EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/ISRC/ 70-7
10 April, 1970

INTERSECTING STORAGE RINGS COMMITTEE

PROPOSAL

MEASUREMENTS OF INELASTIC PROTON COLLISIONS WITH LARGE ENERGY TRANSFERS AT THE ISR

J.V. Allaby, A.N. Diddens, R.W. Dobinson, E. Gygi, L. Rochester,
K. Schlüpmann, F. Schneider, C.A. Ståhlbrandt, A.M. Wetherell

MEASUREMENTS OF INELASTIC PROTON COLLISIONS
WITH LARGE ENERGY TRANSFERS AT THE ISR

INTRODUCTION

A previous communication[1)] to the ISRC has outlined the interest of observing inelastic scattering involving large energy transfers (deep inelastic scattering) at the ISR. The present proposal is to begin at an early stage of colliding beam operation with measurements of the differential distributions of correlated inelastic proton-proton events together with observation of the high energy jets associated with such events.

The essential new feature of the ISR is the possibility of observing, in a controlled way, events of very high multiplicity, on average ~ 10 charged particles, due to the greatly increased possibilities of energy transfer far beyond the range of present accelerator experiments. The average inelasticity of very high energy hadron collisions is estimated[2)] to be ~ 30% so that for 50 GeV in the c.m.s. about 15 GeV is, on the average, available for particle production. At the PS (~ 25 GeV lab.system) the c.m.s. energy is 6.2 GeV and, on the average, only about 1.9 GeV may be given to production processes. Hence the very large change in "average" events let alone those with a "high" inelasticity is rather clear.

The experimental technique involves two distinct parts, the triggering system and the jet detector or more precisely jet core detector. Differential distributions of inelastic p-p events are provided immediately by the trigger system, such distributions being in themselves of great physical interest[1)]. A jet detector, in its most elaborated form, would be perhaps the most advanced piece of equipment to be used at the ISR. This is not the aim at this point, rather it will be attempted to gain some experience with complicated events in the simplest (and crudest) possible way.

To summarize, the aims of this proposal are:

(a) to determine the distributions of inelastic proton scattering over a wide range of energy transfer or inelasticity;

(b) to observe jets associated with given inelasticity;

(c) to observe quasi-stable states ($\tau \sim 10^{-10}$ sec) such as K^0, hyperons or any new phenomena on this time scale;

(d) to observe characteristic phenomena such as quarks of subnormal ionizing power or monopoles of high ionizing power in association with large transfers of energy.

EXPERIMENTAL TECHNIQUE (Phase 1)

(A) Trigger system

At the earliest phase of operation it is assumed that there will be no magnetic elements near to the ISR vacuum chamber.

A system of Čerenkov counters is used to provide energy selection on correlated high energy proton events. Fig. 1 sketches the experimental set-up. Two pairs of 3 m long gas Čerenkov counters are placed on conjugate sides of the intersection region (in-going beams) above and below the median plane. They are mounted on traverse mechanisms so as to be able to cover a certain angular range of particles emanating from the collision region. In the first instance the vacuum chamber may be of the standard type for the ISR running in. This is of course very far from ideal because of the rather large amount of material traversed by the particles.

The telescopes $(ABCDEFGXY)_{1,2}$ are set to detect protons within narrow momentum bands the widths of which will depend on the specific mode of operation. One particular mode, for the detection of protons above 20 GeV/c, may be outlined as follows. Counters ACE register the passage of charged particles within a given acceptance ($\sim 6 \times 10^{-4}$ sr for each arm). The Čerenkov counters X are set to detect particles above a certain velocity e.g. above that for 20 GeV/c protons and, hence, are sensitive to pions of momentum above ~ 3 GeV/c and kaons above ~10 GeV/c. The Čerenkov counters Y are set to detect pions above about 7.5 GeV/c and in this condition are below threshold for protons between 20 and 25 GeV/c. Then the signature $ACEX\overline{Y}$ signals protons of momentum above 20 GeV/c, pions between 3 to 7.5 GeV/c and kaons above 10 GeV/c. Counters G are total absorption devices which discriminate between the pions and the high energy protons; a simple steel-scintillator sandwich$^{3)}$ with an energy resolution of ~ 30% should suffice for this purpose. The kaon contamination should cause no problems as it is expected to be small. A final momentum measurement on the protons detected above 20 GeV/c is achieved by pulse height analysis. Another mode of operation would be to set both Čerenkov counters X and Y above the 20 GeV/c proton threshold and perform pulse height anylysis on them. High energy pions and kaons (> 10 GeV/c) producing larger pulses than 20 - 25 GeV/c protons would be rejected on this basis and the pions in the velocity band of the protons would be signatured by the absorption counters G. Our experience of the Serpukhov detectors$^{4)}$, threshold and differential threshold counters$^{5)}$ indicate that it should be possible to select protons within a momentum band of~1 GeV/c. The resolution can be improved by about a factor of 3 at the expense of detection efficiency.

Angular resolution in the telescopes is provided by small Charpak planes BDF (each x and y) of dimension ~ 20 x 20 cm^2 having ~100 wires per plane. The angular resolution provided for the telescopes is then a fraction of a milliradian.

(B) Counting Rates

A reliable estimate of the counting rates of either single or correlated protons is difficult to make considering the very large energy increase beyond present measurements. A model can be made however on the basis of results on single proton spectra measured$^{6)}$ at 30 GeV/c. It was shown that a reasonable fit is given by

$$\frac{d^2\sigma}{dp_T dp_L} = K\, p_T^2 \exp\left(\frac{-p_T}{0.166}\right)$$

p_T and p_L being the c.m.s. transverse and longitudinal momenta. At 30 GeV/c the maximum value of p_L = 3.69 GeV/c and K = 610 (mb/GeV^4) Assuming that the total cross section, σ_i, for producing inelastic protons, that is the integral of the above formula, is constant with energy then $K \sim \frac{\sigma_i}{p_L(\max)}$ and hence for the ISR momentum (25 GeV/c) $K = \frac{3.69}{25} \times 610 = 90$. Taking a scattering angle of 35 mrad and a momentum bite between 20 and 25 GeV/c the differential cross section obtained using this constant in the above formula is $\frac{d\sigma}{d\Omega} = 250$ mb/sr and the counting rate in a solid angle of 6.10^{-4} sr assuming that the ISR intensity is such that a 40 mb total cross section gives 10^5 interactions per second is $\frac{250}{40} \times 10^5 \times 6\times10^{-4} = 375$/sec. It is not very clear how to estimate a correlated proton rate and again one has to make some sort of a crude model. As a first guess one may factor the correlation into a part involving a momentum interval and a part concerned with the angular distribution. For simplicity and as an example let us take the telescopes set at conjugate angles of 35 mrad with respect to the ISR beams and each accepting a Δp of 5 GeV/c from 20 to 25 GeV/c. Then as the inelastic proton momentum distribution is essentially flat over its whole range at small p_T there will be a momentum factor in the correlation of 5/25 = 0.2. Having detected a proton in one telescope we now assume that the other correlated inelastic proton will be distributed about the axis defined by the first one. The distribution function about this axis we take as $\exp(-A\, p_T'^2)$ where p_T' is now referred to this axis. One might guess that the parameter A would decrease for increasing energy loss and we shall calculate the amount of the distribution accepted by the telescope for various values of A. The telescopes accept an angular range of $\pm 12\frac{1}{2}$ mrad or a transverse momentum range of about ± 0.28 GeV/c. Hence, one simply evaluates $\int_{-0.28}^{.28} e^{-A\, p_T^2}\, dp_T$ and includes the momentum factor given above. The result is given in the following table:

A(GeV^{-2})	Correlated rate (sec^{-1})
10	52
5	40
1	19

To recapitulate, these rates are for the nominal luminosity and for telescopes such that $\Delta p = 5$ GeV/c (from 20-25 GeV/c) and $\Delta\Omega = 6.10^{-4}$. The uncertainty of these numbers is hard to assess and indeed it is for that basic reason that the measurement of correlated protons is interesting.

(C) Jet Detector

It is proposed to use isotropic spark chambers[7] to detect forward going jet particles associated with leading protons of specified inelasticity. Two chambers of dimensions ~50 x 50 x 20cm^3 are placed at conjugate positions above and below the median plane, as shown in Fig. 1. In this configuration forward going particles of high multiplicity jets may be detected. Background tracks according to the measurements of Agoritsas et al.[8] should be no problem. Operation of the chambers in the linear mode ensures their isotropic response, multi-track sensitivity (Fig. 2 shows 2 photographs from our quark search[9] illustrating these features) and furthermore their unique possibility to measure the ionizing power of the particles in the jet. Each chamber is viewed in stereo by an image intensifier, the resulting picture being photographed in a conventional way. The aim is to have an essentially visual device for observing potentially complicated events. This should be a distinct advantage at an early stage of ISR experimentation. It is worth remarking that visual spark chambers will be used for the detection of complex events in the first years of operation of the Ω project at PS energies.

(D) Experimental Possibilities

With regard to the aims listed in the Introduction the following remarks may be made.

(i) The scattered proton distributions $\dfrac{d^2\sigma}{dp_T dp_L}$ and $\dfrac{d^4\sigma}{dp_T^{(1)}dp_L^{(1)}dp_T^{(2)}dp_L^{(2)}}$

may be determined with the Čerenkov telescopes detecting either only one or a pair of correlated protons. These distributions provide a lot of information about very high energy processes, in fact results which we have obtained on the single proton distribution at 19.2 GeV/c[10] show very interesting features when compared with deep inelastic electron scattering data. In the ISR measurements the rather moderate momentum resolution mentioned above should not be a serious disadvantage as in the region of large energy transfers bigger than say 2-3 GeV fine structure (resonances) may be expected to play no great role.

Also the momentum spread of the stacked primary beam will be ~2% x 25 GeV/c = 0.5 GeV/c.

(ii) The observation of jets associated with given inelasticity or energy loss of the leading protons would be quite limited in this experiment. The coverage of solid angle is such that only jet particles following closely the leading baryons (the core) could be observed. Even so it seems valuable to examine the situation qualitatively especially as more ambitious experiments could be better designed in the light of such experience. Some results at 30 GeV/c lab momentum should be forthcoming during the next year from an experiment of the type we are proposing by Collins et al.[11)] at BNL.

(iii) V events could be observed well in the isotropic chambers. K^o could be detected with a correlated proton trigger as part of a jet core while peripherally produced hyperons might be better detected with a single proton trigger.

(iv) The possibility of very massive states of lifetime of the order of that of hyperons and decaying into many particles may also be considered in this context.

(iv) So far the evidence for the existence of fractionally charged quarks is based on cosmic ray experiments[12, 13)] in which the experimental technique has been questioned.[14, 15)] Nevertheless whatever this evidence is worth it has suggested that quarks are very massive and are produced in association with many other particles or, in other words, in a jet core. It seems worthwhile, therefore, to look for quark events in the isotropic chambers triggered for large energy transfer and making use of the ionization sensitivity of the devices. Evidently the same may be said for Dirac monopoles. Furthermore there may be more curious things to see than are dreamt of in our philosophy.

We think that the points (i)-(iv) described above should be amenable, with the technique proposed, to a preliminary study which may be regarded in the same light as a first bubble chamber experiment with a new accelerator.

PHASE 2

Assuming that the development of these experiments proves to be interesting it is clear that some magnetic analysis in the trigger arms would increase the precision of the energy measurements, however, discussion of this will have to await the further development of the programme.A larger coverage of the phase space available to the jet configurations by use of larger isotropic chambers would be desirable, but again it is probably better to postpone a detailed discussion of such extensions to a later time.

MONITORING

The Cerenkov counter telescopes themselves, for a fixed condition, constitute a good relative monitor of the ISR luminosity, that is they measure the flux of high energy events from beam-beam interactions. Simple secondary particle counter telescopes 16) around the intersection would provide run to run normalization and all cross sections could eventually be referred to those for elastic p-p scattering which will be inevitably detected by the system.

TECHNICAL IMPLICATIONS

An ingoing beam intersection region is necessary. The earliest possible provision of a special ISR vacuum chamber matched to the detector system is an obvious and necessary improvement. For the phase 1 operation no magnetic analysis is foreseen so that the minimum of resources at an intersection region are needed. It should be noticed also that the apparatus is rather mobile and can be readily moved into or out of a straight section.

The Cerenkov counter telescope equipment is rather straightforward and the counters themselves can be developed in the light of our Serpukhov experience. The demands on Charpak plane technology (~1200 wires) is rather modest and should be readily realised. A small computer such as a Hewlett Packard 2116B would be necessary.

Since no magnets are involved the movable mechanical supports for the detectors should not be a major problem. The isotropic chamber development, for the first part of the programme at least, appears to fall within that of an operating group as for the quark experiment[9] of 1968. All of the apparatus would be put into running order using a high energy secondary beam at the PS.

REFERENCES

1. Allaby et al.,ISRC 69-29.

2. Y. Pal and B. Peters, Mat.Fys.Madd.Dan.Vid.Selsk,33, 15 (1964);
L.F. Hansen and W.B. Fretter, Phys.Rev. 118, 812 (1960).

3. W.V. Jones, Phys.Rev. 187, 1868 (1969); Nuc.Instr.and Methods 72, 173 (1969).

4. Allaby et al., Phys.Letters 29B, 48 (1969).

5. Yu.D. Prokoskhin, IHEP, SEF. 69-7;
Gorin et al., IHEP, SEF 69-63.

6. Anderson et al., Phys.Rev.Letters, 16, 855 (1966)

7. E. Gygi and F. Schneider, CERN 66-14 (1966).

8. Agoritsas et al., NP Int. Report 69-8.

9. Allaby et al., Nuovo Cimento 64, 75 (1969).

10. Allaby et al., Report to Vienna Conf. 1968, see Proceedings p.384.
Allaby et al., paper in preparation.

11. Collins et al., private communication.

12. C.B.A. McCusker and I. Cairns, Phys.Rev.Letters 23, 658 (1969).
Cairns et al., Phys.Rev. 186, 1394 (1969).

13. Chu et al., Preprint Ohio State University 1970.

14. R.K. Adair and H. Kasha, Phys.Rev.Letters 23, 1355 (1969).
D.C. Rahm and R.I. Louttit, Phys.Rev.Letters 24, 279 (1970).
H. Frauenfelder et al. Phys.Rev.Letters 24, 33 (1970).
P. Kiraly and A.W. Wolfendale, Phys.Letters 31B, 410 (1970).

15. M. Derrick, private communication.

16. Agoritsas et al., NP Internal Report 69-32.

FIGURE CAPTIONS

Figure 1 : Schematic diagram of apparatus layout. Left hand telescope is above the median plane, right hand telescope below.

S	isotropic chamber
X,Y	Cerenkov counters
A,C,E	scintillation counters
B,D,F	Charpak planes
G	sandwich counter.

Figure 2 : Isotropic chamber photographs from quark search of Allaby et al.9). The width of the chamber was 10 cm. Beam direction is indicated. The tracks not collinear with the beam direction arise from interactions in the walls of the chamber.

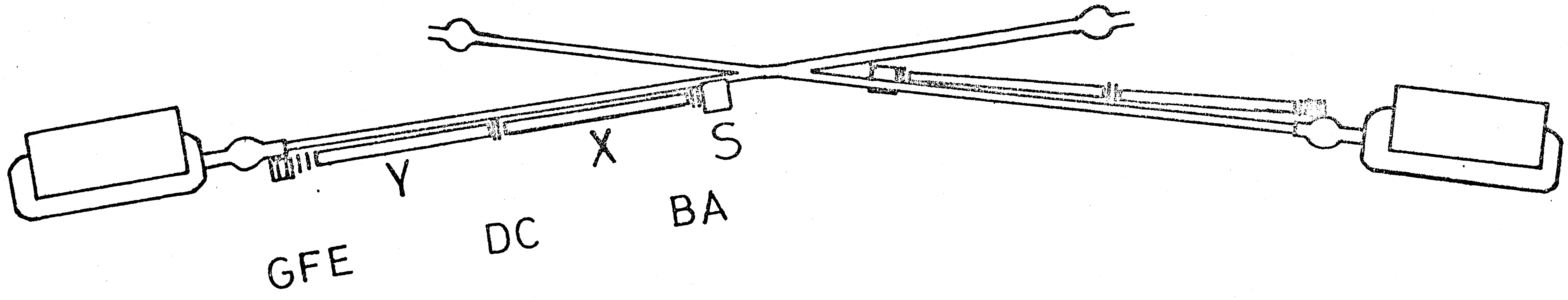

Fig1