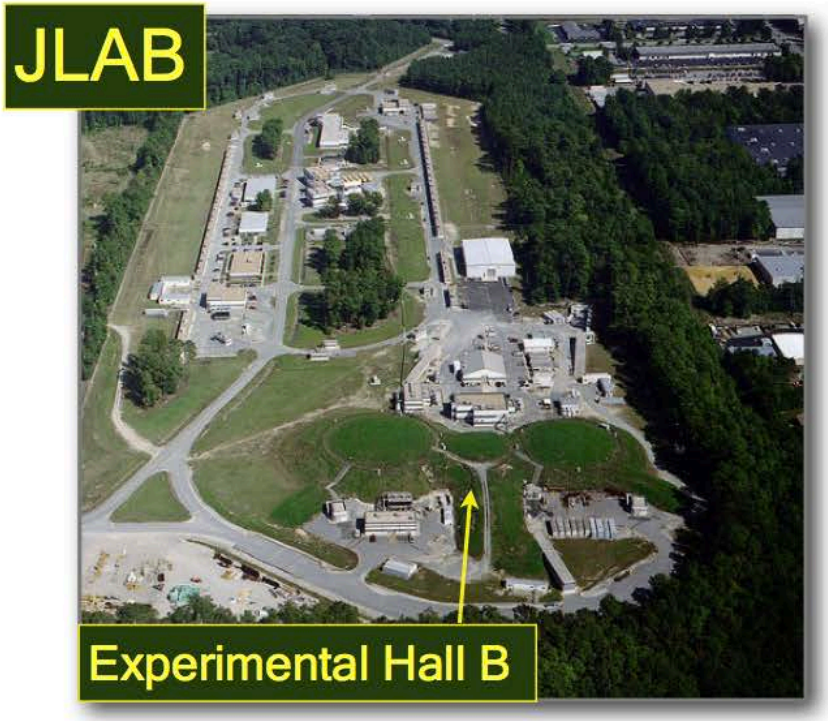
The Large-area Hybrid-optics CLAS12 RICH: Assembling, Commissioning and First Data-taking

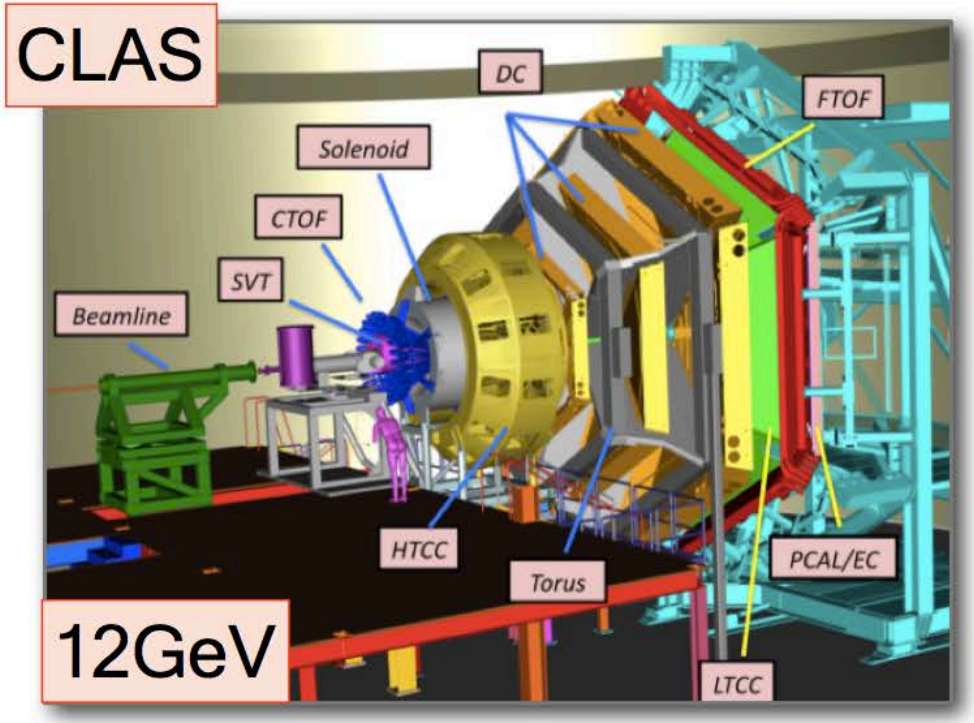
Marco Mirazita (LNF)

The CLAS12 spectrometer at JLab

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



Continuos Electron Beam Accelerator Facility (CEBAF)



CEBAF Large Acceptance Spectrometer (CLAS)

- **Beam delivered simultaneously in 4 Halls**
- **Max beam energy 12 GeV in Hall D**
- **high beam current ~100 μA**

- **Luminosity up to 10^{35} cm^{-2} s^{-1}**
- **Max beam energy 10.6 GeV**
- **High polarization electron beam**
- **H and D targets (polarization), nuclear targets**
- **Wide acceptance**

Why the RICH

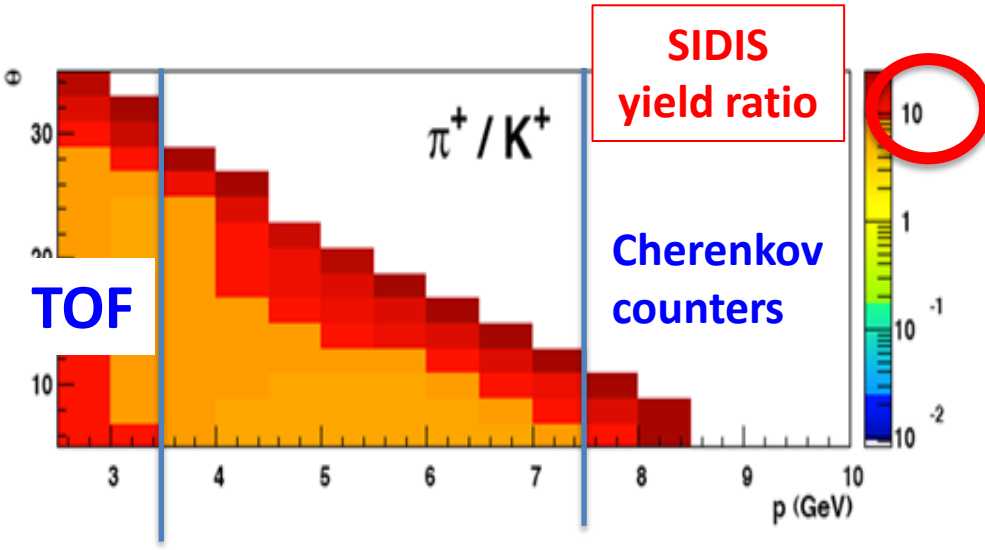
Kaon program at CLAS12

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**



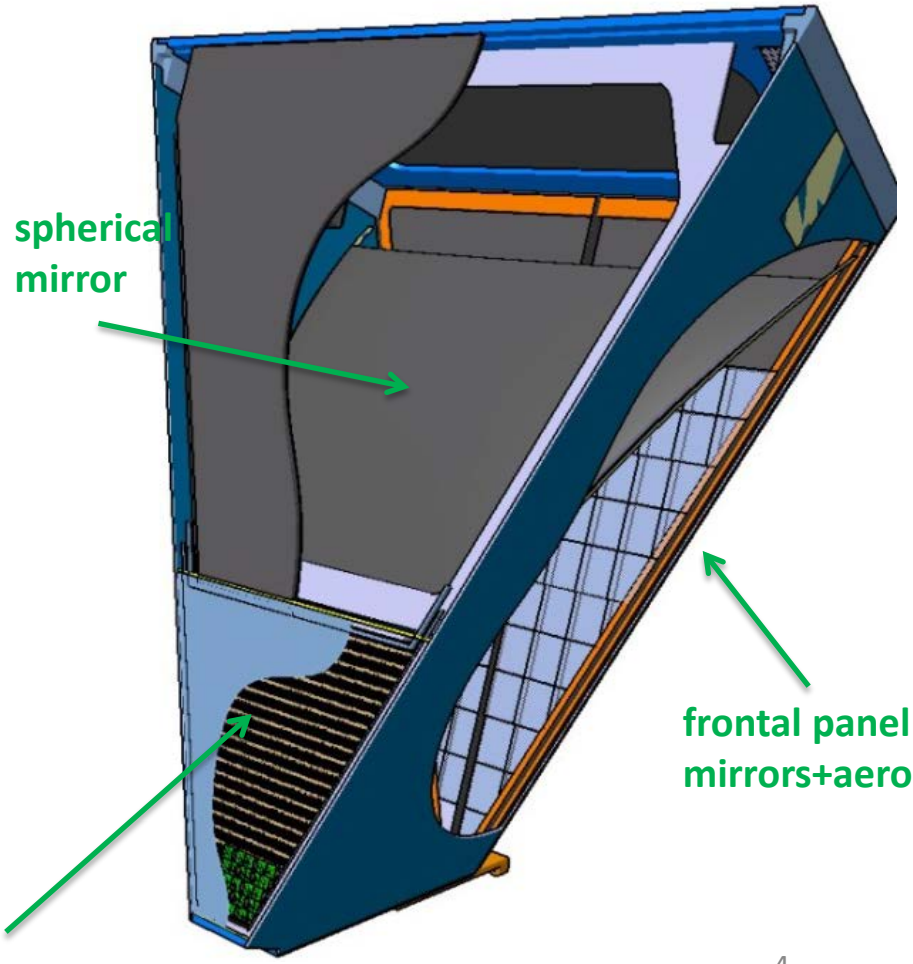
RICH goal: **π/K/p identification from 3 up to 8 GeV/c and 25 degrees**

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

The RICH design

1. Aerogel to match the momentum range
2. Photomultipliers to detect visible photons
3. Mirrors to reduce the detection area

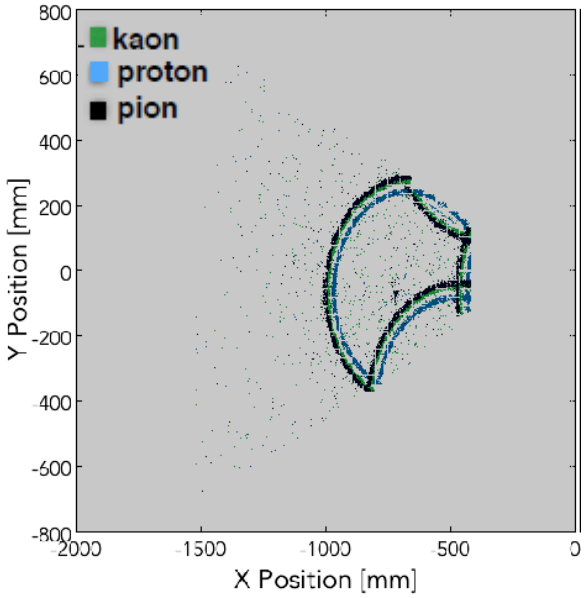
- Mechanical structure in carbon fiber derived from aeronautic engineer
- Carbon fiber spherical mirrors 30% lighter than LHCb
- Glass sandwich planar mirrors first use in nuclear physics
- Largest aerogel tiles with optical quality comparable with Belle
- First massive production of Hamamatsu H12700

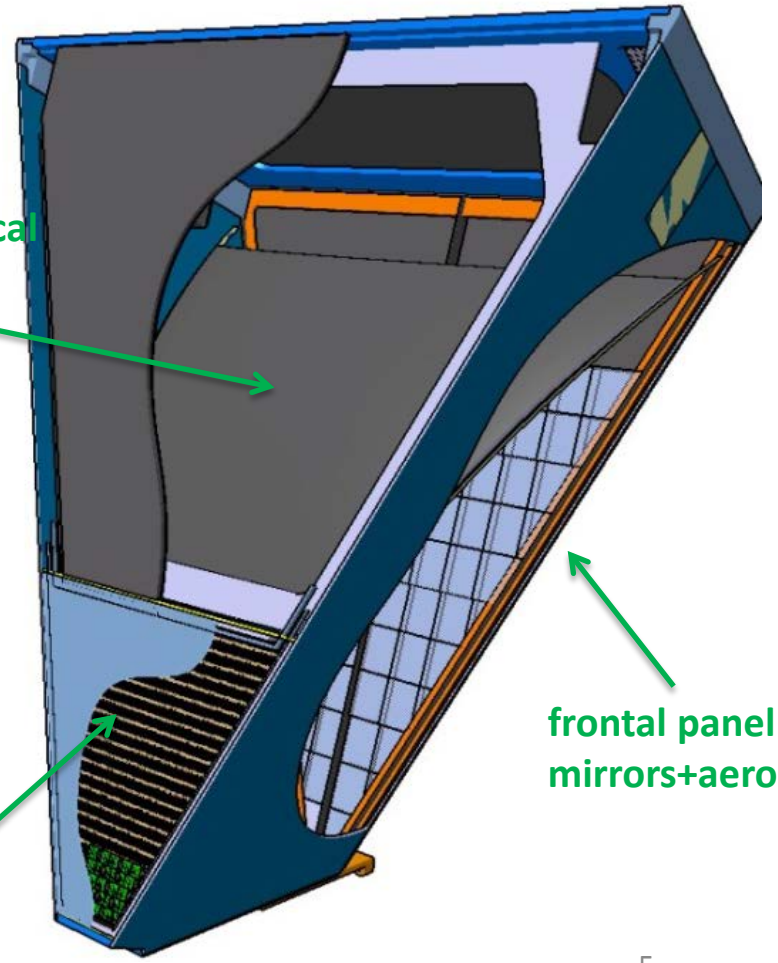


The RICH design

1. Aerogel to match the momentum range
2. Photomultipliers to detect visible photons
3. Mirrors to reduce the detection area

- about 1 track per event
- low background
- hit pattern complicated by mirror reflections

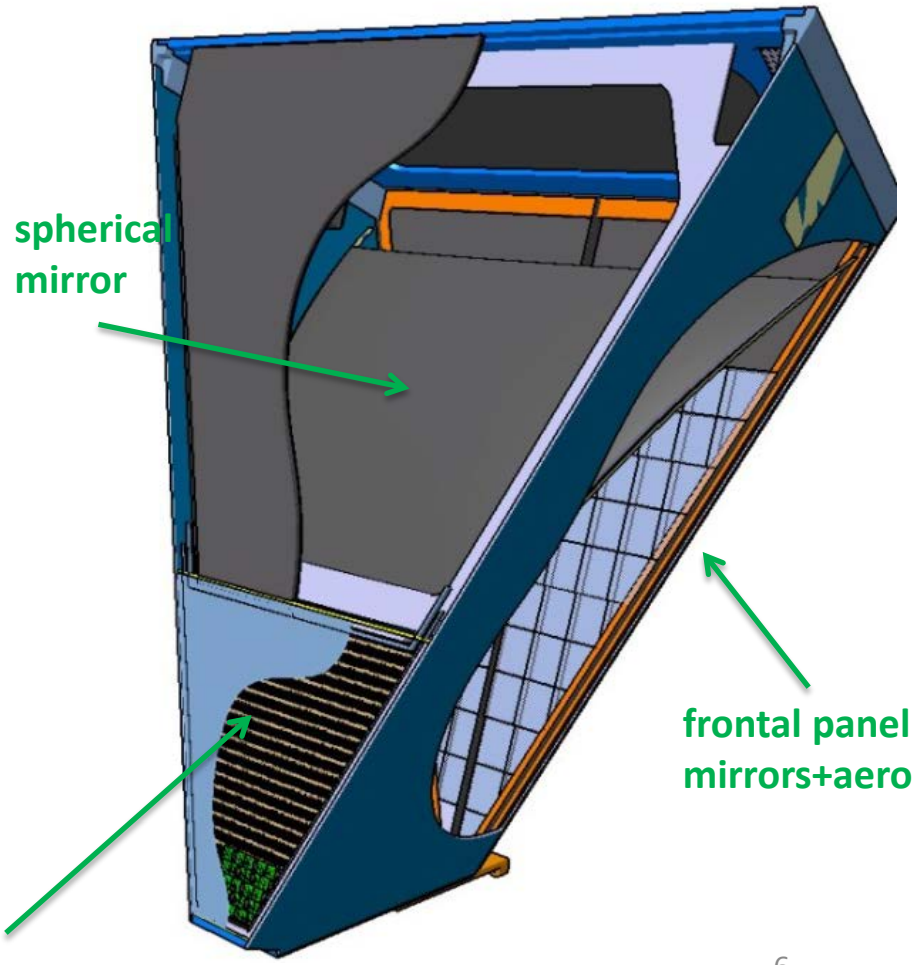




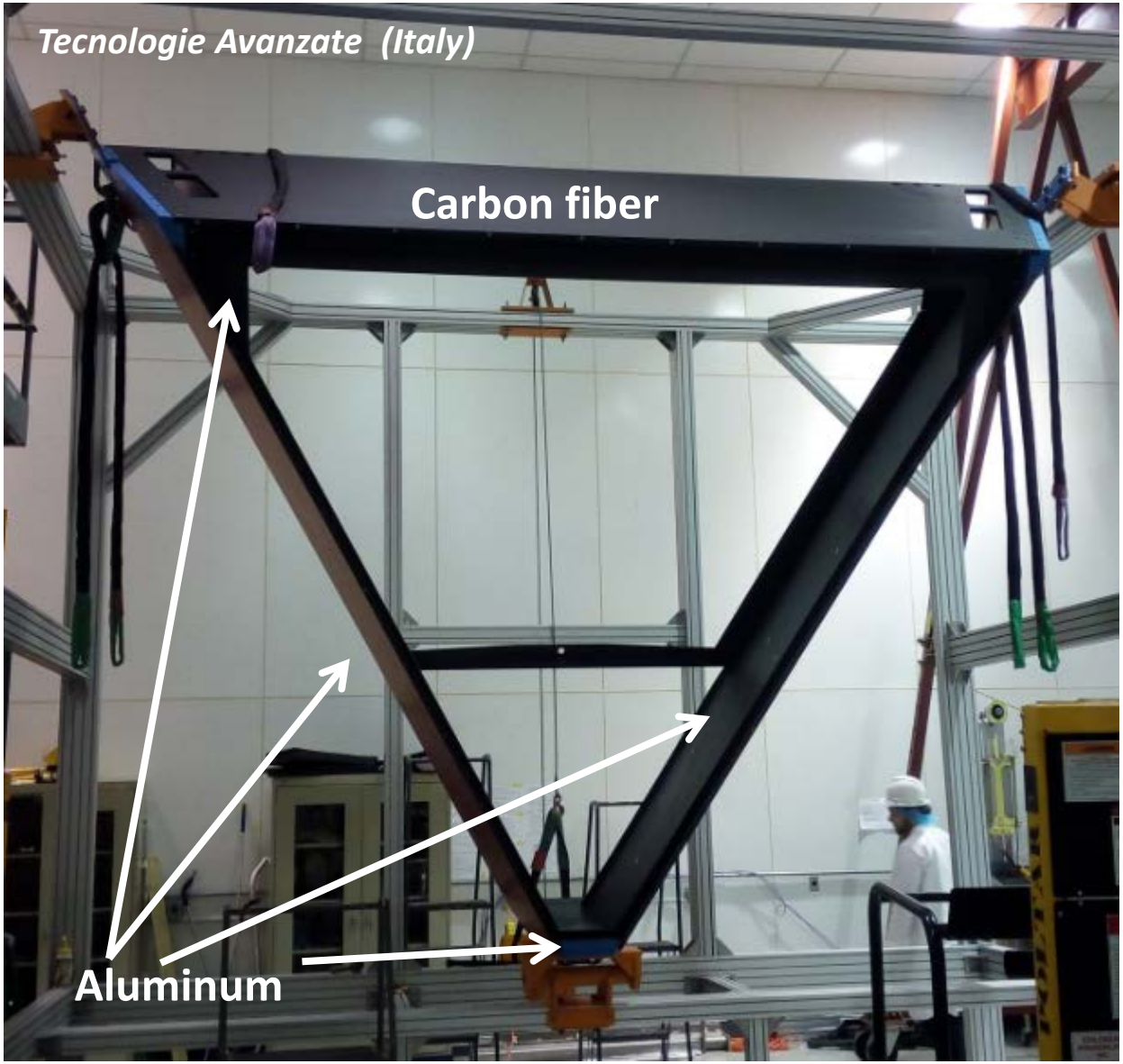
The RICH design

1. Aerogel to match the momentum range
2. Photomultipliers to detect visible photons
3. Mirrors to reduce the detection area

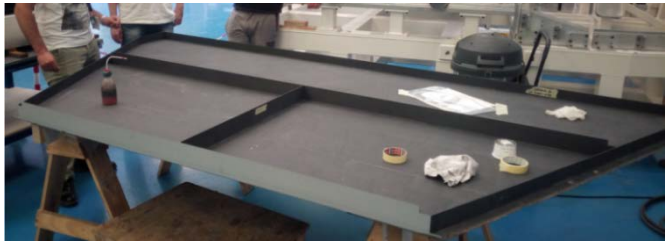
INSTITUTIONS
INFN (Italy) Bari, Ferrara, Genova, L.Frascati, Roma/ISS
Jefferson Lab (Newport News, USA)
Argonne National Lab (Argonne, USA)
Duquesne University (Pittsburgh, USA)
Glasgow University (Glasgow, UK)
J. Gutenberg Universitat Mainz (Mainz, Germany)
Kyungpook National University, (Daegu, Korea)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

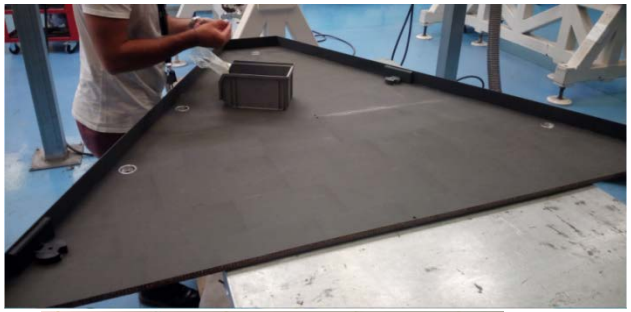


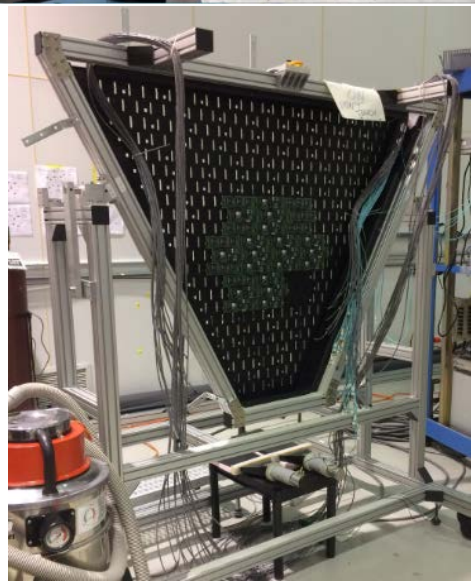
The RICH detector



Carbon fiber



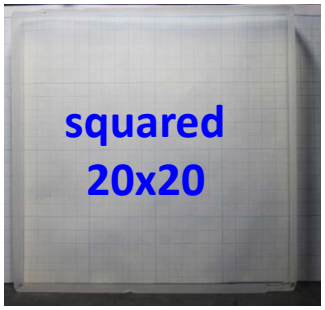




Aerogel radiator

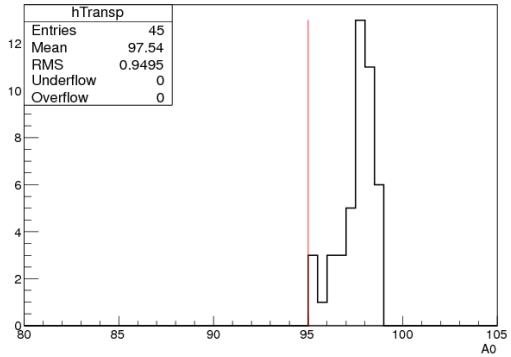
Large tiles produced by the Budker and Boreskov Institutes of Nuclear Physics (Novosibirsk, Russia)

- **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**

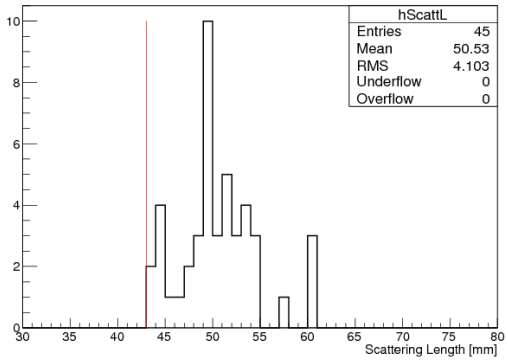


Analysis of optical characteristics (2 cm thickness)

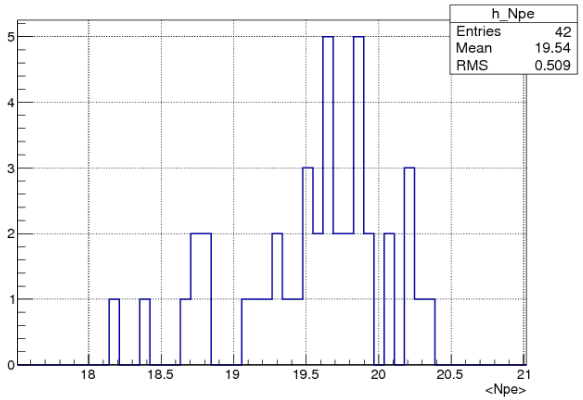
transparency coefficient
A0 > 95 %



scattering length
L > 43 mm

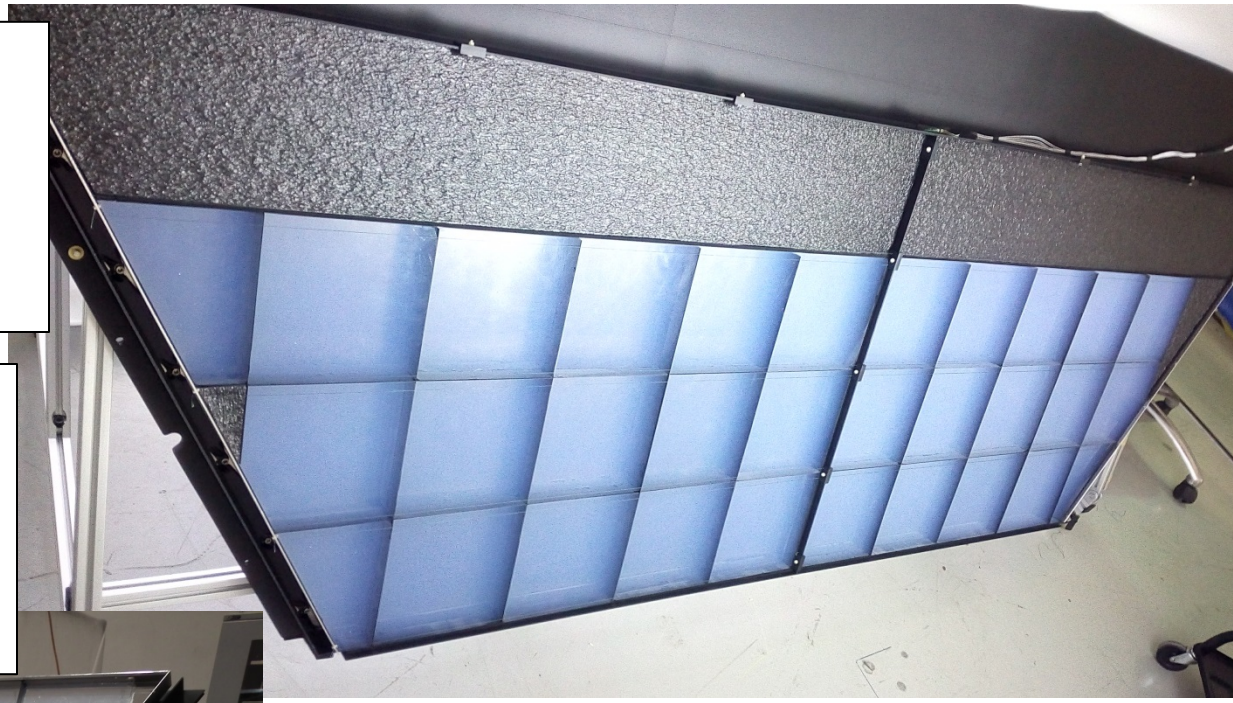


Expected yield production
<Npe> ~ 19

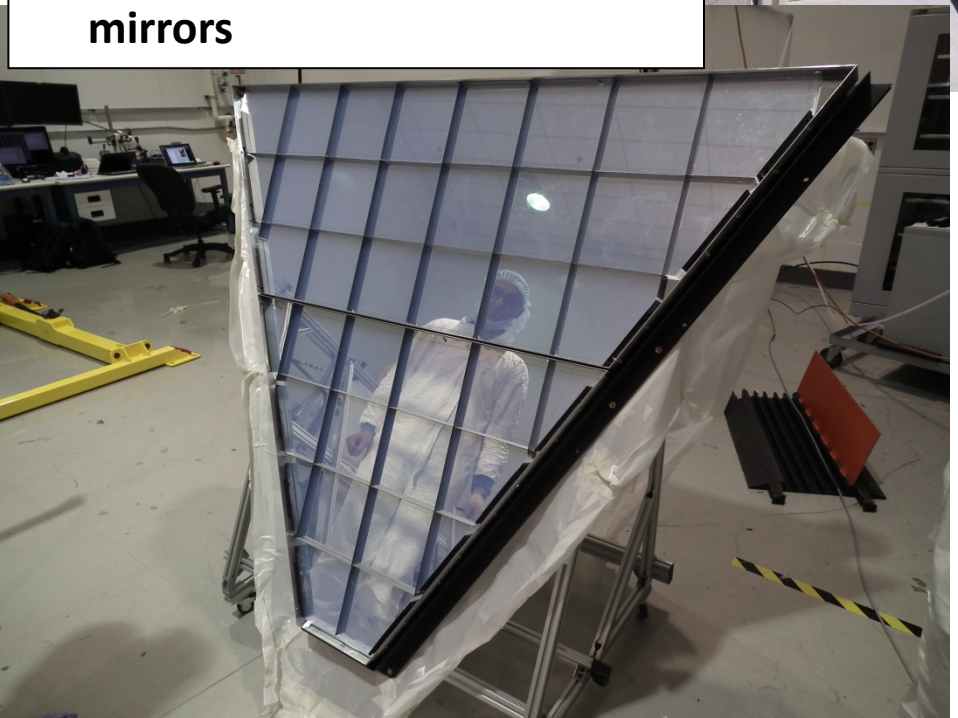


Aerogel assembly

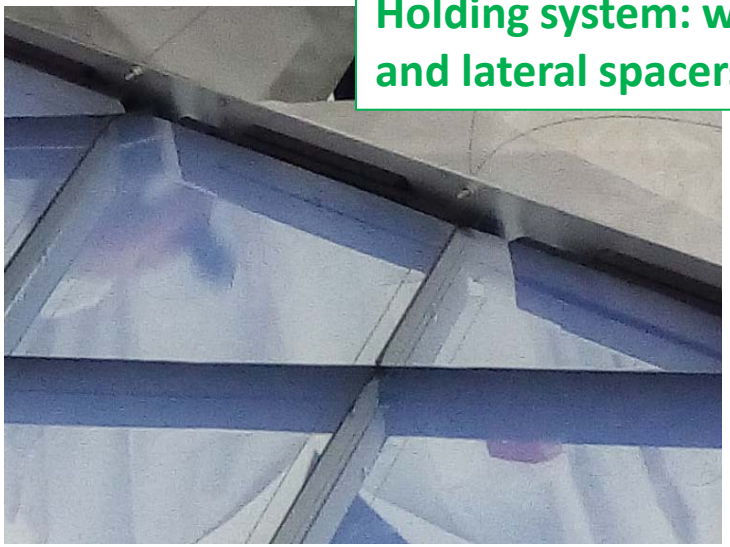
Top section
- 2 layers 3+3 cm thickness
- 64 tiles
- mounted on the frontal closing panel



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



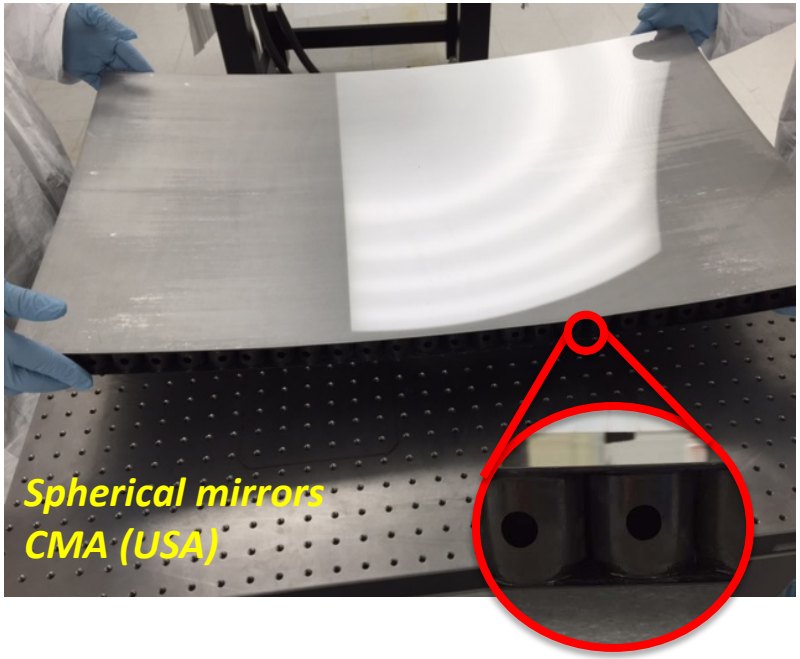
Holding system: wires and lateral spacers



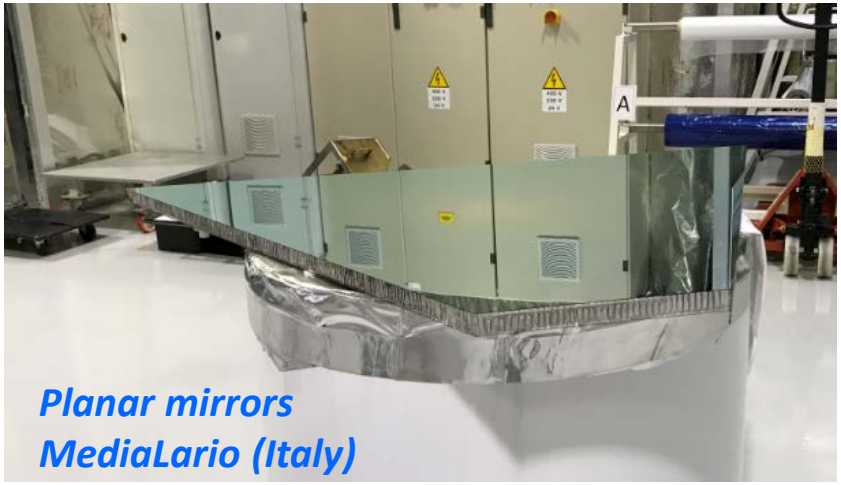
The mirror system

Sandwich technique: two layers of material plus honeycomb core

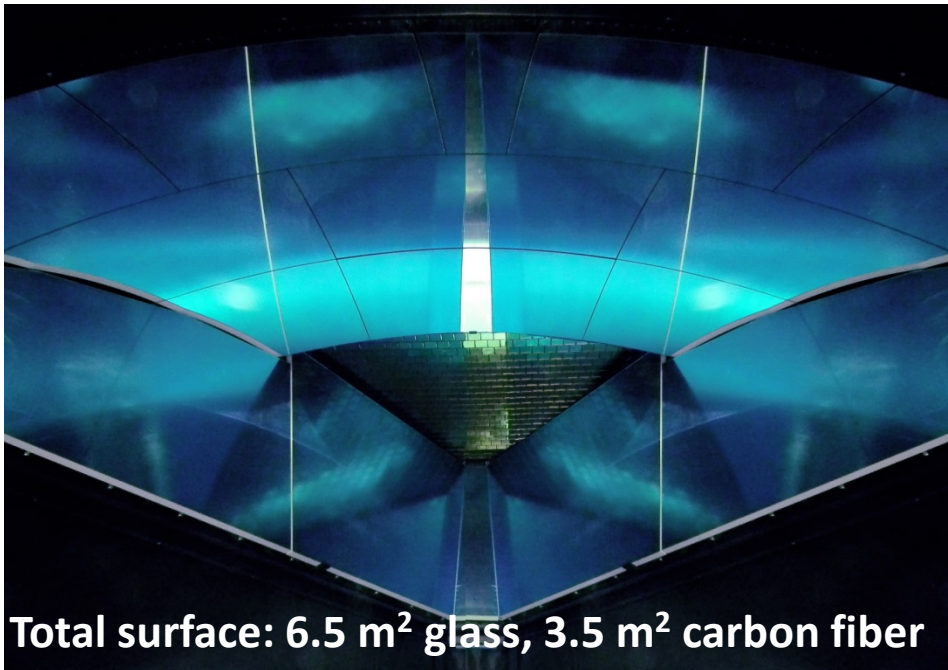
- Mirrors in the acceptance
  - 10 spherical mirrors
    - carbon fiber
  - 2 frontal mirrors
    - thin glass layers
- Mirrors out of the acceptance
  - 4 lateral and 1 bottom mirrors
    - thicker glass layers



Spherical mirrors
CMA (USA)



Planar mirrors
MediaLario (Italy)

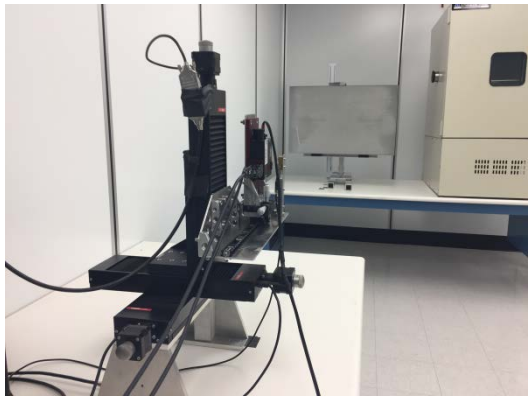


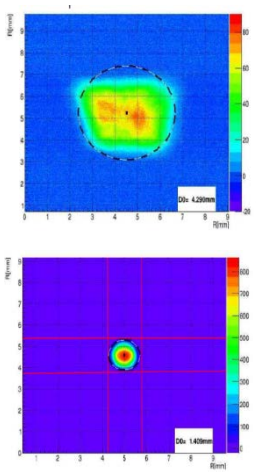
Total surface: 6.5 m^2 glass, 3.5 m^2 carbon fiber

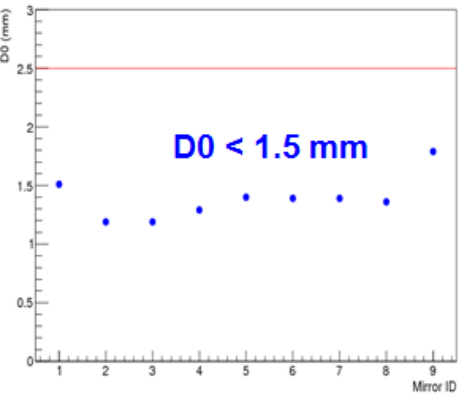
Characterization tests

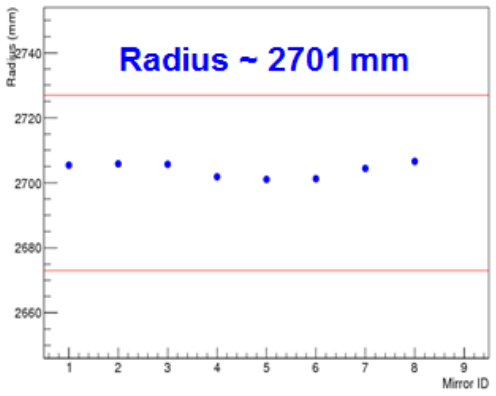
Characterization measurements
- surface accuracy → angular resolution
- reflectivity

Spherical mirrors: Spot size



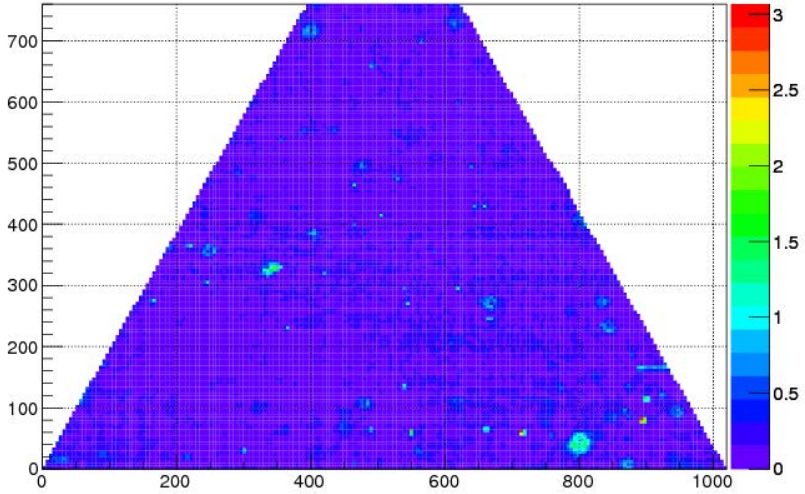






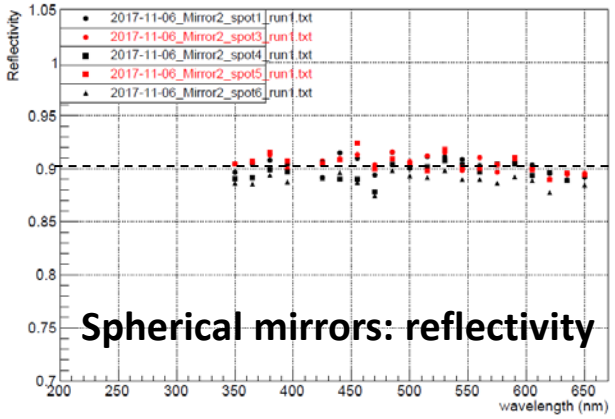
$\sigma_\theta < 0.4$ mrad

Planar mirrors: Coordinate Measuring Machine



- local slope < 0.3 mrad
- imperfections level few % of the total surface

90%

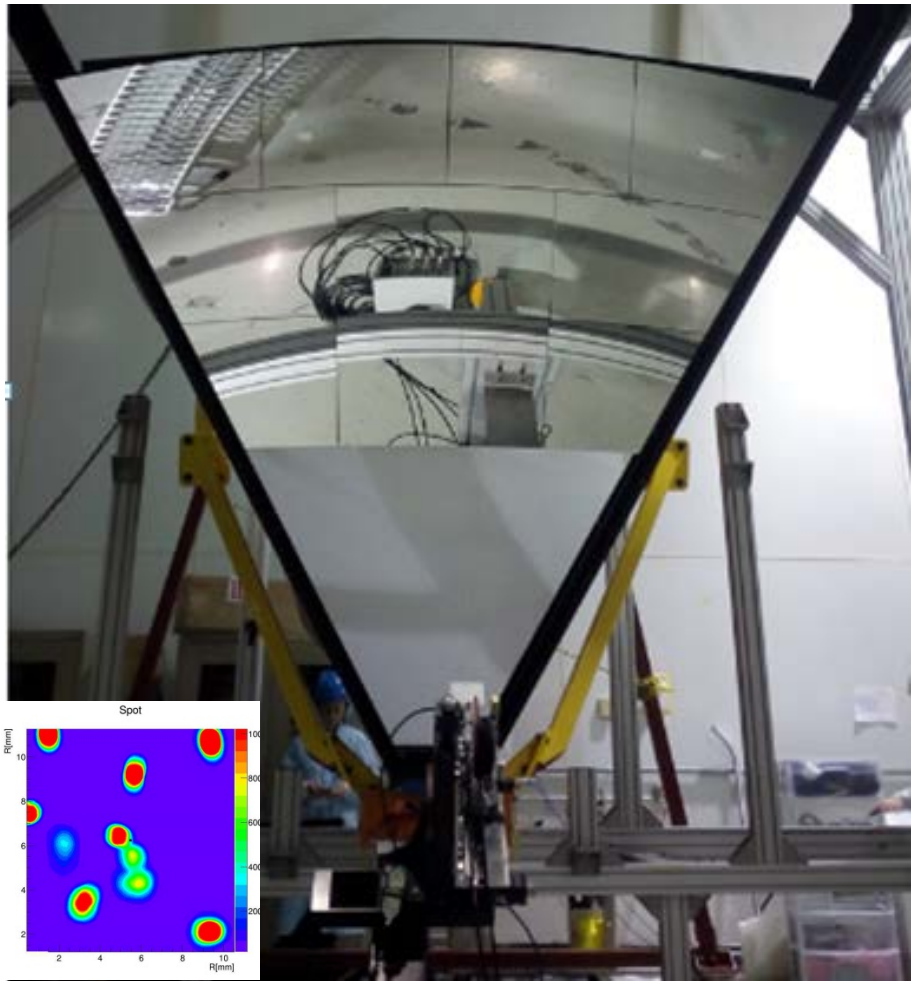


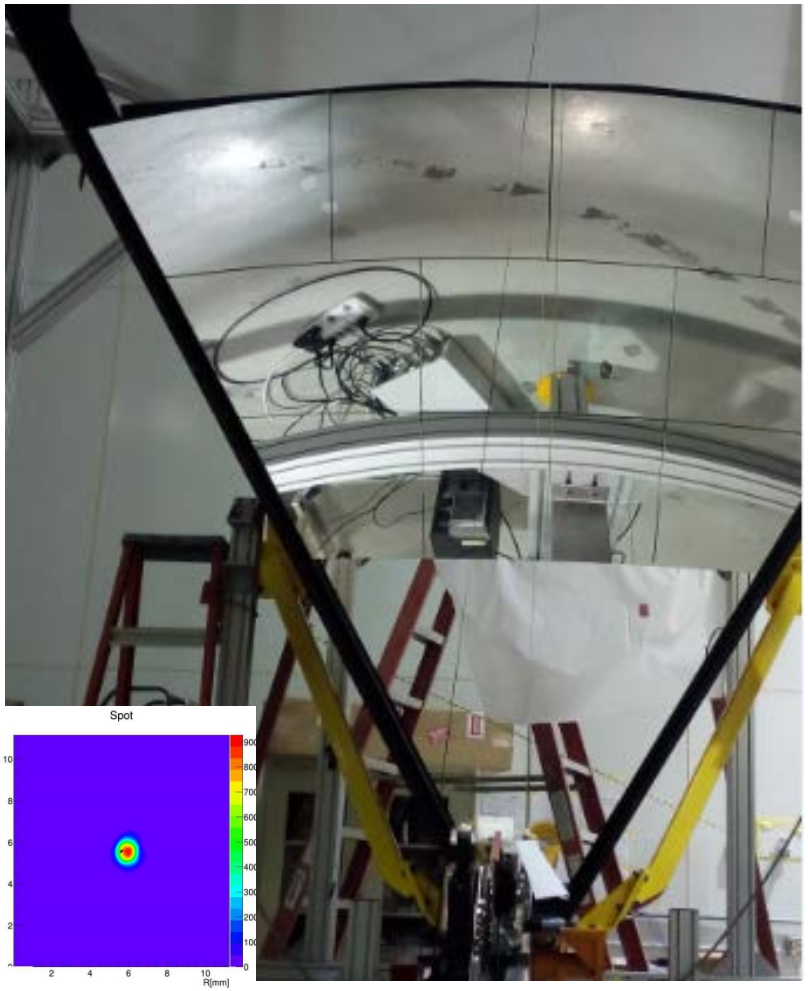
Spherical mirrors: reflectivity

Mirror alignment

Alignment system derived from the technique used for accelerator magnet

- **3 points per mirror**

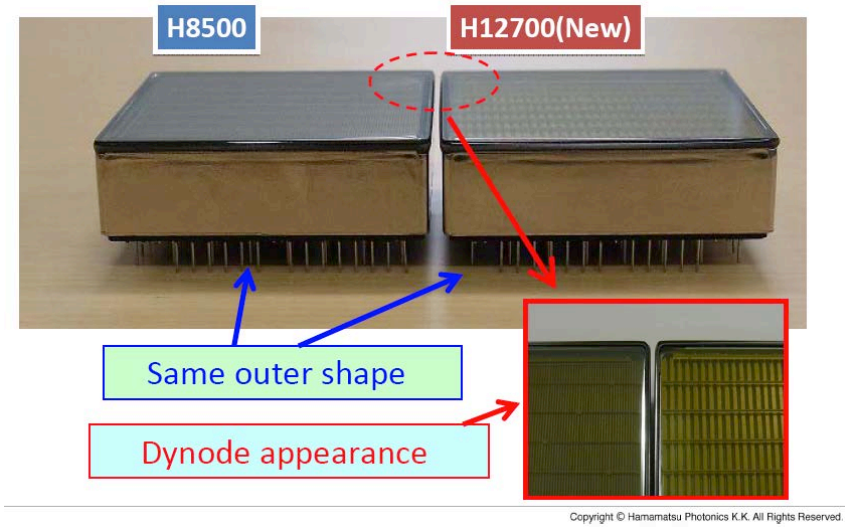




RICH readout

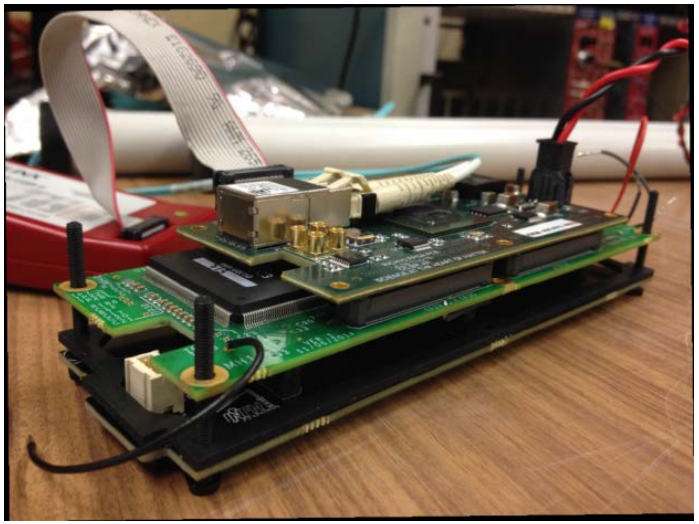
Photomultipliers only available option for visible light detection

- 391 MAPMTs Hamamatsu H8500 and H12700
- large area (5.2x5.2 cm^2) and high packing fraction (89%)
- matrix of 64 6x6 mm^2 pixels
- high visible to near UV light detection efficiency
- fast response
- gain ~ 3 10^6

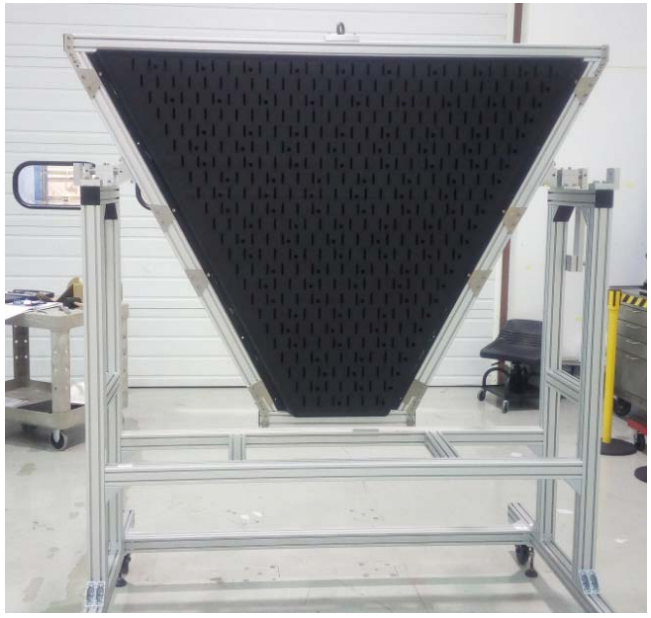


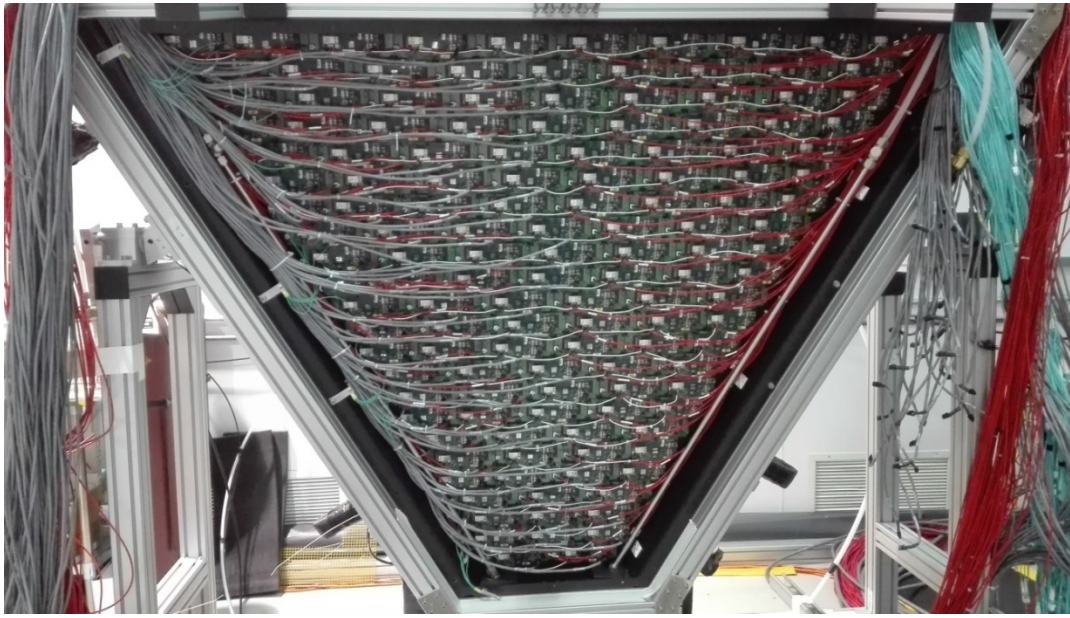
Front-end electronics based on the 64 channel MAROC chip

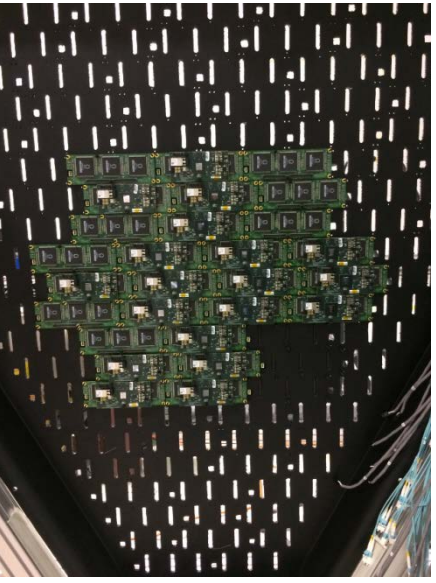
- single channel adjustable preamp
- highly configurable signal shaping
- binary output after fast shaping with adjustable me
- FPGA to configure and readout the chip

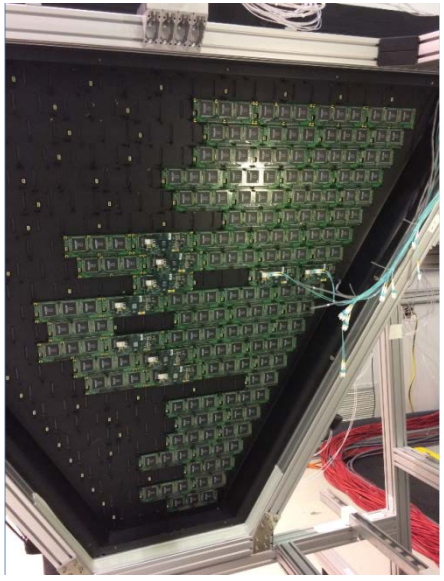


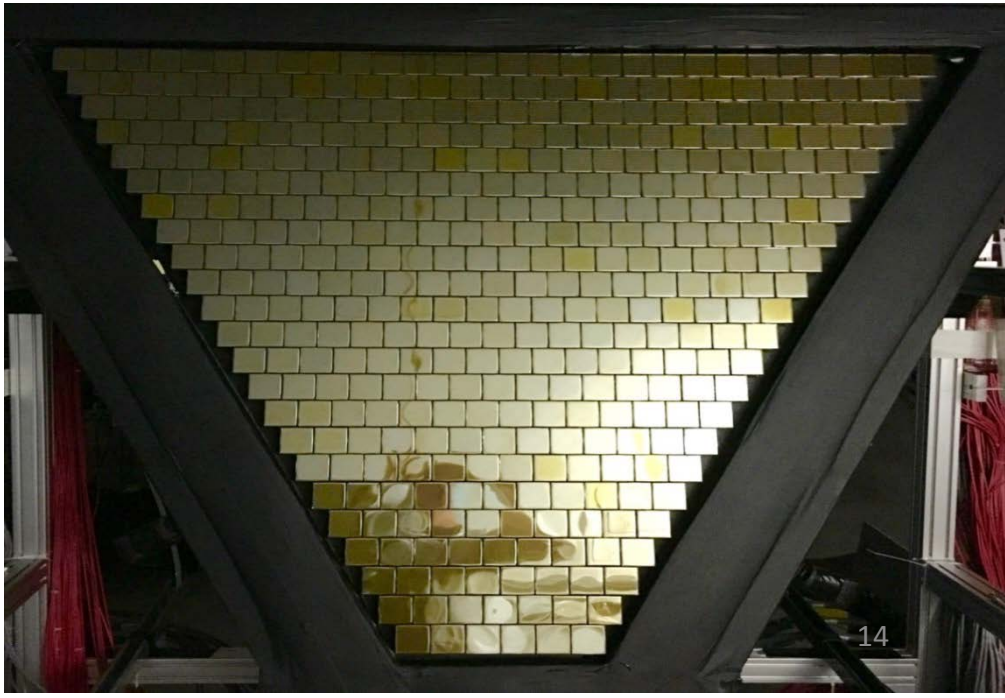
The electronics assembled









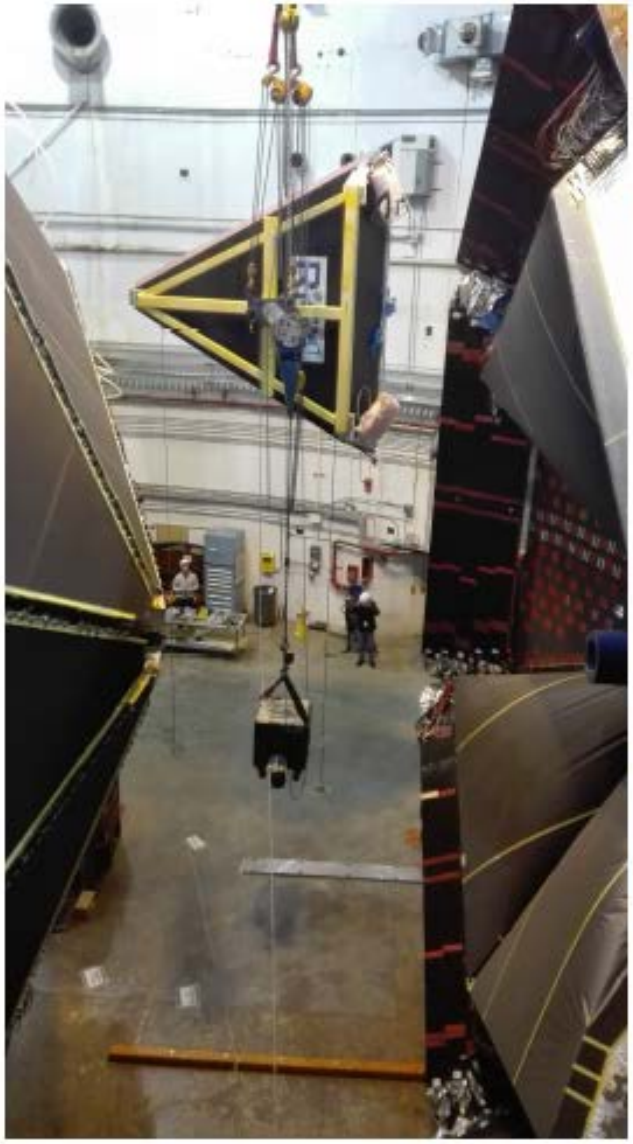


Assembly completed

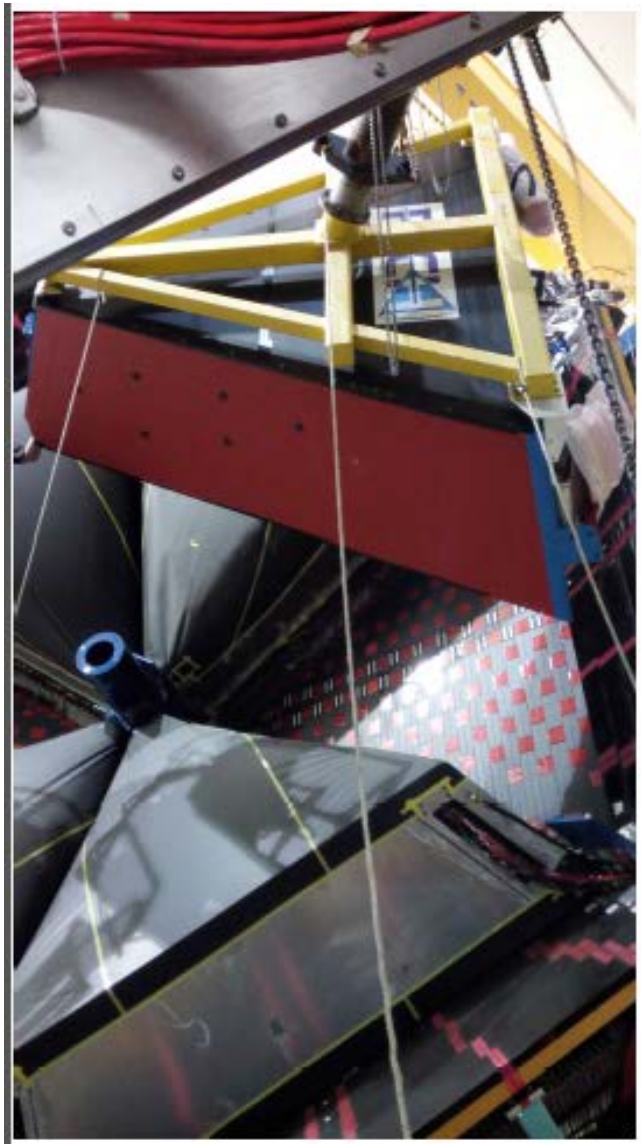
Installation in CLAS12

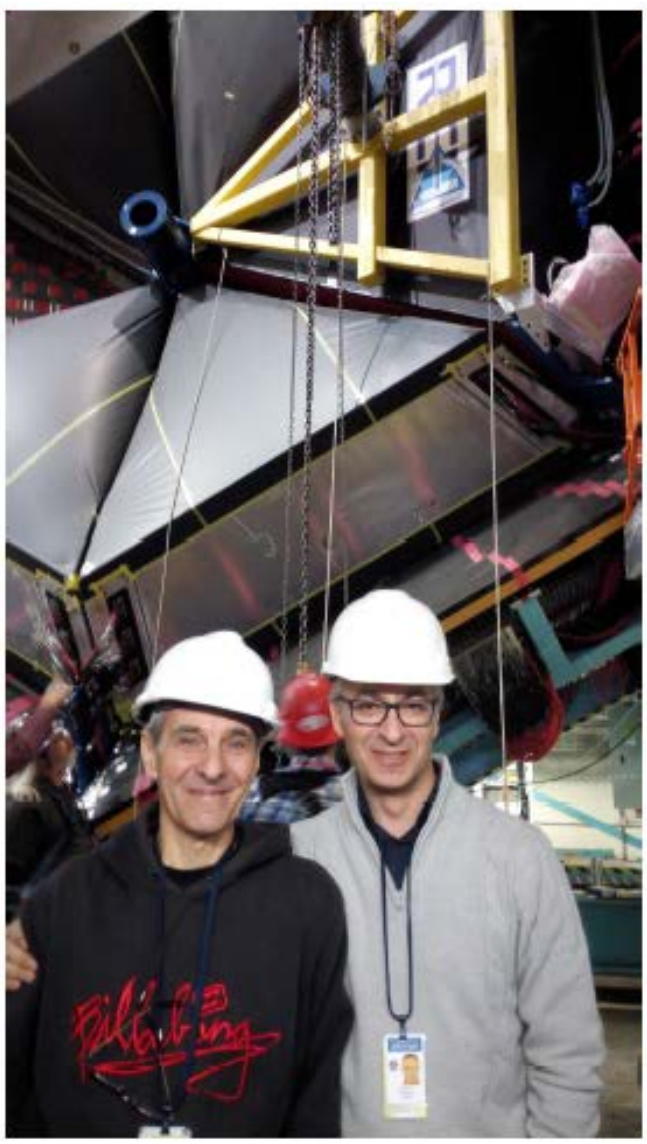
Installation in CLAS12

Installation in CLAS12

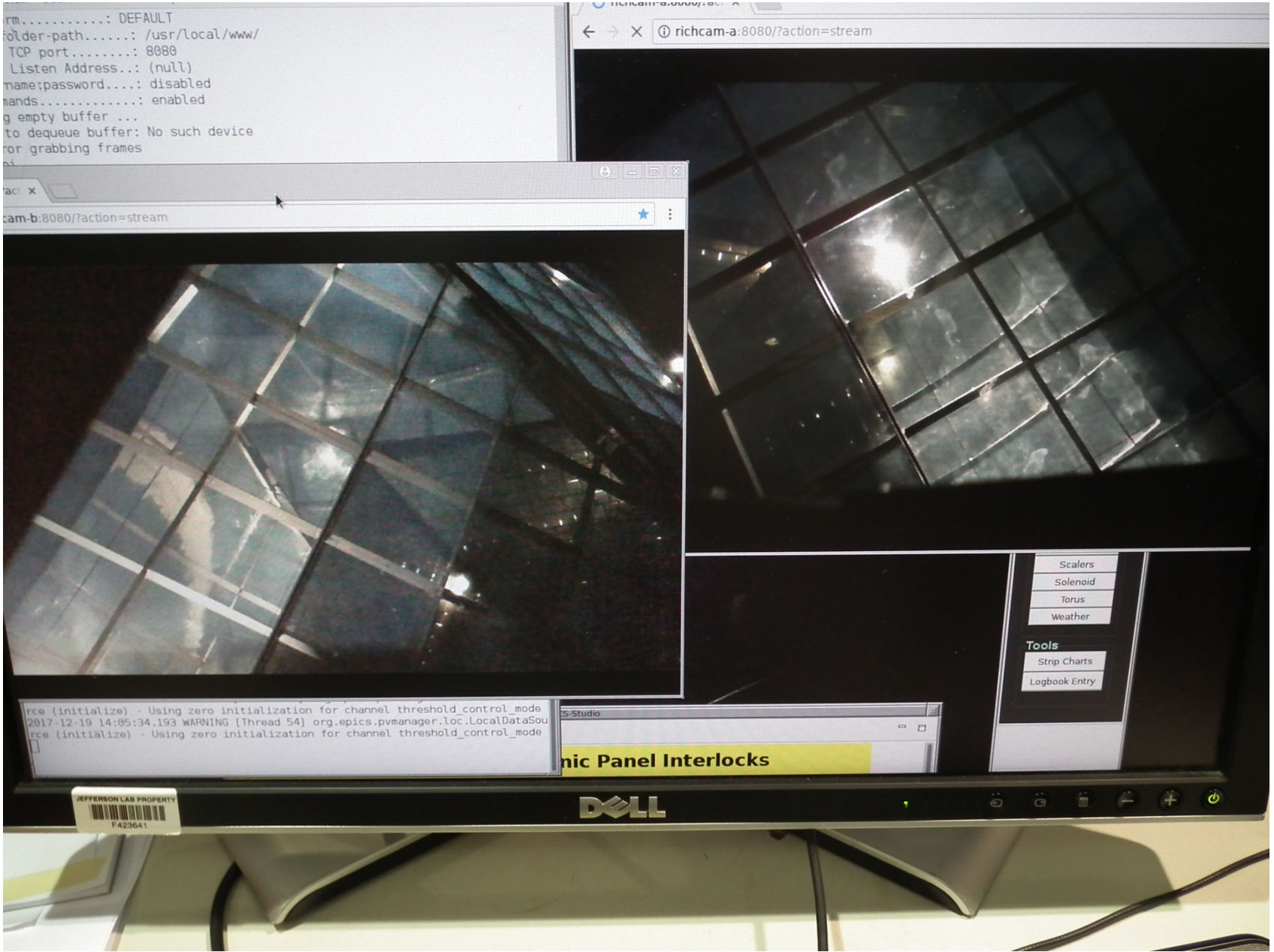


Installation in CLAS12





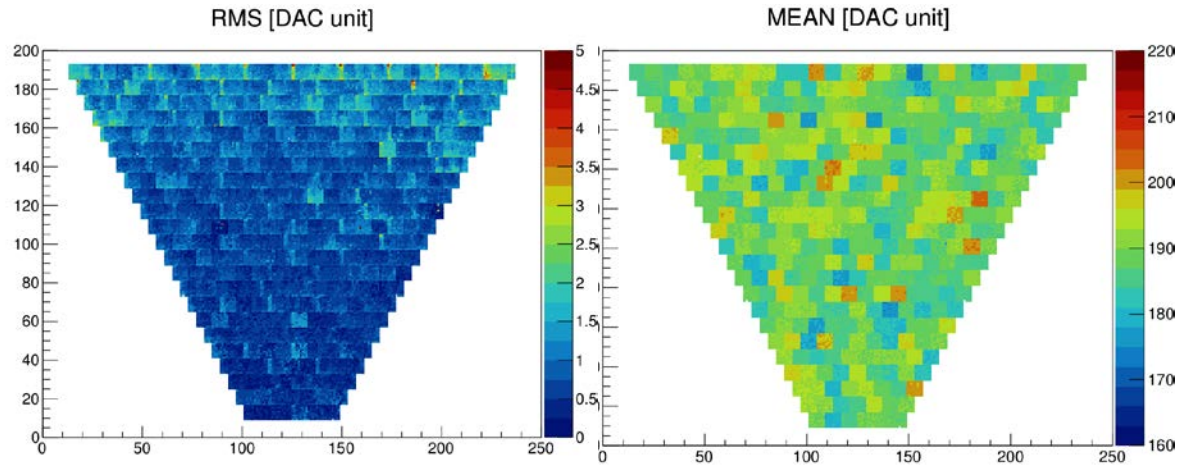
Looking inside the RICH

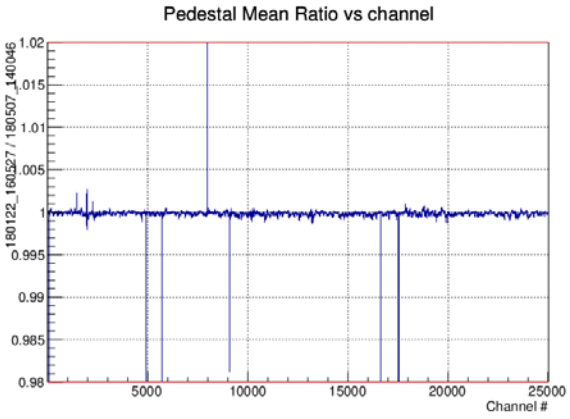


Calibration

Calibration of the 25024 channels using dark noise and scalers

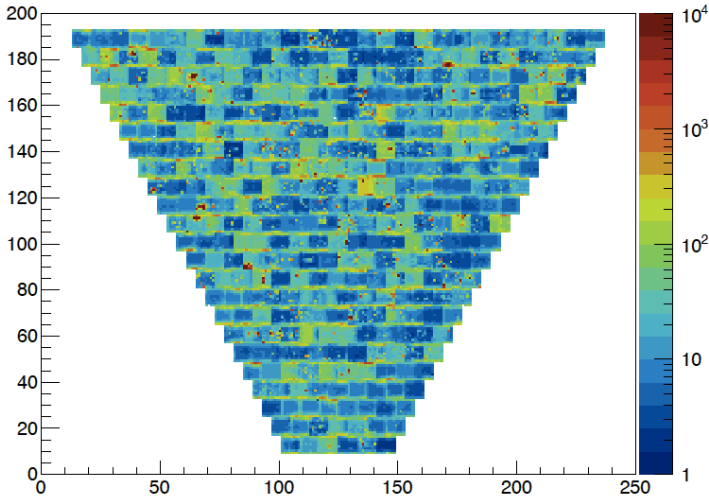
Pedestals





- very narrow (few mV)
- stability better than 0.5% over 4 months

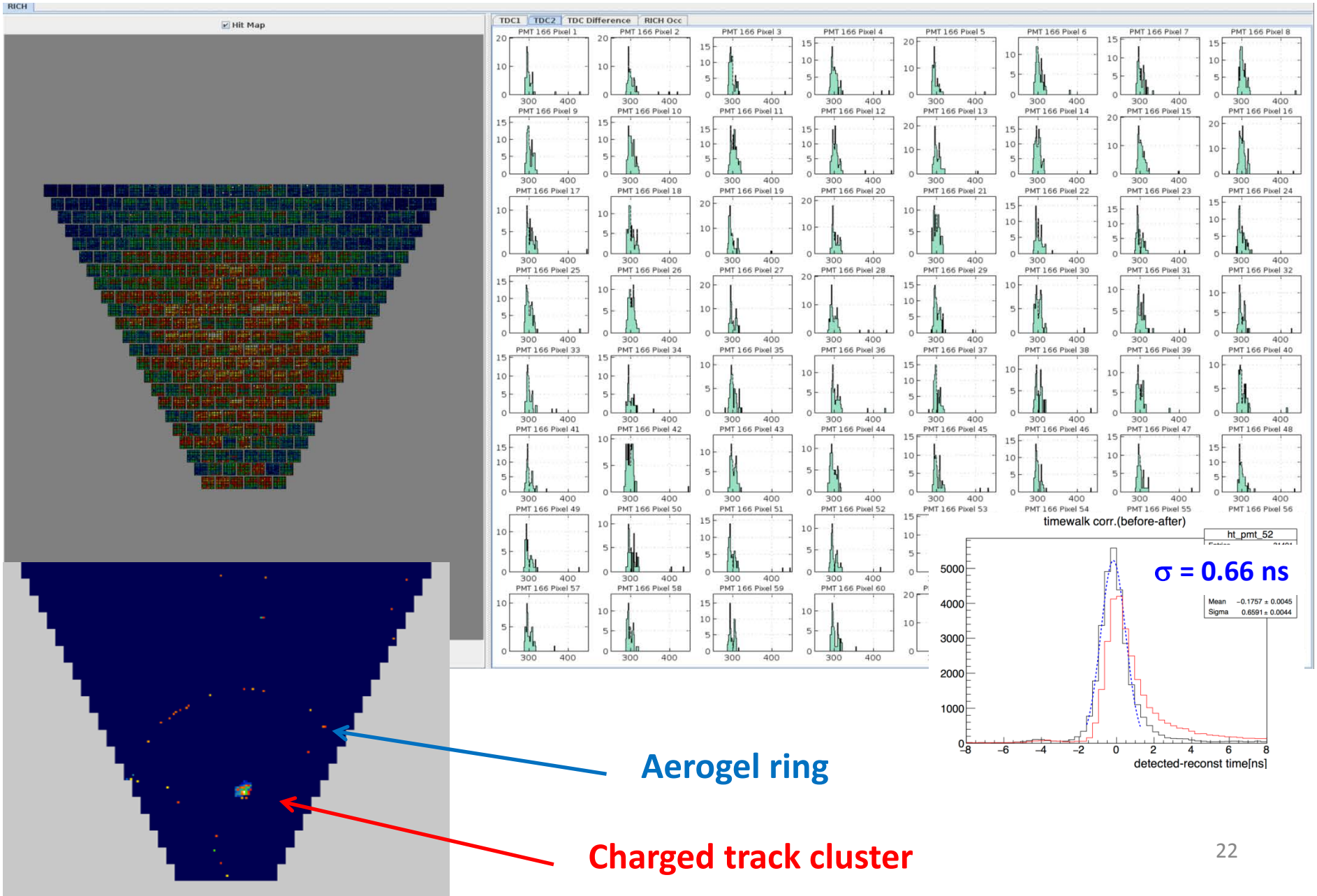
Dark Rate (Hz)



- 99% of the channels with rate < 100 Hz
- few (~10) channels with rate > 10 kHz

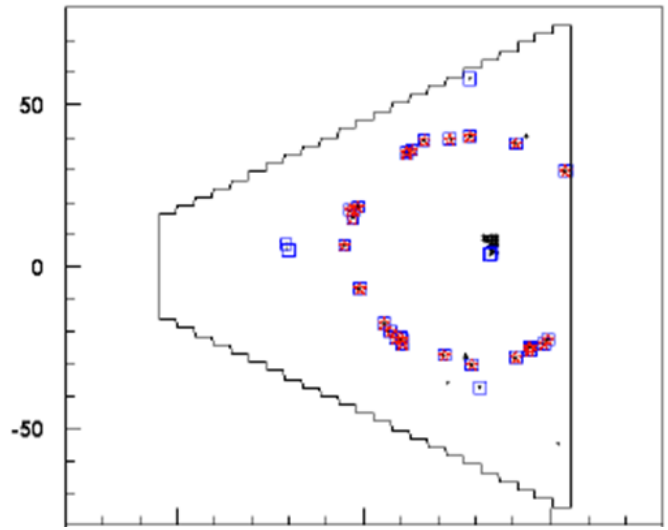
→ *see talk by M. Contalbrigo*

First look at physics data

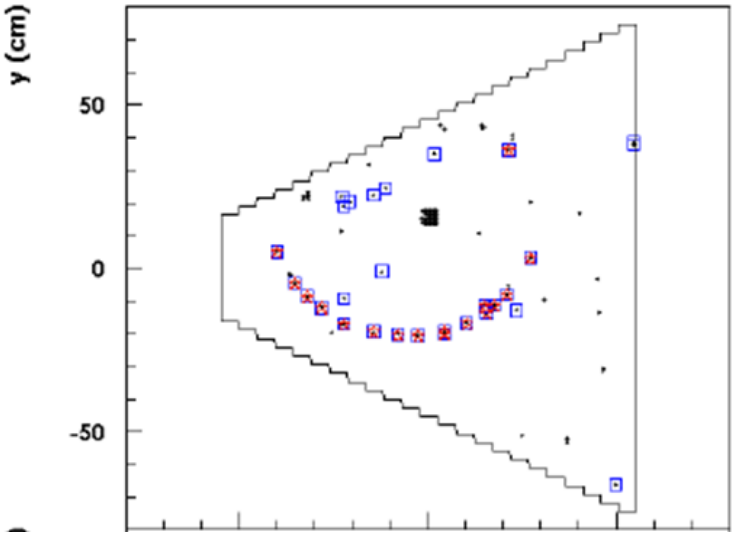


Event reconstruction

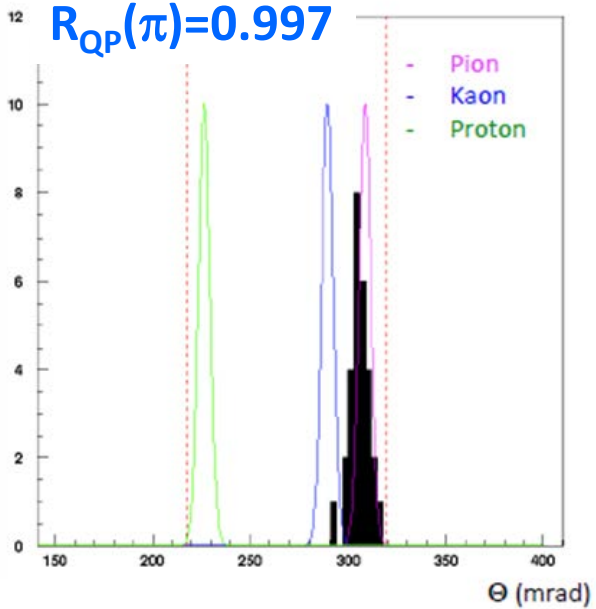
P=4.3 GeV/c



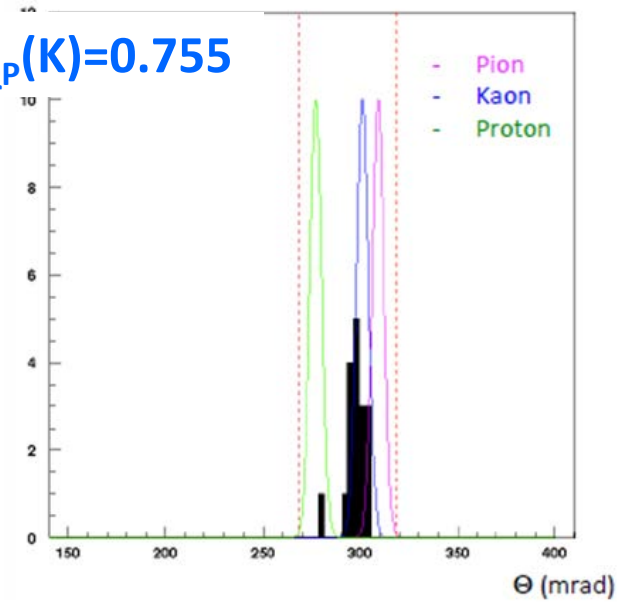
P=6.7 GeV/c



$R_{QP}(\pi)=0.997$



$R_{QP}(K)=0.755$

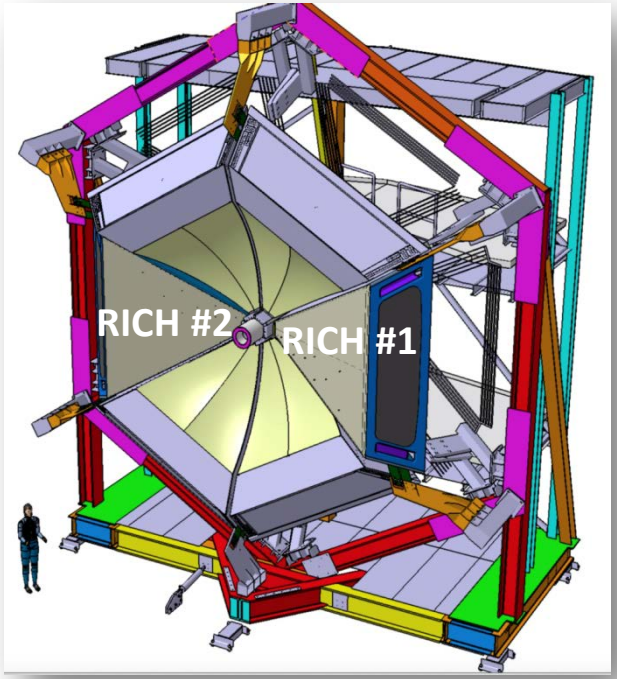


Outlook

- The first module of the CLAS12 RICH has been installed in January 2018
- All the active components met the specifications
- The RICH has taken data for 4 months without any major problem
- First look at physics data is promising
- Next physics run begins in August

The construction of the second RICH module is underway

- **same design of the first module**
- **expected installation not before 2020**

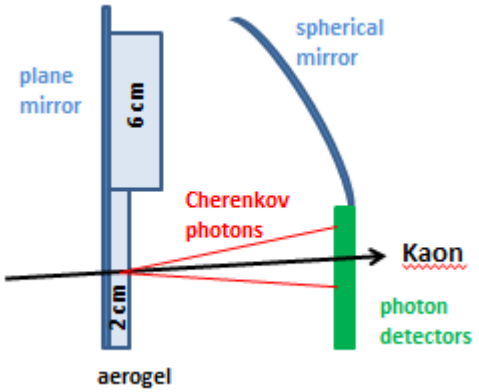


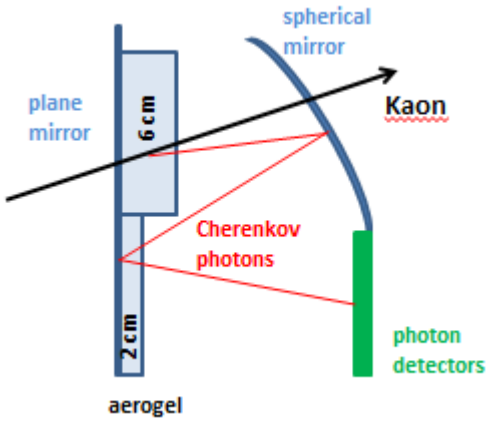
backup slides

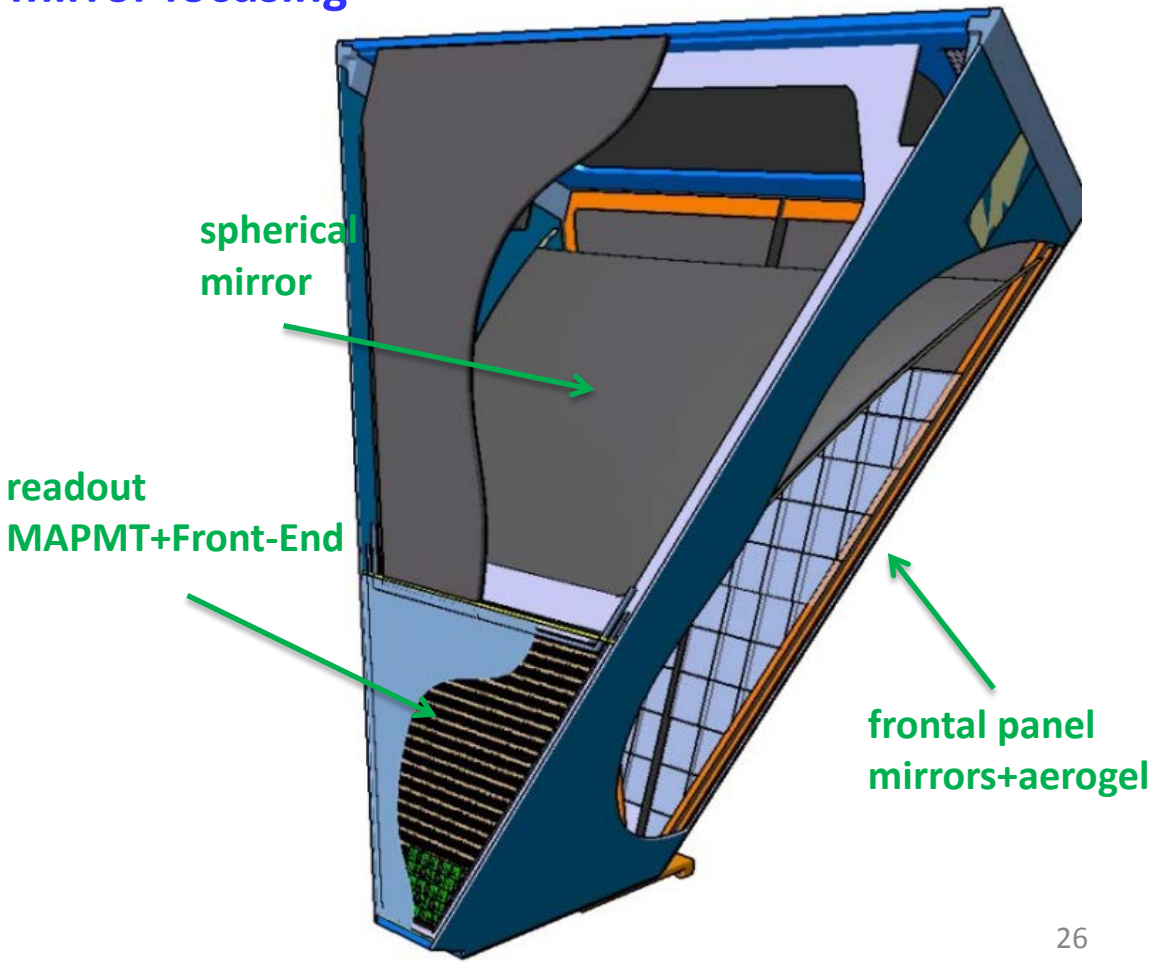
The RICH design

The goal of the detector is to separate kaons from pions and protons in the momentum range 3-8 GeV/c with rejection power > 500

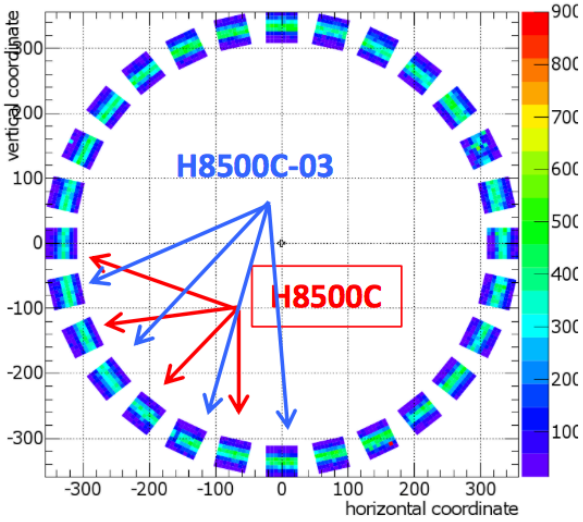
- Aerogel radiator to match the momentum range
- Hybrid optics: proximity and mirror focusing
- Multi-Anode PMTs



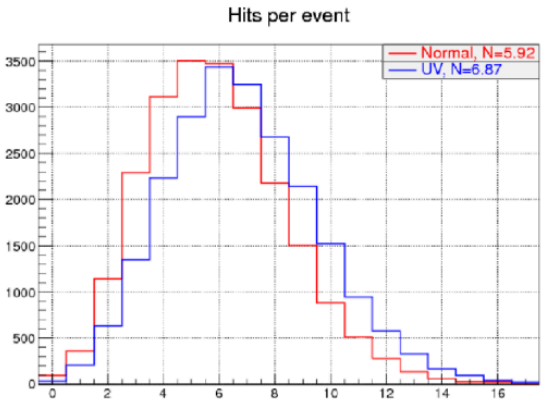


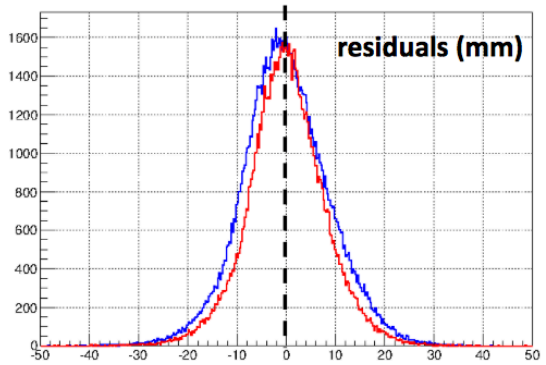


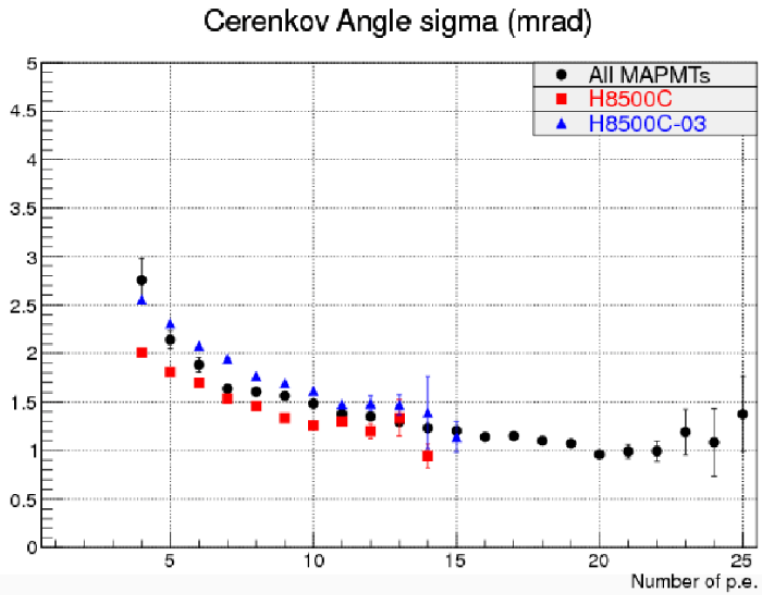
UV photons



14+14 MAPMT with normal/UV glass in alternated positions
Compare ring reconstruction







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

Photon detection requirements

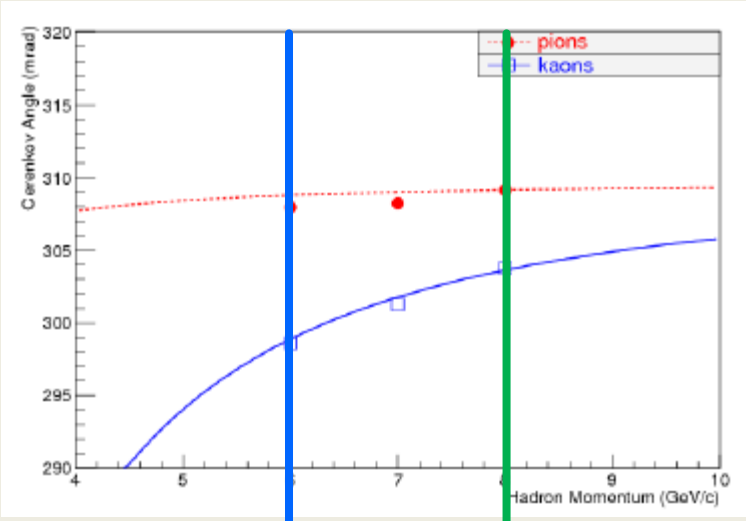
The RICH particle ID capabilities are determined by

- **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}



6 GeV
Δθ~10 mrad

8 GeV
Δθ~5 mrad

- **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

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
Readout 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

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

Minimum required number of p.e.

Validated with prototype data

From Lab. studies

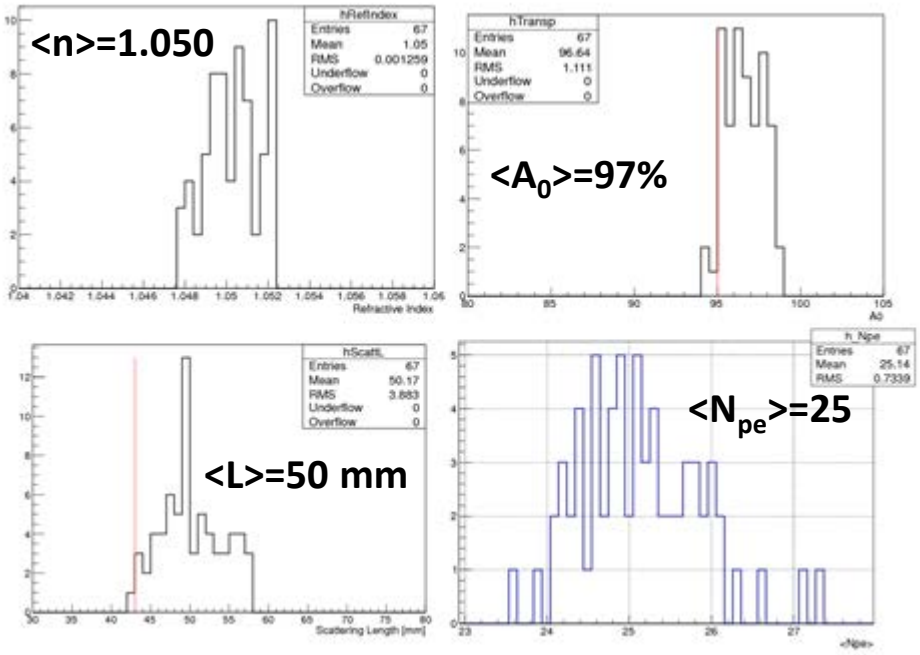
Similar single photon resolutions for the direct and reflected case
A factor of ~3 less yield in the reflected case but larger angular separation
➔ comparable π/K rejection power

Aerogel properties

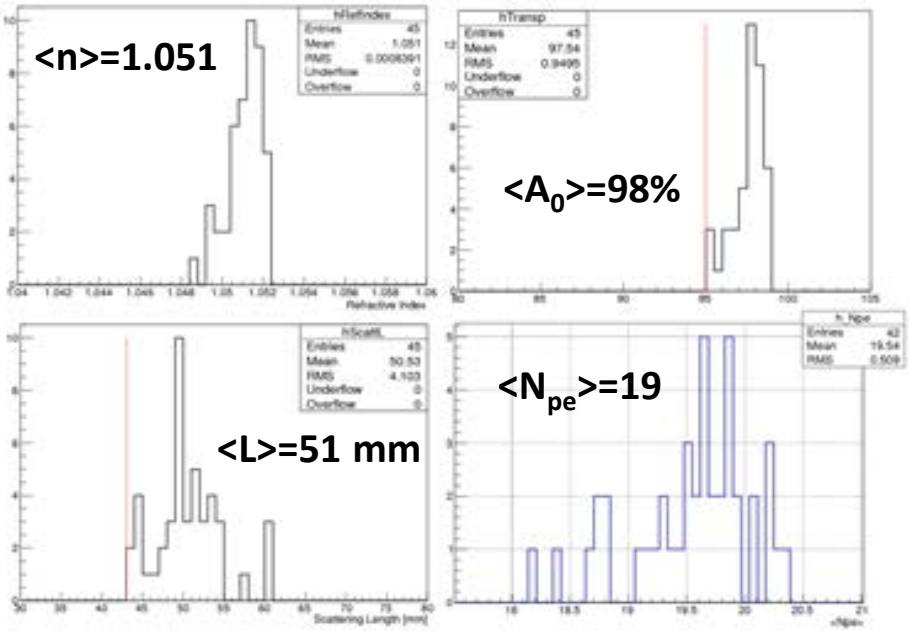
Technical specifications

ref. index: 1.05+/-0.2%
scattering length: L > 43 mm
transparency coefficient: A0 > 95 %

3 cm thickness



2 cm thickness



C ~ 0.0052 μm⁴/cm

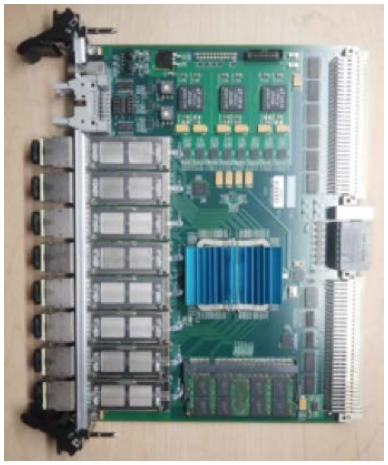
RICH services

HV & LV

CAEN SY4527 power supply

DAQ

SSP with optical link



FE cooling system

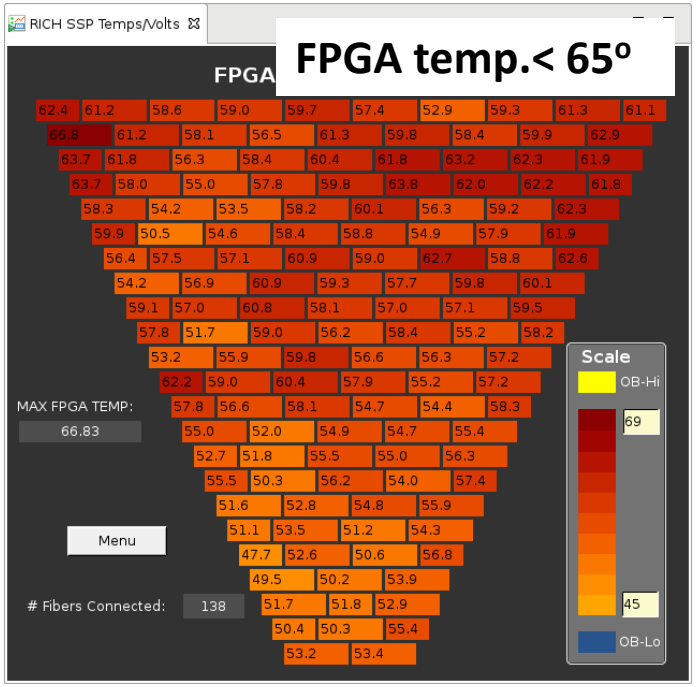
High power compressor, large capacity tank

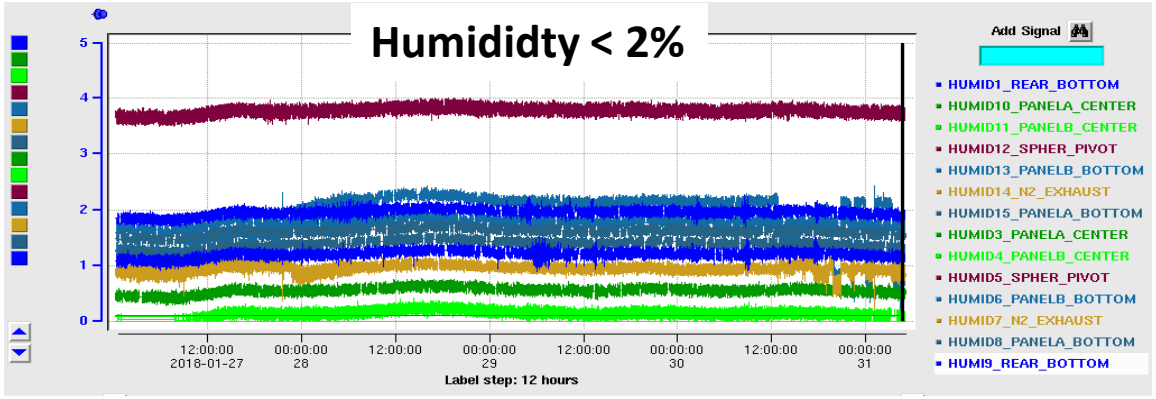
Nitrogen flow system

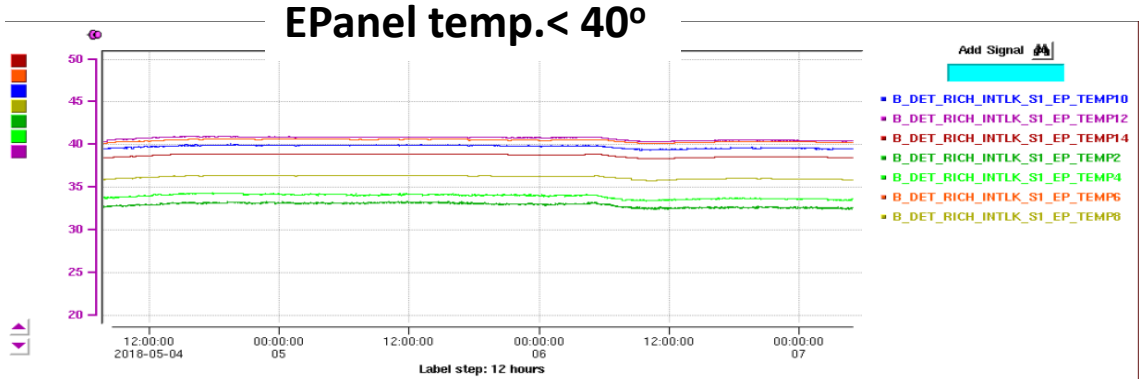
High purity dry N2 supply, emergency backup system

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**



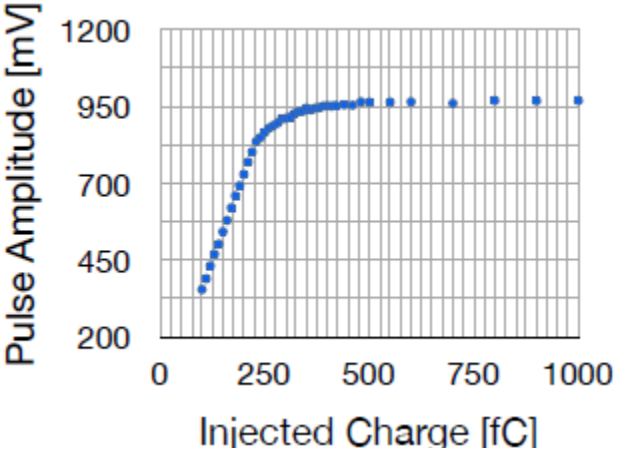


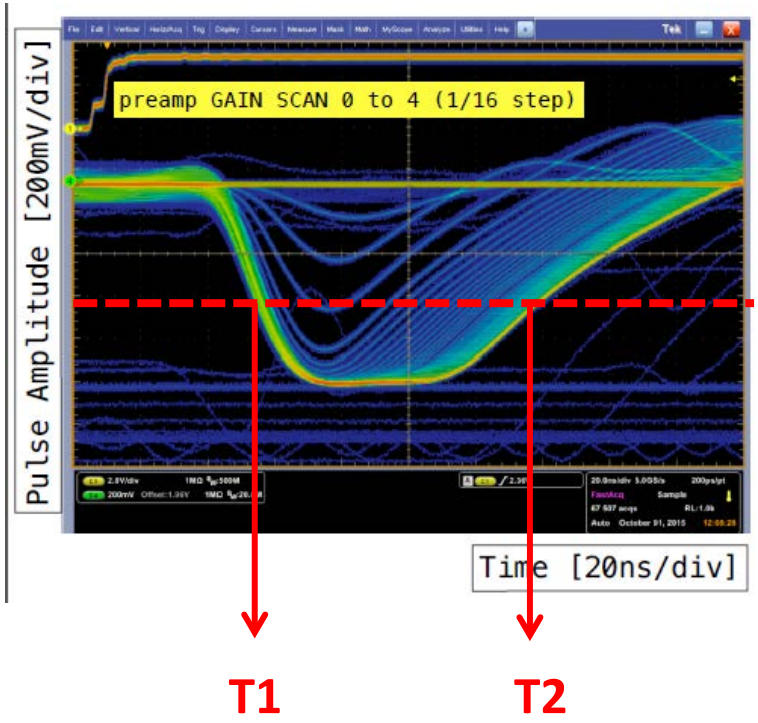


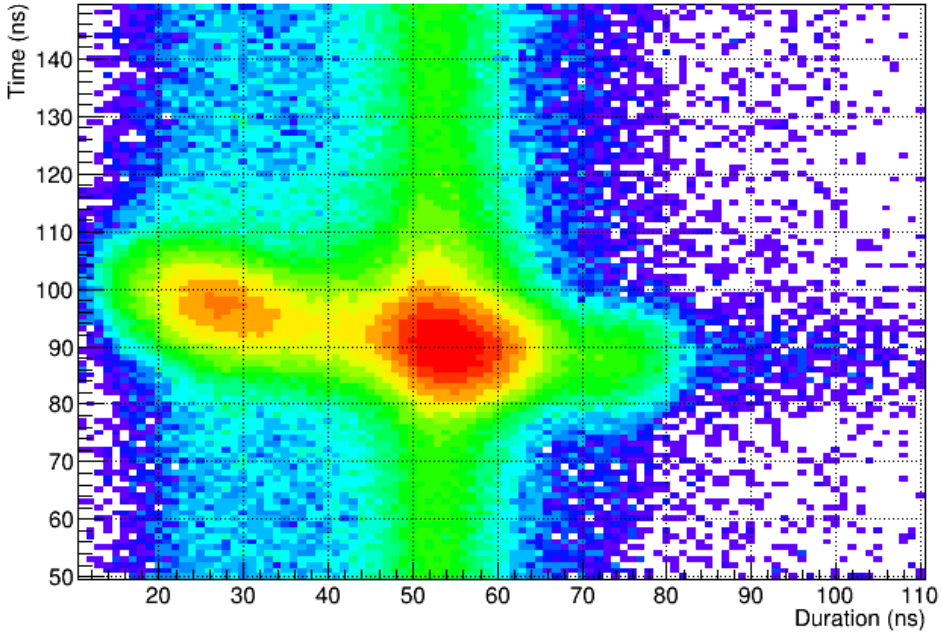
RICH readout

- 391 MultiAnode PMTs grouped in 138 tiles (x2 or x3)
  One MAROC readout chip per MAPMT
- Binary readout on 25024 independent channels

- Fast shaper and preamplifier on each channel
- Adjustable threshold on each chip







RICH timing per channel

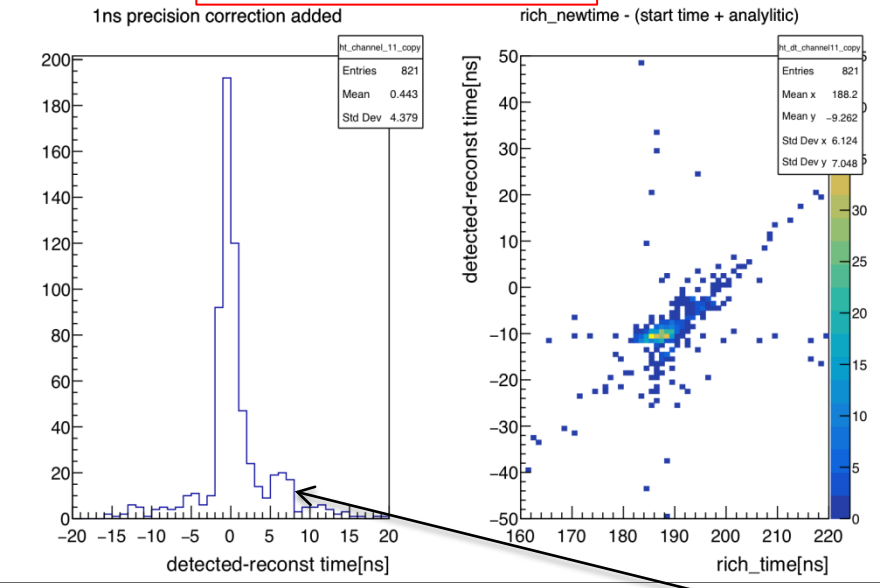
RICH time resolution:

$$\Delta T = T_{meas} - T_{exp}$$

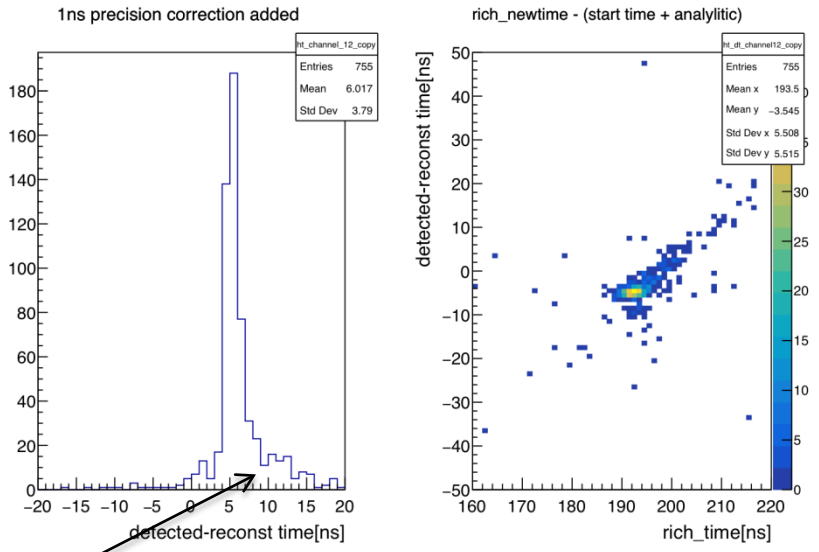
T_{meas} = measured RICH time

T_{exp} = expected RICH time (from CLAS12)

PMT 178 pixel 11



PMT 178 pixel 12

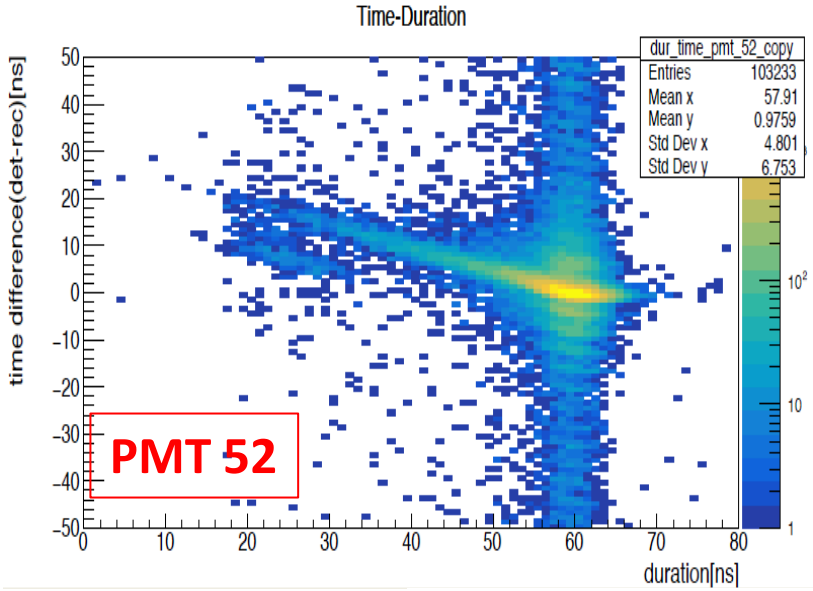


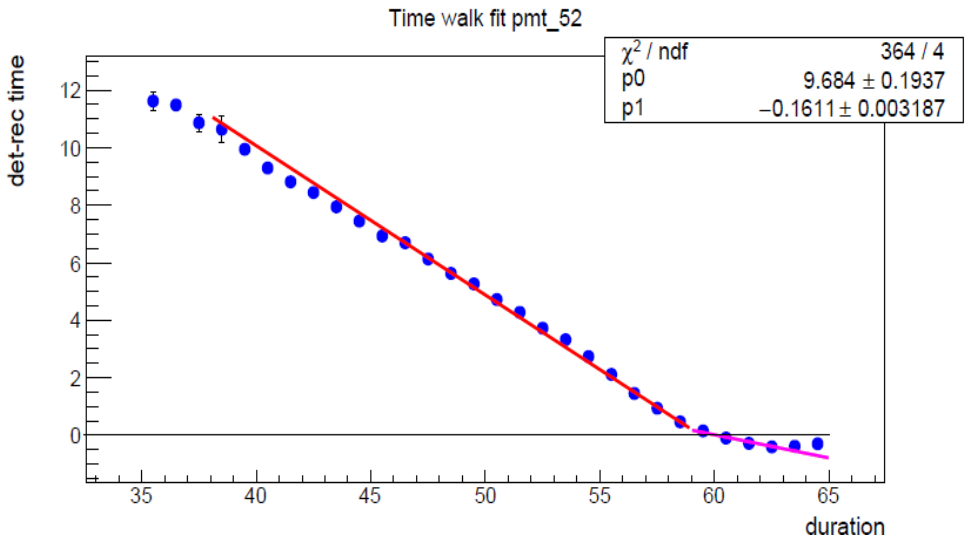
time walk

Channel-by-channel offset to bring the average ΔT to 0

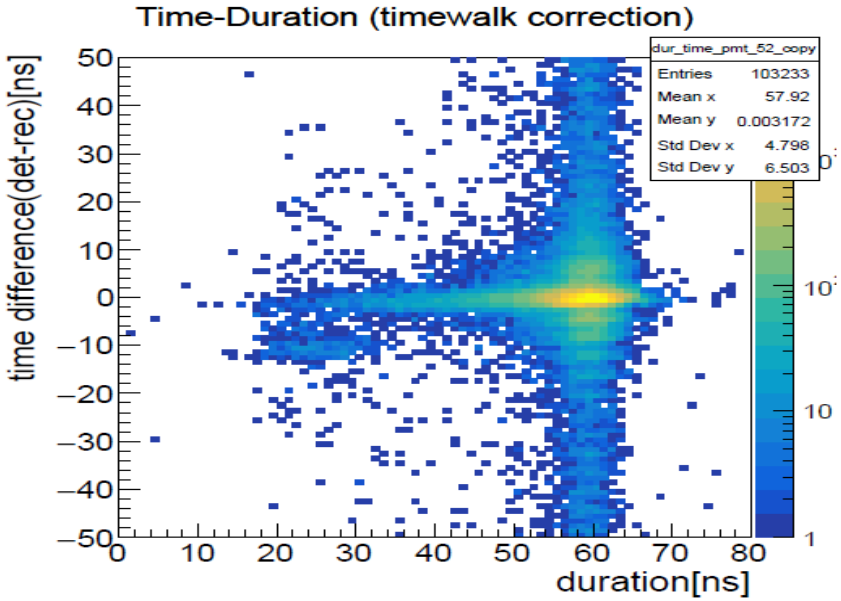
Time walk correction

Time vs duration for 1 PMT after time offset correction





After correction



Present time calibration constants:

- **25024 time offsets**
- **391 time-walk correction functions**

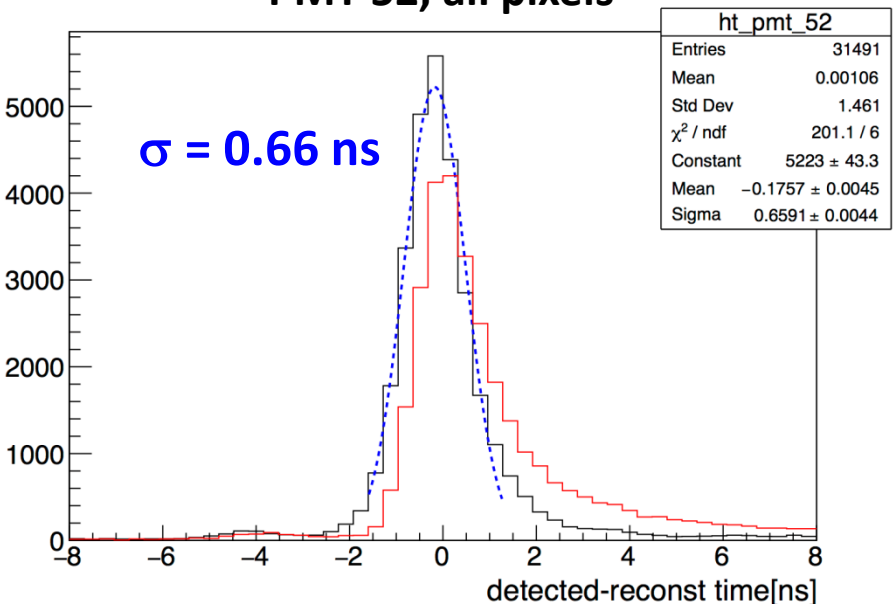
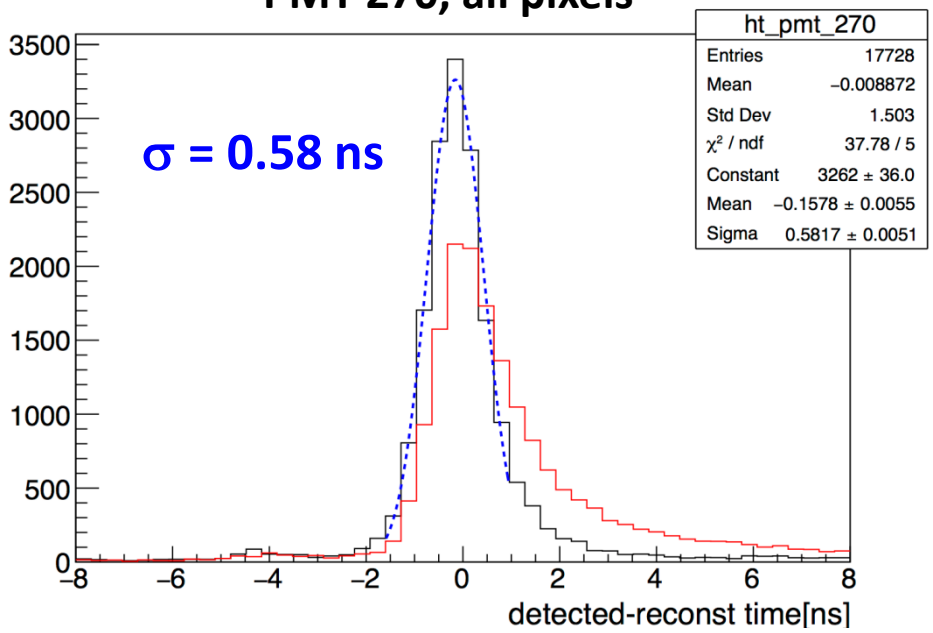
RICH time resolution

- Time information to distinguish direct from reflected photons
- Time resolution goal: σ < 1 ns

RED: before corrections

BLUE: after correction

PMT 52, all pixels



PMT 270, all pixels