Characterization of the components of the Ring-Imaging CHerenkov detector of the CLAS12 experiment

Candidate

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Supervisors

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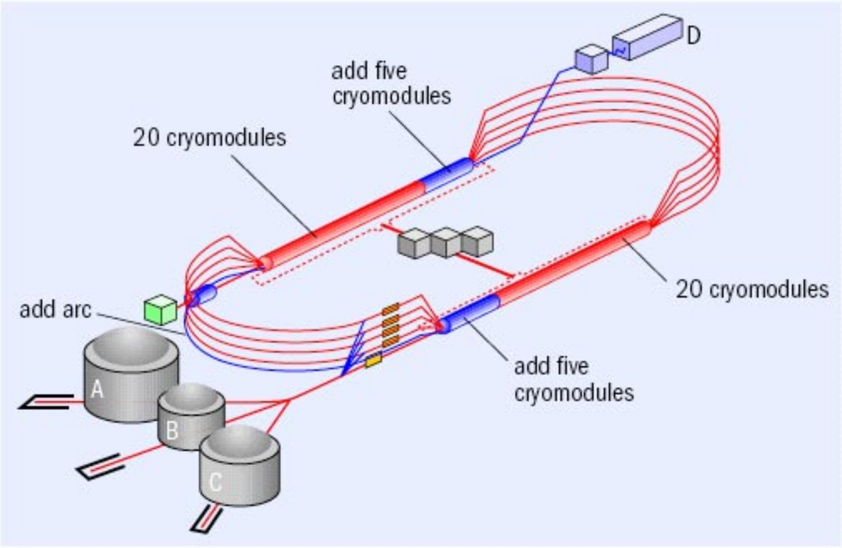
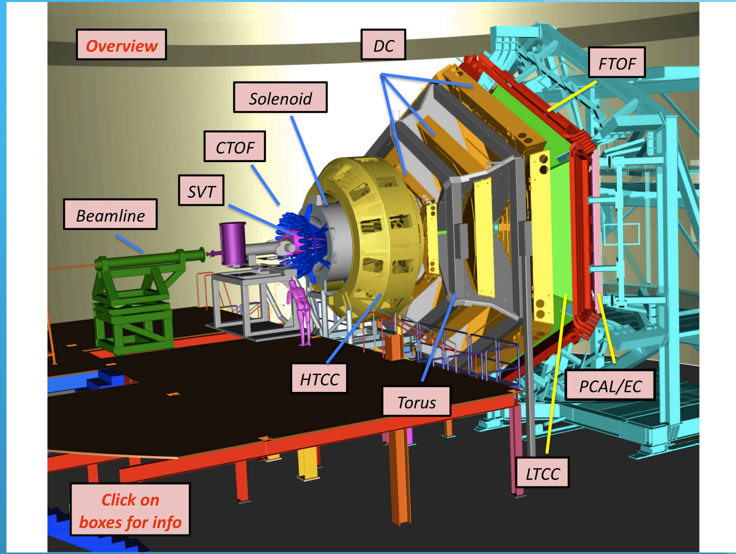
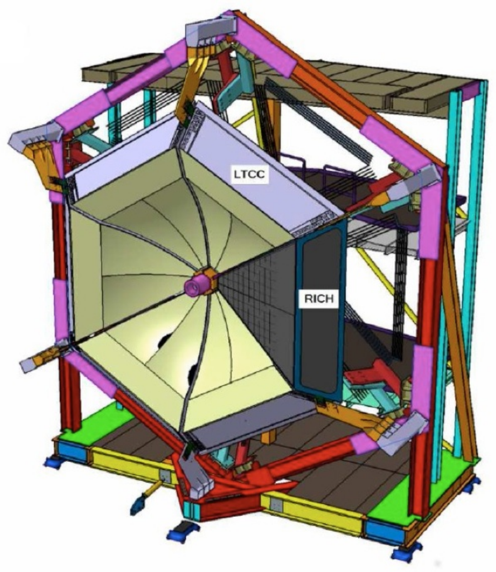
Dott. Marco Contalbrigo

CLAS12 Experiment

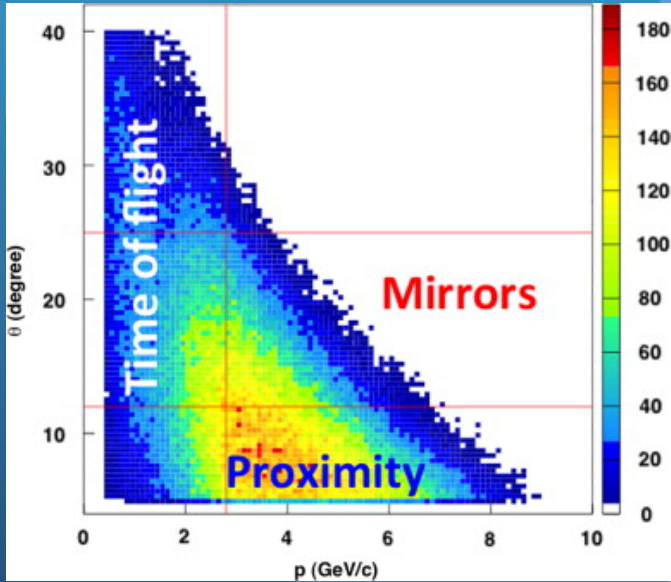






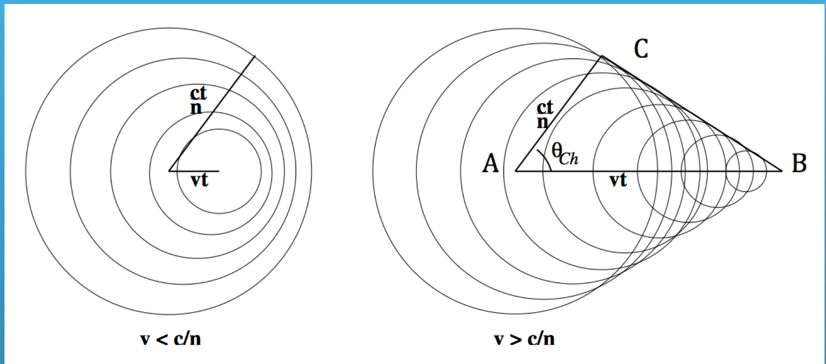
RICH Main goal:
Hadron
Identification

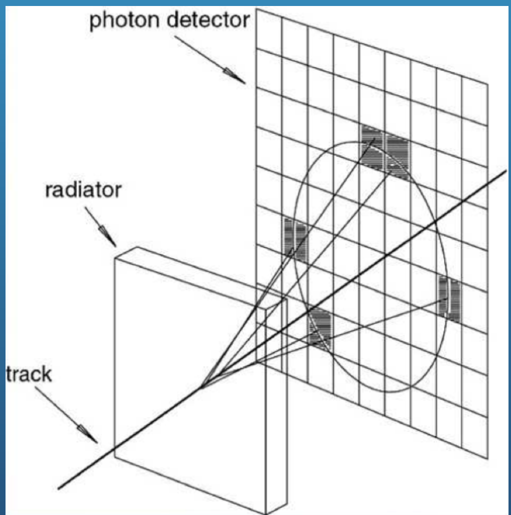
3 – 8 Gev/c



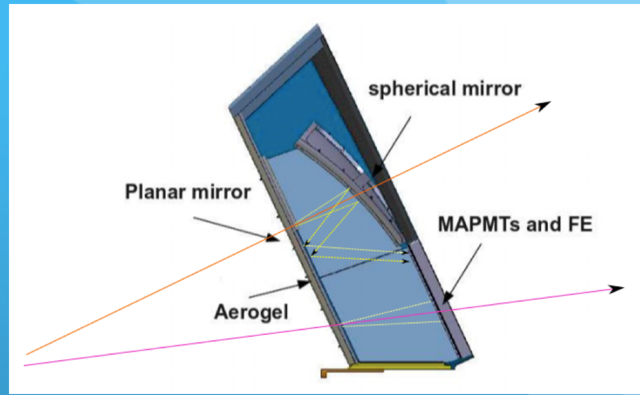
Ring Imaging CHerenkov

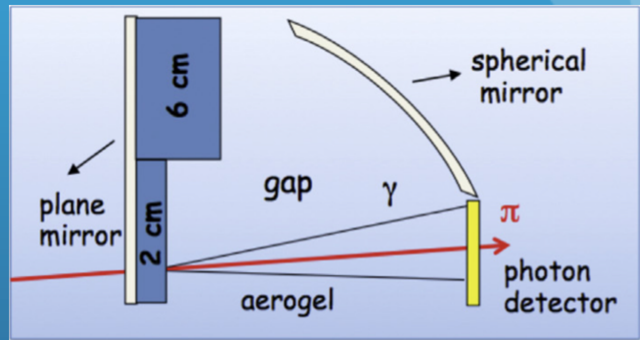
$$\cos\vartheta_{Ch} = \frac{1}{\beta n} \quad v_{th} = \frac{c}{n} \quad n = 1.05$$

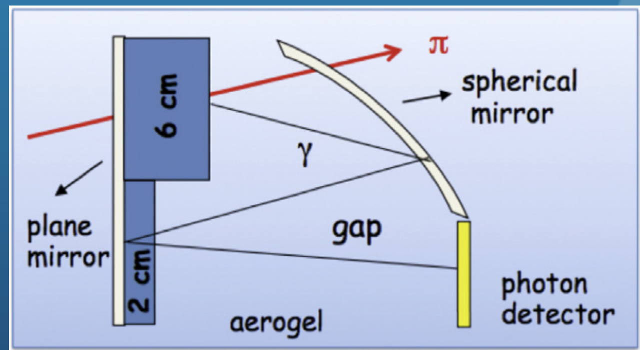




The required single photon resolution is 5 mrad.







Single Photon Resolution

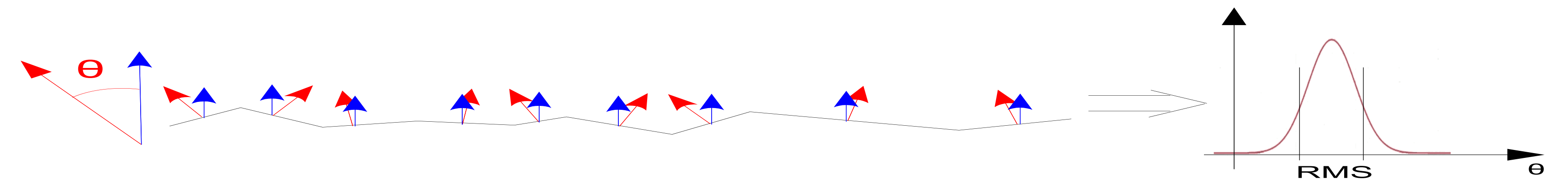
	Focusing mode (mrad)	Proximity mode (mrad)
Emission point	1.7	1.7
Chromatic aberration	2.5	3.3
Readout accuracy	0.82	2.45
Focusing system	≤1	-
$\sigma_{\vartheta Ch}$	3.3	4.5

$$\sigma_{\vartheta_{Ch}} = \sqrt{\sum_i \left(\sigma^i_{\vartheta_{Ch}}\right)^2}$$

The aim of the thesis was to define each contribution of the focusing system resolution measuring the surface RMS of mirrors and the aerogel.

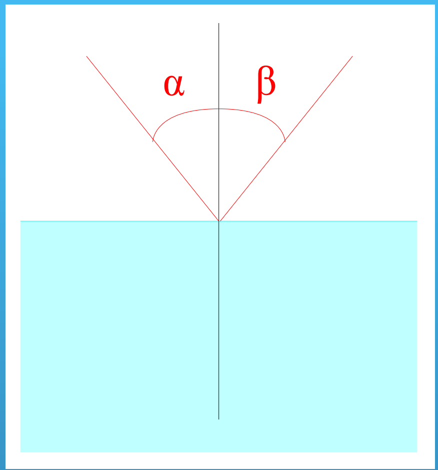
$$\sigma^{focus}_{\vartheta_{Ch}} = \sqrt{\left(\sigma^{spherical}_{\vartheta_{Ch}}\right)^2 + \left(\sigma^{aerogel}_{\vartheta_{Ch}}\right)^2 + \left(\sigma^{planar}_{\vartheta_{Ch}}\right)^2}$$

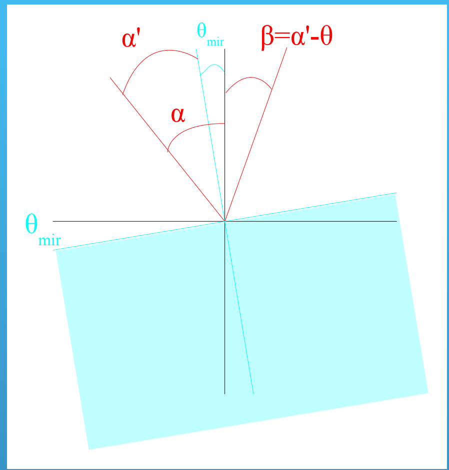
Surface RMS



Mirror Surface Measurements

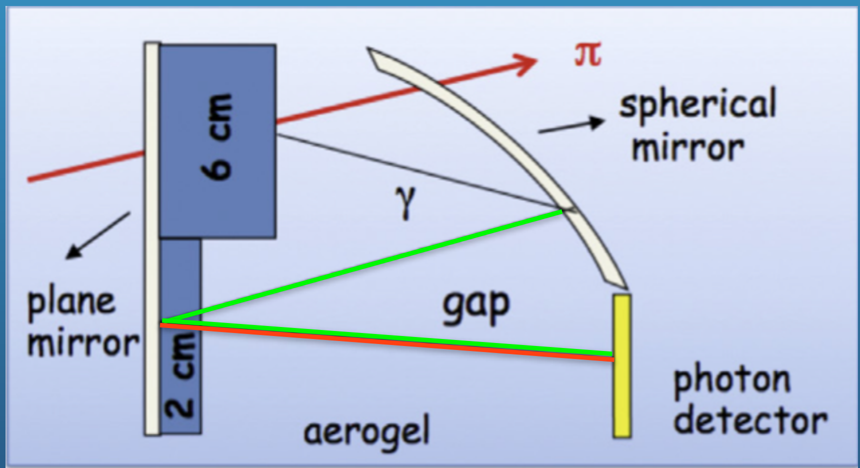
Mirror $\sigma_{\vartheta Ch}$ Contribution





$$\beta = \alpha' - \vartheta_{mir} = \alpha - 2\vartheta_{mir}$$

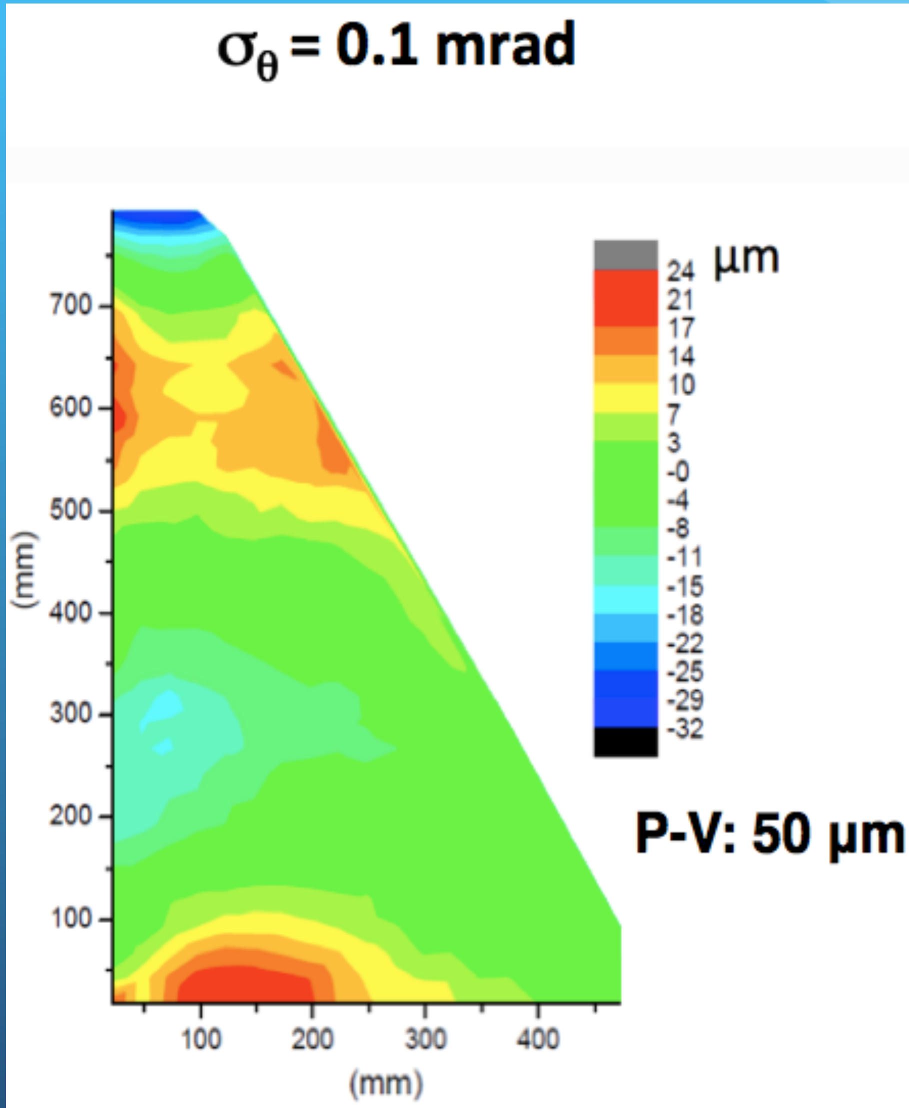
$$\sigma_{\vartheta_{light}} \approx 2 \cdot \sigma_{\vartheta_{mir}}$$



$$\sigma_{\vartheta_{Ch}}^{planar} = \sigma_{\vartheta_{light}} \cdot \frac{1m}{3m} = 2 \cdot \sigma_{\vartheta_{mir}} \cdot \frac{1}{3} = \frac{2}{3} \cdot \sigma_{\vartheta_{mir}}$$

$$\sigma_{\vartheta_{Ch}}^{spherical} = \sigma_{\vartheta_{light}} \cdot \frac{2m}{3m} = 2 \cdot \sigma_{\vartheta_{mir}} \cdot \frac{2}{3} = \frac{4}{3} \cdot \sigma_{\vartheta_{mir}}$$

Planar Mirror Measurement



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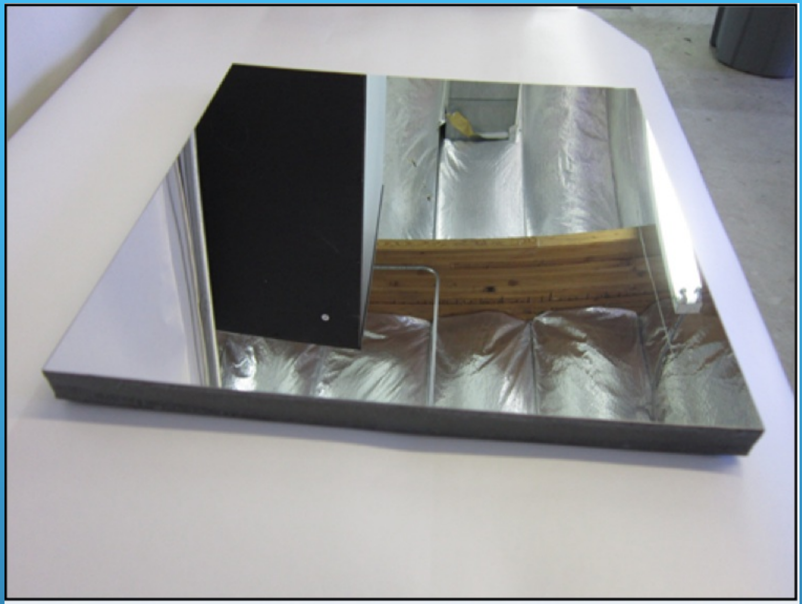
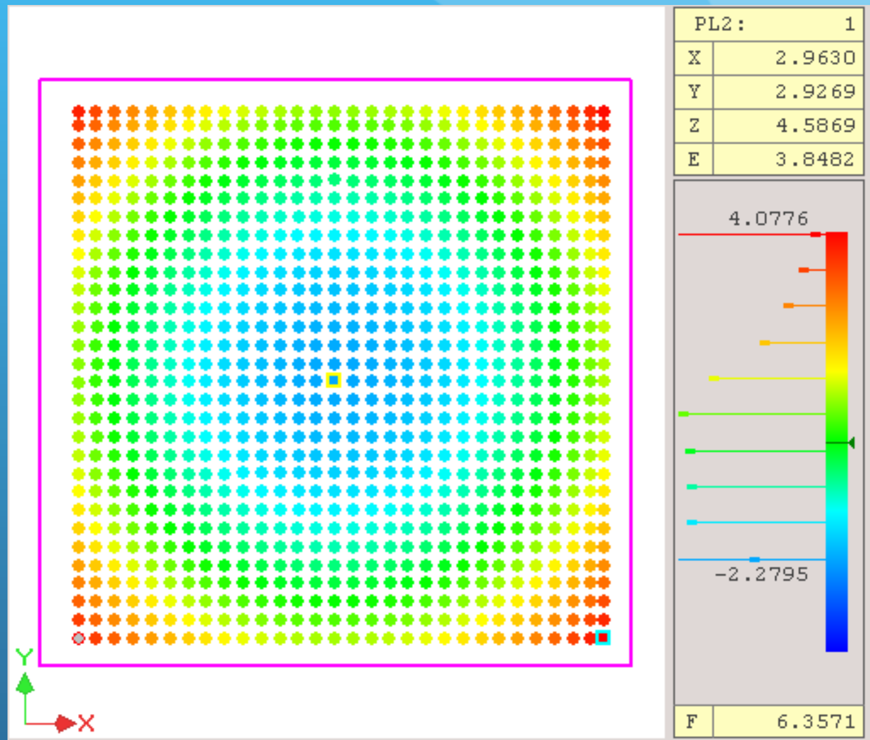
Spherical Mirror Measurement



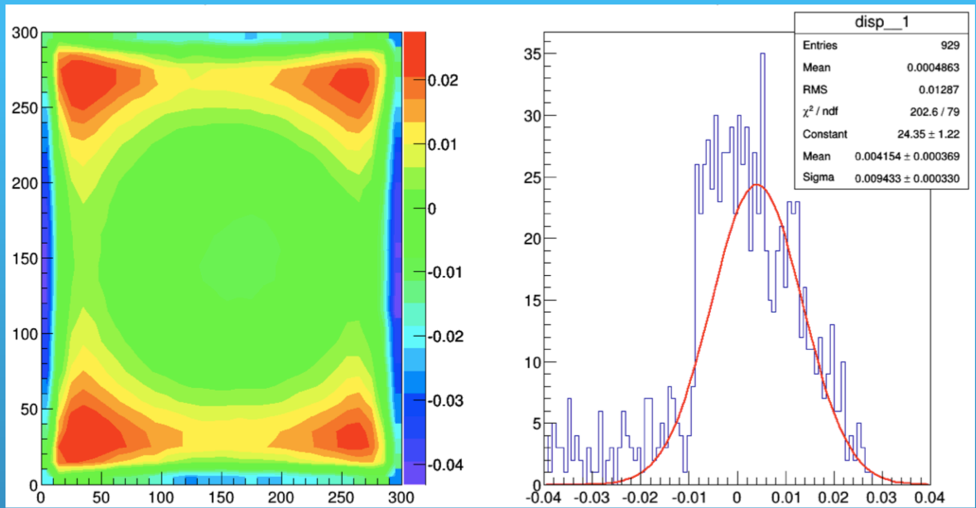
Touching machine scan



Center coordinates
x_0, y_0, z_0 and r
with a maximum likelihood fit

$$\delta r = \sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2} - r$$

Spherical Mirror Measurement

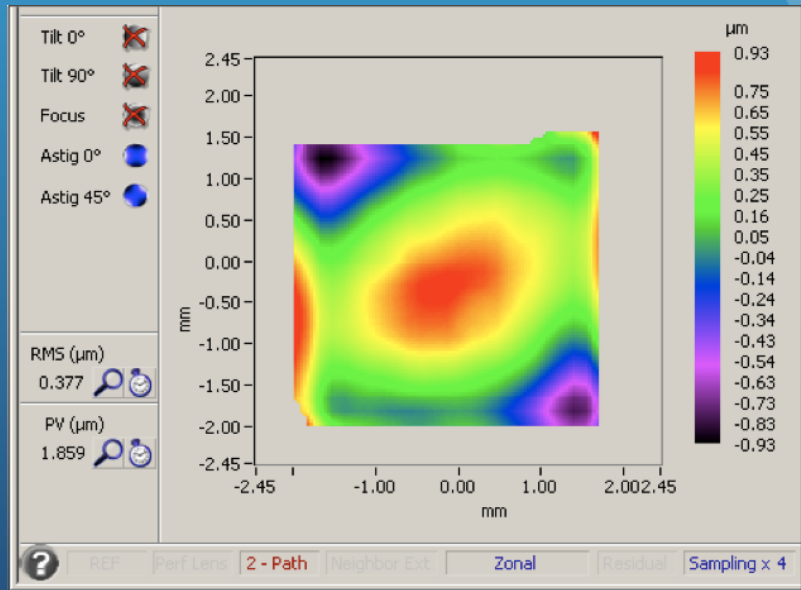


Touch machine scan
September 2014

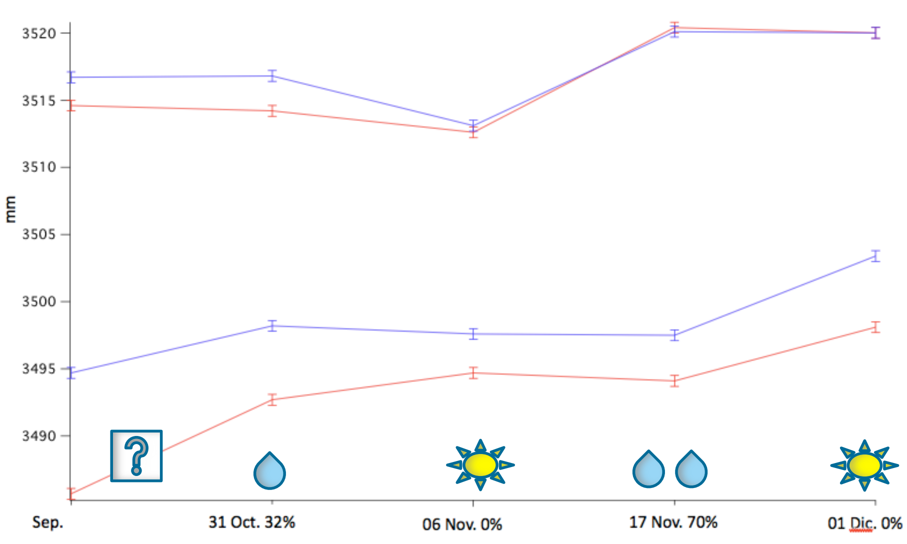
RMS 12.9 μm
PV 70 μm

CMA
measurement
April 2014

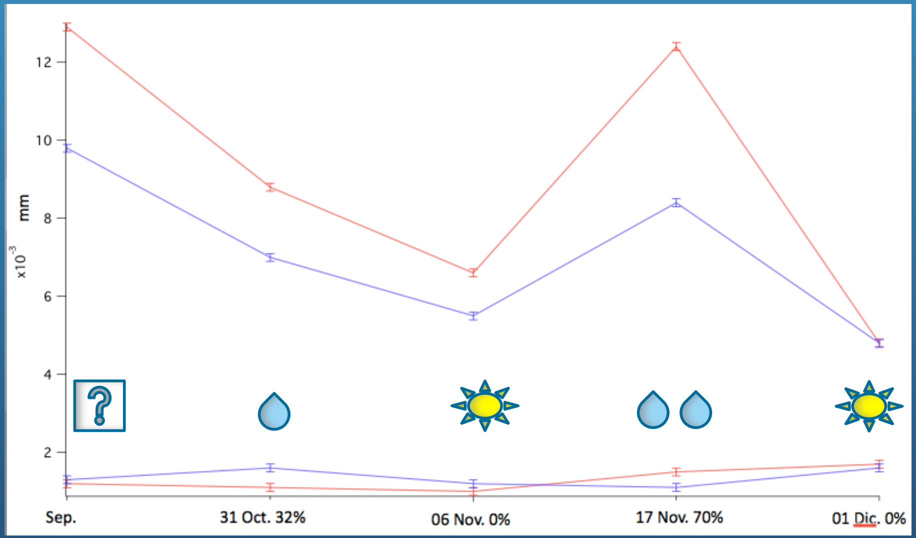
RMS 0.38 μm
PV 1.86 μm



Spherical Mirror Measurement

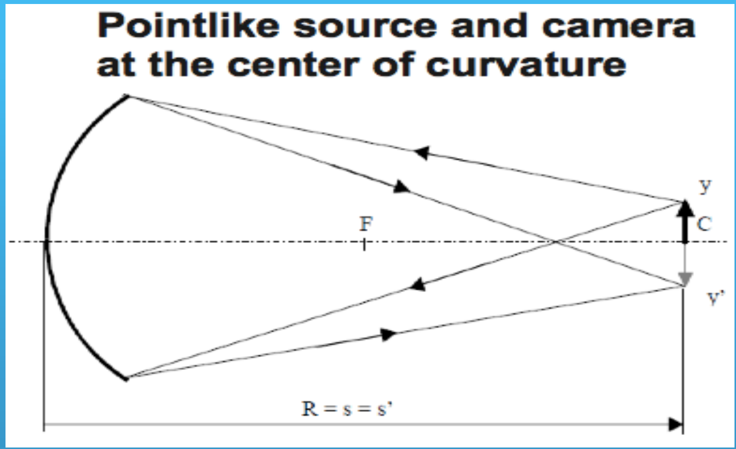


Radius of the mirror

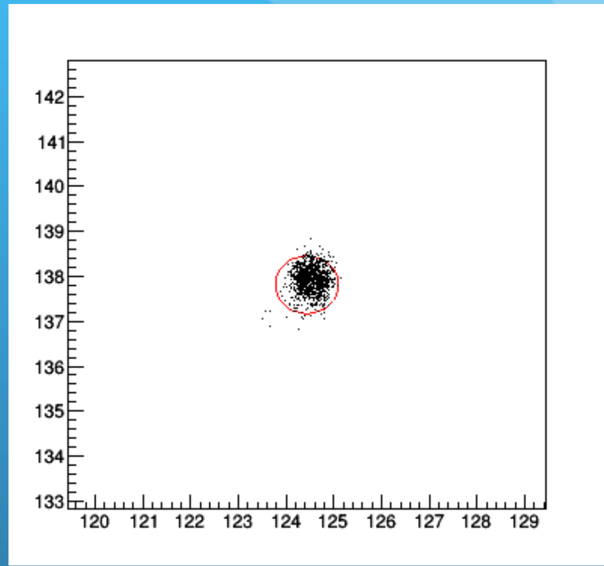


RMS of δr of the mirror

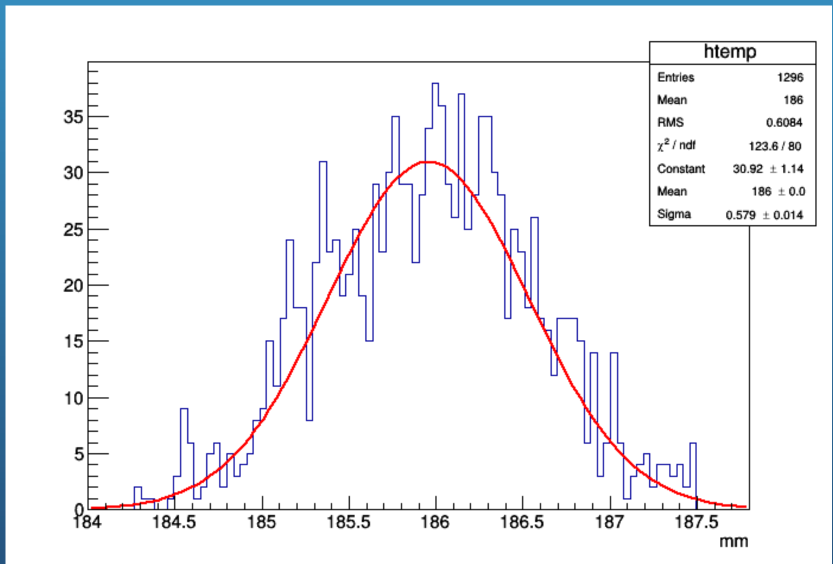
Spherical Mirror Performance



Simulated point-like image



Simulated image profile

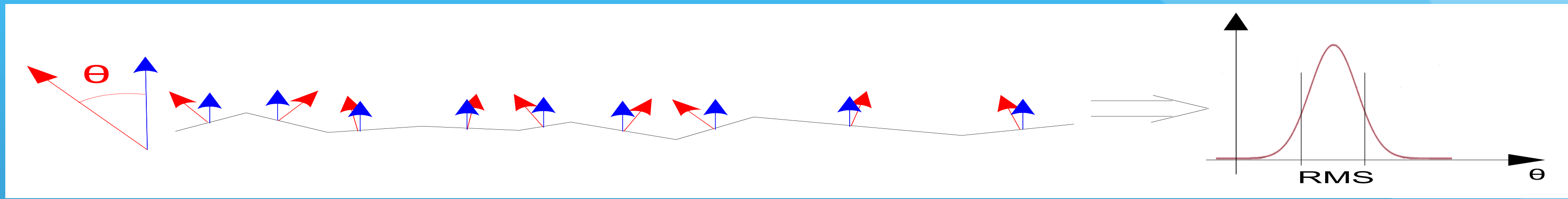


$$\sigma_s = \frac{D_0}{4}$$

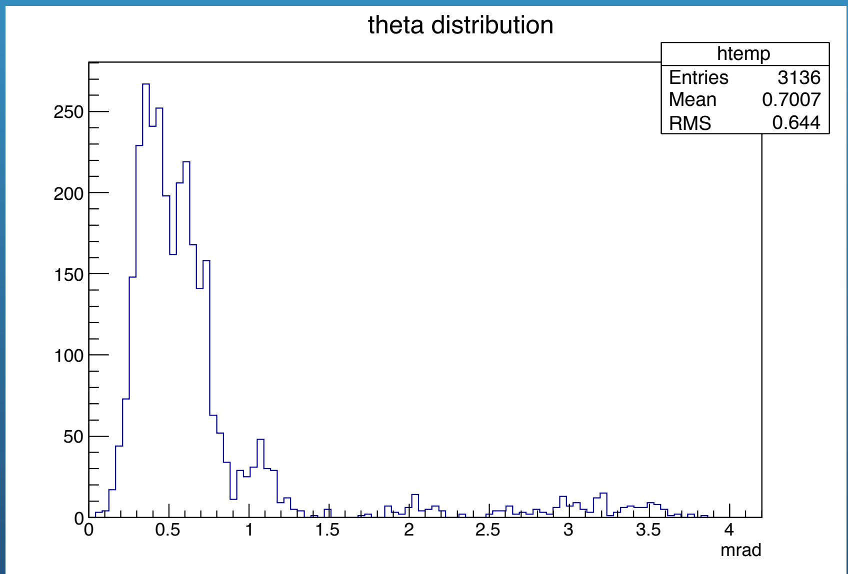
$$\sigma_{\vartheta_{mir}} = \frac{\sqrt{\sigma_s^2 + \sigma_p^2}}{2r} \approx \frac{\sigma_s}{2r} = \frac{D_0}{8r}$$

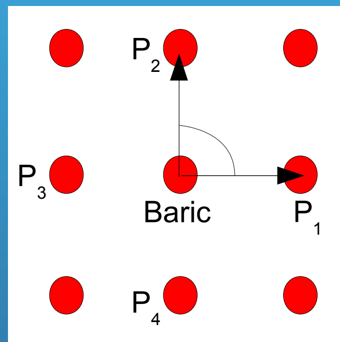
Spherical Mirror Performance

ϑ distribution



Measured ϑ distribution





Normal = $P_n \times P_{n+1}$

$n \in [1,\ldots,4]$

$$f(x) = x \cdot \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

$$\frac{\partial f}{\partial x} = 0 \qquad \sigma^2 - x^2 + \mu x = 0$$

$$\mu = 0 \qquad x = \sigma$$

Spherical Mirror Performance

Total surface

Date		Radius (mm)	P.V. (μm)	RMS (μm)	D0 (mm)	σ_{ϑ} (mrad)	Max ϑ (mrad)
Sep.	PL2	3485.7	70	12.9	24.96	0.9	0.15
	PL3	3494.7	48	9.8	20	0.72	0.08
31 Oct.	PL2	3492.7	46	8.8	12.8	0.46	0.14
	PL3	3498.2	33	7	11.2	0.4	0.11
06 Nov.	PL2	3494.7	36	6.6	8.12	0.29	0.13
	PL3	3497.6	29	5.5	8	0.29	0.08
17 Nov.	PL2	3494.1	59	12.4	22.56	0.81	0.35
	PL3	3497.5	41	8.4	15.6	0.56	0.10
01 Dic.	PL2	3498.1	29	4.8	6.4	0.23	0.10
	PL3	3503.4	24	4.8	6.8	0.24	0.05

Spherical Mirror Performance

Central area

Date		Radius (mm)	P.V. (μm)	RMS (μm)	D0 (mm)	σ_ϑ (mrad)	Max ϑ (mrad)
Sep.	PL2	3514.6	6.4	1.2	1.56	0.06	0.045
	PL3	3516.7	6.4	1.3	1.6	0.06	0.065
31 Oct.	PL2	3514.2	5.3	1.1	1.36	0.05	0.043
	PL3	3516.8	8.2	1.6	2	0.07	0.052
06 Nov.	PL2	3512.6	5.7	1	1.2	0.04	0.054
	PL3	3513.1	5.6	1.2	1.6	0.06	0.045
17 Nov.	PL2	3520.4	8.2	1.5	1.8	0.06	0.050
	PL3	3520.1	5.7	1.1	1.6	0.06	0.045
01 Dic.	PL2	3520.0	7.5	1.7	1.72	0.06	0.055
	PL3	3520.0	7.6	1.6	2.4	0.09	0.057

Mirror Surface Measurements

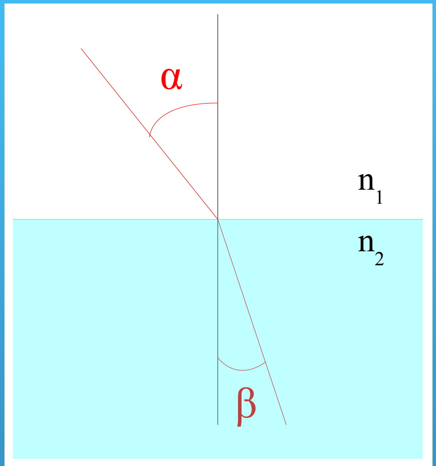
The measured values of $\sigma_{\vartheta Sph}$ and $\sigma_{\vartheta Pla}$ are compatible with the RICH requirements.

The rigidity of the rohacell foam core has been tested in different humidity conditions. Humidity and resin shrinkage are good candidates for the ageing of the spherical mirror.

Another technology has been adopted for the mirror core.

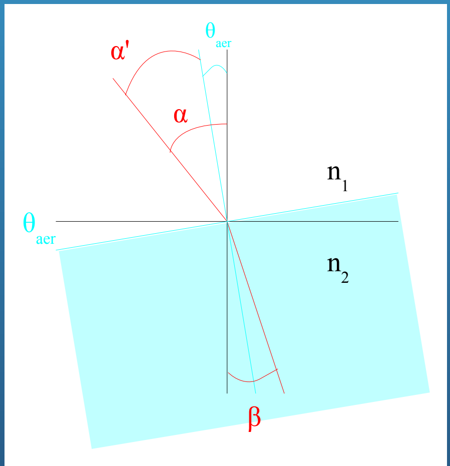
Aerogel Surface Measurements

Aerogel $\sigma_{\vartheta Ch}$ Contribution



$$n_1 \sin\alpha = n_2 \sin\beta$$

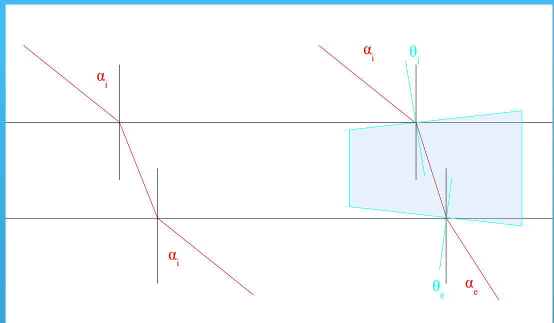
$$\beta = \arcsin\left(\frac{n_1}{n_2}\sin\alpha\right)$$



$$\beta = \vartheta_{aer} + \arcsin\left(\frac{1}{n}\sin(\alpha - \vartheta_{aer})\right)$$

$$\sigma_{\vartheta_{light}} = \left(1 - \frac{1}{n}\right)\cdot\sigma_{\vartheta_{aer}} \approx 0.05\cdot\sigma_{\vartheta_{aer}}$$

Aerogel $\sigma_{\vartheta Ch}$ Contribution



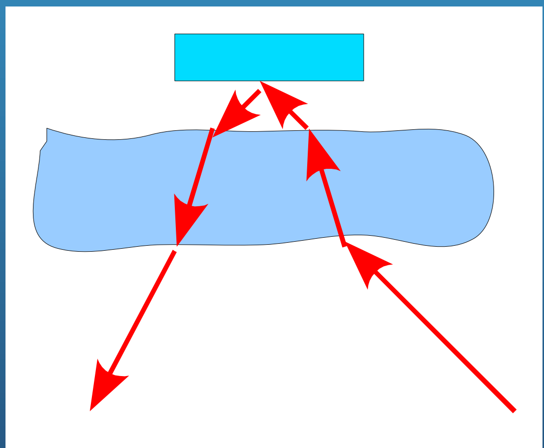
$$\alpha_e = \vartheta_e + \arcsin\left[n \sin\left(\vartheta_i - \vartheta_e + \arcsin\left[\frac{1}{n} \sin(\alpha_i - \vartheta_i) \right] \right) \right]$$

$$\sigma_{\vartheta_{light}} = (n-1)\sqrt{\sigma^2_{\vartheta_i} + \sigma^2_{\vartheta_e}} \approx 0.05 \cdot \sqrt{2} \cdot \sigma_{\vartheta_{aer}}$$

$$\alpha_e = \alpha_i$$

In the RICH configuration

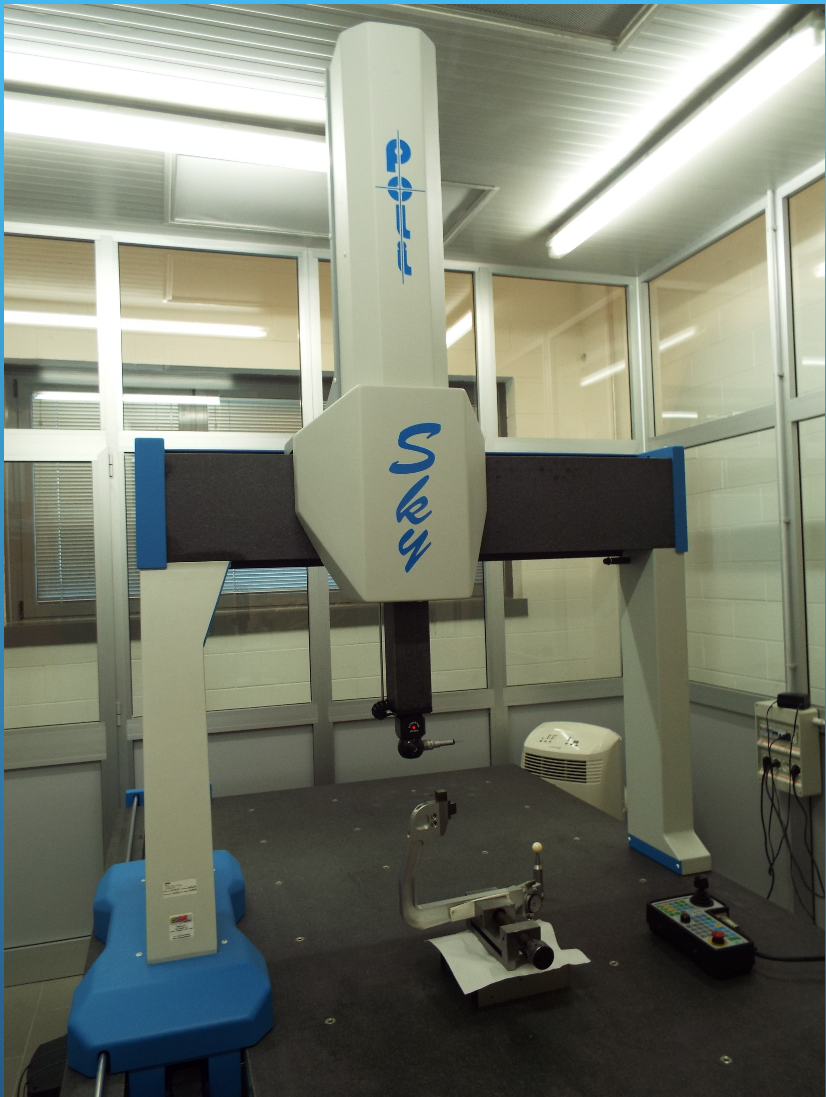
$$\frac{\sigma_{\vartheta_{light}}}{\sigma_{\vartheta_{aer}}} = 0.1$$

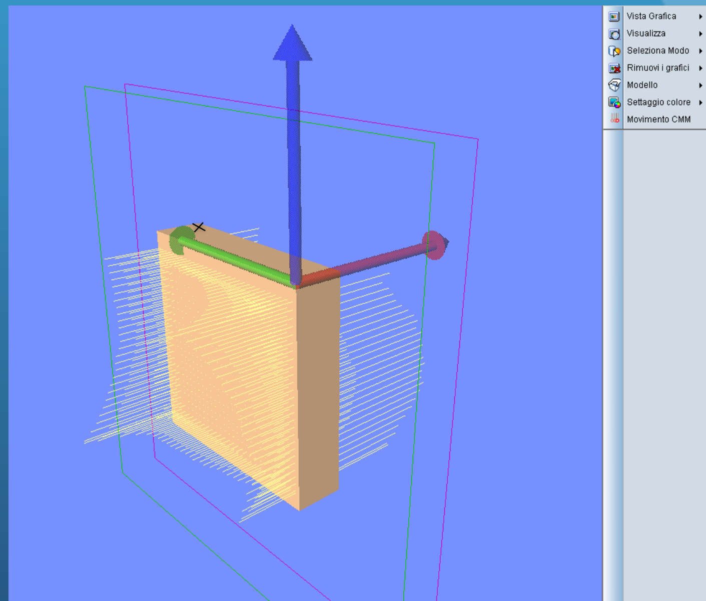


$$\sigma_{\vartheta_{light}} = (n-1)\sqrt{\sigma^2_{\vartheta_i} + \sigma^2_{\vartheta_e} + \sigma^2_{\vartheta_i} + \sigma^2_{\vartheta_e}} \approx 0.1 \cdot \sigma_{\vartheta_{aer}}$$

$$\sigma_{\vartheta_{Ch}} = \sigma_{\vartheta_{light}} \cdot \frac{1m}{3m} = 0.1 \cdot \sigma_{\vartheta_{aer}} \cdot \frac{1}{3} = 0.03 \cdot \sigma_{\vartheta_{aer}}$$

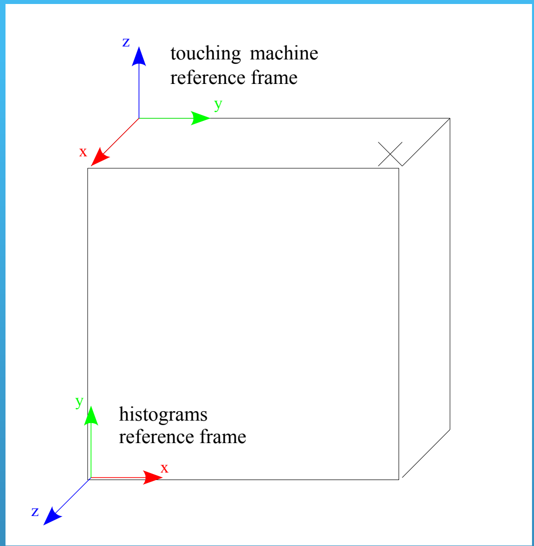
Touching Machine Measurement



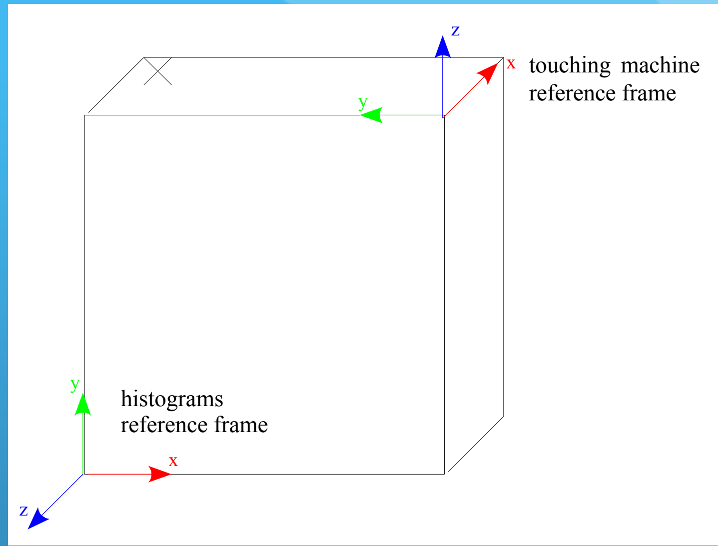


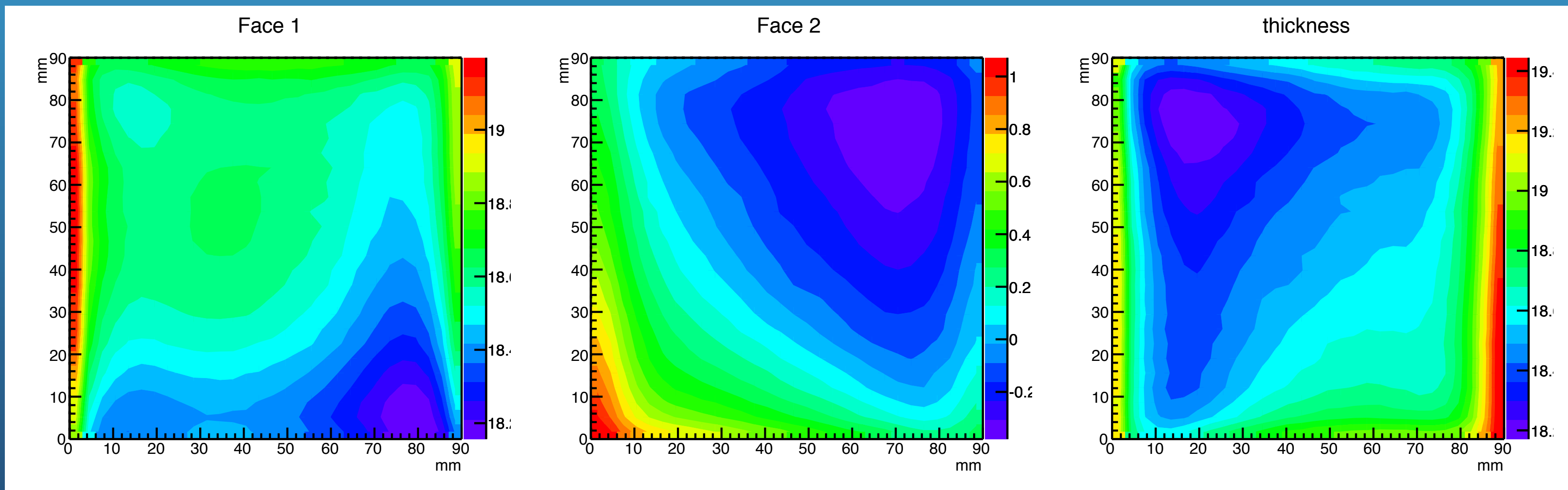
Touching Machine Measurement

Face 1



Face 2





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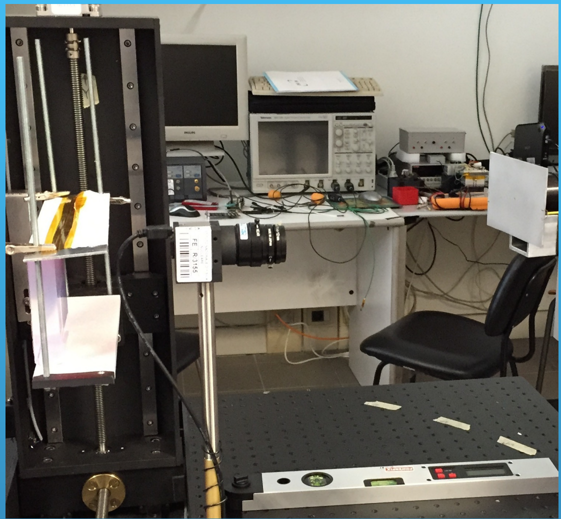
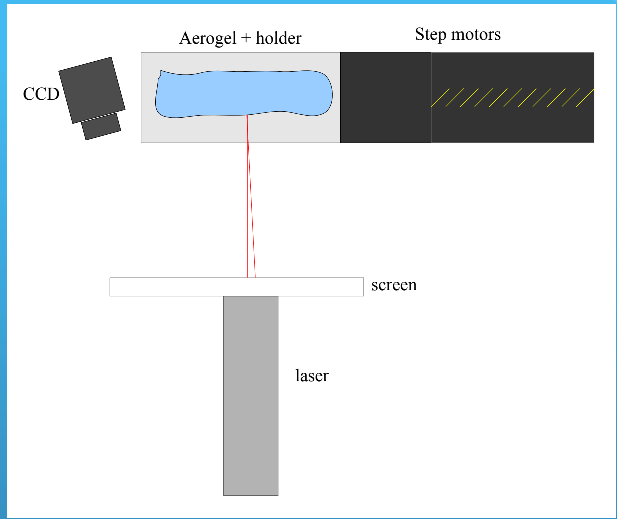
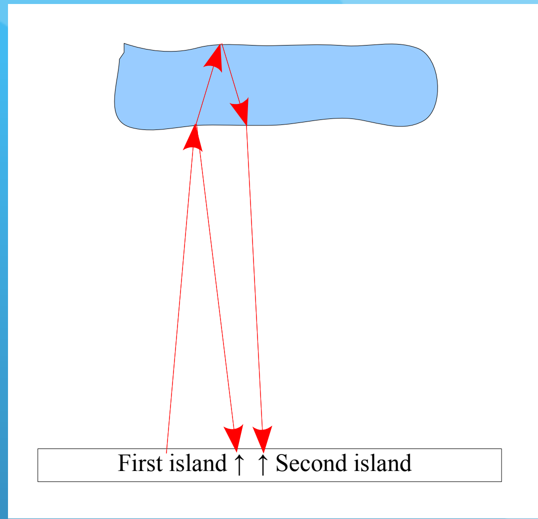
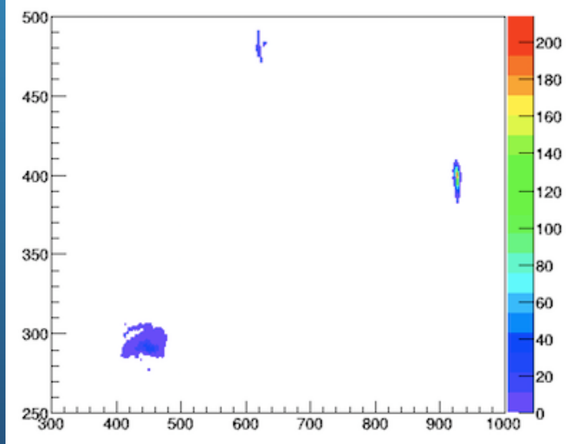
Laser Reflection Measurement



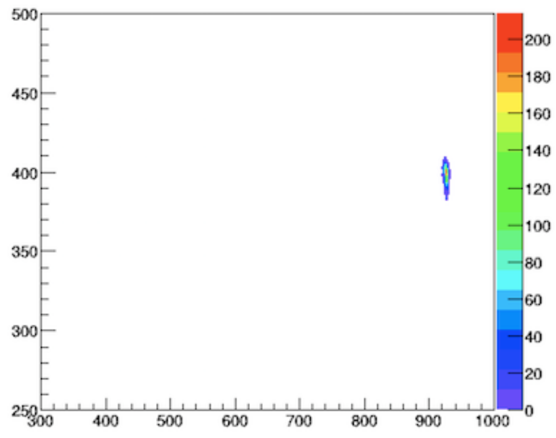




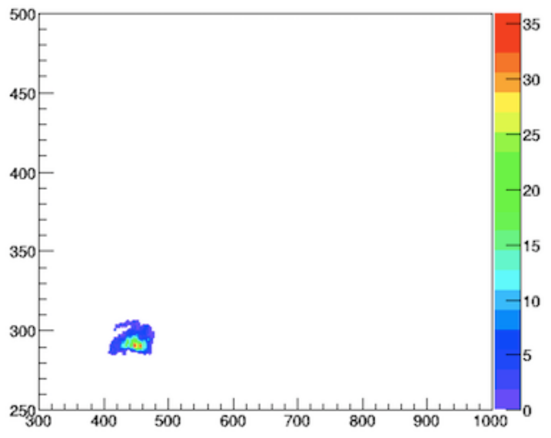
histogram



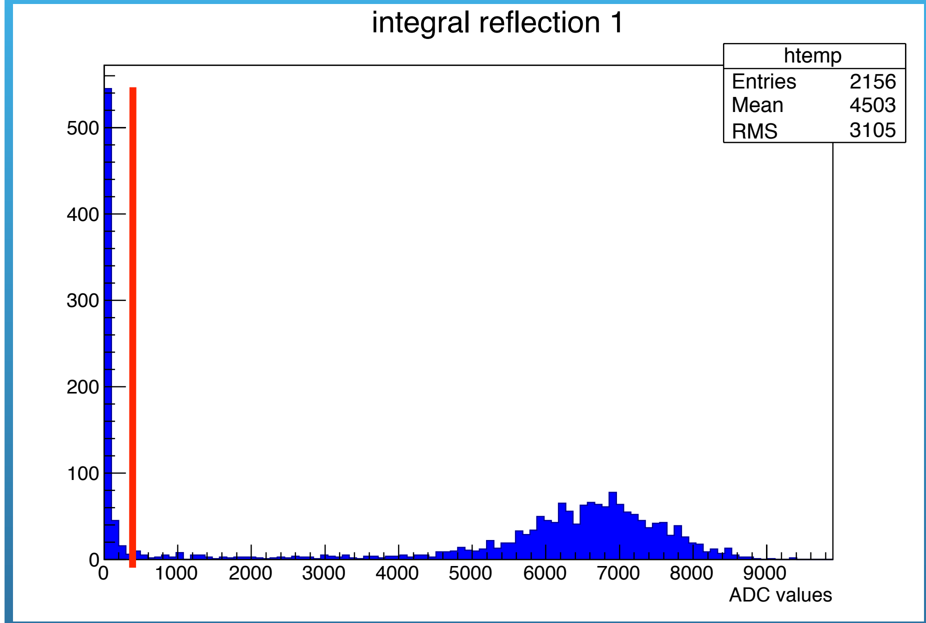
first reflection

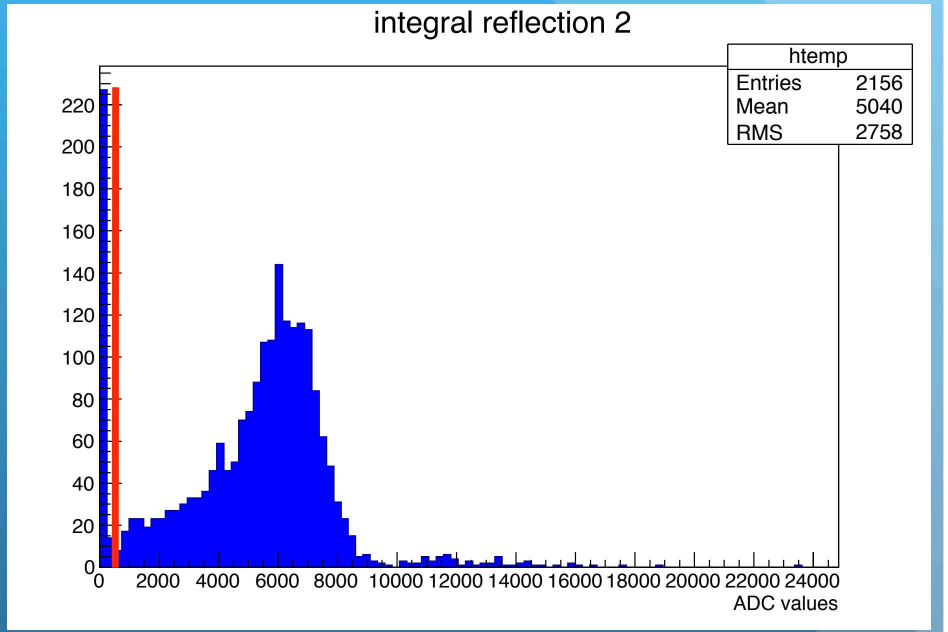


second reflection

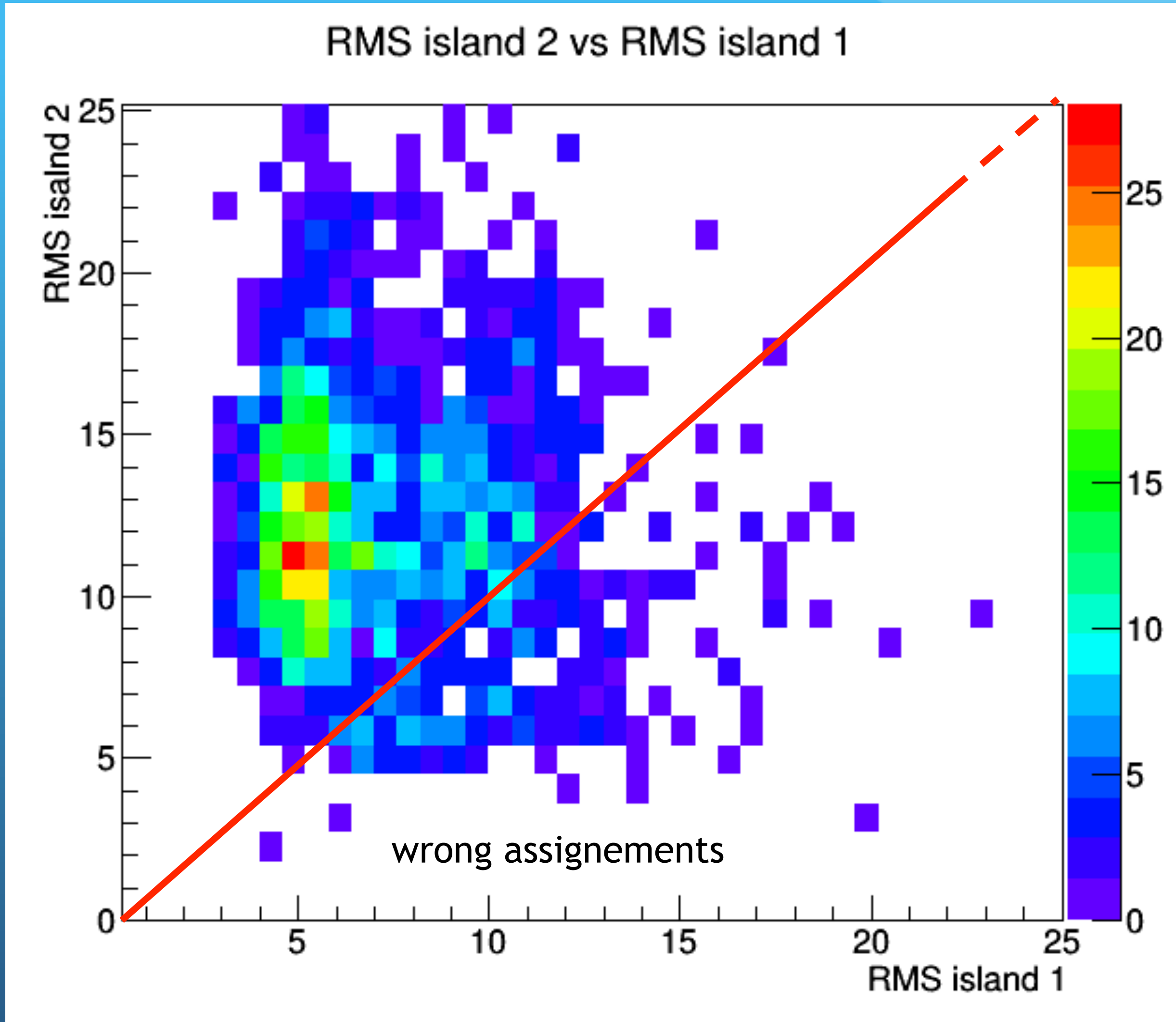


Laser Reflection Measurement



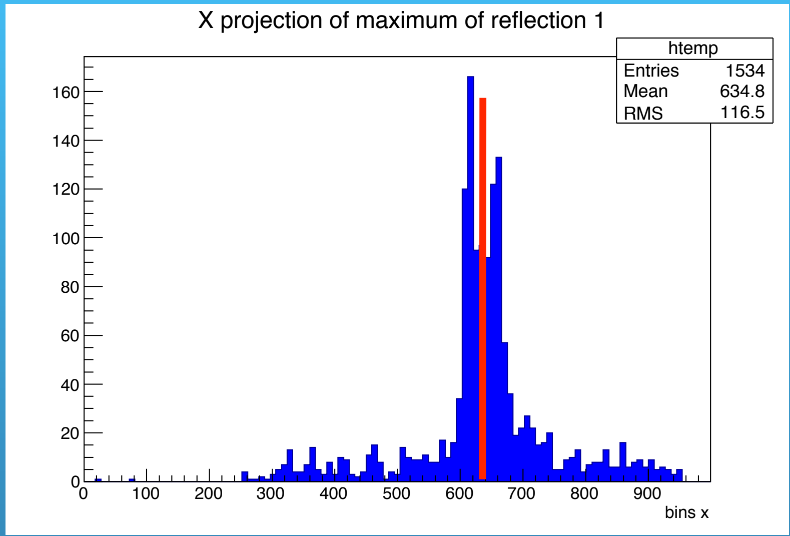


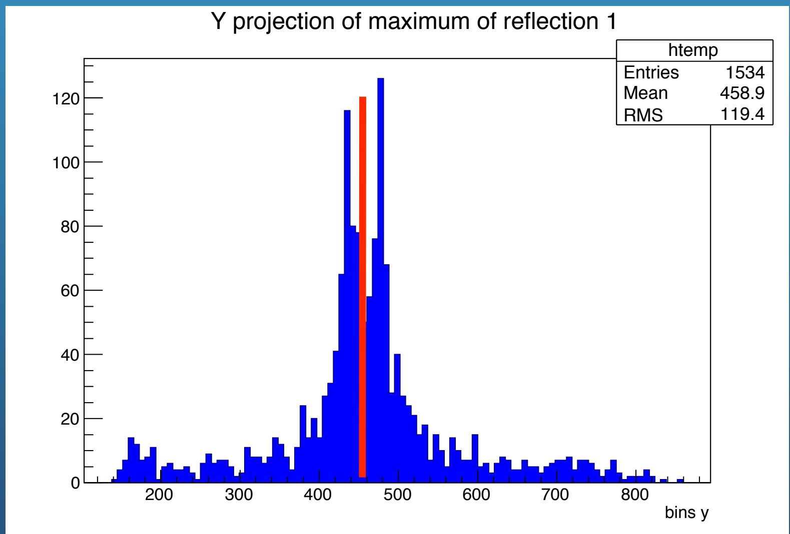
Laser Reflection Measurement



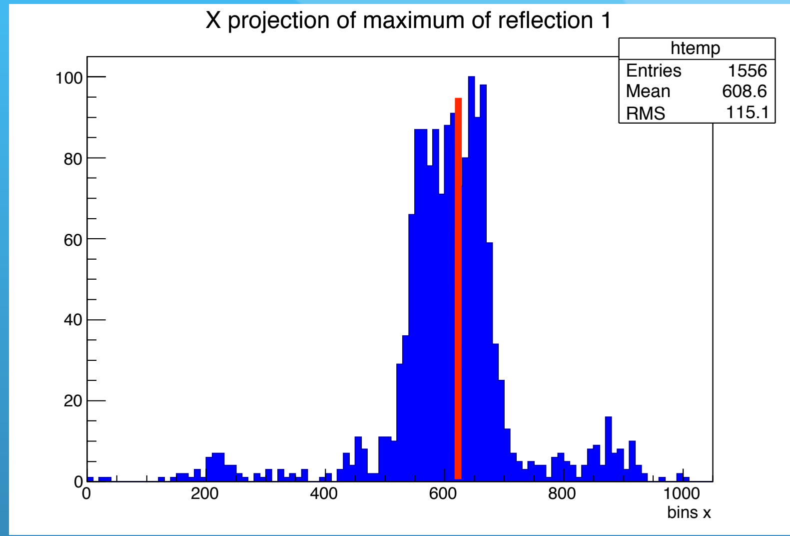
Reference Position

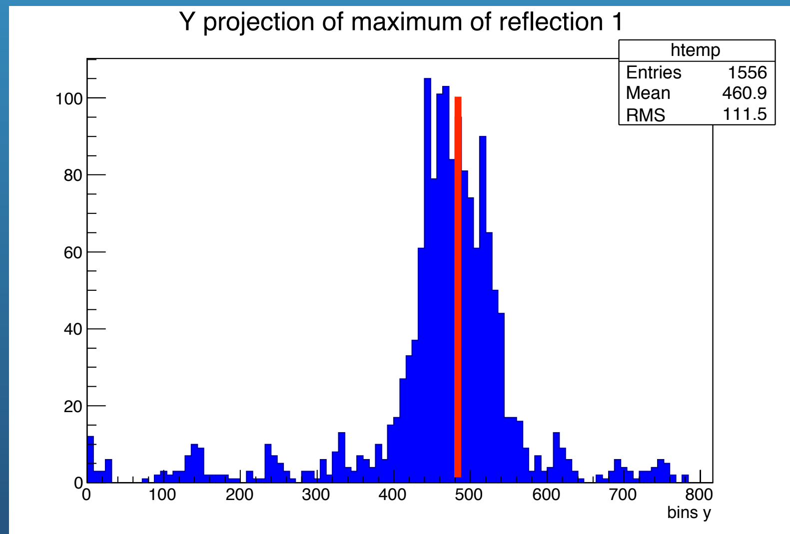
Face 1





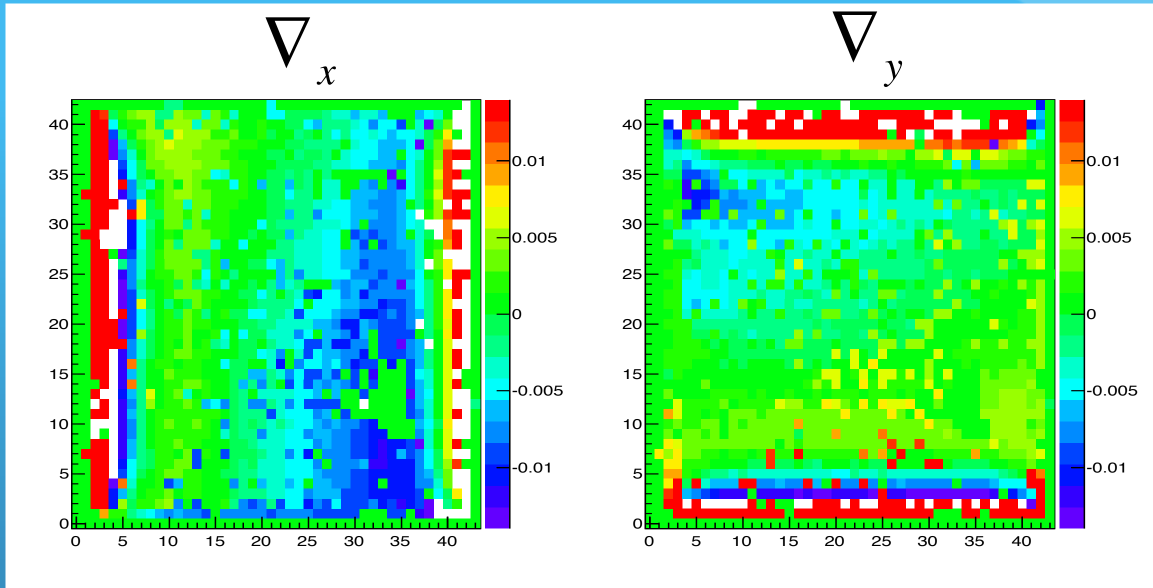
Face 2





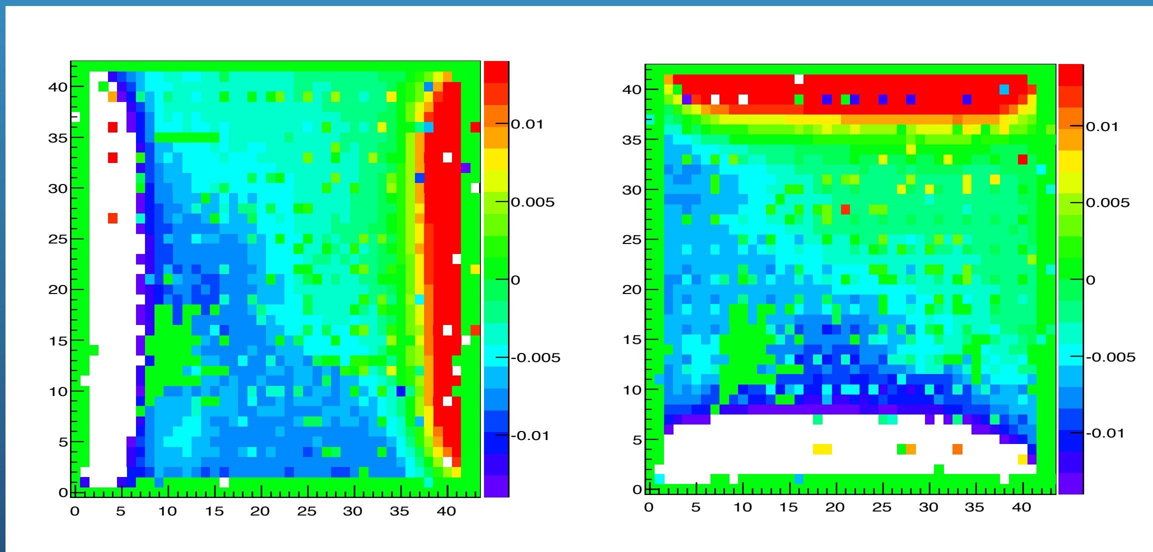
Laser Reflection Measurement

Face 1



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

Face 2

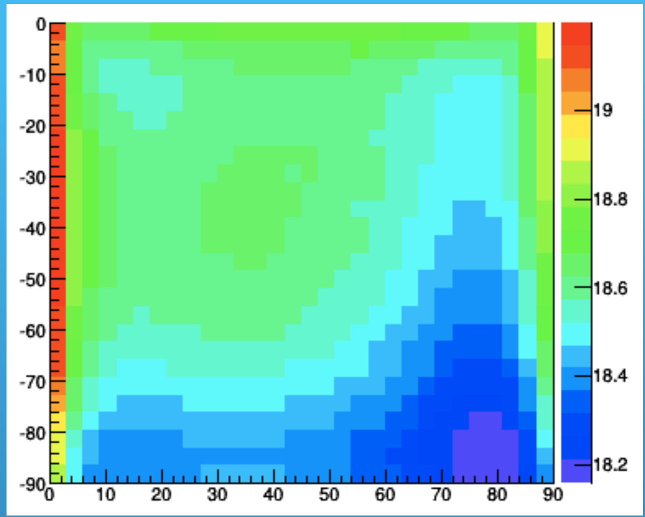


$$\nabla_y = \frac{(y - y_{mean}) \cdot c_l}{2 \cdot L}$$

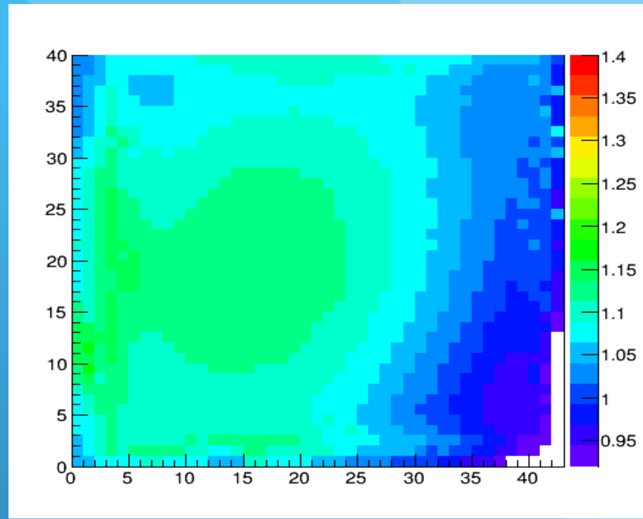
Surfaces Comparison

F a c e 1

Touch Machine

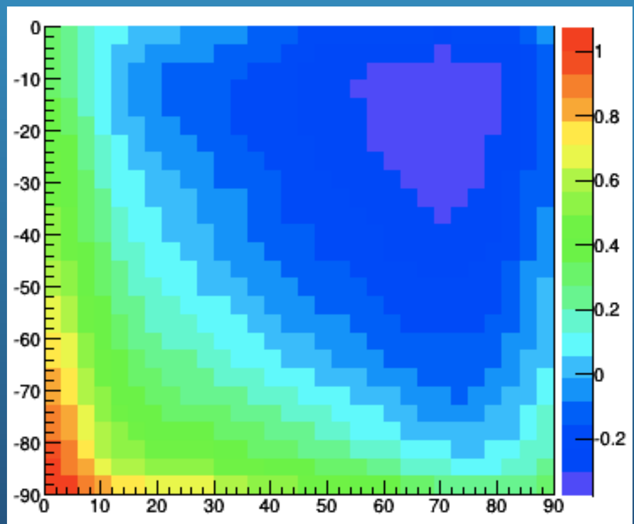


Laser Setup

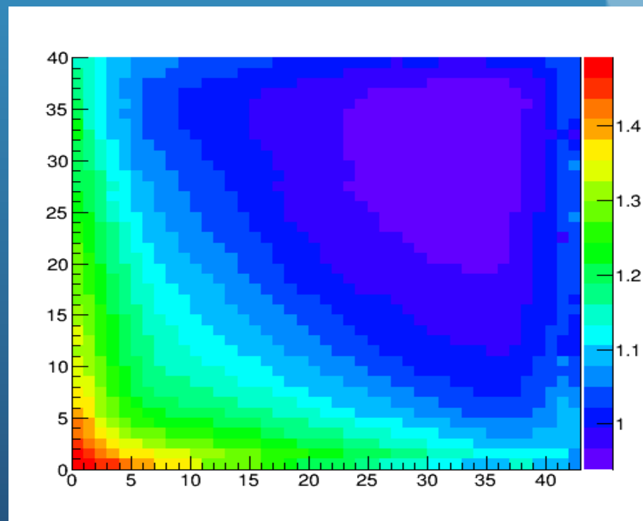


F a c e 2

Touch Machine



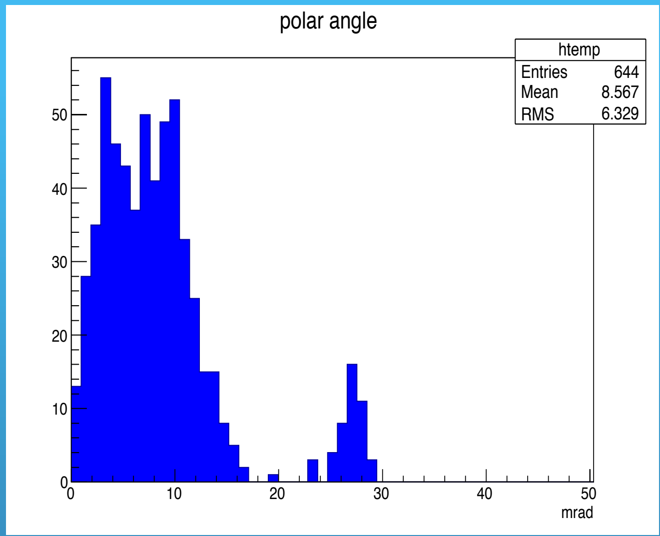
Laser Setup



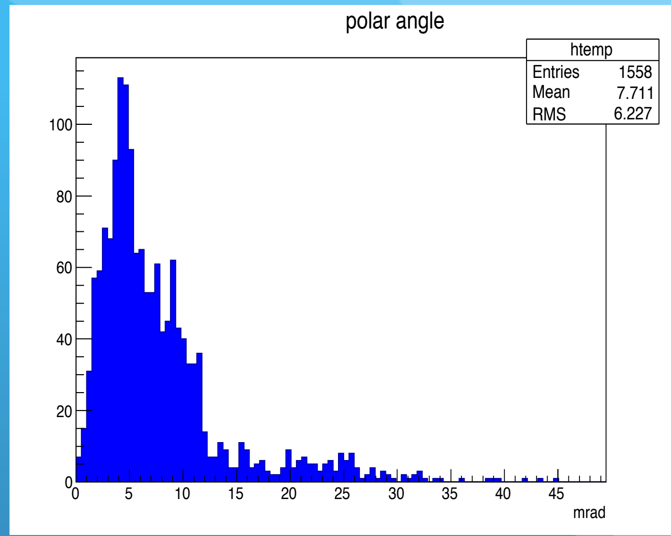
Surfaces Comparison

F a c e 1

Touch Machine

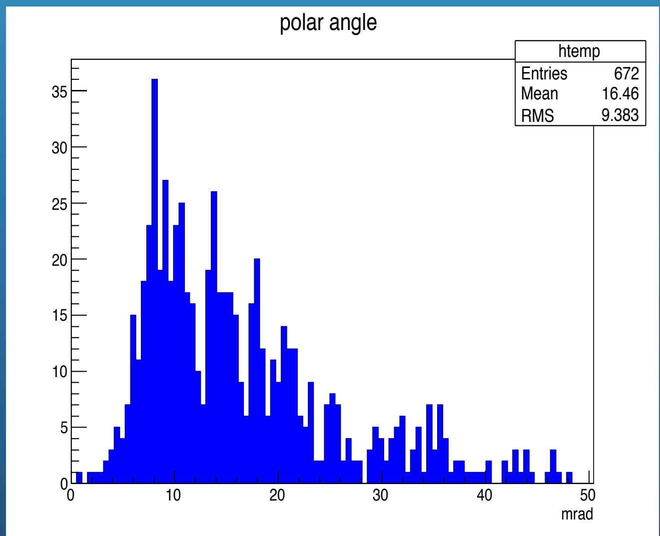


Laser Setup

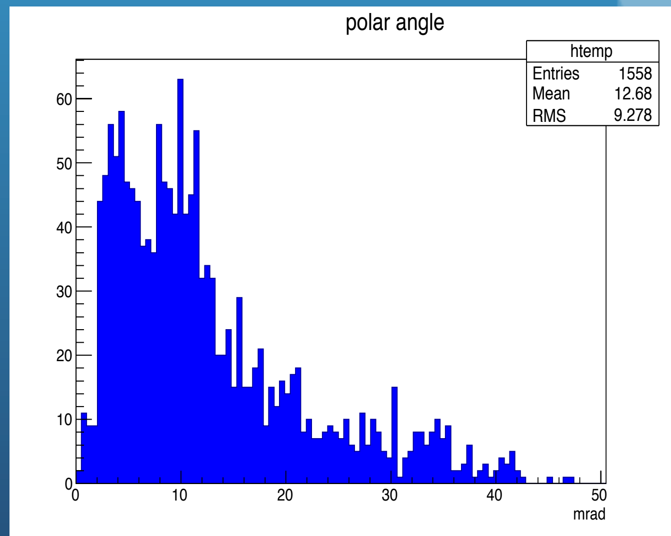


F a c e 2

Touch Machine

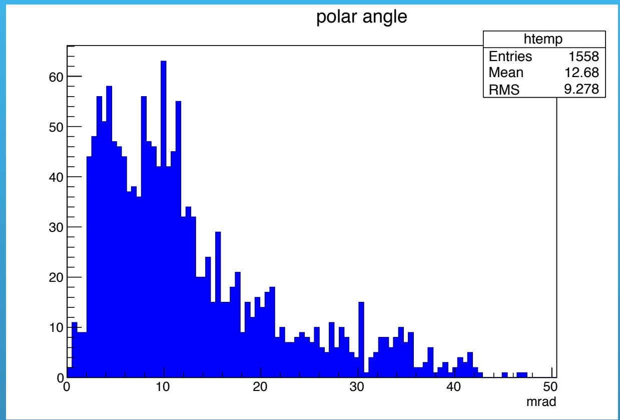


Laser Setup

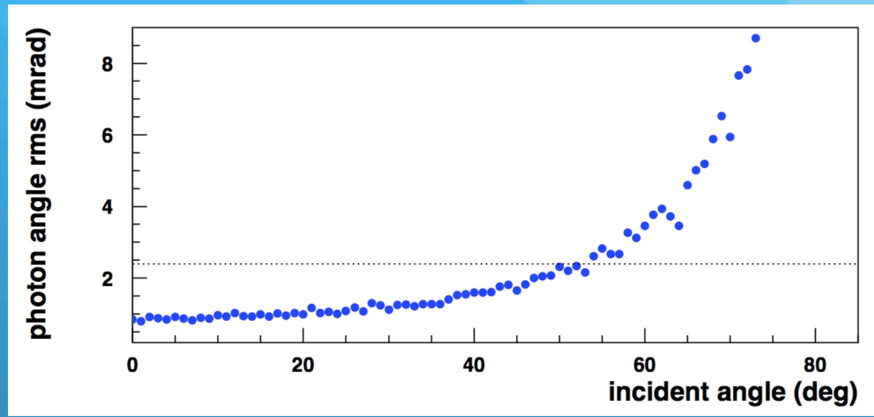


Light Dispersion Measurement

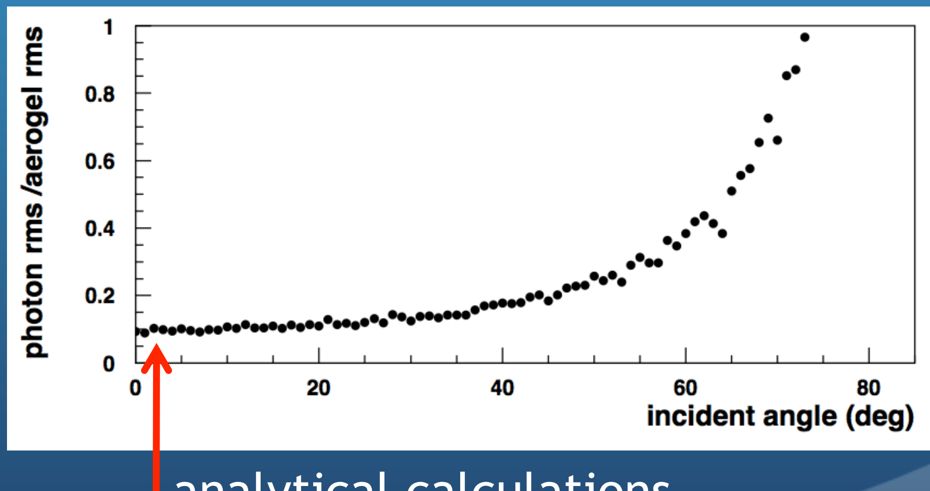
measured aerogel



simulated light dispersion

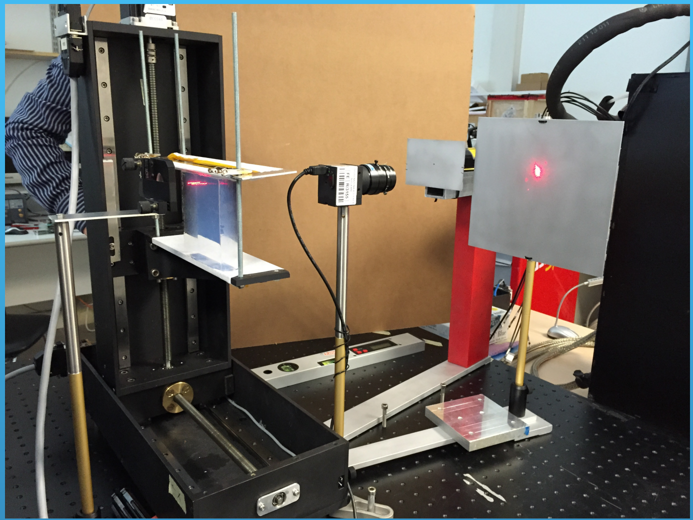


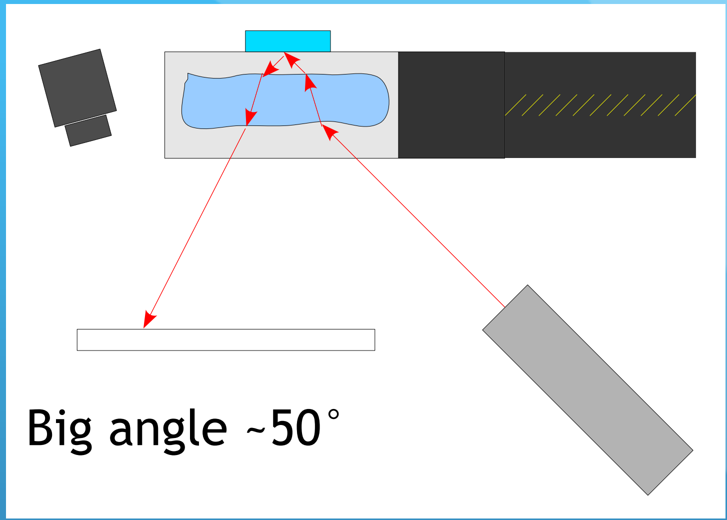
light dispersion vs aerogel surface RMS

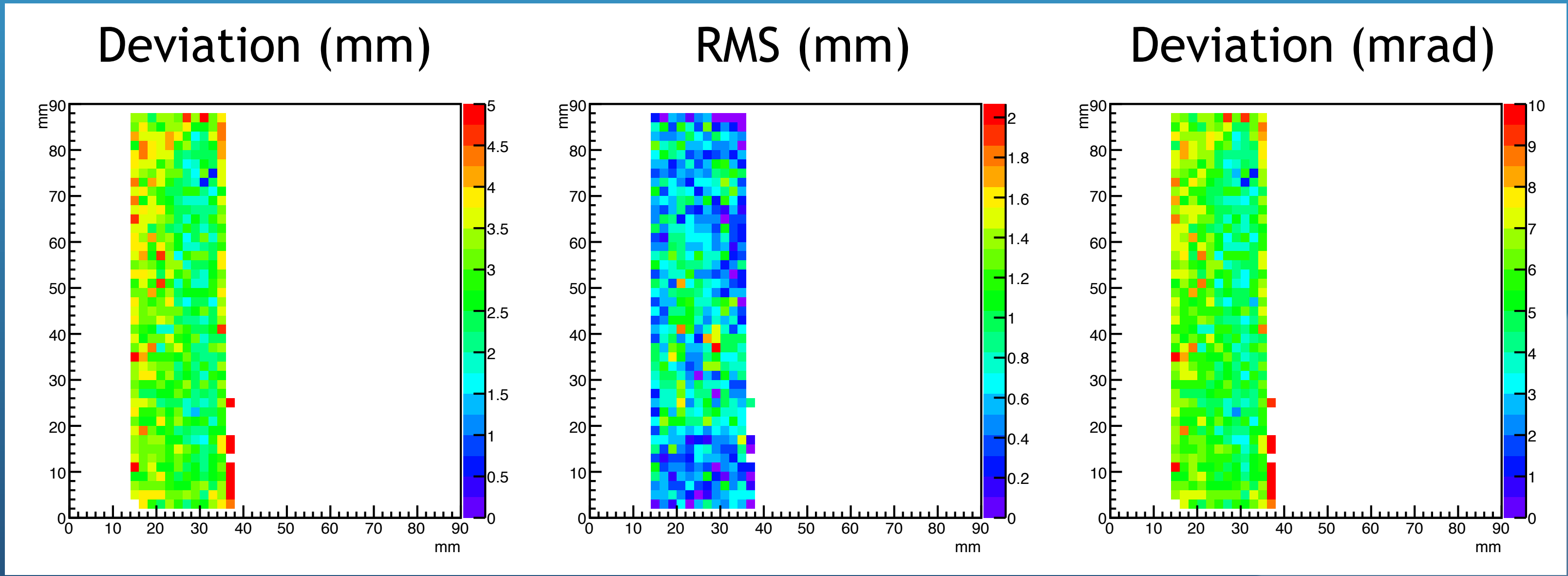


analytical calculations

Light Dispersion Measurement

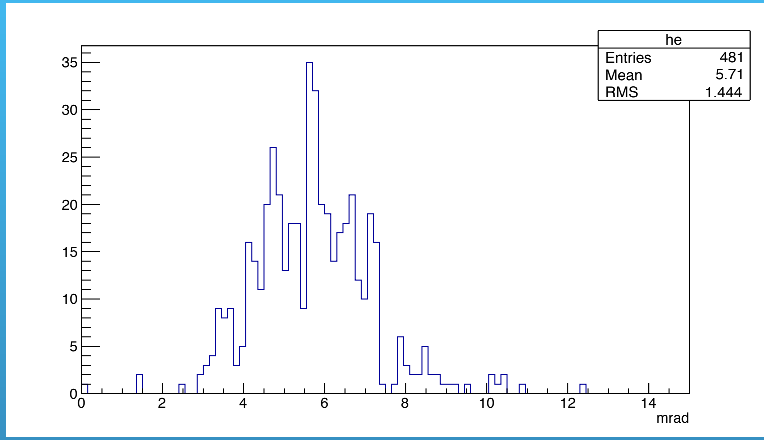




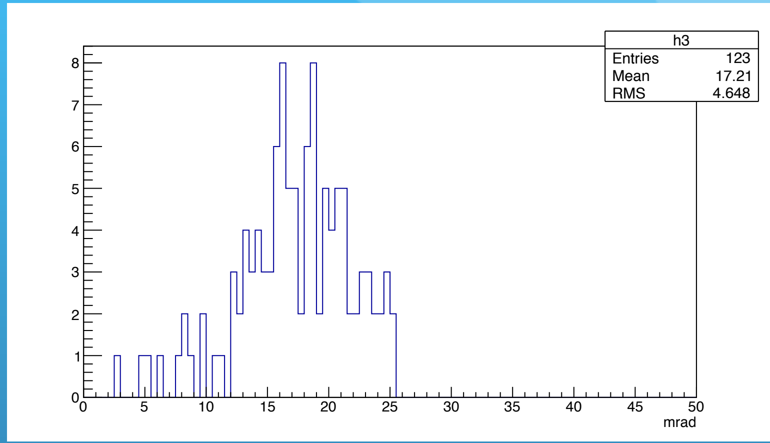


Light Dispersion Measurement

light dispersion



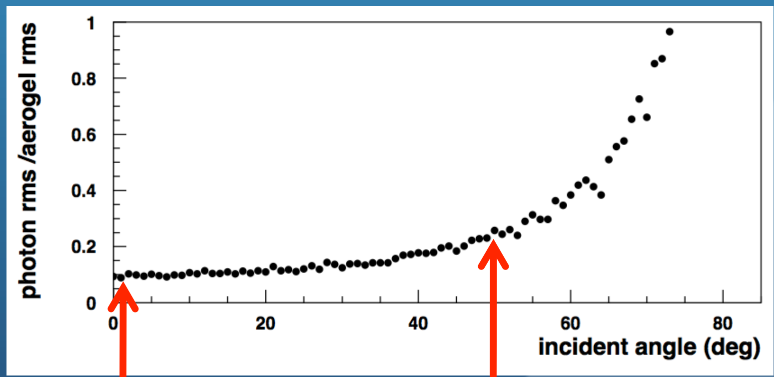
aerogel surface RMS



	$Mean_{(mrad)}$	$RMS_{(mrad)}$
Light dispersion	5.71	1.44
Aerogel surface	17.21	4.65
ratio	0.33	0.31

$$\sigma_{\vartheta_{Aer}} = \frac{pixel\ \ size}{ratio} = \frac{2.45mrad}{0.31} = 8mrad$$

light dispersion vs aerogel surface RMS



measurement

analytical calculations

Aerogel Surface Measurement

A not invasive laser reflection setup has been commissioned and validated.

Compatible results with the touching machine has been obtained.

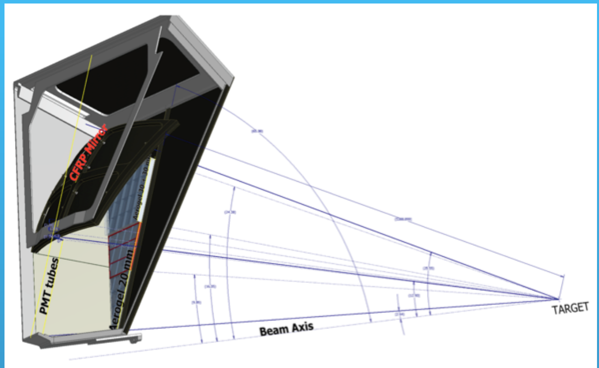
The laser reflection setup can substitute the invasive touching machine characterization.

A general relation between the aerogel surface quality and transmitted light dispersion has been found.

It gives an upper limit of 8 mrad for the aerogel surface RMS.

The laser setup has been used to characterize the aerogel surface and validate the relation.

Single Photon Resolution



$$\sigma_{\vartheta_{Sph}} = 0.16 \ mrad$$

$$\sigma_{\vartheta_{Pla}} = 0.1 \ mrad$$

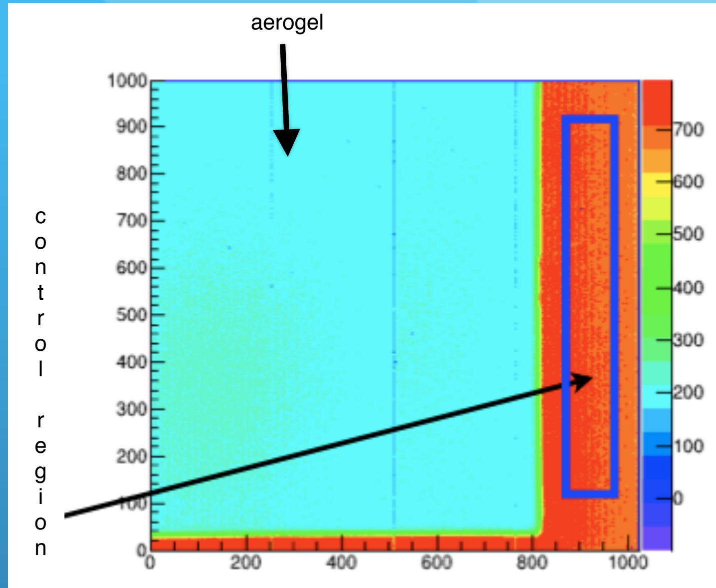
$$\sigma_{\vartheta_{Aer}} = 8 \ mrad$$

$$\sigma_{\vartheta_{Ch}}^{focus} = \sqrt{\left(\frac{4}{3}\sigma_{\vartheta_{Sph}}\right)^2 + \left(\frac{2}{3}\sigma_{\vartheta_{Pla}}\right)^2 + \left(0.03\sigma_{\vartheta_{Aer}}\right)^2} =$$

$$= \sqrt{(0.21)^2 + (0.06)^2 + (0.24)^2} = 0.32 mrad$$

Aerogel Density Measurement

X-ray Measurement



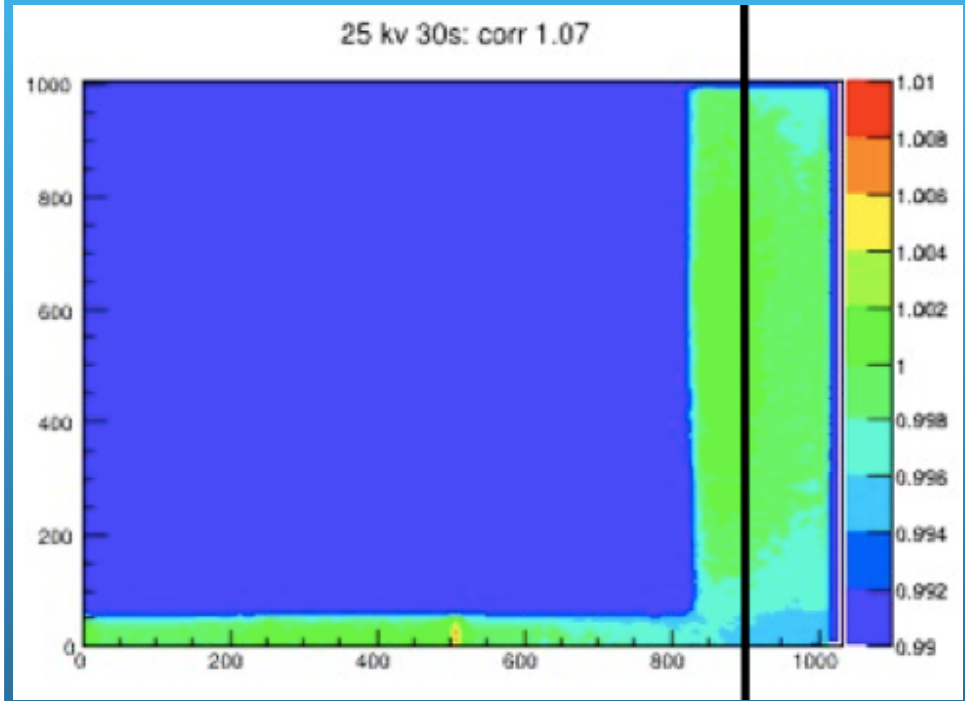
	X-ray rate	Exposition time
Aerogel image, With aerogel and X-ray	a	τ_a
White image, Without aerogel	w	τ_w
Dark image, Without aerogel and X-ray	d	τ_d

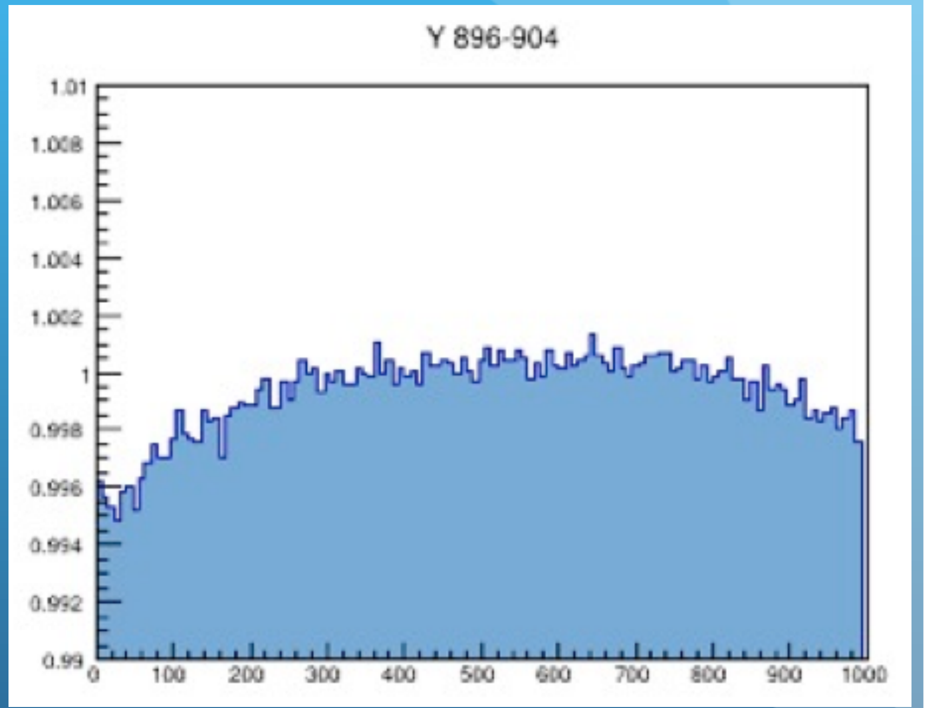
$$\Re = \frac{(a+d)\tau_a - c_1 d\tau_d}{c(w+d)\tau_w - c_1 d\tau_d}$$

$$c_1 = ?$$

$$c = \frac{\tau_a}{\tau_w} = \frac{Integral_a}{Integral_w}$$

X-ray Measurement





$$\Delta\mathfrak{R} \leq 4‰$$

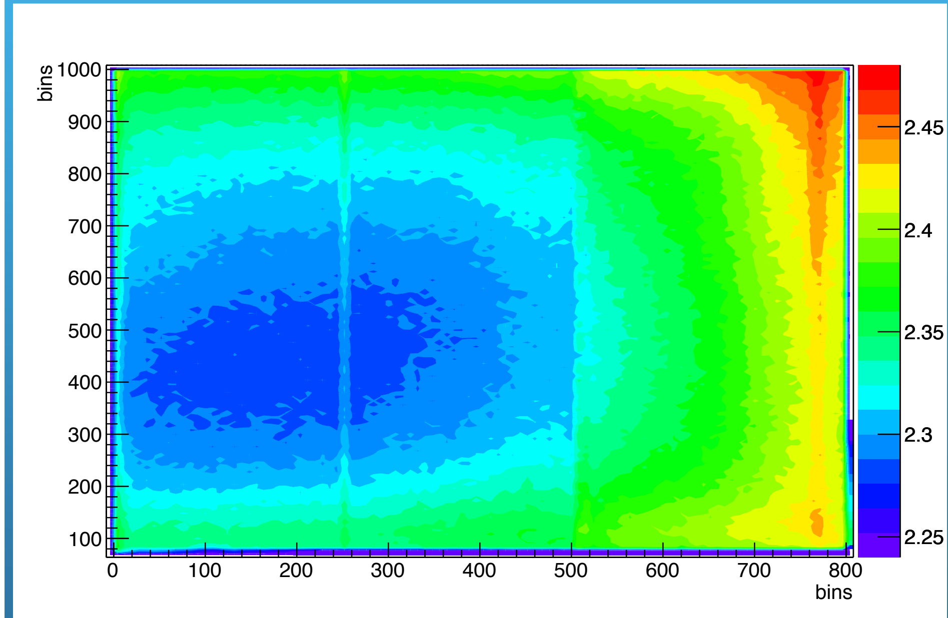
X-ray Measurement

$$\sigma_\tau = \frac{(a+d)\tau_a - c_1 d\tau_d}{c(w+d)\tau_a - c_1 d\tau_d} - \frac{a}{w} \approx \frac{d}{w}\left(1-\frac{a}{w}\right)\frac{\tau_a - \tau_d}{\tau_a}$$

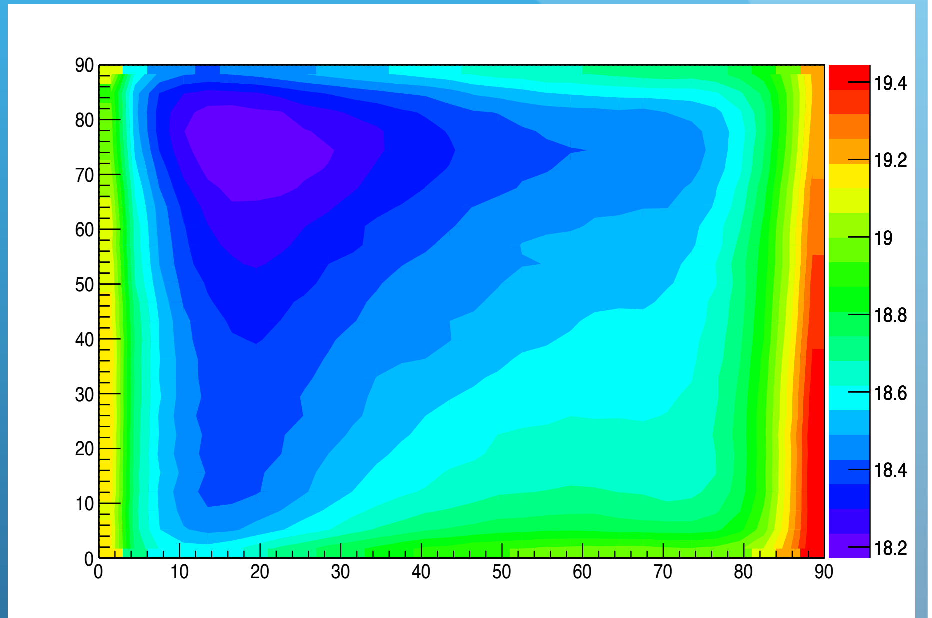
Energy$_{(kV)}$	d/w	a/w	σ_τ	$\tau_{a\ (s)}$	$\tau_{d\ (s)}$	$\tau_{w\ (s)}$
12	3.3	0.990		45	40	45
15	0.9	0.990		20	25	20
16	12.0	0.197	0.9636	35	35	35
18	4.0	0.200	0.3200	37	40	40
20	1.2	0.290	0.0852	35	35	35
25	0.4	0.437	0.0225	30	30	30

Measurement Comparison

X-ray



Touch machine



(2.43 – 2.28) / 2.43 = 6.17 %

(19.4 – 18.2) / 19.4 = 6.19 %

Aerogel Density Measurement

An X-ray radiographic technique for density measurements has been studied.

After optimization, the X-ray results are compatible with the thickness variations measured by the touching machine.

This is indicative of small density variations but additional work is required to really access the density profile.

Conclusion

•A not invasive laser reflection setup has been commissioned and validated.
The laser reflection setup can substitute the touching machine.

•The spherical mirror surface RMS is compatible with the RICH requirements.
The rigidity of the rohacell foam core is not stable under different humidity conditions.
Another technology has been adopted.

•A specification for aerogel surface quality has been defined and a laser tool to verify it commissioned.

•The quality of the studied components is generally suitable for the CLAS12 RICH but possible improvements has been suggested.

Light Dispersion Measurement

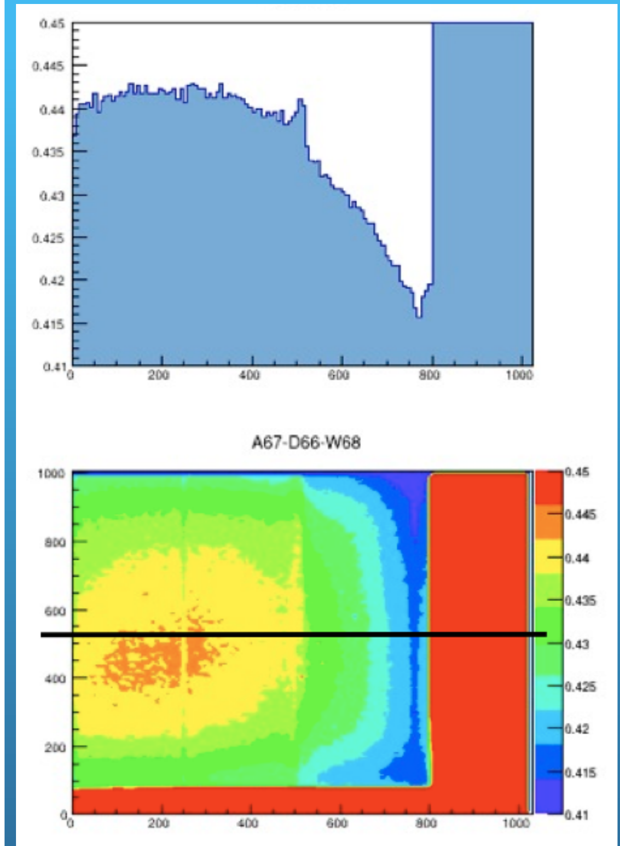
Light Dispersion Measurement

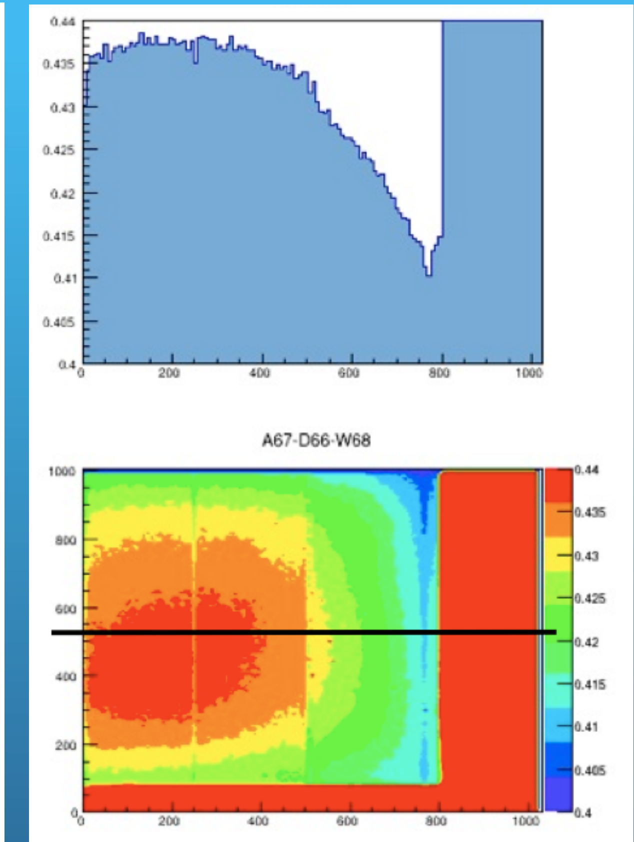
A general relation between the aerogel surface quality and transmitted light dispersion has been found.

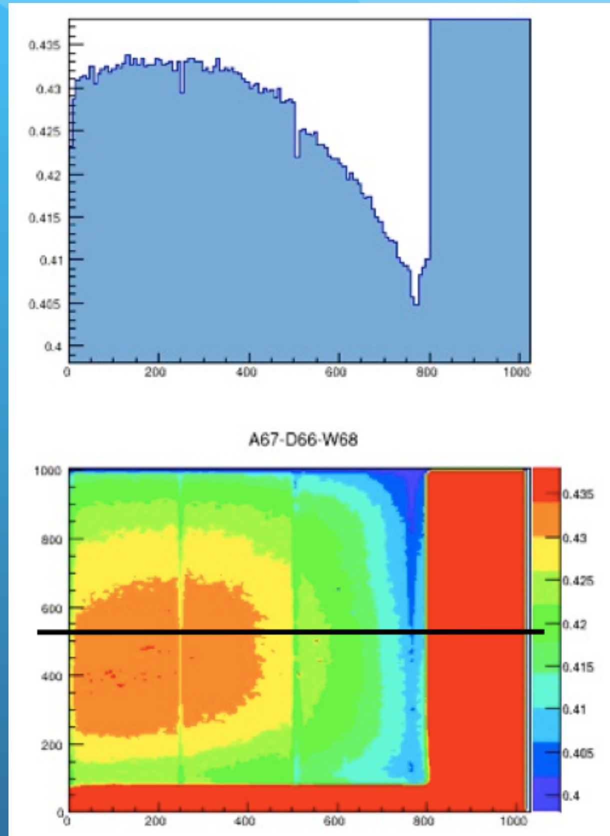
It gives an upper limit of 8 mrad for the aerogel surface RMS.

The laser setup has been used to characterize the aerogel surface and validate the relation.

X-ray Measurement





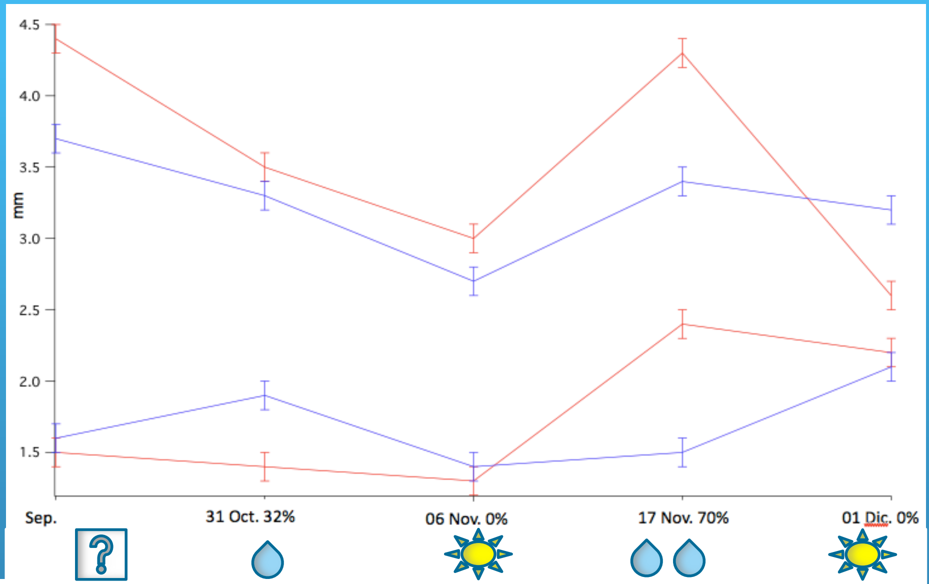


c1=1.07

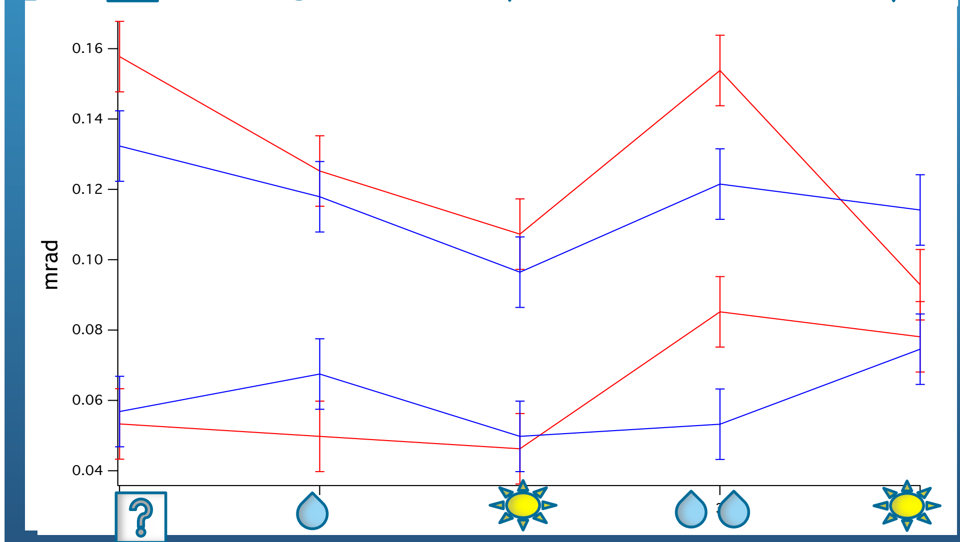
c1=1.09

c1=1.11

Spherical Mirror Performance



D_0 of the mirror



$\sigma_{\vartheta Sph}$ of the mirror