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DESCRIPTION OF A PAIR SPECTROMETER USED TO STUDY THE SMALL ANGLE SCATTERING OF HIGH ENERGY PHOTONS

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INTRODUCTION

A pair spectrometer has been designed to detect and measure photons in the GeV region scattered into the angular range of 1 to 4 mrad with respect to a well collimated, high intensity bremsstrahlung beam. Since it was essential to know the scattering angle the design makes a reconstruction of the conversion point possible. The pair spectrometer was used in an experiment at DESY, Hamburg to study the small angle scattering of high energy photons by heavy nuclei (Delbrück scattering and Photon splitting)*.

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* G Jarlskog et al, preprint 1972

THE PHOTON BEAM

The bremsstrahlung beam was produced from a 0.1 mm internal tantalum target ($2.63\ 10^{-2}$ rad. length) by the 7.4 GeV Electron Synchrotron DESY. The maximum beam intensity used in the experiment was about $9 \cdot 10^{8}$ effective quanta/sec (at 7.225 GeV). The beam was defined by three square collimators with openings of $0.2 \times 0.2\ (cm)^2$, $0.7 \times 0.7\ (cm)^2$, and $1.7 \times 1.7\ (cm)^2$, and positioned at a distance of 11.4, 27.1 and 42.1 m from the machine target respectively (see Fig 1). This collimating system (designed according to the trumpet principle, i e the photon produced at the machine target must not see the walls of the second collimator and the photons scattered off the wall of the first collimator must not see the third) reduced the intensity in the beam halo by seven orders of magnitude. The beam intensity was measured by a quantameter of the Wilson type its constant being $(1.83 \pm 0.04)\ 10^{19}$ (MeV/Coul).

THE PAIR SPECTROMETER

A scetch of the experimental set-up is shown in Figure 1. The scattered photons emerging from an upstream target were detected in a magnetic pair spectrometer. The converters were 2 mm aluminium rings ($2.24 \cdot 10^{-2}$ rad length) with a central hole to let the primary beam pass through. One covered the angular range from 1.7 mrad to 3.25 mrad (= $3.13\ 10^{-5}$ sr), a second one covered the range 0.95 to 1.15 mrad (= $1.38\ 10^{-6}$ sr). Their dimensions range from a minimum of 3 cm for the inner diameter to a maximum of 15 cm for the outer diameter. A set of converter rings and a thin aluminium foil for the measurement of the bremsstrahlung spectrum were mounted in a remotely controlled revolving target holder. The assembly was mounted in vacuum in order to reduce scattering and showers from air. For the same reason most of the beam line from the scattering target to the intensity monitoring quantameter far downstream is passing through beam pipes evacuated to pressures below 10^{-4} torr. The electron-positron pairs were momentum analysed in a conventional bending magnet (type MA, DESY) with an aperture of 16.8×48.3 cm^2 and a maximum bending power of 21.6 kGauss m. The particles left the magnet through two mylar windows and were detected in two legs of the spectrometer each containing two plastic scintillators and two proportional chambers.

The front counter was positioned next to the exit window of the bending magnet to define a clean trigger (this consideration was more essential than was the loss in momentum resolution due to multiple scattering ($\sim 0.5\%$)).

The sensitive areas of the front and rear multiple-wire proportional chambers were 19×19 cm^2 and 36×19 cm^2, respectively. Each chamber had two gaps with wires oriented in the horizontal and vertical directions. The wire planes on the high voltage side were not read out. The 30μ thick goldplated molybdenum sense wires of the ground plane are spaced 2 mm apart and are mounted on frames made of sheets of glass-fiber reinforced epoxy. They are accurately kept in position by stretching them cross thin sawtooth stripes with approximately 50 g of force.

The high voltage planes consist of 100μ thick copper wires stretched parallel to the sense wires at 1 mm spacing. The frames were stacked together in such a way, that the thickness of the frames (6.5 mm) determines the gap width. Sealing was achieved by rubber O-rings and thin mylar sheets for the windows. The chambers were operated with a mixture of 5% propane in argon at a voltage of 2.85 kV per gap.

The total number of wires in this system was 1000. Each wire is connected to a preamplifier mounted directly on the chambers. Its input impedance is 1 kΩ and its output pulse has a decay constant of about 200 nsec. The preamplifiers have a gain of 1.5 only and mainly served as cable drivers. They are connected to the terminated inputs of the main amplifying and readout units via 2 m long cables with 50Ω impedance.

The main units are designed closely following the recommendations put forward in "Preliminary specifications for a monolithic integration of wire electronics, LRL, Berkeley, Nov. 1970" and need not to be described in detail here. The read-out unit (shown in Fig 2) contains an amplifier with a threshold of less than 0.5 mV, a one shot for signal delaying, strobe gate, and shift register. All shift registers were connected to form a chain for series readout. The total dead time for the amplifier amounts to 0.6 μsec.

TRIGGERING SYSTEM

As trigger condition the fourfold coincidence between the four scintillation counters was required. The time resolution of this coincidence was 10 nsec (F W H M).

Coincidence rates as well as random coincidences were continuously monitored on scalers. The fourfold coincidence signals were transformed from NIM logic levels to the standard levels for the integrated circuits employed. It then was stretched and delayed to give a strobe pulse which opened the strobe gates of all amplifiers to pass information to the shift registers. This happened about 400 nsec after the passage of the particle. We set the width of the strobe pulses as narrow as possible but such that we still achieved an efficiency of 99% or better for the chambers. This gave a time resolution for the total wire system of about 100 nsec which includes the time jitter of the chambers and electronic variations from unit to unit as well.

The whole trigger system was gated with the spill signal from the accelerator to reject spurious events during off--spill time. Furthermore, a busy signal from the readout system vetoed the strobe signal.

DATA COLLECTION

The readout system consisted of a "Series Readout unit" and a PDP8 -computer connected on-line to the DESY IBM-360-75 computer facility. The information stored in the registers was shifted out with a clock frequency of 1 MHz and transferred to the PDP 8, i e the readout time for an event amounts to about 1.1 msec. The PDP8 accumulated events by switching between two buffers of 500 words each. When one buffer was filled (about 25 events) the information was transferred to the IBM 360. This analysed some of the data for monitoring and for displays while storing all data on magnetic tapes for final analysis. The information from the sampled events was transmitted by the PDP8 on request and displayed on a storage display scope.

The length of each run was determined by the quantameter, which yields the integrated flux of photons, to an accuracy of about $\pm$ 2.2%.

TRACK RECONSTRUCTION

Each particle track was defined by two points in space. For each leg of the spectrometer arm the on-line program combines the coordinates obtained from the two chambers to form all possible particle track candidates. The false tracks are sorted out by requiring that the cross-point between the extrapolated track and a vertical plane through the centre of the bending magnet (perpendicular to the spectrometer axis) is reasonable. The remaining tracks of the two legs were traced back to the converter target. If the distance between the conversion points was not too large an average origin of the pair was calculated. Finally loose criteria about the size of the converter ring and the sum of the energies of the conversion electrons were applied. In cases with more than one surviving combination the best one was chosen. This procedure yields the energy and the point of conversion of the scattered photon.

Figure 3 shows a scatter plot of the converter ring as reconstructed with our analysis program. The events in the centre of the ring stem from photons of the unscattered photon beam which converted on residual gas molecules. In addition, the supporting rod for the ring is clearly visible.

We estimate the mean error of the coordinates of the conversion point to be $\pm$ 3.0 mm. In terms of angular resolution this corresponds to $\Delta\theta_{scatt} = \pm 0.15$ mrad.

TEST OF SYSTEM PERFORMANCE

In order to check the whole apparatus we have measured bremsstrahlungspectra at various energies. We reproduce the theoretical spectrum within 4% (see Fig 4). This accuracy gives us full confidence in the results of the acceptance calculation. This was done using the Monte Carlo method, taking into account the following effects: energy distribution of incoming photons (including corrections for collimation), geometry, opening angle and multiple scattering of the electrons produced, absorption of photons and electrons and the inefficiency of the proportional wire chambers.

RATES

The main restriction on rates is given by the maximum tolerable rate for an individual wire. The highest rates were measured in the plane with wires perpendicular to the magnetic field of the analysing magnet at the height of the primary beam. However, due to the sharp collimation necessary for the Delbrück experiment we were mainly limited by the available synchrotron intensity. In a few cases only we had to lower this intensity in order not to exceed an instantaneous rate of 15 kHz per wire which gives about 1% deadtime per wire. Under these worst-case conditions the twofold instantaneous coincidence rates for each spectrometer arm were of the order of 32 kHz with negligible differences between both arms except at 7 GeV where we found differences up to 30%, probably due to beam halo. Maximum single rates were of the order of 1.2 MHz instantaneously. The accidental rates amounted to less than 5%. The trigger rate, which is the coincidence between both spectrometer legs, was $\leq$ 30 Hz.

CONCLUSIONS

The energy resolution of the pair spectrometer was $\pm$ 1% and the accepted momentum band for chosen magnet current was 25% of E_{max}. The reconstruction accuracy of the conversion point was $\pm$ 3 mm resulting in an angular resolution of 0.15 mrad. The set-up was used during a data taking period of more than three months. During that time it worked reliably without any major faults. It proved to be a powerful tool for the detection and measurement of small angle photon scattering in the GeV region in the immediate vincinity of a high intensity photon beam.

FIGURE CAPTIONS

Fig 1. Lay-out of the photon scattering experiment showing the beam elements and the details of the pair spectrometer. MR, MC, QA and MA are standard DESY magnets. The following abreviations are used: Sy T = synchrotron target, K_i = collimator, S T = scattering target, C T = converter target, Qu = quantameter, Sc = scintillation counter, MWPC = multiwire proportional chamber.

Fig 2. Logic diagram of the data collection system.

Fig 3. The converter ring as mapped by reconstructed events.

Fig 4. Measured Bremsstrahlung spectrum compared with the calculated spectrum.

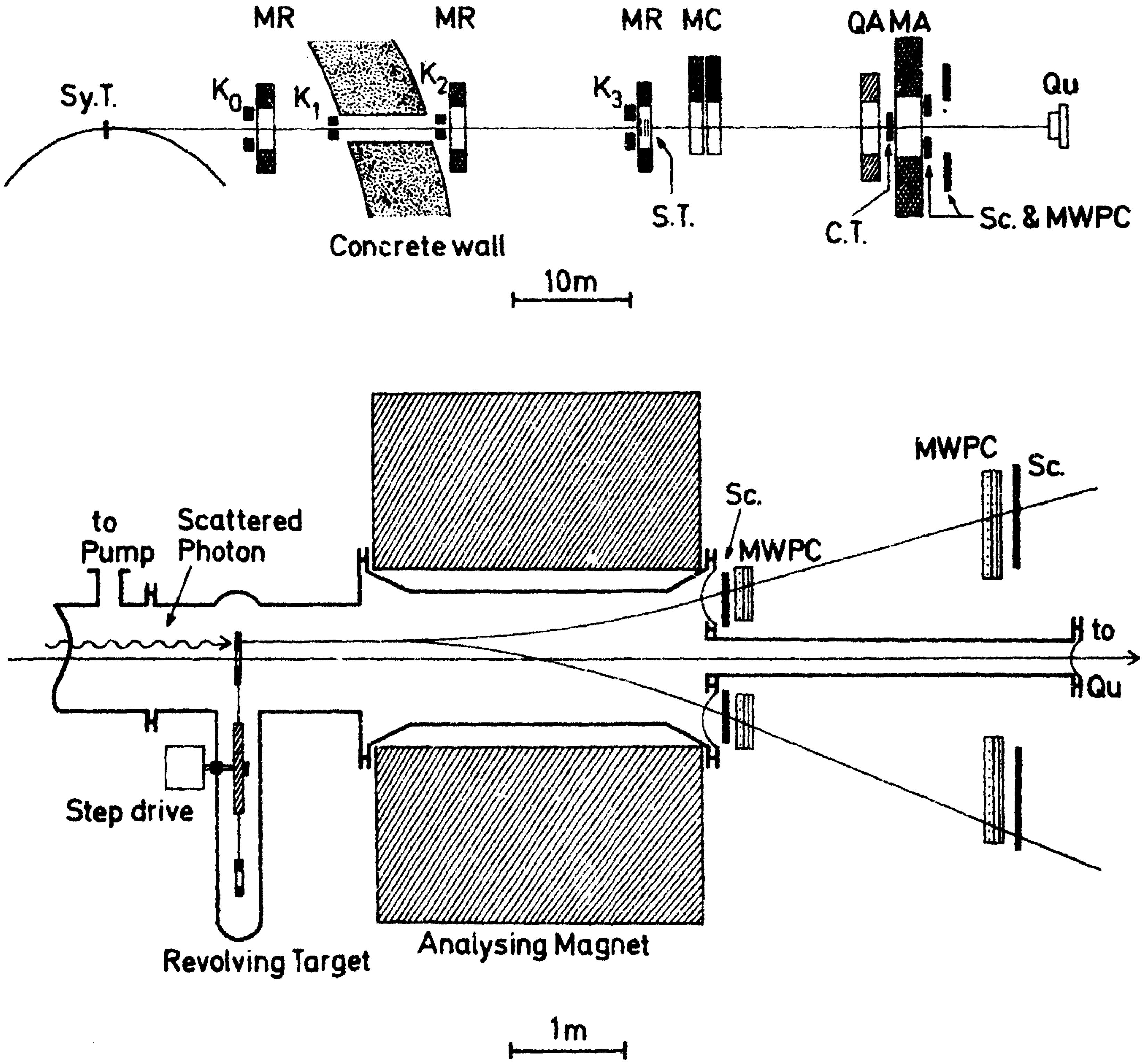
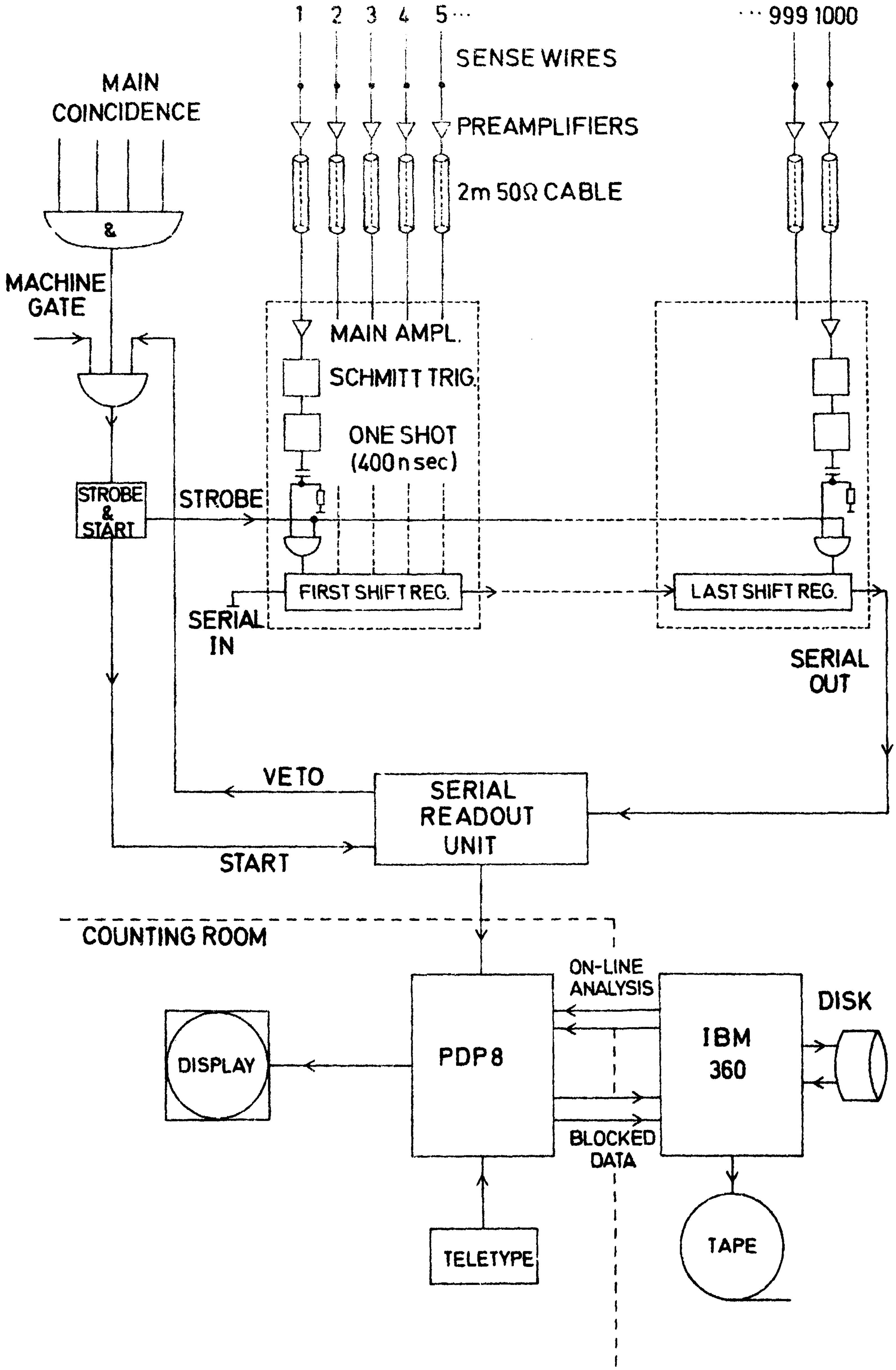

MR
MR
MR
MC
QA
MA
Sy.T.
K_0
K_1
K_2
K_3
Qu
S.T.
C.T.
Sc. & MWPC
Concrete wall
10m
MWPC
Sc.
Sc.
to
Pump
Scattered
Photon
MWPC
to
Qu
Step drive
Revolving Target
Analysing Magnet
1m

Fig 1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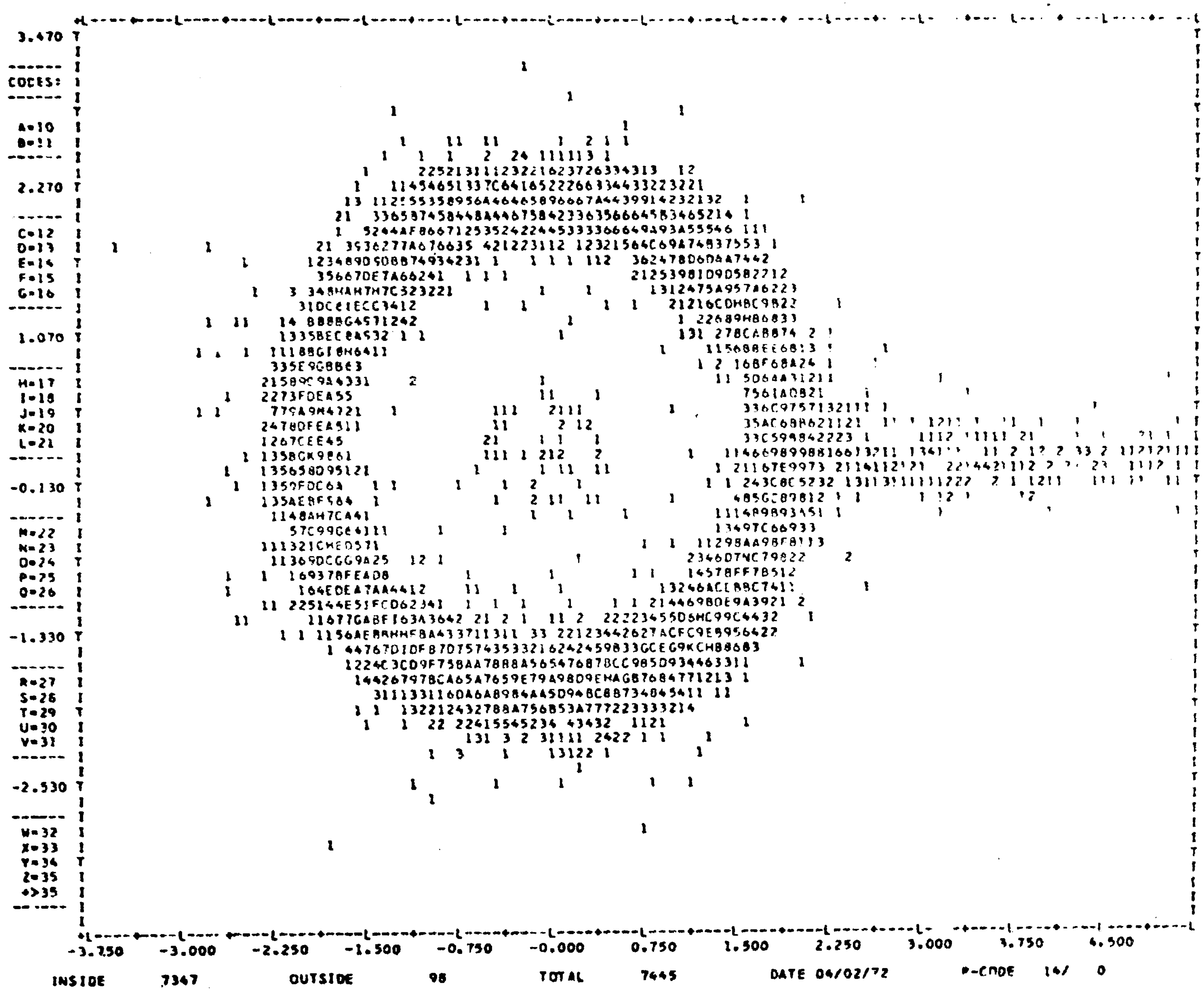
··· 999 1000
SENSE WIRES
PREAMPLIFIERS
2m 50Ω CABLE
MAIN
COINCIDENCE
&
MACHINE
GATE
MAIN AMPL.
SCHMITT TRIG.
ONE SHOT
(400 n sec)
STROBE
&
START
STROBE
FIRST SHIFT REG.
LAST SHIFT REG.
SERIAL
IN
SERIAL
OUT
VETO
SERIAL
READOUT
UNIT
START
COUNTING ROOM
ON-LINE
ANALYSIS
DISK
DISPLAY
PDP 8
IBM
360
BLOCKED
DATA
TELETYPE
TAPE

Fig 2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C=12
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F=15
G=16
H=17
I=18
J=19
K=20
L=21
M=22
N=23
O=24
P=25
Q=26
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S=28
T=29
U=30
V=31
W=32
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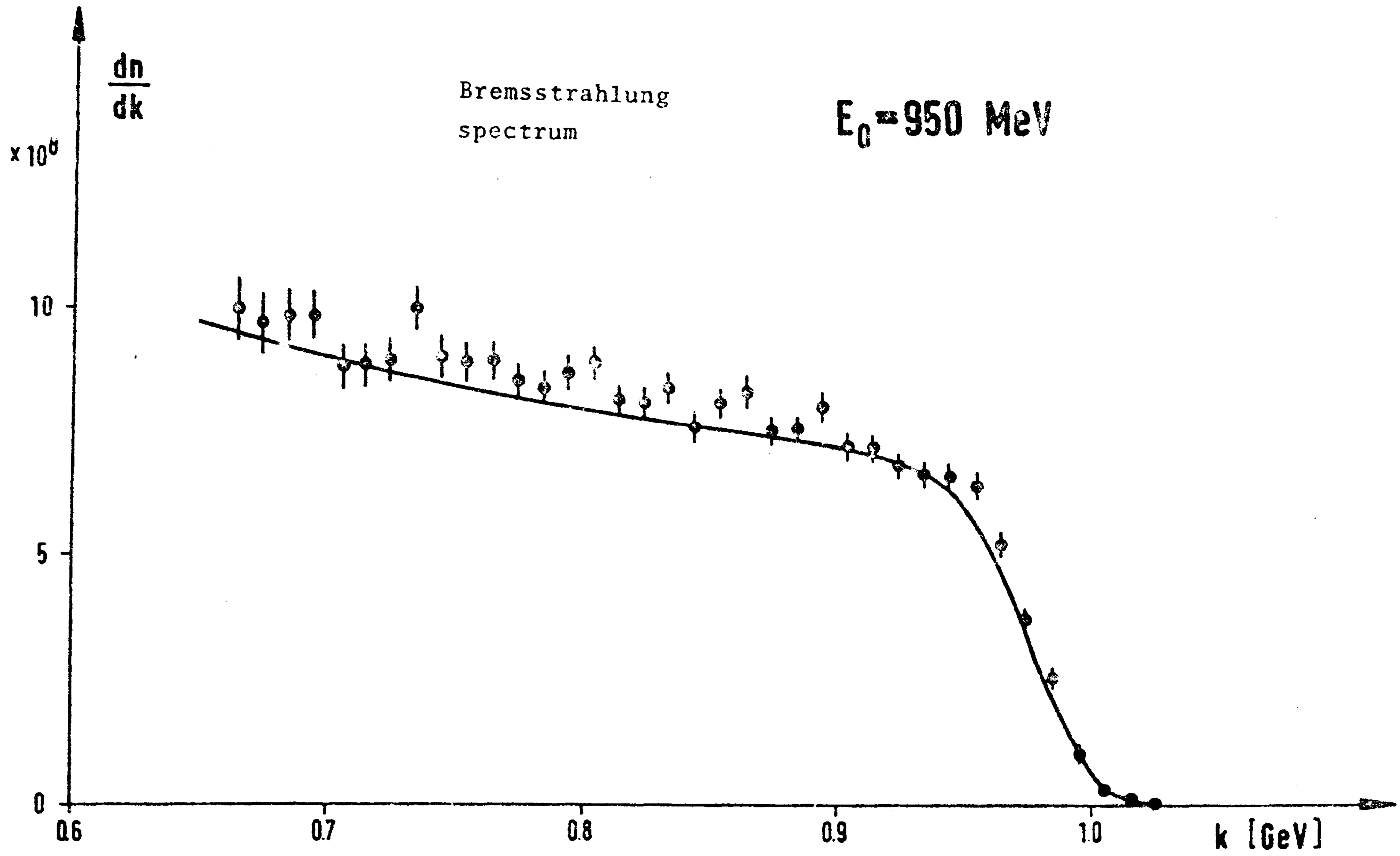
Fig 3



dn/dk
x 10⁶
Bremsstrahlung spectrum
E₀=950 MeV
10
5
0
0.6
0.7
0.8
0.9
1.0
k [GeV]

Fig 4