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LEPTON PROBES IN NUCLEAR PHYSICS

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ABSTRACT

1. Introduction

This review concerns the facilities which use the lepton probe to learn about nuclear physics. Since this Conference is attended by a large audience coming from diverse horizons, a few definitions may help to explain what I am going to talk about.

1.1. Leptons versus hadrons

The particle physics world is divided in leptons and hadrons. Leptons are truly fundamental particles which are point-like (their dimension cannot be measured) and which interact with matter through two well-known forces : the electromagnetic interaction and the weak interaction which have been regrouped in the 70's in the single electroweak interaction following the theoretical insight of S. Weinberg (Nobel prize in 1979) and the experimental discoveries of the Z^o and $W^{\pm}$ bosons at CERN by C. Rubbia and Collaborators (Nobel prize in 1984).

The leptons comprise 3 families : electrons (e), muons (μ) and tau (τ) and their corresponding neutrinos : ν_e, ν_μ and ν_τ. Nuclear physics can make use of electrons and muons but since muons are produced at large energy accelerators, they more or less belong to the particle world although they can also be used to study solid state physics. They are covered by another talk at this conference.

Neutrinos beams (ν_e or ν_μ) have also be used in particle and nuclear physics experiments. Electron neutrinos are produced in high flux reactors and muon neutrinos in beam dump experiments at particle physics installations. In each case their use represent a minor (even if one of fundamental interest) utilisation of these machines.

Tau leptons are still a curiosity at high energy accelerators and the ν_τ neutrino has even never been observed directly although its existence is not doubted.

Therefore we will restrict ourselves, in what follows, to electron facilities.

The second half of the particle world is made of quarks. There are 6 quarks regrouped, like the leptons, in 3 families.

$$\begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix} \quad \begin{pmatrix} b \\ t \end{pmatrix}$$

The heaviest one, the top quark t, has just been discovered (see e.g. ref. 1).

Quarks interact with each other via the strong force mediated by gluons. They do not exist as free particles but only in associations of 3 quarks (the hadron family to which the familiar proton and neutron belong) or pairs of quark-antiquark (the mesons which mediate the strong force in the macroscopic world). This is due to the phenomenon of quark confinement which is not yet understood.

The object of nuclear physics used to be the study of nuclei made up of protons and neutrons. Today it has been enlarged toward the understanding of the strong force at the microscopic level of quarks and gluons : why are quarks confined ? why only $3q$ and $q\overline{q}$ combinations do exist in nature ? how is the old nuclear force mediated by mesons related to strong interactions acting between elementary constituents ?...

Both leptons and hadrons can probe a nucleus but each has its peculiarities which make them truly complementary.

Leptons couple directly to quarks via virtual photons or an intermediate boson (Z°, $W^\pm$) through the rather feable electroweak interaction. At the energies of interest for nuclear physics the weak interaction is almost negligible except in very special situations (as e.g. in parity violation studies) and only the electromagnetic interaction has to be considered. The coupling constant $\alpha = 1/137$ is small enough for perturbation expansion to converge and that makes the theoretical calculations more reliable. In short leptons are a clean probe but with rather small cross-sections (they are proportional to α^2) which make electron experiments challenging. Moreover virtual photons couple only to quarks and not to the neutral gluons.

Being composite objects with a definite size, hadrons are more messy (except at very high energies where they act as 3 almost free quarks) but, at the meson-nucleon level, the coupling constant g is of the order of unity or larger. Perturbation theories are definitely not applicable except in very limited cases but cross-sections (proportional to g^2) are huge compared to electron rates. Moreover the quarks and gluons in the projectile can interact with the quarks and gluons in the target which allows the possibility to study the gluon-gluon interaction.

Therefore hadrons are very adequate at discovering new phenomena and leptons are better suited for subsequent clinical studies. This rule has been verified many times in the short history of nuclear and particle physics although one may always find one's favourite exception to it.

2. Review of accelerating methods

Due to the high intensity requirements, electron accelerators are most often linear accelerators (linacs). They are also used widely as injectors into circular machines. Room temperature linacs are pulsed machines with small duty cycles, which range typically from a few 10^{-4} (SLAC) to a few per cent [2-5], and high peak currents. In coincidence measurements the number of true events is proportional to the intensity but the number of random coincidence events (background) goes like the square of the peak current. Since the physics has also evolved requiring more and more the simultaneous detection of several particles in exclusive experiments (where all the reaction products are detected) or semi-exclusive experiments (where a few but not all particles are detected in the final state), the intrinsic limitations of low duty factor facilities have finally overcome the ingenuity of the experimentalists. Three avenues have been explored to increase the duty-factor of electrons accelerators and they all have led to practical applications.

2.1. Synchrotrons

Internal beams in synchrotrons have naturally a low duty factor (a pulse is typically of the order of 1 ms or less with a repetition rate up to 50 hertz so duty factor is of the order of 10^{-2}-10^{-3}), which make them suitable machines in the colliding mode (LEP, HERA, DAΦNE...). For nuclear physics purpose the beam can be extracted slowly, increasing the duty factor up to 50 % - 90 %. But in that case the peak intensity is spread then limiting the average intensity to a fraction of a micro-ampere. Electron synchrotrons are also at a disadvantage at high energies due to the effect of synchrotron radiation onto the energy resolution. They are used best as synchrotron light facilities.

A synchrotron can be followed by a stretcher ring which can also be used as a post-accelerator to boost the energy of the beam. The only representative of this technique is the ELSA facility at Bonn after the closure, to make room for the DAΦNE e^+-e^- collider (phi-factory), of the ADONE synchrotron in Frascati.

2.2. Stretcher rings

The energy gain ΔT of a linac structure is given by [2]

$$\Delta T \sim (r_0.L.P)^{1/2}$$

where r_0 is the shunt impedance, L is the length of the accelerating structure and P the total R.F. power. The shunt impedance is related to the quality factor Q_0 by

$$r_0 = \left(\frac{r}{Q}\right)Q_0$$

where (r/Q) is the normalised impedance which depends only on the geometry of the cavity. Typically (r/Q) is of the order of 1000-2000 Ω/m and Q_0 is of the order of a few 10^4 for a cavity at room temperature. Therefore r_0 is of the order of 50 Ω/m. Due to this rather low value the power requirements are enormous. For a gradient of 100 MV/*m* and a peak current of 100 mA a normal conducting linac operating at 11.5 GHz needs 240 MW/*m*. Only pulsed operation is possible at this level.

A natural upgrade of such a linac is the addition of a Pulse-Stretcher-Ring (PSR) to produce CW or near CW beams. A PSR is essentially a synchrotron which is injected by a linac. The duty factor can reach up to 90 % but one problem is to avoid time structures in the extracted beam which affect the micro duty factor.

For energies above 100 MeV, PSR's must be equipped with accelerating R.F. cavities to compensate for synchrotron radiation losses. Those can also be used to ramp up the energy at the expense of the duty-factor. Experiments can be done with the extracted beam or in a storage mode with internal targets.

Representatives of this mode of operation are : AmPS (900 MeV) at Amsterdam in Europe, SSTR (130 MeV) at Tohoku in Japan, EROS (300 MeV) at Saskatoon in Canada and Bates (1 GeV) at MIT (USA).

2.3. Microtrons

The electron acceleration techniques have undertaken dramatic evolutions in the 80's. One of them lead to the concept of microtrons [6].

Microtrons are recirculated linacs using single massive magnets instead of a ring. For n recirculations the total energy becomes :

$$T = n.\Delta T \sim n(r_0.L.P)^{1/2}$$

Therefore a linac recirculated 30 times would save a factor of 3 orders of magnitude in combined length of accelerating cavities and R.F. power, allowing a rather modest, room temperature linac to be used.

In the race-track microtron whose principle is shown in fig. 1, the beam is bent at the extremities by two solid magnets.

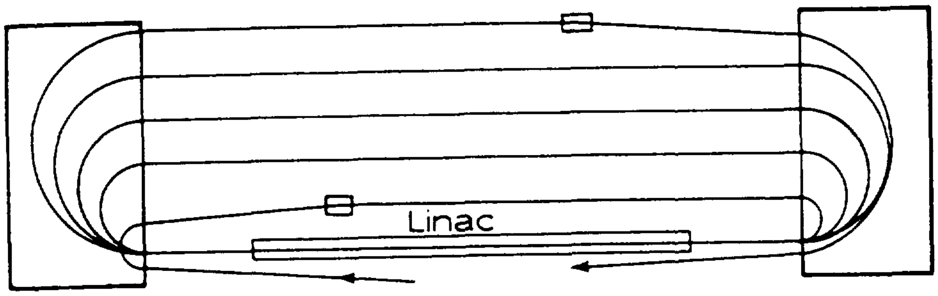


Fig. 1 - Scheme for a Race-track Microtron.

Microtrons are very stable and economical devices (the cost of the linac is usually the most important factor). The microtron can be injected by a single linac whose energy must be larger than one-tenth of the final energy. To reach higher energies, microtrons can be used in cascade, one example being the MAMI facility in Mainz which comprises three microtrons.

Due to the size of the end magnets whose dimension goes like the cube of the energy and to the fact that these magnets must have very tight tolerances, microtrons with massive magnets seem to be limited to energies around 1 GeV. For higher energies microtrons with segmented end-magnets (polytrons) have been proposed but no one has yet been built.

Besides Mainz, there is a microtron injecting into a stretcher ring in Sweden (MAX at Lund). Other low energy microtrons are used as injectors or for pluridisciplinary research in Moscow (Lebedev Institute), Tokyo (Aurora, 150 MeV) Berlin (COSY, 50 MeV), Frascati (ENEA, 100 MeV) and Sao Paolo (IFUSP, 31 MeV).

2.4. Super conducting linacs

The second revolution in accelerating techniques is the development of low frequency (L-band) super-conducting cavities which has led to the successful development of super-conducting (S.C.) linacs at the end of the 80's.

S.C. cavities have smaller accelerating gradients than normal conducting cavities (of the order of 10-20 MV/*m* compared to ~ 100 MV/*m* for a S-band linac) but due to their much higher shunt impedance (of the order of 5×10^{12} Ω/m at 1.5 GHz) their power requirement is orders of magnitude lower so that they can be used in a CW mode (in fact the micro time structure is pulsed to the R.F. frequency, typically 1.5 GHz corresponding to a pulse separation of less than a nanosecond which is integrated out by the experimental detection system).

Due to the limited accelerating gradients of existing cavities, recirculation schemes appear to be more economical than using single high-energy linacs. This situation may change depending on progress made with the super conducting technology.

There are two recirculated S.C. linacs in Europe, the S-DALINAC in Darmstadt operating at an energy of 130 MeV and the LISA facility (49 MeV) in Frascati.

The main contender in the field will be the 4 GeV CEBAF S.C. accelerator in Newport News (USA) which has delivered recently (July 94) its first beam into an experimental area at energies up to 800 MeV.

3. Detailed review of some existing facilities

3.1. S-DALINAC (Darmstadt, Germany)

This small, recirculated S.C. linac with Nb-cavities has logged more than 10000 hours of operation [7,8]. The injector is a 10 MeV linac and the 40 MeV linac is recirculated twice giving a total energy of 130 MeV (fig. 2). It is used partly for nuclear physics and partly as Free Electron Laser (FEL).

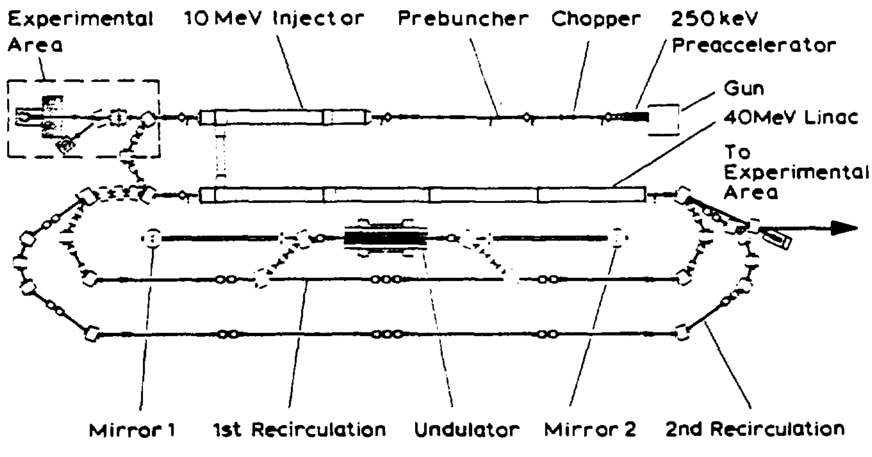


Fig. 2 - Lay-out of the S-DALINAC and FEL.

Being the first S.C. electron accelerator to become operational at the end of 1990 it has allowed to gain a lot of insight on S.C. cavity operation.

3.2. MAMI (Main, Germany)

This facility comprises a 3.5 MeV injector followed by 3 microtrons in cascade : a 14 MeV microtron (built in 1979), the 180 MeV MAMI A (operating in 1983) and the large 855 MeV MAMI B dedicated in 1991 [9]. They replaced a 400 MeV, room-temperature linac with a low duty cycle (10^{-3}).

Although built as a local facility and funded by German institutions, the laboratory is largely open to international collaborations. The plan of MAMI is shown in fig. 3 with its machines and five experimental areas.

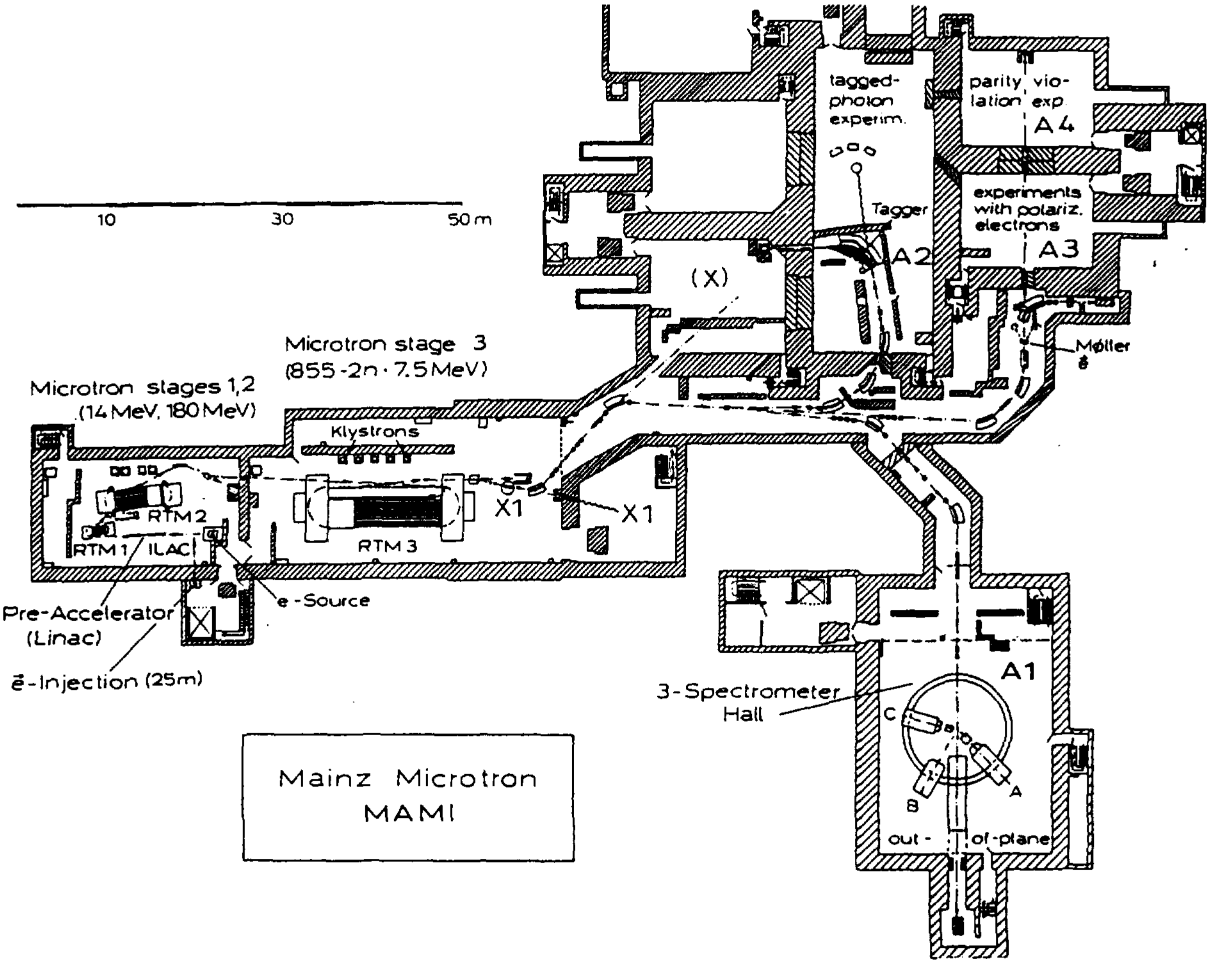


Fig. 3 - Floor Plan of the MAMI Microtrons and Experimental Areas.

Due to the high precision and homogeneity of the end magnets the accelerator complex is rather easy to operate and there are no operator interventions over long periods of time (more than 10 hours). The horizontal beam emittance is 10^{-8} π.mrad at the maximum energy essentially determined by synchrotron light emission. The vertical emittance is very low due to damping (0.7×10^{-9} π.mrad). Beam spot is typically of the order of 0.5 mm with a very small halo (10^{-6} at 2.5 mm from the center). The absolute precision on the energy is ± 160 keV and long term stability of the order of 4×10^{-5}. The energy resolution is 50 keV also determined by synchrotron radiation. A source of polarised electrons has been installed in 1992. More than 10000 hours of beam time have been produced since 1992.

There are four large nuclear physics collaborations and one applied physics program.

A1 Collaboration : Coincidence experiments with electrons.

This program makes use of three high resolution spectrometers whose parameters are given in Table 1. Reactions $(e,e'p)$, $(e,e'n)$ and $(e,e'\pi)$ are investigated. Extensions include a) the investigation of triple coincidence reactions $(e,e'p\pi)$ and $(e,e'pp)$ b) the installation of a focal-plane proton polarimeter for the study of $(e,e'\vec{p})$ and $(\vec{e},e'\vec{p})$ reactions.

Spectrometer configuration		A QSDD	B D*	C QSDD
Maximum momentum	*[MeV/c]*	735	870	551
Maximum induction	*[T]*	1.51	1.50	1.40
Momentum acceptance	*[%]*	20	15	25
Solid angle	*[msr]*	28	5.6	28
Long-target acceptance	*[mm]*	50	50	50
Scattering angle range	*[°]*	18–160	7–62	18–160
Length of central trajectory	*[m]*	10.75	12.03	8.53
Dispersion (central trajectory)	*[cm/%]*	5.77	8.22	4.52
Magnification (central trajectory)		0.53	0.85	0.51
Dispersion to magnification	*[cm/%]*	10.83	9.64	8.81
Momentum resolution		$\leq 10^{-4}$	$\leq 10^{-4}$	$\leq 10^{-4}$
Angular resolution at target	*[mrad]*	≤ 3	≤ 3	≤ 3
Position resolution at target	*[mm]*	3–5	≤ 1	3–5

*clamshell dipole

Table 1 - Main Parameters of the Three MAMI Spectrometers.

A2 Collaboration : Experiments with real photons.

A photon tagging spectrometer was built by Glasgow University. Photons are tagged from 50 to 800 MeV in 2 MeV steps. Linearly polarised photons can be produced via coherent bremstrahlung on a diamond radiator. The present maximum flux is 10^8 photons per second over the full energy range limited by the counting capabilities of the target ladder detector. The photon experiments make use of a variety of detectors : DAPHNE (a 4π-detector provided by Saclay), TAPS (a photon detector also used as neutral mesons detector in different laboratories), CATS (Compton and Two Photon Spectrometer) and COPP (Compton Proton and Photon Spectrometer). Broad fields of physics are investigated : total photon absorption, production of neutral mesons (π^o, η), two-pion production, Compton scattering on the proton.

The use of polarised photons will be enhanced in the future. In particular an experimental test of the Gerasimov-Drell-Hearn (GDH) sum rule which is related to the quark structure of the proton, is scheduled.

A3 Collaboration : Electric form-factor of the neutron.

This collaboration aims at the measurement of one single, but very important quantity, the neutron electric form-factor $G_{E,n}$. The apparatus is shown in fig. 4.

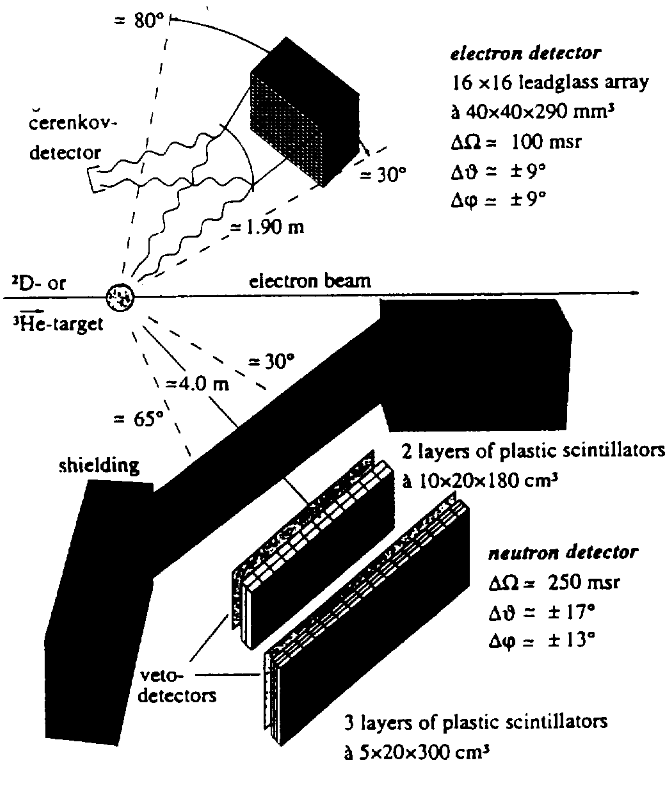


Fig. 4 - Set-up for the G_{En} experiments at MAMI.

There are two ways of measuring $G_{E,n}$: spin correlations between polarised electrons and polarised neutrons $\vec{n}(\vec{e},e'n)$ or spin transfer $n(\vec{e},e'\vec{n})$. Since there are no free neutron targets, the experiment is done with polarised ^{3}He and unpolarized deuterium targets : $^3\vec{H}e(\vec{e},e'n)$ and $D(\vec{e},e'\vec{n})$. The reactions $H(\vec{e},e'\vec{p})$ and $D(\vec{e},e'\vec{p})$ have also been studied to check that the response is the same in the elastic and quasi-elastic reactions.

The goal is to measure $G_{E,n}$ with a precision of ± 10 % in the range Q^2 = 5-15 fm^{-2} within a year. The first results have recently been published [10].

A4 Collaboration : Parity violation in electron scattering.

The emphasis is on the analysis of the spin-flavour structure of the nucleon rather than on a test of the standard-model (SM). Accepting the validity of the latter, the experiment will determine the strangeness contribution to the Dirac proton form-factor $F_1^S(Q^2)$ at $Q^2 = 0.225$ GeV^2.

A total number of ~ 5 × 10^{13} events are expected to be measured in 1500 hours, which will yield a precision of ± 0.011 on the quantity $F_1^S(Q^2) + 0.12\ F_2^S(Q^2)$ dominated by $F_1^S(Q^2)$. Most theoretical models predict values of $F_1^S(Q^2)$ of the order of 0.05 to 0.10.

X1 Collaboration : X-ray production (applied physics).

This collaboration investigates the production of bright X-ray sources using different methods a) transition radiation, b) parametric X-ray and c) Smith-Purcell radiation. Brilliance's close to the ones obtained at synchrotron radiation facilities (but without insertion devices) have been obtained.

3.3. Amsterdam Pulse-Stretcher AmPS (The Netherlands)

The AmPS is an upgrade of the MEA 500 MeV, 1 % duty factor electron linac at NIKHEF [11] which has been modified to enhance its capabilities as injector : higher energy (900 MeV instead of 500 MeV), higher current (80 mA instead of 10 mA), addition of an energy compressor between linac and ring.

The ring lattice has a 4-fold symmetry. Each of the 90° bends is a double achromat connected by long, dispersion-free, straight sections in which the injection and extraction septa are located. A third straight section is used for an internal target facility (fig. 5).

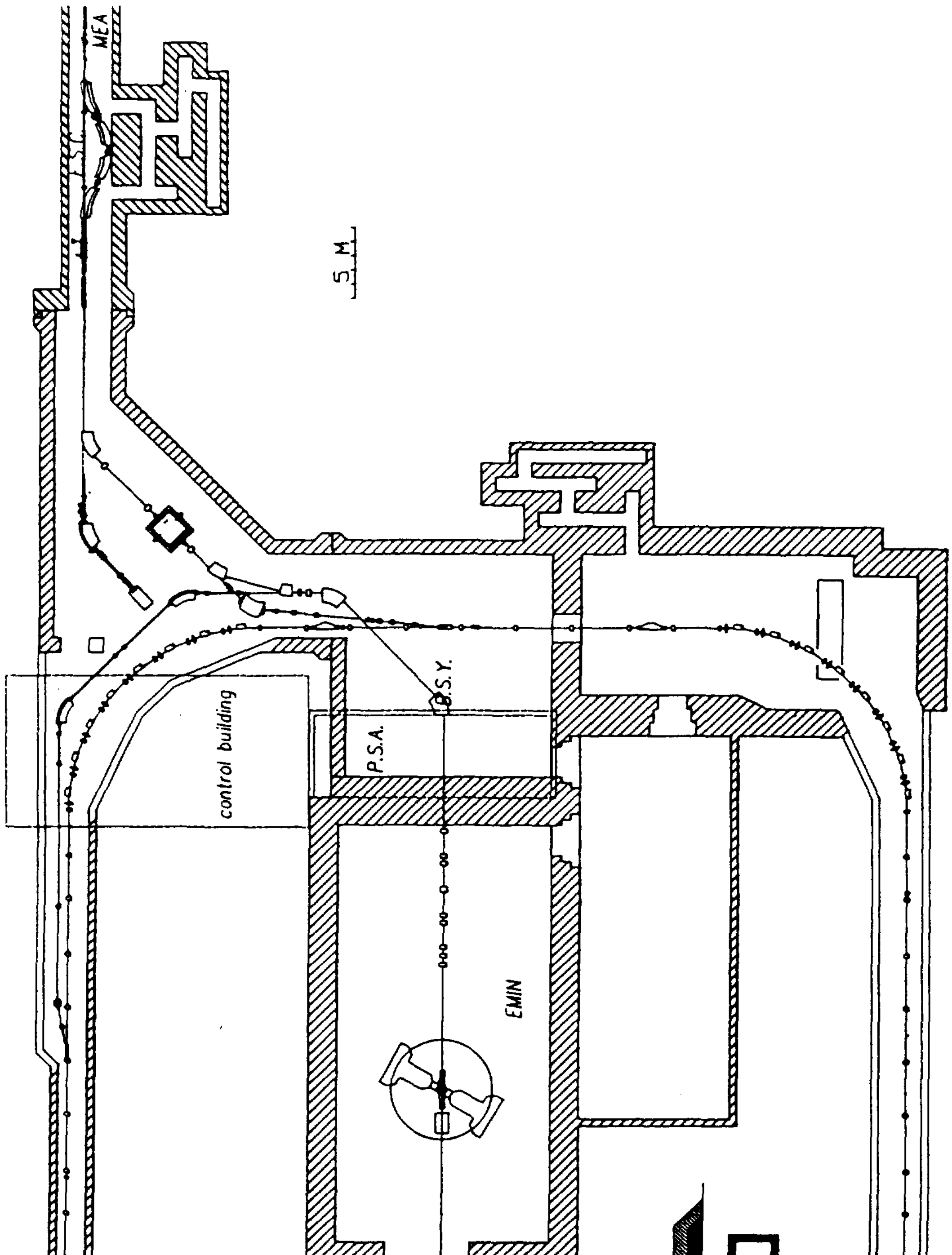


Fig. 5 - Lay-out of the AmPS pulse stretcher magnetic ring.

In the stretcher mode, short pulses with width 2.1 μs and peak current 80 mA are injected from the MEA using a three-turn injection scheme and slowly extracted (resonance extraction) with a repetition rate of 400 Hz at energies up to 700 MeV and average currents up to 40 μA (see table 2).

Duty factor	100	%
E_{min}	250	MeV
E_{max}	900	MeV
I_{stored}	240	mA
Circumference	212	m
Revolution time	0.71	μs
Linac pulse	2.1	μs
Synchrotron radiation		
energy loss/turn		
at 900 MeV	17	keV
RF frequency		
linac	2856	MHz
ring	500	MHz

Table 2 - Parameters of the AmPS ring in the storage mode.

In the storage mode an effective current of 200 mA can be stored either in a three-turn injection or by stacking a large number of low intensity pulses. The maximum energy in this case is close to 900 MeV.

The first CW beams were obtained in 1992 and the AmPS became operational for physics in 1993. It has made constant progress since then. A polarised electron source and Siberian snakes (to control the polarisation in the ring) are being developed. Polarised electrons are expected to be available for physics in summer 95.

Physics can be done with the extracted beam which is sent to a target station EMIN surrounded by a pair of spectrometers located at the center of the ring (fig. 5). Two large solid angle detectors are also being built for triple coincidence *(e,e'pp)* experiments.

A strong emphasis has been put on polarisation measurements with the internal target facility SPITFIRE which is located in the Internal Target Hall (ITH). This mode of operation distinguishes AmPS from MAMI, both accelerators having otherwise similar capabilities.

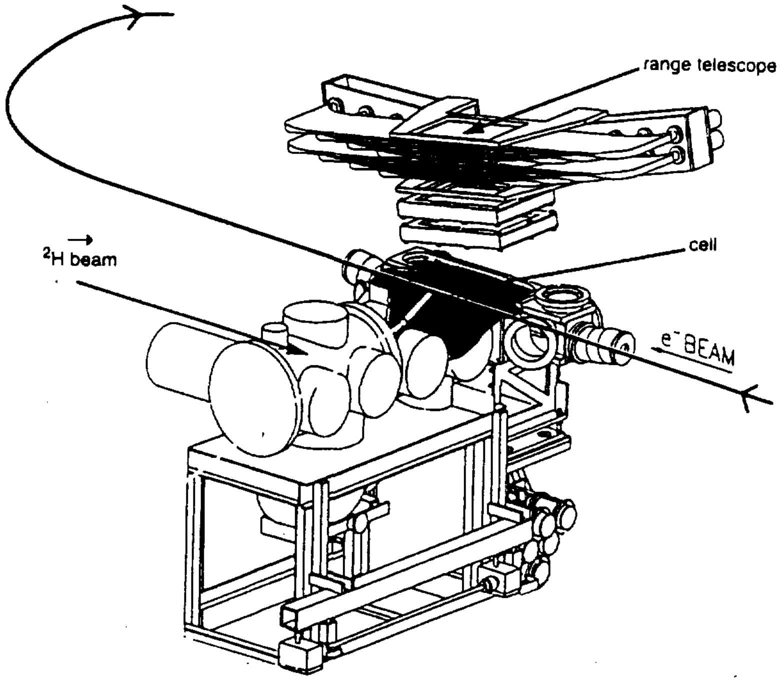


Fig. 6 - The AmPS polarized internal target facility.

The large current circulating in the ring allows novel types of experiments with very thin internal targets to be performed. In the case of a gas jet target the small thickness and absence of windows allow the detection of low-energy recoil particles. Internal polarised targets have distinctive advantages compared to solid state polarised targets : high polarisation, no radiation damage, no dilution by unpolarized background, weak holding field and rapid polarisation reversal (fig. 6).

The physics program includes the following topics :

- longitudinal-transverse separation in knock-out processes $(\vec{e},e'\vec{p})$ and $(\vec{e},e'\vec{n})$
- determination of spin-dependent form-factors, study of medium effects
- electric form-factor of the neutron $G_{E,n}$ using a polarised ^{3}He-target
- measurement of the quadrupole deformation of Δ-isobars excited in the reaction $e+N \rightarrow e'+\Delta \rightarrow e'+N+\pi$ as predicted by standard quark models of the nucleon and the Δ. In order to obtain information for both the proton and the neutron the experiment will be done with hydrogen and ^{3}He-targets.
- form-factors of bound nucleons : possible modifications of bound nucleon properties will be searched for in ^{4}He where the central density is close to nuclear matter density (0.16 fm^{-3}). By using polarised electrons and measuring the polarisation of the recoil

nucleon one will disentangle different reaction mechanisms and get rid of final state interaction effects. This experiment will use a new neutron polarimeter HARP. A proton polarimeter is also under study.

- contribution of meson degrees of freedom....

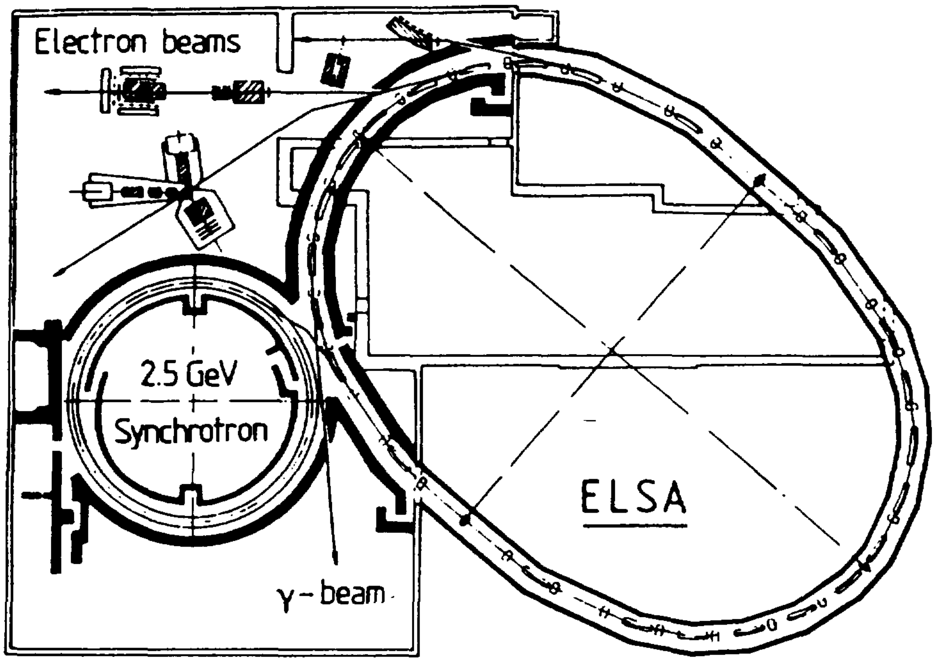


Fig. 7 - Plan view of the ELSA Synchrotron and Pulse-Stretcher Ring.

3.4. ELSA (Bonn, Germany)

ELSA is a PSR which was built to improve the duty factor of the Bonn 2.5 GeV synchrotron and to increase the available energy up to 3.5 GeV. Since October 1987 ELSA has been operated in three different modes a) pure stretcher, b) post-accelerator and stretcher and c) synchrotron radiation source. It is operated for 5000 hours per year on the average.

The lattice consists of 16 separated-function cells containing a deflecting magnet in each drift-space. Two straight sections are formed by omitting these magnets in two adjacent cells resulting in an almost ellipsoidal shape (fig. 7). Bending radius is 10.88 m and the circumference of the ring is 164.4 m which is 2.35 times the circumference of the synchrotron.

The stretcher mode can be used up to 1.6 GeV (1.8 GeV after a modification of the extraction magnets which is under way). In this mode of operation high energy electrons from the synchrotron are injected at 50 Hz and extracted continuously over the 20 ms separating two injections. Two methods of extraction can be used : resonant extraction or multiple scattering on an internal wire target.

With resonant extraction external beam intensities up to 100 nA and a duty factor of 50 % can be obtained. The current limit is set by radiation background in the experimental hall. The duty factor is limited by the imperfect filling of the stretcher ring resulting from the odd 2.35 ratio between ring and synchrotron circumference.

The multiple scattering extraction on a 50 μm thick beryllium wire stretched vertically near to the closed orbit can be used up to 1.2 GeV. It provides external currents up to 1 nA with a duty-factor reaching 80 %.

In the post acceleration and stretching mode some ten pulses are injected at 1.2 GeV and 50 Hz. The accumulated current of about 50 mA can be ramped up to 3 GeV (2.2 GeV in routine operation) within 1 second. Monochromatic extraction then starts and can last up to 50 s, the macro duty-factor reaching 90 % but with very low extracted intensities. This mode of operation is used essentially for real photon production.

In the synchrotron radiation mode currents up to 100 nA are accumulated at 1.2 GeV, then ramped up to 2.3 or 2.7 GeV and stored for about 2 hours before refilling. Synchrotron radiation use represents about 20 % of the beam time.

Improvements of ELSA concern the acceleration of polarised electrons : a new source following the SLAC design is being built (the present GaAs source suffers from a short lifetime of half an hour) and studies for understanding and correcting depolarising resonances during acceleration have been carried out. The necessary software and hardware are being prepared.

	operation mode			no. of injected pulses
	stretcher	postaccelerator (ramping)		
duty factor	95 %	60 %	6 %	
internal current	12 mA	12 mA	12 mA	1
		24 mA	24 mA	2
			60 mA	5
average external current	200 nA	5 nA	10 nA	1
		10 nA	20 nA	2
			50 nA	5

Table 3 - ELSA beam currents in different operation modes.

The physics program is centred around 3 experimental facilities [12].

a) ELAN is a magnetic electron spectrometer reaching 1.8 GeV coupled to large acceptance non-magnetic detectors for the detection of recoiling heavy particles and mesons. The experimental program aims at studying electro-induced reactions on light nuclei (up to ^{4}He). The reactions studied include the measurement of left-right asymmetry in *d(e,e'p)n*, the measurement of the neutron magnetic form-factor in the region $Q^2 < 1$ GeV using the $d(\gamma,pn)$ reaction, π^o and eta$^-$ electroproduction.

b) PHOENICS is a photon tagging spectrometer working in the region 250 MeV to 1150 MeV coupled to a large angle detector set-up measuring nucleons as well as mesons. Experiments include pion- and eta-photoproduction (in conjunction with the SPES∅ lead glass detector from Orsay and SENECA photon counter from Göttingen) and the measurement of the GDH sum rule (in collaboration with Mainz).

c) SAPHIR is a large solid angle detector to investigate photon induced reactions with multiparticle final states up to 3.3 GeV. They include $\gamma d \rightarrow pp\pi^-$ and $\gamma d \rightarrow pn\pi^+\pi^-$. The most important results have been obtained in the photoproduction of hyperons where both production cross-sections and the hyperon polarisation have been measured. In particular the first results on the Σ^o polarisation in $\gamma p \rightarrow K^+\Sigma^o$ have been obtained. A program aiming at studying baryon resonances in the $\gamma p \rightarrow \omega p$ reaction is investigated.

Experiments with frozen spin polarised targets have been done ($\gamma p \rightarrow \pi^+ n$ and $\gamma p \rightarrow \pi^o p$) or are in preparation (GDH sum-rules η-photoproduction).

3.5. CEBAF (Newport News, USA)

CEBAF, a Continuous Electron Beam Accelerator Facility, will produce D.C. beams of electrons up to 4 GeV. Although not located in Europe it has attracted some large European groups in view of its unique features. It consists of two linacs of 0.5 GeV each connected by recirculation systems which allow up to 8 linac passages to produce the final energy of 4 GeV (fig. 8).

Super conducting cavities follow the Cornell design at 1.5 GHz. Four pairs of such cavities are housed in a single 4 m long cryostat. The initial accelerating gradients was fixed to 5 MeV/*m* but most of the delivered S.C. cavities have exceeded this value and it is expected that CEBAF could reach an energy of 6 GeV shortly after its commissioning. The recirculation arcs are separated vertically by "spreader" and "recombiner" magnets.

The basic experimental equipment includes three experimental halls (fig. 9).

Hall A : 2 high resolution spectrometers (electron and hadron arms) expected to run at the end of 1995.

CEBAF

The Continuous Electron Beam Accelerator Facility

SCIENTIFIC MISSION

Investigate strongly interacting matter at the quark-gluon level.

- Nature of quark and gluon confinement
- Quark-gluon picture of the nucleus

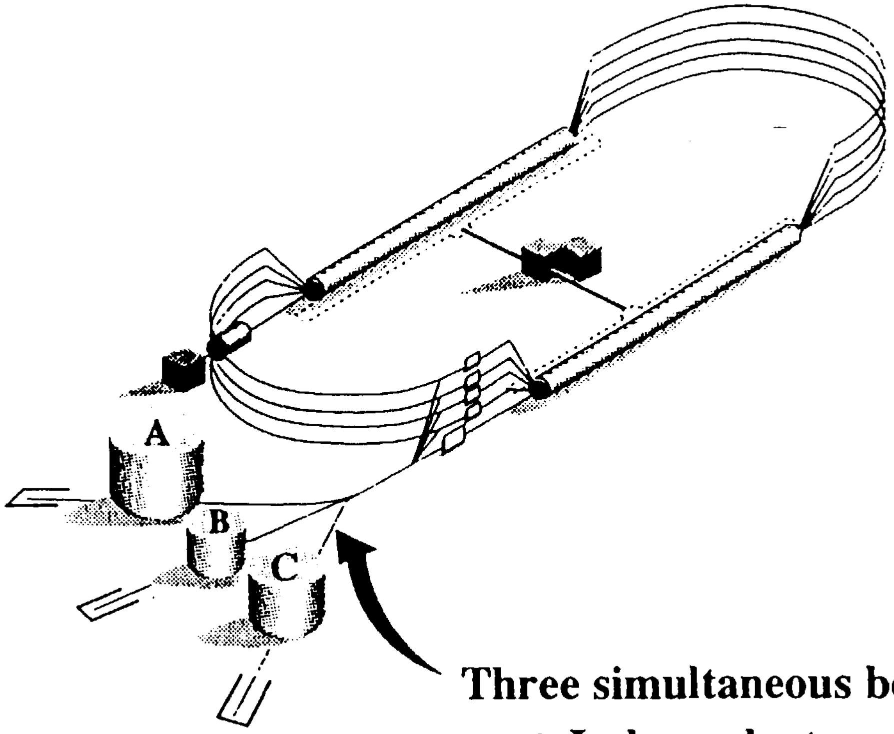
MACHINE CHARACTERISTICS

Energy:	.5-4 GeV
Current:	200 μA
Duty Factor:	cw
Emittance:	$\varepsilon \sim 2 \times 10^{-9}$ m$\cdot$rad
Energy Spread:	$\frac{\sigma_E}{E} \sim 2.5 \times 10^{-5}$

PHYSICS START SPRING 94

PAC 4 and 5

34 proposals with a total of 783 proposal beam days have been approved. This is ~ 1/2 the beam time available or 1/3 of the total requests.



Three simultaneous beams into three experimental areas

- Independent energy and intensity
- Major equipment components procured in all halls

Fig. 8 - CEBAF Scheme and main parameters.

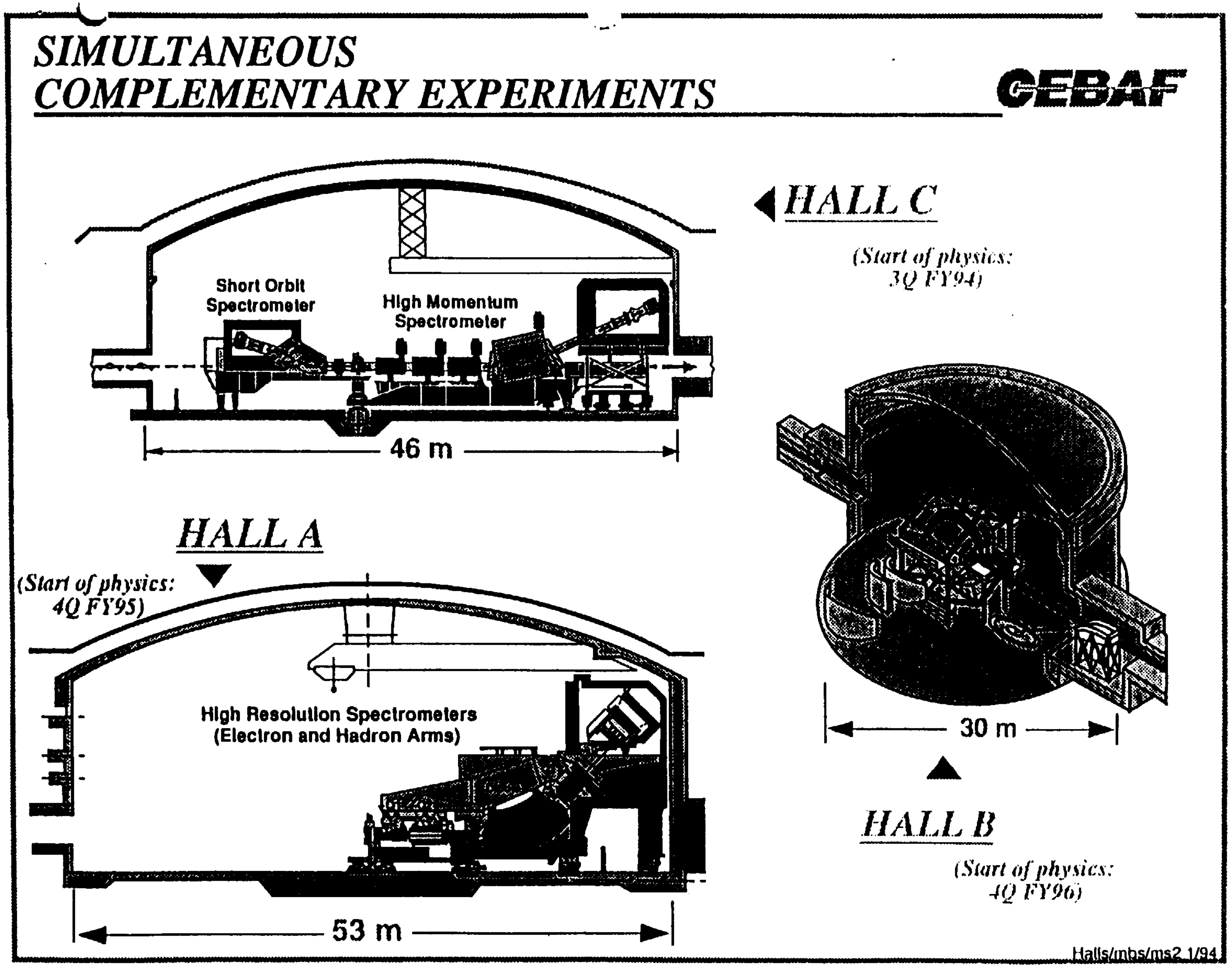


Fig. 9 - CEBAF main experimental facilities

Hall B : a 4π-detector with super conducting coils (CLAS) expected to run at the end of 1996.

Hall C : a high momentum spectrometer (HMS) coupled to a short-orbit spectrometer (SOS) for detection of short-lived unstable particles like kaons which is in the commissioning phase.

In July 94 a 800 MeV beam has been accelerated for the first time over the whole structure and sent onto target station C.

Although CEBAF has still to reach its design performances, 61 experiments were already approved in dec 93, involving 424 authors, 101 institutions and 18 countries, for a total of 1257 days (a couple of years of operation when considering possibilities of parallel running).

The physics program covers a large spectrum from nuclear structure to meson physics to, or at least attempts at, quark physics. It cannot be detailed here.

4. The ELFE project

4.1. Introduction

As the preceding panorama has shown there is a large spectrum of machines covering the low and intermediate energy (100 MeV to 1 GeV) aspects of nuclear physics. In the few GeV domain there is a 3.5 GeV facility with limited capabilities (ELSA at Bonn) and a large comprehensive 4-6 GeV facility near completion in the USA (CEBAF).

As we have also seen in the introduction, there is a growing interest in studying quantitatively the transition from mesonic nuclear physics where the degrees of freedom are mesons and baryons to perturbative QCD where the relevant degrees of freedom are quarks and gluons. One hopes to understand the mechanism of confinement, which is one of the fundamental problems of nature, since if it had not acted a tiny fraction of a second after the beginning of the universe, there would have been no matter as we know it and, at the end, we would not be here to talk about it.

What we need to study this domain of physics is :

i) an electron accelerator since electrons are point-like particles,

ii) an energy larger than 10 GeV since one knows from the early SLAC work at the end of the sixties that one needs 10-12 GeV to reach the so-called Bjorken scaling region [13,14] where the virtual photon couples to a quark,

iii) large intensities since cross-sections decrease as powers of Q^2,

iv) a good duty factor (ideally 100 %) to minimise the random background in the detection of several particles in coincidence,

v) and a small emittance for clean experimental conditions.

No single machine meeting all these requirements exist in the world. As we have seen high duty cycle machines have a maximum energy of a few GeV. In the energy domain above 10 GeV there are 2 facilities dedicated essentially to particle physics : the electron beam (30 GeV) of the HERA *e-p* collider and the SLAC linac (30-50 GeV). Due to their low luminosities ($L \leq 10^{32}$ cm^{-2}.s^{-1} compared to 10^{38} cm^{-2}.s^{-1} for the proposed facility) and small duty factors ($\leq 10^{-3}$) they can only be used as testing grounds for the physics idea we are pursuing.

These considerations led to the development of the ELFE (Electron Laboratory Facility for Europe) project. It originated from a French proposal to build a 3-4 GeV machine which was abandoned after a firm decision on the financing of CEBAF had been taken in the USA. It followed recommendation made in 1989 by an ad-hoc Committee of the french Academy of Sciences chaired by G. Charpak [15] and, at the European level, by NuPECC (Nuclear Physics European Collaboration Committee) in 1991 [16].

The project was co-ordinated by a European Steering Committee of 4 members from France, Germany, Italy and The Netherlands, which was set up in fall 1991. It was punctuated by several topical workshops (in Amsterdam, Clermont-Ferrand, Frascati, Orsay and others) and Conferences (Seillac, 1988 [17] ; Dourdan, 1990 [18] ; Amsterdam, 1991 [19]) culminating in October 1992 by the Mainz Conference fully devoted to the ELFE project and to which about 200 physicists took part.

The Mainz meeting was very lively but it did lack some focus : there were 32 different letters of intent, most of them originating from a single lab or country. It took another year to merge them in ten large international letters of intent and to arrive at a fully formulated proposal which appeared at the end of 1993 [20].

In parallel with the physics case, the machine was studied by a group of accelerator specialists coming from the most important accelerator laboratories in Europe.

4.2. The ELFE machine

The accelerator is shown in fig. 10. It is a single 5 GeV linac recirculated twice to arrive at a final energy of 15 GeV. The characteristics are shown in table 4. The extension to 30 GeV will be made possible by increasing the accelerating power of the super conducting cavities.

$E \geq 15$ GeV for a first step - Up to 30 GeV later
$I \leq 50$ μA at 15 GeV
100 % duty-cycle
$\Delta E/E \leq 3\ 10^{-4}$ at 15 GeV (FWHM)
$\Delta E/E \leq 10^{-3}$ at 30 GeV (FWHM)
$\varepsilon/\pi \leq 10^{-8}$ m.rad at 15 GeV (horizontal emittance, 95 % of the beam particles)
$\varepsilon/\pi \leq 3\ 10^{-7}$ m.rad at 30 GeV (horizontal emittance, 95 % of the beam particles)
3 beams (time-shared with different energies and intensities)
Beam polarization > 80 %, I maximum

Table 4 - Main parameters of the ELFE project.

The size of the machine is fully determined by the energy resolution $\frac{\Delta E}{E}$ which is directly related to the synchrotron radiation losses in the last arc :

$$\sigma\left(\frac{\Delta E}{E}\right) = 1.14 \quad \frac{E^{2.5}(GeV)}{\rho(m)}$$

where E is the energy and ρ the magnetic radius. The size of the arcs has been chosen so that at 10 GeV the energy resolution will be of the order of 10^{-4} (or 1 MeV) allowing, for example, to separate the elastic and inelastic contributions in *e-d* scattering (deuteron binding energy is 2.3 MeV). At 15 GeV, $\frac{\Delta E}{E}$ will be of the order of 3×10^{-4} (or 4.5 MeV) still sufficient to separate major shells in nuclei (which is of the order of 10 MeV). At 30 GeV the resolution will be 10^{-3} (or 30 MeV) allowing to separate events below and above pion production ($m_\pi \sim 140$ MeV).

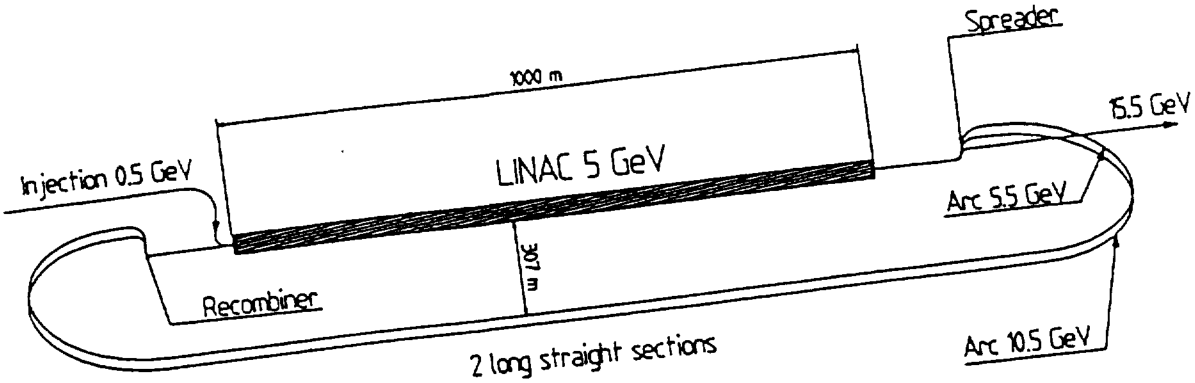


Fig. 10 - The ELFE project : a three pass single linac race-track.

4.3. Detectors

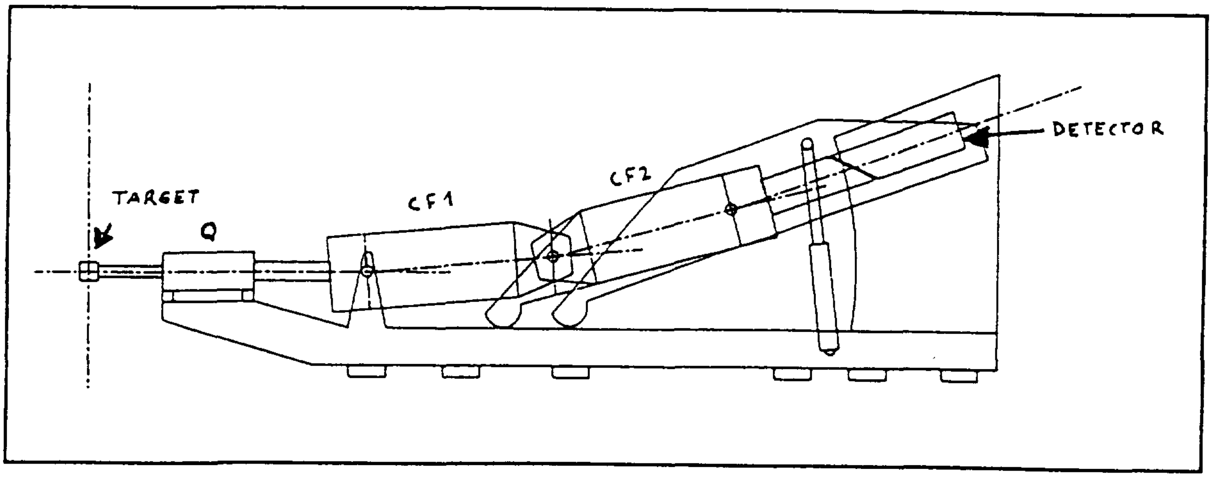
The foreseen experimental equipment is similar to CEBAF with 3 end stations :

i) a high luminosity ($L \sim 10^{38}$ $cm^{-2}.s^{-1}$) experimental area with a pair of high resolution spectrometers (and eventual additional detectors) seen in fig. 11 ;

ii) a mid-luminosity area ($L \sim 10^{35}$-10^{36} $cm^{-2}.s^{-1}$) with a 2π-detector, FAST (Forward Angle Spectrometer, fig. 12) and/or a specialised Di-Muon Spectrometer (DMS, fig. 13) ;

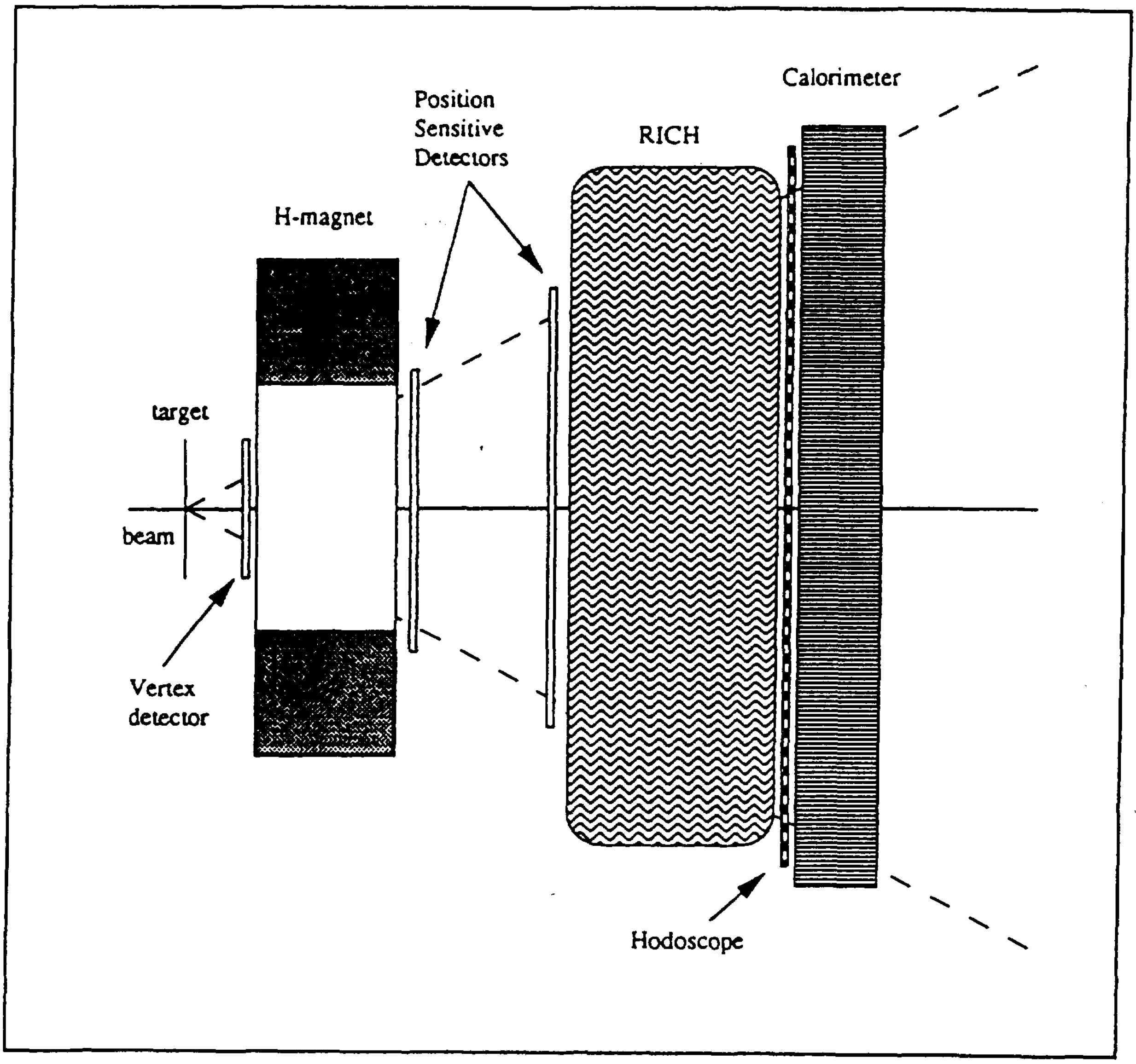
iii) a low to mid-luminosity area ($L \sim 10^{34}$-10^{35} $cm^{-2}.s^{-1}$) with a 4π-detector (MEMUS, fig. 14).

The experimental conditions have been extensively studied through simulation and tracking but the detector themselves are not yet fully studied. They will greatly benefit from the R and D presently done for the LHC detectors.



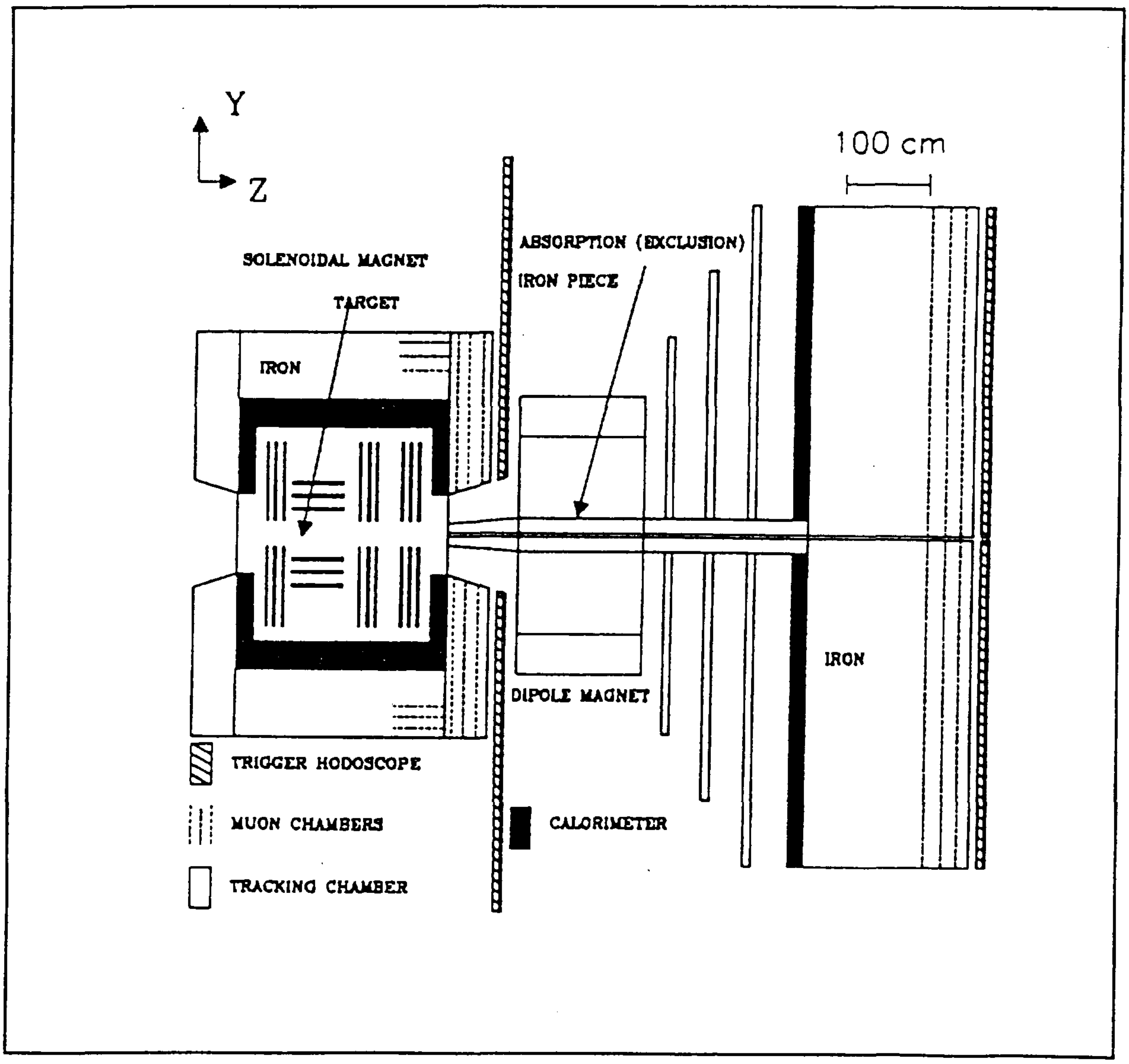
Characteristics for 10 GeV/c momentun at 22° bending angle :	
Distance target →focal point	32.5m
Momentum acceptance	20% (±10%)
Solid angle (elliptical)	7 msr
Magnification	−1.56
Dispersion	2.55 cm/%
First order momentum resolution	0.64 10^{-4} FWHM
Overall resolution	5. 10^{-4} FWHM (estimate)
Vertical (dispersive) angle resolution	1 mrad FWHM
Horizontal (transverse) angle resolution	1 mrad FWHM (0.5 mrad in parallel-to-point optics)
Horizontal position resolution at target	1 mm FWHM
Q:	
length	2.5 m
useful radius	0.5 m
field at useful radius	2. T
CF1:	
length	8. m
useful radius	0.5 m
field at useful radius	dipole: 0.8T Qpole: 0.5T
CF2:	
length	8. m
useful radius	0.5 m
field at useful radius	dipole: 0.8T Qpole: 0.4T

Fig. 11 - High Resolution Spectrometers.



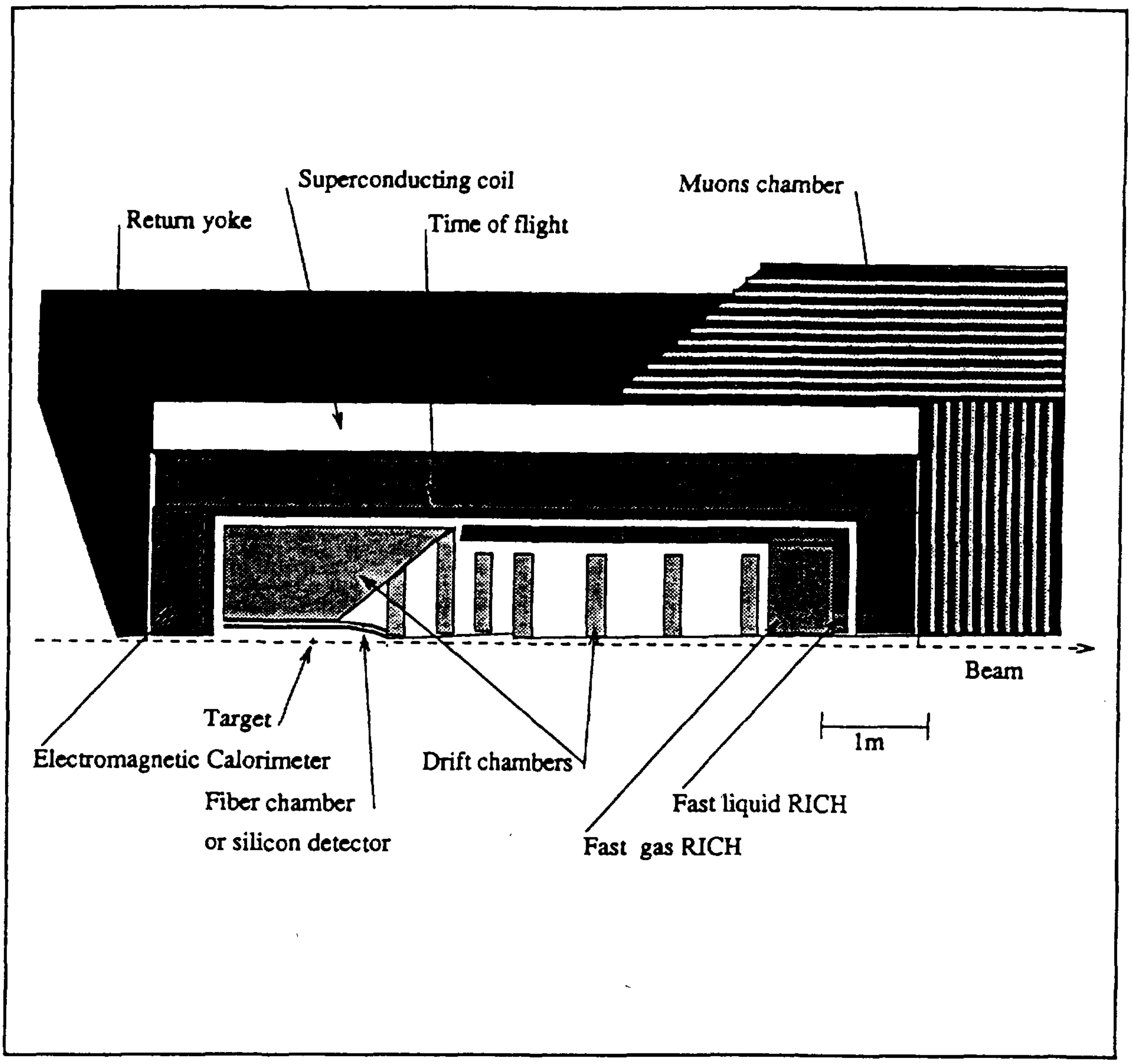
Angular acceptance	< 35°
Energy resolution	<0.5%
Angular resolution	2.5 mrad
Electron energy range	0.5 — 14 GeV
Hadron energy range	1 — 14 GeV
Luminosity	$\approx 10^{35}$ nucleons $cm^{-2}s^{-1}$

Fig. 12 - The forward angle spectrometer (FAST).



Solenoidal magnetic field	2T
Dipolar magnetic field	1.5 T
Angular acceptance	$\theta_e > 2°$ et $\theta_\mu < 50°$
Di-muon acceptance	50% of 4π
Electron momentum range	2.0—20 GeV
Momentum resolution $\Delta p/p$	2%
Minimum muon momentum	1 GeV/c
Luminosity	$\approx 10^{36}$ nucleon cm^{-2} s^{-1}

Fig. 13 - The Di-muon Spectrometers (DMS).



Solenoidal magnetic field	3T
Minimum forward angle	2°
Minimum transverse momentum	.05 to .10 GeV
Momentum resolution for $\theta>5°$	$\frac{\delta p}{p} \approx 0.5\%$
Momentum resolution for $2°<\theta<5°$	$\frac{\delta p}{p} \leq 2\%$
Electomagnetic calorimeter (Forward part: $\theta<40°$)	$\frac{\delta p}{p} \approx \frac{2\%}{\sqrt{E}}$
Solid angle	98% of 4π
Luminosity	$\approx 10^{35}$ nucleon cm^{-2} s^{-1}

Fig. 14 - 4π detector (MEMUS).

4.4. ELFE Physics Program

The physics program would concentrate on the following topics :

4.4.1. Exclusive Reactions

At large momentum transfer they can be cleanly factorized in 3 steps : a central hard scattering which can be described by PQCD and an initial and final hadronic states in which non-perturbative aspects of the interaction enter. Factorization has 2 important consequences which can be tested at high momentum transfer : dimensional scaling and helicity conservation.

Dimensional scaling

The applicability of a partonic description to the hard process entails the existence of dimensional counting rules which apply to the amplitudes, and cross-sections of exclusive process [21]. At high energy and momentum transfer the hard scattering amplitude should scale as $M \sim (\sqrt{s})^{4-n}$ where n is the total number of elementary lepton, photon or quark fields entering or leaving the hard scattering subprocess and s is the square of the total energy in the center-of-mass system.

Combining with the phase-space dependence

$$\frac{d\sigma}{dt} \sim \frac{1}{s^2}|M|^2$$

one deduces the following dimensional counting rule for the cross-section

$$\frac{d\sigma}{dt} = \frac{1}{s^{n-2}} f(\theta_{cm})$$

where $f(\theta_{cm})$ is a functional form at θ_{cm} fixed. In elastic lepton scattering the target partons must share the momentum of the incident virtual photon in order to stay grouped together in the final state. From the scaling behavior of the amplitude one can derive dimensional counting rules for elastic form-factors [22] ,

$$F(Q^2) = \left(\frac{1}{Q^2}\right)^{n-1}$$

where n is the number of partons in the hadron. In the asymptotic limit the simplest quark configurations will be dominant. Therefore n =2 for mesons, n = 3 for baryons, n = 6 for deuterons...

$$F_{\pi}(Q^2) \sim \frac{1}{Q^2}$$

$$F_1^N(Q^2) \sim \frac{1}{Q^4}$$

$$F_d(Q^2) \sim \frac{1}{Q^{10}}$$

Dimensional counting rule is surprisingly well verified for Q^2 as low as 2(GeV/c)^2 for pions and 3-4(GeV/c)^2 for nucleons. Its empirical success for the power law fall-off of form-factors and other reaction mechanisms such as hadron-hadron scattering (not discussed here) has given important evidence for scale invariant quark and gluon interactions at short distances.

In high luminosity, high duty cycle experiments made possible by the ELFE accelerator, dimensional scaling could be checked at much higher transfers (up to 10-15 (GeV/c)^2) where QCD predicts calculable logarithmic corrections to the nominal dimensional counting (running of the strong running constant) and higher order corrections to the hard scattering amplitude (Sudakov effect, pinch singularity, evolution of factorizable non-perturbative wave-functions,...).

In summary the dynamics of exclusive reactions reflect not only the behavior of quark-gluon scattering processes at the amplitude level, but also the fundamental structure of the hadron wave-functions themselves. In a relativistic quantum field theory a bound state cannot be described in terms of a fixed number of constituents. In the case of exclusive reactions at large momentum transfer only the lowest valence-quark Fock state contribute $|q\bar{q}\rangle$ or $|qqq\rangle$. Higher Fock state contributions such as $|qqqg\rangle$ are suppressed by power of the momentum transfer Q for each additional gluon, ensuring a strong simplification.

Experiments which will exploit the unique capabilities of the ELFE project, in terms of luminosity and duty cycle, for exclusive experiments include

a) Virtual Compton scattering from nucleons

b) Elastic and transition form-factors of baryons (proton, excited baryons, deuterons)

c) Meson form-factors

d) Parity-violating experiments

Helicity conservation

Helicity conservation is a consequence of pQCD. At high momentum transfer, the total helicity of hadrons in the initial state must be equal of the total helicity of hadrons in the final state. This selection rule is independent of any photon or lepton spin appearing in the reaction and it is valid to any order of α_S in perturbation theory. The result follows from

a) neglecting the quark masses
b) the vector coupling of gauge particles
c) the dominance of valence Fock states with zero angular momentum projection.

Helicity conservation has many non-trivial consequences such as the suppression of the Pauli nucleon form-factor $F_2 (Q^2)$ compared to the Dirac form-factor $F_1(Q^2)$ at large Q^2. Helicity non-conserving form-factors should fall off with an additional power of $1/Q^2$ [23]. A corollary of hadron helicity conservation is that transverse polarization quantities (polarizations of outgoing particles or analyzing powers) will be zero at high momentum transfers [24]. Deviation from these predictions at sufficiently high momentum transfers would put stringent tests on the factorization hypothesis or the dominance of short transverse distances. They would be a signature of genuine non pQCD effects such as quark-quark correlations (diquarks).

4.4.2. Colour Transparency

This effect is related to the fact that, at high momentum transfer, one can excite pure 3-quark states which have a much smaller transverse radius (typically 0.1 fm or less) than a normal hadron, hence their nickname of "mini-hadrons" [25,26].

These states can then propagate essentially without interaction through nuclear matter. Being colour neutral (the expression "colour transparency" is somewhat misleading) they will expand over a few fermis, that is the typical size of a nucleon, towards the normal size of a hadron which is detected. Then the nucleus will act as a filter, retaining through inelastic interactions the largest states and letting go through the smallest configurations [27].

Colour transparency can be most easily studied with $(e,e'p)$ and $(e,e'\pi)$ reactions but it should manifest in any hadron producing reaction. The first experimental hint at colour transparency in strong interactions came from $pA \rightarrow pp'(A-1)$ reactions between 6 and 12 GeV [28].

Subsequent experiments induced by high energy electrons at SLAC (NE18 experiment) up to momentum transfers of 7 $(GeV/c)^2$ have shown little transparency in Carbon [29] but they are not in contradiction with most theoretical models in view of the limited momentum-transfer and high target mass. Experiments at ELFE would reach momentum of transfers of 15-30 $(GeV/c)^2$.

4.4.3. Heavy Quark Production : Strangeness and charm

Electro-production of strangeness and charm can be accomplished through the production of particles with hidden flavour like the ϕ- or J/ψ vector mesons or through open (and associated) flavour production of final states like $K\Lambda$ or $D\Lambda_c$.

Elastic photo-production of heavy vector mesons (ϕ, J/ψ) involve at least the exchange of two gluons if the ground-state of the proton does not contain a sizeable amount of intrinsic strange or charm component. In the high energy limit two-photon exchange in ϕ production predicts a dip between 2 and 3 $(GeV/c)^2$ as shown in fig. 15 [30,31]. There are presently no data above 1 $(GeV/c)^2$. This experiment would require the developing of a real photon beam and it would be feasible in the first stage (E_e = 15 GeV). It would use the MEMUS 4π-detector shown in fig. 14 with luminosities reaching 10^{36} $cm^{-2}.s^{-1}$, four orders of magnitude larger than present set-ups like HERMES [32].

Due to the large mass of the charmed quark, charm production can be described in a perturbative way (α_S (m_c^2) ~ 0.3). Near threshold the J/ψ is a pure $c\bar{c}$ pair with small spatial extension. It can be used in an ideal way to test the concept of colour transparency.

In order to disentangle effects due to modification of the nucleon structure (which depend only on the density of the medium and not on the particular final state) from those due to colour transparency which depend on the particular charmonium state which is produced, it will be necessary to detect both J/ψ and ψ'.

They will be detected through $\mu^+\mu^-$ pair detection (branching ratio for J/ψ is 7 %) and identification of the final state in the DMS detector shown in fig. 13.

Charm-production would benefit from an increase in the incident energy from 15 GeV to 25-30 GeV. Counting rate estimates show that at 25 GeV one can produce almost 5 millions J/ψ elastically and 50000 inelastically (for L = 10^{36} cm^{-2} s^{-1} and a 100 % acceptance). This is to be compared to the 279 inelastic J/ψ events reconstructed by the NMC collaboration on hydrogen and deuterium, the main experimental information on this topics at this time.

4.4.4. Short-range structure of nuclei

Above 1 GeV/c quark rearrangement and gluon exchanges are expected to take over meson-exchanges as the main interaction mechanism. Two topics will be under investigation at ELFE.

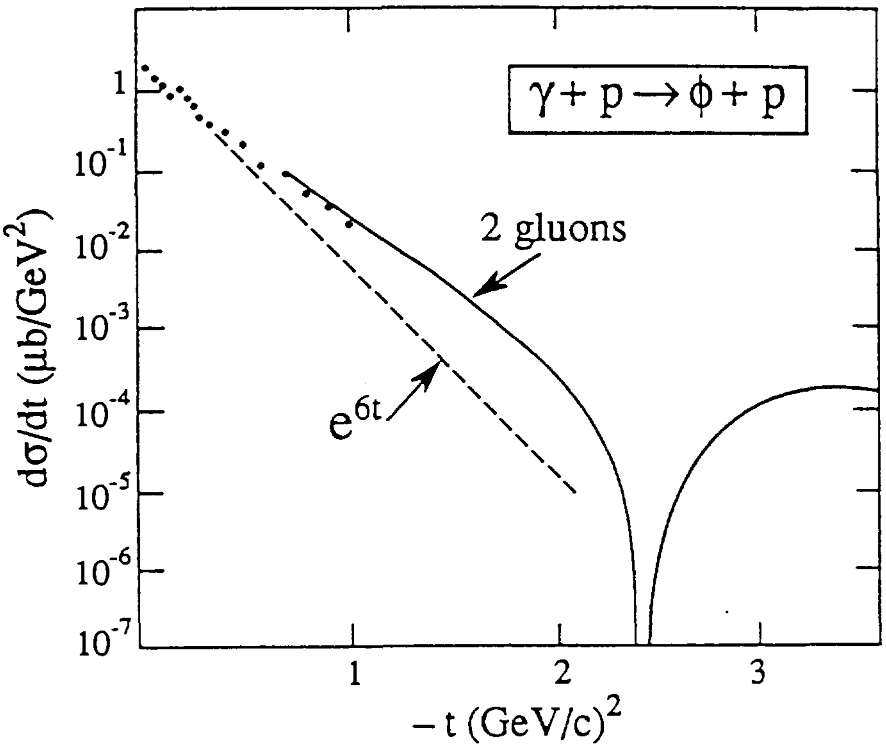


Fig. 15 - Cross-section of the $\gamma p \rightarrow \phi p$ reaction at $E_\gamma = 10$ GeV. The dashed line corresponds to the parametrization of the existing experimental data below $-t = 0.4$ (GeV/c)^2, in the framework of the Vector Dominance Model. The full line corresponds to the two gluon exchange mechanism.

a) *Structure functions at x > 1*

The Bjorken variable x is defined as $x = Q^2 / M_N \nu$ where Q^2 is the four-momentum of the virtual photon, ν is the energy transfer and M_N the mass of the nucleon. In the naive parton model x_i is the fraction of longitudinal momentum carried out by parton i with respect to the proton moving with total momentum P. The elastic scattering corresponds to $x = 1$. In deep inelastic scattering (DIS) on a nucleon x is ≤ 1 : no one quark can carry a momentum larger than the total momentum P. In DIS on a nucleus x is $\leq A$ but for x to be larger than 1 one needs the cooperation of more than 3 quarks. Large values of x imply strong quark-quark correlations between quarks belonging to different nucleons. This would yield fundamental information on the question of quark confinement in nuclei.

An experiment aiming at measuring semi-inclusive DIS on the deuteron is proposed. The detection of a fast recoil proton will select large relative momenta k_F of the two nucleons (from 0.5 to 3 GeV/c) which cannot be explained by trivial effects coming from the Fermi momentum smearing of nucleons in nuclei ($k_F \sim$ 0.2-0.3 GeV/c) which allow only slight excursions above $x = 1$.

This experiment requires a high resolution electron spectrometer ($\Delta p'/p \sim 10^{-3}$) and a large acceptance and moderate ($\Delta p/p \sim 2.10^{-2}$) resolution spectrometer for the proton detection. The availability of a large luminosity ($L \sim 10^{38}$ cm^{-2}.s^{-1}) and high duty cycle will be essential.

b) *Tagged structure functions*

ELFE will investigate to what extent the origin of the EMC effect is in the nucleon correlations. The detection of a backward moving proton in coincidence with the scattered proton will allow to tag the DIS structure functions.

High momentum nucleons that recoil in the backward hemisphere reveal short distance initial-state correlations as opposed to slow moving nucleons which originate mostly from long range correlations.

These experiments may start at HERA, using the Hermes set-up but they will be limited by the luminosity ($L < 10^{32}$ cm^{-2}.s^{-1}) and duty factor. The high luminosity and duty factor of ELFE would extend the coverage in x and momentum of the backward protons.

4.4.5. Colour Neutralization

In DIS at high momentum transfer the virtual photon interacts with a single quark in the target. Being a coloured object the quarks get dressed with a cascade of quark-antiquarks and gluons which neutralize its colour. As a result a jet is formed in a very short time (formation time) over a distance much smaller than a nuclear radius. Then the jet develops interacting with the nucleus on its way out. The measurement of the final state hadrons allows to study the jet space-time structure. In the proposed experiment an emphasis is put on the distribution of the fast hadrons in the current fragmentation region, i.e. the hadrons which take a substantial fraction of the virtual photon energy. A nuclear target provides the opportunity to scrutinize the mechanism of deconfinement at microscopic times and distances. Here the nucleus acts as a detector for any possible reinteraction of the final state particle at a scale of a few fermis. The stronger these reinteractions, the more softened will be the differential energy distributions of the produced hadrons and the largest reduction of the multiplicity of fast forward produced hadrons will be observed through nuclear attenuation.

Different theories predict completely different ν-dependence, momentum distributions and nuclear attenuation : direct production [33], String models [34,35,37,38] or Gluon Bremstrahlung Model [36].

These studies can be extended to the production of hadrons with different flavours. For example in the String model the effective attenuation of a quark at an early stage of hadronization depends on the behaviour of the quark fragmentation function in vacuum at large hadron energies, which is strongly flavour dependent. Therefore fast kaons should be more suppressed than pions and negative kaons more than positive ones.

Due to the low cross-sections for production of very fast hadrons there are only a few scattered data with large error bars obtained with present facilities and they do not differentiate between different theoretical models. The combination of higher luminosity and duty-cycle of ELFE would allow to disentangle these models and improve the comprehension of the deconfinement mechanism.

Other aspects of the scientific program which cannot be discussed within the limited frame of this talk include polarized structure functions (transverse spin distributions, structure functions for targets with spin ≥ 1) whose investigation will start at the HERMES facility, parity violation in quasi-elastic scattering, electro-production of polarized Λ's, high energy exclusive reactions in heavy nuclei, etc...

4. Multidisciplinary applications

ELFE has been optimized for nuclear and particle physics research but its high intensity beams at 5-10 and 15 GeV can be used to drive a powerful Free Electron Laser (FEL) which could produce photon beams with high brilliance in the wavelength range of a few nm, not accessible to present conventional lasers or FEL's. This region corresponds to the "water window" of particular interest for biological imaging and other applications [39].

At these wavelengths there are no mirror available to built an optical cavity and techniques not requiring optical elements will have to be used. The approach proposed [40,41] uses Self Amplified Spontaneous Emission (SASE) in a long (~ 40 m) undulator where the spontaneous emission starts to be amplified by the electron beam itself. Since in the SASE mode there is a single bunch interacting with its own radiation a large beam peak current (of the order of a thousand Amps) is needed which does not correspond to the D.C. mode used for nuclear physics studies. Therefore a separate injector with very short pulses (of the order of 1 ps or less) will be required for producing a high saturated output power (up to 10^{14} coherent photons per pulse). The availability of very short pulses will permit imaging of a sample "in vivo" before it has time to change or to be affected by radiation.

FEL in this wavelength range have been studied at SLAC, DESY and CEBAF. Preliminary studies [42] show that the ELFE characteristics are well adapted for production of FEL radiation if a separate injector with short, high intensity pulses is made available. In view of the very different duty cycle and mode of operation of the two electron beams in the D.C. mode (tens of pics second pulses at 1.3 GHz) and in the FEL sub-picosecond mode (pulses at a few MHz), both modes of operation may be run simultaneously with negligible degradation of the beam qualities as studies at CEBAF have shown [43].

This relatively modest investment would enlarge considerably the scope and users' community of ELFE.

6. Conclusions

There is an adequate supply of electron accelerators dedicated to the study of the nucleus in the energy domain below 1 GeV. In the 4-6 GeV region a new facility built in the USA will provide, world wide, the beams necessary to understand the nucleus at a deeper level but still outside the realm of quarks and gluons. To understand the nucleus at the most microscopic level one needs an accelerator with an energy of the order of 15 GeV or higher, with a large intensity and duty factor.

The ELFE project is a real chance for Europe. The first ELFE report has shown that the machine is feasible without great technological risks and it has shown the interest of the physics program. NuPECC has examined this project and the preliminary recommandations are very positive.

Further studies will most probably allow to reduce the projected cost of the machine (in particular in the domain of super-conducting cavities) and to strengthen the physics case. A great effort of communication has also to be made in direction of our colleagues of other disciplines whether they are close to nuclear physics as the particle physics community or farther away as in biology or solid state sciences to convince them of the fundamental interest of this new facility both for our comprehension of confinement, one still unsolved mystery of nature, and as a multidisciplinary tool by addition of a short wavelength Free-Electron Laser.

A decision on the construction of this facility in 1996-97 would be timely in view of the anticipated shut-down of several existing facilities.

7. Acknowledgements

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