Internal Note 08/2010

Beam-test of a Scintillator Paddle combined with Time-of-Flight walls in the Kaos spectrometer

P. Achenbach and S. Hirose

Institut für Kernphysik, Johannes Gutenberg-Universität Mainz, Germany

DATED: 30 August 2010

Set-up and Environment

The beam-time in August was primarily scheduled for data-taking with the fibre detector from the electron-arm of the KAOS spectrometer, however, time was available for tests of a neutron detector prototype, an aerogel detector prototype, and one prototype scintillator paddle. The beam was available for this scintillator paddle test from 26 August until 27 August 2010. The paddle was placed on the hadron-side of the spectrometer behind the scintillator walls.

Wall F is a segmented scintillator wall with 30 paddles of 38 cm × 3.7 cm × 2 cm size, made from material "Pilot F" (modern equivalent brand name: Bicron BC 408) and read out at both ends by fast PMT (Hamamatsu R1828). The paddles are tilted by 37° around the longitudinal axis in order to achieve an almost perpendicular flight path of the incoming particles into the 3.7 cm wide lateral surface. The total length covered by the wall is 189 cm. The wall is located near the focal-surface of the hadron-arm and a momentum resolution of approximately 4 % could be obtained with this segmentation. A second wall, labelled G, is used to discriminate valid tracks against background events. It consists of 30 paddles of 47 cm × 7.5 cm × 2 cm size with a flat geometry spanning a length of 2.2 m and read out at both ends by the same type of photo-tubes. The scintillating material is Bicron BC408. The width of the G paddles is 75 mm with black tape wrappings of 1 mm thickness.

A top-bottom mean timing for deriving the trigger is performed by summing the analogue signals. The hadron-arm trigger of the spectrometer is generated by a coincidence of hits in the two scintillator walls. It was derived by a VUPROM module, which is equipped with a Virtex-4 FPGA chip. Such modules were developed at the Experiment Electronics Department of GSI for general purpose logic operations and are routinely operated for the triggering of the hadron arm as well as the electron arm of the KAOS spectrometer. Several trigger conditions were loaded into the chip, the actual trigger type being chosen via the slow-control. A fraction of 88 % of the individual amplitude and the summed signals are brought to constant-fraction discriminators. The signals from the walls are digitised with Fastbus TDC and ADC modules. An intrinsic time-of-flight resolution of $\Delta t_{FWHM} \approx 420$ ps could be reached for pions traversing both walls.

The prototype scintillator paddle was connected to the same chain of electronics as the paddles from wall F and G. Some experimental settings during the beam-test are listed in Table 1. A scheme of simulated particle trajectories through walls F and G is shown in Fig. 1. Two sets of data were taken, one with the prototype paddle aligned with wall G and a second set with the paddle rotated by circa 60°.

Table 1: Experimental settings during the beam-test for the prototype scintillator paddle at MAMI in August 2010.

beam energy	510 MeV
beam intensity	0.1–100 μA
target material	^{12}C foil
target thickness	45 mg/cm^2
spectrometer angle	37.5°
magnetic field polarity	positive
coil current	766.6 A
magnetic field strength	0.7184 T

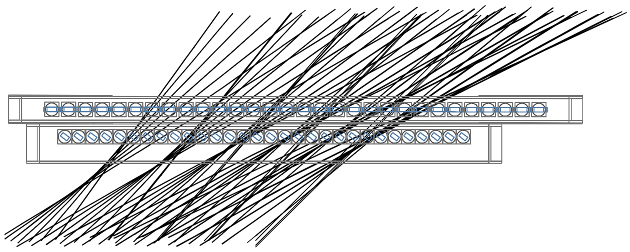

Figure 1: Scheme of the particle trajectories crossing both scintillator walls (F at bottom, G at top), defining a pattern of valid paddle combinations. The track angles are distributed around 60° to the normal for tracks within the spectrometer acceptance.

Figure 2: Photograph of the setup inside the KAOS spectrometer.

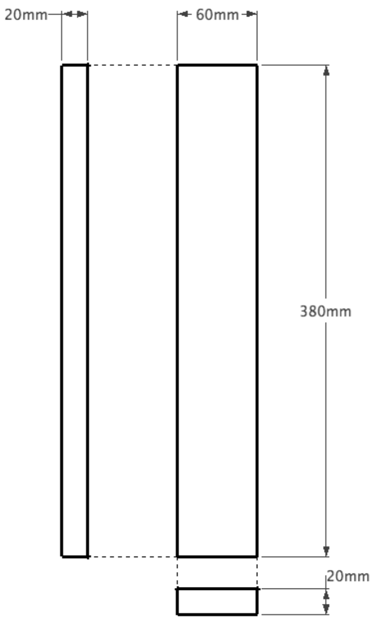

Figure 3: Scintillator dimensions.

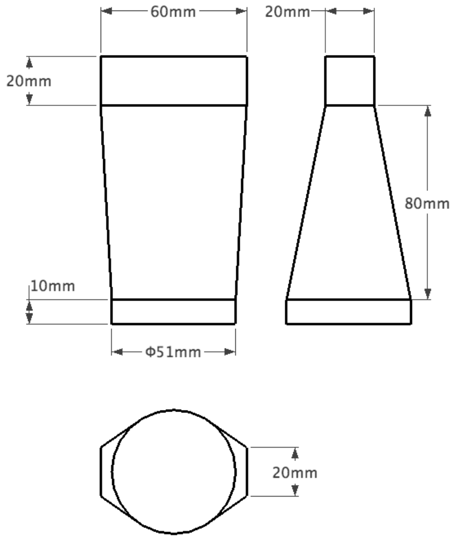

Figure 4: Light-guide dimensions.

Table 2: Characteristics of the scintillator paddle and attached PMTs.

scintillator dimensions	$380 \times 60 \times 20\,\mathrm{mm}^3$
material	Bicron BC-408
fish tail length	110 mm
fish tail diameter	51 mm
PMT type	Hamamatsu H1949
HV bottom PMT	-1699 V
HV top PMT	-1678 V

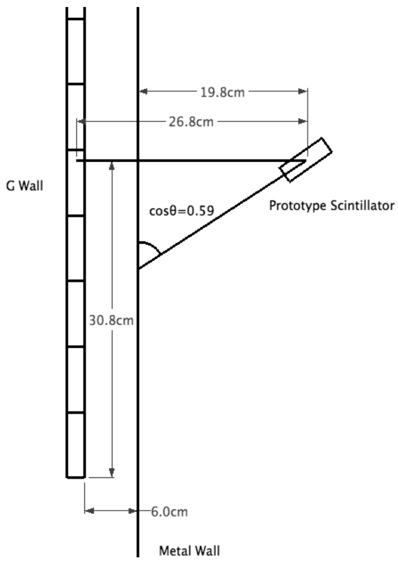

Figure 5: Geometry of prototype scintillator setup. The prototype is adjacent to paddle no. 25 in wall G.

Results

The HV was calibrated with pions and protons as shown in Fig. 6. The CFD threshold for the analogue sum was adjusted to suppress noise below the pion peak, which is seen as a low-energy tail in the spectra.

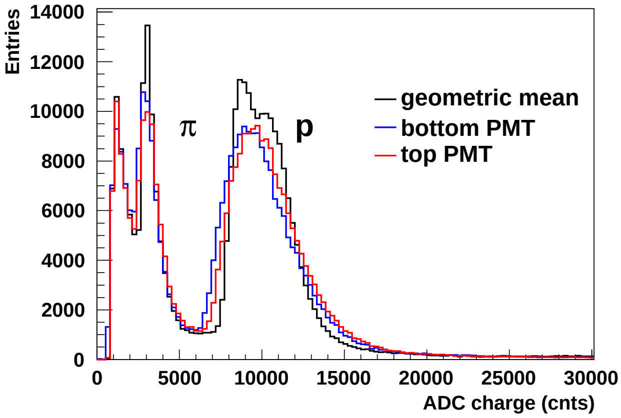

Figure 6: ADC spectra from the prototype scintillator. The two ADC channels were pedestal corrected and the dual-range recording (high-range above ADC channel 4096 with factor 8 lower sensitivity) was transformed into a single histogram. The HV of both PMTs was calibrated by bringing the pion and proton peaks from the top and the bottom channel into overlap. In the data analysis the geometric mean from both amplitudes was used to correct for any exponential light absorption in the paddle.

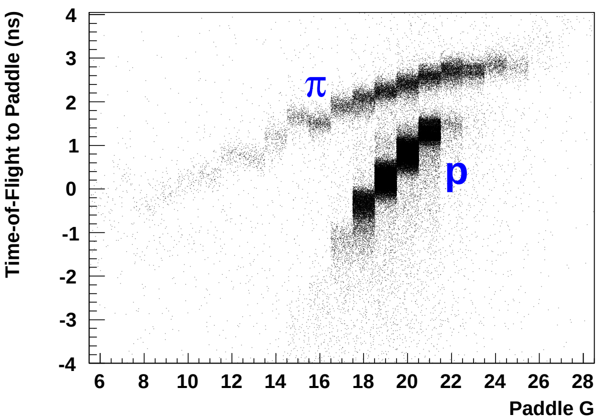

Figure 7: Time-of-flight between wall G and the prototype scintillator as a function of the paddle no. in G for protons and pions. Pions easily scatter in the wall or the metallic protection following the wall and can arrive to the prototype from a greater range of angles. The flight time has no absolute calibration. The flight-time variation due to the change in flight-path is seen.

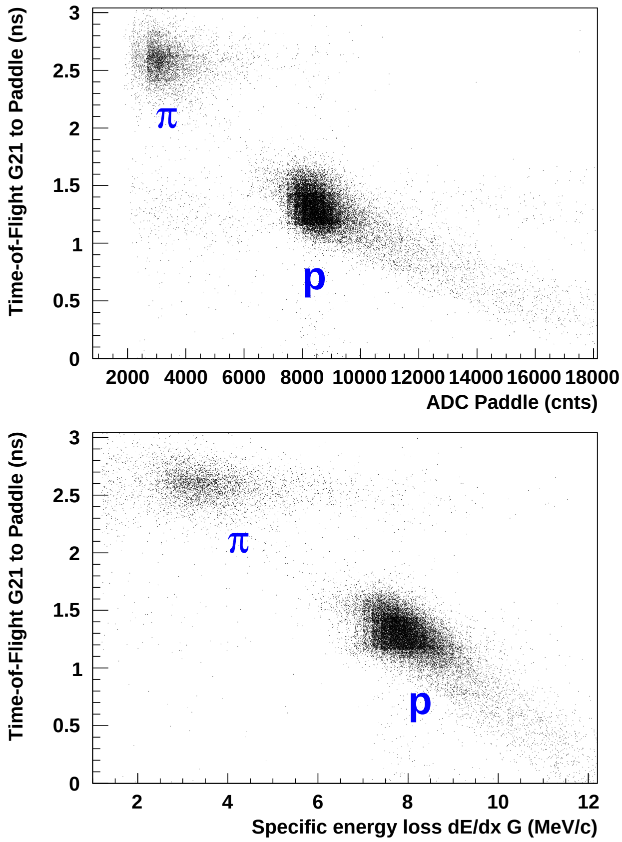

Figure 8: Particle ID through measured time-of-flight and charge, an example for paddle G21. The top panel shows the geometric mean of the charge in the prototype scintillator, the bottom panel the specific energy loss $\mathrm{d}E/\mathrm{d}x$ as measured with wall G. The proton peaks show some characteristic high-amplitude tails correlated with the time-of-flight.

Table 3: Recorded trigger rates, R, in the hadron arm of the KAOS spectrometer during beam-tests for different beam currents, I, and different trigger settings (P means prototype scintillator).

I (μA)	trigger type	R (kHz)
1	P	2.2
4	P & any F & any G	0.45
10	P	21.5
10	P & any F & any G	0.9
30	P	71.5
30	P & any F & any G	8.0

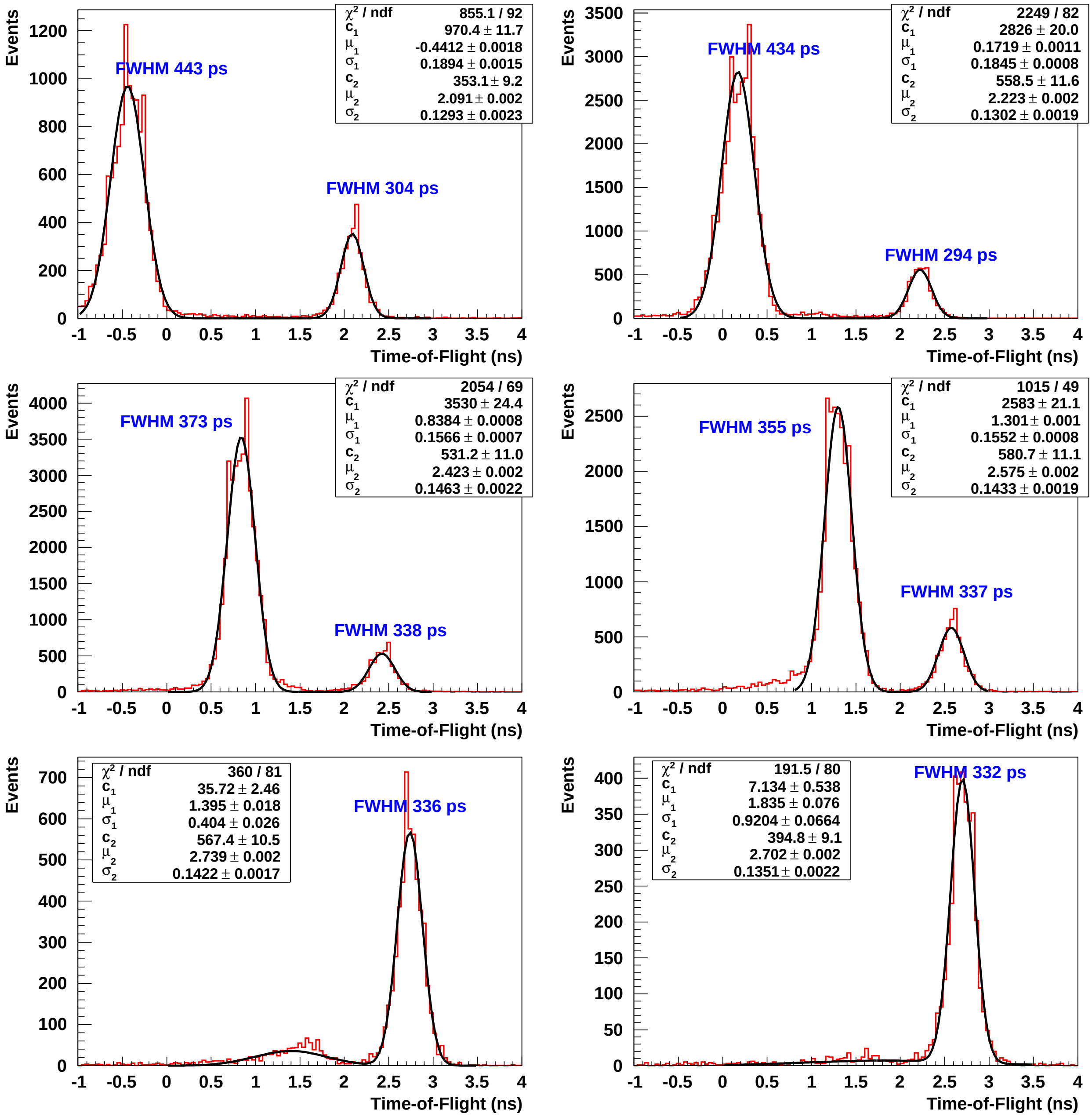

Figure 9: Fits to the time-of-flight spectra from wall G to the prototype scintillator for paddle nos. 18 to 23 (from top left to bottom right). Pions are on the right side of the histograms, protons to the left side. No time-walk corrections were applied.

Table 4: Path-length from the centre of a G paddle to the centre of the prototype scintillator, average relative momentum at this paddle position, expected relativistic speed of pions and protons of this momentum, measured time-of-flight from this paddle to the prototype scintillator for pions and protons (normalized to pion flight-time from paddle no. 22), and flight-time differences between pions and protons. The central momentum was 540 MeV/c.

paddle no.	x (cm)	p (MeV/c)	Lorentz β		length (cm)	Δt G–P		
			π	p		π (ns)	p (ns)	π–p (ns)
18	52.8	+5%	0.97	0.52	59.2	0.65	3.18	2.53
19	45.2	+8.5%	0.97	0.53	52.6	0.52	2.57	2.05
20	37.6	+12%	0.97	0.54	46.2	0.32	1.90	1.58
21	30.0	+16%	0.98	0.55	40.2	0.17	1.44	1.27
22	22.4	+19%%	0.98	0.56	34.9	0.00	—	
23	14.8	+23.5%	0.98	0.58	30.6	-0.04	—	

Conclusion

Preparations, operation and data analysis of the beam-time were successful. The paddle showed very good time resolution $\Delta t_{FWHM} = 0.3$–0.4 ns and large amplitudes leading to a high separation power for charged particles in the 400–600 MeV/c momentum range.