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LNF-76/21(P)
18 Marzo 1976

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(Presented at the 'Discussion Meeting on Petra Experiments - Frascati, March 1-5, 1976').

This Meeting of March is one of the last occasions to take decisions on the basic characteristics of the machine. One of these is the straight section's length l and the space Δs available around them. Our contribute here is not a proposal of an experiment, which would not be in the spirit of our meeting, but it is rather intended to give some quantitative indication on the minimum values of l and Δs.

To get these indications, we take into consideration a few possible experimental dispositions, which are based on apparata of general use, and we make an estimate of their geometrical dimensions when they are used to analyse multihadronic events, with separation between different reaction channels. It is important to remind that at 30-50 GeV c.m. total energy the separation of different channels may be a real necessity to get sound theoretical interpretations: for instance (§ 2,3) it is not garanteed that the pure one photon annihilation channel is by far relevant respect to the others.

More specifically, careful analysis shall be done to distinguish multiparticle production due to the following different contributions:

a) one photon annihilation:

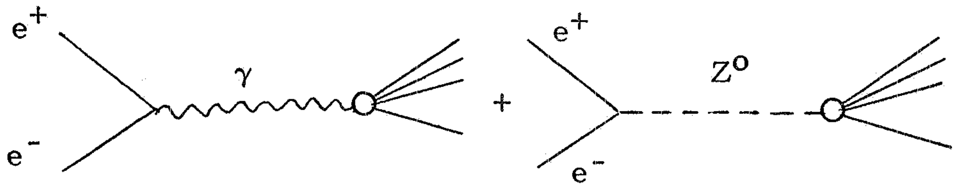
$$e^+e^- \rightarrow \gamma \rightarrow \text{hadrons} \; ; \qquad (1)$$

b) two photon channel:

$$e^+ + e^- \rightarrow e^+ + e^- + X \, . \qquad (2)$$

This channel has been already examined in many occasions, with a general conclusion that it is more and more difficult to separate it from channel (1) with increasing energies.

c) interference effects between e.m. and weak fields, like:



Such effects would appear in multiparticle events as a lower degree of geometrical and dynamical symmetry of produced particles, with respect to the case (1) (see ref. (1)).

d) possible production of superheavy lepton pairs:

$$e^+e^- \rightarrow L^+ + L^- \rightarrow \text{hadrons} + \text{leptons}\, .$$

The decays of these hypothetical leptons may simulate reaction (1), with a comparable cross section (perhaps 20% of reaction (1)).

Reactions (1) and (2), as well known, may be separated by tagging the outgoing electrons in reaction (2), but this is possible only in a percentage of reactions (2) (§ 2, 3); the necessity to separate all the quoted contributions, invites to have a good calorimetry and detailed geometrical analysis of the events; weak interactions effects can be studied in the best way using transverse and longitudinal polarization of electron beams. It is on this basis (calorimetry, tagging, polarization) that we shall try to fix some limits to 1, Δs.

The present contribute is therefore divided into the following paragraphs:

1. - The apparata we are taking into consideration, and their exigencies to be good calorimeters;
2. - The contribute of two-photon reactions, and the separation between reactions (1) and (2);
3. - The tagging of the electrons in reaction (2), and in general the measurements at small angles;
4. - The polarization of the beams;
5. - A synthesis of the requirements for 1, Δs from the paragraphs above, and their interferences.

1. - THE GENERAL EXPERIMENTAL APPARATA WE ARE TAKING INTO CONSIDERATION. -

It is not excluded of course that some simple apparata without magnetic field and with rather poor solid angle and energy measurement may be useful during the first campaign at PETRA; and it may be that some of us are interested in this first experimental stage. But in the present analysis we assume that the decisions on 1, Δs shall be rather irreversible for a number of years, when the more complete apparata shall be really necessary. Therefore, to discuss here 1 and Δs, we consider apparata with a magnetic field with large solid angle acceptance, particularly designed for the identification of charged and neutral particles.

We have taken in consideration three basic apparata prepared to study hadronic events. Two of them, apart few changes, have already been considered in PEP 1975[(2)] and in SUPERADONE[(3)]. The third one is particularly related to study possible interference effects between e.m. and weak interactions.

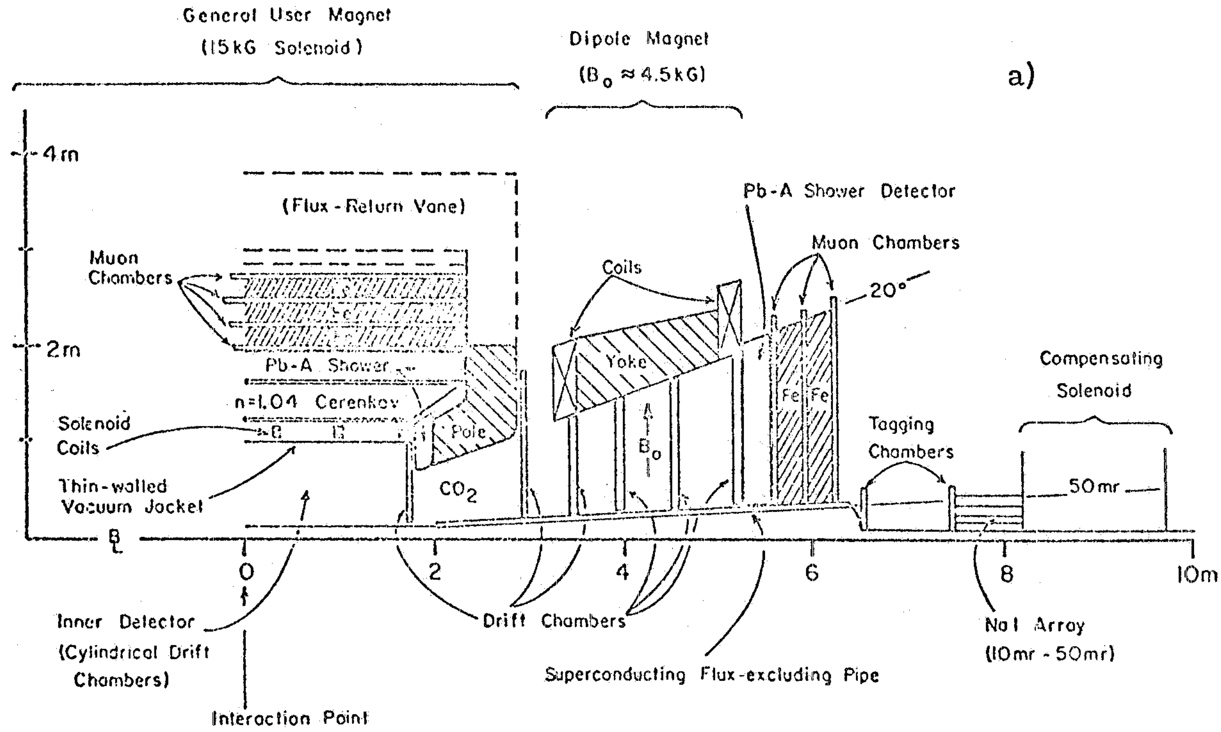
In Fig. 1 is GUM (General Use Magnet), proposed at PEP in 1975: it is based on a superconducting solenoid, whose field is along the beam's direction. The design reported by us was rather dedicated to the 2γ experiments, eq. (2), but with some changes it can be considered for 1γ experiments, as far as encumbrance of the solenoid is considered. We consider it in two versions. One is just the PEP 1975 proposal (Fig. 1a; see PEP 1975, page 168). The other is GUM at the center, but with two toroidal fields for the small angles (Fig. 1b). The toroidal structure seems to us very efficient for small angles respect to the dipole magnet of Fig. 1a. This solution can save some space in the straight section.

In both cases the tagging for the final electrons of reaction (2) is indicated: in Fig. 1a the length of the tagging system is the same than in PEP proposal; in Fig. 1b this length is reduced: it is our opinion (see § 3) that this contraction does not really reduce the physical informations on reactions (1) and (2).

A solenoid field needs compensating solenoids: in case of GUM (Fig. 1) this extra length is rather heavy (3 meters). Unfortunately our analysis until now seems to exclude that compensation may be made outside the free space of the straight sections.

In Fig. 2 it is shown a general apparatus with toroidal magnets, as considered at SUPERADONE[(3)]. Considering the higher energies at PETRA it has been scaled by a factor ~ 1.5 respect the SUPERADONE proposal. Tagging length is reduced as in Fig. 1b.

In Fig. 3 we have given a rather different solution. We have assumed that the transverse horizontal field used to polarize the eleca)



b)

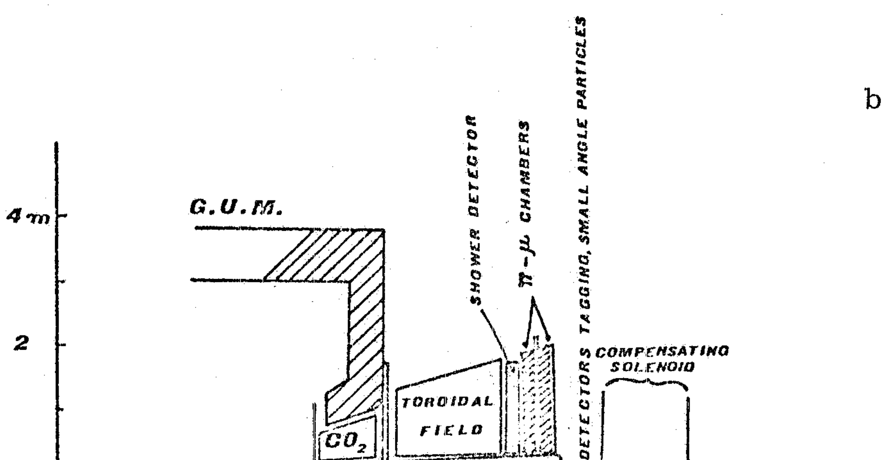


FIG. 1 - a) A possible detector system particularly designed for two-photon processes, taken from ref. (2)(Fig. 15). The apparatus is symmetrically placed on both sides of the interaction point and around the beam line. b) A different version of the apparatus shown in a). GUM magnet is always at the center, but with a toroidal field (for the small angles) in the place of the dipole magnet. Moreover the space for tagging system, l_T, is reduced according to some considerations reported in § 3 (see text).

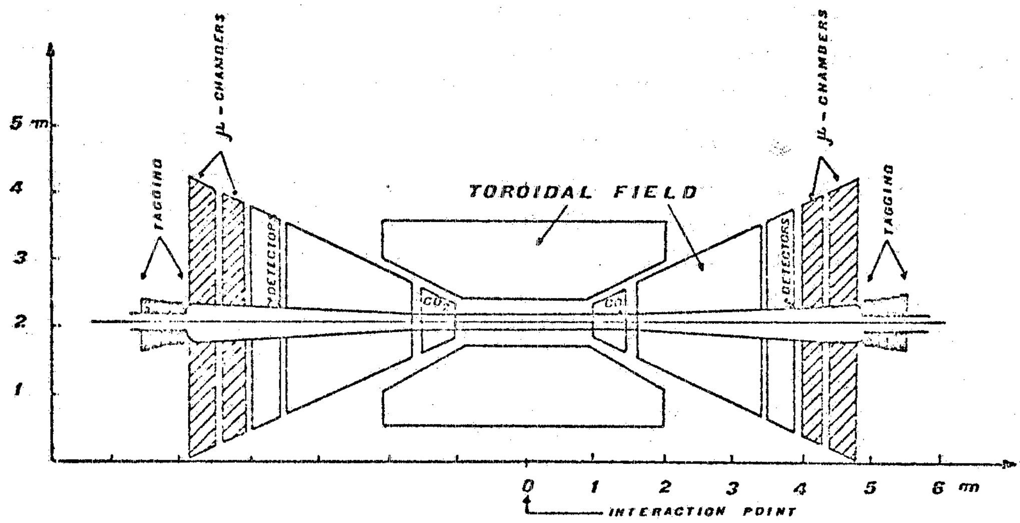
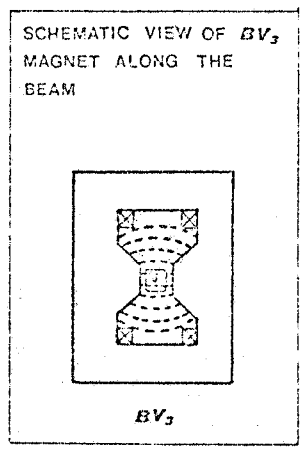
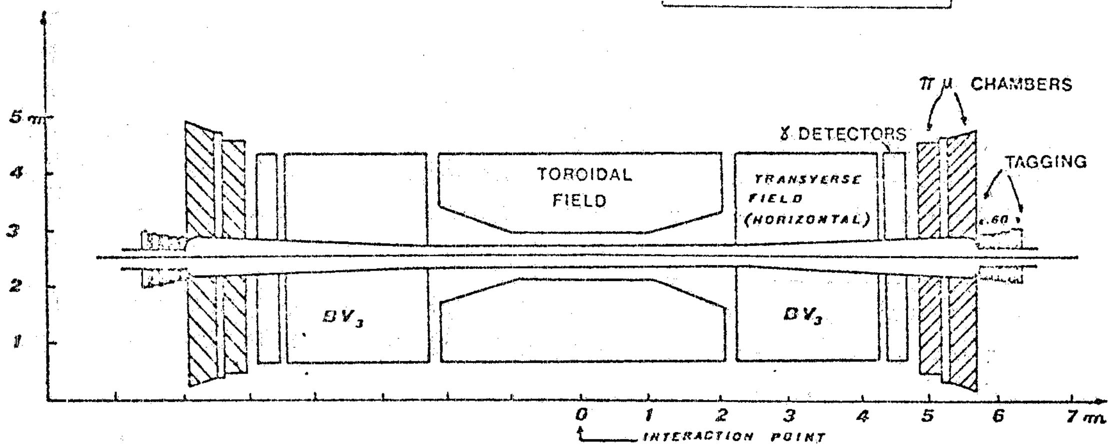


FIG. 2 - A further different version of Fig. 1a. A toroidal field is designed for both small and large angles. Both solutions, Figg. 1a, 1b, requires a compensating magnet. The present solution, on the contrary, doesn't need such a magnet for this reason it could be parti cularly suitable in the case of PETRA straight section lenght lower than 15 meters.

FIG. 3 - A modified version of solu tion shown in Fig. 2. The toroidal field for small angles detection has been here replaced by a transverse field magnet, BV_3. This magnet is a part of a magnetic device designed to obtain a longitudinal polarisation of the beams (see text, § 4). In this figure a schematic view along the beam of the BV_3 magnet is also repor ted.





trons in a longitudinal way is also emploied to analyze the particles emitted at small angles. Of course, the magnetic dipole BV_3 is rather long, for one must provide about 20.000 gauss x meter (see § 4).

Let's compare solutions 1a, 1b, 2, 3. Solution 1a requires $l = 20$ meters, as decided at PEP for the total free length of the straight sections. Solution 1b gives $l = 16$ m. Solution 2 is among the shortest, due to absence of compensating solenoids : $l = 11$ m (of course, the solenoid GUM could be compensated inside, with a small radius solenoid giving opposite field : but this, due to encumbrance, would give the same limitations in the observation of the produced hadrons than the toroidal magnet). Solution of Fig. 3 is at present the most uncertain : it requires $l \cong 14$ m.

In first approximation (§ 2, 3, 4, 5) one would say that $l = 20$ m is not strictly necessary : $l = 10$ m may be too short. But, at this point, we must remind that a comparison between the two types of central magnet (solenoid versus toroid) is not easy. In fact, a lot of discussions have been previously done on this argument, see f. i. ref. (2, 3).

We only remind that in terms of gauss x meters, i. e. the quantity $\int_{R_1}^{R_2} B\,dR$ calculated along the radius R, GUM has a value :

$$\int_{0.1}^{0.9} 1.5 \times 10^4 \, dR = 1.2 \times 10^4 \text{ Gauss x meters.}$$

A toroid with $R_1 = 0.2$ m and $R_2 = 1.4$ m (Fig. 2) should have a field $B(R_1) = 3 \times 10^4$ Gauss to have the same value of $\int B\,dR$. This is a very high field, with a lot of mechanical problems around the donut.

It seems to us, therefore, difficult for a toroid to compete with a solenoid, when high resolution $\Delta p/p^2$ is really needed. But which is the most convenient value of $\Delta p/p^2$? We can compare it with two absolute numbers : one is the natural energy resolution of PETRA at 20 GeV. This is $\sim$ 80 MeV (FWHM). The corresponding request to a calorimeter system would be $\Delta E/2E \sim 2.0‰$ and this is clearly too much. The other is the k-π mass difference. This is $\Delta E/2E \sim 300/30.000 \simeq$ $\simeq 1\%$. This number seems to be compatible with the value $\Delta p/p^2 =$ $= 0.5$ (% GeV^{-1}) which has been chosen for a magnet like GUM[(x)].

(x) - It is difficult to say more on this point without acuurate and exhaustive calculations. For discussions and details on this subject see ref. (2) and (3).

Our conclusion is therefore that the dimensions (size and power) of a magnet like GUM seems to be a reasonable choice.

In the following two paragraphs we report some basic reasons, which may impose good calorimetry and the necessity of tagging.

2. - SOME REMARKS ON THE CONTRIBUTE OF TWO-PHOTON REACTIONS. -

The possible contribution of two photon processes has been studied extensively in the SuperAdone study[4] and in the PEP 1975 Summer School[5]. In what follow, we shall try to add some more considerations in order to conclude if, to study one photon reactions, it is necessary to separate these from two photon processes (singularly or at least on a statistical basis, in each experiment).

It was already reported by Gatto and Preparata[1] that for a total energy around 20 GeV the one photon annihilation process :

$$e^+e^- \doteq \pi + X \quad , \qquad (1a)$$

dominates over the two photon processes :

$$e^+e^- = e^+e^- + \pi + X \qquad (2a)$$

for transverse pion momenta larger than $p_T^2 \sim 1\text{-}1.5\ \mathrm{GeV}^2$.

We shall see however that, in our opinion, at energies $\gtrsim 30$ GeV the separation between these reactions is not immediate and without problems. Starting from the analysis done by ref. (1) the situation is specified in some more detail in Fig. 4. In this figure we compare, for $2E = 30$ GeV, the differential cross section $(d^2\sigma/d\Omega dp)$ vs p (pion momentum, LAB) expected for processes (1a) and (2a), in corrispondence of some peculiar pion production angle, $\theta = 75^o$, 40^o, 15^o (Lab. system). One can see that, f.i., at $\theta = 40^o$ the contribute of pions with $1 < p < 1.5$ GeV is about the same for reactions (1a) and (2a). To have a fraction $\# \pi$ (2γ reactions)/$\#\pi$(1γ reactions) $\leq 10\%$, one must select pions with $p > 1.5$ GeV. This must be compared with the average expected energy of pions in processes (1a), which could be $\sim 2\text{-}2.5$ GeV. So, it is a rather severe cut.

The situation would be definitively severe at $\theta = 15^o$, where the larger part ($p_\pi < 3.5$ GeV) of the inclusive spectrum could be dominated by reaction (2).

Moreover, it is well known that the cut-off in pion momentum, which results to be necessary in order to reduce in the measured spectra the background due to process (2a)[x] increases with increasing the

(x) - See, for instance, the quoted analysis of Gatto and Preparata[1].

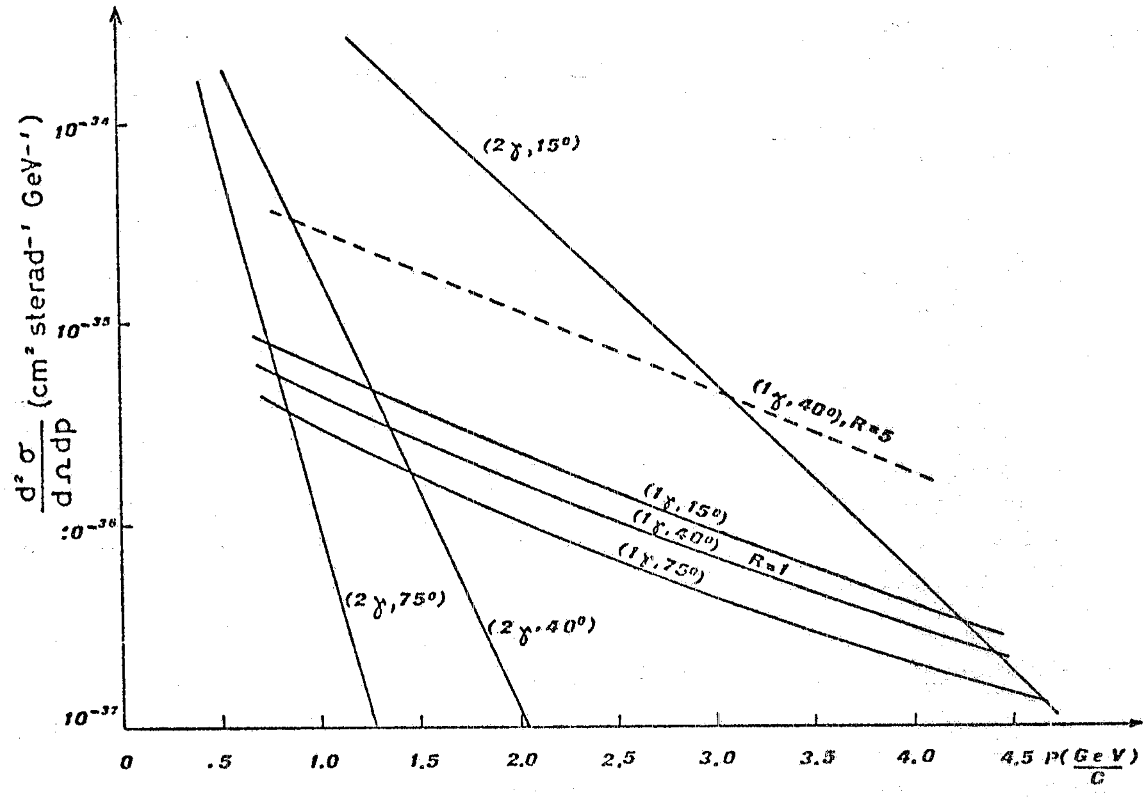


FIG. 4 - One pion inclusive cross section ($d^2\sigma/d\Omega dp$) vs p (pion's momentum) as calculated for one photon annihilation process (1), and two photon process (2) for 2E = 30 GeV and θ (L.S. pion production angle) = 75°, 40°, 15°. The one photon contribution has been calculated assuming $R = \sigma_L/\sigma_{\mu\mu} = 1$ and $\langle n_{ch}\rangle = 6$. (For convenience also the case R = 5 and $\langle n_{ch}\rangle = 6$, θ = 40°, has been reported, broken line). Moreover the scaling function used in ref. (1), eq. (1.34) has been modified in order to have a better agreement with pion inclusive spectra, recently measured (Dasp[6]).

total energy. So the separation between processes (1a) and (2a) comes to be more and more difficult with increasing energies, and one cannot hope to get a "blind" inclusive spectrum of reaction (1a) without subtracting the two photon contributions.

The following features can help in distinguishing between the two quoted processes : i) the angular distribution of hadrons due to two photon processes ; ii) the total energy of these events.

As for angular distribution, the one photon multihadronic events, at 2E = 30 GeV, are expected to appear as Jets or as large "stars" with many particles (or prongs). The expected angular distribution (of the type $a+b\cos^2\theta$) largerly includes large angles. Moreover the c.m. is fixed with respect to the laboratory system.

The two photon events, on the contrary, will exhibit a c.m. usually moving fast, so a very large fraction of events contain particles emitted at small angle in the Lab. system (f. i. $< 10^{o}$). This point is, for example, evident from Fig. 4, which shows that the contribution of particles (with $p > 0.5$ GeV/c) is definitely larger at small angles.

Concerning the total energy distribution of multihadrons produced by two photon interactions most of these events have a total energy (in their c. m. as well as in the L. S.) definitely lower than 2E. Let us look, for instance, to the case of a tagging system accepting electrons (and positrons) scattered by an angle $10 < \theta < 200$ mrad. Starting from the virtual photon energy spectrum (Fig. 4 in ref. (5)) one can estimate that at 2E = 30 GeV, about 15% of two-photon events(x) have, in the L. S., a total energy larger than 1/2(2E). These considerations indicate that good calorimetry (that is a good mesurement of the energy of the neutral and charged particles at all angles) and a good geometric analysis of each event are important to separate events (1a) and (2a).

Summarizing, the conclusions of this short analysis are :

a) A one particle inclusive spectrum would be very difficult to interpret, if we do not proceed in separating singularity events due to processes (1a) and (2a);

b) In order to separate these two channels one must use at least two of the following elements :

   1) tagging system to detect the surviving electrons (see next section: tagging cannot be used to anticoincide all events (2a) respect to (1a);

   2) a good picture of each event (charged and neutral particles);

   3) a good measurement of the total energy of each event (a good calorimeter).

In general we tend to agree with the statement (cfr. PEP 1975, p. 172) that every PETRA experiment should have a two photon tagging system. Some discussion on tagging system is reported in the next section.

(x) In carrying this calculation a lower energy cut off ~ 0.1 E has been supposed on the energy spectrum of the detected two photon events. Our estimate of 15% (see text) agrees with a similar estimate carried out in ref. (5) (f. i. see Fig. 8).

3. - TAGGING FOR TWO PHOTON PROCESSES. -

The simple tagging used at ADONE at 1.2-3 c.m. GeV would be impossible at PETRA. In fact a simple calculation shows that in average, with $L = 10^{32}\ cm^{-2}s^{-1}$, more than one bremsstrahlung single act happens at each (bunch + bunch) interaction, and the two accidental bremsstrahlung acts are so close in time (10^{-10} sec) that they simulate an $e^+ + e^- \rightarrow e^+ + e^- + \gamma + \gamma$ process (cf. SUPERADONE, PEP).

This already excludes a 100 % tagging, that is use of tagging to anticoincide all events 2) respect to events 1), 3). But it is still possible (and necessary) to study by tagging technique processes 2) - which are as well known very interesting by themselves - and to identify their nature in order to separate statistically, if not one by one, events 2) from events 1).

The way out is in fact to profit of the fact that the average angle θ of the outgoing electron in reactions 2) is much larger (6 mrad with $\sim \theta^{-1}$ decrease) than the corresponding angle θ_B in bremsstrahlung $e^+ + e^- \rightarrow e^+ + e^- + \gamma$ ($\sim 3 \times 10^{-2}$ mrad with typical θ^{-3} decrease).

Therefore it shall be possible not to consider electrons emitted at angles in the region of θ_B. In Fig. 5 we have evidenciated the situation in a quantitative way by reporting the angular distribution for bremsstrahlung, calculated according to ref. (13). In Table I we estimate in a few cases the efficiency in detecting the tagged electrons coming from angles definitely larger than θ_B.

TABLE I

Fractional geometrical acceptance for tagged electrons (positrons) at 15 GeV. Presumable PETRA parameters have been assumed. $E_\gamma \geq 0.2$ GeV has been requested for quasi-real photons.

Logic	Angular acceptance (mrad) / process	12-60	10-50	12-300	>10	1-10	1-60
SINGLE TAGGING	$e^+e^- \rightarrow e^+e^- + (\gamma\gamma) \rightarrow X$	24×10^{-2}	25×10^{-2}	32×10^{-2}	42×10^{-2}	45×10^{-2}	70×10^{-2}
(double ended)	$e^+e^- \rightarrow e^+e^-\gamma$	1.4×10^{-4}	1.9×10^{-4}	1.6×10^{-4}	1.9×10^{-4}	1.6×10^{-2}	1.6×10^{-2}
DOUBLE TAGGING	$e^+e^- \rightarrow e^+e^- + (\gamma\gamma) \rightarrow X$	1.7×10^{-2}	1.8×10^{-2}	4.1×10^{-2}	5.3×10^{-2}	5.4×10^{-2}	7×10^{-2}
	$e^+e^- \rightarrow e^+e^-\gamma$	1×10^{-9}	1.7×10^{-8}	1.3×10^{-9}	1.7×10^{-8}	1.2×10^{-4}	1.2×10^{-4}

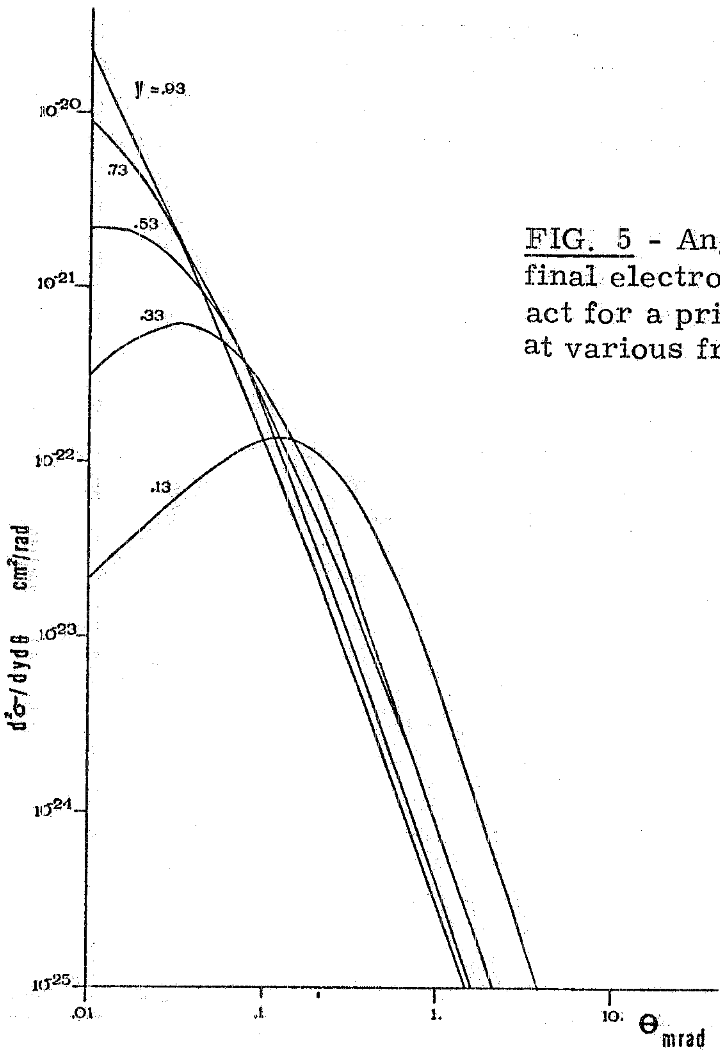


FIG. 5 - Angular distribution of the final electron in a bremsstrahlung act for a primary energy of 15 GeV, at various fractional momenta.

In order to detect two photon reactions 2), one can consider tagging in two places. The first place (A) is inside the free straight section itself. The second (B) is tagging out of the straight sections, by placing detectors in the free space available between magnetic elements.

Place (A) has been already indicated in Figg. 1-3. In Fig. 1a the GUM design is reported, and we can see that a rather large space l_T is left between tagging chambers, with the addition of a NaI array. This, adding the two sides of the straight sections, makes $l_T \simeq 3.50$ meters, to be added to get the total length l of the strainght sections. We think that l_T may be reduced by more than a factor 2 without any damage, still maintaining the possibility to distinguish (by shower counters and scintillators) electrons by other particles, with a measure ($\pm$ 15%) of their individual energy. This reduction is indicated in Figg. 1b, 2, 3. The value of l_T, at the very limit, could go to $\sim$ 0.4 m or so.

In case of place (A), the contribute of $e^+e^- \rightarrow e^+e^-\gamma$ bremsstrahlung electrons - which is the main source of background - has been calculated taking also account of beams' divergency: it results to be 0.025 occupancy (1 bremsstrahlung act every 40 bunch-bunch collisions).

As for tagging (B), inside the machine optics, we are making an analysis similar in principle to that for SUPERADONE (p. 216): some detailed results are shown in Fig. 6. Our present conclusions are:

- Occupancy of bremsstrahlung acts is definitely less than one at each element in the magnetic optics, when a cut $\theta > 1$ mrad is practiced. It seems possible to operate in a logic with simple tagging.
- Tagging in region (B) results to be definitely convenient, for (see

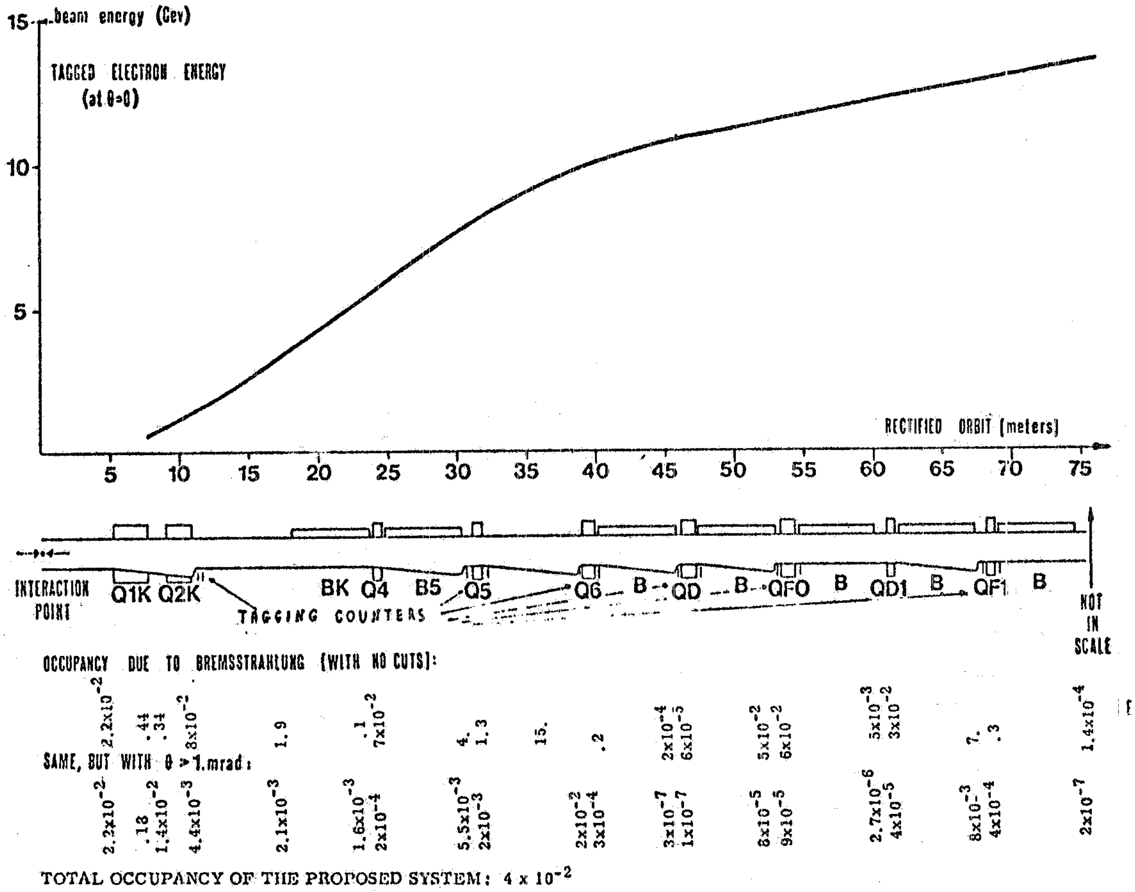


FIG. 6 - Possible tagging systems at zero degrees for PETRA: results of detailed calculations, assuming the optics shown in the middle (where the shaping of the beam pipe is shown too, together with the position of the tagging counters). The upper curve describes the variation of tagged electron energy (if $\theta=0$), along the machine optics. The lower figures give the occupancy due to the bremsstrahlung at the points of interest for tagging. Detailed presumable parameters of PETRA have been assumed.

Table I) we gain for reaction 2) a geometrical acceptance of at least a factor two.

- Tagging (B) should be distributed in 5-7 places on each side. To realize it the shaping of donut in each place should be similar to that considered in Figg. 1-3. This is not much, respect to the advantage of controlling more fully reactions 2).

Combining both tagging (A) and (B) it seems possible to achieve a tagging efficiency for two photon processes of 40-50%.

4. - THE POLARIZATION OF THE BEAMS. -

4.1. - It is well known that electrons (positrons) rotating in a storage ring can acquire a transverse polarization which is antiparallel (parallel) to the magnetic field of the machine[7]. The synchrotron radiation process is responsible for this transverse polarization, which grows up with a time dependence

$$P_T = P_o(1 - e^{-t/\tau})$$

where $\tau = \tau_{pol} \dfrac{1}{1 + \tau_{pol}/\tau_{dep}}$; $P_o = 0.924 \dfrac{1}{1 + \tau_{pol}/\tau_{dep}}$

τ_{pol} is a characteristic polarization build up time, and it is given by

$$\tau_{pol}(\text{sec}) \cong \left[98/E^5 \text{ (GeV)}\right] R_B^2 R$$

(R_B = magnetic bending radius ; R = average radius ; E = one beam energy).

In the case of PETRA it is :

$R_B \simeq 197$ m ; $R \simeq 365$ m ; $\tau_{pol} \sim 1800$ sec (15 GeV)
~ 121 h (5 GeV) .

The time constant τ_{dep} has been evaluated by many authors[8]. We shall assume that transverse polarization is possible, and we shall discuss now how to convert transverse into longitudinal polarization, in view of the great interest of this conversion in the study of weak interactions (Cfr. PEP Summer study and PETRA Proposal).

Let us remind a few essential concepts on the spin behaviour in an electromagnetic field. The interaction H of the electron with the field takes place through the magnetic moment μ of the particle:

$$H = -\bar{\mu} \times \bar{B}_o \; ; \quad \mu = \frac{ge}{4m} \hbar \; ; \quad \text{with } \frac{g-2}{2} \cong 1.16 \times 10^{-3}$$

(for an electron at rest in the field B_o).

From these relations one can deduce easily the classical equation of motion for the angular momentum P of the particle

$$\frac{d\bar{P}}{dt} = - \bar{\omega}_o \wedge \bar{P} \qquad (4.1)$$

where $\omega_o = \frac{1}{2} g \frac{e B_o}{m}$ is the angular frequency of precession of the polarization vector.

To get the polarization vector behaviour in the Lab. System one has to move from the rest frame of the electron to the L. S., by using the transformation rules of relativity.

A rigorous treatment has been given in ref. (9). We only recall that in a relativistically covariant description one can define a polarization (axial) four vector whose spatial part, in the electron rest frame, coincide with the spin operator (in units of $\hbar$). At the end one finds that when an electron moves with a velocity v in a field $\bar{E}$, $\bar{B}$, the angle ϕ between the polarization vector P and the velocity varies according to the law

$$\frac{d\phi}{dt} = \Omega = \frac{e}{m_o} \left[a \hat{n} \cdot \hat{v} \wedge \bar{B} + \frac{a - g/2\gamma^2}{v} \hat{n} \cdot \bar{E} \right] \qquad (4.2)$$

where $\hat{v}$ and $\hat{n}$ are unit vectors parallel and perpendicular to $\bar{v}$, respectively. In a pure magnetic field, which is our case now, and for $\bar{v} \perp \bar{B}$, if the electron spends a time Δt in the magnetic field, it has a deflection $\Delta\varphi$ such that $\Delta t = \Delta\varphi \cdot \rho / v$ and equation (4.2) gives

$$\Delta\phi = a\gamma\Delta\varphi \ ; \qquad a = \frac{g-2}{2} = 1.16 \times 10^{-3} \ ; \qquad (4.3)$$

$$\gamma = 1/\sqrt{1-\beta^2} = \frac{E}{m_o} \ .$$

From (4.3) one deduces that to transform transversal polarization into longitudinal ($\Delta\phi = \pi/2$) one has to turn the velocity direction of an angle $\Delta\varphi$ such that

$$\pi/2 = 1.16 \times 10^{-3} \gamma \Delta\varphi \ .$$

We then get, for the overall variation of the velocity direction of the electron :

$$\Delta\varphi = 138 \text{ mrad} = 7.92^o \qquad E = 5 \text{ GeV} ,$$
$$= 46 \text{ mrad} = 2.64^o \qquad = 15 \text{ GeV} ,$$
$$= 23 \text{ mrad} = 1.32^o \qquad = 30 \text{ GeV} .$$

We see therefore that a general arrangement for rotating the spin may be of the type proposed by B. Richter and R. Schwitters[10] for PEP (see Fig. 7). In the R-S solution, starting from (4. 3) one finds, at 15 GeV per beam :

$\Delta\varphi$ = 46 mrad

BL = 23 KGauss x m

L = 2. 8 m $\Rightarrow$ B = 8. 2 KGauss, and $D_2 = D_1 + L/2$.

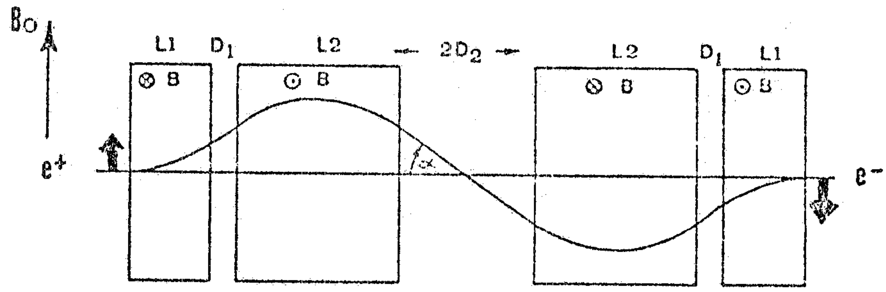


FIG. 7 - The Schwitters-Richter scheme, as proposed in ref. PEP-87, to transform the transversal polarization into a longitudinal one, at the interaction point.

The overall distance AB in the R-S solution is around 20 m. This device can therefore hardly be contained in the PETRA experimental straight sections.

One way out could be to put the polarising magnets between the beam optics elements of the machine.

4. 2. - Among different possible solutions we selected the following ones :

- Solution 1 (see Fig. 8a). This solution leaves the straight section free for experiments, but requires the radial bending magnet positioned before the B (90%) magnet being removed and its the bending action reabsorbed in the last radial magnet.
  Of course, it would have been preferable to remove the last radial bending magnet, but from the bahaviour of D_x function we see that this magnet is very important to obtain vanishing values of D_x and its derivative at the intersection point. Anyhow it must be still verified that it is possible that our solution is compatible with the magnetic optics constraints.
  The possibility of inserting a radially bending magnet between the vertically bending magnets is based on the fact that the first two vertically bending magnets have an opposite bending action so that the spin is left vertical.

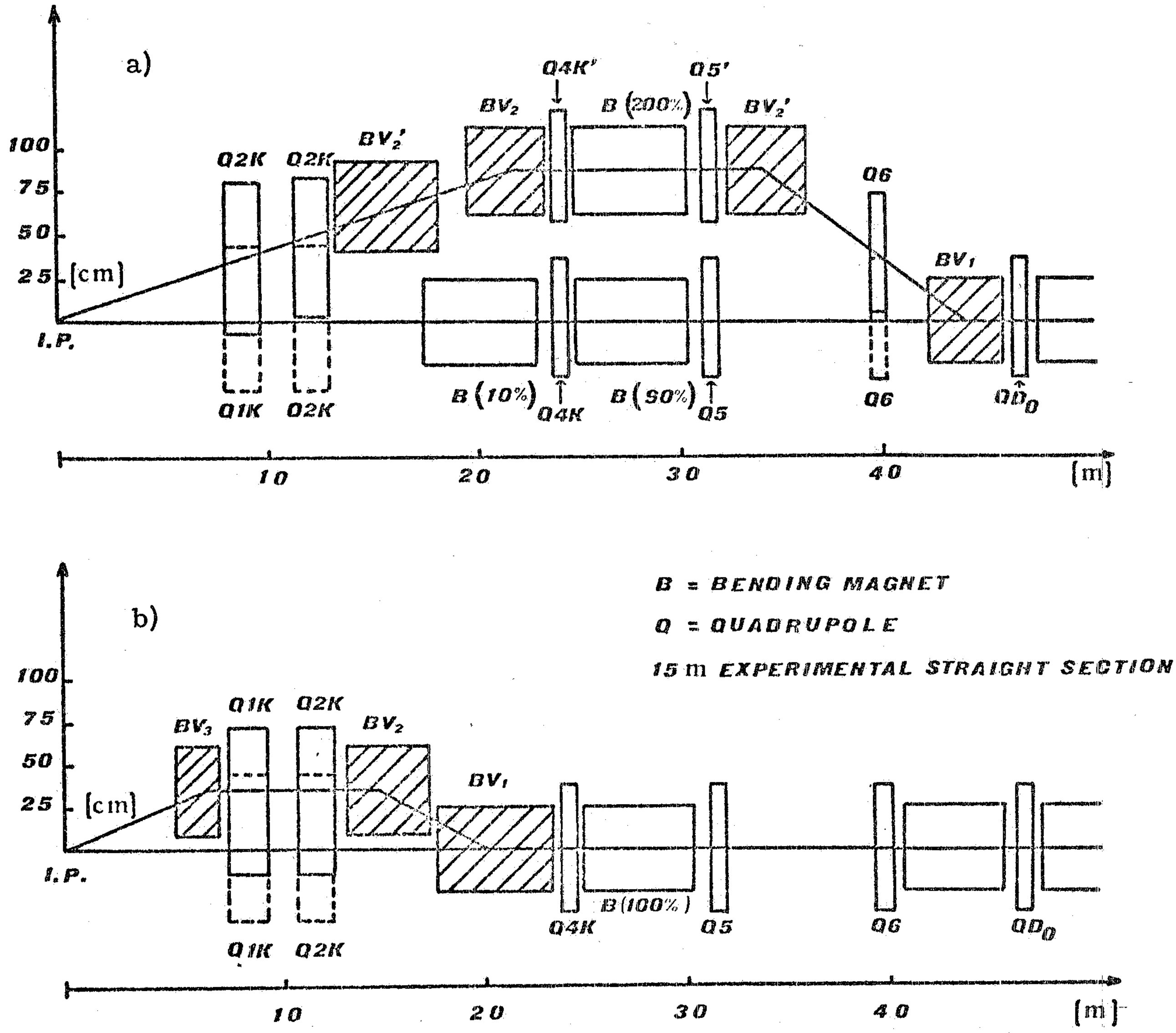


FIG. 8 - Schematic side view of the insertion in the basic PETRA lattice of the polarisation magnets, according to the different solutions discussed in § 4.

- Solution 2 (see Fig. 8b). This second solution requires i) 2 magnets inside the beam optics and another one in the straight section, and ii) a vertical displacement of quadrupoles Q1K, Q2K. We see that the maximum displacement is ~ 18 cm at 15 GeV (~ 12 cm at 20 GeV).

4. 3. - Radiation problems. The radiated energy in a magnet of length L and magnetic field B (for small bending) is :

$$\Delta E \; (\mathrm{MeV/e^-}) = 1.27 \times 10^{-5} \; E^2 \; (\mathrm{GeV}) \; B^2 \; (\mathrm{KGauss}) \; L \; (\mathrm{meters}).$$

The spectral distribution of the radiation, for a bending α, with a curvature ρ in the magnet L is given by:

$$dn/d\lambda = 12.76 \times 10^{8} \psi(\lambda/\lambda_c)/\rho^{2/3} \lambda_F^{4/3} ,$$

where $\lambda_F = 0.7\,\lambda_c$ (Å) $= 0.7 \frac{5.59 \times 10^{3}}{E^{3}\,(\mathrm{GeV})} \frac{L\,(\mathrm{m})}{\alpha(\mathrm{mrad})}$, $\psi(\lambda/\lambda_c)$ is an "universal function", and n the number of photons. The maximum of intensity is at

$$\lambda_m = 0.42\ \lambda_c .$$

The radiation is emitted at angle $\theta_c \sim m/E \Rightarrow 3 \times 10^{-5}$ radiant at 15 GeV.

This in general. The relevant numbers for our examples (Fig. 8) are reported in Table II. As we shall see, they may be rather important in influencing our choices. The numbers of Table II are obtained for a PETRA machine energy of 15 GeV.

TABLE II

	Solution 1 (Fig. 8a)				Solution 2 (Fig. 8b)		
	BV_1	BV'_1	BV_2	BV'_2	BV_1	BV_2	BV_3
L (meters)	4	4	4	5	6	4	2
B (KGauss)	12	12	4.5	1	3.3	4.9	11.5
α(mrad)	90	90	36	10	39.4	39.4	46
ΔE (MeV)	1.7	1.7	0.24	0.01	0.19	0.28	0.77
W (kW)	150	150	21	1	16.8	25	68.4
λ_{max} (keV)	405	405	126	36	78.5	126	280

E energy radiated in the magnet; W the corresponding power; λ_{max} the wave length value corresponding to the maximum of intensity of radiation.

4.4. - Comments on the different solutions. As a first comment it is clean that from the point of view of the machine, solution 2 is more convenient, for it needs smaller vertical displacement of the quadrupoles; but conversely it leaves less space available for the experimental apparatus.

Let's consider now the synchrotron radiation power emitted in the magnets, for each beam, as reported in Table II.

We fear that the radiation emitted in the bending magnet can give serious limitations both on the donut characteristics and on the experimental set up. In fact to absorb the synchrotron radiation the donut must be cooled and be rather thick in the interaction region, where we would rather have it as thin as possible.

In solution 1 (Fig. 8a) a standard thin donut is still allowed, because the radiation emitted in the last magnet $BV_2^{!}$ and directed along the beam toward the crossing point is not very intense. So in this case no experimental apparatus is seriously disturbed by the radiation.

In solution 2 the situation is more critical, because to avoid heating of the donut in the straight section one must have a large donut radius ($r \gtrsim 35$ cm), which is not convenient for the usual experimental sets up. Perhaps the solution 2 is more convenient for some special experiments like the iron ball(11). In this case one can more easily accept a thick donut.

We did not make yet a sufficient analysis of a few problems of beam optics (vertical dispersion, matching, etc.), as already indicated, for instance, in ref. (12).

5. - ON THE MEASUREMENT OF THE TRANSVERSAL POLARIZATION OF THE ELECTRON BEAM. -

5. 1. - General considerations. -

The problem of measuring the transversal polarization of electrons circulating into a storage ring has been discussed extensively by many authors(7, 14, 15); we limit ourselves to investigate among the fast methods which appears to be the most promising for PETRA (see also the conclusions on this problem in ref. (15)).

The method chosen consists in measuring the up-down asymmetry of back scattered photons coming from collision of circulary polarized laser light on the electrons of PETRA. This up-down asymmetry is due to term $\bar{\varepsilon} \cdot \bar{k}$ in the cross section, where $\bar{\varepsilon}$ is the electron polarization vector and $\bar{k}$ the outgoing photon momentum, so the differential cross section can be shown in the form(14):

$$d^2\sigma = d^2\sigma_o + \xi_\gamma |\xi_e| d^2\sigma_1 \sin\varphi ,$$

where ξ_γ is the degree of circular polarization of laser light and ξ_e the degree of transversal polarization of electrons and φ is the azimuthal angle between the polarization of electron and the normal to the scattering plane. The explicit form of $d^2\sigma_o$ and $d^2\sigma_1$ is:

$$d^2\sigma_o = 4r_o^2 \frac{n}{(1+2\lambda+n^2)^2}\left[\frac{2\lambda^2}{(1-n^2)^2+2\lambda(1+2\lambda+n^2)} + \frac{1+n^4}{(1+n^2)^2}\right] dn\, d\varphi \ ,$$

$$d^2\sigma_1 = -8r_o^2 \frac{n^2\lambda}{(1+2\lambda+n^2)^3(1+n^2)} dn\, d\varphi \ ,$$

where $2\lambda = (4\omega\gamma/m)$ (E and m are the energy and the electron mass, ω the incident photon energy in the lab. frame and $\gamma = E/m$) and $n = \gamma_1\theta$ (θ is the scattered photon angle in respect to incoming electron direction) and r_o is the classic radius of electron.

The magnitude of the up-down asymmetry at PETRA energies grows with λ and so with γ (at PETRA energy of 15 GeV λ is about 0.6), so that the ratio $d^2\sigma_1/d^2\sigma_o$ is better than that of the nowadays existing storage rings. But on the other hand, as the Compton cross section is peaked on $1/\gamma$ angle along the incoming electron direction, it appears a serious problem handling with angles of about 30 μrad under several aspects :

1) As the detector must be placed very far (at least 100 m) from the interaction region (on this distance practically all back scattered photons hit a frame 8 x 8 cm^2), the alignement accuracy doesn't appear to be too easy.
2) The vertical spread of PETRA electrons could wash off any symmetry effect unless suitable conditions are not fulfilled (see the argument on paragraph 2).
3) The crossing angle of the laser and electron beam must be considered to be not lower than 1 mrad, owing to reduce the energy flux of the synchrotron radiation on mirrors and optical windows: this fact produces a limitation on the length of the electron-photon interaction region to about 5 m.

5.2. - Results of calculations and conclusion. -

Using the "PETRA optics parameter" we have looked for the better points as possible laser-electron beam interaction regions. The electron density distribution in vertical projection can be written[15]:

$$D(Z,Z') = \frac{\beta_z}{2\pi\sigma_z^2}\, e^{-\frac{(1+\alpha_z^2)Z^2+2\alpha_z\beta_z ZZ'+\beta_z^2 Z'^2}{2\sigma_z^2}}$$

being z the distance above the beam axis and Z' the slope of the trajec tory and α_z, β_z and σ_z the parameters of every optical component of the ring.

The most favorable configuration of electron density in the phase space corresponds to a minimum of the mean squared value of vertical angular spread $\langle Z'^2 \rangle$, which can be shown to be equal to

$$\left(\frac{1+\alpha_z^2}{\beta_z}\right)\left(\frac{\sigma_z^2}{\beta_z}\right) .$$

Now the minimum of the factor $(1+\alpha_z^2/\beta_z)$ allows us to select several points of the machine while the factor σ_z^2/β_z depends (only through σ_z) on the operating condition of the ring (see our choices in Table III as possible interaction regions and also in Fig. 9 their disposition in the map of the machine).

TABLE III -

PETRA optical element parameters in the chosen laser-electron beam interaction region.

NR	TVP	ALFAZ	BETAZ/M	SIZ/MM	L(EL)/M	$(1+\alpha_z^2)/\beta_z$	$\sqrt{\langle Z'^2 \rangle}$ (μrad)
8	D3K	1.75	40.26	1.80	5.8	0.10	89.
19	D6	0.20	5.03	0.63	7.2	0.21	41.
183	D02	0.60	22.10	1.33	7.1	0.06	70.

We have performed numerical integration relatively to three PETRA elements, as specified in Table III (labels in NR, TVP correspond to "PETRA optics parameters").

The results of this calculation are the rates[16] of back scattered monochromatic photons (about 5 GeV in energy for a PETRA energy of 15 GeV) on a transverse plane placed 100 m far from the interaction region along the photon flight direction (see in Fig. 10 the pattern of the photon yield in arbitrary units). Thus, if we indicate with UP (DW) the rate of upper (lower) part of plane, we can define as asymmetry parameter the expression (UP-DW)/((UP+DW)/2), which results equal to

$$2\,\xi_\gamma |\xi_e| \iint d^2\sigma_1 / \iint d^2\sigma_o \quad .$$

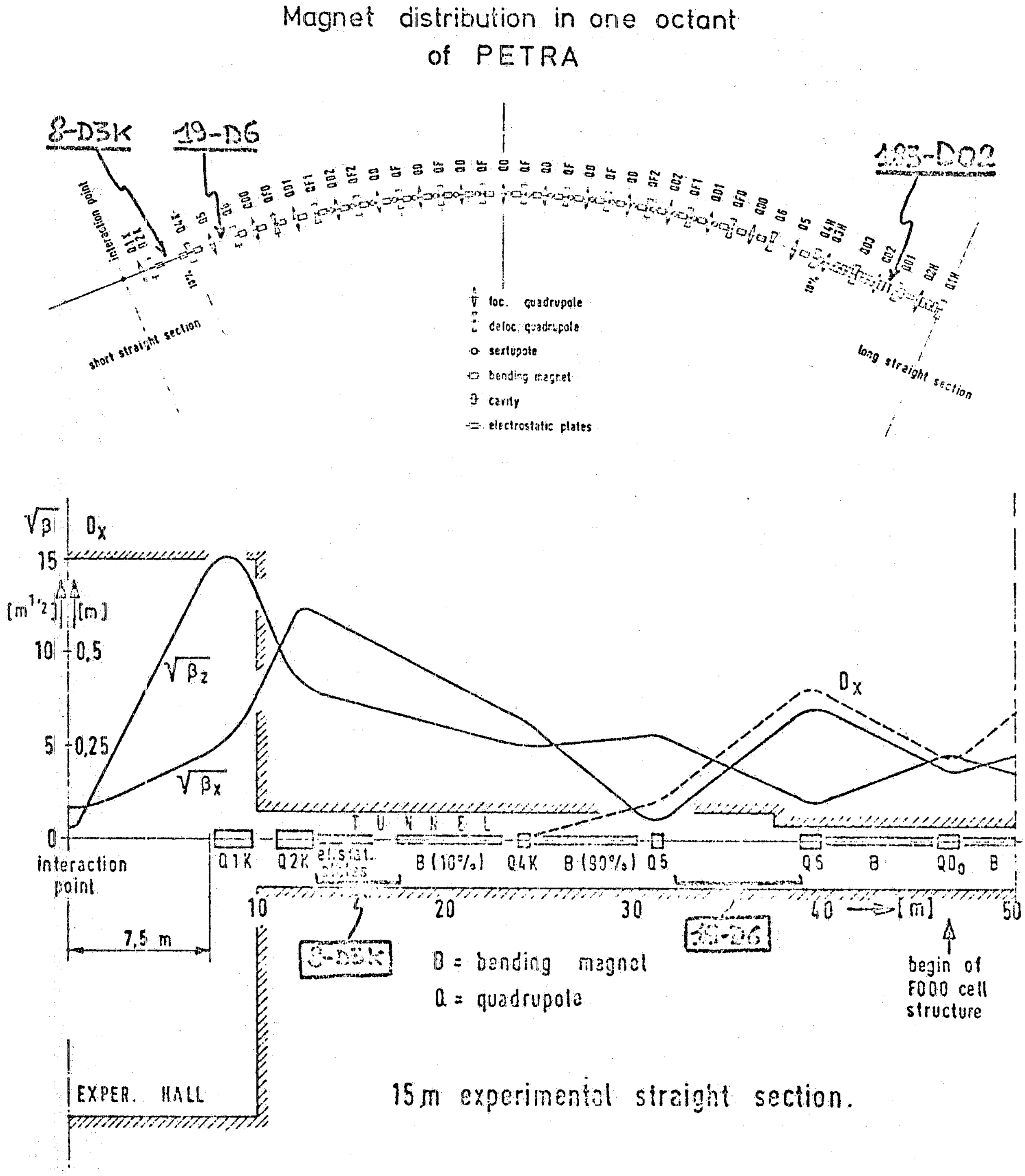


FIG. 9 - Map of the selected regions for laser-electron beam interaction.

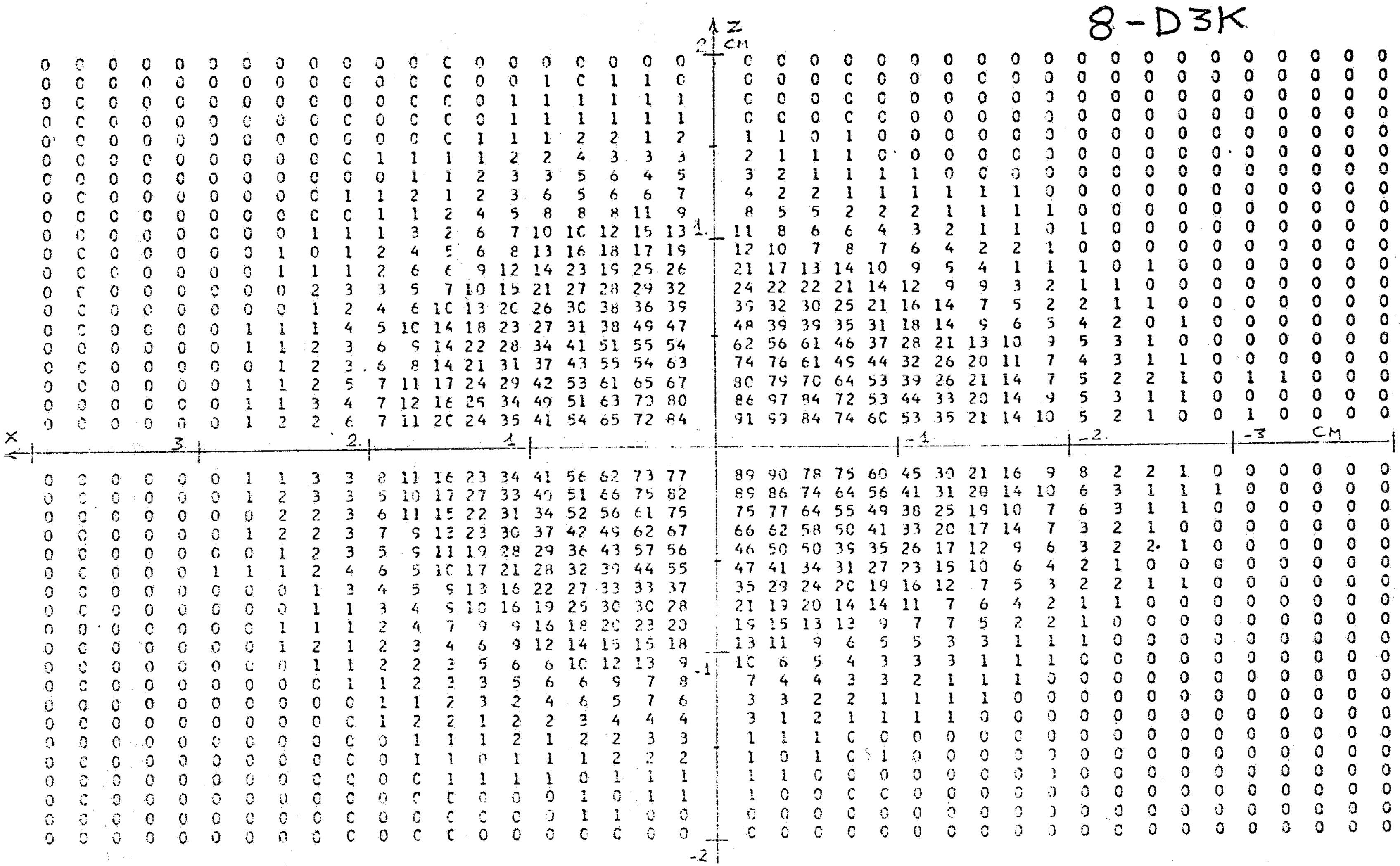


FIG. 10 - Pattern of the back scattered photon yield on a frame 8 x 8 cm^2, 100 m far from the interaction region. The yield is in arbitrary units and the interaction region is the 8-D3K PETRA element.

It is important, for evident reasons, to study the asymmetry and the rate behaviour (in analogy with the paper of the ref. (16)) as a function of the offset of both half-planes symmetrycally shifted in opposite directions. Figs. 11, 12 and 13 show the asymmetry and the rate curves for all considered cases.

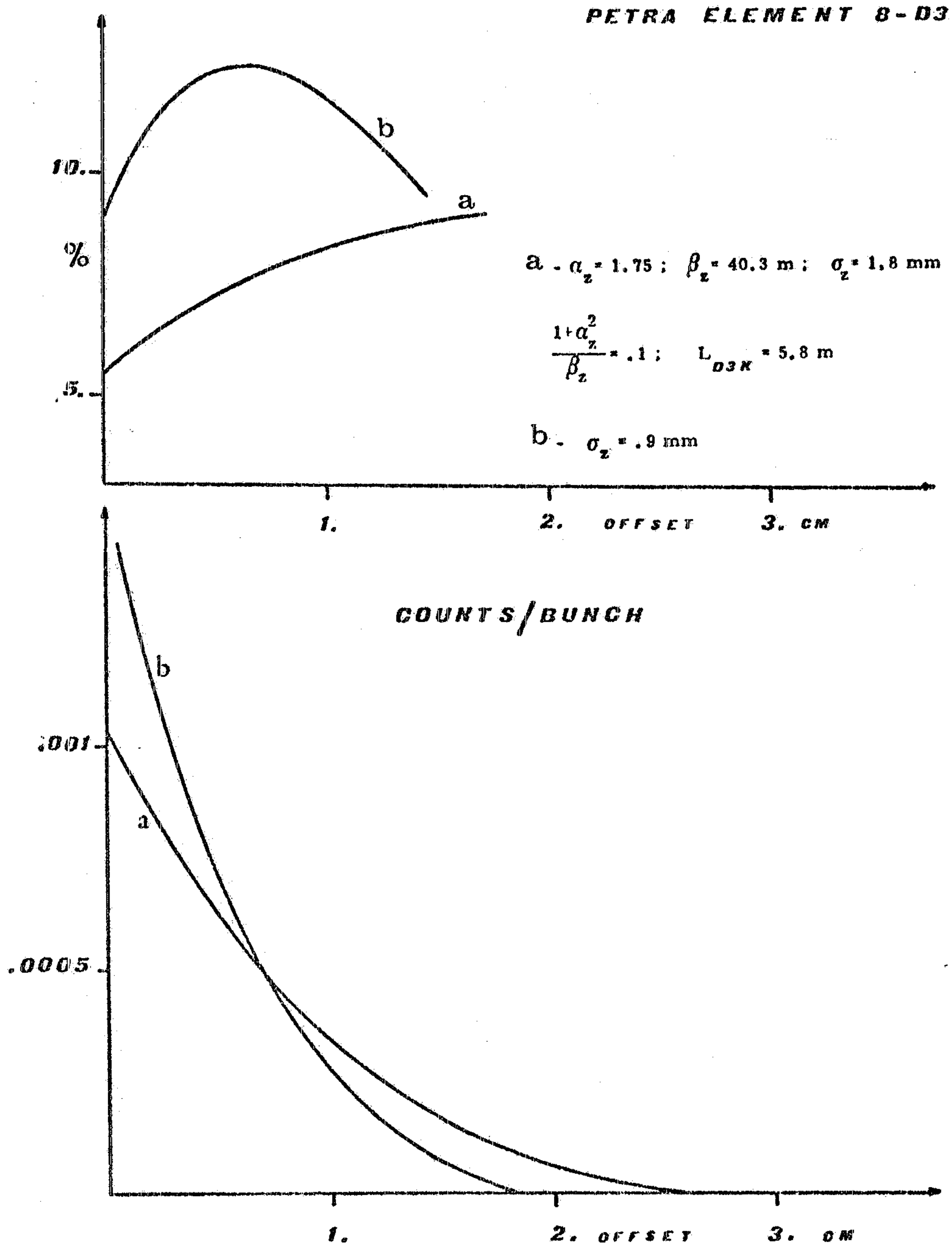


FIG. 11 - The behaviours of the symmetry (in percent) and of the rate (in counts per bunch) as function of the offset parameter. The machine conditions are specified on the figure. Curves 'a' and 'b' only refer to different values of σ_z parameter. The interacting region is the 8-D3K element.

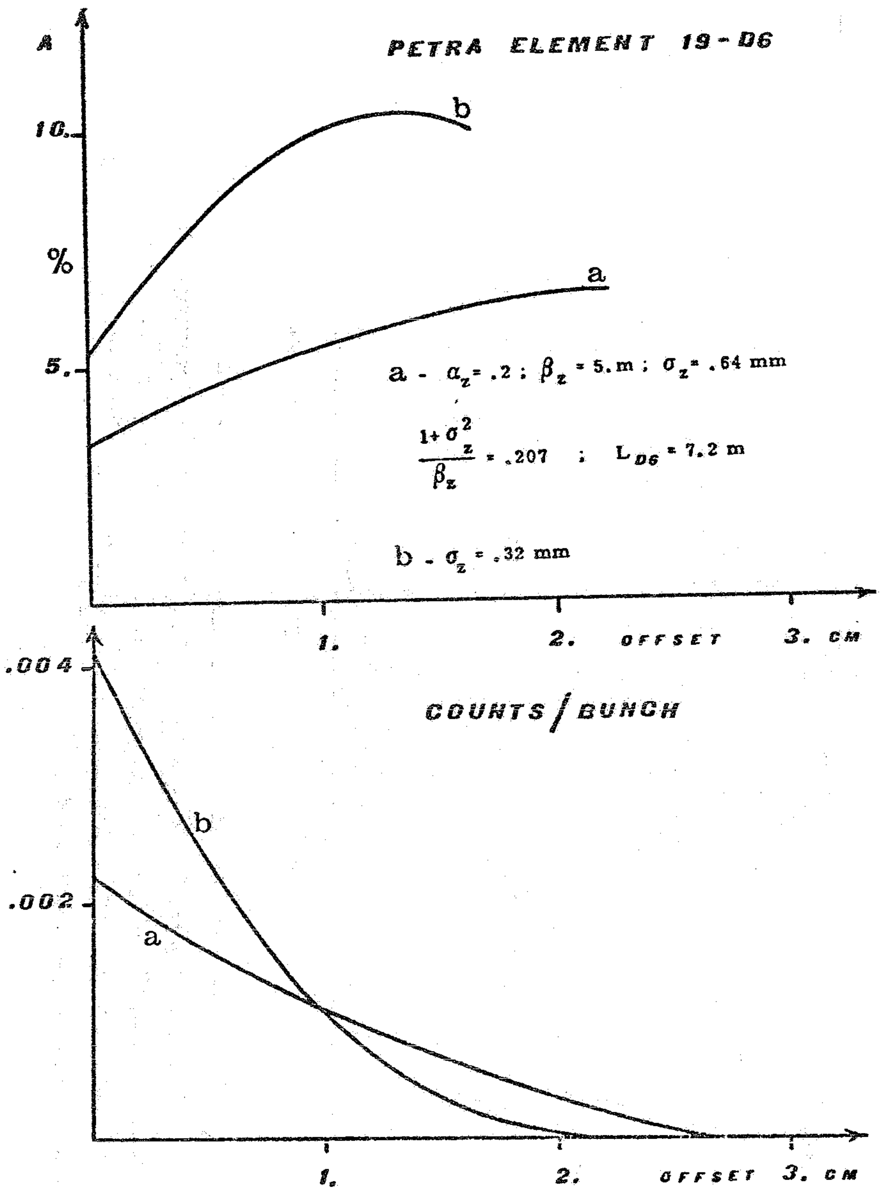


FIG. 12 - Same as Fig. 11, but referring to 19-D6 element.

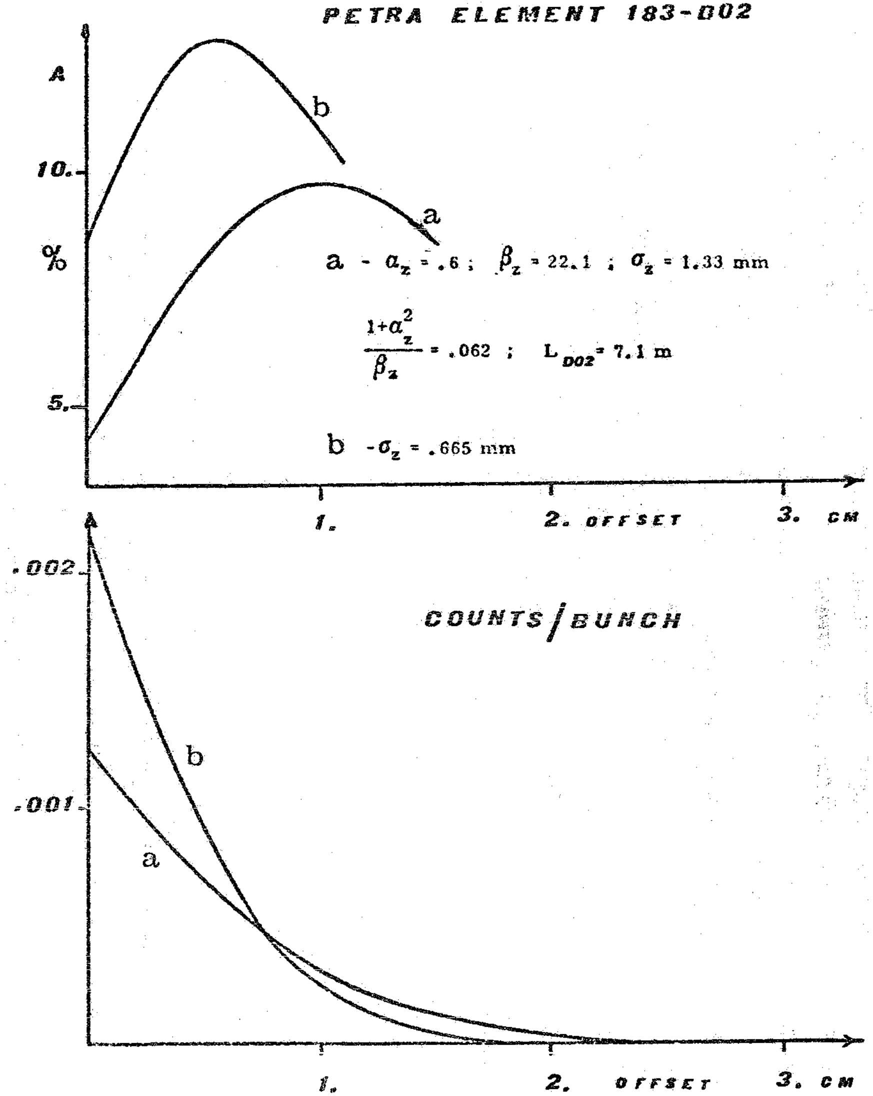


FIG. 13 - Same as Fig. 11, but reffering to 183-DO2 element.

We point out that all values given by "PETRA optics parameters" refer to "full coupling" without beam interaction, so that σ_z^2/β_z value reaches the maximum one (this is the case of curves 'a' in Figs. 11, 12 and 13). This means that the up-down asymmetry can improve (or at least to be different) as the ring operating conditions are going "off coupling". The sensitivity of asymmetry to this change is shown in Figs. 11, 12 and 13, through curves 'b' corresponding to an half-value of σ_z employed in curves 'a'. Thus the comparison between the curves 'a' and 'b' indicates how well we must know the σ_z parameter for a correct evaluation of the experimental results.

The method described above, for the back scattered photons, needs a path practically free from heavy material (only a fraction of radiation length is tolerated). In order to verify if the considered solutions fulfill this condition and also if these ones interfere with the machine set-up, we have performed a rough analysis relatively to 8-D3K and 19-D6 interaction regions (see Fig. 14).

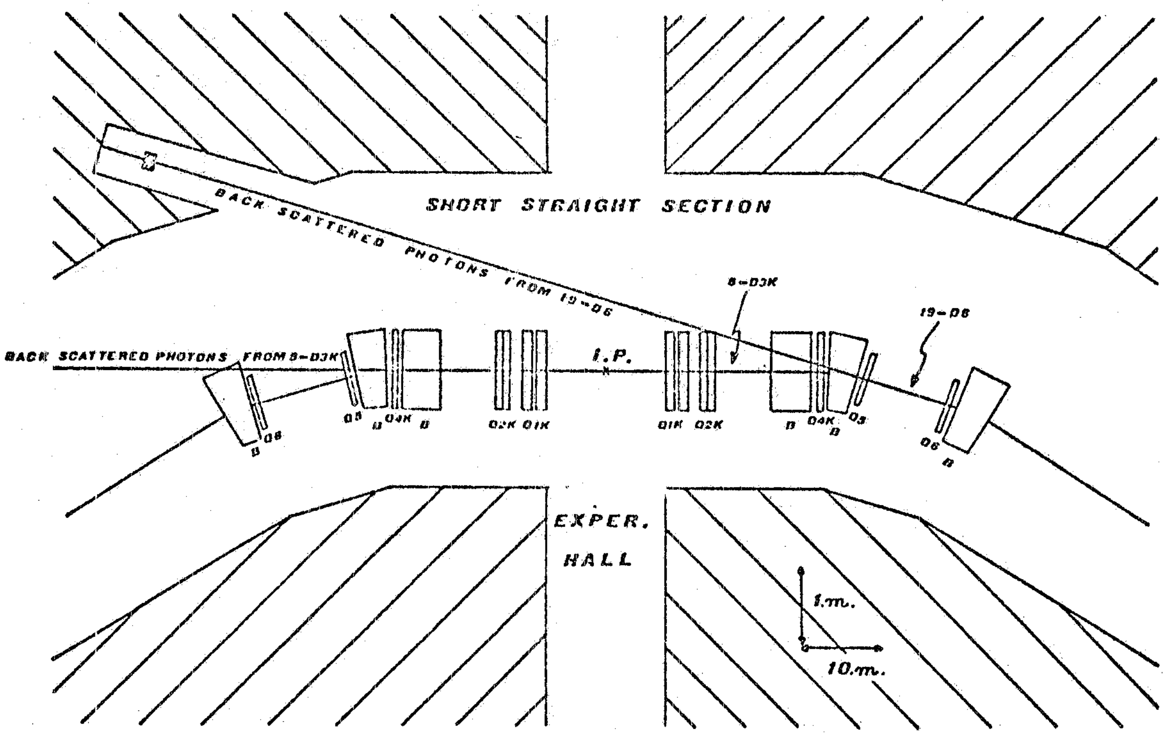


FIG. 14 - Path of the back scattered photons from 8-D3K and 19-D6 laser light-electron beam interactions regions on the PETRA map. The horizontal scale is 10 times the vertical one.

The conclusions are that in both cases the photon path avoids large thickness of material (essentially quadrupole iron); moreover the solution for 8-D3K region seems to be better than that for 19-D6 region at least for two reasons : no passage through a possible experimental apparatus in the straight section and no necessity of building work requirements for setting up a sufficiently far photon detector.

6. - A SYNTHESIS OF THE REQUIREMENTS FOR THE LENGTH 1 AND THE TRANSVERSAL DIMENSIONS Δs OF THE FREE STRAIGHT SECTIONS. -

In order to foresee the request of the users one can again go through our Figures 1-3 and 8.

It seems evident that if the reasons to have good magnets for measuring momenta at large and small angles are accepted (§ 1, 2) then the length 1 should be at least 15 meters. The demand in case of longitudinal polarization has been also indicated in § 4 and Fig. 8 in at least 15 m. Of course some "first generation" experiments, with magnet or not, can stay within 1 ~ 10-12 m and perhaps less (see, for instance, Fig. 2). But, unless we consider that it may be easy to increase in a second time the value of 1, it is convenient to think since now of the necessities for the second generation experiments, which shall certainly require high precision and large solid angle. These necessities must be compared with the prevision 1 = = 10 m for the experimental free straight sections in the PETRA Proposal 1974, a length which seems to us to be insufficient. Even if we are not in favour for having straight sections of different lengths (for instance 10 and 20 m), we do not have for the moment precise arguments against this possible choice. As for Δs, the space around the interaction region, we agree with the demands of PEP Summer Study 1975 (p. 215-227), for a pit ~ 4 m deep, and for spaces at the side which allow in-out position of the experiments.

ACKNOWLEDGEMENTS. -

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(16) - The rates have been performed in the hypothesis to employ a no-pulsed Argon laser beam (10 Watt in output power) operating on second armonic (corresponding to photon energy of 5. 1 eV) with gaussian-like intensity distribution (σ = 1. 5 mm) and interacting for 5 m on the electron beam. Particles per bunch at PETRA are supposed to be 10^{12}. The photon yield evaluated corresponds to a full polarization.