



The CLAS12 large area RICH detector

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ARTICLE INFO

Available online 28 October 2010

Keywords:
 RICH
 CLAS12
 Particle identification

ABSTRACT

A large area RICH detector is being designed for the CLAS12 spectrometer as part of the 12 GeV upgrade program of the Jefferson Lab Experimental Hall-B. This detector is intended to provide excellent hadron identification from 3 GeV/c up to momenta exceeding 8 GeV/c and to be able to work at the very high design luminosity up to $10^{35} \text{ cm}^{-2} \text{ s}^{-1}$. Detailed feasibility studies are presented for two types of radiators, aerogel and liquid C_6F_{14} freon, in conjunction with a highly segmented light detector in the visible wavelength range. The basic parameters of the RICH are outlined and the resulting performances, as defined by preliminary simulation studies, are reported.

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The aerogel radiator: optical characterization and performances

of the nucleus and quark hadronization processes [2]. Important observables that will be extensively investigated are transverse Momentum Distribution functions (TMDs) describing intrinsic spin-orbit effects and Generalized Parton Distribution functions (GPDs), containing information about the spatial distribution of quarks and the relation (by a sum rule) to the elusive orbital momenta. Several experiments have been already performed by the JLab12 PAC to study kaon versus pion production in exclusive and semi-inclusive scattering, providing access to the decomposition of the two sets of non-perturbative wave functions.

The main features of CLAS12 include a high operational luminosity of $10^{35} \text{ cm}^{-2} \text{ s}^{-1}$, an order of magnitude higher than the current setup, and operation of highly polarized beam and target. The conceptual design of the CLAS12 detector is shown in Fig. 1. The central detector with the high-field (5 T) solenoid is used for particle tracking at large angles. The forward detector detects charged and neutral particles in the angular range between 5 and 40° . It employs a 2 T torus magnet with the detector symmetry of CLAS. In the base equipment,

and event reconstruction can be achieved in this momentum range by replacing the existing low-threshold Cherenkov counter (LTCC) with a RICH detector without any impact on the baseline design of CLAS12.

2. The CLAS12 RICH

To fit into the CLAS12 geometry, the RICH should have a projective geometry with six sectors that cover the space between the torus cryostats and covering scattering angles from 5° to 40° . Fig. 3. Being downstream to the torus magnet at a distance of 1.5 m from the interaction point, the RICH has to cover a scattering angle of each sector spanning an area of the order of 4 m^2 . Being placed between detectors which are already in the construction, the gap depth cannot exceed 1 m. The proposed solution is a focusing RICH.

A setup similar to the one adopted in Hall-B (C₅F₁₂ or C₆F₁₄) radiator and a CsI-deposited on a quartz window chamber as a UV-photon detector, is required pion rejection factor at momenta above 3 GeV/c.

The preliminary results on ongoing Monte Carlo studies, based on a GEANT3 toolkit with simplified geometry and optical surface

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0168-9002/\$ - see front matter
doi:10.1016/j.nima.2010.10.047

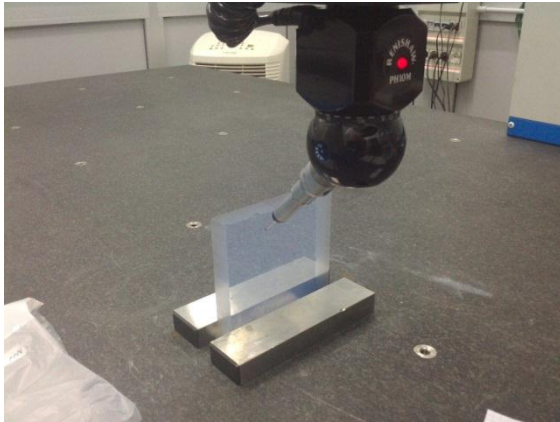
mcontal@ictp.ac.cn (M. Contalbrigo).

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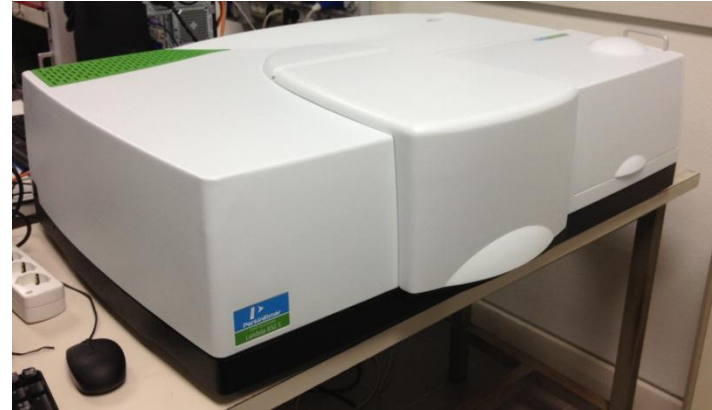
L.L. Pappalardo
INFN - University of Ferrara

Characterization of aerogel tiles

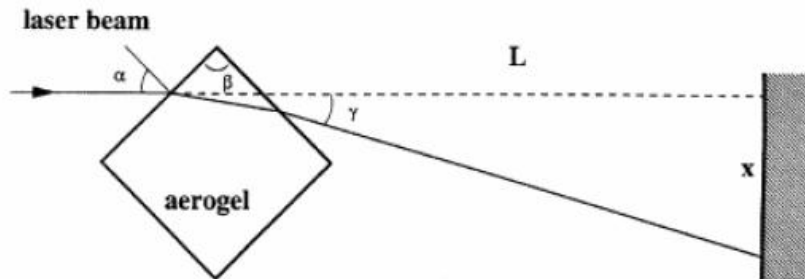
➤ Geometry (thickness map)



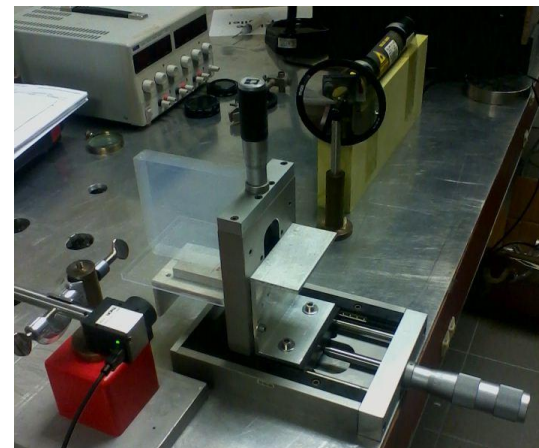
➤ Transmittance, abs/scatt. length



➤ Chromatic dispersion



➤ Refractive index mapping



The tiles analyzed

Manufacturer	Production	n	thickness (cm)	area (cm × cm)	Number of tiles
Matsushita (Japan)	< 2012	1.03	1.0	11.5 × 11.5	3
Matsushita	< 2012	1.05	1.0	11.5 × 11.5	3
Novosibirsk (Russia)	Jun 2012	1.04	2.0	6.0 × 5.5	4
Novosibirsk	Jun 2012	1.05	2.0	6.0 × 5.5	4
Novosibirsk	Jun 2012	1.06	2.0	6.0 × 5.5	4
Novosibirsk	Jun 2012	1.05	3.0	6.0 × 5.5	4
Novosibirsk	Jun 2012	1.06	3.0	6.0 × 5.5	4
Novosibirsk	Jun 2012	1.05	2.0	11.5 × 11.5	8
Novosibirsk	Dec 2012	1.05	2.0	11.5 × 11.5	5
Novosibirsk	Dec 2012	1.05	2.0	6.0 × 5.5	4
Novosibirsk	< 2012	1.05	3.0	11.5 × 11.5	4
Novosibirsk	Feb 2102	1.05	1.0	11.5 × 11.5	1
Novosibirsk	Feb 2012	1.05	2.0	11.5 × 11.5	1
Novosibirsk	Feb 2012	1.05	3.0	11.5 × 11.5	1
Aspen (USA)	Nov 2012	1.05	1.7	9.5 × 9.5	2
Aspen	Nov 2012	1.05	1.7	6.5 × 6.5	1
Aspen	Nov 2012	1.01	1.7	6.5 × 6.5	1

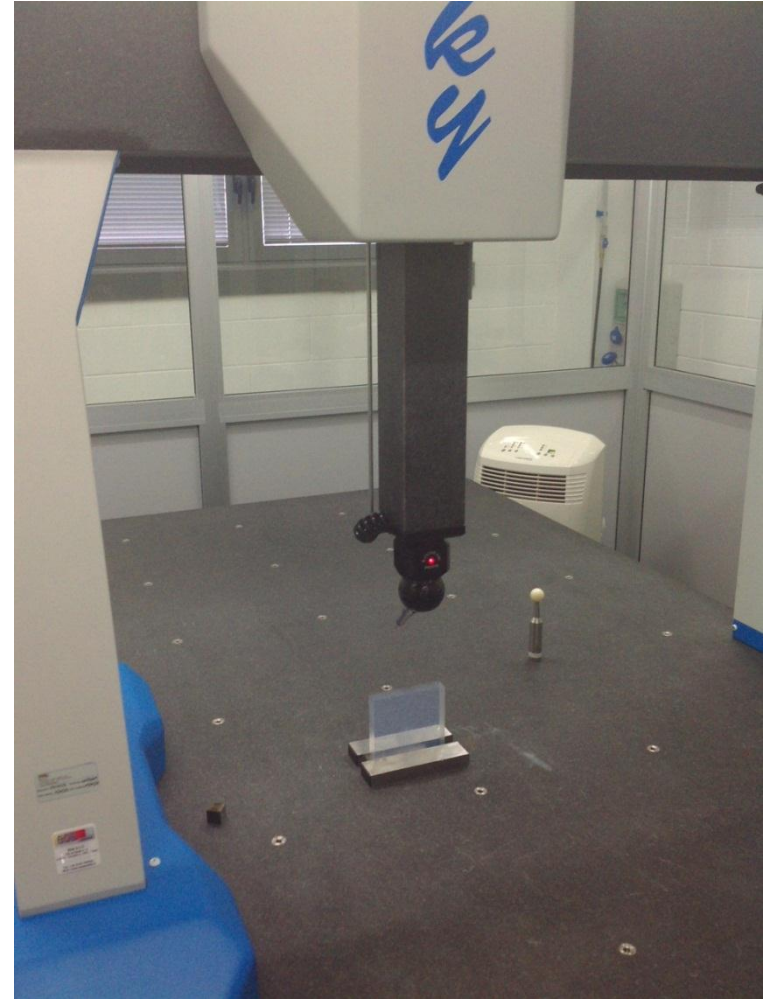
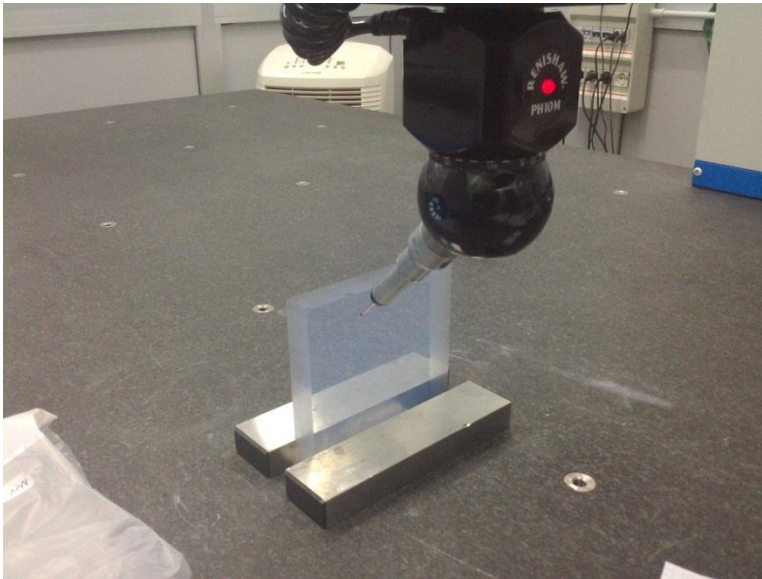
- **3 manufactures** (Matsushita, Novosibirsk, Aspen)
- **5 refractive indices** (1.01, 1.03, 1.04, 1.05, 1.06)
- **4 thicknesses** (1cm, 1.7cm, 2cm, 3cm)
- **3 areas** (6.0×6.5 , $11.5 \times 11.5 \text{ cm}^2$, $9.5 \times 9.5 \text{ cm}^2$, $6.5 \times 6.5 \text{ cm}^2$)

Part 1

Mapping the tile thickness

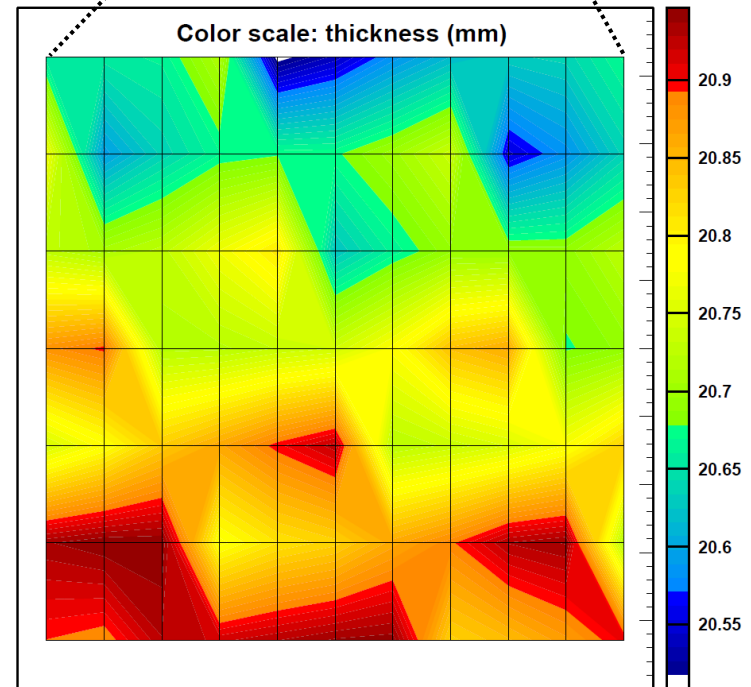
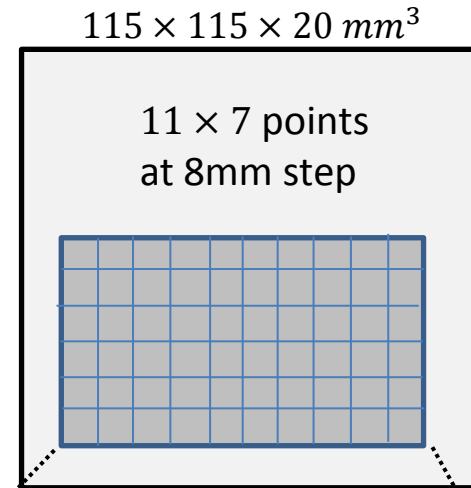
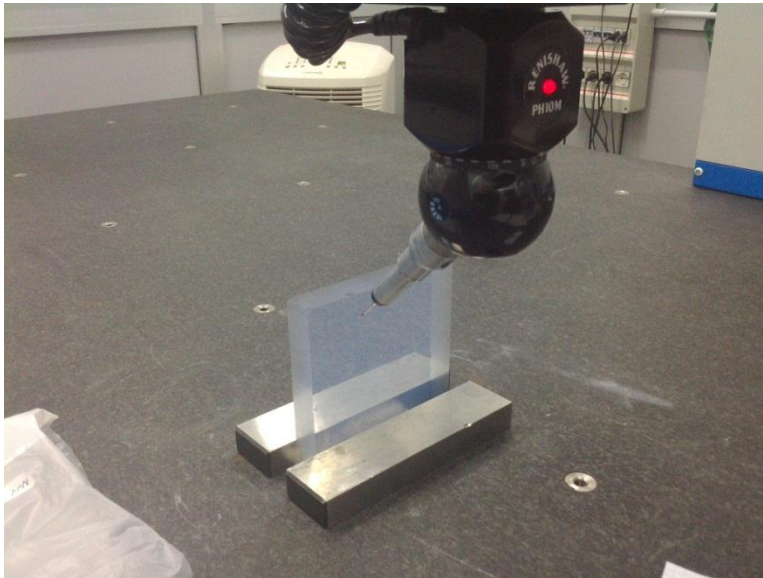
Thickness mapping

- High precision electro-mechanical tool ($\Delta z \approx 1\mu m$)
- Relatively fast (manual mode ~ 100 points/h)
- Programmable: allows for systematic measurements on grid of points (much faster)
- Soft touch: does not affect the aerogel surface



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- High precision electro-mechanical tool ($\Delta z \approx 1\mu m$)
- Relatively fast (manual mode ~ 100 points/h)
- Programmable: allows for systematic measurements on grid of points (much faster)
- Soft touch: does not affect the aerogel surface
- **Observed thickness variations up to 0.4 mm**



$$\delta z \sim 0.4 \text{ mm} \quad (\delta z/z \sim 2\%)$$

Part 2

Measuring Transmittance,
scattering and absorption length

Formalism and selected results (Novosibirsk)

Transmittance

$$T(\lambda) = e^{-\frac{t}{\Lambda_{tot}}} = e^{-t\left(\frac{1}{\Lambda_A} + \frac{1}{\Lambda_S}\right)} = e^{-\frac{t}{\Lambda_A}} \cdot e^{-\frac{t}{\Lambda_S}} = A \cdot e^{-\frac{Ct}{\lambda^4}}$$

Hunt formula

$$A = TF = e^{-t/\Lambda_A}$$

Clarity parameter

Transflectance

$$\Lambda_A = -t/\ln A \quad \text{Absorp. length}$$

$$\Lambda_S = \frac{\lambda^4}{Ct} t \quad \text{Scarrering length}$$

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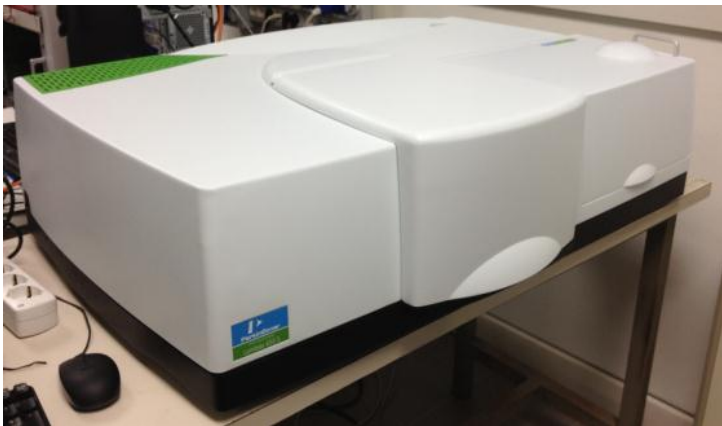
Clarity parameter

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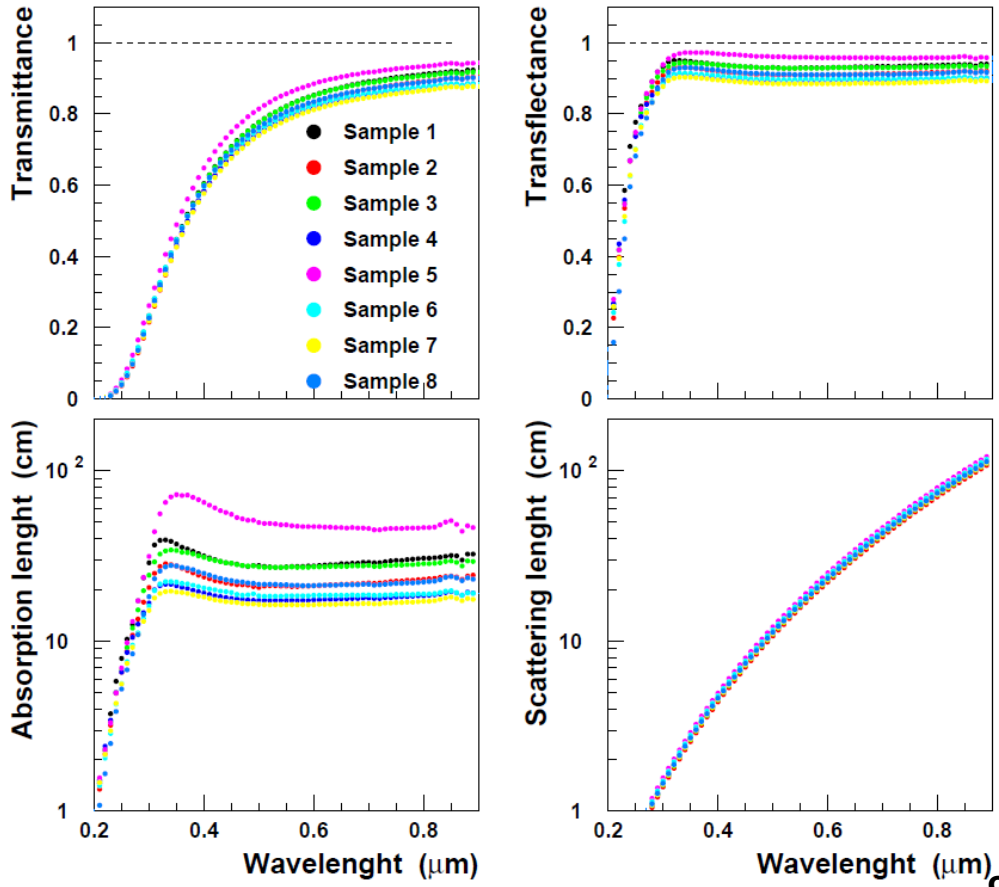
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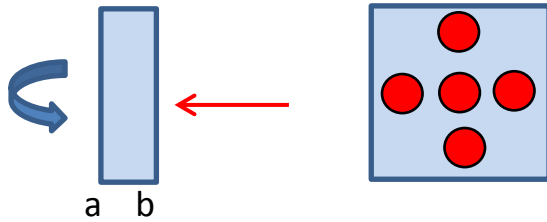


Novosibirsk Samples 1-8 (1.05)

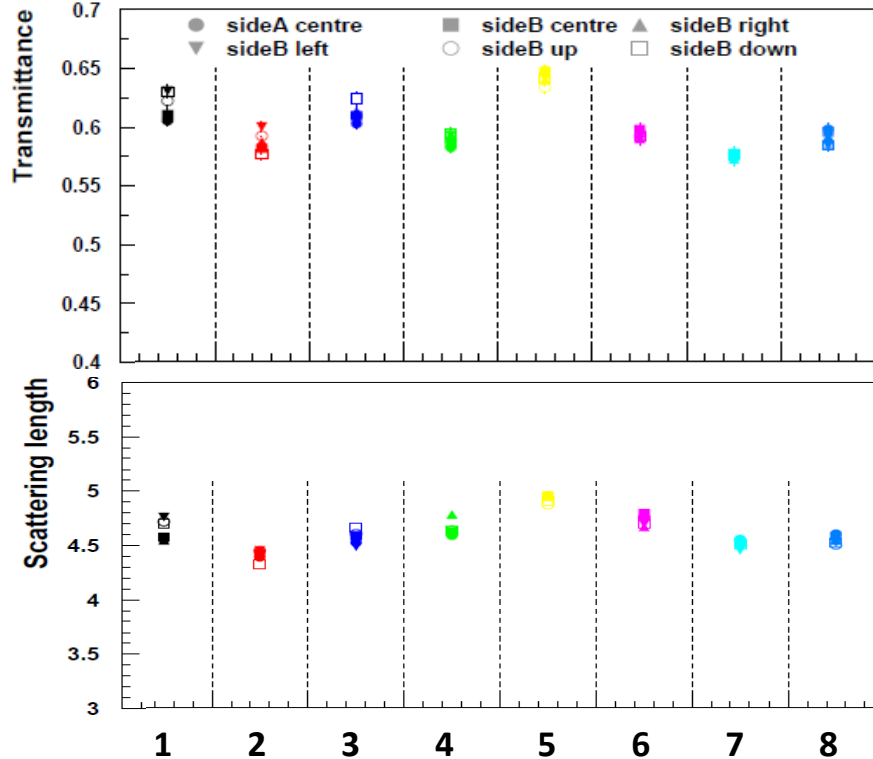


Measurements at 400nm (Novosibirsk)

For each tile, measurements repeated
“illuminating” 6 different positions:

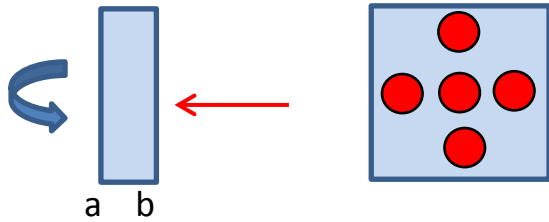


Novosibirsk Samples 1-8 (1.05 2cm)



Measurements at 400nm (Novosibirsk)

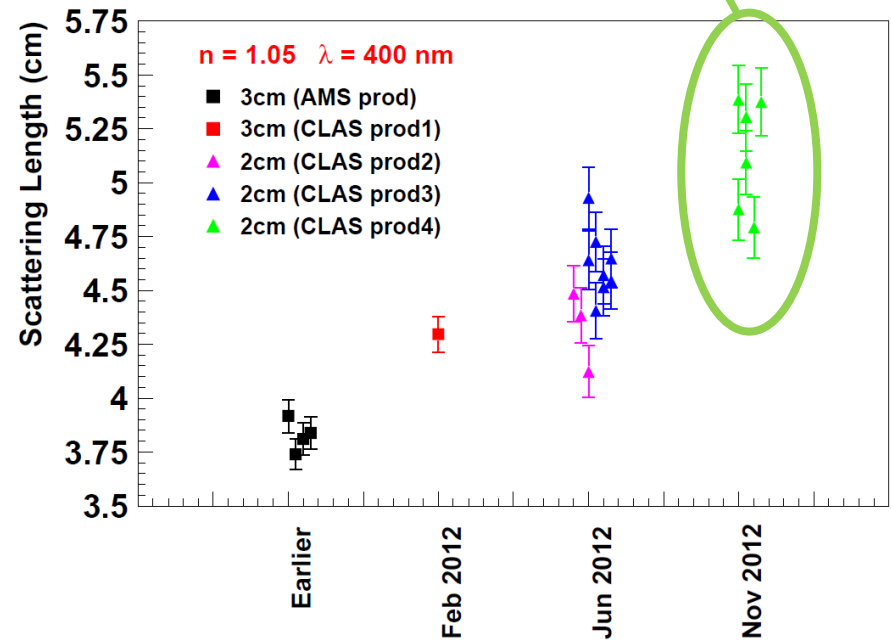
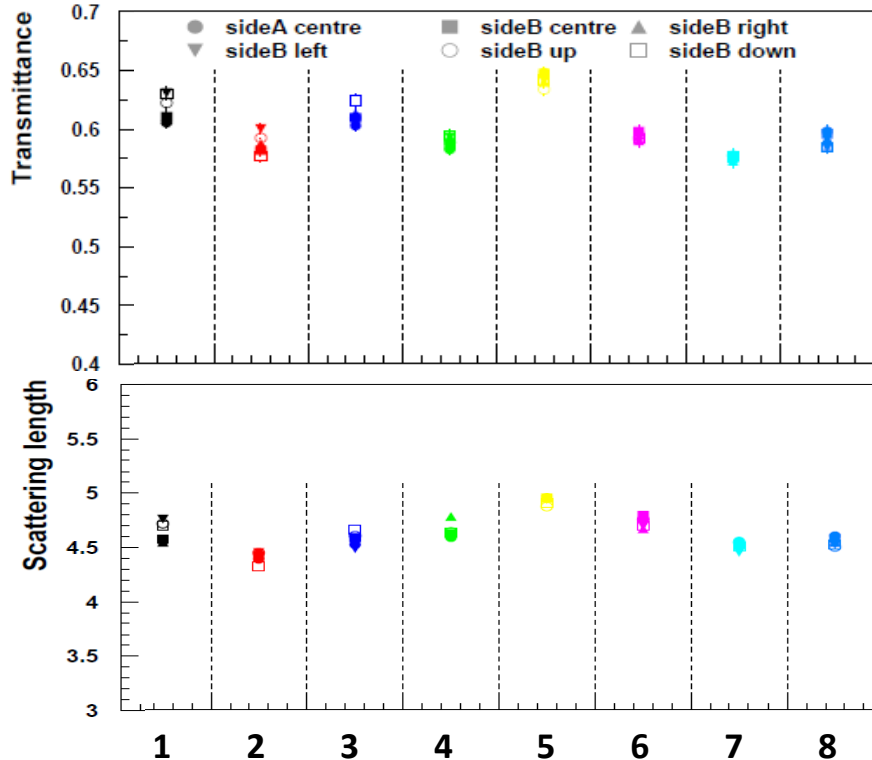
For each tile, measurements repeated “illuminating” 6 different positions:



$$\text{Clarity} \sim 0.0050 \frac{\mu\text{m}^4}{\text{cm}} \text{ for } n=1.05$$

$$(\text{LHCb has } 0.0064 \frac{\mu\text{m}^4}{\text{cm}} \text{ for } n=1.03)$$

Novosibirsk Samples 1-8 (1.05 2cm)

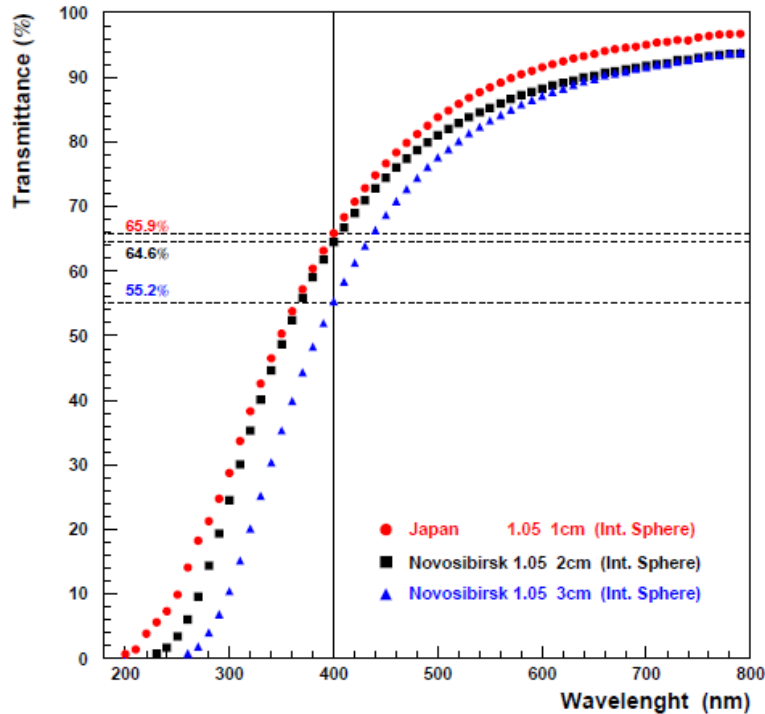


Aerogel quality significantly improved in time following the requirements of the project!

The Matsushita and Aspen aerogel

Matsushita (Japan)

- 1 format ($11.5 \times 11.5 \text{ cm}^2$)
- 1 thickness (1cm)
- 2 refractive indices (1.03, 1.05)

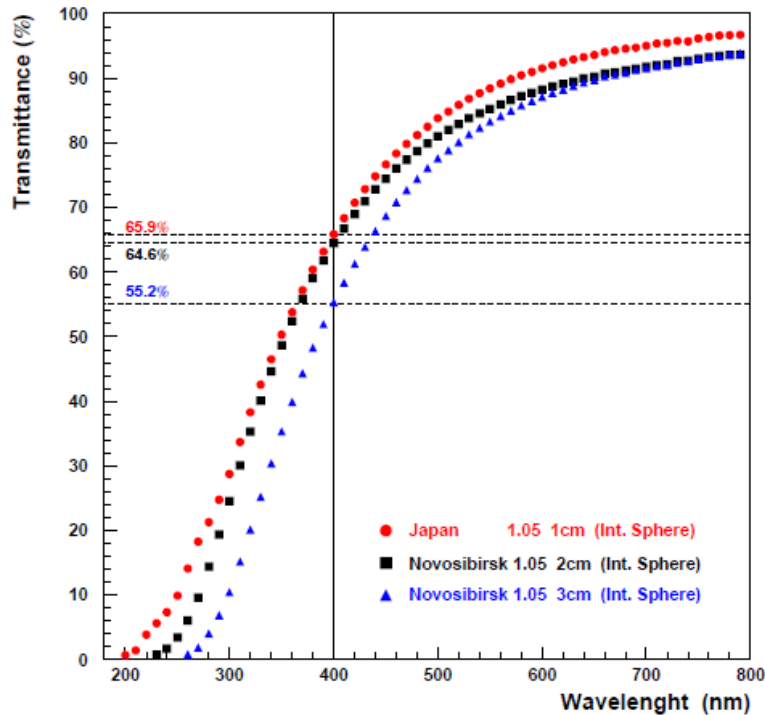


At 400nm 1cm Matsushita has same transmittance than 2cm Novosibirsk

The Matsushita and Aspen aerogel

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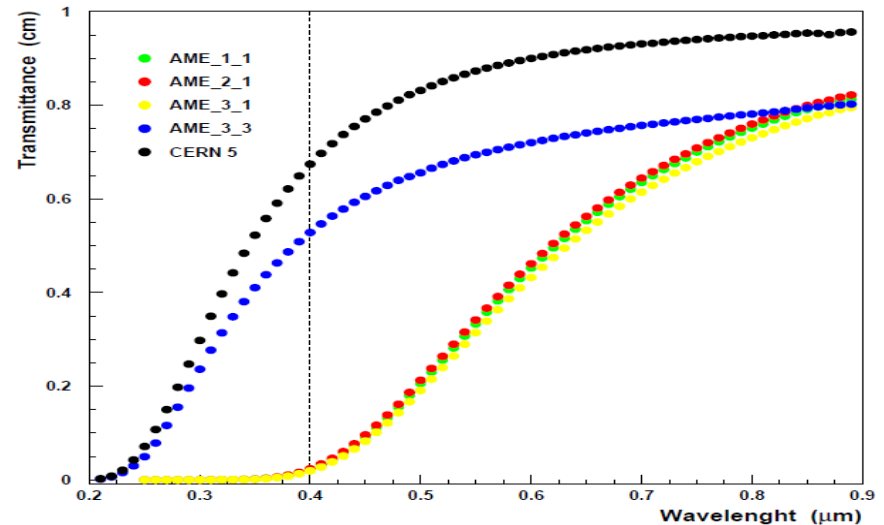
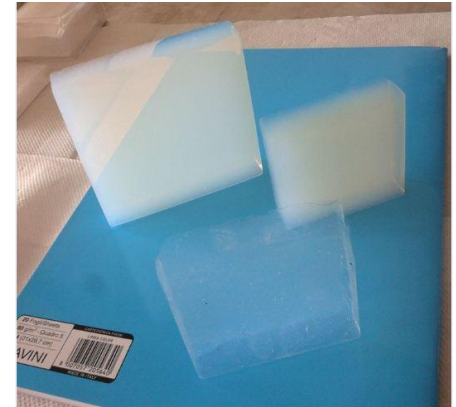
- 1 format ($11.5 \times 11.5 \text{ cm}^2$)
- 1 thickness (1cm)
- 2 refractive indices (1.03, 1.05)



At 400nm 1cm Matsushita has same transmittance than 2cm Novosibirsk

Aspen (US)

- 3 formats: large, medium, small
- 2 thickness: 1.7 cm, 0.95 cm
- 2 refractive indices (1.01, 1.05)



Reasonable transmittance and scattering length only for $n = 1.01$

Part 3

Monitoring the aerogel transmittance over time

Monitoring the transparency

The Novosibirsk aerogel is **hydrophilic**, i.e. tends to absorb humidity from the air, resulting in a worsening of the optical performances \rightarrow need to periodically monitor the transmittance

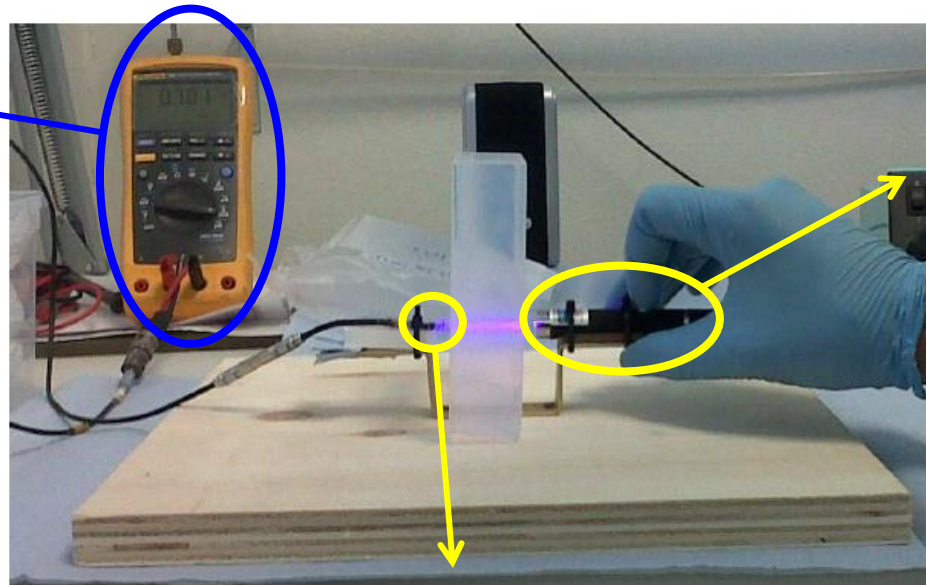
Fast measurements were performed with a very simple set-up:

Multimeter:
reads current

$$T_i = \frac{I_{\text{aerogel}}}{I_0}$$



$$\langle T \rangle = \frac{1}{10} \sum_{i=1,10} T_i$$



Laser:
blue light (405 nm)

photodiode output in mA

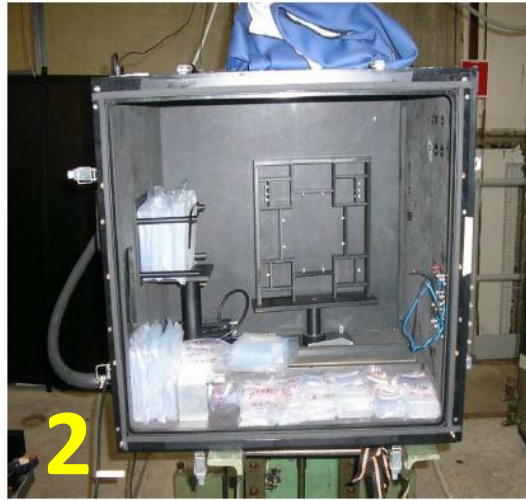
The method is fast (few minutes for each set of 10 measurements) but introduces several **systematic effects** (laser-photodiode distance, aerogel local non-homogeneities, laser instabilities) that result in a broadening of the measured transmittance.

The RMS of each set of measurements was assigned as a global systematic uncertainty ΔT

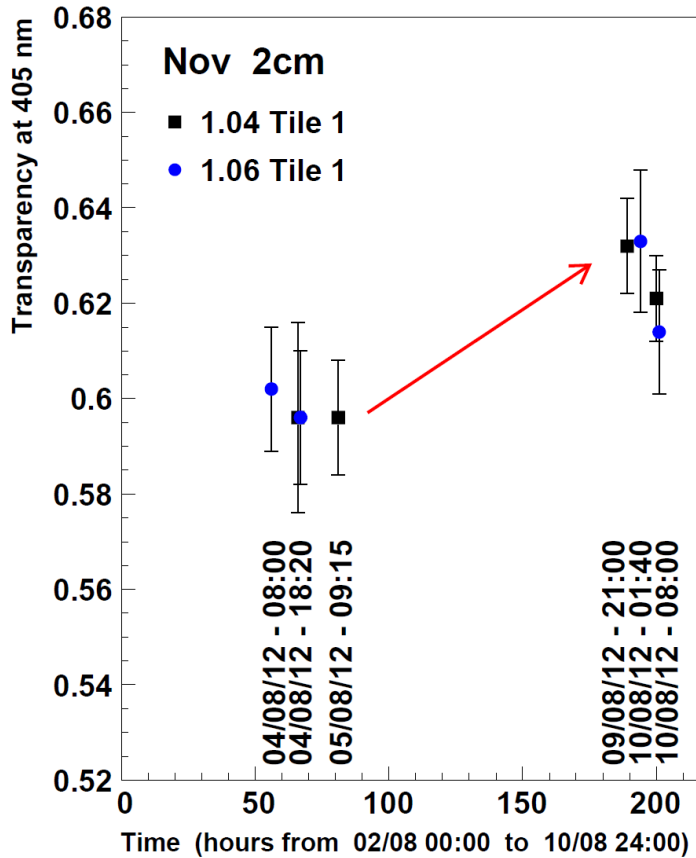
Restoring/preserving the transparency

Several methods were tested to preserve/restore the transparency after exposure to air

1. Storing tiles in a dry cabinet
2. Storing tiles in a box fluxed with nitrogen
3. Sealing in small plastic bags



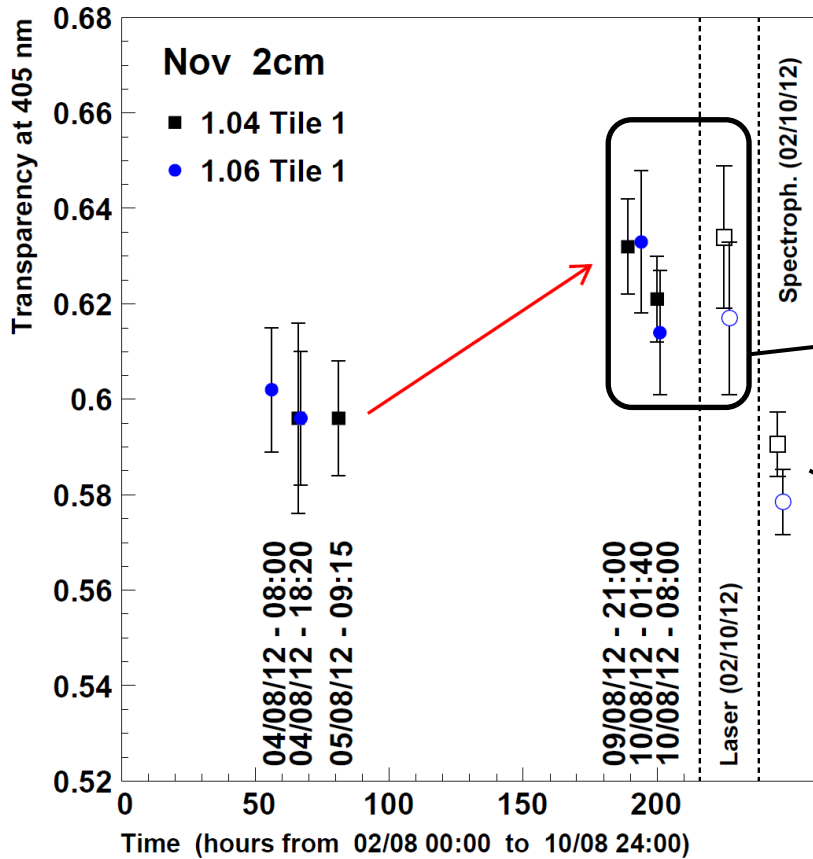
Some results



Storage in box with nitrogen

partial transmittance restoration (fluxed with nitrogen for > 100 h)

Some results



stability over time
(2 months sealed in plastic bag)

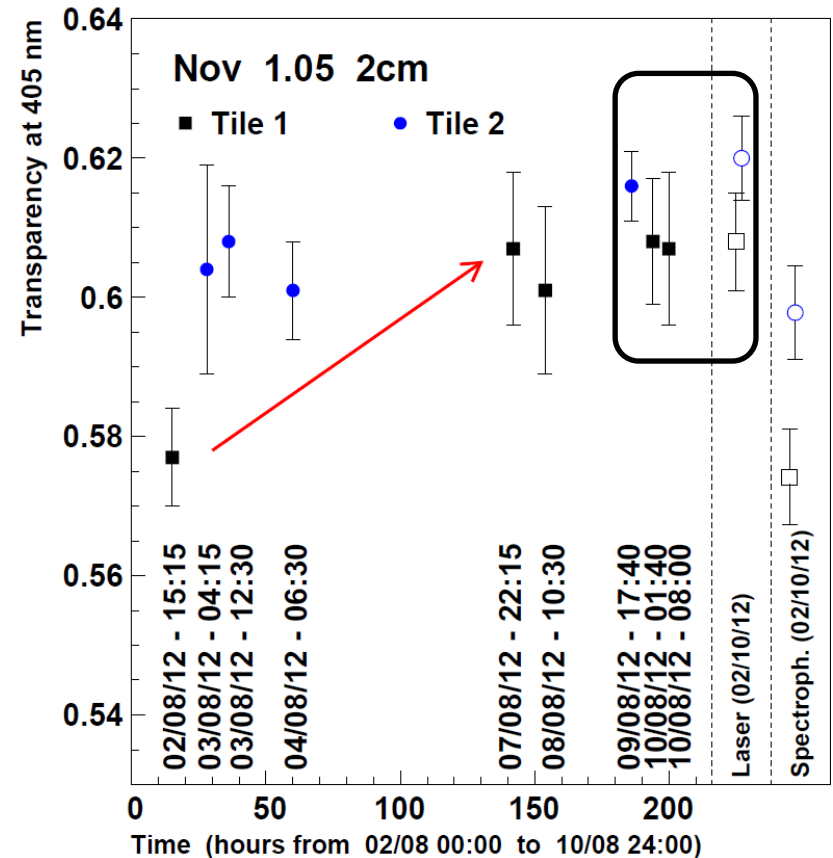
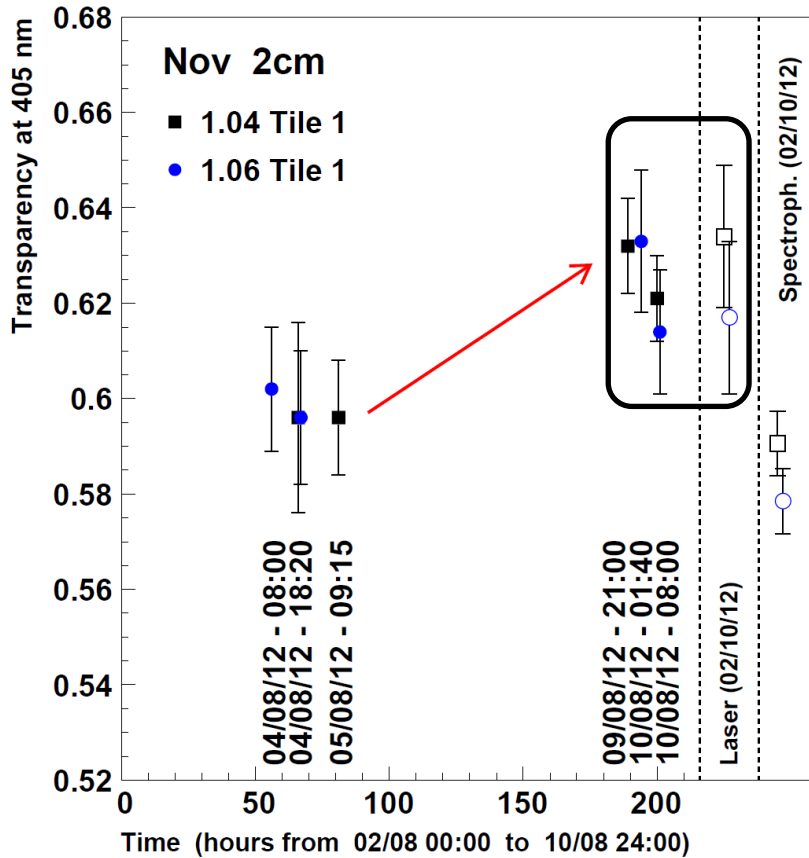
spectrophotometer measurements
(more reliable) systematically smaller.

108 h

Storage in box with nitrogen

partial transmittance restoration (fluxed with nitrogen for > 100 h)

Some results



108 h

Storage in box with nitrogen

127 h

- Evidence of partial transmittance restoration after at least 60 hours of storage in dry (nitrogen) atmosphere
- Sealing the tiles in plastic bags preserves the transmittance over long periods
- Smaller values measured with spectrophot. indicate systematic effects in laser meas.

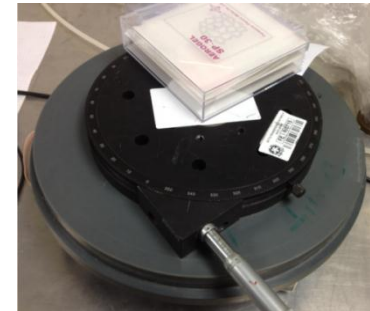
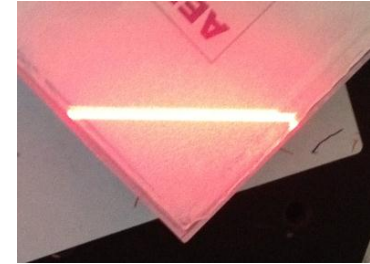
Part 4

Measures of chromatic dispersion

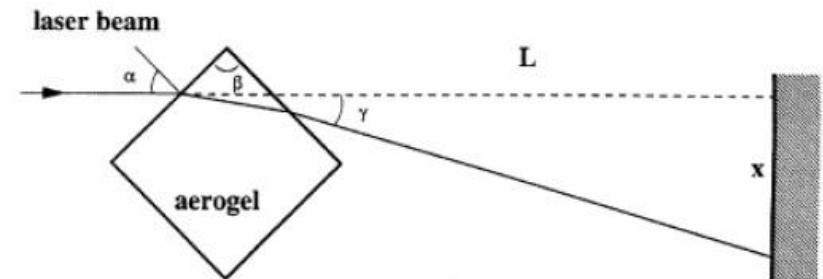
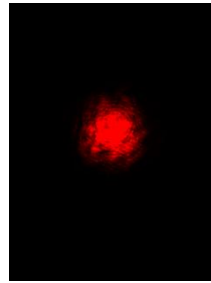
Main motivation: From MC simulations the chromatic error is expected to be among the largest contributions to the final uncertainty on the Cherenkov angle.

The "standard prism" method

- The adjacent edges of the aerogel tile form a prism
- The tile is placed on a graduated rotating stage
- One measures the deviation of a light beam passing through the tile edges at different incident angles
- A CCD camera acquires the position of the spot on a screen placed downstream



1280 × 1024 pxls



- The aerogel **refractive index n** can be determined by fitting the angular distribution of the spots of the refracted beam with the **Snell-Descartes law**:

$$\delta = \alpha - \beta + \arcsin \left\{ n \cdot \sin \left[\beta - \arcsin \left(\frac{\sin \alpha}{n} \right) \right] \right\}$$

The setup

beam extracted from spectrophotometer

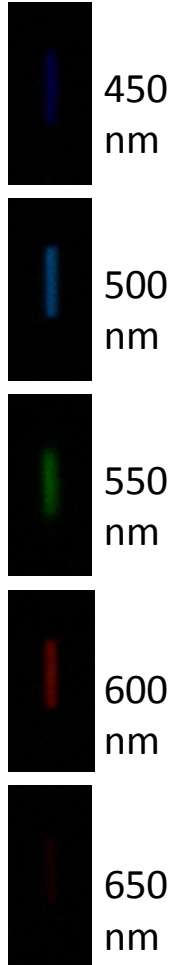
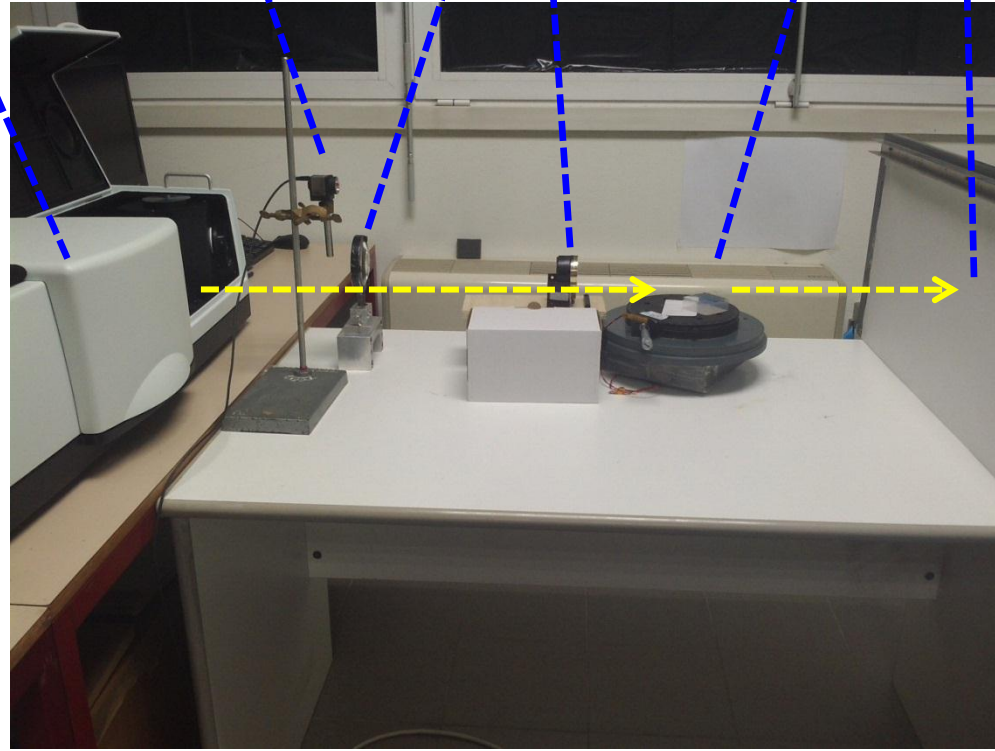
Spectrophotometer

CCD camera

focusing lenses

aerogel

screen



Advantages:

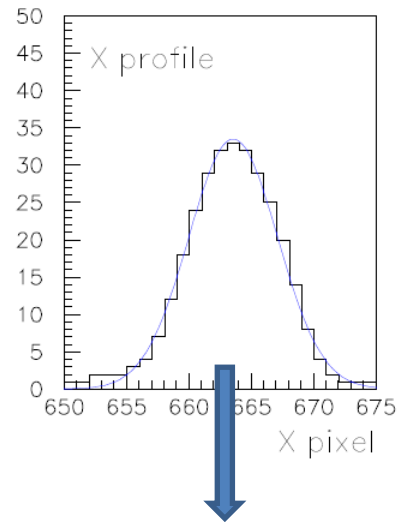
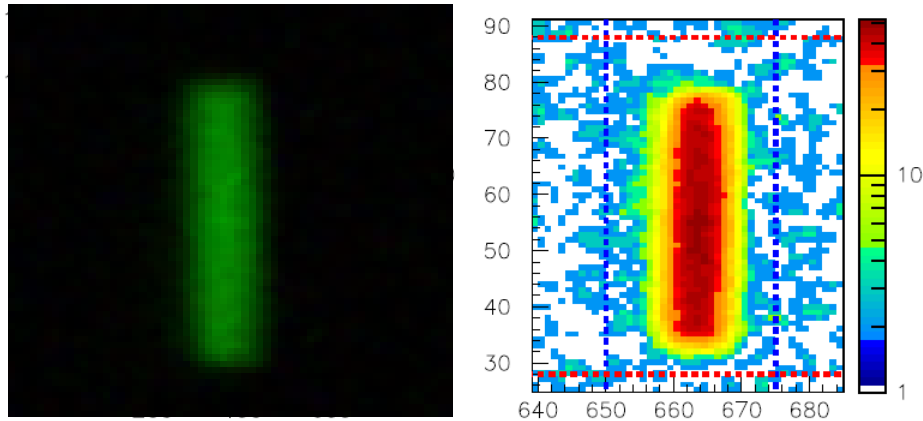
- Can use any wavelength in range 450 – 650 nm
- Alignment is same for all wavelengths
- Dispersion law well constrained (many points)

Disadvantages:

- Beam intensity is low
- Spots are weak
- Cannot measure below 450 nm (spot too weak)

Analysis of the spots

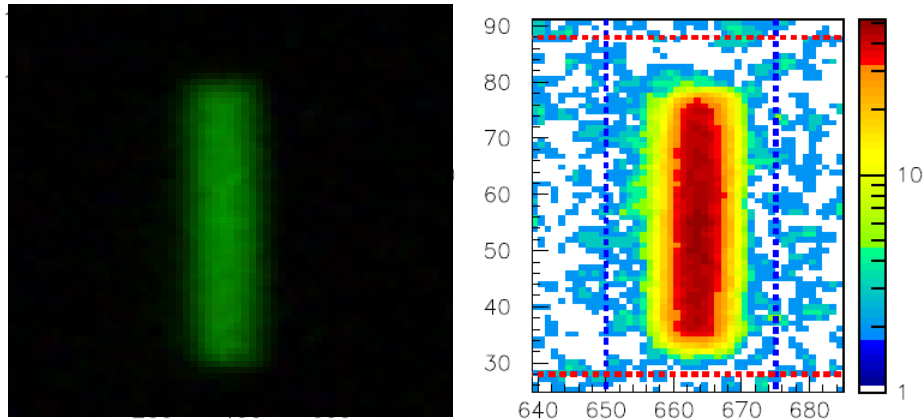
550nm No aerogel (reference)



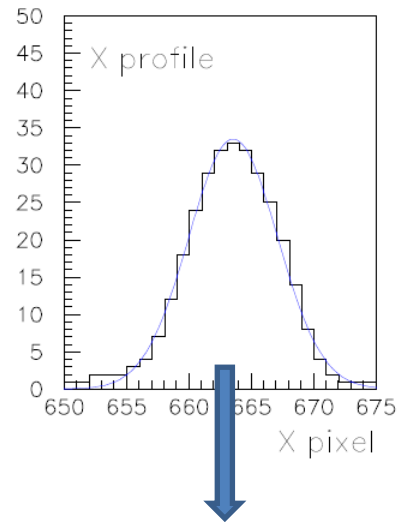
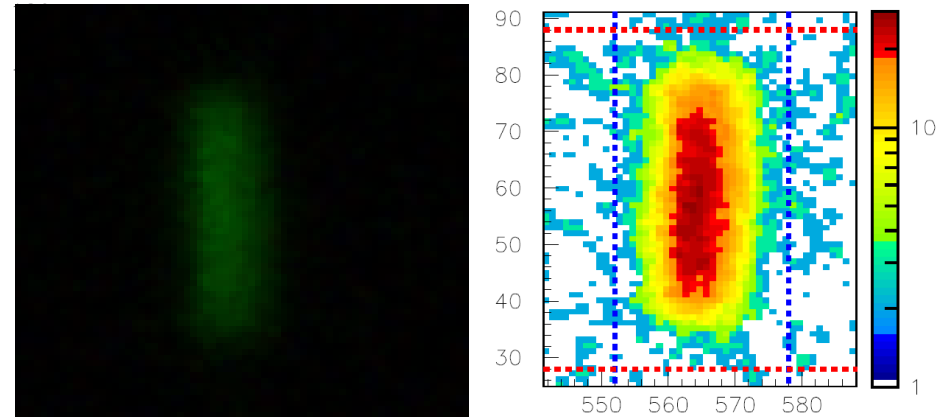
centroid gives the
reference position

Analysis of the spots

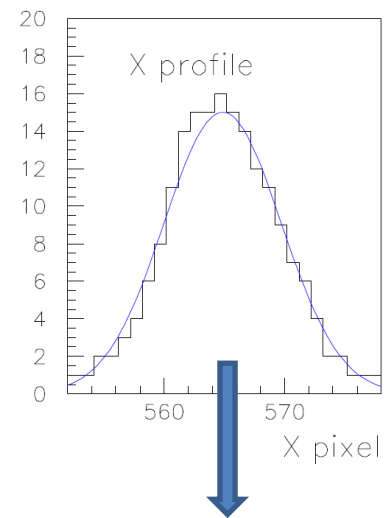
550nm No aerogel (reference)



550nm with aerogel (minimum position)



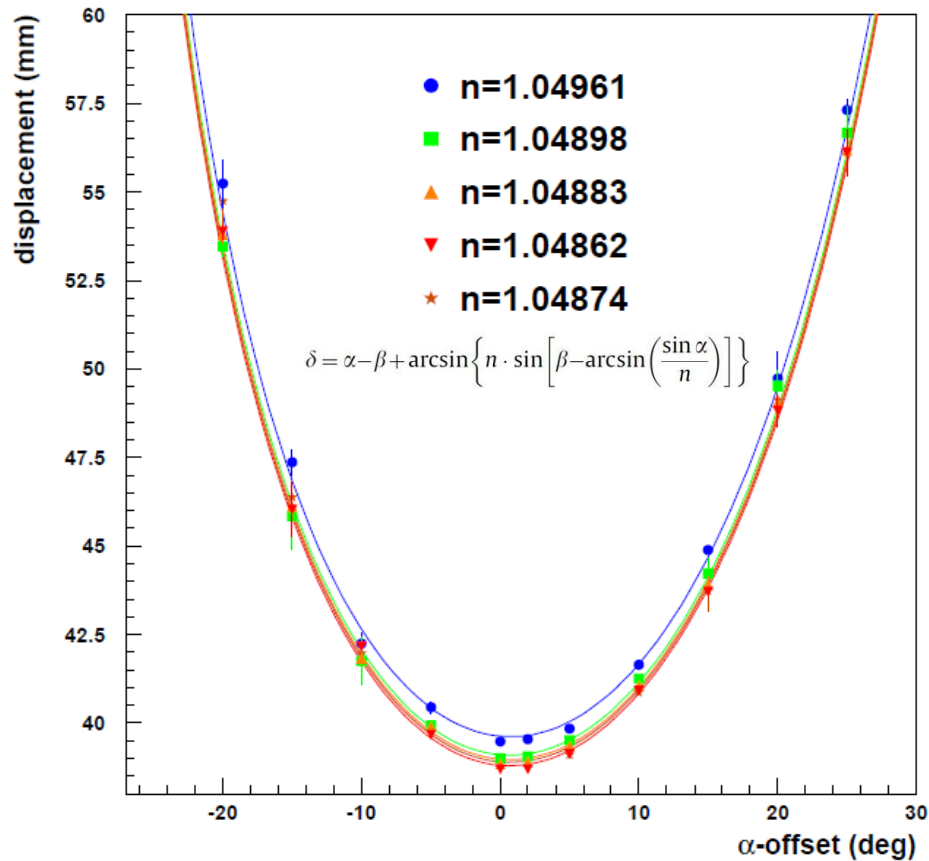
centroid gives the
reference position



centroid gives the
horizontal displacement

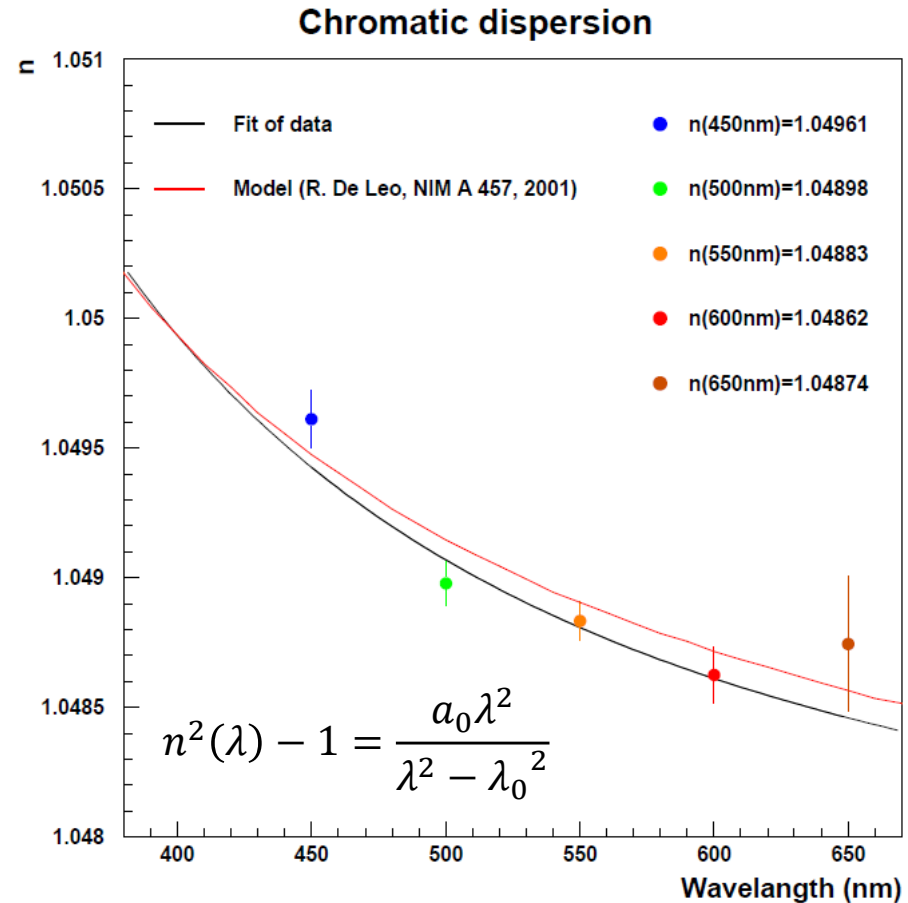
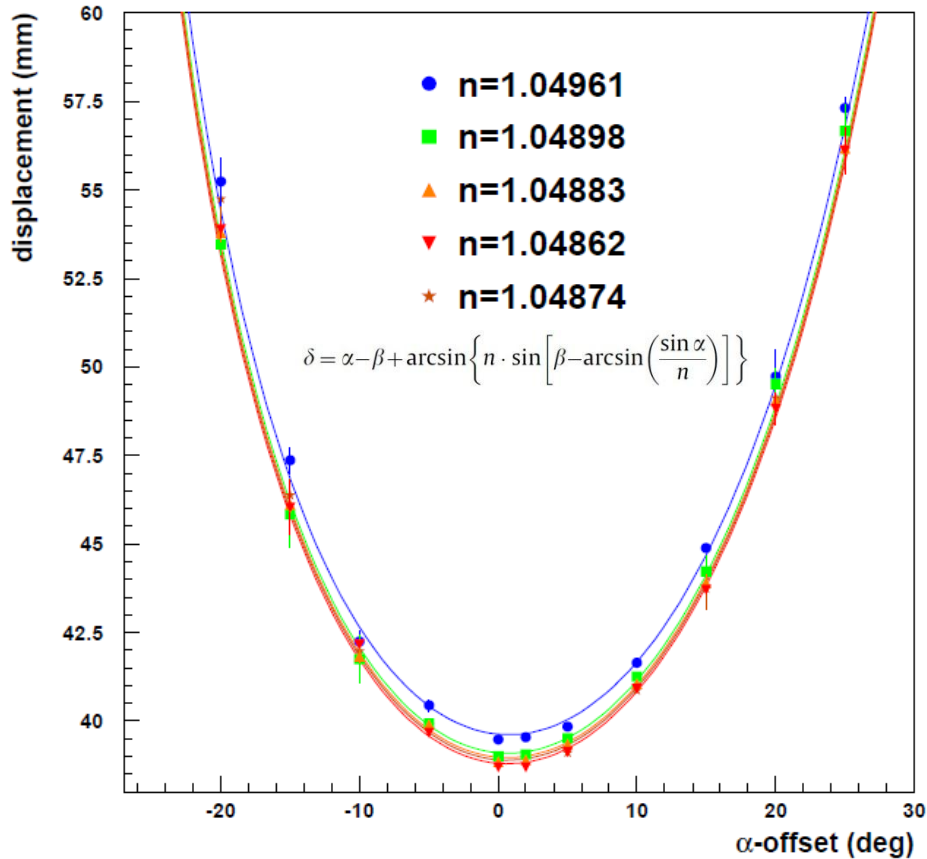
Measuring the chromatic dispersion (new setup)

1. Spectrophotometer beam with 5 wavelengths: 450, 500, 550, 600, 650 nm
2. The position of the centroids is extracted from the analysis of the spot images
3. The five refractive indices are extracted fitting the displacements with **Snell-Descarted law**



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1. Spectrophotometer beam with 5 wavelengths: 450, 500, 550, 600, 650 nm
2. The position of the centroids is extracted from the analysis of the spot images
3. The five refractive indices are extracted fitting the displacements with **Snell-Descarted law**
4. **Chromatic dispersion** extracted by fitting $n(\lambda)$ with the **dispersion law**



Part 5

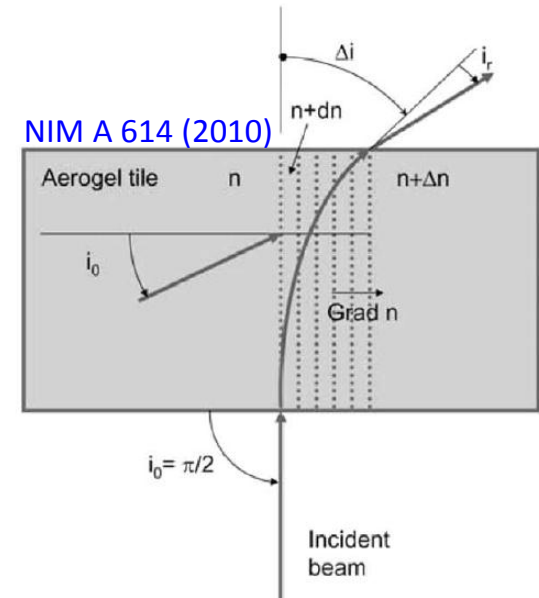
Refractive index uniformity ("gradient method")

- The prism method allows measuring n only at the tile edges
- n can vary significantly throughout the tile (observed $\delta n \approx 10^{-3}$)
- The *gradient method* allows to map the refractive index over the whole tile

The gradient method

The principle of the method [NIM A 614, 2010] :

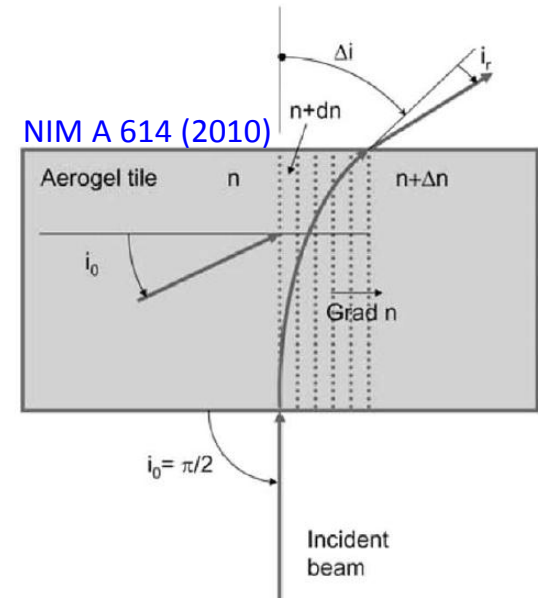
- in the presence of a local transverse gradient of n , a laser beam impinging normally to the tile surface is deflected by a continuous refraction effect
- The deflection of the beam observed in different points of the tile can be related to local transverse gradients of n



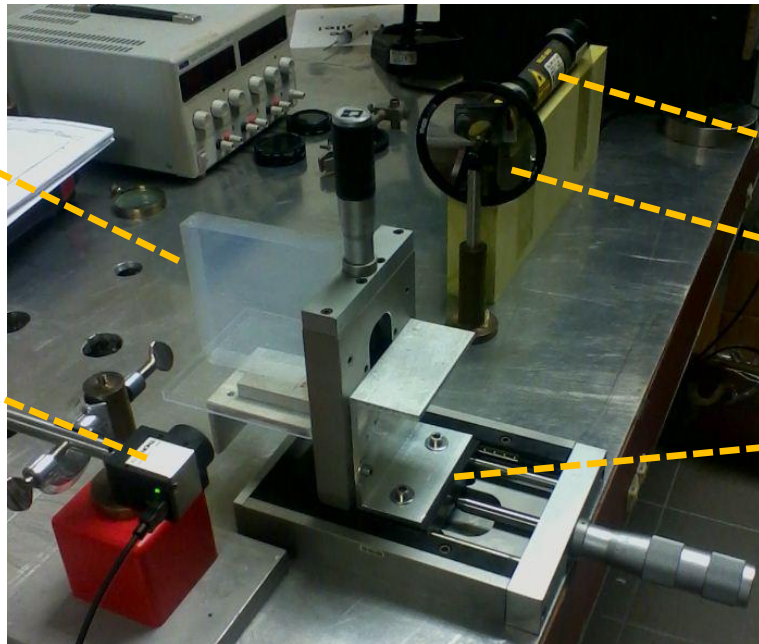
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Setup (preliminary test)



aerogel

red laser

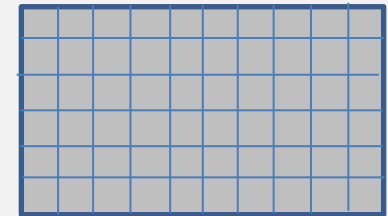
attenuator

CCD camera

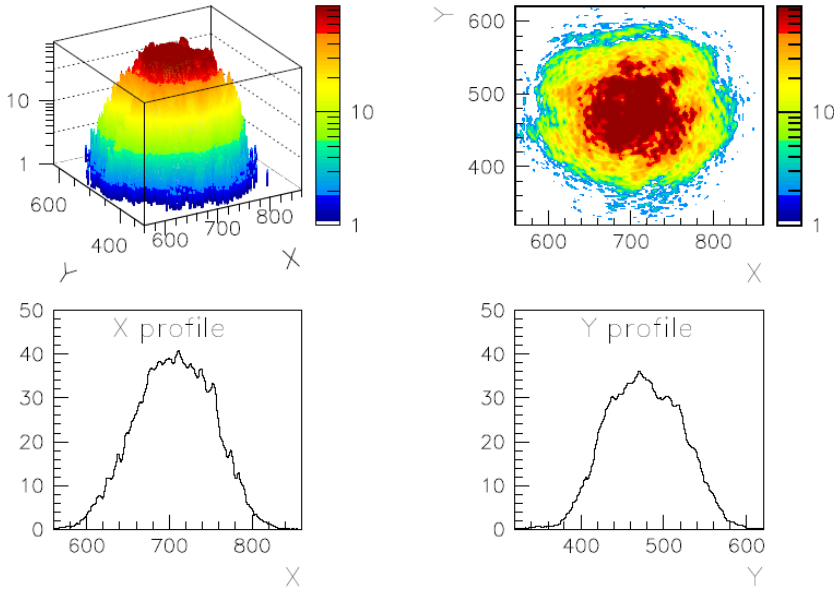
tool for micrometric movements

$115 \times 115 \times 20 \text{ mm}^3$

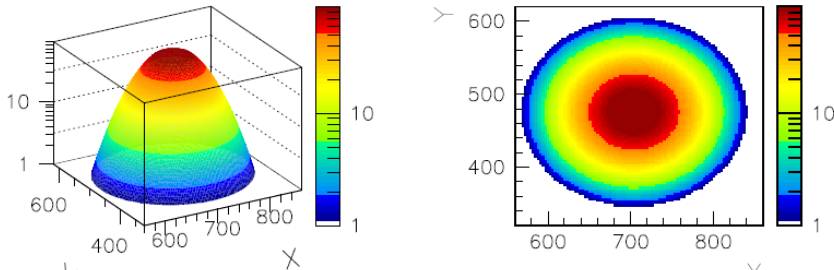
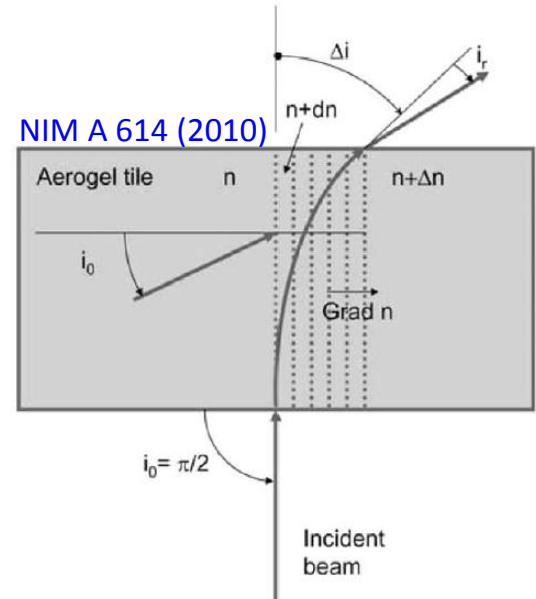
11 × 7 points
at 8mm step



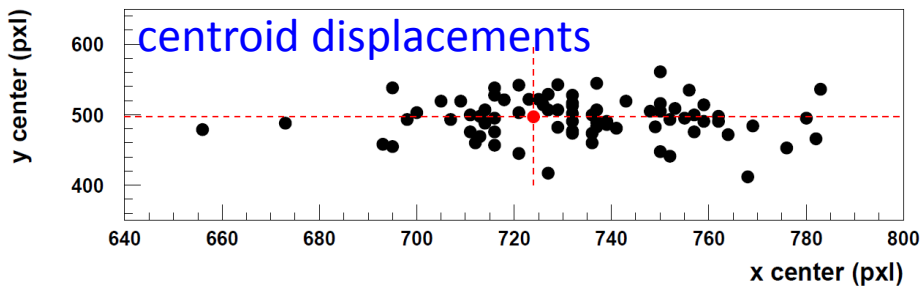
The gradient method



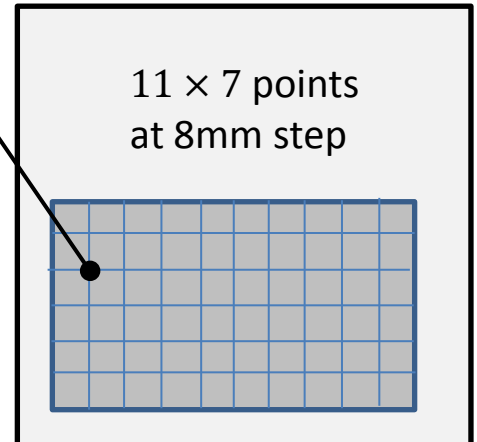
NIM A 614 (2010)



2D Gaussian fit to extract position of centroid



$115 \times 115 \times 20 \text{ mm}^3$

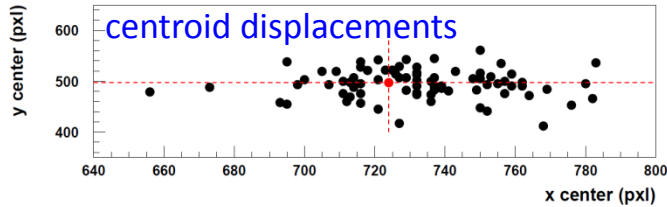


The gradient method

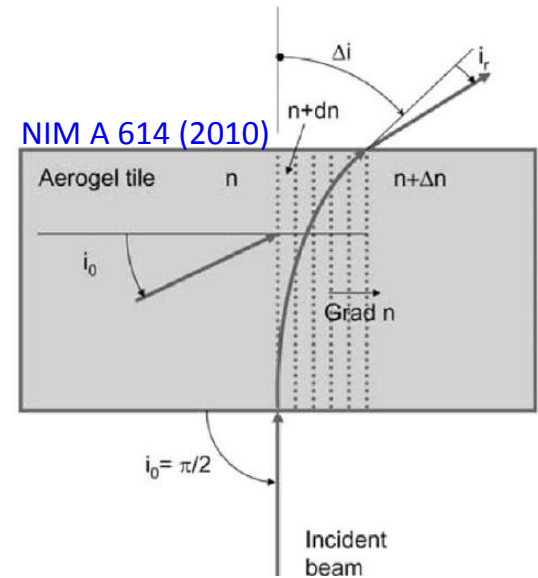
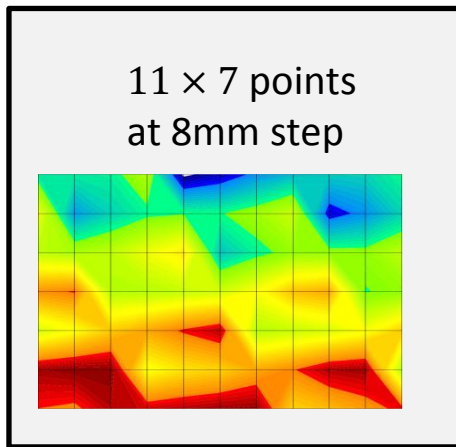
- 1) assume Snell law for adjacent aerogel layers

$$n \sin \vartheta = (n + \Delta n) \sin(\vartheta + \Delta\vartheta)$$

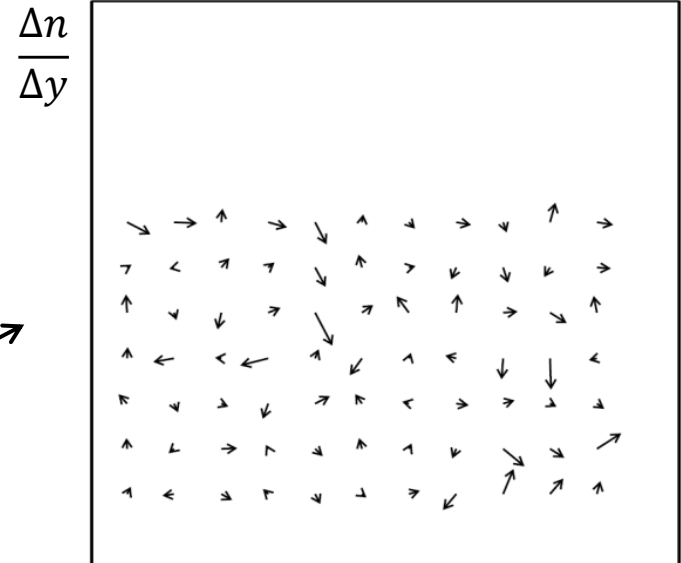
- 2) extract Δn along x and y from measured displacements



- 3) Divide Δn by the x (y) displacements along the tile thickness (using the actual thicknesses measured in each point \rightarrow **thickness map**)



gradient map (10^{-4} cm^{-1} : \rightarrow)



- 4) Build the **refractive index gradient map**

The refractive index map

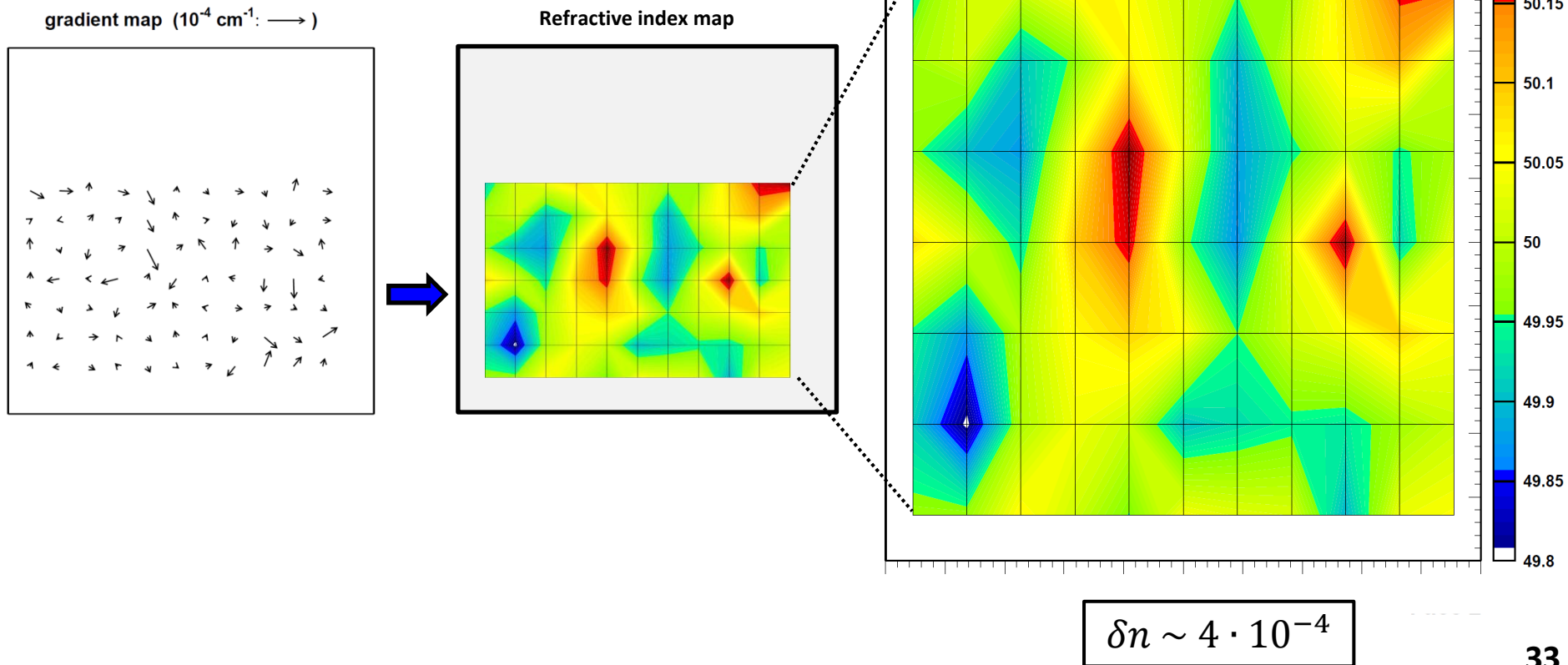
Since the refractive index at each point depends on the gradients at the neighbors points, the values of n in the 77 points are extracted simultaneously by minimizing a global χ^2 which accounts for the gradients along x and y :

$$\chi^2 = \sum_i \sum_{j \in \text{neighbors}} (n_i - \tilde{n}_i^j)^2 \quad \text{where} \quad \tilde{n}_i^j = n_j + (\Delta n / \Delta x)(x_i - x_j) + (\Delta n / \Delta y)(y_i - y_j) \quad [\text{NIM A 614 (2010)}]$$

The refractive index map

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Conclusions and outlook

The Collaboration has developed skills and tools for the optical characterization of aerogel radiators for the CLAS12 RICH

- High precision and fast thickness measurements allow for thickness mapping of tiles
- Transmittance, absorption and scattering length measurements were performed with a spectrophotometer for a variety of aerogel tiles from different manufacturers
- Measurements of refractive index and chromatic dispersion were performed with the prisms method.
- The gradient method allows to map the refractive index throughout the tile

The new generation aerogel from Novosibirsk has higher performances (transparency, scattering length, chromatic dispersion) and is the most suitable for the CLAS12 RICH

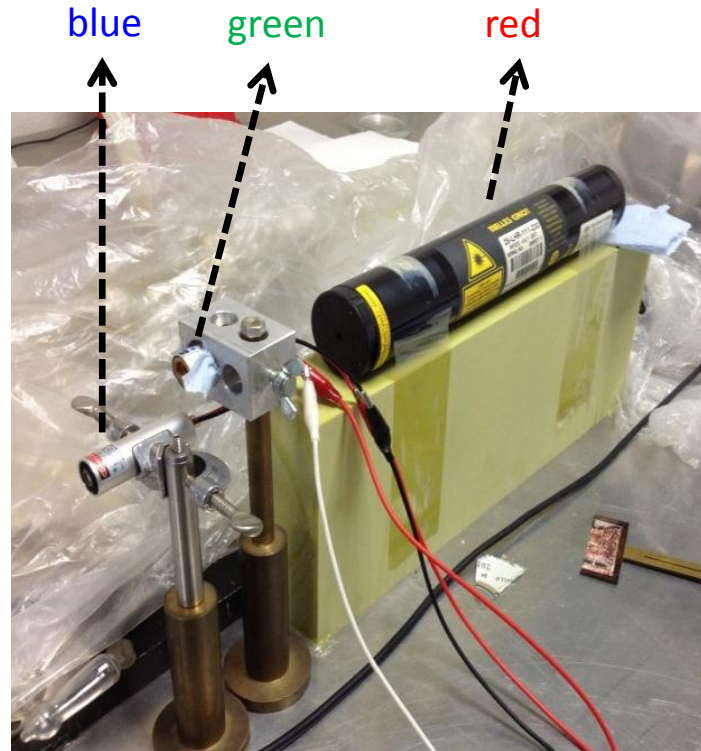
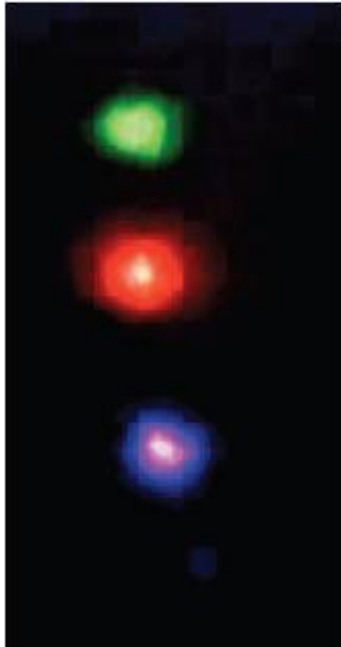
The aerogel tiles for the CLAS12 RICH:

- **Size:** $20 \times 20 \times 2$ (3) cm^3
- **Refractive index:** 1.05
- **Clarity parameter:** $\leq 0.0050 \mu m^4/cm$
- **Manufacturer:** Novosibirsk (best quality, reliability and experience (AMS,LHCb))

Backup

The original setup

3 lasers: red ($\lambda=632.8$ nm), green ($\lambda=532$ nm), blue ($\lambda=405$ nm)



Advantages:

- beams are intense and narrow
- spots well visible also at large angles
- blue laser correspond to wavelength region of highest relevance for the RICH (400nm)

Disadvantages:

- Relative alignment of lasers is not trivial
- Measurements only possible for 3 wavelengths
- Constrain the dispersion law with only in 3 points