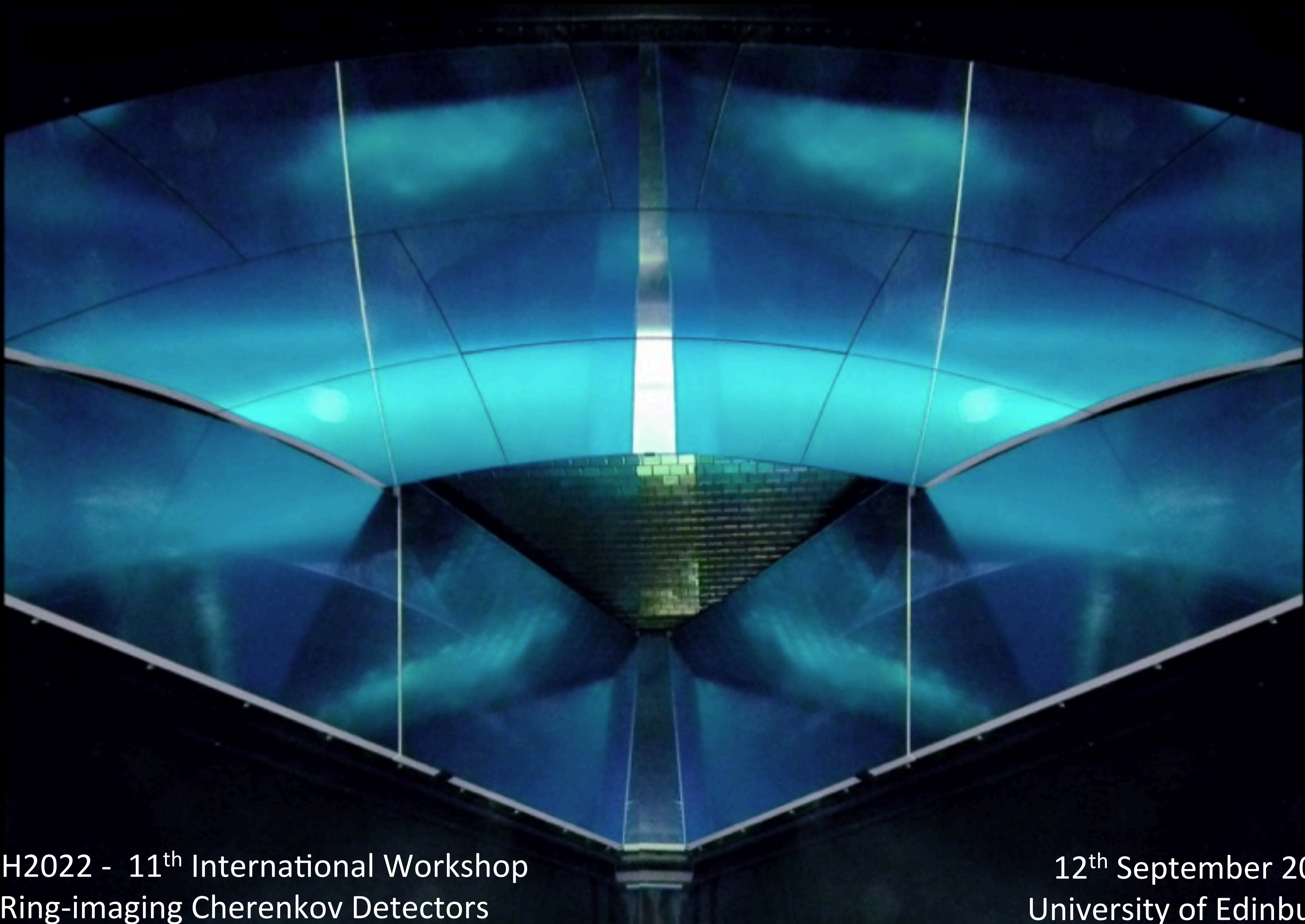
The Large-area Hybrid-optics CLAS12 RICH: First years of Data-Taking

M. Contalbrigo – INFN Ferrara – on behalf of the CLAS12 RICH group

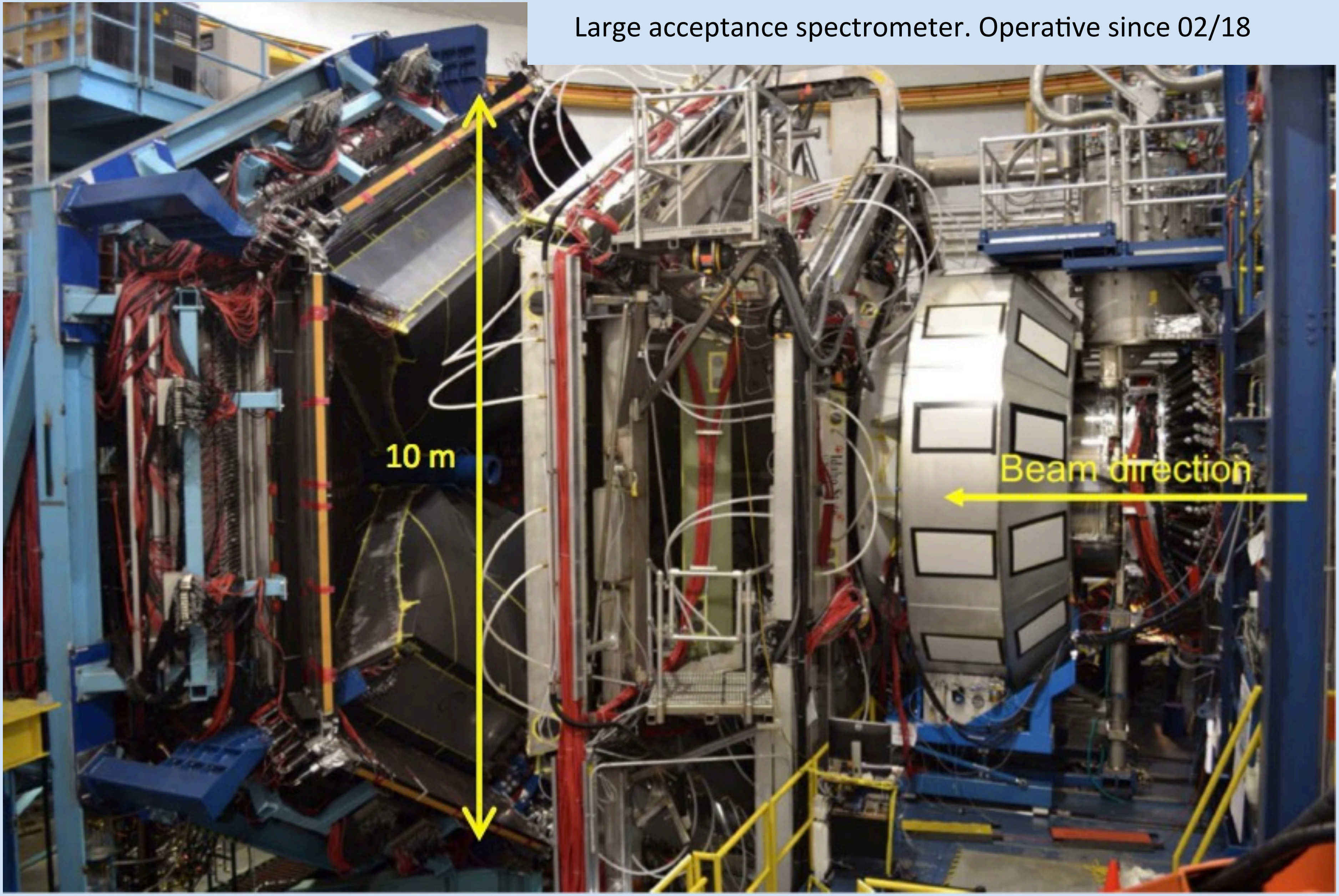


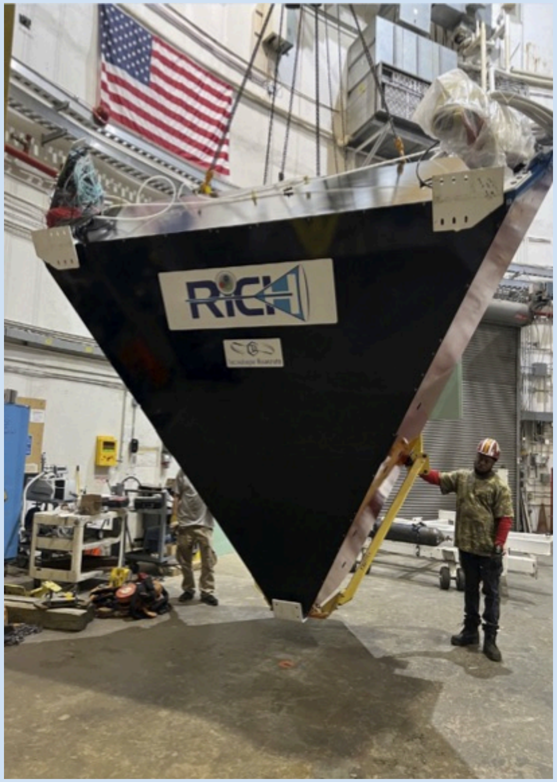
RICH2022 - 11th International Workshop on Ring-imaging Cherenkov Detectors

12th September 2022, University of Edinburgh

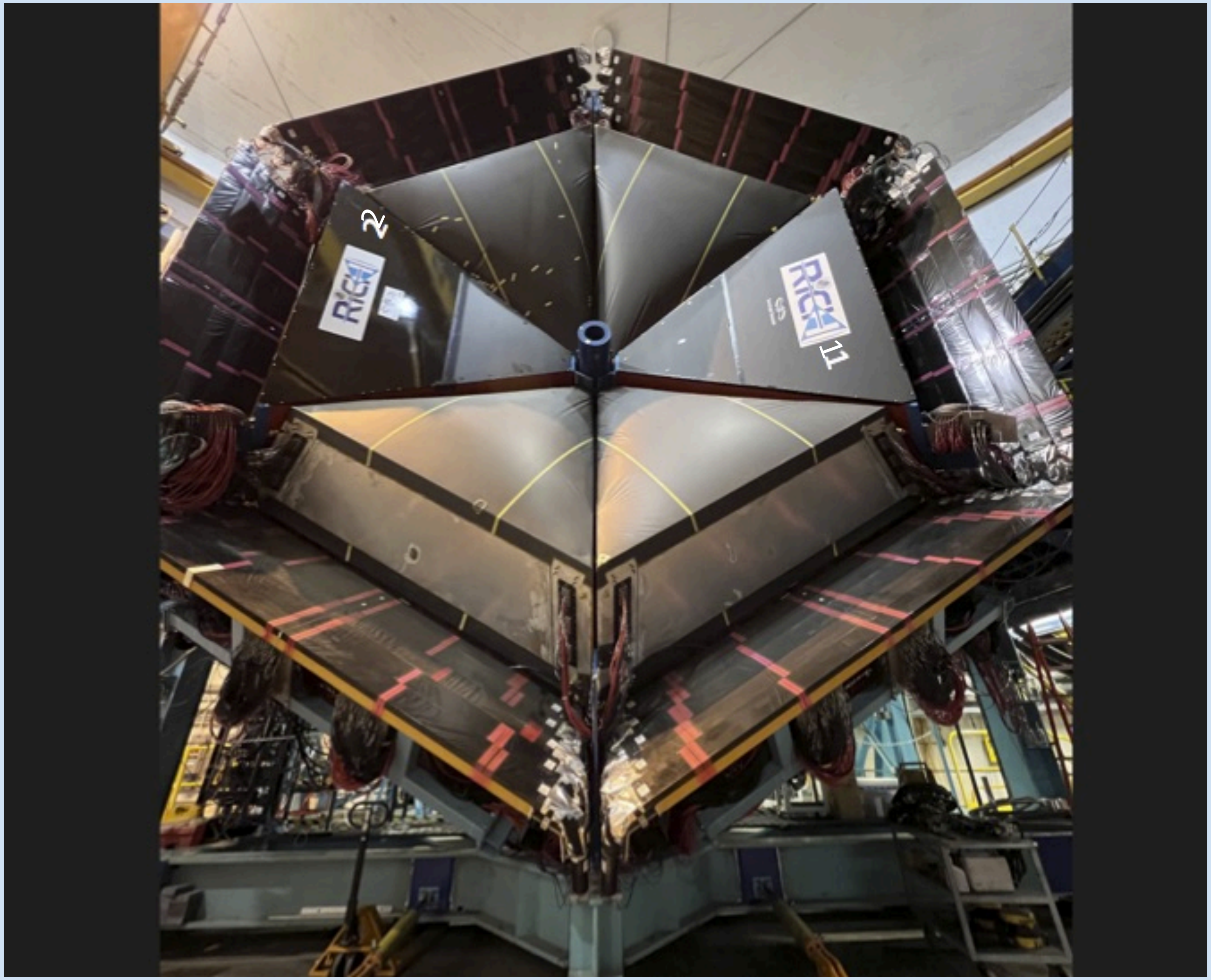
CLAS12

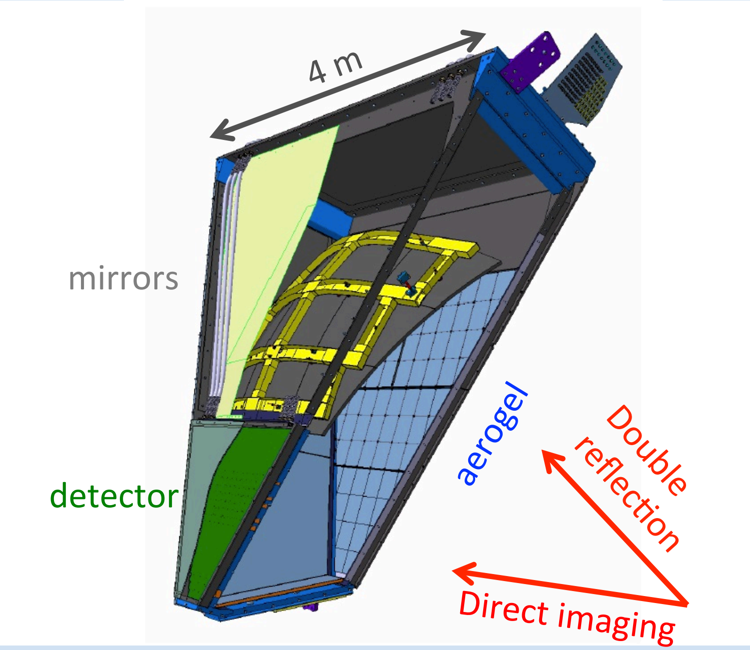
Large acceptance spectrometer. Operative since 02/18





Completed in June 2022 with the symmetric configuration dedicated to the runs with polarized targets (now ongoing)

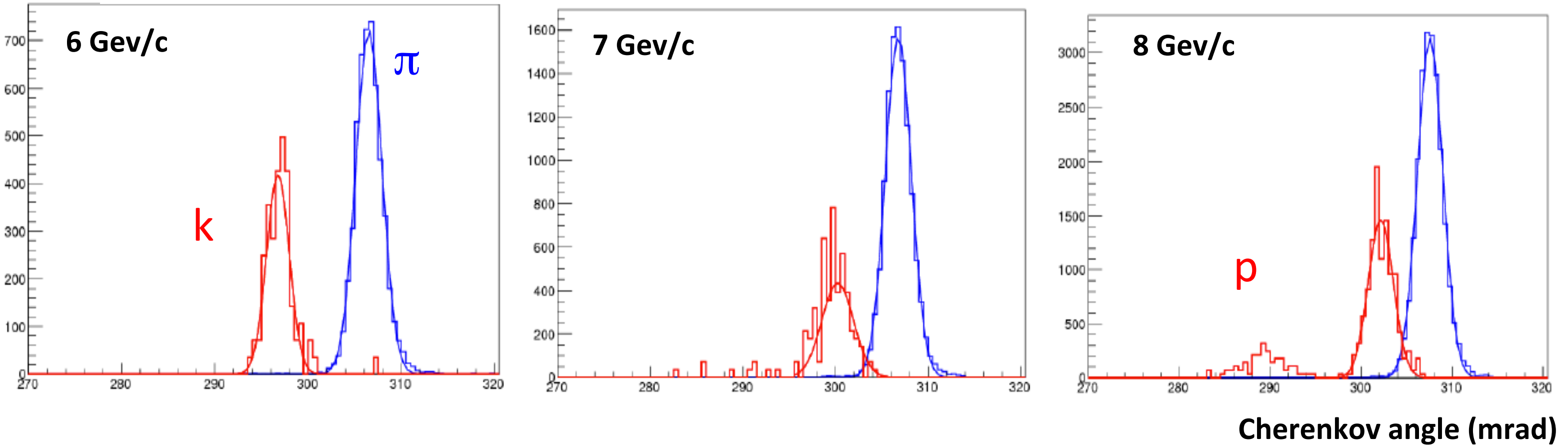




INSTITUTIONS
INFN (Italy) Bari, Ferrara, Genova, L.Frascati, Roma/ISS
Jefferson Lab (Newport News, USA)
Argonne National Lab (Argonne, USA)
Duquesne University (Pittsburgh, USA)
George Washington University (USA)
Glasgow University (Glasgow, UK)
Kyungpook National University, (Daegu, Korea)
University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

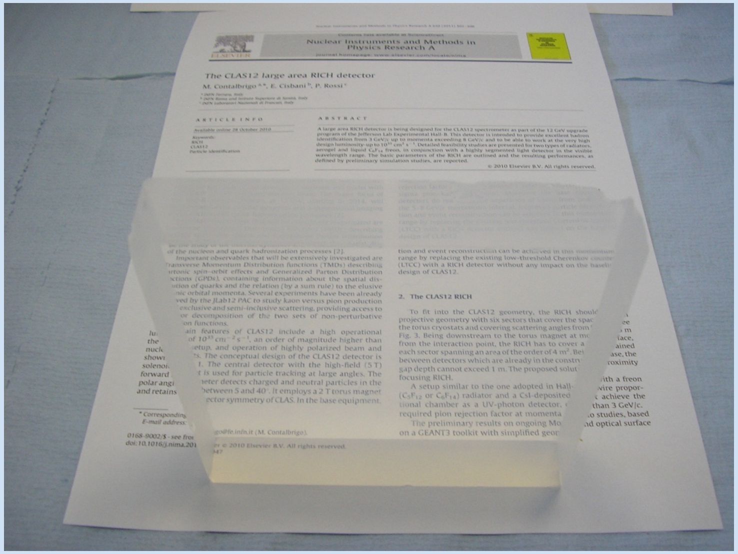
Goal kaon-pion separation up to 8 GeV/c (prototype results):

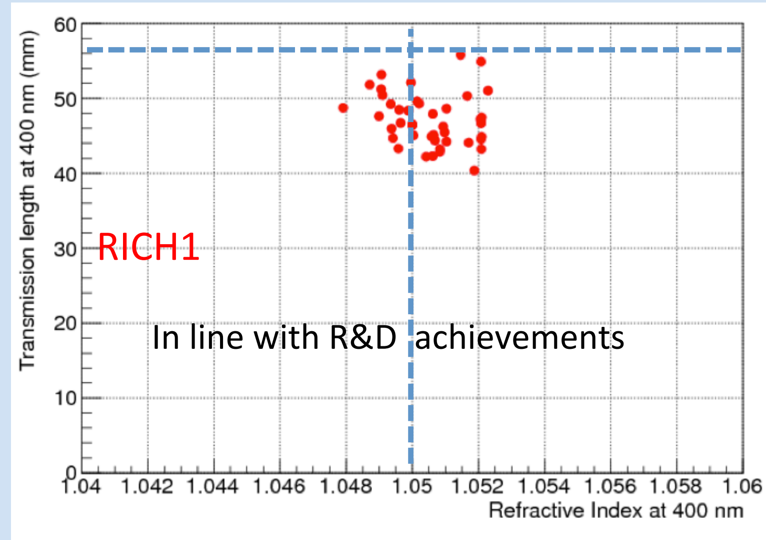
@RICH2013



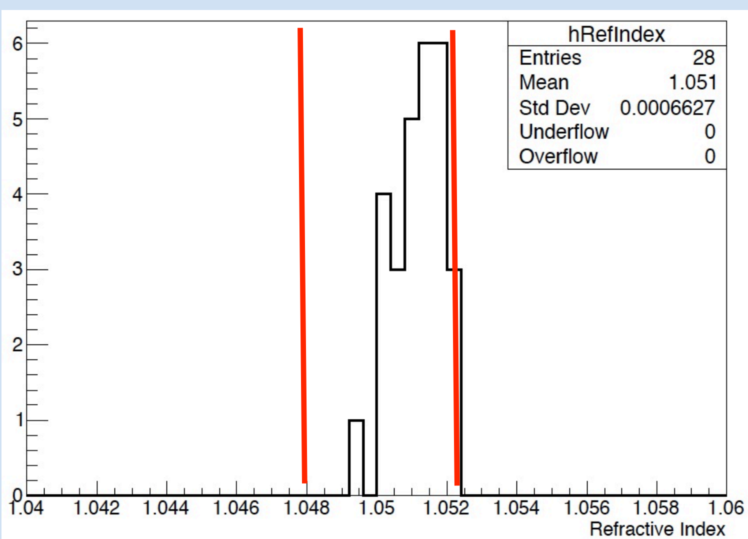
Aerogel

n=1.05, 20x20x3 cm^3 aerogel tiles produced by the Budker and Boreskov Institutes of Novosibirsk

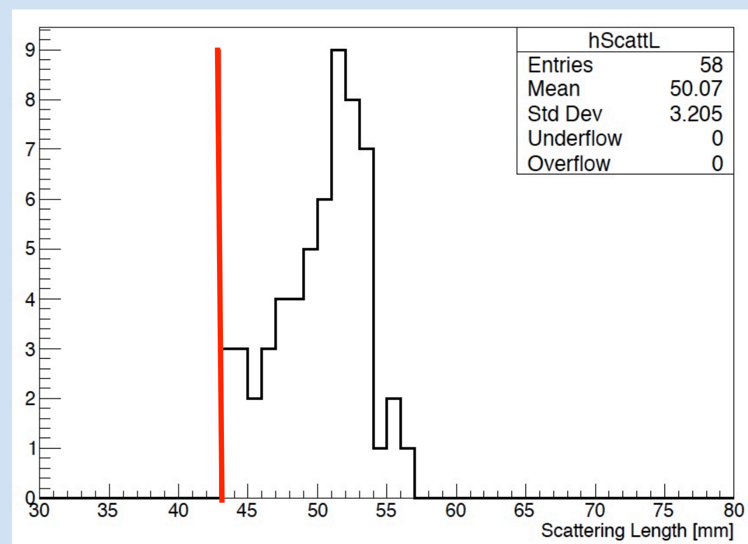




RICH2 – 2 cm layer

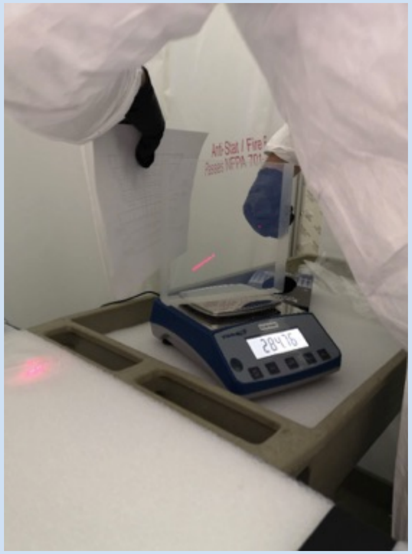
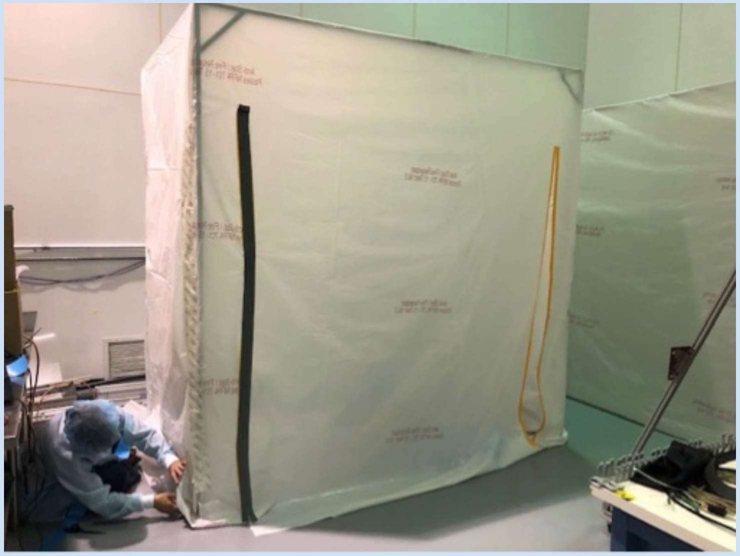
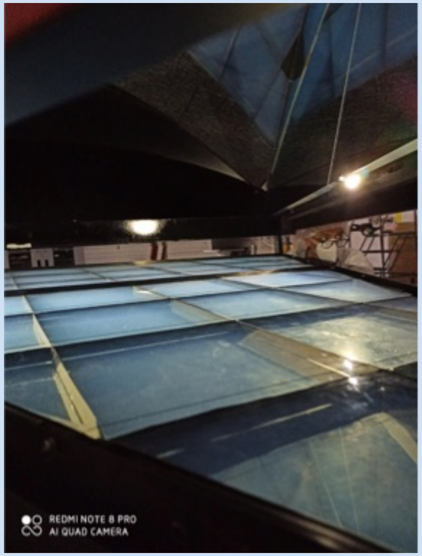


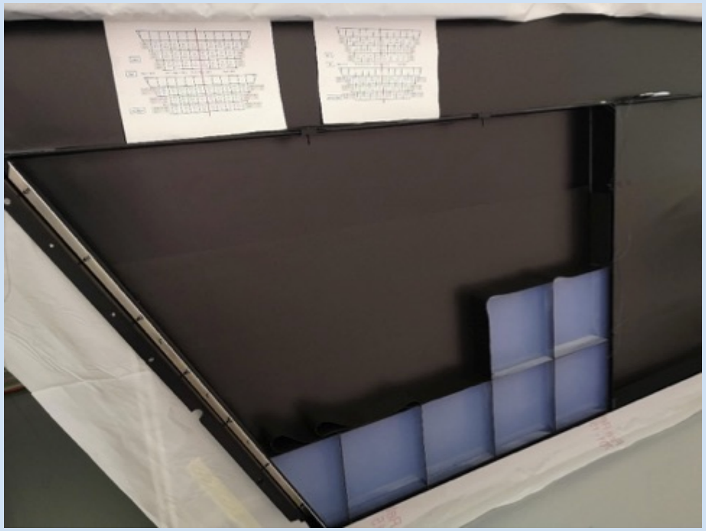
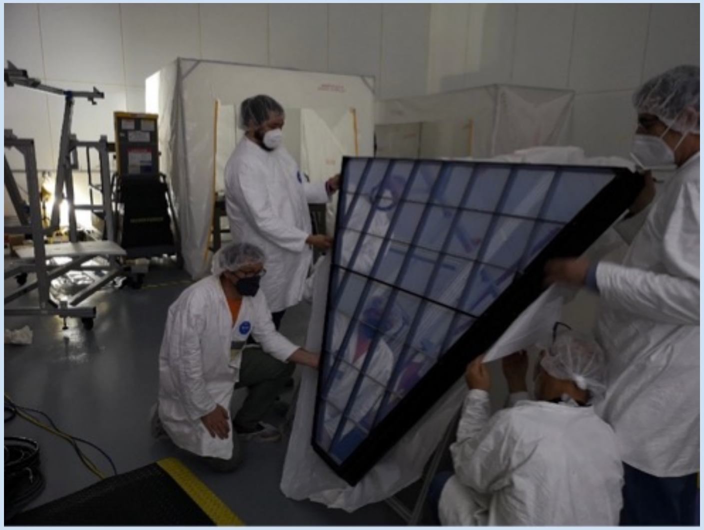
RICH2 – 3 cm layer



Aerogel Assembling

Hydrophilic & shaped by machine cutting: handling care, mechanically and optically isolated by thin foam strips

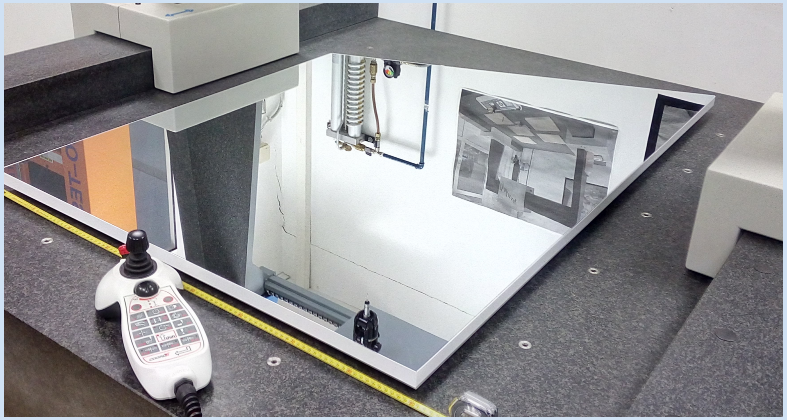




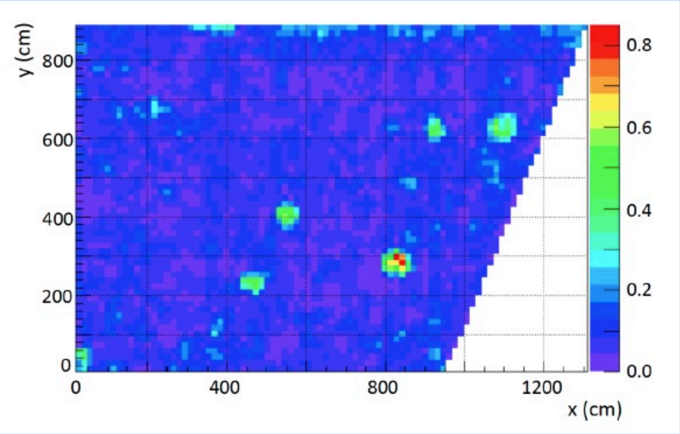




Glass-Skin Mirrors (planar) - Media-Lario, IT

Innovative technology never used in nuclear experiments (foils of 1.5 mm outside, 0.7 mm inside acceptance)

~ 1/5 cost for squared meter vs CFRP, surface defects (from dust on mold) within specifications

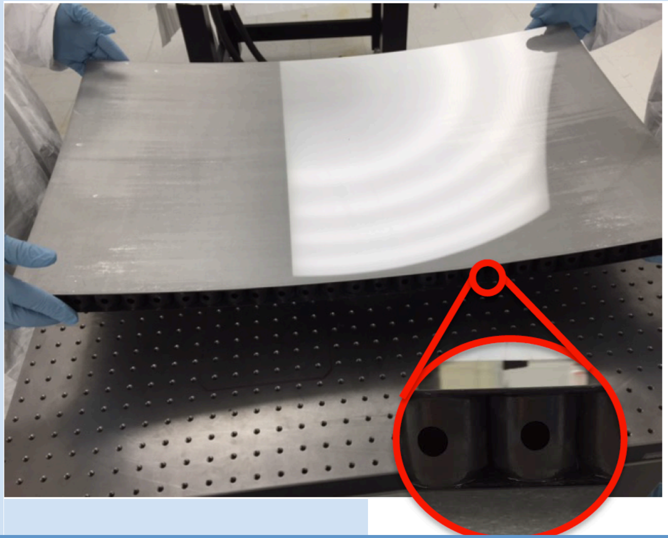


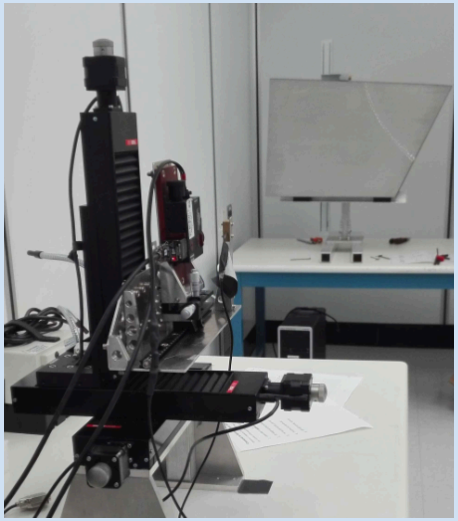


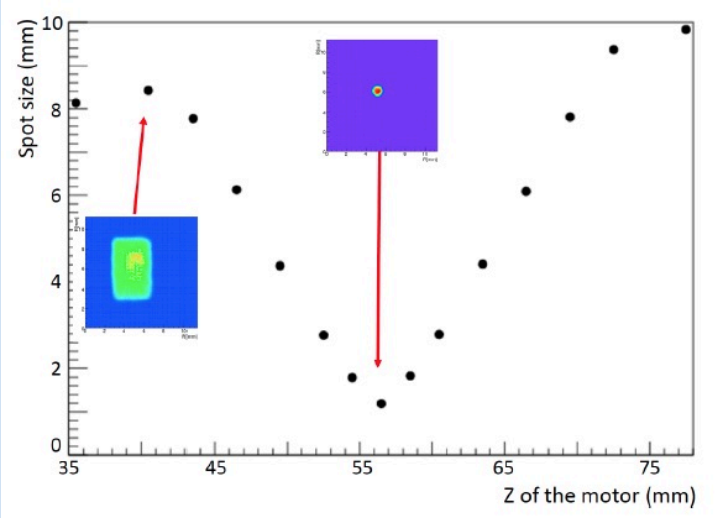
Carbon Fiber Mirrors (spherical) - Composite Mirror Applications, USA

to maximize lightness and stiffness. Consolidate technology (HERMES, AMS, LHCb)

~ 20 % material budget reduction vs precedents, radius and shape better (RICH1) or comparable (RICH2) than specs

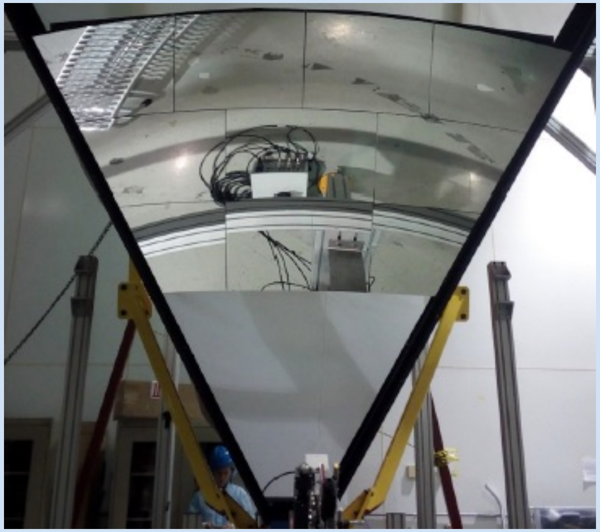




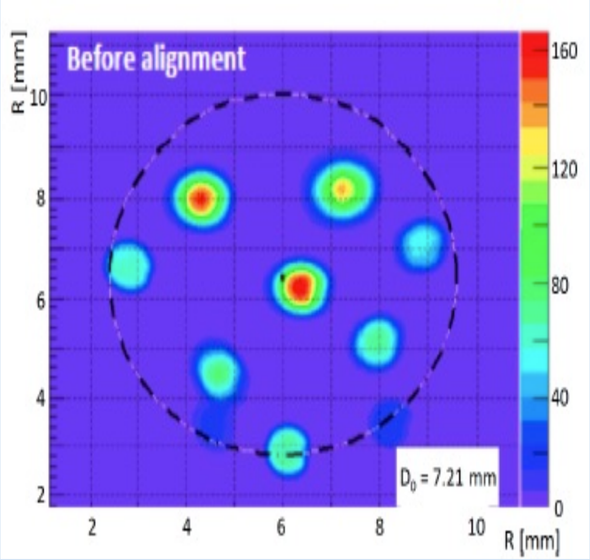


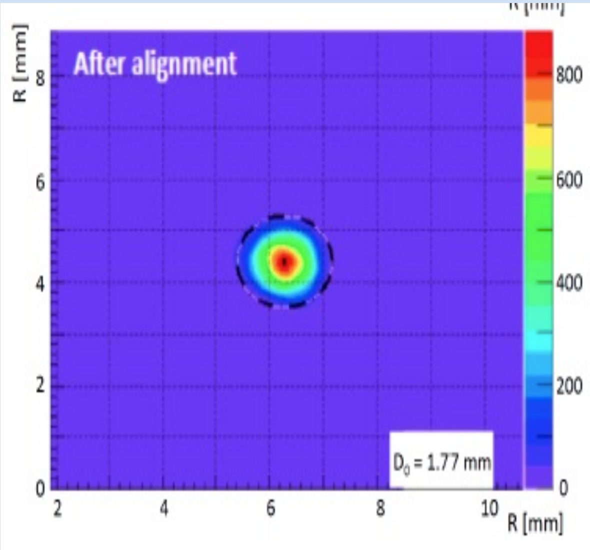
Use of composite CFRP and Al materials (Tecnologie Avanzate, IT) to realize a light but stiff supporting structure

Mounting



Alignment

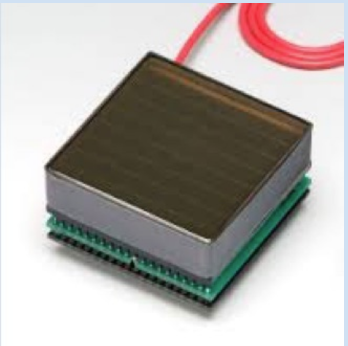




Hamamatsu H12700 (+ H8500)

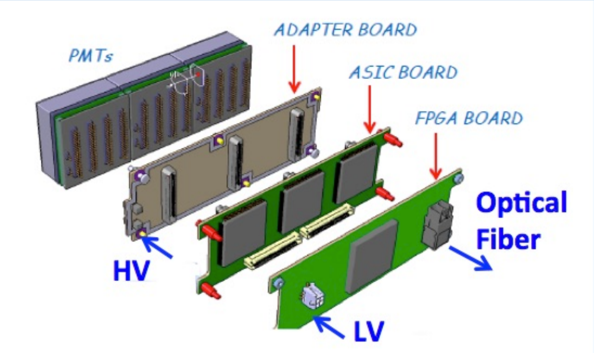
< 1 cm spatial resolution
< 1 ns time resolution
Compatible with the low torus fringe field

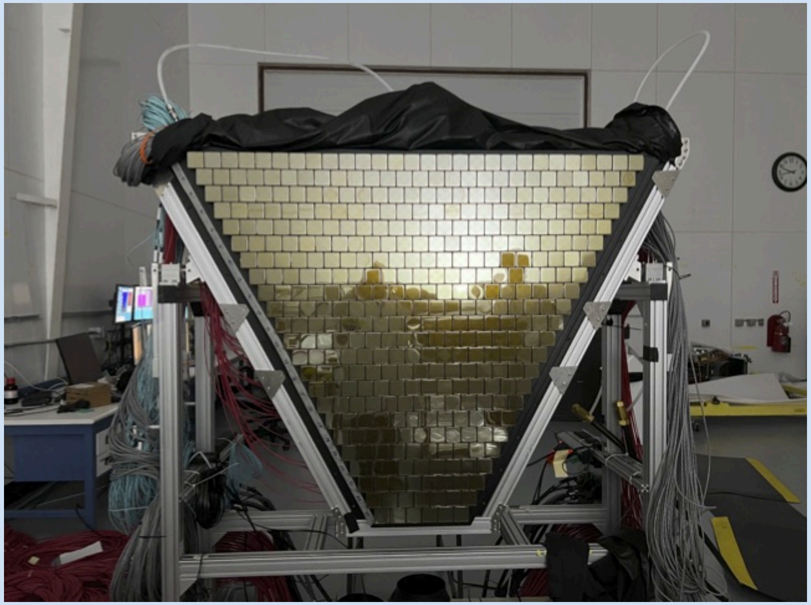
Average gain ~ $2.7\ 10^{6}$
eq. to SPE ~ 400 fC

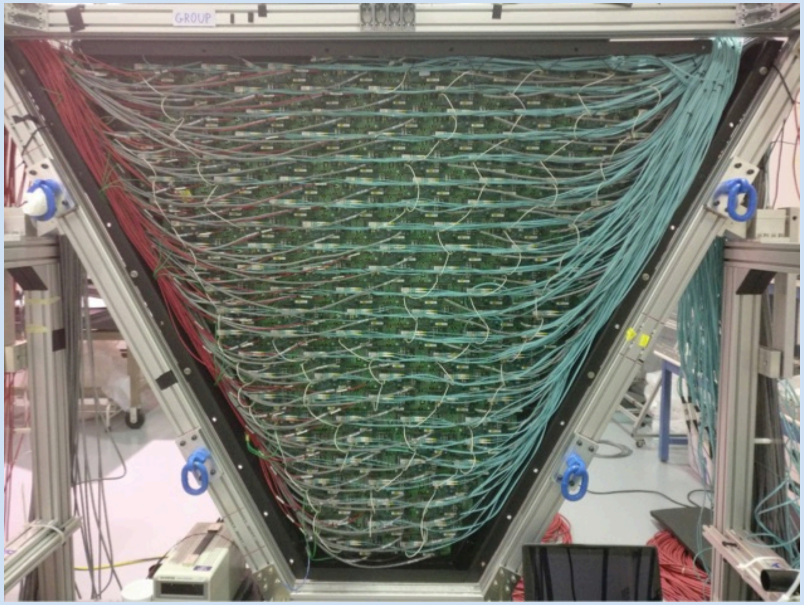


Readout Electronics

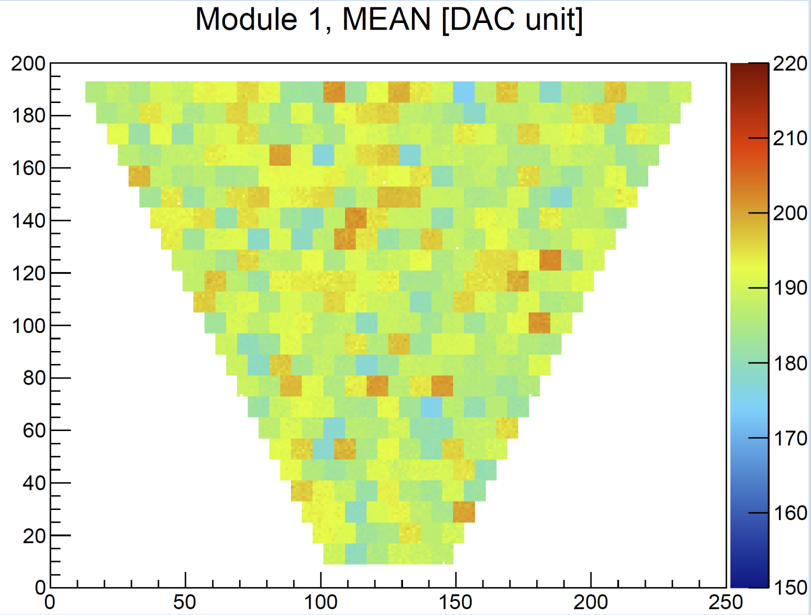
Compact, modular (adapter, MAROC3, FPGA) and scalable
Threshold: Fraction (<10%) of SPE
Trigger latency (8 μs)
Optical ethernet (2.5 Gbps)

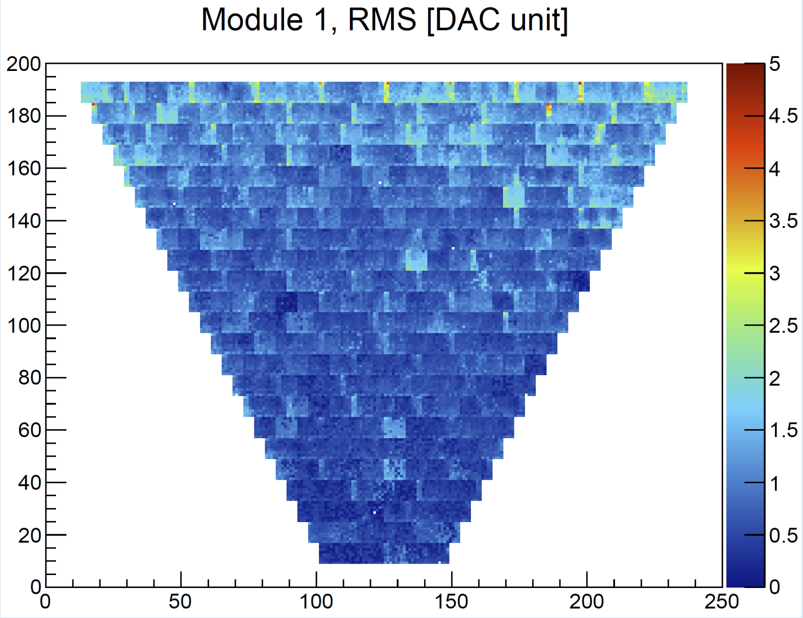


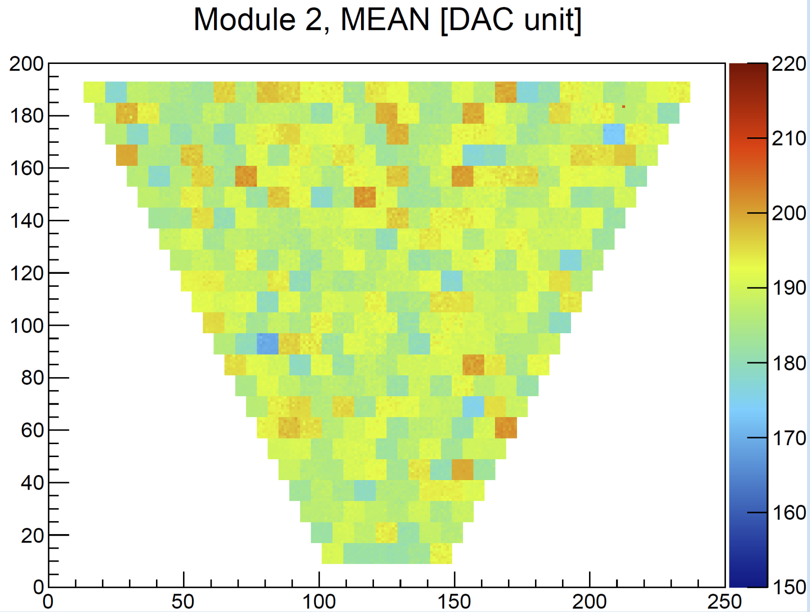


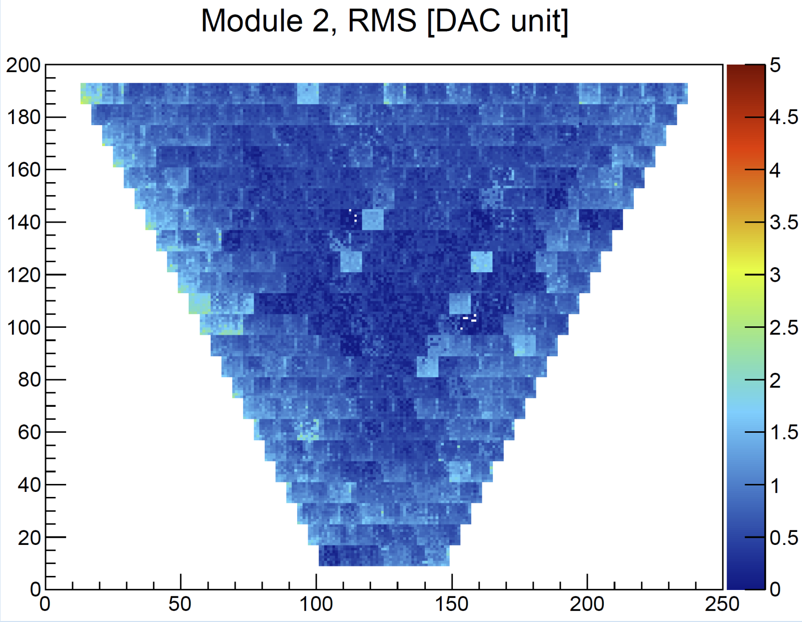


Pedestals


Module 1, MEAN [DAC unit]


Module 1, RMS [DAC unit]


Module 2, MEAN [DAC unit]

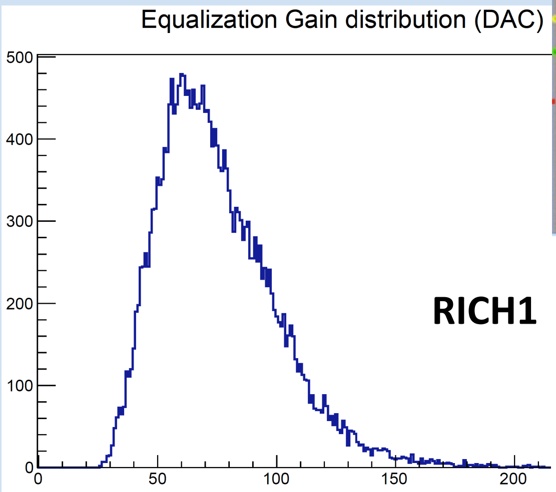

Module 2, RMS [DAC unit]

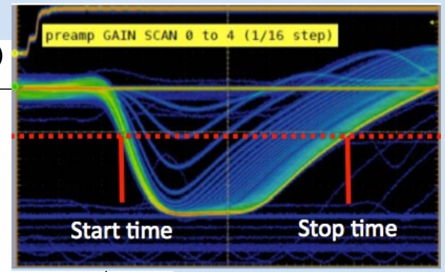
MAROC: ToT in an almost saturated regime

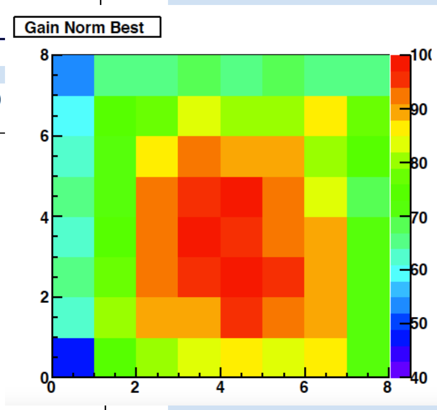
Pixel-by-pixel gain variation is compensated by the front-end amplification stage

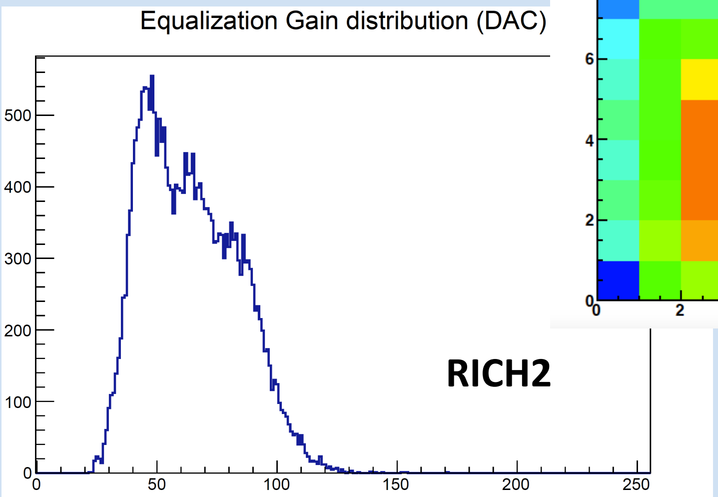
With equalization:

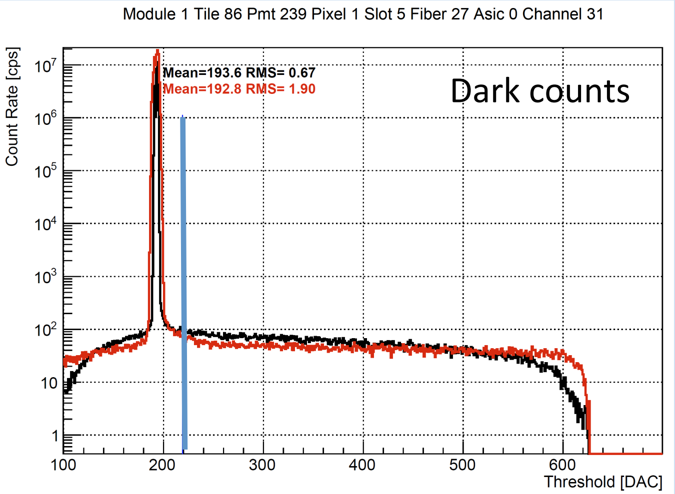
- The plateau vs threshold is extended
- Threshold at 25 DAC (~5 % SPE)

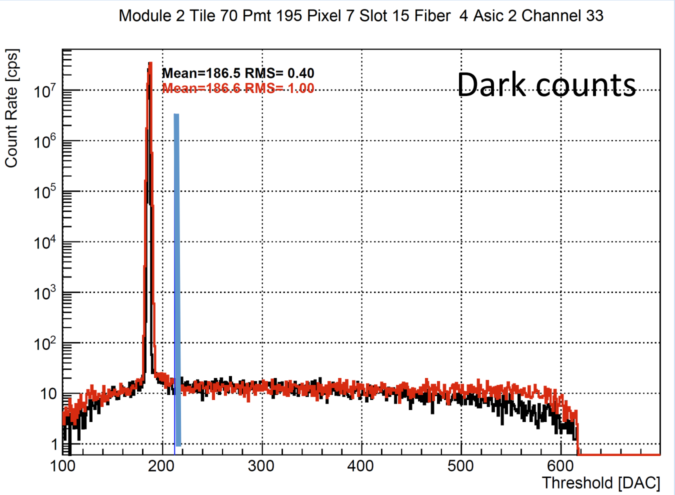




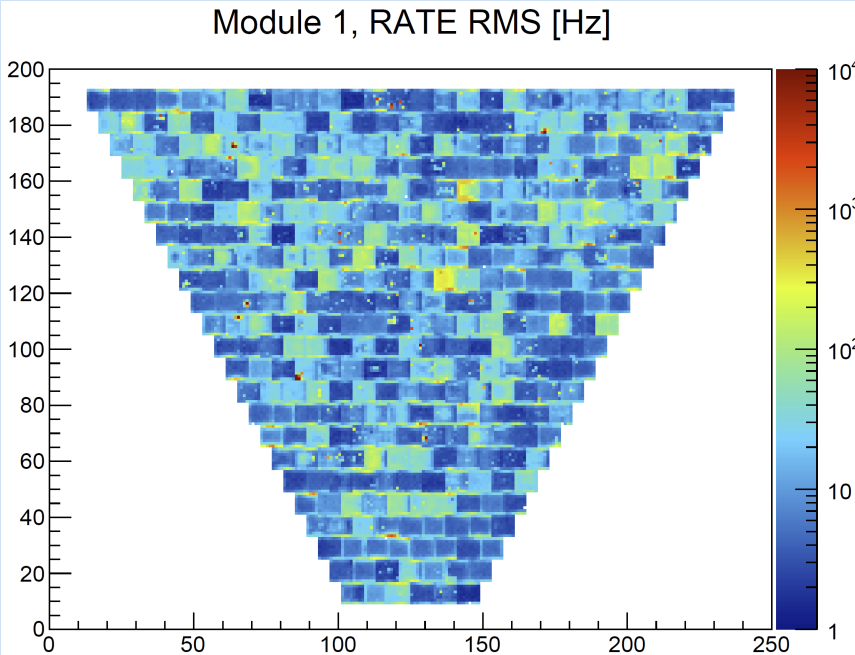


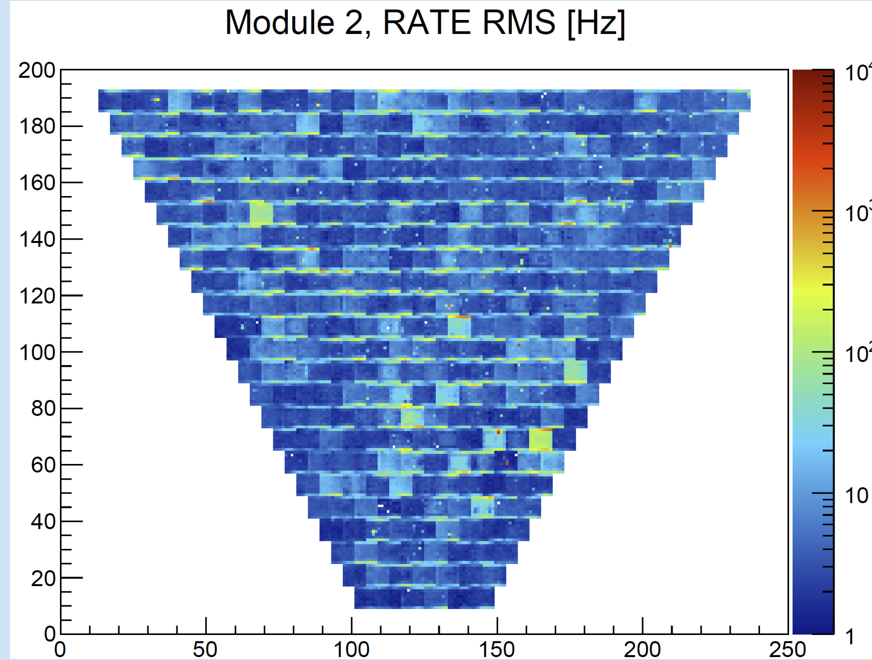




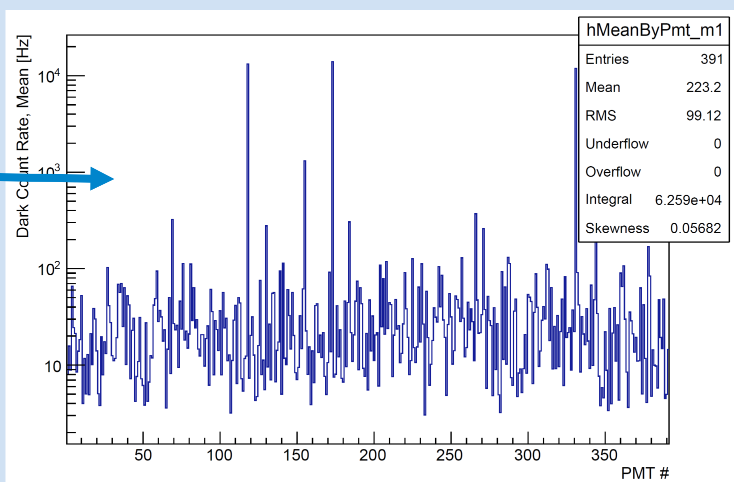


Dark Counts

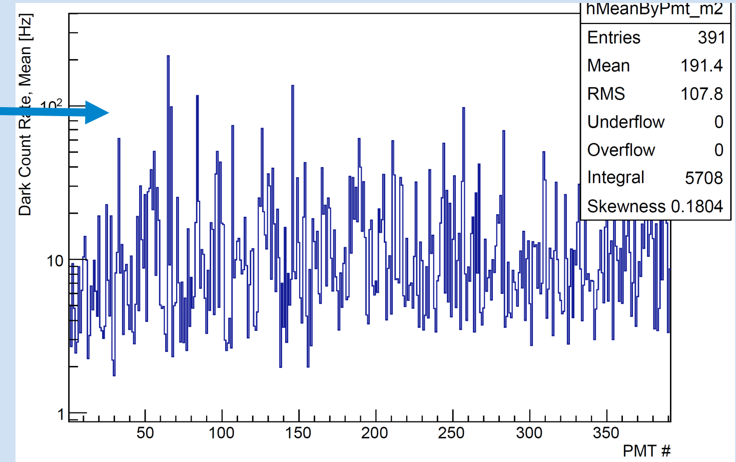




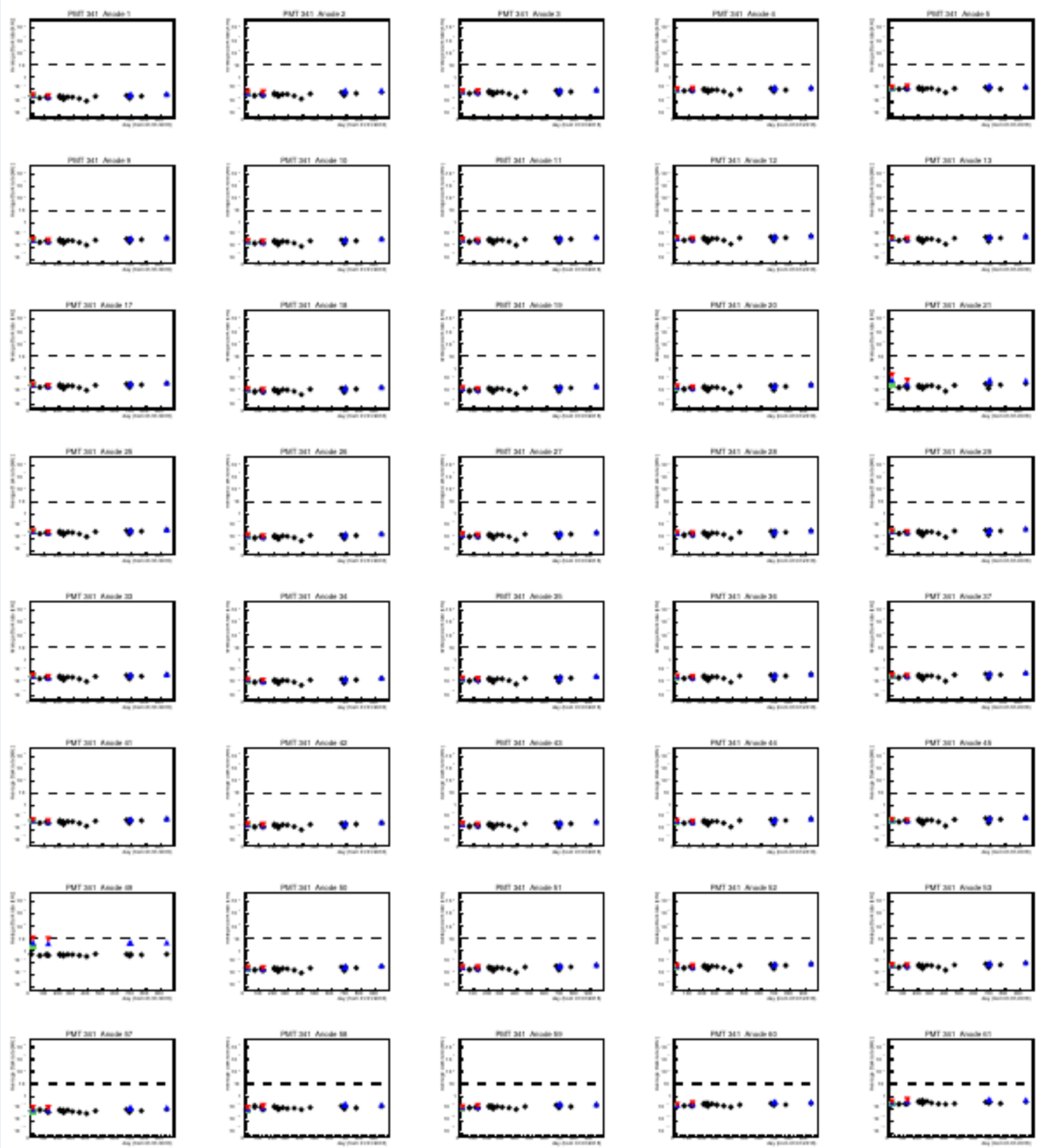
1 kHz

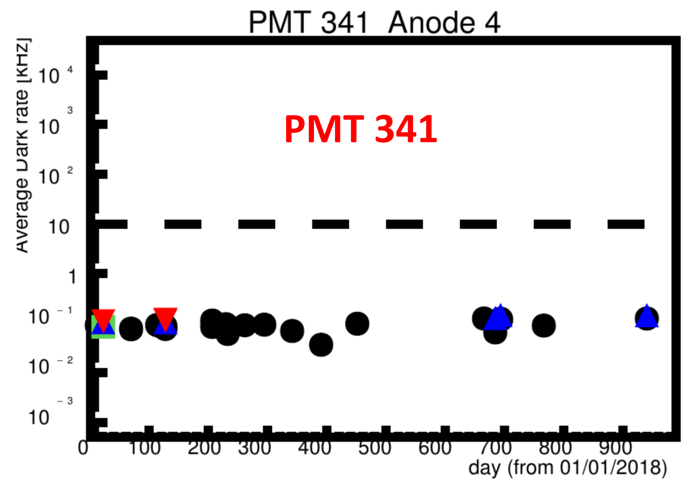


100 Hz



Dark Rate





Dark rate in kHz vs time in days since 1//1/2018

HV=1000 **HV=1050** **HV=1075** **HV=1100**

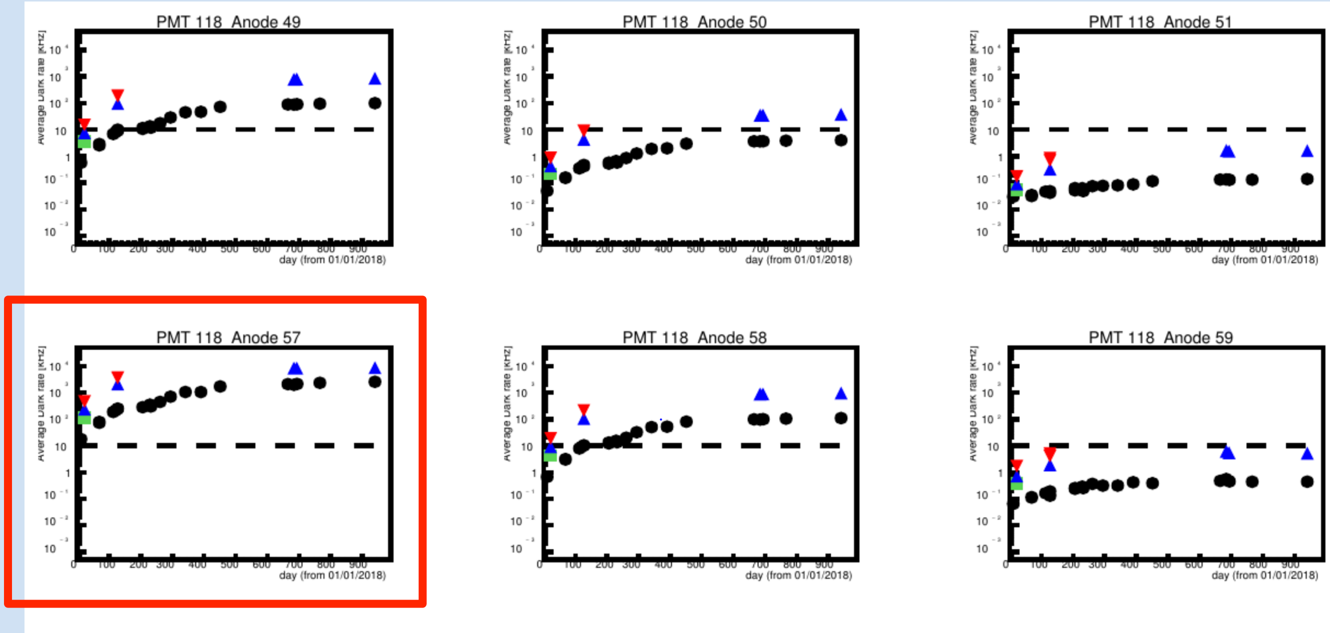
Dark Rate

High-dark rate channels
RICH1 ~ 10
RICH2 none so far

PMT 118 Anode 57

Problematic channel:

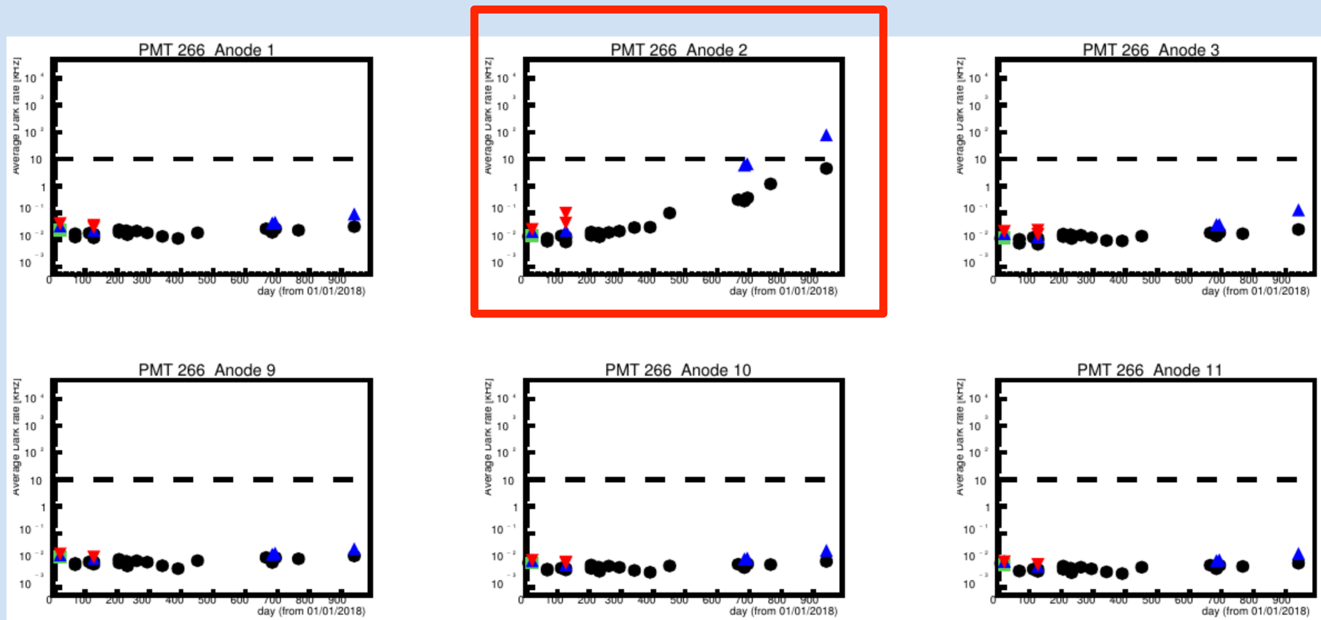
- **DR above 1 MHz**
- **Going to saturation**
- **Cross-talk on neighbors**



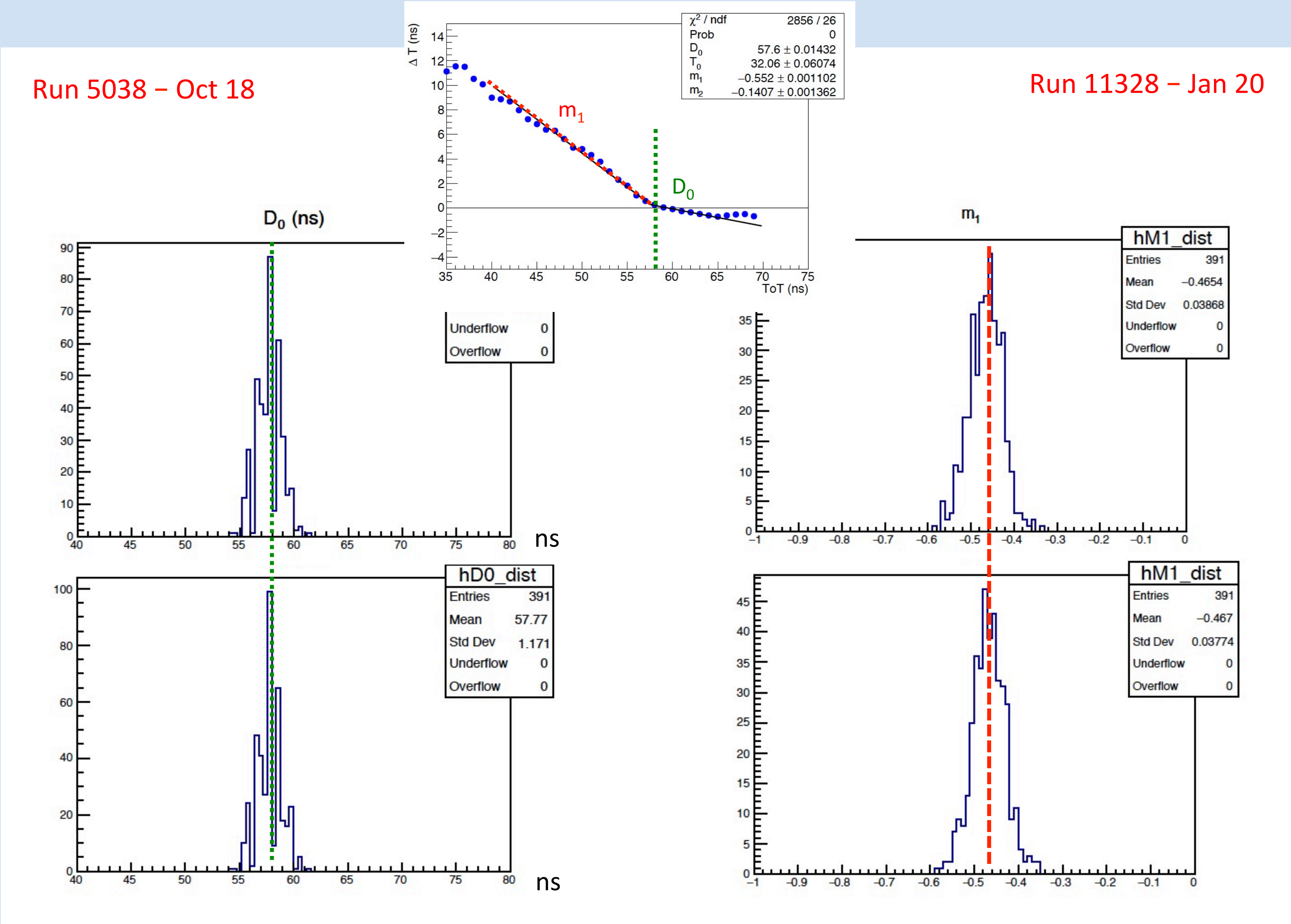
PMT 266 Anode 2

Problematic channel:

- **Initial DR 13 Hz**
- **Increasing to 4 kHz**

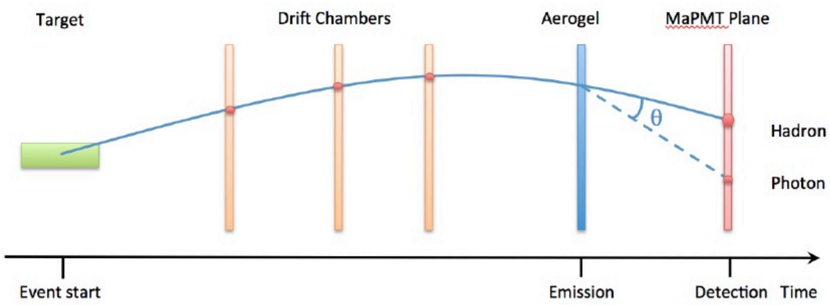


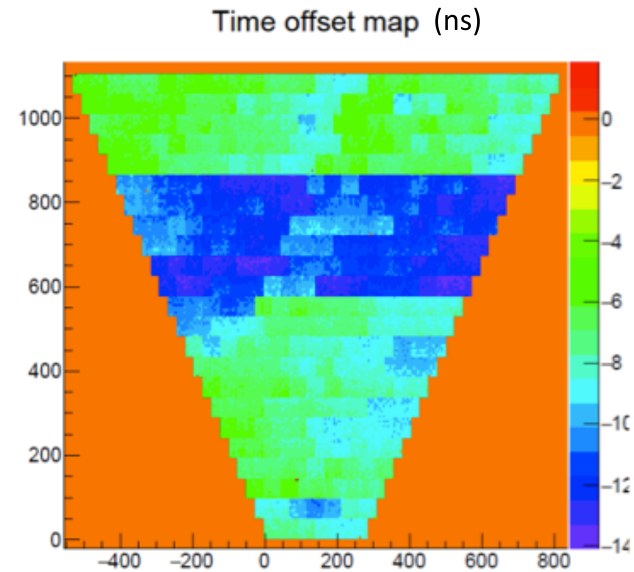
Time Walk

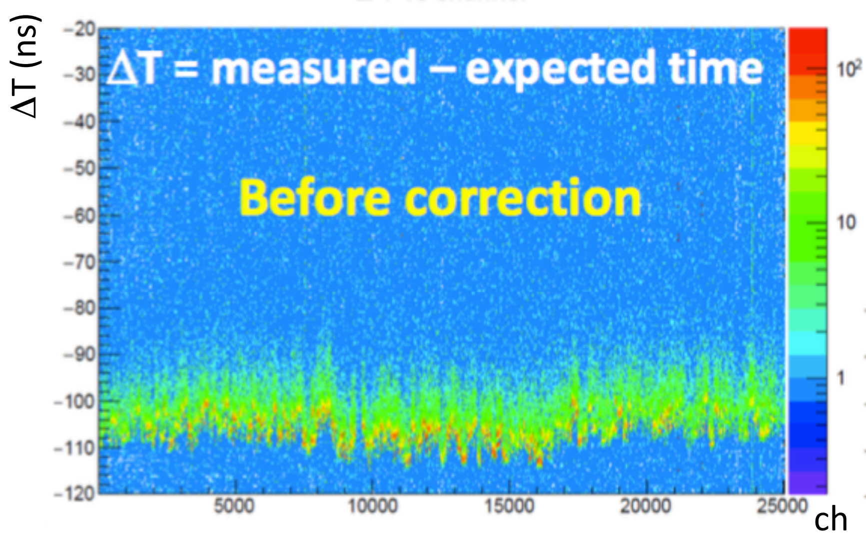


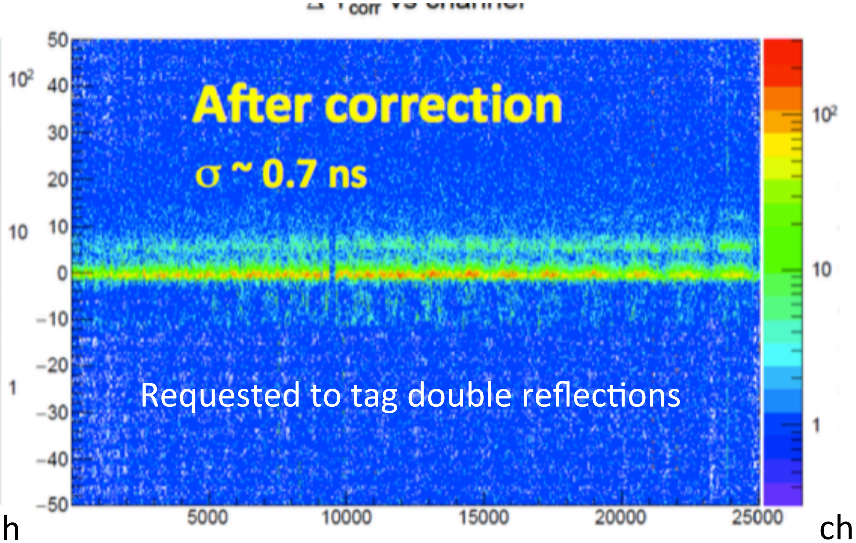
Run 5038 – Oct 18
Run 11328 – Jan 20
χ^2 / ndf 2856 / 26
Prob 0
D_0 57.6 ± 0.01432
T_0 32.06 ± 0.06074
m_1 −0.552 ± 0.001102
m_2 −0.1407 ± 0.001362
Δ T (ns)
ToT (ns)
m_1
D_0
D_0 (ns)
Underflow 0
Overflow 0
ns
hD0_dist
Entries 391
Mean 57.77
Std Dev 1.171
Underflow 0
Overflow 0
ns
m_1
hM1_dist
Entries 391
Mean −0.4654
Std Dev 0.03868
Underflow 0
Overflow 0
hM1_dist
Entries 391
Mean −0.467
Std Dev 0.03774
Underflow 0
Overflow 0

RICH time calibration with CLAS12 time-of-flight detector + bunch crossing









Cross-Talk

Optical

1 32	2 30	3 31	4 29	5 33	6 35	7 34	8 36
9 28	10 26	11 27	12 25	13 37	14 39	15 38	16 40
17 24	18 22	19 23	20 21	21 41	22 43	23 42	24 44
25 20	26 18	27 19	28 17	29 45	30 47	31 46	32 48
33 16	34 14	35 15	36 13	37 49	38 51	39 50	40 52
41 12	42 10	43 11	44 9	45 53	46 55	47 54	48 56
49 8	50 6	51 7	52 5	53 57	54 59	55 58	56 60
57 4	58 2	59 3	60 1	61 61	62 63	63 62	64 64

pixel
maroc

Electrical

1 32	2 30	3 31	4 29	5 33	6 35	7 34	8 36
9 28	10 26	11 27	12 25	13 37	14 39	15 38	16 40
17 24	18 22	19 23	20 21	21 41	22 43	23 42	24 44
25 20	26 18	27 19	28 17	29 45	30 47	31 46	32 48
33 16	34 14	35 15	36 13	37 49	38 51	39 50	40 52
41 12	42 10	43 11	44 9	45 53	46 55	47 54	48 56
49 8	50 6	51 7	52 5	53 57	54 59	55 58	56 60
57 4	58 2	59 3	60 1	61 61	62 63	63 62	64 64

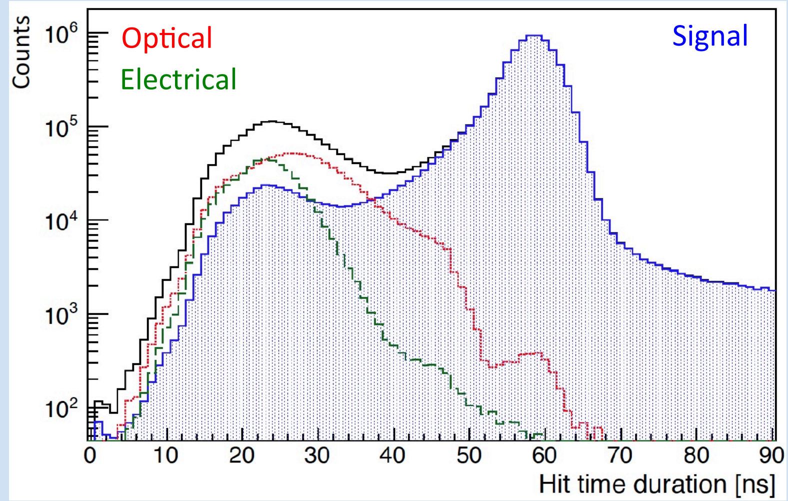
pixel
maroc

Optical & Electrical

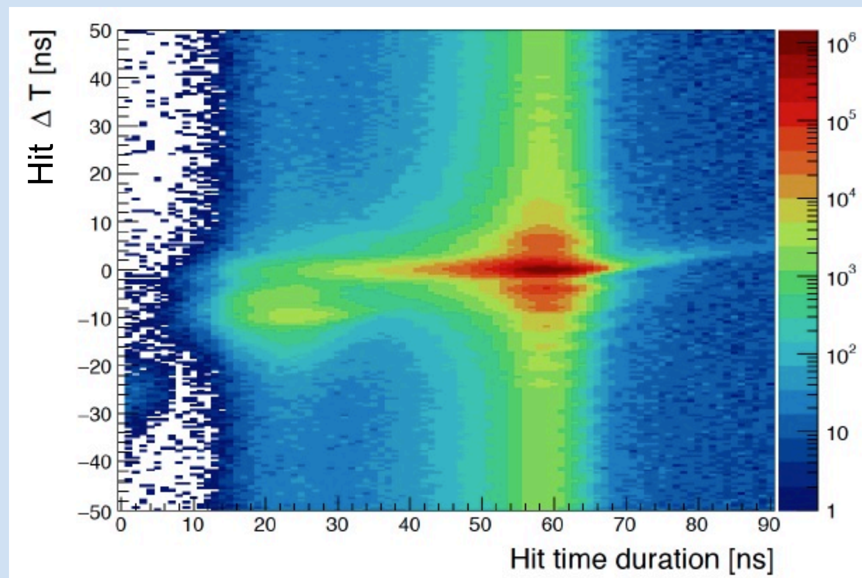
1 32	2 30	3 31	4 29	5 33	6 35	7 34	8 36
9 28	10 26	11 27	12 25	13 37	14 39	15 38	16 40
17 24	18 22	19 23	20 21	21 41	22 43	23 42	24 44
25 20	26 18	27 19	28 17	29 45	30 47	31 46	32 48
33 16	34 14	35 15	36 13	37 49	38 51	39 50	40 52
41 12	42 10	43 11	44 9	45 53	46 55	47 54	48 56
49 8	50 6	51 7	52 5	53 57	54 59	55 58	56 60
57 4	58 2	59 3	60 1	61 61	62 63	63 62	64 64

pixel
maroc

Analysis based on topology and signal shape



Residual cross-talk is removed after time calibration with TOF



Photon Path Reconstruction

Complex geometry with various photon paths (reflections) off the same particle

From CLAS12:

particle momentum
photon emission point

From RICH:

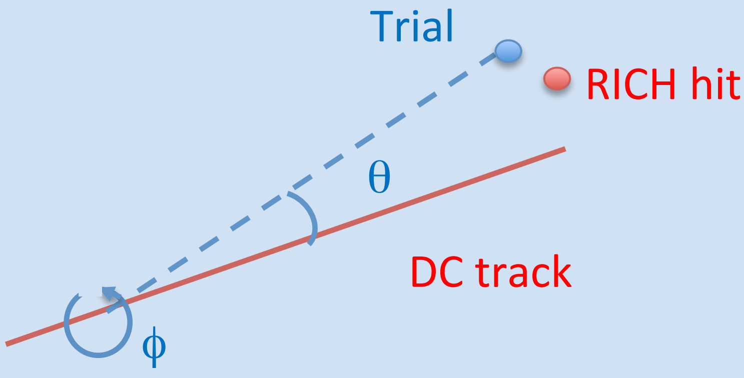
hit time and position

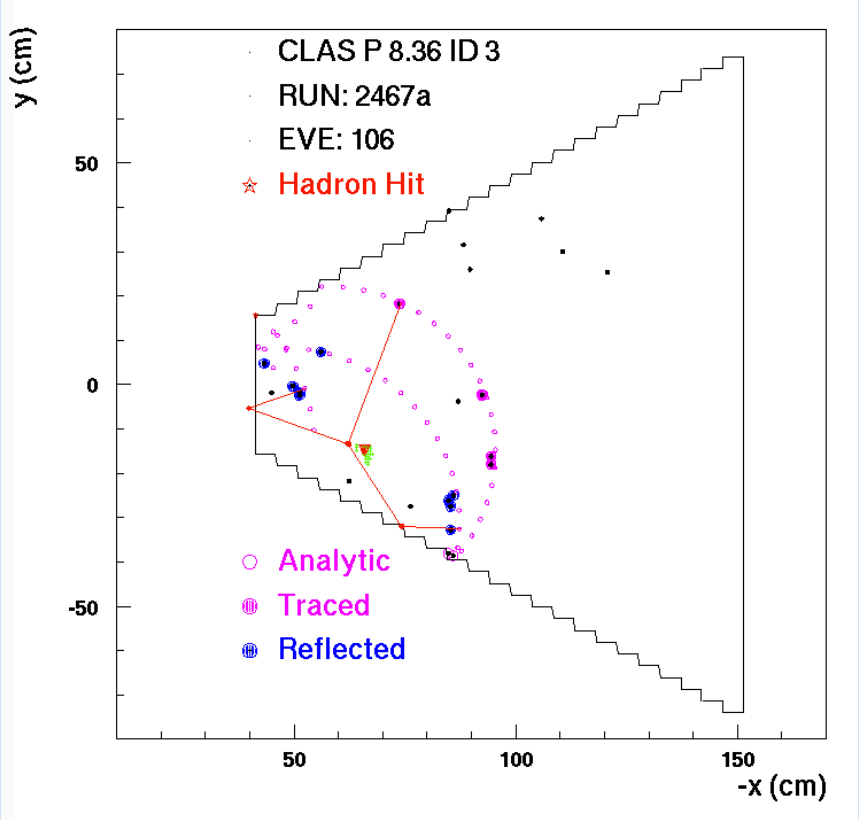
Direct ray-tracing:

ray-trace a limited sample of photon trials (selection of ϕ' s for given θ)

adjust the angles to match the hit starting from the closest trial (convergence in 2-3 iterations)

validate photon reconstructed Cherenkov angle and transit time

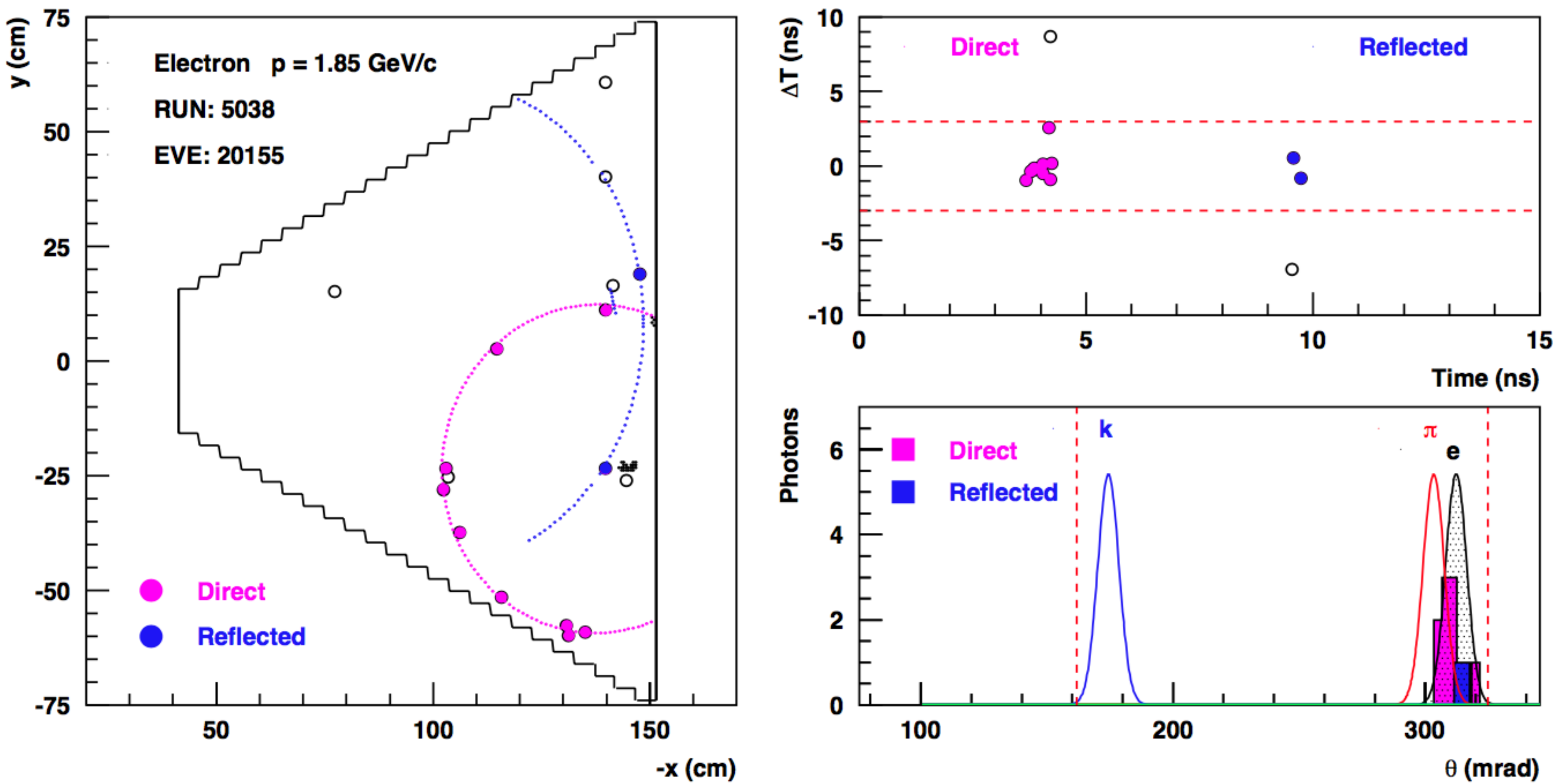




Pattern Recognition

Photon path reconstruction allow to assign the photon to the most likely hypothesis:

- be robust and easy to control (easy to handle multi-reflections, up to e.g. 5)
- discriminate background (hit far from trials, no solution foreseeable)
- provide full information (photon path, time, position and component of each reflection)
- allow relation with nominal optical components, resolution and efficiency

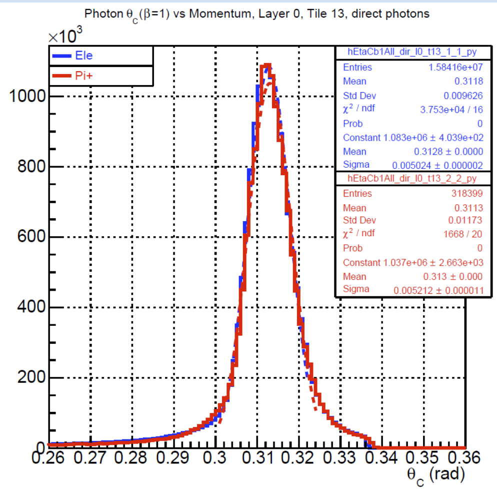


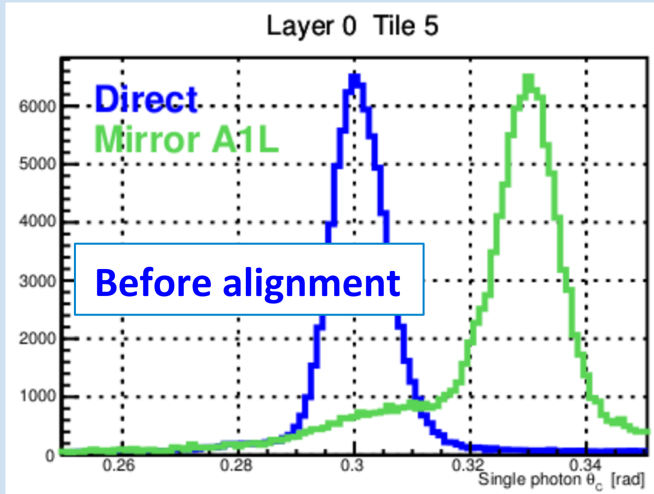
Alignment requires large statistics and full reconstruction to deal with the various photon paths
Angular resolution is comparable for direct and reflected photons

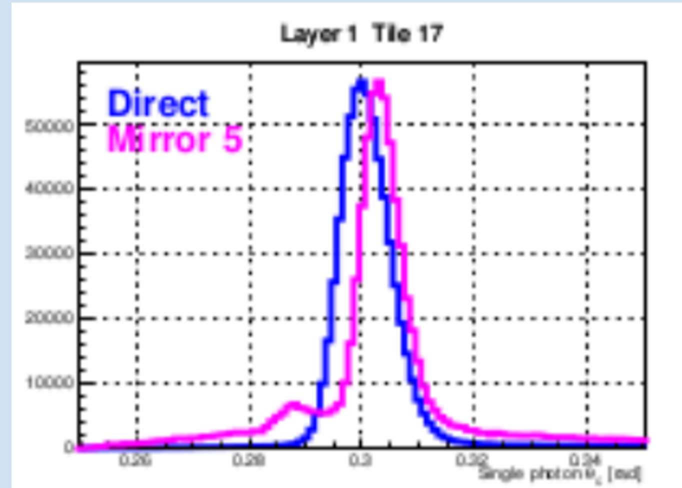
Direct photons: electrons vs pi+

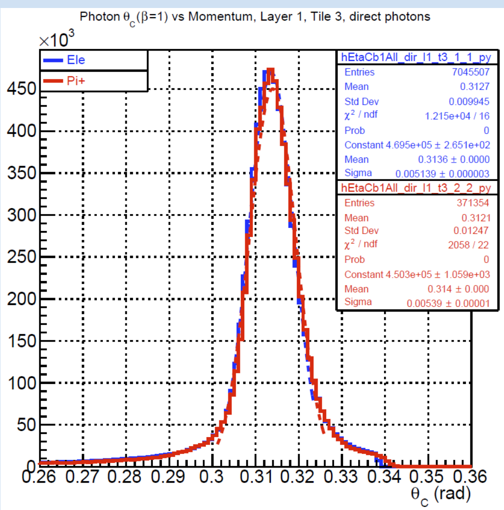
Electrons: direct vs planar reflection

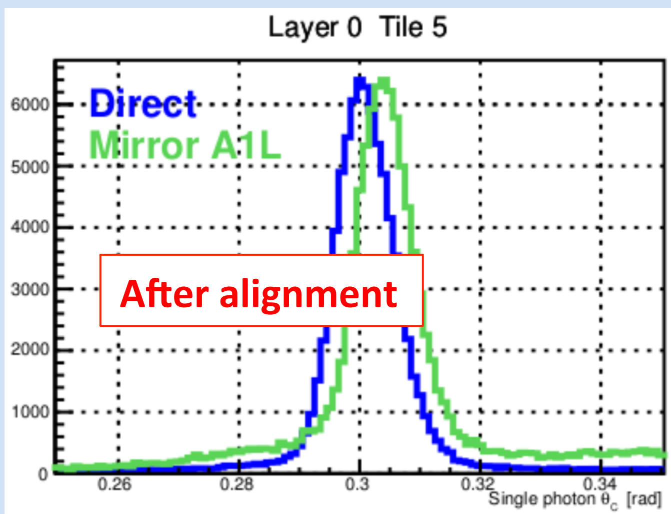
Electrons: direct vs spherical reflection

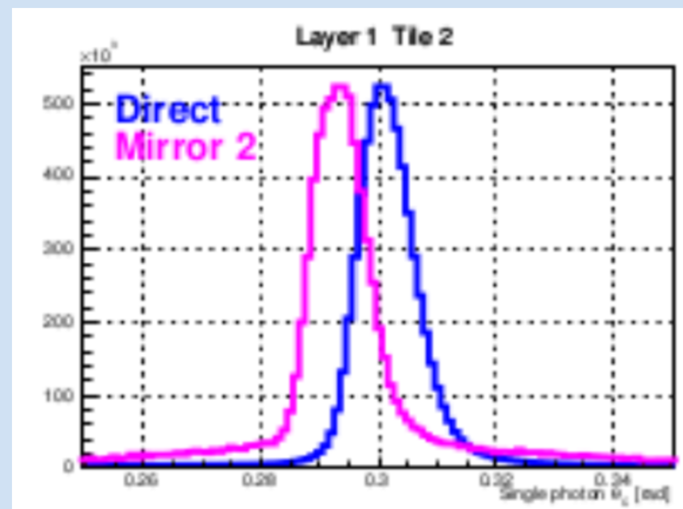






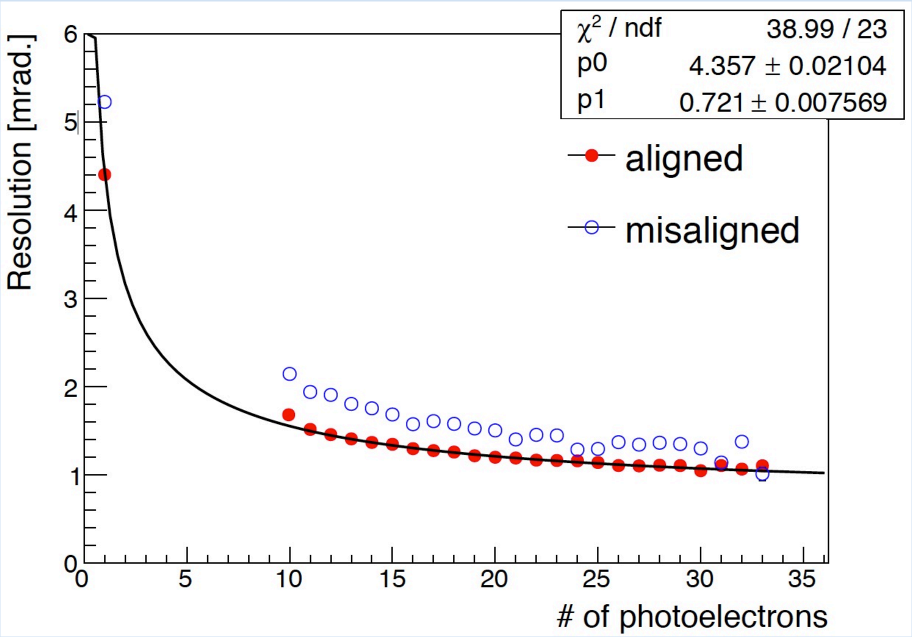


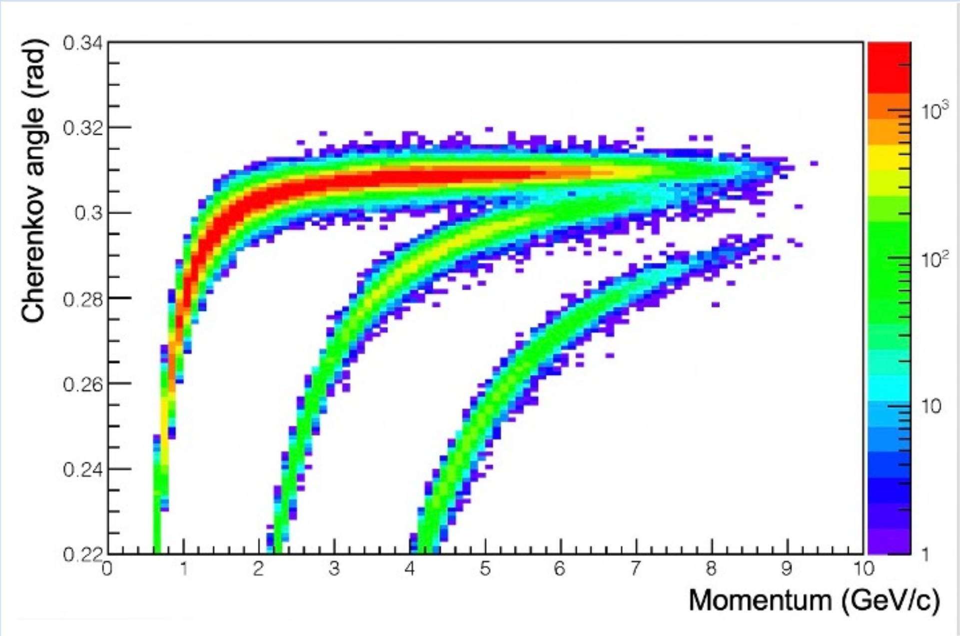




Angular Resolution

The goal of a pion-kaon 4σ separation at 8 GeV/c requires a resolution of 1.5 mrad*
(*forward region, less stringent requirements at large angles)

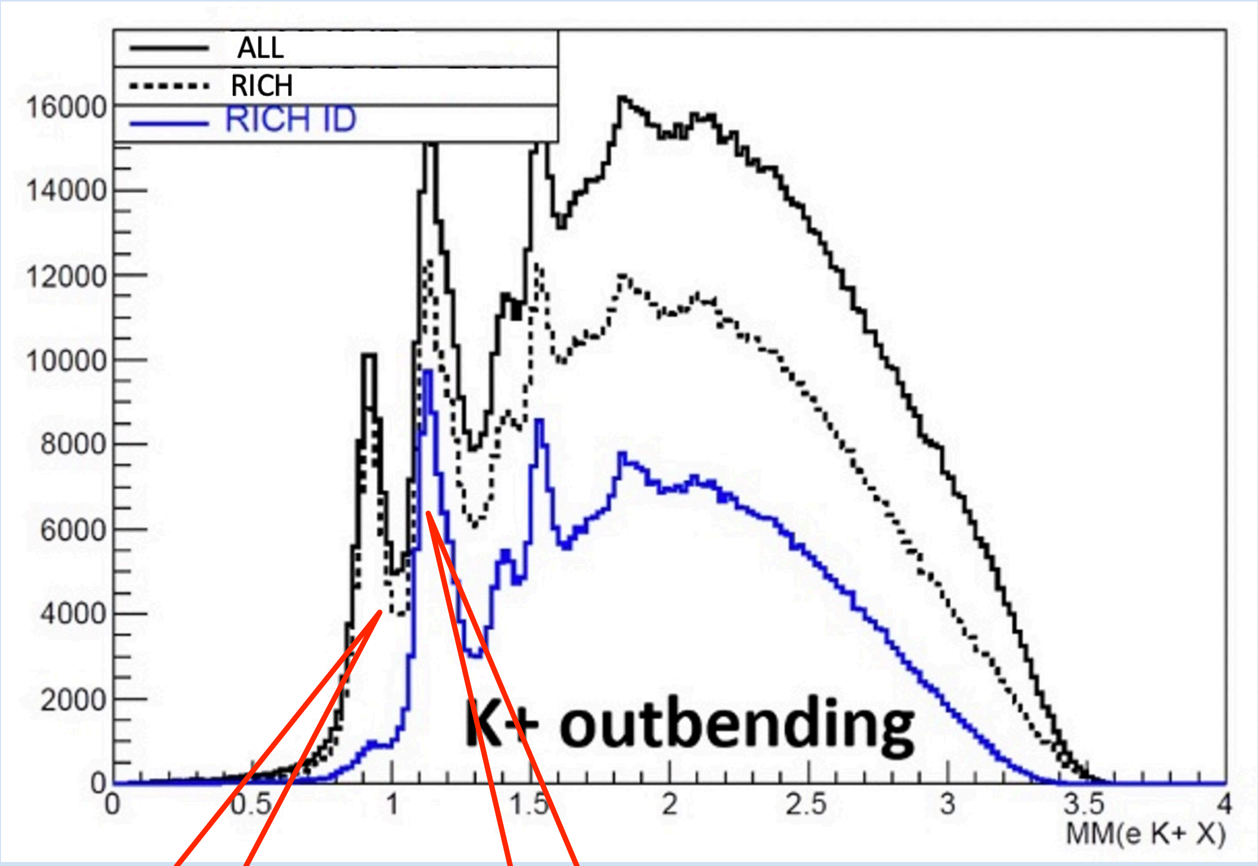




In line or better with respect the TDR targets:

- single-photon resolution of 4.5 ns
- number of photons around 18 for direct imaging

Check with semi-inclusive physics channel $ep \rightarrow eh^{+}X$



$ep \rightarrow e\pi^{+}n$ background

$ep \rightarrow eK^{+}\Lambda$ signal

Conclusions

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

Featuring:

- aerogel with status-of-the-art transmittance and unprecedented volume at n=1.05
- carbon fiber spherical mirrors with reduced material budget
- cost-effective glass-skin planar mirrors used for the first time
- large-area multi-anode photomultipliers adopted for the first time
- modular front-end electronics easy to adapt for other applications
  (in use for GlueX DIRC, SOLID R&D, EIC dRICH R&D)

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

RICH has successfully taken data, performance approaching specifications and supporting physics analysis