

Design of LhARA facility

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Outline

- Introduction and motivation
- Variable energy concept for multiple ions
- Laser source
- General layout
- Gabor lense
- Optics
- End Station
- Stage 2
- FFA types under consideration
- Baseline design
- Magnet options
- Conclusions and future plans

Introduction

- Laser hybrid Accelerator for Radiobiological Applications (LhARA) was proposed within the Centre for the Clinical Application of Particles (CCAP) at Imperial College London as a facility dedicated to the systematic study of radiobiology.
- It will allow study with proton beams in a novel regime of dose delivery (FLASH) at Stage 1
- It will open the study to use multiple ions (including Carbon) at Stage 2.
- It aims to demonstrate a novel technologies for next generation hadrontherapy.

Present multidisciplinary collaboration



Imperial: Academic Health Science Centre, Faculty of Medicine,
Department of Physics, CRUK Cancer Centre
Imperial College NHS Healthcare Trust
Institute of Cancer Research
John Adams Institute
Oxford Institute for Radiation Oncology

The LhARA consortium

University partners:



Accelerator institute partners:



Laboratory partners:



Clinical partners:

Oncologists, medical/biophysics, providers



Industrial partners:



Further interest from:

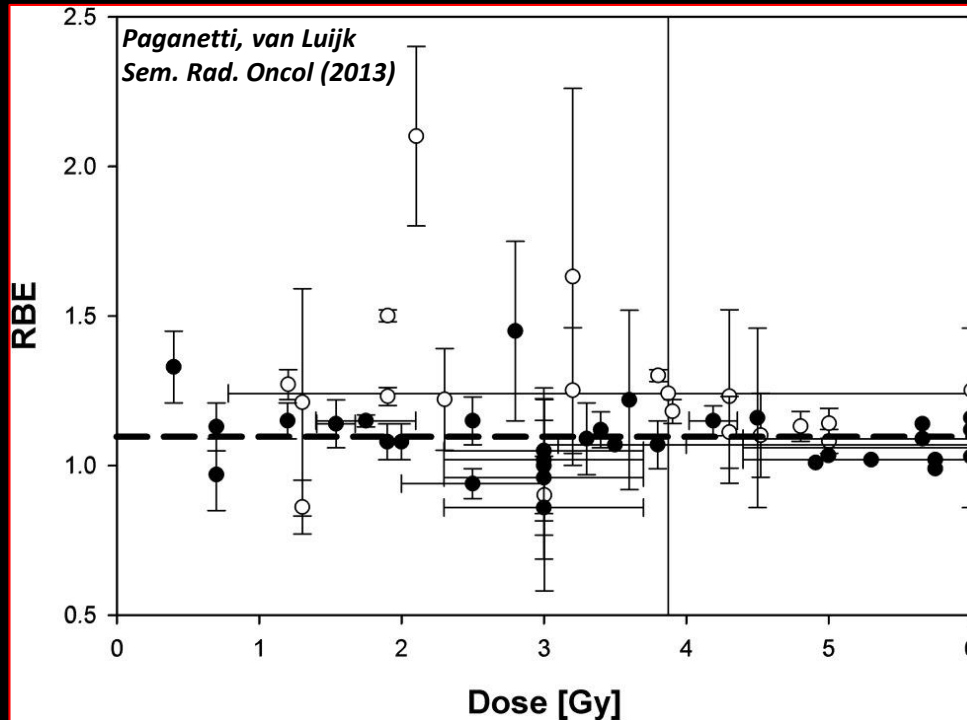
- Groups in the UK and overseas
- The International Biophysics Collaboration [spokespeople: Patera, Prezado]

The radiobiology needs to be understood

- Treatment planning:
 - Based on 'Relative Biological Effectiveness (RBE)'
 - Proton-treatment planning uses $RBE = 1.1$
 - Effective values are used for C^{6+}

RBE:

Ratio of dose required to gain same biological response as reference photon beam



RBE known to depend on:

Energy, ion species
Dose & dose rate
Tissue type
Biological endpoint

Essential: improved, fundamental, understanding of radiobiology

Our vision and our ambition

- Vision:

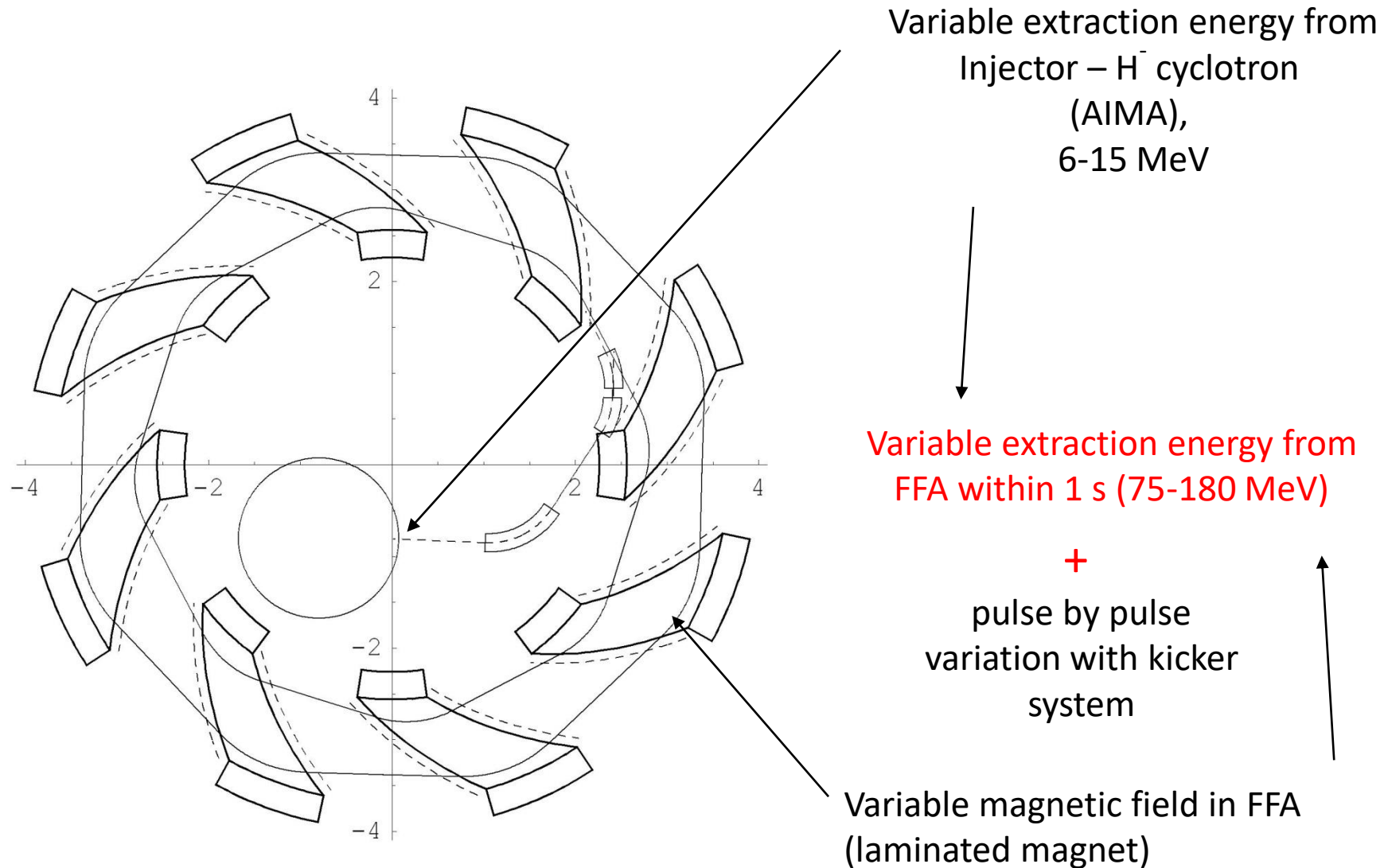
LhARA will be a uniquely-flexible, novel system that will:

- *Deliver a systematic and definitive radiobiology programme*
- *Prove the feasibility of the laser-driven hybrid-accelerator approach*
- *Lay the technological foundations for the transformation of PBT*
 - automated, patient-specific: implies online imaging & fast feedback and control

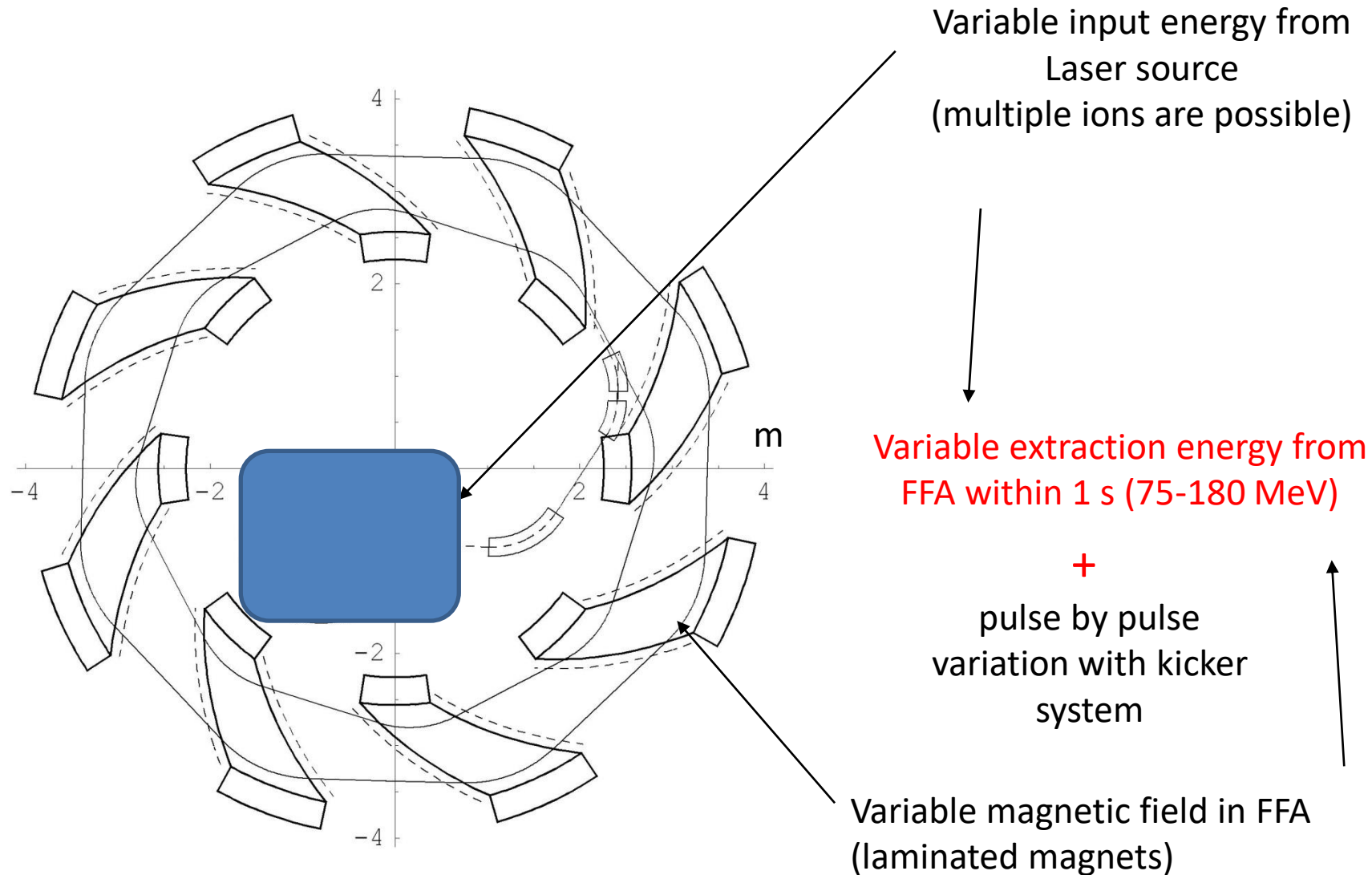
- Ambition:

- Develop:
necessary techniques, technologies, and systems
- Exploit:
system approach to novel bring techniques into clinical practice as they mature
- Integrate:
production prototypes in a production system for radiobiological research
- Engage:
industry and clinical PBT centres
during development of techniques, technologies, and systems

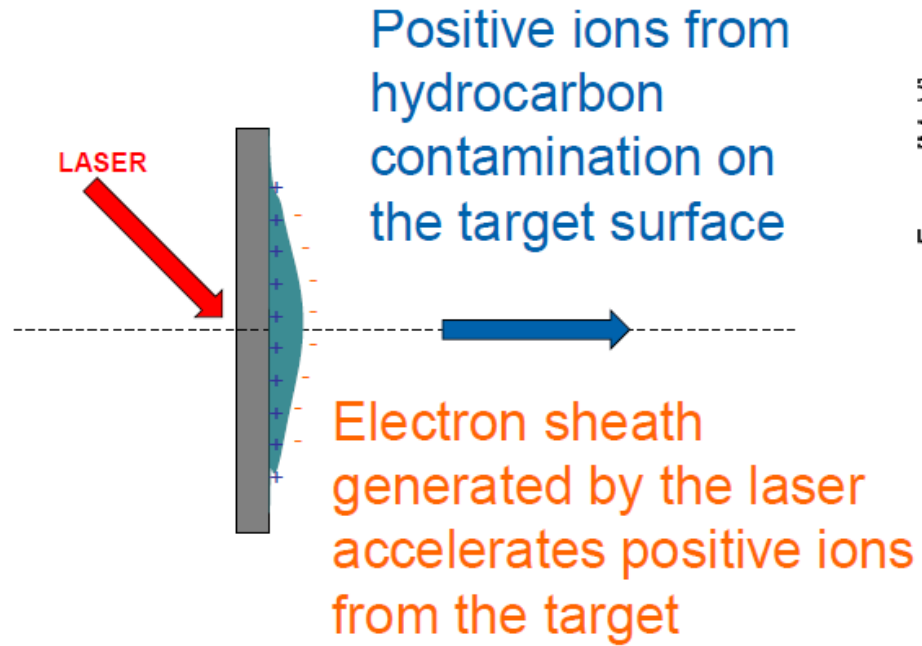
Principle of Energy Variability for RACCAM System



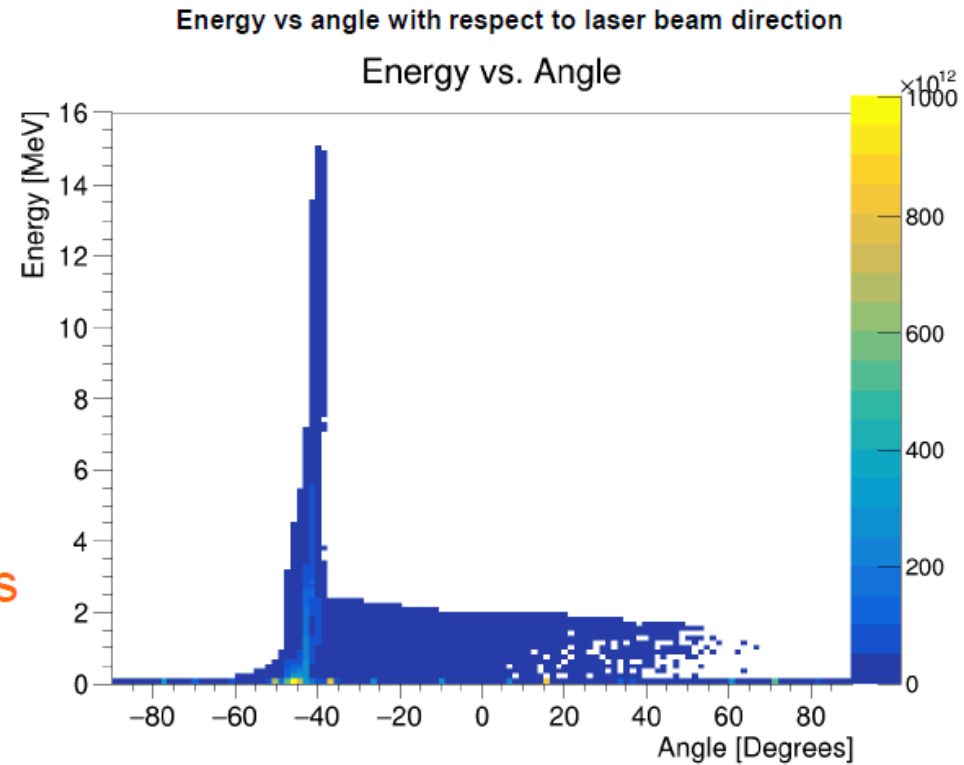
Alternative Energy Variability using Laser Accelerated Ions



LASER SOURCE

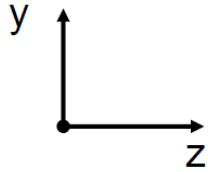


- Produces intense beams and multiple species, e.g. proton and carbon ions.



Laser driven ion beam simulation using EPOCH.

Layout of LhARA Stage-1



LASER TARGET

Laser used to generate intense ions beams and beams of different types of ions, e.g. protons and carbon ions.



ENERGY SELECTION

A Gabor lens and a collimator slit are used to select particle energy, as the focal point of the Gabor lens is energy dependent.

END STATION

Where the cells will be irradiated. The beam will be delivered vertically from below the cell culture plate.

FFA type or conventional

beam

CAPTURE SECTION

Gabor lenses used for compact focussing to capture the large divergence and energy spread of the laser driven ion beam.

Solenoids are a possible backup

11.58m

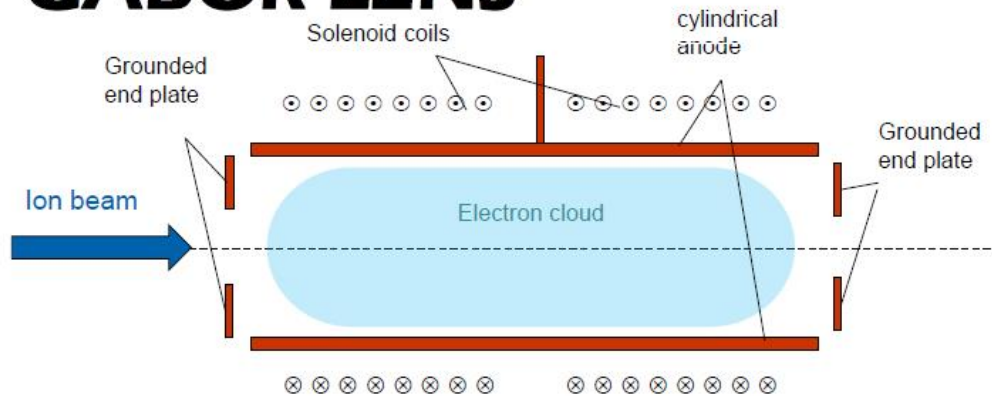
MATCHING

Two Gabor lenses are used to adjust the beam size and divergence in the end station.

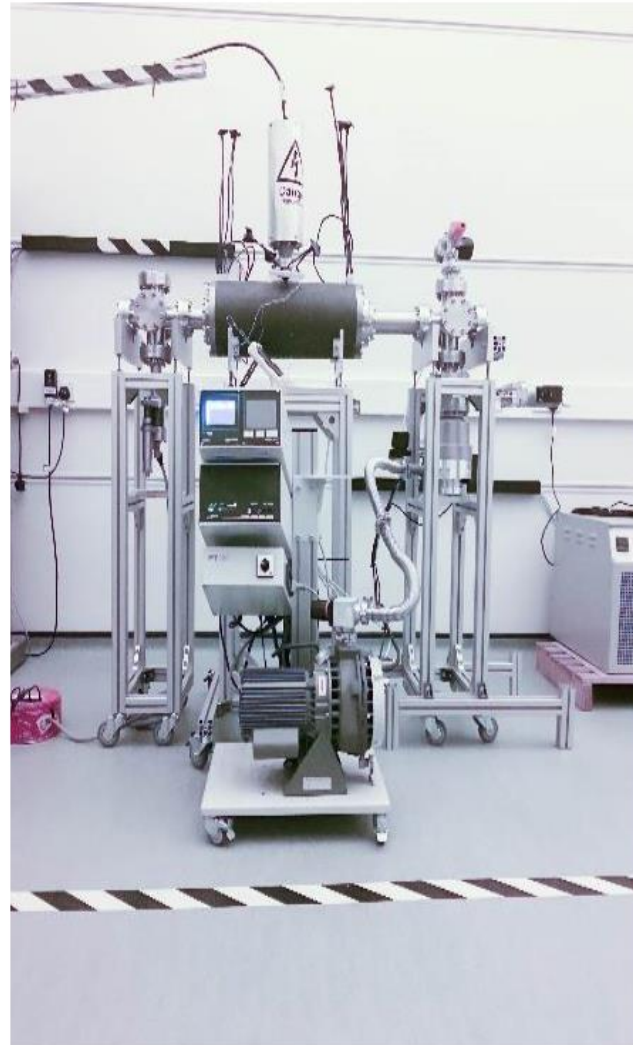
90° VERTICAL BEND

Combined function sector magnets and collimators are used to select momentum and deliver the beam vertically to the end stations.

GABOR LENS



- The Gabor lens uses an electron plasma to generate a strong electrostatic focusing field.
- Assembled lens prototype is being tested at Imperial.

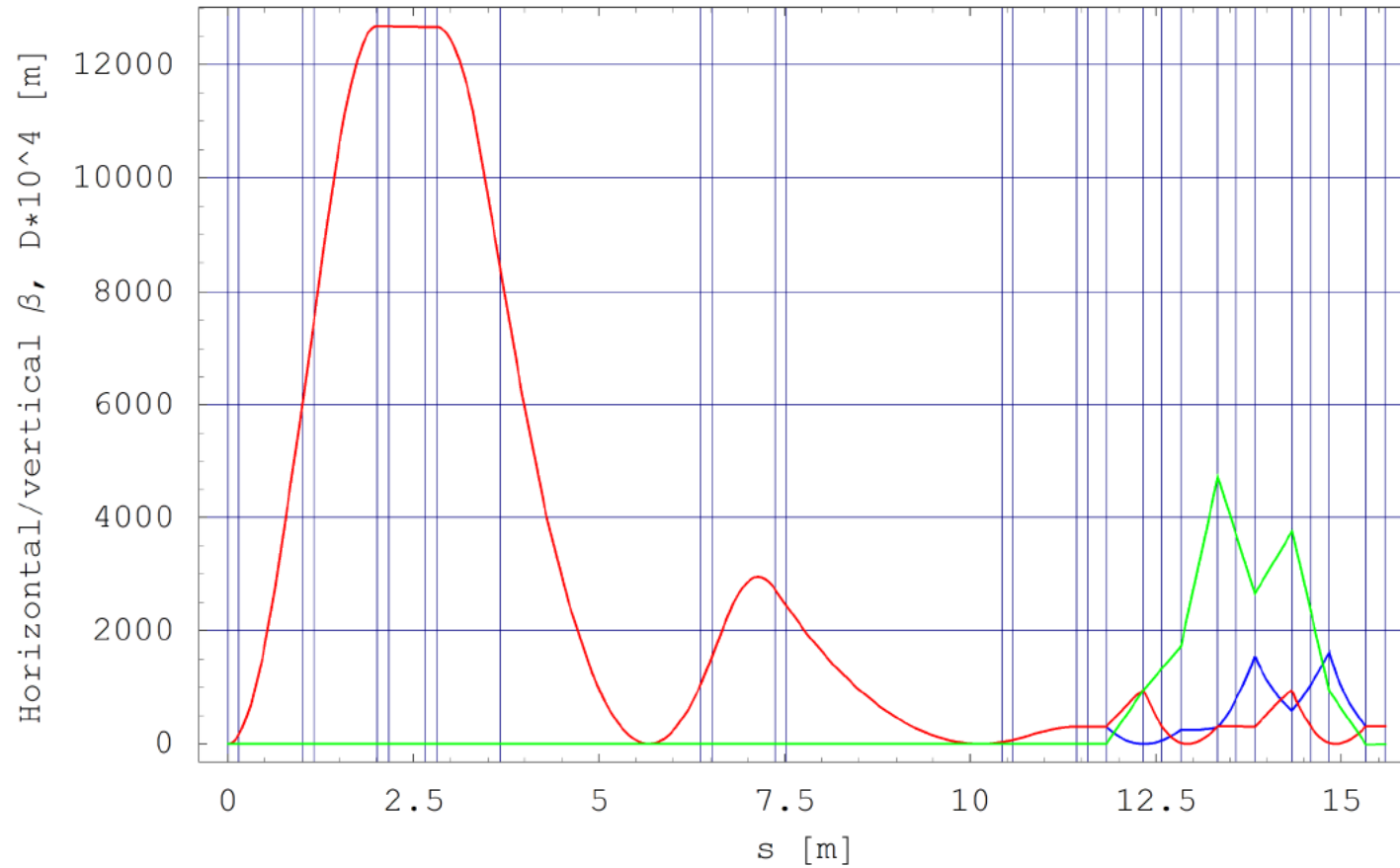


Parameters of Gabor lenses

Table 1: Parameters of Gabor lenses assumed in LhARA

Parameter	Value	Units
Total length	1.157	m
Effective focusing length	0.857	m
Max. Cathode voltage	65	kV
Cathode radius	0.0365	m

Optics in LhARA Stage 1



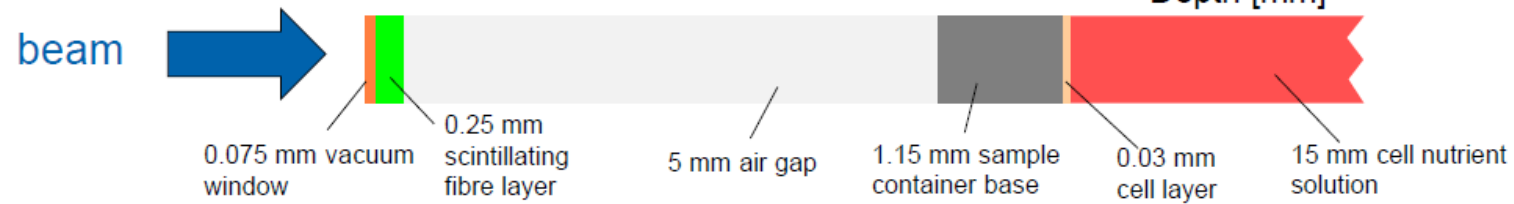
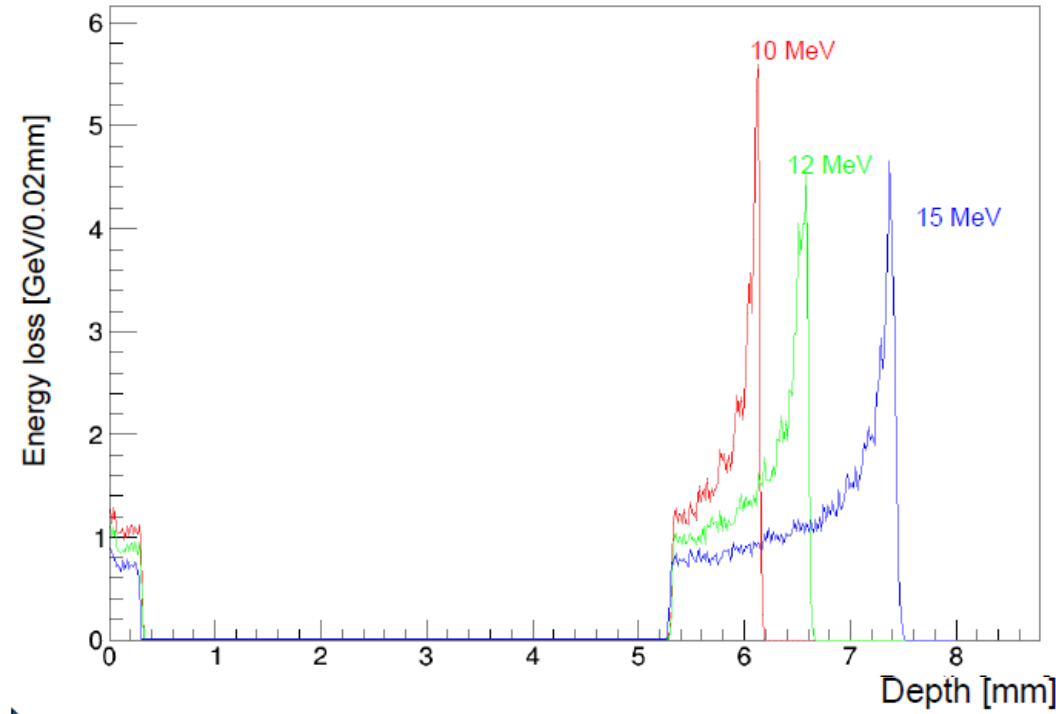
Vertical (red) and horizontal (blue) betatron functions, and dispersion (green, scaled by 10^4 in order to be visible on the plot) in LhARA Stage 1.

LhARA Stage 1 parameters

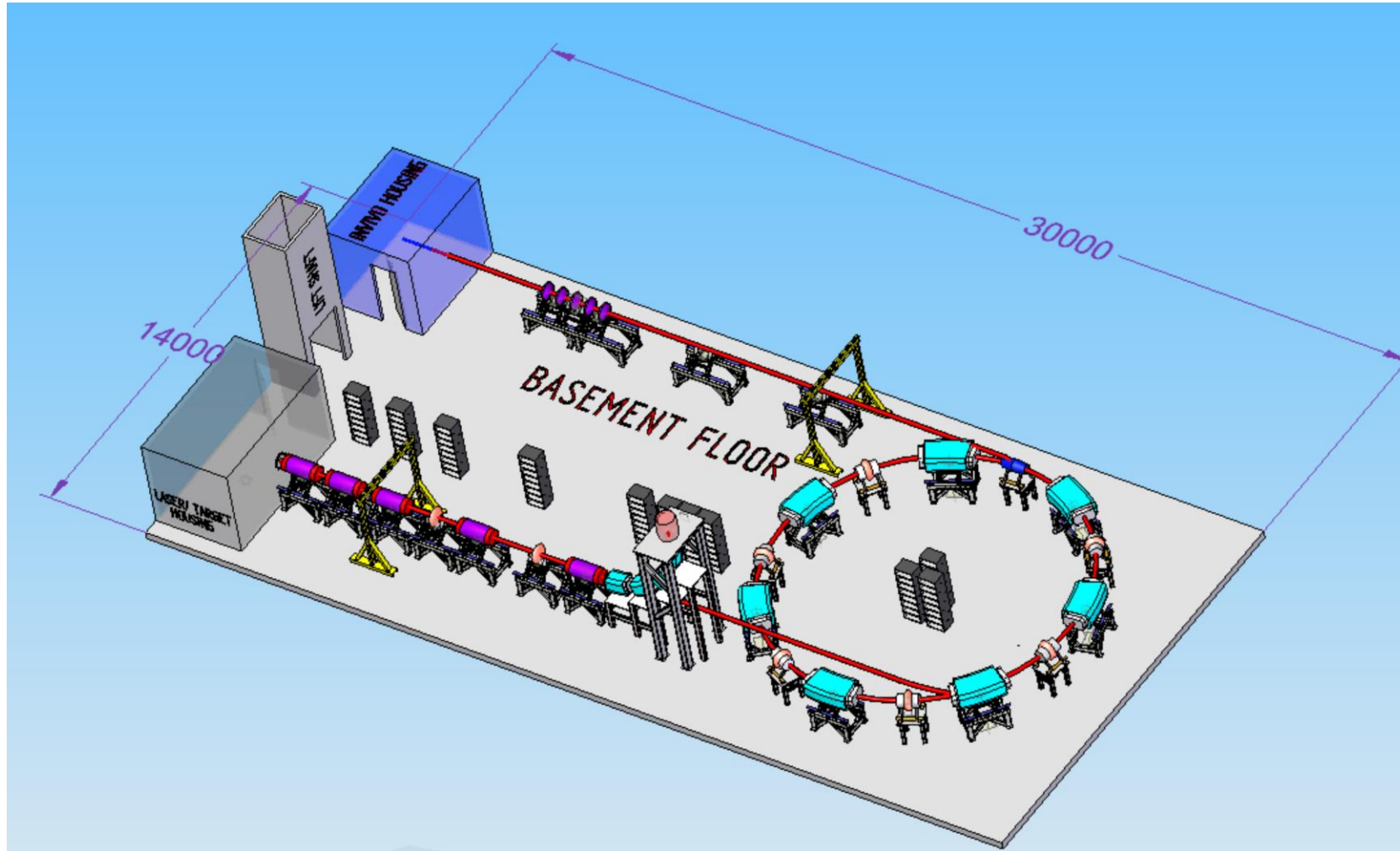
Parameter	Value	Units
Total length	15.58	m
Length w/o arc	11.58	m
Rep. rate	10	Hz
Initial pulse duration (FWHM)	35	fs
Beam spot size at the target (FWHM)	4	um
Physical emittance (rms)	0.021	π .mm.mrad
Proton energy range	12-15	MeV
Final energy spread	$\pm 2\%$	-
Mean dose rate	2	Gy/min
Final spot size (total diameter)	1-15	mm
Final bunch intensity	10^6 - 10^8	-

End Station

Energy loss as a function of depth for different beam energies



Towards Stage 2

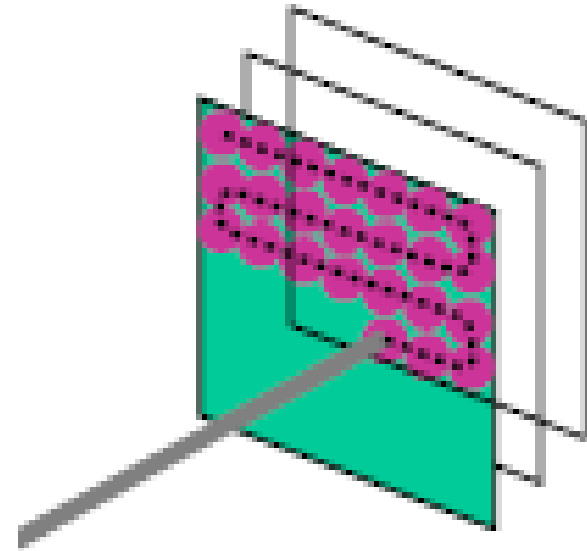


Thanks to L. Clark
from RAL

Motivations for a Medical/Radiobiological FFA (Fixed Field Accelerator)

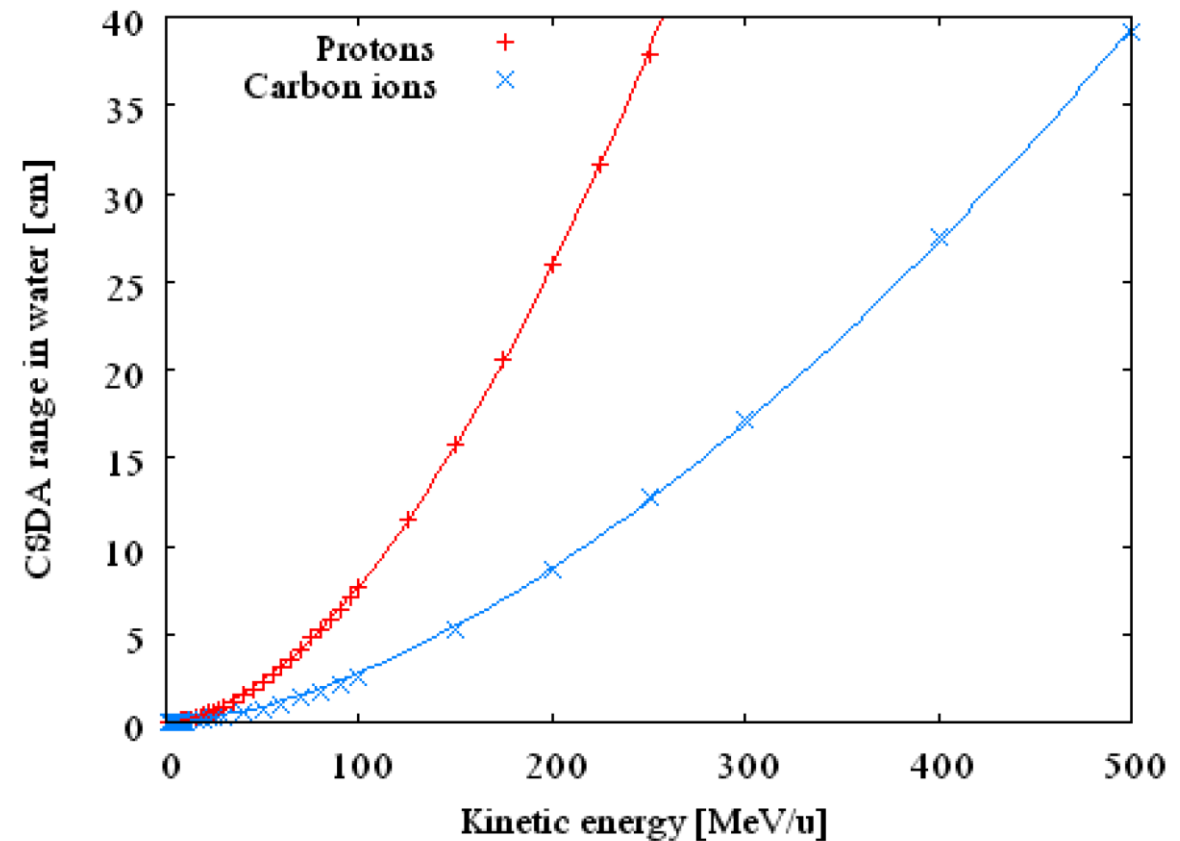
Advantages of FFA for medical/radiobiological applications:

- High/variable dose delivery (high rep rate – 10-100 Hz)
- Variable energy operation without energy degraders
- Compact size and low cost
- Simple and efficient extraction
- Stable and easy operation
- Multiple extraction ports
- Bunch to Pixel treatment.
- Multiple ion capability



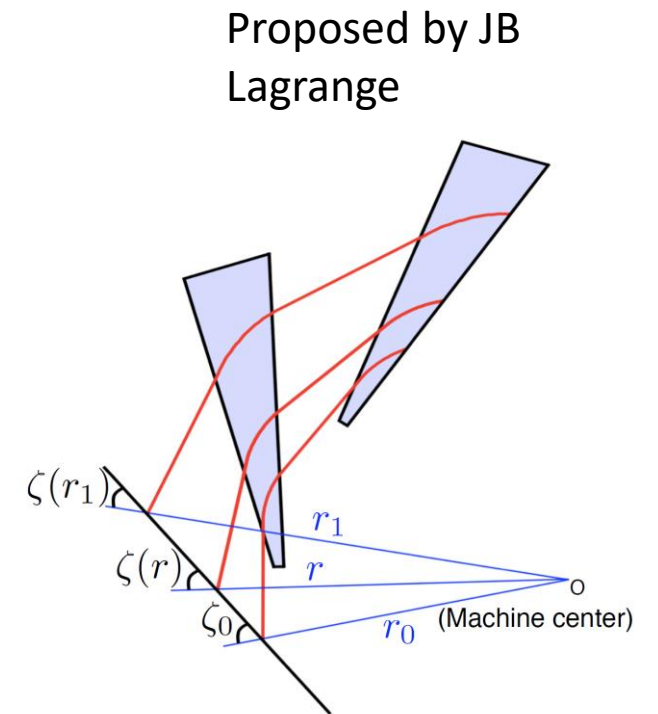
Energy for LhARA Step 2

- FFA accelerator can typically accelerate by a factor of 3 in momentum (or more). This allows to easily achieve 127.4 MeV (starting from 15 MeV).
 - Acceleration by a factor of 4 would be possible. This corresponds to 217 MeV protons.
- This would correspond to 33.4 (58.7) MeV/u for C6+.
- ... and this is still not a lot with respect to penetration depth in water...



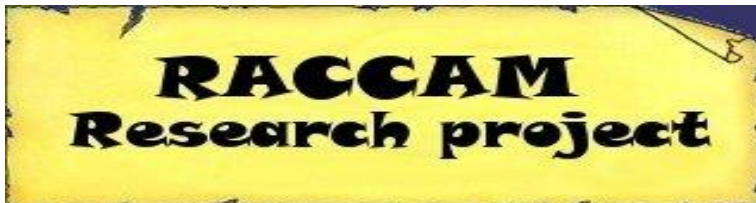
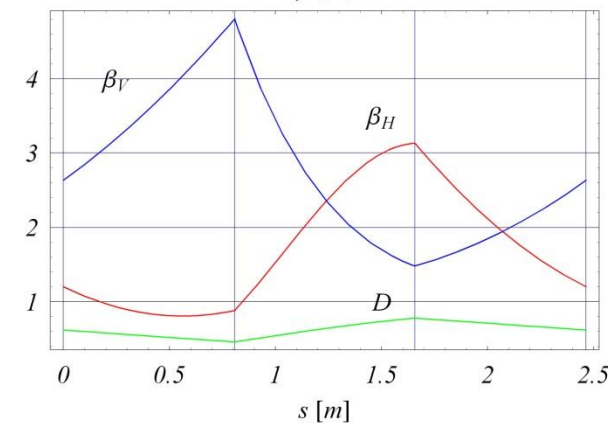
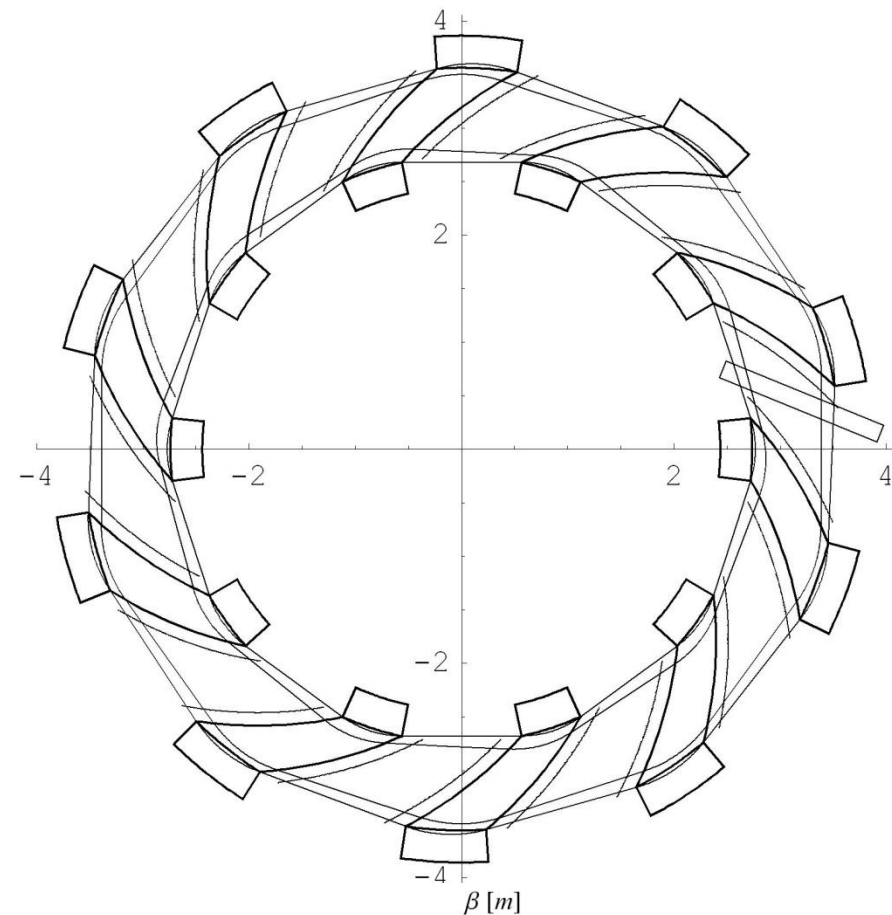
FFA types

- Scaling single spiral type
 - RACCAM project
 - Cost effective
- Scaling double spiral type
 - Two magnets per cell, higher flexibility
 - Considered for ISIS upgrade at RAL
- Vertical Scaling
 - Under study at RAL for ISIS upgrade
- Tilted Sector Type
 - Single Tilted Sector ruled out
 - Double Tilted Sector (two magnets per cell) - concept under development



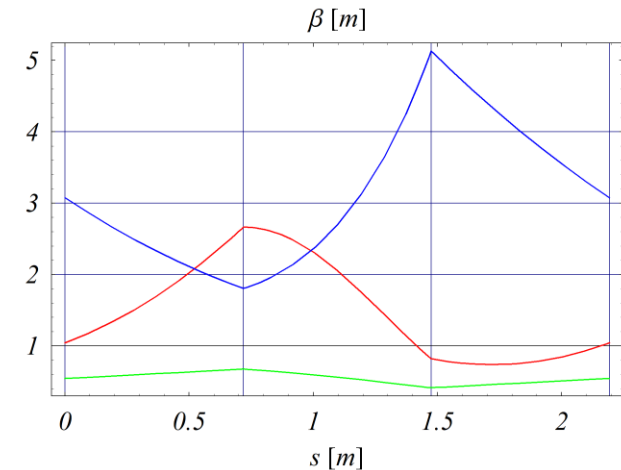
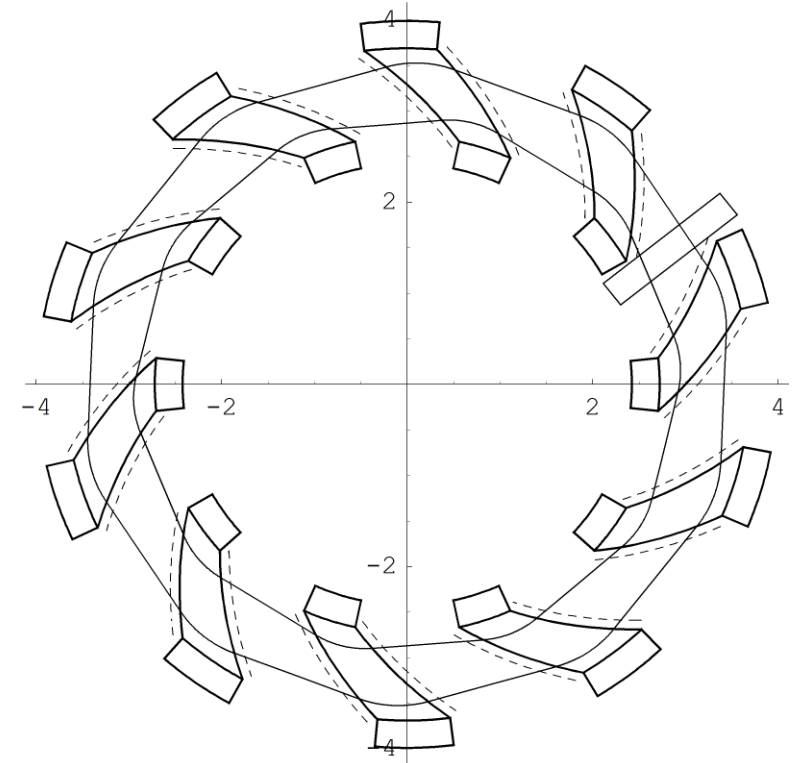
Original RACCAM Machine Parameters

• N	10
• k	5.
• Spiral angle	53.7°
• R_{\max}	3.46 m
• R_{\min}	2.8 m
• (Q_x, Q_y)	(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



LhARA Ring Parameters

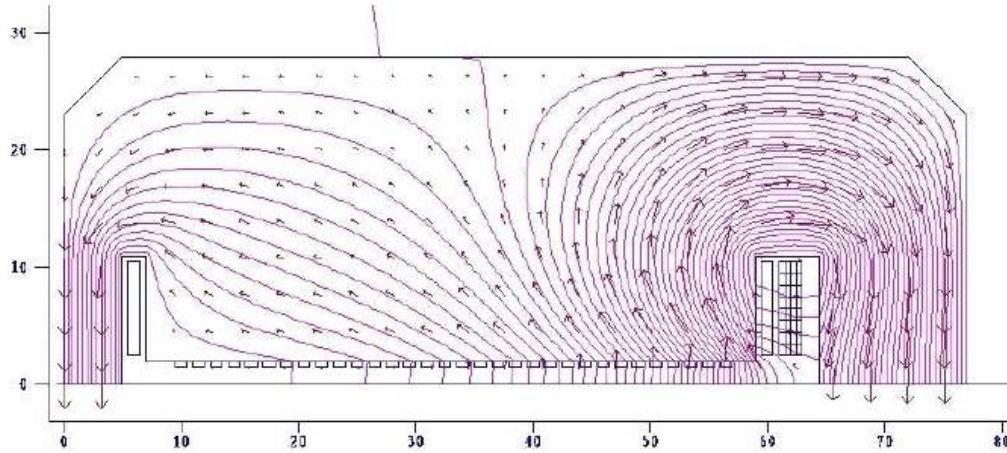
- N 10
- k 5.19
- Spiral angle 47.64°
- R_{\max} 3.49 m
- R_{\min} 2.92 m
- (Q_x, Q_y) (2.82, 1.23)
- B_{\max} 1.4 T
- p_f 0.34
- Max Proton injection energy 15 MeV
- Max Proton extraction energy 127.4 MeV
- h 1
- RF frequency
for acceleration (15-127.4MeV) 2.89 – 6.48 MHz
- Bunch intensity $\text{few} \times 10^8$ protons
- Range of other extraction energies possible
- Other ions also possible



Some RF scenarios for various modes

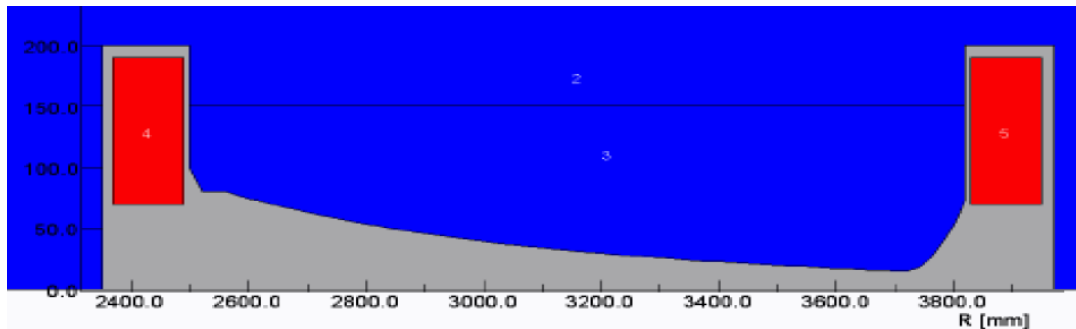
- Main proton mode: $h=1$, $V \sim 0.5$ kV, 15-127.4 MeV, 2.89 – 6.48 MHz
- Min energy proton mode: $h=2$, 1.68-15 MeV, 1.95-4.83 MHz
- Main carbon mode: $h=1$, 3.77-33.4 MeV/u, 1.46 – 3.55 MHz
- Min energy carbon mode: $h=4$, 0.42-3.77 MeV, 1.95-4.83 MHz

Magnet Types Considered for RACCAM



Magnet with distributed conductors:

- Parallel gap – vertical tune more stable,
- Flexible field and k adjustment,



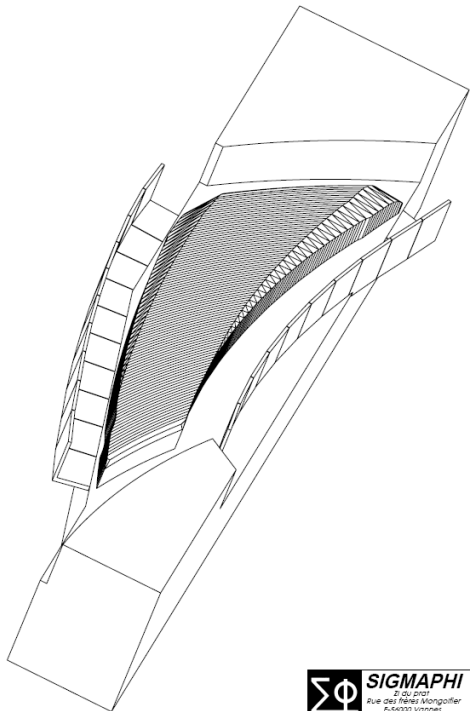
„Gap shaping” magnet:

- Developed by SIGMAPHI
- Initially thought as more difficult
- Behaves very well!
- Chosen for prototype construction!

For LhARA magnet with parallel gap with distributed windings (but single current) would be of choice with gap controlled by clamp. Concepts like an active clamp could be of interest too.

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.



Conclusions and future plans

- Significant progress has been achieved on the design of LhARA Stage 1
- The conceptual design of the arc is now the next milestone, work in synergy with ISIS upgrade at RAL
 - Tilted sector FFA concept to be exploited
 - Full backup with separated function magnets is feasible
- LhARA at Stage 2 can use FFA-type ring accelerator enabling variable energy beam of various types of ions
- It will allow for in-vivo studies with protons and other types of ions + further in-vitro studies with ion beams
- Various types of FFA can be considered for the LhARA ring
- Single spiral-type seems the most cost effective at the moment
- Baseline design based on adjusted RACCAM parameters is a solid choice for further studies
- We are working towards CDR now
- Please join us, your contribution is very welcome!

Spare

Space charge effects in Stage 1 – Phase space plots (GPT)

