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Inclusive Hadron Production in e^+e^- Annihilation at $< s > = 53$ GeV^2 *

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ABSTRACT

We report on inclusive hadron production in e^+e^- annihilation at $< s > = 53$ GeV^2, using a small solid-angle magnetic spectrometer with good particle identification at 90^o to the beams at SPEAR II.

The cross sections of $\pi^\pm$ and $K^\pm$ when compared with data at $s = 23$ GeV^2 exhibit scaling in $(s/\beta)d\sigma/dx$ with $x = 2E/s^{1/2}$. The invariant cross section depends on the momentum as p^{-4}.

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We measured the inclusive hadronic cross section with a small solid-angle spectrometer at the highest SPEAR II energies between $s = 49$ and $58\ GeV^2$. This was an extension of a previous experiment at SPEAR I.[1]

The single-arm magnetic spectrometer used in this experiment was similar to that used in our earlier experiment.[1,2] It was situated at $(90 \pm 13)^o$ with respect to the beams. The minimum momentum required for traversal of the spectrometer was 0.3 GeV/c, and the geometrical acceptance for high-momentum particles was 0.084 sr. Trajectories were measured with proportional wire chambers (PWC) before and within the magnet giving a momentum resolution of $\Delta p/p = 0.011\, p\, (GeV/c)^{-1}$. The entrance of the magnet was covered by a threshold Čerenkov (Č) counter filled with propane at 90 psig with thresholds of 0.8, 1.05 and 3.7 GeV/c for μ, π and K, respectively. Time-of-flight (TOF) was measured along a 4.7-m-long path with a standard deviation of 0.36 ns using a small start scintillation counter near the interaction region and an array of stop counters at the magnet exit. Following the TOF counters were a Pb-scintillation shower counter and a slotted iron hadron filter (799 gm/cm^2) containing 3 planes of scintillation counters. A set of PWC's, shower counter and hadron filter on the opposite side helped identify e^+e^- and $\mu^+\mu^-$ pairs. The central detector,[3] consisting of 4 cylindrical layers of proportional tube counters, covered a solid angle of $0.9 \times 4\pi$. An inclusive one-particle trigger required a coincidence between the TOF start and stop counters, hits in a combination of spectrometer PWC's, and the beam crossing signal.

In the analysis, beam-gas background was determined from the origin distribution and subtracted. Cosmic rays were removed by cuts on the event's origin and their TOF. The information from the Č-counter, TOF, shower detector and hadron filter was then used to identify the particle.[4] Muon events with p > 0.8 GeV/c were identified with the Č-counter together with penetration of the hadron filter. There were 118 collinear μμ events, from which we determined[5] the integrated luminosity: $\int \mathscr{L}\, dt = 8.74 \pm 0.78\ pb^{-1}$. A sample of anomalous muon events in excess of QED has been discussed elsewhere.[6] The contribution to the hadronic spectra below 0.8 GeV/c from misidentified μ's is less than 5% from leptonic decays of the heavy lepton τ,[7] less than 3% from semi-leptonic decays of charmed mesons based on inclusive electron data,[8] and less than 4% from the 2-photon process ee → eeμμ.[9] Electrons were recognized by the large pulse height in the Č-counter and the shower counter.

Protons and antiprotons were identified by TOF. Only antiprotons were used and their number doubled. Pions and kaons with p < 1.2 GeV were identified by TOF. 15% of all hadron events with momentum below C threshold were found to have a Č-counter pulse above pedestal. This contamination was corrected for in the π,K sample with momenta above 1.2 GeV where the Č-counter was used for π,K separation. The final sample of 950 hadrons contained 863 π's, 74 K's and 13 $\bar{p}$'s. Using a Monte Carlo simulation the data were corrected for geometrical acceptance, nuclear interaction, hadronic punch-through and π,K decay in flight.

The inclusive momentum spectra $4\pi(d^3\sigma/d\Omega dp)$ at $<s> = 53\ GeV^2$, $\theta = 90^o$ for $\pi^\pm$, $K^\pm$, $2 \cdot \bar{p}$ are shown in Figure 1. The error bars include the statistical errors and the uncertainty of the applied corrections. Not included is an additional 10% overall normalization error. We calculate the following particle fractions: for 400 MeV/c < p < 100 MeV/c, $f_\pi = 0.87 \pm 0.01$, $f_K = 0.12 \pm 0.02$, $f_p = 0.014 \pm 0.005$; for p ≥ 1000 MeV/c, $f_\pi = 0.76 \pm 0.02$, $f_K = 0.16 \pm 0.03$, $f_p = 0.07 \pm 0.02$.

In order to test predictions of scaling models, we compare the present data with our results at $s = 25\ GeV^2$. The latter represent a reanalysis of previously published data,[1] extending them to lower momenta (p_{min} = 400 and 700 MeV/c for $\pi^\pm$ and $K^\pm$ respectively) with improved reconstruction and identification methods.[2] One form of scaling predicts[10] that the invariant cross section $E(d^3\sigma/dp^3)$ should behave as $f(x) \cdot p^{-4}$ with $x = 2E/s^{1/2}$. Figure 2 shows the invariant cross sections for $\pi^\pm$ for s = 53 and 23 GeV^2 as a function of momentum. The data for both CM energies are well described by p^{-4} (see Table I), i.e., the structure function f(x) is only a weak function of x. The p^{-4} behavior should be compared with the $p_\perp^{-8}$ form of the pp → hadrons inclusive cross sections.[11]

In analogy to deep inelastic ep-scattering, scaling has been predicted[10] in the form of $(s/\beta)(d\sigma/dx) = F(x)$. Figures 3a and 3b show these cross sections for $\pi^\pm$ and $K^\pm$, respectively, at s = 25 and 53 GeV^2. The π and K cross sections separately exhibit scaling; furthermore, the scaling functions F(x) have similar x dependence for π and K and show the x^{-3} behavior corresponding to scaling in p^{-4} mentioned above (see Table I).

Data on inclusive hadron production in e^+e^- annihilation[12,13,14] are published in the form of the scaling cross section in x. We find that at s ∿ 25 GeV^2 our $\pi^\pm$ data are about 30% higher than the data of DASP[12], while the $K^\pm$ spectra agree. Adding up the different hadrons allows us to compare the data at s = 53 GeV^2 with preliminary non-particle-separated inclusive cross sections of SLAC-LBL[13] at the same s-value. We find agreement at low x_p $\left(x_p = 2p/s^{1/2}\right)$ but at higher x_p (x_p ∿ 0.7) the cross sections of Reference 13 are higher by a factor of 2. If we correct for the observed angular distribution of the jet structure,[15] our high momentum points at s = 53 GeV^2 increase by less than 25%. It is interesting to note that our $K^\pm$ data agree with the $2 \cdot K^o_s$ data of SLAC-LBL[16] at s ∿ 50 GeV^2.

In the statistical or hydrodynamical model[17] the invariant cross section of all hadrons separately is described by an universal function $\exp(-E_h/kT)$, where E_h is the hadron energy and $kT \approx 160$ MeV. For $s = 23$ GeV^2, the data are well described by the function $\exp(-E_h/206)$ (Figure 4b), while at $s = 53$ GeV^2 neither an exponential with the slope parameter 1/206 MeV nor any other slope fits the data (Figure 4a).

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Table I: Results of cross section fits

		s(GeV²)	53	23	53 + 23	
$E \frac{d^3\sigma}{dp^3} = \frac{A}{p^n}$	π	A	0.65 ± 0.04	0.82 ± 0.06	0.70 ± 0.03	Fig. 2
		n	4.0 ± 0.1	4.3 ± 0.2	4.1 ± 0.1	
		χ^2/DF [(a)]	16.7/12	13.4/9	37.5/23	
$4\pi \frac{s}{\beta} \frac{d^3\sigma}{d\Omega dx} = \frac{B}{x^m}$	π	B	30 ± 5	28 ± 5	33 ± 4	Fig. 3a
		m	3.1 ± 0.1	3.5 ± 0.2	3.1 ± 0.1	
		χ^2/DF [(a)]	14.9/12	12.1/9	36.8/23	
	K	B	6.8 ± 2.9	15 ± 8	10.9 ± 3.0	Fig. 3b
		m	3.8 ± 0.4	3.6 ± 0.7	3.5 ± 0.3	
		χ^2/DF	4.6/6	3.2/5	11.6/13	

(a) Fits without the highest momentum point yield the same results with considerably increased confidence level.

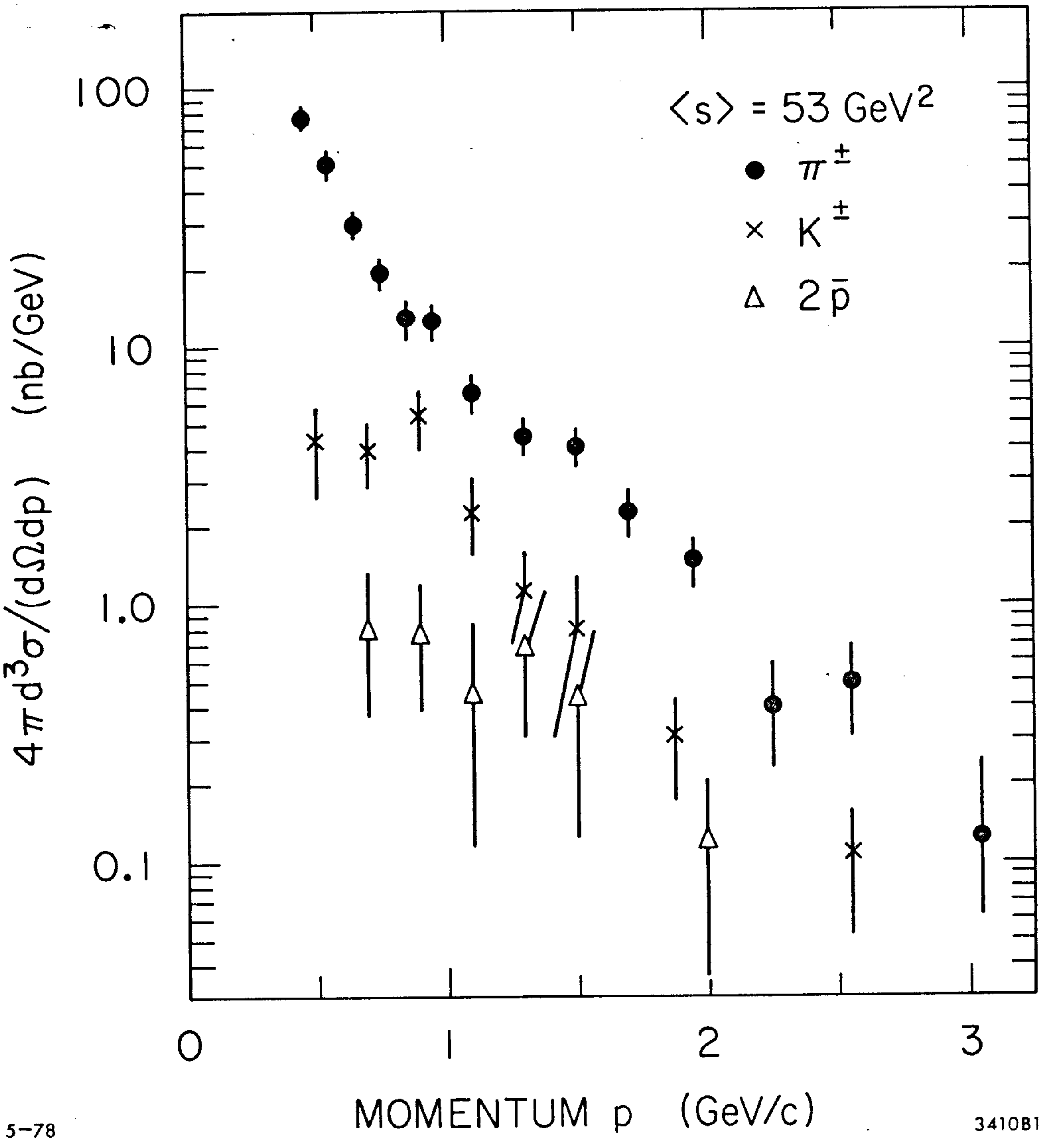
Figure Captions

Figure 1. Momentum spectrum at $\langle s \rangle = 53$ GeV^2 and $\theta = 90^o$ for $\pi^{\pm}$, $K^{\pm}$, $2 \cdot \bar{p}$.

Figure 2. Invariant cross sections for $\pi^{\pm}$ as a function of momentum p at $\langle s \rangle = 53$ and 25 GeV^2. The curve is the fit to the combined data: $Ed^3\sigma/dp^3 = 0.72 \cdot p^{-4}$.

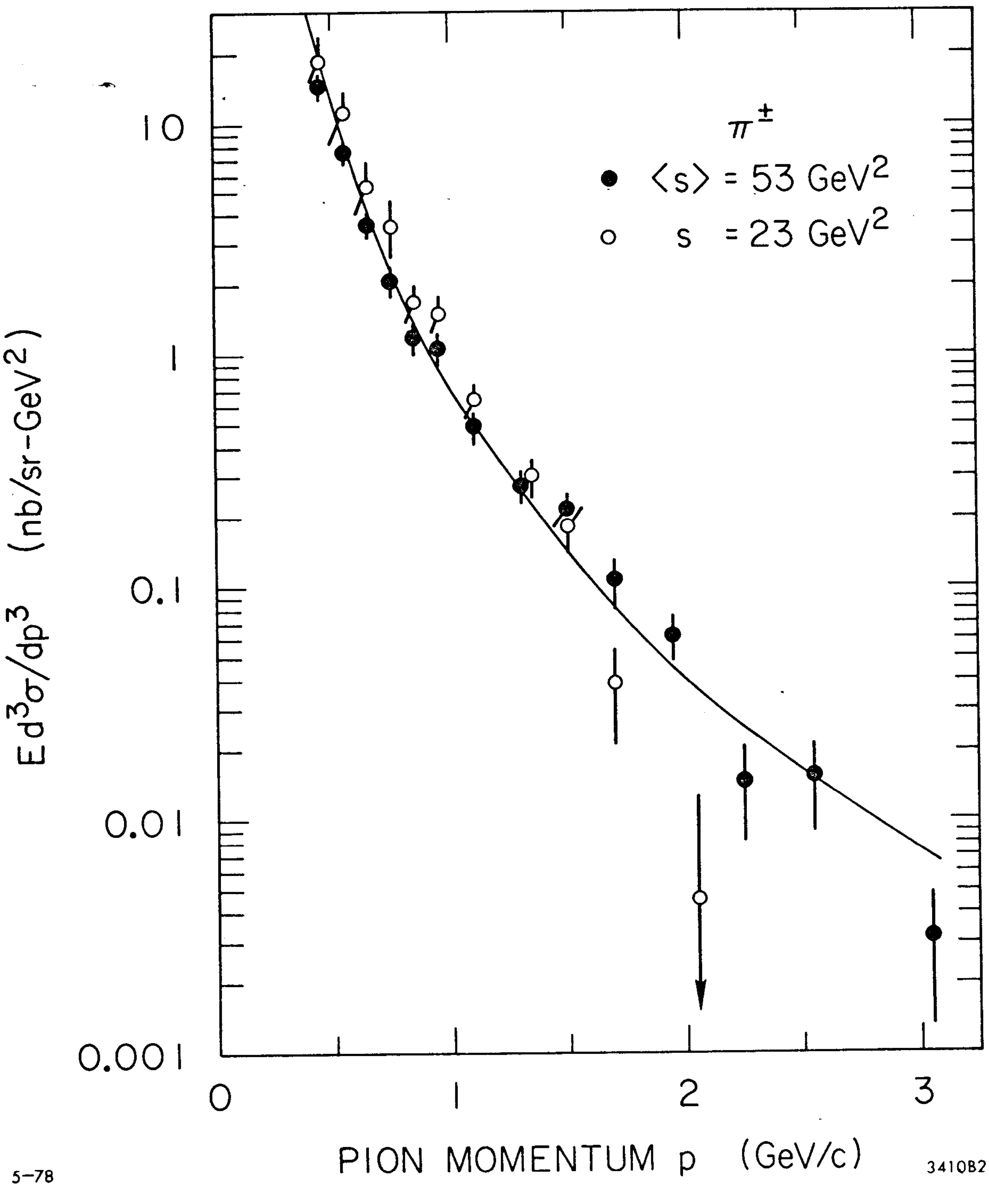
Figure 3. Scaling cross sections for (a) π and (b) K at $\langle s \rangle = 53$ and 23 GeV^2. The curves are fits to the data at both s values combined of the form B/x^m (see Table I).

Figure 4. Invariant cross section as a function of hadron energy E_h at (a) $\langle s \rangle = 53$ GeV^2 and (b) $s = 23$ GeV^2 for $\pi^{\pm}$, $K^{\pm}$ and $2 \cdot \bar{p}$. The curves are of the form $\exp(-E_h/206 \text{ MeV})$.



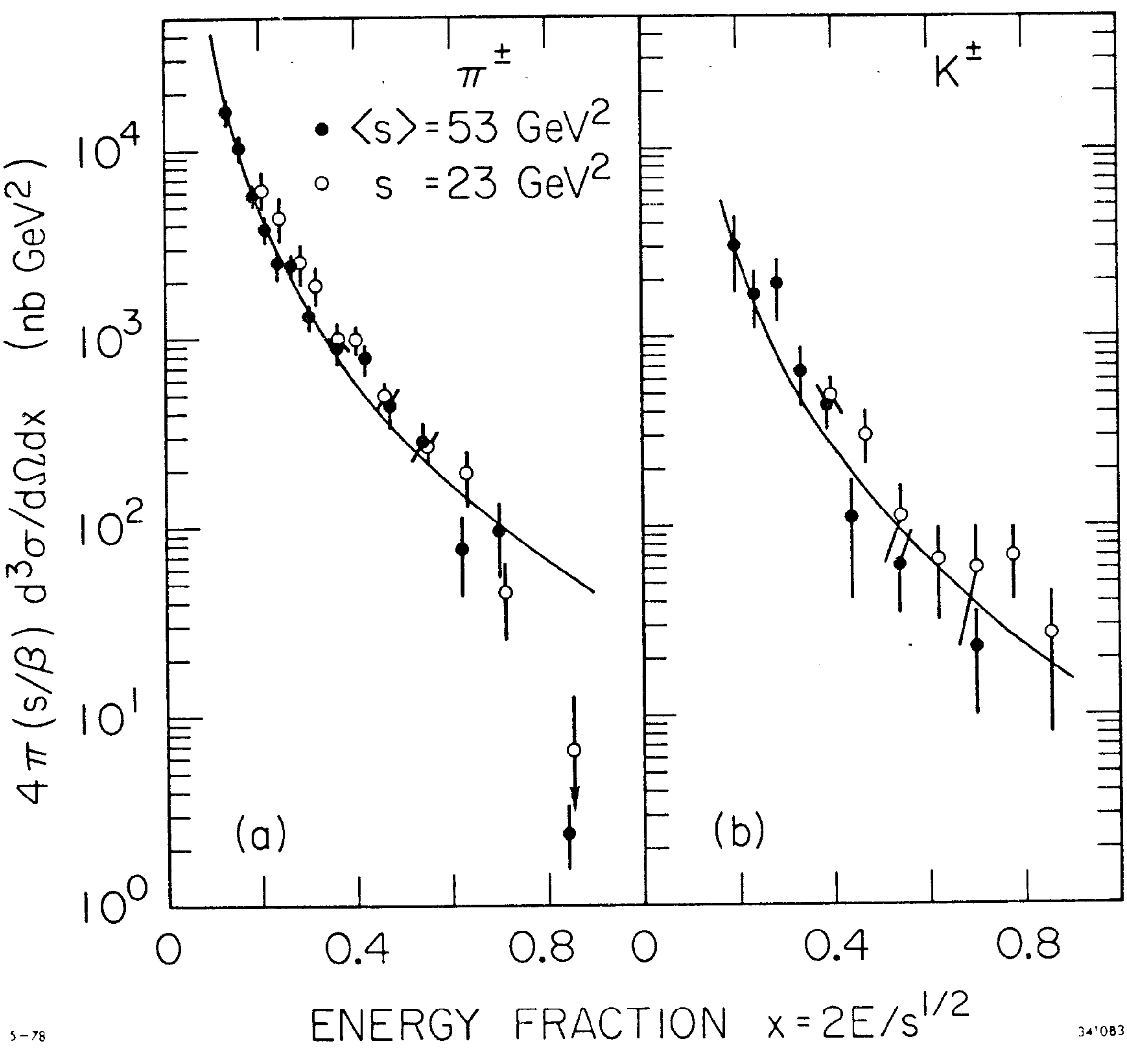
$\langle s \rangle = 53\ GeV^2$
$\pi^{\pm}$
$K^{\pm}$
$2\bar{p}$
100
10
1.0
0.1
$4\pi d^3\sigma/(d\Omega dp)$ (nb/GeV)
0
1
2
3
MOMENTUM p (GeV/c)
5-78
3410B1

Fig. 1



$\pi^{\pm}$
$\langle s \rangle = 53\ GeV^2$
$s = 23\ GeV^2$
$E\, d^3\sigma/dp^3$ (nb/sr-GeV^2)
10
1
0.1
0.01
0.001
0
1
2
3
PION MOMENTUM p (GeV/c)
5-78
3410B2

Fig. 2



$\pi^{\pm}$
$K^{\pm}$
● ⟨s⟩ = 53 GeV²
○ s = 23 GeV²
$4\pi(s/\beta)\ d^3\sigma/d\Omega dx$ (nb GeV²)
10^0
10^1
10^2
10^3
10^4
(a)
(b)
0
0.4
0.8
ENERGY FRACTION $x = 2E/s^{1/2}$
5-78
34'083

Fig. 3

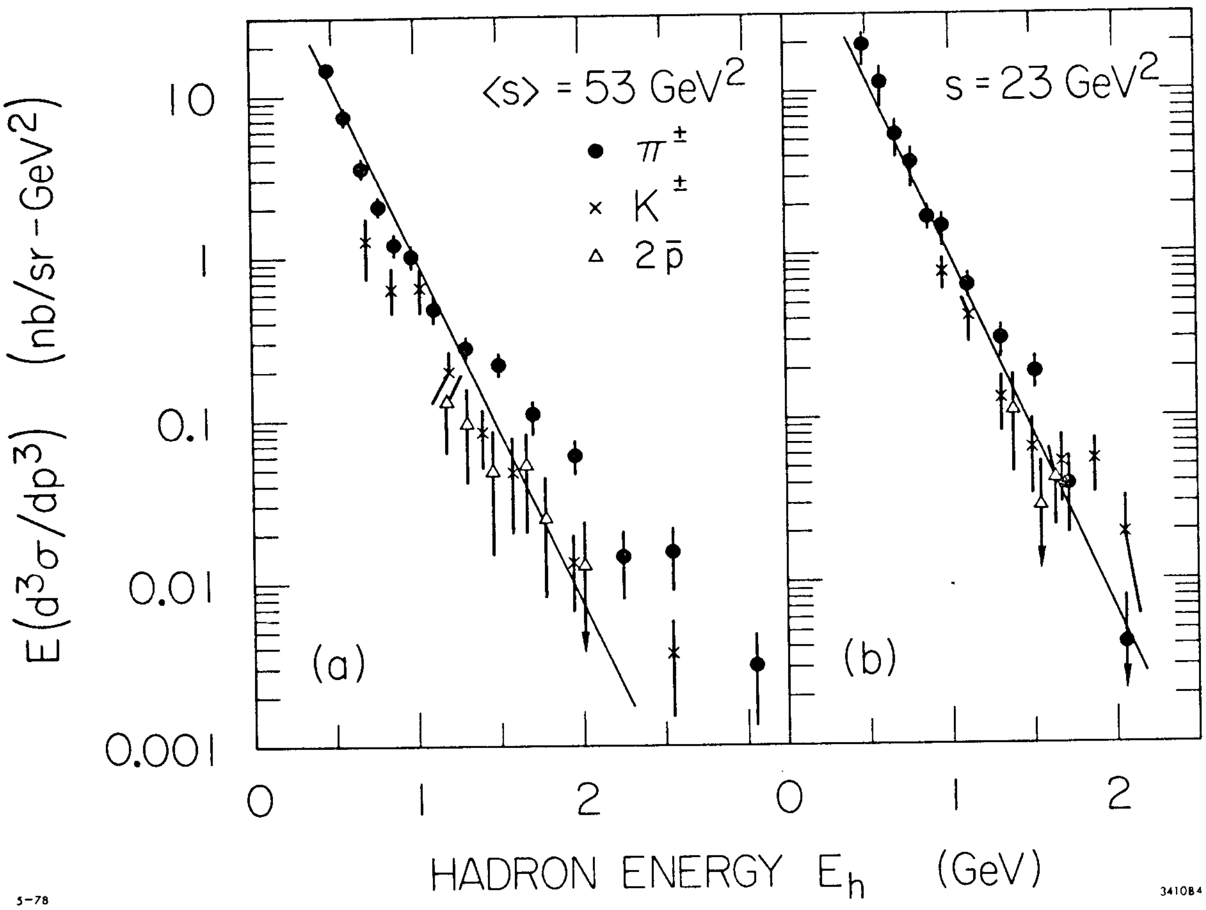

⟨s⟩ = 53 GeV^2
s = 23 GeV^2
$\pi^\pm$
$K^\pm$
$2\bar{p}$
10
1
0.1
0.01
0.001
(a)
(b)
0
1
2
0
1
2
E(d$^3\sigma$/dp^3) (nb/sr-GeV^2)
HADRON ENERGY E_h (GeV)
5-78
341084

Fig. 4