

Programme non thématique 2005

APPEL A PROJETS DE RECHERCHE

I - FICHE D'IDENTITE DU PROJET

N° dossier : :NT05-1_41853:Meot:Francois:

(reprendre la référence qui vous sera attribuée automatiquement par le logiciel de soumission)

Secteur disciplinaire principal (*cf. liste en dernière page de ce dossier*) :

Autre secteur disciplinaire facultatif (*cf. liste en dernière page de ce dossier*) :

Project title (*maximum 120 caractères*)

FIXED FIELD SYNCHROTRONS
 - APPLICATION : SECOND GENERATION MEDICAL SYNCHROTRON -

Acronyme or short title (*12 caractères*) **RACCAM** (Recherche en ACCélérateurs et Applications Médicales)

Key-words (la liste des mots-clés sera donnée sur le logiciel de soumission)

Physics : nuclear physics– particles. Biology and health : imaging, immunology

Project coordinator (Partner 1)

	Name	First name	Laboratoire (nom complet)	Type (établissement public, fondation, association, entreprise)
Mr	Méot	François	IN2P3 / LPSC & CEA / DAPNIA	
Mr	Froidefond	Emmanuel	IN2P3/LPSC	
	Fourrier	Joris	IN2P3/LPSC	PhD
Mr	Autin	Bruno	CERN (retired)	
Mr	Collot	Johann	IN2P3 / LPSC	

Other partners¹

	Name	First name	Laboratoire (nom complet)	Type (établissement public, fondation, association, entreprise)

¹ Insérer autant de lignes que nécessaire

Mr	Neuvéglise	Damien	SIGMAPHI	Industrial company
Mr	Balosso	Jacques	Radiation – Oncology Department, Grenoble Univ. Hospital	Public hospital
Mr	Pommier	Pascal	Centre Léon Bérard, Lyon	Public hospital

Number of persons involved in the project (equivalent full time : ETP) :

Chercheurs et enseignants-chercheurs permanents __ **1.05**

Post-doctorants déjà recrutés _____ PhD __1_____ Ingénieurs et techniciens __ **1**

Project duration : **■36 mois**

Total funding request :

(reporter ici le total du tableau D-a)

600 000 €

Estimation (for information) of total cost of the project :

(reporter ici le total du tableau D-b)

1 068 539 €

Abstract of the project (*maximum 3000 caractères*)
(objectifs, résultats attendus, méthodologie)

CONTEXT :

Fixed field alternating gradient synchrotrons (FFAG) are based on the use of magnets with field constant in time, by contrast with pulsed synchrotrons (e.g., hadrontherapy machines, LHC) of which the magnetic field increases in synchronism with particle acceleration. The unique properties of FFAGs have caused a regain of interest in the last years, motivated in particular by recent progress in high gradient accelerating systems, in 3D magnet computation codes, and by modern concepts as “non-scaling” optics and fast acceleration.

FFAGs are fast cycling accelerators (kHz range), with enormous geometrical and momentum acceptance. The combination of these two properties yields beams with large average intensity, comparable to cyclotrons ; in addition the quality of the manipulation of beams is that of synchrotrons : strong focusing, variable energy, efficiency of transmission and extraction.

This context, as well as on-going works in the frame of the international collaboration on the rapid acceleration of muons in the neutrino factory, has seen the birth of a **project of a 10-20 MeV electron demonstrator. This electron model could be based in Europe, and would aim at proving the feasibility of the innovative concepts of “non-scaling” optics and fast acceleration.**

This new class of FFAGs is a credible concurrent of cyclotron, Linac and pulsed synchrotron accelerators, as an answer to the present needs in high average intensity beams, and offers variable energies as desired in medical applications.

The goal of the RACCAM project presented here is to contribute to the FFAG R&D

- **within the on-going international collaborations,**
- **in Europe by contributing to the electron model of a non-scaling FFAG, in domains as beam dynamics studies, machine design, and by the realisation of a prototype of an FFAG magnet.**

In addition, RACCAM has the ambition of studying the application of this new class of FFAGs in the medical domain, as a second generation proton and light ion accelerator for cancer treatment by radiotherapy.

If a technological breakthrough could make proton beams easily available to radiotherapy, protons would totally dominate radiotherapy and would undoubtedly represent in the future more than two thirds of the indications, if not even more. This is a domain with potentially very strong development, with purely technical and economical constraints.

These synchrotrons will be simpler to build and to operate, more compact, more performing, cheaper than conventional synchrotrons, with proton dose rates comparable to cyclotron ones, and with variable energy allowing 3D conformational irradiation of tumors (“active scanning”).

The innovative character of the researches and related R&D, as well as the collaboration between Physics, Industry and Medical domains, confer to RACCAM a strong potential of genesis of industrial and intellectual property.

Je déclare exactes toutes les informations contenues dans ce document

Visa du Directeur du laboratoire

Lu et approuvé, date et signature du coordinateur du projet

Nom, prénom, date et signature

François Méot

8 juin 2005

En cas de recouvrement thématique avec d'autres appels à projets lancés par le GIP ANR, les porteurs de projet devront veiller à choisir l'appel d'offres le mieux adapté à leur projet. Les équipes impliquées dans plusieurs AAP soumis au GIP ANR devront le mentionner explicitement.

François Méot (IN2P3 et CEA) and Damien Neuvéglise (SIGMAPHI) participate in the « SOPHI », positron source, project

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APPEL A PROJETS DE RECHERCHE

II - PRESENTATION DETAILLEE DU PROJET

A - Identification du coordinateur et des autres partenaires du projet

Acronym or short title :	RACCAM
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A-1 – Partner 1 = Project coordinator

Un coordinateur, responsable scientifique du projet, doit être désigné par les partenaires.

Civilité ²	Nom ²	Prénom ²
Mr	Méot	François
Grade ²	Ing-Dr / HDR	
Mail ²	meot@lpsc.in2p3.fr	
Tél ²	+33 (0)4 76 28 40 90	Fax ² +33 (0)4 76 28 40 90

Laboratoire ² (nom complet)					
Laboratoire de Physique Subatomique et de Cosmologie, CNRS-IN2P3					
N° Unité (s'il existe)				
Adresse complète du laboratoire ²					
53 Av. des Martyrs F-38046 Grenoble Cedex 09					
Ville ²	Grenoble	Code postal ²	38046	Région ²	Rhône-Alpes
Organismes de tutelle (indiquer le ou les établissements et organismes de rattachement, souligner l'établissement susceptible d'assurer la gestion du projet) :					
CNRS IN2P3 LPSC					

Main publications :

Liste des principales publications ou brevets (max. 5) de l'équipe partenaire (définie tableau ci-dessous) au cours des cinq dernières years, relevant du domaine de recherche couvert par la présente demande dans l'ordre suivant : Auteurs (faisant apparaître en souligné les auteurs faisant effectivement partie de la demande), Year, Titre, Revue, N°Vol, Pages. N'indiquez pas les publications soumises.

² Champ obligatoire

- 1: F. Méot, Fixed field alternating gradient synchrotrons, Procs. HHH 2004 workshop, CERN, Nov. 2004, Invited talk ([http://care-hhh.web.cern.ch/care-hhh/HHH-2004/Proceedings/Session 5/paperHHH04-Meot.pdf](http://care-hhh.web.cern.ch/care-hhh/HHH-2004/Proceedings/Session%205/paperHHH04-Meot.pdf)).
- 2: F. Lemuet, F. Méot, Developments in the ray-tracing code Zgoubi for 6-D multiturn tracking in FFAG rings, NIM A (2005).
- 3: B. Autin, R.C. Fernow, S. Machida, D. A. Harris, NuFact02 Machine Working Group Summary, J. Phys. G: Nucl. Part. Phys. 29 (2003) 1637-1647.
- 4: H. D. Haseroth, B. Autin, R. Bennett, F. Méot, S. Gilardoni, C. Prior, P. Sievers, A. Verdier, Neutrino Factory R&D in Europe, NuFact & Superbeams, A. Para Editor, AIP Conference Proceedings, Vol 721, 48-56 (2003).
- 5: P. Bertrand, J.-L. Biarrotte, J.-M. De Conto, R. Duperrier, E. Froidefond, N. Pichoff, D. Uriot, F. Varenne, Status Report on the Beam Dynamics Developments for the SPIRAL 2 Project, Procs. EPA Conf. (2004).

Coordinator (Partner 1)

	Surname	Name	Present position	% of time to give to the project	Task and responsibility in the project
Coordinator	Méot	François	Chercheur	50	Beam dynamics, machine design, code development
Members of the team	Froidefond	Emmanuel	Ingénieur	50	Magnet calculations & measurements, beam dynamics
	Autin	Bruno	Physicien	25	Beam dynamics, machine design, code development
	Collot	Johann	Director of LPSC	10	Machine design, medical application of FFAG beams

Pour chacun des membres de l'équipe dont l'implication dans le projet est supérieure à 25%, fournir une biographie **d'une page maximum** qui comportera :

A/ Nom, prénom, âge, doctorat, stage post-doctoral, situation actuelle

B/ Autres expériences professionnelles

C/ Liste des 5 publications (ou brevets) les plus significatives des cinq dernières years

D/ Prix, distinctions

Partner 2

	Surname	Name	Present position	% of time to give to the project	Task and responsibility in the project
In charge	Neuvéglise	Damien	Ingénieur	50	In charge of magnet design, construction, and field measurements

Pour chacun des membres de l'équipe dont l'implication dans le projet est supérieure à 25%, fournir une biographie **d'une page maximum** qui comportera :

A/ Nom, prénom, âge, doctorat, stage post-doctoral, situation actuelle

B/ Autres expériences professionnelles

C/ Liste des 5 publications (ou brevets) les plus significatives des cinq dernières années

D/ Prix, distinctions

Acronyme ou titre court du projet RACCAM

A-3 : Other partners of the project ³ - Partner 3

Un responsable scientifique de l'équipe partenaire doit être désigné

Partner 2

⁴	Name ⁴	First name ⁴
Mr	Balosso	Jacques
Grade ⁴	PU-PH (University Professor – Physician)	
Mail ⁴	JBAlosso@chu-grenoble.fr	
Tél ⁴	04 76 76 54 35	Tél ⁴

Laboratory ⁴ (nom complet)					
Radiation Oncology Department, University Hospital of Grenoble (France)					
N° Unité (s'il existe)				
Complete address of the laboratory ⁴					
Hôpital A. Michallon BP 217 F-38043 GRENOBLE Cedex 09					
Town ⁴	Grenoble	Town ⁴	Grenoble	Town ⁴	Grenoble
Administration for research : Medical School of Grenoble which belongs to the Joseph Fourier Scientific University - Grenoble 1					

³ Remplir une fiche par équipe partenaire

⁴ Champ obligatoire

Main publications :

- 1: Corde S, Joubert A, Adam JF, Charvet AM, Le Bas JF, Esteve F, Elleaume H, **Balosso J**. Synchrotron radiation-based experimental determination of the optimal energy for cell radiotoxicity enhancement following photoelectric effect on stable iodinated compounds. Br J Cancer. **2004** Aug 2;91(3):544-51.
- 2: Biston MC, Joubert A, Adam JF, Elleaume H, Bohic S, Charvet AM, Esteve F, Foray N, **Balosso J**. Cure of Fisher rats bearing radioresistant F98 glioma treated with cis-platinum and irradiated with monochromatic synchrotron X-rays. Cancer Res. **2004** Apr 1;64(7):2317-23.
- 3: Adam JF, Elleaume H, Joubert A, Biston MC, Charvet AM, Balosso J, Le Bas JF, Esteve F. Synchrotron radiation therapy of malignant brain glioma loaded with an iodinated contrast agent: first trial on rats bearing F98 gliomas. Int J Radiat Oncol Biol Phys. **2003** Dec 1;57(5):1413-26.
- 4: Corde S, **Balosso J**, Elleaume H, Renier M, Joubert A, Biston MC, Adam JF, Charvet AM, Brochard T, Le Bas JF, Esteve F, Foray N. Synchrotron photoactivation of cisplatin elicits an extra number of DNA breaks that stimulate RAD51-mediated repair pathways. Cancer Res. **2003** ;63(12):3221-7.
- 5: Pommier P, **Balosso J**, Bolla M, Gerard JP. [The French project ETOILE: review of clinical data for light ion hadrontherapy] Cancer Radiother. **2002** Dec;6(6):369-78. French.

Partner 3

	Surname	Name	Present position	% of time to give to the project	Task and responsibility in the project
Responsible	Balosso	Jacques	Professor and physician (radiation oncologist)	10%	Determination of medical needs, and medical context for the application for anti-cancer therapy and disease diagnosis. Development of new concept of use based on the original characteristics of FFAG machines.
Team member	Pommier	Pascal	Physician (radiation oncologist)	10%	Organisational and economical study of needs, implementation and recruitment for machines of new generation

Pour chacun des membres de l'équipe dont l'implication dans le projet est supérieure à 25%, fournir une biographie **d'une page maximum** qui comportera :

A/ Nom, prénom, âge, doctorat, stage post-doctoral, situation actuelle

B/ Autres expériences professionnelles

C/ Liste des 5 publications (ou brevets) les plus significatives des cinq dernières années

D/ Prix, distinctions

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B - Description of the project

Acronym or short title of the project	RACCAM
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B-1 – Objectives et context : *(2 pages maximum en arial 11, simple interligne)*

On situera le projet dans le contexte international en y précisant les objectifs et les enjeux.

The goal of RACCAM is, on the one hand to contribute to theoretical studies and to on-going international R&D activities concerning FFAGs, on the other hand to contribute to the project of an electron model of a non-scaling FFAG based in Europe, in particular by developing within our laboratories a prototype of a non-scaling, non-linear magnet. In addition, RACCAM has the goal of studying the use of this “second generation” class of light ion and proton synchrotrons in the medical domain, in view of the radiological treatment of tumors. These synchrotrons will be of simpler construction and operation, more compact, and much cheaper than conventional synchrotrons, with better performance of dose delivery in protons (comparable to cyclotrons) and with variable energy. If such innovation was made available, the large majority of radiotherapy, certainly more than the two third, could be done by proton beams.

CONTEXT – ACCELERATORS. Fixed field synchrotrons (FFAG) are based on the use of magnets with field fixed in time, by contrast to pulsed synchrotrons (e.g., hadronthérapie machines, LHC) in which the magnetic field increases in synchronism with particle acceleration. The unique properties of FFAGs have caused a regain of interest in the last years, motivated in particular by recent progress in high gradient accelerating systems, in 3D magnet computation codes, and by modern concepts as “non-scaling” optics and fast acceleration.

The two key characteristics of FFAGs are, the fast cycling (kHz range), and the enormous geometrical and momentum acceptance. The combination of these two properties yields beams with large average intensity, comparable to cyclotrons ; in addition the quality of the manipulation of beams is that of synchrotrons : strong focusing, variable energy, efficiency in transmission/extraction.

These properties make the FFAG a credible concurrent of cyclotron, Linac and pulsed synchrotron accelerators, as an answer to today’s needs in high average intensity beams with variable energie as is the case in medical applications, in high power beams (ADS/Reactor, proton dirver), or in fast acceleration (instable beams, neutrino factory).

The FFAG technique can be divided in two main categories. On the one hand “scaling” FFAGs, characterized by invariant focusing whatever the energy ; this type of optics is based on voluminous, non-linear dipole magnets, the acceleration uses low frequency (MHz range), high gradient RF. On

the other hand, “non-scaling” FFAGs, an innovation of the late 90’s, in the US, characterized by the focusing varying in the course of acceleration ; this type of optics is based on dipole magnets of much smaller volume (closer to pulsed synchrotron magnets), linear or non-linear, yielding compact machines, with possibility of ultra-fast acceleration using high frequency RF (e.g., 200 MHz, 15 MV/m for the acceleration of muons in the neutrino factory).

Today’s activities of FFAG R&D form three categories :

- Japan is the main actor, with several projects and facilities based on the scaling technique : a “Proof Of Principle” 500 keV proton ring (2000) ; a prototype of a proton medical machine, 150 MeV (2003) ; an ADS/Reactor installation at KURRI, Kyoto (2005) ; manipulation of intense muon beams (PRISM) ; a neutrino factory design (“Japan NuFact”)
- a US design of a neutrino factory based on the rapid acceleration of muons using non-scaling FFAGs (“US Study II-a of a NuFact”)
- an international project (US/EU/Japan) of an electron model of a non-scaling FFAG.

This project aims at the construction of a demonstrator, in an economical manner : acceleration of electrons from 10 to 20 MeV, 15 to 20 m circumference ring, 1.3 GHz RF. This model is presently subject to extensive studies within a US/EU/Japan collaboration, a implementation site has been proposed at Daresbury by CCLRC.

CONTEXT – MEDICAL During the recent decades few medical teams managed to use light ions beams for cancer treatment purpose. These medical experiences developed as “parasitic” programs in the frame of large physics research centres (Berkeley, GSI-Darmstadt, PSI-Villigen) or by the « medicalisation » of old nuclear physics research machines (Harvard, Orsay). These early experiences demonstrated the feasibility and the medical utility of proton beams and ions beams and allow the development of highly specialized and rather accessible anticancer treatments (MGH-Harvard, USA; CPO-Orsay, France). For a medical point of view, these applications are totally devoted to loco-regional anti neoplastic cure. One estimates the rate of cancer patients dying of uncontrolled local disease to be 25%, this is about 60 000 patients per year in France. For these patients the use of light ions and protons would be a definitive improvement of there cure rate.

For the circa 160000 radiotherapy delivered each year in France (60 millions inhabitants) the continuous progress of photontherapy have brought real improvements.

However, the quality of proton beams is so high that most of the radiotherapy treatment plan would be dramatically improved by the general use of protons. Should a technological breakthrough happenned, giving an easy and cheap access to protons, that the large majority of radiotherapy would be done by proton beams; certainly up to the two third or even more. There is undoubtedly here a tremendous field of development depending mostly of technology and economical constrains.

For heavier particles, such as carbon ions, the figure is different. It is a modality that should be reserved to radioresistant tumours because of the particular radiobiological characteristic of these beams. The number of patient potentially needing such ion beams should be around 20 000 per year

in France. Projects in relation with this demand are in development in Europe (Heidelberg, Pavia and Lyon) or already running in Japan (Chiba and Hyogo). All of them are based on the variable field synchrotron technology. The potential is probably in the order of one machine / one centre for 20 millions of inhabitants in developed countries.

As we can see, a demand of new machines, specifically medical, is rising, with particular specifications: relatively low energies in relation with the size of human body, low cost, high intensity, high precision, security, reliability and versatility. Certainly, a new generation of machine is expected.

GOALS – ACCELERATORS The scaling FFAG is well established, as shown by Japan realisations. The non-scaling technique, by contrast, involves principles of beam dynamics that need be validated experimentally, before any construction of a full scale machine. The goals will be in particular to demonstrate the validity of the dynamics of ultra-fast acceleration and of the related crossing of multiple resonances.

The RACCAM project presented here has several goals :

- constitute in France a team of accelerator physicists and engineers specialist in FFAGs,
 - active in the ongoing international collaborations,
 - equipped with and/or active at developing the necessary tools for beam dynamics, 3D magnet calculations, etc.,
- contribute to the electron model of a non-scaling FFAG,
 - in domains as beam dynamics studies, machine design,
 - by realizing a prototype of a non-linear, non-scaling optics magnet,
- contribute to the study of the application of this new class of FFAGs in the medical domain.

The knowledge and expertise so acquired will have a strong impact on the development of these accelerators for medical applications, with the goal of a second generation medical synchrotron, performing better, simpler to build and to operate, more compact, much cheaper than conventional pulsed synchrotrons.

GOALS – MEDICAL

Medico-economic objectives - Study of the medico-economic and structural development of health care offer, that will allow to consider the introduction of new generation hadron machines in the frame of the present network of treatment centres.

Beam medical physics - Study of the applicability of « bunch to pixel » principle. – Evaluation and adaptation to this type of beam of the different types of beam control: passive control, active control (as raster scanning). – Study of the macro- and micro-motion of the target in the situation of very high dose rate: flash irradiation, respiratory gating, target tracking...

Radiobiology - Study of biological consequences of very high dose rates. – Study of the variation and modelisation of the equivalent dose in such conditions. Study of the potential variation of the radiosensitivity. – Theoretical radiobiological study to new radiotherapy modality using very high flux of particles delivered in a very short time.

Organisation and logistics - Proposition of a doctrine for the application of this new type of equipment with the aspect of multiparticle possibilities, multiple treatment rooms receiving the beam simultaneously, the very short duration of the treatment sessions...**B-2 – Description of the project and results expected**

B-2.1 Schedule, costs

Planning and cost evaluation sheets are given in an appendix at the end of this Section B2.

B-2.2 Intermediate stages

B-2.2-a Parameters of an electron model of an FFAG

One goal of this project is to participate to the design and construction in Europe of a model of a non-scaling, fast acceleration FFAG, by contributing to the theoretical and technological studies. Validation of the working parameters of such an accelerator is therefore implied with all foreseen studies and in particular to studies proposed in the present ANR proposal. These studies will accompany all steps of the project, from beginning to end. This is the reason why typical values of these parameters are given now, in order to help clarify the discussions that follow.

The basic cell consists of 2 to 5 magnets, their number varying with focusing and acceleration criteria; these magnets are typically 5 to 10 cm long, their aperture is on the order of 5 to 6 cm, thus containing the transverse horizontal excursions of the beam as high as 3 cm across the acceleration range. It is worth noticing the poor diameter/length form factor requiring the use of 3-D codes for magnet calculations. The field at the pole in the magnets is on the order of 1 kGauss. The ring consists of about 40 cells, covering a total perimeter of about 15 m. The RF is distributed around the ring. The RF frequency is constant for isochronous or quasi-isochronous acceleration of electrons across a typical range of 10 to 20 MeV.

B-2.2-b Beam dynamics studies

- Preliminary optical studies

These studies aim to define the characteristics of the basic cell (Fig. IsoCell): number and position of magnets, length, field and field index (Fig . IsoField), as well as the characteristics of the ring: number of cells, distribution of accelerating systems (RF) in an electron FFAG prototype.

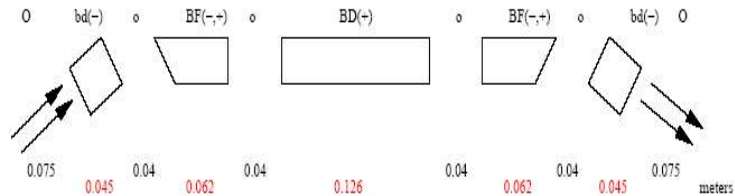


Fig. IsoCell – 5-dipole non-linear cell (see Fig. K's) of an isochronous FFAG, 10-20 MeV electrons (the ring comprises on the order of 40 such cells)

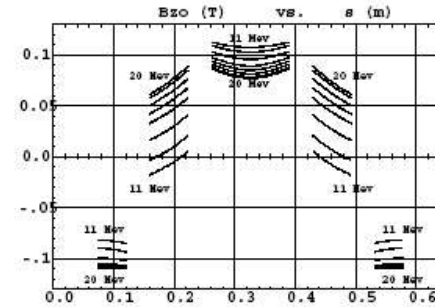


Fig. IsoField – Magnetic field on closed orbits in a cell.

These studies will yield general parameters such as closed orbits as a function of energy (Fig. co), optical functions, envelopes, tunes (Fig. tunes), chromaticity, accelerating modes (synchrotron or isochronous), longitudinal stability requirements, repetition frequency.

- Dynamics studies

Once the structure of the basic cell, the ring and the acceleration are known, extensive dynamics studies are required. They aim to validate the proposed scheme and imply detailed numerical simulations. For example, the machine acceptance (size and divergence of the input beam), the stability limits (area of stable beam motion, see Fig. LimStab), the behaviour of the beam during acceleration, the effect on the beam of various parameters (transverse and longitudinal emittance, cell parameters, etc...), the effect of magnet field and positioning errors, the effect of frequency and cavity phasing in terms of emittance growth and transmission efficiency, need to be studied.

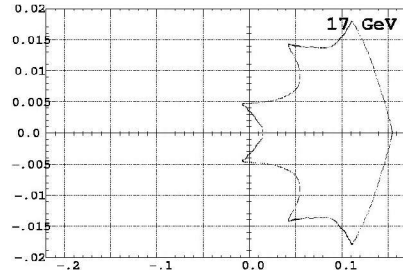
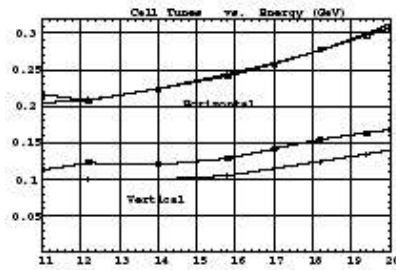
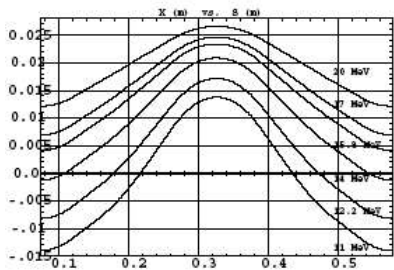


Fig. co – Closed orbits in the isochronous cell at various energies

Fig. Tunes – Horizontal and vertical tunes as a function of energy.

Fig. StabLim – Motion stability limit at 17 MeV in the horizontal phase space.

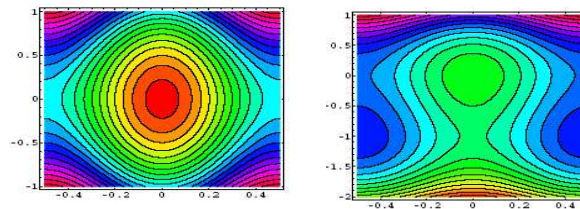
- Acceleration

The necessary detailed analysis of the acceleration process requires significant amounts of calculations and CPU time. This step is a key milestone in the validation of the optical system as it involves phenomena that are specific to fixed field synchrotron, for which an electron based prototype is needed: resonance crossing, fast acceleration (Fig. x), possibly isochronous, transmission, transmitted phase space, tolerances to defects.

- Magnetic parameters

The previous steps of the cell definition also validate the magnetic parameters, prerequisite to the magnets calculations. The «magnet phase» of the project is described in Section B-2.2-d.

Fig. Accel - – Compared to regular synchrotron motion (e.g.: scaling FFAG), which features a bucket in the time-energy phase space (closed region, “stationary bucket” on the left figure), fast acceleration in a non-scaling FFAG takes place out of bucket: the accelerated bunch runs across the S-shaped light blue region on the right figure, from bottom left to top right, within a few machine turns.



- Validation of the magnetic measurements.

The building of the magnet prototype will be followed by magnetic measurements (this is addressed in Section B-2.2-d). The field maps will be used to reiterate the analysis described previously, in order to control the field quality and to validate *in fine* the magnet prototype.

B-2.2-c Development of computer based beam dynamics tools

The definition of the electron based FFAG prototype, as described in this proposal, requires for the theoretical accelerator studies, the use of two main calculation tools corresponding to the main steps of the work. On one hand, matrix based calculations that allow determining the geometry of the basic

optics cell and its focusing properties, studying the effects of the field and alignment defects and their compensation, analyzing the longitudinal beam dynamics, etc. On the other hand, particle tracking codes, will allow detailed simulations of the running conditions of the accelerator using realistic models of magnetic fields.

Generally, every new accelerator project imposes specific constraints that require development of standard calculation tools. On the other hand, the evolution of codes follows that of computers (memory, calculation speed). This accompanies each and every project, from beginning to end.

In the case of FFAG synchrotrons, optical elements (magnets) and their assembly method (e.g.: curvature inversion, overlap of end fields, lack of optical axis) are very different from those involved in the case of pulsed synchrotrons and therefore require significant developments based on existing codes but also on new calculation tools.

Symbolic computing tools.

A prime goal in symbolic computing developments is to obtain efficient and fast tools for the definition and optimization of FFAG optical parameters.

Among the scientific computing tools recently developed, Mathematica is especially appreciated since it combines, in a user friendly way, symbolic and numeric computing, powerful graphics representation and effective programming. Associated with the geometry software Geometrica, it has been applied to accelerator physics in the BeamOptics code developed at CERN (BeamOptics, a program of analytical beam optics, B. Autin, editor, CERN98-06).

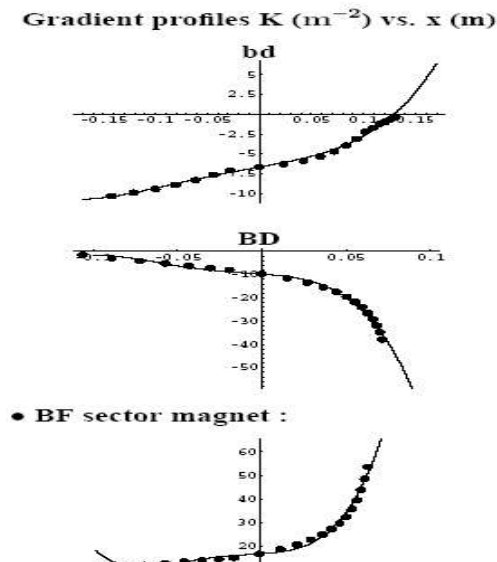


Fig. K's – Transverse fields profiles in the non-linear cell magnets (see Fig. IsoCell).

The problems of lattice definition in an accelerator are treated using a set of functions acting on a small number of variables. The techniques of list processing, pattern recognition and naming by rules are employed to make both syntax and results easy to use.

The accelerators of FFAG type raise a new range of problems although they belong to the class of storage rings. The energy variations are indeed of several units and, typically, there is a factor 3 between the injection and extraction energies. In contrast, the energy range in storage rings does not exceed a few percents.

There are already in BeamOptics the functions IsoHalfPeriod[n,options] and IsoPeriod[n,options] to define isochronous systems using an half or full FODO cells. The optional arguments (location of missing magnets, nominal bending angle, cell length and orbit resonance) have default values and it is straightforward to get structures where the transit time of a particle is, to first order, independent of energy. The development needed for FFAG's is the determination of the magnetic field law which preserves the isochronicity on all orbits for a large momentum range.

A second problem concerns the dynamic aperture of FFAG's which has to be compatible with the large emittances of input beams at least in muon machines. An approach to the solution of that problem consists of placing non-linear lenses in regions of small orbit dispersion to decouple geometric and chromatic aberrations as far as possible (B. Autin, Non-linear betatron oscillations, CERN Accelerator School, Third Advanced Accelerator Physics Course, Uppsala University, CERN 90-04). Last, a universal data base for lattice, simulation and magnetic programs should be set up to avoid all the difficulties related to format conversion.

Magnet code ; purchase of TOSCA

TOSCA is a module added to OPERA-3d from Vector Fields Ltd. Pre- and post-processor environment developed to analyse electromagnetic engineering design problems in three dimensions, along with analysis modules. TOSCA allows calculating current flow, magnetostatic or electrostatic field maps, including non linear media properties. The code is made of state of the art algorithms for the calculation of electromagnetic field, advanced finite element and non-linear equation numerical analysis procedures.

Today, this code is the most spread for the calculation of magnets using finite elements. For example, it allowed calculating the magnetic elements of the synchrotrons for SOLEIL and CNAO (medical synchrotron) projects. TOSCA has also been used to calculate magnets of a fixed field alternating gradient synchrotron in Japan. Today, specialists of magnetism consider TOSCA as a reference.

Training.

The use of a modelling environment based on finite elements implies a training period because it requires the utilization of mathematical basis hard to apply on a model. Mesh generation has to be adapted to the considered shape, and the precise knowing of code characteristics, for instance the calculation of physics parameters, is necessary to overcome design difficulties. This period can be set to six months for someone not used in calculating with a finite elements code. This training period will be leaded in collaboration with SIGMAPHI S.A., partner of this project.

B-2.2-d Magnet prototype

Deliverables by SIGMAPHI in the collaboration :

- a prototype of a magnet

Entry points :

- technical data of the magnet

Role of SIGMAPHI :

- 3D magnet calculation in tight collaboration with beam dynamics experts (LPSC)
- Magnet fabrication
- Magnetic measurements
- Power supplies

Method :

The beam dynamics calculations will determine the strength of each harmonic component needed for the magnet. This is our entrance point for the magnetic calculation of the magnet as well as for calculating the mechanical tolerance required to achieve the magnetic field quality. This will be done in very close collaboration with beam dynamics experts in order to determine the best technical and financial solution. The magnetic field complexity will require the use of a 3D code. We foresee today 2 possible types of magnets. The best technical and economical compromise will be determined. Once the magnet is defined, the beam dynamics should be checked using the magnetic charts calculated in 3D. This mandatory step may impose to modify the magnetic design.

Using the conceptual design done in the previous phase, we will then produce the magnet drawings and fabrication specification. This will be achieved by SIGMAPHI drawing department that have all the necessary skills for that.

SIGMAPHI will build the magnet as it is our main business.

Magnetic measurements will end the magnet fabrication. Magnetic charts will be used in the beam dynamics program for a final check and for finding the machine working point. The company is equipped with a rotating coil bench as well as a Hall probe measuring bench that should be upgraded for the dipole measurement.

Originality :

Through this project we choose to strengthen our skills in our main business area, most of our customers will take advantage of our development. Today's trend is that major companies involved in medical accelerators (IBA, ACCEL ...) wish to buy parts more and more complete and no longer just magnets. Also most of light sources under construction buy key in hands linacs. Most research centres or companies involved in accelerators design don't have any more the resources to build accelerators from scratch. They are then very interested to find high technical level companies.

SIGMAPHI Company has already began to move in this direction by strengthening its magnetic measurement department in order to deliver a validated magnet ready to be installed in beam lines. Magnet performance demands are constantly increasing and we should more and more use 3D calculation that we sub-contract today.

It is also vital for SIGMAPHI to reinforce our links with major worldwide known laboratories. Indeed, the market of magnet fabrication is world wide and we compete more and more against low fabrication cost countries (India, Russia, China, Brazil...). Only a high industrial and technical know how could allow us to resist against these competitors. It is then vital for us to participate to this kind of collaboration in order to keep the technical advance we have.

We have already began to move in this direction by creating a collaboration with CERN for the fabrication of superconducting magnets, new area for us. This has lead to the realisation of a prototype and then an order of 30 magnets. Following this first experience, we have tried to develop this activity and begin to interest ourselves to the conception. We have then contacted CEA with whom we have developed a close collaboration for the conception and fabrication of magnets using low temperature superconductors but also in the more recent field of the use of wire at high critical temperature. CEA is here in its role of technical help to companies. As industrial company we bring to these collaborations our experience and our care of cost and schedule.

RACCAM is multidisciplinary because it needs vacuum technique, physical instrumentation, magnetic conception and mechanics. Collaborations will also be necessary with other laboratories and companies to define both technical and financial solutions, in particular for power supplies. SIGMAPHI is the only French magnet builder with a production capacity of 20 magnets per month. We are ISO 9001 certified. We provide most of research centres trough the world (80% of our turn over is done at exportation) in Europe, USA and Japan. We also have a strong experience with very large coils fabrication (about 5m by 3m), we have recently fabricated coils for CERN detectors ALICE and ATLAS. GSI has also trust us for delivering most of the magnets for the Heidelberg hospital hadrontherapy facility, including the last gantry magnet which weight 70 tons. We also have delivered all magnets for the Boston hospital (for IBA) and for München (for ACCEL). We have doubled our turn over in 2004 and our business plan for this year will lead to the same order of turn over. As far as we know 2006 will be of the same order of magnitude.

Our investment in this project allows us to develop our capacity in 3D magnetic calculation, magnetic measurement and our knowledge of beam problems. We will use laboratories experience which will then participate to the diffusion of there knowledge in French industrial companies. With the experience gained during this project we would be able to participate more ahead in our customers projects and offer them a higher technical level. In this field our main western competitors are ahead of us.

B-2.2-e Application of FFAG beams to Hadrontherapy

Three types of know how will be use to study the principal aspects of medical applications of FFAG machines

- A competence in medico-economics will use existent and adapted model for economical and patient recruitment simulation. This work will be carried out with the collaboration of Dr Pascal Pommier of the Centre Léon Bérard and Lyon University in the frame of a the Master of medical economics (one and a half year of work for three successive students).

- A competence in radiobiology that will be derived from the ongoing works on the radiobiology of ligh ions in France and Europe (ETOILE program, CEA and ERANET network). The principal point to study is the high dose rate and the effects of multiple successive high dose rate irradiation in a short period of time (a few minutes in case of the use of multiple beam for the same session). These questions are already on study for the development and the assessment of the radiobiological model used to calculate the equivalent dose and the relative biological effectiveness of hadrons beams. The extension of these study to FFAG will be possible by the cooperation with these different research fields and in particular the participation of the PhD students involved in these research in the following teams: INSERM U647 « RSRM » at Grenoble ; EA3738 at Lyon Sud, Laboratoire de Radiobiologie Cellulaire et Moléculaire (équipe 4, EA 3738 – UFR Médicale Lyon-Sud) and the IPNL : Institut de Physique Nucléaire of Lyon (UMR UCBL / Institut National de Physique Nucléaire des Particules (IN2P3) of the CNRS. These cooperations justify a support for running cost.

- A competence in medical physics at a high level of expertise that will be found in the frame of a post-doctoral position during the second and the third years of the project. Starting from the most probable characteristics of the machine FFAG, studies will be done on the theoretical and practical aspects of the beam control, its use, its ballistics, the optimal procedure of beam delivery (bunch to pixel, raster scanning, ...), the solution for target movements, quick positioning...

B-2.3 Methods

The RACCAM project will be accomplished as follows.

- Constitution of a team of accelerator specialists, physicists and engineers
- investment in a 3D magnet code and formation of an expert, in collaboration between LPSC and SIGMAPHI,
- development of accelerator design and beam dynamics tools,
- definition of the optical and acceleration parameters of a electron FFAG model, participation in the international non-scaling FFAG model project
- extensive 6D beam dynamics simulations,
- Description of the future modalities of the medical applications of the FFAG with non-scaling optics at the point of view of implementation, medical technology and biology, taking into account the specific characteristics of these machines.
- magnet prototype : parameter definition, 3D calculations, construction, magnetic measurements, tests. Validation by beam dynamics simulations using field maps
- periodic meetings, involving the 3 partners,
- publication of reports, technical notes, etc.
- participation to workshops. Participation to FFAG and to hadrontherapy networking activities.

B-2.4 Originality, ambitions of RACCAM

The concept of “non-scaling” FFAG is new. It demands a “proof of principle” experiment to be accomplished. This concept results in compact magnets, comparable in size with pulsed synchrotron magnets, by contrast to scaling FFAGs ; it also results in the possibility of ultra-fast, [quasi-] isochronous fixed frequency acceleration, using high frequency, high gradient cavities. The originality of this researches is therefore, on the one hand in

the demonstration of the feasibility of the non-scaling FFAG, a program to which RACCAM will contribute substantially, on the other hand in the development of a second generation synchrotron for hadrontherapy, a machine much more compact than scaling FFAGs, delivering much higher intensity than pulsed synchrotrons, simpler to build and operate, and cheaper.

The ambitions of RACCAM are three-fold. An active and substantial participation in the international FFAG R&D and in particular in the project of an electron model. Contribute to the demonstration of the feasibility of a second generation hadrontherapy synchrotron for 3D conformational irradiation (active scanning), combining the qualities of the cyclotron (intensity) and of the synchrotron (beam manipulation, variable energy), in addition to other FFAG specificities as multiple extraction. Contribute to the national dissemination of knowledge and know-how, in matter of research, industry and medicine.

The innovative character of these researches and of the related R&D, as well as the collaboration between Physics, Industry and Medical domains, confer to RACCAM a strong potential of genesis of industrial and intellectual property.

B-2.5 Interdisciplinarity

RACCAM combines activities in research : accelerator theory and design, numerical computing, industry : développement and fabrication of a magnet prototype, magnetic measurements, medical : the implementation of rapid-cycling in treatments (« bunch to pixel »), parameters of the cycling, dose manipulation, use of this type of beam in research (e.g., biology).

B-2.6 Collaborations

RACCAM feeds itself from multiple collaborations. At a National level, with research organisms (CNRS, CEA - accelerator physics and technology), in medical applications (several of us work in the hadrontherapy projects, ETOILE, ASCLEPIOS, CNAO), with the industry (SIGMAPH), with medical/radiotherapy actors (Grenoble University Hospital). At a European level : participation to the FFAG electron model of a non-scaling FFAG (involving CCLRC, BNL, FERMILAB, KEK, TRIUMF, CERN, CEA, etc.). At an international level : participation to the US/Japan/EU FFAG R&D group, in the frame of the neutrino factory activities (rapid acceleration of muons by FFAG).

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N°	Nom de la tâche	05		2006				2007				2008				2009				2010				2011				
		T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3		
29	Validation prototype aimant																											
30	Collaboration internationale																											
31	Collaboration avec le projet de maquette international																											
32	Définition de la cellule optique																											
33	Définition de l'accélération																											
34	Etudes de dynamique faisceau																											
35	Intégration des résultats du prototype d'aimant																											
36	Fourniture des cartes de champ																											
37	Fourniture de tolérances géométrie/magnétisme																											
38	Rapports d'activité, documents techniques																											
39	Devlpmnt de codes																											
40	Etudes d'optique / dynamique																											
41	R&D médicale																											
42	Etudes aimant																											
43	Participation workshop																											

B-2.2-e Cost sheets

Propositions d'experts et confidentialité

- Chaque porteur de projet devra fournir une liste de 3 à 5 noms d'experts français ou étrangers (avec coordonnées complètes : adresse postale et adresse électronique) susceptibles d'évaluer le projet avec lesquels il n'a ni conflit d'intérêt, ni collaborations en cours.
- Les membres du Comité d'évaluation et du Comité stratégique sont astreints à la confidentialité.

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Programme non thématique 2005

C - Moyens financiers et humains demandés par chaque équipe partner du projet

Chaque équipe partenaire remplira une fiche de demande d'aide selon les modèles proposés ci-dessous (laboratoire public ou fondation ; entreprise ou association) en fonction de son appartenance.

On présentera une brève justification scientifique des moyens demandés pour chacune des équipes impliquées dans le projet.

The justifications of our funding requests are given next to each « partner » sheet, in the following pages

Programme non thématique 2005

Funding request sheet – Public Laboratory / Foundation

Acronym or short title of the project	RACCAM
---------------------------------------	--------

« PARTNER 1 »

Responsable scientifique (coordinateur ou partenaire) (nom, prénom) :	Méot François
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Estimation du cost marginal du projet pour le laboratoire :

Les valeurs obtenues dans les cellules du tableau P à W serviront à renseigner le tableau « estimation du cost complet » ci-dessous

Programme non thématique 2005

D – Summary of the funding request for the project

Acronyme ou titre court du projet :	RACCAM
-------------------------------------	--------

a-Total de l'funding request

(reporter les valeurs (W) des fiches des différents partenaires)

	Requested funding
Coordinateur (Partner 1)	256 500
Partner 2	241 000
Partner 3	102 500
Total à reporter sur la première page du dossier	600 000

b-Estimation (pour information) du cost complet de cette demande

(reporter les valeurs (X) des fiches des différents partenaires)

	Total cost
Coordinator (Partner 1)	475 528
Partner 2	408 800
Partner 3	184 211
Total à reporter sur la première page du dossier	1 068 539

Contrats sur les trois dernières years (effectués et en cours)

Nom du membre participant à cette demande	% d'implication	Intitulé de l'appel à projets Source de financement Montant attribué	Titre du projet	Nom du coordinateur	Date début - Date fin
Jacques BALOSSO	10%	EDF contract RB2001-11 100 kF	Pre-clinical research on the application of the synchrotron radiation to radiotherapy at ESRF.	Jacques BALOSSO	2001-2003
Jacques BALOSSO	10%	EDF contract RB2003-26 15000 €	Study of the molecular mechanism of the genomic damages and their repair in condition of photo-electric effect enhanced by heavy atoms (platinum, iodine, gadolinium).with a monochromatic X ray beam issued from synchrotron radiation. Application to radiotherapy for high doses and to medical imaging with low doses.	Jacques BALOSSO	2003-2004
Jacques BALOSSO	10%	EDF contract RB2005-08 17940 €	Do Iodides be inhibitors of DNA repair ? A comprehensive study at the levels of molecules, cells and tissues in a preclinical situation.	Jacques BALOSSO Nicolas FORAY	2005-2006
Jacques BALOSSO	10%	ROCHE PhD fellowship one year 36 000 €	Role of the tyrosine kinase modulation in the orientation of DNA repair pathways after irradiation.	Jacques BALOSSO	1/2005 à 12/2005

Demandes de contrats en cours d'évaluation ⁵

Nom du membre participant à cette demande	% d'implication	Intitulé de l'appel à projets Source de financement Montant demandé	Titre du projet	Nom du coordinateur
Méot François	10	GIP ANR	Source de positons de haute intensité (SOPHI)	Jean-Michel Rey (CEA)
Neuvéglise Damien	10	GIP ANR	Source de positons de haute intensité (SOPHI)	Jean-Michel Rey (CEA)

⁵ *Veillez mentionner ici les organismes auprès desquels vous avez déposé un autre projet, en particulier au GIP ANR, que ce soit comme coordinateur ou comme partenaire. Pour chacun donnez le nom de l'appel à projet, le titre du projet et le nom du coordinateur.*

Secteurs disciplinaires

- Sciences et technologies de l'information et de la communication (STIC),
- Sciences pour l'ingénieur,
- Chimie,
- Physique,
- Mathématiques et interactions,
- Sciences de l'univers et géo-environnement,
- Sciences agronomiques et écologiques,
- Biologie et santé,
- Sciences humaines et sociales