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MEDIUM ENERGY PION BEAM MONITORING SYSTEM

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A monitoring system for the LNF-LEALE positive and negative medium energy pion beams is described. The system is based upon the integral measurement of the beam charge, in analogy with Faraday-cup methods used for electron beams. Results of experimental tests are reported together with a discussion of correction methods obtained by Monte-Carlo techniques.

1. Introduction

Measuring the intensity and monitoring secondary beams of particles, such as those obtained by high intensity linear accelerators, with a low duty cycle ($\lesssim 5\%$), turns out to be rather difficult.

Unfortunately, this is just the case of the medium energy, "fairly" high intensity ($\approx 10^6$ particles/s) pion beams already developed, or scheduled for the next future, in various laboratories (Frascati, Saclay, MIT).

Therefore a number of methods have been proposed, also recently[1]), for the solution of this problem, which can be roughly schematised into three major groups:

a) counter techniques, such as the detection at a fixed angle of the decay μ from the pion, or the scanning of small transverse sections of the beam by means of counter "stars", etc.;

b) charge measures of the secondary beam, by means of secondary emission monitors, ionization chambers or integrating devices (Faraday cups);

c) calorimetric methods, based upon the measurement of the amount of heat released by the primary photon beam into the pion-producing target.

The choice of either of those methods is strictly connected not only to its complexity or to the requested precision and reliability but, mainly, to the actual experimental conditions one has to deal with. For various reasons to be explained later, we restricted our attention to the preceding item (b). Some developments are now in progress also on item (c).

In this paper we describe in detail the apparatus (Faraday cup) and the method we developed for measuring the integrated charge of the LNF pion beam[2]).

The apparatus has been operated during extensive machine runs and yielded satisfactory results. Though it is especially tailored for our experimental conditions (high neutral background of gamma rays and neutrons), we think it could easily be adapted to different situations, insofar as its performance is that of an absolute instrument.

2. Principle of the method

The outstanding features of our experimental situation are:

- low machine duty cycle ($\lesssim 1$‰);
- high neutral background in the experimental area;
- pion beam intensity $\approx 10^6\ \pi^{\pm}$/s.

This automatically excludes the use of counter (coincidence) techniques and the non-destructive measure of charge "in flight" (ionization chambers) for monitoring purposes.

We have therefore oriented ourselves toward an integral charge measurement performed by means of a Faraday cup in analogy with the method usually adopted for electron beams[3]).

This monitor, as known, collects in a destructive way the integrated charge of the beam and transfers it to a calibrated capacitor. For electron and positron beams the charge collection mechanism of a Faraday cup is based upon the development followed by absorption of the electromagnetic shower in a high Z material. In this case various phenomena must be accounted for, which can lead to a loss of precision (in an absolute sense), apart from the intrinsic instrumental accuracy: shower penetration, backscattering, creation of secondary electrons, etc.

On the other hand, the total absorption of a pion beam (in such a device) is essentially due to ionization energy losses and nuclear interactions. The current of our pion beam, however, is lower by several orders of magnitude than that of a linear accelerator electron beam, with the result that particular care must be devoted to the sensibility of the charge collecting and measuring devices, taking into account also the radiation background level existing in the experimental area.

We may therefore conclude that two major types of limitations arise in actual measurements. First, the leakage current of the whole charge collection system (Faraday cup plus electrometer), which must obviously be lower than the (small) expected signal. Second, the peculiar features of pion absorption and decay in condensed matter, which can lead to erroneous results; in particular it is not the same for π^+ and π^-.

A more detailed description of the absorption mechanism will be given in section 4, together with the corrections to be applied to the experimental data.

3. The experimental apparatus

The Faraday cup for pions of the Leale Laboratory (fig. 1) has a central core made up of four circular copper plates, 50 cm diameter, total thickness 12 cm, which allows the absorption of up to 200 MeV pions. The plates are mounted inside a vacuum envelope closed by a thin (≈ 2 mm) aluminum entrance window.

The ionization of the residual gas atoms in the vacuum surrounding the central core affects the instrumental leakage current, thus placing a lower limit to the detectable current.

With a vacuum of 10^{-4} torr, the leakage current is stable within a few units in 10^{-16} A.

The vacuum in the assembly is maintained by means of a titanium pump (fig. 2) which is connected so as to avoid that the ions from the pump itself can reach the vacuum area. The vacuum pressure is read by a vacuum-meter* directly connected to the container. The meter is normally off during the actual charge measurement, because it could alter it by injecting to the collecting plates a relatively high number of ions and electrons. As shown in fig. 1, the copper core is kept in place at the top and the bottom by double teflon

* Varian type.

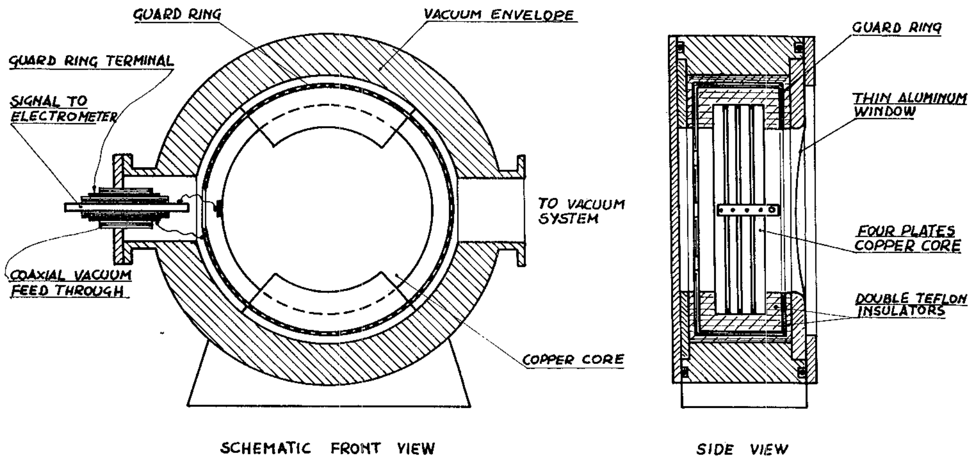

Fig. 1. Faraday cup assembly.

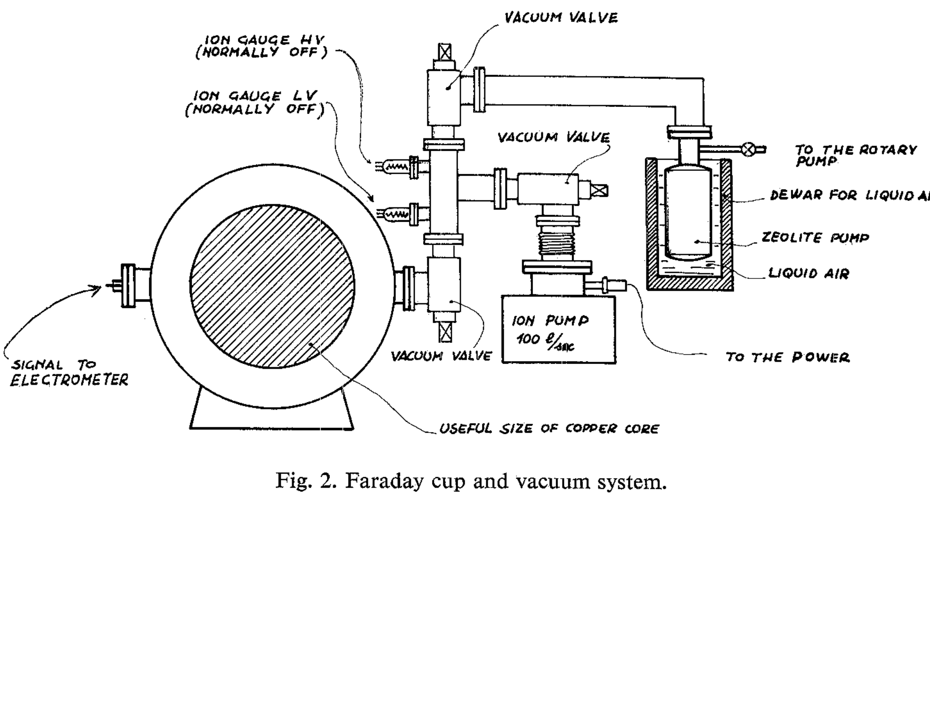

Fig. 2. Faraday cup and vacuum system.

insulators, cradle-shaped, separated by a guard shielding. The collected charge is picked up from the central core by means of a silvered copper wire leading to a special triaxial connector provided with a ceramic insulator and a guard ring.

The mean current with pion beam on is sent to a preamplifier through a special polyethylene low noise coaxial cable†. The resulting voltage drop across a high value resistor (10^8–10^{12} Ω) is measured by a very high sensitivity vibrating reed electrometer+ whose output signal is converted by a standard voltage-to-frequency converter and finally read by a scaler.

The vacuum container of the Faraday cup is connected to the general ground of the experimental area, while the guard shielding is connected, through the triaxial connector guard ring, to the electrometer's virtual ground. The electrometer chassis is, in turn, connected to the general ground. Ionization of the air inside the preamplifier envelope turns out to be one of the most important background sources, mainly because of the high radiation level in the experimental area, which is originated by the primary electron beam. This effect has been diminished by keeping the preamplifier far from the "hot" area and enclosing it in a lead box 1 cm thick.

4. Corrections and experimental data

We want now to analyze the different behaviour of nagative and positive pions in their interaction with condensed matter.

All the negative pions can be thought as giving rise to nuclear disintegrations after coming to rest[4]). In most cases the ultimate goal is the production of stars, whereas sometimes the nuclear disintegration consists in the evaporation of the nucleus, with emission of neutrons only. The charged prongs of stars are less favoured than the neutral ones: in any case most of them have not enough energy to escape from the absorbing material.

Quite different, instead, happens to be the situation for positive pions. Most of them undergo the $\pi^+ \rightarrow \mu^+ + \nu$ decay, which is followed by the $\mu^+ \rightarrow e^+ + \nu + \bar{\nu}$ decay. The final positron can now possibly leave the central core of the cup, depending on its creation point, on the energy of the primary pion and on the geometrical design of the detecting apparatus. This process would, of course, lead to a loss in our charge collection efficiency.

† AMPHENOL no. 21-541, terminated by coaxial connectors type UG-260/U and UG-290/U.
+ CARY 401 Vibrating Reed Electrometer–CARY Instruments.

A Monte-Carlo calculation has been performed in order to correct the experimental results concerning the positive pions. For each π^+ in the incident beam the points where the two cascaded decays occur are calculated. The angles θ and φ of the emitted positron, with respect to a prefixed reference system, are randomly extracted with an isotropic distribution. The positron energy is also extracted with a probability distribution given by the well known e^+ energy spectra in the μ^+ decay. The program then uses the above parameters to trace each created positron throughout the central core of the cup, in order to establish the fractional percentage of escaped e^+. The tracing routine takes into account the positron ionization and bremsstrahlung energy losses, together with their statistical fluctuations. Also the probability of e^+ annihilation in flight and the multiple Coulomb scattering, which largely deviates positrons from their initial trajectories, are considered. Instead, the contribution of the Compton e^- by the bremsstrahlung is neglected.

In fig. 3 we have indicated the experimental mea-

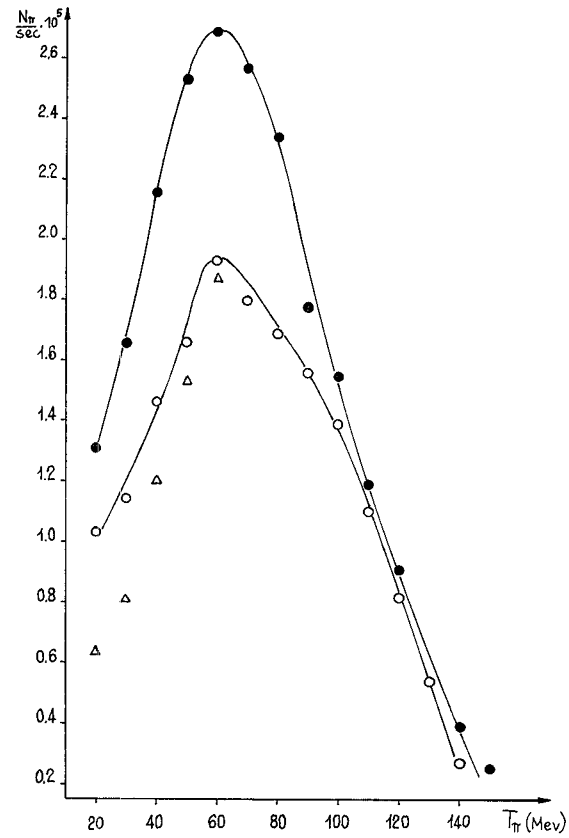

Fig. 3. Experimental results obtained with pion beams on: ● $= \pi^-$; △ $= \pi^+$ uncorrected; ○ $= \pi^+$ corrected.

surements of the pion yield from the Frascati electron linac at different pion energies[2]). The measurements have been performed with a primary electron energy of 320 MeV, a peak electron current of 100 mA, 150 pulses per second, each 3.2 μs long, a tantalum bremsstrahlung radiator of 0.075 radiation lenghts and a pion source of 10.5 g/cm^2 of carbon.

The π^- yields are the raw experimental results. For the π^+ we have indicated the raw data and the same data where the decay correction has been applied.

The different energy points on the curves have not been taken simultaneously. Therefore they are sensitive to all kinds of instabilities in the primary electron and photon beams as well as to spurious charges produced in the device by the very high intensity background radiation, etc. The errors introduced by the charge measuring apparatus are due to fluctuations in leakage currents produced in the electrometer high impedance preamplifier head and to the intrinsic electrometer's precision: we have estimated all this to produce an error of 2% at most.

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