WORKSHOP ON FUTURE ISR PHYSICS

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pp Interactions at ISR Energies

by

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This report summarizes the conclusions of the Working Party on p\bar{p} interactions at ISR energies. A review of the material presented during the plenary session on p\bar{p} physics is circulated separately as ISR WORKSHOP/2-9.

1. Introduction

The purpose of this note is not to give a review, biased by our present ideas, of the many possible p\bar{p} experiments which can be envisaged at the ISR, but rather to attempt a "measurement" of the ISR potentialities with p\bar{p}. A few specific areas of research will be considered to achieve this aim. It should be kept in mind, throughout this paper that although present experience with pp and respected theoretical ideas may lead to expectations for p\bar{p}, surprises might well occur.

More detailed discussions on p\bar{p} physics and experiments at the ISR are given in the reports on specialized topics presented during the Workshop (ISR WORKSHOP/2-9). The reader is also referred to the p\bar{p} Study Group Report at the first session of the Workshop*.

The working assumptions which we have made here are (see the contribution by K. Hübner in document ISR WORKSHOP/2-9):

\[
L = 2 \times 10^{28} \text{ cm}^{-2} \text{ s}^{-1} \quad (800 \text{ int/sec})
\]

in a standard intersection, and

\[
L \simeq 10^{29} \text{ cm}^{-2} \text{ s}^{-1} \quad (4000 \text{ int/sec})
\]

in a low-\beta intersection.

As present or conceivable scenarios, some of them being illustrated in Figure 1, one has:

(i) p\bar{p} collisions in the SPS (L \simeq 10^{30} \text{ cm}^{-2} \text{ s}^{-1})

(ii) secondary p\bar{p} beams from SPS p beams, giving √s = 24 GeV and intensities

- \(5 \times 10^5\) p\bar{p}/sec in the North Area hadron beams (p/π⁻ \simeq 3 \times 10^{-3})

- \(10^3\) p\bar{p}/sec in the "enriched" p\bar{p} beams from \(\Lambda^0\)'s (10 \div 20% of p\bar{p}'s)

(iii) primary p\bar{p} beams from the SPS used as an accelerator, fed by the p\bar{p} cooling and accumulation ring. The average intensity can be \(5 \times 10^6\) p\bar{p}/sec.

* L. Bertocchi, J. Ellis, G. Flügge, V.G. Goggi, K. Hübner, M. Jacob, D. Möhl, and P. Storlin, Physics with Antiprotons, Deuterons and Light Ions, Workshop on Future ISR Physics, 4-15 October, 1976
The technical problems implied by this last possibility have been studied in some detail during the first session of the Workshop, and more recently by N. Doble of the SPS Division. The reversal of the SPS polarity required to accelerate and eject $\bar{p}$'s in the same beam lines as those used for $p$'s appears possible. The main problem comes from the extraction channel, as the highly sophisticated electrostatic septa (specially designed to minimize the radioactivity induced by even small fractional losses of the intense proton beams) would not stand a polarity reversal. However, the much higher fractional losses which can be tolerated with $\bar{p}$'s will permit the use of standard septa, e.g. magnetic.

(iv) An ortho-ISR scheme, with particles circulating in the same direction in the two rings, has been proposed by U. Gastaldi for study of the formation of $p\bar{p}$ atoms and of baryonium states. Special attention was paid at this Workshop to the $p\phi$ mode. For a discussion of this low energy physics with high energy particles, the reader is referred to the contribution of U. Gastaldi at this Workshop, as included in ISR WORKSHOP/2-9.

We now examine in turn several physics topics.

2. Total Cross-section and Elastic Scattering

The simplest way to measure $\sigma_t$ is through small-$t$ elastic scattering. It implies an extrapolation at $d\sigma/dt$ elastic to $t = 0$ with a small correction for the real part of the nuclear scattering amplitude. One uses the optical theorem to derive $\sigma_t$. The ISR luminosity, measurable in the $pp$ case by the Van der Meer method to better than $\pm 0.9\%$ (Pisa-Stony Brook and CERN-Rome, 1975) enters only as a square root in the expression of $\sigma_t$, which decreases its influence on the experimental error. The latest published ISR data give $\sigma_t$ with $\Delta\sigma_t/\sigma_t = 0.7 \pm 0.8\%$, i.e. $\Delta\sigma_t(pp) \approx 0.3$ mb. This is only a few times less than the precision obtainable with fixed target experiments by means of the transmission method ($\Delta\sigma_t \approx 0.1$ mb).

With $p\bar{p}$, small angle elastic scattering can be obtained with great accuracy. The ACHGT pp data shown in Figure 2 contain $10^6$ events, with a $\phi$ acceptance $\Delta\phi/2\pi = 1/6$ and $L = 10^{28}$ cm$^{-2}$ s$^{-1}$. Similar $p\bar{p}$ data can be obtained in three days of effective running time. The Coulomb interference experiment to measure the real part is, on the contrary, problematic because of rates; it in fact requires high statistics over a tiny $t$ range, with narrow beams and restricted $\phi$ acceptance. The accuracy which can be expected on $\sigma_t(p\bar{p})$ is then

$$\Delta\sigma_t(p\bar{p}) \approx 0.5$$ mb

The measurement of $\sigma_t(pp)$ is certainly highly worthwhile. Extrapolations of low energy data (Figure 3) indicate that $\sigma_t(p\bar{p}) - \sigma_t(pp) = 1 \pm 3$ mb in the ISR energy range, and a test of the convergence of the two cross-sections is certainly a most interesting experiment at the ISR.
Figure 1: Possible schemes for $p\bar{p}$ interactions
Figure 2: pp Elastic scattering at √s = 52 GeV (data from the ACHGT collaboration, 1971). Similar data on pp elastic scattering could be obtained in one day of running with Δφ = 2π/6 and L ≈ 10^{28}
Figure 3: Extrapolation of the pp and p̅p cross-sections according to the measurement of the real part of the forward elastic amplitude by the CERN-Rome Collaboration, 1976.

The asymptotic behaviour is parametrized as
\[ \sigma = (29 \pm 1) + (0.17 \pm 0.8) (\ln s)^{2.1 \pm 0.1} \]

The difference between the two cross-sections behaves as
\[ (P_{lab})^{-0.55 \pm 0.02} \]

On the other hand, the precise measurement of the Regge behaviour of \( \sigma_L (pp) - \sigma_L (pp) \) is a hard experiment. Taking for this difference 3 mb at \( \sqrt{s} = 20 \text{ GeV} \) (Figure 4) according to \( s^{-0.4} \) or \( s^{-0.6} \) law it becomes 1.2 or 0.8 mb respectively at \( \sqrt{s} = 60 \text{ GeV} \). This has to be compared to the experimental errors \( \Delta \sigma_L (pp) = \pm 0.3 \text{ mb} \) and \( \Delta \sigma_L (p̅p) = \pm 0.5 \text{ mb} \). Note that a number of systematic errors are beam dependent, rather than detector dependent, so that they unfortunately do not cancel out even if \( \sigma_L (pp) \) and \( \sigma_L (p̅p) \) are measured with the same apparatus.

Figure 5 shows that a very significant measurement of the p̅p elastic differential cross-section until \( -t = 3 - 4 \text{ GeV}^2 \), well beyond the dip, is possible at the ISR with the conservative integrated luminosity \( 10^{28} \text{ cm}^{-2} \text{ s}^{-1} \times 10 \text{ days} \).

It should be stressed in this context that, even with the above discussed limitations in the measurement of \( \sigma_L (p̅p) - \sigma_L (pp) \), the difference in shape of the p̅p and pp diffractive patterns is measurable with great accuracy and, through an impact parameter analysis, can give a very sensitive and detailed description of the pp and p̅p profile functions and of their differences. A good instrument for the measurement of p̅p elastic scattering in this \( |t| \) range is the SFM. It is already on the floor.
Figure 4: The Regge behaviour of the differences between total cross-sections
Figure 5: The elastic differential cross-section at medium $|t|$. It would be easy to measure the corresponding cross-section for $p\bar{p}$ beyond the dip region. This is very interesting as discussed by M. Moshe and A. White in ISR WORKSHOP/2-10

c) Low $p_T$ physics

Without going into a detailed description of possible experiments, discussed in the contributions of Donnachie and Braccini (ISR WORKSHOP/2-9), we emphasize here that there is a class of low-$p_T$ experiments where systematic errors are to a good extent detector dependent. Typical examples are:

- multiplicity distributions and their moments, in particular $f_2^{--}$
- correlation functions
- rise in the rapidity plateau
- particle ratios.

A detailed comparison between $pp$ and $p\bar{p}$ induced reactions should then be relatively easy.

Even though low $p_T$ physics is usually considered as already well explored within the ISR possibilities, it should be stressed that very important new developments have recently emerged and could well trigger a revival. In par-
(i) the study of large multiplicity configurations. This was extremely
difficult with the early detectors;

(ii) the rise of the central "plateau" with energy. The actual shape of the
"plateau" should then be better determined;

(iii) the fact that correlation studies in the central region have been so
far limited to pions when they should be extended to heavy particles.
This is now possible with the time of flight detector of the SFM.

A more detailed discussion of these points can be found in document
ISR WORKSHOP/2-10. They deserve further study. What should be stressed here is
that, in so doing, comparisons between pp and p\bar{p} induced reactions are of great
interest. The inherent asymmetry of the p\bar{p} initial state and its influence on
the final states should provide important clues sorting out dynamic mechanisms.

In these experiments accurate measurements of p\bar{p}/pp differences should
be feasible. Among such experiments, we find the production of baryon-antibaryon
pairs in the central region, which is of interest in order to single out the
rôle of the annihilation process at very high energies and its relation to the
total cross-section difference \sigma_{t}(p\bar{p}) - \sigma_{t}(pp). In connection with that it
would be interesting to study the feasibility of an experiment which would trigger
on the absence of leading baryon (antibaryon).

d) Large mass lepton pairs

The basic process in lepton pair production being (according to Drell-
Yan) q-\bar{q} annihilation into one photon, important differences are expected between
p\bar{p} and pp reactions, due to the valence Q's in antiprotons. Drell-Yan calcula-
tions for pp compare well with FNAL results (Figure 6). There is no evidence for
scaling violation to the present degree of accuracy and within the present mass
and energy ranges.

In the case of p\bar{p} induced reactions, there is always a rapid rise which
brings one close to the maximum practical yield at s/M^2 \approx 10 (see Figure 6). The
cross-section is of the order of \frac{d\sigma}{dM} = \frac{1}{M^2} \times 10^{-32} cm^2/GeV, with M in
GeV. Taking the production of 1 event/(day x GeV) as the limit on sensitivity
(the detection efficiency which may be of the order of 20% is not included in the
quoted number) a luminosity of \text{10}^{29} limits practical experimentation to M < 5 GeV.
If a higher luminosity (say \text{10}^{30}) which would allow for reaching masses of the
order of 9 GeV is not achieved, one does not expect dramatically higher yields in
p\bar{p} than in pp induced reactions at the ISR: the difference in yields may be of
the order of a factor 2 only. Therefore the interest for p\bar{p} at the ISR does not
only reside in the attainment of larger masses due to the presence of valence $\bar{q}'$s, but rather in the study of $pp/\bar{p}\bar{p}$ differences over the ISR energy range. In fact, going down in energy (down in $s/M^2$) should bring a very sharp decrease of the proton induced yield, but not of the antiproton induced one, which should not change much down to $s/M^2 = 10$ (e.g. $M \approx 7$ GeV and $\sqrt{s} = 23$ GeV) as shown in Figure 6. This is a very important test of the proton structure, with the corresponding $J/\psi$ yields also studied at the same time. The interesting result of the SPS beam dump experiment at 40 GeV (factor of 6 between the $p\bar{p}$ and pp yields) calls for experiments at higher energies.

We note that for large mass lepton pair production, fixed target experiment at the SPS (e.g. at the proposed hall EHN3, with intense bursts of $p$ accumulated, cooled and accelerated once in a while) are of great interest.

Nevertheless, as discussed in detail in ISR WORKSHOP/2-8, as soon as one does not consider a beam dump experiment but asks questions about the associated particles (bare target experiments), the ISR retains some advantages.

e) Large $p_T$ physics

Figure 8 shows the large $p_T$ invariant cross-section as measured by the CCRS collaboration at the ISR. These data have been obtained with an integrated luminosity of $0.9 \times 10^{36}$ cm$^2$ (say 50 hours at $5 \times 10^{30}$ cm$^{-2}$ s$^{-1}$), using a detector with 0.17 sr solid angle for $\pi^0$'s. Present detectors, e.g. the CCOR solenoid, cover a solid angle $\sim 2$ times larger. This, together with a few times longer useful running time, is sufficient to compensate for a $p\bar{p}$ luminosity a couple of orders of magnitude lower than the one for $p$'s quoted above. One should therefore be able to study large $p_T$ pp interactions in a kinematical range at least as wide as the one so far covered at the ISR in pp collisions, and certainly with higher efficiency, in particular for correlation studies.

This is another example (the same was in fact true for elastic scattering) of how much ISR physics has been done with low integrated luminosities. Initially, the luminosity was also low for $pp$. This should provide a strong encouragement to go on with $p\bar{p}$, even if the luminosity appears low compared to our present high pp standards. To this one adds that the large and sophisticated experiments now on the floor or in preparation for $pp$ (directly usable for $p\bar{p}$), have acceptances which are much larger than those of the first generation experiments.

Large $p_T$ inclusive experiments are therefore feasible up to $p_T = 8 - 9$ GeV/c, i.e. $x_T = 0.3-0.4$ and this with existing instrumentation. At such $x_T$ values valence $\bar{q}'$s play a major rôle (Figure 9) and therefore large differences are expected between $p\bar{p}$ and pp. Also, the large ISR energy span is
Figure 6: Parton model calculations for lepton pair production in pp and $p\bar{p}$ reactions. The calculated values include colour (a factor of 3 down as compared to a colourless approach).
Figure 7: Drell-Yan estimates of cross-sections for lepton pair production in pp and p\bar{p} reactions at the ISR. Also shown are the expected yields for SCISR.
Figure 8: Large $p_T$ inclusive pion yields. Data from the CCRS collaboration. A drop by a factor $10^2$ in luminosity can be partly compensated by the gain in solid angle by a factor 20 provided by present detectors.
crucial for scaling tests. Large $p_T$ is clearly the most interesting part of particle production, and very large energy makes these phenomena more prominent. These are therefore experiments of the greatest interest.

Another extremely important area of research within large $p_T$ physics concerns "jets" and correlations. There the ISX has the best rôle over fixed target experiments because:

(i) "jet" cross-sections are large and observable with a not too high luminosity;

(ii) the large c.m. energy strongly enhances the production of large $p_T$'s, for which jets are collimated and more likely to stand out of the soft pion cloud; for these studies what has to be high is $p_T$, and not $x_T = 2 p_T/\sqrt{s}$;

(iii) the extension of the ISR rapidity range is very important for correlation studies.

A simple argument, presented by Cronin in his talk at the Workshop (document ISR WORKSHOP/2-7) and related to point (ii) above, can be quoted to stress the importance of ISR experiments. For jet collimation one wants, say $E_{\text{jet}} > 10 \text{ GeV}$. Since clearly $E_{\text{jet}} < \sqrt{s}/2$, this means that we require energies a few times larger than $\sqrt{s} = 20 \text{ GeV}$, e.g. in the ISR energy range.

Present instrumentation at the ISR provided results (see the report by G. Flügge at the Workshop, document ISR WORKSHOP/2-14) which support the above point of view. The pp instrumentation can be directly used for pp. For such experiments, involving high multiplicities and eventually particle identification, the expertise and the mastering of the equipment acquired with pp at the ISR will be a major asset also with regard to new machines and detectors.

An example of large $p_T$ correlation studies where pp/p\overline{p} differences might be important is provided by the recent SPM data of the British-French-Scandinavian collaboration reported by Albrow and Hansen at this Workshop (see ISR WORKSHOP/2-7 and 2-9). Figure 10 shows the away side multiplicity (of particles with $|y| < 1$, $p_T > 1.5 \text{ GeV/c}$) when triggering on large $p_T$ (more precisely $3 < p_T < 4.5 \text{ GeV/c}$) $K^\pm$, $p^\pm$ over the corresponding multiplicities with a similar $\pi^\pm$ trigger. Multiplicities of negative and positive particles are plotted separately. One then remarks that $K^-$ and $\overline{p}$ produce "different" away side negative multiplicities. Is this related to the fact that $K^-$ and $\overline{p}$ have no valence quarks in common with the colliding protons? Experiments with p\overline{p} should bring information on such questions. Use of different projectiles have taught a lot in fixed target experiments. Whenever possible it should also be done in very high energy physics, in the domain proper of the ISR.
Valence and sea quarks
distributions from $v$ experiments

$V(x) = 3.45 \, x(1-x)^4 \quad x > 0.2$
$= 0.99 \sqrt{x} (1-x)^2 \quad x < 0.2$

$S(x) = 0.09 \, (1-x)^5$

Figure 9: Valence and sea quark distributions. If jets are due to quark fragmentation into hadrons, predicted effects for $x_t \approx 0.3 - 0.4$ could be checked in ISR experiments.
Figure 10: Away side multiplicity (particles with $|y| < 1$ and $p_T > 1.5$ GeV/c) observed when triggering on large $p_T$ particles of different kinds (with $3 < p_T < 4.5$ GeV/c). The observed multiplicities are normalized to those found with $\pi$ triggers.

f) Tests of CP invariance

Particle yields at large $p_T$ and at $90^\circ$ can give a test of CP invariance. This is an example of exclusively $p\bar{p}$ physics, without terms of comparison in the pp case, while in the experiments previously discussed $\bar{p}$'s are expected to quantitatively enhance phenomena which at a lower level also occur with p's. A similar CP invariance test experiment has been approved at FNAL (Exp. 302, Fitch et al.). As suggested by Rubbia, the feasibility of such an experiment could also be studied for the ISR. The expected effect is null. Yet it might turn out to be worth a try.

g) Conclusions

Very rich physics should be expected from $p\bar{p}$ at the ISR, with the luminosities which are envisaged and the available detectors. A rapid realization of a $p\bar{p}$ programme at the ISR should therefore be strongly encouraged. Even if the limits of our present knowledge make us unable to think in other terms than check of present ideas, experiments with $p\bar{p}$ might well be the opportunity to change them.
These are the conclusions of the pp group at the ISR Workshop, as already stated in ISR WORKSHOP/2-5, which was distributed shortly after the Workshop.

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