EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/EP 82-5
18 January 1982

COMPARISON OF $p\bar{p}$ AND pp INTERACTIONS AT $\sqrt{s} = 53$ GeV

UA5 Collaboration

Bonn-Brussels-Cambridge-CERN-Stockholm

K. Alpgård⁵, R.E. Ansorge³, B. Åsman⁵, S. Berglund⁵, D. Bertrand²,
K. Böckmann¹, C.N. Booth³, C. Buffam⁴, L. Burow¹, P. Carlson⁵,
J.R. Carter³, J.-L. Chevalley⁴, B. Eckart¹, G. Ekspong⁵, J.-P. Fabre⁴,
K.A. French³, J. Gaudaen^{2a}, M. Gijsen⁴, K. von Holt¹, R. Hospes¹,
D. Johnson², K. Jon-And⁵, Th. Kokott¹, L. Leistam⁴, R. Mackenzie⁴,
M.N. Maggs³, R. Meinke¹, Th. Müller¹, H. Mulkens⁴, D.J. Munday³,
A. Odian^{4b}, M. Rosenberg¹, J.G. Rushbrooke³, H. Saarikko^{1c},
T. Sarrikko¹, S. Tavernier², F. Triantis^{4d}, Ch. Walck⁴, C.P. Ward³,
D.R. Ward³, A.R. Weidberg³, T.O. White³, G. Wilquet² and N. Yamdagni⁵.

- ¹ Physikalisches Institut der Universität Bonn, Bonn, Germany
- ² Inter-University Institute for High Energies (ULB-VUB), Brussels, Belgium
- ³ Cavendish Laboratory, Department of Physics, Cambridge University, U.K.
- ⁴ CERN, European Organization for Nuclear Research, Geneva, Switzerland
- ⁵ Institute of Physics, University of Stockholm, Sweden

ABSTRACT

Results are presented from the first $p\bar{p}$ colliding beam runs at the CERN ISR, using the UA5 streamer chamber detector. $p\bar{p}$ interactions at $\sqrt{s} = 53$ GEV are compared with pp data taken in the same experiment. The results are in good agreement with extrapolations of low energy $p\bar{p}$ data.

Submitted to Physics Letters B

-
- a Also at Universitaire Instellingen Antwerpen, Antwerp, Belgium
 - b Visiting scientist from SLAC, USA
 - c Visiting scientist from Helsinki University, Finland
 - d Visiting scientist from Ioannina University, Greece

Introduction - In April 1981 collisions between proton and antiproton beams were observed for the first time at the CERN ISR. In this paper we report on some of the data taken in this first run, using an apparatus [1] designed for the UA5 experiment at the CERN SPS Collider, consisting of two streamer chambers triggered by forward hodoscopes. We compare pp and $p\bar{p}$ interactions at c.m. energy $\sqrt{s} = 53$ GeV obtained by the same apparatus and therefore reducing the influence of systematic errors in the comparison.

At low energies it is well known [2,3] that ($p\bar{p}$ -pp) differences are dominated by $p\bar{p}$ annihilations. In experiments up to $\sqrt{s} = 14$ GeV an approximate $s^{-1/2}$ energy dependence for these differences is observed [3] from which we would expect by extrapolation differences to be at the 1-3% level at $\sqrt{s} = 53$ GeV. However, a recent quark model calculation [4,5] inspired by the dual topological unitarization scheme has different mechanisms for particle production in pp and $p\bar{p}$ non-annihilations, and so predicts much larger ($p\bar{p}$ -pp) differences, typically 10-15% at $\sqrt{s} = 53$ GeV. Our results are compared with these predictions.

Apparatus and running conditions - The apparatus is shown in fig. 1, and a detailed description may be found in ref. [1]. Two 6m long streamer chambers were placed above and below the ISR beam pipes. The chambers were equipped with lead glass plates to convert photons over most of the rapidity range accepted. Each chamber is viewed by three cameras, a main camera at each end viewing slightly more than half of the chamber at demagnification 50, and a supplementary one viewing the whole chamber at demagnification 80. Image intensifier tubes were used with the cameras, allowing one to run with small streamers (5-10 mm long). The two-track resolution was found to be 2-3 mm in space. Mirrors were arranged so as to fold a stereo pair of views onto each camera. The geometrical acceptance in pseudorapidity $\eta = -\ln \tan \theta/2$ was $|\eta| < 3.5$, θ being the c.m.s. particle production angle.

Two planes of scintillation counter hodoscopes at each end of the apparatus were used to trigger the chambers. A normal event trigger (" $n \geq 1$ " trigger) demanded at least one hit on each end in coincidence. This trigger accepted 89% of inelastic events with negligible ($< 1\%$) background under normal pp running conditions. All our pp data were taken using this trigger. However, for the $p\bar{p}$ running the luminosity was very low, in the range $(2-8) \times 10^{24} \text{ cm}^{-2} \text{ s}^{-1}$. Under such conditions the $n \geq 1$ trigger gave an unacceptably high ratio of background to real events ($\sim 10:1$). It was therefore necessary during $p\bar{p}$ running to employ a more restrictive trigger requiring at least two hits at each end (" $n \geq 2$ " trigger), whereby a much better ratio of events to background was obtained ($\sim 1:1$). The additional loss of events was 33%, but these were mainly of low multiplicity, so that the fraction of tracks lost from inelastic events was in fact 22%. A small amount of data was also taken with a single proton beam circulating, in order to investigate background effects.

Data reduction - Before measurement the streamer chamber film was scanned to reject obvious background events such as upstream interactions. No attempt was made to distinguish primary and secondary tracks at the measurement stage, all tracks being measured except for those which scattered appreciably in the chamber gas (mainly low energy δ -rays). The tracks were geometrically reconstructed using measurements on all views on which they were visible, i.e. usually on either 2 or 4 views. The overall efficiency for track measurement and reconstruction was determined by remeasuring a sample of events, and found to be 98%. The results presented in this paper are based on measurements of 3600 pp events and 4000 $p\bar{p}$ events.

In addition to the tracks resulting from primary interactions, there were those originating from decays, and from γ -conversions and secondary interactions (mainly in the beam pipe), which had to be removed. This was done by first identifying primary and secondary vertices. The primary vertex of each event could be found from the intersection of those tracks which pointed back to the beam-crossing region (diamond). For the

secondary vertices, two or more tracks would generally be found to intersect in a known piece of material e.g. the beam pipe. Tracks associated with secondary vertices could then be removed, and charged primaries corrected accordingly.

To calculate the effects of trigger efficiency, acceptance and vertex finding efficiency, a Monte-Carlo program was used. Various event generators were employed: we principally used a longitudinal phase space generator, including resonances and leading baryons, adjusted to fit previous ISR data [6]. It was checked that the corrections applied were insensitive to reasonable variations in the event generator. The particles generated in the Monte-Carlo simulation were tracked through the material of the apparatus, allowing for track measurement errors, multiple Coulomb scattering, γ -conversions, bremsstrahlung, hadronic interactions and the production of δ -rays (above 1 MeV). The same algorithm used for identifying primary and secondary vertices was then applied to the generated tracks. Comparing the primary tracks found with the Monte-Carlo input an overall detection efficiency ϵ as a function of η was derived, which therefore incorporated (in decreasing order of importance) the acceptance of the apparatus, trigger efficiency and the efficiency of the vertex finding algorithm. The quantity $\epsilon(\eta)$ is shown in fig. 2(a) and is seen to be $> 75\%$ over most of the range $|\eta| < 3.5$.

pp data - The distribution $1/\sigma_{inel} d\sigma/d\eta$ was calculated from the measured tracks after weighting by $1/\epsilon(\eta)$ to correct for acceptance. Further corrections were made for scanning and measurement losses. In calculating η the transformation from the laboratory system (15° crossing angle) to the c.m.s. system was performed assuming massless particles.

To normalize the data the number of events having >1 primary track was taken, and the Monte-Carlo was used to correct for untriggered events and for inelastic events with no primary tracks in the chambers.

The resulting distribution is given in fig. 2(b) where the errors shown are statistical only. The systematic errors are estimated to be $\sim 5\%$, and are dominated by the uncertainty in the trigger efficiency.

Our results are compared with published pp data [6] taken at the same energy. The shapes of the two distributions are in good agreement, the slight difference in normalization being well within the quoted systematic errors.

p $\bar{p}$ data - As mentioned above about half the triggers used in p $\bar{p}$ running were from background, i.e. from beam-gas interactions or from beam-halo interacting in the beam pipe and other material. Such background events are expected to be highly asymmetric, and because the proton current was ~ 1000 times greater than the antiproton current the asymmetry would be mainly in the proton direction. The following procedures and checks were made:

- Beam-halo events were rejected by requiring that primary vertices lay within 2 cm of the plane of the current. The events rejected were indeed highly asymmetric. Events with only one primary track had to be rejected, since their vertex could not be determined.
- The data still show an average surplus of $1.7 \pm 0.7\%$ of tracks in the direction of the proton beam, indicating some remaining background. Since the data taken at lowest luminosity have the highest asymmetry, this confirms that beam-gas interactions are the source of the effect. We would therefore conclude from this that 2-3% of the events passing our cuts could be background.
- The film taken with a single proton beam was measured and analysed in the same way as the p $\bar{p}$ data. From these data we independently estimate that $1 \pm 1\%$ of events passing our cuts could be background.
- To estimate the effect of any background contamination on our normalized distributions we removed all events with more tracks in the proton hemisphere than the antiproton hemisphere, and counted twice those events asymmetric in the opposite sense. We thereby conclude that the effects of background on our normalized distributions are below the 1% level.

Results - comparison of p $\bar{p}$ and pp - For the comparison of pp and p $\bar{p}$ data one has to take the different triggering conditions into account. One could of course, rely on the above Monte-Carlo procedure alone, but that is

liable to introduce different systematic errors into the two sets of data, and so prejudice our attempt to look for differences at the $\sim 2\%$ level. Instead the $n \geq 2$ trigger was applied to the pp data off-line, and direct comparisons were made between raw uncorrected pp and $p\bar{p}$ data. In fig. 3(a) we show the $p\bar{p}/pp$ ratio as a function of η for this raw uncorrected data. Over the range $|\eta| < 2.5$ this ratio is consistent with unity though at larger rapidities there is some indication of a fall-off. We are in agreement with another ISR result [7] in the region $|\eta| < 0.8$.

Measurement of ($p\bar{p}$ -pp) differences up to $\sqrt{s} = 14$ GeV indicate that they follow a power law behaviour, roughly as $s^{-1/2}$ (as suggested [3] by Regge theory). We have used such fits to estimate both the difference in total cross sections and the difference in inclusive pion production cross sections in the central region. This gives a $p\bar{p}/pp$ ratio of 1.01 in the central region (dashed curve in fig. 3(a)). Our value of 1.015 ± 0.012 taken over the central rapidity plateau, $|\eta| < 2$, is thus clearly compatible with lower energy data. We also show as the full line in fig. 3(a) the prediction of a quark fragmentation model of Capella et al. [4]. This model for the dominant non-annihilation (or pomeron exchange) process has been extended to include $p\bar{p}$ annihilations [5], which we have allowed for although they contribute only $\sim 2\%$ to the ratio. Our data are inconsistent with this model ($\chi^2/\text{d.f.} = 66/7$).

Having now shown that any difference between $p\bar{p}$ and pp is small, it is reasonable to correct the $p\bar{p}$ data for the effect of the $n \geq 2$ trigger by observing its effect off-line on the pp data, and then using the Monte-Carlo to correct for the $n \geq 1$ trigger. The resulting distribution $1/\sigma_{\text{inel}} \cdot d\sigma/d\eta$ for $p\bar{p}$ interactions is presented in fig. 3(b).

In fig. 4(a) we compare the charged multiplicity distributions in $p\bar{p}$ and pp interactions at $\sqrt{s} = 53$. For this comparison uncorrected data were again used as in fig. 3(a) in order to minimize the effect of systematic errors on any small differences between $p\bar{p}$ and pp. The $p\bar{p}/pp$ ratio given in fig. 4(b) indicates that there are no significant

differences. In fig. 4(b) we also give the result of an extrapolation^(*) from lower energy data, where a Monte-Carlo calculation is used to take the acceptance of our apparatus into account. It is clear that only a small rise with multiplicity is to be expected, and the extrapolation from low energy data is entirely consistent with our results.

We have unfolded the true charged multiplicity distribution from the data of fig. 4(a) following the method of ref. [6]. The errors on individual topological cross sections are very large because our apparatus was not optimized for the ISR, but nevertheless we can make reliable estimates of the mean multiplicity and various moments of the multiplicity distribution. These are presented in table 1. From extrapolation of low energy annihilation data [3] we would expect $\langle n \rangle$ to be ~ 0.1 units higher in $p\bar{p}$ than pp .

Conclusions - We have made a first study of complete events from $p\bar{p}$ interactions in the CERN ISR at $\sqrt{s} = 53$ GeV. We have compared our results with pp data recorded in the same apparatus and analysed identically. We find that differences between $p\bar{p}$ and pp interactions at this energy are very small, typically $< 2\%$. The results are in line with power-law extrapolations from data at lower energy, but inconsistent with a recently proposed quark model.

Acknowledgements - The contributions of many CERN staff to this experiment are gratefully acknowledged and in particular of EF and ISR Divisions for assistance with the building, installation and operation of our detector.

(*) The ratio $R_n = (\sigma_n(\bar{p}p) - \sigma_n(pp)) / \sigma_n(pp)$ is found to follow the form $A:\beta^n$ at all energies [8]. We estimate values of A and β at $\sqrt{s} = 53$ GeV as follows. The difference in total cross sections can be estimated from a power law extrapolation of low energy data. Also, the average multiplicity from $p\bar{p}$ is found to be ~ 2.5 units higher than from pp over a wide range of energies [3], and we assume this continues to ISR energies. Then using measured values of $\sigma_n(pp)$ at $\sqrt{s} = 53$ GeV we can determine values for A and β . Our best estimates are $A = 0.0085$, $\beta = 1.07$.

From the Brussels group thanks are due from D.B. and G.W. for the financial support of the Fonds National de la Recherche Scientifique and the Institut Interuniversitaire des Sciences Nucléaires, and from J.G. and D.J. to the Interuniversitaire Institut voor Kern Wetenschappen for financial support. We also acknowledge with thanks the financial support of the Bonn group by the Bundesministerium für Wissenschaft und Forschung, of the Cambridge group by the U.K. Science and Engineering Research Council, and of the Stockholm group by the Swedish Natural Science Research Council. Last, but not least, we acknowledge the contribution of the engineers, scanning and measuring staff of all our laboratories.

REFERENCES

- [1] UA5 Collaboration, Bonn-Brussels, Cambridge-CERN-Stockholm, *Physica Scripta* 23 (1981) 642.
- [2] H. Muirhead, Proc. II European NN Symposium, (1974) CERN 74-18 p. 488.
- [3] J.G. Rushbrooke and B.R. Webber, *Phys. Rep.* 44C (1978) 1.
- [4] A Capella et al., *Zeit. Phys.* C3 (1980) 329.
- [5] U. Sukhatme, *Phys. Rev. Lett.*, 45 (1980) 5.
- [6] W. Thomé et al., *Nucl. Phys.* B129 (1977) 365.
- [7] A. di Ciaccio et al., *Phys. Lett. B* (to be published).
- [8] J.G. Rushbrooke et al., *Phys. Lett.* 59B (1975) 303.

TABLE 1

	pp		$\bar{p}p$
	ref. 6	this expt	this expt.
$\langle n \rangle$	11.77 ± 0.10	11.55 ± 0.17	$11.47 \pm .16$
D_2	6.31 ± 0.08	5.70 ± 0.12	$5.77 \pm .11$
$\langle n \rangle / D_2$	1.857 ± 0.032	$2.03 \pm .05$	1.99 ± 0.04
γ_2	$0.295 \pm .008$	$0.291 \pm .015$	$0.304 \pm .014$
γ_3	$0.127 \pm .006$	$0.110 \pm .016$	$0.127 \pm .017$

Moments of multiplicity distributions found at $\sqrt{s} = 53$ GeV

$$D_q = \langle (n - \langle n \rangle)^q \rangle^{1/q} \text{ for any } q, \text{ and } \gamma_2 = \frac{D_2^2}{\langle n^2 \rangle}, \quad \gamma_3 = \frac{D_3^3}{\langle n^3 \rangle}.$$

FIGURE CAPTIONS

- Fig. 1 View of the experimental apparatus as used at the ISR. The two streamer chambers, placed centrally above and below the beam pipes, each have dimensions $6 \times 1.25 \times 0.5 \text{ m}^3$.
- Fig. 2 (a) Overall track detection efficiency ϵ as a function of c.m. pseudorapidity η .
- (b) Normalized rapidity distribution for pp interactions at $\sqrt{s} = 53 \text{ GeV}$. Data from ref. [6] are shown for comparison. Errors are statistical only.
- Fig. 3 (a) Normalised rapidity distribution for $p\bar{p}$ interactions at $\sqrt{s} = 53 \text{ GeV}$.
- (b) Ratio of pseudorapidity densities from $p\bar{p}$ and pp interaction as a function of η . The solid curve is the prediction of the quark model of refs [4,5]. The dashed line represents the ratio expected in the central region from an extrapolation of low energy data.
- Fig. 4 (a) Charged multiplicity distributions for $p\bar{p}$ and pp interactions, uncorrected for acceptances (see text).
- (b) Ratio of probabilities for obtaining a given multiplicity in $p\bar{p}$ and pp interactions as a function of multiplicity. The solid curve is from an extrapolation of low energy data of the form $A\beta^{-n}$ (with $A = 0.085$, $\beta = 1.07$). The dashed lines represent the uncertainties in the extrapolation.

SCHEMATIC LAYOUT OF THE STREAMER CHAMBER SYSTEM

FIG. 1

FIG. 2

FIG.3

FIG. 4