WP6: Design and Integration

William Shields

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LhARA Collaboration Meeting #8

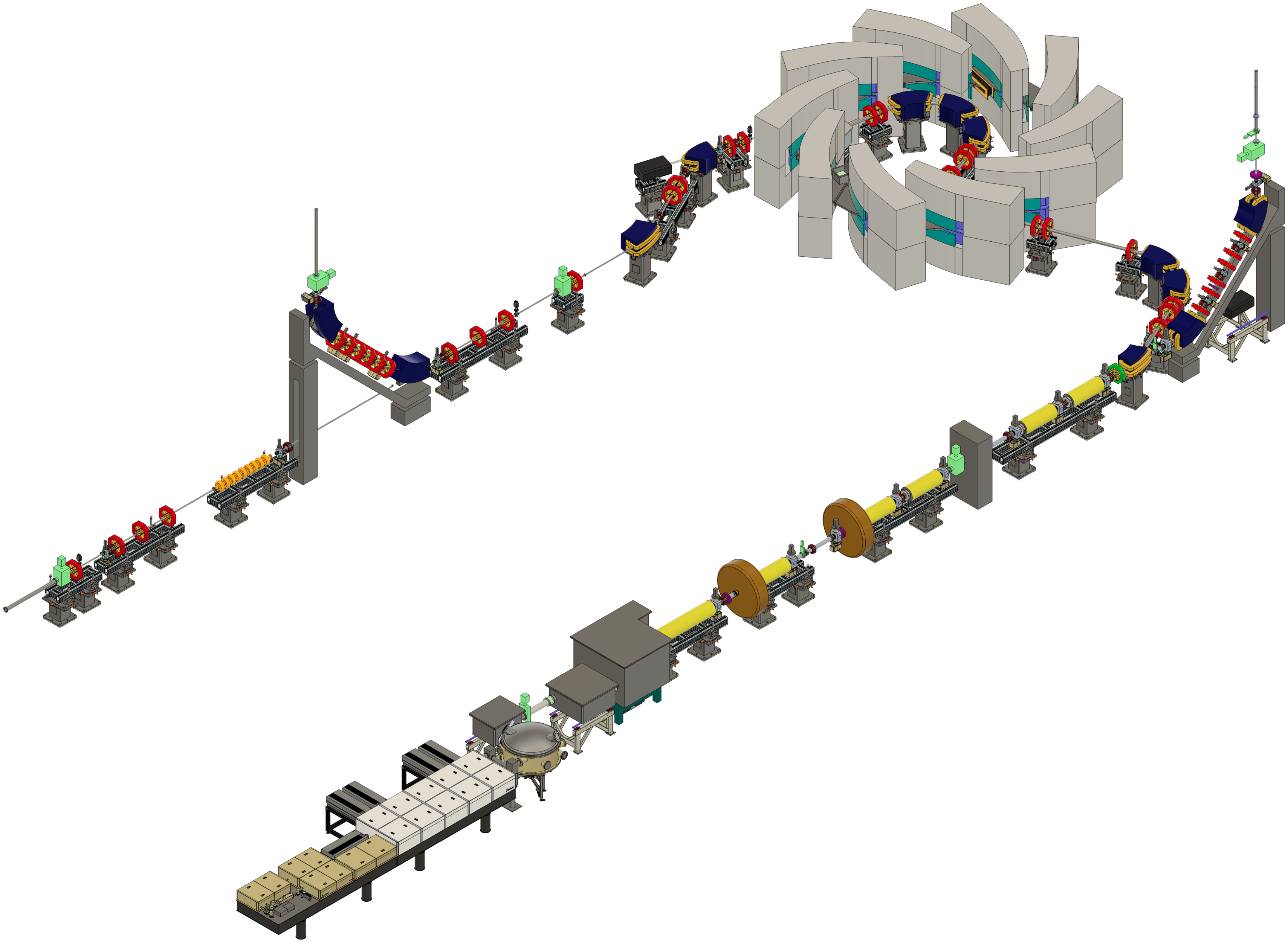
19th September 2025

ROYAL HOLLOWAY UNIVERSITY OF LONDON

LhARA Laser-hybrid Accelerator for Radiobiological Applications

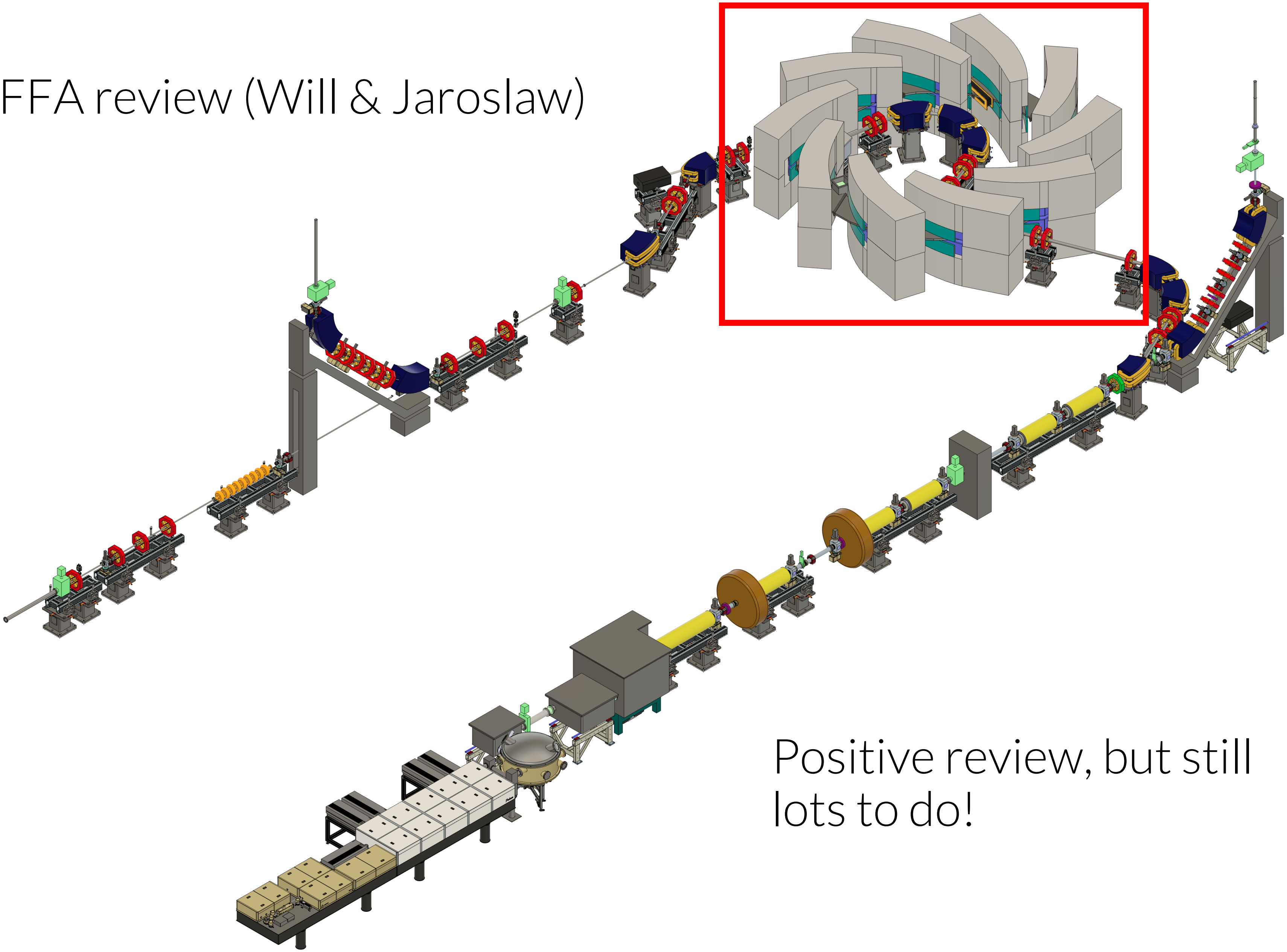
JAI John Adams Institute for Accelerator Science

The LhARA Accelerator



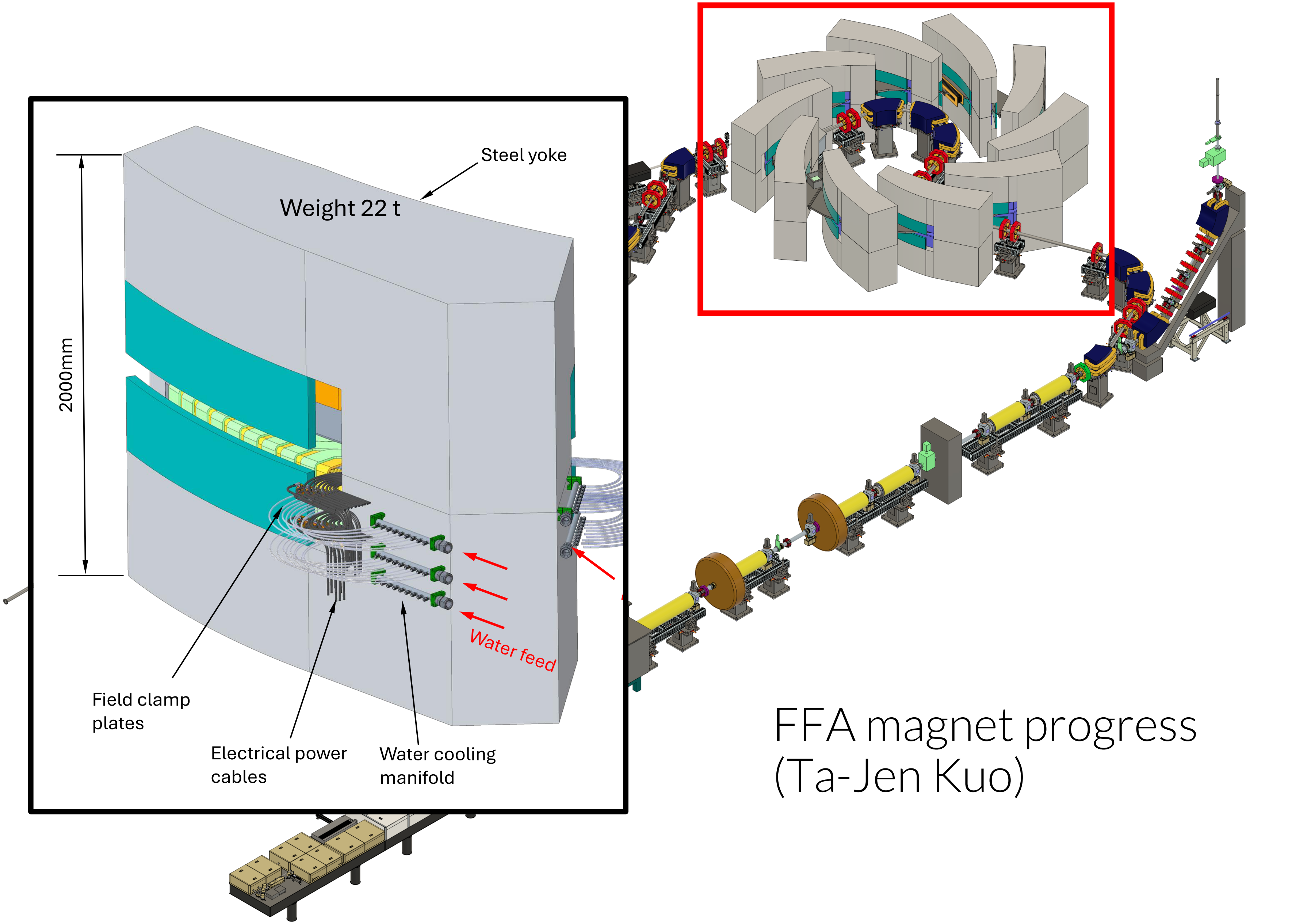
LhARA FFA Magnet

FFA review (Will & Jaroslaw)



Positive review, but still lots to do!

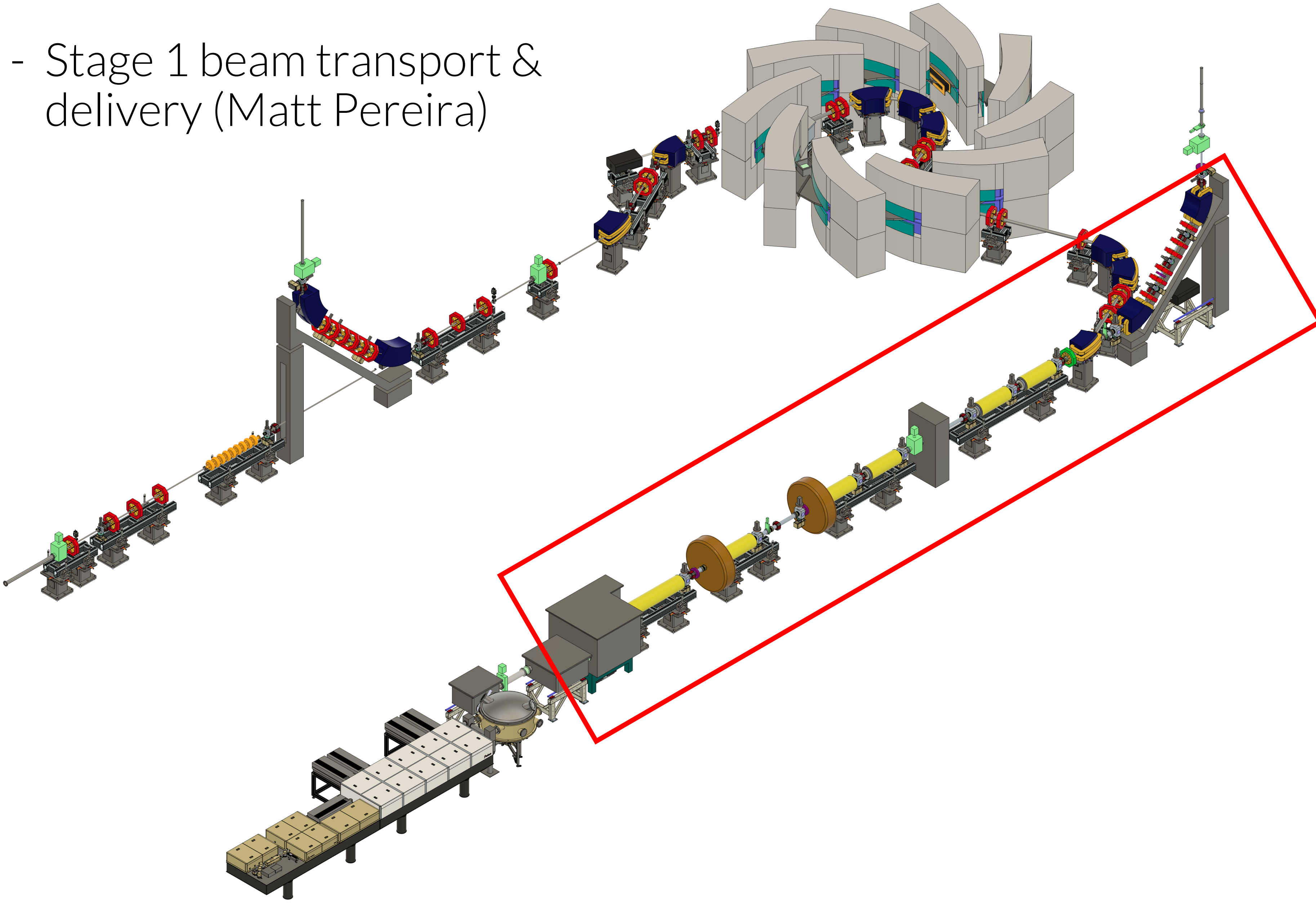
LhARA FFA Magnet



FFA magnet progress
(Ta-Jen Kuo)

LhARA Stage 1

- Stage 1 beam transport & delivery (Matt Pereira)



FFA Review

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FFA Review

MILESTONES

Task Name	Start	Finish	Resource Names
WPA	Tue 01/10/24	Mon 30/06/25	
Task 7	Tue 01/10/24	Fri 30/05/25	J. Parsons
7.1 Develop beamline and bespoke facilities at SCAPA for radiobiology experimentation	Tue 01/10/24	Fri 30/05/25	
7.2 Preliminary radiobiology results at SCAPA	Tue 01/10/24	Fri 30/05/25	
Task 9	Tue 01/10/24	Fri 30/05/25	R. Gray
9.1 Demonstration of beam delivery to end station at SCAPA	Tue 01/10/24	Fri 30/05/25	
Task 4	Mon 30/06/25	Mon 30/06/25	J. Bamber
4.1 Report on Ion Acoustic Results		Mon 30/06/25	
Task 5	Mon 30/06/25	Mon 30/06/25	R. Amos, T. Price
5.1 Deliver PoPLaR end-station	Mon 30/06/25	Mon 30/06/25	
WPB	Tue 01/10/24	Mon 30/06/25	
Task 2	Mon 30/06/25	Mon 30/06/25	
2.1 Assessment of beam performance during PoPLaR experiment on SCAPA	Mon 30/06/25	Mon 30/06/25	
Task 3	Mon 30/06/25	Mon 30/06/25	
3.1 Progress report on increased voltage penning trap simulations and operation	Mon 30/06/25	Mon 30/06/25	
Task 6	Mon 30/06/25	Mon 30/06/25	
6.1 Review of FFA R&D work	Mon 30/06/25	Mon 30/06/25	
WPC	Tue 01/10/24	Mon 30/06/25	
Task 1	Mon 07/04/25	Tue 08/04/25	C. Pugh, C. Whyte
1.1 Initial PoPLaR and LhARA update: Collaboration Meeting	Mon 07/04/25	Tue 08/04/25	
Task 8	Wed 30/04/25	Mon 30/06/25	P. Price
8.1 Peer group meeting		Wed 30/04/25	
8.2 Benefits map for LhARA		Mon 30/06/25	

- FFA Review Meeting February 26th 2025.
- Report complete, awaiting publication on the wiki.

FFA Review

- Talks:
  - FFA Overview (Jaroslaw)
  - Engineering (Clive Hill)
  - Injection Line (Will)
  - FFA Magnet Design (Ta-jen)
  - FETS-FFA Magnet Prototype (Jean-Baptiste Lagrange)
  - Future Direction (Jaroslaw)

- FFA review by Andy Wolski (University of Liverpool)
  - Comments & recommendations.

- Feasibility, strategy, & direction.
  - Identify showstoppers, highlight challenges.

Cost Estimation

1. Cost estimate appears consistent with current design.

- £142M presented (excluding in-vivo costs)
  - £50M building & infrastructure.
  - 10% contingency.

- LhARA's novelty will add uncertainty to cost accuracy.

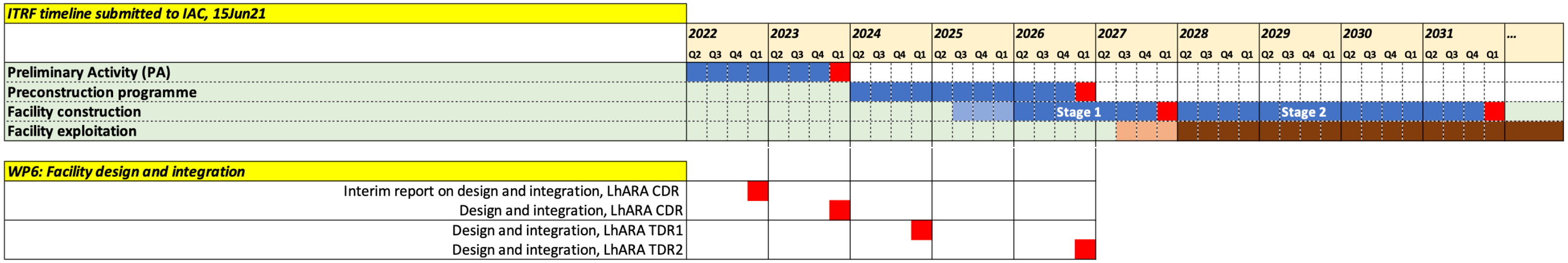
- Topical breakdown of contingency costs recommended
  - Global 10% may be insufficient
  - Contingency can vary significantly from system to system.

Strategy

2. A clear strategy is needed, identifying each design stage with explicit goals.

- Proposed strategy:
  1. **Conceptual design** – demonstrate feasibility in terms of physics
  2. **Technical design** – demonstrate feasibility in terms of technology
  3. **Engineering design** – detailed & complete design to allow final costing

- We currently follow the traditional particle accelerator design strategy:



- An engineering <u>facility</u> design stage could provide:
  - a lighter accelerator technical design programme,
  - time to source dedicated engineering resources,
  - a more timely & accurate cost estimation phase.

Flexibility Needs

3. The strategy must account for the accelerator's flexibility.

- LhARA's science case is strongly dependent on the machine providing flexibility
  - Repetition rate, species, energies, etc.

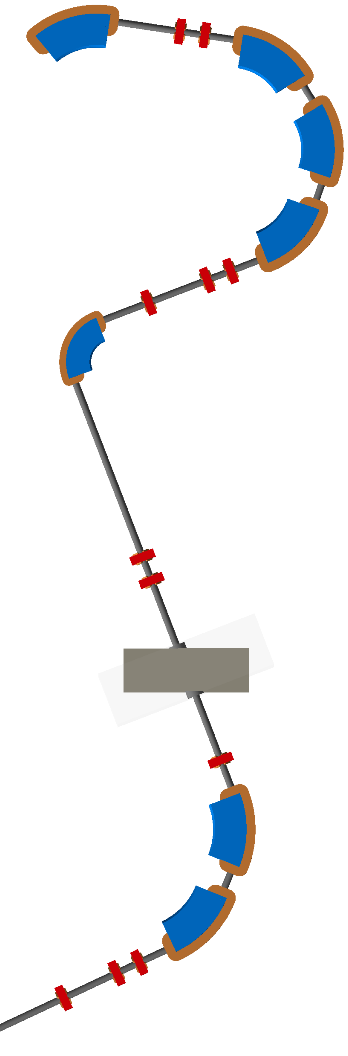
- Be aware of the need for either:
  - **Compromises** in certain areas
  - A **more staged approach** to construction and delivery.

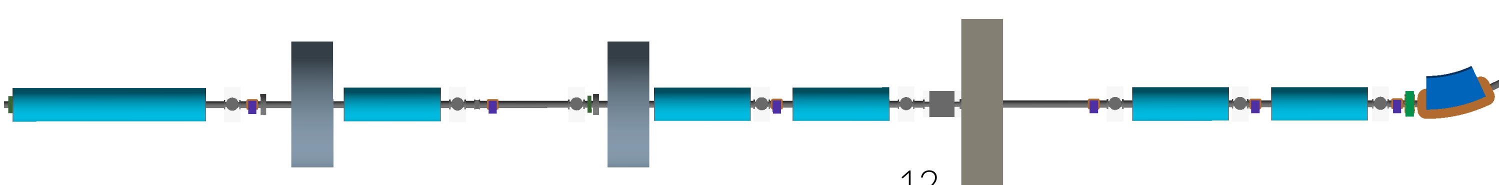
Ongoing Physics Challenges

4. Significant physics questions remain unsolved:
   - Impact of space-charge effects in the injection line
   - Beam properties on injection to the FFA
   - Capture and accelerate ions as well as protons
   - Longitudinal dynamics in the FFA

- A **mature physics design** is needed to fully understand:
  - Stage 1 emittance growth
  - FFA tune variation

- A better understanding of the upstream performance would improve confidence in answering physics challenges.





Simulation Codes

5. Codes used are sufficient, but challenges will be encountered.

- BDSIM, GPT, LhARALinearOptics, BeamOptics, MADX.

MAD-X

- **Noted challenges:**
  - Modelling the Gabor lens
  - Space charge with bunch lengths comparable to beamline components
  - Dispersion in the FFA injection line

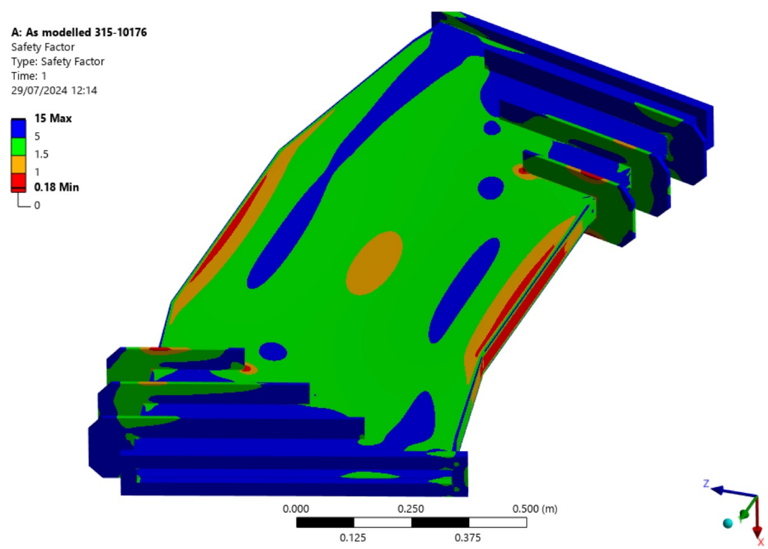
- Alternative & new codes being investigated/considered
  - RF Track, ASTRA, WARPX, TRACEWIN (£££)
    - Cross-consistency study
  - FFA codes: Zgoubi, OPAL, fixedfield.

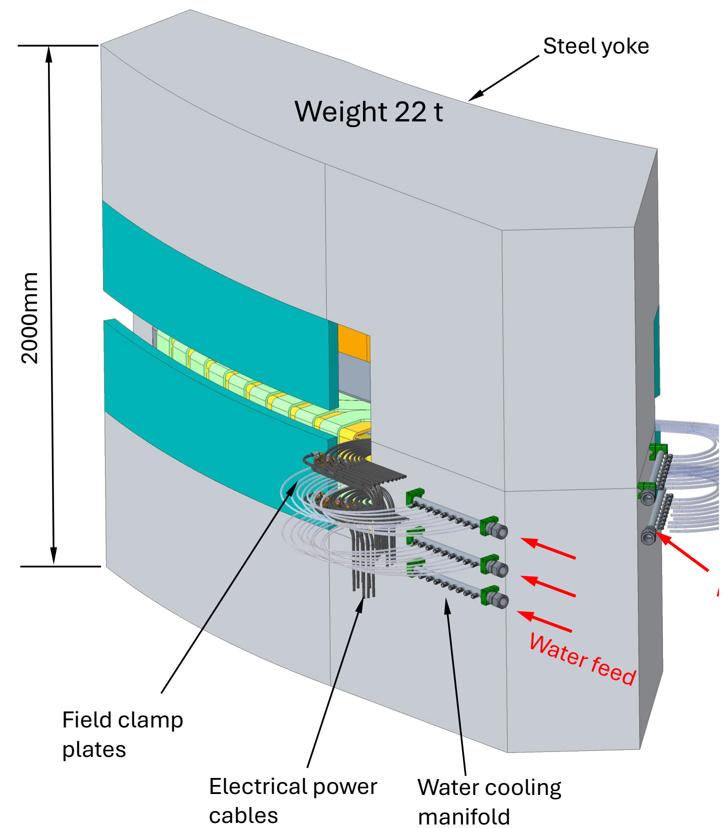
TRACEWIN RF Track ZGOUBI

Engineering

6. Be cautious about premature engineering effort.

- FFA engineering effort focused on the magnet coil assembly & vacuum modelling.
- Necessity for ensuring FFA magnet feasibility
  - Large gap – insufficient field quality, magnet saturation.





Collaborative Opportunities

7. Explore collaborative opportunities.

- Previous studies (RACCAM) recognised as a sensible design upon which to develop the LhARA FFA solution.

- **FETS-FFA** highlighted as a collaborative opportunity that should be explored.
  - Simulation tools & techniques
  - Impact of errors
  - Physics studies

- New LhARA FFA effort (PhD student, TBC)
  - Longitudinal studies, FETS-FFA synergy + expertise.

Technical Challenges (1)

8. Identified topics requiring further work

   a) Exploration of alternative working points for the FFA.

   b) RF system technical design and detailed studies of longitudinal dynamics.

   c) Assessment of the impact of errors and specification of tolerances.

   d) Further investigation of dynamic aperture.

   e) Space charge effects in the later stages of the injection line.

   f) Design of the FFA injection system, including specification of component parameters and positions. Good flexibility is needed to allow for variations in injection conditions.

   g) Beam dynamics and evolution of beam parameters in the injection process (including with space charge).

Space-charge tune shift: $$\Delta Q_{sc} = -\frac{n_t r_p}{2\pi\beta^2\gamma^3\varepsilon}$$

Technical Challenges (2)

8. Identified topics requiring further work:

   h) Modelling of key systems with a range of ion species.

   i) Specification and design of beam diagnostics system:

      a) What diagnostic devices will be required?

      b) Where should they be located?

      c) What level of performance (including, for example, dynamic range) will be needed?

   j) Further development of the FFA magnet design: although the magnet design is relatively advanced, further options and optimisations need to be explored.

   k) Better understanding of the effects of field leakage from the magnets into adjacent RF cavities.

      - Where necessary, effective solutions (e.g. the use of clamp plates) need to be identified.

Iterative FFA Design

9. Design iterations will be needed

- A number of topics are invariably independent:
  - RF system & longitudinal dynamics
  - Tune value & impact of space charge
  - FFA gap & vacuum chamber feasibility
  - ...

- Iterations can be complex & time-consuming, and should be managed to ensure convergence on a reasonable time scale.

Summary

- Positive FFA review.

- Reinforced confidence in strategy and direction.

- Effort is continuing going forward.

Thank you

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