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SOFT HADRONIC INTERACTIONS AT THE CERN COLLIDERS

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SOFT HADRONIC INTERACTIONS AT THE CERN COLLIDERS

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INTRODUCTION

Our experimental knowledge of "conventional" (low transverse momentum) strong interactions has been considerably improved by the recent few years of operation of the CERN \bar{p} complex. The (long awaited) comparison of $\bar{p}p$ and pp collisions has been possible at the ISR ($31 \leq E_{CM} \leq 63$ GeV), while the SppS Collider has provided a first global picture in a new energy regime ($E_{CM} = 540$ GeV). Low p_T (large distance) strong interactions make up more than 99% of hadronic cross sections (often referred to as "minimum bias" physics, or "log s" physics for its weak logarithmic dependence on the c.m. energy $E_{CM} = \sqrt{s}$) and have been studied by several generations of accelerators. The understanding of the general phenomenon of hadronization and of diffractive (coherent) processes, in particular, is believed to be an essential ingredient of a field theory of multiparticle production and confinement. Only models, however, have been so far available as a guidance. Significant theoretical advances are needed in this difficult area, to escape the conclusion that the phenomena involved may be intrinsically too complicate for any basic explanation.

$\bar{p}p/pp$ COMPARISON AT THE ISR

The global features of $\bar{p}p$ interactions at ISR energies have been found in satisfactory agreement with expectation:

- (a) The total cross section $\sigma_T^{\bar{p}p}$ starts [1,2] to grow (like σ_T^{pp}) with E_{CM} , while the difference $\Delta\sigma = \sigma_T^{\bar{p}p} - \sigma_T^{pp}$ decreases (figs 1(a) and 1(b)). There is no urge for crossing-odd components of the amplitude ("odderons").
- (b) Inelastic final states are essentially indistinguishable [3]. Small differences (excess of short range correlations in $\bar{p}p$ [4], wider multiplicity distribution [5] in $\bar{p}p$, different yields [6] of forward baryons with well-defined quantum numbers) all support the view that $\Delta\sigma$ is due to what little is left of the annihilation mechanism (very important in $\bar{p}p$ at lower \sqrt{s}).

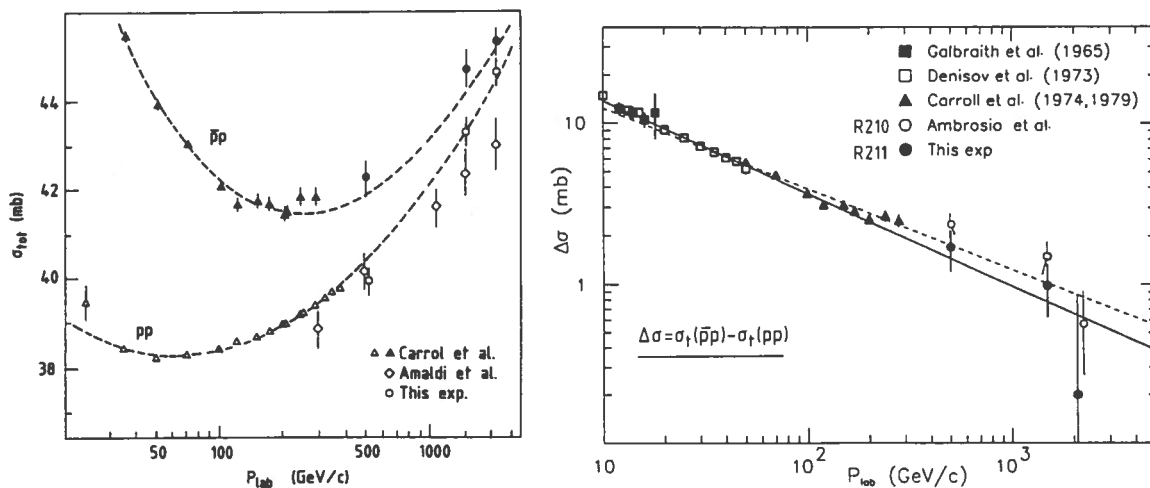


Fig. 1

(a) The energy dependence of $\sigma_{tot}(\bar{p}p)$ and $\sigma_{tot}(pp)$ up to ISR energies as measured by R210. Data from R211 are consistent.

(b) The total cross section difference versus the laboratory momentum. The curves are fits to low energy data.

- (c) The difference $b_{\bar{p}p} - b_{pp}$ of the forward (low momentum transfer t) exponential slopes of the elastic differential cross sections has been shown to decrease (fig. 2) towards zero with energy, in agreement with the expectation [7] of Cornille-Martin, by experiments R210 [8], R211 [2], R420 [9].
- (d) The ratio ρ of the real to imaginary part of the forward elastic amplitude (measured at ISR by R211 [2] in 1982) smoothly approaches the pp value. The behaviour of $\rho_{\bar{p}p}$ with \sqrt{s} agrees with the dispersion relation fit performed by Amaldi et al. [10] in 1977.

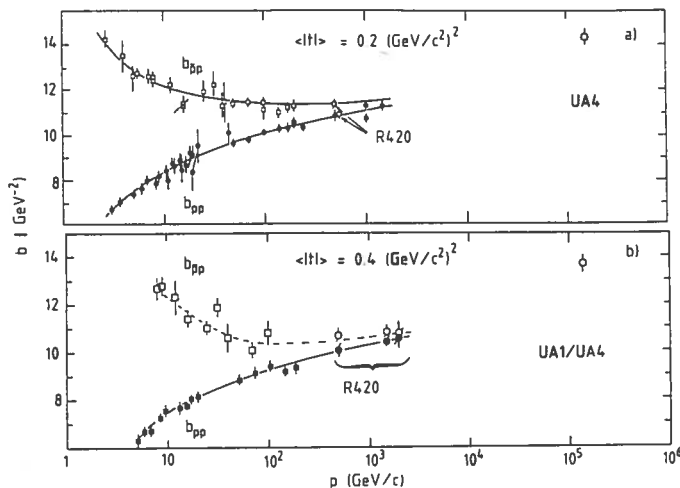


Fig. 2 The local slope parameter b at $\langle t \rangle = 0.2 \text{ GeV}^2$ and $\langle t \rangle = 0.4 \text{ GeV}^2$ for pp and $\bar{p}p$. The SppS $\bar{p}p$ points are also shown.

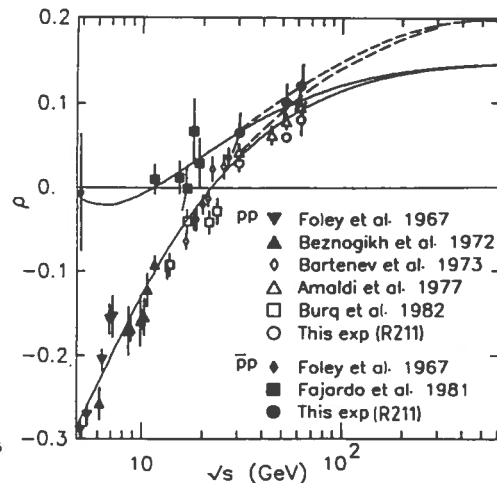


Fig. 3 Measurements of the parameter ρ for $\bar{p}p$ and pp scattering. Results of the dispersion relation fits of ref. [10] (full line) and [11] (dashed line) are also shown.

A recent result [12] from R420, however, points to a potentially very important difference in larger t elastic scattering (dip-bump region). The long known [13] pronounced dip structure at $t \approx 1.4 \text{ GeV}^2$ is well visible in R420 pp data, while only a very shallow dip, probably just a shoulder or kink, is present in $\bar{p}p$ (fig. 4). The final shutdown (Spring 1984) of the ISR prevented R420 from ever reducing the large statistical errors affecting their pp data sample and from making a conclusive statement. It may have been the first definite indication of a crossing-odd component in diffraction. The (preliminary) evidence [14] for the absence of a dip at the SppS presented by UA4 (fig. 5) in 1983, in fact, can still be attributed to the difference in c.m. energy.

ELASTIC SCATTERING AT THE SppS COLLIDER

It has been studied by UA4 and UA1. Elastic scattering detectors, at very small angles (few mrad), are positioned beyond the first (or more) set of machine quadrupoles. The acceptance range in 4-momentum transfer t depends therefore strongly on the optics of operation of the collider. Most of the running is of course devoted to low- β , high luminosity mode ($\beta =$ betatron function) where one is sensitive to larger t elastic scattering ($.5 \leq t \leq 1.6 \text{ GeV}^2$). Only limited samples of data are available in the small t ($.03 \leq t \leq 20 \text{ GeV}^2$) range (high β) and in the medium t ($.20 \leq t \leq .50 \text{ GeV}^2$) range (medium β). Fig. 5 shows all the data available in 1983.

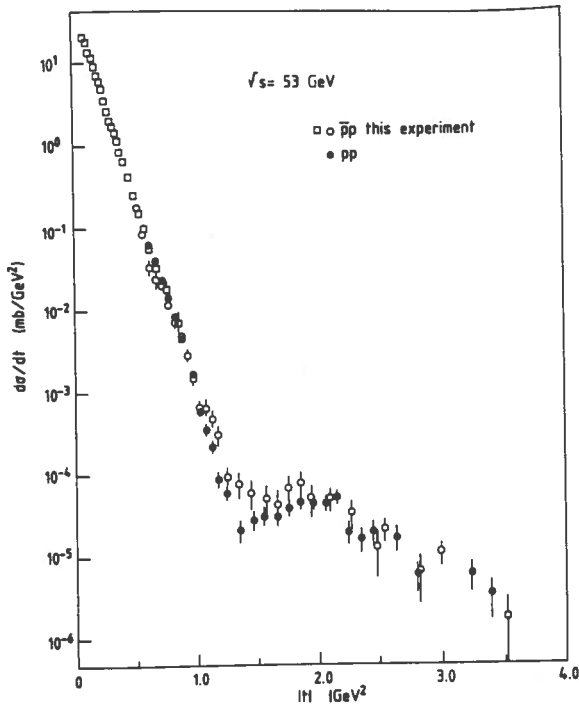


Fig. 4 Elastic differential cross section for $p\bar{p}$ and pp at the ISR (expt. R420) at $\sqrt{s} = 53$ GeV.

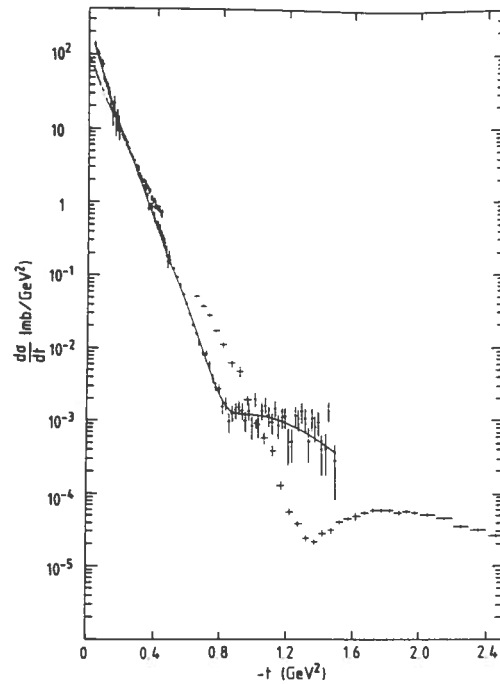


Fig. 5 Comparison of elastic differential cross section at the SppS (the line through the data points guides the eye) and at the ISR (pp) at $\sqrt{s} = 53$ GeV.

New 1983 data (being now analyzed) in the larger t range appear to confirm the finding that the ISR dip ($t \approx 1.4$ GeV²) is replaced by a kink ($t \approx .8$ GeV²), while the cross section at the second maximum grows significantly. The most relevant new piece of data, however, is a 100 thousand low t elastic events sample collected by UA4 in 1983, during the first successful high- β run. The data (fig. 6) show a rapid exponential fall-off with t with a sharp break in the exponential slope around $t \approx .14 \pm .02$ GeV². UA4 [15] quotes:

$$b = 15.2 \pm .2 \text{ GeV}^{-2} \quad \text{for} \quad .03 \leq t \leq .14$$

$$b = 13.6 \pm .8 \text{ GeV}^{-2} \quad \text{for} \quad .21 \leq t \leq .32$$

The second result is in agreement with previous measurements by UA1 [16] and UA4 [17]. The new small t data supersede previous less precise measurements [18, 14, 19], yielding significantly higher values of the slope ($b \approx 17 \pm 1.0$ GeV⁻², from samples of about 1000 events). Part of the ($\sim 2\sigma$) discrepancy is accounted for by a more precise measurement of the beam energy (273 ± 1.4 GeV) and the consequent adjustment of the t scale. Most of the variation is due to a careful study, permitted by the new large sample of data, of the critical clearance of the quad iron poles in front of the detectors. Fig. 7 compiles data on the s dependence of the forward slope b . Significant disagreements in the low energy data make extrapolations uncertain. The rate of shrinking of the diffraction peak (with this caveat) appears compatible with a $\log s$ behaviour. If one writes $b = b_0 + 2\alpha' \log s$, the best value of $2\alpha' \approx .5$ is in reasonable agreement with the conventional Pomeron slope. A $(\log s)^2$ term (multiplied by a small coefficient) cannot of course be ruled out. Fig. 8 compiles pp data at ISR [20] and SppS data on the t dependence of b . A break is clearly visible in both sets of data, at about the same value of t .

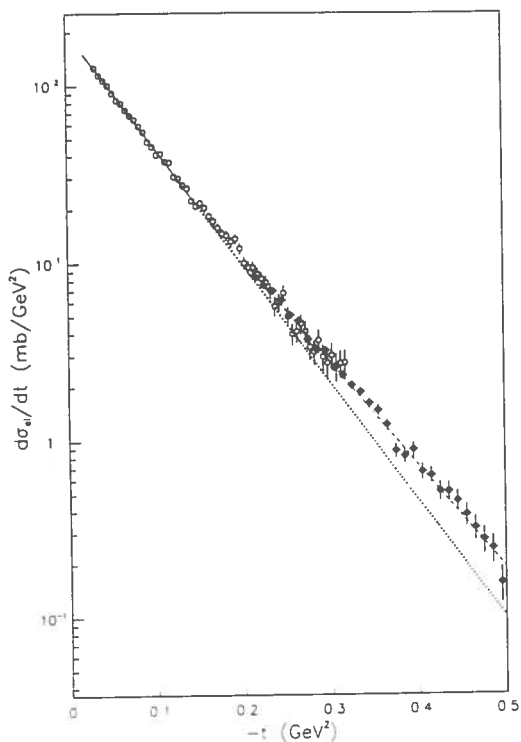


Fig. 6 Forward elastic differential cross section at the SppS (1984 UA4 data). Fits to a single and to a double exponential are shown.

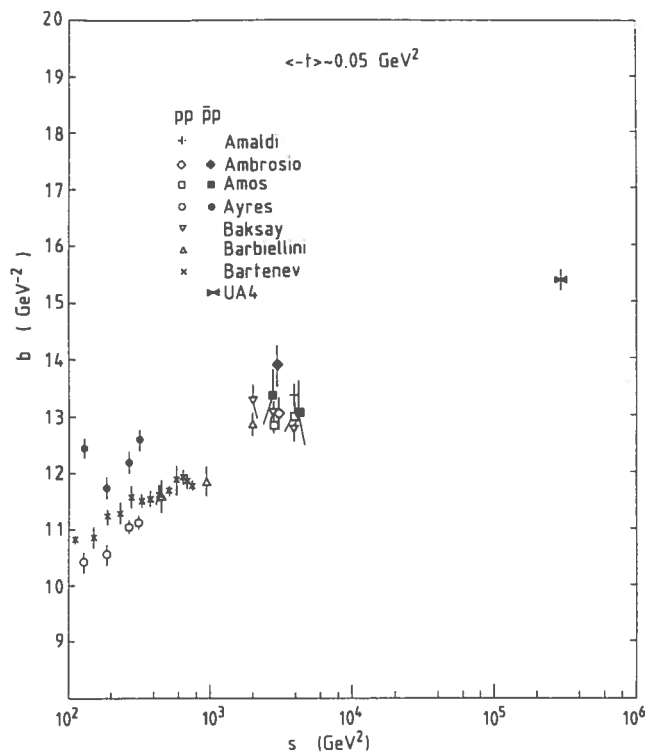


Fig. 7 The forward slope parameter at the collider compared to pp and $\bar{p}p$ results at lower energy.

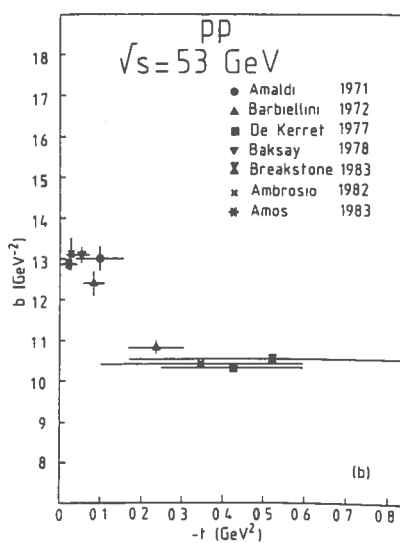
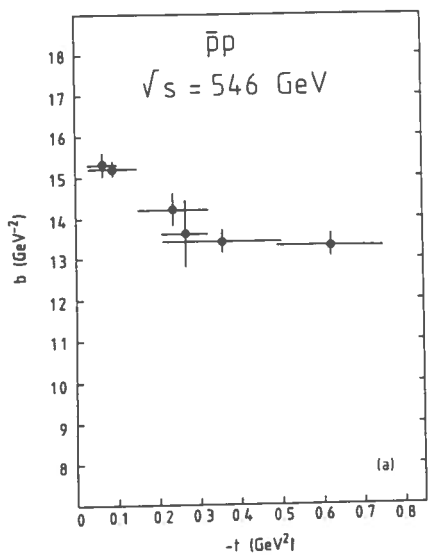


Fig. 8 The dependence of local slope parameter on t at the SppS and ISR, respectively (the horizontal bar indicates the t interval where the exponential fit was performed).

TOTAL CROSS SECTION AT THE SppS COLLIDER

A precise measurement of the total cross section σ_T at the SppS is seriously complicated by the poor knowledge of the machine luminosity ($\sim 10\%$ uncertainty from the beam profile wire scan technique, to be compared to the 1% possible at the ISR with the Van der Meer technique). Three methods of measurement are possible:

Total rate method:
$$\sigma_T = (N_{el} + N_{in})/L \quad (\sim 10\% \text{ error}) \quad (1)$$

Optical theorem method:
$$\sqrt{(1 + \rho^2)} \sigma_T = \sqrt{16\pi} \left. \frac{dN_{el}}{dt} \right|_{t=0} / \sqrt{L} \quad (\sim 5\% \text{ error}) \quad (2)$$

Combined method:
$$(1 + \rho^2) \sigma_T = 16\pi \left. \frac{dN_{el}}{dt} \right|_{t=0} / (N_{el} + N_{in}) \quad (\sim 2\% \text{ error}) \quad (3)$$

where N_{el} and N_{in} are elastic and inelastic event rates. Method (3) (and (2)) requires detection of small t elastic events. The power of the luminosity independent method was thus fully exploited only with the 1983 high- β UA4 sample. Some knowledge of ρ is also required ($\rho = .15$ was assumed, see fig. 3).

A (fully inclusive) detection of the total inelastic rate was performed [21] by UA4, with the help of the UA2 central detector. Most (83%) of N_{in} consists of double arm coincidence triggers; one arm triggers (where one, or more, small angle particles on the opposite side are lost in the beam pipe) are 17%, mostly due to diffraction dissociation processes. Possible losses at small ($\theta \leq .5^\circ$) and intermediate angles ($10^\circ \leq \theta \leq 20^\circ$), estimated by small and large angle extrapolations, are found to be small.

The dominant error on σ_T comes from the uncertainty ($\sim 2.5\%$) in the absolute elastic rate. Eq. (3) gives

$$(1 + \rho^2) \sigma_T = 63.3 \pm 1.5 \text{ mb} \rightarrow \sigma_T = 61.9 \pm 1.5 \text{ mb (for } \rho = .15)$$

A less accurate measurement, based on method (2), gives

$$\sqrt{(1 + \rho^2)} \sigma_T = 61.7 \pm 3.0 \text{ mb} \rightarrow \sigma_T = 61.0 \pm 3.0 \text{ mb (for } \rho = .15)$$

consistent with the above value and three previous preliminary measurements by UA4 [22,23] and UA1 [19]. Fig. 9 shows the available data for the energy dependence of σ_T for pp and $\bar{p}p$. The growth of σ_T continues the trend seen at the ISR. A (purely phenomenological) fit to all σ_T data using a logarithmic term ($\log s$) in addition to the usual power terms needed to describe the low energy region, gives $\gamma = 1.90 \pm .10$. The 1977 CERN Rome [10] fit adopted the same parametrization and gave (using also ρ data and their link to σ_T via dispersion relations) $\gamma = 2.10 \pm .10$. The new data are compatible with the prediction of the 1977 fit.

The ratio σ_{el}/σ_T (elastic to total cross section) is plotted versus energy in fig. 10. UA4 quotes [21] $\sigma_{el}/\sigma_T = .215 \pm .005$ ($\sigma_{el} = 13.3 \pm .4 \text{ mb}$), the ratio b/σ_T being $.245 \pm .010$. The two ratios are constant (.175 and .30 respectively) over the entire ISR energy range [24].

DISCUSSION OF ELASTIC AND TOTAL CROSS SECTION DATA

The pattern emerging is the following: σ_T is presently growing somewhat faster than b ; the ratio σ_{el}/σ_T (equal to $\sigma_T/16\pi b$ for a purely exponential t dependence and for $\rho = 0$) grows accordingly. In fact, the Mc-Dowell-Martin [25] bound ($\sigma_{el}/\sigma_T \geq \sigma_T/18\pi b$) is saturated within 12%. The fast growth of σ_T is very close to the $(\log s)^2$ behaviour of the Froissart [26] bound (saturation of the bound, however, would require a cross section of a few barns).

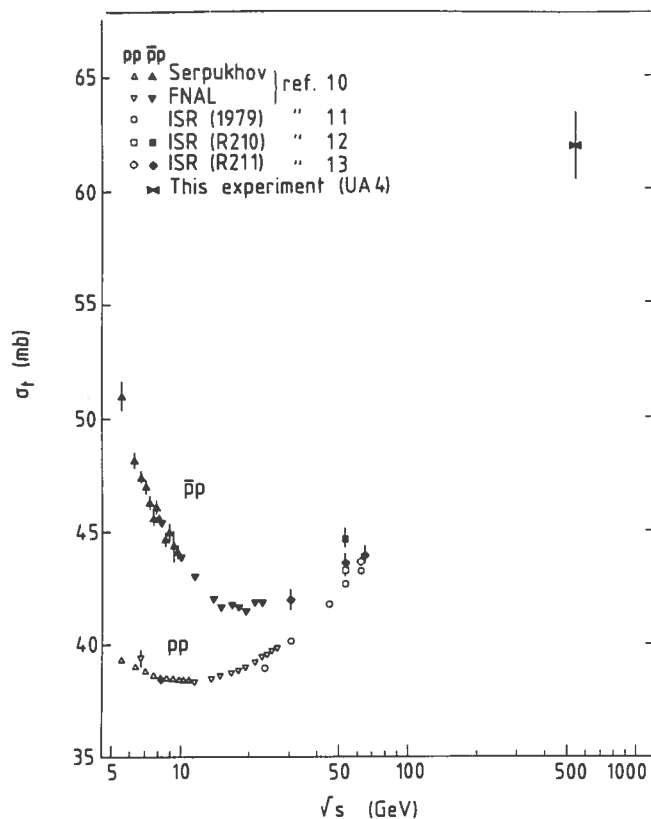


Fig. 9 The collider result on the $\bar{p}p$ total cross section is shown together with lower energy pp and $\bar{p}p$ data.

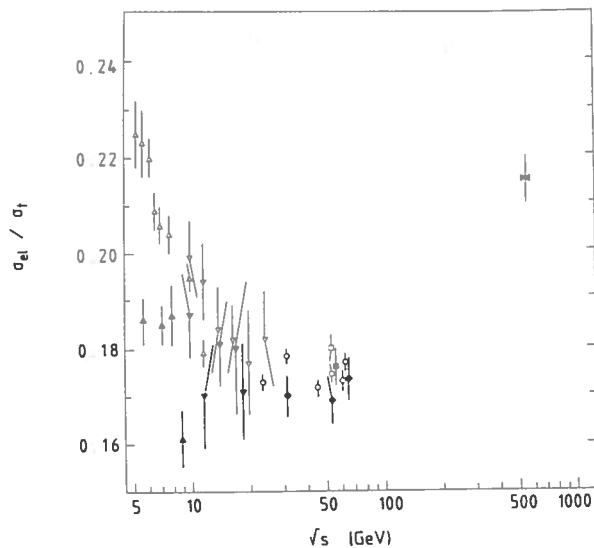


Fig. 10 The collider result on the $\bar{p}p$ ratio of elastic to total cross section is shown with lower energy pp and $\bar{p}p$ data.

In the simplest optical models [27] of scattering of hadrons of transverse size R and absorption power β one has

$$b \sim R^2 \qquad \sigma_{el}/\sigma_T \sim \beta \qquad \sigma_T \sim \beta R^2$$

The ratio σ_{el}/σ_T would be a direct measure of absorption in hadronic interactions. Protons exhibit, at $\sqrt{s} = 540$ GeV, not only a growing effective size (like at the ISR [24]) but also a darkening "blackness". No limiting absorption appears to be in sight; the onset of the "asymptotic regime" may well have escaped one more generation of colliders.

A more precise formulation can be given in the impact parameter (i.e. the distance a of the directions of flight of the colliding hadrons) language [24]. The proton profile function $\Gamma(a)$, defined as the Bessel transform of the elastic scattering amplitude $f(q)$, is accessible from the data ($q^2 = |t|$)

$$\Gamma(a) = \frac{1}{i\sqrt{\pi}} \int_0^\infty dq q f(q) J_0(qa) \approx \frac{1}{i\sqrt{\pi}} \int_0^\infty dq q \sqrt{\frac{d\sigma}{dt}} J_0(qa)$$

where the assumption $\rho \approx 0$ can be checked a posteriori not to be critical [24]. One defines the eikonal ("opacity") function Ω via $\Gamma(a) = 1 - e^{-\Omega(a)}$ and the elastic and inelastic overlap functions $G_{el}(a)$ and $G_{in}(a)$ as

$$\sigma_{e1} = \int |\Gamma(a)|^2 d^2a = \int G_{e1}(a) d^2a$$

$$\sigma_{in} = \int [2\text{Re } \Gamma(a) - |\Gamma(a)|^2] d^2a = \int G_{in}(a) d^2a$$

Henzi and Velin have performed such a model independent impact parameter analysis [29] of the data in fig. 5. The shape of $G_{in}(a)$ at the Spps and at one ISR [30] energy (53 GeV) is shown in fig. 11(a).

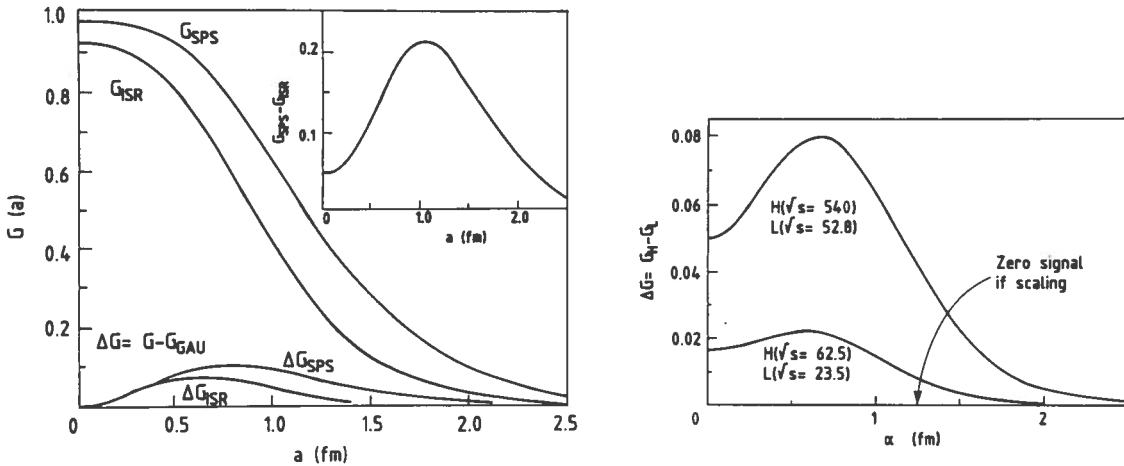


Fig. 11

(a) Inelastic overlap functions [29] at ISR and Spps as a function of the impact parameter a . G_{GAU} is a gaussian approximation to the overlap function.

(b) The "blacker and edgier" component of ΔG . The lower curve is from a 1979 analysis of ISR data [30].

It is a gaussian, with a tail. The insert shows the variation $G_{SPPS} - G_{ISR}$ from 53 to 540 GeV. The increase is mostly peripheral, the proton is getting larger. Let its size ($R \sim \sqrt{b}$) be R_H and R_L at the higher and lower energy, respectively. ΔG is plotted versus the scaled impact parameter $\alpha = (R_H/R)a$ in fig. 11(b). The growth in size having been subtracted out, ΔG is still non zero for all values of α , the proton is getting also blacker. At the Spps $G_{in}(a)$ is less of a gaussian and more of a step function than it used to be at ISR. The proton is getting edgier.

MODELS OF ELASTIC SCATTERING AND σ_T

One can distinguish [31] a few different scenarios:

- (a) The Froissart bound is not to be saturated ($\sigma_T / \ln^2 s \rightarrow 0$); such models are of course disfavoured by the recent data; among them, the "critical" Pomeron models [32], where a gentle decrease of opacity accompanies the expansion of the proton radius, giving $\sigma_T \sim (\ln s)^{2/3}$ and a decreasing σ_{e1} / σ_T (plus a pronounced dip at the Spps).

- (b) The Froissart bound is eventually to be, but not yet, saturated; such models view the ISR and SppS energies as a "transition region" where σ_T is approaching a $\ln^2 s$ behaviour and σ_{el}/σ_T is rising to its asymptotic constant value; among them, various factorizing eikonal (FE) models [33-37] and the "supercritical" Pomeron [38] approach of Kaidalov-Ter-Martyrosian. The new data agree, qualitatively, with these ideas. All models, however, have problems with a more careful scrutiny (table 1).

In the Chou-Yang "geometrical" FE model [33] the opacity function $\Omega(a,s) = \beta(s) F(a)$ is assumed to have an essentially fixed shape (derivable from the hadron electromagnetic form factor) and an energy dependent absorption $\beta(s)$ (fixed by data for σ_T). As the absorption increases with energy, the predicted rise is qualitatively correct for σ_{el}/σ_T . But it is of course much too gentle for the forward slope b . In addition, the model does not say anything about ρ and its action in filling the dip; it also predicts too large a $d\sigma/dt$ beyond the dip. A possible generalization of the "geometrical picture", capable to keep its intuitive simplicity while reproducing better the data, has been recently proposed by Glauber and Velasco [34].

The Cheng-Walker-Wu "impact picture" model [35] recently revisited by Bourrely et al. [36] and by Chiu [37], was the first model to predict a rising σ_T , based on field theoretic studies showing that at high energy the dominant exchanges give amplitudes varying as s^{1+c} . Multiple exchanges produce an (FE) eikonalised amplitude, with $\Omega \sim s^c G(b)$. The model, using a parametrization of $G(b)$ capable to fit the available (ISR) data (with $c \approx .08$), makes predictions for higher energies. It approaches probably better than any other the BEL (Blacker, Edgier, Larger) behaviour of Henzi and Velin. The predicted forward slope, however, is somewhat low. σ_{el}/σ_T rises and the dip disappears naturally (both for $\bar{p}p$ and pp) at the energy of the SppS.

Gauron and Nicolescu have recently proposed [39] an amplitude featuring an explicit asymptotic $(\log s)^2$ term ("froissaron"); its manifestation (finite energy correlations between the behaviour of b and σ_T) may be already present in the SppS data and should appear clearly at future colliders.

Table 1 Predictions of various models compared to collider data. Unavailable predictions are marked (-), clear discrepancies (*), uncertain predictions or data (?).

	σ_T (mb)	ρ	b (GeV ⁻²)	σ_{el}/σ_T	Dip	bump (mb GeV ⁻²)	$\bar{p}p=pp$
Chou-Yang	(-)	(-)	14.1 (*)	.23	Fillable (?)	$\sim 10^{-2}$ (*)	YES
Cheng-Wu	62	.13	≥ 14.2 (*)	.21	Filled	$\sim 10^{-3}$	YES
Geometrical scaling	(-)	.14 (?)	17.5 (*)	.175 (*)	Filled	$\sim 10^{-4}$ (*)	YES
Donnachie-Landshoff	63	.14	15.4	Grows	Filled	$\sim 10^{-4}$ (*)	NO
Collider data	61.9±1.5	.15?	15.2±.2	.215±.005	Filled	$\sim 10^{-3}$?

(c) The Froissart asymptotic regime is already reached; this was proven [40] years ago (from first principles, regardless of the dynamical mechanism) to imply "τ scaling", i.e. $\text{Im}f(s,t) = \text{Im}f(s,0)\phi(\tau)$, where ϕ is a function of the scaling variable $\tau = t\sigma_T$ only. If the real part is not too large geometrical scaling (GS) emerges as a consequence [41]; in impact parameter language $\Omega(a,s) = \Omega(a/\sqrt{\sigma_T})$, i.e. σ_T rises from a scaled expansion of the profile function; the hadron will not get "blacker", σ_{e1}/σ_T will stay constant, b will grow like σ_T . Furthermore, $\phi(\tau)$ as extracted from ISR data and the measured σ_T at the SppS will predict $d\sigma/dt$ there (ρ can be either measured or estimated from asymptotic phase relations). The dip is nicely predicted [42] to be filled (by the real part) but the value of $d\sigma/dt$ in that region can match the data only for the (admittedly high) value $\rho \approx .25$. GS (i.e. early asymptoticity) does not appear to hold, its apparent success over the ISR range [24] may only have been accidental.

At the risk of oversimplifying differences and experimental consequences of the models, a rough sketch of the energy evolution of $G_{in}(a)$ is given in fig. 12. The length of the arrows indicates the relative energy increase at any given a . In FE models the profile or overlap function is too black and not large enough (small forward slope); in GS models, instead, it does not become blacker, but increases too much in size (large forward slope).

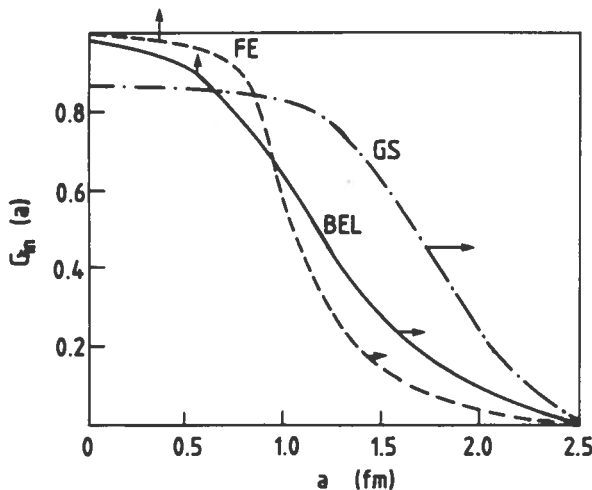


Fig. 12 Rough sketch of the energy evolution of $G_{in}(a)$. The length of the arrows shows the relative energy increase at any given impact parameter a .

A rather different (non crossing-symmetric) model by Donnachie and Landshoff [43] gives a reasonable description of forward scattering (b , ρ , σ_T) via the exchange of one (or more) Pomeron with effective intercept $\alpha_p(0) = 1.08$ (obtained from a sum over photon-like Pomeron-quark couplings). The dip in pp is generated by destructive interference with a triple gluon (ggg) term dominating large t scattering. Since the ggg term is crossing-odd, this cancellation does not occur in $\bar{p}p$ and only a shoulder remains. The model fits well the ISR data; the R420 result, in particular, may support a mechanism of this type. At the SppS, however, the predicted $d\sigma/dt$ in the shoulder region comes out too low (fig. 13).

Obviously the most unsatisfactory feature of all models is their lack of truly basic content. Geometrical and optical models do contain some truth, but they do not tell us why $\Gamma(a)$ is what it is, or what builds up the hadron size ($\sim\sqrt{\sigma_T}$). A fundamental theory of pointlike constituents will eventually have to be able to reproduce geometrical features. A possible picture is sketched

[44] in the work of several authors (it looks at hadronic interactions as interactions of wee partons; fast partons must cascade down to slow quarks and gluons in order to interact, thus generating a spatial smearing which is the transverse size of the hadron; the growth of σ_T with energy would come [45] from the rise of wee parton multiplicity overcoming the decrease of elementary cross sections). Predictive power appears limited at the moment.

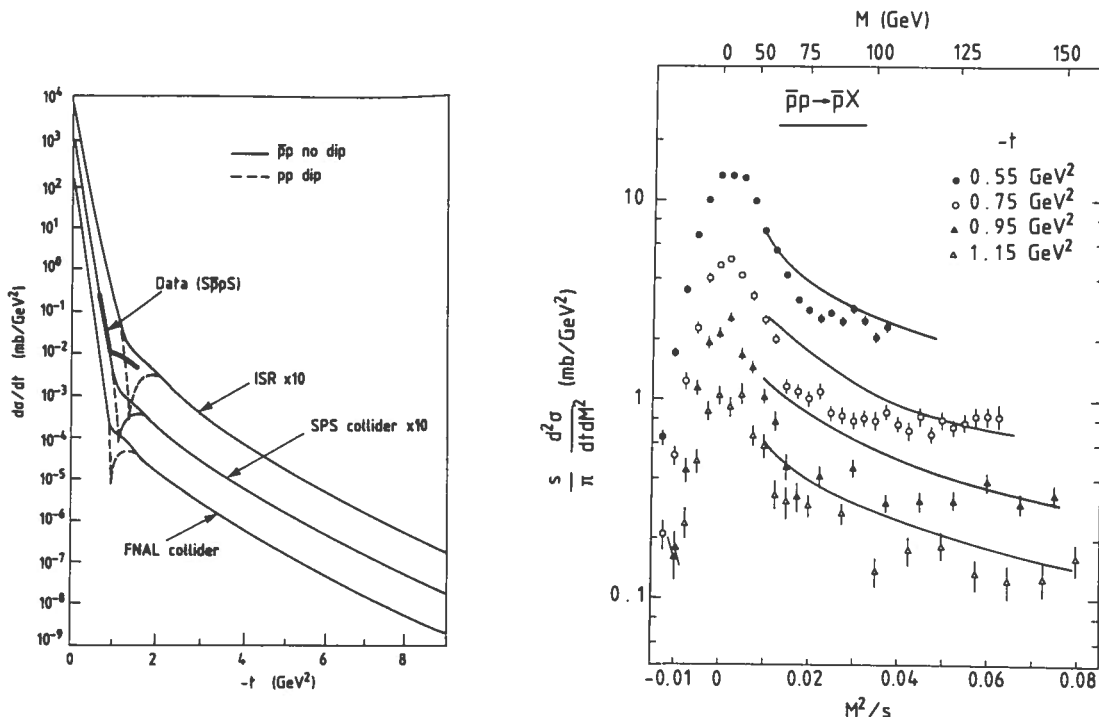


Fig. 13 Predictions of Donnachie-Landshoff photon-like Pomeron model for: (a) Differences in larger t elastic scattering between pp and $\bar{p}p$. (b) Invariant cross section for single diffraction at the SppS. The data are from UA4 [46].

DIFFRACTION DISSOCIATION

Data on diffraction dissociation ($\bar{p}p \rightarrow \bar{p}X$) at the SppS were published by UA4 [46] for the larger t range (low- β). New small- t (high- β) data are being analyzed. The mass M_X of the system X can be determined by measuring the \bar{p} momentum in the quadrupoles of the machine. The analyzing power is rather good ($\Delta p/p \approx .6\%$) in low- β , rather poor ($\Delta p/p \approx 8\%$) in high- β [47].

A quasi-elastic peak, typical of inelastic diffraction, is clearly isolated for $M_X^2/s < .03$. Scaling of the invariant cross section (within large errors) from ISR to SppS was shown, together with the persistence of a $1/M_X^2$ spectrum at fixed t (expected if the mechanism described by the triple Pomeron graph is dominant). The Pomeron-photon analogy of Donnachie and Landshoff also gives a reasonable description [48] of the data, with no adjustable parameters (fig. 13(b)). The pseudorapidity (η) distributions of the fragments of the system X has been studied [49]. They are plotted, for various intervals of M_X , in fig. 14(a). Only tracks in the $2.5 \leq |\eta| \leq 5.5$ range of the UA4 telescopes are shown.

Both width and height of the η distribution grow with M_X . The η distribution for $M_X \sim 50$ GeV, in particular, agrees well (in shape and size) with the one (fig. 14(b)) from normal ISR minimum bias events at $\sqrt{s} = 53$ GeV (only shifted by

the difference in beam rapidity). The fragmentation of M_X looks very similar to a normal hadronic event at $\sqrt{s} \sim M_X$ (and disfavours the picture of isotropic fragmentation of an independent "fireball").

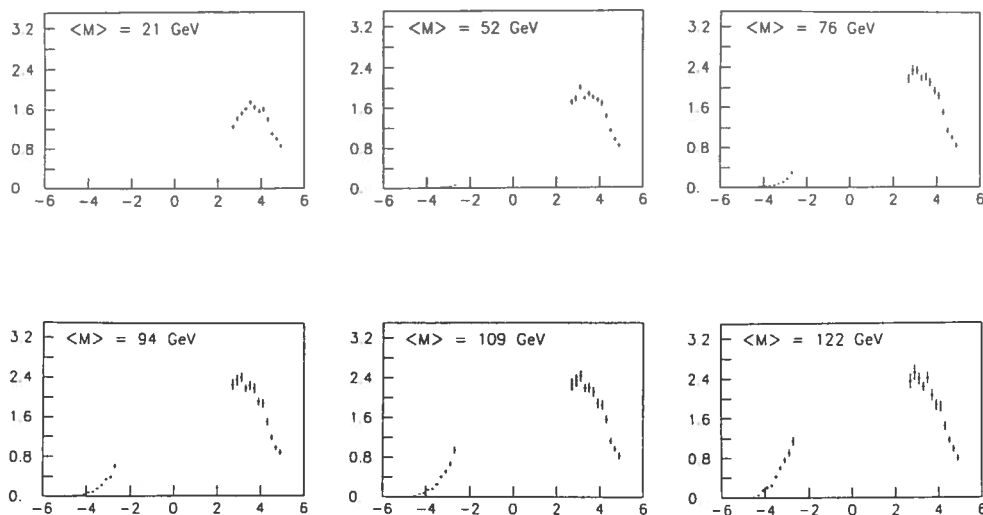


Fig. 14(a) Pseudorapidity distributions of fragments of the X system

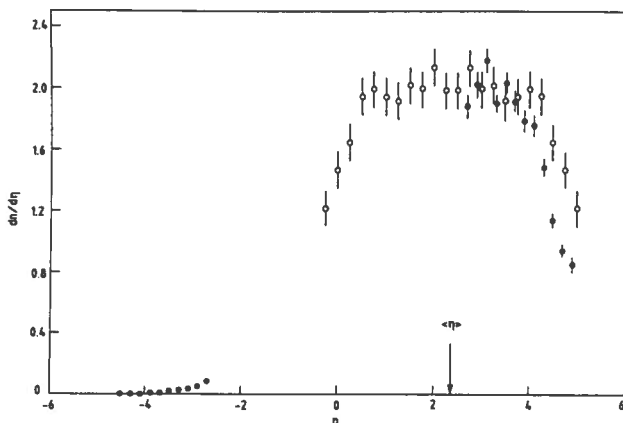


Fig. 14(b) Comparison of η distribution for diffractive masses of about 52 GeV with η distribution of minimum bias events at $\sqrt{s} = 53$ GeV (ISR).

The single diffractive cross section σ_{SD} was measured [50] years ago at ISR (CHLM) by mapping $d\sigma/dtdM_X^2$ and integrating it in t and M_X^2 (up to $M_X^2/s \sim .05$). σ_{SD} , being strongly peaked at low t , is accessible in high- β . Here, however, the poor $\Delta p/p$ makes difficult the isolation of the quasi-elastic peak (i.e. the safe tagging of diffractive interactions) using only the \bar{p} momentum; rapidity gap requirements will also have to be imposed, using the combined UA2 + UA4 detection system.

At the present time, preliminary σ_{SD} values have been quoted by UA5 and UA4, using the percentage of one arm events, corrected for trigger losses and contamination of non-diffractive events. UA5 quotes $\sigma_{SD} = 5.0 \pm 1.5$ mb, UA4 obtains $\sigma_{SD} = 8.4 \pm .4$ mb (i.e. $\sigma_{SD}/\sigma_{el} \sim .6$, $\sigma_{SD}/\sigma_T \sim .13$). σ_{SD} would then be relatively less important (fig. 15) at the SppS than at the ISR (where $\sigma_{SD}/\sigma_{el} \approx 1$ and $\sigma_{SD}/\sigma_T \approx .17$). This may be hard to concile with a $1/M_X^2$ spectrum. An improved result from the UA4 high- β data should be available soon.

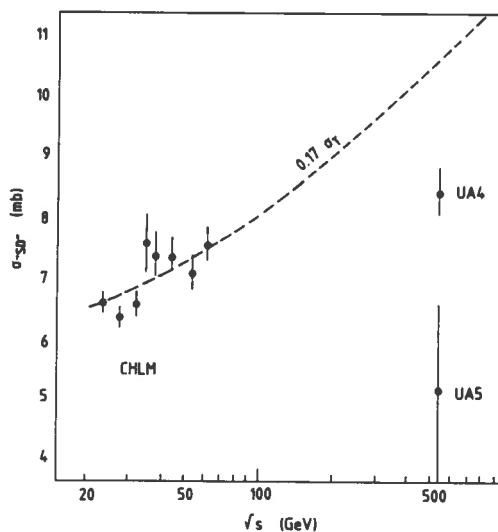


Fig. 15 Two preliminary measurements of σ_{SD} from UA4 and UA5. The dashed line extrapolates the ISR (CHLM) points ($\sigma_{SD} \approx .17 \sigma_T$).

GENERAL FEATURES OF HADRONIZATION AT THE Spps

The average multiplicity $\langle n \rangle$ of charged secondaries was measured [51] by UA5. It is $27.5 \pm .4$ for inclusive events, $28.9 \pm .4$ if single diffraction is excluded (NSD). A $\ln^2 s$ term is clearly needed to reproduce the observed (fig. 16) energy dependence of $\langle n \rangle$ (it accounts for 67% for it!). A discussion of the discriminating power of this measurement among various models of the hadronization process (Fermi-Landau thermodynamical model, scaling LPS models, soft gluon dominance, scale violating Bose-Einstein enhancement and others) has been given by Gavai and Satz [52] and by Ekspong [53].

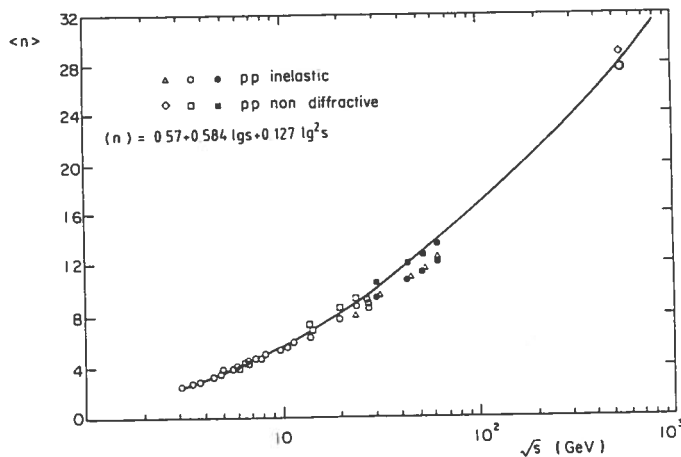


Fig. 16 The energy dependence of the average charged multiplicity (of fully inclusive and non-diffractive events). An explicit quadratic fit is shown.

Violation of Feynman scaling in the central region of the inclusive η distribution was also shown; a definite plateau develops around $\eta = 0$ and its height grows, about like $\log s$, from ISR to Spps. Scaling may instead be valid, within 15%, in the fragmentation region ($|\eta| \geq 4$), though more precise data would be welcome.

Inclusive p_T spectra for charged particles have been measured [54] by UA1 (and UA2). The experimental distribution is definitely not an exponential, not even below $p_T \approx 1$ GeV; a power law p_T^{-m} fits the data ($m \approx 8-9$). The average

p_T is higher (420 MeV) than at ISR (360 MeV). It is larger for events of larger multiplicity (fig. 17). This is a novel effect (also seen by R420 at the top ISR energy). Its significance as a signal of transition of hadronic matter to quark-gluon plasma has been discussed by Van Hove [55]. The study of the n dependence of $\langle p_T \rangle$ could provide more insight.

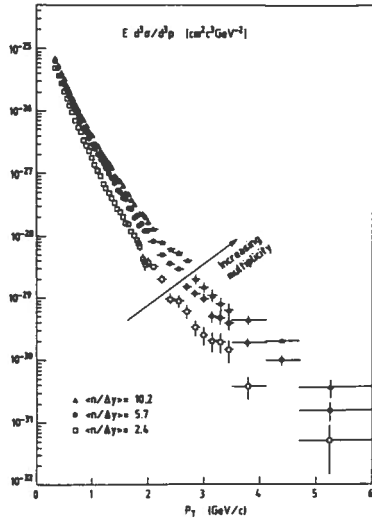


Fig. 17 Variation of the p_T spectrum with multiplicity at $\sqrt{s} = 540$ GeV.

Fluctuations of the charged multiplicity around $\langle n \rangle$ are known to be large, with a dispersion roughly proportional to $\langle n \rangle$. The multiplicity distribution $P(n)$ has often been analysed in terms of the KNO scaling hypothesis, expressed by the relation $\langle n \rangle P(n) \equiv \langle n \rangle \sigma_n / \sigma_{in} = \psi(z)$ (where $\sigma_n = n$ -prongs cross section, $z = n/\langle n \rangle$). KNO scaling (derived [56] from the hypothesis of Feynman scaling in 1971 and proven to be basically obeyed up to ISR energy) means that $\psi(z)$ is an energy independent universal function. At the SppS, however, UA5 [57] finds an excess of large z events definitely violating KNO scaling (fig. 18). About 6% of the events (2.2% at the ISR) have $z > 2$ (i.e. $n > 60!$) while there is a depletion for $.8 \leq z \leq 1.6$. The strong energy dependence of the moments of $P(n)$ (expected to be constant if scaling holds) can also be used to quantify the violation. We may be observing the onset of a new phenomenon.

In spite of its violation, KNO scaling remains a valuable framework. Models will have to explain its approximate validity, even before tackling its violations. A list of models, some predicting KNO scaling, some incorporating violations (sometimes in the wrong direction) is given in ref. [53]. A critical discussion was recently given by T.T. Van [58].

A phenomenological analysis of $P(n)$ at the SppS has been recently proposed [59] by the BCF group at CERN; their systematic analysis of hadronization as a general phenomenon has shown, in the past few years, that hadronic systems produced in e^+e^- collisions are hardly distinguishable from the ones from ep (one leading proton) and pp collisions (two leading protons) if only one removes the energy of the leading particle(s) and consequently redefines, collision by collision, the energy $\sqrt{s'}$ effectively available for particle production. BCF maps at the ISR the multiplicity distribution $P(n, s')$ and (from the leading particle spectra) the probability $F(s'; s)$ of having available the energy $\sqrt{s'}$ in collisions with c.m. energy \sqrt{s} . Assuming that the leading effect and the charged multiplicity distribution scale with energy and that the dependence of $\langle n \rangle$ on $\sqrt{s'}$ can be extrapolated to SppS energy, BCF predicts at 540 GeV a $P(n, s) = \int ds' F(s', s) P(n, s')$ capable to closely reproduce the UA5 data (fig. 19).

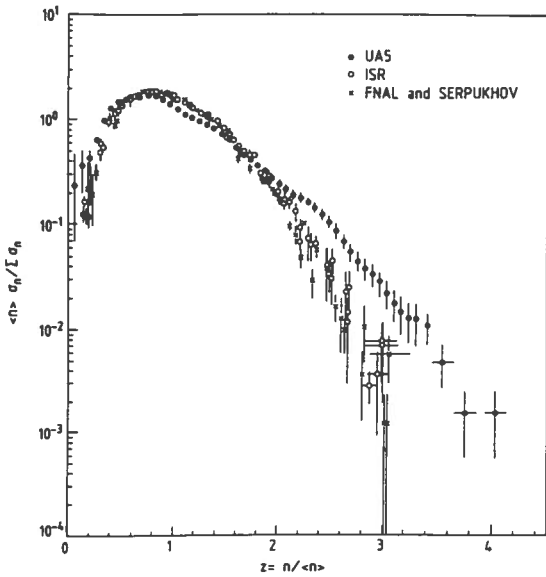


Fig. 18 The (normalized) non-single diffractive multiplicity distribution (at FNAL, ISR and SppS [57]) as a function of the KNO scaling variable z .

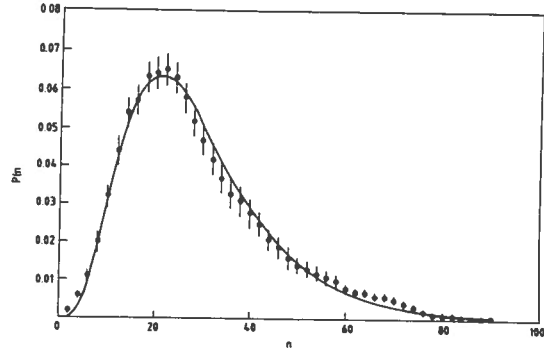
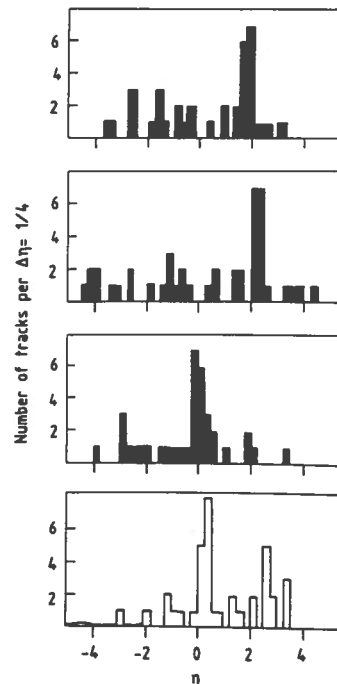


Fig. 19 The non-single diffractive multiplicity distribution at the SppS compared to the predictions from the analysis of the BCF group [59].

A search for unusual phenomena in events in the high z tail has been performed [60] by UA5. They looked for very big local fluctuations, i.e. a very high track density in a limited pseudorapidity range. The η distributions for a few of those "spike" events (isolated by asking large multiplicity in a sliding window $\Delta\eta = .5$ anywhere along the η axis) are shown in fig. 20. They typically have 15 tracks in $\Delta\eta = .5$, i.e. a value $z \approx 10$ (locally) and an energy density of $\sim 10 \text{ GeV fm}^{-3}$, well above the "expected" threshold for transition to quark-gluon plasma phase. However, the UA5 cluster Monte-Carlo is able to reproduce features (and rates) of these unusual events; no new physics ("hot spots") but rather a tail of the known large fluctuations is probably being observed.

Fig. 20 Track density for three events from the data sample and one event (bottom) from the Monte-Carlo simulation. The events were found in a scan where the maximum number of tracks in an interval $\Delta\eta = 0.5$ was searched for.



LONG AND SHORT RANGE CORRELATIONS

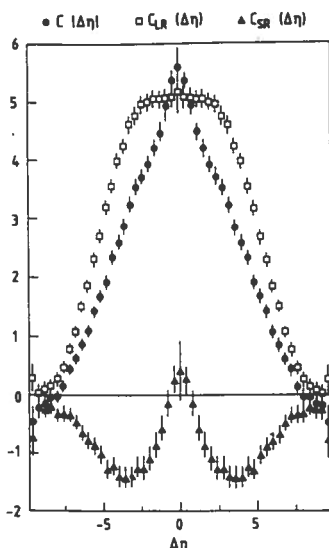


Fig. 21 Inclusive charged particle correlation function $C(\Delta\eta)$ and its long and short range components, $C_L(\Delta\eta)$ and $C_S(\Delta\eta)$.

The presence at the SppS of forward-backward correlations significantly larger than at the ISR was pointed out [61] by UA5 already in 1982. Subsequent studies showed [53] no real need for intrinsic (dynamical) long range correlation. The experimental value of the correlation coefficient $b = d\langle n_B \rangle / d\langle n_F \rangle$ (n_B and n_F being backward and forward multiplicity) could be explained by the random emission along the η axis of small clusters (of average decay multiplicity about 2) and by the known large (KNO-like) fluctuation in (cluster) multiplicity. Other mechanisms cannot be however excluded. The nature of the clusters remains unclear.

Clusters emerge also from the UA5 recent analysis [62] of short range correlations. The experimental correlation function $C(\eta_1, \eta_2)$ is shown in fig. 21. It is dominated by the calculable and large long range correlations, anywhere except for small $\Delta\eta = |\eta_1 - \eta_2|$. After subtraction of long range correlations (and background) UA5 finds, like at ISR, a roughly gaussian short-range correlation function, the correlation length is somewhat less than one unit of η ($\approx .7$), average decay multiplicity again 2. A consistent picture of the gross features of clusters thus emerges from the study of both types of correlations.

AVERAGE PARTICLE CONTENT OF MINIMUM BIAS EVENTS

A reasonable picture has been outlined, in spite of the severe difficulties of particle identification. It is summarized in table 2. Quarks (or rather fractionally charged light particles) have been searched [63] and not found.

Photons have been observed in the UA5 [64] streamer chamber (small angle e^+e^- pairs) and in the UA2 [65] calorimeter. Neutral pions and etas have been observed by UA2; the η^0/π^0 ratio ($\approx 30-50\%$) is consistent with the excess of photons over charged pions observed by UA5.

Neutral strange particles ($K^0, \bar{K}^0, \Lambda, \bar{\Lambda}$) have been seen [66] as coplanar V's in the streamer chamber. Charged kaon decays are either unambiguous 3-prong or 1-prong decays separated from π decays by a decay angle cut. They have also been identified by time-of-flight (up to 1.1 GeV/c) in the UA2 [67] wedge spectrometer. The K^\pm/π^\pm ratio (12%) is significantly higher than at ISR (5%). The average p_T of kaons is about 600 MeV, larger than the value for all charged tracks at the SppS and than the one of kaons at ISR (440 MeV). UA5 has recently presented [60] evidence for $\Xi/\bar{\Xi}$ production at the SppS.

Table 2 is obtained [51] from these measurements, reasonable extrapolation from ISR (p/n/A ratios) and the assumption that all remaining charged tracks are pions. There is also a larger fraction baryons than at ISR. Long lived

particles from the primary interaction are marked by an asterisk. In total, for $|\eta| < 5$, 42.7 primary tracks per event. This extrapolates to 44 tracks per event in the full η range, plus two leading baryons.

Table 2 Average particle multiplicities at SppS collider. Items underlined are directly measured. The other values are estimated [51]. Items marked with an * are long lived particles from the primary interaction, including products of strong decays.

K^+ / K^-	<u>2.5</u>	*	5.8%	} 12.2%	} 13.9% (strangeness)
K^0 / \bar{K}^0	<u>2.7</u>	*	6.3%		
$\Lambda / \bar{\Lambda}$	<u>.5</u>	*	1.2%		
$\Sigma / \bar{\Sigma}$.25	*	.6%	} 9% (baryons)	
p / \bar{p}	1.5	*	3.5%		
n / \bar{n}	1.5	*	3.5%		
π^+ / π^-	22.3				
γ	<u>31.5</u>				
η^0	3.5	*	8.2%		
π^0	10.1	*	23.6%	} 71% (pions)	
π^\pm (from η)	2.1				
π^\pm (not η)	20.2	*	47.2%		
TOTAL	42.7 ($\eta \leq 5$) $\rightarrow \approx 44 + 2$ leading baryons in the full η range				

UA5 has performed [68] an interesting analysis (in spite of the amount of guesswork involved) of the average content of prompt hadrons, stable particles or resonances. The result in table 3 is obtained, with a set of "plausible" assumptions for centrally produced hadrons. There would be 27 prompt hadrons per collision, mostly π 's and ρ 's, in equal amount. Resonances would thus be copiously produced.

Table 3 Estimates of the average multiplicities of resonances and stable hadrons "promptly" produced at $\sqrt{s} = 540$ GeV from ref. [68].

π	ρ	ω	η	K	K_{890}^*	K_{1430}^*	Baryons	Others	Total
6.2	6.1	2.0	2.9	2.1	2.6	0.5	3.4	1.0	26.8

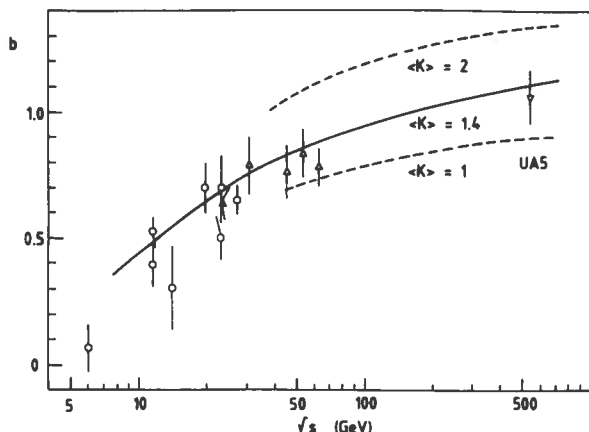


Fig. 22 Correlation strength b for photons and charged particles versus energy. Curves are from a Monte-Carlo simulation for various average decay multiplicity $\langle k \rangle$ for resonances.

Some resonances (ω , η , A_2 , K^*) decay both into charged and neutral pions. A correlation between photon and charged particles multiplicity is implied by copious resonance production. The measured [69] correlation coefficient $b = d\langle n_\gamma \rangle / dn_{ch}$ is large ($1.05 \pm .1$) and grows with energy. Fig. 22 shows the data and the prediction of a simple Monte-Carlo resonance production simulation. The value of the average resonance decay multiplicity k_R which fits best the energy dependence of b is $\langle k_R \rangle \sim 1.4$. Clusters average decay multiplicity is $\langle k_c \rangle \sim 2$. The tentative conclusion is that clusters are not resonances; there would be about 1.4 resonances per cluster.

CONCLUDING REMARKS

- (a) $\bar{p}p$ interaction at the ISR are more and more similar to pp interactions. The R420 result will stand as a puzzle; its impact being reduced by its limited statistical significance.
- (b) The pattern of $\log s$ physics, slowly varying with energy, is confirmed by the SppS collider.
- (c) Among new effects, KNO scaling violations and long range correlations may and may not have basic importance. The growth of $\langle p_T \rangle$ with energy and multiplicity may well carry a basic message. The rise of σ_{el}/σ_T is an indication that an asymptotic regime has not yet been reached.

Further progress should come in 1985 from a first run at 900 GeV, when the SppS will be used in a pulsed mode [70] for minimum bias and elastic data. A super-high- β run should give UA4 access to the t region of Coulomb-nuclear interference and provide a measurement of ρ . It will discriminate better than σ_T between models and will allow to repeat the extrapolation procedure to predict σ_T and ρ at the many TeV energies of future large hadron colliders. Before them, one looks forward to the strong minimum bias physics program being prepared at the Fermilab Tevatron.

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