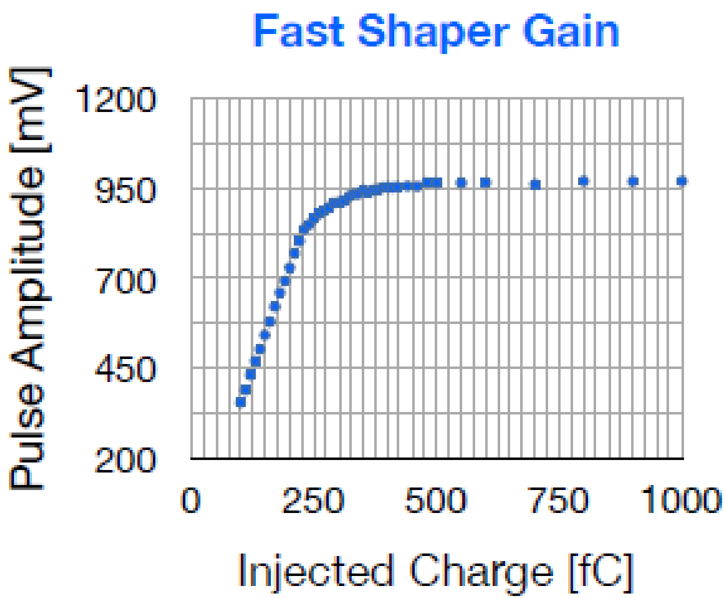


Single channel fast shaper response,

High gain shaper precedes the discriminator

3.75 Volt/pC in the linear region

20-25 ns rise time

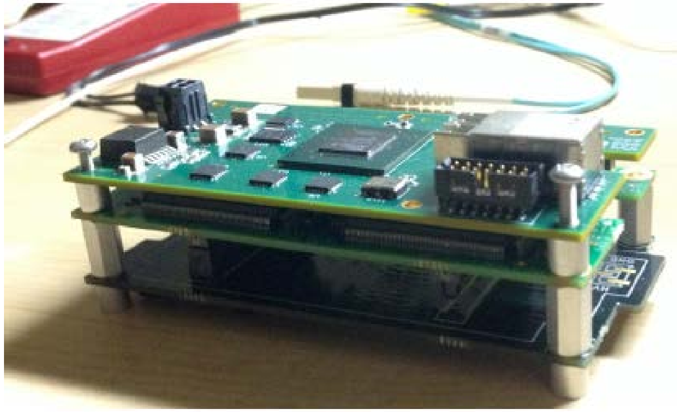


FE electronic lab tests

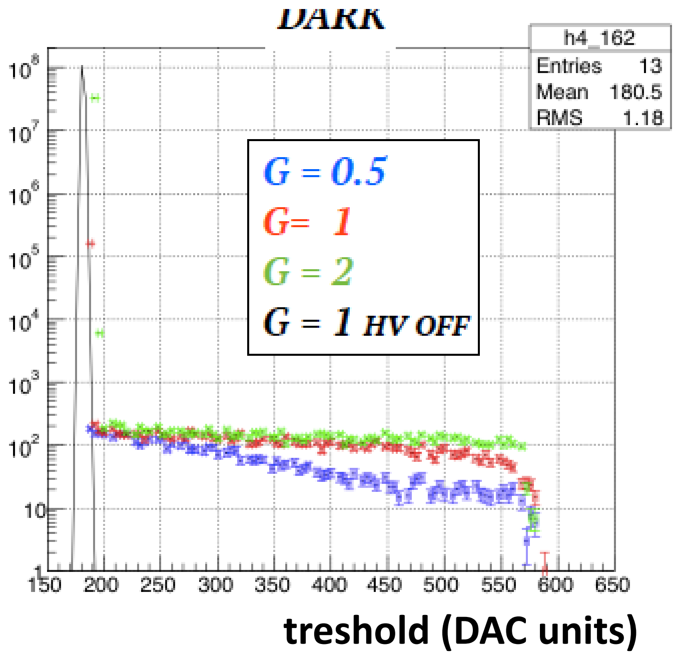
Test of the FE tile response to:

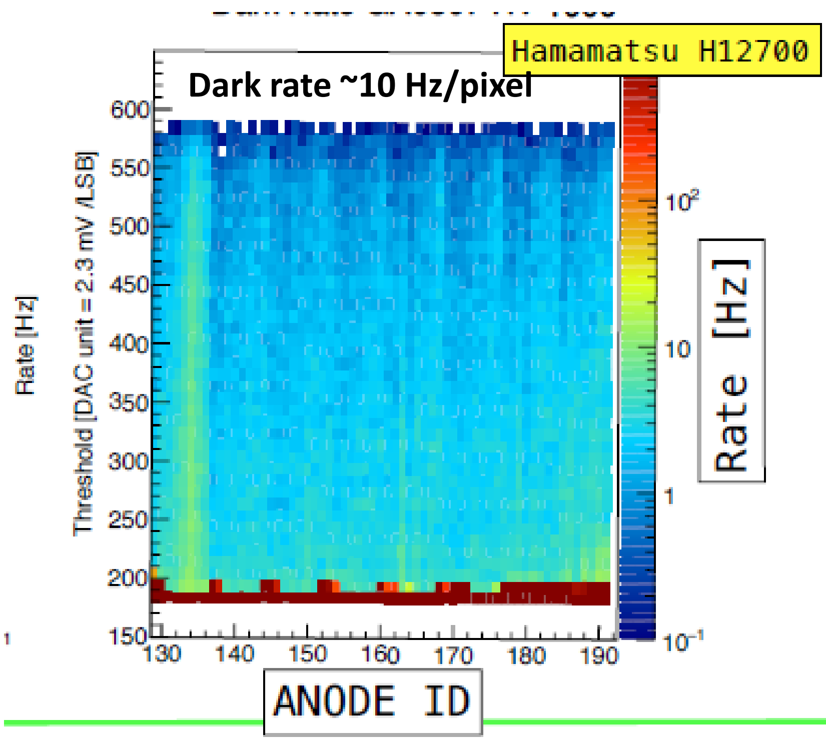
- **external and onboard programmable injector**
- **MAPMT dark noise**
- **laser in s.p.e. regime**

Study the count rate as a function of the threshold



Dark noise
Counts in 30 s





- Large region of uniform response for G≥1: possibility to compensate pixel non-homogeneity
- Small slope vs threshold : easy working point
- Measured dark rate compatible with Hamamatsu specifications

Simulations

All the relevant RICH volumes are imported in GEANT from CAD