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INDICATION OF AN ONSET OF HARD-LIKE EFFECTS
IN K^+p , π^+p AND pp COLLISIONS AT 250 GeV/c

EHS/NA22 Collaboration

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Abstract:

Similarly as in lepton-hadron scattering, but less pronounced than in e^+e^- annihilation at comparable energies, we observe a rise of the "sea-gull" wings with cms energy. The large average transverse momenta around Feynman $|x_F| = 0.4$ are mainly due to high multiplicity events, for which also a tail develops in the multiplicity distribution. Neither of these effects can be reproduced by currently used low- p_T fragmentation models.

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A distribution particularly sensitive to the onset of hard effects in lepton-hadron and e^+e^- collisions has turned out to be the energy dependence of the average transverse momentum of particles produced around Feynman $|x_F| = 0.4$.

The dependence of the average transverse momentum on Feynman x_F has first been observed in hadron-hadron collisions at lower energies [1]. It has a characteristic shape resembling a “sea-gull” with its head lowered at $x_F = 0$ and its wings raised around $|x_F| \approx 0.4$. This “sea-gull effect” is also visible in e^+e^- [2] and lh [3-5] collisions and qualitative similarities between all three types of collision (hh , lh and e^+e^-) at comparable energies have been observed [5,6].

In e^+e^- annihilation, a dramatic rise with cms energy [2] has set in for one of the wings, as a consequence of the onset of emission of a hard gluon by one of the two leading quarks. This rise is satisfactorily reproduced by a QCD model of independent quark fragmentation [7] and by a string model [8] when hard processes are included. For e^+e^- annihilation, these processes become significant at an energy of about 10 GeV and lead to a rise of $\langle p_T^2 \rangle$ by a factor of two from 14 to 22 GeV.

Neutrino experiments [3] have shown that already at hadronic masses $W < 10$ GeV, the sea-gull is lifting its “current fragmentation wing” with increasing W . The EMC collaboration [4,5] has increased the W range up to 20 GeV and shown that in terms of LUND fragmentation [9], this effect can be reproduced only if gluon radiation is included.

In this paper, we show that a rise of the sea-gull wings is also observed in hadron-hadron collisions at comparable energy. As in lepton-hadron collisions, the rise may have set in at lower energies [10-11], but is now clearly visible at $p_{\text{LAB}} = 250$ GeV/c ($\sqrt{s} \approx 22$ GeV).

We demonstrate the rise of the sea-gull wings in reaction

$$K^+p \rightarrow C^- + X,$$

for which a systematic analysis for lower energies is available [10], but also compare to the reactions

$$\pi^+p \rightarrow C^- + X$$

$$pp \rightarrow C^- + X$$

at the same energy. The symbol C^- represents a negative particle, by far the largest contribution coming from π^- 's. At our energy, the effect can also be studied for π^0 [12] and for positive particles, but the acceptance is limited in the first case and the contamination from non-identified particles is large in the second.

The experiment (NA22) has been performed at CERN in the European Hybrid Spectrometer (EHS), equipped with the Rapid Cycling Bubble Chamber (RCBC) and exposed to a 250 GeV/c tagged positive meson enriched beam. In data taking, a minimum bias interaction trigger has been used. The experimental set-up and the trigger conditions are described in ref.[13] and references given therein.

The detector consists of an active vertex detector (RCBC) embedded in a 2T magnetic field and a downstream spectrometer. The spectrometer is built of a wire chamber, six drift chambers and an additional 1T magnet. Charged particle momenta are measured over the full solid angle with a resolution $\Delta p/p$ varying from a maximum of 2.5% at 30 GeV/c to around 1.5% above 100 GeV/c.

Events are accepted when measured and reconstructed charge multiplicity n are consistent, charge balance is satisfied within momentum errors, no electron is detected and the number of tracks with poor or bad quality is restricted to 0,1,1,2 and 3 for charge multiplicity 2,4,6,8 and >8 , respectively. After the cuts, our present sample consists of 32700 π^+p , 38100 K^+p and 6200 pp collisions. Badly reconstructed tracks are rejected. Corrections are applied for track losses.

An inelastic sample is defined by a kinematic fit and, in addition, by a simultaneous cut on missing transverse (≤ 100 MeV/c) and on missing longitudinal momentum (≤ 9 GeV/c). The remaining events are given weights according to the corrected inelastic multiplicity distribution [13].

For the comparison to e^+e^- and lh collisions and to the low- p_T models, a “non-(single)-diffractive” sample is defined by excluding low multiplicity events ($n \leq 6$) with at least one positive particle(s) having $|x_F| > 0.88$.

In Fig.1a, we present the “sea-gull” plot in terms of the cms energy weighted average transverse momentum

$$\langle p_T \rangle_E = \frac{\sum E_i p_{Ti}}{\sum E_i}$$

for negative particles in the full samples (i.e. including diffraction) of K^+p , π^+p and pp collisions at 250 GeV/c. The dip at $x_F = 0$ is clearly seen and there is not much difference between the three types of hh collisions at our energy.

In Fig.1b, the distribution for $K^+p \rightarrow C^- + X$ at our energy is compared to that in the same reaction at lower energies [10]. The increase with energy in $\langle p_T \rangle_E$ is small in the central region. However, at $|x_F| \approx 0.4$ both in the forward and backward hemispheres, $\langle p_T \rangle_E$ increases significantly, from 0.4 GeV/c at $p_{LAB} = 12.7$ GeV/c ($\sqrt{s} = 5$ GeV) to > 0.5 GeV/c at 250 GeV/c (22 GeV).

In Fig.2a, our combined non-single-diffractive K^+p and π^+p data are shown in terms of $\langle p_T^2 \rangle_{thrust}$, the average of the square of the particle p_T with respect to the thrust axis, and compared to e^+e^- results at $\sqrt{s} = 22$ and 14 GeV and to μp results at $10 < W < 20$ GeV. In all cases, multiplicities $n \geq 4$ are used to be able to define the thrust axis. In our data the wings of the sea-gull distribution are significantly lower than the (folded) wings from e^+e^- at the same energy, but higher than those from μp collisions with $10 < W < 20$ GeV. The K^+ fragmentation wing at 22 GeV is consistent with the folded e^+e^- wings at 14 GeV.

From Fig.1b and 2a we, therefore, conclude that a rise of the sea-gull wing with cms energy is also observed for K^+p collisions, but the rise is less dramatic than in e^+e^- annihilation. As for μp collisions [5], part of this difference can be explained by heavy quark fragmentation contributing in e^+e^- , but not in hh collisions. Furthermore, the hadronic energy ($\sqrt{s}$ or W) has to be shared by more quarks in lh and hh collisions than in e^+e^- collisions.

In Fig.2b, the combined non-diffractive K^+p and π^+p data are compared to the predictions from the single-chain (LUND) [14], two-chain (FRITIOF) [15] and Dual Parton (DPM) [16] models. In all three, the same “standard values” for the string fragmentation parameters [17] are used. In particular, primordial transverse momentum $k_T = 0$ is assumed. In the sea-gull plots of Fig.2b and Fig.4 (see below), the same “non-(single)-diffractive” cut is applied to the models as to the data. In the standard version, *neither model fits our data*.

A number of adjustments are possible without changing the basic assumptions of the models. Among these are:

- (i) adjustment of the p_T distribution in fragmentation ($\sigma_q = 0.40$ GeV in the standard version),
- (ii) primordial k_T of valence quarks,
- (iii) transverse momentum exchange in the primary collision,
- (iv) inclusion of tensor meson production,
- (v) correction of the multiplicity distribution,
- (vi) emission of gluons.

The choice in option (i) is restricted by the value of $\langle p_T \rangle_E$ at $x_F \approx 0$. Increase of k_T (ii) or/and transverse momentum exchange (iii) raise the large $|x_F|$ tips of the sea-gull distribution above the data, before a satisfactory improvement is reached in the intermediate $|x_F|$ region. This is in agreement with a recent observation of the EHS-RCBC (NA23) Collaboration [18], where a $k_T = 0.4$ GeV/c needed to reproduce the overall p_T distribution can be seen to overestimate the sea-gull already in the intermediate $|x_F|$ region ($0.1 < |x_F| < 0.4$).

Inclusion of tensor mesons (iv) increases $\langle p_T \rangle_E$ in the intermediate $|x_F|$ region, but not sufficiently in the wings. Even a combination of options (iii) and (iv) with an unreasonably large fraction of tensor mesons cannot reproduce the shape of the distribution at our energy, let alone its energy dependence.

Since we observe a significant dependence of the average transverse momentum on multiplicity [19], a potentially promising possibility is the adjustment of the multiplicity distribution (option v) to that observed in the data. In Fig.3 we compare our experimental multiplicity distribution for π^+p , K^+p , and pp interactions with those from the models. At low multiplicities, LUND and DPM are low, simply because these models do not contain diffraction. (As stated above, this effect is excluded in the comparison of the sea-gull plots). Significant differences between the data and the models, however, show up at *large* multiplicities, where the

data develop a tail (see ref.[13] for more detail on the widening with energy) not at all reproduced by LUND and underestimated by DPM and FRITIOF in their present form.

The multiplicity dependence of the sea-gull distribution in our combined non-single-diffractive π^+p and K^+p data is shown in Fig.4, together with the predictions from the three models in their standard versions. Again, the most significant differences appear in the sea-gull distribution for high multiplicities, where the rise of the wing with $|x_F|$ is most strongly underestimated. Therefore, even forcing the models to agree in the multiplicity distribution will not lead to a correct prediction of the sea-gull.

Gluon emission (option vi, above) is most naturally included in the FRITIOF model and could be combined with a non-zero k_T to increase $\langle p_T \rangle$ in the large x_F tips. It would be expected to lead to higher multiplicities and to larger transverse momenta for intermediate and large $|x_F|$. As it stands, however, it neither reproduces the large n tail of the multiplicity distribution nor the steep rise with $|x_F|$ of the sea-gull wings.

To summarise, similarly as in lepton-hadron scattering, but less dramatic than in e^+e^- annihilation at comparable energies, we observe a rise of the “sea-gull” wings with cms energy. The large average transverse momenta around Feynman $|x_F| \approx 0.4$ are mainly due to high multiplicity events, for which also a tail develops in the multiplicity distribution. Neither of these effects can be reproduced by currently used fragmentation models, but is exactly what would be expected if an onset of hard-like effects takes place in hadronic collisions already below $\sqrt{s} = 22$ GeV.

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Figure Captions

- Fig.1 The energy weighted average transverse momentum $\langle p_T \rangle_E$ as a function of Feynman x_F for
- a) π^+p , K^+p and $pp \rightarrow C^- + X$ data at 250 GeV/c and
 - b) $K^+p \rightarrow C^- + X$ between 12.7 and 250 GeV/c incident momentum.
- Fig.2 a) The average squared transverse momentum $\langle p_T^2 \rangle_{thrust}$ with respect to the thrust axis for the combined non-single-diffractive K^+p and π^+p sample (indicated as M^+p) with multiplicity $n \geq 4$ at $\sqrt{s} = 22$ GeV, compared to that for e^+e^- collisions at 14 and 22 GeV, and μp collisions with $10 < W < 20$ GeV.
- b) The energy weighted average transverse momentum $\langle p_T \rangle_E$ for the combined non-single-diffractive M^+p sample compared to the predictions from "non-diffractive" LUND, DPM and FRITIOF Monte Carlos. The statistical uncertainty in the Monte Carlo curves is 10, < 5 and 5-10 MeV/c for $x_F = -0.5, \pm 0.2$ and $+0.5$, respectively.
- Fig.3 The charge multiplicity distribution for π^+p , K^+p and pp at 250 GeV/c compared to the predictions from LUND, FRITIOF and DPM. Predictions from LUND and DPM are multiplied by $\sigma_{NSD}/\sigma_{inel}$.
- Fig.4 The energy weighted average transverse momentum $\langle p_T \rangle_E$ as a function of Feynman x_F for the combined non-single-diffractive π^+p and K^+p sample, in final states of charge multiplicity n as indicated. The statistical uncertainty in the Monte Carlo curves is around 15, 5 and 10 MeV/c for $x_F = -0.5, \pm 0.2$ and $+0.5$, respectively.

Fig. 1

Fig. 2

Fig. 3

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