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CM-P00040496

CERN/ISRC/81-27
ISRC/P109
October 11, 1981

CHARM AND BEAUTY AT THE ISR

A proposal to study heavy flavours production in (pp) interactions at $\sqrt{s}$=62 GeV.

M. Basile, G. Bonvicini, G. Cara Romeo, L. Cifarelli, A. Contin, G. D'Ali, P. Di Cesare, B. Esposito, M. Esposito, P. Giusti, T. Massam, R. Nania, F. Palmonari, A. Petrosino, F. Rohrbach, V. Rossi, G. Sartorelli, M. Spinetti, G. Susinno, G. Valenti, L. Votano and A. Zichichi

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1. INTRODUCTION

The present proposal is based on the results obtained by the R415 experiment in the study of charm and beauty production at the SFM.

1.1. CHARM

The results [1-9] were obtained from the study of 20 reactions, 9 where charm production was observed (set-A) and 11 "control" reactions where, as expected, no charm signal was observed (set-B).

Set-A

The index TOF indicates that the particle has been identified by the time-of-flight system (TOF).

$pp \to \Lambda_c^+ \;(\hookrightarrow pK^-\pi^+)$ + (anticharmed state $\hookrightarrow e^-$) + anything (1)

$pp \to D^+ \;(\hookrightarrow K^-_{TOF}\,\pi^+\pi^+)$ + (anticharmed state $\hookrightarrow e^-$) + anything (2)

$pp \to D^0 \;(\hookrightarrow K^-\pi^+)$ + (anticharmed state $\hookrightarrow e^- + K^+_{TOF}$) + anything (3)

$pp \to D^+ \;(\hookrightarrow K^-\pi^+\pi^+)$ + (anticharmed state $\hookrightarrow e^- + K^+_{TOF}$) + anything (4)

$pp \to D^0 \;(\hookrightarrow K^-_{TOF}\,\pi^+\pi^+\pi^-)$ + (anticharmed state $\hookrightarrow e^-$) + anything (5)

$pp \to D^- \;(\hookrightarrow K^+_{TOF}\,\pi^-\pi^-)$ + (charmed state $\hookrightarrow e^+$) + anything (6)

$pp \to \bar{D}^0 \;(\hookrightarrow K^+_{TOF}\,\pi^-\pi^-\pi^+)$ + (charmed state $\hookrightarrow e^+$) + anything (7)

$$pp \rightarrow \Lambda_c^{+} + (\text{anticharmed state}) + \text{anything} \quad (8)$$
$$\Lambda_c^{+} \hookrightarrow \underset{\text{TOF}}{p}\; K^-\pi^+ \qquad (\text{anticharmed state}) \hookrightarrow e^-$$

$$pp \rightarrow \Lambda_c^{-} + (\text{charmed state}) + \text{anything} \quad (9)$$
$$\Lambda_c^{-} \hookrightarrow \underset{\text{TOF}}{\bar{p}}\; K^+\pi^- \qquad (\text{charmed state}) \hookrightarrow e^+$$

For the set-A reactions, the trigger was a "prompt" electron (for charm states) or positron (for anticharm states) with, in some cases, a $K^{\pm}$ of the appropriate charge sign identified by the time-of-flight (TOF) system.

The eleven "control" reactions were

Set-B

$$pp \rightarrow (pK^-\pi^+) + e^+ + \text{anything} \quad (1a)$$

$$pp \rightarrow (\underset{\text{TOF}}{K^-}\; \pi^+\pi^+) + e^+ + \text{anything} \quad (2a)$$

$$pp \rightarrow (K^-\pi^+) + e^+ + \underset{\text{TOF}}{K^-} + \text{anything} \quad (3a)$$

$$pp \rightarrow (K^-\pi^+) + e^- + \underset{\text{TOF}}{K^-} + \text{anything} \quad (3b)$$

$$pp \rightarrow (K^-\pi^+) + e^+ + \underset{\text{TOF}}{K^+} + \text{anything} \quad (3c)$$

$$pp \rightarrow (K^-\pi^+\pi^+) + e^+ + \underset{\text{TOF}}{K^+} + \text{anything} \quad (4a)$$

$$pp \rightarrow (\underset{\text{TOF}}{K^-}\; \pi^+\pi^+\pi^-) + e^+ + \text{anything} \quad (5a)$$

$$pp \rightarrow (\underset{\text{TOF}}{K^+}\; \pi^-\pi^-) + e^- + \text{anything} \quad (6a)$$

$$pp \rightarrow (\underset{\text{TOF}}{K^+}\; \pi^-\pi^-\pi^+) + e^- + \text{anything} \quad (7a)$$

$$pp \rightarrow (\underset{\text{TOF}}{p}\; K^-\pi^+) + e^+ + \text{anything} \quad (8a)$$

$$pp \rightarrow (\underset{\text{TOF}}{\bar{p}}\; K^+\pi^-) + e^- + \text{anything} \quad (9a)$$

In these "control" reactions, no charm/anticharm signals were observed in association to a trigger given by an electron/positron (plus in some cases a TOF identified K) of the "wrong" charge sign.

The main results were:

i) charm production in (pp) interactions was observed in the nine reactions mentioned above (set-A);

ii) the longitudinal and transverse momentum distributions of the charm particles were studied. For associated (baryon-antimeson) pairs, the baryon is produced following the "leading" effect and the antimeson in the "central" way. For associated (meson-antimeson) pairs, both are produced in the "central" way.

1.2. BEAUTY

The results [10-12] were obtained from the study of the reaction

$$pp \to \Lambda^0_b + M_{\bar{b}} + \text{anything}$$

$$M_{\bar{b}} \hookrightarrow e^+ + \text{anything}$$

$$\Lambda^0_b \hookrightarrow pD^0\pi^-$$

$$D^0 \hookrightarrow K^-\pi^+$$

The main conclusions were:

i) the observation of 25 Λ^0_b events;

ii) the longitudinal momentum distribution of Λ^0_b follows the same trend as Λ^+_c, i.e. the "leading" way. The antimeson produced in association is consistent with being produced "centrally".

1.3. (e/π)

The results of R415 extended also to the determination of the basic quantity (e/π) [13], which was directly measured to be slightly above previous measurements, even if consistent with them. It is worth emphasizing that this new measurement of (e/π) was obtained using the same experimental set-up and identical hard- and software conditions as for the charm and beauty studies.

This new (e/π) result is not high enough to account for the rate of charm and beauty production observed, unless peculiar production mechanisms are at work.

2. IMPROVEMENTS

In order to improve the results obtained from R415 experiment on charm and beauty production in (pp) collisions, a new experiment should satisfy the following general requirements:

i) the highest (pp) collision energy;

ii) the best possible selection of events where a charm or beauty flavoured particle has been indeed produced;

iii) the momentum analysis of charged secondaries over a fraction of the total solid angle as large as possible;

iv) the mass identification of charged and neutral secondaries over a solid angle and momentum range, both as large as possible.

According to these requirements, the choice of the ISR (point i) and of the SFM (point iii), coupled to a powerful electron detector (point ii), is still the best option. The new experiment would therefore be an upgraded version of R415 and the areas where improvements are possible are listed below:

i) the solid angle for the (e^+/e^-) detection:

ii) the selection of prompt (e^+/e^-):

iii) the particle identification.

2.1. THE SOLID ANGLE FOR (e^+/e^-) DETECTION

In R415 experiment, the prompt (e^+/e^-) identification was limited,as shown in fig. 1, to the 90^0 region outside of the SFM (the so called β^- region).

We propose to extend the solid angle for (e^+/e^-) detection, by adding an electron detector to the 90^0 region inside of the SFM (the so called β^+ region).

The detector for the β^+ region is shown in fig.2a. It is based on the same principles as those of the β^- side detector and has a dE/dx chamber to reject (e^+e^-) pairs due to external γ conversions plus internal γ conversions from π^0 and η Dalitz decays, followed by two gas threshold Cherenkov counters and an electromagnetic shower detector (EMSD) to reject the charged hadrons background.

All the elements of this detector exist, with the exception of the EMSD. The addition of this detector on the β^+ side increases the solid angle for (e^+/e^-) by a factor of about 2.

Under the conditions specified in section 2.2.2 , a larger increase in solid angle (up to a factor of about 3) could be achieved by using, as shown in fig.2b, only one gas Cherenkov counter, coupled to an EMSD with an adequate π/e rejection. This solution would offer the additional advantage of leaving two Cherenkov counters available for charged hadrons identification.

2.2. THE SELECTION OF PROMPT (e^+/e^-).

2.2.1. NEUTRAL HADRON BACKGROUND

The results obtained with R415 show that the background from neutral hadrons (π^0 and η Dalitz decays and external γ conversions) constitutes about 50% of the total electron sample for momenta greater than 800 MeV/c. Therefore an effort should be made to reduce this type of background.

To this purpose we are studying, via Monte Carlo simulation, the design of a new dE/dx chamber where the low energy partner of the (e^+e^-) pair could be more efficiently detected.

Amongst the various possibilities, we list the following

i) increase the number of proportional gaps, so as to improve the pulse height resolution;

ii) use horizontal, vertical and inclined wires, so as to be able to detect low energy tracks in the chamber itself;

iii) detect low energy spiralling electrons from the total pulse height in the chamber once the contribution from high momentum tracks reconstructed in the outside detector has been subtracted.

Of course the first step of this study is to determine the background level due to undetectable electrons originating from Dalitz decays or γ external conversions, i.e. those that are curled up by the magnetic field inside the vacuum chamber. In fact, only a relevant gain in the background rejection would justify the development and construction of a new dE/dx chamber. All this is under active investigation.

2.2.2. CHARGED HADRON BACKGROUND

The total rejection power against charged hadrons of the outside (β^- side) electron detector in R415 was 7.5 x 10^{-6} and therefore we do not need to improve it.

The same, obviously, applies for the β^+ side detector, if the solution with two Cherenkov counters plus an EMSD is chosen. As mentioned before, all the elements of this detector already exists, apart from the EMSD.

The present developments of electromagnetic shower detectors based on the limited streamer tube (LST) technique [14], show that these detectors are faster and cheaper to produce than the standard lead/scintillator sandwich detectors, and have the following characteristics:

i) good energy resolution ;

ii) longitudinal shower sampling to discriminate electromagnetic and hadronic showers;

iii) high spatial resolution and determination of the shower axis to reject the background from overlapping charged hadrons and γ's $(h^{\pm}\text{-}\gamma)$ and electromagnetic showers originated by charged π's through charge exchange reactions.

The use of these limited streamer tubes appears, therefore, as a convenient solution for the new electromagnetic shower detector to be built.

Moreover, the π/e rejection factor of such a detector, in the range 0.5-2 GeV, has been measured to be of the order of 10^{-3} [15]. Notice that this figure has been obtained using a detector with a few radiation lengths and a rough sampling and, therefore, a better choice of the parameters should produce a π/e rejection better than 10^{-3}.

We are planning to clarify this point via experimental tests, and, if the results are successful, we could use, for the (e^+/e^-) detector on the β^+ side, only one gas Cherenkov counter coupled to a limited streamer tubes EMSD, with the advantages specified in section 2.1.

The main drawback of the limited streamer tubes is, however, their time resolution. As for most gaseous detectors their time jitter is quite large ($\simeq$ 200 nsec) and their information cannot be used at the fast trigger level.

Therefore we propose to use a hybrid electromagnetic shower detector constituted by layers of tubes interspaced by some layers of scintillators. In this case the scintillator information would provide a first rough energy measurement for the fast trigger.

An accurate determination of the shower energy can then be made with the tubes information to be used at the slow trigger level.

2.3. PARTICLE IDENTIFICATION

In R415, the charged hadron identification was based on the TOF system, for momenta below 2 GeV/c, and on the p/π ratio versus $x = 2p_L/\sqrt{s}$ for $x>0.3$.

For the new experiment, we are considering the following improvements.

2.3.1. THE SMALL-x REGION

The use of Aerogel Cherenkov counters would extend the momentum range over which π's can be separated from K's and protons. However, the amount of Aerogel needed to cover a solid angle adequate for invariant mass studies, would imply a major production effort at the Bologna University Institute.

Another interesting possibility would be the use of high pressure ($\simeq$4.5 atm.) Freon Cherenkov counters to separate π's from K's and p's, in a momentum interval between 1 and 6 GeV/c.

We are, at present, studying the details of this improvement program.

In any case, the disposition of the TOF hodoscopes around the SFM, will be changed with respect to R415 and, eventually, a few counters will be added in order to improve the TOF acceptance.

2.3.2. THE LARGE-x REGION

A way to improve the identification of the "leading" proton, is to use gas threshold Cherenkov counters filled with Freon 114 at atmospheric pressure. These counters would be installed in front of the large compensator magnets of the SFM and would separate π's from K's and p's in the momentum interval between 3 and 9 GeV/c, with unambiguous p's identification for momenta greater than $\simeq$18 GeV/c.

Unfortunately, the two Cherenkov counters used by previous experiments at the SFM, are not suitable for our purposes, due essentially to the fact that their optics has been designed for negative particles and, consequently, their detection efficiency for positive particles is too low.

3. THE MINIMUM CHOICE

A proposal with all the improvements outlined in chapter 2, would require a large effort in terms of cost and manpower, and a time interval which could be incompatible with the present ISR schedule.

In order to take in due account the present plans for the ISR running, we have restricted the present proposal to the minimum choice in order to exploit, as efficiently as possible, the ISR before its closing date, i.e. end of 1983. The minimum choice is based on a preparation time for all items which should allow data taking by 1st January 1983 and for all the year. This is in fact, the last possibility for studying "heavy flavours" production in the $\sqrt{s}$ = 62 GeV (pp) energy range.

3.1. EXPERIMENTAL SET-UP.

The proposed set-ups are shown in figs. 3a and 3b, depending on which solution is chosen for the (e^+/e^-) β^+ side detector. The outside electron detector is essentially the same as for R415. The electrons are identified by the coincidence of two gas threshold Cherenkov counters (COC3 or COC4) followed by an electromagnetic shower detector (SW3,SW4) constituted by the lead/scintillator sandwiches already used in R415. Also the Cherenkov counters and the dE/dx chamber are those which have been used in R415.

The inside electron detector (β^+ side) is constituted by

i) a dE/dx chamber which has already been installed but needs some calibrations to provide the analog information necessary for the rejection of background e^-e^+ pairs;

ii) three gas threshold Cherenkov counter, C1, C2 and C5, which have already been used in R415 as a part of the electron pair detector (fig.3a), or, as shown in fig.3b, only one Cherenkov counter, C1;

iii) an electromagnetic shower detector based, as specified before, on limited streamer tubes plus some scintillator planes.

The charged hadron identification is based

i) on the existing TOF system for the small-x region;

ii) on two Freon 114 threshold Cherenkov counters for the forward large-x region (fig.3a). As shown in fig.3b, if the two Cherenkov counters C2 and C5 are not used for the (e^+/e^-) detector on the β^+ side, they will be installed in the forward direction, to increase the solid angle for large-x charged hadrons identification.

3.2. ESTIMATES OF RATES, EXPECTED EVENTS, TOTAL RUNNING TIME AT $\sqrt{s}$=62 GeV

The trigger of the experiment will be divided into three separate steps.

1) The fast trigger. The purpose of this trigger is to provide a fast rough selection of events within the time limits imposed by the need to strobe the MWPC one-shots into the memory flip-flops. It will be based on the fast information from the MWPC fast-or (FOR) signals, the Cherenkov signals, the EMSD signals. The use of fast programmable units will allow for a more sophisticated fast trigger than in R415 and, on the basis of our previous experience, we extimate the fast trigger rate to be of the order of 50/sec., with the energy cut $E_{min}(e) > 500$ MeV.

2) The slow trigger. The purpose of the slow trigger is to provide a better selection of events using the more detailed informations available, at this stage, from the various detectors. It will be based on momentum

selecting roads defined by the MWPC memory-or (MOR) signals in coincidence with a more precise spatial matching of the energy clusters in the EMSDs and a better determination of the shower energy. The expected trigger rate is ≃ 10/sec.

3) The on-line filter. In this last stage of the trigger chain we will use the PDP 11/20 computer to perform a further refinement of the event selection with a fast track finding in the detector region determined by the slow trigger, to define the candidate (e^+/e^-) track using the single wire informations from the various chambers. The expected trigger rate is ≃ 6/sec.

The purpose of the experiment is to reach a statistics, on charm and beauty signals, a factor 10 higher than the R415 one.

Having doubled the (e^+/e^-) detector acceptance, this new experiment should collect a factor 5 more luminosity than R415, i.e. a total integrated luminosity of 2.2×10^{37} cm^{-2}.

At an average luminosity of 0.8×10^{31} cm^{-2} sec^{-1}, the above figure corresponds to ≃ 760 hours of ISR running.

As we expect the data taking efficiency to be around 20% in the first period of run (≃ 250 hours), and to reach the 50% value in the following, the total ISR running time needed by the experiment is ≃ 2300 hours. This includes the on-line calibrations of the EMSDs and the other on-line apparatus checks, but does not include about 300 hours needed for setting-up.

The total ISR time needed is, therefore, ≃ 2600 hours.

From the expected trigger rate and the total luminosity to be integrated in order to reach the above mentioned increase in statistics for charm and beauty signals, the total expected number of raw events to be collected is 1.6 x 10^7.

3.3. COMPUTER TIME NEEDS

To optimize the computer time utilization, a filtering procedure, similar to that used in experiment R415, is foreseen.

This filter selects a sample, as clean as possible, of "prompt" (e^+/e^-) events and is based on the analysis of the informations from the MWPCs, the Cherenkov counters, the dE/dx chambers and the EMSDs (lead/scintillator sandwiches and LSTs).

The computer time needed for this filtering will be of about 40 msec. per raw event on the 7600 CDC computer, which means about 200 CDC equivalent hours for the full statistics of 1.6 x 10^7 raw events.

The time needed to fully reconstruct the events (≃ 6 x 10^5) selected by the filter is of the order of 1000 CDC hours (≃ 6 seconds/event).

The Bologna University and the LNF[1] VAX computers and the CINECA 7600 CDC computer can provide, in two years, about 500 CDC equivalent hours of computing, which will be

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[1] Laboratori Nazionali di Frascati

used to perform half of the full reconstruction of the selected events.

Therefore, about 700 CDC hours / 2 years will be spent at CERN.

We are studying the possibility of using the E/168 computer, available at the SFM, to perform the raw events filtering, equivalent to 200 CDC hours, as mentioned above. This will reduce the needs for the CERN 7600 CDC computer to 500 hours divided into two years.

3.4. ESTIMATES OF FINANCIAL SUPPORT FOR THE EXPERIMENT.

The following table summarizes the financial support needed by the experiment.

	KSFr
EMSD on the β^+ side	150
Forward gas Cherenkov	400
PM's for existing Cherenkov and TOF counters	50
Fast electronics	200
ADC, TDC CAMAC crates	150
Mechanical supports	100
Stores	150
TOTAL	1200

This cost corresponds to the "minimum choice" set-up. The addition of Aerogel or high pressure Cherenkov counters, would imply an additionad cost of about 300 KSFr.

3.5. TECHNICAL SUPPORT NEEDED FROM CERN

3.5.1. OPERATION OF THE SFM DETECTOR

We require the support of the SFM detector group for the standard maintenance, control of working conditions and reparation in case of break-down, of the various parts of the detector:

i) the multiwire proportional chambers and the dE/dx chambers;

ii) the gas threshold Cherenkov counters;

iii) the scintillation counters used for the measurement of the luminosity and background;

iv) the system electronics.

3.5.2. CONSTRUCTION OF THE LIMITED STREAMER TUBES AND OF THE FORWARD GAS CHERENKOV COUNTERS

We require a support of the EF division for the construction of the limited streamer tubes at the same level as for the NUSEX experiment. Notice that the tubes that we intend to use have the same characteristics as those presently being produced for the NUSEX experiment; therefore, the production chain does not require any modification.

We would also require the support of the EF division for the construction of the two forward gas Cherenkov counters.

3.5.3. ELECTRONICS FOR THE SLOW TRIGGER

We require the support of an electronics expert to help in the development of the electronics associated to the limited streamer tubes read-out and of the slow-trigger electronics.

3.5.4. ON-LINE COMPUTING

We require the experiment to be provided with a dedicated on-line computing specialist to help in the development of the on-line monitoring and filtering programs.

3.5.5. OFF-LINE COMPUTING

One professional programmer is needed to help in the development of the off-line filter programs, in the optimization of the reconstruction programs and their installation on the VAX computers.

4. THINGS TO BE URGENTLY DONE

i) All the lead/scintillator sandwiches are to be tested and calibrated in an electron beam in the momentum range 0.5-4. GeV/c.

ii) All the electronics associated with the electromagnetic shower detectors and the Cherenkov counters is to be installed and checked. The same applies for the fast trigger electronics relative to the single electron trigger and to the various control and calibration triggers.

iii) The TOF counters have been in operation for several years and present performances should be checked in a test beam.

iv) The dE/dx chamber installed in the β^+ side needs to be calibrated in order to provide the necessary analog informations.

v) All gas Cherenkov counters (C0 to C5) should be checked in a test beam.

vi) A prototype of the LST electromagnetic shower detector should be tested as soon as possible to finalize its design.

5. TIME TABLE FOR THE "MINIMUM CHIOCE"

1) Testing of all existing equipment, i.e. TOF, Cherenkov counters, EMSDs, dE/dx chambers: 6 months;
2) construction of the LST (EMSDs): 6 months;
3) construction of the forward Cherenkov counters: 8 months;
4) assembling at the SFM: July - August 1982;
5) ready to start run: October 1982;
6) data taking: all during 1983.

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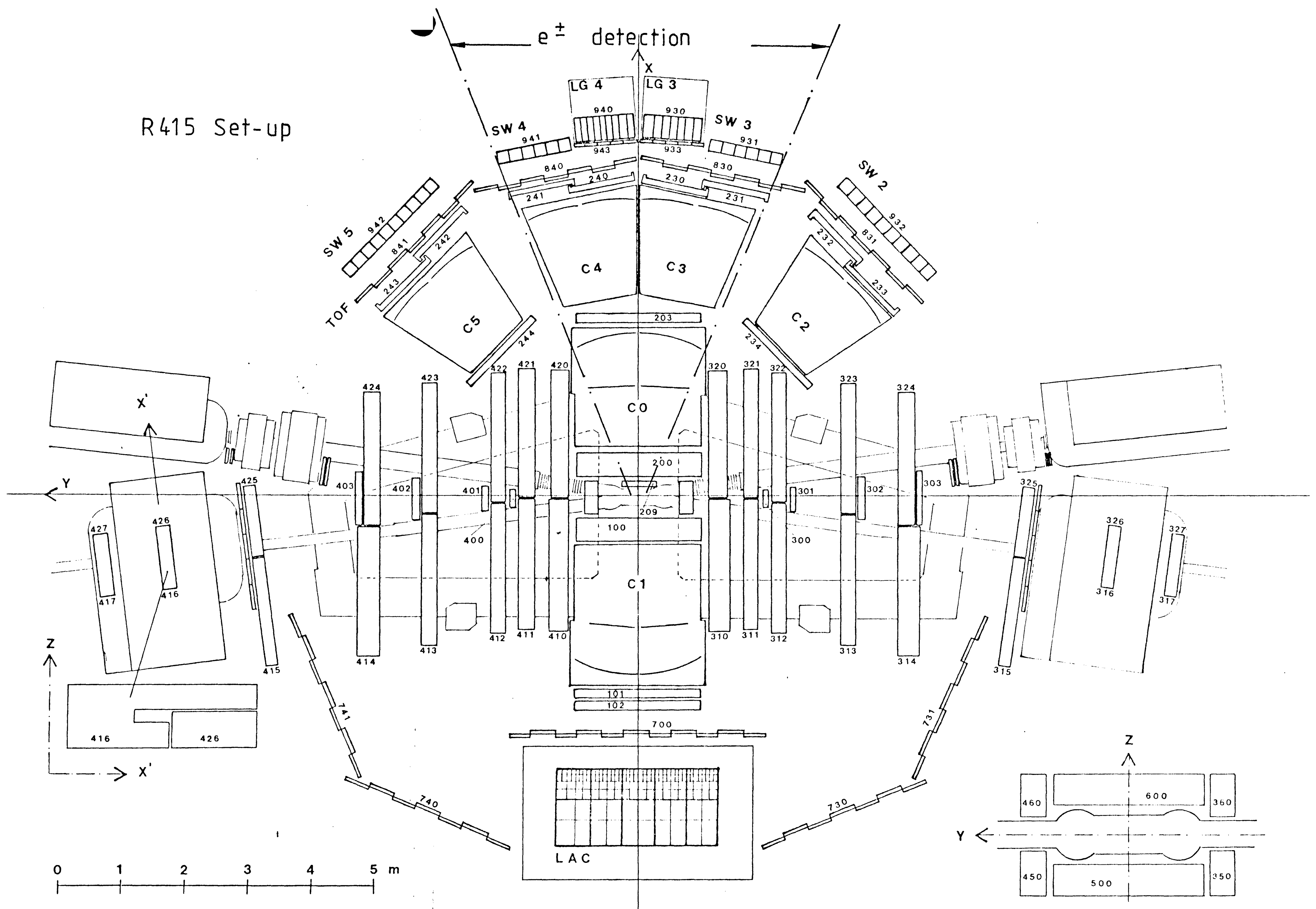
R415 Set-up
e± detection
LG 4
LG 3
SW 4
SW 3
SW 2
SW 5
TOF
C0
C1
C2
C3
C4
C5
LAC
x
Y
Z
x'
0 1 2 3 4 5 m

Fig. 1

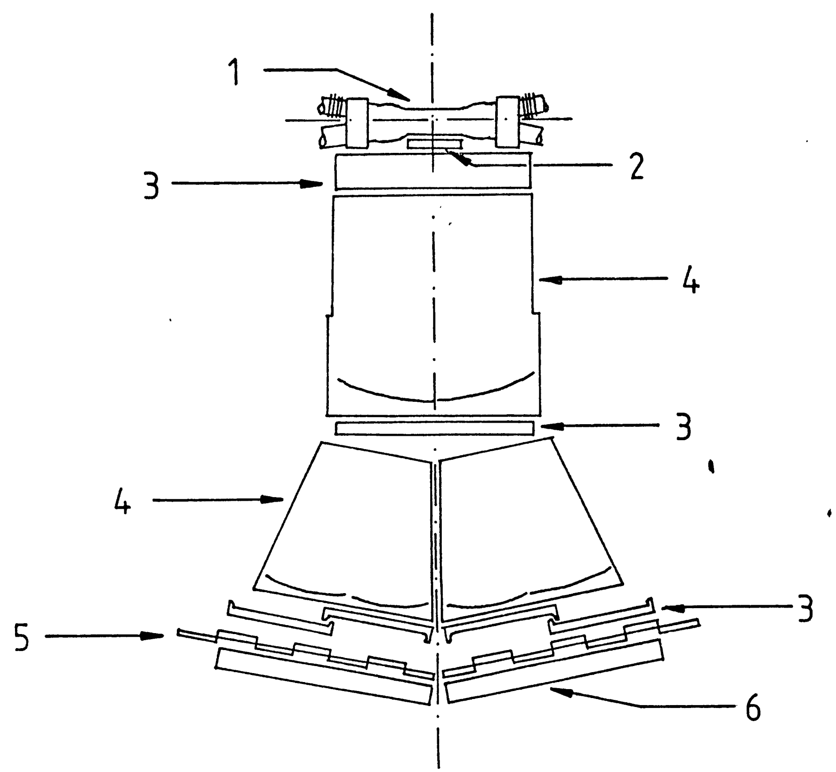

Fig. 2a

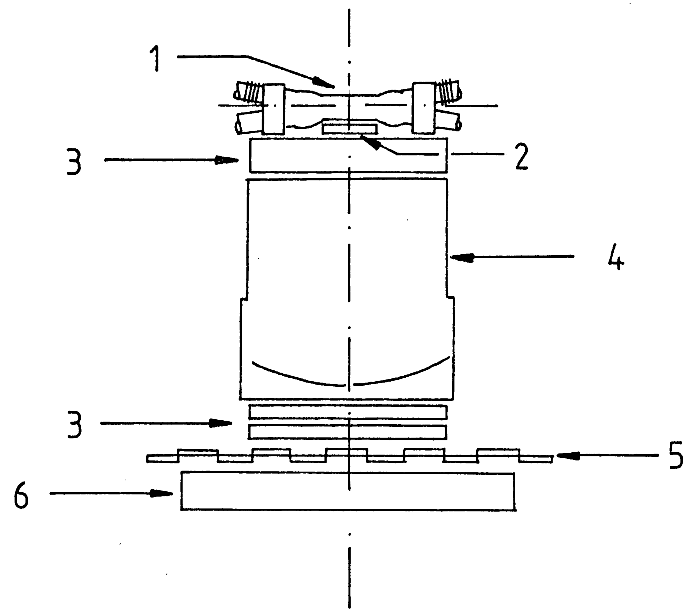

Fig. 2b

1 - Vacuum chamber
2 - dE/dx chamber
3 - Wire chamber
4 - Gas Cherenkov
5 - Scintillators
6 - EM shower detector

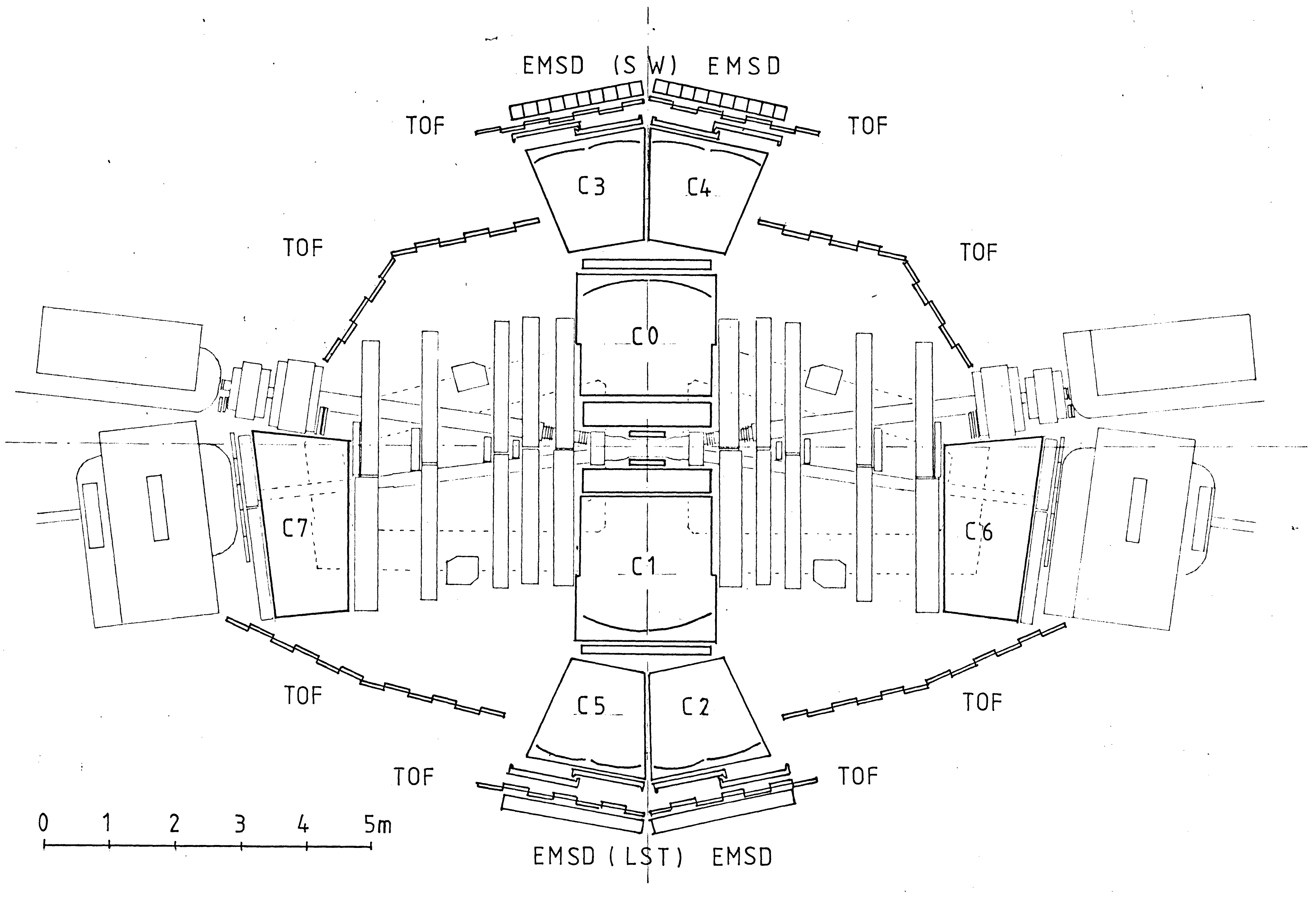
EMSD (SW) EMSD
TOF
TOF
C3
C4
TOF
TOF
C0
C7
C6
C1
TOF
TOF
C5
C2
TOF
TOF
0 1 2 3 4 5m
EMSD (LST) EMSD

Fig. 3a

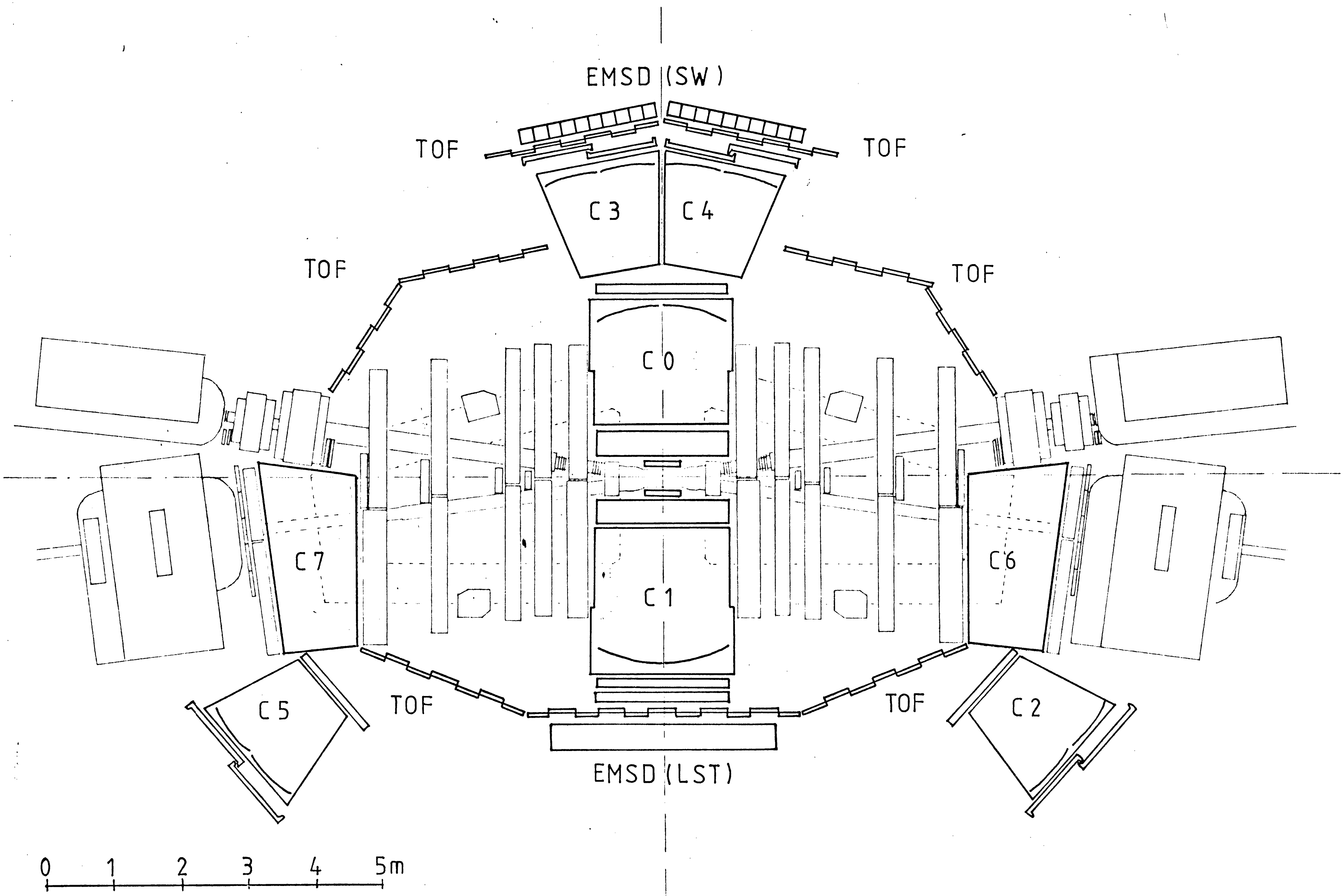
EMSD (SW)
TOF
TOF
C 3
C 4
TOF
TOF
C 0
C 7
C 6
C 1
C 5
TOF
TOF
C 2
EMSD (LST)
0
1
2
3
4
5m

Fig. 3b

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