PHOTON AND HADRON PRODUCTION OF OPEN HEAVY FLAVOURS

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1. MOTIVATIONS

The production of heavy flavours by neutrinos, photons, and hadrons is widely studied at present, with a threefold purpose.

i) It is a source of information on the production mechanism of heavy quarks. Our interest in such processes is obviously connected with our prejudice that perturbative QCD, owing to the high mass involved, should be a relevant description. However, we should also be prepared for surprises: the discovery of abundant forward production of charm in hadronic collisions was indeed a major one, and it is still mysterious. Another important reason to reach some understanding of the production mechanism, besides scientific curiosity, is that we need it in order to extrapolate reliably to the future machines, have an idea of what we could expect there, and build the relevant detectors.

ii) It is a source of information on the internal structure of the particles involved in the collision. For instance, if one knows how to identify and isolate the contribution of the γ-gluon fusion mechanism in photoproduction, one will get the distribution of gluons in the target nucleon. Another question, much debated at this meeting, is the possible existence of an intrinsic heavy-flavour component inside the hadrons. We have just heard about the strange sea of the nucleon, extracted from charm neutrino production -- and so on.

iii) It is a source of information on the spectroscopy of heavy flavours. Up to the recent past, this was considered as a monopoly of e^+e^- rings, and this point of view is still basically correct. However, it should be remembered that the absolute rates in photoproduction, and especially in hadroproduction, are much higher than at e^+e^- rings. Let us, for instance, compare the 9 nb of cross-section on the "charm factory" with the tenths or hundredths of microbarns we will be considering in charm hadronic production. Therefore if owing to the existence of a favourable production mechanism or a favourable decay mode, the usual smallness of the signal/background ratio can be circumvented, information on heavy-flavoured particles can be obtained. It may even be reasonable to think of these processes as a method of discovery.

2. METHODS

How do we proceed? Three methods can be used, generally in combination.

2.1 Bump hunting

This is the classical way. We have first to ensure a reasonable signal/background ratio. This clearly depends on the projectile, i.e. on the proportion of relevant events we are starting with: it is well known that for neutrinos, photons and hadrons they are ~ $10^{-1}/10^{-2}/10^{-2}$-10^{-3}, respectively. Then, a crucial feature governing the visibility of a signal is the combinatorial level, which has to be decreased as much as possible. A good mass resolution (to fully exploit the quasi-zero width of the signal), much information on the identity of particles, the elimination of events with a too large multiplicity -- these are the usual weapons in that fight. This is well known and I will not dwell on it any further here.

I would like, instead, to discuss briefly the statistical significance of the signal that can be obtained. First, in relation to the mass calibration: Suppose you have a perfectly well calibrated spectrometer and you are looking for a known particle. What you can do is to prepare your mass binning in advance, centring it where you expect the particle to be, and choosing the bin width in accordance with your mass resolution. This procedure will provide the maximal significance. If on the contrary you do not know your mass calibration well, and allow the signal to appear anywhere in a substantial mass interval, the freedom you take should be considered in the expression of the statistical significance of your result in order to decrease it (and eventually destroy it).

Then in relation to cuts. Ignoring the physics, one is naturally led to try various cuts on data. It is a general tendency to consider as "good" a cut which gives one the expected signal, and to forget about the others. Even if this is indeed the right signal, the cut may have selected a favourable fluctuation and the cross-section will be overestimated.

2.2 Prompt leptons from semileptonic decays

This is now widely used, and most of the results presented here have been obtained through prompt leptons. Some experiments, such as those with the beam dumps, just measure the prompt lepton yield. Others tag the event by a prompt lepton from one member of the created pair, and look for the hadronic decay of the other one. The inconvenience is that one does not know for sure which individual state has provided the lepton and therefore which semileptonic branching ratio one should use. People generally adopt reasonably weighted mean values of different branching ratios.

2.3 Seeing short-lived particles

This may turn out to be the best solution. Many techniques used in connection with spectrometers have already given results. They provide the only way to measure lifetimes. But in principle they can also give unbiased information on production mechanisms and total cross-sections. Such an ideal detector has to be: i) fast, because luminosity and therefore high fluxes are needed; ii) visual, in the sense that it should allow each track to be attributed individually to a vertex (primary or secondary), so that inside the event you have no more combinatorial problems. A mere silicon-active target[1] does not fulfil this requirement. However, extrapolation methods from a downstream silicon microstrip detector could provide the solution. It can indeed be shown that, in order to isolate the decay vertex of a particle of lifetime τ_0, a transverse accuracy of ~ $c\tau_0$ is needed in the extrapolation. For $\tau_0 = 10^{-13}$ s, this implies ~ 30 μm accuracy, which is severe but by no means unrealistic. Figure 1 describes one such existing device[2].

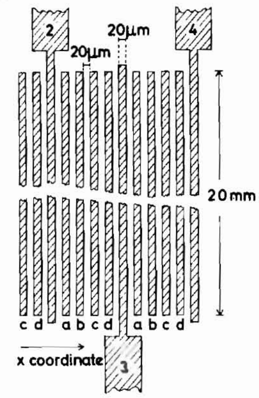


Fig. 1

3. INPUT

When performing these studies of production mechanisms, we should know the main properties of the objects we are looking for. Some input, from theory or from other experiments, is needed. It is clear that up to now most of the information was due to the e^+e^- rings.

Again, this year, a new set of data became available, tightening the constraints. Beauty, although not seen directly, is nevertheless familiar[3]. Its semileptonic branching ratio has been measured and is around 10%. Cascading through charm seems to be its favourite decay. Decay to (ψ + anything) is not excluded at the 2% level. Its mass is well constrained, both theoretically and experimentally. All this is good news for spectroscopy. However, its lifetime is still unknown. The present limit[4] $< 5 \times 10^{-12}$ s is still far from the goal, and we do not know yet whether it will be accessible through visual techniques.

The existence of Truth has not been demonstrated but it is likely, as inferred from the properties of b decay: namely, the absence or low level of flavour-changing neutral currents[3].

About Charm, it seems that there is some hesitation about lifetimes. For instance, a question was recently raised[5] (Fig. 2) about the possible admixture of long-lived baryons (csd, for instance) among the neutral decay generally attributed to D^0's. This is relevant not only for lifetime measurement but also for production mechanisms. The Λ_c properties have been determined quite well by e^+e^- experiments[6].

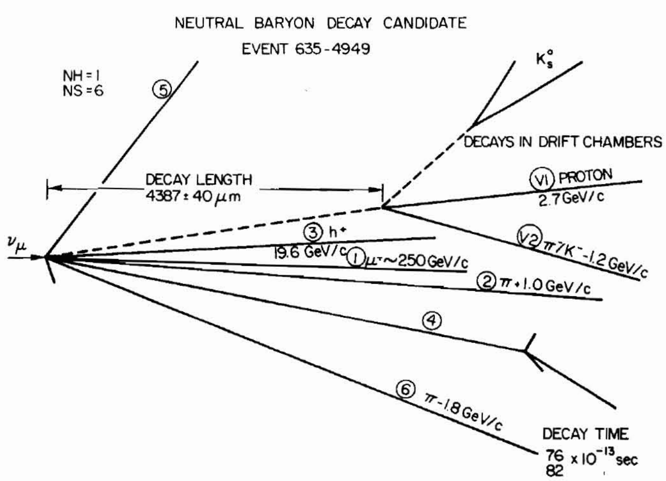


Fig. 2

However, many unknowns are still present. One example is the semileptonic decay of Λ_c, and we will see that this ignorance will prevent us from drawing conclusions about some production models. Another example is the F: apart from its first observation at DASP[7], the F has been very elusive in e^+e^-, and only upper limits on its production have been obtained since[8]. From emulsions, information on F's is generally suffering from ambiguities[5].

4. PHOTOPRODUCTION

4.1 Survey of high-energy experiments

4.1.1 CIF[9,10]

This collaboration, using the broad-band beam at Fermilab, has obtained results at a mean photon energy of 165 GeV. They have observed $D^{*\pm}$, Λ_c and $\bar{\Lambda}_c$, D^0 and $\bar{D}^0$, and find that the production is particle-antiparticle symmetric. They extracted the cross-section, assuming a "diffractive" mechanism. Here and in the following, "diffractive" simply means that the $c\bar{c}$ quark pair has taken most of the photon energy; it does not imply a genuine diffractive mechanism. For instance, γ-gluon fusion would belong to that category. This collaboration obtained cross-sections for the channels listed above (Fig. 3), all of which have been published[10]. Adding them, with some reasonable hypothesis on the relative populations of unobserved channels, they come to a cross-section of ~ 1 μb. This is not supposed to be the total charm production cross-section, since, owing to the acceptance of their set-up and of their trigger, they would not be sensitive to mechanisms such as central production. Let us call it the "diffractive" charm cross-section.

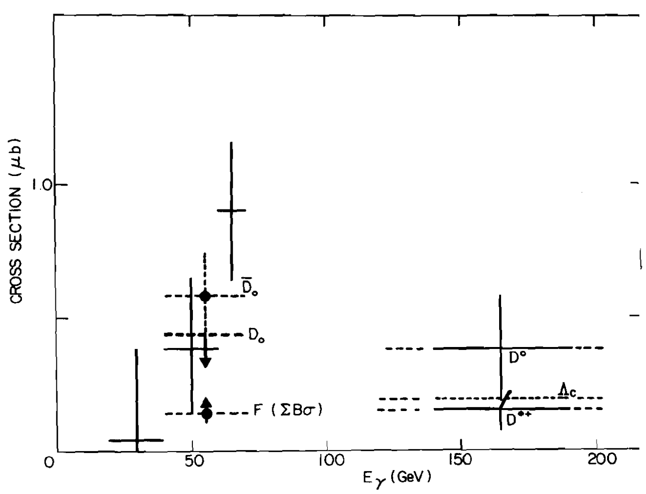


Fig. 3

4.1.2 WA4[11,12]

This collaboration used the tagged γ beam and the Omega spectrometer. The photon energy was 40-70 GeV. The observed production is particle-antiparticle asymmetric: the $\bar{D}^0$ is seen, not the D^0 (Fig. 3). This is likely to be due to $C\bar{D}^0$ associated production, since tagging by a proton supposed to come from the C, is beneficial to the extraction of the $\bar{D}^0$ signal.

The F is observed[13], faintly, but in four independent channels at the same mass (Fig. 4 and Table 1). The sum of observed (Bσ)'s already reaches ~ 100 nb. This is not in conflict with e^+e^-

THE SIGNAL $F^\pm \to \phi\rho^\pm$

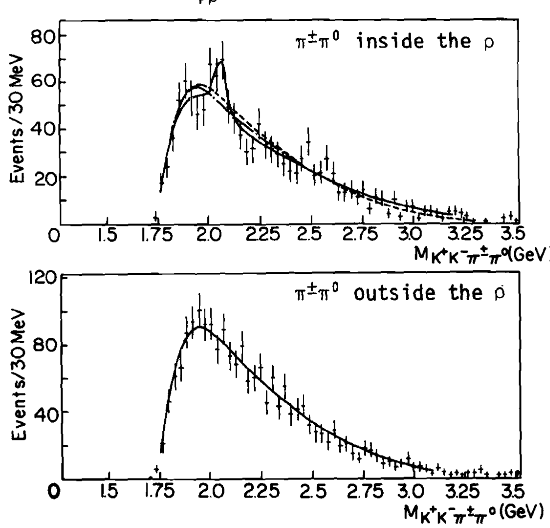


Fig. 4

Table 1

Mode	M (GeV)	B•σ (nb)
$\eta 3\pi$ [3]	2.021 ± 0.013	60 ± 15
$\eta' 3\pi$	2.008 ± 0.020	20 ± 8
$\eta\pi$	2.047 ± 0.023	27 ± 7
$\phi\pi$		< 4.0
$\phi\rho^\pm$	2.049 ± 0.015	33 ± 10
$\phi(\pi\pi\pi)^\pm$		< 15

data or limits. However, this would imply that the annihilation channels leading to π's, and not observable in this experiment, do not represent the majority of F decays -- otherwise the F photoproduction cross-section would reach an unreasonable value.

This experiment has a broad x^* acceptance, and it is not likely that it would miss any production mode because of a lack of coverage. It is supposed, therefore, to measure the total cross-section. Adding up channels is a delicate operation owing to the scantiness of the numerical information available. Anyway, it is clear that a value of at least 1 μb will be obtained (Fig. 5).

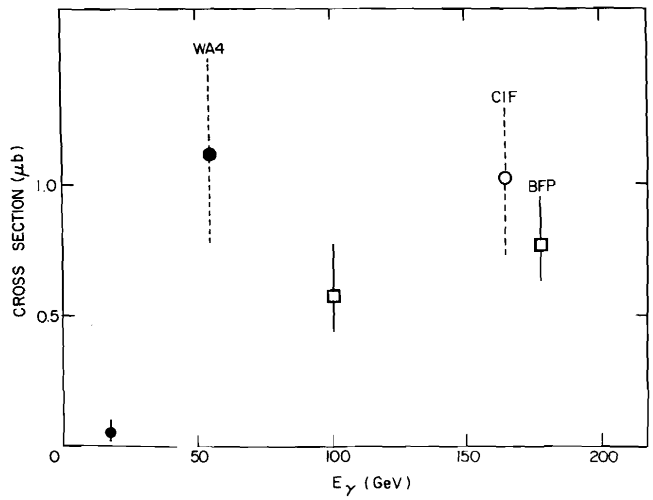


Fig. 5

4.1.3 Virtual photoproduction

This has been covered by Strovink[14] at this Conference. Both BFP[15,16] and EMC[17,18] measure, through dimuons (and trimuons for EMC), the "diffractive" charm photoproduction. They extract their cross-section in the framework of a γ-gluon fusion mechanism which seems to reproduce the data satisfactorily. Only the BFP Collaboration has performed the extrapolation to $Q^2 = 0$, but the two experiments are certainly in agreement (Fig. 6). The BFP cross-sections are shown in Fig. 5). Again these two experiments would be insensitive to mechanisms such as central production. A qualitative argument given elsewhere[19] seems even to suggest that beyond this "diffractive" cross-section an extra amount of charm production is required. All available data are shown in Fig. 3 (channels) and Fig. 5 (σ_{tot} or $\sigma_{diffractive}$). These data are rather meagre, and one would clearly dream of a high-luminosity, wide-acceptance experiment spanning that domain. One piece of good news is that γ physics seems to have obtained high priority at the Tevatron.

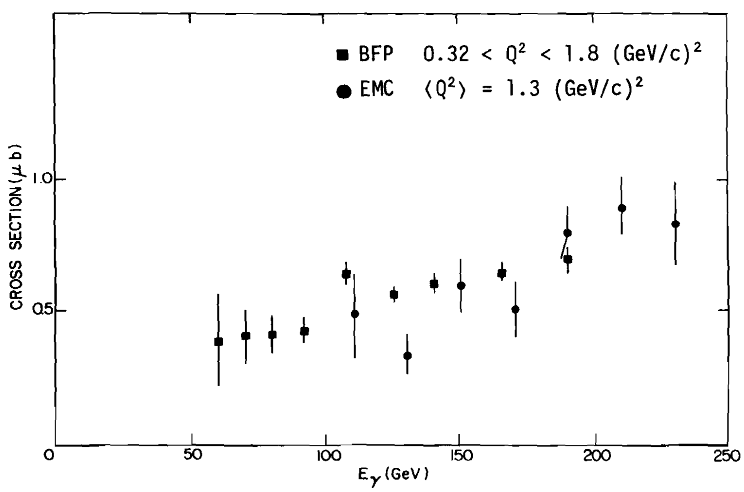


Fig. 6

4.2 The SLAC experiment[20,21]

Figure 5 shows a low-energy measurement. This is new and is due to a nice experiment performed at SLAC with the Hybrid System (Fig. 7) fed by a back-scattered laser beam peaking at 19.5 GeV (Fig. 8). Figure 9 shows the quality of the pictures taken in the rapid-cycling bubble chamber. Lifetime measurements have been performed (see Foà's talk at this Conference) as well as a measurement of σ_{tot}. The estimate of event visibility, i.e. the probability to see at least one multiprong decay (Fig. 10), has been made under various reasonable assumptions for lifetimes. It does not depend much on the production mechanism, and ranges between 0.25 and 0.5. This group can thus give a σ_{tot} of $50 \pm ^{45}_{20}$ nb, where the errors include all possible uncertainties.

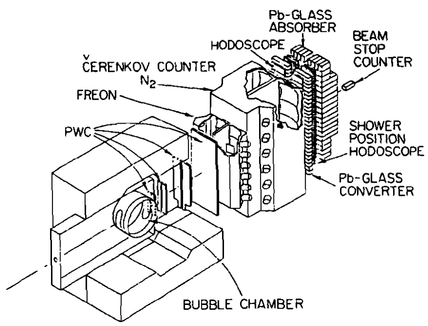


Fig. 7

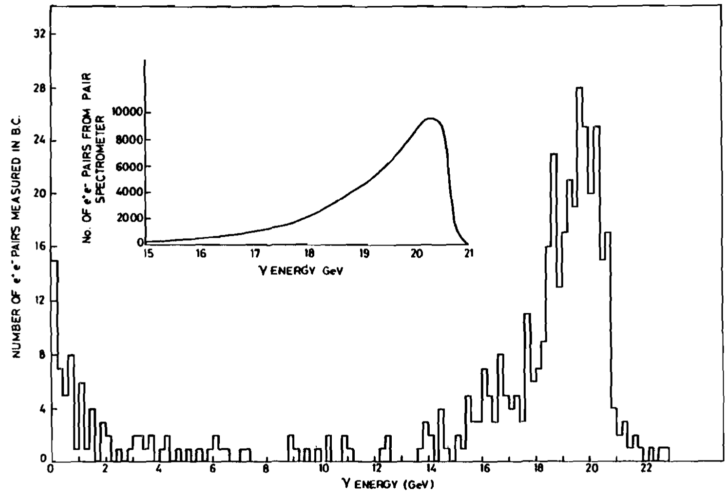


Fig. 8

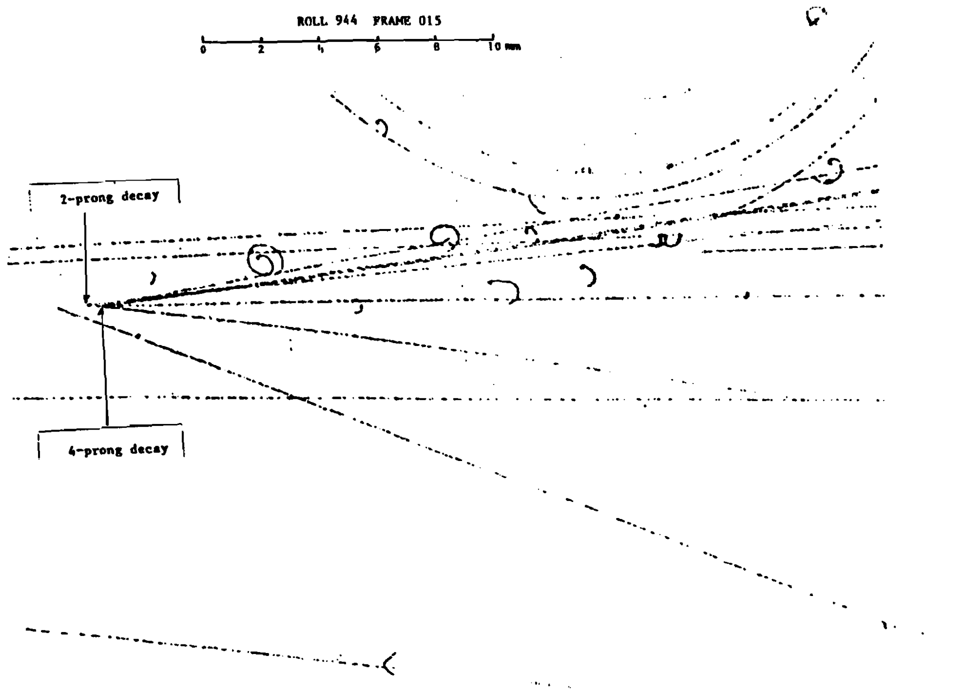


Fig. 9

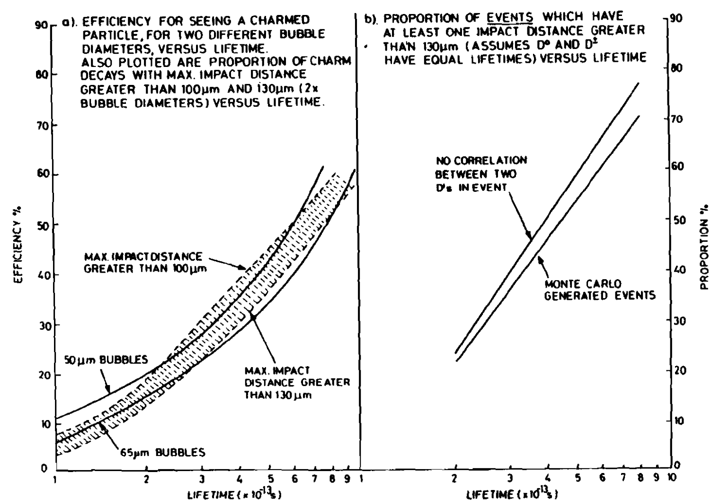


Fig. 10

4.3 Comparison with models[22]

The γ-gluon fusion models are compatible with all measurements except the σ_{tot} found by WA4 (Fig. 11). The freedom due to the possible choices of the gluon distributions is visible there. however the "naive" choice with exponent 5 is quite adequate. Not indicated is the freedom due to the choice of the charmed quark mass, m_c: varying it inside the domain (1.5 ± 0.4) GeV, mostly frequented by the community of theorists, changes the predictions by an order of magnitude or so. There again, the classical choice m_c = 1.5 GeV is adequate. It is clear from these figures that i) data are not accurate enough to impose many constraints on the model; ii) the WA4 point cannot be reproduced "naturally" by such a model. However, one may ask whether it should. The γg fusion model, by construction, is relevant only for "diffractive" production and is unrelated to mechanisms such as central or associated production. Here one may recall what happens for ψ inelastic photoproduction: a substantial inelastic production is present, which may be related to higher-order QCD terms (although the absolute magnitude seems to be very different) but not to the lower-order γg fusion mechanism.

The generalized vector meson dominance[23] (Fig. 12) has also some degrees of freedom. For instance λ, the VDM correction term, experimentally measured to be 2.5 ± 0.3 at the ψ mass[24],

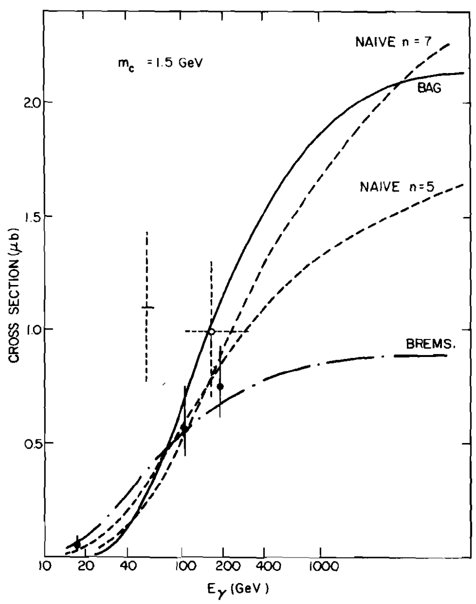


Fig. 11

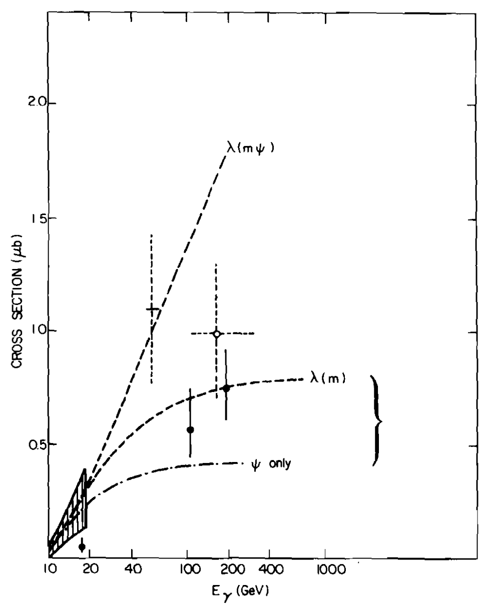


Fig. 12

is basically unknown for the ψ family and the continuum. Choosing λ(mψ), or guessing a variation of λ with the mass, makes a lot of difference. Other quantities are important, such as the exact variation with energy of σ(ψN) and, at low energy, the Re/Im ratio. With all that freedom, the model can certainly reproduce the high-energy data but not the SLAC measurement at 19 GeV, which is definitely too low.

Finally, the model[25] combining QCD (asymptotically) and a shape at finite energies dictated by unitarity (i.e. deduced from ψ photoproduction data) seems higher than all data, except the WA4 result (Fig. 13).

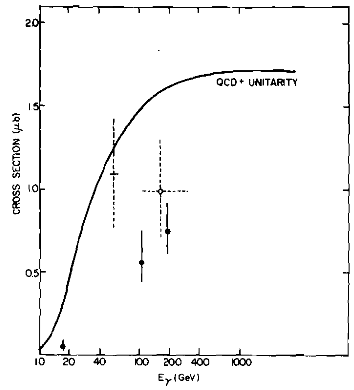


Fig. 13

4.4 Production mechanism

It seems that the type of asymmetric production observed by WA4 is very reminiscent of what happens in strangeness production. Probably mechanisms involving fusion processes and diquarks could explain it[26].

Experimentally, it would be interesting to check it against other data. Both the SLAC experiment, at lower energy, and the experiment WA58[27,28] using emulsions (Fig. 14) and the Ω' spectrometer, at the same energy, could do it. However, inspection of their reconstructed events (see Foà's lecture) shows that it is too early to reach any conclusion: limited statistics and frequent ambiguities make it impossible, for the moment, to confirm or disprove a substantial contribution of associated production or asymmetric behaviour of D's and D̄'s.

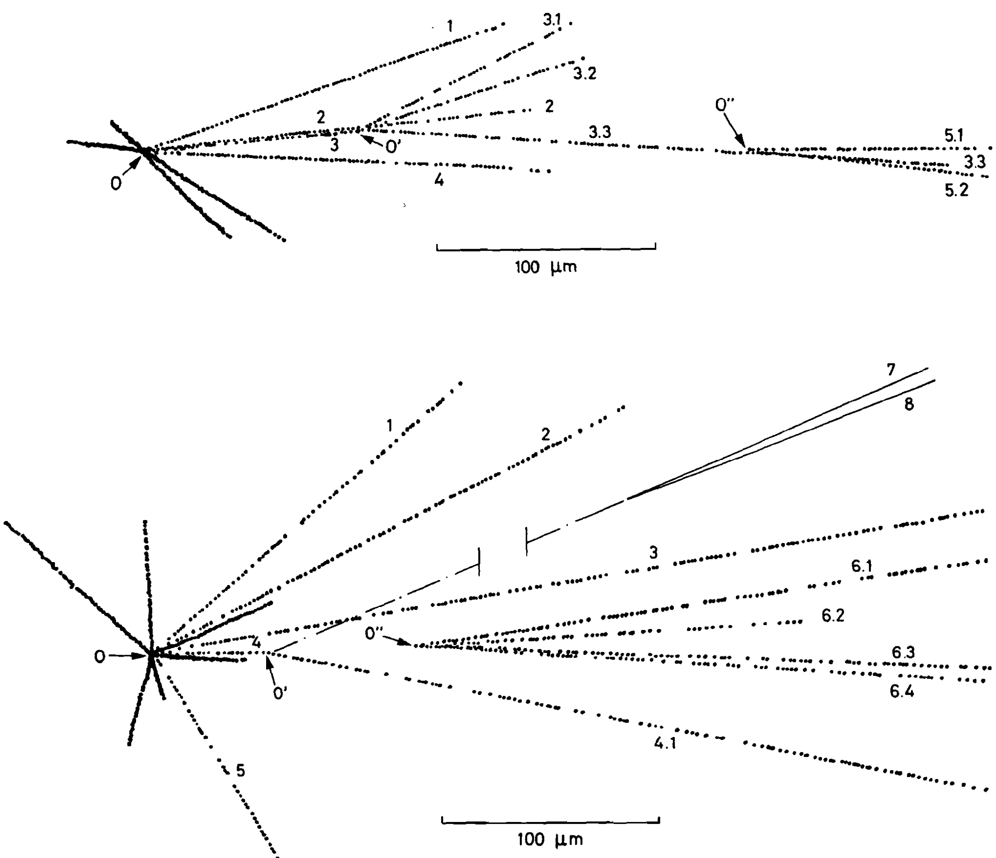


Fig. 14

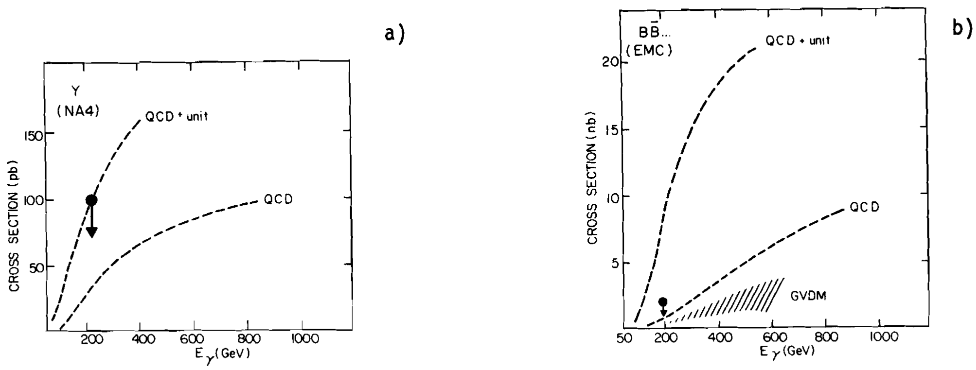


Fig. 15

4.5 Υ and beauty photoproduction

A new upper limit on Υ production by muons has been given at this conference[29]. It is shown in Fig. 15, where it has been re-expressed for real γ of 200 GeV. It can be seen that it falls right on the prediction of the already mentioned (QCD+unitarity) model. The QCD prediction is still much below.

For B production, the upper limit obtained from the three exotic trimuons of the EMC[30] is already below the (QCD+unitarity) model. However, large systematic errors could be present.

5. HADROPRODUCTION AT CERN SPS AND FERMILAB ENERGIES

I would like to give a brief description of:

- the results of the CERN beam dump experiments[31] (prompt ν) from the point of view of charm production;
- the results of the Fermilab beam dump experiment[32] (prompt μ);
- and the results of four recent experiments which have measured charm production under very different conditions.

5.1 The CERN beam dump experiments

The signal observed was that of prompt neutrinos from 400 GeV pFe interactions at a very small angle, < 1.8 mrad. Three experiments [BEBC[33], CHARM[34], CDHS[35]] have recorded data. Here I will just mention what the data imply for charm hadroproduction and refer to previous reviews[31]:

i) If, as advocated by these experiments (or at least by two of them), the ν_e flux is smaller than the ν_μ flux, then charm cannot account for that effect and another explanation should be added.

ii) If, as advocated by CDHS, the ν_μ flux is larger than the $\bar{\nu}_\mu$ flux (the ratio quoted is 2.3, but the very existence of a prompt $\bar{\nu}_\mu$ signal is questioned by this experiment), then Λ_c or charmed baryon production could be a relevant explanation. If the production spectrum of the Λ_c is rather flat (~ 1-x, see later) and assuming that the totality of the prompt ν_μ signal is due to that source, it would correspond to $\sigma(\Lambda_c)B(\Lambda_c)(\to \nu \ldots) \leq 1\ \mu b$. This implies either a small Λ_c production or a small semileptonic branching ratio. Furthermore, the associated charmed particle, say a $\bar{D}$, should not be produced in the same way. However, the CDHS data do not like a $(1 - |x_F|)$ distribution. With a $(1 - |x_F|)^3$ distribution, the limit on $\sigma(\Lambda_c)B(\Lambda_c)$ is ~ 3.5 µb, which is much less stringent. (I am indebted to H. Wachsmuth and F. Dydak for discussions on these matters).

iii) If the results are classically interpreted as being due to associated central $D\bar{D}$ production with a linear A dependence, one gets the cross-sections indicated in Table 2. Note that in the extraction, different assumptions on the ν_μ/ν_e ratio are made by the experiments.

Table 2

$\sigma(pp \to D\bar{D}X)$

for $E(d\sigma/dp^3) \simeq (1 - x)^4\ e^{-2p_T}$,

an 8% branching ratio, and a linear A dependence

CHARM	BEBC	CDHS
18 ± 6 µb	17 ± 4 µb	~ 10 µb
with $\frac{\nu_e}{\bar{\nu}_e} = 1$		with $\frac{\nu_\mu}{\bar{\nu}_\mu} = \frac{\nu_e}{\bar{\nu}_e} = 2.3$

5.2 Fermilab beam dump experiment[32]

This experiment was carried out by sending 350 GeV protons into a muon spectrometer (Fig. 16). Using a variable density technique, this group obtained a signal for prompt μ's of either sign. The angular and x domains covered are quite different from those of the CERN beam dump experiments. Part of the Fermilab experiment was done with a cut-off below 20 GeV for the muon; they have also a preliminary measurement with a cut-off reduced to 8 GeV/c. From the integral curve (Fig. 17a) giving the yield of prompt μ's above a given momentum, they can extrapolate to the origin and get the total μ flux. They find

$$\mu^+ = (12.2 \pm 3.8) \times 10^{-6}$$
$$\mu^- = (10.1 \pm 2.6) \times 10^{-6}$$

i.e. the equality of μ^+ and μ^- yields. Therefore they do not support the particle/antiparticle asymmetry found by CDHS (note, however, the difference in the domains covered).

Both the integral curve (Fig. 17a) and the differential spectra (Fig. 17b) are well fitted by assuming central $D\bar{D}$ production,

$$E\frac{d^3\sigma}{dp^3} \sim (1-x)^{4.7} \exp(-2.5 p_T) ,$$

with a total amount of 16 μb.

Also shown in Fig. 17b are curves indicating the maximum yield that can be tolerated from charm because of an intrinsic component in the projectile[36], i.e. symmetric large-x production of $\bar{D}\Lambda_c$. The Λ_c would contribute to μ^+: the maximum tolerable $\sigma(\Lambda_c)B(\Lambda_c)$ is ~ 0.1 μb. Again, we can fall back on our ignorance of B. However, $\bar{D}$ would contribute to the μ^-; the limit is again $\sigma_{\bar{D}}B_{\bar{D}}$ ~ 0.1 μb, and her B is known. Even assuming an $A^{2/3}$ dependence for the production, since this is not a hard process, t experiment shows that only 3 μb can be attributed to charm production owing to the intrinsic componen This model was invented to explain Λ_c forward production at the CERN Intersecting Storage Rings (ISR) with a cross-section ~ 100 hundred times bigger; it would therefore have to exhibit a fantastic rise between $\sqrt{s} \simeq 27$ and $\sqrt{s} = 63$ GeV. This is in contradiction with the modest rise (~ 3) it predicts between these two values.

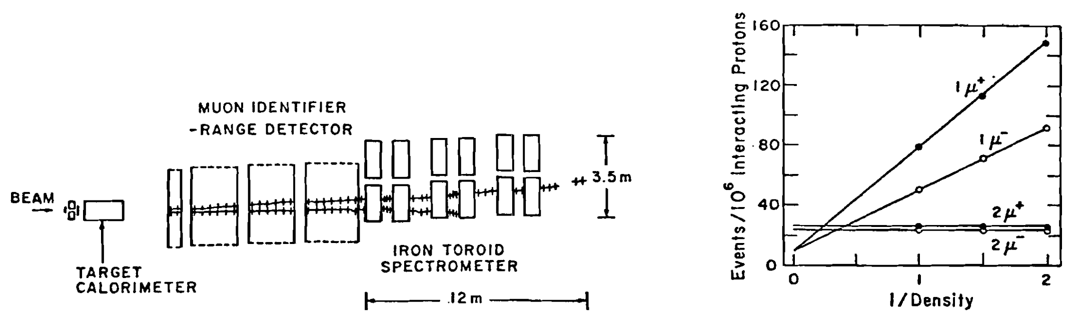


Fig. 16

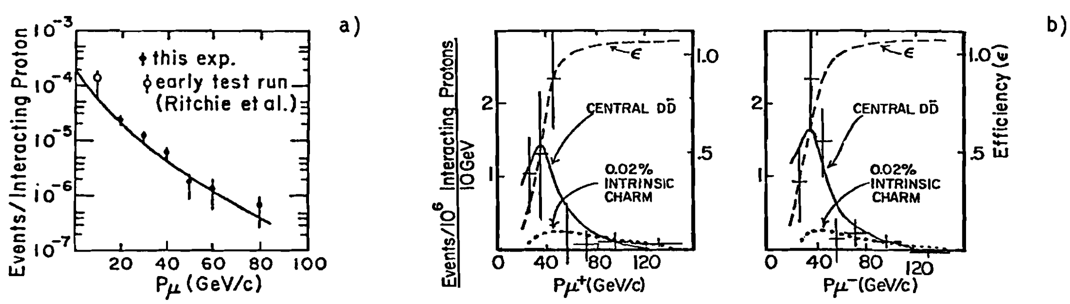


Fig. 17

5.3 Central production of D* [37] (Fig. 18)

This was done by the FPS Collaboration[38] at Fermilab, where 200 GeV π^- were sent on Be, the idea being to observe the $D^{\pm *} \to D^0\pi^{\pm}$ cascade. The $K^{\pm}\pi^{\mp}$ decay of the D^0 is detected by a bispectrometer, and the π from the cascade in a soft-pion spectrometer. Peaks are observed both in $m_{K\pi}$ and in the Q-value spectrum. A model-independent value for

$$\left.\frac{d\sigma}{dy}\right|_{y=0} = (1.6 \pm 0.5)\ \mu b$$

is found. If interpreted as central production,

$$E\frac{d^3\sigma}{dp^3} = A(1-|x|)^3 \exp(-1.1p_T^2)\ ,$$

this would correspond to a total cross-section for D^* production:

$$\sigma(D^*) = [\sigma(D^{*+}) + \sigma(D^{*-})]/2 = (4.2 \pm 1.4)\ \mu b\ .$$

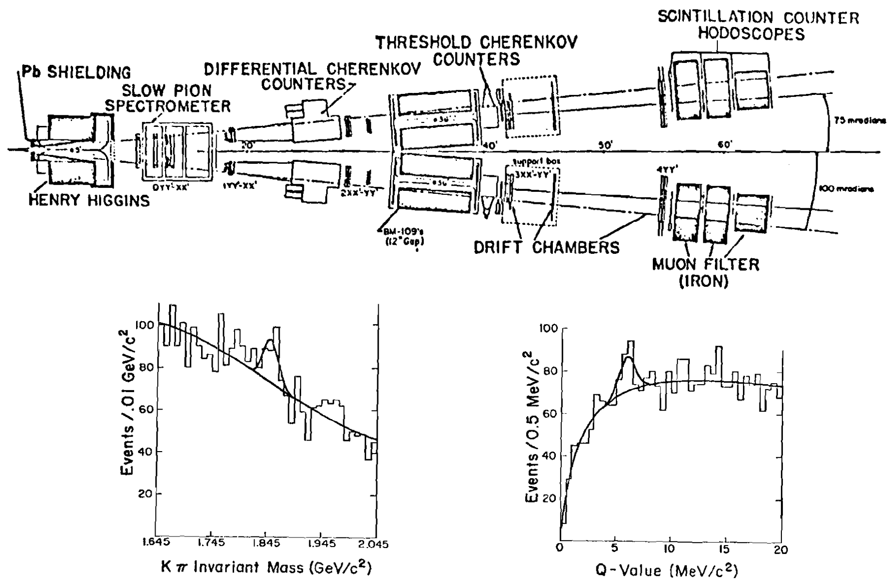


Fig. 18

5.4 Diffractive production of $D\bar{D}$ [39]

This experiment (using the Chicago Cyclotron set-up) (Fig. 19) has measured the production of $D\bar{D}$ systems produced in the diffractive excitation of 217 GeV incident π^- on protons. The idea is to tag by a prompt μ, to select the mass range of the forward system through the recoiling proton (TOF,

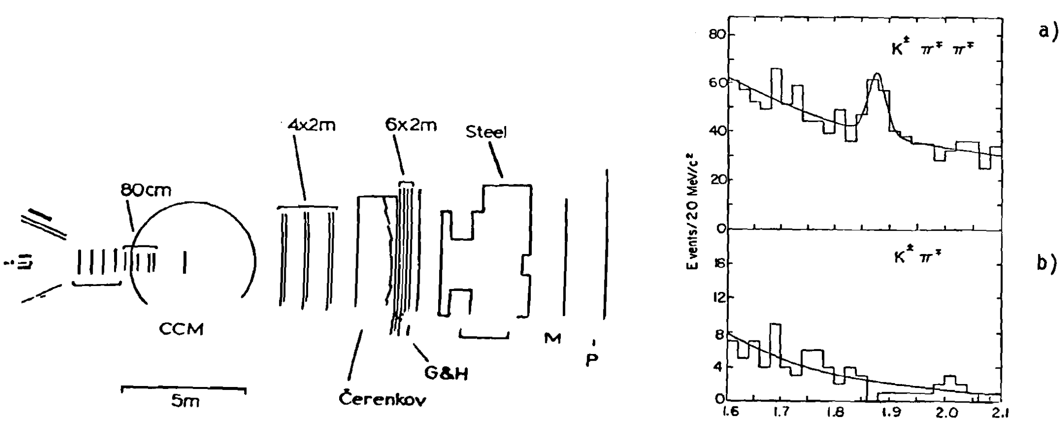


Fig. 19

angle), and to observe the other charmed particle in the exotic mode $K^{\mp}\pi^{\pm}\pi^{\pm}$. Because of the semi-leptonic branching ratios, this experiment selects mostly D^+D^- pairs. The signals are quite clear and the yields are particle-antiparticle symmetric. The x distribution favours the idea that the charm particles indeed come from the decay of a diffractively excited π. Assuming such a diffractive mechanism and under various hypotheses, the authors give a cross-section $\sigma(D^+D^-) = (7\text{-}10) \pm 4$ μb. This should represent only part of the diffractive cross-section, since channels such as $(D^0\bar{D}^0 \ldots)$ or $(D^{\pm}D^0)$ are missed.

5.5 Charm at the EHS [40]

Data are now available from the mini bubble chamber LEBC associated with the European Hybrid Spectrometer (EHS). Exposures to π (360 GeV) and p (360 GeV) were performed. The trigger was an int action one. Only a modest amount of information for track identification was available. The sensiti vity corresponding to data processed up to now is still modest: 5 evts/μb for π, ~ 2 evts/μb for p.

From their reconstructed events, the EHS group can, for a given assumption on the lifetime, extract a cross-section for charged D (through the three-prong decays which are supposed to represent 45% of all decays):

$$\sigma(D^{\pm})|_{x_F>0} = 12.5 \pm 5 \ \mu b \ .$$

This is limited to $x_F > 0$ for reasons of acceptance. The cross-section for D^0's is of the same order The properties of reconstructed charm particles favour a central $[(1-x)^{3.2}]$ production, and pairs of reconstructed particles exhibit a striking correlation in rapidity $(\langle\Delta y^*\rangle \sim 0.4)$ (Fig. 20).

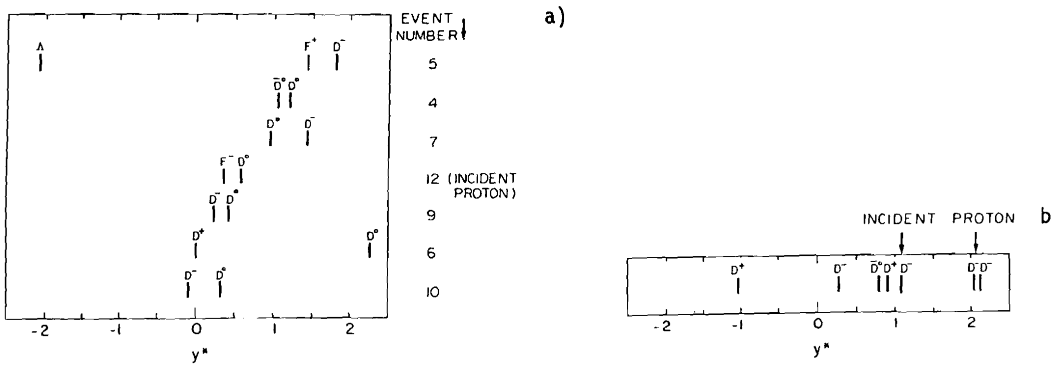


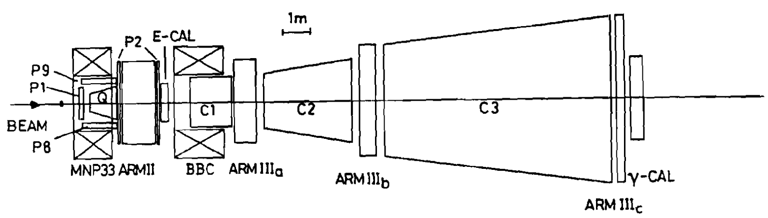
Fig. 20

The results on lifetimes will be described elsewhere[41].

Note that the non-observation of Λ_c in the proton exposure is not meaningful, because of the low sensitivity they get from the only currently accessible modes, $pK\pi(n\pi^0)$.

5.6 D^* and Λ_c from the ABCCMR Collaboration[42-44]

The ABCCMR spectrometer (Fig. 21) was exposed to π^- (175-200 GeV) and p (150 GeV). The trigger was on an $e^{\pm}$. On-line (Čerenkov + total absorption counters + μ processors) and off-line filtering provided a spectacular signal/background improvement (170, finally) which, however, corresponded to a substantial reduction in the absolute yield of charm. Both a faint inclusive D signal and a clear



MNP33/BBC	SPECTROMETER MAGNETS
ARM II,III	DRIFT CHAMBERS (48 PLANES)
C1,C2,C3	MULTICELL THRESHOLD CERENKHOV COUNTERS
P1,8,9,2	MULTIWIRE PROPORTIONAL CHAMBERS

Fig. 21

$D^* \to D\pi$ cascade (Fig. 22) were observed with incident π's. The cross-section given under the assumption of linear A dependence and correlated production (through the decay of a 5 GeV object produced according to 1-x) is

$$\sigma(D\bar{D} + X) = 5.4 \pm 2\ \mu b\ .$$

It would be 70% higher if no correlation and a (1-x) distribution for D^* were assumed.

In the 150 GeV proton exposure a clear Λ_c (Fig. 23) signal is seen, reinforced by some evidence for the $\Sigma_c^{++}(2440) \to \Lambda_c\pi$ cascade (Fig. 24). The cross-section, extracted assuming a rather flat (1-x) dependence for the Λ_c and a central one $[(1-x)^{4.5}]$ for the meson providing the tagging e, is pretty large

$$\sigma(\Lambda_c) = 75 \pm 50\ \mu b\ .$$

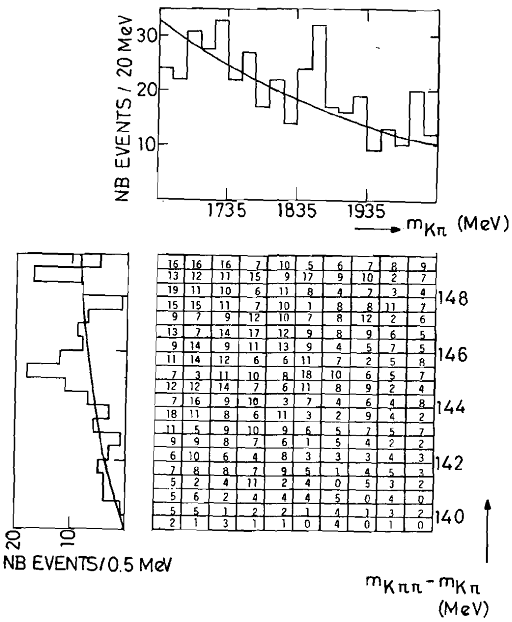


Fig. 22

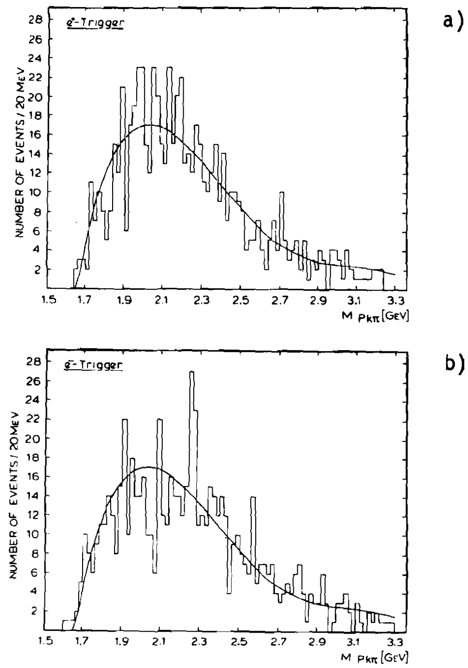


Fig. 23

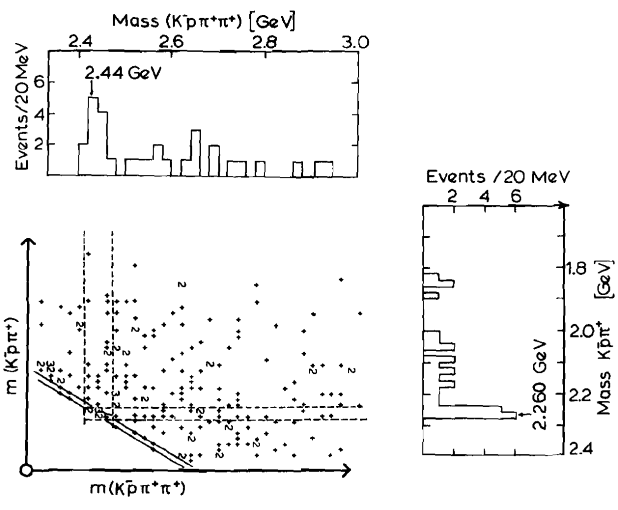


Fig. 24

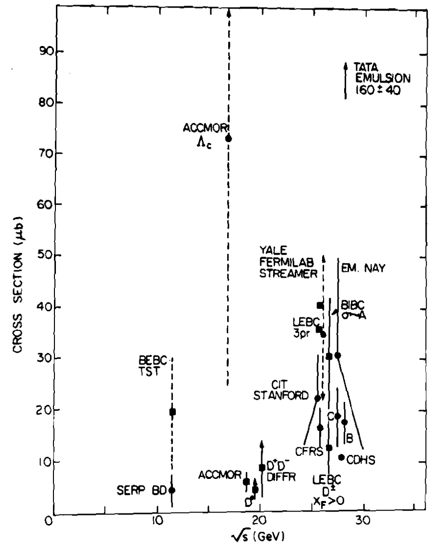


Fig. 25

The large error bars reflect the preliminary nature of these data. If confirmed, this is an important result. First the strong limit set by the beam dumps on $\sigma(\Lambda_c)B(\Lambda_c)$, under the assumption of a similar (1 - x) distribution for the Λ_c, will force us to conclude that the $B(\Lambda_c)$ is very small (less than 1% if we were to take the numbers at their face value). Secondly, this would give a more satisfactory rise between SPS and ISR results: the Λ_c production would only rise by a factor of 3 or so, which looks reasonable in several models. However, ABCCMR should also prove that forward $\bar{D}$'s are *not* produced with substantial rates; otherwise a conflict with the beam dump results would arise This has not yet been looked for.

The available data are plotted in Fig. 25. Except for the outstanding Λ_c, one can say that a slowly rising cross-section in the 10-20 μb region would accommodate all results.

6. CHARM AT THE ISR

I will not describe here all the results on charm at the ISR[45], but will concentrate on the most recent ones from the BCF Collaboration[46,47], and underline several problems and possible interpretations.

6.1 The BCF results

The BCF Collaboration used the Split-Field Magnet (SFM) set-up (Fig. 26). Table 3 gives the list of channels explored and the way they tagged them (by an $e^{\pm}$; and sometimes, in addition, by a

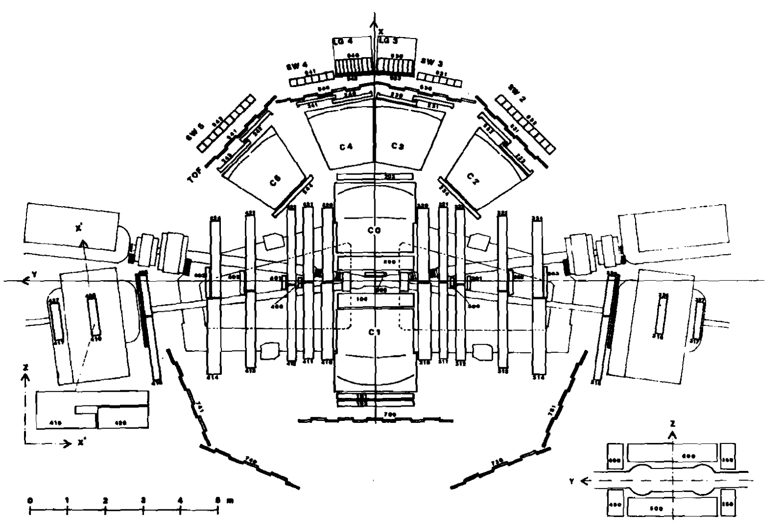


Fig. 26

K identified by TOF). One can summarize their results by saying that they always observe charm when the $e^{\pm}$ sign is in accordance with the GIM mechanism, never in the opposite case.

Let us consider the $D^0 \to K\pi$ signal. It is made quite convincing by a p_T cut (Fig. 27). The peak is well centred. A (peak minus wings) method allows some properties of the D to be extracted:

- the p_T dependence, well fitted by $\exp(-2.5\ p_T)$;
- the x dependence (Fig. 28), incompatible with a flat x distribution, with central production preferred but flat y not excluded.

Figure 28 also shows the x distribution obtained in a similar way for the Λ_c: here a rather flat distribution is observed, similar to the one of the Λ, and totally different from the $\bar{\Lambda}$. This supports the general idea of the presence of leading baryons at the ISR, which the BCF group will exploit for beauty.

Figure 29 shows the results for charm production[48]. Depending on the model used to extract it, the cross-sections can vary by an order of magnitude. The lowest values -- which we are tempted to consider as the most reasonable ones -- are obtained assuming a flat x distribution for Λ_c and a central one for D's. We have seen that this is also what a direct determination favours.

Table 3

Particle	Trigger	Signal
$\Lambda_c^+ \to pK^-\pi^+$	e^-, $x_L(p) \geq 0.3$	YES
	e^+, $x_L(p) \geq 0.3$	NO
$D^+ \to K^-_{TOF}\pi^+\pi^+$	e^-	YES
	e^+	NO
$D^0 \to K^-\pi^+$	e^-, K^+_{TOF}	YES
	e^+, K^+_{TOF}	NO
$D^+ \to K^-\pi^+\pi^+$	e^-, K^+_{TOF}	YES
	e^+, K^+_{TOF}	NO
$D^0 \to K^-_{TOF}\pi^+\pi^+\pi^-$	e^-	YES
	e^+	NO
$D^- \to K^+_{TOF}\pi^-\pi^-$	e^+	YES
	e^-	NO
$\bar{D}^0 \to K^+_{TOF}\pi^-\pi^-\pi^+$	e^+	YES
	e^-	NO
$\Lambda_c^+ \to p_{TOF}K^-\pi^+$	e^-	YES
	e^+	NO
$\Lambda_c^- \to \bar{p}_{TOF}K^+\pi^-$	e^+	YES
	e^-	NO

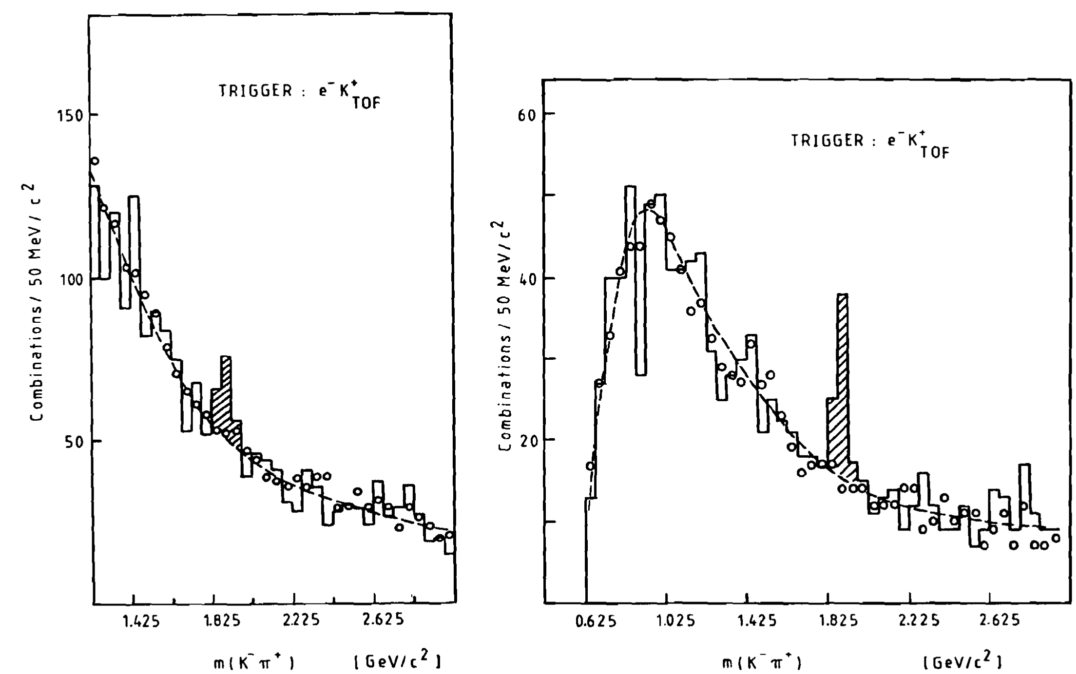


Fig. 27

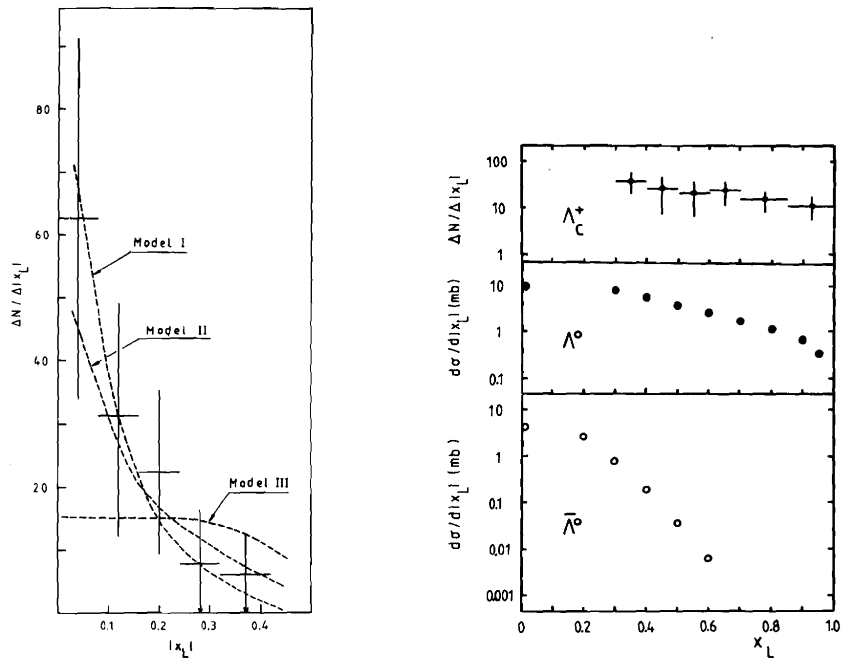


Fig. 28

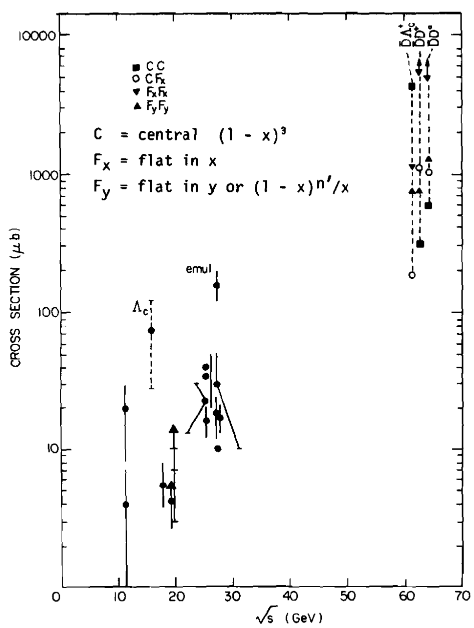


Fig. 29

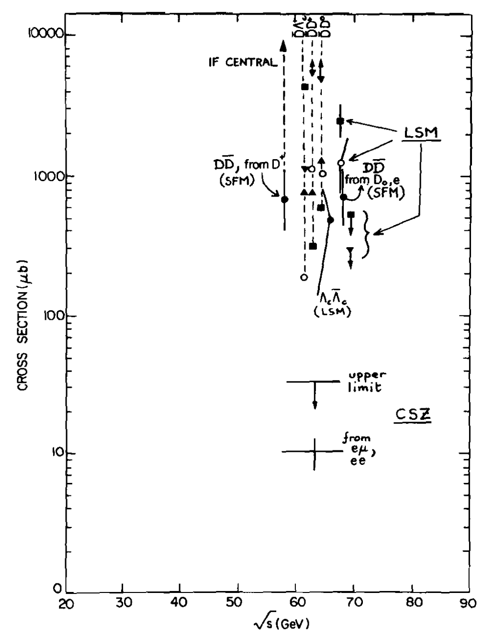


Fig. 30

6.2 Some problems

One can compare this set of results with other ISR results (Fig. 30). First the "old" CSZ[49] measurement[50] of central charm production through dilepton pairs. They extracted the cross-section assuming a central process parametrized à la Bourquin-Gaillard[51], and found values which are far below the BCF ones. It seems impossible, by a simple updating of branching ratios and other parameters, to reconcile these two measurements. Considering now the cross-section obtained by previous experiments at the SFM from their D^0 (e tagged)[52] and D^+ (K triggered)[53] signals, one could at first sight conclude that there is agreement. However, the value from D^+ quoted in Fig. 30 has been obtained assuming a flat y distribution. Since the D^+ observed is at quite a large x, if one considers it as representing the tail of a central production, the resulting cross-section explodes to several millibarns! These are two examples of discrepancies existing within the various data. One could also mention a problem with Λc production: the LAS[54] measurement[55] seems too high compared with others. In such discrepancies it is difficult to tell which is due to experimental distortions and which part is due to misunderstanding, i.e. extraction of the cross-sections under different hypotheses on production mechanism, branching ratios, etc. Clearly a systematic and collective job of reprocessing, along the lines previously indicated[56], would be welcome.

Another still more basic problem that such a study could help to elucidate is the incompatibility between the e/π ratio measured at the ISR[57] and the charm cross-section reported at present. Even taking the lowest values, 1 mb is reached by adding up channels, with a large fraction of charm centrally produced. However it looks impossible, within a central production mechanism, to accommodate more than 150-200 μb within the measured e/π (at 90°). A flat y production would allow for more charm, as previously demonstrated (using e/π 30° data)[58], but the charm cross-section would also be found to be higher and the contradiction is still there. It amounts to a factor of ~ 5 or so.

Whatever the problems and disagreement among the data, it should not mask the important fact that charm is observed at the ISR with quite substantial cross-sections. It would simply be desirable to go from semiquantitative results to a more accurate situation. For the moment, it is difficult, for instance, to discard the possibility that ISR cross-sections, extracted from bump-hunting, could be generally overestimated.

6.3 Possible interpretation

It is reasonable to look for:

i) mechanisms leading to a central production, and

ii) processes explaining the forward production of baryons and eventually mesons.

In the first category, the mechanisms considered[59] (for instance gluon-gluon scattering) (see Fig. 31), generally turn out to be insufficient to explain the ISR cross-sections (remember, however, some preceding remarks on the experimental situation). Furthermore, at low p_T, their relevance is doubtful.

For the second type of production, let me simply list three attempts to explain it.

1) Diffraction excitation: This is a genuine prediction[60]. The mechanisms of Fig. 32 were considered, leading to a logarithmically rising cross-section which could reach ~ 150 μb at the ISR, under likely assumptions on the probability of the creation of a $c\bar{c}$ pair relative to other flavours. As with any diffractive mechanism, it predicts also $\bar{D}$ production forward and eventually D production as a competitor of the Λ_c. The $\bar{D}$ has not been observed, but one can use as an excuse the difficulty of

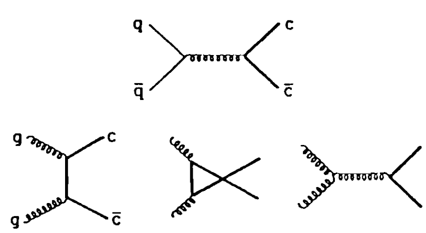


Fig. 31

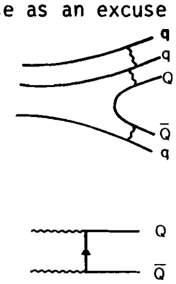


Fig. 32

isolating a pure sample of K^+ in a large background of protons. Another problem is that between the SPS and the ISR this model predicts only a rise of 2-3: this would lead us to expect Λ_c production at the SPS, at the level observed by ABCCMR. However, as already mentioned, the presence of forward D's, unavoidable within this model, would contradict beam-dump data.

2) Intrinsic charm[36]: This was introduced precisely to explain this forward production. We have seen in this meeting that at least two experimental results from the Fermilab beam dump on the rate of prompt μ, and from the EMC Collaboration on the charm structure function[37] (Fig. 33), do not seem to support it. This mechanism would lead to the same problems as those of the preceding one.

3) Extrinsic charm[61,62]: Some recent papers support the idea that the charm content needed is not intrinsic but extrinsic, i.e. generated by the QCD evolution itself. Resurrecting flavour excitation diagrams (Fig. 34) these authors feel they could explain the forward production of Λ_c, maintaining

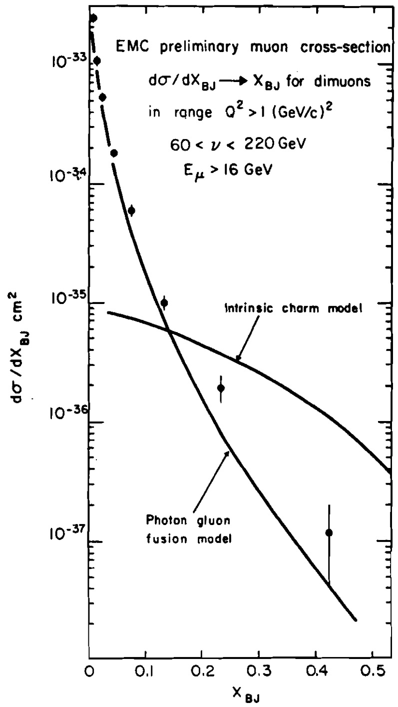


Fig. 33

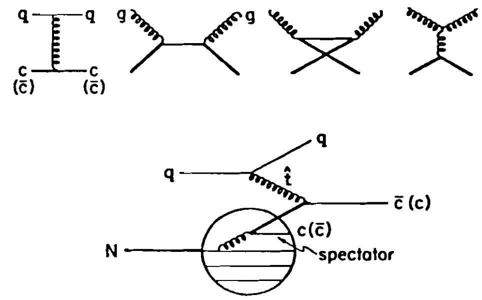


Fig. 34

a more central production for the $\bar{D}$ since the flavour excitation and the subsequent rearrangement (the $\bar{c}$ expelled, the spectator c fusing with a diquark) have no reason to lead to a symmetric final state. This model raises two questions: first, it is not yet fully formulated, and the role and meaning of some quantities -- the t_{min} cut-off in Fig. 34, for instance -- has to be elucidated; secondly, since rearrangement is invoked, one may ask whether the instrinsic charm assumption could not be saved in the same way.

7. BEAUTY AT THE ISR

In the last few months there was much excitement about the following results: in the Split Fiel Magnet, experiment R415 (BCF Collaboration) sees a signal that this group interprets as a beautiful baryon Λ_b [63]; while in the same set-up and under similar but not identical conditions, experiment R416 [ACCDHW[64]] does not[65]. Let us split the discussion into:

- an exposé of available published facts for the two experiments;
- a brief presentation of the major controversial points as both teams, in still informal discussion and write-ups, analyse them. Solving this controversy is beyond my role as rapporteur and beyond my competence; I will therefore just present the arguments, leaving the debate in its contradictor state.

7.1 The signal

The basic *a priori* idea of R415 is to exploit the leading baryon property[66] to look for beauty on a sample of events tagged by e^+. They have chosen the simplest relevant channel

$$pp \rightarrow e^+ + \Lambda_b^0 + X, \quad \Lambda_b^0 \rightarrow pD^0\pi^-, \quad D^0 \rightarrow K^-\pi^+$$

Selection of prompt e^+, supposed to come from the antibeauty cascade to charm, is performed on line (Čerenkov, total absorption counters) and off-line (dE/dx chamber and various refinements). Then a p_T cut ($\geq$ 0.8 GeV) is performed -- mostly to get rid of a large fraction of e from charm -- as well as a cut on the momentum measurement accuracy. The final selected sample of e^+ contains ~ 50% of real prompt e^+ ones and a negligible amount of contamination due to hadrons.

The leading baryon condition is imposed on a set of four particles compatible with Λ_b decay: a positive one, called a proton, required to have $x_F > 0.32$, and three others called K^-, π^+ and π^-, i·

the TOF information does not contradict this assessment. This set of particles has finally to satisfy the condition:

$$|y_{pK\pi\pi}| > 1.4 .$$

For the other particles (the "X" system), only charged multiplicity ($\geq$ 4) and some topological requirement (something has to balance the e^+ p_T) are imposed.

From the events satisfying all these criteria (~ 1600), the BCF Collaboration extract the Λ_b signal by the procedure shown in Fig. 35, which basically consists in exhibiting first a D signal in the $K\pi$ spectrum and then retaining only the $K\pi$ mass domain corresponding to that D. An ~ 6 s.d. signal is obtained. The number of events in the peak is ~ 25 (30 combinations).

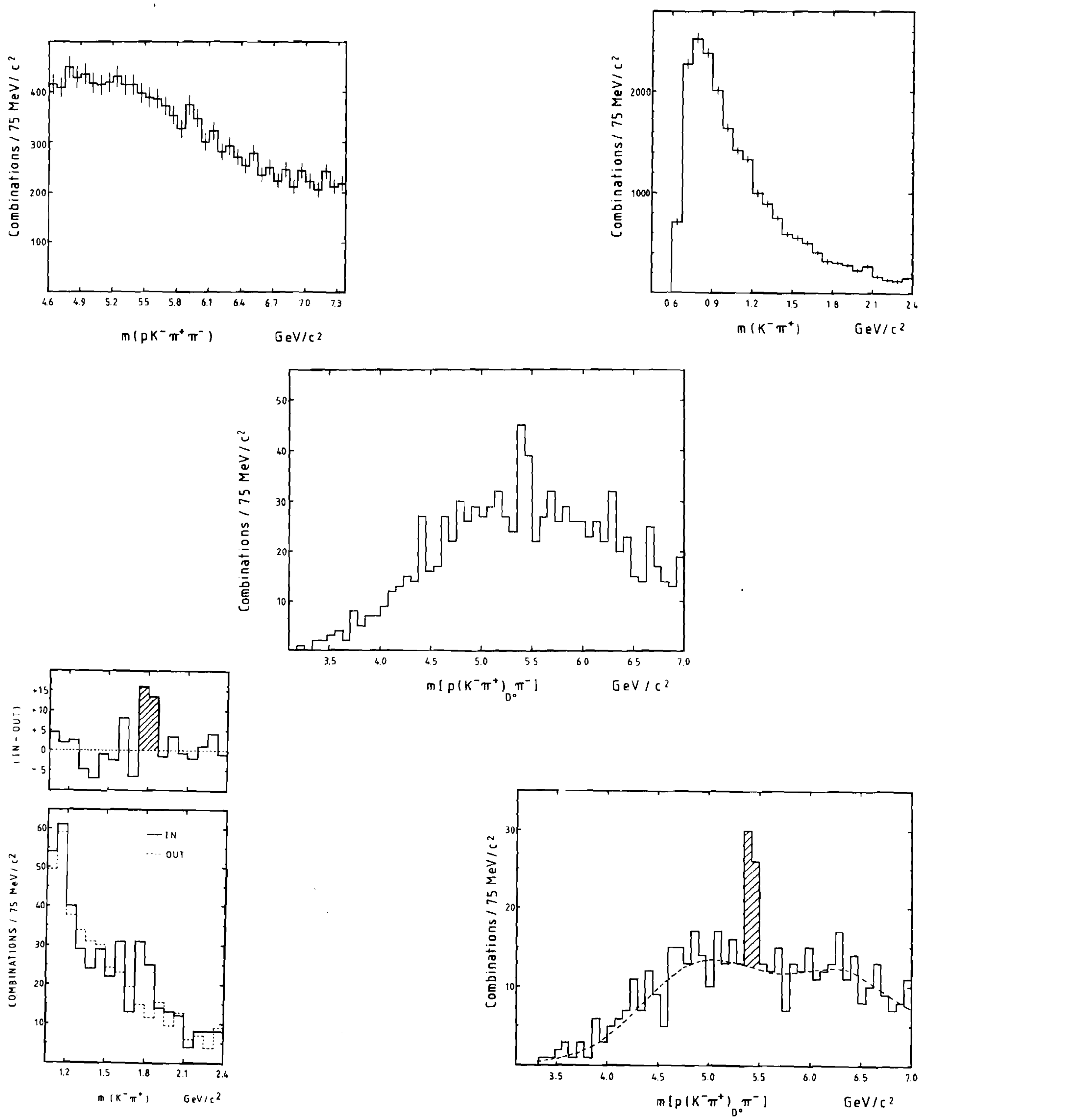


Fig. 35

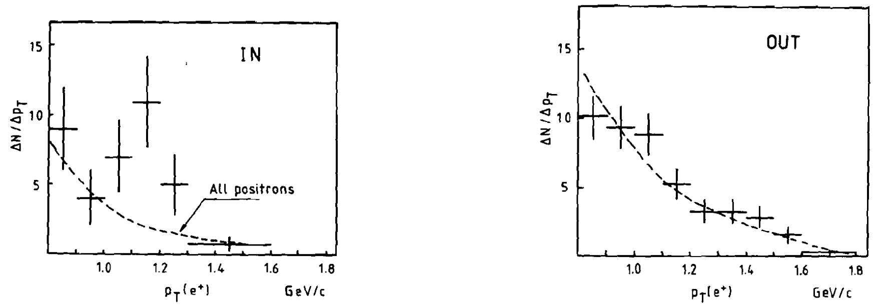


Fig. 36

If interpreted as the Λ_b, it would correspond to a value of:

$$\sigma(\Lambda_b)B(\Lambda_b \rightarrow pD^0\pi) \sim 3\text{-}30\ \mu b$$

depending on the production mode.

As proof of the reality of the signal, R415 refers to the difference in the e^+ p_T spectra on the peak and outside (Fig. 36).

7.2 Remarks

Two remarks made at the very beginning are relevant here. The D, because of unknown mass calibration, is allowed to appear in a 300 MeV mass range. It is actually found 60 MeV below the nominal mass. The freedom taken does not appear in the expression of the statistical significance. Then about cuts; who can tell their exact effect on the significance when the region to retain in a mass spectrum is selected *a posteriori*, with a width and a location chosen simply to get the most favourable answer?

7.3 R416 result[65]

With a similar integrated luminosity, this experiment has tried to check this result on previously recorded data. However, when the data were taken (with another motivation) the total absorption counters which play an important role in the selection of e^+ were not available. *A posteriori* measurements indicate that the fraction of prompt e^+ in the selected sample is ~ 32%; 35% to 40% of the sample is simulated by hadrons. Experiment R416 imposes the same requirements on hadrons as does the previous experiment. The number of events retained turns out to be larger for R416, and this is attributed to a set-up that gives a better performance, and to a more efficient processing. Finally, when plotting the equivalent of the spectrum of Fig. 35, they obtain (Fig. 37), at the position of the hypothetical peak, a background level 10 times higher than the R415 one, and consider that this ratio also corresponds to the ratio expected for the magnitude of the signals. If the signal was true, they would therefore expect

$$\sim 25 \times 10 \times \frac{32}{50} = 160 \text{ events} ,$$

which they clearly do not observe (Fig. 37), and they conclude that the two experiments are incompatible.

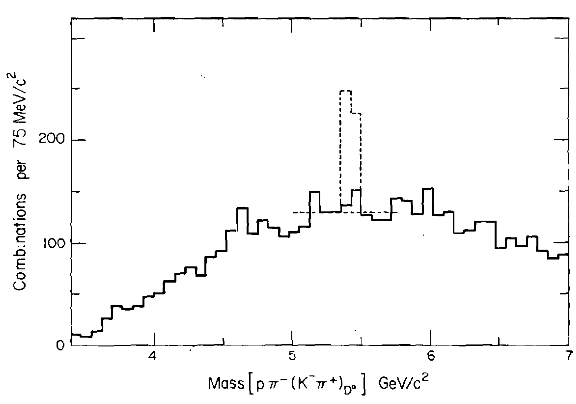


Fig. 37

7.4 Controversial points

We have seen up to now how each experiment presents its own data. However, they also exchange several criticisms, which should be mentioned here.

1) R416 about R415: the "numerology"

Experiment R416 points out that there is an internal inconsistency in R415 results; namely, that given the R415 number of selected events N (1600), it is impossible for them to get such a signal S (25 events). The N and S are related by

$$S = N \times \varepsilon \times \varepsilon_{SFM} \times B_D \times B_1 \times B_2 \times \rho ,$$

where

ε is the percentage of prompt e in the sample;
ε_{SFM} is the probability of reconstructing the K, π, π belonging to the hadronic system;
B_D is the ($D_0 \to K\pi/D_0 \to$ all) branching ratio;
B_1 is the ratio: No. of Λ_b's/No. of beauty hadrons produced
B_2 is the ratio: $\Lambda_b \to pD^0\pi^-/\Lambda_b \to p + \ldots$
ρ is the ratio: No. of prompt e from B/No. of prompt e,

and ε, ε_{SFM}, B_D are known: 0.5, 0.5 and (3 ± 0.6)%, respectively (ε_{SFM} for R415 is < 0.5 according to R416). Even setting $B_1 = B_2 = \rho = 1$, which is unrealistic (although the B's which are here conditional probabilities, once a fast proton has been selected, may be quite different from their "free" values), one would expect only S = 12 and there is already a problem. The experiment R415 answer is explained in Fig. 38: provided B_D is substantially larger than the nominal value, they could consider their result as being due to a strong upward fluctuation. However, the substantial errors attached to the various quantities are not sufficient to make this fluctuation likely, since all these quantities have an upper bound equal to one. It is clear that this problem of internal consistency is not avoided easily. Experiment R416's own conclusion is that neither of the two experiments, with their sensitivity, should in fact observe the least signal: this can be demonstrated *a priori* by assigning measured or guesstimated values to the quantities defined above.

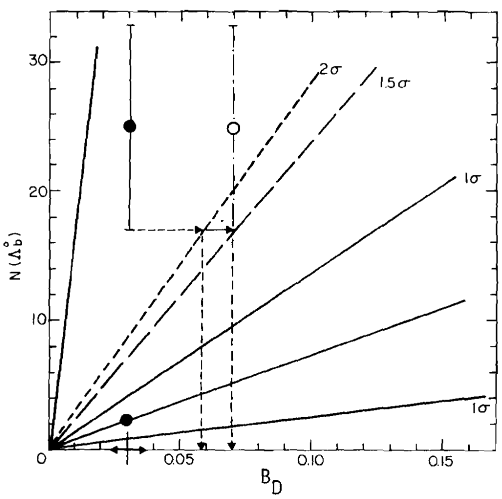


Fig. 38

2) R415 about R416

There the controversy rests on two points:

a) The ratio of prompt leptons in the R416 sample: the R415 experiment, from its own analysis, finds that a selection made without total absorption counters introduces much background due to hadrons (and knock-ons). They estimate that the fraction of real prompt e^+ in the R416 sample is only ~ 16%, a number which they get from two different methods.

b) The ratio of sensitivities: R415 agrees that the processing and the set-up efficiency are better in R416, but not that much better. They refuse to consider the ratio of the background levels in the final spectrum as a measure of the improvement, and admit only a factor of 4-5.

Therefore according to R415, R416 can expect only about one fourth of what they claim, which is not in disagreement with what they find. So, following R415, the two experiments are not in disagreement.

Here I will stop. This exchange of arguments, where one experiment reassesses the numbers given by the other one, is certainly the right thing to do -- but in private discussions between the two teams, until an agreement or the evidence of an irreducible disagreement is reached.

My personal conclusion is that owing to the low statistical significance of the positive result and the internal problem linked to its extraction (and also to the lower performance in selecting electrons of the experiment which does not observe the signal), the only reasonable attitude is to ask for more data. New global, precise experiments are needed, which at the same time could attempt to solve the contradictions noted above about charm production (e/π first!). I know well that this i easier to say than to do, and I apologize to the people who will have to resurrect the instrumentatio needed. But this is unfortunately one of the unavoidable shackles of our discipline.

Acknowledgements

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Discussion

M. Block, Northwestern University: I would like to give the following comment: The same models that give the ISR p-p charm production total cross sections also give an e/π ratio that exceeds the measured value (CERN-HARVARD-ORSAY-RIVERSIDE-MUNICH-NORTHWESTERN, the first measurement plus later Bologna) by factors of the order of 10. The problem must be in the models, since we don't want an e/π crisis, and there is thus new physics.

L. Cifarelli, CERN: Concerning charm results, I agree with H. Block's comment. Moreover, some correlations surely exist in associated charm production, in particular for $D\bar{D}$ pairs, which have not been so far taken into account. These would likely cause a variation of the present cross-section estimates by non negligible factors.
Concerning your Λ_b^0 presentation, Dr. Treille, you have shown a sequence of $(pK^-\pi^+\pi^-)$ and $(K^-\pi^+)$ invariant mass spectra. I would like to make clear that such a sequence has the following basic meaning: in the scatter plot of the $(pK^-\pi^+\pi^-)$ mass versus the $(K^-\pi^+)$ mass, we observe a significant condensation of events in a definite region which corresponds to a correlation between the D^0 mass and the Λ_b^0 mass (at about 5.4 GeV/c²). This is for sure an effect. Moreover, for those who have not heard previous presentations of the Λ_b^0 analysis, I would like to mention that a bump is observed in the p_T distribution of the positrons associated to the Λ_b^0 peak and that there is also evidence for the $\Sigma^\pm \rightarrow \Lambda_b^0\pi^\pm$ cascade decay. Finally, I would like to recall that the Λ_b^0 disappears when using a wrong trigger, for instance an e^-. This means once again (as you said it happened for all the charm signals observed in the same experiment), that we do see a signal where it is expected, whilst we do not see it where it is not expected. These effects, altogether, cannot but build up a striking picture of beauty production.

Treille: I agree I was aware of this bump in the electron spectrum. But, indepently of all that, what is your own interpretation on this numerology - how can you turn it away?

L. Cifarelli: I think that numerology is the kind of argument you use when you make a proposal for an experiment. Then you perform the experiment, you carry on the analysis and you find your results. At this point, it is not obvious at all whether numerology, which is based on very inclusive considerations, applies any more at the end of your data selection. Moreover, numerology requires the knowledge, with an extreme accuracy, of all the acceptances and efficiencies involved. This is not the case at the SFM which is, as everybody knows, a very complex instrument. Finally, when using numerology for the Λ_b^0 signal, it is crucial to take the errors into account; since this signal only contains 25 events after all.

E. Gabathuler, CERN: I would just like to say as answer to the question made by Treille, that it is planned to repeat the experiment. I think we have all heard a lot of discussion and numerology. The only way to find in fact a number or do something is to repeat the experiment with improved statistics and this is planned to be done.