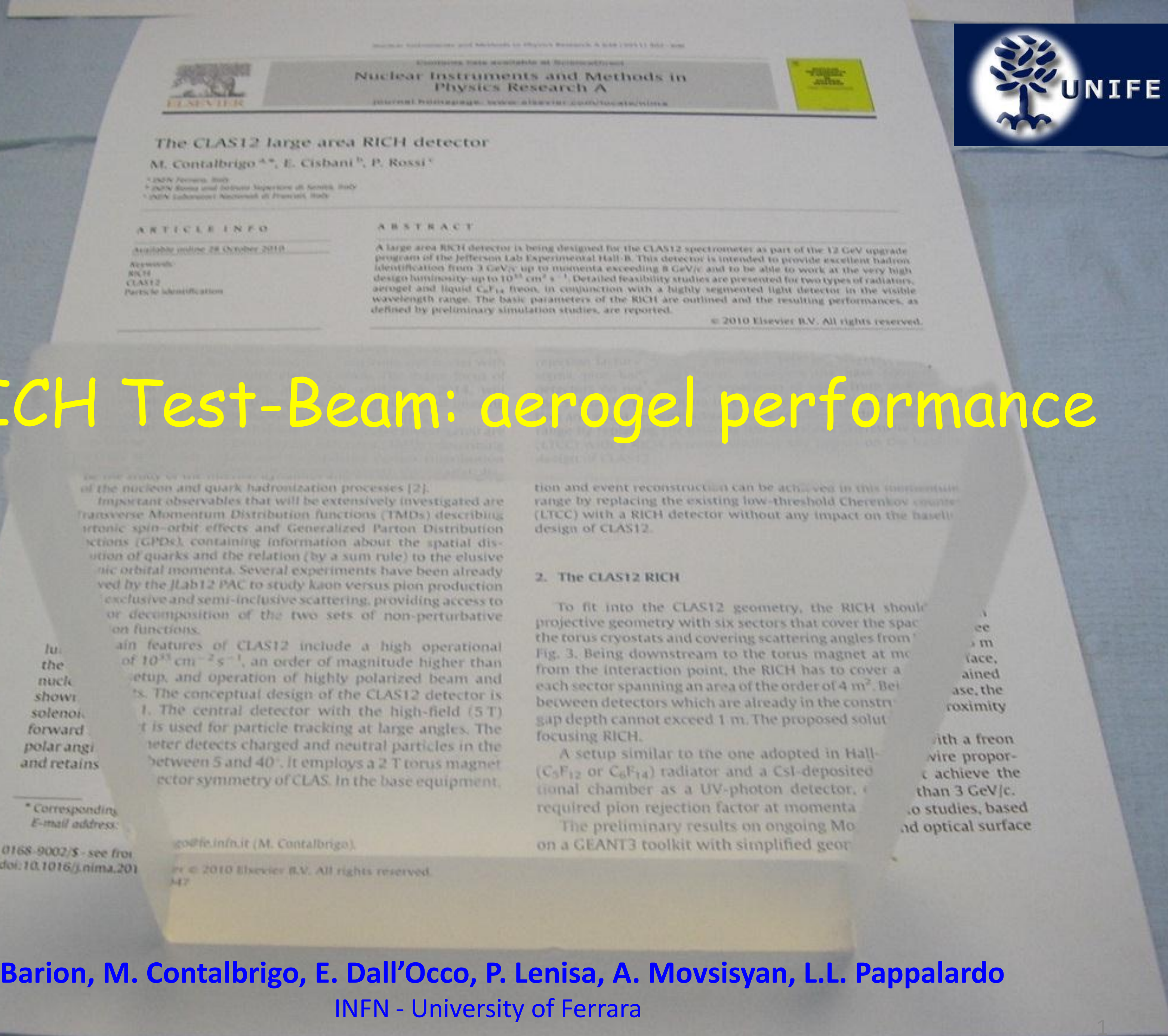
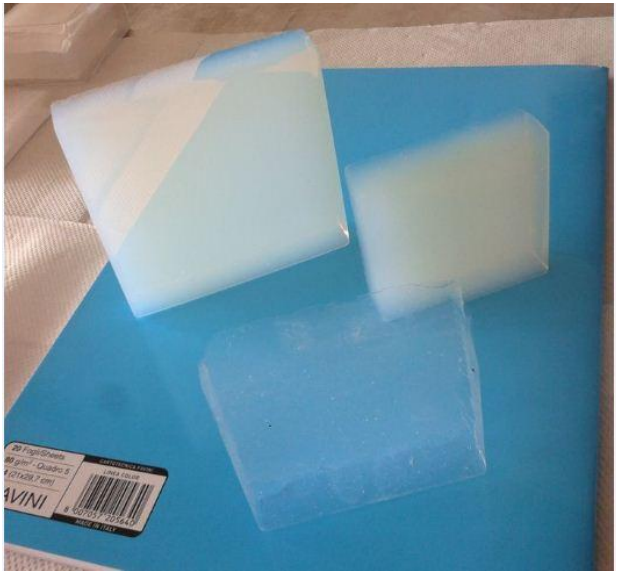


RICH Test-Beam: aerogel performance

L. Barion, M. Contalbrigo, E. Dall'Occo, P. Lenisa, A. Movsisyan, L.L. Pappalardo
INFN - University of Ferrara

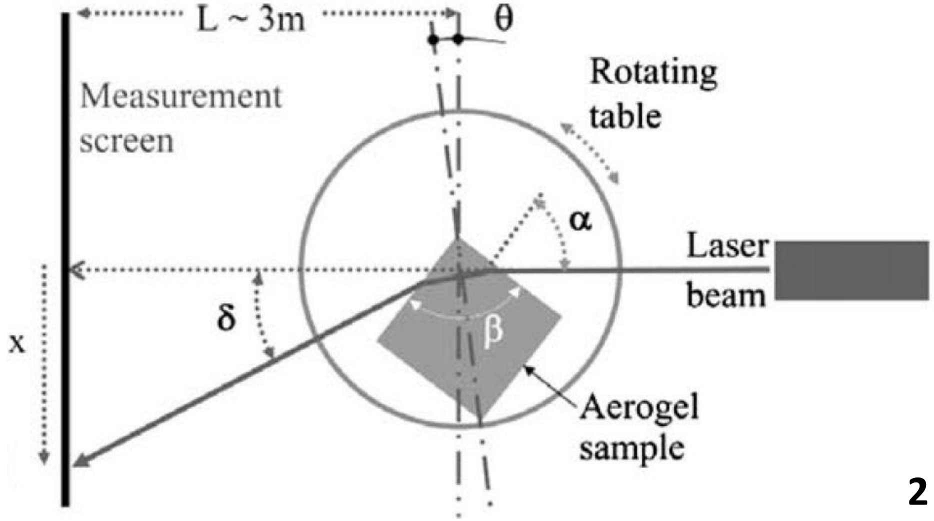
Characterization of aerogel tiles

- Geometry (area, thickness) →

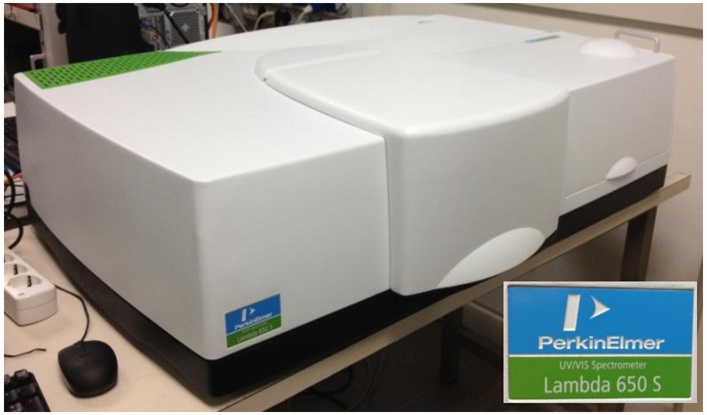


- refractive index
- Transmittance
- Absorption length
- Scattering length

prism method

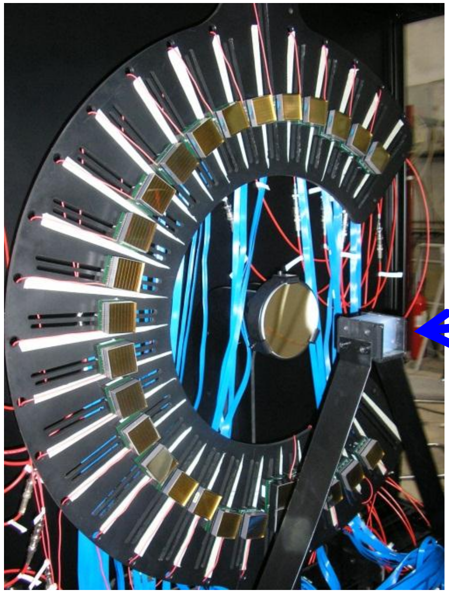


spectrophotometer

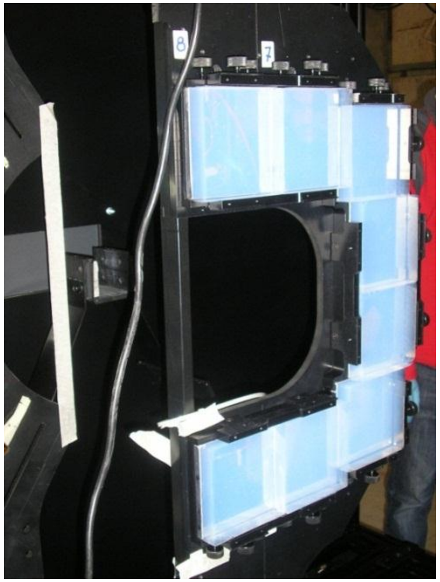


Part 1
Measuring Transmittance, scattering and absorption length

direct light



reflected light

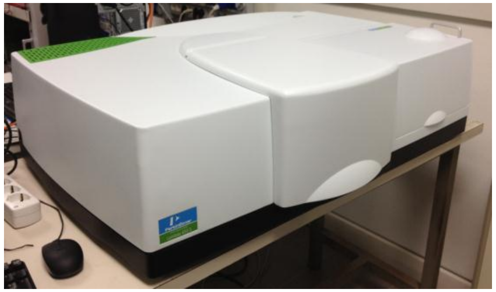


Aerogel tiles used in August 2012 Test-beam

Name	n	thickness (cm)	area (cm × cm)
Nov 1.04 2cm tile1	1.04	2	6×6
Nov 1.05 2cm tile1	1.05	2	6×6
Nov 1.05 2cm tile2	1.05	2	6×6
Nov 1.06 2cm tile1	1.06	2	6×6
Nov 1.05 3cm tile1	1.05	3	6×6
Nov 1.05 3cm tile3	1.05	3	6×6
Nov 1.05 3cm tile4	1.05	3	6×6
Nov 1.06 3cm tile1	1.06	3	6×6
Nov 1.06 3cm tile2	1.06	3	6×6
Nov 1.05 2cm Sample1	1.05	2	10×10
Nov 1.05 2cm Sample2	1.05	2	10×10
Nov 1.05 2cm Sample3	1.05	2	10×10
Nov 1.05 2cm Sample4	1.05	2	10×10
Nov 1.05 2cm Sample5	1.05	2	10×10
Nov 1.05 2cm Sample6	1.05	2	10×10
Nov 1.05 2cm Sample7	1.05	2	10×10
Nov 1.05 2cm Sample8	1.05	2	10×10
Nov 1.05 3cm AMS1	1.05	3	10×10
Nov 1.05 3cm AMS2	1.05	3	10×10
Nov 1.05 3cm AMS3	1.05	3	10×10
Nov 1.05 3cm AMS4	1.05	3	10×10

- 3 refractive indices (1.04, 1.05, 1.06)
- 2 thicknesses (2cm, 3cm)
- 2 areas $6 \times 6\ cm^2, 10 \times 10\ cm^2$)

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

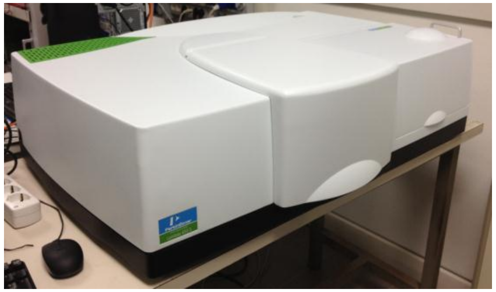
$$A = TF = e^{-t/\Lambda_A} \Longrightarrow$$

Transflectance

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

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

Basic formalism and selected results



Transmittance

Hunt formula

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Transflectance

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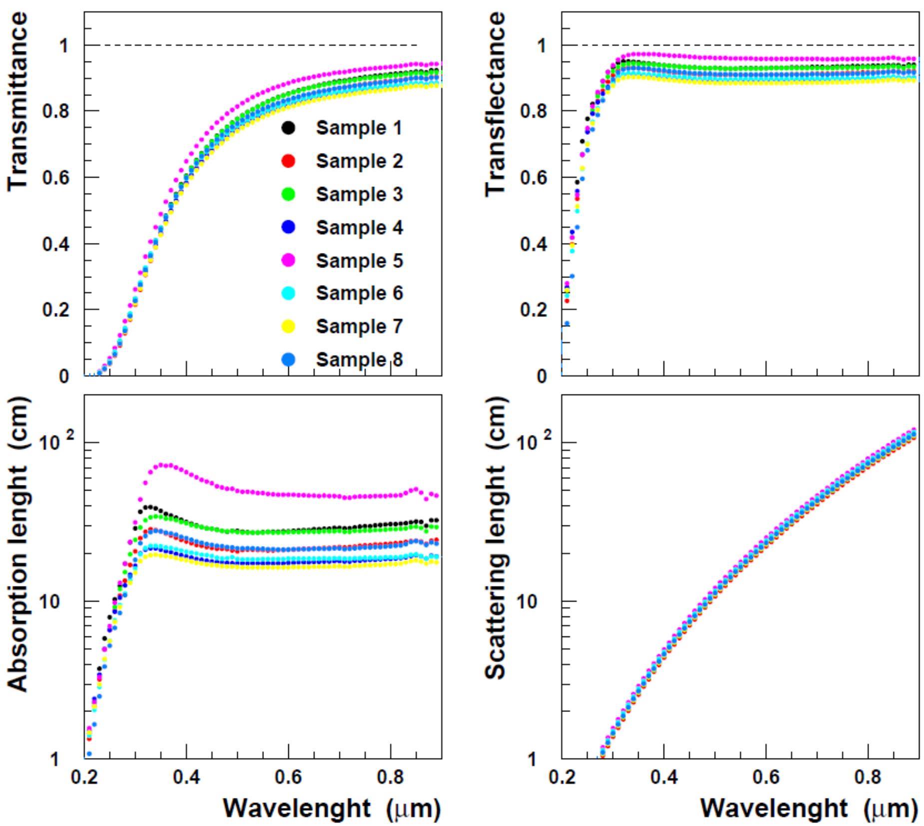
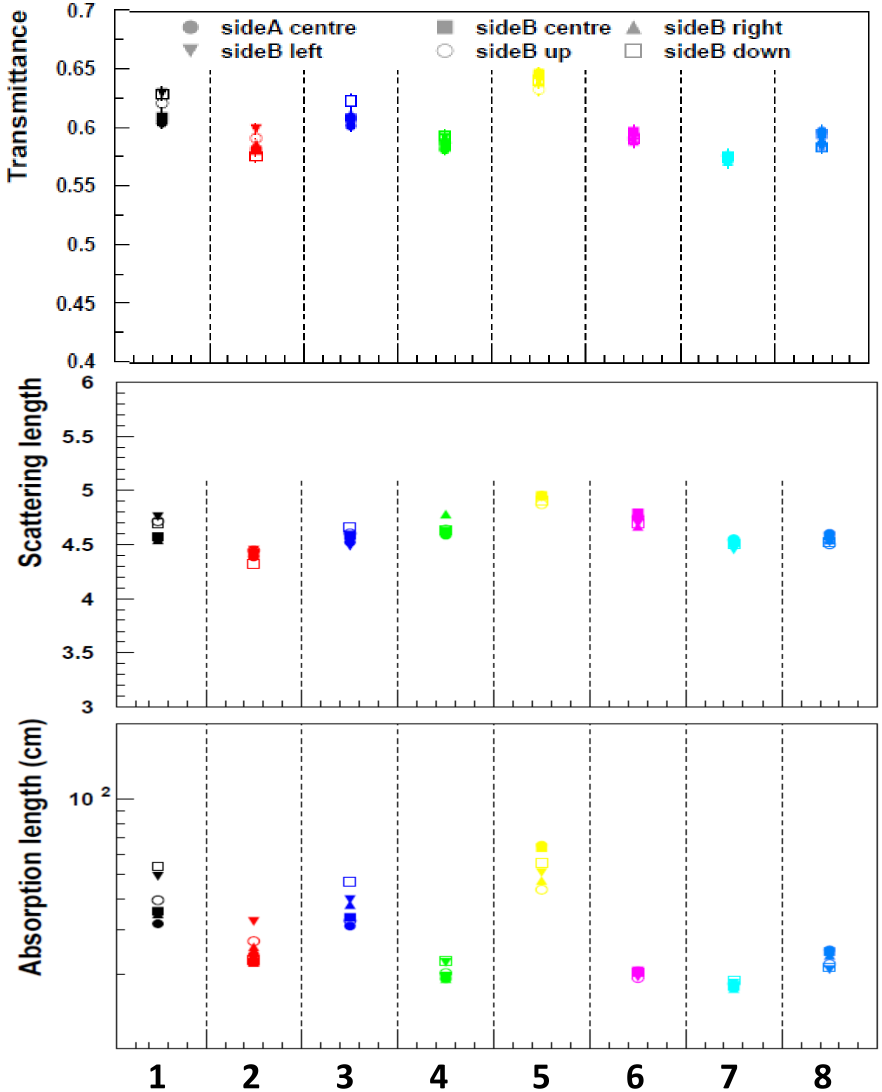


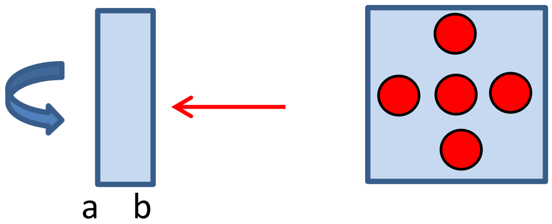
Aerogel tiles used in August 2012 Test-beam

Name	n	thickness (cm)	area (cm × cm)
Nov 1.04 2cm tile1	1.04	2	6 × 6
Nov 1.05 2cm tile1	1.05	2	6 × 6
Nov 1.05 2cm tile2	1.05	2	6 × 6
Nov 1.06 2cm tile1	1.06	2	6 × 6
Nov 1.05 3cm tile1	1.05	3	6 × 6
Nov 1.05 3cm tile3	1.05	3	6 × 6
Nov 1.05 3cm tile4	1.05	3	6 × 6
Nov 1.06 3cm tile1	1.06	3	6 × 6
Nov 1.06 3cm tile2	1.06	3	6 × 6
Nov 1.05 2cm Sample1	1.05	2	10 × 10
Nov 1.05 2cm Sample2	1.05	2	10 × 10
Nov 1.05 2cm Sample3	1.05	2	10 × 10
Nov 1.05 2cm Sample4	1.05	2	10 × 10
Nov 1.05 2cm Sample5	1.05	2	10 × 10
Nov 1.05 2cm Sample6	1.05	2	10 × 10
Nov 1.05 2cm Sample7	1.05	2	10 × 10
Nov 1.05 2cm Sample8	1.05	2	10 × 10
Nov 1.05 3cm AMS1	1.05	3	10 × 10
Nov 1.05 3cm AMS2	1.05	3	10 × 10
Nov 1.05 3cm AMS3	1.05	3	10 × 10
Nov 1.05 3cm AMS4	1.05	3	10 × 10

Measurements at 400nm

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



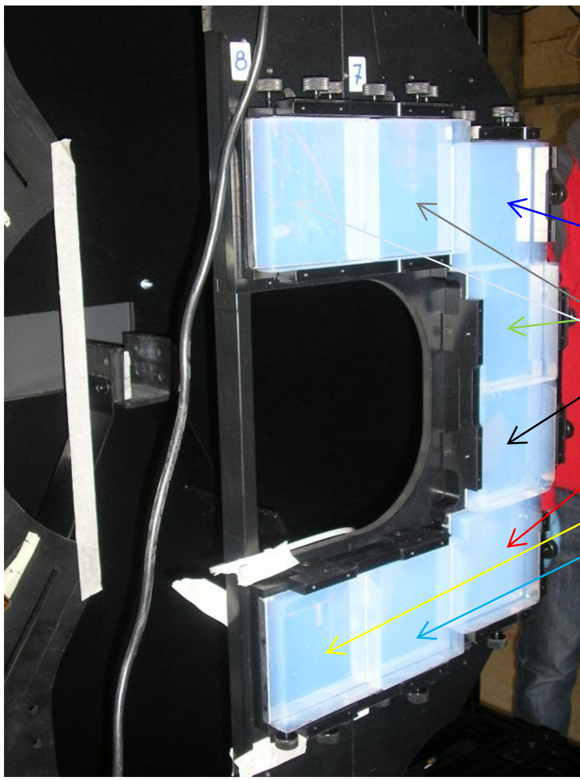


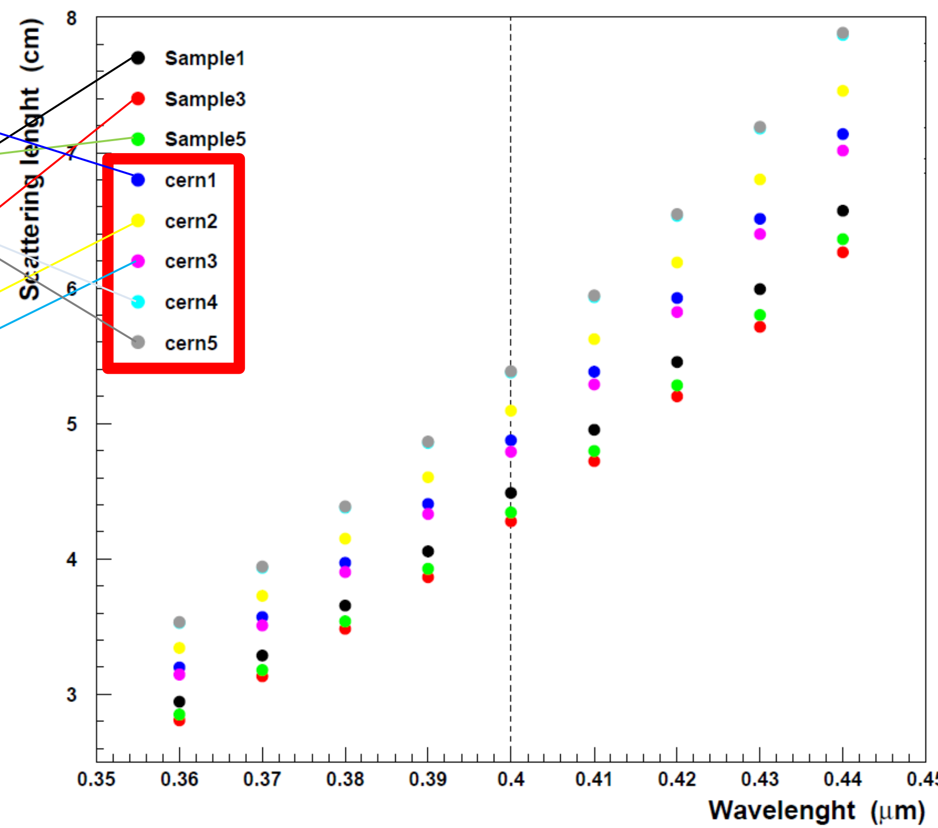
Name	T	Λ_A (cm)	Λ_S (cm)
Sample 1	0.617	40.7	4.6
Sample 2	0.587	26.6	4.4
Sample 3	0.610	36.9	4.6
Sample 4	0.589	20.4	4.6
Sample 5	0.642	54.5	4.9
Sample 6	0.593	20.1	4.7
Sample 7	0.575	18.1	4.5
Sample 8	0.590	22.9	4.5
Average	**0.600**	**31.4**	**4.6**

Improvements in production techniques (Novosibirsk)

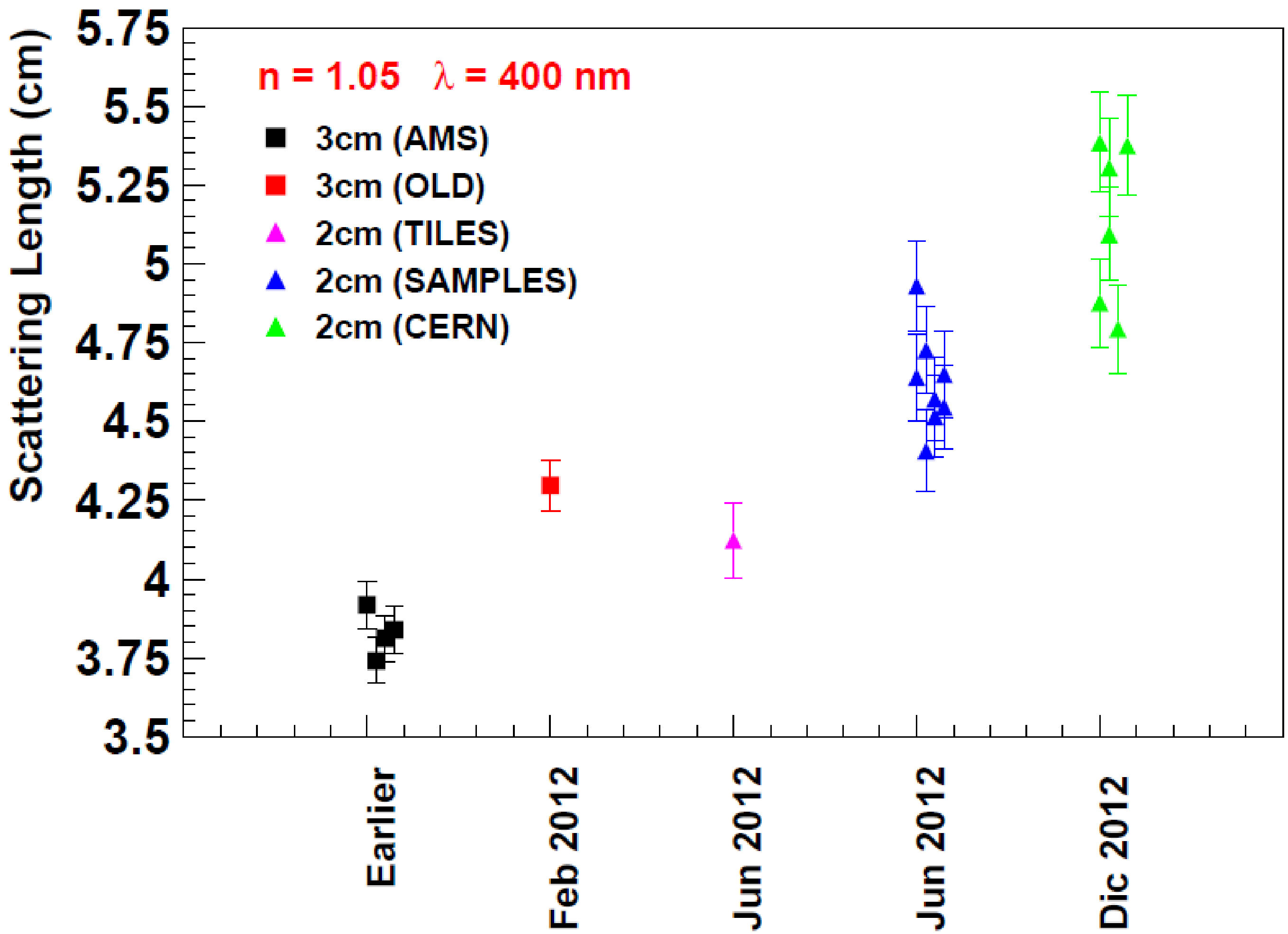
Name		n	thickness (cm)	area (cm × cm)
Nov 1.05 2cm	cern1	1.05	2	10 × 10
Nov 1.05 2cm	cern2	1.05	2	10 × 10
Nov 1.05 2cm	cern3	1.05	2	10 × 10
Nov 1.05 2cm	cern4	1.05	2	10 × 10
Nov 1.05 2cm	cern5	1.05	2	10 × 10

December 2012 test-beam



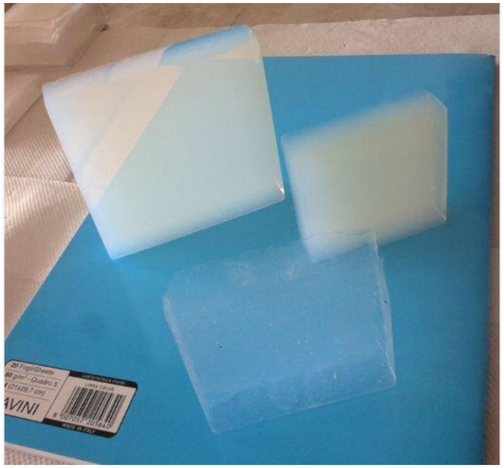


Improvements in production techniques (Novosibirsk)

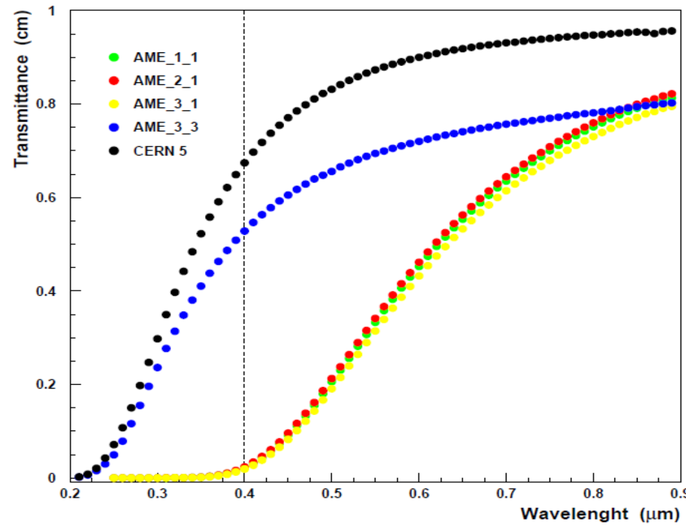


There is a clear trend showing that the production technique and the resulting quality of the aerogel is significantly improving in time.

Optical properties of APEN aerogel

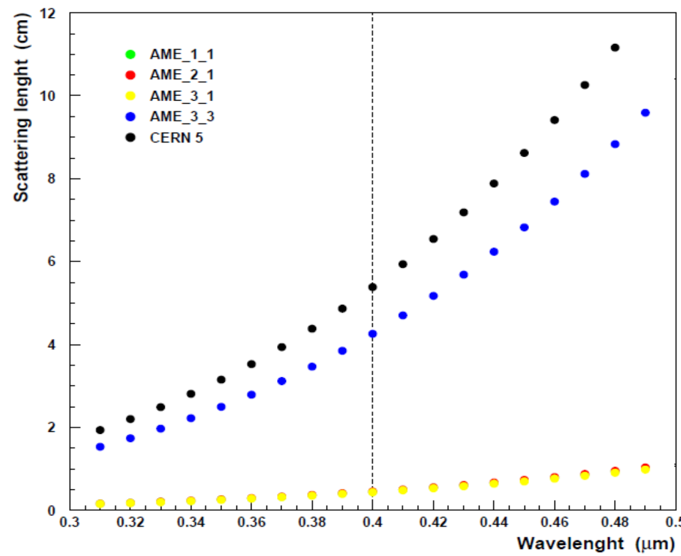


- 10 tiles
- 3 formats: large, medium, small
- 2 thickness: 1.7 cm, 0.95 cm
- 2 refractive indices:
  $n = 1.05$ (9 tiles)
  $n = 1.01$ (1 tile)



@ 400 nm (T, Λ_A, Λ_S)

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

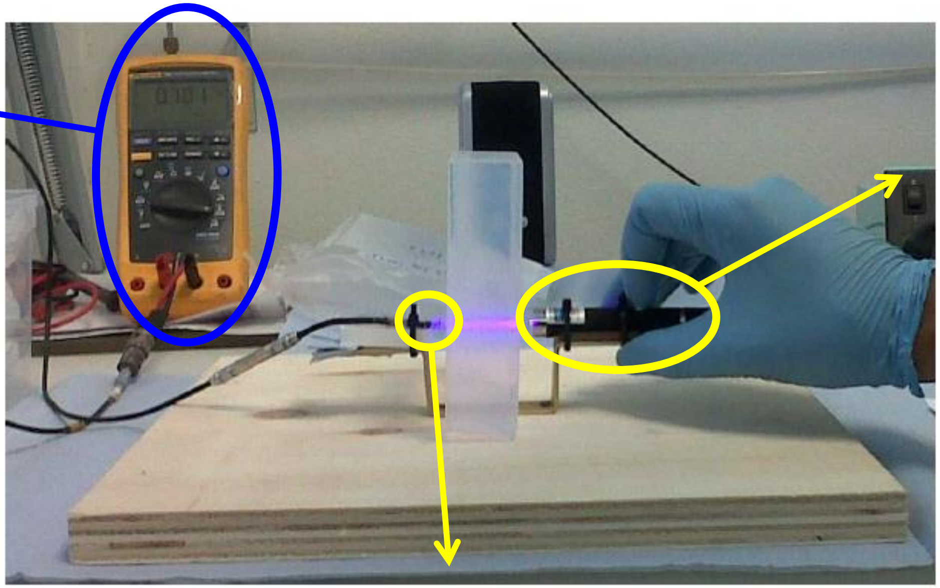
The Novosibirsk aerogel is **hydrophilic**, i.e. tends to absorb humidity from the air, resulting in a worsening of the optical preformances ➡ need to periodically monitor the transparency

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

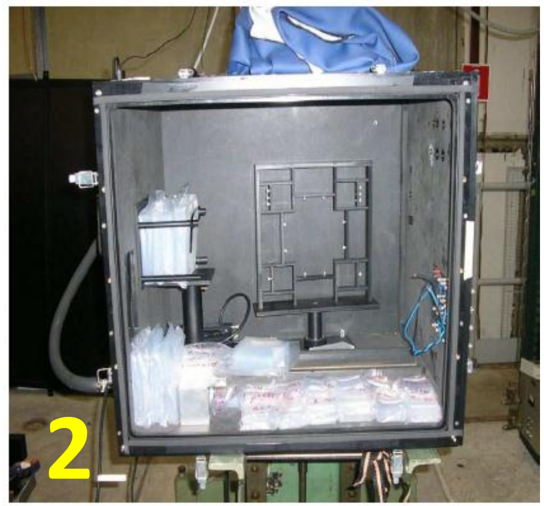
The method is fast (few minutes for each set of 10 measurements) but introduces several systematic effects (laser-photodiode distance, aerogel local non-homogeneities, laser instabilities) that result in a broadening of the measured transparencies.

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 tet-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

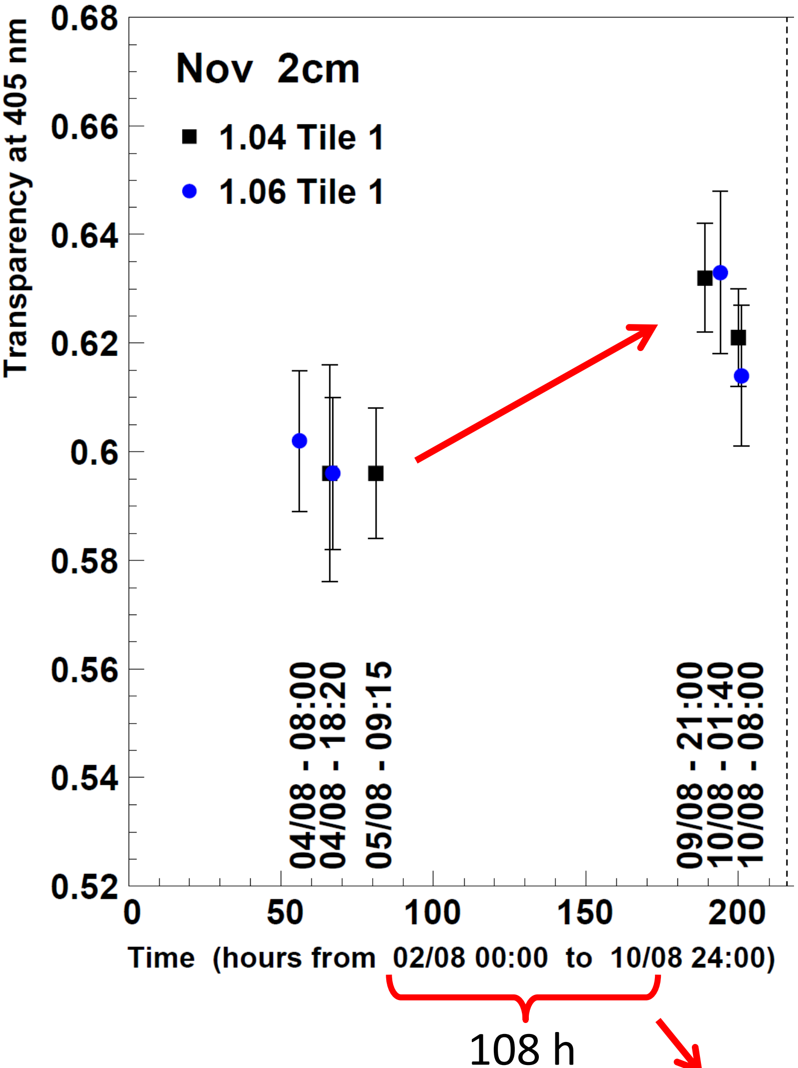


Table 2: Nov. 1.04 2cm tile1

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

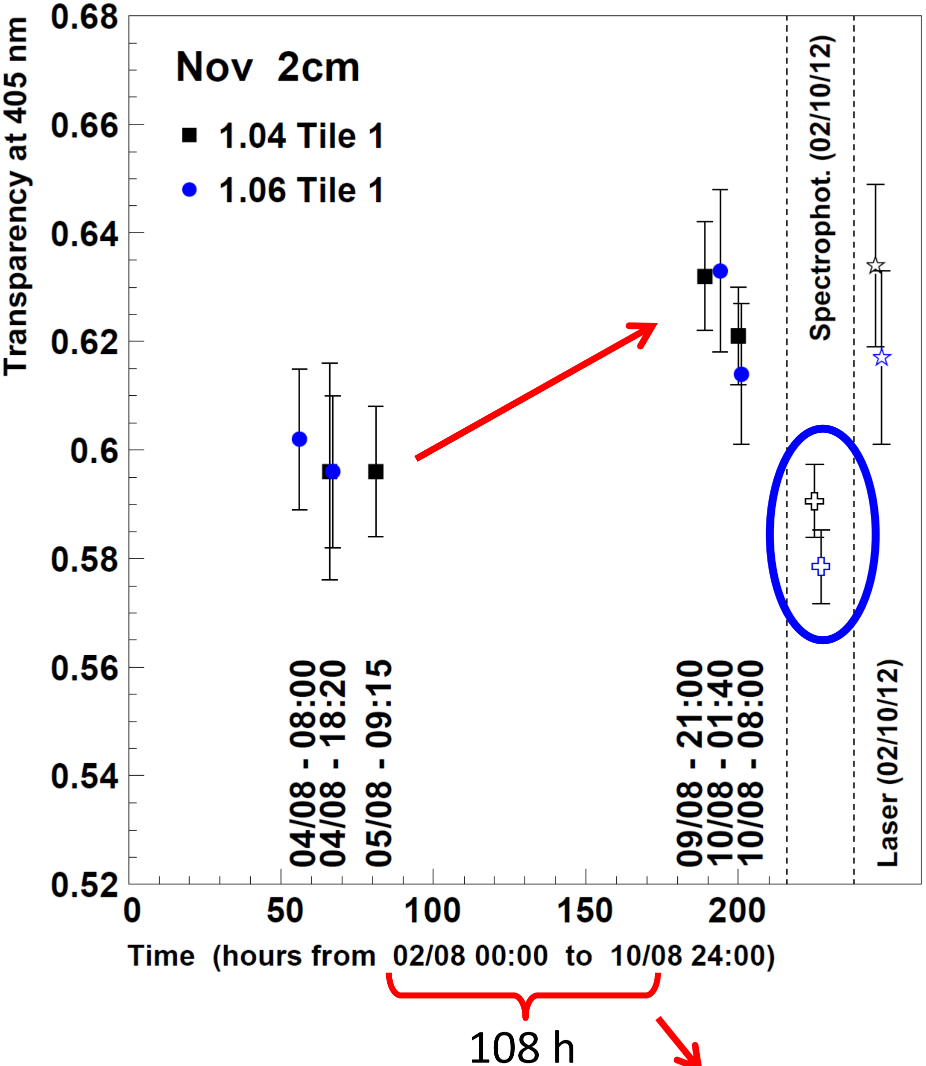
Table 3: Nov. 1.06 2cm tile1

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

Storage in box with nitrogen

Some results

Spectrophotometer measurements are found to be systematically smaller



Storage in box with nitrogen

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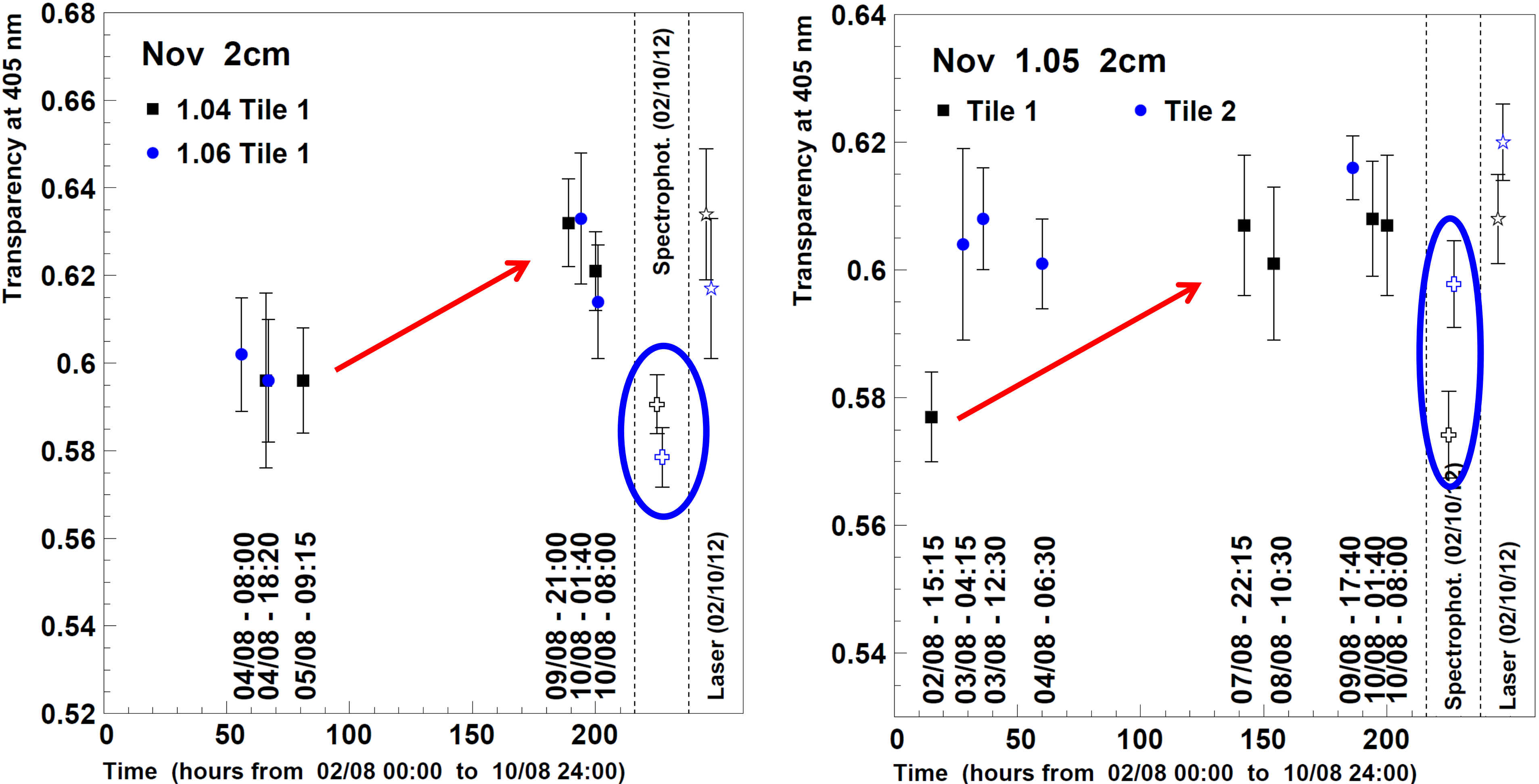
10/08/2012 08:00	0.608	0.637	0.621	0.009	meas. before final packing
02/10/2012	0.608	0.654	0.634	0.015	meas. in Ferrara (laser)
02/10/2012			0.591	0.007	meas. in Ferrara (spectrophot.)

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
02/10/2012	0.590	0.639	0.617	0.016	meas. in Ferrara (laser)
02/10/2012			0.578	0.007	meas. in Ferrara (spectrophot.)

Some results

Spectrophotometer measurements are found to be systematically smaller



108 h

127 h

Storage in box with nitrogen

Looking for a general trend

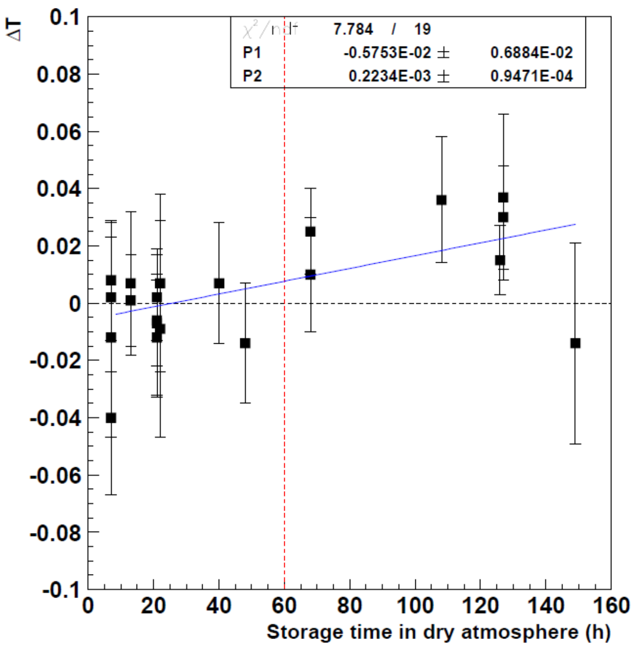
After storage in dry atmosphere (box fluxed with nitrogen)

Aerogel tile	storage time (h)	T_{before}	T_{after}	ΔT
Nov. 1.05 3cm tile4	149	0.391 ± 0.018	0.377 ± 0.017	-0.014 ± 0.035
Nov. 1.06 2cm tile1	127	0.596 ± 0.014	0.633 ± 0.015	+0.037 ± 0.029
Nov. 1.05 2cm tile1	127	0.577 ± 0.007	0.607 ± 0.011	+0.030 ± 0.018
Nov. 1.05 2cm tile2	126	0.601 ± 0.007	0.616 ± 0.005	+0.015 ± 0.012
Nov. 1.04 2cm tile1	108	0.596 ± 0.012	0.632 ± 0.010	+0.036 ± 0.022
Nov. 1.06 3cm tile1	68	0.455 ± 0.007	0.465 ± 0.013	+0.010 ± 0.020
Nov. 1.06 3cm tile2	68	0.455 ± 0.007	0.480 ± 0.008	+0.025 ± 0.015
Nov. 1.05 3cm tile3	48	0.392 ± 0.009	0.378 ± 0.012	-0.014 ± 0.021
Nov. 1.05 2cm tile1	40	0.601 ± 0.012	0.608 ± 0.009	+0.007 ± 0.021
Nov. 1.05 3cm tile1	22	0.386 ± 0.023	0.377 ± 0.015	-0.009 ± 0.038
Nov. 1.05 3cm tile3	22	0.363 ± 0.015	0.370 ± 0.016	+0.007 ± 0.031
Nov. 1.05 3cm AMS1	21	0.459 ± 0.009	0.461 ± 0.006	+0.002 ± 0.015
Nov. 1.05 3cm AMS2	21	0.471 ± 0.009	0.465 ± 0.007	-0.006 ± 0.016
Nov. 1.05 3cm AMS3	21	0.459 ± 0.013	0.452 ± 0.013	-0.007 ± 0.026
Nov. 1.05 3cm AMS4	21	0.463 ± 0.007	0.451 ± 0.013	-0.012 ± 0.020
Nov. 1.06 3cm tile1	13	0.458 ± 0.012	0.465 ± 0.013	+0.007 ± 0.025
Nov. 1.06 3cm tile2	13	0.475 ± 0.007	0.476 ± 0.009	+0.001 ± 0.016
Nov. 1.05 2cm sample1	7	0.641 ± 0.007	0.649 ± 0.014	+0.008 ± 0.021
Nov. 1.05 2cm sample3	7	0.638 ± 0.011	0.626 ± 0.024	-0.012 ± 0.035
Nov. 1.05 2cm sample4	7	0.620 ± 0.008	0.580 ± 0.019	-0.040 ± 0.027
Nov. 1.05 2cm sample5	7	0.656 ± 0.015	0.658 ± 0.011	+0.002 ± 0.026

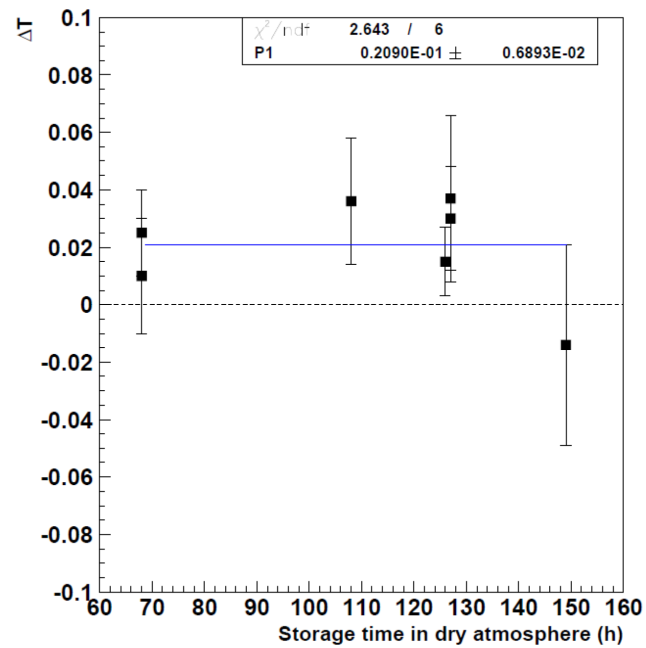
$> 60\ h$ (first 7 rows)

$< 60\ h$ (remaining rows)

Looking for a general trend



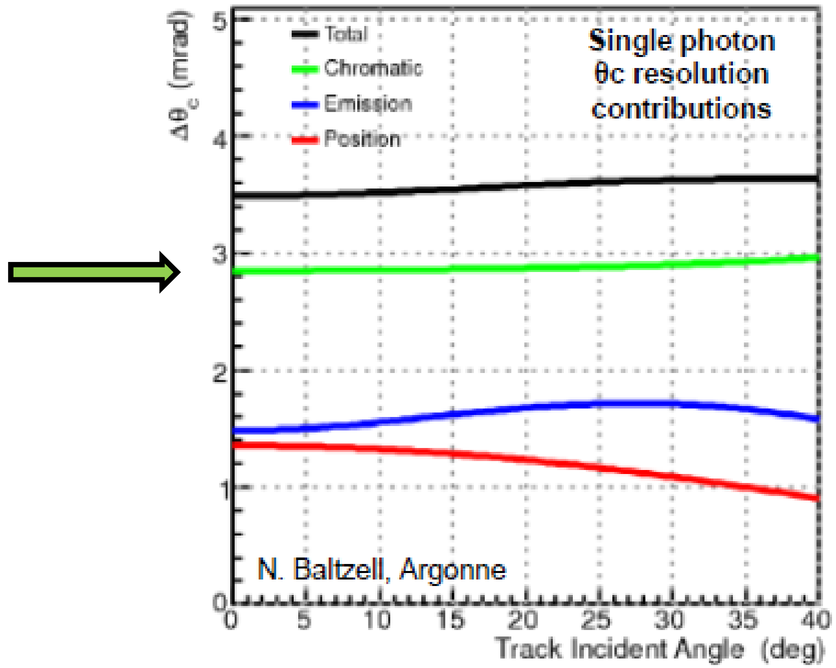
1^{st} order polynomial fit:
hint of a slop (but low significance)



0^{th} order polynomial fit (constant):
$const \approx 0.021 \pm 0.007 \quad \rightarrow 3\sigma$

- There is an evidence of partial transparency restoration after at least 60 hours of storage in dry (nitrogen) atmosphere
- Storage periods shorter than 60 hours do not result in appreciable improvements
- Periods in which the aeogel was exposed to air (i.e. To humidity) were too short (< 60h) to produce any appreciable effect on the transparency

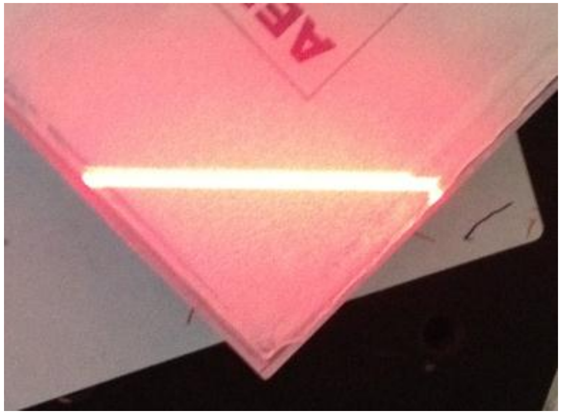
Part 3
Measures of refracting index and dispersion law



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

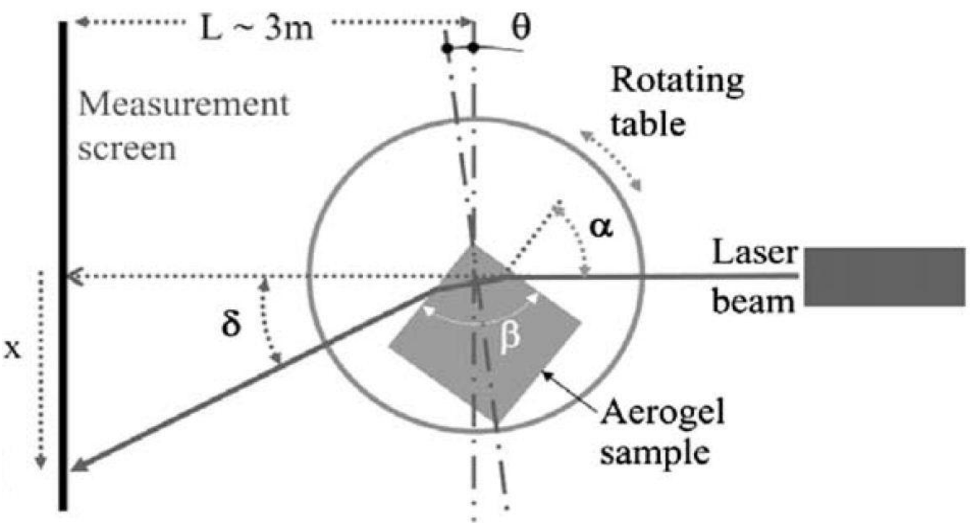
The “standard prism” method

- 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:**

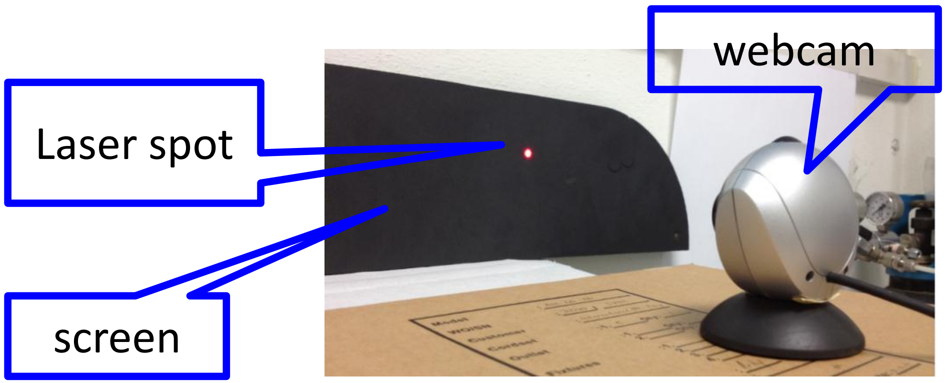
$$\delta = \alpha - \beta + \arcsin\left\{ n \cdot \sin\left[\beta - \arcsin\left(\frac{\sin\alpha}{n} \right) \right] \right\}$$

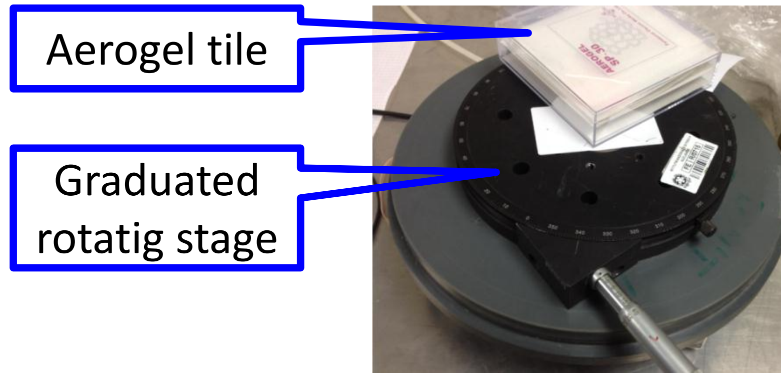


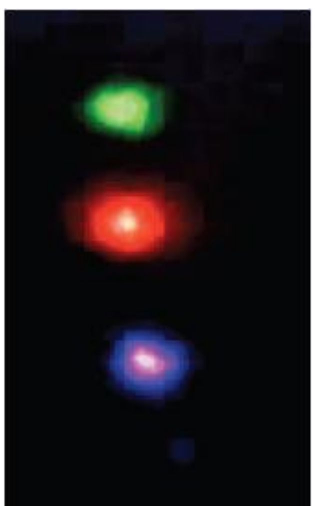
NIM A 614 (2010)

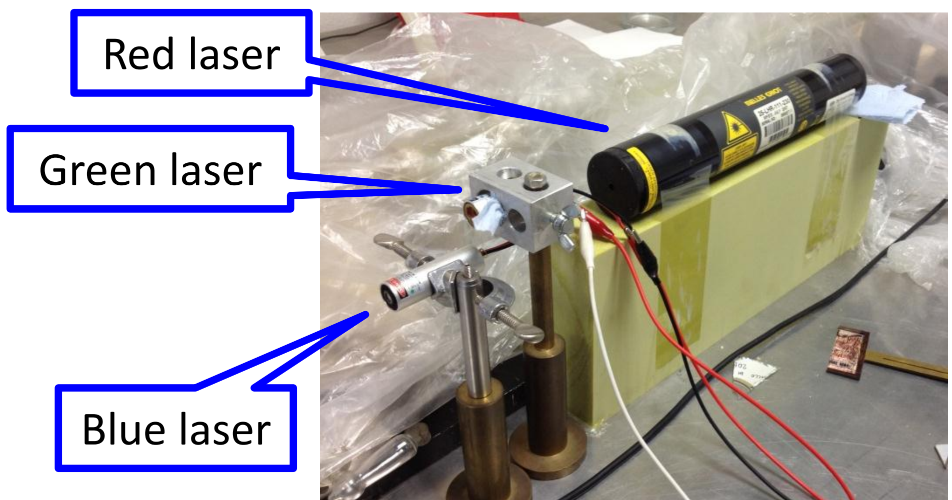
The Ferrara set-up

- 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)



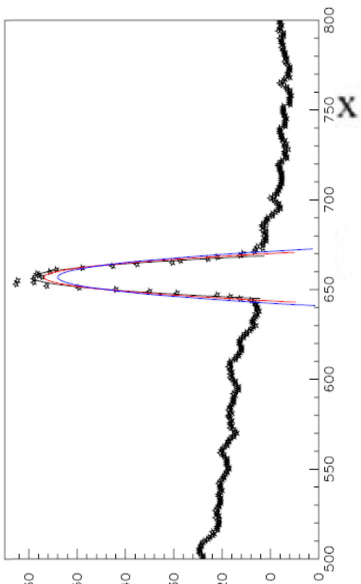


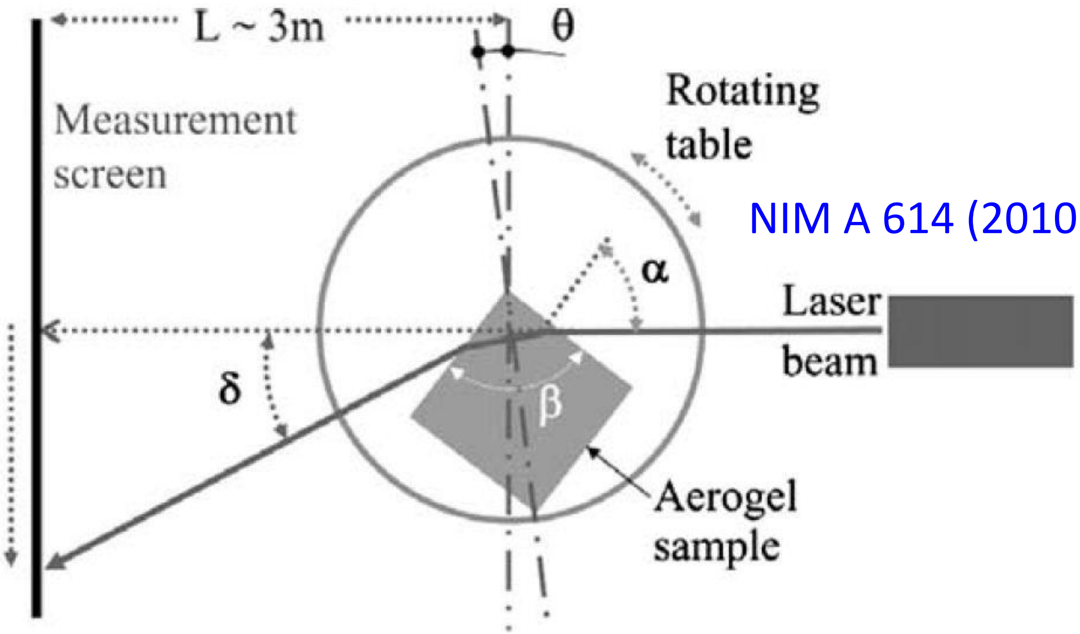




The procedure

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

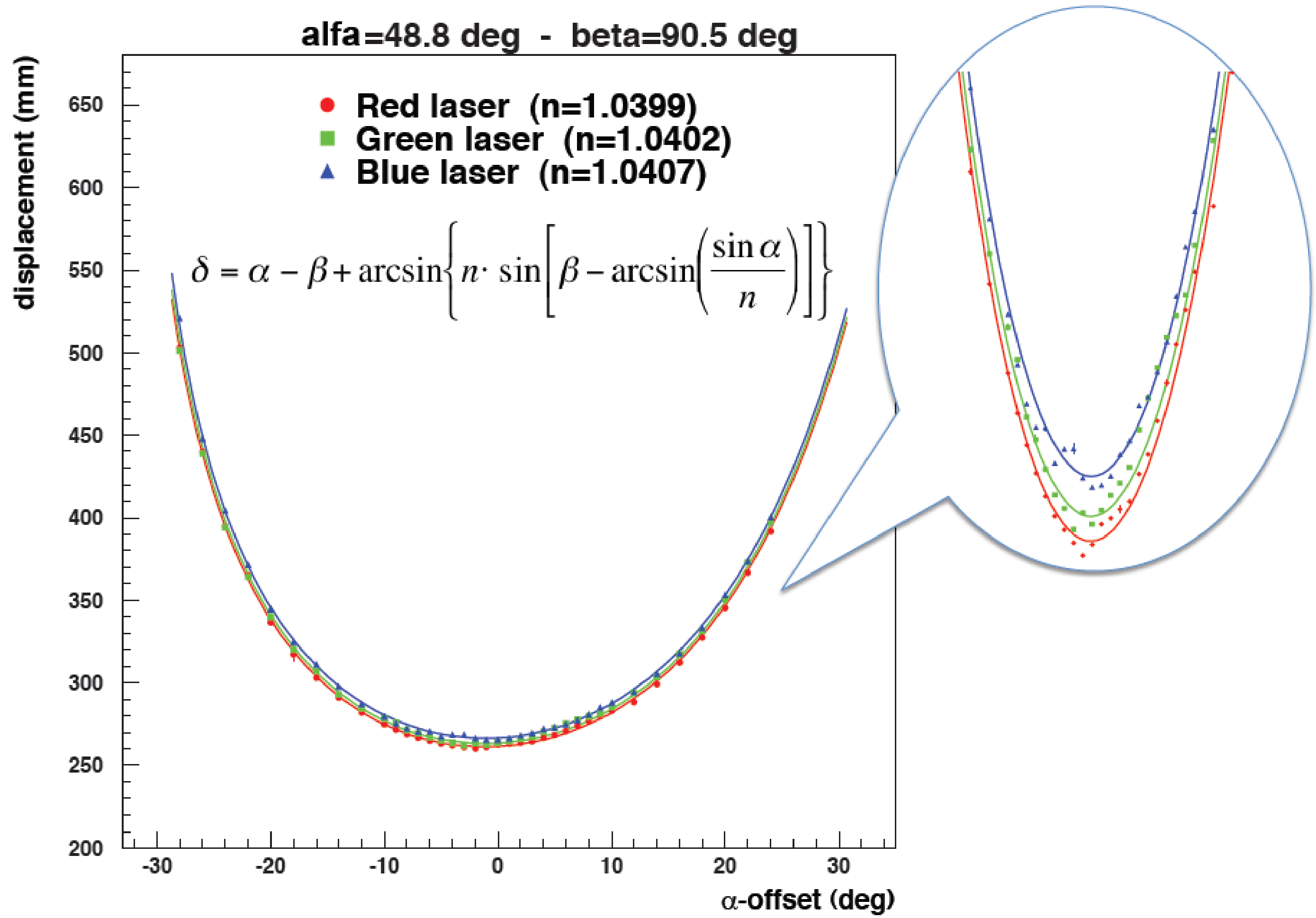




NIM A 614 (2010)

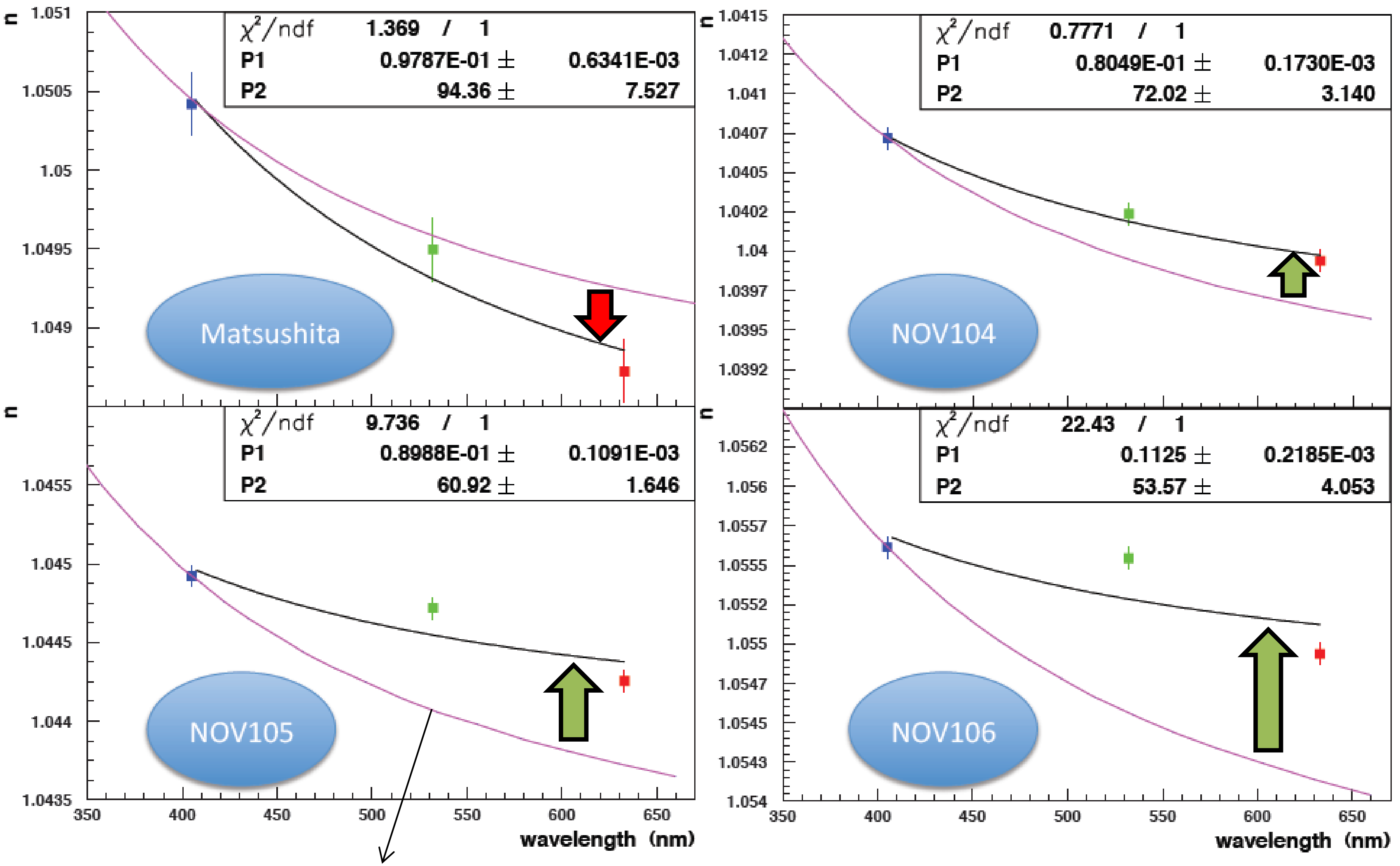
3. The positions of the maxima are plotted vs. α and fitted with the **Snell-Descarted law**

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

Ferrara is developing skills and tools for the characterization of the optical properties of aerogel tiles for the CLAS12 RICH

- A PerkinElmer spectrophotometer is being employed for the optical characterization of aerogel tiles (transmittance, absorption length and scattering length)

- Measurements show that the new generation aerogel from Novosibirsk have higher performances (higher transparency, longer scattering length)

- Studies on transparency deterioration (due to humidity absorption) have been carried out during the CERN test-beams using a simple set-up.
  Several procedures to recover/preserve transparency were tested and are being used.

- Measurements of refractive index and dispersion law were performed with the prims method using blue, red and green lasers. Preliminary data show a chromatic dispersion smaller than current expectations.

Back-up slides

The aerogel tiles from US

The refractive index at 400 nm, not provided by the manifacturer, was estimated through rough measurements of density using the empirical relation:

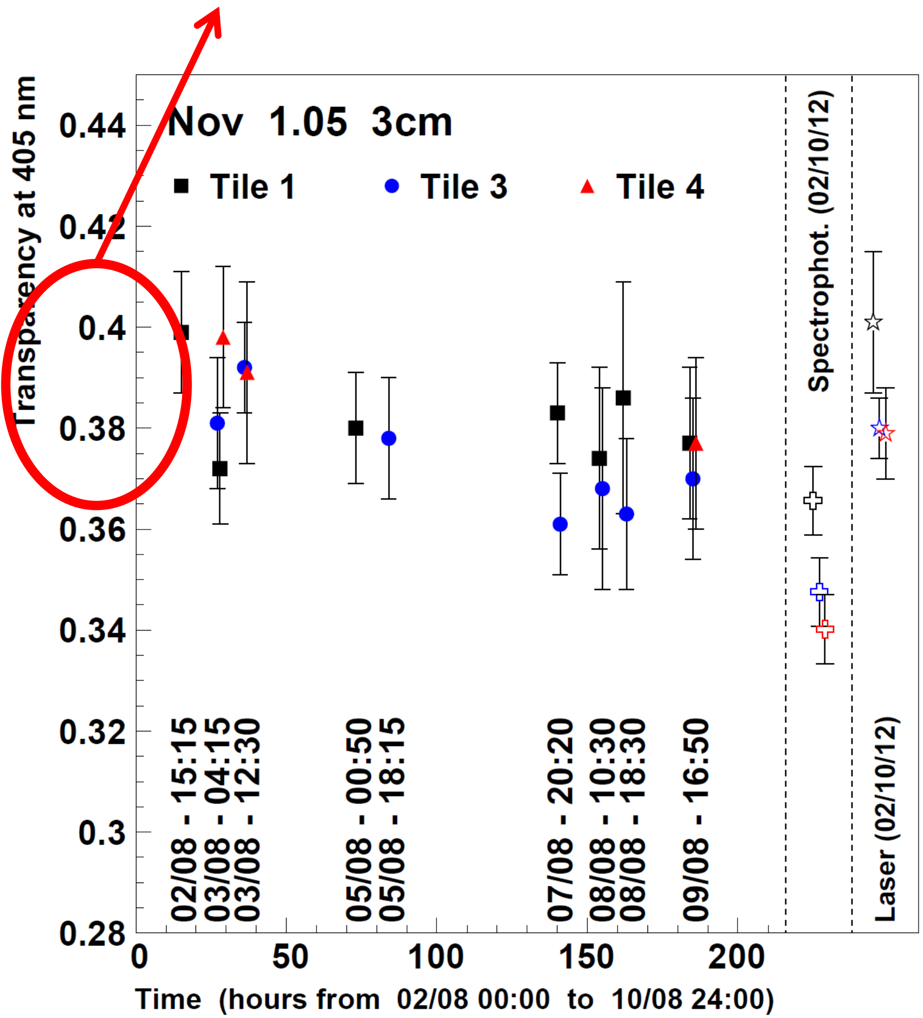
$$n^2(400\ nm) = 1 + 0.438 \cdot \rho$$

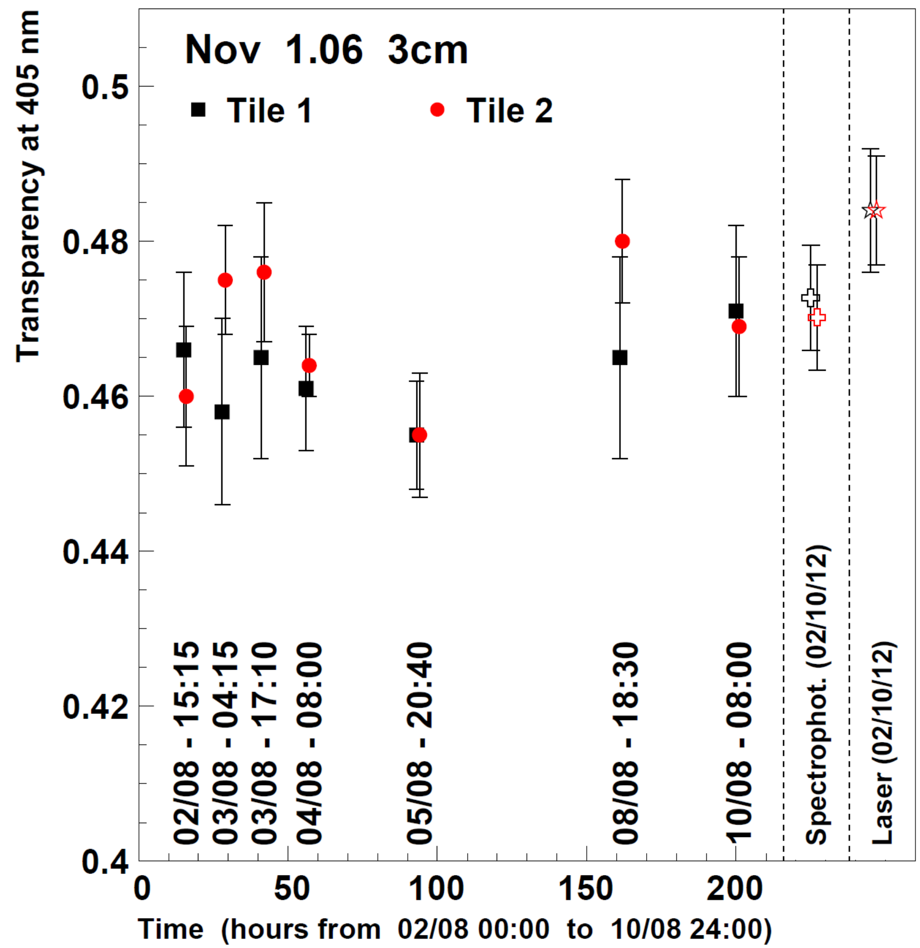
[A.F.Danilyuk et.al., Recent results on aerogel development for use in Cherenkov counters, NIM A494 (2002) 491]

Name	Size $[cm^3]$	ρ $[g/cm^3]$	n (400 nm)
AME_1_1	$9.5 \times 9.5 \times 1.7$	0.218	1.047
AME_1_2	$9.5 \times 9.5 \times 1.7$	0.223	1.048
AME_1_3	$9.5 \times 9.5 \times 1.7$	0.225	1.048
AME_2_1	$9.5 \times 9.5 \times 1.7$	0.219	1.047
AME_2_2	$9.5 \times 9.5 \times 1.7$	0.226	1.048
AME_3_1_A	$6.5 \times 6.5 \times 1.7$	0.217	1.046
AME_3_1_B	$6.5 \times 6.5 \times 1.7$	0.217	1.046
AME_3_2_A	$6.5 \times 6.5 \times 0.95$	0.246	1.052
AME_3_2_B	$6.5 \times 6.5 \times 0.95$	0.231	1.049
AME_3_3	$7.2 \times 7.2 \times 1.7$	0.070	1.015

Results

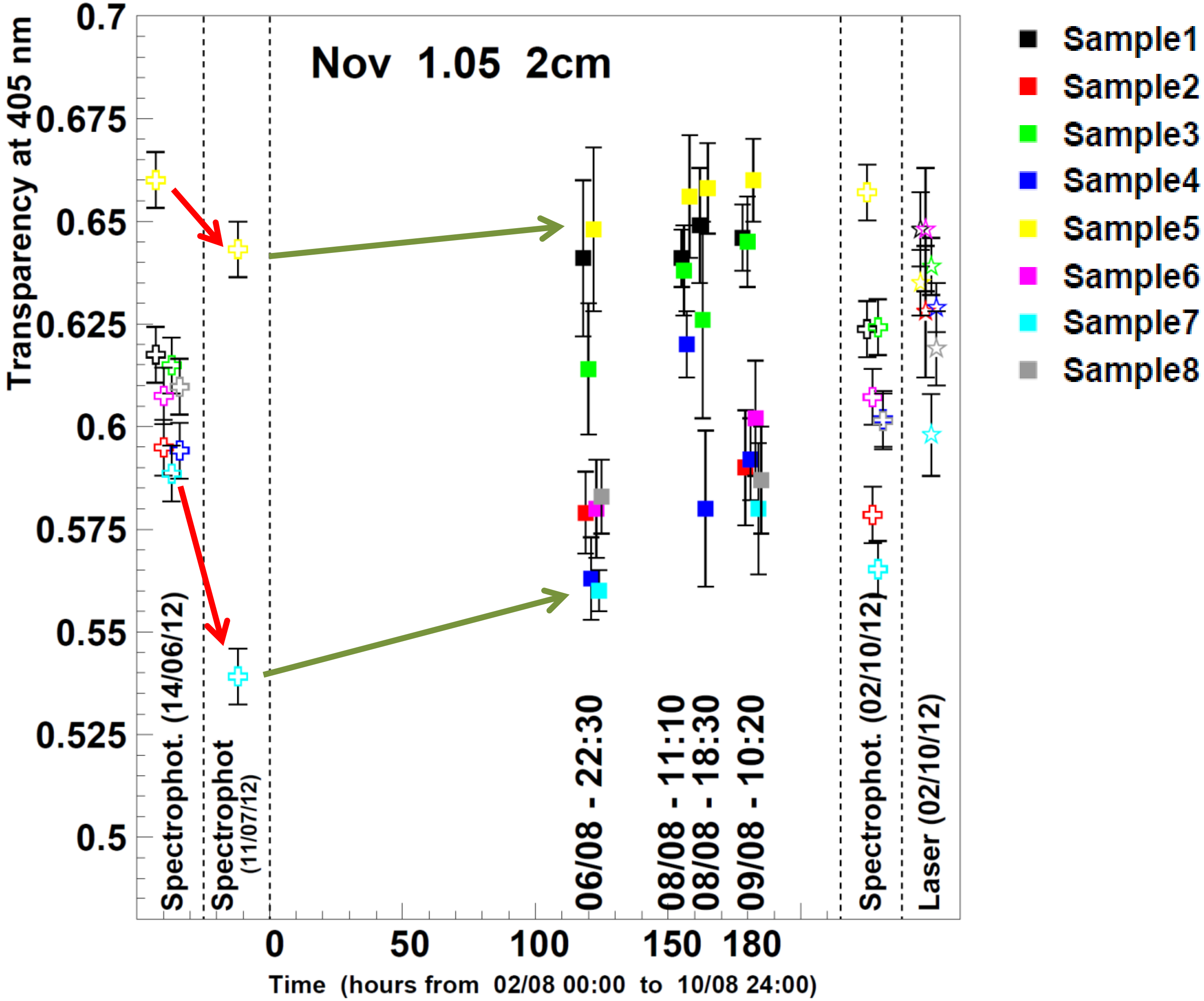
Very poor performances





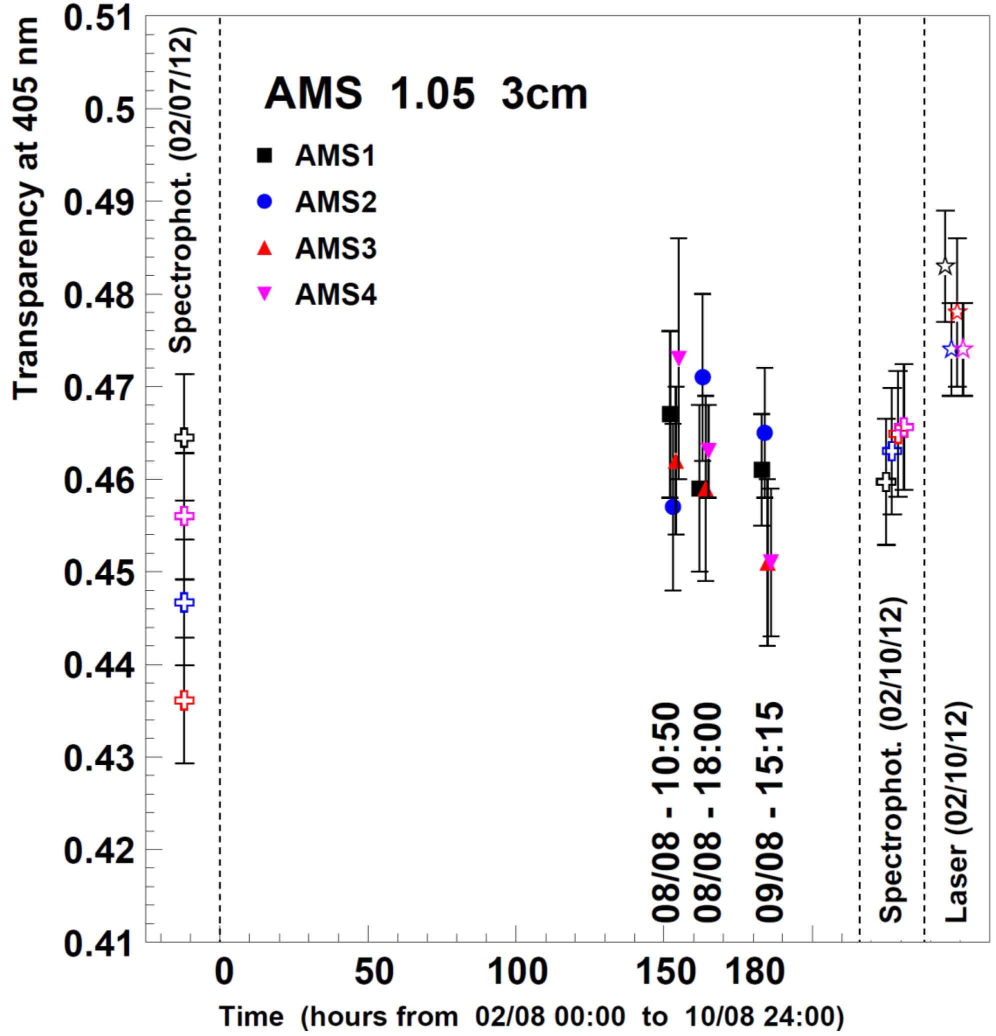
Results are relatively stable

Some results



After storage in dry cabinet

Results



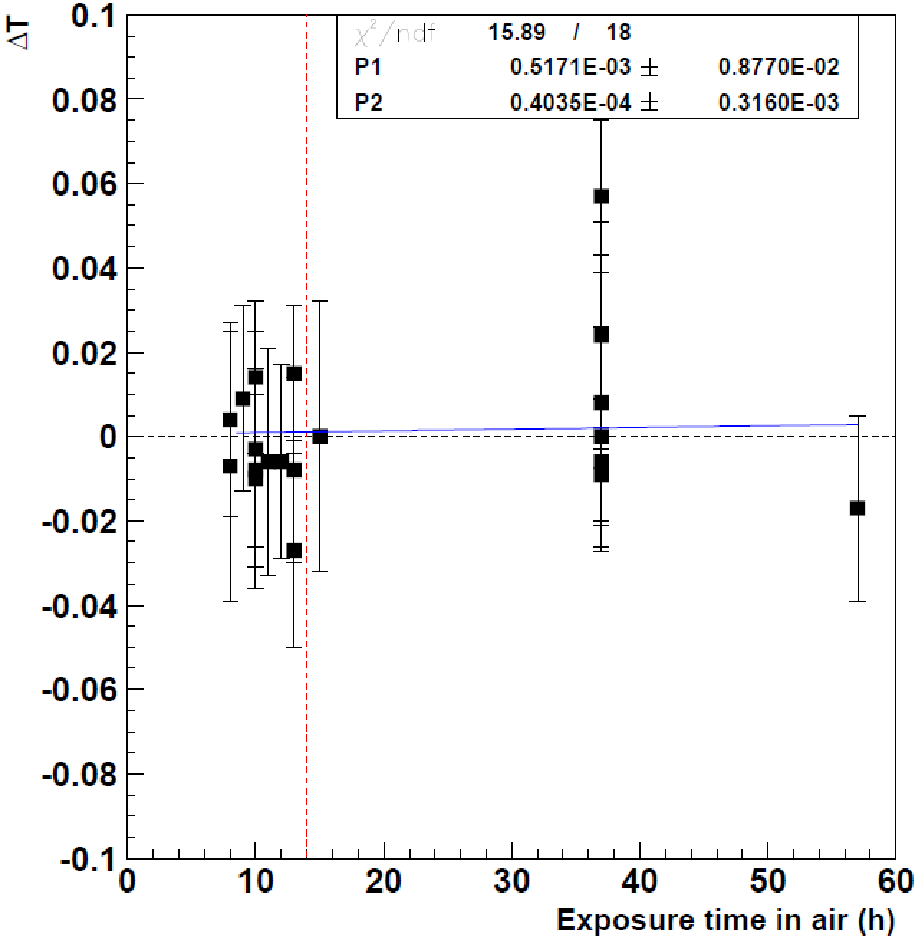
AMS 1.05 3cm
AMS1
AMS2
AMS3
AMS4
Transparency at 405 nm
0.51
0.5
0.49
0.48
0.47
0.46
0.45
0.44
0.43
0.42
0.41
Spectrophot. (02/07/12)
08/08 - 10:50
08/08 - 18:00
09/08 - 15:15
Spectrophot. (02/10/12)
Laser (02/10/12)
0
50
100
150
180
Time (hours from 02/08 00:00 to 10/08 24:00)

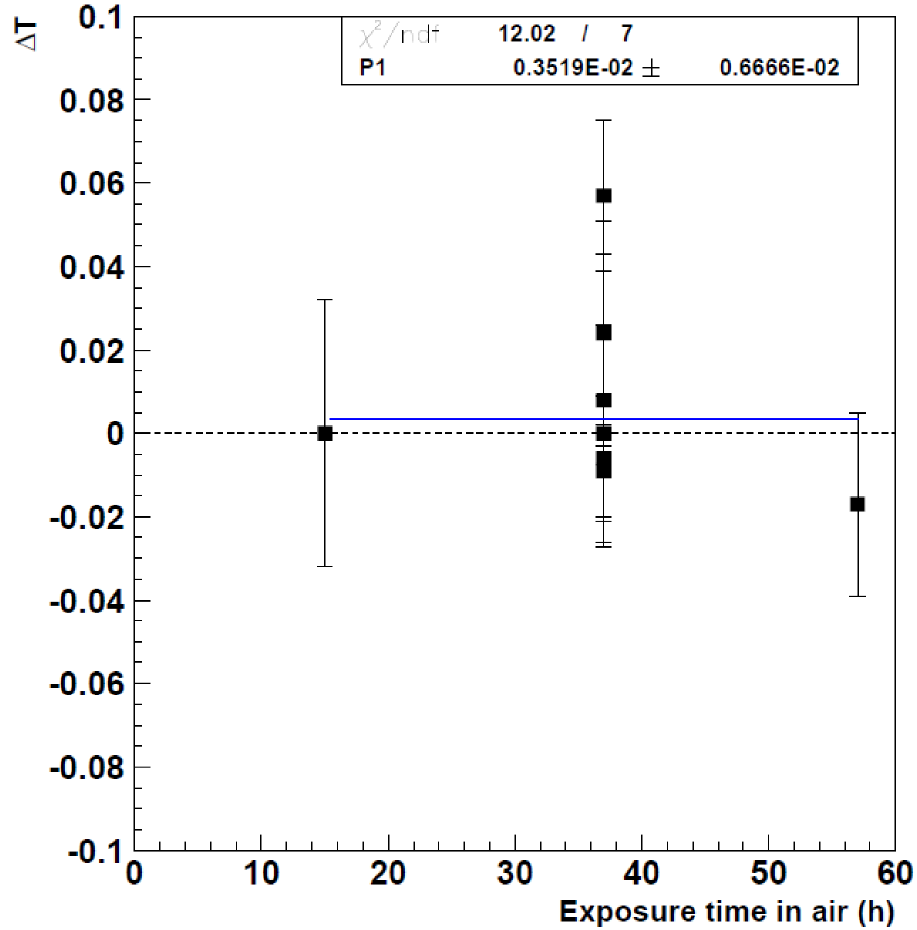
Looking for a general trend

After exposure to air

Tile	exposure time (h)	T_{before}	T_{after}	ΔT
Nov. 1.05 3cm tile3	57	0.378 ± 0.012	0.361 ± 0.010	-0.017 ± 0.022
Nov. 1.06 3cm tile1	37	0.461 ± 0.008	0.455 ± 0.007	-0.006 ± 0.015
Nov. 1.06 3cm tile2	37	0.464 ± 0.004	0.455 ± 0.007	-0.009 ± 0.011
Nov. 1.05 2cm sample1	37	0.641 ± 0.019	0.641 ± 0.007	0.000 ± 0.026
Nov. 1.05 2cm sample3	37	0.614 ± 0.016	0.638 ± 0.011	+0.024 ± 0.027
Nov. 1.05 2cm sample4	37	0.563 ± 0.010	0.620 ± 0.008	+0.057 ± 0.018
Nov. 1.05 2cm sample5	37	0.648 ± 0.020	0.656 ± 0.015	+0.008 ± 0.035
Nov. 1.04 2cm tile1	15	0.596 ± 0.020	0.596 ± 0.012	0.000 ± 0.032
Nov. 1.05 3cm tile1	13	0.399 ± 0.012	0.372 ± 0.011	-0.027 ± 0.023
Nov. 1.06 3cm tile1	13	0.466 ± 0.010	0.458 ± 0.012	-0.008 ± 0.022
Nov. 1.06 3cm tile2	13	0.460 ± 0.009	0.475 ± 0.007	+0.015 ± 0.016
Nov. 1.05 2cm tile1	12	0.607 ± 0.011	0.601 ± 0.012	-0.006 ± 0.023
Nov. 1.06 2cm tile1	11	0.602 ± 0.013	0.596 ± 0.014	-0.006 ± 0.027
Nov. 1.05 3cm AMS1	10	0.467 ± 0.009	0.459 ± 0.009	-0.008 ± 0.018
Nov. 1.05 3cm AMS2	10	0.457 ± 0.009	0.471 ± 0.009	+0.014 ± 0.018
Nov. 1.05 3cm AMS3	10	0.462 ± 0.015	0.459 ± 0.013	-0.003 ± 0.028
Nov. 1.05 3cm AMS4	10	0.473 ± 0.019	0.463 ± 0.007	-0.010 ± 0.026
Nov. 1.05 3cm tile3	9	0.381 ± 0.013	0.392 ± 0.009	+0.009 ± 0.022
Nov. 1.05 2cm tile2	8	0.604 ± 0.015	0.608 ± 0.008	+0.004 ± 0.023
Nov. 1.05 3cm tile4	8	0.398 ± 0.014	0.391 ± 0.018	-0.007 ± 0.032

Looking for a general trend





1^{st} order polynomial fit:
No significance (too short exposure times)

0^{th} order polynomial fit (constant):
No significance (too short exposure times)