PHYSICS WITH ELECTRON STORAGE RINGS

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The title of this talk is obviously a blunder: the purpose of this conference is to bring machine builders and physicists together. In the development of electron storage rings machine builders and physicists have now been together for up to seven years and it has become quite difficult to tell the one from the other. I shall therefore leave to you the subtle distinction between physics and storage rings and talk simply about the latter.

Indeed we are fortunate that in this meeting we shall witness storage rings making the grade from physics promised to physics done. In today session we are going to hear a report from Stanford about the first high momentum transfer experiment actually carried out with a storage ring. This is such an important occasion that I feel that a discussion of how future experiments will be interpreted by theorists would be comparatively pallid. I shall therefore say very little about this, particularly since this theme has been excellently exposed by Gatto at the Hamburg meeting. His talk is now available as a preprint here at Frascati.

What I hope to convey in this talk is that the work on colliding beam experiments (which has for so long been watched in an air of gleeful impatience) has developed quite logically and at a reasonable speed.

To judge the order of magnitude of the effort which had to go into the development of the new technique we may think of the experimental arrangement as consisting of two parts one of which is an accelerator the other being a target of quite revolutionary properties: providing it is equivalent to creating a new stable state of matter. This I think is well beyond straight forward machine building and could be judged as being not less physics than the experiments which it will ultimately serve.

The avowed aim of a colliding beam experiment is a measurement of the differential cross section of any high energy reaction between the particles of the two beams.

A first generation of experiments is limited to two particle reactions, viz

$$e^- + e^- \rightarrow e^- + e^- \qquad e^- + e^+ \rightarrow A + \bar{A} \qquad [1]$$

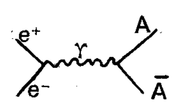
This way of writing the reactions ignores the production of soft γ's, which gives rise to the conspicuous radiative corrections (of up to 35 %) discussed in Gatto's paper.

We shall hear more about the 1st reaction from Gittelman. Experiments on the 2nd type - which we call annihilation experiments extending the meaning of the word also to electron-positron scattering, in which annihilation (scattering) only plays an important role at large angles - are intended to supply a cross-section.

$$d\sigma_A = f_A(E, \theta)\, d\Omega \qquad [2]$$

for every pair of particles $\bar{A}A$. (We have ignored the possibility of measuring polarization for particles A, $\bar{A}$ with a spin different from 0.

In most cases the Θ dependence is trivial for annihilation processes. This is due to the fact that these processes are due to the annihilation graph



in wich the virtual photon has no momentum and energy 2 E. All the angular "information" that can be carried from the initial into the final state must go via the polarization of the photon.

The matrix element can therefore only be of the form $M = \alpha \cos \theta + \beta \sin \theta$ and not contain higher powers of e θ. Angular momentum conservation and the statistics of the final particles often determine a relation between α and β.

The significant part of the measurement will therefore be found in the energy dependence of the cross-section, which makes it necessary to be able to compare measurements which have been carried out at different energies.

Since generally the properties of the "target" will change with energy it is seen that it is necessary to be able to check the target by means of a monitoring reaction, which therefore is of decisive importance in annihilation esperiments. (This is not the case for $e^- + e^-$ scattering, where the θ-dependence alone already gives significant information).

The reasons for wanting to measure the functions [2] with a storage ring have been widely discussed. They can be sumed up thus.

A) Colliding beam experiments are one way to obtain information about processes with very high momentum transfer.

B) Though there exist other methods of obtaining this information as for example the observation of leptons in proton-antiproton annihilations or of large angle electromagnetic events, the colliding beam technique has the advantage that it admits as clean a separation between strong and electromagnetic interactions as nature will allow.

C) The numerical accuracy of colliding beam experiments promises to be very high. The energy definition of Adone for example is about 1/2000.

I should now like to say a few words about the physics — which G. Bernardini would spell with a small f — which had to be negotiated in order to make colliding beam experiments possible. This type of physics has given much more trouble than technology, which so far has treated no kindly: vacuum thecnology has lept ahead by about 3 order of magnitude since the work on storage rings was started and the handling of strong pulsed eletcromagnetic fields necessary for transporting the beams from the source into the ring has proved less formidable than what was generally anticipated.

The effects, which have given trouble and in part still do with the existing machine were the following.

1) The synchrotron radiation emitted by the circulating beams caused desorption from the walls. If this desorption cannot be kept under a reasonable limit the signal to noise ratio of an experiment does not improve if the beam currents are increased.

2) There is a limitation to the life time of the beams, which is independent of the residual gas and the r. f. voltage: it is due to the Rutherford scattering of the electrons of a bunch by one another. The effect is worse in small machines with small energies.

3) Another limitation to beam intensity results from the direct electromagnetic interaction between the two beams.

4) Instability may be caused by the resistive wall self interaction of one beam or by the resistive wall beam-beam interaction.

5) Longitudinal instabilities have been first observed and diagnosed in Novosibirsk as due to the coupling of the r.f. cavity to the circulating beam.

With the exception of the direct beam-beam interaction — which has been considered as a fatal yet tolerable limitation to the intensities which can be achieved with a storage ring — all these effects were painfully discovered as the work was going on. There are now satisfactorily understood and devices for rendering them innocuous have been found. The discovery of these effects required that beams can be stored for a time which is sufficient to permit an observation of sufficient accuracy. An important technique, which served the latter purpose was the observation and measurement of the betatron radiation. This technique has helped us both to see what happens to a beam and to determine its intensity with great accuracy.

The discovery of what was at once recognised as the resistive wall instability at Stanford obviously posed the question of whether the two beams could be made to meet at all. This added importance to the efforts of the AdA group of finding and observing a suitable monitoring process. The idea behind this measurement is the following: a reaction with cross-section d_σ will give a yeld of

$$d\dot{n} = \frac{4f}{K} N_1 N_2 \frac{d_\sigma l_\sigma}{V} \eta_\sigma \text{ per encounter region} \quad [3]$$

where f is the frequency of rotation, Kf the radiofrequency, N_1, N_2 the number of particles in the beam, V the volume of overlap between the two beams l_σ the length of the overlap region actually observed and η_σ measures the efficiency of observation.

N_1 and N_2 can in principle be measured accurately since the observation of the betatron radiation allows one to see a single electron. The unknown quantity is d_σ, which is measured against V, which in its turn depends upon the energy. A measurement of V therefore allows one to give an absolute value to d_σ.

Such a measurement can be effected by means of any reaction which has a known cross-section — or a cross-section that is believed to be known. In the latter category are all those electromagnatic processes which involve very small momentum transfers — for it is these processes that determine the value of the constants of electrodynamics. They have the further advantage that their cross-sections are big, since low momentum transfer corresponds to big impact parameters. Our first choice fell on two quantum annihilation

$$e^+ + e^- \rightarrow 2\gamma \qquad [4]$$

in which the annihilation γ's would be observed in a direction tangential to the colliding beams. (The cross section for the forward process is finite in contrast to Coulomb-scattering, so that monitoring could be done in « bad geometry »). A further recommendation of [4] was that the observation of coincidences would greatly reduce the background: the sensitivity of the arrangement was better than 1 event/hr.

The experiment led to the realization that the two quantum annihilation was completely flooded by double bremsstrahlung, i.e.

$$e^+ + e^- \rightarrow e^+ + e^- + 2\gamma \qquad [5]$$

itselfs a good monitoring process,. its sole disadvantage at the time being that its cross section had not been calculated. This lacuna has meanwhile been filled by the work of the theorists in Novosibirsk, Stanford and Rome. The proces [5] has also been observed in Stanford.

The definite proof for the existence of conditions in which the two beams could be made to meet was given by means of single bremsstrahlung as a monitoring reaction. The process

$$e^+ + e^- \rightarrow e^+ + e^- + \gamma \qquad [6]$$

was observed with AdA in Orsay and it was shown that the common volume of the two beams coincided with that of a single beam. The latter volume was determined in terms of the life time, which owing to Rutherford scattering is directly proportional to the volume. The measurements were made with currents of less than 0.5 mA per beam and in these conditions the effect [6] was about twice as big as the bremsstrahlung contribution from the atoms of the residual gas.

To add to the list of small f physics with storage rings one should not forget the development of the Linac which has been installed here in Frascati — or for that matter the arrangement at Orsay — which produces a very high intensity positron beam. This achievement may open a new branch of physics, in which the electrical properties of the proton may be clearly separated from its magnetic properties by comparing electron to positron cross section measured in nearly identical conditions and with high precision.

Coming to the end of this very brief paper I think that it is worth pointing out that this meeting differs in two ways from previous ones. We do not only celebrate the first experiment in high energy physics carried out with the colliding beam technique, but also — I think — the first conference on the subject in which no new apocalyptic alarms are raised threatening the future of our enterprise — touch wood.

DISCUSSION

WIDERÖE: You mentioned 1% efficiency for production of positrons. Does this take into consideration emitance i. e. those you can catch in your storage ring or is it the total conversion rate?

AMMAN: 1% is the total conversion rate; you can only catch about 1/10 of all i. e. about 1‰ into the storage ring.