M E S O N   F A C T O R I E S

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INTRODUCTION

The Meson Factories are high-intensity proton accelerators conceived in the sixties to produce pions, and use them as probes of strong interactions, particularly for nuclear physics, but also for particle physics. When their constructions were approved there was also a strong expectation that the availability of the intense pion and muon beams would open up a broad range of new applications, like Muon-Spin Rotation (μSR) and pion cancer therapy. At present three Meson Factories exist and have successfully been in operation for more than a decade, one in USA (LAMPF), one in Canada (TRIUMF) and one in Switzerland (PSI, formerly SIN), while a fourth is being commissioned in USSR, at the Institute of Nuclear Research in Moscow. They all produce a primary proton beam of a few hundreds μA intensity and 500-800 MeV kinetic energy.

The same name is also used for proton accelerators of similar current but higher energies which have been conceived of in the last ten years. In the early 80's they were usually referred to as Kaon Factories, and designed in the energy range 10-20 GeV: the production of high fluxes of kaons for particle and nuclear physics was the main motivation. After the technological advances of CERN in storing and cooling antiprotons, and the success of the LEAR scientific program, these early design were upgraded in energy to allow aboundant production of antiprotons and the name Hadron Facilities has entered common language, to stress the variety of secondaries which can be produced.

After a brief summary of the performances and of the achievements of the Meson Factories, my talk will be dedicated to the scientific motivations for the Hadron Facilities and to a survey of the Proposals which have been put forward in the last couple of years for such Facilities.

PERFORMANCES AND ACHIEVEMENTS OF THE MESON FACTORIES

The techniques adopted at the three existing Meson Factories to accelerate the proton beam are quite different, and result in important differences in the performances, which make the three laboratories somewhat complementary. LAMPF possesses a Linear Accelerator providing the most intense beam and whose structure has constituted a major technological advance. Both TRIUMF and PSI have developed isochronous cyclotrons, allowing for 100% duty cycle, a crucial issue in some coincidence experiments. The relativistic isochronous separated sector-focussed cyclotron at PSI is a very compact and economic accelerator. Acceleration of H^- by the spiral-ridge sector-focussed cyclotron at TRIUMF allows the extraction by stripping of a variable energy proton beam. Table I summarizes some parameters relative to the operation of the three Facilities.

These three Facilities serve a community of over 1000 scientists clustered mainly in small university groups. In spite of the intrinsic diversity of the scientific program, some major guidelines can be identified, both in particle and in nuclear physics[1].

In particle physics the effort has been concentrated on precision experiments in QED and in Weak Interactions, where comparison between data and theory is possible, and discrepancies are clear signals of new physics, and in systematic surveys in the strong interaction sector. Just to quote some results, I can mention

i) the discovery at LAMPF and at TRIUMF[2] of the Lamb shift in muonium points towards another milestone test of QED;

ii) the purely leptonic muon decay is being used to test the standard model of weak interaction. Experiments at TRIUMF in particular have provided the most accurate values for the Michel parameters. The mesurement of the ξ-parameter[3], still gives the most precise limit to the existence of any right-handed weak bosons;

iii) rare and forbidden muon decays are being investigated to provide signals of new physics. Sensitivities in the range 10^{-11}-10^{-12} in branching ratio have been achieved in processes like $\mu \to e\gamma$, $\mu \to 3e$ and $\mu \to e$ conversion in nuclei in the three Laboratories[4], and the Crystal Box collaboration at LAMPF[5] and the SINDRUM collaboration at PSI[6] aim at improvements of more than an order of magnitude;

iv) the primary beam stop provides a clean source of low energy neutrinos from π and μ decay. A very ambitious program on searches for ν-oscillations and ν_e-e elastic scattering has been pursued at LAMPF[7], where the Proton Storage Ring (PSR), which has recently been commissioned, is opening up an ideal and unique facility for ν physics[8].

v) as regards strong interaction, a monumental effort has gone on to obtain the scattering amplitudes for the Nucleon-Nucleon Interaction by a "complete" series of experiments. The program is almost fulfilled for pp scattering, but much work is still needed for the np channel. Some important problems (dibarions) are still open, and important contributions are coming also from higher energy accelerators (Saturne and KEK).

TABLE I: Performances of the Meson Factories

	LAMPF		TRIUMF	PSI
part. accelerated	p	H^-	H^-	p
kin. energy (MeV)	up to 800		180-520	590
average int. (μA)	900	30	150	250
record int. (μA)	1200		200	380
goal int. (μA)	1000	100	500	1500
duty cycle	6 - 9 %		100%	100%
losses	10^{-3}		10^{-1}	2×10^{-4}
pol.beam int.(μA)		0.02	0.6	5
goal int. (μA)		10	10	10

In nuclear physics, the Meson Factories marked the transition from classical nuclear physics, in which only nucleons and the two-body potential between them plaid a role, to a new situation in which many more degrees of freedom (mesons, nucleonic excitations, antinucleons) are all playing a role. There is by now large evidence of these new degrees of freedom: in single and double pion charge exchange reactions, in (π, η) reactions, in pion absorption. To quote only one example, a precision measurement[9] of the spin rotation parameters in polarized proton-nucleus scattering has shown that relativistic effects must be included in the description of low-energy nuclear phenomena.

Quite numerous are also the practical applications:

i) neutron scattering for physics, chemistry, materials science, biology. At all factories the ~1MWatt power beam is eventually used to produce neutrons (PSI is realizing a Pb-Bi target surrounded by a D_2O Moderator to produce cold neutrons). PSR at LAMPF provides neutrons in short pulses (270 nsec);

ii) negative-pion cancer therapy. Very encouraging results have been produced and the program is still being vigorously pursued at both SIN and TRIUMF;

iii) eye-cancer therapy with proton beams;

iv) studies on μ-catalyzed d-T fusion;

v) production of radioisotopes, particularly for positron emetters.

HADRON FACILITIES

By the name Hadron Facilities one refers to new research facilities which are proposed for basic research in Nuclear and Particle physics in the years 1990's and beyond. They consists of a complex of accelerators to produce a high-intensity ($\approx$ 100 μA) proton beam of intermediate energy (in the range 30-60 GeV), which is meant to provide a broad range of intense, high-quality secondary beams of pions, kaons, antiprotons and hyperons, plus muons and neutrinos by decay.

The design energy of at least 30 GeV is determined mainly by the desire to produce copious beams of antiprotons.

The design intensity of $\approx$ 100 μA primary protons is the prerequisite for the envisaged research program. This intensity, two orders of magnitude more than at any comparable accelerator, is the distinctive features of these facilities, because

- it offers the unique ability to perform a few experiments of particular scientific value and priority,
- it allows the simultaneous operation of secondary beam facilities,
- experiments with high intensity beams could give access to new phenomena, not foreseen on the basis of present knowledge and theoretical ideas.

At present three proposals exists,one at LAMPF[10], one at TRIUMF[11] and one in Europe[12], and plans are being formulated both in Japan[13] and in USSR[14]. Both the physics case and the specific accelerators of the various proposals have been thoroughly discussed over many years in International Conferences and Workshops, so that there is a strong expectation in the scientific comunity for the first approval. In the while work is going on to improve the accelerator design and possibly reduce the costs, through international workshops organized regularly by Los Alamos, TRIUMF and the EHF group. This international effort can be appreciated also at this Conference, where more than a dozen contributed papers on different aspects of the Hadron Facilities have been submitted.

The availability of intense secondary beams of different flavours will guarantee a rich and diversified experimental program. Although the description of the sub-atomic world has undergone spectacular achievements over the last decades, many fundamental problems are still unresolved, and require dedicated experiments at low energy. Broadly speaking:

i) the dynamics of quarks and gluons is still not described by a complete and self-consistent theory. Quantum-Chromo-Dynamics is surely an important step, but so many problems (first of all confinement) are either unresolved or uncalculable that strong interactions are still an open problem. Vigorous experimental programs on hadron spectroscopy and reaction mechanisms, with particular care to spin effects, are proposed at the Hadron Facilities, as well as selected experiments with nuclear targets, to probe confinement in the nuclear medium.

ii) the existence of several families of quarks and leptons is a puzzle. The dynamical origin of the masses of the fermions, the only parameter differentiating the various families, is completely unknown. The search for the presence of high masses in rare or forbidden processes is probably the best way to get signal of new Physics. The study of the decay modes of the kaons has always been considered of such an importance to justify by its own the construction of dedicated facilities.

No unique "magic experiment" can be proposed today to solve the two problems above, but the intrinsic variety of experiments which can be performed at a hadron facility is the best guarantee of important findings and possibly new physics.

From the experience we have with the Meson Factories, we may add that the Hadron Facilities will surely contribute also to various applied fields such as studies on muon-induced fusion, neutron physics, medical programs, and others.

THE EUROPEAN HADRON FACILTY

I will describe the EHF project first not only because it is the one I know best, but also because it is a "green-field" project, not relying on any existing injector, and consequently can be regarded as an optimal project. Unlike the other proposals, EHF is not being proposed by an existing laboratory. It is a project which is being proposed for Europe by a group of physicists, the EHF Study Group, on behalf of a community of interested European physicists[15]. The accelerator concept has been worked out by an international team of accelerator physicists in close collaboration with the experts from Los Alamos and TRIUMF, the so-called EHF Design Group. The activities of the group have been sponsored mainly by Germany (Bundisministerium für Forschung und Technologie) and by Italy (INFN).

The proposed EHF is the complex of accelerators schematically illustrated in Fig. 1, whose main components are a high-energy LINAC, accelerating a H^- beam to 1.2 GeV, and two fast cycling synchrotrons,

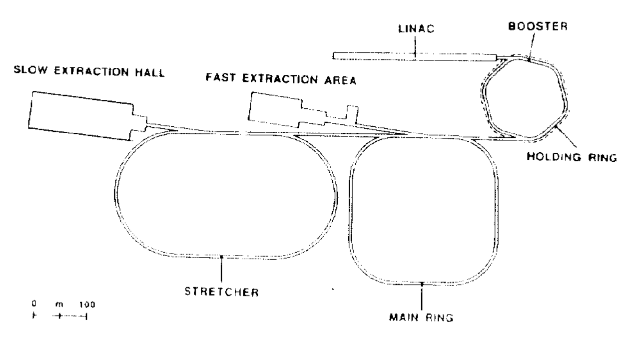

Fig. 1: The complex of accelerators of the European Hadron Facility.

a 9 GeV Booster Ring and a 30 GeV Main Ring, with radii and repetition rates of ratios 1:2 and 2:1 respectively. The Main Ring circumference has been chosen to be 960 m. The repetition rates of the LINAC and of the Booster are the same, 25 Hz. The H^- beam pulse coming from the LINAC is stripped into a proton beam by passing through a thin foil and injected directly into the Booster over 200 turns.

Two more rings complement the system, a 9 GeV Holder Ring, with the same radius as the Booster, and where the Booster pulses are stored before being transferred to the Main Ring, and a 30 GeV Stretcher Ring, having the same length as the Main Ring Synchrotron, where the fast extracted 30 Gev beam from the Main Ring is stored and then slowly extracted to produce 100% duty factor secondary beams. The 1:2 ratio between the repetition rates of the Main Ring and the Booster allows to have a Holder Ring of the same size as the Booster, rather than of the same size as the Main Ring as customary. Only one Booster pulse is thus stored in the Holder Ring, the second one passing through the just emptied Ring and going directly to the Main Ring. The use of these two relatively low-cost storage rings allows to continuously run acceleration cycles in the Booster and Main Ring without the need to "flat-top" or "flat-bottom" the magnet cycles. The net advantages are less strain on the RF system and a 100% duty factor for the slowly extracted proton beam.

The facility also includes two experimental areas: one that takes beams in the fast extraction mode, and the other for extraction with high duty cycle.

The repetition rate of the Main Ring, 12.5 Hz, follows directly from the EHF current requirements (100 μA) and from the limit to the maximum number of protons per pulse given by current experience with existing similar machines ($\simeq 5 \cdot 10^{13}$).

Further constraints on the machine parameters have been provided by the requirement of accelerating polarized proton beams of the same intensity as the unpolarized beams. This will be achieved by fast Q-jump across the few residual resonances in the Booster and by maintaining polarization in the Main Ring with a Siberian Snake.

The design of the accelerator is based on two major considerations: beam losses and cost. Because of the large current required, it is crucial to minimize losses in order not to create a hazardous situation with radiation levels which would entail costly and cumbersome remote handling equipment. The requirement for losses means reliability both of the complex design and of the components finally adopted. The losses over the entire accelerating cycle have been assumed to be of the order of 1%, mainly occuring at injection from the LINAC into the Booster and at the slow extraction. Since losses at the extration septum are unavoidable, separate tunnels are proposed for the Main Ring and the Stretcher, whose lattice could thus be optimized indpendently of geometric constraints. The proposed racetrack design allows for a high β insertion in the Stretcher, yielding a highly efficient slow resonant extraction.

Minimization of beam losses has been achieved by (i) properly choosing the main accelerator parameters which are of relevance for the beam instabilities, (ii) phase locking all the machines, so that the beam is always transferred bunch-to-bucket, (iii) proposing a new beam injection technique for entering into the Booster, and (iv) placing very safe margins on the magnet apertures.

A great amount of work has been devoted to the optimization of the injecton scheme from the LINAC into the Booster. The beam pulse coming from the LINAC is a train of bunches, at a frequency (400 MHz) which is 8 times the rf frequency at injection in the Booster (50 MHz). To optimize the filling of the Booster bucket, a certain number (six in the present design) of the eight buckets coming from the LINAC are left empty, and by a special "painting" technique the central part of the bucket area is filled uniformily. The possibility of losses by placing the beam too close to the boundary of the r-f bucket is thus eliminated.

This scheme requires

i) an efficient phase-compression of the dc beam coming from the H^- source, to prepare the empty-bucket structure in the Linac. This is achieved with a cascade of two RFQ's;

ii) an efficient "painting" technique in both transverse and longitudinal phase space to properly populate the Booster bucket;

At present,the EHF Design Group is still dedicating a considerable effort to investigate these two problems, as well as

iii) the slow extraction system, where an invention is probably needed to cut down drastically the losses;

iv) the design of the siberian snakes in the Main Ring. An original suggestion of E.D. Courant[16] allows for designs with small orbit excursion inside the magnets, so that further optimization of the transfer energy between the Booster and the Main Ring synchrotrons is still possible.

THE TRIUMF KAON FACTORY

The primary aim of the TRIUMF proposal for a KAON Factory, where KAON stands for Kaons, Antiprotons, Otherhadrons and Neutrinos, is the same as in the EHF case, mainly to provide a 100 μA beam of protons at 30 GeV. The differences in the accelerator complex are mainly due to the decision to use the existing cyclotron as injector. To match the cw beam coming from the cyclotron with the frequency of the booster synchrotron (50 MHz) an Accumulator ring is needed, where the 450 MeV H^- are stripped into protons and accumulated over the many thousands of turns required. The Booster synchrotron then accelerates the proton pulse to 3 GeV. In the main tunnel are the Collector ring, which collects 5 Booster pulse trains, the 10 Hz Main Ring Synchrotron (the Driver) and the dc Stretcher Ring (the so-called Extender) where beam is stored for slow resonant extraction. As in the case of EHF, various design features, such as H^- stripping injection, no crossing of transition energy, and bucket-to-bucket transfer are meant to avoid or reduce beam losses.

Since the editing of the Proposal, considerable ammount of work has been devoted to improve the design and to carry on hardware studies.

For what concerns the first point, studies are concentrated on

- the slow extraction. By use of a short additional pre-septum one can dilute the beam density at the main septum and reduce losses to 0.2% (in a simulation);
- the lattices for the Main Ring and the Stretcher. To improve even more on the slow extraction, a racetrack design has been studied for the Stretcher, which in the original design had a circular geometry, like the Main Ring. To put the Main Ring in the same tunnel, a racetrack lattice is being investigated and checked against depolarizing effects and betatron resonances. Fig. 2 shows a possible arrangement of the new rings on the TRIUMF site.

As regard the second point, R & D is going on for

- the H^- extraction, which is not the standard way to extract the beam from the cyclotron;
- the radio-frequency system, in close collaboration with the Los Alamos group. The original Los Alamos cavity, using perpendicularly-biased microwave ferrite, has been operated with good Q-values over the entire frequency range required at TRIUMF;

–the Magnet Power Supply. In all the projects dual frequency magnet excitation is planned, with a rise -time three times longer than the fall, to reduce the rf voltage requirements.

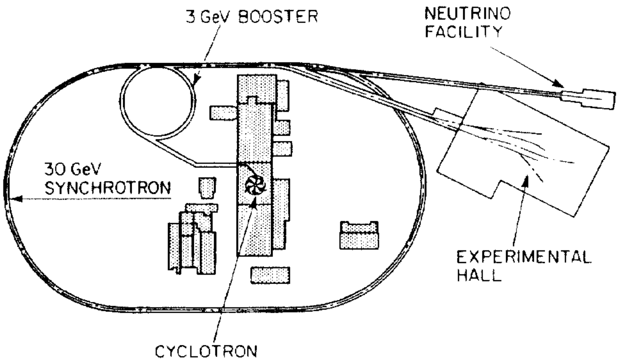

Fig. 2: Possible site layout of the TRIUMF KAON Factory.

THE LOS ALAMOS ADVANCED HADRON FACILITY

The 800 MeV Linac at LAMPF being an almost ideal injector for a Hadron Facility, it is natural that the Los Alamos Laboratory has been the first to work out a specific proposal, LAMPF II, and to push for a strong R & D program on ferrite-tuned rf, on ceramic vacuum chambers, and on magnets and power supplies. This original proposal is now being reconsidered and a new concept for an Advanced Hadron Facility (AHF) is being prepared[17], which includes much of the original design but takes into account new users' requirements and the initial experience from the new Proton Storage Ring (PSR) commissioning.

The main differences from the other two projects are

- the Facility foresees a Neutron Spallation Source for Materials Science with $\sim 10^{17}$ n/(cm^2 sec) peak flux;
- to better match the requirements of the proposed scientific programm, AHF is a dual energy machine [600 μA at 1.6 GeV for ν's and neutrons and 25 μA at 60 GeV], with fast extraction at low energy, and slow extraction at high energy;
- to reduce the operation and maintenance costs careful consideration is given to accelerator designs with fewer rings, in particular without the Stretcher (at the expense of the duty cycle).

At present, the most favourite design consists of

- the existing 800 MeV Linac as injector (suitably modified),
- a new 800-1600 MeV Afterburner Linac,
- a 1.6 GeV Compressor Ring (600μA),
- a 1.6-10 GeV Booster, 635 m circumference, 25μA, 12 Hz,
- a 10 GeV Holder Ring, 635 m circumference, dc,
- a 10-60 GeV Main Ring, 1270 m circumference, 25μA, 6 Hz.

Similar design with different ratios between the lengths of the Booster and of the Main Ring are also being investigated, in particular

- a full-size Booster and Main Ring (thus not needing a Holder Ring).
- a fourth-size Booster, full-size Collector and Main Ring.

Much attention is also given to an option in which a 2.2 GeV Linac injects directly into the Main Ring. A special Siberian Snake has been designed[18] in which the spin rotation is performed with small orbit excursions, and is therefore particularly suited for low energy rings. Using a 20-m discrete snake at 1.5 Tesla, the orbit excursion is 7.5 cm at 2.2 GeV, so the single-ring option is the most appealing for the acceleration of the polarized beam (there being no booster, there are new resonances to cross). Clearly, there are many problems in this scheme (essentially they are all concentrated in a single synchrotron!) so much more work is needed before a specific architecture will be chosen.

In parallel with these design studies, a vigorous program on hardware development is being pursued, mainly for

- rf cavities. The Los Alamos high voltage group has been working on a ferrite-tuned high voltage booster cavity for several years, and has achieved 140 KV on a single gap with 15% duty factor, 20% tuning range, and R/Q of 35 Ohms. In the framework of the Los Alamos-TRIUMF collaboration they are now undertaking the design and construction of a second generation cavity for the Main Ring, to be tested in PSR;
- fast kickers for ring-to-ring beam transfer and abort systems;
- H^- injection. Studies of beam losses at PSR have revealed the importance of single and multiple scattering of the proton beam in the stripper foil, and the necessity of a painting scheme at injection into the booster which minimizes foil hits;
- ceramic vacuum chambers. The rapid cycling magnets of the Hadron Facilities Synchrotrons pose difficult constraints to the vacuum chambers. To minimize the coupling impedence without interference with the ac guide field, the Los Alamos group proposed and developed a special ceramic vacuum chamber with conducting stripes on the inside to carry the image of the beam current. Development work will go on, in collaboration with industry.

OTHER PROJECTS

As already mentioned, two more Hadron Facilities are being actively designed, one by the Institute for Nuclear Research, Moscow, where a 600 MeV proton LINAC is expected to enter into operation in 1990, and the second by KEK. No proposals exist yet. Both Facilities aim at ∿ 100 μA proton beam at 30 GeV, and the conceptual designs are very similar to that of EHF. Very much like Los Alamos, KEK puts a lot of weight on interdisciplinary science, and proposes as first stage a 1 GeV Linac and a Compressor Ring where condensed matter physics with pulsed spallation neutrons would complement nuclear and particle physics.

PERSPECTIVES

The cost of any of the proposed Facilities is in the range US$ 400-500 M, somewhat more for EHF to create the laboratory infrastructure, so in spite of the strong pressure of the interested physicists the approval procedure is not straightforward.

The project which at present is closer to approval is the one proposed by TRIUMF, which has found a strong international support in the scientific comunity. The province of British Columbia has made the KAON Factory its top priority project with the Canadian federal government, and has agreed to fund the building and the tunnels (Cdn$ 87 M), provided the federal government funds the technical equipment. The province also agreed to support an $ 11 M one-year study on a cost-shared basis with the federal government. A joint federal-provincial delegation has traveled abroad to seek international support, and found that a number of countries would consider significant contributions to the cost. With this favourable signs British Columbia is pressing the Canadian federal government to approve the project as early as in 1988.

Los Alamos is looking at AHF in the long-term future of the laboratory. The goal is to start construction in 1993, once CEBAF is completed and RHIC is well underway, and to carry on R & D in the meantime to optimize the project. The situation is somewhat similar for the KEK project and for the Moscow Hadron Facility.

EHF has been carefully considered by INFN in the framework of building a new international laboratory in Italy, and as such it is explicitly mentioned in the new five-year plan (for the years 1989-1993). Availability of resources and of manpower is clearly a problem, so no funding has been allocated yet, a decision in this sense being considered premature. Still, there is enough flexibility in the new five-year plan to allow for the start up of a big project like EHF if agreement is found in the scientific comunity. What has not been exploited in so far in Europe is the interdisciplinary character of the Hadron Facility, and the bridge it constitutes not only between particle and nuclear physics, but also between pure and applied science. Very little overlap has there been in the past between different disciplines, so probably big technological and scientific advances will in the future stem mainly in new interdisciplinary areas where biologists, physicists and chemists share their competence and work on new problems.

CONCLUSIONS

It is of great importance for the International community that TRIUMF be quickly approved.

I must stress, however, that the approval of TRIUMF does not satisfy the demand for such Facilities, in particular it does not satisfy the demand of the several hundred physicists who want a Hadron Facility in Europe, which has a long and solid tradition in Intermediate Energy physics.

The Italian Minister for the coordination of Scientific and Technological Research, prof. A. Ruberti, said yesteday in his opening speech that.... "CERN, Desy, Grenoble, Rutherfort, Trieste and the Gran Sasso constitute a sort of United European Network of Large Facilities.... which is a unique achievement in the world." My recommandation to the scientific community at this first European accelerator conference is that EHF be the next member in this network.

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