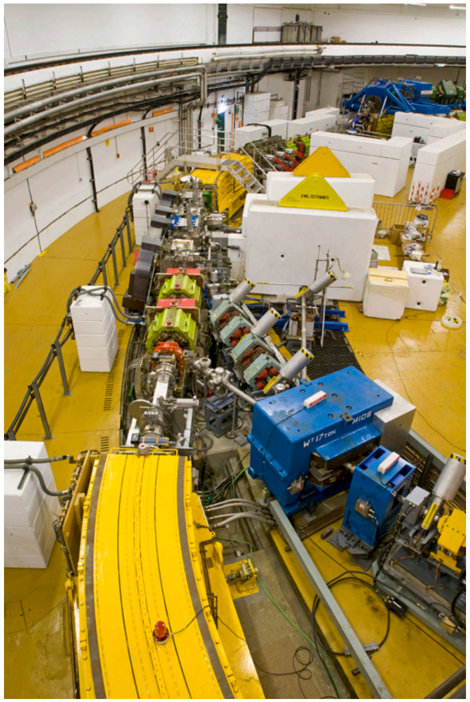
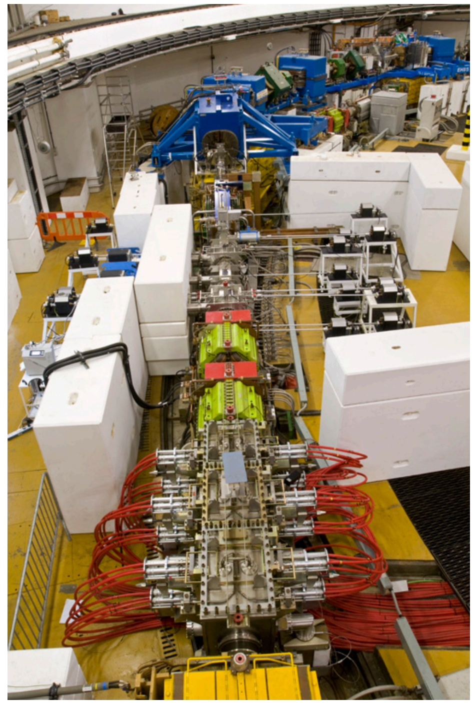
Science & Technology Facilities Council
ISIS

Commissioning Experience on the ISIS Ring


C M Warsop on behalf of past and present ISIS staff

ISIS, Rutherford Appleton Laboratory, UK

ICFA workshop on beam commissioning, China, June 2015

Science & Technology Facilities Council
Rutherford Appleton Laboratory

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2 Outline of ISIS and Ring Commissioning

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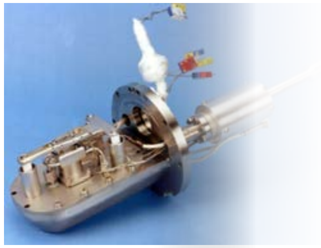
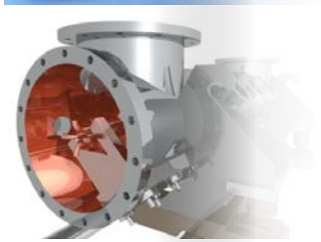
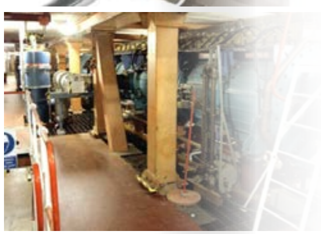
This talk will be followed by:

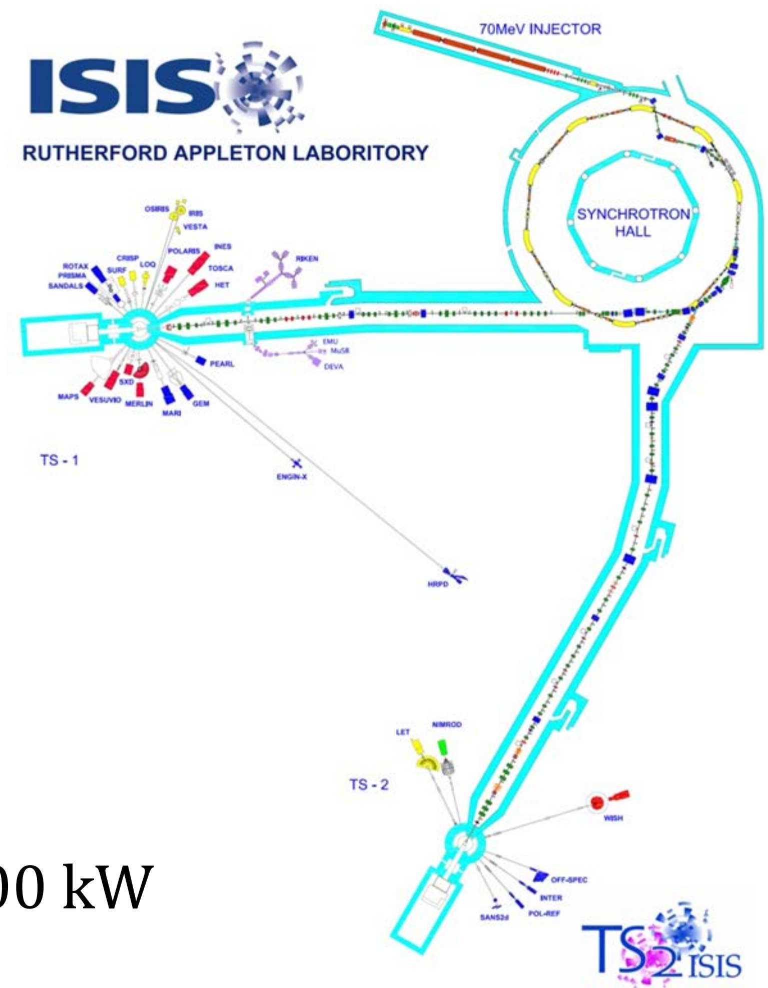
Commissioning of ISIS Ring RF Systems, A Seville

The ISIS Facility

Outline of ISIS

- Injector
  - H^- Penning Ion Source
  - 665 keV RFQ
  - 70 MeV DTL Linac
- Ring
  - 70 - 800 MeV RCS
- Target Stations
  - TS1 40 Hz
  - TS2 10 Hz
- Mean beam power ~ 200 kW



1. The ISIS Synchrotron

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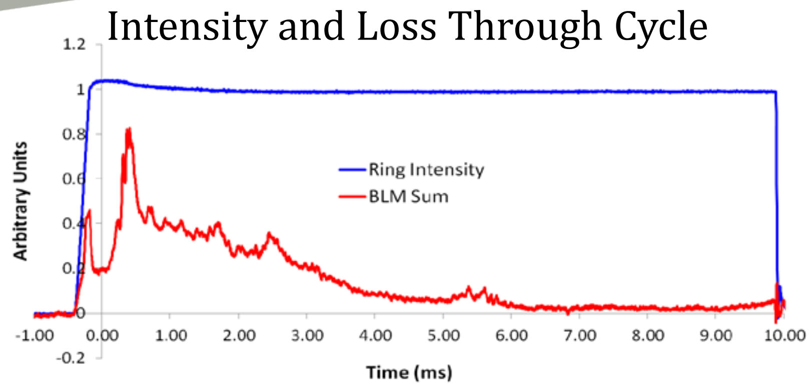
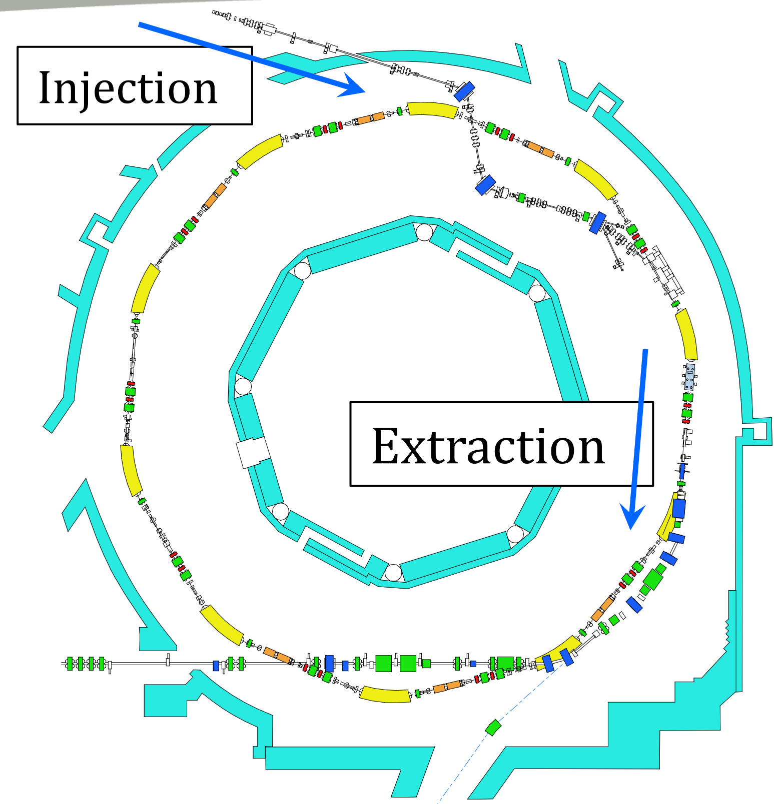
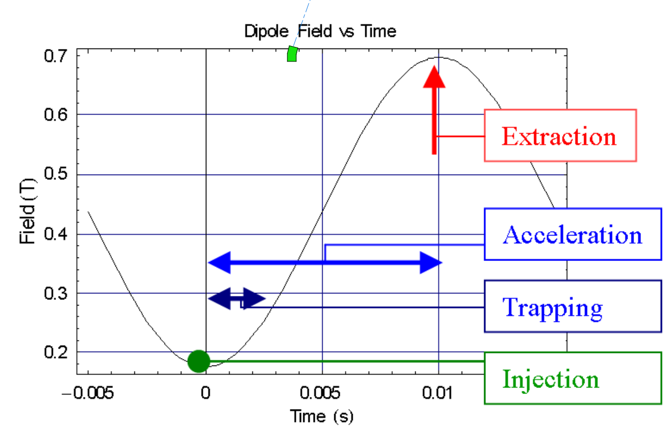
2.8 x10^{13} ppp

Loss limited machine





Circumference:	163 m
Energy Range:	70-800 MeV
Rep Rate:	50 Hz
Intensity:	2.5-3.0×10^{13} ppp
Beam Power:	160-200 kW
Losses:	Inj: 2%, Trap: <3%, Acc/Ext <0.5%
Injection:	130 turn, H^- charge-exchange
Acceptances:	Collimated ~350 π mm mr
RF System:	h=2, f_2=1.3-3.1 MHz, V_2 ~160kV/turn
(*2 bunches*)	h=4, f_4=2.6-6.2 MHz, V_4 ~80 kV/turn
Extraction:	Single turn, vertical
Tunes:	(Q_x, Q_y)=(4.31, 3.83) (*programmable*)



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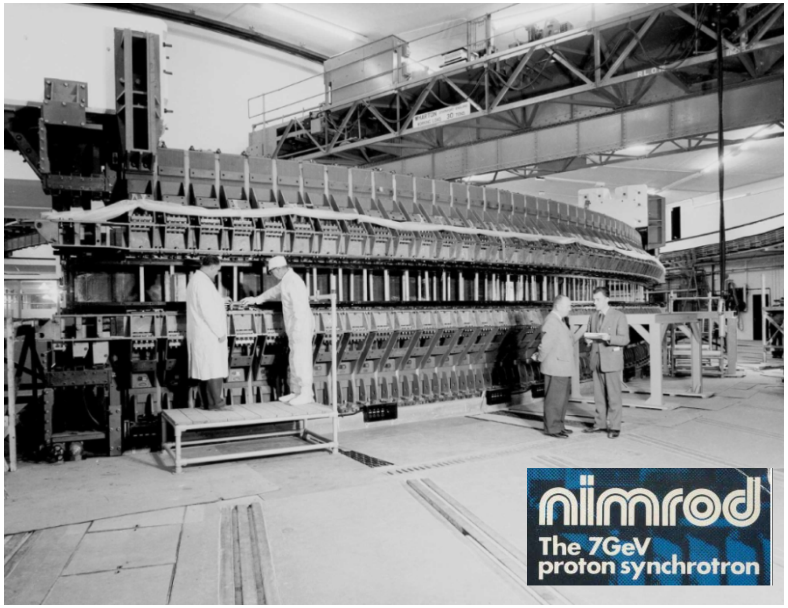
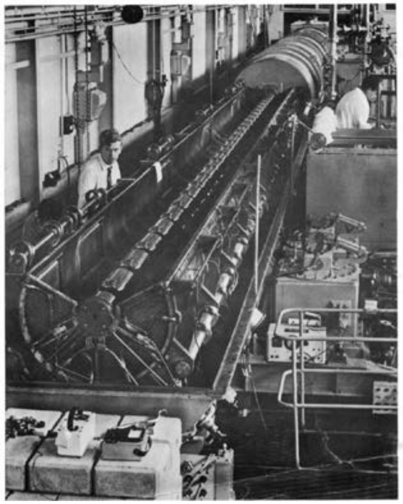
2. Outline of ISIS Commissioning

- 1976: ISIS (SNS) proposal submitted
  - A new Spallation Neutron Source
  - Cost savings: use NIMROD infrastructure
  - *Buildings, linac, magnets, power supplies, …*
- NIMROD 7GeV proton synchrotron
  - Weak focussing, 1.0-5.0×10^{12} ppp, 0.5 Hz
- 1977: ISIS construction approved
- 1978: NIMROD closed

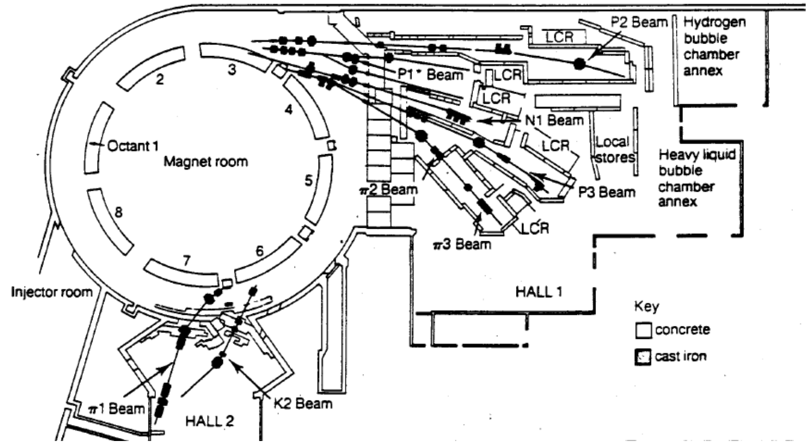
NIMROD 7 GeV proton ring



50 MeV PLA linac



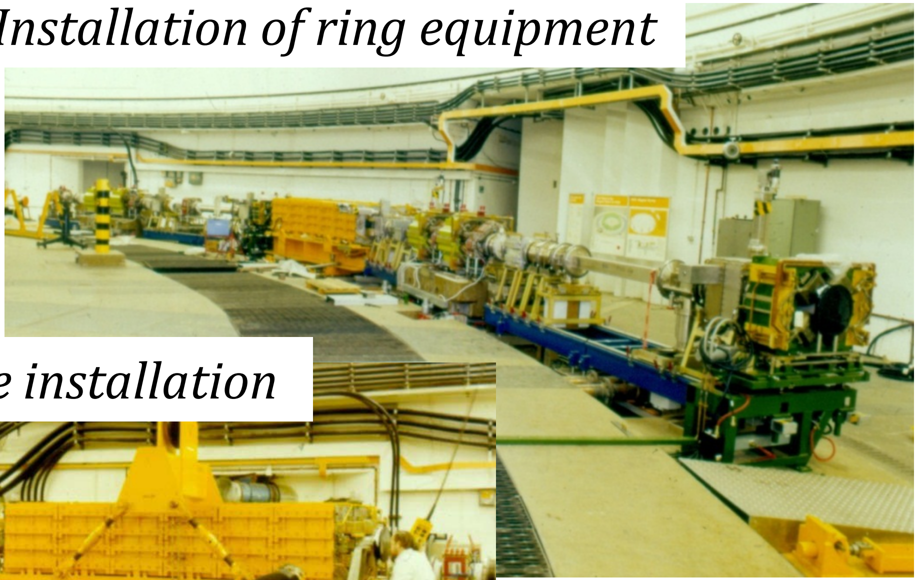
NIMROD & particle physics experiments



2. Outline of ISIS Commissioning

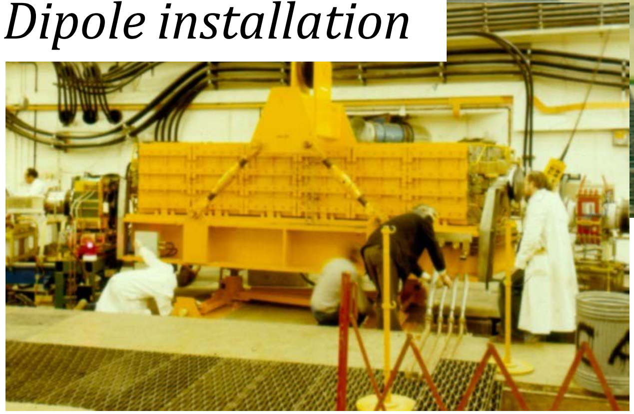
- 1978-1983: ring installation

Installation of ring equipment



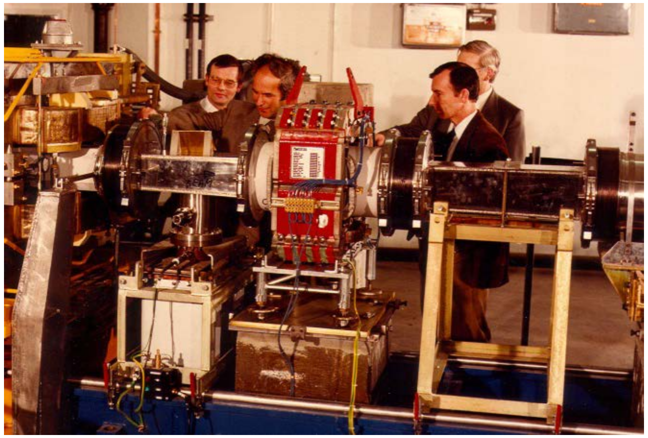
NIMROD magnets removed

Dipole installation



Synchrotron hall cleared

December 1983 : last vacuum joint in the ring completed

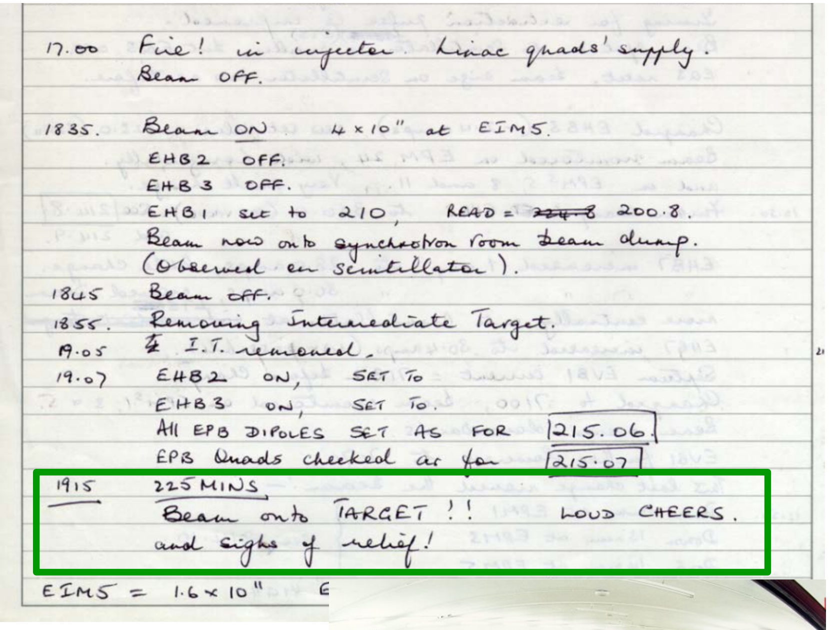


2. Outline of ISIS Commissioning

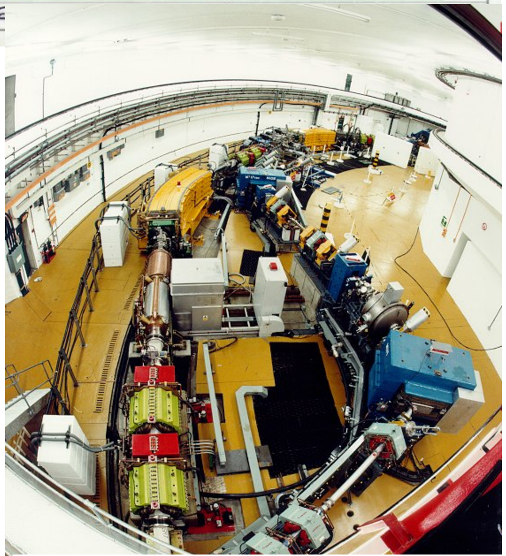
- 1984: start commissioning ring
- 15 Jan – *injection at 70 MeV*
  1 μs pulse, circulated ~100s turns*
- 8 April – *acceleration to 140 MeV*
  two RF cavities, 2.8×10^{12} ppp accelerated
- 5 June – *acceleration to 550 MeV*
  four RF cavities, 1.2×10^{12} ppp accelerated*
- 28 Sept – *extraction at 550 MeV*
  1.5×10^{12} ppp to beam dump*
- 16 Dec – *first neutrons*
  5×10^{11} ppp to target*
  2 hour run for instruments

- *Most on first attempt**
- *All at low rep rate (~ 1 Hz)*

ISIS experimental log 16 Dec 1984


17.00 Fire! in injector Linac quads' supply.
Beam OFF.
1835. Beam ON 4×10^{11} at EIMS.
EHB2 OFF.
EHB3 OFF.
EHB1 set to 210, READ = ~~224.8~~ 200.8.
Beam now onto synchrotron room beam dump.
(Observed on scintillator).
1845 Beam off.
1855. Removing Intermediate Target.
19.05 I.T. removed.
19.07 EHB2 ON, SET TO
EHB3 ON, SET TO.
All EPB DIPOLES SET AS FOR 1215.06
EPB Quads checked as for 1215.07
1915 225 MINS
Beam onto TARGET!! LOUD CHEERS.
and sighs of relief!
EIMS = 1.6×10^{11}

Celebrations for first neutrons!



Ring injection region

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2. Outline of ISIS Commissioning

- 1985: regular runs established
  Beam: 550 MeV, 10 μA (25 Hz)
  Initial problems & developments
    665 kV pre-injector breakdowns
    Linac RF high power drives
    Ring RF feed forward system

  Official opening by Prime Minister

- 1986: regular neutron operations
  Beam: 550 MeV, 30 μA (50 Hz)
    Pre-injector breakdowns reduced

- Operational phase from 1986
  Developments *in parallel* with operations

ISIS pre-injector (1990s)

Inauguration by Prime Minister, Margaret Thatcher, 1 October 1985

2. Outline of ISIS Commissioning

1987-90: Reached 750 MeV 100 μA

- 1987: 750 MeV operation

  6 RF cavities operational

  New extract septum installed
- 1989: 750 MeV 100 μA
- Key developments

  Injector beam reliability and control

  Injection bump magnet cooling

  Ring: Dynamic betatron Q control (measured)

  Closed orbit control (correction system)

  RF control & beam loading improvements

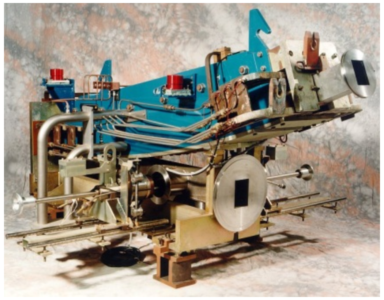
  Beam loss protection and control

  Problems

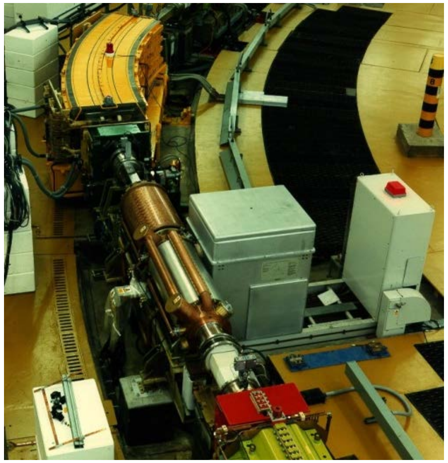
  Extraction kickers damaged 1989

  Episodes of beam damage and vacuum rises

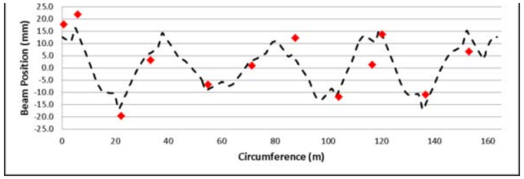
Septum magnet



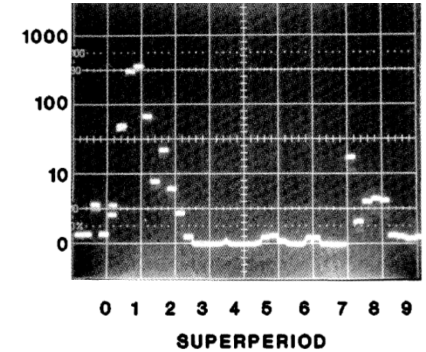
RF cavity (h=2)



Ring orbit correction



On-line display of loss



2. Outline of ISIS Commissioning

1991-94: Reached 800 MeV 200 μA

Extra funding (German govt. KARMEN expt.)

- 1991: 800 MeV 100 μA ops

  New extraction kickers (redesigned, replaced)

- 1993: Design 200 μA reached in tests

  Key developments

  Increased injector current and control

  Well defined injection (diagnostic chopper)

  Ring: RF dual tetrode operation, improved control

  Betatron Q (space charge, head tail-instability)

  Quadrupole error corrections (harmonics)

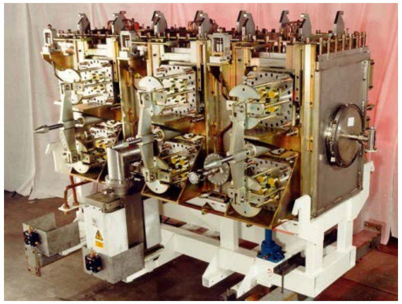
  Closed orbit control (13 correctors installed)

  Programmable time dependent corrections

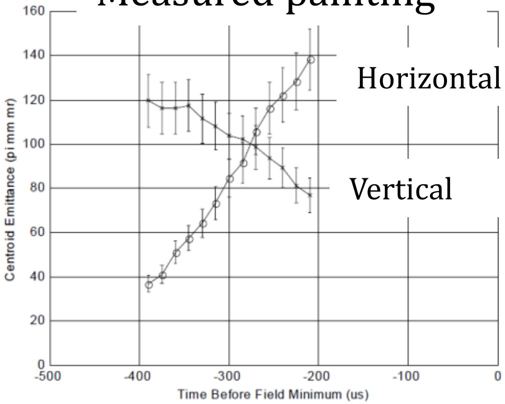
  Comprehensive protection: beam trips on BLMs

- 1994: 800 MeV, reached 200 μA levels in ops

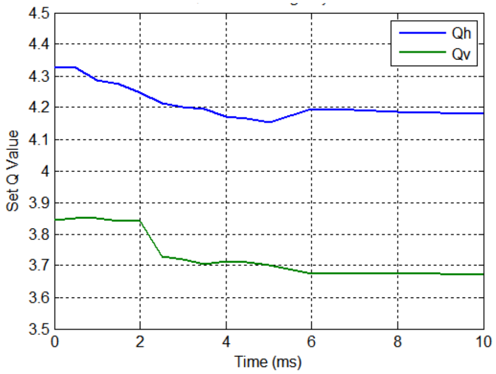
New extract kickers



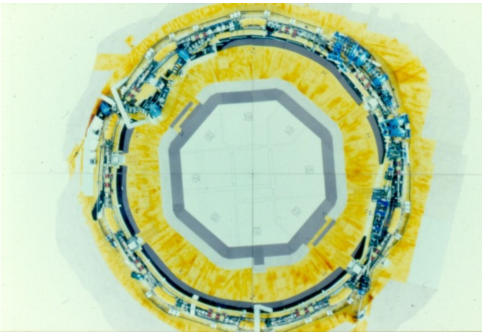
Measured painting



ISIS Q values through cycle



2. Outline of ISIS Commissioning



1995-2001: 800 MeV 200 μA running

- Consolidation and improvement of operations

  Improve running and reliability
  Ongoing improvement and updating of equipment
  (E.G. magnet power supply updates)

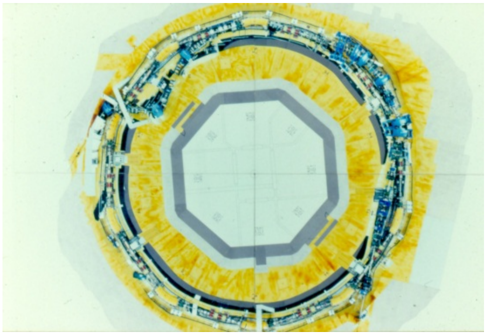
- Work for the ISIS second target station (higher intensity)

  Optimise target designs for more neutrons per proton
  Straight 1 replacement
  RFQ upgrade to pre-injector
  Dual Harmonic RF system
  New extraction and EPB line designs

- Some problems with beam damage

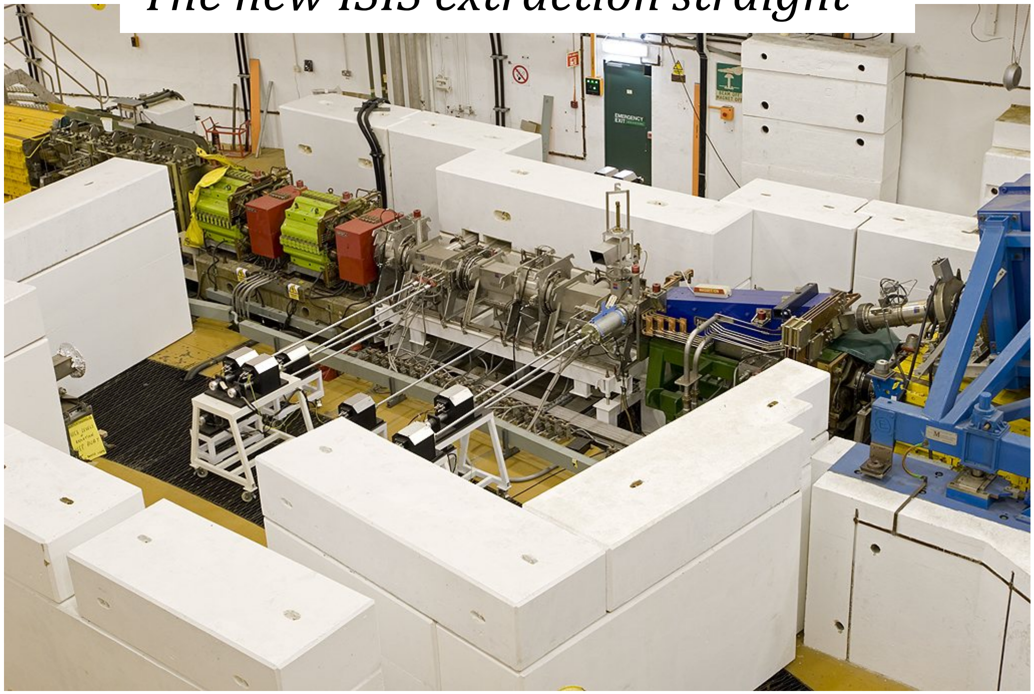
  Further developments to overcome this (new beam loss monitors)

2. Outline of ISIS Commissioning



- 2002: “Straight 1” replacement installed
  Extraction and collimation straight
- Extraction – increased acceptance
  New extraction septum magnet
  Larger apertures
- Collimators
  Optimisation of jaws & geometry
  Improved protection, monitoring
- Improved modular design
  For quick replacement
  (lower doses – “hottest” area)

The new ISIS extraction straight



2. Outline of ISIS Commissioning

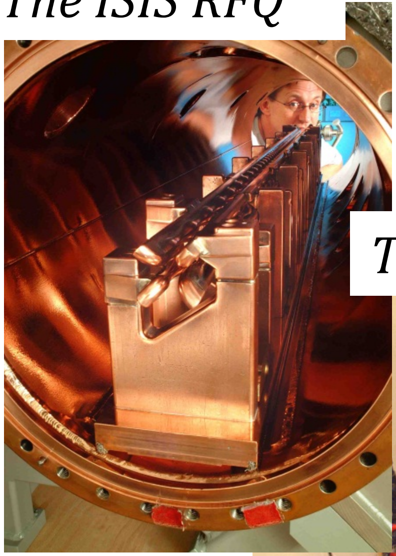
- 2004: New ISIS RFQ installed

- 665 keV RFQ
  202.5 MHz, 4 rod
  Replaced old Cockcroft-Walton
  Improved LEBT

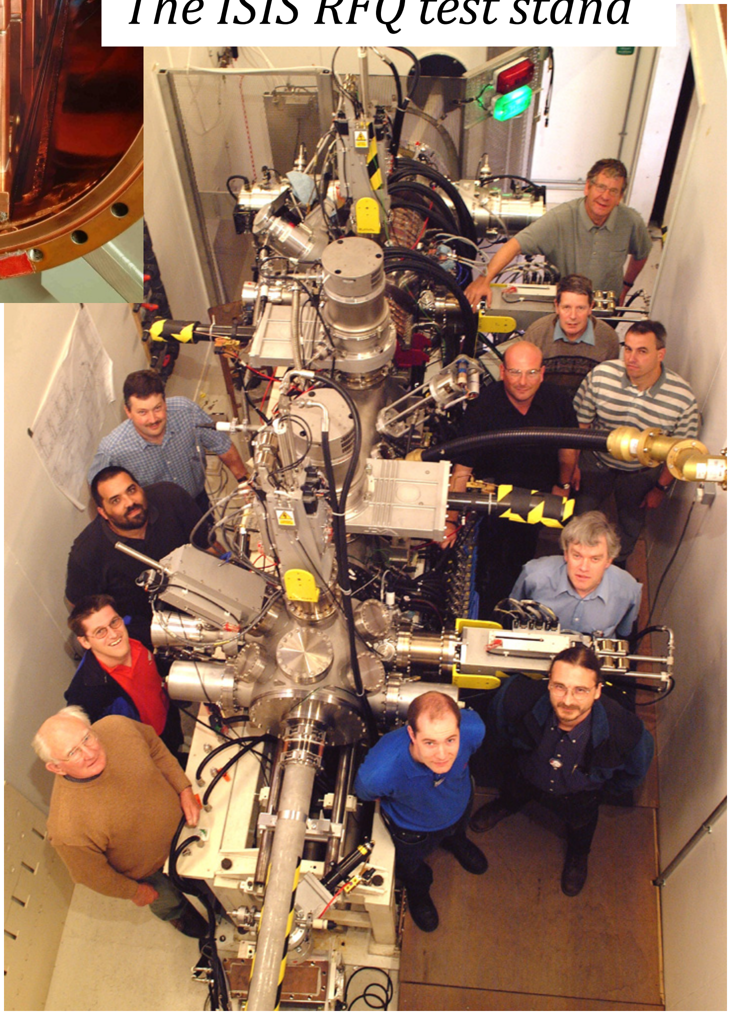
- "Soak Testing"
  Dedicated test stand
  6000 hours running ensured reliability
  Characterised performance

- Successful operation
  Cockcroft-Walton problems removed
  Potential for upgrades …

The ISIS RFQ

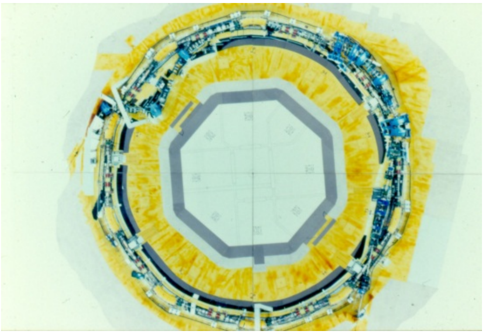


The ISIS RFQ test stand



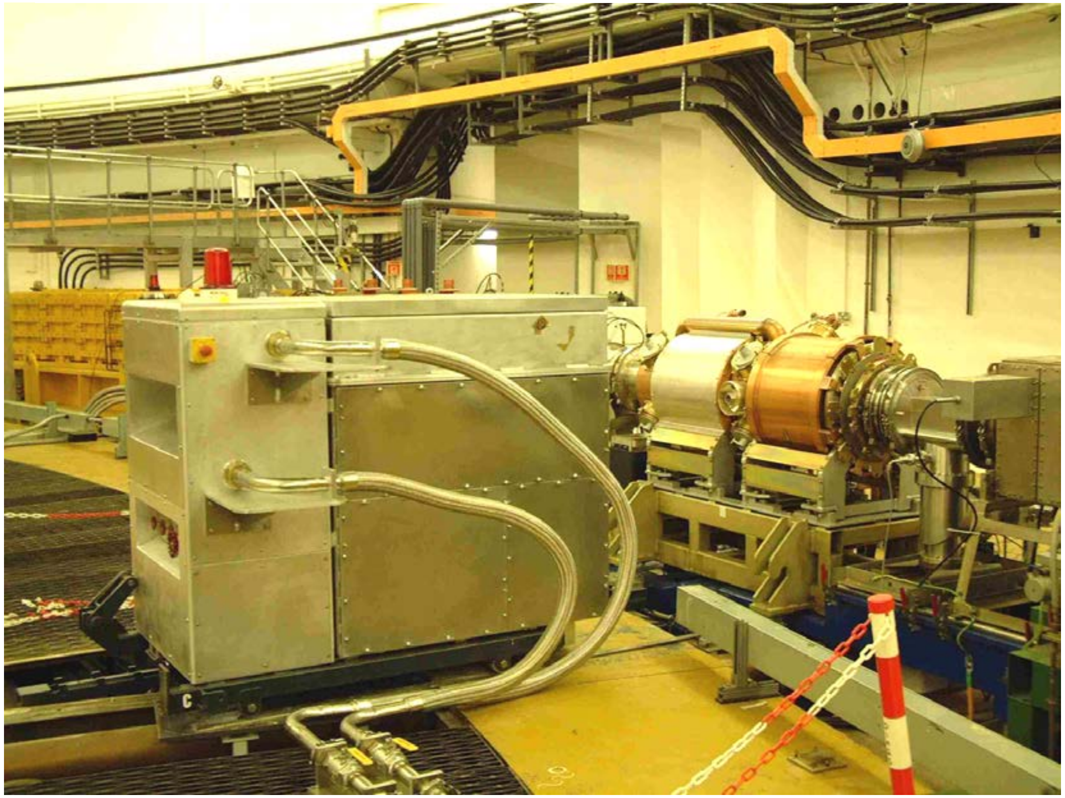
2. Outline of ISIS Commissioning

- 2004: Dual harmonic RF system installed



- Four new h=4 cavities
  Higher capture efficiency
  Larger acceptance
  Improved bunching factor

New h=4 RF cavity installed in the ISIS ring



- Key for higher intensity
  Reduced trapping loss
  More potential ...

See talk by A Seville

2. Outline of ISIS Commissioning

- 2004: ISIS was included in the Guinness book of records

The most powerful pulsed neutron source in the world

(for a while!)

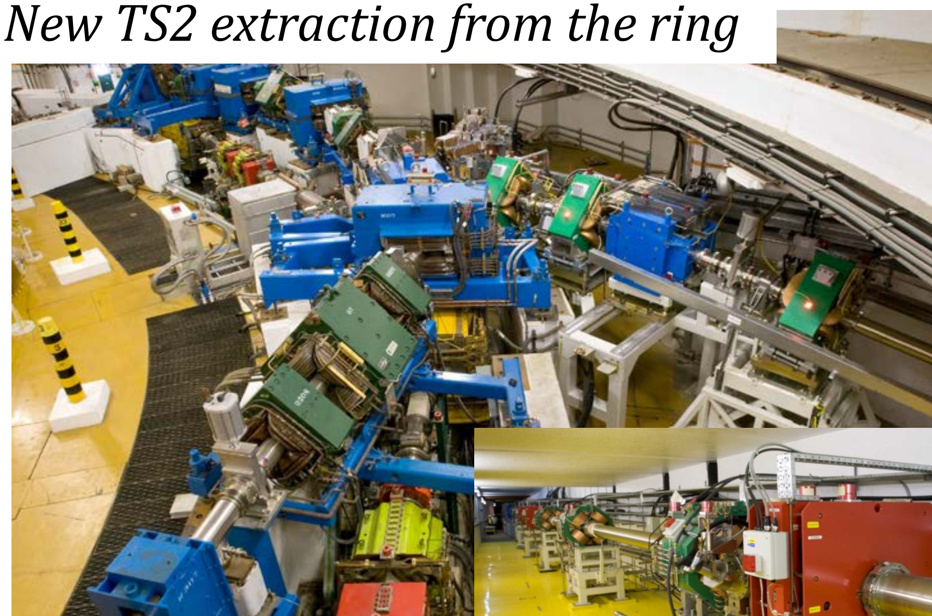
2. Outline of ISIS Commissioning

2003-2008: Construction Target Station 2

- 2003: Funding approved
- 2007: First neutrons
- 2008: User programme starts

Celebration of first beam to TS2

New TS2 extraction from the ring



New TS2 beam line

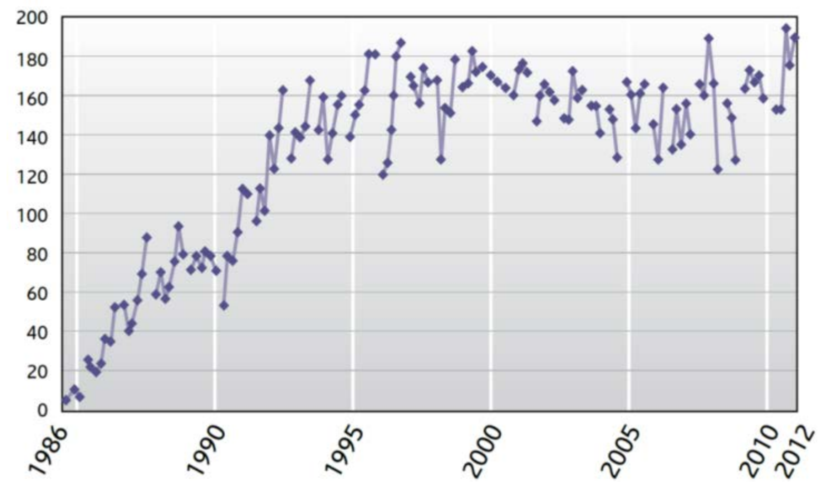
ISIS Facility showing TS1 and TS2

2. Outline of ISIS Commissioning

2008 ~ onwards

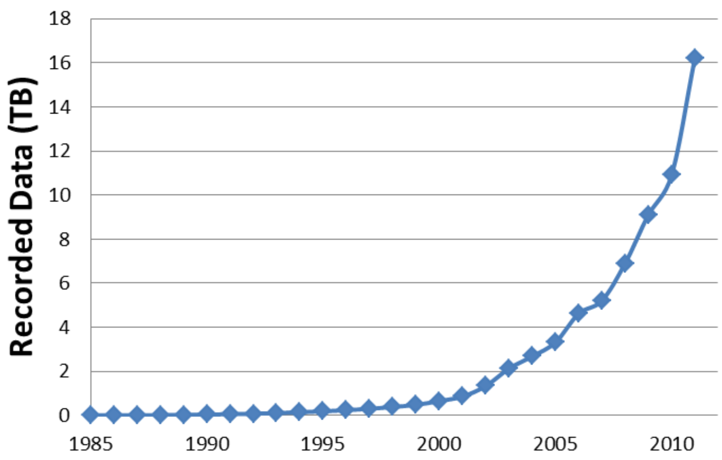
- User priority: neutron flux
  Reliability, optimal targets & instruments
  Large increase in neutron data …
  ISIS extremely productive scientifically
  Next: Target station 1 upgrade study

Average beam current per cycle (μA)



- Typical running intensity 210 μA
  Want consistent 240 μA (peak so far 252 μA)
  Minimise losses, activation
  High intensity phenomena impose limits

Neutron data taken (TB)



- High intensity R&D …
  Head-tail instability with space charge
  Space charge effects: images, half integer
  Dual harmonic RF optimisation
  Still much to understand!

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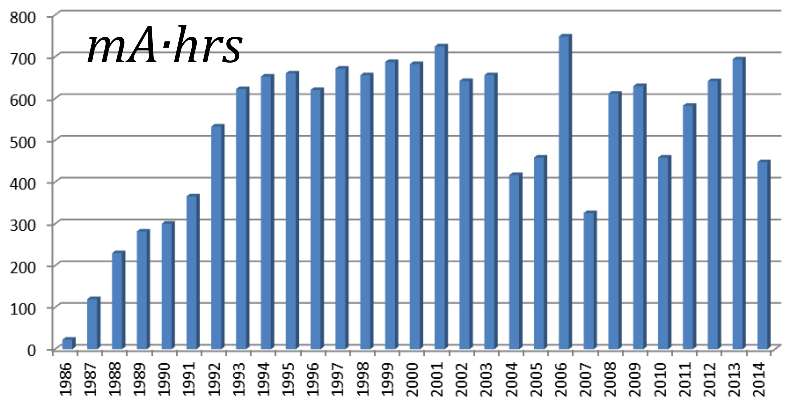
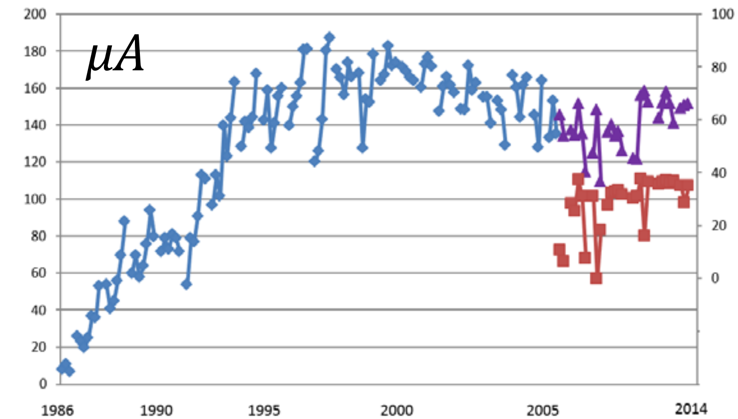
Summary of ISIS Performance

Standard operations data 1986 – 2014

Annual integrated current



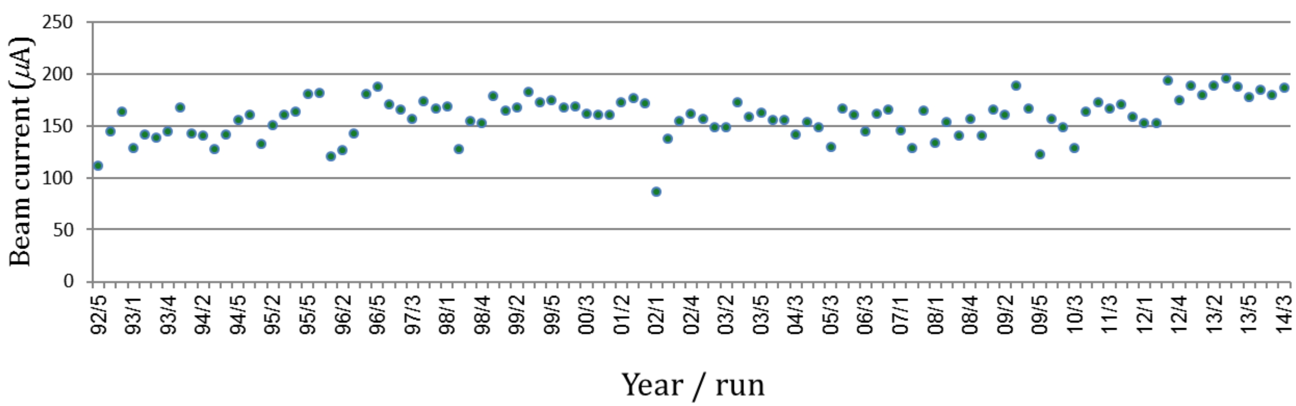
Average beam current per cycle



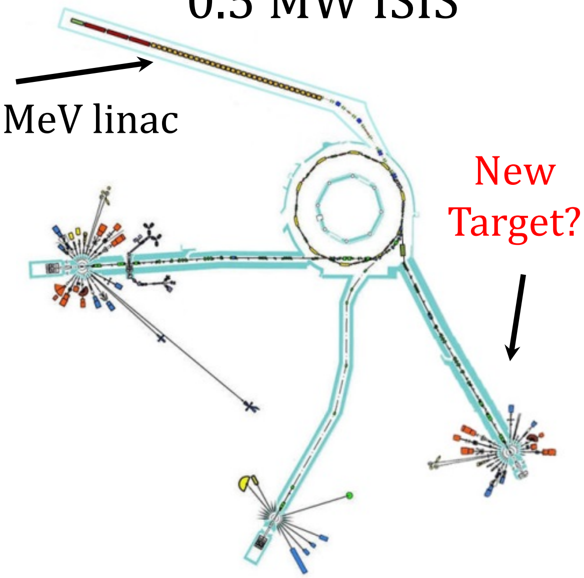
Ring performance 1992 – 2014

Average beam current per cycle (µA)

Beam to both targets



ISIS Upgrade Studies



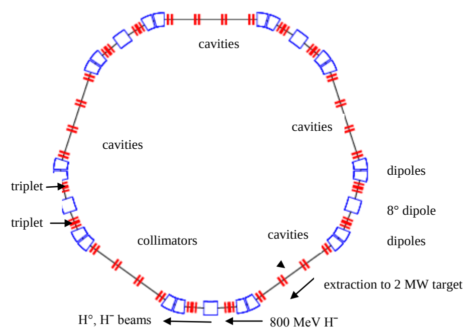
ISIS Accelerator Upgrade Studies

- Injection Upgrade ~ 0.5 MW
  Install new 180 MeV injector
  Use existing ring (upgrade injection, etc)
  Or smaller piece wise improvements …

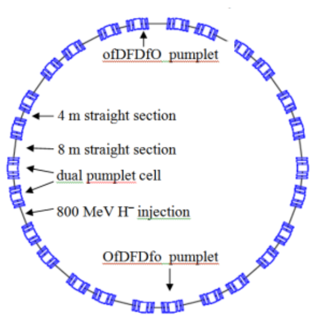
- ISIS II ~ next generation short pulse source …
  Study options e.g. 1-10 MW flexible, upgradable, multi-target facility
  Present ideas based on 5 MW RCS or FFAG's (studies with ASTeC/IB)

Studies underway with ISIS and ASTeC/IB group

0.8-3.2 GeV RCS



0.8-3.2 GeV FFAG

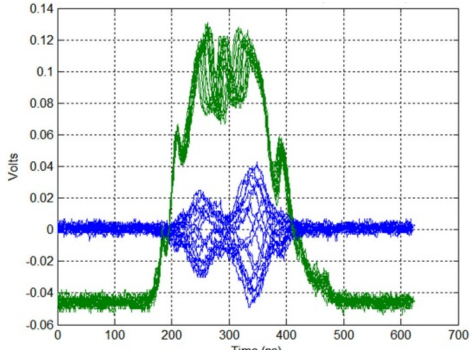


Importance of R&D

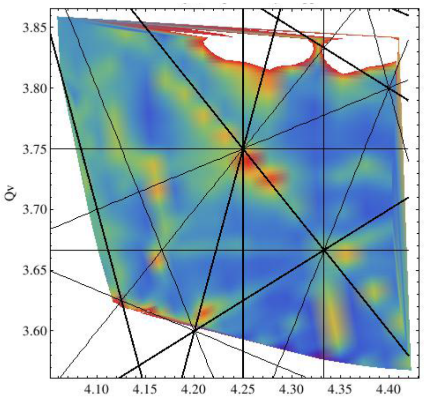
- Ultimate limits often set by high intensity effects
  Assuming hardware problems are overcome …

- Important to do R&D on *real machines*
  Better understanding of loss = better performance
  Important for existing and future machines
  (e.g. ISIS RCS is loss limited ~ high intensity effects)

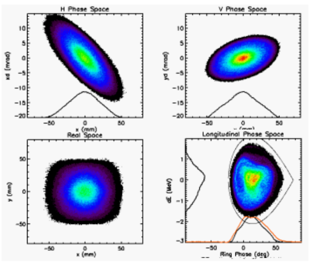
ISIS: Head-tail motion



ISIS: Q vs loss map



ISIS: ORBIT model



- Acknowledgements

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D J Adams, D J S Findlay, I S K Gardner