CCLRC

ISIS Upgrades — A Status Report

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ISIS OPTIMVS NEVTRONVM SPALLATIONENSIVM FONS ORBIS TERRARUM

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S J Payne
C R Prior
A Seville
J W G Thomason
C M Warsop
+ many, many more

CCLRC

– one of the UK's Research Councils

Daresbury Laboratory

SRS

Rutherford Appleton Laboratory

ISIS

Diamond

ISIS – world's leading spallation neutron facility

PSI ISIS SNS J-PARC	↓ Decreasing power – at present

ISIS: 800 MeV protons on to tungsten target

200 μA → 300 μA, 160 kW → 240 kW

But ISIS accelerators primarily a neutron factory

~800 experiments/year

~1600 visitors/year

Typical machine parameter list

Machine parameters

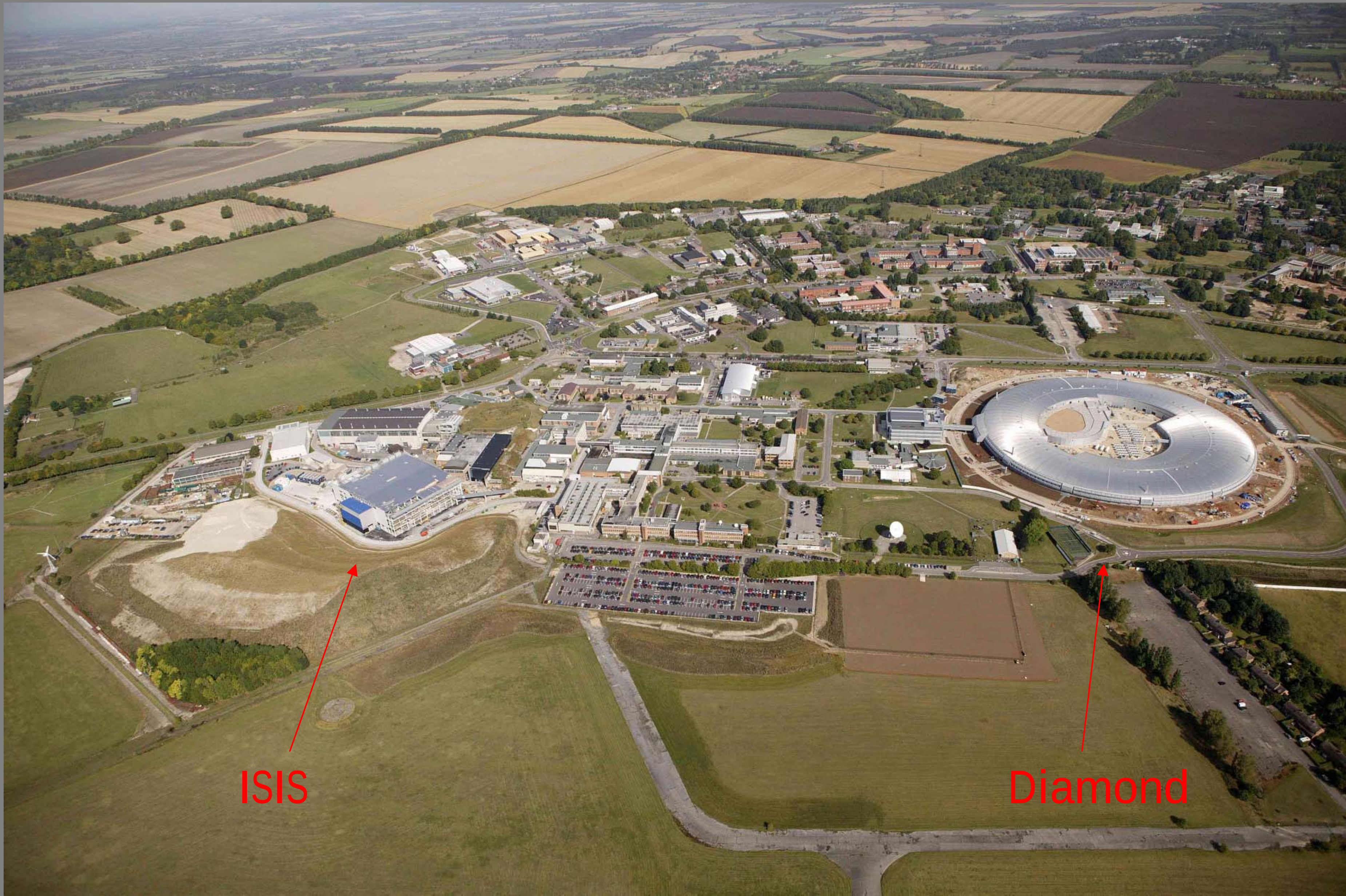
Mean radius (3 × ISIS)	78.0 m
Repetition frequency	50 Hz
Injection energy from ISIS	0.8 GeV
Extraction energy (option of 8 GeV)	3 GeV
Number of circulating protons	3.75×10^{13}
Ring acceptance	304 π mm mrad
Magnet lattice type	racetrack
Number of ring superperiods	2
Number of 3-cell periods per arc	5
Number of arc cells	2 × 15
Number of straight section cells	2 × 7
Number of main B dipoles	2 × 10
Number of secondary b dipoles	2 × 5
Number of main D quadrupoles	2 × 22
Number of trim d quadrupoles	2 × 12
Number of main F quadrupoles	2 × 22
Number of trim f quadrupoles	2 × 12
Gamma transition	13.8
Horizontal betatron tune	11.7
Vertical betatron tune	7.4
Bending angle for B dipoles	16.5°
Bending angle for b dipoles	3.0°
Bending angle for 3-cell arc periods	36.0°
Length of main B dipoles	5.940 m
Length of secondary b dipoles	1.080 m
Length of main D quadrupoles	1.036 m
Length of main F quadrupoles	1.200 m
Length of trim quadrupoles	0.200 m
RMS unnorm. injection trans. emittance	19 π mm mrad
100% unnorm. injection trans. emittance	125 π mm mrad
100% unnorm. 3 GeV trans. emittance	50 π mm mrad
100% unnorm. 8 GeV trans. emittance	25 π mm mrad
100% norm. longitudinal emittance	<1.0 eV sec

CCLRC ISIS

ISIS – key machine parameter list

Reliability

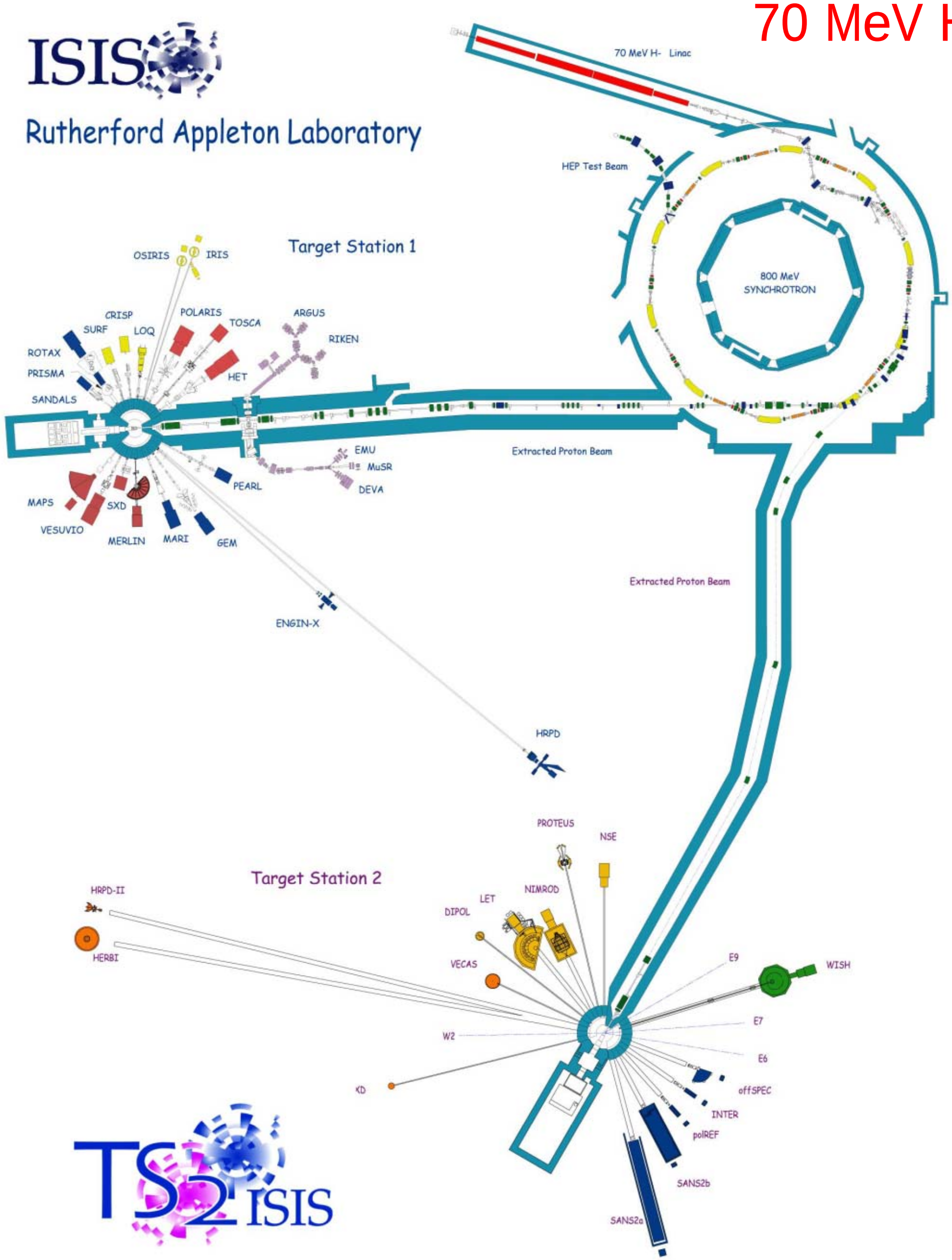
Output

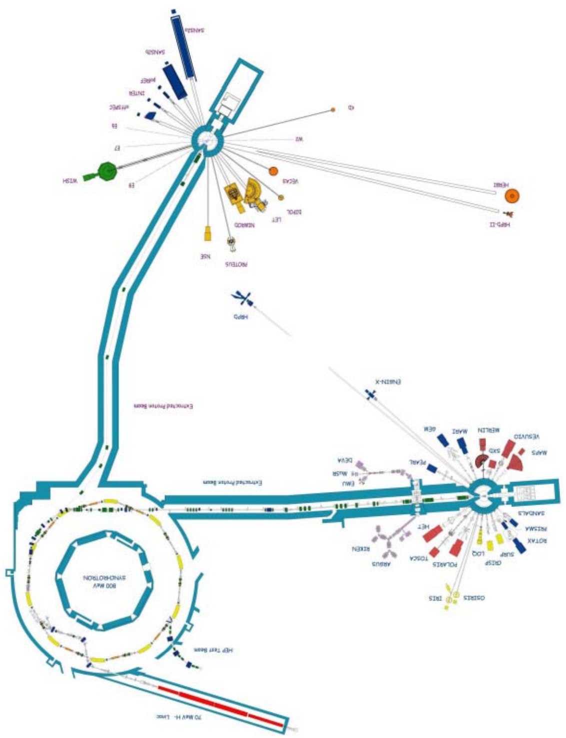


Rutherford Appleton Laboratory, looking north

70 MeV H$^-$ linac

800 MeV proton synchrotron





ISIS from air

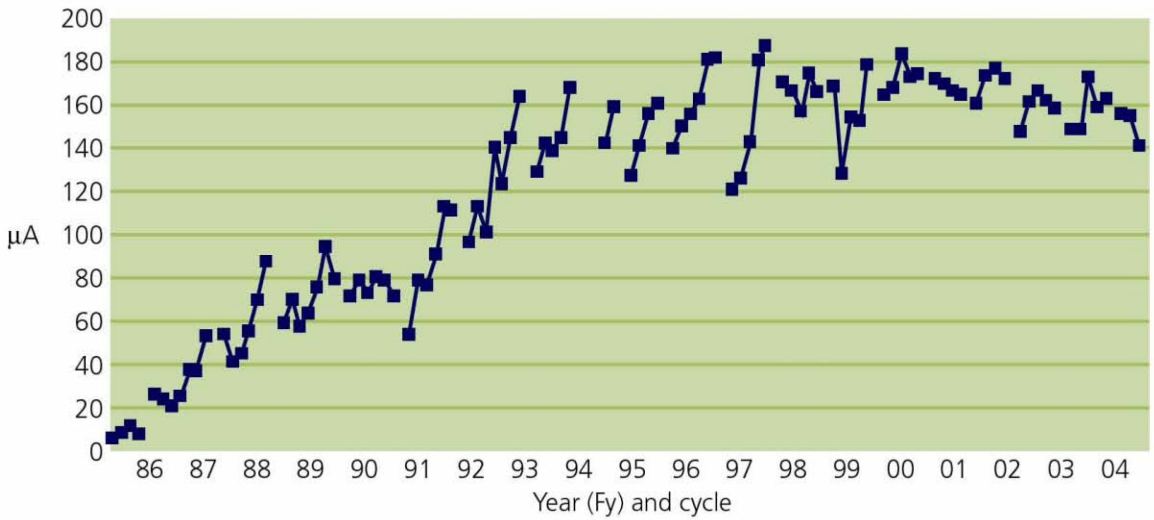
ISIS

First beam December 1984

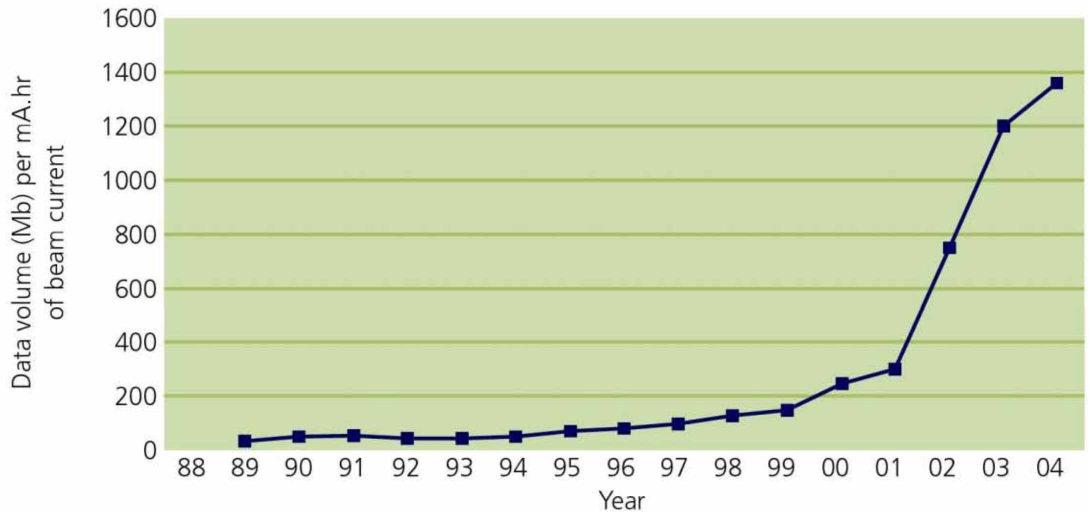
10 amp-hours delivered on 12 December 2005

36,000 C
2.25E+23 protons
4.4E+24 neutrons
7.5 g neutrons

~£30M/g (excl. capital costs)



Average ISIS beam current per cycle.



As ISIS instrument performance has increased, the amount of data taken per mA.hr of proton current has risen sharply.

ISIS development from 1985 to 2005

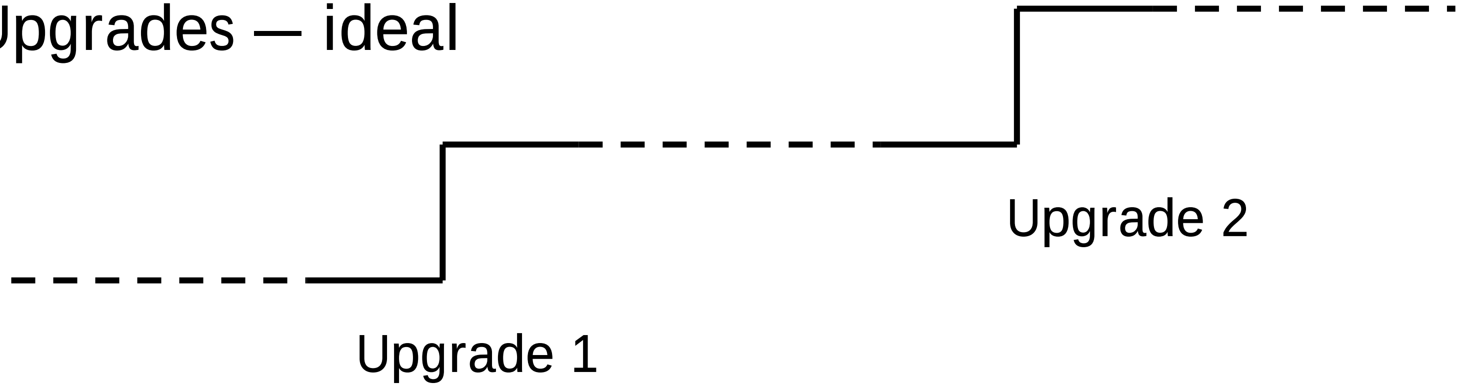
Factors determining success of accelerator facility

- Source strength ← often wrongly consider only this
- Reliability
- Instrumentation
- Innovation
- Investment
- Support facilities
- Support staff
- Cost effectiveness
- User community

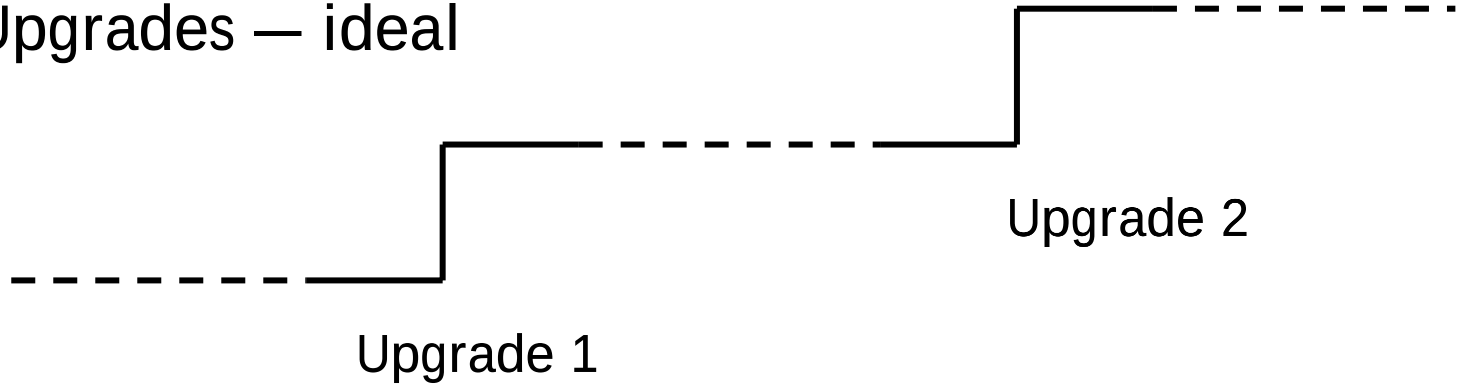
ISIS upgrades:

- New extraction straight for the synchrotron
- Replacement of the Cockcroft-Walton by RFQ
- Installation of a second harmonic RF system
- Replacement and upgrading of installed equipment
- Improved diagnostics + beam dynamics simulations
- Construction of a second target station
- Design and construction of a front end test stand
- MICE experiment
- Upgrade schemes for ~1 MW and beyond

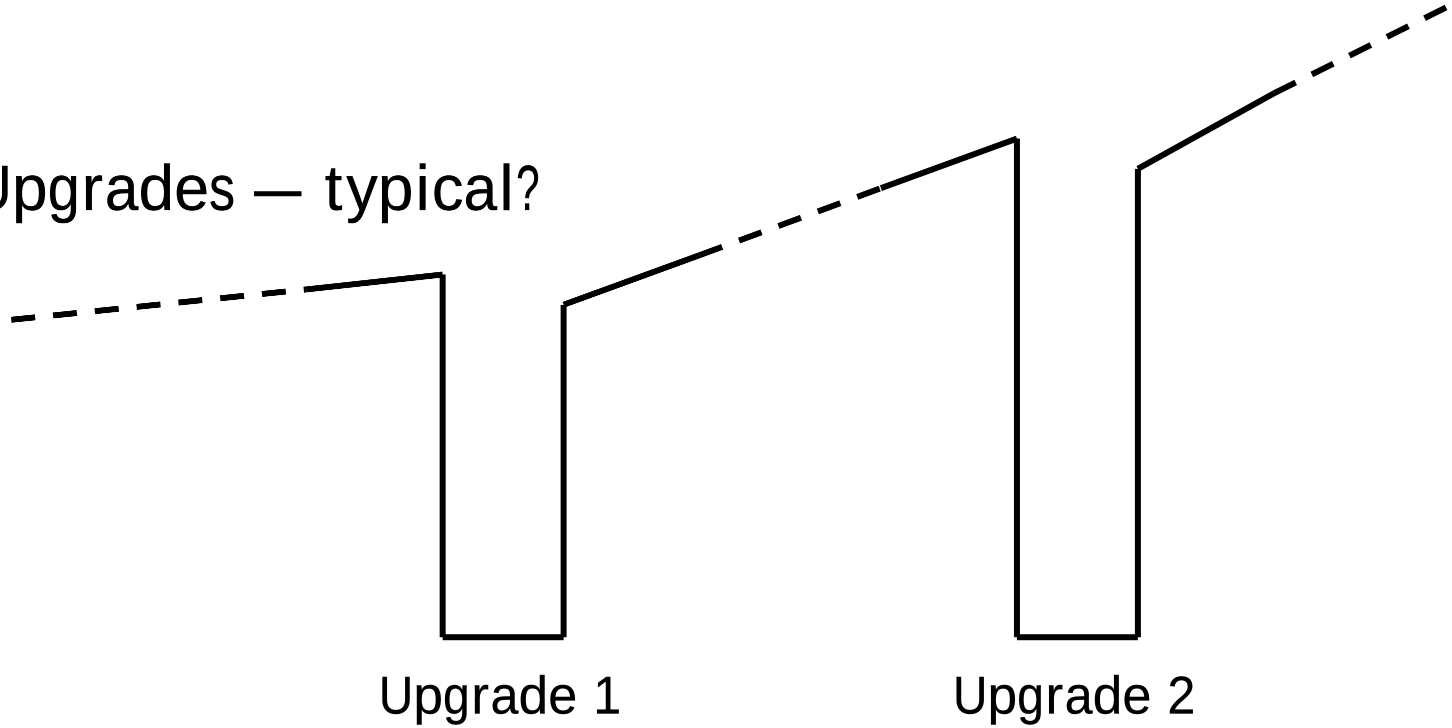
Upgrades – ideal



Upgrades – ideal



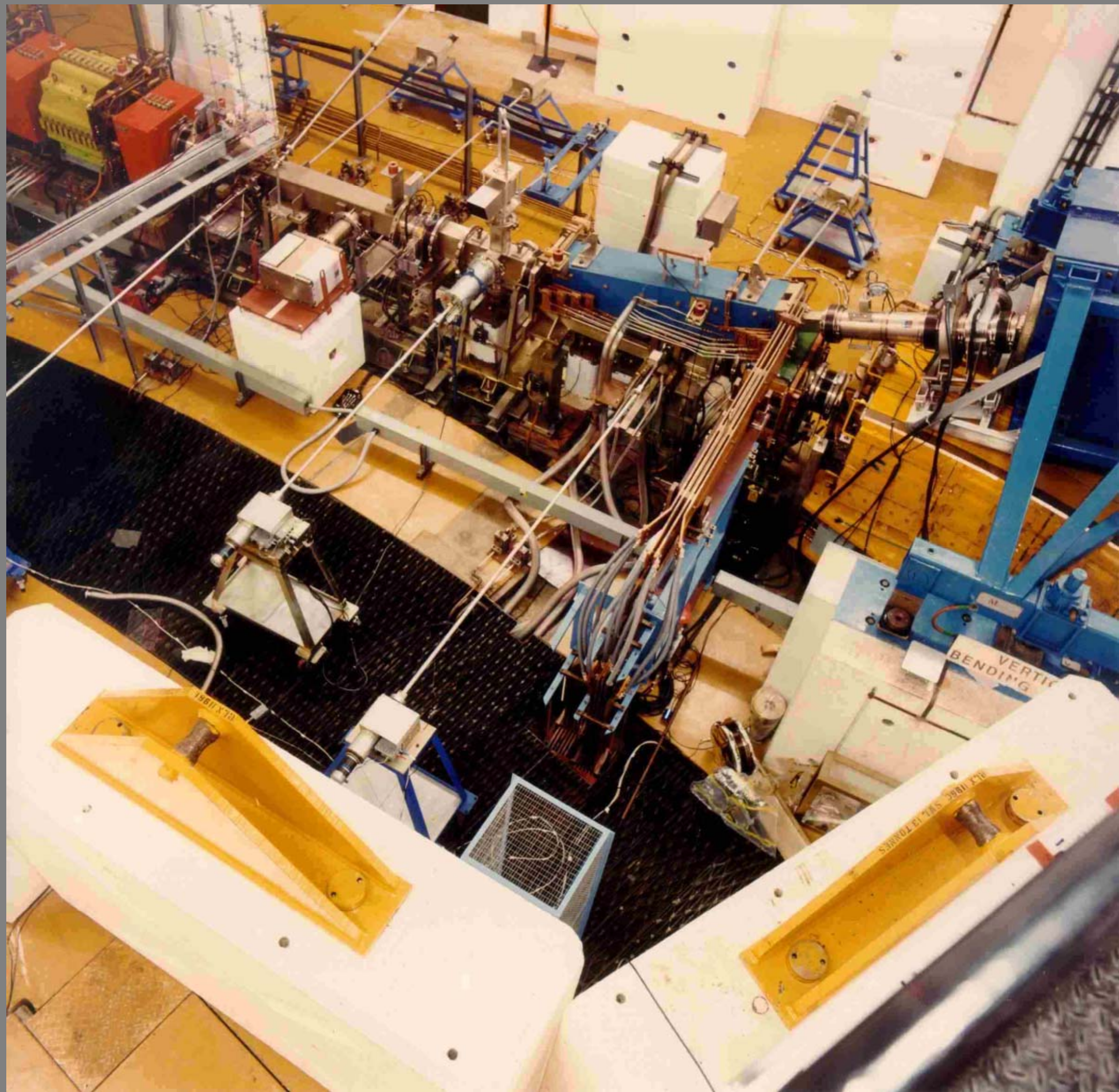
Upgrades – typical?



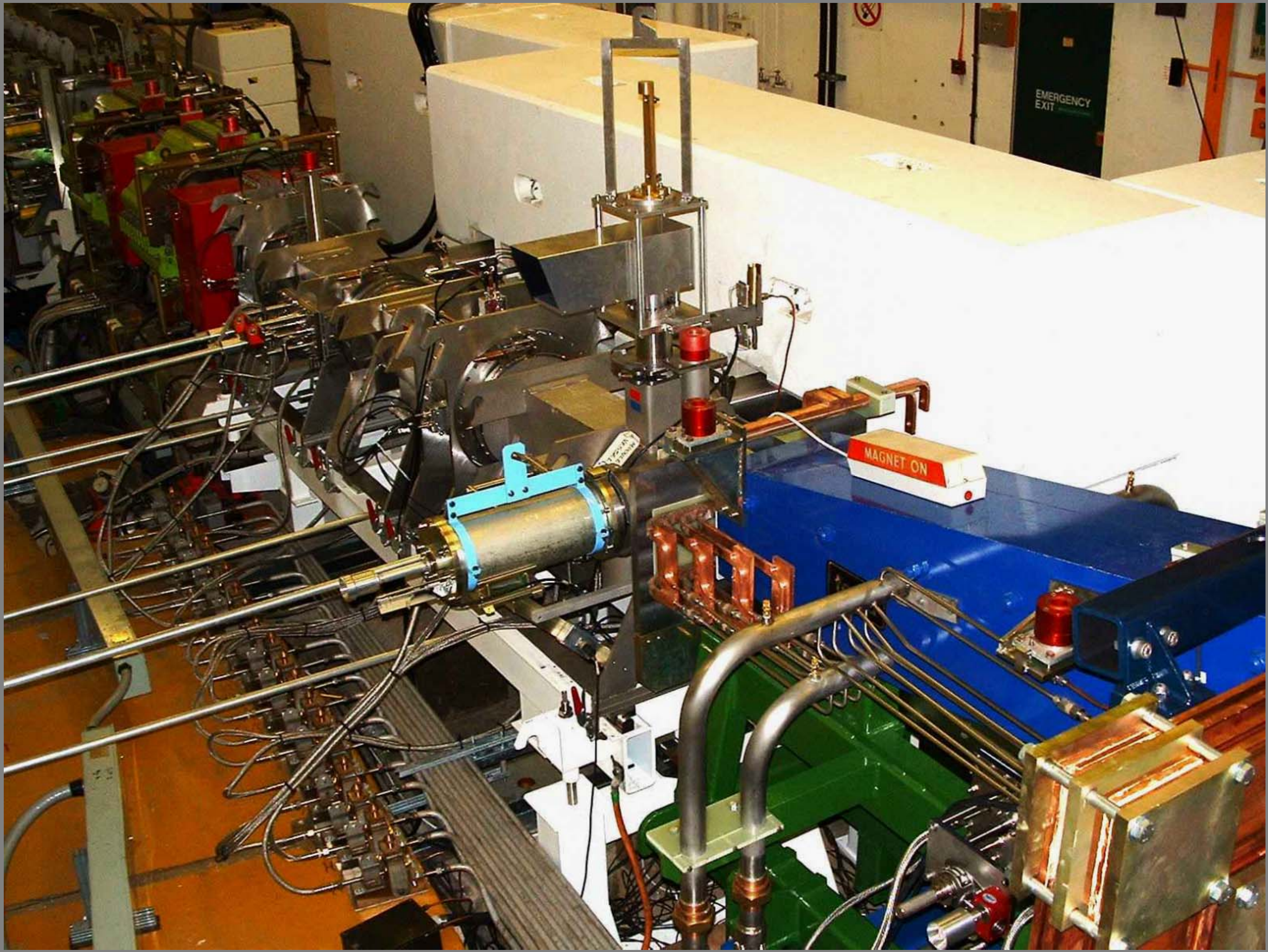
View down north side of ISIS 70 MeV H⁻ MeV linac

Superperiods 9, 0 and 1 of the ISIS 800 MeV synchrotron

ISIS experimental hall

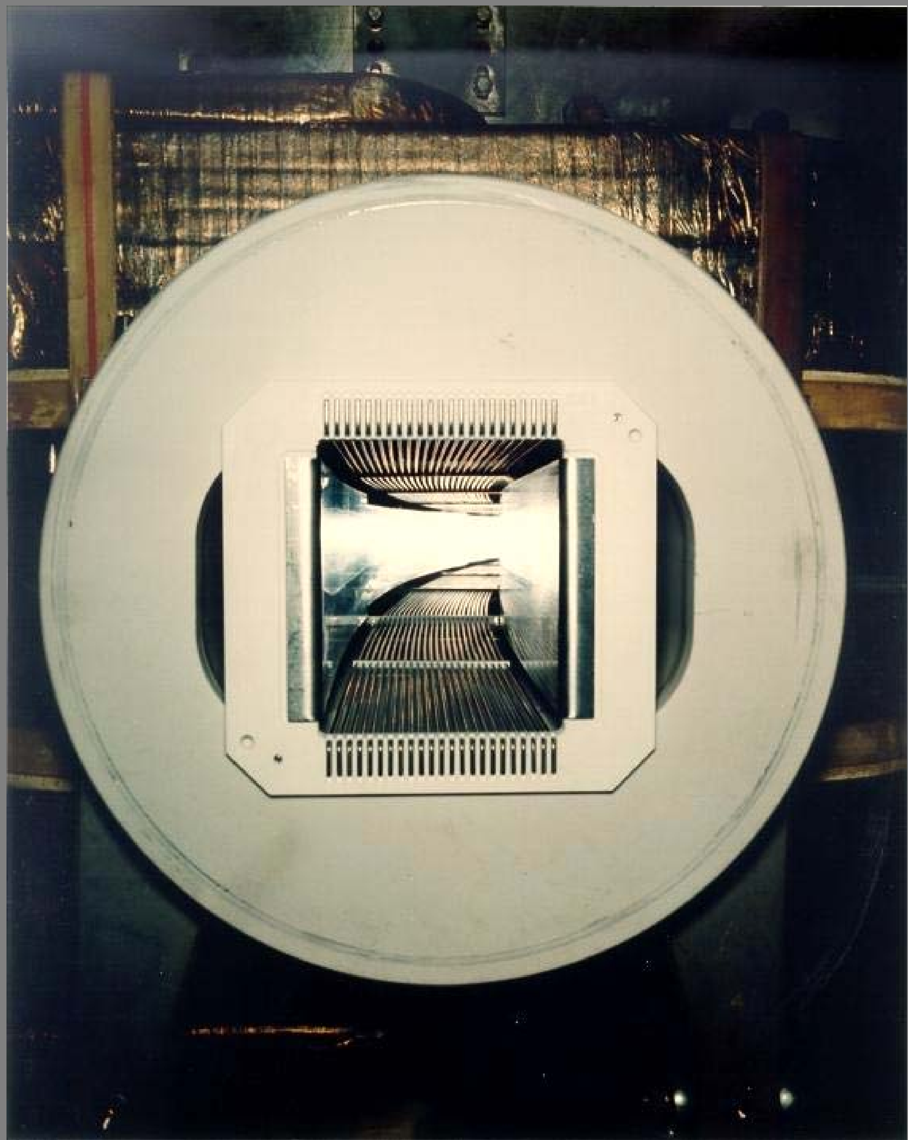


Old extraction straight with collimators



New extraction straight with collimators and septum

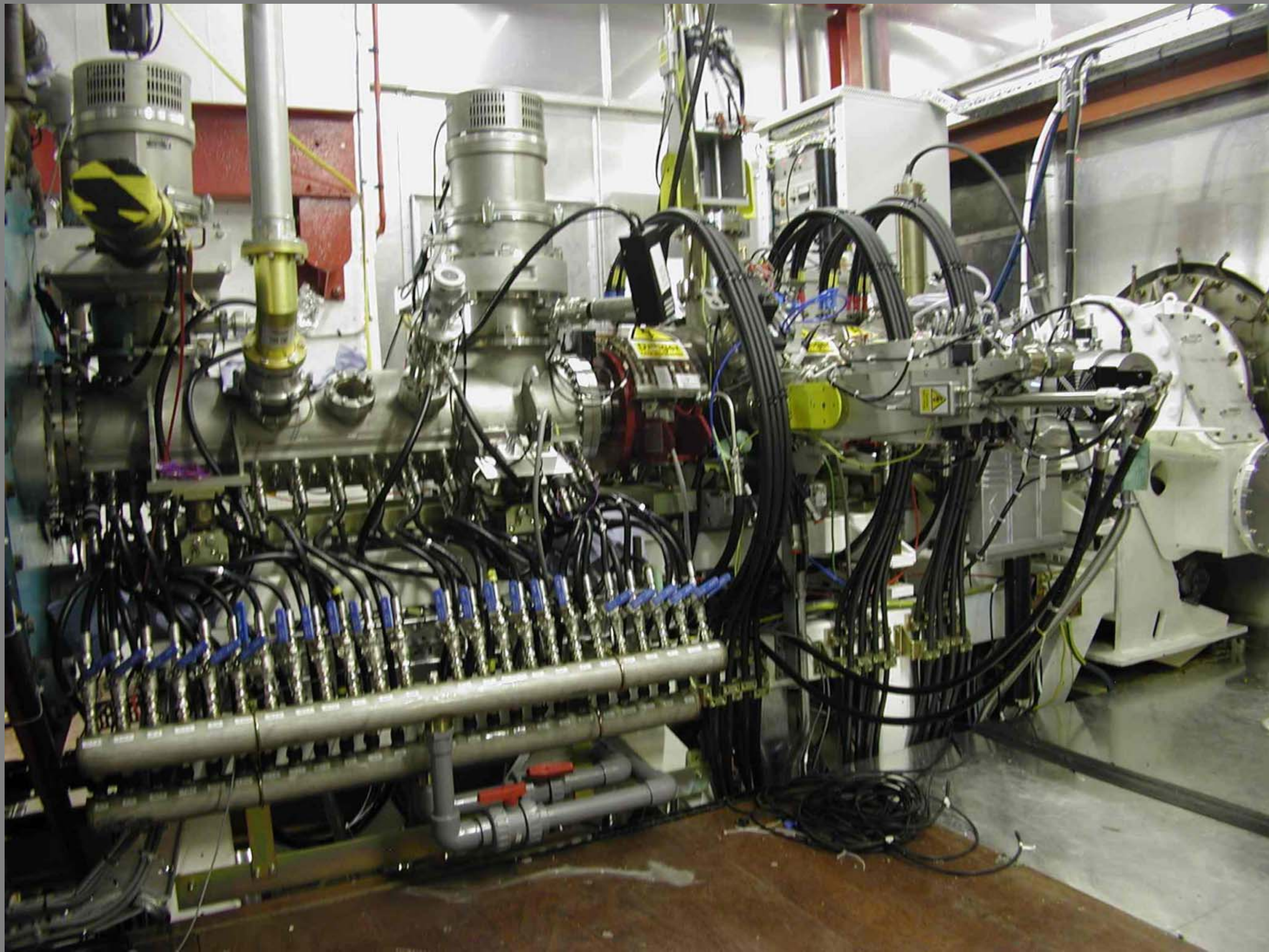
New extraction straight with collimators and septum (2)



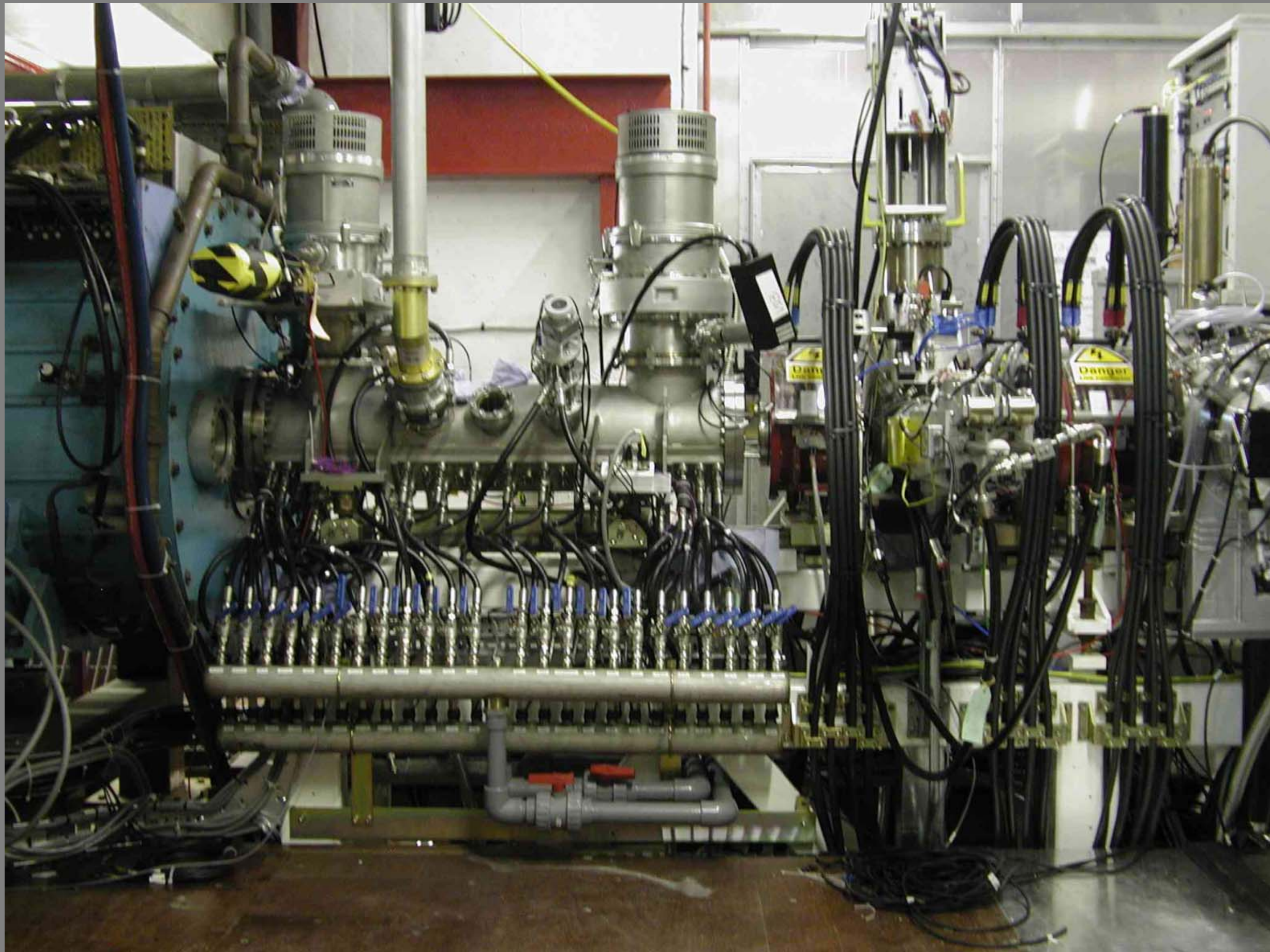
RF screen inside ceramic vacuum chamber

New collimators, looking downstream

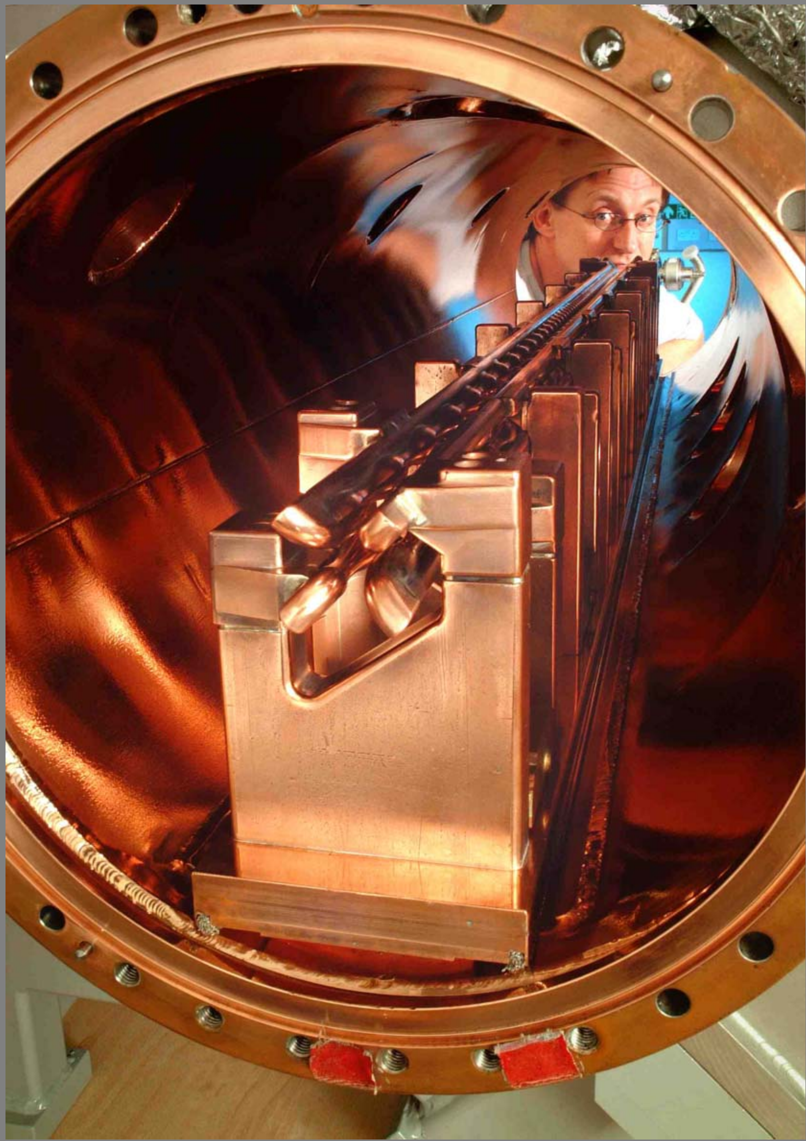
Old Cockcroft-Walton 665 kV H^- pre-injector



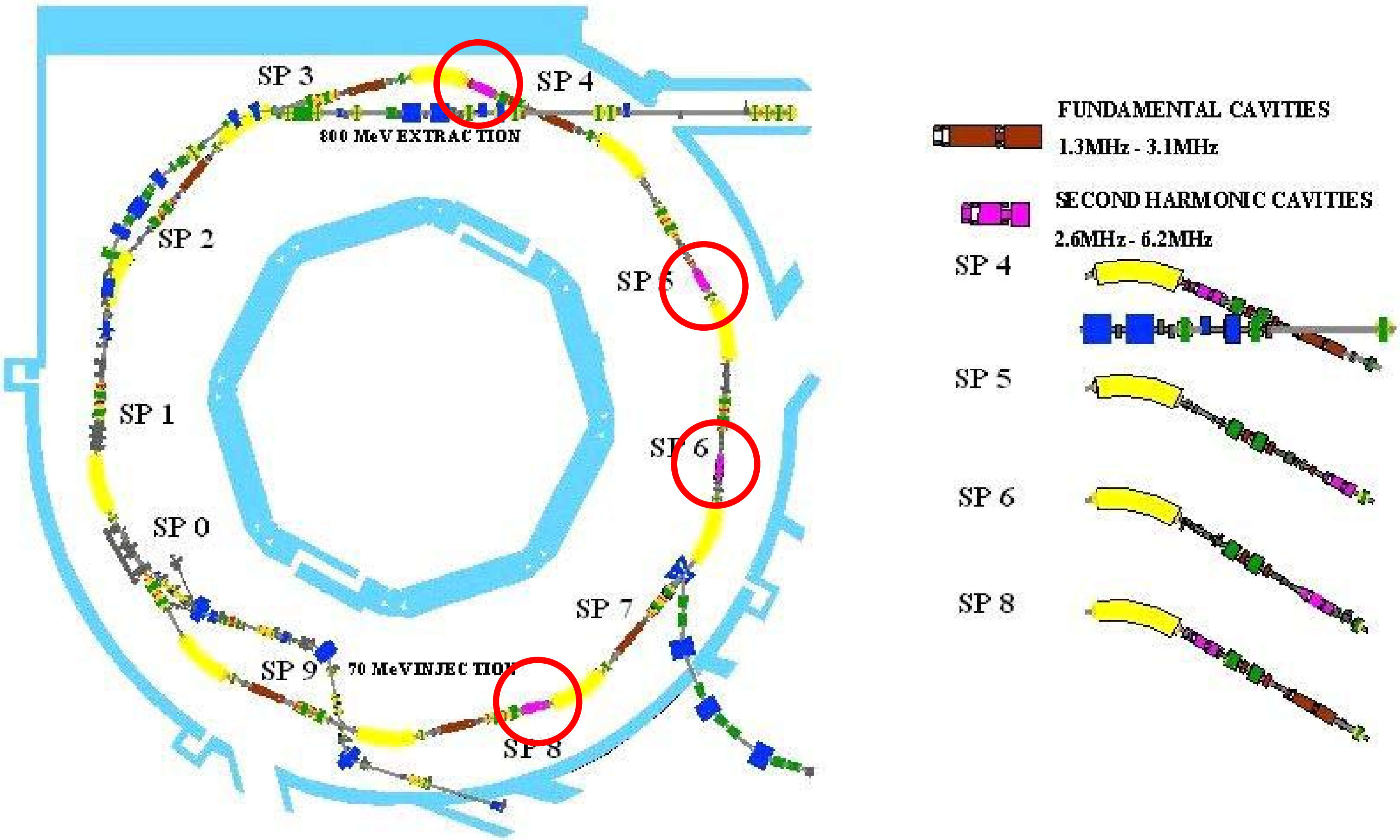
665 keV 202.5 MHz four-rod RFQ pre-injector
(Frankfurt – RAL collaboration)



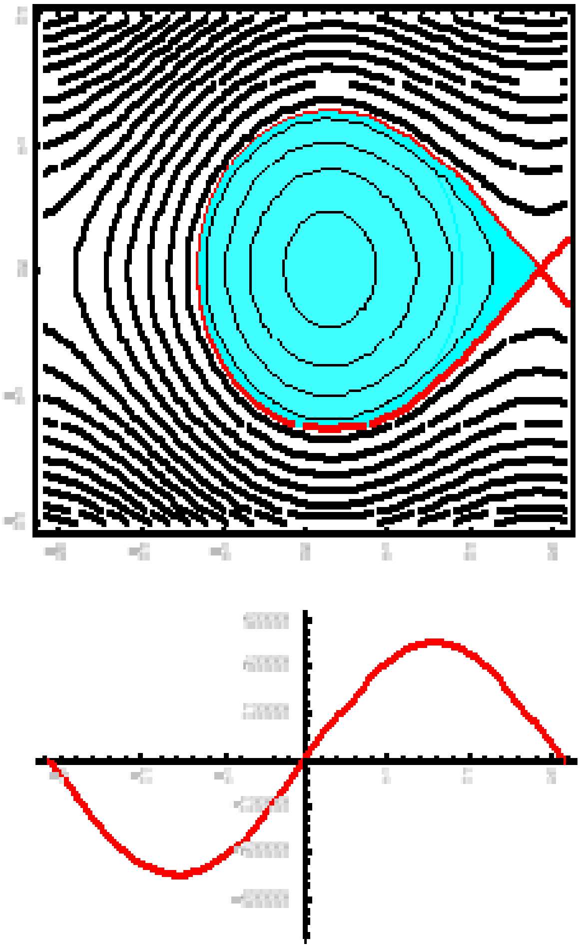
RFQ closely coupled to Tank 1 of drift tube linac



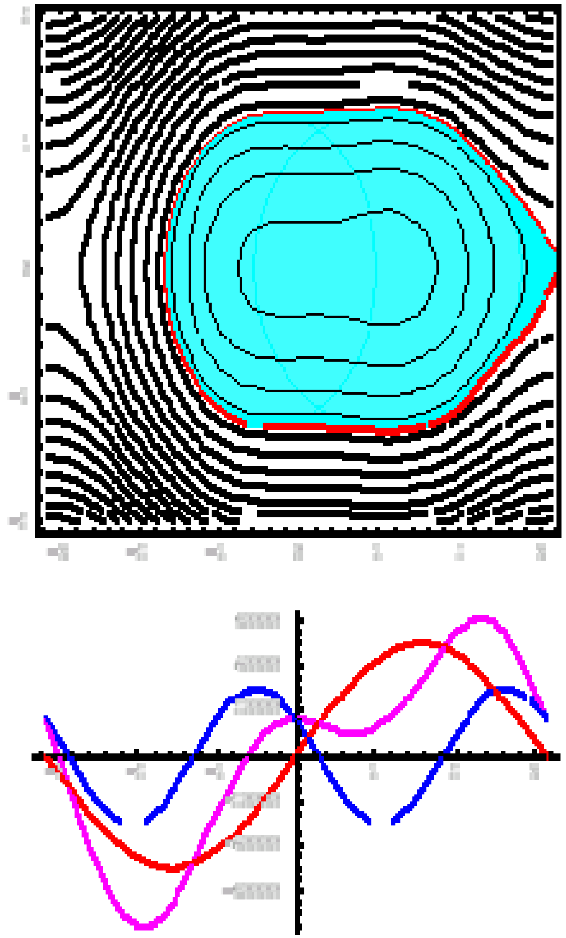
RFQ 202.5 MHz rod and stem structure



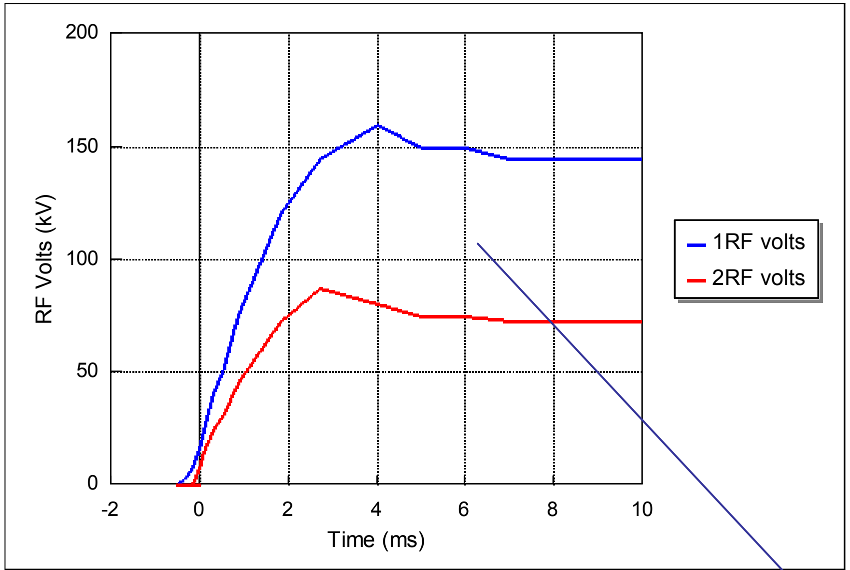
Four 2RF cavities in Straights 4, 5, 6 & 8

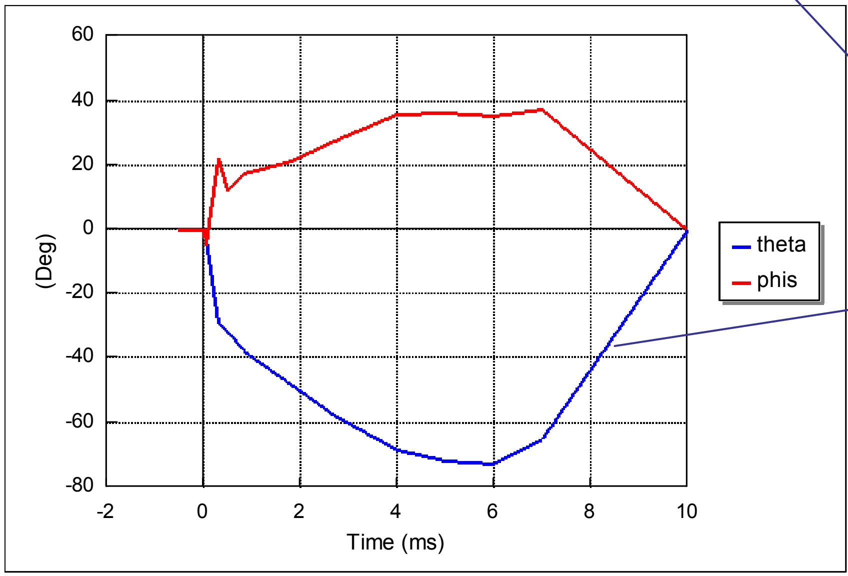


1RF



1RF + 2RF

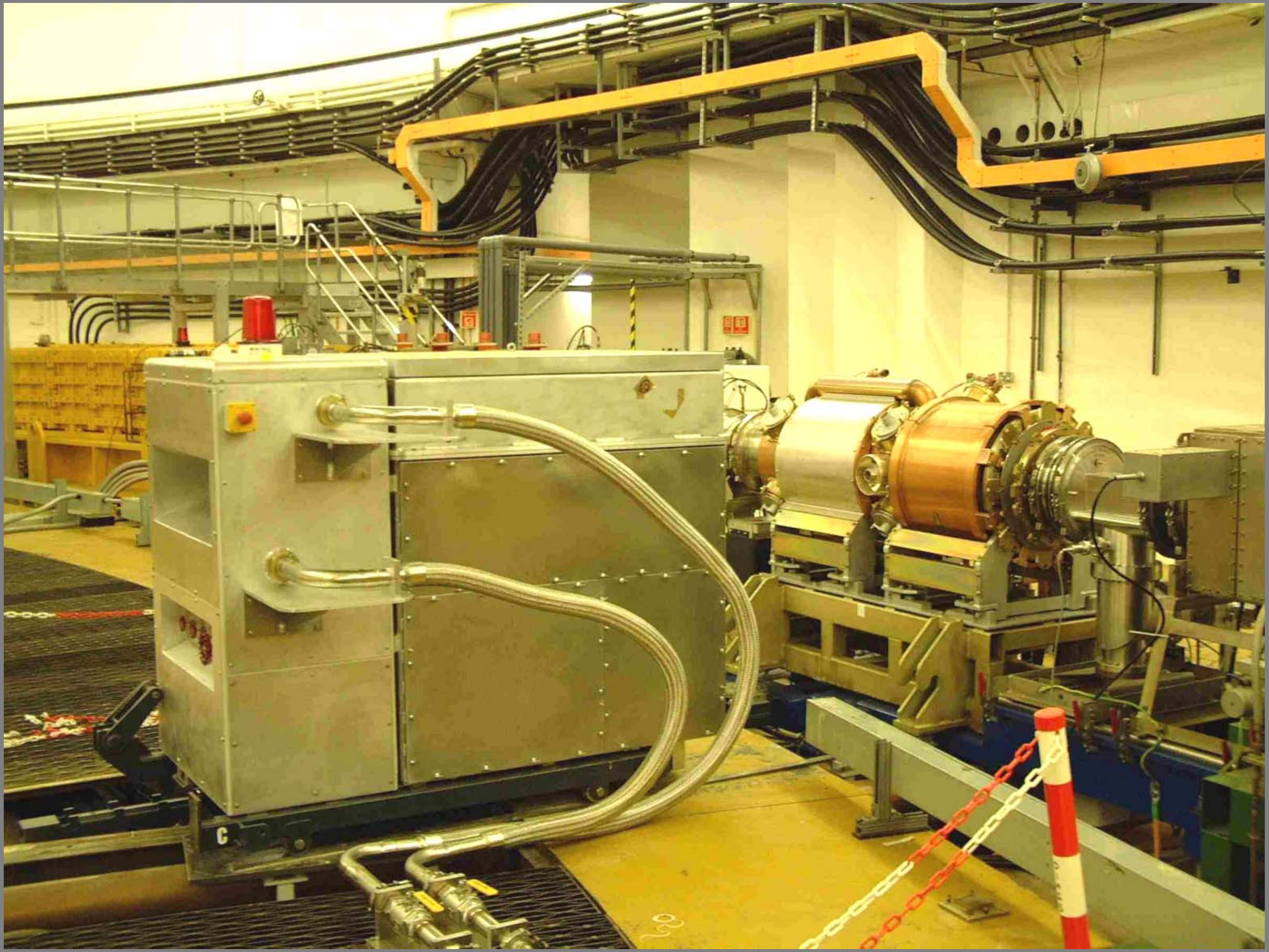




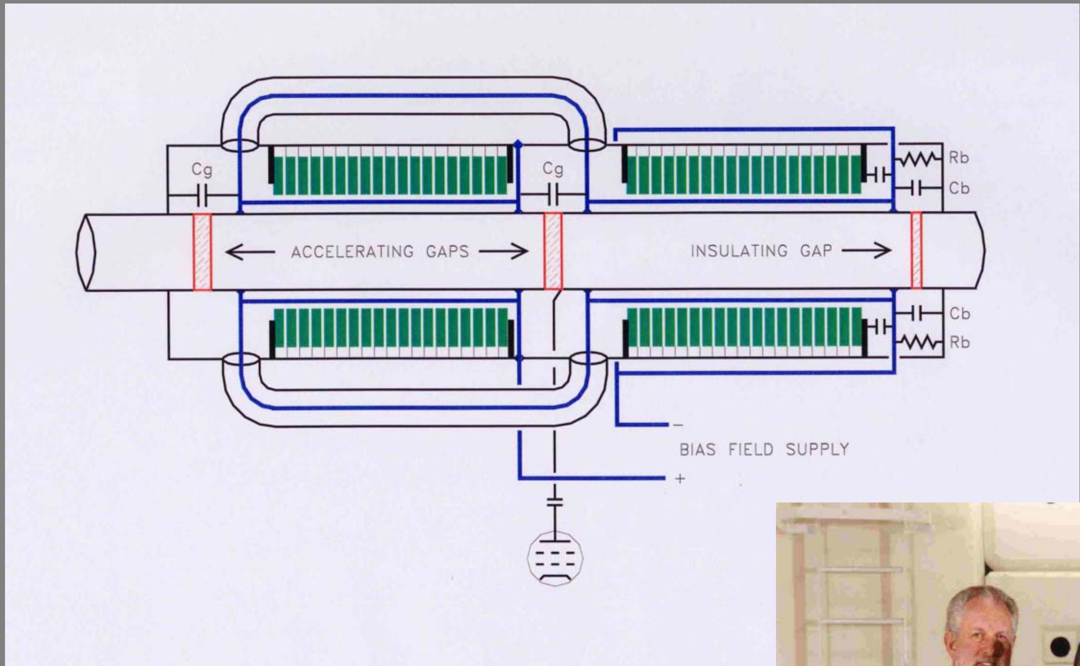
RF voltage

$V = V_0(\sin\phi + \delta \sin(2\phi + \theta))$

δ and θ chosen to minimise loss during injection, trapping and acceleration cycle

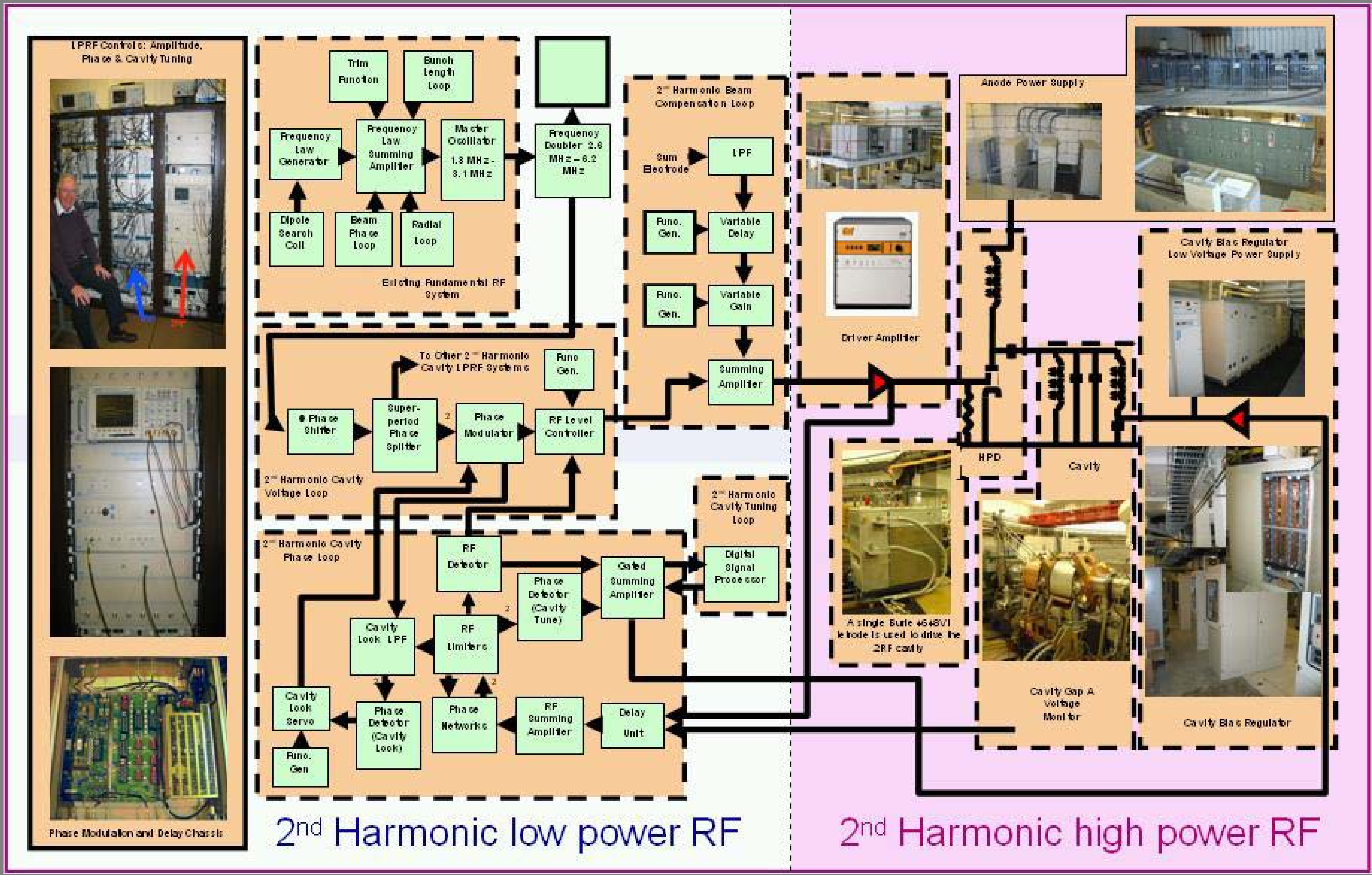


2RF: High power driver Cavity



Ferrite-loaded 2RF cavity
2.6 – 6.2 MHz over 10 ms

(200 – 2000 A bias)

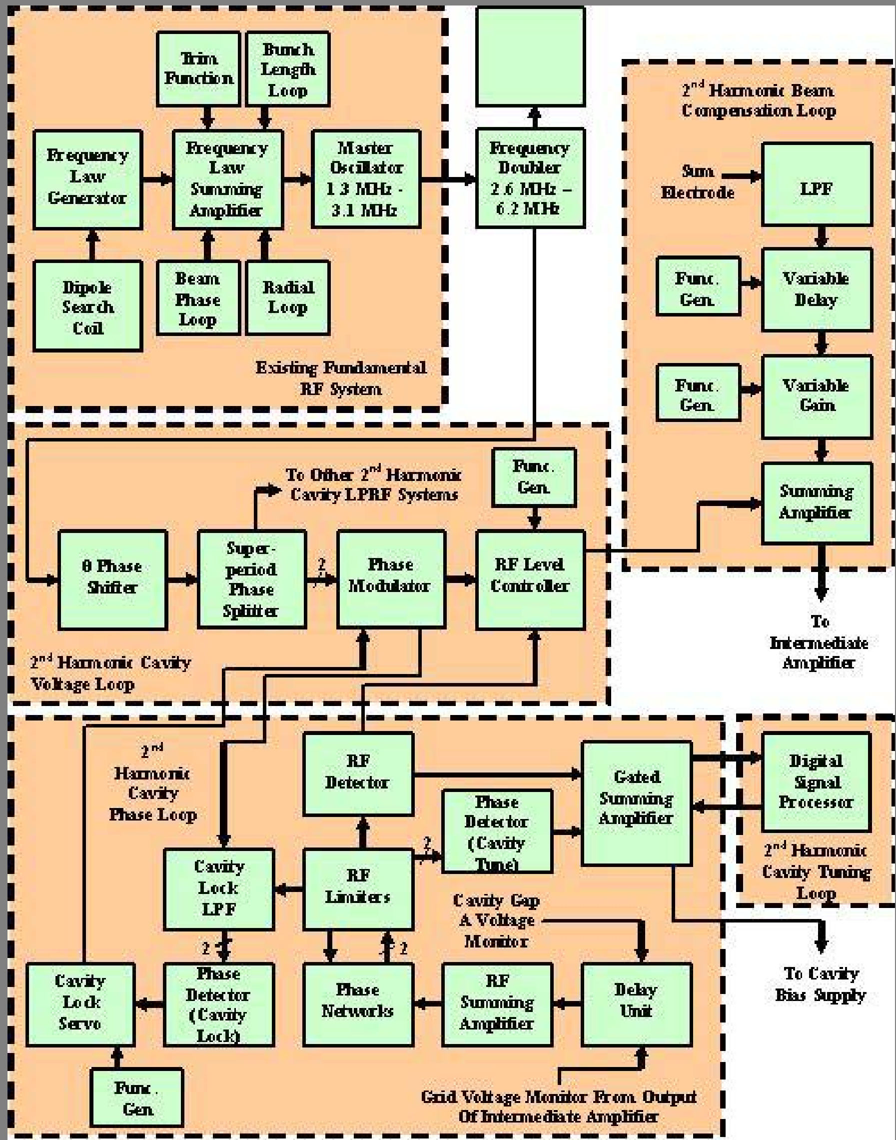


2RF schematic

Frequency sweeper

Voltage loop

Phase loop



Beam compensation loop

Cavity tuning

2RF control block diagram

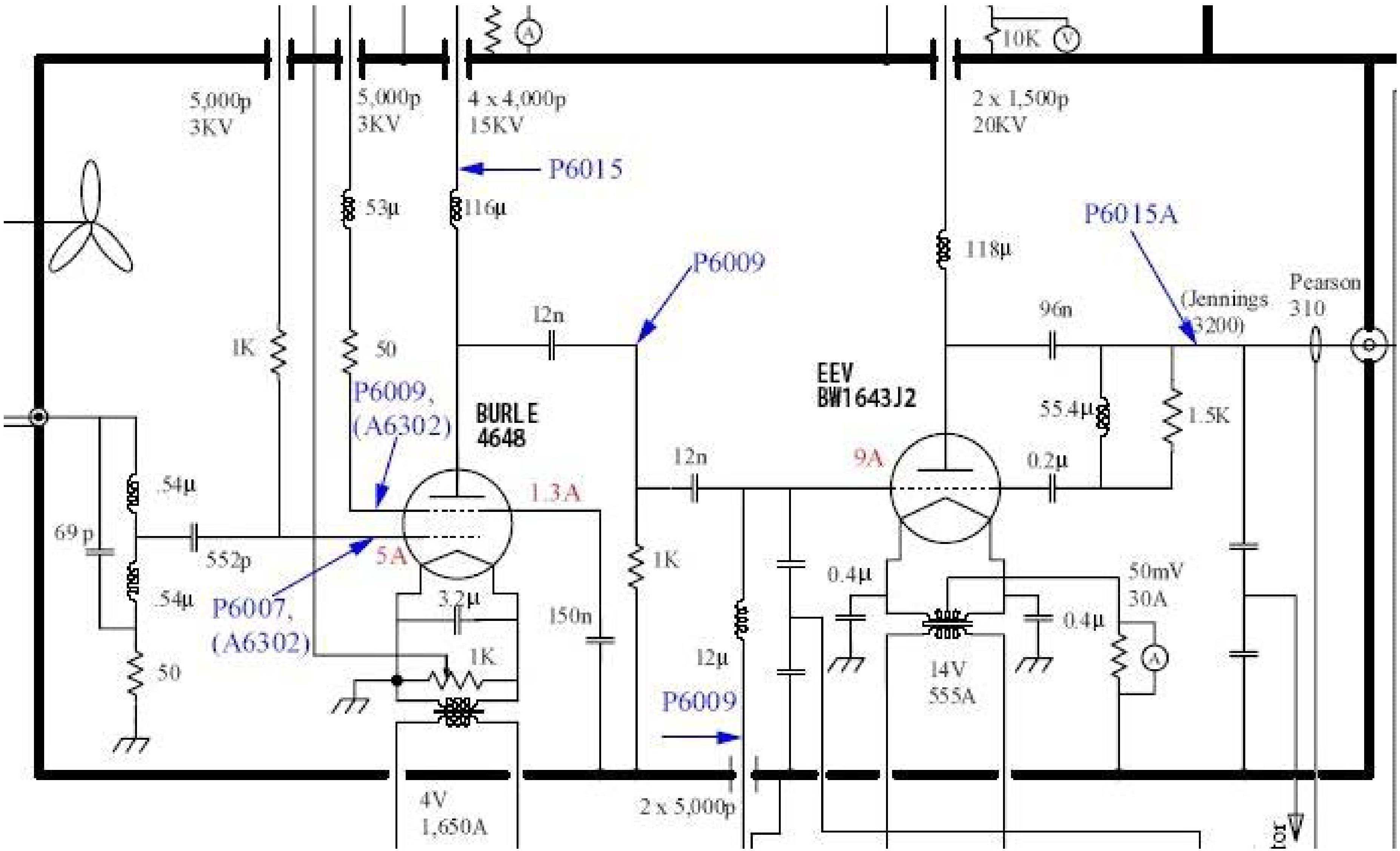
Progress on dual harmonic RF system

- Hardware commissioning complete
- Odd teething trouble
- Commissioning with beam being fitted around user programme – restrictive in practice
- Scheduled to run DHRF in user cycle starting September
- Details: Seville, MOPCH114
  Appelbee, THPCH111

Low output impedance RF cavity driver

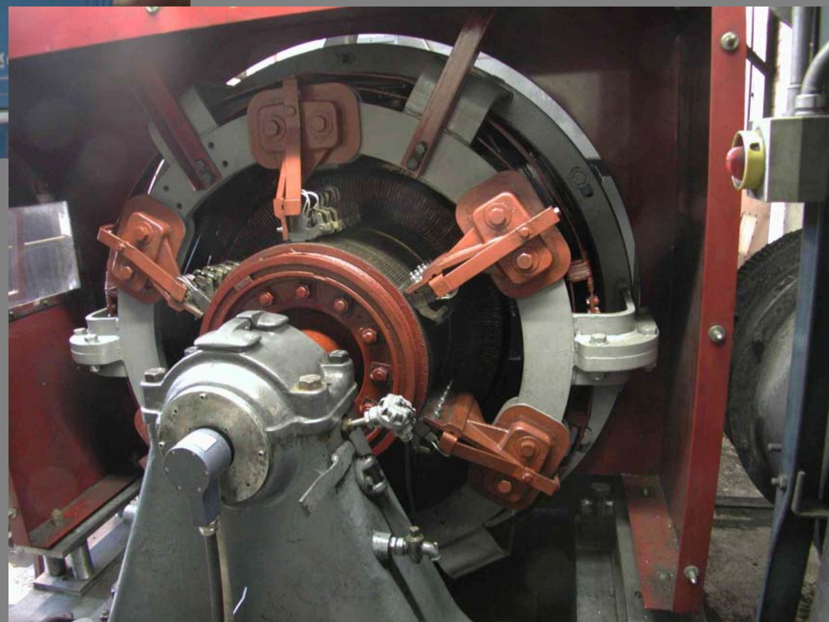
- To reduce sensitivity to beam-induced voltages in cavities
- Original aim was cathode follower
- Now anode follower
  (tube analogue of inverting op-amp circuit)
  - LOI HPD output impedance 30 – 50 Ω
  - Normal ISIS HPD output impedance ~few kΩ
  - Factor ~100 reduction

ANL – ISIS - KEK collab. Irie, MOPCH118



5,000p
3KV
5,000p
3KV
4 x 4,000p
15KV
2 x 1,500p
20KV
10K
P6015
53µ
116µ
118µ
P6015A
P6009
12n
96n
(Jennings
3200)
Pearson
310
1K
50
P6009,
(A6302)
BURLE
4648
EEV
BW1643J2
55.4µ
1.5K
12n
9A
0.2µ
.54µ
1.3A
69 p
552p
5A
1K
.54µ
P6007,
(A6302)
3.2µ
150n
0.4µ
50mV
30A
0.4µ
1K
12µ
50
14V
555A
P6009
4V
1,650A
2 x 5,000p

Old and new chokes for synchrotron
main magnet power supply

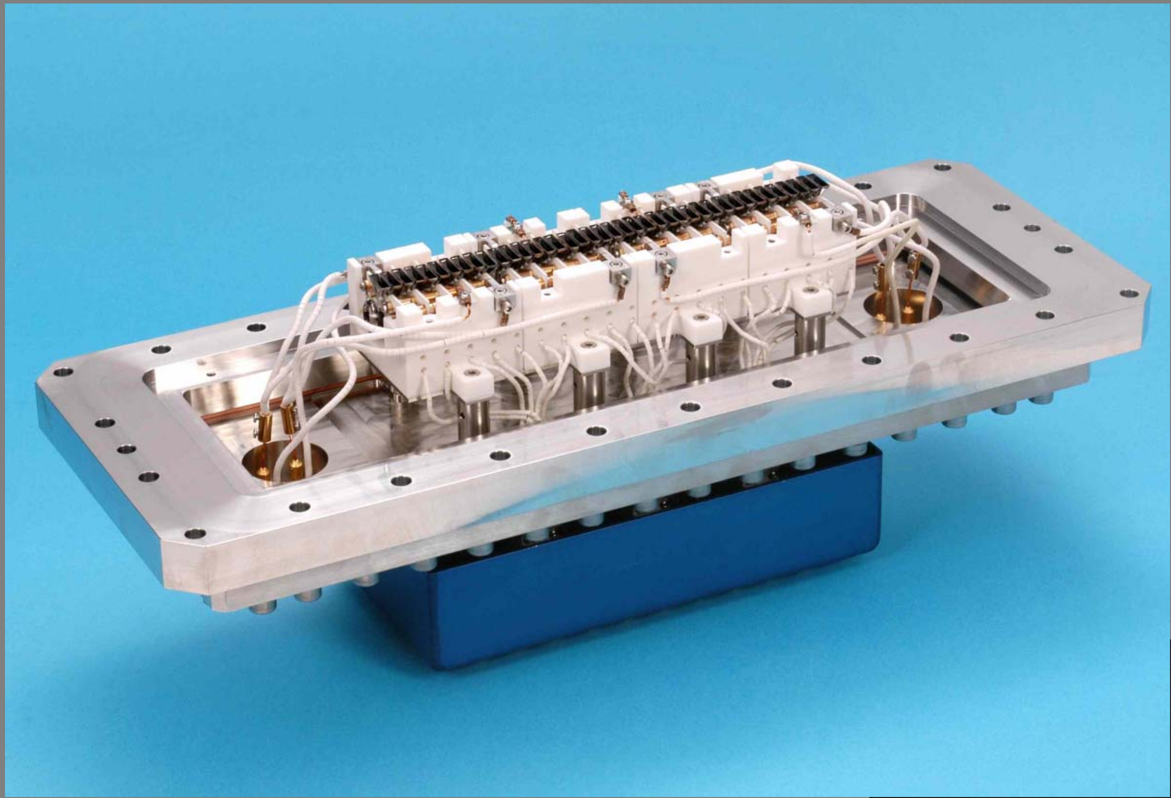


Old motor-alternator set for 800 A p-p AC current for synchrotron main magnets

New UPSs for AC current for synchrotron main magnets

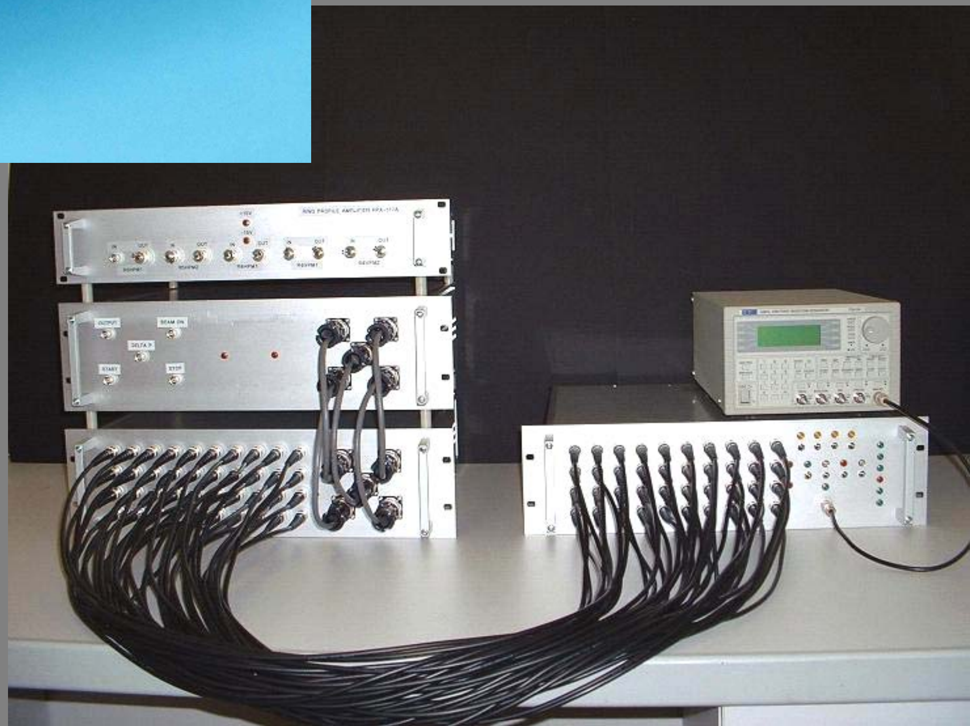
Old capacitor bank for resonating at 50 Hz with synchrotron main magnets

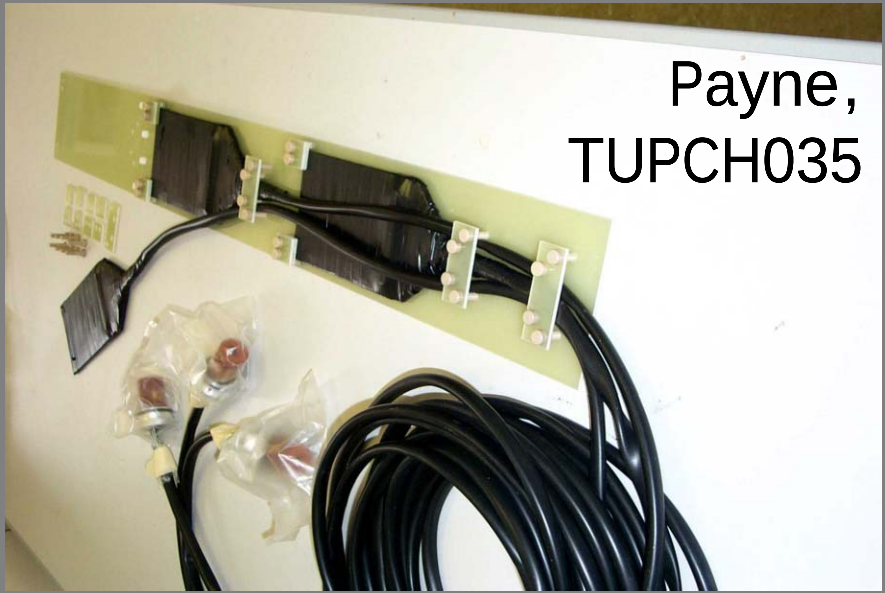
New capacitor bank (~one-third of size)

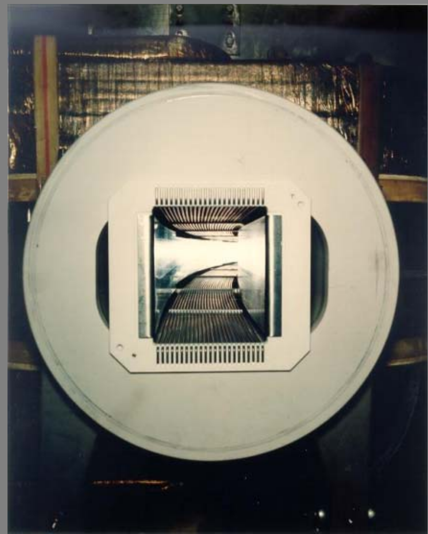


Warsop, MOPCH115
Pine, TUPCH036

Multi-channel residual gas ionisation beam profile monitor







Scintillator-based beam loss monitors

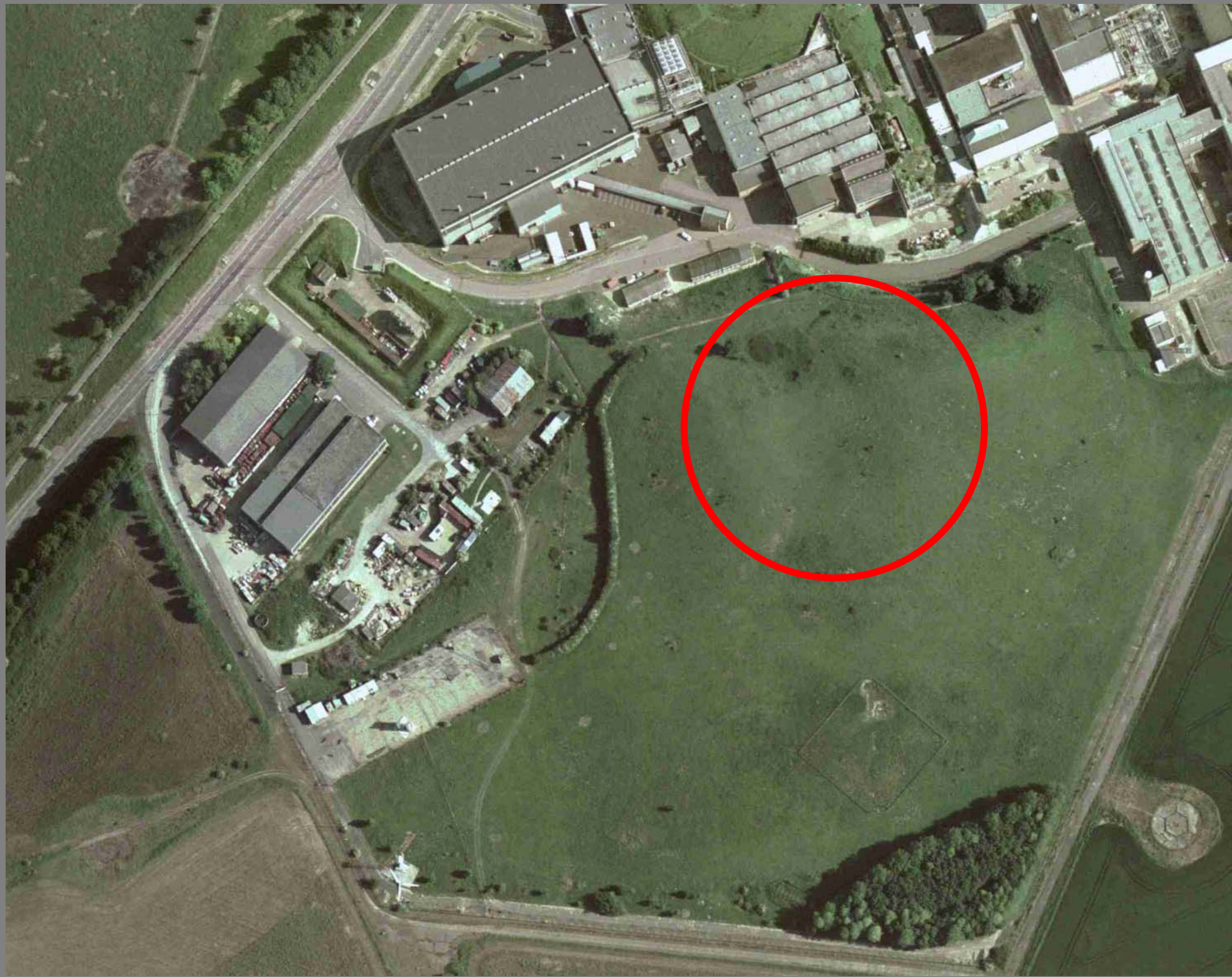
TS2 ISIS
second target station project

Optimised for cold neutron production

Low repetition rate
- 10 Hz
- 100 ms frame

Low power
- 48 kW
- 60 µA

TS-2 Instrument	Performance *cf*. TS-1	Performance *cf*. ILL	Particular features
INTER	***x 20*** compared to SURF	World Leading	Wide simultaneous Q range
polREF	***x 20*** compared to SURF / CRISP	World Leading	Wide simultaneous Q range, control of polarization direction
offSPEC	***x 20*** compared to SURF	World Leading Unique capability	Wide Qx, Qy range . First instrument dedicated to off-specular studies
SANS2a/b	***x 40*** compared to LOQ	Comparable to D22 at ILL	Particularly wide simultaneous Q range. Q min limited to 0.002 Å-1
NIMROD	***x 10*** compared to SANDALS for Q 0.01 to 1 Å-1 with comparable resolution	World leading Unique capability	High Q range, extended to low Q values
LMX	***x 40*** compared to SXD	Highly competitive with VIVALDI at ILL	Quasi Laue: benefits from TOF
HRPD-2	***x 10*** compared to HRPD for d spacings > 1.5Å	World Leading	Emphasis on larger structures, highest resolution
WISH	***x 10*** compared to GEM for d-spacings > 10Å	World leading for high resolution magnetic powder diffraction	Dedicated high resolution magnetic powder diffractometer
LET	***x 10*** compared to MARI at 10 meV; unique access to lower energies.	World Leading	Wide dynamic range: 0.01 to 80meV Position sensitive detector
HERBI	***x 10*** better resolution than IRIS, wider dynamic range, similar flux	Highly competitive with IN16 at ILL	Particularly wide dynamic range



Aerial view with location of Second Target Station

Hill to be removed

Hill being removed — 1

Hill being removed — 2

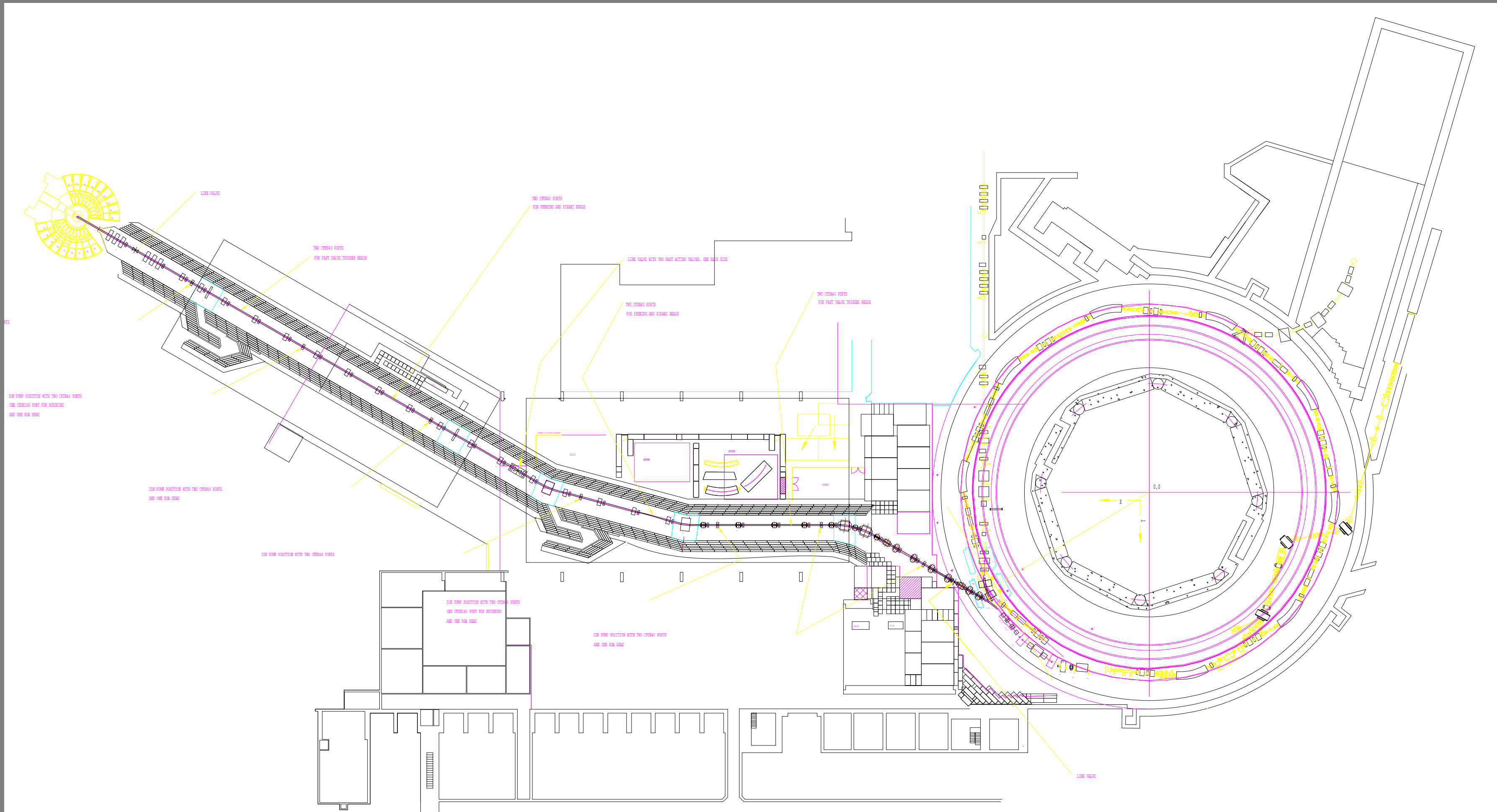
Hill removed

Building starts on excavated site

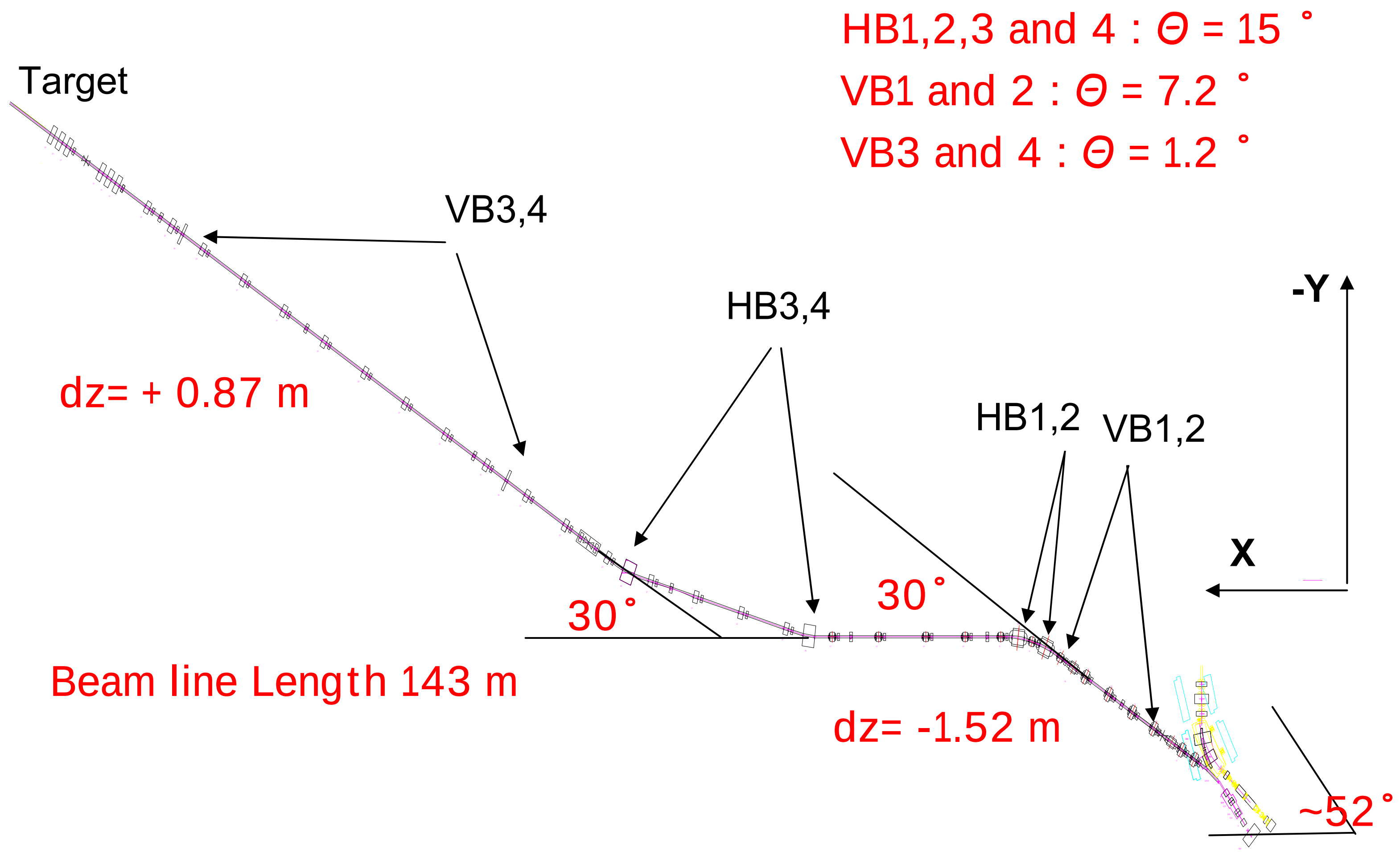
Second Target Station (TS-2) at present

Reconfiguration of existing buildings

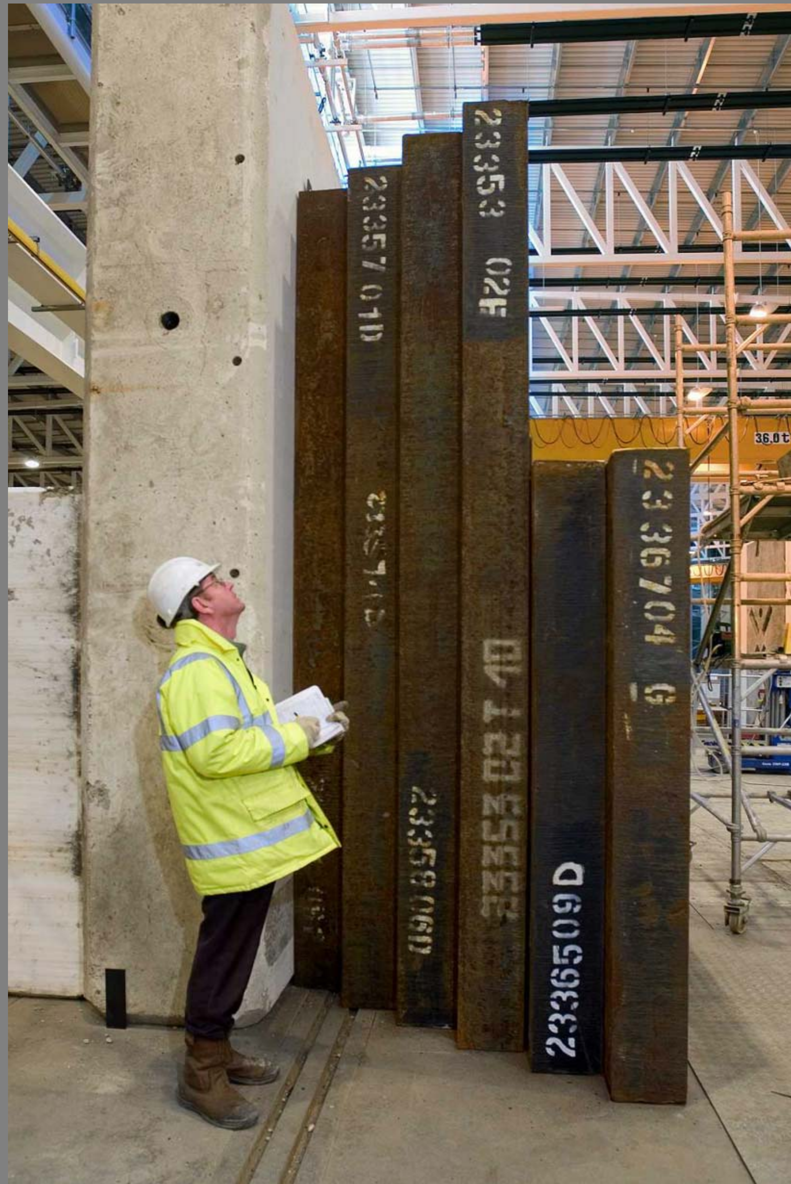
Route of proton beam line to TS-2 (looking upstream)



143 m proton beam line from synchrotron to TS-2

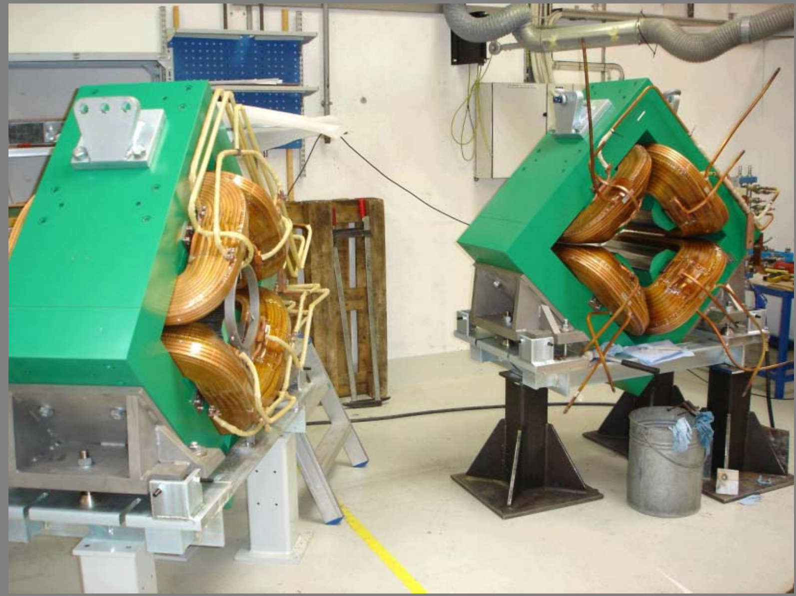


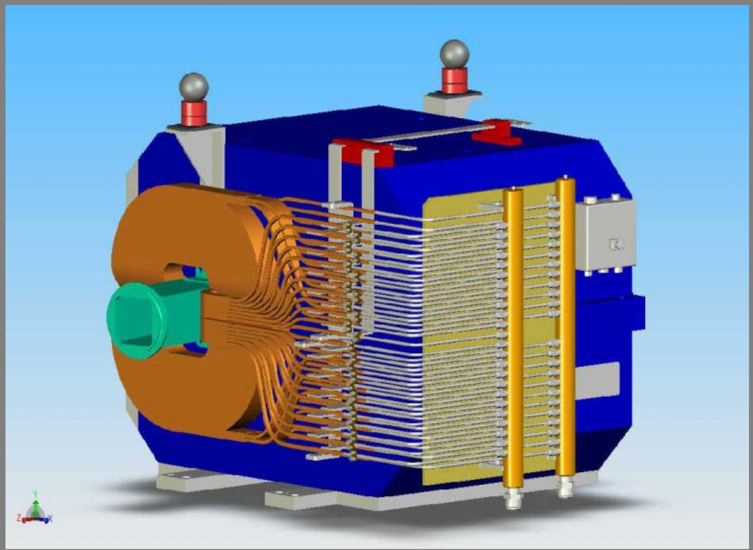
At target: 36 mm diameter, non-divergent, achromatic



Shielding around proton beam line to TS-2

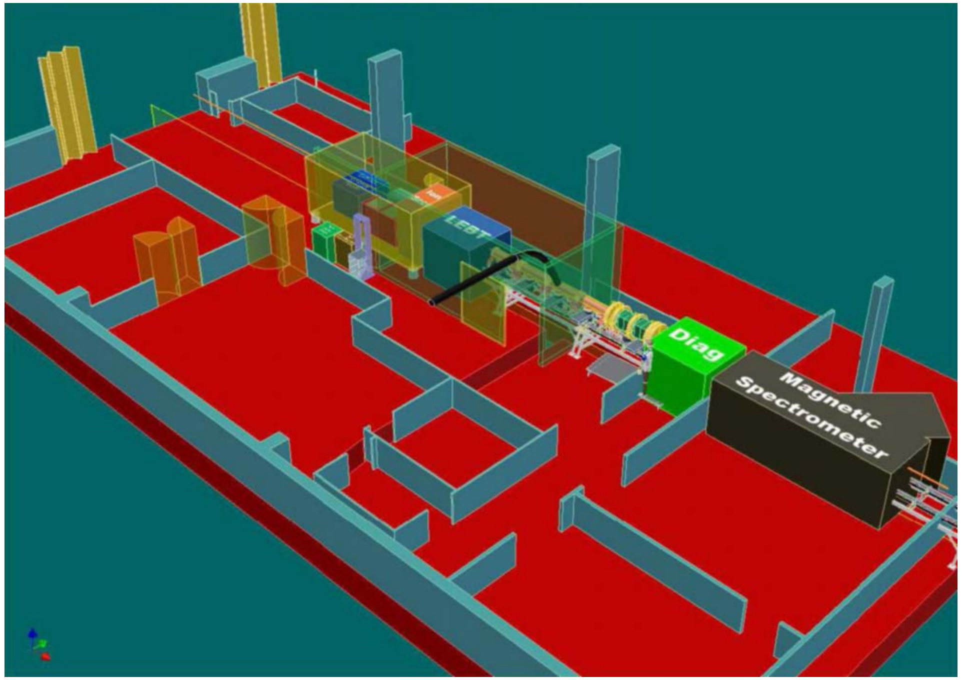
Birch,
WEPLS119





Magnets for new proton beam line to TS-2

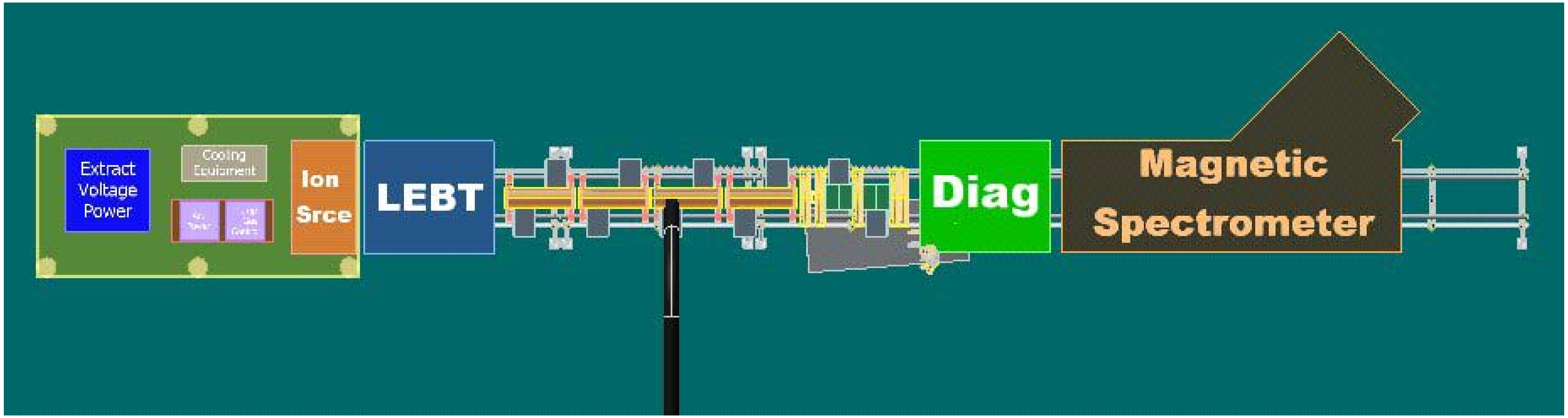
RAL Front End Test Stand



Posters

MOPCH112
MOPCH116
MOPCH117
TUPCH019
TUPCH037
TUPLS088
TUPLS090

1. Demonstration of high quality chopped beam for HPPAs
2. Front end of possible new ISIS linac

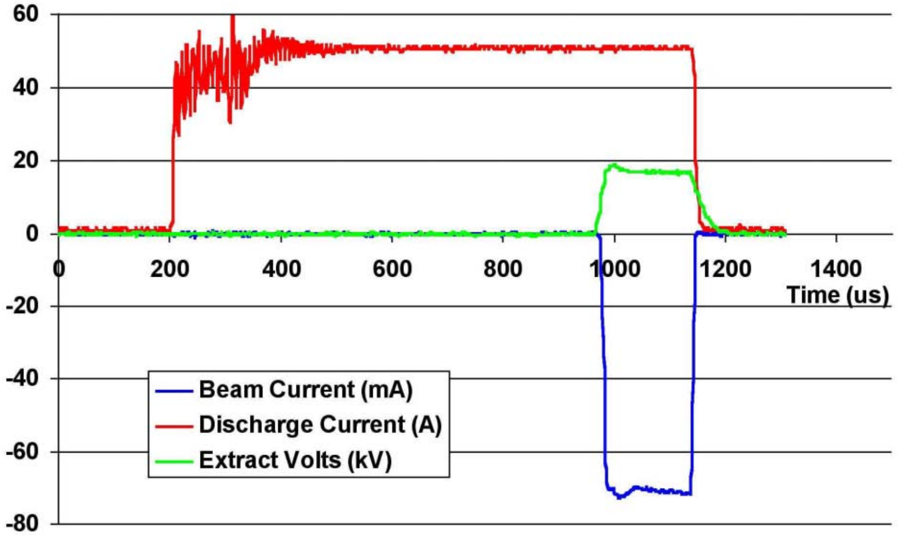


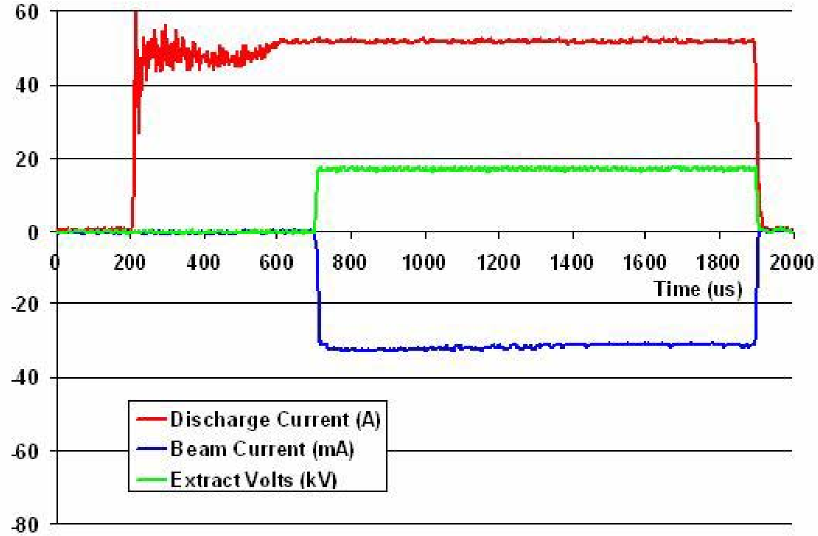
Front End Test Stand main components

- High brightness H^- ion source (60 mA, 2 ms, 50 pps)
- Magnetic Low Energy Beam Transport (LEBT)
- High current, high duty factor RFQ (3 MeV, 324 MHz)
- Very high speed beam chopper (1–2 ns switching)
- Comprehensive diagnostics

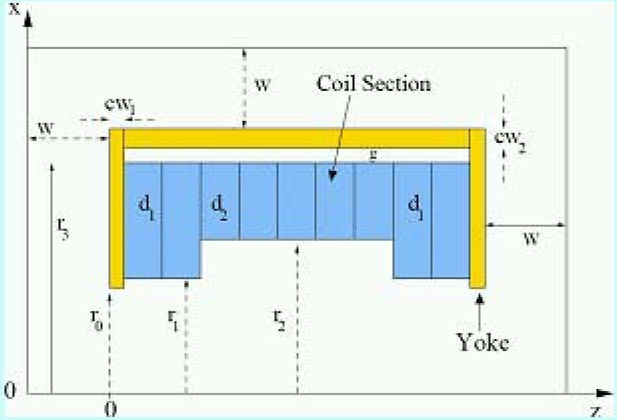
ASTeC - Imperial College – ISIS – Warwick collab. (+ EU)

Ion source development programme – based on ISIS surface Penning source

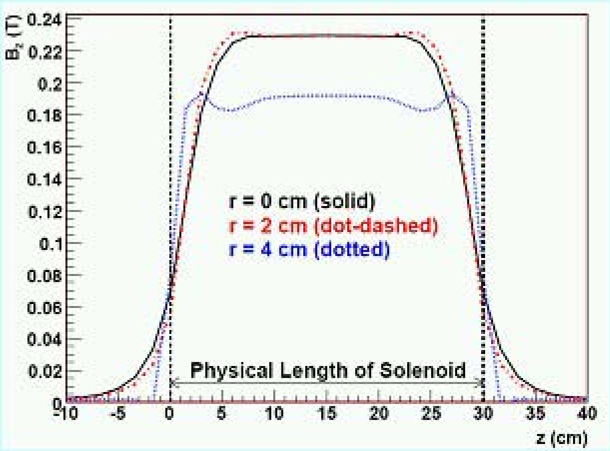


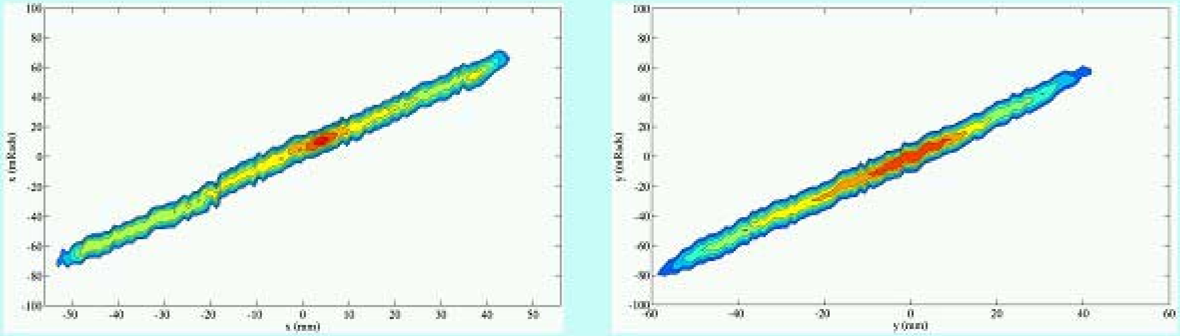


70 mA and 1200 µs *cf*. ISIS 35 mA, 200 µs

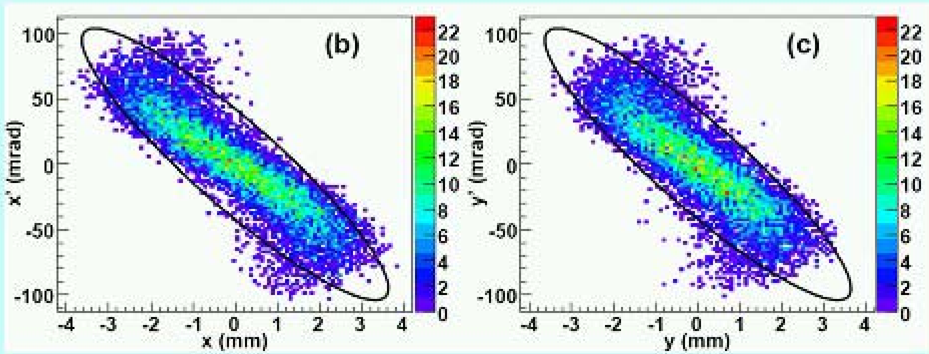


Solenoid design (above) and calculated field (below)

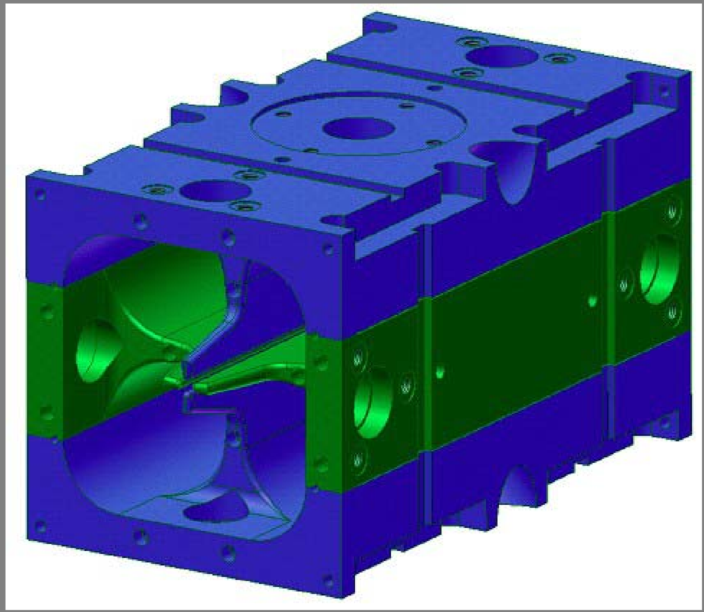


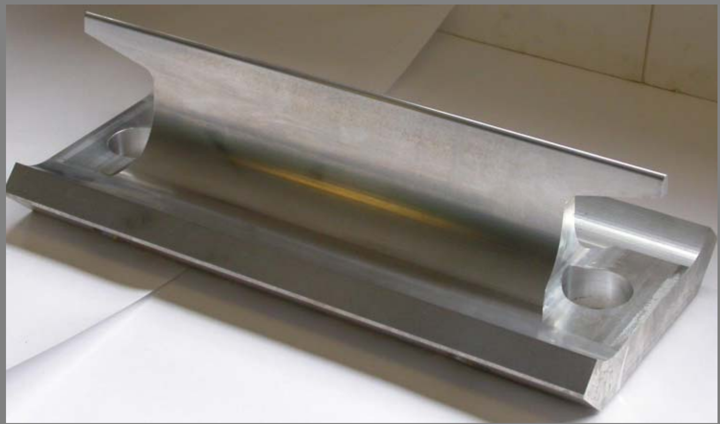


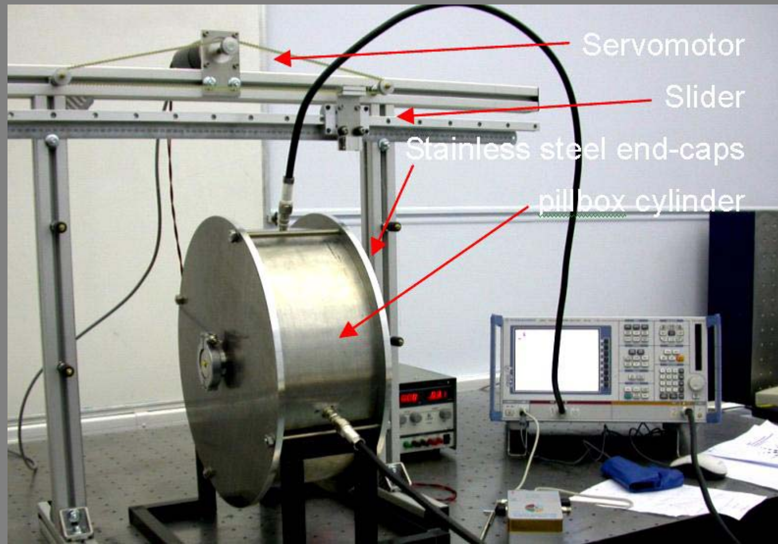
Measured ion source beam (above) and calculated RFQ input beam plus RFQ acceptance (below)



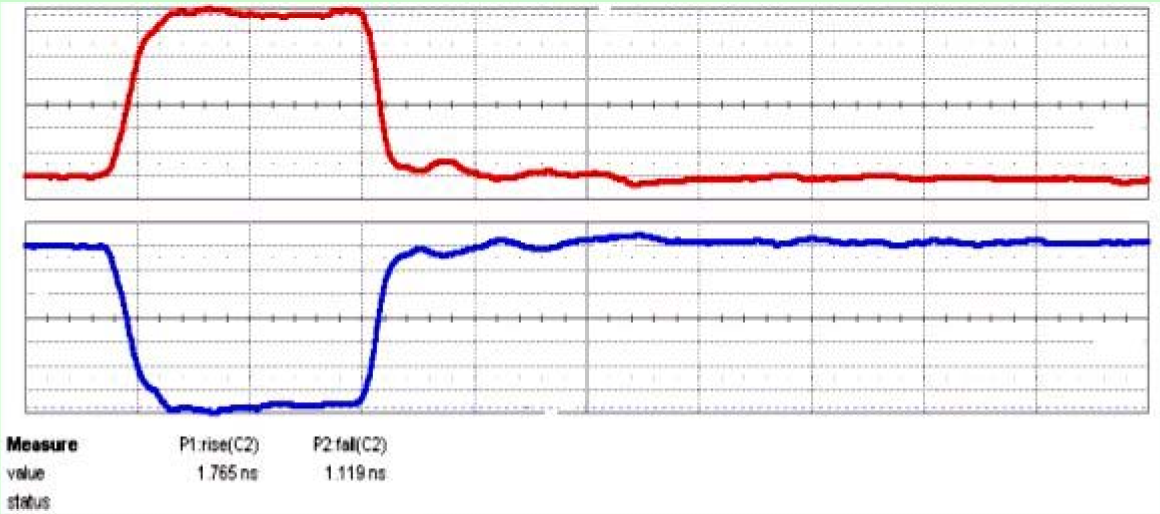
3-solenoid magnetic LEBT



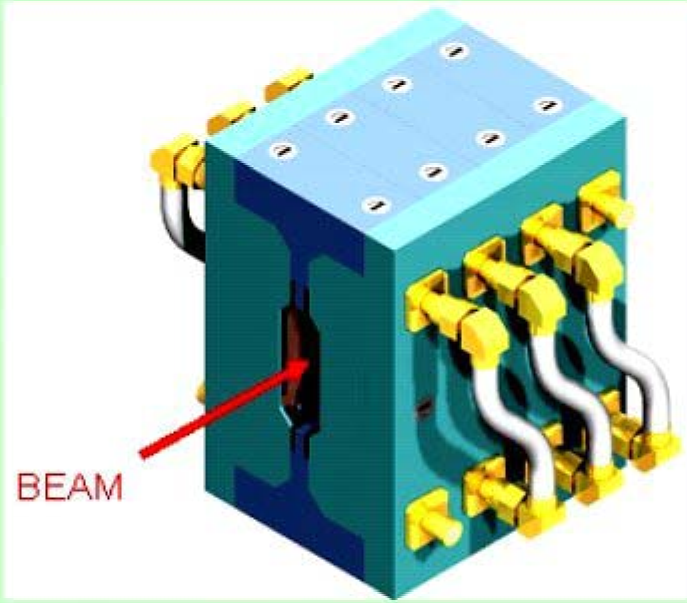




324 MHz RFQ cold model and bead pull machine



1.4 kV pulses with sub-2-ns rise- and fall-times



A tuneable helical structure with adjustable delays replaces the meander line deflector.

Beam chopper (tandem chopper originally developed for ESS)

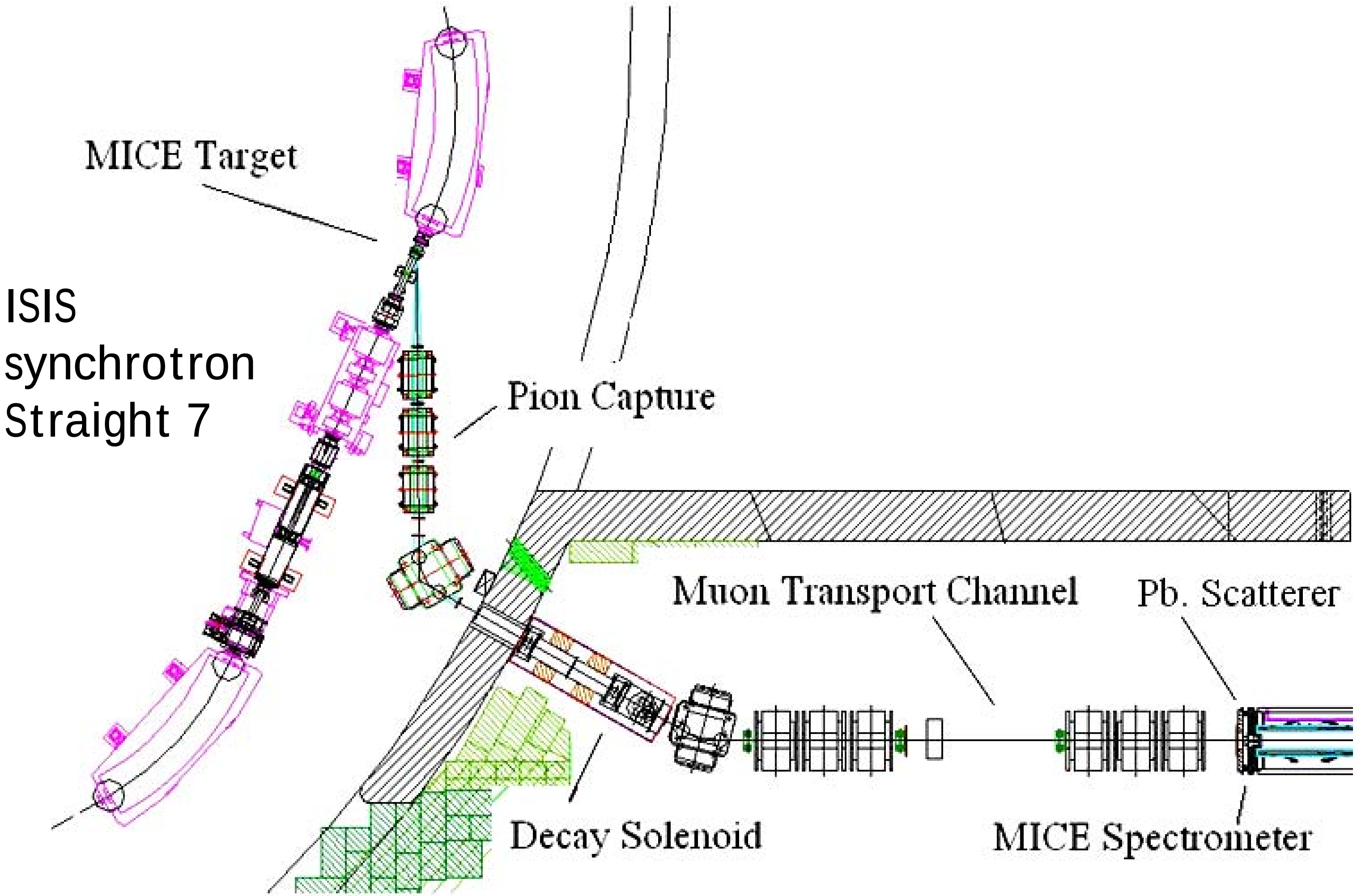
MICE – Muon ionisation cooling experiment

International collaboration using muons from parasitic target on ISIS synchrotron (UK, EU, CH, US, Japan)

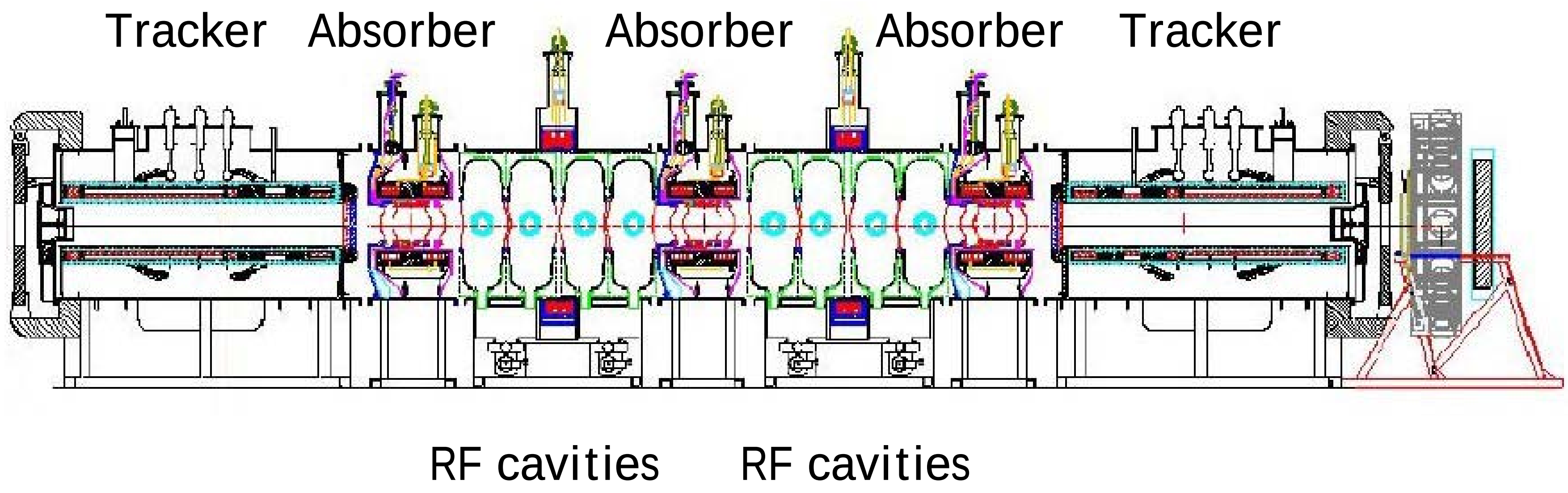
Aim: to design, construct and operate a section of muon cooling channel for a neutrino factory

Integrated into ISIS operations programme

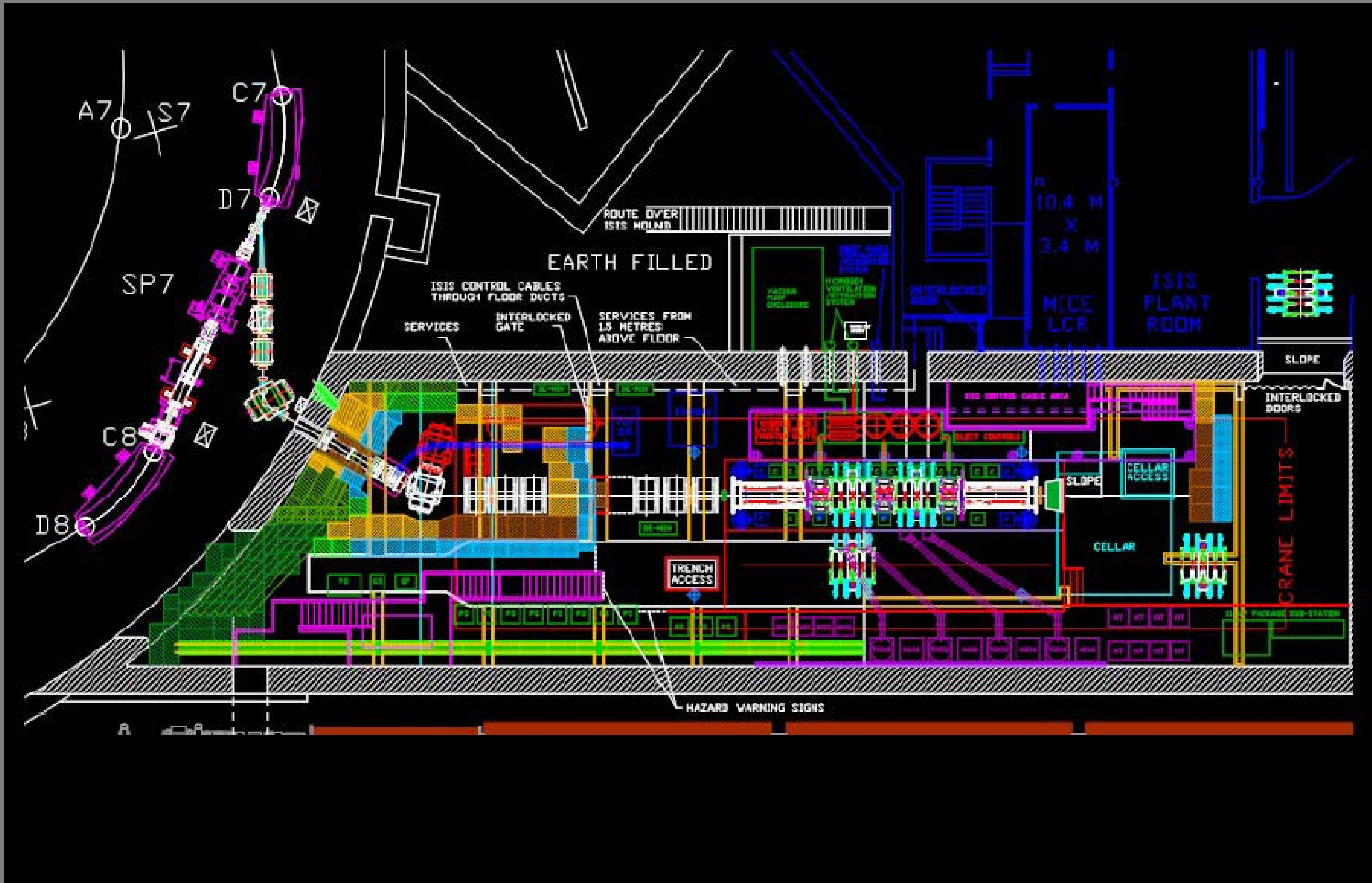
Yoshida, WEOAPA03,
Tilley, WEPLS002
Blondel, THPCH164



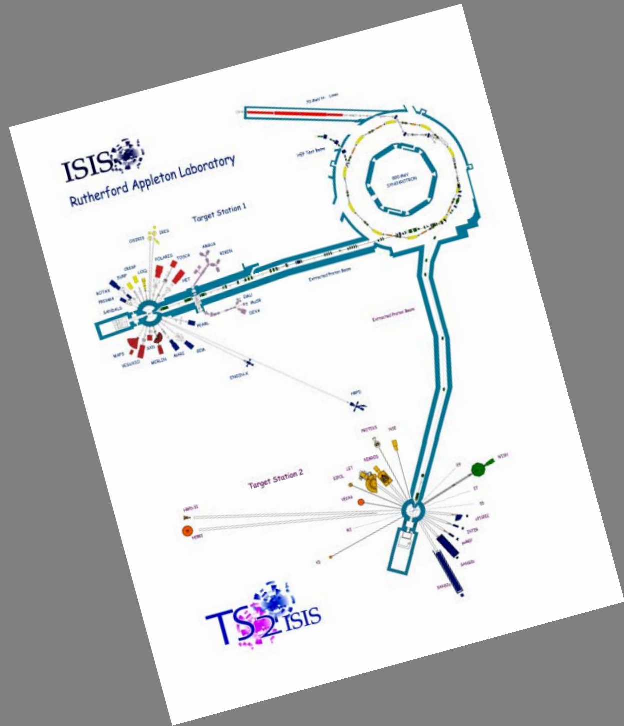
MICE beam line on ISIS synchrotron



Experimental cooling channel

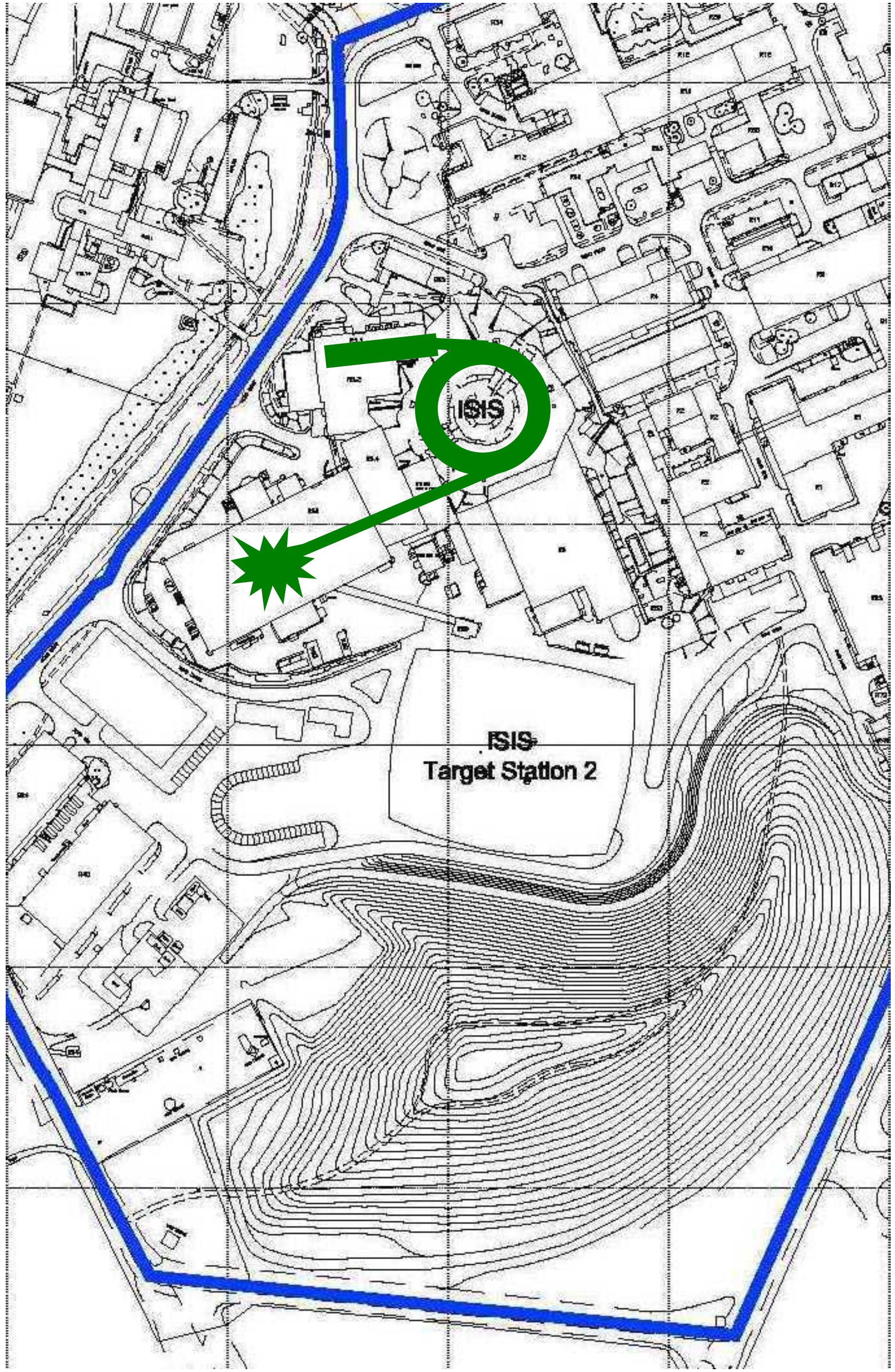


MICE overall layout


ISIS
Rutherford Appleton Laboratory
Target Station 1
Target Station 2
TS2 ISIS

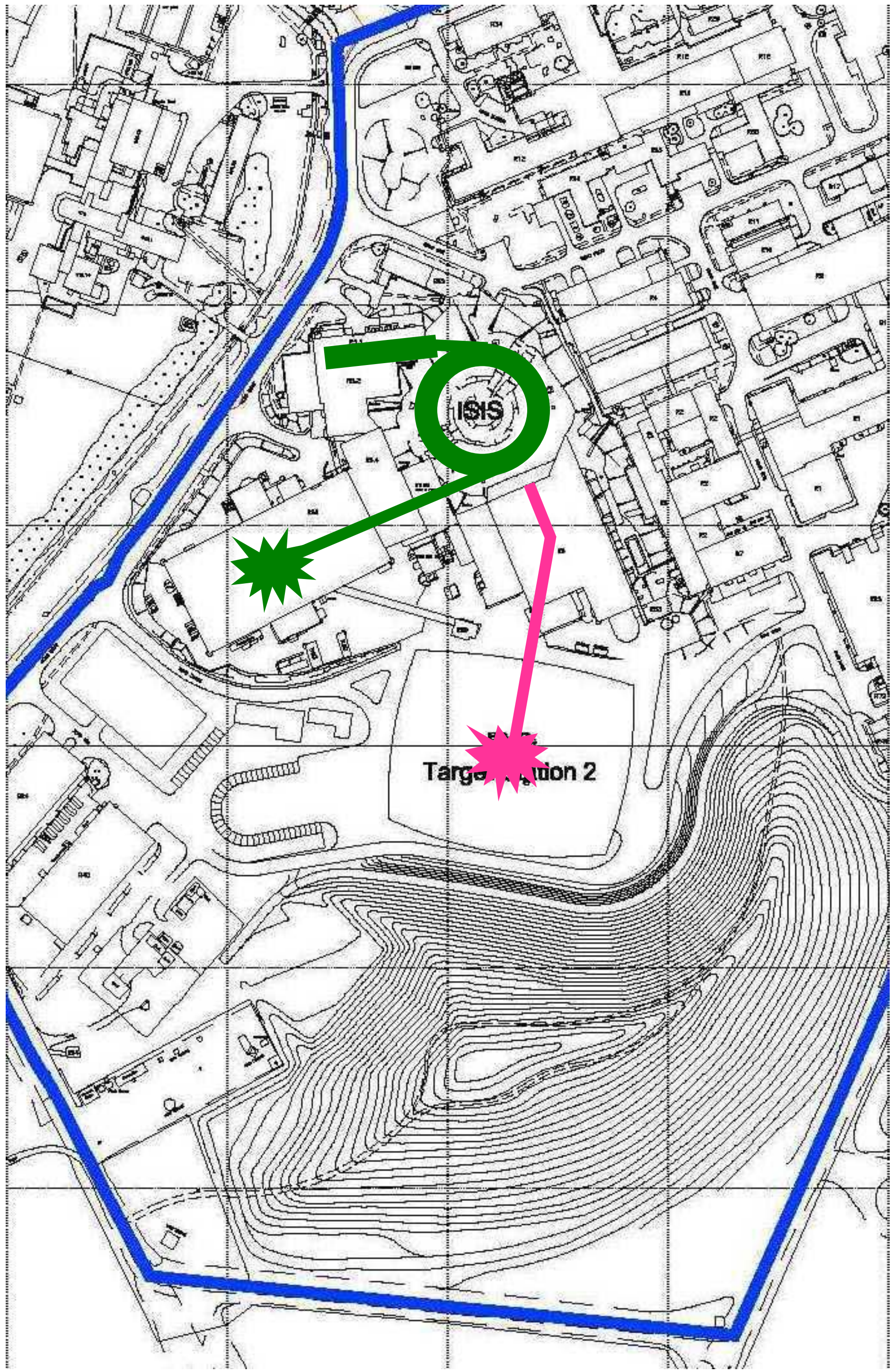
ISIS as built

4 µC per pulse
→ 6 µC with 2RF



Second Target Station (TS-2) being built

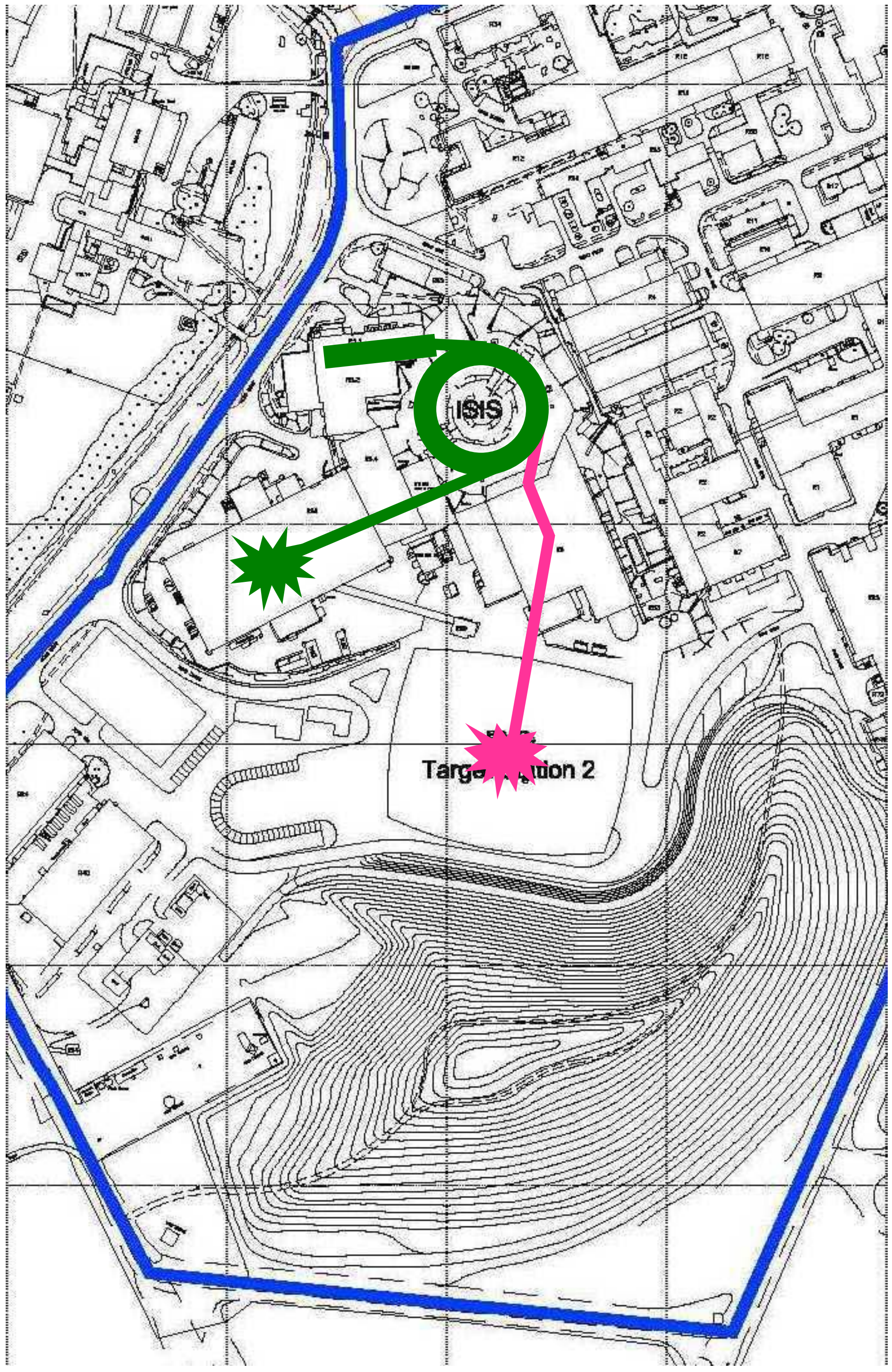
Existing target station (TS-1) continues to run



Beam line EPB-2 to TS-2 joined to synchrotron

First protons to TS-2: Oct. 2007

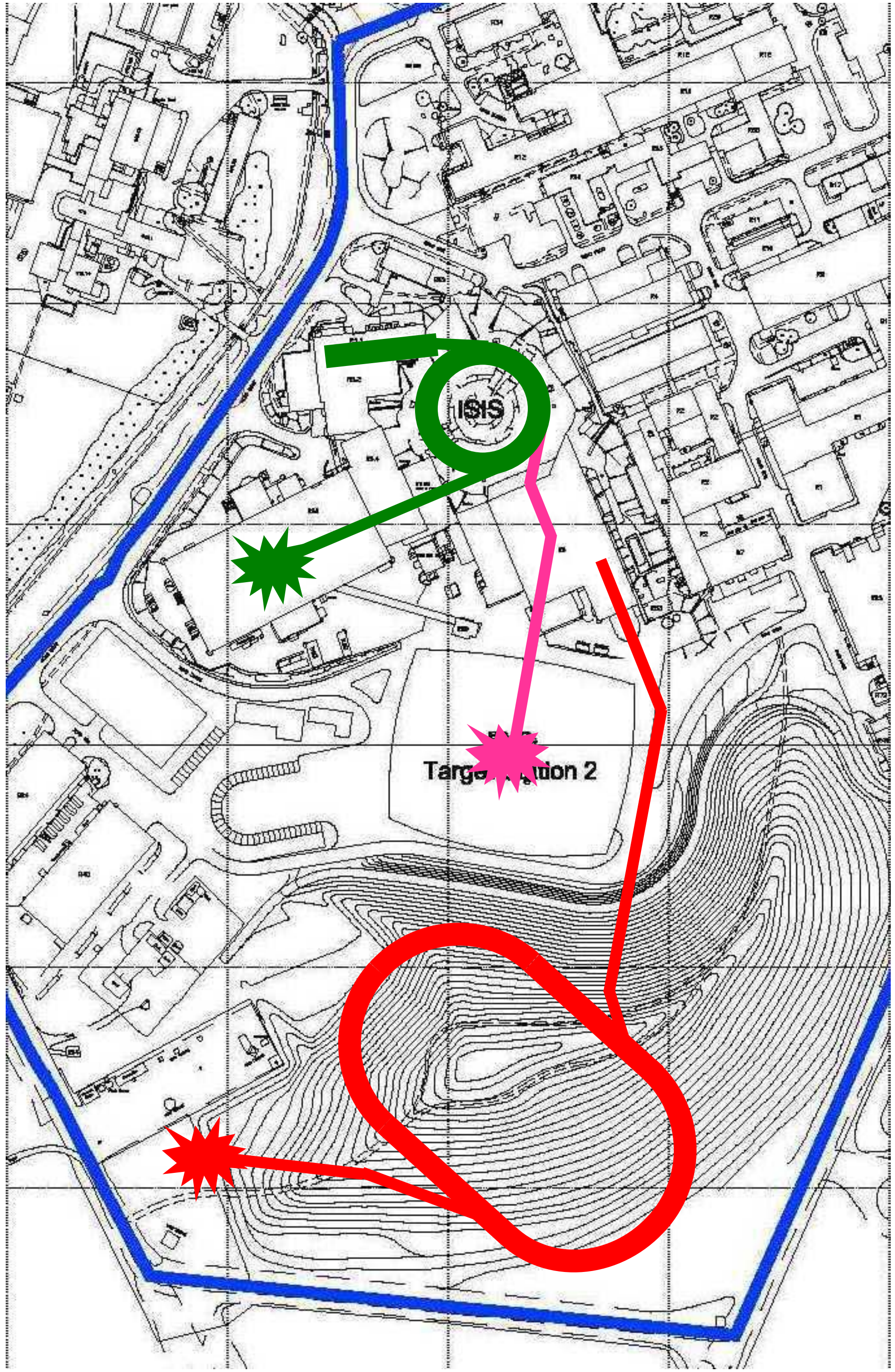
Both TS-1 and TS-2 run



Possible future scenarios:

3 GeV 50 pps synchrotron and third target station (TS-3) built

Both TS-1 and TS-2 continue to run



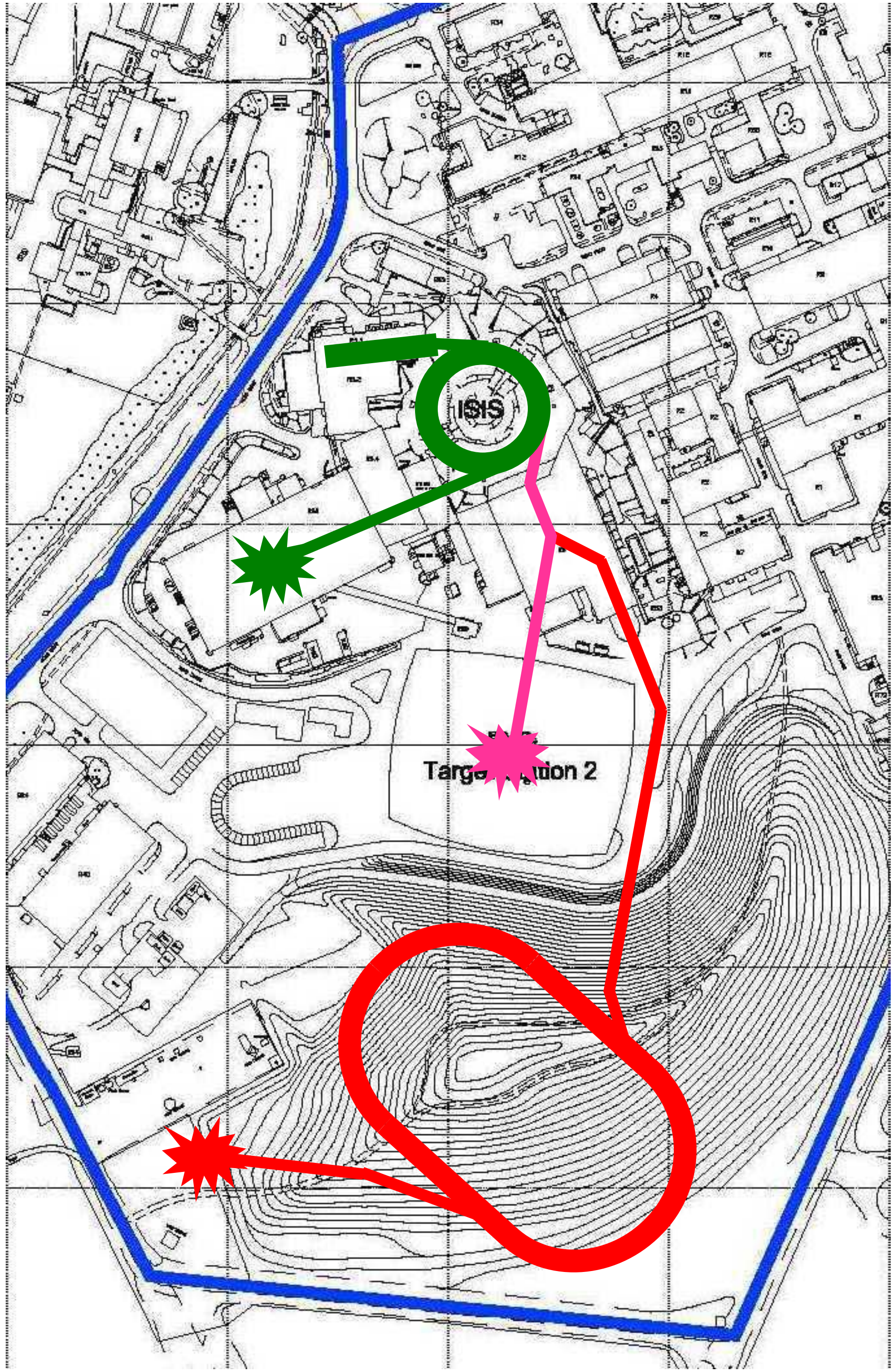
Beam line EPB-3
joined to EPB-2

800 MeV protons
accelerated to
3 GeV

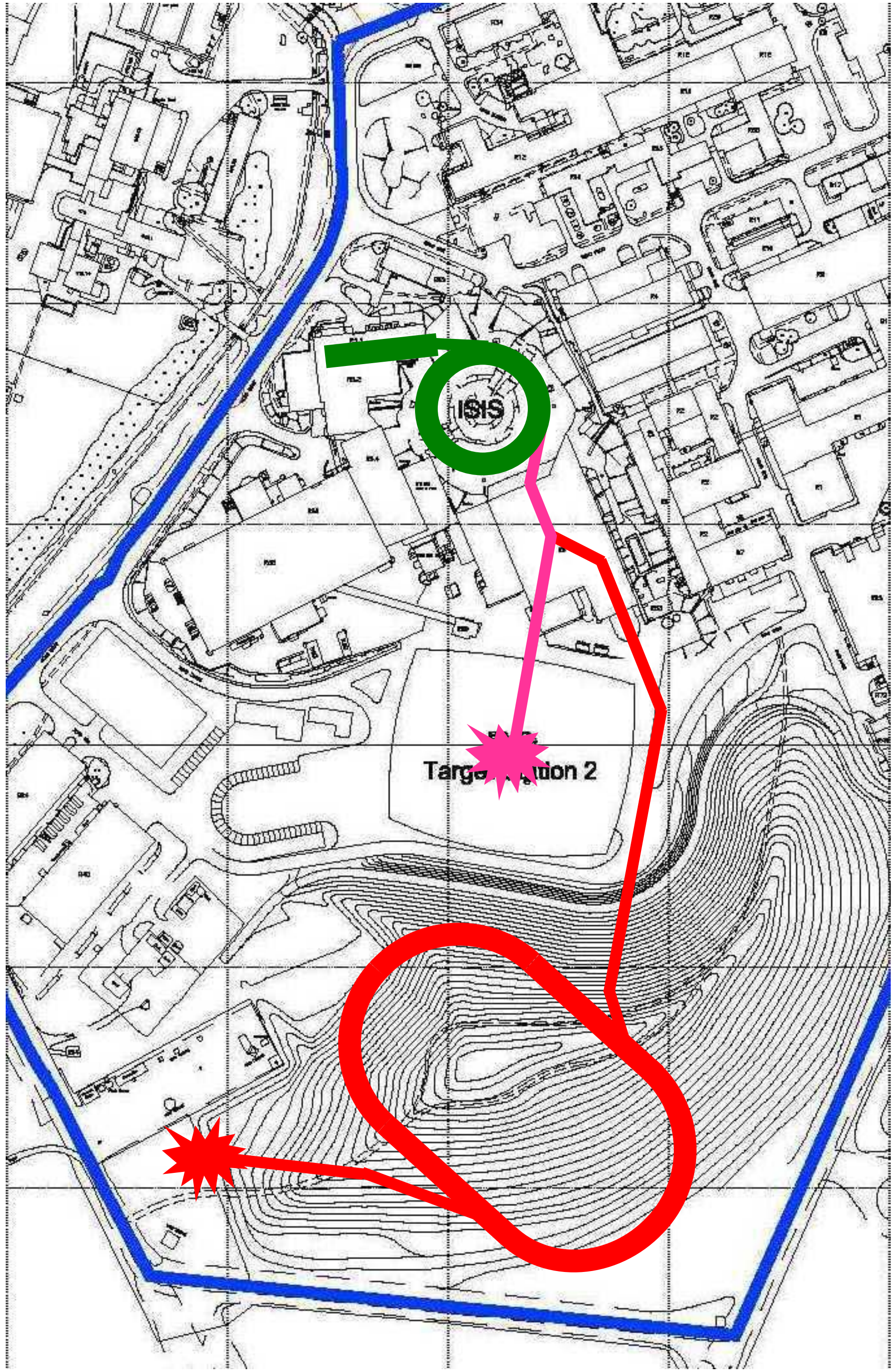
3 GeV × 300 μA ≈ 1 MW

1 MW can be
delivered to TS-3

TS-1, TS-2 and
TS-3 can all run

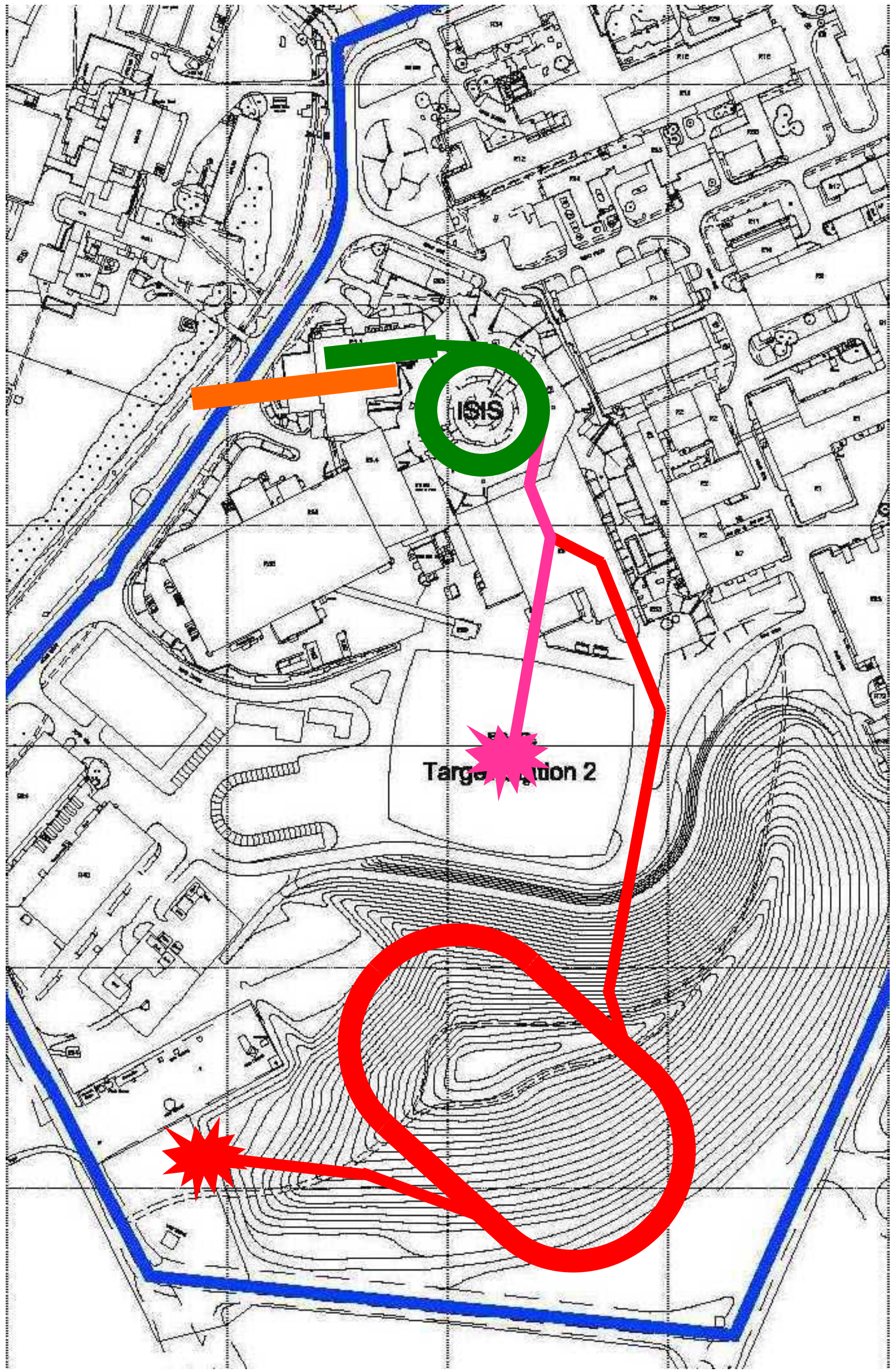


Probably rationalise operating régime by closing down TS-1



New 180 MeV linac built

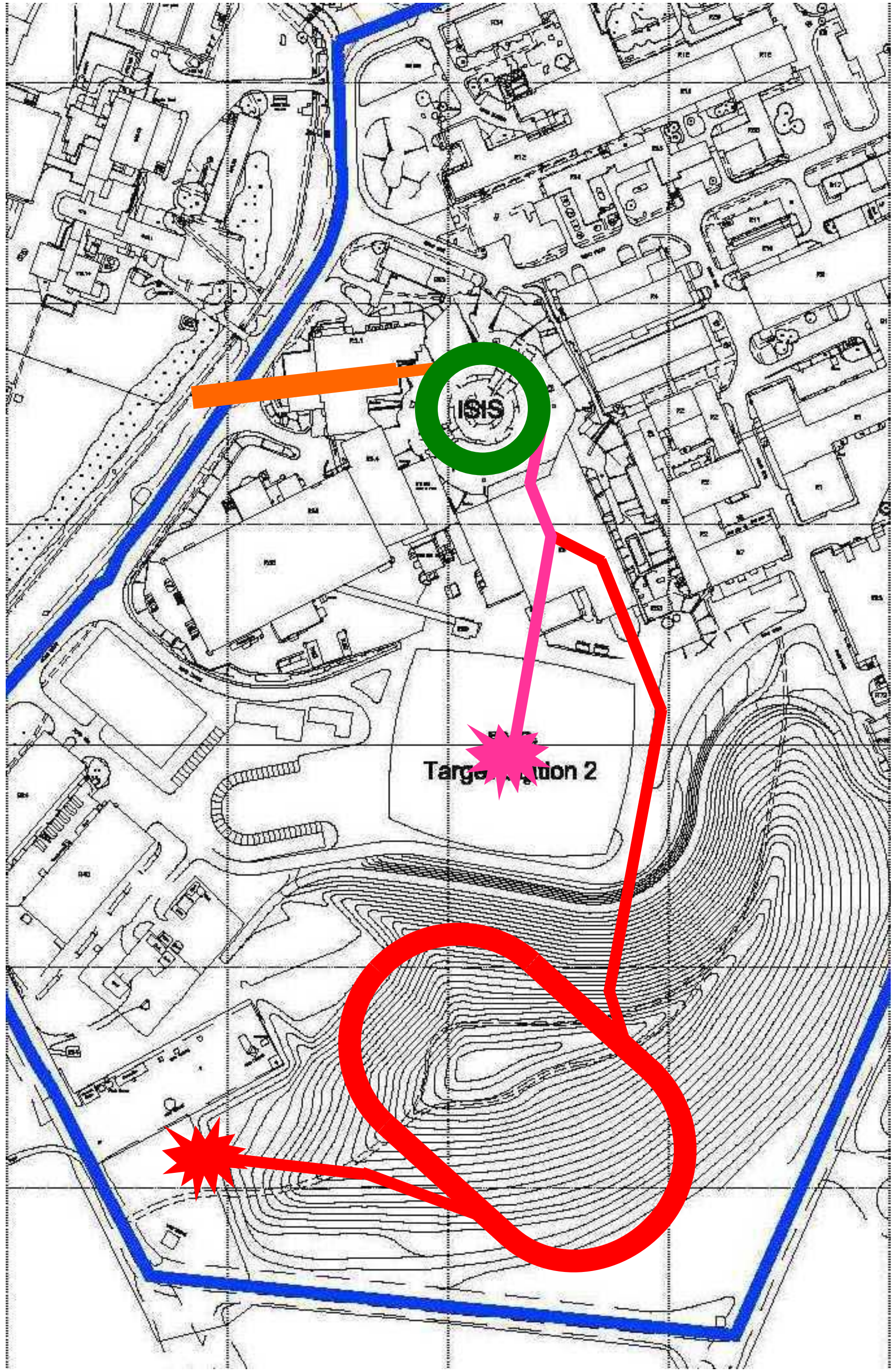
TS-2 and TS-3 continue to run



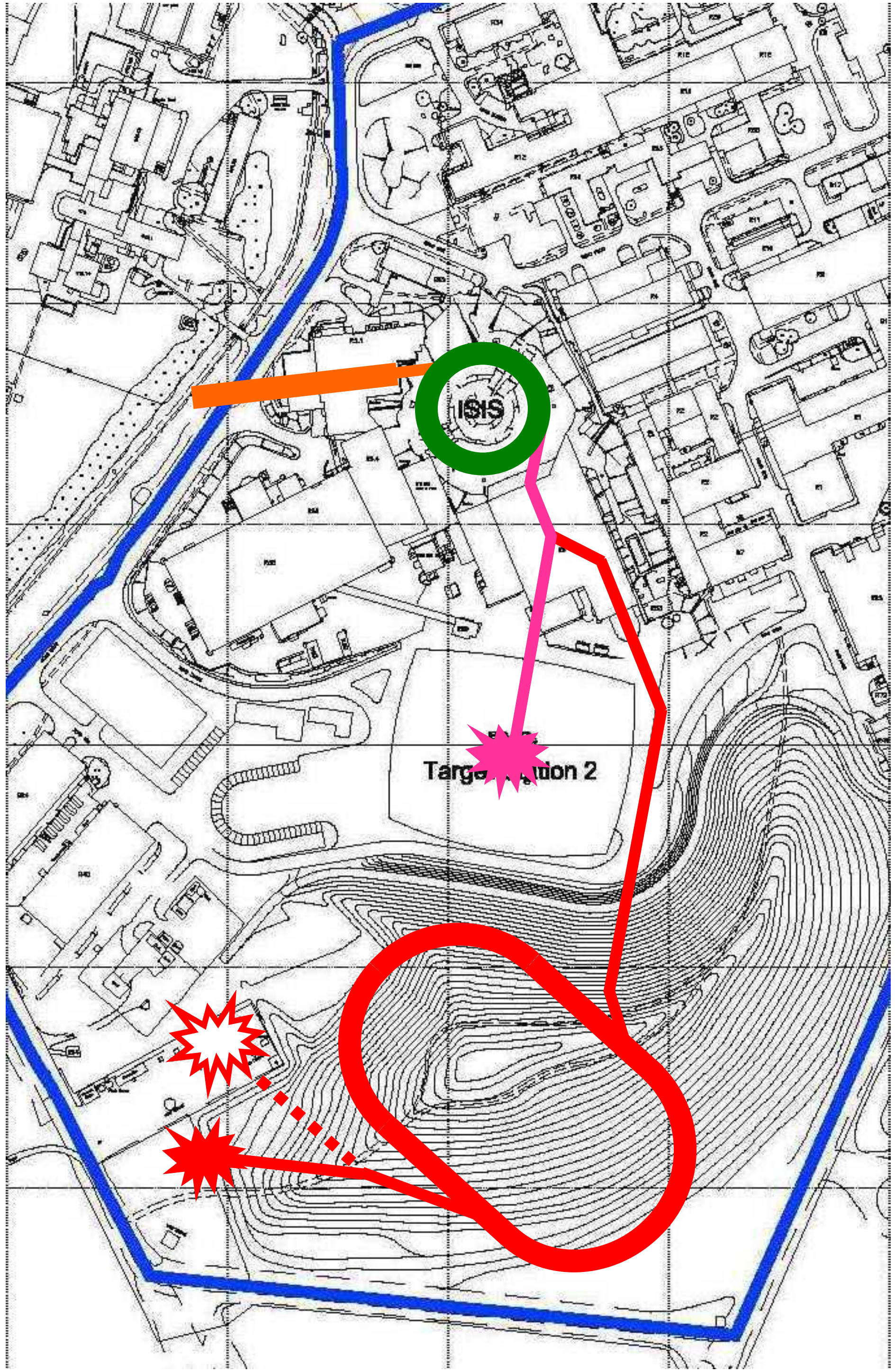
New 180 MeV linac
replaces old
70 MeV linac

TS-2 and TS-3 run

>1 MW to TS-3 now
possible,
provided that
3 GeV synchrotron
can hold >3 μC per
bucket



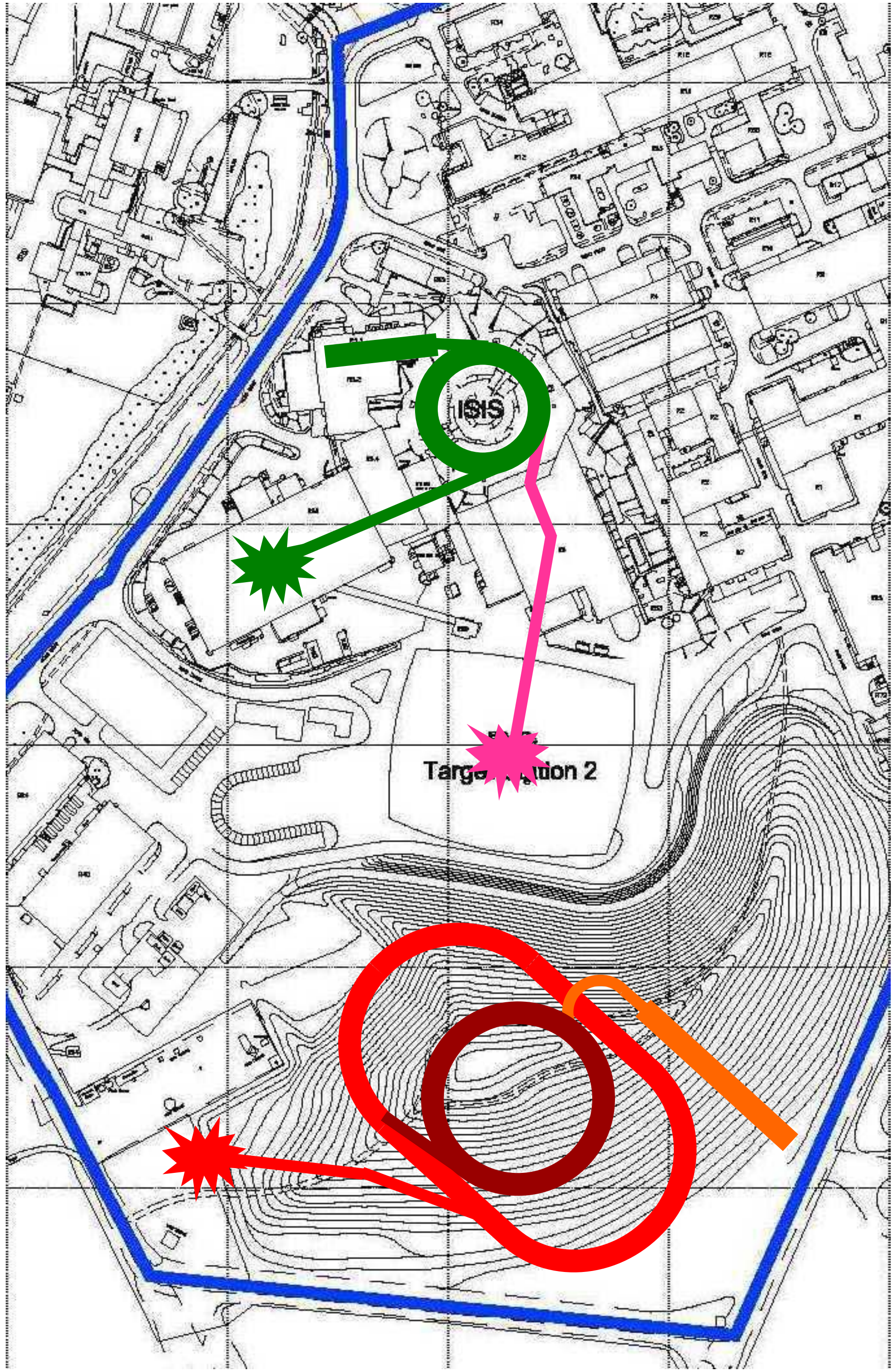
If 3 GeV synchrotron designed to allow acceleration to 8 GeV at reduced repetition rate, muon-producing target for neutrino factory possible



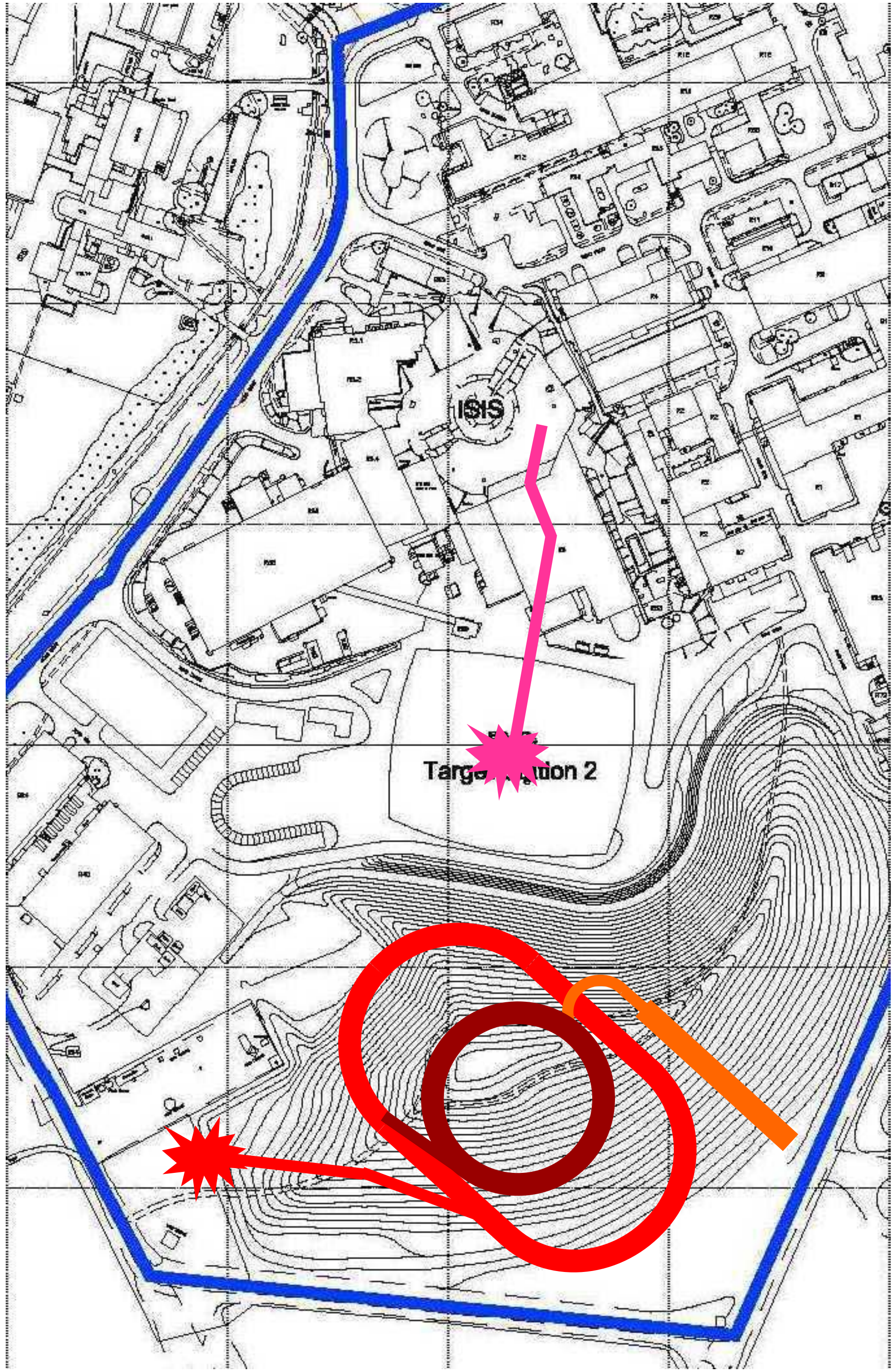
Alternatively, build stand-alone system based on 3 GeV synchrotron with 180 MeV linac + two 1.2 GeV booster synchrotrons

TS-3 can now run at 2½ MW quite separately from TS-1 and TS-2

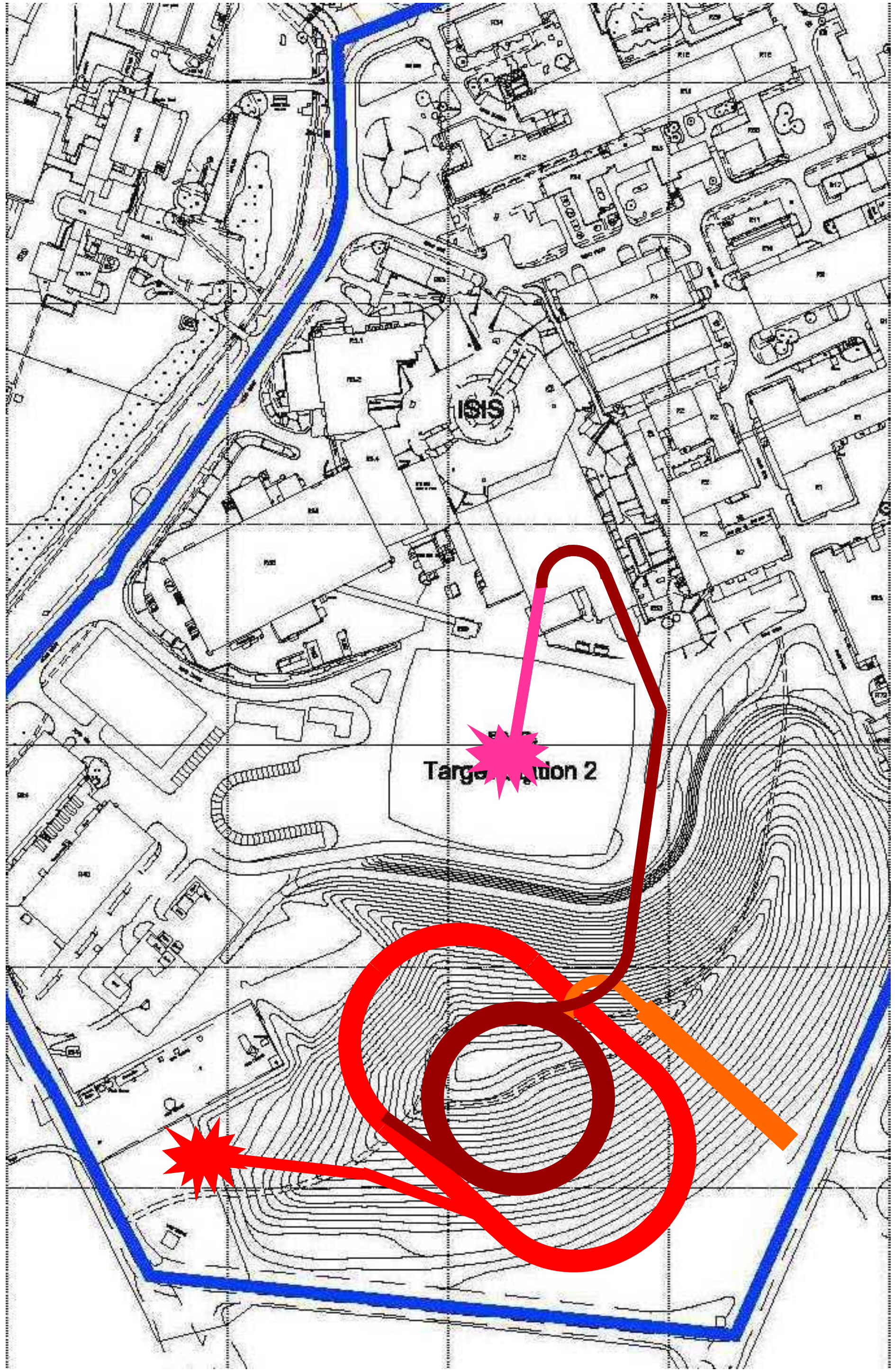
5 MW option also possible



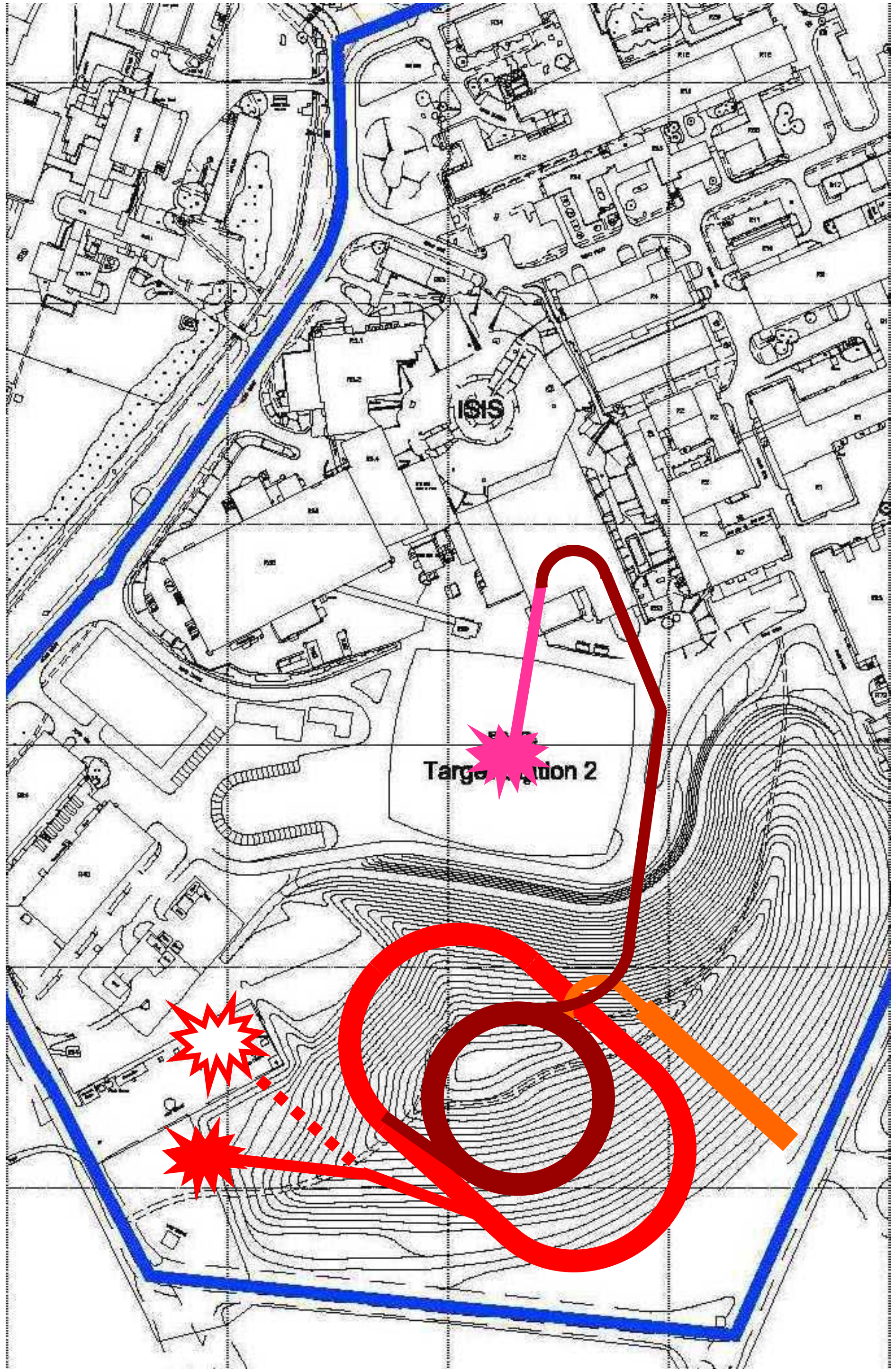
Could let present ISIS linac and synchrotron go



But keep TS-2 running by taking beam from booster synchrotron



Muon-producing target for neutrino factory added



ISIS:

Began running in 1984

Continuous series of upgrades since 2002

Second Target Station running ~end 2008

Expect to run ISIS until ~2020

CCLRC ISIS

ISIS