The aerogel radiator: optical characterization and performances

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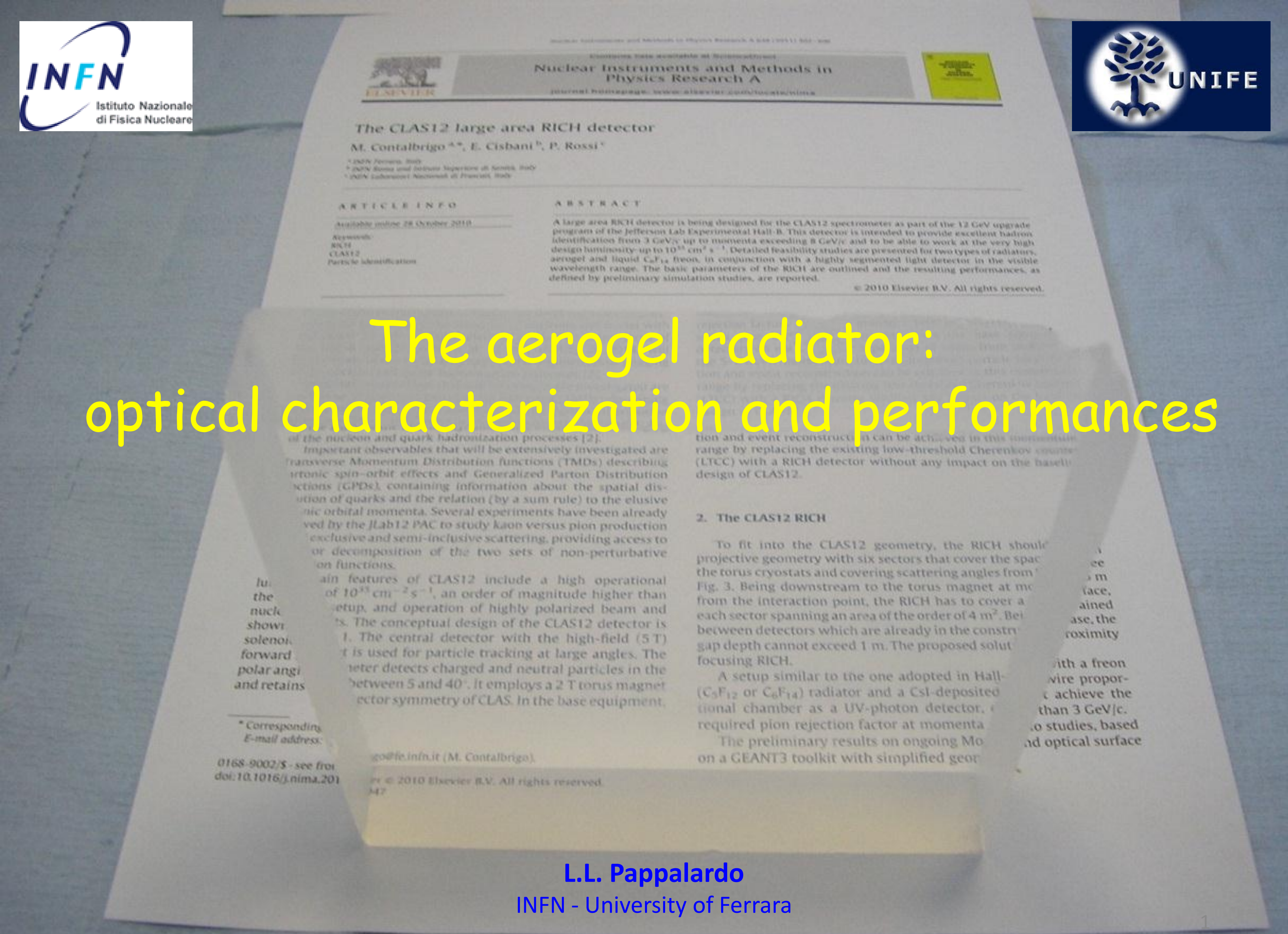
CLAS12 RICH Review – Jlab - September 5th 2013



Nuclear Instruments and Methods in Physics Research A

The CLAS12 large area RICH detector

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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} cm^{-2} 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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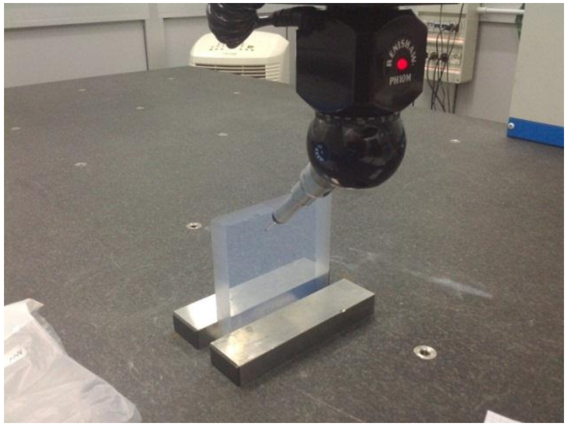
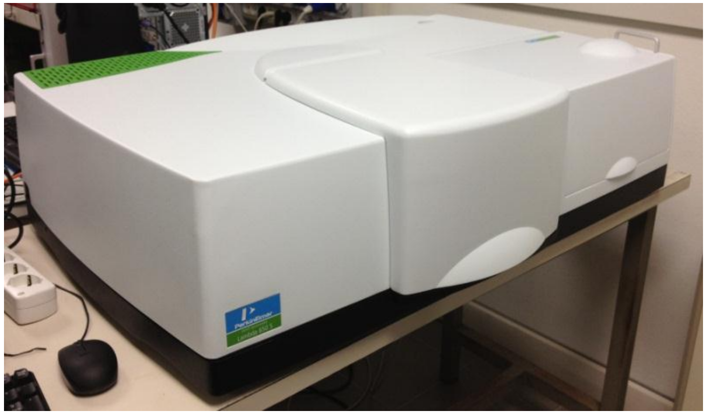
2. The CLAS12 RICH

Characterization of aerogel tiles

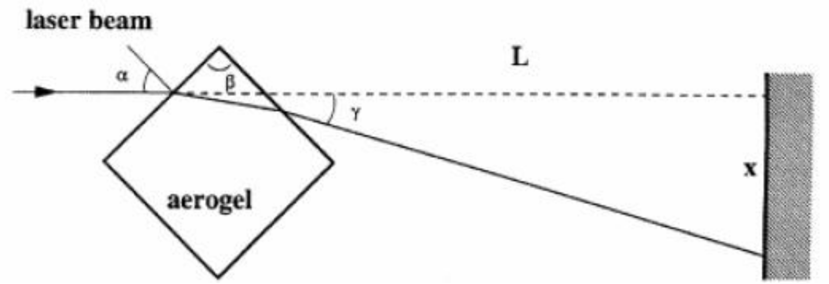
- Geometry (thickness map)



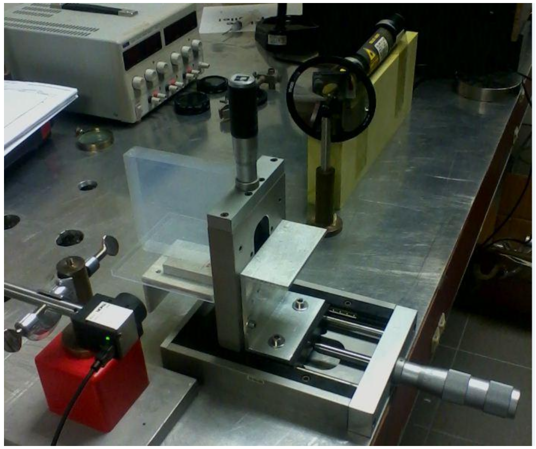
- Transmittance, abs/scatt. length



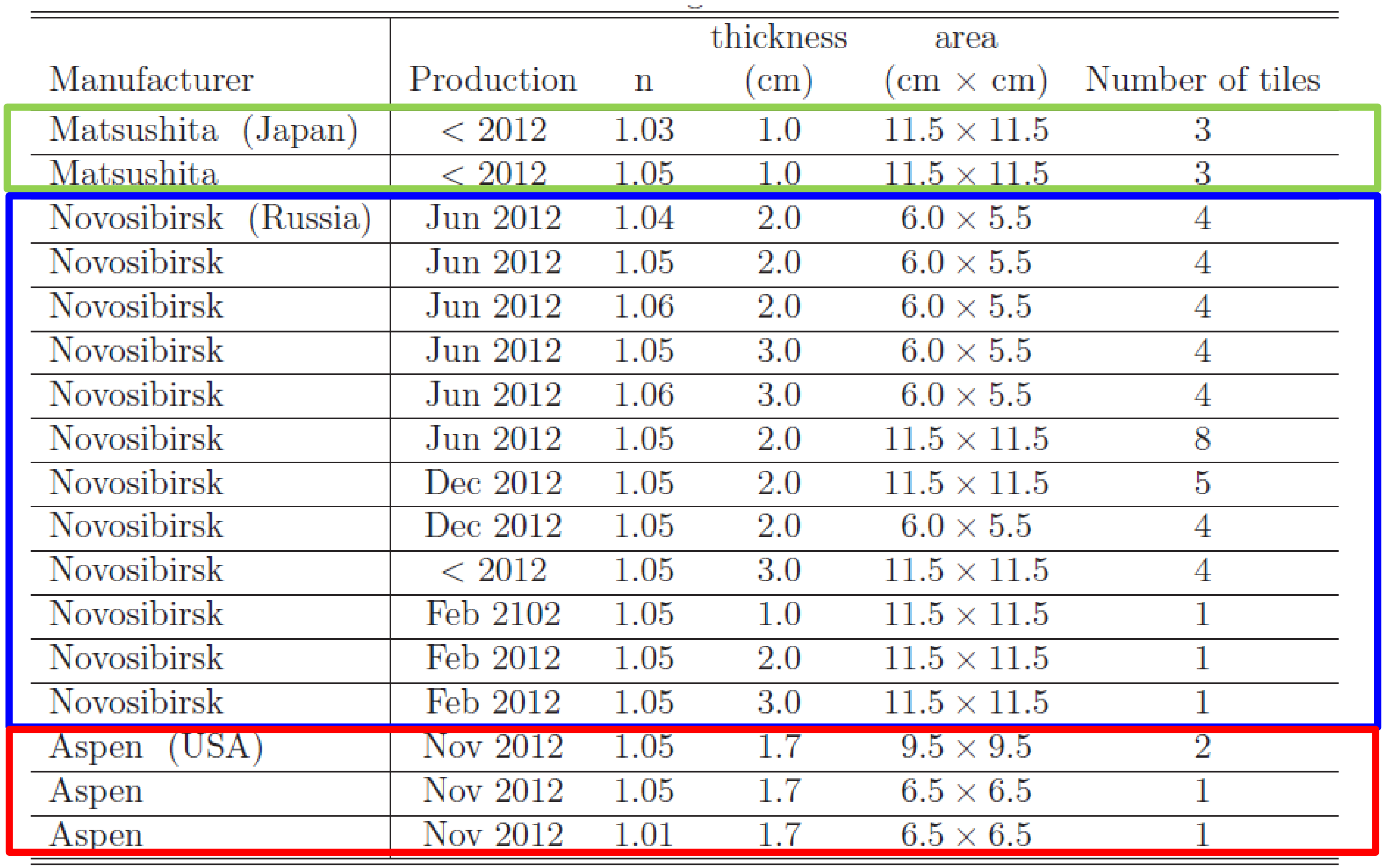
- Chromatic dispersion



- 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

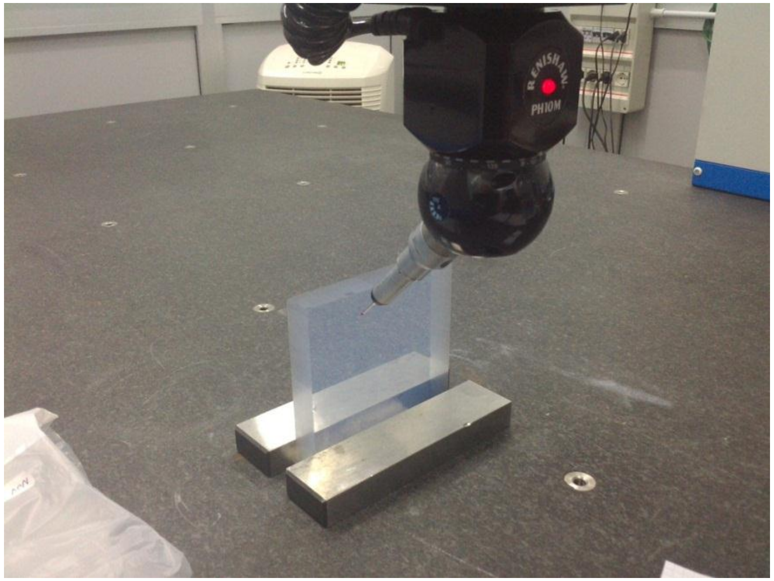
- **3 manifactures** (Matsushita, Novosibirsk, Aspen)
- **5 refractive indices** (1.01, 1,03, 1.04, 1.05, 1.06)
- **4 thicknesses** (1cm, 1.7cm, 2cm, 3cm)
- **3 areas** $(6.0 \times 6.5, 11.5 \times 11.5\ cm^2, 9.5 \times 9.5\ cm^2, 6.5 \times 6.5\ cm^2)$

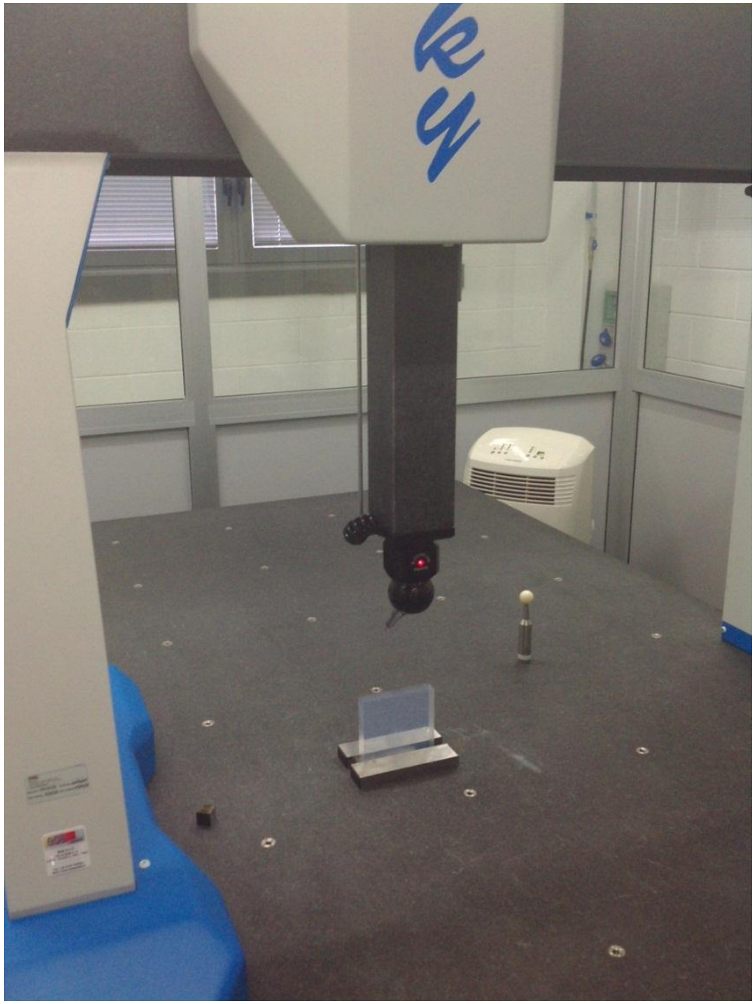
Part 1

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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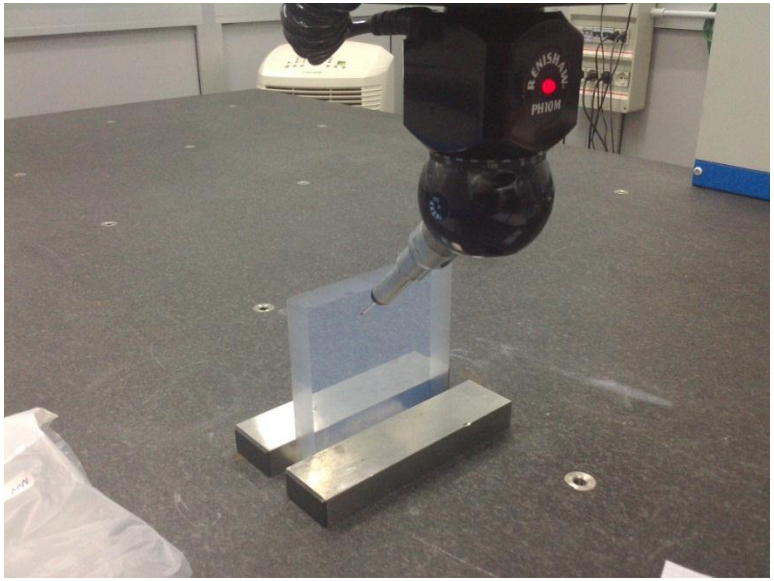
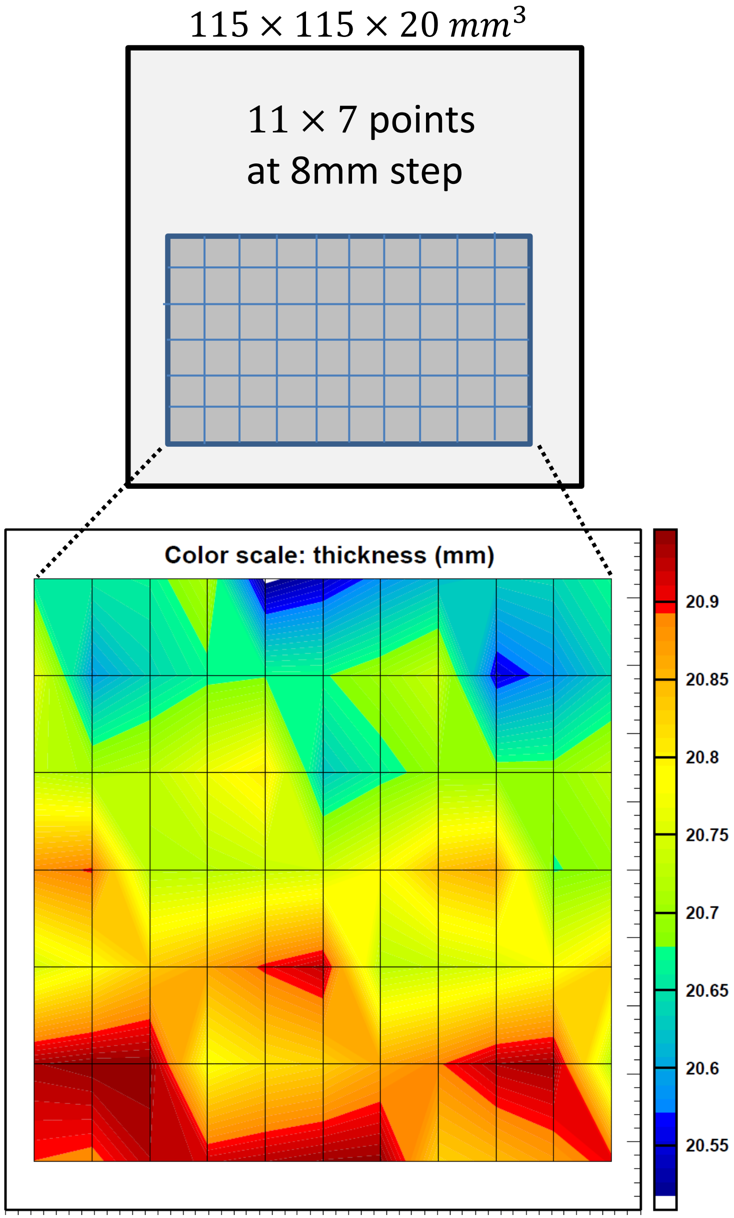
- **Observed thickness variations up to 0.4 mm**




$115 \times 115 \times 20\ mm^3$

11×7 points
at 8mm step

Color scale: thickness (mm)

$$\delta z \sim 0.4\ mm \ \ (\delta z / z \sim 2\%)$$

Part 2

Measuring Transmittance, scattering and absorption length

Formalism and selected results (Novosibirsk)

Transmittance

Hunt formula

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

Clarity parameter

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

Transflectance

$\Lambda_A = -t/lnA$ **Absorp. length**

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

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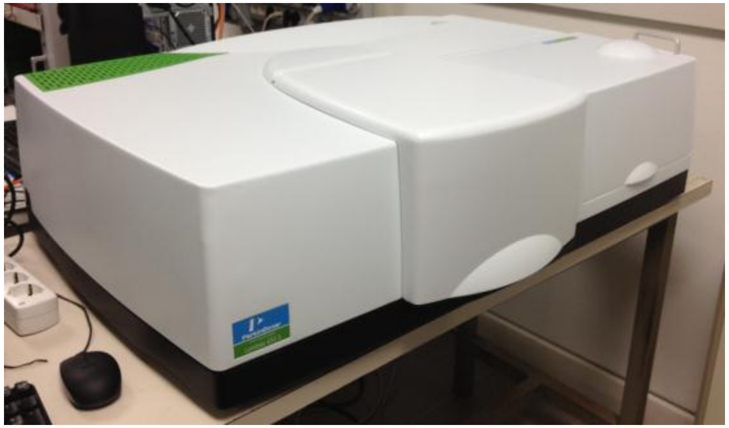
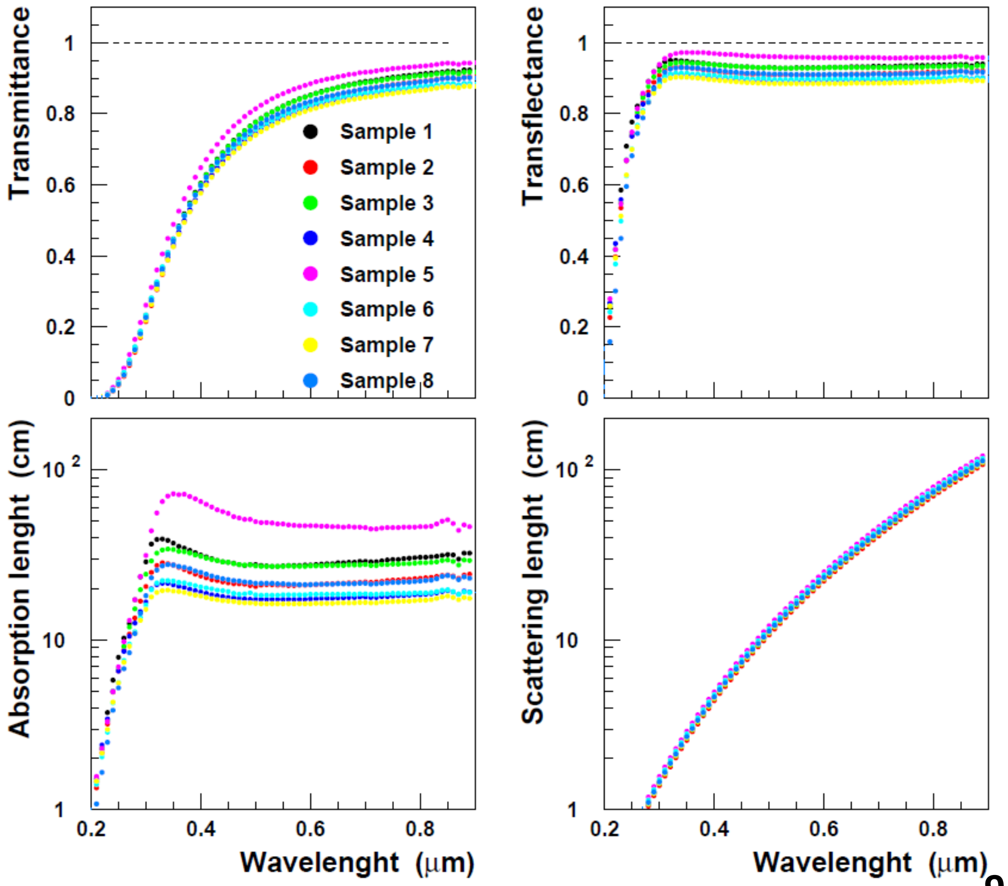
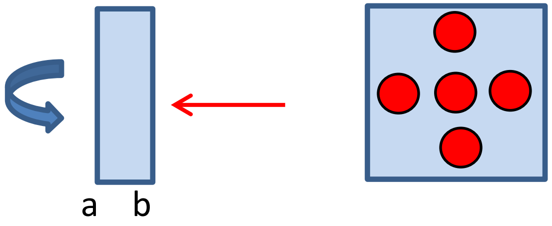


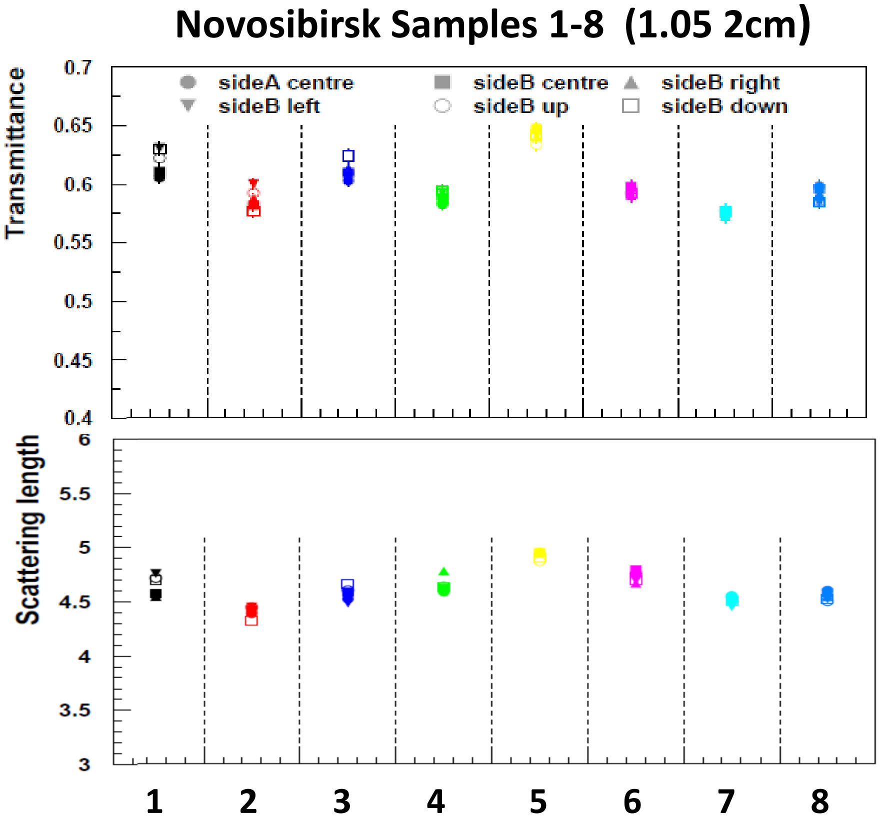
Novosibirsk Samples 1-8 (1.05)



Measurements at 400nm (Novosibirsk)

For each tile, measurements repeated "illuminating" 6 different positions:





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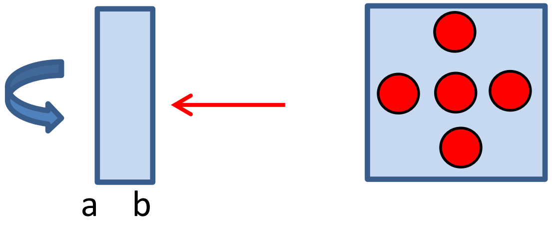
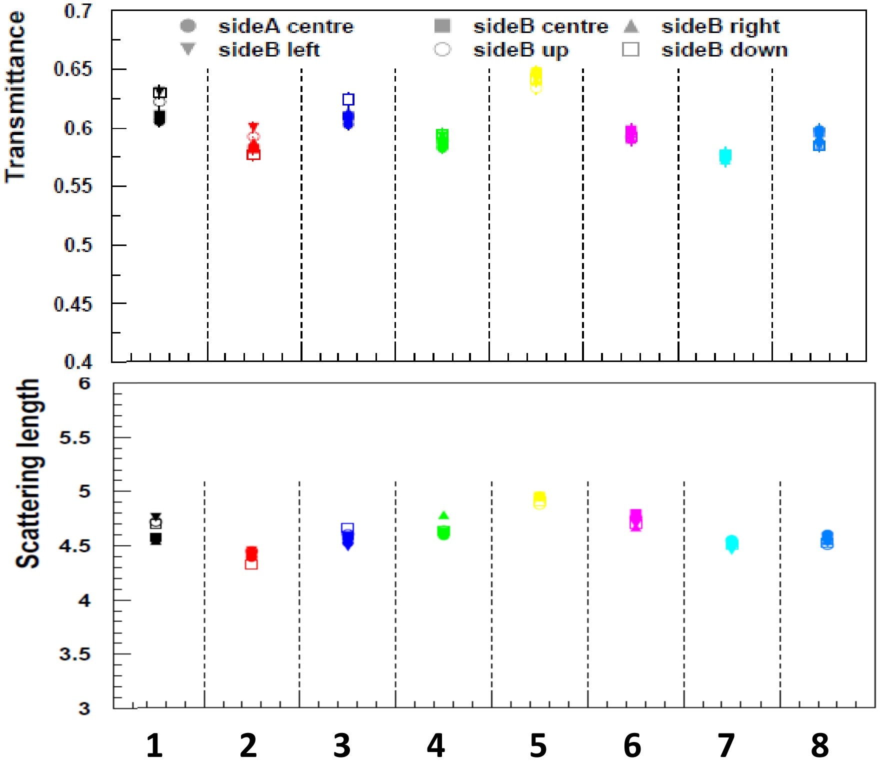
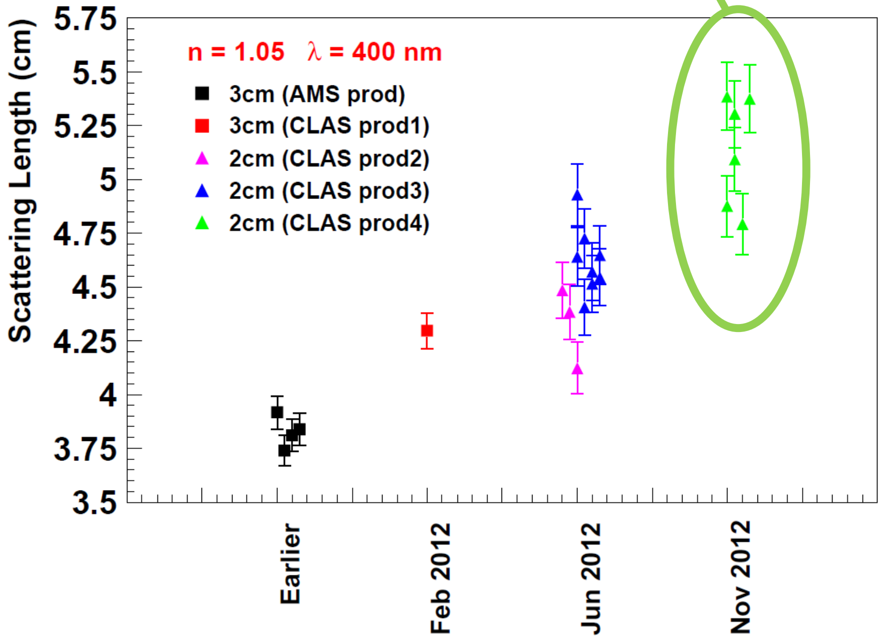


Clarity ~ 0.0050 $\frac{\mu m^4}{cm}$ for n=1.05

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



Novosibirsk Samples 1-8 (1.05 2cm)

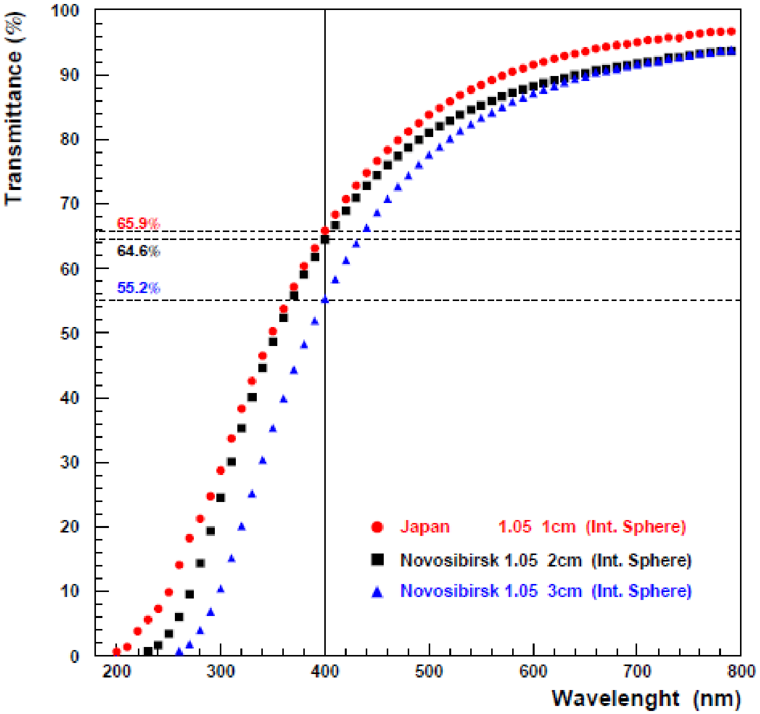


Aerogel quality significantly improved in time following the requirements of the project!

The Matsushita and Aspen aerogel

Matsushita (Japan)

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



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

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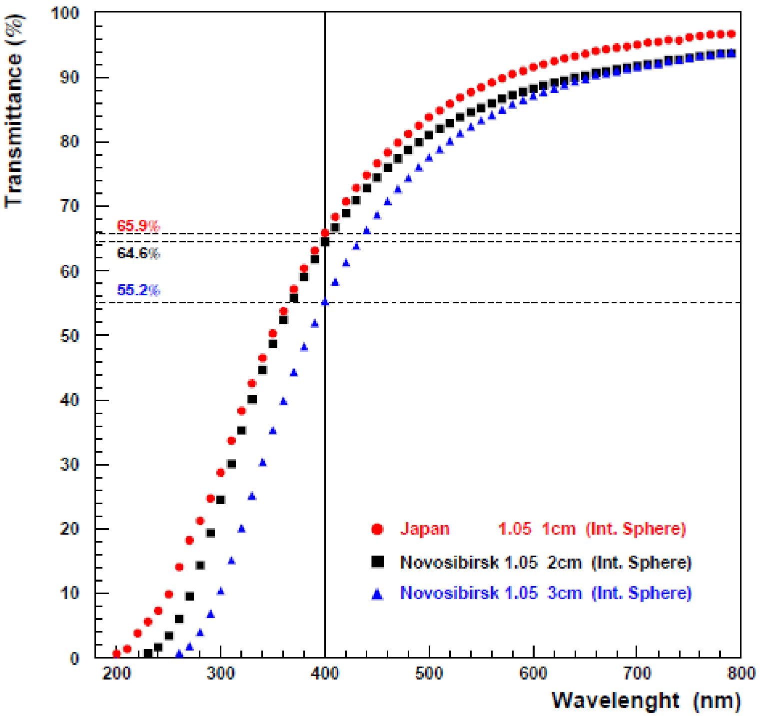
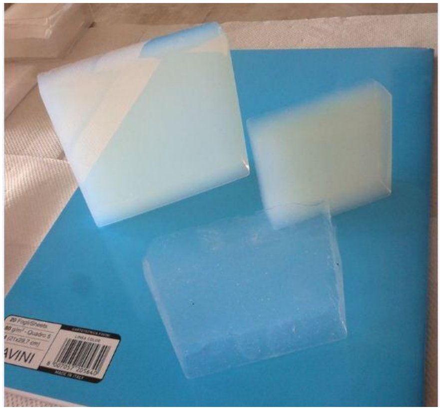
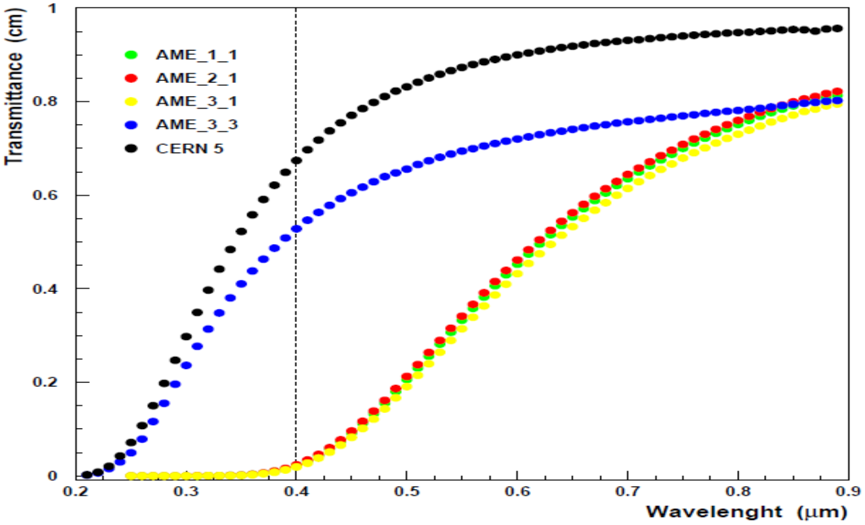


At 400nm 1cm Matsushita has same transmittance than 2cm Novosibirsk

Aspen (US)

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





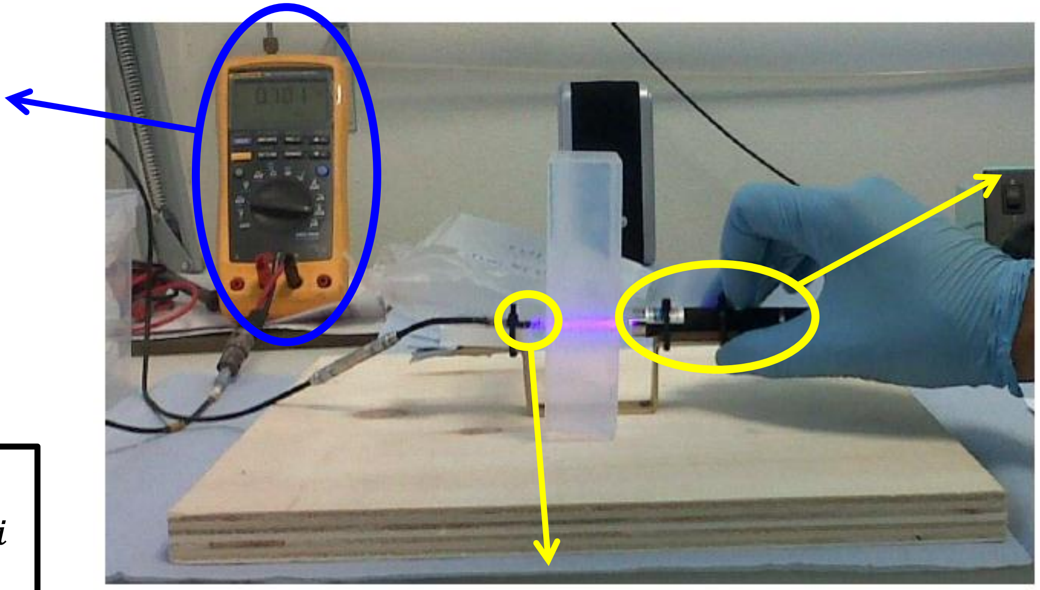
Reasonable transmittance and scattering lenght only for $n = 1.01$

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 preformances ➡ need to periodically monitor the transmittance

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



Multimeter:
reads current

Laser:
blue light (405 nm)

photodiode output in mA

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

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

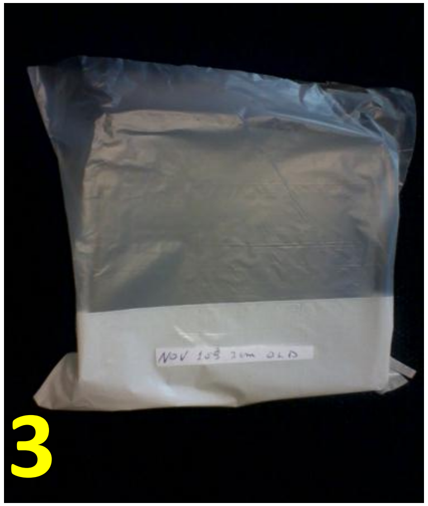
The method is fast (few minutes for each set of 10 measurements) but introduces several systematic effects (laser-photodiode distance, aerogel local non-homogeneities, laser instabilities) that result in a broadening of the measured transmittance.

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

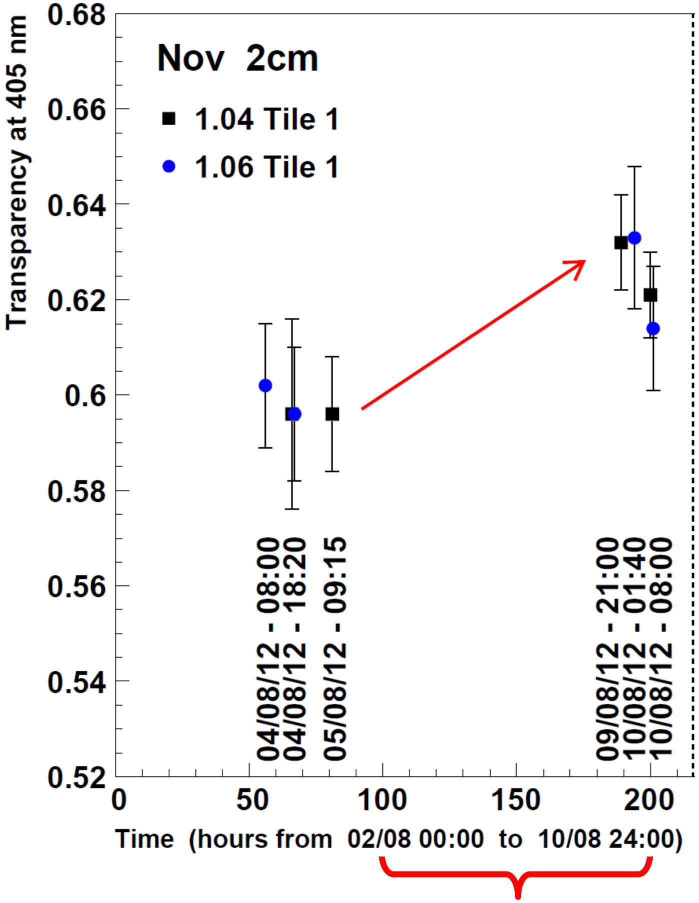
Restoring/preserving the transparency

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



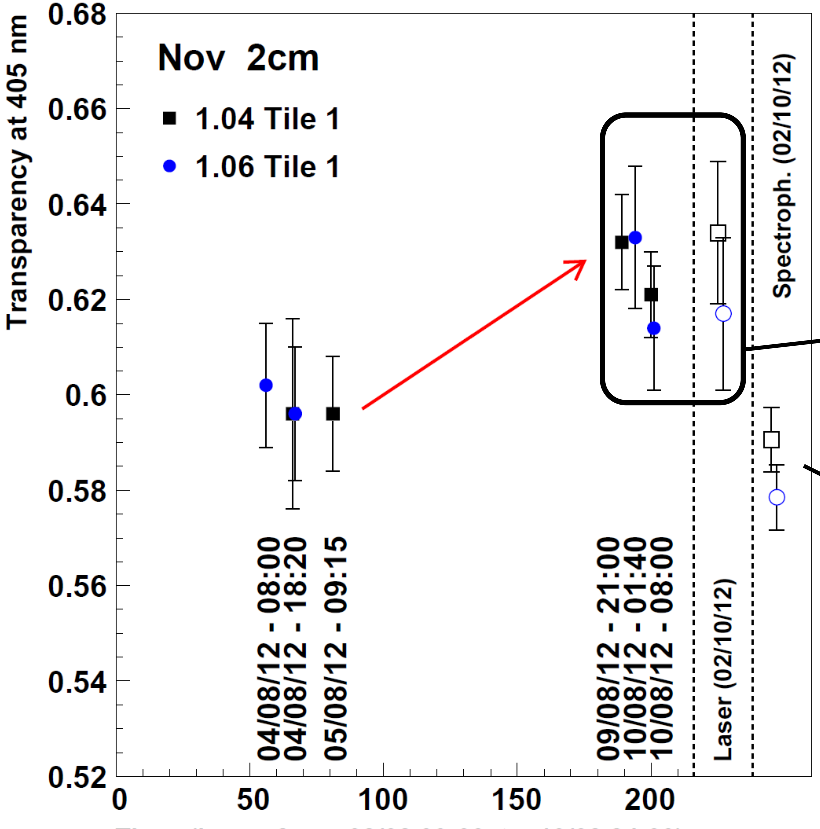
Some results



108 h **Storage in box with nitrogen**

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

Some results



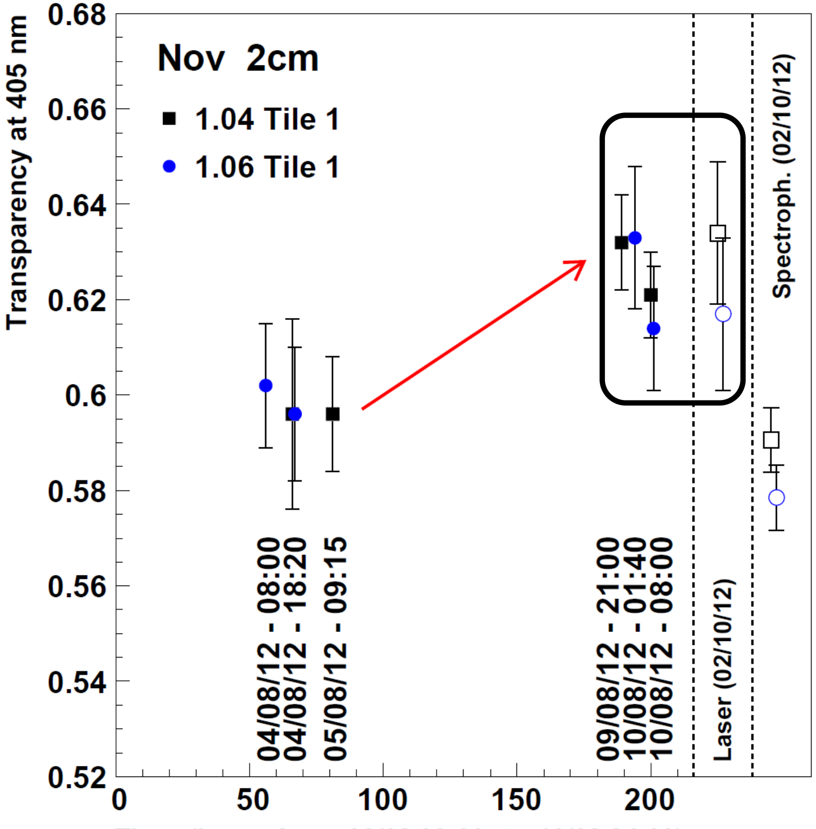
stability over time
(2 months sealed in plastic bag)

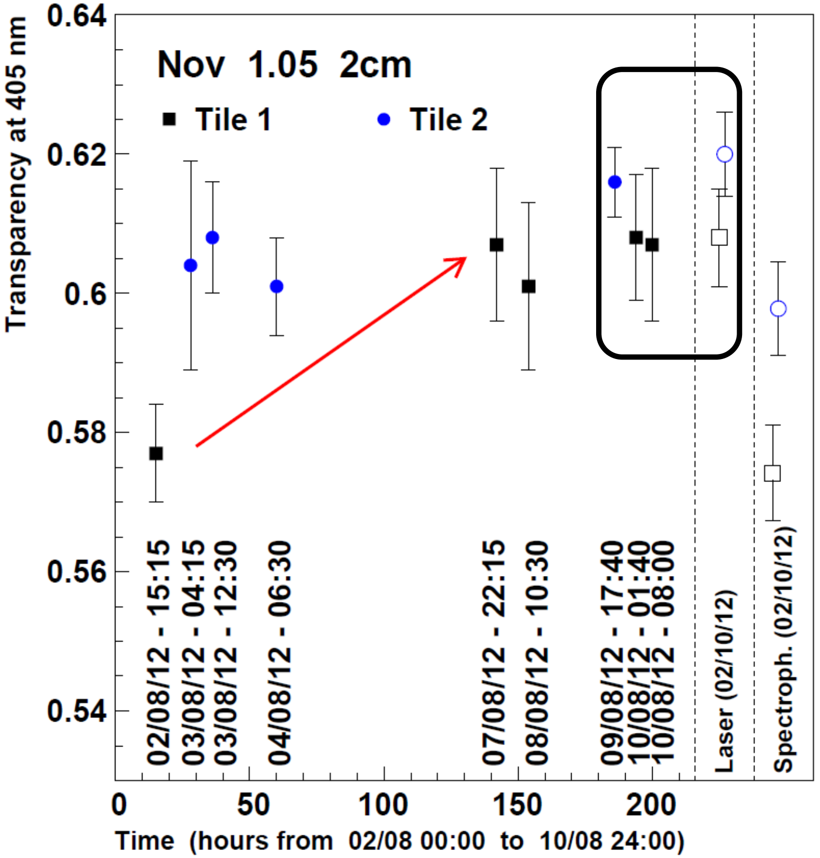
spectrophotometer measurements
(more reliable) systematically smaller.

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

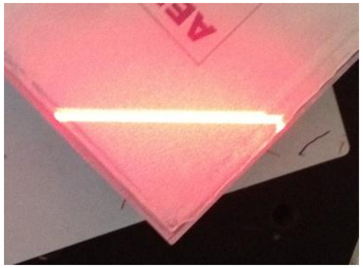
- Evidence of partial transmittance restoration after at least 60 hours of storage in dry (nitrogen) atmosphere
- Sealing the tiles in plastic bags preserves the transmittance over long periods
- Smaller values measured with spectrophot. indicate systematic effects in laser meas.

Part 4
Measures of chromatic dispersion

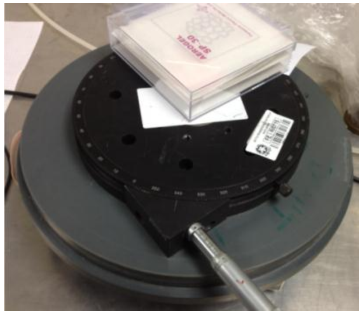
Main motivation: From MC simulations the chromatic error is expected to be among the largest contribution s to the final uncertainty on the Cherenkov angle.

The “standard prism” method

- The adjacent edges of the aerogel tile form a prism

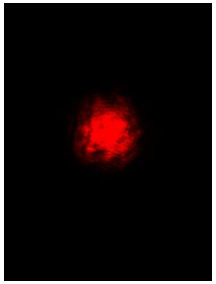


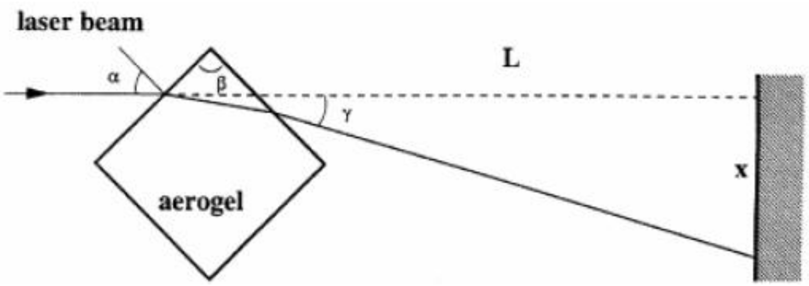
- The tile is placed on a graduated rotating stage



- 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 pleaced downstream

1280 × 1024 pxls



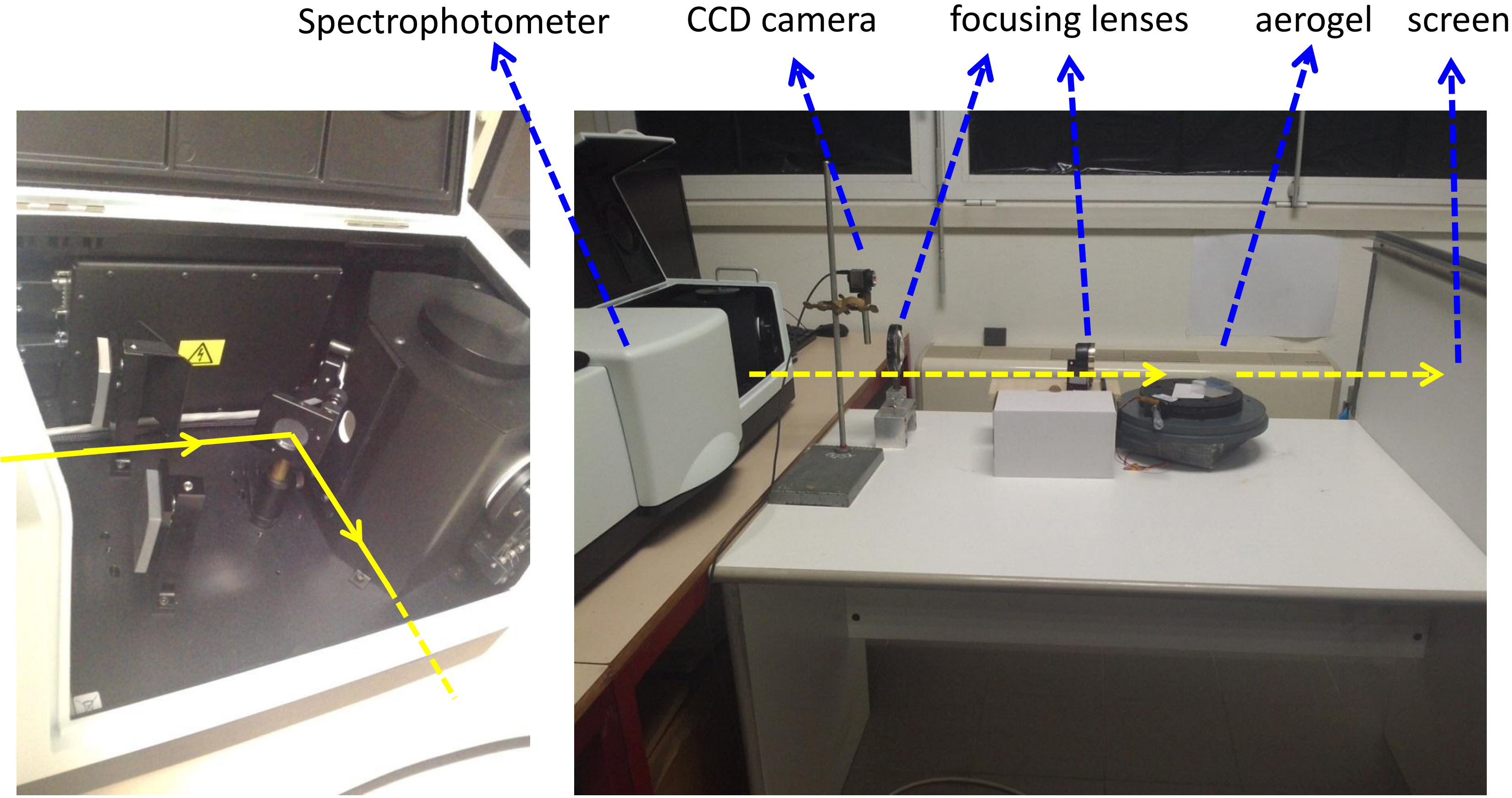


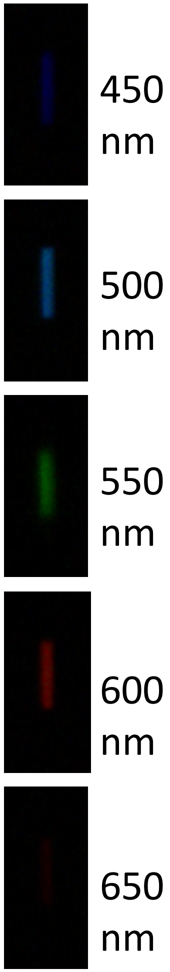
- The aerogel refractive index *n* can be determined by fitting the angular distribution of the spots of the refracted beam with the **Snell-Descartes law:**

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

The setup

beam extracted from spectrophotometer





Advantages:

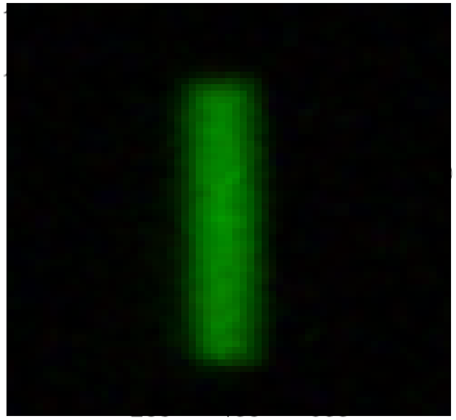
- Can use any wavelength in range $450 - 650$ nm
- Alignment is same for all wavelengths
- Dispersion law well constrained (many points)

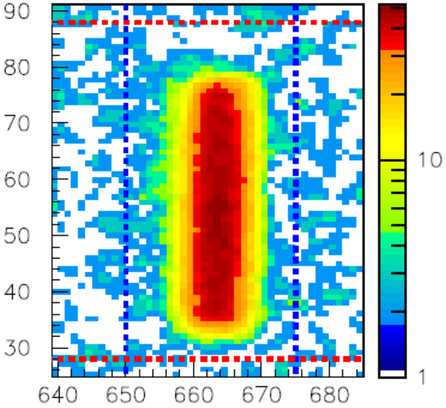
Disadvantages:

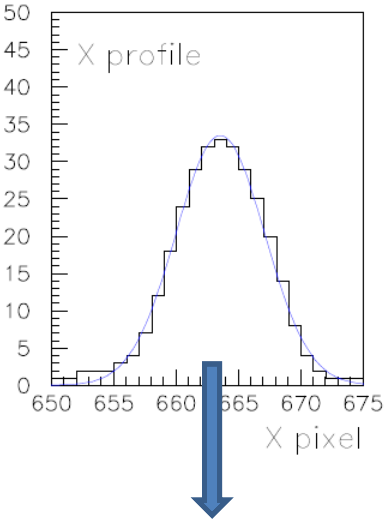
- Beam intensity is low
- Spots are weak
- Cannot measure below 450 nm (spot too weak)

Analysis of the spots

550nm No aerogel (reference)



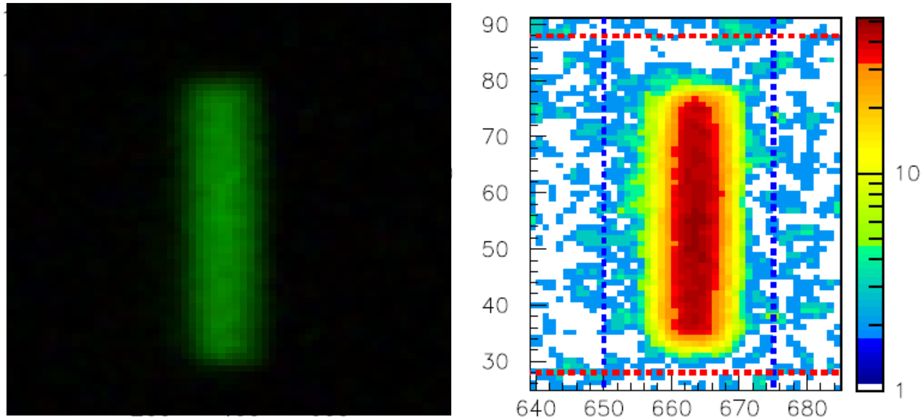




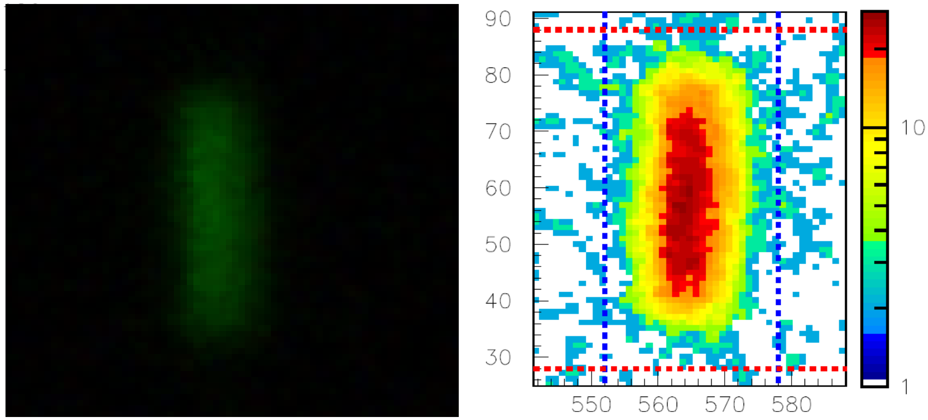
centroid gives the **reference position**

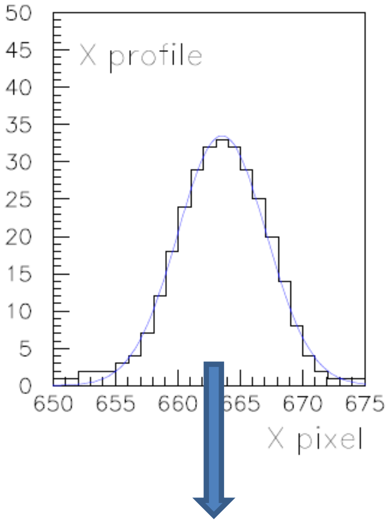
Analysis of the spots

550nm No aerogel (reference)

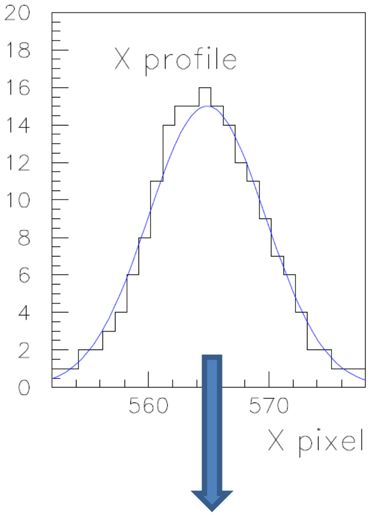


550nm with aerogel (minimum position)





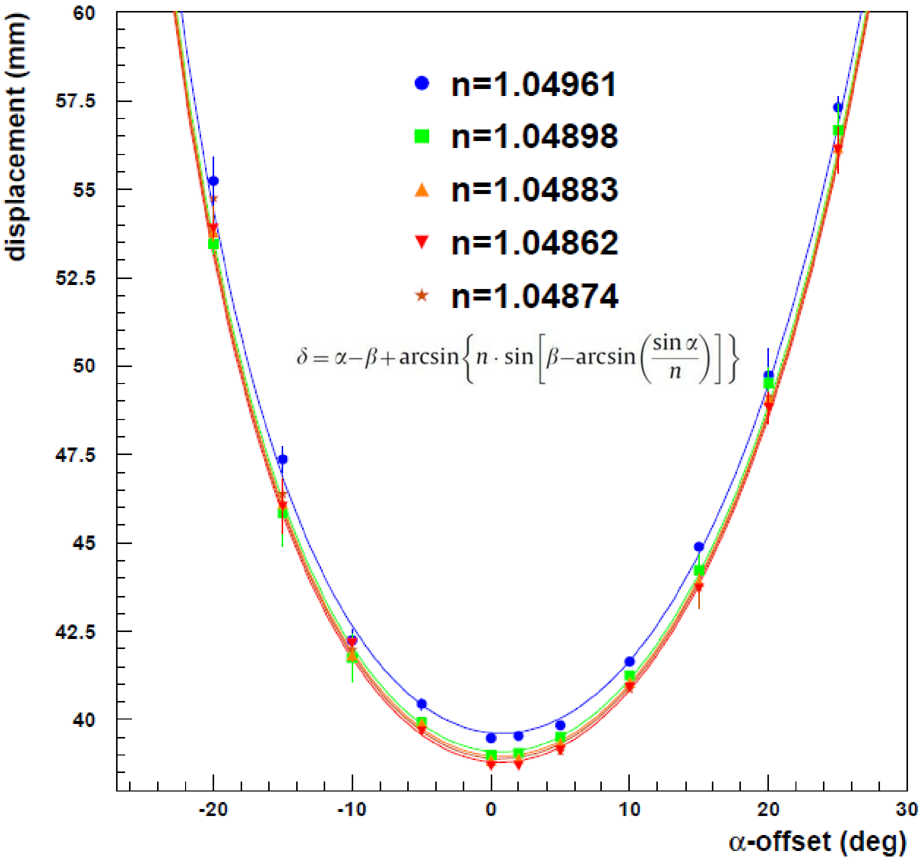
centroid gives the
reference position



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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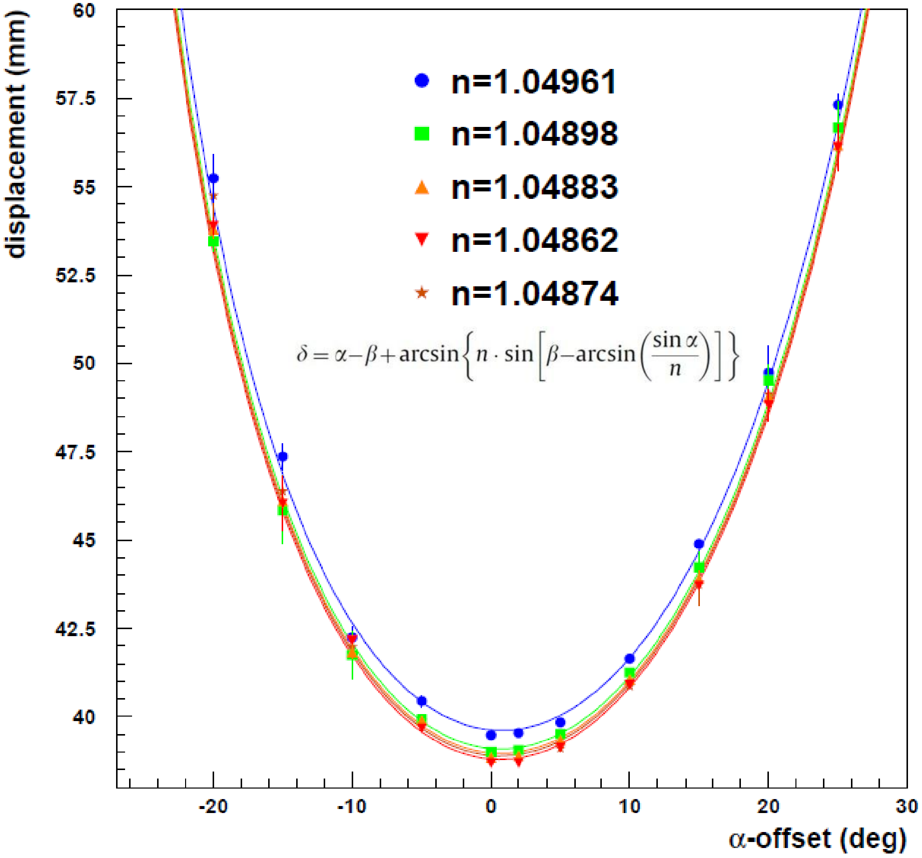
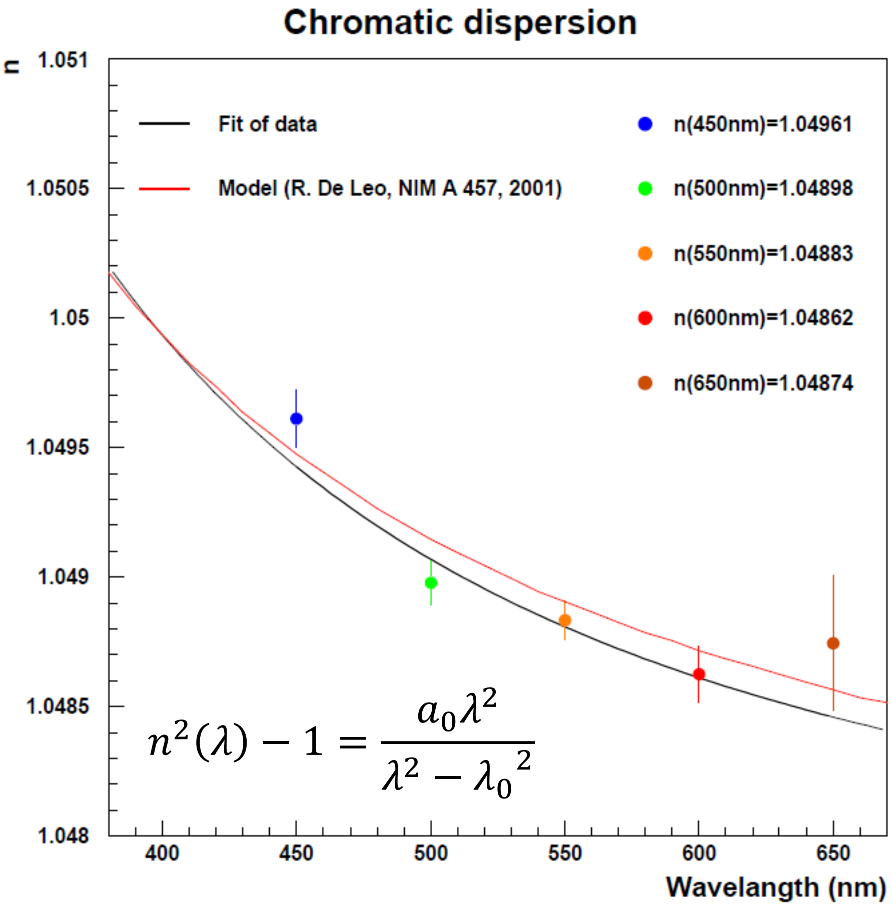
2. The position of the centroids is extracted from the analysis of the spot images
3. The five refractive indices are extracted fitting the displacements with **Snell-Descarted law**
4. **Chromatic dispersion** extracted by fitting $n(\lambda)$ with the **dispersion law**





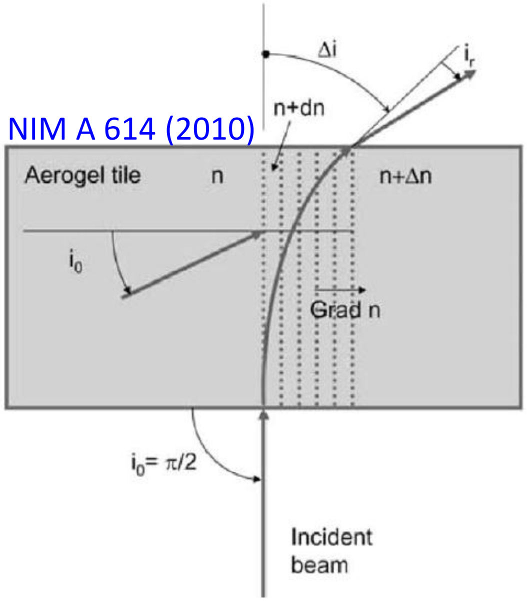
Part 5
Refractive index uniformity
(“gradient method”)

- The prism method allows measuring n only at the tile edges
- n che vary significanlt 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 countinuous refraction effect
- The deflection of the beam observed in different points of the tile can be related to local transverse gradients of n


NIM A 614 (2010)

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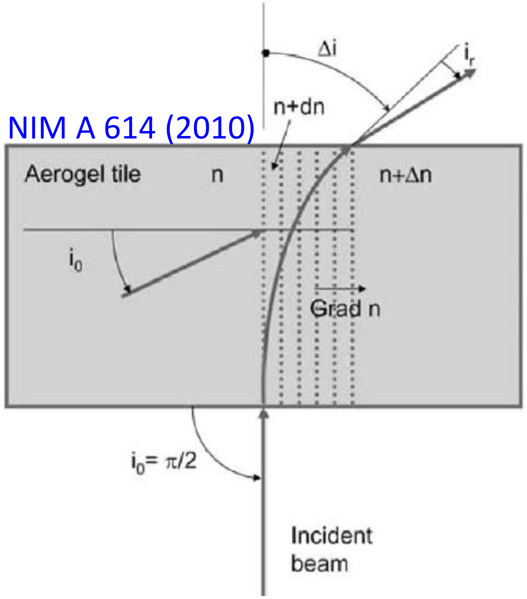
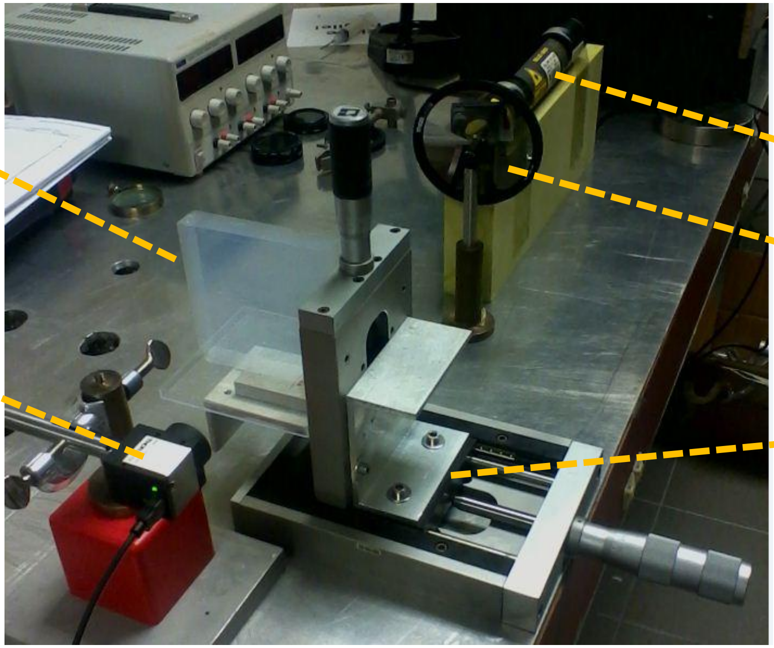
NIM A 614 (2010)



Setup (preliminary test)



aerogel

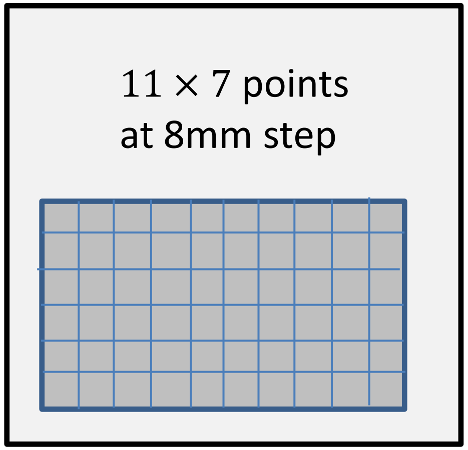
CCD camera

red laser

attenuator

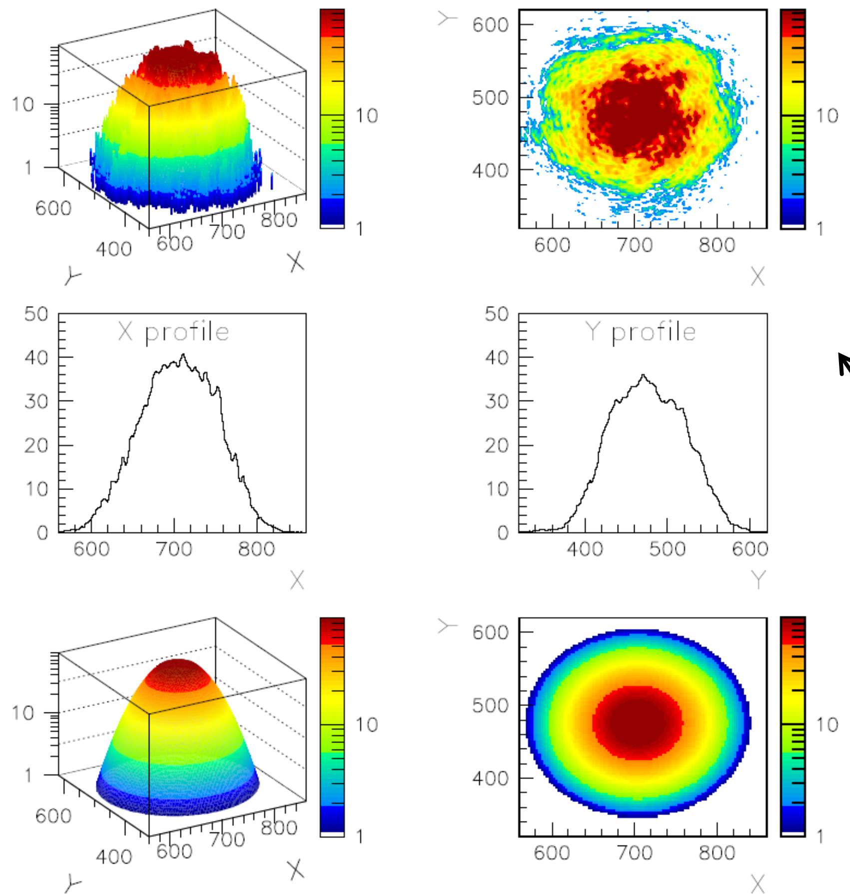
tool for micrometric movements

$115 \times 115 \times 20\ mm^3$

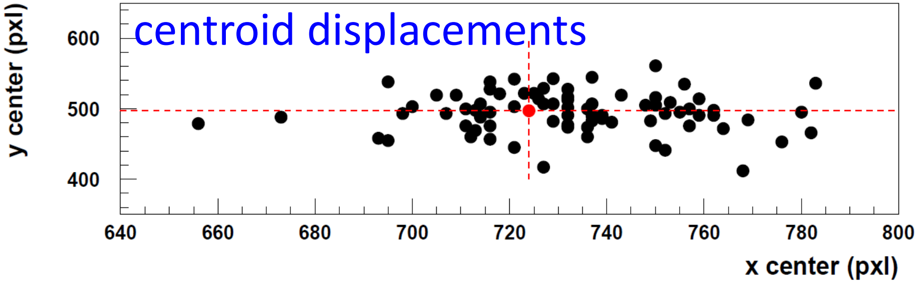


11 × 7 points
at 8mm step

The gradient method



2D Gaussian fit to extract position of centroid



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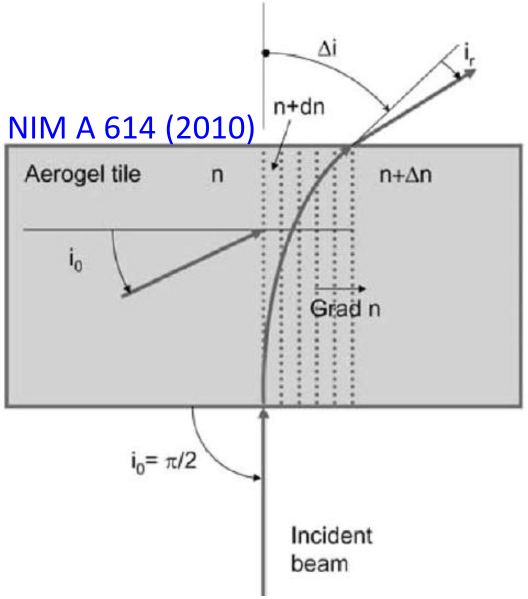
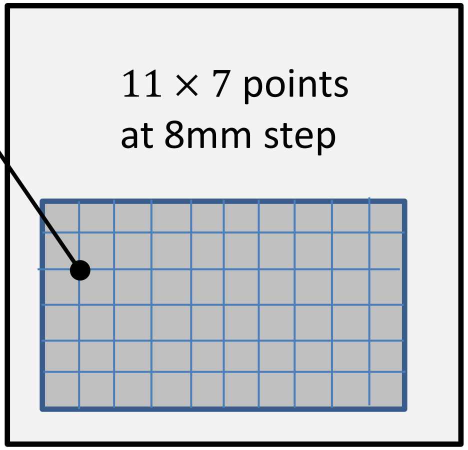


$115 \times 115 \times 20\ mm^3$



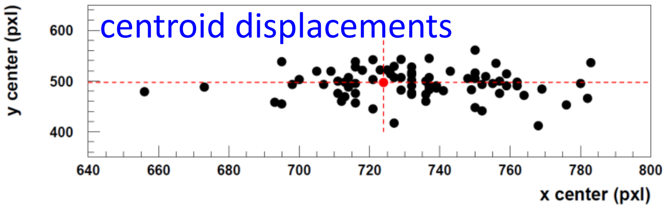
11×7 points
at 8mm step

The gradient method

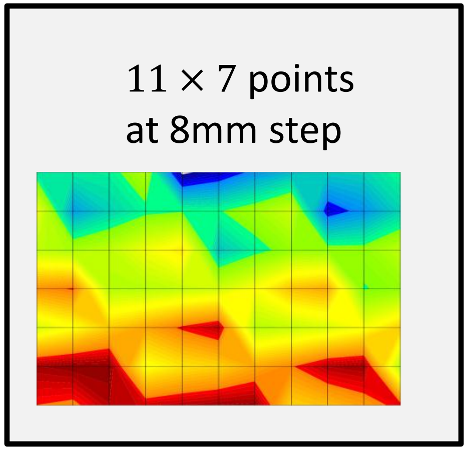
1) assume Snell law for adjacent aerogel layers

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

2) extract Δn along x and y from measured displacements


centroid displacements

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


11 × 7 points
at 8mm step

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

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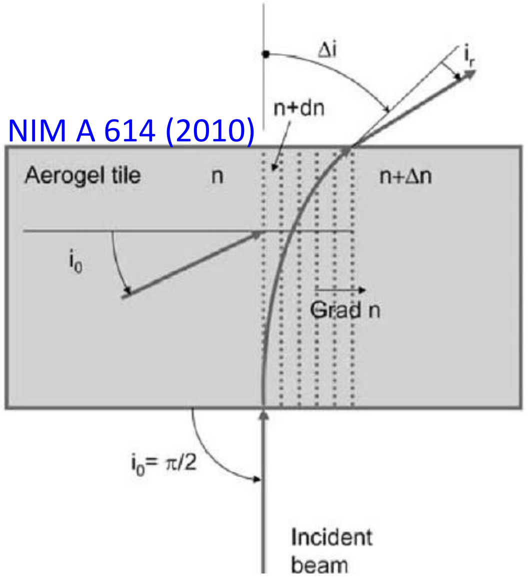

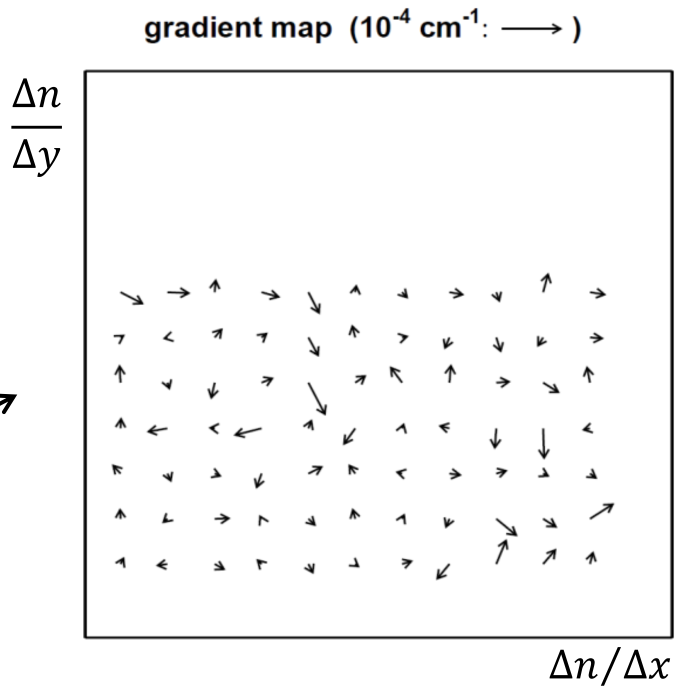
gradient map (10^{-4} cm^{-1}: ⟶)

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:

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

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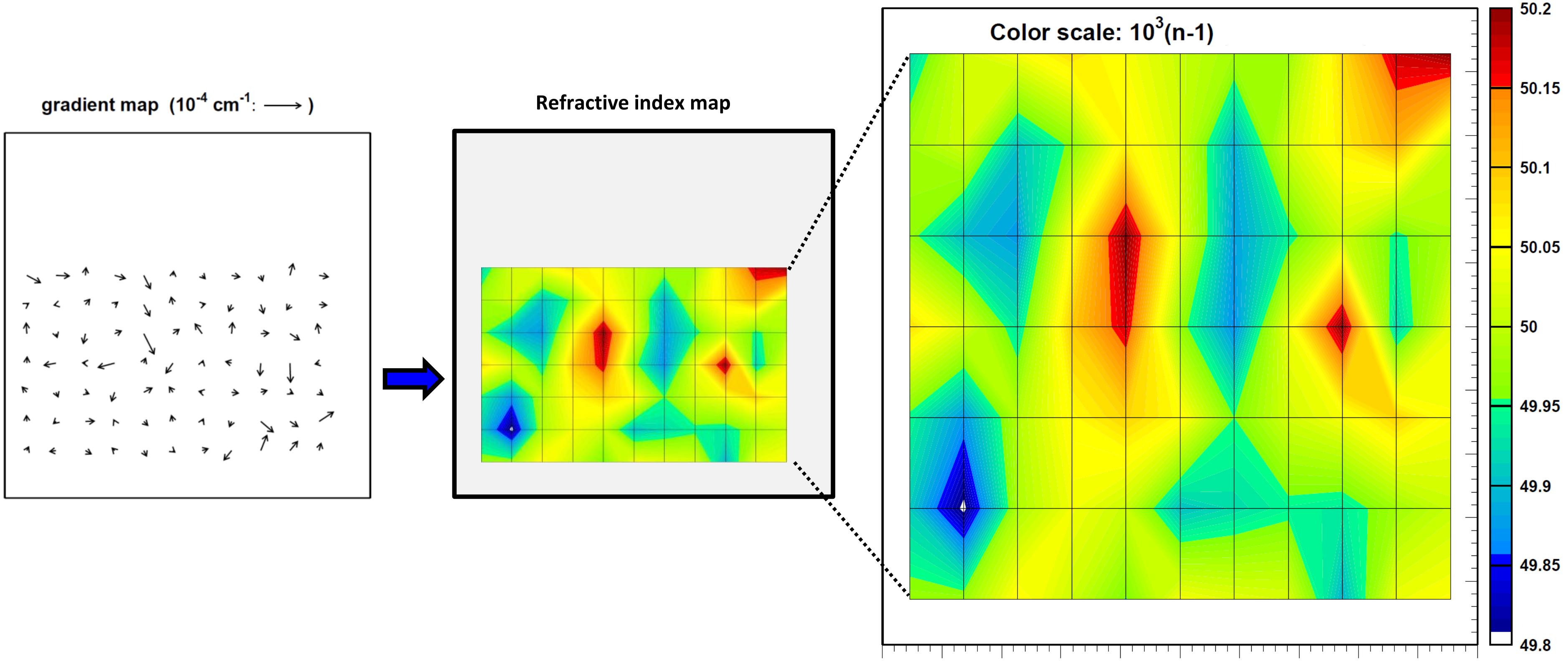
[NIM A 614 (2010)]


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

Refractive index map

Color scale: $10^3(n-1)$

$$\boxed{\delta n \sim 4 \cdot 10^{-4}}$$

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 prims 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

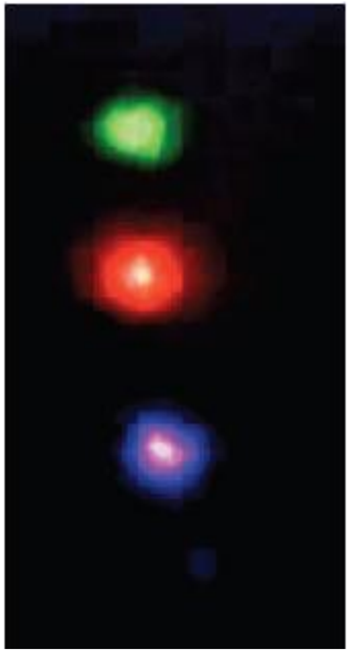
The aerogel tiles for the CLAS12 RICH:

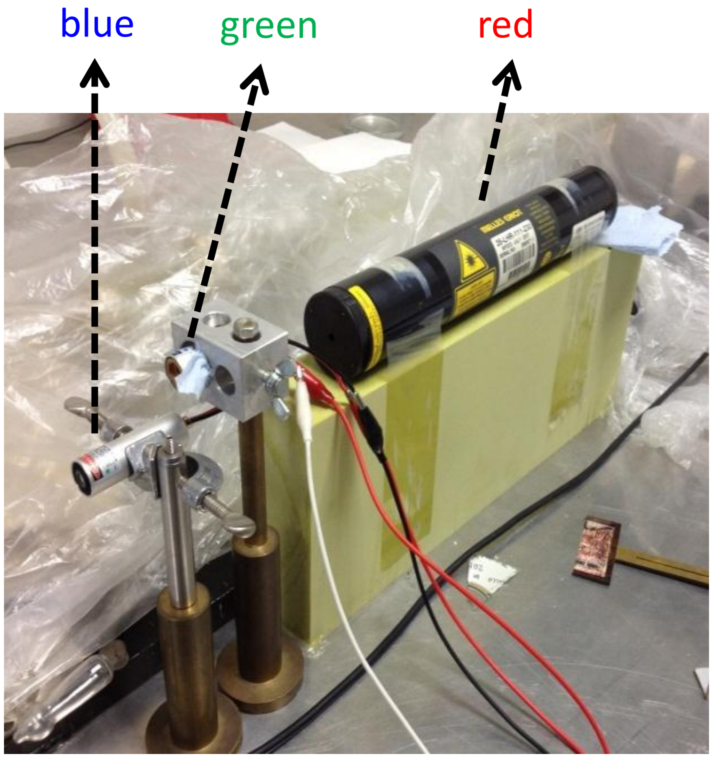
- **Size**: $20 \times 20 \times 2\ (3)\ \ cm^3$
- **Refractive index**: 1.05
- **Clarity parameter**: $\leq 0.0050\ \ \mu m^4/cm$
- **Manufacturer**: Novosibirsk (best quality, reliability and experience (AMS,LHCb))

Backup

The original setup

3 lasers: red (λ=632.8 nm), green (λ=532 nm), blue (λ=405 nm)





Advantages:

- beams are intense and narrow
- spots well visible also at large angles
- blue laser correspond to wavelenght 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