

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 $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$. 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 nucleon 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.

Key features of CLAS12 include a high operational luminosity of $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$, an order of magnitude higher than the JLab12 setup, and operation of highly polarized beam and targets. The conceptual design of the CLAS12 detector is shown in Fig. 1. The central detector with the high-field (5 T) torus magnet 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 and a detector symmetry of CLAS. In the base equipment,

and event reconstruction. It 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 around the torus cryostats and covering scattering angles from 5° to 40° . Fig. 3. Being downstream to the torus magnet at 10 m from the interaction point, the RICH has to cover a solid angle of each sector spanning an area of the order of 4 m^2 . 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 (C₆F₁₂ or C₆F₁₄) radiator and a CsI-deposited radiator chamber as a UV-photon detector, is required pion rejection factor at momenta

The preliminary results on ongoing Monte Carlo studies on a GEANT3 toolkit with simplified geometry

face, aimed at the proximity

with a freon radiator wire proportional counter to achieve the required pion rejection factor at momenta above 3 GeV/c. The studies, based on GEANT3 and optical surface

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Characterization of aerogel tiles

➤ Geometry (area, thickness) →

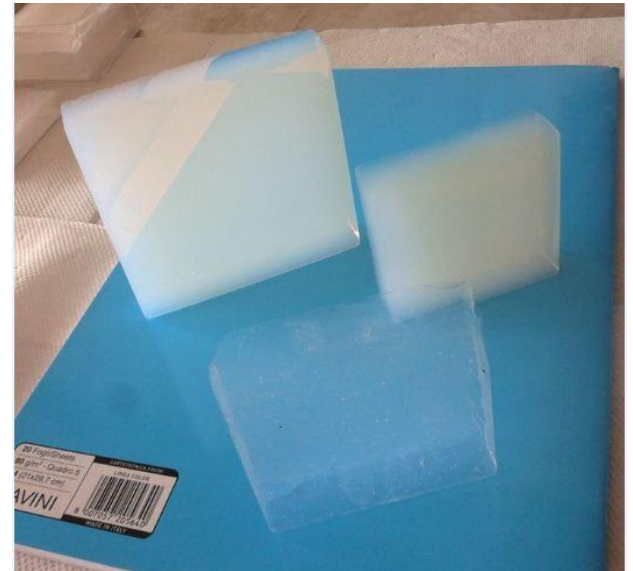
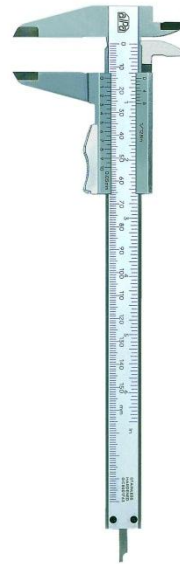
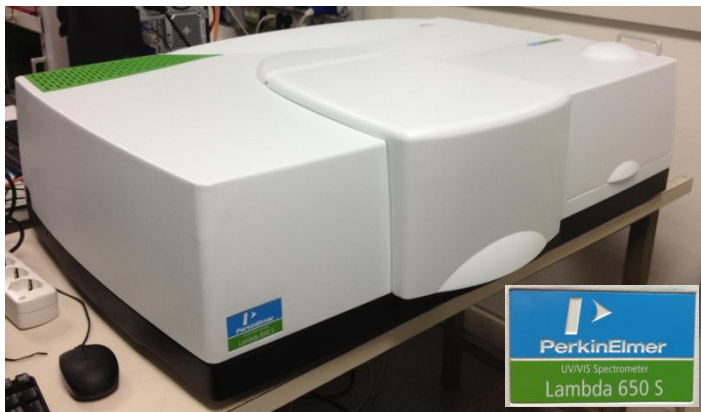
➤ refractive index

➤ Transmittance

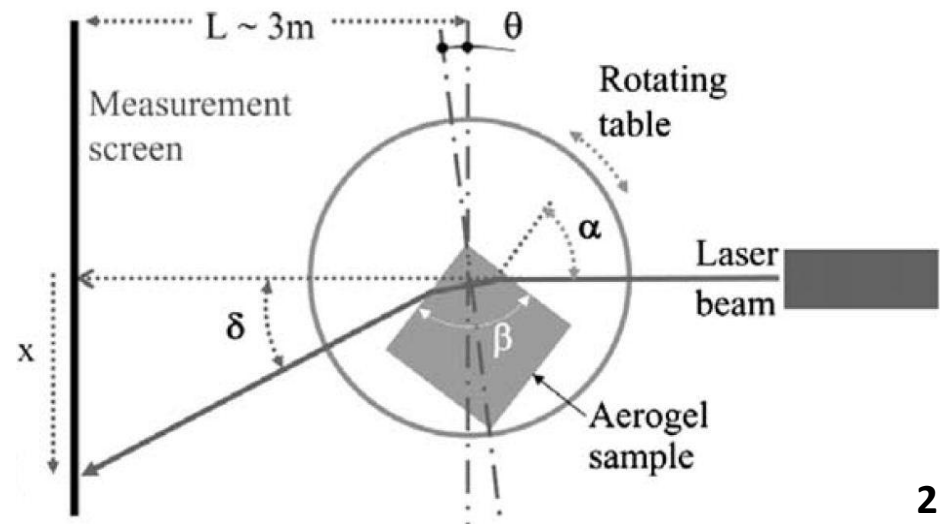
➤ Absorption length

➤ 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 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** ($6 \times 6 \text{ cm}^2$, $10 \times 10 \text{ cm}^2$, $9.5 \times 9.5 \text{ cm}^2$, $6.5 \times 6.5 \text{ cm}^2$)

Part 1

Measuring Transmittance, scattering and absorption length

Basic formalism and selected results

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

Clarity parameter

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

Transflectance

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

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

Basic formalism and selected results

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

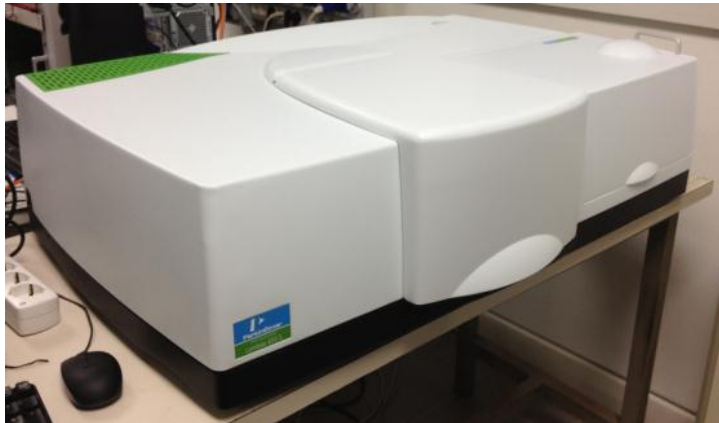
Clarity parameter

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

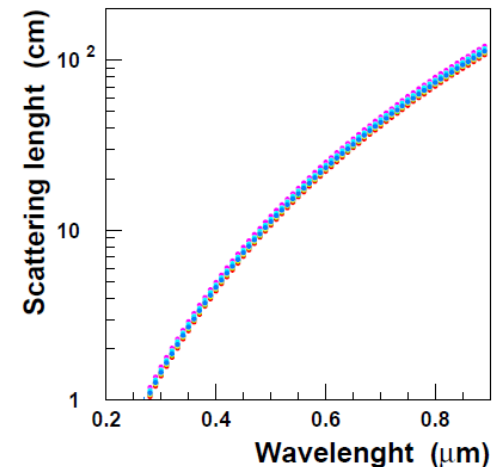
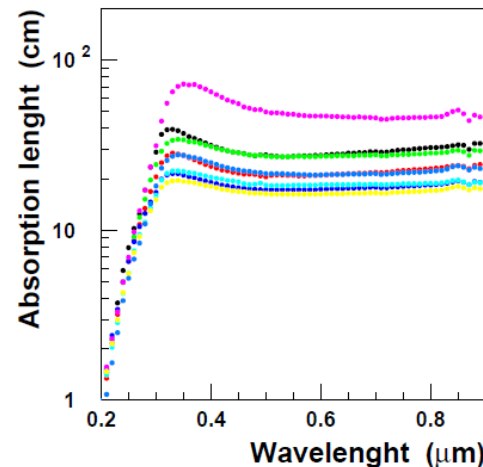
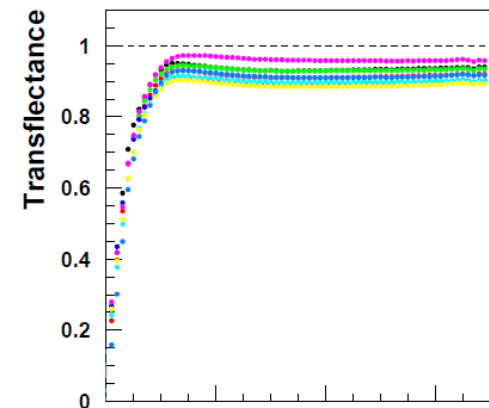
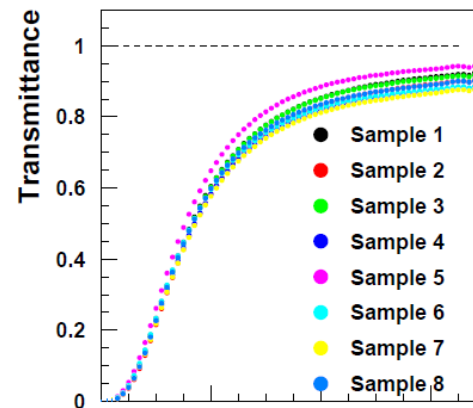
Transflectance

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

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

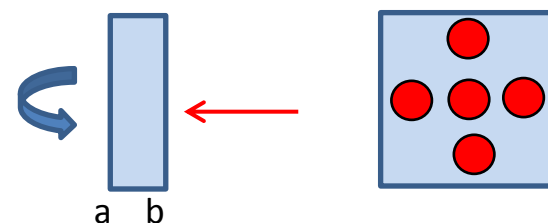
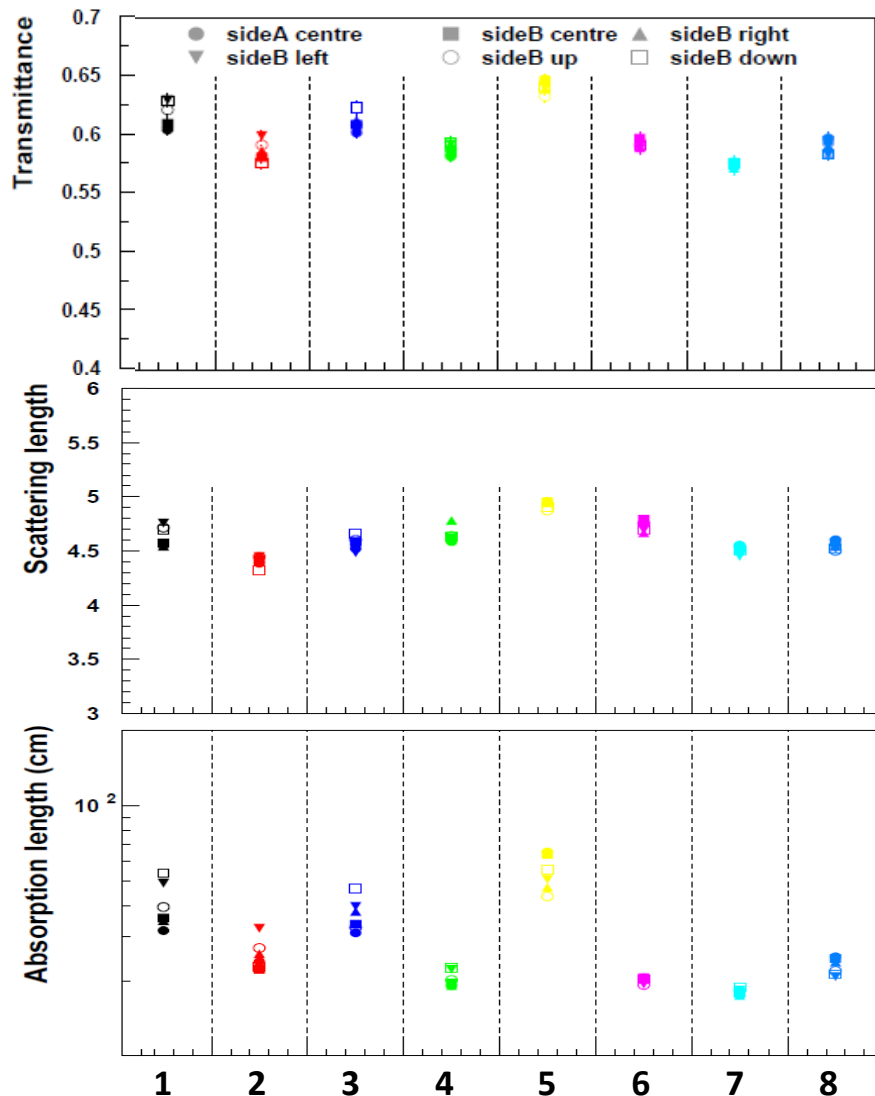


Novosibirsk Samples 1-8 (1.05)



Measurements at 400nm

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

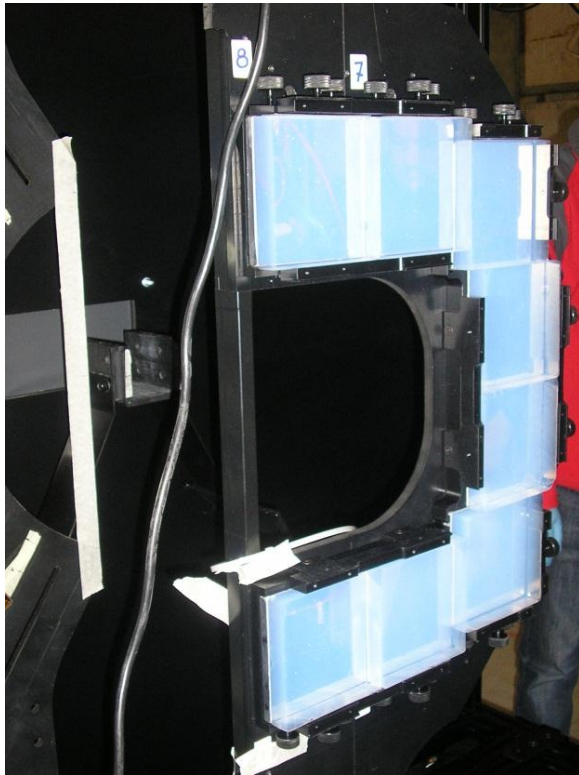


Novosibirsk Samples 1-8 (1.05)

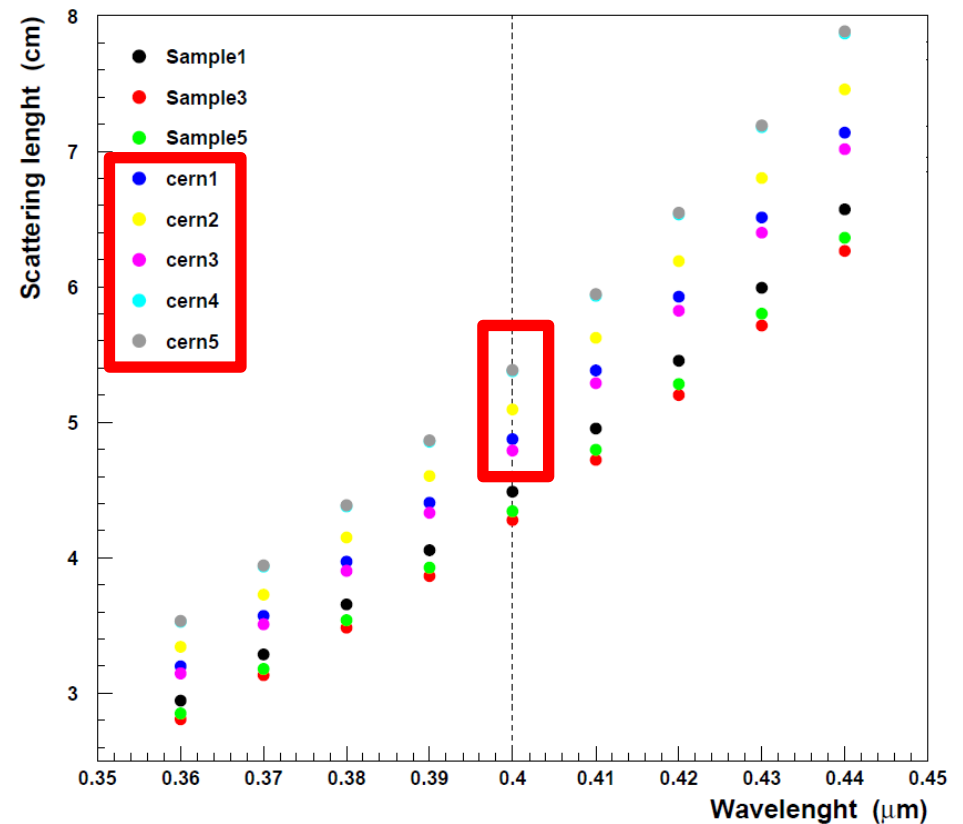
tile	$\langle T \rangle$	Λ_A (cm)	Λ_S (cm)
1	0.618 ± 0.011	40.8 ± 8.8	4.6 ± 0.1
2	0.587 ± 0.008	25.7 ± 3.8	4.4 ± 0.1
3	0.611 ± 0.007	37.0 ± 5.8	4.6 ± 0.1
4	0.589 ± 0.005	20.4 ± 1.5	4.6 ± 0.1
5	0.642 ± 0.005	54.4 ± 8.9	4.9 ± 0.1
6	0.593 ± 0.003	20.1 ± 0.6	4.7 ± 0.1
7	0.575 ± 0.002	18.1 ± 0.5	4.5 ± 0.1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

Improvements in production techniques (Novosibirsk)

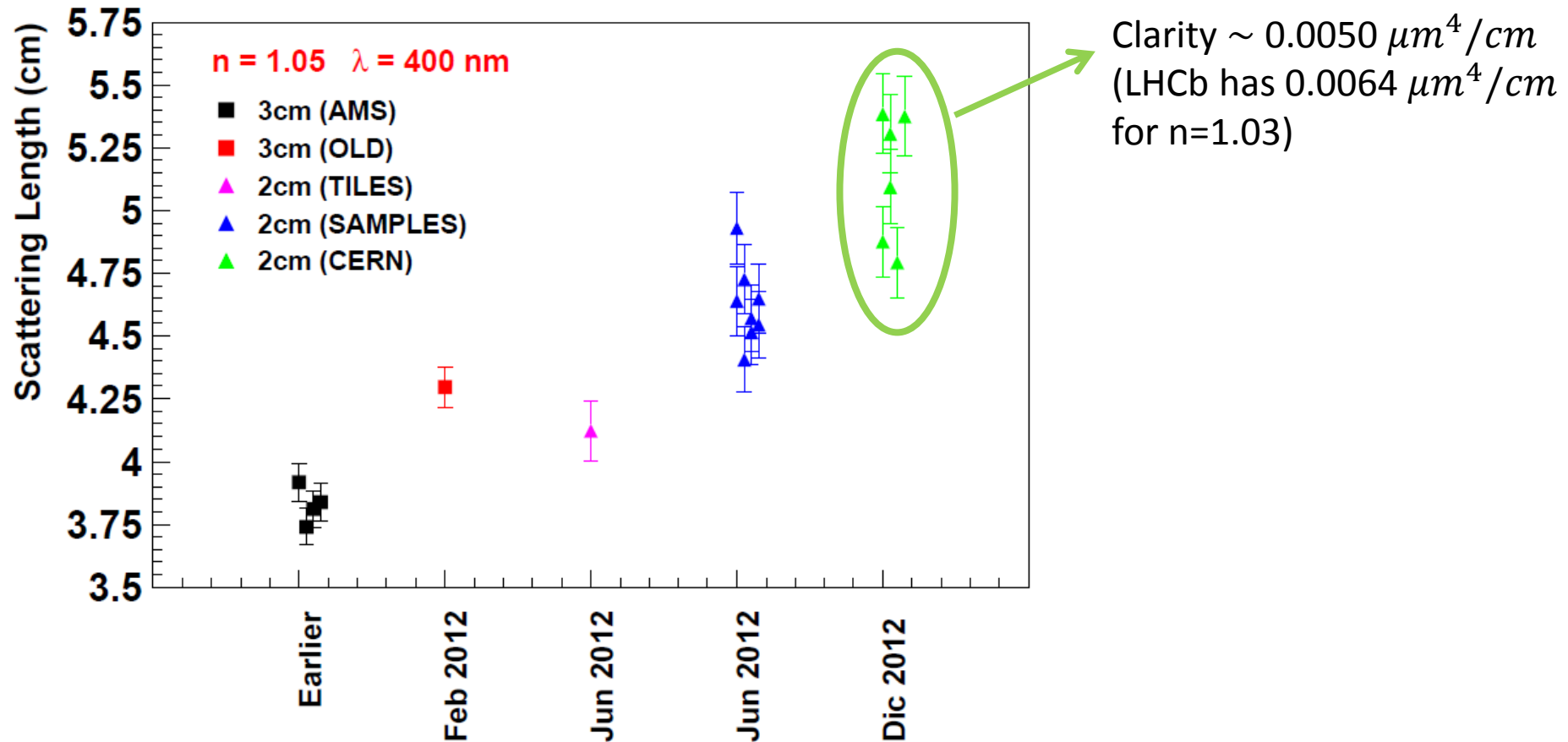
December 2012 test-beam



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)



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

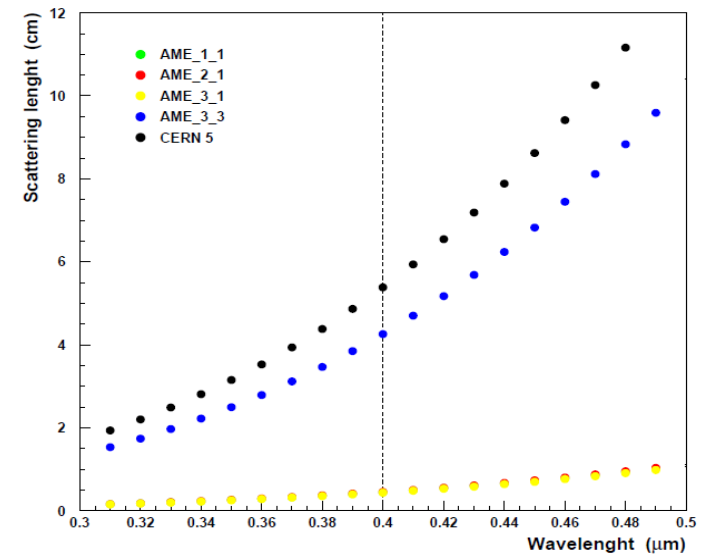
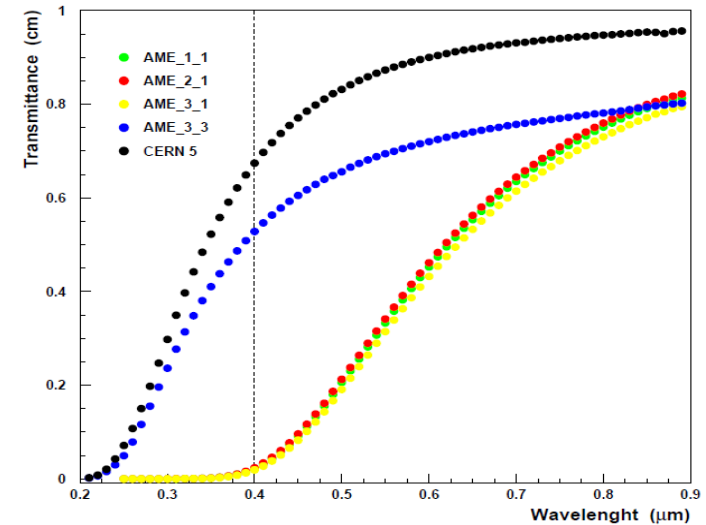
Optical properties of ASPEN aerogel



- 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 $n = 1.01$

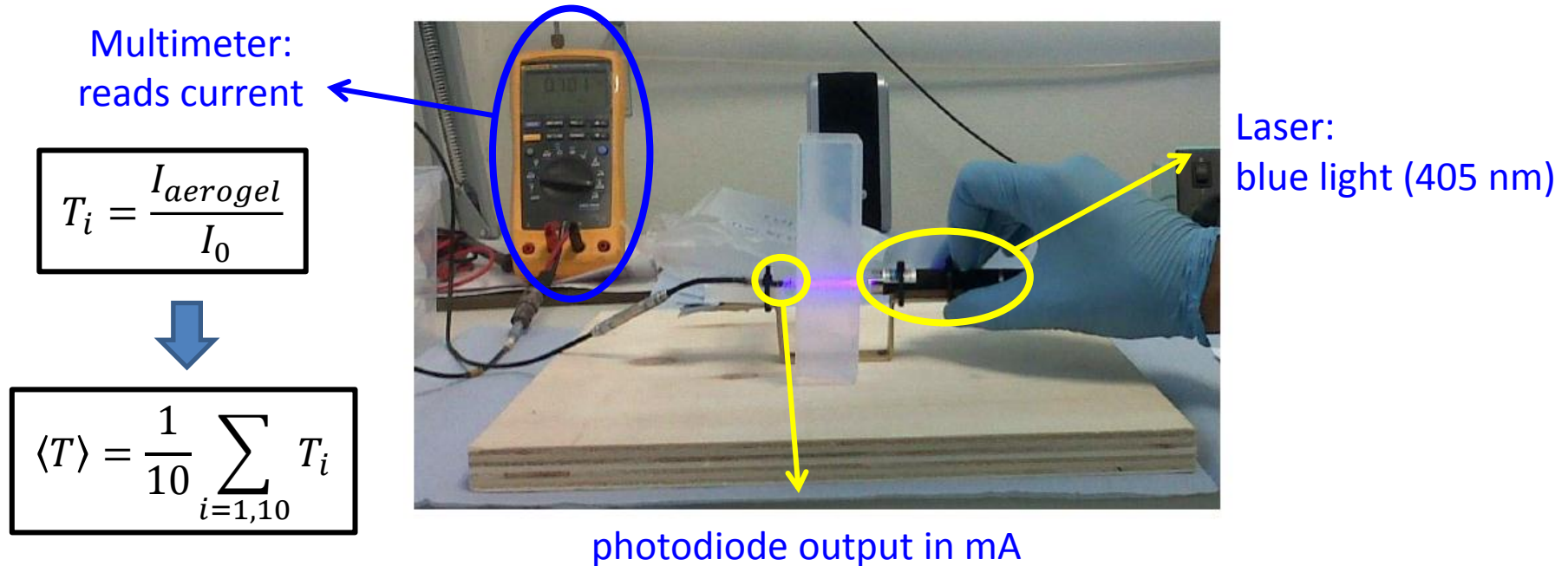
Part 2

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 performances ➡ need to periodically monitor the transmittance

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



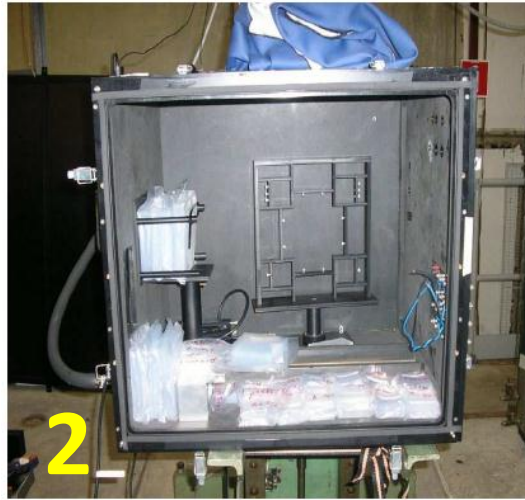
The method is fast (few minutes for each set of 10 measurements) but introduces several **systematic effects** (laser-photodiode distance, aerogel local non-homogeneities, laser instabilities) that result in a broadening of the measured transmittance.

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

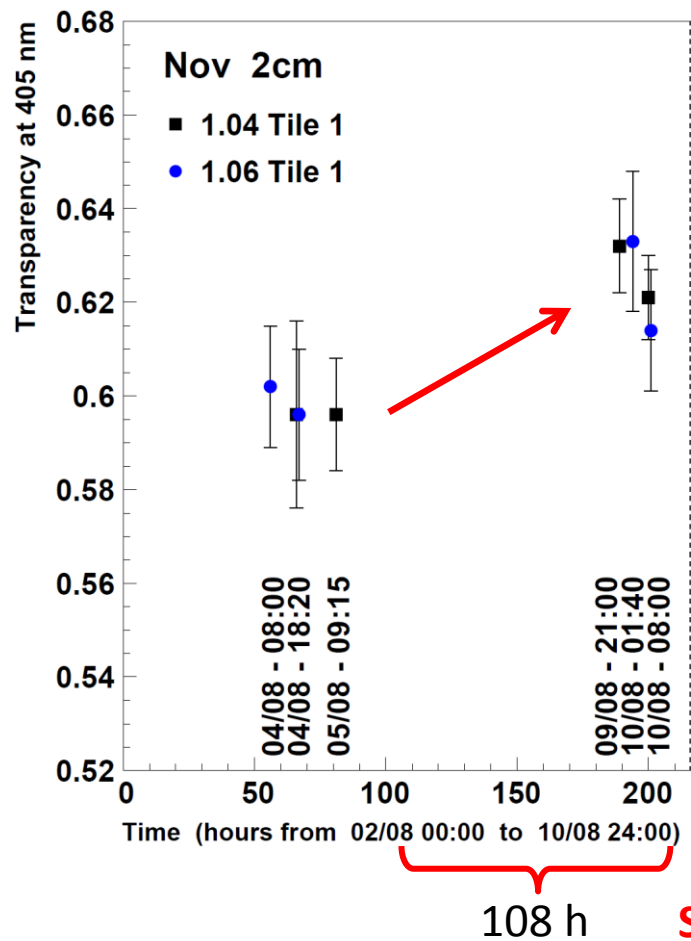


Table 2: Nov. 1.04 2cm tile1

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

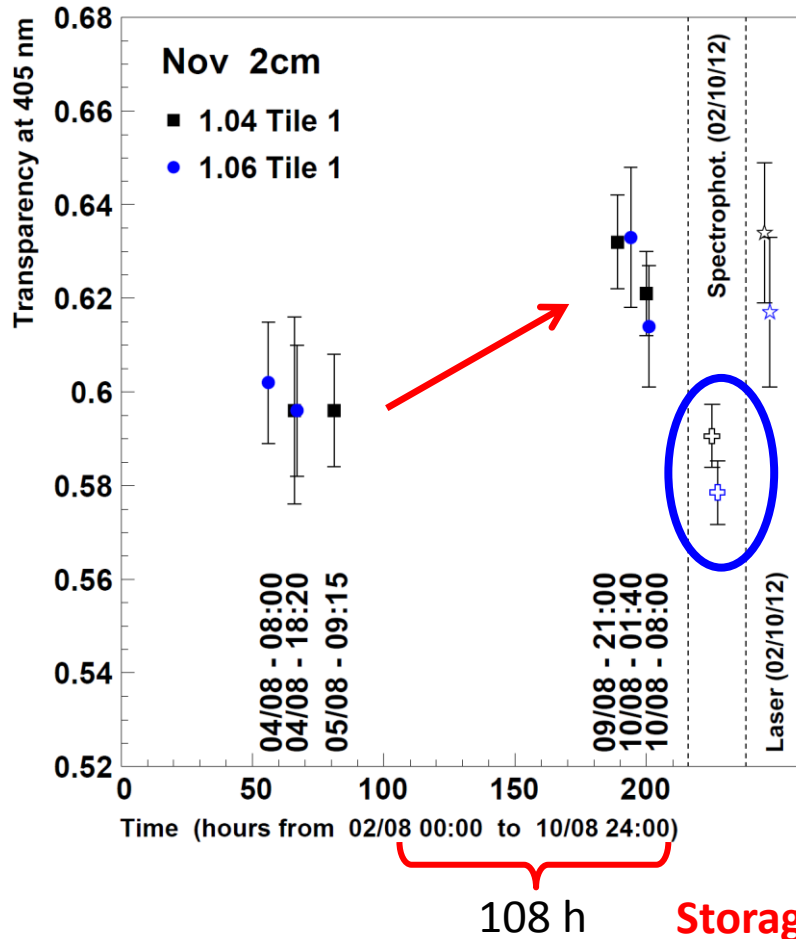


Table 2: Nov. 1.04 2cm tile1

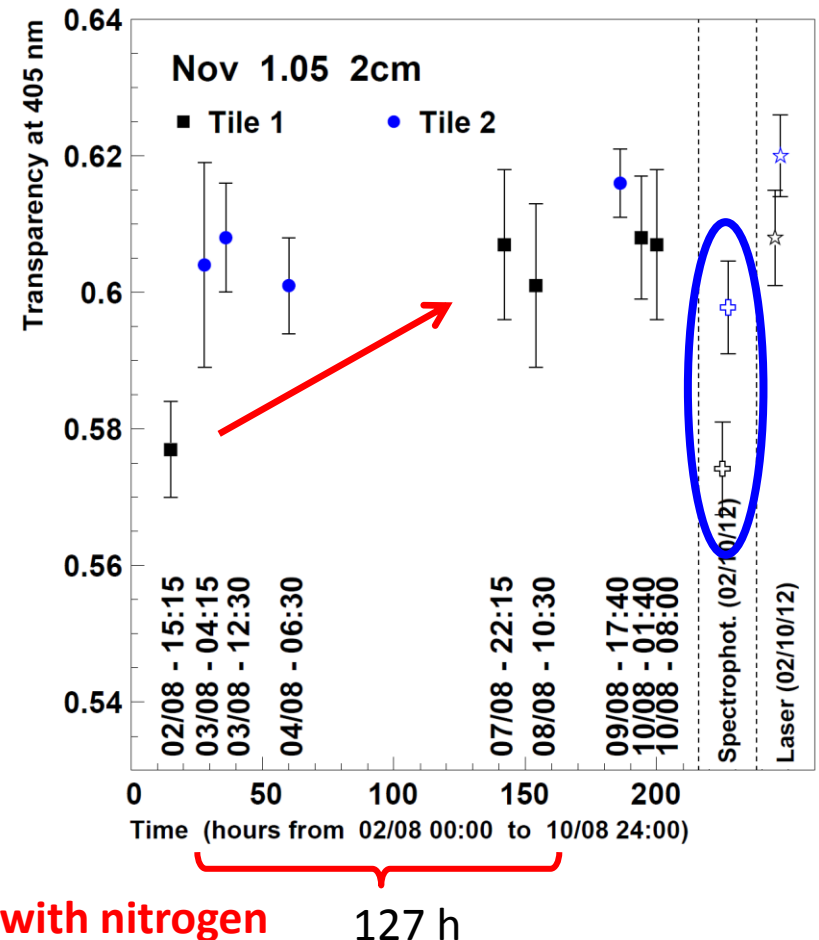
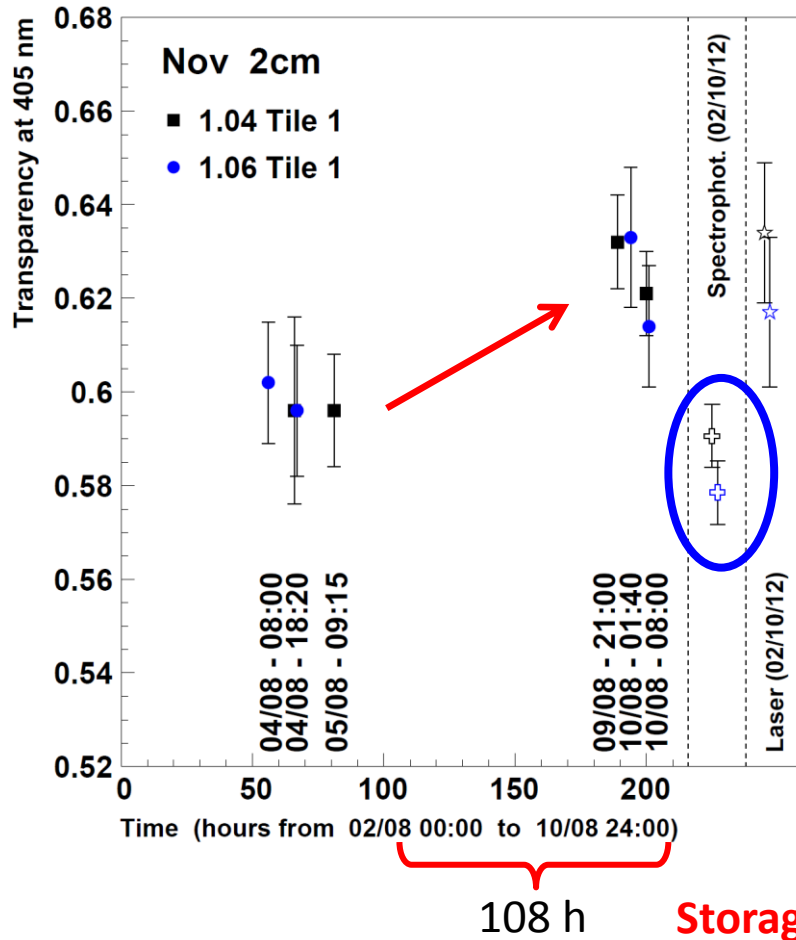
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02/10/2012			0.591	0.007	meas. in Ferrara (spectrophot.)

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

- Spectrophotometer measurements are found to be systematically smaller

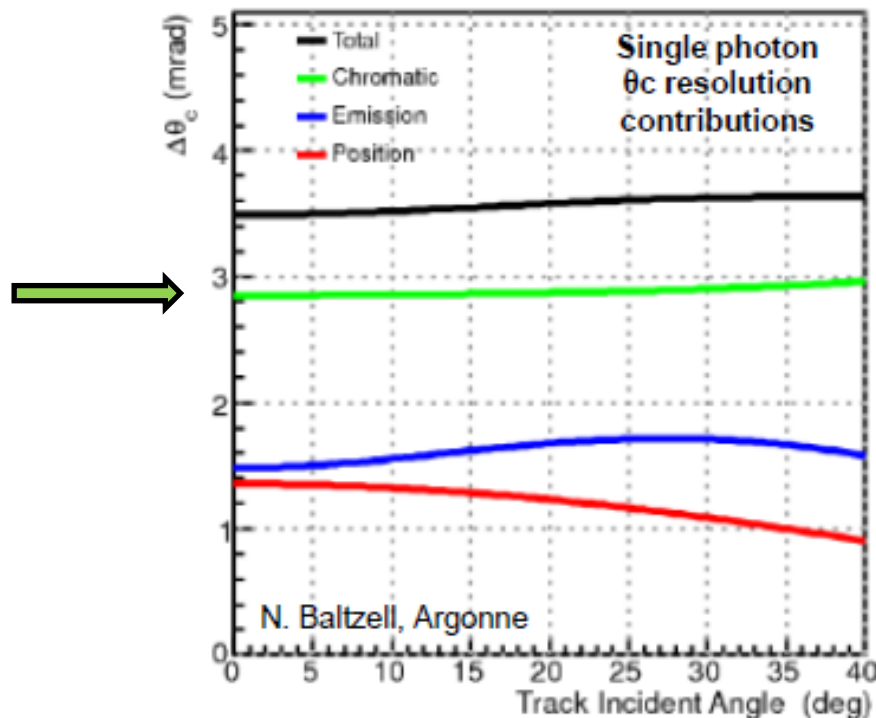
Some results



- 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

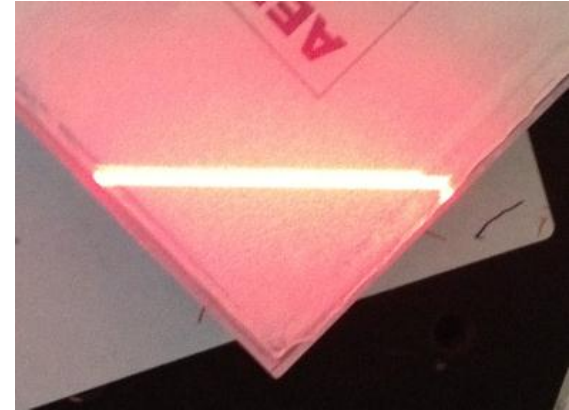
Measures of refracting index and dispersion law




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

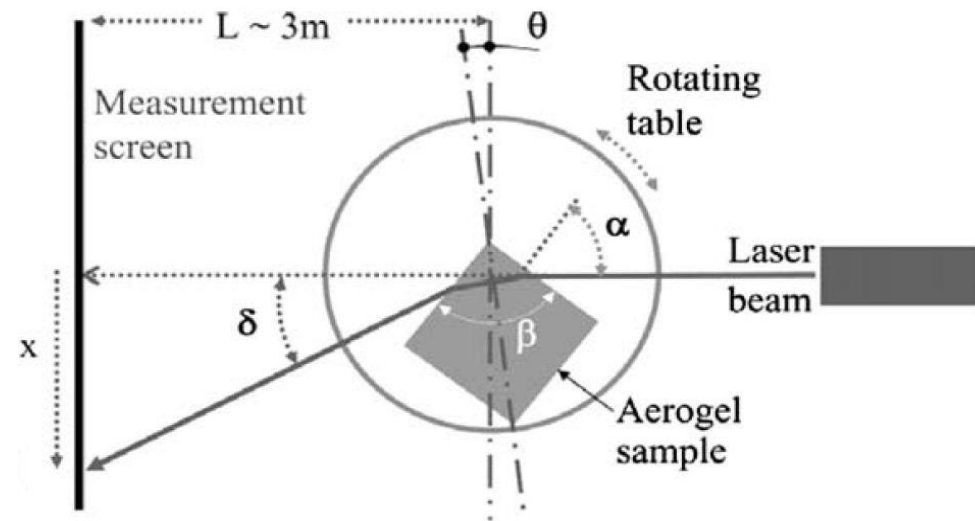
The "standard prism" method

- 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**:

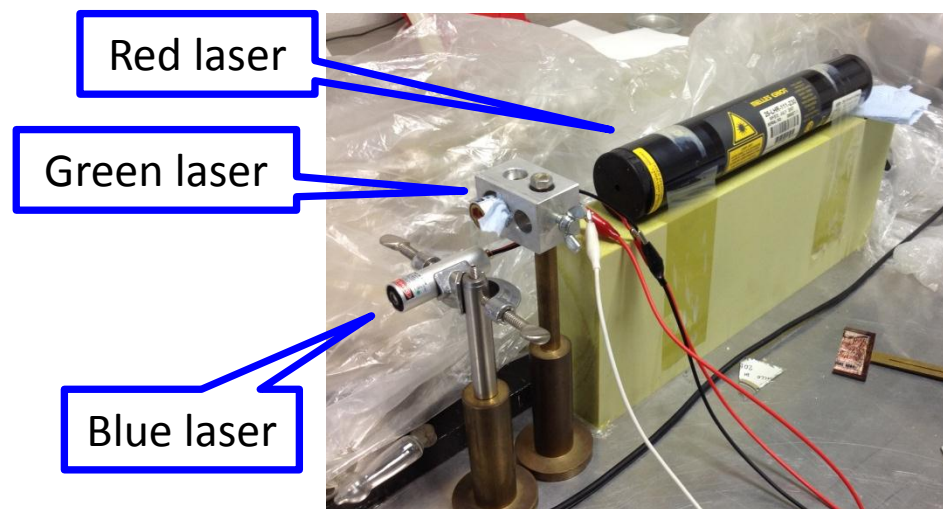
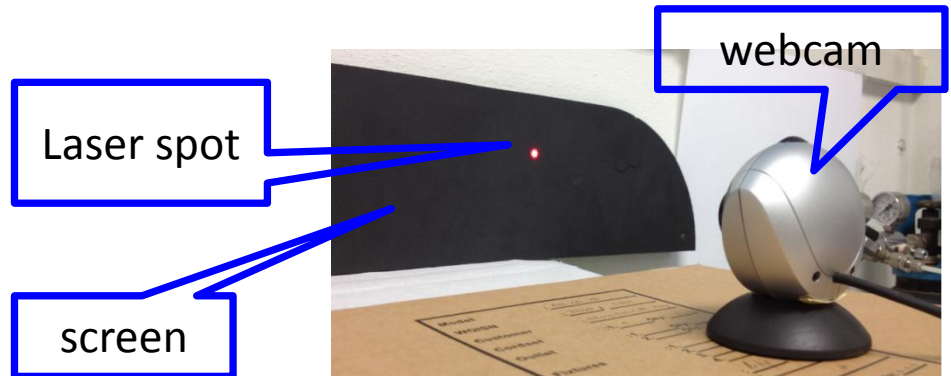
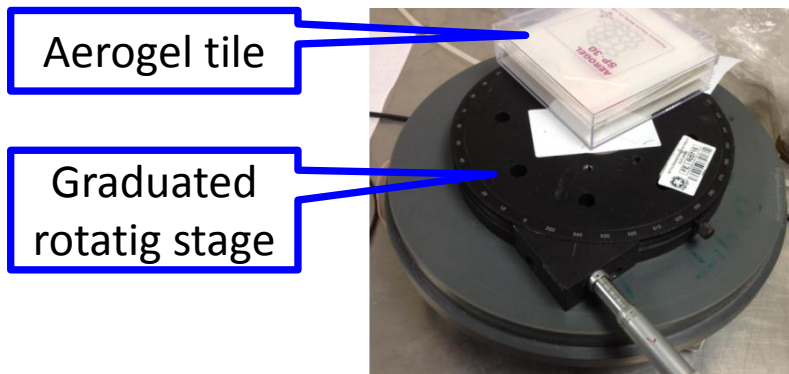
$$\delta = \alpha - \beta + \arcsin \left\{ n \cdot \sin \left[\beta - \arcsin \left(\frac{\sin \alpha}{n} \right) \right] \right\}$$



NIM A 614 (2010)

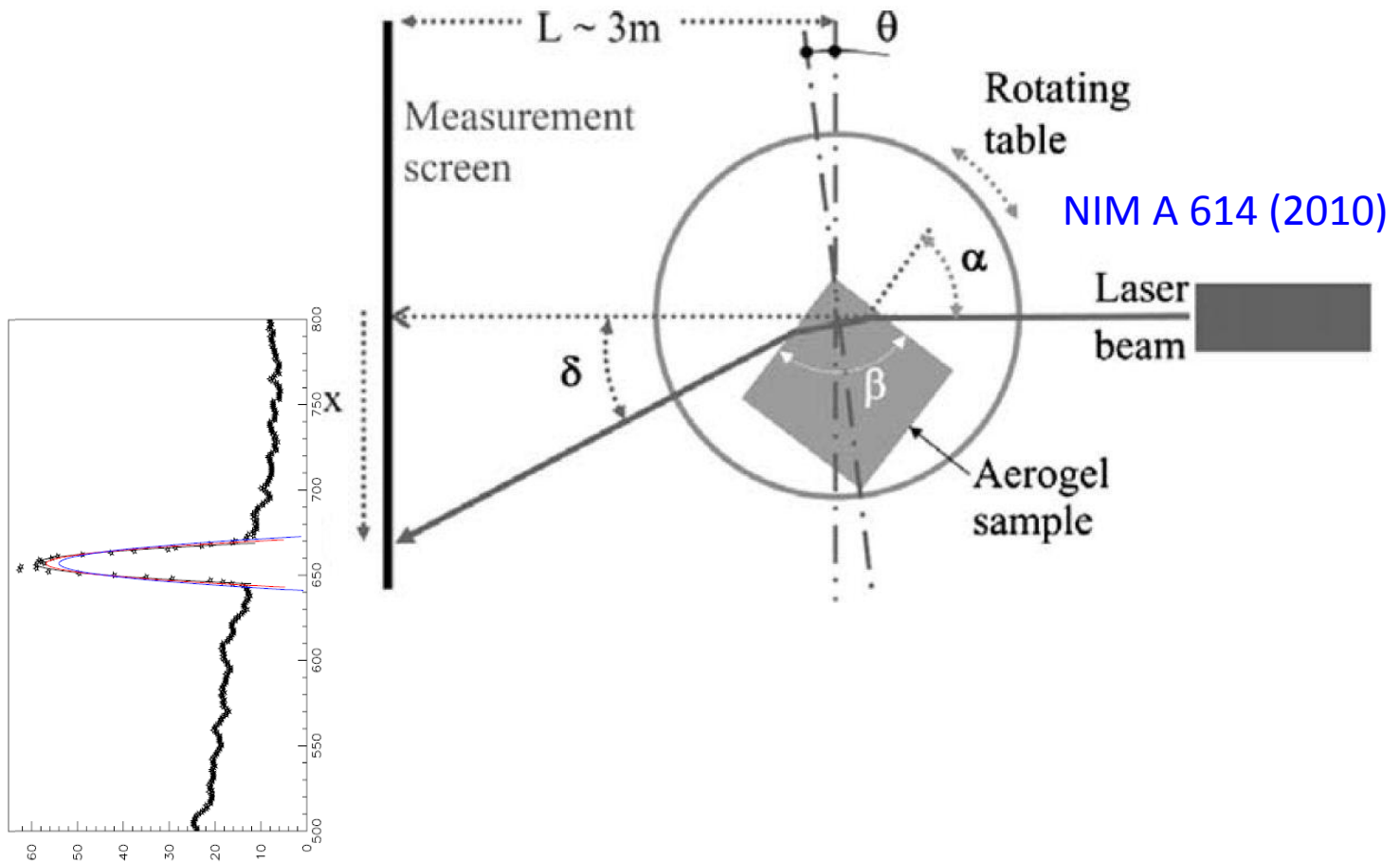
The Ferrara set-up

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



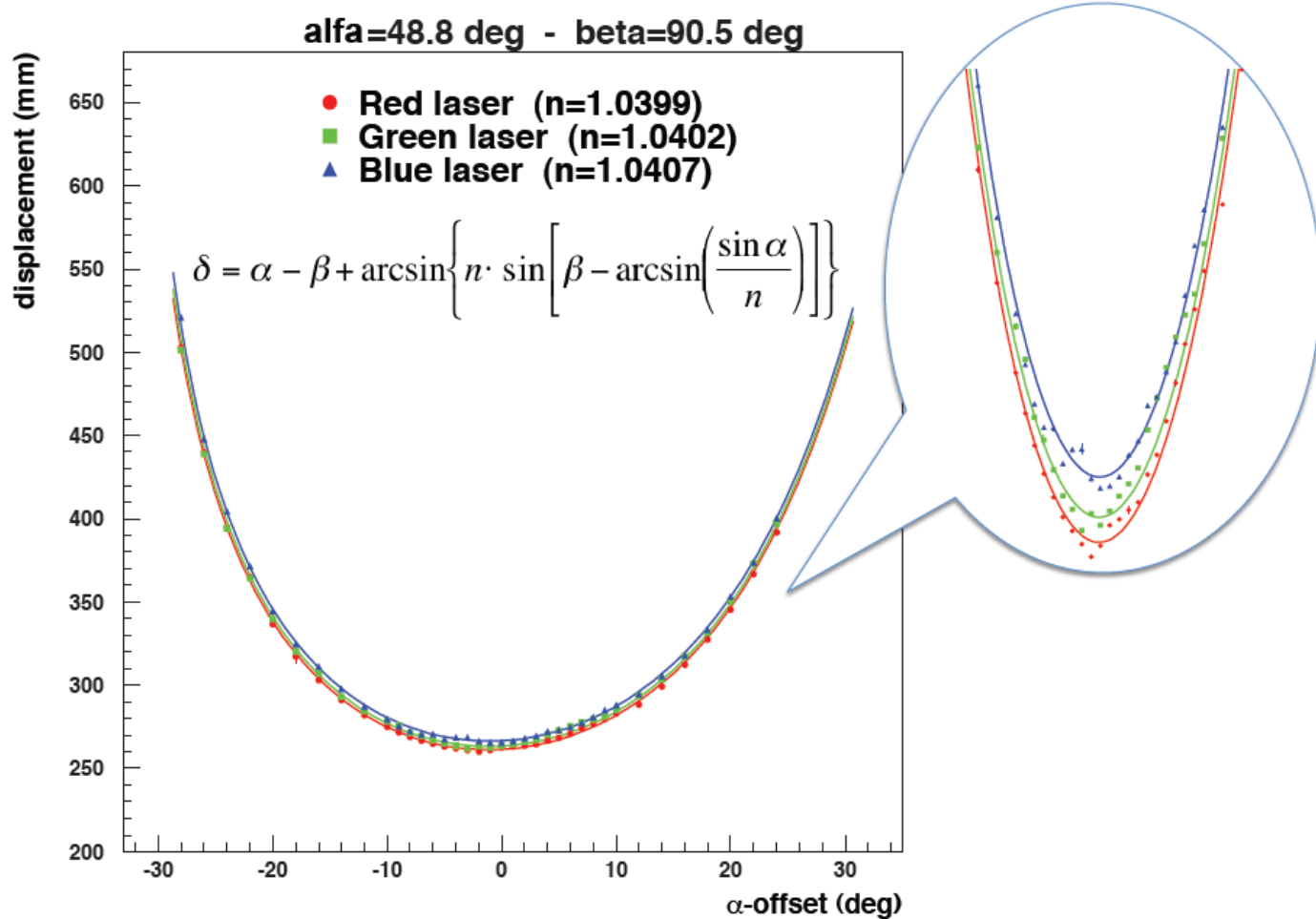
The procedure

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



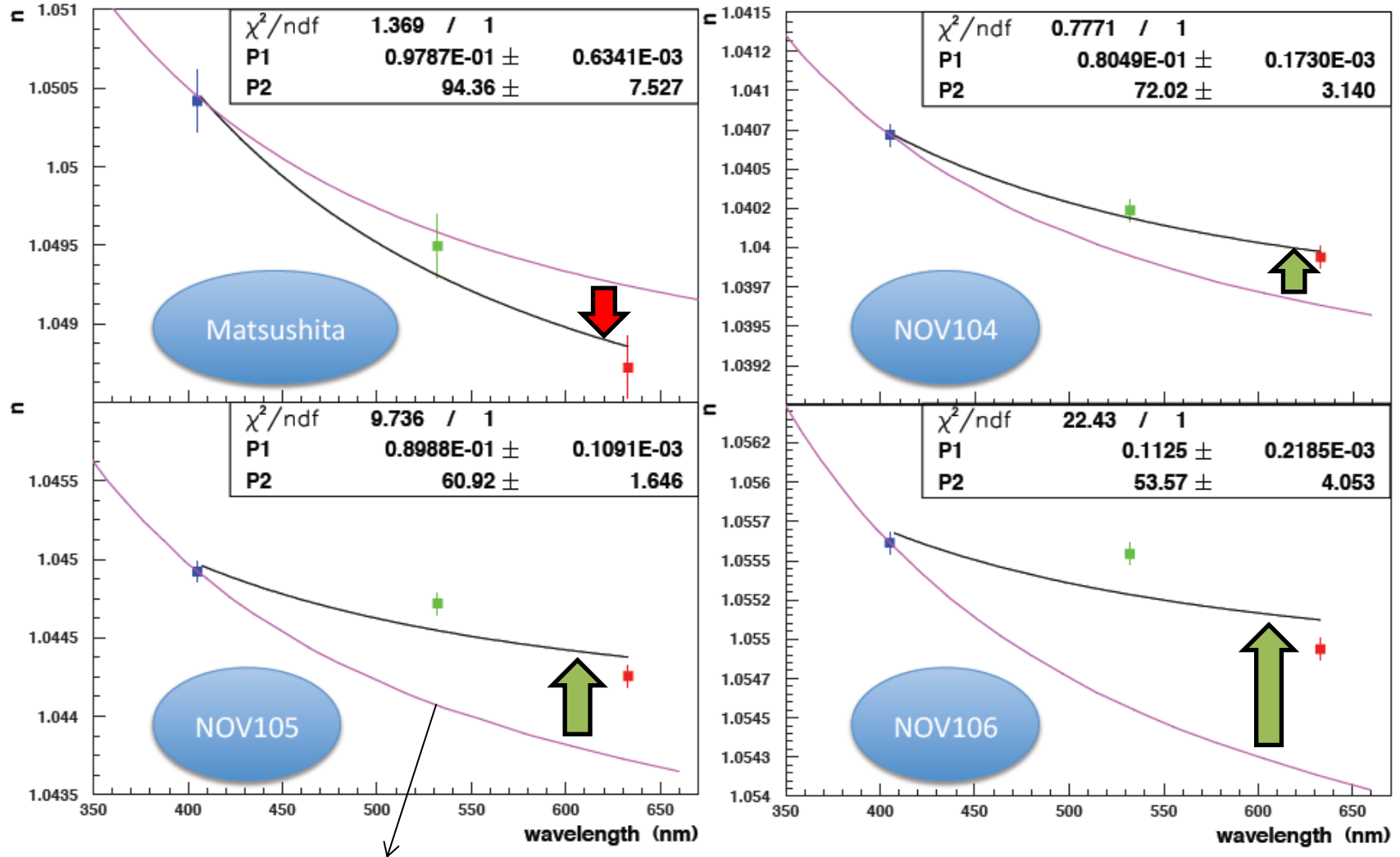
3. The positions of the maxima are plotted vs. α and fitted with the **Snell-Descarted law**

Extracting the refractive index



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

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 prisms 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))