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MEASUREMENT OF INTRA-BEAM SCATTERING IN THE ISR

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Summary

The growth of proton beams coasting for a long time with very low loss-rate has been measured. A comparison with the growth-rate expected from intra-beam scattering is presented. At lower energy measured and calculated growth agree. At higher energy the measured growth tends to exceed the calculated one by about a factor of 3. The growth in momentum spread is in accordance with theory.

Introduction

Low current proton beams coast in the ISR for many hours with a loss-rate of less than $6\cdot10^{-4}$ h^{-1}. The typical loss-rate is $6\cdot10^{-5}$ h^{-1}. It is mainly determined by nuclear scattering on the other beam and on the residual gas in the chamber. The Q-values in these small stacks do not cross any non-linear sum resonances of order less than 8, which are known to produce anomalous amplitude growth [1]. Thus one may hope that the beam growth is dominated by intra-beam scattering and multiple Coulomb scattering on the residual gas. Since the beam can grow virtually without aperture limitation a detailed comparison with theory [2,3], which assumes a beam in free space, suggests itself.

Vertical Growth

Once the beams are stacked and are left circulating for high energy physics experiments, the rate of beam-beam collisions is monitored by counter telescopes in the intersection points. This rate is proportional to $(I_1 I_2)/h$ where I is the beam current per ring and h is the effective height. The latter is defined in the intersection points (β_z = 14 m) by

$$h^{-1} = \int \rho_1\rho_2 \, dz \left(\int \rho_1 dz \int \rho_2 dz\right)^{-1}$$

where ρ is the vertical density distribution in the beams. Hence, variations in h can be derived from the record of collision-rate and beam currents.

Fig. 1 shows measured growth-rates of the beam height h at different energies. The growth due to Coulomb scattering on the residual gas was subtracted. All runs in the year 1974 on the low current working line FP [4] were taken into account. However, two runs at 11,8 GeV/c, where the normalized growth-rate was in the 0,02 $(Ah)^{-1}$ range, are not shown as well as runs where scraping or luminosity measurements ruined the smooth growth of the beam. Since the growth is rather linear, a straight line was fitted to the data of each run. The fit covers a period of typically 10 hours at the beginning of the run.

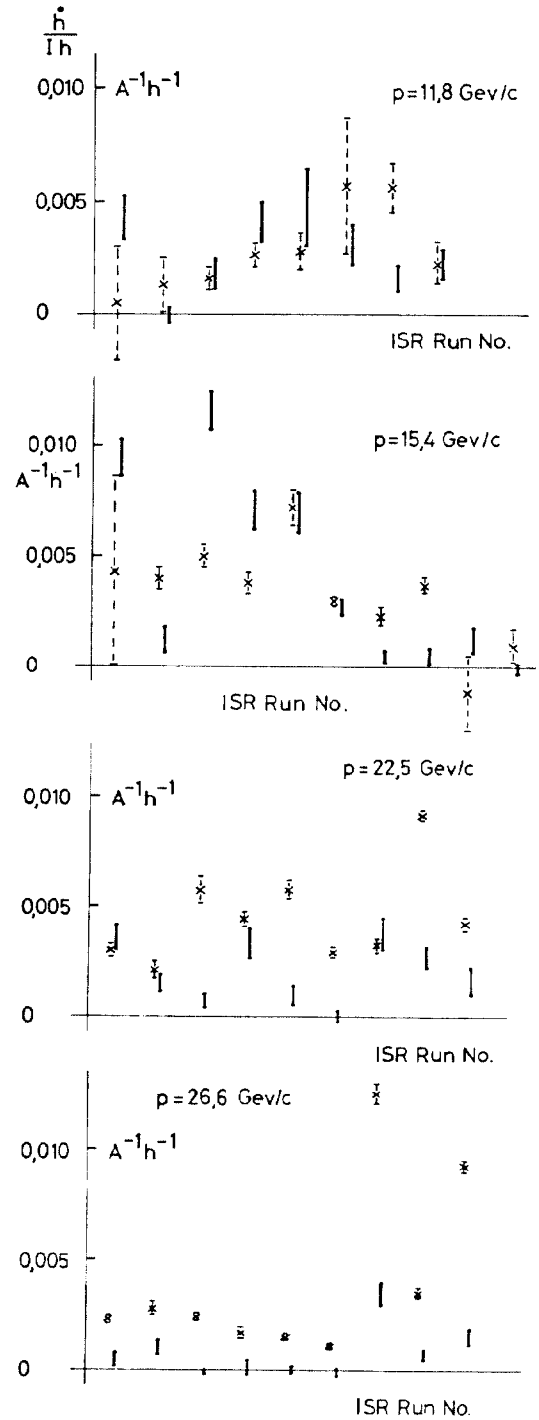

Fig. 1 - Vertical growth-rate normalized to 1 A in low current ISR runs. Dashed lines: measured rate minus multiple scattering. Full lines: calculated rate.

The growth per hour due to Coulomb scattering [5] on the residual gas can be obtained from

$$\dot{h}/h = 2\cdot 10^{12}\ \frac{P_{MS}}{p^2\ h^2}$$

where h is given in mm and the momentum p in GeV/c. The N_2 equivalent multiple scattering pressure P_{MS} was about 10^{-12} torr in all the runs. It was derived from the average pressure, which is monitored in each run, assuming a gas composition of 95% H_2 and 5% N_2 or CO. The average pressure as well as the average gas composition are not known very precisely. However, it turned out that the multiple scattering is always small compared to the error in the measurement of the slope. Coulomb scattering on the other beam is negligible as well as small angle nuclear scattering.

The full lines in Fig. 1 show the growth-rate expected from intra-beam scattering [2]. It was calculated with the parameters of the individual runs. The theory assumes Gaussian distributions in all three variables x, z, p. The actual distribution in the beam was close to this except in longitudinal momentum where the distribution tended to have a flat top at higher currents. Hence the rms momentum spread was calculated from the full width at the bottom $\Delta p/p$ using

$$\sigma_p = \frac{1}{2\sqrt{\pi}}\ \frac{\Delta p}{p}$$

The horizontal emittance was not measured in each run. A few measurements on young stacks indicated $E_x\beta\gamma = (30 \pm 10)\ 10^{-6}$ rad m. The maximum impact parameter was assumed to be equal to the beam height [9]. Since the growth is proportional to the current the results, shown in Fig. 1, are normalized to 1 A to facilitate comparison. The average current was 3,4 A at 11,8 GeV/c, 4,6 A at 15,4 GeV/c, 5 A at 22,5 GeV/c and 6 A at 26,6 GeV/c. It never exceeded 10 A.

Inspection of Fig. 1 shows that experiment and theory agree fairly well except at higher energy where the measured growth-rate tends to exceed the calculated one by a factor of 3. The reason for this discrepancy is not known. No positive correlation between excessive growth and current or increased loss-rate could be established. The spread in the points, corresponding to different runs at a given energy, is due to the variation in beam parameters from run to run.

The dependence of the vertical growth on the beam dimensions was used in an additional test for intra-beam scattering. Fig. 2 gives an example. Three experiments were performed at p = 22,5 GeV/c with different beam aspect ratios. In the first experiment, the horizontal beam size was decreased by scraping each pulse at injection orbit prior to stacking. In the second experiment, the vertical beam size was diminished by scraping and the beam was made larger horizontally by increasing the injection error. Vertical scraping only was used in the last experiment. The current was 6,3 A in both rings and the rms momentum spread was $3{,}8\cdot 10^{-3}$. Table I gives parameters and results.

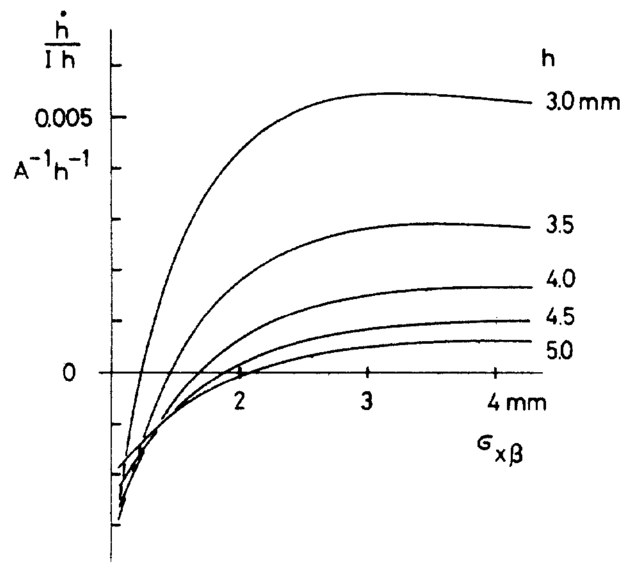

Fig. 2 - Computed vertical growth-rate versus horizontal beam size. p = 22,5 GeV/c, $\sigma_p = 3{,}8\cdot 10^{-3}$. The effective height h is the parameter.

Table I

Vertical growth-rate for different beam aspects

h mm at β_z = 14 m	$\sigma_{x\beta}$ mm at β_x = 17,5	$\dot{h}/Ih$ $(Ah)^{-1}$ calc.	$\dot{h}/Ih$ $(Ah)^{-1}$ meas.
	1,5	- 7	
5,1	2,0	$-\ 1\cdot 10^{-4}$	$-\ (6\pm 10)\cdot 10^{-4}$
	2,6	3	
	2,8	60	
2,9	3,5	$60\cdot 10^{-4}$	$(47\pm 10)\cdot 10^{-4}$
	4,2	57	
	1,9	34	
3,1	2,3	$43\cdot 10^{-4}$	$(30\pm 3)\cdot 10^{-4}$
	2,7	46	

Inspection of Table I indicates that the beam growth follows indeed the trend predicted by intra-beam scattering.

Horizontal Growth

Horizontal emittance in wide stacks is difficult to measure. Using a scraper the emittance in some young and old stacks was determined. Comparison yielded evidence for a substantial blow-up in horizontal direction [6]. It exceeds intra-beam scattering by an order of magnitude.

Growth of Momentum Spread

Diffusion in longitudinal momentum had been measured earlier in the ISR by means of scrapers [7] and a fair agreement with the expected diffusion constant [8] was found.

In the present experiment the evolution of the momentum spread over a relatively long period of time was measured by means of Schottky scans [9]. Two small stacks whose distribution in momentum was very close to a Gaussian were used. The beam current was 1 A in both experiments. The results of both runs are shown in Fig. 3. The full lines represent the calculated rate. Table II gives the parameters used in the calculation and the results.

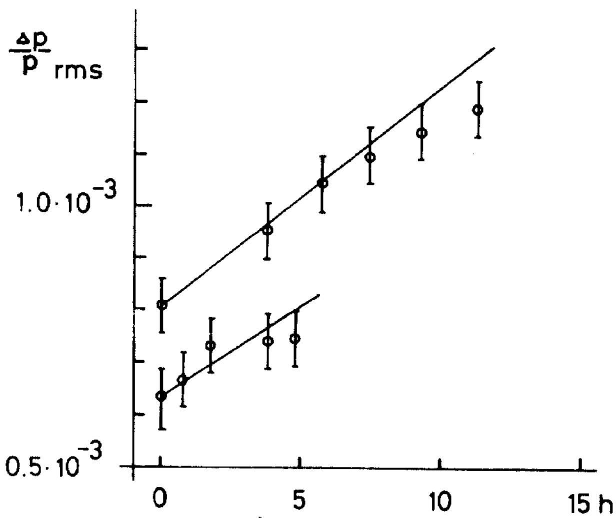

Fig. 3 - Rms momentum spread in an 1 A beam versus time at 26,6 GeV/c. Circles: measured points; full lines: computed growth.

Table II

Growth of momentum spread

h mm	E_x $\pi \cdot 10^{-6}$ radm	$\dot{\sigma}_p$ (calc.) h^{-1}	$\dot{\sigma}_p$ (meas.) h^{-1}
	0,7	0,050	
4	1,1	0,040	0,029 ± 0,009
	1,4	0,035	
	0,7	0,050	
6	1,1	0,040	0,022 ± 0,013
	1,4	0,033	

It is apparent from the table and the figure that the calculated and mesured rate agree within the experimental error.

References

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