# Status of the KLOE Experiment *


## THE KLOE COLLABORATION

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ABSTRACT

The present status of the KLOE Experiment is presented in this collection of recent KLOE notes.

## 1 Introduction

The KLOE detector, at present under construction for operations at the Frascati $\phi$-factory DA$\Phi$NE, is a general purpose detector whose major aim is the study of direct CP violation in the neutral kaon system. Its ultimate goal is to reach an accuracy of $O(10^{-4})$ in the measurement of the parameter Re$(\epsilon'/\epsilon)$. KLOE will be also capable of doing a whole spectrum of other measurements, such as test of CPT in K decays, studies of of chiral perturbation theory and detailed light hadron spectroscopy.

The accelerator complex consists of a superconducting LINAC, which accelerates electrons and positrons to 510 MeV, followed by an Accumulator Ring, which provides up to 120 bunches of each type of particles to the two separate Main Rings intersecting in two regions only. The first collisions are expected for September 1997. The design peak luminosity is $10^{33}$ cm$^{-2}$s$^{-1}$ , which corresponds to a $\phi$ production rate of 5 kHz.

The detector consists of a cylindrical drift chamber surrounded by a lead-scintillating fibres electromagnetic calorimeter. Moreover, two small calorimeters will cover the quadrupoles of the low-$\beta$ insertion which are located inside the detector. It operates in an axial magnetic field of 0.6 T provided by a 2.5 m radius superconducting solenoid.

The design of the drift chamber was driven by the following considerations:

- It has to maximize the homogeneity and isotropy of the active tracking volume, because of the long decay path of the K$_L$ and the isotropic angular distribution of the charged products
- It has to achieve a high efficiency for the reconstruction of the K$_L$ decay to two charged pions
- It has to optimze resolution at low momentum values
- It has to minimize the number of wires, to minimize multiple scattering and maintain the electronics channels count within reasonable limits.

This has resulted in a 3.2 m long, 2 m radius, cylindrical chamber, with carbon fibre plates and all-stereo cell geometry. Its stringing started in November 1996 and is proceeding regularly towards its end, expected for October 1997. In total, more than 52000 wires, both sense and field ones, will be strung.

Reconstruction of the $\pi^0\pi^0$ decay mode of the K$_L$, the determination of its decay point and the efficient rejection of the more abundant three $\pi^0$'s background are the main requirements which have determined the design of the electromagnetic calorimeter. It consists of lead grooved foils, interleaved with layers of scintillating fibres, for a total thickness of 23 cm, corresponding to about 15 radiation lengths. The calorimeter is organized in 24 barrel modules, 4.3 m long, and 64 C-shaped endcap modules with lengths ranging from 1.5 to 4.5 m.

Particularly relevant is the time resolution on photons, which has been proven to behave as $\sigma_t = 52$ ps $/\sqrt{E}$, with E in GeV.

All the calorimeter's modules have been built, and will be assembled together in September 1997, inside the coil, after the complete mapping of the latter will be finished.

The expected data rates together with the very high sensitivity required in the control of all possible systematic effects make the requirements on the trigger and data acquisition system a real challenge in the field. Inefficiencies and error rates must be minimized to insure that no biases are introduced at these levels. Particular care must be taken in order to insure that the channels involved in the measurement of the CP violating parameters are triggered and acquired with very high and equal efficiencies.

This is possible thanks to a very flexible trigger system, and a custom-designed DAQ system which allows to handle data throughput as high as 50 MBytes/s. The status of FEE, DAQ and Trigger systems is well advanced, and everything is expected to be ready for the detector's roll-in, in Spring 1998.

A more detailed discussion of the present status of the various detector's components can be found in the attached notes, listed in the following:

- Quality checks and first calibration of the KLOE e.m. Calorimeter
- The ADC and TDC of the KLOE e.m. Calorimeter
- The construction of the KLOE Drift Chamber: present status
- Electrostatic digital method of wire tension measurement for the KLOE Drift Chamber
- Results for the full length prototype of the KLOE Drift Chamber
- Trigger
- Message system and data transmission in the KLOE DAQ System

# Quality Checks and First Calibration of the KLOE e.m. Calorimeter

ABSTRACT

The construction of the KLOE lead-scintillating fibres electromagnetic calorimeter has been completed. The final results of the extensive quality checks of all the KLOE calorimeter modules are presented here. The measurements have been done at the Frascati Laboratories with a cosmic ray test facility using minimum ionizing particles. The results show that all the calorimeter modules are within the design specifications in order to get the time and the energy resolutions for its operation in the KLOE experiment. Moreover all the calorimeter elements have been calibrated using minimum ionizing particles.

## 2 The KLOE electromagnetic calorimeter

The KLOE electromagnetic calorimeter is a fine sampling lead-scintillating fibres calorimeter [1]. It consists of lead grooved foils 0.5 mm thick intervealed with layers of 1 mm diameter scintillating fibres glued by means of an epoxy resin. The lead-fibre-glue volume composition is 42:48:10. Every module has a thickness of 23 cm, corresponding to about 15 radiation lengths [2].
The calorimeter consists of 24 barrel modules 4.3 m long, and of 64 C-shaped endcap modules with lengths, ranging from 1.5 up to 4.5 m. Every module is segmented in read-out elements of $\sim 4 \times 4\ cm^2$ and the light is read-out through plexiglass light guides and fine-mesh photomultipliers [3] on both sides of every element. The total number of channels is 4880. Two kinds of scintillating fibres have been employed [4]: Kuraray SCSF-81 in the inner half of the calorimeter and Pol.Hi.Tech. 0046 in the outer half.

## 3 Quality checks

The Cosmic Ray Test Stand is a cosmic ray telescope based on 4 layers of streamer tubes, 12 scintillators and 1 fibre counter. It provides an external trigger and allows to reconstruct the cosmic ray tracks and their impact positions on the calorimeter modules under test [5]. The set-up allows to test up to 4 modules with different geometries at the same time.
ADC and TDC spectra are obtained for every read-out element. The following quantities are measured: from the ADC spectra the mip peak at half of the module length ($mip$ in the following), the attenuation length $\lambda$, and the average number of photoelectrons $N_{p.e.}$; form the TDC spectra, the light velocity in the fibres, the time resolution and the resolution in the coordinate along the fibres that is obtained by the time difference between the two sides.
Fig.4 shows the average attenuation length and the average number of photoelectrons at the module centre as a function of the module number for the barrel modules and as a function of the fibre length for the endcap modules. The barrel module number ranges from 0 to 24. Module 0 is the first full-size prototype built in 1994 and tested on beam at P.S.I. [6]; modules form 1 to 24 are the modules that we'll use in the KLOE experiment. The results are shown separately for the inner and the outer hlves of the calorimeter.
For the endcap modules the fibre length is the relevant parameter that determines the performance. Infact the shorter is the fibre length, the larger is the expected light yield for particles impinging at half of the module length. In order to have homogeneous performance, the short modules have been equipped with the worst quality fibrs and the lower quantum efficiency photomultipliers.
The light yield at half of the module length of barrel and endcap modules is almost homogeneous all over the calorimeter. The endcap modules are characterized by a

slightly lower average and by larger fluctuations.
The quality of the barrel modules improves respect to the module 0 in terms of light yield and attenuation length. This is due to the improved quality of the fibres and to the special care devoted to handle the scintillating fibres , as they resulted to be damaged by the ultraviolet component of natural and artificial light [7]. Taking into account that the energy release of a mip in an element corresponds to the energy release of a 32 $MeV$ photon in the calorimeter [6], we extrapolate a slight improvement concerning the energy resolution that is dominated by the sampling fluctuations, and a large improvement for the time resolution that is dominated by the photoelectron statistics term. The expected resolutions are: $\sigma(E)/E = 4.7\%/\sqrt{E(GeV)}$ and $\sigma_t = 52ps/\sqrt{E(GeV)}$

## 4 Calibration

Minimum ionizing particles crossing the calorimeter elements have been used also to obtain a first step calorimeter calibration, by equalizing the charge response of all the elements. The adopted procedure is an iterative one. The $mip$s of all the elements are measured; then the high voltage of every photomultiplier is changed according to the $HV_1 = HV_0(Q_{eq}/mip)^{1/\gamma}$ where $Q_{eq}$ is the equalization charge, and $\gamma \sim 7.2$ is the parameter of the gain-voltage curve; then the $mip$s are measured again. The procedure is repeated until when all the $mip$s are within $\pm 4\%$ that is the measurement accuracy. Fig.4 shows the $mip$ distribution for all the 2880 barrel elements in the three subsequesnt steps: the widths of the three distributions are $\sim 30\%$ at the step 0, $\sim 8\%$ after the first step and $\sim 4\%$ after the second and last one. A similar behaviour is obtained for the endcap elements.

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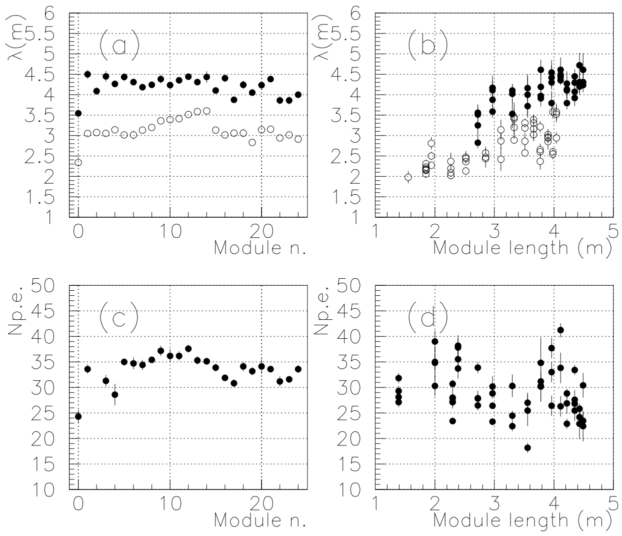


Fig. 1. Summary of the measured performancies of the KLOE calorimeter modules. (a) Attenuation length as a function of the module number for the barrel modules; inner part (full circles) and outer part of the calorimeter (open circles). (b) Attenuation length as a function of the fibre length for the endcap modules. (c) Average number of photoelectrons as a function of the module number for the inner part of the barrel modules and (d) as a function of the fibre length for the inner part of the endcap modules.

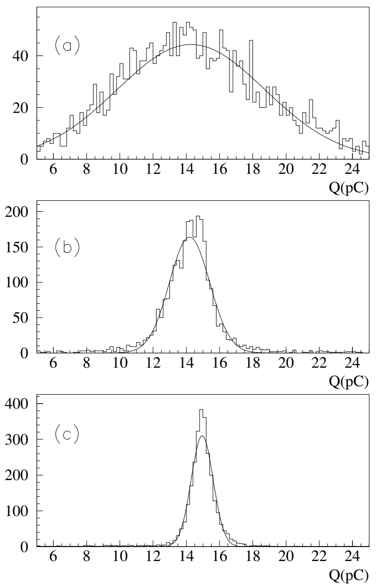


Fig. 2. Result of the equalization procedure for all the barrel elements (2880 channels). (a) Mip distribution after step 0, (b) after step 1 and (c) after step 2. $Q_{eq}$ is fixed at 15 $pC$.

# The ADCs and TDCs for the KLOE Electromagnetic Calorimeter

ABSTRACT

The KLOE electromagnetic calorimeter processes signals arriving over an interval of $\approx$ 200 ns before the trigger time. The KLOE ADC is based on two continuosly analog baseline subtraction systems. A high stability monostable circuit is used at the input of the TDC operating in common start mode.

## 5 Introduction

The KLOE electromagnetic calorimeter (EmC) [1] provides the position, time of arrival and energy for every particle reaching it by measuring charge and time of all read out elements. To face the arrival time spread of the same event particles at the calorimeter ($\approx$ 200 ns) [2], due to the small center of mass energy (1 GeV), and to avoid delaying signals, we developed, in collaboration with CAEN company, special circuits to measure charge and time.

## 6 ADC working principle and performance

The main parameters defining the KLOE ADC are: a maximum detected signal of ≈ 1000 photoelectrons and an arrival time window of 200 ns starting 350 ns before the trigger. The 12 bit digitizing devices, chosen for uniformity with the TDC, provide an adeguate resolution of ≈0.25 photoelectrons/count.

The chosen solution is based on a processing in three stages: an always open charge integrator with the desired sensitivity and a long decay time, a double analog baseline subtraction system plus a final commercial 12 bits, 1 $\mu s$ conversion time monolithic ADC† chip.

In fig. 3 is sketched the KLOE ADC sampling scheme. The two clocks drive

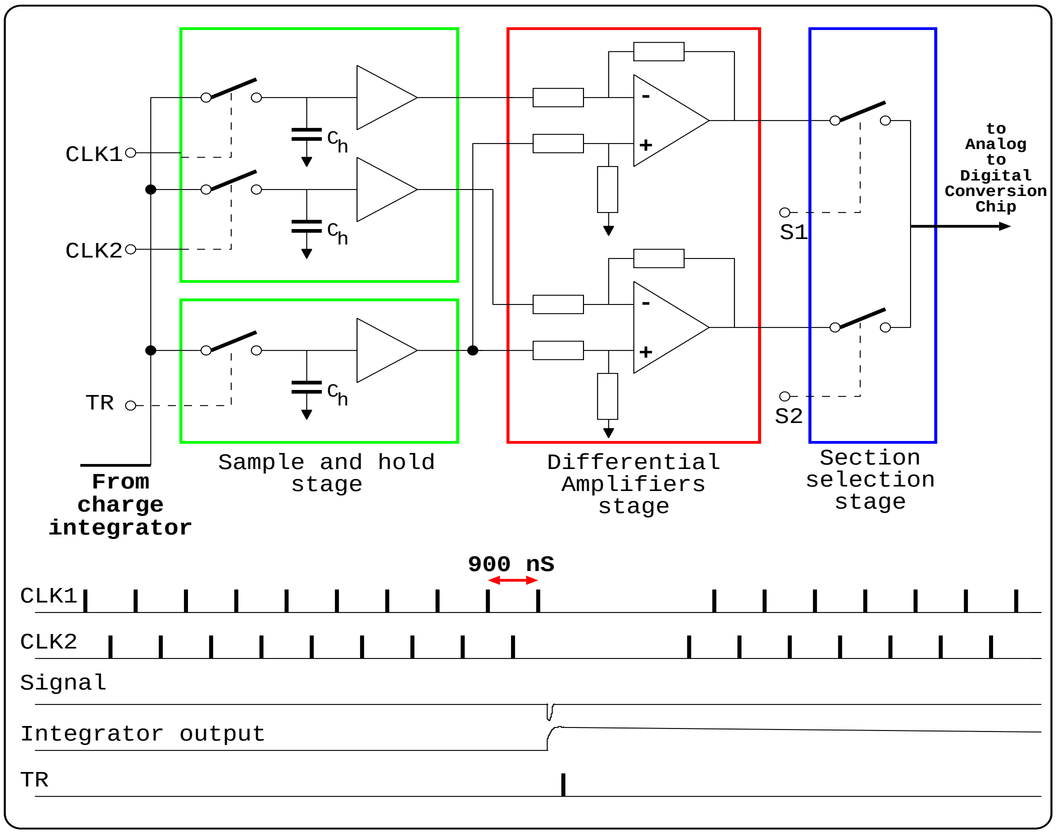


Fig. 3. ADC sampling scheme

the baseline S&H stages, while the TR signal related to the fast trigger T1 starts the signal sampling. A time separation from the pulse of one clock to the other clock following pulse (400 ns) longer than the 350 ns maximum delay of the trigger from the signal, allows to have the rigth baseline value stored in at least one of the two S&Hs. Then, after an analog subtraction, the logic decides via the S1, S2 signals which baseline value is used.

The spread in the arrival time of the trigger versus the signal results in the integrator output to be sampled at different point of its decay tail. A very long decay

† Model AD 7886, supplied by Analog Devices Company.

time of $\approx$ 0.5 ms for the charge integrator is used to reduce the sampling error to the required resolution and does not produce pile up problems due to the average occupancy per channel of $\approx$ 100 Hz. To obtain such a decay time we used large coupling capacitors among the different stages: photomultiplier, splitter and ADC, and a double stage ADC input, formed by a voltage to current converter and a classical cascode based charge integrator [3]. The measured performance on $\approx$3000 channels are a pedestal RMS spread better than 1 count, an integral non linearity of less than 0.3% of full scale and a spread of the pedestal value and gain coefficient of $\pm$3 %.

## 7 TDC working principle and performance

The main constrain for the TDC is to maintain the timing resolution of the EmC [4], it must have also excellent performances with respect to resolution, linearity and stability. The dynamic range is 220 ns and the arrival time window starts 220 ns before the trigger, a 12 bit digitization chip implies a resolution of 55 ps. The different position of the signal acceptance time window from the ADC is compensated by shorter signal cables.

Each TDC channel is built around a monolithic Time-to-Analog Converter

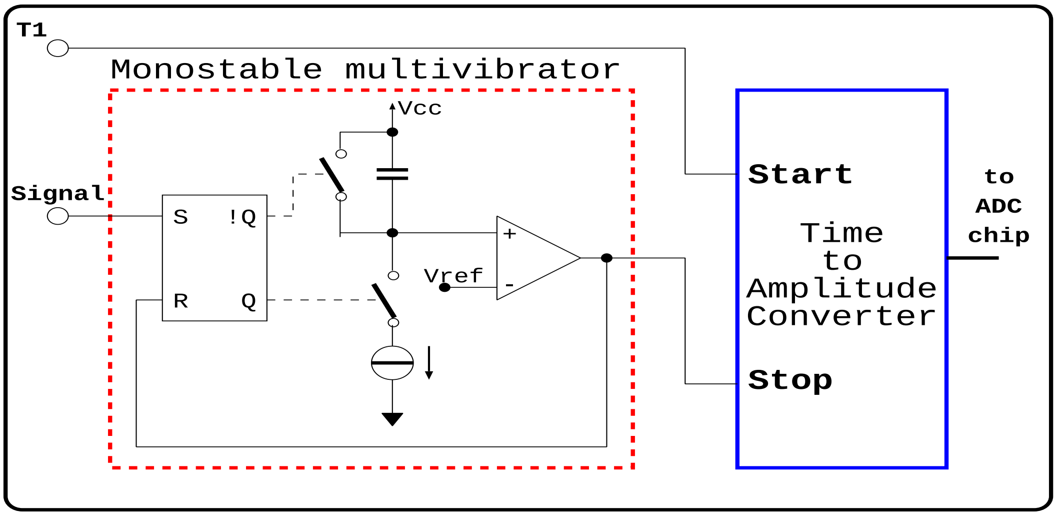


Fig. 4. TDC analog input section

(TAC) developed in bipolar technology, preceded by a delay circuit and followed by the same analog to digital conversion chip used in the ADC, fig. 4. The KLOE TDC works in *common start* mode, the start is provided by the fast trigger signal T1 and the stops are provided by the KLOE discriminators [5] output. The fast trigger T1, which starts the TAC conversion, is synchronized with the bunch crossing time and arrives 200-300 ns after the collision time at a rate of $\sim$ 20 kHz [2]. In order to compensate for the delay of T1, the stop signals are delayed by a monostable multivibrator at the input of each channel. Every trigger starts the conversion process and, if no stop arrives, the TAC overflows. In this case the internal logic resets it to a pedestal value and the overflow condition is signalled in the data words.

The KLOE EmC TDC temperature dependence has been shown to be the same for all channels on a board. A single temperature compensation circuit [6], trimmered at production stage, for the whole board is used.

The measured performance on $\approx 3000$ channels are a pedestal RMS spread less than 1 count, an integral non linearity of less than $0.2$ % of full scale and a temperature stability better than $\pm 0.3$ count/°C.

## 8 ADC/TDC auxiliary (DAQ related) functions

The KLOE ADC and TDC are implemented on a 9U, 400 mm deep board using the VME standard bus (Caen mod. VX559/VX569). The digitizing part is housed on 30 daughter boards for the ADC and 15 daughter boards for the TDC with respectively one or two analog channel each. The digital processing section, common to ADC and TDC, starts after the voltage to digital conversion chip and is placed on the mother board itself; it includes: the latches to store one event after the ADC conversion, the zero suppression mechanism, the pedestal automatic subtraction system, a multi event FIFO (17 events deep) plus the control logic for the AXBUS interface [7], the VME standard interface and the trigger and analog part control logic.

The trigger system [2] produces two signals. The first (T1) is prompt and drives the digitizing operation that stores data on the latches after a 2 $\mu$s fixed dead time. The second (T2) drives the digital processing section; it starts the scan of the latches then passing the data to the zero suppression and pedestal subtracting logic and finally stores the results in a FIFO.

The FIFO consist of two parts.The header FIFO stores the trigger number (12 bits) plus the number of channel data surviving the zero suppression (5 bits to encode 30 channels). The data FIFO, contains the data words that includes: 12 bits of digitized data, 1 bit to indicate for the ADC the baseline used and the overflow condition for the TDC, plus a 5 bits encoded channel number. The FIFOs are readout throught the KLOE synchronous AUXBUS [7] which implements a sparse data scan mechanism and a trigger counter check to control overall synchronization.

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# The Construction of the KLOE Drift Chamber: Present Status


ABSTRACT

The status of the construction of the KLOE Drift Chamber is reviewed. With its 4 m diameter, it will be the biggest drift chamber ever built. The stringing of 52,000 wires is a titanic effort: details are given on the semiautomatic system, on the quality tests on wires and on the monitoring of end-plates deformations.

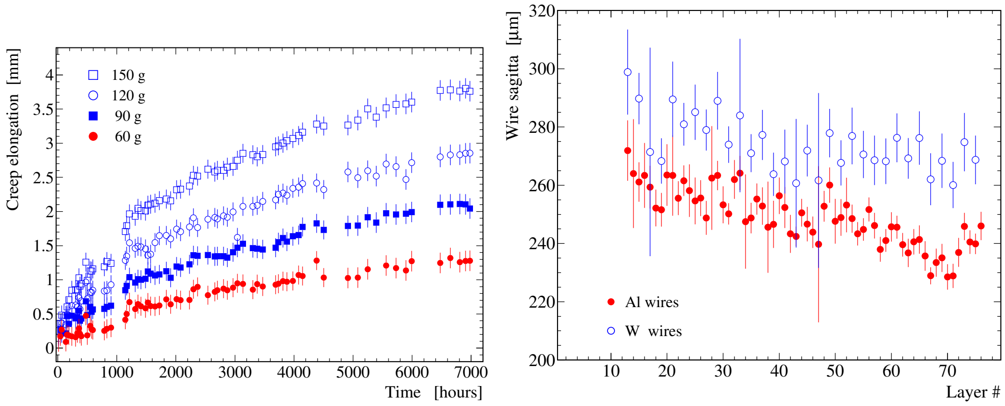

## 9 Introduction

The unconventional characteristics of the chamber are dictated by the physics demands of the KLOE experiment[1]:

- the big size, 4 m diameter, $\simeq$ 3.3 m length, is driven by the large decay path of the $K_L$: $\lambda_L$ = 3.43 m;
- the omogeneous and uniform packing of the cells in the drift chamber is required since the angular distribution of the decay products is rather isotropic. A spatial point resolution of 200 $\mu$m, with a high and well controlled efficiency is needed: the 12,582 cells are approximately square $3\times3$ cm$^2$ side ($2\times2$ cm$^2$ for the inner 12 out of 48 layers), 3:1 field to sense ratio, and only alternating stereo wires (60 $\div$ 150 mrad) for a grand total of more than 52,000 wires;
- light materials were chosen to minimise multiple scattering, to have a good momentum resolution (in a 0.6 T magnetic field) at low momenta and to minimise conversions of low energy photons: carbon fiber composite for the mechanical structure, ultralight gas mixture, He 10%-i$C_4H_{10}$ 90%, 80 $\mu$m Al 5056 (Ag plated) field, 25 $\mu$m W (Au plated) sense wires, for an overall thickness of the chamber, including front-end electronics, of $\simeq$ 0.1 $X_0$.

## 10 Chamber Construction

The two spherical (9.7 m curvature) carbon fiber end-plates, 8 mm thick, (with a 30 $\mu$m Cu foil glued on the external surface) are connected by 12 carbon fiber rods. Since the total load of the wires tension is $\simeq$ 3,500 kg, an external carbon fiber ring is used to recover the 3 mm deformation of each end-plate: the ring extert a radial force to the end-plates - through 48 screws monitored by means of strain gauges - which causes a longitudinal displacement in the direction opposite to that of the wires tension load. The procedure of deformation recovery has been successfully tested up to a static load of 5,000 kg. A carbon fiber cylinder, 0.7 mm thick, provides the inner coverage and 12 carbon fiber panels will close the chamber.




(a) (b)

Fig. 5. The sagittae (b) of the aluminum wires are smaller immediately after stringing, since the elongation from creeping (a) is taken into account.

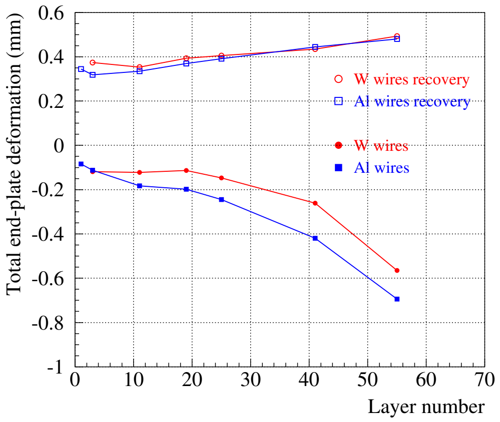
A number of tests have been performed on the wires: systematic measurements of wire linear density, Young modulus, as well as aging tests which show a negligible gain loss (5% after 30 years of KLOE operation [5]). A sample of aluminum wires has been subjected to constant load creep tests (total duration 10 months): a total elongation of about 1.5 mm is expected for the typical field wires tension, so that the field wires are strung slightly overtensioned (fig. 5).

## 11 Chamber Stringing

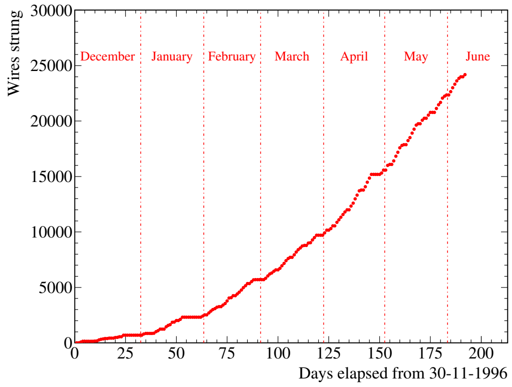
The stringing of the chamber is performed horizontally, in a clean room (class 1,000) by means of a semiautomatic system [6]:

- the two end-plates are supported and rotated by a special rig (accuracy at 2 m radius $\sim 100\ \mu$m);
- a 3 axes robot brings the wire from one end-plate to the other (accuracy $\sim 500\ \mu$m);
- two external stations tension the wire at the nominal mechanical tension and crimp the feed-throughs.

All axes are moved by step motors and are coupled to incremental encoders for position monitoring. The operations of wire feed to the robot and wire insertion into the feed-throughs are performed manually.




(a)




(b)

Fig. 6. (a) The deformation of the end-plates and its recovery are monitored by measuring the mechanical tension on a sample of wires; (b) The integrated “stringosity”, defined as total number of wires strung as a function of the elapsed time of stringing.

In order to get uniform sagittae the mechanical tension of the wires is measured by means of an electrostatic resonance method: the mechanical resonance of the wire is detected by measuring the capacitance to the nearby wires [7]. Since this method does not require any magnetic field, it can be used to monitor any wire at any time. The sense wires are also tested at 3 kV voltage for leakage current measurements in order to identify short circuits or damaged wires. The external ring is tensioned every 300÷350 kg of wire load, in order to recover the wires tension loss due to end-plates deformation. The deformation is monitored on a sample of wires (on different layers) by measuring the wire tension loss, using the Young relation:

$$\frac{\Delta L}{L} = \frac{\Delta T}{EA}$$

where the Young modulus times the cross section area, EA, has been measured for a sample of wire spools and $\Delta L/L$ is the relative wire elongation. The deformation due to the load of wires strung in the period of 25 days is shown in fig. 6(a) together with the recovery: the difference in wire tension loss between aluminum and tungsten wires is due to the creep effect.

## 12 Conclusions

Stringing of the KLOE Drift Chamber began on 30 November 1996 and is now proceeding an average rate of 8,000 wires per month (fig. 6(b)), with a low percentage of replaced wires ($\sim$ 1.2%). A number of quality tests are performed on the wires and the end-plates deformation is monitored. The plate deformation due to the wire load is successfully recovered by means of the tensioning ring.

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# Electrostatic Digital Method of Wire Tension Measurement for KLOE Drift Chamber

ABSTRACT

For the first time an electrostatic method of wire tension measurement (WTM) is used for drift chamber construction. It became possible due to digital approach to sense the wire oscillations induced by alternating potential. The method has excellent signal-to-noise ratio, high accuracy which is well above the stringing requirements and reasonable measuring time. WTM system implemented in CAMAC-Machintosh-Labview environment is now in use for stringing of KLOE drift chamber and for monitoring of the end-plate deformations.

WTM is always used during construction phase of wire chambers for stringing control. The only method of WTM which has been used up to now is the magnetic one which is based on a measurement of a resonance frequency of a wire oscillations induced by alternating current in magnetic field. For large drift chambers (DC) necessity to have a magnetic field about 199 Gs in large volume adds serious problem to already complicated and time consuming stringing procedure. For largest in a world DC of KLOE experiment with its 3 m length a nd 4 m diameter we decided to use another alternative - electrostatic method which is known from early days of MWPC but has been tried with very limited success because of very small signal. We have found a new solution to detect wire oscillations which has good sensitivity to construct reliable WTM system. An alternating high (1 kV) voltage is applied to a wire with respect to other wire(s) to excite forced mechanical oscillations. The periodic change of the wire capacitance to other wire(s) modulates a frequency of HF (10 MHz) LC-generator coupled to the wire. This frequency is measured in two successive quartz stabilised time intervals equalled to half-period of driving voltage. The difference between these frequencies is a measure of a wire oscillation amplitude. Driving voltage and gate pulses are computer synthesised. Changing the driving voltage in small steps an excitation curve of mechanical resonance of the wire is obtained and resonance frequency is extracted by fitting procedure. In Fig.1 a typical resonance curve for a wire in KLOE DC is shown for the case when capacitance between a wire and inner tube is measured. Even now when nearly half of the wires have been strung and the wire-tube distance is near 1 m we have no problems with WTM in this configuration.

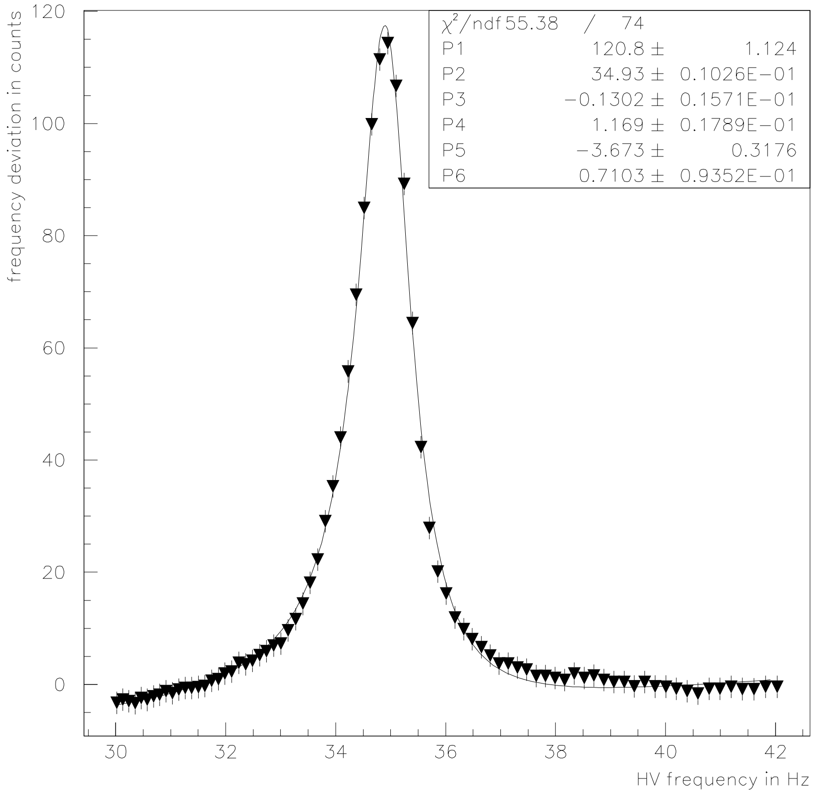


Fig. 7. An example of mechanical resonance curve for a wire in KLOE DC.

# Results from the Full Length Prototype of the KLOE Drift Chamber

ABSTRACT

A full size prototype of the KLOE drift chamber has been built and successfully exposed to a 50 GeV/c pion beam at CERN. The features of the cell response and the performances of the detector in terms of space and energy resolution are presented.

The Drift Chamber (DC) [1] of the KLOE experiment [2] is a rather unconventional detector due to the large size (2m radius and 3.2m length), to the choice of light materials (carbon fiber walls, 80$\mu$m $IHEP$ Al field wires, long $X_0$ gas mixture 90%He10%$iC_4H_{10}$) and to the all stereo geometry. In order to check the design performances a full size prototype was built [3] which consists of 30 coaxial layers, with radii between 28cm and 104cm, of squared single sense wire cells, $3\times\pi$ cm$^2$ in size ($1.5\times\pi/2$ cm$^2$ in the ten innermost layers), strung at alternating sign stereo angles in the range of 50$\div$120mrad between conical, 6.2mm thick, end plates made of carbon fiber. The detector was operated at a gain of $10^5$, provided by 1950V on the 25$\mu$m $IHEP$ W anode wire. A very stable and noise free operation was observed for thresholds as low as 2mV (1/8 of the one electron equivalent with the 1mV/fC gain of the KLOE DC preamplifier, Tektronics VTX). A set of $27\times10^6$ tracks from 50GeV/c pions, collected at the SPS T1-X7 area, allows to study the cell response as a function of the relevant parameters: $\phi$ the angle between the track and the radial direction, $\beta_u$ and $\beta_l$ describing the cell shape deformations due to the cell arrangement on circular layers and to the stereo configuration (see fig.8). The prototype has been used as self tracking device and a special algorithm, described in detail elsewhere [4], for straight track reconstruction in the all stereo geometry (for which the pattern recognition task is highly not trivial) was applied to the analysis of the data sample.

The correlation, $r(t_d)$, between the distance of closest approach (DCA) of the track to the hit sense wire and the drift time, $t_d$, is parametrized by 3 4th order polynomials connected at $t_d = 450$ns (i.e. 1/2 of the maximum impact parameter for $\phi = 0^0$), where $r(t_d)$ is continuous and differentiable, and at $t_d = 880$ns ($\sim$ 1.4cm), where only the function continuity is preserved‡. While the first branch polynomial is stable as $\phi, \beta_l$ and $\beta_u$ change, the anysotropy and the cell deformations affect $r(t_d)$ at impact parameters larger than 1cm by amounts much larger than the resolution. Since $|\beta_l| < 9^0$, two sets of curves ($\beta_l > 0$ and $\beta_l < 0$) in each $\phi$ slice are enough to describe the cell behaviour in the lower half; in the cell upper half, $\beta_u$ ranges

‡ Here, as well as in the following, we refer, without loss of generality, to the $3\times\pi$cm$^2$ cells, where a slightly lower average drift velocity, 1.6cm/$\mu$s compared to 2.1cm/$\mu$s in the smaller cells, enhances the edge and anisotropy effects.

between $\pm 30^0$ and, hence, the parameterization of $r(t_d)$ is split in a number of $\beta_u$ slices, increasing with $|\phi|$ from 1 up to 7, within each $\phi$ slice. By exploiting the cell symmetries ($r(t_d;\phi,\beta)=r(t_d;-\phi,-\beta)$ and $r(t_d;45^0-\phi,\beta_l)=r(t_d;45^0+\phi,\beta_l)$ for $\beta_l\rightarrow 0$), a total number of 36 parameterizations of $r(t_d)$, coupled to the corresponding resolution function $\sigma(t_d)$, has been proven to provide a complete prediction of the cell response (as an example, a set of such curves is shown in fig.8). The trends of both $r(t_d)$ and $\sigma(t_d)$ observed from the data are nicely confirmed by Monte Carlo simulations based on the GARFIELD package.

The space resolution, of the order of $120\mu$m for impact parameters between 0.2 and 1.0cm (well below the KLOE target of $200\mu$m which will be multiple scattering dominated), can be decomposed into several contributions: primary ionization statistics, longitudinal diffusion, electronic noise and extrapolation error. The analysis allows to get a measurement of the mean free path for ionization in 90%He10%$iC_4H_{10}$ $\lambda=(597\pm 43)\mu$m (in agreement with [5]) and of the ratio between diffusion and drift velocity $2D(E)/v_d(E)=(3.4\pm 0.4)\cdot 10^{-4}$ cm (see ref.[6]). The extrapolation error accounts for $(30\pm 3)\mu$m and the overall time resolution (digitizing time and trigger jitter) comes out to be $(3.6\pm 0.3)$ns. As a result of the space resolution, angular resolutions of the order of 0.2mrad in the transverse plane and of 2mrad in the longitudinal plane have been evaluated from the width of the director cosine distributions of radial tracks crossing all the 30 layers (the beam divergency has been safely neglected). The hardware efficiency of the cell, averaged over the cell area, exceeded 99.7% when a discrimination threshold of 4mV, corresponding to a noise frequency per event of 0.002 hits/cell, was set in. Almost 50% of the inefficiencies, clusterized within 1mm from the cell edge, are due to the cut of the drift times longer than $2\mu$s. The average probability of getting a measurement of the drift distance in agreement with the extrapolated DCA within $1\sigma$ is $(66.03\pm 0.04)$%, for $\phi=0^0$, which entails a degree of knowledge of $r(t_d)$ and $\sigma(t_d)$ better than 97.75%.

Finally, charge measurements confirme claims of good dE/dx performances of the gas mixture [7]. A 27% resolution is observed on single cell measurements, while a 15% truncated mean, over the average number of hits for tracks in the $K\rightarrow\pi^+\pi^-$ process, allows to pull down the energy resolution to 3.5%.

In conclusion, the full size prototype of the KLOE DC, besides showing that the challenging conceptual design of the detector will successfully fulfill the requirements of resolution in reliable operation conditions, has provided also a useful first level calibration of the cell response.

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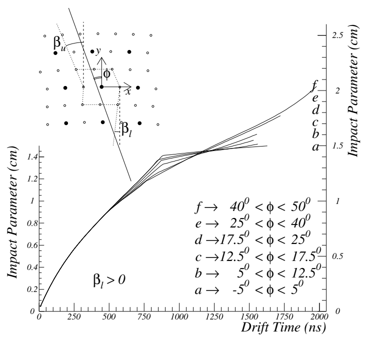


Fig. 8. Time to distance relations, $r(t_d)$, for the lower half of cells with $\beta_l > 0$ crossed by the track at angles $\phi$ within the intervals specified for each curve. The layout of the cell cross section shows the definition of the angles affecting the cell response.

# dE/dx measurement in a He-based gas mixture

ABSTRACT

The performance of a prototype drift chamber operating in a He-based gas mixture as a specific ionisation detector is presented. In spite of the small number of primary ions, Helium performs quite satifactorily in measuring energy losses for charged particles: with $50\,\mathrm{GeV}/c$ pions, we have measured in a $90\%\mathrm{He}-10\%i\mathrm{C_4H_{10}}$ mixture a relative energy loss resolution of $3.1\%$ with 75 samples $3\,\mathrm{cm}$ long, using a modified Truncated Mean technique with $80\%$ accepted fraction.

The dependence of the resolution on several parameters such as the operating voltage, the truncation fraction, the number and length of the samples is discussed.

## 13 Introduction

As a result of the R&D programme for its big drift chamber [1], the KLOE collaboration choosed $90\%\mathrm{He}-10\%i\mathrm{C_4H_{10}}$ as the optimal gas mixture for its long $X_0$ ($\simeq 1$ $300\,\mathrm{m}$), excellent operational stability, high efficiency, good spatial resolution and, last but not least, non flammability and simplicity (it is a binary mixture). In this paper we present results demonstrating that its performances are extremely good also from the point of view of the $\mathrm{d}E/\mathrm{d}x$ measurement.

## 14 Experimental setup

The analysis described in this paper is relative to data collected on a $50\,\mathrm{GeV}/c$ pion beam at the CERN SPS in september '94 with a small size prototype of the KLOE drift chamber (prototype 0.3). A detailed description of the prototype and of the data taking conditions can be found in [2]; only the points relevant to the $\mathrm{d}E/\mathrm{d}x$ measurement are mentioned in the following. The prototype consists of an array of $7\times7$ approximately square cells of $(3\times\pi)\,\mathrm{cm}^2$ area each, with a field to sense wire ratio of 3:1. We consider in the present analysis only the 25 innermost cells, whose gain is made homogeneous by the external ones, which act as guard wires. After preamplifiers with a gain of 1 mV/fC on a $50\,\Omega$ load [3] and post-amplifiers with gain $\simeq 3$, the analog outputs from the sense wires were fed to LRS2249W ADC's with a $3.9\,\mu$s wide gate.

### *14.1 Data sample and quality cuts*

We collected data at five HV settings, every 50V between 1750 and 1950V, both with and without a magnetic field of 0.6T parallel to the wires. At the two highest operating voltages there was a non negligible saturation of the ADC, hence the corresponding data have been used in the gas gain saturation studies, see next section, but not in the $\mathrm{d}E/\mathrm{d}x$ anlaysis.

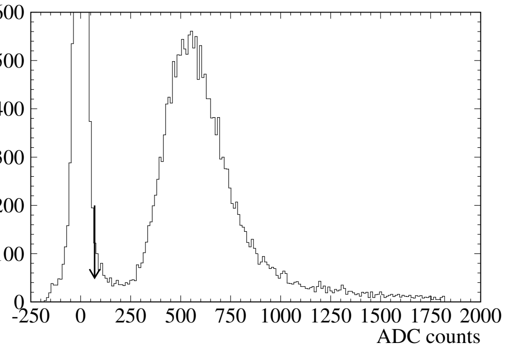


Fig. 9: *Typical ADC spectrum. The arrow shows the three sigma cut.*

The ADC spectrum in one of our 3 cm cells is shown in fig.9. A cell is defined as 'hit' if its ADC reading, pedestal subtracted, exceeeds three times the pedestal width. The relative width $\sigma_{\mathrm{REL}}$ of the peak is typically $\simeq 25\%$. On average about 5 cells are hit [4]. We select a clean sample of events by further requiring to have at least 4 hit cells, a drift time of the first electron less than $2.5\,\mu$s and impact parameter less than 1.5 cm. The combined efficiency of these cuts is about 80%.

## 15 Results

After equalisation of the response of the cells,[§] we calculate the Truncated Mean (TM) to estimate the most probable value of the energy loss distribution ($\mathcal{E}_{\mathrm{MP}}$). Truncated Means are plotted in fig.10 for different fractions of accepted events. We observe that in our $90\%\mathrm{He}-10\%i\mathrm{C_4H_{10}}$ gas mixture the most probable energy loss ($\simeq 136$ pC at 1850V) is correctly reproduced accepting 80% of the hits. Since for a $50\,\mathrm{GeV}/c$ beam the energy loss, regardless of the particle species and the momentum bite of the beam itself, lays on the relativistic plateau, we can combine several

§ We scale each ADC reading by the factor $\mathrm{MP_i}/\langle\mathrm{MP}\rangle$, $\mathrm{MP_i}$ being the Most Probable energy loss in the $i$-th cell, and $\langle\mathrm{MP}\rangle$ the same quantity averaged over all the cells.

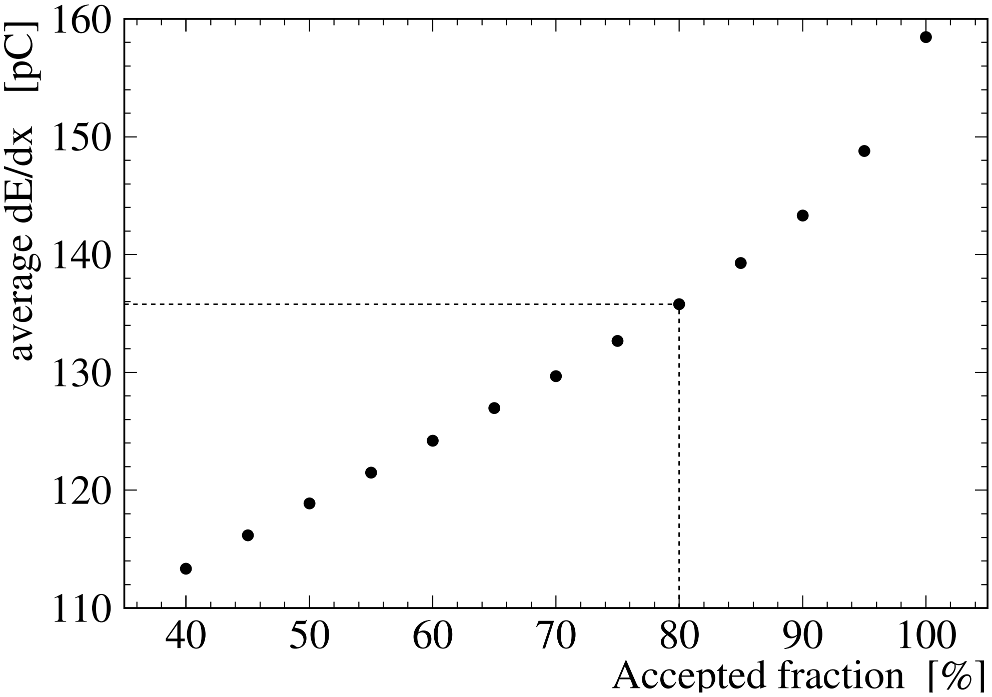


Fig. 10: Truncated Means vs. accepted fraction.

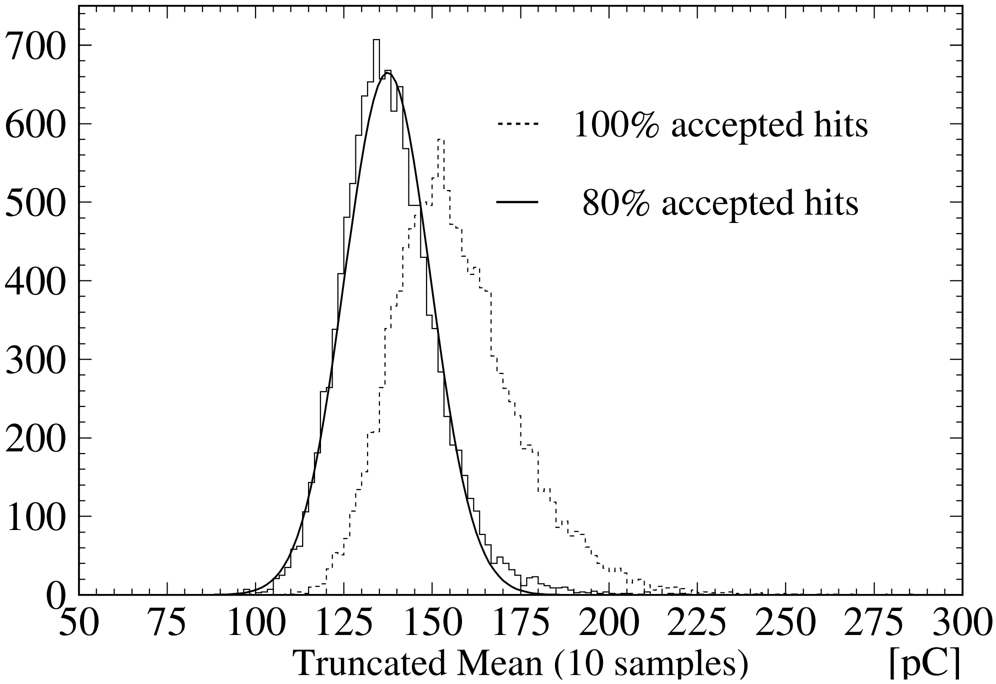


Fig. 11: Effect of the Truncation in samples of 10 hits.

5-hits events to simulate arbitrarily long tracks. The effect of the truncation is pictorially shown in fig. 11: even with samples of only 10 hits, the distribution of the average shifts towards the correct $\mathcal{E}_{\mathrm{MP}}$, shrinks considerably and becomes fairly gaussian at 80% truncation. Completely gaussian distributions are obtained for Napoli (total number of hit cells) $\geqslant$20.

### *15.1 $\mathrm{d}E/\mathrm{d}x$ resolution*

In fig. 12 the $\mathrm{d}E/\mathrm{d}x$ resolution $\sigma_{\mathrm{d}E/\mathrm{d}x} \equiv \sigma(\mathrm{TM})/\langle\mathrm{TM}\rangle$ is plotted vs. the number of used hits (80% accepted fraction). A fit with a power function is superimposed to the points, showing that the scaling law is very close to the Poisson limit of $-0.5$. The resolution exhibits a mild dependence on the accepted fraction (fig. 13): a broad

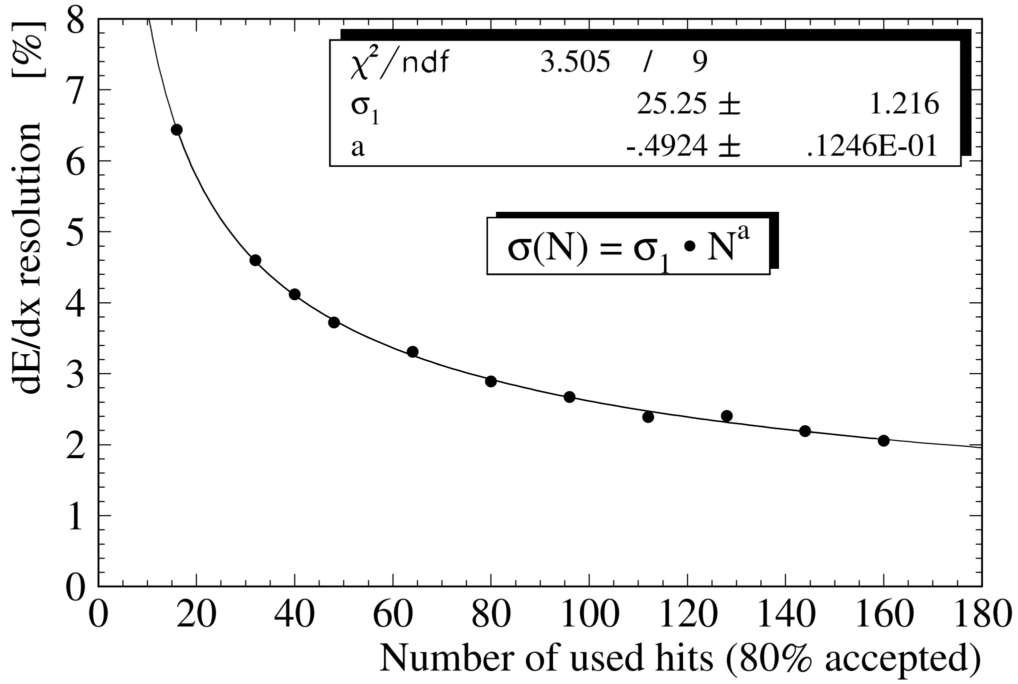


Fig. 12: $\mathrm{d}E/\mathrm{d}x$ resolution vs. number of used hits.

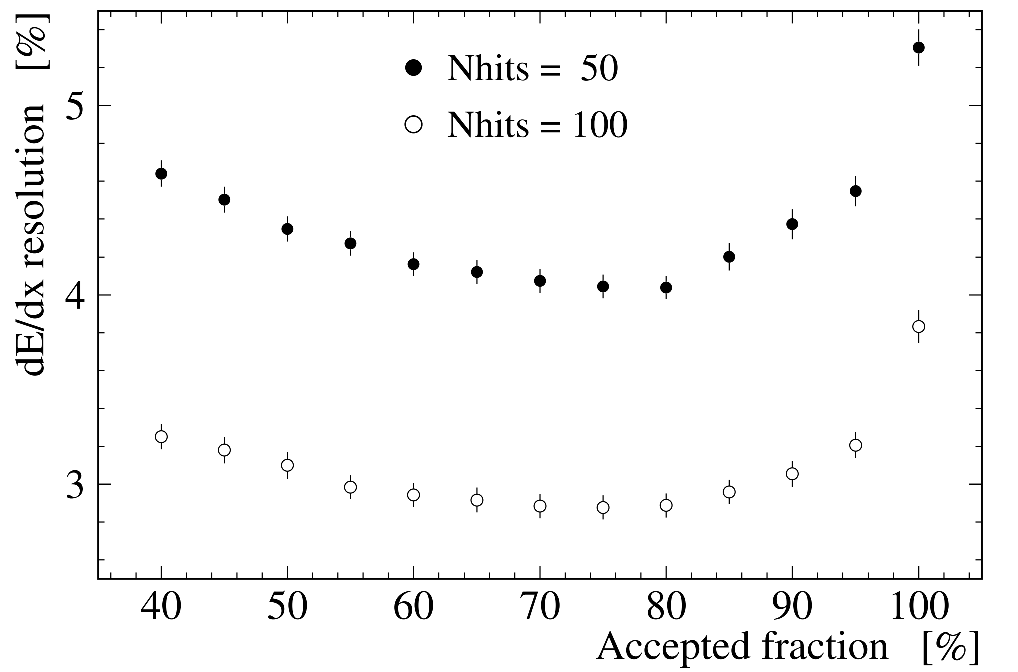


Fig. 13: $\mathrm{d}E/\mathrm{d}x$ resolution vs. TM accepted fraction.

minimum is observed between $\sim 60\%$ and $90\%$, while both for bigger (inclusion of the Landau tail) and smaller accepted fractions (loss in statistics) $\sigma_{\mathrm{d}E/\mathrm{d}x}$ deteriorates.

### *15.2 Linearity of the measurement*

Apart from trivial saturation of the ADC, pulse height saturation may originate from non linearity of the gas amplification. The latter may also result in an artificial reduction of the Landau tails, since at very big gains space charge at the anode could decrease the effective amplification.

Fig. 14 shows the MP pulse height as a function of the operating voltage. Since we find the same slopes within the errors in the 'low' and the 'high' HV regimes, we conclude that there is no gas gain saturation. Saturation could also show up by a decrease of the collected charge with the drift distance: the ionisation clusters arrive more grouped in time to the anode if they originate from distant tracks, therefore saturation phenomena would be more likely. Fig. 15 depicts the average collected charge vs. drift distance: we observe a $2\%$ decrease of the collected charge over the entire cell width. This modest effect is however an upper limit to space charge effects, since the same trend could also be caused by the presence of electronegative agents in the gas mixture or by the finite integration gate.¶

We measure essentially the same resolution at $1800$ and $1850$V, while at $1750$V $\sigma_{\mathrm{d}E/\mathrm{d}x}$ is $\sim 13\%$ worse. Using 75 hits, which is an expected average over several reactions in KLOE, we measure therefore, with $50\,\mathrm{GeV}/c$ pions and $80\%$ accepted fraction, a $\mathrm{d}E/\mathrm{d}x$ resolution of $(3.3\pm0.1)\%$. The error is not only statistical, but includes variations of the cuts and run-to-run differences.

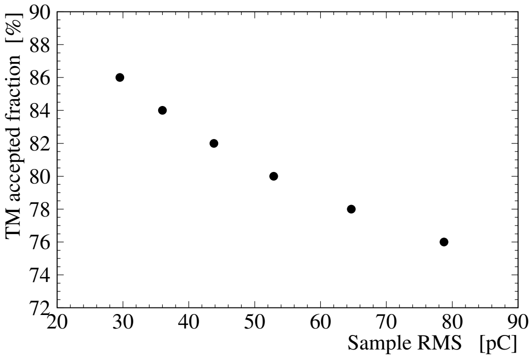


Fig. 16: *TM accepted fraction vs. RMS of the samples.*

A magnetic field of 0.6T does not significantly affect this result, both because of the wide integration gate and of the small Lorentz angle in the mixture [2].

### *15.3 Optimisation of the truncation fraction*

To improve the analysing power of the $\mathrm{d}E/\mathrm{d}x$ measurement, we tune the accepted fraction of the TM on the shape of the particular sample under consideration. Using the correlation between accepted fraction a sample RMS shown in fig. 16, we obtain a $\mathrm{d}E/\mathrm{d}x$ resolution of $(3.1\pm0.1)\%$.

### *15.4 Resolution vs. sample thickness*

The dependence of the $\mathrm{d}E/\mathrm{d}x$ resolution on the number Napoli and the length $x$ of the samples has been parametrised [5] as $\sigma_{\mathrm{d}E/\mathrm{d}x} \propto Napoli^{a} \cdot x^{b}$; in the same reference the authors find for Argon $a = -0.46$, $b = -0.32$. In our mixture (fig. 12), $a = -0.49 \pm 0.01$. To measure $b$, we have simulated 'supercells' of increasing length. From a fit to the ratio $\sigma_{\mathrm{REL}} \equiv \sigma_{\mathrm{peak}/\langle\mathrm{peak}\rangle \propto \mathrm{x}^{\mathrm{b}}}$ as a function of the size of the supercell, we obtain the value $b = -0.40 \pm 0.01$. Finally, we determine the

¶ The wide gate of $3.9\,\mu$s guarantees in our case that practically all the charge is collected by the anode.

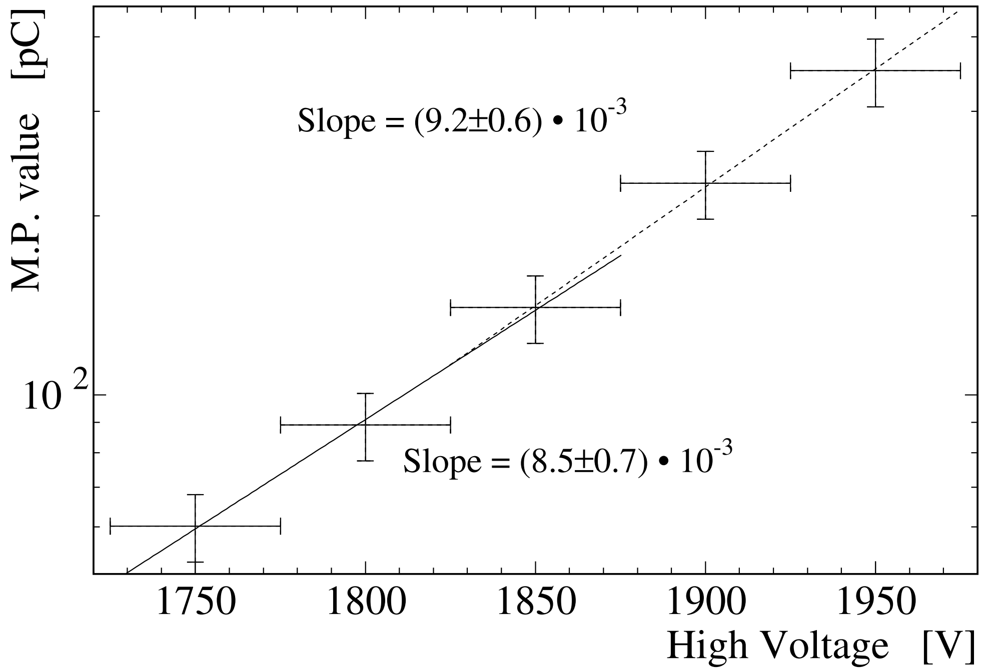


Fig. 14: Most probable energy loss vs. operating voltage.

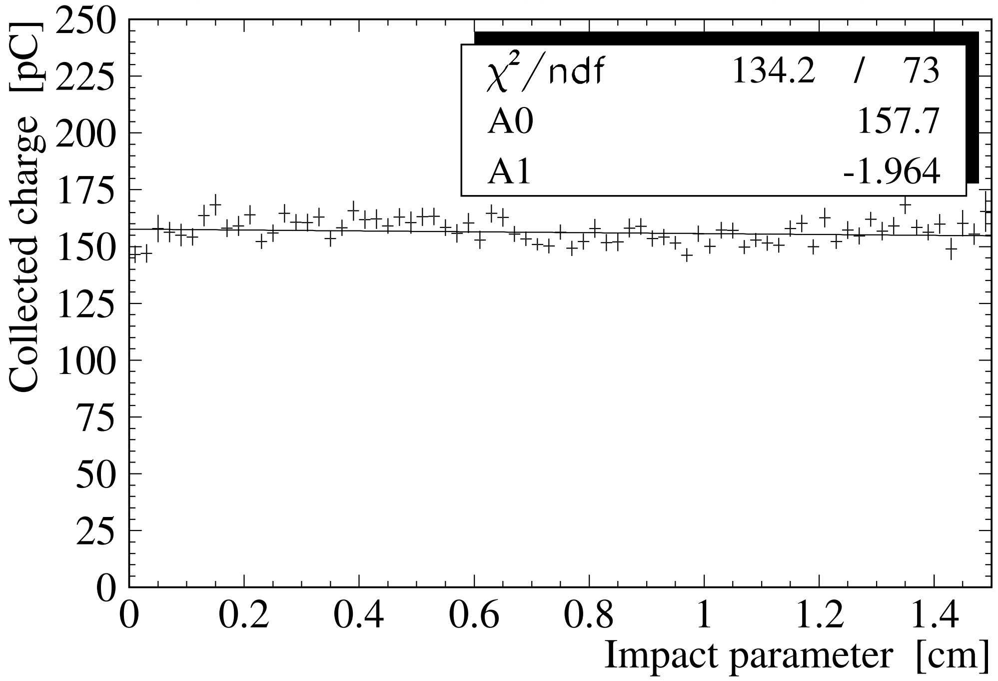


Fig. 15: Collected charge as a function of the track's impact parameter.

difference $a - b$ by sampling a track with a given total length with supercells of different length; fitting the TM resolution of the supercells again with a power law, we find $a - b = 0.07 \pm 0.01$, consistent with the separate determinations of $a$ and $b$.

We want to stress that this result stems from the small value of the cluster multiplicity and of the limited Landau tails in Helium: the difference between the $a$ and

$b$ exponents is to some extent a measurement of skewness of the energy loss distribution: in a completely symmetric distribution the two effects of decreasing the number of samples and increasing the sample thickness would balance out.

## 16 Conclusions

The $\mathrm{d}E/\mathrm{d}x$ resolution in the gas mixture $90\%\mathrm{He}-10\% i\mathrm{C_4H_{10}}$ has been measured. Up to operating voltages of $1900\,\mathrm{V}$ (gain of few $10^5$ [2]) we have found negligible saturation. The dependence of the resolution on the number and the length of the samples has been extracted. We expect, from these measurements, a specific ionisation resolution in the KLOE detector of about $3.5\,\%$.

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# The Trigger and Data Acquisition System of the KLOE Experiment

ABSTRACT

Due to the high peak luminosity of the DA $\Phi$ NE accelerator ($10^{33}$ cm$^{-2}$s$^{-1}$ ) event and data rates at KLOE are higher than in any other $e^+e^-$ collider experiment. The developed 2 level trigger achieves an efficiency larger than 99% for all events relevant to investigate CP violation. The data acquisition system can handle data rates of 50 Mbytes/s using custom designed bus systems and high performance networking techniques.

## 17 Introduction

KLOE (K-LOng Experiment) is one of three experiments under construction for the $\Phi$-factory DA $\Phi$ NE in Frascati. The main goal of KLOE is to investigate CP violation in the neutral kaon system. Particularly a measurement of the ratio Re($\epsilon'/\epsilon$ )with a precision of $O(10^{-4})$ is aimed at. In addition a series of interesting interference measurements can be carried out, in order to determine all parameters of the neutral kaon system ([6]-[9]). The detector and physics program is described elsewhere in these proceedings [10] [11] and in [1]-[9].

Stringent conditions for accelerator and experiment are imposed by the aimed precision of the measurements. To achieve sufficiently high statistics, DA $\Phi$ NE is designed to run at a peak luminosity of $10^{33}$ cm$^{-2}$s$^{-1}$ , which corresponds to a $\Phi$-decay rate of 5 kHz. Given the average event size of 5 Kbytes, maximal data rates of 25 Mbytes/s are expected from physics events.

Various background sources at high rates and with event topologies similar to those of physically interesting events make triggering at KLOE a challenging enterprise.

For data acquisition (DAQ) a flexible system has been developed, which allows data rates up to 50 Mbytes/s. If necessary the data throughput can easily be enhanced without changing the existing structure of the system.

## 18 The Trigger System

### *18.1 Principle of the KLOE Trigger*

The KLOE trigger is a two level system, using information of the electromagnetic calorimeter [10],[2] and the drift chamber [3]. It runs continuously, since the high bunch crossing rate of 370 MHz excludes a trigger decision to be formed between bunch crossings. Trigger signals are synchronised to the DA $\Phi$ NE clock before being sent to the Front End Electronics (FEE), to permit offline determination of the specific bunch crossing of a triggered event.

For several physical measurements the efficiencies off all involved $\Phi$ decay channels have to be known with a precision of $O(10^{-4})$. In order not to introduce biases in the measurement of the four branching ratios $K_L(K_S) \rightarrow \pi^0\pi^0$ , $K_L(K_S) \rightarrow \pi^+\pi^-$ the corresponding trigger efficiencies must be close to unity. Monte Carlo simulations have shown, that for all events involved in CP violation measurements the efficiencies are larger than 99.5%. The following table shows efficiencies for three important CP-violating $K_{S,L}$ decay channels.

| | level 1 | level 2 |
|---|---|---|
| $\Phi \rightarrow K_L K_S$ | $\epsilon$ (%) | $\epsilon$ (%) |
| $\rightarrow \pi^0\pi^0\pi^0\pi^0$ | 99.9 | 99.9 |
| $\rightarrow \pi^+\pi^-\pi^+\pi^-$ | 99.7 | 99.6 |
| $\rightarrow \pi^+\pi^-\pi^0\pi^0$ | 99.8 | 99.6 |

Particles from background events are entering the KLOE detector with a rate of several hundred MHz. Main sources are machine background (beam gas interactions, Touchek effect), cosmic ray muons, and Bhabha scattering. Cosmic ray muons can be tagged without degrading the efficiency for physics events by triggering on events with 2 hits in the out most layer of the barrel calorimeter. The presence of the focusing quadrupoles in the detector volume make Bhabha events in the polar angle range from $3^\circ < \theta < 9^\circ$ (rate: $\approx 300$ kHz) and part of the machine background difficult to recognise on trigger level, because particles start to shower in the material of the quadrupoles, leaving a continuous energy spectrum in the calorimeter (figure 17) or a large number of hits in the drift chamber. It follows, that it is not sufficient to trigger on the visible energy of an event, but sensitivity to the number of particles in the detector volume is required.

To achieve a high trigger purity, the following differences between physics and background events are exploited:

- Calorimeter hits of background events are concentrated in the endcaps, since the particles have a low transverse momentum with respect to the beam.
- Background events have drift chamber hits predominantly in the region close to the beam pip, whereas in physics events they are distributed all over the chamber volume (figure 18).
- Background events in general have relatively low multiplicities in the calorimeter and the drift chamber.

Table 1 shows Monte Carlo results for trigger rates of the discussed background processes.

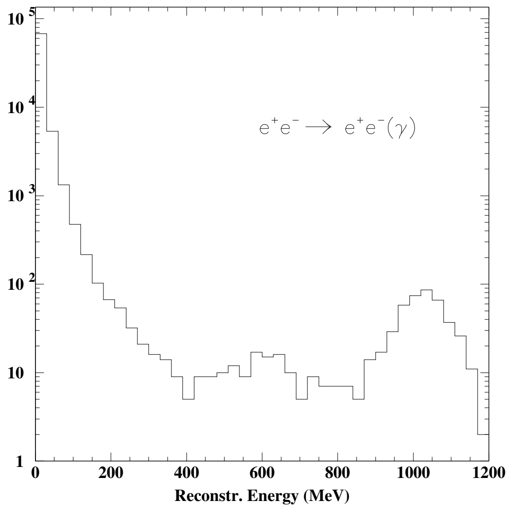


Fig. 17. Energy deposit in the entire calorimeter for Bhabha events in the angular range of $1^\circ < \Theta < 179^\circ$.

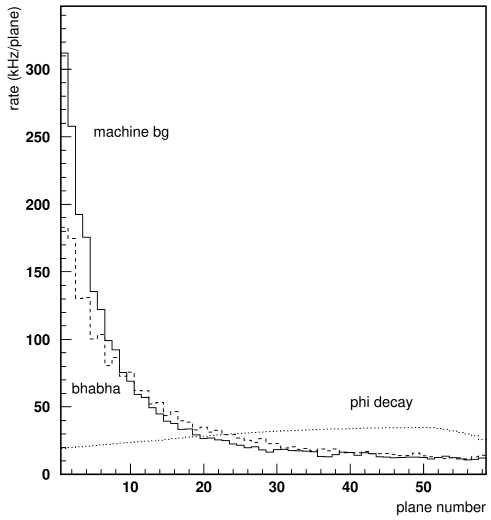


Fig. 18. Hit distribution for various event types in the KLOE drift chamber. Planes are ordered from small to large radii.

### *18.2 Implementation of the Trigger System*

The block diagram in figure 19 shows the trigger logic and the trigger conditions foreseen for KLOE.

For triggering purposes the whole granularity of the calorimeter (5000 photo-multipliers) is not needed. The calorimeter is divided into 200 overlapping sections comprising 20 to 30 adjacent photo-multipliers on each readout side of the calorimeter. Analogue signals of these sectors are summed for each readout side separately, and are then applied to 2 programmable trigger thresholds. The lower threshold is

Table 1
Monte Carlo results for trigger rates on $\Phi$ decays and various background sources.

| | level 1 | level 2 |
|---|---|---|
| event type | rate [kHz] | rate [kHz] |
| all $\Phi$ | $\sim$5 | $\sim$5 |
| Bhabha | 7.22 | 3.10 |
| Machine | 1.30 | 0.98 |
| Cosmic | 1.55 | 1.55 |
| total | 10.07 | 5.53 |

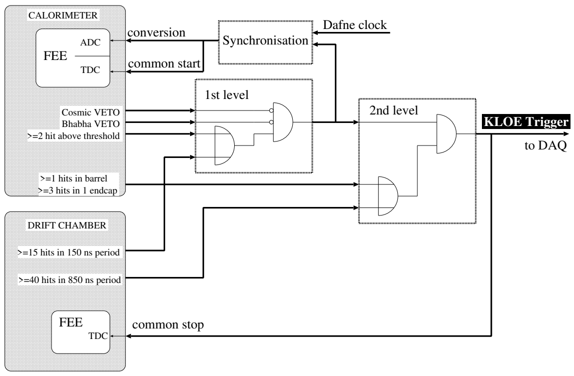


Fig. 19. Architecture and conditions of the KLOE trigger system.

needed to trigger on small energy deposits by low energetic particles, the higher to form a veto for Bhabha events.

The drift chamber is divided into concentric rings (*"superlayers"*), for which the number of hits in the last 150 ns is counted. Particles from background events with low transverse momentum spiralise in the magnetic field, leaving a large amount of hits in a small number of different superlayers. In order to weigh these particles less, hit counting saturates in each superlayer at values between 2 and 5. Then the total number of hits is formed and compared to the threshold for the first level trigger. Due to the drift time, 150 ns after an interaction only 25% of the hits in an event are available. This information is not sufficient to provide a 99% efficiency for $K_{S,L}$ decays with many charged tracks. Therefore a second trigger level is introduced, which accumulates information of the drift chamber for 850 ns after the first level trigger. In this time more than 80% of the hits have arrived in the chamber, allowing a sufficient discrimination of background and $\Phi$ decays.

The final trigger decision will be generated in an crate, the *trigger box*, which to a large extend will be programmable in order to be able to respond quickly to changing trigger requirements.

## 19 The Data Acquisition System

Figure 20 shows a block diagram of the DAQ architecture. In order to make the

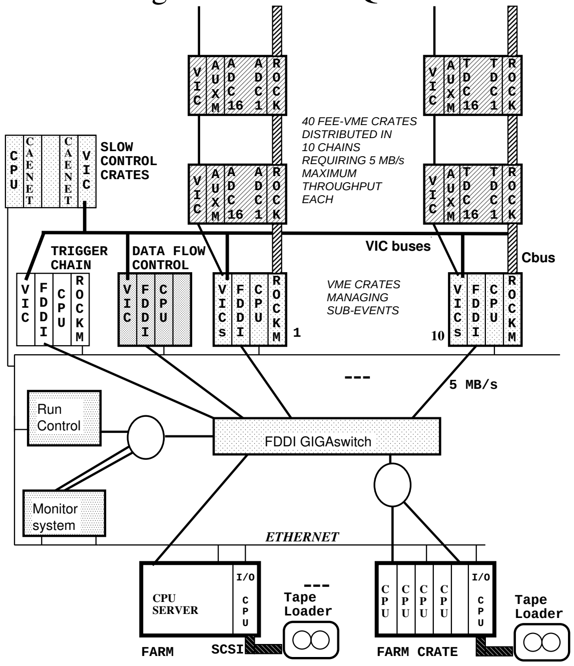


Fig. 20. Architecture of the KLOE DAQ system.

DAQ system tolerant against peaks in the data rates, and to guarantee a fixed dead time of 2 $\mu$s for every given 1st level trigger, every FEE module is given a local buffer, so that its readout need not be synchronised to the actual trigger signal.

The acquisition process can be divided into three different stages. Each FEE crate houses a *Read Out Controller for Kloe* (ROCK), which on a given signal from the Trigger initiates the readout of the crate for a specific event number. The crate readout uses a custom designed bus system (AUX-bus), which has been optimised for the relatively low channel occupancy in KLOE events. The FEE crates are grouped into 10 chains, which all end in dedicated crates housing a chain controller (the ROCK-Manager, ROCKM), and a CPU with an FDDI interface. Each ROCKM is collecting event data from the ROCKs of its chain via the custom designed chain bus (C-bus). The CPUs then send the sub events via FDDI to a switch, from where they are distributed to a farm of powerful processors, which perform event building, event preprocessing, and finally write events to tape. By maintaining address tables in all CPU-crates, the Run Control system guarantees that all sub events originating from the same event are send to the same processor.

Each C-bus allows data rates up to 5 Mbytes/s resulting in a maximum of 50 Mbytes/s for the whole experiment with 10 chains. If in future higher rates are needed, the system can be upgraded by simply adding new chains. The data throughput of the switch with 3.6 Gbytes/s is largely sufficient for KLOE needs. The final choice for the processor farm will be delayed as long as possible in order to optimise cost effectiveness.

The performance of the AUX-bus and the readout chains has been simulated using the Verilog Hardware Description Language. With the conservative assumptions of 80 words/event for a calorimeter chain and 120 words/event for a drift chamber chain, the readout time for an event results in $\approx 35\ \mu s$ , allowing a total trigger rate of 10 kHz.

## 20 Summary

For KLOE a flexible and conceptually simple two level trigger system has been developed. Trigger decisions base on the number of particles in the calorimeter and a weighted hit sum of the drift chamber. Simulation calculations have shown that the system satisfies all requirements imposed by accelerator configuration, hardware of the detector, and physics needs. The total rate of the trigger at peak luminosity is $\approx 10$ kHz with a signal to background ratio of 1:1. The efficiencies for all important $K_{S,L}$ decay channels are higher than 99.5%, allowing to control their uncertainties to a level of $O(10^{-4})$.

The data acquisition system handles a data rate of 50 Mbytes/s. It uses custom designed bus systems optimised for the low channel occupancy in KLOE. By simply adding more readout chains to the system, its performance can be increased without modifying the existing structure.

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# Message System and Data Transmission in the KLOE Data Acquisition System

ABSTRACT

Since the KLOE Data Acquisition System is distributed in a multi-platform UNIX environment, event data, status information and run control commands have to be transmitted over the network. Different protocols are used for the different types of information transfers in order to achieve the best performances in speed and reliability. The communication methods used in the KLOE DAQ and the results of some performance tests will be presented.

## 21 A short Introduction to the KLOE DAQ Architecture

The KLOE experiment [1], being built at the new $\Phi$ factory DA$\Phi$NE in Frascati, is planned to run at the beginning of 1998; it will perform CP-violation studies at sensitivity of the order of $10^{-4}$. The data rate from the detector at full luminosity is estimated to $10^4$ events/s, corresponding to a total throughput of 50 MBytes/s. With these requirements, fast electronics, fast data transmission and efficient on-line software had to be designed for KLOE Data Acquisition.

The KLOE DAQ system uses a FDDI GIGAswitch to connect 10 readout chains to 10 farms of processors. In the readout chains - through custom modules and buses - the data coming from the detector pass a two level concentration; a commercial VME-CPU board in each chain is in charge of collecting packets of sub-events and sending them through the switch to a given processor in a farm. The packets of sub-events related to the same trigger number have to be sent to the same farm, where the complete event is build. The correspondence between data packets and event building processors is dynamically managed by the Data Flow Control (DFC), that optimises the traffic on the switch ports and the load of the farm processors.

In the described architecture network functionalities are crucial for the system operation. While standard TCP/IP is used for data transmission, network management and "inter-node" communication (from now on we will call "node" each DAQ processor) are implemented using the Simple Network Management Protocol . The standard SNMP [2] is based on reliable UDP and is widely used to manage network devices. Information about the managed objects is represented as tree of variables in a Manager Information Base (MIB), where variables can be retrieved or set by a SNMP daemon running on the remote device. Extensions of the standard MIB allow to manage private information.

## 22 The Message System

The commands issued by the Run Control and the requests by monitoring and debugging tasks are distributed in the system in the form of messages, with command acknowledge mechanisms. All the programs taking part to the KLOE DAQ comply with a common skeleton, that implements the message system and the storage of relevant information in a shared memory.

Inside a single node the inter-process communication is implemented, according to the UNIDAQ [3] model, with standard UNIX facilities: each process has a message queue, where commands are queued by the sender process, and a signal is also sent to inform the receiver of command arrival. The message queue number is hold in a shared memory, where relevant parameters for each process running on the node are registered.

To carry out communication between remote nodes, a "command server" implemented as a SNMP daemon runs on each node; the standard MIB has been extended to introduce the KLOE subtree, where the command server maps all the variables held in the local shared memory. This makes information about each local process accessible from the network.

Let's have a closer look to the way of sending commands to remote processes and to get two levels of acknowledgement. The sender transmits its communication request to the command server of the node where the destination process is running, locating in this way the MIB variables corresponding to the destination process.

The message is forwarded to the local process by the command server, with the procedure previously described for communication inside the single node.
The first level of acknowledgement means that the message has been received by the process: it is obtained when the destination process itself writes the received command string in a variable stored in shared memory. In fact the sender process continues querying this value to the command server, until it corresponds to the sent message. Then the sender begins to require to the command server the second level of acknowledgement, which is got when the destination process completes the execution of the command and updates a state value in the shared memory to "success" or "error". Opportune timeouts are set to assure the communication termination in case of faults.

A command syntax has been defined that allows the Run Control to send a message to a list of destinations, in a sequential or parallel mode, depending if the execution of the command by the different processes in the list is correlated or independent. In the first case the command is sent to the next process in the list only when the previous one has acknowledged a successful execution. In the case of parallel mode, the message is dispatched to all the destinations in the list, command execution takes place in parallel and a global acknowledge is obtained when all processes have completed their executions.

Performance measurements have shown that less then 30 ms are needed to send a remote command and get all the related acknowledgements, while 1.2 ms is needed if the command is sent locally (on a HP 900/735 processor ).

## 23 The Data Transmission

The flow of event data in our system, as described in the introduction, is shown with more details in Fig. 1. In the second level of the readout chain, the "collector" process reads from a FIFO the sub-event data coming from the electronic modules and builds packets containing a fixed number of sub-events. These streams are distributed in a multiple circular buffer, where each buffer has a defined destination assigned by the DFC [4].

The circular buffer allows to pass event data between two processes with very simple mechanisms and avoids unnecessary data copies; in particular a multiple circular buffer behaves as a parallel pipe between processes. The "sender" is the level-2 process in charge of opening the TCP/IP connections with the destination farm nodes, extracting the sub-event streams from the parallel pipe and sending the packets in parallel through the FDDI GIGAswitch.

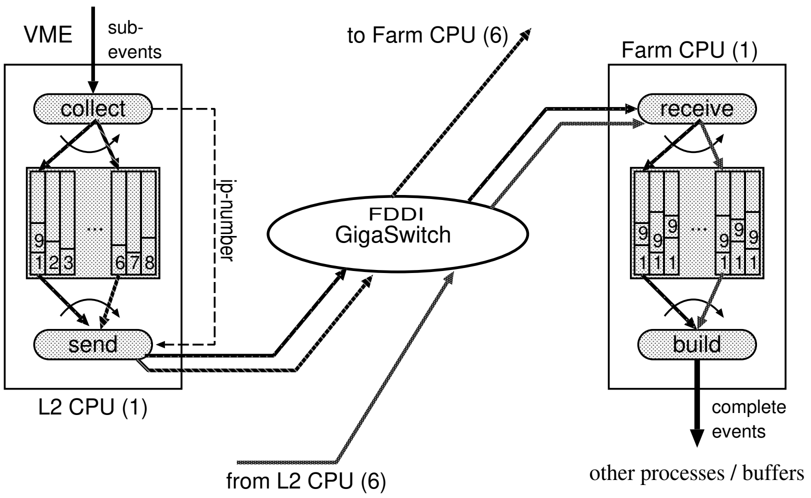


Fig. 21. Event Data Flow in the KLOE DAQ

On each farm node a "receiver" process runs, that accepts the TCP/IP connections from the senders and gets sub-event packets in parallel, filling another parallel pipe, from which the process that performs event building takes its input.

The described data transmission model has been tested in different configurations using 10 processors connected to the FDDI GIGAswitch to verify the performances of TCP/IP event transfer, the send/receive software and the switch behaviour under load. The test environment was very heterogeneous (HP/HP-UX, Alpha/OSF1, PowerPC/LynxOS) which represent a bad case for TCP/IP communication.
Only one readout chain was available, so collectors producing random sub-events have been used for the tests with N senders and N receivers. With an estimated event size of 5 KBytes, packing 100 sub-events per stream, the average length per chain is simulated to be 50 KBytes. Using optimised TCP/IP parameters in a 4 (senders) $\times$ 4 (receivers) configuration, a throughput of $\sim 6.8$ MBytes/s per each receiver was achieved which is compatible with our requirements. Performing the same test in $1 \times 1$ and $1 \times 8$ configurations, we verified that N $\times$ N configuration does not put additional load on the system compared to $1 \times 1$ and that $1 \times 8$ slightly increases the throughput.

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