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## Abstract

A method is described for compensating the depolarizing effects caused by vertical orbit distortions. The technique has been successfully applied during measurements of beam polarization at PETRA and reproducible polarizations of 70 to 80 % have been obtained both in single beam and colliding beam operation.

## INTRODUCTION

During the last few years it has been observed /1/ that the electron beam in PETRA can become polarized by the Sokolov-Ternov effect: the spins of the circulating electrons are gradually aligned antiparallel to the guiding field as a consequence of the emission of synchrotron radiation photons. The observed degree of polarization is smaller than the theoretically predicted maximum degree of about 92 % /2/. Strong depolarizing effects disturb the polarization and make it impossible to reproduce the degree of polarization from one filling of the machine to the next /2/. The reasons for these fluctuations have been investigated by computer simulation from which it was found that the observed depolarization is possibly caused by a vertical closed orbit distortion of the beam. The computer simulations also confirmed the previously existing idea that it is not the vertical orbit distortion as a whole which disturbs the polarization but only a certain small component of the whole closed orbit. By compensating this small component it should therefore be possible to minimize the depolarizing effects. This possibility was successfully tested in January 1982. After compensating these dangerous orbit components the sensitivity of the degree of polarization to betatron tunes and to the synchrotron tune was investigated and the optimum working point was chosen. It was found that in the vicinity of this working point the degree of polarization is almost reproducible. After optimizing the degree of polarization the machine was filled with both electrons and positrons and the influence of the beam-beam effect on the degree of polarization was studied. It was found that with luminosities of about $3 \cdot 10^{30} cm^{-2} sec^{-1}$, polarizations of 70 to 80 % can be obtained. All measurements were performed with a so-called MI15-optics ($\beta_z^* = 15$ cm, $Q_x = 25, \ldots, Q_z = 23, \ldots$).

## The Method of Measuring the degree of polarization in PETRA

The principle underlying this method is described in detail in several previously papers /1, 3/. Expressed in simple terms, circularly polarized laser photons are scattered by the electron beam. The scattering angle and the energy of the photons are related to each other. For the measurement of the electron beam polarization the only photons of importance are those which are scattered at an angle of about $1/\gamma$ to the direction of the incoming electron and these photons can be separated from the other photons by energy selection. The vertical distribution of these photons depends on the degree of polarization of the electron beam and on the sign of the helicity of the laser photons. The number of photons scattered into one vertical interval is first measured with one helicity for the laser beam and then the helicity is changed and the measurement repeated. The magnitude A is defined in the following manner

$$A = \frac{n_+ - n_-}{(n_+ + n_-) \quad 0.5}$$

$n_+$: number of $1/\gamma$ photons entering the detector within a certain vertical interval. The helicity of the laser beam is positive.

$n_-$: same definition as for $n_+$ with one exception: the helicity of the laser beam is negative.

A is measured as a function of the vertical coordinate.

Fig. 1 shows the lay-out of the detector in PETRA consisting of a shower counter and a vertically movable slit (height of slit = 2 mm). The slit selects the photons falling into a certain vertical interval and the shower counter selects the photons with the correct energy. The slit is controlled by a computer which also collects the data coming from the shower counter and calculates the asymmetry. Thus the whole system is almost completely automatized.

The laser and the optical system are described in the above mentioned papers.

Fig. 2 shows the result of a measurement of the asymmetry versus vertical slit position when the electron beam is polarized. The saturation values of A give information regarding the degree of polarization. The scaling factor relating the asymmetry to the degree of polarization is computed with a simulation program. The absolute degree of polarization can also be obtained by measuring the build-up time of the polarization as a function of time at a beam energy of 16.52 GeV as shown in Fig. 3.

Taking into account depolarizing mechanisms the polarization builds up according to /4/:

$$P(t) = \frac{P_o}{1 + \frac{\tau_p}{\tau_D}} \left(1 - \exp\left(-t \left(\frac{1}{\tau_p} + \frac{1}{\tau_D}\right)\right)\right)$$

$P_o$ ... 92 %

$\tau_p$ ... rise-time of polarization due to the emission of synchrotron radiation

$\tau_D$ ... time constant of the assumed depolarizing mechanism

The asymptotic degree of polarization is given by

$$P(t = \infty) = P_o \frac{\tau_{ex}}{\tau_p}$$

$\tau_{ex}$ ... measured rise-time of polarization

$$\tau_{ex} = \frac{\tau_p \cdot \tau_D}{\tau_p + \tau_D}$$

A least square fit of $\tau_{ex}$ in Fig. 3 gives

$$\tau_{ex} = 13.6 \pm 0.8 \ \text{min}$$

$\tau_p$ is calculated from the well known Sokolov-Ternov formula and in the case of PETRA /1/ is:

$$\tau_p \, [\text{sec}] = \frac{132 \cdot 10^9}{E^5 \, [\text{GeV}]}$$

Thus the asymptotic polarization was measured to be 70 ± 4 % in good agreement with that obtained by the asymmetry measurement.

Compensation of depolarizing effects caused by vertical orbit distortions

In a storage ring the most dangerous depolarizing resonances are those for which

$$a\gamma = n \qquad\qquad a\gamma = m \pm Q_{x,z,s}$$

$a = (g-2)/2$, n,m ... integers, $\gamma$ ... Lorentz factor
$Q_x$ is the horizontal betatron-tune, $Q_z$ is the vertical tune and $Q_s$ the synchrotron tune.
Part of these resonances are excited by vertical orbital displacements as shown schematically in fig. 4. In this case, the slope of the vertical trajectory is changed in the quadrupoles and therefore the spin precesses both in the bends and the quadrupoles: around the vertical axis z in the bends and around the radial axis x in the quadrupoles. The phase advance of both precessions is shown schematically in fig. 5.

Depolarization occurs when the spin deviates from the vertical direction. This is most pronounced when the precession frequency around the radial axis due to the quadrupoles coincides with the precession frequency around the vertical axis due to the bending magnets. In order to find the depolarization strength from fig. 5 the curve must be Fourier-analysed. The amplitudes of the harmonics next to the spin tune strongly influence the degree of polarization. Minimizing these harmonics leads to minimization of the depolarization effects.

Unfortunately in a real machine it is not possible to measure the orbits with the necessary accuracy. At a beam energy of 16.588 GeV (spin tune a = 37.644) the dangerous 37 th and 38 th harmonics in the definition of fig. 5 must be compensated. This can be done by taking into account that each vertical correction coil changes the vertical orbit and therefore the amplitudes of the various harmonics in the diagram. The existing dangerous harmonics of the unknown orbit are compensated in the following manner: a set of 8 correction coils is chosen which only influences the sine-like part (called A-component) of one of the dangerous harmonics. Likewise another set of 8 correction coils which only influences the cosine-like part (called B-component) of one of the dangerous harmonics is chosen. Then the polarization is measured as a function of the A and B excitations. Fig. 6 + 7 show the result of such a measurement for the A(38) and B(38) components and show that the degree of polarization can indeed be improved by adjustement of these components. With these corrections the degree of polarization was measured as a function of energy in the range $a\gamma = 37$ to $a\gamma = 38$ (Fig. 8). The measurement shows deep valleys of zero polarization in the vicinity of the two integer resonances. The width of these valleys is probably determined by the incompletly compensated 37 th and 38 th harmonics and the following resonances

$$a\gamma = 12 + Q_x$$
$$a\gamma = 14 + Q_z$$
$$a\gamma = 61 - Q_z$$
$$a\gamma = 63 - Q_x$$
$$a\gamma = 38 - Q_s$$
$$a\gamma = 37 + Q_s$$

($Q_s$ was 0.069, the horizontal tune $Q_x$ was 25.17 and the vertical tune $Q_z$ was 23.27)

Adjustment of the Q-values

After optimizing the orbit at an energy of 16.588 GeV the new working point was chosen as $a\gamma = 37.5$ (16.52 GeV).

Using the orbit correction scheme as mentioned above the Fourier-components A(37) and B(37) were roughly minimized at this energy.

The dependance of the polarization on the Q-values was investigated near the working point:

$Q_z = 23.27$

$Q_x = 25.17$

No essential change of the polarization degree was observed by changing the tunes by ∿ 0.02. After this optimization the degree of polarization of a single beam was about 80 %. This could be reproduced with subsequent fillings of PETRA.

## Polarization with Beam-Beam Interaction

Polarization measurements were also made under colliding beam conditions. PETRA was filled with two electron and two positron bunches. The current was about 3 mA per bunch and the beam energy was 16.516 GeV ($a\gamma$ = 37.5). The PETRA polarimeter only measures the polarization of the electron beam and this was monitored as a function of time. The final degree of polarization was the same as for the single beam, i.e. about 80 %. The luminosity measured by the MARK J detector was $2.7 \times 10^{30} cm^{-2} s^{-1}$. There was also no essential change of the polarization when the betatron tunes were changed by ∿ 0.02 /5/.

In order to demonstrate that the beam-beam effect results in depolarization the following experiments were performed: a relatively strong positron beam was collided with a relatively weak electron beam ($e^+$: 4 mA/bunch and $e^-$: 1 and 2 mA per bunch, respectively). The weak electron beam blew up and the degree of polarization became smaller. In another filling ($e^+$: 3.4 mA per bunch, $e^-$: 0.9 mA per bunch) the vertical betatron frequency was changed between 37 and 39 kHz (by ∿ 0.015) but no significant influence of the Q-value on the degree of polarization was found.

## Acknowledgements

The authors wish to thank Prof. Dr. G.-A. Voss for his support and for many stimulating discussions.

## References

/1/ H.D. Bremer et al.: Proceedings High Energy Physics with Polarized Beams and Targets, p.52 and 469, Lausanne 1080, Birkhäuser Verlag Basel
and DESY Internal Report M-80/20

/2/ H.D. Bremer et al.: Zusammenfassung der Ergebnisse der Polarisationsmeßschichten, Mai 1981. Internal Note DESY M/VM-81/03

/3/ R. Schmidt: Aufbau und Test des Polarisationsmonitors in PETRA, DESY Internal Report M-80/04

/4/ For a Recent Review see for example:
A. Chao "Polarization of a stored electron beam" SLAC-PUB-2781(1981)

/5/ D.P. Barber et al, Physics Reports <u>63</u>, 7 (1980), 337

## Figure Captions

Fig. 1: The detector system consisting of a movable slit and a shower counter. The computer almost completely automizes the whole system.

Fig. 2: Measurement of A vs vertical slit position when the electron beam is polarized

Fig. 3: Build up of the polarization. Beam energy 16.52 GeV

Fig. 4: Schematic drawing of a part of a storage ring lattice. Assuming vertical orbit displacements the spin precesses in the bending magnets around the z-axis and in the quadrupoles around the x-axis.

Fig. 5: Movements of the spin in a model storage ring in the case of a vertical closed orbit distortion. One revolution of the beam is finished after the spin precessed $2\pi a\gamma$ radians around the z-axis.

Fig. 6: Measured asymmetry vs amplitude of the A(38) component generated by eight correction coils.

Fig. 7: Measured asymmetry vs amplitude of the B(38) component

Fig. 8: The polarization between the two resonances $a\gamma = 37$ and $a\gamma = 38$.

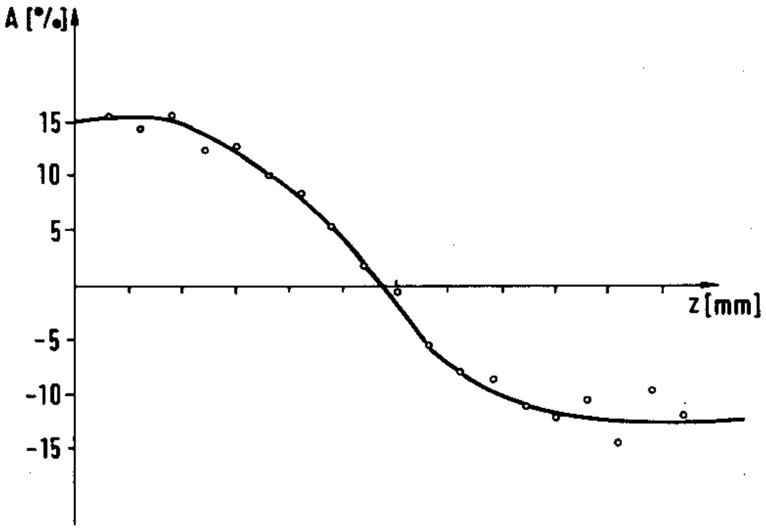

A [%]
15
10
5
-5
-10
-15
z [mm]

Fig. 2

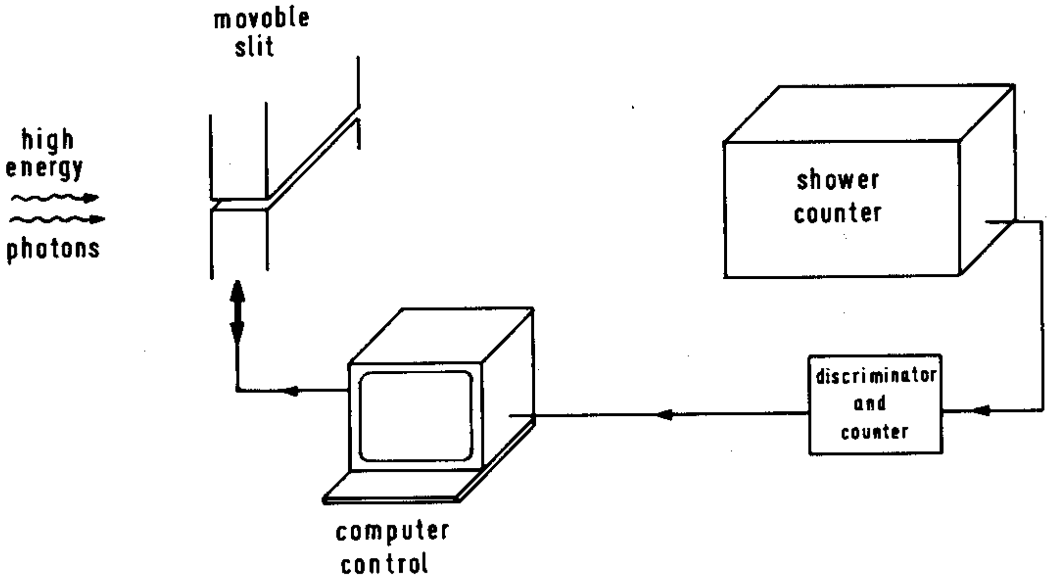
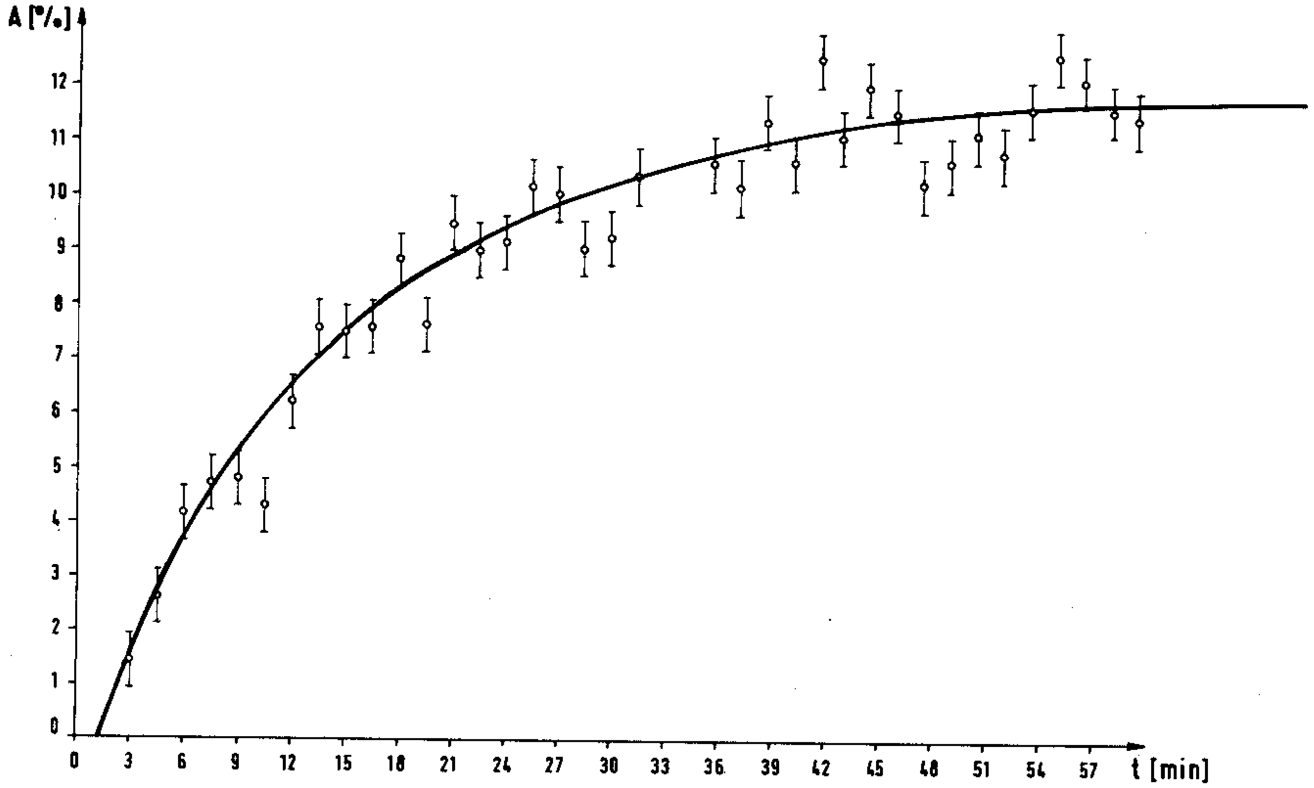
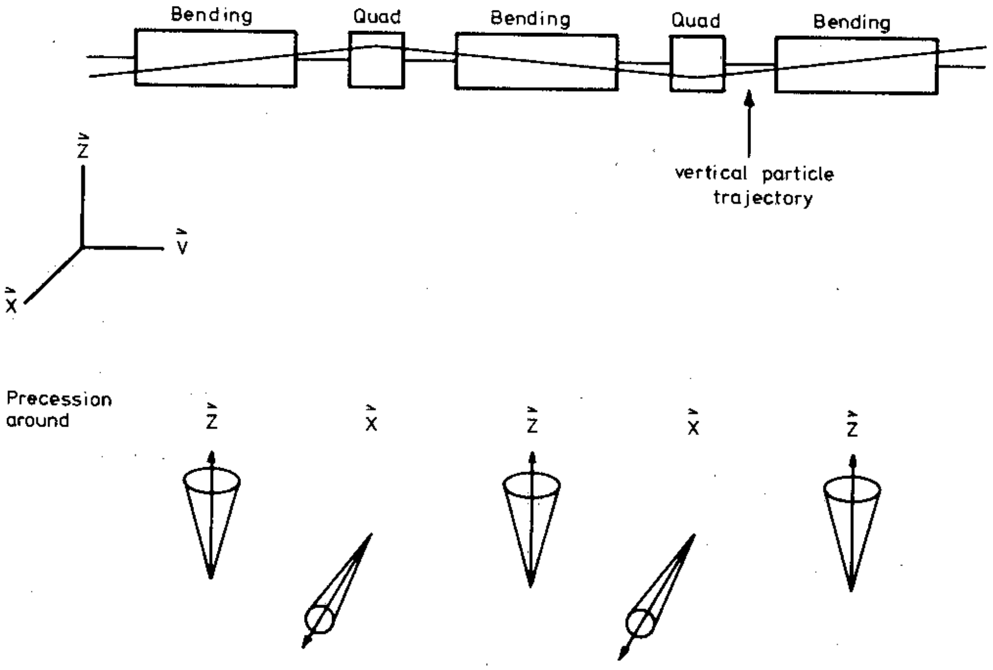

movable slit
high energy photons
shower counter
discriminator and counter
computer control

Fig. 1



A [%]
0
1
2
3
4
5
6
7
8
9
10
11
12
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
48
51
54
57
t [min]

Fig. 3



Bending
Quad
Bending
Quad
Bending
vertical particle trajectory
$\hat{z}$
$\hat{v}$
$\hat{x}$
Precession around
$\hat{z}$
$\hat{x}$
$\hat{z}$
$\hat{x}$
$\hat{z}$

Fig. 4

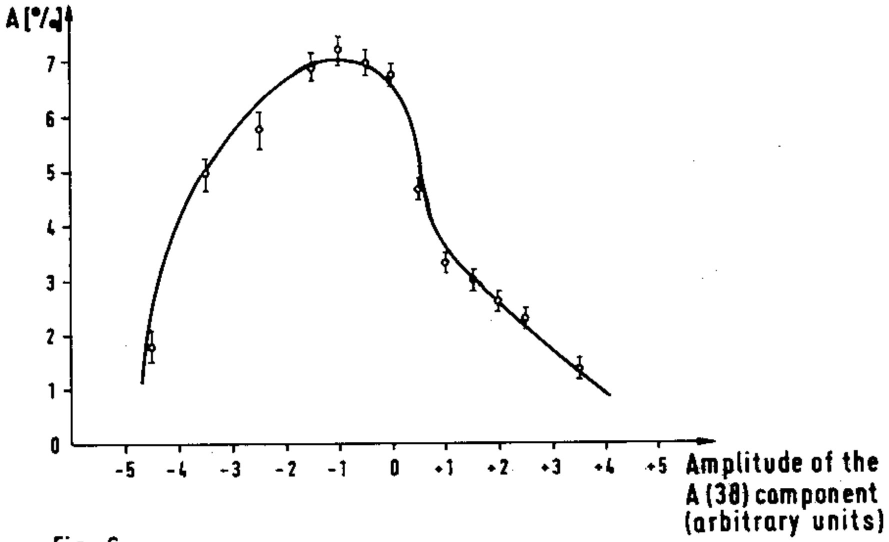

A [°/o]
7
6
5
4
3
2
1
0
-5
-4
-3
-2
-1
0
+1
+2
+3
+4
+5
Amplitude of the A (38) component (arbitrary units)

Fig. 6

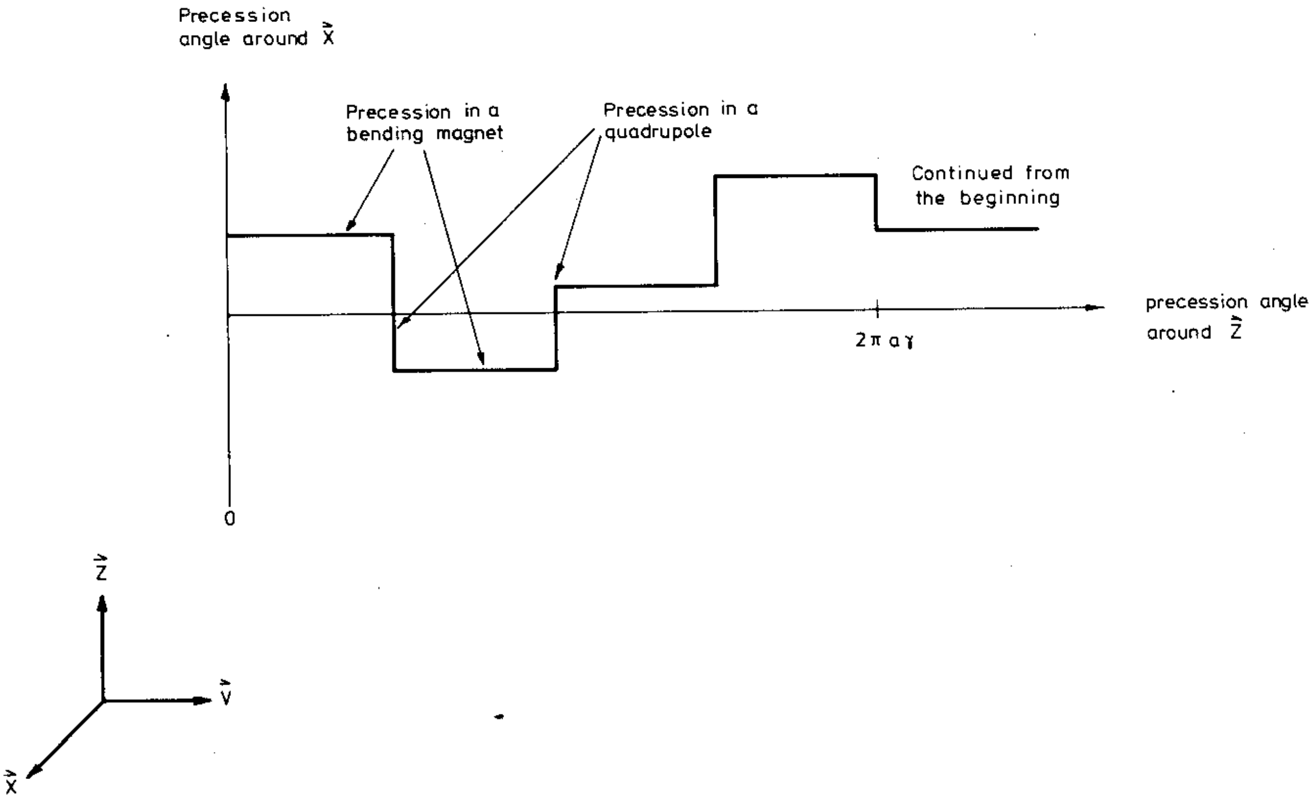

Precession angle around $\vec{X}$
Precession in a bending magnet
Precession in a quadrupole
Continued from the beginning
precession angle around $\vec{Z}$
$2\pi a\gamma$
0
$\vec{Z}$
$\vec{V}$
$\vec{X}$

Fig. 5

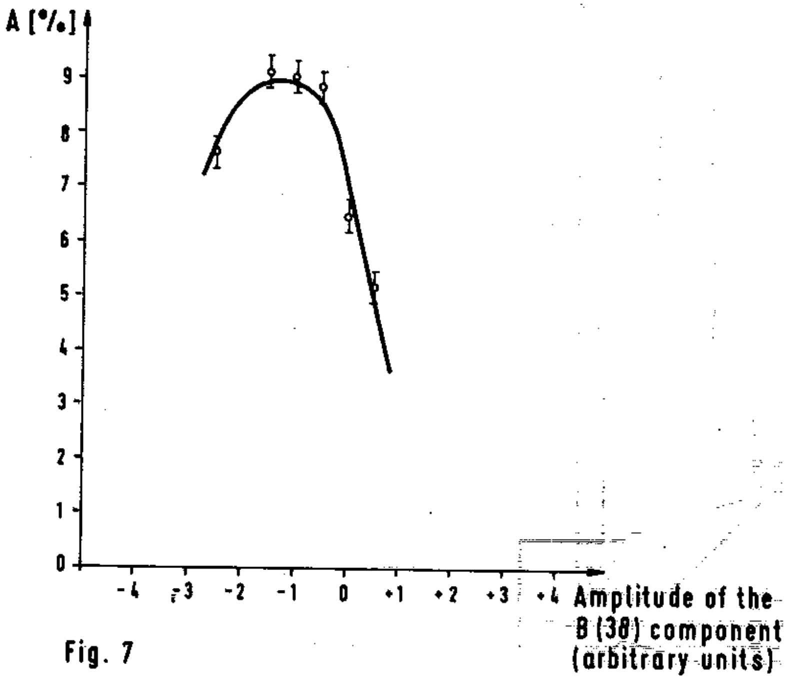

A [%]
9
8
7
6
5
4
3
2
1
0
-4
-3
-2
-1
0
+1
+2
+3
+4
Amplitude of the B (38) component (arbitrary units)

Fig. 7

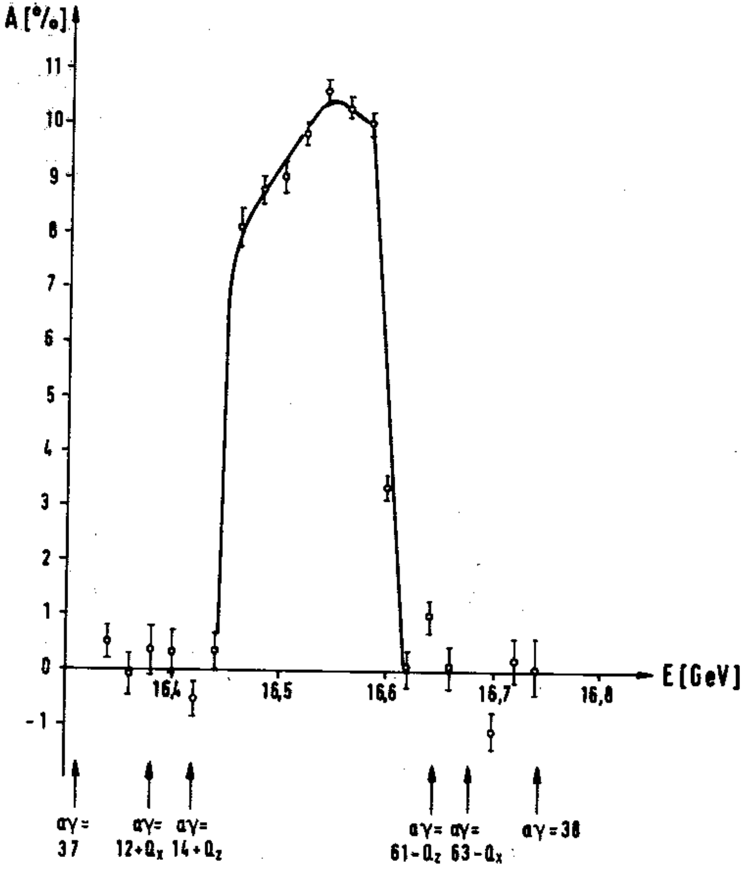

A [%]
11
10
9
8
7
6
5
4
3
2
1
0
-1
16,4
16,5
16,6
16,7
16,8
E [GeV]
aγ= 37
aγ= 12+Q_x
aγ= 14+Q_z
aγ= 61-Q_z
aγ= 63-Q_x
aγ=38

Fig. 8