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HIGH ENERGY BACKGROUND AT PETRA

by

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ABSTRACT

Beam gas bremsstrahlung as the main source of high energy backgrounds in PETRA experiments is discussed. Tracking programs are used for background simulations and for the design of collimators to protect the PETRA experiments from off beam particles.

PETRA experiments are limited in two ways by machine background [1]. Firstly charged particles and low energy photons may produce a high space charge in the central tracking chamber. This can cause a discharge, which might damage the chamber. Secondly, background particles which hit the detector may set a trigger bit and cause prohibitively high trigger rates. The first type of background is, to a large extent, due to synchrotron radiation. However also electromagnetic showers which penetrate into the central detector often create a high space charge. High trigger rates, on the other hand, are mainly caused by off momentum beam particles and particles with large deviations from the nominal orbit, which then give rise to electromagnetic showers when they hit the material in the vicinity of the detector. Also inelastic nuclear reactions of the beam particles with the residual gas in the interaction region can give a sizeable contribution to the overall trigger rate.

This report describes an investigation of the background due to high energy particles and some measures which might suppress the high energy background in the experimental areas.

The investigations have been performed with a tracking program which is described in the appendix [2]. In order to simplify the calculations, particles which are lost have only been tracked up to the point where they hit an obstacle and no further shower development has been considered. Thus in this approximation all particles which are lost within 7 m of the interaction point are treated as candidates for causing a spurious trigger. Furthermore, the efficiency of causing a false trigger is assumed to be independent of the distance from the interaction point within the 7 m limit.

1. Beam Gas Bremsstrahlung

Bremsstrahlung production due to the interaction of the beam particles with the residual gas may lead to background triggers in two ways :

a) high energy bremsstrahlung photons originating from certain regions of the machine may hit the detector;
b) a loss of degraded electrons or positrons may occur due to aperture limitations close to the detector.

The relevant formulae for calculating bremsstrahlung cross sections are summarized below [3]

$$d\sigma = \frac{1}{x_0} \frac{dE}{E}$$

$$x_0 = \text{unit radiation length} \quad .$$

The number of particles which lose an amount of energy greater than ΔE on passing through 1 m of residual gas assuming it is pure CO [4] can be calculated to be

$$-\frac{dn}{n\,dx} = \frac{\ln E_0/\Delta E}{x_0} \cdot \frac{M \cdot P}{R \cdot T}$$

E_0 = beam energy
ΔE = minimum energy loss by bremsstrahlung
x_0 = radiation length of the residual gas $X_0(CO) = 38.5\ g/cm^2$
M = mole weight = 28 g/mole for CO
P = partial pressure of CO .

Inserting numbers yields the experession

$$-\frac{dn}{n\,dx} = 4 \cdot 10^{-15} \cdot P\ [10^{-5}\ m] \quad \ln E/\Delta E \quad .$$

Assuming a pressure of $5 \cdot 10^{-9}$ Torr in PETRA, one finds

$$-\frac{dn}{n\,dx} = 2.14 \quad 10^{-14} \ln E/\Delta E \qquad [m^{-1}] \quad .$$

a) Background from high energy photons

High energy photons which originate from a bremsstrahlung process between the middle of the 16% magnet and the beginning of the 83% magnet will hit aperture limitations close to the experiment.

The effective target length for this process is 4.5 m.

Assuming a minimum energy loss of 5 GeV at 17.5 GeV beam energy gives

$$\frac{dn}{n} = 1.2 \cdot 10^{-13}$$

For 10 mA stored beam in 2 bunches with $2.5 \cdot 10^{11}$ electrons per bunch there will be

$$N_\gamma = 3 \cdot 10^{-2} \qquad \gamma\text{'s per crossing}$$

hitting the material around the detector.

b) Background from degraded electrons

For electrons and positrons which lost energy due to the emission of a bremsstrahlung photon, the closed orbit will be changed. They will continue on dispersive trajectories and if the change of energy occurs at a place with non zero horizontal dispersion $\vec{D}_x$, the particles acquire a sudden displacement from the off energy closed orbit

$$\begin{pmatrix} \delta_x \\ \delta_{x'} \end{pmatrix} = - \vec{D}_x \frac{\Delta E}{E}$$

corresponding to an excitation of horizontal betatron oscillations. Depending on the place of the beam gas interaction, a fraction ε of degraded electrons or positrons may hit the aperture limitations in the neighbourhood of the experiments and cause a trigger to fire.

The fraction ε has been calculated for various positions in the arc next to an interaction region. In these calculations it has been assumed that the direction of the electron is not affected by the emission of a bremsstrahlung photon, it merely loses energy. Furthermore, it has been assumed that electrons which lose an amount of energy which is smaller than the natural energy spread in PETRA are not affected and consequently the minimum energy loss has been set to the value of the natural one standard deviation energy spread

$$\Delta E_{min} = 6.2 \cdot 10^{-5} E^2 \qquad [\mathrm{GeV}]$$

The degraded electrons are tracked through the machine lattice and tests on the aperture limitations are performed after each PETRA element.

The results of these calculations are summarized in Table I. It is observed that the probability to lose a degraded electron in the interaction region depends strongly on the horizontal betatron phase at the place of the energy loss. If the relative phase angle is measured with respect to a point which is about half way between the interaction point and the quadrupole Q1K, i.e. at the exit of the mini beta quadrupole QA1, then for angles around 90° and 270° the probability for a particle loss in the interaction region is particularly small. For angles around 180° and 360°, ε is large because particles which have a large betatron amplitude there, will also have a large amplitude in the interaction region. Thus the 180° position would be an excellent place for a horizontal collimator to protect the interaction region against high energy off beam particles.

In order to estimate the number of degraded electrons out of the arc next to an experiment, we assume a constant value of $\varepsilon = 6 \cdot 10^{-2}$ between 100 and 50 m from the interaction point.

$$- \frac{dn}{n} \cdot \varepsilon = 2.1 \cdot 10^{-14} \cdot \ln E/\Delta E \cdot l[m] \cdot \varepsilon$$

$$= 1.4 \cdot 10^{-13} \cdot 50 \cdot 6 \cdot 10^{-2}$$

$$= 4.2 \cdot 10^{-13}$$

$$dn = 4.2 \cdot 10^{-13} \cdot 2.5 \cdot 10^{11}$$

$$= 1 \cdot 10^{-1} \qquad \text{particles per crossing} \quad .$$

TABLE I

Probability for degraded electrons to be scattered into the interaction region originating from various places in the machine lattice. The phase angle is measured relative to the phase at the exit of QA1.

Distance from IP [m]	relative horizontal phase angle	ε no collimator	ε with ±40 mm collimator at 40 m
118	72^0	$2 \cdot 10^{-3}$	
103	14^0	$5.7 \cdot 10^{-2}$	$4 \cdot 10^{-2}$
89	349^0	$7.3 \cdot 10^{-2}$	$1 \cdot 10^{-3}$
81	331^0	$6.1 \cdot 10^{-2}$	$< 3 \cdot 10^{-4}$
74	298^0	$4.4 \cdot 10^{-2}$	$< 3 \cdot 10^{-4}$
67	270^0	$< 5 \cdot 10^{-4}$	$< 3 \cdot 10^{-4}$
60	234^0	$< 5 \cdot 10^{-4}$	$< 3 \cdot 10^{-4}$
53	212^0	$3.1 \cdot 10^{-2}$	$< 3 \cdot 10^{-4}$
45	176^0	$6.9 \cdot 10^{-2}$	$6.8 \cdot 10^{-2}$
30	75^0	$1.2 \cdot 10^{-2}$	
23	18^0	$2.1 \cdot 10^{-2}$	
15	7^0	$2.3 \cdot 10^{-2}$	
IP : 0	$- 76^0$		

Electrons which interact between 45 and 23 m from the interaction point, i.e. the region of the weak bending magnets have a high probability ($\varepsilon \approx 10^{-1}$) of being lost in the interaction region. Their number is estimated to be

$$- \frac{dn}{n} \cdot \varepsilon = 1.4 \cdot 10^{-13} \cdot 22 \cdot 10^{-1} = 3.1 \cdot 10^{-13}$$

$$dn = 3.1 \cdot 10^{-13} \cdot 2.5 \cdot 10^{+11} = 7.8 \cdot 10^{-2} \quad \text{particles per crossing .}$$

As already mentioned above, degraded electrons from more than 50 m from the interaction point could be stopped by a collimator at 180^0 relative horizontal betatron phase angle with respect to the interaction point. It would be mechanically possible to install such a collimator about 40 m from the interaction point between the 83% magnet and the first full bending magnet without major changes in the vacuum system. The effect of such a collimator (which is ±25 mm wide in the horizontal plane) may be inferred from Table I. It essentially stops all degraded electrons from the arc.

The jaws of this collimator need not be thick. About 5 radiation lengths would be sufficient. For a first test in PETRA movable collimators should be installed in the NW area on both sides of the interaction point, because there no machine elements would interfere and JADE has a sensitive tracking chamber as a central detector. The test set up should be used to find out an appropriate collimator opening so that fixed collimators could eventually be inserted into the other interaction regions.

Degraded electrons from the region of the weak bending magnets are more difficult to shield. In this region of PETRA it is essential to improve the vacuum, for instance by introducing NEG pumps and building stainless steel chambers which could be baked. Furthermore a horizontal collimator with a width of about ±40 mm between Q2K and the 16% bending magnet would stop about 80% of the degraded electrons. However, secondary particles leaking out of the jaws of such a collimator would have a high probability to get focussed into the interaction region and further detailed shower calculations are necessary to investigate the effect of this collimator. This collimator should be 30 - 40 radiation lengths thick.

2. Other Sources of Background

In the present approximation with 0°angle bremsstrahlung emission, an energy loss behind the 16% bending magnet would not affect the experiment. However one could imagine that electrons which have large deviations from the nominal orbit ($\Delta x > 4\sigma_{hor}$) and lose a large fraction of their energy ($\Delta E/E > 0.5$) may be overfocussed and hit the experiment. Their contribution is suppressed by the factors

$$\begin{array}{lll} & (a)\ 10^{-4} & (\text{Gaussian} > 4\sigma) \\ \text{and} & (b)\ 10^{-1} & (\ln E/\Delta E) \end{array} .$$

With $\varepsilon \sim 10^{-1}$, the total suppression factor is about 10^{-5} compared to the sources discussed earlier, and no further investigations have been made.

Secondary particles of both signs from inelastic beam gas collisions behind the 16% magnet could be focussed into the interaction region. This type of background has not been investigated yet. It can be reduced by having a good vacuum and a collimator at Q2K to catch at least the large angle scatters.

In a Coulomb scattering process electrons will change their direction without losing energy. The cross section for observing a scatter through an angle greater than θ_{min} is given by

$$\sigma = \frac{4\pi \cdot r_o^2 \cdot z^2}{\gamma^2\ \theta_{min}^2}$$

(r_o = classical electron radius, $\gamma = E/m_e$).
The average scattering angle is of the order of

$$\langle\theta\rangle = m/E \sim 3 \cdot 10^{-5} \qquad (E = 17\ \text{GeV}) .$$

Assuming a pressure of $5 \cdot 10^{-9}$ Torr of CO and a minimum scattering angle of $\theta_{min} = 10^{-4}$, the scattering rate is

$$-\frac{dn}{n\,dx} = 5.5 \cdot 10^{-14} \qquad [m^{-1}] .$$

The probability to lose a scattered electron in the interaction region is of the order of 10^{-3}. Thus the loss rate for a target length of 100 m is

$$-\frac{dn}{n} \cdot \varepsilon = 5.5 \cdot 10^{-14} \cdot 10^{2} \cdot 10^{-3}$$
$$= 5.5 \cdot 10^{-15} .$$

This rate is smaller than equivalent rates for beam gas bremsstrahlung by a factor of about 100.

It is interesting to note that electrons which undergo large angle Coulomb scattering are preferentially lost at the aperture limitations close to the interaction point, and a ±25 mm wide collimator some 40 m before the interaction point has little effect in reducing the experimental background due to this process, neither has a ±40 mm wide Q2K collimator.

The background due to bad vacuum in the interaction region itself can only come from inelastic beam gas collisions where the reaction products or part of them are scattered into the detector. This process has not been considered in the present context. Obviously it can be suppressed by good vacuum in the experimental beam pipe.

3. Summary and Conclusions

Three major sources of background in a PETRA experiment have been considered. They arise from the primary interaction of beam gas bremsstrahlung as follows :

a) Photons of $E_\gamma > 5$ GeV from bremsstrahlung at the 16% magnet produce a loss rate of high energy particles in the interaction region given by

$$\frac{dn}{n} = 1.2 \cdot 10^{-13}$$

b) Degraded electrons are lost out of the arc next to the experiment with a rate

$$\frac{dn}{n} = 4.2 \cdot 10^{-13}$$

c) Degraded electrons originate from the last two weak bending magnets with a rate of

$$\frac{dn}{n} = 3.1 \cdot 10^{-13} \quad .$$

Particles which undergo an energy loss in the arc can very effectively be removed from the beam by a collimator between the 83% magnet and the last full bending magnet. A second horizontal collimator attached to the quadrupole Q2K would greatly reduce the particles which undergo beam gas scattering at the weak bending magnets.

To reduce the experimental background it is essential to improve the vacuum at the weak bending magnets. The installation of a second collimator at Q2K can only be a supporting measure.

An estimate of the possible improvement in the trigger rate of a typical PETRA experiment may be obtained from a compilation of the event composition in the JADE experiment, Table II.

TABLE II

Event composition at 17.5 GeV as observed by JADE

Beam-beam interactions	16%
Beam-gas	35%
High energy background	46%
Cosmic	3%

The event classification of Table II is performed on-line on the basis of z-vertex information and a rough track selection. The table shows that about half the triggers are due to off beam particles. If this background could be reduced, the dead time would go down and the experiment would be able to cope more easily with the conditions which may be worse at higher energies.

A p p e n d i x

Description of the tracking programs

All programs are available on the NEWLIB files

	F11BAR.	PETRA.S	(Source)
and	F11BAR.	PETRA.L	(Load)

Several program versions are available for simulating various types of background.

1. Program flow

An arc of the PETRA machine is segmented into (154) elements between a long and a short straight section. The subroutine DATEN reads in the definition of the elements and their magnetic and geometrical properties. The identification of the elements is done by numbers 1 ... 47. The machine lattice is built up by assembling the individual elements in a sequence as defined by data cards, which are read by DATEN. The present version of the program assumes MI8-optics. If an element number is increased by 100, the element receives special treatment via a computed GOTO in the main program. The program DATEN further reads in starting values for the tracking program, the element number at which a scatter occurs and the total number of elements to be tracked through.

Aperture limitations are defined in a BLOCK DATA Macro APERTUR. Collimators are defined by overwriting individual apertures in the MAIN program. All dimensions are in mm. The BLOCK DATA also initializes the parameters SCAL and SCAL1 which set the region of the beam that should be traced, e.g.

SCAL = 0, SCAL1 = 2

means the central part of the beam in the x, y plane is taken between 0 and 2σ.

SCAL = 2 SCAL1 = 4

means only the part of the beam between 2 and 4σ is tracked. For normalization the number of trials and the number of failures is printed in an output table.

The transfer matrices for a momentum offset DP = DE/E are computed in the subroutine ENVAR (DP) .

Tracking normally starts in the long straight section and the initial conditions for a trajectory are tossed in ANFB (Member name ANFO). It is assumed that the phase ellipses are on axis at the long straight section, thus x, and x' (z, z') are tossed as independent Gaussians.

The MAIN program after initialization loops over the elements of an arc 1 ... IOBS, fills plots and takes care of scattering and aperture limitations.

2. Program Versions

a) Beam gas bremsstrahlung at a place as defined by data cards

```
#MI8        JCL  +  data cards
 MAINO      main program
-----------------------------------------------
 ANFO       initialize trajectory. The
            member ANFO has to be attached
            via an INCLUDE in the LKED-step.
```

b) Coulomb scattering

```
#MI8COUL
 MAINCOUL
```

c) The vacuum chamber or a collimator ring is the source of both sign particles which are tracked to the interaction point

```
#MI8CUT
 MAINCUT
 GETPAR        generate initial conditions
```

This program is still under development and it has to be considered a prototype program, which not necessarily runs without error messages. Interested persons are invited to copy the programs and if necessary change them. The authors would be grateful if essential improvements were reported to them

REFERENCES

1. W. Bartel, DESY F11-81/02 Internal Report (July 1981)
   S. Kadyk, PEP-NOTE 362 (1981).

2. Background calculations with tracking programs through the last few magnetic elements have been done by
   D. Trines, DESY-Internal Report DESY-PET 77/11 (October 1977), and
   U. Koetz (private communication).

3. H. Lynch, R.F. Schwitters, W.T. Toner, PEP-Summer Study, pg. 542 (1974)

4. On the average the residual gas in PETRA has the composition 10% H_2, 30% CO, 30% CO_2, 30% H_2O.

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