Concept and development of the Focusing Aerogel Ring Imaging Cherenkov (FARICH) detector for HMPID-systems

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Theoretical basis of the problem

- PHENIX [1] and STAR [2] (RHIC, BNL) heavy ion collisions had shown the unexpected suppression of the inclusive high-P_t particle yields (neutral pions and charged hadrons in central Au–Au collisions at $P_t > 2$ GeV/c).

The recent experimental data at PHENIX (RHIC) [3,4] give the evidence of a large enhancement of baryons and anti-baryons relative to pions at $P_t > 2$–5 GeV/c by almost a factor of three.

This experimental fact is called “baryon puzzle” or “jet quenching effect” at RHIC.

References:
[1] K. Adcox, PHENIX Collab., et al., Phys. Rev. Lett. 88 (2002) 022301
[2] C. Adler, STAR Collab., et al., Phys. Rev. Lett. 89 (2002) 202301
[3] S.S. Adler, PHENIX Collab., et al., Phys. Rev. C 69 (2004) 034909
[4] S.S. Adler, PHENIX Collab., et al., Phys. Rev. Lett. 91 (2003) 172301

Theoretical basis of the problem

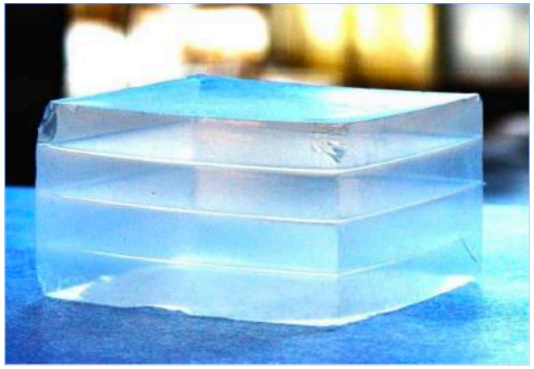
- Among the most popular theoretical models of the observable suppression of hadrons are those based on recombination of quarks [5,6]. Other approaches predict that “jet quenching effect” gives the indication on a different loss of energy by partons and gluons in the compressed nuclear matter.

To study this phenomenon in details all detector PID-systems have to expand their particle separation capabilities for momenta more than 10 GeV/c.

References:
[5] R.J. Fries, et al., Phys. Rev. Lett. 90 (2003) 202303
[6] R.J. Fries, et al., Phys. Rev. C 68 (2003) 044902

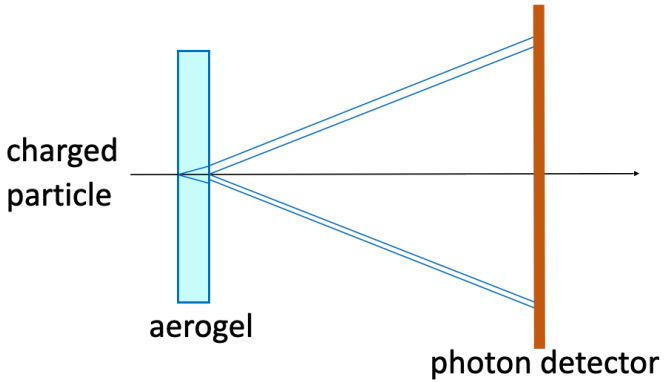
The FARICH concept

- Goal: To develop a prototype detector that would extend the momentum range of charged particle identification:
  up to 10 GeV/c for pion-kaon separation and
  up to 14 GeV/c for kaon-proton separation
  at the ALICE HMPID system [1, 2]. The project was proposed by Prof. Aleksei Kurepin, INR RAS, Moscow in 2008.



Aerogel

- We have proposed the **Focusing Aerogel Ring Imaging CHerenkov** (FARICH) prototype detector - it employs a multilayer silica aerogel as a radiator.
  In June 2012, the prototype was tested, using the Digital Photon Counters (DPC - dSiPM) by Phillips Company at the CERN PS T10 beam line with a particle momentum up to 6 GeV/c [A.Yu. Barnyakov (Novosibirsk, IYF) et al., Nucl.Instrum.Meth. **A732 (2013)** 352-356].

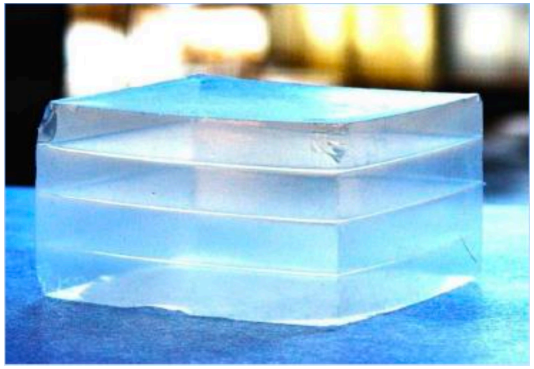


Aerogel setup

References:
[1] Berlev (Moscow, INR) et al., Nucl.Instrum.Meth. A598 (2009) 156-159.
[2] A Very High Momentum Particle Identification Detector (VHMPID) for ALICE. Letter of Intent, Version 19.0, ALICE VHMPID Upgrade, 2012.

The FARICH concept

Silica aerogel (SiO_2) is a highly porous material which contains air by more than 90% of volume. It is transparent to the visible light. Transmittance at wavelength of 400 nm is roughly 77% for n=1.05

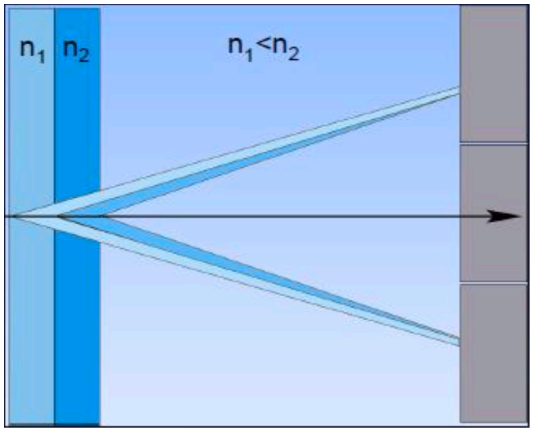


Aerogel

$$\cos\vartheta_c = \frac{1}{n\beta} \rightarrow \beta_{th} = \frac{1}{n} \rightarrow p_{th} = \frac{m}{\sqrt{n^2 - 1}}$$

Cherenkov relation

Momentum threshold as the function of n



Aerogel setup

Material	Refractive index	p_{th} [GeV/c]				λ_{cut} [nm]
		e	π	K	P	
C_4F_{10}	1.0015	0.009	2.5	9.0	17	136
Aerogel	1.05	0.0016	0.44	1.54	2.9	300

The FARICH concept - key goals

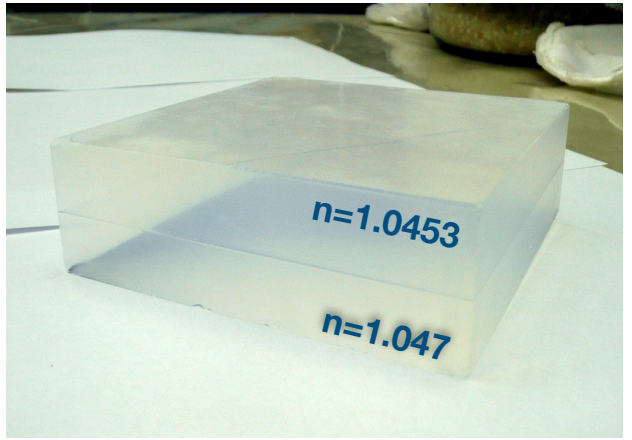
- to increase the number of photons emitted by using thicker radiator
- to use several layers of the aerogel for focusing of Cherenkov cones on the detector sensitive plane without degrading the angle resolution.

Simulation data for multilayer aerogel radiator (10GeV/c)

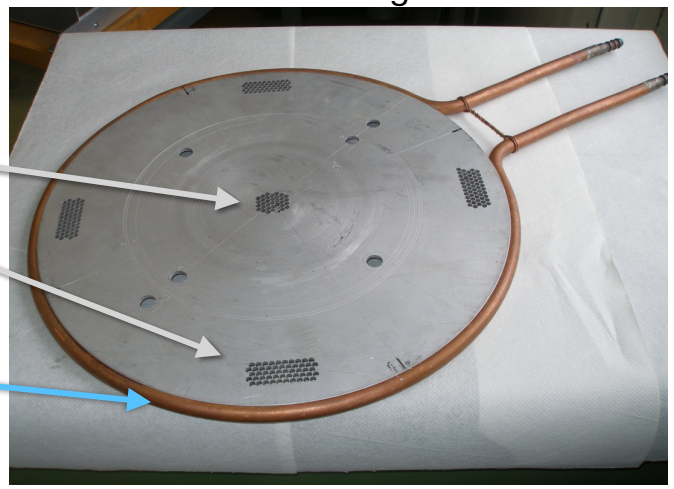
Radiator type	T total, mm	$N_{photoelectrons}$	$r_{Cherenkov\ ring}$, mm	σ_r, mm	Ring area, mm^2	σ(θ), mrad	π/K separation, σ
n=1.03, 2 layers	33.1	20	121.3	1.5	$6.86 \cdot 10^3$	0.65	7.1
n=1.03, 3 layers	45.8	26	121.5	1.4	$6.41 \cdot 10^3$	0.53	8.7
n=1.05, 2 layers	35.6	**35**	157.2	2.0	$1.19 \cdot 10^4$	0.61	5.8
n=1.05, 3 layers	50.0	**47**	157.4	1.9	$1.13 \cdot 10^4$	**0.49**	7.2

The FARICH concept - beam test

- light-isolating box of 400x400x1000 mm^3;
- thin carbon entrance window for beam particles;
- double-layer focusing Aerogel Cherenkov radiator 120x120x31 mm (made in Novosibirsk);
- plate with a matrix of Winston-cone holes;
- the array of MRS Avalanche PhotoDiods: five clusters of 25 APDs (125 total);
- the water cooling system;
- Time Readout Modules (TRB) on the basis of the NINO-chip processor.

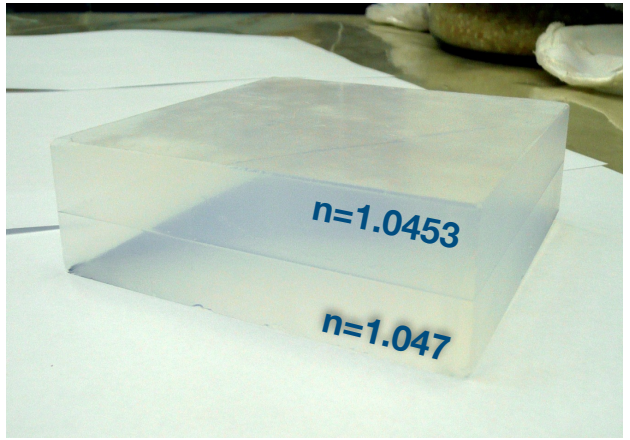


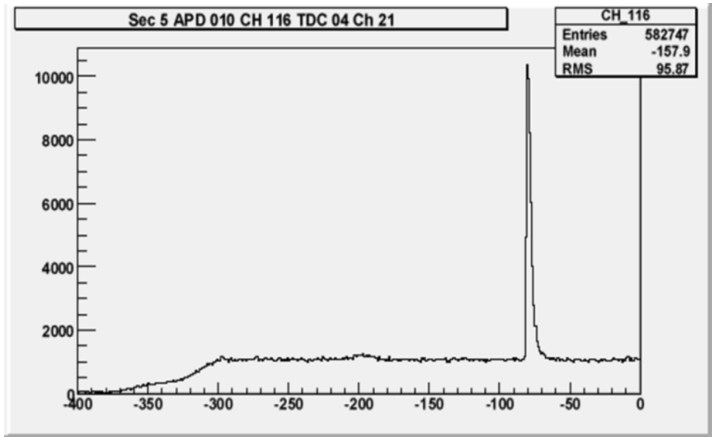
Aerogel


MRS APD setup

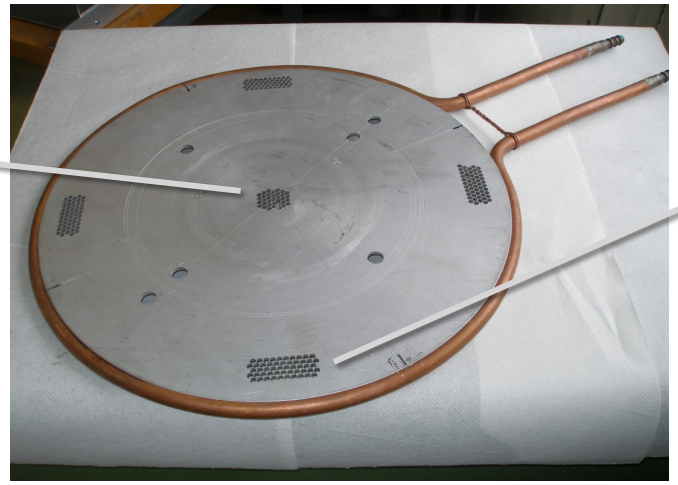
The FARICH concept - beam test

NAME OF THE EXPERIMENT: FARICH-Prototype (ALICE)
TEST CHANNEL: T10 PS / Bld.157/EP-T10
SPOKESPERSON: Andrei RESHETIN
TECHNICAL COORDINATOR: Arturo TAURO
START AND COMP-N DATES: (in according to PS Schedule-2011, P2): 14 – 29 June, 2011

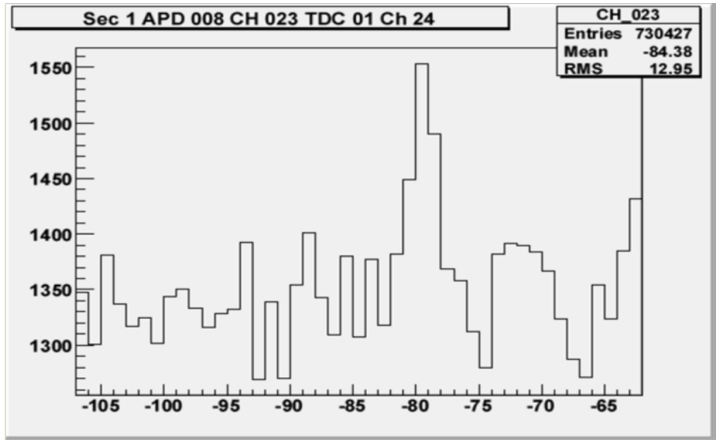




Typical MRS APD time spectrum - center (scintillation photons)



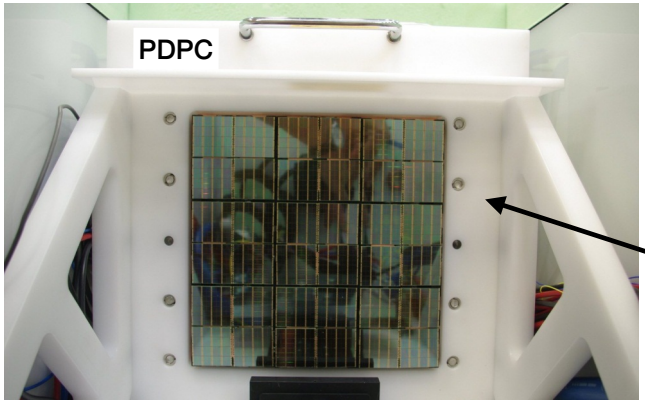
MRS APD setup



Typical MRS APD time spectrum - radial (Cherenkov photons from a two-layer Aerogel)

The FARICH concept - PDPC readout

The setup

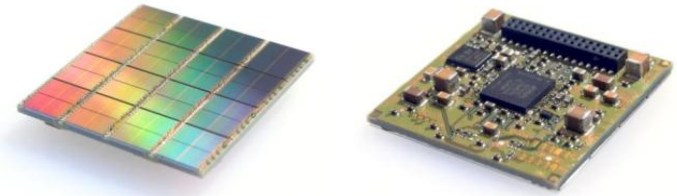


Philips Digital Photon Counting:

PDPC is built around scalable detectors based on digital Silicon PhotoMultiplier (dSiPM) technology – a new type of advanced solid state light detector.

It features high time resolution and includes integrated FEE (discriminators, TDC)

DPC3200-22-44
1 tile is 8x8 pixels



The setup is 6x6 tiles, or 48x48 pixels, 20x20 cm^2

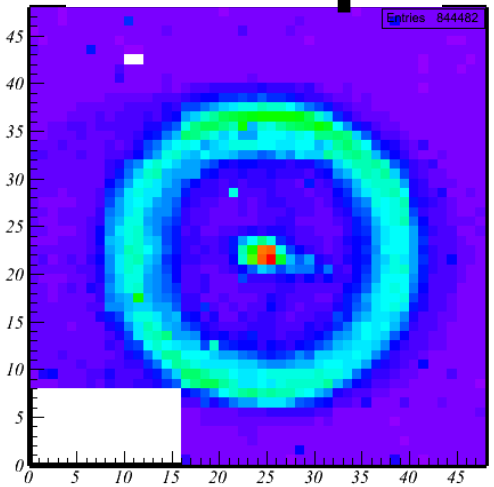
It features 576 time channels and 2304 amplitude channels

Requirements for photon readout:

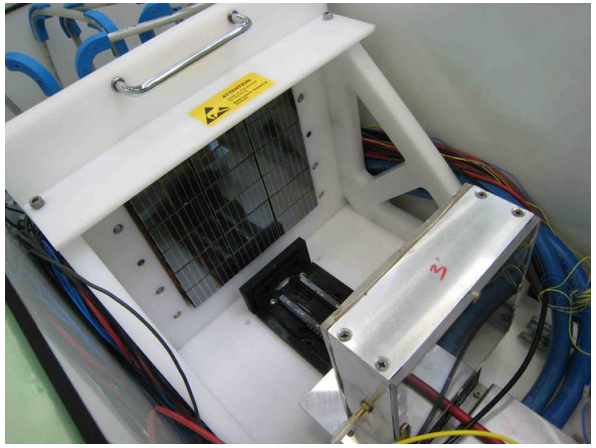
- Operation in magnetic field
- High proton detection efficiency
- Resolution approx. 1 mm

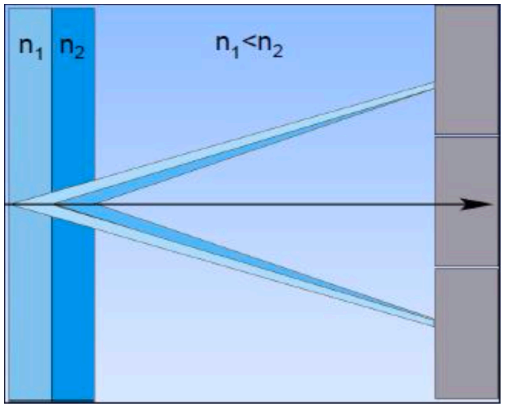
The FARICH concept - PDPC readout

The setup



Pixel map of Cherenkov ring



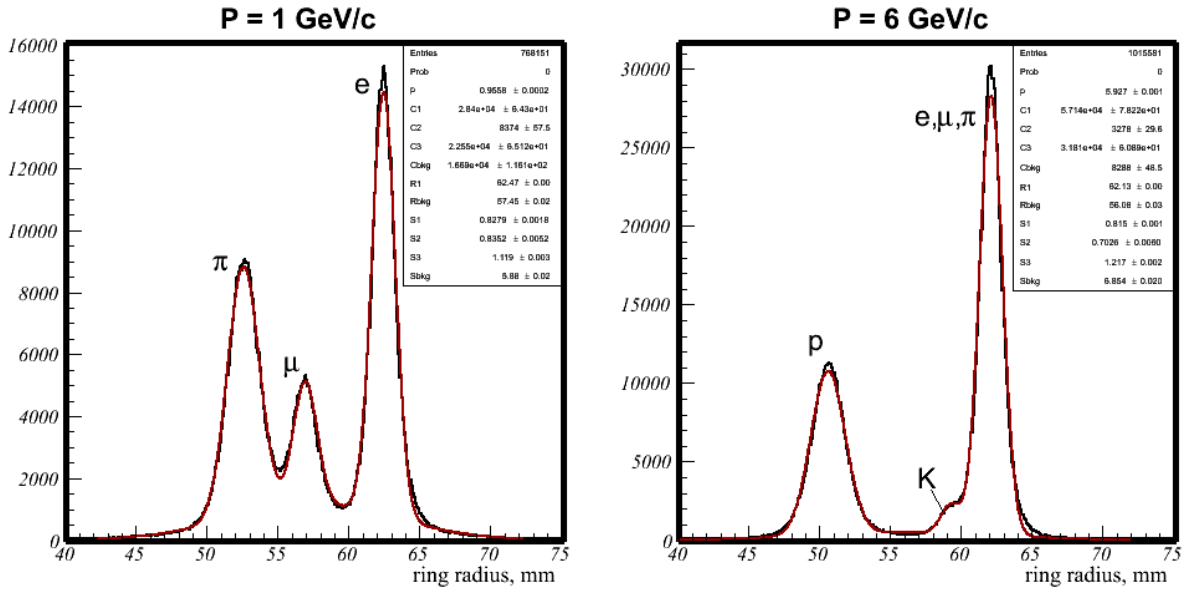


Aerogel setup

Thomas Frach,
Inventor of DPC

FARICH prototype at
CERN PS T10 beam channel

The FARICH concept - PDPC readout



The distribution of the radiuses of the Cherenkov ring

A.Yu. Barnyakov et.al., Nuclear Instruments and Methods in Physics Research A 732 (2013) 352-356

The article concludes:

"A beam test of the FARICH detector prototype with DPCs has been successfully carried out. An excellent timing resolution of σ_t = 48 ps for single proton has been obtained. We observed Cherenkov rings with 12 photoelectrons in average and a Cherenkov angle resolution of $\sigma_{\theta c}$ = 3.61 ± 0.04 mrad for relativistic particles. π/K separation at 6 GeV/c is 3.5σ and μ/π separation at 1 GeV/C is 5.3σ. A satisfactory agreement with the Geant4 simulation results is achieved."

Studied aerogel samples were produced in Novosibirsk.

The FARICH concept - further usage

Antonello Di Mauro on “ALICE 3: First workshop on physics and detector” (October 2020) made a new Aerogel-RICH proposal for ALICE 3 Upgrade:

- The ALICE 3 detector introduced in the EoI fully covers the requirements of flagship cases for which PID is focused on low p_t (approx. 3 GeV/c).
- However, in the ongoing discussion to define the physics programme, various measurements could require PID at larger p_t. In addition one cannot exclude the possibility of unexpected new physics channels which would benefit of a larger PID coverage.
- A proximity focusing RICH using aerogel Cherenkov radiator represents the simplest and potentially most cost-effective solution to complement the TOF measurement and extend the hadron PID range up to 15-20 GeV/c, still remaining consistent with the original idea of a new experiment fully based on silicon sensors.
- A timing layer for TOF based on SPADs has intrinsically single photon detection capability, therefore…

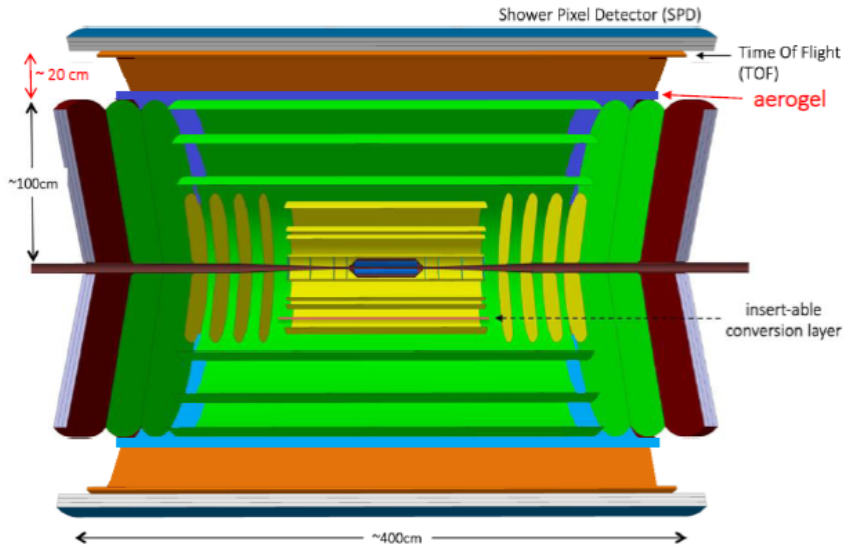
This is a slide from:

A. Di Mauro, E. Nappi, R. Preghenella, G. Volpe
ALICE 3: First workshop on physics and detector
14/10/2020

The FARICH concept - further usage

Antonello Di Mauro on “ALICE 3: First workshop on physics and detector” (October 2020) made a new Aerogel-RICH proposal for ALICE 3 Upgrade:

Aerogel-RICH first idea



...in the ideal case of MIPs and Cherenkov photons detection by the same layer, one would implement the RICH by increasing the radius of the TOF layer by ~ 20 cm to insert the aerogel radiator and a Cherenkov expansion gap

This is a slide from:

A. Di Mauro, E. Nappi, R. Preghenella, G. Volpe
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Conclusions

- Silica aerogel is a good material to expand the effective range of particle separation
- Focusing Aerogel Ring Imaging CHerenkov (FARICH) prototype employs a multilayer silica aerogel as a radiator to increase number of photoelectrons and for focusing of Cherenkov cones on the detector sensitive plane
- Detector prototype with Phillips DPCs has an excellent timing resolution of σt = 48 ps for single proton; Cherenkov angle resolution of $\sigma_{\theta c}$ = 3.61 ± 0.04 mrad for relativistic particles. π/K separation at 6 GeV/c is 3.5σ and μ/π separation at 1 GeV/C is 5.3σ was shown by the experimental setup
- Using FARICH detectors for the ALICE 3 could extend its PID range up to 15-20 GeV/c

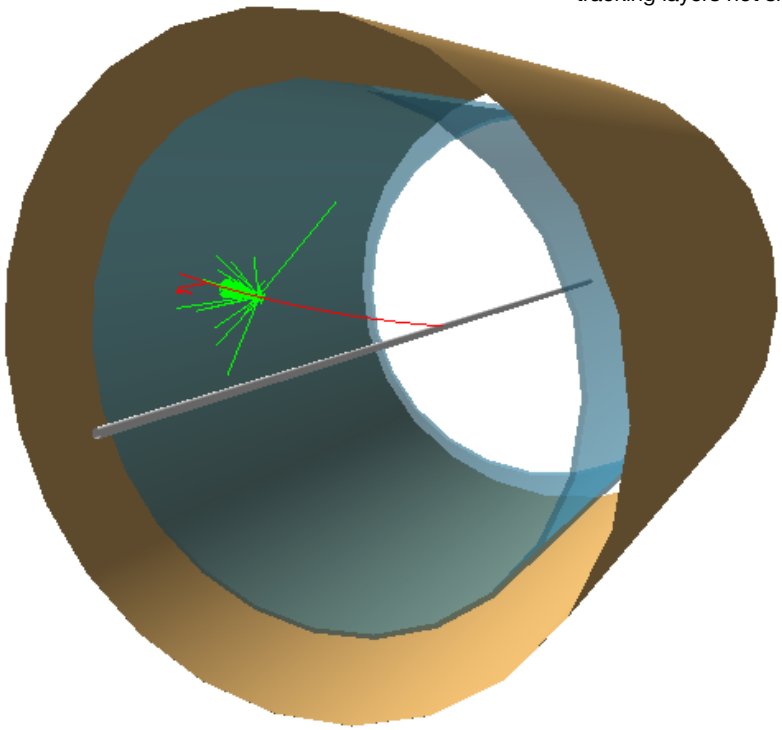
Thank you for your attention!

Backup slides

Geant4 geometry

- aerogel radiator
  - cylinder, inner R = 100 cm
  - 2 cm thick
  - refractive index n = 1.03
  - material properties to be tuned
  - optical properties from measurements
- expansion region
  - 20 cm thick
  - Argon gas
  - n = 1.00 (it is anyway small < 1.0003)
- Photo-detector surface
  - cylinder at R = 122 cm
  - silicon sensors, SiPM HPK 3050CS
  - 3x3 mm^2 active area, 3.14x3.14 mm^2 pitch, 3.1 M channels (91% fill factor)

tracking layers not shown



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