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Bremsstrahlung in the nuclear medium

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Chapter 4

Setup of the experiment

Data presented in this thesis were obtained from two experiments. The first experiment was designed to measure deep sub-threshold pions [Aph98], while the second experiment was aimed to measure photon-nucleon coincidences, the main focus of this thesis. Both experiments were performed at the Accelérateur Groningen Orsay (AGOR), the cyclotron facility of the Kernfysisch Versneller Instituut (KVI) at Groningen. AGOR is a compact superconducting cyclotron capable of producing proton beams up to 200 MeV. The experiments have been carried out by the TAPS and SALAD collaboration. The setup of both experiments was nearly identical. In this chapter the relevant details of the setup are discussed.

4.1 The Two-Arm Photon Spectrometer: TAPS

The TAPS collaboration [Nov91] was initiated in 1987 to design and build a spectrometer to measure energetic bremsstrahlung and high-energy photons from neutral meson decays in nuclear reactions in the energy range from 1 MeV up to 15 GeV. Therefore, TAPS can be employed in both high- and medium-energy physics. In figure 4.1 a detector module, is shown. The TAPS detector consists of 384 of these modules. The modules have two components, an inorganic scintillator (BaF_2) and a plastic scintillator as Charged Particle Veto (CPV) detector to distinguish charged and neutral particles. The modules are arranged in 6 arrays of 64 modules (8 x 8) each. Such an array is called a TAPS-block. The block arrangement is shown in figure 4.1. This arrangement makes it possible to reconstruct the position of the detected particles with a resolution comparable to the module size. This is sufficient for the purpose of this experiment, aiming at an angular binning

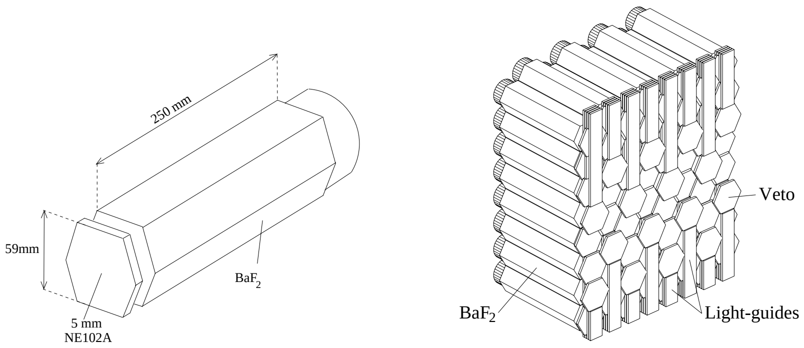

Figure 4.1: *Left side , drawing of an individual TAPS module. Right side, drawing of a TAPS-block consisting of 64 TAPS modules.*

of 15°.

The BaF_2 crystals are hexagonally shaped with an inscribed diameter of 59 mm and a length of 250 mm (12 radiation lengths). BaF_2 has three scintillation components, two fast ones with a decay time of 0.6 ns at 195 and 210 nm, and a slow one with a decay time of 620 ns at 310 nm. The relative light yield depends on the ionization density and, therfore, allows particle discrimination. The scintillation light from the crystals is converted to charge and amplified by a photomultiplier (Hamamatsu R2059-01) mounted on the back of the crystal.

The CPVs are made of 5 mm thick plastic scintillator (NE102A) which is sensitive to charged particles but not to neutral particles [Ras98]. The plastic slices are hexagonally shaped and have an inscribed diameter of 61 mm. The CPVs are slightly larger than the BaF_2 crystals behind it to optimize the overlap. Perspex light-guides lead the scintillation light from the plastic to a photomultiplier mounted at the side of the TAPS block, see figure 4.1.

In figure 4.2 (left) a top view is given of the overall geometry used for these experiments. The TAPS-blocks are arranged facing the target at angles 76.5°, 116.5° and 156.5° degrees on either side of the beam axis. They were aligned in such a manner that the center of each block was positioned at the beam height and the front face of the BaF_2 crystals was located at 66 cm from the target.

The TAPS electronics records for each event the deposited energy and

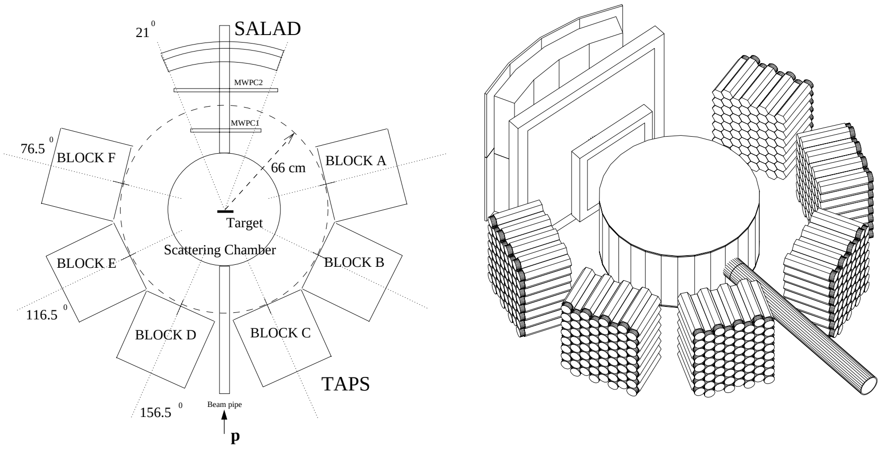

Figure 4.2: *Geometry of the setup. On the left hand side a top view and on the right hand side a 3D impression of the setup.*

the time of all modules. A scheme of the electronics is given in figure 4.3 and will be briefly explained here. The trigger electronics is described in section 4.4.

The BaF_2 signals are split 4-fold by active splitters located close to the detector. Three signals are used to generate three level-discriminating logic signals, one Constant-Fraction Discriminator (CFD) and two Leading-Edge Discriminator signals (LED Low, LED High). The fourth output presents the analogue signal to the QDC. The CFDs have been set to their lowest practical threshold value of about 7-10 mV. Using a ^{22}Na source it was found that this corresponded to an energy threshold of about 0.4 MeV. The LED Low and LED High discrimination levels were set at 7 MeV and 15 MeV, respectively. The calibration of the LEDs was achieved by observing for each module where the discriminators cut the calibrated energy spectrum. It was found that the LED discrimination level could be accurately set to their designated value with a spread of 3 MeV. The analogue BaF_2-signals are integrated by charge-to-digital converters (QDCs). The integration over a short and a long time gate allows one to separate the response from the fast and slow scintillation components. These time gates are individually generated for each module by gate-generators (Retard de Durée Variable, RDV) which are started by the CFD signal of the module. The voltage on the photomultipliers were chosen such that the QDCs cover a dynamic range up to 250 MeV. The intrinsic resolution is then 60 keV/channel. The time of the BaF_2 signal is measured by time-to-digital converters (TDCs). The TDC

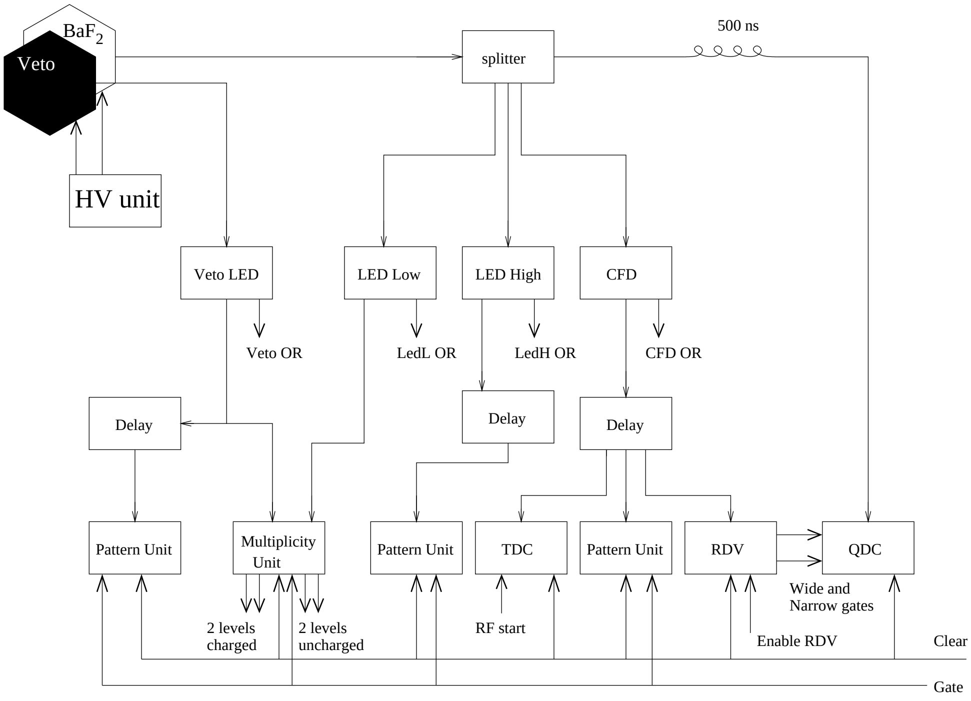

Figure 4.3: *Scheme of the TAPS readout electronics.*

start signal is generated by a logical AND of the cyclotron radio-frequency signal (RF) and the master trigger (MT). The TDCs are stopped by the CFD signal of the individual modules. In this way the time-of-flight from target to crystal is recorded. The TDCs have an intrinsic resolution of 80 ps/channel, far better than the resolution needed to separate nucleons from photons on basis of the difference in time-of-flight which is in the order of 3 to 10 ns. In addition to the energy, pulse shape and time-of-flight information, the logic signals CFD and LED High of each module are recorded in bit-pattern units (BPUs).

The CPV detectors provide two output signals, one from the photomultiplier anode and one from the last dynode [Ras98]. The anode signal was integrated by a charge to digital converter (Fast Encoding Readout ADC, FERA). The dynode signal was used to generate a LED logic signal. The level of the LEDs was set such that it was just above the noise level.

4.2 The Small-Angle Large-Acceptance Detector: SALAD

The Small-Angle Large-Acceptance Detector was designed for the study of proton-proton bremsstrahlung production [Kal98]. This detector was part of the experimental setup and has been used to measure coincidences of protons scattered to forward angles and photons in TAPS. However, the later analysis revealed that the SALAD-TAPS coincidence data were by far dominated by random coincidences which prevented a reliable determination of true coincidence data. Consequently, this limits the exclusive bremsstrahlung spectra shown in this thesis to those obtained using only the TAPS detector, i.e. both the proton and the photon were detected by TAPS. SALAD will therefore not be described further here, detailed information can be found in [Kal98, Hui99, Mes99].

4.3 Beam and targets

The proton beam was generated by the polarized ion source (POLIS) and accelerated by AGOR to an energy of 189.6 MeV. The beam current was monitored using a well shielded Faraday cup. The charge collected by the Faraday cup was converted to pulses with a resolution of 100 pC per pulse, which were counted by a scaler that was read out by the data-acquisition system. The typical range of beam currents used for the experiment was from 0.5 to 2 nA depending on fluctuations in the intensity of the source. During

Target	surface density / ($\frac{mg}{cm^2}$)	anisotropy* 'down'	anisotropy* 'up'
C	56	-0.25	+0.28
Ni	19.6	-0.20	+0.22
Ag	26.2	-0.15	+0.19
Au	22.2	-0.11	+0.12

Table 4.1: *A list of the targets used, with the respective surface densities and effective anisotropies (anisotropy*) measured for beam with polarization 'up' and for the beam with polarization 'down'.*

the experiments POLIS produced beams with a polarization degree of about 56%. The degree of polarization was determined by the In Beam Polarimeter (IBP) [Bie00]. The IBP measures the anisotropy of the p+d reaction which is known from literature. The target of the IBP generates beam halo at the TAPS-SALAD setup site, causing too high count rates in TAPS and SALAD. Therefore the IBP could not measure simultaneously with the experiment. The polarization of the beam is monitored during the experiment exploiting the asymmetry in elastic scattering of protons detected by SALAD. The measured asymmetry is translated to a degree of polarization using an effective value for the anisotropy which is determined by comparing the scattering asymmetry measured by SALAD shortly after the IBP has measured the polarization of the beam. In table 4.1 the targets and surface densities used in this experiment are listed. The target size is 1.5 cm wide by 1 cm high, much larger than the beam spot which is a few mm in diameter. The targets were placed on a target ladder inside a carbon-fiber scattering chamber and could be positioned by remote control. The carbon-fiber chamber has a radius of 35 cm and a height of 50 cm [Hoe99]. The rectangular exit window matches the solid angle covered by SALAD. The chamber wall is constructed from carbon fiber and has a width of 3.75 mm. This design minimizes the conversion of photons to dileptons which is of importance for dilepton studies and for precision measurements of photons. For 10 MeV and 100 MeV photons the conversion probability is about 0.4% and 1.1%, respectively [Hoe99]. For aluminum of the same thickness the conversion probabilities are a factor 2 higher, 0.8% and 2.1 % respectively.

4.4 Trigger and data acquisition

In table 4.2 the definitions of the triggers used in the experiment are listed. For the research goal of this thesis especially the triggers from number 7 and

nr	Description	label	down-scale factor 2^x
1	OR of all BaF_2 CFD	CFD or	14
2	OR of all BaF_2 LED Low	LEDL or	11
3	OR of all BaF_2 LED High	LEDH or	10
4	OR of all CPV LED	VETO	13
5	Pedestal monitor 0.2 Hz	Pedestal	0
6	1-neutral	1n	8
7	2-neutral coincidence	n-n	0
8	1-neutral anywhere and 1-neutral in blocks B-E and	n-g1	0
9	1-neutral in block A or F and 1-neutral in blocks B-E	n-g2	0
10	1-neutral left side of beam and 1-neutral right side of beam	pion high	0
11	1-neutral anywhere and 1-charged in blocks B-E	n-c1	0
12	1-neutral anywhere and 1-charged in block A or F	n-c2	1
13	1-inelastic in SALAD and 1-neutral TAPS	Nucleon-γ	4

Table 4.2: *A list of the trigger descriptions and down-scale factors of triggers which were used in the exclusive bremsstrahlung experiment. 1-neutral means that 1* BaF_2 *LED Low fired but the corresponding CPV LED did not, whereas 1-charged means that 1* BaF_2 *LED Low and the corresponding CPV LED both fired.*

higher are important. In figure 4.4 the electronic realization of the triggers is shown.

Data was recorded with the acquisition (DAQ) scheme shown in figure 4.5. The TAPS data is read out from the CAMAC modules using CVC CAMAC-controllers based on MOTOROLA 68030 processors. Each of the 12 CVCs reads out the data associated with 32 detector channels, thus accomplishing a high degree of parallel processing of the TAPS data-acquisition. A 13th CVC performs the readout of trigger scalers, trigger pattern, and the polarized-source status. The Input Output Logic (IOL) module in the 13th CVC activates the DAQ-software when a master trigger is produced and it sets the

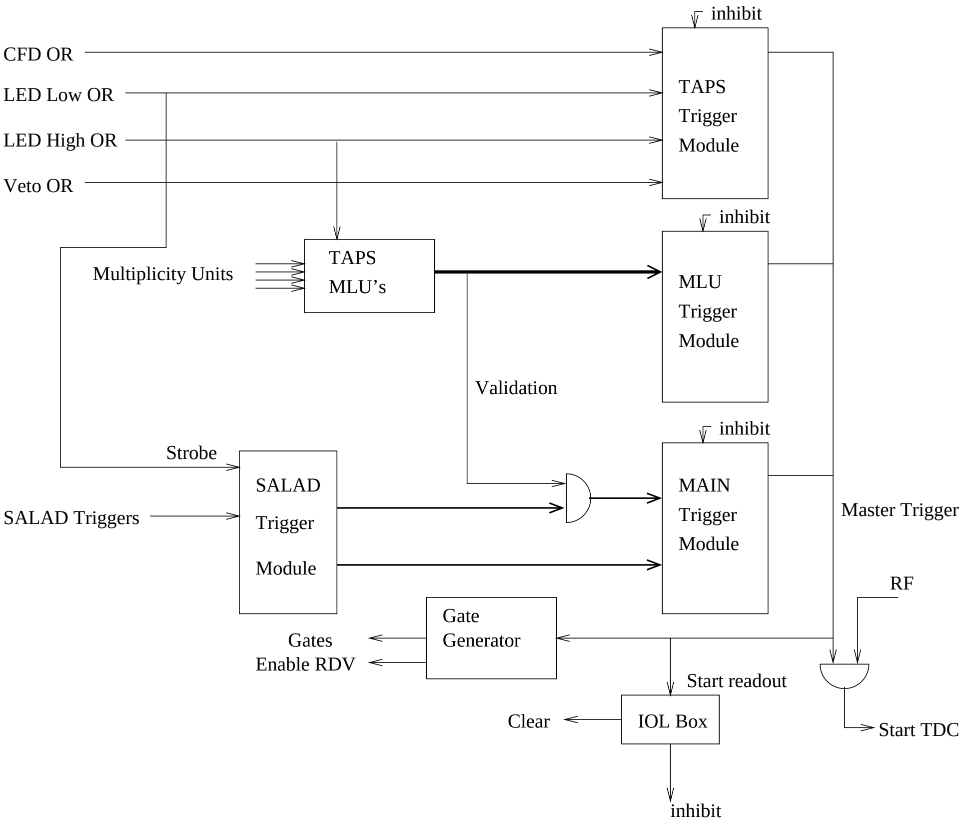

Figure 4.4: *TAPS trigger-electronics scheme.*

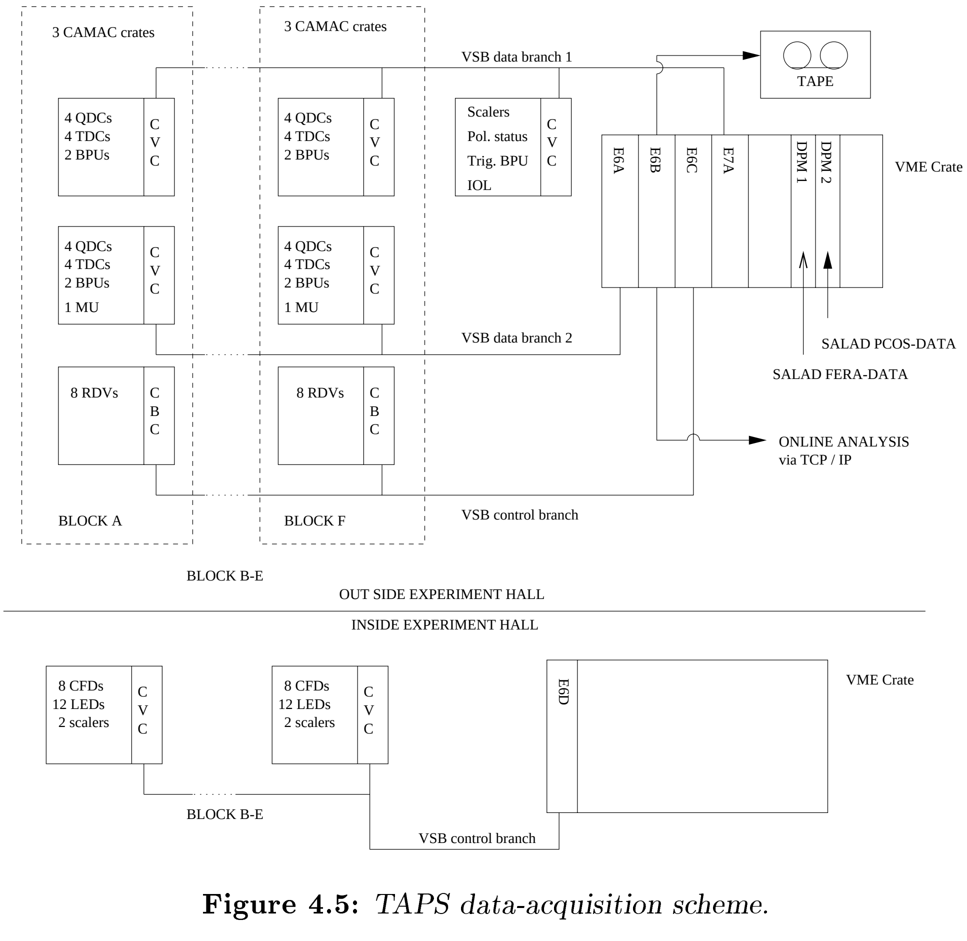

Figure 4.5: *TAPS data-acquisition scheme.*

inhibit signal. The inhibit signal blocks the trigger while the DAQ-software is busy reading out the accepted event data and therefore cannot accept new events. After the DAQ-software has finished its task it resets the inhibit signal and produces a clear signal on the IOL module. While the CVCs read the TAPS electronics, SALAD data is read into two Dual Port Memory modules (LeCroy DPM 1190) using the ECL readout bus of the LeCroy FERA system [Hui99, Mes99]. The typical data rate of the acquisition was about 150 kB/s, allowing an accepted event rate of 500 Hz with a life-time of about 40%. The SALAD and TAPS data are read from the DPMs and the CVCs, respectively, by a VME-based ELTEC Version 6 Computer (E6A) and an ELTEC Version 7 Computer (E7A). After reading the data into the memory it is copied by the E6B to a DLT-tape. For online analysis purposes about 1% of the data is also made available through a TCP/IP connection to analysis programs on other computers. This allows checking of the detector performance during the experiment. The settings of the electronics such as the high voltages and the settings of the CFDs and LEDs, are stored and maintained using a database programmed in SQL (Structured Query Language). The settings are transfered to special programs running on the E6C and E6D VME processors and subsequently loaded via the VSB bus and CBV CAMAC controllers into the electronic modules (the CFDs, LEDs and RDVs).