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Gruppo Adone : PRESENT STATUS AND OPERATION. -

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Gruppo Adone : PRESENT STATUS AND OPERATION(x).

Starting December 10, 1969, Adone has been running for experiments with head-on collisions and beam energies up to 1200 MeV. Four experiments are running at a time.

The present energy limitation is due to the fact that two of the four RF cavities have not been installed yet. Installation of full RF power is scheduled to begin at the end of this year or around February 1971, 1500 MeV beams will then be available.

At the high energy side of the working range the design values of luminosity have been obtained.

Table I contains a short history of operation: values of luminosity integrated over two-beam operation time, L_{int}, average luminosity over the same period, L, and the running time, T, are shown as functions of energy, month by month. The average luminosities are a sizeable fraction of the maximum obtainable ones, at all energies.

INJECTION. -

The Linac beam is modulated at the ring RF frequency to decrease the average current on the converter and to provide for separate injection on different bunches, if needed.

The repetition frequency is 1.5 pulses per second. Maximum injection rates of 35 mA/m of positrons (on three bunches) have been obtained while the average rate is of the order of 20 mA/m. At these rates a sizeable fraction of injection time is spent on performing the operations necessary to switch beams rather than on actual injection. For this reason no great effort has been put into further optimization of injected current. The

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(x) - Presented at the Informal Meeting on Electron and Positron Storage Rings (Frascati 1970) by S. Tazzari.

TABLE I

Data on Adone operation, starting on Dec. 10, 1969
Li = integrated luminosity per experimental section [10^{32} cm^{-2}]
L = average luminosity " " " [10^{32} cm^{-2} hr^{-1}]
T = effective two beam time [hr]

E (GeV) / MONTH	0,700	0,750	0,800	0,825	0,850	0,875	0,900	0,925	0,950	1,000	1,050	1,100	1,200	TOTAL	
Dec. 69					23.8 1.25 19		28 1.45 19.3		6.4 2.14 3	103 2.38 43.3				161 1.9 84.6	Li L T
Jan. 70				33.6 1.26 26.7	11.5 1.58 7.3	88 1.55 57.0	48.2 1.73 27.8			87.5 3 29.3				263 1.78 148.1	
Feb. 70				45 1.38 32.7	101 1.7 59.5	67.6 1.76 38.4				167 2.84 59.0				381 2 189.6	
Mar. 70			91 1.34 67.9	69.5 2 35.0			98.6 2.86 34.4	142 3.16 45	136 2.4 56.6					537 2.25 238.9	
Apr. 70		26 0.9 29					86 2.2 39		61 1.5 42		12.6 1.6 7.7			185.6 1.6 117.7	10 days shutdown
May 70	61 0.7 87	66 0.9 72	1.25 1.8 0.7							0.41 1.2 0.34		40 0.95 42		169 0.84 202	
June 70								202 2 100				33.5 1.6 21	13.5 2.3 6	249 1.96 127	2 weeks shutdown
July 70		55 0.9 61									148 1.6 93			203 1.32 154	
Aug. 70											300 3.05 98.4			300 3.05 98.4	
TOTAL	61 .7 87	147 .9 162	92.25 1.36 68.6	148 1.5 98.9	136.3 1.59 85.8	155.6 1.63 95.4	261 2.17 120.5	344 2.37 145	203.4 2 101.6	358 2.69 133	460.6 2.32 199.1	73.5 1.17 63	13.5 2.3 6	2448 1.83 1360	Li L T

time necessary to have two beams of ~ 40 mA injected, is approximately 10% of the average useful beam life. The beam lifetimes are of the order of 6 hours at 1000 MeV.

The injection procedure is as follows:

- Positrons are injected at ~ 300 MeV;
- Electric fields are switched on to separate positron from electron orbits;
- Electrons are injected;
- The energy is raised to the desired value and the Q's are brought onto the coupling resonance (3. 07, 3. 07);
- The electric fields are switched off to obtain the crossing.

Transverse feedbacks are always acting throughout injection. A longitudinal feedback on the main RF phase is also used whenever the sum of the circulating currents exceeds ~ 10 mA, and a small RF cavity, tuned on a frequency multiple of the turn but not of the RF frequency, is used to separate the synchrotron frequencies of the three bunches.

VACUUM. -

After baking the chamber and restoring the pumping speed to its design value of 14. 000 l/s the static vacuum has reached a value of 2-3 x x 10^{-10} torr (the chamber volume is ~ 6 m^3). Also, beam conditioning has drastically improved the desorption.

After each opening, besides being heated up, the chamber is conditioned by letting an intense e^- beam circulate both ways, for a time corresponding to about 10 Kcoul (total) at 1000 MeV. At the end of this treatment desorption has usually decreased to within a factor of three or four from the asymptotic value (starting from a value 15-20 times higher than asymptotic), and is low enough that machine operation can be initiated.

After conditioning by a total of about 40 Kcoul the desorption reaches its asymptotic value. This value seems to vary to within a factor of ~ 2 from one opening to the next. Our statistics is at present too poor to be able to ascribe the effect to a definite cause.

The gas composition with and without beam is shown in Table II. $\langle Z^2 \rangle$ monoatomic, as calculated from mass spectrometer data is found to be 25. A more reliable value of $\langle Z^2 \rangle$, in fairly good agreement with the observed lifetimes, is given by gas-bremsstrahlung measurements and corresponds to a $\langle Z^2 \rangle$ about a factor of 2 higher.

The best value achieved for the pressure increase with current, at 1 GeV is

$$\frac{\Delta p}{I} = 1.5 \times 10^{-11} \text{ torr/mA} \qquad \text{(1 GeV)}$$

TABLE II

Gas Composition

	Static	With beam: (1 GeV) %
H_2	36	60
H_2O	30	10
CO	4	10
CO_2, C, CH_4, OH, . . .	30	20

With an effective pumping speed of ∿ 7000 l/s this gives for the photon desorption efficiency DE_γ the value of 6×10^{-6}, in good agreement with ACO and CEA data.

The dependence of $\Delta p/I$ on energy is in agreement with the Bernardini-Malter assumptions(1) and rules out the possibility that the pressure rise be given by beam heating of the chamber walls. This last point has also been checked by water cooling a portion of the chamber.

TRANSVERSE INSTABILITIES. -

The transverse instabilities at Adone have characteristics consistent with those predicted by the head-tail effect theory.

Furthermore all data are consistent, within experimental accuracy, with the hypothesis that the zero'th order mode (center of mass moving) accounts for all of the instability.

This circumstance allows us to control the antidamping by means of a feedback. Since each bunch goes unstable independently one fast (bunch--to bunch) feedback, or several feedbacks, one per each mode, are required. We chose the first solution.

One half (the radial one) of the block diagram is shown in Fig. 1. The vertical half is identical. The dynamic range of the final nonsaturating amplifier is of the order of ± 15 V with a risetime of ∿ 15 ns. The total nominal gain is 10^4. The noise level is of the order of ± 2 V.

The actual gain, defined as the voltage produced at the feedback electrode, per unit beam displacement at the pick-up electrode, and per unit current is of the order of 0. 1 V/mm x mA (circulating current).

We can summarize our results by saying that, in the present situation, the feedback consistently prevents beam losses at least up to 60 mA

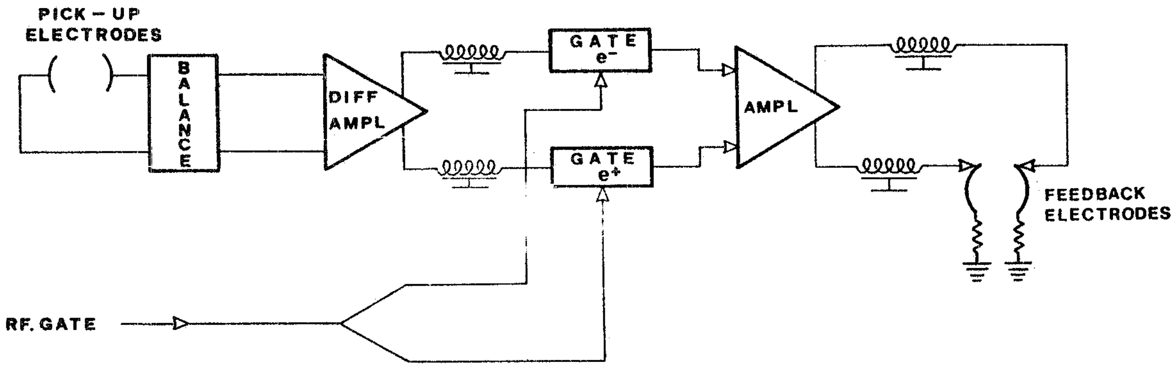

FIG. 1

per beam, but does not always succed in completely stabilizing the two beams, when they are separated.

This has fortunately very little influence on luminosity since, when the beams cross, the additional nonlinearities produce complete stability.

An increase in gain would nonetheless be desirable and is being worked on.

LONGITUDINAL INSTABILITIES. -

The zero'th order mode of phase oscillation is stable at Adone, and the higher order modes are stabilized by means of a small cavity as mentioned earlier.

In both cases though the margin of stability is very low and occasionally some perturbation (like tuning) will trigger an instability.

If this happens during injection the beams are usually lost.

We have therefore installed a feedback system to control the zero'th order mode (or c. of m. mode). The phase of an RF signal extracted from beam pick-up electrodes is compared with that of the RF pilot oscillator and the information is used to correct the main RF phase. Of course this feedback loop is external to the phase stabilization loop.

The system works well and makes center of mass instabilities disappear. A similar system for stabilizing the higher order modes is being worked on.

BUNCH LENGTH. -

Measurements performed at ACO(2), Kharkov and Adone have shown that the ratio of measured to natural bunch length increases with current and the lengthening is a function of energy and RF voltage.

We have recently repeated some measurements of the effect and the results can be summarized in the following formula:

$$(1) \qquad \left(\frac{L}{L_r}\right)^2_{fwhm} = 1+(2\pm0.2)\times10^{-2}\, V_{kV}^{0.3\pm0.05} \times \frac{I_{mA}^{1.05\pm0.05}}{E_{GeV}^{4\pm0.2}\, L_{nS}}$$

where L_r is the length due to radiation only. The formula is the result of a four parameter best fit of ~140 points. Our measurements are accurate to the order of 10%.

The formula is similar to that given in the Nov., 1969 ACO$^{(2)}$ report on bunch lenghtening, except for the presence of $V^{0.3}$. The Kharkov formula, as reported on the same ACO paper, is similar to ours but the energy dependence has not been measured.

The following features of the effect are also in agreement with the ACO results:

1) The lengthening is a function of current per bunch and not of total current.
2) It does not appear to depend on transverse density. On this point we have few data. Some checks were made by enlarging the beam with a sweeping oscillator.

Most remarkably we found a strong correlation between length and width of beam.

Let R_r be the width due to radiation only. Fig. 2 shows our L/L_r data and the fit by formula (1). Fig. 3 shows $(R/R_r)^2$ against $(L/L_r)^2$.

Our transverse dimension measurements are affected by systematic errors on calibration and resolution, whose magnitude we can estimate to be of the order of 30% and that could vary in a quasi random way from one series of measurements to the next. We therefore chose to plot our points without error bars intending only to evidence the correlation.

Tests were made on both the e^+ (with feedback) and the e^- (without feedback) beam, with one and with three bunches per beam, and also with one e^+ bunch and a resonant feedback instead of the usual fast one. All results confirmed the existence of the anomalous widening to within experimental uncertainties.

We have considered the possibilities that the anomalous width be due to the feedback when e^+'s are studied and to the ions for the e^- case but, to decide on these points, we need more accurate measurements and these are difficult to perform with our present dimension monitor.

Several theories have been proposed to account for this effect. The correlation between R and L rules out all theories that propose only a modification of the potential well, although for instance a Pellegrini-Sessler theory$^{(3)}$, that assumes beam interaction with resonant structures in the

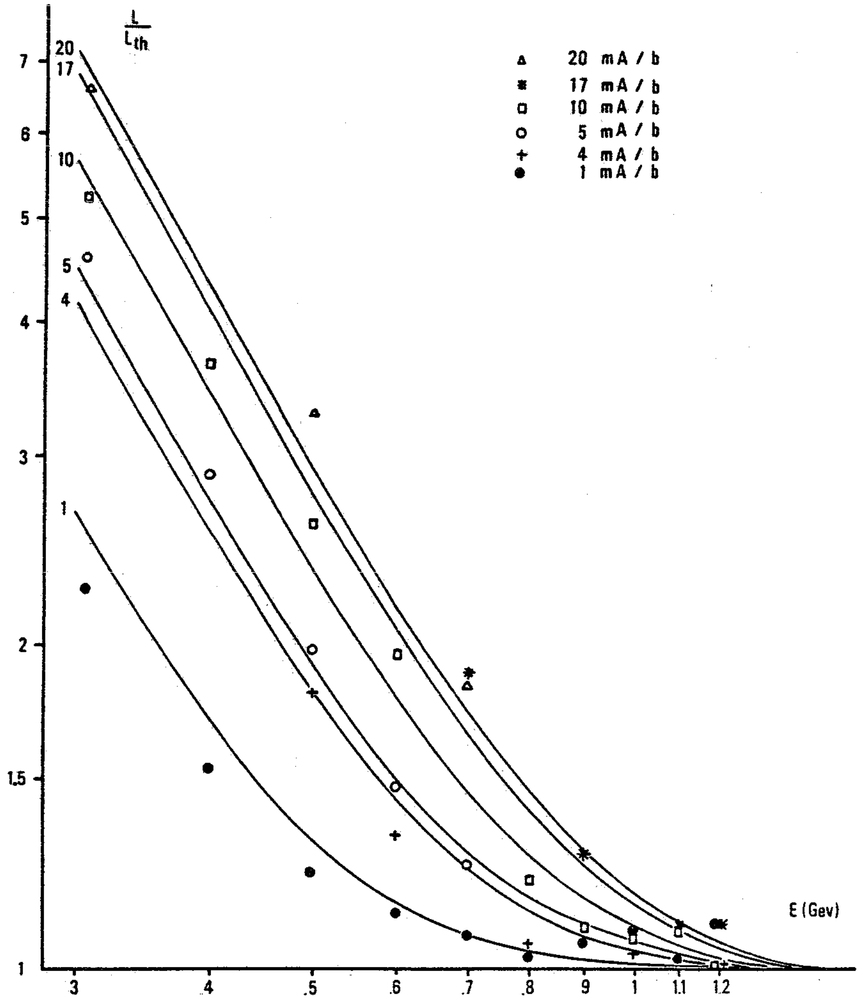
L/L_th
7
6
5
4
3
2
1.5
1
20
17
10
5
4
1
▵ 20 mA / b
✱ 17 mA / b
□ 10 mA / b
○ 5 mA / b
+ 4 mA / b
● 1 mA / b
E (Gev)
.3
.4
.5
.6
.7
.8
.9
1
1.1
1.2

FIG. 2

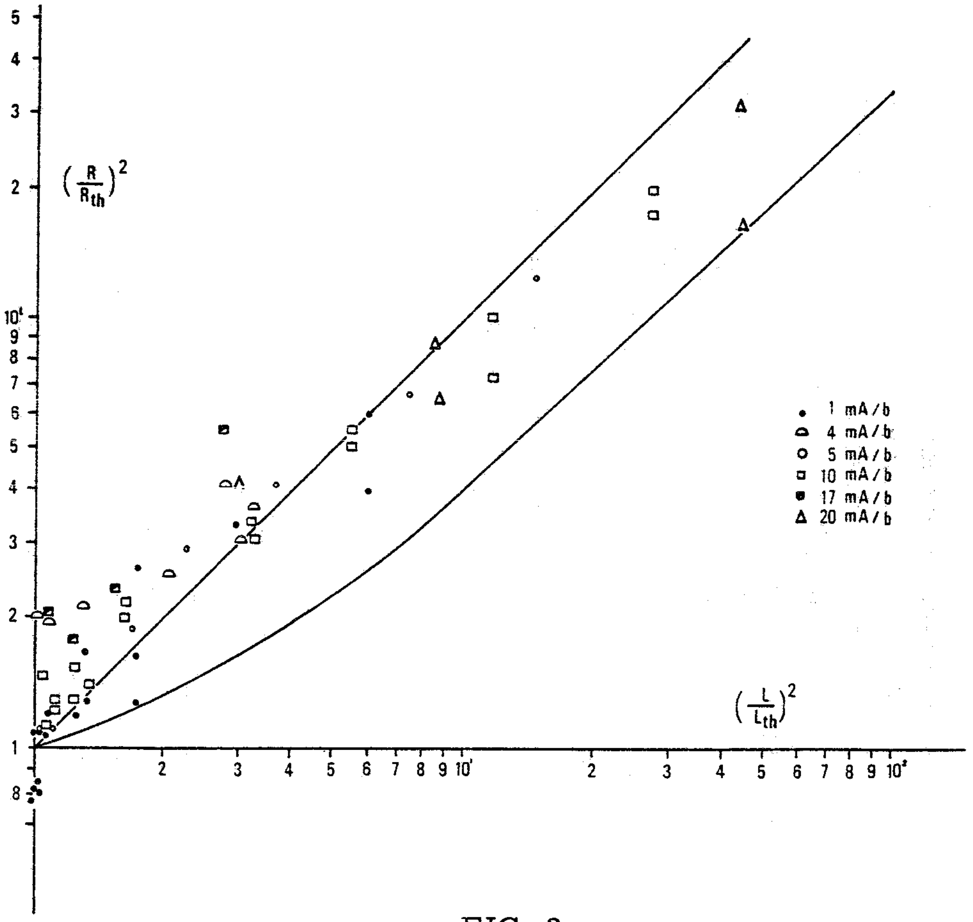
(R/R_th)^2
5
4
3
2
10^1
9
8
7
6
5
4
3
2
1
8
• 1 mA/b
◒ 4 mA/b
○ 5 mA/b
□ 10 mA/b
■ 17 mA/b
Δ 20 mA/b
(L/L_th)^2
2
3
4
5
6
7
8
9
10^1
2
3
4
5
6
7
8
9
10^2

FIG. 3

chamber, gives functional dependences for the bunch length that are very similar to those of ACO and Adone. A theory by Lebedev(4) (assuming coherent phase oscillations, inside the bunch, excited by RF fields present in the chamber that would give a noise-like effect when confronted with radiation damping) predicts V_{RF} and energy dependences that are not in agreement with (1), but is compatible with our R-L correlation data. It has been suggested by Lebedev himself that introduction of Landau damping and a different excitation mechanism in the theory could change the functional dependences. Modifications of Δp due to bremsstrahlung and multiple diffusion have been calculated to be negligible.

In the range of parameters used up to now during experimental runs the bunch lengthening was at most of the order of 20%.

LUMINOSITY MEASUREMENTS. -

Three known reactions have been measured: small angle elastic scattering (SAS), single beam-beam bremsstrahlung (SB) and double beam-beam bremsstrahlung (DB). The scattering apparatus was designed by the μ pair experimental group(5). The bremsstrahlung apparatus consists of two sandwich counters one on each side of interaction straight section 11 (the same section where the scattering apparatus is mounted) and one lead glass Cerenkov counter facing non-interaction straight section 8.

The scattering monitor has been used throughout operation as a continuous machine monitor while the bremsstrahlung monitors have been used to provide a check on the absolute value of luminosity. The reason for this is apparent from the fact that on one hand S. B. needs a missing bunch to be operative and D. B. suffers from poor signal to background ratios under ordinary working conditions, while on the other hand both reactions are quite insensitive to counter positioning, possible beam deviations from the ideal closed orbit and source dimensions. In addition, single bremsstrahlung has a very good counting rate and was useful for machine measurements in the low and very low luminosity regions.

Double bremsstrahlung is mainly useful as a check on the background subtraction procedures. In fact, while background to DB can be directly subtracted out by means of a delayed coincidence, the procedure for SB is more complicated and requires one missing bunch.

If one bunch is missing the corresponding bunch in the other beam produces only background and no S. B. counts and therefore provides us with a very good local measurement of the product of the number of particles in the bunch times the background yield per particle ($K \cdot i_B \cdot P_{loc} \cdot Z^2_{loc} \cdot 1$). On the other hand the counter facing the non-interaction strainght section provides an accurate measurement of the number of particles in the bunch relative to the other two bunches.

Background to single bremsstrahlung can be measured to an accu-

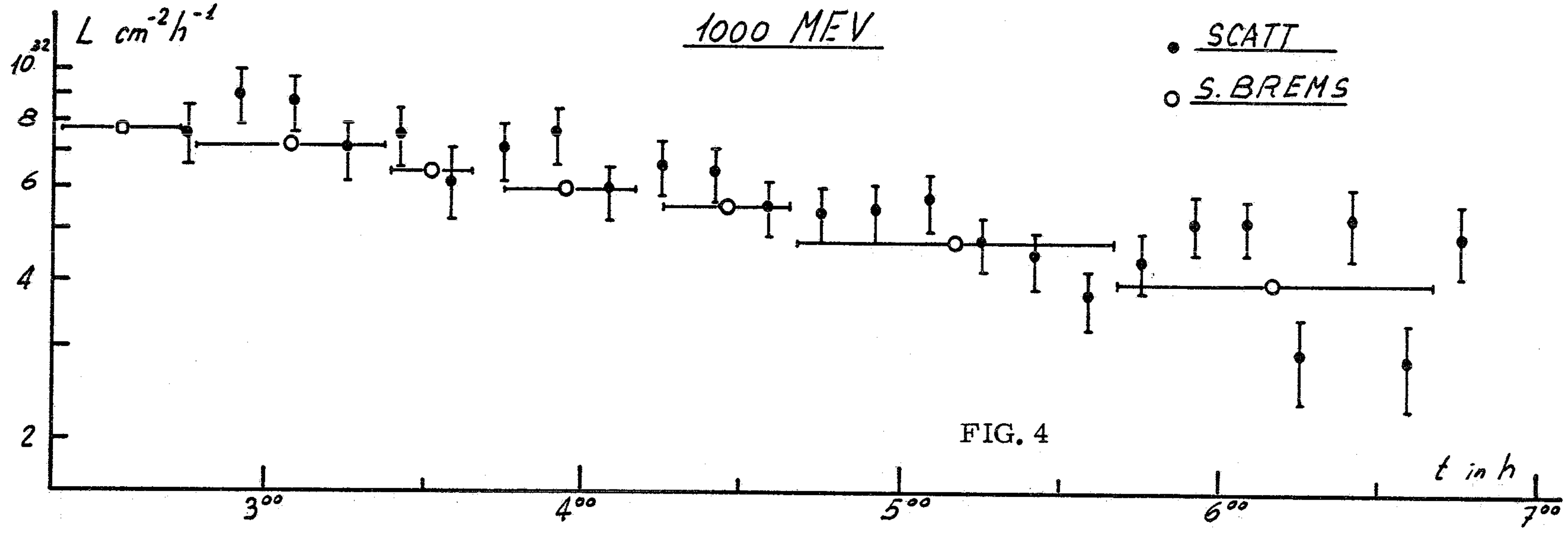
1000 MEV
● SCATT
○ S. BREMS
10^{32} L cm^{-2}h^{-1}
10
8
6
4
2
t in h
3^{00}
4^{00}
5^{00}
6^{00}
7^{00}

FIG. 4

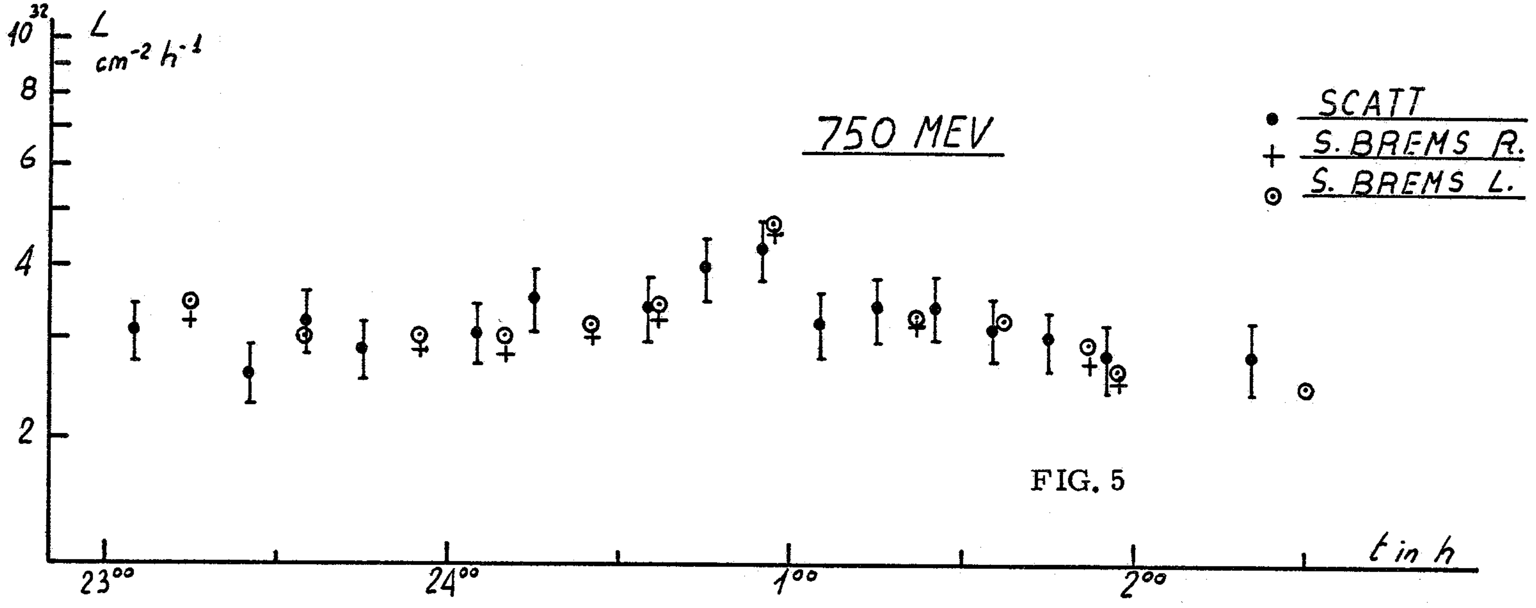
750 MEV
● SCATT
+ S. BREMS R.
⊙ S. BREMS L.
10^{32} L cm^{-2} h^{-1}
10
8
6
4
2
t in h
23^{00}
24^{00}
1^{00}
2^{00}

FIG. 5

racy that we estimate to be 1%.

The measurement of the absolute value of luminosity by bremsstrahlung obviously requires the knowledge of the detection thresholds for γ rays. These were determined by taking pulse amplitude spectra, feeding them to a computer and fitting them to the theoretical ones with counter resolution folded in.

This calibration procedure was checked against a calibration obtained through photon tagging and the two maximum energies were found to agree to within the estimated error of 1.5%. The total error on the determination of the threshold is being worked on.

S. B. luminosity was usually measured with two different thresholds, one at around 0.1 E_{MAX} (L_R) and the other at around 0.3 E_{MAX}, L_L).

The average signal to background ratio during all runs was of the order of 20%. The results of some experimental runs are shown in Figs. 4 and 5. The errors are statistical and they do not show on S. B. measurements.

The ratio of luminosity measured by S. A. S. and that measured by SB and DB was found to lie between 0.95 and 1.15 independent of energy and thresholds. A detailed analysis of errors and corrections is still under way. The experimental points are shown in Fig. 6.

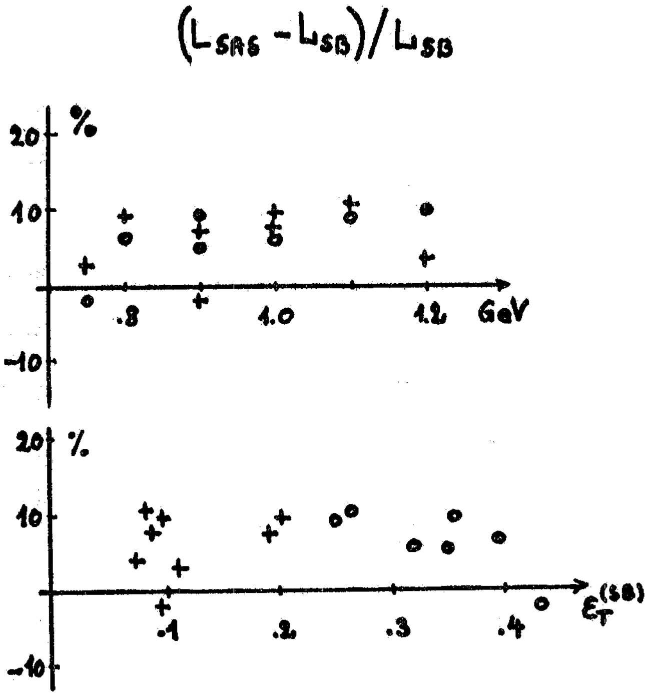

FIG. 6

To improve the accuracy of the comparison further measurements would be necessary but the need for improvement has, up to now, not been felt.

MAXIMUM LUMINOSITY. -

A few words to define our symbols. The small amplitude frequency shift due to crossing is given by the following formulas:

$$\delta Q_V \left(1 + \frac{p \cdot \delta Q_V}{2\Delta\nu_V}\right) = \frac{1}{\gamma}\,\frac{L}{i_w} K(\eta) \qquad \Delta\nu = Q - 3$$

$$\eta = \sigma_z/\sigma_x \simeq 0.4$$

$$\delta Q_R \left(1 + \frac{p \cdot \delta Q_R}{2\Delta\nu_R}\right) = \frac{1}{\gamma}\,\frac{L}{i_w} K(\eta)\,\frac{\beta_r}{\beta_v}\,\eta \qquad k(\eta) \simeq 1/1+\eta$$

p is the number of crossings and δQ the small amplitude Q shift per crossing.

Since in our case $p\,\delta Q_V/2\Delta\nu \approx 1.1$ the usual approximation of neglecting it with respect to 1, does not apply.

The right hand side is a measure of the space charge interaction so that for a given space charge it is a constant. It can therefore be seen that, if the limit to luminosity is set by space charge, L/i_W must be a linear function of γ.

The maximum values of L/i_W, obtained during operation in the last few months (May through September) are shown as a function of energy in Fig. 7. They are about a factor of 1.5 higher than those previously obtained. This factor has been gained through the skill acquired by the machine operating crew during these months of continuous operation at the same energies, and through small improvements in the controls. The values of luminosity obtained at lower energies on a test basis have therefore become obsolete and establishing an energy dependence of L/i_W some more difficult. We think though that the γ^2 dependence previously reported, and attributed to a limitation in the storable current, is still present.

Fig. 8, where the maximum luminosities obtained during operation are shown as a function of energy, seems to confirm this fact.

The small amplitude Q shifts per crossing, corresponding to the value of L/i_W at 1 GeV, are:

$$\delta Q_r \approx \delta Q_V = 0.026.$$

The value of the total Q shift (6 crossings) is therefore ~ 0.16.

The data at energy higher than 1 GeV are to be handled with some

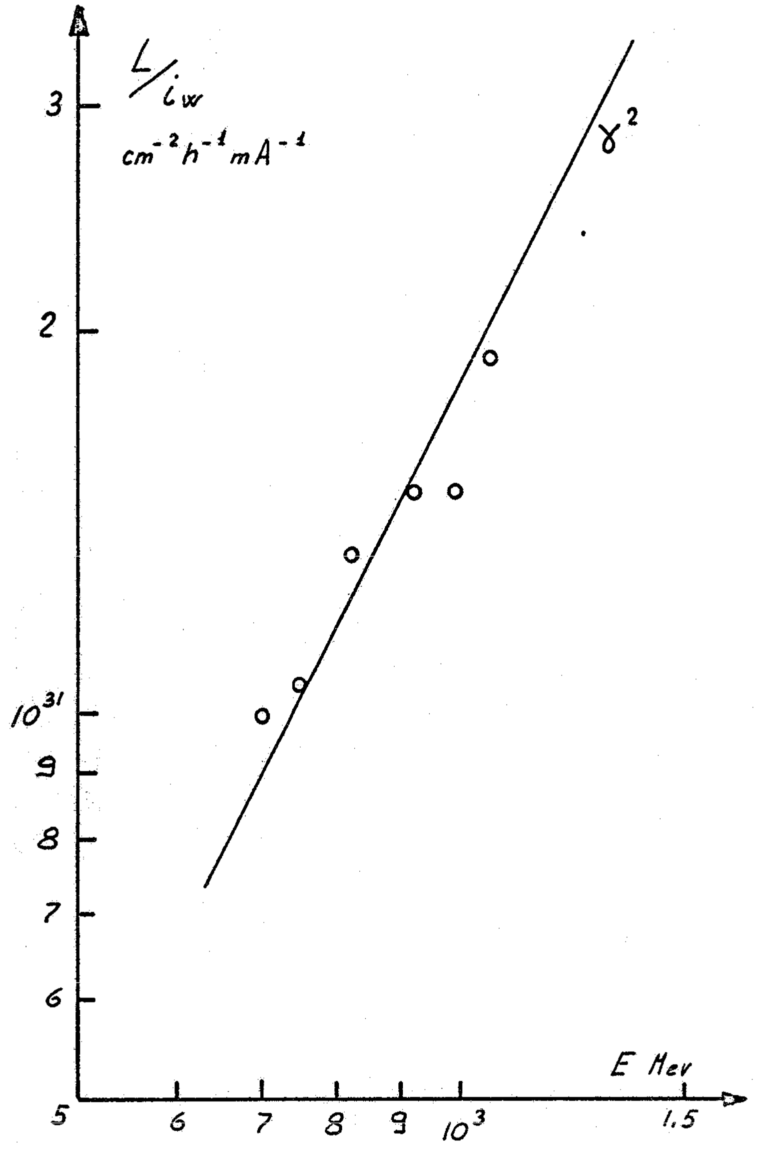
L/i_w
$cm^{-2} h^{-1} mA^{-1}$
γ^2
3
2
10^{31}
9
8
7
6
5
6
7
8
9
10^3
1.5
E Mev

FIG. 7

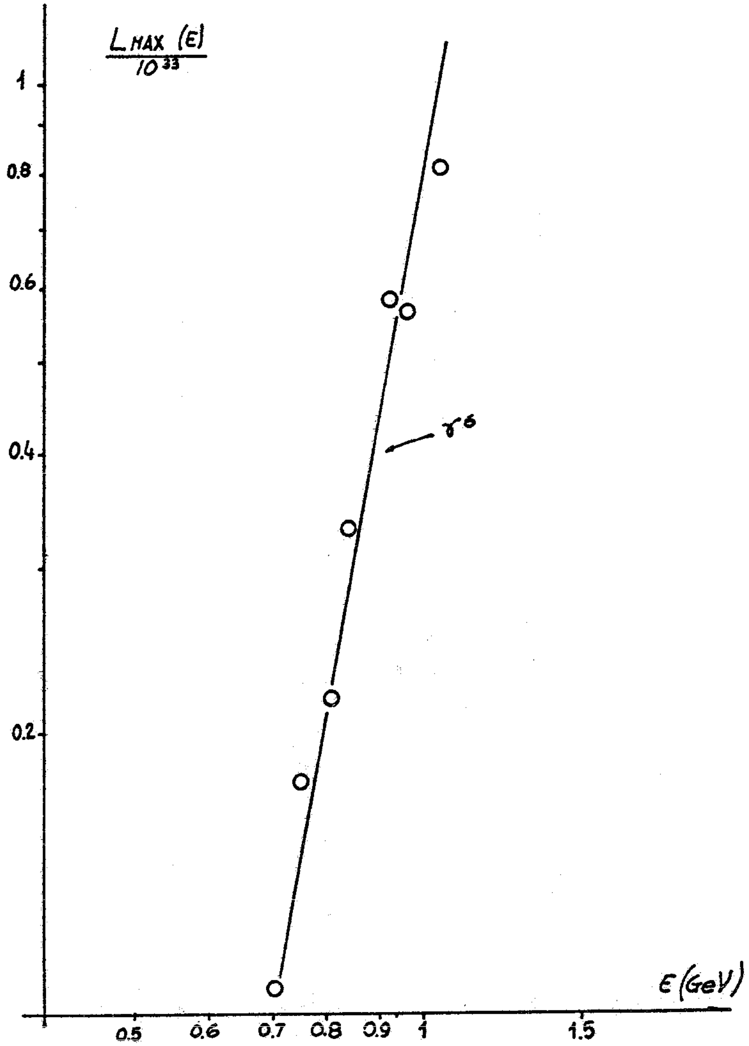
$\frac{L_{MAX}(E)}{10^{33}}$
1
0.8
0.6
0.4
0.2
γ^6
0.5
0.6
0.7
0.8
0.9
1
1.5
E (GeV)

FIG. 8

care since the currents needed to reach the density limit are higher than those we can at present handle without trouble.

It is therefore not known whether 0.026 is the density limit or if, at 1 GeV, we are still limited by the γ^6 law.

A qualitative explanation of the intensity limitation has been given by A. Renieri(6). He explains the effect as a consequence of the beam interaction that provides a feedback loop for the head tail effect. The explanation could be correct but we have not yet been able to prove it by experiment.

CROSSING AT AN ANGLE. -

We have tried for some time to obtain a crossing at an angle. We can summarize the results by saying that we have never succeded in obtaining a crossing with currents higher than those that were anyway stable at zero angle, contrary to what one would expect from conventional theory. An explanation for this could also be found in the frame of Renieri's interpretation.

Since no progress was made during our trials we eventually chose to turn the machine over to experiments without completing the study of the effect and, up to now, no new tests have been performed.

In order to better understand these phenomena we have installed an electric quadrupole to separate beam frequencies. The installation has been recently completed and no data have yet been taken.

REFERENCES. -

(1) - M. Bernardini and L. Malter, LNF-64/19 (1964).

(2) - Allongement des pagnets dans ACO, ACO Report n. 34/69 (1969).

(3) - C. Pellegrini and A. M. Sessler, Report UCRL-19895 (1970).

(4) - A. N. Lebedev, On the bunch lengthening effect in storage rings, LNF-69/52 (1969).

(5) - G. Barbiellini et al., Un dispositivo per la misura della luminosità assoluta di macchine a fasci collidenti di elettroni, Istituto di Fisica di Roma, N. I. 55 (1968).

(6) - A. Renieri, Two beam transverse coherent instability in colliding beam rings, LNF-70/8 (1970).