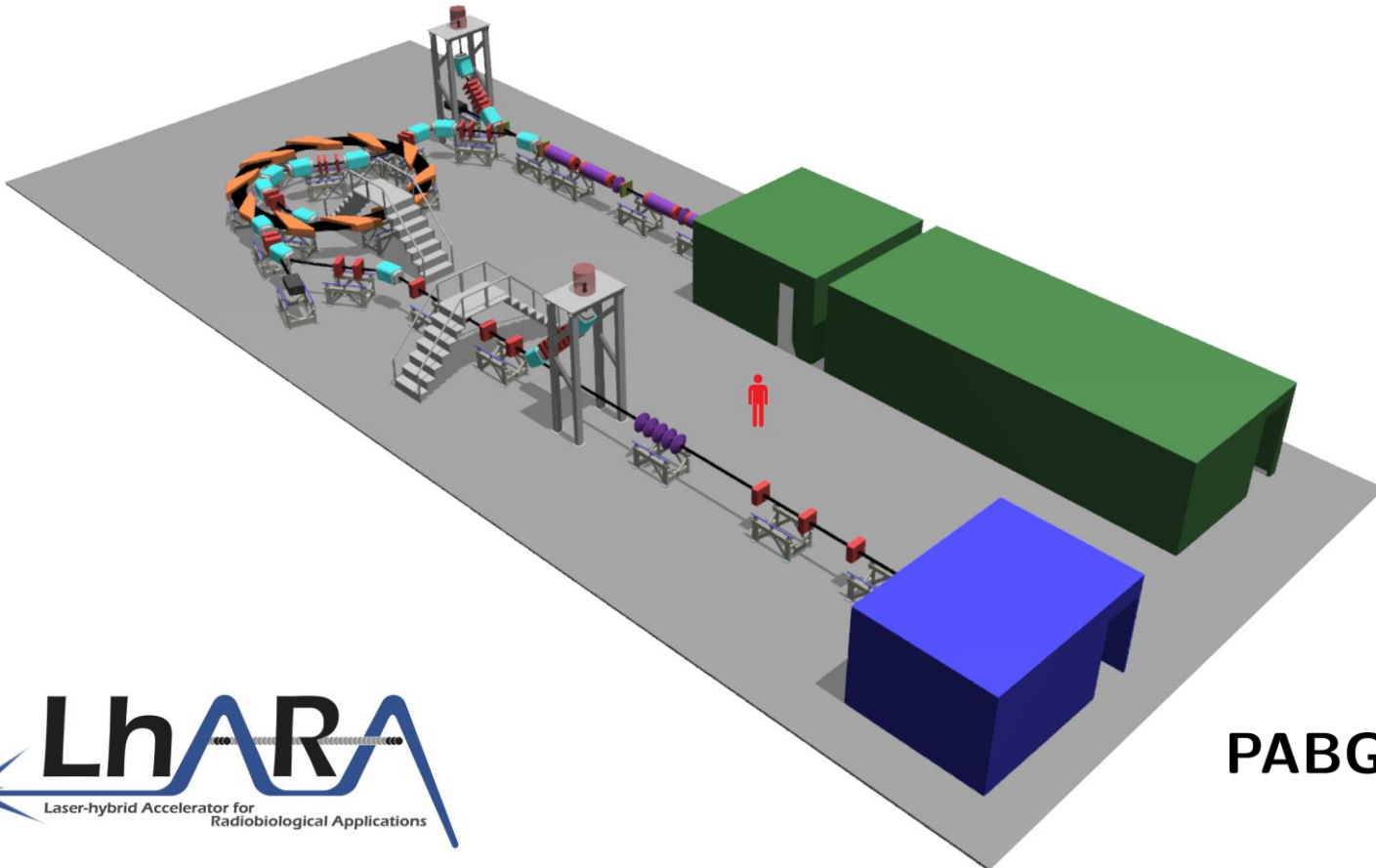


The Laser-hybrid Accelerator for Radiobiological Applications (LhARA)



Titus-Stefan Dascalu
for the LhARA collaboration

Imperial College London
t.dascalu19@imperial.ac.uk

The collaboration



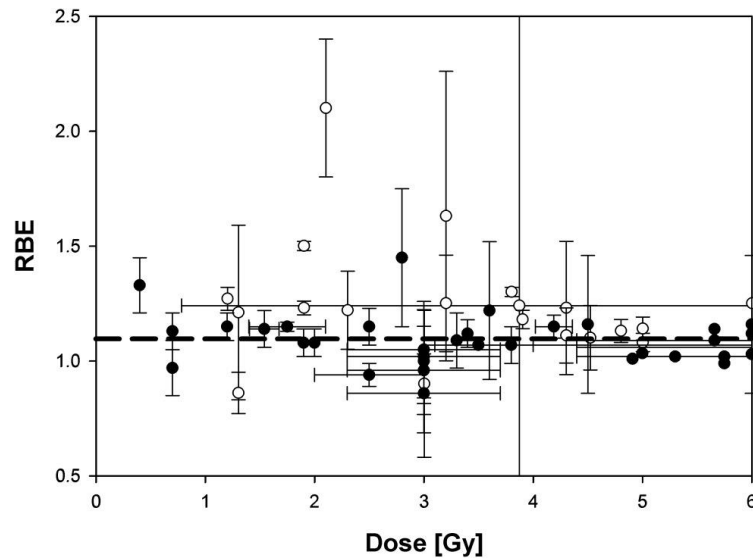
Mission

- Deliver a systematic radiobiology programme
- Prove the laser-hybrid approach
- Lay the foundations for transformative ion-beam therapy
 - Highly automated, patient-specific treatment

Motivation: strong case for...

Systematic study of radiobiology

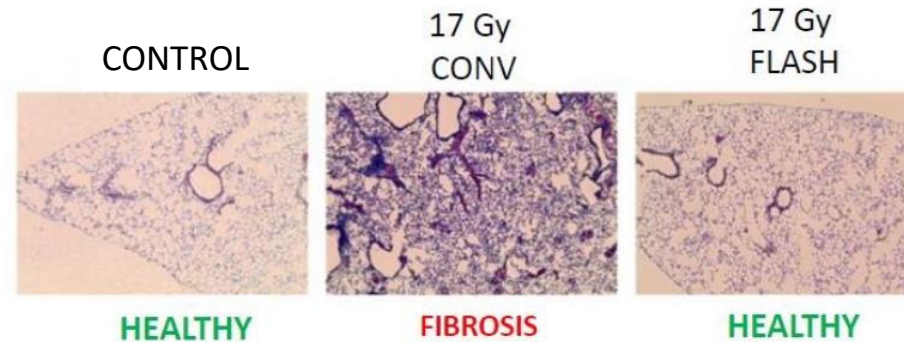
Paganetti and van Luijk, Sem. Rad. Oncol. 23, 77-87 (2013)



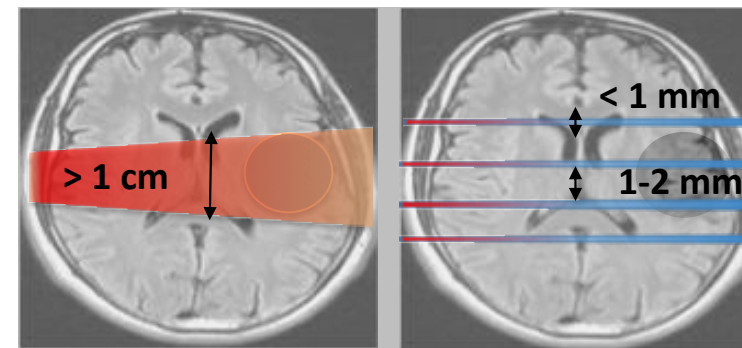
Novel beams for radiobiology

Favaudon et al., Sci. Transl. Med. 6, 245 (2014)

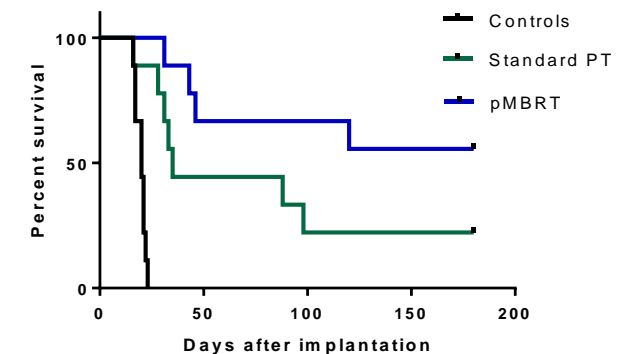
Prezado et al., Red Journal 2, 104 (2019)



FLASH



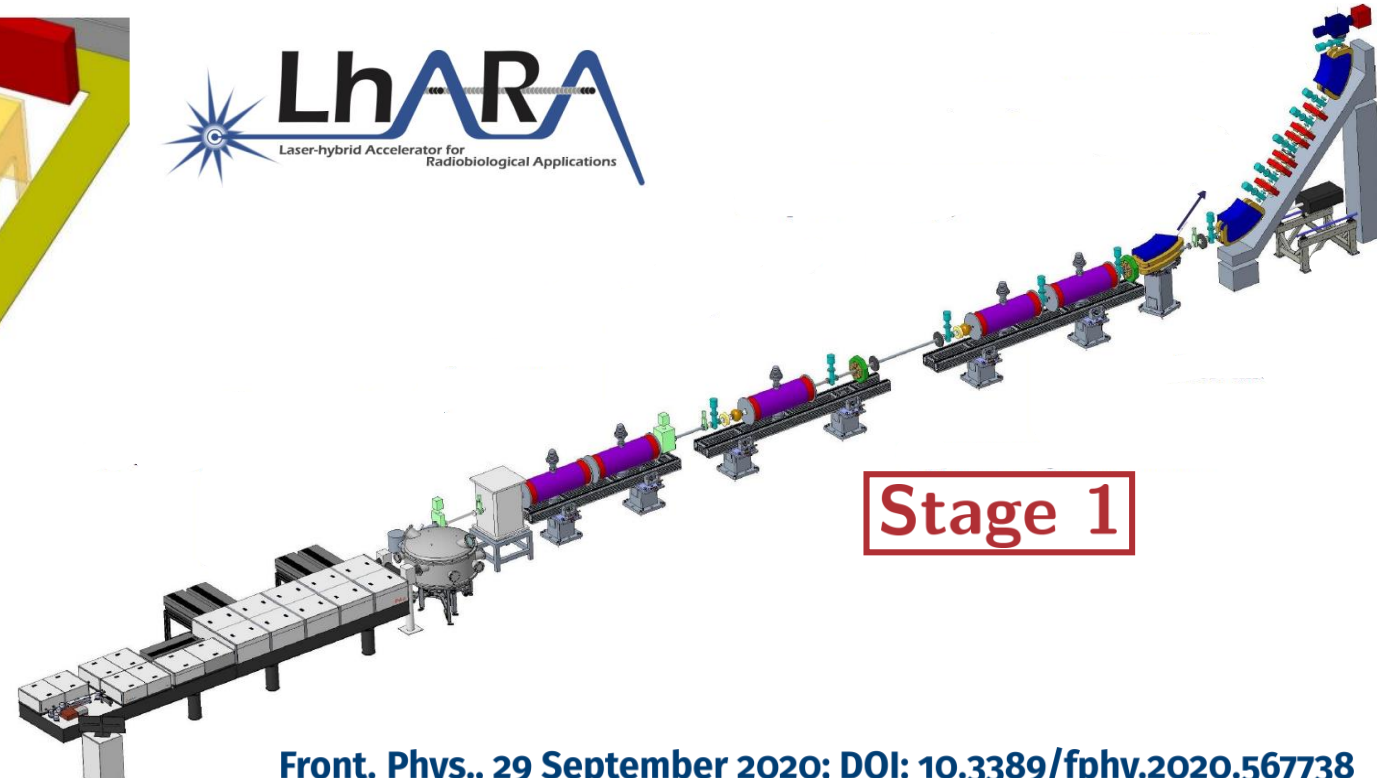
minibeams



Transformative ion-beam therapy

- Radiotherapy (RT) used in $\sim 50\%$ of cancer patients and involved in 40% of cancer cures
- 17 million new cases per year at present \implies 27.5 million new cases per year by 2040
- Nearly 70% of patients globally do not have access to RT (facilities predominantly located in high-income countries)

Laser-hybrid approach



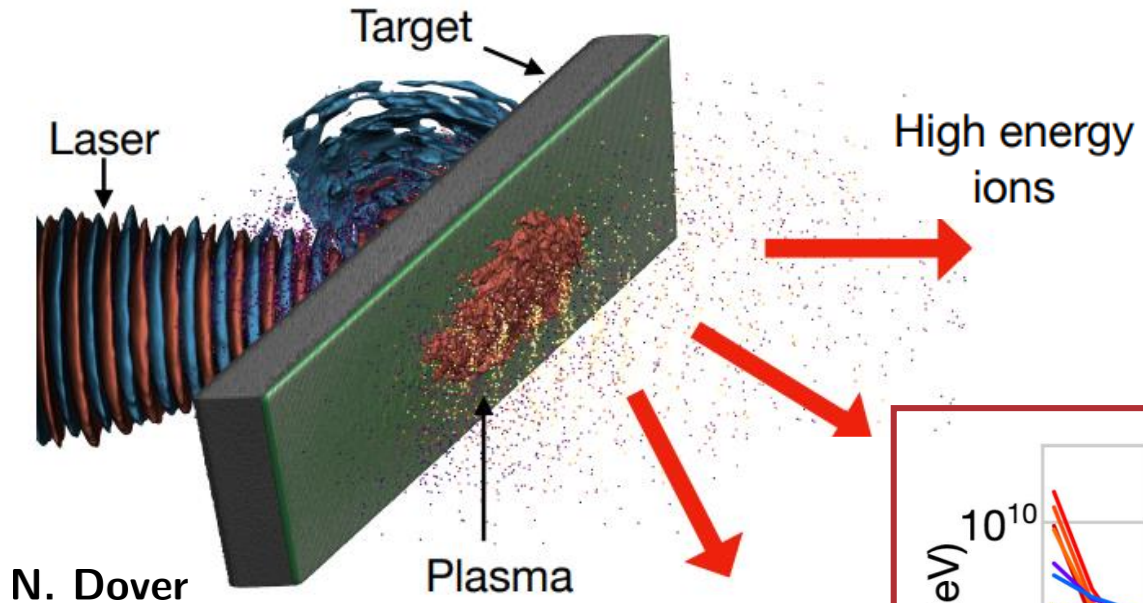
Front. Phys., 29 September 2020; DOI: 10.3389/fphy.2020.567738

LhARA: R&D proposal for the preliminary, pre-construction phases ([link](#))

- **Laser-driven, high-flux proton/ion source**
 - multiple ion species & ultra-high dose rate
- **Electron-plasma lenses for capture and beam focusing**
- **Fast, flexible post-acceleration with an FFA**
 - Variable energy
 - * Protons: 15–127 MeV
 - * Ions: 5–34 MeV/u

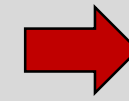
The laser-driven source

target normal sheath acceleration (TNSA)



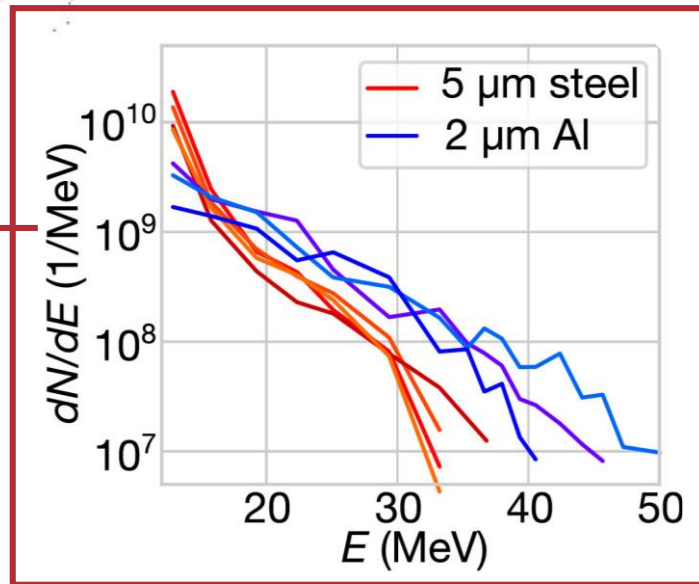
Initially approximately charge neutral
Protons (and ions) produced at “high energy”

reduce impact
of space-charge



**high instantaneous
dose-rate**

Dover et al.,
High Energy Density Phys. 37,
100847 (2020)



Typically broadband energy
Highly divergent ($>10^\circ$)

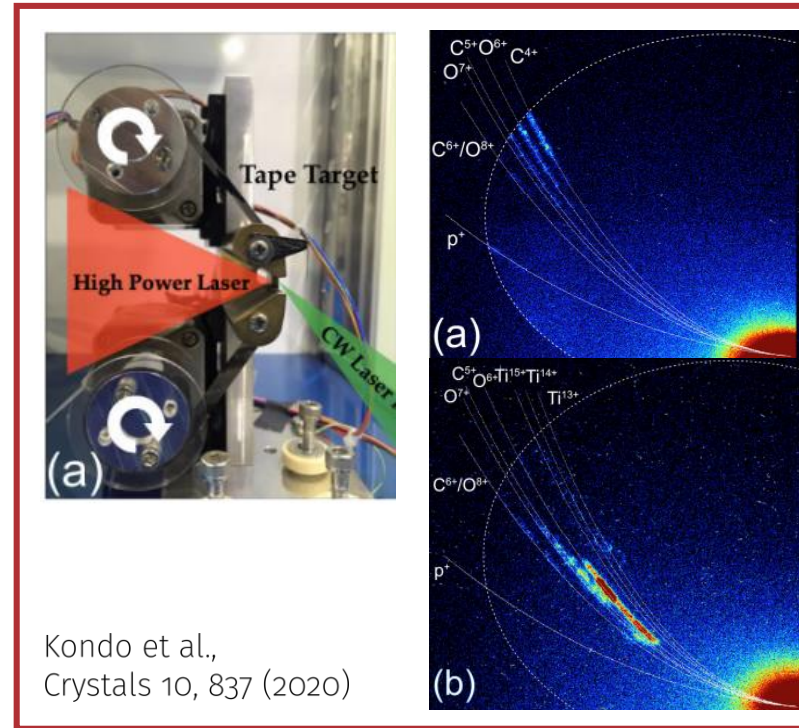
High brightness

$10^{11} - 10^{13}$ particles/shot

Small emittance & short duration

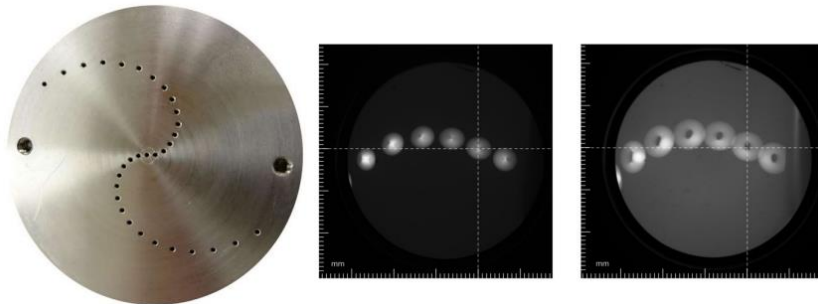
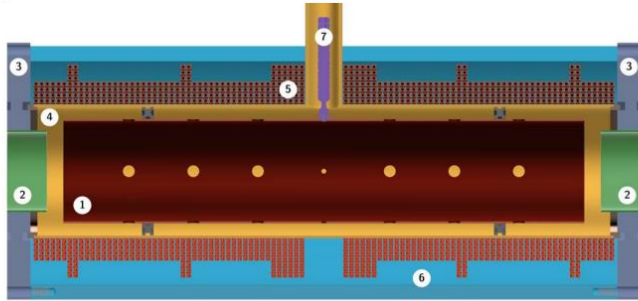
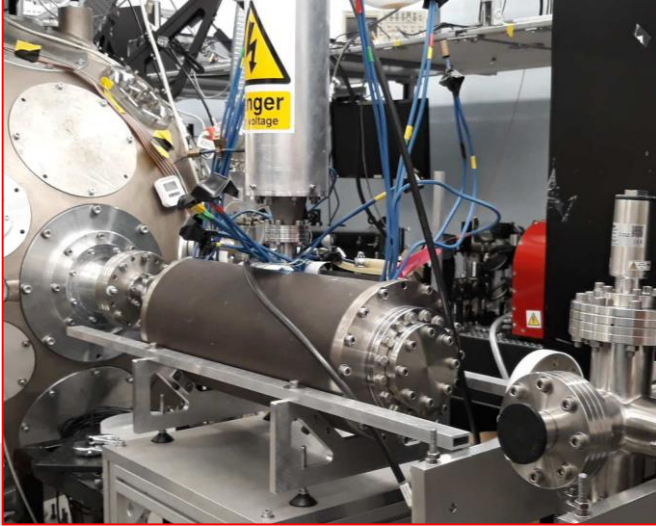
rms emittance $\sim 0.01\pi$ mm-mrad
ps at source

Triggerable and on-demand

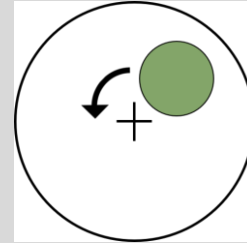


Kondo et al.,
Crystals 10, 837 (2020)

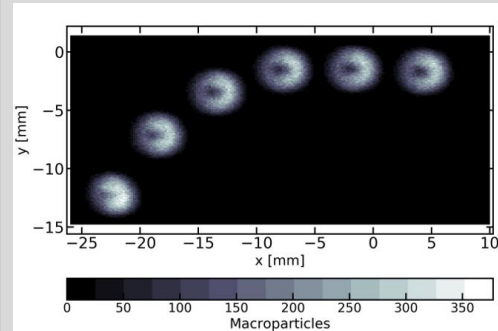
Development of a plasma lens for LhARA



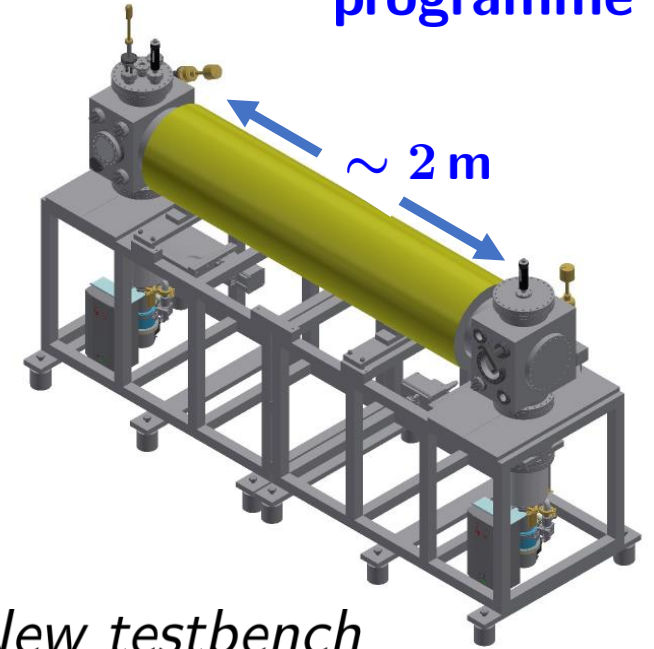
Plasma
coherent
rotation



+ beam-tracking



“Preliminary Phase”
programme



New testbench

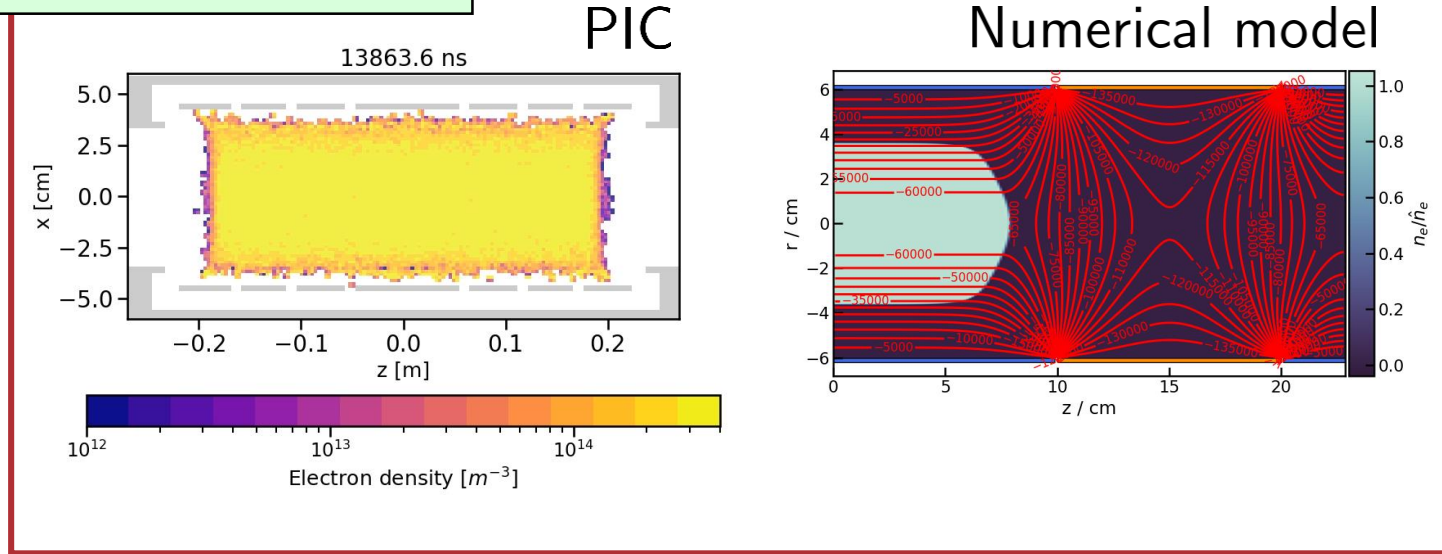
produce & study larger plasmas

$$r_w = 10 \text{ cm} \quad L_p \sim 1 \text{ m}$$

$$\phi_{sc} \sim 2-10 \text{ kV}$$

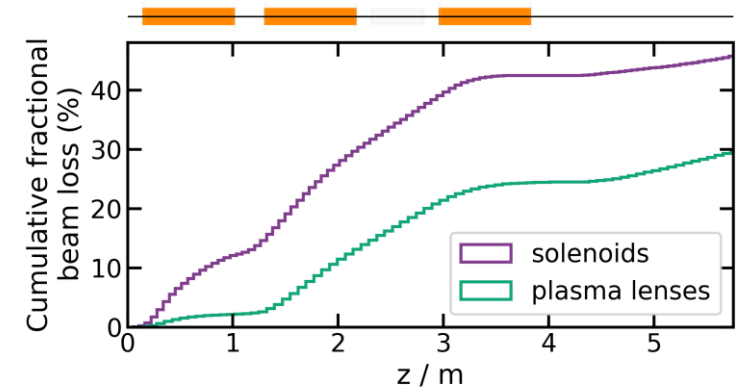
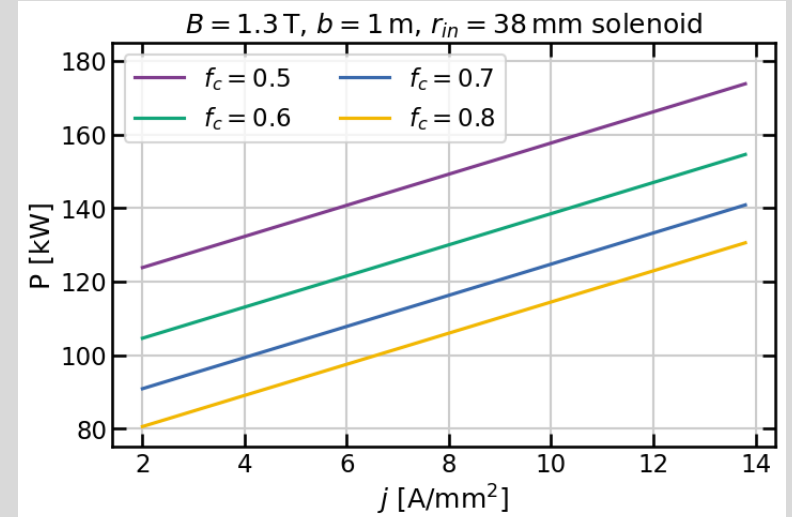
Development of the capture section

Plasma simulations

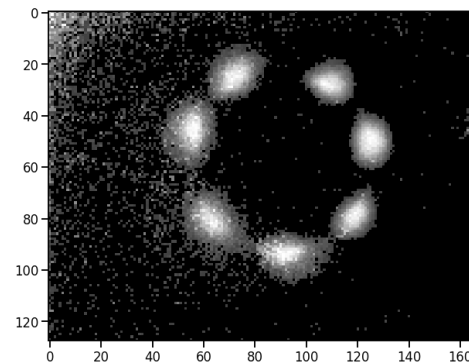
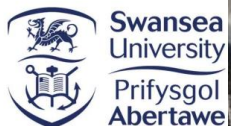


Design more conventional alternative

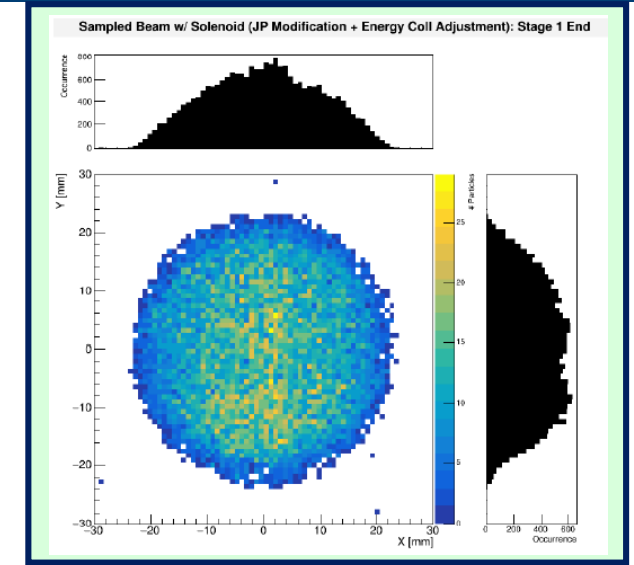
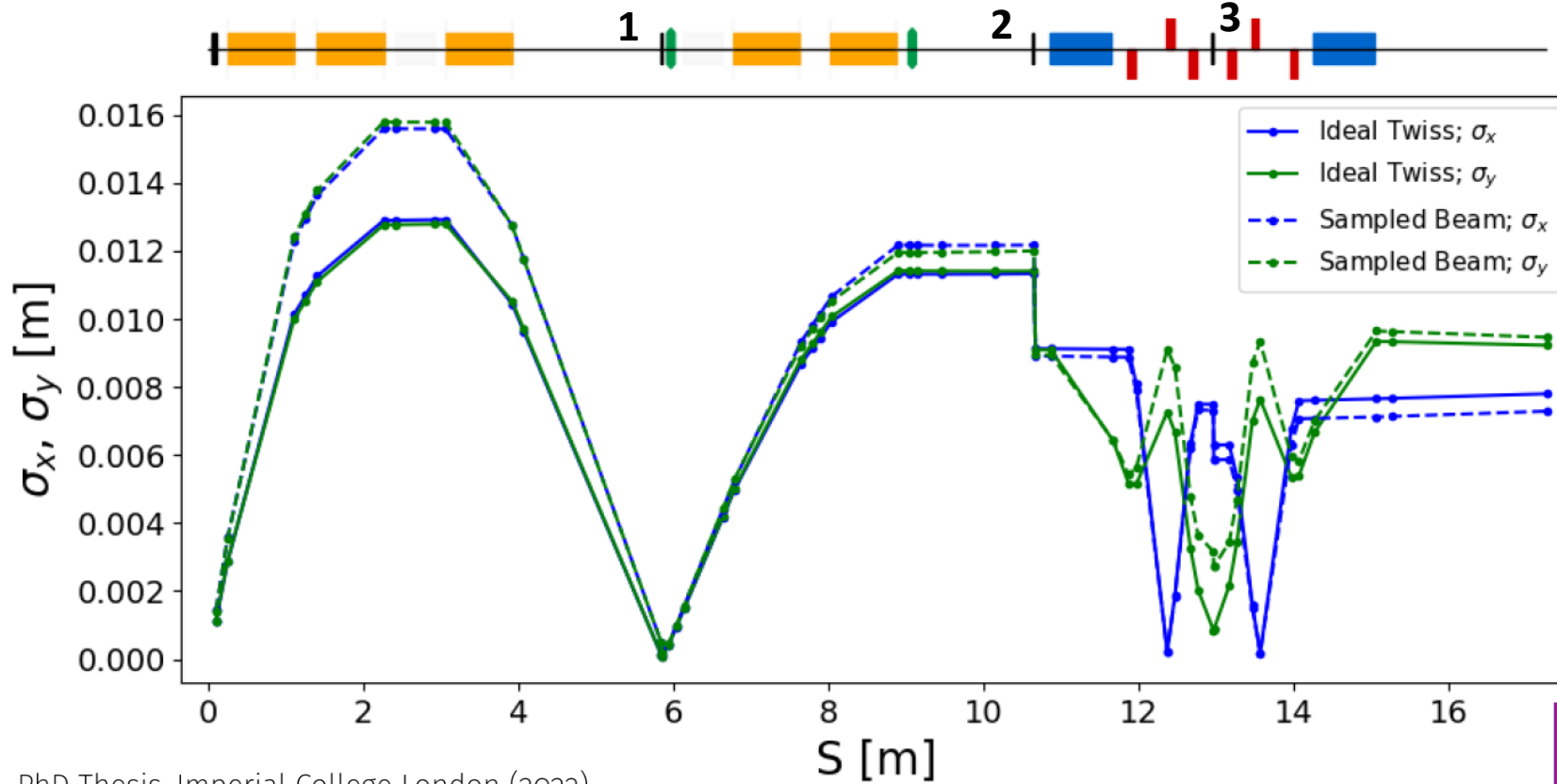
normal-conducting solenoids



Measurements with confined electrons

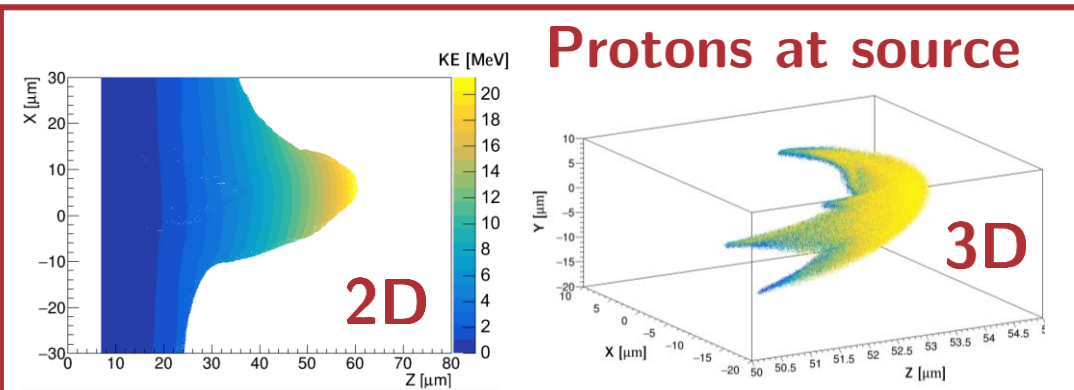


LhARA Stage 1 for *in-vitro* studies



Dose uniformity at end station

H.T.Lau, PhD Thesis, Imperial College London (2022)

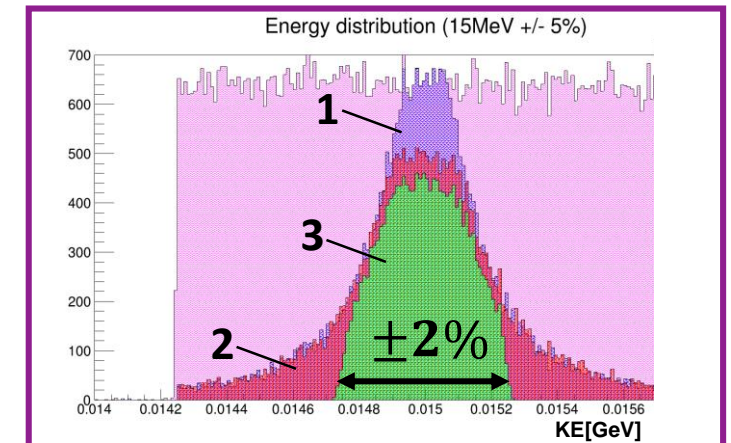


Protons at source

Energy collimation

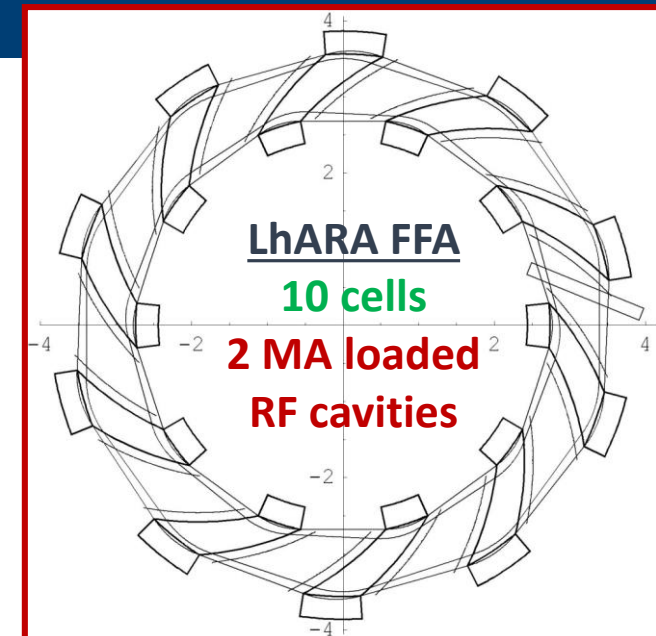
Smilei)

BDSIM
Beam Delivery Simulation

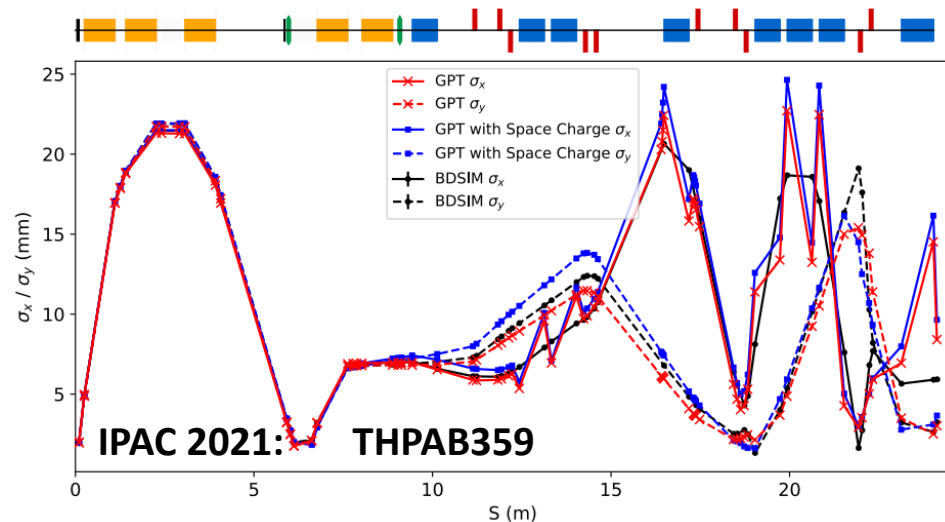


Rapid, flexible acceleration for Stage 2

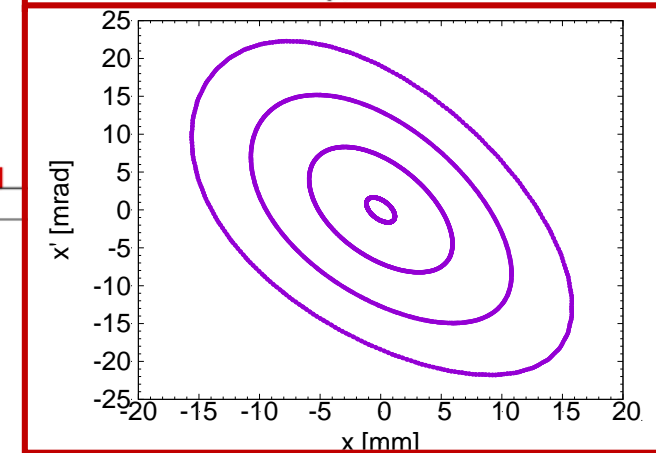
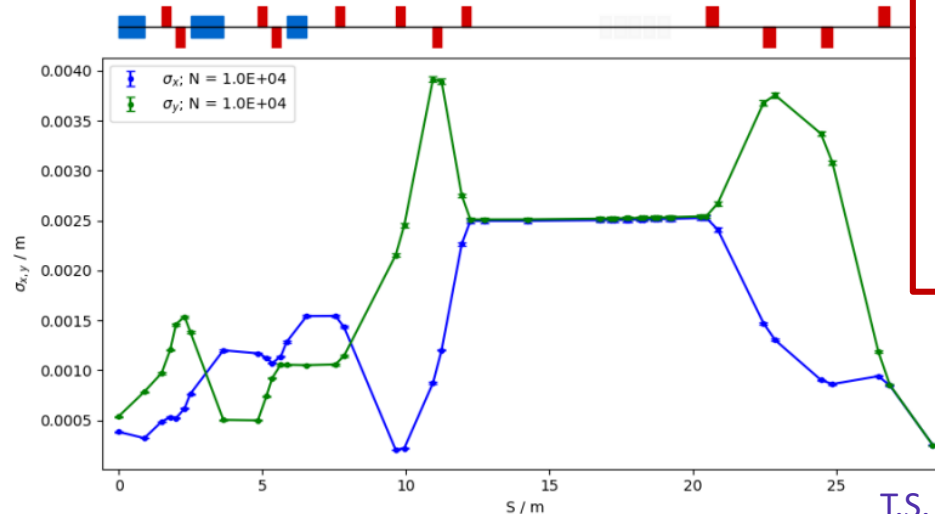
- **Baseline:** $\times 3$ increase in momentum
- **Spiral scaling FFA** shows a good performance in tracking studies.
 - Dynamical acceptances much larger than physical ones
 - FFA model with space charge in development
- Feasible ring injection, extraction and beam transport to the end stations have been designed.



Injection into FFA



To in vivo end-station



Aymar et al., *Frontiers in Physics*, 432 (2020)

LhARA performance

Aymar et al., *Frontiers in Physics* (2020):432

Doses and dose rates

LhARA performance summary

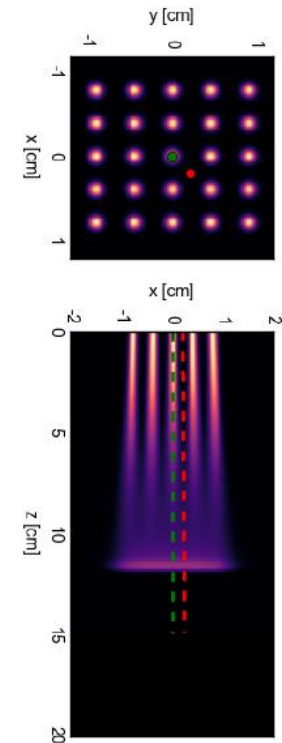
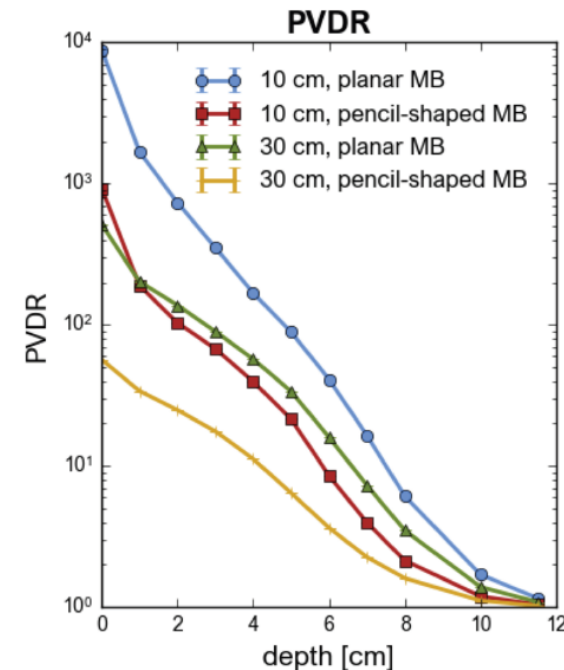
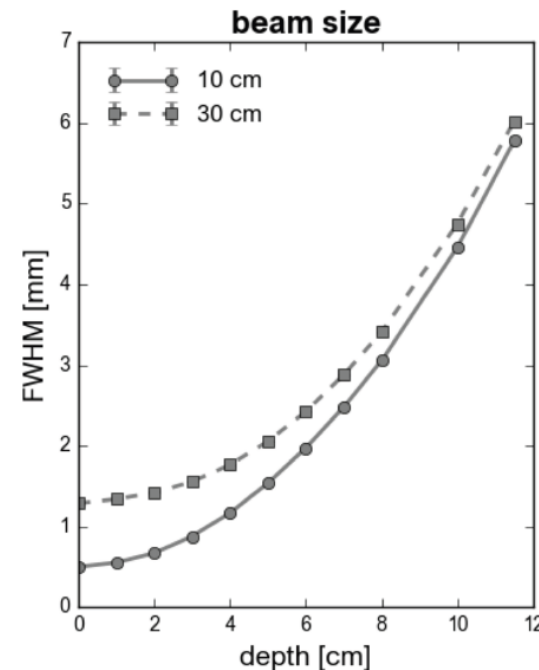
	12 MeV Protons	15 MeV Protons	127 MeV Protons	33.4 MeV/u Carbon
Dose per pulse	7.1 Gy	12.8 Gy	15.6 Gy	73.0 Gy
Instantaneous dose rate	1.0×10^9 Gy/s	1.8×10^9 Gy/s	3.8×10^8 Gy/s	9.7×10^8 Gy/s
Average dose rate	71 Gy/s	128 Gy/s	156 Gy/s	730 Gy/s

Worked example: FLASH

Conventional regime: ~ 2 Gy/min
FLASH regime: ≥ 40 Gy/s

Worked example: minibeam

LhARA + clinical nozzle for magnetically focused proton minibeam



T.Schneider, PhD Thesis, Universite Paris-Saclay (2020)

Conclusions

- **Laser-driven sources are disruptive technologies...**
 - with the potential to drive a step-change in clinical capability.
- **Laser-hybrid approach has potential to:**
 - Overcome dose-rate limitations of present proton and ion beam therapy sources.
 - Deliver a uniquely flexible facility:
 - * **Range of ion species, energy, dose, dose-rate, time and spatial distribution**
- **LhARA design is flexible and compact.**
 - Good performance in tracking studies.
 - Feasible FFA ring, injection, extraction, and beam transport designed.
- **Funding from the UKRI Infrastructure Fund has recently been announced**
 - 2-year “Preliminary Activity”
 - to deliver a CDR for the Ion Therapy Research Facility served by LhARA.

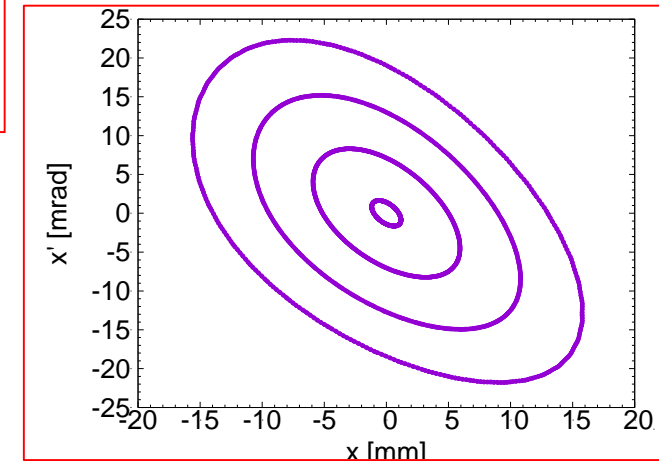
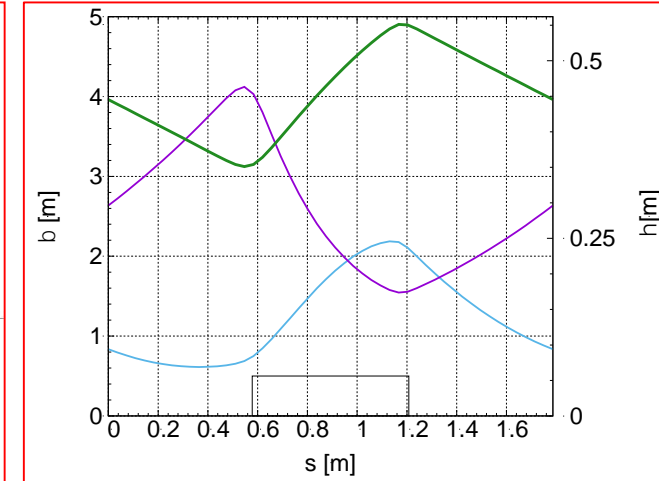
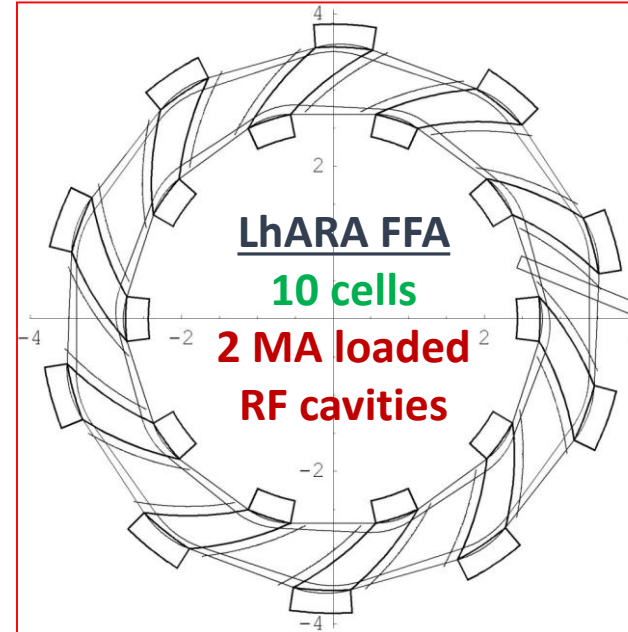
Backup Slides

Rapid, flexible acceleration for Stage 2

Aymar et al., *Frontiers in Physics*, 432 (2020)

- **Fixed-field alternating-gradient accelerator (FFA):**

- Compact, flexible solution:
 - * Multiple ion capability
 - * Variable energy extraction
 - * High repetition rate (10–100 Hz)
 - * Large acceptance
- Single scaling spiral FFA:
 - * Baseline lattice type
 - * Single magnet per lattice cell
 - * Spiral magnet needed



- Spiral scaling FFA shows a good performance in tracking studies.
 - Dynamical acceptances much larger than physical ones
 - FFA model with space charge in development

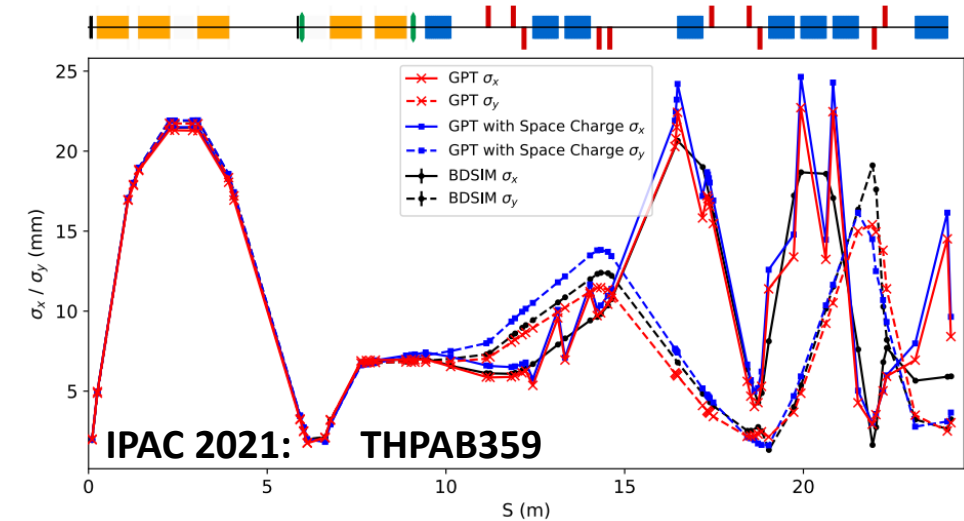
FFA in LhARA Stage 2

- **Baseline: $\times 3$ increase in momentum:**
 - 15 MeV protons accelerated to 127 MeV
 - 3.8 MeV/u carbon 6+ ions accelerated to 34 MeV/u
- Feasible ring injection, extraction and beam transport to the end stations have been designed.
- Preliminary ideas for slow extraction

Essential R&D:

- finalisation of lattice design
- **main FFA magnet**
(parallel gap, distributed windings)
- **technology transfer for Magnetic Alloy (MA)**
loaded RF cavities

Injection into FFA



To in vivo end-station

