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MEMORANDUM

To: ISRC

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Subject: Search for Charm Signals in 3 Body Final States at $\sqrt{s}$ = 63 GeV.
(Request for an extension of R 607)

Recently [1,2,3], signals have been observed at the ISR in the $pK^-\pi^+$ and $\Lambda^0(3\pi)^+$ finals states, consistent with the production of charmed baryons (Λ_c^+) with mass 2.26 GeV. In all three experiments the observed Λ_c^+'s were produced predominantly at high momentum and small angles. Fig.1 shows the results.

In an earlier note (CERN/ISRC/79-24,11 July 1979) we have informed the ISRC of our intention to exploit the present R607 equipment, designed to function at small angles and high momenta, to search for supporting evidence for the Λ_c and to obtain further information on its decay modes on a relatively short time scale. Our preliminary conclusion was that this is possible by placing the two R607 spectrometer arms one on top of the other as indicated in Fig.2.

In this note we summarise the final conclusions regarding the feasibility of such a measurement. We discuss, in turn, the expected rate of events, the rate handling and tracking capability of the two (identically equipped) spectrometer arms in use in R607, and the technical aspects associated with moving one arm from its present location above arm 2 to a new location below arm 1.

II EXPECTED RATE OF Λ_c - EVENTS

II.1 ACCEPTANCE

We consider the configuration of Fig. 2, with 2 arms placed symmetrically above and below the downstream pipe of beam 1 in intersection I6. We generate the process

$$p + p \rightarrow \Lambda_c + \text{anything}, \quad \Lambda_c \rightarrow p + K^- + \pi^+$$

at $\sqrt{s}$ = 63 GeV and track the decay products through the two arms in four different trigger modes :

MODE A : All 3 decay products go through one arm, with no particles going through the other arm. This mode corresponds to the current R607 set-up, with the two arms triggered independently by a 3 track requirement. Mode A serves as a reference for comparing the event rate one would have in the current, "R607" set-up with the event rate in the set-up of Fig.2.

MODE B : P and K go through one arm, π through the other.

MODE C : P and π go through one arm, K through the other.

MODE D : K and π go through one arm, P through the other.

For each trigger mode the acceptance is calculated for values of the mass M of the PKπ systems in the range between 1.6 GeV (close to threshold) and 2.5 GeV. For the purpose of comparing different modes, acceptance is defined as a fraction of events, generated with ± 20 mrad horizontally, ± 40 mrad vertically with respect to the forward direction and with longitudinal momenta in the range $15 < p_z < 30$ GeV/c. It has been checked that no events generated outside these limits are accepted at any mass and in any mode.

The resulting acceptance vs mass curves are shown in Fig.3. In trigger mode A the acceptance is largest at the lowest masses and then drops by a factor ∿ 100 in the range $1.6 < M < 2.0$ GeV as the Q-value of the decay increases. The acceptances in modes B,C and D go through maxima at $M \approx 1.8$ GeV due to the fact that at low mass there is too little Q-value for any of the 2 + 1 track configurations, while at high mass there is too much. Comparing the R607A configuration with e.g. R607B it is seen that in mode A there is a huge low pKπ mass tail, while at the mass of interest, $M(\Lambda_c) = 2.26$ GeV, the acceptance is not significantly larger than that of mode B. In the mass region of interest a 2 + 1 track mode is thus more effective in suppressing unwanted pKπ events than a 3 + 0 track mode.

The different 2 + 1 track modes, B,C, and D, can be distinguised from each other at the trigger level by noting that each arm is equipped with 3 1-atm Cerenkov counters and with 2 scintillator hodoscopes with which the particle identity and the track multiplicity is routinely defined in the current R607 triggers. For high density gases, e.g. FC114, most events are accepted by either one of the following triggers (n = track multiplicity; $\check{C} = \check{C}_1$ AND $\check{C}_2$ AND $\check{C}_3$; u = UPPER ARM, d = LOWER ARM) :

MODE B :

$$(\check{C}_u = 0)*(n_u = 2)*(\check{C}_d = 1)*(n_d = 1)+(\check{C}_d = 0)*(n_d = 2)*(\check{C}_u = 1)*(n_u = 1)$$

MODE C :

$$(\check{C}_u = 1)*(n_u = 2)*(\check{C}_d = 0 + 1)*(n_d = 1) + (\check{C}_d = 1)*(n_d = 2)*(\check{C}_u = 0 + 1)*(n_u = 1)$$

MODE D :

$$(\check{C}_u = 1)*(n_u = 2)*(\check{C}_d = 0)*(n_d = 1)*(\check{C}_d = 1)*(n_d = 2)*(\check{C}_u = 0)*(n_u = 1)$$

In particular, for $M \simeq 2.3$ GeV the trigger efficiency in mode B is 100%.

II.2 NORMALIZATION, x AND p_T DEPENDENCE

The yield of Λ_c's is determined by the acceptance, the Λ_c production cross section and its x and p_T dependence.

In Ref. I Λ_c's were seen in the process $p + p \to p + X$, $X \to \Lambda_c + X^1$, where X is a diffractively produced state of mass M_x in the range $10 < M_x < 28$ GeV, the lower limit being determined by the requirement of high ($n \geq 6$) overall multiplicity in the hemisphere containing the Λ_c, and the upper limit being determined by the criterium $M^2/s < 0.2$ characteristic for diffraction dissociation into high mass states 4). The resulting cross section, for Λ_c's with $0.3 < x < 0.8$, $0 < p_T < 1$ GeV/c, was found to be, at $\sqrt{s} = 63$ GeV :

$$B.\sigma(pp \to pX, 10 < M_x < 28, X \to \Lambda_c + X^1, 0.3 < x(\Lambda_c) < 0.8, 0 < p_t(\Lambda_c) < 1) = 0.6\mu b \quad (1)$$

From this result we obtain the cross section for <u>inclusive</u> Λ_c production by multiplication by 2 factors :

$$\text{a)} \quad R_1 = \frac{\sigma(pp \to pX, M_{min} < M_x < 28)}{\sigma(pp \to pX, 10 < M_x < 28)} = 1.9 \quad (2)$$

for $M_{min} = M(\Lambda_c) + M(\bar{D}) = 4.12$ GeV and noting that, for diffractive production 4):

$$\frac{d\sigma}{dM_x{}^2} \sim \frac{1}{M^2}$$

$$\text{b)} \quad R_2 = \frac{\sigma(pp \to \tfrac{1}{2}S.D + D.D + INEL)}{\sigma(pp \to \tfrac{1}{2}S.D)} = 4.5 \pm 2.3 \quad (3)$$

where the denominator refers to the single diffractive (S.D) trigger in one hemisphere of the set-up in Ref. 1, while the numerator refers to the "inclusive" set-up of R607 and includes single diffractive, double diffractive (D.D) and non-diffractive inelastic events. The 50% error reflects the uncertainty in the relative acceptance for diffractive and inelastic events. At $\sqrt{s} = 63$ GeV σ(S.D) = 2 x 4.5 mb, σ(D.D) = 5.5 mb, σ(INEL) = 21 mb.

Combining these factors we obtain for the cross section for inclusive production of Λ_c's deduced from the data of Ref.1 :

$$B.\sigma(pp \to \Lambda_c + \text{anything}, 0.3 < x(\Lambda_c) < 0.8, 0 < p_T(\Lambda_c) < 1.0 \text{ GeV/c}) = 5\ \mu\text{b}. \quad (4)$$

Recently data [5)] have been obtained by this collaboration, using the same equipment, on the inclusive production of Λ's, $\Lambda^* = \Lambda(1520)$ and $\phi(1020)$'s at $\sqrt{s} = 63$ GeV. These results are shown in Fig.4. In the range $x > 0.5$ the invariant differential cross sections can be parameterized as :

$$\sigma_{INV}(\phi) = 5.3 \times 10^{-3} \exp(-2.9\, p_T^2)\, (1-x)^{2.4} \quad \text{mb/GeV}^2 \quad (5)$$

$$\sigma_{INV}(\Lambda) = 1.71 \quad \exp(-\,2.9\, p_T^2)\, (1-x)^{1.53} \quad \text{mb/GeV}^2 \quad (6)$$

$$\sigma_{INV}(\Lambda^*) = 0.151 \quad \exp(-2.9\, p_T^2)\, (1-x)^{0.8} \quad \text{mb/GeV}^2 \quad (7)$$

Data on the x dependence of the inclusive production of these and other particles [6)] suggest that forward Λ production is governed by the exchange udu → uds with a valence quark in the beam proton being exchanged against a strange sea quark. In Λ_c production we then have udu → udc and hence, with the heavier c quark, one expects the fall off at increasing x to be at least as steep as that of the Λ. The Λ spectrum, on the other hand, is affected by the decay into Λ's of higher lying states, in particular $\Sigma(1385) \to \Lambda\pi$ (branching ratio 88%), tending to raise the exponent in $(1-x)^n$. The Λ^* spectrum may therefore be a better indicator of the x dependence resulting from u → s exchange than the Λ spectrum. We shall, in view of these uncertainties, compute the Λ_c rate for both x distributions. The exponent obtained in ϕ-production may be considered as an upper limit, since in that case two sea quarks are involved in the exchange. In all three parametrizations the p_T dependence has been chosen in agreement with earlier Λ production data at 300 GeV[7)] and at $\sqrt{s} = 63$ GeV [8)].
Normalizing the Λ and Λ^* distributions in eqs 6 and 7 to the integrated Λ_c cross section in eq. 4 we obtain for inclusive Λ_c production :

$$\sigma_{INV}(\Lambda_c, \Lambda\text{-model}) = 0.013 \exp(-2.9 p_T^2)\, (1-x)^{1.53} \quad \text{mb/GeV}^2 \quad (8)$$

$$\sigma_{INV}(\Lambda_c, \Lambda^*\text{-model}) = 0.008 \exp(-2.9 p_T^2)\, (1-x)^{0.8} \quad \text{mb/GeV}^2 \quad (9)$$

where the normalisations in the Λ, Λ^*, and hence in the Λ_c distributions are uncertain by a factor of two.

The result can be checked to some extent by comparison with the data of Ref. 2. In Ref. 2 Λ_c's are observed inclusively with cross section :

$$B\sigma(\Lambda_c, 0.75 < x < 0.95,\ 0 < p_T < \infty) = 2.3 \pm 0.3 \text{ mb} \qquad (10)$$

Integrating eqs (8) and (9) over the same x, p_T range gives ∿ 0.2 and 0.4 mb respectively. We note that this strong disagreement between the results of Ref.1 and 2 is independent of the normalisation of the R607 Λ and Λ^* data.

II.3 RATE OF EVENTS

The rate of events is calculated by weighing the accepted events by the cross sections in eqs (8) and (9) and including the corrections due to tracking efficiencies (∿ 0.5 for mode A and $(0.95)^3 = 0.86$ for modes B,C and D) and trigger efficiencies (essentially 1.0) We compute the rate for two decay modes :

$\Lambda_c \to PK^-\pi^+$ and $\Lambda_c \to PK^-K^+$ with branching ratio

$$\frac{\Lambda_c \to PK^-K^+}{\Lambda_c \to PK^-\pi^+} = \left(\frac{\mathrm{Cos}\theta_B\ \mathrm{Sin}\theta_A}{\mathrm{Cos}\theta_B\ \mathrm{Cos}\theta_A} \right)^2 * \frac{\mathrm{PHASESPACE}(PK^-K^+)}{\mathrm{PHASESPACE}(PK^-\pi^+)} \qquad (11)$$

$$= 0.05 \quad * \quad 0.3 \quad = \quad 0.015$$

assuming the "strange" Cabibbo angle θ_A to be equal to the "charmed" Cabibbo angle θ_B.

For the calender period 1 March - 15 July ≃ 1400 hours of ISR running, an effective running time of ∿ 1000 hours and an average luminosity at $\sqrt{s} = 63$ GeV of $1.5 \times 10^{31}/\mathrm{cm}^2/\mathrm{sec}$ we obtain the following rate of events for the yield of Λ_c's with a mass of $M \approx 2.3$ GeV :

YIELD OF Λ_c EVENTS IN 1000 HOURS

PRODUCTION MODEL	DECAY MODE	TRIGGERMODE					
		A	B	C	D	B+C+D	A+B+C+D
Λ (eq(8))	$PK^-\pi^+$	9	168	74	21	263	272
	PK^-K^+	1	14	10	8	32	33
$\Lambda^*(1520)$ (eq(9))	$PK^-\pi^+$	35	502	237	98	837	872
	PK^-K^+	3	43	32	25	100	103

The following comments can now be made :

1. By moving one spectrometer arm from its current location to the position indicated in Fig.2 the total yield of Λ_c's is increased by a factor 25 - 30.
2. About 60% of the increase in yield is obtained in trigger mode B. This mode is favoured since the requirement of two tracks in one arm with no Cerenkov light in 3 Č-counters in series is more effective in suppressing background than modes C and D. Triggering in mode B yields 4 to 12 events per day.
3. The rate calculation is based on the lower of the two cross sections measured in Ref. 1 and 2. The higher one would increase the yield by a factor 11 in the Λ-model and a factor 6 in the Λ^*-model.
4. The yield of PK^-K^+ events is based on the current value of the Cabibbo angle. Recent SLAC data [9)] on $D^o \rightarrow K^-K^+$, $D^o \rightarrow K^-\pi^+$ and $D^o \rightarrow \pi^-\pi^+$ present a very weak (2 s.d) indication that θ_A may be larger than θ_B. Taken litterally this would raise the observed $PK^-K^+/PK^-\pi^+$ ratio from ∿8 to ∿16%.
5. The ratio

$$\frac{\Lambda_c \rightarrow PK^-\pi^+}{\Lambda_c \rightarrow PK^+\pi^-} = tg^2\,\theta_A \; tg^2\,\theta_B = 2.5 \times 10^{-3}$$

can be used to monitor the background PKπ signals.

III PERFORMANCE OF THE SPECTROMETER ARMS

Since we propose to displace one arm without modifying the arrangement of counters and drift chambers we can rely on the experience gained in $\sim$ 7 months of data taking to estimate the trigger rate and the mass resolution.

The trigger rate has been measured requiring the number of hodoscope hits n to be $n \geq 1$, ≥ 2, ≥ 3 and the Čerenkovs to be in veto or in coincidence. Expressed as fractions of the interaction rate ($\sim$ 0.8 x 10^6/sec typically) we found

Č	$n \geq 1$	$n \geq 2$	$n \geq 3$
0+1	5.8%	0.4%	0.06%
0	3.3%	0.1%	0.008%

From these data we deduce the n = 3 hit background trigger rate in mode A to be $\sim$ 200/sec and the background due to arm-arm coincidences in mode B to be $\sim$ 30/sec and in mode C + D to be $\sim$ 55/sec.

These results constitute yet another reason for running the experiment in mode B, rather than in mode A : in the latter case the data taking rate exceeds the deadtime limit of 100 - 150 events per sec, with a corresponding loss in good event.

The mass resolution for $\Lambda^*(1520)$, the resonance closest to the mass range of interest observed thus far in exp. R607 is indicated in Fig. 5 and compared with the result of Ref. [1]. The natural full width of the $\Lambda^*(1520)$ is 16 MeV, the observed width is 20 MeV, hence the mass resolution is approximately 12 MeV, in agreement with numerical estimates.

As mentioned earlier the tracking efficiency for the modes B,C and D, with 2 tracks in one arm and 1 track in the other arm is $\sim(0.95)^3$. In the 3 + 0 track configuration of mode A there are extra losses resulting in a 3 track efficiency of $\sim$0.5.

The equipment-down time of experiment R607 has been <5% over the last 10 months.

IV TECHNICAL IMPLICATIONS

The technical aspects of moving one of the spectrometer arms to its new position (see Fig.2) have been examined in collaboration with the ISR/ES group. The modifications have been summarized in a note by O. Leistam 10). The main points are :

1. The down stream vacuum pipe of ring 1 is currently equipped with 3 pumps located at <7m from the intersection. They need to be replaced by other pumps that leave more free space below the pipe. It turns out that this can be done during the January 1980 shutdown.
2. Several support structures, both for the magnets and the driftchambers have to be modified. An assembly drawing has been made; detailed drawings would have to start not later than October 1979.
3. The magnets require new septum plates. The magnetic characteristics of a new design have been examined and turn out to be acceptable.

The ISR/ES group has concluded that the proposed modifications are possible and that there is just enough time to prepare the rearrangement for the Jan-Feb 1980 shutdown.

V CONCLUSIONS

There is clearly a strong case for following up the recently observed Λ_c signals with equipment that is around and operational at the ISR now.

The counting rates show that in the period March - July 1980 some 100 - 500 Λ_c's may be collected and that some information on the PK^-K^+ mode may also be obtained.

The modifications are simple and can be carried out as part of already planned activities during the January 1980 shutdown in I6.

Interference with the preparations of R608 is minimal. In case this group would require a diffractive proton signal before July 1980, a high resolution trigger using an "or" condition between the two R607 magnets is available.

For the data taking we expect to write 1000 to 2000 magnetic tapes. Using the tracking programmes of R607 implies a computer time for analysis of roughly 200 CDC 7600 hours.

4th September 1979

Note added in proof :

Recent data (Chicago Lepton Photon Conference August 1979) have shown that

$e^+ e^- \to \Lambda_c + X \qquad M(\Lambda_c) = 2285 \pm 6$ MeV (a)

$pp \to \Lambda_c + X \qquad M(\Lambda_c) = 2260 \pm 30$ Mev (b)

Consequently :

$M(\Sigma_c^{++}) - M(\Lambda_c) = 2426 - 2285 = 141 \leq m\pi$ (a)

$M(\Sigma_c^{++}) - M(\Lambda_c) = 2426 - 2260 = 166 > m\pi$ (b)

and hence Σ_c^{++} proceeds weakly only in case a, strongly in case b.
If Λ_c's are observed in sufficient quantity, the proposed experiment may contribute to the solution of this point.

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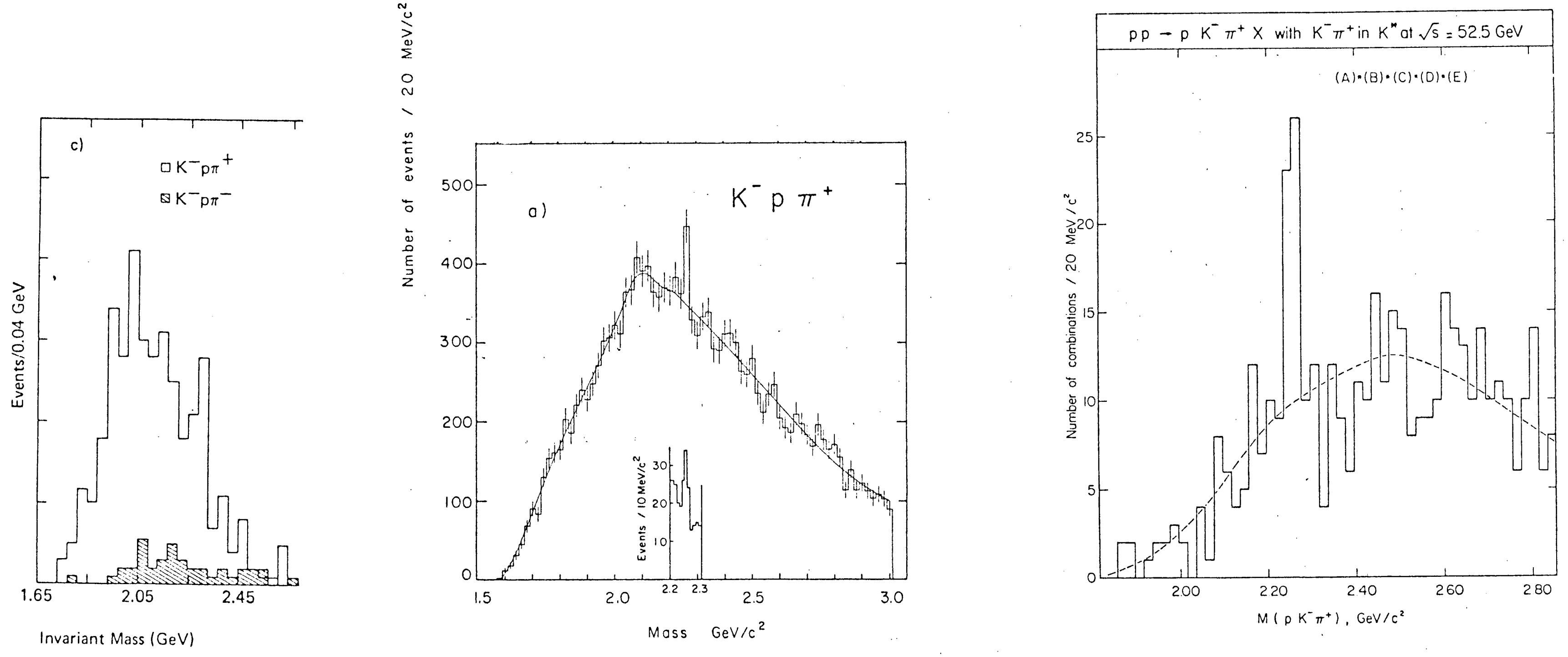
9. G.S. Adams et al PRL 43,481(1979)
10. O. Leistam ISR-ES/OL/cc



Lockman et al.

Giboni et al.

Drijard et al.

Fig. 1

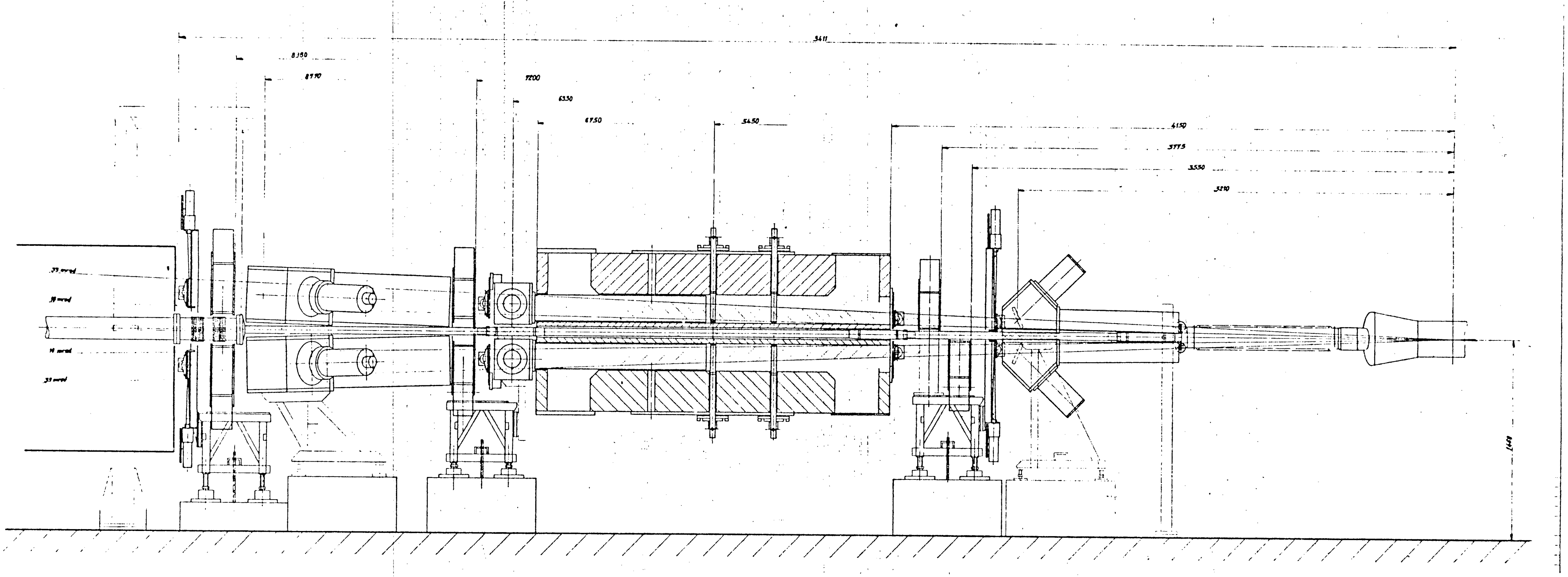
9411
8380
8790
7200
6330
6750
5450
4150
3775
3550
3210
33 mrad
19 mrad
14 mrad
33 mrad
1449

Fig. 2

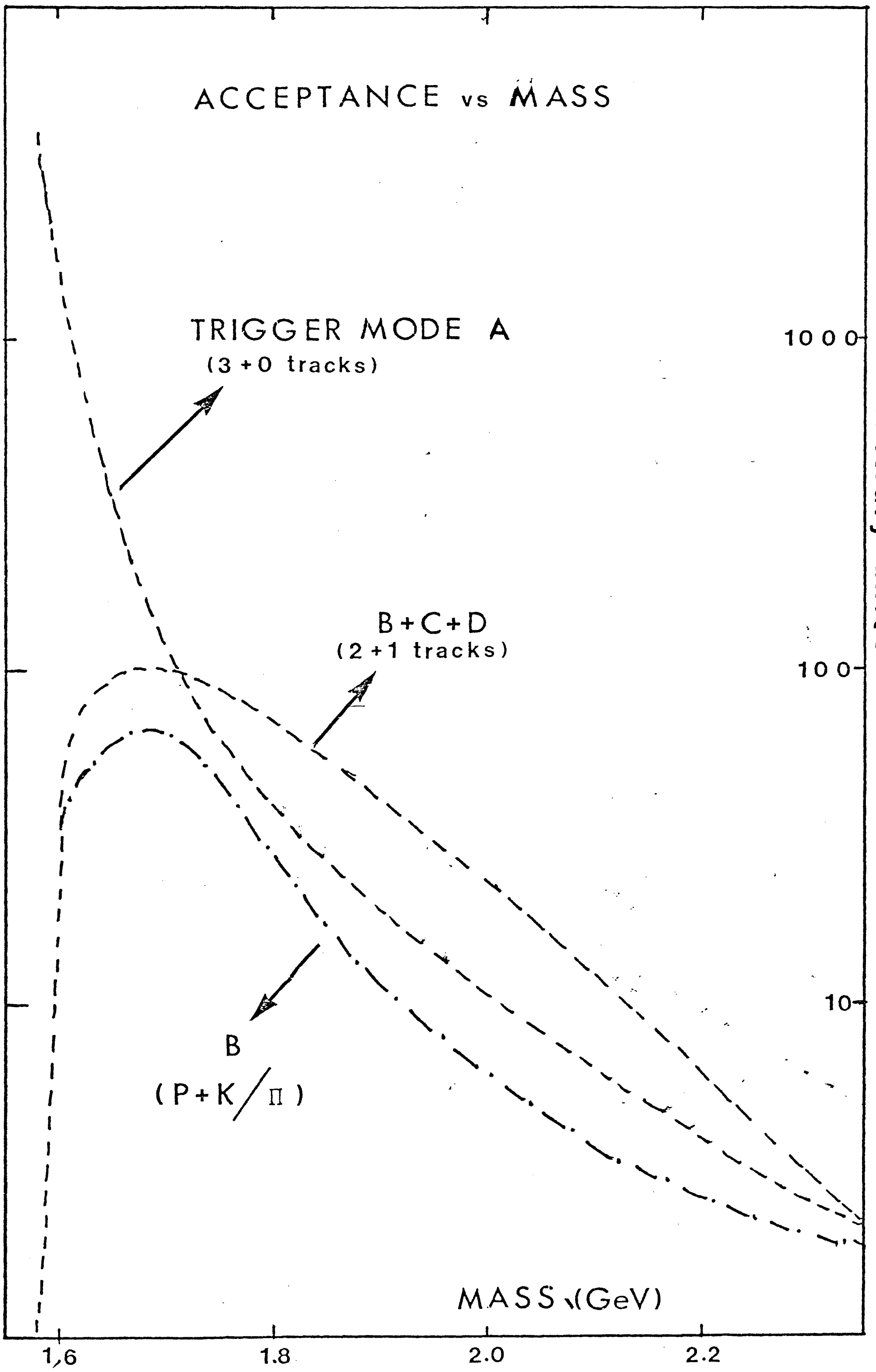

ACCEPTANCE vs MASS
TRIGGER MODE A
(3 + 0 tracks)
B + C + D
(2 + 1 tracks)
B
(P + K/π)
1000
100
10
arbitrary units
MASS (GeV)
1,6
1.8
2.0
2.2

Fig 3

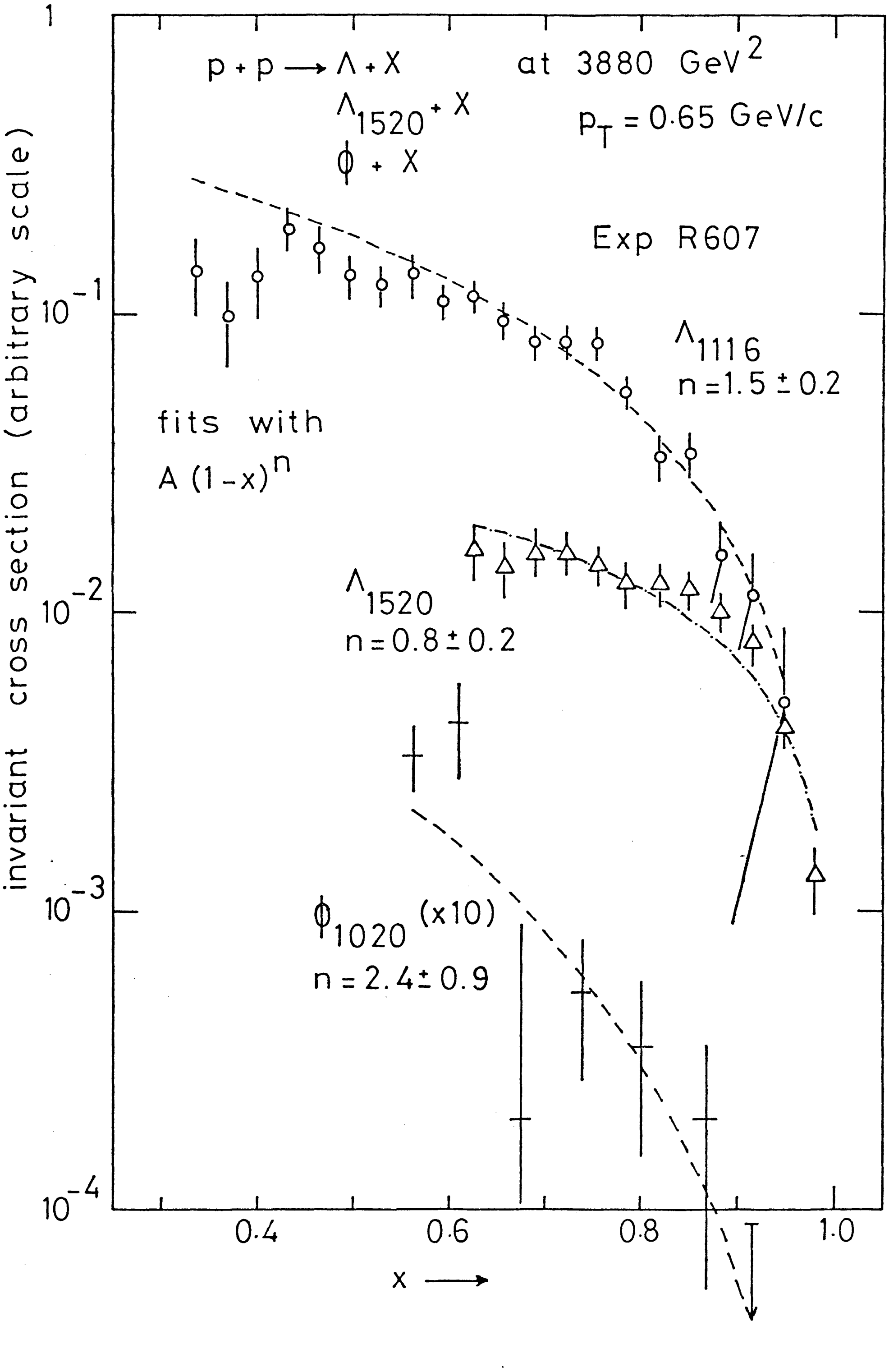

p + p ⟶ Λ + X
Λ1520 + X
ϕ + X
at 3880 GeV²
pT = 0.65 GeV/c
Exp R607
Λ1116
n = 1.5 ± 0.2
fits with
A (1 − x)ⁿ
Λ1520
n = 0.8 ± 0.2
ϕ1020 (x10)
n = 2.4 ± 0.9
invariant cross section (arbitrary scale)
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
0.4
0.6
0.8
1.0
x ⟶

Fig. 4

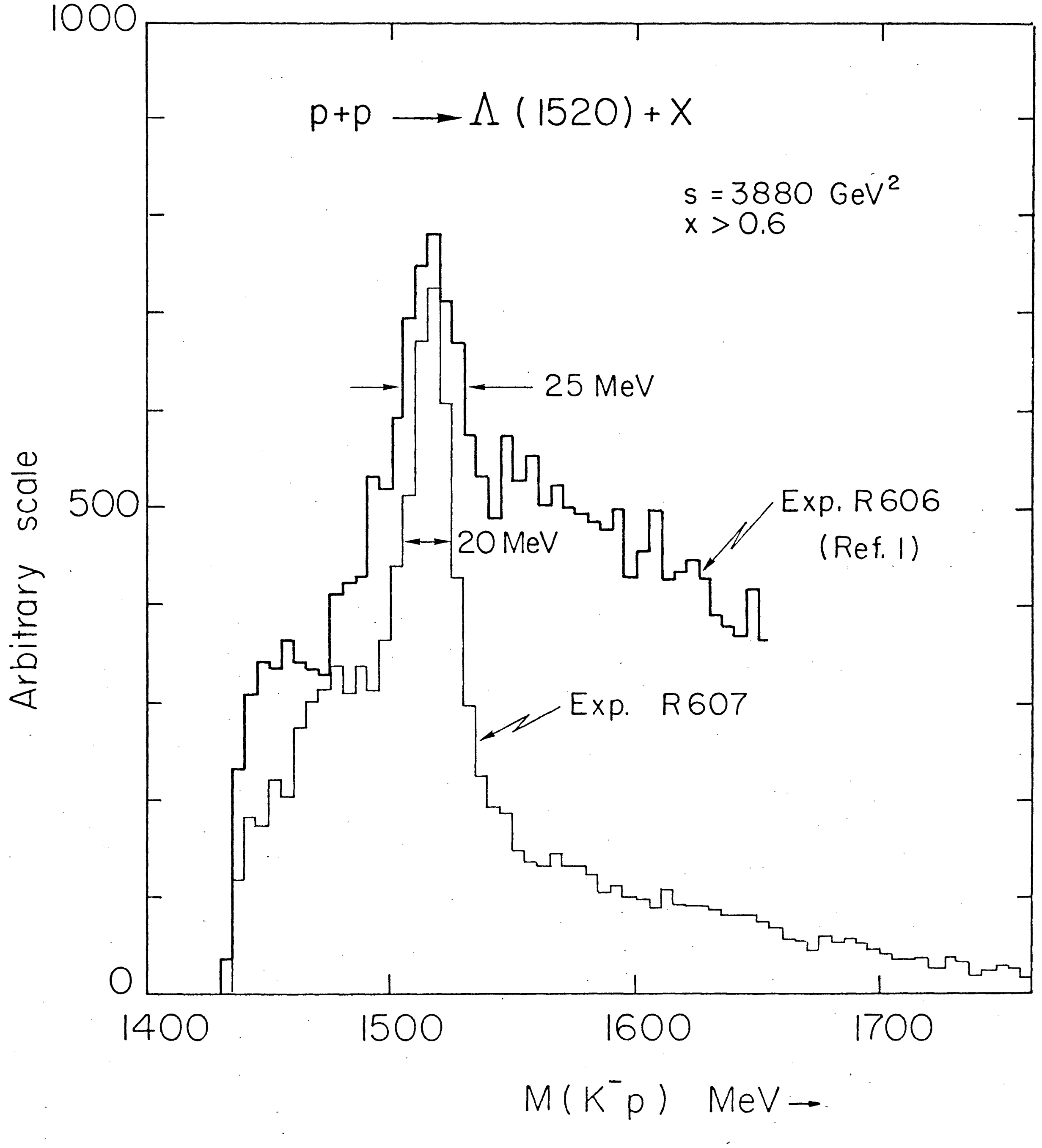
$p+p \longrightarrow \Lambda(1520)+X$
$s = 3880\ GeV^2$
$x > 0.6$
25 MeV
20 MeV
Exp. R606 (Ref. 1)
Exp. R607
Arbitrary scale
1000
500
0
1400
1500
1600
1700
M(K⁻p) MeV →

Fig. 5