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The low energy tagger for the KLOE-2 experiment

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ABSTRACT

The KLOE experiment at the upgraded DAFNE e^+e^- collider in Frascati (KLOE-2) is going to start a new data taking at the beginning of 2010 with its detector upgraded with a tagging system for the identification of gamma–gamma interactions. The tagging stations for low-energy e^+e^- will consist in two calorimeters placed between the beam-pipe outer support structure and the inner wall of the KLOE drift chamber. This calorimeter will be made of LYSO crystals readout by Silicon Photomultipliers, to achieve an energy resolution better than 8% at 200 MeV.

1. $\gamma\gamma$ physics at KLOE

The term "$\gamma\gamma$ physics" (or "two-photon physics") stands for the study of the reaction

$$e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^- + X$$

where X is some arbitrary final state allowed by conservations laws. Since the two-photons are in a $C=+1$ state and the value $J=1$ is excluded (Landau–Yang theorem), photon–photon scattering [1] at the e^+e^- colliders gives access to states with $J^{PC}=0^{\pm +}, 2^{\pm +}$, not directly coupled to one photon ($J^{PC}=1^{--}$). These processes, of $\mathcal{O}(\alpha^4)$, with a cross-section depending on the logarithm of the center of mass energy E, so that, for E greater than a few GeV they dominate hadronic production at e^+e^- colliders.

The cross-section $\sigma(\gamma\gamma \rightarrow X)$ was studied at e^+e^- colliders, from PETRA to CESR to LEP, over the years. However, the experimental situation in the low-energy region, $m_\pi \leq W_{\gamma\gamma} \leq 700$ MeV, [2] is unsatisfactory for several reasons:

- large statistical and systematic uncertainties due to small data samples and large background contributions;
- very small detection efficiency and particle identification ambiguities for low-mass hadronic systems.

The upgraded DAΦNE Φ factory at the Frascati laboratories of INFN has reached a peak luminosity greater than $4 \times 10^{32}\,\mathrm{cm^{-2}\,s^{-1}}$, giving the opportunity for precision measurements of low-mass hadronic systems with a new run of the KLOE experiment (KLOE-2).

The main source of background while running on the peak of the ϕ resonance, i.e. $\sqrt{s}=1.02$ GeV, comes from ϕ decays, so that we need to perform background suppression adding the information coming from a tagger system with an efficient detection of scattered electrons.

Most of the scattered e^+e^- are emitted in the forward directions, escaping the detection by the present KLOE detector. Since the energy of these electrons is below 510 MeV, they deviate from the equilibrium orbit during the propagation along the machine lattice. Therefore a tagging system should consist of one or more detectors located in well identified regions along the beam line, aimed to determine the energy of the scattered electrons either directly or from the measurement of their displacement from the main orbit.

2. Placement of taggers on the DAΦNE beam lattice

In order to properly locate the $\gamma\gamma$ taggers in DAΦNE, we need to accurately track the off-energy particles along the machine optics. The code we used for optics calculations is BDSIM [3], which allows us to estimate with similar reliability the nominal and the off-energy particle tracks. With this tool we evaluated the trajectories of all particles with energy from 5 up to 510 MeV.

This simulation shows that low energy e^+e^-, i.e. the ones with energy below 250 MeV, will exit from the beam pipe within 1 m from the interaction point. These particles can be identified by a detector very close to the beam pipe in the horizontal plane. Off-energy e^+e^- detectable in this way are only those traversing the beam pipe in a region where no magnetic element is present, where placing a detector is possible. Combining all these

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constraints, the allowed region is between the first two quadrupoles close to the interaction point. In that place, most of the off-energy e^+e^- coming out of the beam pipe will have an energy between 160 and 230 MeV and an average angle of 11° with respect to the beam axis. The presence of these particles will tag radiated photons in the main detector, with energies between 280 and 350 MeV.

This simulation also shows that for these off-energy e^+e^- there is only a rough correlation between particle energy and trajectory. For this reason is necessary to design an energy-sensitive detector, i.e. a calorimeter, instead of a position-sensitive one.

A further constraint to be considered is the presence of the KLOE drift chamber inner wall and the beam pipe support structure. This limits the radial dimension of the detector between 13 and 21 cm, when accounting also for the clearance necessary to install the inner detectors and the beam pipe.

The low-energy station of the $\gamma\gamma$ tagger will therefore consist of two identical calorimeters, symmetrically placed at both sides of the interaction point. This inner detector will be referred as Low Energy Tagger or LET. These detectors must reach high energy and time resolutions in order to:

- improve the invariant mass resolution on the reconstruction of $\gamma\gamma$ decay products,
- allow correlation between the bunch crossing and the detected events, and reject accidental particles coming from the machine background.

A second tagging station, called High Energy Tagger or HET [4], will be placed after the first bending dipole, to detect high-energy e^+e^-. In order to get 5% energy resolution on the LET–LET coincidence we must reach 8% energy resolution on the single LET station. Combining all the three possible tagging combinations, we can get a clean data sample of $\gamma\gamma$ physics events with an efficiency of about 10%. In the first year of KLOE-2 data taking, aiming at $\sim 5\,\text{fb}^{-1}$ of integrated luminosity, this will provide us an effective integrated luminosity of about $500\,\text{pb}^{-1}$ for $\gamma\gamma$ physics.

3. Technology: crystals and photosensors

By the above-mentioned requirements we can impose some technological constraints to our detector:

- it must be made by high-Z material, in order to place a detector with good shower containment in a small volume so to minimize shower leakage. Crystals are a good option: these should have a high light yield, and a fast emission time, in order to get the desired timing and energy capabilities,
- photodetectors must be thin, with high gain and insensitive to magnetic fields.

To cope with all these different requirements, suitable choices are offered by the most recent scintillating crystals and photodetectors. To this purpose the Lead Tungstate ($PbWO_4$) and the new Cerium doped Lutetium Yttrium Orthosilicate (LYSO) crystal scintillators have been considered, coupled to Silicon Photomultipliers (SiPM) photodetectors.

These two scintillators have a radiation length X_0 of ~ 1 cm, a Moliere radius $R_M \sim 2$ cm, and a fast emission time of 10–40 ns. The two crystals differ significantly for the light yield: while LYSO has a relative output of 83% with respect to NaI(Tl), $PbWO_4$ has hundreds of times smaller light output. Dedicated measurements of these two crystals, exposed to cosmic rays and electron test beams, have been used to choose the best option between the two scintillators.

SiPM (also known as G-APD or MPPC) are arrays of very small Avalanche Photodiodes (APDs) operated in Geiger mode, parallel-connected via individual quenching resistors. The sum of the "digital" signals of each G-APD, one for each photoelectron, makes the device analog again. SiPM response is linear until the number of incident photons is more than 20% of the number of pixels. Then the probability for two photons to fall into the same pixel becomes non-negligible, inducing a non-linear response (*pixel saturation*).

Main advantages with respect to APDs and PIN diodes are:

- high gain (10^6 with respect to PIN diodes, 10^4 with respect to APDs),
- no nuclear counter effect due to leaking shower particles reaching photosensor, thanks to reduced thickness,
- almost no avalanche fluctuations from excess noise factor,
- low bias voltage (70 V or less).

4. Front-end electronics

The front end electronics has been custom designed to satisfy the detector requirements and to be compatible with the KLOE Electromagnetic Calorimeter (EmC) readout chain [6].

From the detector point of view, the main requirements are:

- a very stable, low noise power supply for the SiPMs,
- a working voltage setting and monitor for each SiPM channel,
- a low noise, good linearity, low power consumption preamplifier,
- a good packing factor.

At the same time to be compatible with the EmC readout, the preamplifier output must be well matched with the input stage of the KLOE SDS (Splitter-Discriminator-Shaper) board.

To fulfill the specifications, a transimpedance preamplifier with embedded voltage regulator has been developed. The block diagram of the complete system is shown in Fig. 1. The remote power module generates the main power supply for the on-board voltage regulator and allows setting and monitor of SiPM working voltage. A main DC voltage of 90 V with 100 mV of residual ripple can be distributed in parallel to several channels. The working voltage of each SiPM is set via a programmable current sent to the correspondent voltage regulator. The use of a control current instead of a control voltage is needed to reach the required setting precision, solving the problem of the cables and contacts series resistance.

To obtain a very stable voltage minimizing the number of components, the voltage regulator uses a new architecture based on a constant current source and a voltage reference source to control a variable impedance to regulate the input voltage. The output voltage can be regulated in the range 60–80 V with a

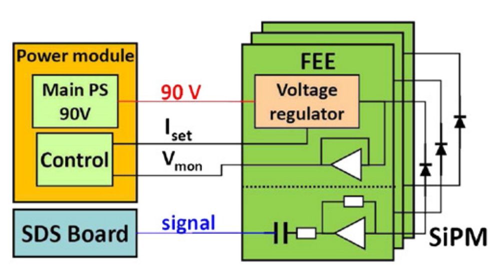

Fig. 1. Block diagram of the LET front-end electronics.