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Tests of FARICH prototype with precise photon position detection

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A B S T R A C T

In June 2012 a FARICH prototype from Philips Digital Photon Counting (PDPC) based on a photon camera with dimensions of 200 × 200 mm has been tested at CERN. Remarkable particle separation has been achieved with a 4-layer aerogel sample: the π/K separation at a 6 GeV/c momentum is 3.5σ, the μ/π separation is 5.3σ at 1 GeV/c. The analysis of the data has shown that the main contribution to the accuracy of the ring radius measurement comes from aerogel. The development of focusing aerogels is proceeding in two main directions: tuning of production technology of multilayer blocks and development of a new production method with continuous density (refractive index) gradient along the block depth. The beam test was carried out in December 2012–January 2013 at the electron beam test facility at the VEPP-4 M e^+e^- collider. The goal of this test was to measure different single layer and focusing aerogel samples, both multilayer and gradient. Aerogel samples were tested with a PDPC FARICH prototype. A part of DPC SPADs in each pixel was disabled to form an active area of 1 × 1 mm^2. The collected data proved that gradient aerogel samples focus Cherenkov light.

1. Introduction

Focusing Aerogel Ring Imaging Cherenkov (FARICH) detector is suggested for particle identification at a Super-$c\tau$-factory (SCTF) in Novosibirsk [1]. The 'focusing aerogel' refers to aerogel radiators for proximity focusing RICH detectors with a nonuniform refractive index. Basically, we distinguish two types of such radiators: multilayer and gradient aerogel radiators. The first one is done in such a way that rings from different layers having particular refractive indices overlap on the photon detection surface. Such radiators could consist of separate aerogel samples [2] or this could be a monolith aerogel sample with several (2–4) layers [3]. This concept was first proposed in 2004 to minimize the contribution of the finite radiator thickness to the Cherenkov angle error [2,3]. The second one is a monolithic aerogel sample, where refractive index inside the sample gradually changes in such a way that generated Cherenkov photons are projected to a ring with zero width on the photon detection surface. In a sense, a gradient radiator is a multilayer radiator with the infinite number of layers.

One of the important physics cases of the SCTF is a search of $\tau \to \mu\gamma$ lepton-flavor-violating decay. The ability of FARICH to separate muons and pions up to 1.7 GeV/c a 3σ level combined with precise calorimetry and kinematic analysis should help to set an upper limit of the order of 10^{-9} on the corresponding branching fraction [4].

The main parameters of the FARICH for the SCTF detector are

- 4π geometry;
- 17 m^2 of the radiator and 20 m^2 of photon detectors;

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- silicon photomultipliers (SiPM) for photon detection, $\sim 3\times 3$ mm^2, pitch 4 mm;
- 4-layer 'focusing' aerogel, $n_{max}=1.07$, total thickness 35 mm; and
- the expansion gap 200 mm.

SiPMs are promising candidates to be used as photon sensors in FARICH detectors due to their high gain, photon detection efficiency, immunity to magnetic field, compactness and potentially low cost. However, a high dark count rate of the order of 1 MHz/mm^2 at room temperature of present SiPMs requires some challenging technical solutions such as cooling the detector and/or achieving a high photon timing resolution ($\sim$100 ps) combined with a fast data acquisition.

Several years ago the PDPC has developed a digital silicon photomultiplier called Digital Photon Counter (DPC) by integrating readout electronics on the same chip as the array of single pixel Avalanche diodes (SPAD) using conventional CMOS process technology [5]. Each cell (one SPAD), when it is hit, generates a logical signal that enables counting the number of fired cells and constructing coincidences of cell groups to produce the trigger signal and measure its timing. The DPC cardinally solves the problem of front-end electronics integration, offering an easily scalable solution for a high channel number and density. It has much lower dark counting rate and superior timing resolution than the conventional 'analogue' SiPM.

In 2012 a Focusing Aerogel RICH detector prototype based on DPC by Philips was tested at the CERN PS T10 beam line. The measured π/K separation at 6 GeV/c momentum was 3.5σ, the μ/π separation was 5.3σ at 1 GeV/c. We would like to note that these numbers for particle separation are 2.6 times worse than in the initial Monte Carlo simulation. One of the main reasons of such discrepancy is the difference of the actual parameters of focusing aerogel sample from the ideal design values [6].

2. Test of FARICH prototype #1

A beam test with the first FARICH prototype was done in 2011 at the electron beam test facility at VEPP-4 M collider (Budker INP, Novosibirsk) (Fig. 1).

The 4-layer focusing aerogel block was tested. The dimensions of the block were $100\times 100\times 31$ mm^3. The light scattering length in the sample was 43 mm at 400 nm wavelength. The index of refraction and thickness of the layers is presented in Table 1.

The FARICH prototype used 32 SiPMs from the CPTA company (Moscow, Russia) as photon detectors. The SiPMs pixel size was 2.1×2.1 mm^2. The custom made discriminator boards and the CAEN V1190B multihit TDC were used for the signal readout. The test beam apparatus also comprised the trigger and veto scintillation counters, the coordinate drift chambers and the NaI calorimeter.

In the experiment we measured the position of the track of 1 GeV/c electrons in the photon detection plane that gave us the radius of the detected Cherenkov photons. To suppress SiPM dark count rate contribution we selected hits within $\pm 3\sigma_t$ of mean Cherenkov photon timing for each channel. The timing resolution of channels σ_t varies from 300 to 900 ps.

The distance between the downstream face of the aerogel block and SiPMs (expansion gap) could be varied. According to calculations the minimum width (σ_r) of the Cherenkov ring should be observed for the expansion gap of about 62 mm. This value could be defined as a 'focal' length of the aerogel sample. The density of photoelectrons on radius measured at the 62 mm expansion gap for one SiPM is presented in Fig. 2. The measured spatial resolution for Cherenkov photons is equal to 1.1 mm which is comparable with a photon position resolution of about 0.7 mm. The measured σ_r is dominated by photon position resolution and track resolution. This restricts precise examination of uncertainty due to parameters aerogel samples. Based on the results from the FARICH prototype #1 and the PDPC FARICH prototype we made the conclusion that to investigate parameters of focusing aerogel samples and tune the production technology, we need to improve the coordinate resolution of the photon detection.

3. Focusing aerogel radiator development

The development of focusing aerogels is going in two main directions: tuning of the production technology of multilayer blocks and developing a new production method with continuous

Table 1
The refractive index and thickness of the layers of tested focusing aerogel sample.

Layer number	1	2	3	4
Index of refraction	1.050	1.041	1.035	1.030
Thickness (mm)	6.2	7.0	7.7	9.7

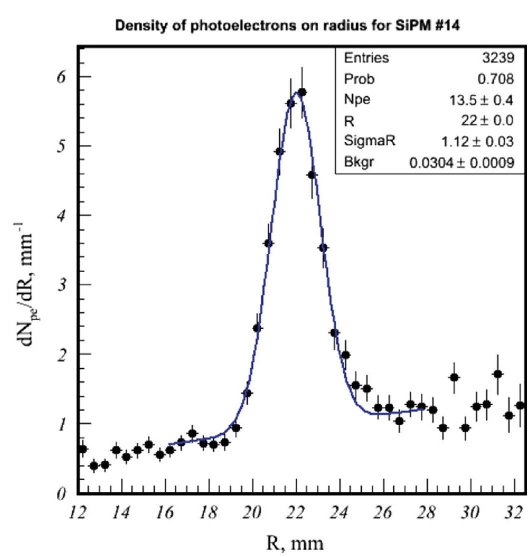

Fig. 2. Density of photoelectrons on radius for SiPM 14.

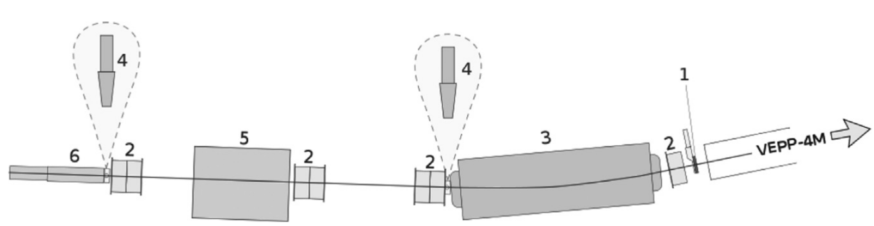

Fig. 1. The test beam apparatus layout: 1 – the converter of Bremsstrahlung gammas to electron–positron pairs, 2 – the drift chambers, 3 – the dipole magnet, 4 – the trigger scintillation counters, 5 – the FARICH prototype, and 6 – NaI scintillation counter.