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The Inclusive Transverse-Momentum Distribution in Hadronic Systems Produced in Proton-Proton Collisions.

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Summary. The single-particle inclusive transverse-momentum distribution in the multiparticle systems produced in low-p_T proton-proton interactions at $\sqrt{s} = 30$ and 62 GeV has been studied. The analysis was performed removing from the final state the leading proton and redefining the effective hadronic energy available for particle production. Excellent agreement for effective hadronic energies up to 13 GeV is found between (pp) and (e^+e^-). At higher energy the (pp) data show a less pronounced growth than the (e^+e^-) data.

Introduction. The study of the properties of the multihadron systems produced in low-p_T proton-proton collisions using the method of removing the leading proton and then redefining the effective hadronic energy (E_{had}) available for particle production, has produced several interesting results [1-8]. In particular, the inclusive

(1) M. BASILE, G. CARA ROMEO, L. CIFARELLI, A. CONTIN, G. D'ALÍ, P. DI CESARE, B. ESPOSITO, P. GIUSTI, T. MASSAM, F. PALMONARI, G. SARTORELLI, G. VALENTI and A. ZICHICHI: *Phys. Lett. B*, **92**, 367 (1980).
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fractional momentum distribution turns out to agree quite well in the effective energy range from 3 to 30 GeV with the equivalent distribution obtained in the study of $e^+e^- \to$ hadrons. These distributions reproduce well even the dramatic increase at low x ($x \leqslant 0.1$) of the particle density. Furthermore, the average charged multiplicity, when expressed in terms of E_{had}, also agrees well with the average charged multiplicity measured in e^+e^- annihilations. It is, therefore, very interesting to test whether these similarities extend to the inclusive transverse-momentum distributions which represent a key feature of the dynamics of multihadron production.

The experiment was performed at the CERN Intersecting Storage Rings (ISR) with protons at two nominal total c.m. energies: $\sqrt{s} = 30$ and 62 GeV. The reason for the choice of these energies is that they allow the study of the widest range of the effective hadronic energy, *i.e.* $E_{had} = (3 \div 32)$ GeV.

Data analysis. Similarly to our previous analysis [1-8], for all reconstructed events (at least two tracks fit a common vertex), we identify for each hemisphere the leading proton as the fastest particle with positive charge and

$$0.4 \leqslant x_F = \frac{2|p_L|}{\sqrt{s}} \leqslant 0.85 \tag{1}$$

(where p_L=longitudinal momentum). The measurement of the momentum of the leading proton is required to satisfy the condition $\Delta p/p \leqslant 8\%$. The particles accompanying the identified leading proton in the same hemisphere are analysed if their momenta are measured with $\Delta p/p \leqslant 30\%$.

The available effective hadronic energy is determined by

$$E_{had} = \frac{\sqrt{s}}{2} - E_{leading} \tag{2}$$

with $E_{leading}$ being the leading-proton energy.

The transverse momentum for each particle is determined with respect to the (pp) line of flight in the (pp) c.m. system. This choice is suggested by the consideration that the missing momentum $\boldsymbol{p}_{had} = \boldsymbol{p}_{inc} - \boldsymbol{p}_{leading}$ (*), a natural choice for the jet axis, turns out to be always very close to the beam axis.

The inclusive transverse-momentum distribution, normalized to the number of events N_{ev}, $(1/N_{ev})(dN/dp_T^2)$ has been determined by correcting the number of tracks dN corresponding to the interval dp_T for acceptance loss via Monte Carlo simulation. The quantity N_{ev} is the total number of events with at least one charged particle produced. This number has been computed from

$$N_{ev} = N_{I.p.}(1 - \exp[-\langle n_{ch}\rangle]) , \tag{3}$$

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(*) $\boldsymbol{p}_{inc}$ = incident-proton momentum, $\boldsymbol{p}_{leading}$ = leading-proton momentum.

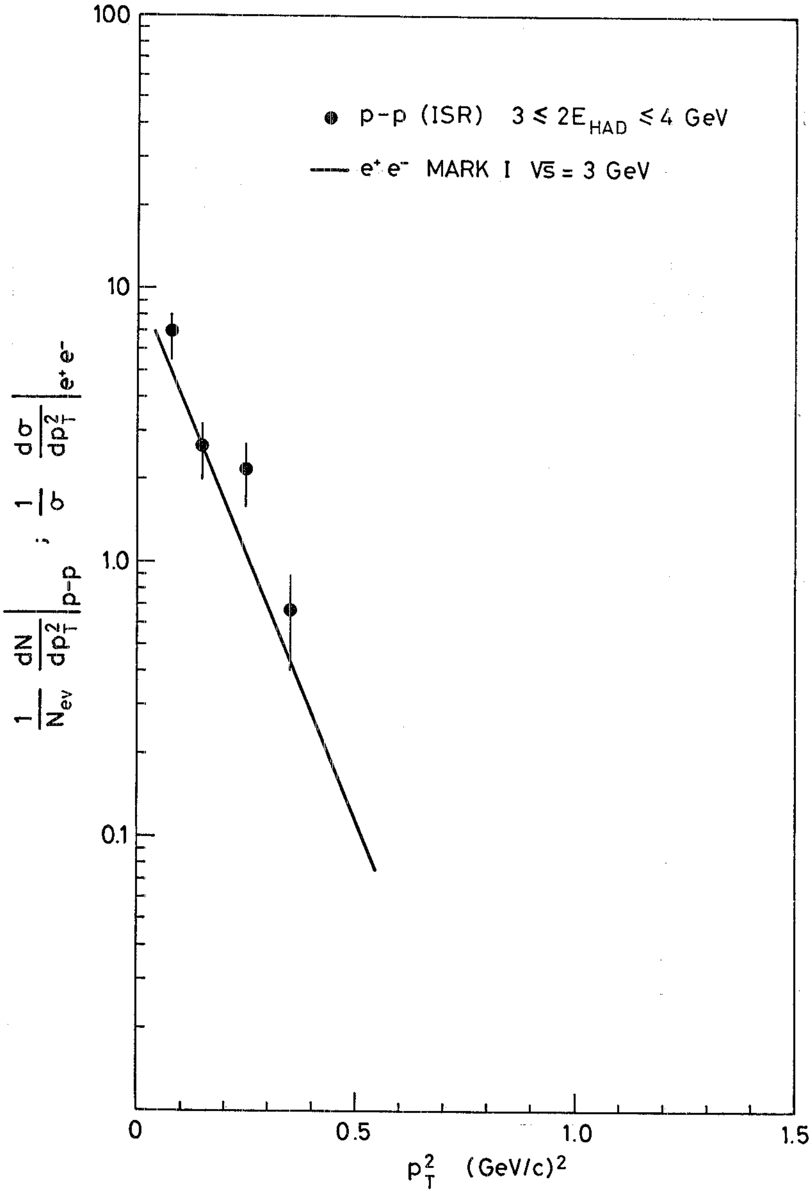

Fig. 1. – The inclusive single-particle transverse-momentum distribution $(1/N_{ev})(dN/dp_T^2)$ for $3 \leqslant 2E_{had} \leqslant 4$ GeV compared with $(1/\sigma)(d\sigma/dp_T^2)$ measured at SLAC (MARK I) at $\sqrt{s} = 3$ GeV.

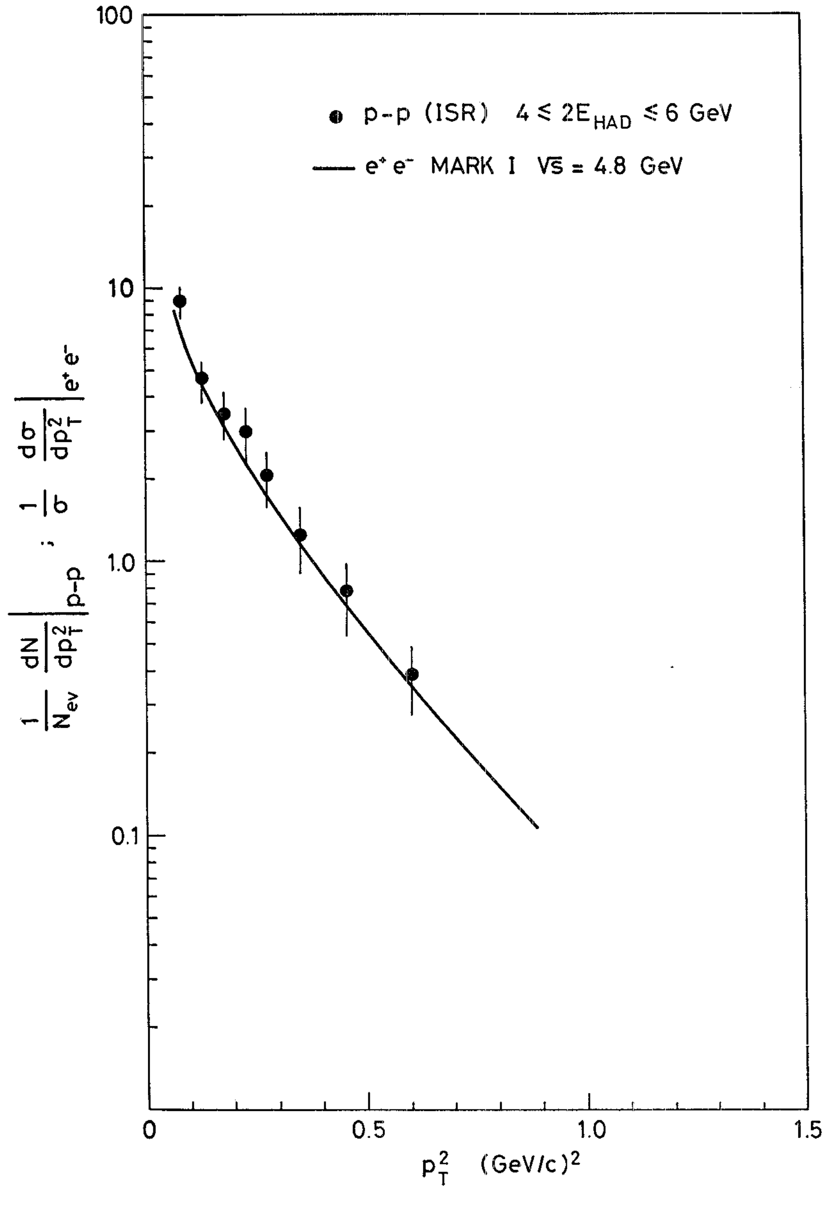

Fig. 2. – The inclusive single-particle transverse-momentum distribution $(1/N_{ev})(dN/dp_T^2)$ for $4 \leqslant 2E_{had} \leqslant 6$ GeV compared with $(1/\sigma)(d\sigma/dp_T^2)$ measured at SLAC (MARK I) at $\sqrt{s} = 4.8$ GeV.

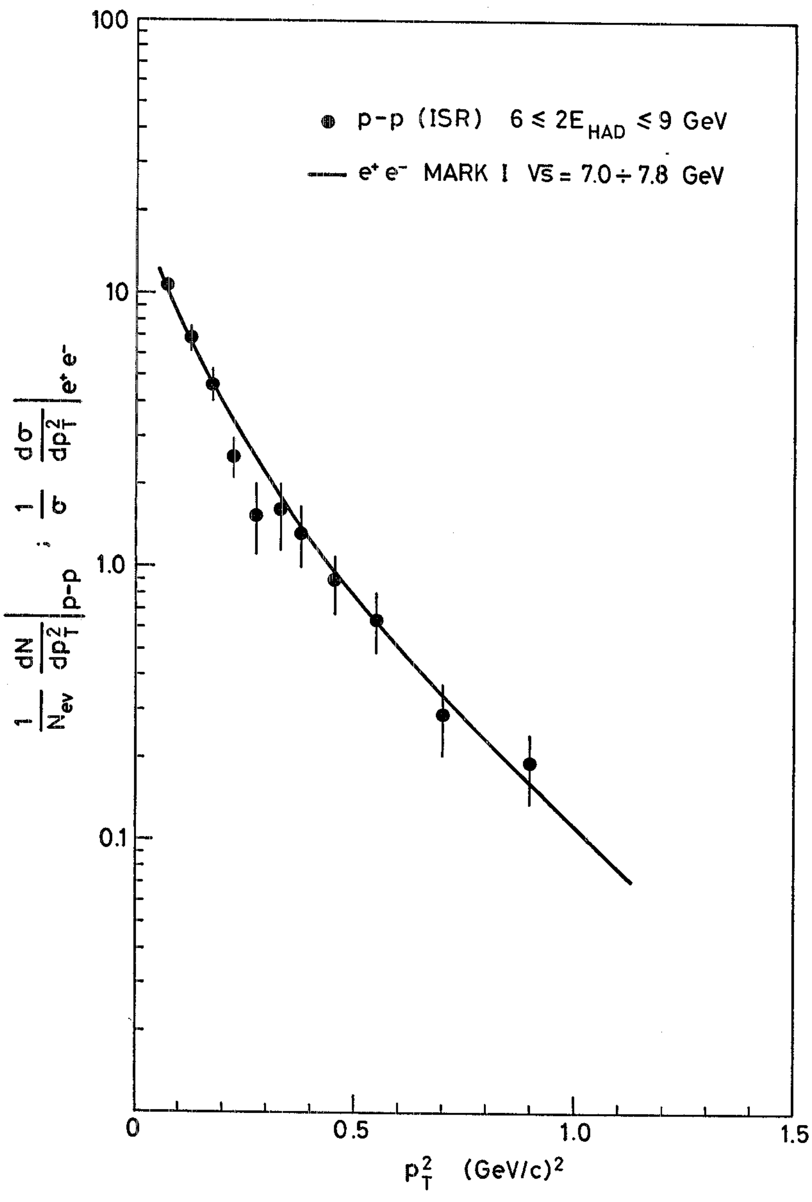

Fig. 3. – The inclusive single-particle transverse-momentum distribution $(1/N_{ev})(dN/dp_T$ for $6 \leqslant 2E_{had} \leqslant 9$ GeV compared with $(1/\sigma)(d\sigma/dp_T^2)$ measured at SLAC (MARK I) at $\sqrt{s} = (7.0 \div 7.8)$ GeV.

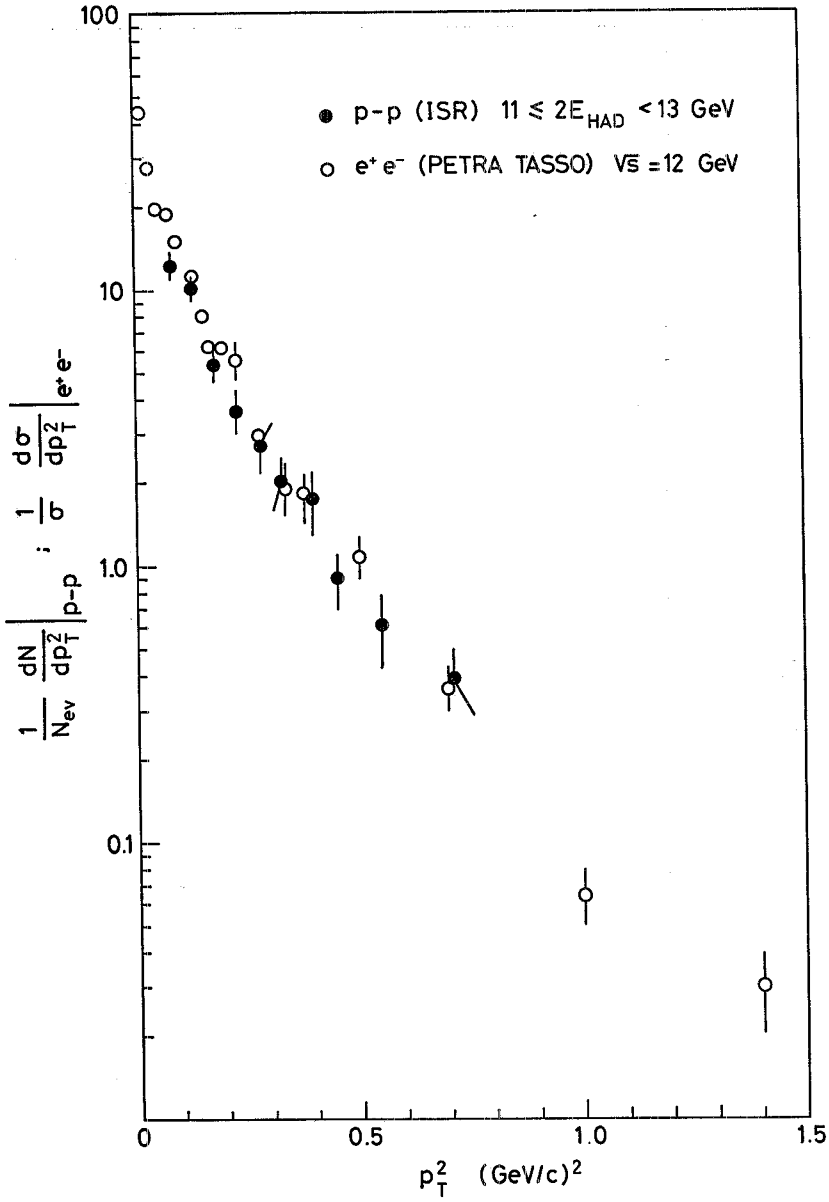

Fig. 4. – The inclusive single-particle transverse-momentum distribution $(1/N_{ev})(dN/dp_T^2)$ for $11 \leqslant 2E_{had} < 13$ GeV compared with $(1/\sigma)(d\sigma/dp_T^2)$ measured at PETRA (TASSO) at $\sqrt{s} = 12$ GeV.

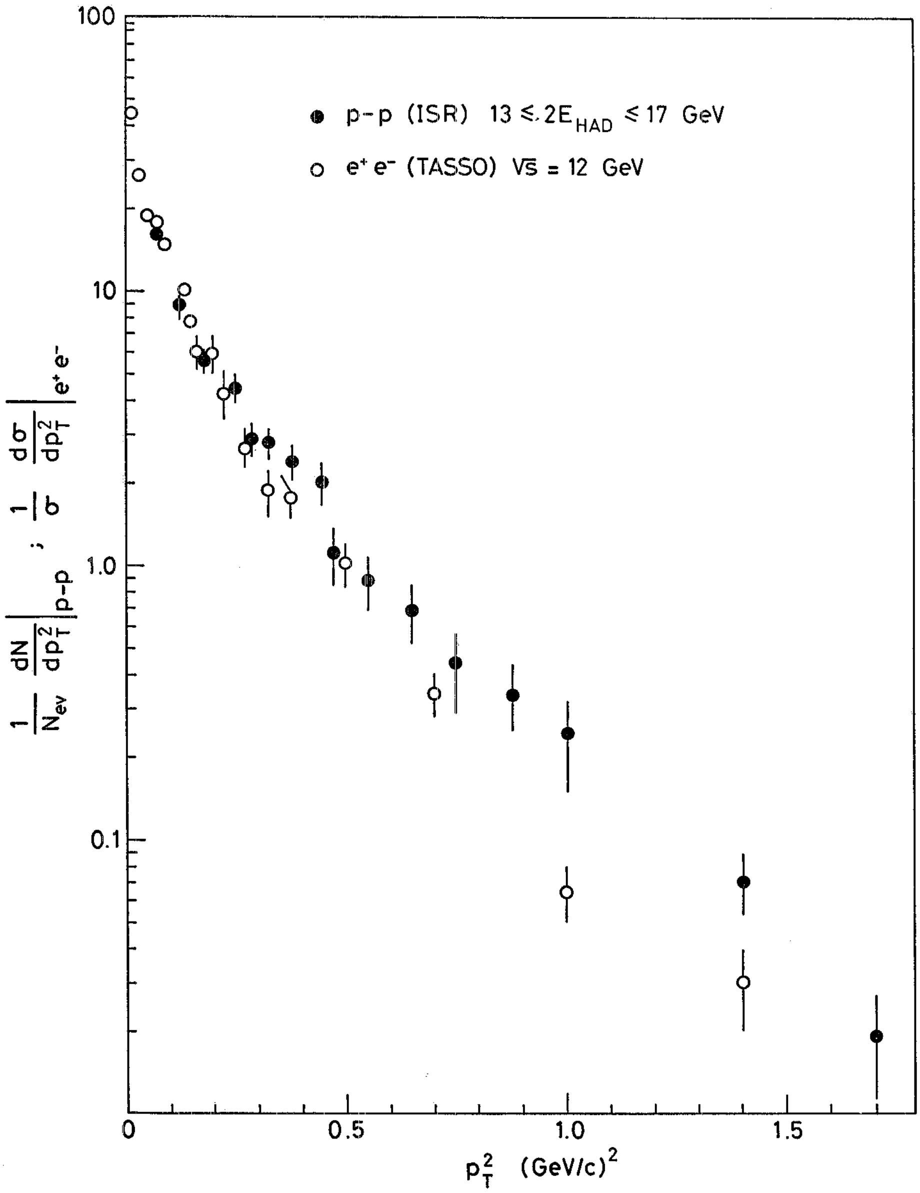

Fig. 5. – The inclusive single-particle transverse-momentum distribution $(1/N_{ev})(\mathrm{d}N/\mathrm{d}p_T^2)$ for $13 \leqslant 2E_{had} \leqslant 17$ GeV, compared with $(1/\sigma)(\mathrm{d}\sigma/\mathrm{d}p_T^2)$ measured at PETRA (TASSO) at $\sqrt{s} = 12$ GeV.

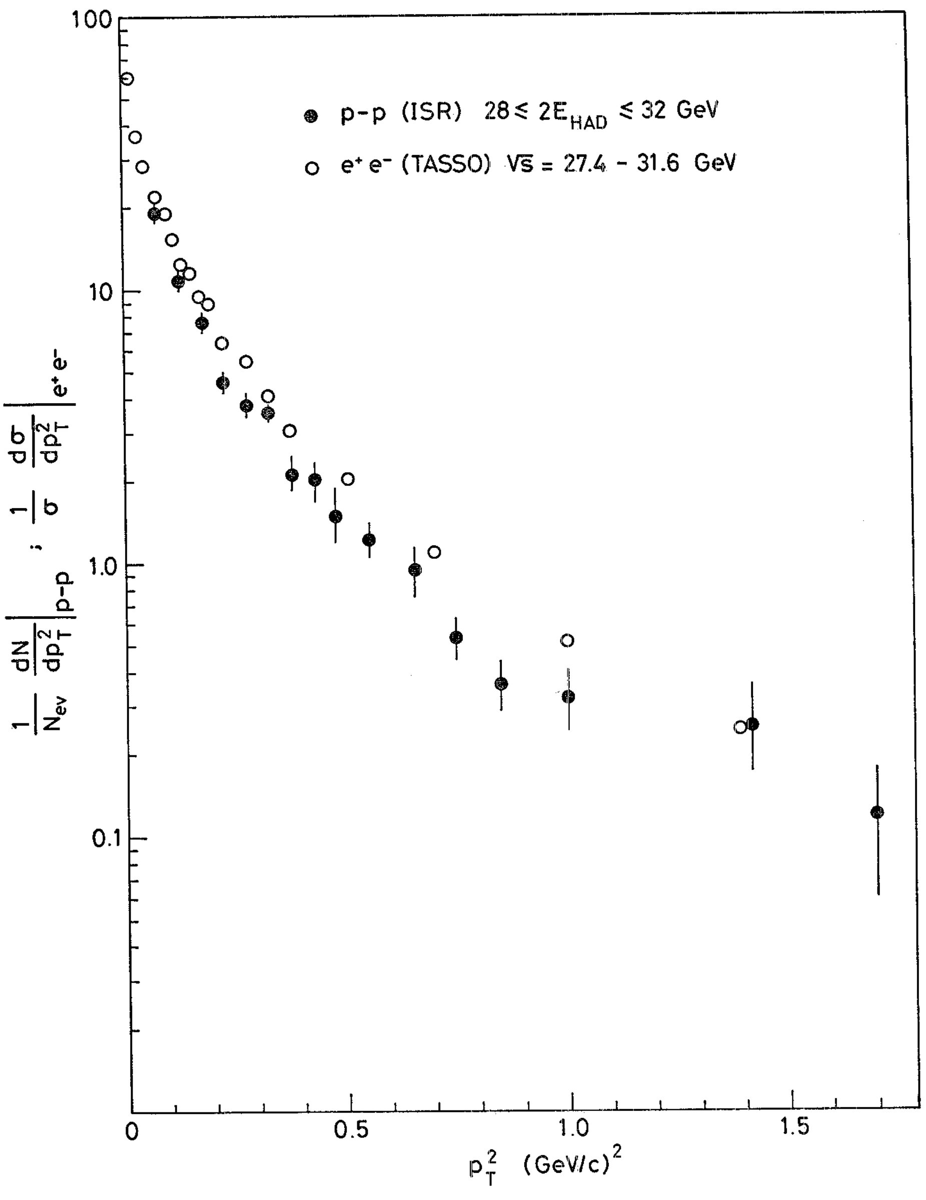

Fig. 6. – The inclusive single-particle transverse-momentum distribution $(1/N_{ev})(dN/dp_T^2)$ for $28 \leqslant 2E_{had} \leqslant 32$ GeV compared with $(1/\sigma)(d\sigma/dp_T^2)$ measured at PETRA (TASSO) at $\sqrt{s} =$ $= (27.4 \div 31.6)$ GeV.

where $N_{\text{l.p.}}$ = number of leading protons including the case with no accompanying particle, $\langle n_{\text{ch}}\rangle$ is the measured average charged multiplicity in the same hemisphere as that of the leading proton and for the E_{had} interval under study. We have also assumed that the charged multiplicity is Poisson distributed.

The above choice implies that the (e^+e^-) distributions have to be normalized to one hemisphere and that the relation between the (e^+e^-) annihilation energy $(\sqrt{s})_{e^+e^-}$, and the effective hadronic energy $(E_{\text{had}})_{\text{pp}}$ in (pp) interactions is given by

$$(\sqrt{s})_{e^+e^-} = 2(E_{\text{had}})_{\text{pp}} . \tag{4}$$

Results. Six hadronic energy intervals have been studied:

$$2E_{\text{had}} = (3\div 4),\ (4\div 6),\ (6\div 9),\ (11\div 13),\ (13\div 17),\ (28\div 32)\ \text{GeV} .$$

The corresponding number of analyzed events, with at least one charged particle detected at these energies is

184, 488, 897, 652, 1099, 1153,

respectively.

The data in the $2E_{\text{had}}$ energy range, from 3 to 13 GeV, are obtained from (pp) collisions at $\sqrt{s} = 30$ GeV. The data from 13 to 32 GeV are obtained from (pp) collisions at $\sqrt{s} = 62$ GeV.

The inclusive transverse-momentum distributions $(1/N_{\text{ev}})(\text{d}N/\text{d}p_{\text{T}}^2)$ are shown in fig. 1-6, where they are compared with data from SLAC (MARK I) ($\sqrt{s} = 3$, 4.8, $7.0\div 7.8$) (9) and PETRA (TASSO) ($\sqrt{s} = 12$, $27.4\div 31.6$) (10).

These data show that in the lower $2E_{\text{had}}$ energy range, *i.e.* from 3 to 13 GeV (fig. 1-4), the agreement with (e^+e^-) data in the same energy range is excellent. This means that the inclusive transverse-momentum distributions of the particles produced in (pp) interactions, when relation (4) is used, do follow the same pattern as the inclusive transverse-momentum distributions of the particles produced in (e^+e^-) annihilations. This pattern changes for effective hadronic energies, $2E_{\text{had}}$, above 13 GeV, as shown in fig. 5 and 6, where the (pp) data corresponding to two $2E_{\text{had}}$ ranges, ($13 \leqslant 2E_{\text{had}} \leqslant 17$) GeV and ($28 \leqslant 2E_{\text{gad}} \leqslant 32$) GeV, are reported. The (pp) distributions do not show a significant variation. However, the corresponding (e^+e^-) data show a clear change; from $\sqrt{s} = 12$ GeV to $\sqrt{s} = (27.4\div 31.6)$ GeV. A comparison of the data in fig. 5 and 6 shows that in this energy range, the growth of high-p_{T} particles in (pp) data is less pronounced than for the (e^+e^-) data.

Conclusions. We have extended our previous study of the properties of multiparticle production in proton-proton collisions to the inclusive single-particle transverse-momentum distributions in an energy range from 3 to 32 GeV. Here again the method of removing leading protons shows that for energies below 13 GeV, the transverse-momentum distributions of the particles produced in (e^+e^-) annihilations and in (pp) interactions are the same.

Above 13 GeV, the (pp) data show a growth which appears to be less pronounced than in the (e^+e^-) case; this is bound to be of great importance in the understanding of the hadronization mechanisms at work in (pp) collisions and in (e^+e^-) annihilations.

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