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ONE MORE PROJECT FOR AN ELECTRON ACCELERATOR

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I) The investigation of hadronic physics with the electromagnetic probe receives nowadays increasing attention, as witnessed by the numerous electron accelerator projects that one hears about. The present experimental facilities, although powerful and productive, present limitations which the future installations try to overcome. The next accelerators, whether planned or under construction, answer essentially the question of the duty cycle, which in all cases, will reach 100 %.

The point I want to make here is that this criterion should not be considered isolately when defining a new experimental facility.

Let us instead return to the basic questions :

1) What have we already explored about the nucleus (or the hadrons) ?
2) What more has to be learned ?
3) How can we acquire eventually new information ?

1) Most of the electromagnetically induced reactions are explored with real photons :

$$\gamma + A \to x + B \qquad x = n,\ p,\ \pi \ldots \ .$$

By so doing, one obtains the value of the Fourier transform of the transition current or magnetization density at one argument :

$$k = E(x + B) - E(A)$$

for instance, in a non-relativistic situation :

$$M_{(A \mid x + B)}(k) = \int d^3r \, e^{i\underline{k}\cdot\underline{r}} \, \varepsilon < x + B \mid \mathcal{J}(r) \mid A > \ .$$

The content of this information is limited. But if $M_{(A \mid x B)}$ is measured in a wide range of momentum transfer q by using electron scattering, this information is enormously enriched and constrains much more the models for $\vec{J}(r)$.

2) The majority of the possible processes are today extremely costly the explore in this way, the reasons being that i) the virtual photon spectrum is much less intense than the real photon spectrum produced by Bremsstrahlung, ii) for a given final state of the hadronic target, the measurement must be done at many values of the momentum transfer. In practice, few reactions have been investigated in this perspective :

- elastic scattering,
- inelastic scattering to bound states or resonances,
- quasi-free proton ejection,
- electro-production of the π^+ off proton at threshold.

Among interesting subjects which are today out of reach, let us cite :

i) electro-production of π off nuclei, particularly off ^{3}He at threshold ;

ii) inelastic scattering to unbound states (giant resonances, quasi deuteron region, ..) ;

iii) "complete" inelastic scattering in order to obtain precise experimental sum rules and detailed information about the photon absorption.

3) The systematic use of electron scattering in investigating nuclear reactions (more generally, reactions between hadrons) represents clearly a maximal program exhausting the potentialities offered by the electromagnetic interaction.

To bring to life such a program requires that an experimental facility presents at least the following advantages :

1) detectors with a large acceptance ($\frac{\Delta E}{E} \sim 1$, $\Delta\Omega \sim 1$ sr) ;

2) 100 % duty cycle ;

3) high as possible an energy in order to increase cross sections at a given momentum transfer ;

4) simultaneous operation of the experimental area.

II) A possible scheme will now be shortly outlined.

The essential piece is an electron storage ring with internal targets surrounded by large acceptance detectors.

To be more specific, consider a one turn injection, assuming for simplicity the duration of the injected pulse equal to the revolution time in the ring, ΔT_1. We assume that during injection, the electron already in the ring are not perturbed.

At equilibrium, the number of circulating electrons varies cyclically as :

$$n = n_1 \frac{e^{-t/\tau}}{1 - e^{-T_1/\tau}}$$

where n_1 is the number of electrons captured in the ring at each injection, T_1 is the cycling time, $\tau >> \Delta T_1$ is the lifetime in the ring.

The average current in the ring is thus :

$$\bar{i} = \frac{\bar{n}}{\Delta T_1} = \frac{1}{\Delta T_1} \frac{\int_o^{T_1} n\, dt}{T_1} = \frac{n_1}{\Delta T_1} \frac{\tau}{T_1} = j \frac{\tau}{T_1} = \bar{j} \frac{\tau}{\Delta T_1}$$

where j and $\bar{j}$ are respectively the peak and average injected current.

This regime has not strictly a 100 % duty cycle : for the $T_1 = \tau$, the duty cycle is 0.63.

The lifetime τ is essentially determined by the internal targets :

$$\tau = \frac{\Delta T_1}{\sigma \nu}$$

where ν is the number of atoms per unit area in the targets, and σ the cross section for an electron to be lost out of the ring, due to e-e collisions and e-N Bremsstrahlung (neglecting nuclear interactions) :

$$\sigma = 4\pi\, r_o{}^2\, Z\, \frac{1}{\varepsilon} \frac{1}{\Delta_{min}} + f\, \alpha\, Z^2\, r_o^2 \,\mathrm{Log}\, \frac{1}{\Delta_{min}}$$

where ν is the electron energy in electron mass unit,

$r_o = e^2/m_e\, c^2$,

Δ_{min} is the relative energy loss above which the electron is lost from the ring.

f in the Bremsstrahlung cross section has a value ∿ 12 (complete screening).

The average rate of interesting events, whose cross section is σ_N and detection efficiency is ε_N, is thus :

$$\bar{p}_N = \bar{i}\ \sigma_N\ \varepsilon_N\ \nu = \bar{j}\ \frac{\sigma_N \varepsilon_N}{\sigma} .$$

This rate is to be compared to the one obtained with an external beam of average intensity $\bar{j}$ crossing a target with ν' atoms per unit area :

$$\bar{q}_N = \bar{j}\ \varepsilon_N\ \sigma_N\ \nu'$$

hence :

$$\bar{p}_N/\bar{q}_N = \frac{1}{\sigma\nu'} = \frac{1}{\sigma\nu}\ \frac{\nu}{\nu'} = \frac{\tau}{\Delta T_1}\ \frac{\nu}{\nu'} .$$

In view of the wide range of parameters, there is a great flexibility in the design of such an accelerator. A numerical example, however, should help to concretize the matter.

III. We choose $\varepsilon = 2$ GeV.

$\Delta T_1 = 1$ μsec (ring circumference = 300 m).

$T_1 = 1$ msec.

$n_1 = 6 \times 10^{11}$ el. stored at each injection, corresponding to the average current :

$$\bar{j} = 100\ \mu\text{A}.$$

We assume :

$$\Delta_{min} = 10^{-3}$$

and investigate the case of an hydrogen or a lead target with superficial mass 100 μgr cm^{-2}.

The corresponding lifetimes are respectively :

$$\tau_H = 5 \times 10^{-2} \quad \text{and} \quad \tau_{Pb} = 10^{-2}\ \text{sec.}$$

In each of these cases, the average number of electrons in the ring is :

$$\bar{n} = \bar{j}\,\tau = 3 \times 10^{13} \quad \text{and} \quad 6 \times 10^{12}.$$

As for the smallest cross section measurable, on lead with $\Delta\Omega = 10^{-2}$ sr and 10^{-2} counts sec^{-1}, it turns to be $\frac{d\sigma}{d\Omega} = 5 \times 10^{-37}$ cm^2 sr^{-1}.

IV. Some problems.

1. The synchrotron radiation is a further cause for electron losses. As an example, with 20 m. of curvature, the loss per turn at 2 GeV is 70 keV.

2. Multiple scattering in the targets with individual losses $\Delta < \Delta_{min}$ decreases further the lifetime. These two effects must be cancelled by reacceleration of the electrons with an R.F. cavity.

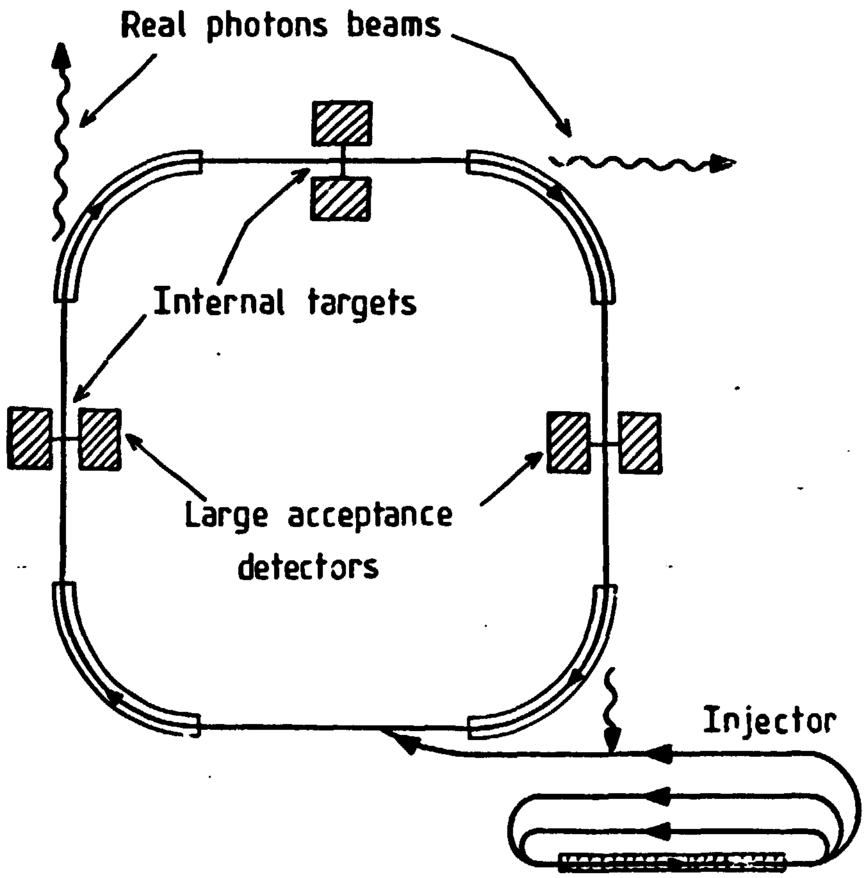
3. The injector energy must equal the ring energy, because there is no time enough left for accelerating the beam in the ring.

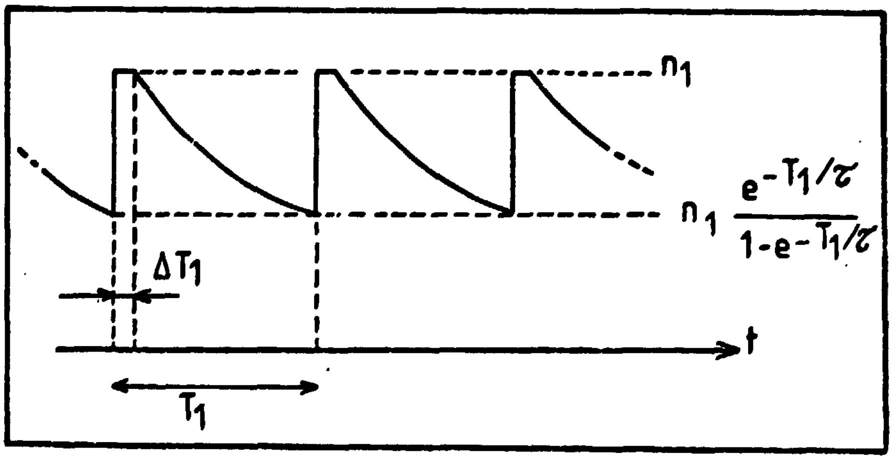
4. The intense beam loss from the ring (in the given example, $\bar{j} = 100\ \mu A$), must be carefully controlled.

5. Solid targets could not bear the intense beam. Gazeous jets of high density (up to 200 μgr cm^{-2}) are now developed, by it is not sure that any nucleus can be put in this form.

V. In conclusion, a project along these lines offers interesting features, eliminates the extraction device associated with a beam stretcher when an external beam is needed. If the difficulties mentioned above were overcome and the system proved feasible, it remains nevertheless that such an experimental facility would be very complex and expensive.

I acknowledge many discussions with my colleagues in Saclay and especially Dr Netter who tries to substantiate what is merely an idea.


Real photons beams
Internal targets
Large acceptance detectors
Injector


n_1
$n_1 \frac{e^{-T_1/\tau}}{1-e^{-T_1/\tau}}$
ΔT_1
t
T_1