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NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS

Performance of the BaF_2-calorimeter TAPS[1]

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The electromagnetic calorimeter TAPS (Two/Three Arm Photon Spectrometer) - comprising in its present set-up 384 individual plastic-BaF_2 scintillator telescopes - has been constructed to identify and measure hard photons and neutral mesons via the reconstruction of the invariant mass from their two or three photon decay modes. Photons can be detected up to an energy of 15 GeV with high resolution (σ/E = 2.5% at 1 GeV). Neutrons and charged particles are identified by pulse-shape analysis (PSA) and time-of-flight techniques (TOF) with high efficiency. The optional modification into modular plastic/BaF_2 phoswich telescopes allows improved particle spectroscopy at medium energies simultaneously.

1. PHYSICS MOTIVATION

The calorimeter TAPS [1] was planned and built by an European collaboration [2] to investigate high energy photons as well as neutral mesons (π^0, η, ω) in relativistic and ultra-relativistic heavy ion collisions or photonuclear reactions, respectively. The point of impact and the total energy of the electromagnetic shower (E.M.) have to be determined precisely to reconstruct the invariant mass from the meson decays into two or three photons.

The high multiplicity of hadronic reaction products requires a very efficient discrimination against charged or neutral particles as well. BaF_2 is the most appropriate scintillator material due to its high light output, fast response and intrinsic selectivity of its pulse-shape to the nature of the impinging probe [3]. The envisaged very broad range of the diversified and rich research program at different accelerator facilities in Europe (AGOR, CERN-SPS, GANIL, GSI, MAMI) requires the modularity of the device and high flexibility in the geometrical arrangement of the experimental setup.

2. THE DETECTOR CONCEPT

2.1. The individual detector

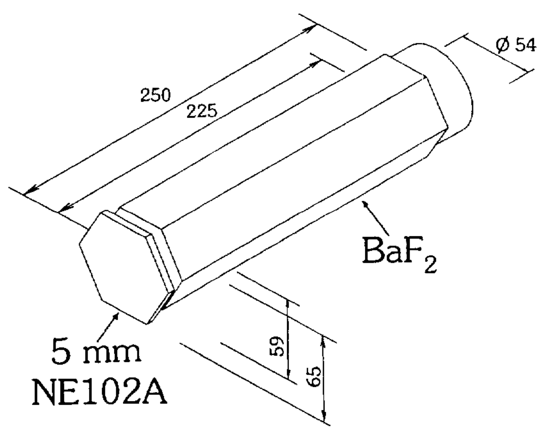

Figure 1. The geometry of the individual plastic- and BaF_2-scintillator. The dimensions are given in mm.

Each of the almost 400 detector components consists of a 250 mm long ($12X_0$) hexagonally shaped BaF_2-crystal (inscribed circle Ø = 59 mm) [4]. The last 25 mm are

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machined cylindrically in diameter (∅ = 52 mm) to allow optimum magnetic shielding (see Figure 1). Laser light can be fed into each crystal by a quartzfibre for gain monitoring and calibration of the read-out electronics. The crystals are wrapped with PTFE and an additional layer of aluminum foil as UV-reflector and coupled optically to the quartz window of the photomultiplier tube (Hamamatsu R2059-01) with high viscosity grease. The assembly of the individual module including the base is achieved using 0.2 mm thick heat shrinkable PVC-tubing [1], which is light tight and provides the sufficient mechanical strength.

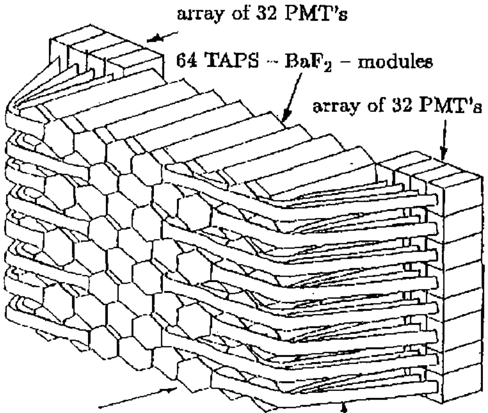

Figure 2. The fully assembled detector block consisting of 64 plastic-BaF_2 scintillator telescopes.

The modular detectors can be grouped in blocks (see Figure 2) arranged either on top of each other in two/three movable towers or in a ring in the horizontal plane through the target as shown in Figure 3. Alternatively, a large annular hexagonal supercluster can be formed. A charged particle veto (CPV) consisting of hexagonal plastic scintillators (5mm NE102A) read-out individually by lightguides and photomultipliers can be mounted in front only in case of the standard block geometry of 8 by 8 modules as illustrated in Figure 2.

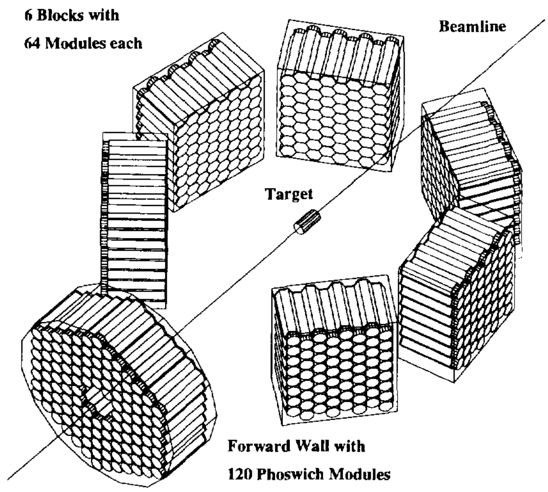

Figure 3. The TAPS set-up as used at the tagged photon facility of MAMI at Mainz.

The optical transmission, signal shape, energy response of the fast and slow scintillation component to low energy γ-sources and the contamination of α-emitting radionuclei (identified via the analysis of the pulse-shape) are measured carefully for each crystal. Table 1 shows the obtained test results averaged over 450 accepted crystals (in collaboration with A2 at Mainz) in comparison to the required specification limits. Crystals of a total length of 350 mm (quadratic diameter 35x35mm^2), recently manufactured by SICCAS (Shanghai, China), have been investigated in an identical manner and the results are shown for comparison.

The processing of the BaF_2-signals foresees the determination of the time-of-impact (TOF-analysis) and the integration of the total as well as the fast scintillation component separately (integration gates 2μs and 40ns, respectively) to perform pulse-shape analysis of the E.M. shower.

Table 1: Test results obtained for 450 accepted TAPS crystals compared to the required specifications and to recently produced samples of different geometry (see text for details).

performance parameter	TAPS average	CHINA average	CHINA best results	spec.limits
absorption length Λ [cm]				
at λ = 200 nm	41.7	22.8	27.5	18.0
at λ = 220 nm	76.7	41.8	56.6	28.0
at λ = 300 nm	488.7	139.2	188.6	292.0
^{137}Cs: E_γ = 662 keV				
fast: ΔE/E [% FWHM]	35.3	45.7	40.2	45.0
total: ΔE/E [% FWHM]	11.5	14.0	11.5	12.5
intensity ratio fast/slow at Δt=40ns	9.5	9.4	12.0	7.0
^{60}Co: E_γ = 1.33 MeV				
peak/valley ratio	2.28	1.61	2.30	2.00
α-activity				
dN/dt [counts s^{-1} cm^{-3}]	0.021	0.175	0.071	0.133

2.2. Particle/Photon Identification

The identification and discrimination of neutral and charged particles can be achieved exploiting the intrinsic properties of BaF_2 in combination with a fast plastic scintillator used either as a separate CPV system or as a phoswich detector when coupled optically to the BaF_2-crystal. The short decay time and the high light output of BaF_2 allow time resolutions better than σ=85 ps even for the large TAPS modules [5]. Therefore, particle identification and even energy determination can be performed based on TOF-technique at a typical distance of 1 - 2 m from the vertex using a start-counter system as time reference. In particular, low and medium energy neutrons, which react via (n,γ)-processes with BaF_2 and induce a signal-shape identical to that of photons, can only be identified via TOF.

Restricted to the standard TAPS block geometry, the CPV system allows as well an online tagging of charged or neutral hits as the measurement of the specific energy loss ΔE of charged particles for identification by means of ΔE-E-correlations.

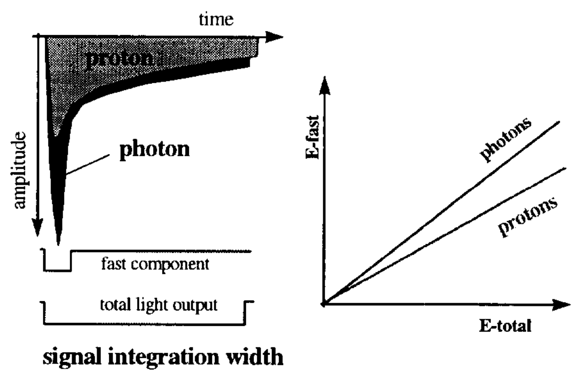

Figure 4. <u>left:</u> The typical signal shape of BaF_2 for photons and charged particles. The integration gates for signal processing are indicated. <u>right:</u> Particle identification based on the correlation of the separately integrated yield of the fast and total light-output.

The shape of the BaF_2-signal is extremely sensitive to the nature of the impinging particle. The contribution of the fast scintillation component (λ = 195, 210 nm) to the total light output (dominated by the slow scintillation component at λ ~ 320 nm) diminishes with the increase of the energy density deposited by the ionizing particles. Figure 4 illustrates schematically the typical response of photons and protons and the crude pulse-shape analysis performed in TAPS.

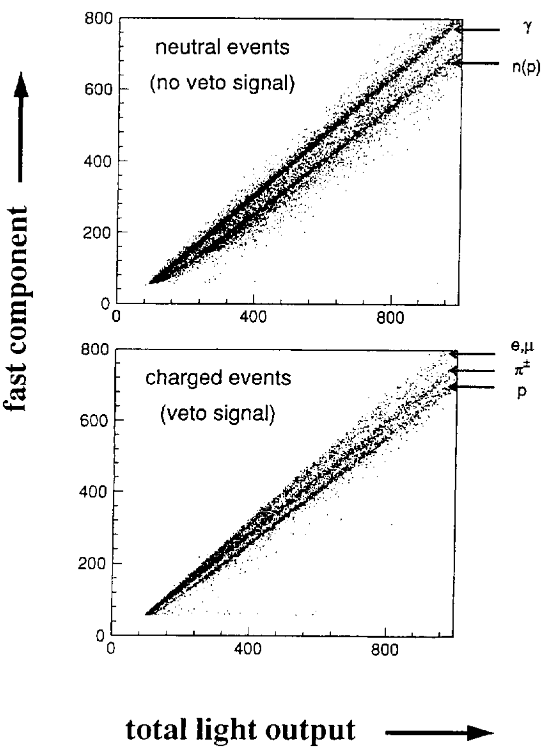

Figure 5. Scatter plot of the fast scintillation component versus the total light-output of a TAPS BaF_2-detector. The correlation pattern is shown for neutral (top) and charged events (bottom) selected by the CPV system.

It has been established that the ratio of both contributions remains constant over the full dynamic range up to relativistic and even ultra-relativistic energies [6]. E.M. and hadronic showers contribute differently to the fast scintillation component. Figure 5 shows as an example of the PSA two scatter plots of the fast scintillation component versus the total light output accumulated for neutral and charged events (identified by the CPV) from data taken in photonuclear reactions. A dynamic range up to approx. 250 MeV photon equivalent energy is displayed. As marked, the distinct lines correspond to leptons, pions, protons as well as photons. The lower branch in the plot for neutral hits can be addressed to secondary protons recoiled by high energy neutrons which interact in the crystal via (n,p)-reactions. Measurements of the response function of TAPS detectors to neutrons deduce an efficiency which approaches a nearly constant value of 17 % above 750 MeV kinetic energy of the neutrons.

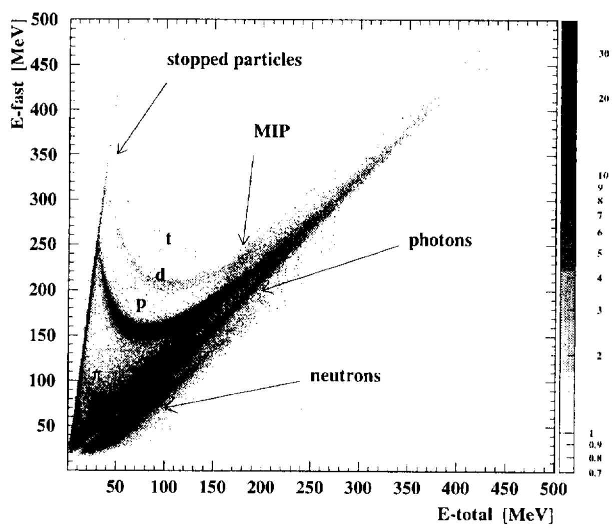

Figure 6. Pulse-shape correlation of a 15 mm plastic-BaF_2 phoswich detector identifying reaction products from the collision 2 AGeV Ca + Ca measured at GSI, Darmstadt.

The particle sensitivity can be further improved by a fast plastic scintillator (15mm NE102A) optically coupled to the front face of the BaF_2-crystal in phoswich technique [7]. The energy loss of charged particles in the plastic layer leads to a substantial increase of the total fast light output. The corresponding pulse-shape correlation is illustrated in Figure 6 identifying reaction products from the collision 2 AGeV Ca + Ca. Structures in the scatter plot above the clearly distinct branch due to photons can be assigned to charged particles either stopped within the ΔE-section or fully or partly stopped within the BaF_2-crystal. The distinct area near E_{total}~170 MeV is caused as an artifact by minimum ionizing particles generating additional Cherenkov photons within the quartz window of the photomultiplier. Again, neutrons identified via (n,p)-reactions can be observed below the proton branch well separated.

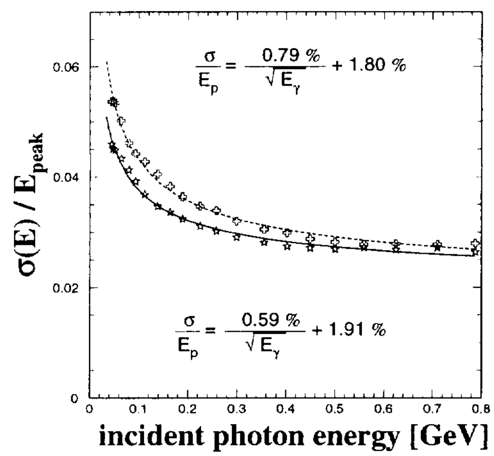

Figure 7. Energy resolution of the total light output (stars) and the fast scintillation component (crosses) as a function of the incident photon energy. The energy dependence has been parametrized by $\sigma / E = A / \sqrt{E} + B$ as shown in the figure.

2.3. Response to electromagnetic probes

The photon response of TAPS has been determined in the energy regime up to 800 MeV using monochromatic photons provided by the tagging facility of MAMI at Mainz [8]. The experimental results are shown in Figure 7. The excellent energy resolution for a collimated photon beam (∅ = 1.3 cm) amounts to $\sigma / E = 0.59\%\ E_\gamma^{-1/2} + 1.9\%$ (E_γ given in GeV) and $\sigma / E = 0.79\%\ E_\gamma^{-1/2} + 1.8\%$ for the fast component, respectively. The achieved resolution at 1 GeV of $\sigma / E = 2.5\%$ is comparable to operating 4π-calorimeters such as *L3*, *CleoII* or *Crystal Barrel*, respectively. The obtained experimental data can be well reproduced by GEANT3-simulations taking into account the exact geometry, dead material such as reflector or light tight housing and experimental thresholds.

The point of impact can be reconstructed from the electromagnetic shower distribution within the cluster of responding detectors with a resolution Δx < 2 cm limited due to the large diameter of the crystals. In spite of the insufficient depth of the crystals ($12X_0$) an energy resolution for 10 GeV electrons of $\sigma / E = 5.1\%$ has been achieved within a cluster of only 7 modules.

3 NEUTRAL MESON SPECTROSCOPY

Within the last few years of operation TAPS has pursued a broad and versatile research program which covers topics such as the early phase of nuclear reactions and energy dissipation mechanisms via the detection of hard photons below 100 MeV/u projectile energy. In the 1 GeV/u regime, the investigation of baryonic excitations in nuclei via photonuclear reactions and the study of hot and dense nuclear matter via the production and propagation of neutral mesons represent the main experimental goals.

In particular, the meson reconstruction in heavy ion collisions relies on the efficient neutral and charged particle discrimination provided by TOF- and PSA-techniques as illustrated in the previous sections. The very good energy resolution achieved with BaF_2

allows an invariant mass resolution of typically 8-15% (FWHM) which is necessary to identify the weak meson signal on top of a huge combinatorial background in the invariant mass spectrum. Figure 8 shows an example taken at the so far highest bombarding energy of 450 GeV/c p+Be operating TAPS assembled in a supercluster in coincidence with the dilepton spectrometer CERES at CERN-SPS [6].

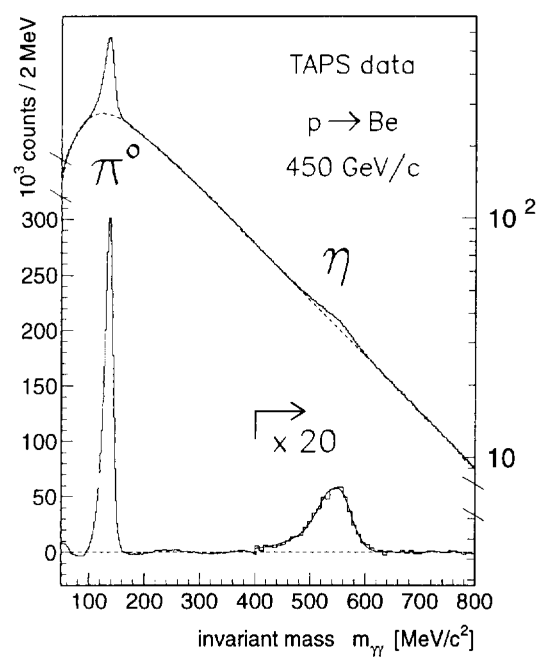

Figure 8. Invariant mass distribution measured with TAPS at the CERN-SPS in the system 450 GeV/c p+Be in coincident operation with the dilepton spectrometer CERES. In the lower part the combinatorial background has been subtracted.

5 SUMMARY

The BaF_2-calorimeter TAPS - designed for high energy photon detection - is operating very successfully since several years as an European device with high performance and allows high resolution photon and particle spectroscopy [9]. The excellent and unique properties of the fast scintillator material BaF_2 such as time response and pulse-shape sensitivity and the combination with plastic scintillators in different concepts guarantee the required clean , selective and efficient photon detection.

The various instrumental techniques and geometrical arrangements made it possible to adjust to the experimental constraints imposed by the very widely scattered physics program. The proposed coincident operation with future generation detector systems such as the dilepton spectrometer HADES at GSI requires as a new major milestone the implementation of much faster analog and logic electronics and a highly selective 2nd level trigger processor which are under development now.

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