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ADDENDUM 1

Common Muon and Proton Apparatus for Structure and Spectroscopy

The COMPASS Collaboration

The COMPASS Collaboration

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Contents

1 REFEREES' QUESTIONS

This addendum answers the questions we have received from our referees, P. Bagnaia, F. Close, B. Gavela, and R. Landua.

In this section we list the questions. In section 2 we answer the questions on physics. In section 3 we answer the questions on the experimental techniques.

1.1 QUESTIONS ON PHYSICS

1. $\Delta G/G$

What is the kinematical range in the gluon momentum fraction effectively covered by this experiment? That is, what is the range over which the result will come out averaged?

It would be convenient a more detailed comparison with RHIC concerning the above question, accuracies, and possible schedule.

2. Charmed Hadrons

Could we have more precisions on masses, semileptonic decays and lifetimes, as compared with other experiments, such as Selex, B-factories, etc.?

For instance, up to what point you would say that an improvement of 10 in statistics would translate into qualitatively new knowledge?

Could you please point out more precisely which discoveries are foreseeable, which will not be done before and/or better elsewhere?

3. Diffractive production.

If there is a K partner to the $\pi(1.8)$ (fig. 4.6) at a mass of about 1.9 to 2 GeV, decaying into $K\pi\pi$, will you have sensitivity to this?

Up to what mass will you be able to separate Primakoff excitations from diffractive production? In particular, is it possible to extract an electromagnetic excitation strength for the $\pi(1.8)$? what essential improvements are anticipated by Compass relative to the current Protvino set up for this particular state (i.e., will you improve the information on the question of whether there is a rho omega decay, and if so whether this is from the same $\pi(1.8)$ or from a different state with 0^{-+} quantum numbers)?

1.2 QUESTIONS ON THE EXPERIMENTAL SETUP

1. Muon target + magnet

A detailed plan on the polarised target (+ solenoid), as a function of time, including the costs of the different parts, and the laboratory responsibilities in following the construction, testing the pieces and assembling them.

2. Tracking chambers

A more detailed description of the chambers, especially an evaluation of the performances required by the physics (ex. resolution, calibration and alignment errors necessary to get $\Delta M = 10$ MeV in $D^\circ \rightarrow K\pi$). Details on the calibration strategy and alignment, especially for the consequences in the chamber design. An assessment on the possibility to make prototypes. A plan on the manpower necessary to build, calibrate and operate the chambers, including laboratory responsibilities.

3. RICH

Comments on prototypes (i.e. what has to be tested each year), plans on the availability of manpower/resources for construction, including lab. responsibilities. Comments on the possibility of replacing RICH1 with threshold Cherenkov(s) (maybe keep this possibility as a possible contingency?).

4. Muon walls

Comments on the choice of the detector techniques, i.e. performances required by the physics vs. detector features, costs and available resources and expertise. Time scale and responsibilities in the construction.

5. Calorimeter Readout

ADC resolution: Assuming a 12-bit dynamical range (instead of 13-bit), what would be the resulting deterioration (e.g. in mass resolution, S/B)? Would there be a noticeable impact on the physics results, and –if yes– on which results?

6. Silicon Strips

1. The foreseen parameters for the target Silicon detector is 150 μm thickness, 10 μm strip distance, and 40 MHz readout clock. Have there been prototype tests with such a detector and readout system, and what are the results? In particular, what is the signal-to-noise for minimum ionising particles?

2. By how much would a 20 or 10 MHz readout clock increase the deadtime for a) charm semileptonic decay, b) search for double-charmed baryons, c) central production?

3. After what time would it be necessary to change the target Silicon detectors, when running at full proton intensity?

7. Data Acquisition

1. What type of DAQ programs will be used (CERN-provided, self- written, others)?
2. Which real-time operating system will be used (OS-9, Lynx, others)?
3. What type of CERN support is expected?

8. Offline Analysis - Scheme

Using the charm spectroscopy setup, COMPASS will write about 50 DLT-7000 tapes (30 GB each) per day, over a period of 100 days or more. Could you describe:

1. How the calibration of the various detector components will be done (for each tape? for every n'th tape?)? Is "online calibration" (like NA48) needed?
2. Do you foresee central data recording, or local mounting of tapes?
3. Will the processing farm be at CERN?
4. If so, will the data be stored at the farm or centrally?
5. How the tapes will be processed (how many processors, tape stations, operators)?
6. If the processing is done at CERN: what will be the load on the CERN network? Will there be any central facilities used? If yes, which ones?
7. With respect to the WA89 or WA102 reconstruction speed, a factor of about 1000 has to be gained. How will that be achieved?

2 ANSWERS TO THE QUESTIONS ON PHYSICS

2.1 $\Delta G/G$

Questions of the Referees:

What is the kinematical range in the gluon momentum fraction effectively covered by this experiment? That is, what is the range over which the result will come out averaged?

It would be convenient a more detailed comparison with RHIC concerning the above question, accuracies, and possible schedule.

2.1.1 Measurement of $\Delta G/G$ in COMPASS

Figure 2.1a shows the gluon momentum fraction η from our Monte Carlo studies of the open charm production by photon-gluon fusion (see par. 3.1.2 of the COMPASS proposal for a description of Monte Carlo event generators) integrated over the quasi-real photon energy spectrum ν from 35 to 85 GeV. The input unpolarized gluon distribution is the Duke–Owens set 1.1 and $m_c = 1.5$ GeV/c^2. Other distributions, like the $MRSA$, give similar spectra. The η distribution is basically a convolution of the unpolarized gluon distribution with the elementary photon-gluon fusion cross section and the quasi-real photon spectrum. In the ν range of 35–85 GeV this distribution is peaked at $\eta \sim 0.14$, it starts at $\eta_{min} = 4m_c^2/2M_p\nu < 0.07$ and extends over $\eta > 0.4$, with a good coverage in the $0.08 < \eta < 0.35$ region. According to recent parametrizations, $\Delta G(\eta)$ has a maximum in the range of our proposed measurement.

With increasing ν, η decreases; by splitting the covered ν interval in smaller ν bins (or using a higher beam energy as mentioned in the proposal) we cover different η regions. Figure 2.1b shows the η distributions for two different ν bins of 30–45 GeV and 75–90 GeV, respectively. It can be seen how the low ν bin covers the *high* η region and is peaked at $\eta \sim 0.22$ while the high ν bin covers the *low* η region and is peaked at $\eta \sim 0.10$. By splitting our ν interval, for instance into 4 ν bins, the measurement error on the A_{LL} asymmetry for each single ν bin will increase roughly by a factor of 2, each ν bin having now a $\delta A_{LL} \sim 10$ %. Such an analysis will also allow us to determine approximately the

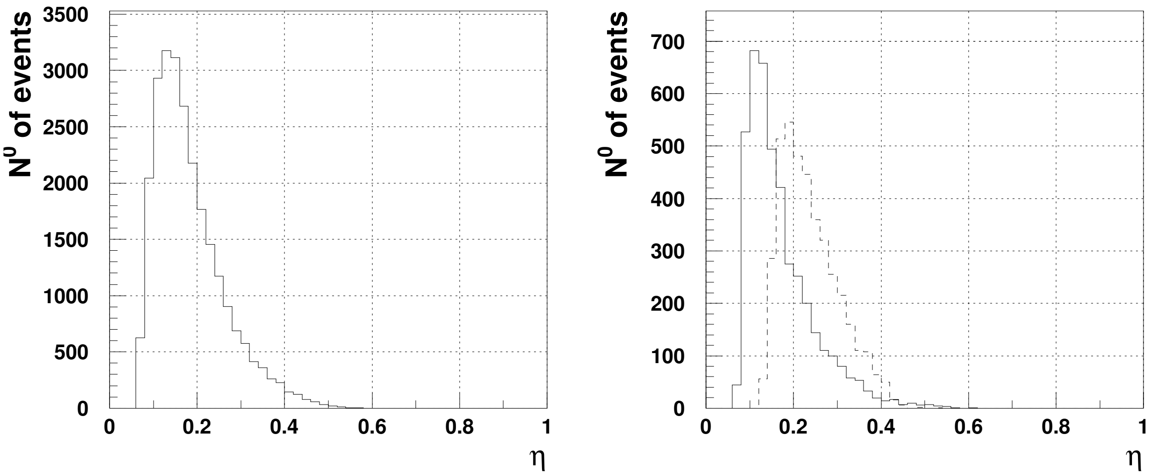

Figure 2.1: η distribution of gluons in open charm production: a) $35 < \nu < 85$ GeV; b) dashed line $30 < \nu < 45$ GeV, solid line $75 < \nu < 90$ GeV.

$\Delta G(\eta)$ shape in this η range.

It has to be added that the error estimates reported in the proposal were based on the $D^0 \to K^- + \pi^+ + c.c.$ decays only (with and without D^* tagging). We can expect a considerable improvement on the A_{LL} measurement including other D decay channels, giving δA_{LL} smaller than 4 %, and hence a better sensitivity on $\Delta G/G$.

2.1.2 Measurement of $\Delta G/G$ at RHIC

RHIC will be primarily a collider for heavy ion physics; a spin physics program has been recently approved and involves the acceleration and storage of polarized proton beams and experiments with the two major detectors STAR and PHENIX. This program will run during the calibration proton runs for the heavy ion program (20 % of the running time per year).

Several measurements to access the polarized gluon and sea quark distributions are proposed. The measured asymmetries are a convolution of the unknown polarized parton distribution functions in both colliding protons with the elementary scattering asymmetry summed over the different subprocesses that contribute to the observed events. The extraction of the polarized gluon distribution is then not straight forward and adds some uncertainty to the extracted results.

To access ΔG the theoretically cleanest process proposed at RHIC is the prompt–γ production. In symbols this reads:

$$A_{LL} \cdot d\sigma \sim \sum_a \int \Delta q_a \cdot \Delta G \cdot d\Delta\sigma(q_a + g \to \gamma + X) \, .$$

In our proposed experiment, the asymmetry for the open charm photo–production reads

$$A_{LL} \cdot d\sigma \sim \int \Delta G \cdot d\Delta\sigma(\gamma + g \to c\bar{c} + X) \, .$$

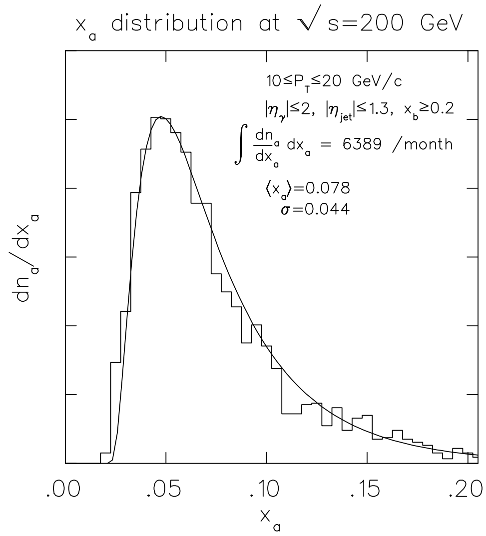

Figure 2.2: The gluon momentum fraction covered in prompt-γ production.

Thus the extraction of ΔG requires different theoretical inputs in the two proposed experiments (RHIC and COMPASS), which can be regarded as complementary. In particular, to achieve good sensitivity on ΔG in RHIC measurements, better knowledge of polarized valence quark distribution functions is essential. The measurement of Δu and Δd, however, will not be accessible at RHIC from the presently proposed measurements, and will be taken from existing or forthcoming semi-inclusive deep inelastic scattering experiments, like COMPASS, where we will probe to a high accuracy also the polarized valence and sea quark distribution functions.

In the following we first describe the prompt–γ and the jet production. Then we compare the time scale and the experimental methods adopted, and finally we summarize our conclusions.

Inclusive prompt–γ production

The single inclusive prompt–γ production is the clearest signal for accessing the gluon polarization. It is dominated by the *up quark–gluon* scattering. In order to measure $\Delta G(\eta)$, both the prompt–γ and the *away–side* jet must be detected in coincidence so that the kinematics of the incoming partons can be approximately calculated, and in particular one must select events with Bjorken x_q of the *up* quark larger than 0.2–0.3 so that $|\Delta u(x_q)|$ is sizable. The gluon spectrum at $\sqrt{s} = 200$ GeV, $10 \leq p_T(\gamma) \leq 20$ GeV/c and $x_q \geq 0.2$ is shown in Figure 2.2 [2]. It is peaked around 0.06, starts at 0.03 and doesn't extend much above 0.1. This η range is lower than the one covered in COMPASS, and hence the two experiments will probe the gluon polarization over complementary η intervals. The Q^2 scale in COMPASS is set by m_c and $Q^2 \sim 10$ GeV^2; for the high p_T prompt–γ and jet events at RHIC the scale is set by the prompt–γ or jet p_T and Q^2 about a few 100 GeV^2. A potential uncertainty on the measurement comes from the role of NLO corrections to the prompt–γ production as well. These corrections were calculated for the unpolarized case and are not small.

There are some discrepancies on the reported accuracies for this measurement, in particular concerning the study of systematic effects. The reported accuracies range from $\delta A_{LL} \sim 0.03$ [3] to $\delta A_{LL} \sim 0.01$ and less [4] at $\sqrt{s} = 200$ GeV. The RHIC high luminosity option ($8 \times 10^{31}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ at $\sqrt{s} = 200$ GeV, 10 times higher than the original RHIC design luminosity) was assumed for these estimates. These measurement accuracies will lead to a sensitivity on $\Delta G/G$ ranging roughly from 0.15 to 0.05. Also a precise knowledge of $|\Delta u(x_q)|$ is essential. In the present estimates it was assumed that $|\Delta u(x_q)|/u(x_q) = 0.4$ at $x_q = 0.2$ with infinite precision, while recent SMC results show still large uncertainty on this quantity for $x_q > 0.2$. Taking into account also this uncertainty the sensitivity on $\Delta G/G$ will decrease.

Jet production

An other proposed reaction is the study of inclusive single and di-jet production. The cross sections of these processes are large. These measurements, however, are difficult to analyze, since different partonic sub-processes contribute, like the GG fusion, qG scattering and $q\bar{q}$ annihilation and the sensitivity on the gluon polarization is not yet well established. Typically the GG process dominates at lower p_T's and covers the low η region ($0.01 < \eta < 0.1$). Also for this process the detection of both jets is important to calculate approximately the kinematics of the incoming partons and a large acceptance is then required. A sensitivity on $\Delta G/G$ from the study of di-jet events 3 times better than for the prompt–γ plus *away–side* jet production has been reported [4]. However, to our knowledge, no detailed study for this process, including for instance systematic effects, as extensive as the one for the prompt–γ plus *away–side* jet, has been yet presented.

Time scale

In the RHIC spin proposal [1] the following time scale is foreseen:

- in 1999 commissioning and setting up of the accelerator with heavy ion beams;
- in 2000 first polarized proton beams and accelerator studies.

One can expect in the year 2001 the completion of upgrades in STAR and PHENIX for spin physics and first physics runs with polarized proton beams at $\sqrt{s} = 200$ GeV. There might be some contingency to this schedule. The quoted precisions at RHIC are based on a 100 days operation with polarized protons which will require at least 2 years of data taking (10 weeks/year - time sharing with the heavy ion program) for the completion of the first round of measurements at $\sqrt{s} = 200$ GeV. First results can be expected then in the year 2003 or later due to the complexity of the measurements and analysis. In COMPASS the year 2001 will be fully dedicated to the proton spin program (measurements will be also taken in the year 2000) and significant results can be expected by the year 2002.

Experimental method

The experimental technique in COMPASS is well established. Experiments with polarized muon beams and polarized targets have been active at CERN during the last 20 years. On the other hand, the acceleration of polarized beams to high energy (100–250 GeV at RHIC), the accumulation of polarized protons in storage rings at 100 GeV and more, the precise measurement of their polarization and the monitoring of beam polarization fluctuations are far from trivial tasks to be achieved. Encouraging results were obtained with the use of *siberian snakes* at lower energies, but additional studies and developments are needed before they become a fully operative technique.

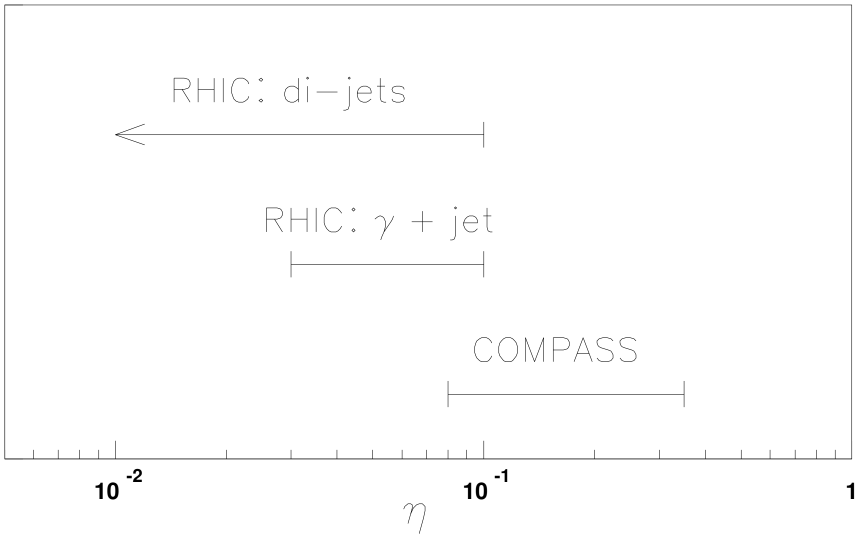

Figure 2.3: Comparison of gluon momentum fraction intervals covered in different measurements.

The experimental setup proposed in COMPASS is a dedicated apparatus, capable of several different measurements, based also on a long experience in this physics sector. The STAR and PHENIX detectors at RHIC are experiments designed for heavy ion physics and they need substantial upgrades to meet some of the requirements for the study of spin effects in polarized proton collisions. Their small acceptance limits the accessible kinematical region. In particular the PHENIX acceptance, with a coverage of $|y| < 0.7$, appears too small for the prompt–γ plus *away–side* jet studies. Both experiments will measure jets with electromagnetic calorimeters only, which rises problems on the containment of hadronic showers and precise energy determination. The high luminosity option is essential to obtain sufficient event yields.

Conclusions

In summary, RHIC will access ΔG in the prompt–γ plus *away-side* jet channel at $\eta \sim 0.06$ over the interval $0.03 < \eta < 0.1$ with a sensitivity on $\Delta G/G$ of about 0.05–0.1. The interpretation of other channels, like the inclusive prompt–γ (no *away-side* jet tagging), inclusive single jet and di-jet events, is more delicate. The η region covered by RHIC (0.03–0.1) is lower than the η interval covered in COMPASS (0.08–0.35). In Figure 2.3 the η intervals covered in different measurements are compared. At RHIC the Q^2 scale is about a few 100's GeV^2 and in COMPASS $Q^2 \sim 10$ GeV^2. The expected accuracy at RHIC for the prompt–γ plus *away-side* jet is similar to the one expected in COMPASS in the open charm process. In any case a deeper discussion of systematic effects at RHIC is desirable, before any final conclusion on that can be drawn. COMPASS can provide significant results on the proton spin structure already in 2002, while RHIC could most likely come up with first results not before the year 2003.

It is clear that RHIC as a polarized collider will have a far reaching agenda and impact on spin physics for many years to come. However, on the short and medium time scale, COMPASS is likely to provide sooner crucial answers on the specific questions of the proton spin structure.

References

[1] M.E. Beddo *et al.*, Proposal on Spin Physics Using the RHIC Polarized Collider, April 1992.

[2] M.E. Beddo *et al.*, Report ANL-HEP-TR-92-59, STAR Note 77.

[3] M.E. Beddo *et al.*, Proposal on Spin Physics Using the RHIC Polarized Collider Update, 1993.

[4] D. Underwood, talk at the Workshop on the Prospects of Spin Physics at HERA, DESY Report, DESY 95-200, page 49.

2.2 PHYSICS WITH CHARMED HADRONS

Question of the Referees:

Could we have more precisions on masses, semileptonic decays and lifetimes, as compared with other experiments, such as Selex, B-factories, etc.?

For instance, up to what point you would say that an improvement of 10 in statistics would translate into qualitatively new knowledge?

Could you please point out more precisely which discoveries are foreseeable, which will not be done before and/or better elsewhere?

With the start-up of new experiments like E781 [1] and E831 [2] at FNAL, the continuation of CLEO [3] and BES and the arrival of Hera-B, BaBar and Belle at the turn of the century the field of charmed hadrons has become very competitive. In the following we will therefore try to evaluate the strengths of the newly proposed COMPASS experiment as compared to the other projects. This comparison is very difficult in those cases, where charm physics only represents a side product and no numbers are given in the proposals of the relevant competitors.

2.2.1 Charm production studies

Owing to the very high rate charm production can be studied at 3-4 different energies (100 - 450 GeV/c) using 2-3 different projectiles (π, K, p). No other single experiment has yet performed such a systematic investigation. E781 will produce cross section measurements for π and Σ^- at 600 GeV/c. It is not clear, how well they will do on charm correlation due to the limited acceptance at low values of Feynman x. We thus feel that no direct competition has to be discussed in this field.

2.2.2 Doubly charmed baryons

This field will most probably stay in the domain of fixed target experiments since not enough energy is available in the decay of a B-meson (the minimal decay chain would be B$\rightarrow$ $\Xi_{cc}\overline{\Lambda_c}$). The observation power is directly related to the total number of charm events observable. Baryon beams may have an advantage over π or γ beams. The use of a hyperon beam by E781 probably gives no advantage over the use of a proton beam. However, the beam energy could be of importance (E781 has 600 GeV/c as compared to 280 GeV/c for COMPASS in its first stage). Since COMPASS aims at 10 times higher statistics as compared to E781 and the projected yields are of the order of 50-500 reconstructed events, it seems unlikely that E781 could study these objects first. Even if a first observation were done by E781 (which would imply a relatively high production cross section) this would in turn imply a richer physics program in this field for COMPASS. In addition the COMPASS target detector should be better suited to disentangle complex event topologies.

2.2.3 Semileptonic charmed baryon decays

As mentioned in detail in the proposal, the study of semileptonic decays of charmed baryons is intimately connected to the question of event purification. CLEO II has observed about 700 Λ_c^+ decays. With the start-up of CLEO III in 1999 the total statistics available from CLEO will probably go up by about a factor 10 by the year 2001 leading to about 7000 decays. COMPASS will observe a similar number in one run of 65 days. For Ξ_c, the currently existing sample from CLEO II contains about 40-50 events which may thus go up to about 400. It is currently difficult to predict the production rate for Ξ_c in proton beams but estimates lead to a total sample of about 600-1000 reconstructed events. The advantage of COMPASS is an acceptance almost independent of the momentum transfer q^2 involved while CLEO has almost no acceptance for small values of q^2, where predictions of form factor ratios leading to decay asymmetries are safest. It should be noted that identification of s.l. decays is difficult and will be subject to very different systematic errors in CLEO and COMPASS.

Another competitor in this field is E781. Aiming at a total charm yield about a factor 10 down of COMPASS they might have an advantage for charmed hyperons due to the use of a hyperon beam. No μ identification is foreseen in E781 but a TRD in conjunction with an electromagnetic calorimeter should give very good electron identification. This information, however, will not be used in the trigger and the use of electrons might be less favourable than the use of of μ owing to bremsstrahlung losses. No rate estimates were given in the E781 proposal.

2.2.4 Leptonic decays

Leptonic decays of D_s are currently searched for in CLEO II and BES who have reported the observation of 15 $\pm$ 3.2 events and 3 events, respectively. No observation of leptonic decays of D-mesons has yet been reported, owing to the smaller branching fraction. We may expect approximately 150 D_s decays from CLEO III by the year 2001. Also E831 will search for such decays. Like COMPASS their technique involves a D-tagging by detection of the π from the decay $D \rightarrow D\pi$. Since the p_T of the μ is not measured in their set up, they must employ other techniques to discriminate against backgrounds from semileptonic decays. The rejection powers and remaining backgrounds have not been estimated. Thus, no expected numbers are quoted concerning the achievable precision. The design goals for COMPASS are again a higher statistics by about a factor 10 as compared to CLEO/E831. In addition, the use of a target detector allowing the detection of the decay kink of the charged meson, should lead to a clean sample of such decays. For this field high statistics is only part of the requirements, the other being a clean identification of the decay topology. Both conditions could also be fulfilled at a τ/charm factory.

2.2.5 Discoveries

Many speculations have been done concerning hints for physics beyond the standard model. One of the promising areas, where such physics could be studied, is the decay of charmed mesons. D-mixing or CP-violations are predicted within the standard model to be very low ($r_{mix} \leq 10^{-8}$ and $\alpha_{CP} \leq 10^{-3}$, respectively) [5] and will most likely remain unobserved. However, this drawback could be turned into a virtue since no standard model background is expected for measurable unexpected effects.

Table 2.1 shows some of the best current limits on rare decays or other phenomena. For COMPASS, we estimate the limits attainable on the basis of 3 10^6 reconstructed D^0-

Decay	current limit	experiment
CP-Violation $D^0 \to K^+K^-$	$-11\% \leq \alpha_{CP} \leq 16\%$	E791
CP-Violation $D^+ \to K^{*0}K^+$	$-33\% \leq \alpha_{CP} \leq 9.4\%$	E791
CP-Violation $D^0 \to K^+K^-\pi^+$	$-14\% \leq \alpha_{CP} \leq 8\%$	E791
D^0-$\overline{D^0}$ mixing	3-4 10^{-4}	E691/E687
$D^0 \to \mu^+\mu^-$ (FCNC)	8. 10^{-6}	WA92
$D^0 \to e^+\mu^-$ (LFNV)	4.1 10^{-5}	E691
$D^0 \to \pi^-e^+e^+$ (LNV)	1.7 10^{-4}	E687

Table 2.1: Current limits on some rare decays channels

decays and about 1-2 10^6 D^+ decays (the same number of CP conjugate states should be reconstructed). It should be noted that the limits on the rare decays decrease with 1/N only in the case of no background. When background becomes important upper limits only decrease with $1/\sqrt{N}$. At this stage, possible backgrounds are difficult to estimate. Most limits may therefore be regarded as lower bounds on those limits.

D^0-$\overline{D^0}$ mixing. Mixing can be observed in different ways. Certainly the cleanest way is flavour tagging by means of full reconstruction of the associated D-meson. We estimate that we may detect mixing if r_{mix} is $\geq 10^{-4}$.

Higher statistics may be obtained if c-flavour tagging is performed by tagging of the decay $\pi^\pm$. However, this method is limited by backgrounds from double Cabibbo suppressed decays (DCSD) which may in part be reduced by observing the time evolution of the D-decays. Limits which may be achieved are of the order 10^{-3} ($1/\sqrt{N}$ behaviour) - 10^{-6} (1/N behaviour).

Competing experiments are E831 with about 1/5-1/10 of the expected COMPASS statistics but with the advantage of cleaner events (γ-production). CLEO III and BaBar will have similar discovery potentials with BaBar expecting about 10^7 D's of each kind produced in total. Their estimated sensitivities to mixing are in the order of 10^{-4}-10^{-5}. Again, a τ/charm factory would probably do better than COMPASS or any B-factory.

CP-violation in the D-system. With standard model predictions of the order of 10^{-3} for direct CP-violation (assuming a favourably large FSI in Cabibbo suppressed decays) the D-system is the most unfavourable for standard model tests. Samples of $\geq 10^7$-10^8 reconstructed charmed D-mesons are needed to possibly observe a signal. According to various models, possible FSI giving raise to CP-violation might be enhanced. In particular the Penguin diagram, responsible for a possible effect in Cabibbo suppressed D-decays, might get contributions from exotic meson states like the $\pi(1800)$ [4].

Promising decay channels are $D^+ \to K^{*0}K^+$ and $D_s \to K^0\pi^+$, $K^{*+}\eta$' [5]. If no background is present, sensitivity in α_{CP} of about 0.005-0.01 may be achieved where

$$\alpha_{CP} = \frac{\Gamma(D)-\Gamma(\overline{D})}{\Gamma(D)+\Gamma(\overline{D})}$$

where Γ(D) is the decay rate for a given decay channel.

Competition again comes from E831 and B-factories. E831 expects a sensitivity of of about 2-3%, B-factories may be sensitive to asymmetries below 1% [6].

Indirect CP-violation is not discussed here since its observation is even less probable due to the low D^0-$\overline{D^0}$ mixing expected.

Rare or forbidden decays. Flavour changing neutral currents (FCNC) may be searched for in $D^0 \rightarrow \mu^+\mu^-$. This decay channel has very good acceptance and trigger efficiency in COMPASS. We should thus be sensitive to branching ratios of the order of 10^{-6} - 10^{-7}, one to two orders of magnitudes below current limits. A possible feed-through of $D^0 \rightarrow \pi^+\pi^-$ has to be taken into account and good π/μ separation has to be achieved.
$D^0 \rightarrow e^+\mu^-$ + cc (lepton number violation) is less favourable due to bremsstrahlung effects and the more difficult task of clean electron identification. Still, one can hope to obtain a similar improvement on upper limits as in $D^0 \rightarrow \mu^+\mu^-$.

Competition again comes from E831 which may reach limits of order 10^{-5}, about a factor 10 above COMPASS, and from the B-factories, which, however, do not quote any numbers. CLEO II has reported upper limits of $3{\cdot}10^{-5}$ and $2{\cdot}10^{-5}$ on $D^0 \rightarrow \mu^+\mu^-$ and $D^0 \rightarrow e^\pm\mu^\mp$, respectively. The tenfold increase in statistics expected by CLEO III for the year 2001 will decrease these limits to between $5{\cdot}10^{-6}$ and 10^{-5}, assuming the limits scale as $1/\sqrt{N}$ [7].

Other interesting decays which only can be studied with high statistics charm samples are ΔS=1 transitions in charmed strange systems. Such decays (e.g. $\Xi_c^0 \rightarrow \Lambda_c^+\pi^-$) should have branching ratios of about 10^{-3}. The topology of such a cascade decay resembles the decay of doubly charmed baryons with the exception that only one additional D-meson is present in the event. Again, excellent vertex resolution will be needed to sort out this decay and distinguish it from $\Sigma_c^0 \rightarrow \Lambda_c^+\pi^-$ which has a mass only 16 MeV/c^2 lower than Ξ_c^0. About 25-50 such events might be observed. The observation of this decay gives information complementary to ΔS=1 decays from hyperons and may shed more light on the ΔI=1/2 rule [8].

2.2.6 What to do with 10^7 reconstructed charmed hadrons?

For many years charm physics has suffered from a lack of precision and statistics. With the development of high resolution vertex detectors excellent signal/background ratios have been obtained for charmed hadrons. However, the use of more sophisticated tagging techniques needed for further purification of the event samples leads to a big loss in usable data. Thus large acceptance spectrometers and very high statistics are needed to study rare events including all the topics discussed above as well as simply charmed baryons.

Owing to its special target detector COMPASS can contribute to a high precision determination of baryon lifetimes and to the study of semileptonic decays. Although high statistics may seem of lesser importance for the lifetime measurement it is needed for a careful study of the systematics. The precision of the mass measurement of ground state hadrons is less related to statistics but to a good calibration of the complete apparatus.

Established states which will be observed in large quantities will serve as calibration lines over a large part of the available phase space.

Large statistics on the other hand is essential to observe broader excited states which might only be detected by their decay chain via intermediate charm resonances. Currently only one $3/2^+$ state is known for the baryons, no radially excited charmed meson has yet been observed. There is no guarantee that the foreseen COMPASS statistics will reveal many new states. However, at present we are still far from the situation in the light quark system where large data samples allow the use of complex analysis procedures revealing the nature of the observed states. A large increase in statistics should thus improve the situation in the charm sector considerably.

Concerning the spectroscopy of charmed strange baryons, E781 using a hyperon beam might do just as well as COMPASS and be ahead in time by about 4 years. No other experiment will probably reach the expected yields. If the advantage of a strange quark in the beam is clearly demonstrated COMPASS also can switch to a hyperon beam of intensities again about a factor 10 higher as compared to E781.

2.2.7 Comments on Hera-B

Owing to the very high interaction rate and unfriendly environment (fixed target experiment with 4 interactions/bunch crossing on average) Hera-B clearly is the most difficult experiment to be judged in this context. Although many more charmed hadrons should be produced in minimum bias interactions as compared to COMPASS the very stringent trigger conditions requiring a J/ψ in the final state suppress charm events from direct production. Owing to their short lifetime charmed baryons are difficult to detect, in particular in a high track multiplicity environment. The use of only one spectrometer magnet strongly reduces the acceptance for decays with hyperons in the final state. Therefore competition may only be important concerning charmed mesons. It should be noted that no estimates on the quality of charm physics could currently be obtained from this collaboration [9].

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2.3 PHYSICS WITH PRIMAKOFF REACTIONS AND THE $\pi(1800)$

Question of the Referees:

If there is a K partner to the $\pi(1.8)$ (fig. 4.6) at a mass of about 1.9 to 2 GeV, decaying into $K\pi\pi$, will you have sensitivity to this?

Up to what mass will you be able to separate Primakoff excitations from diffractive production? In particular, is it possible to extract an electromagnetic excitation strength for the $\pi(1.8)$? What essential improvements are anticipated by Compass relative to the current Protvino set up for this particular state (i.e., will you improve the information on the question of whether there is a rho omega decay, and if so whether this is from the same $\pi(1.8)$ or from a different state with 0^{-+} quantum numbers)?

2.3.1 Search for the strange partner of the $\pi(1800)$

In order to obtain a better understanding of the nature of the $\pi(1800)$, it might be important to search for a corresponding kaon state. Since we intend to also use a kaon beam, the same excitation mechanism for a high mass K-state could be used as for the production of the pion state in a pion beam.

We can tag the incoming kaon with the CEDARs and the final states via the spectrometer Cherenkov counters. Thus, technically, the discovery potential is present. However the much lower kaon fluxes in the beam will reduce the statistics.

After 3 months of running with a 300 GeV/c π/K beam we will collect an event sample of few (3-5) times smaller statistics as compared to the currently available statistics in the 3 π system and still an order of magnitude more than in the $K\pi\pi$ system. These studies can be done also at 160 GeV/c, where the K/π ratio is 0.1 and 0.075 for positive and negative beams respectively and K^+ intensities of up to $1{\cdot}10^7$/spill could be obtained [1]. In this case about 3 times larger statistics will be collected.

2.3.2 Primakoff vs. diffractive production

While the Primakoff cross section depends on the mass M of the produced meson as $1/M^3$ (at a given radiative width Γ), the diffractive one falls just as $1/M^2$. But the essential quantity allowing to distinguish the two processes is the differential cross section $\frac{d\sigma}{dt}$ where t is the four-momentum transferred squared. The Primakoff cross section reaches a maximum at $t=2t_{min}=2{\cdot}M^4/p^2$ (where p is the incoming meson momentum) and then falls rapidly as e^{-bt}/t (b=400 GeV^{-2} for lead). The peak height scales as p^2/M^7. The

[1] Using a block of Be or LiH a proton filter could be built taking advantage of the different p and K^+ total cross sections. If the proton background is reduced considerably (almost a factor 2) we can increase the beam intensity accordingly.

strong diffractive production falls off much smoother, as e^{-bt}. Thus, at low values of $|t|$ the Coulomb excitation should lead to an excess in the cross section which can be extracted by partial wave analysis (PWA) and the different dependence of the two processes on the nuclear mass number.

A good example to illustrate the problem are the a_1 Primakoff production measurements at p=200 GeV/c on lead and copper nuclei (e.g. π^+ A $\rightarrow \pi^+\pi^+\pi^-$ A). A rough estimate (valid within factor of 2-3) shows that $\frac{d\sigma_{Prim.}}{dt_{max}} = 6.4 \cdot 10^3$ mb/GeV^2 for Γ=640 keV [1] and M=1.25 GeV (on lead) while the diffractive cross section is about $4 \cdot 10^3$ mb/GeV^2. Thus the two processes are of the same order of magnitude and may still be separated by their different t-dependence.

For the higher masses the situation is more problematic. In the region of M=1.8 GeV at 300 GeV on lead the Primakoff peak height is only about 200 mb/GeV^2 assuming a typical radiative width of 100 keV. For the diffractive 3 pion cross-section we can expect a value of about 10^3 mb/GeV^2, 3-4 times lower than at M=1.3 GeV (extrapolated from VES data to a lead target and higher energies). Thus it is impossible to extract the Primakoff production of such a heavy object in this particular decay mode using the t-distribution alone. However, due to the difference in the population of the different helicity states at small values of $|t|$ by the two processes PWA has to be employed as in the case of the a_1 at M $\approx$ 1.2 GeV/c^2. This allows a rather clean extraction of the a_1 Coulomb excitation amplitudes [2]. Using again the 3π mode the same method also gives consistent results for the a_2.

In order to ease the task at higher masses we will use a high beam energy of 300 GeV/c which gives a more than twofold rise of the Primakoff peak cross section as compared to ref. [2] using a 200 GeV/c π^+ beam. We expect that the (radiative) study of the $\pi_2(1670)$ could be thus become accessible, taking into account also its higher spin giving a factor of 2J+1 in the cross-section.

This measurement is also interesting for the a_1 owing to a discrepancy with different theoretical predictions. For instance recent calculations based on Chiral Theory give for its radiative width 250 keV [3] as compared to 640 keV from the measurement.

But there are still other classes of states which can be studied with Primakoff production at high masses. One of them is a class of states which can not be produced diffractively at all – for example ρ'. Even in this case there can be coherent production on nuclei (i.e. by means of ω-exchange) having a sharp t-distribution, but its cross-section drops with energy according to the corresponding Regge trajectory intersection. Another class is the diffractive production of states with non-zero spin projection onto the Gottfried-Jackson axis – as in the case of a_2 (and others 2^+, 4^+ ,...). The energy dependence is similar to that of a_1 [4], but the t-distribution has a dip at small t.

In the following we estimate the apparatus resolution necessary to meet the required precision in the kinematic variable t. The scattering angle of each of the three outgoing 100 GeV/c pions has to be measured with an accuracy of $3 \cdot 10^{-5}$ to achieve a t resolution of $0.3 \cdot 10^{-4}$ GeV^2, which is half the t-value of the Primakoff cross sections peak at M=1.3 GeV/c^2 at p=300 GeV/c. This corresponds to a required spatial resolution of 300 μm/ at a lever arm of 10 m which seems reachable, if it is not degraded by multiple scattering in the detector itself. A target of 1/20 X_{rad} is thin enough, but probably it gives too little yield per incoming beam particle. A four times thicker target would contribute about $4.2 \cdot 10^{-5}$ to the multiple scattering angle. Thus the forward peak in the t-distribution could not be resolved cleanly. This, however, seems to be still permissible.

2.3.3 $\pi(1800)$ by Primakoff production

Because the decay $0^- \rightarrow 0^-\gamma$ is forbidden kinematically the corresponding Primakoff process for $\pi(1800)$ is suppressed by a photon virtuality (q^2/M_ρ^2). In addition the absence (or suppression) of the decay $\pi(1800) \rightarrow \rho\pi$ indicates that even at large q^2 the electromagnetic excitation strength for $\pi(1800)$ is small.

2.3.4 $\pi(1800) \rightarrow \omega\ \pi\ \pi$ channel

One of the problems performing a PWA of a system with neutral mesons decaying into γ's is the combinatorial background. This background strongly depends on the resolution of the electromagnetic calorimeter. In COMPASS we expect a higher resolution with increasing energy and thus will benefit in the signal/background ratio, in particular in the $\omega\ \pi^0\ \pi^-$ system. Also important are statistical limitations. For this specific channel it prevented to measure the phase of the 0^- wave with respect to the less intensive reference wave.

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3 ANSWERS TO THE QUESTIONS ON THE EXPERIMENTAL SETUP

3.1 MUON TARGET AND MAGNET

Question of the Referees:

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A detailed plan on the polarised target (+ solenoid), as a function of time, including the costs of the different parts, and the laboratory responsibilities in following the construction, testing the pieces and assembling them.

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3.1.1 Construction schedule

In the following it is assumed that after the approval of the COMPASS proposal and after the budget regulations in various countries the preparations in hall 888 can be started.

The Superconducting Magnet

There are three quotations for the new large-acceptance magnet which differ in price by a factor of 1.7. Due to budgetary regulations at the University of Nagoya, the order has to be placed by the end of 1996. Discussions with the manufacturers about technical details are still going on. The technical realizations differ mainly in the maximum current, requiring new power supplies in some cases. The magnet will be initially tested at the manufacturer's premises before transport to CERN, where the tests, including field mapping, will be repeated after mounting the magnet in hall 888.

Task	*Completion*
Order	November 96
Delivery	July 98
Installation	August 98
Leak tests at 300K	September 98
Cooldown to 4K	October 98
Tests with warm bore:	October 98
Nominal field check	
Field mapping	
Field rotation test	
Warmup and dismounting of warm bore	October 98

Table 3.1: Schedule for the new magnet.

The Dilution Refrigerator

Design of the modifications of the dilution refrigerator can be started as soon as the dimensions of the new magnet are fixed. Some of the new parts have to be fabricated outside the workshop of Helsinki University of Technology. This concerns especially the microwave cavity and the target holder (precision sheet metal workshop), the mixing chamber (superfluid leaktight reinforced plastic technology) and the sintered heat exchanger (vacuum oven and electron beam welding machine). CERN workshops would be a natural choice because of their former experience.

Task	*Completion*
Design of modifications	July 97
Subcontracting	September 97
Manufacturing of parts	April 98
Delivery to CERN	May 98
Disassembly	June 98
Assembly	September 98
Leak tests at 300K	September 98
Cold tests at 2K in clean area	October 98
Transport to hall 888 and mounting into magnet	November 98

Table 3.2: Schedule for the modifications of the dilution refrigerator.

The Vacuum System and Infrastructure

As for the dilution refrigerator, the design of the modifications of the cryostat platform and the pumping lines can be started as soon as the magnet dimensions are fixed. In case that the target position will be changed, the pumping lines to the dilution refrigerator have to be modified. The gas handling system of the magnet has to be redesigned and rebuilt for the part not included in the magnet delivery. This is a major work and requires in addition to the manpower of the universities specific help of CERN technicians. The helium liquefier in hall 888 must be started before the testing of the magnet will start.

Task	*Completion*
Overhaul of pumps	April 97
Delivery of pumps	July 97
Installation and tests of pumps	September 97
Design of vacuum line modifications	April 97
Modification of vacuum lines	June 97
Leak tests	September 97
Modification of cryostat platform	September 97
Modification of loading equipment	October 97

Table 3.3: Schedule for the modifications of the vacuum system.

The Microwave System

New microwave sources and their power supplies will be purchased. The design and construction of the microwave cavity and the waveguides inside the cryostat is included in the modifications of the dilution refrigerator. The new power supplies have an optional remote control possibility and the mounting of the microwave sources on the cryostat platform will be considered.

Task	*Completion*
Order of new EIO and HV	April 97
Delivery	October 97
Installation of EIO and HV	October 97
Installation of waveguides	October 97
Tests	November 97

Table 3.4: Schedule for the upgrade of the microwave system.

The NMR and DAQ Systems

The analog section of the NMR system will remain as used by SMC. On the digital side, at least the controlling minicomputer DEC MicroVAX will be replaced by a UNIX workstation and the NMR software rewritten. In the present system the A/D conversion and the front-end processing is realized using CAMAC-based STAC modules, developed at CERN (A. Rijllart). The support for these modules cannot be guaranteed any more in the future and therefore, available funding and manpower allowing, they will be replaced by modern VME/VXI-based commercial modules.

The control and DAQ system for the SMC magnet, developed at Saclay, has to be modified for the new magnet. This involves modifying the readout of the new instrumentation and control of the new magnet current supplies. In the control and DAQ system of the dilution refrigerator only minor changes are foreseen.

Task	*Completion*
Development of new NMR interface	June 98
Development of new NMR readout	June 98
Upgrade of magnet DAQ	September 98
Upgrade of cryogenic DAQ	October 98

Table 3.5: Schedule for the upgrade of the NMR and DAQ systems.

The Target Material

The NH_3 material will be available from the SMC 1996 run but the ^{6}LiD material has to be purchased and prepared for the dynamic nuclear polarization process.

The paramagnetic centres needed for the polarization are created in these materials by irradiation with an electron beam. The ammonia for SMC has been irradiated with the 20 MeV linac at Bonn and the same will be done with ^{6}LiD. For this a bigger irradiation cryostat has to be built. The paramagnetic centres in NH_3 decay during a long-term storage in liquid nitrogen. To overcome this the material can be stored in liquid helium or re-irradiated before its use. Negotiations with CERN (M. Rieubland) are needed to find the most cost-effective solution.

Sources for purchasing of ^{6}LiD are France, Russia or United States. Because of the strategic nature of ^{6}LiD contacts from CERN management as well as from the German authorities are needed in order to import the material to Germany (where the preparation will be made) and later to CERN for the COMPASS experiment.

Test irradiations and polarization tests with small samples will be done at Bonn before preparing all the ^{6}LiD material.

Task	*Completion*
LiD purchase	July 97
Preparation of beads	November 97
Design of irradiation cryostat	January 97
Fabrication of irradiation cryostat	July 97
Test irradiations and EPR/DNP tests	December 97
Irradiation	July 98
Transport of material to CERN	July 98

Table 3.6: Schedule for the target material preparation.

Tests

After separate tests of the magnet with the warm bore in the hall 888 and leak testing the dilution refrigerator in the clean area they will be combined for a final test run. After the cooldown of the complete system, final leak tests will be made and the cooling power of the dilution refrigerator and the microwave power will be measured. Afterwards the target material (NH_3 or ^6LiD) will be loaded, the NMR system tuned and polarization tests will be done.

Task	*Completion*
Leak tests at 300K	December 98
Sensor tests	"
Startup of cold box	January 99
Cooldown of magnet	"
Cooldown of DR	"
Leak tests at 4K and at 1K	"
Cooling power measurements	"
NMR system set-up	"
Loading of LiD	February 99
DNP tests of LiD	"

Table 3.7: Schedule for the final target tests.

3.1.2 Cost Estimate

Item	Cost (kCHF)	Institute
Magnet	1500	Nagoya
Power supplies (optional)	100	Bielefeld
	1600	

Table 3.8: Cost of the polarized target magnet.

Item	Cost (kCHF)	Institute
Mixing chamber (x3)	30	
Sintered heat exchanger	20	
Heat exchanger support	10	
Microwave cavity	30	
Target holder	30	
Instrumentation upgrade	20	
Refrigerator-magnet interface	10	
	150	Bielefeld

Table 3.9: Cost of the dilution refrigerator.

Item	Cost (kCHF)	Institute
Overhaul of He-3 pumps	55	
Reparation of He-4 pump	5	
He transfer line for magnet	5	
Modification of vacuum lines	20	
Modification of platform	20	
Electrical installations	10	
	115	Bielefeld

Table 3.10: Cost of pumps, vacuum lines and the platform.

Item	Cost (kCHF)	Institute
EIO tube (x2)	70	Bielefeld/Bochum
HV supply (x2)	130	Bielefeld/Bochum
NMR and DAQ	50	Bielefeld
	250	

Table 3.11: Cost of the microwave system, NMR and DAQ.

Item	Cost (kCHF)	Institute
6LiD purchase	200	
Fabrication of beads	30	
Irradiation cryostat	70	
Irradiation	50	
	350	Bochum

Table 3.12: Cost of the target material.

3.1.3 Responsibilities and Manpower

The responsibilities for the different subsystems will be shared and manpower allocated as follows:

Magnet	Nagoya
Dilution refrigerator	Helsinki/Bielefeld
Vacuum system	Bielefeld
Microwave system	Bochum/Bielefeld/Nagoya
NMR and DAQ systems	Bochum/Bielefeld/Nagoya
Target material	Bochum

Table 3.13: Sharing of the responsibilities.

At CERN a full-time coordinator and two technicians familiar with CERN will be needed during the modifications of the vacuum system and platform, assembly and tests of the dilution refrigerator, installation and tests of the magnet and final mounting and tests of the target. The upgrade of the NMR and DAQ systems requires 1 to 2 students for one year. During the assembly and tests of the dilution refrigerator at least two additional persons are needed. During the installation and tests of the magnet some manpower will be provided by the manufacturer. A microwave expert will be needed for the modification of the microwave system. At least 5 persons are needed during the test run with the complete target setup.

3.2 TRACKING CHAMBERS

Question of the Referees:

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A more detailed description of the chambers, especially an evaluation of the performances required by the physics (ex. resolution, calibration and alignment errors necessary to get $\Delta M = 10$ MeV in $D^\circ \to K\pi$). Details on the calibration strategy and alignment, especially for the consequences in the chamber design. An assessment on the possibility to make prototypes. A plan on the manpower necessary to build, calibrate and operate the chambers, including laboratory responsibilities.

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3.2.1 Chamber description and performance evaluation

The invariant mass resolution for the $D^0 \to \pi + K$ decay in the muon program is mainly affected by the multiple scattering in the target region (the total thickness of the target itself is $d \approx 60$ g/cm^2). Table 3.14 summarizes the main contributions to multiple scattering of the K and the π in the proposed apparatus. As stated in the proposal, multiple scattering alone gives a contribution of almost 10 MeV/c^2, essentially independent of the D energy, to the invariant mass resolution.
The requirements on the tracker system are the following:

- The trackers should be light enough not to increase significantly the total amount of material traversed by the π and the K. This can be achieved by using pocalon foils for the honeycomb chambers (HC) to reduce the thickness to 75 μm from 150 μm mentioned in the proposal.
- The location errors and the alignment errors should give a contribution to the D invariant mass resolution well below 10 MeV/c^2.

material	thickness d (g/cm^2)	d/Xo
Polarised target	15	0.20
Target region	4	0.10
Air	3.7	0.10
7 MWPC	1.2	0.03
11 HC	5	0.12

Table 3.14: Material encountered by outgoing hadrons (average values).

As explained in section 5.2.5 of the proposal, a simplified layout was used to investigate the invariant πK mass resolution for the $D^0 \to \pi + K$ decay. Also, to avoid complications with tracking in the magnetic field, the fields of the two spectrometer magnets were taken as box fields, and all the chambers were placed outside the field regions. More specifically:

- In order to have a good efficiency, each tracker provides 6 coordinates (two horizontal, two vertical and two inclined). Only one horizontal and one vertical were used in the simulation.
- For the HC trackers, a coordinate was always given by a weighted average of two staggered planes, so that a 100 microns location accuracy can safely be assumed throughout all the cell volume.
- In the LAS only three trackers were used before M1 (MWPC1, MWPC2, MWPC3) and three after M1 (HC1, HC2, HC3).
- In the SAS only five trackers were used before M2 (HC3, HC4, HC5, HC6, HC7) and three after M2 (HC8, HC9, HC10).

It is apparent therefore, that the present simulations provide only upper limits to the obtainable resolution and that the use of a complete reconstruction program will result in a mass resolution better than the values we presently quote.

In Table 3.15 we give overall values for the invariant mass resolution for D's entering the geometrical acceptance of the apparatus. Several situations are considered :
(a) multiple scattering errors + location errors
(b) multiple scattering errors only
(c) location errors only
(d) location errors + a systematic shift of 100 microns in both horizontal and vertical coordinate of every tracker, while the direction of the shift is given randomly at the initialisation of the program.

D energy (GeV)	$(a)\ \Delta m$ (MeV/c^2)	$(b)\ \Delta m$ (MeV/c^2)	$(c)\ \Delta m$ (MeV/c^2)	$(d)\ \Delta m$ (MeV/c^2)
10-20	11.3	10.7	3.7	4.2
20-30	11.5	10.4	5.2	6.2
30-40	11.4	9.9	5.9	7.3
40-50	11.5	9.7	5.9	7.4
50-60	11.1	9.1	5.7	6.5

Table 3.15: Resolution of the reconstructed D^0 mass for conditions (a) - (d), explained in the text, and different energies of the D meson.

We can conclude that the proposed layout meets the stated requirements and an alignment accuracy of 100 microns, well within reach and already obtained with trackers of similar dimensions at SMC, is sufficient.

3.2.2 Details on alignment and calibration

To obtain 100 micron transverse accuracy in the large trackers the following considerations are important:

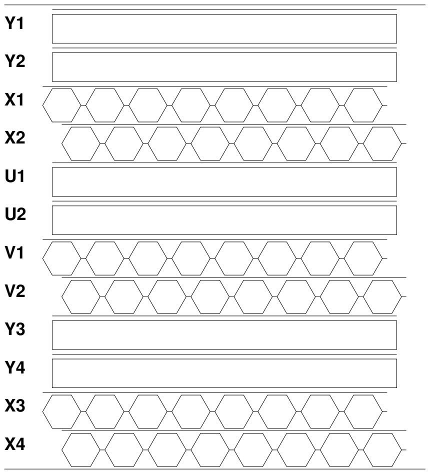

Figure 3.1: Chamber module consisting of 12 layers honeycomb cells.

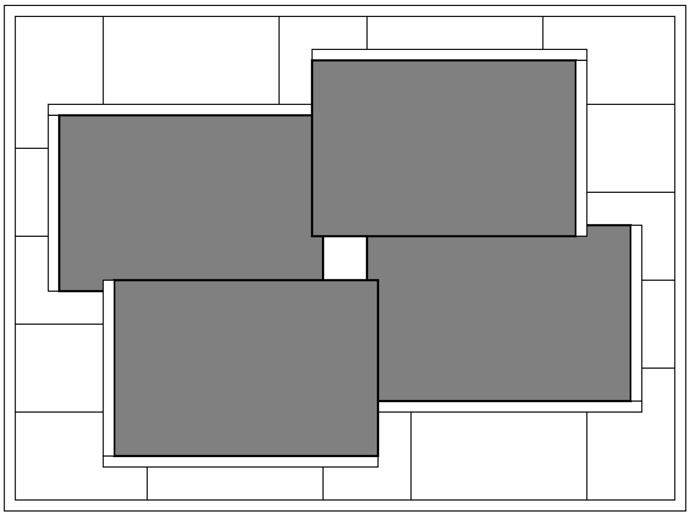

Figure 3.2: Geometry with 4 identical modules around the beam hole.

- *Internal rigidity of a single chamber*
  A single chamber consists of 12 layers glued together. The best stability can be obtained with so called mono-layer planes, where each plane consists of 2 folded foils forming the honeycomb cells and 1 flat foil for stiffness glued together (figure 3.1). The position of the anode wires is the essential information needed to extract the track position from the measured drift times. The anode wires are positioned by the V groves in the plastic blocks at the ends of each honeycomb cell with an rms accuracy of 10 μm within a block for 8 wires. These blocks are glued together while positioned on a template, which provides relative positioning of all blocks and the folded foils. Under appropriate thermal conditions a final position accuracy of 18 μm has been obtained over several meters.

  The plastic blocks as well as the pocalon foils have a large thermal expansion coefficient of $K \approx 50$ μm m^{-1}K^{-1}, which will effect the location accuracy under experimental conditions. Therefore, even with a rigid honeycomb structure, optical monitoring of alignment references on the chamber is important to obtain 100 μm location accuracy.

  Independent of the overall thermal expansion of a single chamber, with all planes glued together, the relative positions around a local track stay fixed and this is important for the drift time calibration.

- *Auto-calibration of the drift time*
  From a sample of local tracks in a single chamber a global fit can be made for the function $r(t)$, which relates the distance r between track and anode wire to the measured drift time t. This is possible due to the redundancy of planes and the fixed local positions inside a single chamber [1] No special calibration runs are needed; the auto-calibration can be done with the same tracks as used in the analysis.

- *Alignment of a chamber with respect to other chambers*
  In the previous EMC, NMC and SMC experiments the chambers were aligned with respect to each other by using data from special alignment triggers on halo par-

ticles and beam particles at low intensities and with the magnetic fields switched off. Straight tracks through reference chambers were used to align the other chambers. The large chambers were aligned with respect to the small chambers using tracks in the overlap regions. Some proportional chambers had their dead regions in the beam activated during these measurements. This procedure defined a fixed relation between the chambers at the moment of the alignment measurements. No changes were assumed until the next alignment measurement or when chambers were physically moved.

- *Optical monitoring of the chamber coordinates*
  New with respect to the previous muon experiments is that we intend to monitor the positions of the honeycomb chambers during data-taking. In this way temperature or other temporal changes of the relative positions can be automatically taken into account in the track reconstruction. External optical alignment monitoring can be done with RASNIK, a system consisting of infrared illuminated pattern masks, lenses and small CCD cameras. Due to the open structure of the spectrometer, where most of the chambers can be sled in from the top and from the sides, several options for monitoring the chamber positions are still open. The precision of these monitoring systems are in all cases better than the 100 μm needed.

3.2.3 Prototype testing

At CERN three test chambers (P2) with 8 layers and 11.5 mm cell diameter with a size of about 3×1 m^2 are available for tests. Initial small prototype chambers with the chosen plane configuration may be obtained from NIKHEF from the material used for the honeycomb chambers, which were recently constructed for CHORUS. For the beam either an empty space between honeycomb modules (see figure 3.2) or a dead chamber region is needed. A prototype study for dead beam regions and for U and V coordinate readout is considered. Full size chambers will be tested during the construction phase.

3.2.4 Manpower for construction and operation

For the construction, calibration and operation of the honeycomb chambers the group of Munich University (project-leader Faessler) has signed responsible. This group has requested 4 positions for the COMPASS experiment from the BMBF (Federal German Ministry for Education and Research) for the 3 year period starting from April 1997 (in addition to 2.5 MDM of investment support and to travel money).

In addition to the requested and not yet approved federal support, the university will provide support by means of positions paid by the Bavarian state for 3 physicists and 1 technician (per year) dedicated to the COMPASS experiment, i.e. taking into account other involvements of the persons who will participate in COMPASS.

The future availability of infrastructure, in particular of laboratory capacity and technical manpower still needs further clarification and coordination with other groups using the same laboratory in Garching. Therefore a detailed construction schedule is not yet available at the moment. The mechanical laboratory in Garching comprises 12 technicians and is, in principle, large enough to accommodate the set-ups needed for the construction of eleven 12-layer honeycomb chambers of the planned size (up to 6×4 m^2).

A test area will be provided for testing ATLAS muon chambers in one of the experimental halls of the accelerator in Garching. Presumably, this test area will be also accessible, even simultaneously with ATLAS tests, for COMPASS chambers, once they are built.

Other groups interested to participate in the construction of the COMPASS honeycomb tracking chambers are from Freiburg and Warsaw.

References

[1] H. Tolsma, PhD-thesis, NIKHEF Amsterdam and University Twente, April 1996

3.3 RICH

Question of the Referees:

————————

Comments on prototypes(i.e. what has to be tested each year), plans on the availability of manpower/resources for construction, including lab. responsibilities. Comments on the possibility of replacing RICH1 with threshold Cherenkov(s) (maybe keep this possibility as a possible contingency?).

————————

The first question is answered separately for the main components of the detectors, i.e.

1. radiator vessels (section 3.3.1)
2. mirror systems (section 3.3.2)
3. radiator gas systems (section 3.3.3)
4. photon detectors (section 3.3.4)

The second question is answered in section 3.3.5. In section 3.3.6 we summarize the status of the funding.

3.3.1 Radiator vessel

Here follows a summary of the parameters of the radiator vessels of the two COMPASS RICH's:

1. Volume: 25 m^3 for RICH1, 55 m^3 for RICH2
2. Materials: no radiator pollution (purity better than 5 ppm for O_2 and H_2O has to be achieved)
3. Mechanical structure: gas tight matching with photon detectors
   provide supports for photon detectors
   closing system in front of the photon detectors

Laboratory Responsibility

At present, three institutes have taken up responsibility for the vessels, Dubna, Mainz, and Trieste.

Radiator vessel design for RICH1 and RICH2 and the cost estimates for the construction in the Dubna workshops will be done by Dubna engineers. The work will be started immediately after the approval of the COMPASS experiment at CERN, once the geometry and the assembling procedure for the MWPC are finalized. The modularity and the tilt of the MWPC planes have to be included in the existing specification list for the design.

The construction of the radiator vessels in Dubna will need funding from outside. Funding requests for RICH1 and for RICH2 have been submitted by Trieste and Mainz respectively.

3.3.2 Mirrors

Here follows a summary of the parameters required for the mirrors of the COMPASS RICH's:

	RICH1	RICH2
surface	5.6×4.0 m^2	4.4×2.2 m^2
shape	spherical	spherical
focal length	3.3 m	8.0 m
mirror segmentation	to be decided	
reflectivity	$\geq 80\%$ for $\lambda \geq 160nm$	
quality of mirror shape	$\Delta\theta(local) < 10^{-4}rad$	
mechanics:	a) 3 degrees of freedom for each mirror segment: z, θ_x, θ_y b) 3 degrees of freedom of the overall mirror support: z, x, y	

Laboratory Responsibilities

At present three institutes have taken up responsibilities for the mirror systems, Dubna, Mainz, and Turin. Mainz has submitted a request for funding of the mirror system for RICH2. Turin plans to ask for funding of the mirror system for RICH1.

The RICH mirrors can be designed and fabricated by Dubna if the feasibility of fabrication is proved and the corresponding funding is available. This study can start after the participation of the Dubna team in the COMPASS experiment is approved by J.I.N.R. management. The most important parameters which are needed to start this study, and which are not yet known are:

1. the size of the mirror modules and
2. the minimal thickness of the glass, which is still tolerable for the mirror considering limits on mechanical stability.

Ongoing Monte Carlo studies are expected to guide the final choices.

Depending on the results of the study (and mirror prototype construction) Dubna can take responsibility either for the entire job or for part of it (e.g. mirror coating). The possibility of doing moulding, grinding and polishing at CERN will be also studied.

3.3.3 Gas radiator system

The two RICH detectors will have separate gas systems, because different radiator gases are needed for the different momentum ranges to be covered by the two detectors.

The RICH1 detector will be operated with C_4F_{10} as radiator gas. As this gas is used in the Forward RICH of DELPHI and will be used in the RICH of HERA-B, experiences and knowledge gained there can be relied upon. For instance, the recirculation gas system can be modelled after DELPHI's Forward RICH (see Fig.5 in [1]).
An estimation of the cost for the different items (condenser unit, evaporator vessel, purifiers, compressor, differential pressure gauge and actuators, valves and pipes) leads to 100 kCHF. In addition, a monitoring system for H_2O and O_2 concentrations, for UV-light transmission and for gas composition will be needed ($\approx$75 kCHF).

As radiator for RICH2 we now plan to use C_2F_6/N_2 rather than C_2F_6 / Ne as indicated in the proposal. With this choice we can use most of the existing gas system of the Omega RICH. Chromatic aberrations using nitrogen rather than neon increase somewhat. On the other hand the dispersion figure for C_2F_6 we have used in our proposal and which was obtained by a first order extrapolation from refractive-index measurements of liquid C_2F_6 [2] is contradicted by later measurements [3] so that the difference is probably not very large.

The Omega RICH gas system has been operated either with pure N_2 (WA89) or with a C_2F_6/N_2 mixture (WA94). Parts of this system need to be upgraded in order to preserve its proper functioning and its reliability. This applies in particular to the gas compressor and to the control system. The system includes monitoring devices for H_2O and O_2 concentration, for UV transmission, and for gas composition. The cost for the upgrade is estimated to be $\approx$ 25 kCHF.

Bielefeld will take up responsibility for the gas system and provide funds (in part).

	Estimated Cost	
RICH1 gas system		
Re-circulation, purifying, and safety part	100 kCHF	Bielefeld
Monitoring part	75 kCHF	
RICH2 gas system		
Upgrade	25 kCHF	

	Estimated Manpower
RICH1 gas system	20 man-months
RICH2 gas system	4 man-months

3.3.4 Photon detectors

The technique proposed for the Photon detectors is MWPC's with pad cathodes covered with a CsI film, as developed by RD26. Being a member of the RD26 Collaboration [4], Trieste has already started in 1995 some prototype work and has taken up the responsibility for both the photon chambers and the read-out electronics for both RICH1 and RICH2.

In the following we discuss separately:

- prototype construction and testing
- design, construction, and testing of all the photon detectors
- read-out electronics
- manpower availability.

Prototype construction and testing

A first prototype of a MWPC with CsI photo-cathode (active surface: 20×20 cm^2) has been built in Trieste. The design of the chamber follows the RD26 experience. The CsI film deposit was made at CERN, where the chamber has been brought last April and is presently being tested.

The chamber performances are under study: with UV lamp (May 96) and in a test beam with a liquid radiator (August and September 96), in a proximity focusing geometry. Figures 3.3 and 3.4 show the very recent results of the tests with the UV lamp, which were obtained during week 20 of 1996. Two sets of data are shown, the first obtained with a cathode plane without CsI, the second with a cathode plane on which a CsI film was deposited. In both cases the pulse height distributions of single electron signals, as well as the pad multiplicity distributions, look perfectly normal, and in agreement with the standard RD26 results.

Without CsI

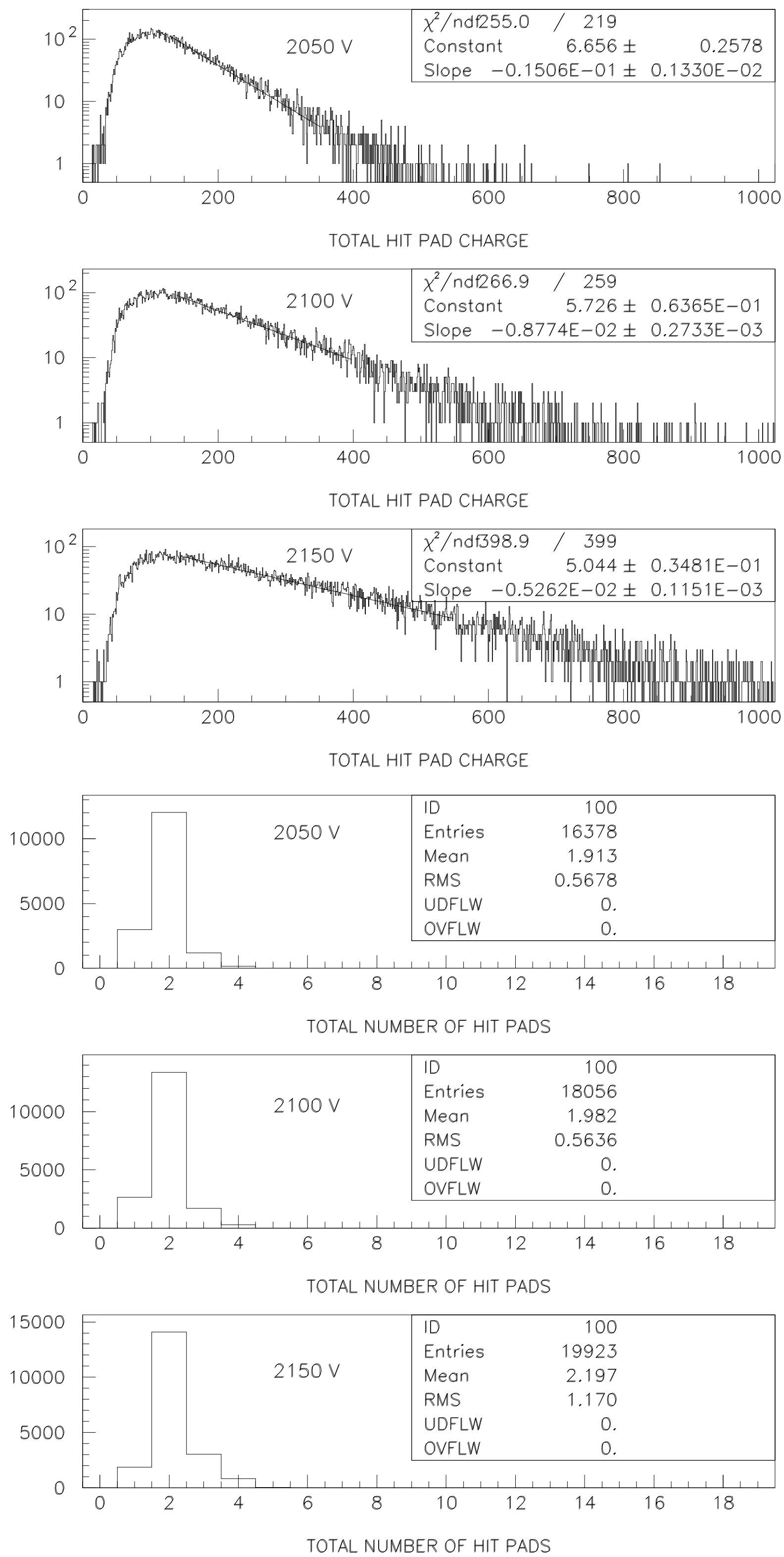

Figure 3.3: Results of tests on the photon detector prototype, using a UV lamp and a pad cathode plane without the CsI deposit: a) Spectra of signal amplitude for single photon detection; the efficiency for single photo-electron detection is 90% at 2100 V. b) Distribution of the number of cathode pads giving signal above threshold for single photon detection.

CsI

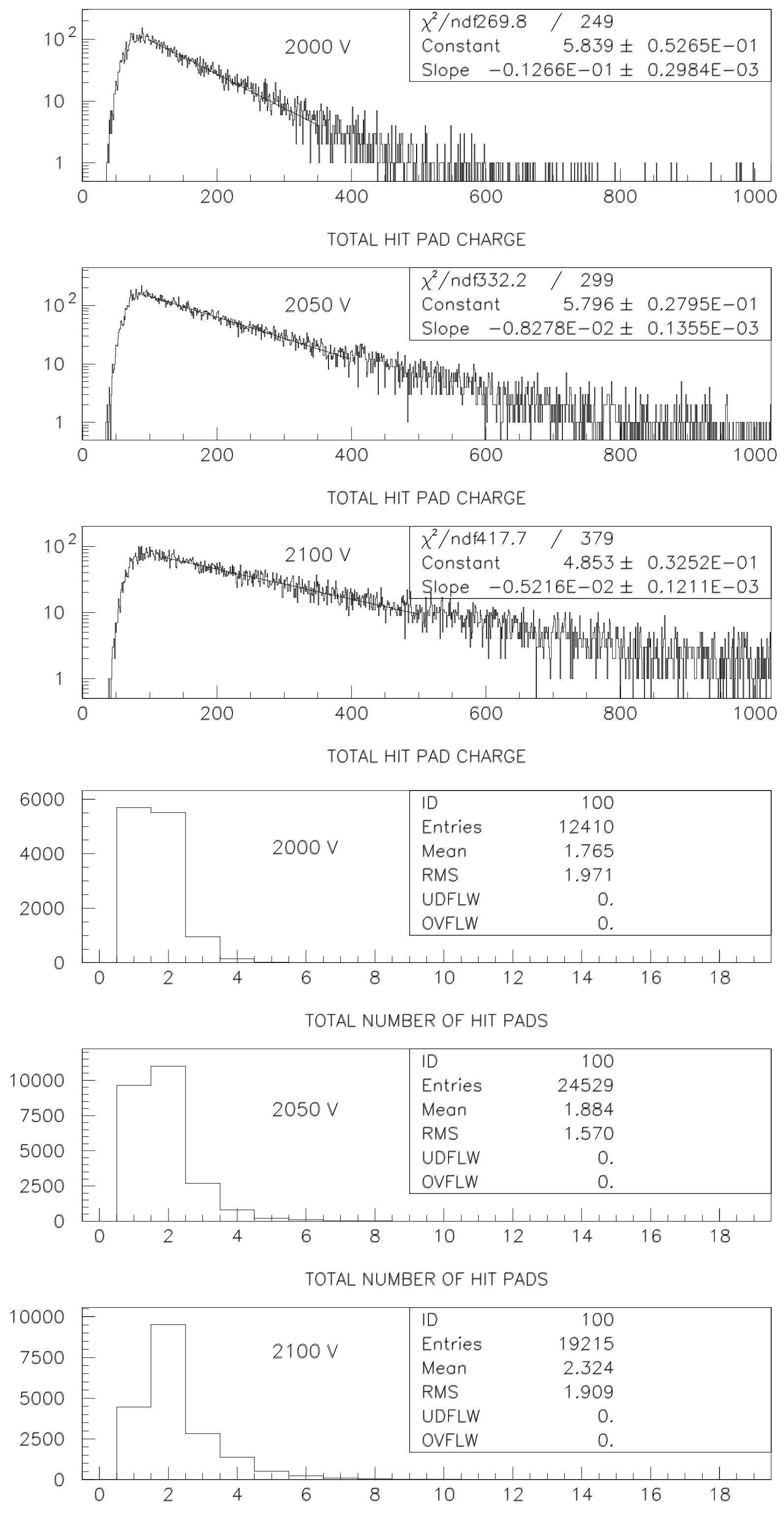

Figure 3.4: Results of tests on the photon detector prototype, using a UV lamp and a pad cathode plane with the CsI deposit: a) Spectra of signal amplitude for single photon detection; the efficiency for single photo-electron detection is 90% at 2050 V. b) Distribution of the number of cathode pads giving signal above threshold for single photon detection.

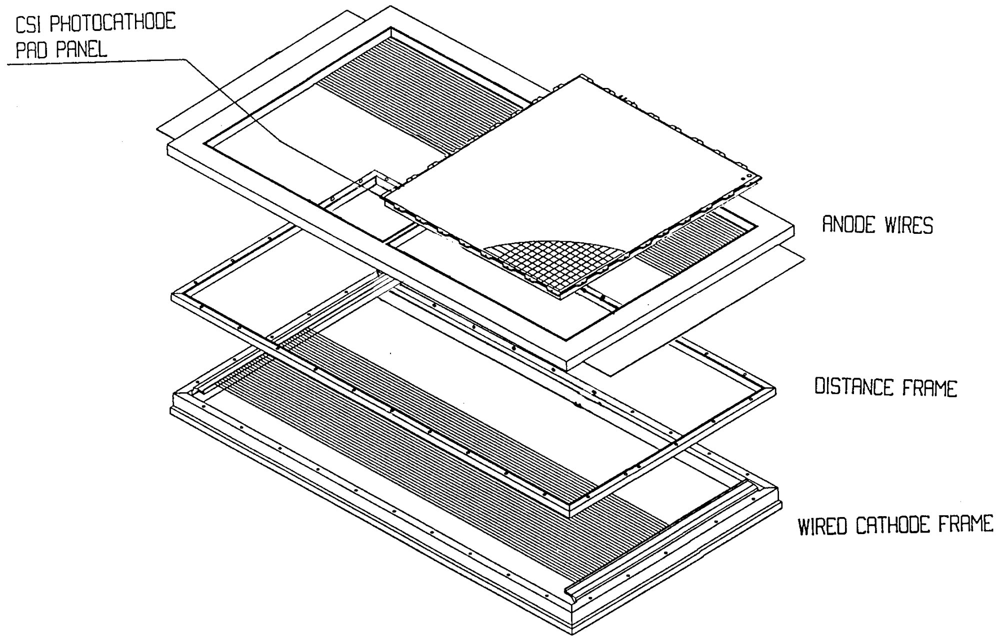

Figure 3.5: General view of the modular photon chamber (100×60 cm^2)

Construction of all the photon detectors

The photon detectors for the COMPASS RICH's will consist of a set of 14 identical MWPC's. The active surface of each chamber will be 100×60 cm^2. (4 + 4) chambers will be used for RICH1 and (3 + 3) for RICH2. The mechanical design will be based on that of the photon chambers which are being designed for the ALICE experiment. The design of the photon chamber is shown in fig. 3.5.

The first chamber that will be built, will be tested using "end 96 state of the art" CsI photo-cathodes. The final photo-cathodes for all the chambers will be produced later to take advantage of further improvements in MWPC CsI technology.

As soon as the RICH radiators will be built, tests of one (or more) chambers will be performed; later, we plan to study the overall RICH performances detecting photons produced in the final radiators.

The foreseen schedule is the following:

design of the chambers	April 96 - October 96
construction and test of the first chamber (chamber 1)	November 96 - June 97
test of the first chamber in a test beam with liquid radiator	from July 97 on
construction of chambers 2 and 3	July 97 - December 97
construction of chambers 4 - 9	January 98 - December 98
construction of chambers 10 - 14	January 99 - December 99
final cathodes for all chambers	January 99 - December 99
test of 1 chamber with the final radiator	from July 98 on

This schedule is illustrated in figure 3.6.

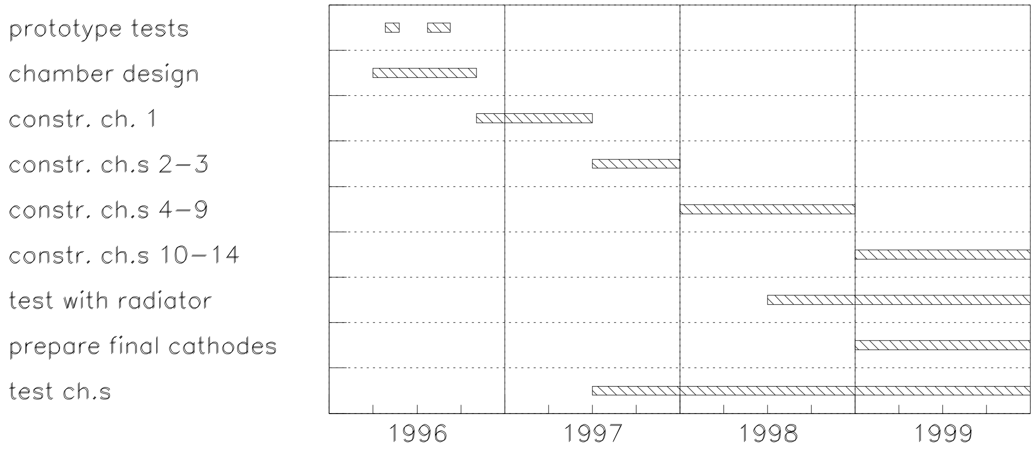

Figure 3.6: Schedule foreseen for the construction of the photon detectors of the RICH's.

Read-out electronics

To diminish the read-out time of the present RD26 system, based on the GASSIPLEX chip, more parallelism in the data flow has to be achieved. The design of a 16-channel MCM-DIGITPLEX printed-circuit board which has been asked to CERN will follow the existing 64 channel version. After prototype tests, the work of assembling the electronics for the whole detectors can be commissioned, starting from July 97.

Mainz has asked for funding the electronics of RICH2. Trieste plans to fund the electronics for RICH1.

Manpower and resources

The construction of all the 14 chambers will be done in the INFN laboratory in Trieste. To match the schedule illustrated above we have estimated the following manpower (HLT - high-level technician):

- 3 technicians (1 HLT,) full time for prototype modifications, assistance during tests and for chamber design in 96
- 4 technicians (1 HLT,) full time for mechanical constructions and assistance during tests in period 97 - 99
- 2 technicians (1 HLT) 50% time during 97 for printed-board circuits design, prototype construction and tests
- 1 technician (1 HLT) 50% time during 98 to follow production by industry.

These resources should be available in Trieste for COMPASS.

3.3.5 Comments on the possibility of replacing RICH1 with threshold Cherenkovs

The replacement of RICH1 with two threshold Cherenkov counters is a relatively simple and "cheap" option. Many counters of this type exist and have been operated successfully over many years. For these reasons this option was put forward in the CHEOPS Letter of Intent, despite the well-known drawbacks of this solution in comparison with the RICH option.

The main advantages of the RICH solution are:

1. the inherent very high granularity, which allows to disentangle the Cherenkov rings from close tracks. Quite complicated patterns are expected for COMPASS events on the basis of the present Monte Carlo simulations;

2. the higher number of photons (one radiator rather than two in the same space), which gives a higher efficiency;

3. the upper momentum limit for particle separation is much higher, since it does not depend on the threshold.

The disadvantages of the RICH solution are its cost and its complexity, which could affect the time of construction. Since anyway one RICH will be built, the technical problems will be solved, and there remains the less complex task of duplicating the construction efforts within the given cost and time frames.

On the other hand, photon detection with MWPC's with CsI photo-cathodes allows to obtain an excellent granularity at reasonable costs: after several years of R&D [5], the proposed technique has proven to be feasible, and guarantees performances which are just unthinkable by using PM's. The presently remaining uncertainties on the efficiencies of mass-produced photo-cathodes do not affect us much. Our estimate of 34 photo-electrons per particle is based on CERN test results on the five large-area photo-cathodes which have been constructed in 1995. Some groups (HERA-B, HADES) do not reproduce the CERN results and claim QE values a factor of about 1.5 smaller. This would still leave us with more than twenty photo-electrons per ring, which is known to give excellent results (for comparison, the Omega-RICH had about 15 photo-electrons per ring).

The main parameters of the two options are given in Table 3.16. The two threshold Cherenkovs have the same total length as the RICH, and their design is that given in the CHEOPS Letter of Intent.

3.3.6 Funding

The institutes which have taken responsibilities for the RICH system either have already applied for funding to their respective agencies, or have the intention of doing it. With reference to table 7.3 of the proposal, the overall funding situation has been summarized in table 3.17.

	RICH	2 threshold C
π/K separation range	3 - 65 GeV/c	3 - 30 GeV/c
$\pi/\mathsf{K}/\mathsf{p}$ separation range	11 - 65 GeV	—
no. of photoelectrons ($\beta = 1$)	34	$8 + 8$

Table 3.16: Comparison of Cherenkov parameters for the two options.

	RICH1	RICH2
Radiator - gas system	Bielefeld (part)	Bielefeld
Radiator - vessel	Trieste	Mainz
Mirror system	Turin	Mainz
MWPC photon detectors + UV transparent windows + gas system	Trieste	Trieste
MWPC read-out	Trieste	Mainz

Table 3.17: Funding for the RICH system of COMPASS

References

[1] W. Adam, *Nucl.Instrum.Methods* **A 338** (1994) 284

[2] J. Seguinot, *Instrumentation en Physique Nuclèaire et Physique des Particules*, edited by M. Buenerd (Edition Physique, Paris, 1989), p.249;
T. Ypsilantis and J. Seguinot, *Nucl.Instr.Methods* **A 343**(1994) 30.

[3] R.Abjean et al., *Nucl.Instr.Methods* **A 354** (1995) 417.

[4] RD26 Collaboration:LDRB Status Report, **LHCC 96-20**, March 1996

[5] F. Piuz, *Nucl.Instr.Methods* **A 371** (1996) 96.

3.4 MUON WALL DETECTORS

Question of the Referees:

Comments on the choice of the detector techniques, i.e. performances required by the physics vs. detector features, costs and available resources and expertise. Time scale and responsibilities in the construction.

3.4.1 Physics requirements

Two muon walls are foreseen for the COMPASS detector which are dedicated to different physics objectives.

The first muon wall is mainly needed for the detection of low energy muons (up to 25 GeV) from the semileptonic decays of charmed baryons. Less than 10% of muons from deep inelastic scattering with $y > 0.5$ will hit this wall. The first two muon stations of the first muon wall will be placed after the hadron calorimeter HCAL1, followed by 1 m of iron and two more muon stations. The multiple scattering of low energy muons in the absorber is quite high (about 12 mrad for 10 GeV muons) and the demands on the detector resolution are thus quite modest. The spatial resolution needed to match the effect from the multiple scattering in the iron is about 5 mm. In addition we have to consider the scattering in the hadron calorimeter which is relevant to match the downstream muon track with the upstream one. We assume the multiple scattering to be again about 12 mrad at 10 GeV and arrive at a needed spatial resolution of about 0.5-1 cm.

The second muon wall is dedicated to the detection of the high energy muons in the deep inelastic scattering program and the high momentum part of the decay muons from charmed hadrons. The muon detectors will be located after 2 m of iron downstream of HCAL2. The multiple scattering of 200 GeV muons in 2 m of iron is about 0.7 mrad. The detector resolution should match this value. Using two stations of the detector with spatial resolution of 300 μm each with distance of 50 cm between them meets this requirement.

The background rate for the detectors from the muon halo is 50-180 Hz/cm^2.

3.4.2 Choice of detectors

Several detector types fulfil these physics requirements. In our collaboration there are 2 groups (JINR-Dubna and IHEP-Protvino) that have been previously involved in the construction of muon detectors.

- The Dubna expertise is in the field of Plastic Iarocci tubes. The workshop produced more than 25000 tubes for the hadron calorimeter of the DELPHI experiment. A detailed description of the workshop and the results of the mass production can be found in [1].

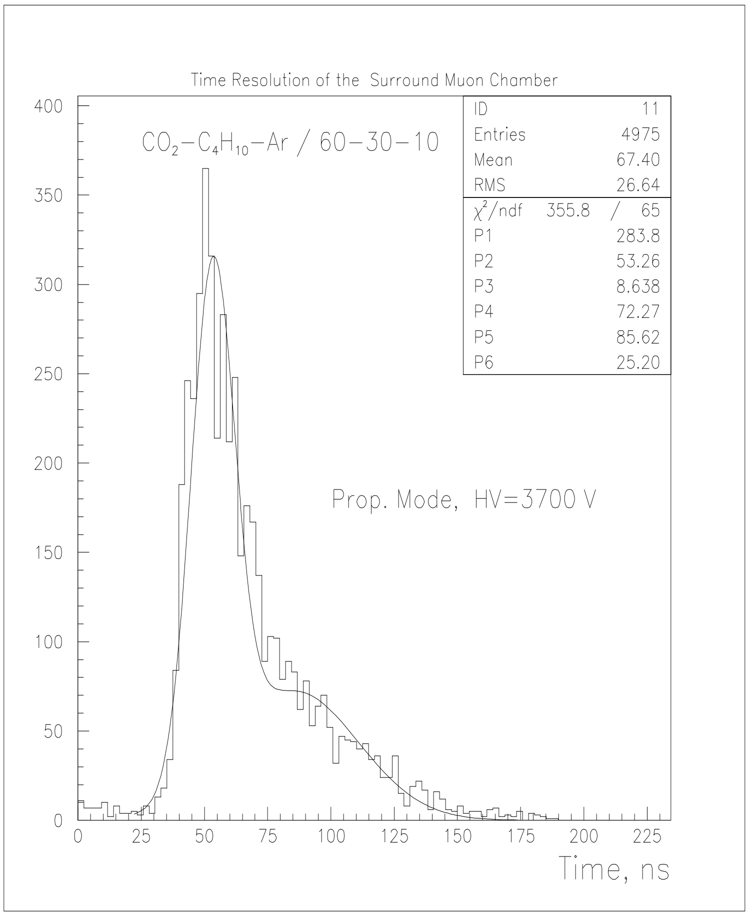

Figure 3.7: Measured time spectrum of PIT used in the DELPHI Surround Muon Chamber.[1)]

Furthermore Dubna Iarocci tubes are used as muon surround chambers in DELPHI [2] and an agreement with the D0 collaboration at Fermilab to produce 6000 Iarocci tubes was signed recently.

Typical characteristics of the PIT are the following:

- The maximum drift time is about 50 ns (for fast $90\% CF_4 + 10\% CH_4$ gas used in the D0 tubes), or about 100 ns (for slow $10\% Ar$ + $30\% C_4H_{10}$ + $60\% C0_2$ mixture used in the DELPHI tubes) (see Fig.1).
- The typical spatial resolution of a tube is better than 200-300 μm, when read via TDC's. The spatial resolution of a muon station is limited by the mechanical precision and is about 1 mm. However, for our case even a standard readout of the PIT is adequate, providing a resolution of 1cm/$\sqrt{12}$ and 2cm/$\sqrt{12}$ for the wire and strip readout, respectively.
- Aging tests have been done for D0 prototypes and no effects up to a dose of 1.67 C/cm were found. At a rate of 200 Hz/cm^2 10 years of operation give a total charge of the order of 0.1 C/cm. So no significant aging effects are expected.

The construction of the 6000 tubes for the D0 experiment is foreseen for 1997. The preparation work and necessary R&D will be financed by Fermilab and JINR. The 1200 tubes for COMPASS could be produced in 1998 as an extension of the activity

[1]This figure replaces the wrongly labeled figure 5.15 in the proposal.

connected with the Fermilab contract. The average capacity of the workshop is 50 tubes per day and a total of 3 months is needed for the production and testing of all the tubes. The tubes including frontend electronics would be financed by Dubna. The corresponding cost estimate is 310 kCHF.

- IHEP Protvino has experience in the production of drift tubes. The same type of drift tubes proposed for COMPASS is already used in the SAMUS muon spectrometer of the D0 experiment at Fermilab [3]. In total, the workshop produced 6000 drift tubes. The drift tube technology is proven to work well and reliably ensuring high enough spatial resolution. No aging problem is expected to be encountered. Part of the material for the production is already available in Protvino and the workshop is capable of producing the 3000 tubes for COMPASS by the year 1998 (the average capacity of the workshop is 30-50 tubes per day).

  IHEP would be responsible for construction and production of both tubes and frontend electronics (amplifiers & shapers), equipped with low voltage supplies. The corresponding cost estimate is about 170 kCHF.

The two different detector types for the muon detection in COMPASS meet the requirements of the experiment. The share of responsibilities for the subdetectors between the two groups follows the expertise of the institutes.

References

[1] G.D. Alekseev et al., NIM A305 (1991) 344.

[2] P.Abreu et al., CERN preprint, PPE/95-194.

[3] Yu. M. Antipov et al., NIM A297 (1990) 121.

3.5 ELECTROMAGNETIC CALORIMETERS

Question of the Referees:

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ADC resolution: Assuming a 12-bit dynamical range (instead of 13-bit), what would be the resulting deterioration (e.g. in mass resolution, S/B)? Would there be a noticeable impact on the physics results, and –if yes– on which results?

—————————

The ADC range foreseen for the readout of the electromagnetic calorimeters of COMPASS is determined by the capabilities of the detector technique. The best electromagnetic shower reconstruction in a cellular calorimeter with a cell size of about one Moliere radius requires the analysis of a 5x5 matrix, i.e. 2 rings of cells around the cell with the maximal amplitude. This is essential for two shower separation where the shower shape deformation is used as an indication of the two overlapping signals. If a photon hits the centre of a calorimeter cell, the energy deposited in this cell is about 80% of the total and the energy deposited in each corner of the 5x5 matrix is about 0.1%. Hence a dynamic ADC range of 10 bits is desired for the appropriate shower reconstruction.

The maximum photon energy in the COMPASS ECALs depends on the beam momentum. It will be slightly below 300 GeV and 450 GeV for the first stage and the second stage of the experiment respectively. The minimum photon energy for which high precision measurement can be performed is defined by the light yield of the lead glass calorimeter, which is about 1 photo-electron per MeV of electromagnetic shower energy. If we assume that 20-30 photoelectrons is a minimal statistically significant signal which could be detected by the calorimeter cell, the energy down to 20-30 MeV can be measured in the corners of 5x5 matrix and photons down to 20-30 GeV can be analysed with a high precision. This requires an extra factor 10 in the dynamical range, so a 13 bit total ADC range is needed.

To summarize, an ADC readout with 13 bit range would let us make use of the full potential of the electromagnetic lead glass calorimeters of COMPASS over the whole range of photon energies.

The requirements of the various physics programs of COMPASS lead to a photon energy range from 0.5 GeV as lower limit to 200 GeV as upper limit. The current experiments on charm and central production - WA89 and WA102 - are using 12 bit ADC systems that are practically sufficient to cover the above photon energy range.

In conclusion, the choice between 13 bit or 12 bit dynamic ADC range is not crucial for the performance of the electromagnetic calorimeters of COMPASS. Practically all physics programs could be carried out with 12 bit dynamic range ADCs, but some improvements of the ECALs performance with 13 bit range ADCs could be achieved. In particular a better two-shower separation might be obtained over the wide energy range. This would improve the acceptance for asymmetrical decays and might be essential for high quality spin analysis.

The design of the ADC system, which is currently under development by the KEK and IHEP groups, is based on two parallel QVC channels with 10 bit linearity and different sensitivities. The difference between 12 bit and 13 bit dynamic range would only be a factor 4 or 8 between these sensitivities. The wider dynamic range does not affect significantly the overall ADC design and leads practically to the same cost per channel.

3.6 SILICON DETECTORS

Questions of the Referees:

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1. **The foreseen parameters for the target Silicon detector is 150 μm thickness, 10 μm strip distance, and 40 MHz readout clock. Have there been prototype tests with such a detector and readout system, and what are the results? In particular, what is the signal-to-noise for minimum ionising particles?**

2. **By how much would a 20 or 10 MHz readout clock increase the deadtime for a) charm semileptonic decay, b) search for double-charmed baryons, c) central production?**

3. **After what time would it be necessary to change the target Silicon detectors, when running at full proton intensity?**

3.6.1 Signal to noise ratio

The present silicon target detector layout foresees 2 sets of 10 microstrip planes with a pitch of 10 and 20 μm respectively. The silicon planes should be 150 μm thick in order to limit the amount of scattering material. The readout will be performed by a fast chip like the FELIX or APV5-RH developed by the RD20 Collaboration.

No prototype of such system exists yet but preparatory work has started already.

In the meanwhile, based on the experience of WA92 [1] and on informations from the RD20 Collaboration [2], we can make a first estimate as follows.

Because of the reduced thickness of the silicon counters, only half of the usual 25000 electrons will be created in a detector by traversing MIPs. Due to charge diffusion during the drift time and capacitive sharing, we expect to collect about 5000-6000 electrons per strip.

Because of the fine pitch (and consequently of the high ratio between the strip width and the strip pitch), the interstrip capacitance is expected to be rather high (of the order of 3-4 pF/cm). We thus expect something like 10 pF as total load capacitance to the input of the preamplifiers. For fast readout chips as FELIX and APV5 this implies an equivalent noise charge (ENC) of about 700-800 electrons.

As a consequence a signal to noise ratio of about 6-8 can be expected.

At the same time, we have started the preparations for prototype assembly and test.

We have already ordered some silicon microstrip counters with 12 μm pitch (this resulted to be the minimum safe size to realize). The detectors will have an active area of about 20x20 mm^2, polysilicon bias resistors and integrated AC coupling. The active area will be surrounded by a region with the fanout of the single strips to 50 μm pitch lines with bonding pads, at both edges of the detector.

Samples with both 150 and 300 μm thickness will be delivered.

On such samples we will be able to measure static electric parameters like the total resulting load capacitance per channel.

In a first stage we plan to read out these counters using a very low noise but slow electronics, for example the VA2 chip. These tests will allow us to measure the amount of charge collected and study the mechanism of charge sharing between neighbouring strips.

In a second stage we will use the faster electronics, realizing a device almost identical to the final detector if satisfactory results will be obtained.

We expect the detectors to be delivered by late summer 1996. The first tests could be completed by the end of 1996.

3.6.2 Readout frequency

The foreseen trigger rate of 10^5 events/sec allows 10 μsec readout time per event. In addition, with the beam specifications proposed ($5{\cdot}10^7$ ptc/sec spread over a 1 cm^2 area), we expect a rather low occupancy.

The time needed to readout a full chip (according to the RD20 design) is of 4, 8 or 16 μsec with the clock of 40, 20 or 10 MHz respectively.

Consequently 40 MHz and 20 MHz readout frequencies will not cause any dead time. But using 10 MHz clock would make us loose all features of the RD20 chip and cause 16 μsec dead time.

A possible solution would be to use 20 MHz clock and 100 nsec peaking time. The use of a deconvolution algorithm would guarantee a time resolution of $\approx$50 nsec [3]. In this situation we would have 2-3 beam particles recorded per event and a double interaction recorded in 5% of the cases.

3.6.3 Radiation damage

Running at full proton intensity, the radiation damage induced on the silicon counters is certainly a serious issue.

Assuming 100 effective days of run time, with 5000 spills per day at a beam intensity of $5{\cdot}10^7$ ptc/sec, one can roughly expect $5{\cdot}10^{13}$-10^{14} ptc/cm^2 as a maximum upper limit.

With such a high particle flux, it will be *mandatory* to replace the detectors after every full year of run. In the meanwhile the counters will have to be operated at very low temperature ($\approx 0^o$C) because of the very high leakage current which will be developed (general informations about radiation damage on single sided silicon microstrip detectors can be found in reference [4]).

In view of the frequent change of the counters, we plan to mount them in such a way that only the silicon will be replaced while the electronics can be re-used. For example a silicon piece with metal lines and several bonding pads per line can be used as a bridge between the readout chips and the changeable silicon planes.

As already mentioned in the proposal, the possibility of diamond detectors is also taken into account. They would have the clear advantage of much better radiation resistance, lower load capacitance, low leakage currents. On the other side still more developments are needed to make these detectors a safe technology.

We are in contact with the RD42 Collaboration to follow the developments in progress and acquire some basic experience with this kind of detectors.

3.6.4 Conclusion

We are fully aware of the challenging characteristic of the silicon target detector proposed. This detector tries to satisfy in the optimal way the requirements for the charm physics program.

Aware of the open questions regarding the effective performance, we already started the preparations to perform full scale device tests within the current year.

These tests together with the constant contacts with the RD20 group will allow us to judge rather quickly the feasibility of the current design, to collect new ideas and to obtain prospects for improvements or alternatives.

References

[1] M. Adinolfi et al., Nucl. Instrum. Methods A 329 (1993) 117.

[2] The RD20 Collaboration, preprint CERN/DRDC 94-39 (Geneva,1994).
Peter Weilhammer, private communication.

[3] S. Gadomski et al., Nucl. Instrum. Methods A 320 (1992) 217.

[4] The RD20 Collaboration, Nucl. Instrum. Methods A 339 (1994) 511.

3.7 DATA ACQUISITION

Questions of the Referees:

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1. **What type of DAQ programs will be used (CERN-provided, self- written, others)?**
2. **Which real-time operating system will be used (OS-9, Lynx, others)?**
3. **What type of CERN support is expected?**

In this section we focus on some additional details of the data acquisition system for COMPASS. We mostly deal with the level of large spill buffers in VME along with CPUs to control them and the level of the DAQ machine. Furthermore the question of the possibility of a central data recording scheme is raised. The collaboration is in contact with the CN and ECP division to discuss in more detail issues raised in this section.

3.7.1 Schedule for the design and tests of the DAQ

The immediate goal should be, to develop the architecture of the DAQ system within the year 1996 to a level, where a first test setup can be fixed. This test setup should then be assembled within 1997. Apart from allowing to gather experience with its components this system should also serve as testbeam DAQ if possible. The availability of the components is as follows:

- The DAQ machine will be bought only as late as possible to have processors of an as high performance as possible. However a single processor workstation with PCI slots should be available at CERN by next year. It should be preferably of the same brand as the projected DAQ machine to have compatibility of interfaces and software.
  A 6 processor AlphaServer 8200 with the same I/O capabilities as the projected DAQ machine is currently operated at the MPI Heidelberg and could be made available for short I/O tests at.

- There are several options for the interfaces used to transfer data from the large spill buffers to the DAQ machine. The company Genroco already provides FibreChannel interfaces for PCI slots on Digital workstations and for PMC slots on VME modules running at rates of 100MB/s. HiPPI interfaces for Digital workstations are available as well, their PMC counterparts are under development.
  Interfaces for SCI-PCI and SCI-PMC are about to be manufactured commercially and will be available by beginning of the year 1997.

- The proposed main memory and I/O module MIDAS 100 by VMETRO will be available by the end of the third quarter 1996. Technical briefings on this module have already taken place at CERN.

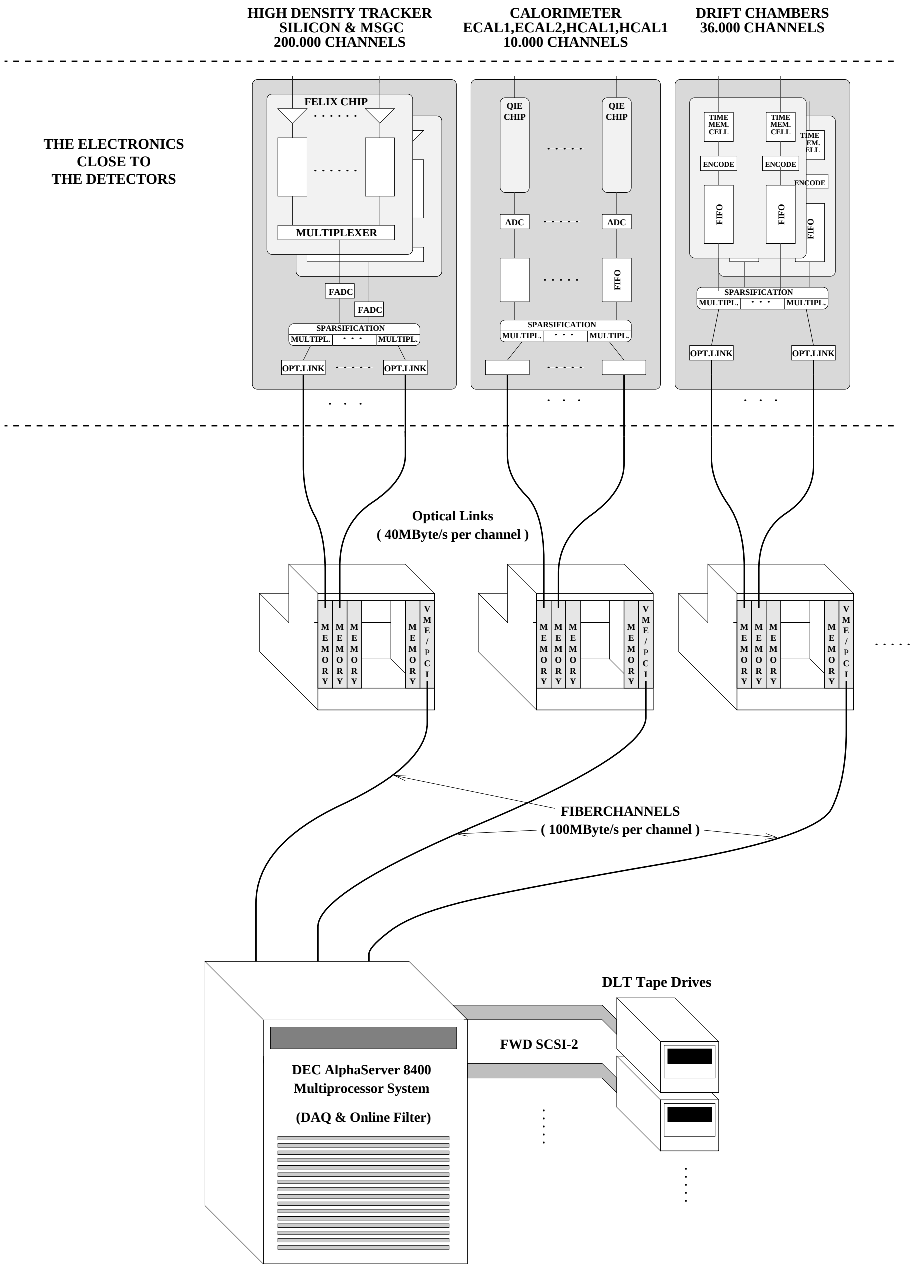

Figure 3.8: The data flow of the proposed data acquisition system. The first level consists of the frontend electronics mostly mounted close to the various detectors. The second level consists of large memory modules in VME controlled by simple processors. Master CPUs provide run control, slow control software links etc. The third level is the DAQ machine, which does event building and online filtering.

The further development of the detector readout electronics should follow this architecture and will be included into the setup, when ready. This should be completed for all detectors by mid 1998 to a level, that first tests of all the various types of detector readout systems can be performed.

3.7.2 DAQ programs

The DAQ programs needed for the COMPASS experiment can be grouped into three categories:

- Software for frontend processors managing the collection of data from the detector readout electronics and memory management will be probably self-written and tailored to the architecture of the experiment.

- The DAQ machine serves (in the concept presented in the proposal) as eventbuilder and online filter. This multiprocessor system will have a standard UNIX operating system and programs and algorithms specific to the various physics runs of COMPASS.
  Alternatively to eventbuilding in the DAQ machine the possibility of using ATM as transfer protocol to let the data organize itself by the routing mechanism should be studied. This scheme has been investigated by RD31 and would profit from the experience and cost efficiency of ATM achieved in the commercial sector.

- Run control, slow control and calibration will be provided by a system of CPUs mounted in the frontend crates connected to few workstations providing storage, user interfaces and tools for software development. These rack mounted CPUs would profit from a UNIX-like real-time operating system like Lynx.

CERN offers as a general purpose DAQ the product CASCADE. This system ran originally under OS9 and has been ported in large part to run under Lynx-OS, as well. Under Lynx, versions exist to run on single board computers based on the 68K and Power-PC families of microprocessors.

Under Lynx, the first indications are that, to obtain maximum performance, the product would have to rewritten to replace a heavy dependence on signals for interprocess communication with a multiprocessing design based on threads. This would require manpower and a commitment to CASCADE for the future: an unclear situation but one which CMS interest may fuel.

In any case, it is unlikely that CASCADE would be appropriate at the moment to a DAQ requiring a very high bandwidth transfer of data, although tests in collaboration with RD24 have taken place, and high-performance network interfaces (FDL and SCI) have been incorporated in its framework. If at all used in COMPASS, CASCADE could be adapted for the monitor/event control function of the COMPASS DAQ, with the event-building being done largely in hardware or within the DAQ machine.

However it was understood, that an extension of CASCADE support by the ECP division beyond currently running experiments and testbeams is not planned.

It is clear that experience gained in the implementation of CASCADE (especially in its involvement with RD24) and the realization of high rate experiments such as NA48 will be invaluable in the COMPASS implementation.

3.7.3 Real-Time operating systems

IO-submodules such as the MIDAS products seem suitable to collect, buffer and redistribute the high data output from COMPASS. The data organization, flow and memory management is provided by the i960 onboard processors. Such processors, however, do not support OS-9 and Lynx as they have no memory management unit. They would most likely be used without operating system exclusively running programs cross-compiled and downloaded from a standard workstation. Furthermore such an I/O-processor, although ideal for the data flow management, would probably be inappropriate for the control/monitor schemes required.

In such a scenario, Lynx running on a PPC platform would provide a (pretty-nearly) real-time operating system with efficient POSIX features and a comfortable (nearly) UNIX environment. OS-9's real-time performance is likely better, but such a machine, being more loosely coupled to the hardware than today's event-builders, would suffer less than would have those earlier systems from such weaknesses and benefit more from the obvious advantages of UNIX-type-compatibility.

The choice of the real-time operating system is however not regarded as crucial to the design of the DAQ of COMPASS.

3.7.4 Support by CERN

The COMPASS collaboration expects to profit from the various ongoing R&D projects at CERN aiming at the development of components for a high rate DAQ system for LHC. Support for the modification of the design of the GASSIPLEX chip (RD26) is requested. Furthermore we are interested in the developments of readout electronics for microstrip detectors by RD20 and calorimeters by RD16, which are partly also taken up by experiments outside CERN (e.g. HERA-B).

In addition, exchange of information with R&D projects on triggering (RD11, RD12), data transfer (SCI: RD24) and eventbuilding (RD31) are welcome.

CERN already provides OS9 and Lynx support, and most likely will continue to do so. COMPASS would like to profit from the experience gained with these operating systems at CERN.

The COMPASS collaboration is prepared to provide a data recording system using high speed, high capacity tape media as outlined in the proposal, if it will prove necessary. However we would very much appreciate to cooperate with CERN to set up a scheme for central data recording as currently implemented for NA48. This scheme, widely used at other HEP laboratories, would have several advantages in comparison to the standalone option:

- First of all, manpower could be used efficiently.
- In addition a more cost effective maintenance can be provided at the central site.
- Lower latency in case of a tape drive failure is possible by a temporary use of other units not assigned to any specific task at the moment of data taking.
- Finally, central data recording would have a logical continuation in the processing of the data on a centrally operated COMPASS cluster within the framework of SHIFT.

3.8 OFFLINE COMPUTING

Questions of the Referees:

Using the charm spectroscopy setup, COMPASS will write about 50 DLT-7000 tapes (30 GB each) per day, over a period of 100 days or more. Could you describe:

1. **How the calibration of the various detector components will be done (for each tape? for every n'th tape?)? Is "online calibration" (like NA48) needed?**
2. **Do you foresee central data recording, or local mounting of tapes?**
3. **Will the processing farm be at CERN?**
4. **If so, will the data be stored at the farm or centrally?**
5. **How the tapes will be processed (how many processors, tape stations, operators)?**
6. **If the processing is done at CERN: what will be the load on the CERN network? Will there be any central facilities used? If yes, which ones?**
7. **With respect to the WA89 or WA102 reconstruction speed, a factor of about 1000 has to be gained. How will that be achieved?**

In the following we discuss possible scenarios for the offline data handling at the COMPASS experiment. Data rates and event complexity in the hadron program of COMPASS will be slightly higher than in the muon program. The benchmarks for the capacity of the COMPASS offline data processing will therefore be set by the hadron program. All estimates below are given on this basis.

3.8.1 COMPASS Data Rates to Tape

The amount of data which needs to be written to tape can be estimated on the basis of the projected interaction and trigger reduction rates. Table 3.18 summarises the data rates at the different stages of trigger and data acquisition. The tape writing has to cope with a data rate of 30 MB/s which leads to a total amount of 200 TB for one year of running.

To minimise the amount of tape handling and I/O overhead the data recording will be done on high density/speed tape media. A good candidate as tape device is the SONY 19 mm ID-1 tape with a projected performance of 64 MB/s I/O speed and medium capacity of about 200 GB or higher. Experience with similar devices was gained already at NA49. With this type of tape medium the data of one year running will fit on about 1000 cartridges. Tape media with better capacity/price ratio like the DLT 7000 (30 - 50 GB or higher in the year 1999) or the IBM 3494 will also be considered.

Interaction rate	10^8 particles /spill $\times 2\% = 2 \cdot 10^6$
1st level trigger rate	$2 \cdot 10^5$/spill
2nd level event rate (after online filter)	$2 \cdot 10^4$/spill
Number of spills per year	5000 spills/d $\times 100$ d $= 5 \cdot 10^5$
Number of events per year	$1 \cdot 10^{10}$
Data per event	20 kB
Data per spill (14.4s)	400 MB
Data rate	30 MB/s
Data per year to tape	200 TB

Table 3.18: **COMPASS Data Rates**

The data rate of 30 MB/s can be transferred over long distances (few km) already with present day technology (dedicated multiple FDDI or HIPPI connection). Therefore a central data recording for COMPASS in the CERN computer centre is considered to be favourable for reasons of an efficient use of the I/O infrastructure. With the high capacity tape media local tape recording and mounting at the experiment site however is still feasible.

3.8.2 Calibration

As the time dependence of the calibration constants varies for the different detector types we foresee online calibration per run (approximately every 20 minutes) where needed and in addition calibration in longer intervals.

For the online calibration special data streams will be written to disk buffers and analysed online by the calibration procedure. The data will be written to separate tapes to allow fast recalibration later on. This procedure was applied already at WA89 for vertex detector alignment and lead glass calibration. Calibrations have been performed for time intervals of 20 minutes. This procedure is easily expandable to other detector types.

3.8.3 Offline Computing and Data Reconstruction

The amount of CPU resources needed for the event processing in the hadron program of COMPASS is estimated on the basis of the current experience with WA89 data. Table 3.19a shows the total number of events recorded and the processing time for one event.

The WA89 data was stored on 2000 Exabyte 8200 tapes and is processed on 36 DEC-Stations 5260 and a 6 CPU AlphaServer 8200.

After the online filter stage COMPASS will write about 30 times more events per year than WA89. Although the event complexity in COMPASS will be higher than in WA89 we expect a gain in reconstruction speed of 1.5 due to much faster reconstruction algorithms available. This gain together with a projected increase in CPU performance of 2.5 (e.g. Digitals Alpha ev7 announced for 1999) leads to the corresponding numbers for COMPASS listed in Table 3.19b

The total processing time of $4 \cdot 10^8$ s for one year of data taking will lead to a total processing time of about 100 days on a farm equivalent to 40 fast processors. Multi-

total number of events per year	$3 \cdot 10^8$
event processing time on one DEC Alpha ev5 CPU	150 ms
total CPU time	$4.5 \cdot 10^7 s$

(a) WA89

total number of events per year	$1 \cdot 10^{10}$
event processing time on a single CPU	40 ms
total CPU time	$4 \cdot 10^8 s$

(b) COMPASS (projected)

Table 3.19: Comparison of CPU times and processing speeds.

processor arrays with low cost CPUs will also be considered.

In the COMPASS data processing model we do not foresee a real time online data processing. The processing farm is foreseen to be located at CERN. Experiment dedicated CPU farms like the one described above are already existing at CERN and are integrated in the CERN computing environment in the framework of the centrally operated SHIFT service, currently operating about 120 CPUs of different types. To minimise the network load at the first data processing stage a COMPASS dedicated tape server is envisaged. The possibility to integrate the COMPASS offline processing farm into the centrally operated computing environment is considered to be favourable over an offline farm operated by the experiment, especially in connection with the possibility of central data recording. A centrally operated cluster would also limit the load on the CERN network at later stages of the COMPASS data analysis.

3.8.4 DST Analysis

The further data analysis will be based on the output data summary tapes from the event reconstruction. The size of this data sets will strongly vary for the different physics analysis carried out. Events with special physics tags will be written to separated output streams of the initial event processing. Usual reduction rated e.g. for the charm sector range in the order of 50-100 or higher at the first filter stage. This data will be analysed at CERN and at the participating institutes.

3.8.5 Cost Estimates

The projected costs for CPUs in the year 1999 are difficult to estimate. To give a cost estimates for the first stage data processing farm we assume that our model CPU (e.g. Digital's ev7) or equivalent processors will be available in the year 2000 at about the same price as Digital's highest performing CPU of today. Under this assumption the total cost for the CPU farm will be about 1.2 MCHF. For the peripherals a cost estimate is even more difficult. The total cost for the offline computing will be of the order of 2.0 MCHF. This costs for the computing farm and it's maintenance will be shared among the participating institutes. The use of already existing infrastructure in case of a centrally operated farm would help to reduce this costs.

The cost for the recording media will add about 500 kCHF/year to the running cost of the experiment.