EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/81-147
10 November 1981

A PREDICTION FOR THE TOTAL CHARGE MULTIPLICITY IN HADRONIC INTERACTIONS AT EXTREME HIGH ENERGIES

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ABSTRACT

The study of the average charge multiplicity $\langle n_{ch} \rangle_{pp}$, in terms of the effective hadronic energy available for particle production, makes it possible to extrapolate to any hadronic interaction the results obtained in the (pp) case, once the "leading" proton effects are subtracted. This method can therefore be extended to the ($\bar{p}$p) case, and a prediction for the total average charge multiplicity at $\sqrt{s}$ = 540 GeV can be made. This prediction with all its implications, can soon be checked, thanks to the CERN ($\bar{p}$p) Collider.

(Submitted to Nuovo Cimento Letters)

When two protons interact, the average charge multiplicity $\langle n_{ch}\rangle_{pp}$ depends on the effective hadronic energy E^{had} which is available for particle production.

We have recently shown[1-3] that, using protons at Intersecting Storage Rings' (ISR) energies, the quantity $\langle n_{ch}\rangle_{pp}$ has the same functional dependence on E^{had} as the average charge multiplicity measured in (e^+e^-) annihilation, $\langle n_{ch}\rangle_{e^+e^-}$, has on the total c.m. energy of the (e^+e^-) system, i.e. $(\sqrt{s})_{e^+e^-} = 2E^{beam}_{e^+e^-}$. In other words, the basic quantity for producing a multiparticle hadronic system is the total energy available for particle production. In (e^+e^-) annihilation this total energy is $(\sqrt{s})_{e^+e^-}$; in (pp) interactions it is not $(\sqrt{s})_{pp} = 2E^{beam}_{pp}$, because of the "leading" hadron effect[4,5]. This means that if two protons at the ISR collide, each with $E^{beam} = 31$ GeV, the total c.m. energy in the (pp) system is $(\sqrt{s})_{pp} =$ $= 62$ GeV, but the effective hadronic energy available for particle production, E^{had}, can vary within a wide range. The quantity E^{had} depends on how much energy and momentum have been subtracted by the leading proton.

In the ISR energy range the inclusive differential cross-section

$$\frac{d\sigma}{dx_F} = \int \frac{1}{E}\left(E\frac{d^3\sigma}{d^3p}\right) dp_T^2 d\phi \tag{1}$$

scales, and is almost flat over the whole x_F range[6-9] $[x_F = 2p_L/(\sqrt{s})_{pp}$, p_L being the final-state longitudinal momentum of the "leading" proton]. This means that in a (pp) interaction it is possible to predict the probability of having a final-state proton with a given amount of "leading" momentum. As mentioned above, this probability does not change with $(\sqrt{s})_{pp}$ because of the observed scaling behaviour of Eq. (1).

Before the discovery of the importance of subtracting the "leading" proton effects from a (pp) interaction[4,5], the quantity $\langle n_{ch}\rangle$ was expressed[10] in terms of $(\sqrt{s})_{pp}$. Our new way of studying the mechanism for multiparticle production in (pp) interactions makes it possible to extend the validity of our study, which started with (pp) interactions, to a large variety of interactions. For example, we have shown[4,5] that, provided there is a hadron in the initial state, the "leading" hadron effect is going to be present, in the final state, even if the interaction is induced by electromagnetic or weak forces. Therefore the analysis of the multi-particle systems produced should be performed after having removed the effect of the "leading" hadron -- no matter the nature of this hadron.

A special case is the interaction between protons and antiprotons ($p\bar{p}$) and its comparison with the (pp) case. A detailed analysis[4,5] has shown that the "leading" effect in ($p\bar{p}$) interactions is present exactly as in the (pp) case. The quantity $\langle n_{ch}\rangle_{\bar{p}p}$ measured in ($\bar{p}p$) interactions can also be understood in terms of the "effective" energy available for particle production E^{had}, as it is for the (pp) case. It does not matter whether we are dealing with ($\bar{p}p$) or with (pp) interactions; once the leading hadron effects are removed, the two processes ($\bar{p}p$) and (pp) should produce the same average charge multiplicity.

With the advent of the very high energy ($\bar{p}p$) Collider at CERN[11,12], these (pp) and ($\bar{p}p$) similarities established in the Fermilab and ISR energy range can be extended and checked at $(\sqrt{s})_{\bar{p}p}$ = 540 GeV.

For example, as we will see later, if we take the standard way of interpreting $\langle n_{ch}\rangle$ in terms of $(\sqrt{s})_{pp}$, the extrapolation of the standard fit would give $\langle n_{ch}\rangle \simeq$ $\simeq$ 25 at $\sqrt{s}$ = 540 GeV. The (pp) data can, however, be interpreted in terms of our new method[1-5]; that is, in a (pp) interaction at fixed $(\sqrt{s})_{pp}$, the quantity $\langle n_{ch}\rangle$ is the result of all $\langle n_{ch}\rangle_{pp}$ produced according to the probability of having an effective energy E^{had}, and this probability depends on $(d\sigma/dx_F)_{proton}$.

Extending the scaling for $(d\sigma/dx_F)$ already observed at the ISR[6-9] (see Fig. 1), and taking for $\langle n_{ch}\rangle_{pp}$ versus E^{had} the values (see Fig. 2) measured at ISR energies[1-3] (with the "leading" proton subtraction technique), we can extrapolate $\langle n_{ch}\rangle$ versus $(\sqrt{s})_{pp}$ at the highest energy so far reachable in a hadronic interaction, the CERN Collider energy,

$$(\sqrt{s})_{\bar{p}p} = 540 \text{ GeV} .$$

In the Collider we do not have (pp) but antiprotons against protons. However, our study of high-energy hadronic interactions[4,5] implies, as mentioned above, that the average charge multiplicity produced in (pp) and ($\bar{p}p$) interactions should be the same, because the basic quantities are E^{had} and the probability of producing it in a given (pp) or ($\bar{p}$p) interaction.

In order to calculate the total average charge multiplicity in (pp) and ($\bar{p}$p) interactions, two basic ingredients are therefore necessary:

a) *The x_F distribution of the proton and of the antiproton, i.e.* $d\sigma/dx_F$. The $d\sigma/dx_F$ for protons is deduced from the data of Fig. 1[6-9]. This distribution has been fitted, for $x_F < 0.85$, with an exponential formula

$$\frac{d\sigma}{dx_F} = \exp(a\ x_F)\ . \tag{2}$$

The best fit gives $a = -0.7 \pm 0.2$.

Diffraction processes[13,14], for $x_F \geq 0.85$, have been properly taken into account, with their own average multiplicity: the effect is to lower the total multiplicity everywhere by less than ≈ 10%.

As an over-all check, the generated $d\sigma/dx_F$ is reported in Fig. 1.

This distribution is assumed to be the same for both ($\bar{p}$p) and (pp), and the same at all energies.

b) *The average charge multiplicity $\langle n_{ch} \rangle_{pp}$ versus E^{had}*. In order to have a functional behaviour for the measured $\langle n_{ch} \rangle_{pp}$, the data (see Fig. 2) have been fitted[1] with the expression suggested by QCD:

$$\langle n_{ch} \rangle_{pp} = a + b\ \exp\left[c\sqrt{\ln\ (2E^{had}/\Lambda)^2}\ \right]\ . \tag{3}$$

The fit gives:

$$a = 2.47 \pm 0.06, \quad b = 0.030 \pm 0.004, \quad c = 1.97 \pm 0.05\ .$$

Now we are ready to calculate the total average charge multiplicity in (pp) or in ($\bar{p}$p) interactions. For this we proceed in two steps: i) two leading protons (or a proton plus an antiproton) are Monte Carlo generated, according to $d\sigma/dx_F$ (Fig. 1) and, for each leading particle, the effective hadronic energy E^{had} is calculated accordingly. ii) Each effective hadronic energy E^{had} generates a certain number of charged particles according to Eq. (3) (Fig. 2). After averaging over all Monte Carlo generated events, two charged particles, (pp) or ($\bar{p}$p) must be added to the final state in order to have the total charge multiplicity.

In Fig. 3 the known experimental data of $\langle n_{ch} \rangle$ are reported for different $(\sqrt{s})_{pp}$ [1,10,15,16]. The dashed line is the standard logarithmic fit to the experimental data, extrapolated up to the highest energies.

The result of our computation is shown also in Fig. 3: the continuous line represents the behaviour of the total charge multiplicity $\langle n_{ch} \rangle$ versus $(\sqrt{s})_{pp,\bar{p}p}$ over the whole energy range, from PS to ISR and up to the Collider energy and beyond. The agreement with the available data up to ISR energy is very good. Beyond 62 GeV the agreement with the scarce data so far available is reasonable, up to the Centauro "events". These are "events", not a measurement of $\langle n_{ch} \rangle$.

Notice that our prediction for the total average charge multiplicity to be observed at the CERN Collider is:

$$\langle n_{ch} \rangle \left[(\sqrt{s})_{\bar{p}p} = 540 \text{ GeV} \right] = 33.8 \pm 1.8 \pm 1.0 \ . \qquad (4)$$

The first uncertainty ±1.8, is due to the uncertainty on the parameters of the best fit [Eq. (3)], i.e. the way in which the average charge multiplicity varies with the effective hadronic energy E^{had}; the second, ±1.0, is due to the uncertainty in the best fit to $d\sigma/dx_F$ [Eq. (2)].

Our prediction [Eq. (4)] is much higher than the extrapolation of the standard logarithmic fit to the (pp) data, based on $(\sqrt{s})_{pp}$, which would give a value of ~ 25. Experimental checks should soon be available from the CERN $\bar{p}$p Collider data.

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Figure captions

Fig. 1 : The inclusive differential cross-section for protons ($d\sigma/dx$) at ISR energies. This quantity scales in the ISR energy range. "Leading" protons are generated according to the continuous line. For $x_F >$ > 0.85 diffractive and inelastic processes are considered separately, as shown by the dashed lines. This separation is based on Ref. 13.

Fig. 2 : The average charge multiplicity $\langle n_{ch}\rangle_{pp}$ measured in (pp) interactions, versus the effective hadronic energy $2E^{had}$ available for particle production. Notice that these data agree with $\langle n_{ch}\rangle_{e^+e^-}$ versus $(\sqrt{s})_{e^+e^-}$ measured in (e^+e^-) annihilation. The dashed curve is the fit to our data[1].

Fig. 3 : The full line is the prediction for the total average charge multiplicity $\langle n_{ch}\rangle$ expected for (pp) and ($\bar{p}$p) interactions, using our method of dealing with hadronic reactions, in terms of effective hadronic energy available for particle production. The dashed line is the prediction based on the "standard" logarithmic fit. At the Collider energy, $\sqrt{s}$ = 540 GeV, our prediction is given with its uncertainty, which comes from uncertainties on the best fits of Eqs. (2) and (3).

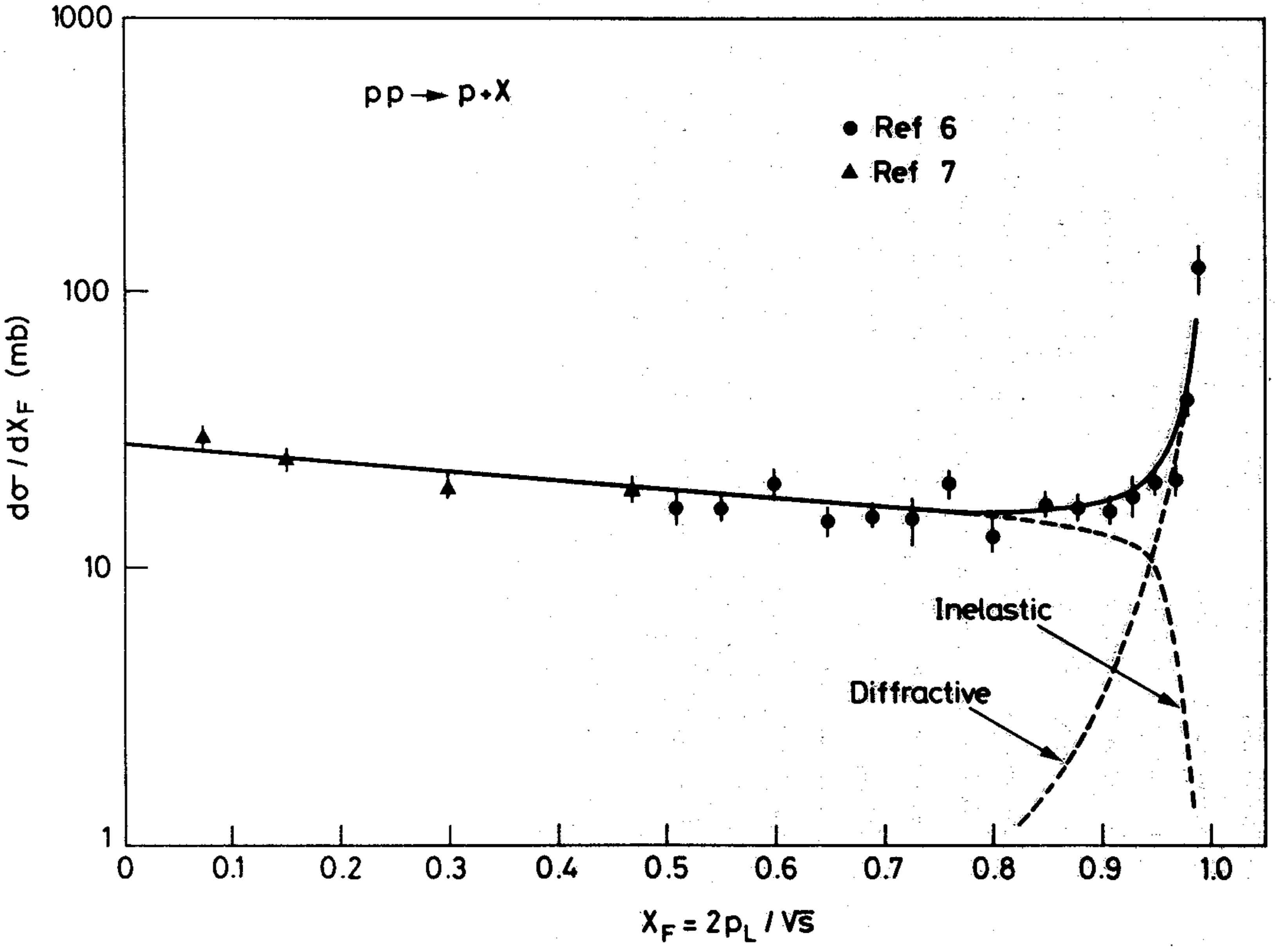
pp → p+X
Ref 6
Ref 7
1000
100
10
1
dσ / dX_F (mb)
Inelastic
Diffractive
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
X_F = 2p_L / √s

Fig. 1

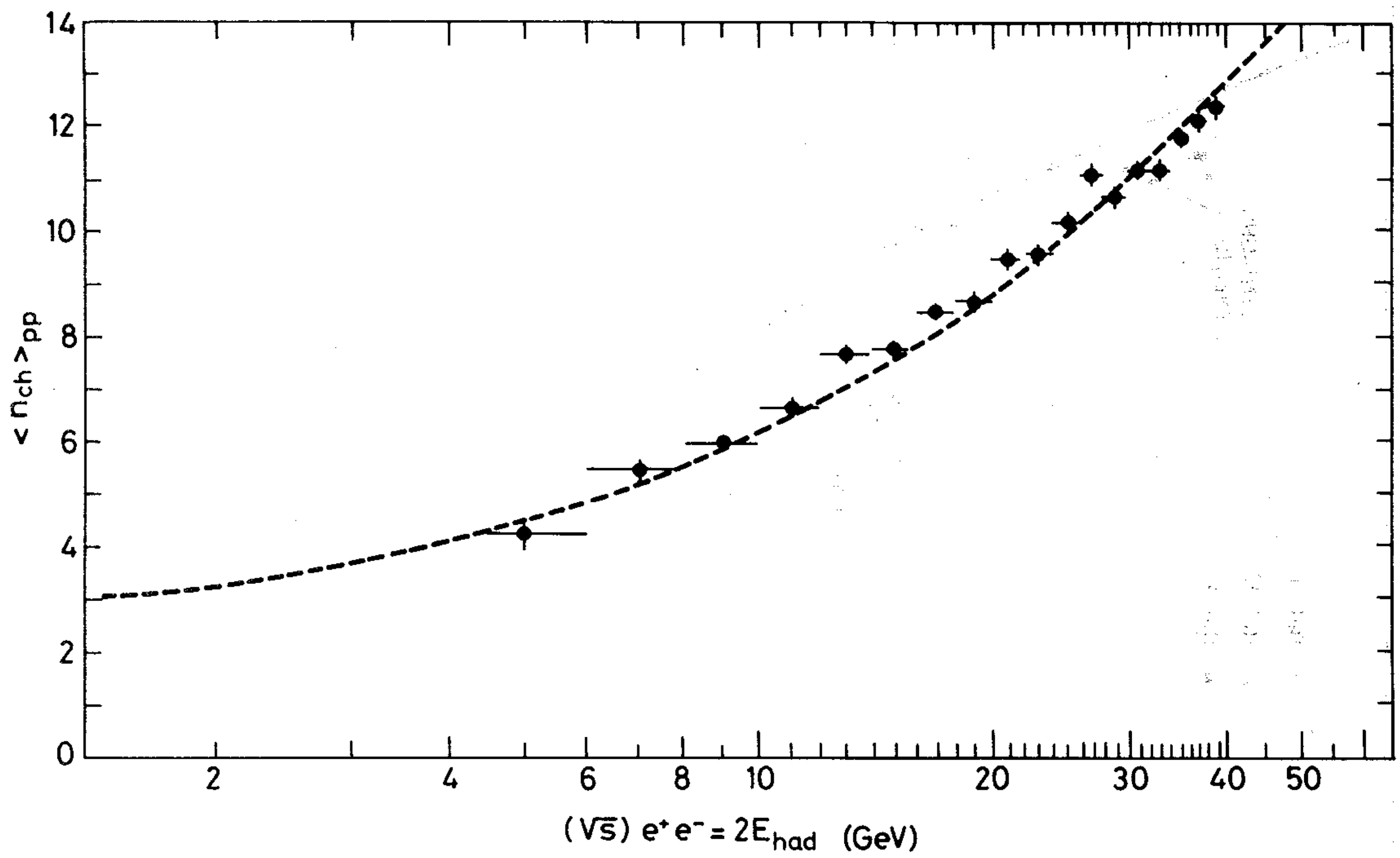

Fig. 2

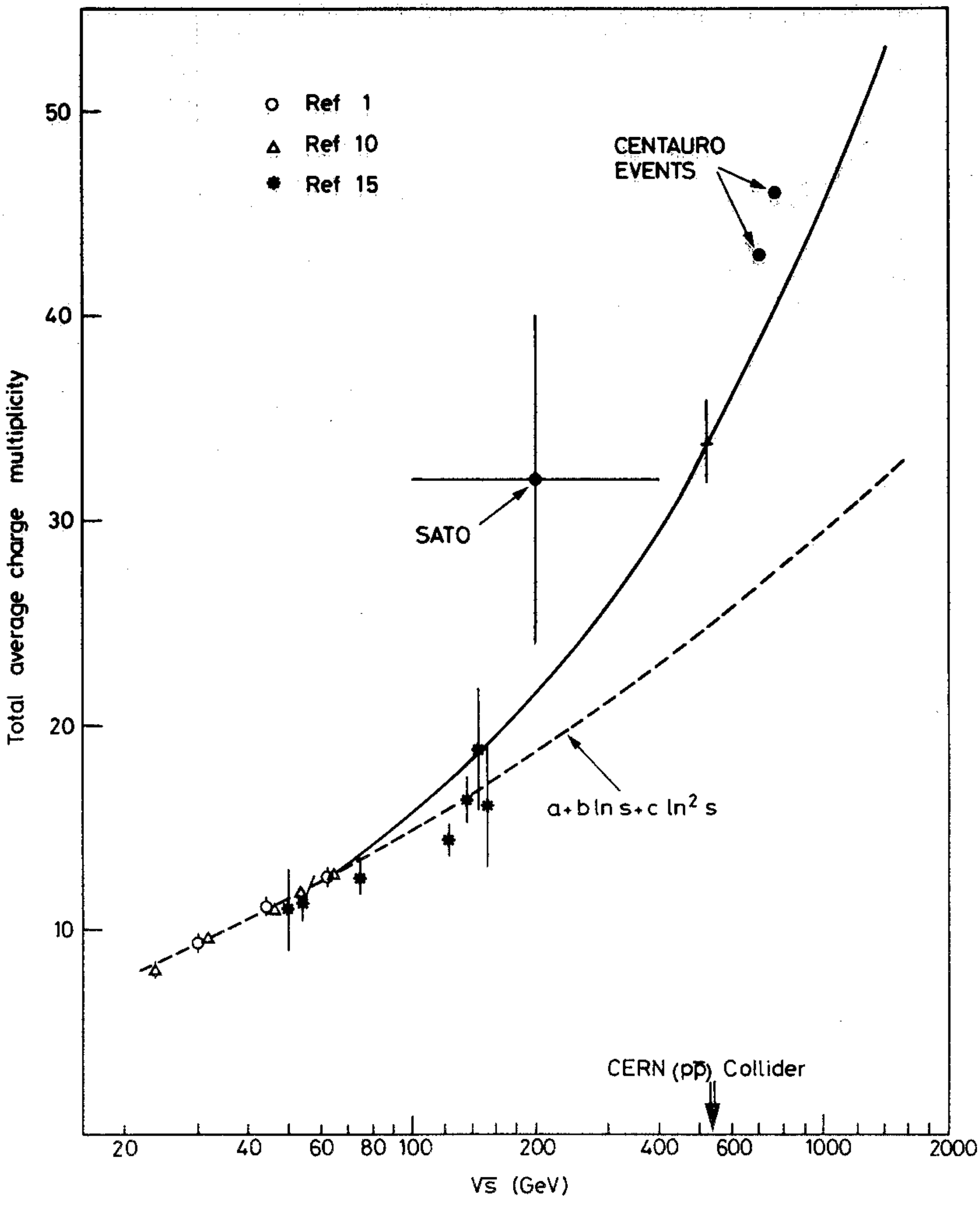
Ref 1
Ref 10
Ref 15
CENTAURO
EVENTS
SATO
a+b ln s+c ln² s
CERN (pp̄) Collider
Total average charge multiplicity
√s (GeV)
50
40
30
20
10
20
40
60
80
100
200
400
600
1000
2000

Fig. 3