Design Evolution of FFA for LhARA

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Outline

- Introduction
- LhARA baseline
- LhARA double spiral candidate
- Conclusions

Imperial College London

Science & Technology Facilities Council ISIS

LhARA

- 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 with a flexible dose delivery (including a novel FLASH regime) at Stage 1.
- It will open the study to use multiple ions (including Carbon) at Stage2 for both in-vitro and in-vivo end stations.
- It aims to demonstrate a novel technologies for next generation hadrontherapy.
- We are now funded project within ITRF (Ion Therapy Research Facility) initiative to deliver CDR in October 2024.
  - We hope to deliver TDR in 2028 and start the construction phase – we seek to obtain further funding.

Imperial College London

Who are we?

Science & Technology Facilities Council ISIS

Imperial College London

ICR The Institute of Cancer Research

Medical Research Council

Oxford Institute for Radiation Oncology

University of Oxford

JAI John Adams Institute for Accelerator Science

CCAP Centre for the Clinical Application of Particles

Imperial College Academic Health Science Centre

Cancer Research UK | Imperial Centre

NHS Imperial College Healthcare NHS Trust

LhARA Laser-hybrid Accelerator for Radiobiological Applications

Manchester 1824 The University of Manchester

University of Birmingham

University of Liverpool

NHS University Hospitals Birmingham NHS Foundation Trust

NHS The Clatterbridge Cancer Centre NHS Foundation Trust

NHS The Christie NHS Foundation Trust

institut Curie

Queen's University Belfast

Swansea University Prifysgol Abertawe

UCL Medical Physics & Biomedical Engineering

Netherlands Cancer Institute Antoni van Leeuwenhoek

Hampton University Proton Therapy Institute Fighting Cancer, Saving Lives

University of Strathclyde Glasgow Department of Physics

Royal Holloway University of London

Lancaster University

UKRI Science and Technology Facilities Council

ASTeC
Daresbury Laboratory
Particle Physics Department
ISIS Neutron and Muon Source

CLF central laser facility

University of Birmingham | Cyclotron Facility | Positron Imaging Centre

Corerain 鲲云科技

INFN Catania

The Cockcroft Institute of Accelerator Science and Technology

CERN

LEO Cancer Care

Maxeler Technologies Maximum Performance Computing

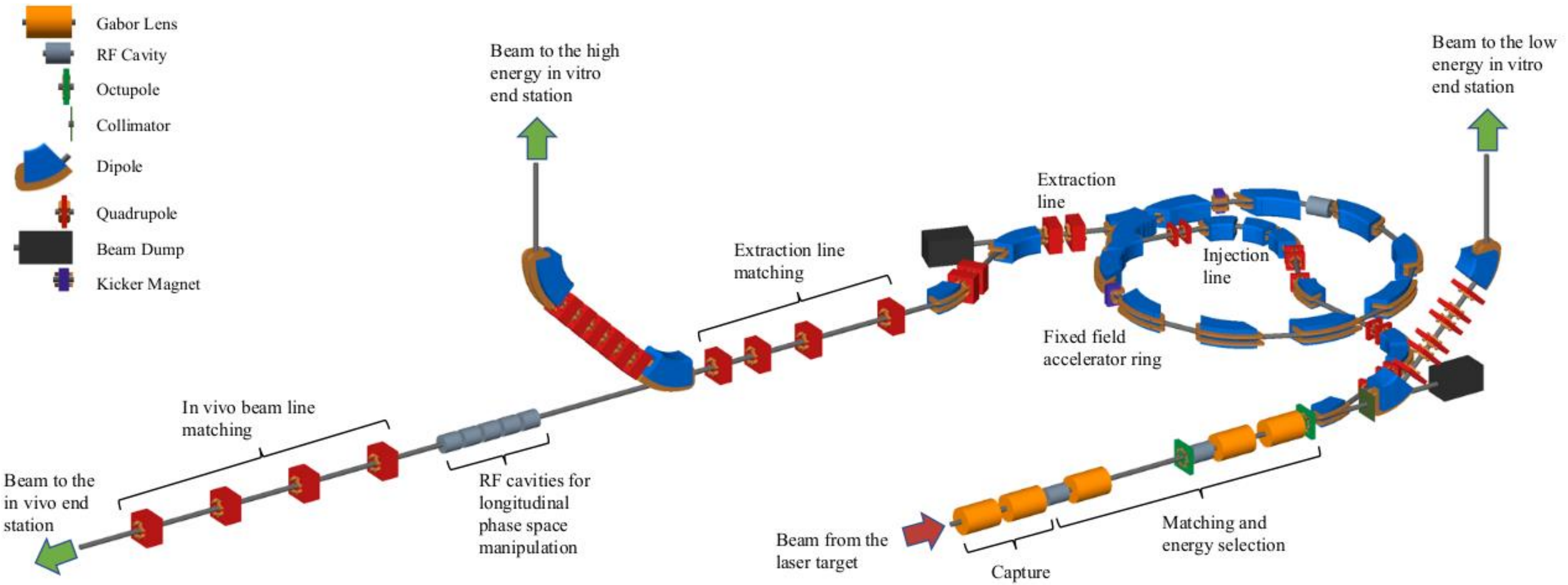
The Rosalind Franklin Institute

NPL National Physical Laboratory

Imperial College London

LhARA, introduction

Science & Technology Facilities Council ISIS



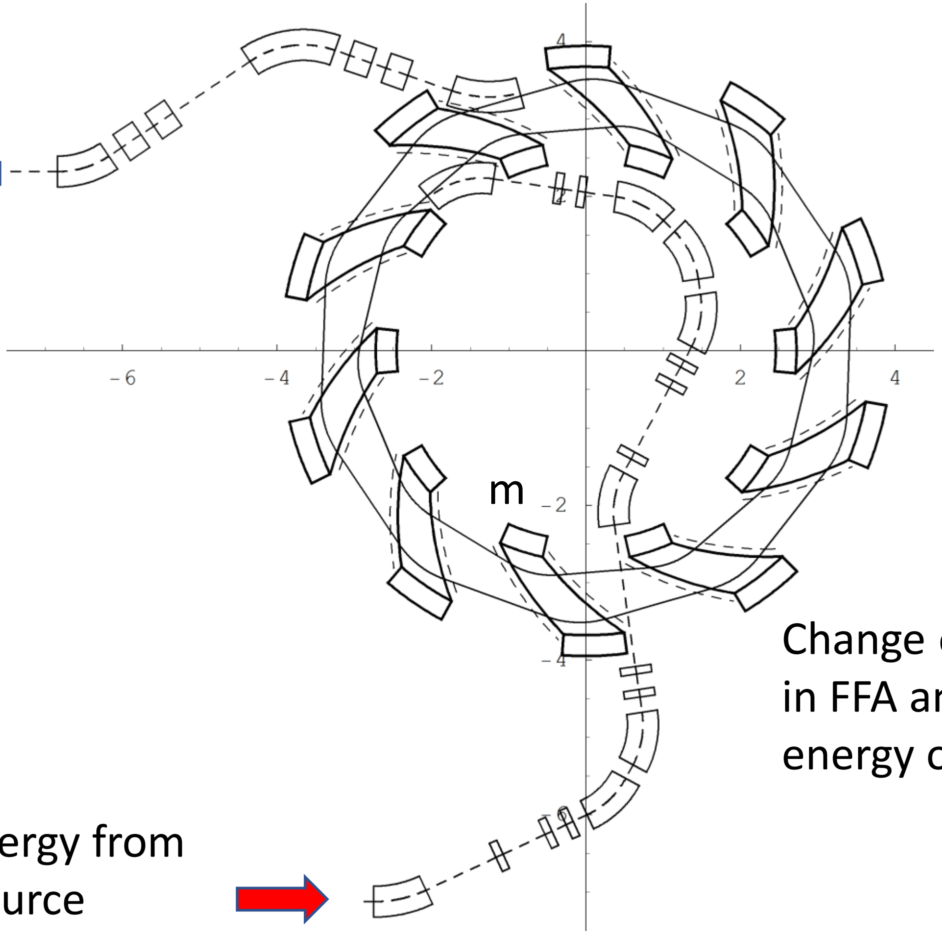
- LhARA will use laser ion source based on sheath acceleration
- Gabor plasma lenses will be used to capture and focus the beam in the front-end
  - NC solenoids could be used instead
- Variable energy FFA will be used as post-accelerator
- Fully instrumented end-stations will allow for precise radiobiological experiments

Energy Variability using Laser Accelerated Ions

Variable extraction energy from
FFA within 1 s (20-125 MeV)
at fixed geometry

+

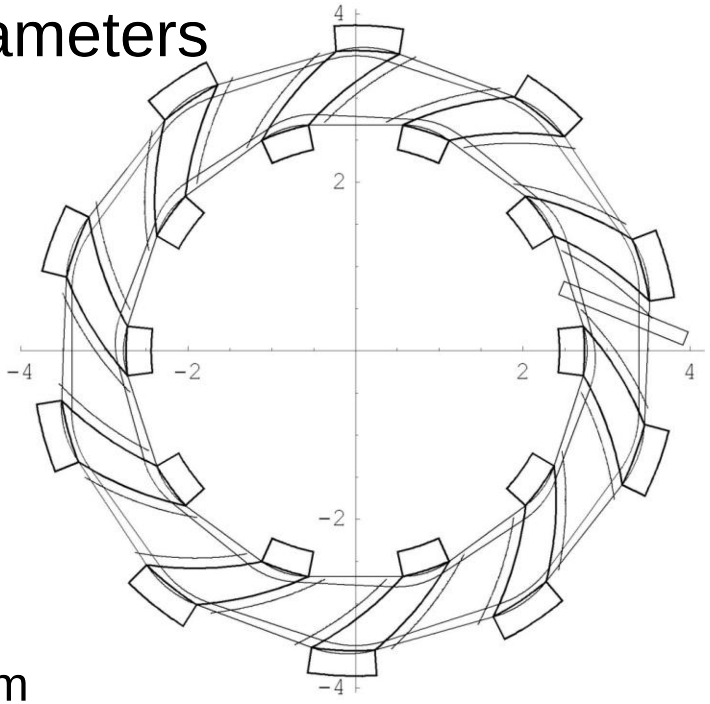
pulse by pulse
variation with kicker
could be implemented

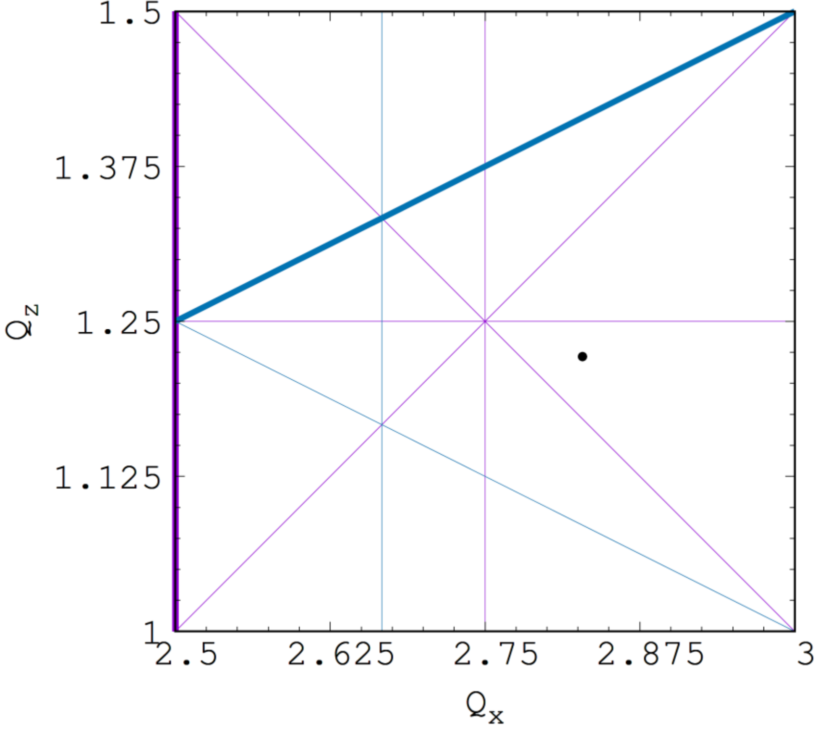


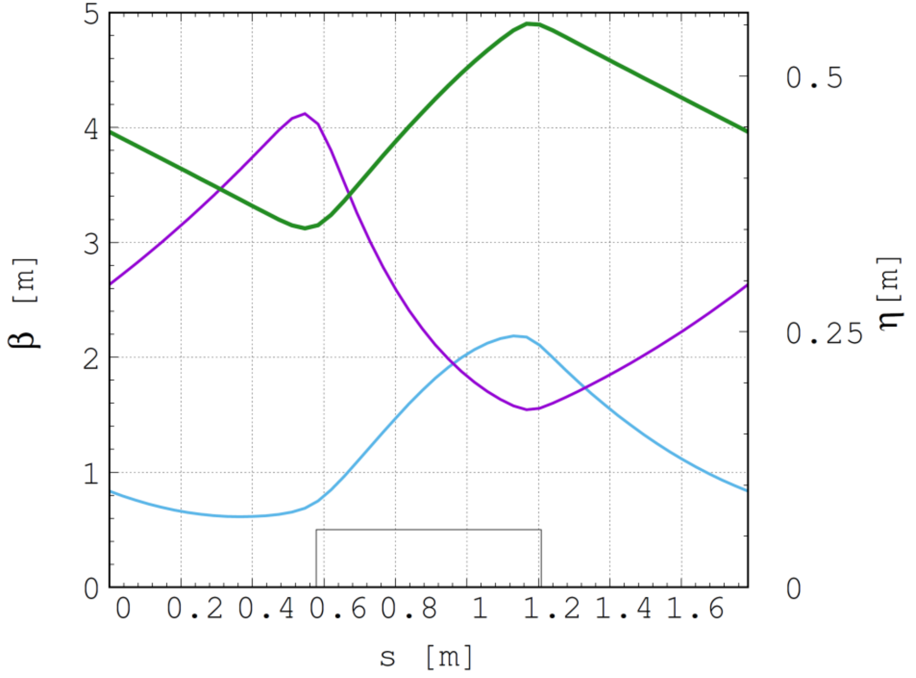
Change of the value of magnetic field
in FFA and transfer lines for a specific
energy operation (laminated magnets)

Variable input energy from
the Laser Source
(multiple ions are possible)

LhARA FFA baseline ring parameters







- Lattice type — single spiral scaling FFA
- N — 10
- k — 5.33
- Spiral angle — 48.7°
- R_{max} — 3.48 m
- R_{min} — 2.92 m
- (Qx, Qy) — (2.83, 1.22)
- 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 proton acceleration (15-127.4MeV) — 2.89 – 6.48 MHz
- Bunch intensity — few×10^8 protons
- Range of other extraction energies possible
- Other ions also possible

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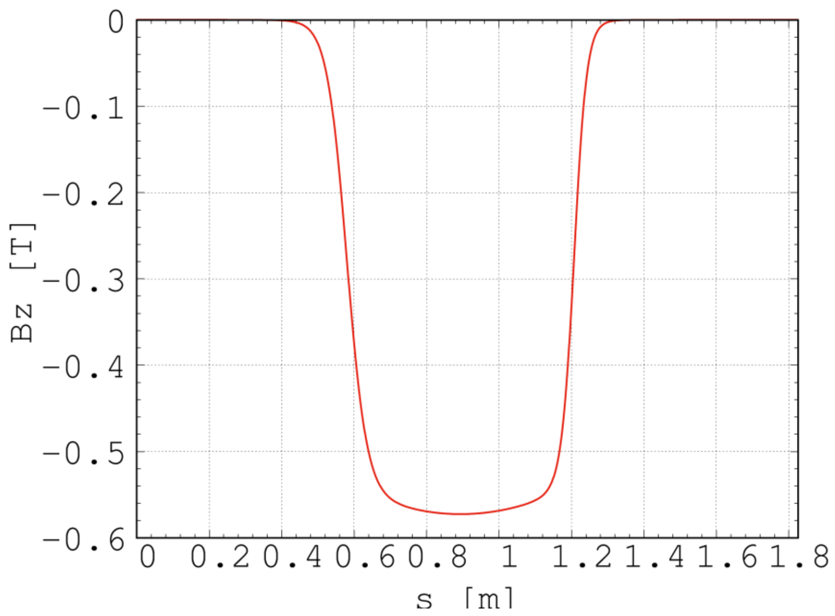
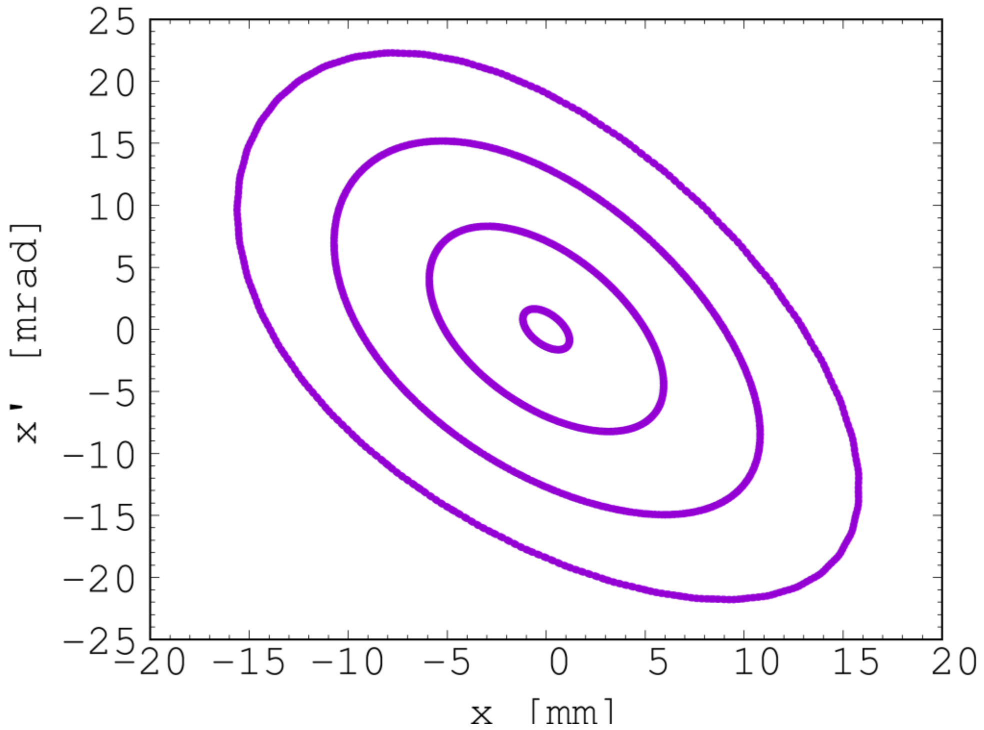
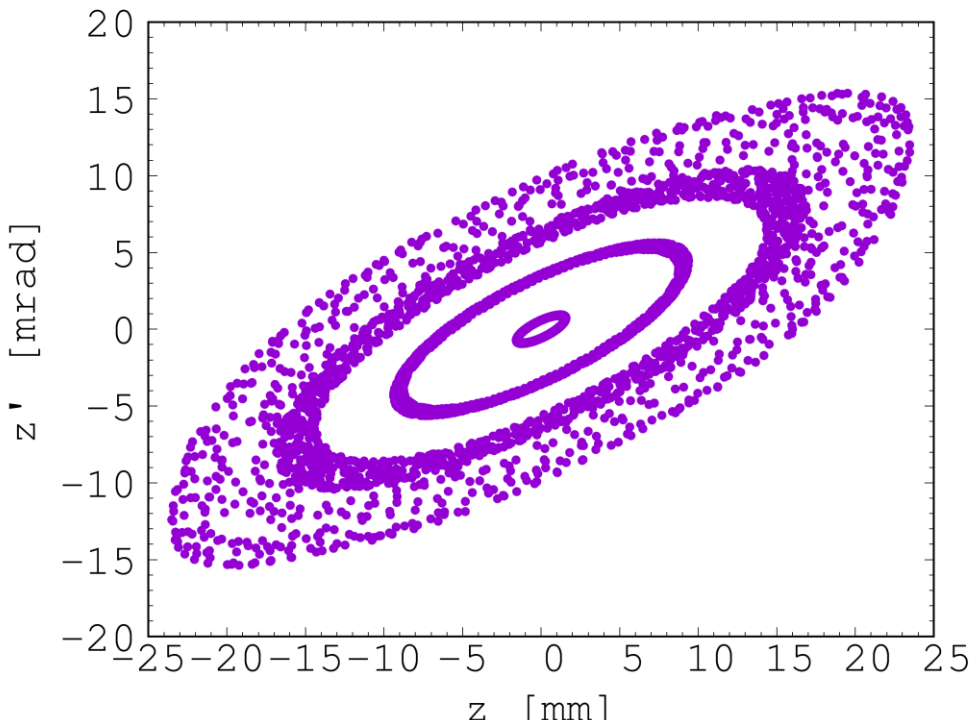
LhARA Ring Tracking



- Performed using proven stepwise tracking code
- It takes into account fringe fields and non-linear field components
- Results show dynamical acceptances are large
- No space charge effects included yet
- Tracking performed using FixField code

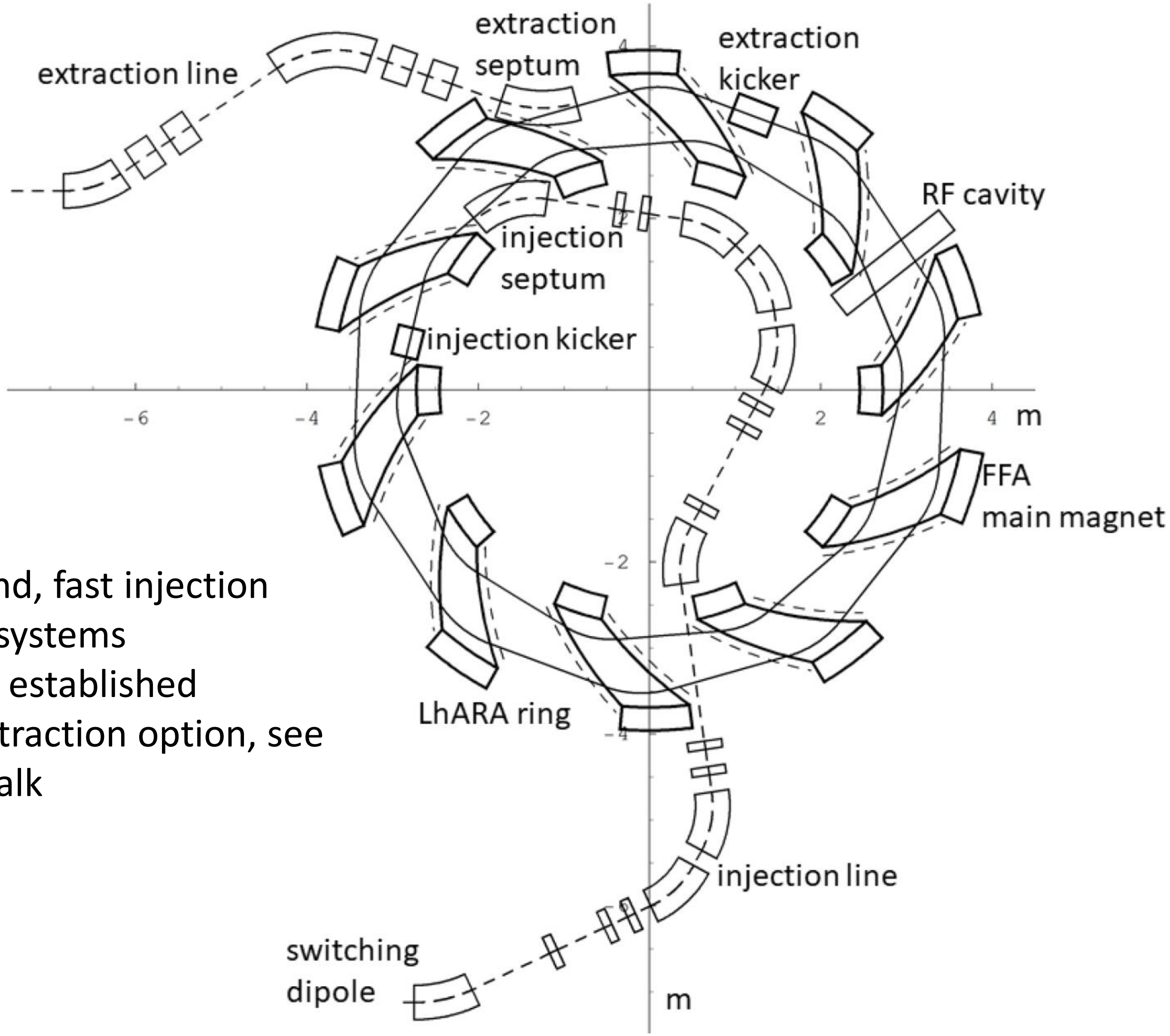




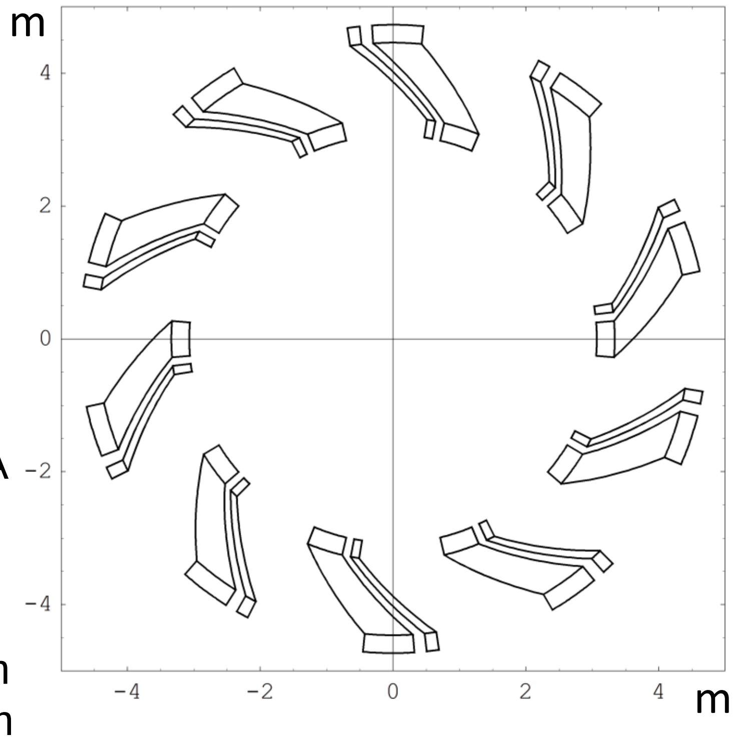
FFA Ring with subsystems

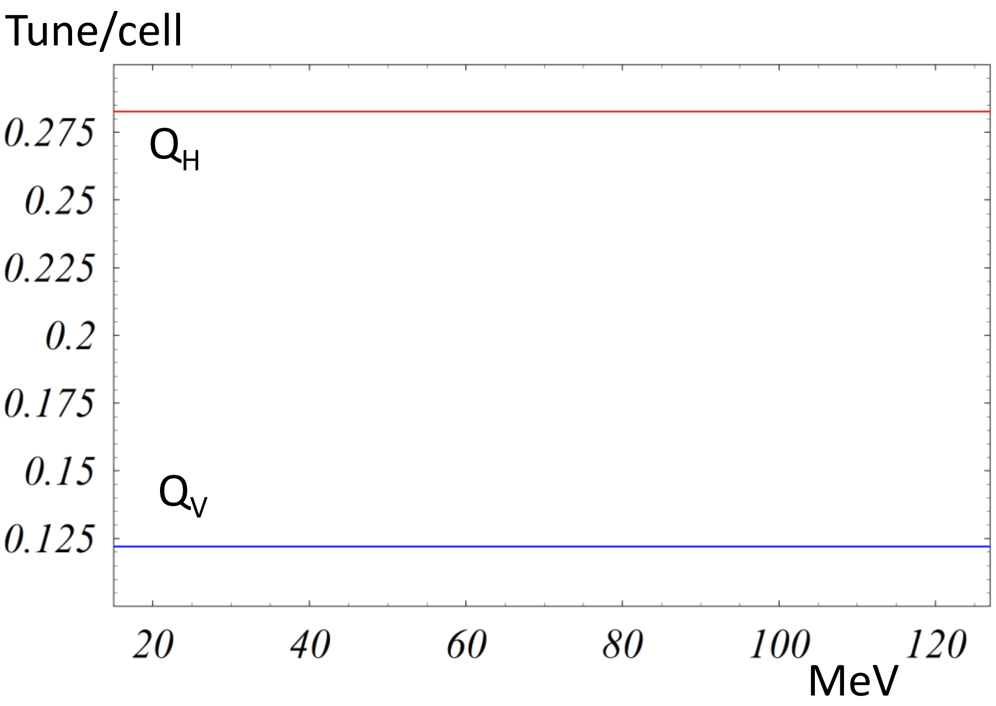
Parameter	unit	value
Injection septum:		
nominal magnetic field	T	0.53
magnetic length	m	0.9
deflection angle	degrees	48.7
thickness	cm	1
full gap	cm	3
pulsing rate	Hz	10
Extraction septum:		
nominal magnetic field	T	1.12
magnetic length	m	0.9
deflection angle	degrees	34.38
thickness	cm	1
full gap	cm	2
pulsing rate	Hz	10
Injection kicker:		
magnetic length	m	0.42
magnetic field at the flat top	T	0.05
deflection angle	mrad	37.4
fall time	ns	320
flat top duration	ns	25
full gap	cm	3
Extraction kicker:		
magnetic length	m	0.65
magnetic field at the flat top	T	0.05
deflection angle	mrad	19.3
rise time	ns	110
flat top duration	ns	40
full gap	cm	2

- Injection line and, fast injection and extraction systems parameters are established
- For the slow extraction option, see A. Steinberg's talk

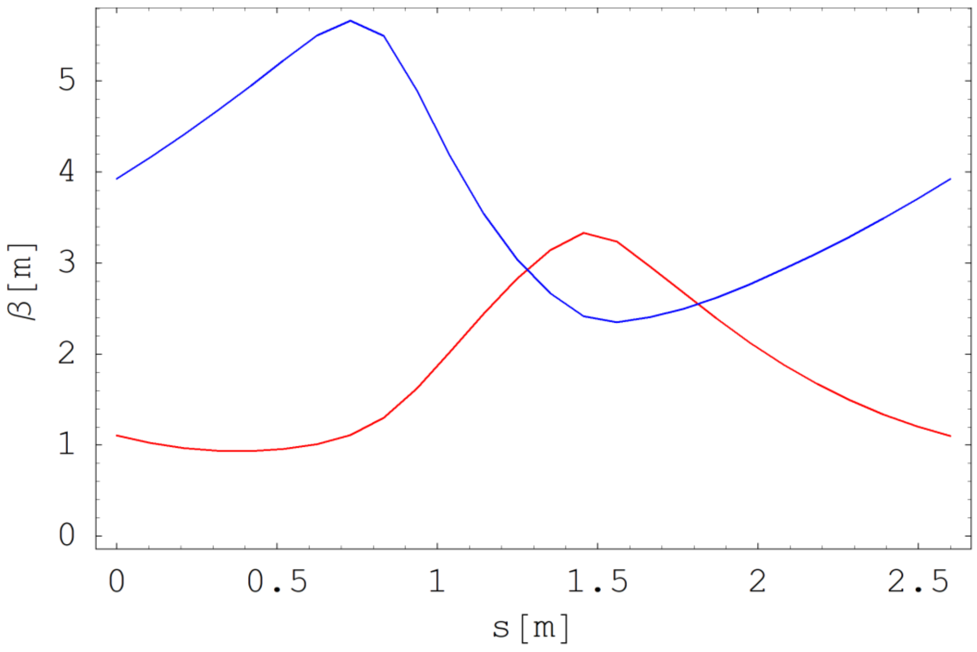


LhARA double spiral baseline candidate, Ff configuration (nominal tune)





- Lattice type — double spiral scaling FFA
- N — 10
- k — 5.26
- Spiral angle — 45.87°
- R_{max} — 4.14 m
- R_{min} — 3.55 m
- (Qx, Qy) — (2.83, 1.22)
- B_{max} — 1.5 T
- p_f — 0.386
- Max Proton injection energy — 15 MeV
- Max Proton extraction energy — 127.4 MeV
- h — 1
- RF frequency for proton acceleration (15-127.4MeV) — 2.37 – 5.47 MHz
- Bunch intensity — few×10^8 protons
- Range of other extraction energies possible
- Other ions also possible



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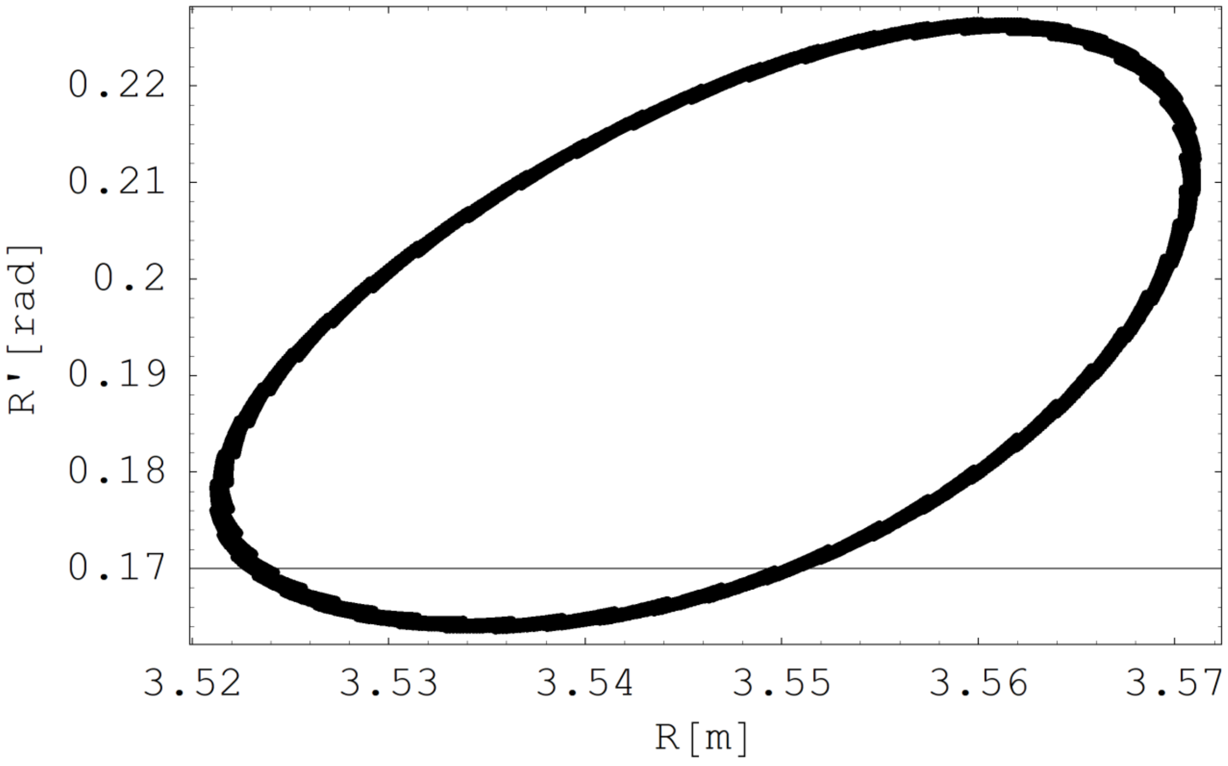
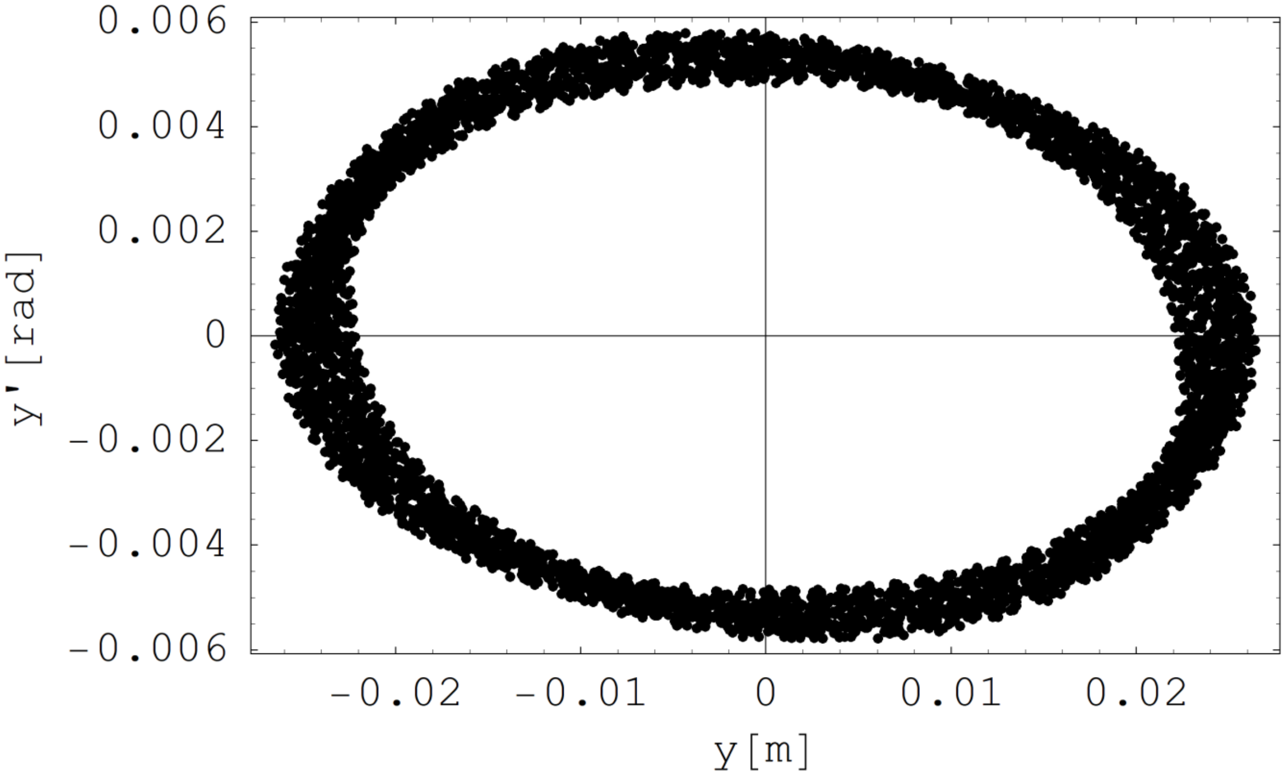
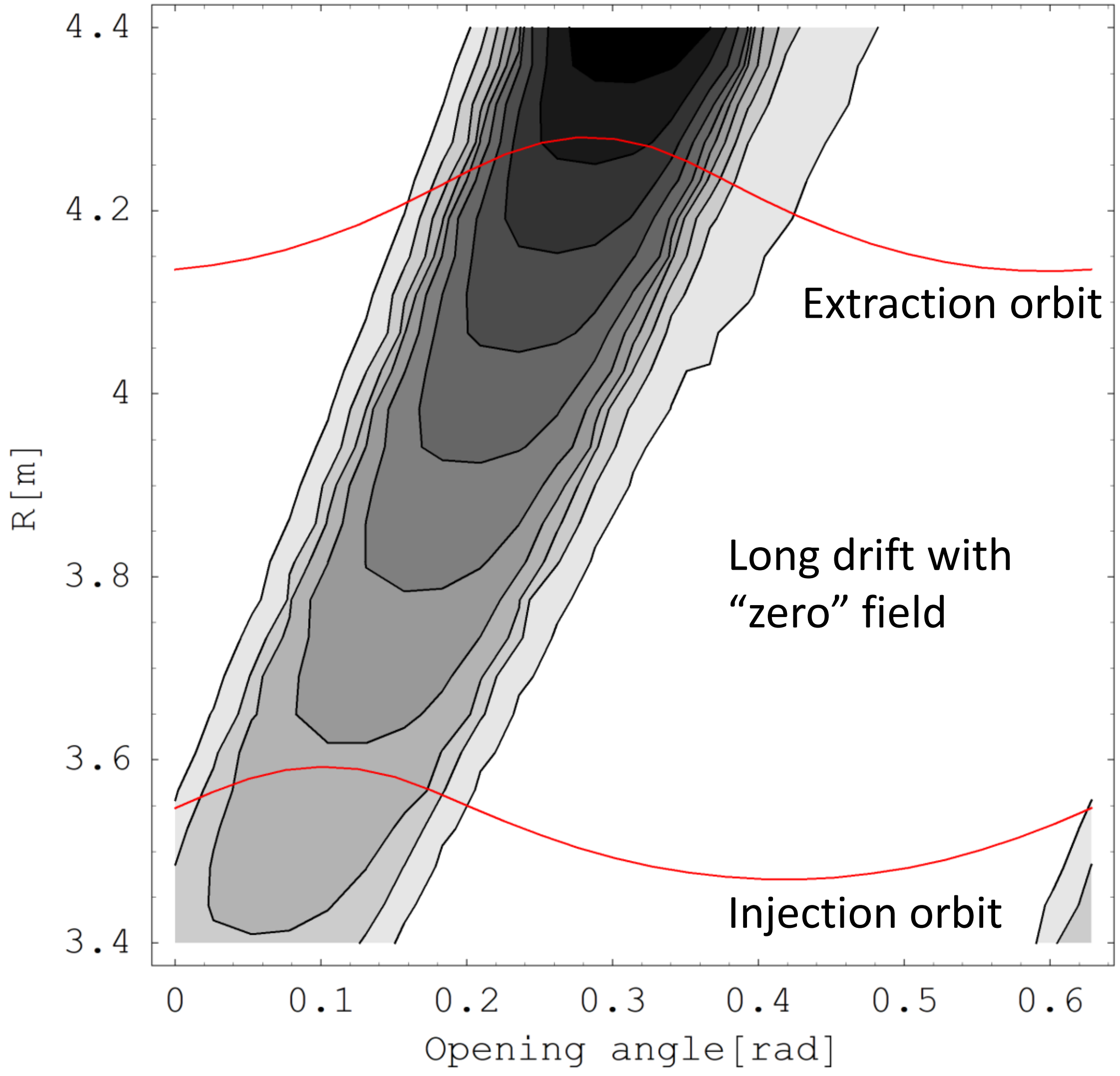
DA studies in double spiral candidate (Ff, nominal tunes)

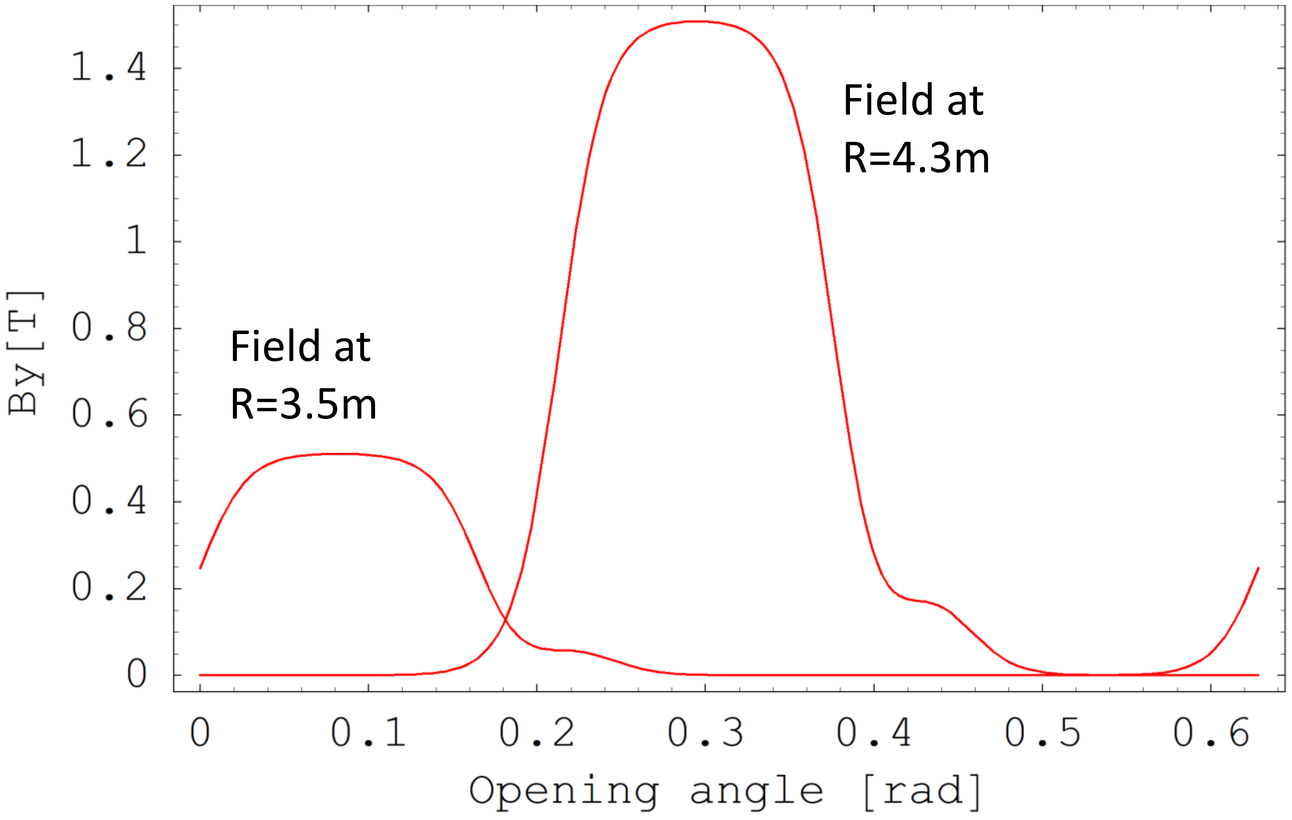




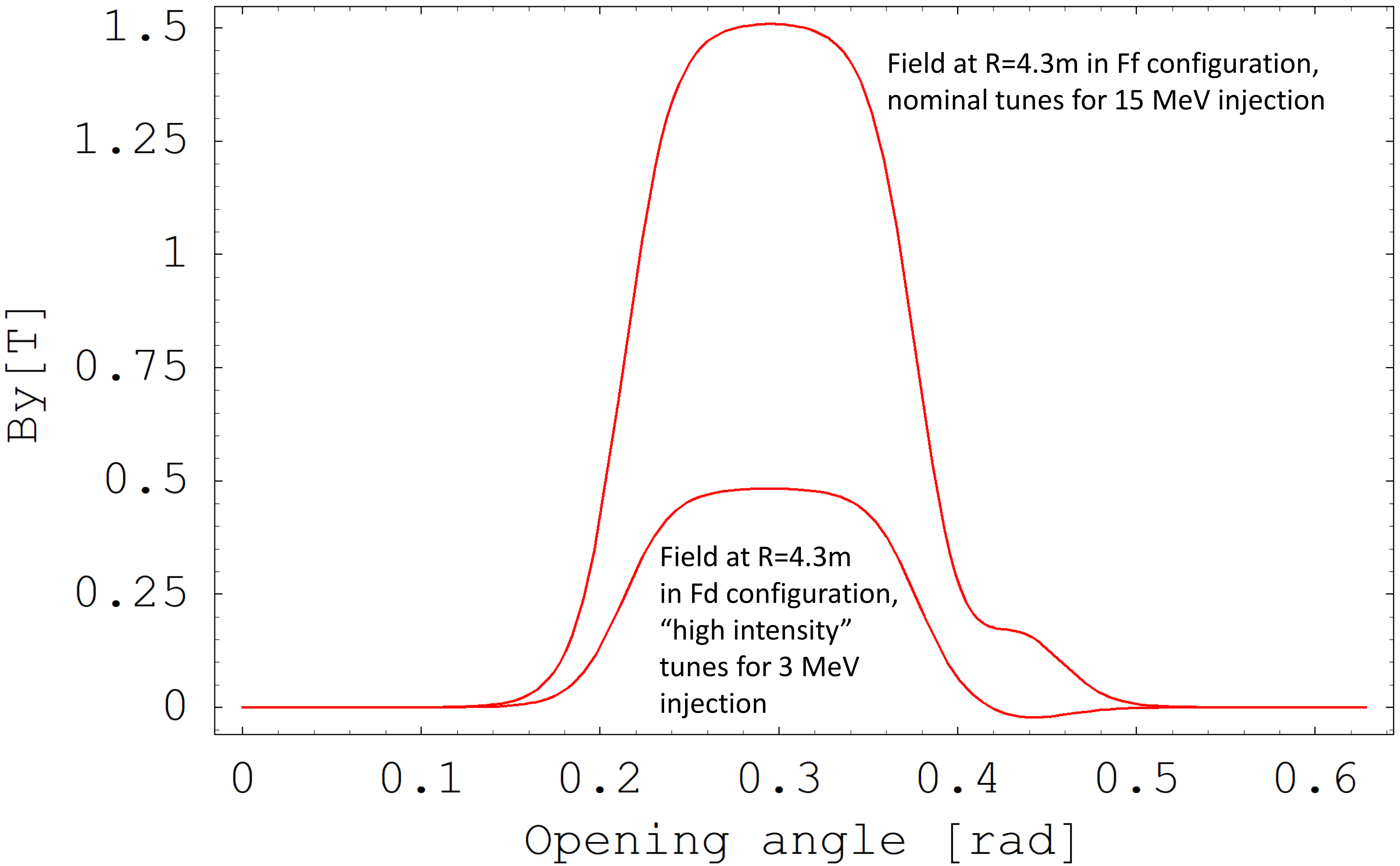
Tracking studies show sufficient DAs in both transverse planes

B field in double spiral candidate (Ff, nominal tunes)



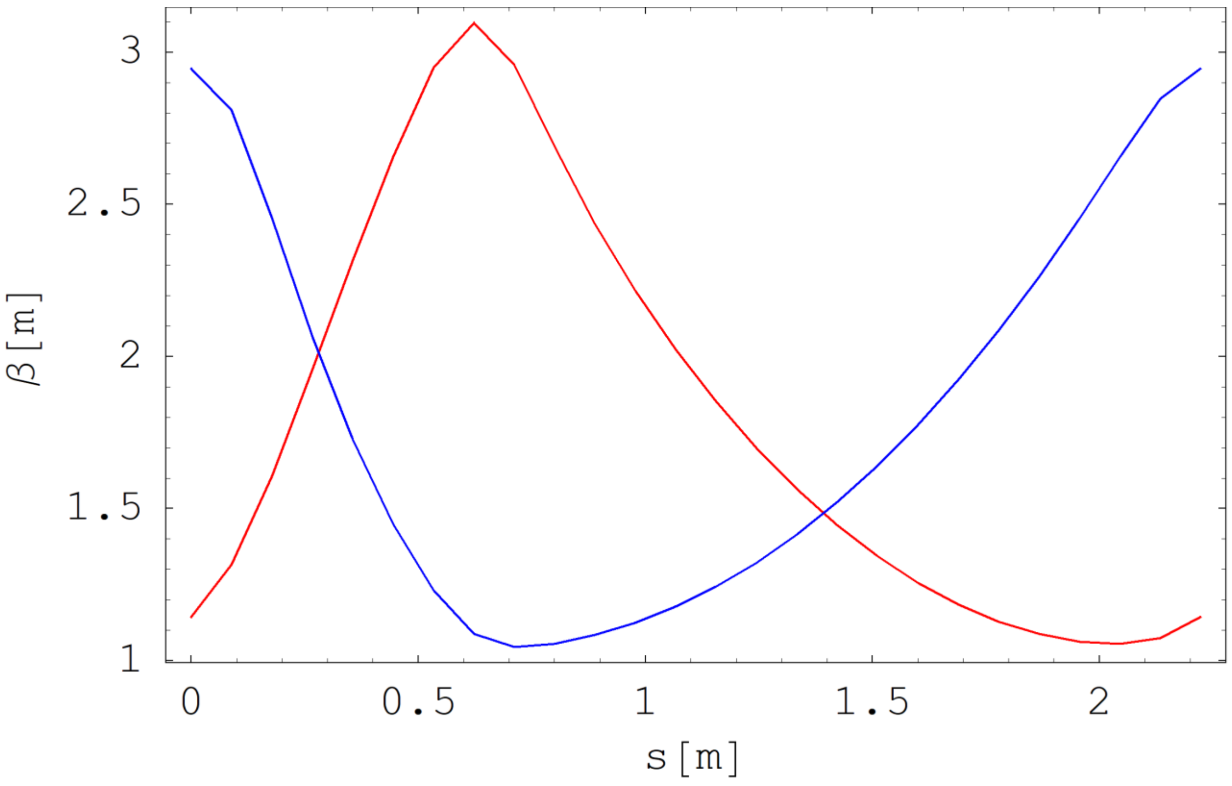


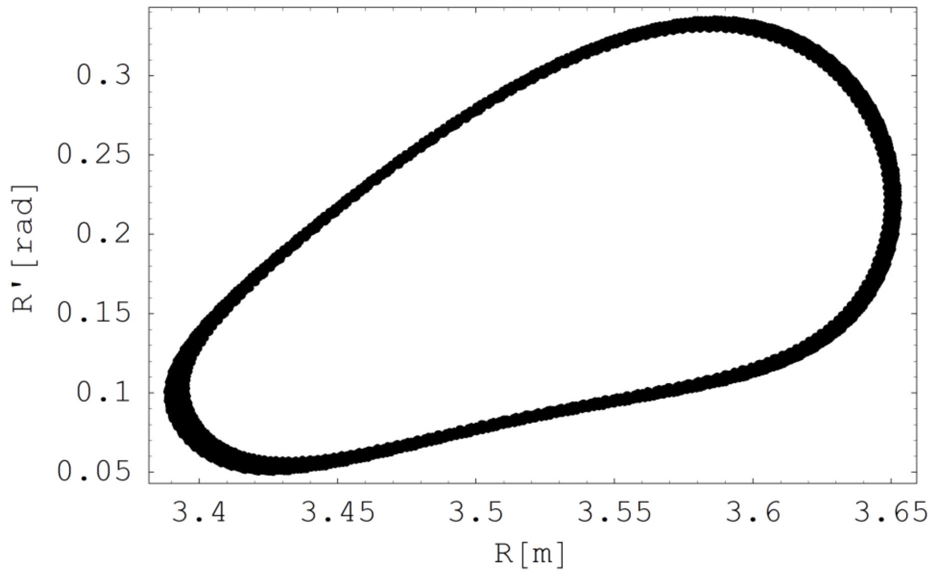
Ff vs Fd configurations (nominal tunes vs “high intensity” tunes)

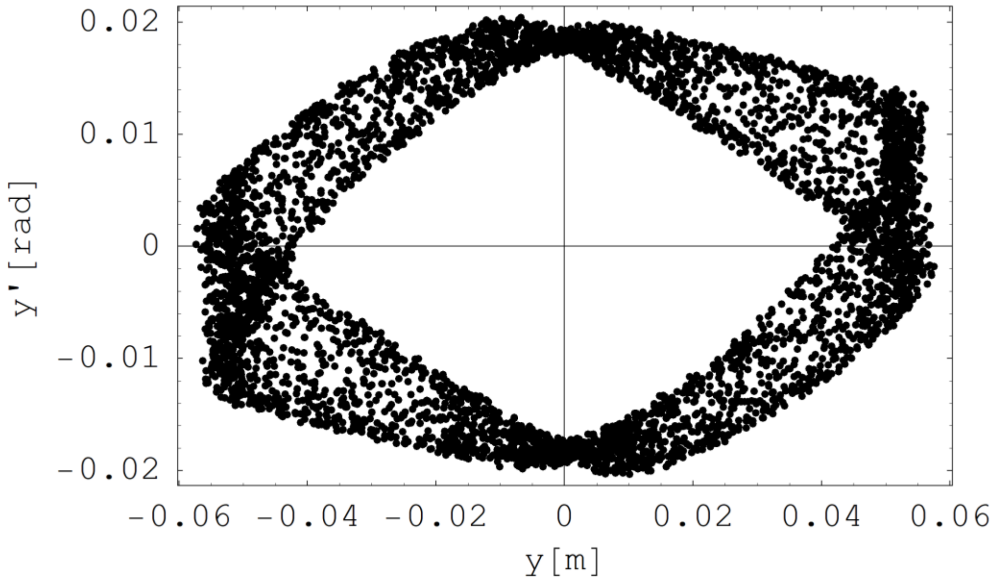


- Geometry of the doublet is informed by the FETS-FFA developments
- Second magnet can be considered as an “active clamp”
  - Effectively changing the flutter function
- It allows to vary the vertical tune in a wide range
- When polarity switched with respect to the main F magnet “f” turns into “d”.
- Allows to test double spiral concept in the focusing-defocusing configuration
  - It could be set at“high intensity” Tunes (both tunes close to each other), which may allow for space charge experiment

Optics an DA studies in double spiral candidate (Fd, “high intensity” tunes)



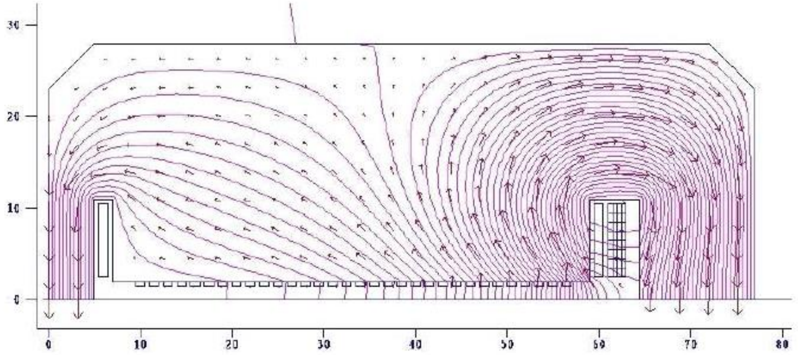


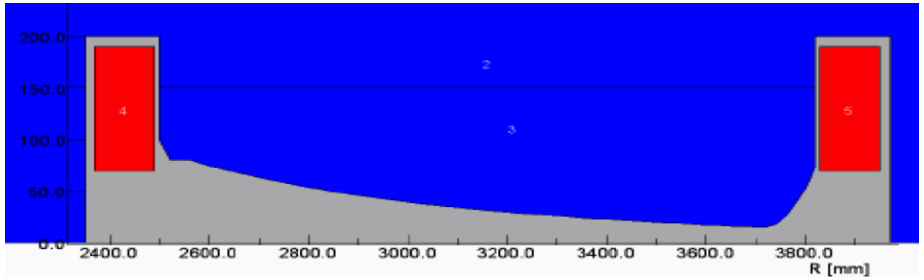


- “High intensity” tunes: $(Q_H, Q_V)=(2.22,2.19)$ provide similar betatron functions
- This working point is limited to low energy
- DAs are larger than in the nominal working point
- We could perform space charge experiments
  - Beam is space charge dominated at injection due to the short bunch length from the laser source

Essential R&D

Magnet types to be considered





- For LhARA magnet with parallel gap with distributed windings would be of choice with gap controlled by the clamp. Concepts like an active clamp could be of interest too.
- Another important aspect of the R&D is the technology transfer for Magnetic Alloy (MA) loaded RF cavities for the ring. Those type of cavities are in routine, operation for example at J-PARC, Kyoto University (KURNS) and at CERN
  - Prototype for FETS-FFA in development

Magnet with distributed conductors:
• Parallel gap – vertical tune more stable,
• Flexible field and k adjustment,
• Constructed for IonBeta machine at Kyoto University (KURNS)
- Prototype is in development for FETS-FFA, see Ta-Jen Kuo's talk
    - This will inform LhARA design

„Gap shaping" magnet:
•Developed by SIGMAPHI for RACCAM project
•Initialy thought as more difficult
•Behaves very well
•Chosen for the RACCAM prototype construction

Conclusions

- LhARA at Stage 2 can use FFA-type ring as a post-accelerator enabling variable energy beams of various types of ions.
- The cost effective, single spiral scaling FFA chosen for the baseline shows a good performance in tracking studies
- Feasible ring injection, extraction and beam transport to the end stations at Stage 2 have been designed
- Alternative double spiral scaling lattice was proposed
  - Allows for the independent tuning of both tunes over a wide range
  - Allows to work with a nominal tune (2.83, 1.22) in the Ff configuration
  - Allows to obtain working point with both tunes close to each other (2.22,2.19) at low injection energy (3 MeV) in Fd configuration
    - May be suitable for space charge experiments

- Essential R&D items:
  - finalisation of the lattice design
  - the main FFA magnet
    - in collaboration with ISIS
  - the RF system for the ring
    - in collaboration with ISIS