Accelerator R&D in the UK

Mike Poole

ASTeC Director

History

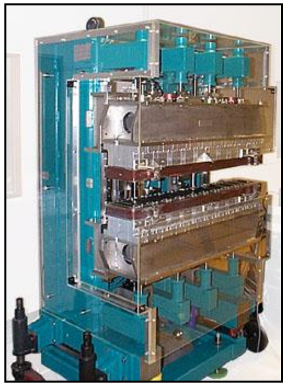
- UK has long traditions in particle accelerator development
- Particle physics applications saw national decline (1970's)
- Birth of major facilities - photons and neutrons

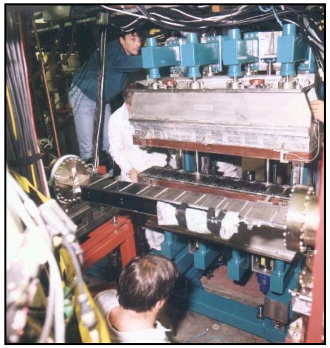
  SRS at DL   ISIS at RAL   NSF at DL

- High brightness electron beam expertise
- High intensity proton beam expertise
- Skills base concentrated on Facility support
- SRS closure in 2008 but ISIS ongoing developments

SRS Legacy

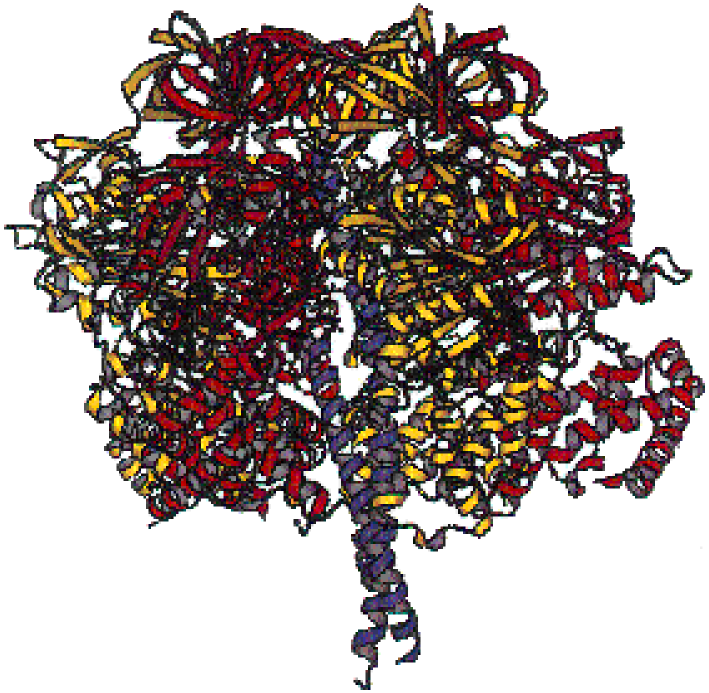
- Electron beam dynamics   (eg nonlinear)
- High power RF systems
- Ultra-high vacuum science and technology
- Advanced diagnostics
- Novel insertion device solutions -   magnetics

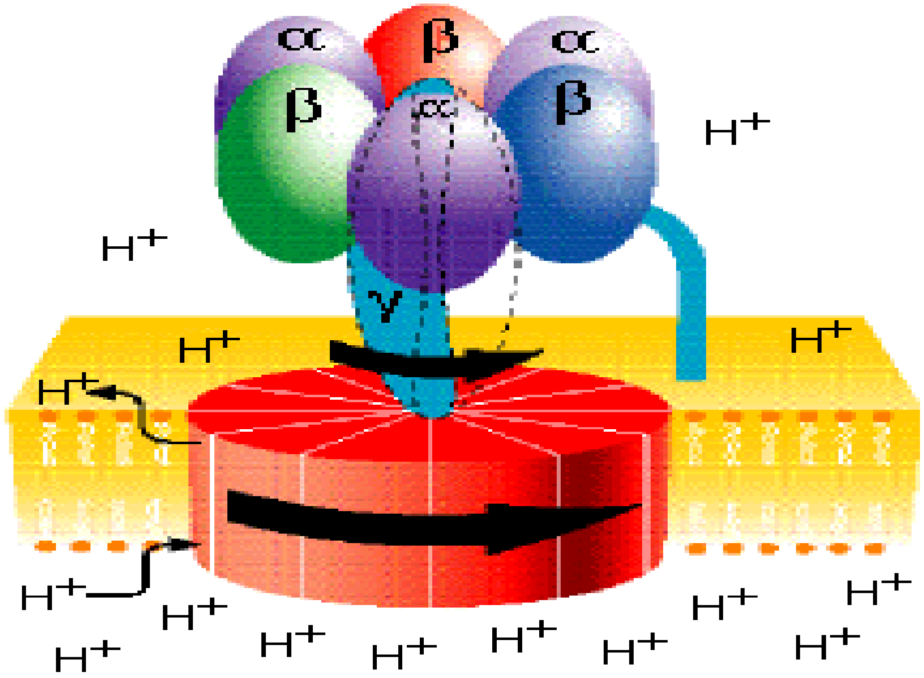




The Nobel Prize: F1 ATPase structure

- Sir John Walker shared 1997 Nobel Prize for Chemistry - structure of the F1 ATPase enzyme, using the SRS





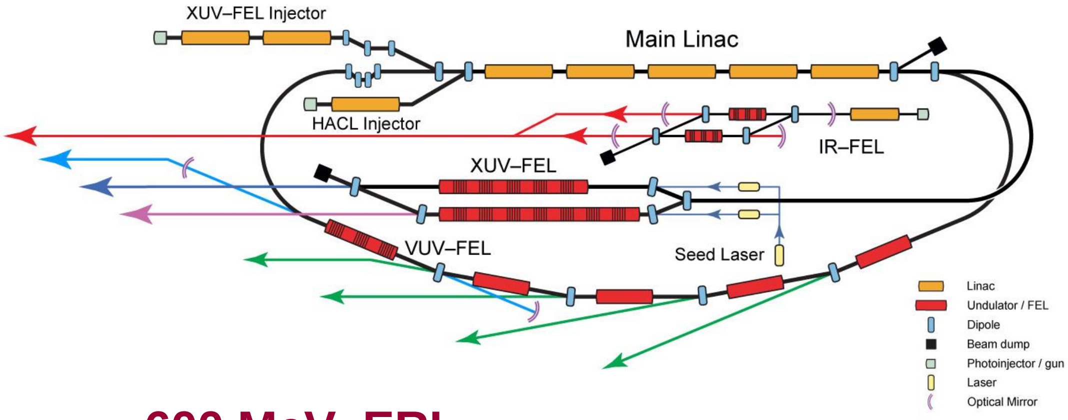
New Light Sources

- HELIOS - industrial applications
- Diamond Light Source - conceived and designed by SRS team
- 4GLS
- NLS

700 MeV

4.5 T

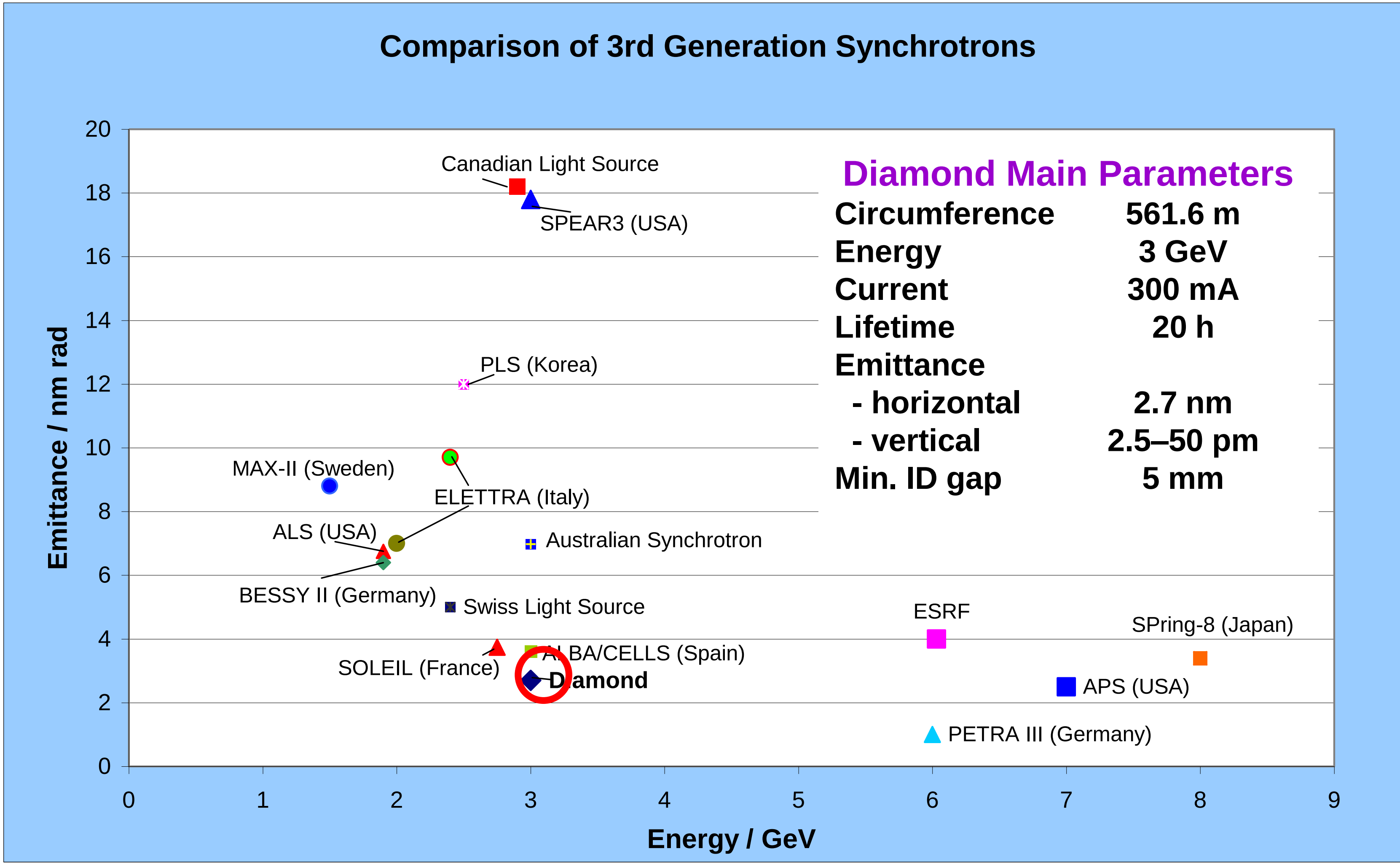
Lithography source designed at Daresbury
Sold by Oxford Instruments to IBM in 1990 -
Operated successfully for 10 years



600 MeV ERL

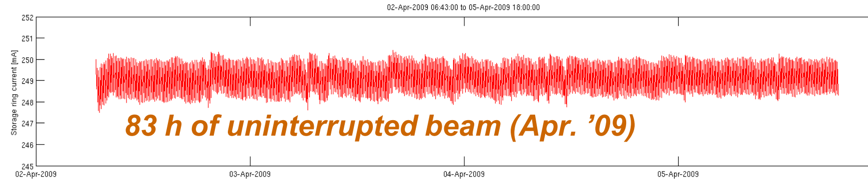
Diamond on Harwell Campus

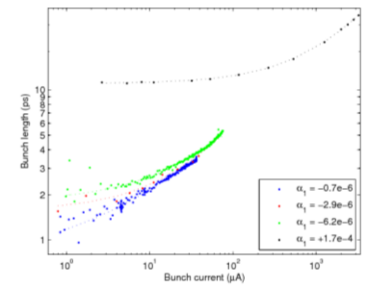
Lowest Emittance Medium Energy Ring



R&D Programme at DLS

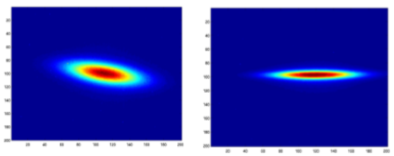
- **Top-up and low-alpha modes**





- **Reduced coupling**

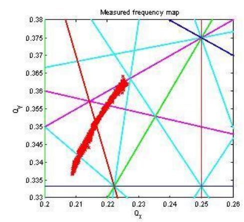
  coupling ~0.08% achieved
  → vertical emittance ~ 2.2 pm



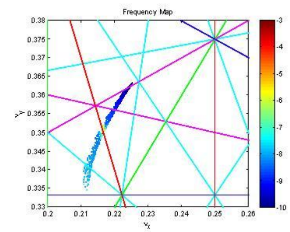
- **Nonlinear dynamics**

- **Collective effects**

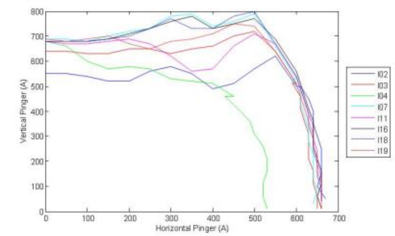
- **Insertion devices**

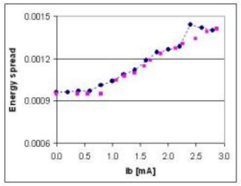


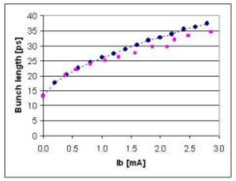
Measurements

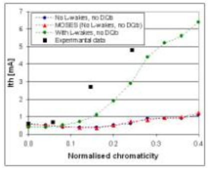


Simulations

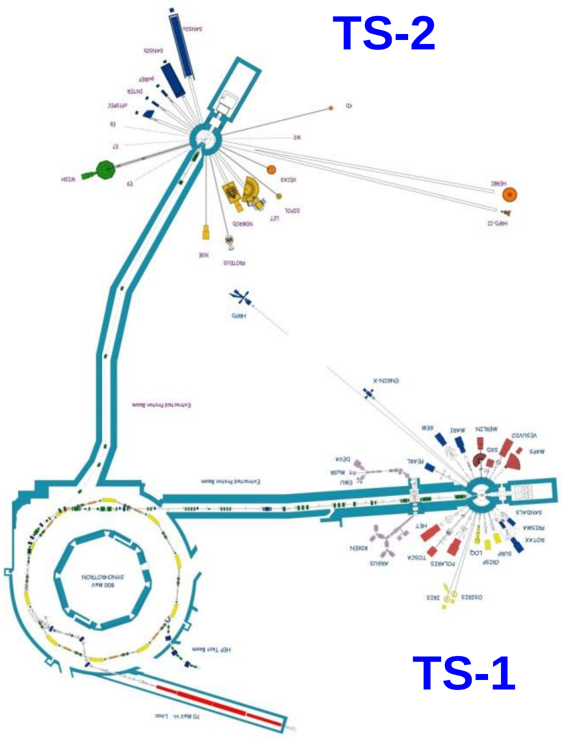








View of ISIS on RAL Site



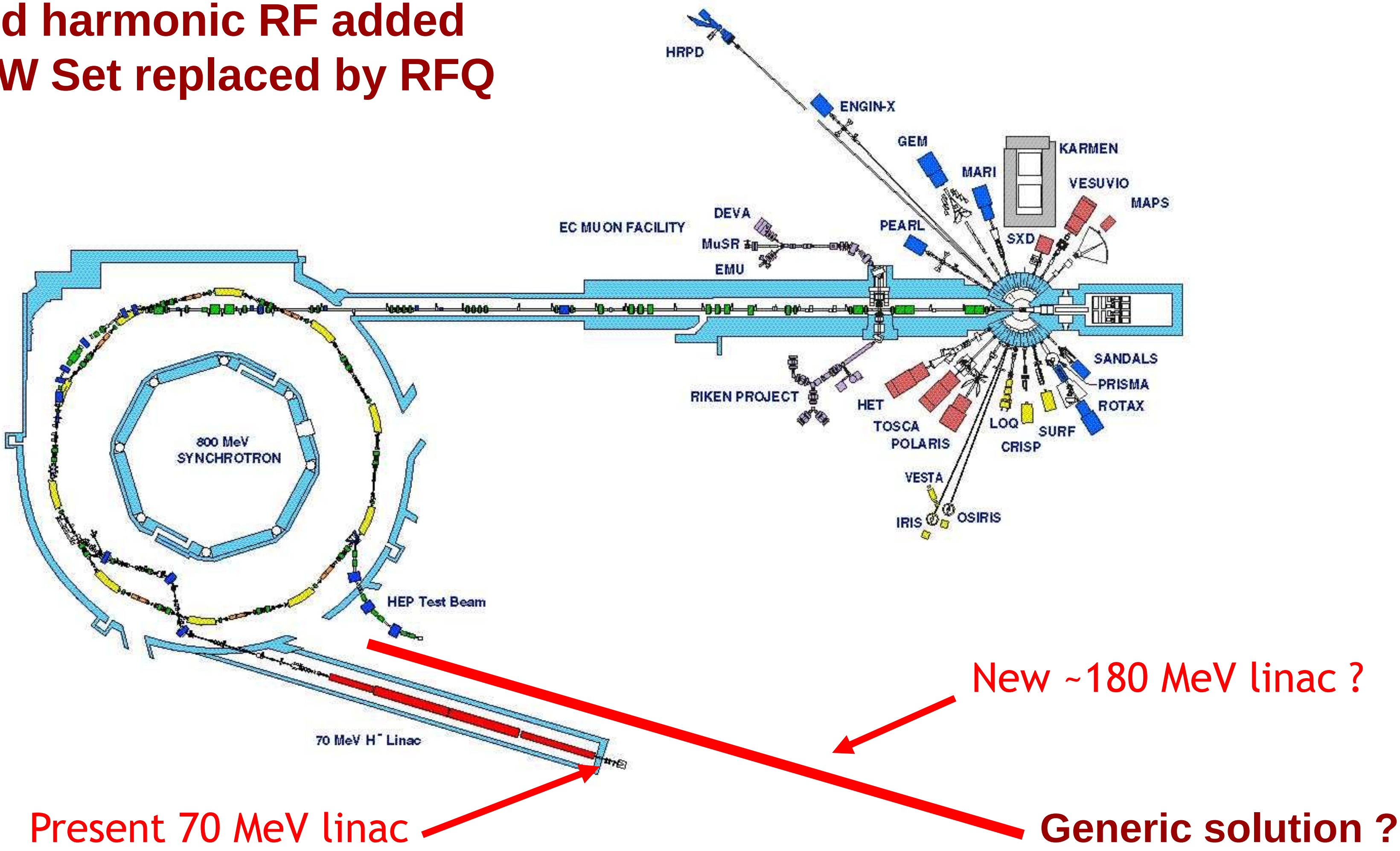
ISIS Upgrade Studies

- **Second harmonic RF installed** **(50% current increase to 300μA)**
- **New injector ?**
- **New ring ?**

Scenario studies underway
Target station upgrades also needed
Beam loss simulations
Intensity limitations

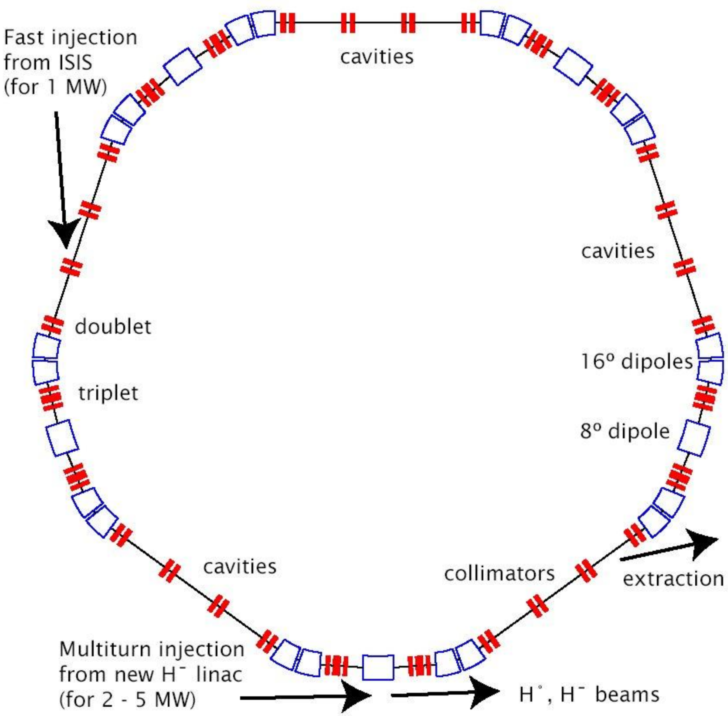
ISIS Upgrade Paths

2nd harmonic RF added
C-W Set replaced by RFQ

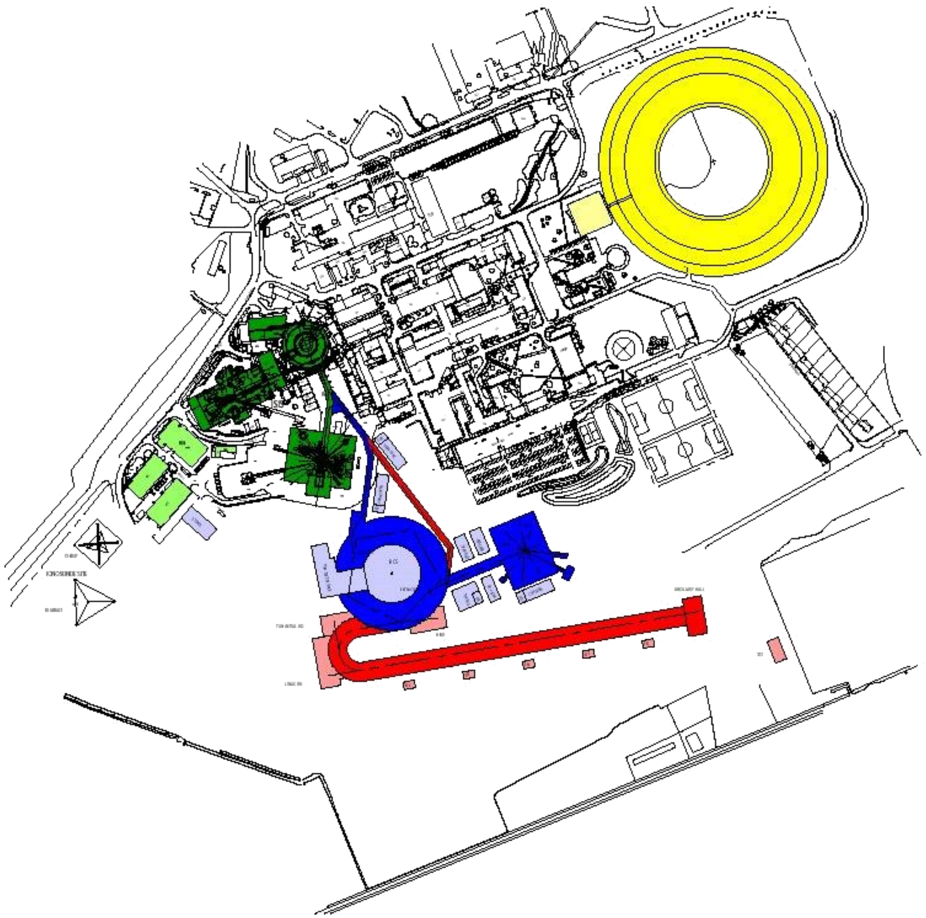


Second Ring - RCS Concept

Energy	0.8 – 3.2 GeV
Rep Rate	50 Hz
C, R/R_0	367.6 m, 9/4
Gamma-T	7.2
h	9
f_{rf} sweep	6.1–7.1 MHz
Peak V_{rf}	~ 750 kV
Peak K_{sc}	~ 0.1
□$_l$ per bunch	~ 1.5 eV s
$B[t]$	sinusoidal



Major Upgrade Paths



1) Replace ISIS linac with a new ~180 MeV linac (~0.5MW)

2) Based on a ~3.3 GeV RCS fed by bucket-to-bucket transfer from ISIS 800 MeV synchrotron (1MW)

3) RCS design also accommodates multi-turn charge exchange injection to facilitate a further upgrade path where the RCS is fed directly from an 800 MeV linac (2 – 5 MW)

2001 - An R&D Odyssey

- Diamond project approval raised awareness of activities
- Recognition that restriction on innovative programmes
- Need to rekindle university contribution
- Participation in international initiatives
- Accelerator Science and Technology Centre (ASTeC)
- Central government injection of explicit funding - 2004
- Cockcroft and John Adams Institutes in place
- Major design studies and generic programmes commenced

Linear Collider Design Studies

- **Collaboration of 11 HEIs with ASTeC : LC-ABD**
  - **Birmingham Cambridge Dundee Durham Lancaster Liverpool Manchester Oxford QMUL RHUL UCL**
- **Major funding 2004-2008, but then reduced !**
- **Strategic decision to focus on Beam Delivery System for ILC**
- **Additional topics : positron source damping rings linac**
- **Built major international role, including GDE appointments**
  - **source damping ring BDS integration crab system diagnostics fb control**
- **Evolving CLIC studies – future under negotiation**
- **EuCARD topics also include linac optimisation and LHC crab**

Recent LC Activities

- SC undulator modules under construction
- Target wheel experiments
- 5 GeV damping ring lattice (SCW, bpm, ..)
- Linac structure modelling - ILC and CLIC
- BDS central integration solutions and matched optics
- Collimation and damage studies
- Crab systems
- Diagnostics – bpms, laser-wire, e-o, ...
- Feedback control
- Machine alignment and stabilisation

Neutrino Factory Design Studies

- **Collaboration of 6 HEIs with ASTeC**
  - **Glasgow IC Liverpool Oxford Sheffield Warwick**
- **Funding also boosted in 2004 – and sustained**
- **Sponsored International Scoping Study and now IDS**
- **Proton drivers and muon accelerators (eg FFAG)**
- **Technology programme**
  Front End Test Stand Targets RF breakdown studies
- **MICE**

FP7 EuroNu Design Studies

NLS Design Studies: Baseline Specification

- **Free-Electron Lasers to cover the range 50 eV to 1 keV :**

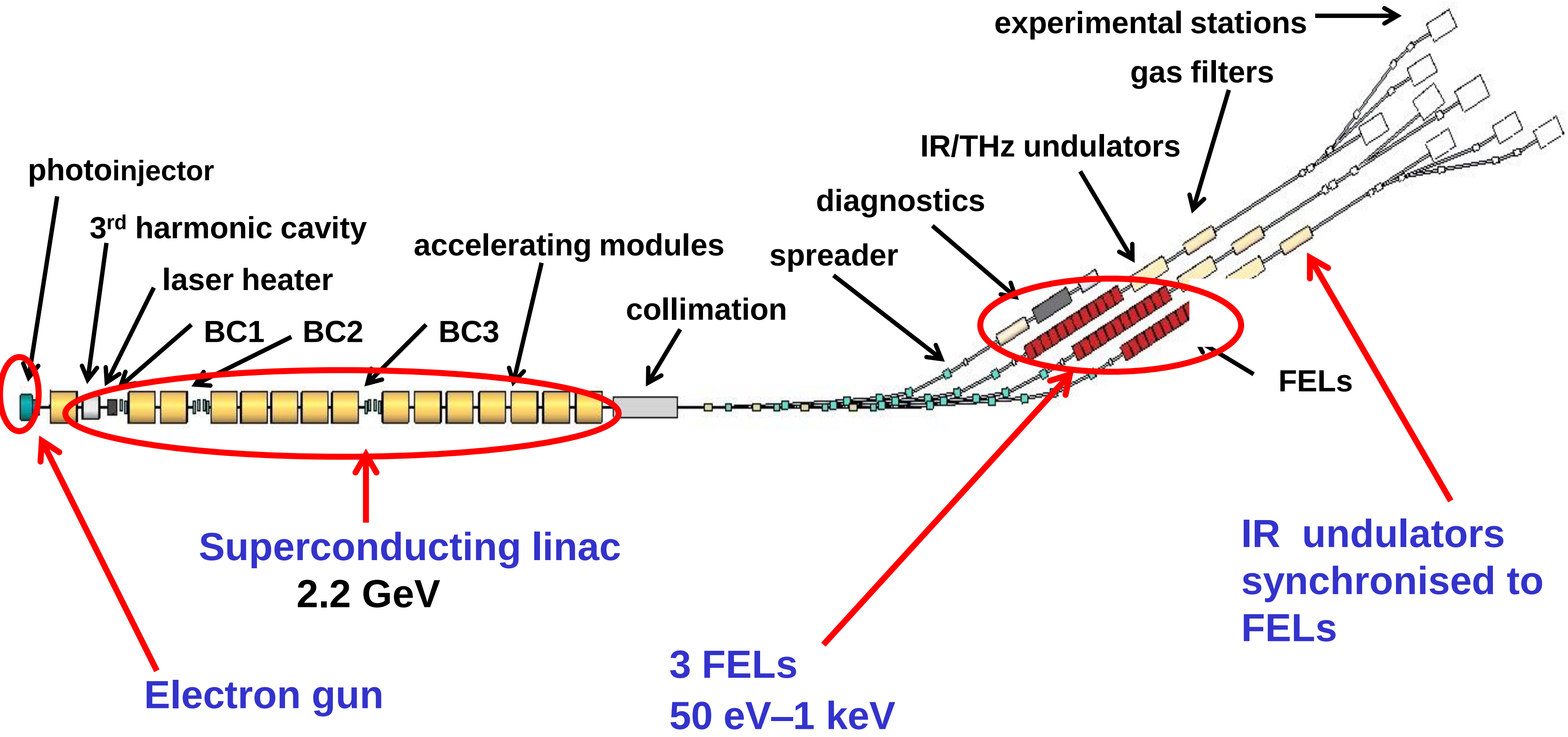
  FEL1: 50 - 300 eV **FEL2:** 250 - 850 eV **FEL3:** 430 - 1000 eV

  - **harmonics up to** 5 keV
  - **independently tunable via undulator gap variation**
  - **variable polarization using APPLE-II undulators**
  - **seeded in order to provide longitudinal coherence, in 20 fs pulses, and better synchronisation to conventional lasers**

- **Conventional lasers + HHG:** **60 meV (20 μm) – 50 eV**

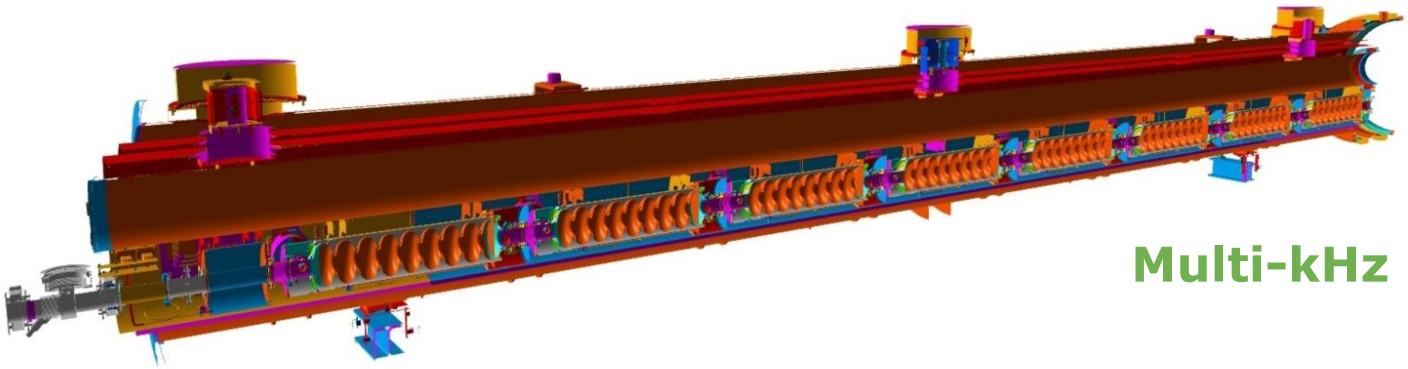
- **IR/THz source:** **e- beam generated and synchronised to the FELs** **20 – 500 μm**

New Light Source (NLS) for the UK



Active STFC/DLS design team producing CDR for May 2010

NLS Linac Technology



Multi-kHz CW solution

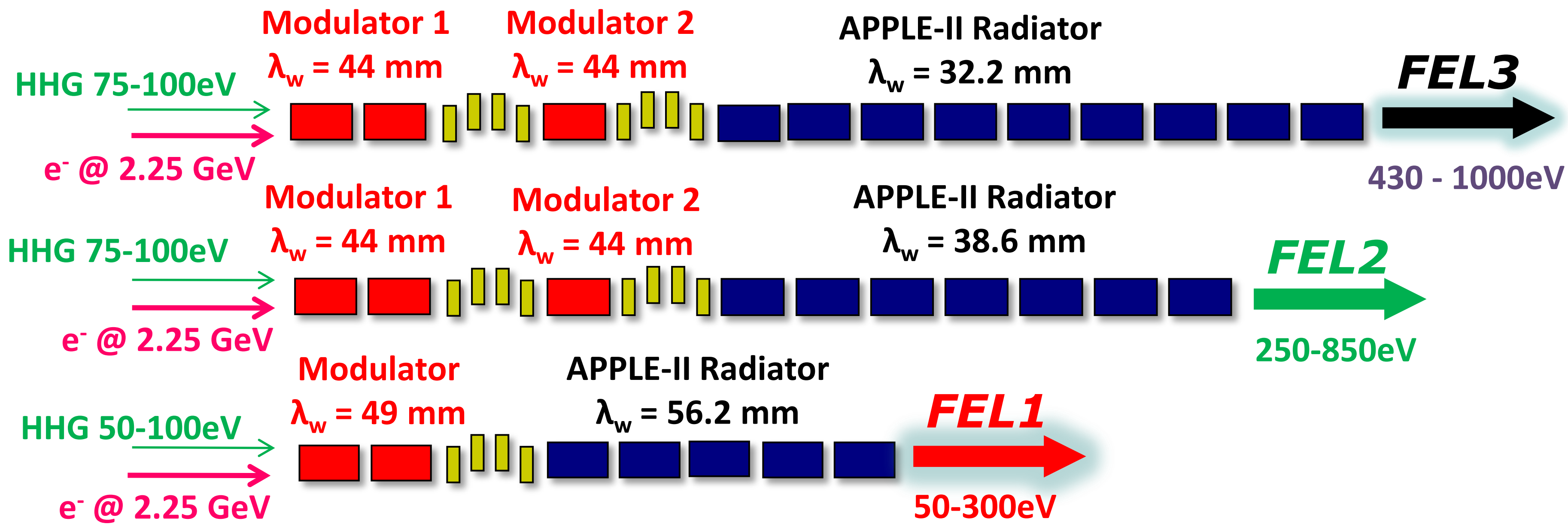
Adapted TESLA/XFEL cryomodule with major modifications for the higher input power and x10 higher cryogenic load:

- Larger two phase line
- Installation of JT valves
- Incorporating LHe reservoir with level control
- Installation of compensating heaters
- Possible additional magnetic shield
- Modifications due to change in RF couplers
- Modified end caps to suit the transfer line Jumpers

most of these modifications have already been studied by BESSY/DESY or separately validated.

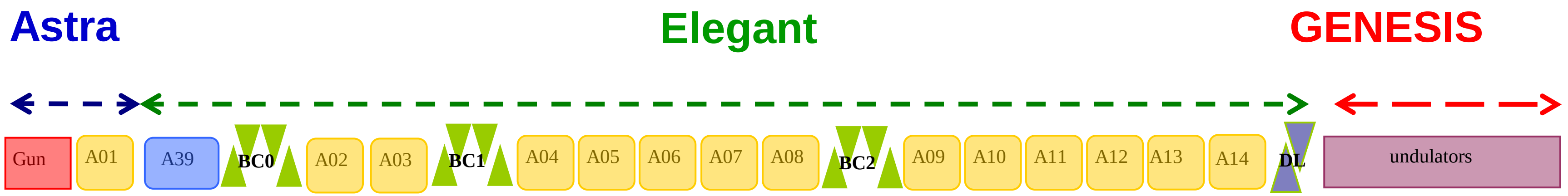
A full scale prototype is required to validate the complete design before production

FEL Systems



- common electron energy for all 3 FELs, allows simultaneous operation
- HHG seeding with realistic laser parameters, up to 100 eV
- harmonic cascade scheme to reach up to 1 keV

Start-to-End Simulations

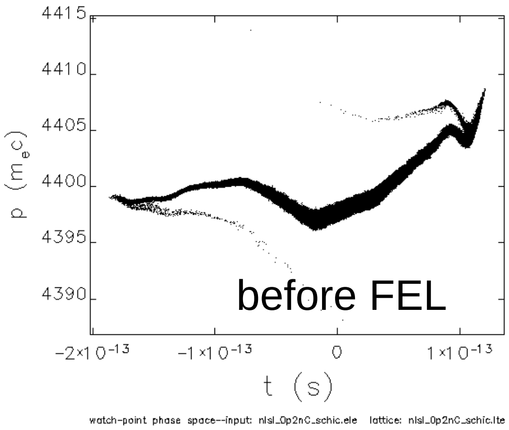


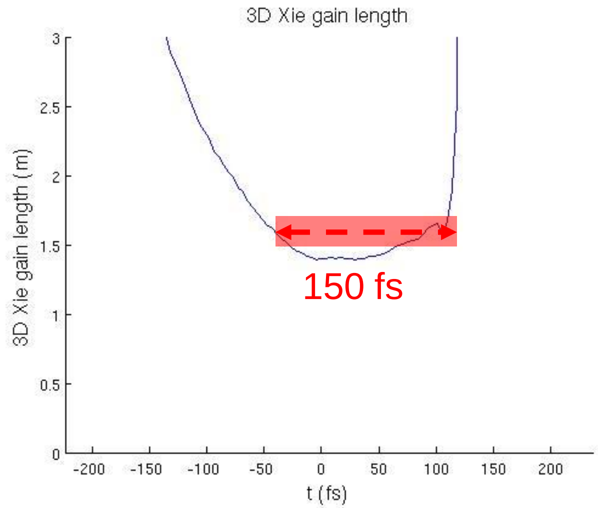
- **Astra** - optimise the injector, including space-charge effects
- **Elegant** - optimise beam quality delivered to the undulators, including CSR, longitudinal space charge, wake-fields, …
- **GENESIS** - validate the optimisation with full start-to-end time dependent FEL simulations

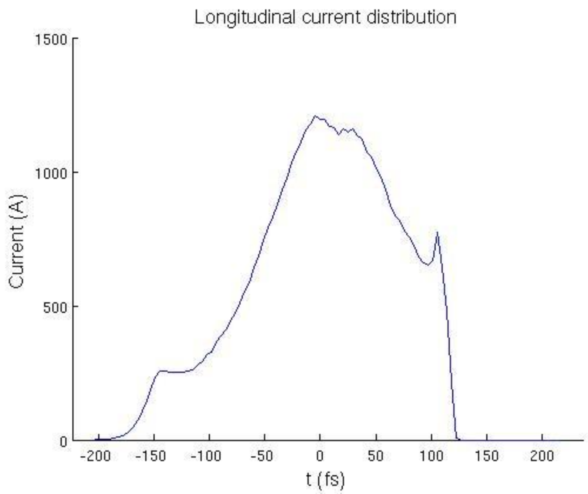
Operating in a seeded mode adds a vital factor to the optimisation:

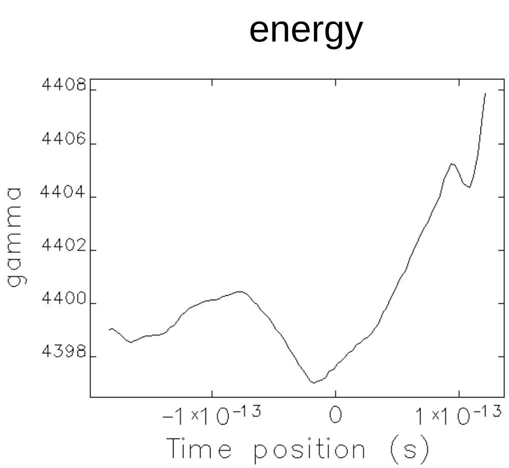
the need for a relatively long region with constant beam parameters to tolerate jitter between the seed laser and the electron beam pulses

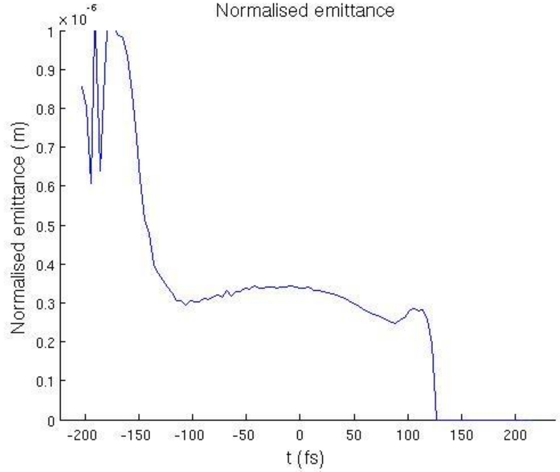
Baseline Optimisation (0.2 nC)

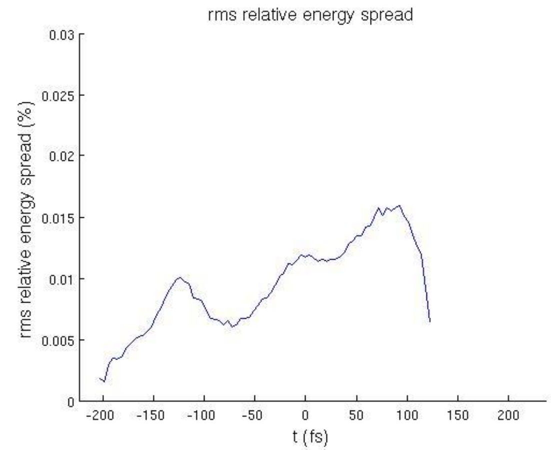




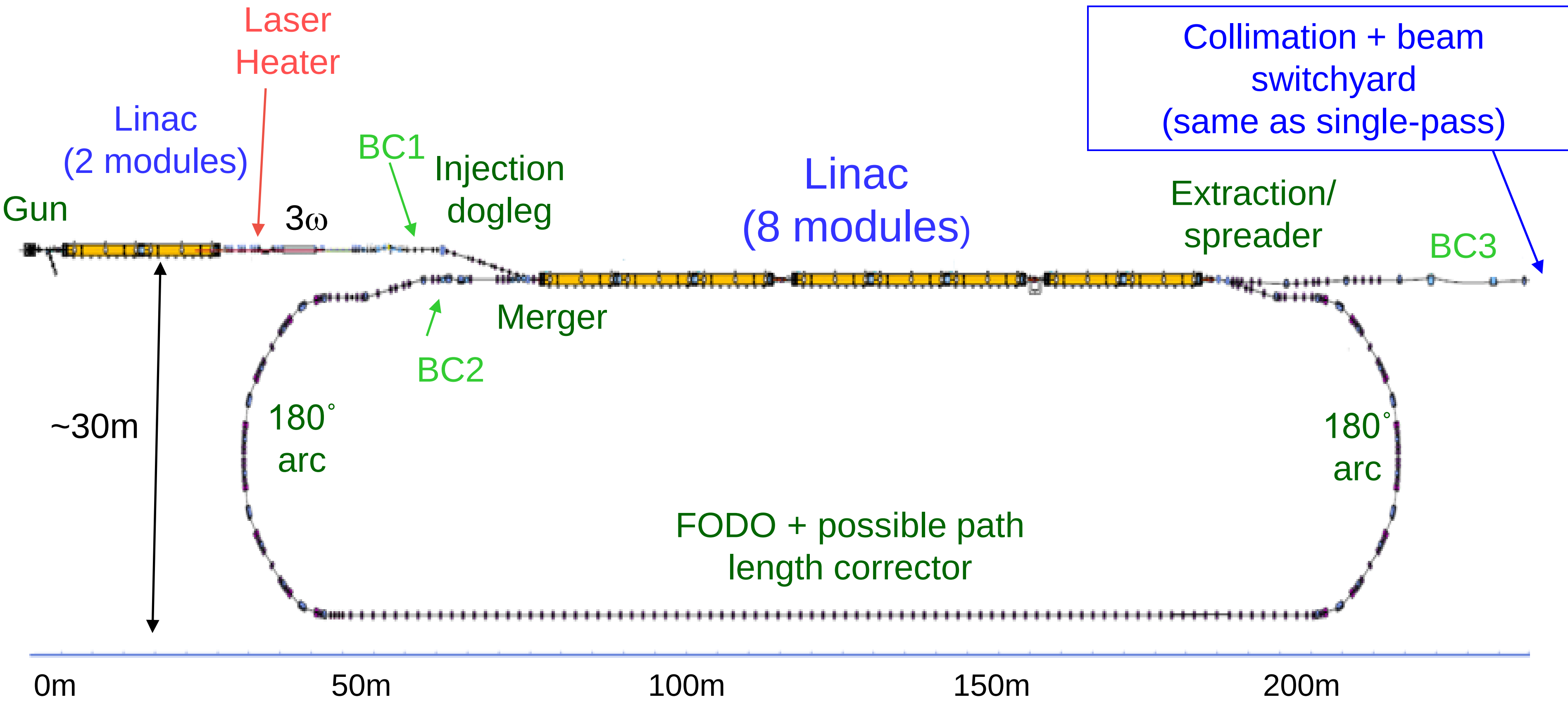








Recirculating Linac Layout



Inject at ~200 MeV, two passes through 1 GeV

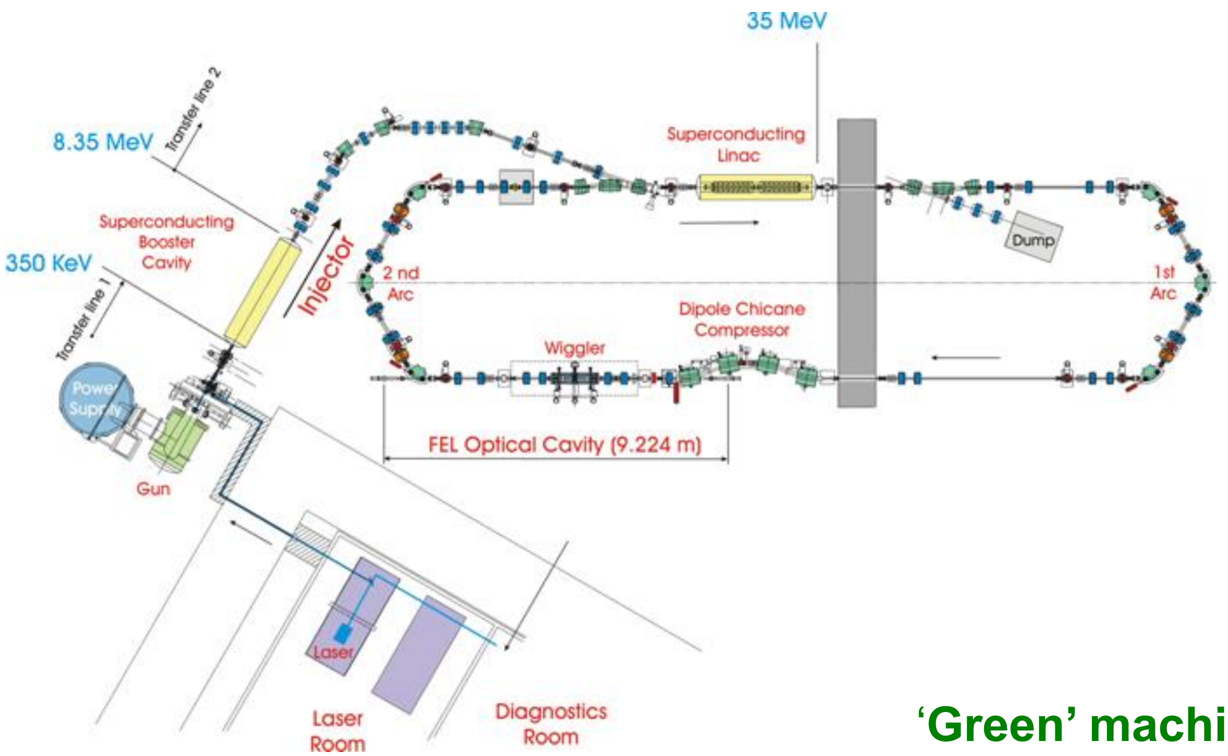
Total 10 SC modules -- Compared to 18 in single pass

Major UK Test Facilities

- **ALICE - Accelerators and Lasers in Combined Experiments**
- **EMMA - Electron Model with Many Applications**
- **MICE - Muon Ionisation Cooling Experiment**
- **FETS - Front End Test Stand**

See more details in 3 other talks

ALICE Test Facility



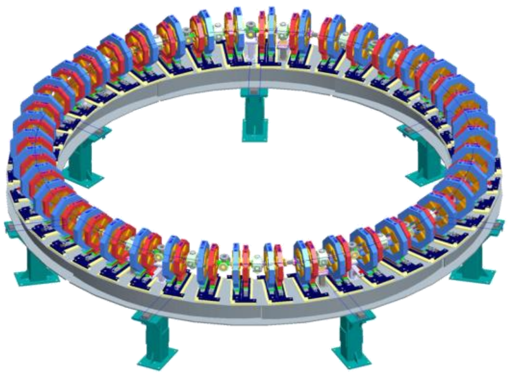
Chirped beam compression ~100 fs

FEL included

'Green' machine: energy recovery

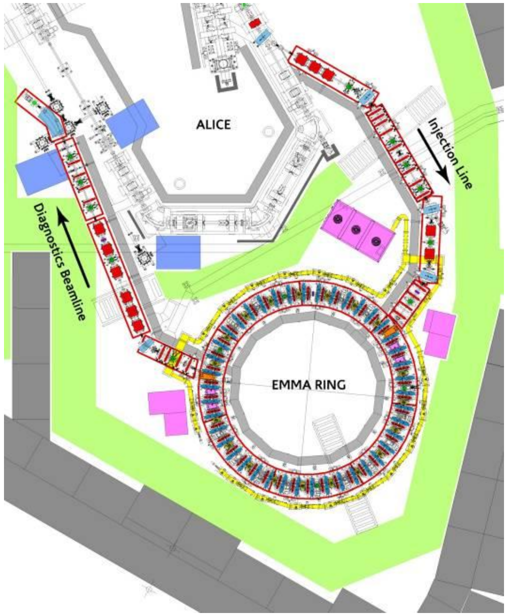
ALICE = Accelerators and Lasers in Combined Experiments

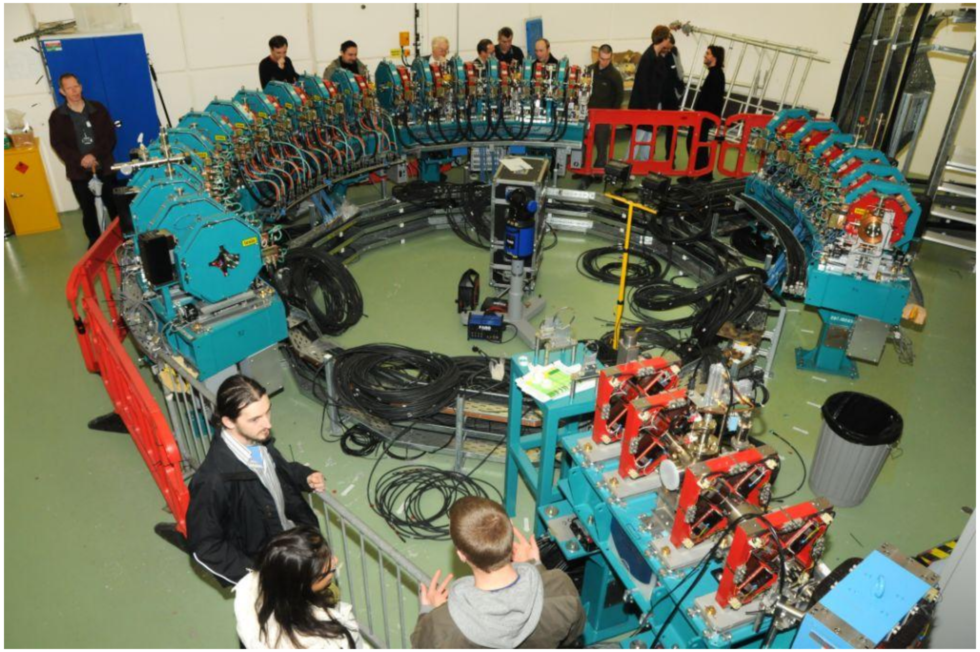
EMMA – A Very Compact Solution !



Proof of principle experiment

ns-FFAG





Front End Test Stand (FETS)

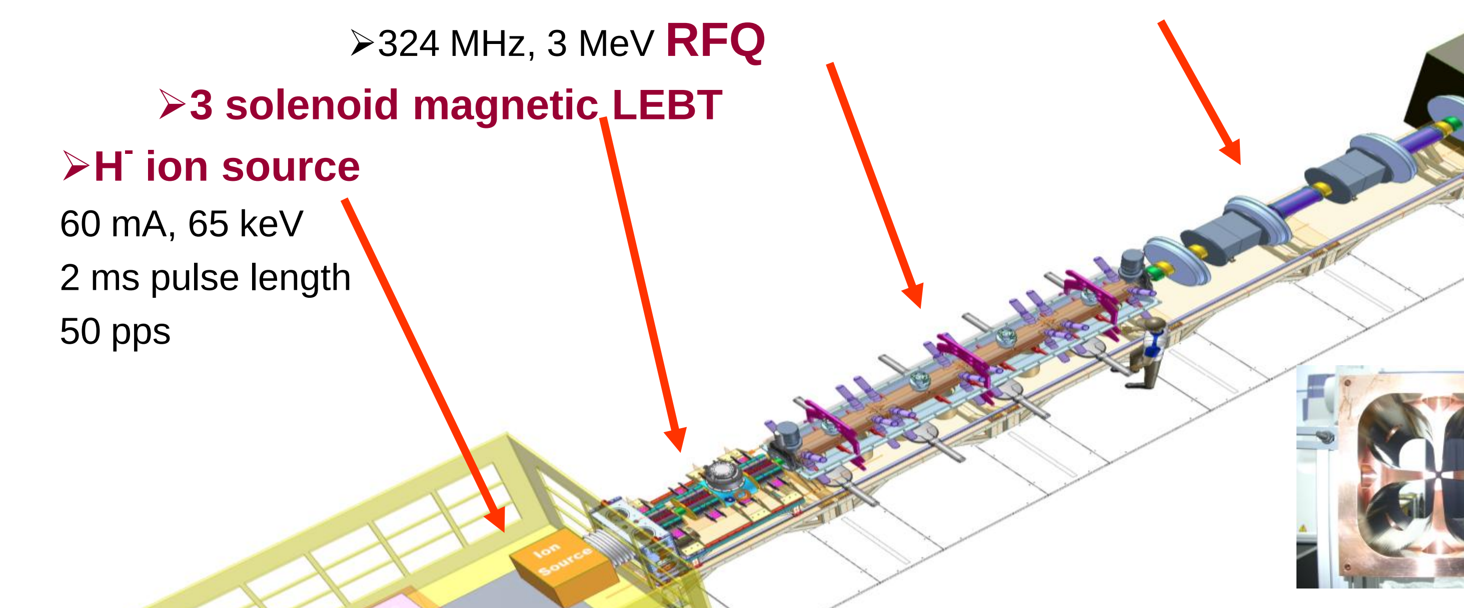
High speed beam chopper & MEBT

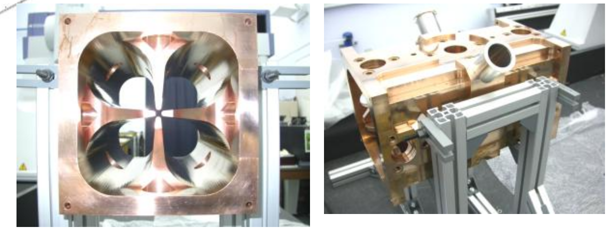
- 324 MHz, 3 MeV **RFQ**
- **3 solenoid magnetic LEBT**
- **H⁻ ion source**

60 mA, 65 keV

2 ms pulse length

50 pps

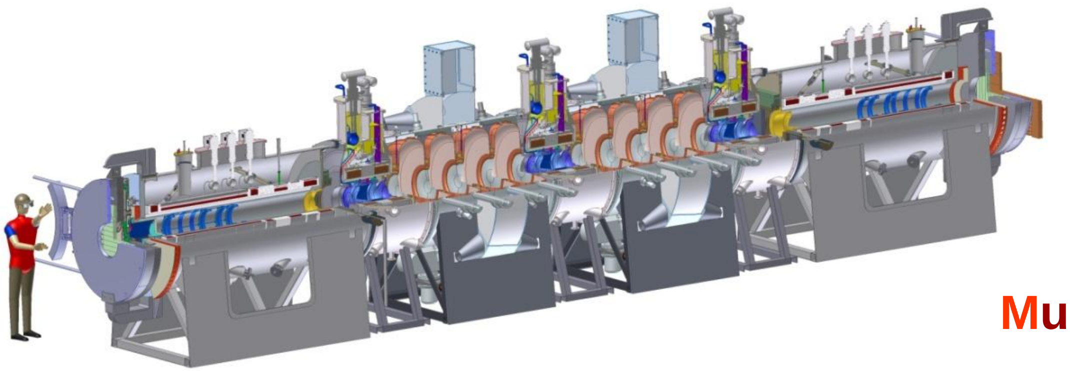




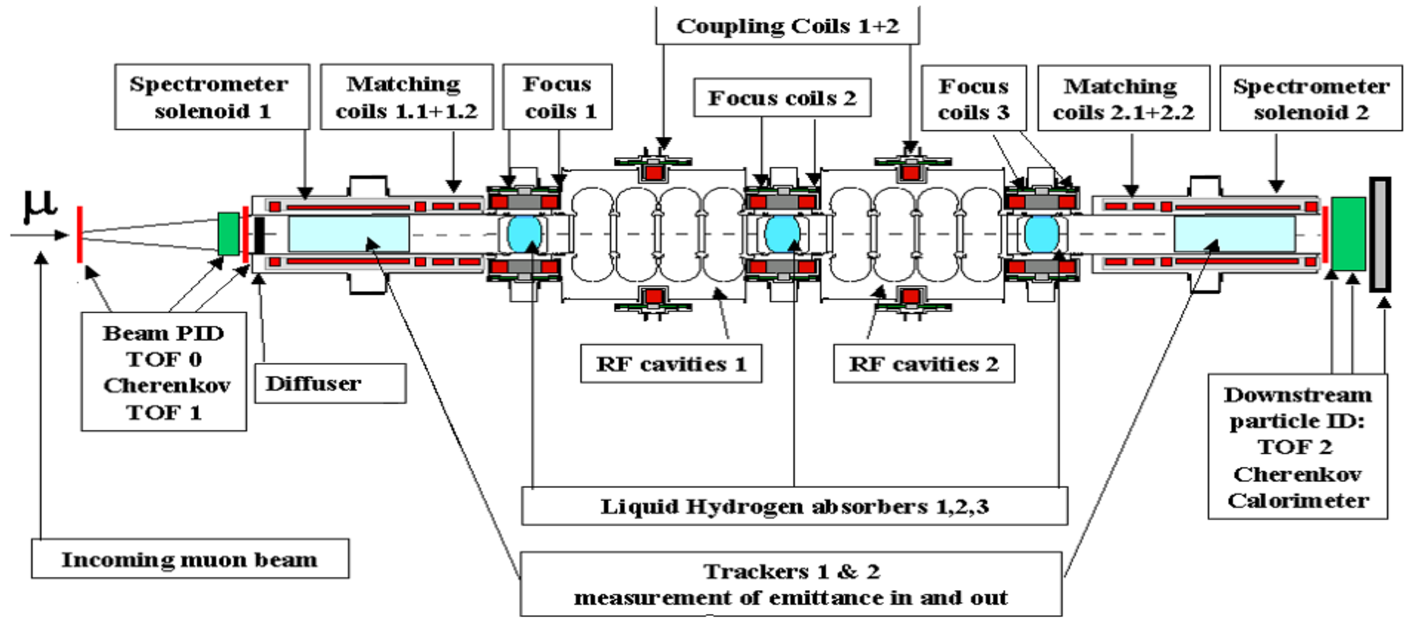
RFQ Model - IC

Demonstration of injector for multi-MW source

MICE Layout



Muon Ionisation Cooling Experiment

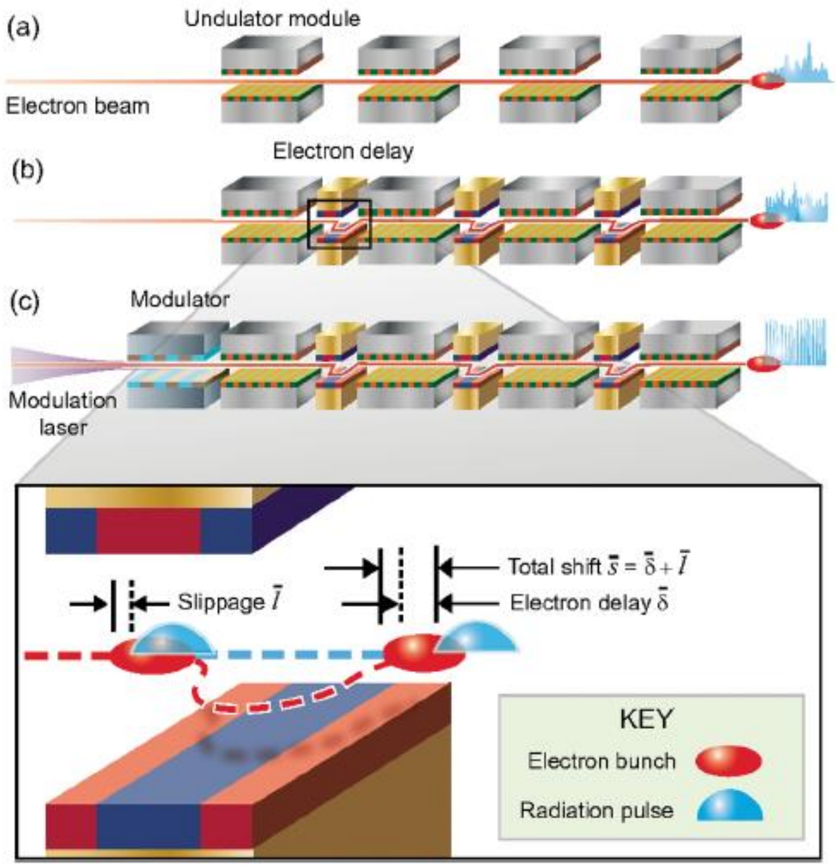


Generic R&D Activities in the UK

Exotic photon sources
Laser driven processes
Magnetic undulator technology
SRF system developments
Vacuum system solutions
High power targets

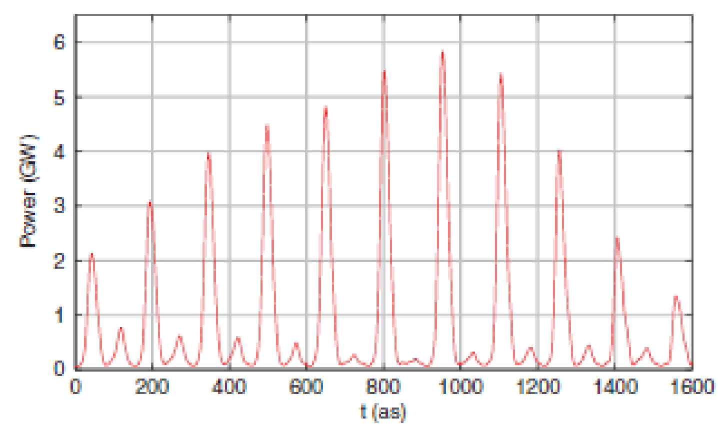
Ultra-short FEL Pulse Generation

- **Ultrashort photon pulses can be used to probe ultrafast processes in atoms and molecules**
- **DL & Strathclyde Uni are developing schemes that generate trains of x-ray pulses – each pulse only ~20 attoseconds long**



Scheme is conceptually similar to mode-locking which is used in conventional lasers to generate short pulses

Typical Pulse train at 0.15nm

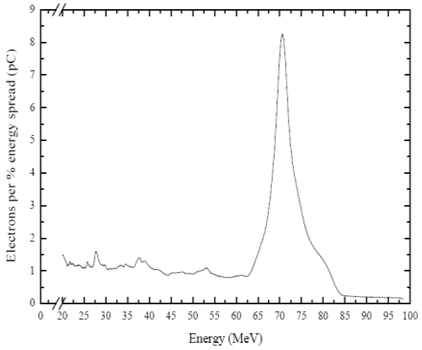


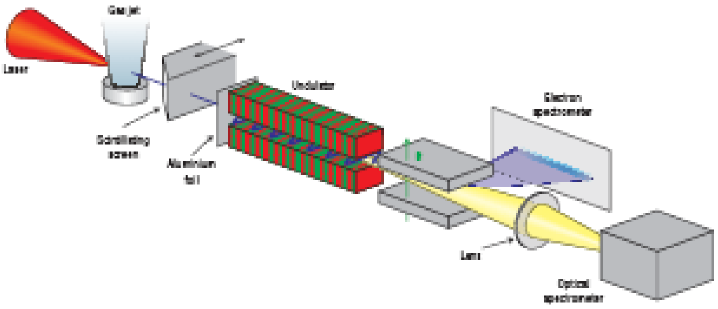
J A Clarke/ B J McNeil/ N R Thompson

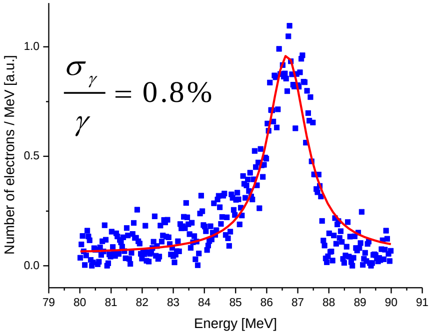
N.R. Thompson … McNeil, PRL 100, 203901 (2008)

Laser Plasma R&D

- **Substantial UK activity – RAL and Strathclyde experiments**
- **Astra-Gemini upgrades at RAL**
- **ALPHA-X consortium – 7 HEIs + RAL/DL + international**
- **Theory modelling too**
- **Also target foil proton/ion projects (LIBRA)**



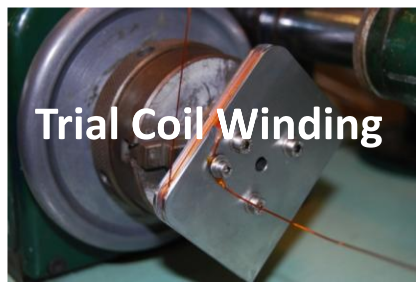




Applications of Superconducting Undulators

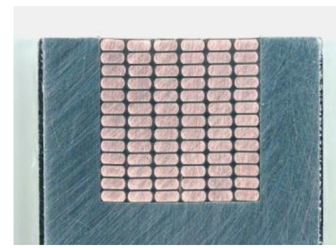
- **SC undulators offer stronger fields and shorter periods – allowing access to shorter wavelengths or use of lower energy e⁻ beams**
- **DL & RAL have experience and success in building helical SC undulators – motivated by the ILC positron source**
- **Now applying that to planar devices that are better suited to light sources and FELs**

4m Helical Undulator

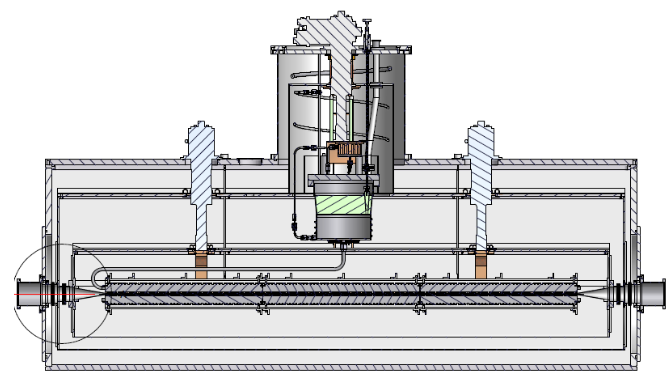


Trial Coil Winding

Trial Coil Former



Cross-section through Coil



sign of 2m Planar Undulator

Vessel AC Resistance

- High field SC undulators - small gap vessels
- Image current vessel heating
- Material resistance: high frequencies and cold ?

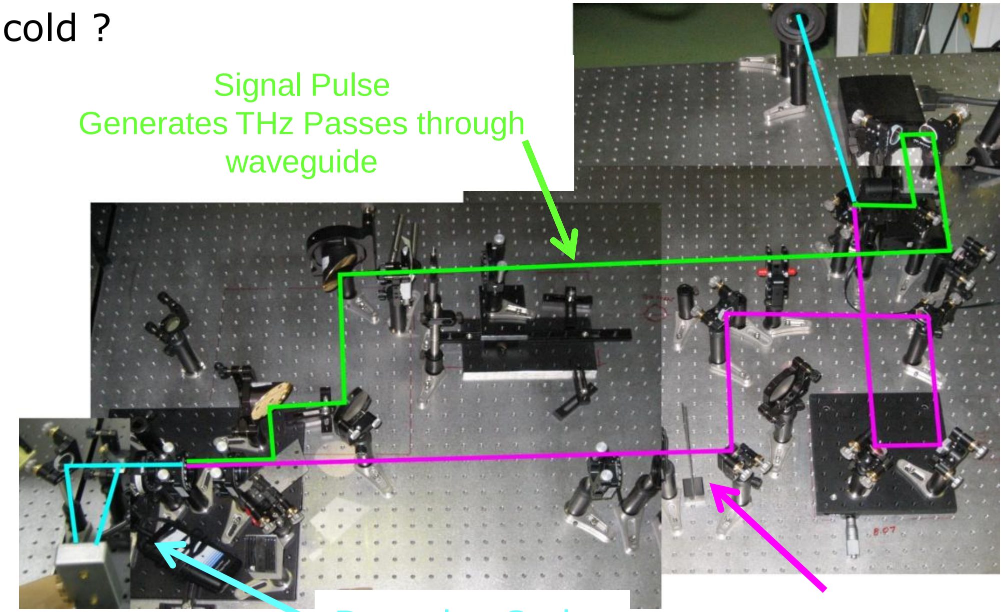
- Traditional experiments measure reflectivity from metal surfaces,
  - Not real vessels, very small S/N<1%

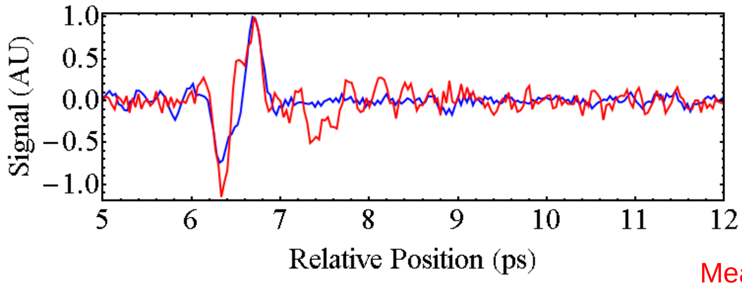
- Experiment to measure *R* for real vessels
  - sub-picosecond time-resolved measurement of attenuation of THz pulse generated by optical rectification

- Stage 1: AttenuateTHz pulse in Waveguide
  - Couple THz to room temperature waveguide, known modes and attenuation
  - Measure attenuation of THz pulse for different waveguide lengths determine *R*

- Stage 2: Develop for 4K and real vessels

Input Pulse
•fs Ti:Saph Laser





Generic Vacuum R&D

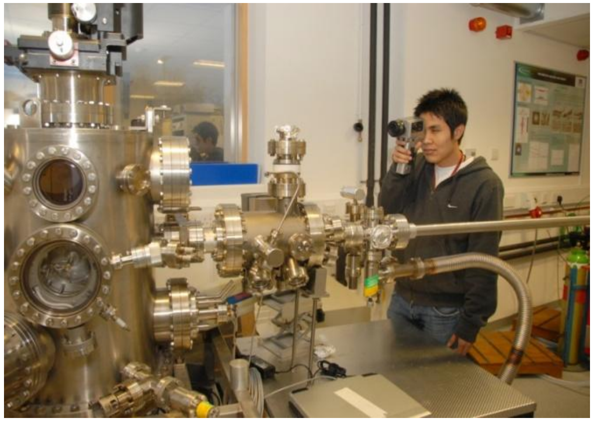
Non-Evaporable Getter Coatings

- Low Pressure Performance (Low Outgassing)
- Reduced Secondary Electron Emission
- Increased Pumping Capacity
- Reduced Temperature Activation
- Coating Complex Shaped Chambers

PVD Coating Facility

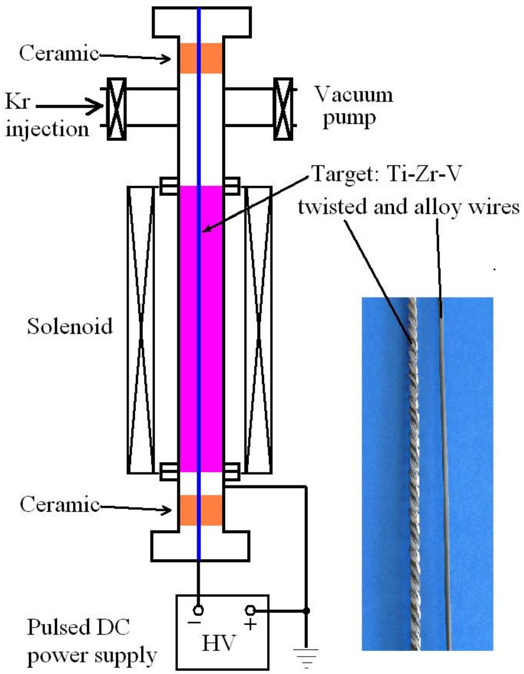
Photoinjector Development

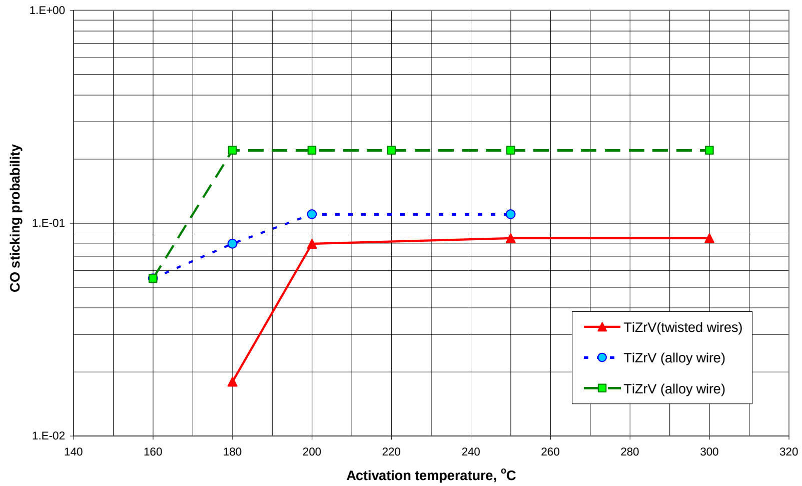
- XHV Techniques
- Low Particle Vacuum Environment
- Enhanced Cathode Performance
- Reduced Partial Pressures
- Improved Cathode Activation Procedures
- In-situ Cathode Replacement Mechanisms

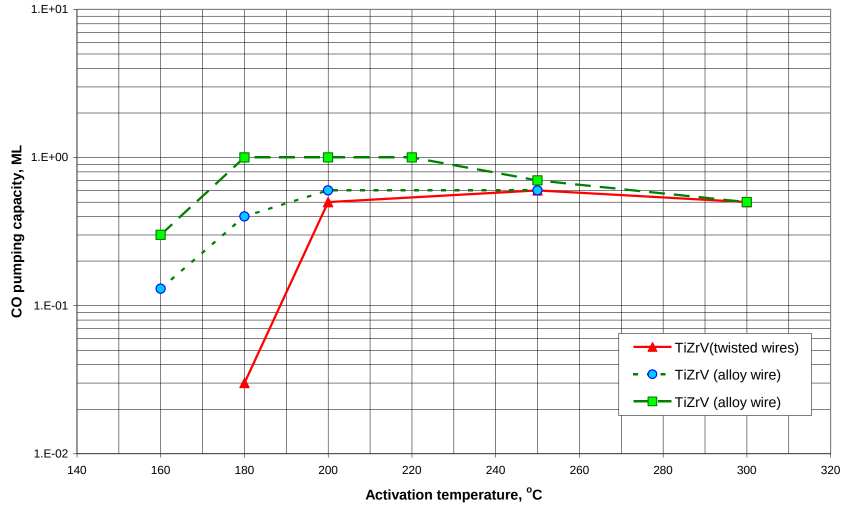


XPS Surface Analysis

Reducing NEG Activation Temperatures



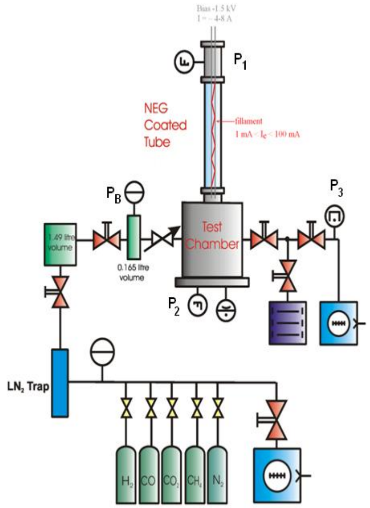




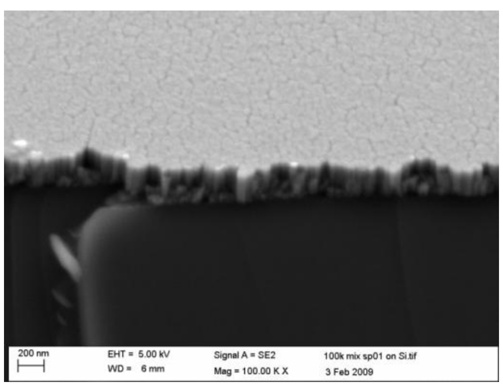
ASTeC Alloy target:

- Uniform coating with the same coating composition
- Lower NEG activation temperature than that found for films formed using a conventional twisted wire target (160 ºC instead of 180 ºC)
- Added advantage that smaller diameter (ID) tubes can be coated.

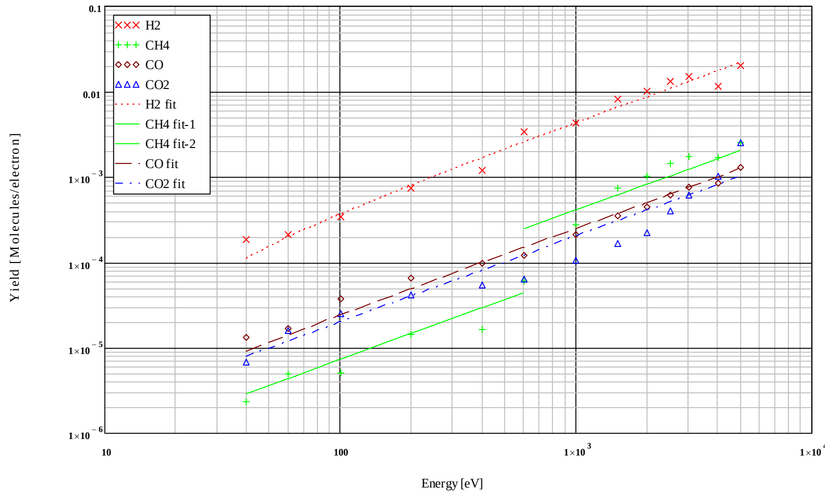
Electron stimulated desorption from uncoated and NEG coated stainless steel as a function of electron energy



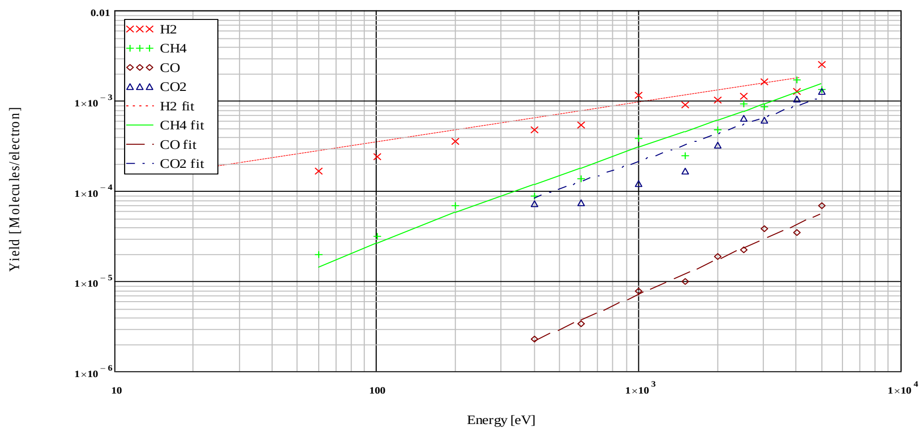
SEM for NEG film



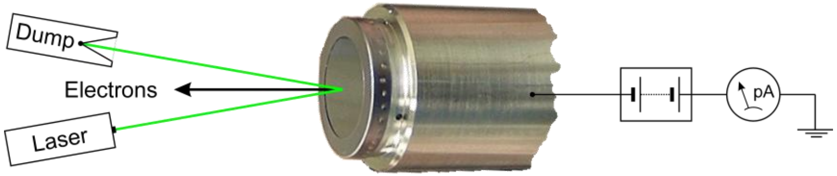
Uncoated 316LN



NEG coated 316LN



Photoinjector Vacuum R&D



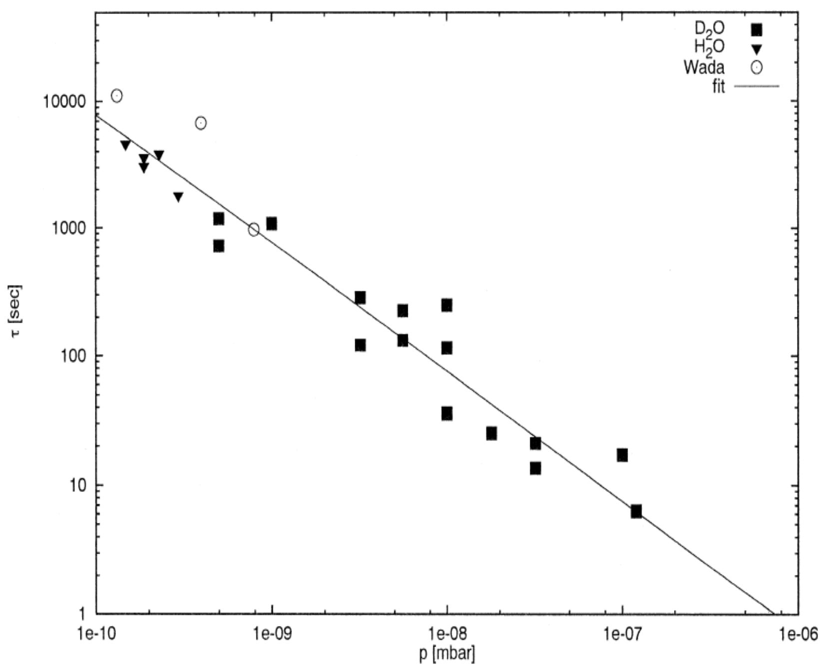
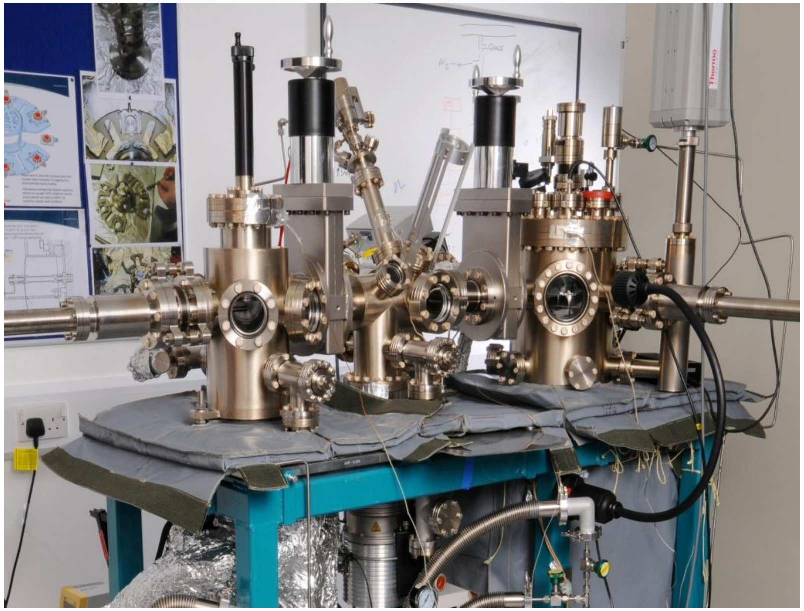
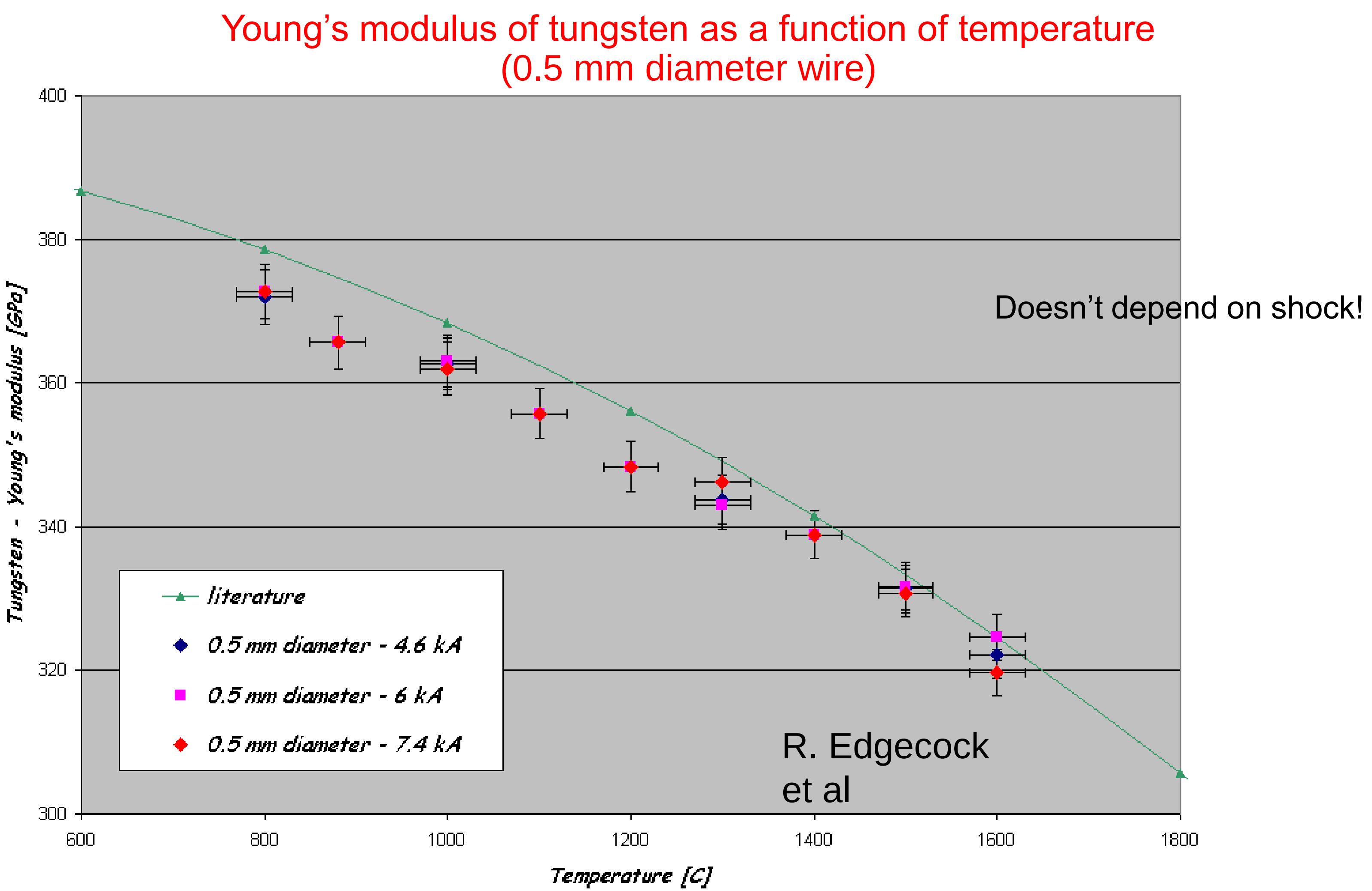


Fig. 2. Lifetime vs. partial pressure.



New Load-Lock Cathode Replacement System for ALICE

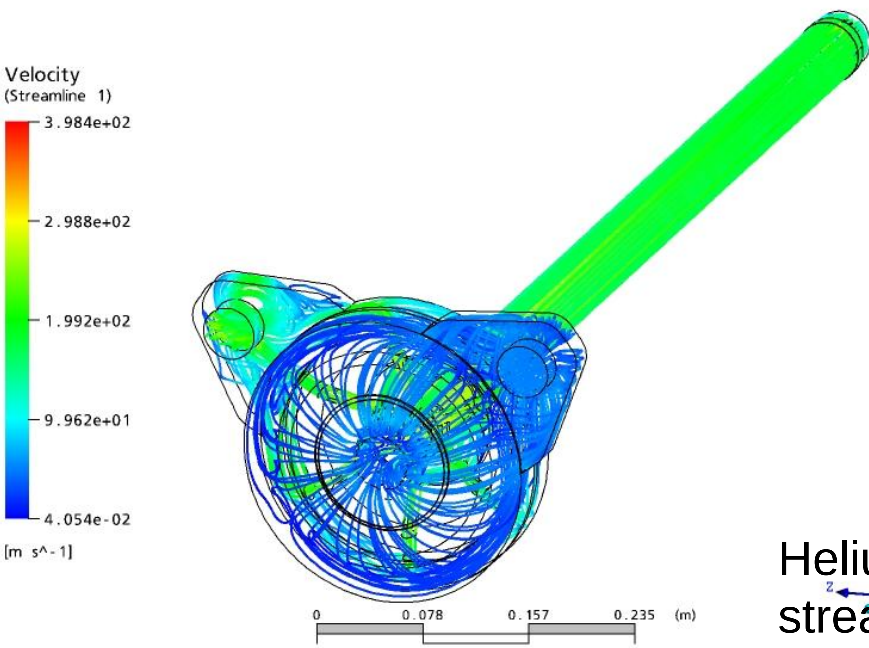
Tungsten Pulsed Heating



T2K Target for 0.75 MW

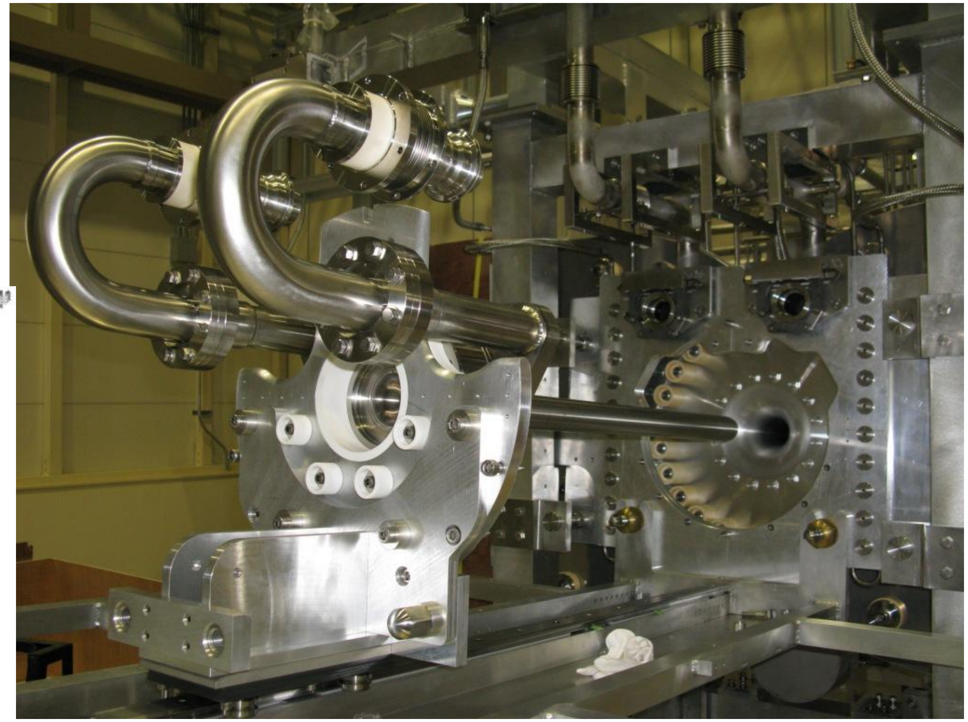
Helium cooled graphite target rod within titanium alloy container

Design and engineering at



Helium cooling velocity streamlines

Maximum velocity = 398 m/s



Installation of target in 1st magnetic horn

Fluidised Target Studies

Achieved dense and coherent tungsten jet:
1m long, 20mm diameter pipe generates flow

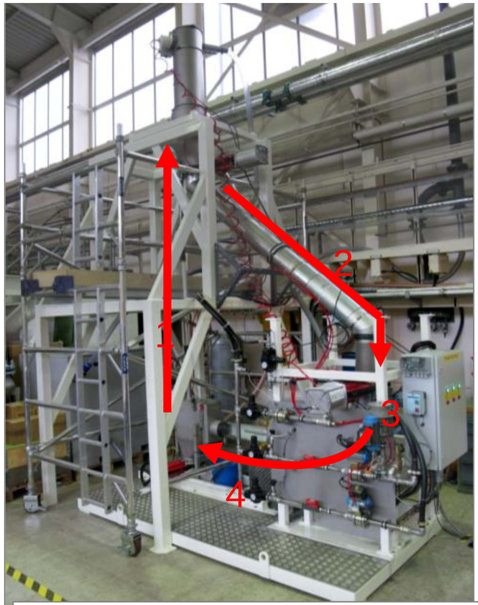
Little erosion of dense phase conveying components:
no scratching of glass discharge pipe

Steady flow achieved in pipe:
flow restarts even with a packed nozzle

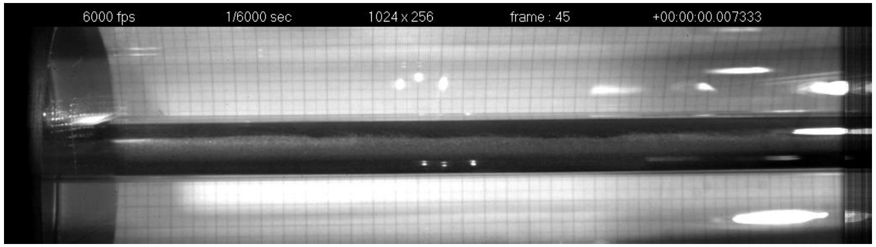
Particle Image Velocimetry analysis of high speed video of jet

Plant has reliably conveyed ~10 tonnes of tungsten powder

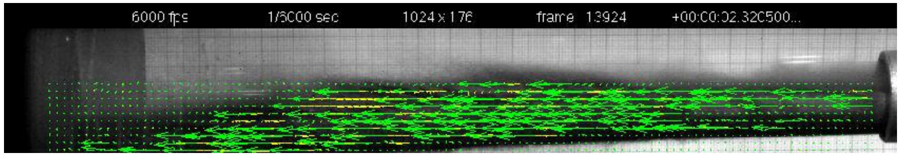
Re-circulating powder plant



1. *Suction / Lift*
2. *Load Hopper*
3. *Pressurise Hopper*
4. *Powder Ejection and Observation*

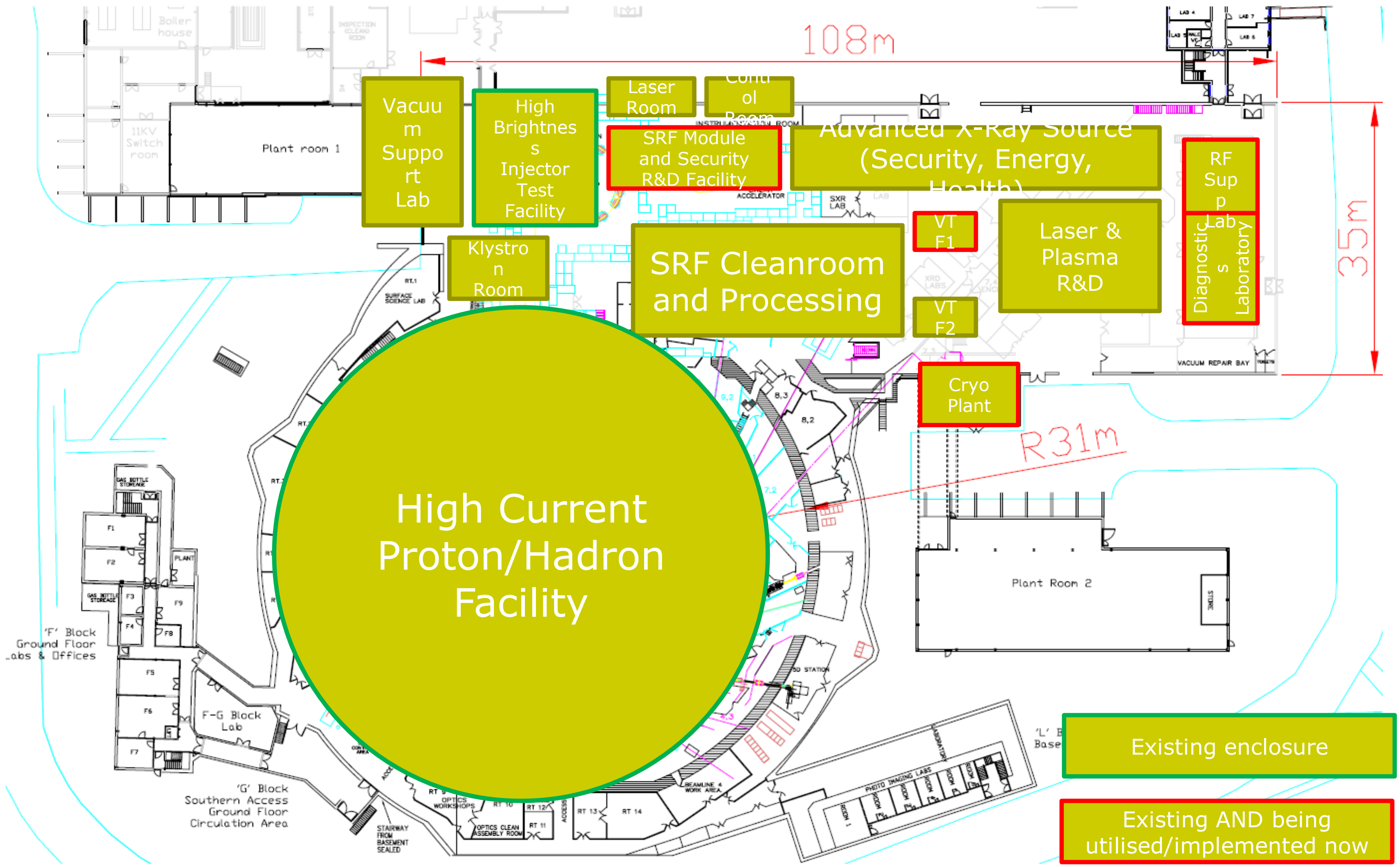


High speed image: tungsten powder flow in a glass pipe



Particle Image Velocimetry applied to an open tungsten powder jet

Conceptual Plan for R&D Infrastructure at Daresbury



Latest Developments and Prospects

- UK budgets severely constrained !
- STFC has prioritised accelerator R&D activities
- Cockcroft and John Adams Institutes continued support
- ASTeC strengthened by launch of Accelerator Centre
- Skill base will be protected
- Temporarily limited new investments, but ...
- New applications pursued (eg ADSR, medical, ...)
- EuCARD activity will be underpinned