EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

CERN-ISR-OP/74-2

ISR-OPERATION IN 1973

by

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Geneva, January, 1974

CONTENTS

1. INTRODUCTION ON ISR-OPERATION

At the end of 1973 the Intersecting Storage Rings (ISR) had completed the 407th run, representing a total of 8.586 hours of operation since the first circulating beam was obtained in Ring 1 on October 29th, 1970.*

During 1973 the ISR was in operation for 3.582 hours.** Of this time, 2.719 hours were devoted to colliding beam physics experiments, including the time needed for filling and adjustments, and 863 hours for machine development.

The ISR started operation on February 26th after the annual long PS-shutdown. The operation year was divided into 10 periods, each about 4 weeks long, interrupted in July and September with an extra week of shutdown. This structure of the periods in the schedule is established by the PS-accelerator division, which supplies the ISR with the high energy protons and which, at the same time, serves other experiments located primarily in the PS-Easthall and in the Westhall.

Priority was given on alternate periods to Easthall and Westhall experimenters. During the Easthall period, the ISR can use the PS beam at all standard energies (11.8, 15.4, 22.5 and 26.5 GeV) and, therefore, operates over the full 4 weeks' time. During the Westhall period there is a restriction on PS-beam sharing between the ISR and the Westhall because they both have to use ejection-16 and the dc beam transfer channel TT2 together. During this period the ISR operates only on 2 out of the 4 weeks and at a fixed energy of 22.5 GeV for nearly all of the runs. The other two weeks in the Westhall were needed for work on the experimental equipment at the intersections, work on the machine involving lengthy

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* The first colliding beams were obtained on January 27th, 1971.

** 3.200 hours in 1972, 1.756 hours in 1971 and 48 hours in 1970.

vacuum chamber bakeouts etc. A major addition in 1973 was the Split Field magnet (SFM) facility which was installed in Intersection 4 during a longer shutdown (21st May - 17th June).

The ISR operates on a 24-hour-day basis, 7 days a week, with a pattern of, in principle, one colliding beam physics run every day and one and sometimes two machine development (MD) runs per week.

The daily schedule is established several weeks in advance.

Machine development runs vary in duration between 12 and 26 hours.

The pattern for daily physics runs is not completely regular from day to day but follows, in principle, the following sequence. The cycle starts with 2 hours of controlled access into the ISR tunnel, required primarily for the experimental teams to work on their complex detector set-ups to change film in cameras etc.

The controlled access time often implies a hectic period of activity for the operator in the Control Room from where each person is checked in and out by remote control. This is due to the many experiments that are working around the ISR simultaneously in 6 of the 8 intersections. In 1973 the ISR accommodated 12 experiments and some of the teams for one experiment consist of more than 20 persons, and are backed up by additional technical personnel. Due to this rather extensive activity in the ISR, there were 2-hour controlled access periods whereby 104 persons had to be let into and back out of the ring via the access control procedure involving the usual safety keys, the checking of the number and the names of people entering each door, on film badges, pocket dosimeters etc.

After the controlled access period, the ISR machine equipment is switched on and both rings are tuned up so as to be ready for stacking. This work generally takes 1 to 2 hours and was mostly done on a beam sharing basis, taking only every third PS-pulse (1 pulse every 6.6 seconds).

From this stage onwards there are two alternative sequences to prepare for colliding beam physics:

a) Make a low current stack (about 3 Amps) in each ring, perform with these stacks a luminosity calibration simultaneously in all intersections, dump the low current stacks and build final high current stacks at the optimum vertical positions. This sequence of activities takes 3 to 4 hours and was applied rather frequently in 1973.

b) The alternative sequence is less time consuming. It foresees stacking straight away to the desired high beam current followed by a minimum of steering at the intersections. This sequence was applied less frequently for reasons we will not discuss further here.

When the final stacks are made and when several other operational actions have been executed, the beams are declared stable by the operator. The experimenters can then switch on their counters for data taking, in principle, until the next morning. During the physics runs there have generally been frequent interruptions in data taking in order to clean up the beam halo by scraping.

The beams are deflected at the end of the approximately 16 hours long physics run onto an internal dump block, followed by machine switch off and controlled access, thus completing the operation cycle.

The running conditions specified for each subsequent run are in most cases different. The weekend runs are always longer; the filling is done on Saturday afternoon, and the beams are then kept circulating until Monday morning.

On certain occasions one or both beams are lost prematurely due to ISR equipment failure or due to external causes, such as perturbations on the 18kV power line. An emergency refill could be arranged in most of these cases and data taking could then be resumed after a delay of 2 to 4 hours.

The ISR Operations Group also operated the Westhall beam line for the Omega spectrometer and the bubble chamber (BEBC) in the Westhall representing 2.896 hours in 1973.

The operations crew on shift duty consists of an engineer or physicist who is in charge of the operations, assisted by 3 operators (only 2 operators on data taking runs).

2. STATISTICS ON RUNNING TIME

The ISR has accumulated 3.582 hours of operation, including 97 extra hours added during the year to compensate partly for the 481 hours lost due to various causes (see section 4). The effective running time, therefore, was 3.101 hours. The PS ejection system has been in operation for 1.421 hours.

A breakdown of these figures between machine development, filling and colliding beam time is shown in Table 1.

	Total 1	Machine Develop- ment 2	Physics	
			Filling and Preparations 3	Colliding Beam time 4
Operating	3.582 hrs.	863 hrs.	558 hrs.	2.161 hrs.
Lost	481 hrs.	120 hrs.	94 hrs.	267 hrs.
	13,5%	13,9%	16,6%	12,4%
Effective running	3.101 hrs.	743 hrs.	464 hrs.	1.894 hrs.
PS ejection operating	1.421 hrs.	863 hrs.	558 hrs.	-
Full PS-rate equivalent	778 hrs.	572 hrs.	206 hrs.	-
Estimated PS beam time used at full PS rate equiv.	(430 hrs.)	(345 hrs.)	(144 hrs.)	-

TABLE 1

The 863 hours indicated for machine development time in column 3 is actually not only used for pure performance studies but also to bring the ISR back into good operating condition after the long shutdowns and often for checking out special conditions requested by the ISR experimenters.

The PS ejection equipment is switched on during the full MD time, that is 863 hours. However, we use three beam sharing schemes on many of the MD runs, namely :

4 out of 20 bunches on each PS-pulse
every second PS pulse at 20 bunches
every third PS pulse at 20 bunches.

Taking this into account, we find that the 863 scheduled hours in 1973 were equivalent to 572 hours at the full PS-rate. We are discussing here scheduled hours of which only a fraction are actually used during the MD time. I estimate this fraction to be 60%, which means that the ISR-MD program is carried out with the equivalent of 345 hours PS beam time at full rate. This represents only a small part of the total annual PS running time of about 6.200 hours (5.6%).

The scheduled time for filling and preparations for physics in 1973 was 558 hours (column 3). This is quite a considerable amount of time, of which only a small fraction is needed, strictly speaking, for the filling. To give an idea, a stack of 10 Ampères in one ring takes about 10 minutes with the normal PS beam intensity (no booster) at full repetition rate (1 pulse per 2.2 seconds).

The relatively longer time invested in "filling and preparations" is due to three reasons :

1) The filling period is nearly always preceded by controlled access into the ring, which requires that the machine is completely switched off. Considerable time is, therefore, needed for switching on and tuning up.

2) Nearly all this work was done, for reason of beam sharing with the other PS users, with a beam pulse rate of 1 out of 3. The machine tuning takes more time in that case, while the 10 Amp stack in the example given above will take 30 instead of 10 minutes.

3) The preparation time often includes beam steering in order to give the experimenters in each intersection the benefits of maximum luminosity combined with a minimum background, and frequently a full luminosity calibration for their counters, which easily takes one to one and a half hours of the scheduled time.

The PS beam time actually used for these reasons is, of course, much less than the scheduled time. Taking into account the sharing (point 2), this reduces the scheduled 558 hours to 206 hours. Taking into account the unused PS beam time during switching-on, during luminosity measurements etc. and making up the balance between "good days", where the filling was finished early and some bad occasions where unforeseen refills were needed, brings us to an estimated PS time used of 70% of 206 hours. Therefore, the ISR physics program is carried out with the equivalent of about 144 hours PS beam time at full rate. This represents about 2.4% of the total of 6.200 hours of annual PS operation.

Column 3 of Table 1 shows the running time for colliding beam physics. The total of 2.161 hours includes 69 hours extra, added during the year to the scheduled 2.092 hours to compensate partly for lost physics time.

The total losses were 267 hours or 12.4%. They are defined as no beam in both rings. These losses are caused partly by ISR unreliability, partly by non-availability of the PS for filling and partly by external causes. This will be discussed further in Section 4.

3. RUNNING CONDITIONS

Table 2 shows the distribution of the running time for physics and values for beam currents and luminosities at the standard energies. The table also indicates the running time with the Terwilliger scheme and the Split Field magnet (operational since September).

Acceleration by phase displacement from 26.5 to 31.4 GeV now operates fairly satisfactorily. There have been 8 runs at this energy.

212 hours of physics were provided with a different beam energy in ring 1 from that in ring 2. One special run was done with a 22.5 GeV stack in one ring and 3 separated low current stacks at 11.8 GeV in ring 2.

Energy GeV	Physics				Beam current range Ampères	Luminosity x 10^{30} cm^{-2}sec^{-1}	
	Hours	%	TW	SFM		Max.	Average
11.8	251	11.6	16	43	4 - 6	0,68	0.4
15.4	299	13.8	16	32	5 - 8	1,25	0.6
22.5	660	30.5	39	118	7 - 14	4.4	1.8
26.5	604	28	16	113	7 - 14	5.4	2
31.4	135	6.3		16	3 - 5	0.36	0.15
$E_1 \neq E_2$	212	9.8			-	-	-
	2.161						

TABLE 2

Figures 1 - 5 show graphically for each energy separately the initial and average luminosity, the product of the beam currents in the beginning and at the end of the physics runs and the initial value of the effective beam height.

Figures 1A - 5A show for the corresponding runs the lowest and the average beam loss rate for each ring. It has not been possible to collect representative background conditions. The type of workline (FP, 5C or 8C) used during each run and whether or not the Terwilliger scheme (T) or the Split Field magnet (S) was used, is also indicated in figures 1A - 5A (look under the run number).

The FP worklines have given excellent and reproducible results but they can only be used for beam ucrrents up to 7A (at the higher momenta). The 5C lines made for high beam intensity have given increasingly disappointing results and were replaced later in the year by the still experimental 8C lines (Ref. 1). These new lines were used successfully at the highest luminosity runs under acceptable background conditions at 22.5 GeV (see Fig. 3 runs 396 and 402) and at 26.5 GeV (see Fig. 4 runs 399 and 406). Further comments on the running conditions for physics and on general ISR performance can be found in Ref. 2.

A few data on maximum performance obtained during the machine development runs are given below :

The highest beam currents obtained are : in R1 22.1 Amp at 26.5 GeV during run 400, and in R2 20.7 Amp at 26.5 GeV during run 357.

The maximum luminosity of 6.7 $10^{30}\text{cm}^{-2}\text{sec}^{-1}$ was obtained on the last run of the year (MD run 407). This was the first ISR run with the high intensity beam accelerated in the PS with the booster.

4. LOSS OF MACHINE TIME

481 hours were lost of the total operations time of 3.582 hours, or 13.5% (Table 1.).

In this section we will have a somewhat closer look at these losses

Table 3 gives the breakdown of the losses for the three possible origins, that is, the mains power (18kV), the PS or the ISR proper.

	Total	Machine Development Hours		Filling and Adjustments Hours		Physics Hours	
1. Mains 18kV	50	3	2.5%	1	1%	46	17.2%
2. PS or PS ejection	150	42	35 %	43	46%	65	24.4%
3. ISR	281	75	62.5%	50	53%	156	58.4%
TOTAL	$\boxed{481}$ 13.5%	120 13.9%		94 16.6%		267 12.4%	

TABLE 3.

For the ISR the figures refer to the worst of the 2 rings. Ring 2 was, in fact, about 30% less reliable than Ring 1.

We shall discuss first the influence of the mains (18kV). The 18kV supply line shows occasional dips or even full interruptions caused by disturbances outside CERN, in many cases as a result of thunderstorms in the area.

These disturbances have not provoked much lost time during machine development and the filling periods, however, they show up significantly in the losses on physics time (17.2%). This is, of course, understandable since a short 18kV spike may switch off a power supply via its interlock chain, which in turn causes the beam dump to be fired with many hours of physics lost as a consequence.

Let us now look at the other two causes of beam loss, that is the reliability of the PS and the ISR equipment. We see that the time lost due to PS faults (second line in Table 3) is lower than that due to ISR faults (3rd line). The explanation for this is different for the 3 modes of operation (MD, filling and physics) :

1) During the machine development time, the PS is on a stable beam regime while the ISR is often in a setting up condition in this period. In addition, during the MD time, tests are executed which require frequent changes, and sometimes rather extreme conditions. This naturally enhances the appearance of faults.

2) The higher ISR fault rate during the filling period may be explained in a similar way by the fact that the controlled access before the filling period requires the machine to be switched off completely. The machine, therefore, needs first to be switched on and to be tuned up.

3) The argument for the physics runs is different. The 65 hours due to the PS in this case stem mostly from PS breakdowns which lasted a long time and which prevented the possibility of filling according to the normal schedule, thus provoking beam-loss time. The 156 hours of physics lost, caused by the ISR equipment, represents a reliability figure which refers to stable ISR operating conditions. It corresponds to 7.2% of the 2.161 hours of scheduled physics time. This is actually a very good reliability figure if one takes into account the difference with respect to an accelerator where a 30 minute breakdown of a power supply counts as 30 minutes lost time, while at a storage ring it counts as the time needed to do a restack as well, and that means easily 3 hours.

Table 4 shows further details of the origin of the time lost in the ISR. This information has been analysed throughout the year but only for the total ISR running time , that is it refers to the 281 hours of time lost in Table 3. Table 4 lists the contribution in per cent of the various ISR systems (including operation errors) to the total time lost. This fault analysis shows us a rather homogeneous distribution.

ORIGIN OF ISR FAILURE	%
Beam transfer power supplies	12*
Ring power supplies	23
Experimenters equipment	2
Split Field Magnet	8
Water Cooling System	6
Inflectors	3
Radio frequency	8
Beam observation	2
Vacuum and clearing electrodes	11
Dumping system	4
Computer	8
Operator's error	4
Miscellaneous	9

TABLE 4

Comparing the fault figures with those of 1972 leads to the conclusion that so far fault trends of the machine are rather stable. Some differences could be related to modifications in equipment.

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* This figure shows too high a percentage due to the fact that the fault time for the runs to the Westhall are included.

In 1972 about 200 hours were lost due to accidents with the beam, which caused holes to be burnt in the vacuum chamber. These kinds of accidents have fortunately not reoccurred in 1973.

The PS ejected beam line availability has been better this year; Difficulties with the Septum magnets experienced in 1972 have reoccurred but compensation for the time lost was received and, therefore, does not appear in these statistics.

The 150 hours of time lost due to PS on the total of 1.421 operating hours of the ejection system represent 10.6 per cent.

Table 3 lists the total effect of the three origins of error discussed in this section; the overall average loss = 13.5%. For the 3 modes of operations it is : 13.9% on MD, 16.6% on filling and physics and 12.4% for physics.

Beams were lost and restacked again on 10 occasions during the course of this year. In 7 of the 10 cases it concerned 1 ring only, the other 3 occasions required a refill in both rings.

5. WESTHALL RUNS

The ISR Division operated the Westhall beam for 2.896 hours. 31 hours (1.1%) were lost due to equipment under ISR control.

6. ACKNOWLEDGEMENT

I should like to thank R. Jung and P. Martucci for collecting and checking the statistical data on ISR faults, and T. Verbeeck for his work on the machine operations statistics and graphical work shown in Figs. 1-5. Extensive use was made of the periodic analysis of physics runs produced by F. Lemeilleur.

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7. REFERENCES

Ref. 1 ISR-MA/PJB/JPG/rf, 20th December 1973
P.J. Bryant, J.P. Gourber, Run 390, "8C" a dynamically compensated working line. (Unpublished internal report).

Ref. 2 CERN-ISR/DI/73-50
Annual Progress Report from the ISR Department 1973.

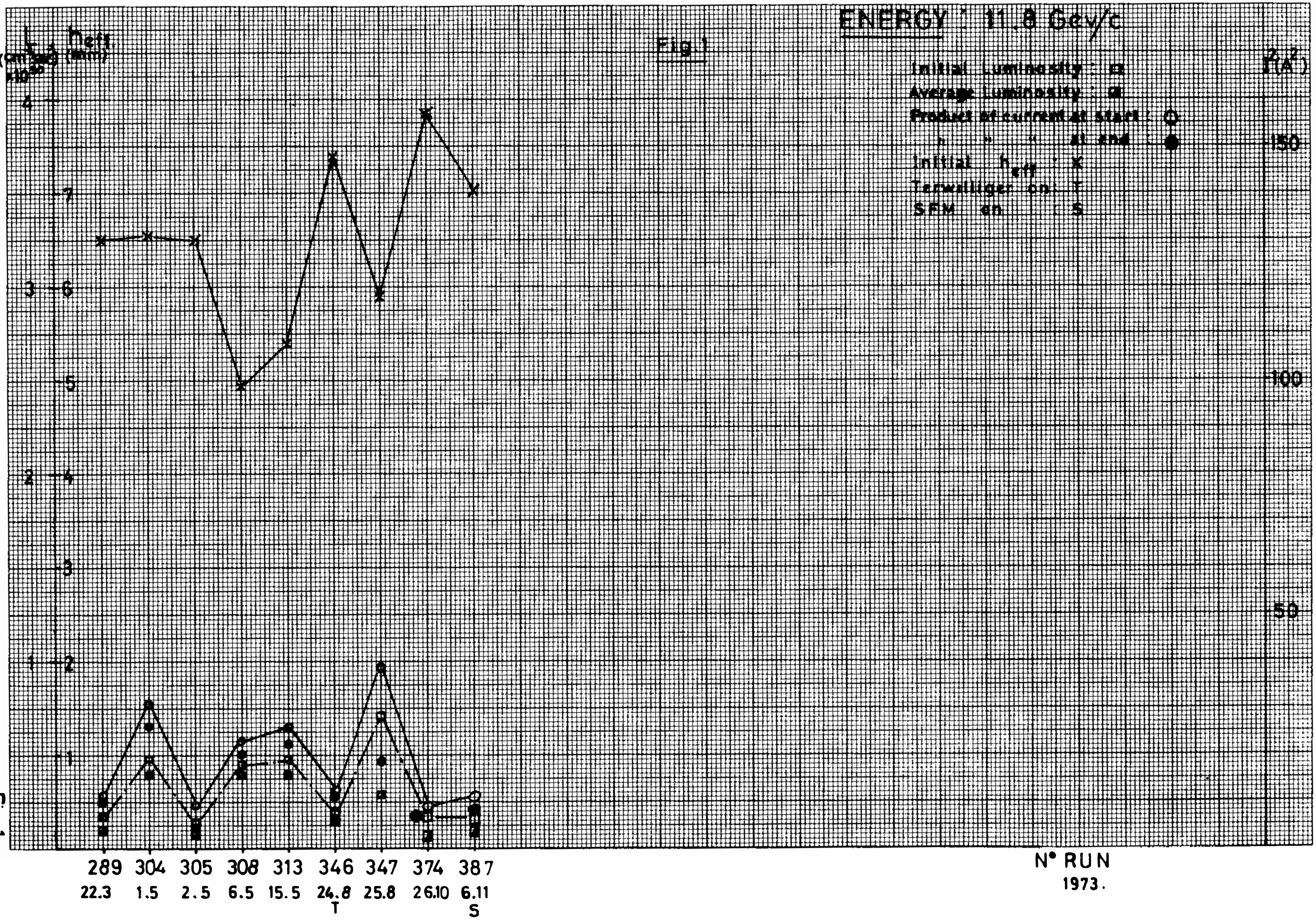
ENERGY : 11.8 Gev/c
Fig.1
L (cm⁻²sec⁻¹) ×10³⁰
h_eff (mm)
I² (A²)
Initial Luminosity : ⊠
Average Luminosity : ▣
Product of current at start : ○
" " " at end : ●
Initial h_eff : X
Terwilliger on : T
SFM on : S
4
3
2
1
7
6
5
4
3
2
1
150
100
50
289
22.3
304
1.5
305
2.5
308
6.5
313
15.5
346
24.8
T
347
25.8
374
26.10
387
6.11
S
N° RUN
1973.
FABRICATION SUISSE

Fig.1

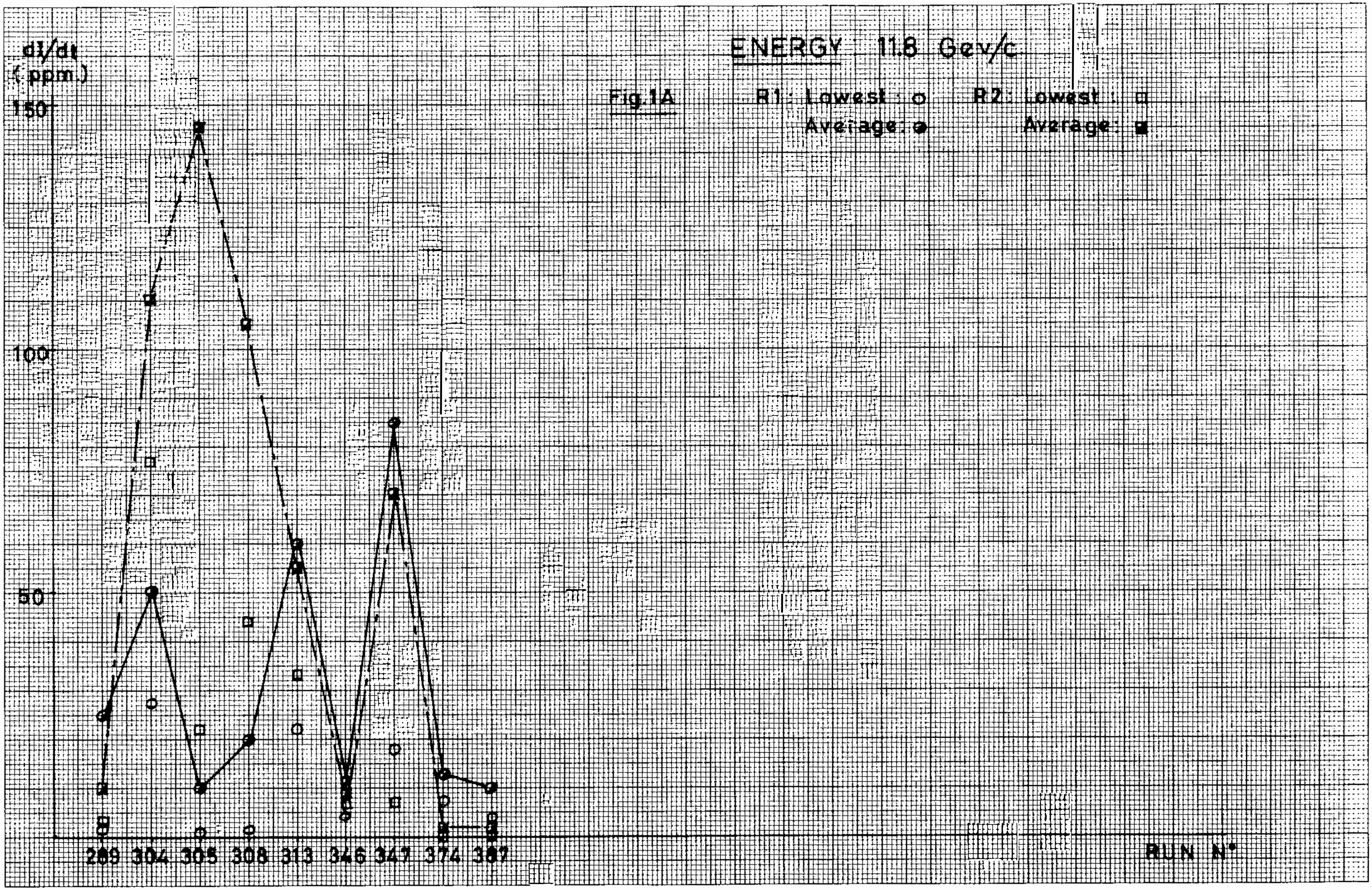
ENERGY 11.8 Gev/c
Fig.1A
R1: Lowest : ○
Average: ●
R2: Lowest : □
Average: ■
dI/dt
(ppm)
150
100
50
RUN N°
289
304
305
308
313
346
347
374
387

Fig.1A

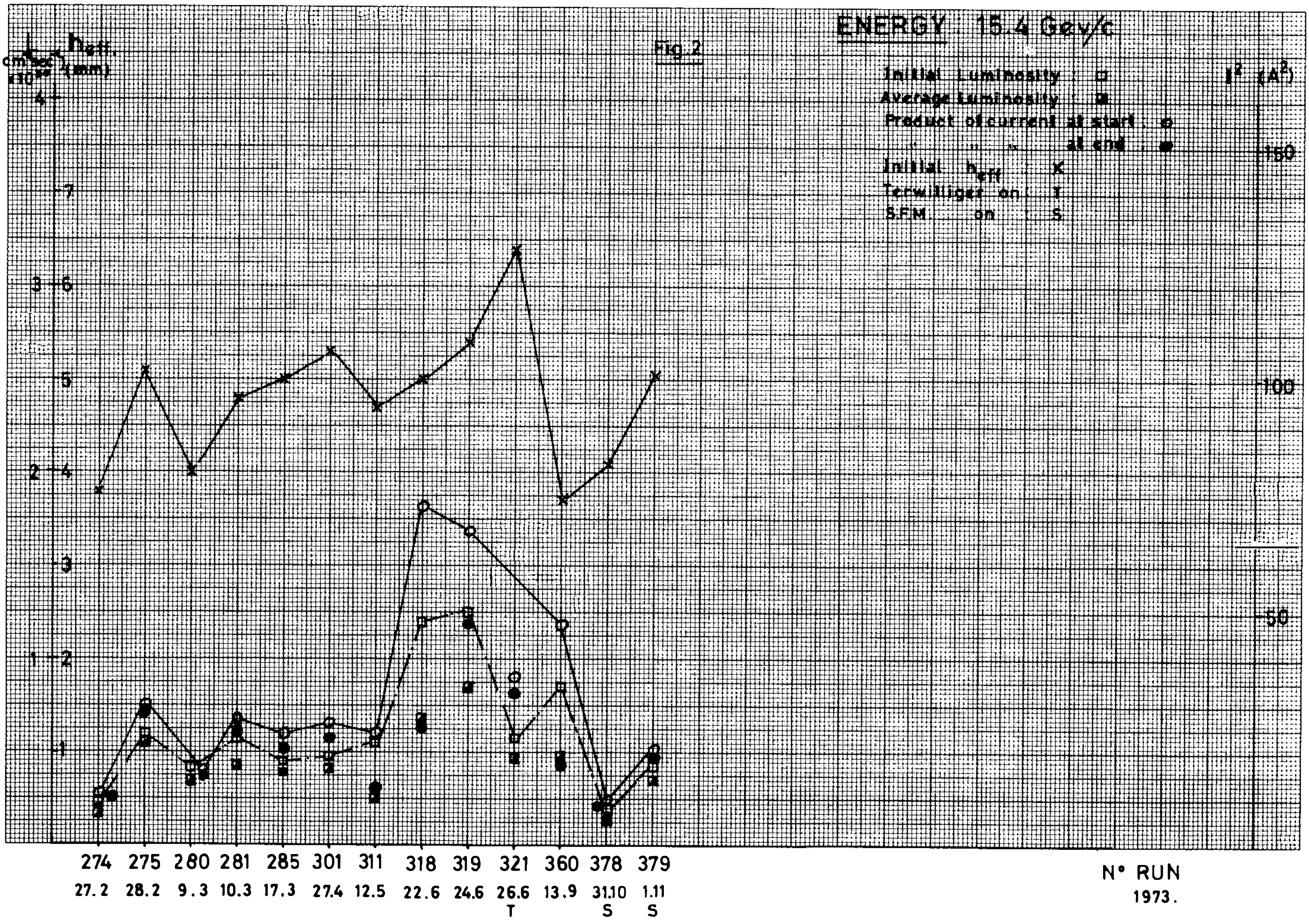
ENERGY : 15.4 Gev/c
Fig.2
L
h_eff.
(cm⁻²sec⁻¹)
×10²⁹
(mm)
I² (A²)
Initial Luminosity : □
Average Luminosity : ■
Product of current at start : ○
" " " at end : ●
Initial h_eff : X
Terwilliger on : T
S.F.M. on : S
4
7
3
6
5
2
4
3
1
2
1
150
100
50
274
275
280
281
285
301
311
318
319
321
360
378
379
27.2
28.2
9.3
10.3
17.3
27.4
12.5
22.6
24.6
26.6
13.9
31.10
1.11
T
S
S
N° RUN
1973.

Fig. 2

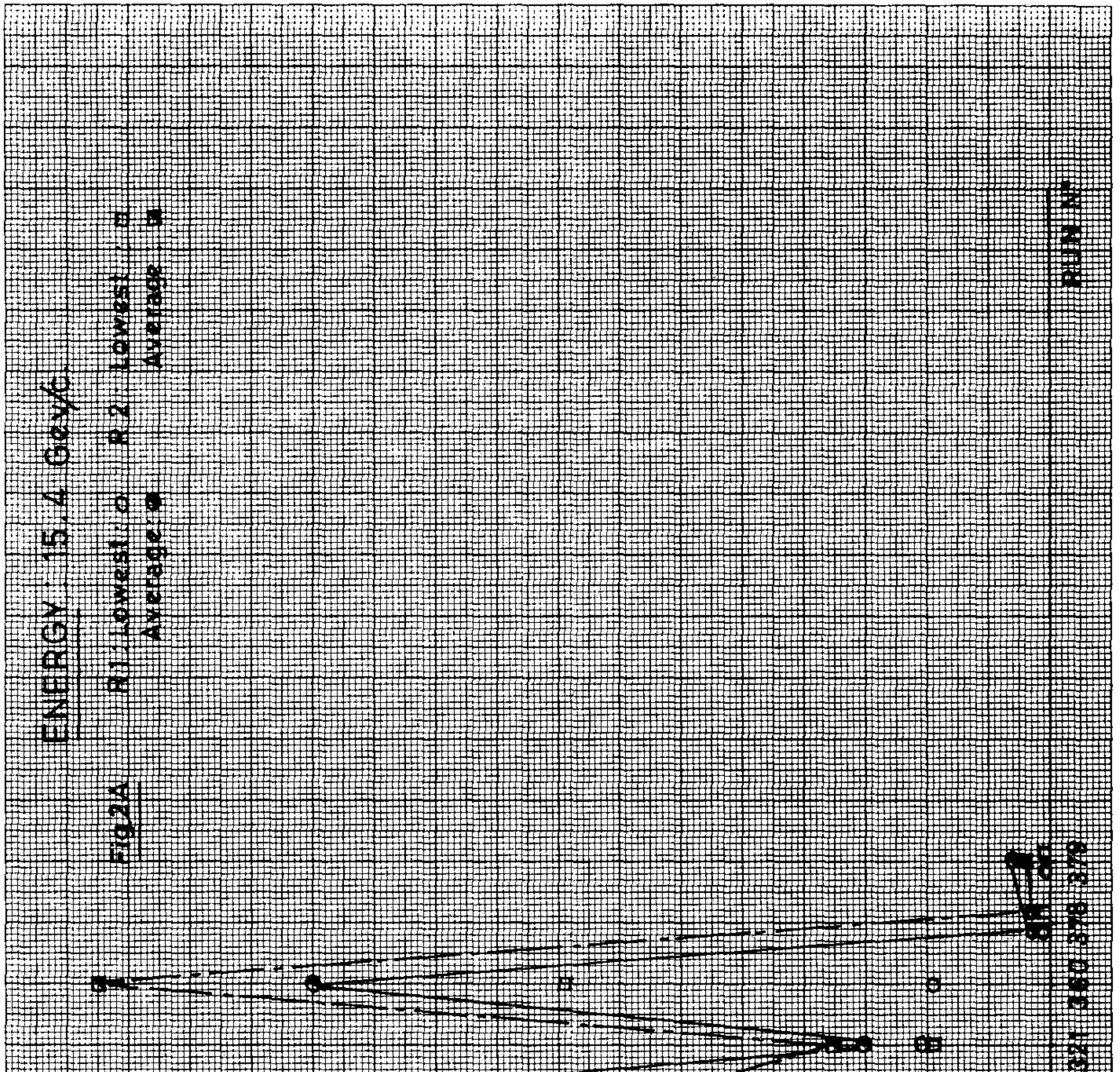
ENERGY 15.4 GeV/c
Fig.2A
R1 Lowest ○
Average ●
R 2 Lowest □
Average ■
dI/dt
(ppm)
150
100
50
RUN N°
274
275
280
281
285
301
311
316
318
321
360
378
379

Fig2A

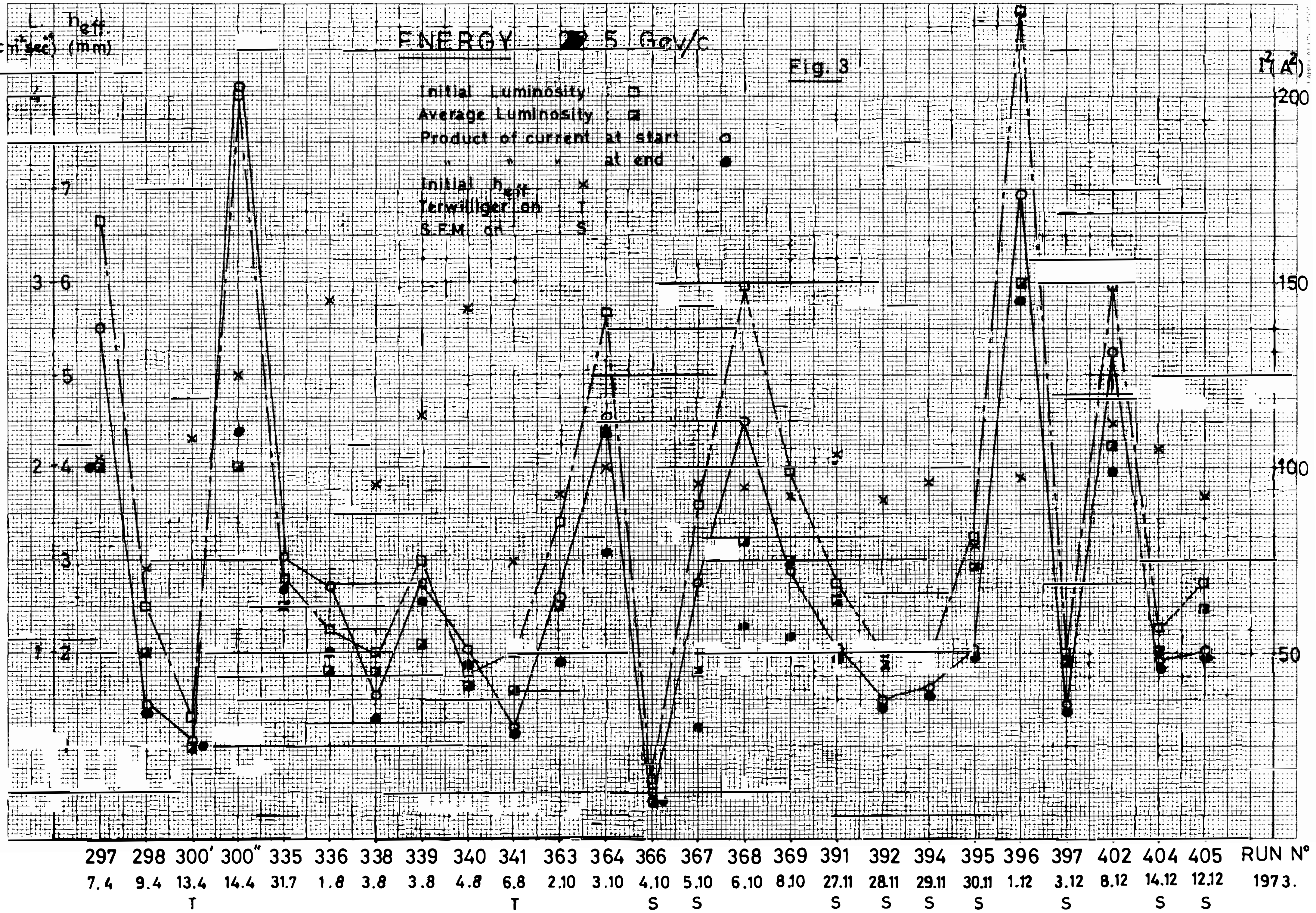
ENERGY [illegible] 5 GeV/c
Fig. 3
L h_eff
(cm⁻²sec⁻¹) (mm)
I² (A²)
Initial Luminosity : □
Average Luminosity : ▣
Product of current at start : ○
" " " at end : ●
Initial h_eff : ×
Terwilliger on : T
S.E.M. on : S
7
3 6
5
2 4
3
1 2
200
150
100
50
297 7.4
298 9.4
300' 13.4 T
300" 14.4
335 31.7
336 1.8
338 3.8
339 3.8
340 4.8
341 6.8 T
363 2.10
364 3.10
366 4.10 S
367 5.10 S
368 6.10
369 8.10
391 27.11 S
392 28.11 S
394 29.11 S
395 30.11 S
396 1.12
397 3.12 S
402 8.12
404 14.12 S
405 12.12 S
RUN N°
1973.

Fig. 3

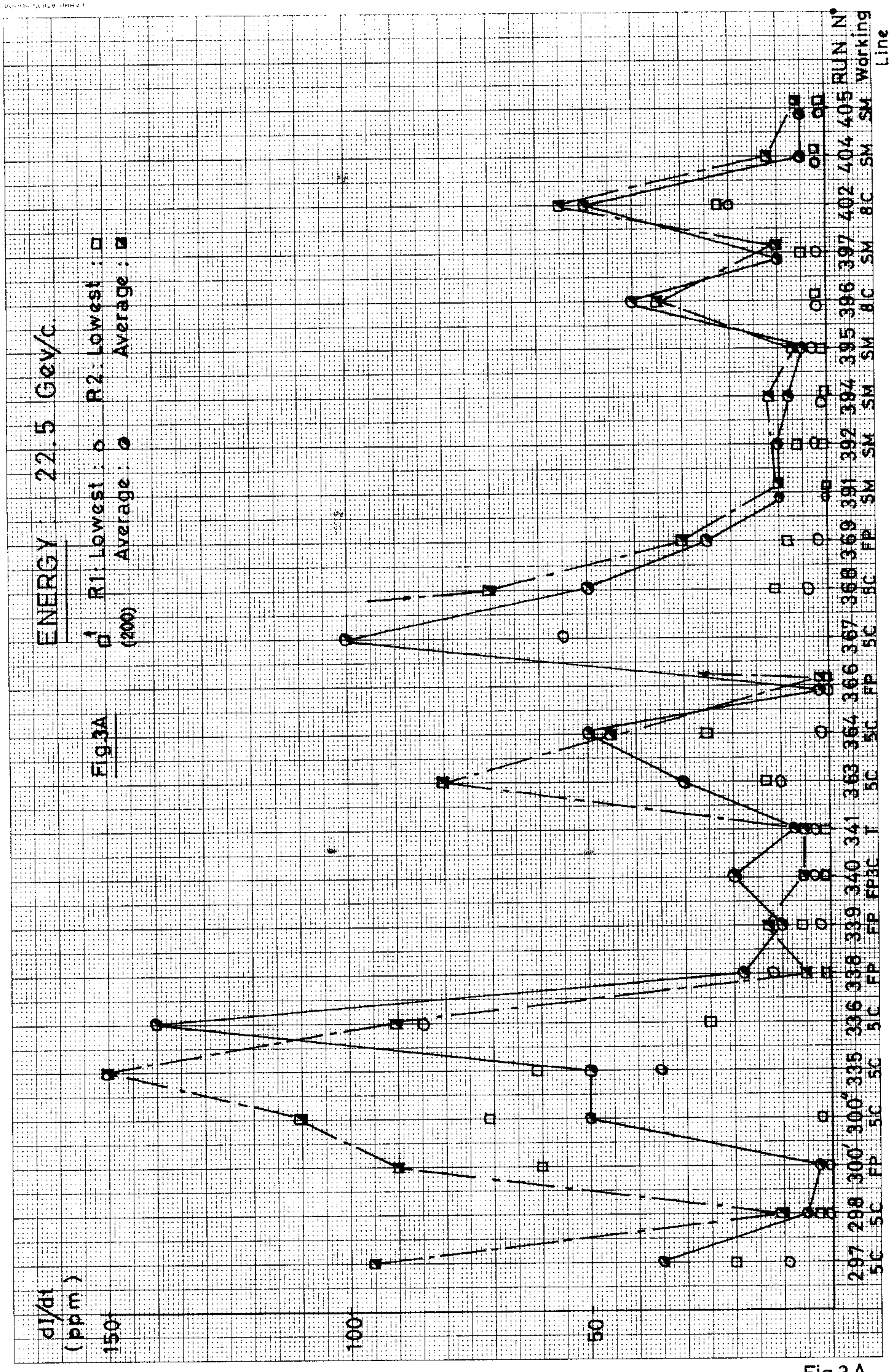
Fig.3A
ENERGY : 22.5 Gev/c.
R1: Lowest : ○
Average : ●
R2: Lowest : □
Average : ■
(200)
dI/dt
(ppm)
150
100
50
RUN N°
Working Line
297 5C
298 5C
300' FP
300" 5C
335 5C
336 5C
338 FP
339 FP
340 FP5C
341 T
363 5C
364 5C
366 FP
367 5C
368 5C
369 FP
391 SM
392 SM
394 SM
395 SM
396 8C
397 SM
402 8C
404 SM
405 SM

Fig.3 A

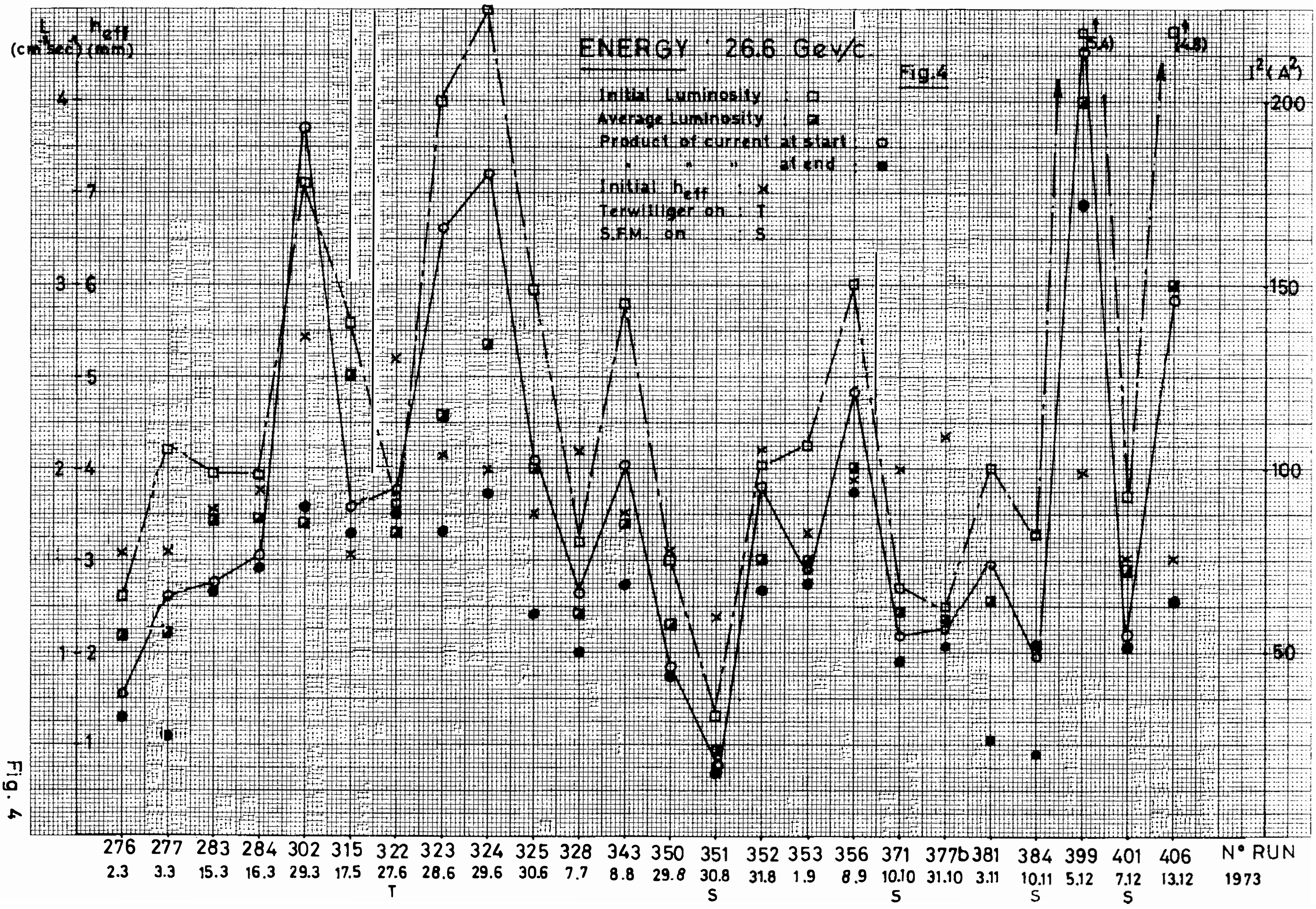
ENERGY 26.6 GeV/c
Fig.4
Initial Luminosity : □
Average Luminosity : ■
Product of current at start : ○
" " " at end : ●
Initial h_eff : ×
Terwilliger on : T
S.F.M. on : S
L (cm⁻² sec⁻¹)
h_eff (mm)
I² (A²)
1
1-2
2-4
3-6
4
2
3
4
5
6
7
50
100
150
200
(5.4)
(4.8)
276 2.3
277 3.3
283 15.3
284 16.3
302 29.3
315 17.5
322 27.6 T
323 28.6
324 29.6
325 30.6
328 7.7
343 8.8
350 29.8
351 30.8 S
352 31.8
353 1.9
356 8.9
371 10.10 S
377b 31.10
381 3.11
384 10.11 S
399 5.12
401 7.12 S
406 13.12
N° RUN
1973

Fig. 4

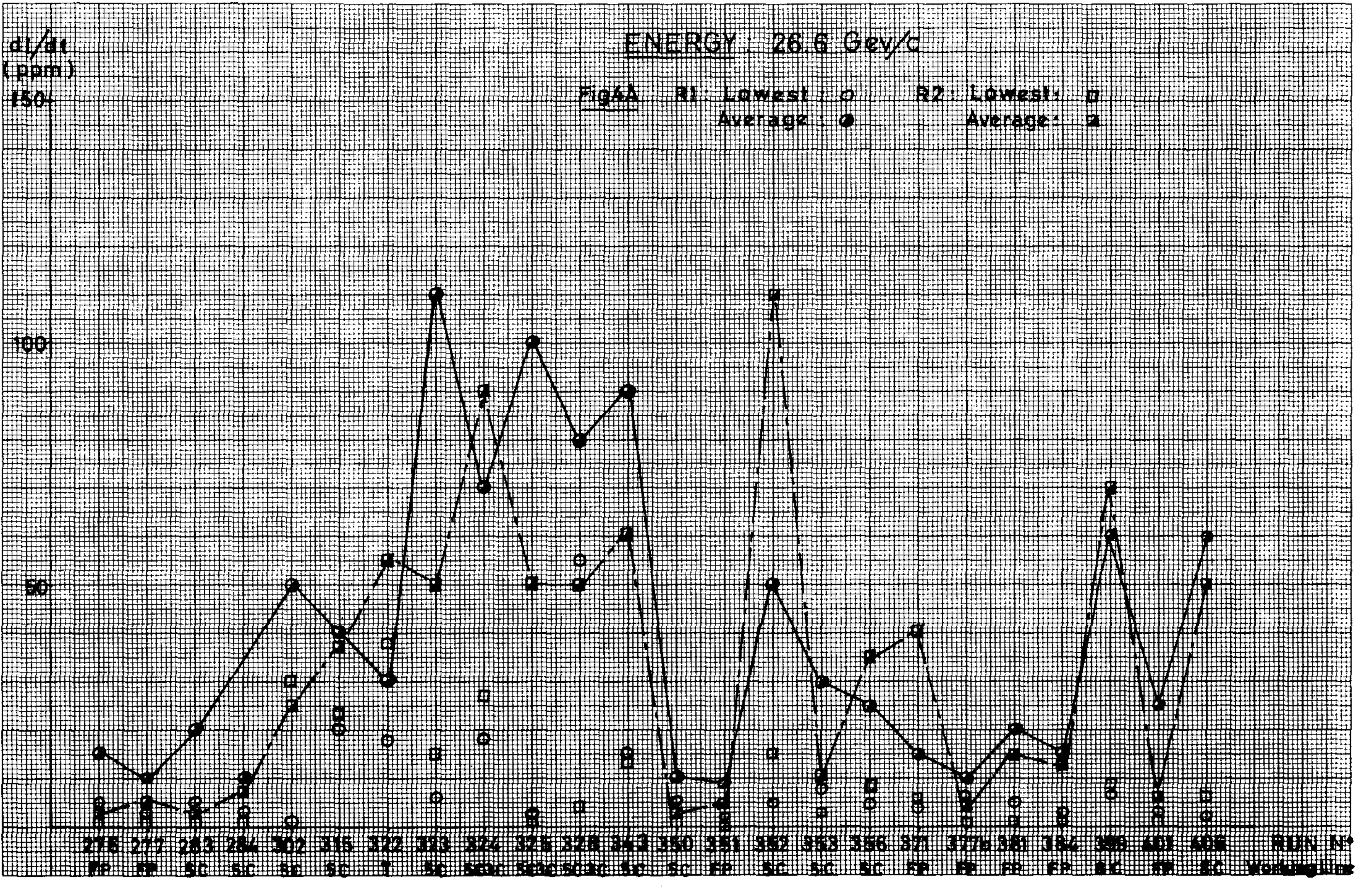
ENERGY : 26.6 Gev/c
Fig4A
R1 : Lowest : ○
Average : ●
R2 : Lowest : □
Average : ▨
dI/dt (ppm)
150
100
50
276 FP
277 FP
283 SC
284 SC
302 SC
315 SC
322 T
323 SC
324 SC3C
325 SC3C
328 SC3C
343 SC
350 SC
351 FP
352 SC
353 SC
356 SC
371 FP
377b FP
381 FP
384 FP
389 SC
403 FP
406 SC
RUN N°
Working line

Fig. 4 A

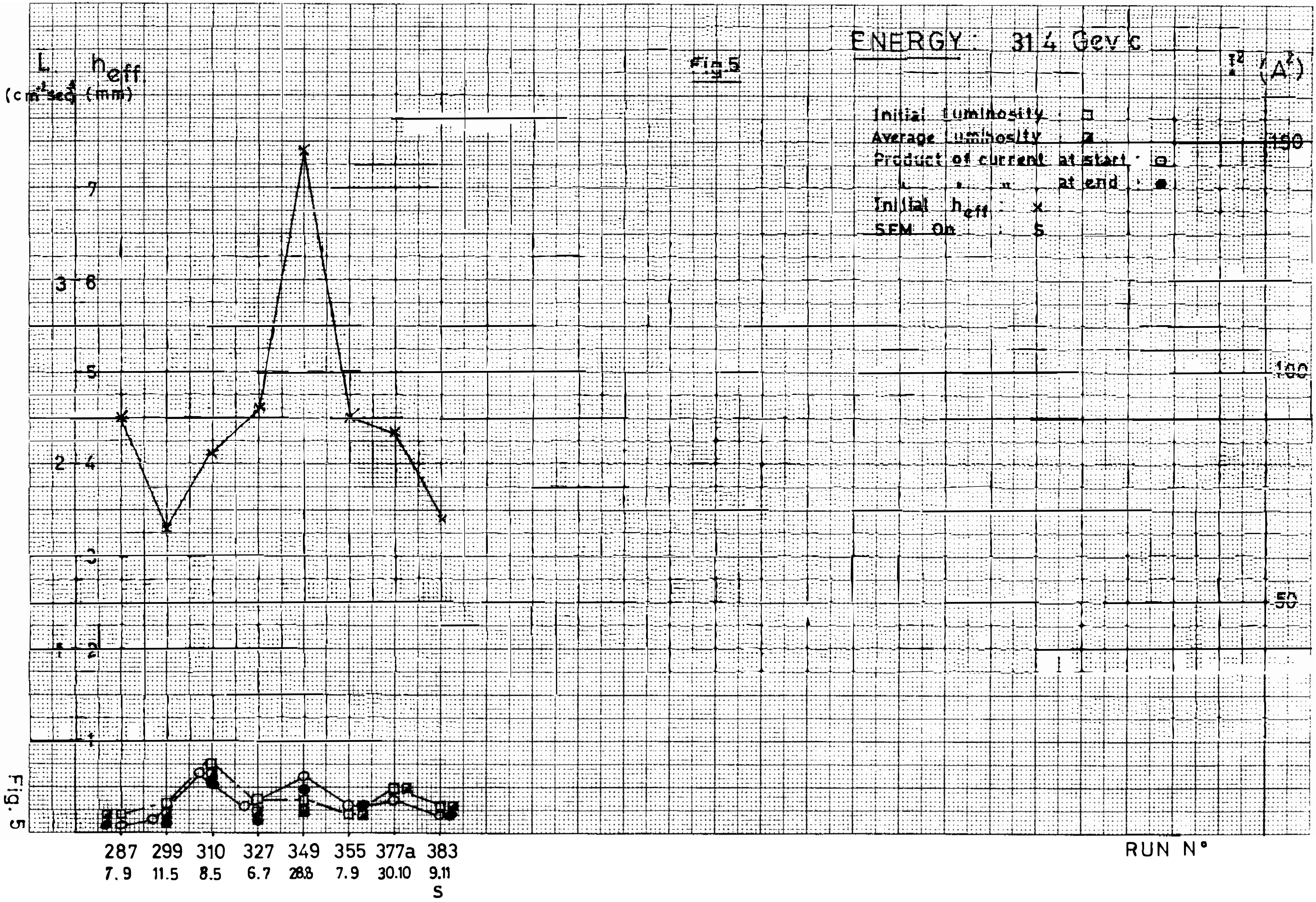
ENERGY : 31.4 Gev/c
L h_eff
(cm⁻² sec⁻¹) (mm)
I² (A²)
Initial luminosity : □
Average luminosity : ▣
Product of current at start : ○
" " " at end : ●
Initial h_eff : ×
SEM On : S
7
3 6
5
2 4
3
1 2
1
150
100
50
287 299 310 327 349 355 377a 383
7.9 11.5 8.5 6.7 28.8 7.9 30.10 9.11
S
RUN N°

Fig.5

Fig. 5

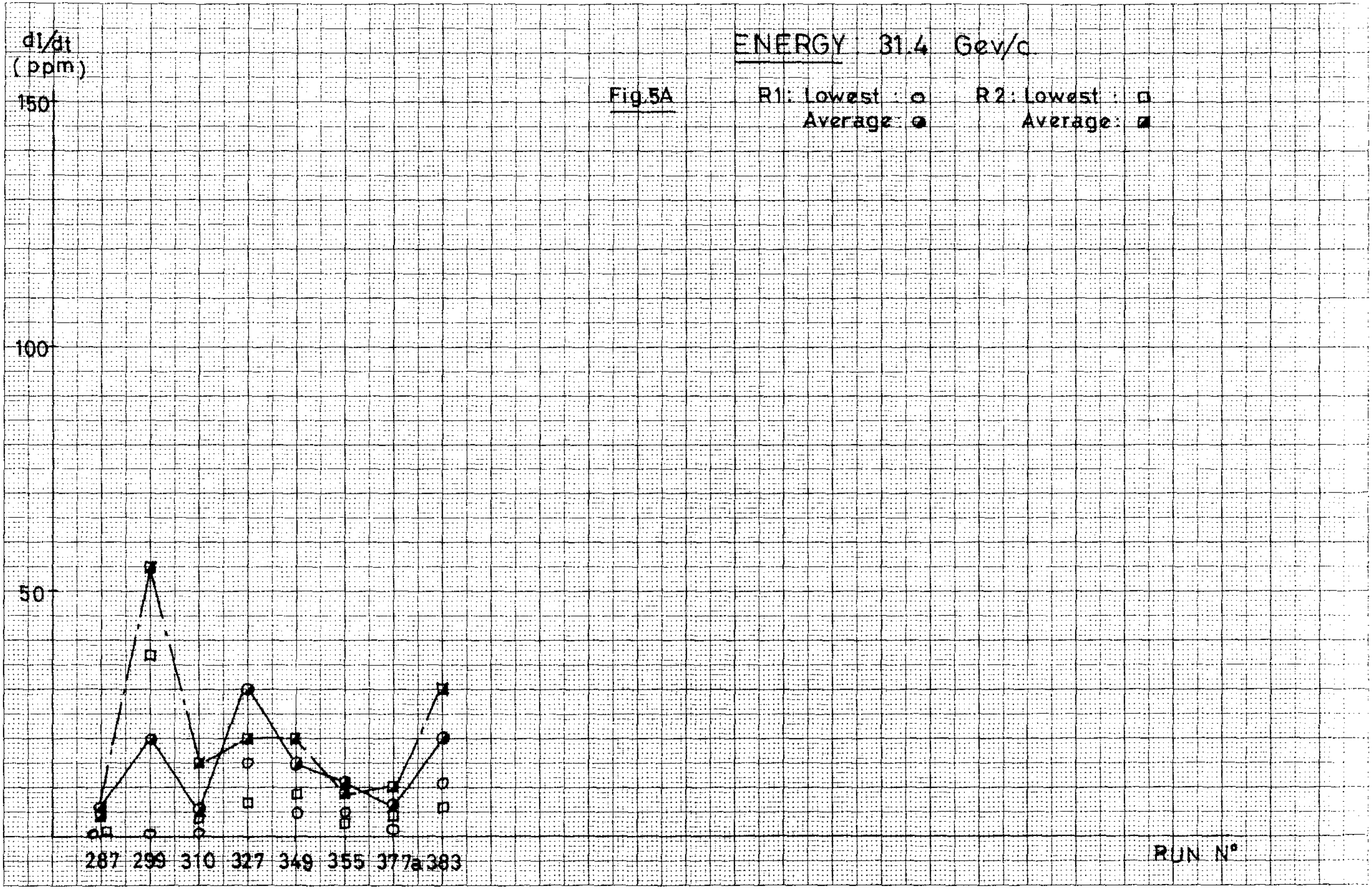
dI/dt
(ppm)
150
100
50
ENERGY : 31.4 Gev/c
Fig.5A
R1: Lowest : ○
Average: ●
R2: Lowest : □
Average: ■
287
299
310
327
349
355
377a
383
RUN N°

Fig.5A