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CHEOPS

CHarm Experiment with Omni-Purpose Setup

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Yu. Alexandrov[8], F. Balestra[14], M. Beck[4], R. Bertini[14], W. Brückner[4], C. Büscher[4], M.P. Bussa[14], E. Chudakov[9a], A. Dolgopolov[10], S. Donskov[10], F. Dropmann[4], L. Fava[14], L. Ferrero[14], H. Fischer[2], J. Franz[2], R. Garfagnini[14], S. Gerassimov[8b], A. Grasso[14], Th. Haller[4], M. Heidrich[4], A. Inyakin[10], G. Khaustov[10], K. Königsmann[2], A. Kondashov[10], I. Konorov[4], A. Lednev[10], A. Maggiora[14], K. Martens[5], S. Masciocchi[4], M Moinester[13], U. Müller[15], D.M. Newbold[1], P. Netchaeva[8], W. Oelert[6], D. Panzieri[14◇], **S. Paul**[4], L.S. Peak[12], G. Piragino[14], S. Polovnikov[10], V. Polyakov[10], B. Povh[4], Yu. Prokoshkin[10],R. Ransome[11], Z.L. Ren[4], K. Röhrich[6], S. Sadovsky[10], V. Samoylenko[10], P. Shagin[10], A. Shtannikov[10], H. Schmitt[2], L. Schmitt[4], H.W. Siebert[5], A. Singovsky[10], V.J. Smith[1], V. Sugonyaev[10], G.N. Taylor[7], O. Thilmann[5], F. Tosello[14◇], S.N. Tovey[7], J. Ulrichs[12], K. Vorwalter[4], R. Werding[4], U. Wiedner[3], E. Wittmann[4], M. Zavertiaev[8b], J. Zimmer[4], G. Zosi[14]

Abstract

We propose to build a new state of the art high intensity fixed target spectrometer in the North Area of the CERN SPS. The main physics goals are the observation and study of doubly charmed baryons and charmed baryon semi-leptonic decays. In addition a large program concerning a comprehensive and high statistics search for exotics is proposed together with a dedicated study of hadronic structure in Primakoff reactions. The program requires a large variety of beam projectiles and energies possibly extending to high intensity lead beams. Beam intensities of up to $5 \cdot 10^7$ particles/spill in conjunction with fast readout and dedicated triggers should allow us to obtain data samples exceeding projected data samples from running experiments by about a factor 10. By using, in part, existing equipment such an experiment could start first set up runs in 1998.

1 - H.H. Wills Physics Laboratory, Univ. of Bristol, United Kingdom
2 - Fakultät für Physik der Univ. Freiburg, Germany
3 - I. Physikalisches Institut der Univ. Hamburg, Germany
4 - Max Planck Institut für Kernphysik, Heidelberg , Germany
5 - Physikalisches Institut der Univ. Heidelberg, Germany
6 - KFA, Jülich, Germany
7 - University of Melbourne, Australia
8 - Lebedev Physical Institute, Moscow, Russia
9 - Moscow State Univ., Moscow, Russia
10 - IHEP, Protvino, Russia
11 - Physics Department, Rutgers University, Piscataway, USA
12 - Univ. of Sydney, Australia
13 - School of Physics, Tel Aviv Univ., Ramat Aviv, Israel
14 - INFN and Univ. of Torino, Torino, Italy
15 - present address : CERN, Div. PPE, Geneva, Switzerland

⋆ The KEK group currently involved in WA102 has expressed strong interest in this experiment

contact person : S. Paul E-mail : snp@vsnhd1.cern.ch

[a]Currently at the Inst. für Kernphysik, Mainz Univ., Germany
[b]Currently guest of the Max Planck Inst. für Kernphysik, Heidelberg, Germany
[◇]not yet confirmed

Contents

Summary

We propose a modern high-rate fixed-target experiment for use with secondary hadron beams at the CERN SPS. Many physics questions can be addressed with such a spectrometer, but the set-up has been optimised for a study of semileptonic decays of charmed baryons and for a search for doubly charmed baryons. However, the spectrometer is designed to be adaptable to different needs, including a search for exotic hadrons, reactions based on the Primakoff effect, and studies using heavy ions.

Previous experiments

The production, spectroscopy, and decay properties of charmed baryons are currently being investigated in the WA89 experiment at CERN as well as in the Fermilab experiment E781 which will start data taking in spring 1996. Both experiments, being second generation experiments in this field, focus on detailed studies of these phenomena using Σ^- or π beams of fixed energy. They are designed to give good acceptance for charmed baryons produced by hyperons in the forward direction ($x_F \geq 0.25$ for WA89 and $x_F \geq 0.1$ for E781). Although results from the WA89 experiment show a strong leading effect such that charmed baryon formation is favoured over charmed meson formation in the forward direction, no strong cross section enhancement is observed in this kinematical regime. In spite of the large data samples expected, these experiments are limited by the accuracy achieved in the vertex reconstruction and in the total statistics of the charm sample.

A) Physics goals

We wish to study two important issues which are unlikely to be addressed by these experiments: **inclusive semileptonic decays** and **doubly charmed baryons**. There is also the important question of unexpected production phenomena observed in earlier experiments. This seems to be intimately connected to the baryon number flow. A systematic investigation requires acceptance over the largest possible solid angle extending to negative values of x_F $(= p_L^{cm}/\sqrt{s})$, variable beam energies, and projectile type.

• semileptonic decays of charmed baryons

The knowledge of semileptonic properties is one of the most important issues in charm physics. In the absence of any normalisation for the production rate of charmed hadrons they constitute the link between the measured lifetimes and the observed hadronic decay branching ratios. Secondly, they provide the best test of our understanding of charm baryon decays, since many precise theoretical predictions on rates and form factors are available to be tested experimentally.

For the first of these, it is necessary to find the total s.l. decay width. This is only possible if we measure inclusive s.l. decays. Theoretically, the ratio of inclusive decay widths for different baryons can be calculated with good reliability ([1]). By normalising hadronic branching ratios to the inclusive s.l. ones we can thus connect the measurements from different charmed baryons. The uncertainty of the absolute scale for all measurements is thus reduced to the uncertainty of the best known charmed baryon, namely Λ_c^+ (for which absolute b.r. have been measured in MARKII [2] and in B-decays [3]) or to the uncertainties in the theoretical calculations for absolute decay rates.

Form factors and their q^2-dependence have recently attracted much attention within the framework of Heavy Quark Effective Theory (HQET). Although the charm quark mass is at the lower limit of application of the theory, the necessary corrections to be made are believed to be of the order of 20%. The theory should be tested at low values of q^2 where counting rates are small.

• doubly charmed baryons

Almost all the $\frac{1}{2}^+$ states of singly-charmed baryons have been observed, but nothing is known about the multiply-charmed baryons. The properties of $ccq-$baryons were discussed by Bjorken [4], Richard [5] and others [6–8]. Their structure should resemble a heavy meson with a heavy cc-diquark in the centre surrounded by a light quark. Typically such states are expected in the mass range from 3.6 GeV/c^2 (ccu, ccd) to about 3.8 GeV/c^2 (ccs). In addition to their spectroscopical interest, these states offer important insights into decay dynamics analogous to the singly charmed baryons. If their decays are dominated by the spectator diagram their lifetime would be expected to be about 1/2 that of the Ξ_c^+(about 200 fs). For each doubly charmed baryon, however, different effects will modify the free quark decay. In the Ξ_{cc}^{++} (ccu) we have u-type interference, for the Ω_{cc}^+ (ccs) an s-type interference and for the Ξ_{cc}^+ (ccd) the internal $W-$exchange. (The ultimate Ω_{ccc}^{++} would allow a clean study of the free quark decay).

Although intriguing on paper, the study of ccq-baryons is severely hindered by very low production cross-sections. If we assume that $\sigma(ccq)/\sigma(cqq) \approx \sigma(c)/\sigma_{incl} \cdot k$ where k describes the probability that both c-quarks are present in the same baryon we can estimate the production cross section of ccq-baryons to be about $10^{-6} - 10^{-7} \cdot \sigma_{incl}$. Higher production cross sections have been estimated by Brodsky and Vogt[9] using an intrinsic charm model. For details on these estimates we refer to the Appendix.

The technical challenge

Measurements of semi-exclusive s.l. decays (reconstruction of a lepton and associated baryon with a common origin) are difficult since the charmed baryons cannot be fully reconstructed (due to the missing neutrino). This leads to enhanced backgrounds which are difficult to understand and are the cause of systematic errors. In order to reduce such backgrounds the detection of the associated charmed meson would be very helpful since it provides a good tag for a charmed baryon. This, however, requires a spectrometer with large solid angle and acceptance extending to the backward hemisphere. Other charmed baryon tagging methods also require large solid angles for low energy decay photons or pions (see chapter A.1 and B.5). For the measurements of inclusive decays of charged charmed baryons it is necessary to observe the decay process itself. This might be achieved if the parent baryon can be tracked and the kink angle between the charmed baryon and the outgoing lepton can be observed. The short flightpath of a charmed baryon turns this into an experimental challenge. For neutral charmed baryons, s.l. decays will always leave a charged multiprong vertex and the accuracy and background depend strongly on the vertex quality achieved.

For full reconstruction of ccq-baryons we must observe the full decay chain. This involves an intermediate singly charmed hadron (baryon or meson). Naively we may guess typical branching ratios to be of the same order as for the decay of singly charmed baryons. Estimates for some branchings have been given by Bjorken [4]. The decay $\Xi_{cc}^{++} \rightarrow \Sigma_c^{++} K^{*0}$ could be of the order of 5%. Typically about 60% of the $ccq-$decays could be hadronic. Clearly, a high efficiency for detecting singly charmed hadrons is mandatory in order to observe such states.

B) Proposed experiment

We propose an experiment with a high-rate capability (a few 10^7 beam particles/second) with excellent tracking, a 2-stage magnetic spectrometer, good particle identification and calorimetry, and specialised triggers. The beam line should be versatile to allow high intensity π, K, p, hyperon or even heavy ion beams with a variable beam momentum as high as 360-400 GeV/c (charged hyperons) or 450 GeV/c (protons). The spectrometer, shown in fig. I.1, should be mounted on rails to allow a flexible set up (for instance decay zones of variable length). State of the art, LHC-type detectors are necessary to fulfill the requirements on rate and radiation stability. Very fast on-board electronics has to be used to cope with the large data flow. This also allows an easier rearrangement of the detectors when needed.

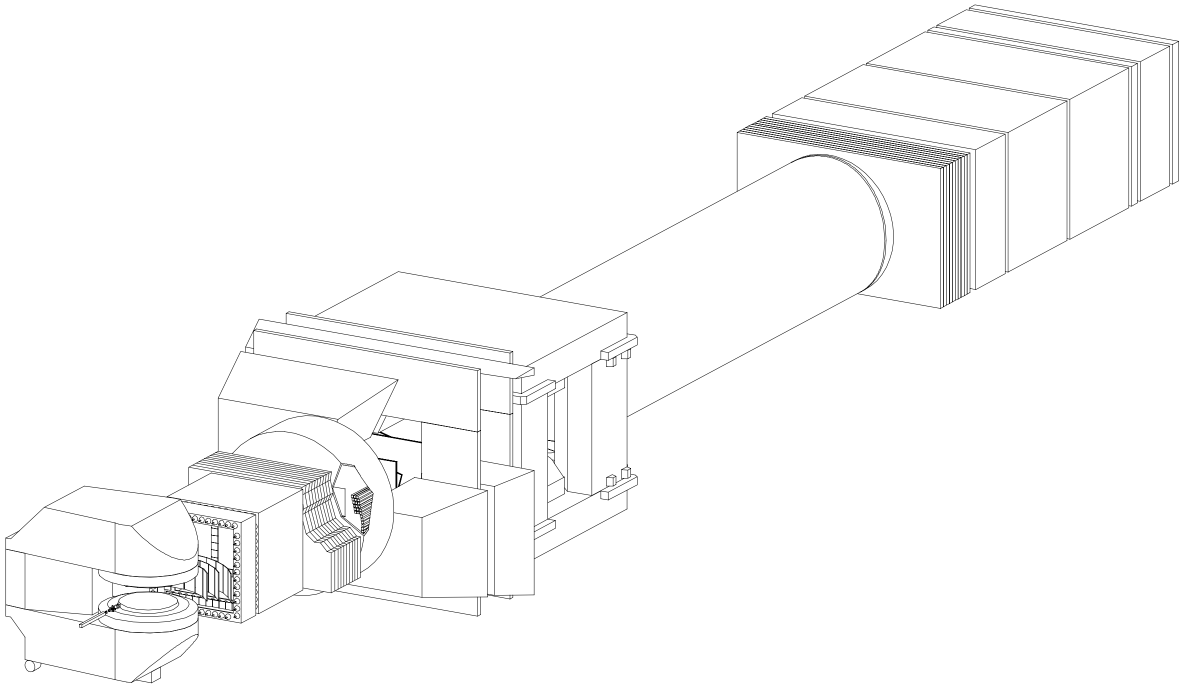

Figure I.1: Artists view of the proposed experiment

A Physics Goals

In the following section we will discuss in turn the different physics questions to be addressed with the proposed experiment, stressing the most important investigation of charmed baryon production, decays, and spectroscopy. Of particular interest is the search for doubly-charmed baryons. We will also cover such diverse fields as a search for new particles, a study of baryon structures, and heavy ion physics.

The physics at a high intensity charm experiment has been discussed recently at Fermilab [10]. However, most of the discussion centred on charmed mesons. The proposed experiment is more concerned with charmed baryons and hopes to collect about ten times more charmed hadrons than the two proposed Fermilab experiments E781 and E831.

A.1 Charmed Baryon Decays

The study of charmed baryon decays can be divided into three mutually connected categories:

- semi-leptonic decays
- lifetimes
- non-leptonic decays

Semi-leptonic decays. The semileptonic decay rates of charmed mesons and baryons can be calculated theoretically with good precision since only the free c-quark decay rate has to be evaluated with form factors, which can be obtained using the Heavy Quark Effective Theory (HQET). Effects of the finite c-quark mass are estimated to be on the order of 20%. Furthermore, symmetries in the light quark degrees of freedom can be utilised in these calculations, such as for the semileptonic decays of Λ_c and Ξ_c.

We can use the theoretical semileptonic decay width Γ_{sl}^{th} together with the experimentally accessible ratios of branching fractions B_{had}/B_{sl} to determine the hadronic partial widths: $\Gamma_{had} = \Gamma_{sl}^{th}\, B_{had}/B_{sl}$, for which different models give widely differing results[1]. Once a lifetime measurement is performed, we can calculate *absolute* hadronic branching ratios by multiplying with the above determined hadronic width: $B_{had} = \Gamma_{had}\, \tau$.

Theoretical uncertainties in the free decay rate disturbed by short distance corrections are small and expected to be very similar for the various charmed hadrons. However, large uncertainties exist in the long distance effects, described by the w.f. overlap of initial and final states. Nevertheless, various possibilities exist to relate such effects for different hadrons giving reasonably reliable predictions for the ratios of the s.l. decays rates [1].

[1] Note that the experimental determination of B_{sl} has to be inclusive, i.e. include *all* hadrons produced along with the lepton and neutrino.

To date, the study of semileptonic decays of charmed baryons has been the domain of experiments at e^+e^- colliders, since the low event multiplicity allows an easier reconstruction. Recently, CLEO for the first time has measured decay asymmetries in semileptonic decays of Λ_c using about 500 Λ-lepton pairs [11]. At large q^2, where the predictions from HQET are most trustworthy, they observed good agreement between decay asymmetry and predictions. From a bigger sample of about 700 Λ-lepton pairs they extracted [12] the ratio of two form factors, averaged over q^2 for reasons of small statistics. A full test of HQET requires, however, the individual observation of both form factors as a function of q^2. The required large statistics of many thousand semileptonic decays will be accumulated by the proposed high intensity experiment.

Modern fixed target experiments have become very competitive with e^+e^- experiments. This is especially true for the D-meson sector, where one tags the semileptonic decay of a D-meson by observation of the the right-sign lepton-kaon pair in coincidence with the low energy pion from the $D^* \to D$ transition. To determine semileptonic decays for charmed baryons a similar technique can be exploited if mass excitations exist just above the one pion threshold. Such heavier charmed baryons have still to be discovered. Another signature, which is known from WA89, is the observation of the decay photon from the transition Ξ_c' $\to \Xi_c\ \gamma$, where Ξ_c' is the partner of Ξ_c with symmetric light-quark content. This transition can be identified with sufficient precision even though the neutrino is not observed, to discriminate against background from processes with uncorrelated Ξ^- and positrons in the final state. Similar tagging techniques are also possible for Λ_c^+ from Σ_c decays as well as Ω_c^0 from decays of Ω_c^{0*}.

Lifetimes. Charmed hadron lifetimes constitute a good testing ground for the understanding of the hadronic environment on the decay of the naked charm quark. The effects of the hadronic environment are about a factor 10 larger for charmed hadrons than for beauty hadrons – as evidenced by the factor 10 spread of lifetimes for charmed hadrons – but significantly smaller than in strange hadrons. Due to the small Q-value in the decays of strange hadrons not many different decay channels exist for an investigation of the strong interaction phenomena. Thus it is this intermediate region of charmed hadrons which offers the best chance for studies of strong interactions in a regime where perturbative and non perturbative effects overlap. Finally, a better understanding is also needed to better predict and interpret results for beauty lifetimes, where differences are expected only at the 10% level.

Two concurring processes govern the lifetimes of charmed baryons: W-emission and W-exchange, with further modifications due to the wave function overlap between initial and final hadronic states, yielding large uncertainties. The relative strengths and phases give the predicted – and in part already confirmed – lifetime hierarchy. Theoretical uncertainties stem mainly from the determination of the coefficients for the two operators involved and uncertainties in the overlap of the quark wave functions.

To aid theory in its understanding of these hadronic effects requires precise measurements of the lifetime of all charmed baryons to better than 5% (see e.g. [13]). Current precision for the lifetimes of charmed hadrons is of the order of a few percent, whereas those of the charmed-strange baryons is around 20%, with improvements expected within the next few years to a level of 10%. The main difficulty lies in the shortness of the charmed-strange baryon lifetime and their small production rate, which also yields rather large systematic uncertainties. A dedicated set up with a high intensity beam should allow improvement of the situation.

A precise knowledge of charmed hadron lifetimes can also be used to determine absolute charm branching ratios with sufficient precision, as discussed above. These branching ratios are needed in order to interpret beauty hadron decays.

Non-leptonic decays. To gain insight into the interplay of the different decay diagrams for hadrons with different light-quark contents we must compare absolute decay rates of non-leptonic decays. Such absolute decay rates can either be obtained from ratios of branching ratios together with the theoretical semileptonic decay width (see above) or from observing as many final states as possible for an estimate of single branching ratios and using the measured lifetime. From a theoretical point of view it is the decay width to *two-body* final states that allows a comparison with calculations. In particular, the assumption of factorisation has yet to be tested in baryon decays.

To date, absolute decay rates have not been obtained in fixed target experiments since the observation of semileptonic branching ratios is rather difficult. Only for the Λ_c^+ exist absolute rates from the e^+e^- experiments MARK II [2] and CLEO / ARGUS [3]. The first experiment observed in scanning mode a change in proton production rate, whereas the latter experiments tag Λ_c^+ from B-meson decays. Both results, however, are not consistent. As discussed in the section on semileptonic decays, a high statistics fixed target experiment would utilise the ratio of hadronic to semileptonic branching ratios together with the theoretical semileptonic width to obtain absolute branching fractions.

A.2 Charm Production Studies

The WA89 experiment with acceptance for $x_F \geq 0.2$, is currently running in the CERN West-hall and is expected to observe a total of about 10^3 charmed baryons in the most prominent decay modes. It has obtained interesting results on the leading particle effect in charmed baryon production by hyperons: An enhancement is observed in the production rate of baryons and mesons sharing one or two quarks with the beam. However, the differential x_F-distributions show, within large errors, the same slope for all charmed particles [14], while the LUND model [15] predicts a dramatic redistribution of the charm production cross section to larger values of x_F for particles sharing a di-quark with the incoming projectile. In order to understand the observed effect one needs large statistics and good acceptance to small or even negative x_F.

Ideas for production mechanisms which cause a strong leading effect range from colour flow models (as included in the LUND MC program PYTHIA), to models using inherent charm in hadrons, to models assuming prebinding of charm by the strange quark. If colour flow were the correct way to describe the observed effects, a forward-backward production symmetry should exist and furthermore a dragging of the charm quark by a di-quark from the incoming baryon should show up in the backward direction. The most stringent test is a study of the correlation in the production of charm and anti-charm hadrons.

Another very important measurement is the energy dependence of the leading particle effect. Charm production at low beam energies has been studied in the previous hyperon beam experiment WA62 [16] as well as in the neutron beam experiment BIS-2 [17] and more recently in EXCHARM [18]. In all experiments large production cross sections for charmed baryons have been observed at large values of x_F. These data indicate that a process exists which at low energies binds charm quarks very efficiently into baryons. Experiments with different projectiles and energies are therefore necessary to investigate the energy dependence of the total charm cross section in a single experiment. To be able to evaluate total cross sections for charmed-strange baryons it is necessary to have reliable branching ratios beforehand established.

A.3 Double Charmed Baryons

The topic of doubly charmed baryons has not yet been addressed by any running experiment. The study of such systems is an experimental challenge owing to the expected very low cross sections and small branching ratios. The production of two c-($\overline{c}$-) quarks can result either in two charmed (anticharmed) hadrons or in a doubly charmed (anti) baryon. For the first case the kinematical correlations between the two charmed hadrons will give insight into the production mechanisms, in particular concerning the question whether these quarks are created in separate processes or come from a single parton-parton interaction. The production of doubly charmed baryons will depend very much on the details of the fragmentation process. Their properties - masses and lifetimes - will tell us more about heavy/light quark systems. Details on the subject of doubly charmed baryons can be found in the Appendix.

A.4 Search for Exotics

QCD allows for states other than the usual $q\overline{q}$ mesons and the qqq baryons, for example, glueballs, hybrids, and multi-quark states, consisting of gluons only (gg), a valence gluon coupled to a meson ($q\overline{q}g$), and four or more quarks (antiquarks), respectively. Their masses can be estimated using various approximations to the low-energy perturbative regime of QCD — e.g. the bag–model, the flux-tube model, chiral perturbation theory, and lattice calculations.

A.4.1 Glueballs and hybrids

Owing to its non-abelian character one fundamental prediction of QCD is the existence of states containing the valence gluons: glueballs and hybrids. Since QCD cannot predict the spectrum of the non-$q\overline{q}$ states we have to resort to various models [19–25]. All models predict a rich spectrum of non-$q\overline{q}$ states. Although ratios of glueball masses can be predicted rather reliably, the absolute mass scales are highly model-dependent. Nevertheless almost all models predict the lowest glueball state in the mass region of 1200-1600MeV/c^2 and the lowest hybrid state at about 1900MeV/c^2.
For many years experiments have tried to establish the existence and the absolute mass of glueballs and hybrids. The following has been suggested to identify gluonic states: a) to look for "oddballs", states with the quantum numbers not allowed for $q\overline{q}$ states, for example $J^{PC} = 1^{-+}$; b) to look for 'extra' states, that is states having quantum numbers of an already completed nonet and a mass which is too low to belong to the radially exited nonet; c) to look for states with branching ratios not compatible with $q\overline{q}$ mesons; d) to look for states preferentially produced in gluon-rich processes such as Pomeron-Pomeron scattering (since the Pomeron can be described as a multi-gluon state), J/ψ hadronic and radiative decays as well as $p\overline{p}$ annihilation (since the annihilation of quarks and antiquarks is a source of gluons). Several exotics candidates have been found so far:

The E/$f_1(1420)$ state with $J^{PC} = 1^{++}$ has been observed by WA76 and WA91 in the reaction $pp \to p_f(K^0_S K^\pm \pi^\mp)p_s$ [26]. Initially this state was thought to be the $s\overline{s}$ member of the 1^{++} nonet. But then it should also be produced in K^-p interactions which is not the case. Since the $E/f_1(1420)$ decays predominantly to $K^*(892)\overline{K}$ interpretations as a hybrid [27], a four-quark[28] state, or a $K^*\overline{K}$ molecule-like state [29] were suggested.

The G/$f_0(1590)$ scalar meson was discovered in a partial wave analysis of the $\eta\eta$ system produced in the π^-p charge-exchange reaction at 38 GeV/c [30] and 100 GeV/c [31]. Its unusual decay properties: BR(G$\to \eta\eta'$) > BR(G$\to \eta\eta$) > BR(G$\to 4\pi^0$) $\gg$ BR(G$\to \pi\pi$,KK) favours its interpretation as a 0^{++} glueball candidate [32].

The Crystal Barrel experiment has uncovered a $J^{PC} = 0^{++}$ state with mass $1500 MeV/c^2$ and width $150 MeV/c^2$ decaying to $\pi^0\pi^0$, $\eta\eta$, and $\eta\eta'$ with about the same strength [33,34]. The observed decay pattern makes it impossible for this state to be a $q\overline{q}$ member of the nonet for any mixing angle. Such behaviour is suggestive of the flavour-blind decay modes of a glueball.

For these and many other candidates exotic interpretation are very probable but not definitive since almost any single unusual feature can be explained by a specific combination of model parameters. It is clear that in order to make a new step towards the solution of the exotics problem a systematic experimental study is required of as many decay modes and production mechanisms as possible. High statistics is particularly needed to allow a partial wave analysis and definition of the quantum numbers of the observed objects. The proposed set up is suitable for these studies since it can be configurated for highly efficient detection of mesons in the 1.2 - 2.0 GeV mass region, it is equipped with dedicated triggers for central production and charge exchange reaction, and it can cope with very high beam flux.

The proposed merger of the WA91 and GAMS experiments expects to accumulate some 5000 centrally produced $\eta\eta$ events in 180 days of beam time. Given the higher beam flux together with the possibility for dedicated triggering, we expect for a North Area experiment to substantially increase the number of $\eta\eta$ events.
If the glueball ground state has really been discovered by previous experiments it becomes important to find further glueball states. The $3g$ glueballs are expected naively to be a factor 1.5 heavier than $2g$ glueballs which brings them into the mass range above 2.1 GeV/c which would render detection at LEAR impossible ($\sqrt{s}_{max} \approx 2$ GeV).

A.4.2 Search for the U(3100)

Evidence for the U(3100), a narrow state decaying to $\Lambda\overline{p}$ and pions, was reported by two experiments: WA62 [35] at CERN, which used a 135 GeV/c Σ^- beam, and BIS-2 [36] at Serpukhov, which used a neutron beam with 70 GeV/c maximum momentum. The strongest evidence found by WA62 was in the $\Lambda\overline{p}\pi^+\pi^+$ decay channel, which corresponds to an open-strangeness exotic state with minimum valence quark combination $su\overline{dd}$.

Both experiment WA89 and the ongoing experiment EXCHARM at Serpukhov, which uses the same neutron beam as experiment BIS-2, are presently searching for U signals. Results are not yet available, but the WA89 analysis so far seems to indicate that the cross section for U-production by Σ^- must be considerably lower at 340 GeV/c than at 135 GeV/c, if the U exists.

Since the possibility that the cross section depends strongly on beam energy, cannot be excluded, as it appears to do for charm baryon production, it would also be important to search for the U at lower beam energies. This can be done simultaneously with the other cross section studies discussed above.

A.4.3 Search for the H

The H di-baryon is a hypothetical di-baryon state with the quark content *uuddss* minimising the colour magnetic interaction [37]. Although many experiments have been searching for this state using various approaches, no experimental evidence for its existence has yet been reported. As the production mechanisms are unknown, no real exclusion for such a state can yet be formulated. In the WA89 experiment final states of $\Lambda\Lambda$ and $\Xi\Lambda$ have been studied. Although no structure could be found in their respective invariant mass spectra, the data on $\Lambda\Lambda$ and Ξ^-p production were used to estimate the H-production cross section using a coalescence model [38]. The validity of this model is currently being tested in deuteron production [39]. It turned out that the current hyperon beam experiment has a sensitivity which is too low by a factor 10 if we assume a lightly bound state of two baryons. A new high rate experiment could therefore be able to either produce such a state or set strong limits on its mass deduced from a (model dependent) production analysis.

A.4.4 Double charmed exotics

Another possibly existing exotic state is a tetra-quark structure involving two c-quarks and two light antiquarks [5,8,40–42].

In analogy to the hydrogen-structure of the doubly charmed baryon such a system could be compared to a He-atom, with the charm quarks playing the role of the nucleus and the two light quarks the role of the electrons. Alternatively it could be viewed as a hydrogen molecule where the heavy c-quarks play the role of the two protons. The latter would appear as a weakly bound meson-meson $D^{*+}D^0$ configuration bound by long-range one-pion exchange potential (called deuson [40]). Needless to say, the observation of such a system would tell us a great deal about confinement forces and models for hadronic structures. The mass of such a structure is expected to be about 3.6 GeV/c^2, comparable to masses for ccq-baryons. The decay of deusons is expected to proceed via the dissociation into two mesons + π or γ, depending on its binding energy. For more details we refer to the Appendix.

A.5 Studies of Hadron Structures

The study of nucleon structure has been addressed over the past 20 years in many different experiments. This field, however, has gained considerable new interest owing to the progress in the description of non-perturbative QCD. In particular, chiral perturbation theory now allows one to make definite predictions for a number of measurable quantities such as polarizabilities and cross sections in $\pi\gamma$-interactions. Currently these questions are almost solely addressed at low energy electron accelerators like MAMI, ELSA and others. Using high energy π or Σ beams we can make complementary measurements using the Primakoff reaction mechanisms. Other processes like hyperon semileptonic decays or diffractive dissociation will also reveal important information about the internal structure of hadrons. In the following we will discuss a few items.

A.5.1 Primakoff reactions

Scattering of various particles of a high-Z nucleus accompanied by the emission of soft photons can be used to test the electromagnetic structure of these particles by exposure to a high electric and magnetic field. The process can be described by the Primakoff scattering cross section which corresponds to Compton scattering with virtual photons and inverse kinematics. Several physics aspects can be addressed in such experiments.

π and Σ polarizabilities. For Compton scattering on composite systems the expression for the cross section has to be modified to take into account their internal structure. These additional terms are called the electric and magnetic polarizabilities. The magnitude of the polarizability tests the response of the particle's charge distribution to an exposure of a high electromagnetic field. Naively one expects larger values of the polarizability for systems made from quarks with opposite charge (like $\Sigma^+(uus)$) as compared to those made from equal charge quarks (like $\Sigma^-(dds)$) as the electromagnetic fields exert forces in opposite directions for Σ^+ and in the same direction for Σ^-.

Electric and magnetic polarizabilities are described by two terms each, one term reflecting the action of the electromagnetic field on the charge and magnetic moment of individual partons and the other term being a form factor of the composite system. From a study of the magnetic moments of Σ^- and Σ^+ we can infer that the main difference between these two isospin partners comes mainly from the intrinsic structure and less from a global form factor. Various predictions have been made for the polarizabilities of neutron, proton and pion, but little work has been done for hyperons or the kaon.

Antipov et al. [43,44] measured the $\gamma\pi$ scattering with 40 GeV pions at Serpukhov via pion scattering in the nuclear Coulomb field: $\pi^- + Z \rightarrow \pi^- + Z + \gamma$. This reaction corresponds to $\gamma + \pi^- \rightarrow \gamma + \pi^-$ scattering for laboratory gamma-ray energies in the range 60-600 MeV on a π^- target at rest. The pion electric polarizability $\bar{\alpha_\pi}$ was deduced in this low statistics experiment ($\sim$ 7000 events) to be $\bar{\alpha}_\pi = -\bar{\beta}_\pi = 6.8 \pm 1.4 \pm 1.2$, where $\bar{\alpha_\pi} + \bar{\beta_\pi} = 0$ was assumed as expected theoretically [45].

For the γ-π interaction at low energy, chiral perturbation theory (χPT) provides a rigorous way to make predictions. The method establishes relationships between different processes. The experimental ratio $h_A/h_V = 0.45 \pm 0.06$ from radiative pion decay leads to $\bar{\alpha}_\pi$ = -$\bar{\beta}_\pi$ = 2.7 ± 0.4, in disagreement with the Antipov et al. experiment. Improved experiments will allow serious tests of chiral symmetry and chiral perturbation theory; and of different available polarizability calculations in QCD.

Σ Radiative Transitions. Measurements of the Primakoff production of hyperon resonances (spin 3/2 states) which proceed by spin flip of the incoming spin 1/2 hyperon are easier to interpret than polarizabilities. The cross section constitutes a complementary measurement of the hyperon's magnetic moment. The observed pattern of static magnetic moments in the baryon octet cannot exactly be described by any model. Small but significant deviations from the predictions occur for the Σ^+ and Ξ^-. Different cross sections are for example expected for the Primakoff production of Σ^{-*} by Σ^- and Σ^{+*} by Σ^+. This may be used to single out the role of the strange quark concerning the magnetic moment in the various hyperons. In the SU(3) symmetry limit, the magnetic moments of the d and s quarks are equal. However, an analysis [46] shows that the strange quark contribution to the magnetic moment of the Σ is suppressed by an order of magnitude compared to that of the d-quark in the proton or the s-quark in the Lambda.

In a description of SU(3) symmetry breaking in the Σ^- to Σ^{*-} transition, the ratio of M1 decay widths for the Σ^- and proton can be estimated to be [46]:

$$\frac{\Gamma(\Sigma \to \Sigma^{*-})}{\Gamma(p \to \Delta^+)} \approx \frac{1}{9}(1 - \frac{\mu_s}{\mu_d})^2 .$$

Here μ_s and μ_d are empirical magnetic moments of s and d quarks. Within the validity of the constituent quark model the size of the Σ^- M1 transition determines directly the relative magnitudes of s- and d-quark magnetic moments.

Chiral anomaly tests. The chiral axial anomaly can be studied with high energy pion beams. For $\gamma\pi$ interactions, the abnormal intrinsic parity component (chiral anomaly) of the effective chiral Lagrangian leads to a prediction [47–49] for the process $\gamma \to 3\pi$. The amplitude is calculated to be $F_{3\pi} = N_c\sqrt{4\pi\alpha}/(12\pi^2 f_\pi^3) \simeq 9.7 \pm 0.2\,\mathrm{GeV}^{-3}$, where N_c is the number of colours in QCD and f_π is the pion decay constant.

The amplitude $F_{3\pi}$ was also measured by Antipov et al. [49]. They studied pion production by a pion in the nuclear Coulomb field via the Primakoff reaction $\pi^- + Z \to \pi^- + \pi^0 + Z'$, where Z is the nuclear charge. In the one-photon exchange domain, this reaction is equivalent to $\pi^- + \gamma \to \pi^- + \pi^0$. The experimental result is $F_{3\pi} = 12.9 \pm 0.9 \pm 0.5\,\mathrm{GeV}^{-3}$, which differs from the $O(p^4)$ expectation by at least two standard deviations. Therefore, the chiral anomaly prediction at $O(p^4)$ is not confirmed by these data. Bijnens et al. [50] studied $O(p^6)$ corrections using vector meson dominance, yielding an increase in $F_{3\pi}$ of about 10%. This makes the theoretical calculation almost consistent with data.

For the proposed experiment the Primakoff cross section at 300 GeV pion energy is about 100 nb for a ^{12}C target [51]. The expected number of two-pion events will exceed 2×10^4. This large number of events will allow an analysis of the data separately in different intervals of $s = M^2_{(\pi^-\pi^0)}$.

Another reaction to determine $F_{3\pi}$ is $\pi^- + e \to \pi^- + \pi^0 + e$, whereby a high energy pion scatters inelasticly from a target electron. The number of such events observed by Amendolia et al. [52] was 36 for a Hydrogen target, and no value for $F_{3\pi}$ was extracted. The number of expected events in the proposed experiment will exceed 2000 using a carbon target. How well does χPT work in the anomalous sector? A CERN North Area experiment can give improved answers to this question.
More on chiral anomaly tests can be found in ref. [53].

Quark gluon plasma. Can one expect [54–57] gamma-ray rates from a QGP to be higher than from a hot hadronic gas phase? Xiong, Shuryak, Brown (XSB)[58] calculate photon production from a hot hadronic gas via the reaction $\pi^- + \rho^0 \to \pi^- + \gamma$. They assume that this reaction proceeds through the $a_1(1260)$. However, for $a_1(1260) \to \pi\gamma$, the experimental radiative width is more than two times less than the value 1.4 MeV estimated and used by XSB. The gamma production reaction can be studied at the proposed experiment [57] (via the inverse reaction, with detailed balance) via the Primakoff reaction $\pi^- + \gamma \to \pi^- + \rho^0$. Such a study can provide the data base for evaluations of the utility of gamma production experiments in QGP searches. One can experimentally check the a_1 dominance assumption of XSB.

In general, Primakoff experiments require high Z targets, low mass tracking detectors, good momentum resolution and high resolution (spatial and energy) electromagnetic calorimetry.

A.5.2 Colour transparency and colour fluctuations

In hadronic interactions at large energies the incident hadron can be considered as a superposition of different size configurations. Large inelastic diffractive cross sections arise only if there are significant differences in the absorption cross sections of the different configurations, as described in references [59,60] and references therein. The term *colour fluctuations* is used to describe how the hadron fluctuates between its various configurations, and how colour dynamics affects the interaction strengths of the different configurations [59]. From the concept of colour transparency (CT) one expects that at very large momentum transfers, small size configurations (SSC) of the hadron wave function should dominate in the scattering [61]. Those configurations should traverse the nucleus without suffering large absorption since by virtue of their small size the colour fields cancel each other and the interaction with other nucleons in the target is small. However, most of the current colour transparency experiments are performed where the SSC does not have high enough energy. As a result, the produced small system expands within a short distance, and the CT effect is strongly suppressed [62,63].

Hints for colour transparency and small size configurations have been obtained from exclusive muonic production of ρ-mesons at large Q^2 in experiments E665 [64] and NMC [65]. Also HERA data on exclusive electroproduction of ρ-mesons can be interpreted in the same line [66]. At CERN, we can study the elemental 2-body scattering $\pi^-\pi^+ \rightarrow \pi^-\pi^+$, for an incident high energy pion, scattering from a virtual pion in the target A. Such data as a function of incident pion energy, momentum transfer of scattered π^-, target mass A, and $\pi\pi$ invariant mass, should be very sensitive to CT, according to calculations in progress by Frankfurt et al. [67]. In order to complete the picture of CT it is necessary to perform studies using different projectiles, since different hadrons have different probabilities to be in SSC. Furthermore, the relative importance of various reaction mechanisms may vary with the projectile. Other reactions to be studied are described in ref. [59,60].

Soft coherent diffractive dissociation of an incident hadron by a nuclear target can provide important complementary experimental tests of the idea of size fluctuations in the projectile wave function [59,60,68–71]. In such reactions the target remains in its ground state, while the incident hadron dissociates diffractively. Since the nucleus acts as a size filter a strong A-dependence should exist.
Such measurements require the observation of exclusive final states as e.g. in π A$\rightarrow$nπ +A with n=3,5,7... at large momenta (200-400 GeV/c) for different momentum transfers and different target nuclei. A large number of predictions exists for diffractive cross sections and their A-dependence.
The FMS colour fluctuation calculation predicts [59] very large diffractive cross sections; 40-50 mb for π-Nucleus interactions at 200 GeV at A $\sim$ 100 and $p_\pi \sim$ 200 GeV/c. The calculation agrees with the A-dependence of semi-inclusive data of [72] on $\pi^+ + A \rightarrow \pi^+ + \pi^+ + \pi^- + A$ for p_{π^+} = 200 GeV/c. The observed pion data correspond only to roughly 20% of the prediction [59]. A proper demonstration of the success of the colour fluctuation predictions requires experimentally measuring the cross section and A-dependence of a larger percentage of the total diffractive cross section. It is important to get improved data compared to Zielinski et al. [72] for the three-pion case, and new data for the many other channels, and other hadrons.

A.5.3 Hyperon semileptonic decays

The breaking of isospin symmetry is caused by the electromagnetic interaction acting on the different charges of the u and d quarks and by the difference in the masses of the u and d quarks. The latter could produce a measurable mixing between members of different isospin multiplets, even where electromagnetic effects are very small, for example the Λ and Σ^0 hyperons [73,74].

Such a mixing would make small changes to the Λ properties. One place where it might be seen is in a comparison of the mirror decays: $\Sigma^\pm \to \Lambda\, e^\pm\, \nu$. Recent estimates [75,76] suggest that the ratio of the two decay rates could differ by as much as 6% from the value expected with no symmetry breaking.

Present data on these decays are not of sufficient precision to test this: the $\Sigma^- \to \Lambda\, e^-\, \overline{\nu}$ decay has been measured to $\pm 5\%$ with 1843 events [77] of which 1620 events were collected by the WA2 experiment at the CERN SPS [78]. The $\Sigma^+ \to \Lambda\, e^+\, \nu$ decay has only been measured to $\pm 25\%$ accuracy with 21 events [77] (11 of these in the Saclay bubble chamber at the CERN PS [79]).

We propose to measure these branching ratios to an accuracy of $\approx \pm 1\%$ (*i.e.* to about 10^{-7} in the total rates.) If the beam rates are $10^7\, s^{-1}$ and making reasonable assumptions of duty cycle, $\Sigma^\pm$ fractions, fiducial volume in which decays can be accepted, trigger lifetime and the $\Lambda \to p\pi^-$ branching ratio, this could be achieved in a run of approximately 6 weeks.

With a good determination of the $\Lambda - \Sigma^0$ mixing, more accurate comparisons between experiment and theory can be made regarding hyperon magnetic moments and the F and D parameters in hyperon semileptonic decays.

Notice that any measurement of the ratio of these partial decay widths to better than 1% would also require improved measurements of the Σ^+ and Σ^- lifetimes (presently known to $\pm 0.5\%$ and $\pm 0.7\%$ respectively [77].)

A.5.4 Heavy ion physics

Charmonium interaction in nuclear matter. It was recently pointed out by Kharzeev and Satz [80] that the J/ψ interaction with strongly interacting matter depends crucially on whether or not the gluons in that matter are confined to hadrons. This makes J/ψ production a probe for the hadronic surroundings in which the production occurs. Due to its small size ($r_{J\psi} \simeq 0.2$ fm) and large binding energy ($2M_D - M_{J/\psi} \simeq 640$ MeV), a J/ψ can be dissociated into open charm mesons only by interaction with hard gluons. The momentum spectrum of gluons confined to nucleons is determined by the gluon distribution function measured in deep inelastic scattering, and it is strongly peaked at low momenta. As a result, the inelastic J/ψ-nucleon cross section is very small near threshold and reaches its asymptotic value only at very high interaction energies. This energy dependence is calculated in short distance QCD [80], and it would be very interesting to measure it in proton-nucleus collisions. Since this requires the study of J/ψ's which are slow in the nuclear rest frame, it is not possible in the usual interaction of a proton beam with a nuclear target, in which only fast J/ψ's can be detected. To measure the low energy interaction of the J/ψ with nucleons inside the nucleus, one has to use inverted reaction kinematics, with a nuclear beam incident on a hydrogen or deuterium target. In this case, fast J/ψ's in the lab system will be slow in the rest frame of the fast-moving nucleus and hence undergo low energy collisions with its nucleons. Since such J/ψ's are fast in the lab system, their decay dimuons can be detected and used to determine the threshold behaviour of the J/ψ-nucleon interaction cross section.

Although the complete detector set up has to be modified the high rate tracking and PID may still be used for such an experiment. Studies are under way how such a program could be incorporated into the proposed set up which has foreseen complete muon coverage.

B The Experiment

B.1 Beam and Experimental Areas

One of the most important issues for this experiment is the choice of beam particles. For part of the program, mostly concerning the study of the incoming projectile, this question is easy to answer. A high intensity proton beam (400-450 GeV/c) is needed to continue the study of central glueball production, described in section A.4.1. Most of the reactions based on the Primakoff effect have to be performed with π beams of various energies. The study of Σ semileptonic decays clearly needs a charged hyperon beam of high energy and high intensity. For charm production, however, the choice is more difficult. Existing experimental results have already been presented in section A.2 and will only shortly be repeated here.

According to calculations of perturbative QCD and results from π beam experiments the highest possible beam energy should be used for the production of charmed hadrons. There is good experimental evidence that the production of fast baryons is strongly enhanced in baryon beams. From these observations the choice of a 450 GeV/c proton beam is favourable. The choice of protons over hyperons or neutrons will probably hold for the topic of double charmed baryons. For a study of charmed hyperons, however, a Σ^- beam such as used presently in WA89 may be more useful. It should be noted, however, that the price to pay is a large background in such beams from π contamination and accompanying μ. Also the neutron and π background from beam particle decays in the detector will cause large damage to downstream calorimeters since no well defined 'beam hole' can be inserted. Besides of the particle type, the beam energy is of great importance. Considering the results from "low energy" beams (50-70 GeV/c neutrons and 120 GeV/c Σ) where surprisingly large charmed baryon samples have been obtained, the choice of low beam momenta should be favoured. However, trigger and reconstruction of s.l. decays rely strongly on the observation of charm decays downstream of the first multiplicity counter or within the target detector, respectively. The requirement of long flightpaths can only be met using highest possible momenta. The low energy option should however be kept if possible. Smaller hyperon beam and proton beam momenta can for example be obtained by pre-extracting a lower energy proton beam from the SPS. This has been done in the past and its only drawback is a 200 MHz bunch structure since no debunching can be performed.

While the installation of a beam line for primary and secondary beams of p, π and K does not pose any problems the construction of a high intensity hyperon beam with about $2 \cdot 10^7$ Σ^-/spill is a larger effort due to the large shielding requirements. Fig. B.1 displays the rates which can be obtained if $5 \cdot 10^{12}$ protons are dumped onto the hyperon production target using a single bend hyperon beam (fig. B.2).

If the channel is designed for a maximum momentum of 400 GeV/c even primary protons (using a high duty cycle option) could be passed through after removal of the production

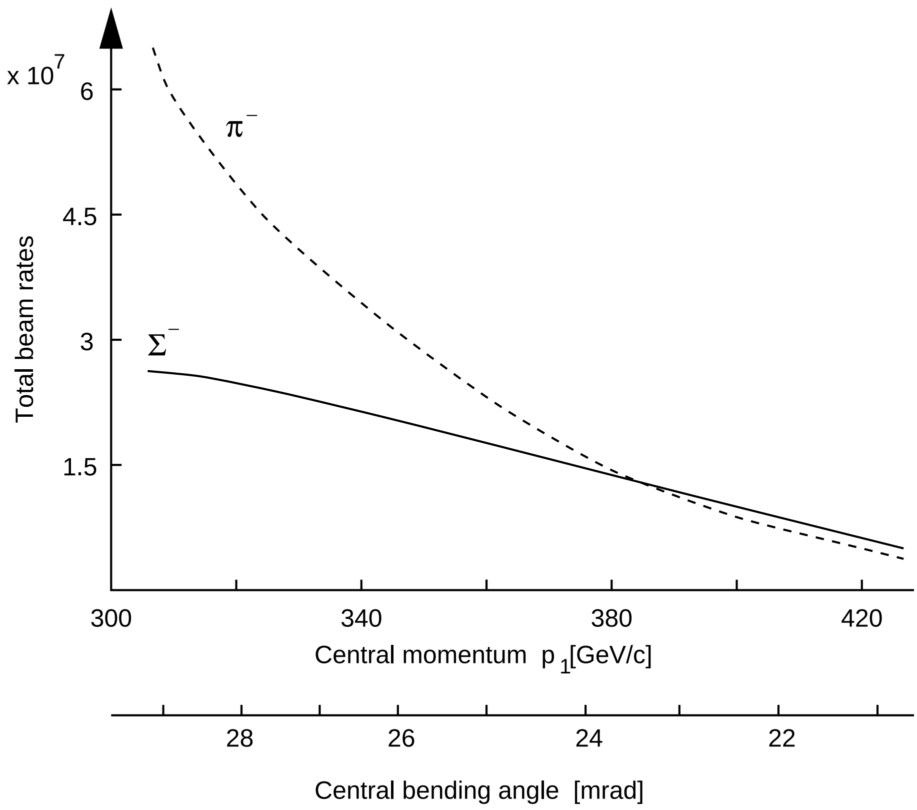

Figure B.1: Hyperon beam rates for a single bend beam

target [1]. The only drawback in using such a channel for secondary meson or primary baryon beams is the lack of focussing. However, the beam spot foreseen for such a high rate experiment is of the order of 1 cm^2 which can be given by the geometrical size of the collimator channel.

The use of high intensity beams in combination with a new large spectrometer sets stringent requirements on the experimental areas. In the West area the Omega spectrometer magnet could well be used for such an experiment and all installations could be kept but no high intensity hyperon beam could be used. However, since the West area is being closed such an experiment has to be inserted into the experimental program of the CERN North area. Two experimental areas could be envisaged.

- The high intensity lab (ECN3) is currently occupied by the experiments NA48 and NA50. While NA48 has not yet started and is planned to be operational until the year 2000, the foreseen physics program for NA50 will most likely stop at the end of 1997 or 1998. However, the limited space in this hall makes the installation of a new spectrometer very difficult, in particular since only the months of the SPS shutdown can be used for such an operation. In addition, the two experiments housed in this hall cannot simultaneously be served with beam within the current beam line set up. A beam time sharing might have to be developed which would probably affect the physics program of both experiments.

[1] For such beams any wall collisions have to be avoided and the beam channel should be evacuated. This certainly needs more careful investigations

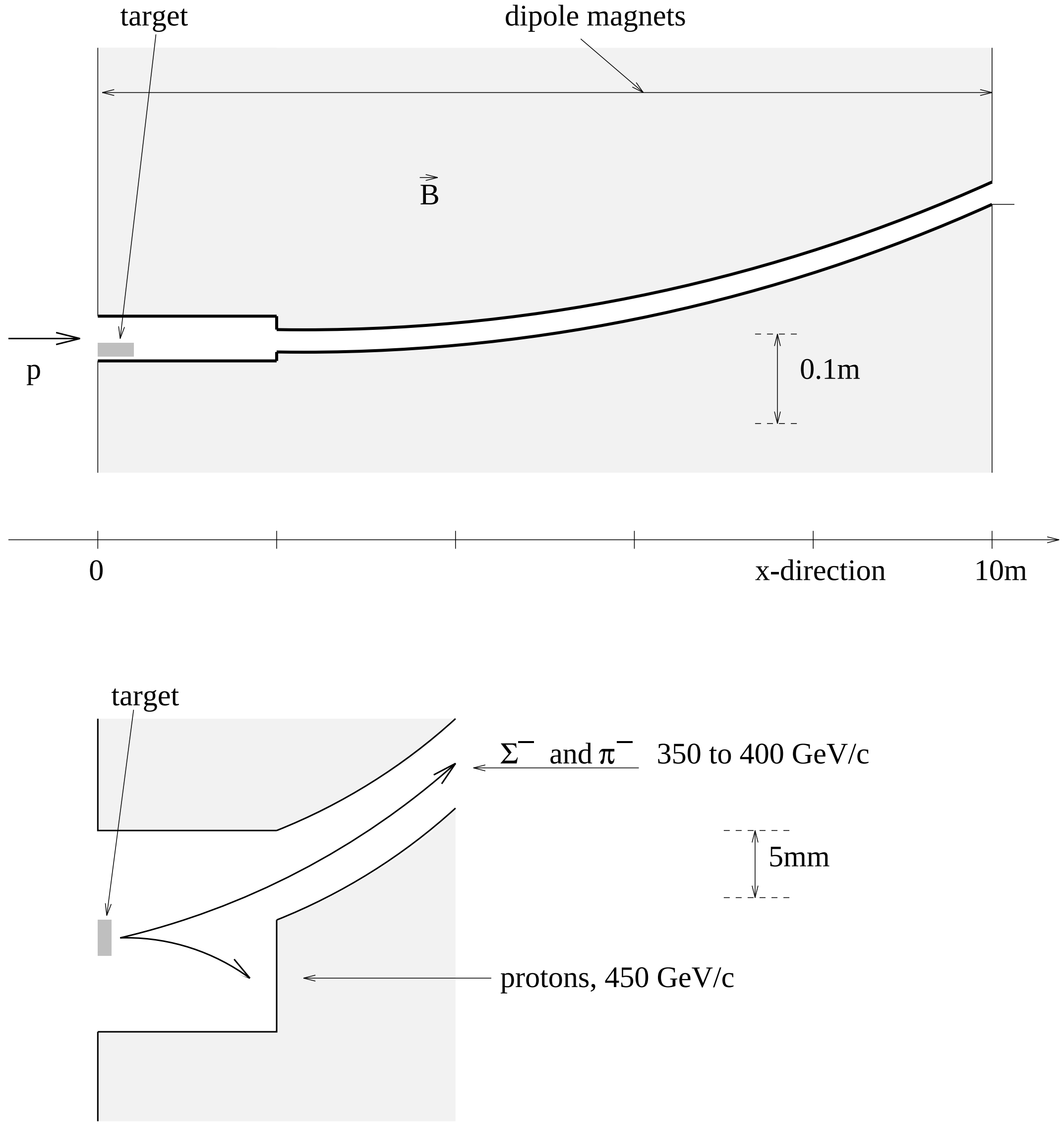

Figure B.2: Layout for a possible hyperon beam

- With the foreseen end of the NA47 experiment in the muon hall by end of 1996 a large experimental area could be liberated. Although the current beam line cannot transport 450 GeV/c protons to the area the necessary equipment can be recuperated from the primary beam lines in the West hall [81]. In contrast to the EHN2 area no special arrangements exist to accommodate a high intensity beam. However, the hall is located in front of a large earth beam dump and additional shielding in form of a concrete bunker can be arranged within the hall owing to its large spatial dimensions [82]. The elements for the hyperon beam line including part of the iron shielding could in part be recuperated from the West area. A new collimator, however, would have to be designed and constructed.

B.2 The Detector

The most important requirements for this experiment come from the need to obtain the largest possible sample of reconstructed charm particles. The detector has to provide excellent spatial resolution for the reconstruction of, for instance, double charm events or semileptonic decays within complex multi-track events. This is of special importance in the vertex area. Furthermore it has to sustain the high beam rates necessary and has to allow for efficient triggering. The acceptance should extend down to negative x_F values. In order to cover charm particles produced in the x_F-range [-0.1,1.] a two stage spectrometer is necessary. Such a design, however, leads to a doubling of calorimetry and particle identification. The proposed set up is shown in figure B.3. In the following we will describe the general set up and give details where new technology will be used.

B.2.1 Beam identification

As we will most likely use a secondary beam we have to provide particle identification in the beam. At momenta above 250 GeV/c π suppression can be achieved by means of fast transition radiation detectors (see e.g. WA89 [83]). Typical rejections by a factor 10 have been achieved at momenta around 300 GeV/c at the trigger level. However, classical designs will not be able to cope with the high beam rate envisaged ($5 \cdot 10^7$/spill). We thus want to use a fast TRD based on thin micro strip gas chambers (MSGCs) [84]. Development of such a fast detector has been foreseen in the framework of the RD28 project [85]. It could consist of a large number of MSGCs with thin ($400\mu m$) gas gaps. These MSGCs could be manufactured on thin (20 μm) plastic substrates which at the same time act as radiator. This design would be the first TRD with photon detection downstream of every single radiator foil (active radiator). It has the advantage that efficient use is made of low energy TR-photons so that much fewer transitions will be necessary. We would also benefit from short drift times ($\approx$ 15ns) and a relatively simple design. The detector area can be kept small ($4cm^2$) with an anode pitch of 500 μm. 10 (possibly segmented) detector planes could be connected to one preamp largely reducing the number of electronic channels.

A set of 9 silicon microstrip counters with 25 μm pitch reading 3 different projections is used to determine the position of the incoming beam particle (called Si-beam). Also a fast scintillating fibre hodoscope is used in order to tag the beam particle timing in case of pile up.

B.2.2 Target region

In order to perform high precision measurements of lifetimes and to ensure a high charm tagging efficiency also for short lived hadrons, we must aim at the highest possible spatial resolution. Also highly efficient triggering on secondary vertices must be ensured. A layout of the target region is shown in fig. B.4. The target is made from 4mm copper equivalent to about 2.5% of a nuclear interaction length and is placed about 30cm in front of the entrance of the first magnet. In order to select interactions in the target a thin silicon counter is placed at the downstream edge of the target. This counter can be segmented and is read by means of a fast preamp. For the detection of secondary vertices it is necessary to know the longitudinal position of the primary interaction with a precision of better than 1mm. One possibility is to replace the solid target block by a sandwich of seven 500 μm thick Cu sheets interleaved with silicon detectors of 150 μm thickness.
The target is followed by the first of two multiplicity counters (MUCs) to be used in the

trigger (see trigger section). Both MUCs are made from 1mm thick MgF_2 read at all 4 edges by UV sensitive PMs also equipped with MgF_2 windows.

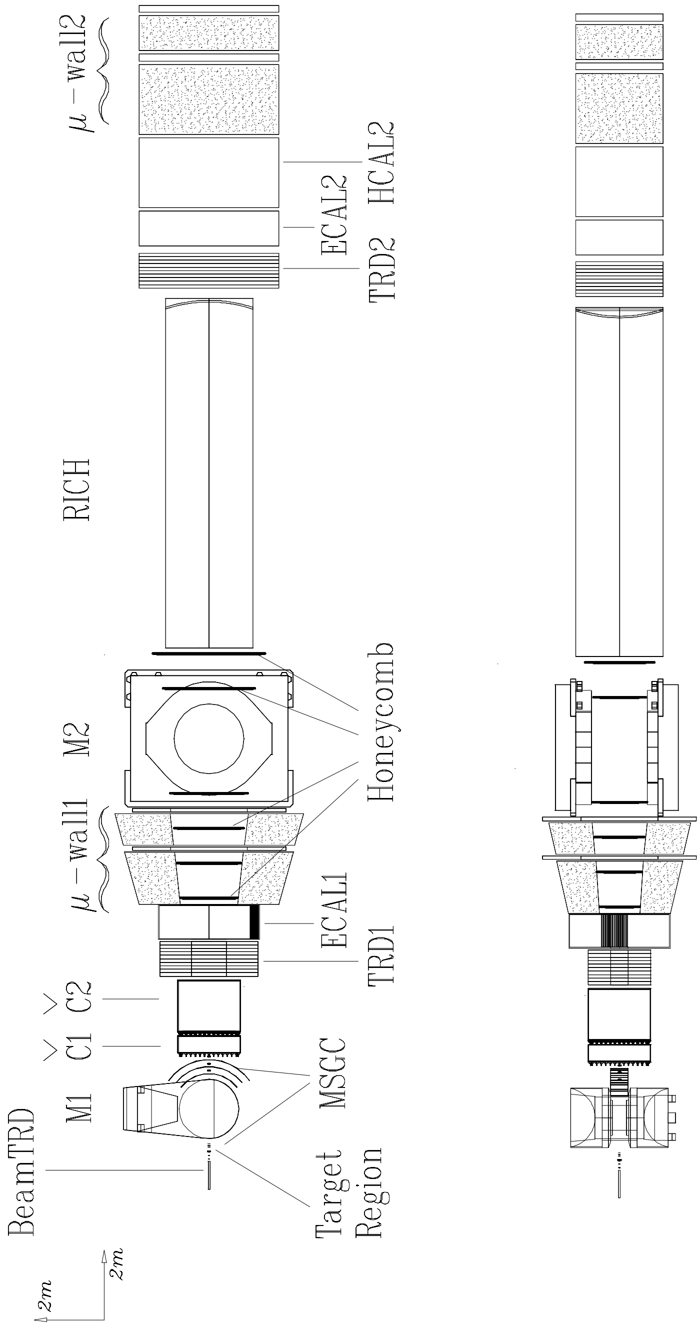

Figure B.3: Top and side view of the proposed experiment

The design of the tracking detector following the target is based on the 'target detector' of the WA92 experiment [86]. It consists of 15 planes of silicon strip detectors with a pitch of $10\mu m$ and a thickness of about 150 μm. The readout direction is alternating between horizontal and vertical (Si-target). The first ten counters will be spaced by 1mm, the other five by 2mm, which will provide longitudinal vertex resolutions better than $75\mu m$.

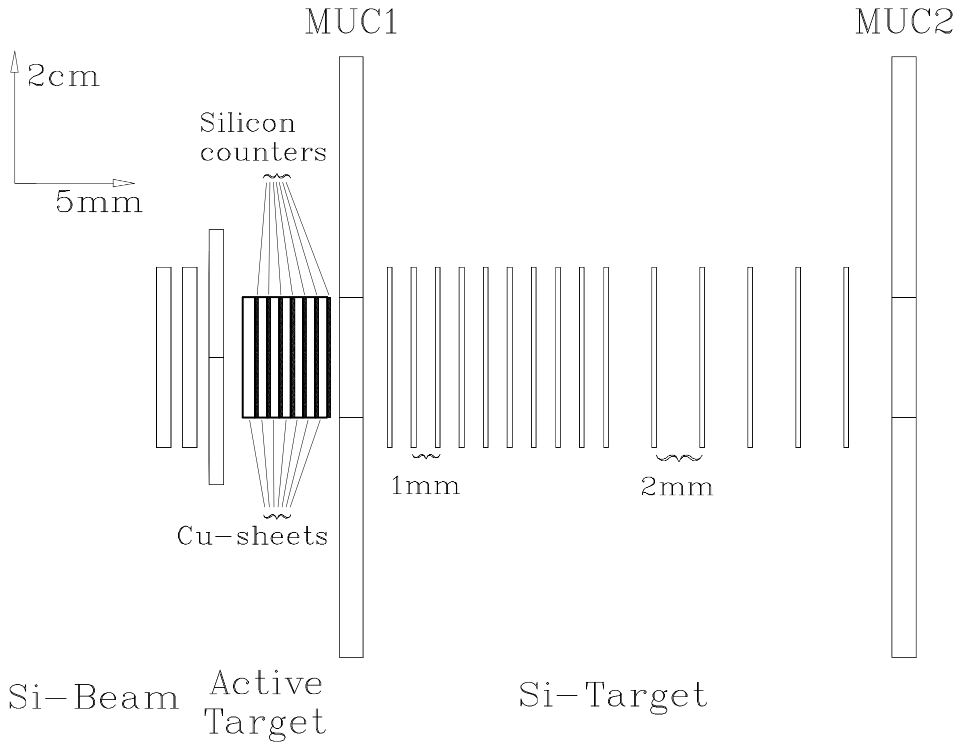

Figure B.4: Side view of the target region

The first counter will be located about 1mm downstream of the first MUC. The analog information from all channels will be read so that secondary interactions in the detectors can be isolated. Downstream of the 'target detector' the second MUC will be placed.
In order to obtain the desired interaction rate, two such set ups will be placed in series. They are followed by three more sets of silicon counters (Si-vertex). Each set consists of 2 double sided detectors 300 μm thick with orthogonal readout (6.3x6.3 cm^2). They are arranged in such a way that tracks are measured in 4 projections to allow track reconstruction in space. The alternative use of silicon pixel detectors is being studied. The advantage of fast and unambiguous track reconstruction in space is obvious (in particular for trigger purposes). Detectors with zero suppression and fast readout are currently being developed by RD19 [87]. However, it is not clear whether the desired readout speed can be achieved.
It should be noted that radiation damage will become a serious issue in such an experiment. Possible alternatives to silicon like GaAs or diamond are therefore being explored.

B.2.3 Magnetic spectrometers

Two magnetic spectrometers are foreseen in the setup. The first can use the magnet S170, previously used in experiment PS170 at LEAR and now at SATURNE as part of the DISTO set up. It provides a field of 1.5 T in a cylindrical volume of 50 cm radius and 46 cm height. Cylindrical C-shape magnets suffer from large fringe fields. On the other hand, the cylindrical form reduces the bending for low momentum tracks and thus the active area of the tracking detectors downstream of the magnet. (A custom-made cylindrical magnet could be made minimising the fringe fields. See LOI for LHCB). As the field integral is rather low good spatial resolution is needed in order to obtain high momentum resolution. Upstream of the first magnet (M1) we intend to install large area MSGCs with 200 μm pitch and readout in three projections (MSGC-vertex). Two such MSGC-sets will be placed between Si-vertex and the entrance yoke of M1. The total size needed is about $50 * 25cm^2$. MSGCs will also be used at the exit of the spectrometer to determine the angle of the outgoing particles (MSGC-M1). Three sets of MSGCs are mounted on concentric cylindrical surfaces. The cylinders are cut at $\pm 50^0$ and are spaced by about 50cm. MSGCs typically provide spatial resolutions of about $50\mu m$. The cylindrical mounting reduces the number of tracks passing through the chambers at large angles for which the position resolution is considerably worse. The bending of high momentum particles with low p_T can be measured by a set of double sided silicon microstrip counters with an active area of 6.3x6.3 cm^2 (Si-M1). The first spectrometer accepts momenta down to below 1 GeV/c. We are also investigating the possibility of placing sets of MSGCs in the field for the reconstruction of low momentum Λ and K^0.

The second spectrometer is placed 10m downstream of the first one in order to provide a decay volume for hyperons. We currently envisage the use the GOLIATH magnet for M2, recently modified and used by the WA98 collaboration. This magnet provides a field strength of about 1T at a pole gap of 1m. The radius of the cylindrical magnet is 1m. Operated at a polarity opposite to M1 it provides an integrated field strength of -2Tm for high momentum particles. The operation of the two magnets with opposite polarity has the advantage that the downstream part of the detector can be kept rather small as most tracks coming from the primary interaction will emerge at small angles from the second magnet (the residual bending power is -.5 Tm). Although appealing for trigger purposes, an opposite but equal bending power of both magnets would lead to a very small dispersion of the tracks entering the downstream RICH. Cherenkov rings would thus overlap too frequently on the photon detector reducing the identification power of this detector.

The tracking for this spectrometer is mainly based on fast large area straw tube arrays [88] or honeycomb chambers [89]. Two such arrays are positioned upstream of the magnet, two other ones downstream. In order to improve the high rate performance of this system we also plan to place MSGCs into the central part of both detector sets (MSGC-M2).

B.2.4 Particle identification

To improve the purity of the reconstructed charm samples down to very low values of x_F we have to perform particle identification at correspondingly low momenta. This requires the use of Cherenkov counters downstream of each spectrometer magnet.

Two threshold Cherenkov counters between the magnets M1 and M2 will be used for pion suppression. Their thresholds might be $\gamma = 25$ and $\gamma = 60$, using C_2F_6 and a He/N_2 mixture as radiators. With $N_0 = 100/cm$ including light collection losses, and radiator lengths of 0.5m and 1.5m, we would have 8 and 4 photo-electrons per fast particle. This would provide effective thresholds for pions at 4 and 10 GeV/c and for kaons at 14 and 30 GeV/c, thus pions could be suppressed from 4 to 35 GeV/c and kaons could be positively identified from 14 to 33 GeV/c.

The mirrors cover a total surface of about 1.2 m (hor) x 0.7m (vert) and 1.8m x 1.0m respectively, with inner rectangles of about half-size linear dimensions left free for high-momentum particles. The Cherenkov light is focussed by matrices of spherical mirrors onto arrays of phototubes. With a granularity of 100 phototubes and a mean of 10 fast charged particles in the counter acceptance, one would expect about 15% of random suppressions for slow particles in each counter, which is acceptable.

For the high-momentum particles passing the magnet M2, the use of threshold Cherenkov counters is not possible. The large particle fluxes expected in this experiment exclude the use of the existing Omega RICH counter as well, since it uses driftchambers with 40cm drift path as photon detectors. However, a RICH counter of the type presently used by the SELEX experiment using phototubes, is fully capable to handle the expected rates [90]. It provides $\pi/K/p$ separation up to at least 100 GeV/c. At higher momenta, only (anti)protons can be separated from kaons and pions. The SELEX counter has a 10m long radiator volume. The Cherenkov light is focussed by an array of spherical mirrors onto a matrix of 2842 phototubes, each covering a hexagon of 1.6 mrad angular diameter. The total angular acceptance is ± 20 mrad horizontally and ± 65 mrad vertically. In beam tests, a mean number of 12 phototubes per particle have been fired using neon as radiator, which has a Cherenkov threshold of $\gamma = 87$. Since the data taking of the SELEX experiment will most likely stop in the beginning of 1998 we are currently discussing whether or not this detector would be available for this experiment. Although particle momenta at E781 are higher by about 50% (which determines the length and type of the radiator used) we could adapt the radiator gas for this experiment. This has to take into account the desired proton threshold and the Cherenkov ring separation necessary for particle separation and will be studied in more detail.

B.2.5 Calorimetry

Good photon detection is mandatory to reconstruct final states including single photons or π^0. This and the need to reconstruct neutrons from charm or hyperon decays requires good electromagnetic and hadronic calorimetry. In order to have a high acceptance for photons and neutrons there will be two electromagnetic and one (possibly two) hadronic calorimeters. The first pair of calorimeters (ECAL1 and possibly HCAL1) will be placed about 5 m upstream of the entrance of magnet M2. Both detectors will have a central hole fitting to the acceptance of M2. The second pair of calorimeters (ECAL2 and HCAL2) will be placed downstream of the RICH counter. Operation of the two magnets with opposite polarity leads to an increased particle multiplicity on the calorimeters. Good spatial resolution and two particle separation is therefore necessary. In order to have a precise knowledge of the momentum of the mother particles of the detected photons and neutrons (mainly π^0 and $\Sigma^\pm$) also a good energy resolution of the calorimeters is important. Typical energy resolutions required are a few MeV/c^2 for π^0 or 3-4 MeV/c^2 for the mass resolution of radiative decays of excited charmed hadrons. A spatial resolution of a few mm is needed for Primakoff reactions in order to obtain good resolution for the determination of the 4-momentum transfer. In the following we describe a possible layout of the calorimetry:

For ECAL1 a lead glass or lead/scintillating fibres array of 1.5 m radius and an individual tower size of about 4×4 cm^2 would be suitable. A device with this granularity can reach energy resolutions of $\frac{\sigma}{E}(\%) = \frac{5.3}{\sqrt{E}} + 1.1$ for lead glass[91] and $\frac{\sigma}{E}(\%) = \frac{9}{\sqrt{E}} + 0.6$ for lead/scintillators[92]. Their position resolution has been measured to be $\sigma_x(mm) \simeq \frac{6.0}{\sqrt{E}} + 0.5$ ($\sigma_x(mm) = 1.3$ at 25 GeV [91])or $\sigma_x(mm) = \frac{1.8}{\sqrt{E}} + 0.01$[92], respectively. A lead glass calorimeter with these specifications (GAMS4000 [93]) is currently used by WA102. The area covered by this detector is 6m^2. When the inner modules are removed to form a hole of 0.5 m^2 area we can assemble a calorimeter with a radius of 1.45 m which covers well the surface needed. This detector, equipped with new readout electronics (see section devoted to this subject) could fit into the proposed set up.

The hadronic calorimetry could be made of the "spaghetti type" systems where the active material could either be plastic scintillator fibres or quartz fibres (providing more radiation hardness and faster signals)[94]. The ratio of passive and active material will be chosen such that compensation is achieved. A total front face of about 2.5·5 m^2 fits well the angular distribution of the neutrons to be detected behind M2. An individual tower front face of about 50 cm^2 (hexagons) allows for an energy resolution of $\frac{\sigma}{E}(\%) = \frac{30.6}{\sqrt{E}} + 1.0$[95] and a position resolution of $\sigma_x(mm) = \frac{31.4}{\sqrt{E}} + 2.4$[96]. A particularly appealing set up could be the use of compensating scintillating fibre calorimetry for both, ECAL2 and HCAL2, with different sampling rates. Thus good hadronic energy resolution can also be obtained in ECAL2. An alternative solution is the use of a "shashlik"-type calorimeter. Such a device gives similar performances as the "spaghetti" calorimeter with the advantage of simpler mechanical design.
A compensating hadronic calorimeter of a similar type has been developed by [97] in the more classical sandwich design (alternating lead and scintillator plates) using w.l.s. bar readout. The cell size is $10 \cdot 10 cm^2$ and the energy resolution obtained is $\frac{\sigma}{E}(\%) = \frac{57}{\sqrt{E}}$. The typical spatial resolution is about 8 mm at 40 GeV/c. A prototype module of 60 cells is currently used by WA97. A large area device ($\approx 8m^2$) could be built up relatively easily as all components are already existing. This would cover a large fraction of the total area needed.
The good coordinate resolution and two particle separation required for the central part of ECAL2 can be achieved in a calorimeter made of dense media having a small e.m. shower size. One of the best materials of this type is the recently developed $PbWO_4$ (PWO) scintillating crystal[98]. Its very small Moliere radius, R_M=2.2 cm, and radiation length, X_0=0.87 cm, result in a best possible two shower separation, which can be estimated to be about 2 cm scaled down from results obtained with a lead-glass detector[99]. Additional essential advantages of PWO crystals are good energy resolution ($\frac{\sigma}{E}(\%) = \frac{2.48}{\sqrt{E}} + 0.48$[100]) and radiation hardness (no significant damage up to 2 Mrad[101]). These crystals are considered as a baseline options for the electromagnetic calorimeters of CMS and ALICE detectors at LHC.
In order to cover the large area needed lead glass could be used for the peripheral part of ECAL2.

B.2.6 Muon detection system

In order to cover muons from semileptonic decays we need a large area μ identifier. It consists of a 2 or 3-layer sandwich made from iron and tracking detectors. One possibility is the use of resistive plate chambers (RPC) which are fast, cheap and can be made industrially in large areas. This design has been proven to work in the WA92 and E771 experiment [102]. Two such stations are placed at the end of each spectrometer, respectively.

B.2.7 Electron identification

In order to cleanly identify decay electrons a fast transition radiation detector will be placed between the RICH and the photon detector. The TRD can be made using large area wire chambers in combination with radiator stacks. Alternatively we can use the design from RD6 [103], based on straw tubes embedded in a radiator foam. The latter scenario has the advantage that it can be used also downstream of the second spectrometer where the beam passes through the detectors. Typically, a 10-stage detector gives π-rejection of more than

2 orders of magnitude with high efficiency for electrons.

B.3 Readout and DAQ

A possible readout and DAQ schematics is shown in Fig. B.5. The foreseen interaction rate of about 10^6/sec requires LHC type front-end electronics. In order to make a deadtimeless system we foresee a full pipelining of all signals from all detectors with a typical sampling frequency of 40 MHz. The length of such a pipeline must be of the order of the decision time for an efficient 1st level trigger which should provide a reduction rate of about a factor 10. A buffer of about 1 μs depth will thus be filled. For analog information such a buffer will consist of a switched capacitor array from which the charge is transferred to a FADC. For cases where only digital or timing information is used the buffer follows a discriminator or TDC. From this buffer data corresponding to good events (first level trigger) will be transferred to an associated memory ($\approx$ 8-16 events deep), which can be preceded by an FADC if this has not been incorporated into the front pipeline. In order to reduce the data flow sparsification should be performed.

A fast data multiplexer feeds the data into a large memory array. Two such data storages are necessary. The full data can be fed into FIFOs for the data stream written to tape. Data which are used for high level filters could be written to RAMs or separate FIFOs providing the possibility of parallel processing via DSPs or pipelined processors, respectively. The large event memories (FIFO) are located in FastBus crates which are connected via fibre channel (SFI/PCI) links to fast multi-CPU AXP machines. From there data are written to a large storage medium. Currently systems with 80GB storage on parallel arrays with 5 separate DLT drives (digital linear tape) exist with transfer rates of 10 MB/sec on fast-wide SCSI buses. With an estimated amount of 100 MB/spill (with data filter) or 1GB/spill (without data filter) we would need 1 or 10 such systems, respectively.
Due to the short time schedule foreseen for the installation of the experiment the proposed readout has to rely on currently existing or progressively being developed VLSI electronics [104]. From the readout point of view three different systems have to be addressed:

- High density microstrip trackers (silicon or MSGC) can be read using the FELIX chip designed within the RD-20 project [105] which provides full analog information (using a 2 μs analog pipeline) important for the silicon target detectors and MSGCs. The information from this chip (128 channels) can be transferred into a FADC within 4 μs without deadtime using an internal multiplexer. The FADC information (8 bit) will then be fed via a serial bus into a fast sparsifying logic with a double buffering (Fig. B.6).

- The calorimeter information can be treated in different ways following the ATLAS [106] or KTEV[107] design (fig. B.7). The basic feature is a FADC system with large dynamic range (14-16 bits) using a switchable attenuator technique giving about 8-10 bit accuracy.

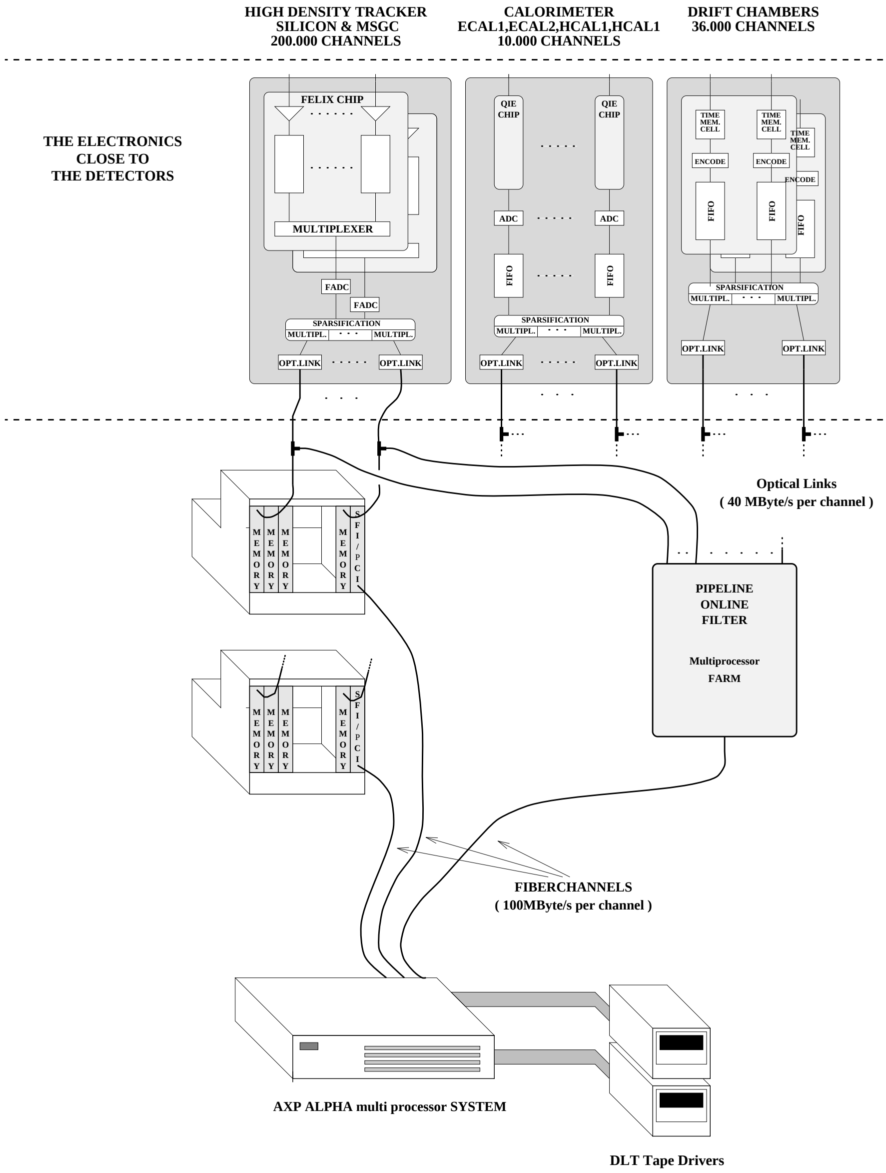

Figure B.5: Overview of Readout and DAQ scheme

As for the FELIX chip the analog signal is pipelined (500ns-2μs depth). Due to the high integration the readout board will be located on the detector modules themselves. The FADC will be followed by a FIFO memory. These memories will then be read in daisy chain into an event buffer using a sparsifying logic.

- The signals of honeycomb chambers or drift tube arrays have to be fed into TDCs after amplification and discrimination. Fast TDC-chips without conversion time are currently being developed. The TMC4004 [108] e.g. operates at a 40 MHz cycle. The time within a cycle can be measured with about 5 bit accuracy (1-1.5 ns). After pipelined encoding the information is fed into a FIFO from where the relevant clock cycle information for valid events (1-st level trigger) is extracted into a 16 event deep buffer chip. This chip performs zero suppression and presents the data for a multiplexed readout of many (e.g. 256) channels via a serial link into an event buffer.

Table 1 summarises the estimated number of electronic channels needed together with the amount of data to be read/event, separately for each detector part. Using sufficient zero suppression, the data rate can be kept below 10 Kbyte/event resulting in a total data rate of about 50-100 Mbyte/spill. Such rates can be handled by a modern DAQ.

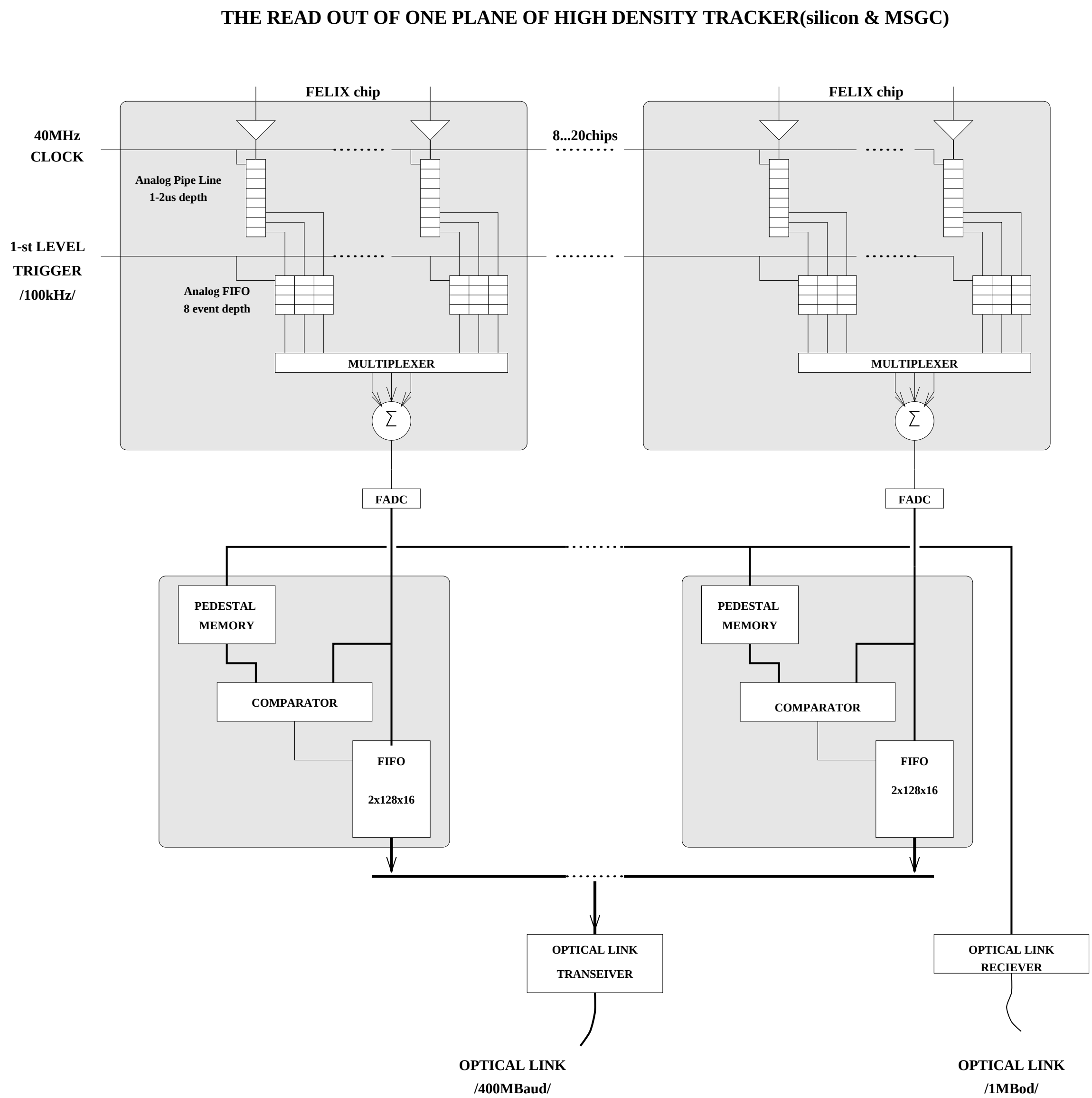

Figure B.6: Possible readout scheme for tracking detectors

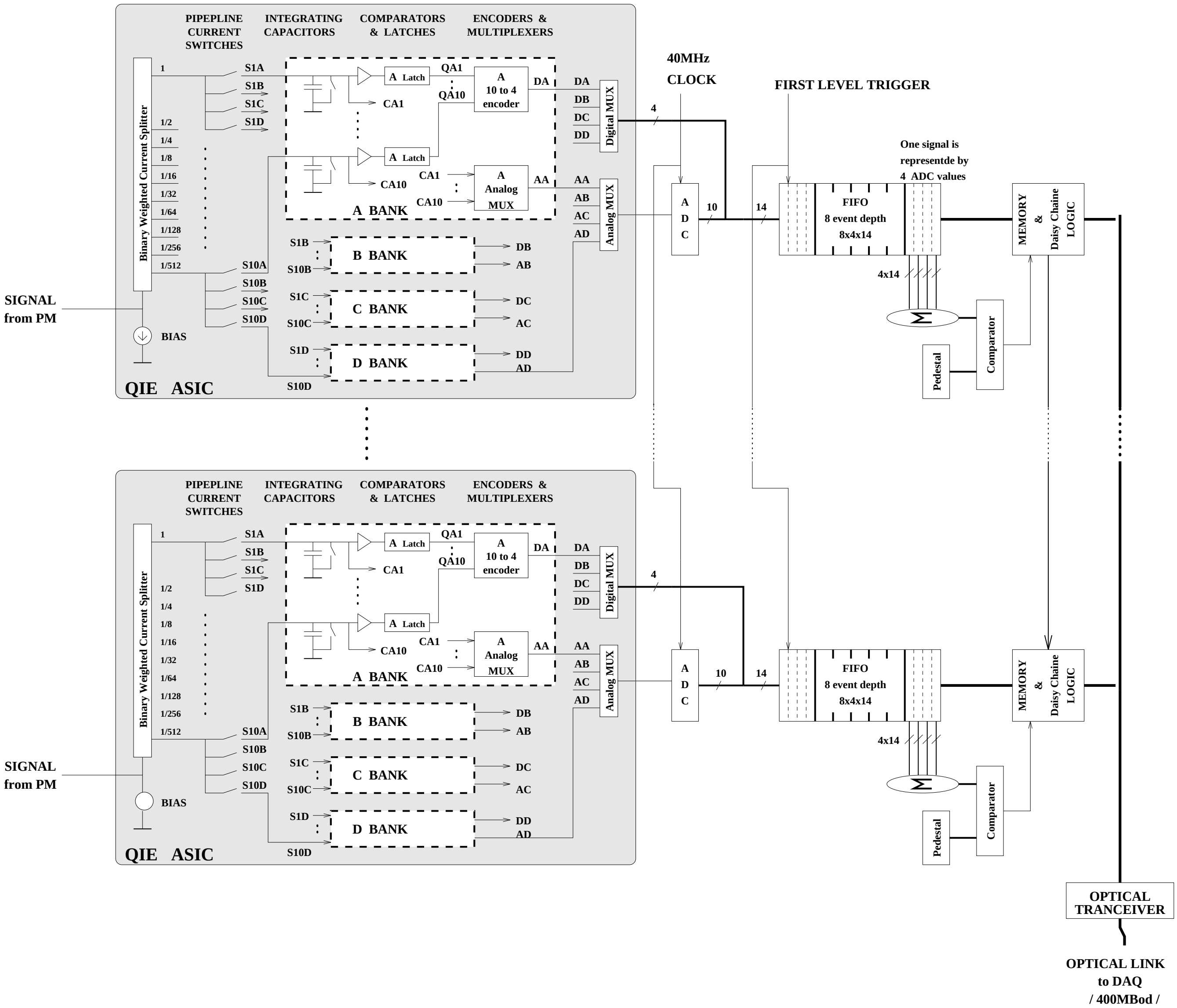

Figure B.7: Possible readout scheme for calorimeters

Table 1 : Data size for different detectors				
Detector	Type	# of Channels	Byte /event	Valid data /event
Beam TRD	MSGC	1000	2 KB	0.2 KB
Target detector	Silicon	65,000	190 KB	1.5 KB
Pixel Detector	Silicon	3*170,000	0.6 KB (sparse)	0.6 KB
Spectrometer 1	MSGCs	120,000	240 KB	1 KB
	M1 upstream	15,000		
	M1 centre	35,000		
	M1 downstream	70,000		
Spectrometer 1	Silicon	8*1280	10.2 KB	.34 KB
Decay region	4 sets with 8 planes			
	Honeycomb - strips	12000	24 KB	.5 KB
	Honeycomb - wires	3300	6.6 KB	.2 KB
Spectrometer 2	2 sets with 8 planes			
	Honeycomb - strips	16000	32 KB	.4 KB
	Honeycomb - wires	5000	10 KB	.15 KB
C1	Thresh. Cheren	400	.4 KB	.1 KB
C2	Thresh. Cheren	400	.4 KB	.1 KB
C3	RICH	2500	5KB	.1KB
TRD1	drift tubes	15*800	36 KB	1 KB
TRD2	drift tubes	10*1200	36 KB	.7 KB
ECAL1	Lead glass	4000	8 KB	0.5 KB
ECAL2	Spaghetti or crystals	4000	8 KB	0.5 KB
HCAL1				
HCAL2	Lead/Scintillator	800	1.6 KB	0.5 KB
MU1	RPCs			
MU2	RPCs	pad readout		
	$2 \cdot 2000$ pads	4000	8 KB	0.1 KB
Total		912,000		7.6 KB

B.4 Event Reconstruction

In view of the large data sample to be acquired event reconstruction and data analysis are an important issue. Assuming an average event rate of 5000/spill about $5 \cdot 10^9$ events will be recorded within 2 years. This corresponds to about 10 times the accumulated sample of the hyperon beam experiment WA89. The total time spent for event reconstruction in this experiment was 1 year operating about 30 DEC-stations 5000/260 operated by the collaboration. Using the experience from this experiment a faster reconstruction algorithm could be developed reducing the processing time/event by about a factor 2. In addition faster CPU's are already available now. Projecting the development of CPU power into the near future we may safely assume a factor 10-15 in processor speed. We thus assume that event reconstruction could be done on a a time scale not exceeding 6-12 months.

B.5 Trigger

In high intensity experiments one of the main challenges is the design of a fast trigger. Various steps are foreseen to achieve the necessary reduction. In order to avoid deadtime from complicated trigger scenarios we envisage a complete and fast buffering of all events into a large memory (see section B.3). This leads to a derandomization and therefore allows deadtime free triggering as long as the trigger decision time for all events does not exceed the length of one accelerator cycle. A fast first-level trigger has to be implemented which reduces the event rate below $\approx$ 100 kHz, the limit for the serial data transfer. The size of the first stage event buffer is determined by the decision time of this first level trigger.
Such a scenario is currently being installed for the NA48 experiment. Any trigger can run on the stored events and consecutive events can therefore be treated in parallel if necessary. The following section tries to sketch possible trigger scenarios for the different physics items addressed. (The term trigger is being kept although we mostly deal with event filters.)

B.5.1 Charm

This trigger clearly is the most challenging part of the whole experiment. The very short lifetimes of charmed baryons make efficient triggering almost impossible. However, charmed baryons will mostly be produced in association with a long lived charmed meson on which such a trigger can work with higher efficiency. Some of the physics questions addressed even require the observation of the associated particle. Using high resolution silicon strip or pixel devices one can envisage a fast reconstruction of secondary vertices using either a hardwired processor as designed for WA92 or a fast high power CPU farm as currently set up for E781 at FNAL [109]. However, the foreseen interaction rate of about 1 MHz is far too large for such a system. We therefore envisage to reduce the trigger rate by about a factor 10 using other fast triggers. A simple cut on a minimum number of charged particles already reduces the number of interactions by a factor 2. Another factor 3-5 could be obtained by means of a multiplicity jump trigger. Using two thin solid Cherenkov counters right downstream of the target and spaced by a few centimetres we can detect decays of short living particles in the volume between the counters by comparing the total light produced in each counter. Such a trigger has been tested in E791 at FNAL giving very promising results [110,111]. The reduction is limited by two factors, one determined by concurring physical processes and the other one by the performance of the Cherenkov detectors. Considering the results from the E791 test we conclude that about 7-10 photons should be observed per traversing track for high efficient multiplicity separation. The trigger rate caused by strange particle decays and secondary interactions between two Cherenkov counters is expected to be below 10% of all interactions.
Another quantity useful for rejection of non-charm events is the transverse energy E_t observed in calorimeters (used by E791 at FNAL). A cut at about 8 GeV should retain about 70% of all charmed mesons reducing the total trigger rate by about a factor 4 [112]. Furthermore, it was studied recently that p_t could be a more powerful quantity. Further details will have to be studied also using WA89 data.
A fast beam TRD can give π rejection when used with a hyperon beam (as currently employed by WA89 [113]). resulting in another reduction of 3 for the interactions fed to a vertex processor.

B.5.2 Charm semileptonic decays

Triggering on semileptonic decays may make use of a high momentum muon emerging from the target region and/or the fast identification of an electron track. The muon might thereby emerge from the decay of charmed baryons or accompanying mesons. The first possibility has been tested in the WA92 experiment searching for beauty production with a π beam and E653 at FNAL, looking for s.l. charmed meson decays in a proton beam. The trigger reduction obtained is very large. Apart from this s.l. decays should already be included in the general charm trigger through the decay of the associated charmed hadron.

B.5.3 Primakoff reactions

Primakoff scattered particles emerge from the target with almost the incoming momentum and a very small scattering angle, typically 150 μrad. A fast trigger should therefore include the detection of the soft Primakoff photon to tag a reaction. We might also detect the scattering of the beam particle itself. This could be achieved using fast high resolution scintillating fibre detectors to reconstruct the beam track upstream and downstream of the target. We can require a minimum kink angle in order to select a scattering event.

B.5.4 $\Sigma^{\pm}$ semileptonic decays ($\Sigma^{\pm} \rightarrow \Lambda\, e^{\pm}\, \nu$)

These semileptonic decays have a very clean signature. After identification of a beam particle we have to require 3 charged tracks coming from the fiducial decay volume with the correct charges. We can also make a rough momentum analysis to tag a high momentum positive particle from the subsequent Λ decay. The standard decay mode (nπ), which has to be observed in parallel for normalisation purposes, can be triggered on using a hadron calorimeter, as is presently done in WA89, prescaling its rate by a large factor.

B.6 Rate Estimates

In the following we present a few estimates for the number charmed hadrons and double charmed baryons which could be observed in the proposed experiment. At this stage such estimates are crude since in particular the detailed production properties of charmed baryons are not known.

The number of observed charmed particles should be proportional to the number of interactions in the target. In order to estimate the number of interactions for the experiment proposed we used the following assumptions:

- beam rate:	$2 \cdot 10^7$ particles/sec;
- target thickness:	2.5%;
- beam time:	2 runs $\times$ 150 days, which correspond $2 \cdot 10^6$sec of beam taking into account a duty cycle of 2.5sec/14.5sec and an average beam delivery efficiency of 50% .

This results in about 10^{12} interactions.

In order to estimate the expected number of charmed particles observed per interaction, we used results from E791, which had a relatively high acceptance for $x_f > -0.1$ and used a weak, unbiasing trigger. This experiment observes about one charmed particle per 10^5

interactions. The experiment proposed should have a higher efficiency for charm reconstruction than E791 due to better tracking, but may have a lower trigger efficiency
Using the expected number of interactions and the charm yield of 10^{-5} we estimate the expected number of all charmed particles reconstructed to be about 10^7.

For doubly charmed baryons such an estimate is even more difficult. Based on the arguments discussed in the appendix we estimate $\sigma(ccq)$ to be $\approx 1 - 10$ nb/nucleon, i.e. about 10^{-4}-10^{-3} of the full $c\overline{c}$ cross section. Weak decays of ccq include a single charmed particle. We assume that about 10% of these decays could be reconstructed for cases when the daughter charmed particle is reconstructed. Thus the yield of double charmed particles is expected to be about 10^{-4}-10^{-5} of the yield of single charmed particles, yielding about 100-1000 of reconstructed events.

We may also consider the expected efficiency for the charm events, by comparison to E781 estimates [114]. The E781 efficiencies for cqq decays include a tracking efficiency of 96% per track, a trigger efficiency averaged over x_F of roughly 18%, and a signal reconstruction efficiency of roughly 50%. The trigger efficiency of the proposed experiment may be higher than in E781, if low x_F events are included. However, the signal reconstruction efficiency is low for low x_F events. The reconstruction efficiency may be lower for double charm events, since they are more complex than single charm events. Yet, using the proposed type of vertex detector multivertex events can be reconstructed with good efficiency [115]. Considering all these effects, we assume here an overall average ccq reconstruction efficiency of $\varepsilon \simeq 5\%$, about half the average expected E781 value for cqq detection. The expected yield is then $5{\cdot}10^3$ double charm events for 1nb/Cu-nucleus. For a value of 0.01-0.1 nb/N for the product of cross section and branching ratios, one obtains N(ccq) $\approx$ 50-500 fully reconstructible events. This is the total expected yield for ccu,ccd,ccs production for ground and excited states.
It should be noted, however, that lifetime measurements can also be performed using a ccq-decay chain involving a semi-leptonic cqq-baryon decay. In addition, the production of a ccq state will probably be accompanied by two associated $\overline{D}$-mesons, which will increase the trigger efficiency considerably. Thus, the number of useful events could be larger.
The rate of events where two uncorrelated c-quarks are produced, should be larger by about a factor 10.

B.7 Competition

In the following we present a list of experiments which might do part of the proposed program before a new CERN experiment can be established.

- SELEX
  This is by far the most important competition. Scheduled for many years, this Fermilab experiment will probably run in 1996-1998 for about 15 months. It is similar to the WA89 experiment with the advantage of a higher beam energy (unless some leading particle effects are more prominent at lower energies), an acceptance down to almost x_F=0 due to the use of a triple magnetic spectrometer, and a higher beam flux. The higher flux is obtained in part by the higher duty cycle of the Fermilab Tevatron and in part by the higher proton flux possible in the high intensity area at FNAL. However, the beam flux is not a problem for an experiment in the high flux hall in the North Area at CERN where rate limits are only given by the detectors. When running with a smaller primary proton energy (e.g. 400 GeV/c) it also possible to lengthen the extraction from the SPS and a better duty cycle can be reached (about 25% duty cycle has been reached for lead ions).

  SELEX may obtain a statistics increase in the **charm** sector over WA89 by about a factor of more than 10 at large x_F, more of course at very small values of x_F. However, their DAQ relies on a software charm trigger not experimentally tested up to now (except for a measurement of the spatial resolution in a parasitic run).

  It is not clear how well Primakoff physics can actually be addressed in their run as this requires a non-trivial trigger to be installed and a dedicated set up.

- CLEO
  This experiment clearly will be very competitive for the study of charmed baryon decays. The experiment has undergone a major upgrade and has proven its excellent photon reconstruction capability at many occasions in the past. They have already observed the Λ_c^+in may final states and have seen clear signals from two Λ_c^+-resonances. They have also obtained interesting results for semileptonic decays of Λ_c^+, but their "tagging" technique leads to systematic errors very different from the ones expected in a fixed target experiment.
  In contrast to fixed target experiments, however, they have not yet observed the Ω_c^0.

- E831
  The FNAL tagged-photon beam experiment has been approved to run again for the next fixed target period in 1996 with an upgraded detector and DAQ. Although very successful in the sector of charmed and charmed-strange baryons, it will not represent a major competition in charmed baryon physics. The expected increase in statistics by a factor 10 will constitute only a small gain compared to the presently expected data sample from WA89.

- E791
  This pion-beam experiment has accumulated about 10 times as many interactions as WA89. The use of this particular beam, however, will not allow a detailed study of charmed baryon production. They might contribute to charmed baryon decay studies with a yet unknown quality/quantity.

- HERA-B
  The HERA-B experiment is designed to detected as many B-meson decays as possible using 800 GeV protons from the HERA proton beam halo impinging on a wire target within the ring. Although much charm will be produced in these interactions it is not yet clear how well it can be used as their trigger will be highly selective for B-meson decays and at the current stage charm physics will only constitute a by-product.

- SLAC-B
  This e^+e^- collider experiment [116] is scheduled to run from the beginning of 1999. As for HERA-B the main physics issue is CP violation in the B-system. However, they will also use the expected large sample of D-mesons ($\approx 10^7$ of each species) to perform precision measurements of semileptonic D-decays and their form factor, measurements of the D-decay constants f_D and f_{D_s} as well as possible direct CP violation in the D-system. As CLEO III they will also constitute a competition especially in the non strange charmed baryon sector.

APPENDIX

Doubly Charmed Baryons and Exotics

This appendix is based on contributions at the workshops which preceded this LOI. It gives a detailed description of systems with double charm, including their spectroscopy, production and decays. More information can also be found in ref. [117].

Introduction

Quantum Chromodynamics includes the existence of doubly charmed baryons: Ξ^+_{cc} *(ccd)*, $\Xi^{++}_{cc}(ccu)$, and Ω^+_{cc} *(ccs)*, as well as *ccc* and *ccb*. Properties of *ccq* were discussed by Bjorken [4], Richard [5], Fleck and Richard [118], Savage and Wise [119], Savage and Springer [120], Kiselev et al. [6,121], Falk et al. [7], and by Bander and Subbaraman [8]. Singly charmed baryons are an active area of current research [122–124,77,125,126], but there are no experimental data on the doubly charmed variety. Since double charm physics is in the mainstream and part of the natural development of QCD research, a dedicated state-of-the-art experiment on double charm is desirable. The required detectors and data acquisition system would need very high rate capabilities, and thus could serve as a testing ground for LHC detectors.

The ccq baryons should be described by a combination of perturbative and non-perturbative QCD. For these baryons, the light q orbits a tightly bound cc pair. The study of such configurations and their weak decays can help to set constraints on different models of quark-quark forces [118,127]. Hadron structures with radii less than $1/\Lambda_{QCD}$ should be well described by perturbative QCD, since the small size assures that α_s is small, and therefore the leading term in the perturbative expansion is adequate. The tightly bound $(cc)_{\bar{3}}$ diquark in *ccq* satisfies this condition. For *ccq*, on the other hand, the radius is dominated by the mass of the q, and is therefore large. The relative *(cc)*-*(q)* structure may be described similar to mesons $\bar{Q}q$, where the *(cc)* pair plays the role of the heavy antiquark. Savage and Wise [119] discussed the ccq excitation spectrum for the q degree of freedom with respect to the cc ground state system in analogy to the spectrum of $\bar{Q}q$ mesons. Fleck and Richard [118] calculated excitation spectra and other properties of *ccq* baryons for a variety of potential and bag models, which describe successfully known hadrons. The ccq calculations contrast with *ccc* or *ccb* or *b*-quark physics, which should be completely perturbative.

As pointed out by Bjorken [4], one should also strive to study the *ccc* baryon. Its excitation spectrum, including several narrow levels above the ground state, should be calculable perturbatively. The *ccq* studies are a prerequisite to any attempt on *ccc* studies.

A tetraquark $(cc\bar{u}\bar{d})$ structure (designated here by T) was described by Richard, Tornqvist, Bander and Subbaraman, Lipkin, Nussinov, and Chow [5,8,40–42]. This $4q$ hadron is of particular interest, as all studies indicate that it may be bound. One can compare the tetraquark structure to that of the antibaryon $\bar{Q}\bar{u}\bar{d}$, which has the coupling $\bar{Q}_{\bar{3}}(\bar{u}\bar{d})_3$. In the T, the tightly bound *(cc)*$_{\bar{3}}$ plays the role of the antiquark $\bar{Q}$. Alternatively,the tetraquark may have a deuteron-like meson-meson weakly bound $D^{*+}D^0$ configuration, coupled to 1^+, and bound by a long range one-pion exchange potential. Such a structure has been named "deuson" by Tornqvist [40]. It may have a molecular structure, similar to the H_2 molecule, with the heavy and light quarks playing the roles of protons and electrons, respectively. The discovery of such an exotic hadron would have far reaching consequences for QCD, for the concept of confinement, and for specific models of hadron structure (lattice, string, and bag models). Detailed discussions of exotic hadron physics can be found in recent reviews [128]. Some other exotics that can be investigated in the proposed experiment are: pentaquarks $uud\bar{c}s, udd\bar{c}s, uds\bar{c}s, uud\bar{c}c, udd\bar{c}c, uds\bar{c}c$ [129], Hybrid $q\bar{q}g$ [130], $us\bar{d}\bar{d}$ $U^+(3100)$ [131], $uuddss$ H hexaquark [37,132], $uuddcc$ H_{cc} hexaquark [42], $q\bar{q}s\bar{s}$ or $q\bar{q}g$ C(1480) [128], and $\bar{c}\bar{c}qqqq$ heptaquark [8]. These will not be discuss these in detail here.

An interesting problem is whether only the $cc\bar{u}\bar{d}$ (or $D^{*+}D^0$) is bound or whether the $c\bar{c}d\bar{u}$ (or $D^{*-}D^0$) also is bound: the $D^{*+}D^0$ state can decay strongly only to double charm systems, and cannot decay strongly at all if it is below the DDπ threshold. In contrast, the $D^{*-}D^0$ state has numerous open strong decay channels to charmonium plus pions. There is no hope in seeing any state like this in any search experiment with hadron beams, although the production cross sections for one $c\bar{c}$ pair is much higher than for two pairs. There is yet another reason not to expect a $D^{*-}D^0$ bound state. The sign of the potential binding for the two D mesons depends on the product of the sign of the two vertices associated with the pion exchange. The sign of the D^* vertex depends on T_z, which changes from +1 to -1 in changing from positive to negative D^*. Therefore, if the potential is attractive in the case of $D^{*+}D^0$, it will be repulsive in the case of $D^{*-}D^0$. Consequently, if one accepts the calculations [40,145] for a bound $D^{*+}D^0$, we can conclude that the $D^{*-}D^0$ is unbound. Still, in the $D^{*+}D^0$ search, it may be worthwhile to look at $D^{*-}D^0$ data. Although no bound state is expected, the combinatorial backgrounds may help to understand those for $D^{*+}D^0$.

Masses of *ccq* baryons and tetraquarks

Bjorken [4] suggests $M(\Omega^{++}_{ccc}/\Psi) = 1.60$ and $M(\Omega^{-}_{bbb}/\Upsilon{=}1.57)$, which follows from an extrapolation of $M(\Delta^{++}/\rho,\omega)$ and $M(\Omega^-/\phi)$. He assumes the validity of the "equal-spacing" rule for the masses of all J=3/2 baryons, which gives the possibility to interpolate between *ccc*, *bbb*, and ordinary baryons. The masses of *ccq* baryons with J=1/2 were estimated relative to the central J=3/2 value. The *cc* diquark is a colour antitriplet with spin S=1, leading to J=1/2 or J=3/2 for the baryon. The magnitude of the splitting is inversely proportional to the product of the masses of the like and unlike quarks. These are taken as 300 MeV for u and d, 450 MeV for s, 1550 MeV for c, and 4850 MeV for b. The equal spacing rule for J=3/2, with n_i the number of quarks of a given flavour, then is [4]:

$$M = 1/3[1232(n_u + n_d) + 1672n_s + 4955n_c + 14852n_b]. \qquad (B.1)$$

This equation for M(*ccq*) gives results close to those of Fleck and Richard [5,118], who also estimate the tetraquark mass. Fleck and Richard have shown that *ccq* and $cc\bar{u}\bar{d}$ masses near 3.7 GeV are consistent with expectations from QCD mass inequalities.

The estimates lead to the following masses for the $J^P = (1/2)^+$ states[4,5]: *(ccs)* 3.8 GeV, *(ccu)* 3.7 GeV, *(ccd)* 3.7 GeV, $(cc\bar{u}\bar{d})$ 3.6 GeV.

Lifetimes of ccq baryons and tetraquarks

The Ξ_{cc}^{++} and Ω_{cc}^{+} decays should be dominated by spectator diagrams, with lifetimes roughly half of the D^0 or Ξ_c^+, about $200 fs$. For Ω_{cc}^+ decay, Fleck and Richard [118] suggest that positive interference will occur between the s-quark resulting from c-decay and the existing s-quark in Ω_{cc}^+. Its lifetime would then be less than that of Ξ_c^{++}. Bjorken [4] and also Fleck and Richard [118] suggest that internal W exchange diagrams in the Ξ_{cc}^+ decay could reduce its lifetime to roughly half the lifetime of the Λ_c^+, around $100 fs$.
T decay is governed by D^{*+} decay, therefore its lifetime should be much shorter. These estimates are consistent with the present understanding of charmed hadron lifetimes [122,133–135].

Production cross section of ccq baryons

For an experiment on *ccq* baryons, one can envisage the use of pion, proton or Σ^-beams. Pion beams are more effective in producing high-x_F D$^-$ mesons, compared to Σ^-beams. Baryon beams probably are more effective than pion beams in producing *ccq* and *cqq* baryons at high x_F. In the following, we will present estimates of *ccq* production cross sections.

A very simple estimate is:

$$\sigma(ccq)/\sigma(cqq) \approx k \cdot [\sigma(c\bar{c})/\sigma(in.)] \approx k \cdot R. \qquad (B.2)$$

Here, $\sigma(c\bar{c})$ is the charm production cross section, roughly 25 μb; $\sigma(in.)$ is the inelastic scattering cross section, roughly 25 mb; thus $R \approx 10^{-3}$ [136]. The factor k describes the probability that the two c-quarks produced join in the same hadron. The estimate for R is half-way between two experimental results on double charm production: $\sigma(D\overline{D}D\overline{D})/\sigma(D\overline{D}) \approx 10^{-2}$ [137] and $\sigma(\Psi\Psi)/\sigma(\Psi) \approx 3 \times 10^{-4}$ [138]. Note the suppression factor k does not appear in either ratio. In the absence of calculations of k, we assume $\sigma(ccq)/\sigma(cqq) = 10^{-2} - 10^{-4}$ and obtain, with $\sigma(cqq) \approx 10\mu b$ per nucleon, an estimate of $\sigma(ccq) = 0.1 - 10$ nb per nucleon.

Kisselev et al. [6] calculated cross sections for double charm production at an electron-positron collider with $\sqrt{s}$= 10.6 GeV. They found $\sigma(ccq)/\sigma(c\bar{c}) = 7. \times 10^{-5}$. This work established several important calculational steps. The same authors obtained an estimate of $\sigma(ccq) \approx 10$ nb/N in hadronic production at $\sqrt{s}$= 100 GeV.

Predictions for double charm production are also possible in the framework of the intrinsic charm picture of Brodsky and Vogt [9]. These authors have suggested that there may be significant $c\bar{c}$ components in the proton wave function, as much as 1-3%. These percentages imply $cc\bar{c}\bar{c}$ components at the level $10^{-4} - 10^{-3}$. Such large intrinsic charm probabilities would lead to enhanced ccq production, as the cc pairs are available preformed with as many as one-third in the required anti-triplet combination, and can be released in hard processes. However, recent experiments [139] on diffractive production of $D\bar{D}$ pairs with a proton beam have claimed an upper limit of only 0.2% on the intrinsic charm component in the proton wave function.

We can also apply the thermodynamical model to the production of hadrons with mass M in central collisions [140]:

$$d\sigma/dp_t^2 \propto exp(-B\sqrt{M^2 + p_t^2}) \qquad (B.3)$$

To illustrate the universality of B, we evaluate it for a few cases. Data on Λ_c^+ and Ξ^0 production can be fitted as $exp(-bp_t^2)$, with b=1.1 and 2.0 (GeV/c)$^{-2}$, respectively [141,142]. Since M$\gg$ p_t, we have B$\approx$2Mb and thus B=5.0 and B=5.3 (GeV/c)$^{-1}$, respectively. Data on inclusive pion production can be fitted as $exp(-bp_t)$. Since M is small, we have B = b = 6 (GeV/c)$^{-1}$ [143]. This agreement for production of states with very different masses and flavours encourages us to use the above formula with an additional factor for spin statistics, for an estimate

$$\sigma(ccq)/\sigma(D) \approx (2J+1)\cdot exp[-5[M(ccq)-M(D)]] \approx (2-4)\cdot 10^{-4} \qquad (B.4)$$

With $D\overline{D}$ production cross sections of about 20 μb at SPS energies, we obtain $\sigma(ccq) \approx (0.4-0.8)$ nb per nucleon. The same estimate holds for the T production cross section.

Decay modes and branching ratios of *ccq* baryons

The semileptonic and nonleptonic branching ratios of ccq baryons have been estimated by Bjorken [4] in unpublished notes of 1986. He uses a statistical approach to assign probabilities to different decay modes. He first considers the most significant particles in a decay, those that carry baryon or strangeness number. Pions are then added according to a Poisson distribution. The Bjorken method and other approaches for charm baryon decay modes are described by Klein [124]. Savage and Springer [120] examined the flavour SU(3) predictions for the semileptonic and nonleptonic ccq weak decays. They give tables of expected decay modes, where the rates for different modes are given in terms of a few reduced matrix elements of the effective Hamiltonian. In this way, they also find many relationships between decay rates of different modes. Savage and Springer discuss the fact that the SU(3) predictions for the decay of the D-mesons can be understood only by including the effects of final state interactions [144]. They suggest that FSI effects should be much less important for very charming baryons (ccq) compared to charmed mesons.

The c decays weakly, for example by $c \rightarrow s{+}u\bar{d} + \mathrm{n}(\pi^+\pi^-)$, with n=0,1, etc. In that case, for example, $ccs \rightarrow css + \pi^+\pi^+\pi^-$. The event topology contains two secondary vertices. In the first, a css baryon and 3 pions are produced. This vertex may be distinguished from the primary vertex, if the ccs lifetime is sufficiently long. The css baryon now propagates some distance, and decays at the next vertex, in the standard modes for a *css baryon*. The experiment must identify the two secondary vertices.

We describe some decay chains considered by Bjorken [4]. For the Ξ_{cc}^{++}, one may have $\Xi_{cc}^{++} \rightarrow \Sigma_c^{++}K^{*0}$ followed by $\Sigma_c^{++} \rightarrow \Lambda_c^+\pi^+$ and $K^{*0} \rightarrow K^-\pi^+$. The $\Lambda_c^+\pi^+K^-\pi^+$ final state was estimated to have as much as 5% branching ratio. Bjorken also estimated 1.5% for $\Xi_{cc}^{++} \rightarrow \Xi_c^+\pi^+$ and 1.5% for $\Omega_{cc}^+ \rightarrow \Xi_c^+\pi^+K^-$. He finds that roughly 60% of the ccq decays are hadronic, with as many as one-third of these leading to final states with all charged hadrons. The decay topologies should satisfy a suitable charm trigger, with reasonable efficiency. The remaining 40% are semi-leptonic decays. However, with a neutrino in the final state, it is not feasible to obtain the mass resolution required for a double charm search experiment.

Decay modes and branching ratios of the tetraquarks

One can search for the decay of T $\rightarrow$ π D D, or T $\rightarrow$ γ D D [145]. The pion or gamma are emitted at the primary interaction point, where the D* decays immediately. The two D mesons decay downstream. The D* decay to π-D is more useful for a search, since the charged pion momentum can be measured very well. One can then get very good resolution for the reconstruction of the T mass. For the gamma decay channel, the experimental resolution is worse. There will therefore be relatively more background in this channel, since the gamma multiplicity from the target is high, and one must reconstruct events having two D mesons, with all gammas.

Signal and background considerations

High energies are needed for studies of baryons with high mass and short lifetime, in order to obtain the Lorentz boost necessary for the separation of secondary and primary vertices. The Lorentz factor for a particle produced at x_F=0 with beam of momentum p_{in} is $\gamma = \sqrt{p_{in}/(2M_N)}$. For a CERN experiment with $p_{in} \approx 400$ GeV/c, this corresponds to $\gamma \approx 15$ and a momentum of 55 GeV/c for the ccq. The mean decay length then would be $450\mu m$ for a lifetime of 100 fs.

One can identify charm candidates by requiring that one or more decay particles from a short-lived parent have a sufficiently large impact parameter or "transverse miss distance" S relative to the primary interaction point. S is almost Lorentz-invariant. It is calculated by extrapolation of tracks that are measured with a high resolution detector close to the target. Its mean value is $S \approx \pi c\tau/2$. For example, Λ_c with $c\tau \approx 60\ \mu m$ should have S $\approx 90\mu m$. The E781 on-line filter cut requires a track with momentum p>15 GeV/c and S>$30\mu m$ [114]. This cuts suppresses events with no secondary vertex. With a vertex detector with 20 micron strips, the E781 resolution in S is about 4 μm for very high momentum tracks [146]. Owing to multiple scattering, the resolution deteriorates to about 9 μm for tracks of 15 GeV/c momentum, and becomes even worse for lower momenta. Decreasing resolution on S implies increasing backgrounds, since the S-cut no longer adequately separates charm decay tracks and tracks from the primary interaction vertex. The background triggers are not only caused by tracks from the primary vertex, but also by tracks from the decays of the associated anti-charm hadrons. A trigger requiring to see two related secondary vertices may have a significantly lower background level.

Some bqq production and decay, with two secondary vertices, may also be observed in the proposed experiment. The *bqq* and *ccq* events may be distinguished by the larger *bqq* lifetime, and the higher transverse energy released in the *b* decay. It is not the aim of this experiment to study bqq baryons. Experiments at CERN gave only a small number of reconstructed *bqq* baryons, at a centre of mass energy around 30 GeV [115].

The proposed experiment considers using a multiplicity jump trigger (see section B.5), which exploits the increase in the number of charged tracks following a charm decay. Such a trigger for high rate beams has not yet been used in a complete experiment, and still requires research and development. Backgrounds can come from secondary interactions in the targets and in the multiplicity jump detectors following each target. Also, gamma rays from a primary interaction may convert afterwards to electron-positron pairs, and falsely fire the trigger. If the rejection ratio of such non-charmed events is not sufficiently high, the trigger may not be sufficient to reduce the accepted event rate to manageable values. This trigger would be sensitive to events with x_F> -0.1, and therefore has effectively an "open" trigger x_F-acceptance. Most of the charm events accepted will then be associated with charm mesons near x_F=0, since these dominate the cross section in hadronic processes. In events with a ccq produced, the decay of the *ccq* to a singly charmed hadron or the decay of that charmed hadron may fire the trigger. The event also has two anticharmed quarks, associated with charmed hadrons, and these may also fire the trigger. The multiplicity jump trigger could be supplemented by a momentum condition trigger P $>$ 15 GeV/c, similar to this requirement in E781, which could enhance the high-x_F acceptance, and give higher quality events.

The target design is important. To achieve a high interaction rate and still have small multiple scattering effects, one may choose five 500μm thick Copper targets, separated by 150μm thick silicon counters. The total target thickness is limited to 0.025 interaction lengths in order to keep multiple scattering under control. A longitudinal vertex resolution of 200-300 μm is necessary to identify the target segment associated with a given interaction. The knowledge of the target segment allows the on-line processor to reconstruct tracks, and identify a charm event. The tracking detectors would then be placed as close as possible to the targets, to achieve the best possible transverse miss-distance resolution. The optimum target design and thickness for double charm requires study via Monte Carlo simulation.

One may require separation distances of secondary from primary vertices of $\approx$ 1-4 σ, depending on the backgrounds. The requirement for two charm vertices in ccq decays may reduce backgrounds sufficiently, so that this separation distance cut is less important than in the case of cqq studies. For a lifetime of 100 fs, with a laboratory lifetime boost of 15, the distance from the production point to the decay point is around 450 μm. E781 can attain roughly 300 μm beam-direction resolution for x_F =0.2, with a 650 GeV beam, and 20 μm pitch silicon detectors. For lower x_F events, the resolution deteriorates due to multiple scattering, and there is little gain in using narrower strips. The proposed experiment aims to achieve $\leq$75μm resolution for the higher x_F events.

Signal and background and trigger simulations and target design development work are in progress.

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