ISIS-II Update

D. W. Posthuma de Boer

On behalf of:
D. J. Adams, H. V. Cavanagh, B. Kyle, H. Rafique, C. M. Warsop, R. E. Williamson,
S. Machida, E. Yamakawa, J. B. Lagrange, D. Kelliher, C. Jolly, J. Pasternak, C. Rogers,
Y. Ishi, T. Uesugi

20th Annual Meeting of the Accelerator Society of Japan

2023-08-30

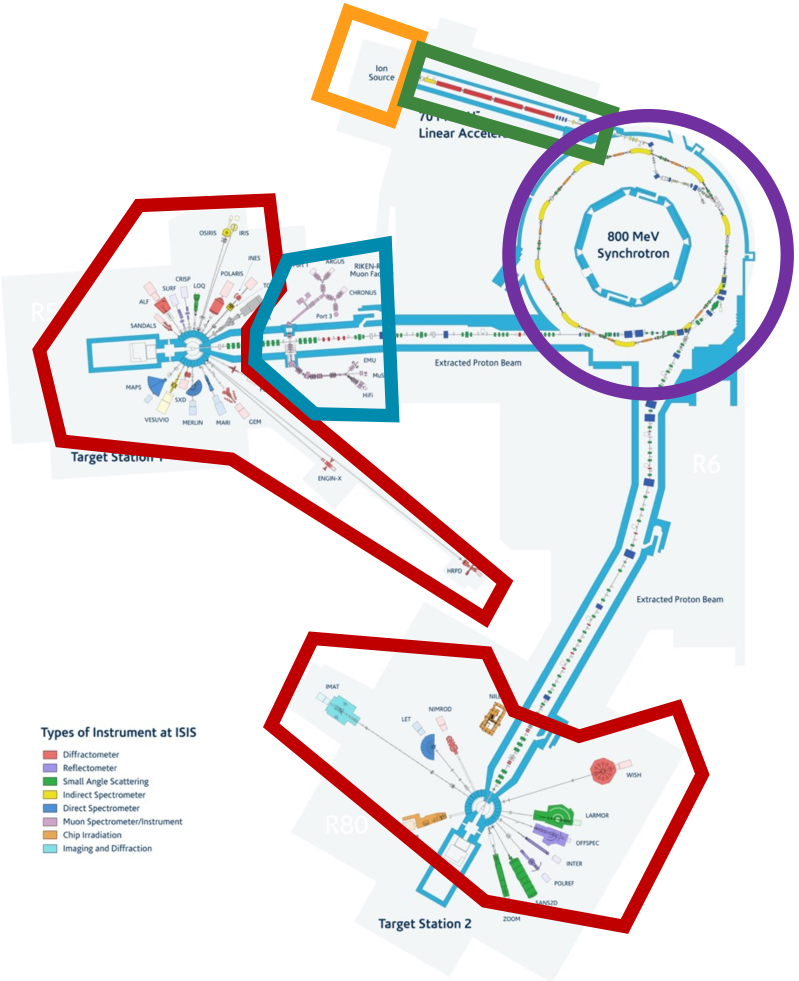
Science and Technology Facilities Council

ISIS Neutron and Muon Source

Contents

ISIS Neutron and Muon Source

- ISIS is a Neutron and Muon source at the Rutherford Appleton Laboratory in the UK [1].
- ISIS started operations in 1985 and continues to produce world-leading science in many fields, such as materials, medicine, magnetism etc.
- The primary constituents are:
  - Penning H- ion source
  - RFQ
  - 70 MeV H- drift-tube linac
  - 800 MeV, 50 Hz rapid cycling proton synchrotron
  - Two, tungsten fixed targets + instruments
  - One, graphite target + instruments



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www.isis.stfc.ac.uk

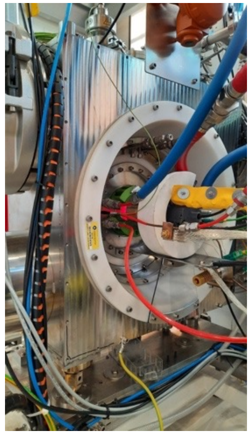
@isisneutronmuon

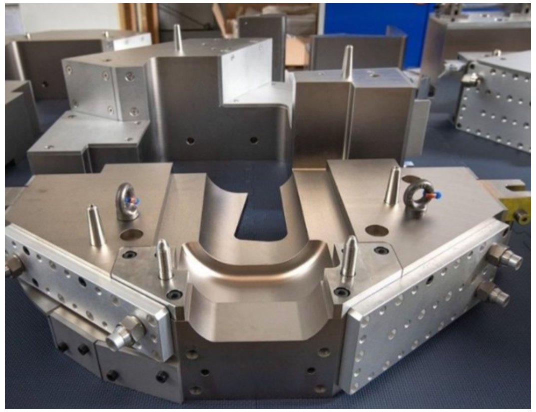
uk.linkedin.com/showcase/isis-neutron-and-muon-source

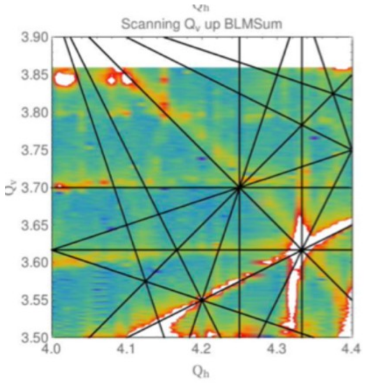
ISIS Today

- Research and development is ongoing

- Some current and recent upgrade projects include:
    - All RF drive systems upgraded, with all parts except cavities being replaced. [2]
    - RF ion source development [4]
    - TS1 upgrade [3]
    - All linac wire scanners upgraded including new control and DAQ systems [5]
    - Linac tank-4 was replaced in 2021
    - Beam dynamics and model development [6]
    - Instrument upgrades







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Neutron Sources in Europe

- Europe is a leader in neutron-based research [7, pp.66].
- The eventual closure of ILL will significantly reduce the number of available instrument-days; even with contribution from ESS.
- Long-term plans are needed for Europe to maintain its leading position.
- For the UK, STFC Strategic Review[8,9] recommendations:
  - *"[…] maintaining and developing ISIS should be the highest priority for the UK and ISIS should continue to be fully supported over at least the next 10 to 15 years."*
  - *"Support continued development of the ISIS II concept."*

[7, pp.75]

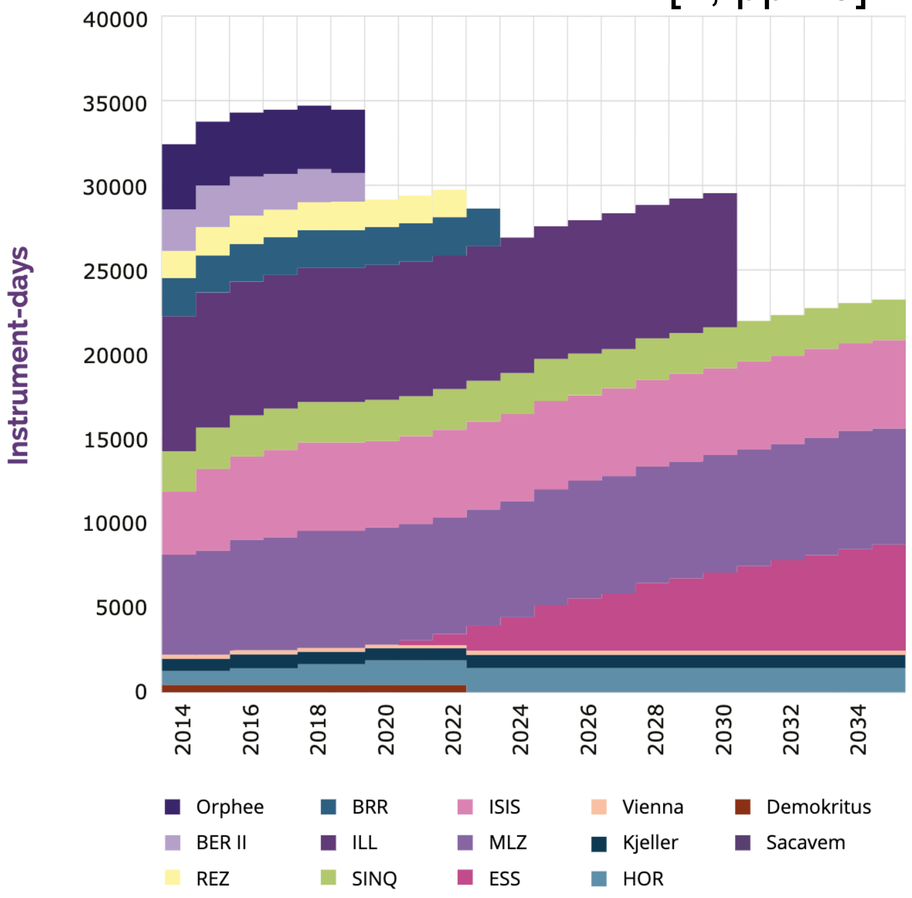

Figure 11. Enhanced Baseline Scenario

The predicted delivery of instrument beam-days in the Enhanced Baseline Scenario: ILL operates until 2030, ESS with 35 instruments beyond 2035.

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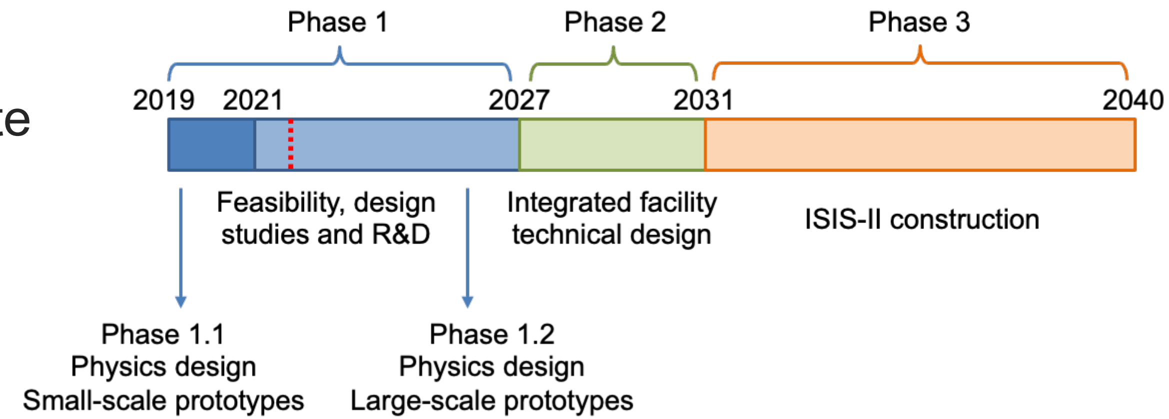
ISIS-II

- ISIS-II is a proposed short-pulsed neutron source to address the gap in instrument day capacity.
- £5.1e6 UKRI infrastructure funding has been allocated for Feasibility, Design Studies and R&D.
- ISIS II Working Group is optimising for neutrons and considering a range of options. Here, I will concentrate on accelerator studies.

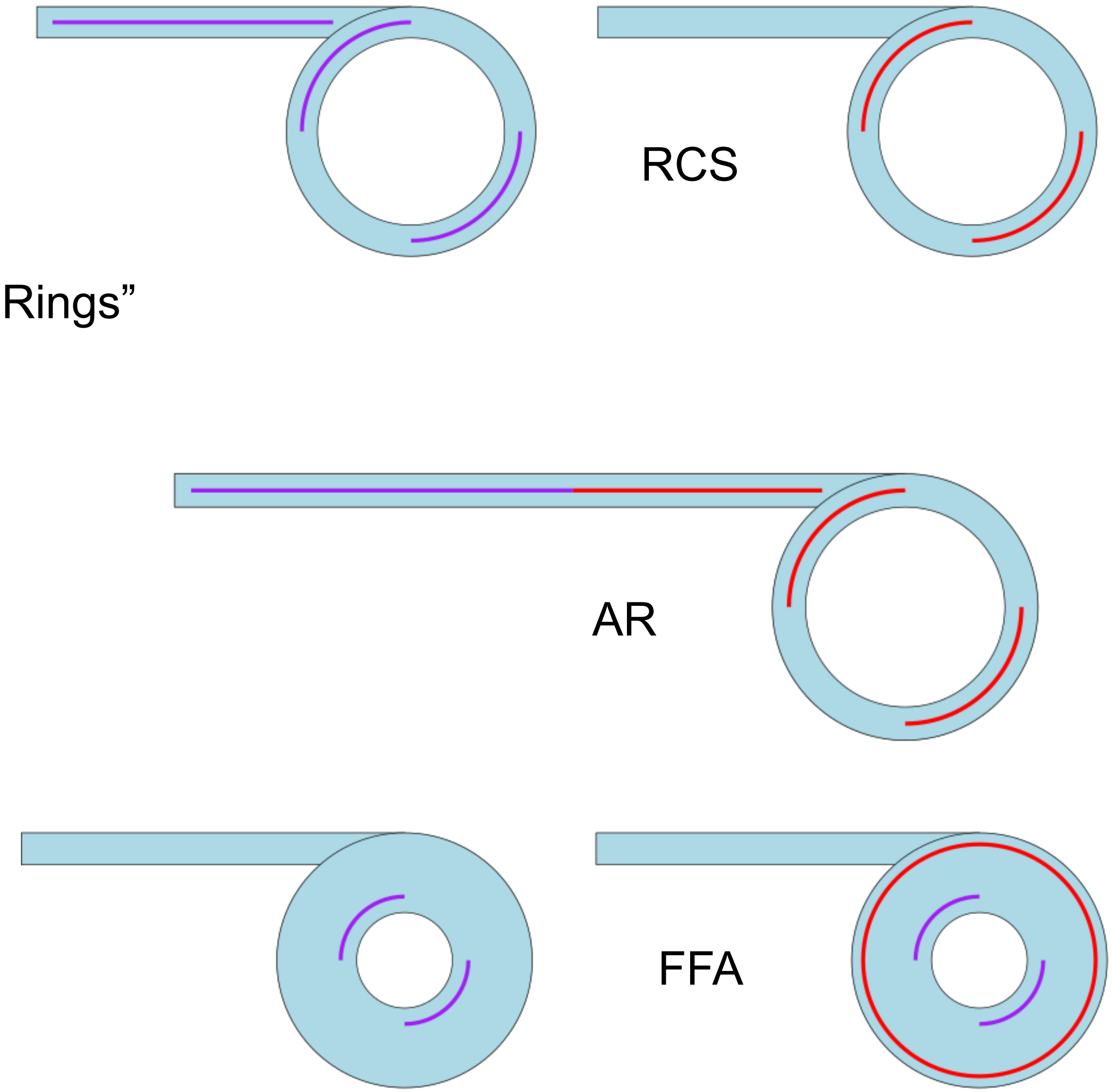


- <u>Headline Specifications (subject to change)</u>
- 1.25-2.50 MW power on-target
- 1.2 GeV beam energy on-target
- 0.1% beam loss during operations
- Environmental impact is fundamental consideration

ISIS-II Accelerator Options

- Machines that could be capable of meeting these requirements are:
  - Rapid Cycling Synchrotron (RCS)
  - Accumulator Ring (AR)
  - Fixed Field Alternating Gradient Acc. (FFA)

} "Conventional Rings" (RCS and AR)

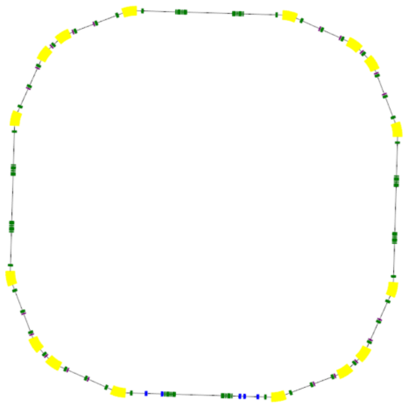


- Two site options
  - Reuse existing ISIS accelerator hall
  - **New accelerator halls**

- Existing RCS and AR designs have demonstrated similar specifications.
- FFA has not yet demonstrated high intensity operation.

Conventional Rings

- Designs are in active development, all numbers subject to change. Lead by D. J. Adams
- RCS design will be influenced by JParc
- AR design will be influenced by SNS
- Achromatic Arc (4x90deg FODO cells)
- Straight: Reverse doublet
- Tune control in straight, 4 trim quads



	RCS	AR
Energy Range	0.4 -1.2 GeV	1.2 GeV
Intensity	1.3e14 ppp	1.3e14 ppp
Repetition Rate	50 Hz	50 Hz
Mean Power	1.25 MW	1.25 MW
Circumference	282 m (45 m)	282 m
No Super Periods	4	4
Magnet Excitation	Sinusoidal	DC
Dipole Fields	0.42-0.84 T	0.84 T
Betatron Tunes (Qx, Qy)	(6.40, 6.32) (±~0.2)	(6.40, 6.32) (±~0.2)
Gamma Transition	5.2	5.2
Peak RF h=(2,4)	(300, 150) kV/turn	(50, 28) kV/turn
RF Frequency (h=2)	1.52-1.91 MHz	1.91 MHz
Number of Bunches	2	2
Acceptance ($\Delta p/p$ ±0.01) (painted, collimator, aperture) (π mm mr)	400, 600, 750	300, 350, 500

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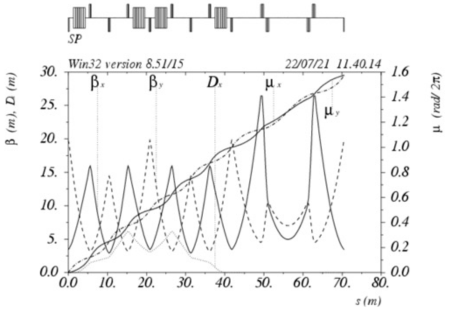
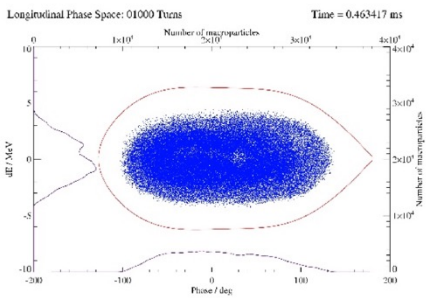
Conventional Ring Development

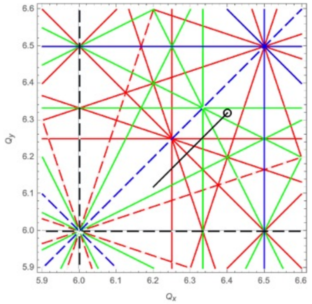
Lattice design
(D. J. Adams)



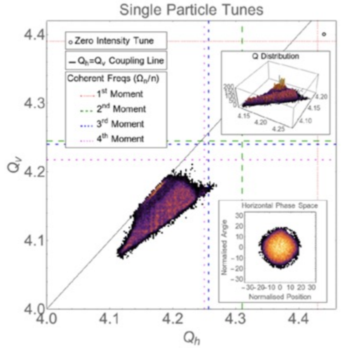
Longitudinal dynamics
(R. E. Williamson)



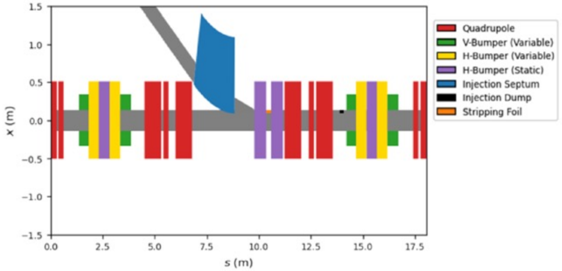
Transverse dynamics
(C. M. Warsop)



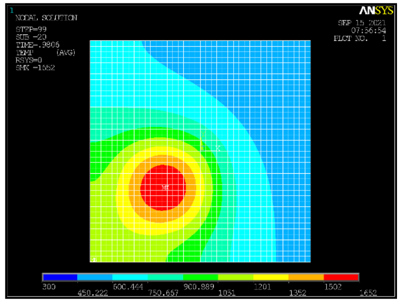
Space charge
(C. M. Warsop)



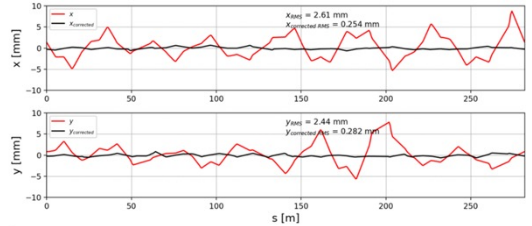
Injection straight design (B. Kyle)



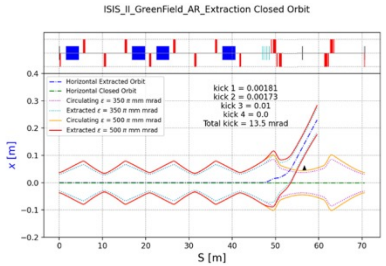
Stripper foil development
(H. V. Cavanagh)



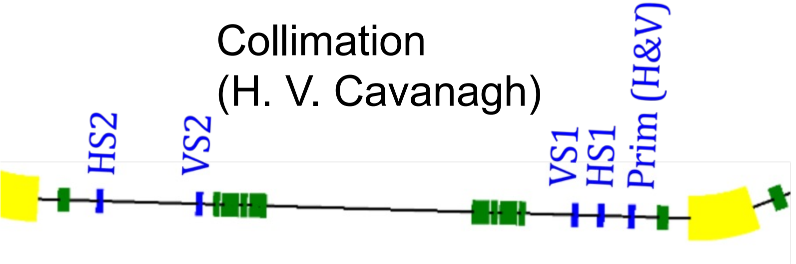
Correction systems
(H. Rafique)



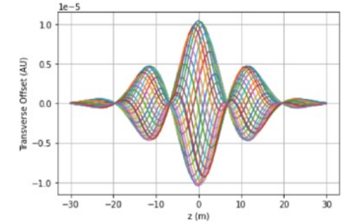
Extraction (H. Rafique)



Collimation
(H. V. Cavanagh)



Instabilities
(R. E. Williamson,
D. W. Posthuma de Boer)



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FFA Option

- Designs in active development. Numbers subject to change. Lead by S. Machida.
- A vertical FFA was considered, but did not fit within project timelines. Horizontal now being designed [10].
- Several potential advantages:
  - Environmental impact may be smaller as DC or even permanent magnets can be used
  - DC Magnets are more reliable than AC magnets
  - Flexible acceleration pattern as magnets not ramped
  - Beam stacking alleviates space charge at injection and allows flexible extract rate.
- It would be the first high intensity FFA and cannot be directly based on any existing accelerator.
- A demonstrator FFA must be built.

	FFA
Energy Range	0.4 -1.2 GeV
Intensity	1.3e14 ppp
Mean Power	1.25 MW
Circumference	~250 m
Magnet Excitation	DC
Acceptance ($\Delta p/p$ ±0.01) (painted, collimator, aperture) (π mm mr)	100, 200, 400

FFA Demonstrator: FETS-FFA

- FETS is a 3 MeV, 60 mA H^- linac at RAL [11]. It will be used as an injector to a demonstrator FFA called the “FETS-FFA”.

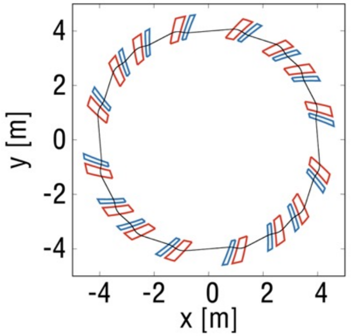
- Several aims for demonstrator:
  - Develop low-loss FFA injection techniques
  - Develop beam stacking techniques
  - Develop recapture and extraction methods
  - Verify low-loss acceleration to top energy
  - Gain experience in FFA design

- Whilst the FETS-FFA is lower power than ISIS-II, its incoherent tune spread will be -0.25; similar to that of ISIS-II [6].

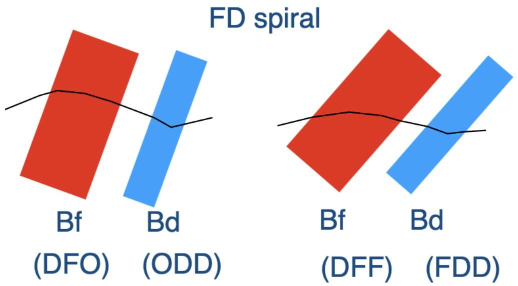
	FETS-FFA
Energy Range	3 -12 MeV
Intensity	3e11 ppp
Repetition Rate	100 Hz
Mean Power (equiv.)	60 W
Mean Orbit Radius	3.6 – 4.2 m
Magnet Excitation	DC
Normalised Acceptance (painted, collimator, aperture) (π mm mr)	10, 20, 40

FETS-FFA Development

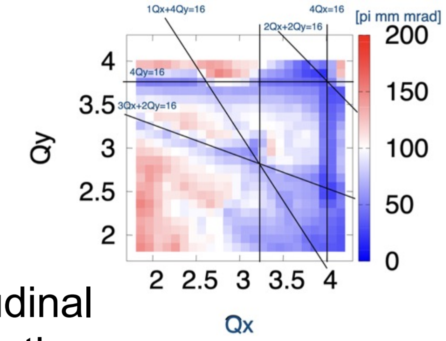
Lattice (S. Machida)



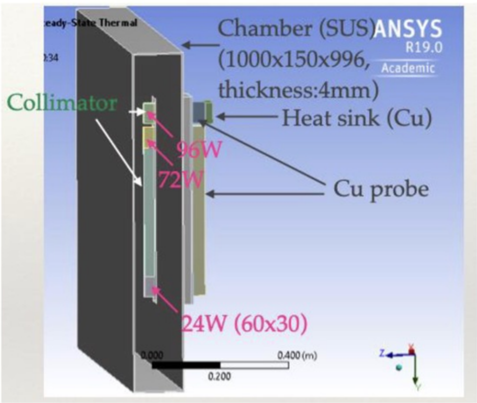
Optics (S. Machida)



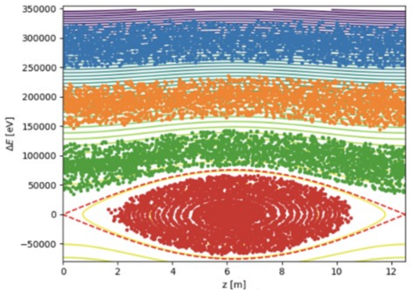
Dynamic aperture study (S. Machida)



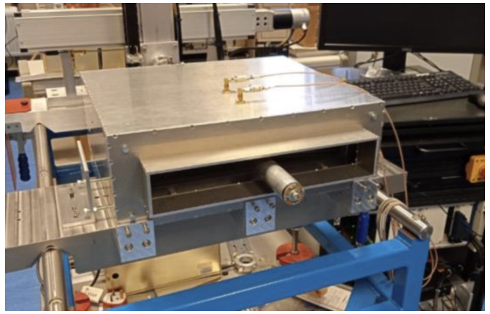
Collimation (E. Yamakawa)



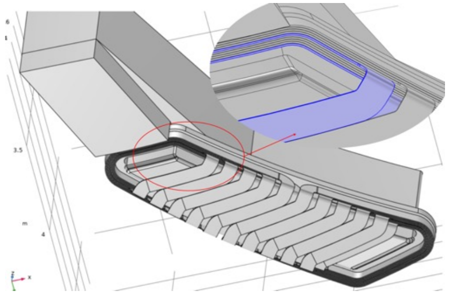
Longitudinal Gymnastics (D. Kelliher)



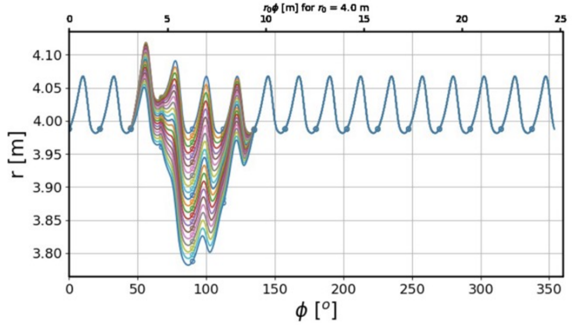
Diagnostics (E. Yamakawa, D. Posthuma de Boer)



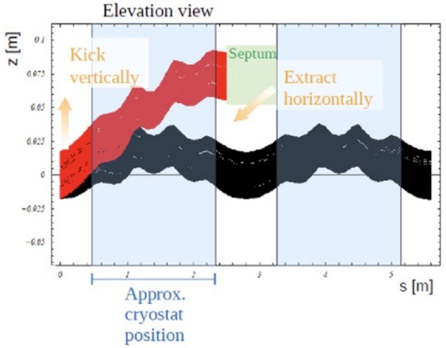
Magnet design (J. B. Lagrange, I. Rodriguez)



Injection (C. Rogers)



Extraction (J. Pasternak)



RF cavity design (I. S. K. Gardner, R. J. Mathieson, B. Kirk)

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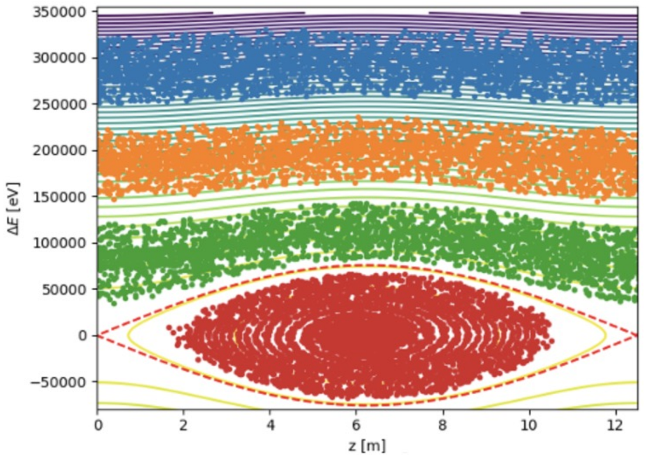
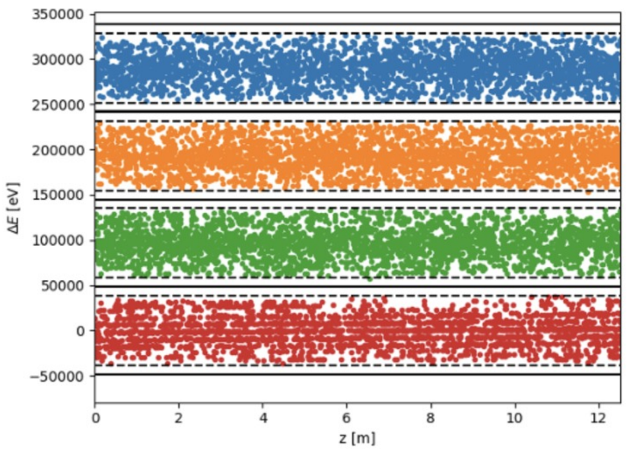
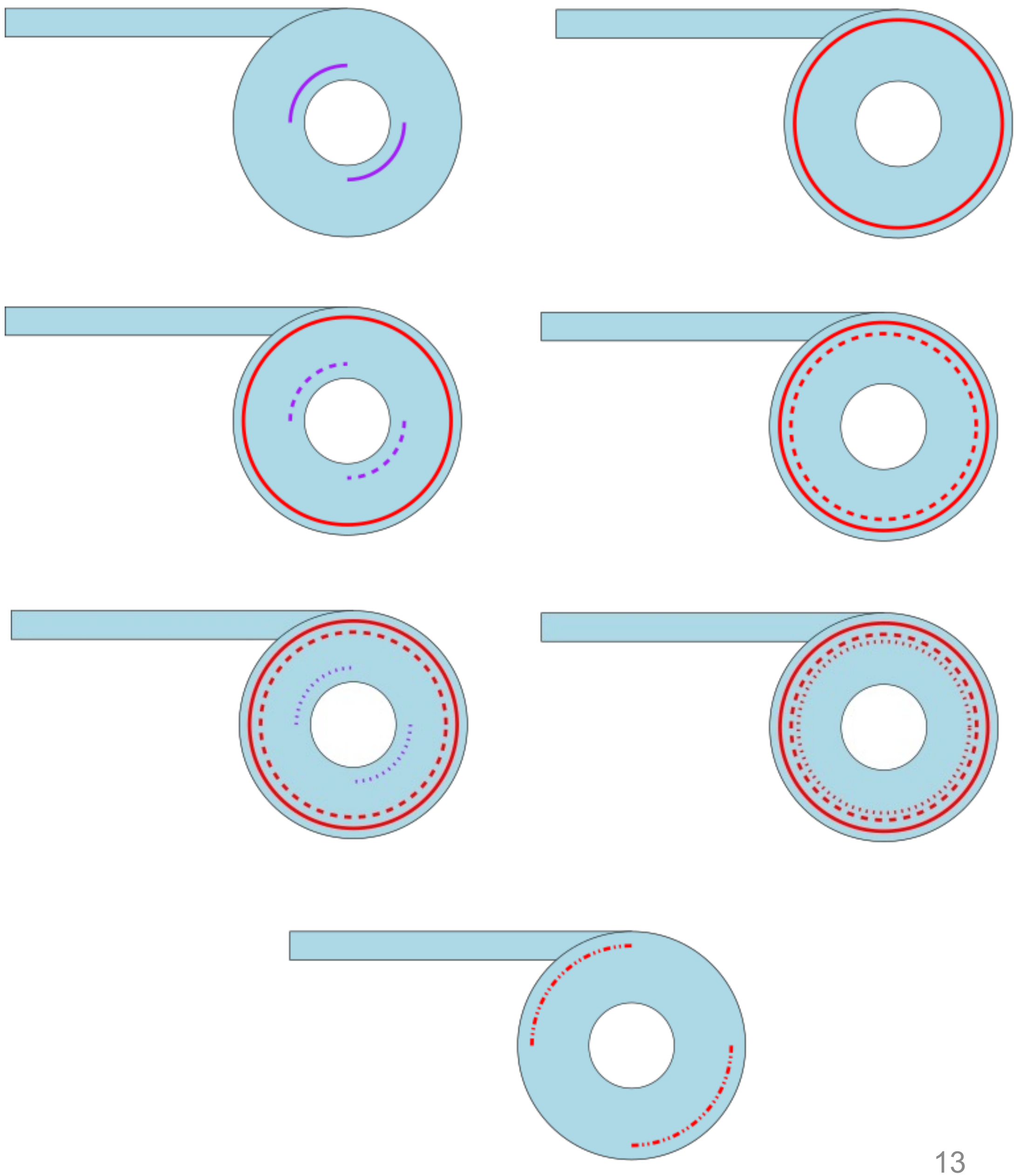
Beam Stacking

- “Beam stacking” is where several lower-charge bunches are combined.
- It allows extracted beam intensity to be varied, and for extraction repetition rate to differ from injection repetition rate.
- Stacking is being considered for AR and FFA options.
- In the FFA, stacking will also alleviate intensity limits imposed by space-charge tune-spread at injection.





Simulation plots from D. Kelliher

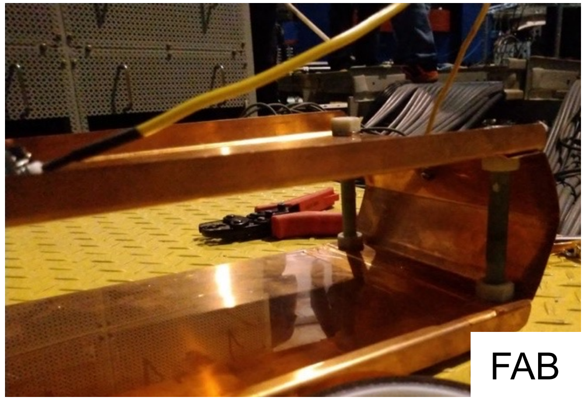


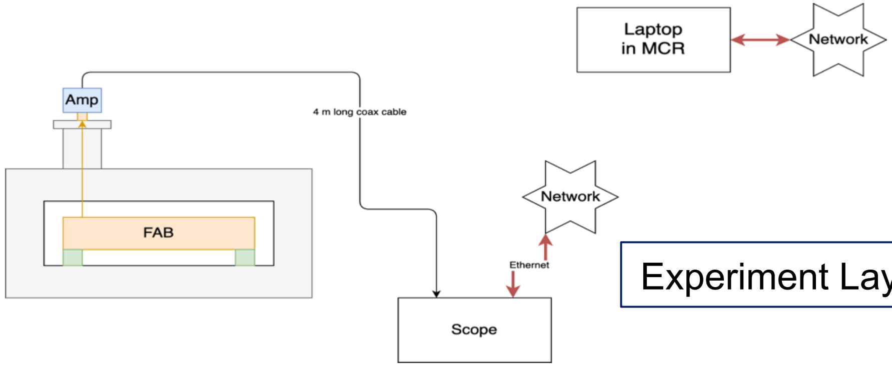
FFA Beam Stacking Experiment

- Experiment to demonstrate momentum stacking in an FFA was performed in March 2023, at the Institute for Integrated Radiation and Nuclear Science at Kyoto University (KURNS) [12].
- Aim was to stack and recapture two bunches.
- Measured incoherent revolution frequency distribution of both coasting beams with Schottky noise.
    - Used electrostatic pickup (Full Aperture Bunch Monitor, "FAB", [12])
    - Remote controlled oscilloscope ~4m from FAB
    - 80MHz low-pass filter, 500 MSa/s
    - 1 MΩ amplifier connected to vacuum feedthrough

	KURNS-FFA Main Ring
Energy Range	11 – 150 MeV
Intensity	1e9 ppp
Mean Current	1 nA
Average orbit radius	4.58 – 5.32 m


KURNS FFA.

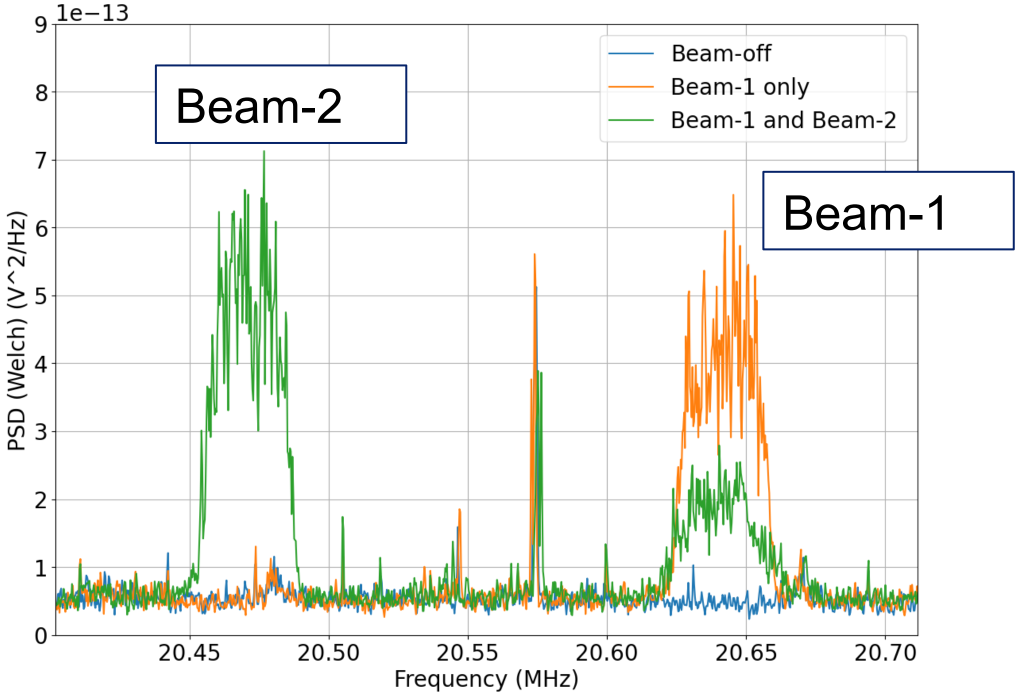

FAB



Experiment Layout

FFA Beam Stacking Results

- With a single injected beam, Schottky revolution harmonics were visible after debunching.
  - Plots shows power spectral density (PSD) around 8th harmonic, estimated with Welch method [13].
- With two injected beams, two revolution harmonics were visible.
  - Beam-1-losses were observed and are currently being investigated.
  - Believe this problem was previously investigated at Midwestern University Research Association (MURA) in the 1950's [14]
- <u>Beam-stacking in an FFA has been demonstrated experimentally at KURNS.</u>



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Conclusion

- To maintain its position as a world leader in neutron science, Europe needs to develop new facilities over the coming decade.
- ISIS-II is a proposed short-pulse neutron science facility, driven by a MW-class accelerator. Designs are currently centred on three types of accelerator: RCS, AR and FFA.
- FETS-FFA will act as a demonstrator for a high-intensity FFA.
- Beam-stacking is being considered for the FFA and AR designs.
- Stacking has been demonstrated experimentally at the KURNS FFA. Beam-1 losses are currently under investigation.
- Development work on conventional rings and the FFA option are ongoing.
- Further updates to be given at HB 2023

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[13] - P. Stoica and R. L. Moses, "Spectral Analysis of Signals", Pearson Prentice Hall, 2005, ISBN: 9780131139565.

[14] - K.M. Terwilliger, ‘Radio frequency knockout of stacked beams’, 1956. https://inspirehep.net/literature/39027

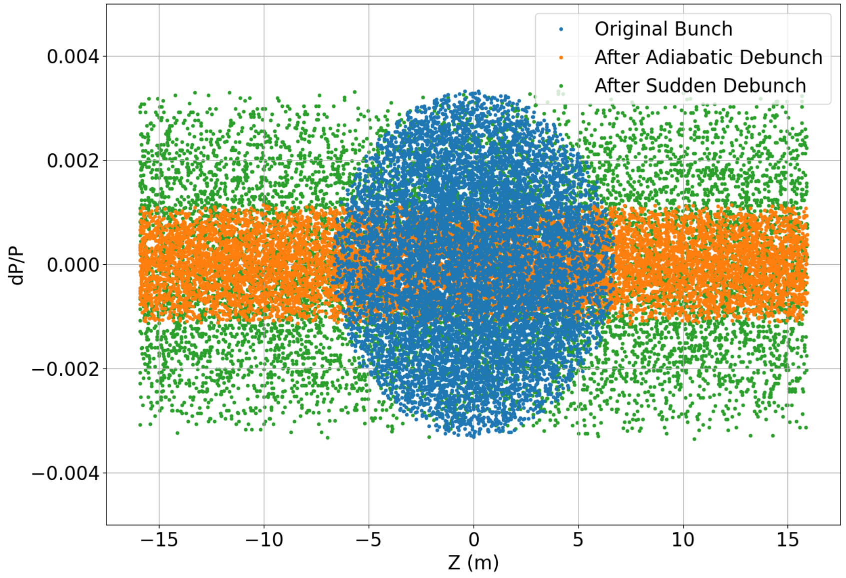
[15] - A.A. Kolomensky and A. N. Lebedev, “Theory of cyclic accelerators”.

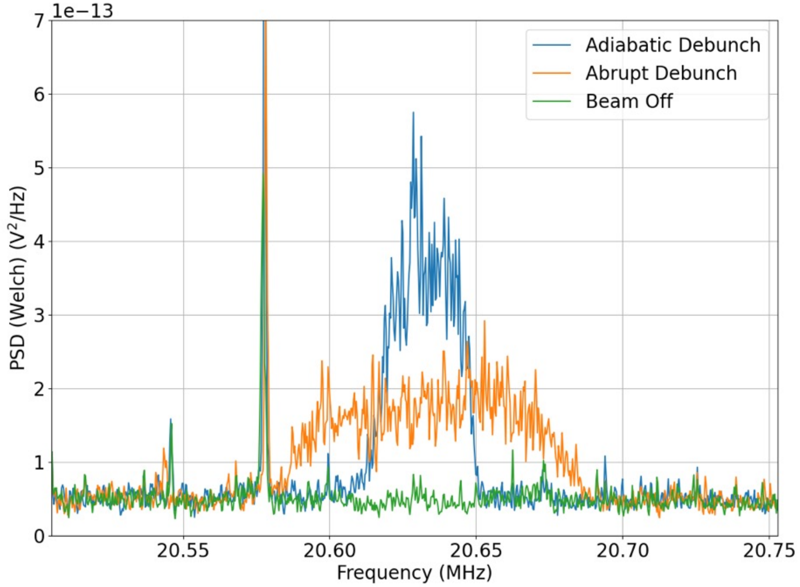
Thank You

Extra Slides

Schottky Signal Verification

- Verified that peak in PSD was a Schottky signal from two measurements with a single injected beam (no stacking).
- In first case, RF amplitude was reduced slowly.
  - Ideally, this conserves phase space area.
- In second case, RF amplitude was suddenly reduced, causing abrupt debunch.
  - Phase space area is not conserved; frequency spread is increased.
- Observed increased peak width when RF amplitude was suddenly reduced.
  - Conclude that this is a Schottky signal.





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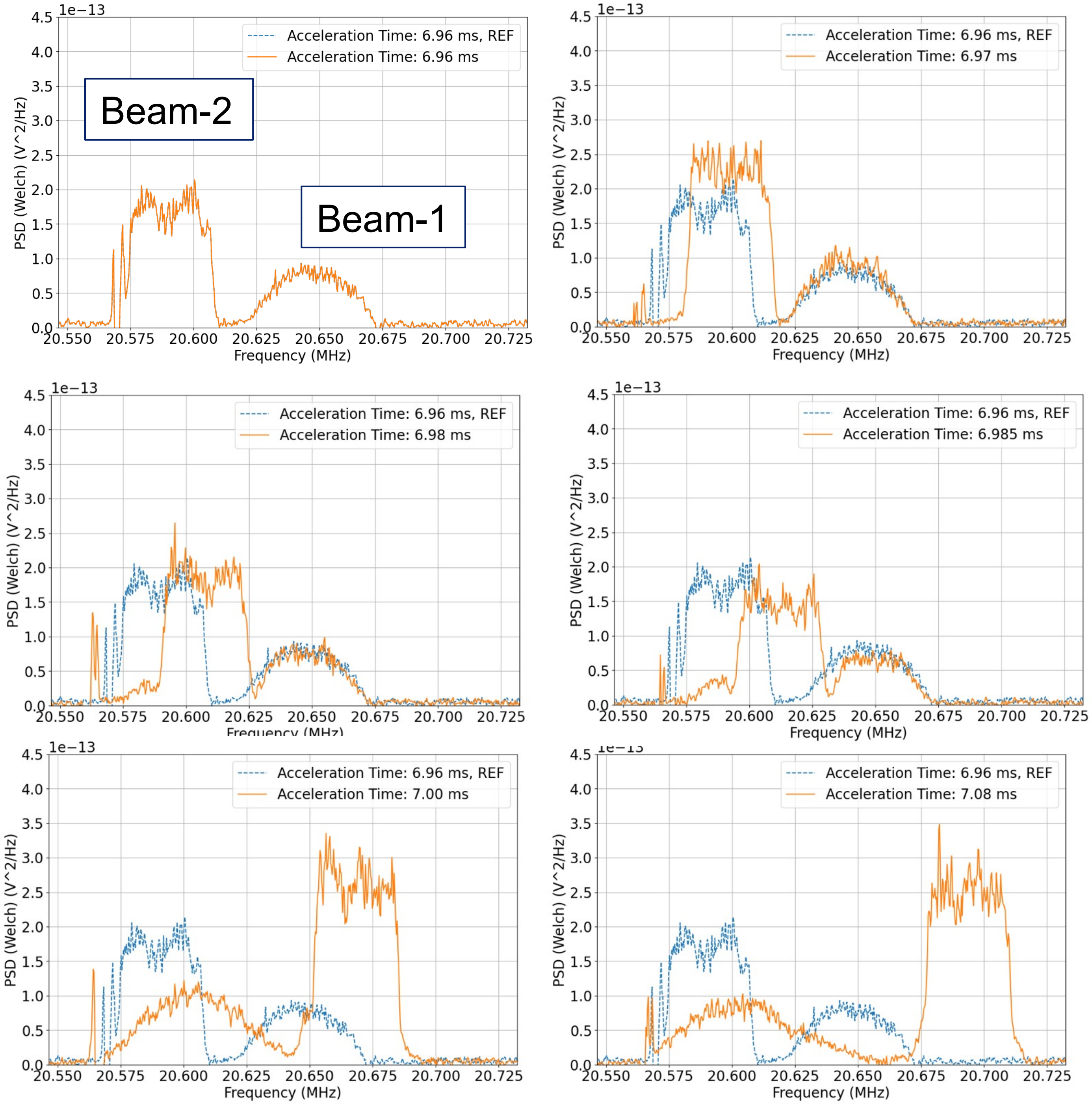
FFA Beam Stacking Control

- Momentum spread after stacking should be minimised to reduce RF voltage required for recapture.
- Optimum acceleration time was found by sweeping beam-2 acceleration time.
- Phase displacement of beam-1 was also observed [15].



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