BEAM LOSS CONTROL IN THE ISIS ACCELERATOR FACILITY

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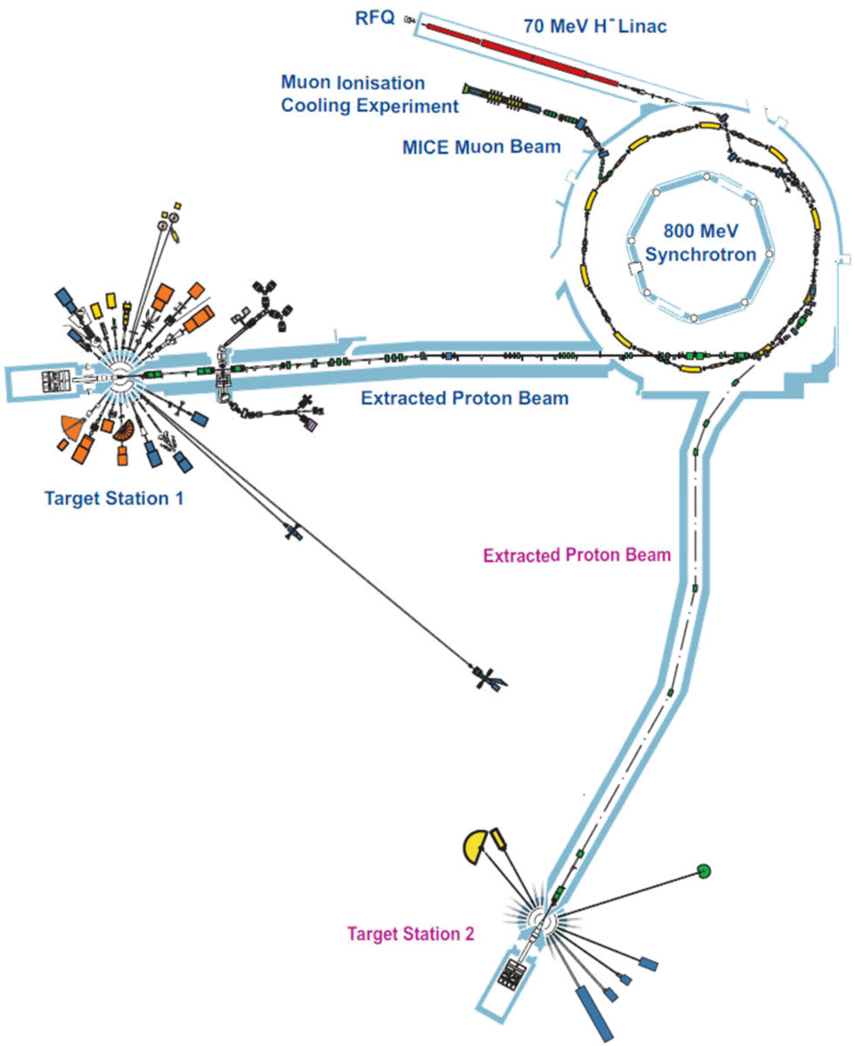
Facility Overview



- H^- Ion Source: ~50 mA, 300 μs pulse length.
- 665 KeV RFQ.
- 70 MeV Linac.
- 70 MeV injection line (HEDS).
- 800 MeV Synchrotron, 50 Hz, H^- charge exchange injection, accelerating up to $3x10^{13}$ protons per pulse, 200 KW.
- EPB1 delivers beam to Target station 1 at 40 pps.
- EPB2 delivers beam to Target station 2 at 10 pps.

A loss limited high intensity machine

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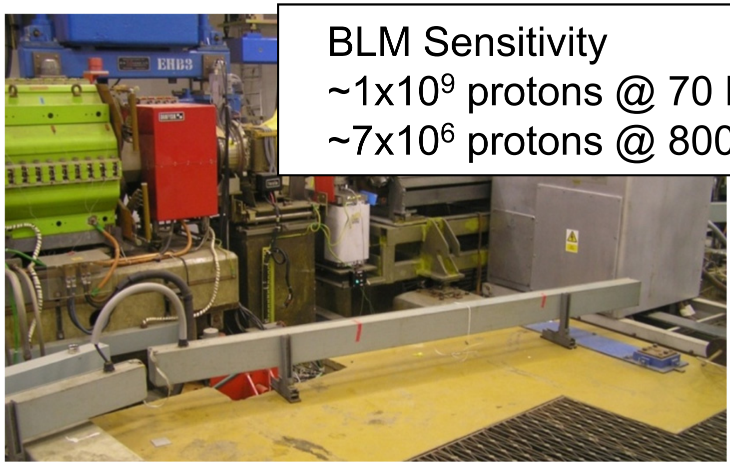
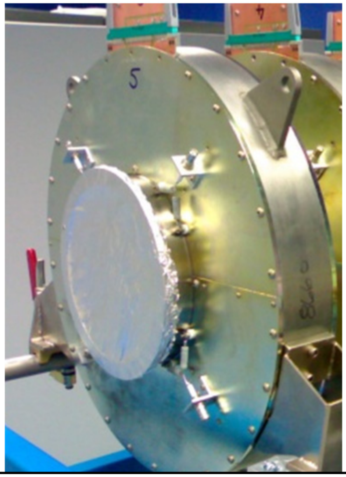
Beam Loss Diagnostics

- ISIS Beam Loss Monitors
(3 m, coaxial ionisation chambers)



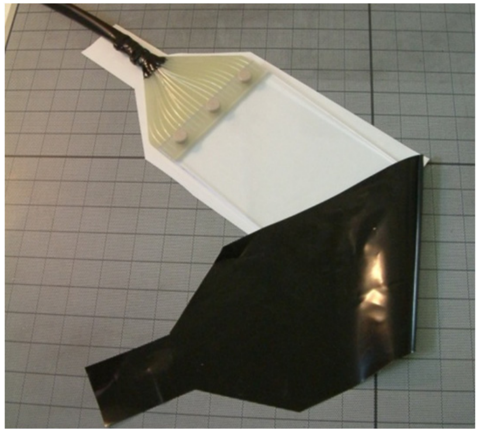
BLM Sensitivity
~1x10^{9} protons @ 70 MeV,
~7x10^{6} protons @ 800 MeV

- ISIS Intensity Monitor
(transformer)

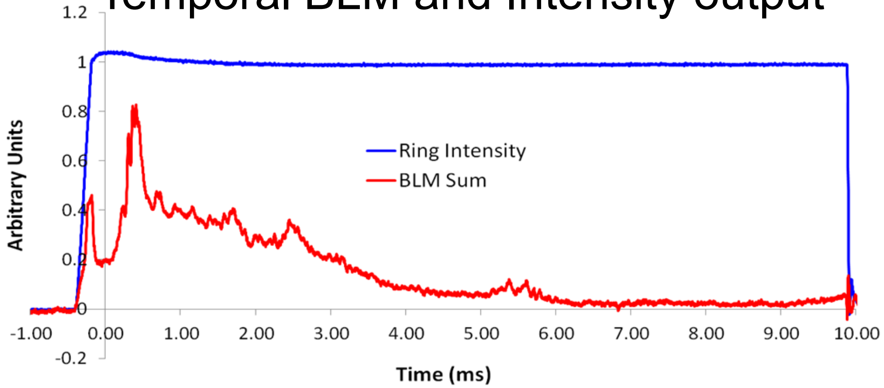


Intensity monitor sensitivity
±3x10^{10} ppp

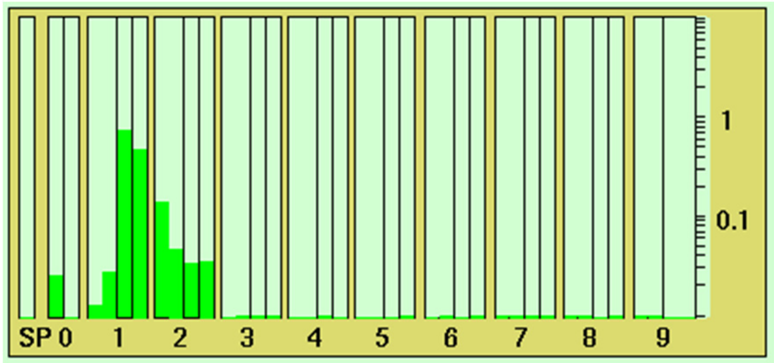
- Scintillator Loss Monitor
(plastic BD408)



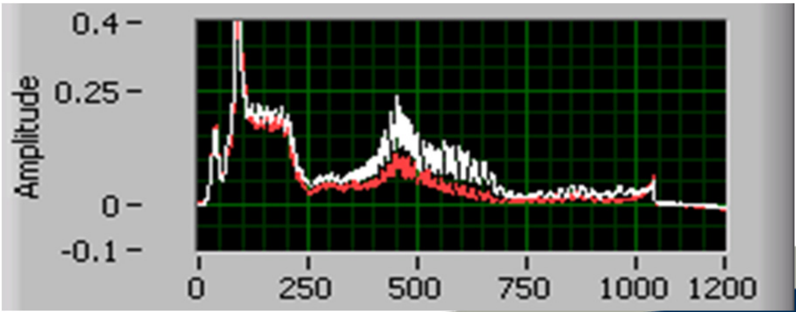
Temporal BLM and Intensity output



BLM spatial integrated (0-10ms) output



Temporal Scintillator output



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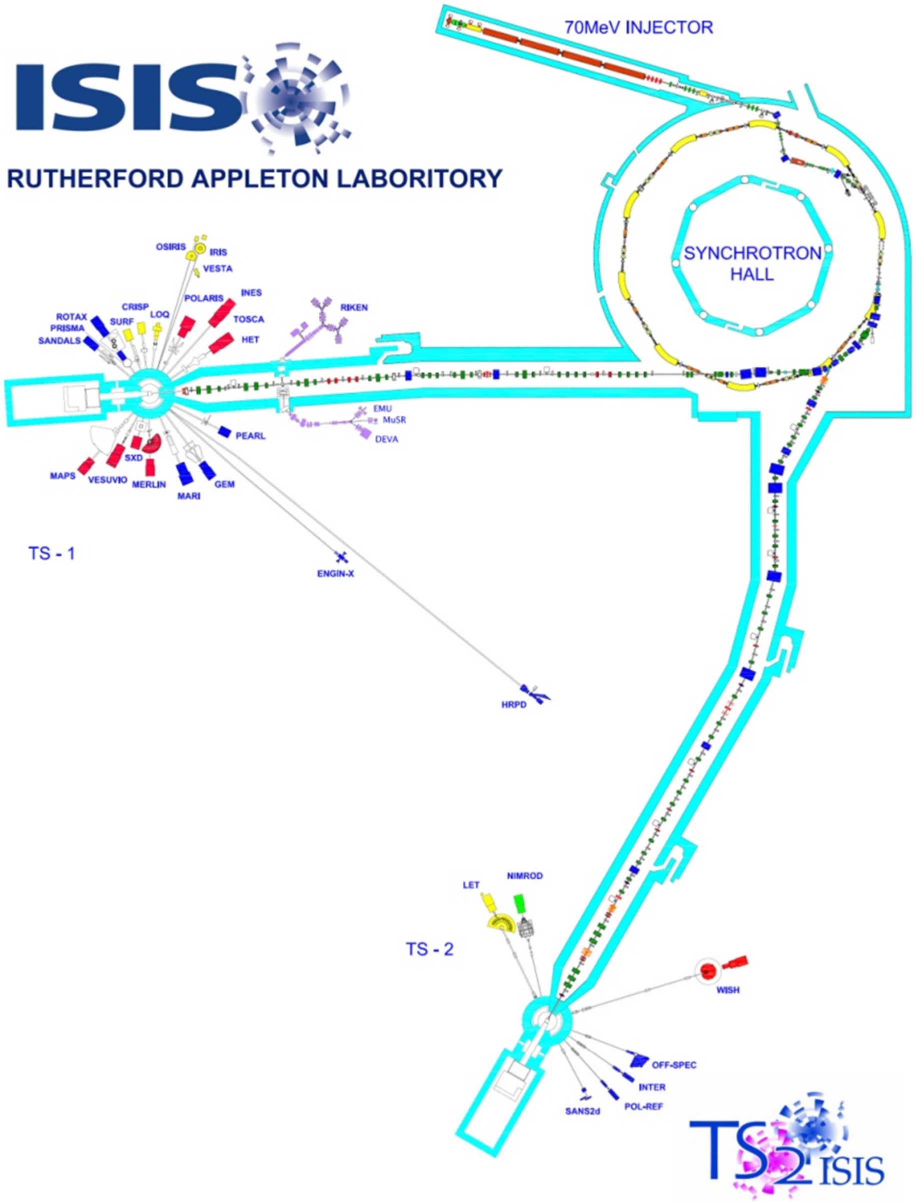
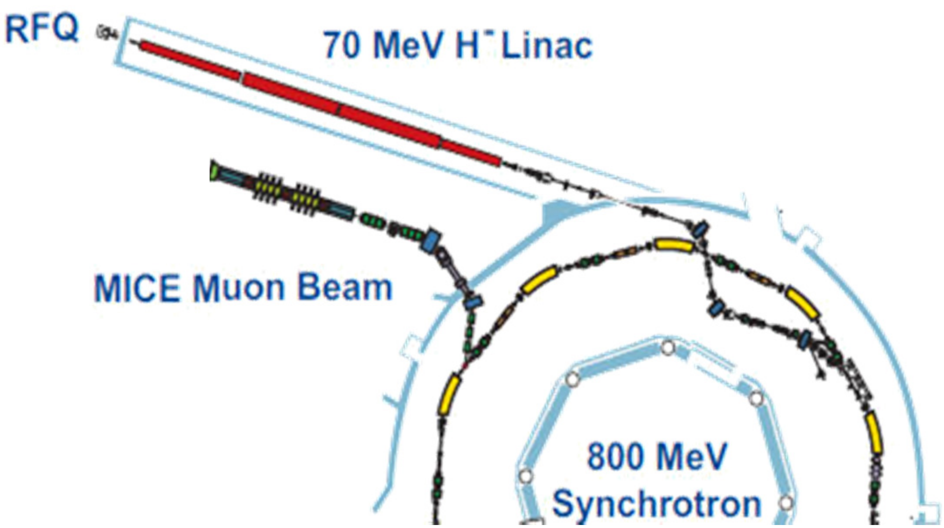
Beam Diagnostic Layout



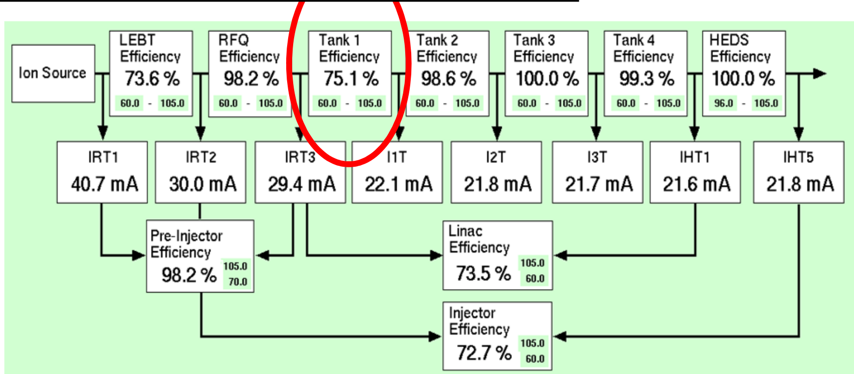
	Intensity Monitor	Beam Loss Monitors
Ion Source	1	0
RFQ	2	0
Linac	4	9
HEDS	4	8
Synchrotron	1	39
EPB1	6	10
EPB2	5	15

- Loss levels from these diagnostics are monitored every 50 Hz pulse
- The protection system response depends on severity and longevity of the beam loss and associated hazard
- Ranging from switching beam off, inhibiting for a few pulses, to issuing warnings

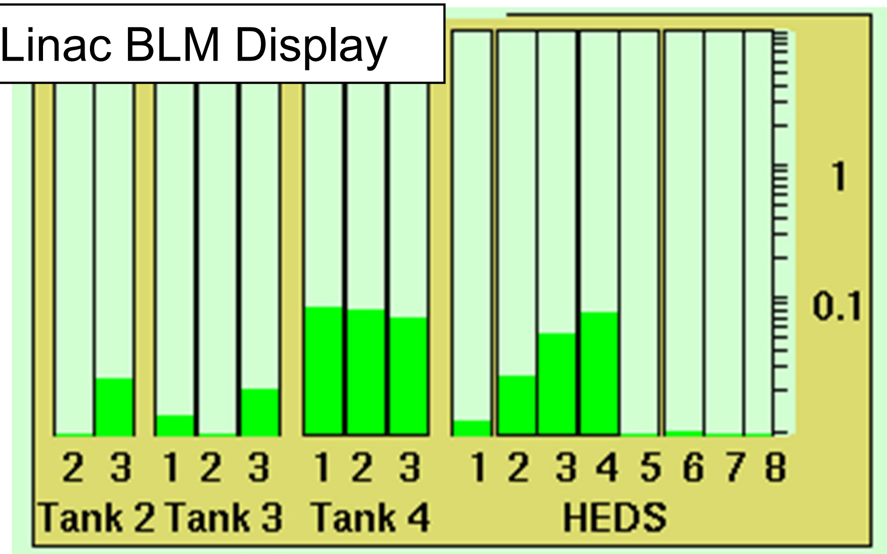
Injector Operation



Linac Summary Display



Linac BLM Display



0.1 Vs is equivalent to 2.3x10^9 lost H^- particles

- Beam loss optimised using:
  - Ion source extract volts
  - LEDS solenoids
  - RFQ and linac phases
  - Tank and HEDS quadrupoles.
- Dominant loss is Tank 1: 70-80 % transmission.

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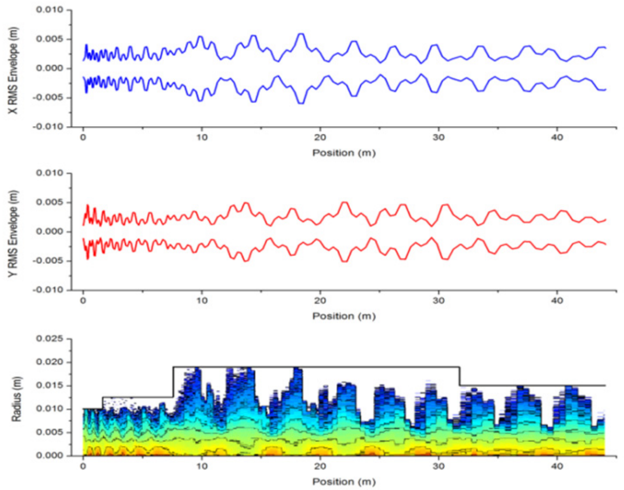
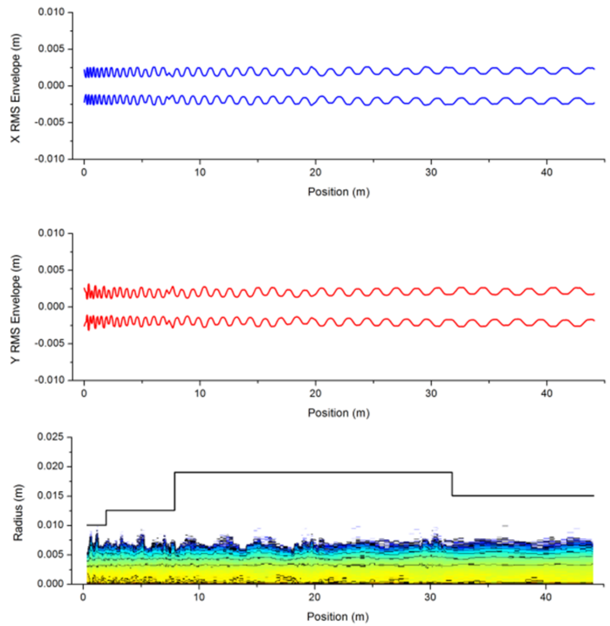
Injector Operation: Simulation and Possible Upgrade

Envelopes of existing linac

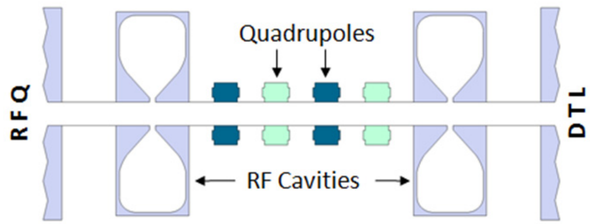


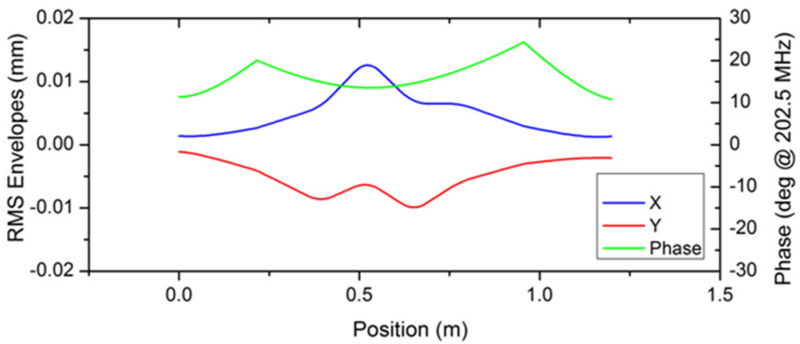
Envelopes of linac after matching



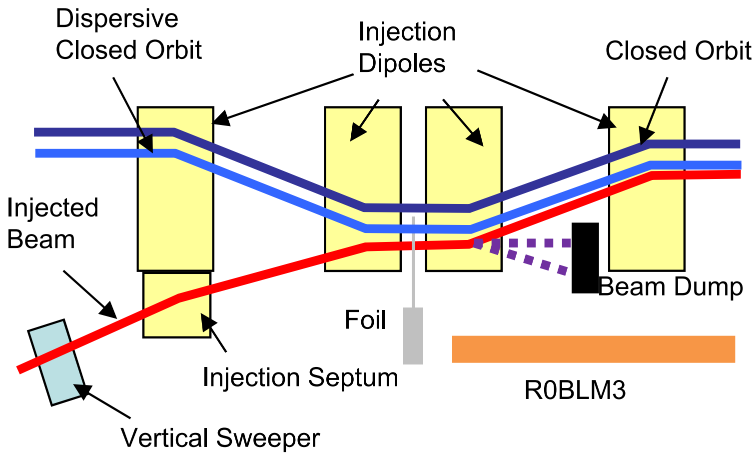
From: C Plostinar, C Prior, G Rees, A Mitchell, A Letchford, "Modelling the ISIS 70 MeV Linac", p3859, THPPP052, IPAC12

- Improve Matching between RFQ and Linac tank 1 with the addition of 4 quads and 2 buncher cavities.
- Simulations suggest almost lossless transmission.





Ring Operation: Injection



• H$^-$ charge exchange injection over ~130 turns accumulating ~3E10^{13} protons with efficiency >98 %. Anti-correlated painting.

• Foil stripping efficiency ~98 %. Un-stripped beam transported to dump producing BLM signal R0BLM3.

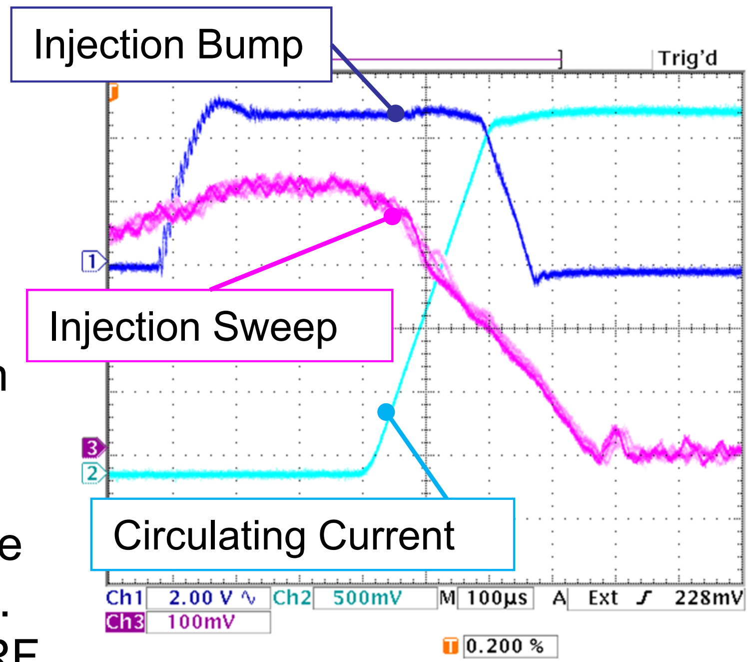
• Un-tunable increases in R0BLM3 give indication of foil failure.

• ~30 foil re-circulations for each injected proton result in scattering and losses.

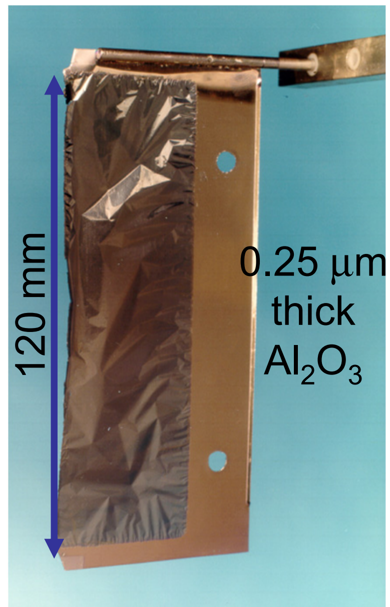
• These are localised mostly in the injection and collector straight.

• Beam loss optimisations include 6D phase space control in both injection line and ring. Use: HEDS quads, dipoles, linac RF, ring RF, and transverse injection painting parameters.

Key Signals for Injection



Foil



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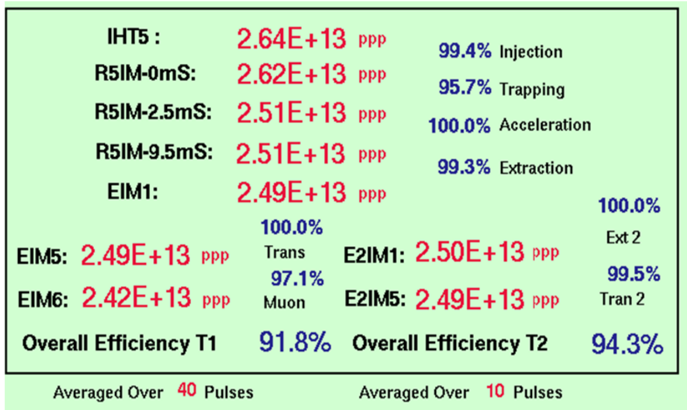
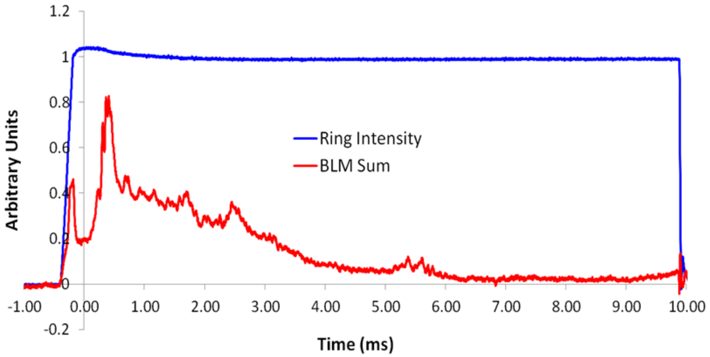
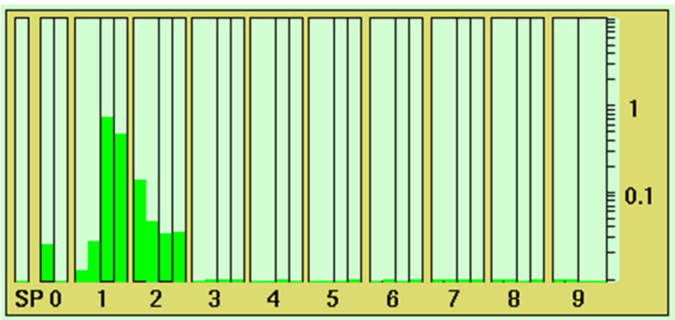
Ring Operation: Trapping and Acceleration







- Beam trapped and accelerated from 70-800 MeV in 10 ms
- Addition of dual harmonic RF system increased operating trapping efficiency (0.0-2.5ms) from >90% to >95%
- Acceleration losses (2.5-10.0 ms) <1%
- Longitudinal losses driven by fast trapping of unbunched (non-chopped) injected beam
- Transverse losses driven by high intensity effects mostly mitigated by betatron tune variation.
- Losses localised to super period 1 and 2 by the use of collectors

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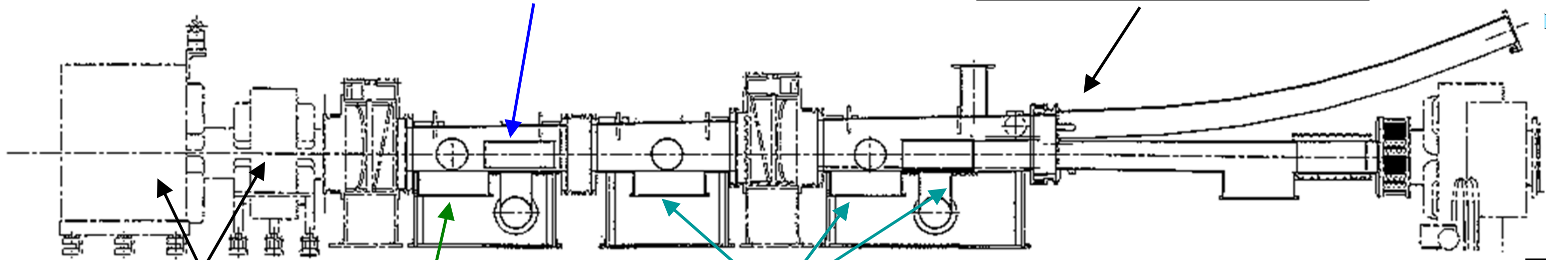
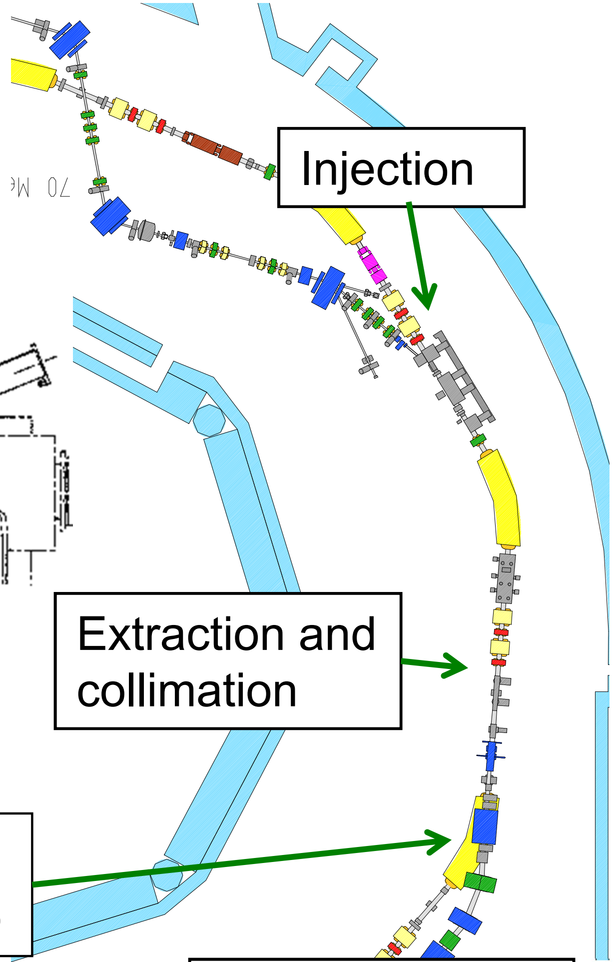
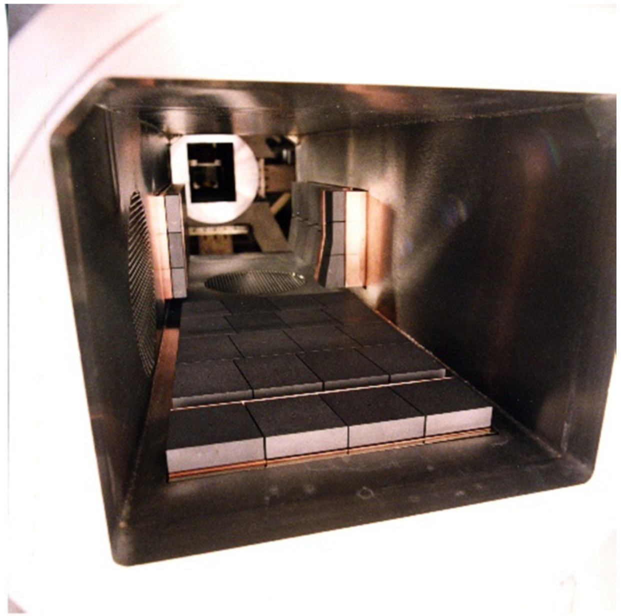
Ring Operation: Collectors

Side View of Collimator Straight

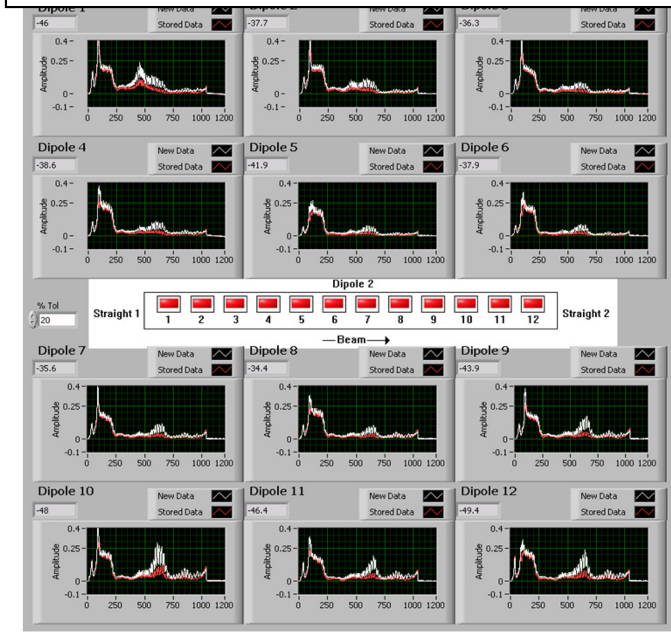




View of ISIS Collectors



Output from Scintillator BLMs (in ISIS main dipole after collectors)



Beam Damage!

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Ring Operation: Extraction

- Ring extraction: Vertical closed orbit bump and single turn fast extraction using 3 kickers.
- Originally operated with 12 μVs loss.

- Vertical beam emittance 283±20 π mm mrad (measurements using orbit bumps and BLMs)

- Engineering vacuum vessel apertures show acceptance on extracted turn is 220 π mm mrad. (acceptance limited by quad doublet and septum)

- New larger aperture septum and new vertical bump increases acceptance to 280 π mm mrad. (new elements installed in 2000)

Vertical beam loss on near-by blm reduced from 12 μVs to <1 μVs.

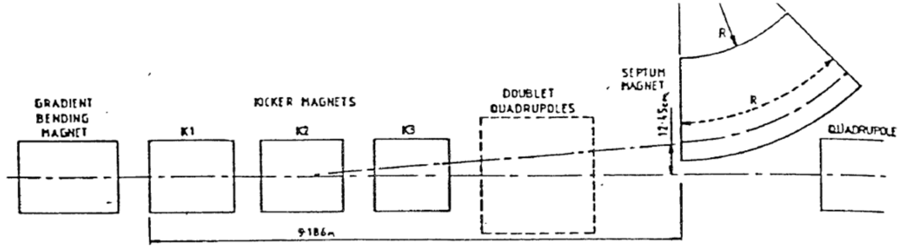
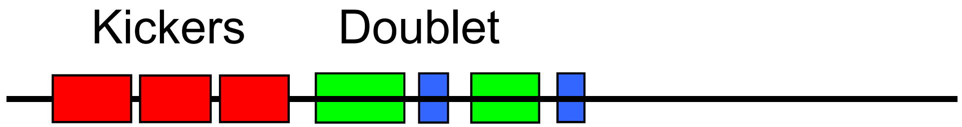
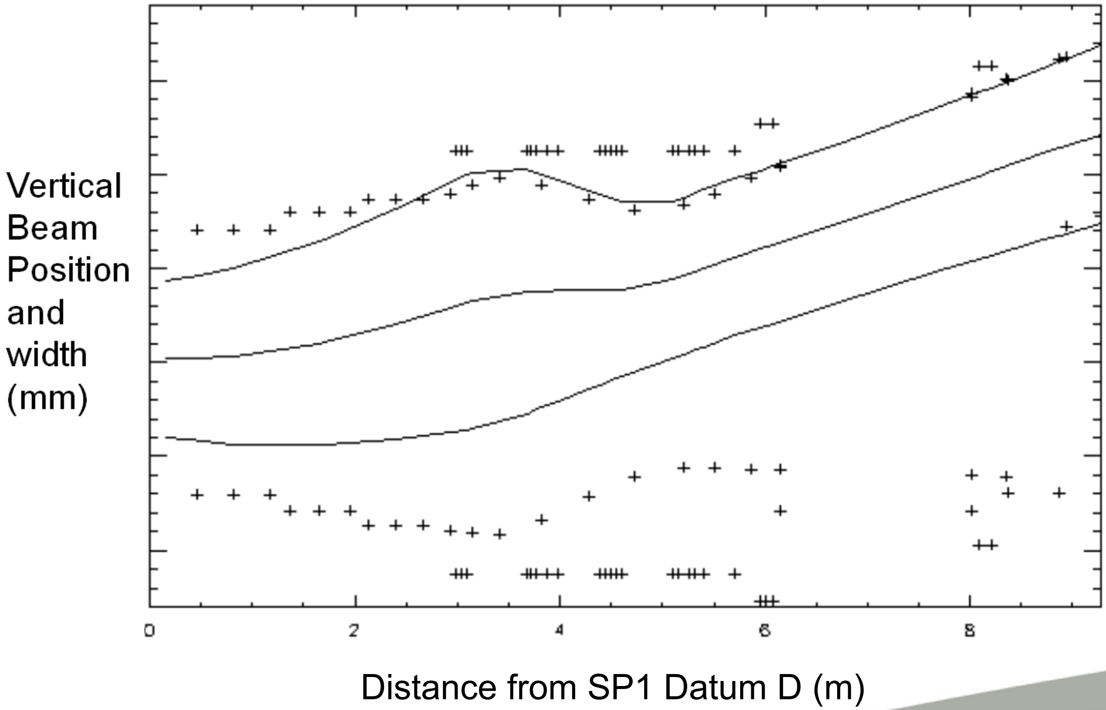


FIG 1·15 EXTRACTION COMPONENTS IN SUPERPERIOD 1





Beam Optimisation

- Many key parameters require time dependent control
- Use in-house arbitrary waveform "function generators"

  Typically optimise at 20 points during 50 Hz cycle

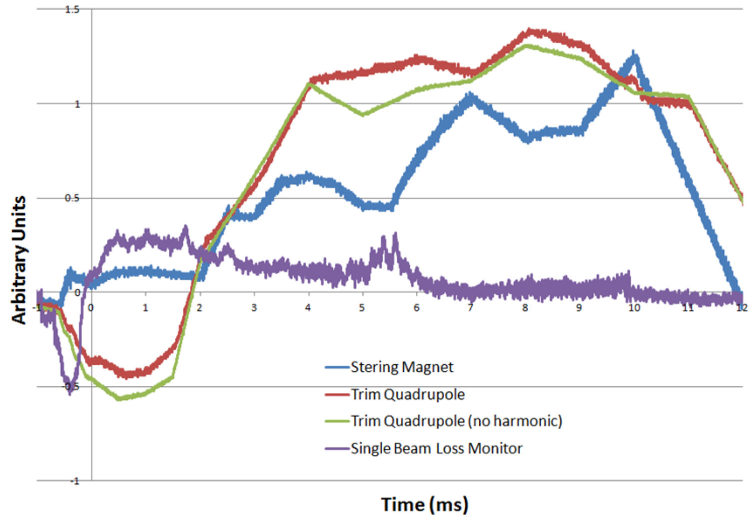
  e.g.

  Vertical sweeper (injection painting)

  Trim quadrupoles (betatron Q's)

  Steering magnets (closed orbits)

  RF volts, phase, loops (longitudinal params)

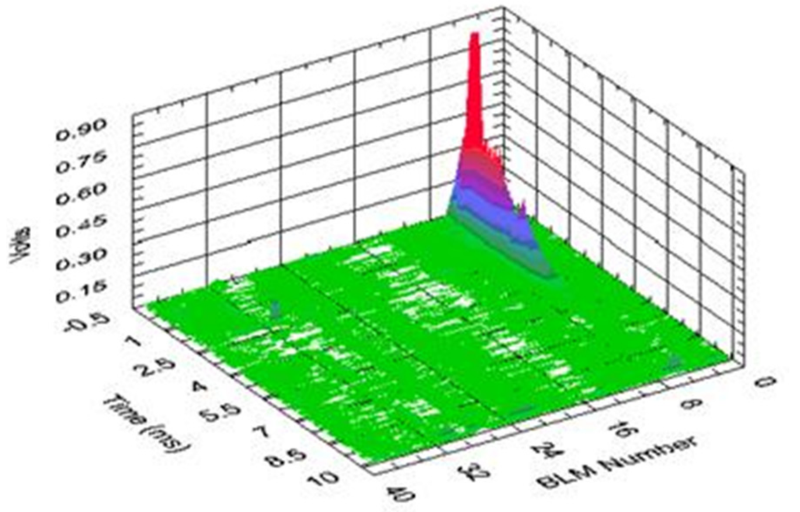


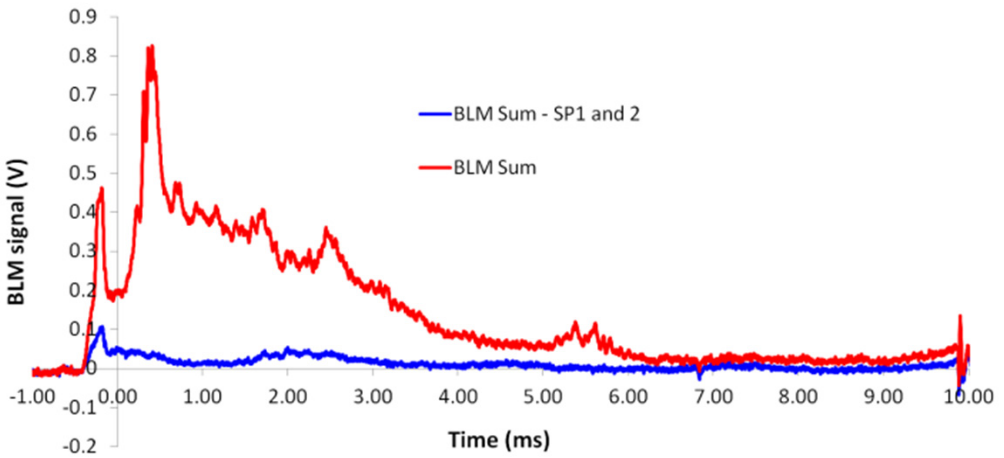
- For many of these there are two sets of generators

  Normal (~50 Hz) and *Experimental* (< 1.6 Hz)

  Allow online optimisations during user runs.

- Beam loss management strategy is to push all losses onto collector straight in sp1.





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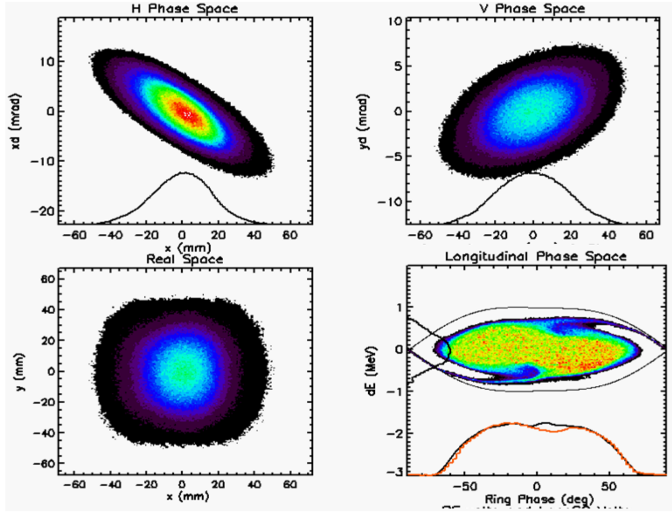
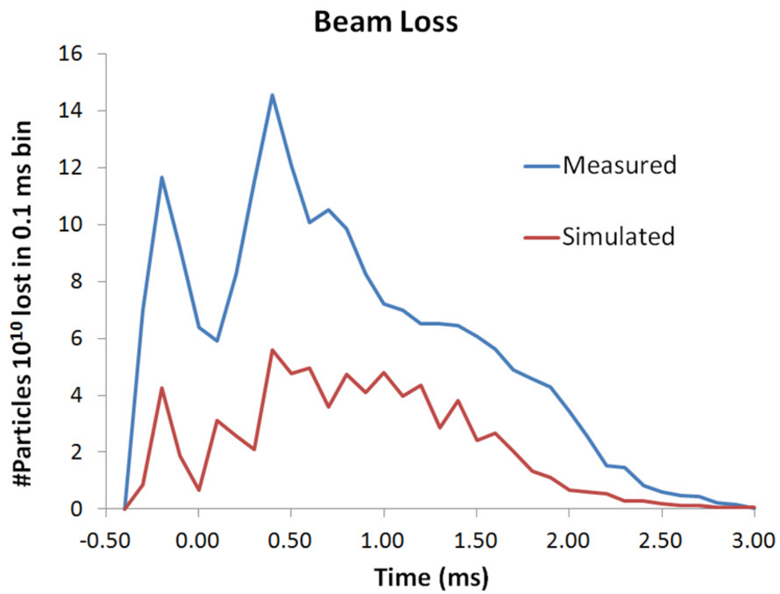
Ring Beam Loss Simulations



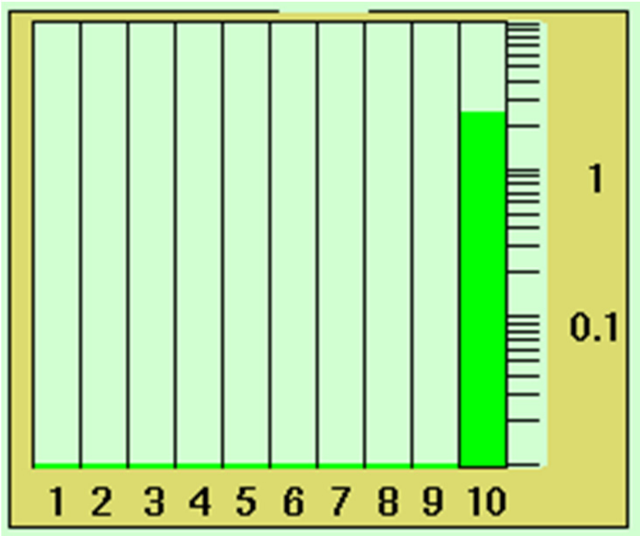
- ORBIT simulations of ISIS RCS include
  - Injection and Acceleration (3D space charge)
  - Injection painting, foil scattering, …
  - Corrected RF (close agreement in longitudinal)
  - Collimators and vacuum vessel apertures
  - (D J Adams, IPAC12, THPPP088, p3942)

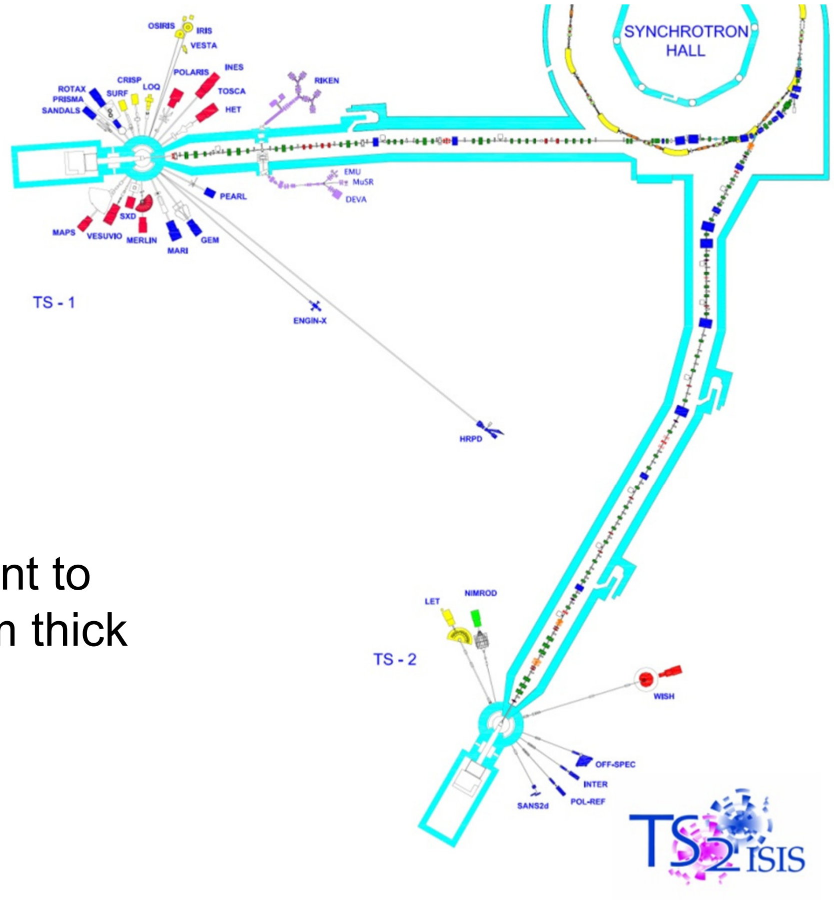


- Total Beam Loss
  - Simulated 3%, Measured 7%
- Time structure - reasonable agreement
- Beam loss on H&V collimators
  - About 50% on each as measured
- Very valuable tool
  - Doesn't include all effects (errors, instabilities …)
  - Shows we still have much to understand!

800 MeV Transport

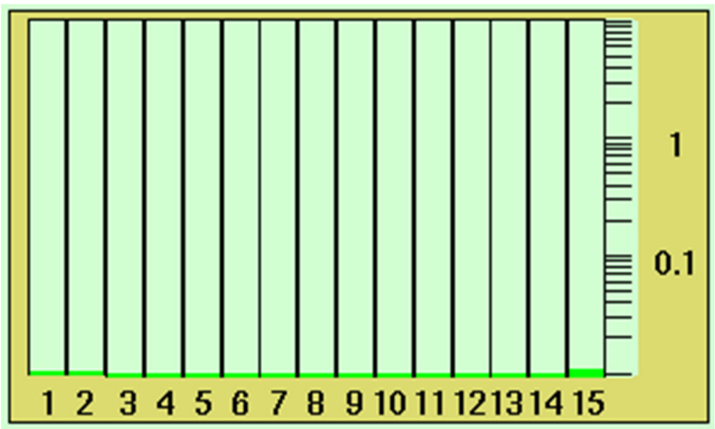
EPB1
BLM





3.5 Vs signal on BLM number ten equivalent to 1.2 x10^{12} lost protons. Produced by 10 mm thick graphite target used for muon production

EPB2
BLM



Low loss achieved by setting beam line aperture at 100% emittance + 20 mm

Summary

• We have outlined the diagnostics, methods and systems used to operate ISIS – a loss limited high intensity machine

• These systems have allowed reliable operation with well controlled dose rates and minimal machine damage over ~28 years

• We expect use of very similar systems and ideas for proposed ISIS upgrades