After ChipIr: ISIS-II & Irradiation

Christopher Frost

GB-RADNEXT Workshop 12-13 June 2024

Science and Technology Facilities Council

ISIS Neutron and Muon Source

ISIS-II

Next generation neutron source with construction 2030's and operation 2040's.

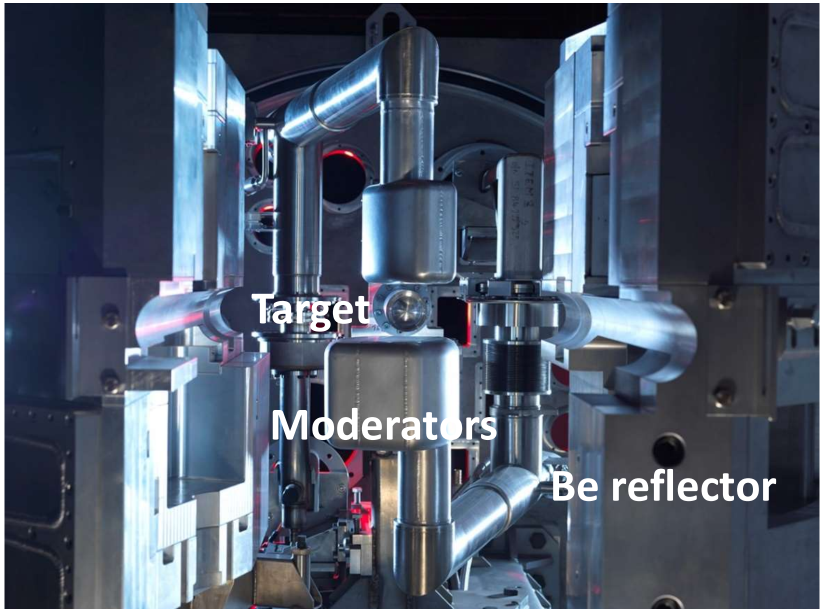
Irradiation Capabilities

ISIS-II provides opportunity to consider UK's and European future irradiation needs

Neutron Irradiation Facilities: ChipIr

In the mid 2000s ISIS developed the idea of creating a new beamline for the accelerated testing of electronics to utilise the fast, high energy neutrons that had not yet been exploited at this kind of generalised neutron sources

Simple idea: extract a high intensity, fast neutron beam to mimic the atmospheric cosmic rays neutron spectrum



‘**Moderators**’ and **Beryllium ‘reflector’** are used to optimise high fluxes of **thermal neutrons** for condensed matter studies.

Problem: target complex optimised for **thermal neutron** beamlines; no ‘good’ direct view of target

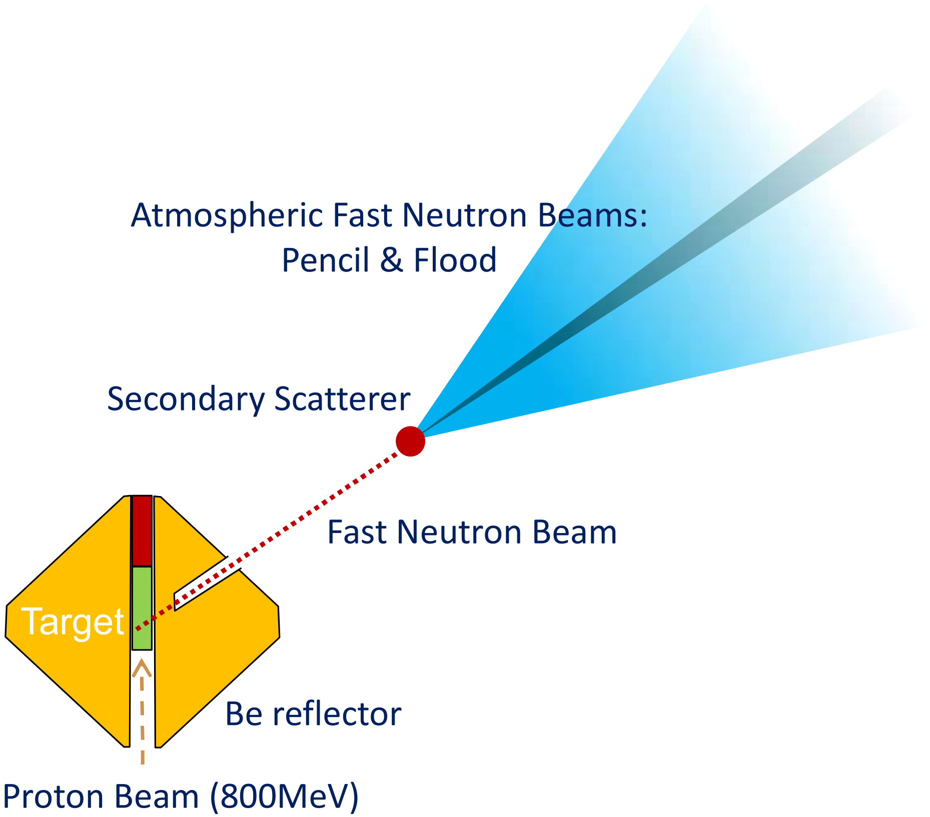
New Approach Needed at ISIS

Neutron Irradiation Facilities: ChipIr

Uses fast neutron flux from ISIS source in two stage process

Quite a simple concept:-

- Create hardened spectrum from Target/Moderator/Reflection
- Illuminate secondary scatterer to produce beams



Atmospheric Fast Neutron Beams:
Pencil & Flood

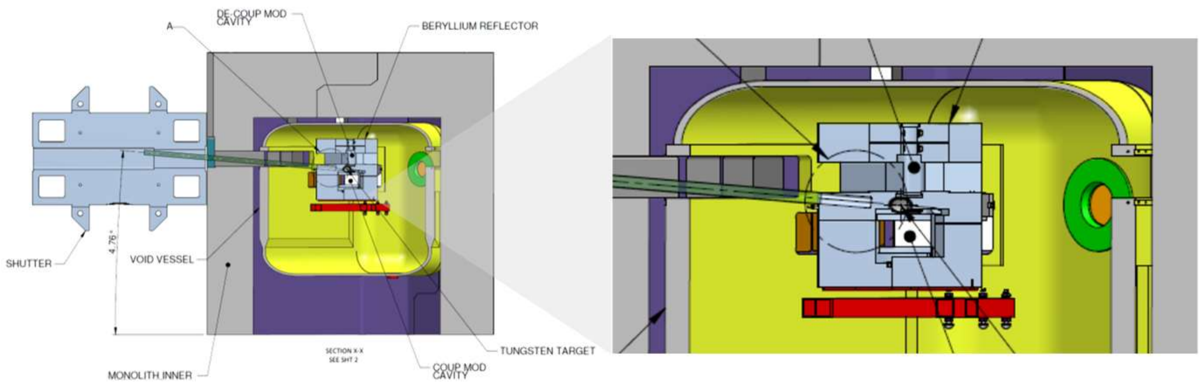
Secondary Scatterer

Fast Neutron Beam

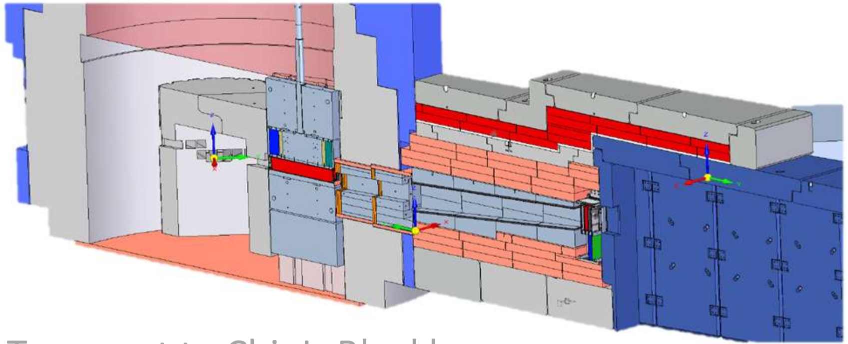
Target

Be reflector

Proton Beam (800MeV)



Fast Neutrons from Target 2



Transport to ChipIr Blockhouse

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Neutron Irradiation Facilities: ChipIr

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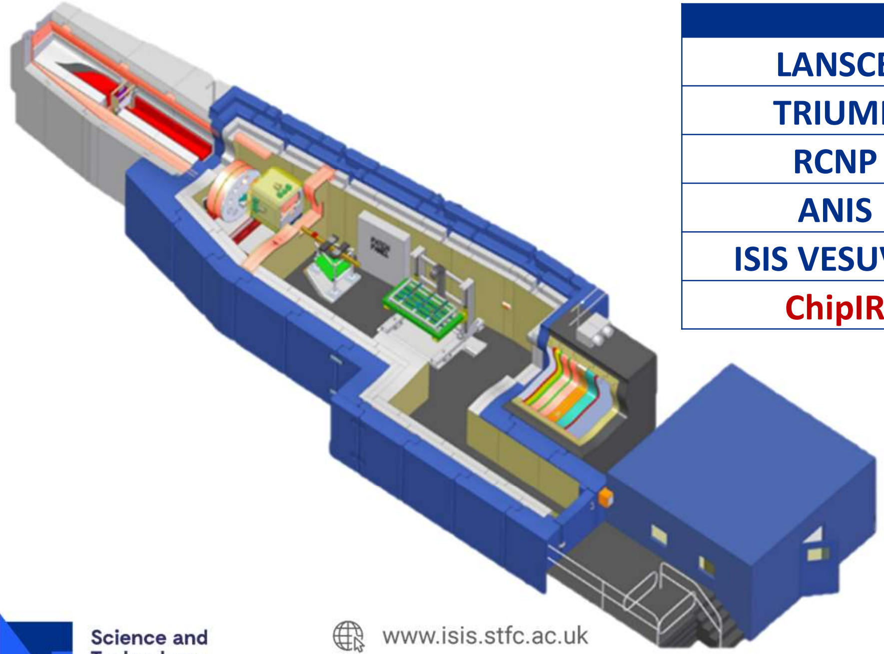
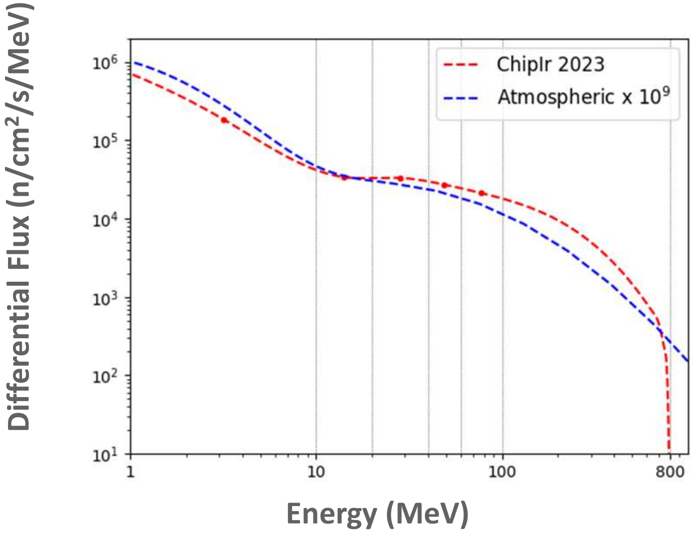


	Flux ($cm^{-2}\ s^{-1}$) >10MeV
LANSCE	1-2x10^6
TRIUMF	6x10^6
RCNP	7x10^5
ANIS	10^7
ISIS VESUVIO	5.8x10^4
ChipIR	5.4 x10^6

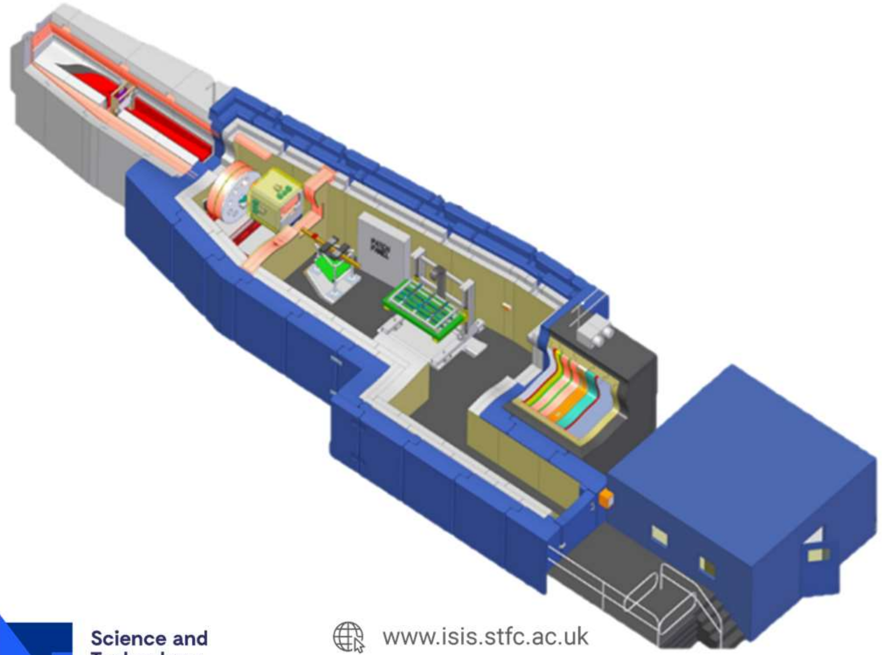


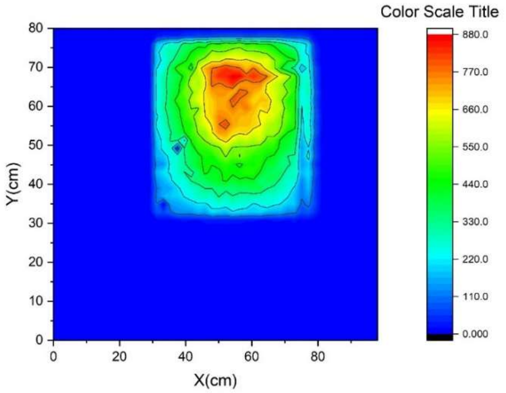
Neutron Irradiation Facilities: ChipIr

Created highly capable irradiation facility

BUT ‘retro-fit’ forced compromise in the design:-

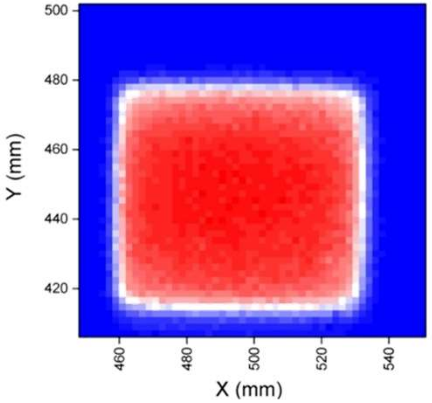
- Angled beam is not ideal
- Collimation more difficult (space and angle)



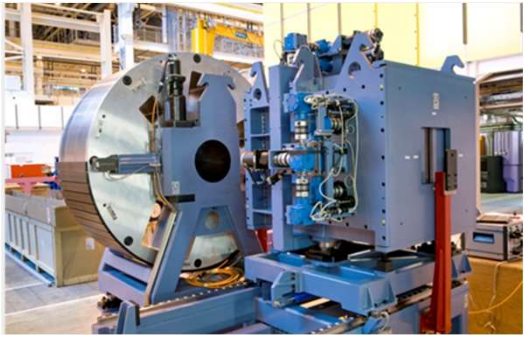


800MeV, largest collimation setting with no jaws

Intensity Maps of ChipIr beam

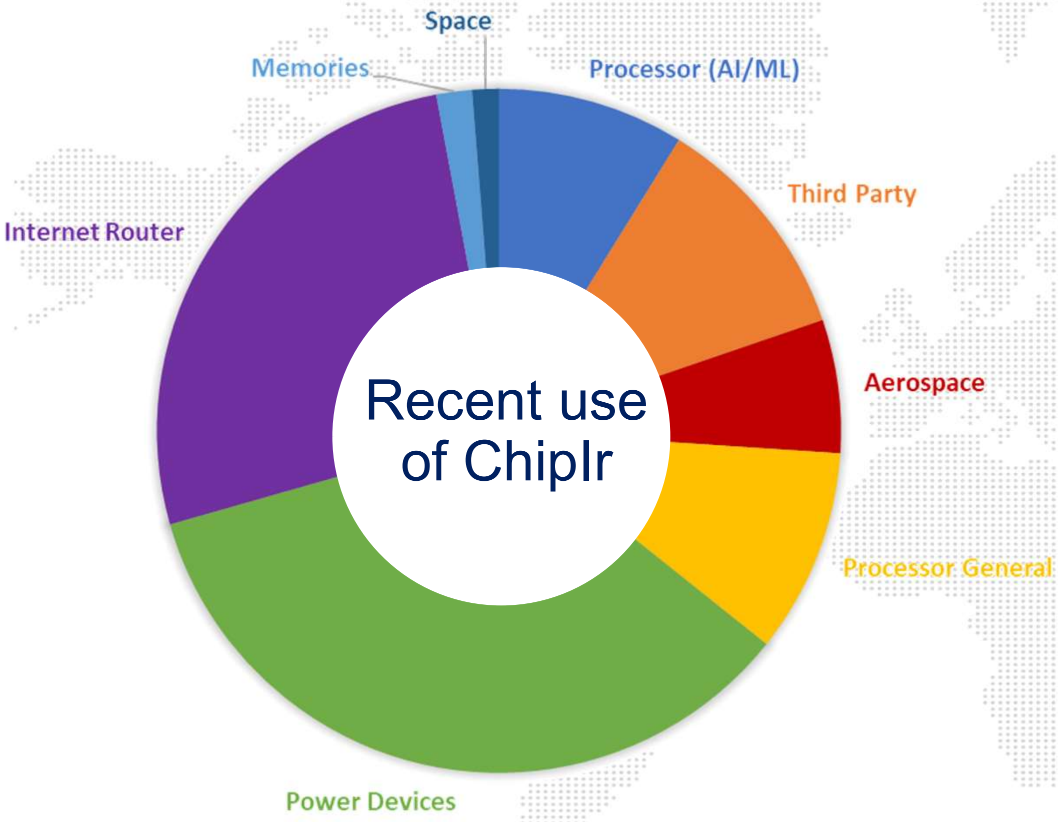


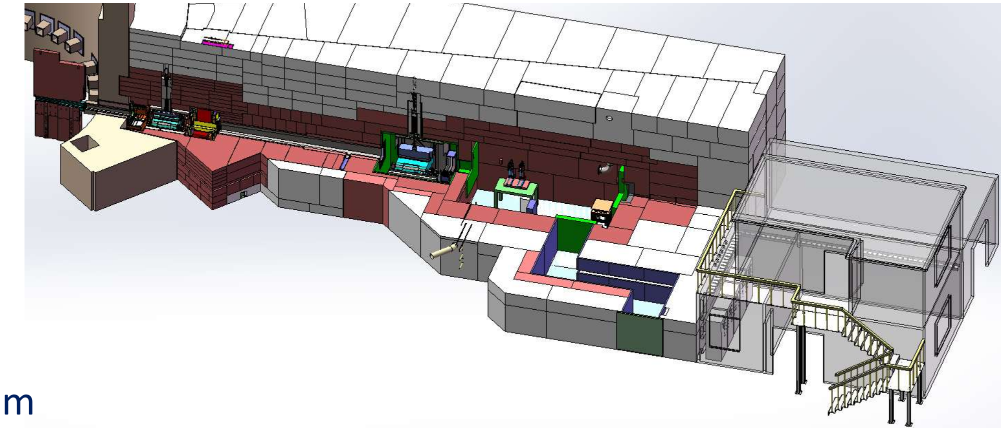
Typically Collimated beam (70mmx60mm)



Neutron Irradiation Facilities: ChipIr

Created highly capable irradiation facility



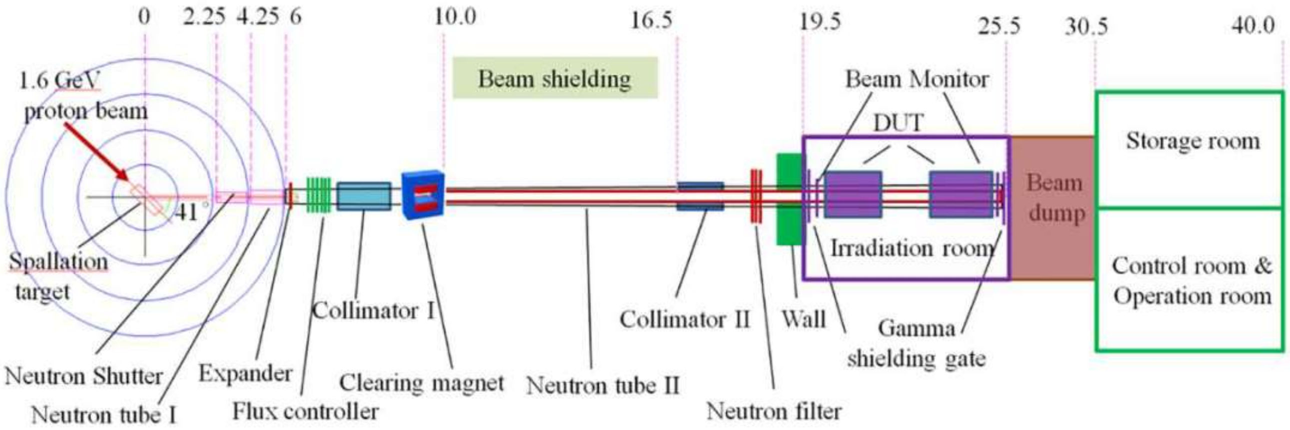


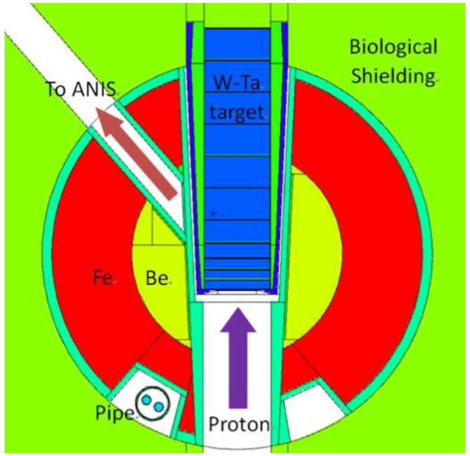
Neutron Irradiation Facilities: ANIS@CSNS

Second iteration of this type of design

Also quite a simple concept:-

- Create hardened spectrum from Target/Moderator/Reflection
- Deliver this to blockhouse with ‘optical’ components shaping beam





Talk later in session….

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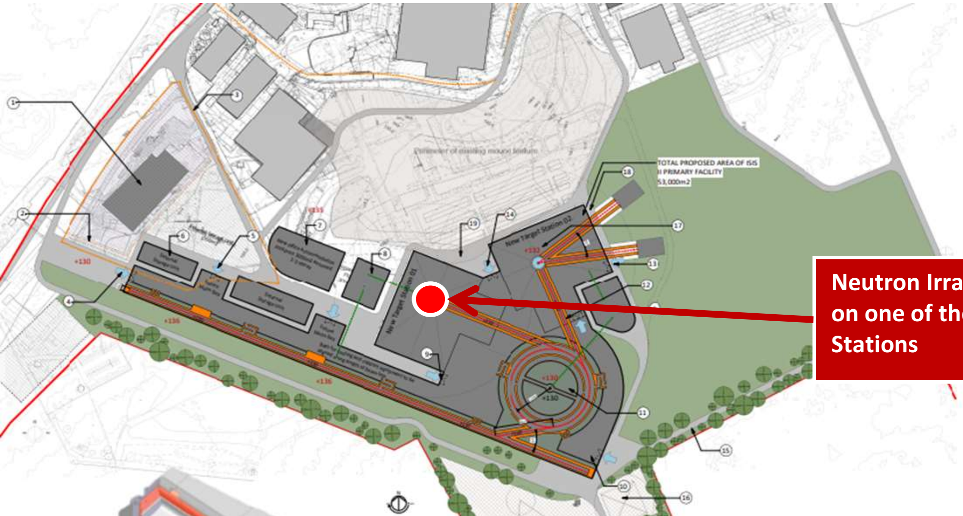
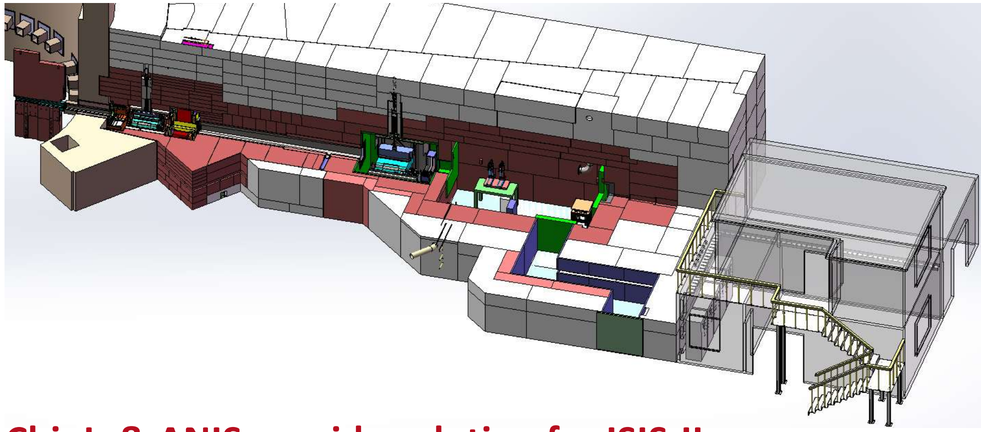


Scenario I

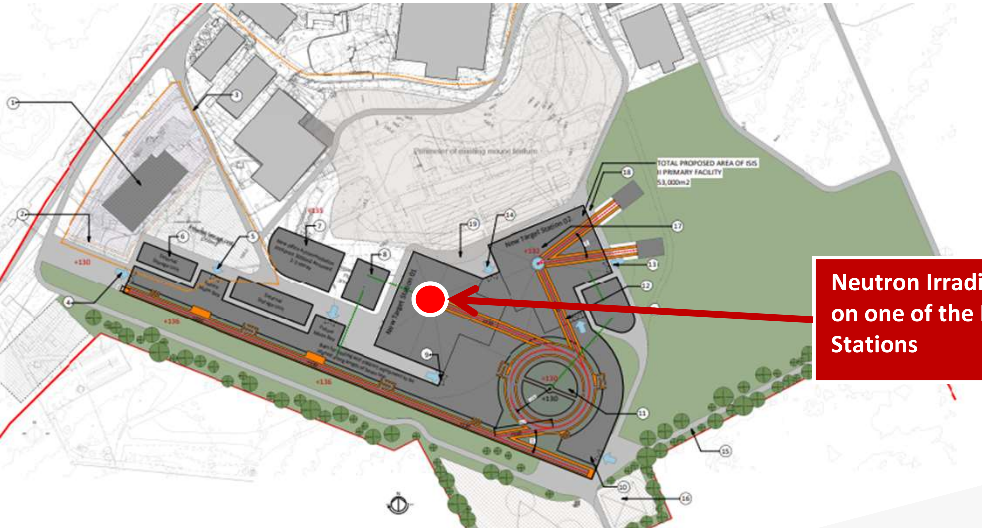
Neutron Irradiation Beamline on one of the ISIS-II Target Stations



ChipIr & ANIS provide solution for ISIS-II

For discussion

Proton Driver Energy	>500MeV
Proton Beam Delivery	individual proton pulses to generate neutron intensity in test position no greater than current ISIS TS2 ($2.8x10^5$ neutrons per pulse) >= 10Hz frequency (i.e.no worse than current TS2)
Target	W-Ta (static, solid target)
Neutron Intensity & Control	$>10^6$ n/cm2/s integrate above 10MeV at instrument distance ability to control intensity by factor 100
Neutron Spectrum	Atmospheric (matching JEDEC89, IEC)
Fast Neutron Channel in Reflector	Forward direction and horizonal with direct view of target from instrument



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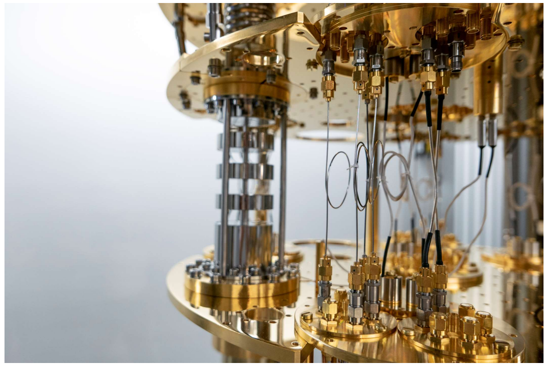

Image Oxford University

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Cosmic rays may soor

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Jennifer Chu | MIT News Office
August 26, 2020

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physicsworld

QUANTUM COMPUTING RESEARCH UPDATE

Cosmic-ray threat to quantum computing greater than previously thought

28 Jul 2021 Margaret Harris

Quantum computers may need a redesign to p

Article

Impact of ionizing radiation on superconducting qubit coherence

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☐ Check for updates

Antti P. Vepsäläinen, Amir H. Karamlou, John L. Orrell, Akshunna S. Dogra, Ben Loer, Francisca Vasconcelos, David K. Kim, Alexander J. Melville, Bethany M. Niedzielski, Jonilyn L. Yoder, Simon Gustavsson, Joseph A. Formaggio, Brent A. VanDevender & William D. Oliver

Technologies that rely on quantum bits (qubits) require long coherence times and
high-fidelity operations[1]. Superconducting qubits are one of the leading platforms for
achieving these objectives[2,3]. However, the coherence of superconducting qubits is
affected by the breaking of Cooper pairs of electrons[4-6]. The experimentally observed
density of the broken Cooper pairs, referred to as quasiparticles, is orders of
magnitude higher than the value predicted at equilibrium by the Bardeen–Cooper–
Schrieffer theory of superconductivity[7-9]. Previous work[10-12] has shown that infrared
photons considerably increase the quasiparticle density, yet even in the best-isolated
systems, it remains much higher[10] than expected, suggesting that another generation
mechanism exists[13]. Here we provide evidence that ionizing radiation from
environmental radioactive materials and cosmic rays contributes to this observed
difference. The effect of ionizing radiation leads to an elevated quasiparticle density,
which we predict would ultimately limit the coherence times of superconducting
qubits of the type measured here to milliseconds. We further demonstrate that
radiation shielding reduces the flux of ionizing radiation and thereby increases the
energy-relaxation time. Albeit a small effect for today's qubits, reducing or mitigating
the impact of ionizing radiation will be critical for realizing fault-tolerant
superconducting quantum computers.

Nature | Vol 584 | 27 August 2020 | 551

New Scientist

Quantum computers may be destroyed by high-energy particles from space

26 August 2020

at IBM

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physicsworld

QUANTUM COMPUTING RESEARCH UPDATE

Quantum computers may be heading underground to shield from cosmic rays

Meet Future Challenges

Example: Recent Papers in Nature and Nature Physics show cosmic rays are potentially interfering with quantum computers

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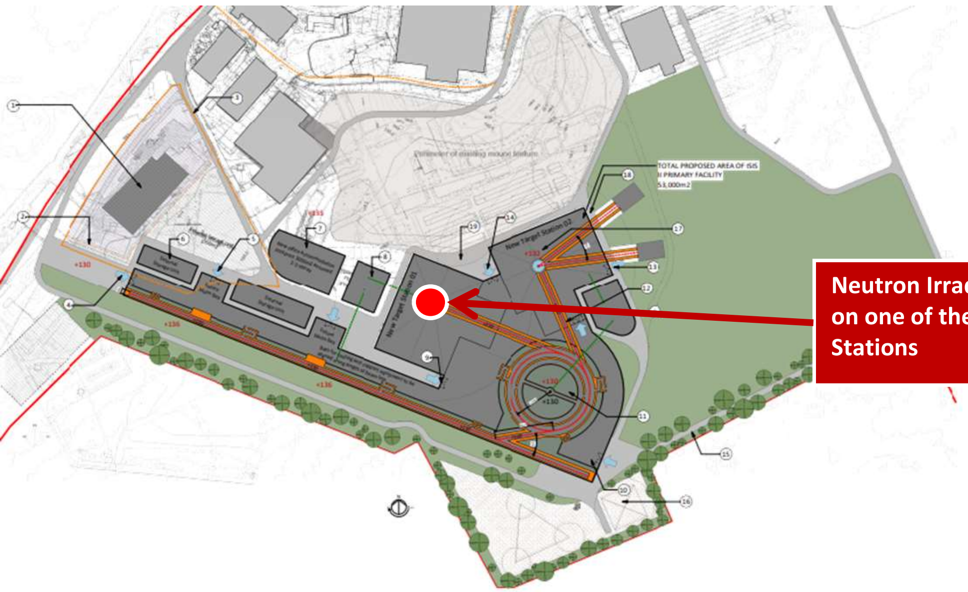
McEwen, M., Faoro, L., Arya, K. *et al.* . *Nat. Phys.* **18**, 107–111 (2022).

Vepsäläinen, A.P., Karamlou, A.H., Orrell, J.L. *et al.* . *Nature* **584**, 551–556 (2020).

Scenario I



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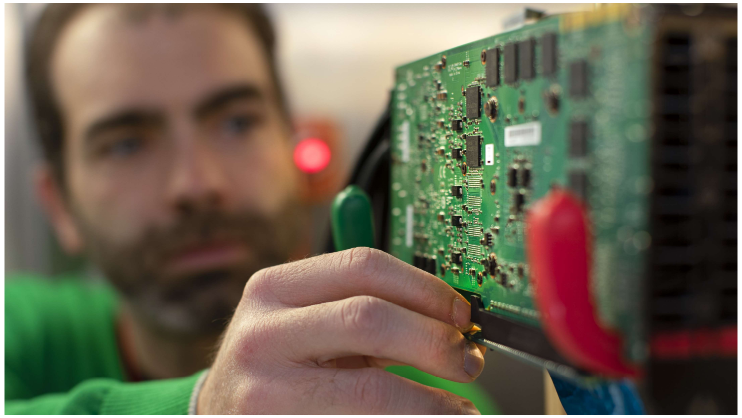
Neutron Irradiation Beamline on one of the ISIS-II Target Stations



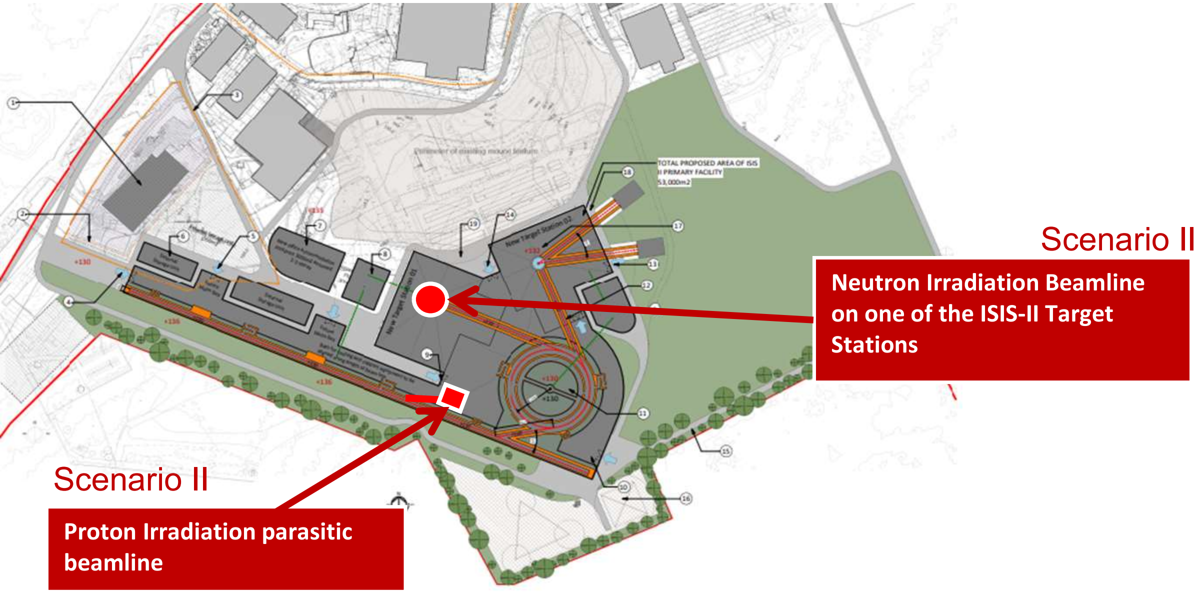
	Advantage	Disadvantage
Neutrons	- design technically possible - clear improvement on ChipIr - lowest total cost (typical instrument cost)	- more complex design (as part of target/reflector design)

Development Level: LOW

Delivers:

- Basic requirement by (neutron) irradiation community
- Continuity of provision if ‘Day One’ instrument

Scenario II



Scenario II

Neutron Irradiation Beamline on one of the ISIS-II Target Stations

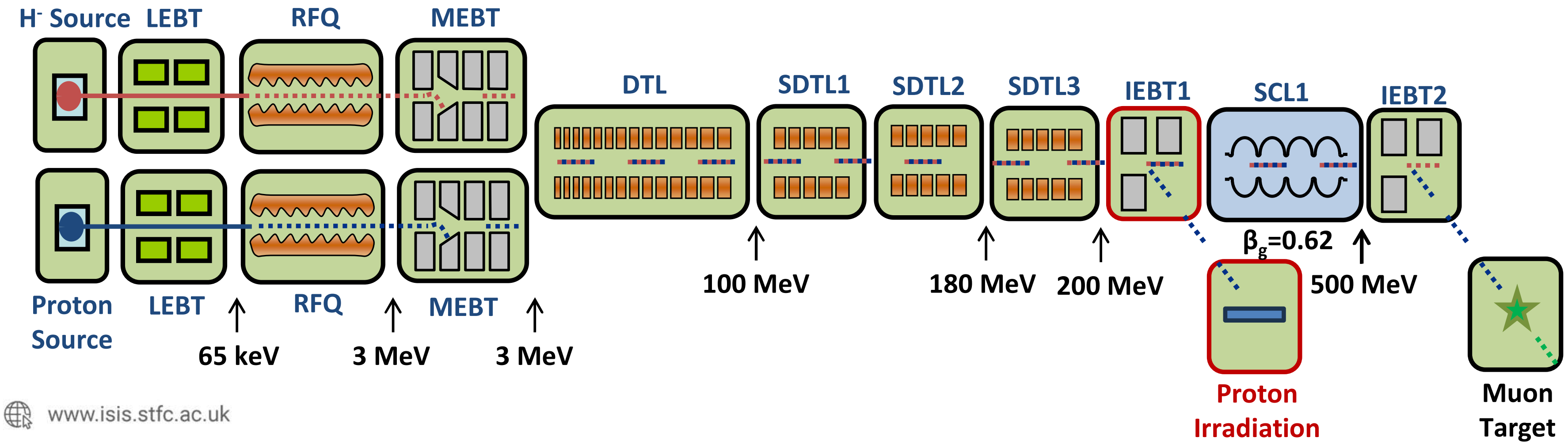
Scenario II

Proton Irradiation parasitic beamline

Extension of Scenario I

Add Parasitic 200MeV Proton Beamline

Extract protons at 200MeV point possibly driven by a proton pulse train interleaved with the H^- pulse train



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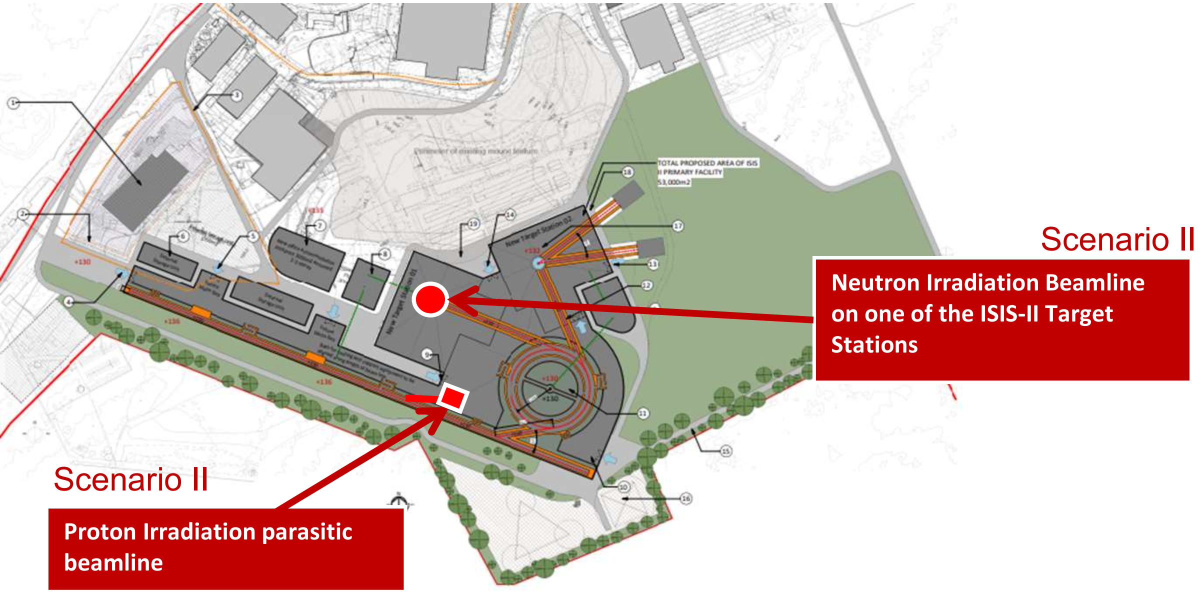


Scenario II

Neutron Irradiation Beamline on one of the ISIS-II Target Stations

Scenario II

Proton Irradiation parasitic beamline

For discussion

Proton Energy	125MeV to >200MeV
Beam Characteristics	Quasi-Continuous/Long pulse preferred to short bright pulses to reduce peak intensity
Flux	10^7- 10^9 p/cm^2/s
Typical test fluence	10^9-10^{11} p/cm2 (hours to days)
Beam size	Variable 1x1cm^2 to 15x15cm^2
Beam uniformity	>80%

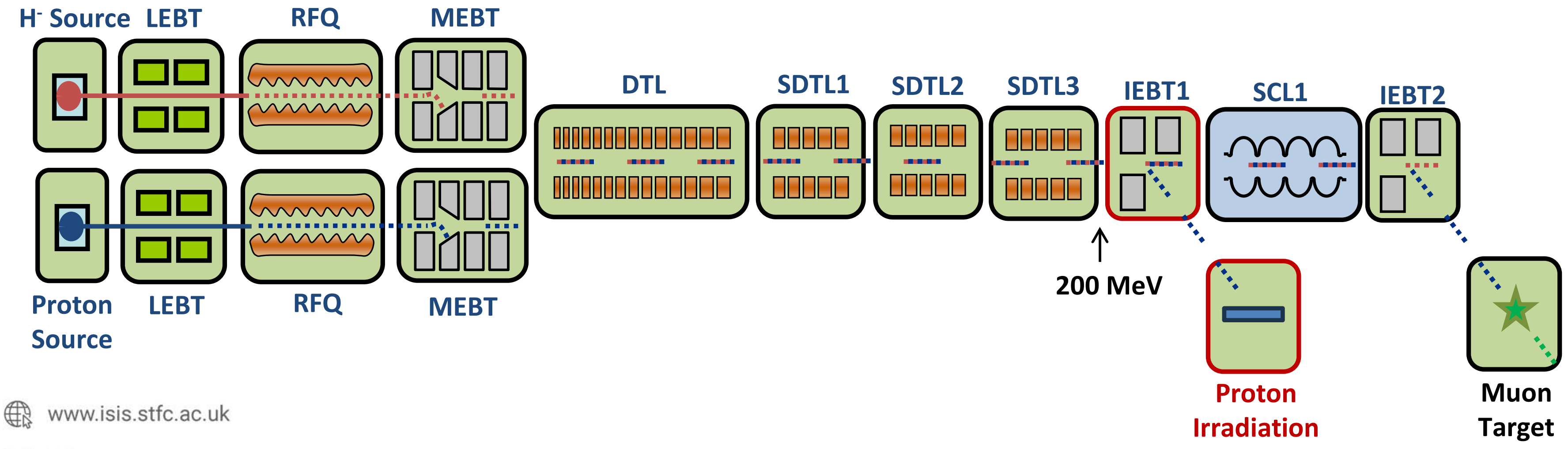
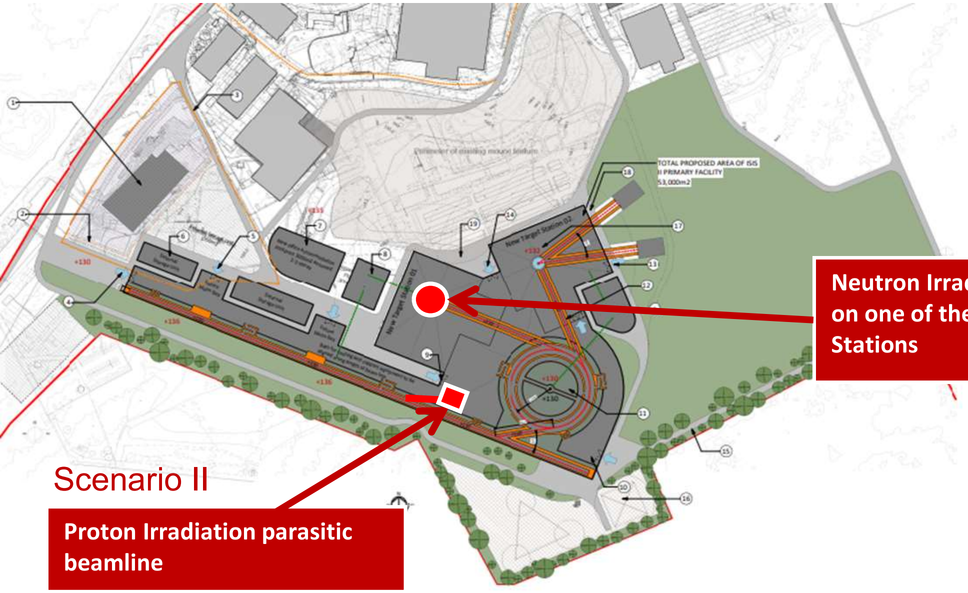


Table: Kenneth A. LaBel, Thomas L. Turflinger; “Protons, Aerospace, and Electronics: A National Interest”

Scenario II



Scenario II

Neutron Irradiation Beamline on one of the ISIS-II Target Stations

Scenario II

Proton Irradiation parasitic beamline

Delivers:

- Scenario I - Neutrons
- Additional laboratory-based proton facility
- Proximity to neutron capability

	Advantage	Disadvantage
Neutrons	design technically possible clear improvement on ChipIr lowest total cost (typical instrument cost)	more complex design (as part of target/reflector design)
Protons	Provides UK capability Increased European provision	unknown design, particularly energy and flux control cost unknown; but likely to be on scale of neutron instrument temporal structure (pulsed beam)

Development Level: MEDIUM

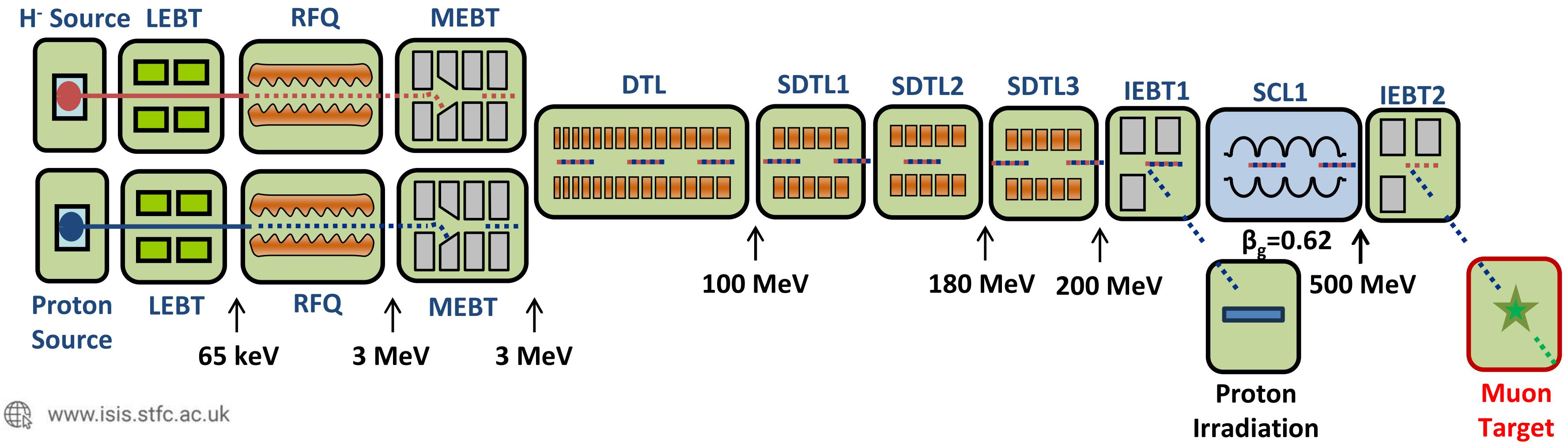
Scenario III

Abandon Scenarios I & II

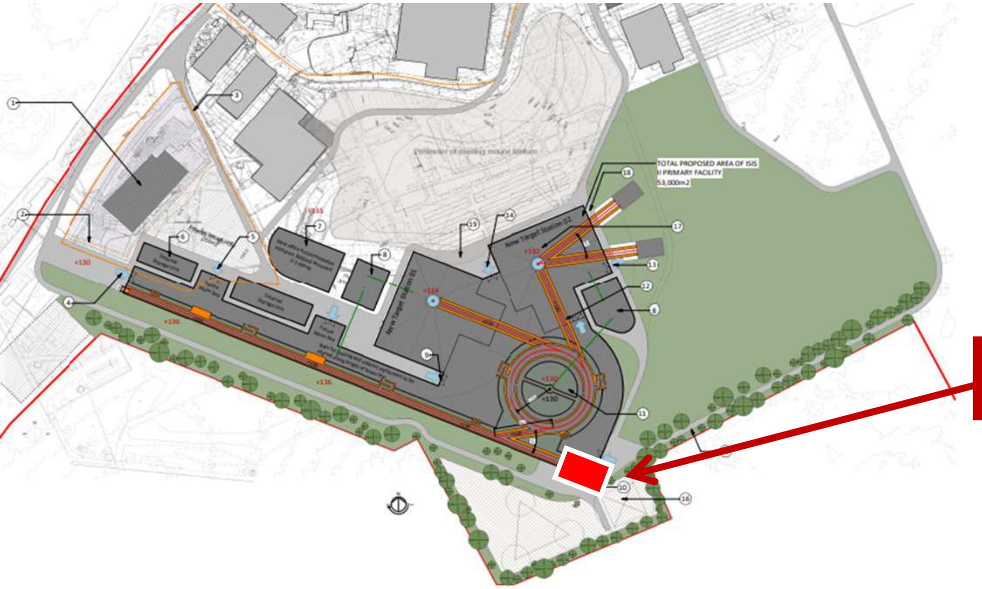
Exploit Proposed 500MeV Proton Beamline for Muons

Proposal to extract protons at 500MeV for Muon capability at end if Linac. Again could be driven by a proton pulse train interleaved with the H^- pulse train

…opportunity for combined facility?

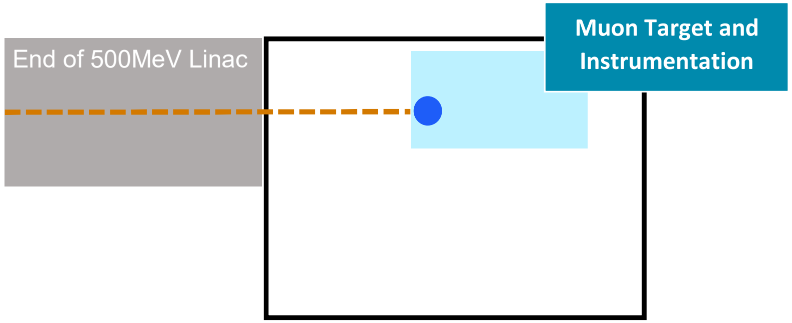


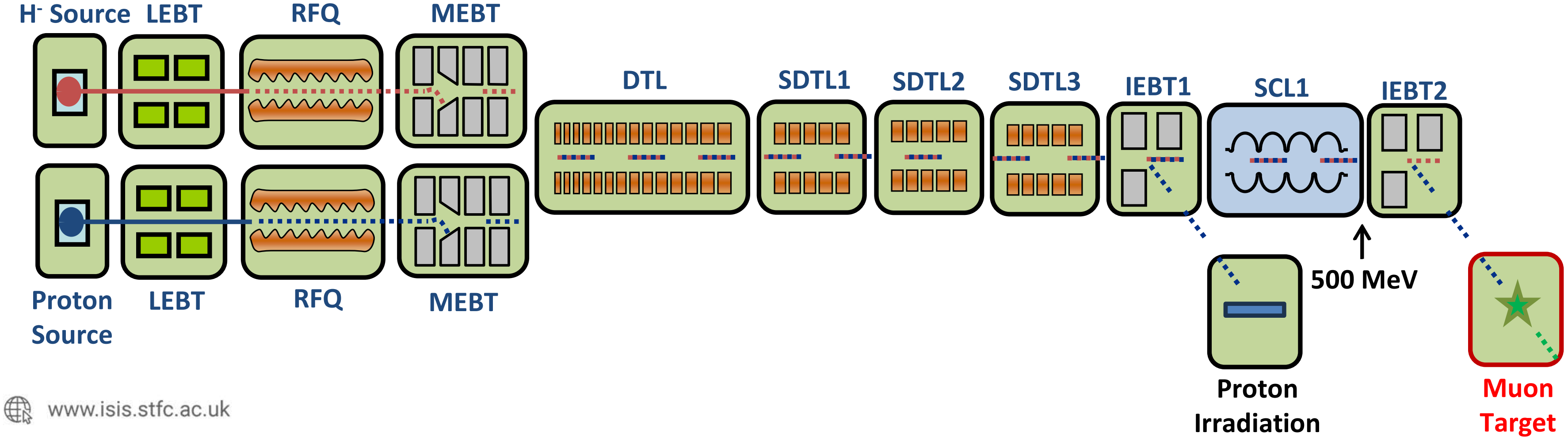
Scenario III



Scenario III

Muon and Irradiation 'Target Hall'





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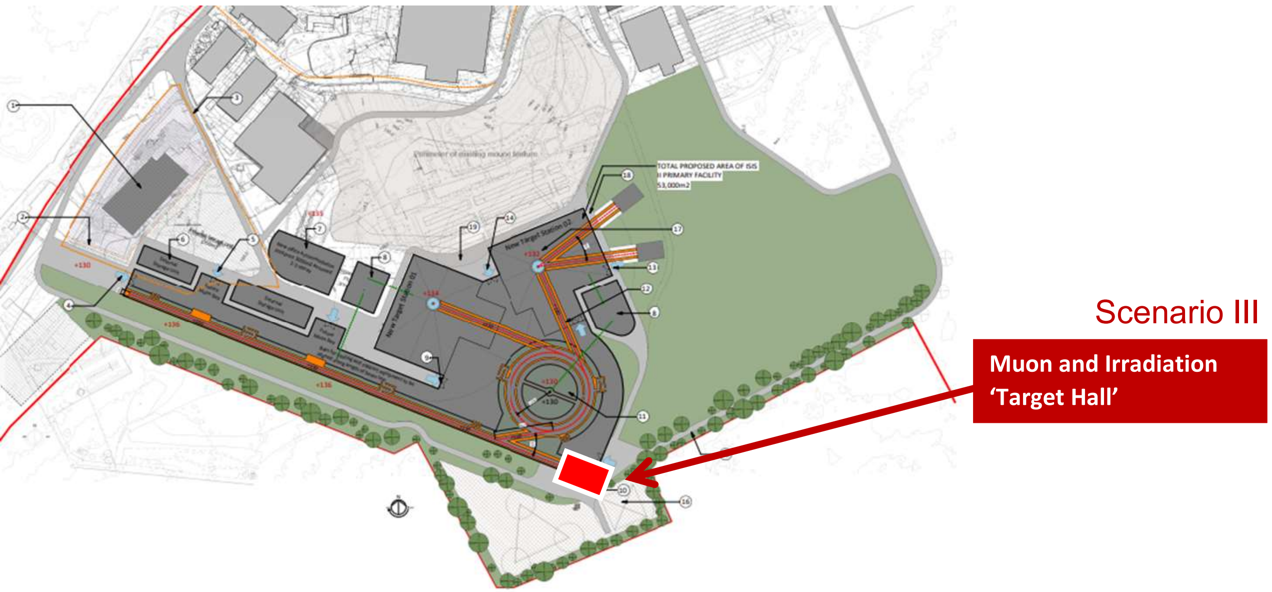

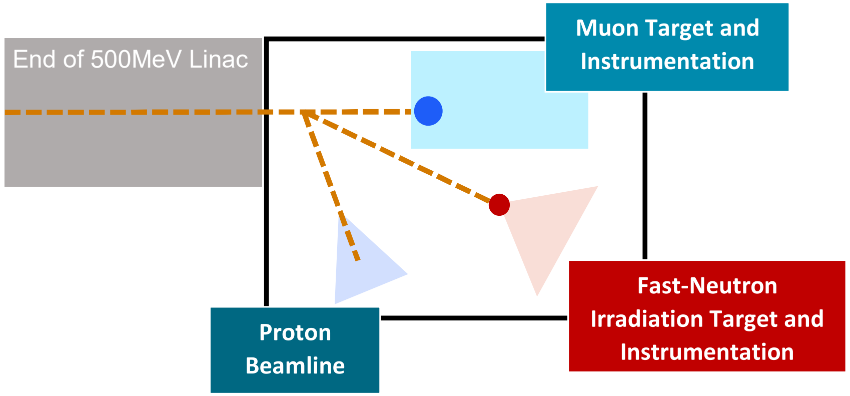

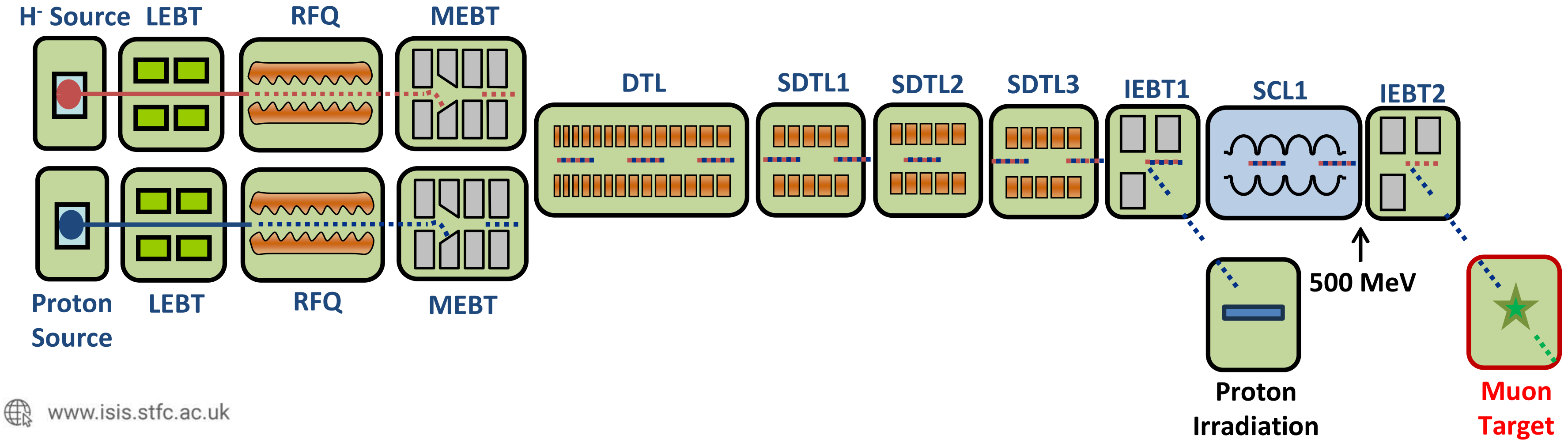

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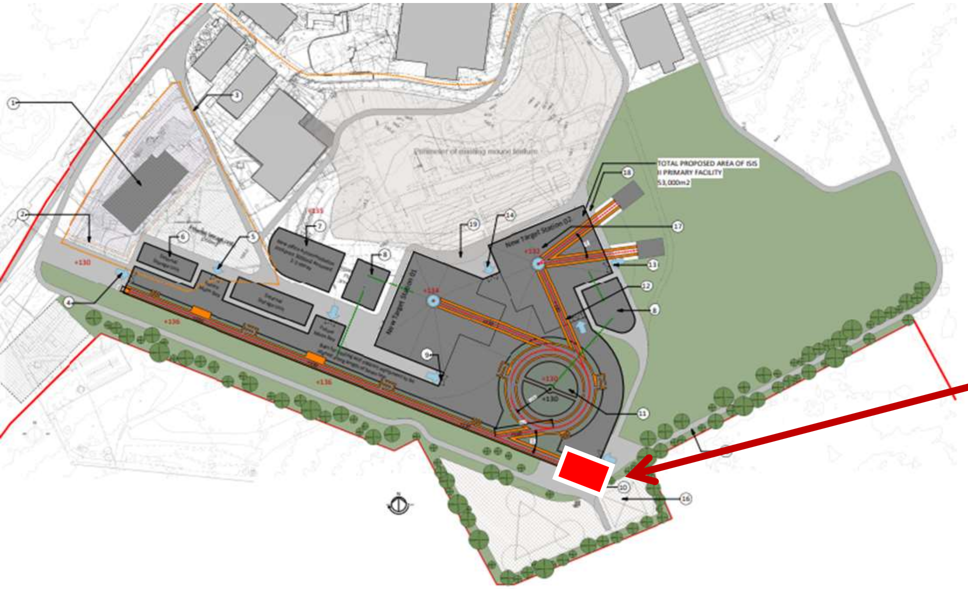


Scenario III

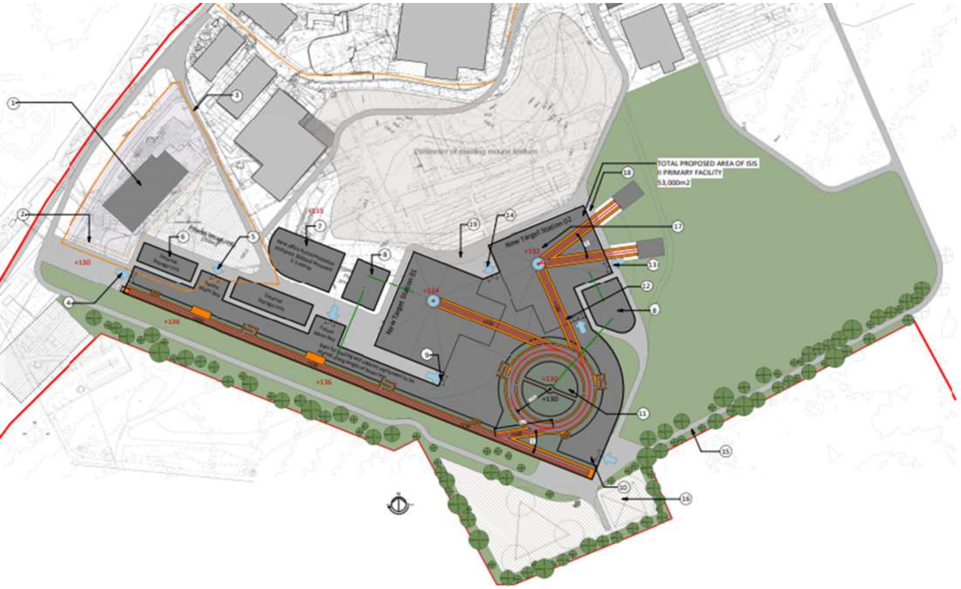
Muon and Irradiation ‘Target Hall’

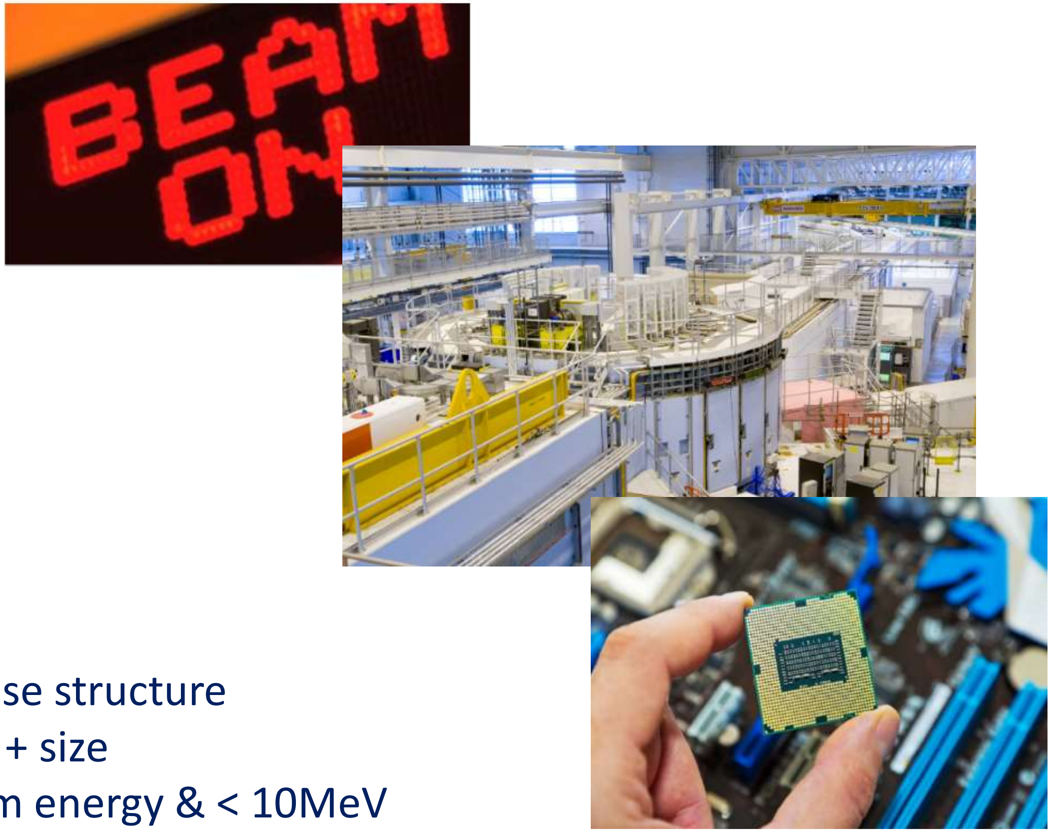
Delivers:

- Combined Neutron, Proton (and Muons)
- Flexibility

	Advantage	Disadvantage
Neutrons	- design technically possible - clear improvement on ChipIr - simpler neutronic design - potential for more flexible control of flux/beams - low cost beamline	- highest cost facility (as hall infrastructure required and neutron target costs)
Protons	- Provides UK capability - Increased European provision - potentially more flexible design	- unknown design, particularly energy and flux control - cost unknown; but likely to be of similar scale as typical beamline

Development Level: MEDIUM/HIGH





Points for discussion…

- Neutron beams: flux and pulse structure
- Neutron beams: flux control + size
- Neutron spectrum: maximum energy & < 10MeV
- Thermal neutrons & Mono-energetic provision
- Proton provision and requirements