ISR WORKSHOP/2-2
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WORKSHOP ON FUTURE ISR PHYSICS

ISR PERFORMANCE AND PRESENT DEVELOPMENTS

1) Introduction

The operation and performance of the CERN ISR reflects not only the possibilities of the machine but also to a large degree the requirements of past and present physics experiments. The fact that the requirements of the experimental programme are constantly changing is reflected in the very large fraction of so-called Machine-Development studies which are devoted to the preparation of operating conditions for particular experiments.

This note attempts to outline the present performance of the machine as it has developed for the current experimental programme and to indicate possible lines of future short-term development.

2) Present Performance

2.1 Luminosity

The most often used parameter to measure the performance of colliding beam devices is maximum luminosity. Table I gives the highest luminosity achieved at the start of a physics run at each of the five "standard" ISR beam energies together with an overall average for physics runs for this year. The difference between maximum and average luminosity results from a number of causes. Luminosity falls at a rate of about 1% per hour for normal beams and runs last about 40 hours on average. In addition the physics requirement is not always for highest possible luminosity and in some cases the difference simply reflects progress in recent months. This last is particularly true at 31 GeV where great improvements have been achieved in the technique of phase-displacement acceleration.

It should be noted from Table I that there has been no physics requirement for 11 and 22 GeV this year, indeed the quoted highest luminosity at 22 GeV dates from 1975.

This year, the ISR will provide about 3300 hours of stable beam time for physics. The distribution of this time among the standard energies depends on physics requirements but has recently been 50% running at 26 GeV, 40% at 31 GeV and 10% at 15 GeV with a tendency to increase the proportion of high energy at the insistence of groups interested in high mass states. At present one year of running at a standard ISR intersection allows cross-sections down to 10^{-38} cm^{2} to be reached.

2.2 Loss rates and Background

The loss rate of an ISR physics beam is typically between 1 and 5 ppm/min. At the present average gas pressure only about 0.2 ppm/min of this is due to beam-gas scattering. Losses due to beam-beam collisions at a luminosity of 10^{31} cm^{-2} sec^{-1} and current of 25 amps amount to another 0.4 ppm/min and the rest of the particle loss is due to high order non-linear resonances. Many of the beam protons excited by resonances are stopped by the dump block and collimator system but sufficient are lost elsewhere to give background problems to some experiments, particularly those with large surface area detectors. At 25 A a loss rate of only 1 ppm/min corresponds to 7.5×10^{6} protons leaving the beam per second, hence the importance of the collimators.

A second source of background results from the relatively high irradiation of the machine and intersections which occurs during set-up and filling operations. The resultant induced radio-activity can cause problems for some detectors. Efforts are made to keep proton losses to a minimum during the filling process using a minimum number of protons during setting-up and an ion-chamber system to continuously monitor losses. Typically the dose received in an intersection at the surface of the vacuum chamber is between 10^{4} and 10^{5} Rad/year.

2.3 Beam Size

The vertical dimension of the beams at an intersection results from the machine optics (βv) and the vertical emittance and can be deduced from the effective height heff which appears in the luminosity expression. The effective height is typically about 4 mm at 26 GeV. Assuming equal height beams

$$\text{heff} = \sqrt{4\pi}\sigma$$

so that σ the standard deviation of the gaussian distribution of the beam is about 1.2 mm.

The beam is usually stacked to completely fill the horizontal aperture, when in terms of momentum (p) $\frac{\Delta p}{p} = 3.3\%$. The horizontal distribution of the beam is approximately rectangular in longitudinal phase space and hence is rectangular with gaussion edges due to betatron motion in real space. The total beam width is around 75 mm and hence the interaction diamond is some 500 mm long.

The beam width and hence interaction diamond length can be reduced at the even intersections by reducing the momentum dispersion function α_p to 0 and hence reducing the beam to a gaussian distribution with $\sigma \simeq 3$mm, giving a total interaction diamond length of about 100 mm. However, the beam width increases at other points around the circumference causing a loss of aperture and restricting the maximum current. The highest current achieved with the Terwilliger scheme has so far been 14 amps but an estimate has been made$^{1)}$ that 23 amp may be possible.

2.4 Low-β scheme

Since Luminosity (L) is inversely proportional to the effective height (heff) of the beams

$$L = \frac{I_1\ I_2}{e^2 c \text{ heff} \tan\frac{\alpha}{2}} \qquad \text{..........(1)}$$

where I_1 and I_2 are the circulating currents and α is the crossing angle 14.773° of the ISR beams, it is of interest to reduce the beam height in an intersection as much as possible.

1) Small Interaction Diamonds at the ISR - Internal Note ISR-MA/TMT/rh by J-P. Bryant and T.M. Taylor, 23 February 1976.

A system of quadrupoles to do this, known as the low-β scheme, is currently installed in intersection 1. With the quadrupoles powered 26 GeV beams can be reduced in height by just over a factor of 2 yielding an increase in luminosity by the same factor. The other intersections are almost unchanged. The present scheme increases the beam width in the intersection by about 25% necessitating an enlarged vacuum chamber. So far the scheme is only operational at 26 GeV but the necessary optimisation studies have been made at 31 GeV and there is no fundamental reason why it cannot be used at lower energies.

2.5 Deuterons

At the end of last year, the ISR stacked deuterons for the benefit of experiment R 417, Study of Exclusive Neutron Reactions and Coherent Proton Deuteron Processes. A summary of the very limited operation with deuterons is given in Table II. The circulating current and hence luminosity achievable with deuterons and heavier particles can be scaled from the phase-space density reached in the PS. Estimates were made at the first session of the workshop[2].

3) Developments

3.1 Increase of Intensity

The maximum current in the ISR is at present limited by vacuum stability. The critical current, or current at which a run-away pressure rise occurs at some point around the ring, is around 40 amps for both rings. The limit has been steadily increased since the phenomena was first discovered at the few amps level by increasing the pumping speed and the cleanliness of the vacuum chamber walls. Argon glow-discharge cleaning is used in addition to extended bake-outs at 300° C to reduce the outgassing caused by the ion bombardment in the presence of a high intensity stack.

[2] Physics with Antiprotons, Deuterons and Light Ions. Study Group Report ISR Workshop/76-F-1

Ions. Group Report
ISR Workshop/76-F-1.

As a result of these measures a large fraction of the ISR now exhibits behaviour in the presence of beams which would allow very high currents to be stacked. However, the limit is given by the weakest point which changes as modifications are made for installation of experiments, machine improvements etc. While it is still hoped to continue to raise the limiting current it has become increasingly difficult and it is impossible to make reliable predictions of future progress.

At 26 GeV limits to the maximum current from other sources, available phase space density and various instabilities, are, for the time being, substantially beyond the vacuum limit. However, an operational limit for physics may be quite close. By operational limit is meant the practical limit of providing, reliably, low background conditions when working close to stability limits and general maximum performance.

In conclusion it seems unlikely that a substantial increase in luminosity at 26 GeV , greater than a factor of two, can be achieved by simply increasing the stacked current.

At lower energies the vacuum limit has so far not been reached. The maxima being set by phase-space density. At 26 GeV the achievable density in stacks has recently been increased by improved RF techniques and if the physics priorities required it this progress could be reflected in improved performance at low energies. A factor of 2 increase in luminosity would probably be possible with an appropriate amount of development work.

Performance at 31 GeV depends on phase displacement acceleration of a 26 GeV stack. As some losses are inevitable during this process (a few amps) the maximum 31 GeV luminosity must always be somewhat below that attainable at 26 GeV. In addition the operational difficulty is considerably increased.

3.2 Future Low-β Insertions

The ISR Division is at present constructing a low-β insertion using super-conducting quadrupoles for one ring of the ISR. This approved project will allow the concept of using super-conducting magnets at proton storage rings to be tested and an evaluation of the performance of a low-β insertion three times more powerful than at present.

The insertion under construction will reduce the beam height at an intersection by a factor of 6.3. It will not of course increase the luminosity unless extended to the second ring when an increase by the same factor would be obtained. With such an extension of the present project a luminosity substantially above 10^{32} cm^{-2} sec^{-1} could be made available in one intersection region in 1980.

In addition to reducing the beam height the insertion also reduces the horizontal betatron amplitude function and the momentum dispersion, the combined effect being a reduction in beam width by a factor of 2.4. This would be a useful reduction in interaction diamond length and in a normal intersection vacuum chamber leaves greater clearance for the beam, reducing local background and risks of vacuum chamber contamination. Initially a normal intersection chamber would be required to allow operation of the ISR with the quadrupoles off, but at a later stage it may be worthwhile considering operating with the scheme always on as is now the case for the SFM. In the latter case a smaller than standard vacuum chamber could be used which would in itself be an advantage for some experiments and may in addition allow a reduction in wall thickness. This is an important difference between the present low-β insertion in intersection 1 and the superconducting version. The present intersection 1 vacuum chamber is 25% wider than normal.

4) Conclusion

While it is hoped to continue the slow improvement in maximum luminosity available at the ISR by raising the maximum stored current the most interesting option for development of the machine seems to rest with low-β schemes. A substantial increase in luminosity can be more reliably achieved in this way, including the requirement to keep beam losses as low as possible. The availability of different luminosity levels in different intersections gives added flexibility to the machine. Indeed one of the reasons why the increase in generally available luminosity has not been faster is that in the physics programme there have always been some experiments not requiring higher luminosities.

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TABLE I

Maximum and Average Luminosity available for Physics

Energy GeV	Maximum Achieved Luminosity $\times 10^{30}$ cm^{-2} sec^{-1}	Average Luminosity during Physics runs in 1977 $\times 10^{30}$ cm^{-2} sec^{-1}
11.8	3.2	-
15.4	7.0	4.5
22.5	13.2	-
26.6	29.0	12.8
31.4	10.5	5.0

TABLE II

Deuteron Beams used for Physics

Energy GeV	Particles	Maximum Achieved Luminosity $\times 10^{30}$ cm^{-2} sec^{-1}
26.6	Deuteron-Deuteron	1.6
	Proton-Deuteron	1.5
31.4	Deuteron-Deuteron	0.6
	Proton-Deuteron	1.5