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Progress on Medical FFAGs

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Imperial College London/RAL STFC

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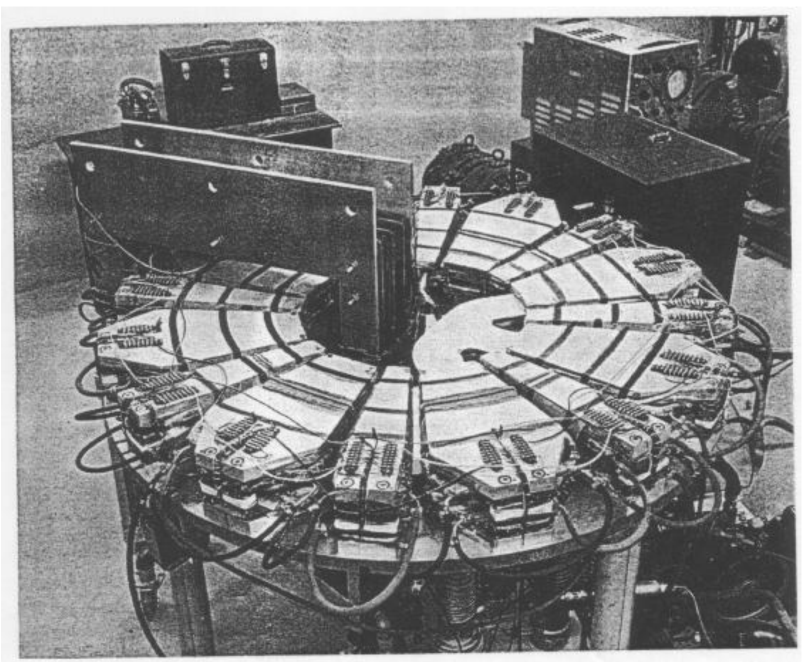
Outline

- Introduction
- RACCAM
- PAMELA
- Summary

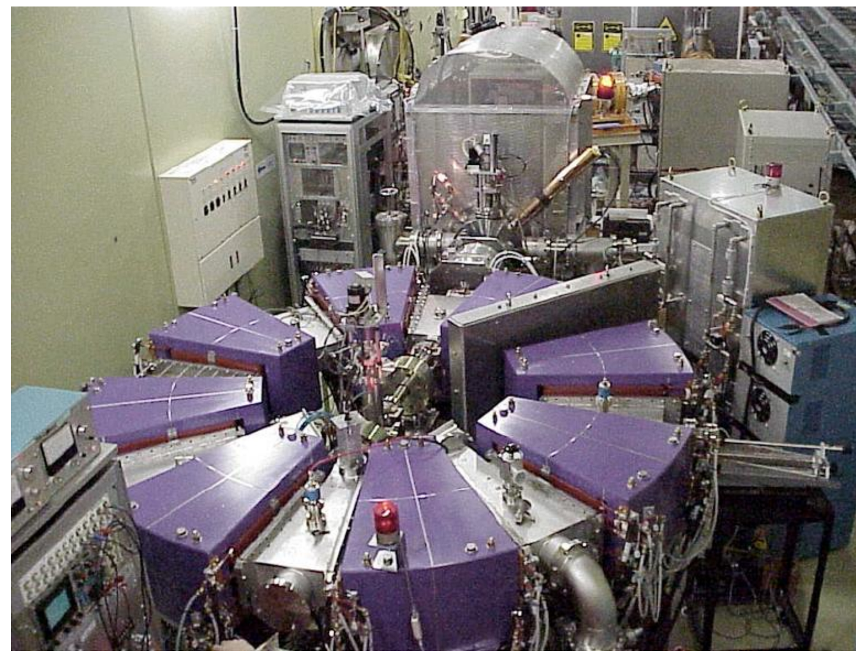
Introduction

FFAG – Fixed Field Alternating Gradient accelerator is a ring with a strong focusing lattice, very large momentum acceptance and small dispersion

First proposed by Okhawa and Symon et al. In 1953



Electron model from 50ties (MURA)



POP-world first proton FFAG (Mori et al.- 2000)

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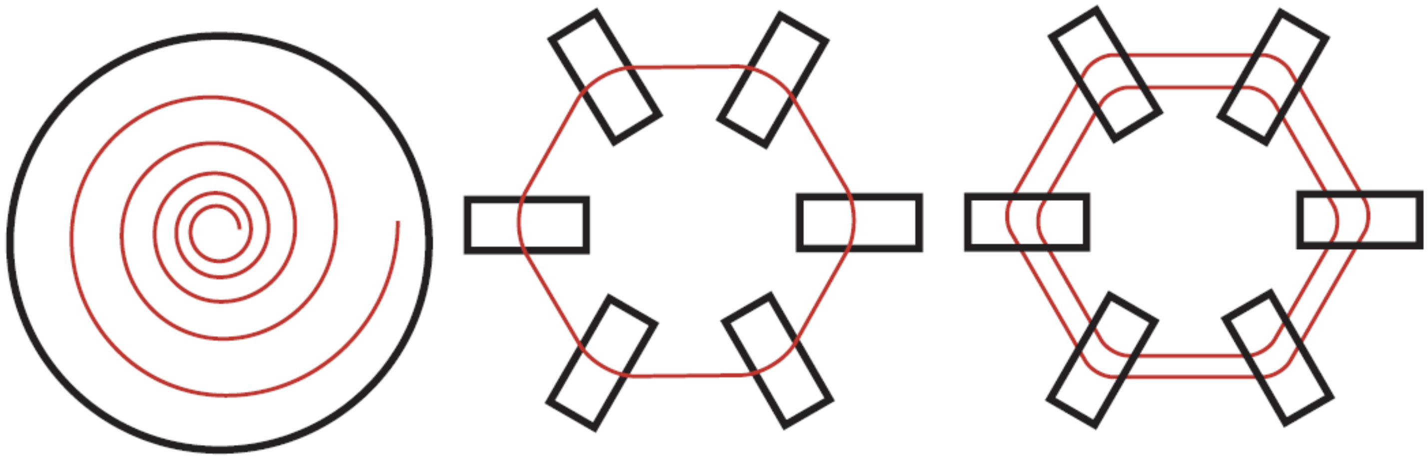
FFAG with respect to other circular machines



Machine	Cyclotron	Synchrotron	FFAG
Magnetic field	constant	changing	constant
RF frequency	constant	changing	changing (not always)
Orbit	changing	constant	changing
Tune	changing	constant	constant (not always)

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Advantages of FFAG accelerators

- Constant fields allow for very high repetition rate (100 Hz – kHz)
- Constant tunes (or linear fields) give large acceptances
- Strong focusing reduces dispersion (orbit excursion), which limits the magnet size

→ High Intensity

FFAG applications:

- High power proton drivers (4-10 MW) for neutrino factory, muon collider, neutron sources, ADS…
- Acceleration of unstable particle beams (muons, radioactive ions)
- Medical applications

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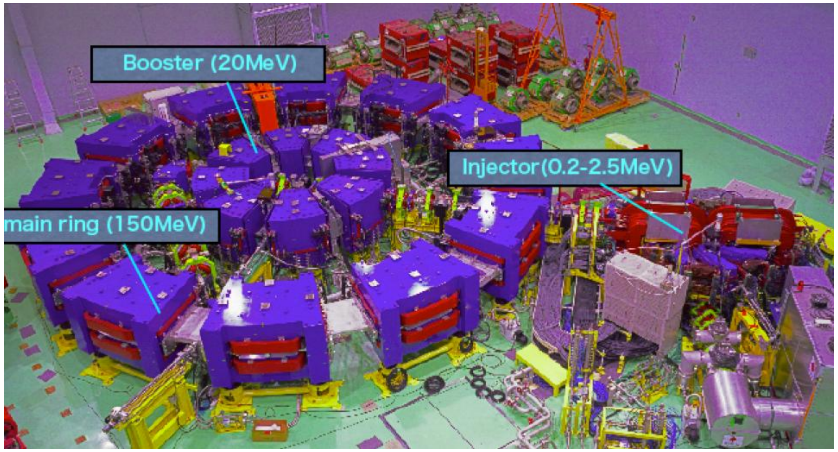
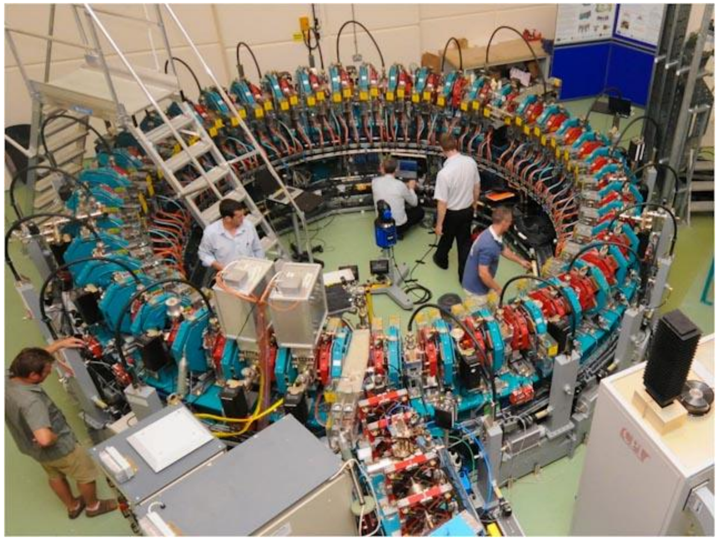
Projects and R&D

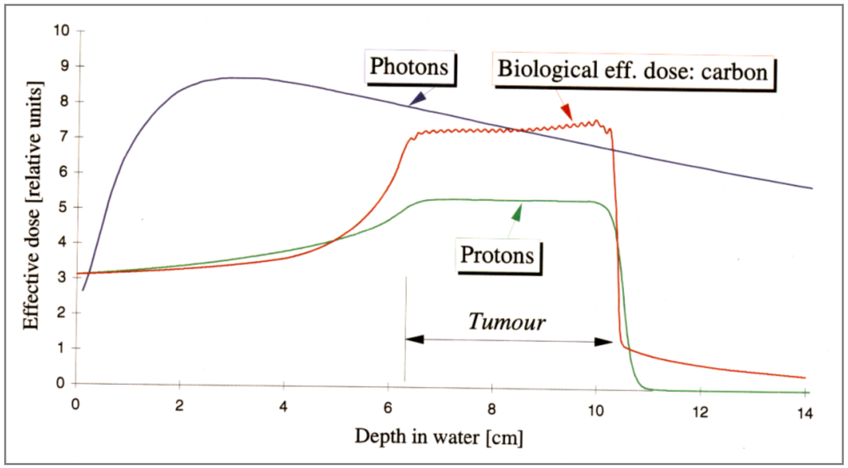
- KURRI FFAG chain for ADS studies
- PRISM – phase rotation for muons
- ERIT – neutron source for BNCT
- EMMA – first non-scaling ring
- RACCAM – R&D for hadrontherapy
- PAMELA – R&D for hadrontherapy





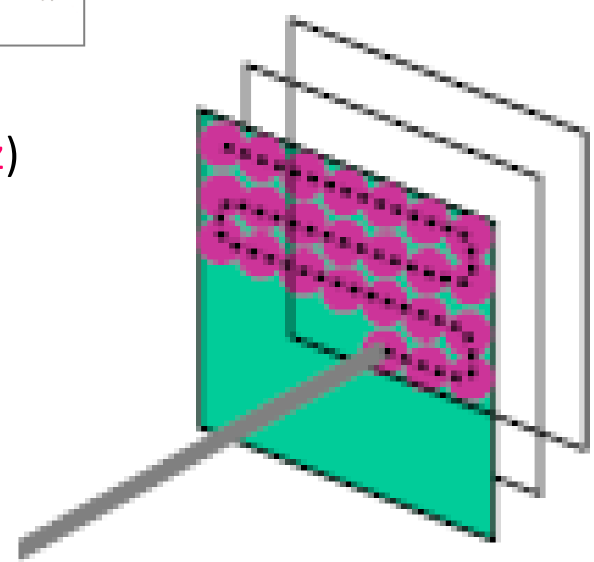
Motivations for a Medical FFAG

Hadrontherapy shows up to be more effective for cancer treatment comparing to the conventional radiotherapy!



Advantages of FFAG for medical applications:

- High dose delivery 5 Gy/min/l (high rep rate – 100 Hz)
- Variable energy operation without enegy degraders
- Compact size and low cost
- Simple and efficient extraction
- Stable and easy operation
- Multiple extraction ports
- Bunch to Pixel treatment.



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RACCAM Project - ANR Contract
(Recherche en ACCélérateur et Applications Médicales)

Bruno Autin	LPSC, collaborator
Jacques Balosso (MD)	Gren. Hospital
Johann Collot	LPSC
Joris Fourrier (PhD)	LPSC
Emmanuel Froidefond	LPSC
Franck Lemuet	CEA & CERN
François Méot	CEA & LPSC
Damiene Neuvéglise	SIGMAPHI
Jaroslaw Pasternak	LPSC
Thomas Planche (PhD)	SIGMAPHI
Pascal Pommier (MD)	Lyon Hospital

students

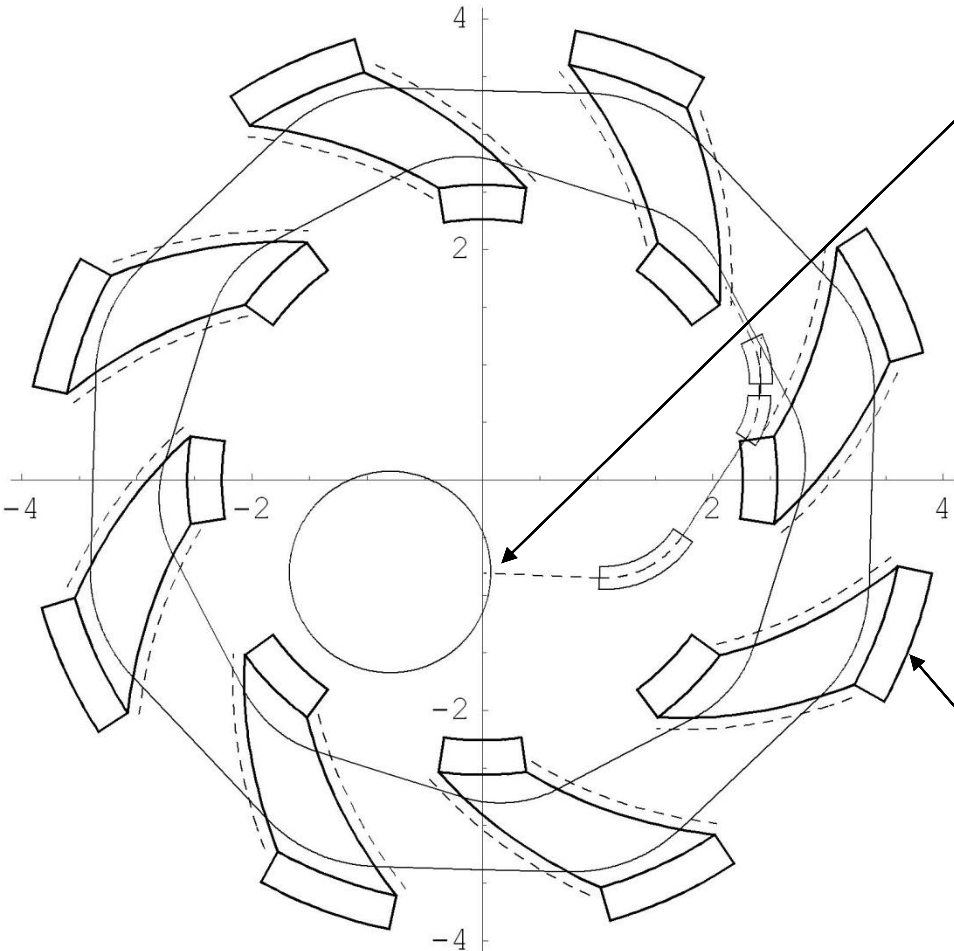
Florence Martinache	ENSPG (2006)
Abdulhamed Chaikh	Medical Phys., Gren.
Matthias Grimm	Munich Univ.
Jean-Baptiste Lagrange	ENSPG

2006-2008

Collaboration:
AIMA, IBA

Project goals:
- Design medical installations based on FFAG principle
- Build magnet prototype
- Participate in ongoing global FFAG effort (EMMA, NuFact, etc.)

Principle of Energy Variability for RACCAM System



Variable extraction energy from Injector – H^- cyclotron (AIMA), 6-15 MeV

Variable extraction energy from FFAG within 1 s (75-180 MeV)

+

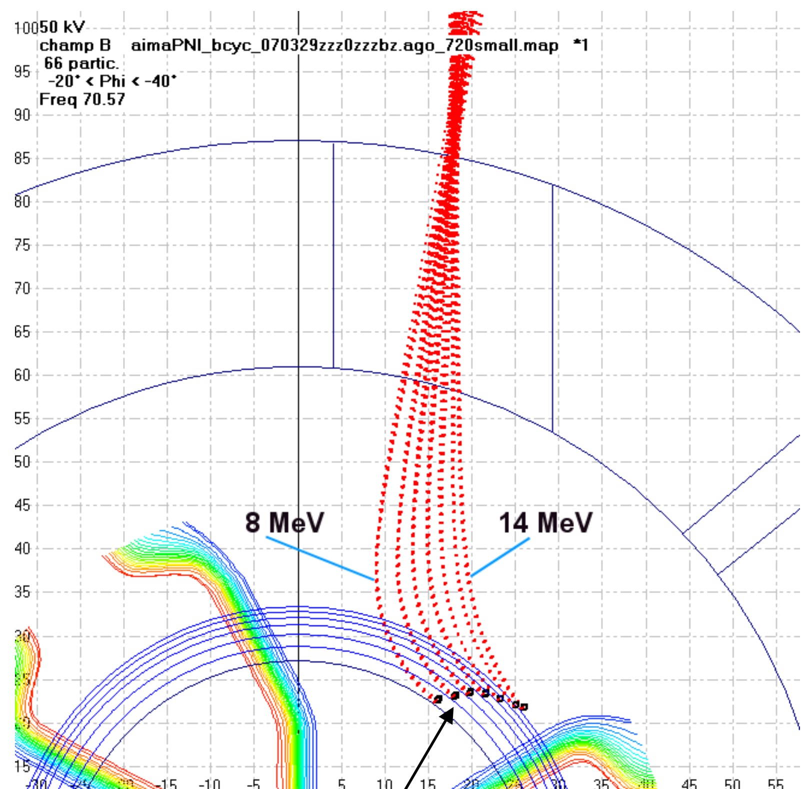
pulse by pulse variation with kicker system

Variable magnetic field in FFAG

Variable Energy Extraction from Injector, RACCAM

AIMA H^- cyclotron – our injector for FFAG

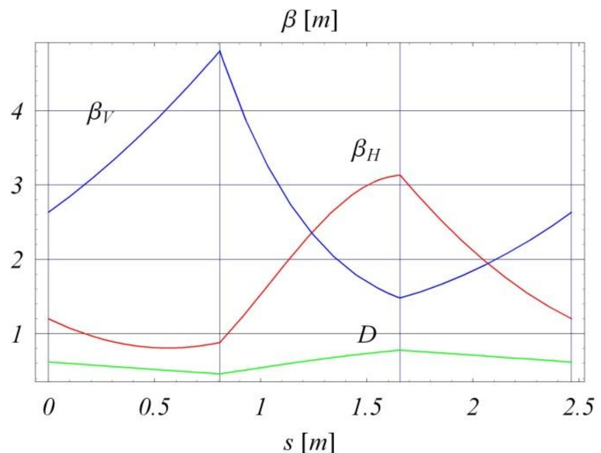
Studies made by AIMA team.

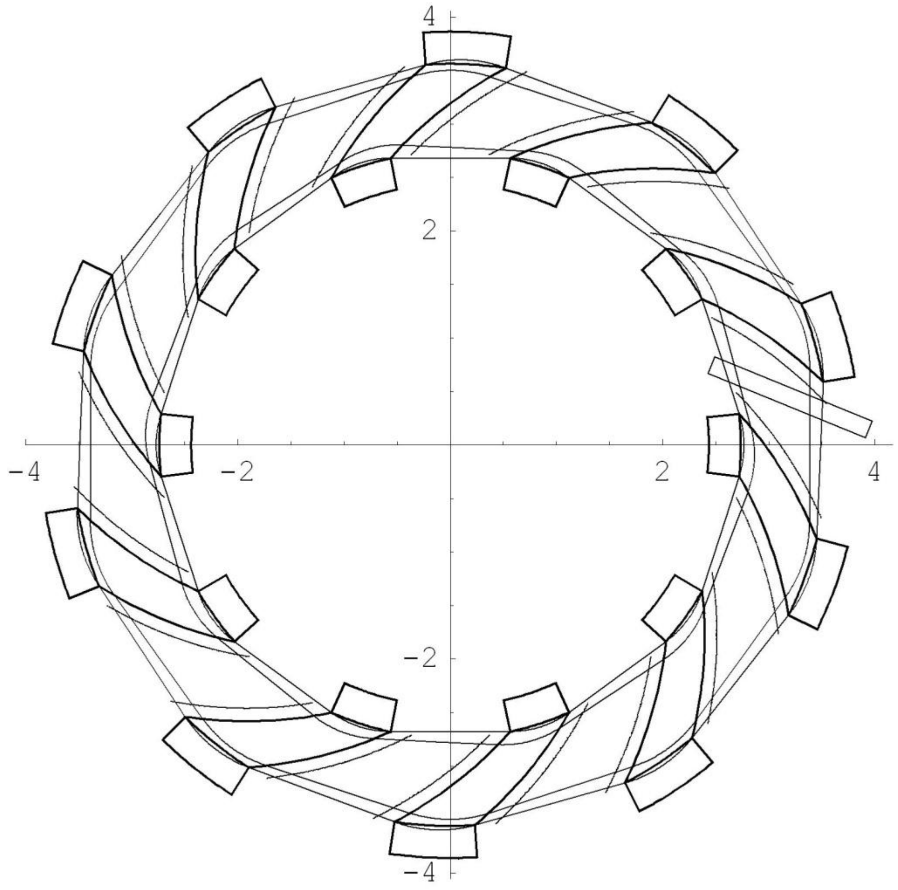


variable stripper position

RACCAM Parameters

- N 10
- k 5.
- Spiral angle 53.7°
- R_{max} 3.46 m
- R_{min} 2.8 m
- (Qx, Qy) (2.77, 1.64)
- B_{max} 1.7 T
- p_f 0.34
- Injection energy 6-15 MeV
- Extraction energy 75-180 MeV
- h 1
- RF frequency 1.9 – 7.5 MHz
- Bunch intensity 3×10^9 protons





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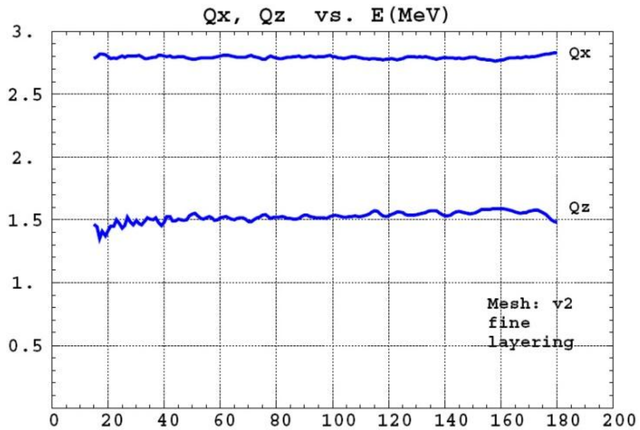
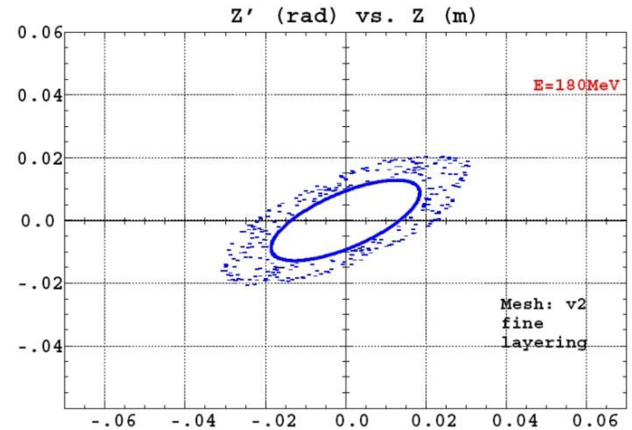
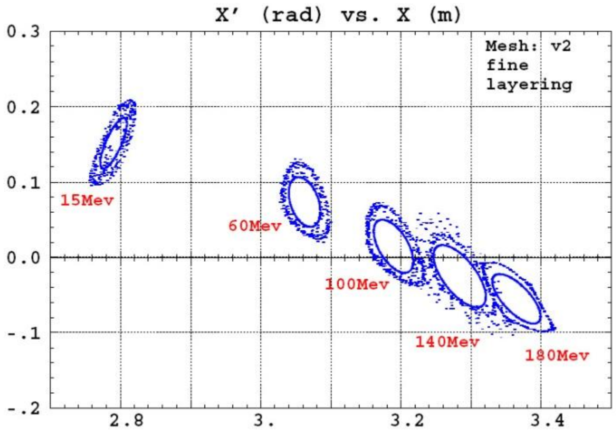
Beam Dynamics in Field Maps with Zgoubi Code



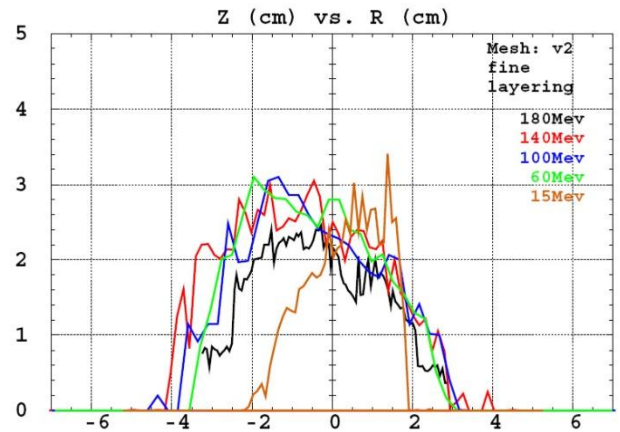
Stable tunes!



Vertical phase space



Horizontal phase space



Stability limits

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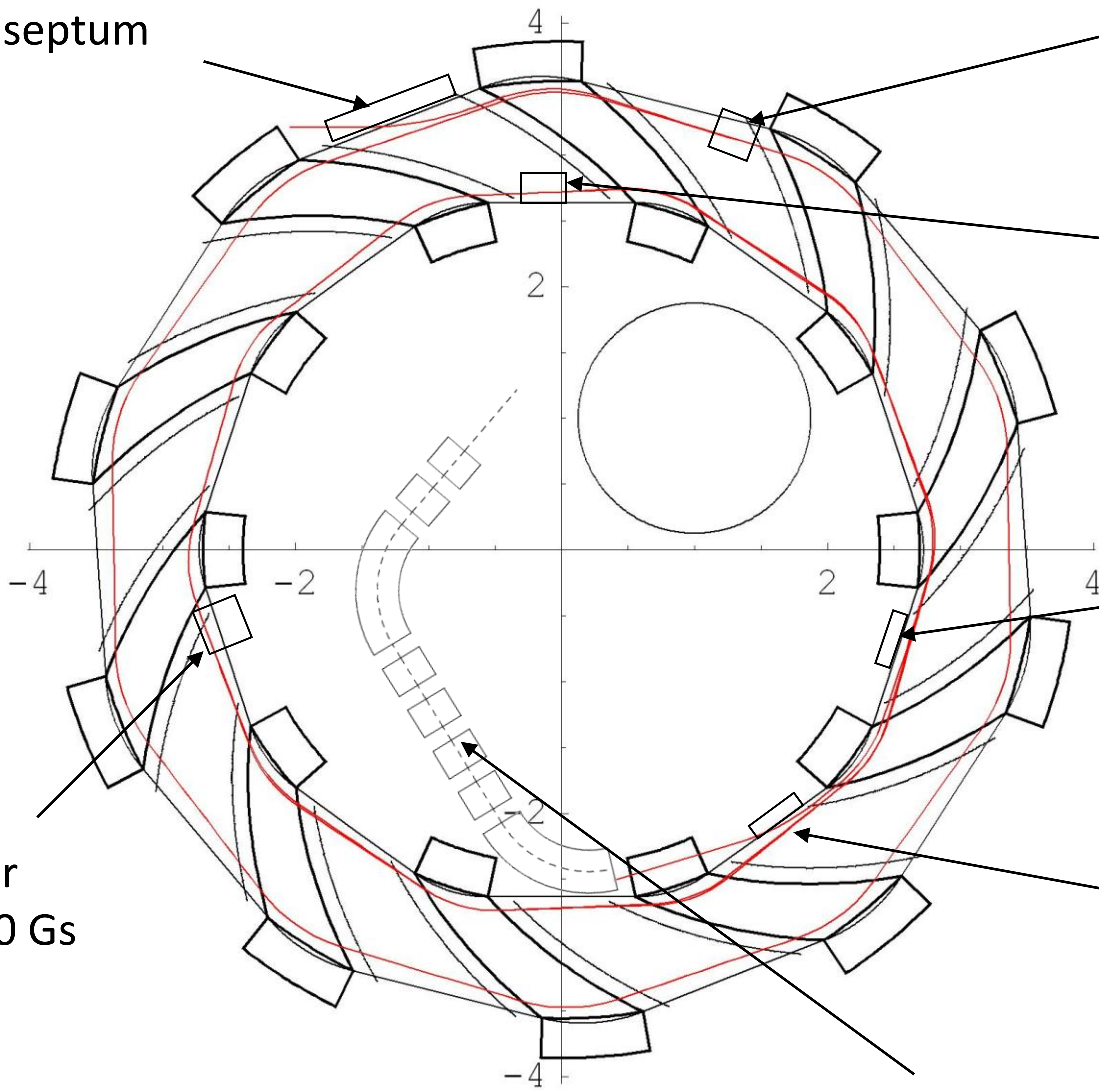
INJECTION / EXTRACTION

Extraction septum
1m, 0.8 T

Kicker
0.6 m, 500 Gs
100 ns

Bumpers
25 cm, 250 Gs



Electrostatic Injection Septum 3 MV/m
0.5 m

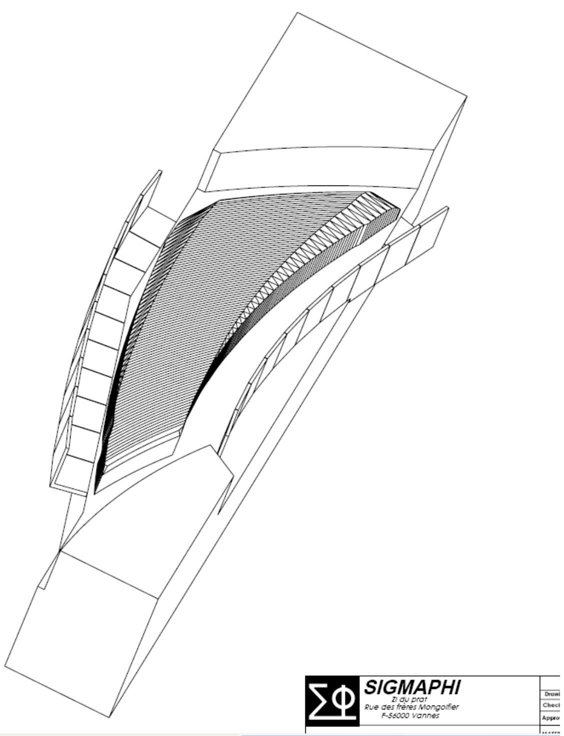
Bumper
25 cm, 200 Gs

Injection Septum
0.5 m, 0.4 T

Injection Line: 6 quads

RACCAM Spiral FFAG Magnet

- Prototype magnet parameters have been successfully designed and constructed in collaboration with SIGMAPHI!
- Magnet uses combination of variable chamfer and field clamp to stabilize the tune.
- Special shape chosen in order to optimize the mass (16 t).
- Power consumption 18 kW
- Magnet is of the laminated type for energy variability.
- Costructed in 2008.



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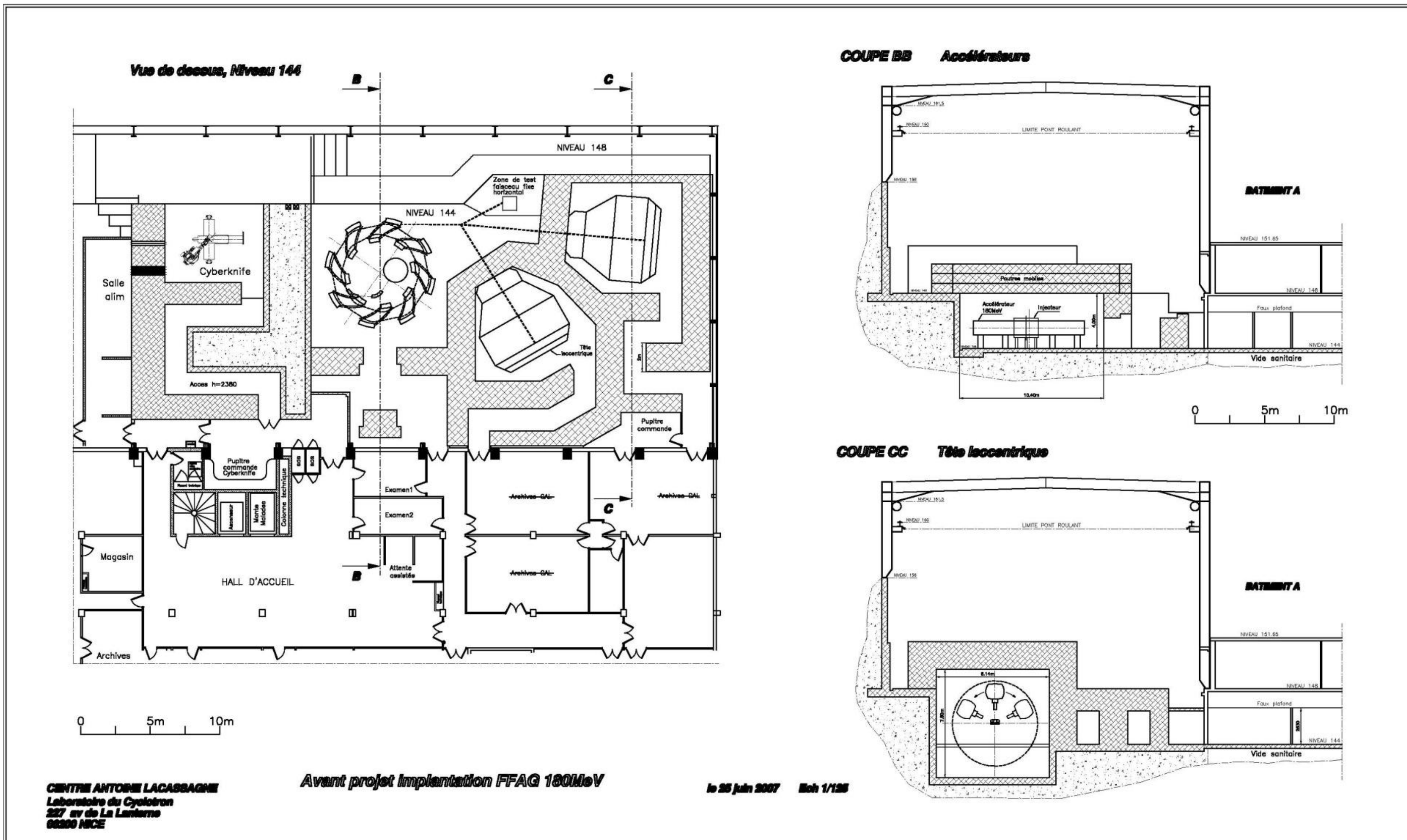
Possible implementation of demonstration machine



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PAMELA Design Team

Particle Accelerator for MEdicaL Applications

2008-2011

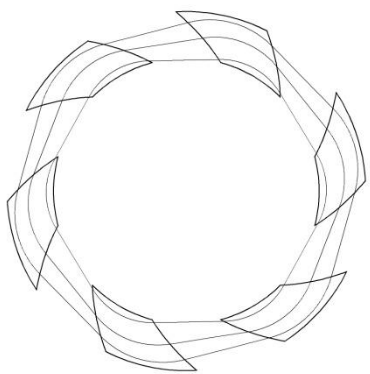
K. Peach[#], J. Cobb, S. L. Sheehy, H. Witte, T. Yokoi, JAI, Oxford, UK,
R. Fenning, A. Khan, Brunel University, UK,
R. Seviour, Cockcroft Institute, Lancaster University, UK,
C. Johnstone, Fermilab, Batavia, Illinois, USA,
M. Hill, B. Jones, B. Vojnovic, Gray Institute, Oxford, UK,
M. Aslaninejad, M. Easton, Imperial College, London, UK,
J. Pasternak, Jürgen Klaus Pozimski, Imperial College, London and STFC RAL, UK,
Carl Beard, N. Bliss, T. Jones, P. McIntosh, S. Pattalwar, S.L. Smith, J. Strachan, S. Tzenov, STFC Daresbury, UK,
T.R. Edgecock, I.S.K. Gardner, D. Kelliher, S. Machida, STFC RAL, Chilton, UK,
R.J. Barlow, H. Owen, S. Tygier Manchester University, UK.

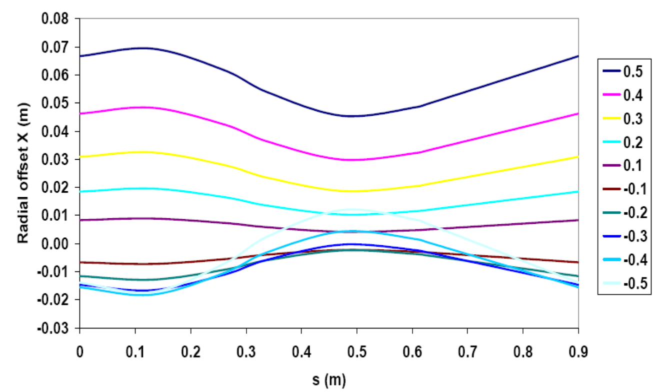
PAMELA

- – Charged Particle Therapy (protons, carbon …)
- – using a “Fixed Field Alternating Gradient” Accelerator
    - like EMMA, but different
    - EMMA is a non-scaling FFAG
    - RACCAM would be a scaling FFAG
    - PAMELA is a “nearly-scaling” FFAG

Scaling versus Non-Scaling FFAG

FFAG type	**Scaling**	**Non-scaling**
Magnetic field	$B = B_0 \left(\frac{R}{R_0} \right)^k$	linear
Orbits	scale	non-scale

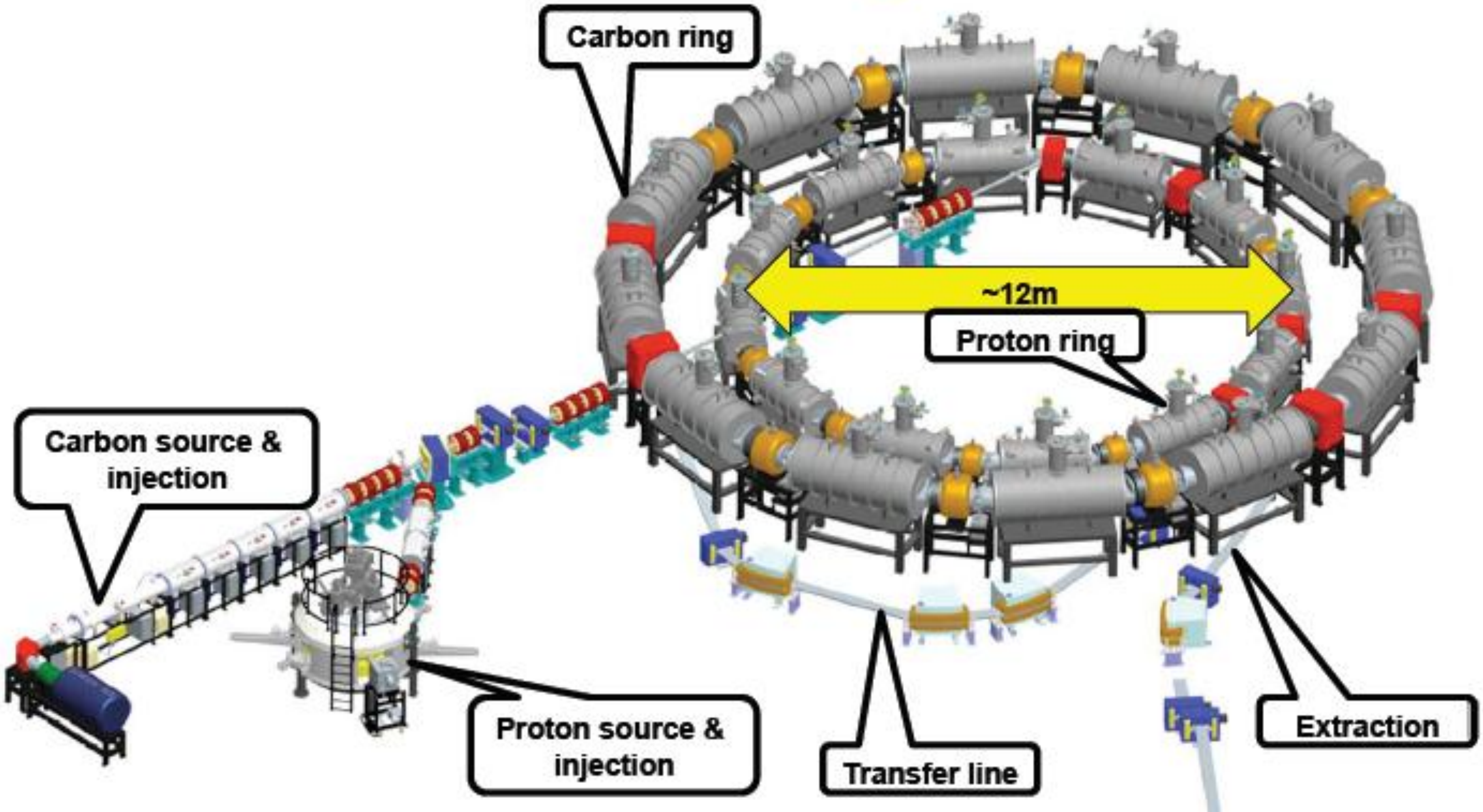




Tune	constant	changing

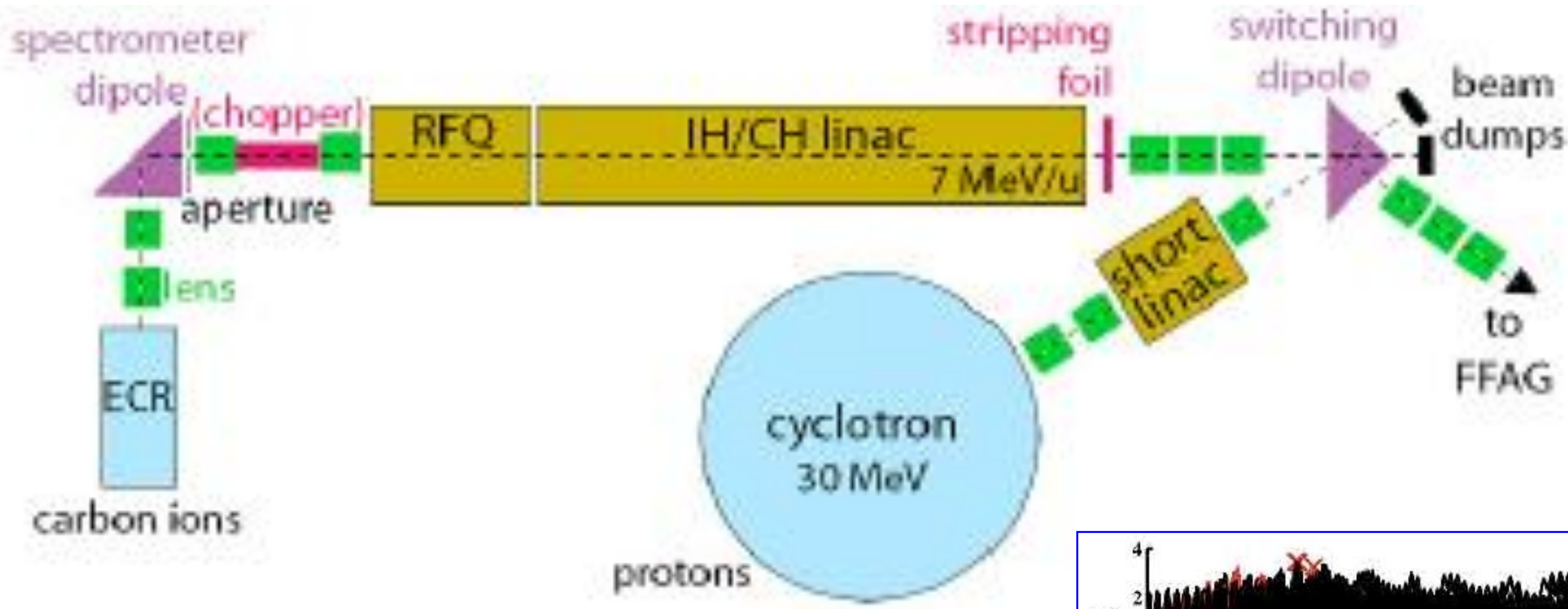
PAMELA combines the flexibility of non-scaling design and the constant tune behaviour of scaling ones providing enough space for components.

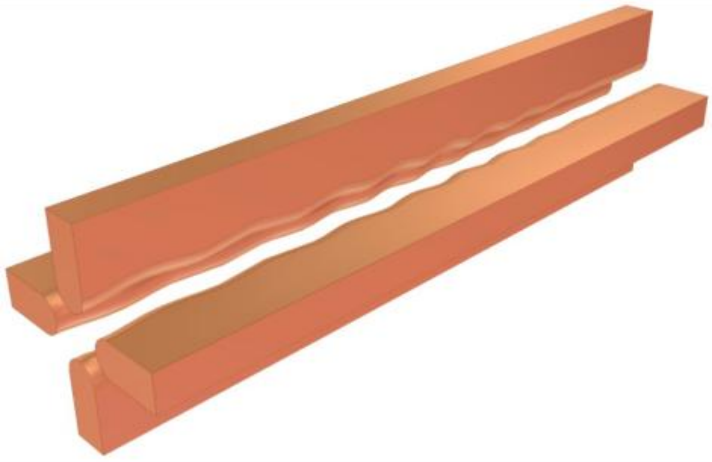
PAMELA Layout



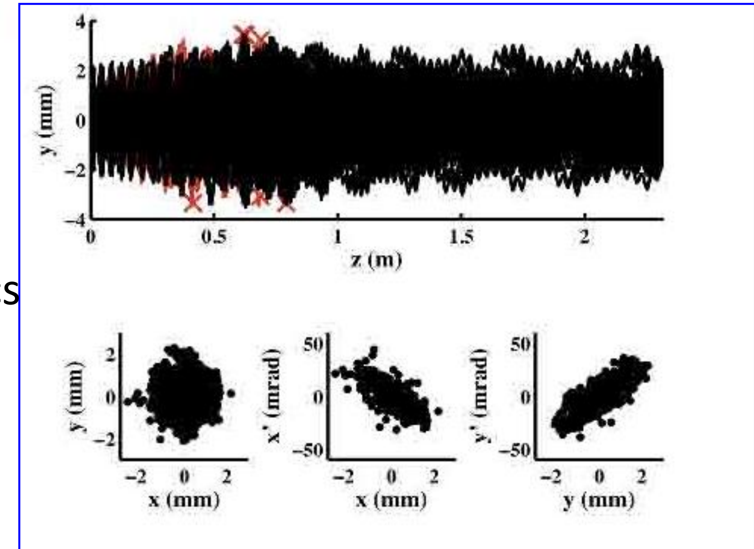
PAMELA Front End

- Proton and Carbon beams need to be produced

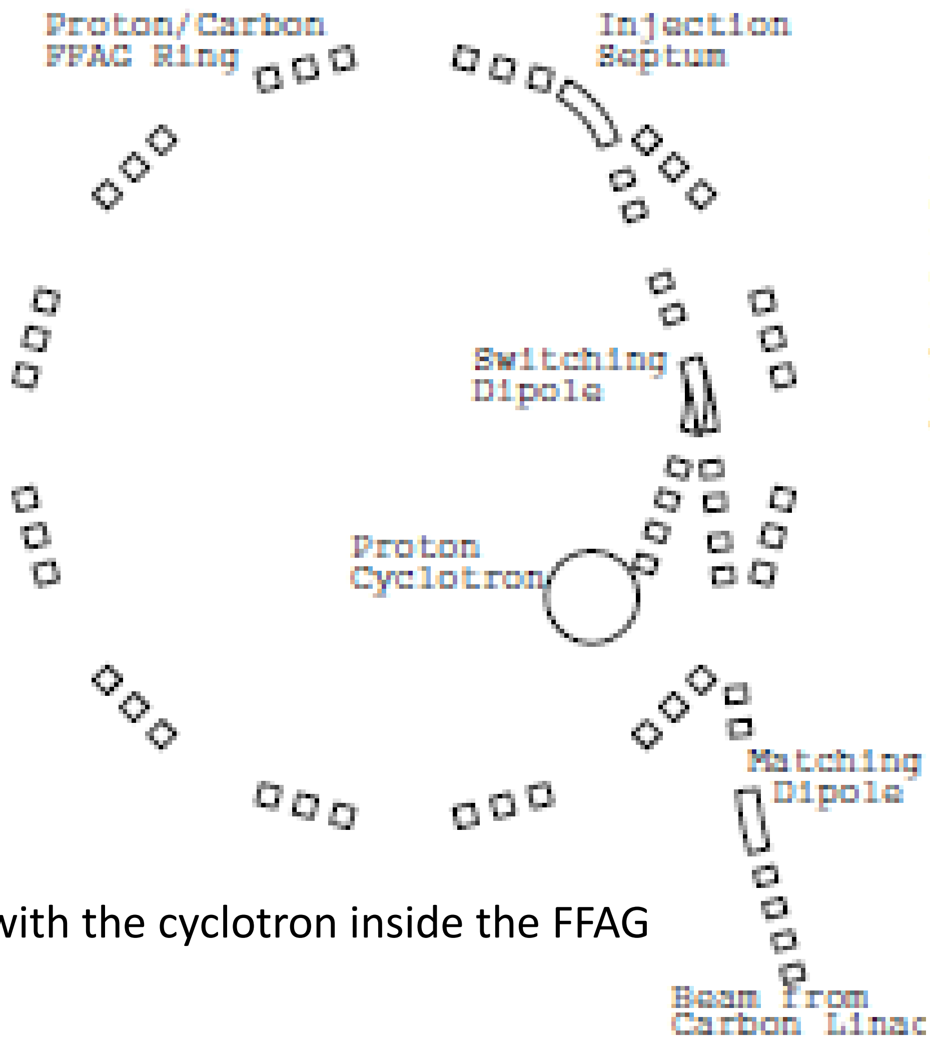




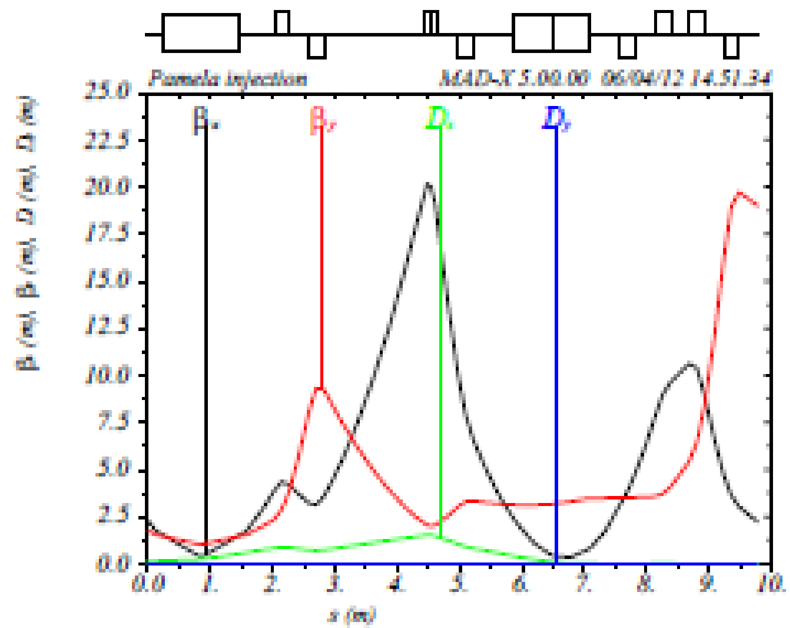
RFQ design (left) and beam dynamics simulations (right).



PAMELA MEBT



Layout with the cyclotron inside the FFAG



Matching between the cyclotron
And the FFAG

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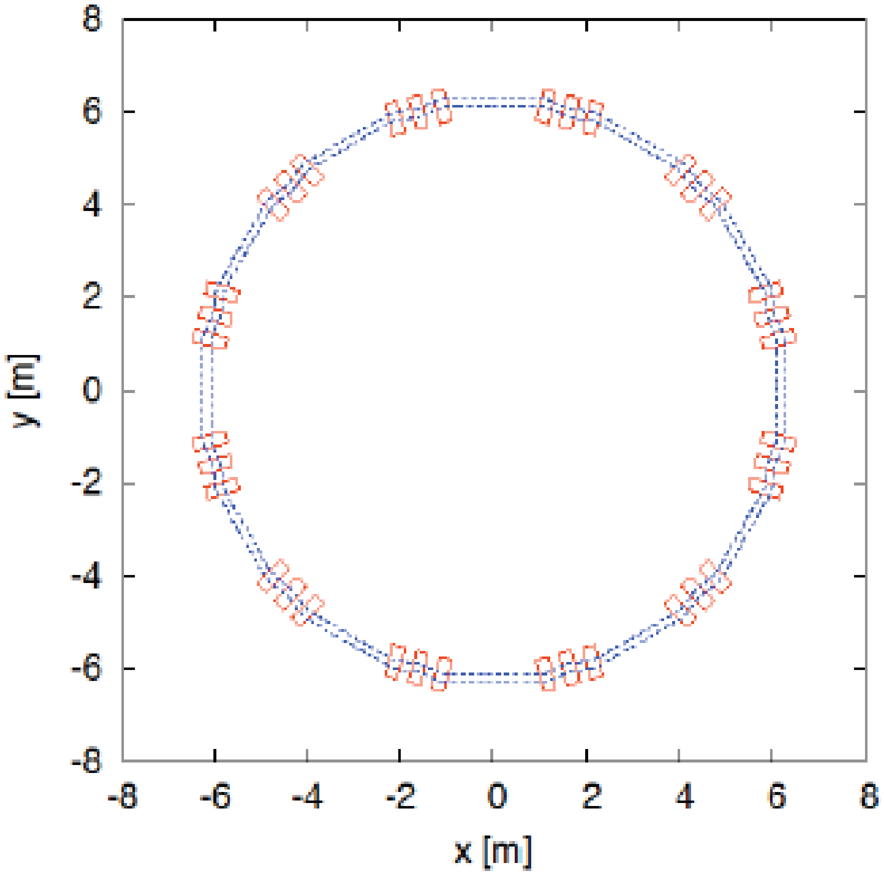
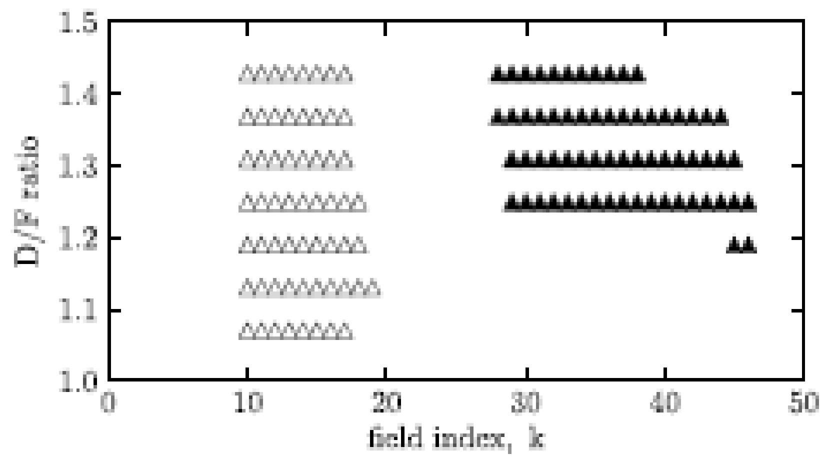
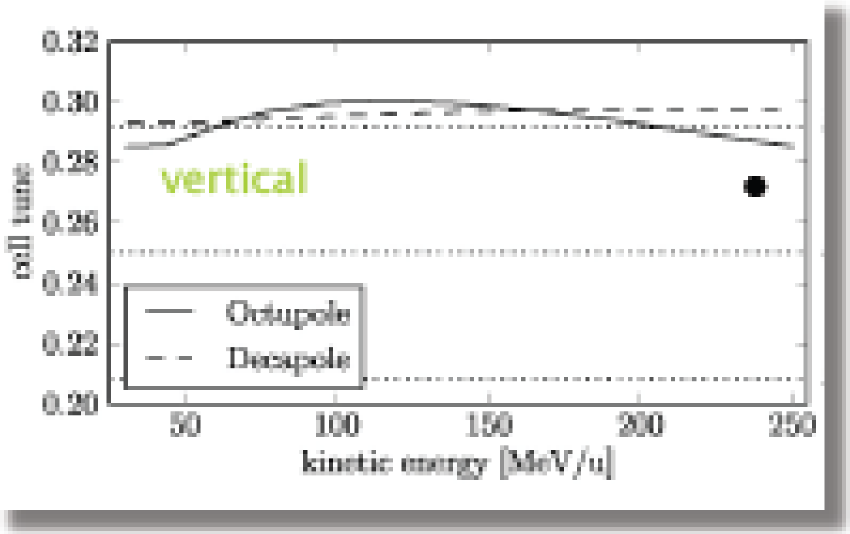
PAMELA Proton Ring Design



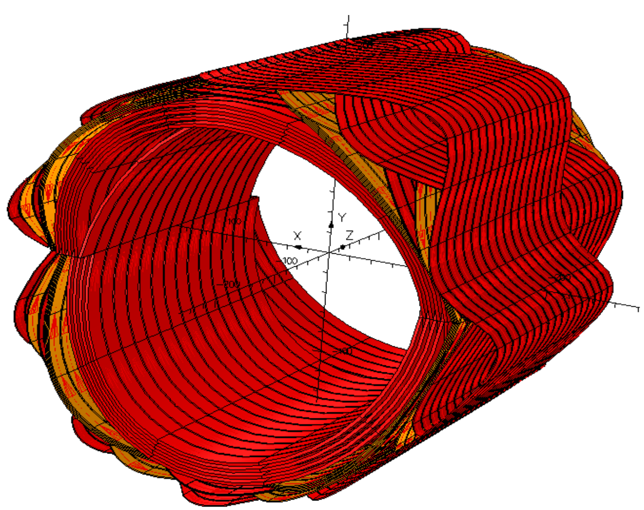
- Proton energy 31-250 MeV
- Carbon energy 7.84-68.4 MeV/u
- Magnetic rigidity 0.811-2.43 Tm
- Cells 12
- R 6.2 m
- k 38
- Packing factor 0.48
- Orbit excursion 0.176 m
- Magnet length 0.3144 m

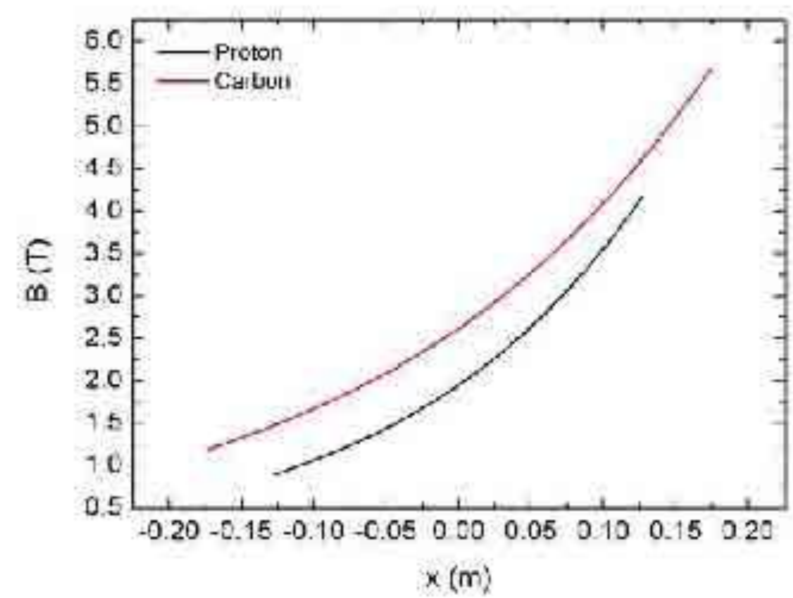


PAMELA Magnet



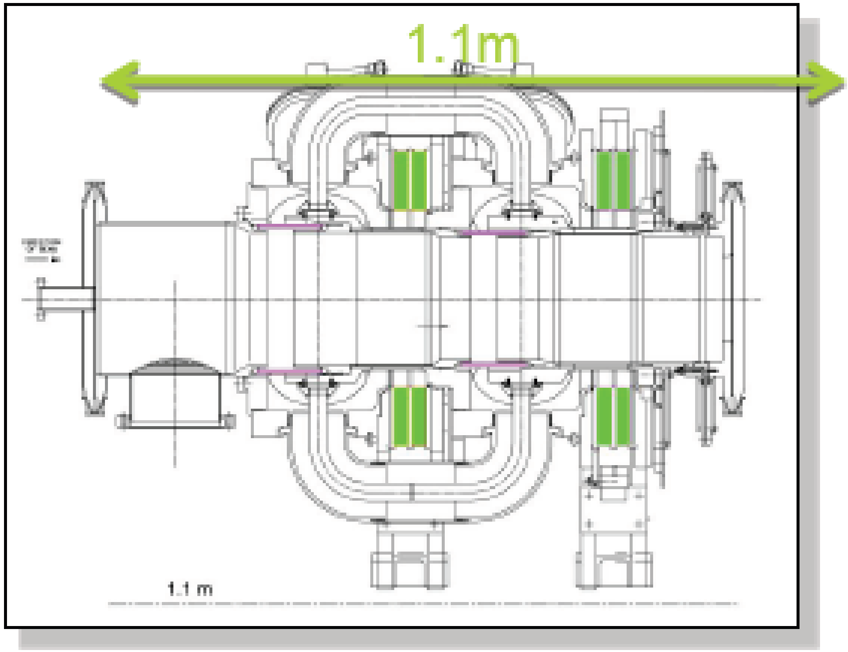
- For tune stabilisation nonlinear B field is needed.
- SC FFAG magnet combining multipoles up to the decapole has been designed.
- Magnets uses a novel double helix technique to create a very compact magnet.





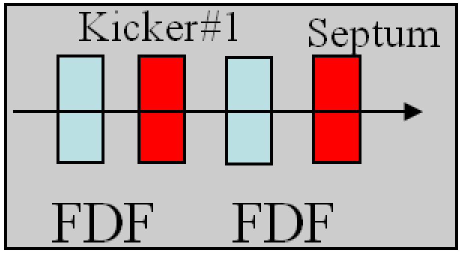
RF System

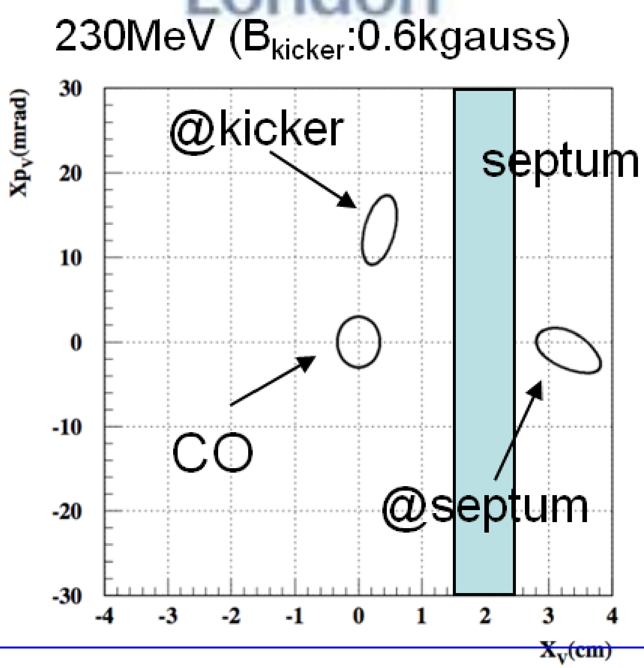
- 1kHz repetition rate ~ 100kV/turn
- Drift space ~1.7m
- Target energy gain:
  - ~16kV/turn/cavity
- Challenges:
  - duty cycle, Modulation, gradient
- Ferrite loaded cavity
  - baseline: ISIS 2nd harm. cavity
    - Relatively high Q (~100)
    - sufficient accelerating field
    - h=10 ?
    - heat load @ 1kHz ~100kW/cavity
- Development started
  - Ferrite property measurement
    - Q-value, FM rate dependence

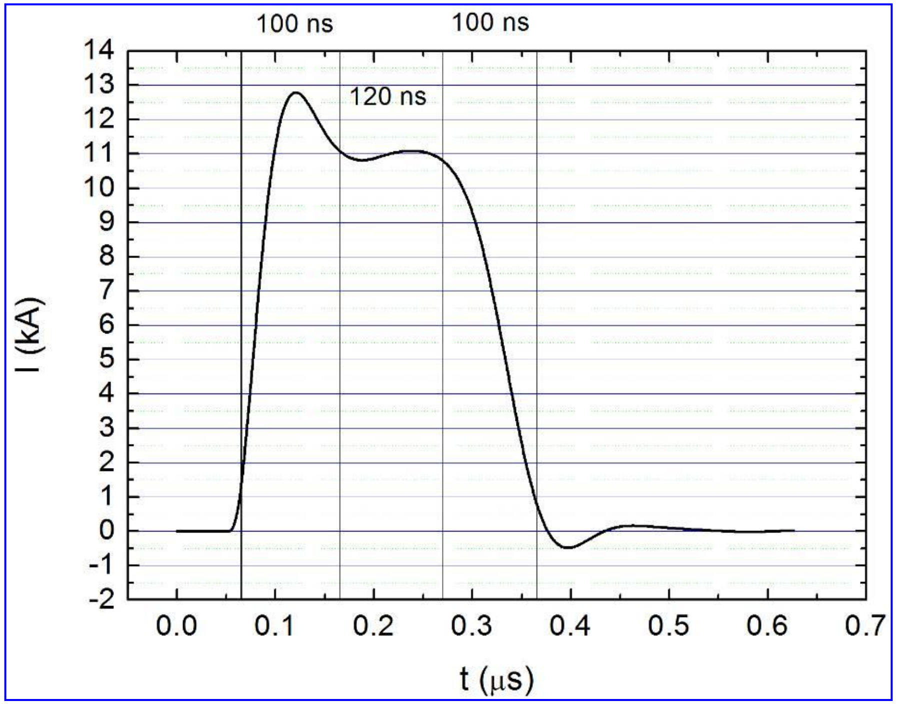


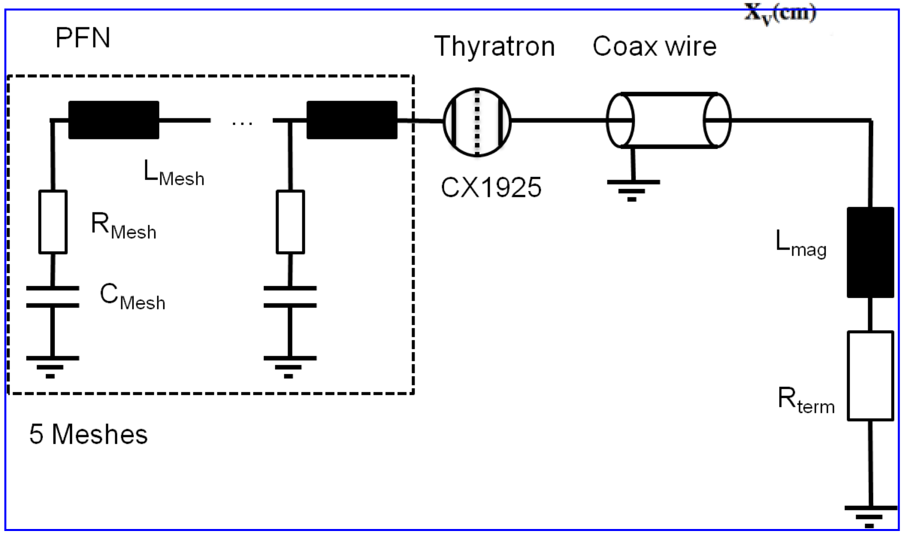
Extraction

- Pamela variable energy extraction uses just kicker and septum



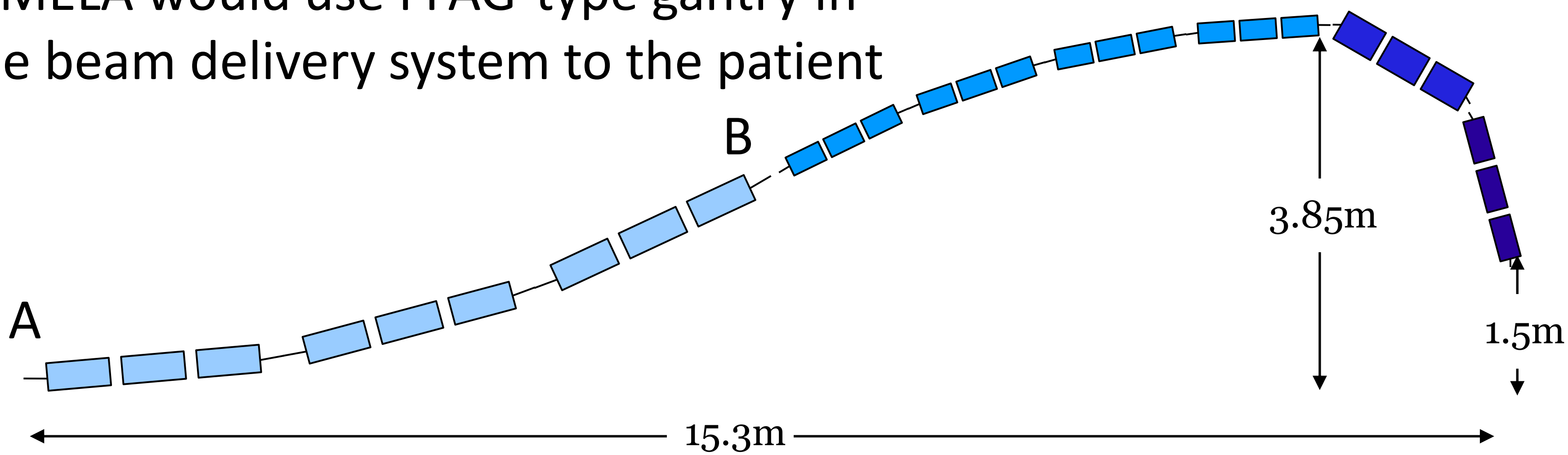


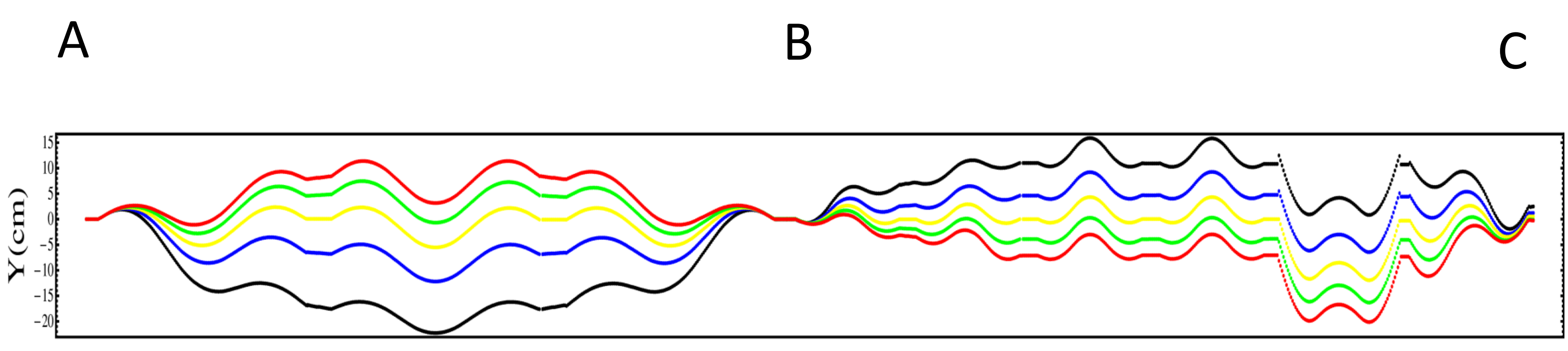




Gantry

PAMELA would use FFAG-type gantry in the beam delivery system to the patient





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Summary

- FFAGs offer an advantage with respect to conventional machines (fast, loss free and cost effective treatment).
- Current design trends go towards a single ring for both proton and carbon ions.
- FFAG rings have been successfully designed, constructed and commissioned, but a dedicated medical demonstrator is needed!