The new large-area hybrid-optics RICH detector for the CLAS12

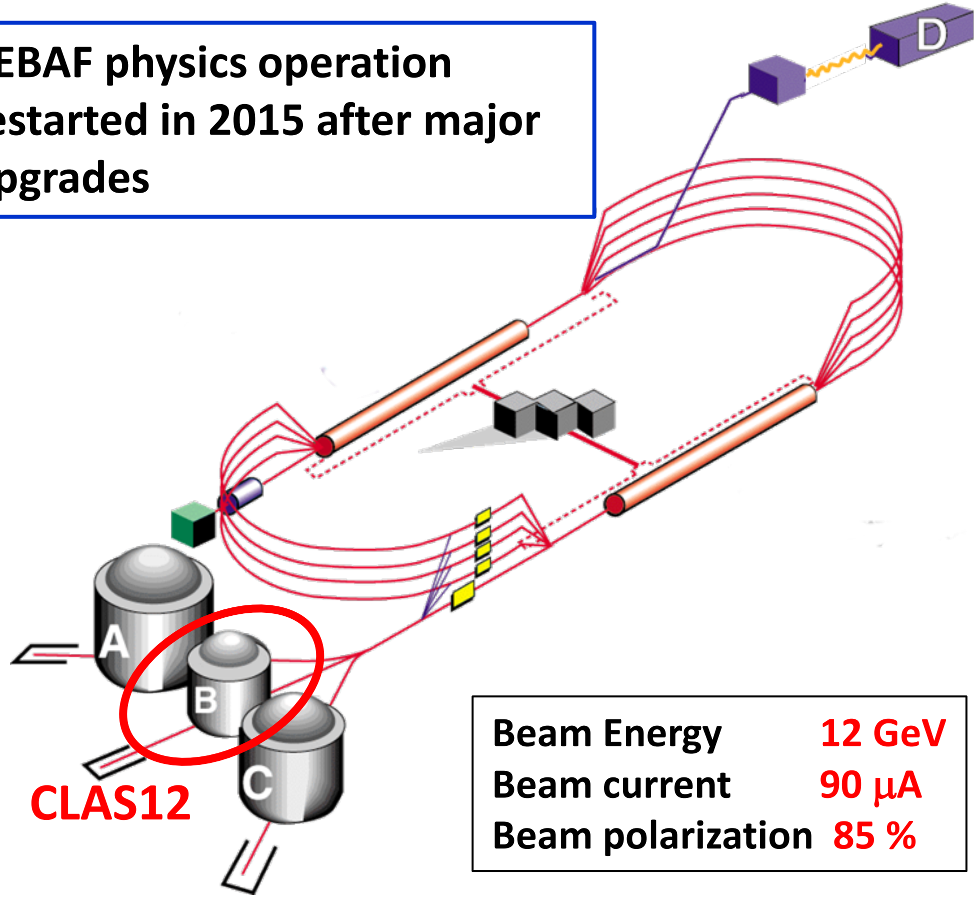
Marco Mirazita

INFN – Laboratori Nazionali di Frascati

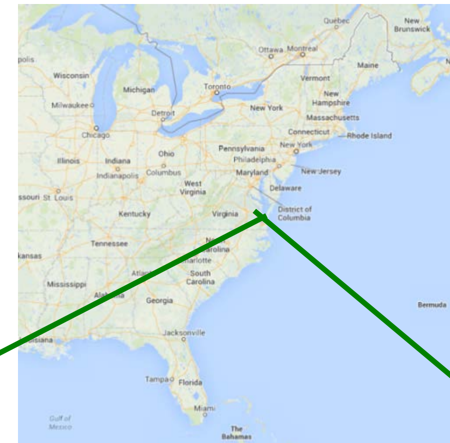
9th International Workshop on Ring Imaging Cherenkov Detectors – 5-9 September 2016 Bled (Slovenia)

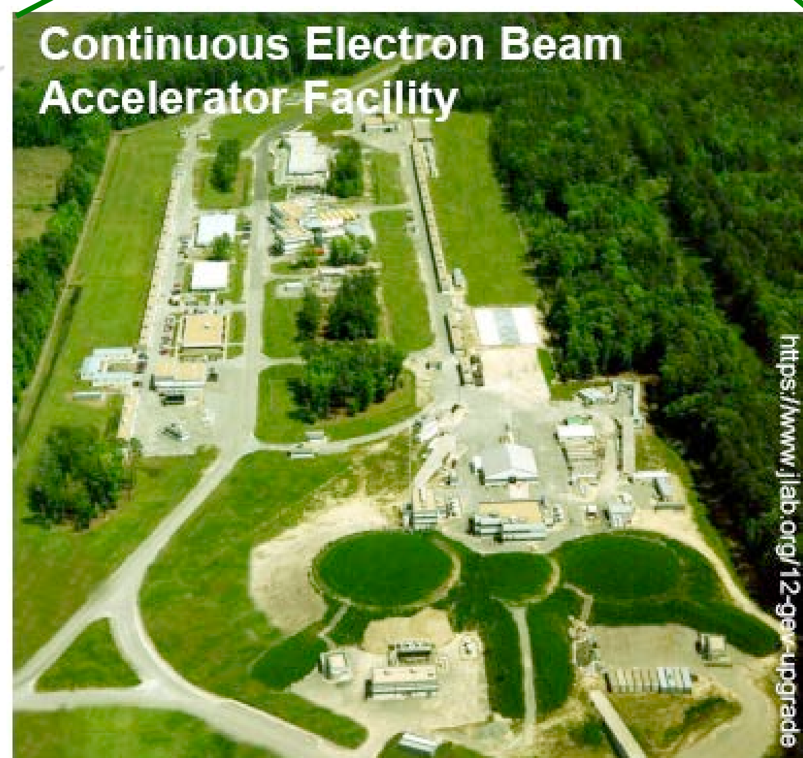
Jefferson Laboratory

CEBAF physics operation restarted in 2015 after major upgrades



Beam Energy	**12 GeV**
Beam current	**90 μA**
Beam polarization	**85 %**





4 Experimental Halls

- **Nucleon structure & Nuclear effects**
- **Hybrid mesons (gluonic excitations)**
- **Low-energy tests of SM**
- **Heavy photon search**

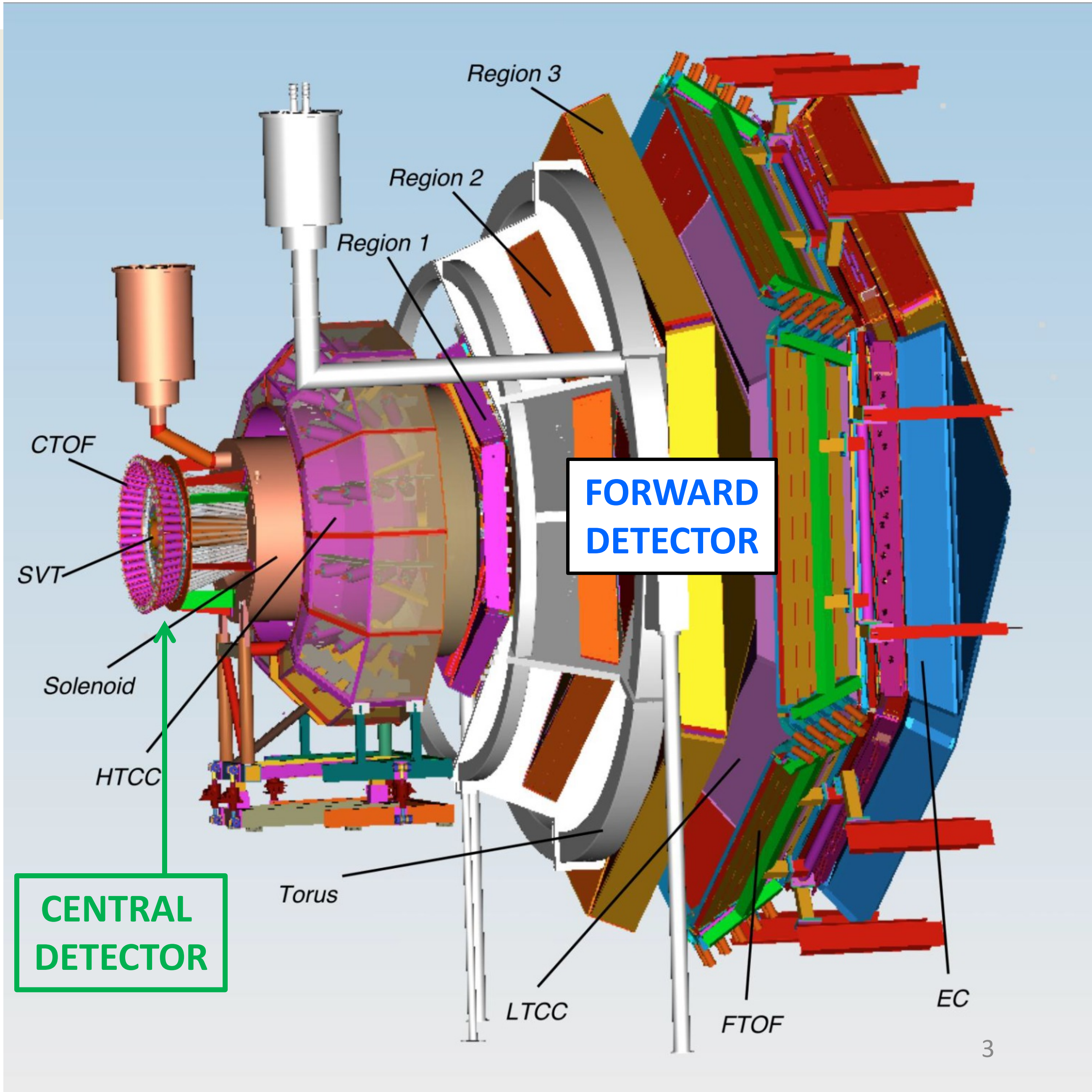
The CLAS12 spectrometer

- Luminosity up to 10^{35} cm^{-2} s^{-1}
- High polarization electron beam
- H and D polarized targets
- Wide acceptance

CLAS12
Baseline configuration

CENTRAL DETECTOR
- solenoidal field
- vertex tracker
- time-of-flight

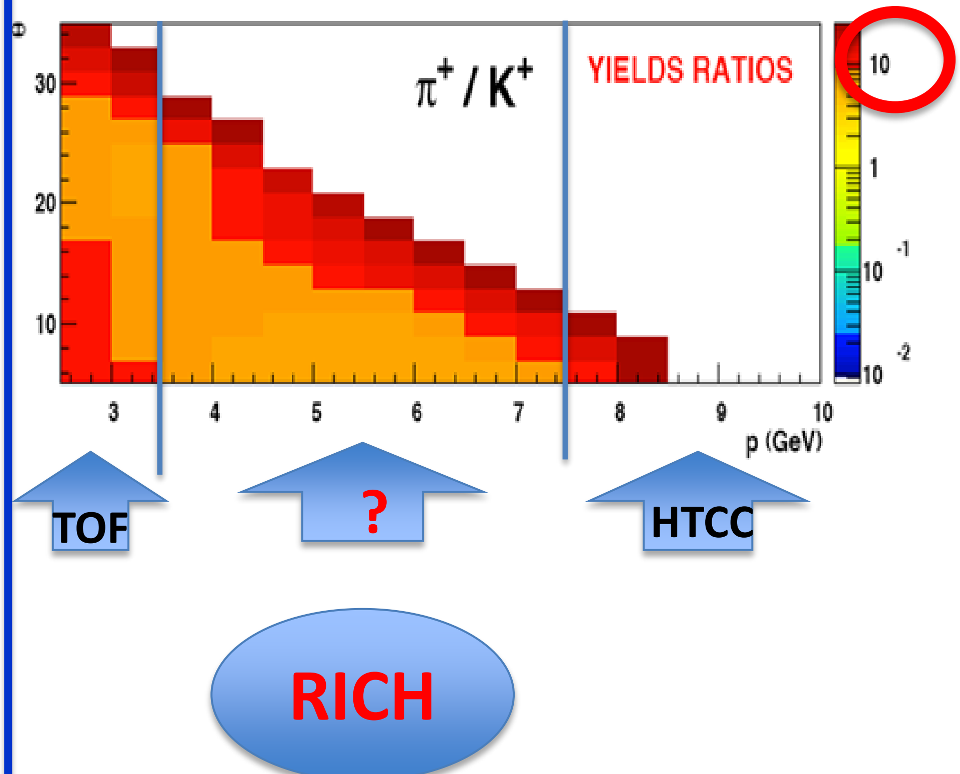
FORWARD DETECTOR
- toroidal field
- 6 sector geometry
- three regions of drift chambers
- time-of-flight
- two threshold Cherenkov counters
- preshower and EM calorimeter



PID in CLAS12

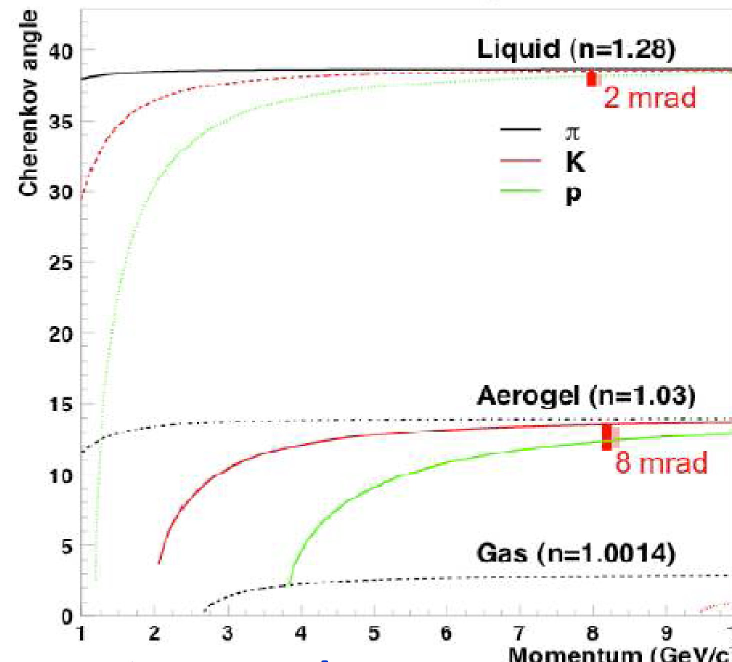
A broad program of measurements with kaons in the final state has already been approved: flavor separation in SIDIS, GPD studies in hard exclusive meson production, exotic hybrid meson spectroscopy

CLAS12 Kaon ID, base configuration



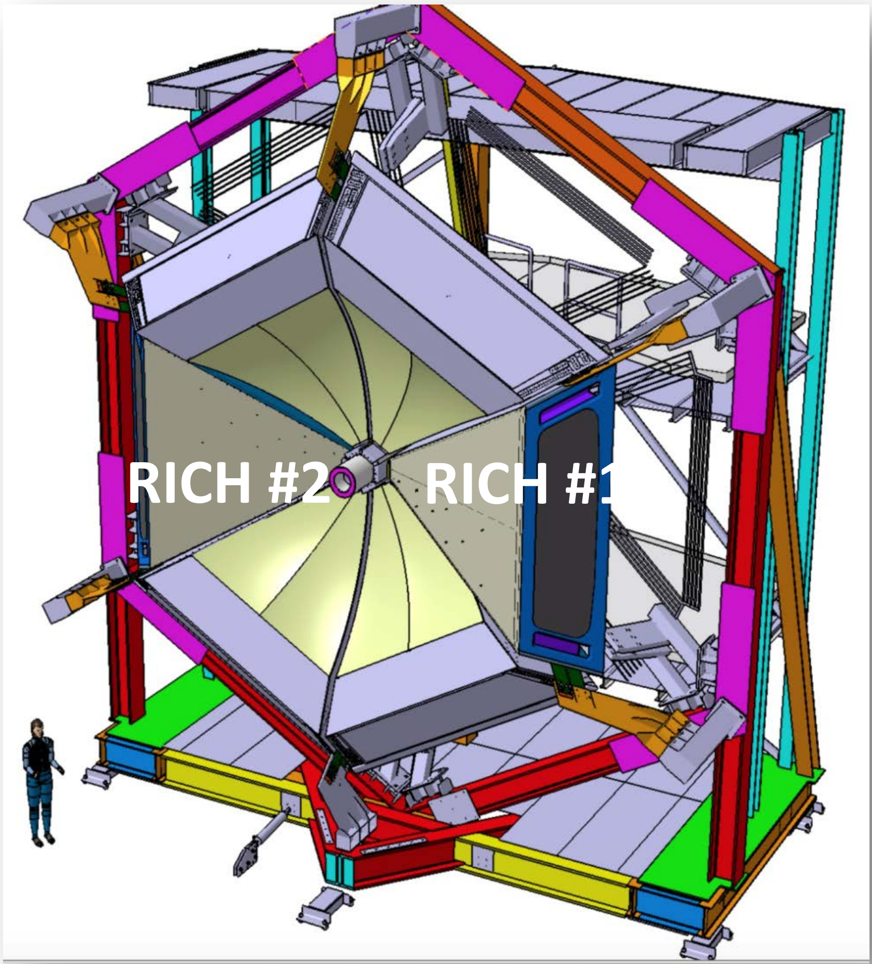
RICH goal

π/K and p/K separation at $>4\,\sigma$ level in the few GeV/c region



→ aerogel
→ visible light
→ PMT

The RICH in CLAS12



The RICH will replace the existing Low Threshold Cherenkov detectors

- first sector for the beginning of the CLAS12 operation (October 2017)
- second sector for operation with transverse target

Challenging project because of the geometry of the detector

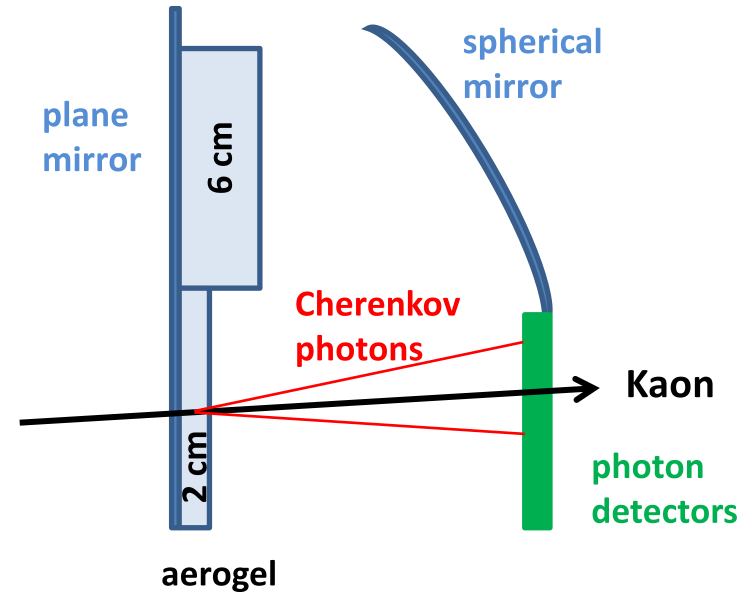
- large size
- no free space out of the acceptance

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

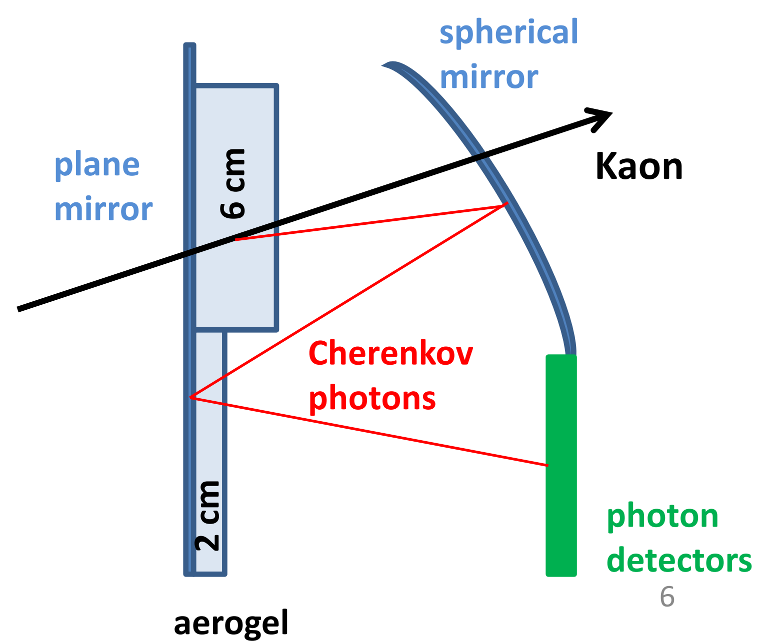
The RICH concept

Hybrid solution:
proximity gap and mirror focusing

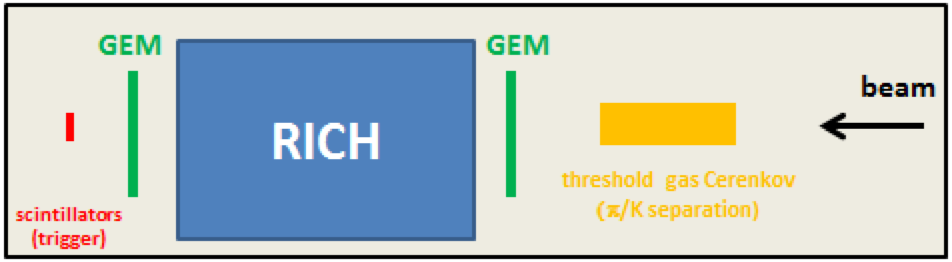
- **Small polar angle, up to 8 GeV/c**
  - **1m gap**
  - **thin aerogel**
  - **direct imaging of the Cherenkov photons**

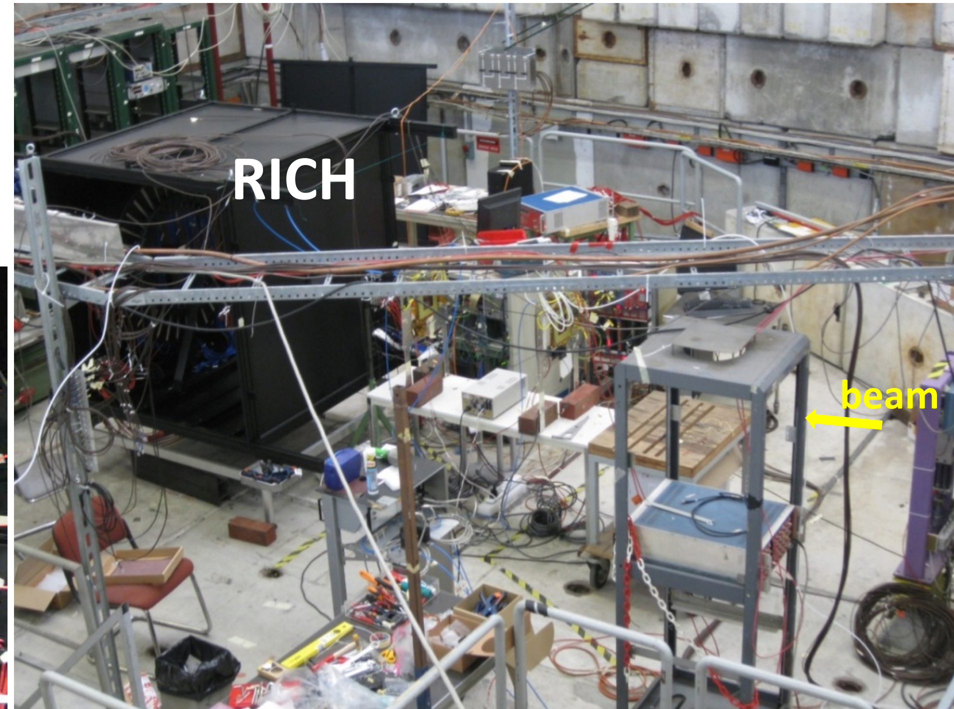


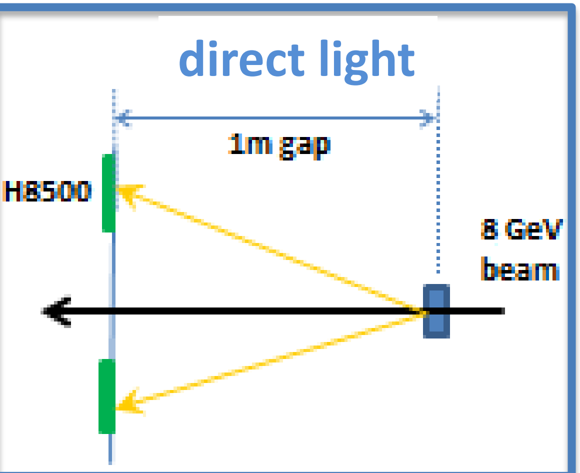
- **Large polar angle, up to 6 GeV/c**
  - **about 3m path length**
  - **multiple passage of Cherenkov photons in aerogel**
  - **thick aerogel radiator (2x3cm) to compensate photon loss**
  - **mirror system to reduce the instrumented area**

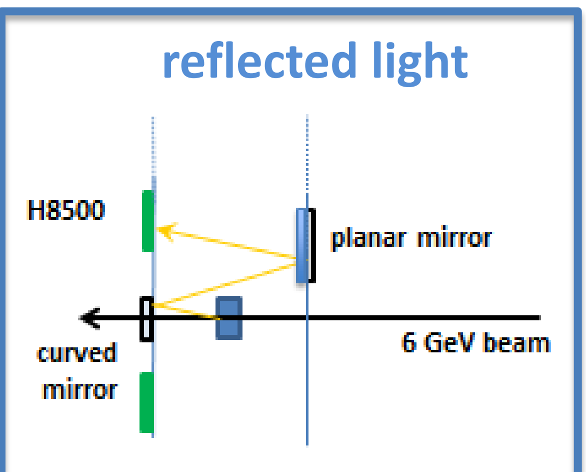


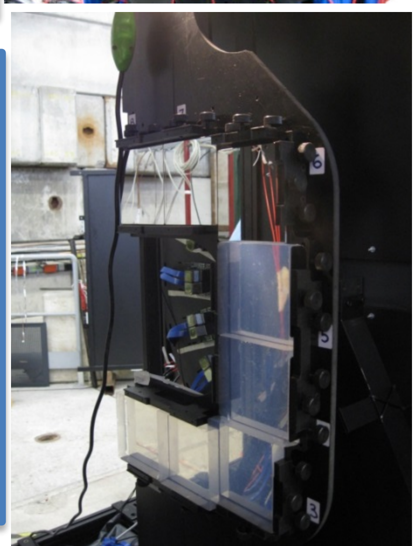
RICH prototype studies at CERN

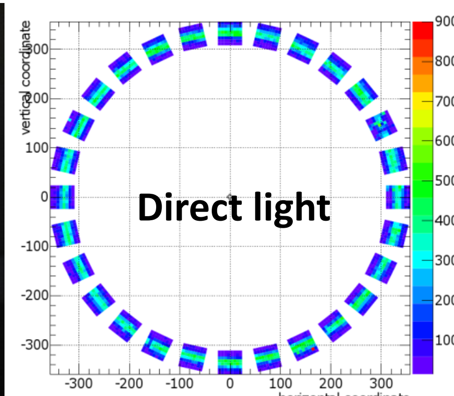


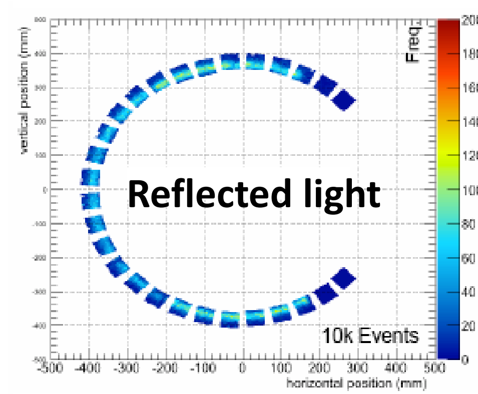






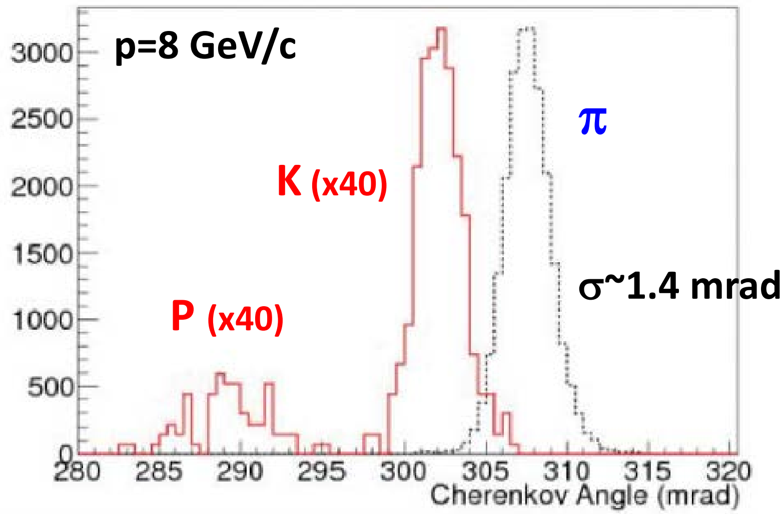


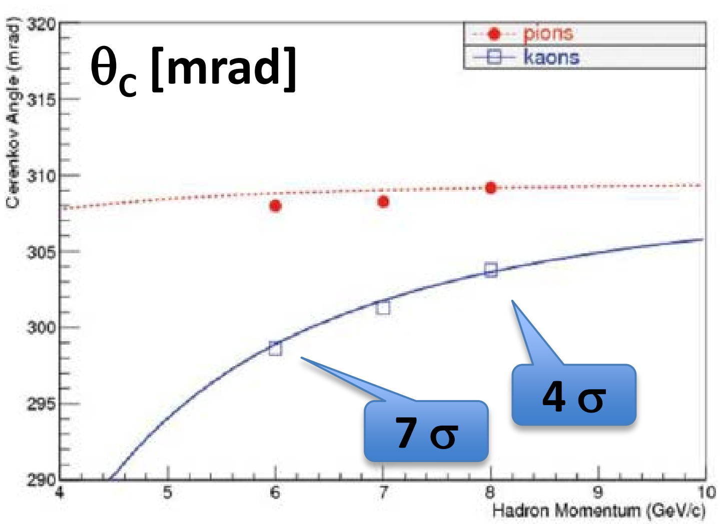




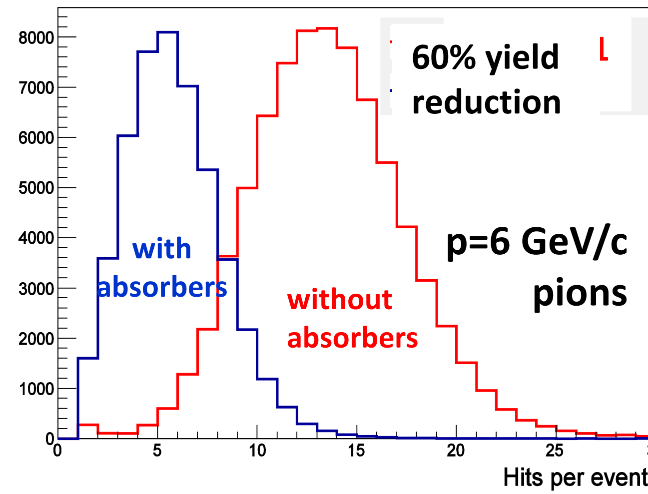
RICH prototype results

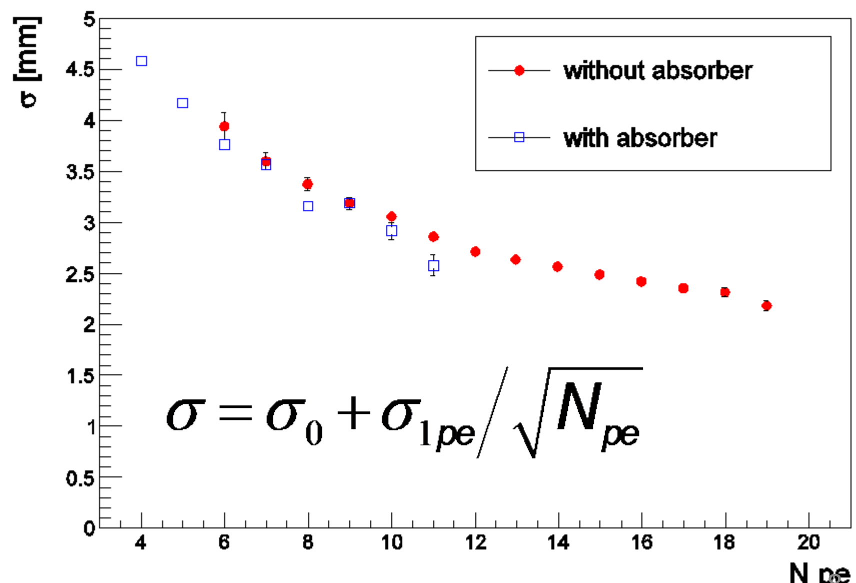
Direct light





Reflected light

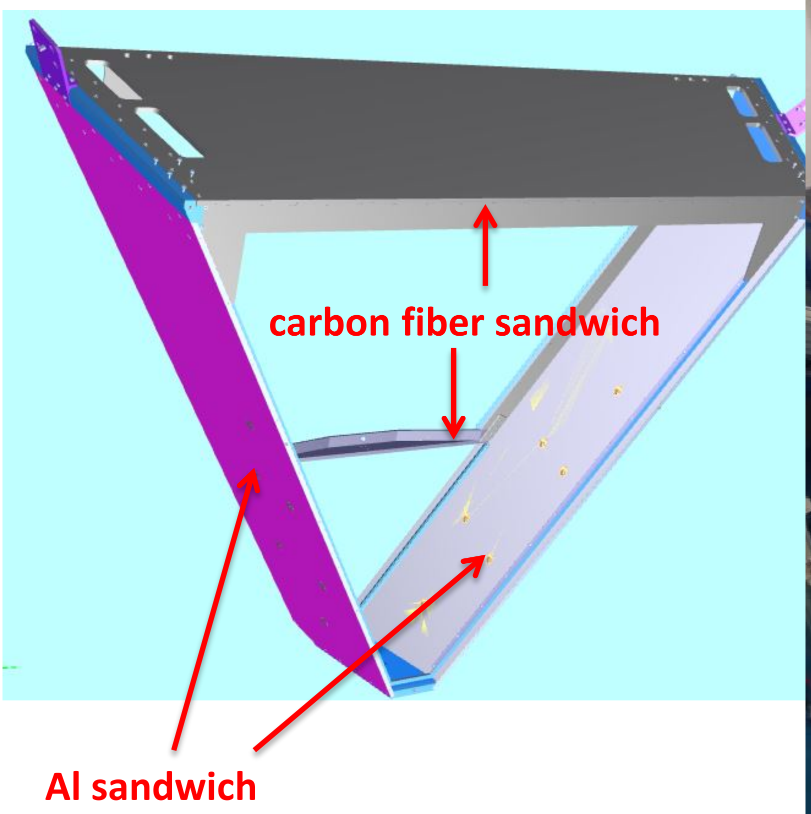


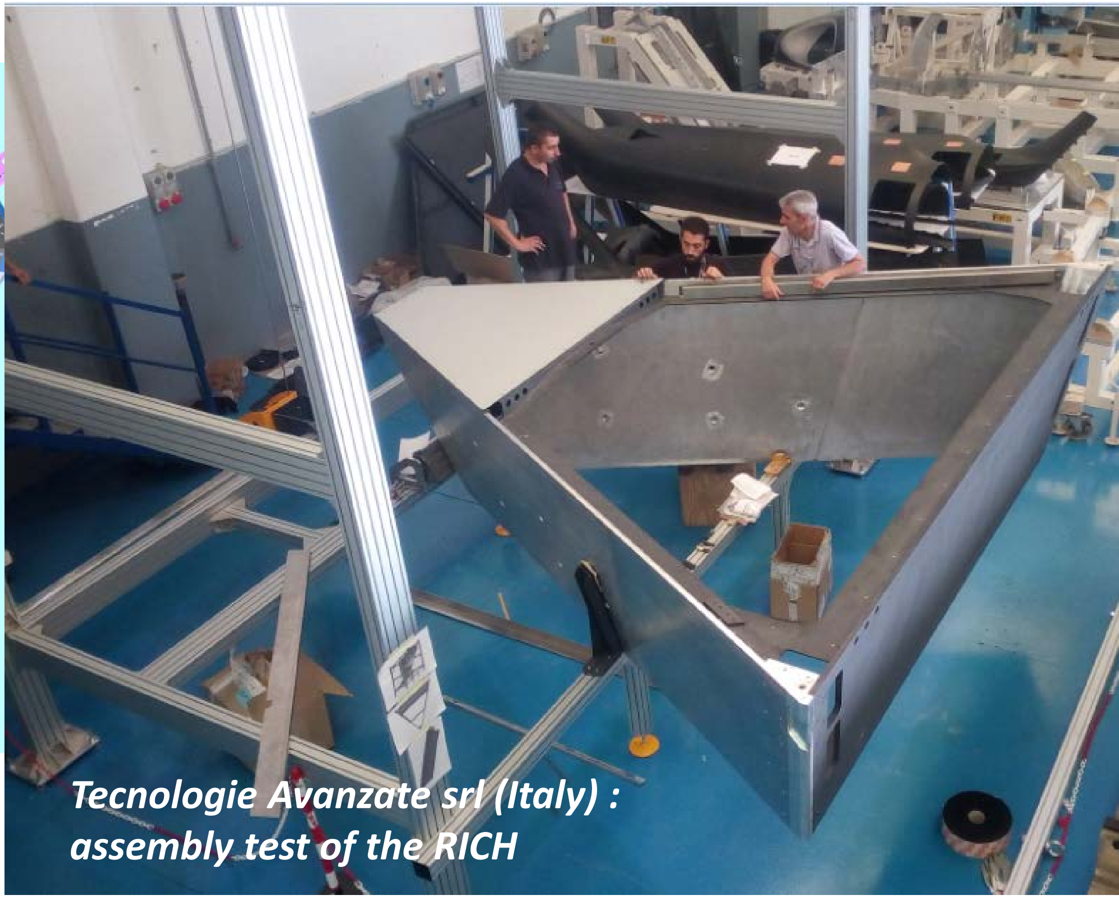


The CLAS12 RICH - 1

The RICH mechanical structure is made by elements in Al and Carbon Fiber

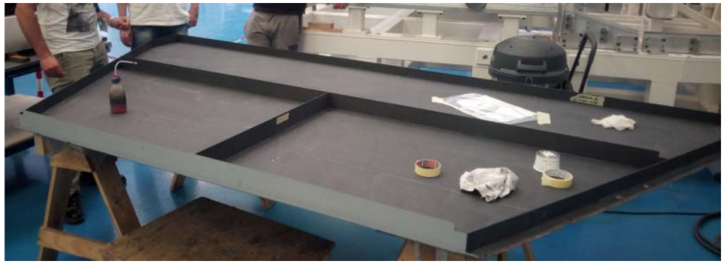
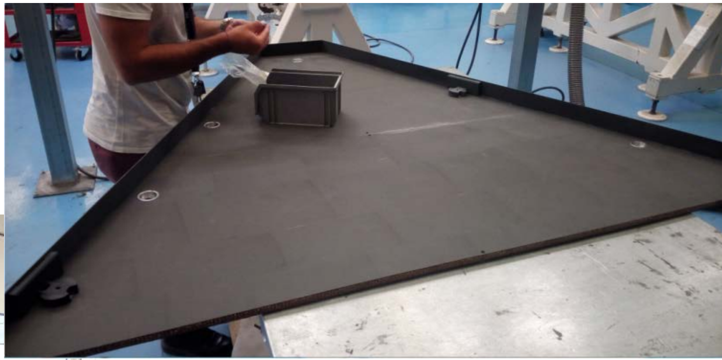
- **The large panels (up to ~4 m) have a sandwich structure of 2 thin skins and a honeycomb core**
  - **derived from aeronautic technology**
  - **high rigidity with low material**
  - **total weight ~600 kg (a factor of 2 less than the existing LTCC)**

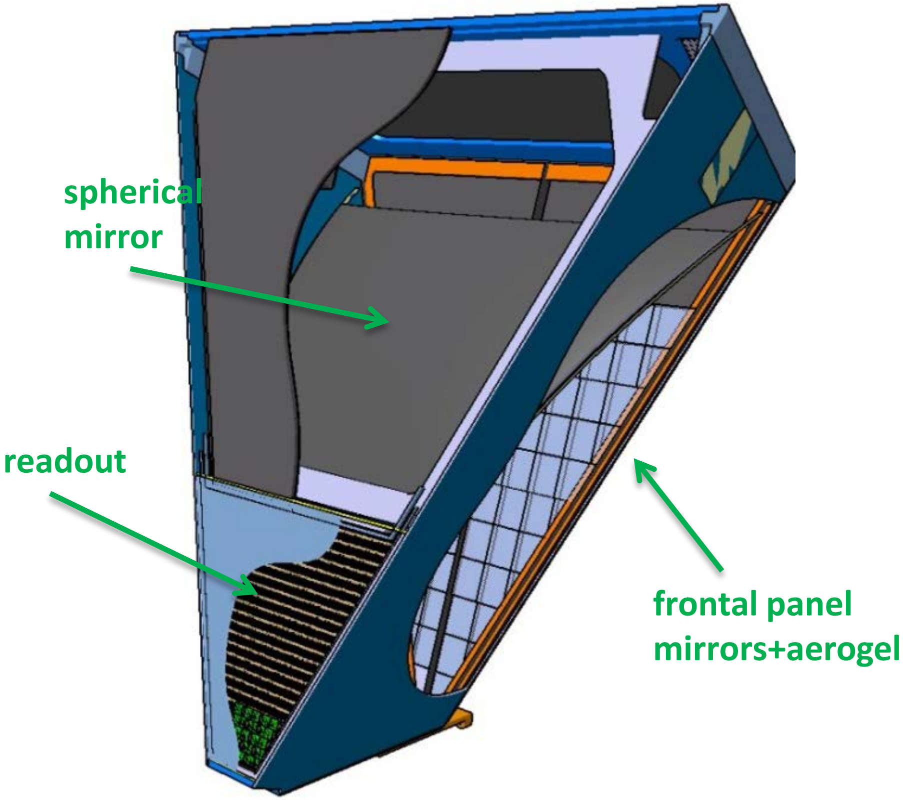




The CLAS12 RICH

- Closing panels inside the acceptance are in carbon fiber to reduce the material budget
- They are also supporting the RICH active elements
  - Frontal panels holding the aerogel and planar mirrors
  - Electronic panel holding the MAPTMs and the FE boards

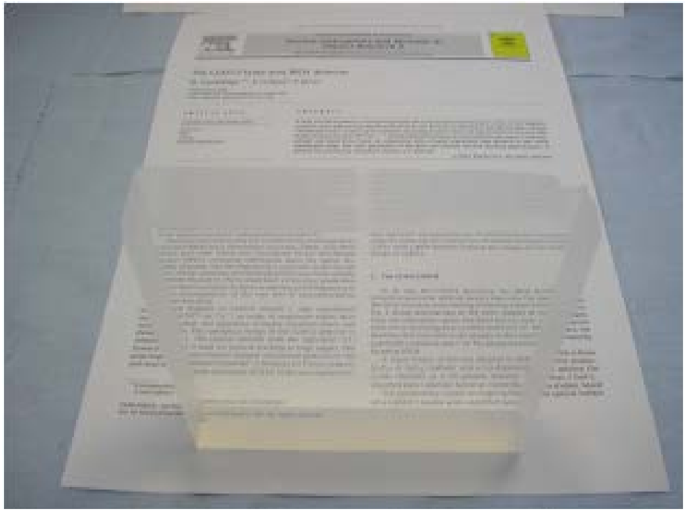


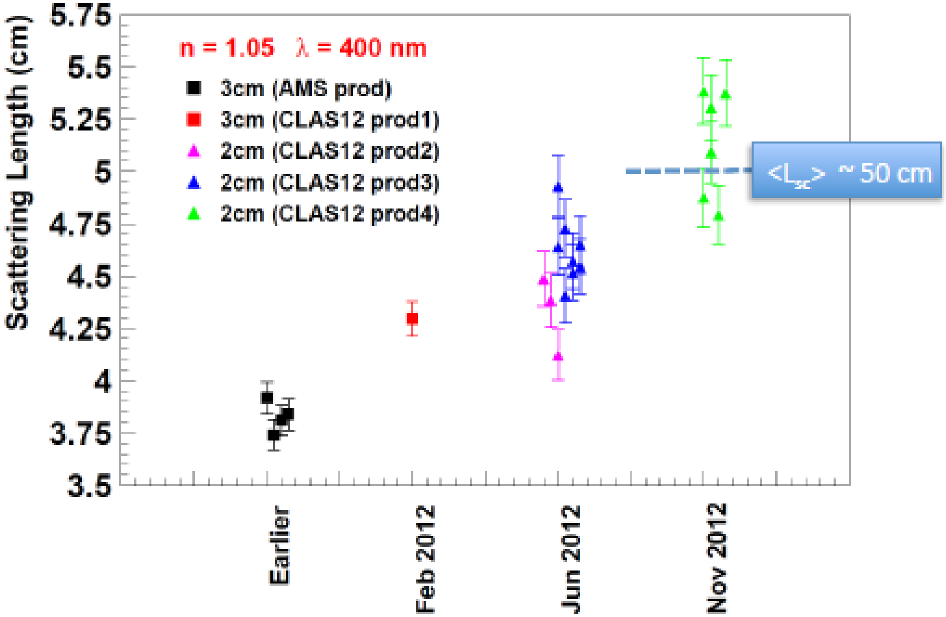
Tecnologie Avanzate srl (Italy) : carbon fiber panels of the RICH

Aerogel

Aerogel with n=1.05 in collaboration with Budker and Boreskov Institutes of Novosibirsk (Russia)

- flexible geometry: large tiles (20x20 cm^2) with variable thickness
- mass production capability
- optical quality continuously improved during the R&D phase of the project





A detailed protocol of optical and mechanical characterization measurements has been set up to ensure the quality of the production

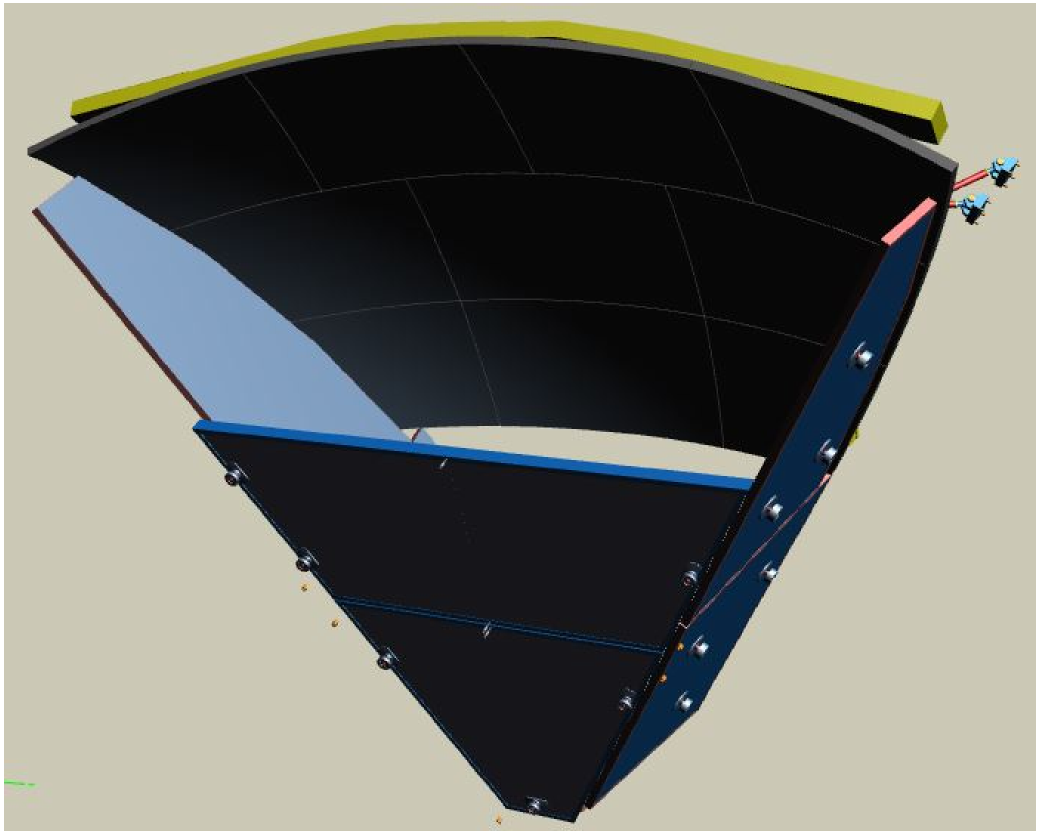
→ talks by M. Contalbrigo. E Kravchenko

Tests of 40% of the production (~50 tiles) have been completed with L_{scatt}>43 mm and A_0>0.95

The RICH mirror system

The system must:

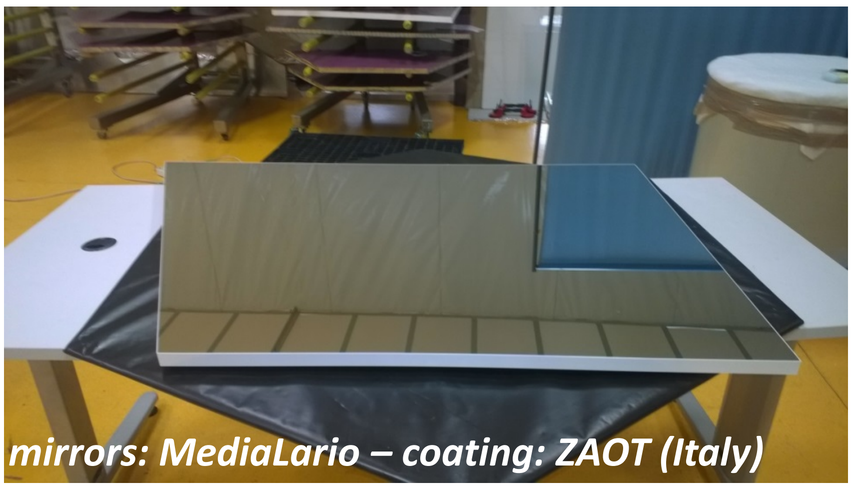
- contain all the Cerenkov photons inside the RICH volume
- direct them toward the MAPMT
- be light
- have high reflectivity
- have angular precision better than ~1 mrad



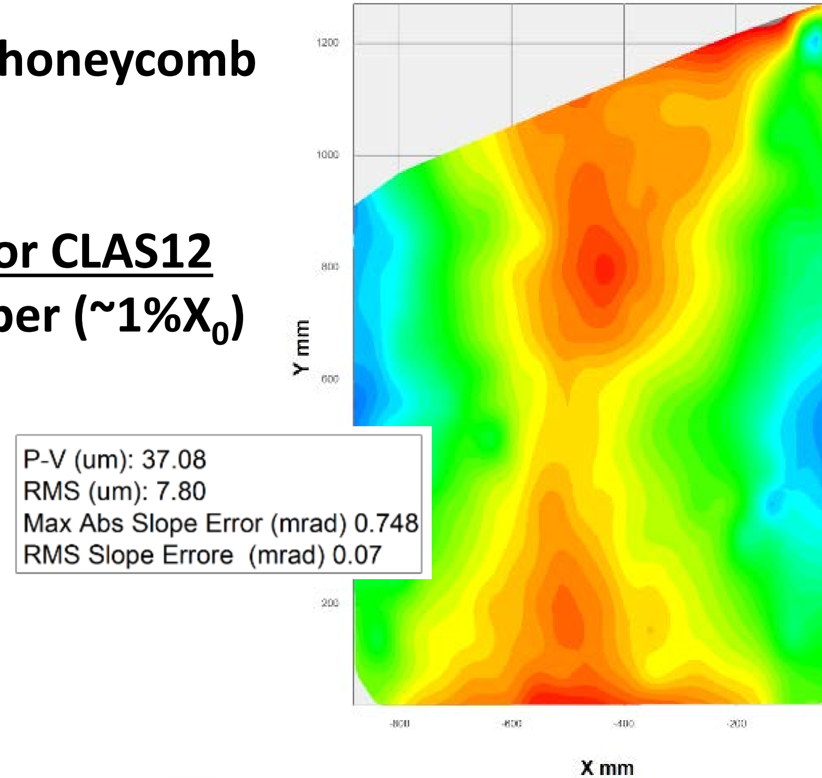
- Ten spherical mirror
  - total surface ~3.6 m^2
  - carbon fiber
  - production completed
- Four lateral and one bottom planar mirrors
  - total surface ~3.7 m^2
  - glass
  - 2 mirrors produced, others in production
- Four frontal planar mirror
  - total surface ~3 m^2
  - glass
  - they hold the aerogel tiles
  - in production

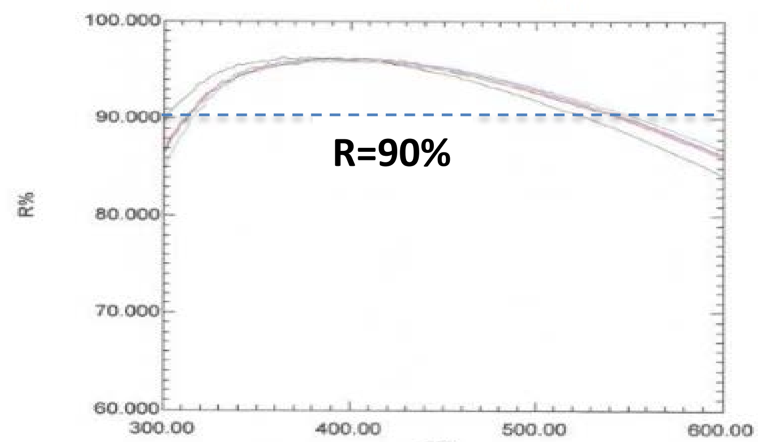
Planar Mirrors

- ➢ Sandwich of two thin layers of glass with Al honeycomb core: technology used in telescopes
  - 2x1.6 mm lateral and bottom: standard
  - 2x0.7 mm frontal: <u>specifically developed for CLAS12</u>
- ➢ Radiation length comparable with carbon fiber (~1%X_0)
- ➢ Much lower costs



mirrors: MediaLario – coating: ZAOT (Italy)

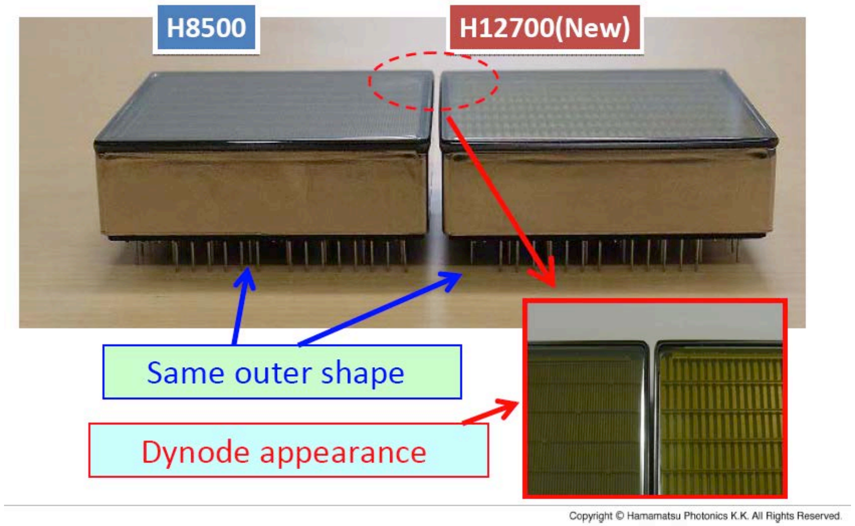




- ➢ Reflectivity above 90% in almost all the range 300-600 nm and around 95% peak
- ➢ Planarity of the surface <30 μm (RMS)
  - → expected contribution to the angular resolution <0.1 mrad

Photodetectors

Photomultipliers only available option for visible light detection



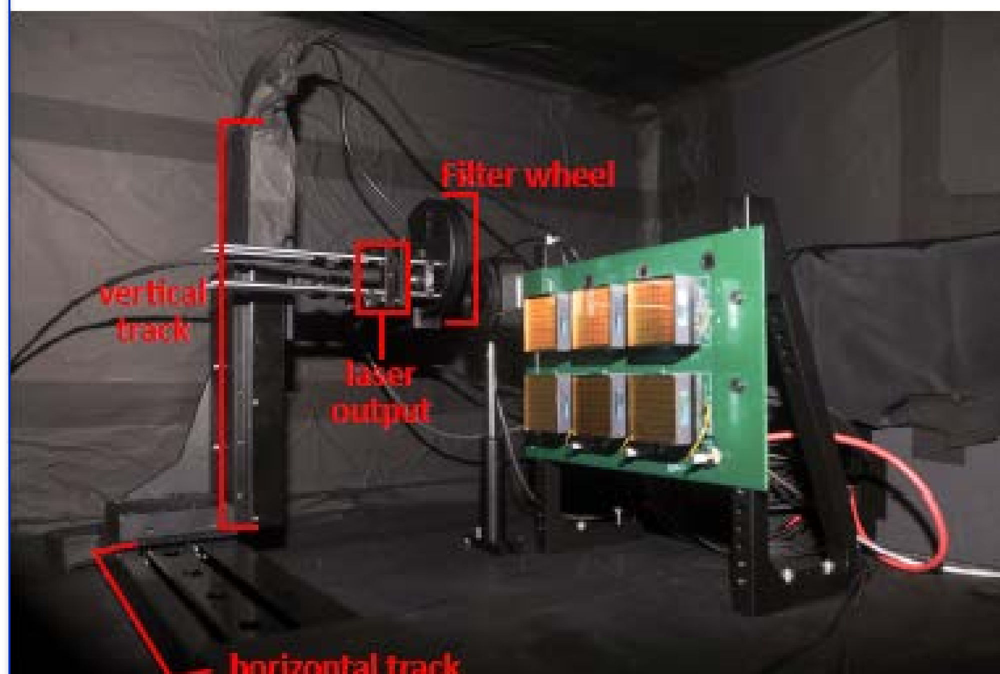
Multi-Anode PMT Hamamatsu H8500/H12700

- 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

Other options like SiPM are under investigation for the second RICH module

I. Balossino – Poster Session B

Test bench for systematic studies in the s.p.e. regime

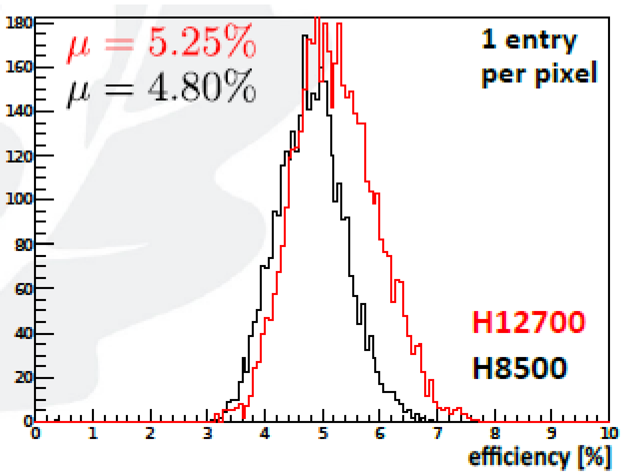


MAPMT tests: H12700 vs H8500

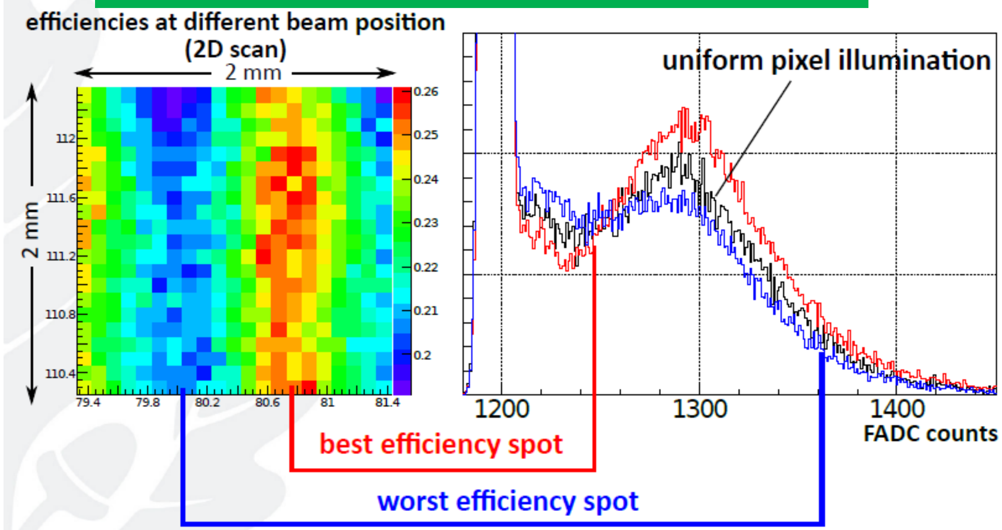
- First RICH to use massive production of the new Hamamatsu H12700
  - optimized for better response to the single photon
- ~400 H8500 and H12700 have been extensively tested in the s.p.e. regime
  - pixel by pixel response
  - HV scans
  - extraction of the parameters of the spectra (*NIM, to be published*)

Global efficiency

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



H12700: sub-mm scan of the surface



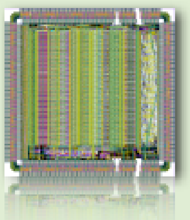
On average, H12700 has superior s.p.e. response
- better efficiency
- improved resolution

But also less uniform response due to the dynode structure

Readout Electronics

RICH readout requirements:

- 100% efficiency at 1/3 p.e. (50 fC)
- gain spread compensation 1:4
- time resolution 1ns
- trigger rate 20 kHz
- latency 8μs

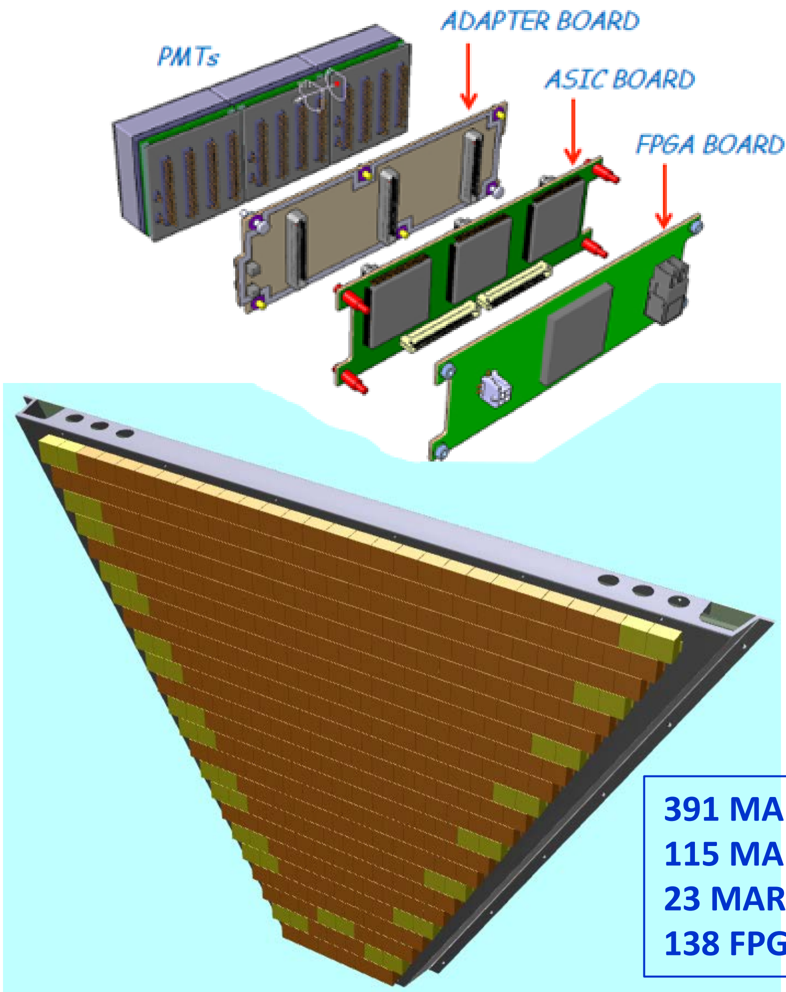


Multi Anode- Read Out Chip
version 3
64 Channel
1.5 mW/channel
by Omega Group
Application Specific
Integrated Circuit (ASIC)

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
- charge measurement available

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



391 MAPMTs
115 MAROC x3
23 MAROC x2
138 FPGA

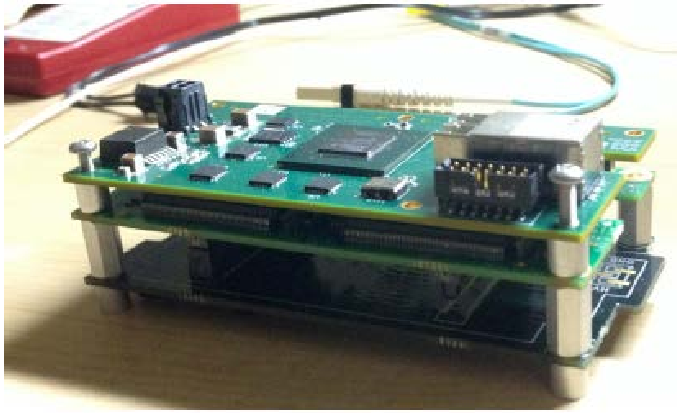
The same electronics will be used for the DIRC of the Gluex experiment in Hall D and for other experiment at JLab (e.g. PET on plants)

FE electronic lab tests

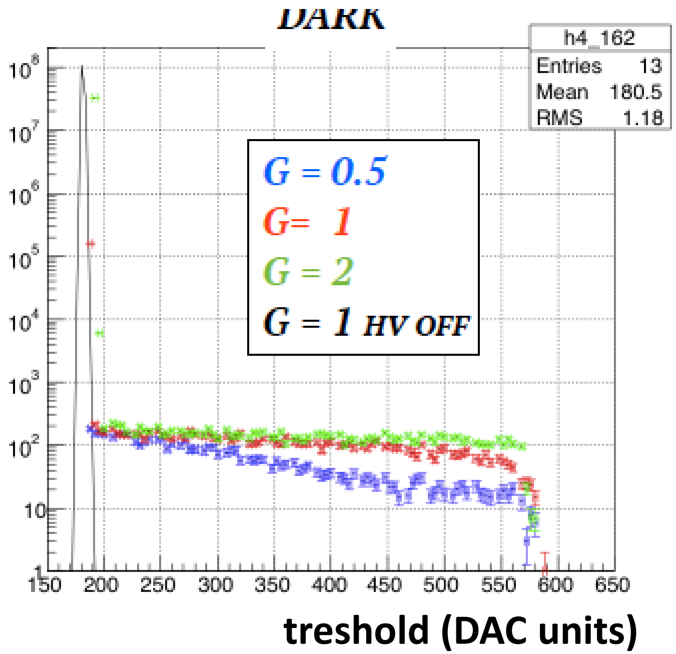
Test of the FE tile response to:

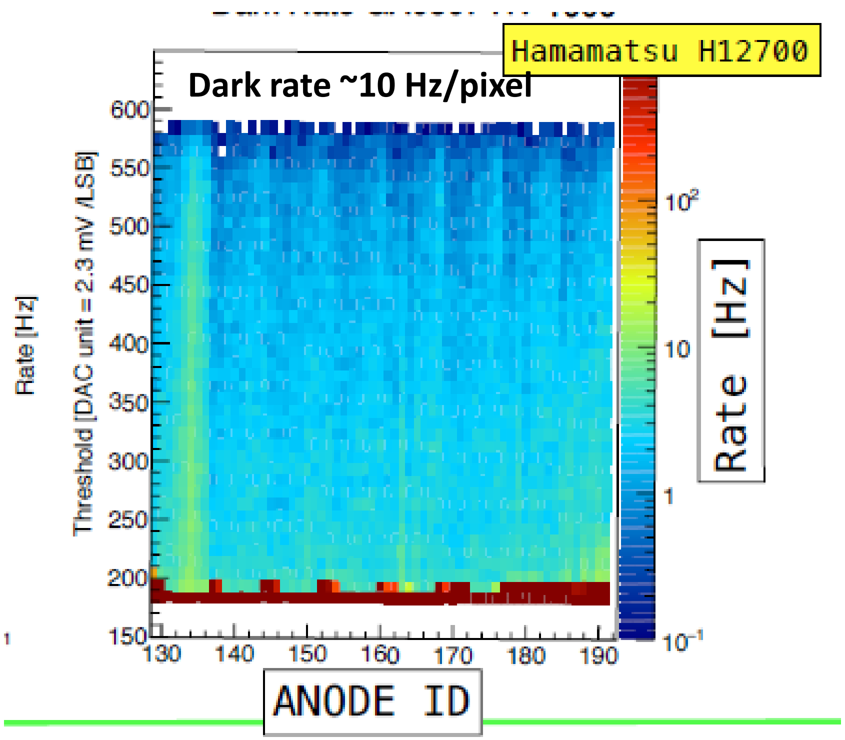
- **external injector**
- **MAPMT dark noise**
- **laser in s.p.e. regime**

Study the count rate as a function of the threshold



Dark noise Counts in 30 s

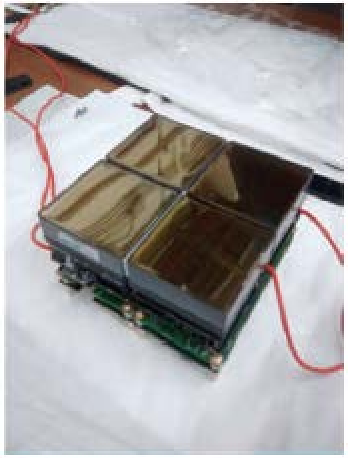




- **Large region of uniform response for G≥1: possibility to compensate pixel non-homogeneity**
- **Small slope vs threshold : easy working point**
- **Measured dark rate compatible with Hamamatsu specifications**

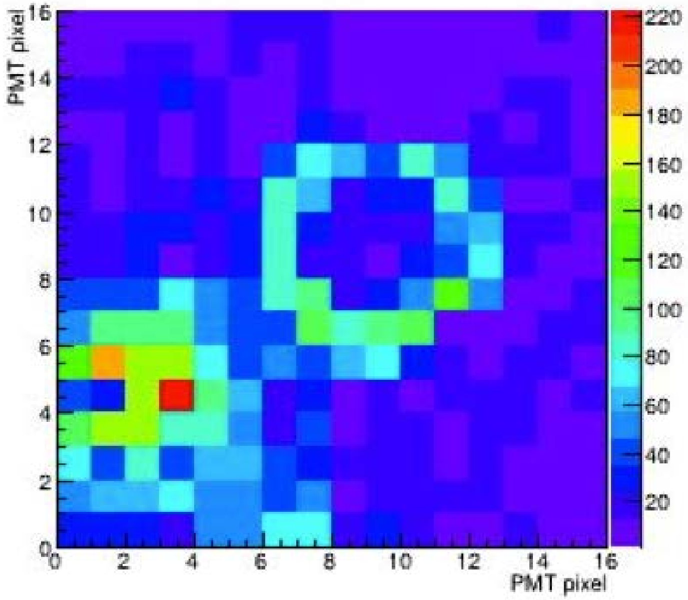
Beam test of the FE electronics

The CLAS12 RICH electronics has been successfully used during a test beam at Fermilab for the EIC project with a s18mall prototype of 2x2 matrix of H12700 (256 channels)

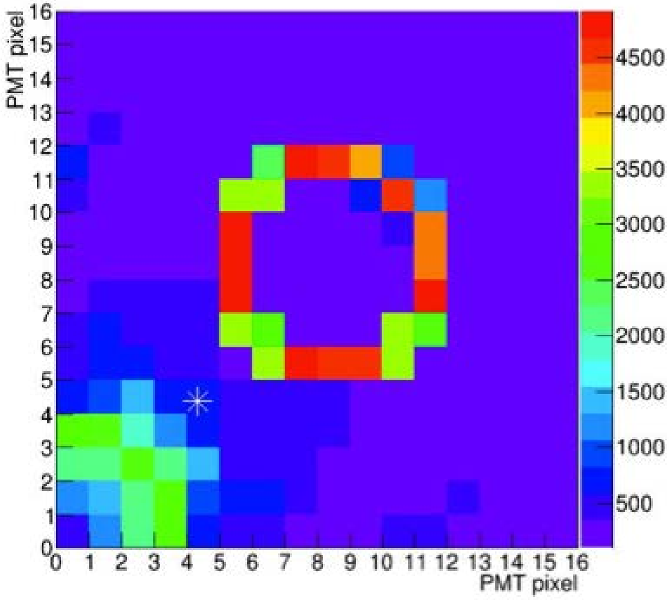


Cherenkov ring produced by 120 GeV/c protons

Experimental data



Simulations



Project timeline

- **R&D of the project started in 2011**
- **Construction of the first module approved by JLab in 2013**
- **Construction started in 2015**
- **Assembly of the RICH at JLab will start in october 2016**
- **Installation in CLAS12 by September 2017**
- **Commissioning of the detector in CLAS12 start in October 2017**
- **Second module in 2019**

backup

CLAS12 RICH resolutions

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

$$\sigma_{\vartheta_{Ch}} = \sqrt{\sum_i \frac{\left(\sigma^i_{\vartheta_{Ch}}\right)^2}{N_{p.e.}}}$$

Validated with prototype data

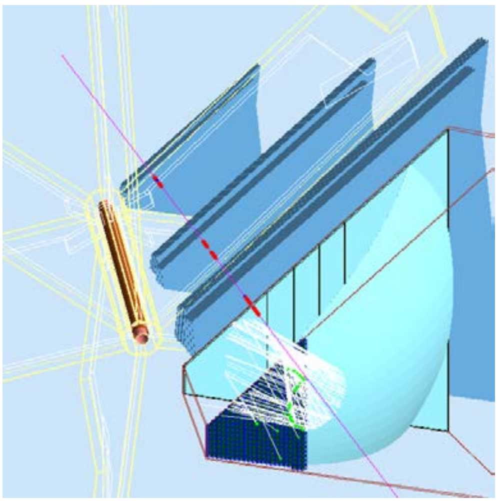
From laboratory studies

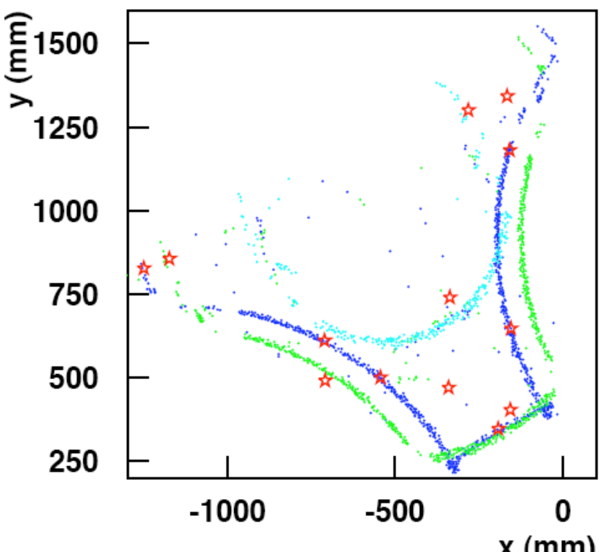
Minimum required number of p.e.

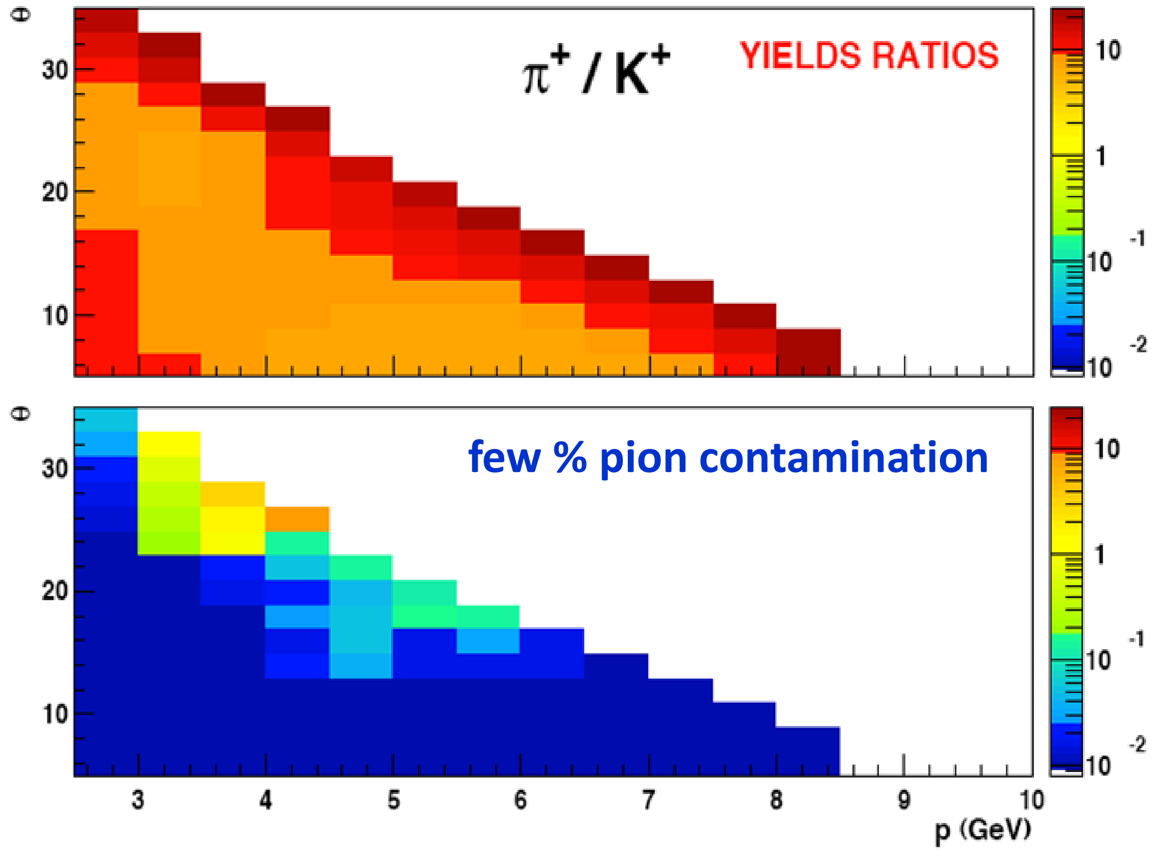
Similar single photon resolutions for the direct and reflected case
A factor of ~3 less yield in the reflected case but larger angular separation
→comparable π/K rejection power

RICH expected performances

- One charged particle per sector in average
- Non trivial RICH light patter due to reflections: pattern recognition and likelihood ID required





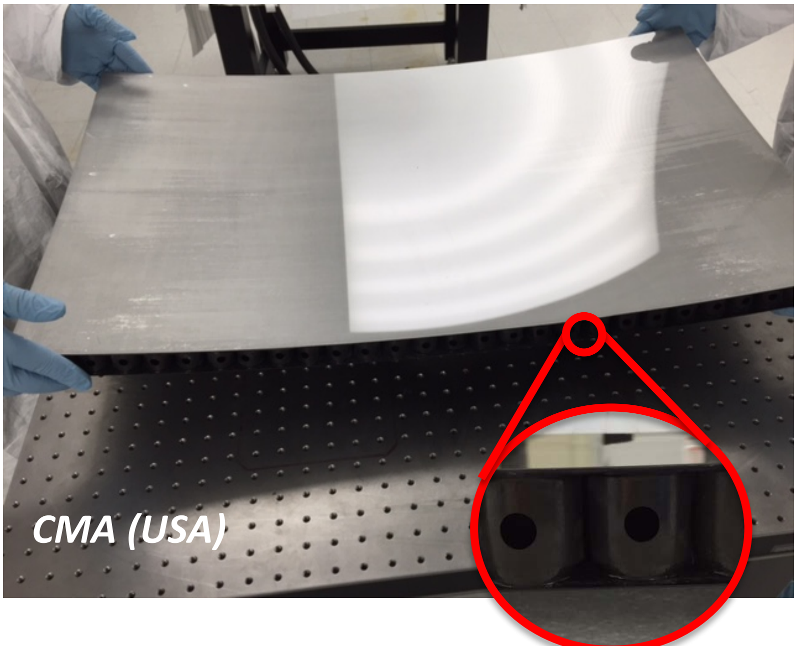


PID algorithm not optimized
Fine tuning of the likelihood parameters
may improve the rejection power

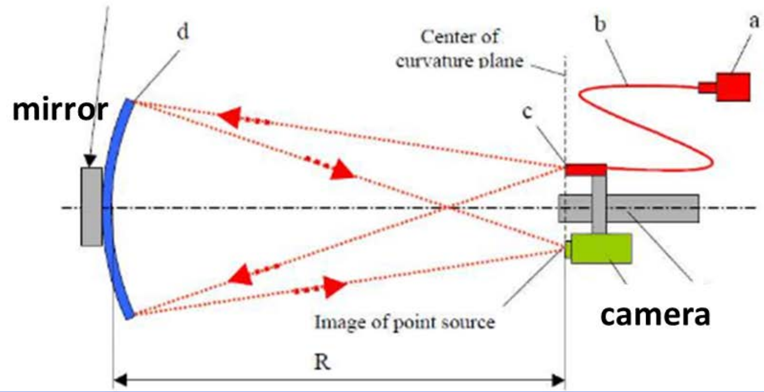
Spherical Mirrors

Sandwich of two thin layers of carbon fiber with honeycomb core: same technology as LHCb mirrors

- **30% improvement in the material budget (areal density ~ 4 kg/m2)**



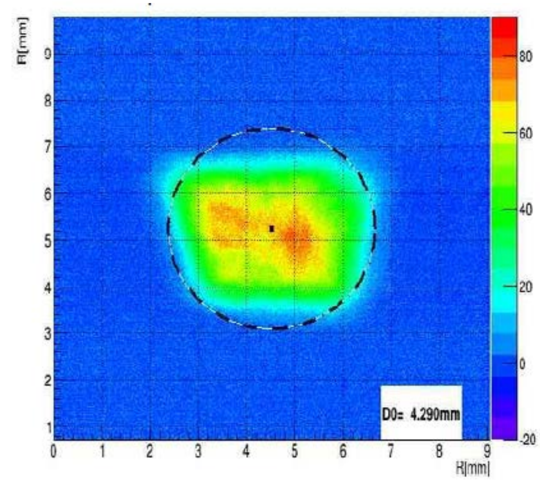
Spot size measurement



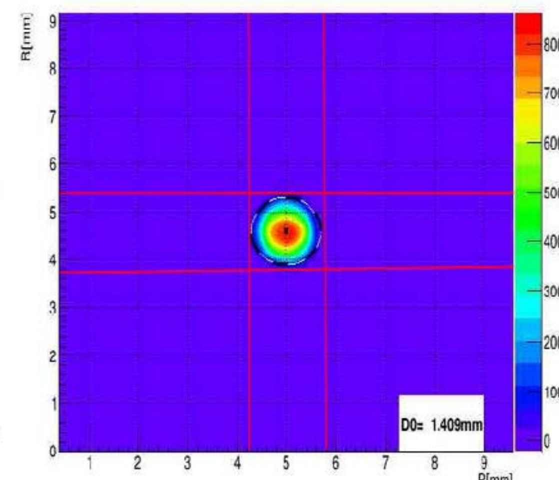
At minimum:

$D_0 < 1.5$ mm

$$\sigma_\vartheta = \frac{D_0}{8R} < 0.1\,mrad$$



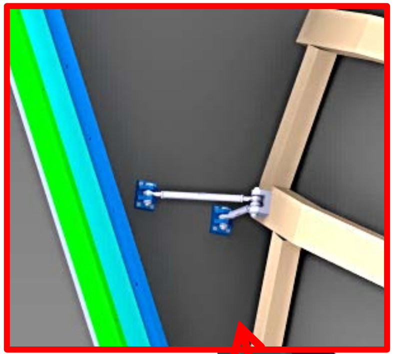
Far from the center: shadow of the mirror

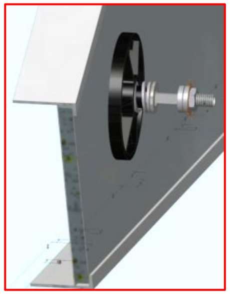


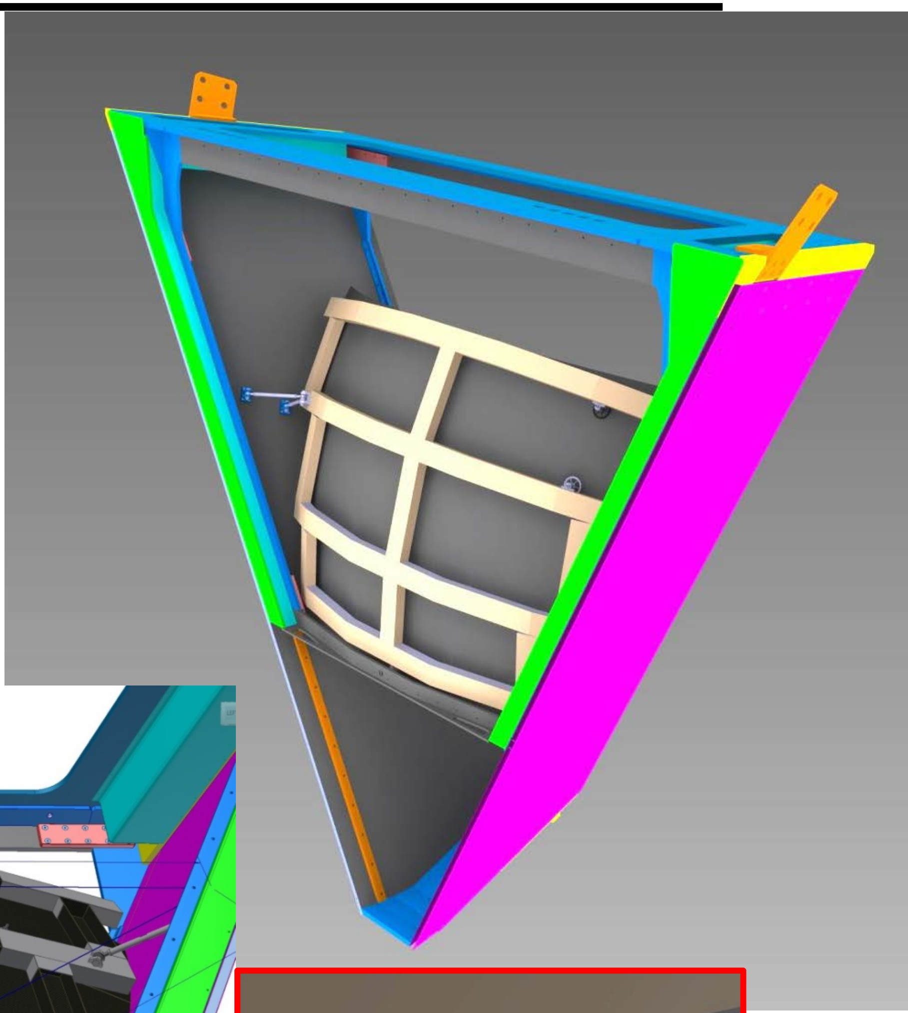
At minimum: small size circle

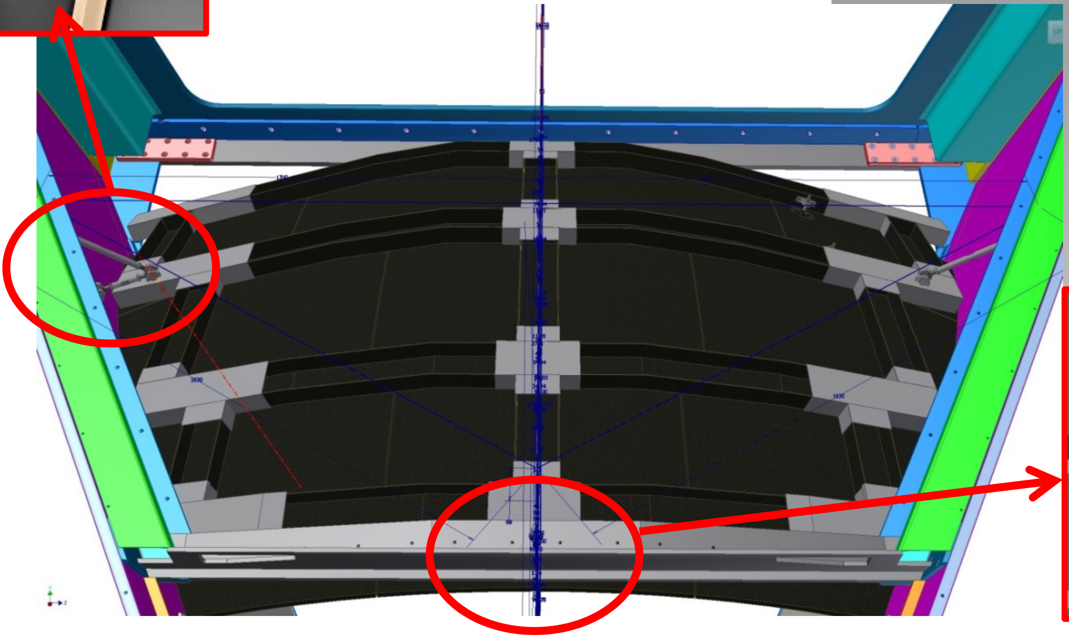
The spherical mirror in the RICH

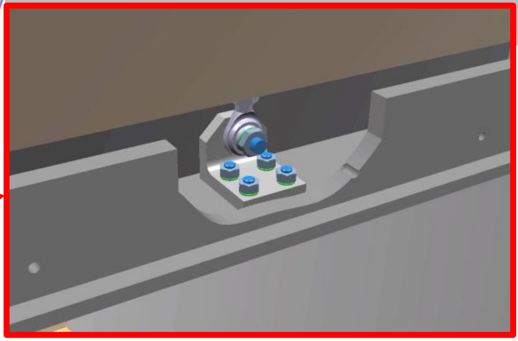
- The ten mirrors are assembled on a stiff supporting frame, with three mounting points for alignment
- Design finalized in cooperation with the mirror production company









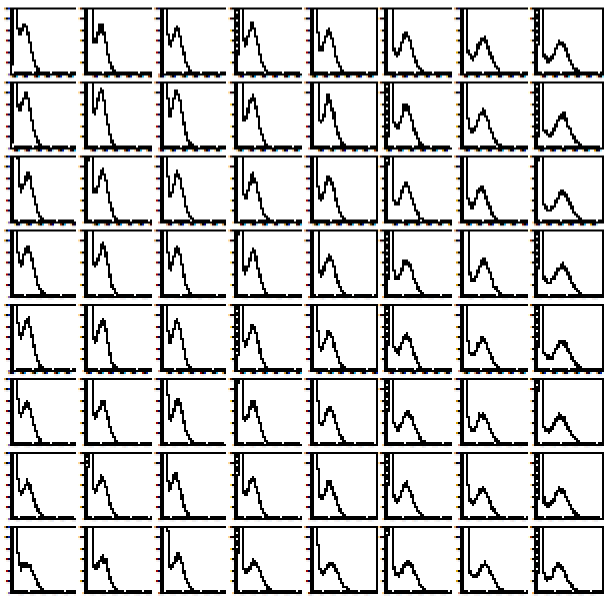


MAPMT tests

pixel by pixel measurements

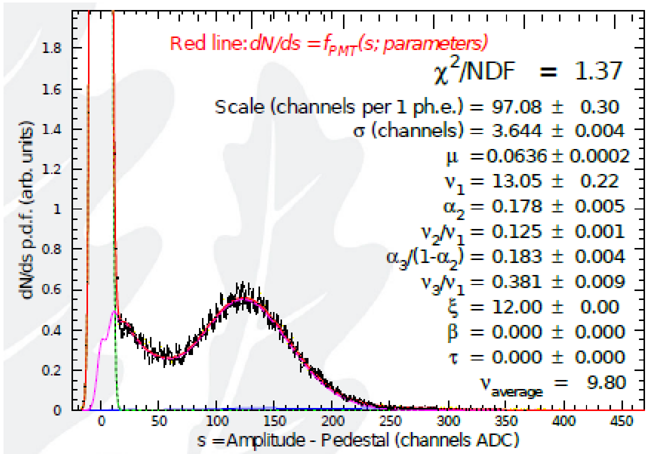
p1 p8

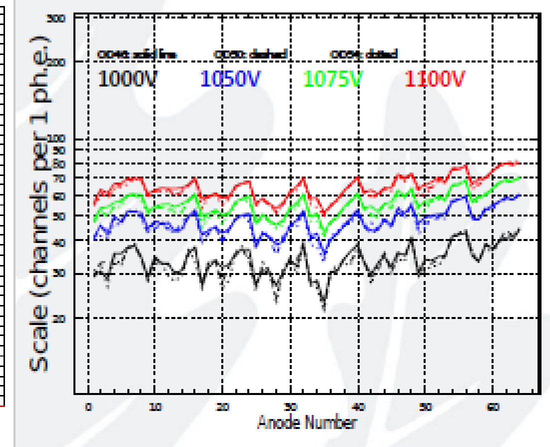
p8



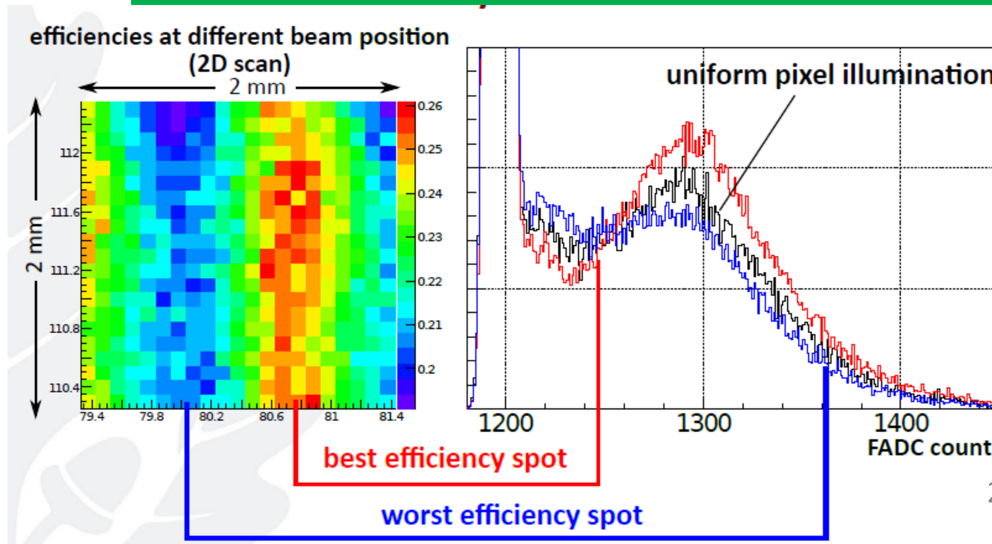
p64

Analysis of the spectra and parameter extraction

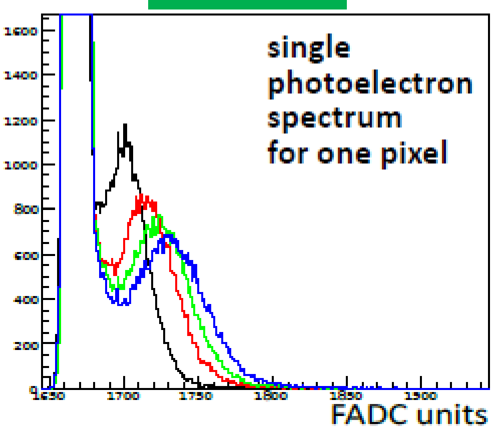




Sub-mm scan of the surface to study the response uniformity



HV scan

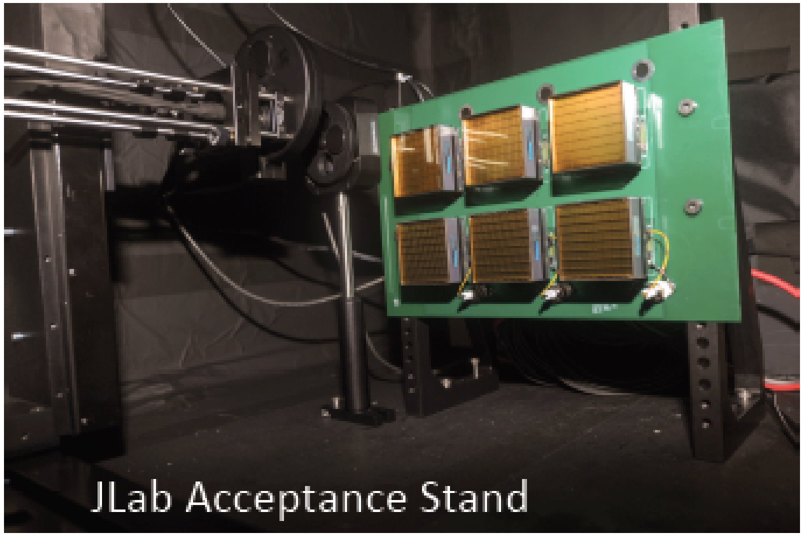


MA-PMT Photon Detector

110 Hamamatsu MAPMT out of 430 delivered and tested at JLab

- 80 H8500
- 110 H12700 with enhanced SPE spectrum

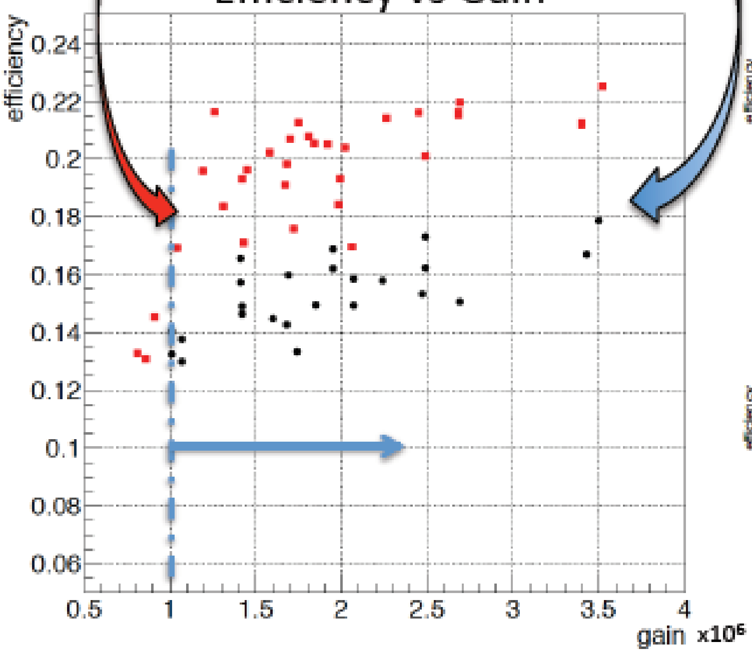
Procurement secured for new H12700 PMTs



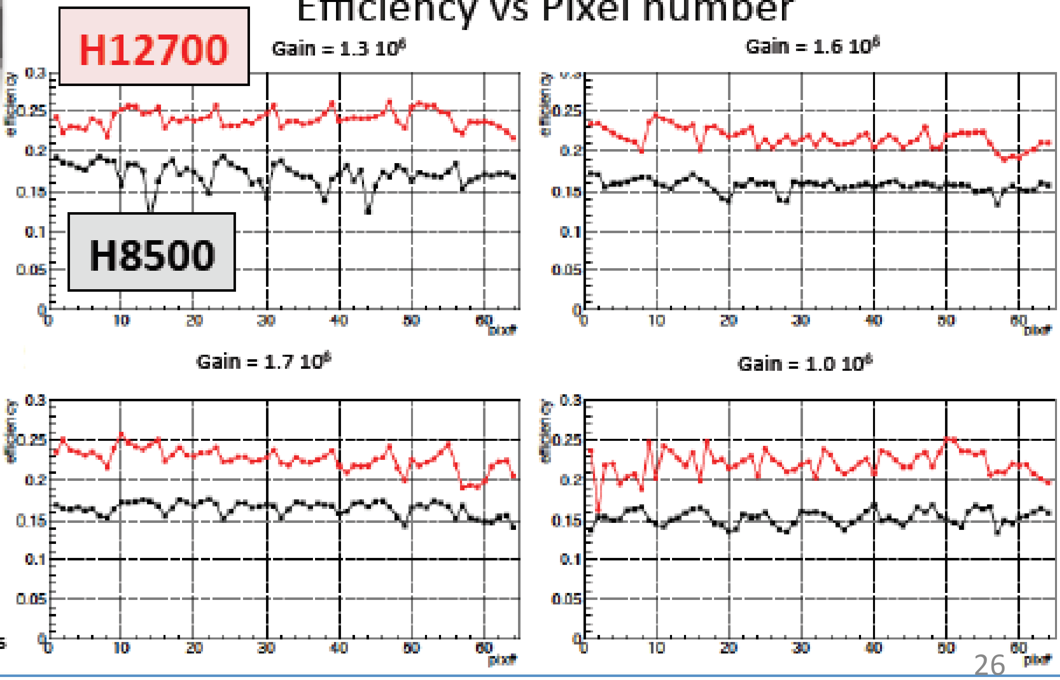
PMT Efficiency Comparison:

H12700 ⟷ H8500

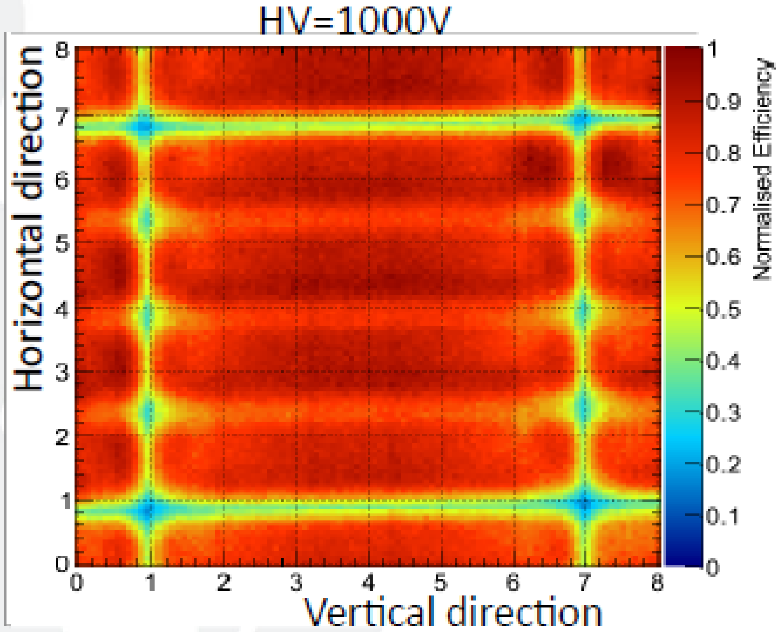
Efficiency vs Gain

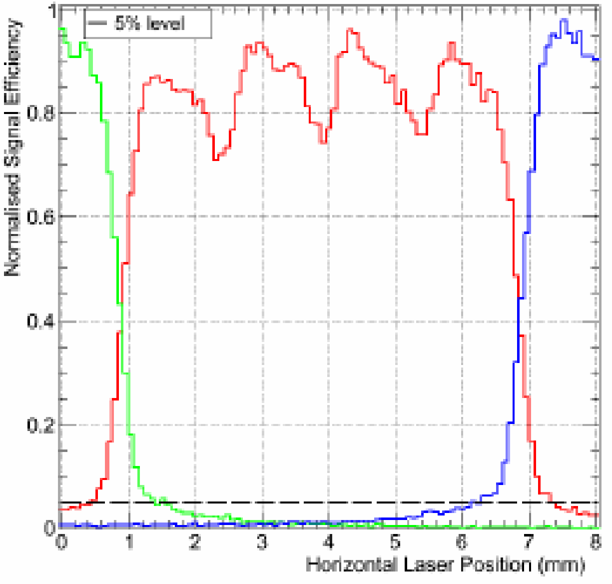


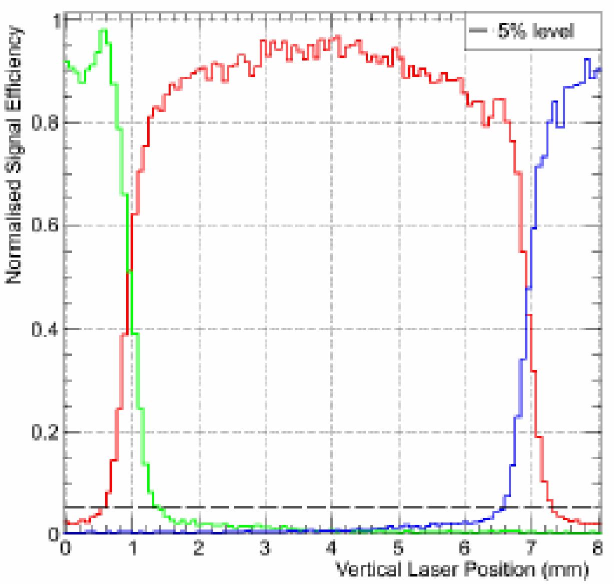
Efficiency vs Pixel number



Pixel surface uniformity





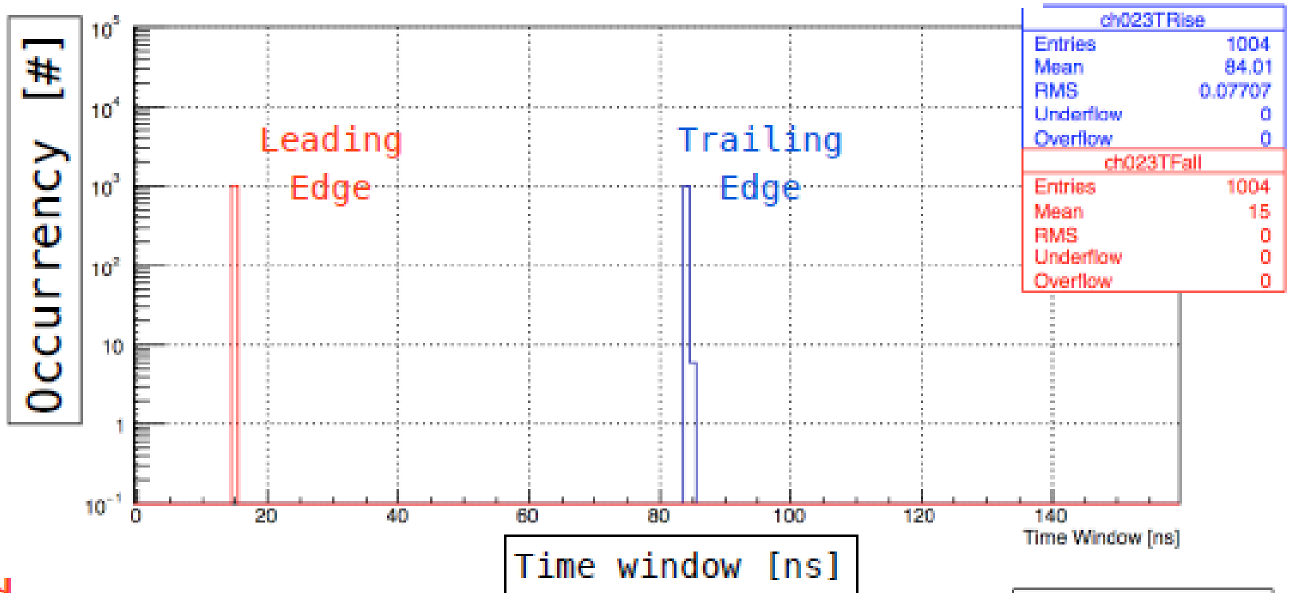


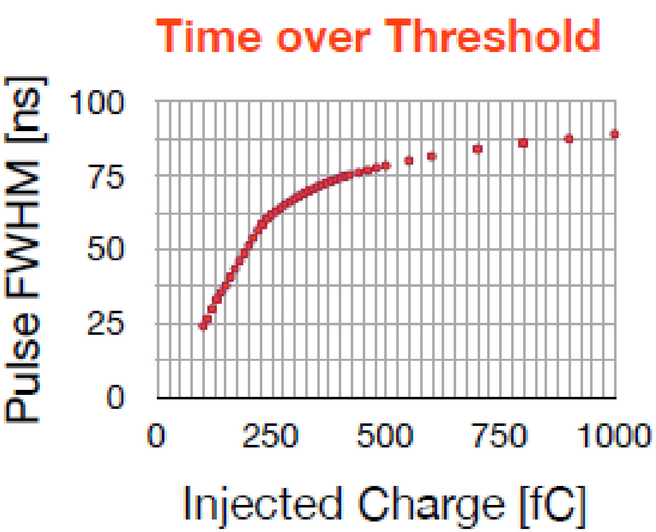
- **Response segmentation depending on dynode mesh structure in horizontal direction**
- **Uniform response in vertical direction**
- **Signal strength drops in deadspace are 40-50% relative to the signal maximum values**

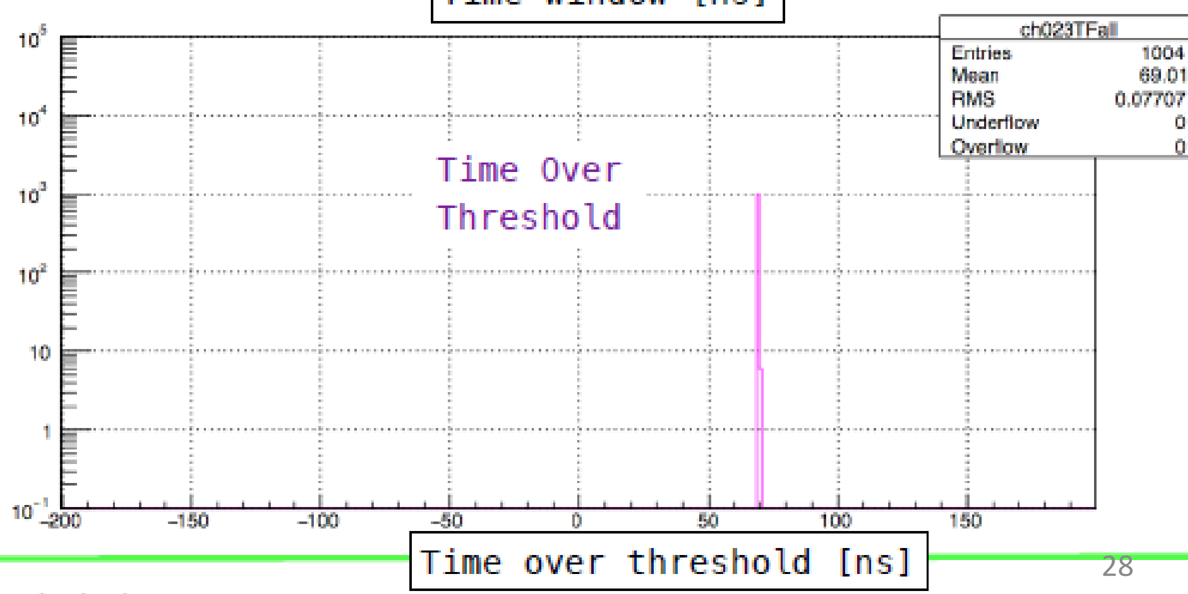
TDC Response Test Pulse

Main acquired data are MAROC binary ouputs time information

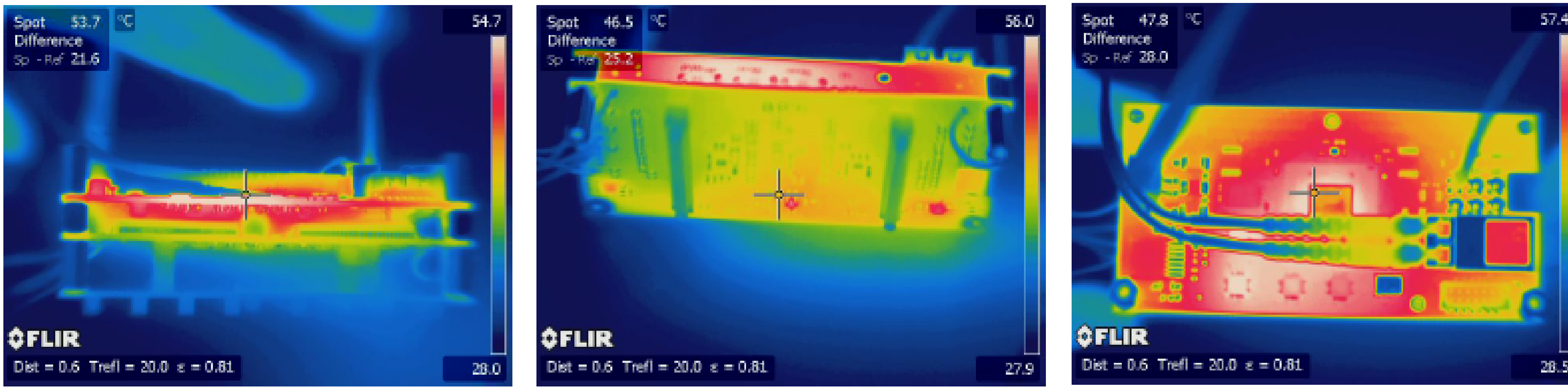
- Jitter introduced by MAROC is below the sensitivity of the TDC (1ns)
- Time over Threshold measurements is feasible







Heat production



Thermografic camera images of a RICH electronic module

- Power Consumption @ 5Volt:

  760 mA (3.80 Watts) 3MA-PMTs variant

  670 mA (3.35 Watts) 2MA-PMTs variant

Compatible with temperature requirements of CLAS12