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CHARM PRODUCTION IN pp COLLISIONS WITH LEBC-FMPS at 1 TeV(*)

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SUMMARY

We propose measuring open charm production in proton-proton collisions at 1 TeV using the second generation hydrogen LExan Bubble Chamber (LEBC II) as a vertex detector and the Fermilab Multiparticle Spectrometer (FMPS) in the M6W beam line. We intend to run parasitically with experiment E711.

We wish to measure the differential and total cross-section for charm production at the highest possible proton energy. Comparison of the data with previous 400 GeV measurements using the same vertex detector will allow us to examine the energy dependence of the total cross section and cross section shape as well as the energy dependence of various production modes. We emphasize that these measurements will be carried out in hydrogen, avoiding the complications of nuclear targets in which the A dependence of charm production has been observed to non-trivial. We also hope to collect large (~2800) and clean samples of charm particles, and possibly to see hadroproduced beauty.

LEBC II is currently running in a similar experiment at CERN (NA27) using protons at 400 GeV. We propose bringing it and its trigger system to Fermilab and setting up at the FMPS. To the existing FMPS, we would add a second bending magnet for Tevatron operation and modify the existing Cherenkov counters. This LEBC-FMPS set-up will allow precise determination of the interaction vertex for production angles and momenta.

We request 500 hours of parasitic M6W beam at 10^5 protons/sec in a 10-second spill with a repetition of 1 spill/minute in the 1984-85 running period. We anticipate that this will be accomplished in a dwell time of about three months exclusive of set up.

I. INTRODUCTION

All present indications coming from SPS, FNAL and ISR charm experiments imply that the total charm cross-section increases rapidly with energy, as seen in fig. 1. However, intrinsic uncertainties in the charm hadroproduction cross-section measurements make a 1 TeV experiment with the same technique at 400 GeV desirable. This is what we propose here.

CERN experiment NA27 will use the high resolution rapid-cycling liquid hydrogen bubble chamber, LEBC II (1) to accumlate ~ 20 evt/μb (2) using a 400 GeV proton beam during fall 1983, with the intention of extending this to 50 evt/μb in spring 1984. We propose to use LEBC II in Tevatron running period 2 to collect a similar data sample using a 1 TeV proton beam. At CERN the momentum analysis and secondary particle identification is achieved with the European Hybrid Spectrometer (EHS), while at Fermilab we will use the Multiparticle Spectrometer, (FMPS).

This experiment will provide:

-pp-charm cross section at $\sqrt{s}$ = 43 GeV under comparable conditions to similar measurements at $\sqrt{s}$ = 27 GeV. The importance of such a determination can be seen from fig. 1 which shows the present status of the pp charm excitation curve. Bad data, unreliable charm branching fractions, and experiments with enormous corrections giving cross-section estimates which cannot be readily compared cause this confused situation (3). The LEBC technique, which has given the cleanest data so far, requires only small corrections to account for short lifetime losses (4).

-Large, clean samples of D^0 and $D^{\pm}$ decays and, assuming sufficient cross-sections, good samples of the apparently shorter lifetime particles, Λ_c and $F^{\pm}$. Even though the forward cone of particles shrink laterally at the same rate that the decay length expands, nevertheless the decay track lengths will be defined by more bubbles and should therefore give cleaner events and cleaner samples of Λ_c and $F^{\pm}$ than in LEBC experiments at lower energy. An example of a D event is seen in fig. 3.

-A few topolgically identifiable B events, if the B cross-section is as large as 200 nb.

II. TECHNICAL CONSIDERATIONS

A. LEBC II

LEBC II (LExan Bubble Chamber) is a 2.1 litre liquid hydrogen rapid cycling bubble chamber, conceived as a vertex detector for EHS and seen in fig. 2. Its design is based on that of LEBC I, the lexan bubble chamber used in experiment NA16 at CERN in 1980. Two vertical optical windows, 7 cm apart, permit straight-through illumination for classical dark or bright field photography. The visible region extends 12 cm along the beam direction and is 5 cm high. The expansion piston is situated at the bottom of the chamber.

The hydrogen temperature is controled by a heat exchanger at the chamber top, where the filling valve and the pressure gauge are also located. The entire chamber body is fabricated from lexan, a thermoplastic polycarbonate with good mechanical properties at cryogenic temperatures. All metal-lexan connections are vacuum sealed without glueing by a shrinking technique, which makes use of the different thermal expansion coefficients of stainless steel and lexan.

LEBC II was specially designed and constructed to visualize decay patterns for particles with lifetimes between 10^{-13} and 10^{-12} s. An example of a D event is seen in fig. 3.

The vertex detector, LEBC II, will be followed by high resolution multiwire proportional chambers, provided by CERN, which will provide a fast trigger processor with multiplicity and position information to enhance the signal to background (see sect. III). These chambers will determine the interaction vertex within a few mms and allow the

reconstruction of outgoing tracks to aid in short lifetime particle identification.

B. Fermilab Multiparticle Spectrometer

Fig. 4 shows a deflection plane view of the FMPS as configured for our experiment. Not shown are two upstream beam measuring stations, BM1 and BM2.

For Tevatron operation it is essential that the momentum resolution be increased. The first bending magnet (M1) will be a modified BM109 with an 0.36 m vertical gap that provides 0.7 GeV/c transverse momentum kick, matching that of M2, the present superconducting spectrometer magent.

In addition to the spectrometer a Cerenkov system is highly desirable. Atmospheric threshold Cherenkov counter C_B will provide charged particle mass identification over the entire spectrometer aperture. Helium, neon, and nitrogen gas mixtures will be used to adjust these thresholds. We will rebuild Cherenkov counters C_B and C_A in a manner so that they can have potential use for other approved experiments by making it easy to add upstream attachments increasing the radiator length. C_A will use the mirrors and phototubes from the present C_A of E623 and the redesigned C_B will use as much from the previous C_B counter as possible. It is expected that Fermilab would provide the modified BM109 magnet M1. The particle tracking system as proposed is a modification of the system used successfully by two previous experiments involving a subset of the proposers.

C. The Beam

The M6 beam at the Tevatron is intended to provide > 10^9 protons/sec of energy 1 TeV in a spot ~ 0.5 x 4 mm^2 (horizontal x vertical) at the location of E711 in the meson lab. We propose to position after E711 a dump/attenuator with a 1x1 mm^2 pinhole to redefine the beam. A fast kicker magnet will follow to prevent protons entering the bubble chamber immediately prior to the sensitive gate start. With the kicker, old beam tracks, which will give large bubbles that obscure the high resolution event tracks, are avoided. After the kicker magnet is another dump/attenuator, a horizontal bending magnet, and quadrupoles designed to bring the 1 TeV protons to a ~1 x 20 mm^2 focus at the bubble chamber. The FMPS is located ~120 m downstream of E711 and our intention is to use the beam in a parasitic mode with ~10^5 protons/sec incident on the bubble chamber. Background calculations indicate that a typical bubble chamber picture will contain <1 muon track, FMPS will have <1 background muon in the 100 ns readout gate.

III. RATE CALCULATIONS

The effective hourly sensitivity, S, can be estimated on the basis of a 30 Hz bubble chamber frequency; 10 sec. Tevatron flat top with a 60 sec cycle; bubble chamber gate of 200 μsec; 10^5 protons/sec, giving a maximum of 20 tracks/picture; 10 cm useful track length; and 30 mb trigger cross section, to be

$$S = 30 \times \frac{10}{60} \times 3600 \times \frac{0.2}{10^5} \times \frac{10^5}{10^6} \times \frac{10}{30} \simeq 0.1 \text{ evts}/\mu\text{b/hour}.$$

This will give about 8 charm pairs/hour if $\sigma_c \simeq 70\mu b$ at $\sqrt{s}=43$ GeV.

Thus with 500 hours at 100% running and 100% trigger efficiency, the sensitivity of the experiment would be 50 evt/μb. With a trigger cross-section of 30 mb, this would produce 1.5 M good triggers and useful two-view bubble chamber photographs.

The trigger has not to date been 100% efficient. The present NA27 trigger, which simply detects an event in the bubble chamber vicinity, has an efficiency ~40% (defined as the number of useful bubble chamber photographs divided by the total number of photographs); improvements planned for the 1984 CERN running period will detect an event in the bubble chamber fiducial volume and should ~ double the trigger efficiency. F r t'e Fermilab run we intend to bring, with LEBC II, the most advanced version of the event trigger. If to be conservative we use the presently obtained efficiency of 40% we would have 1.5M x .4 = .6M useful photographs and therefore a 20 evt/μb exposure.

Experience with the data analysis for NA27 indicates that a typical scanning table can scrutinize (two independent scans plus physicist check scan) 1000 two-view pictures per week, so 1.5 M pictures need 30 machine years. The present collaboration has the resources to fully scan this run within a year of data-taking.

Charm pair production in the 400 GeV region has been measured by LEBC to be in the neighborhood of 40 μb. If $\sigma \propto s^{1.5}$ as predicted for central production, then from the LEBC result we would expect about 70μb at 800 GeV. A 20 evt/μb exposure then would provide some 1400 charm pairs. The ISR measurements indicate a stronger energy dependence so our estimate is conservative.

Our acceptance calculations for 2 typical charm particle decay modes,

$$pp \rightarrow \Lambda_c^+ D^- X;\ \Lambda_c^+ \rightarrow K^- p \pi^+;\ D^- \rightarrow K^+ \pi^- \pi^- \pi^0$$

were generated at 1000 GeV by Monte-Carlo technique according to the distribution

$$\frac{d\sigma}{dx_F dp_T^2} \propto (1 - |x_F|)^n\, e^{-p_T^2}$$

with a = 1.1, and n = 2 for Λ_c^+ and 3 for D^-. Lifetimes of 2 and 8×10^{-13}sec were assumed for Λ_c^+ and D^-, respectively. Our visibility criteria were:: length >1 mm; transverse length <2 mm; at least one decay track impact parameter >50 μm. With these criteria, $\gtrsim$ 20% of the $\Lambda_c^+ \rightarrow K^- p \pi^+$ and $\gtrsim$ 50% of the $D^- \rightarrow K^+ \pi^- \pi^- \pi^0$ would be observed in the bubble chamber scanning.

Our calculations further indicate that in the decay of a charmed particle produced with any $X_F > 0.1$, we will have greater than a 90% probability for having all charged decay particles measureable in the FMPS.

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Figure Captions

Fig. 1. Present status of pp and $\pi^- p$ charm production and excitation curve.

Fig. 2. LEBC II (LExan Bubble Chamber).

Fig. 3. Example of hadroproduced D^o event in LEBC II.

Fig. 4. Deflection plane view of proposed FMPS configuration.

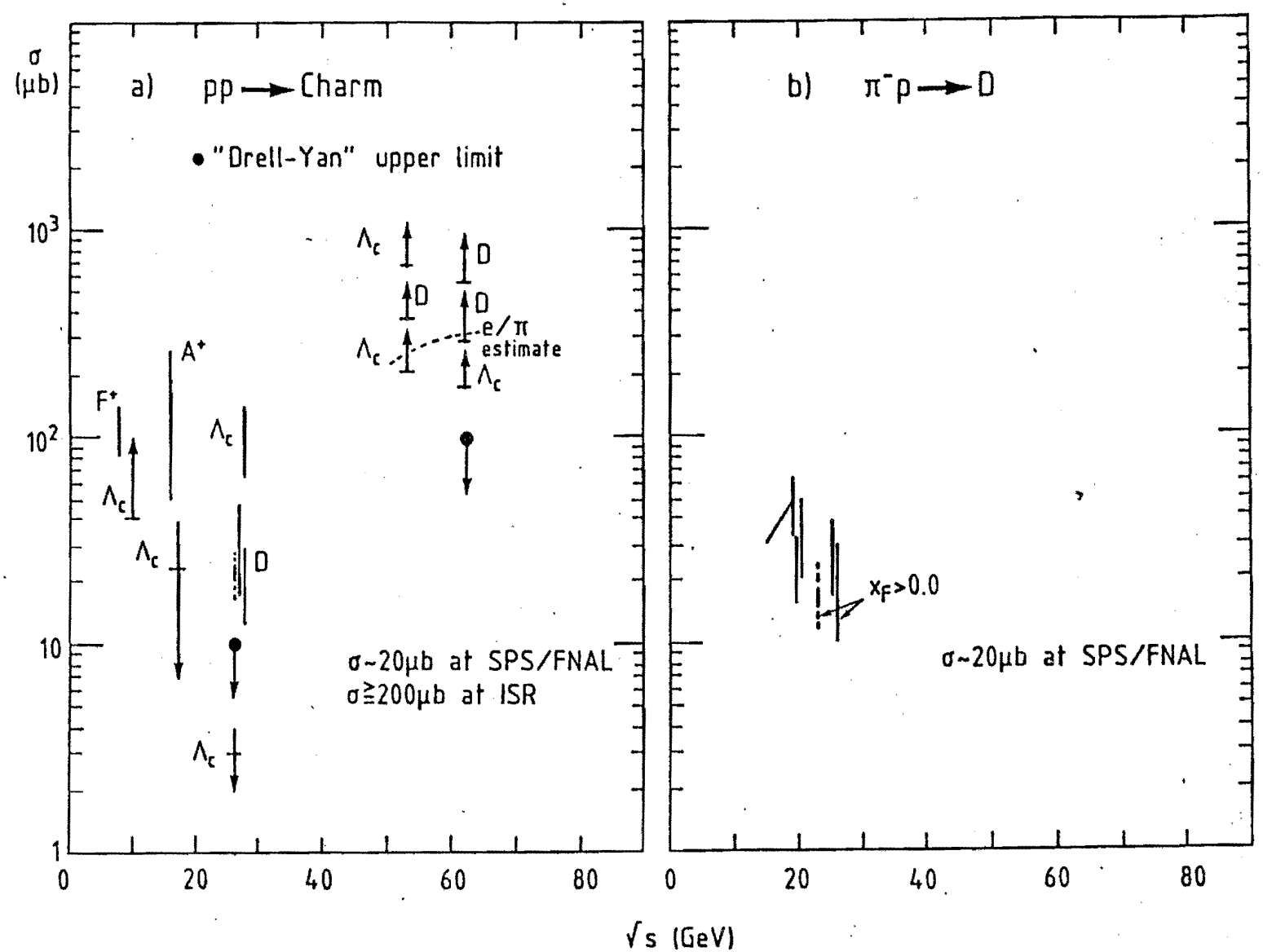
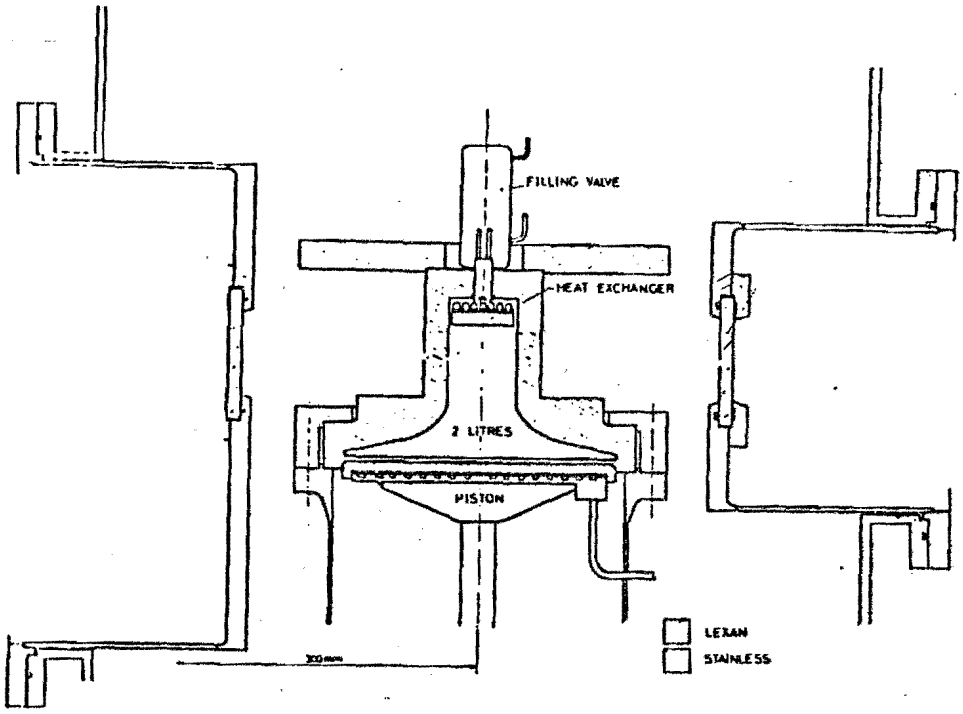

σ (μb)
a) pp → Charm
• "Drell-Yan" upper limit
10^3
10^2
10
1
F^+
A^+
Λ_c
D
e/π estimate
σ~20μb at SPS/FNAL
σ≧200μb at ISR
b) $\pi^- p \rightarrow D$
x_F>0.0
σ~20μb at SPS/FNAL
0
20
40
60
80
√s (GeV)

Fig. 1

a)


FILLING VALVE
HEAT EXCHANGER
2 LITRES
PISTON
LEXAN
STAINLESS

b)

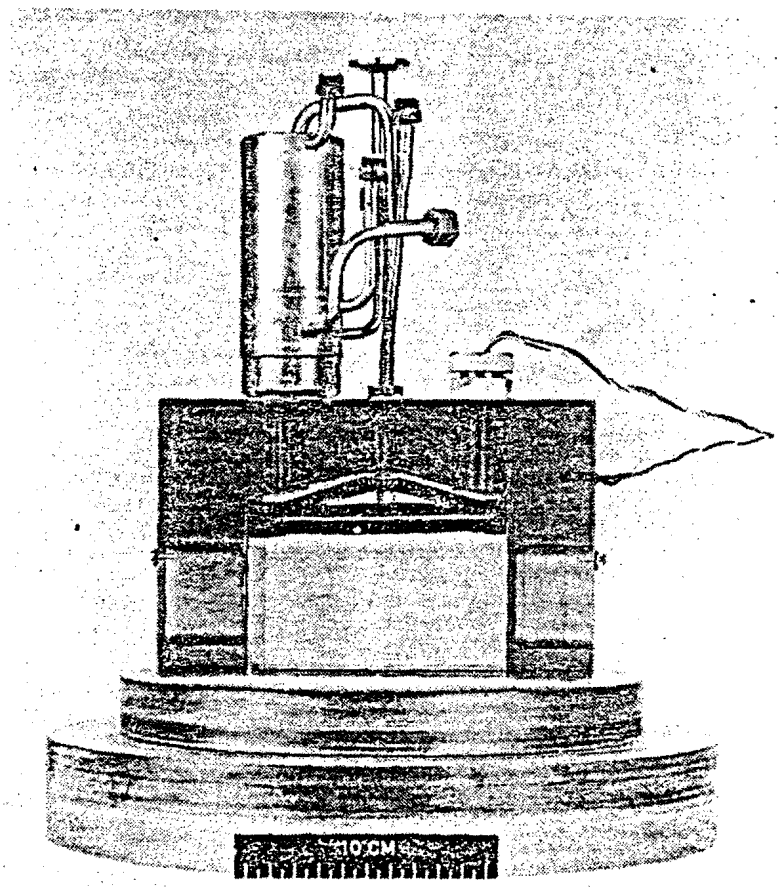

10 CM

Fig. 2

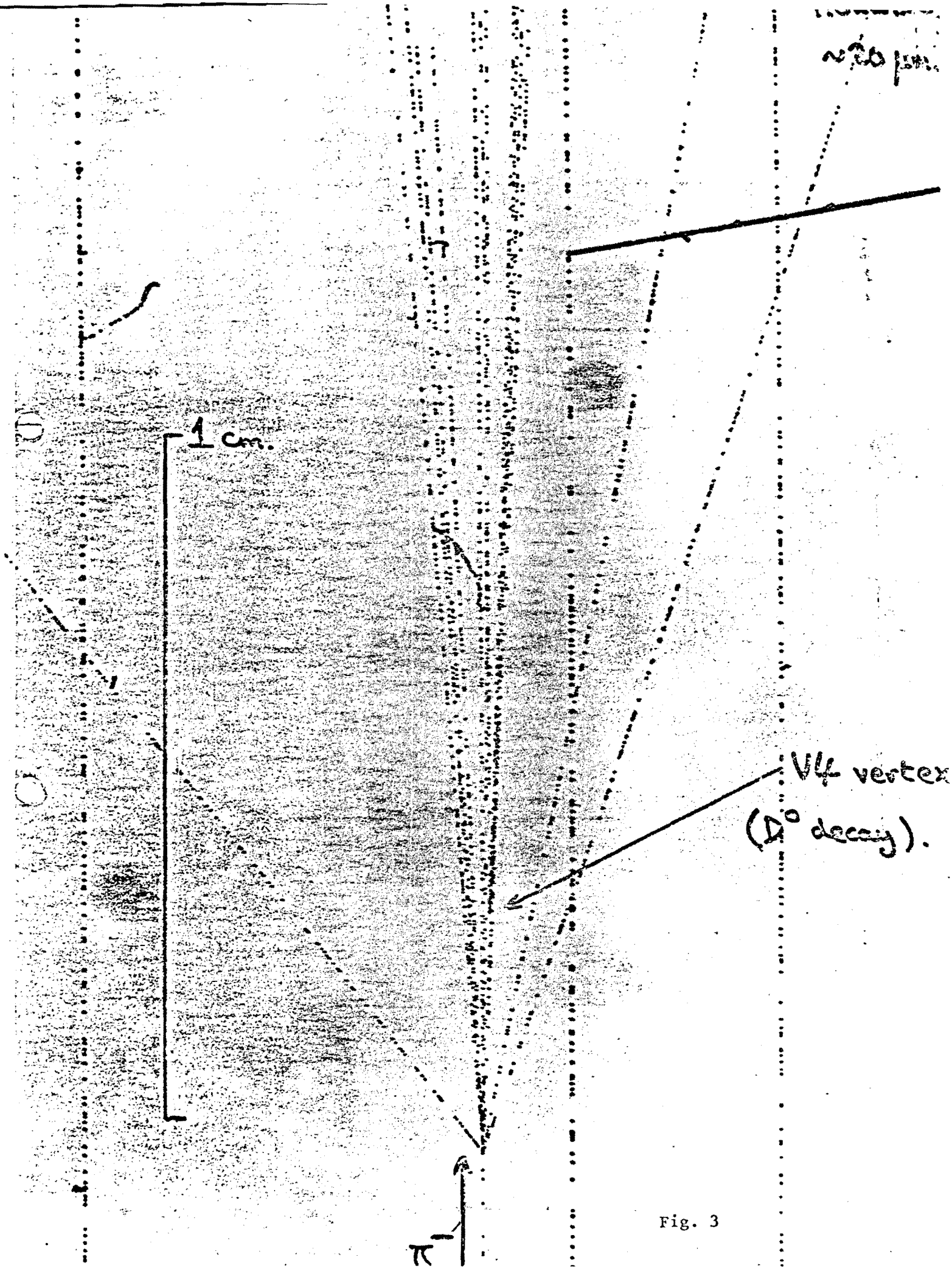


Fig. 3

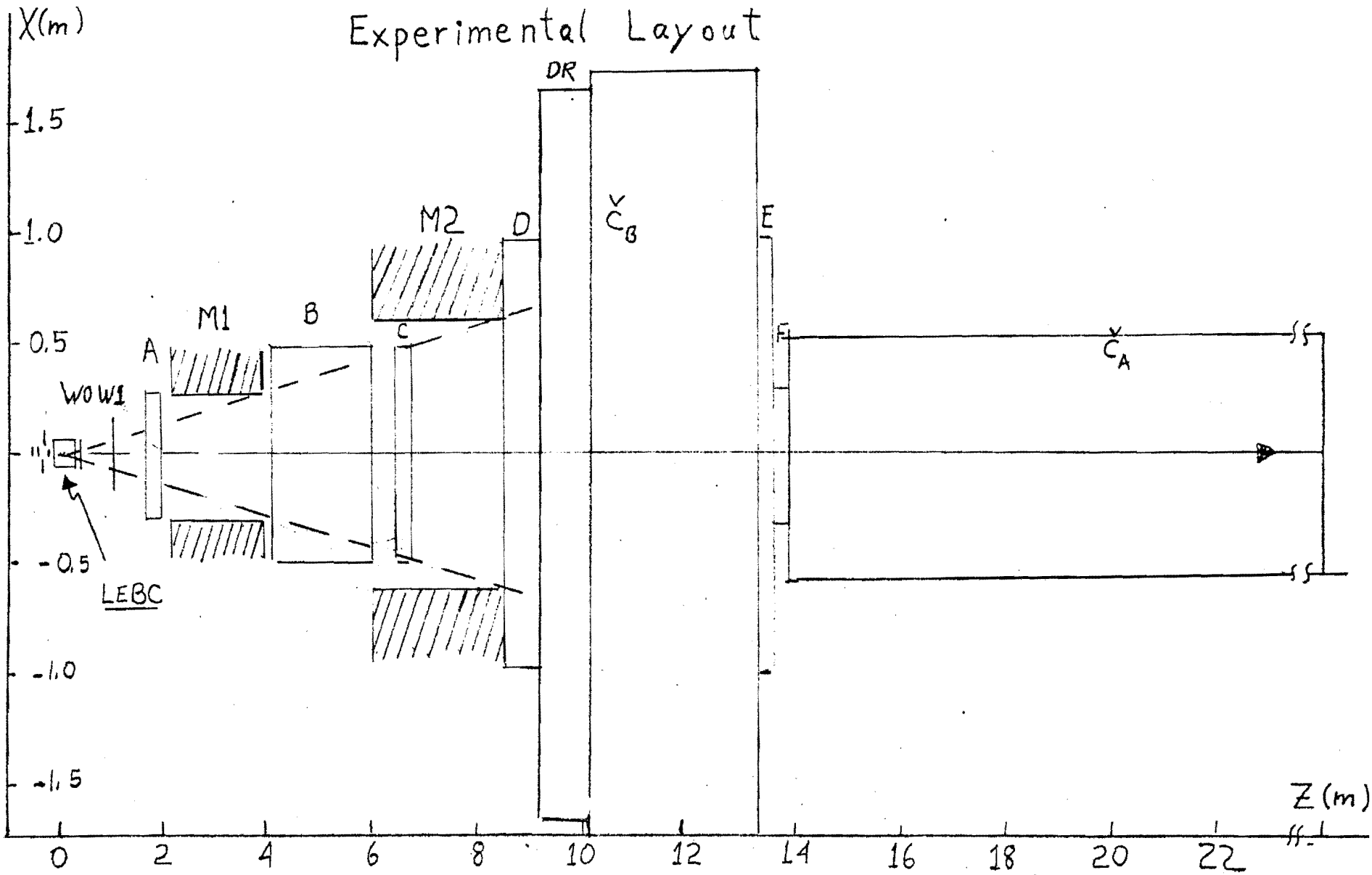

Experimental Layout
X(m)
1.5
1.0
0.5
-0.5
-1.0
-1.5
Z(m)
0
2
4
6
8
10
12
14
16
18
20
22
WOW1
LEBC
A
M1
B
C
M2
D
DR
$\check{C}_B$
E
F
$\check{C}_A$

Fig. 4