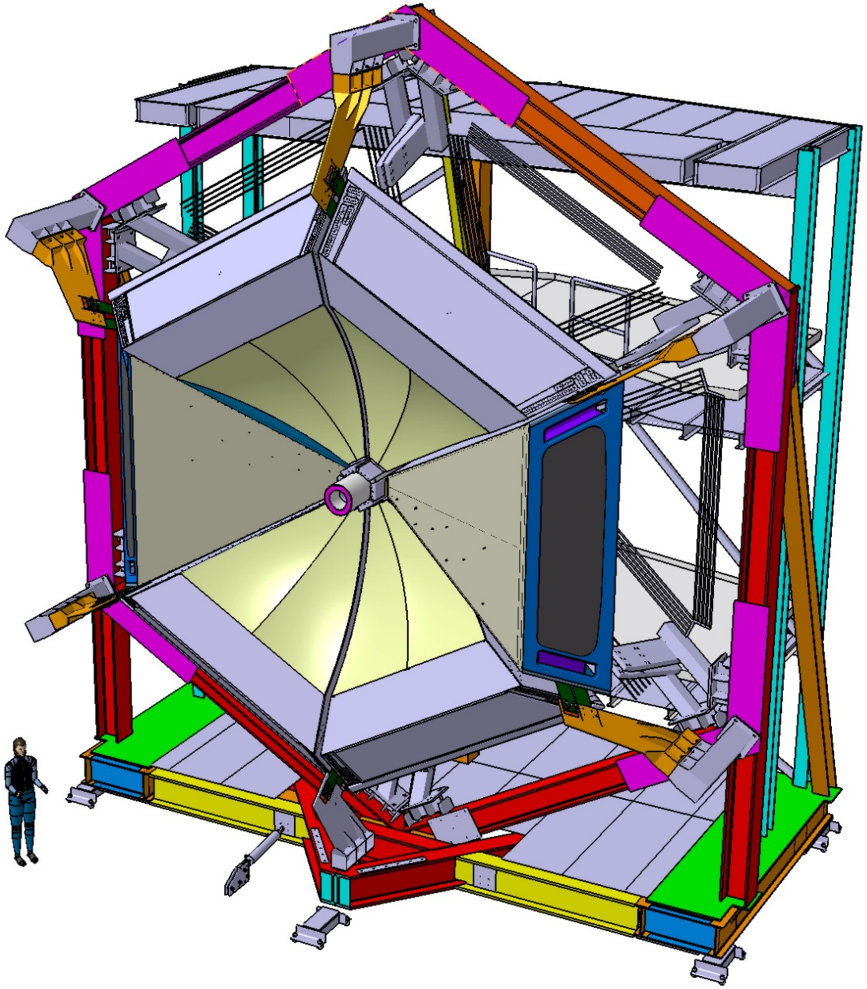


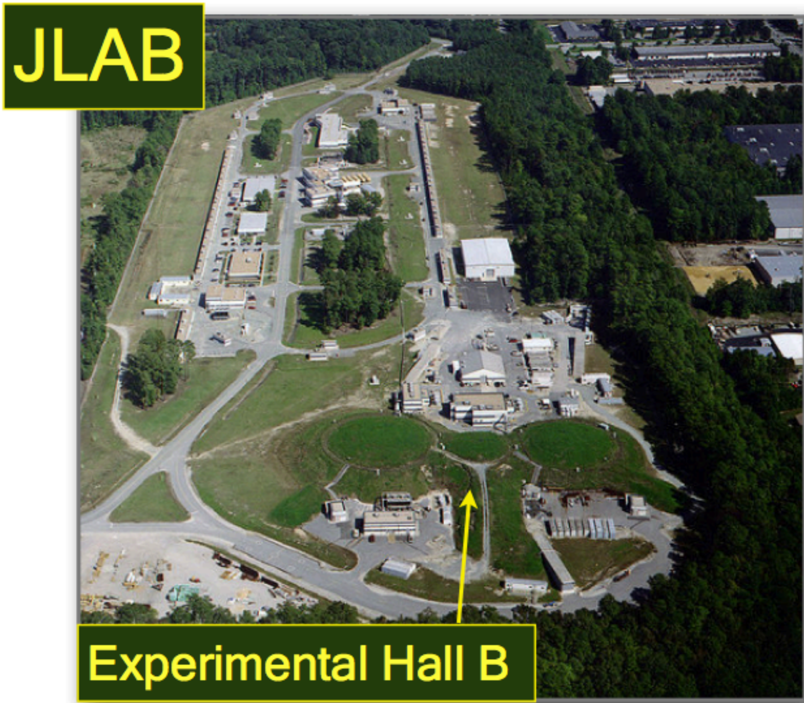
Aerogel mass production for the CLAS12 RICH: Novel characterization methods and Optical Performance

Contalbrigo Marco
INFN Ferrara

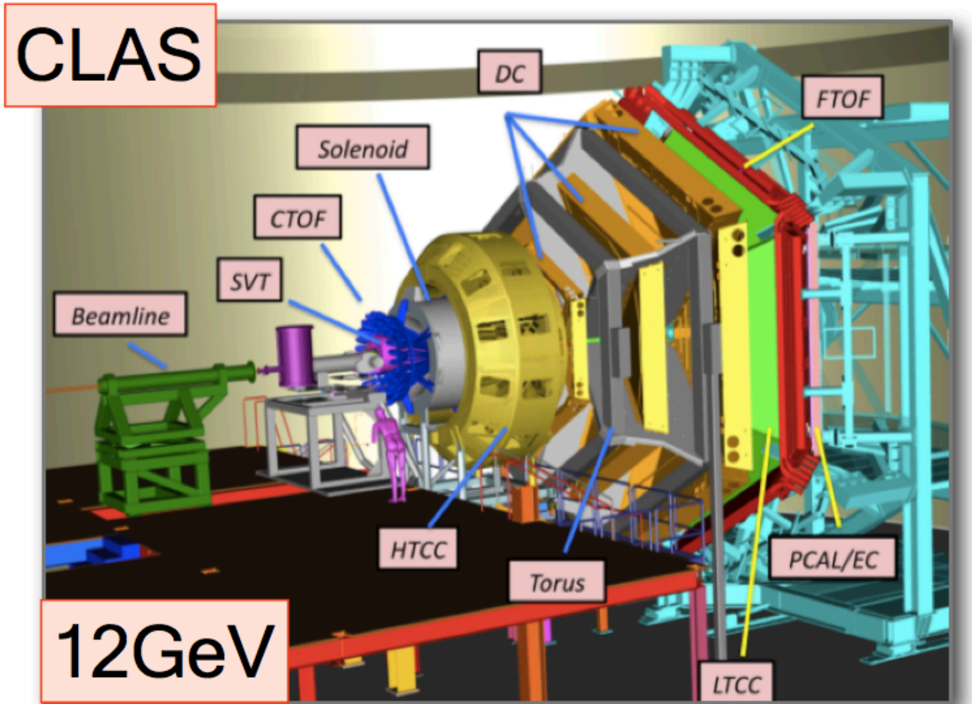
RICH 2016, September 9th 2016, Bled

The CLAS12 RICH

CLAS12 at Thomas Jefferson National Laboratory, Newport News, Virginia, USA



Continuos Electron Beam Accelerator Facility (CEBAF)

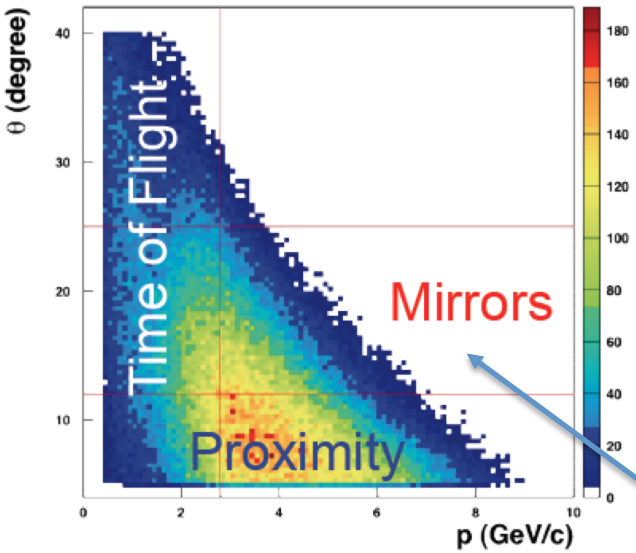


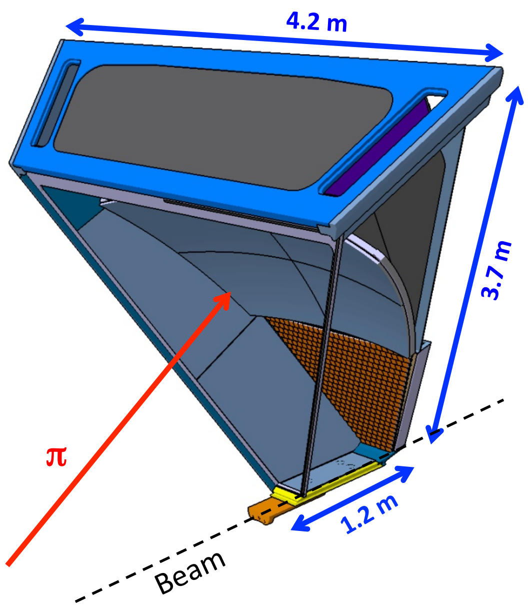
CEBAF Large Acceptance Spectrometer (CLAS)

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

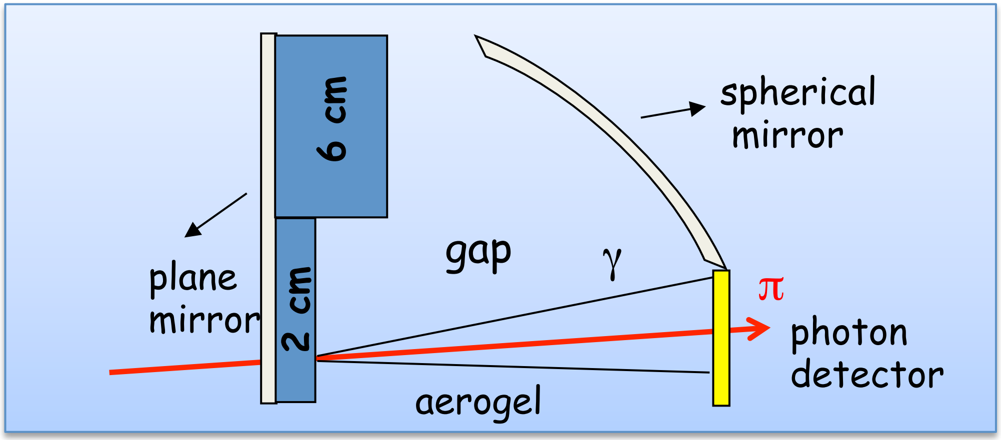
~4σ pion-kaon separation for a pion rejection factor ~ 1:500

The Hybrid Optics Design

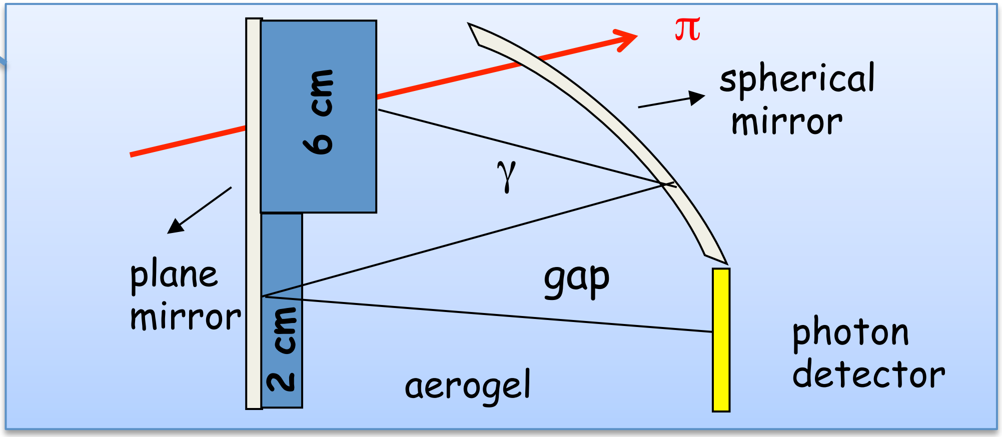




Direct rings and best performance for high momentum particles



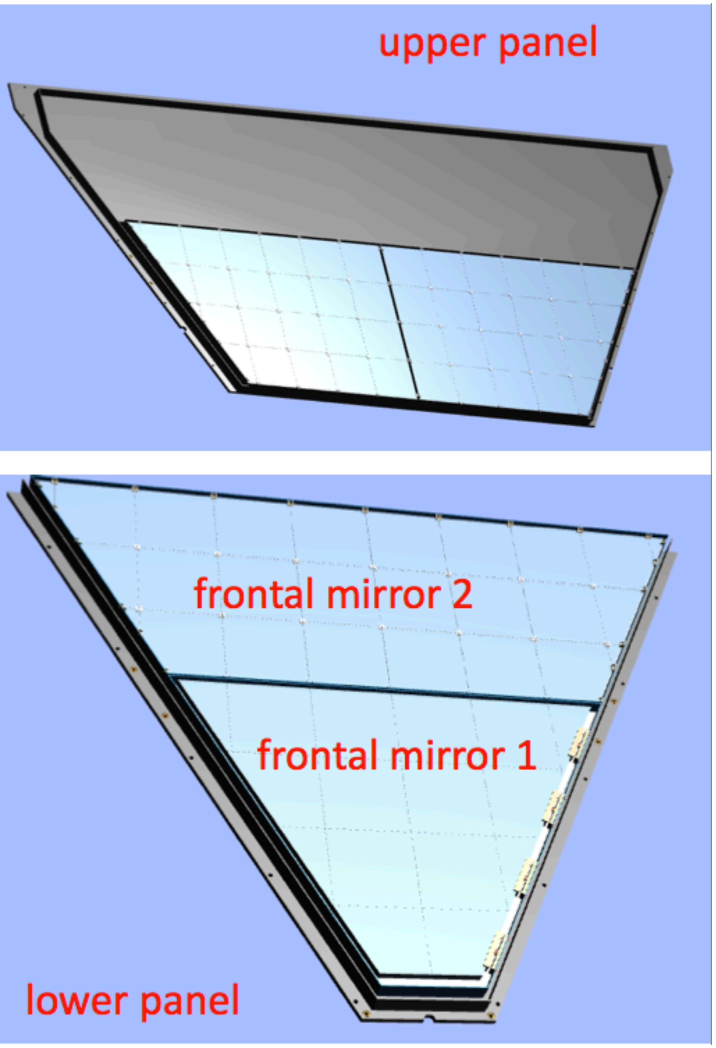
Reflected rings for less demanding low momentum particles

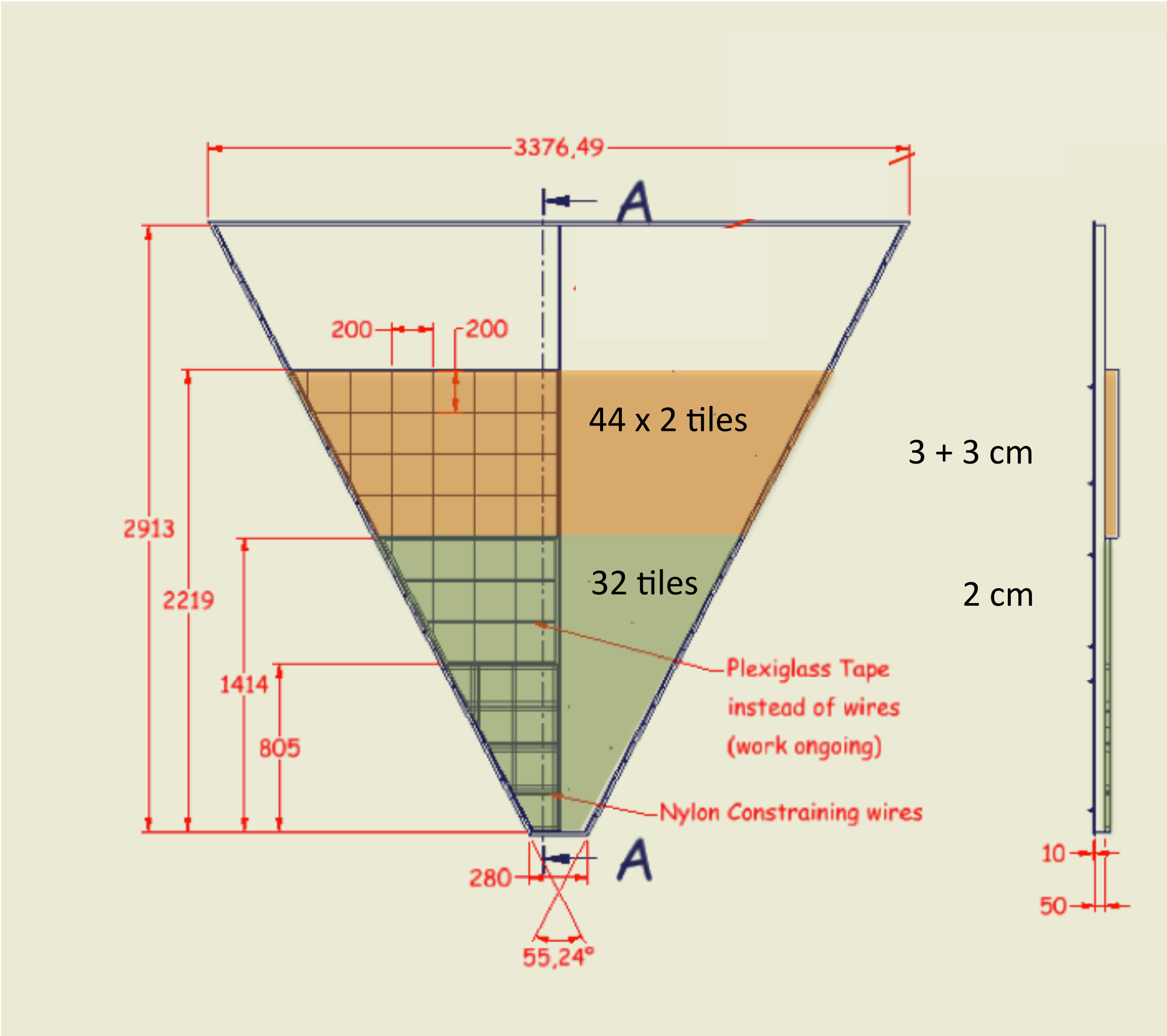


- Minimize active area (cost) to about 1 m^2
- Material budget concentrated where TOF is less effective
- Focalizing mirrors allow thick radiator for good light yield
- Time resolution < 1 ns to distinguish direct and reflected patterns

Aerogel Production

72 (3 cm thick) and 22 (2 cm thick) full squared tile + 30 shaped ones
High transparency and large refractive index (n=1.05) to ensure photon yield
Large area 20 x 20 cm^2 to reduce losses at the edges, variable thickness (2 and 3 cm)



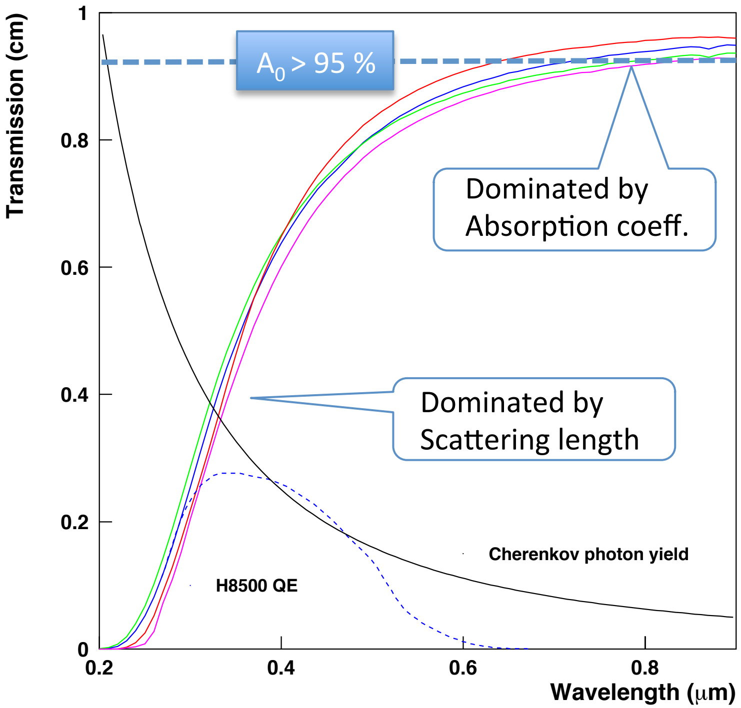


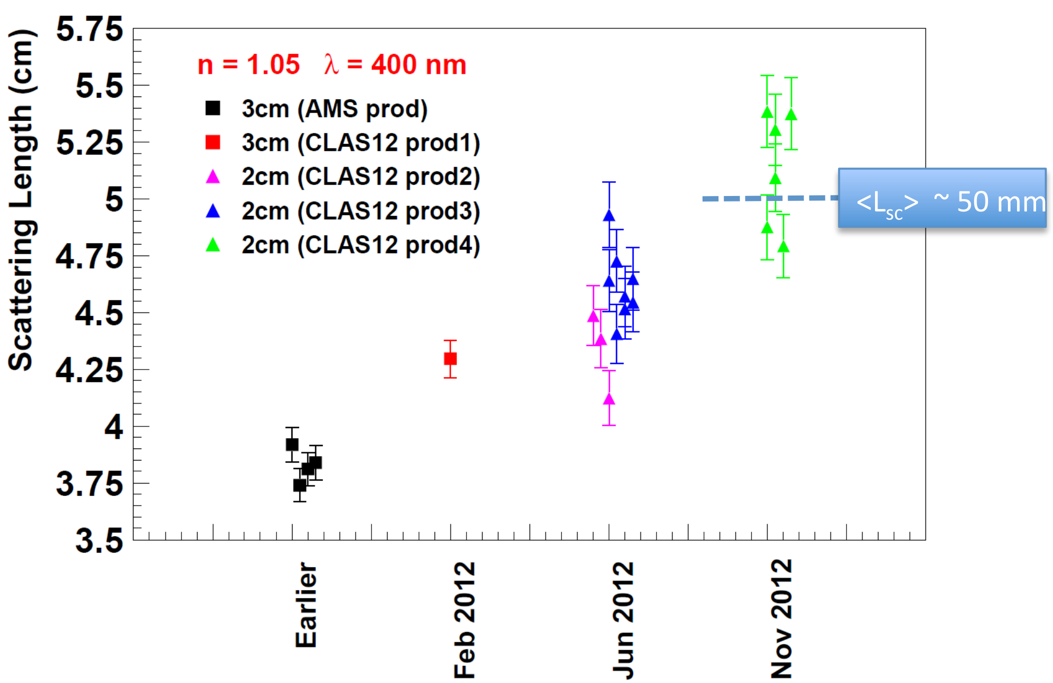
Aerogel Radiator

Collaboration with Budker and Boreskov Institutes of Novosibirsk

Flexible geometry, mass production capability

Achieved ~ 0.0050 $\mu m^4\ cm^{-1}$ clarity for large tiles (LHCb had 0.0064 $\mu m^4\ cm^{-1}$ for n=1.03)

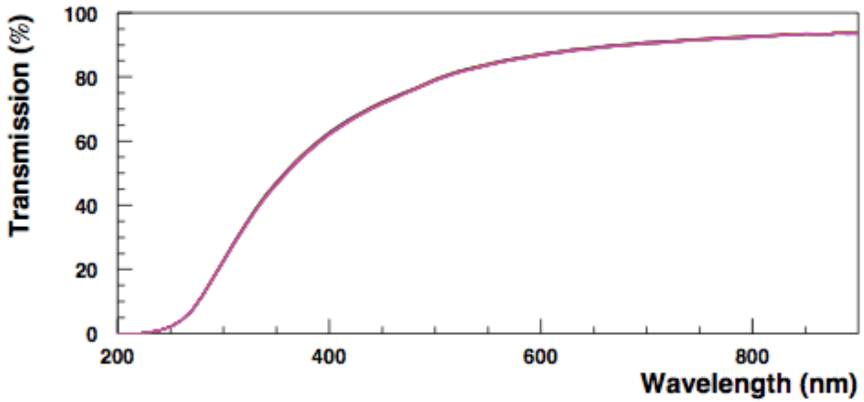


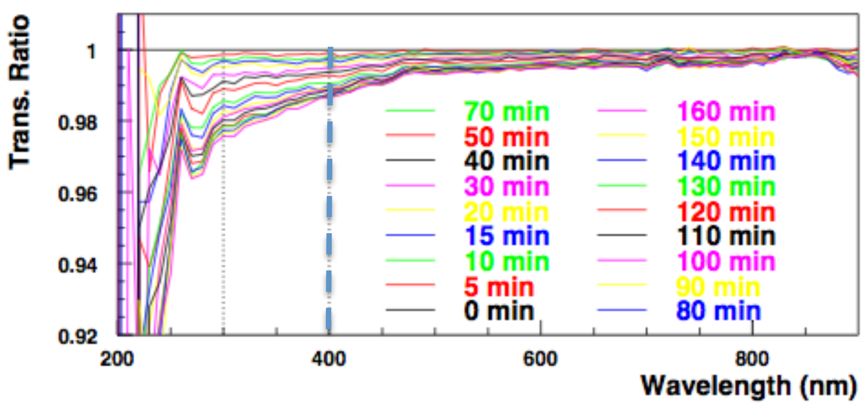


Hygroscopic aerogel requires special care and dry N_2 atmosphere

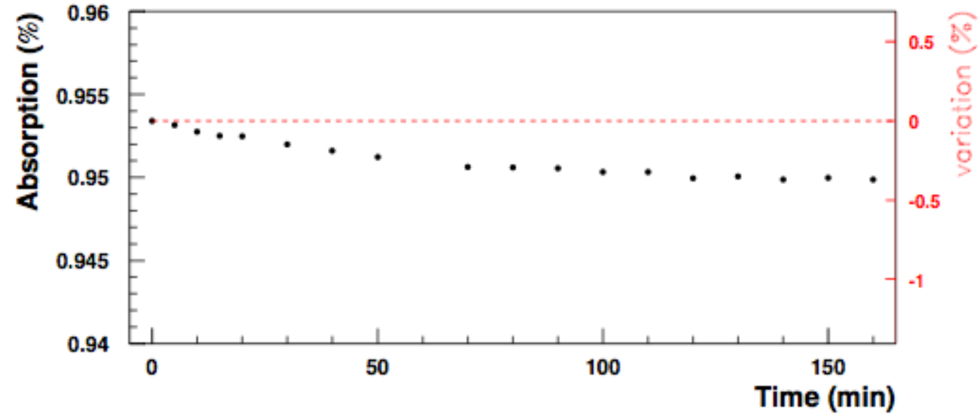
Aerogel Characteristics in the Air

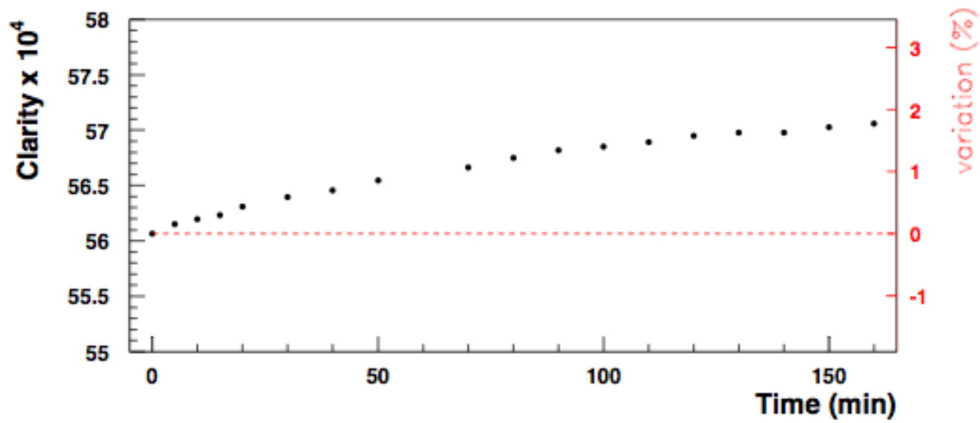
Transmission vs Time





Absorption and Clarity @ 400 nm



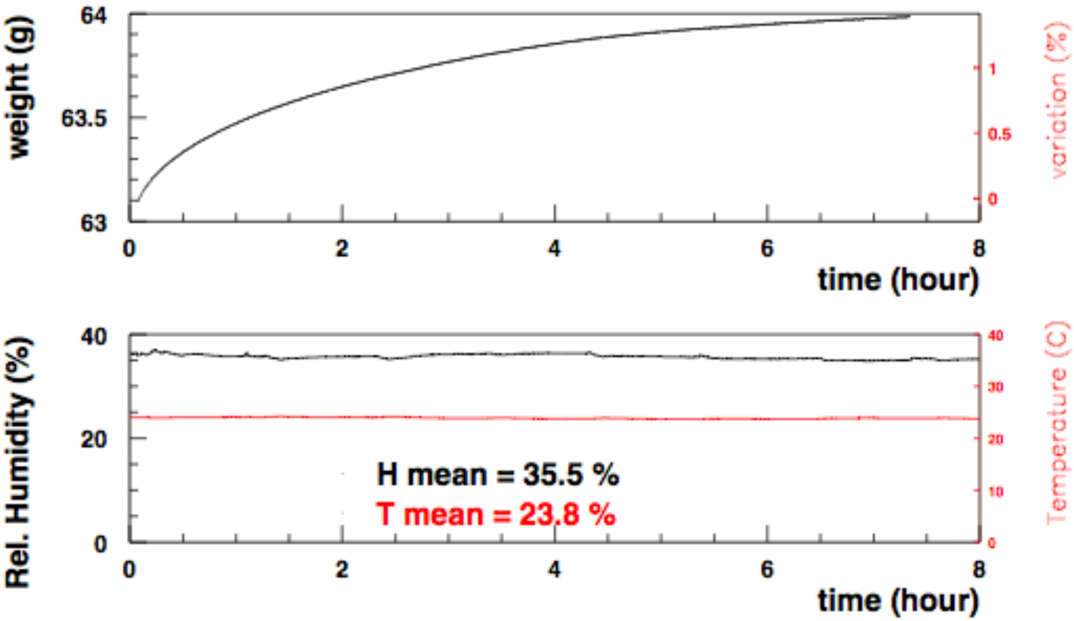


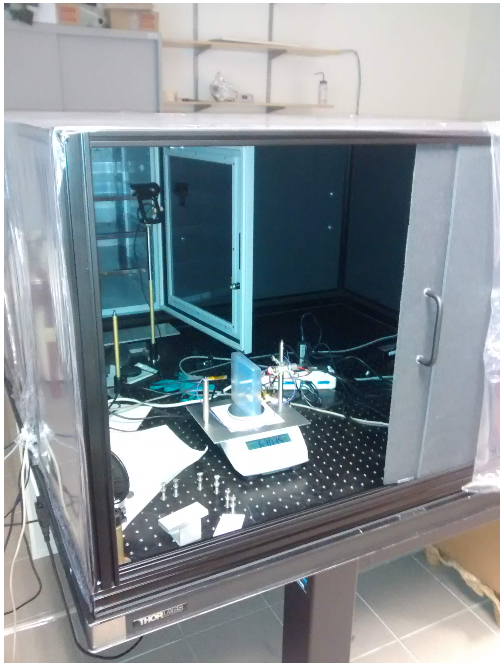
Monitoring the time dependence of the transmission of aerogel tile in environment of non-zero relative humidity (~ 40 %)

Aerogel Storage

Within sealed envelops and inside a dry-cabinet (few % RH)

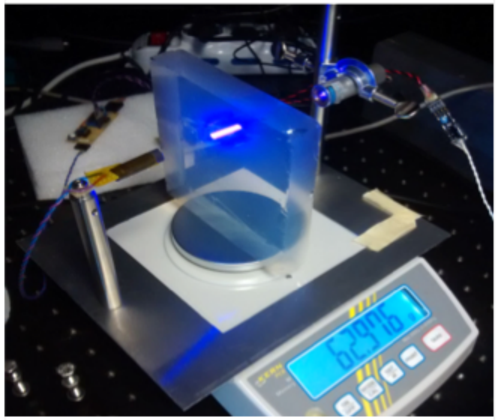
Aerogel Weight

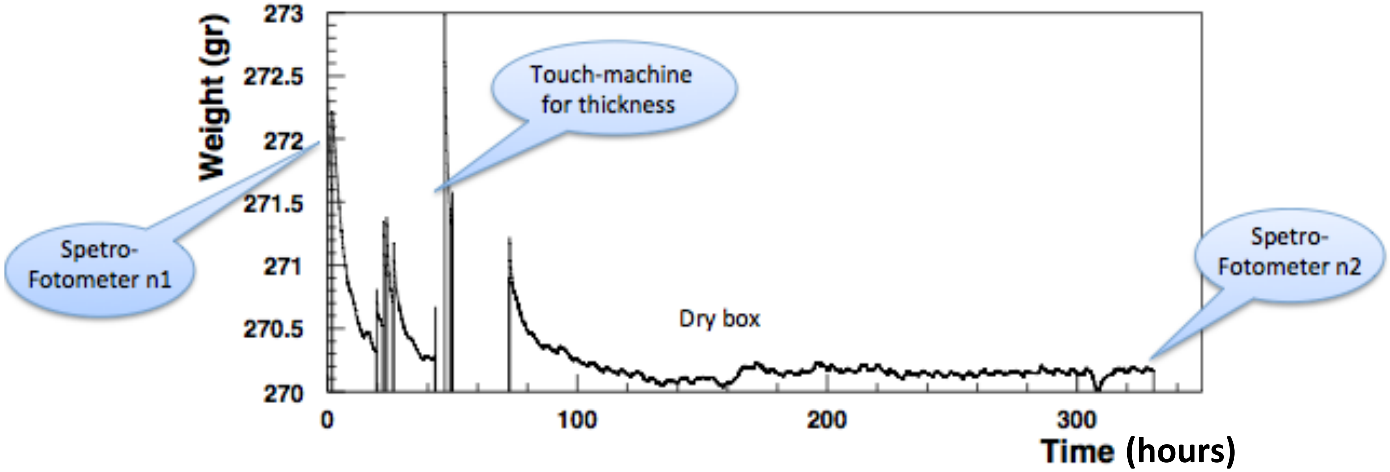




In Air (≈ 40 % RH)

Inside Dry-Box (≈ 1 % RH)





Aerogel Specifications

OPTICAL:

Density	$0.223 < \rho < 0.245$ gr/cm^3
Refractive index ($n^2=1+0.438\,\rho$)	$1.0477 < n < 1.0523$
Scattering length	$L_{sc} > 43$ mm
Absorption coefficient	$A>0.95$

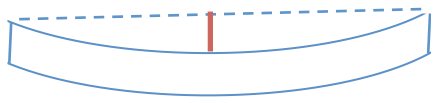
MECHANICAL:

No bubbles, crackes; chips limited to less than 1 % area

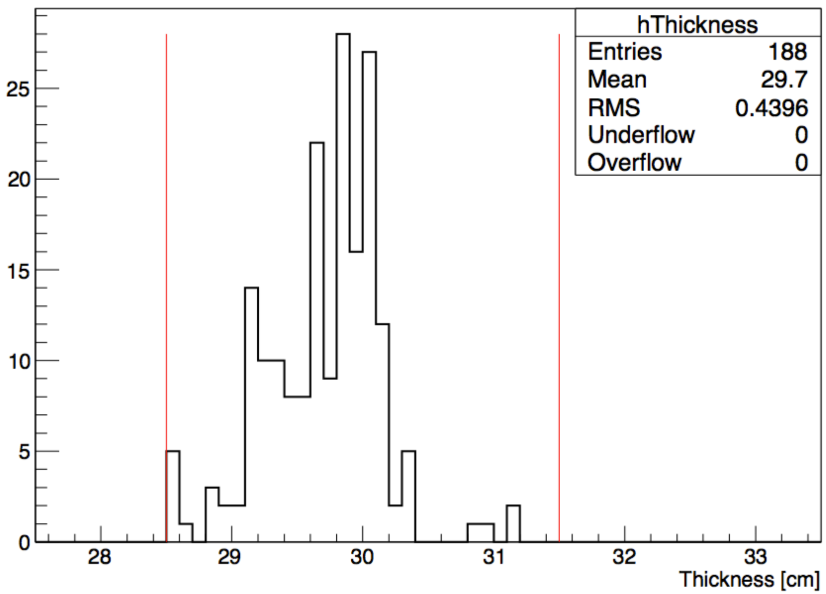
Side to side length variation $\Delta L_{side} < 0.25$ mm

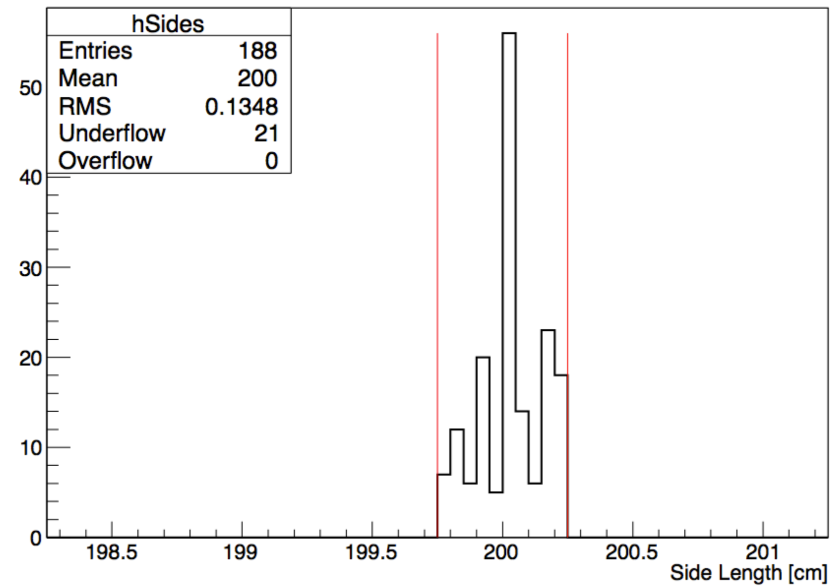
Tile to tile thickness variation $\Delta H_{tile} < 1.5$ mm

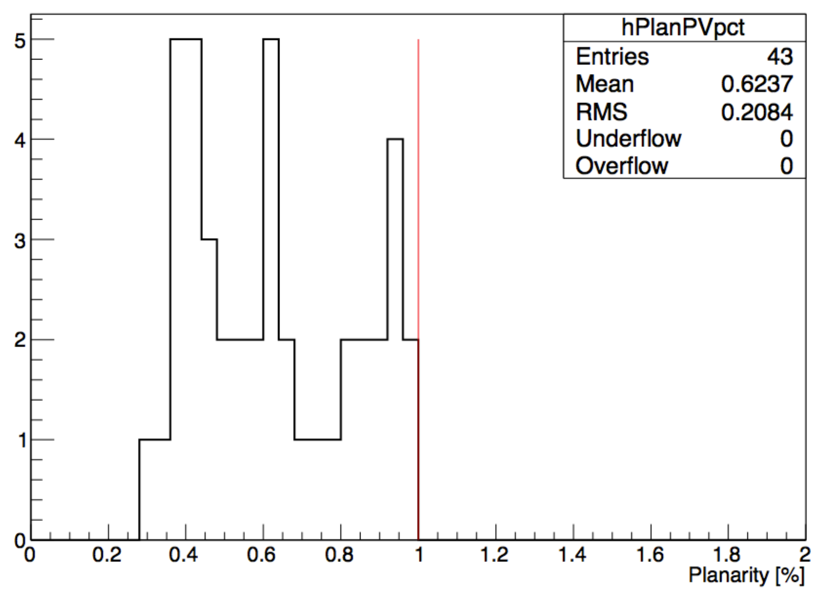
Surface planarity $\Delta S_{surf} < 1$ % of lateral side



Mechanical Performance



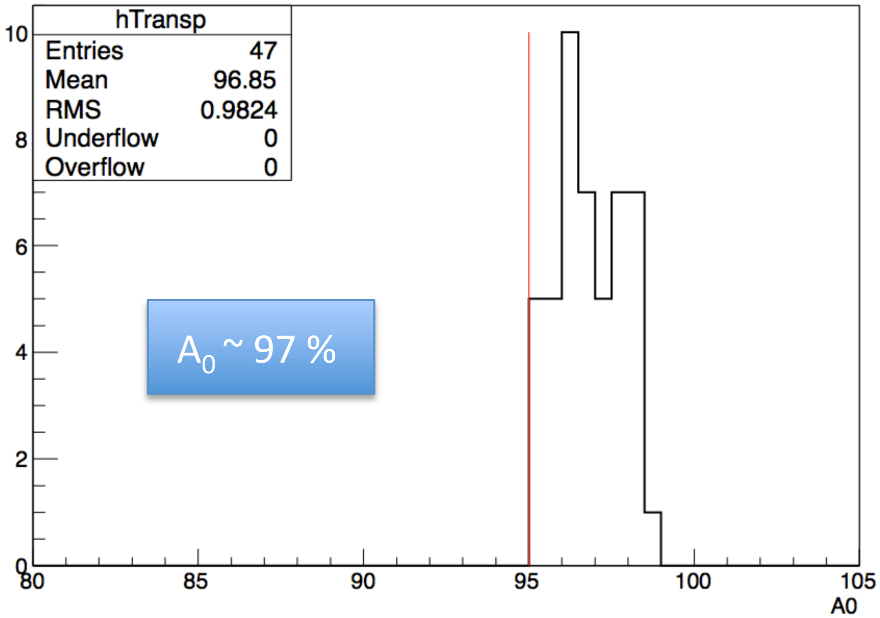


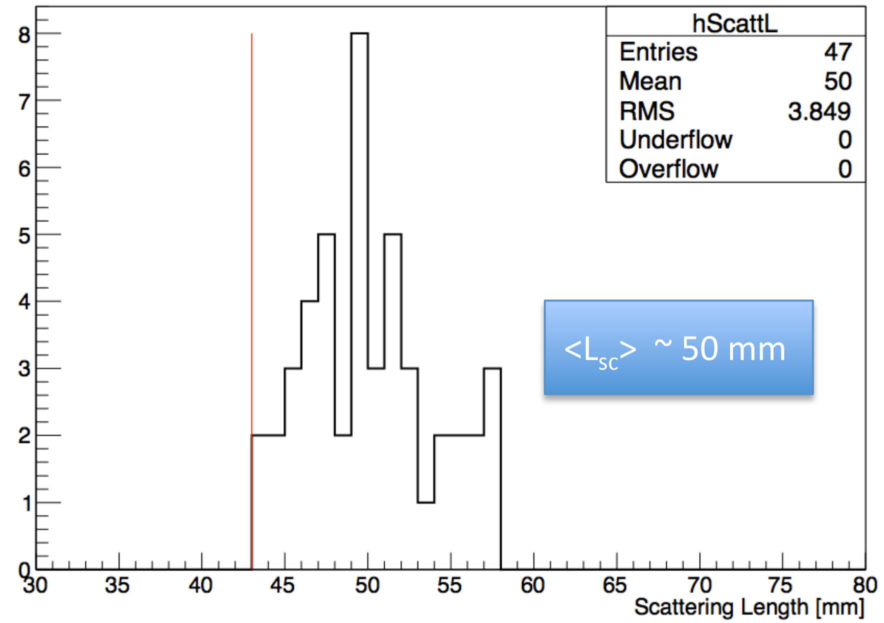


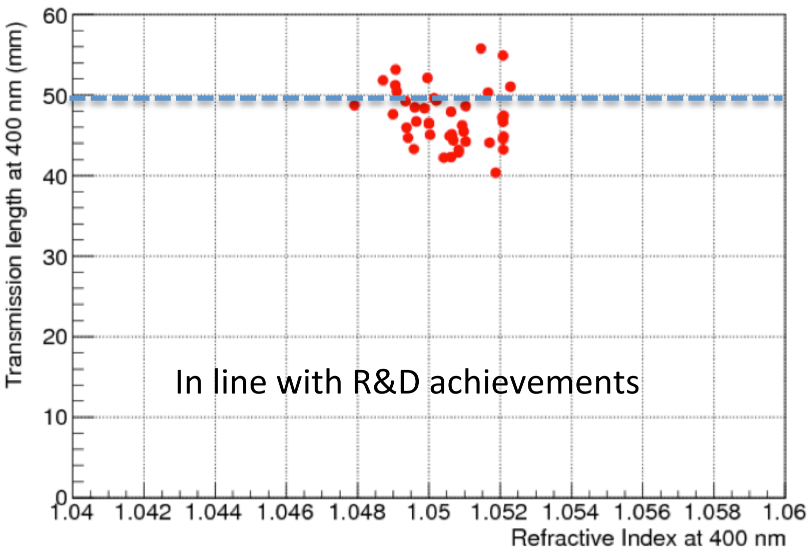
From diamond wire to diamond wheel cut to improve speed and precision, reduce defects (cracks)

Tendency to bend during baking procedure (significant fraction of rejected tiles)

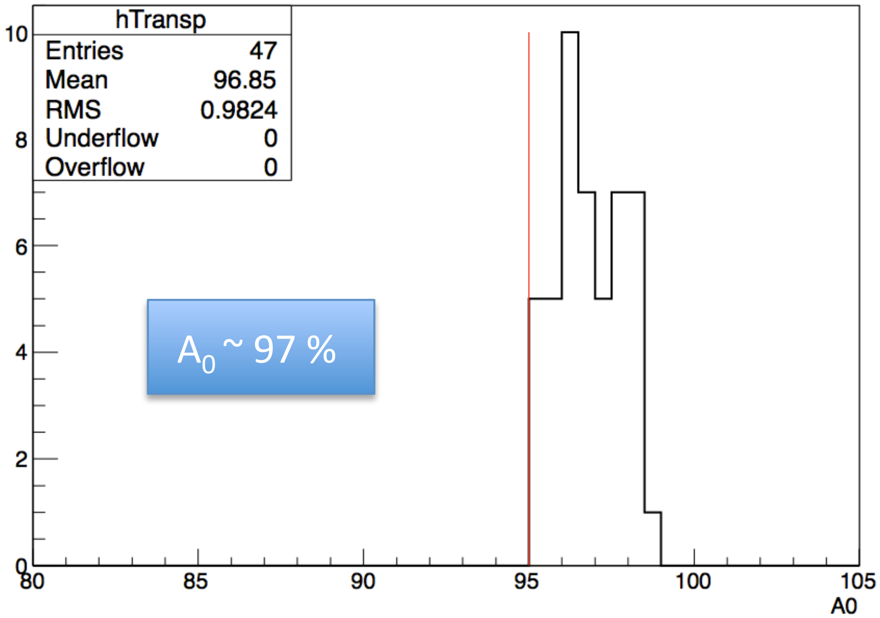
Optical Performance

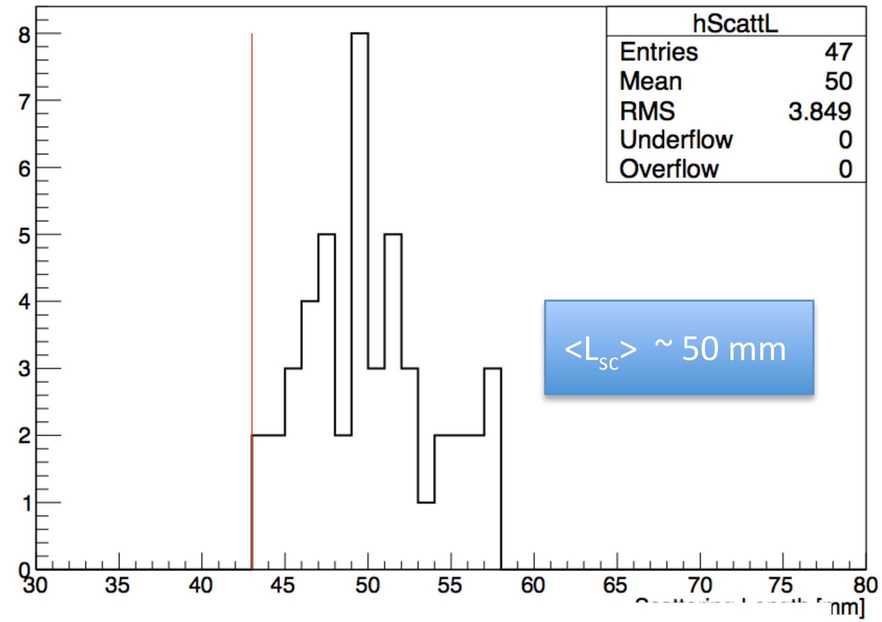


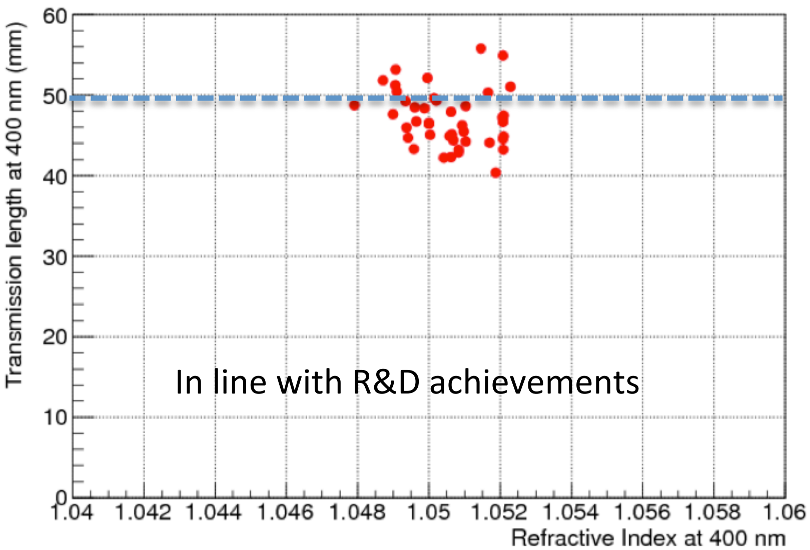


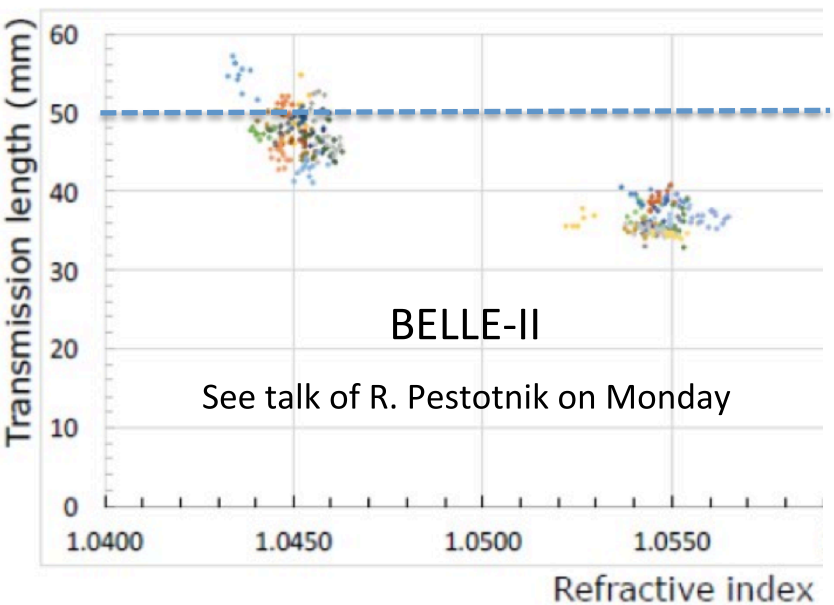


Optical Performance

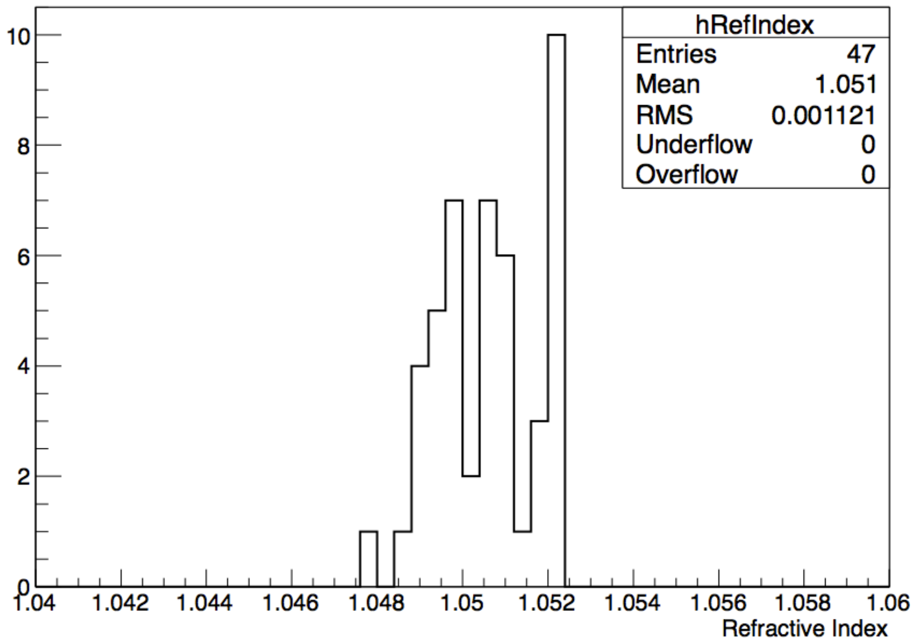


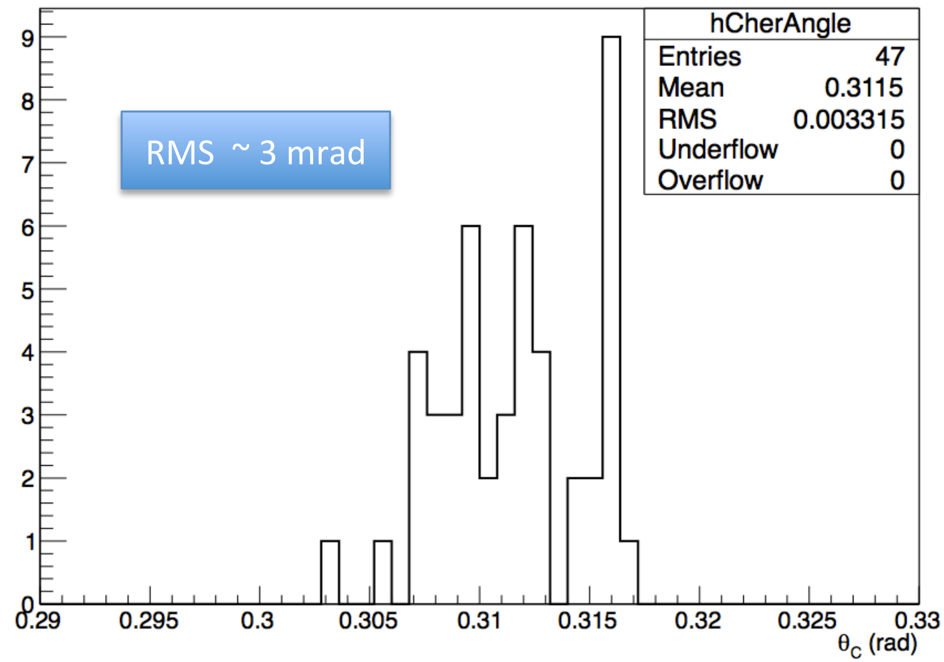






Refractive Index





Spread in refractive index corresponds to ~ 3 mrad of Cherenkov dispersion

Tile by tile index of refraction will be accounted for into the reconstruction program to suppress the spread in refractive indexes (Cherenkov angles)

CLAS12 RHIC: Resolution

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

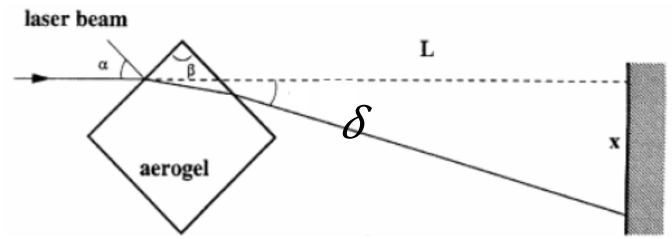
Validated with large scale prototype

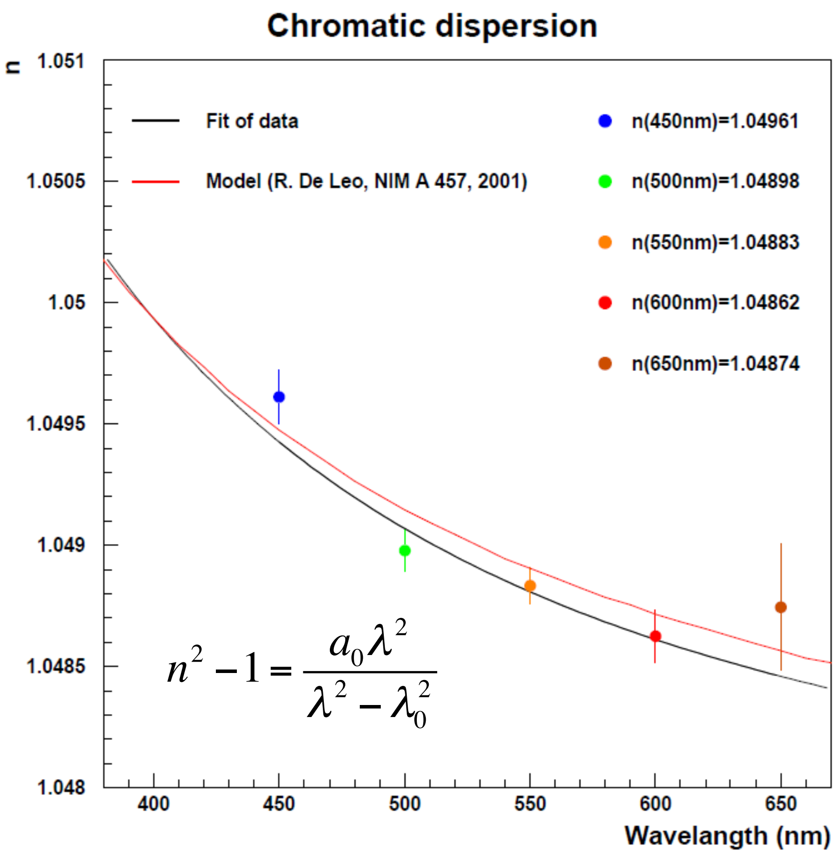
Studied in laboratory

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

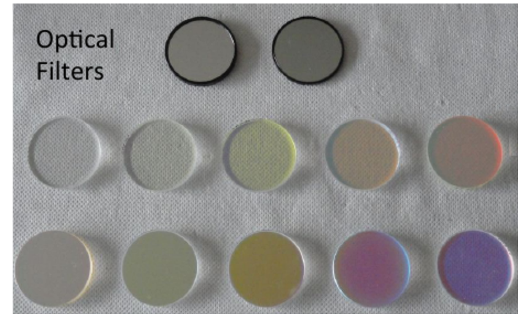
Aerogel Chromatic Dispersion

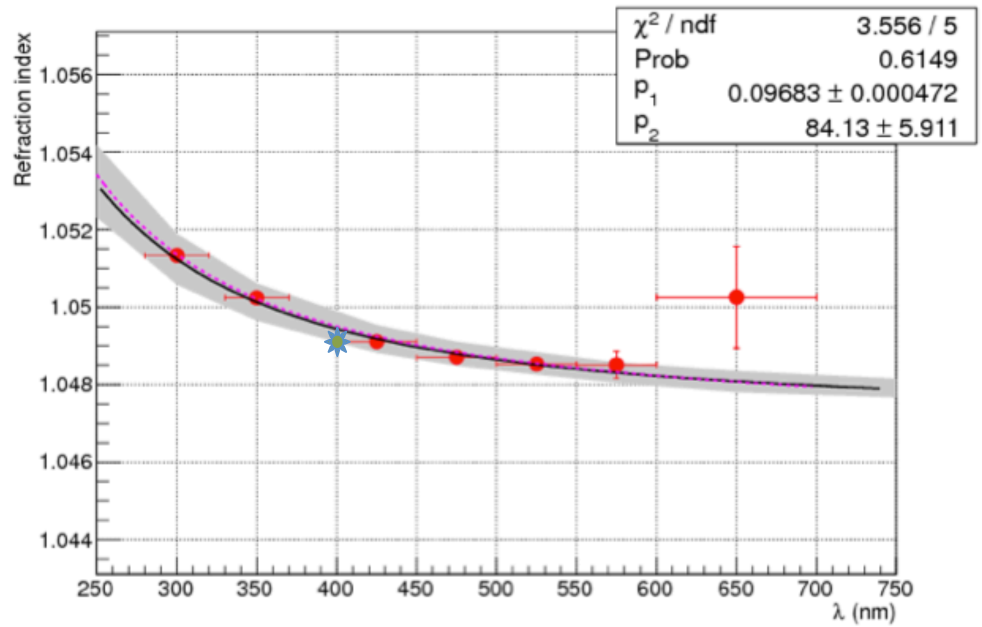
Measured by prisma method:





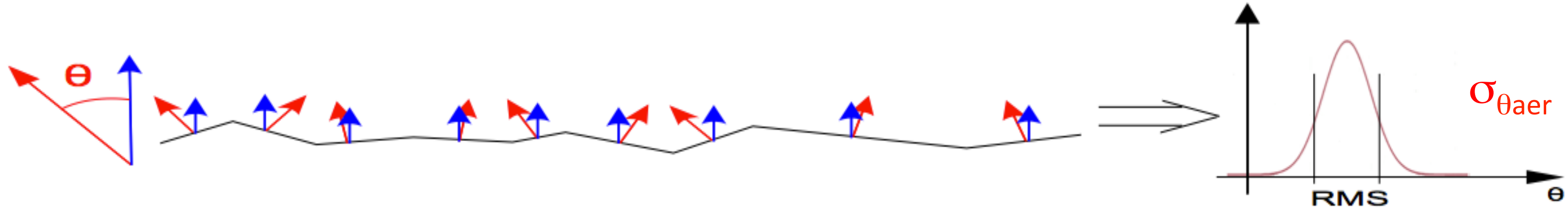
Measured by prototype with optical filters:

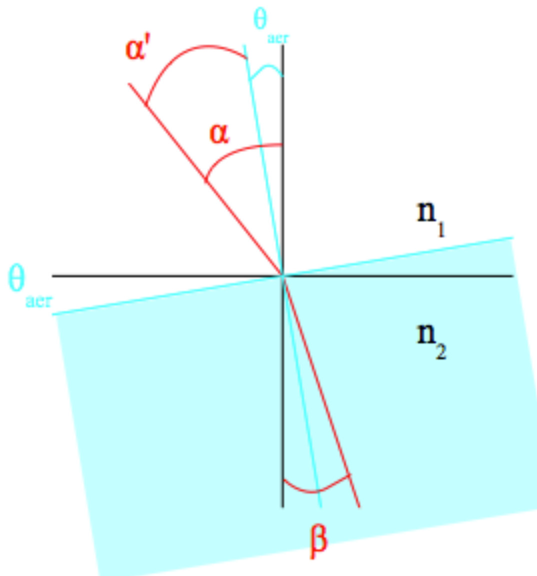


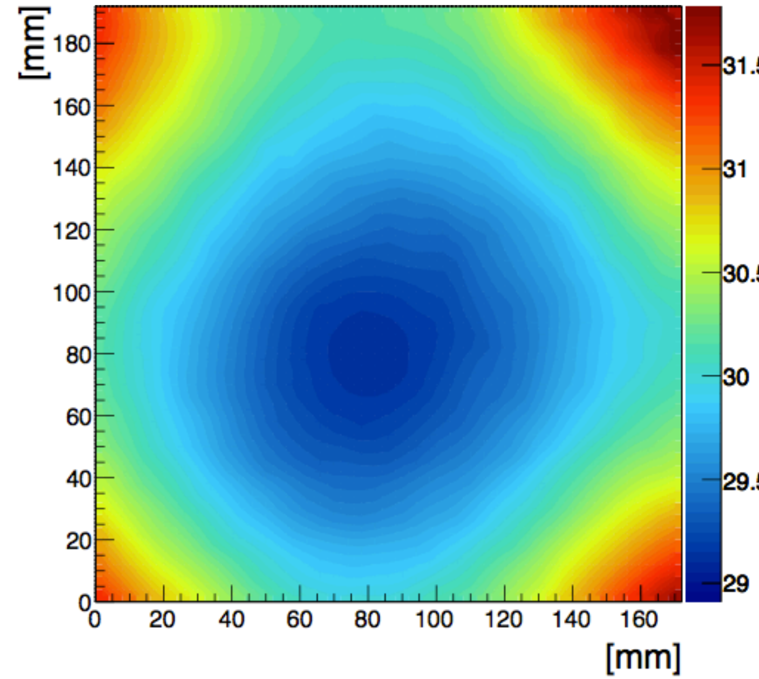


Expected value from density:
n(400nm) = $[1+0.438\rho]^{1/2}$ = 1.0492

Aerogel Surface Quality







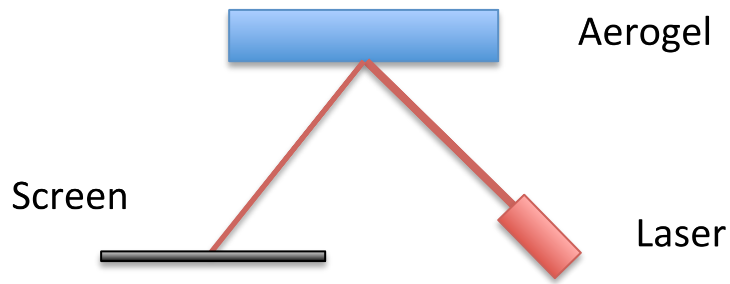
Refraction from a surface
with local normal deviation θ

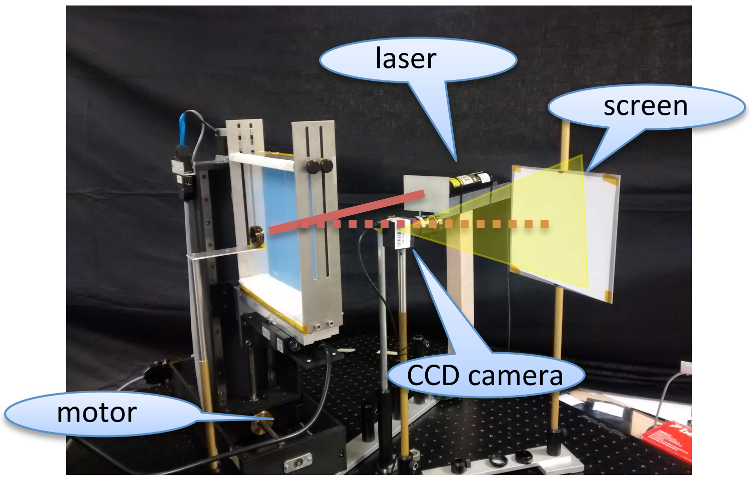
$$\beta = \vartheta_{aer} + \arcsin\left(\frac{1}{n}\sin\left(\alpha - \vartheta_{aer}\right)\right)$$

Contribution on light dispersion
at small incident angles

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

Aerogel Surface Scan

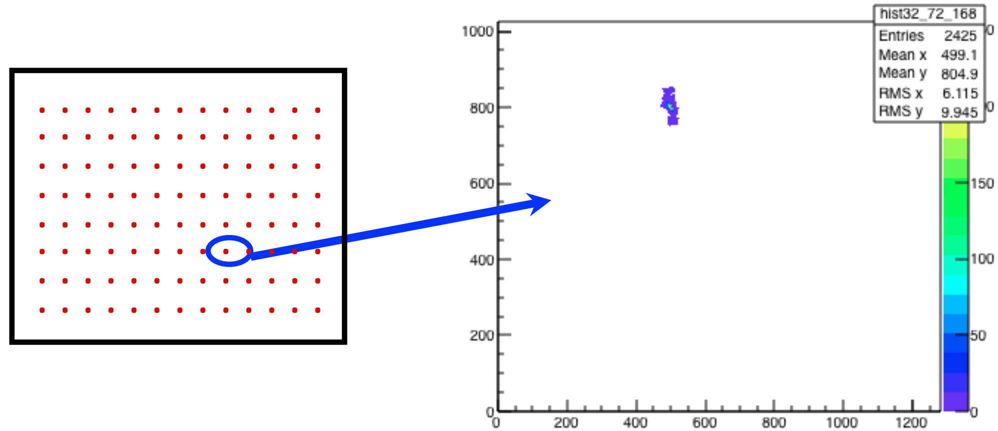




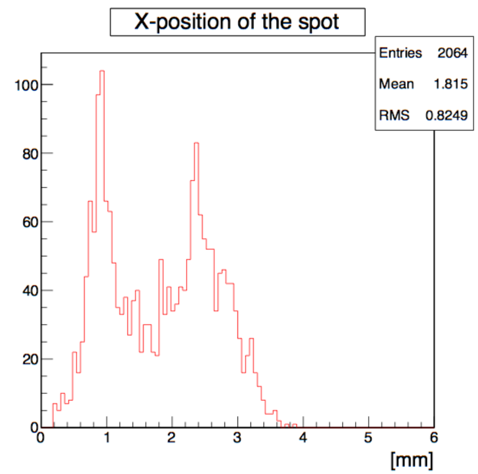
x-y axis movable table

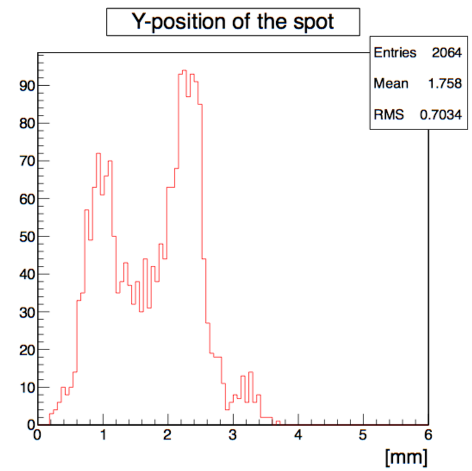
CCD camera [ThorLabs DCU 224c]
- sensitive area [5.95-4.76 mm]
- resolution [1280-1024 pixels]
- pixel size 4.65 μm

Scan of aerogel surface



Distributions of X & Y positions of the spot





Aerogel Surface Planarity

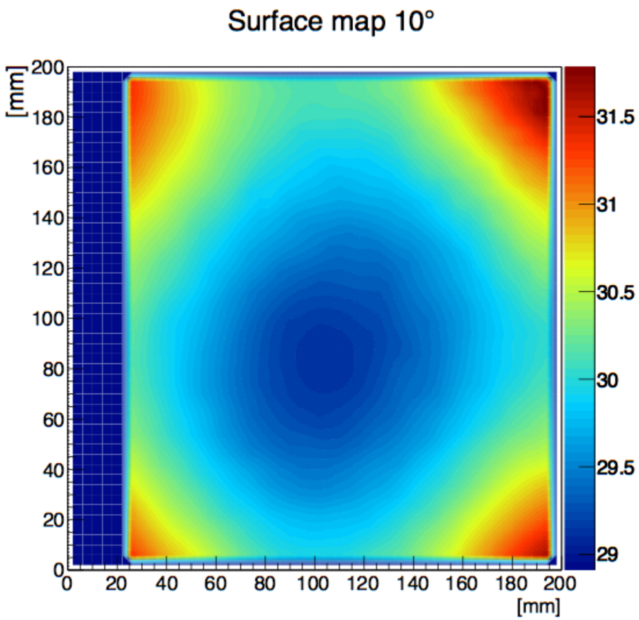
From laser spot shits to surface gradients

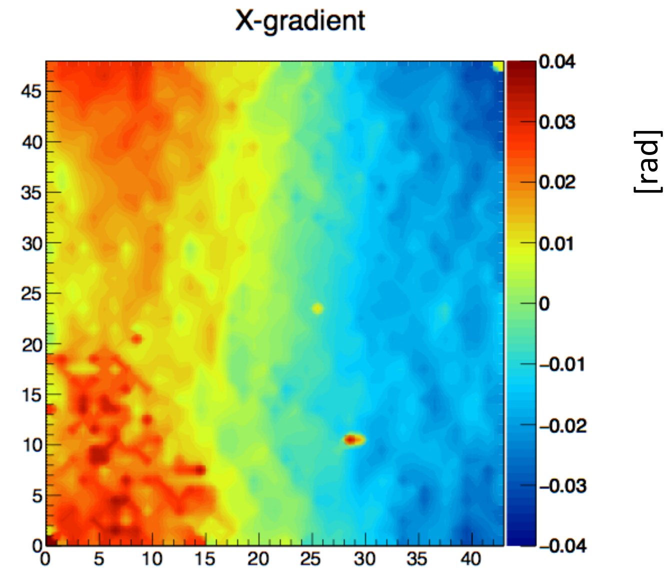
$$\nabla_x = \frac{(x - x_{mean})c_l}{2L}\cos(\theta)$$

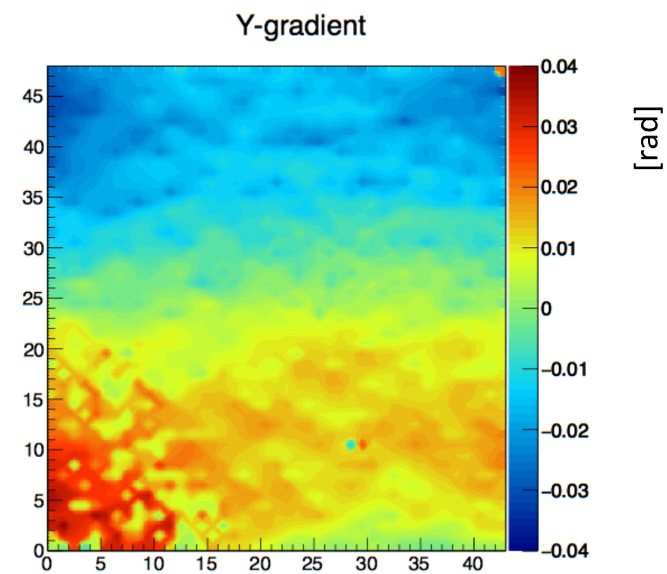
$$\nabla_y = \frac{(y - y_{mean})c_l}{2L}$$

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

From surface gradients to surface map by linear regression





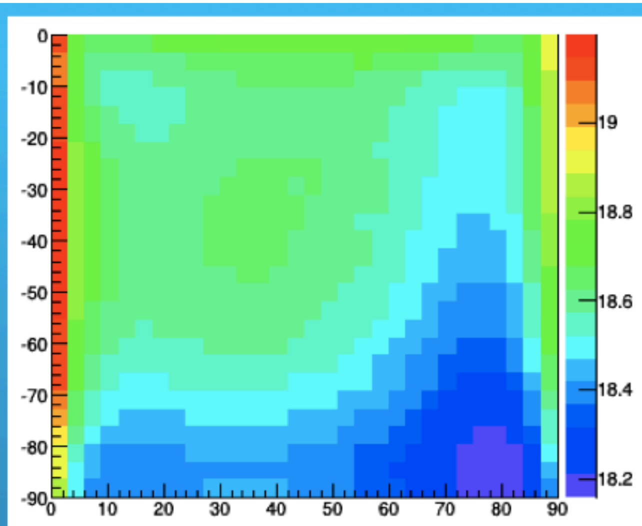


Consistent with Russian vendor planarity evaluation
Validated with touch machine measurements

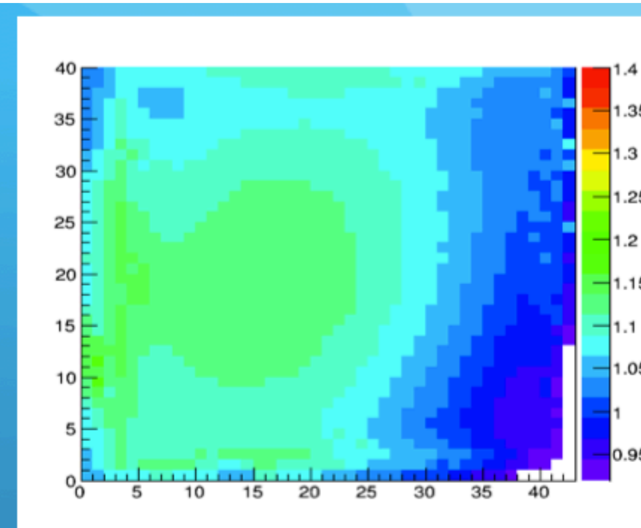
Surface Measurement Validation

Face 1

Touch Machine



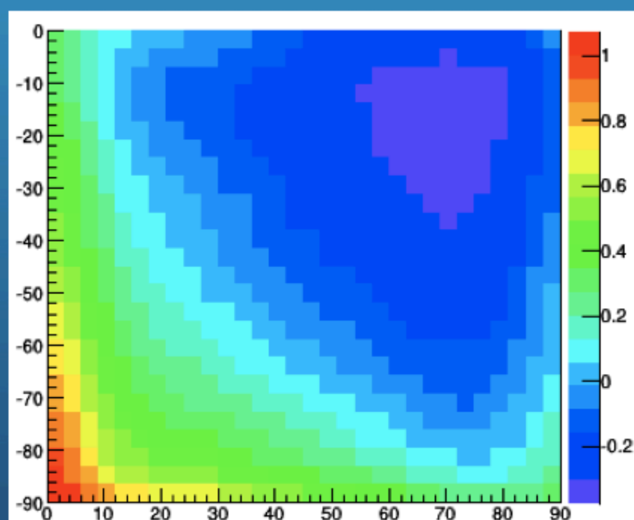
Laser Setup



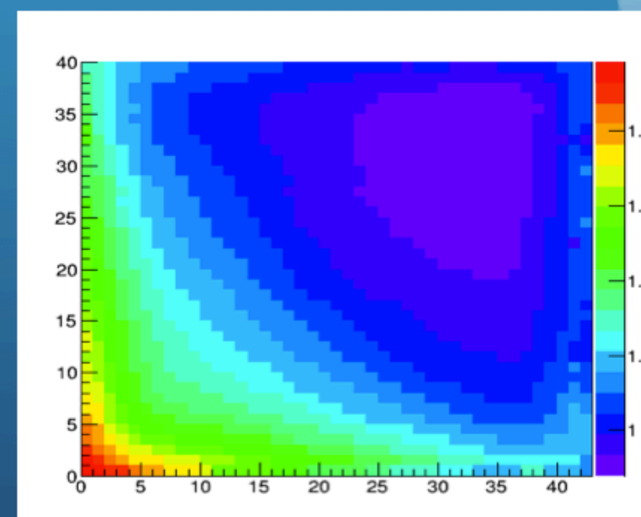
Possibility to derive the thickness profile

Face 2

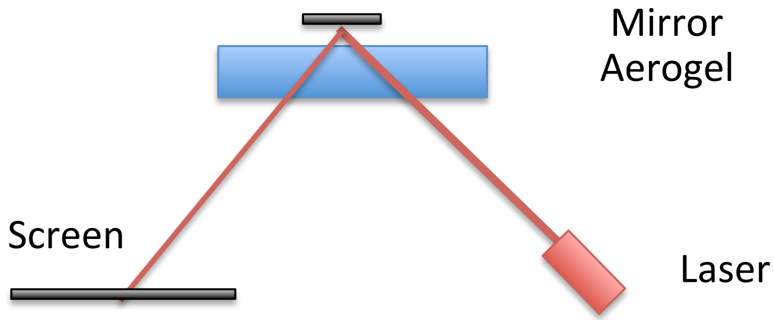
Touch Machine

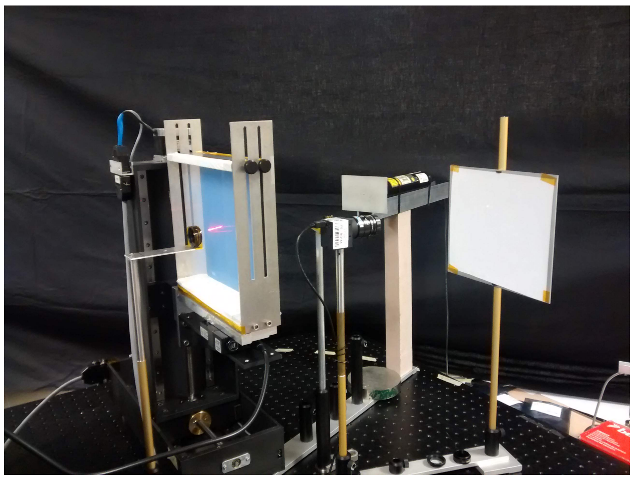


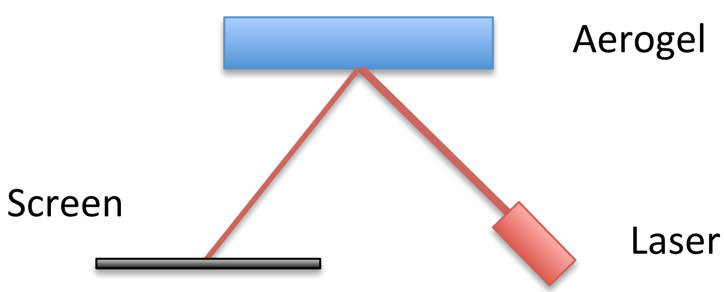
Laser Setup

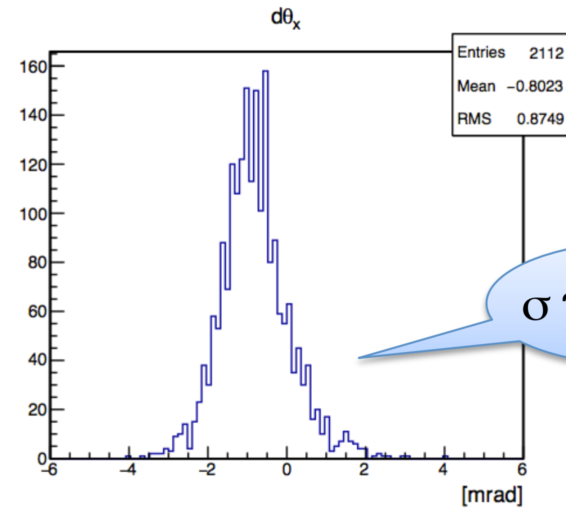


Light Dispersion vs Aerogel Surface Quality

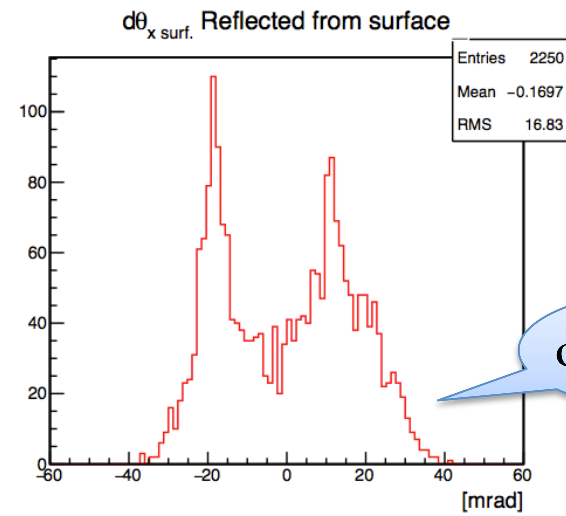








σ ~ 0.9 mrad

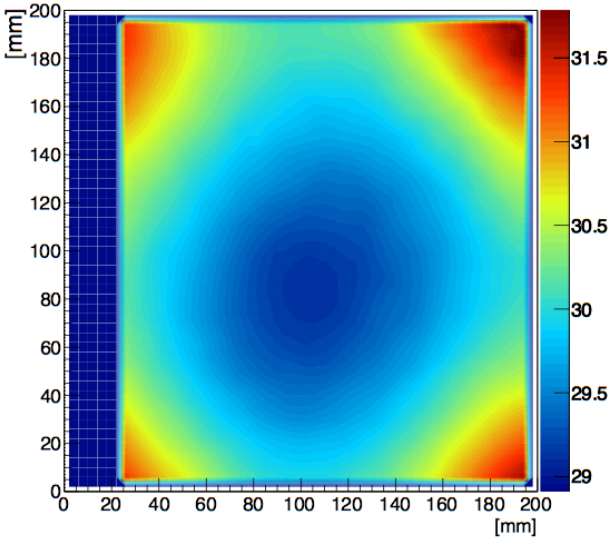


σ ~ 16 mrad

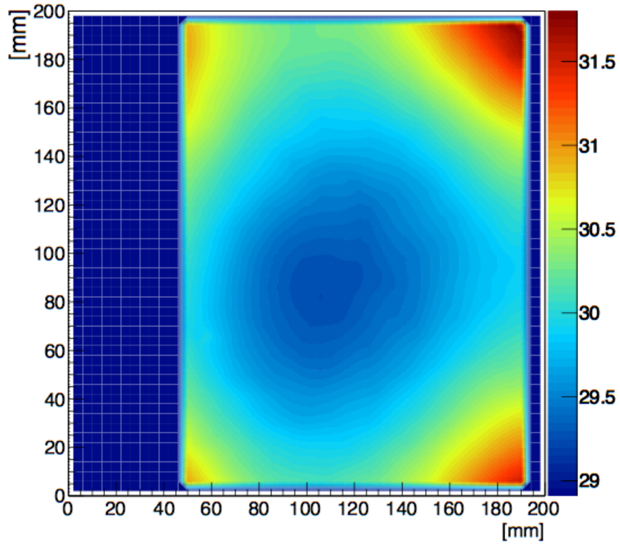
Acceptable light dispersion even for poor planarity ΔS_{surf} = 1.25 %

Aerogel Surface Map

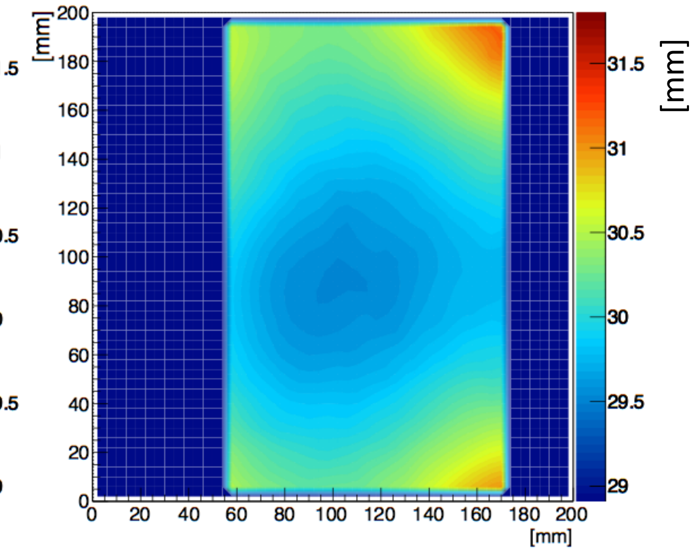
Surface map 10°



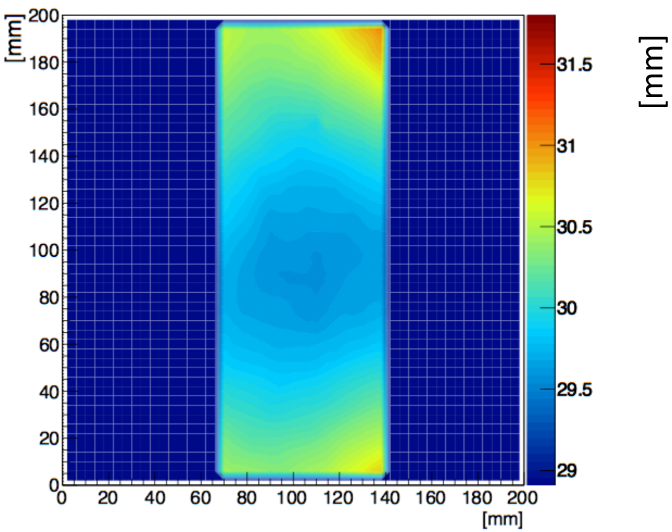
Surface map 20°



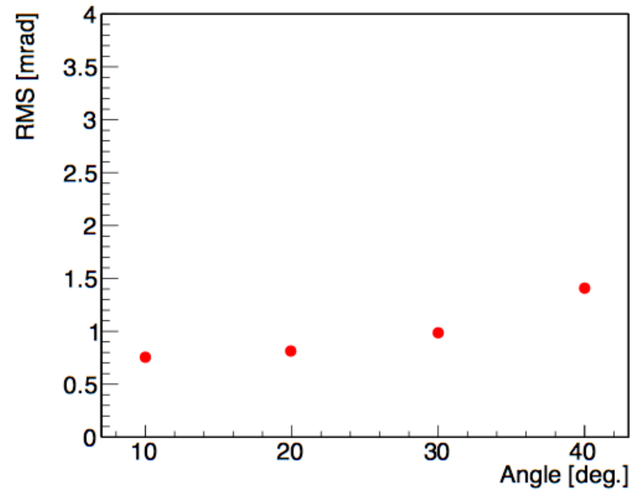
Surface map 30°



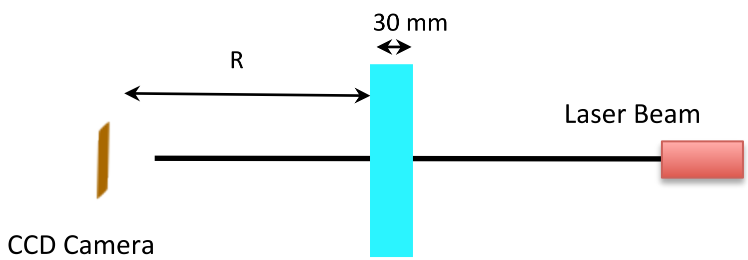
Surface map 40°



Light dispersion as a function of incident angle:



Description of the setup

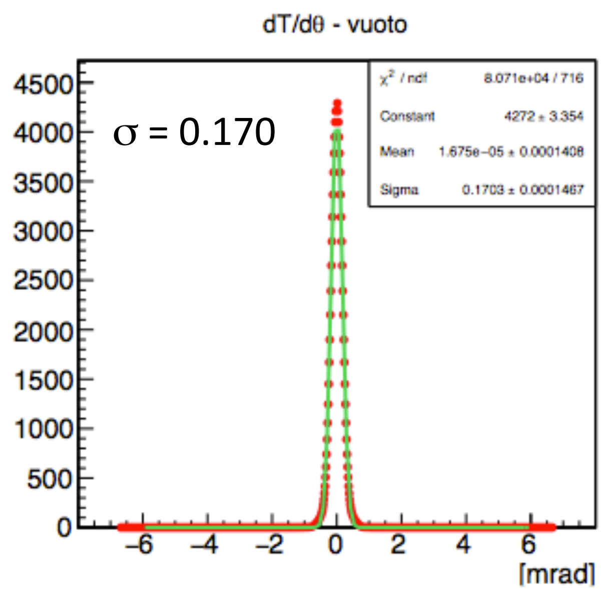


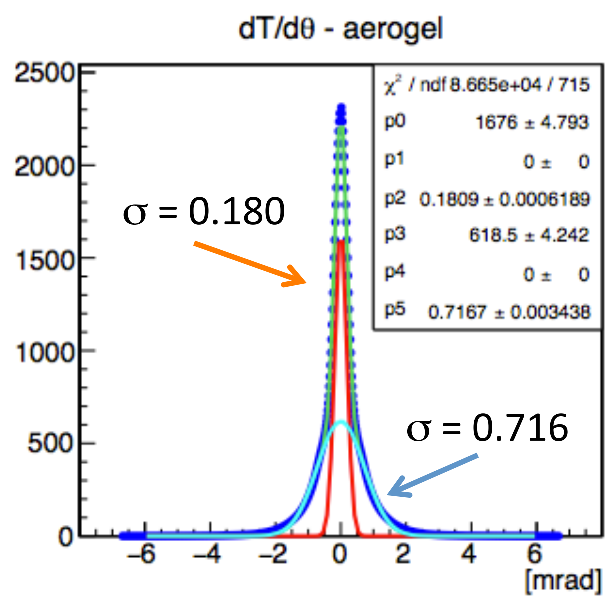
Scattering of the light in the medium due to the anisotropy of the dielectric properties caused by density microscopic fluctuations

Analysis steps:

- Reference beam profile taken without aerogel
- Extract laser beam profile and compare with reference measurement
- Extract angular dependence of light intensity after passage through the aerogel

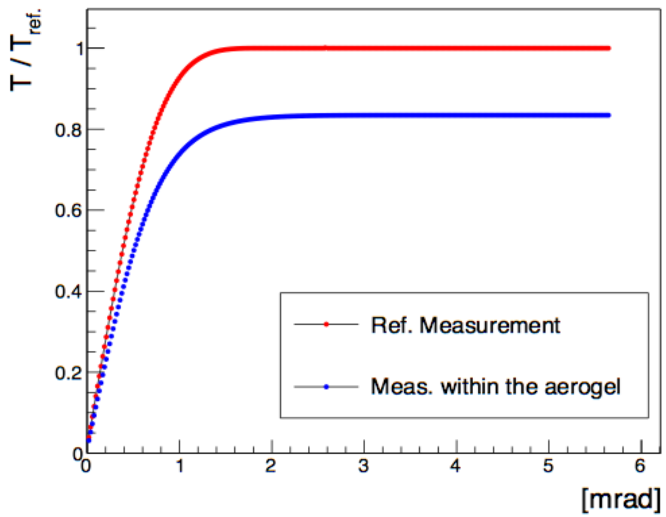
Take the average X & Y profiles of the spot



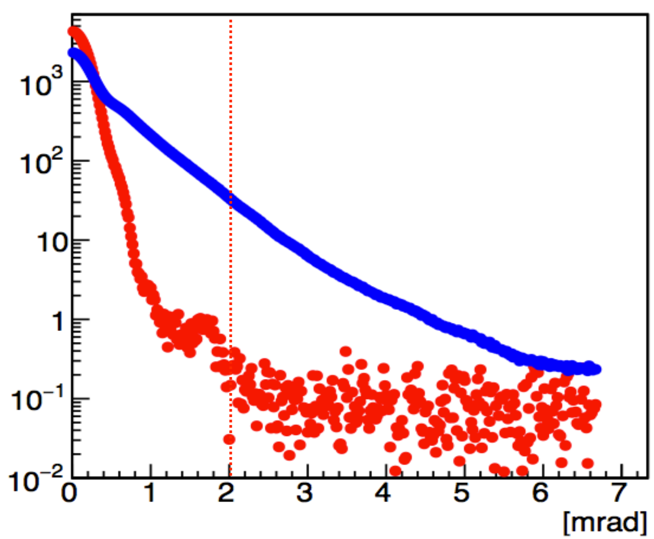


Forward Scattering

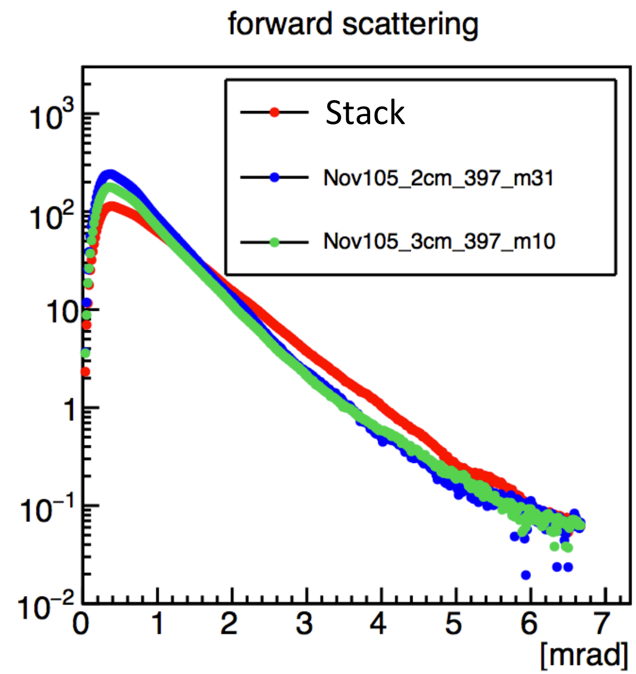
Angular dependence of the measured intensity:



Differential of the measured intensity:



$$\frac{\mathrm{d}^2 T_{\mathbf{FS}}(\theta)}{\mathrm{d}\theta\,\mathrm{d}x} = \left[\frac{dT}{d\theta}\frac{1}{T_1} - \frac{dT}{d\theta}\frac{1}{T_0}\frac{c1}{c0} \right] \frac{1}{thickness}$$



Typical fraction of light above 2 mrad ≤ 1 %

Negligible scattering
at angles relevant for Cherenkov resolution

Conclusions

Aerogel mass production for CLAS12 RICH is ongoing

- ✔ Storing (in dry cabinets) and handling procedures has been defined for the hygroscopic material
- ✔ Steadily improvement of the process
- ✔ Non invasive techniques employed to verify light propagation into the material
- ✔ Tools for measurements and monitoring the aerogel characteristics show stable performance in line with the project design