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**LASER CONTROL SYSTEM
FOR SCINTILLATION CALORIMETER**

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Abstract

Evdokimov V.N. et al. Laser control system for scintillation calorimeter: IHEP Preprint 99-47. – Protvino, 1999. – p. 17, figs. 13, tables 1, refs.: 13.

A 780 channel laser control system for scintillation hadron calorimeter is described. It consists of a nitrogen laser, neutral filters (7 steps of attenuation), an electromechanical commutator that distributes light among calorimeter layers, light fan-outs, control electronics and quartz fibres. The system was studied during a beam test of a calorimeter. The precision of the laser signal pulse measurements was equal to 1% with the system stability is being 1.1%.

Аннотация

Гончаров П.И. и др. Система лазерного контроля сцинтилляционного калориметра: Препринт ИФВЭ 99-47. – Протвино, 1999. – 17 с., 13 рис., 1 табл., библиогр.: 13.

Описана система лазерного контроля сцинтилляционного калориметра на 780 каналов. Она состоит из азотного лазера, нейтральных фильтров (7 ступеней ослабления), электромеханического коммутатора, распределяющего свет по слоям калориметра, разветвителей света, управляющей электроники и кварцевых волокон. Система испытана при изучении калориметра на ускорителе. Точность измерения амплитуды лазерного сигнала в сцинтилляторе равна 1%. Стабильность системы составляет 1,1%.

Introduction

There is wide use of sandwich type scintillation calorimeters for high energy particle measurements (see, for example, [1]). They consist of scintillators interspersed with an absorber. The calorimeters must have, first of all, stable in time characteristics. Nevertheless, due to radiation damage and ageing of a scintillator, fibres and photodetectors, the calorimeters characteristics can deteriorate. A constant control of optical elements allows one to follow all the changes of the calorimeter performance and correct it.

To study hadron interactions, the CMS experiment is planned on LHC collider [2]. One component of the apparatus — the End Cap hadron calorimeter (HE) will operate at a high radiation level. It consists of 17 layers of absorber interspersed with scintillators and divided into 36 sectors. Each active layer contains up to 20 scintillators joint into a so called megatile presented in fig. 1. The light from each scintillator is re-emitted by wave length shifting (WLS) fibres and transmitted by clear fibres to the photodetectors where a tower structure is organised. Below the control system of such calorimeter is presented.

There are the following requirements to the control system: a) a light pulse received by the photodetector must be similar to that produced by charged particles crossing the scintillator, b) each scintillator, optical fibre and photodetector must be controlled, c) the system must be easily reconfigured and operate in a strong magnetic field, d) to cover a wide dynamical range corresponding to the energy range 0.001-10 TeV to study linearity of recording chain and 1% precision of measurements. The time between two beams crossing is 25 ns, therefore, the timing characteristics are also important.

The existing control systems for large scintillation calorimeters [3-6] use μ -mesons, Light Emitting Diodes, Hg-, Xe-lamps and lasers. The presented control system of HE calorimeter for CMS which is based on a UV laser satisfies the above requirements.

1. Laser control layout

For the HE calorimeter a 780 channel laser control system was built and used with a prototype calorimeter during a CERN test beam run. In [7] methods of scintillator damage control with a radioactive source and UV light (337 nm wave length from a nitrogen laser) were studied. Both methods were shown to be identical.

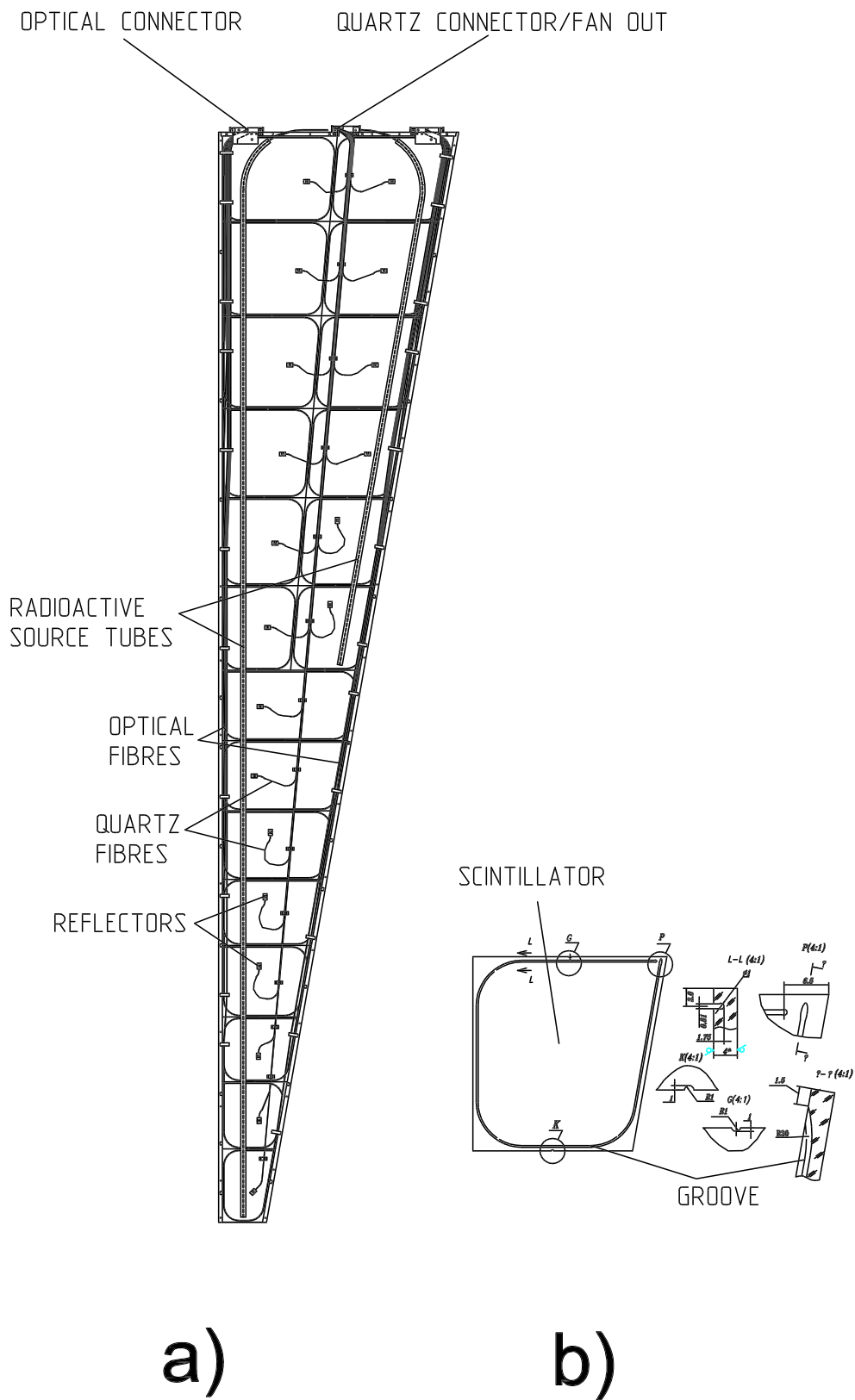


Fig. 1. a) megatile layout, b) scheme of light collection from scintillator.

The conceptual layout of the control system is shown in fig. 2. Light pulses of N_2 -laser pass through neutral filters placed on a rotating wheel and illuminate splitter 1. This is a quartz polished stick with rectangular cross section equalled to transverse laser beam dimensions, its input surface is a diffused one and a bundle of quartz fibres is attached to the opposite end. The fibre number is equal to that of layers.

Then, each fibre is connected to an electromechanical commutator input hole which may be completely closed or opened by a blind thus allowing or blocking light transmission from the fibre. The programmed electronics allows one to keep any combination of blinds in a fixed position. The light from the commutator passes through the main line quartz fibres 30 m long to splitters 2 which distribute the light among sectors.

Then, the light pulses, through the splitters 3 positioned on megatiles, are transmitted to the scintillators. The combination of tower structure with commutation of laser light between the calorimeter layers allows one to control the performance of each scintillator.

For example, a drop of light pulse amplitude from several forward scintillators in a tower indicates radiation damage. A decrease of light from a single scintillator gives evidence that an optical path from the scintillator to the photodetector is damaged (optical contact between WLS and clear fibres, etc.). Thus, for laser control system it's necessary to collect a matrix of pulse height amplitudes from each scintillator at the beginning of the calorimeter work and then to compare the signals from the corresponding channels during the experiment. This is a flexible and easily reconfigurable system. It can work during data taking and the response of scintillators to a UV pulse does not depend on magnetic field in contrast to a radioactive source.

2. The elements of the control system

The required power of the nitrogen laser used for HE control system is about 20 mJ/pulse. This is determined by the number of controlled elements (~ 20000) and the measurement precision (1%). The laser light pulse duration is to be shorter than the re-emission time of WLS fibre (11 ns). The laser has a pulse width of 5 ns (FWHM), jitter ~ 1 ns and the amplitude distribution 30% (FWHM). Therefore, each laser pulse was measured with PIN diode and the pulses from photodetectors were normalized to a PIN diode. For this purpose a quartz plate 2 mm thick was placed into a laser beam at 45° . The light reflected by this plate hit the PIN diode. The laser was triggered during the accelerator cycle, the calibration gate was started by PIN diode. For the measurements laser MSG-300S with 220 mJ/pulse power was used. It had a good electrical shielding so the induced on electronic signal didn't exceed 2 mV/50 ohm.

The splitters of the laser light must have high space uniformity and low attenuation. As splitter 1 a quartz stick with dimensions $250 \times 5 \times 5$ mm³ was used (the diameter of laser beam was 3 mm). The input surface of the splitter was made diffused. To measure the light loss on this surface, two signals were compared after having passed one and, then, two consecutive splitters. The loss on the surface turned out to be 4.8. The uniformity of splitter 1 was studied by scanning the output surface of the splitter with a quartz fibre and found to be about 1%. To the output surface 23 fibres 0.85 mm in diameter were attached. Their ends were thoroughly polished. To minimize the light losses, a short focused lens was used ($F = 7$ mm) instead of the diffused surface. The light loss was 2.5 times less in this case but large nonuniformity of the light forced to reject this approach.

Splitter 2 and 3 were polished quartz sticks with dimensions $60 \times 2.5 \times 2.5 \text{ mm}^3$. From one side there was coupled a quartz fibre 0.85 mm in diameter (0.6 mm diameter core) and to the other end a bundle of 20 quartz fibres with a 0.5 mm diameter (0.3 mm diameter core) was attached. The ends of the fibres were polished. Without diffused surface the uniformity of these splitters was 1%.

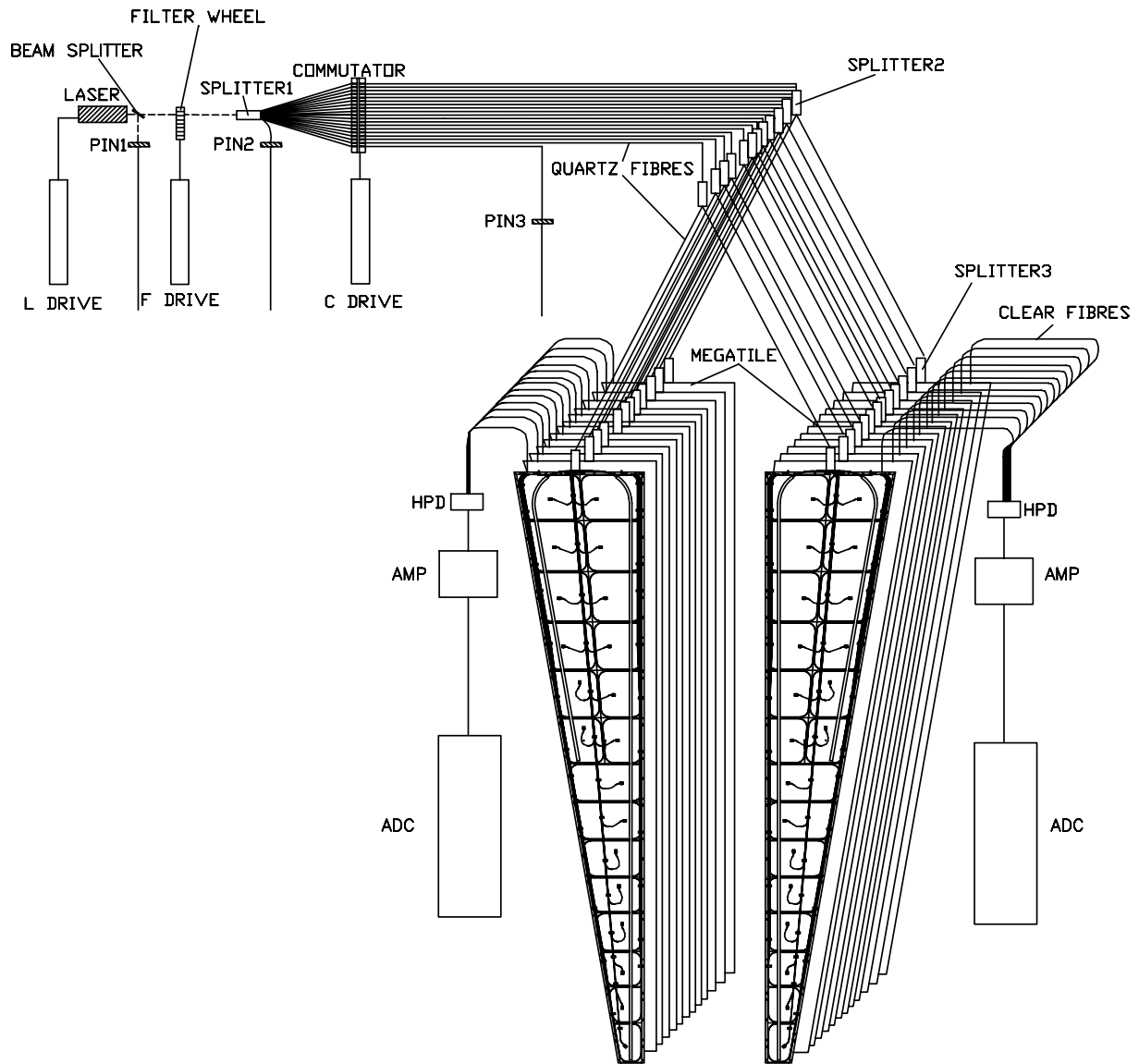


Fig. 2. Principal layout of laser control system of hadron calorimeter.

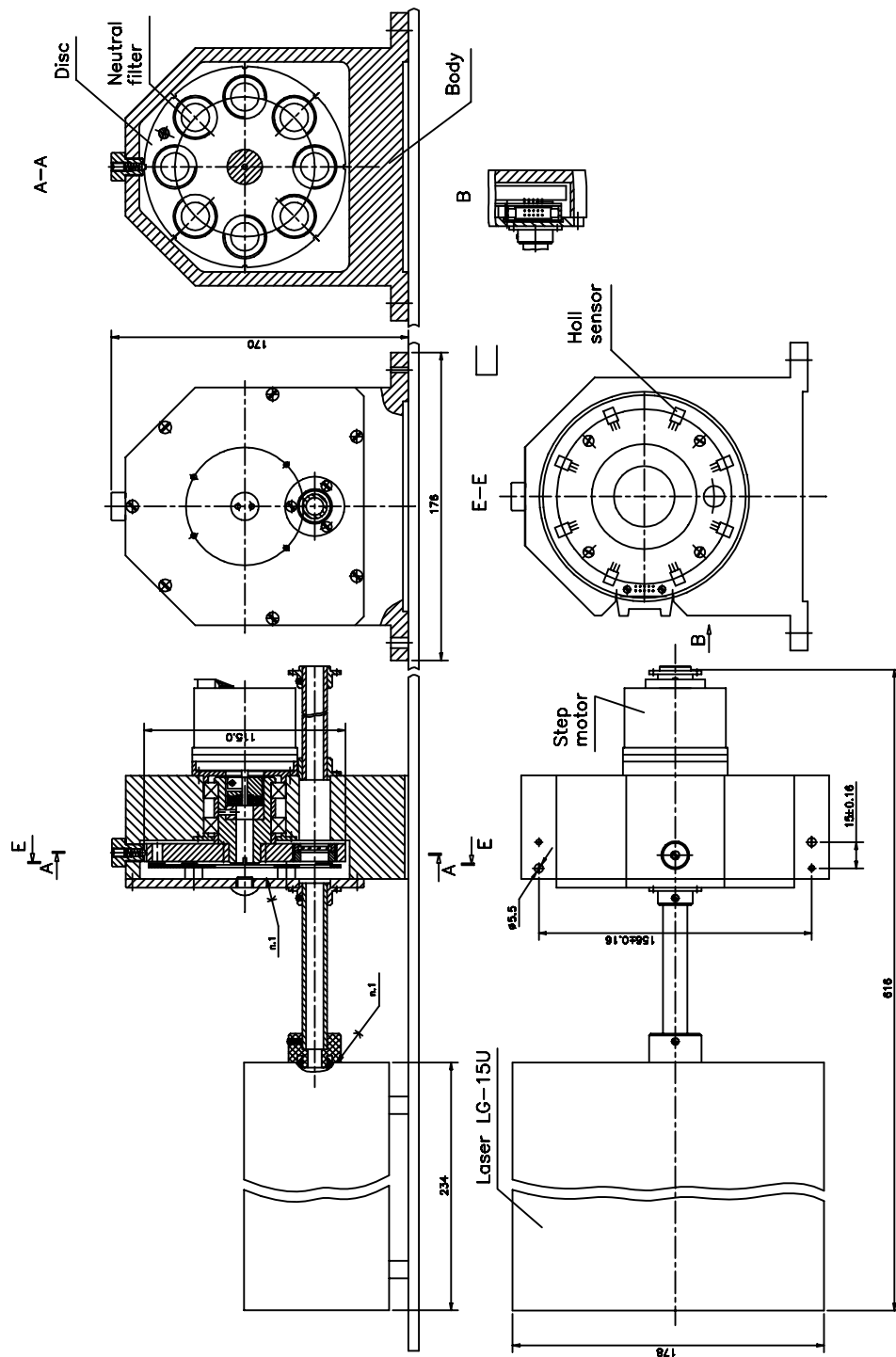


Fig. 3. System of neutral filters (principal scheme).

To control the electronics in the whole dynamical range there were used 7 neutral filters manufactured from quartz with UV stable additives. After having passed through the filter with a maximum attenuation the coefficient of its attenuation didn't change. The characteristics of the filters are tabulated below. The filters were set on a rotating wheel and positioned in the laser beam by a step motor (see fig. 3) controlled by a programmed electron module. The filter position on the axis of the laser beam was controlled by Hall sensors with 0.5 mm precision. The number of the positioned filter was displayed on the light indicator. The wheel filter was PC/manually controlled. The maximum time required to change the filter was 2 s.

Table.

Filter number	Coefficient of attenuation	Nonuniformity, %
1	5.16	1.00
2	23.10	0.35
3	47.00	1.60
4	210.00	1.50
5	435.00	0.35
6	1350.00	0.25
7	3750.00	0.35

The electromechanical commutator (fig. 4) switched the laser light into a determined calorimeter layer. A metallic blind 0.1 mm thick with dimensions $10 \times 10 \text{ mm}^2$ guided with relay PC-22 completely blocked the light from a fibre connected to splitter 1. There was no cross talk from one fibre to another. The position of the blind (open/closed) was controlled by optoelectronics. The gap between the fibres in the commutator was 0.3 mm and their axes were parallel with a precision of 2 mrad. The light losses in the commutator were about 40%.

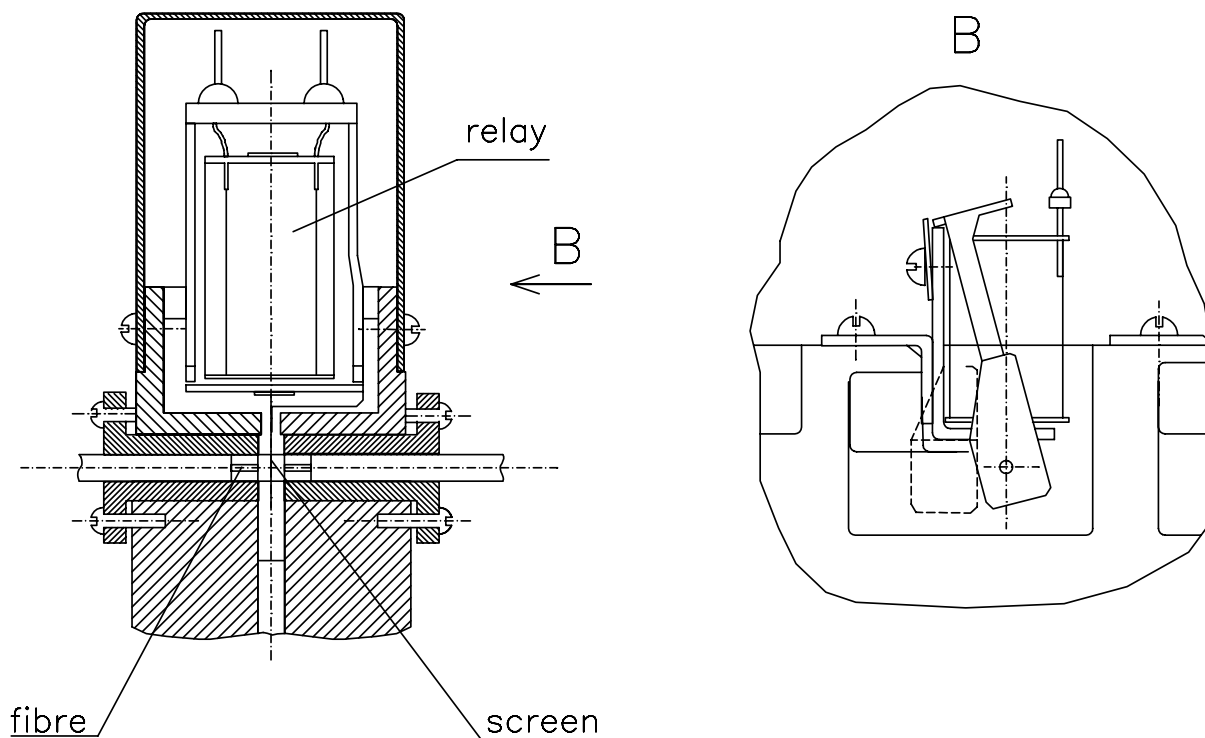


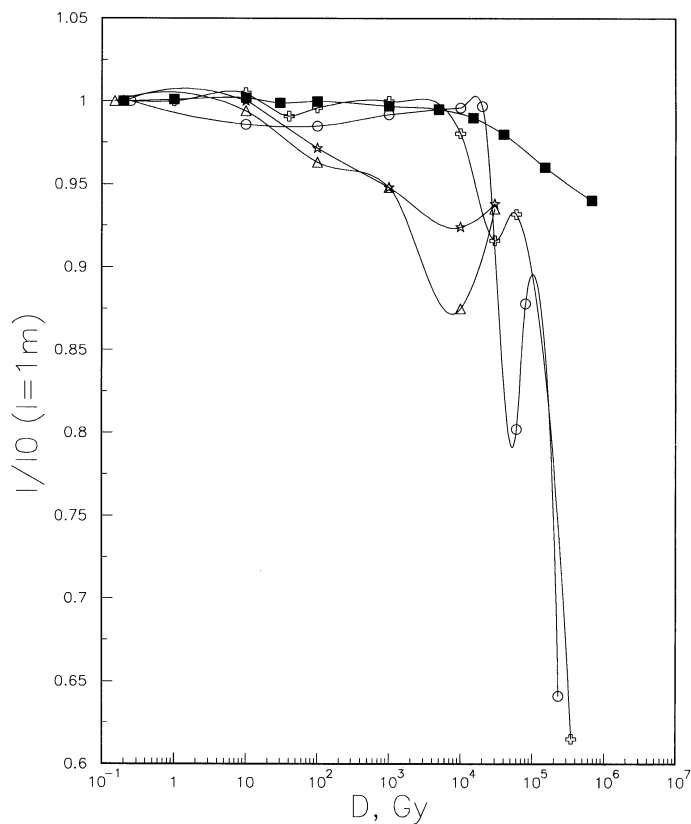
Fig. 4. Electromechanical commutator of laser light (principal scheme).

An important part of the laser control system is the optical fibres. They have to satisfy the following requirements: a) high radiation stability (not more than 10% degradation at 10 Mrad dose [8]), b) low attenuation of UV light (~ 0.2 dB/m), c) high coefficient of filling (the ratio (core area)/(cladding area) ≥ 0.8), d) the fibres have to be flexible, not to crack when bent at 20 mm radius, core and cladding have to be reliably protected from mechanical damage, e) acceptable cost.

Radiation stability of optical light guides was studied in [9-13]. The following points are noteworthy: 1) radiation stability of the fibres drops fast with the decrease of wave length, 2) fibre attenuation length decreases with the rise of dose rate, 3) quartz fibre recovers partially the attenuation length after irradiation.

Due to a small attenuation length (1 m) and low radiation hardness (100 krad), polymer fibres cannot be used for the UV control system. For the same reason and because of low filling coefficient (20%) quartz fibres for optical links cannot be used to this end. For the laser control system we used quartz-quartz fibres (QQAl) with a high content (1200 ppm) of hydroxyl (OH) manufactured at the Institute of General Physics of Russian Academy of Sciences in Moscow. They have Al jacket that substantially improves radiation hardness [10] and protects it against cracking and damage. The fibres are manufactured using a chlorinefree technology. Radiation hardness of the fibres is about 6 Mrad (fig. 5). Fig. 6 shows the dependence of QQAl fibre transparency on the wave length. For 337 nm wave length it is 0.18 dB/m. Notice that “dry” fibres (which contain OH at a level $\sim 0.01\%$) have low radiation hardness (~ 10 krad), quartz-polymer fibres have lower radiation hardness in comparison with QQ-fibres.

Fig. 5. Dependence of ratio I/I_0 — pulse heights of laser signals after and before irradiation dose D of different quartz fibres [11]. Fibre length is 1 m. ■ — quartz-quartz fibres with aluminium sheath and diameter 0.3 mm, quartz is KU-1, outer skin is $SiO_2 + F$ with hydroxyl (OH) content of 1200 ppm.



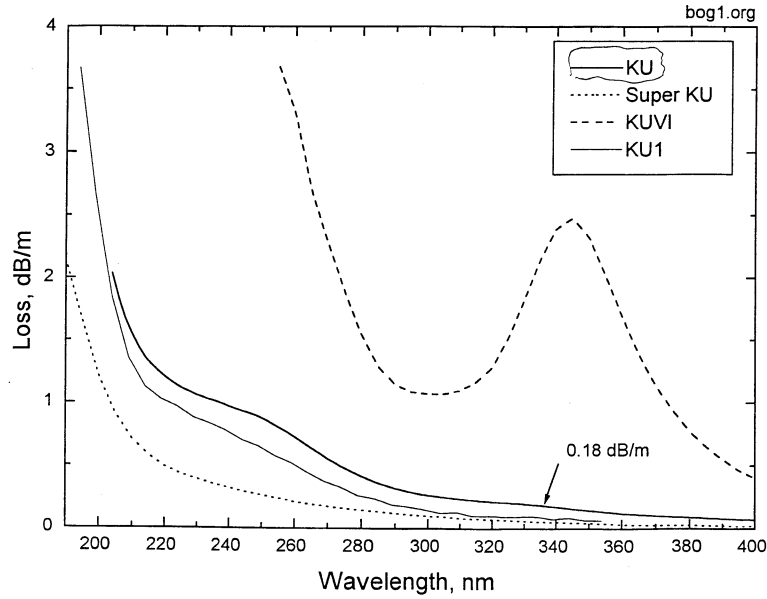


Fig. 6. Dependence of light transmission L (dB/m) for quartz-quartz fibres with aluminium sheath 0.85 mm diameter on wave length λ for different quartz types. The presented control system used KU quartz fibres.

The main quartz fibres (QQA1/600/648/750) have a core diameter of 0.6 mm, the thickness of cladding is $24 \mu\text{m}$ and the Al jacket is $51 \mu\text{m}$ thick. The light intensity distribution at the output of the fibres has RMS 2.7%. Radiation hard fibres inside the calorimeter (QQA1/300/324/400) have 0.3 mm core diameter. Their ends were collected into a bundle and polished. To measure the uniformity of light output from these fibres, 10 fibres were attached to splitter 1 and their pulse height distribution was measured. The RMS was 2%.

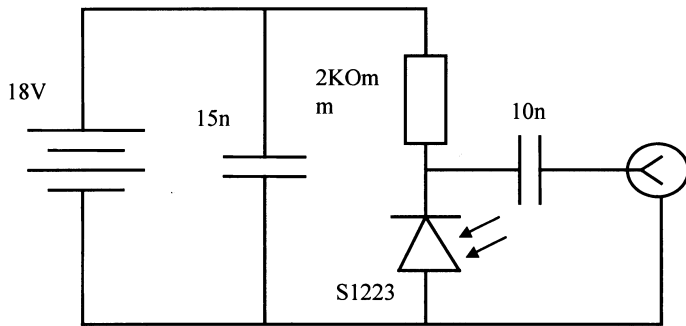


Fig. 7. Layout of PIN diode scheme.

The laser pulse height was controlled by Hamamatsu S1223 PIN diodes. They have a good linearity (10^5) and high temperature stability. The layout of PIN diode scheme is shown in fig. 7. To minimize the induced signals from a power supply, the diodes were coupled to two batteries “Krona” connected in series. The PIN diode linearity was studied with neutral filters whose attenuation is well known. Two schemes of PIN diodes were used in the measure-

ments: the PIN diodes were illuminated by laser directly and through a scintillator 2 mm thick which allowed one to use the diode for all the filters.

The control apparatus is made in CAMAC. It consists of a laser controller LC, a module to control the filter wheel FC and a commutator controller CD. The controller LC provides a switch on/off of the laser, control of high voltage and nitrogen consumption, the timing of the laser with an apparatus trigger and the starting of the laser. Module FC allows one to set the required filter on the laser beam axis according to a computer command or manually from a

front panel and also to control the position and number of the inserted filter. The controller CD makes it possible to close and open the blinds in any combination that provides commutation of light into a required calorimeter layer. The module has a manual control as well. The position of blinds is displayed on the illuminated indicator panel and can be read with a computer.

3. Measurements of the laser induced signals in scintillators

Efficiency ε and reproducibility α of different methods of light injection into scintillator were studied. The best reproducibility (98%) gives the method when fibres were put perpendicular to a scintillator surface. The value ε did not depend on deviation of the angle of the fibre from perpendicular to the scintillator surface up to 80° . Good results gave a method in which the fibre was laid on the scintillator surface and covered with an aluminized mylar. The light from the fibre end was reflected into the scintillator. The values ε and α are 95% and 92%, respectively.

Al plates with a hole for fibre and conical (118°) reflecting surface (see fig. 8) were used from design considerations for light injection into scintillators. The quartz fibres and the plates were placed on a cover plate which closed the scintillator. The efficiency of the method was 80% and $\alpha=95\%$.

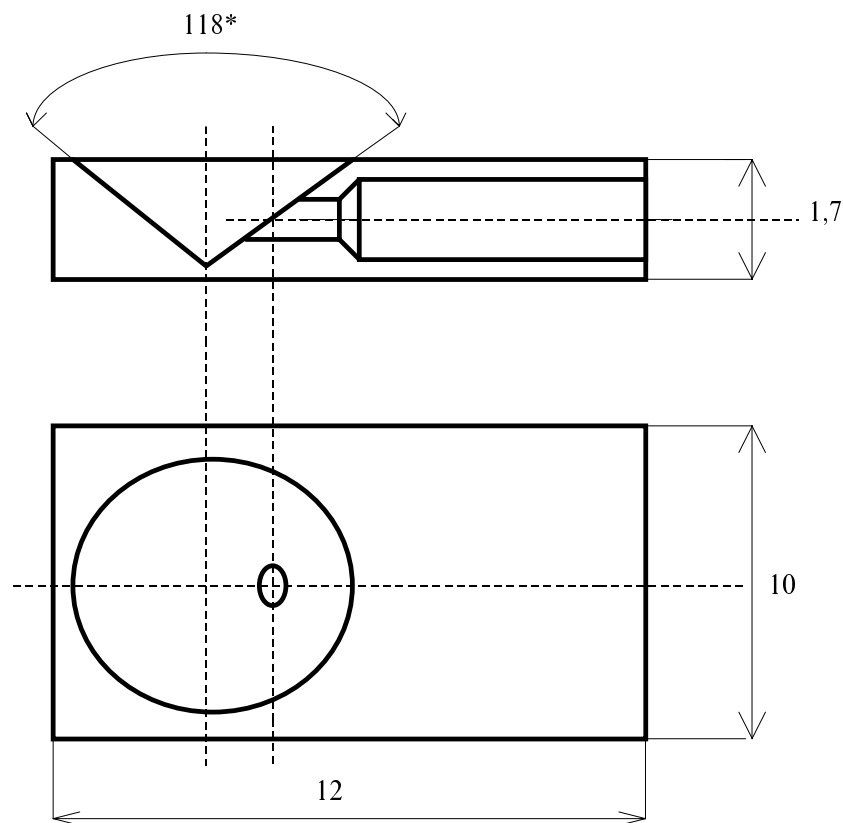


Fig. 8. Design of light injection into scintillator.

Also, the injection of light into a drilled hole of the scintillator with a diameter of 1 mm and 10 mm deep was studied. The angle of slope was 0° , 9° , 18° . Due to difficulties connected with clearing the hole, the value of ε was (50-80)% and $\alpha \sim 70\%$.

The scintillator stability was studied as a large number of UV photons passed through it. A polystyrene-based scintillator with additives of 1.5% P-terphenyl and 0.5% POPOP was irradiated with a laser LGI-21 during 6 hours which corresponded to 10^{20} photons. The photomultiplier FEU-84 measured the current induced by a collimated radioactive source ^{106}Ru in the scintillator which irradiated the same spot illuminated by the laser. Within the measurement errors (3%) the scintillator characteristics did not change.

A coefficient β — loss of N_2 -laser light due to re-emission in the scintillator and WLS fibre was measured in the following way. The laser light attenuated in splitter 2 passed through a quartz fibre to a photocathode of photomultiplier 56-UVP. Then, this fibre exited the scintillator and the light from WLS fibre was measured. The coefficient β was equal to 300 ± 30 .

4. Test of the control system with a prototype calorimeter

The laser control system performance was studied during a test beam on the H2 beam line of CERN SPS. During two runs with a HE prototype light yield from scintillator, precision and stability of the system were measured. The layout of the experimental apparatus is shown in fig. 2. Here the first megatile (0-layer) consists of 16 scintillators 10 mm thick. The light signals from the scintillators were collected by WLS fibres and passed by clear fibres to 19 pixel Hybrid Photo Detector (HPD). The megatiles were placed between copper plates. The pulses from scintillators were fed through optical fibres to 73 pixel HPD. To control its performance, the pulses from Light Emitting Diode were also fed. One pixel collected fibres from different calorimeter layers by means of Decoder Box, so tower structure of information read out was organized. From HPD after amplification (AMP) the electrical signals were fed by coaxial cables to ADC with sensitivity 1 pC/channel.

Control of the calorimeter prototype was realized in an accelerator cycle. The laser was triggered by a generator after a beam end. The length of the calibration gate was 0.2 s. The rate of the laser trigger was 7 Hz. The used laser had 30 μs delay, therefore its own synchronization pulse was not used. The gate for ADC 400 ns long was generated by PIN diode from laser pulse. A similar diode was used to normalize output signals from HPD. To control the performance of the system PIN diodes were set at the output of splitter 1 and at the end of main fibres. Typical pulse height distribution from PIN diode is shown in fig. 9. The width of the distribution is determined by the fluctuation of laser light pulses. The ratio of the width distribution to the average value is 0.19.

The laser control system elements (laser, neutral filters, commutator) were operated by PC using an upgraded program MES. The electron modules were placed in a CAMAC crate. To tune the system and control its performance, there was also placed ADC LeCroy 2249 that recorded the signals from PIN diodes. The data from the ADC were read using controller K-331. The program allowed one to switch on and off the laser, to set a required filter on the laser beam, to control nitrogen consumption and realize any combination of open blinds on the commutator.

The uniformity of light distribution injected into the megatile scintillators was measured with a single scintillator whose WLS fibre light was detected with FEU-115. The uniformity distribution was 5%. It was explained by the difference in polishing the fibre ends, splitters and reflectors.

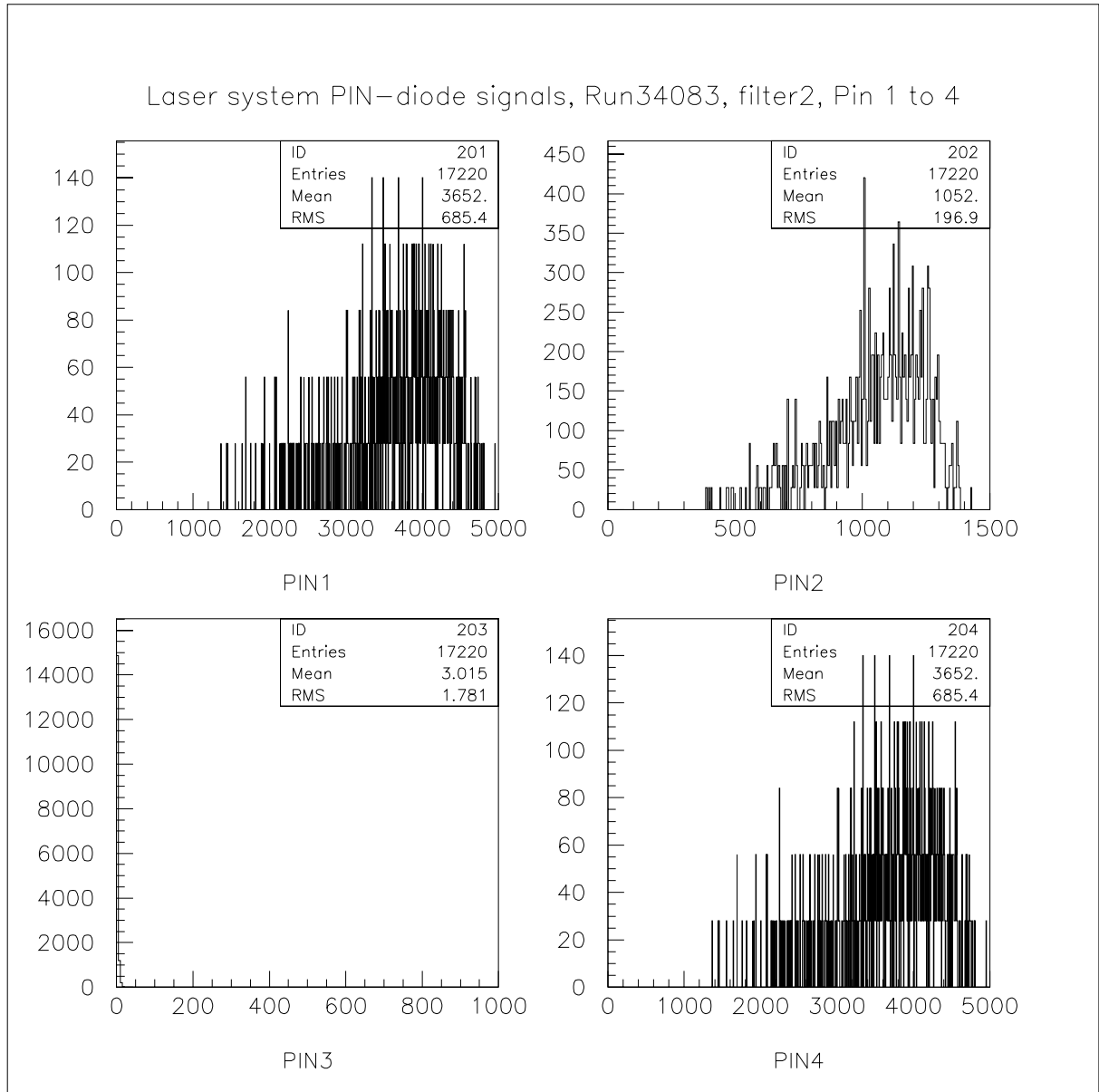


Fig. 9. PIN diode pulse height distribution of laser light signals.

The normalized pulse height distribution for some scintillators of 0-layer is presented in fig. 10a. The number of photoelectrons per single laser pulse equals $(M/\sigma)^2 = 3.5 \times 10^3$, where M is an average meaning, σ is a standard deviation. The precision of light pulse measurement in the scintillator was 1.5% and was determined by photoelectron statistics. This is shown in fig. 10b where the laser control system pulses were recorded with a phototube. There the precision is 0.85%. The number of photoelectrons was 10^5 1/pulse.

Normalized to PIN–diode4 Laser signals, Run34083, filter2, Zero layer 7 to 12

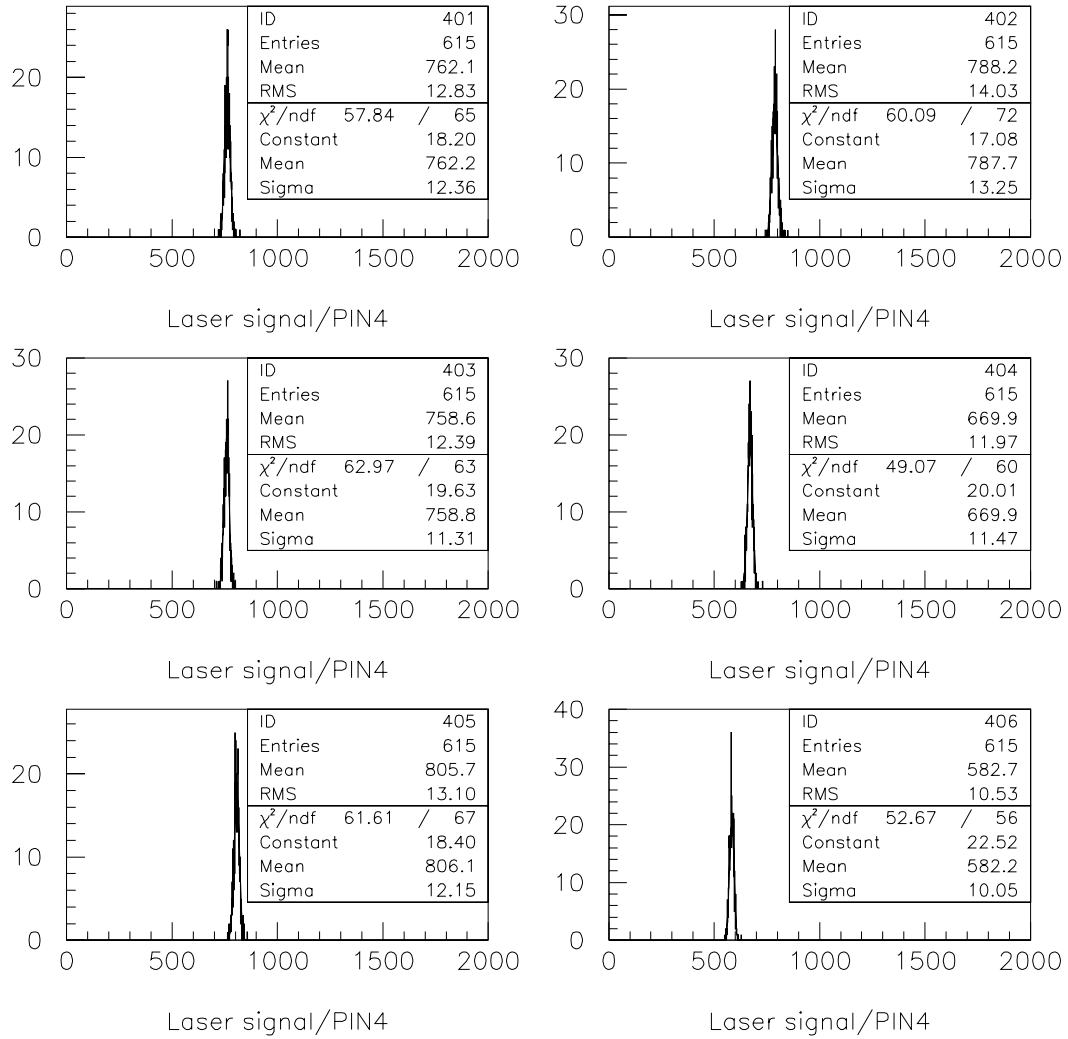


Fig.10a. Normalized to PIN diode pulse height distribution of signals from HE prototype calorimeter scintillator layer induced by laser pulses.

Renormalized laser signals Run 29803 filter 1 2-stage

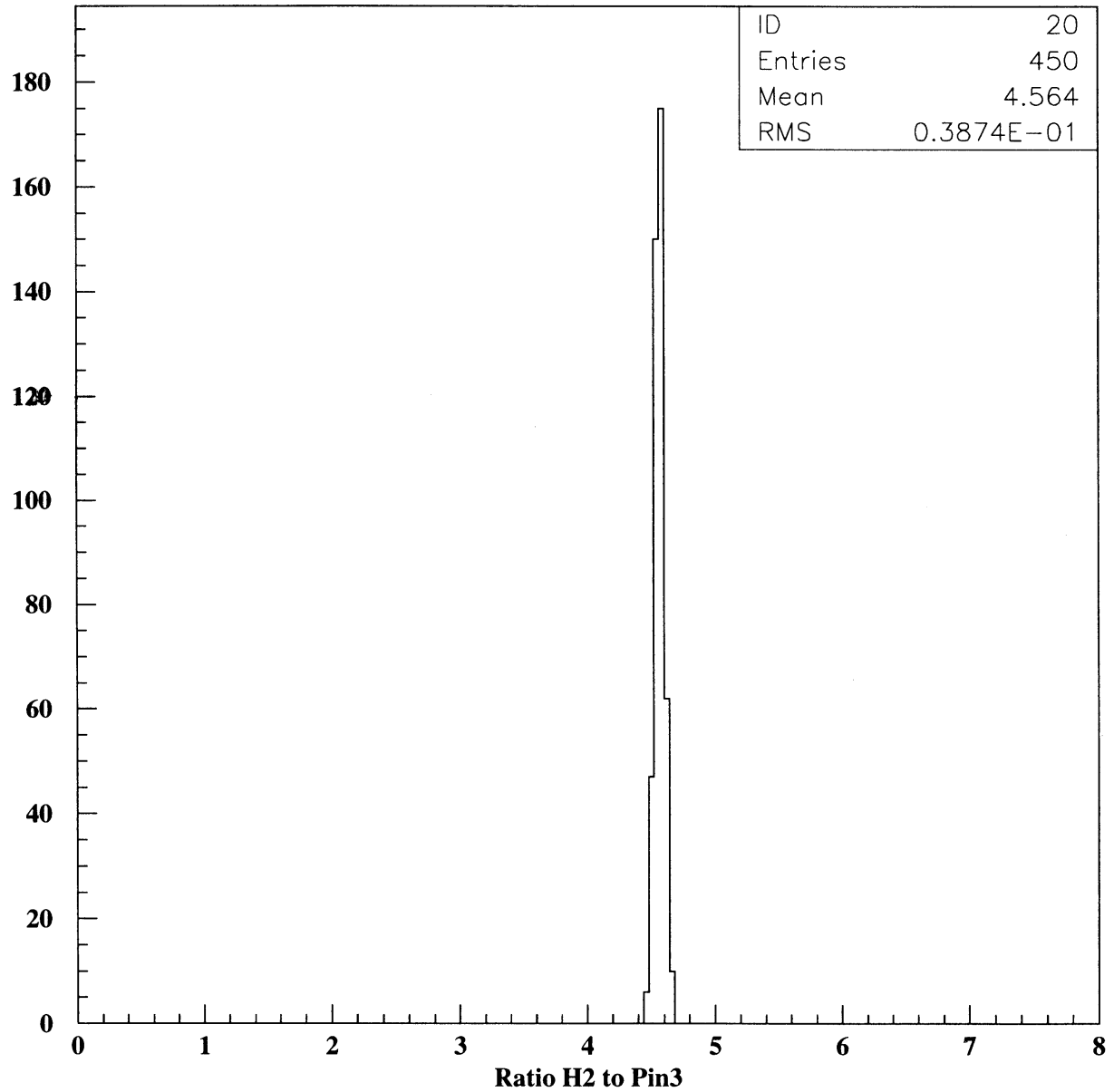


Fig.10b. Normalized to PIN diode pulse height distribution from H1 photomultiplier signals of HE calorimeter prototype.

Pulse height distribution in towers of prototype calorimeter is shown in fig. 11. The RMS for a single tower is 2.2% (filter 2). The number of photoelectrons is $(M/\sigma)^2 = 2 \times 10^3$.

Normalized to PIN–diode4 Laser signals, Run34083, filter2, Towers 7 to 15

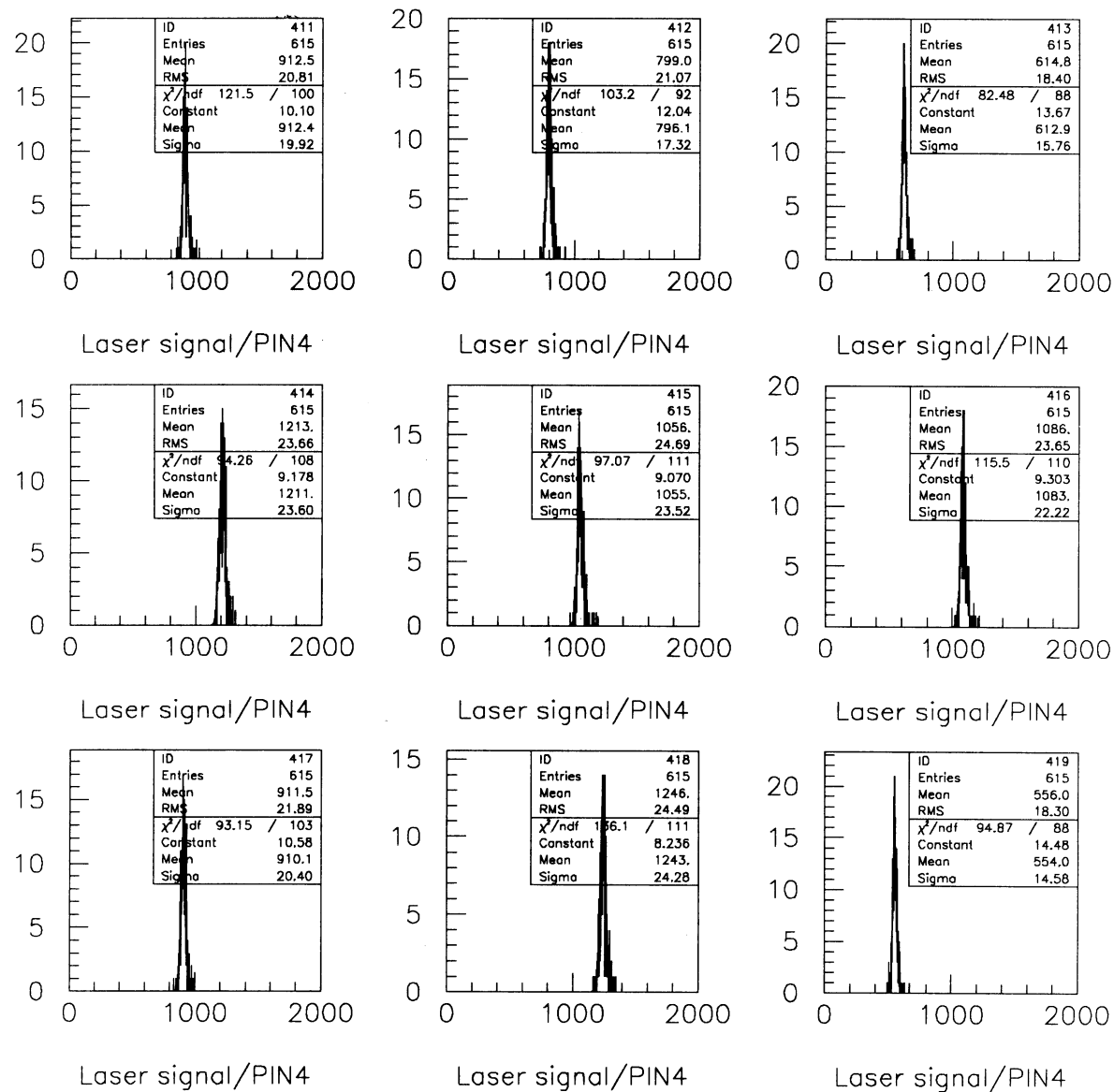


Fig. 11. Normalized to PIN diode pulse height distribution of pulses from calorimeter prototype tower induced by laser pulses.

The linearity of the system can be estimated from fig. 12 which shows the dependence of average values of light pulses in scintillators induced by the laser on pulse height of PIN diodes for different light attenuation by neutral filters. One can see that the system is linear with a good precision.

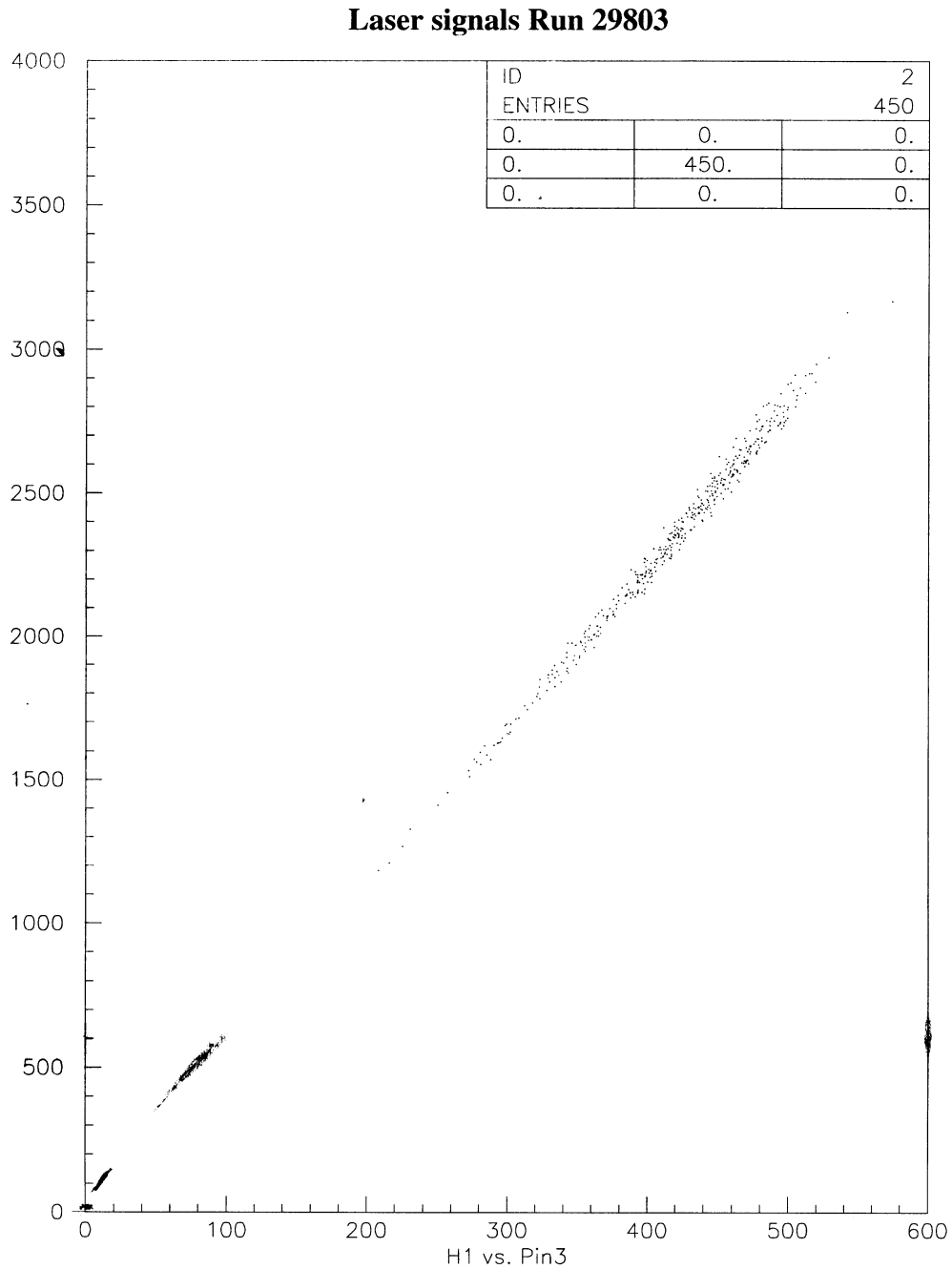


Fig. 12. Dependence of H1 pulse height signals from scintillators induced by laser pulses on PIN3 diode signals for different levels of light pulses attenuation in neutral filters.

The time stability of the laser control system and data acquisition electronics are shown in fig. 13. It presents the dependence of average pulse height values from the scintillator on the time. For towers the stability did not exceeded 1.1%.

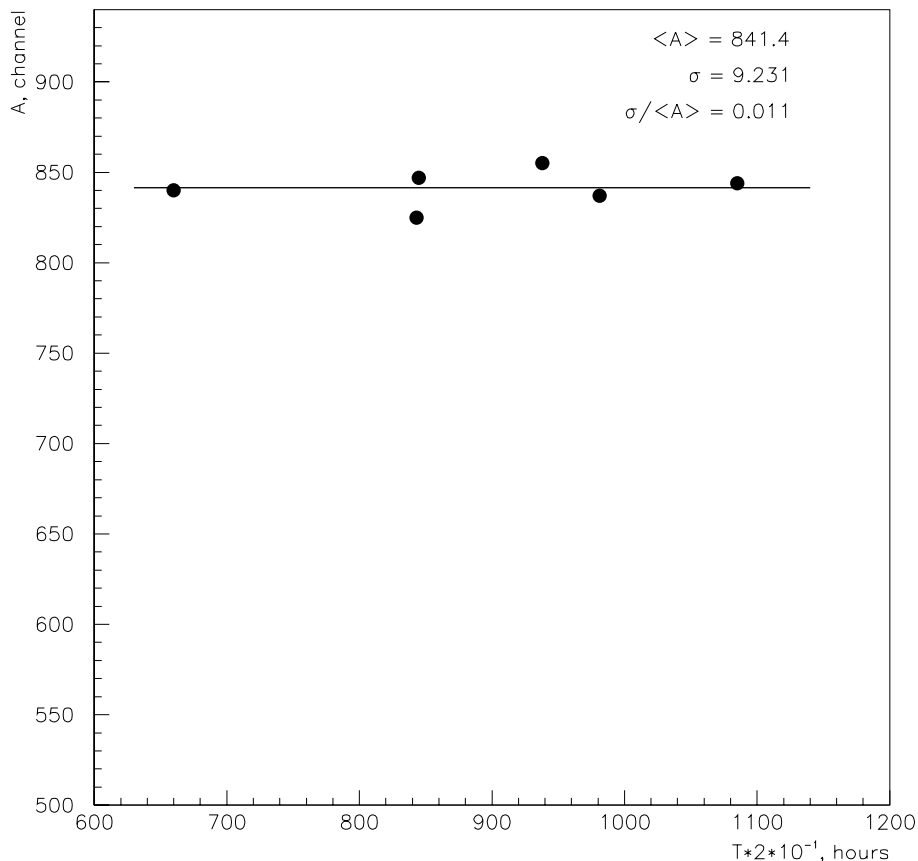


Fig. 13. Dependence of average pulse height A from scintillator induced by laser on time T.

Conclusion

1. The 780 channel laser control system for hadron calorimeter was built.
2. The laser control system was studied during test beam measurements with HE prototype calorimeter.
3. The precision of the system ($\sigma = 1\%$) and its stability ($\sigma = 1.1\%$) was measured .

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