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Hadrontherapy beams from FFAGs and the RACCAM project

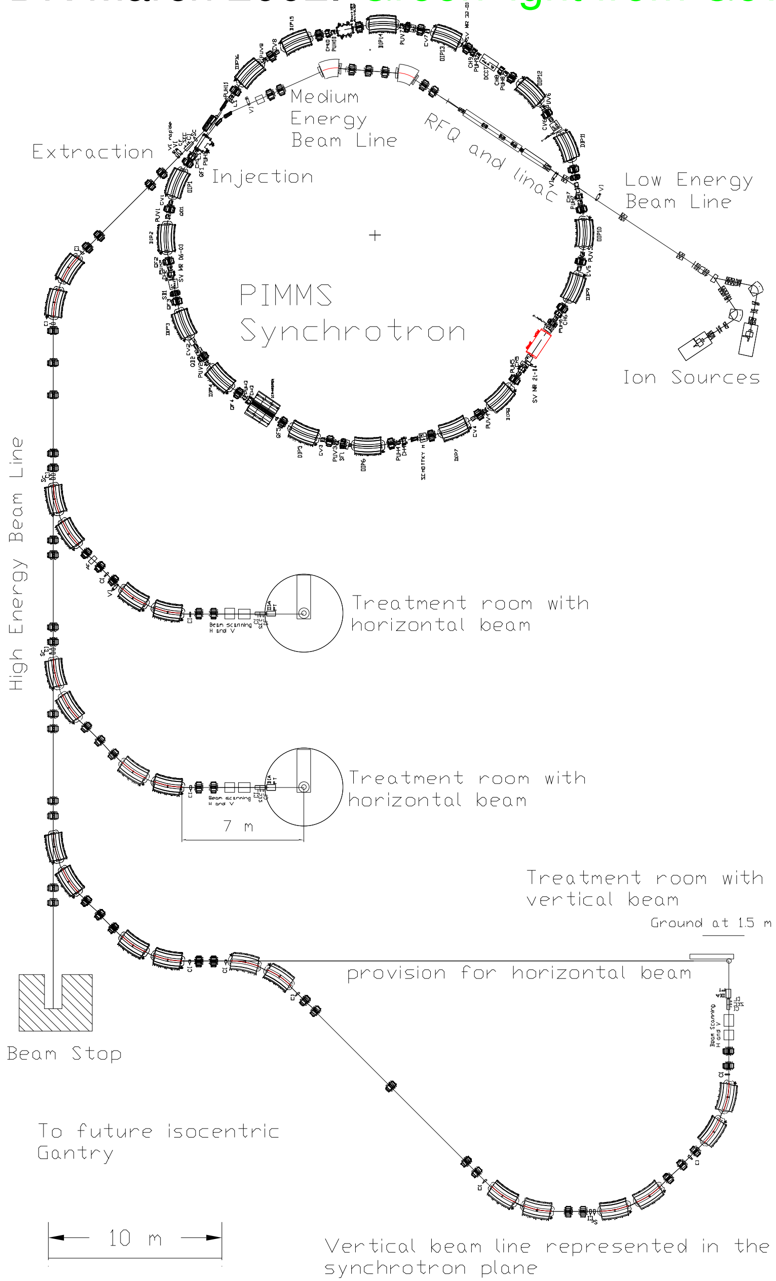
Contents

1 Context of hadrontherapy in France

1.1 ETOILE Carbon project

Carbontherapy installation, to be built in Lyon. Part of the National Anti-cancer Plan 2003-2007.

TDR March 2002. Green light from Government last June, then delayed early this year...



Synchrotron : *PIMMS/CNAO design*

- **C:85-400MeV/u** ($4\,10^8$**/spill)**; **p: 50-200MeV** (10^{10}**/spill)** } **2-27 cm water, 2 Gy.liter**
- **rep. rate** $\leq$ **1 Hz**
- $\mathcal{C}$ **= 75.24 m**
- **8 FODOF ; superperiod = 2**
- **16 bends, B**$\leq$**1.5 T,** ρ**=4.23 m**
- **24 quads, 3 families, G**$\leq$**3.65 T/m**
- **4(**ξ**) + 1(Xtr) sextupoles**
- **Injection equipment :** 2 magnetic septa + electrostatic septum, 2 COB dipoles
- **Extraction :** electrostatic septum, 2 magnetic septa, resonant sextupole, betatron yoke

Injector : *GSI/HICAT design*

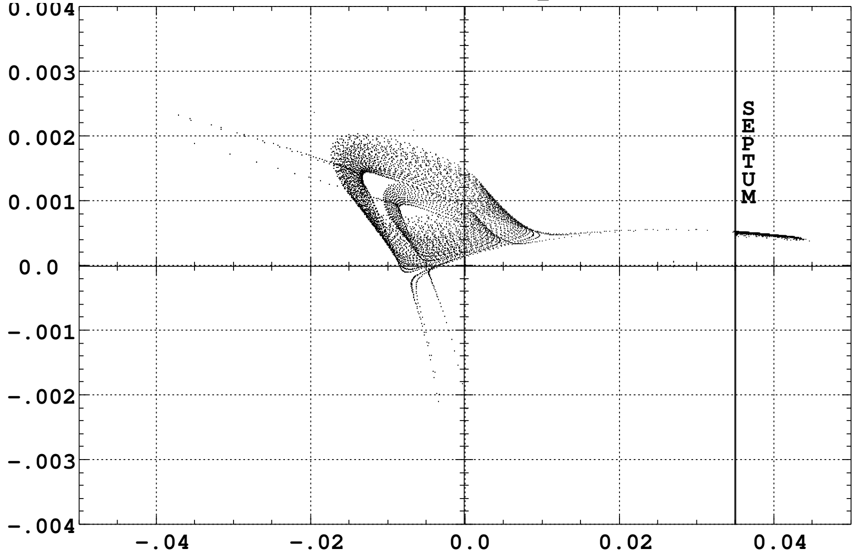
400keV/u RFQ + 7 MeV/u IH-DTL, 216 MHz

Two sources : *Pantechnic*

- C^{4+} **(125**μ**A),** H^+ **(2.4 mA),** $\epsilon_{x,z} < 1.2\,10^{-6}\pi$**norm.**

Slow extraction : delicate beam manipulation

X' vs X at extraction E-Septum



Maximum stable emittance :

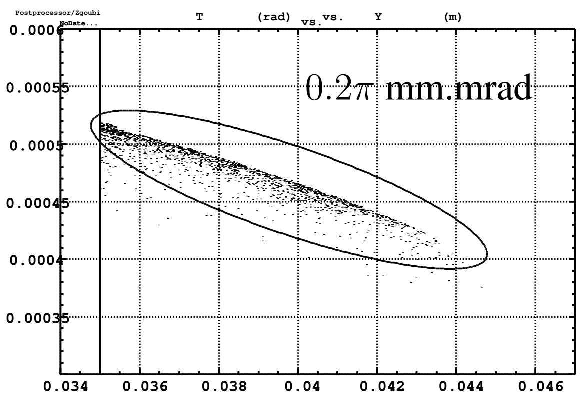
$$\mathbf{A}/\pi = 48\pi\sqrt{3}\left(\frac{\nu_x - \nu_{x,R}}{S}\right)^2$$

$\Delta X \sim SX^2 \Rightarrow$ **spiral step :** $\boxed{\mathbf{S}}$

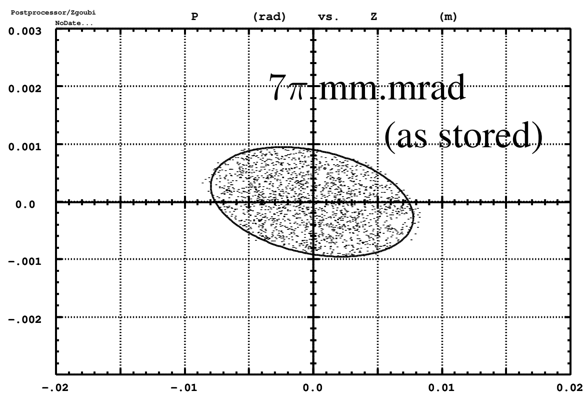
Alignement of separatrices :

$$\frac{\alpha D_x + \beta D'_x}{\sqrt{\beta}} \sin(\phi + \frac{\pi}{3}) + \frac{D_x}{\sqrt{\beta}} \cos(\phi + \frac{\pi}{3})\Big|_{ES} = -\frac{4\pi}{S}\,\boxed{\xi_x}$$

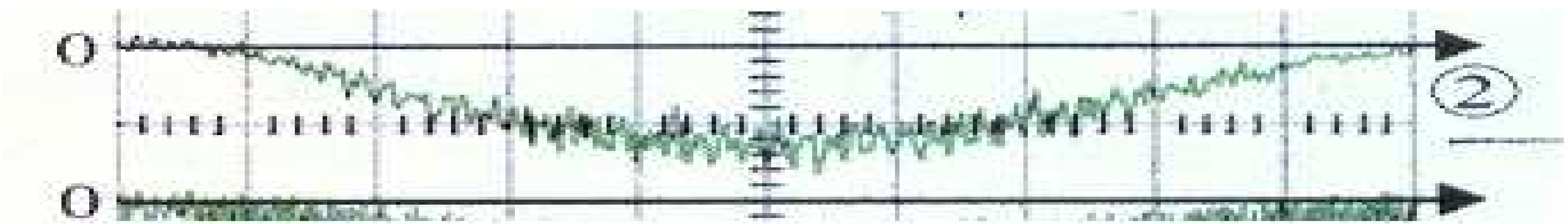
X' vs X



Z' vs Z



Spill, measurements at SATURNE (1997, CNAO project) :

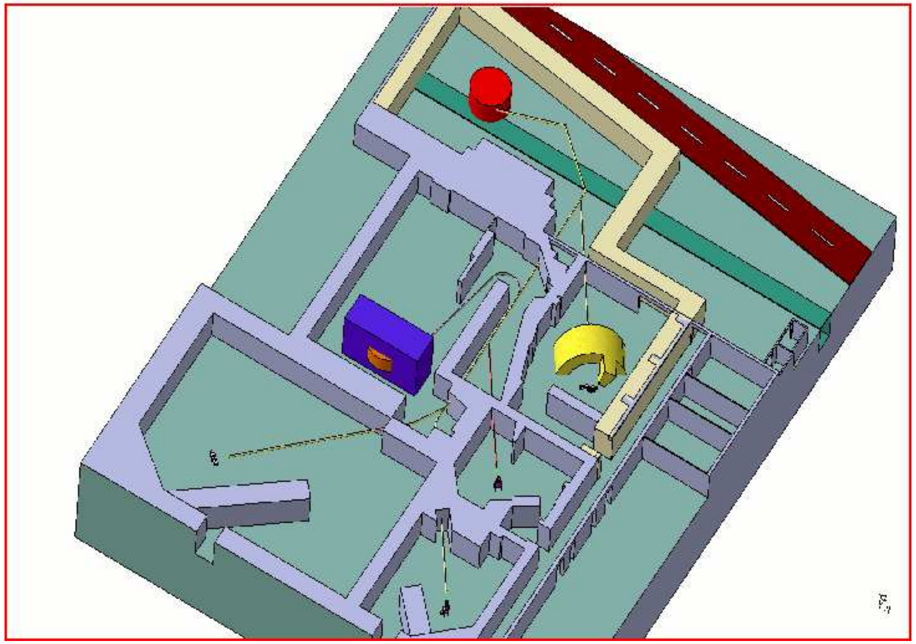


Motivations, as expressed by ETOILE project, as to the choice for a synchrotron [Ref.: TDR]

- better adaptation to the acceleration of high energy ions
- possibility of precise change of enrgy from one spill to the next
- fast commutation between ion species
- 3-D conformal irradiation of deep sitted tumors
- good criterion of maintenance and access for repair
- high reliability

1.2 IC-CPO upgrade

Le projet d'établissement du CPO 2004-2008



- Founded from former IPN-Orsay Nuclear Physics Lab.,
- More than 3000 patients since 1991, now stabilized at 330 / year
- ⇒ 1st EU / third world p-therapy center
  - Tumors treated : eye (Nal recruitment) and skull (EU recruitment)

Equipment :
- Synchro-cyclotron (1975), 201 MeV / 448 Hz
- ED+ESS - from 200 MeV down to 70 MeV (eye)
- 2 rooms
- passive irradiation

Goals of upgrade :
- New accelerator (cyclo. or synchro.), 230 MeV
- Active & passive irradiation
- 4 rooms (vs. 2 now), with gantry
- 1000 patients / year

Total cost, equipmnts and building : 26 MEU

1.3 Centre Lacassagne

Nice, 70 MeV cyclotron, eye treatment.

2 RACCAM : why a FFAG project

2.1 HEP programs in our Labs.

• The project was born in the frame of NuFact activities, within CARE/BENE EU funding program, and as such seen as a way to enhance our involvement in FFAG accelerators R&D.

• Hence the first two goals in RACCAM :

- constitute in France a team of accelerator physicists and engineers active in FFAGs, active in the on-going 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 and magnet design.

2.2 Why medical application

(i) This FFAG project can be simply viewed a sub-product of our hadrontherapy facility design activities these last 5-6 years.

(ii) What we consider a precept [Ref. : J. Balosso, RACCAM bid documents] :
"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. "

- Hence the third goal in RACCAM :

- contribute to the study of the application of FFAGs in the medical domain, 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.

Prototyping

- A 4th goal in RACCAM is magnet prototyping, in association with SIGMAPHI.

Why build a magnet : because a further perspective, this is true whatever the follow-ons foreseen, is the construction of a ring : confer e-model, p-model, etc.

We have to make a decision :

- *linear magnets* are already subject to R&D at Fermi and Daresbury
- *pumplet magnets :* R&D still needs be launched. This would be a possible subject
- *scaling magnets :*

* In relation with the goal of medical application, compactness and simplicity are important matters, cyclotron type of size and simplicity are a challenge
* In that respect scaling spiral lattice is very attractive, provides the smallest circumference factor in the FFAG method
* Designing a variable K, variable flutter ??, spiral magnet for a 230 MeV proton ring is still a challenge
* we think we can usefully contribute in these domains

2.3 RACCAM partners

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

Acronym e 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 : IN2P3 / LPSC

	Name	First name	Laboratoire (nom complet)	
Mr	**Méot**	**François**	**DAPNIA & IN2P3**	
Mr	**Froidefond**	**Emmanuel**	**IN2P3/LPSC**	
	Fourrier	**Joris**	**IN2P3/LPSC**	**PhD**
Mr	**Autin**	**Bruno**	**CERN**	
Mr	**Collot**	**Johann**	**IN2P3 / LPSC**	**Dir. LPSC**

Mr	**Neuvéglise**	**Damien**	**SIGMAPHI**	**Industrial company**
Mr	**Balosso**	**Jacques**	**Radiation Oncology Grenoble Univ. Hsp.**	**Public hospital**
Mr	**Pommier**	**Pascal**	**L. Bérard, Lyon**	**Public hospital**

New comers

New participants :

Jaroslaw Pasternak — Former NuFact-or CERN fellow

Jean-Louis Habrand — MD, IC-CP-Orsay

Samuel Meyroneinc — MedPhys., IC-CP-Orsay

Marie Claude BISTON — MedPhys., Lyon Canceropole

Collaborators

Jean-Luc Lancelot — DG, SIGMAPHI

Horst Schonauer — CERN

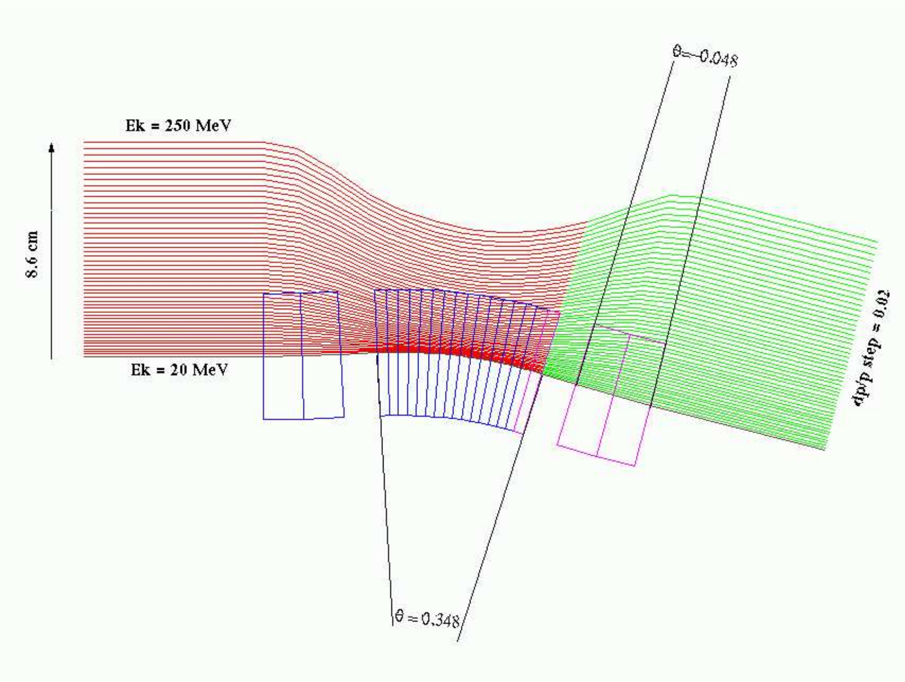
Franck Lemuet — PhD, CERN

Rob Edgecock — RAL

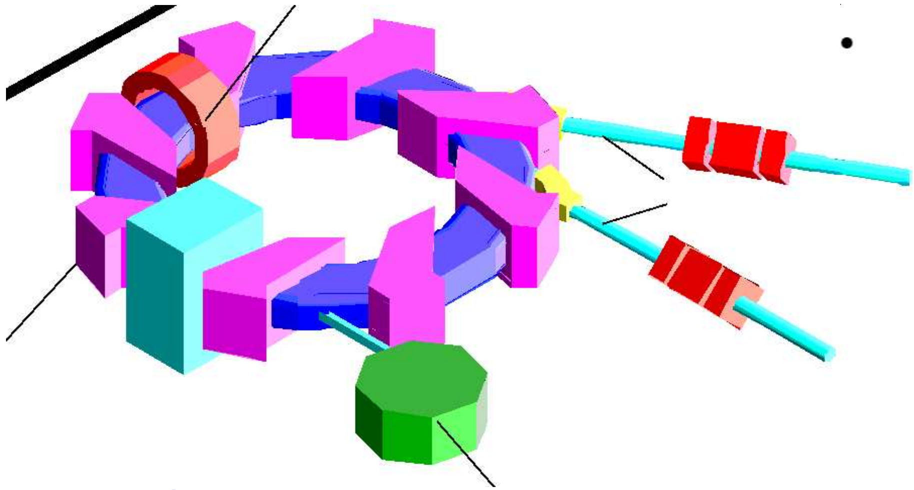
If interested : Welcome !

3 Comments on the FFAG acceleration method, proton

FFAG types of lattices concerned



Linear, non-scaling
30 to 230 MeV acceleration
7 to 230 MeV doable ?



Scaling, non-linear.
7 to 230 MeV acceleration

Comments on the acceleration methods, proton

After questions by J. Flanz (thanks !).

Clinical properties of the beam and accelerator		
Range	2 - 30 cm in water	
Dose Rate	> 5 Gy$\times$liter / min.	potentail for more
Penumbra	not machine dependent	same balistcic for all
Distal falloff	not machine dependent	ibid.
”	E (Bragg peak) spread	see below
Uniformity	density in bunch ?	needs R&D
Intensity	several 100 nA, av.	potential for kHz range of repetition rate
Modulation capability		at source
Beam characteristics		
Current	several 100 nA, av.	potential for high rep. rate
Current dynamic Range	Several orders of mag.	at source
Energy	230 MeV	
Energy Range	50 - 230 MeV	variable K
Energy spread	10^{-3}	
Stability	very good	fixed field magnets
Range of angles for beam delivery	not machine dependent ?	
Expected operational performance		
Availability	very high	technological simplicity
Reliability	very high	ibid.
Complexity	very low	ibid.
Scalability	?	
Stability	very high	fixed field, no RF tracking

Comparing to other machines

Beam Parameters

Operational issues

complexity
availability
reliability

Beam Delivery

Nozzle
Gantry
Positioning

Current status of the technology described

Can this machine be built tomorrow

scale 1 prototype yes
medical machine needs R&D

Limitations of the technology, if any

Table of parameters for use by the rapporteur for comparison purposes.

Comments on the acceleration methods, proton

		SCS	RCS	cyclo	FFAG		
					S		NS
					Spiral	AG	
Injection		multiturn	single bunch	CW	single bunch		
Extraction		slow spill $1-10$ s	fast μs scale	CW	fast μs scale		
machine size	ϕ (m)	$>$8	large R/ρ	$<$5	$<$8 ?	large R/ρ	
multiport		difficult		no	possible		
doable dose	Gy.l/min	2 space ch. limit	$>$5	$>$5	$>$5		
rep. rate	(Hz)	<1	up to 30	CW	potential for kHz limit is RF		
variable E		pulse to pulse		ED+ESS	range shifter (fast) variable K (slow)		
within time scale	Hz	<1 Hz	30	<10	future ? (p 2 p ?)		
beam shape	ϵ_z/ϵ_x	$>$10	round				