Silica aerogel characterization for the ePIC dRICH detector

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on behalf of the ePIC Collaboration

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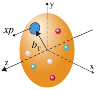
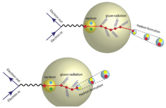
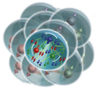
ePIC experiment: Why?

The main goal of the ePIC detector at the Electron-Ion Collider (EIC) is to explore new physics mechanisms and interactions:

- Study the nucleon properties in terms of mass and spin
- Distribution in space and time of the the sea quarks and gluons, and their spins inside the nucleon
- Interaction of the color-charged quarks, gluons and colorless jets with the nuclear medium
- Nuclear binding due to quark-gluon interactions
- Impact of the high-density nuclear environment on the behaviors of quarks and gluons[1]

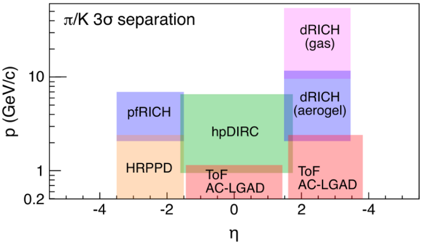


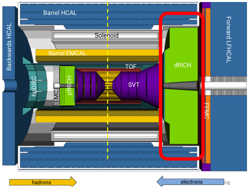




ePIC: Main Goals

- **Physics Requirements**
  - Pion, kaon and proton ID
  - Wide range $|\eta| \leq 3.5$ coverage
  - Better than 3σ separation
  - Significant pion/electron suppression
- **Momentum-rapidity Coverage**
  - Forward: up to 50 GeV/c
  - Central: up to 6 GeV/c
  - Backward: up to 10 GeV/c
- **Demands different technologies**

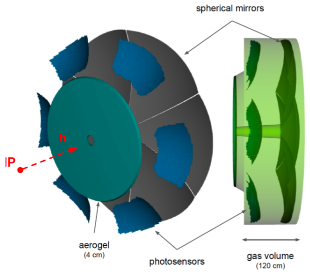


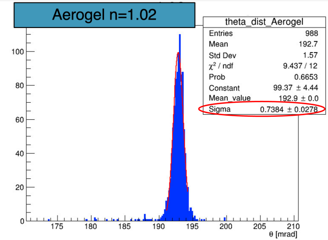


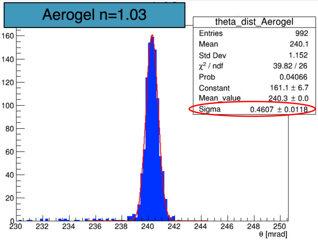
In the **forward region** the dual Ring Imaging Cerenkov (dRICH) detector allows the identification of particles with momenta from a few GeV/c up to about 50 GeV/c by using a 2-radiators + 6-mirrors + photosensors configuration

dRICH detector

- **Radiators**
  - Aerogel ($n \sim 1.02$)
  - C_2F_6 ($n \sim 1.0008$)
- **Mirrors**
  - Large outward-reflecting, 6 open sectors
- **Sensors**
  - Single-photon detection inside high B field ($\sim$1T)
  - SiPM as a cost effective solution







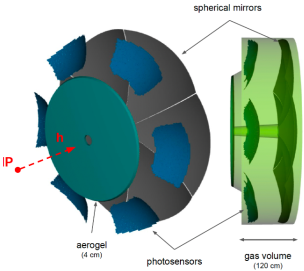
EXPECTED σ_θ

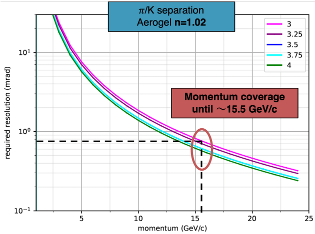
$$\sigma_\theta(n = 1.02) = 0.74 mrad$$

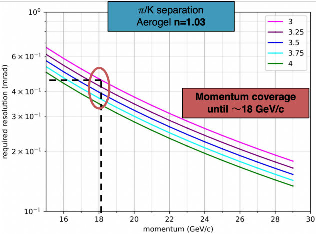
$$\sigma_\theta(n = 1.03) = 0.46 mrad$$

dRICH detector

- **Radiators**
  - Aerogel ($n \sim 1.02$)
  - C_2F_6 ($n \sim 1.0008$)
- **Mirrors**
  - Large outward-reflecting, 6 open sectors
- **Sensors**
  - Single-photon detection inside high B field (∼1T)
  - SiPM as a cost effective solution



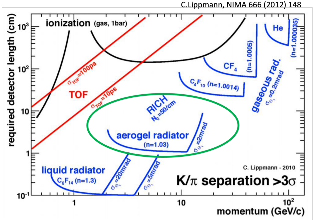




AEROGEL

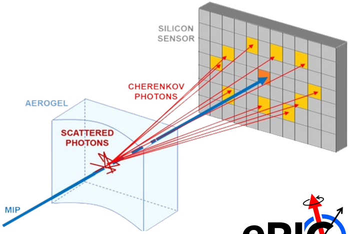
Aerogel performance and separation accuracy strictly dependent on n. Higher n means more photons but larger θ_{Ch}. **Need to balance physics requirements, geometry limits and aerogel refractive index**

Aerogel: the importance of being transparent



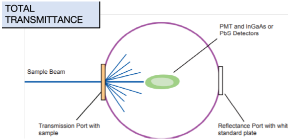
Arranged as a network of interconnected silica nanoparticles, Silica aerogel represents one of the least dense colloidal substance on earth, composed up to **99,8% of air and 0,2% silicon dioxide**. **Silica aerogel aims to partially cover the gap between traditional gas and liquid radiators** with typical refractive index either smaller of 1.0018 ($C_5F_1\ \sim$) or larger than 1.27 (liquid C_6F_{14})[2].

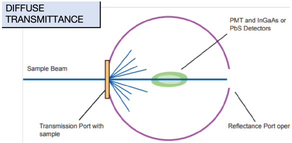
Silica aerogel can be hydrophobic or hydrophilic. The tiles tested in this work are **highly hydrophobic**, which means that they repel water and other liquids. This property helps to maintain the material's transparency even in humid or wet conditions.



Transmittance Setup @CERN

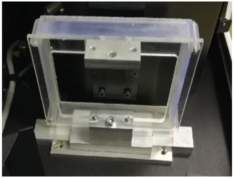
Measurements performed with a **Perkin Elmer spectrometer** at CERN, using an integrating sphere and a light source to cover the range 250 - 800 nm

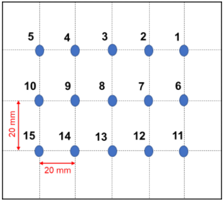


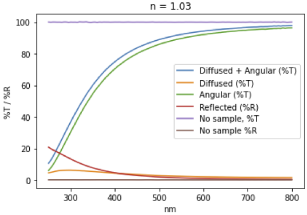


LINEAR TRANSMITTANCE

$$T_{LIN} = T_{TOT} - T_{DIFF}$$







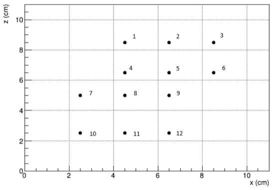
Each tile was placed into a holder (10x10 cm^2) and mounted onto a metal ridge sliding perpendicular to the beam to explore 15 different positions of the samples.

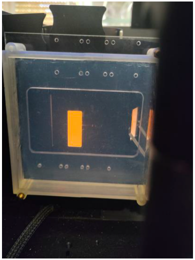
Transmittance Setup @INFN Bari

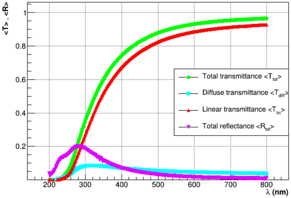
Measurements performed with a **Agilent Cary4000** spectrometer at INFN Bari, using an integrating sphere and two different light sources to cover the range 200 - 900 nm

LINEAR TRANSMITTANCE

$$T_{LIN} = T_{TOT} - T_{DIFF}$$







Measured samples

Tile	n	t [cm]	Tile	n	t [cm]
1		2.00	23		2.05
2		2.00	24	1.02	2.08
3		2.00	25	*(2021)*	2.08
4	1.03	2.00	26		2.08
5		2.00	27		2.05
6		0.98	28		2.06
7		0.97	29		2.04
8		1.96	30		1.95
9		1.96	31		1.99
10	1.04	1.96	32		2.17
11		1.96	33		2.14
12		1.96	34	1.02	2.14
13		2.01	35	*(2022)*	2.13
14		2.01	36		2.12
15	1.05	2.01	37		1.91
16		2.01	38		1.94
17		2.01	39		2.03
18		2.00	40		2.03
19	1.005	2.06	41		2.04
20		2.06	42		1.97
21	1.03	2.02			
22		2.03			

Measurements performed on 22 silica aerogel tiles at CERN in July-August 2022.

- Tiles manufactured at Aerogel Factory Co. Ltd (Chiba, Japan) and delivered in March 2021
- Tiles 6 and 7 manufactured by Matsushita Electric Works (Japan) were bought by INFN-Bari in 2000 as part of the HERMES collaboration
- Tiles having different refractive indices have been characterized in terms of transmittance, thickness and shape

Transmittance measurements on 20 tiles with n = 1.02 (2021 and 2022 production) performed by INFN-Ferrara group

Metrology Setup

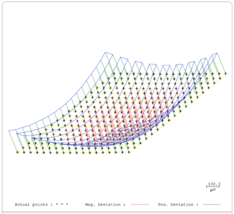
Thickness and flatness measurement in metrology lab at CERN

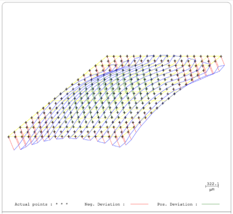
- Results obtained on a tile of n = 1.03 with the touch probe system (force applied by the probe is 2 gr)
- The measuring system is the LEITZ PMMC with $\pm$ 0.3 mm of precision

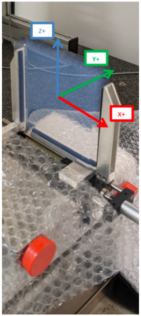
```
n=1.03
min tickness (mm):     19.690
max tickness (mm):     20.385
standard deviation:    0.172
average (mm):          19.955

n=1.04
min tickness (mm):     19.271
max tickness (mm):     21.798
standard deviation:    0.335
average (mm):          19.641

n=1.05
min tickness (mm):     19.965
max tickness (mm):     20.479
standard deviation:    0.098
average (mm):          20.106
```







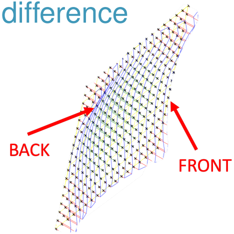
RESULTS

All tiles have a **MENISCUS SHAPE**

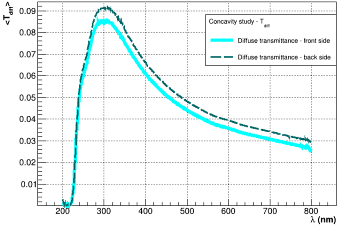
Thickness variation from the centre to the edges, of the order of 0.4 mm, and a **different planarity in the two faces**, one 0.7 mm, the other 1.27 mm

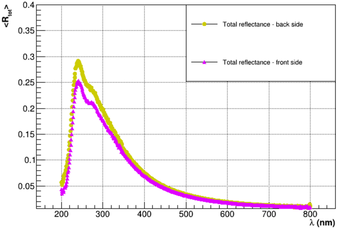
- **Flatness and the thickness uniformity improvable**, according to the manufacturer
- **The planarity can be mapped**, to include the defects in the reconstruction of the Cherenkov angle

Concavity difference



Different concavities on the front and back sides.
Does this impact on the transmittance?





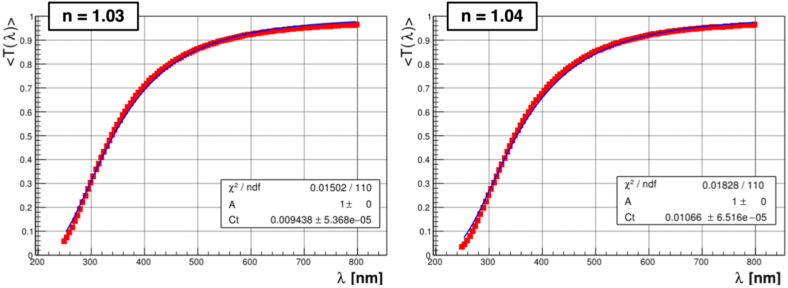
MIND THE PLACEMENT

Lower diffuse transmittance and lower reflectance if the beam hits the more concave side (front)

Transmittance fitting

Transmittance fitted by **Hunt basic formula** [NIM A 440 (2000) 338-347]:

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



QUESTION

CAN WE IMPROVE THE ABSORPTION TERM MODELLING?

NOTE: <T> = transmittance values measured as an average at the different points

Transmittance fitting

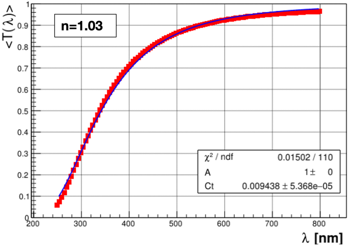
2-parameters **Hunt-basic formula**

$$T(\lambda) = e^{-\frac{t}{\Lambda_{trasm}}} = Ae^{-\frac{Ct}{\lambda^4}}$$

ASSUMPTIONS

$\Lambda_A constant$

$\Lambda_S \sim \lambda^4$



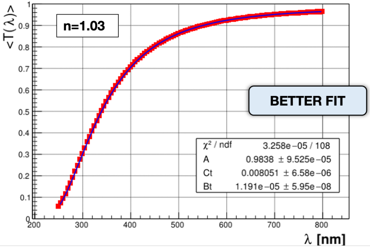
3-parameters **Hunt-extended formula**

$$T(\lambda) = e^{-\frac{t}{\Lambda_{trasm}}} = Ae^{-\frac{Bt}{\lambda^8}} e^{-\frac{Ct}{\lambda^4}}$$

ASSUMPTIONS[3]

$\Lambda_A \sim \lambda^8$

$\Lambda_S \sim \lambda^4$



Transmission length

$$T(\lambda) = e^{-\frac{t}{\Lambda_{trasm}}} = e^{-t\left(\frac{1}{\Lambda_A}+\frac{1}{\Lambda_S}\right)} = Ae^{-\frac{Bt}{\lambda^8}} e^{-\frac{Ct}{\lambda^4}}$$

TRANSMISSION LENGTH

$$T(\lambda) = e^{-\frac{t}{\Lambda_{trasm}}}$$

$$\Lambda_{trasm} = -\frac{t}{ln(T)}$$

SCATTERING LENGTH

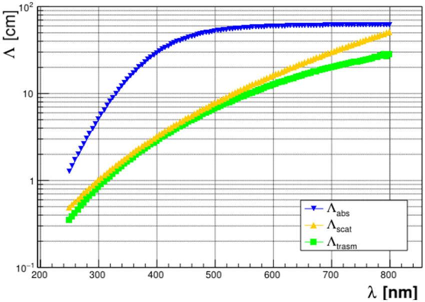
$$e^{-\frac{t}{\Lambda_S}} = e^{-\frac{Ct}{\lambda^4}}$$

$$\Lambda_S = \frac{\lambda^4}{C}$$

ABSORPTION LENGTH

$$e^{-\frac{t}{\Lambda_A}} = Ae^{-\frac{Bt}{\lambda^8}}$$

$$\Lambda_A = \frac{\lambda^8 t}{Bt - \lambda^8 ln(A)}$$



OBSERVATION

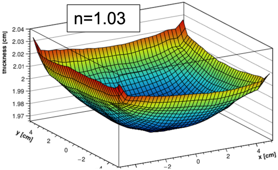
SMALL IMPACT OF THE ABSORPTION ON THE TRANSMISSION LENGHT

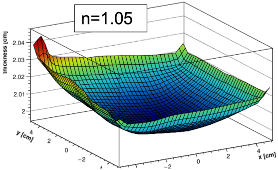
INFN

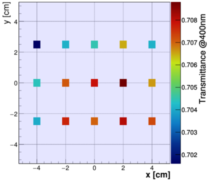
ePIC

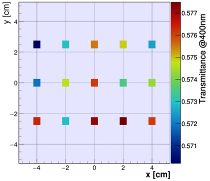
Transmittance Uniformity

The shape of the tile has implications on the transmittance







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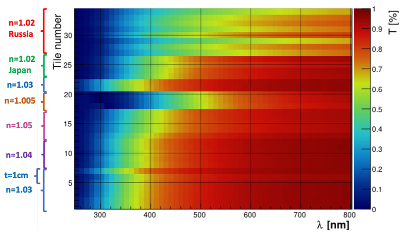
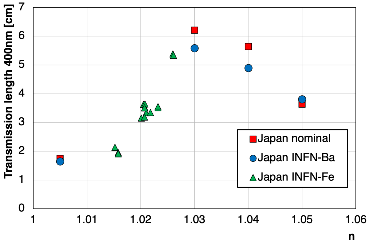
n=1.05
min tickness (mm):    19.965
max tickness (mm):    20.479
standard deviation:   0.098
average (mm):         20.106
```

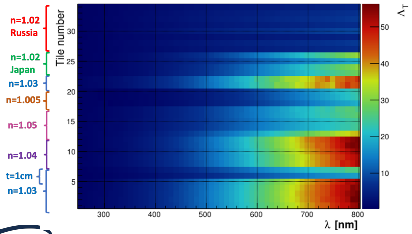
TAKEAWAY MESSAGE

Thickness measurement provides an indication of the transmittance distribution on the tile.
Thinner tiles implies higher transmittance

Results - In brief







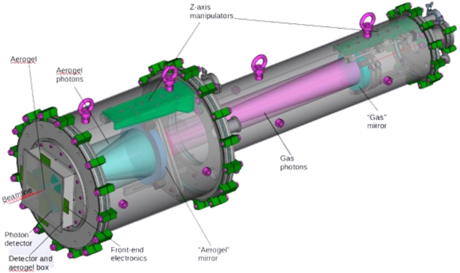
IN A NUTSHELL

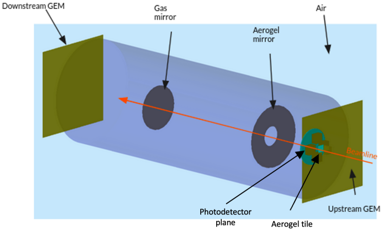
Highest Λ_T at n=1.03, but needs a compromise with Cherenkov radius requirements. Promising results for the tile with n=1.026

Estimated transmission length lower than values provided by the datasheet. Further investigation required.

Testbeam - The Concept

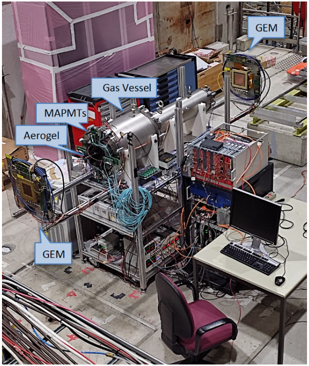
Several prototype beam tests were conducted between 2021 and 2023 at Proton Synchrotron (up to 12 GeV) and Super Proton Synchrotron (up to 200 GeV) at CERN using charged mixed hadrons beams.



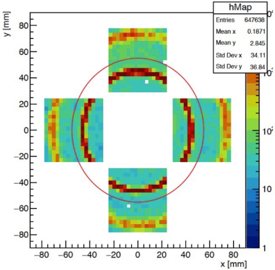


Test beams allowed the study of aerogel tiles of various sizes and refractive indices. Sometimes wavelength filters were applied, and the Cherenkov threshold detectors of the beam were used to help identify different particle types

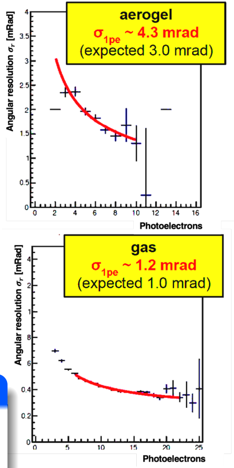
Testbeam - Highlights



Reference readout from CLAS12 RICH:
H13700 MA-PMTs + MAROC3 ToT chip



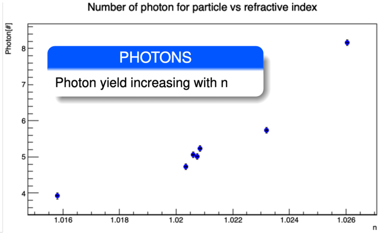
Gas ring coverage: 60%

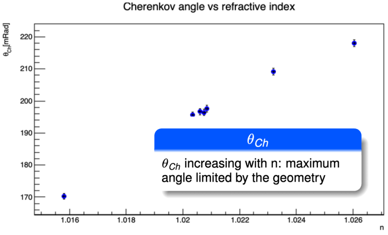


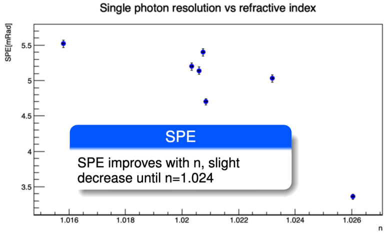
HIGHLIGHTS

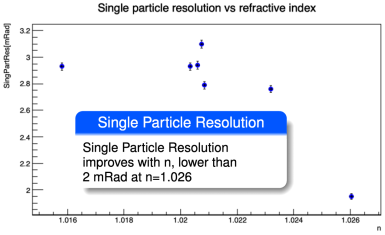
Double ring imaging achieved. Performance in line with expectations except for aerogel single-photon angular resolution (worse by a factor $\sim$1.5)

Testbeam - Highlights









Conclusion and Next Steps

CONCLUSION

- Introduction on the significance of aerogel as a radiator for PID coverage in the ePIC dRICH detector.
- 34 aerogel tiles were characterized at CERN and at INFN Bari in terms of transmittance
  - **Small transmittance dispersion** among the sampling points on the tiles
- Data fitted by a 3-parameters Hunt extended formula
- Transmission, absorption and scattering lengths extracted from transmittance measurements
  - **Absorbance negligible** with respect to the transmission length
- Maximum and minimum thickness value per tile estimated from transmittance data
  - Not uniform thickness on the tile due to its meniscus shape
- **Maximum transmittance and transmission length** observed for tiles with **n = 1.03**, to verify with the limits of the geometry. **Promising results for the tile with n = 1.026**

NEXT STEPS

- Full characterization in terms of transmittance and reflectance of the aerogel tiles with t = 1 cm
- Measurements of the refractive index of the aerogel tiles as a function of the wavelength
- Testing of the monolithic tiles including different refractive indeces in the same tile

Bibliography I

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