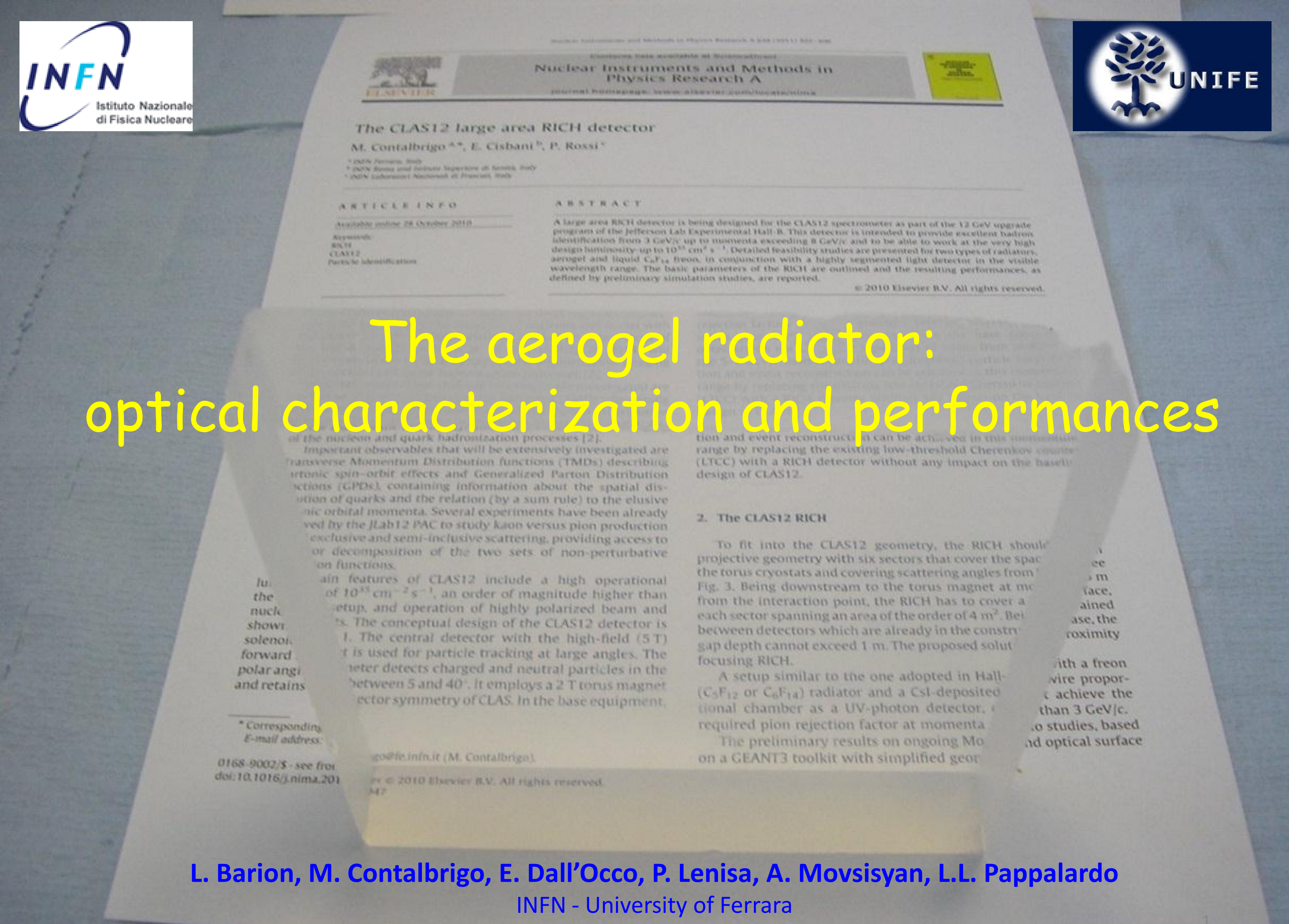


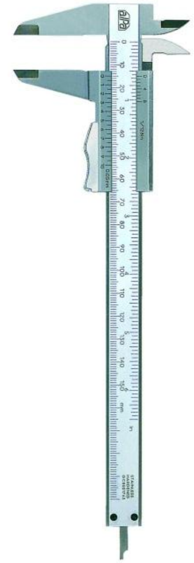
The aerogel radiator: optical characterization and performances

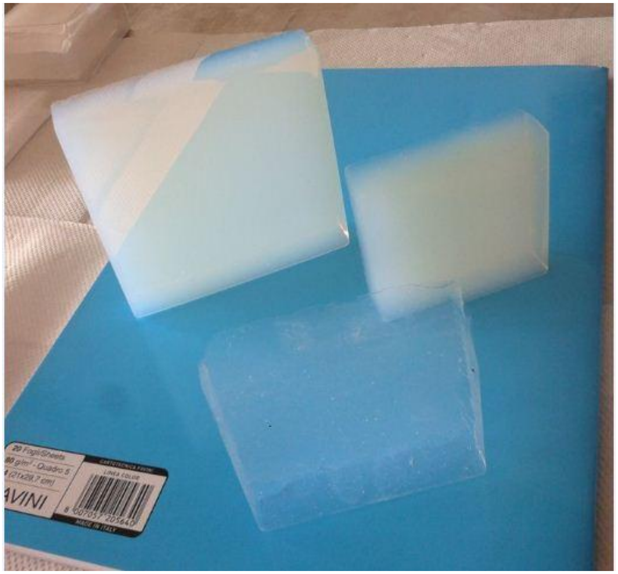
L. Barion, M. Contalbrigo, E. Dall'Occo, P. Lenisa, A. Movsisyan, L.L. Pappalardo

INFN - University of Ferrara

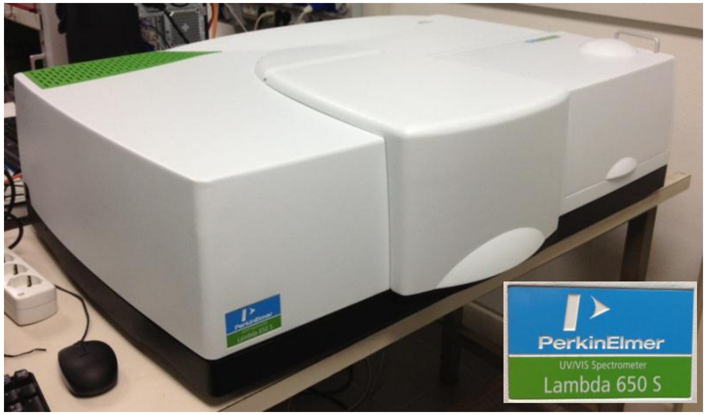
Characterization of aerogel tiles

- Geometry (area, thickness) →
- refractive index
- Transmittance
- Absorption length
- Scattering length

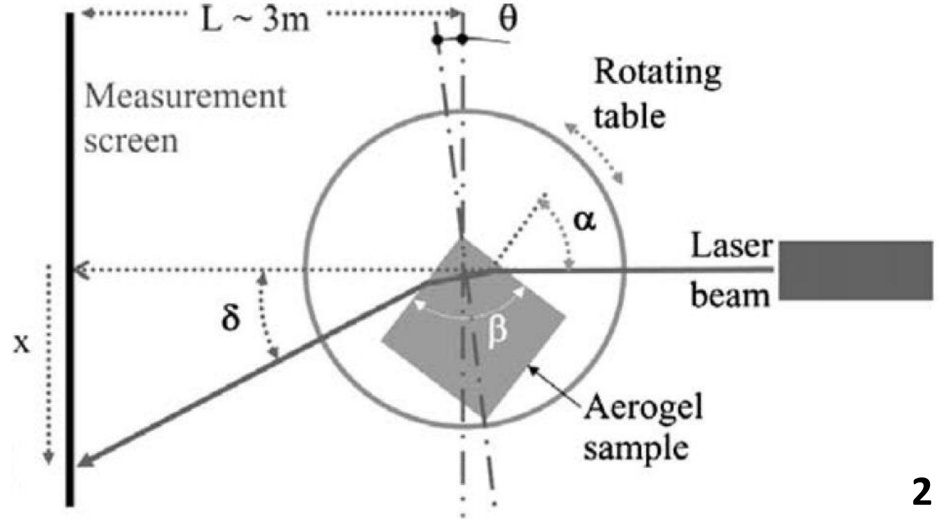




spectrophotometer



prism method



The tiles analyzed

Manufacturer	Name	date	n	thickness (cm)	area (cm × cm)
Matsushita (Japan)	Jap 1.03 Tiles1-3	<2012	1.03	1.0	10×10
Matsushita	Jap 1.05 Tiles1-3	<2012	1.05	1.0	10×10
Novosibirsk (Russia)	Nov 1.04 2cm Tiles1-4	Jun 2012	1.04	2.0	6×6
Novosibirsk	Nov 1.05 2cm Tiles1-4	Jun 2012	1.05	2.0	6×6
Novosibirsk	Nov 1.06 2cm Tiles1-4	Jun 2012	1.06	2.0	6×6
Novosibirsk	Nov 1.05 3cm Tiles1-4	Jun 2012	1.05	3.0	6×6
Novosibirsk	Nov 1.06 3cm Tiles1-4	Jun 2012	1.06	3.0	6×6
Novosibirsk	Nov 1.05 Samples1-8	Jun 2012	1.05	2.0	10×10
Novosibirsk	Nov 1.05 Cern1-5	Dec 2012	1.05	2.0	10×10
Novosibirsk	Nov 1.05 Cern6 Tiles1-4	Dec 2012	1.05	2.0	6×6
Novosibirsk	Nov 1.05 AMS 1-4	<2012	1.05	3.0	10×10
Novosibirsk	Nov 1.05 1cm Old	Feb 2102	1.05	1.0	10×10
Novosibirsk	Nov 1.05 2cm Old	Feb 2012	1.05	2.0	10×10
Novosibirsk	Nov 1.05 3cm Old	Feb 2012	1.05	3.0	10×10
Aspen (USA)	AME_1_1 & AME_2_1	Nov 2012	1.05	1.7	9.5×9.5
Aspen	AME_3_1_A	Nov 2012	1.05	1.7	6.5×6.5
Aspen	AME_3_3	Nov 2012	1.01	1.7	6.5×6.5

- **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** $(6 \times 6\ cm^2, 10 \times 10\ cm^2, 9.5 \times 9.5\ cm^2, 6.5 \times 6.5\ cm^2)$

Part 1
Measuring Transmittance, scattering and absorption length

Basic formalism and selected results

Transmittance

Hunt formula

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

Clarity parameter

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

Transflectance

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

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

Basic formalism and selected results

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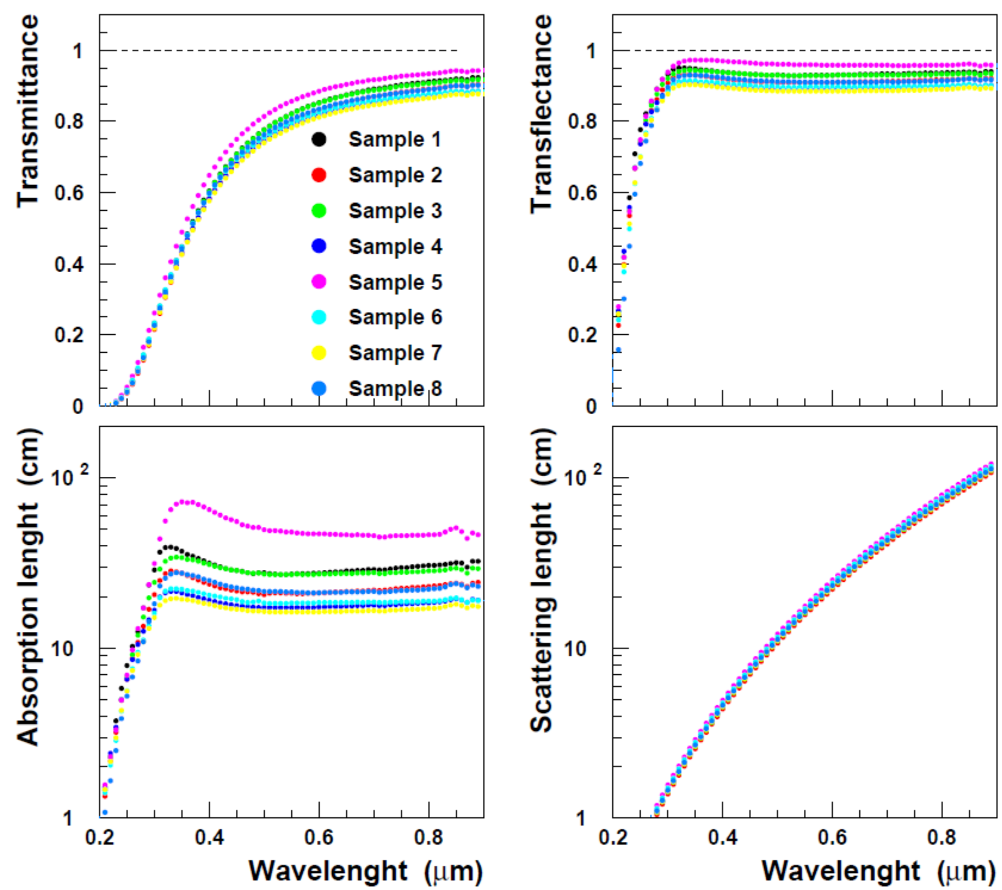
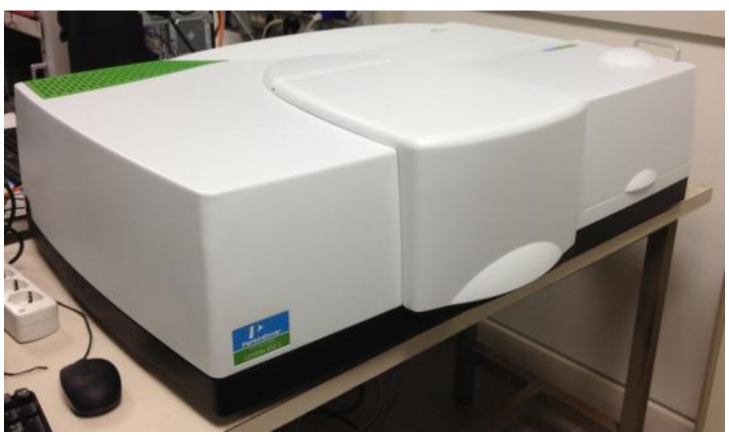
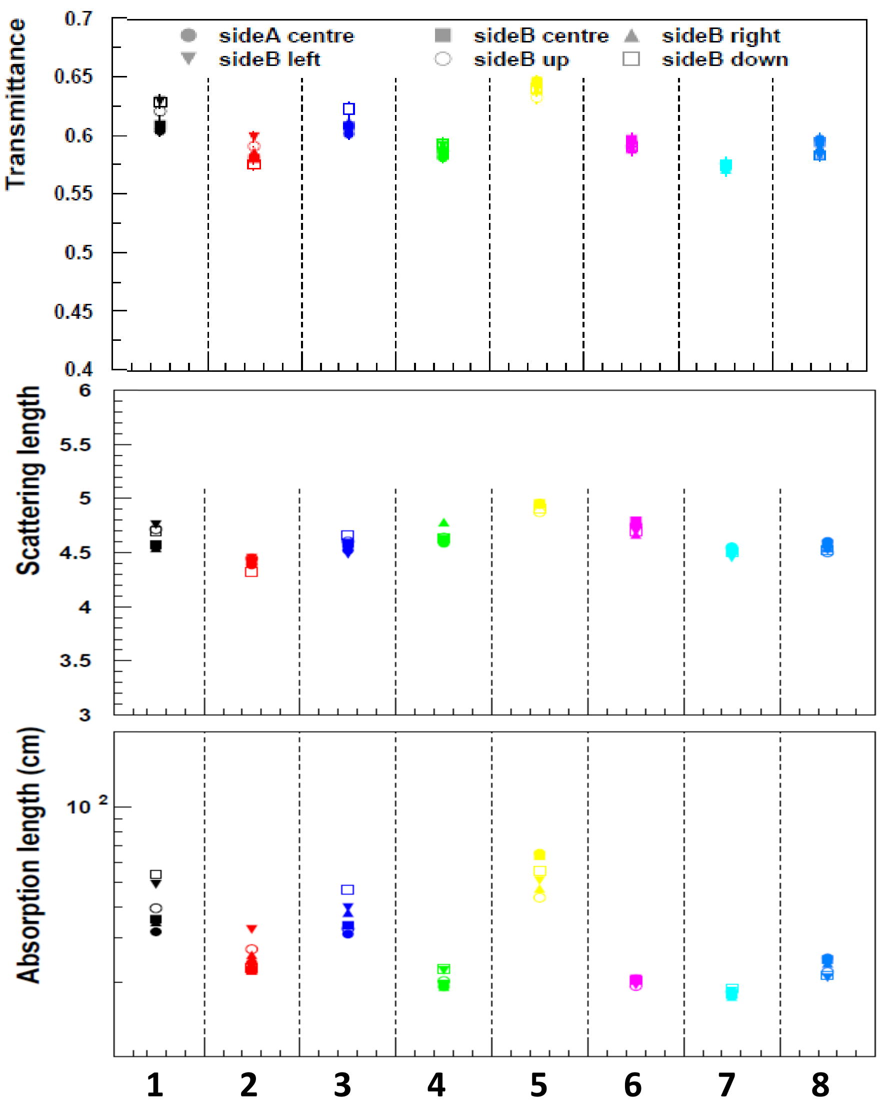
Novosibirsk Samples 1-8 (1.05)

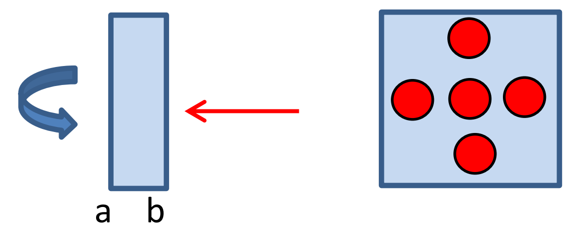




Measurements at 400nm

For each tile, the measurements were repeated by “illuminating” 6 different positions



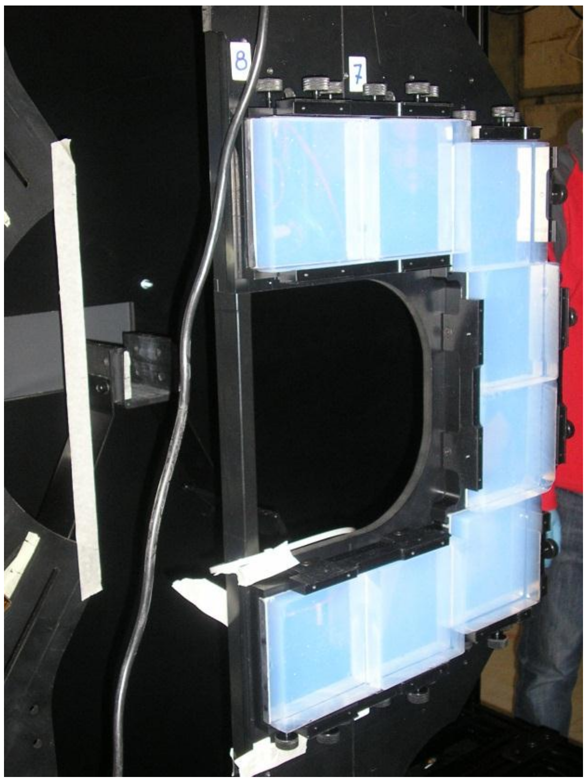


Novosibirsk Samples 1-8 (1.05)

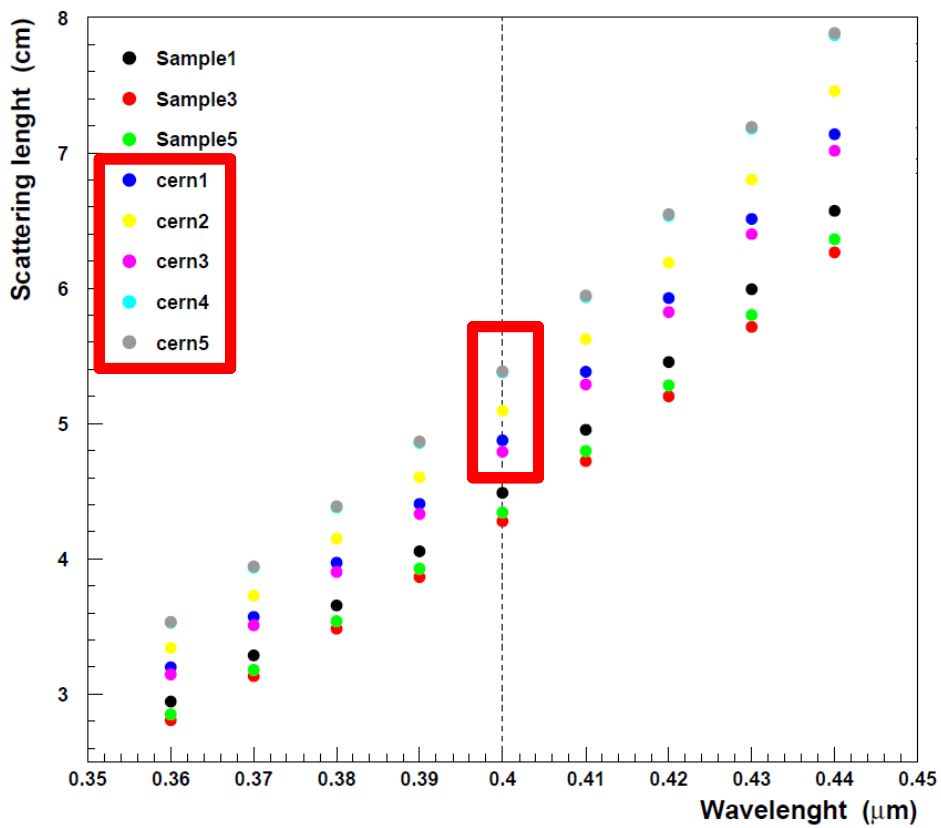
tile	$\langle T \rangle$	Λ_A (cm)	Λ_S (cm)
1	0.618 ± 0.011	40.8 ± 8.8	4.6 ± 0.1
2	0.587 ± 0.008	25.7 ± 3.8	4.4 ± 0.1
3	0.611 ± 0.007	37.0 ± 5.8	4.6 ± 0.1
4	0.589 ± 0.005	20.4 ± 1.5	4.6 ± 0.1
5	0.642 ± 0.005	54.4 ± 8.9	4.9 ± 0.1
6	0.593 ± 0.003	20.1 ± 0.6	4.7 ± 0.1
7	0.575 ± 0.002	18.1 ± 0.5	4.5 ± 0.1
8	0.590 ± 0.006	22.9 ± 1.8	4.5 ± 0.1
Average	$\mathbf{0.601 \pm 0.022}$	$\mathbf{30 \pm 13}$	$\mathbf{4.6 \pm 0.1}$

Improvements in production techniques (Novosibirsk)

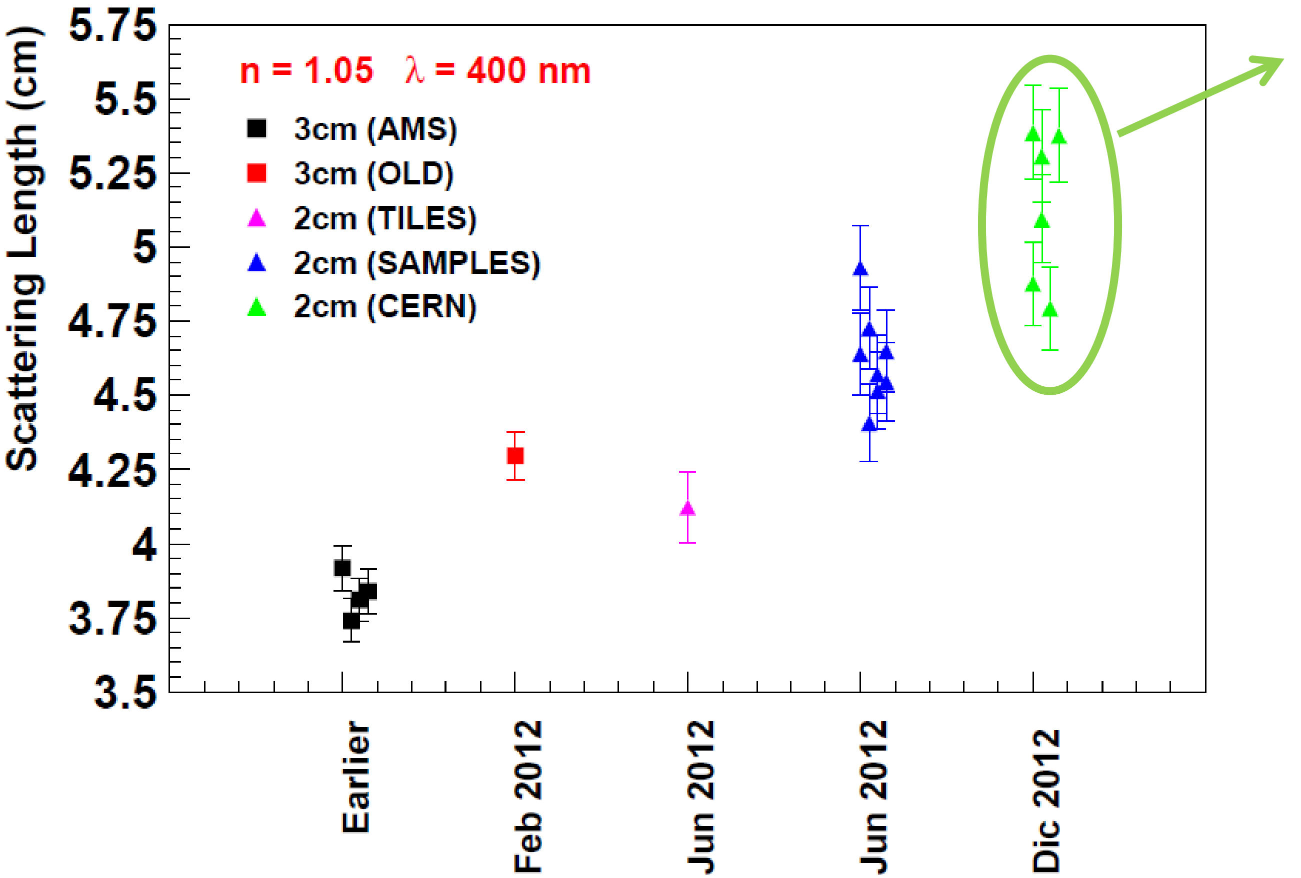
December 2012 test-beam



Name		n	thickness (cm)	area (cm × cm)
Nov 1.05 2cm	cern1	1.05	2	10 × 10
Nov 1.05 2cm	cern2	1.05	2	10 × 10
Nov 1.05 2cm	cern3	1.05	2	10 × 10
Nov 1.05 2cm	cern4	1.05	2	10 × 10
Nov 1.05 2cm	cern5	1.05	2	10 × 10



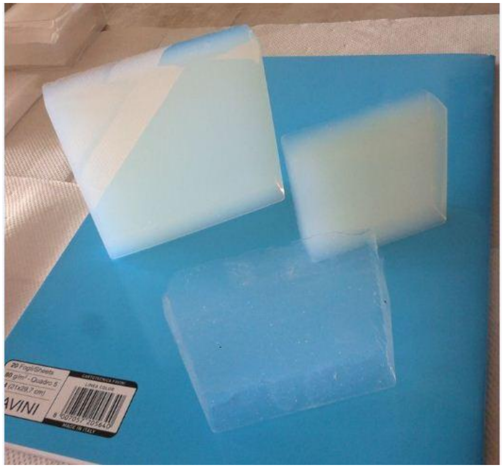
Improvements in production techniques (Novosibirsk)



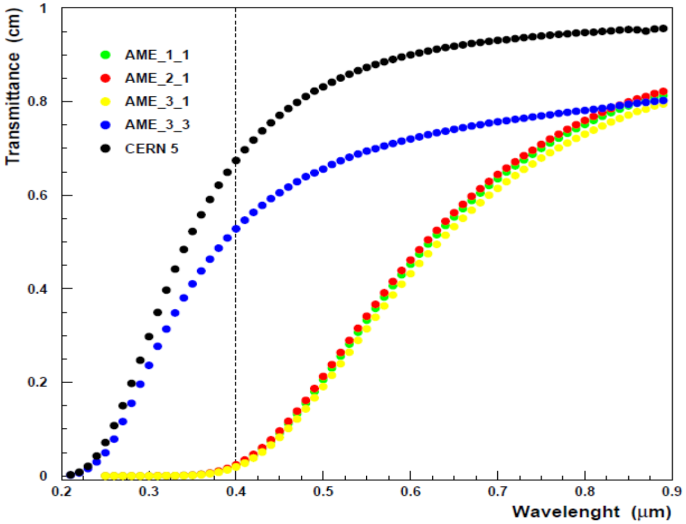
Clarity ~ 0.0050 $\mu m^4/cm$
(LHCb has 0.0064 $\mu m^4/cm$
for n=1.03)

The production technique and the resulting quality of the aerogel has significantly improved in time following the requirements of the project

Optical properties of ASPEN aerogel

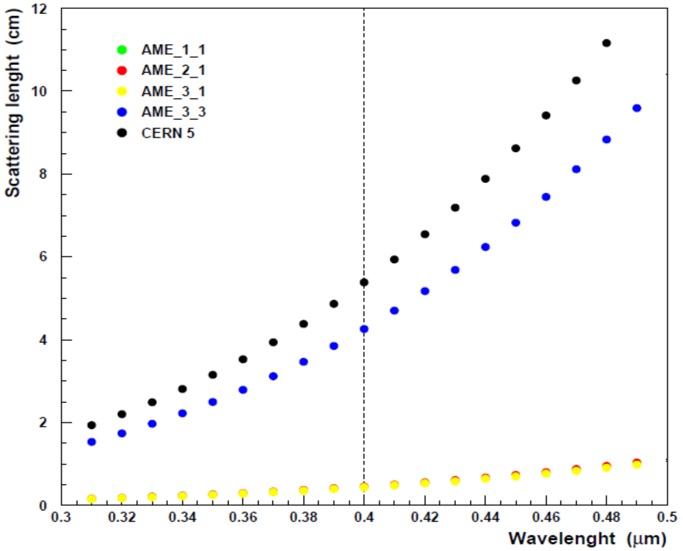


- 10 tiles
- 3 formats:
  large, medium, small
- 2 thickness:
  1.7 cm, 0.95 cm
- 2 refractive indices:
  $n = 1.05$ (9 tiles)
  $n = 1.01$ (1 tile)



@ 400 nm

Name	n	Area (cm^2)	Thick (cm)	T	Λ_A (cm)	Λ_S (cm)
AME_1_1	1.05	9.5x9.5	1.7	2.2 %	26.4	0.4
AME_2_1	1.05	9.5x9.5	1.7	2.4 %	29.7	0.5
AME_3_1_A	1.05	9.5x9.5	1.7	1.9 %	17.9	0.4
AME_3_3	1.01	6.5x6.5	1.7	52.8 %	7.1	4.3
CERN5	1.05	10x10	2.0	67.4 %	85.0	5.4



The only one with reasonable performances has $n = 1.01$

Part 2
Monitoring the aerogel transparency during test beams

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

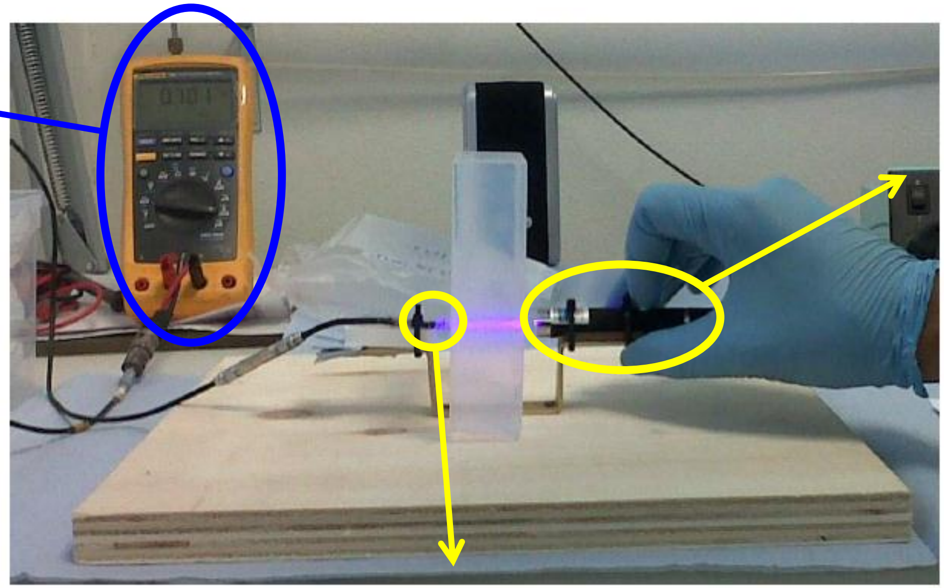
Fast measurements were performed with a very simple set-up:

Multimeter:
reads current

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

⬇

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



Laser:
blue light (405 nm)

photodiode output in mA

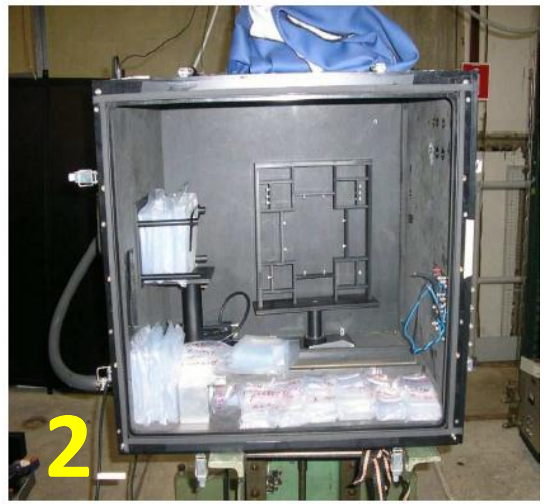
The method is fast (few minutes for each set of 10 measurements) but introduces several systematic effects (laser-photodiode distance, aerogel local non-homogeneities, laser instabilities) that result in a broadening of the measured transmittance.

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

Restoring/preserving the transparency

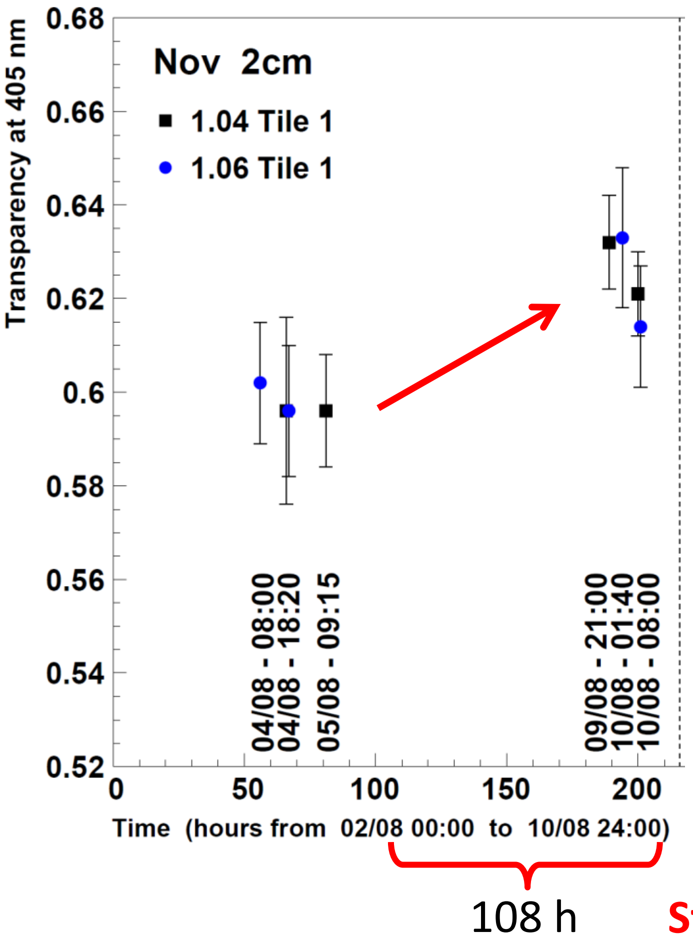
Several methods were tested to preserve/restore the transparency after exposure to air

1. Storing tiles in a dry cabinet (Ferrara)
2. Storing tiles in a box fluxed with nitrogen (August test-beam)
3. Baking tiles at few hundreds (celsius) degrees for a few hours



We experienced that the transparency is approximately preserved if the tile is sealed within a small plastic bag.
(December test-beam)

Some results



Storage in box with nitrogen

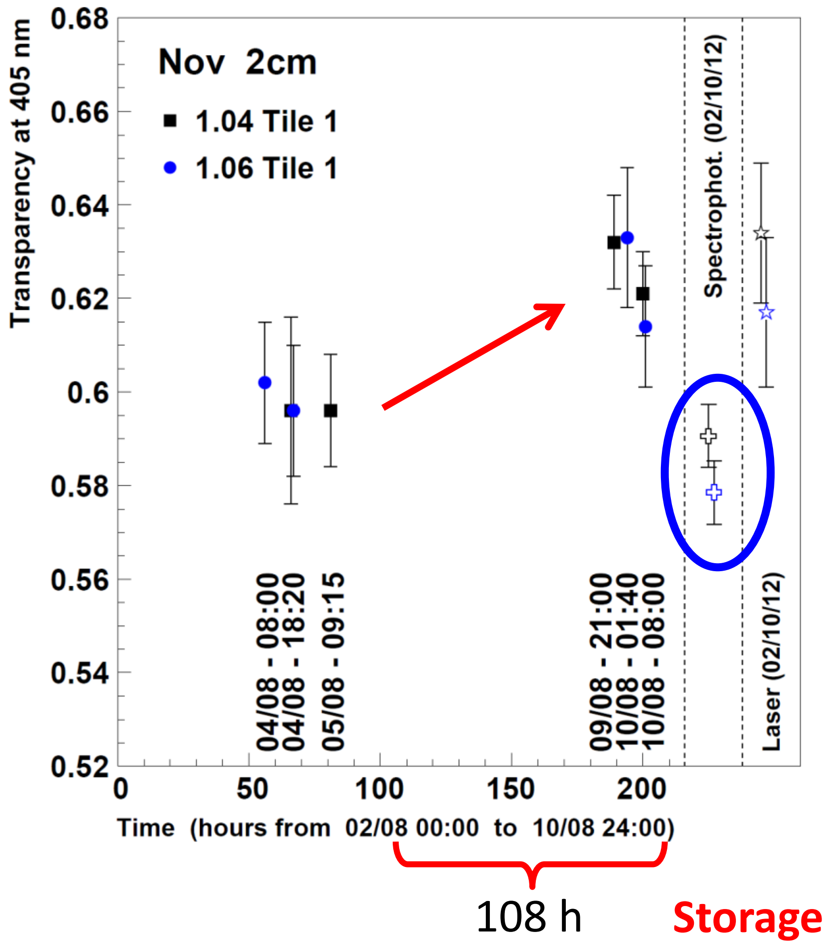
Table 2: Nov. 1.04 2cm tile1

Date/time of meas.	T_{min}	T_{max}	$T_{average}$	ΔT	notes
04/08/2012 18:20	0.570	0.638	0.596	0.020	meas. before SiMP run 390
05/08/2012 09:15	0.580	0.611	0.596	0.012	meas. after SiMP run 390
09/08/2012 21:00	0.614	0.648	0.632	0.010	meas. before SiMP run 432
10/08/2012 08:00	0.608	0.637	0.621	0.009	meas. before final packing

Table 3: Nov. 1.06 2cm tile1

Date/time of meas.	T_{min}	T_{max}	$T_{average}$	ΔT	notes
04/08/2012 08:00	0.584	0.619	0.602	0.013	meas. before SiMP run 383
04/08/2012 18:20	0.575	0.622	0.596	0.014	meas. after SiMP run 389
10/08/2012 01:40	0.615	0.657	0.633	0.015	meas. before SiMP run 439
10/08/2012 08:00	0.597	0.639	0.614	0.013	meas. before final packing

Some results



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02/10/2012	0.608	0.654	0.634	0.015	meas. in Ferrara (laser)
02/10/2012			0.591	0.007	meas. in Ferrara (spectrophot.)

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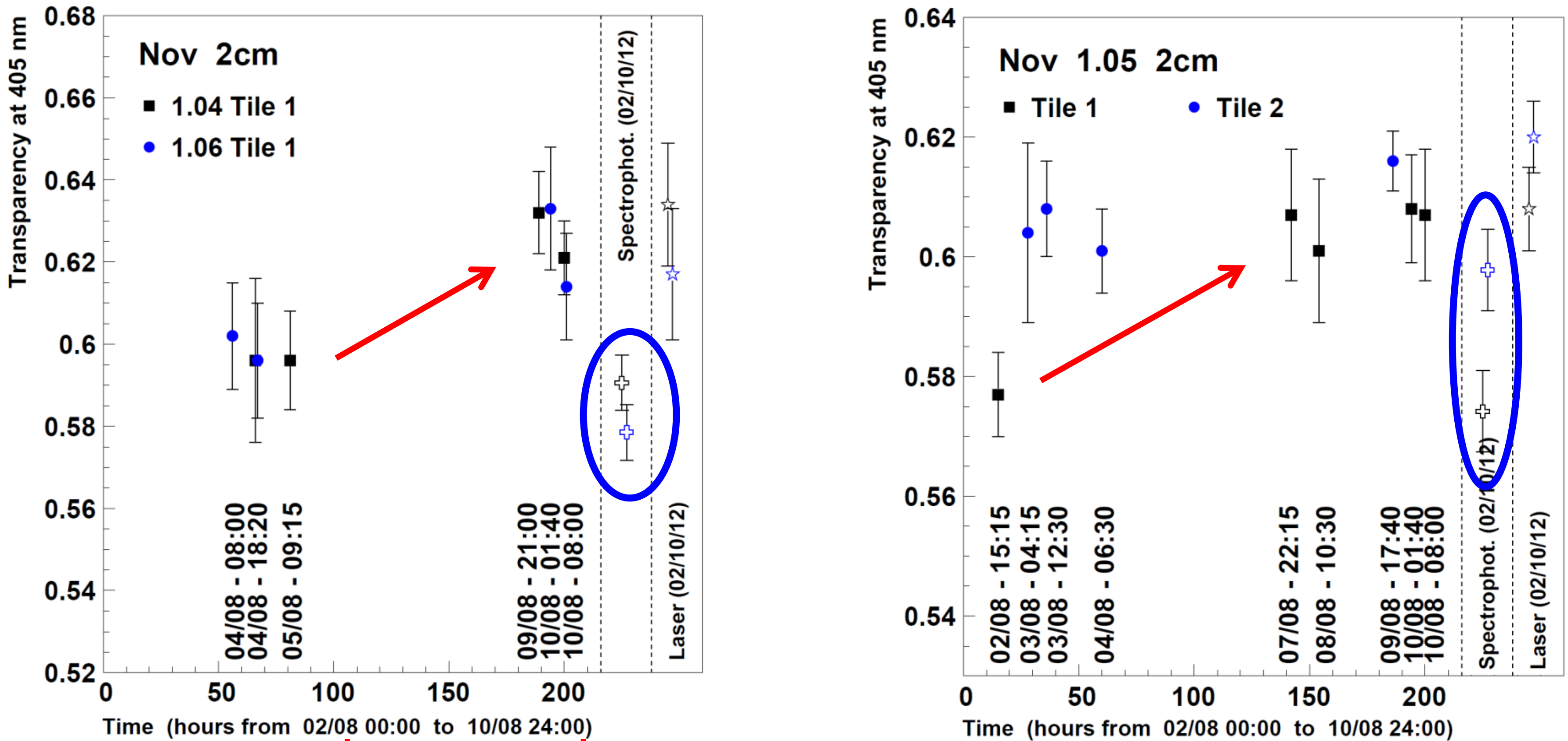
02/10/2012			0.578	0.007	meas. in Ferrara (spectrophot.)

- Spectrophotometer measurements are found to be systematically smaller

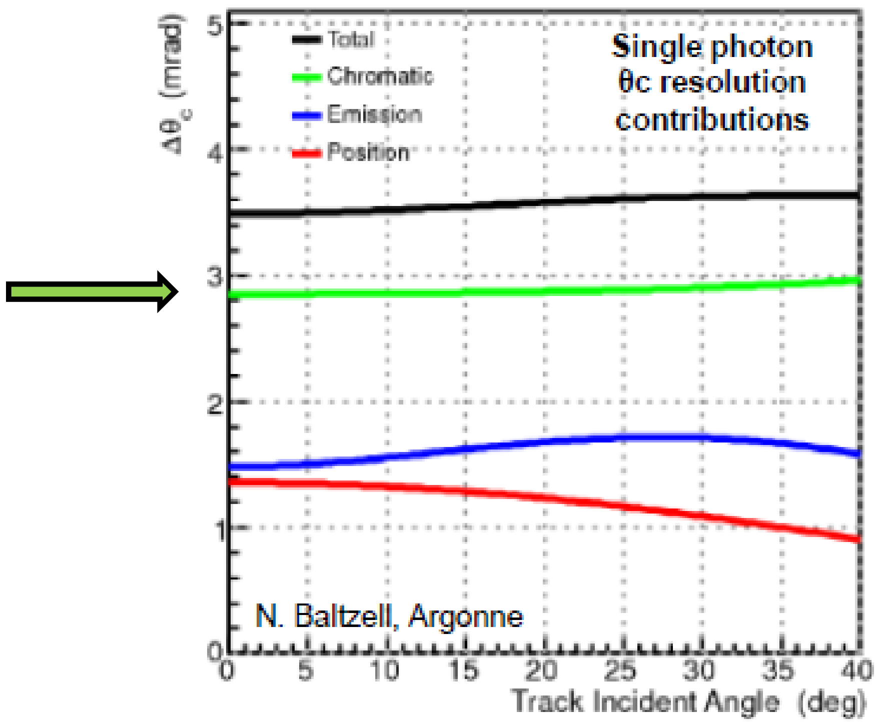
Some results



108 h **Storage in box with nitrogen** 127 h

- Spectrophotometer measurements are found to be systematically smaller
- These is an evidence of partial transmittance restoration after at least 60 hours of storage in dry (nitrogen) atmosphere
- Storage periods shorter than 60 hours do not result in appreciable improvements

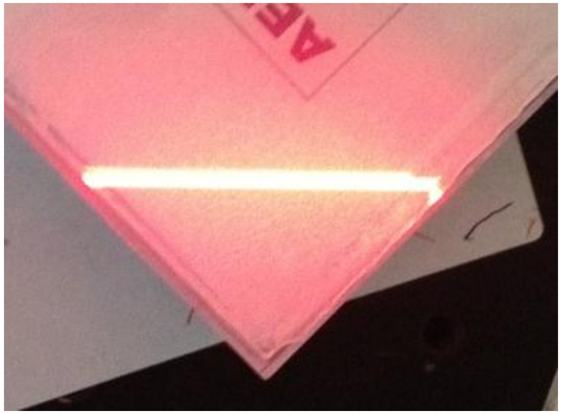
Part 3
Measures of refracting index and dispersion law



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

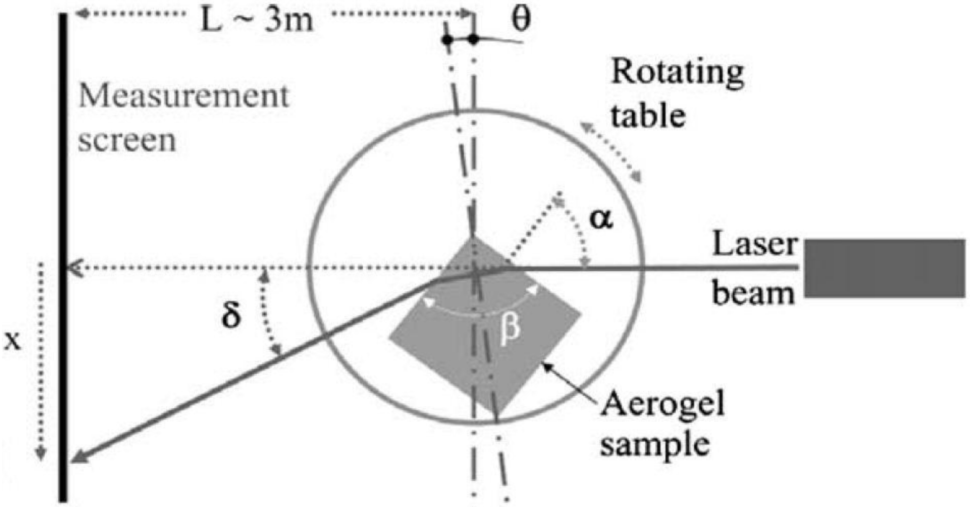
The "standard prism" method

- The adjacent sides of the aerogel tile form a prism
- One measures the deviation of a laser beam passing through the aerogel tile edges (prism)
- The position of the laser beam spot is measured on a screen placed downstream



- 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:**

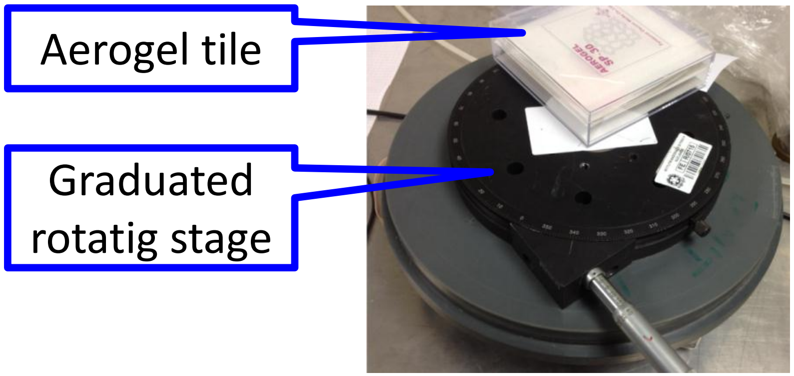
$$\delta = \alpha - \beta + \arcsin\left\{ n \cdot \sin\left[\beta - \arcsin\left(\frac{\sin\alpha}{n} \right) \right] \right\}$$

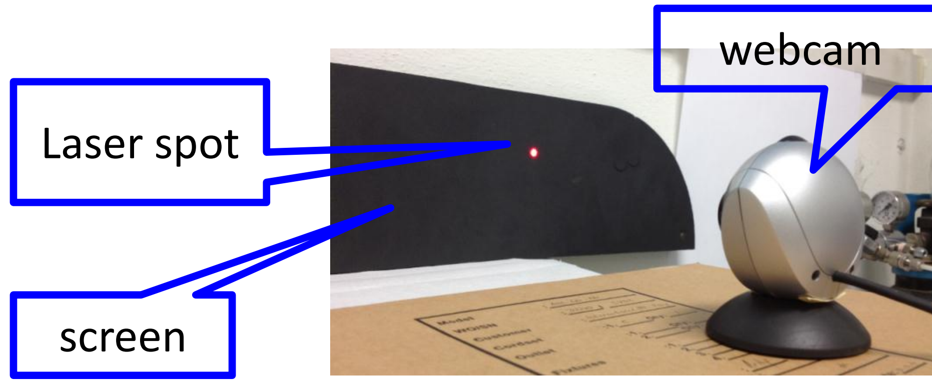


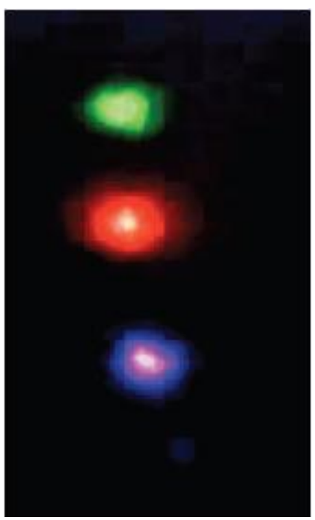
NIM A 614 (2010)

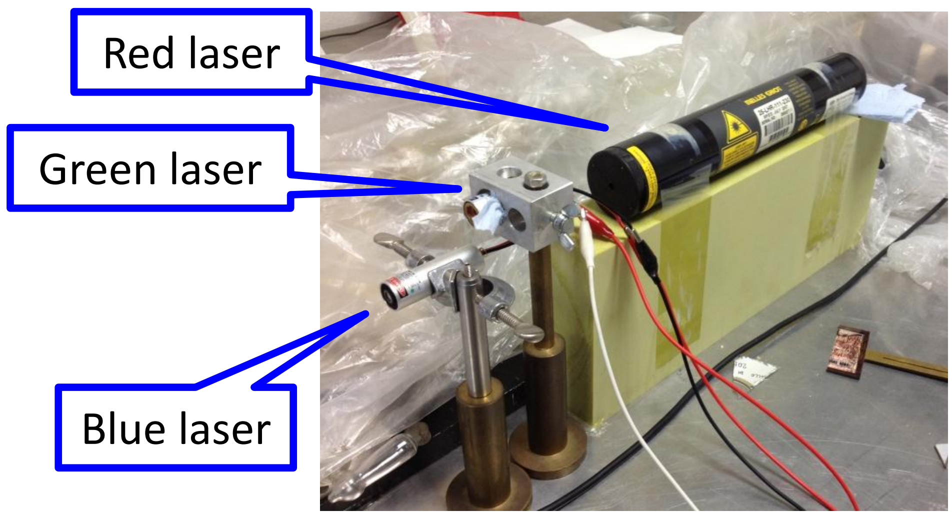
The Ferrara set-up

- The aerogel tile is positioned upon a graduated rotating stage
- Three lasers were used: **red (λ=632.8 nm)**, **green (λ=532 nm)**, **blue (λ=405 nm)**
- The beam spots on the screen are recorded by a digital photocamera
- The screen was placed at a distance L=3016mm
- The “zero” position was obtained using the direct beam (i.e. without the aerogel tile)



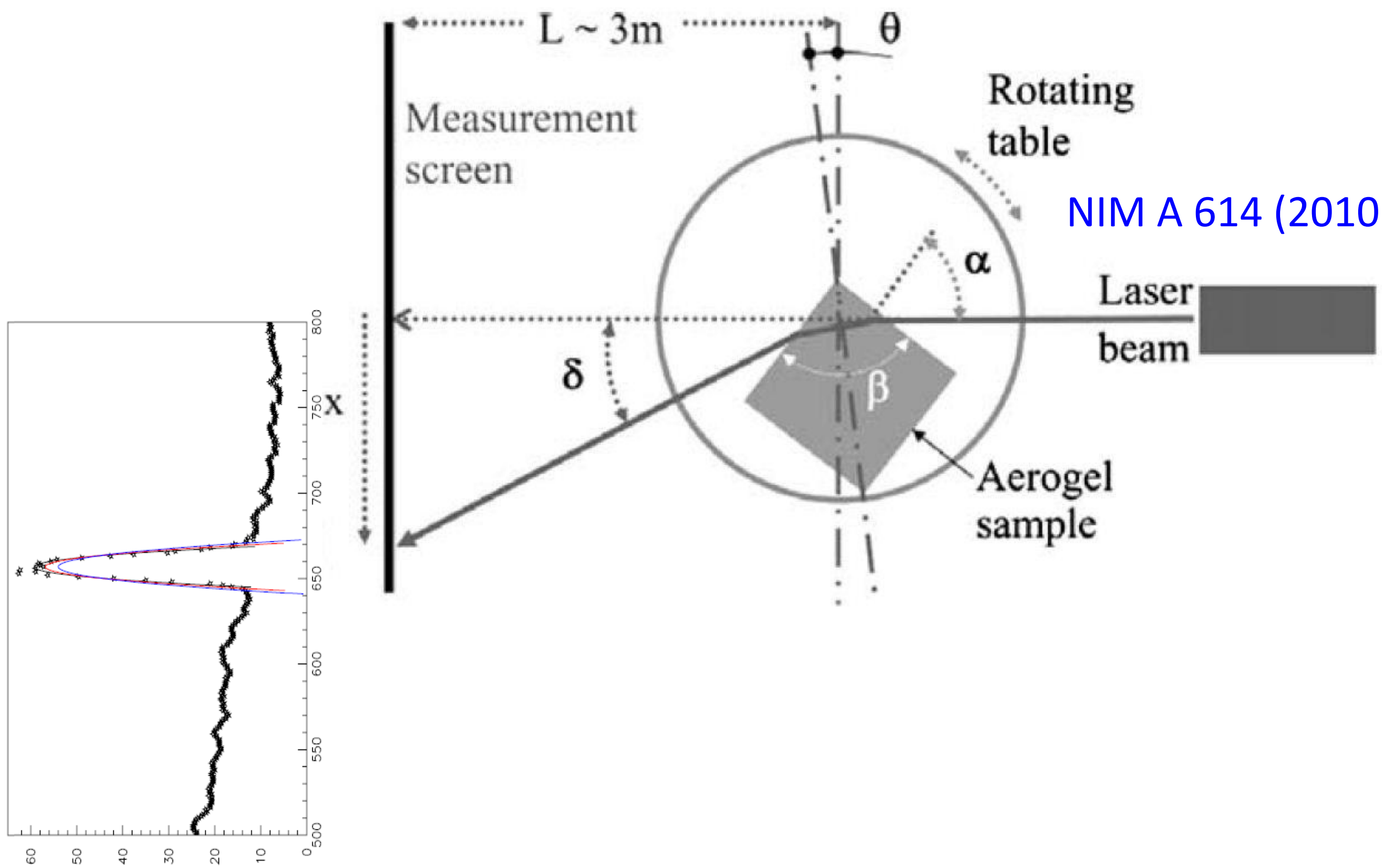






The procedure

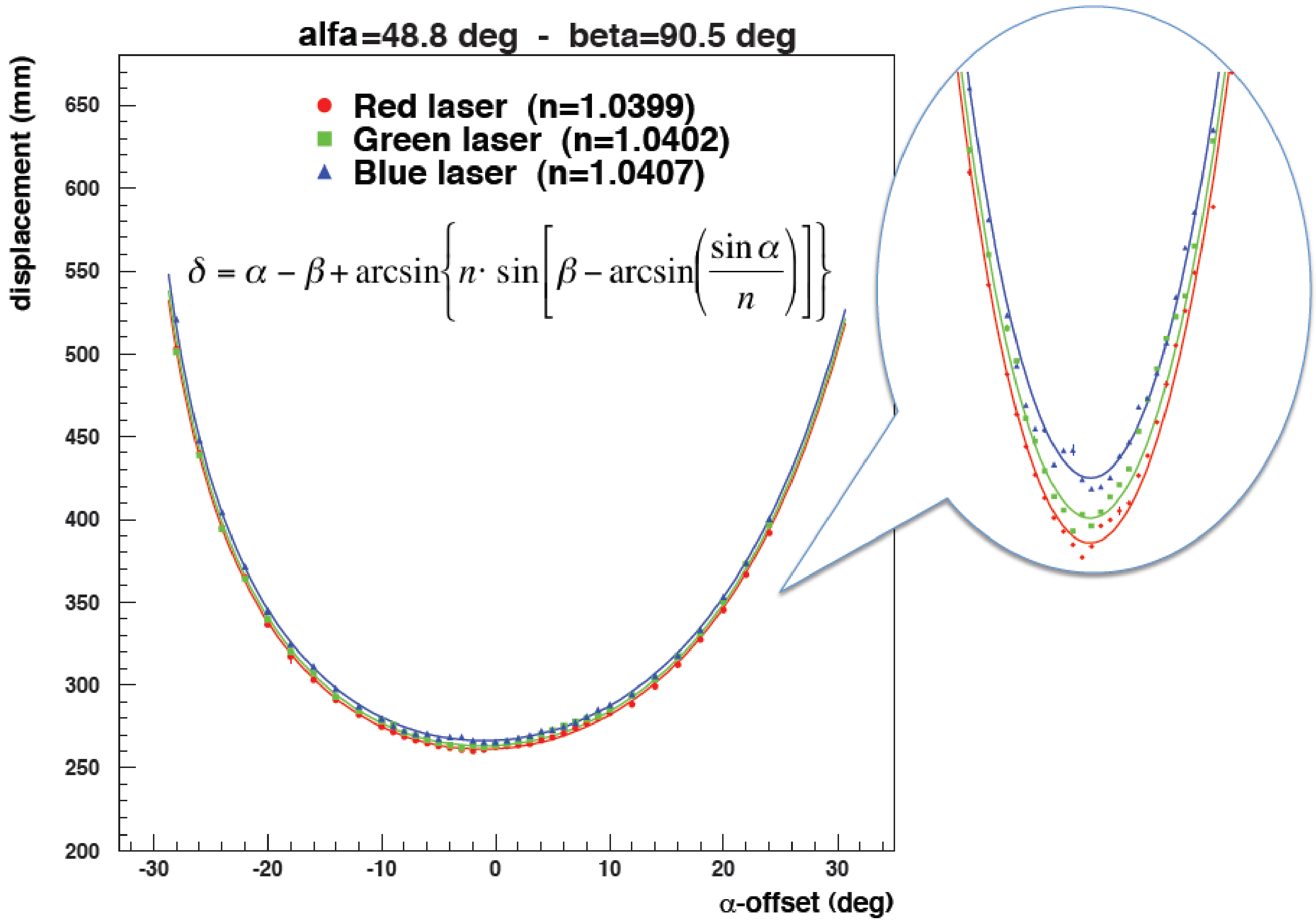
1. The intensity spectra are extracted from the analysis of the spot images
2. The peaks are fitted with a parabola to obtain the position of the maxima



NIM A 614 (2010)

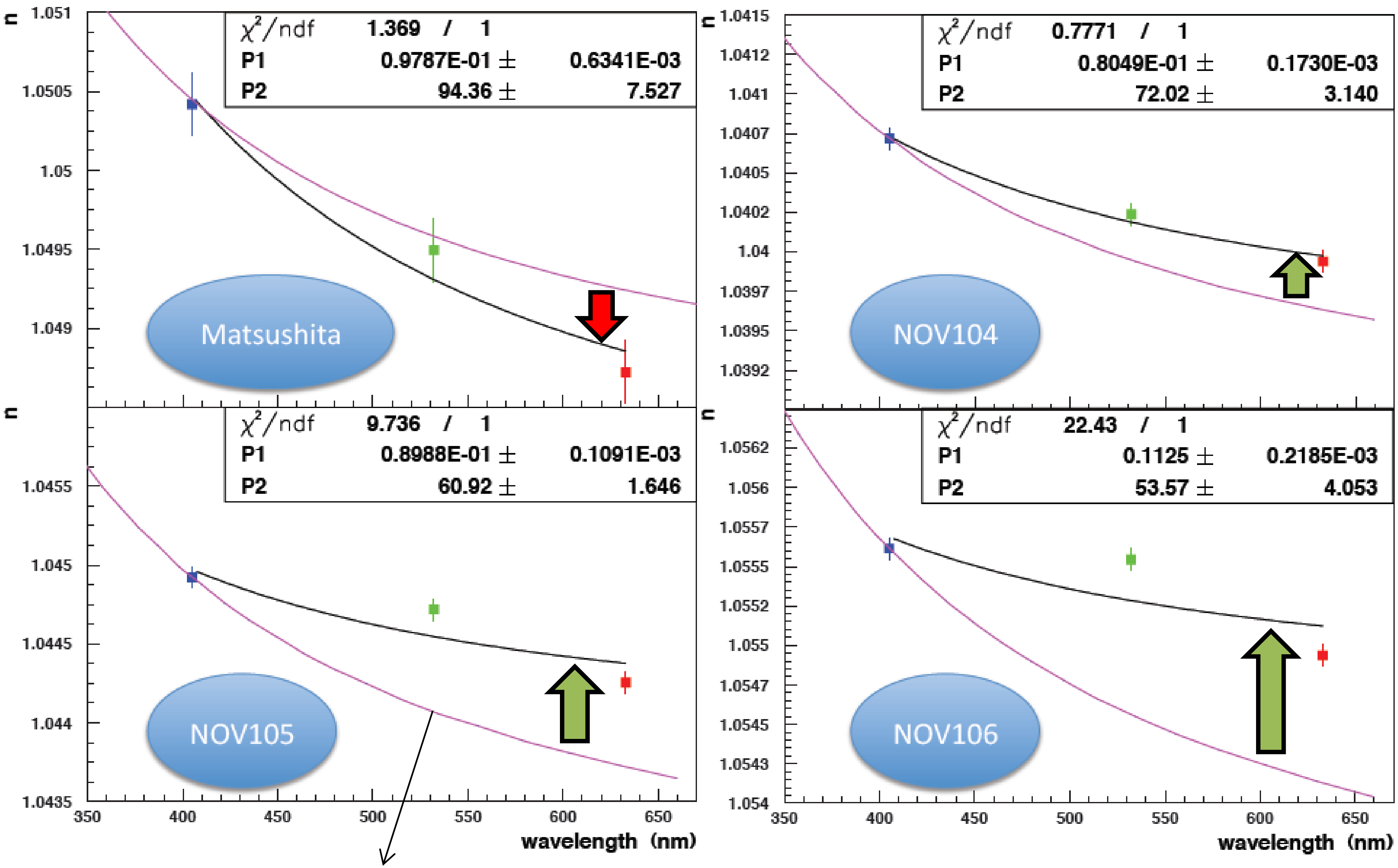
3. The positions of the maxima are plotted vs. α and fitted with the **Snell-Descarted law**

Extracting the refractive index



The dispersion law: $n^2(\lambda) - 1 = \frac{a_0\lambda^2}{\lambda^2 - {\lambda_0}^2}$ ⇒ $n(\lambda) = \sqrt{1 + \frac{P_1\lambda^2}{\lambda^2 - {P_2}^2}}$

Extracting the refractive index



Expected trend: phenomenological estimate based on "old generation" aerogel measurements

- Preliminary data show a chromatic dispersion smaller than expectations for Novosibirsk
- More precise measurements are in order.

Conclusions and outlook

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

- transmittance, absorption length and scattering length measurements were performed for different aerogel tiles

- measurements of refractive index and chromatic dispersion were performed with the prims method.

- The new generation aerogel from Novosibirsk has higher performances (higher transparency, longer scattering length, smaller chromatic dispersion)

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))