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T O P I C A L   M E E T I N G

ON THE PHYSICS OF COLLIDING BEAMS

20 - 22 June 1974

(SUMMARIES AND CONTRIBUTIONS)

MIRAMARE - TRIESTE

July 1974

LARGE TRANSVERSE MOMENTUM HADRON PRODUCTION AT THE CERN ISR

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The notes below are mostly copies of transparencies shown during my talk, with a minimum of editing. They are not intended to be anything more than a reminder for those who attended this talk.

They review some of the recent data produced by the collaborations listed in table 1, without any attempt at being complete. I wish to take this opportunity to thank all those who gave me permission to present some of their unpublished data prior presentation to the London Conference.

Two years ago CCR and SS had discovered that

i) Large $p_\perp$ π's are produced at the ISR at a rate easily detectable down to $\frac{1}{p_\perp} \sim \frac{1}{50}$ fm.

ii) Such a rate is several orders of magnitude above an exponential extrapolation of small $p_\perp$ data. (illustrated in figure 1).

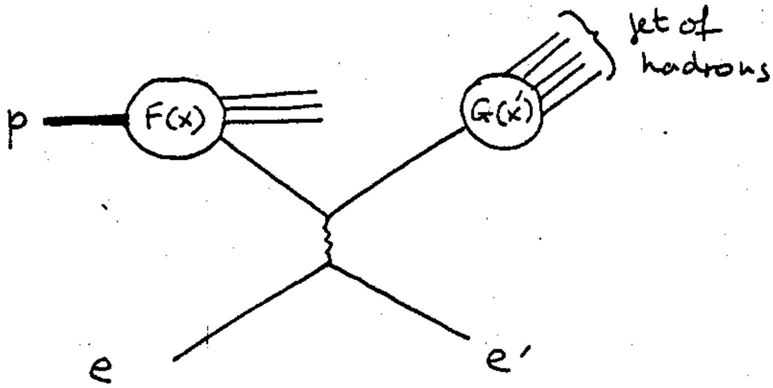
iii) The dependence over $p_\perp$ of the invariant cross section $E \frac{d^3\sigma}{dp^3}$ has a power law behaviour (illustrated in figure 2).

iv) Feynman scaling is broken at large $p_\perp$, and the more the higher s is. (see figure 3).

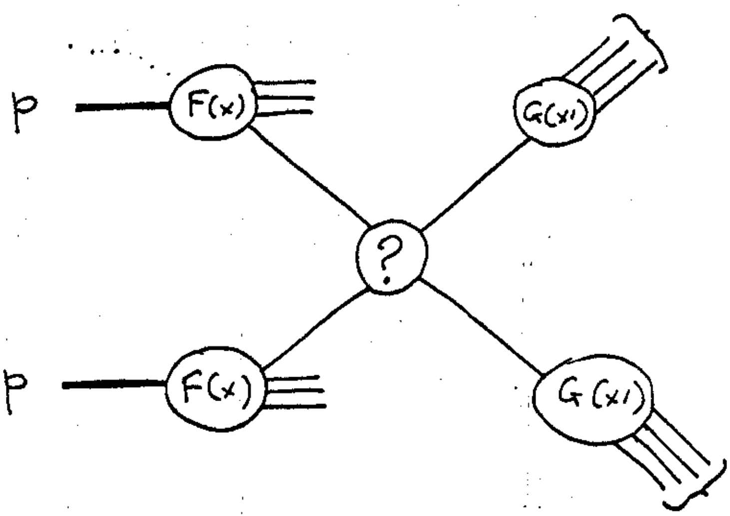
After this discovery several groups tackled the study of high $p_\perp$ production asking the question: can we learn something about strong interactions at small distances?, or, which is equivalent, do the interactions where a large $p_\perp$ is produced differ in a non trivial manner from the usual interactions?

Among the many ideas which have blossomed, parton pictures have been most efficient in making predictions, suggesting new experiments and generating enthusiasm and hope to observe new phenomena. But they shared with others (fireball production, multiple scattering, etc...) the flexibility and promptness to adapt to experimental results.

The basic idea (BBK) was to extend to p-p collisions the mechanism suggested by the SLAC data on e-p deep inelastic scattering.



Deep inelastic electron scattering



high $p_\perp$ proton-proton collision

Many modifications have been made to this picture concerning the nature of the interacting constituents, the nature of

Do data scale in $x_\perp$?

Concentrating on 90° pion production most models predict a form

$$E\frac{d^3\sigma}{dp^3} = \frac{1}{p^n} f(x_\perp) = \frac{1}{s^{n/2}} f'(x_\perp) \quad , \quad x_\perp = \frac{2p_\perp}{\sqrt{s}}$$

$$f'(x_\perp) = \left(\frac{2}{x_\perp}\right)^n f(x_\perp)$$

From dimensional analysis, $n=4$ would not imply the introduction of any new scale.

Let us first establish whether there is scaling. Only then, look at $f(x_\perp)$. To do this we should work at fixed $x_\perp$. Otherwise strong correlations exist between n and the slope of $f(x_\perp)$. Indeed

$$\frac{1}{p_\perp^n} \exp\left(-\frac{2B}{\sqrt{s}} p_\perp\right) = \exp\Big(\underbrace{-n \,\mathrm{Log}\, p_\perp - \frac{2B}{\sqrt{s}} p_\perp}_{\text{not widely different over usual domains of fit.}}\Big)$$

Figure 4 summarizes all data available on pion inclusives at 90° in the form of lines of constant cross section in the $(\mathrm{Log}\, x_\perp, \mathrm{Log}\, p_\perp)$ plane.

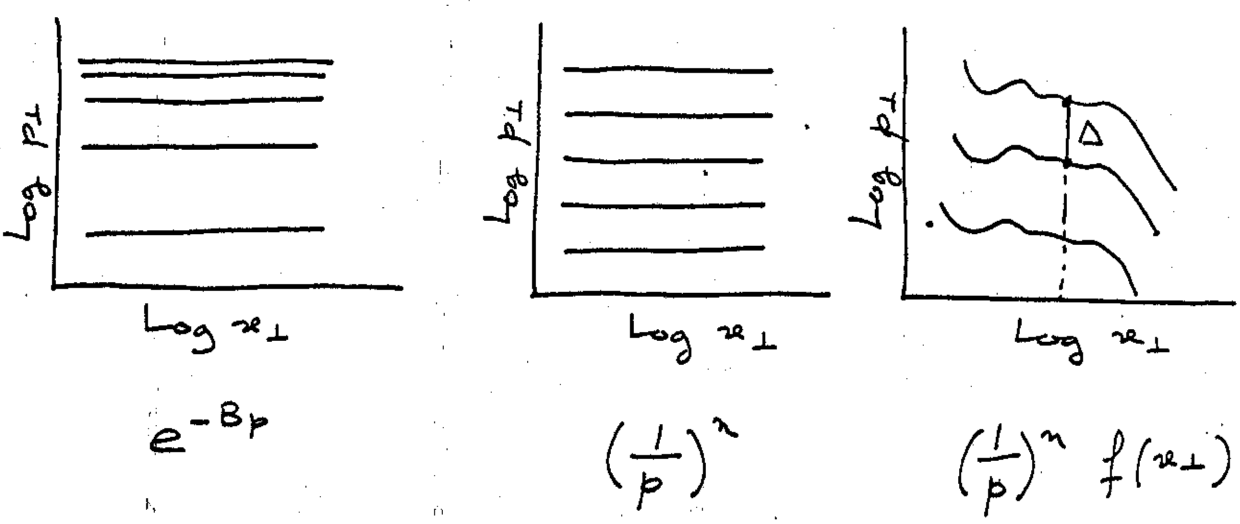
Lines of equal $\sqrt{s}$ are straight lines with slope 1 $\qquad \operatorname{Log} x_\perp = \operatorname{Log} p_\perp + \operatorname{Log} \frac{2}{\sqrt{s}}$

Feynman scaling corresponds to horizontal lines of constant cross section (equally spaced for a p^{-n} law, logarithmically spaced for a e^{-Bp} law).

For a form $E\frac{d^3\sigma}{dp^3} = \frac{1}{p^n} f(x_\perp)$ we see that at a given $x_\perp$ the distance between two successive lines of constant cross section is given by

$$\Delta = \operatorname{Log} p_1 - \operatorname{Log} p_2 = \operatorname{Log}\left(\frac{p_1}{p_2}\right) = \frac{1}{n}\operatorname{Log}\left(\frac{\sigma_2}{\sigma_1}\right) = \frac{K}{n}$$

namely lines of equal cross section are parallel to each other and their spacing is a direct measure of $\frac{1}{n}$.



The data of figure 4 call for several remarks.

- There are no important internal inconsistencies among various data. It is mostly their interpretations which have differed.
- n is not uniquely defined in the presently explored domain of $(x_\perp, p_\perp)$. It is ~ 11 in the high $p_\perp$ region of NAL, ~ 8 in the high $p_\perp$ region of ISR, ~ 6.5 to 7 in the (high s, high $p_\perp$) region of ISR.
- extrapolations of local fits with an ad hoc $f(x_\perp)$ easily lead to nonsense.
- ... phase-space limit $x_\perp = 1$ seems to play a role (all lines of constant cross section must asymptotically approach the line $x_\perp = 1$).
- far from phase-space boundary n is rather smaller than 8 than larger.

2. Charged particle ratios.

The BS collaboration present to the London Conference a large set of data of relative abundances as a function of $\sqrt{s}$, $p_\perp$ and θ.

The observed excess of positives and massives is practically accomodated by all models. Discriminations between them are based upon the $p_\perp$ dependence of the effect (does it keep rising or does it saturate ?).

Two typical sets of data are shown in figures 5 a and 5 b.

3. Correlations

The PSB collaboration was first to evidence the main effect: if a high $p_\perp$ π^0 is produced at 90° an excess of particles are observed opposite to it, in a wide cone $\Delta\varphi \sim 2$ rad, $\Delta\eta \sim 5$. Towards the π^0 however, nothing more than the usual 2-body correlation ($R \sim .6$) is observed. See fig. 6 and 7. This results in a net excess of multiplicity of the order of 4 particles for $p_\perp \sim 3$ GeV/c. The effect rises with $p_\perp$. Confirmations of these results have been recently given by the ACHM and BS collaborations.

Recent data by the ACHM collaboration indicate that when the high $p_\perp$ particle is moved off 90° the excess of multiplicity follows back to back to the π^0, and not at the same η as some fireball models would predict. Figure 8.

Momentum correlations between a π^0 emitted at 90° with momentum p_1 and another emitted either close or opposite to it with momentum p_2 indicate that the higher p_1, the flatter the p_2 dependence of the momentum spectrum. This result, when expressed in terms of correlation coefficients, yields to huge values because of the steep fall of the inva-

riant cross section. Figure 9.
This result is to be contrasted with the low $p_\perp$ behaviour where p_2 ignores where p_1 is. Saclay - CCR have very preliminary data in the transition region for π^+ and π^- which confirm the trend.

"Jet" hunting.

When no momenta are measured one must rely on clustering effects in the η-ϕ plane. Unfortunately the jet width in η, as can be expected for reasonable estimates of $\frac{G(x)}{x}$, is very similar to the size of the clusters introduced in normal events to account for the strong short range correlation observed in the data.

With the limited statistics presently available the observed effects are not sufficient to conclude nor to exclude the presence of jets. They are not statistically significant but are consistent with predictions of Monte Carlo calculations where a jet of particles with $G(x) \sim 1-x$ is added to normal p-p products.

By concentrating on very high $p_\perp$ (say above 6 GeV) one may still hope to observe significant effects without momentum measurements.

FUTURE STUDIES.

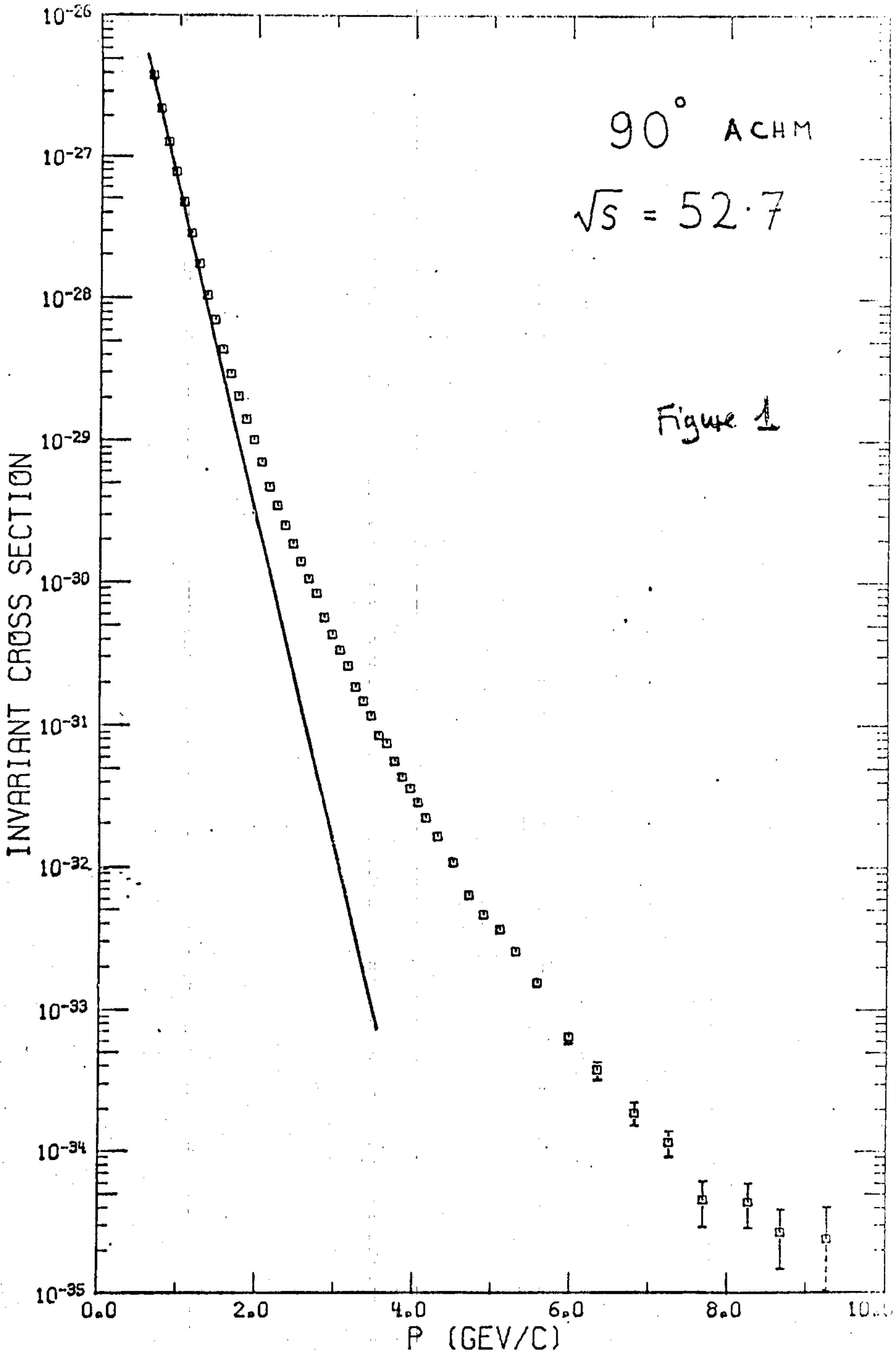
i) Data on 90° pion inclusive production must be confirmed and consolidated in order to better establish the trend presently observed. This, and a detailed study of phase space boundary effects, may help in better defining a scaling value of n.

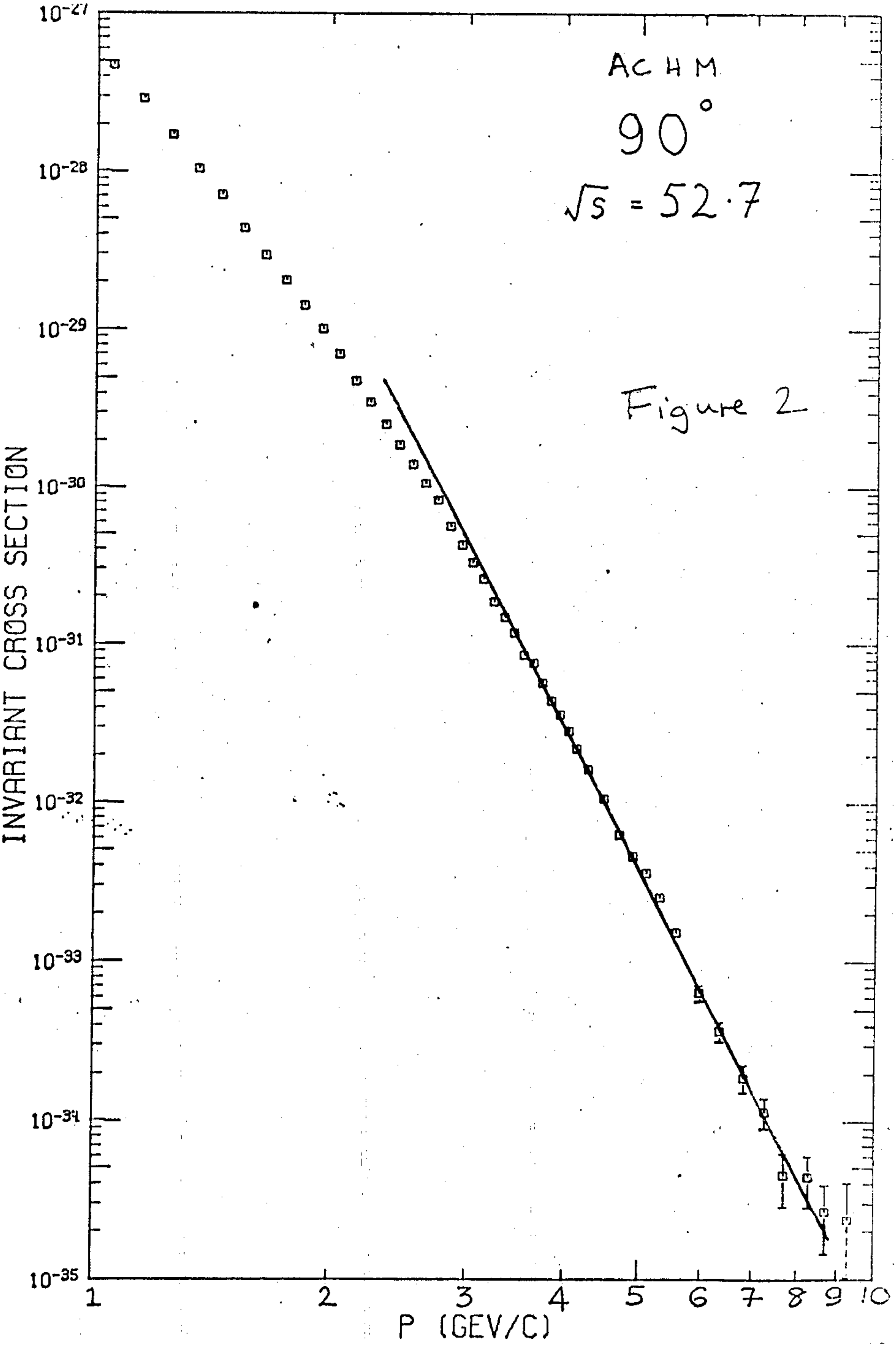
ii) Investigations of the quantum number content (charge, baryon number, etc...) of the multiplicity excess opposite to high $p_\perp$ particle, in correlation with it, are essential

iii) Use of magnetic field to filter out the soft components in the multiplicity excess

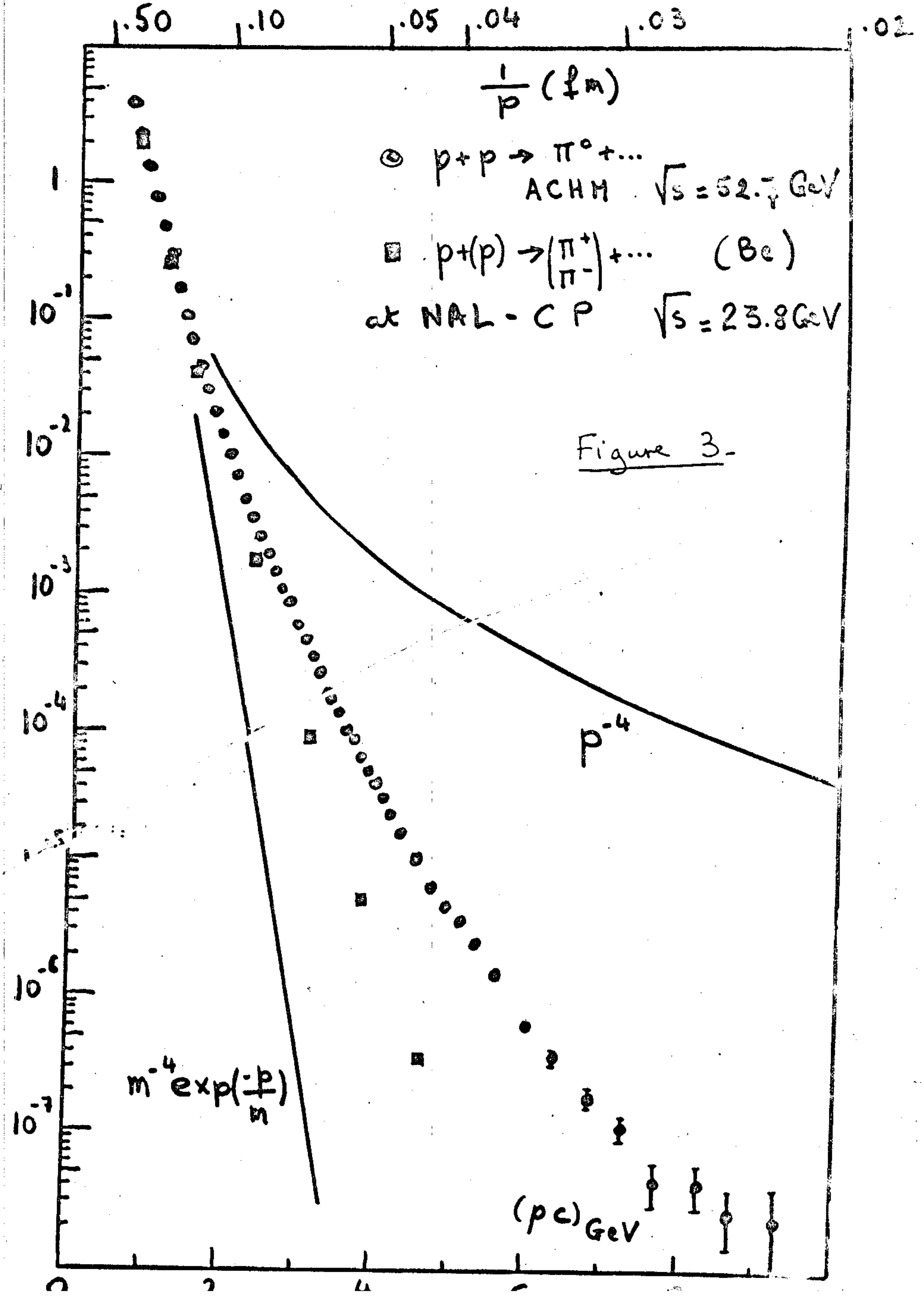
TABLE 1. Recent ISR Contributors to the large $p_\perp$ studies. Principal characteristics of detectors.

Intersection	Collaboration	Detector	Ω	Momentum	Identification
1	CCR Cern-Columbia-Rockefeller	Lead Glass + wire chambers	2x.3sr 2x1sr	yes no	π^0 $x^\pm$
1	SS Saclay-Strasbourg (now Saclay CCR)	Magnetic wire chamber spectrometer + Čerenkov + shower chambers	65msr	yes	$\pi^\pm$ $x^\pm$
4	BS British-Scandinavian	Magnetic wire chamber Spectrometer +2 Čerenkov + μ range	12 msr	yes	$\pi^\pm$ $K^\pm$ $p^\pm$
7	ACHM Aachen-Cern Heidelberg-München	Lead Glass + streamer chambers	.3 sr 4π	yes no	π^0 $x^\pm$ x^0
8	PSB Pisa-Stony Brook	Lead Glass + scintillation counters	.3 sr 4π	yes no	π^0 $x^\pm$


90° ACHM
$\sqrt{s} = 52.7$
Figure 1
INVARIANT CROSS SECTION
P (GEV/C)
10^{-26}
10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
10^{-32}
10^{-33}
10^{-34}
10^{-35}
0.0
2.0
4.0
6.0
8.0



ACHM
90°
$\sqrt{s} = 52.7$
Figure 2
INVARIANT CROSS SECTION
P (GEV/C)
10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
10^{-32}
10^{-33}
10^{-34}
10^{-35}
1 2 3 4 5 6 7 8 9 10



.50
.10
.05
.04
.03
.02
$\frac{1}{p}$ (fm)
⊙ p+p → π° + …
ACHM √s = 52.7 GeV
▪ p+(p) → (π⁺ π⁻) + … (Be)
at NAL - CP √s = 23.8 GeV
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁶
10⁻⁷
p⁻⁴
m⁻⁴ exp(-p/m)
(pc) GeV
0
2
4
6

Figure 3.

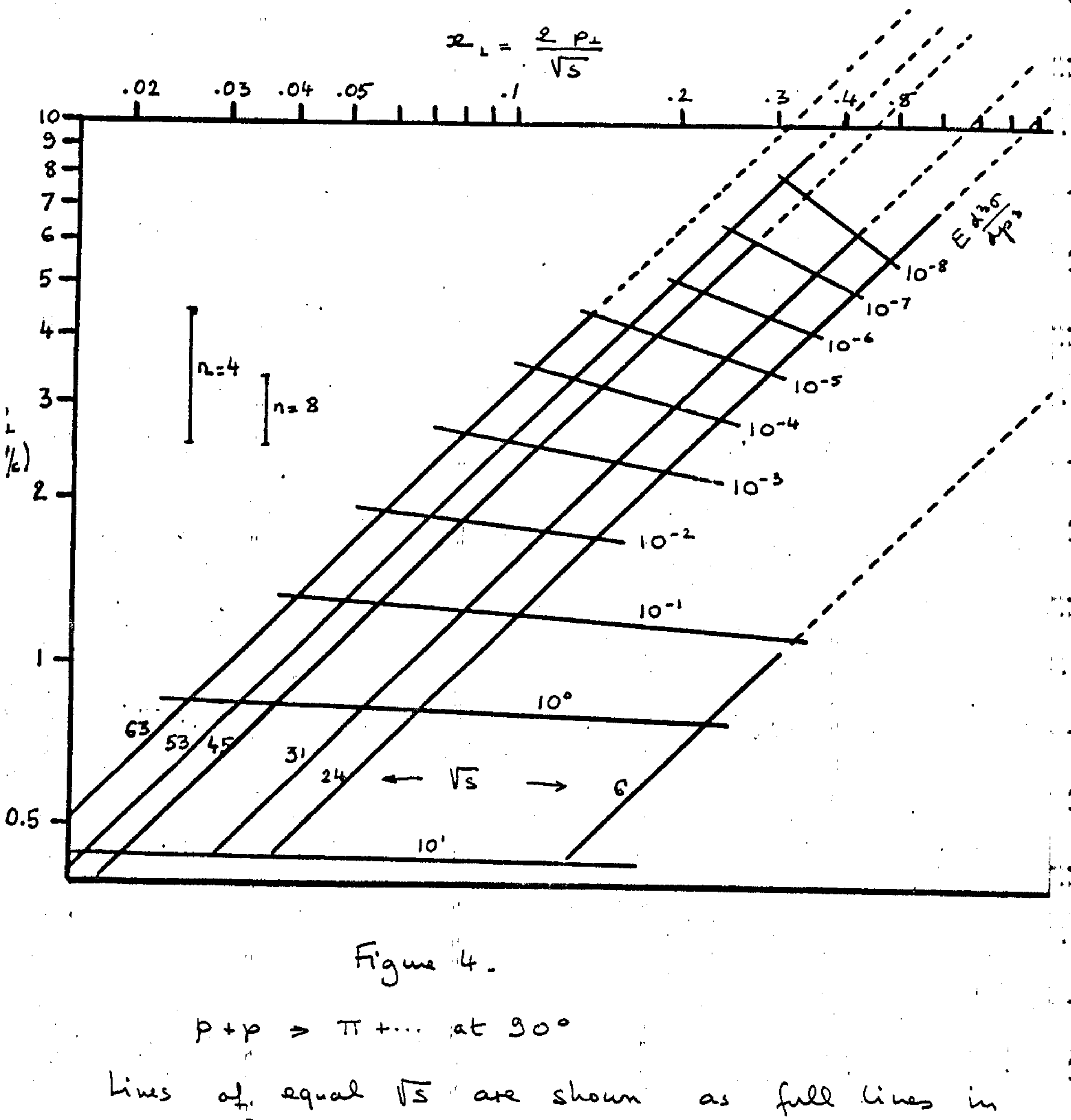


Figure 4.

$p + p \to \pi + \cdots$ at $90°$

Lines of equal $\sqrt{s}$ are shown as full lines in the region where data exist, as dotted lines farther up. Lines of constant invariant cross section are labelled ...

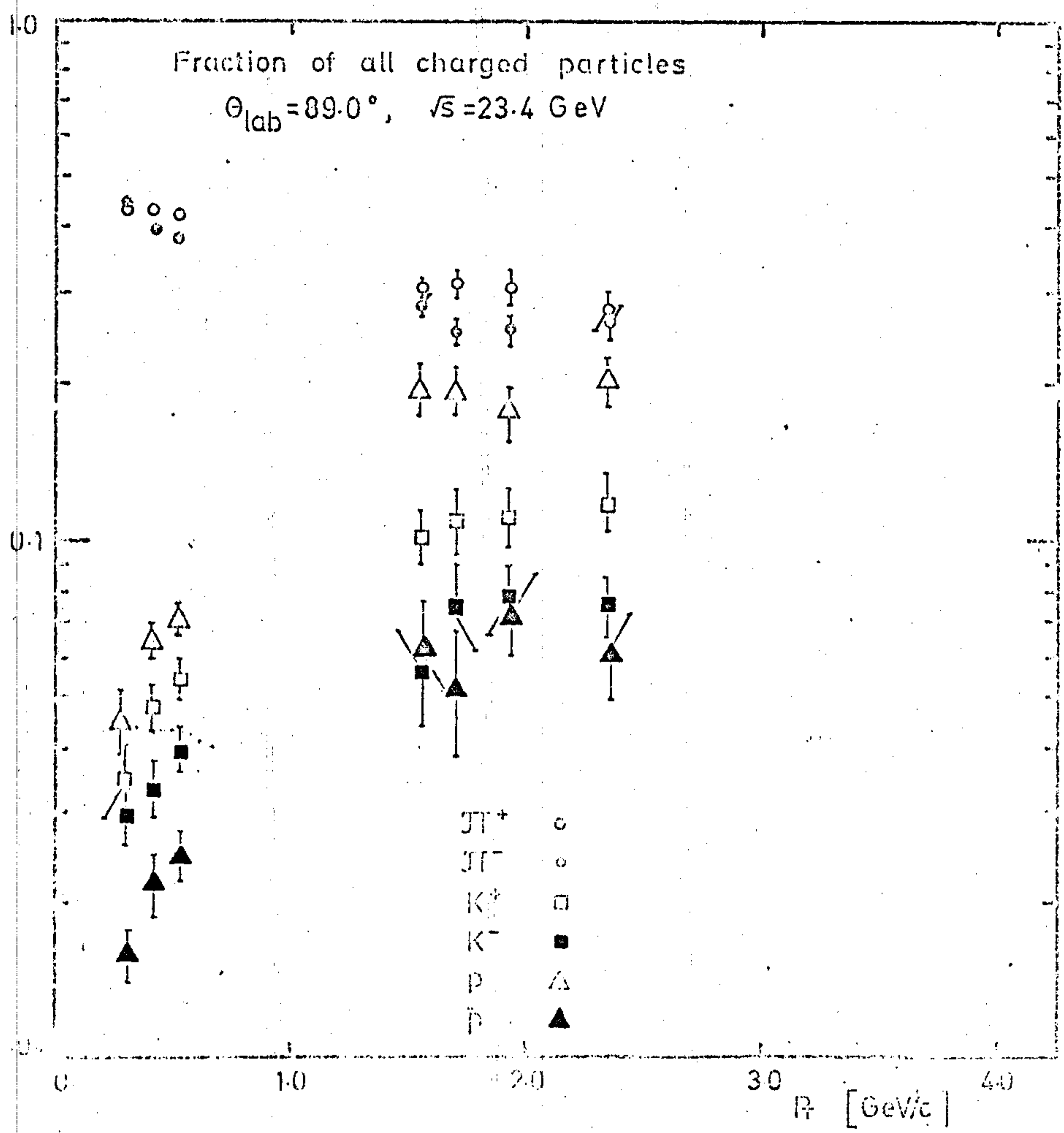


Figure 5a.

B.S collaboration to be presented in London

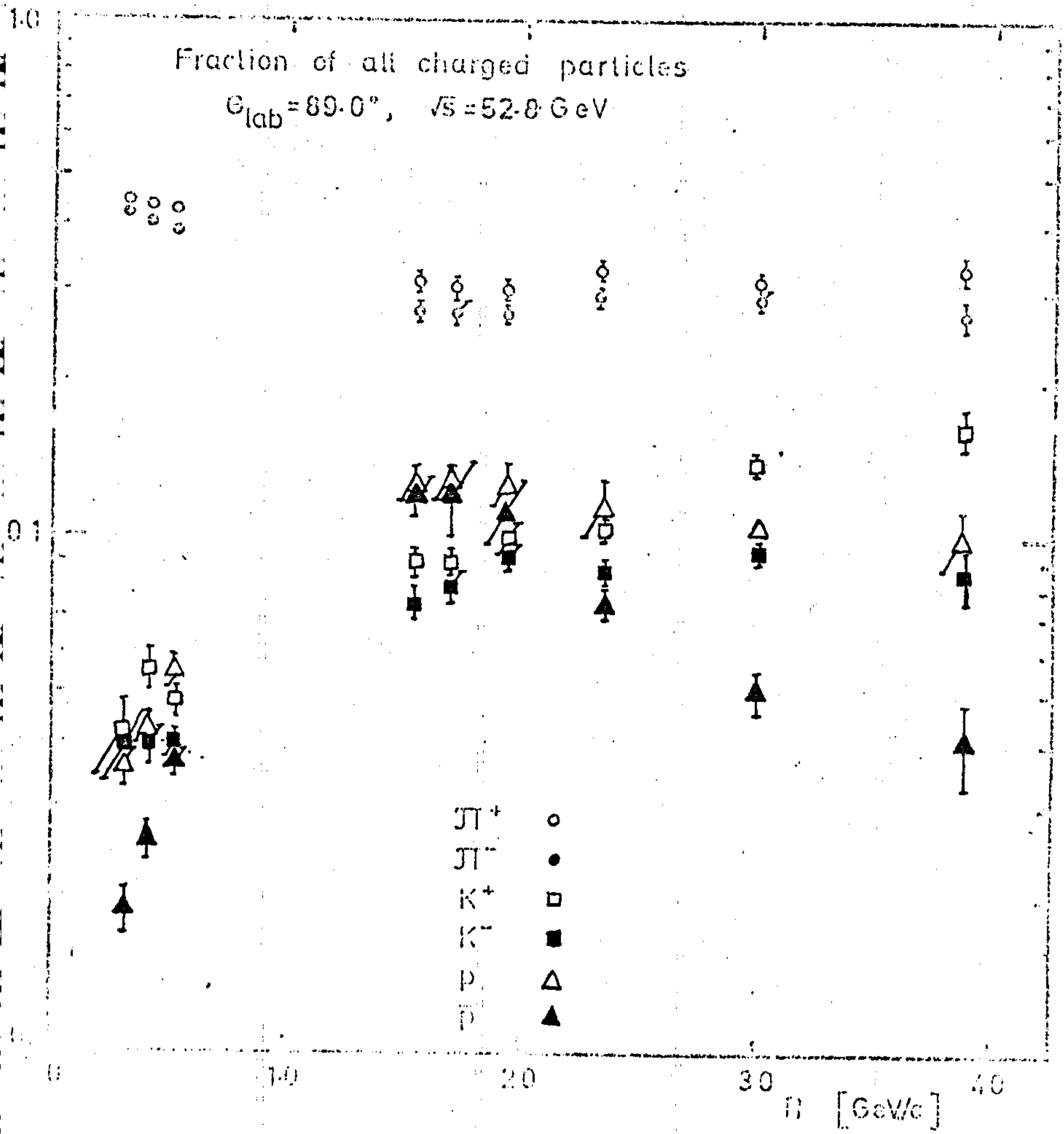


Figure 5 b.

B S collaboration. To be presented in London

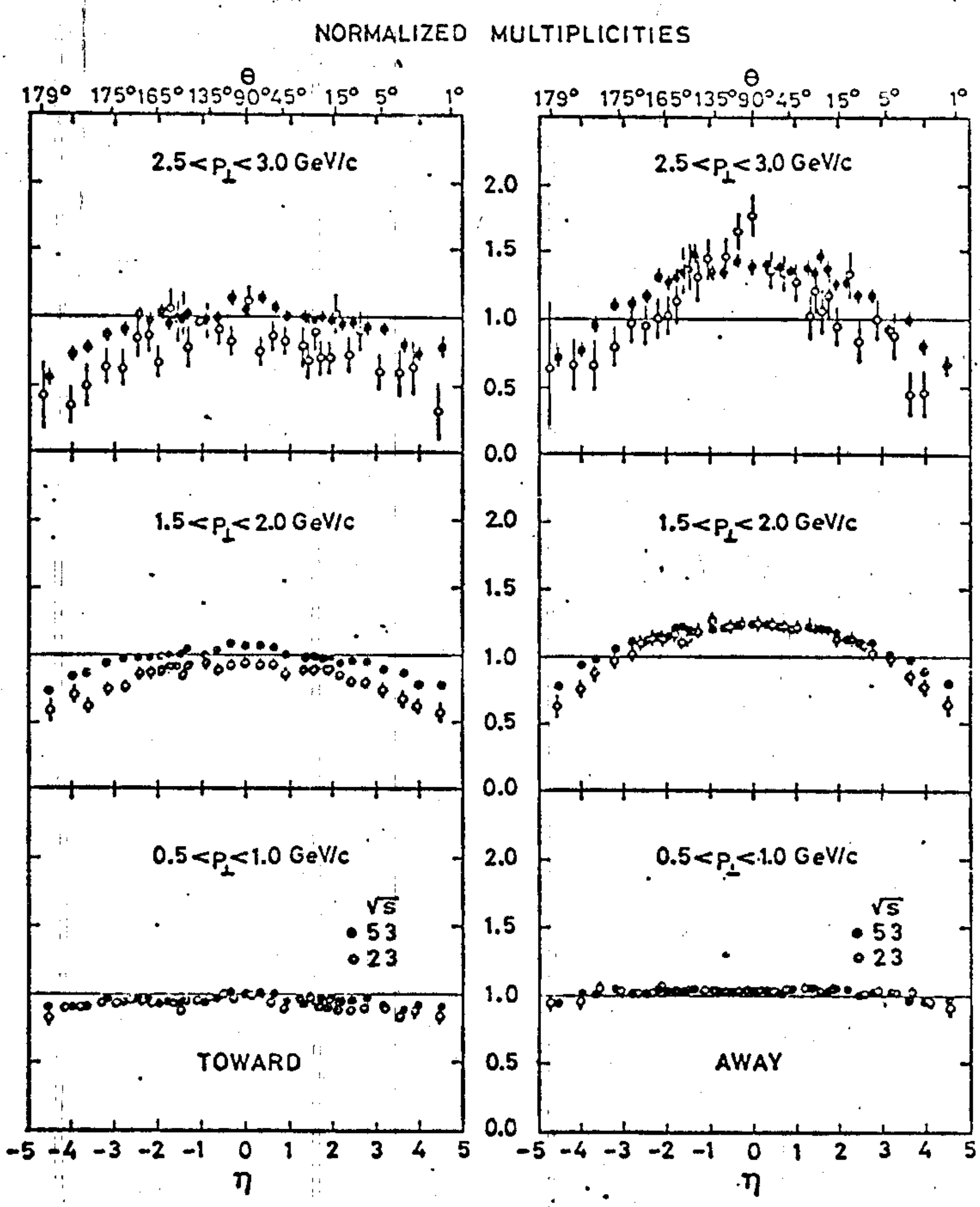


FIG. 6.

PSB COLLABORATION

Normalization is made to very small $p_\perp$ data.

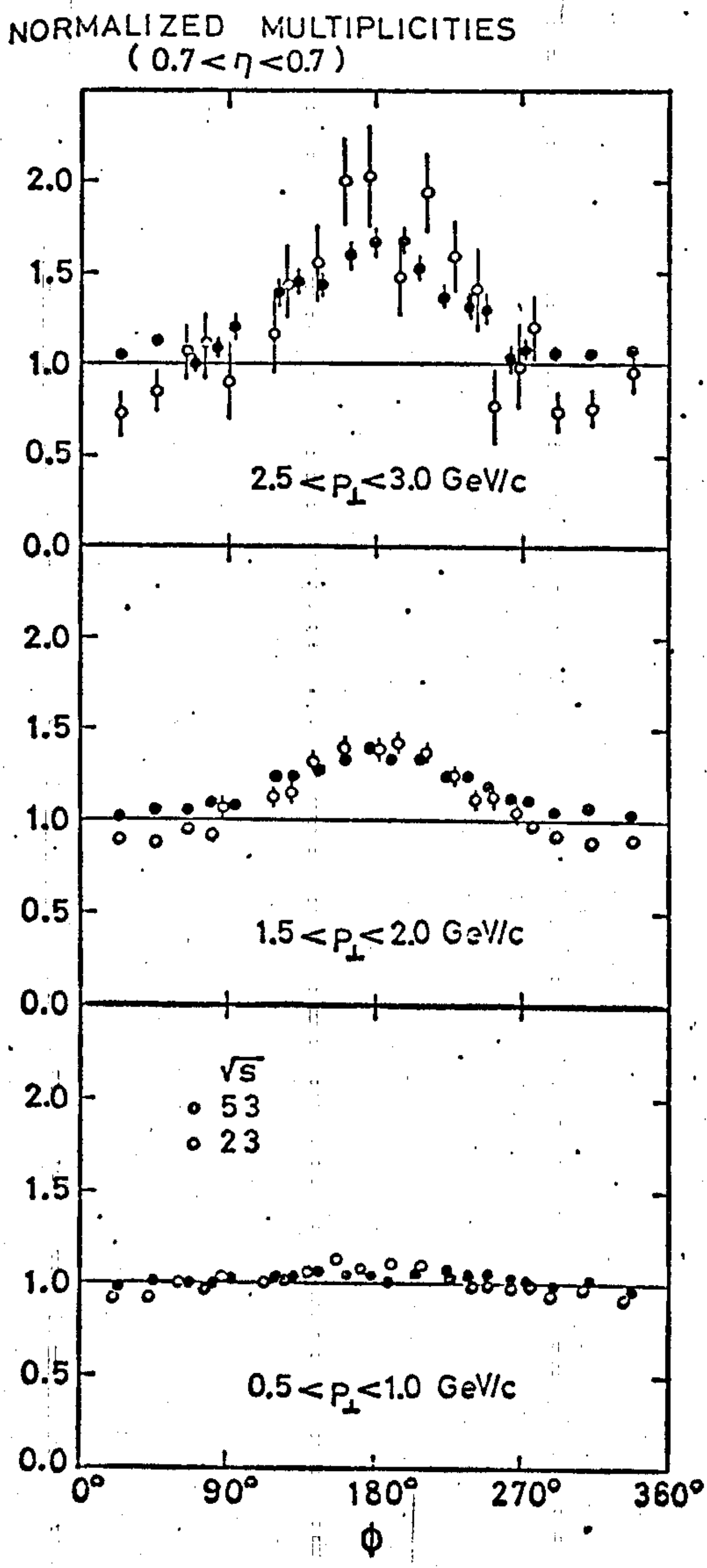

NORMALIZED MULTIPLICITIES
(0.7 < η < 0.7)
2.5 < P⊥ < 3.0 GeV/c
1.5 < P⊥ < 2.0 GeV/c
√s
53
23
0.5 < P⊥ < 1.0 GeV/c
0.0
0.5
1.0
1.5
2.0
0°
90°
180°
270°
360°
φ

FIG. 7

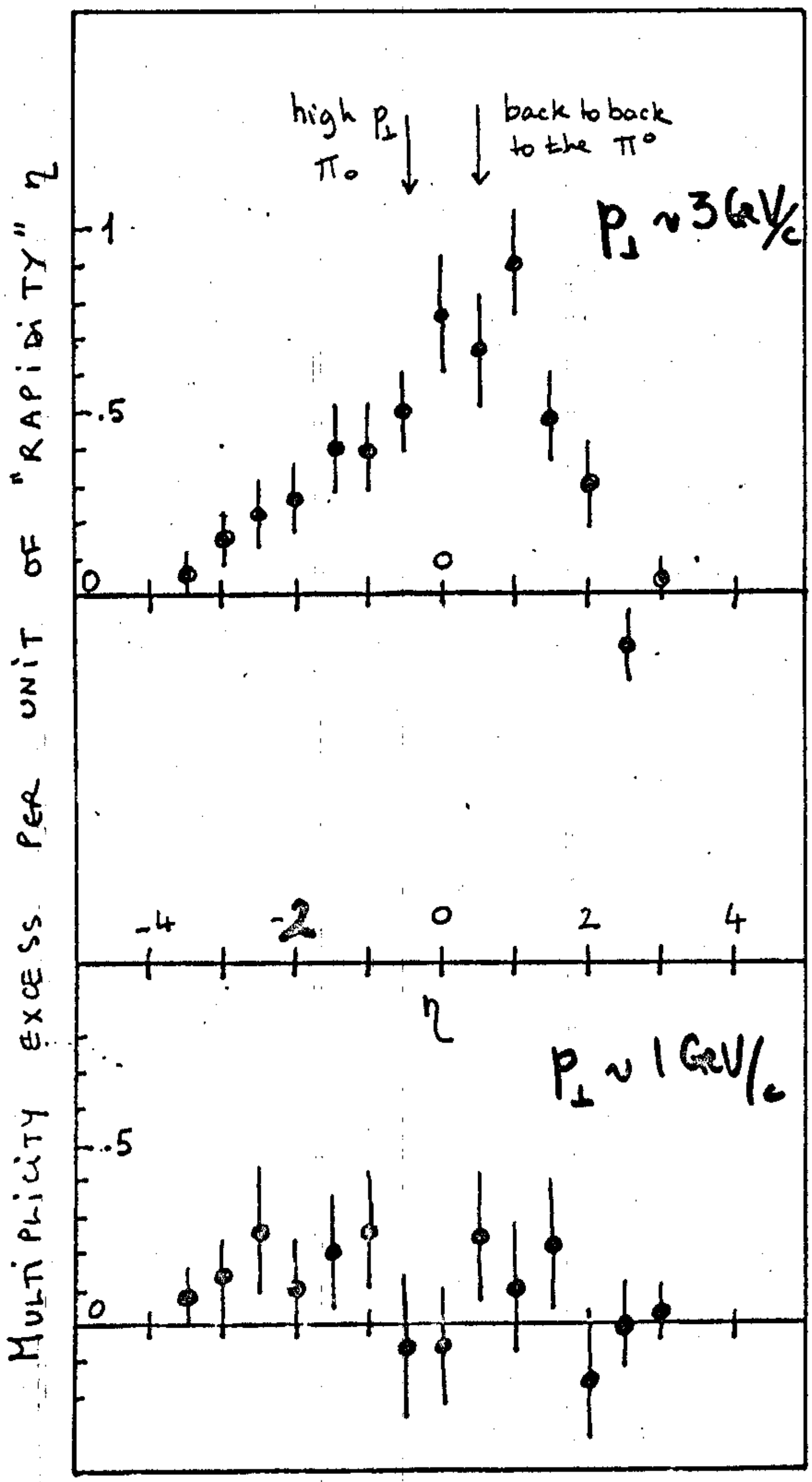


Figure 8 - ACHM Collaboration

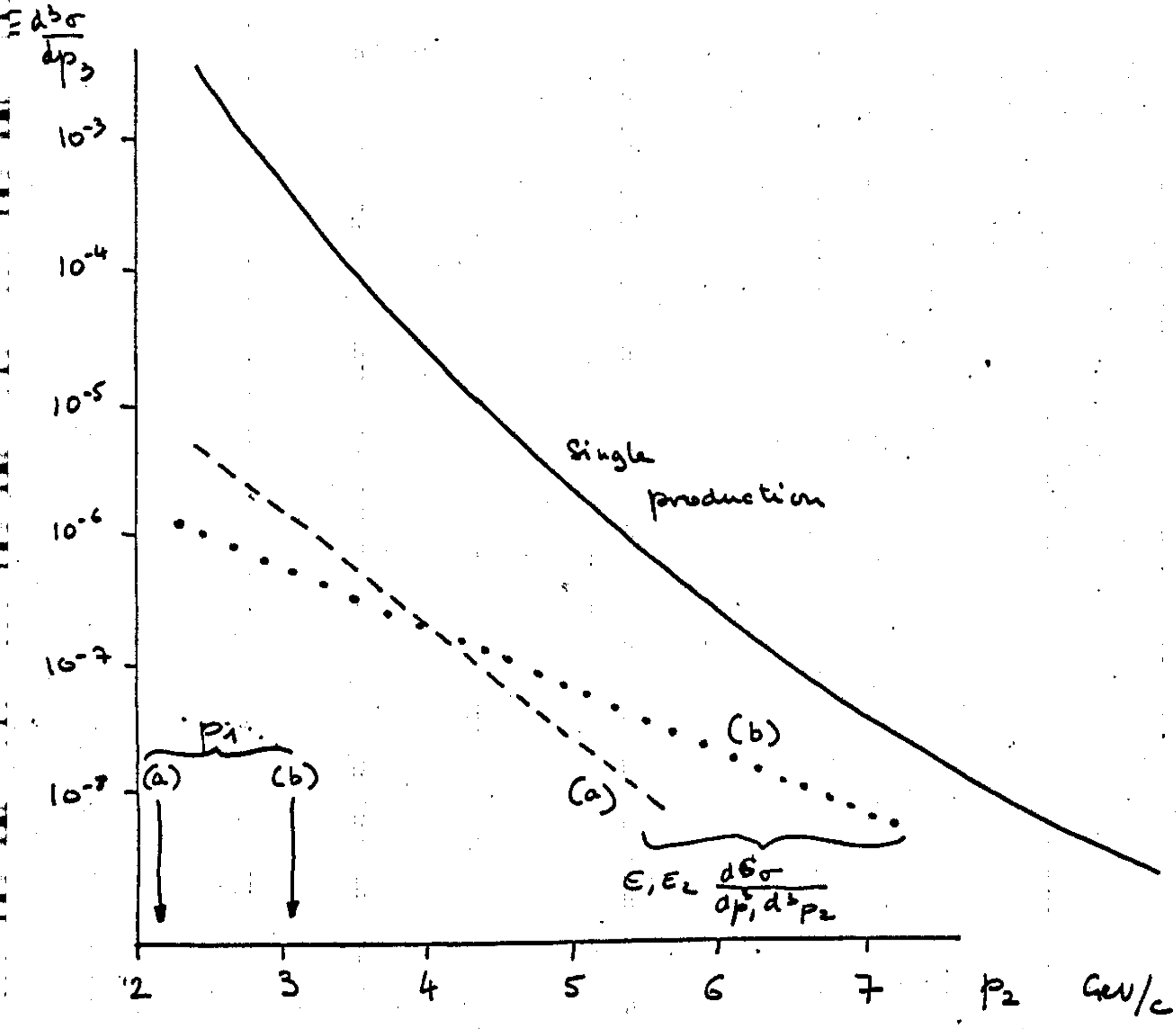


Figure 9.

Schematic representation of the momentum correlation data of the CCR collaboration

$pp \to \pi^0(90^\circ, \phi = 0) + \pi^0(90^\circ, \phi = 180^\circ) + \ldots$