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Limiting Distributions for Inclusive Charged Pion Production at Very High Energy

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Abstract

A conjecture is given, of how limiting distributions are approached in the target fragmentation region and in the central region, for inclusive charged pion production.

Many particle production is the dominating process at very high energy. If a single particle is observed, a limiting function for the longitudinal momentum distribution of this particle has been predicted (Ref. 1,2).

We want to show from data available up to now, how such limiting distributions are approached with increasing primary energy. We will consider only the regions of target (proton) fragmentation (this means slow particles in the lab-system), and the pionization region (90^{o} in the CMS).

We present the data available on inclusive pion production (Ref.3) in the form of invariant cross sections integrated over the transverse momentum $p_{\perp}$

$$(1) \qquad \int_{p_{\perp}} E \frac{d^3\sigma}{d\vec{p}^3} dp_{\perp}^2 \equiv F(y,s)$$

y is the rapidity given by $y = \frac{1}{2} \ln \frac{E + p_{\parallel}}{E - p_{\parallel}}$, where $p_{\parallel}$ is the longitudinal momentum of the pion. As representative for the target fragmentation region, we take F(y,s) at $y_{Lab} = 0$, and for the pionization region $F(y^*,s)$ at $y^* = 0$, this means at longitudinal momentum in the center of mass system equal to zero.

To compare data for different incident particles we take $\frac{1}{\sigma_{tot}} \cdot F(y,s)$, where σ_{tot} is the total cross section at infinite energy. We take the following values for σ_{tot}: $\sigma_{pp} = 38$ mb, $\sigma_{\pi^\pm p} = 24$ mb and $\sigma_{\gamma p} = 0.1$ mb.

From application of regge pole theory to inclusive reactions the prediction (Ref.4 and 5) for the energy dependence of $\frac{1}{\sigma_{tot}}$ F(y,s) is in the target fragmentation region of the form

(2) $$F(y,s) = a + b/\sqrt{s}$$

and for the central region

(3) $$F(y,s) = c + d/(\sqrt{s})^{1/2}$$

We find that the data seem not to follow these predictions. The following functions are more appropriate:

(4) $$F(y,s) = a \cdot e^{-b/\sqrt{s}}$$

in the target fragmentation region and

(5) $$F(y,s) = c + d/\sqrt{s}$$

in the central region (see also Ref.6)
This is shown in Fig.1a and Fig.1b. Furthermore it is observed, that in the target fragmentation region (Fig.1a) π^- production is always lower than π^+ production. The energy dependence (4) extrapolates to different infinite energy limits for π^+ and π^- production by approximately a factor of 2, but independent of the incident particle.

In the central region the behaviour is quite different (Fig. 1b). The energy dependence (5) extrapolates to a common limit for both π^+ and π^- production again independent of the incident particle. But some cross sections are rising to the infinite energy limit ($pp \to \pi^{\pm}$, $\pi^+ p \to \pi^-$, $\gamma p \to \pi^-$) and some are slightly falling ($\pi^{\pm} p \to \pi^{\pm}$, $\gamma p \to \pi^+$). In the regge pole language a rising cross section is difficult to interpret, at least a new trajectory is required (Ref.4).

In the following we want to make a few comments, concerning Fig.1a and Fig.1b.

1.) Part of the data (Ref.3) have been taken from figures in publications, as numbers in tables are not available. This introduces some uncertainties in the data plotted here, which are difficult to estimate. Also the data originate from quite different experiments. Consequently the normalization errors from experiment to experiment are more important then statistical errors. Therefore no error bars are shown in Fig.1a and Fig.1b.

2.) At $y_{Lab} = 0$, all data shown come from track chamber experiments. They have a well known systematic error. Pions with only transverse momentum have partly very short tracks or run approximately along the optical axis and are in both cases unmeasurable. This error is of order 10 % and could in principle be corrected for.

3.) The values for $\sigma_{tot}(s \to \infty)$ taken here, are somewhat arbitrary, but close to commonly accepted values. A change of ±5 % would not spoil our general conclusions, concerning the limiting distributions.

4.) It would be very interesting to prove the conjecture on the approach to scaling in the target fragmentation region at ISR energies (see Fig. 1a). Here data will be soon available.

5.) The absolute value $\frac{1}{\sigma_{tot}} F(y,s)$ has implications on the rise of the mean pion multiplicity $\langle n \rangle_\pi$ with energy.† If F(y,s) in the central region is different from zero, then the mean multiplicity is given by (Ref.7 and 8)

$$(6) \qquad \langle n \rangle_\pi = \left(\frac{\pi}{\sigma_{tot}} F(y,s)_{y^* = 0}\right) \ln s + d$$

From Fig. 1b an energy dependence of the height of the central plateau is seen which has to be taken into account in fitting experimental data to (6), especially in case of incident protons where the rise to the limiting distribution is quite sizable. For incident pions this extra energy dependence (besides ln s) in (6), seems to cancel approximately when the average charged pion multiplicity is taken (see Fig. 1b).

6.) The data in Fig. 1a suggested a ratio for π^+/π^- production of ∿2 in the target fragmentation region at very high energy. Assuming that no charge is transferred to the fragmenting proton, then the multiplicity for proton fragmentation must be small and the number of decay protons and neutrons must be roughly equal.

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† It would be better not to take σ_{tot}, but σ_{incl}, the total inelastic cross section. But σ_{inel} is less well known. At infinite energy σ_{inel} can expected to be a constant fraction of σ_{tot} independent of the incident particle.

<u>Conclusion:</u> From existing data on inclusive charged pion production we conjecture interesting regularities for the pionization and the proton fragmentation region, concerning the approach to the very high energy limit of the invariant cross section. Systematic experiments, to confirm the energy dependence found here and the extrapolation to infinite energy are required.

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Figure Captions

Fig. 1 The energy dependence of the invariant cross section for inclusive $\pi^{\pm}$ production and various incident particles. a.) At $y_{Lab} = 0$, $\frac{\pi}{\sigma_{tot}} F(y,s)$ b.) at $y^* = 0$, $\frac{1}{\sigma_{tot}} F(y^*,s)$ is shown. The sources for the data points are listed under Ref.3) for $pp \to \pi^-$ from 1, 2, 3, 4, for $pp \to \pi^+$ from 3, 4, for $\pi^+ p \to \pi^-$ from 5, 6, 7, 8, 9, for $\pi^+ p \to \pi^+$ from 5, 6, 7, 8, 9, for $\pi^- p \to \pi^-$ from 5, 7, 9, for $\gamma p \to \pi^-$ from 10, 11 and for $\gamma p \to \pi^+$ from 11.

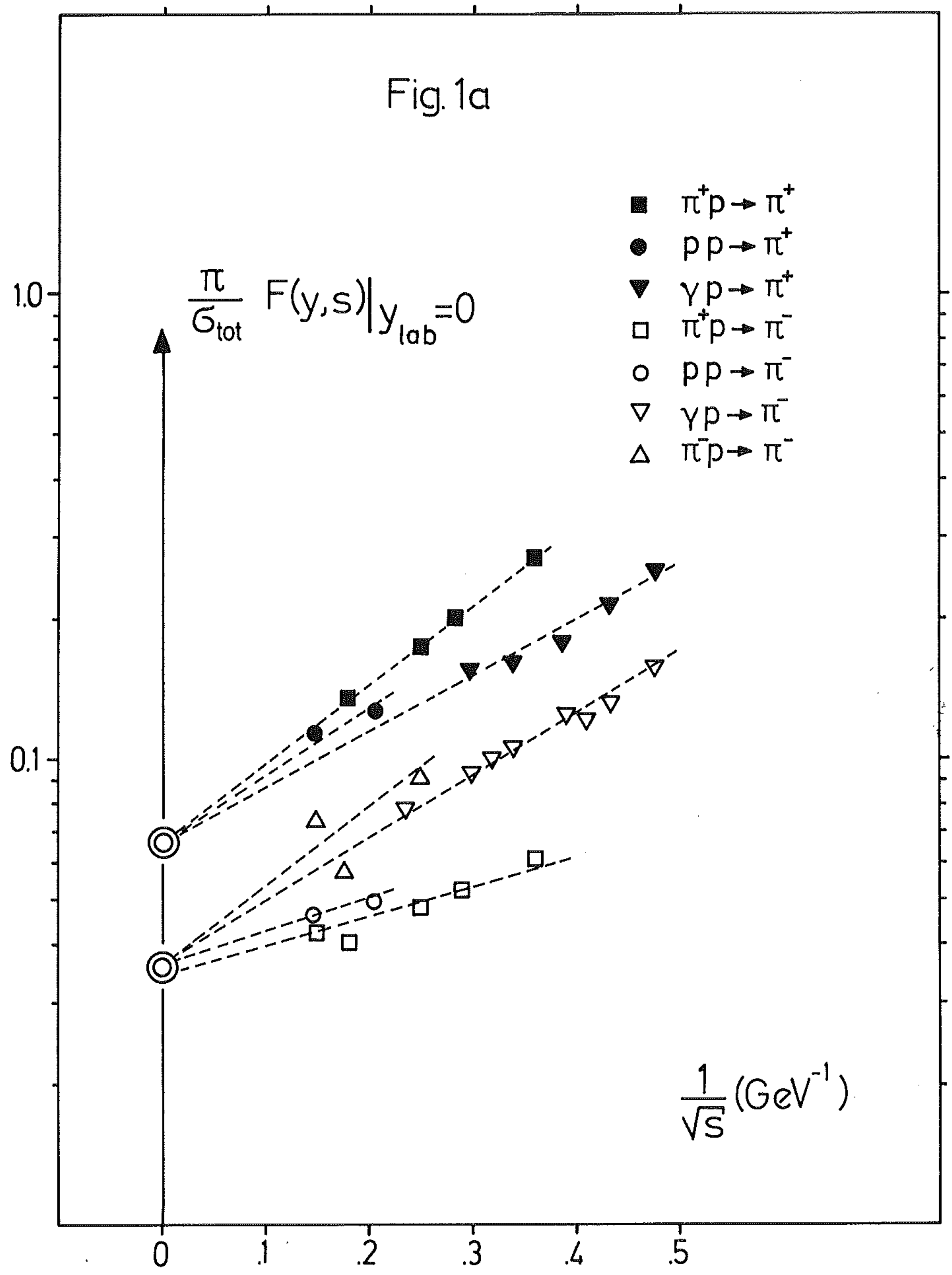
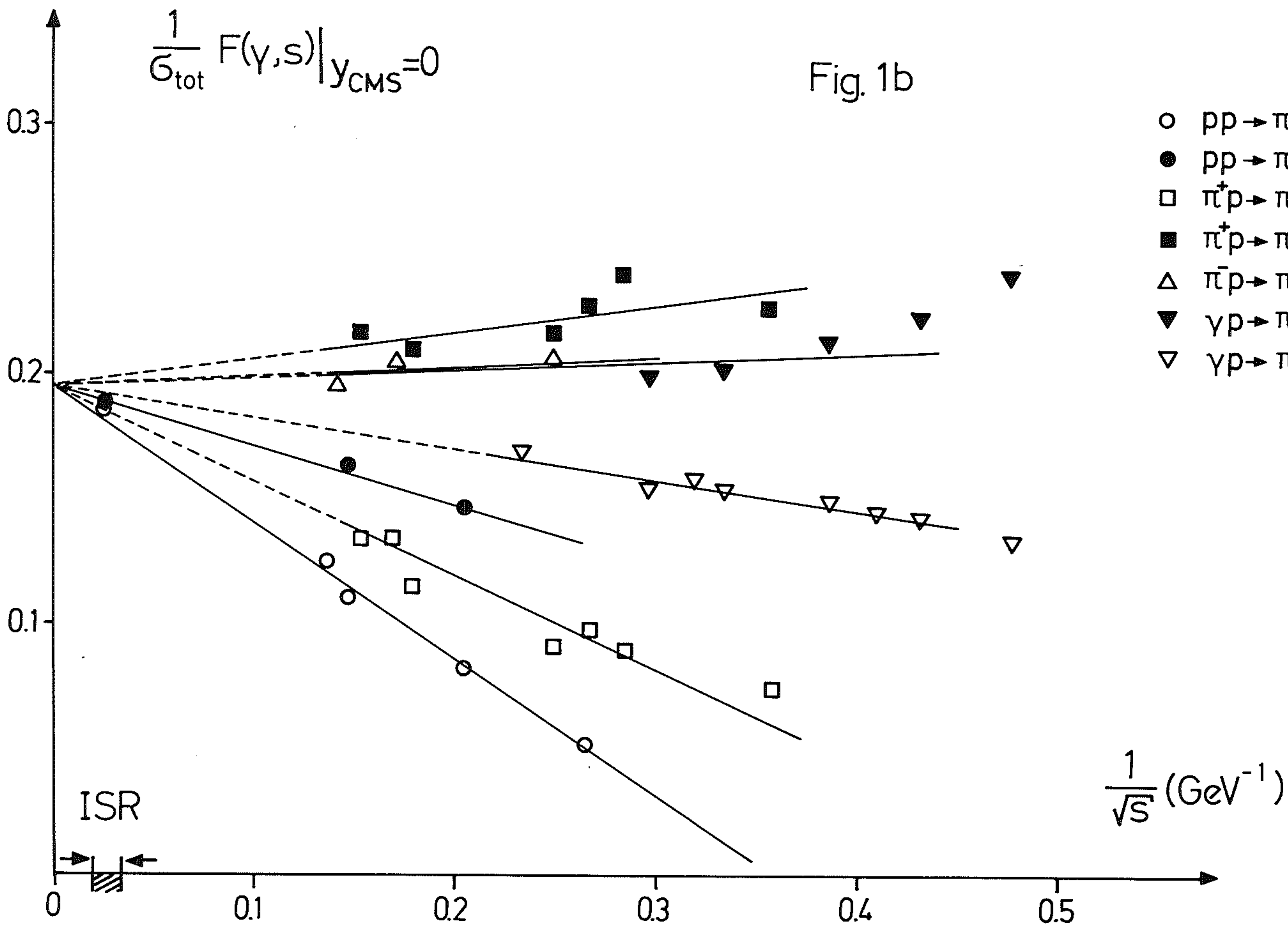


Fig. 1a
$\frac{\pi}{\sigma_{tot}} F(y,s)|_{y_{lab}=0}$
$\pi^+ p \to \pi^+$
$p p \to \pi^+$
$\gamma p \to \pi^+$
$\pi^+ p \to \pi^-$
$p p \to \pi^-$
$\gamma p \to \pi^-$
$\pi^- p \to \pi^-$
1.0
0.1
$\frac{1}{\sqrt{s}}$ (GeV^{-1})
0
.1
.2
.3
.4
.5



$\frac{1}{\sigma_{tot}} F(y,s)|_{y_{CMS}=0}$
Fig. 1b
pp → π⁻
pp → π⁺
π⁺p → π⁻
π⁺p → π⁺
π⁻p → π⁻
γp → π⁺
γp → π⁻
0.3
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
$\frac{1}{\sqrt{s}}$ (GeV⁻¹)
ISR