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SURVEY OF BEAM MONITOR POSSIBILITIES FOR THE EJECTED BEAM AT THE C.P.S. EAST AREA

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SUMMARY

Possible beam monitors for the slow ejected beam at the C.P.S. are discussed. In particular, the optical and direct electrical methods are investigated. The final discussion should enable us to select the most promising monitor for more detailed study.

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INTRODUCTION

The requirements for detectors of the future external proton beams and some possible solutions are summarized in Table I. It is apparent from this survey that some new detectors have to be developed, notably to assist the focusing on the target (spot sizes of a few mm). We also desire to measure the intensity of the slow ejected beam in a non-destructive way. The latter detector constitutes a difficult task, as the beam current is only 0.25 μA to 100 μA (at 3×10^{11} protons/p in the beam), and beam bursts from 200 msec to 0.5 msec.

It is the purpose of this report to select from the multitude of possible beam monitors the most suitable ones for further consideration.

We have divided the beam monitors in three groups:

1) Nuclear reactions (C. Bovet[1])
2) Direct electrical signals (H. Zulliger, Part A)
3) Light emission (C. Fabjan, Part B).

There exists already a report by C. Bovet[1] describing nuclear reactions, but 2 and 3 will be discussed here.

PART A

POSSIBILITIES FOR PROTON DETECTORS BASED ON DIRECT ELECTRIC PHENOMENA

Table II shows a survey of such particle detectors.

	Usable for:
I. Non-intersecting monitors	
1. Electromagnetic pick-up	I (Pos)
2. Electrostatic pick-up	I (Pos)
(3. Cavity)	
II. Semi-intersecting monitors	
1. Residual gas ionization chamber	I
III. Intersecting monitors	
(1. Geiger tube)	
(2. Spark chamber)	
3. Resistance monitor	I,Pos,Pr
4. Thermo-couple monitor	I,Pos,Pr
5. Secondary emission monitor(SEM)	I (Pos)
6. Ionization chamber	I
7. Solid state detectors	Pos (Pr)
8. Faraday cup	I

I = Intensity

Pos = Position

Pr = Profile

The detectors and/or used in brackets are questionable in case of the C.P.S. slow ejected beam.

I. NON-INTERSECTING BEAM MONITORS

1. Electromagnetic Beam Monitor

Because of better coupling with the beam, we prefer a toroidial magnet core which is not position-sensitive. The necessary increase of sensitivity by a factor 10^5, compared to the presently used monitors in the C.P.S., causes problems in amplification and pick-up from external noise sources. The sensitivity can be scaled up by improving the geometry and the permeability of the magnetic core. A toroid with 25 000 turns would have an output voltage of 7.5 μV and 10^{-11} A, (for 3×10^{11} p during 200 ms). These values are smaller than the noise figures of good commercial amplifiers. In order to shield against external noise sources, a magnetic and electric shield is provided. Field effect transistors or cascaded TI 2 N930 transistors may improve the amplifier (For detailed estimates see ref. 3).

2. Electrostatic Beam Monitor

We can increase the sensitivity by having a long electrode, e.g. 100 cm. Under the same beam conditions, this yields a voltage of 37 μV on a capacity of 35 pf. The initial discharge current is 1.3×10^{-15} A for a time constant of 1 sec. Good electrometer tubes have a grid leakage current in the same order of magnitude. Field effect transistors may, however, solve this problem.

Ionization of the rest gas apparently causes severe problems [5]. We suggest a fine grid inside the electrode to collect these free charged particles (For further details see reference 4).

3. Cavity Monitor

The cavity monitor does not work in the slow ejected beam.

II. SEMI-INTERSECTING BEAM MONITOR

The residual gas monitor[6] does not require any end foils; thus only the residual gas is intersecting the beam. This monitor operates on the same principle as an ionization chamber, but has a simpler field distribution, and it is, therefore, easier to calculate the efficiency. The protons ionize the rest gas in the beam pipe, and by varying the gas pressure, one can adjust the sensitivity. The problems involved in this method are: purity of gas, constant gas pressure, recombination and secondary emission.

III. INTERSECTING BEAM MONITORS

1. Geiger tube.

2. Spark chamber.

Neither methods can resolve nor integrate proton flux bursts of 10^{12} p/sec.

3. Resistance Change Monitor

Even though some encouraging information from SLAC[7] was received about Fenwall bead thermistors withstanding 10^{13} erg/g in a 70 MeV electron beam, this application requires further studies. A thin platinum wire still seems to be the most reliable sensor for a resistance change monitor.

A ten times zig-zagged 0.05 mm diameter platinum wire increases its resistance by about 3% (6×10^{11} p/p in the centre gives a temperature rise of approximately 10°C). Employing a difference method measuring the resistance, 0.5% accuracy seems to be possible. The cooling time constant can be adjusted by changing the heating current through the wire. (50 mA heating approximately to 100° C in vacuum). The output voltage is several mV (Details of relevant calculations can be round in reference 8).

4. Thermo-couple Monitor

Philips thermo-couples with 0.05 mm lead diameter can be placed in the beam. The output EMF is proportional to the temperature at the junction. This is a point sensor and, therefore, sensitive to position changes in x and y direction simultaneously. Because of heat conduction in the leads, the temperature distribution becomes very complicated and it is difficult to find a good geometrical arrangement. The output voltage of one Pt Rd-Pt thermo-couple would be approximately 0.5 mV ($\Delta t = 10^{\circ}$ C). Again a series connection of several junctions and a compensation method would yield a reasonable output signal of several mV. Because of the difficulties to adjust the time constant and the unclear temperature distribution, we think this method to be inferior compared with the resistance change device (More information can be found in reference 9).

5. Secondary Emission Monitor

Good results were obtained with transmission dynodes for an electron multiplier, using a thin KQ layer on Al foils, as reported by Sternglass[10]. The flux was, however, only 10^6 p/cm^2 sec .For a larger number of particles, such as 10^{12} protons/p, the voltage drop caused by the high current,and the high resistance of the layer, can exceed the bias voltage and the SEM saturates. Al foil backings oxydize and do not reduce the resistance appreciably. We are still left with the old problem of having a very thin (10 μ) , homogeneous, non-oxidizing and conductive foil. Recently developed diffusion techniques may allow a thin layer of corrosion proof material to diffuse onto an aluminium foil. AMPERO, Embarcadero Rd. in Palo Alto, Cal. USA, could be contacted for diffusion problems.

SLAC[11] reports a stable SEM with aluminium foils. Special procedures are, however, required to keep the surface clean.

6. Ionization chamber

SLAC[12] reports an ionization chamber over a range of $10^5 - 10^{10}$ e/p . Levine and Swartz[13] constructed a chamber for 10^{11} p/p with pulse length from 20 μsec to 250 msec. If the gas pressure could be lowered somewhat more, we might be able to develop a chamber for 10^{12} p/p. The problems involved in building a stable ionization chamber are:

a) Recombination
b) Gas purity
c) Constant pressure
d) Secondary emission.

7. Solid State Detectors [14]

Solid state detector monitors are based on the same principle as ionization chambers, but having the advantage of an energy loss per ion pair of $\epsilon \cong 3$ eV (~ 30 for gas). This number allows to build detectors yielding about 2V output signal in the C.P.S. proton beam. Unfortunately, the devices are radiation sensitive, and the signal strength decreases rapidly with radiation over 10^{13} p. O. Barbalat [14] has built a profile indicator with 8 diodes which works satisfactorily. However, long term stability causes problems and a continuous calibration method would be desirable.

8. Faraday Cup

The Faraday cup is a precise monitor for total charges, but it is not transparent. Because of its large dimensions (~ 2 m length for Stanford Mark III , 1 GeV linac) and high absorption, it could only be used after the target.

PART B

Possibilities for proton detectors based on light emission phenomena

Table III indicates the principles of such particle detectors.

Table III

Type of detector	usable for
I. Non-intersecting monitors (1. Synchrotron light)	(I) Pos
II. Semi-intersecting monitors no detectors existing	
III. Intersecting monitors 1. Scintillation light	(I) Pos, Pr
2. Cerenkov light	(I) Pos, Pr

I. Non-intersecting monitors

1. Synchrotron light

The synchrotron light effect, which is frequently used for electron beam monitoring, is far too small for monitoring in the case of accelerated protons ($I \propto \frac{1}{m^3}$ for particles on a circular path).

III. Intersecting monitors

1. Scintillation light

1.1 Homogeneous scintillators

1.1.1 Zn-S screens

Zn-S screens*) are widely used for position monitoring[15]. Spatial resolution is sometimes insufficient, and it is difficult to obtain screens with comparable scintillating properties. Radiation damage requires frequent replacement.

1.1.2 Discs of a plastic scintillator

Discs of plastic scintillator material, 1 mm thick, have been used for position monitoring. (For experimental details see reference 16). With a standard TV equipment, a particle flux of 10^{10} protons/cm^2 pulse is observeable. This material is easily obtainable with well defined scintillation properties, and it can be machined for any wanted shape.

The intensity region to be observed is simply governed by the thickness of the material. Experiments on radiation damage are under preparation.

1.1.3 Other usable materials

We did not consider in detail standard scintillating material, e.g. NaI (Tl) crystals, since they are more suitable for single particle counting. The higher light output, compared with plastic scintillators, is, however, not a preferable feature, as in our case light intensities obtained with plastic material are high enough for TV operation.

1.2 Scintillating fibres

We have studied the following filament device: about 100 plastic scintillator fibres, 0.5 mm diameter, are inserted into the beam with very little spacing and with the axes of the fibres normal to the beam axis, thus covering with the fibres an area larger than the beam cross-section. By observing the ends of the fibres with a TV camera, we obtain from the video signal the information about position and profile of the beam[16]. Spatial resolution of the device is limited by the fibre diameter; the accuracy of the profile is limited by the noise of the TV camera and the optical properties of the fibres.

*) Perhaps one should study other materials, such as $CdWO_4$

1.3 Scintillating gas

Koch[18] measured the photon yield from noble gases when bombarded by 5 MeV α particles. From these results we note that xenon has the highest light output per unit length and at a given pressure. The photon efficiency can be increased considerably when using a noble gas - nitrogen mixture and operating the cell in an electric field. De Raal gives some possible realizations of gas cells, having a visible length of about 15 cm[17]. For these lengths, the unsharpness of the image is about 10% of the beam size.

2. Cerenkov light

The use of Cerenkov light for beam monitoring seems to be very attractive and there exist already some suggestions[17].

2.1 Cerenkov light from a gas.

de Raad[17] suggests an Argon-Cerenkov cell for electron detecting. Since the refraction index of NTP Argon is n = 1.000281 (for the D line), the threshold energy for Cerenkov light emission, given by $n\beta = 1$, is reached for protons at an energy of about 130 GeV. At our energies a high pressure cell would be required which makes this solution less interesting.

2.2 Cerenkov light from a liquid.

With a water cell, we obtain the following figures:

d = 1 cm   thickness of the cell

N = 190   number of photons produced per cm, in the spectral region λ = 4000 to 650   (for 27 GeV protons).

With a suitable optical system, a flux of 10^{10} protons/cm^2 pulse should be observeable. The r.m.s. scattering angle at 27 GeV is

$$\vartheta_{r.m.s.} = 10^{-3} \text{ radians.}$$

2.3 Cerenkov light from a solid.

de Raad[17] suggests the observation of the Cerenkov light emitted from particles when traversing a thin quartz plate. With a 3 mm thick plate we could expect to observe 10^{11} protons/cm^2 pulse.Since in the region of 10 GeV to 27 GeV, the β for protons varies up to 4%, adjustment of the optical system is necessary for different energies.

A comparison of the various detectors discussed is given in Table IV.

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TABLE I

REQUIREMENTS FOR DETECTORS OF THE EXTERNAL PROTON BEAM AND SOME POSSIBLE SOLUTIONS [2]

Quantity to be measured	Position of beam	Time Dependence	Profile	Intensity
Aim of measurement	1) Steer beam on target 2) (Later) Closed loop control of beam transport magnets	1) Timing of pulsed magnets 2) Counting number of ejected bunches	1) Focusing beam on target 2) Adjusting beam width of slowly ejected beam and verifying the proton distribution in time + space	1) Transmit value to physicist 2) Personnel safety in case of incompletely shielded external beams
Detectors for ejected beam: a) rapidly b) slowly	for 1): screen + TV	current transformer electrostatic pick-up Čerenkov counter	for 1) ? for 2) Diodes	for 1)2) current Transformer for 1) SEM

TABLE IV - COMPARISON OF BEAM MONITORS FOR SLOW EJECTED BEAM OF THE EAST TARGET AREA

Measured Quantity	Pr = Profile Pos = Pos Intensity	I. = Intersect NI = Non-Int. SI = Semi-Int.	Application	Discussion
<u>Profile</u>				
1. Plastic fibres + TV	Pr, Pos (I)	Intersect.	Adjusting the beam for set-up	Visible display of every beam pulse profile to ~ 20% relative intensity. Simple set-up. Radiation damage excludes routine use on every pulse
2. Platinum wire monitor	Pr.Pos.I	"	Gives average beam profile during beam burst	Absolute accuracy of 0.5% possible, but relatively slow method. Direct analogy and digital read-out. Infinite lifetime
3. Diodes	Pr.Pos.(I)	"	Adjusting the beam for set-up and measurement of dynamic behaviour	Visible display and electric read-out. Complication increases with better resolution. Radiation damage starting after 10^{13} protons.
4. Emulsions	Pr.Pos.(I)		Calibration purposes	Slow, but accurate monitor.
<u>Intensity</u>				
1. Electromagnetic pick-up	I	N.Int.	Continuous monitoring of beam intensity. Also dynamic behavior possible to detect	Requires amplifier at the limit of today's development. Excellent magnetic shielding necessary.
2. Electrostatic pick-up	I	N.Int.	Continuous monitoring of the beam intensity and dynamic fine structure	Requires electrometer tube at limit of today's development. Very effective shield against charged particles necessary (grid suggested)
3. Secondary emission monitor	I	Int.	Continuous monitoring of the beam intensity	Long-term stability problems, thus recalibration necessary. Otherwise simple and accurate device.
4. Ionization chamber	I	Int.	Continuous monitoring of the beam intensity	For good accuracy, pressure control and pure gas necessary. Very low pressure required for high beam currents.
5. Residual gas monitor	I	S.-Int.	Semi-intersecting continuous intensity monitor	For accurate results calibration curve nedessary with pressure as parameter. Similar problems as ionization chamber.

TABLE IV (cont'd)

Measured Quantity	Pr=Profile Pos = Pos Intensity	I.=Intersect. NI=Non-int. SI=Semi-int	Application	Discussion
<u>Position</u> 1. Screens: Zn-S Plastic scintillator + TV	Pos.	Int.	Adjusting the beam for set-up	Frequent exchange necessary because of radiation damage. Very good light output.
2. Čerenkov light from a quartz plate	Pos.	Int.	" " " " "	Advantageous, if high resistivity quartz can be found.

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