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THE USE OF THE ISR FOR EXPERIMENTS

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Summary

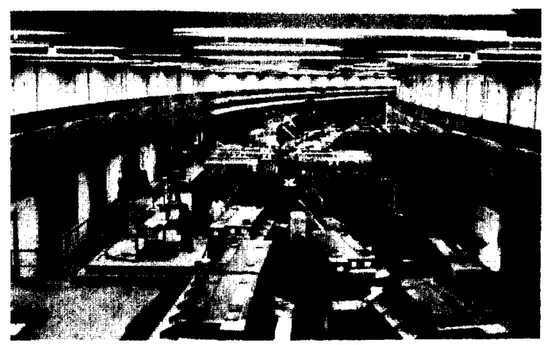
The layout of the ISR is discussed showing the situation of the six intersections presently used for physics experimentation. A brief discussion of some of the physics equipment installed is included. A description of an intersection region is given showing the space available and the constraints imposed by the vacuum chamber. The use of the machine for physics is discussed, the measurement of the luminosity at all the intersections, minimisation of background etc., the ISR control computer playing a large part in these operations. A section describing the so-called Split Field Magnet facility is included.

The Physics Scene

In the two years which have elapsed since the first proton proton collisions were detected in the ISR, 26 experiments have been approved of which 8 have been finished, 7 are still running and 11 are in the process of preparation and installation (7 of the latter will use the Split Field Magnet (SFM) and its detector). Fig. 1 shows the distribution of these experiments amongst the six intersections now in use for physics. A list of the experiments is shown in Table 1.

The apparatus so far used by the physics groups is on the whole orthodox : all experiments using the standard scintillator detector, 80% experiments using either spark chambers, streamer chambers or proportional chambers, about 50% use Cerenkov counters, either gas or lead glass and 60% use magnetic spectrometry. One experiment has used photographic emulsions. One proposal received suggests the use of ice as a quark detector.

The high average multiplicity (i.e. the large average number of secondary particles produced by each proton proton collision) has encouraged the development of detectors which have a solid angle near to 4π and are highly subdivided (hundreds of sections). One such setup (R 801) for example uses many hundreds of scintillators arranged in 17 separate hodoscopes around the intersection region. Another set up is the SFM detector complex which will have 64 000 wires of proportional chambers arranged in 4π around the intersection and immersed in a magnetic field. 4π detection is also necessary in order to measure the total cross section σ_{tot} of proton proton interactions by recognizing and counting all of the collisions occurring. The classical transmission method of measuring σ_{tot} is not possible on the ISR.



Experiment R 105 in I 1

A desire to be able to see the particle energy distributions for high multiplicity events is leading now to discussions on large 4π calorimetric devices which would totally enclose an intersection region, being

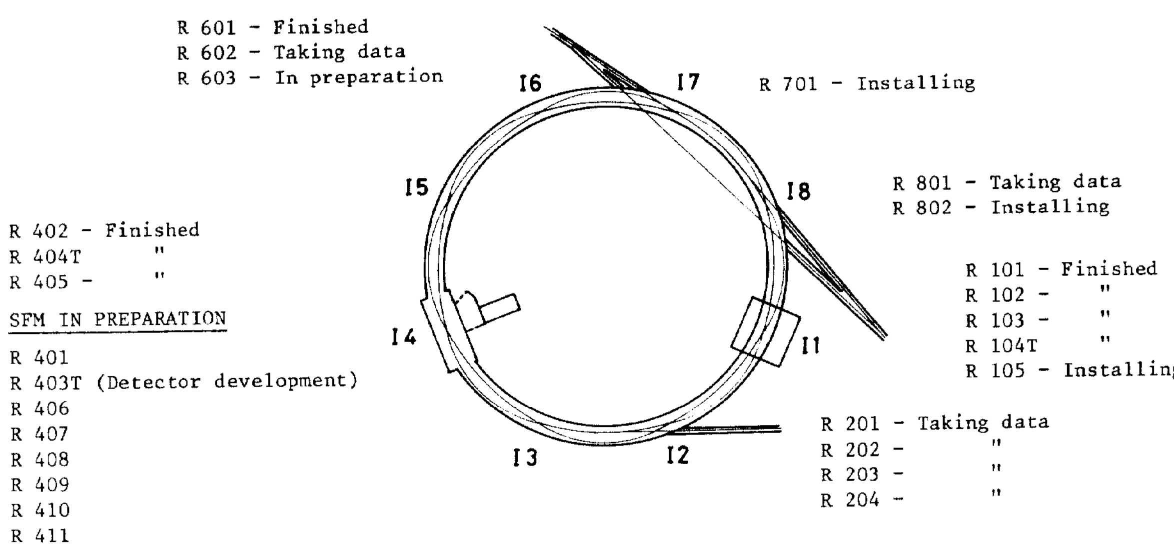


Fig. 1 ISR EXPERIMENTS February 1973

Expt. No.	Composition of Group	Description of Experiment	Principal Apparatus
R 101	CERN-Cracow-Bucharest-Tata	Angular distribution 35°-90°	Nuclear Emulsions
R 102	Saclay-Strasbourg	γ and electrons at large Pt.	Wire chambers, magnet
R 103	CERN-Columbia Rockefeller	Search Massive Dileptons	Wire chambers, lead glass
R 104 T	Brookhaven-Grumman-Rome	High Energy Multigamma Events	As R 103 plus MWPC
R 105	Saclay	High Pt charged particles	Wire chambers, two magnets
R 201	CERN-Holland-Lancaster-Manchester (CHLM)	Stable Particles small angles	Magnetic Spectrometer
R 202	Argonne-Bologna-Michigan	Particle prod. at med. angles	Magnetic Spectrometer
R 203	British Scandinavian Collaboration	Stable particles large angles	Magnetic Spectrometer
R 204	British Universities Collaboration	High Pt Muon Search	Magnetic Spectrometer
R 402	CERN-Munich	Quark search	Scintillators, MWPC
R 404 T	CERN-Hamburg-Vienna	Photon Spectra and Correlations	Lead Glass
R 405	CERN-Karlsruhe	Neutrons at small angles	Calorimeter
R 601	CERN-Rome	Small angle elastic Scattering	Scintillators
R 602	CERN-Aachen-Genova-Harvard-Torino	Elastic Scattering	Two arm magnetic Spectrometer
R 603	CERN-Aachen-UCLA-Harvard	Δ^{++} Spectroscopy	Magnetic Spectrometer, MWPC
R 701	Aachen-CERN-Munich	Inelastic events	Streamer chambers
R 801	Pisa-Stony Brook	σ tot., multiplicities	Scintillator Hodoscopes
R 802	CERN-Rome	Stable particles forward direction	Magnetic Spectrometer

Table 1 : List of ISR Experiments (not including SFM).

several metres in diameter and weighing several hundred tons.

One possibility which is unique to the ISR, where several experiments can share the same intersection region, is the collaboration of the experiments to study correlations between for example, small and large angles. One could even think of moving a complete experiment from one intersection to another to make certain collaborations possible.

An Intersection Region

Interaction Volume

The two beams intersect horizontally at 14.9° giving a diamond shaped interaction volume, 3 to 5 mm high and up to 50 cm long. This volume can be reduced by application of the Terwilliger scheme [1].

Downstream from the interaction point there is about 9 metres of free space available before the first ISR magnet. Upstream there is about 5 metres. The normal beam height above the floor is 1.46 metres. In some intersections this is more, i.e I 1 and I 4 beam heights are 5.06 metres.

Vacuum Chamber

The minimum transverse dimensions of the vacuum chamber in an intersection region are determined by the space necessary for the beam itself and its manipulations such as injection, stacking, vertical and radial bumps and so on. This gives a rectangle 140 mm wide by 40 mm high. A physicist would normally want a vacuum chamber made of the thinnest and most transparent material possible. This requirement has to be satisfied with a vacuum chamber which does not collapse, can be baked to 300°C under vacuum, keeps its alignment and does not perturb the circulating protons.

The present state of the art is exemplified with vacuum chambers of 0.16 to 0.7 mm thick stainless steel in the form of the so-called "bicone" at the intersection point and corrugated cylindrical pipes for the arms. Used with these special chambers are 2.3mm thick stainless steel elliptical tubes of 150 x 50 mm^2 and cylindrical tubes of 160 mm diameter. It must be noted that abrupt changes of section of the vacuum chamber, e.g. from circular to elliptic, constitute a resonant cavity which can be excited by and thus perturb the circulating protons. These electromagnetic oscillations are damped by the insertion of resistors in the cavity. These resistors which consist of thin films of nickel deposited on ceramic cylinders are thus installed in the bicone and all changes of vacuum chamber cross-section.

For work below 10 mrad two special solutions have been found. The first is the use of vertical re-entrant "pots", mounted downstream in the vacuum tubes, which are remotely controlled and brought vertically above and below to within a few millimetres of the circulating beams at the beginning of a physics run after stacking, luminosity measurements and other beam gymnastics have been finished and stable beams established. This technique was used with the experiment R 601 and allowed measurements of elastic scattering down to 1.7 mrad. The second solution is to put special vacuum chambers in the downstream machine magnets to enable essentially zero angle particles to be measured. This solution will be used by the experiment R 802.

An interesting vacuum chamber was that installed in

I 6 for part of experiment R 602 during 1972. Consisting of two large cones and a central box, it was equipped with two large cryogenic pumps each with a pumping speed of about 20 000 litres/second. The vacuum in this section was always better than 10^{-12} torr even in the presence of intense beams of protons. The beams were shielded electromagnetically from this large resonant cavity by surrounding them with a thin conducting mesh.

These special vacuum chambers, at the limit of the available technology were all conceived and constructed by the vacuum and engineering groups of the ISR department. Studies are in hand for thin walled vacuum chambers in titanium and for small general purpose cryogenic pumps for use in intersection regions.

Use of the Machine

Present Physics Operation

Table 2 summarises the present operating parameters of the ISR for physics. The last column of course is being constantly updated. The record luminosity of $4.3 \times 10^{30} cm^{-2} sec^{-1}$ achieved so far during machine development at 22.4 GeV/c was in fact with working lines and stacks which were suitable for physics.

Beam Momenta GeV/c	CM Energy GeV	Equivalent Energy GeV	Typical Luminosity $cm^{-2}\ sec^{-1}$
11.8/11.8	23.4	291	1×10^{29}
15.3/15.3	30.4	491	5×10^{29}
22.4/22.4	44.4	1053	2×10^{30}
26.5/26.5	52.6	1474	2×10^{30}
31.4/31.4	62.3	2062	5×10^{27}

Table 2 : Present Physics Operation

It is hoped this year to improve by up to an order of magnitude the luminosity at 31.4 GeV/c. The technique of rebunching used for accelerating the protons from 26.5 to 31.4 GeV/c has restricted the available stacked current to about 500 ma with a theoretical maximum of 1.5 amperes. By using the originally foreseen method of phase displacement acceleration and improved dynamic control of the working lines between the two energies it is hoped to improve these currents considerably.

Some physics time has been devoted to running with asymmetric energies of 15.3 GeV/c on 26.5 GeV/c mainly for changing the acceptance of spectrometers in the centre of mass.

Luminosity Measurement

The luminosity of the ISR is measured basically in two different ways, by the Van der Meer method and by direct measurement of the vertical beam profiles and subsequent numerical folding. The first method involves vertical movements of both beams simultaneously in all of the intersection regions where physics is done, beam beam interactions being counted for each position with monitor counters. These movements, of about ±5 mm spread in steps of 0.25 mm must be accurate to better than 0.05 mm and must be independent, that is cross-talk with other intersection region below the percent level. Horizontal field bending magnets located before and after the intersection region are used to produce these "bumps". The calibration of these bumps depends upon the working line and whether the Terwilliger scheme is in use or not. Files of power supply currents as a function of energy, working line etc. are kept in the central Argus computer which controls the application of the bumps. The operation of this scheme, involving co-operation between six intersections and the ISR control room, is now a smooth process and is a good example of experimenter / operator / computer communications.

The second method is carried out by the experimenters themselves, essentially by using track reconstruction techniques to plot the profile of the profile of the beams as they collide with the residual gas using, for example, a controlled leak (I 6) or a titanium cloud (I 8).

Other methods to measure the profile exist, such as the sodium curtain profile monitor in I 5, or are under study.

Background

Typical decay rates of the beam currents during physics runs are of the order of 1 part in 10^5 per minute. At 10 A this represents about 3×10^7 protons lost per beam per second around the machine. If one assumes that these are lost evenly around the circumference then one would expect about 6×10^5 protons per intersection per beam as background particles giving on average about 20 particles/sec/cm^2. This background is highly directional and can quite often be successfully gated out. These figures are very rough and it is certainly true that some intersections are worse than others. The single arm spectrometers often ask for running time with one beam only in order to measure the effects of background. Lead shielding placed in the upstream ISR magnets helps to reduce background particles.

Radiation Effects

It is worth pointing out that because detectors and electronics are clustered around the machine they are exposed to large doses of radiation. This is due principally to injection and stacking and to machine development experiments. The experiment R 103 found that the lead glass it uses darken with radiation, adsorbing more in the blue. The calibration of these counters changed by 30% during the experiment. Electronics, such as integrated circuits, are also liable to suffer if they are close to the intersection point. Tests have shown that 10^4rad adsorbed can seriously effect MWPC type electronics. The typical dose measured around an intersection point in the ISR would be about 10^4rad/year. Also, to avoid deteriorating photomultiplier tubes, the HT is turned on only when stable beams are announced.

The Split Field Magnet Facility

An important physics facility of which the magnet is being built by the ISR and the detector by the NP division will be coming into service this year.

Fig. 2 shows a view of the magnet. Some statistics of the magnet are given in table 3, of the detector in table 4. There will be about 36 chambers giving a total of 64 000 wires.

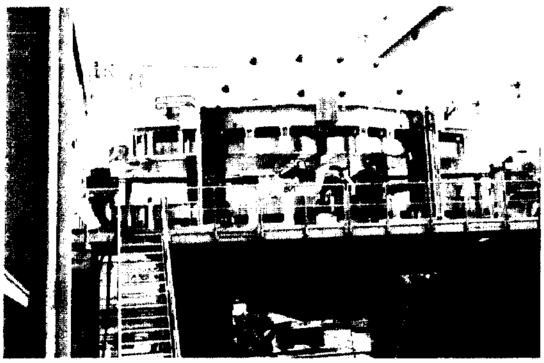


Fig.2 : The Split Field Magnet (SFM)

Length	10.30 m	Useful Field Volume	28 m^3
Width min.	2.00 m	Max. Field	11.4 kg
max.	3.50 m	Weight	850 tons
Gap height	1.10 m	Power	4 MW

Table 3 : SFM Main Magnet

Type : Multi Wire Proportional Chamber	
Wire spacing	2 mm
Time resolution	$\approx$ 50 ns
Space resolution	0.7 mm
Dead time	< 1 μsec
Maximum size	1.05 x 2.05 m^2
Construction; frameless, self supporting foam sandwich	

Table 4 : Principal characteristics of the SPM Detector

Compensator magnets, together with the field of the principal magnet correct the ISR orbit. The larger downstream compensators also serve as analysing magnets for forward particles.

The group which is developing the detector and its electronics and software is composed of nucleus from CERN together with members of every group proposing to use the SFM of which so far there are seven approved.

The central vacuum chamber, which must be wide enough to allow for the movement of the crossing point is made form 0.7 mm stainless steel with an elliptical corrugated cross-section 300 x 560 mm^2 and is 1800 mm long. The downstream chambers are elliptical, corrugated, 100 x 300 mm^2 in 0.7 mm stainless steel.

Development has started to build these chambers in titanium, reducing the wall thickness by two and the wall material by four.

Reference

1) "The creation of Small Interaction Diamonds in the CERN Intersecting Storage Rings", Paper J-7, this Conference.