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Development of FARICH-detector for ALICE experiment at CERN[☆]

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ABSTRACT

In order to extend the momentum range of the charged particle identification up to 10 GeV/*c* for pion–kaon separation and to 14 GeV/*c* for kaon–proton separation of the ALICE experiment at LHC (CERN), the focusing aerogel ring imaging Cherenkov (FARICH) detector employing a multi-layer silica aerogel as radiator has been proposed. The design project of the FARICH Prototype is presented.

Results of the test of the avalanche photo-diodes with metal-resistance-semiconductor structure produced by the Centre of Perspective Technology and Apparatus (CPTA MRS APDs) are shown. Preliminary data of tests of the light-collecting capability for aluminum and stainless steel Winston cone holes of different types are presented.

The performance of the proposed detector was estimated using the GEANT4 simulation. Results of the optimization of characteristics of the aerogel radiators, CPTA MRS APDs with and without wavelength shifter paint are discussed.

1. Introduction

An important experimental direction of the study in the relativistic physics of heavy-ion collisions is the measurement of the yield of high-Pt particles. The experimental study of ultra-relativistic heavy ion collisions at RHIC (BNL) [1,2] shows the unexpected suppression of the inclusive high-Pt particle yields—neutral pions and charged hadrons in central Au–Au collisions at $p_T \geqslant 2$ GeV/*c*. At the same time, the more recent experimental data at PHENIX (RHIC) [3,4] give the evidence of a large enhancement of baryons and anti-baryons relative to pions at $p_T \approx 2$–5 GeV/*c* by almost a factor of three. This experimental fact is called "baryon puzzle" or "jet quenching effect" at RHIC. 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" [1] gives the indication on a different loss of energy by partons and gluons in the compressed nuclear matter.

In order to study this phenomenon in details all current upgrades of the detector systems should extend the kaon–proton separation capability up to 10 GeV/*c* and more.

The present paper reports the development of the focusing aerogel ring imaging Cherenkov (FARICH) detector for the upgrade of the CERN ALICE high momentum PID (HMPID) system.

2. ALICE HMPID-system upgrade

At present, in ALICE, the high momentum particle identification is performed by using HMPID [7,8] in the momentum ranges 1–3 and 1.5–5 GeV/*c* for pion–kaon and kaon–proton separation, respectively. The single photon angle resolution of 12 mrad and the Cherenkov angle resolution of 3 mrad have been achieved.

In comparison with HMPID, the Belle Spectrometer (KEKB e^+e^- collider) by means of the Endcap threshold aerogel Cherenkov (TAC) counters is able to identify—pions and kaons in the range of 1.2–3.5 GeV/*c* [9]. Recently, in order to improve the capabilities of the PID system at the Belle Spectrometer the proximity focusing ring imaging Cherenkov detector with multiple aerogel layers as a radiator was proposed [10].

An extension to higher-Pt of the present PID system was performed by the PHENIX collaboration. The upgrade is being achieved by employing a wall of TAC counters of the integration sphere type [4] and provides the pion–kaon and kaon–proton separation in the ranges from 1 to 5 GeV/*c* and from 5 to 9 GeV/*c*, respectively.

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During last years, the detectors of different types were proposed for the ALICE HMPID-system upgrade. The option on the basis of the TAC counter [11,12] using aerogel as radiator enables one to identify pions in the momentum range 0.75–4.8 GeV/c, kaons: 2.65–4.8 GeV/c and protons: 2.65–9.0 GeV/c. Two layers of aerogel pieces with extremely low refractive indices $n = 1.008$ and 1.005 running in the signal/no signal mode in one or both detectors were proposed. The other development—a very high momentum particle identification (VHMPID) Cherenkov detector was proposed [13]. The simulation results of different detector geometries for the threshold imaging Cherenkov (TIC) detector and two other designs with and without focusing are given.

The development of the FARICH Prototype detector is performed to extend the working momentum range of the charged particle identification at ALICE up to 10 GeV/c for the pion–kaon separation and up to 14 GeV/c for kaon–proton separation.

3. FARICH concept

In a proximity focusing RICH, one of the main contributions to the Cherenkov angle resolution is the emission point uncertainty resulting from the finite thickness of the radiator. In 2004 two groups, one from KEK [10,14–16] and another from Novosibirsk [17] started studies of the multi-layer aerogel Cherenkov radiator aimed at reducing the effect of this contribution.

The idea of the FARICH detector is to employ a Cherenkov radiator composed of several aerogel layers with different index of refraction (Fig. 1). Index of refraction in layers is gradually increasing along the particle's direction so that Cherenkov ring images produced by different layers coincide in the detection plane and form a narrow ring image.

4. Simulation of a multi-layer radiator for FARICH Prototype

The simulation based on the Geant4 software toolkit was used to estimate the performance of the FARICH Prototype. We investigated the response of several FARICH configurations to kaons with the momentum of 10 GeV/c. We varied the number of aerogel layers in the radiator from 1 to 4 optimizing the total thickness of the radiator in terms of Cherenkov angle resolution at each stage. Two values of index of refraction in the densest layer were considered: $n = 1.03$ and 1.05.

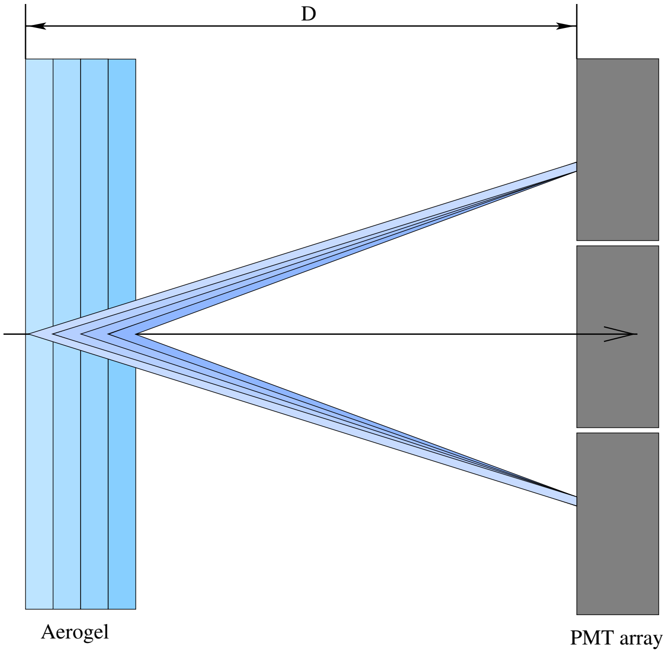

Fig. 1. FARICH detector concept.

Two photodetector options were investigated: a bare avalanche photo-diodes with metal-resistance-semiconductor structure (MRS APD) and a MRS APD with a wavelength shifting (WLS) paint on the entrance window (see Section 6.1). The measured photon detection efficiency (PDE) as function of the light wavelength was used in the simulation. It was preliminarily assumed that the APD array is packed with 100% geometrical efficiency and with the sensitive pixel size of 3 mm. The radiator was placed at the distance $D = 500$ mm from the detection plane.

The Rayleigh scattering length in aerogel is taken as $L_{sc} = 5$ cm at 400 nm wavelength.

Fig. 2 shows the Cherenkov angle resolution per track as function of the number of radiator layers for the options considered. The obvious improvement with increasing the number of layers and the total radiator thickness can be seen. The degradation of the angle resolution by 10–20% for the APD version with WLS paint in comparison with the bare APD version is attributed to the higher chromatic dispersion of aerogel for the blue light to which the former photodetector is more sensitive.

Table 1 summarizes the results of the simulation of the FARICH Prototype. It can be noticed that the radiator with $n = 1.05$ produces 1.5 times more number of photoelectrons than the radiator with $n = 1.03$ of the same thickness. This favors the choice of the higher index of refraction for the Prototype where the geometrical efficiency loss in comparison with the simulation will be essential.

5. Design project of FARICH Prototype with MRS APD matrix

The layout of the FARICH Prototype is shown in Fig. 3. It consists of the following main constructional parts:

- light-isolating box of $400 \times 400 \times 1000\,\text{mm}^3$ dimensions;
- thin carbon entrance window for beam particles;

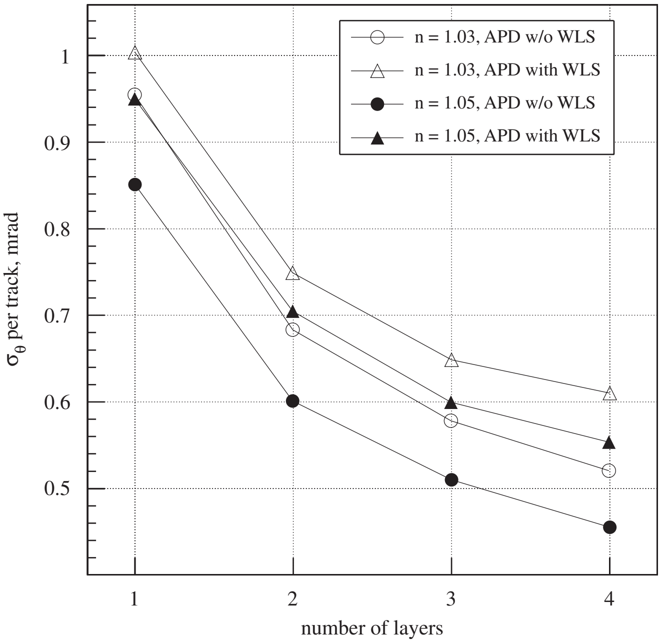

Fig. 2. The simulated Cherenkov angle resolution per track as a function of number of radiator layers for different options of photodetector and radiator.

Table 1
The results of the FARICH simulation

N_{layers}	t, mm	N_{pe}	σ_θ, mrad	π/K sep.
$n = 1.03$, APD w/o WLS				
1	17	10	0.95	4.8
2	33	18	0.68	6.7
3	40	21	0.58	8.0
$n = 1.03$, APD with WLS				
1	26	18	1.0	4.6
2	41	26	0.75	6.1
$n = 1.05$, APD w/o WLS				
1	12	12	0.85	4.1
2	28	26	0.60	5.9
3	**38**	**33**	**0.51**	**6.9**
4	43	37	0.46	7.7
$n = 1.05$, APD with WLS				
1	26	30	0.95	3.7
2	40	41	0.70	5.0

t—total thickness of the radiator, N_{pe}—the detected number of photoelectrons; σ_θ—Cherenkov angle resolution per ring; π/K sep.—pion–kaon separation power in number of standard deviations at 10 GeV/c. The Prototype's baseline option is shown in bold.

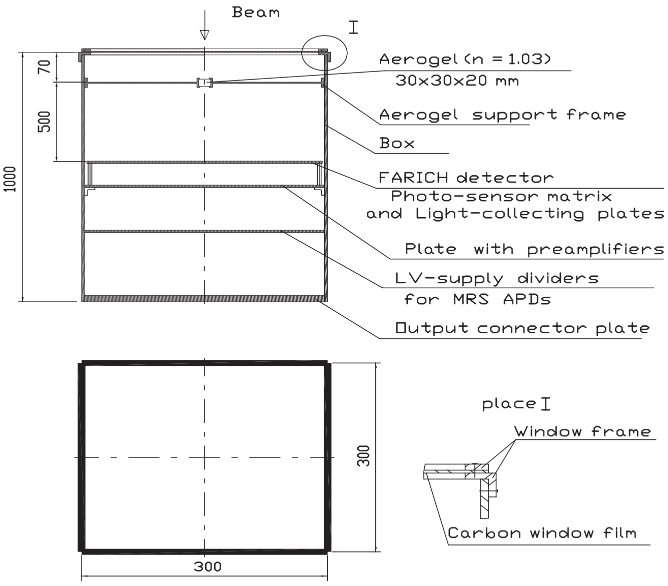

Fig. 3. Layout the FARICH Prototype.

- focusing aerogel Cherenkov radiator of $50 \times 50 \times 40\,\text{mm}^3$ dimensions;
- plate with a matrix of Winston-cone holes. The parabolic polished surface of the Winston-cone holes reflects efficiently Cherenkov photons and enables one to collect them on the sensitive APD window. A light-collecting cell equipped with a Winston-cone hole is shown in Fig. 4. The Cherenkov light photons are focused from 3 to 1.1 mm spot diameter;
- the array of MRS APDs comprises 900 APDs on the ring and 25 in the centre. The geometrical efficiency is about 50% for APD cell sizes and about 47% for 4 ring sectors. We expect the mean number of photoelectrons per ring to be 8–9 for the Prototype and 16–18 for the full-scale array. The cooling system, four Peltier-modules, is able to cool APDs down to 25–30 °C below zero;
- preamplifier card with amplification factor of about 10.

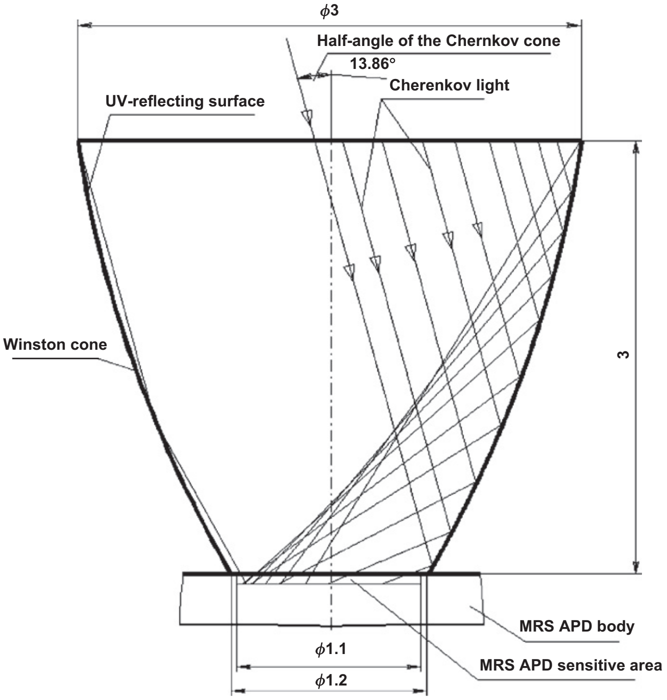

Fig. 4. Light-collection cell equipped with the Winston-cone.

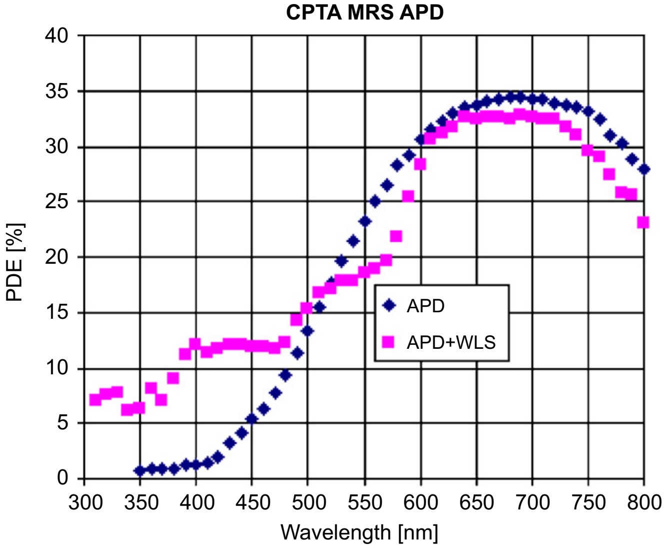

Fig. 5. Dependence of PDE on a light wavelength for CPTA MRS APDs of different types.

6. Preliminary results of the test of the FARICH Prototype

6.1. Centre of Perspective Technology and Apparatus (CPTA) MRS APD performances

Measurements of the MRS APD performance produced by the CPTA, Moscow were carried out at CERN APD Laboratory and INR, Moscow. The entrance windows of a few APDs were covered by a special WLS paint developed by Photonique SA (Geneva). Fig. 5 shows the dependence of PDE on the light wavelength for "50 V-APDs" and "50 V-APDs+WLS-paint" versions of MRS APD. It can be seen that the WLS-paint increases PDE in about two times at 450 nm and about 10 times in the range of 300–400 nm. In spite

Table 2
Electrical and optical performance of APD+WLS

Parameter	Symbol	Condition	Typical value
Wavelength of the PDE maximum	λ_p	$M = 8 \times 10^5$	600–700 nm
Photo-detection efficiency	PDE	$\lambda = 650$ nm	33%
		$\lambda = 410$ nm	11%
Operating voltage (bias)	V_{opr}		50 V
Dark current	I_d	$M = 8 \times 10^5$	2.5 μA
APD capacity	C_{APD}	$V_{opr} = 50$ V	40 pF
Amplification factor	M	$V_{opr} = 50$ V	8×10^5

of the resulting photoelectron gain the simulation disfavors this option because blue and near-UV photons significantly widen the Cherenkov angle distribution.

Measured electrical and optical performance of "50V-APD+WLS-paint" is presented in Table 2.

6.2. Cooling system for MRS APD

The cooling system consists of the heat exchanger Peltier module, water radiator and thermo-pair sensor. Using this system the APD temperature of −25 °C can be achieved. In this case the APD dark noise will decrease by factor of 15–20, down to 2×10^5 Hz. Consequently, the background counts in the time window of 1 ns will drop to 0.2 per ring area.

7. Conclusion

To extend the momentum range of charged particle identification up to 10 and 14 GeV/*c* for pion–kaon and kaon–proton separation, respectively, for the ALICE experiment at LHC (CERN), the focusing aerogel RICH (FARICH) detector employing a multilayer silica aerogel as radiator has been proposed. The FARICH Prototype will be tested with the ALICE test beam channel T10 in April–May 2009. Beam particles—negative pions in the momentum range 2–10 GeV/*c*.

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