EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/ISRC/78-21
P99
10th July 1978

INTERSECTING STORAGE RINGS COMMITTEE

PROPOSAL FOR A STUDY OF LARGE TRANSVERSE MOMENTUM PHENOMENA USING THE SUPERCONDUCTING LOW-β.

L. Camilleri[1], T.J. Chapin[4], R.L. Cool[4], L.M. Lederman[2], J.T. Linnemann[4], N. Phinney[3], R. Rusack[2], A.M. Segar[3], A.M. Smith[1], M.J. Tannenbaum[4].

CERN[1]-Columbia[2]-Oxford[3]-Rockefeller[4] Collaboration

I. INTRODUCTION.

In the document which follows the CERN-Columbia-Oxford-Rockefeller collaboration proposes that the superconducting low-β section now being constructed be installed in intersection I-1 in order to carry out the physics objectives to be outlined below.

Since 1973, this collaboration has consistently argued that several of the most interesting aspects of physics at the ISR are principally limited by low luminosity and has strongly supported the efforts to increase luminosity and thus the rate of interactions. During the intervening years, experimental results, including our own, in both high mass lepton pair physics and in high transverse momentum physics have fully justified this view. Indeed, these results, coupled with the recent theoretical advances, particularly QCD, strongly suggest that even higher luminosity should continue to be highly productive of relevant new data, and quite possibly new and unforeseen discoveries. In many respects, in the period 1981 - 82, the ISR will continue to be an instrument uniquely suitable for answering many questions raised by QCD, as for example, the "scaling" behaviour of lepton pair production at high masses over a range of $m_{e^+e^-}/\sqrt{s} > 0.15$.

We believe it will be > 6 months before the physics potential of the present CCOR research, with presently planned modifications, is clear. It is completely obvious that the issues of lepton pairs of m > 10 GeV and π^0's of $p_T > 12$ GeV/c are seminal experiments requiring the highest luminosity.

In order to pursue these goals we propose the following :

1. A superconducting low β intersection be installed at I-1 (SCLB).

2. An increase in effective solid angle by a factor of 2 be achieved with the addition of lead glass.

3. Modifications be made to the track chamber system in order to improve the efficiency and resolution especially in view of the higher luminosity.

In Section II, we discuss the physics objectives which we propose to carry out together with their relevance to current theoretical ideas.

In Section III we describe experiment R-108 and emphasize particularly two important modifications to the superconducting solenoid detector which are now under construction and scheduled for completion in 1979. In Section IV, we discuss additional modifications to the apparatus which we propose to carry out if this proposal is accepted. Section V summarizes our conclusions.

II. PHYSICS OBJECTIVES WHICH WE PROPOSE TO CARRY OUT.

The physics objectives involve both proton-proton collisions and proton-antiproton collisions. For p p collisions we take the nominal luminosity as $10^{32} cm^{-2} sec^{-1}$. This is an improvement by a factor of 3 over the present non-superconducting low β. An additional factor of 2.7 for e^+e^- pairs comes from the increase by a factor two in c.m. solid-angle of the improved detector, providing a total improvement of a factor of 8 for pairs and 6 for singles over present running. For $\bar{p}$ p collisions the superconducting low β is indispensable providing a nominal luminosity of $10^{29} cm^{-2} sec^{-1}$.

The physics objectives are as follows :

A. Proton-proton Collisions, integrated luminosity $10^{38} cm^{-2}$ per month.

1) $p + p \to e^+ e^- + X$ for $M_{e^+e^-} > 12$ GeV/c^2. ($m/\sqrt{s} > 0.2$).

The Fermilab data at lower values of $\sqrt{s} = 19.4$ to $\sqrt{s} = 27.4$ GeV exhibit scaling in the interval $0.2 < m/\sqrt{s} < 0.4$. Thus to continue these scaling tests at the highest ISR energy, $\sqrt{s} = 62.4$, data is required for lepton pair masses > 12 GeV/c. Also, for the lepton pair continuum, one predicts that $\langle p_T^2 \rangle = a + bs$. At Fermilab $\langle p_T \rangle = 1.2$ GeV/c, and one popular parametrization ($\langle p_T^2 \rangle = 0.70 + .0018\ s$) yields $\langle p_T \rangle = 2.8$ GeV/c at $\sqrt{s} = 62.4$. The improved solenoid has a very large azimuthal aperture, with good acceptance out to $p_T = 5$ GeV/c for 12 GeV/c^2 di-leptons.

The present detector observes roughly 32 continuum e^+e^- per calendar month with m > 6 GeV/c, and 6 $\Upsilon \to e^+e^-$. The Fermilab scaling curve predicts an order of magnitude less yield for m > 12 GeV/c^2 so that the improved detector should provide per calendar month 250 continuum e^+e^- with m > 6 GeV/c^2, 50 Υ and 25 e^+e^- with m > 12 GeV/c^2. Thus a run of 4 calendar months will provide 100 e^+e^- with m > 12 GeV/c^2, which should test scaling very well and provide a measurement of the p_T distribution out to > 4 GeV/c and a measurement of $\langle p_T \rangle$ with 10% precision. These measurements will provide crucial information for testing QCD.

2) Study of Υ Production Mechanisms.

As noted above, 50 Υ/month will be detected in the proposed experiment. Associated charged particles are also detected in a solid angle of 8.9 steradians, and associated γ rays and π^0 in 4.0 steradians. These data should provide important information on Υ production mechanisms.

3) Measurements of the p_T Dependence of Low Mass ($m > 4$ GeV/c^2 Di-leptons).

With the improved rejection from the strip chambers, the improved trigger from a hardware processor, larger solid angle detector and higher luminosity superconducting low β, we should observe thousands of low mass dileptons per month, including hundreds with $p_T > 1$ GeV/c. Measurements of these di-leptons at high p_T, including particles produced in association with them, should provide much new information, particularly relevant to QCD ideas.

4) Inclusive π^0 Production at Higher p_T.

The increase of an order of magnitude in sensitivity, should produce good measurements of π^0 production with p_T up to 17 or 19 GeV/c. The shape of this distribution tests the constituent models in a fundamental, even qualitative way. We know from the present data that the "CCR form", p_T^{-8} is changing at $p_T > 7$ GeV/c. To what form does it go ? Will we ever see p_T^{-4} ? Do higher order QCD terms still interfere ?

5) Jet Studies with $p_T > 12$ GeV/c.

Various ISR experiments, including this one have observed jet phenomena for trigger p_T in the range $3 < p_T < 10$ GeV/c. In particular x_E scaling works reasonably in this range and away associated particles appear in an azimuthal peak of 1.0 radian FWHM, 180° opposite to the trigger. The improved charged particle momentum measurements will enable us to study x_E scaling for higher momentum triggers. Also the larger lead glass array of 1.6 radians azimuthal aperture, and $\Delta y = 1.8$ should be able to contain the entire away jet according to present ideas.

B. Antiproton-proton Collisions, integrated luminosity $10^{35} cm^{-2}$ per month.

1) $\bar{p}\, p \rightarrow e^+e^- + X$.

Di-lepton production with $\bar{p}$ p collisions will be a first opportunity at high $\sqrt{s}$ to test the ideas of annihilation production of lepton pairs, with known distributions for the constituents. Best present-day estimates are that $\bar{p}$ p is about a factor of 4 more effective than p p in producing di-leptons in the range $m/\sqrt{s} \sim 0.1$. Combined with a factor of 10^3 less luminosity, the e^+e^- production rates per month in $\bar{p}$ p collisions should be about 1/250 less than in p p collisions at the ISR, or about 1 event/month with mass > 6 GeV. This doesn't appear too promising. However, measurements at lower masses with both p p and $\bar{p}$ p interactions should provide information on how much di-lepton production is Drell-Yan and how much is due to other reactions.

2) $\bar{p}\, p \rightarrow J(3.1) + X$.

If J(3.1) production occurs in $\bar{p}$ p collisions at $\sqrt{s} = 62.4$ with the same cross section as in p p collisions then ~ 100 events per month of $J \rightarrow e^+e^-$ will be expected in our detector. Systematic comparison of J/Ψ production in p p and $\bar{p}$ p production at high energies would provide interesting information for understanding hadronic production mechanisms of J/Ψ.

3) $\bar{p}\, p \rightarrow \pi^0 + X$.

The original CCR experiment had a total solid angle of 1.4 steradians and an integrated luminosity of $6.4 \times 10^{35} cm^{-2}$. The proposal has a total $\Delta y\, \Delta\phi$ of 4.6 steradians for π^0 production and an integrated luminosity of $10^{35} cm^{-2}$ per month. Thus a run of 2 calendar months will produce comparable results to CCR, for π^0 production in $\bar{p}$ p collisions.

Although not many surprises are expected theoretically for high p_T π^0 production in $\bar{p}$ p collisions compared to p p collisions, it is worthwhile pointing out that the only experimental result on the subject (G Donaldson et al., PRL 40, 917 (1978)) indicates as much as a factor of 2 more π^0 production from $\bar{p}$ p collisions than from p p collisions for large x_T. Thus systematic measurements with high precision can be expected to provide some new and interesting information on the differences of π^0 production in $\bar{p}$ p and p p collisions.

4) Study of Particles Produced in Association with High p_T π^0 in $\bar{p}$ p Collisions.

This is a by-product of the above experiment. With models for high p_T production encompassing quark-quark scattering, quark-gluon, gluon-gluon, quark fusion, constituent-interchange, just to mention a few, there is no reason to believe that jets in $\bar{p}$ p collisions will be the same as in p p collisions.

III. STATUS OF R-108 AND APPARATUS MODIFICATIONS UNDER CONSTRUCTION.

A. Status of R-108.

The last status report was presented to the ISRC in January, 1978. Analysis is nearing completion on π^0-inclusive spectra to ~ 14 GeV/c, on about 50 e^+e^- pairs with $M_{e^+e^-}$ above 6 GeV/c, and on a variety of observations on the correlations in jets with triggers ~ 10 GeV. Examples of the data will be shown and discussed at the ISRC open meeting on July 26.

B. Strip Chambers Outside the Solenoid Coil.

The multi-wire proportional chamber with pulse-height read-out provides both accurate location of shower centres and a measure of their total ionization. We have developed a version of these chambers with pulse-height observed as signals induced on cathode strips (ref. Dimcovski et al.), where the position and ionization information are obtained with maximum economy.

With strip widths of 8 mm, and the present 15 cm thick solenoid coil as converter, we estimate spatial resolution for showers as $\sigma \sim 10$ mm, a considerable improvement on the present apparatus where resolution provided by the individual lead glass blocks gives $\sigma \sim 40$ mm. This improvement is also important in resolving the pairs of showers in π^0 or η^0 decays and gives us the possibility of identifying single γ showers. The feature is also important as it reduces the backgrounds form the overlap of a charged particle with a γ.

For rejection of pions, both pulse-height and shower spread are important and the reference describes an algorithm designed to take account of both these features on individual events. Large rejection factors are then possible with reduced electron detection efficency. However, we expect to work at a high efficiency level $\sim$ 80%, where the rejection provided by the strip chambers is approximately 5 for hadron pairs vs electron pairs. This additional rejection will be helpful in defining the e^+e^- signal.

We are installing the first strip chamber at the ISR this summer, and hope to have two chambers operational before the end of the year. The sensitive area of these chambers is 1.86 x 1.54 m^2, and the two chambers have a total of 680 strips. A read-out system with preamplifiers, amplifiers and ADC's has been developed for delivery to CERN this October. New chambers covering the revised solid angle would be built as an important feature of the new proposal, constructed as a double layer of chambers. The double sampling will improve rejection and provide approximate directional information for incident showers and tracks. The complete new system could be ready for installation in 1980.

(Ref. "Use of a Cathode Read-Out Multiwire Proportional Chamber for Separation of Electromagnetic and Hadronic Showers", Dimcovski et al., Nuclear Instruments and Methods, Vienna Conference, issue to be published).

C. Fast Electronic Drift Chamber Processor.

To select the rare and interesting high transverse momentum and e^+e^- events we have, until now, been limited to the use of high energy deposition in the glass blocks by γ-rays and electrons. Especially with higher luminosity, it becomes increasingly important to provide a more flexible and selective trigger system. A fast electronic processor has been devised and is now under test and advanced design at Nevis. This hard-ware processor will use the drift wire chamber information to find and reconstruct the tracks of charged particles in the solenoid. Its fast output will be the momenta and angle of these tracks. This information, together with that from the Pb-glass arrays can then be used as a "trigger" to select events of interest. For example, we expect to be able to trigger on "total jet energy",that is the sum of the energies of charged tracks and Pb-glass. We can also, for example, require a track to point at a large energy deposition in a particular glass block which will make our trigger for e^+e^- pairs much more selective than at present.

A trigger on total jet energy will not only allow us to extend the range of our study of jets to much higher momentum, but also provide a less biased trigger for comparison to theoretical models. The e^+e^- trigger at present is limited by rate to pair masses above about 6 GeV/c^2. The greater selectivity will allow us to reduce this threshold considerably.

We also expect that the new processor will result in a very substantial decrease in our computer time requirements. Our present energy trigger, although efficient for wanted event types, is not highly selective and thus writes to tape many unwanted events which must be removed in off-line computer time. The more selective trigger will result in a much larger fraction of events of physics interest.

IV. PROPOSED ADDITIONAL MODIFICATIONS.

A. Increased Pb-glass Coverage.

The superconducting solenoid in I-1 is provided with two "thin" windows through which γ-rays and electrons may exit after passing about one radiation length of matter. Each window has an aperture of 90^o in azimuth and 90^o in polar angle. The presently available Pb-glass (336 blocks, 15 cm x 15 cm in cross section) are located 120 cm from the intersection of the beams. The Pb-glass arrays are at present limited to the distance of 120 cm by the fringing field of the magnet. At this distance, the blocks cover only one-half of the solid angular opening of the "thin" window.

With some improvement of the magnetic shielding and some minor changes on the exterior iron of the magnet, which are now under study, we believe that it may be possible to reduce this distance to 100 cm. In this case, we could cover the full available solid angle with 176 additional blocks. If, in the worst case, we find no way to reduce the fringe field, at 120 cm 312 additional blocks would be required to cover the full solid angle.

Thus we propose to increase the acceptance by a factor of 2.1 by a combination of moving the lead glass closer to the interaction region and adding to the existing arrays. The cost can be estimated by using a figure of 2800 SF per block, including phototube and all associated electronics. We note that present experience is that pile up will not be a serious factor even if we increase all rates by a factor of five.

B. Revision of Drift Wire Chambers.

Our present drift wire chamber system consists of four double gap modules which provide up to 8 points per track. The perpendicular, minimum tracklength is the 15 KG field is 45 cm. It is clear that some revision of this chamber system is desirable if this proposal is accepted for two reasons; (1) to take advantage of the smaller bicone made possible by superconducting low-β to achieve greater momentum resolution, and (2) to operate at the higher luminosities provided by superconducting low-β and possible further advance in ISR technique in the years prior to 1981.

Our considerations at this stage involve the following possibilities :

1. We can profit from the decrease in vacuum chamber diameter by installing a new small radius chamber in order to improve resolution and gain redundancy.

2. We can add additional MWPC chambers at intermediate radii These could be useful for several reasons such as :

i) Making hardware roads pointing to the energy deposition in the lead glass to be used in the drift chamber processor pre-trigger.

ii) Building similar software roads to speed up track finding.

iii) Helping to resolve Left/Right ambiguities in the drift chambers.

3. At the present time the chambers have run at luminosities of 3 to 5 x $10^{31} cm^{-2} s^{-1}$ without noticeable deterioration. However, with another factor of 2 or 3 increase in event rate, it might be desirable to rebuild the chambers with smaller wire spacing. The basic design of sense wires with delay line readout at both ends, given 3 dimensional space points, has proved its value. However, possibilities of improvement are under study, such as lower mass chambers, improved cathode design, paired sense wires for ambiguity resolution, etc. We note that the track chamber problem is not simple. The small solenoid radius forces us to high precision while at the same time we must cope with high luminosity and huge multiplicities. We are confident that we can improve on the present system but it will be at least a year before we can fully understand the best solution.

4. Finally in view of many developments in cylindrical tracking systems, it may be desirable to adopt an entirely new arrangement.

V. CONCLUSIONS.

The experiments stressed here require the increased luminosity and solid angle in order to extend the physics which we are now doing. The ISR is used well when the variables x_T (for hadron high p_T physics) and $m/\sqrt{s}$ for pairs approach unity at the highest ISR energy.

In our present research we reach $x_T \sim 0.3$ and $m/\sqrt{s} \sim 0.15$. We propose to extend these significantly. Possibilities for totally new physics are clearly implied : new resonances at $m > 10$ GeV; shape of π^0 inclusive at $x_T > 0.5$, jets and perhaps very high mass dipions.

We note that the SCLB plus increased solid angle, with essentially no further revisions, allows us to study $\bar{p}$ p collisions in the ISR as described in Section II B.

Here we note that lead glass may in fact be available as early as June 1979 (from FNAL and/or from CERN) in which case we may well decide to install this in order to attain this extra factor over a year earlier than SCLB.

Finally, we point out that this effort and in particular chamber revisions will require expenditures and more manpower than is at this stage available.