HADRONIC COLLISIONS AT COLLIDER ENERGIES

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Abstract

New measurements of the $\bar{p}p$ total, elastic and single diffractive cross sections at $\sqrt{s} = 1.8\ TeV$ (E-710) are presented and compared with the theoretical predictions, based on the impact picture for elastic scattering, by Bourrely, Soffer and Wu. A recent conjecture by Kang and White in this context is stated. A new measurement of Double Pomeron Exchange by UA8 is pointed out. UA1 minimum bias data are studied in terms of factorial moments and their power law behaviour (intermittency) in one and two subdivision variables as well as their dependence on the lower p_T bound for charged tracks. As self-similarity and multifractal structure are evoked in connection with intermittency, the latter was analysed by means of G-moments suggested by Hwa yielding the fractal spectrum and multifractal dimensions. The CDF Collaboration has obtained similar results. Finally, Hwa's universality relation for G-moments was preliminarily tested using UA1 data.

1 New Cross Section Measurements

By simultaneously measuring the total inelastic and the small angle elastic scattering rate, the E-710 Collaboration has determined anew the total $\bar{p}p$ total cross section at $\sqrt{s} = 1.8\ TeV$ at the Fermilab Collider independently of luminosity [1]. The summary of their results is:

$$\begin{aligned} \sigma_T &= 72.1 \pm 3.3\ mb \quad (\text{for } \rho = 0.145\ [2]) \\ &= 69.6 \pm 3.2\ mb \quad (\text{for } \rho = 0.24\ [3]) \\ \sigma_{el} &= 16.6 \pm 1.6\ mb, \quad \sigma_{el}/\sigma_T = 0.230 \pm 0.012 \\ \sigma_{inel} &= 55.5 \pm 2.2\ mb, \quad \sigma_{SD} = 11.7 \pm 2.3\ mb. \end{aligned}$$

The luminosity was calculated to 1.16 ± 0.10 times the luminosity given by the accelerator determination ($\pm 15\%$ uncertainty). The comparison of σ_T, σ_{el}, σ_{el}/σ_T, and the total single diffraction cross section σ_{SD} with the values obtained at lower energies in fig. 1 shows that all four quantities are rising with increasing energy. This may be interpreted as an increase of the opacity of the nucleon at collider energies.

The impact picture prediction by Bourrely, Soffer and Wu [4] perfectly confirms the $d\sigma/dt$ distribution of $\bar{p}p$ elastic scattering [5] and, as shown in fig. 2, the σ_T and σ_{el}/σ_T measurements at $\sqrt{s} = 1.8\ TeV$. The t dependence of $\log(d\sigma_{el}/dt)$ in $0.034 \le |t| \le 0.65\ (GeV/c)^2$ is, in agreement with the data, not a straight line, and $\rho = 0.24$ is ruled out.

In order to reconcile, however, the UA4 value of $\rho = 0.24 \pm 0.04$ with the recent E-710 total cross section, Kang and White [6] have constructed a simple dispersion relation model and conjectured a new genuine physical threshold as to the diffractive production of a new particle of mass about 30 GeV/c^2 which may have been seen in Geminion and mini-Centauro cosmic ray events [7].

At the CERN SPS Collider with $\sqrt{s} = 630\ GeV$, the UA8 Collaboration [8] has estimated the Double Pomeron Exchange cross section to be in the range $30 - 150\ \mu b$, using two event samples: (a) Both the final state p and $\bar{p}$ with $1 < |t| < 2\ (GeV)^2$ were detected in Roman Pots, both either above or below the beam line, and the Pomeron-Pomeron produced central system in the opposite solid angle was detected in the UA2 detector; (b) only one of the final state p or $\bar{p}$ with $1 < |t| < 2\ (GeV)^2$ was detected while the other was too peripheral, and the central system was selected by rapidity defining TOF vetos.

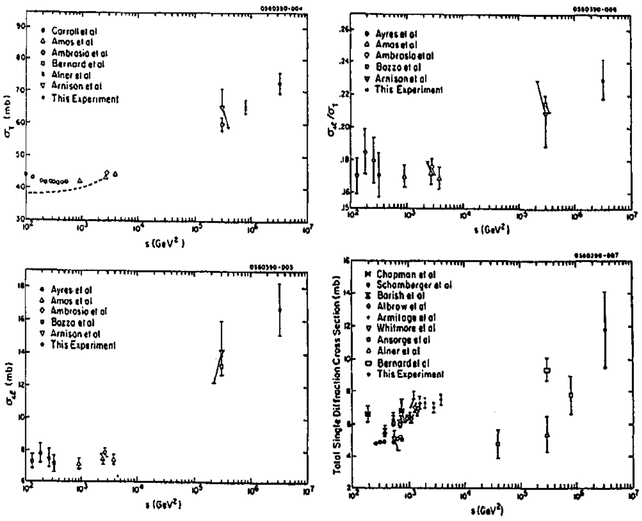

Fig. 1: The σ_T, σ_{el}, σ_{el}/σ_T and the total single diffraction cross section measurements by the E-710 Collaboration at $\sqrt{s} = 1.8\ TeV$ compared with the corresponding results at lower energies [1].

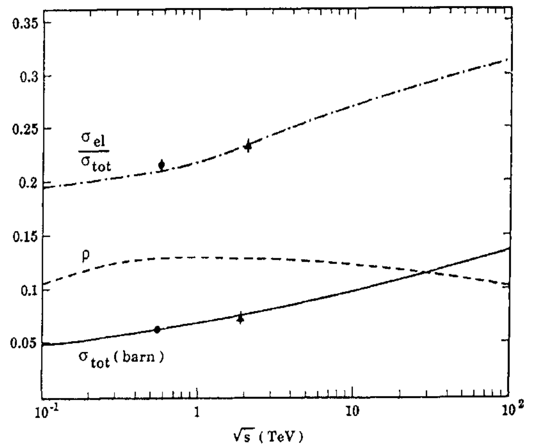

Fig. 2: Impact-picture prediction of σ_T, σ_{el}/σ_T and the ratio ρ of the real to imaginary part of the forward amplitude for pp and $\bar{p}p$ scattering as a function of $\sqrt{s}$ [4].

For the single diffraction cross section $\sigma_{SD} = 9.4\ mb$ has been used.

2 Factorial Moments Analysis

Białas and Peschanski [9] have shown that, for a subdivision of an η (or ϕ) interval into M bins, the scaled moments $\langle C_i \rangle$ of $(1/M) \cdot \sum_{m=1}^{M} (Mp_m)^i$ in terms of bin occupation probabilities p_m per event are equal to the experimental factorial moments of $(1/M) \cdot \sum_{m=1}^{M} \{k_m(k_m-1) \cdots (k_m-i+1)\}/\{N(N-1) \cdot \cdot \cdot (N-i+1)\}$ in terms of particle numbers k_m per event, taking account of statistical bin-to-bin fluctuations. Dynamical fluctuations, to be looked for, imply that the normalized factorial moments have the power law behaviour $\langle F_i \rangle \propto (Y/\delta y)^{\varphi_i}$, which is called intermittency [9].

2.1 *One-Dimensional Factorial Moments*

The UA1 1985 minimum bias data which are from now on, unless otherwise specified, the only data discussed, yielded the following intermittency parameters φ_i obtained by Buschbeck and Lipa [10] from one-dimensional analyses in η and ϕ:

	η	y	ϕ
φ_2	0.011	0.012	0.010
	$\pm 0.001 \pm 0.001$	$\pm 0.001 \pm 0.001$	$\pm 0.001 \pm 0.001$
φ_3	0.025	0.028	0.027
	$\pm 0.003 \pm 0.003$	$\pm 0.002 \pm 0.002$	$\pm 0.002 \pm 0.003$
φ_4	0.050	0.049	0.077
	$\pm 0.005 \pm 0.005$	$\pm 0.005 \pm 0.005$	$\pm 0.006 \pm 0.008$
φ_5	0.077	0.062	0.152
	$\pm 0.020 \pm 0.008$	$\pm 0.020 \pm 0.006$	$\pm 0.030 \pm 0.015$

They thus exhibit weak, however significant intermittency.

Fig. 3 shows, as to $\langle F_3 \rangle$, how well various Monte Carlo models can reproduce this behaviour [11]. Only GENCL of the UA5 Collaboration, which is based on cluster production and decay and has been tuned to CERN collider data, furnishes a good description of intermittency, albeit only for $\delta\eta \geq 0.25$ [11]. The other models seem to fail.

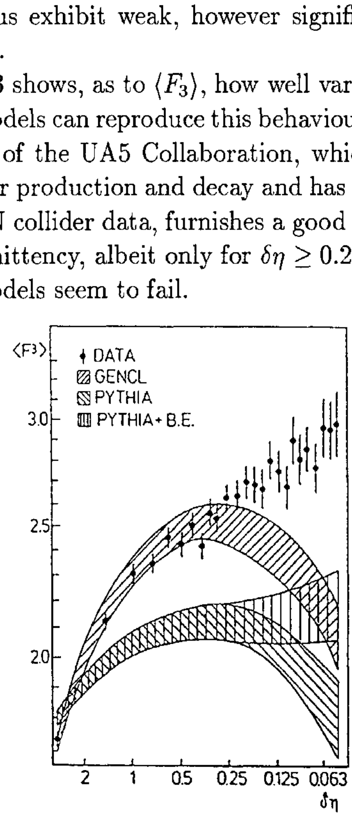

Fig. 3: Comparison of the experimental $\langle F_3 \rangle$ versus $\delta\eta$ distribution with the results of the Monte Carlo models GENCL, PYTHIA 4.8 and PYTHIA 4.8 with Bose-Einstein interference incorporated [11].

As to the variation of intermittency with increasing particle density in rapidity, a decrease of $\varphi_i \propto (dN/d\eta)^{-1}$ [12] is expected because the particles may originate from more and more independent emission sources. This is demonstrated in fig. 4 [11] by comparing the φ_2 and φ_3 results obtained from different experiments and the artificial independent superposition of 2-9 UA1 events with $n_{ch} \leq 20$ and $dN/d\eta = 1.4$.

It is remarkable that the reactions which involve nuclei have considerably larger intermittency parameters φ_2 and φ_3 indicating eventually a higher degree of collective behaviour.

2.2 *Two-Dimensional Factorial Moments*

The simultaneous subdivision of the narrow interval $1.5 \leq \eta \leq 3.0$, in which acceptance losses are minimal, and of the whole azimuth yields 2^ν quadrangles with $\nu = 0, 2, 4, \ldots$ contrary to $\nu = 0, 1, 2, \ldots$ in the one-dimensional case. The intermittency parameters φ_i obtained from fits to $\langle F_i \rangle \propto (1/\delta\eta . \delta\phi)^{\varphi_i}$ are presented in fig. 5 together with those obtained from $\langle F_i \rangle \propto (1/\delta\eta)^{\varphi_i}$. The two-dimensional inter-

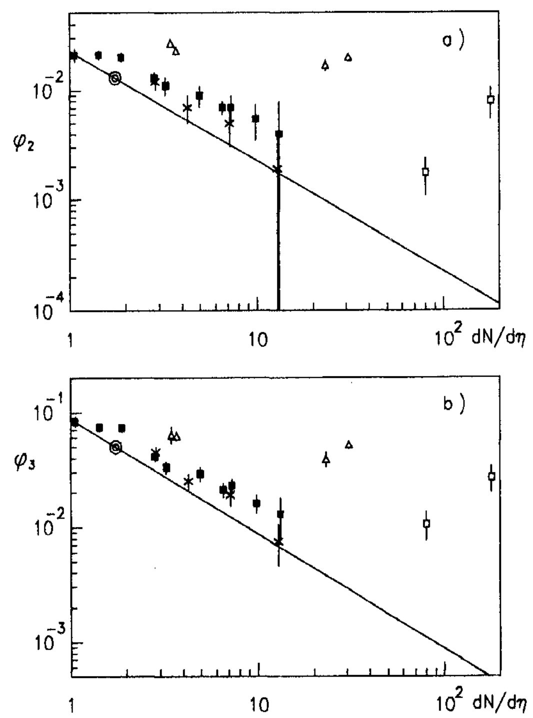

Fig. 4: φ_2 and φ_3 as functions of $dN/d\eta$ from 250 GeV/c π^+p, K^+p (EHS-NA22,⊙); 200 and 800 GeV/c $p+Ag,Br$ and 60 and 200 GeV/N $O+Ag,Br$ (KLM,△); $Ca+C$ and $Si+Ag,Br$ (JACEE,2); and the independent superposition of $2-9$ UA1 events with $n_{ch} \leq 20$ and $dN/d\eta = 1.4$ (×) [11].

mittency parameters are strikingly larger than the one-dimensional ones, in agreement with the original finding by the TASSO Collaboration [13].

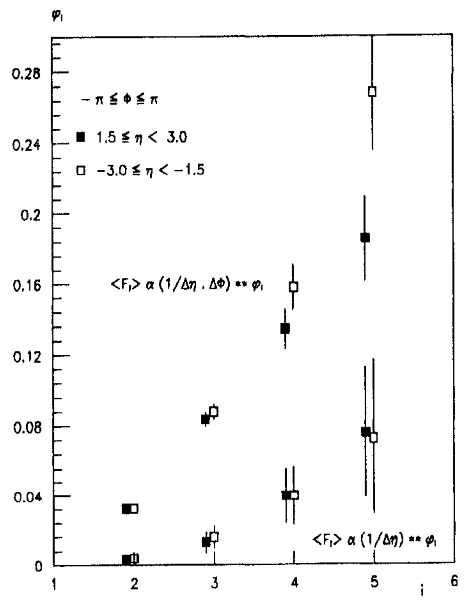

Fig. 5: One- and two-dimensional intermittency parameters φ_i, $i = 2-5$, obtained from subdividing the intervals $1.5 \leq \pm\eta \leq 3.0$ and $-\pi \leq \phi \leq \pi$.

2.3 p_T Dependence of the Factorial Moments

Restricting the rapidity interval to $1.6 \leq \eta \leq 2.4$ in which isotropy is best, and keeping the projected length cut $L_{xy} \geq 0.40\ m$, charged particle production with $p_T \geq p_{Tcut}$ was examined [14]. The dependence of the factorial moments on p_{Tcut} is presented in fig. 6 together with their derivation from the $\langle F_2 \rangle$ values by means of the negative binomial multiplicity distribution relationship for the factorial moments. There seems to be some disagreement in the small p_T region below 0.5 GeV/c. It is not shown here that φ_2 rises from about 0.005 for $p_{Tcut} = 0.15\ GeV/c$ to about 0.1 for 1.6 GeV/c.

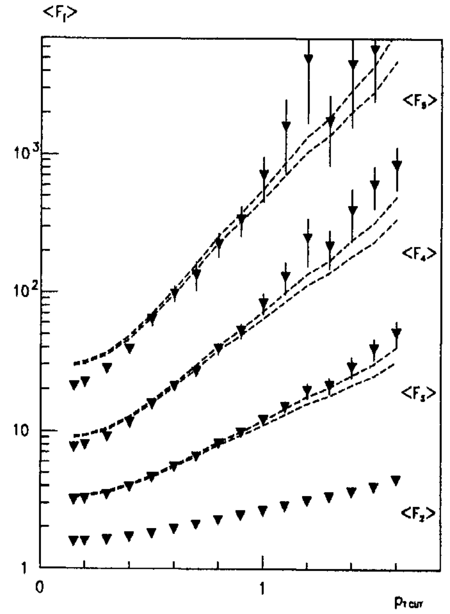

Fig. 6: Dependence of the factorial moments $\langle F_i \rangle$, $i = 2-5$, for $p_T \geq p_{Tcut}$ on p_{Tcut} in $1.6 \leq \eta \leq 2.4$, and on $\langle F_2 \rangle$ using the relationship implied by the negative binomial multiplicity distribution [14].

The $\langle F_2 \rangle$ and $\langle F_3 \rangle$ moments, determined for charged tracks with their p_T in narrow bins, indicate a flat minimum at $p_T = 0.5\ GeV/c$ and a rise for higher p_T similar to that shown in fig. 6.

3 G-Moments and Multifractal Structure

The analysis followed here of multiparticle production in terms of G-moments

$$G_q(\delta) = \sum_{i=1}^{M(\delta)} p_i^q \sim \delta^{\tau(q)} \qquad (1)$$

of the probabilities p_i as to $i = 1 - M(\delta)$ rapidity intervals of width δ for any real positive or negative q, has been proposed by Hwa [15-18]. The grouping of $p_i \sim \delta^{\alpha}$ into classes indexed by α, and expressing their measure as $\delta^{-f(\alpha)}$, yields the dominant G-moments measure if $(d/d\alpha)[q \cdot \alpha - f(\alpha)] = 0$. The solution $\alpha = \alpha(q)$ implies

$$\alpha(q) = \frac{d\tau(q)}{dq} \quad \text{and} \quad f(\alpha(q)) = q \cdot \alpha(q) - \tau(q). \quad (2)$$

$\langle \ln G_q(\delta) \rangle = const + \langle \tau(q) \rangle \cdot \ln \delta$ was experimentally obtained averaging over the event sample using $1.5 \leq \eta \leq 3.0$, $p_T \geq 0.15\ GeV/c$ and $L_{xy} \geq 0.4\ m$ for track selection. $\langle \alpha(q) \rangle$ and $\langle f(\alpha(q)) \rangle$ were then calculated by means of equs. (2). $\langle f(\alpha(q=0)) \rangle = \langle \tau(q=0) \rangle$, $\langle f(\alpha(q=1)) \rangle = \alpha(q=1) \rangle$ and $2 \cdot \langle \alpha(q=2) \rangle - \langle f(\alpha(q=2)) \rangle$, i.e. the fractal, information and correlation dimension D_0, D_1, D_2 respectively, were determined to:

$D_0 = 0.5693 \pm 0.0014$, $D_1 = 0.5164 \pm 0.0020$,
$D_2 = 0.4803 \pm 0.0039$

for the first subdivision of the analyzed rapidity interval with respect to no subdivision. The inequality of the dimensions indicates multifractality.

Fig. 7 shows the $\langle f(\alpha(q)) \rangle - \langle \alpha(q) \rangle$ relationship for the first and second partition into η bins. The creation of empty bins reduces the fractal dimensions. D_1 is shifted down the line $\langle f(\alpha(1)) \rangle = \langle \alpha(1) \rangle$ until the downward concavity contained in equs. (2) breaks down.

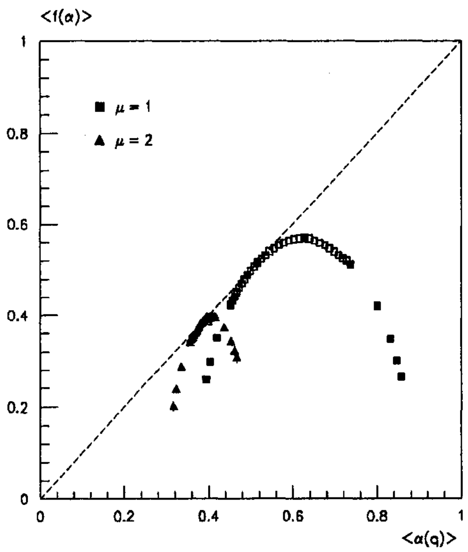

Fig. 7: Relationship between the average fractal spectrum $\langle f(\alpha) \rangle$ and $\langle \alpha \rangle$ for two consecutive subdivision levels of the original rapidity interval [14].

The CDF Collaboration [19] has obtained qualitatively similar results at $\sqrt{s} = 1.8\ TeV$ albeit for narrow rapidity bands. Two Monte Carlo models with gaussian shaped clusters or with a uniform distribution yielded broader and displaced $\langle f(\alpha) \rangle - \langle \alpha \rangle$ relationships compared to the data.

Monte Carlo calculations for $\sqrt{s} = 630\ GeV$ using GENCL, PYTHIA 4.8 and PYTHIA 4.8 with Bose-Einstein interference incorporated also show qualitative similarity with the data, but there are discrepancies in the details of shape and location of the curves which increase going from GENCL to the other models.

4 Universality Property of the G-Moments

It has been shown above that additional subdivisions of the original interval increase fractality. For a given number $N \equiv 2^{\nu}$ of tracks in an event, a subdivision into $M \equiv 2^{\mu}$ bins which only creates empty bins in addition to bins with the minimal content one, does not change the G-moments any more. There seems to be an interplay between ν and μ underlying in the G-moments which has been followed up by Hwa and Florkowski [20].

If $G_q(\mu, \nu) = \sum_k (k/N)^q Q(k)$ with $Q(k)$ being the number of bins with content k, and introducing a bin splitting function $\psi(x, k)$ with x and $1 - x$ being the fractions into which k splits, one obtains in the average over the bins to a good approximation $G_q(\mu + 1, \nu) = G_q(\mu, \nu) \cdot \langle G_q(1, \bar{k}) \rangle$. The solution of the logarithm of this equation was rendered into the following form of a universality property [20]

$$\ln G_q(\mu, \nu) = \Gamma_q(\mu - \nu) - \Gamma_q(-\nu), \quad (3)$$

in which, for the calculation of the $\langle f(\alpha) \rangle - \langle \alpha \rangle$ re-

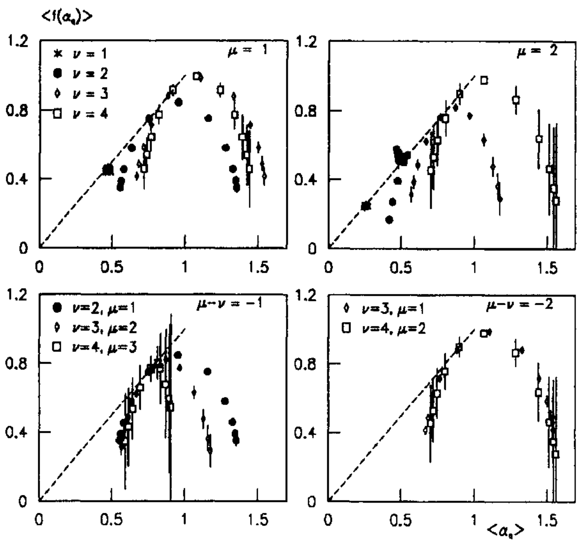

Fig. 8: $\langle f(\alpha) \rangle - \langle \alpha \rangle$ relationship for $\mu = 1, 2$ and $\nu = 1 - 4$, and for $\mu - \nu = -1$ (obtained from $\mu = 1 - 3$ and $\nu = 2 - 4$) and -2 (obtained from $\mu = 1, 2$ and $\nu = 3, 4$).

lationship for given ν, only the $\mu - \nu$ dependence of the first Γ_q term is important.

The preliminary results obtained by Dibon, using the UA1 data with the selection criteria stated in section 3, are shown in fig. 8. They seemingly support the validity of the universality property for $\mu - \nu = -2$; for $\mu - \nu = -1$, however, only for the left-hand leg of the concave multifractal spectrum. This analysis is yet continuing.

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DISCUSSION

Q. **A. Norton** *(CERN)*: Can you explain why GENCL is more successful than other Monte Carlos in reproducing the slopes at large delta Y?

A. **M. Markytan**: GENCL was specifically tuned to many aspects of UA5 collider data, including the two particle correlation.

Sergio Ratti *(Univ. Pavia)*: I wish to add on information and make a general comment to the 3 previous speakers.

1. The I.H.S.C. has submitted a paper (No. 736) in which fractal properties have been investigated systematically through the generalized moment G_q. Our rates on h-h collisions at $\sqrt{s} \sim 17$ GeV in a fixed target experiment, at Fermilab, are *not always* in very good agreement with the fractal idea.

   For some regularity windows we observe linearity, but for the wrong window — or there is linearity but the wrong concavity of $f(\alpha)$ vs α; for some moments we observe the correct concavity only for a limited interval of α. I did not see here any equivalent analysis presented.
2. My comment is the following: Here are *at least* 2 major conditions to ensure that we are dealing with fractal geometry: the first is qualitative i.e., self-similarity; the second is quantitative, i.e., scaling. Now, are we really making *no* fundamental mistakes in dealing with the problem? Are we really using the right "scaling" and "self-similar" variable(s)? The regularity in the top of the longitudinal velocity $B_{11} = \frac{v_{11}}{C}$ $[y = \ln(1 - Bu)/(1 + Bu)]$. Even worse: why should God choose *the logarithm of an angle in the Lab.* to produce hadrons? By chance? Or rather because pseudorapidity is the only variable easy to measure in collider experiments? Finally, scaling in fractal phenomena in solid within a given "range"; what is the lower limit of the scale? *Not* necessarily the resolution! Perhaps the "energy" necessary to have on hadron "brought to life".

J. Rauft *(Leipzig and Orsay)*: I would like to comment on the connection between short range correlations and intermittency and I refer to a forthcoming paper by Boppi, Capella, Tran Thanh Van and myself. We have a Monte Carlo version of the two component Dual Parton Model, which includes the normal soft Pomeron and the minijet component. In this model we get in the collider energy range short range correlations, which agree quite well but not yet perfect with the UA-5 experiment. In this model the short range correlations is partly due to resource decay and partly due to small-soft chains and minijets, which behave somewhat like the clusters of 15 years ago.

We calculate in this model also the factorial moments and find a rise of $\ln\langle Fi\rangle$ with $\ln(1/dy)$. This rise is filled for $dy < 1$ and we obtain the slopes given in the Table, where we also compare with the EHS/NA22 and UA1 data. Our conclusions: For the b_3 and b_5 slopes, where our results are statistically significant, we find slopes about half as large as the experimental slopes. This illustrates, that indeed there is a close connection between conventional short range correlations and rising factorial moments and that at least not all of intermittency is due to the new physics.

Table

	$\sqrt{s}$	b_2	b_3	b_4	b_5
EHS/NA22	22	0.005 ± 0.001	0.038 ± 0.003	0.14 ± 0.01	0.27 ± 0.02
DPM	22	0.0009 ± 0.0015	0.017 ± 0.0029	0.078 ± 0.024	0.071 ± 0.058
UAI	630	0.011 ± 0.001	0.025 ± 0.003	0.050 ± 0.005	0.077 ± 0.011
DPM	200	0.0005 ± 0.0017	0.017 ± 0.0029	0.035 ± 0.008	0.056 ± 0.025
DPM	1800	0.0008 ± 0.0017	0.010 ± 0.0025	0.042 ± 0.007	0.155 ± 0.0228