Science & Technology Facilities Council
ISIS

OPERATIONAL EXPERIENCE AND FUTURE PLANS AT ISIS

D.J. Adams

C.M. Warsop, B. Jones, B. Pine, H. Smith, R. Williamson, A. Seville, R. Mathieson, I.S.K. Gardner. D. Wright, A.H Kershaw, A Pertica, A Letchford, Chris Wilcox

Many members of Accelerator Division

STFC, Oxford, UK

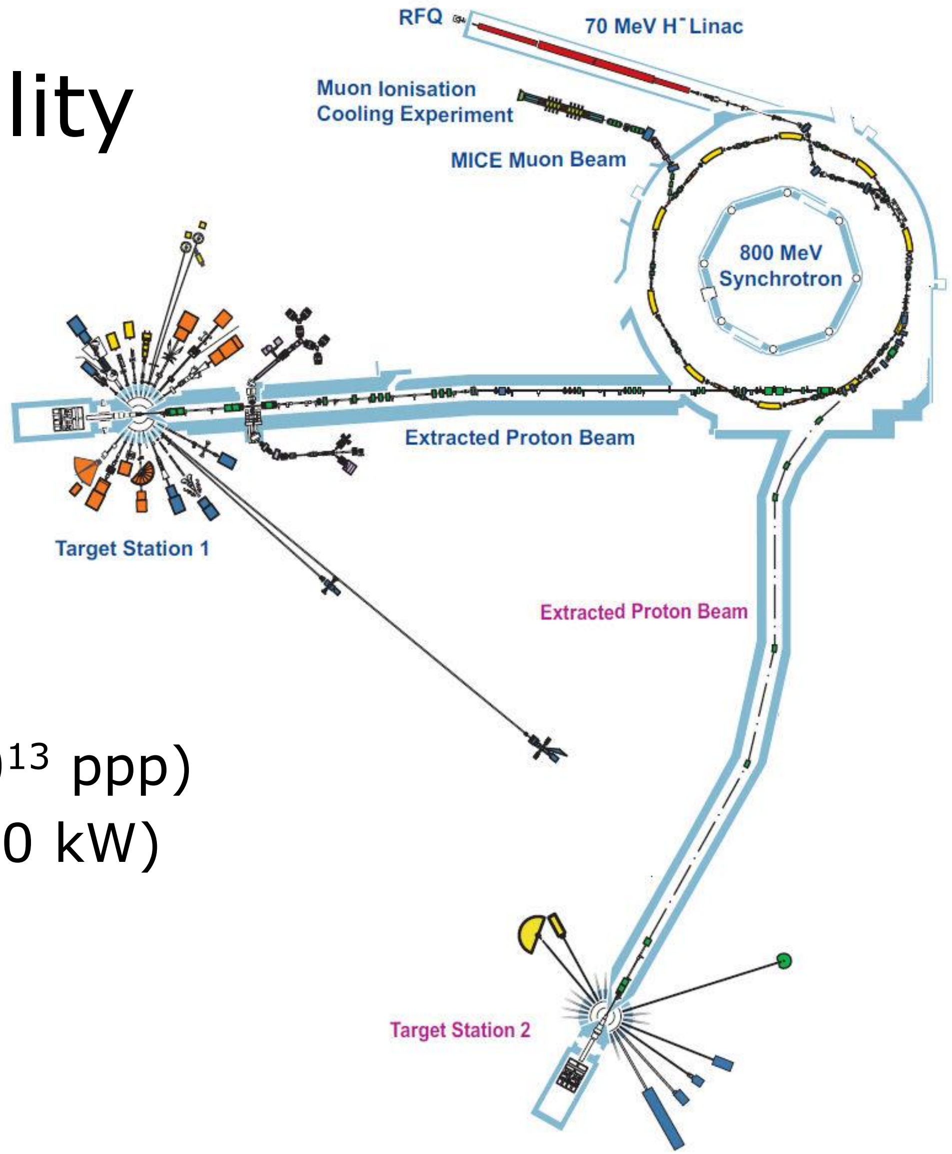
Contents

- Brief overview of ISIS
- Beam performance
- Main Accelerator Upgrades
- Operations and Accelerator R&D
- Future Projects

Science & Technology Facilities Council
ISIS

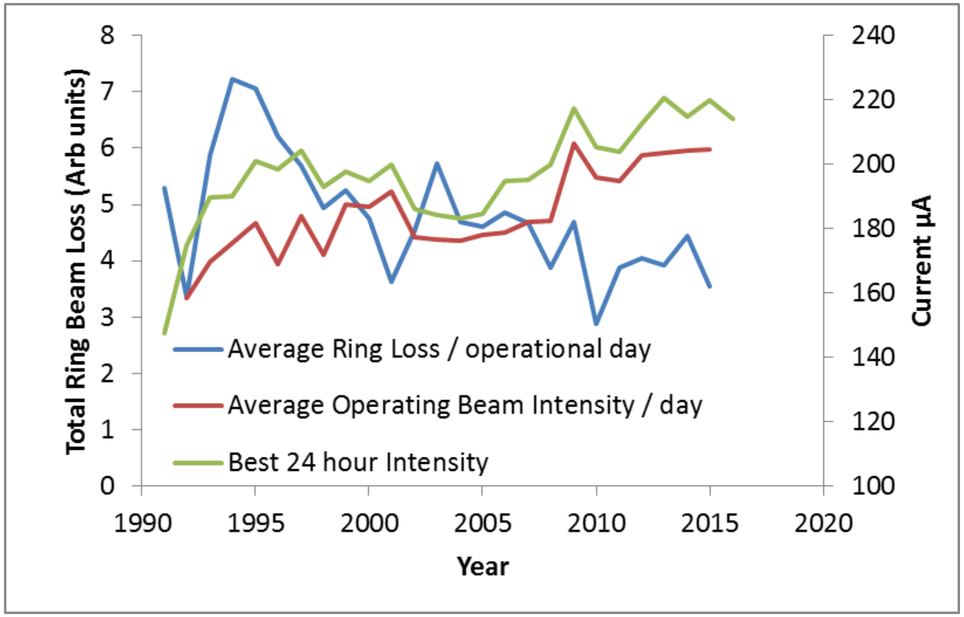
ISIS Facility

- Neutron and Muon source used for condensed matter research by 3000 users.
- H- ion source (55 mA)
- 665 keV RFQ (35 (mA)
- 70 MeV linac (26 mA)
- 800 MeV 50 Hz, RCS ($2.8x10^{13}$ ppp)
- Target 1 + Muon target (140 kW)
- Target 2 (36 kW)



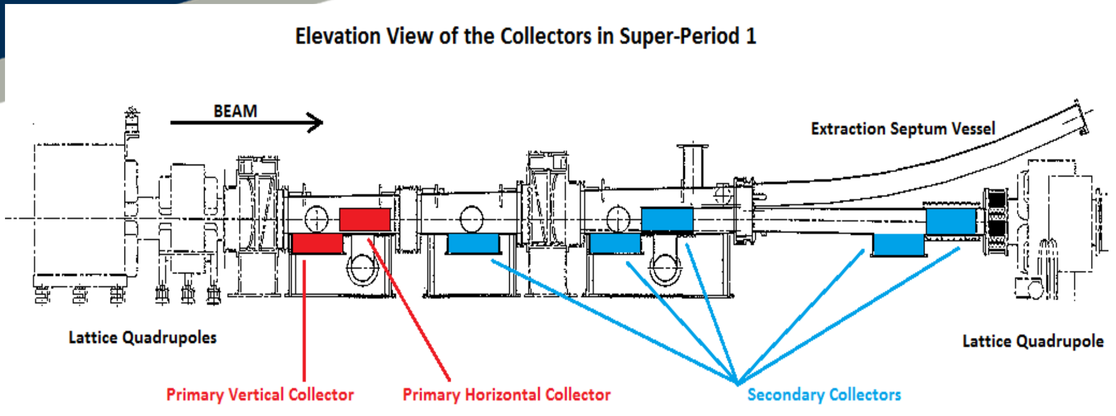
Beam Performance

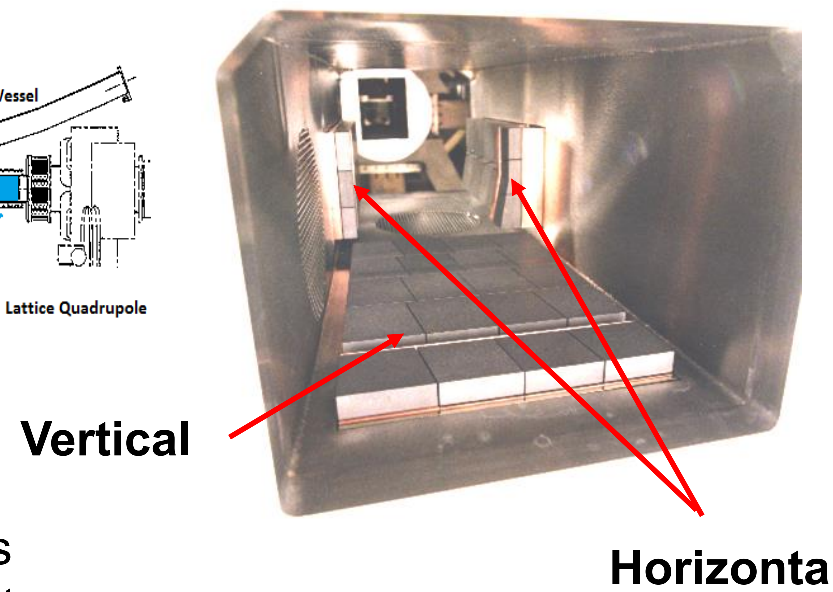
- First Beam in 1984, user operation in 1985, achieving full design current 160 kW (2.5x10^{13} ppp) in 1992.



- Operation is beam loss limited to facilitate hands on maintenance.

Super Period 1 upgrade (2002)





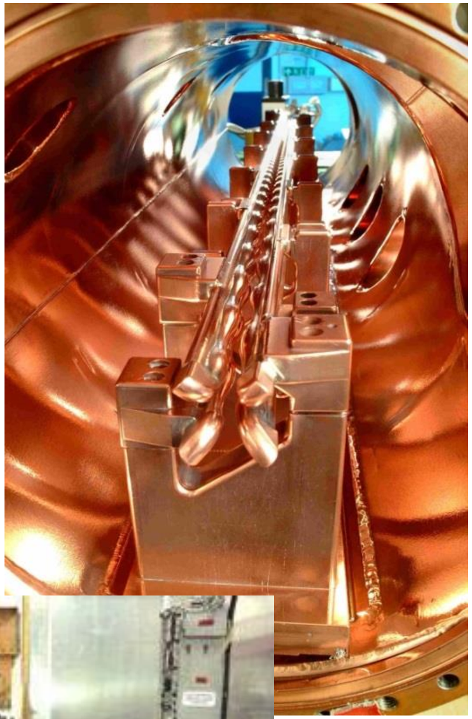
- Up to 10 % Trapping and Acceleration loss managed on collimation systems to prevent machine damage and activation.

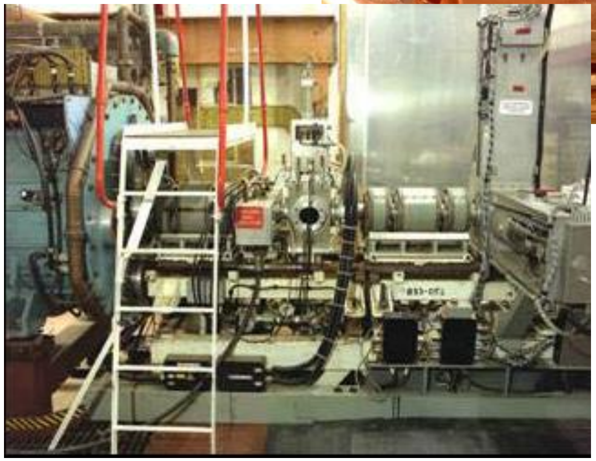
- Collimators upgrades in 2002
  13 Copper and Graphite water cooled blocks intercept ~ 2 KW.
- Energy capture range extended from 100-300 MeV

Science & Technology Facilities Council
ISIS

Pre-Injector Upgrade (2004)

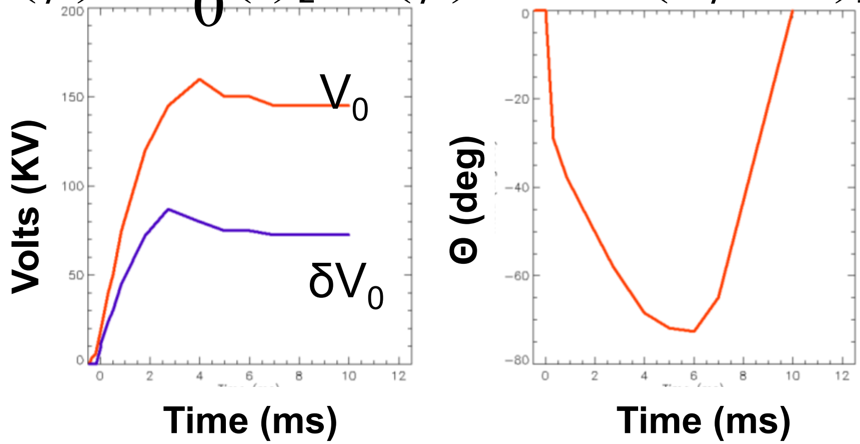
- Replace aging Cockcroft Walton 665 keV injector with an RFQ
- Improved linac current from 19 mA to 26 mA allowing more ring power.
- 18 month offline test, internal cleaning for RF conditioning only issue.





DHRF Upgrade (2006-2012)

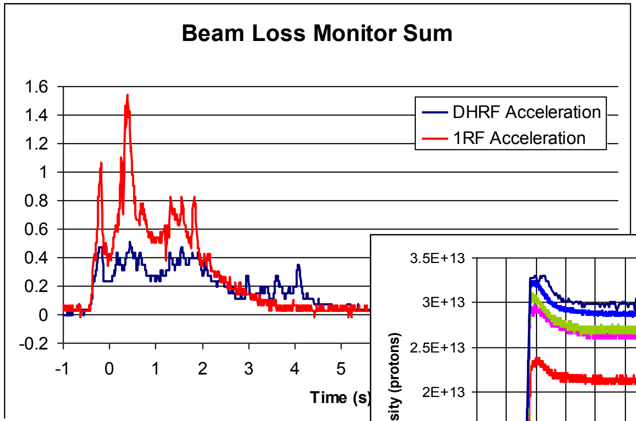
$$V(\varphi) = V_0(t)[\sin(\varphi) - \delta \sin(2\varphi + \theta)]$$

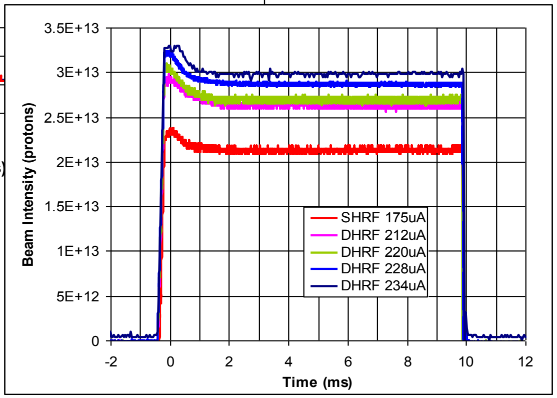


- Ring RF, 6 cavities (h=2), 160 kV/turn 200 μA operation with 9% ring losses

- Add 4 cavities, h=4, 80 kV/turn, increased RF bucket acceptance and better bunching factors, 200 μA operation with 3 % loss.

- Achieved 230μA operationally and 250 μA during machine physics.



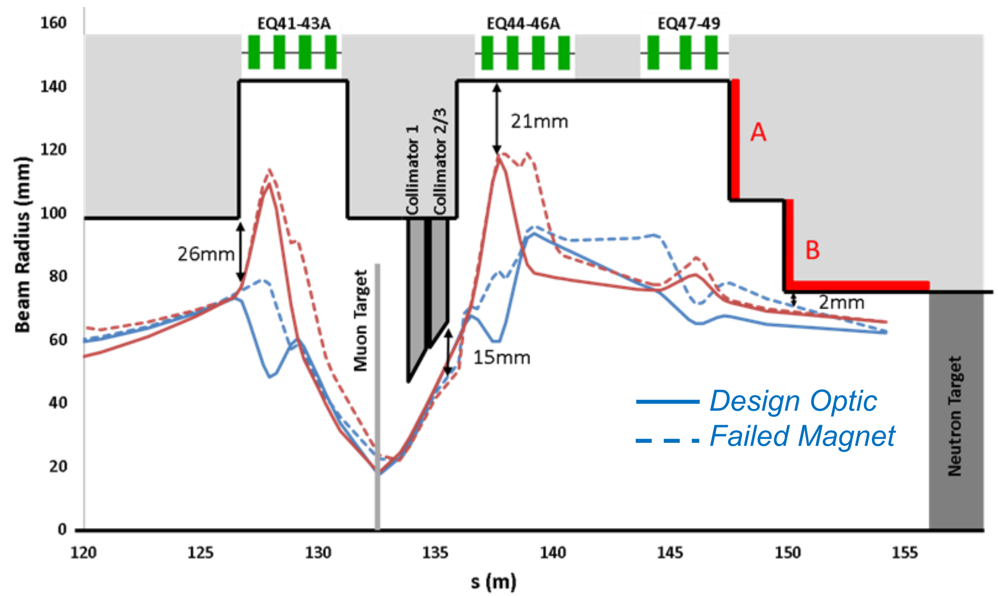


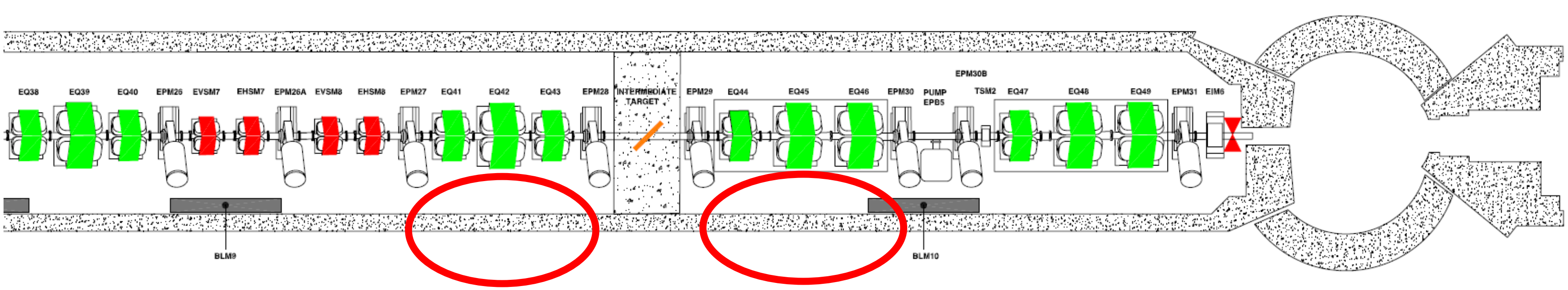
EPB1 Upgrades (2006-2015)

Muon Target (10 mm graphite) scatters proton beam to:
collimators 1.4 %
uncontrolled 0.47 % (quads+B)

Reduce collimator acceptance
Larger quads, 2 extra (optic flex)
Uncontrolled 0.06% @ B

Quad inserts for additional steering.



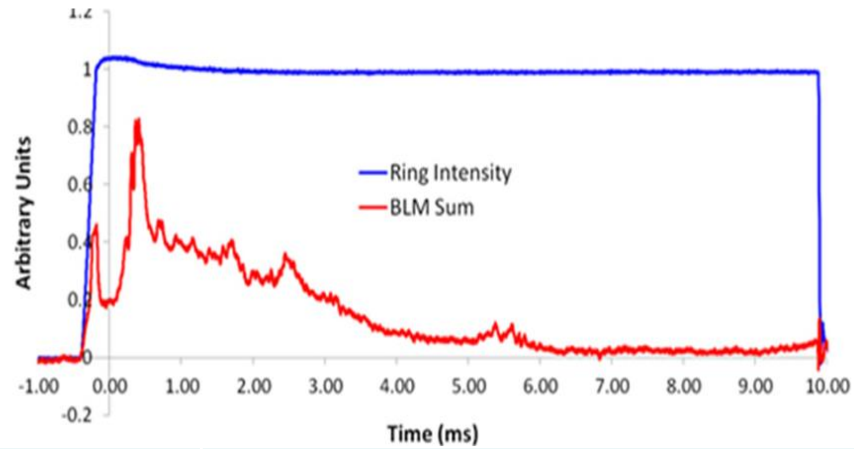


Extracted Proton Beamline

Science & Technology Facilities Council ISIS

Operations and Accelerator R&D

Main operating issues are managing Ring beam loss.

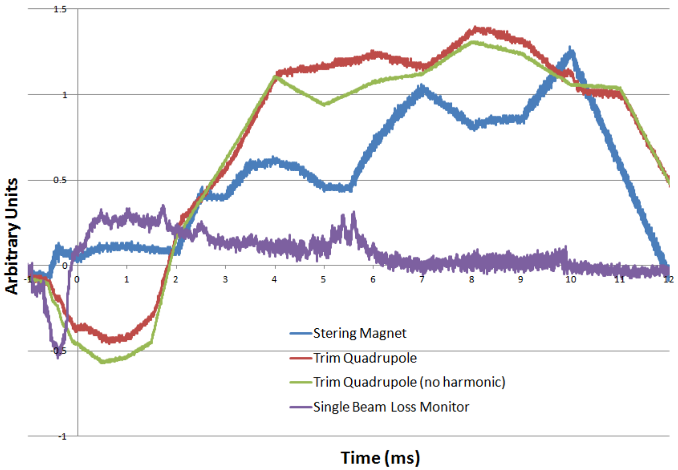


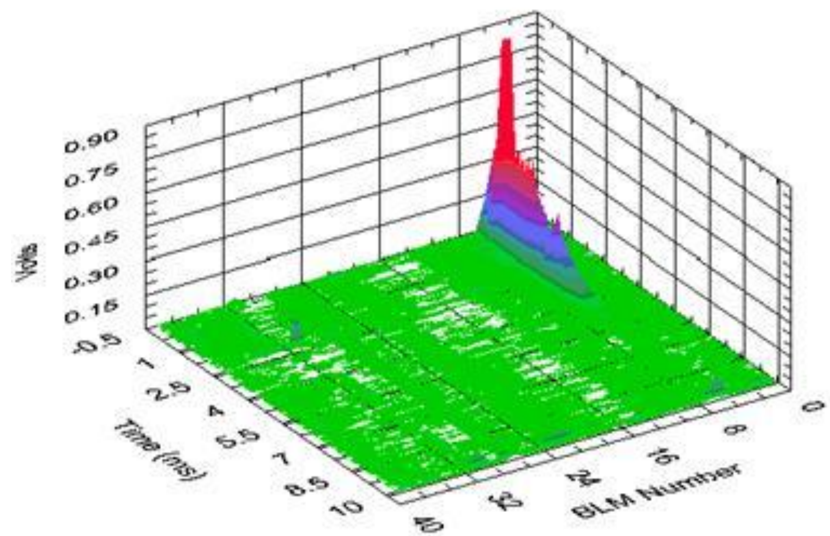
Injection (-0.4-0 ms) 1% loss	Strip efficiency>99 %, scattering loss, ~30 recirculation	Painting emittance Amps, Tune, Transverse Optics
Acceleration (0-10 ms) ~3% Loss	**Transverse :** ΔQ_{inc}>-0.5 @ 0.4 ms. Machine Error. Vertical Head Tail @ 2 ms **Longitudinal:** Non-adiabatic trapping loss.	Painting Amps, Tune, Envelopes Orbits, Bunching Factor. Ring RF. Injected $\Delta E/E$, debuncher Φ, V Ring RF bucket V_1, V2, Φ, freq
Extraction <0.1 %	Horizontal and vertical Halo scraped	Extract position, envelope

Science & Technology Facilities Council
ISIS

Managing beam loss

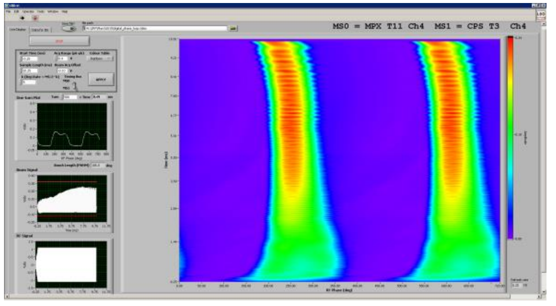
- Operation with 4 % beam loss
- Correct machine orbits and envelopes errors then empirically tune on beam loss.
- 20 quads, 13 dipoles, Time dependant functions, ~20 steps in 10 ms.
- Strategy: Move beam loss to collimators and then minimise overall loss.

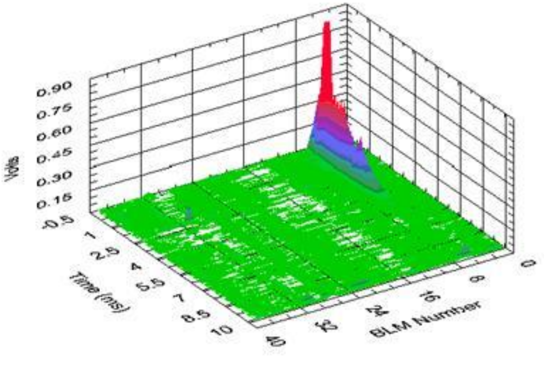




Diagnostic developments

- Ring Diagnostics: Intensity, beam loss, profile, position.
- Make more use of these by utilising developments to DAQ and CPU power: More acquired signals, data visualisation and comparison, automated measurements, model fitting and corrections.
- Fast measurements (< 1s) make machine tuning/error diagnosis, parameter rather than signal lead.
- FPGA technologies, 50 Hz is possible.





Synchrotron Operating Limit

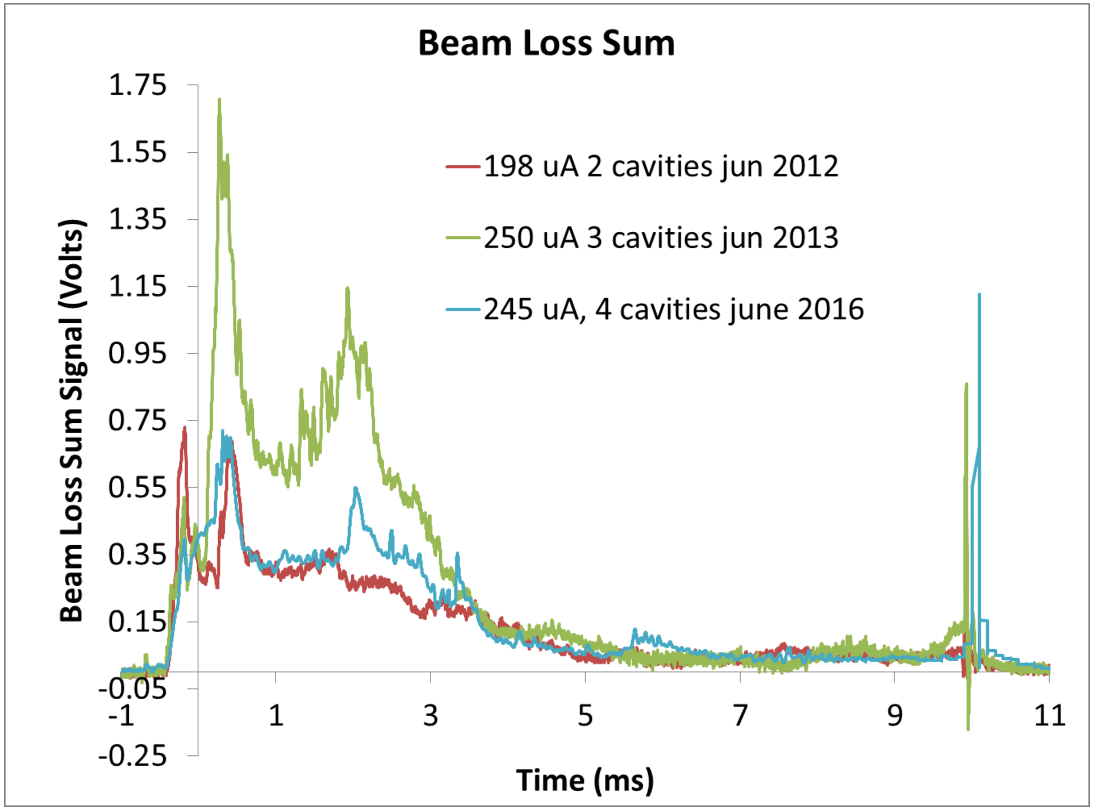
- In current configuration machine capable of accelerating 3.15×10^{13} with 9 % loss equivalent to 250 μA operation (200 kW)

- Limited by:

  machine acceptance
  (collimated to 75 %)
  (beam control/alignment)

  Head Tail Instability

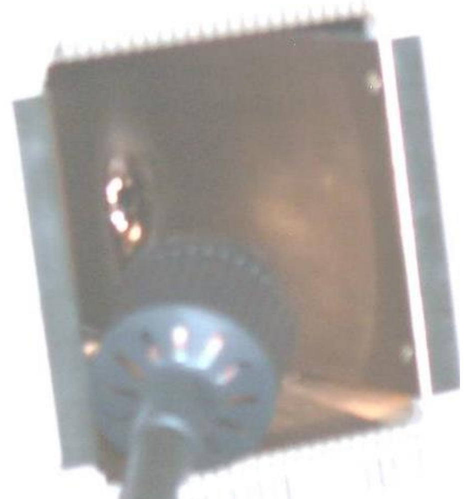
- Operated at 1.6 Hz only

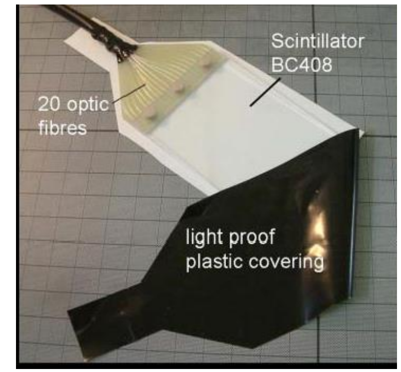


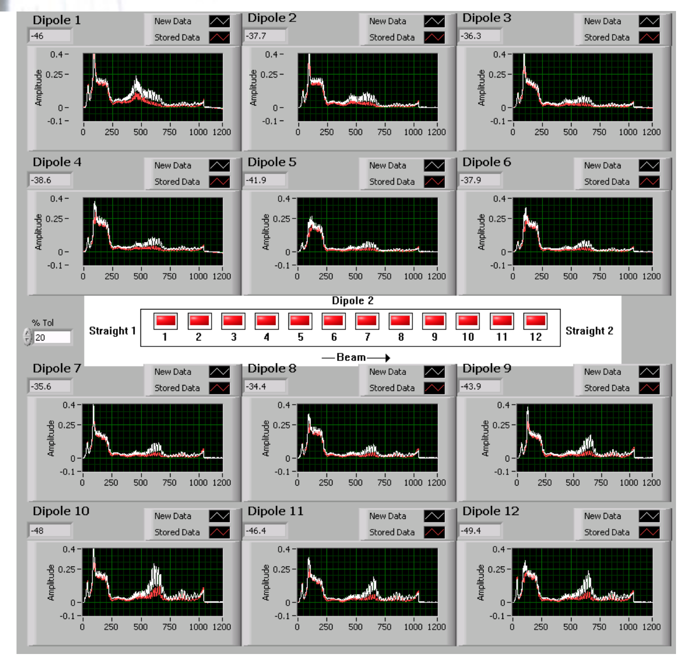
Science & Technology Facilities Council
ISIS

Scintillators

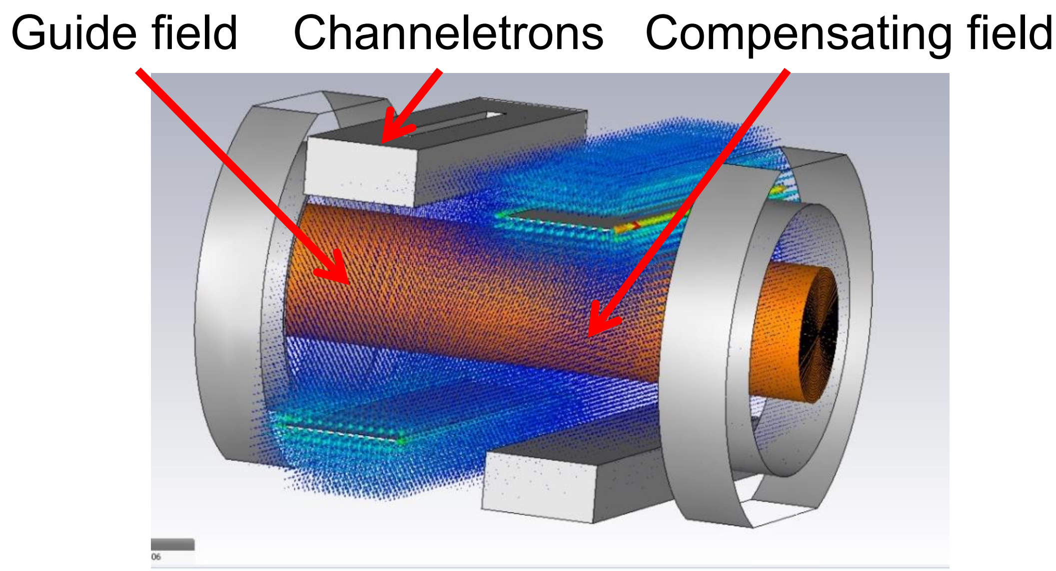
- Beam damage inside dipole caused by small uncontrolled loss from collimation straight.
- Normal BLM’s outside dipole yoke shielded from loss.
- New non-metallic scintillator based BLM positioned inside rapid cycling dipole field to detect losses.
- Scintillators allow collimator and beam tuning setup without hitting dipole
- All ring dipoles will have scintillators by 2017







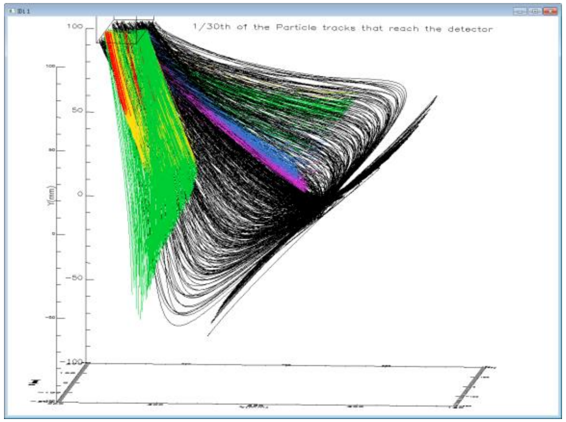
Multi Channel Profile Monitor

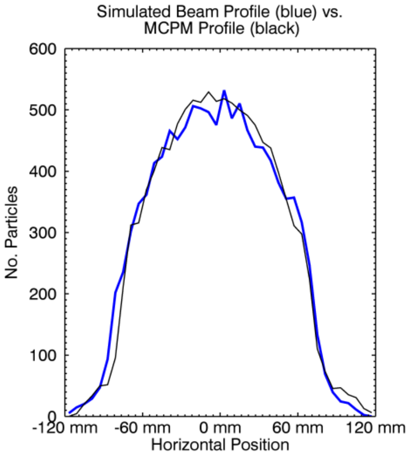


- Accurate transverse profile measurements key to machine setup and R&D topics.

- Residual Ionisation Profile monitors in development:
  40 channeletrons,
  Non destructive

- Accurate reconstructed profiles require understanding effects of ion trajectory from
  - Guide fields
  - Space charge field
  - Channeletron response

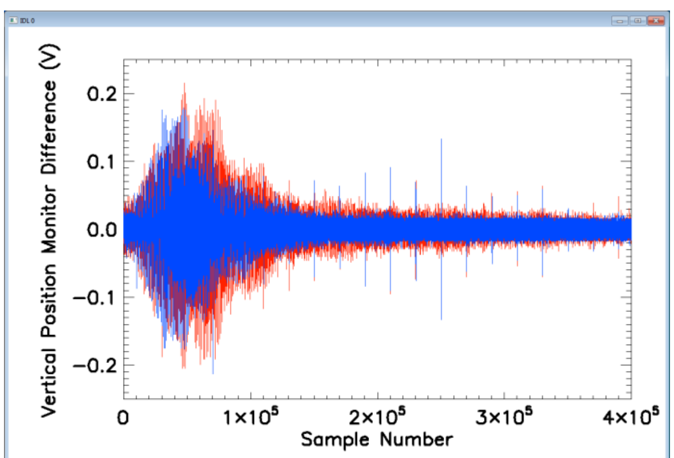




Science & Technology Facilities Council ISIS

Head-Tail Instability

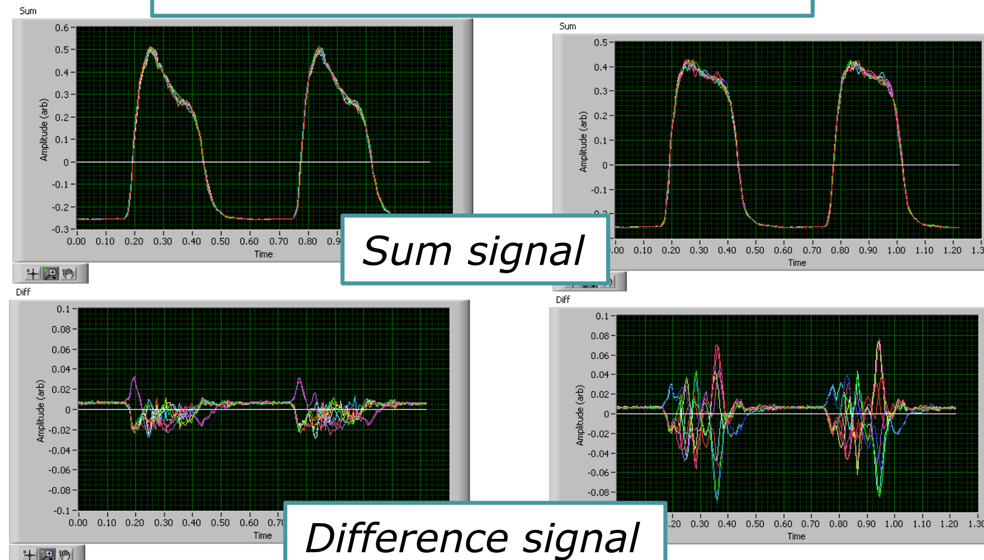
- Driven by impedances
  Resistive wall (?),
  R Williamson MOPR031
  Operation:
    Vertical Q ramp
    Asymmetric bunches
- Damper system in development,
  2018 operation



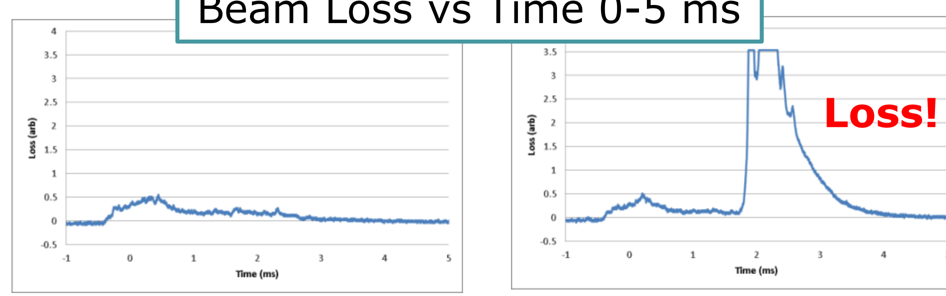
Normal beam
Low loss

Normal beam + Θ shift
Large loss!

ISIS Beam Bunches at ~ 2 ms

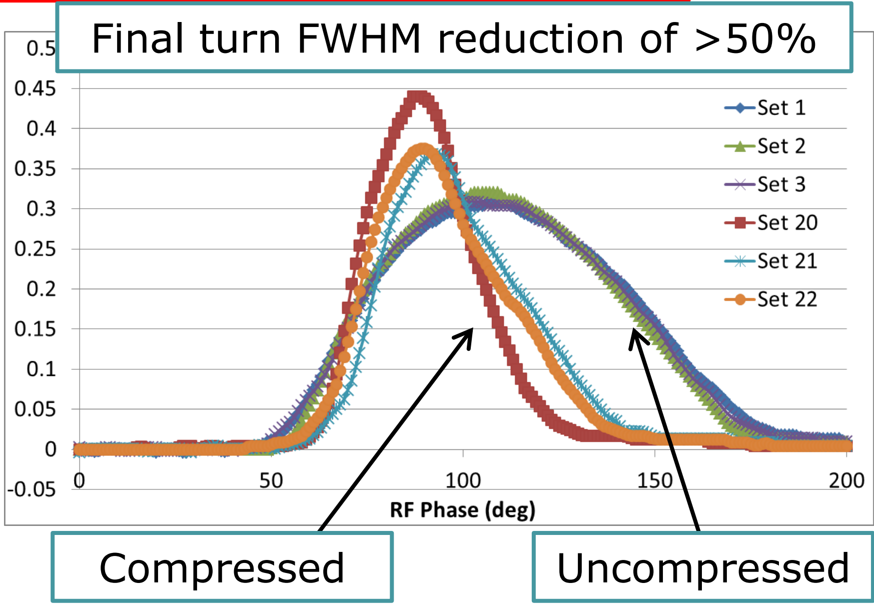


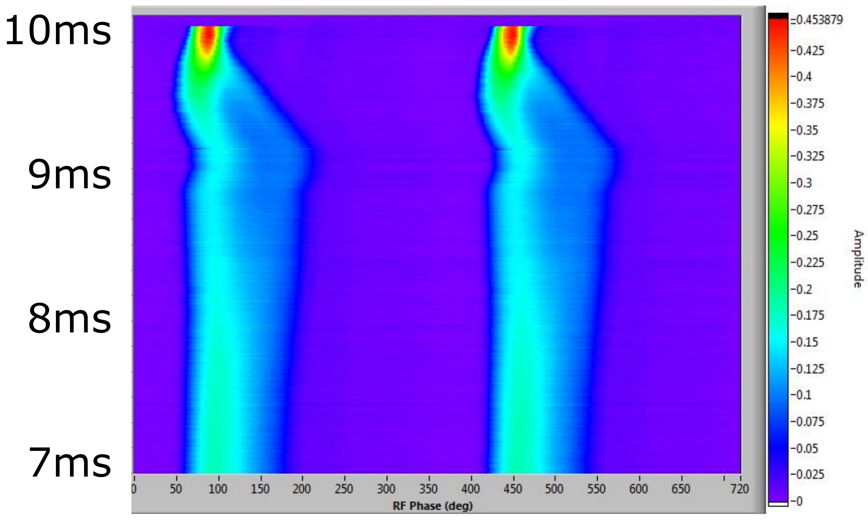
Beam Loss vs Time 0-5 ms



Bunch Compression

- Why shorten bunch?
  - To improve frequency response of muon instruments
  - Maintain low beam loss and good beam quality
- Machine setup
  - Ramp RF voltage down slowly before rapidly increasing ~0.2ms before extraction
  - Step frequency law trim in final 0.2ms
  - Switch off bunch length and phase loops in final 0.2ms
  - Tweak extraction to reduce loss
- Plans
  - Test at higher repetition rates
  - Further extraction beam loss reduction
  - Different methods of bunch compression





R E Williamson, R J Mathieson, D J Adams, et al

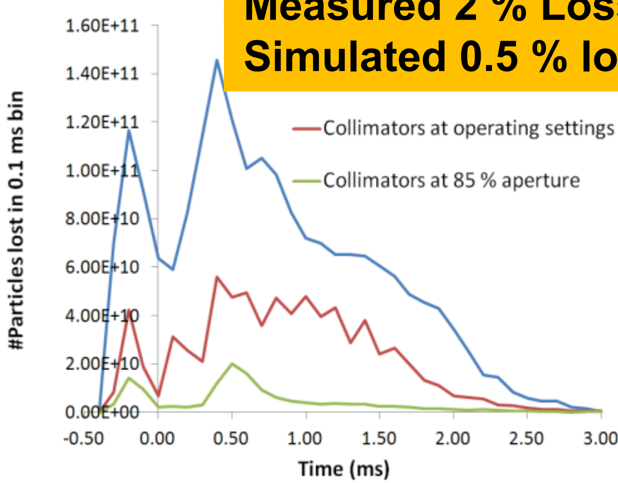
ORBIT Simulations

Goal : Understand ring loss dynamics.

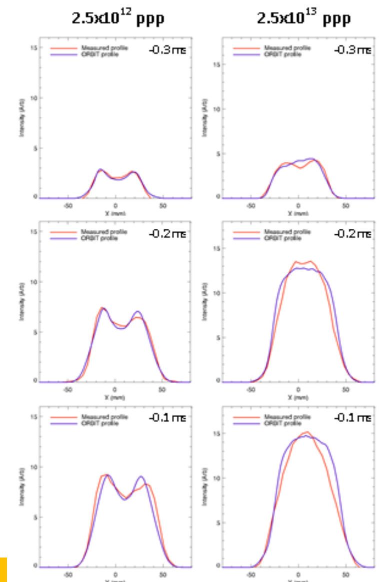
ORBIT model: fitted to measured transverse and longitudinal profiles.

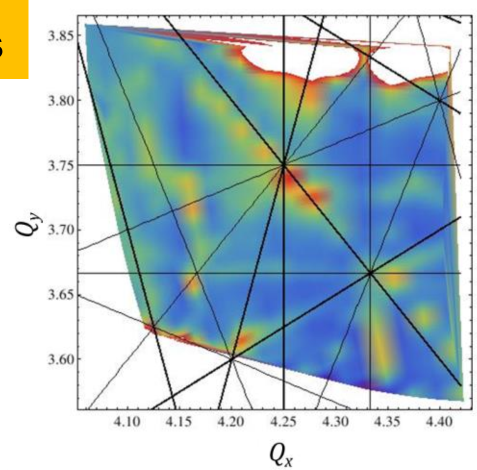
Predict losses and visualise dynamics for machine tuning.

Measured 2 % Loss
Simulated 0.5 % loss

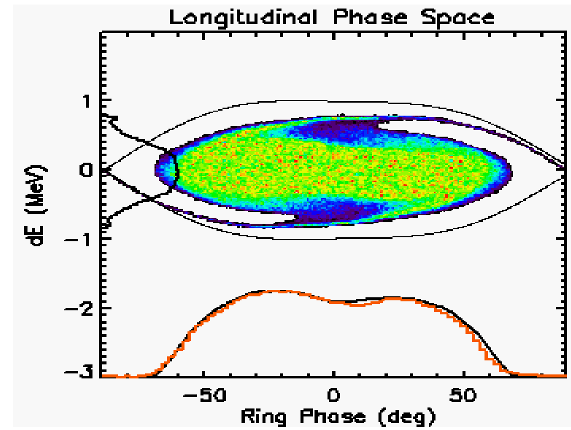


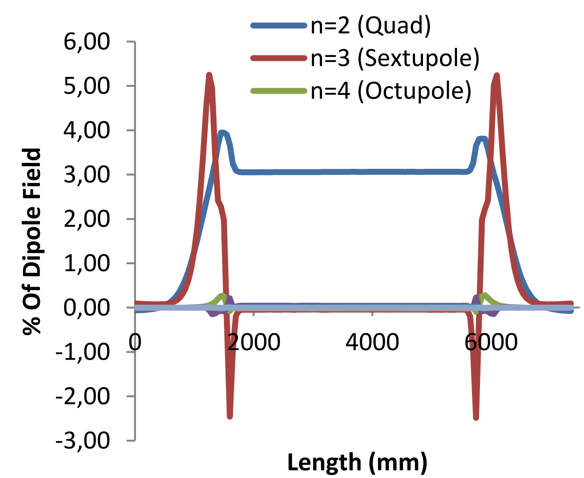
Measured ORBIT injection profiles





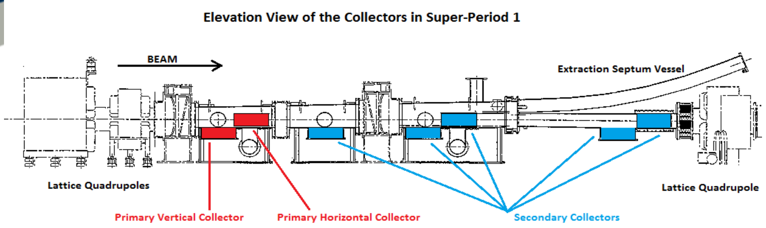
ORBIT@0ms

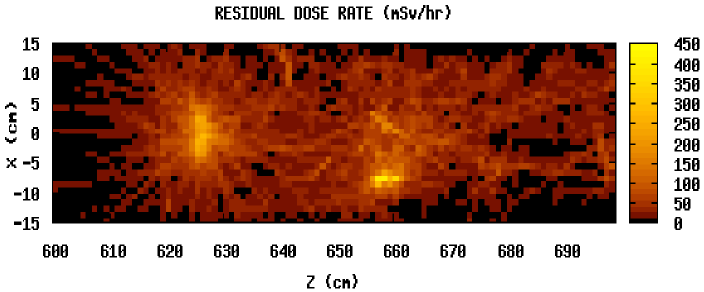


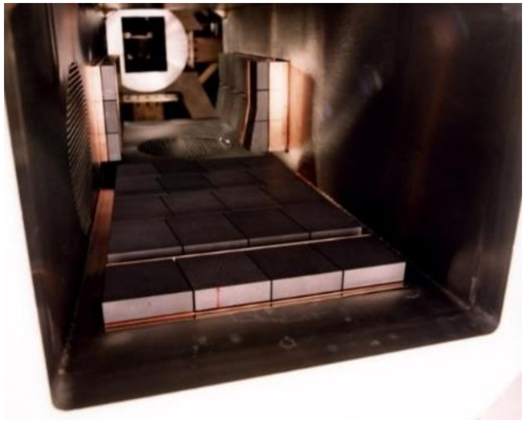


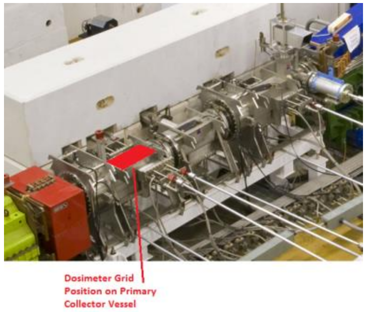
Implementing non linear magnets at moment

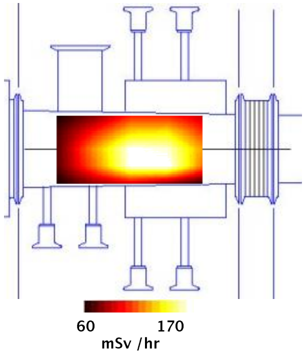
FLUKA Studies – ISIS Collectors

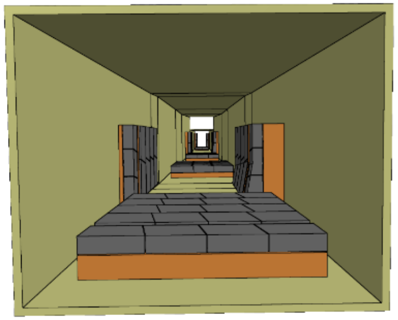








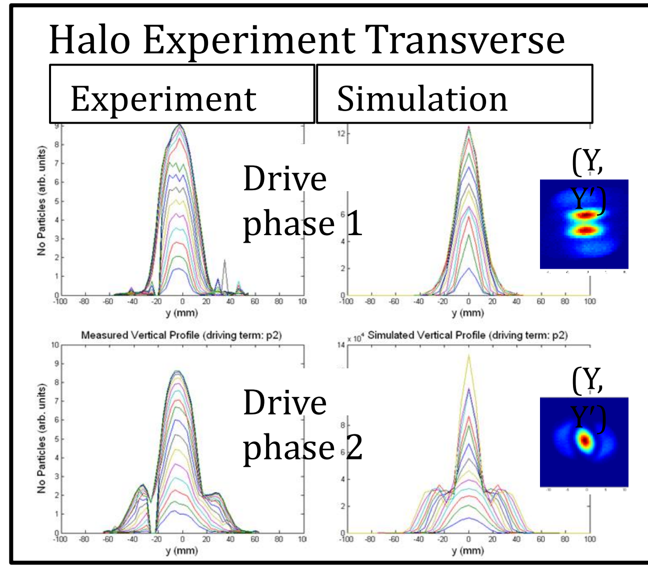


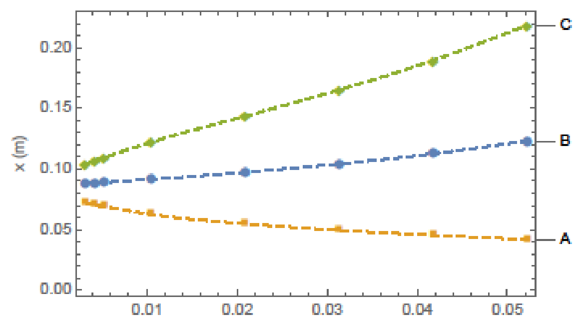


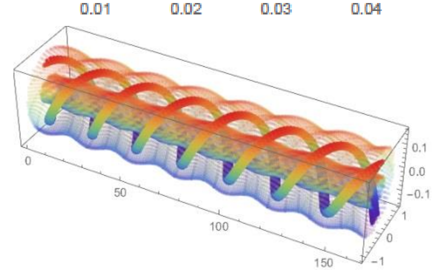
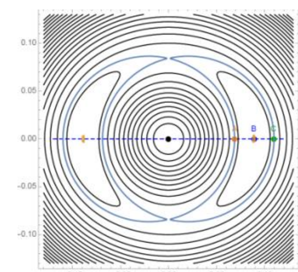
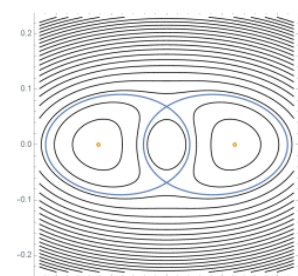
- SP1 collector straight modelled in FLUKA
- ORBIT beam loss input
- 170 mSv/hr measured, 415 mSv/hr simulated
- Total simulated power deposition 663 W, operationally 500-1500 W

Half Integer Resonance

- One of the main loss mechanism on ISIS
- Measured and simulated with ISIS in storage ring mode.
- Lobe behaviour acts as expected as a function of driving term and tune.
- Mathematical description in development with promising results. (Chris Warsop , MOPR030, HB2016)





(Y, Y', s)

Science & Technology Facilities Council ISIS

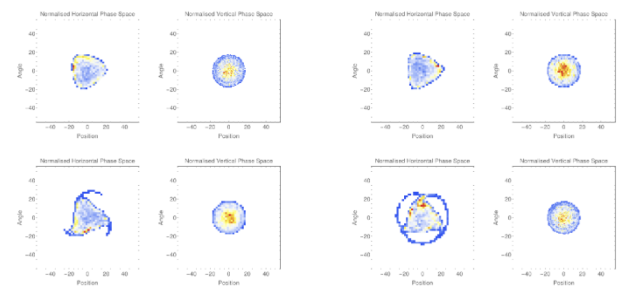
Image Effects

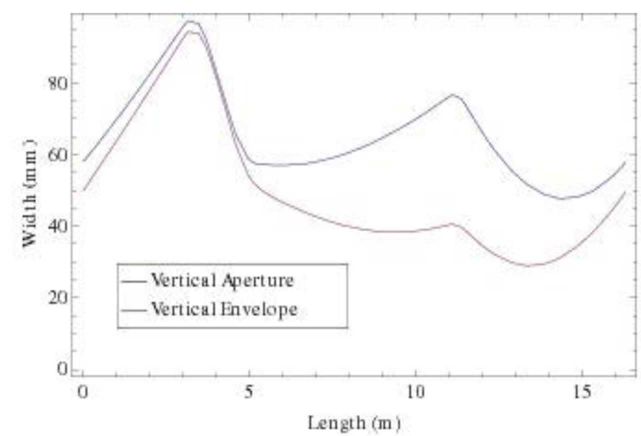
- Effects of space charge and image forces from ISIS conformal rectangular vacuum vessels under study with in house SET3D code.
- Closed orbit errors generating sextupole resonances.
- Large deviations from design tune lead to reductions in machine acceptance and non linear driving terms

Equation for image resonances

$$\frac{E_{yimage}}{4\lambda} = \epsilon_1 \frac{\hat{y}}{h^2} + \xi_1 \frac{\bar{y}}{h^2} + \kappa_{03} \frac{\hat{y}^3}{h^4} + \kappa_{12} \frac{\hat{y}^2 \bar{y}}{h^4} + \kappa_{21} \frac{\hat{y} \bar{y}^2}{h^4} + \kappa_{30} \frac{\bar{y}^3}{h^4} + \ldots$$

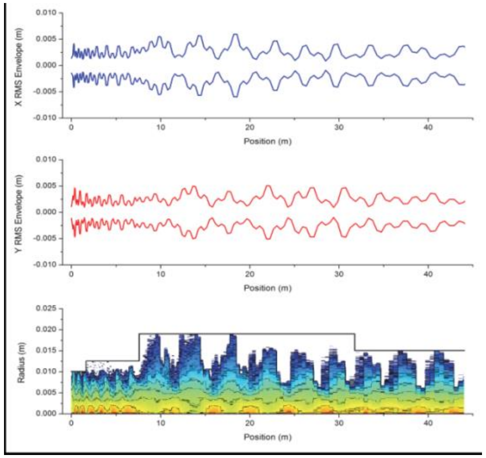
$\kappa_{12} \frac{\hat{y}^2 \bar{y}}{h^4}$ is a sextupole term proportional to the closed orbit



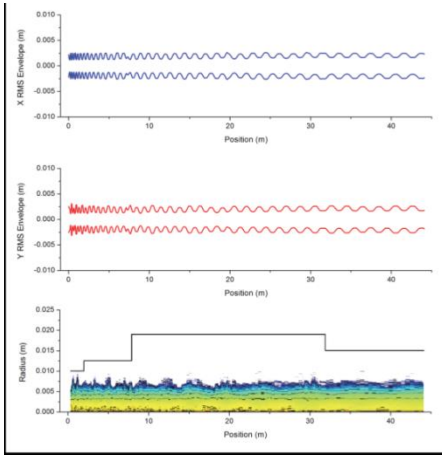


MEBT upgrade

Existing linac envelopes



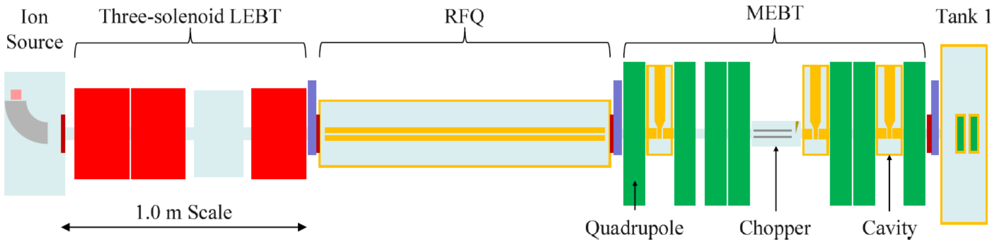
Matched linac envelopes



Improve Matching between RFQ and Linac tank 1

Currently loose ~ 25 % beam.

Install MEBT to match into Linac Tank 1



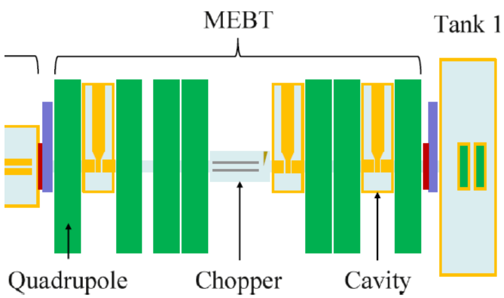
7 Quads and 2 buncher cavities, 96 % transmission

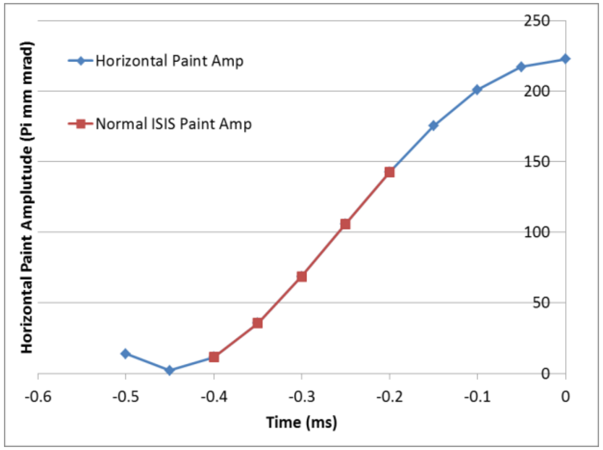
Increase linac transmission current from 26 mA to 36 mA

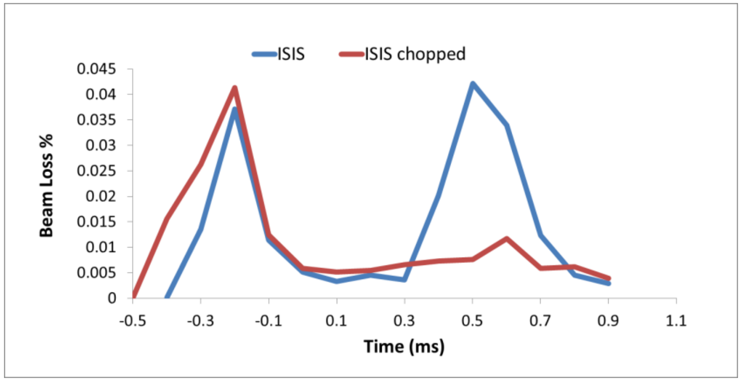
Installation in 2019

MEBT chopper

- ISIS RCS has 200 μs injection interval (133 turns). Dispersive horizontal painting 10-140 π mm mrad, Non adiabatic RF capture losses ~ 3 %
- MEBT chopper, 61 % chopping factor, ± 55° degrees RF in ring. , variable timing. Inj time : 26 mA ~300μs , 36 mA ~ 200 μs
- H^- Paint changes with pulse length, Peak space charge moves from 80 to 70 MeV. Studied in ORBIT to see impact on losses.







Future Upgrades

- Future upgrade paths under study, taking into account ISIS Instrument, Neutronics, Target and Accelerator groups .

- Accelerators options under consideration:
  - Increase ISIS injection energy to 180 MeV with upgraded linac, 0.5 MW
  - Multi MW Synchrotron or FFAG

    (C. Prior WEAM6X01 talk tomorrow)

- Front End Test Stand (FETS): 60 mA, H^-, 3 MeV technology demonstrator for next gen facilities. First RFQ beams this year.
  - Could be used to feed a new low energy FFAG, necessary for high power FFAG R&D.

Conclusion

- Since first operation in 1984 ISIS has continued to improve in operating intensity and beam control maintaining its position as a world class neutron facility.

- Numerous hardware upgrades and Accelerator R&D have provided extensive experience on how to operate a machine for nearly 4 decades and how to manage operations working near a realistic intensity limit.

- A future ISIS-II is under study to best utilise our experience as well as knowledge gained from the operation of other high power facilities.