

Design of the LhARA accelerator facility

J. Pasternak, LhARA Review, 31/03/2020

Outline

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- Stage 1 baseline
- Stage 1 alternative
- Stage 2
- FFA post-accelerator
- Optics for Stage 2 end-stations
- R&D needs
- Conclusions

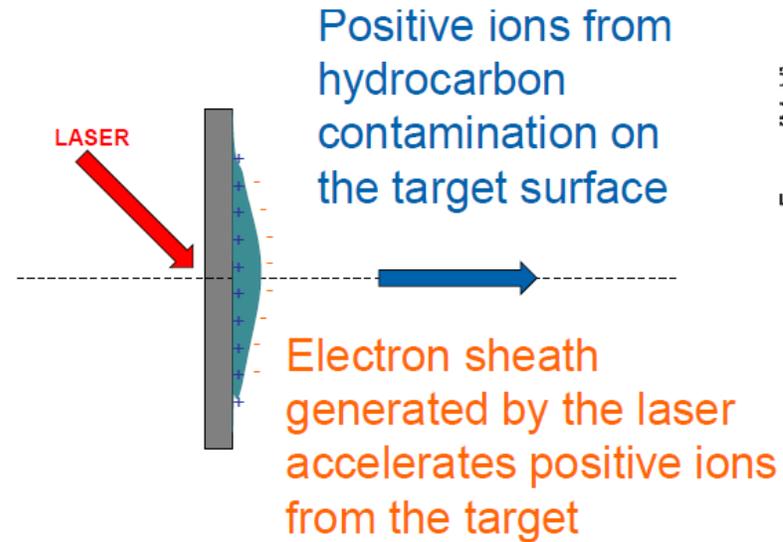
Introduction

- 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.

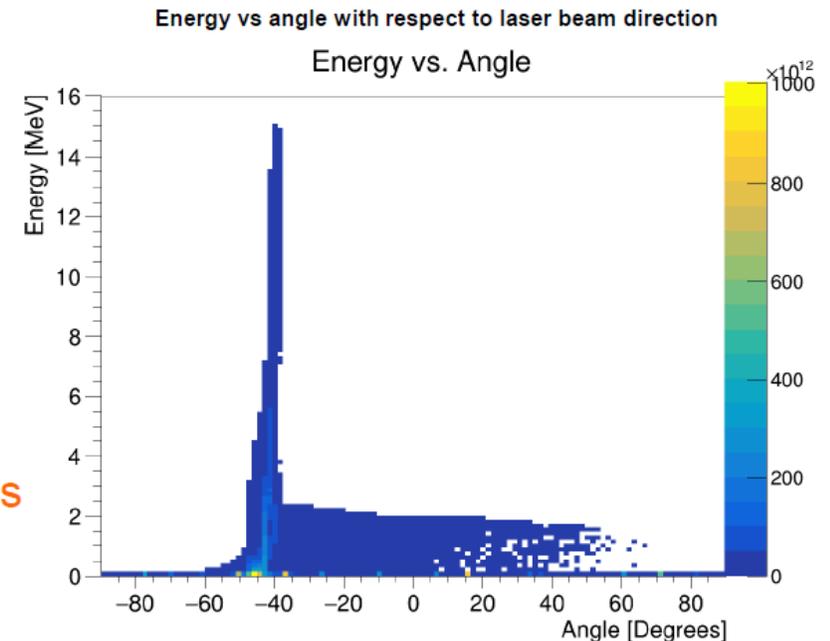
Initial Beam for Laser Source

- Small emittance ($\sim 4.1 \times 10^{-7} \pi \cdot \text{m} \cdot \text{rad}$)
- Huge energy spread
- Small size
- Very large divergence
- Neutral at the beginning then space charge dominated
- Mixture of states

LASER SOURCE

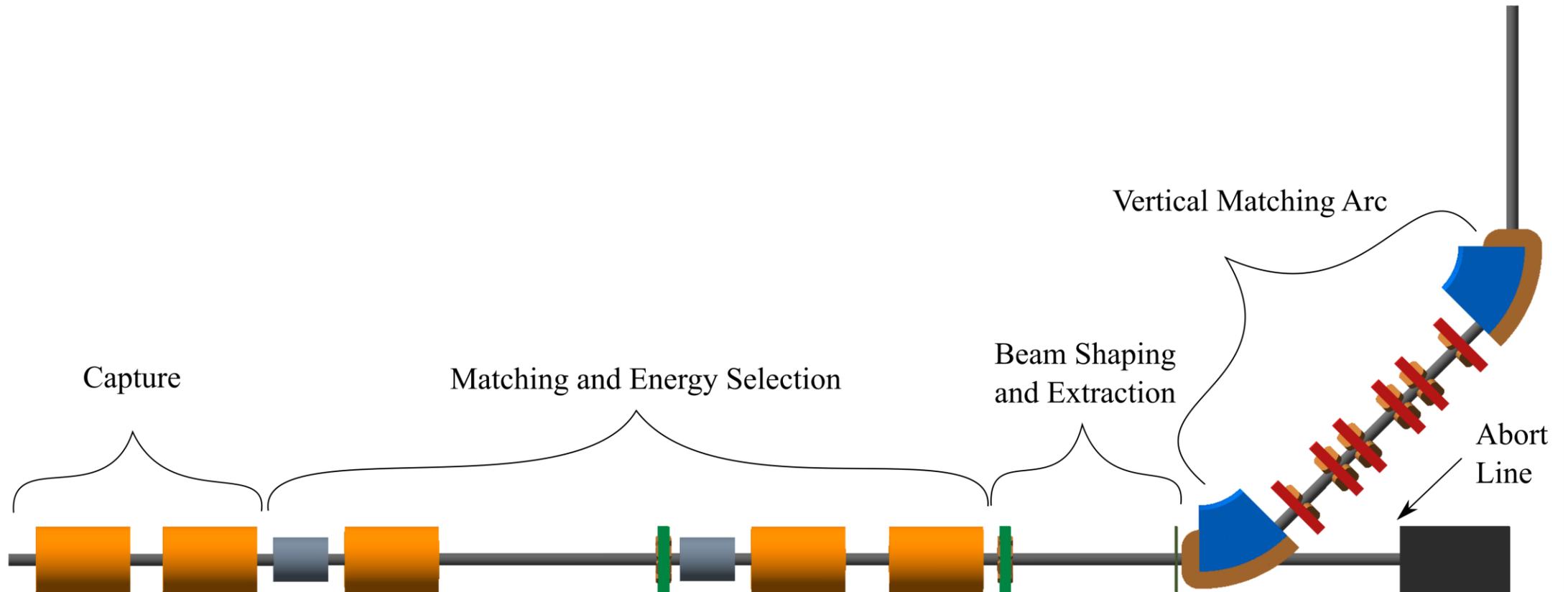


- Produces intense beams and multiple species, e.g. proton and carbon ions.



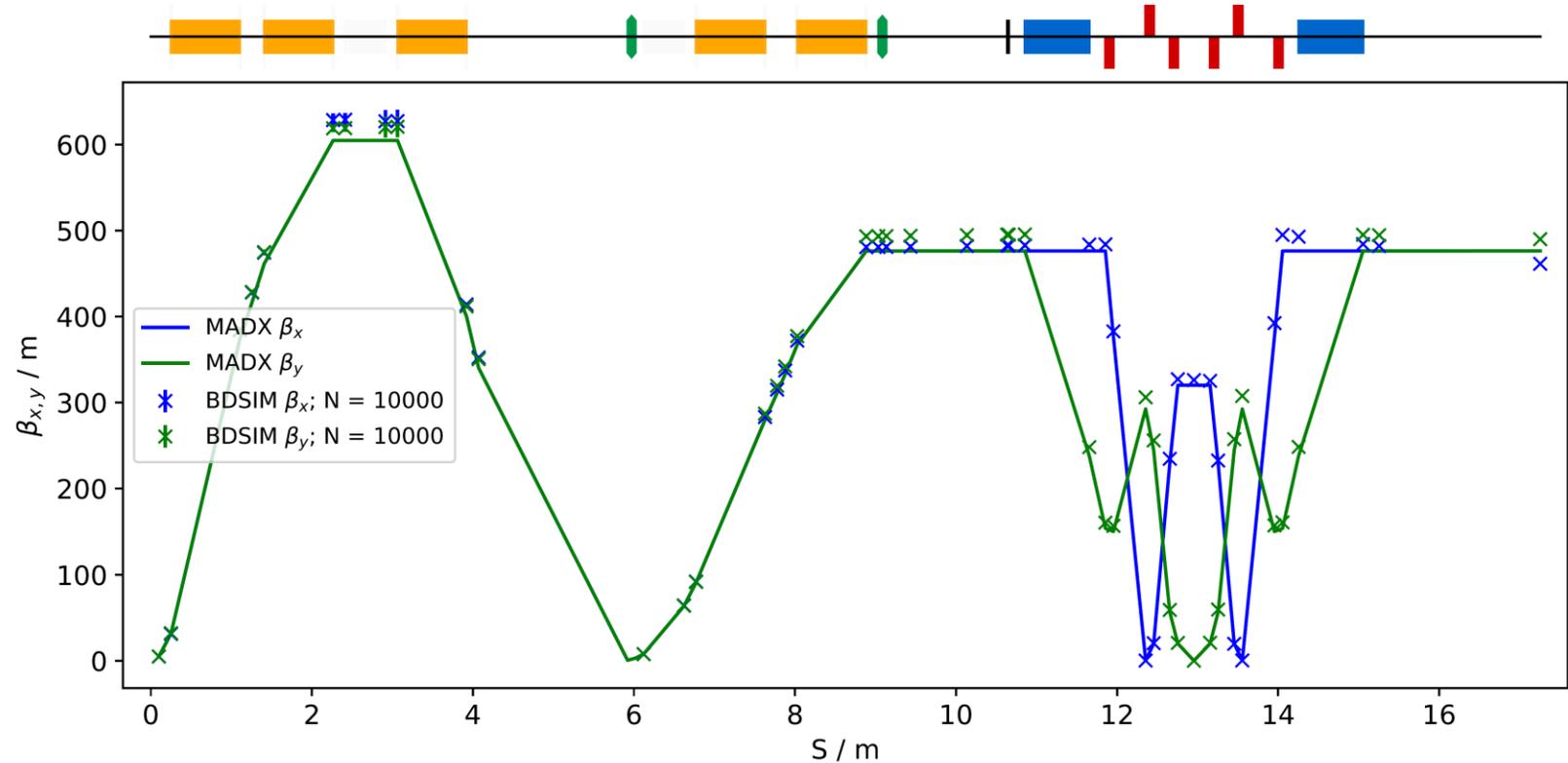
Laser driven ion beam simulation using EPOCH.

Optics in LhARA Stage 1, baseline lattice

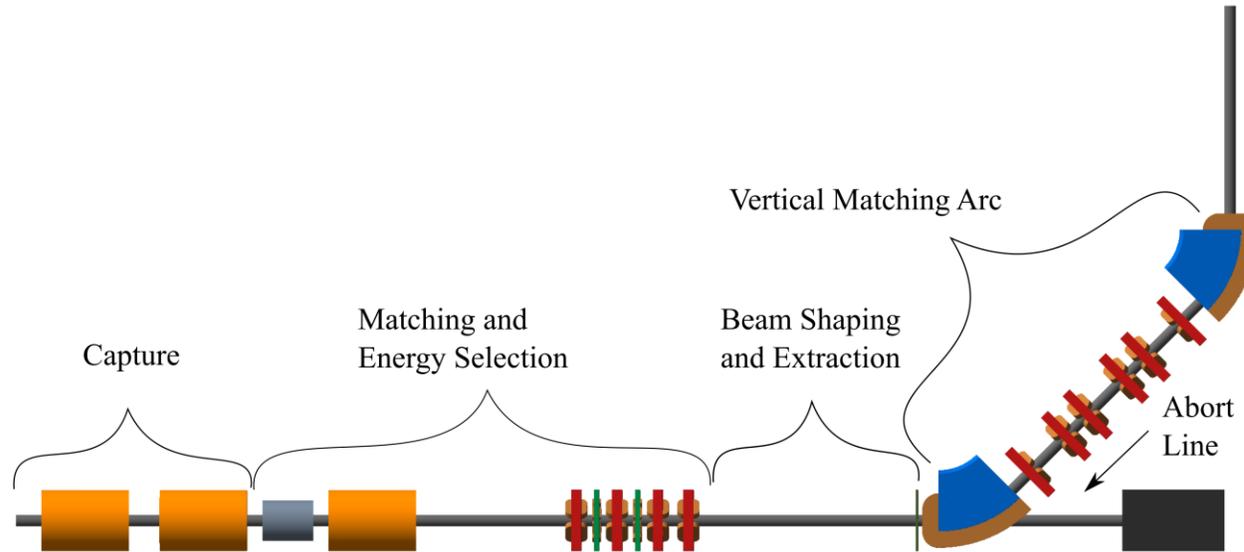


LhARA Stage 1 parameters

- Initial beam assumed neutral first (5cm) and then space charge must be taken into account to fix initial parameters.
- Strong focusing in both planes by Gabor Lenses (or solenoids) essential in the capture section.
- Matching to very small spot size unavoidable and used for the energy selection
- Matching with two lenses to the transparent, achromatic arc
- Redistribution of phase space using octupoles to creat uniform beam

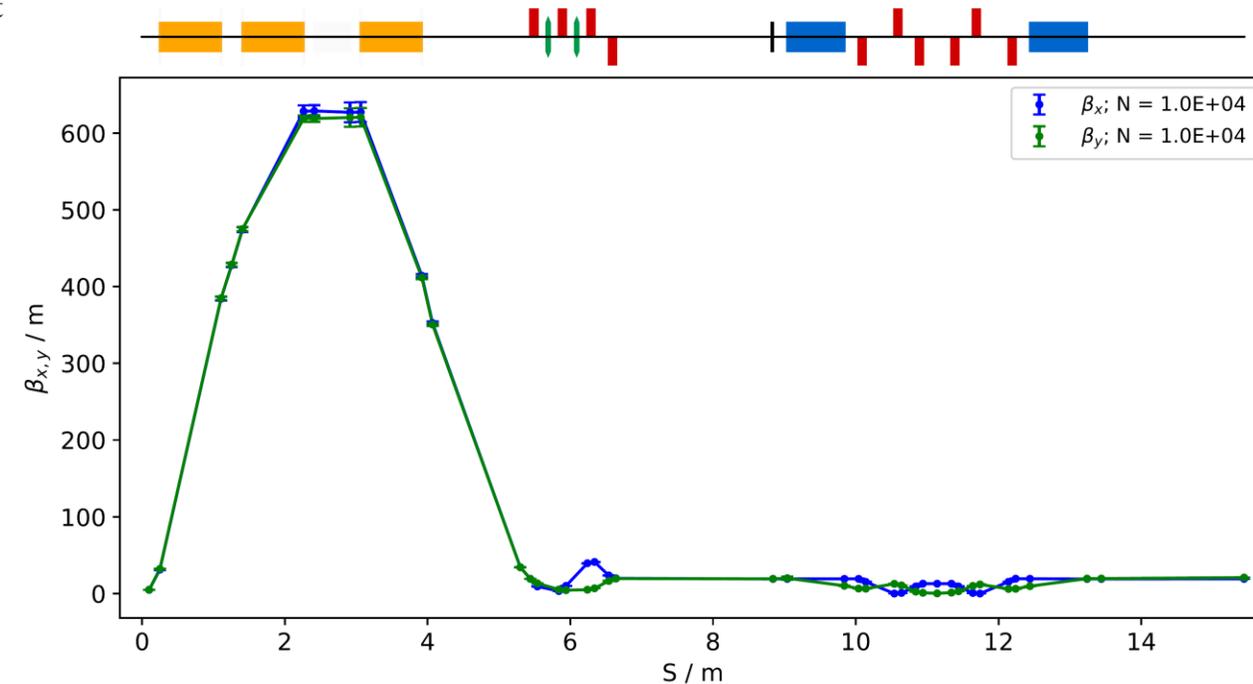


Lhara Stage 1, alternative design



- Alternative design uses quadrupoles to avoid focusing to the spot in both planes simultaneously (space charge mitigation)
- Octupoles would be in the right optical locations
- Optics optimisation with space charge to be done and performance to be demonstrated

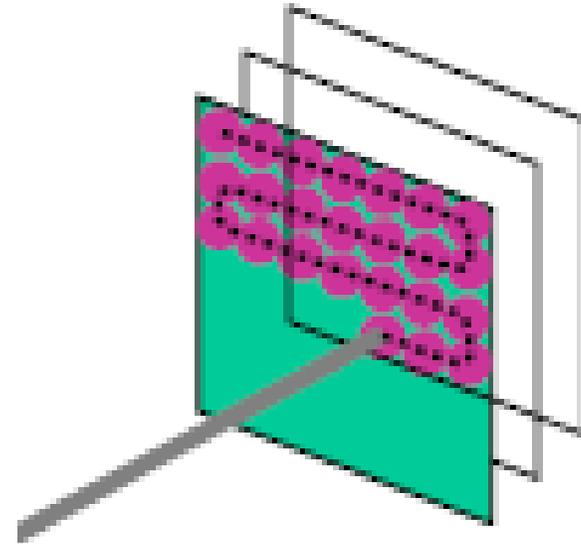
More results on Stage 1 performance, see Will's talk



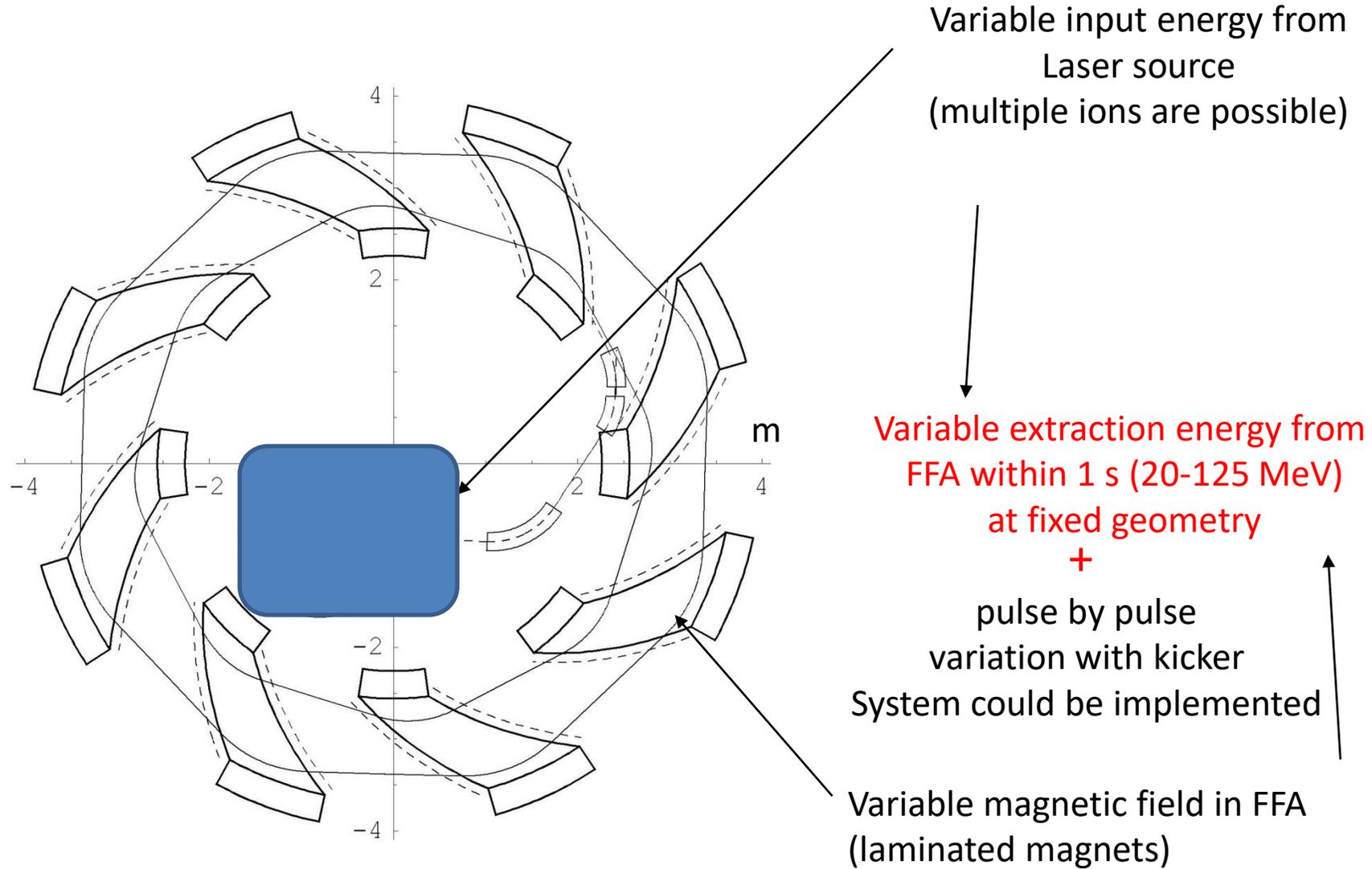
Motivations for a Medical/Radiobiological FFA (Fixed Field Accelerator)

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

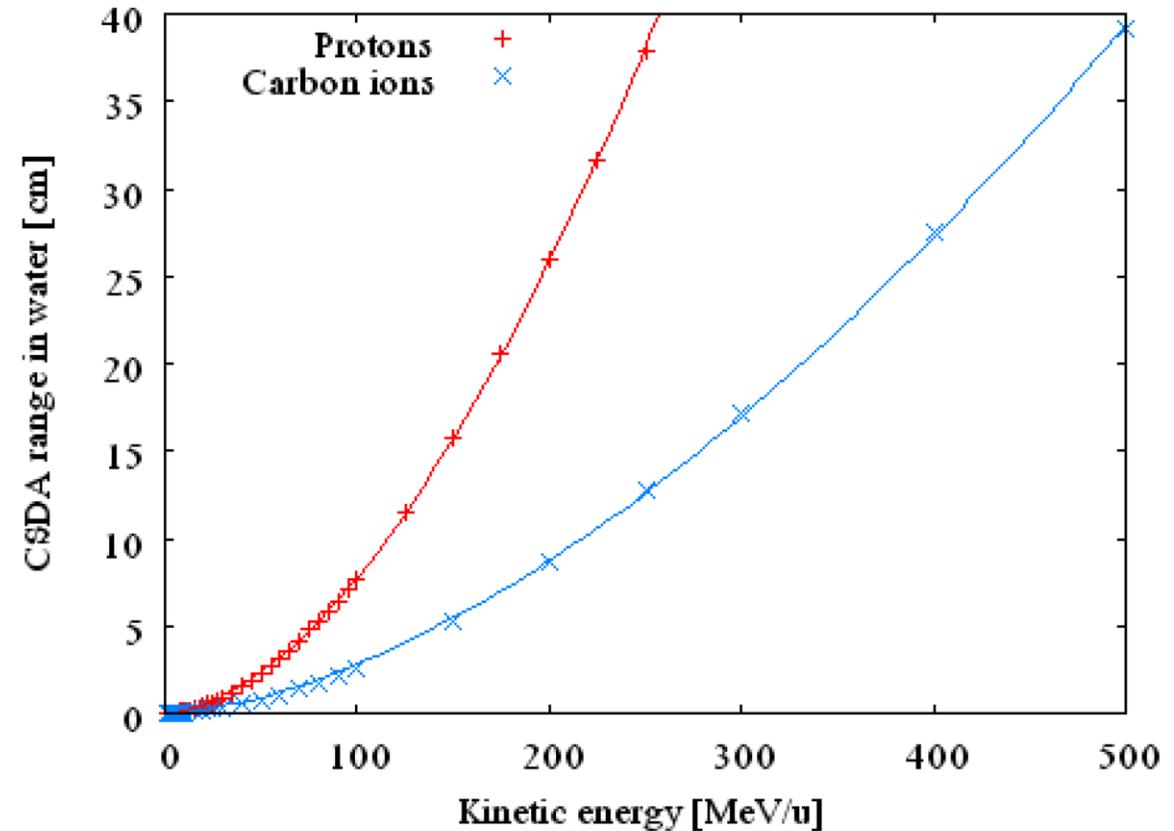


Energy Variability using Laser Accelerated Ions



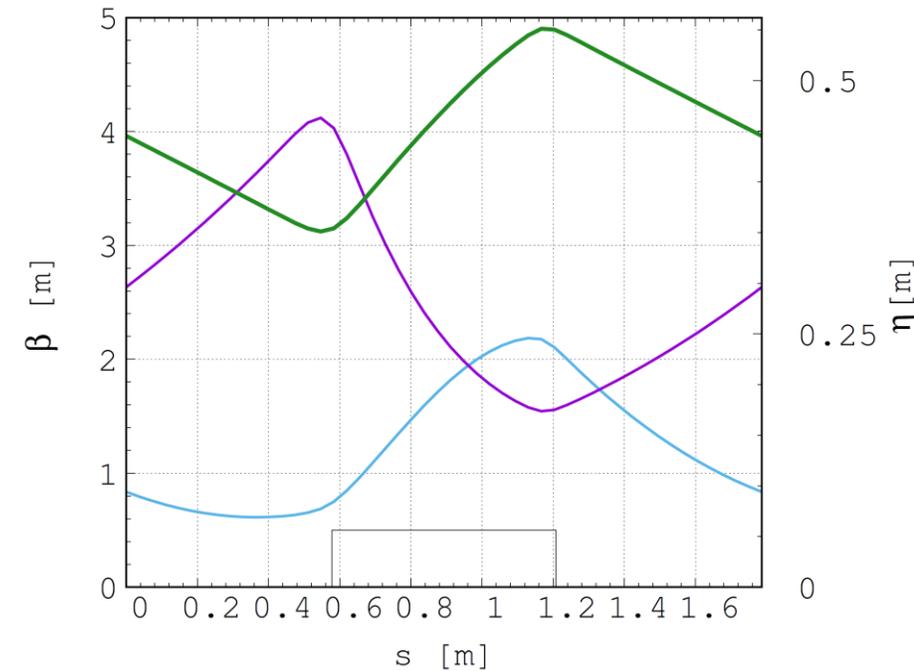
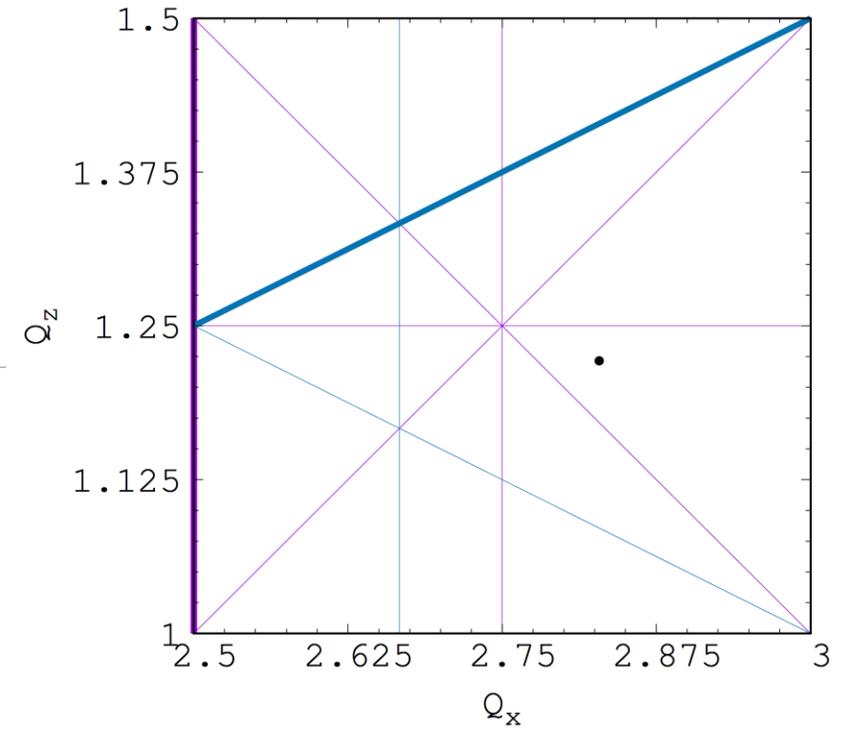
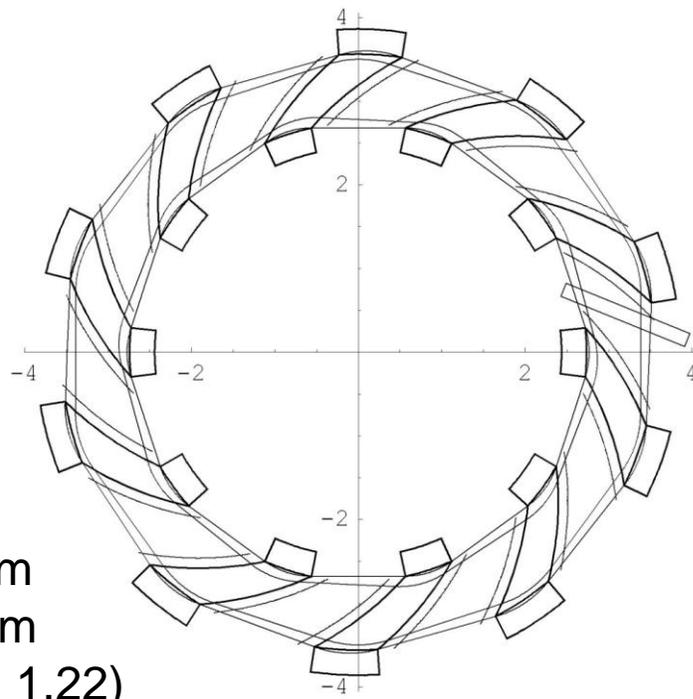
Energy for LhARA Step 2

- 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+.



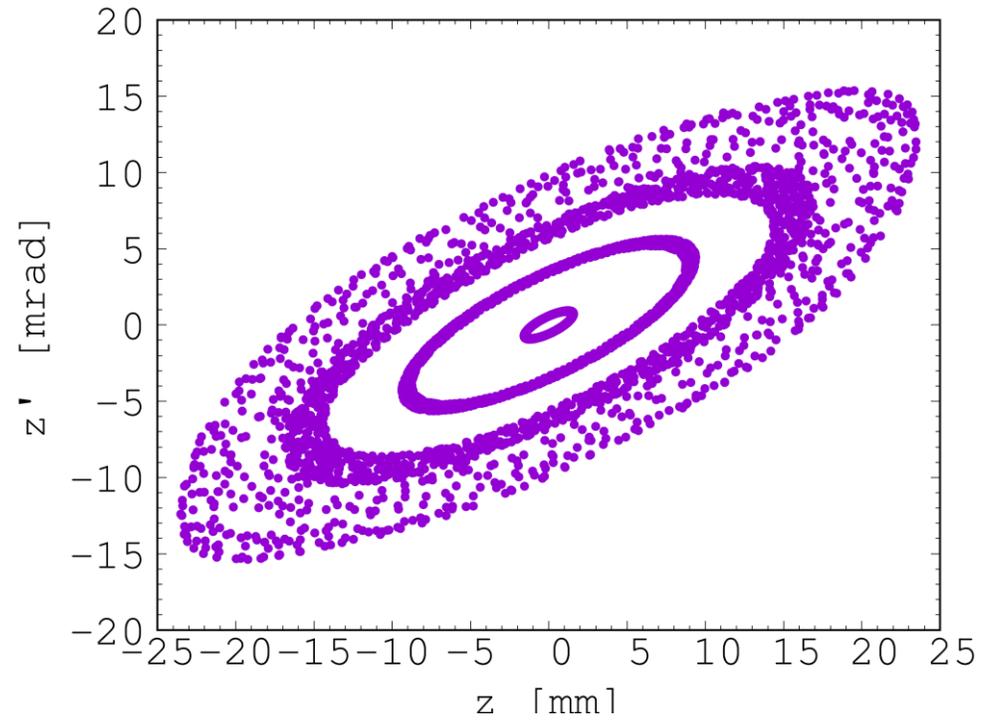
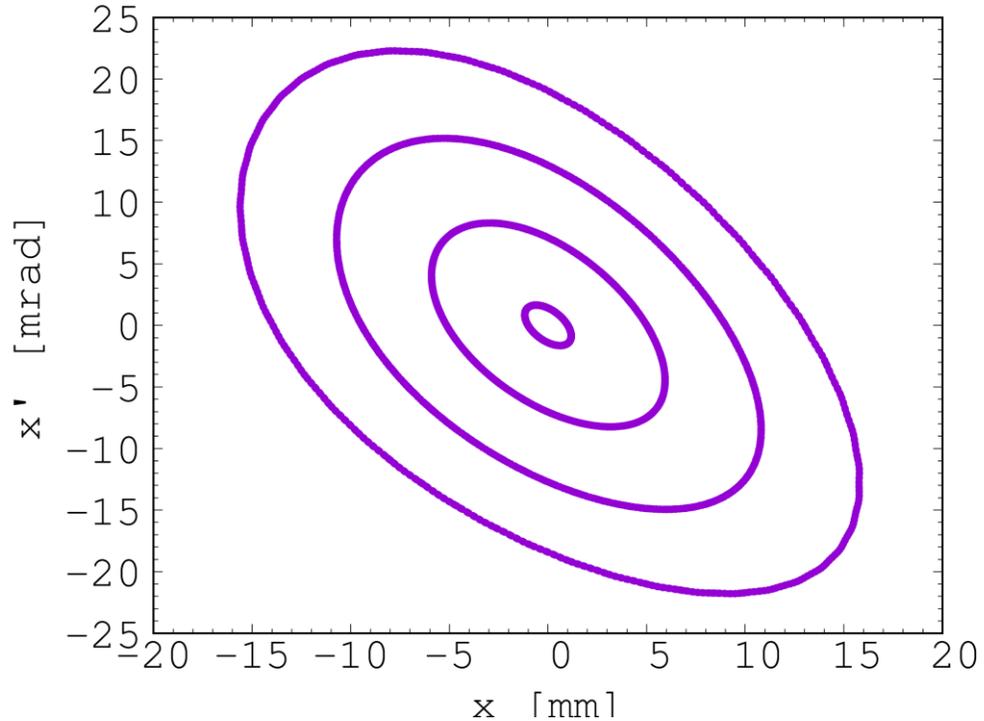
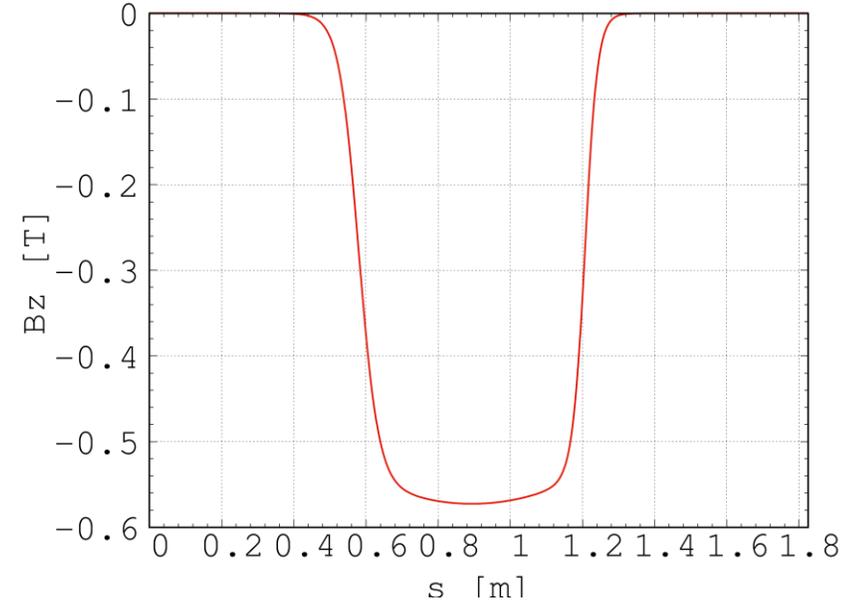
LhARA Ring Parameters

- N 10
- k 5.33
- Spiral angle 48.7°
- R_{\max} 3.48 m
- R_{\min} 2.92 m
- (Q_x, Q_y) (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 $\text{few} \times 10^8$ protons
- Range of other extraction energies possible
- Other ions also possible



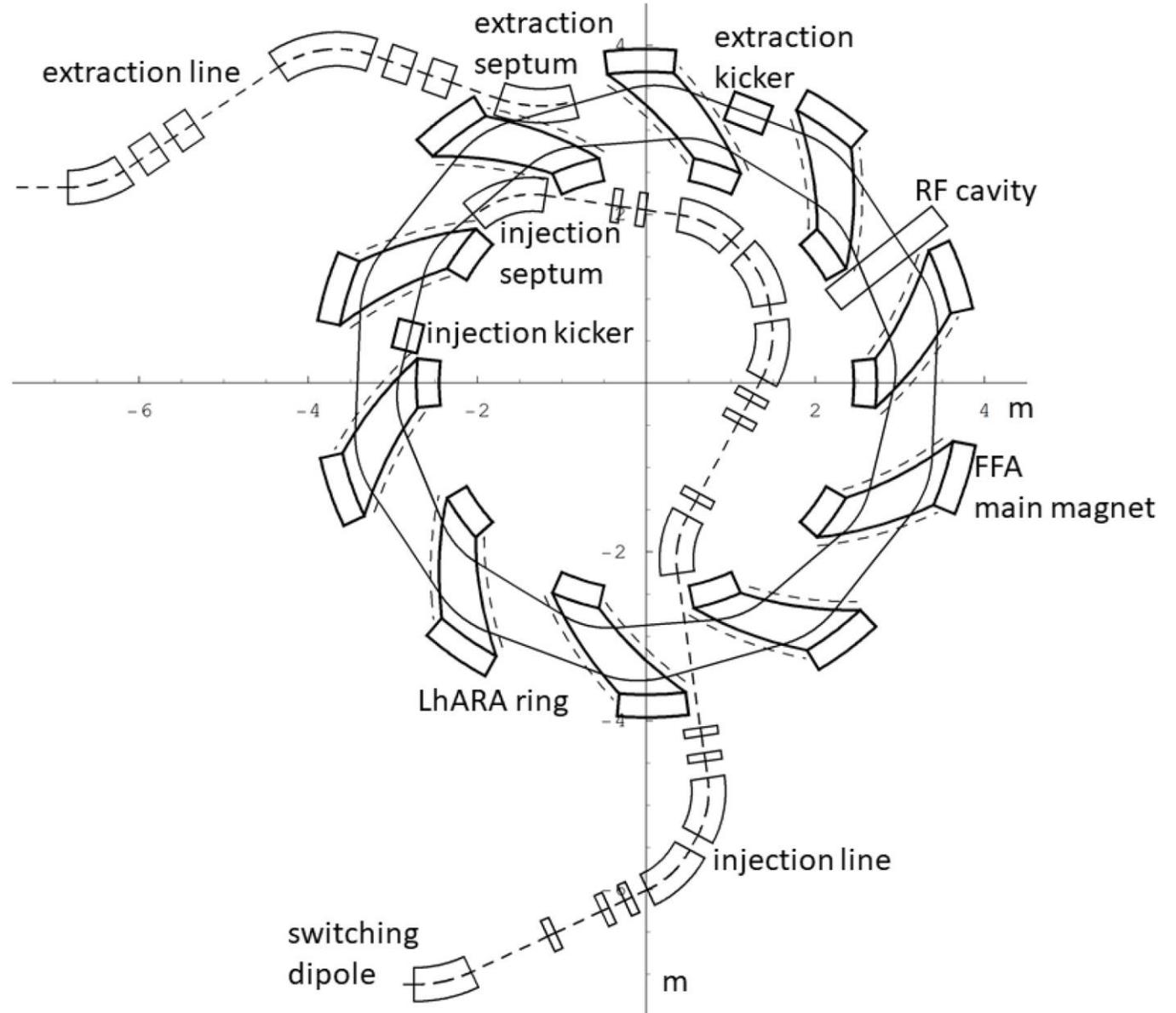
LhARA Ring Tracking

- Performed using proven stepwise tracking code
- It takes into account fringe fields and non-linear field components
- Results shows dynamical acceptance is much larger than physical one.
- No space charge yet.

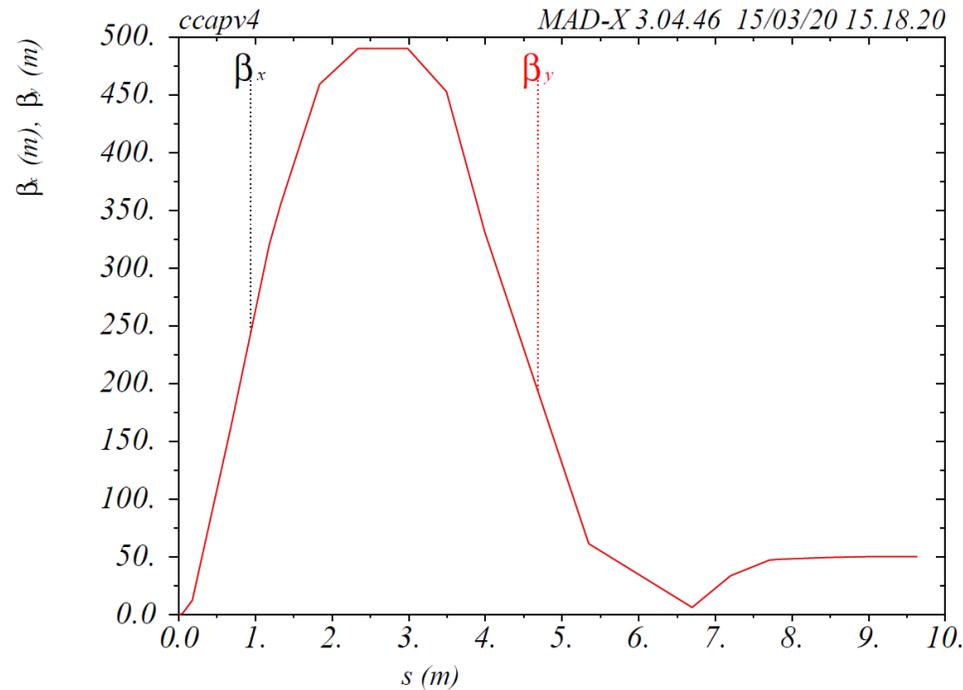


FFA Ring with subsystems

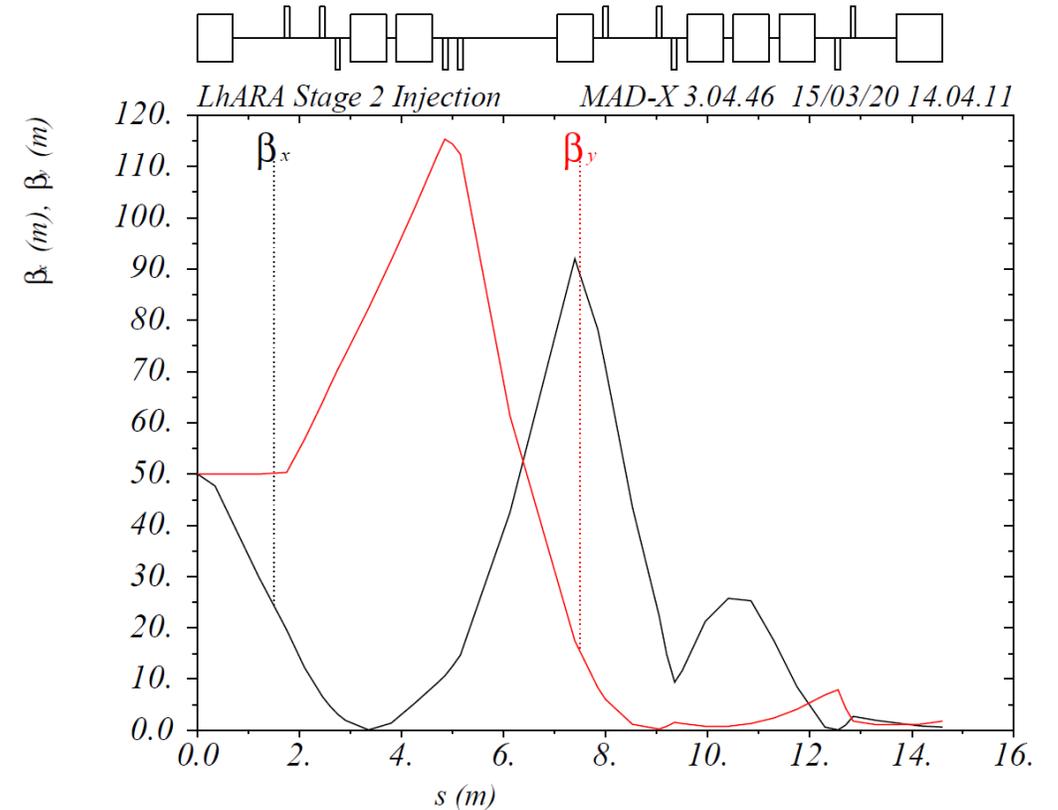
Parameter	unit	value
Injection septum:		
nominal magnetic field	T	0.53
magnetic length	m	0.9
deflection angle	degrees	48.7
thickness	cm	1
full gap	cm	3
pulsing rate	Hz	10
Extraction septum:		
nominal magnetic field	T	1.12
magnetic length	m	0.9
deflection angle	degrees	34.38
thickness	cm	1
full gap	cm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



Injection optics

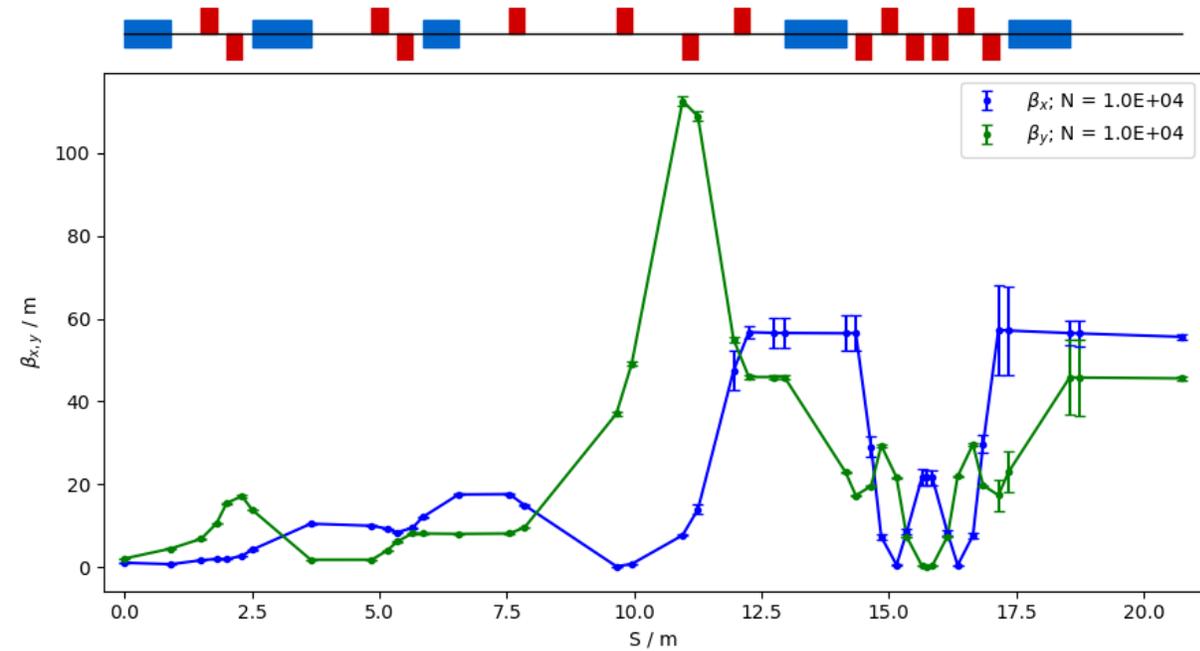


- Stage 1 can be tuned for injection
- Focus point changes location and requires a dedicated system
- Focusing can be realised with normal conducting solenoids

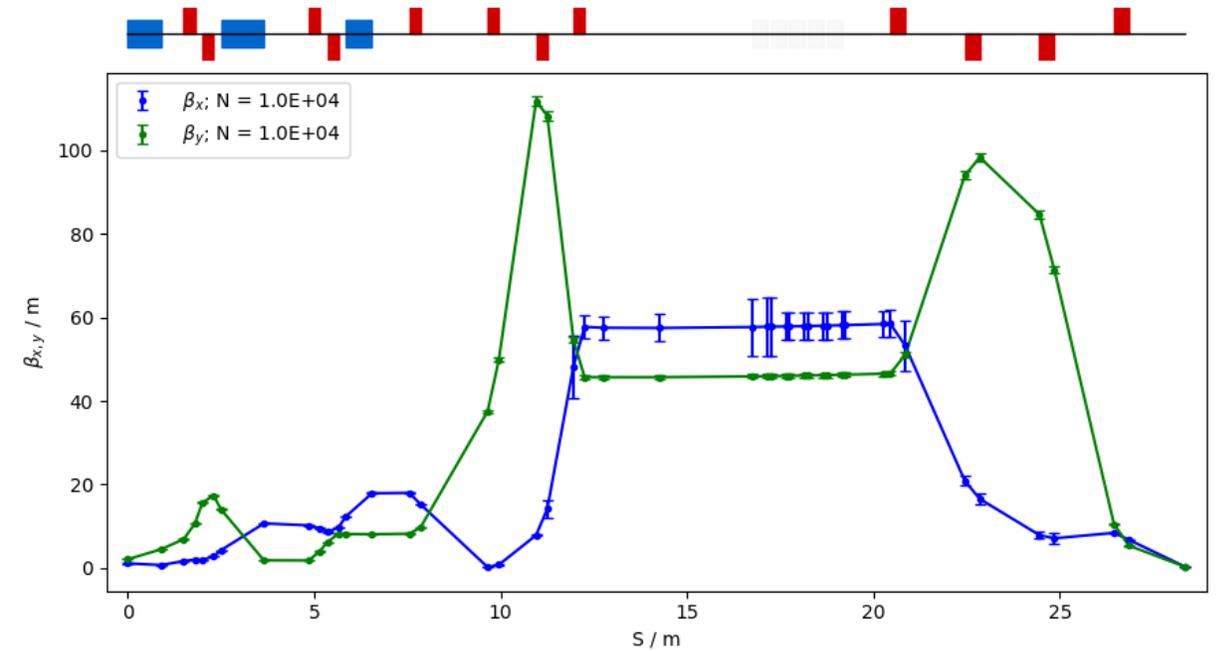


Optics from the switching dipole to the injection septum has been designed

Extraction optics



Optics for Stage 2 in-vitro endstation, arc optics scaled from the Stage 1

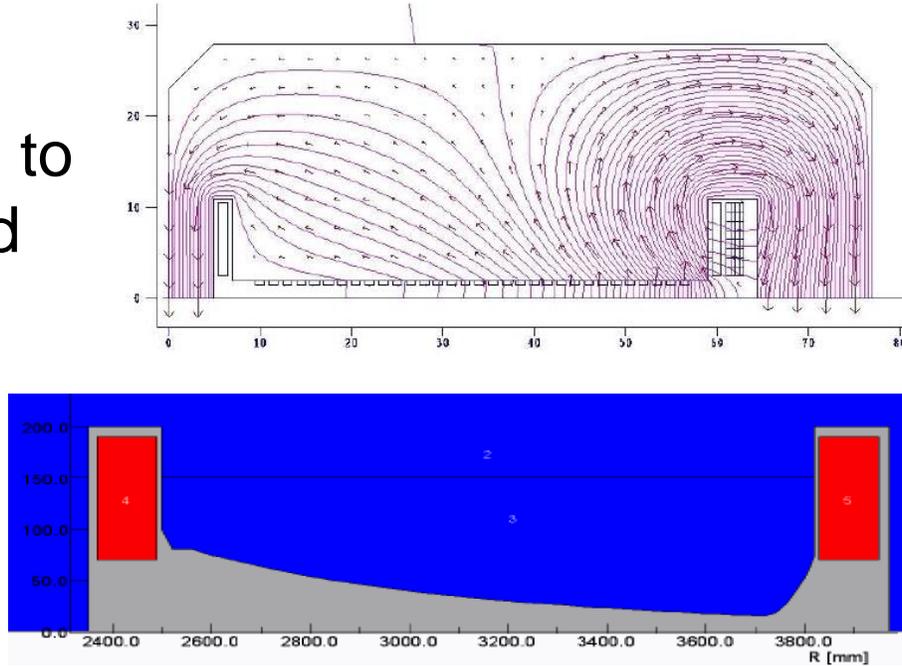


Optics for Stage 2 in-vivo endstation, dedicated final focus has been designed

More details in HT's talk

Essential R&D

Magnet types to be considered



Magnet with distributed conductors:

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

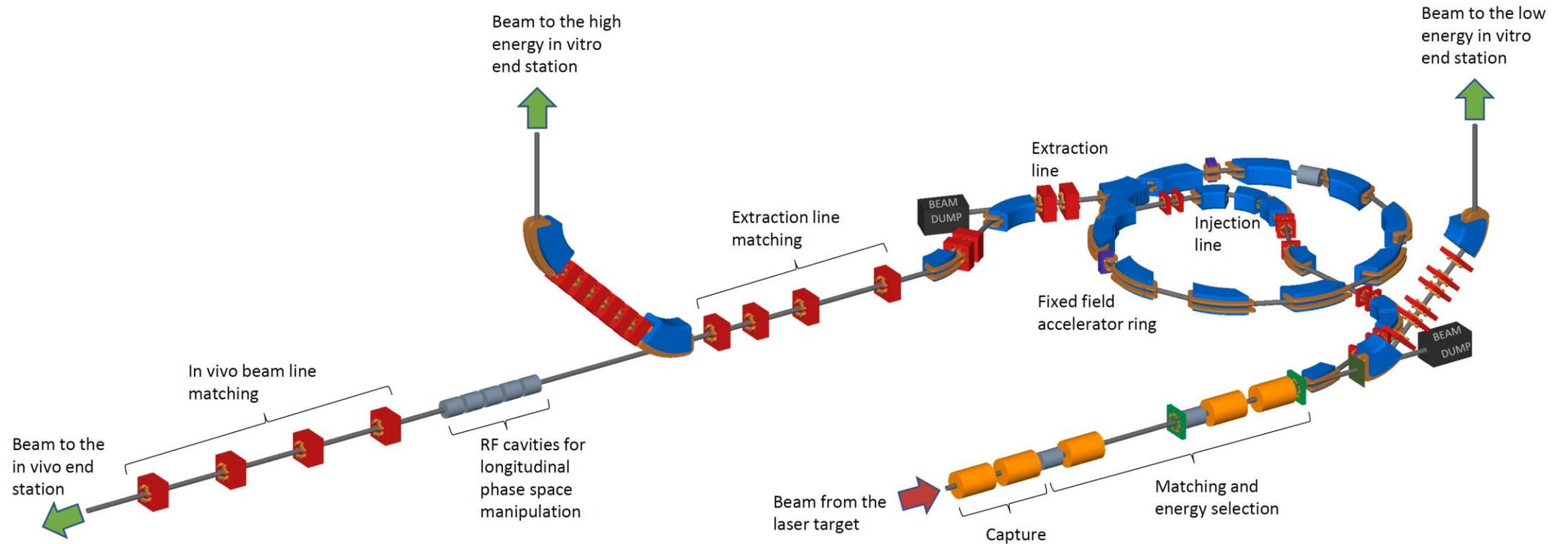
„Gap shaping” magnet:

- Developed by SIGMAPHI for RACCAM project
- 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.
- Another important aspect of the R&D is the technology transfer for Magnetic Alloy (MA) loaded RF cavities for the ring



Layout of the full LhARA facility



Conclusions and future plans

- Conceptual design of LhARA is in a very good shape
- Stage 1 shows good performance including the space charge effects.
- 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
- Single spiral-type FFA seems the most cost effective solution
- Injection into the ring and extraction towards both end-stations at Stage 2 are feasible
- Essential R&D items are the FFA main magnet and the RF system for the ring