Diamond Light Source Vacuum Systems:

The First Four Years of User Operations

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Topics

Overview of Diamond Vacuum Systems

Operational performance

Upgrades

Challenges and issues

Future plans

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What is Diamond Light Source?

- The UK national synchrotron facility, 100 km from London
- Generates brilliant beams of light, from infra-red to hard X-rays, for a range of science applications
- 3rd generation light source making heavy use of insertion devices in straight sections (undulators and wigglers)
- Construction began in early 2003
- User operations began in January 2007 with 7 beamlines operational (Phase 1)
- Now 20 beamlines operational + 2 being installed (Phase 2)
- Will increase to 32 beamlines over the next 6 years (Phase 3)

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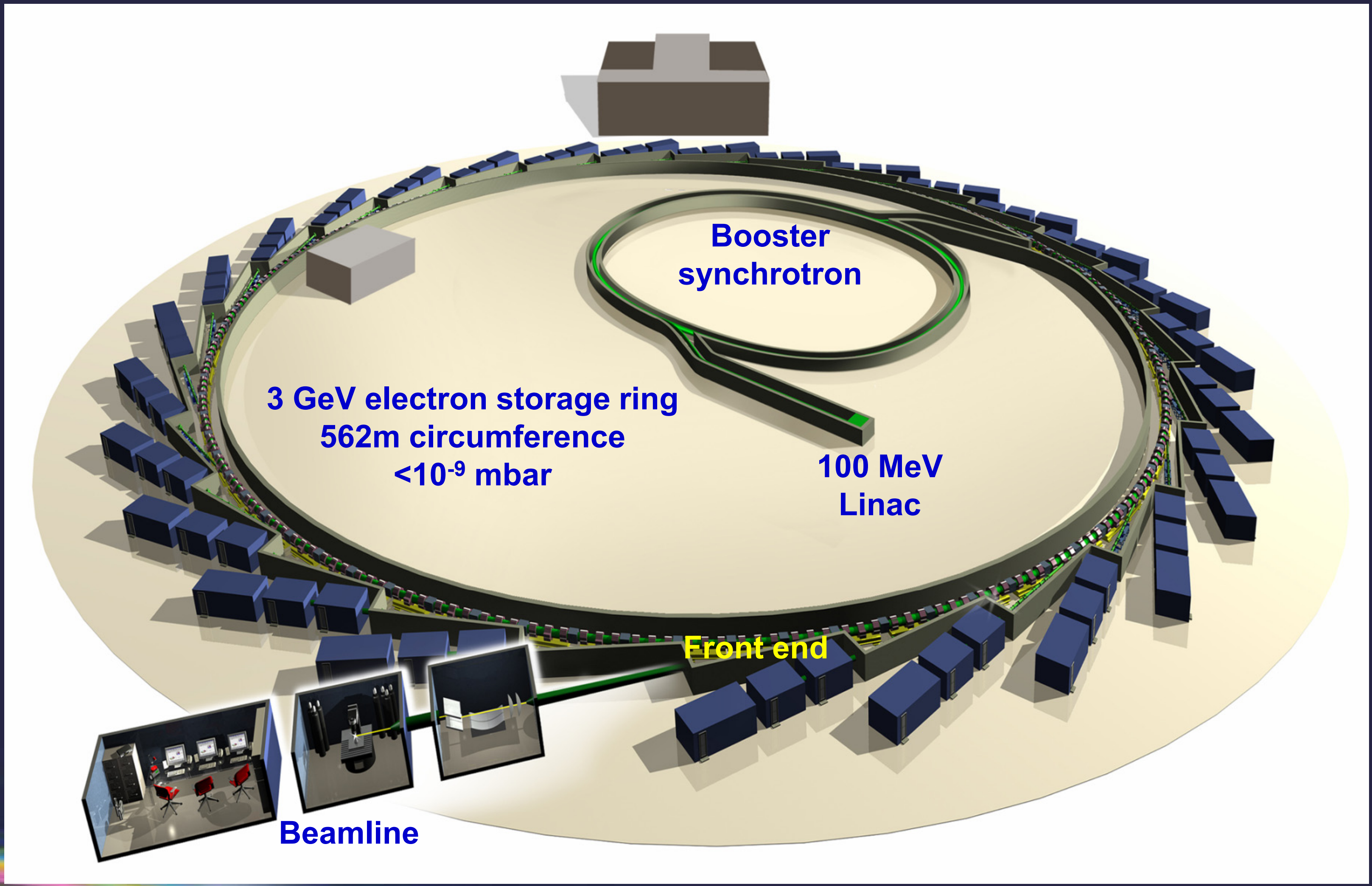
Diamond layout



Aerial view

Why ultra-high vacuum?

- Storage ring
  - $p < 10^{-9}$ mbar
  - Interactions between circulating electrons and residual gas molecules
    - Stored beam lifetime
    - Gas Bremsstrahlung radiation
  - Scales as Z^2 – minimise high Z gases
- Beamlines
  - Hydrocarbon contamination of x-ray optics (mirrors, gratings, crystals)
  - Some sample environments require UHV
  - Gas phase absorption and scattering
- Residual gas
  - Hydrogen often predominant but not a problem – low Z, non-contaminating
  - Water and hydrocarbons need attention
- Electrons
  - Disappear after use!

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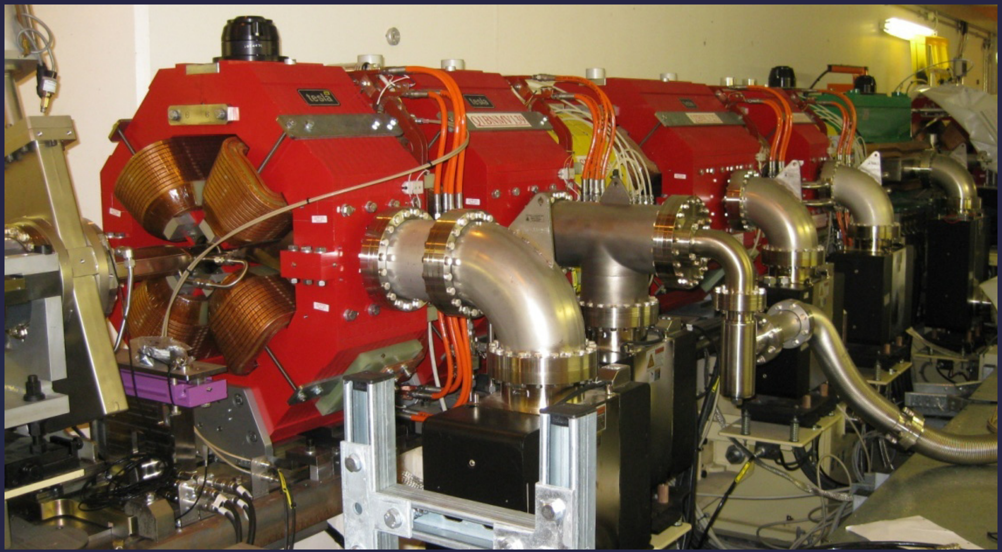
Storage ring vacuum engineering

- High radiation environment in shielding tunnel
  - Materials – stainless steel, copper, ceramic
  - Electronics
  - Personnel access
  - Remote control and monitoring
- High heat loads and power densities – up to 30kW some insertion devices
- Locally high magnetic fields
- Long narrow beam channels with little space for vacuum pumps: conductance limited, many pumps
- High reliability
  - 24/7 operation, 5 shutdowns a year
  - Quality control at every stage is vital
  - Protection from vacuum accidents and electron and photon beam damage is important



Diamond Storage Ring Vacuum Equipment

- Pumps
  - 500 Noble diode ion pumps
  - 50 Titanium sublimation pumps
  - 50 Non- evaporable getter (NEG) cartridge pumps
  - 9 NEG coated vessels
  - Mobile turbomolecular / scroll pump carts for interventions
- Instrumentation
  - 200 Inverted Magnetron Gauges (IMGs) and 200 Piranis
  - 80 Residual Gas Analysers (RGAs)
- Valves
  - 50 RF-shielded pneumatic gate valves
  - 50 All-metal pneumatic gate valves to front ends / absorbers
  - 150 Right-angle manual valves

Bakeout policy

Generally do not bake out in-situ

- Cost
- Limited intervention time
- Labour intensive and prone to human error
- Thermal expansion
- Good results achieved without in-situ bakeout

Instead: Ex-situ prebake and installation under dry nitrogen purge

- Ex-situ bakeout typically 250°C vessel at supplier, 200°C assemblies at Diamond
- Dry nitrogen flow helps to prevent water vapour from entering the system

In situ bake out where:

- Non-evaporable Getter (NEG) coating activation
- Where significant exposure to atmospheric moisture is unavoidable
- Where ultimate pressure or gas composition is particularly critical

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Storage ring vacuum performance

All vacuum systems working well. Performance within specification

3700 A.h beam conditioning dose (July 2011)

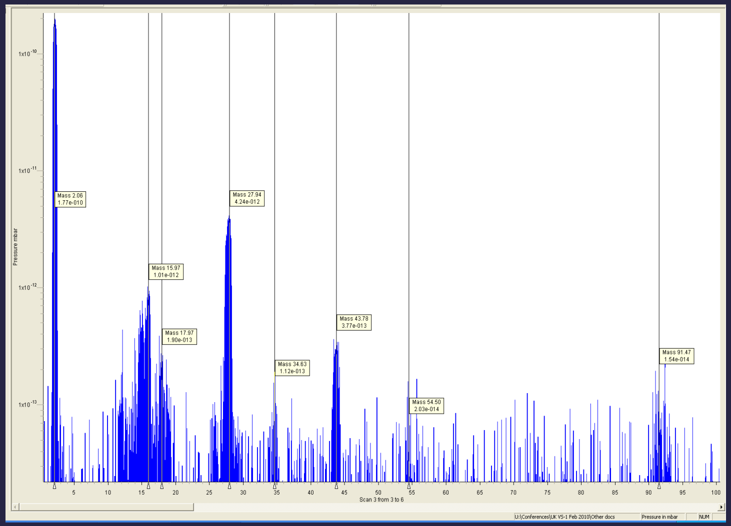
Machine has been tested at 300 mA. Routinely operating at 225 mA in top-up mode (every 10 minutes). Short term will incrementally increase to 300 mA targeting 500 mA longer term.

Average gauge reading (nitrogen equivalent pressure)

- Static pressure (no beam) 2.8 x 10^{-10} mbar
- Dynamic pressure at 225 mA = 4.5 x 10^{-10} mbar

Residual gas composition typically > 95% H_2, balance mainly CO – (RGAs not calibrated)

Beam lifetime typically 20 h at 225 mA (not dominated by gas lifetime)



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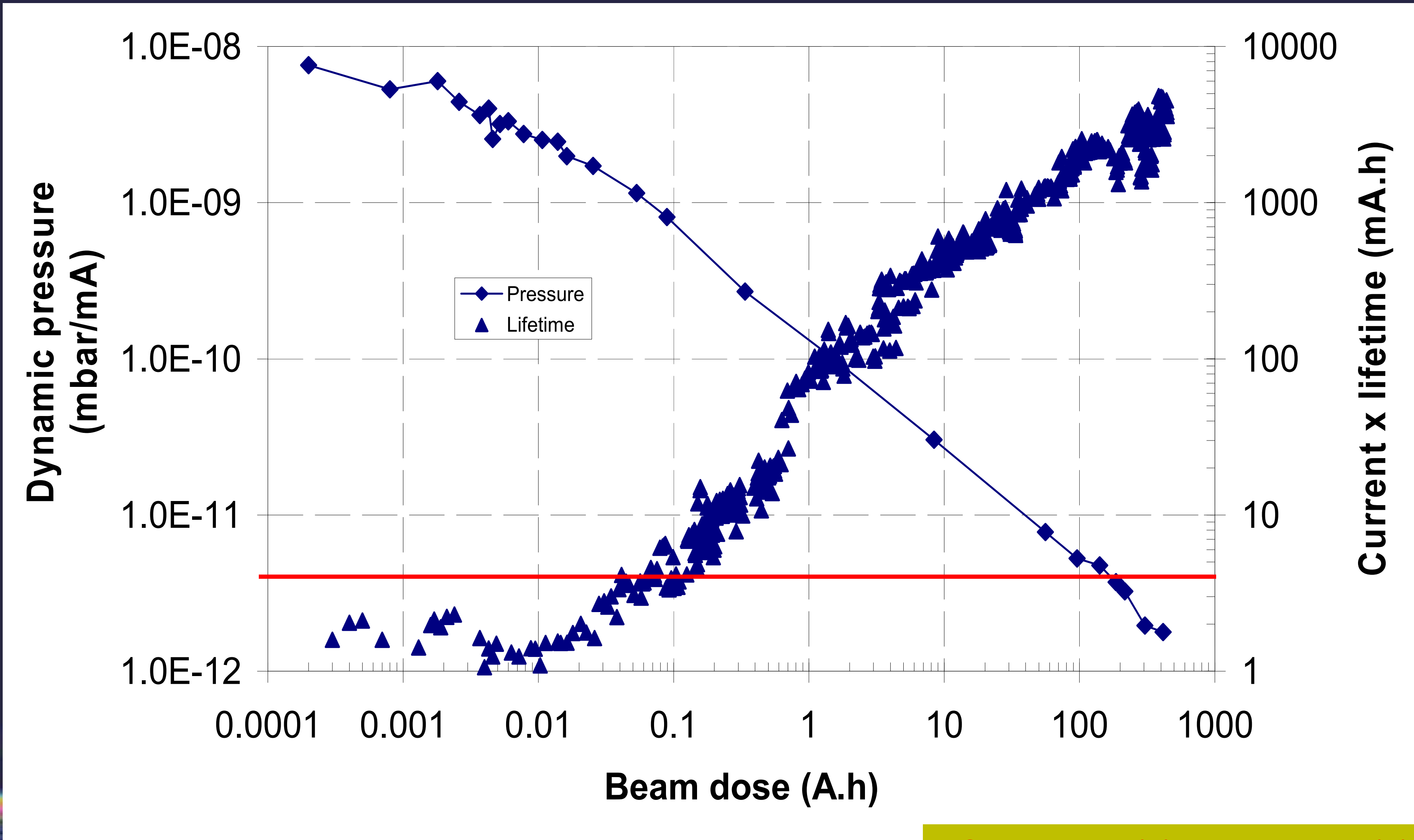
Storage ring beam conditioning



300mA 10^{-9} mbar = 3.3×10^{-12} mbar/mA

PSD yield (η) vs dose (Γ) follows: $\eta \propto \Gamma^{-0.73}$

Operational reliability 2007 - 2011

	2007	2008	2009	2010	2011 (to June 2nd)
User beam (h)	3160	4092	4536	4753	2184
Uptime (%)	92.3	94.9	96.4	97.4	98.2
MTBF (h)	10.64	14.5	21.1	27.3	48.5
MTTR (h)	0.71	0.6	0.77	0.72	0.84
Total beam trips	297	282	217	174	43
Vacuum beam trips	26	22	15	1	3
SR RF beam trips	130	171	114	112	18

Unofficial statistics!

Longest stored beam with no trip 172 hours

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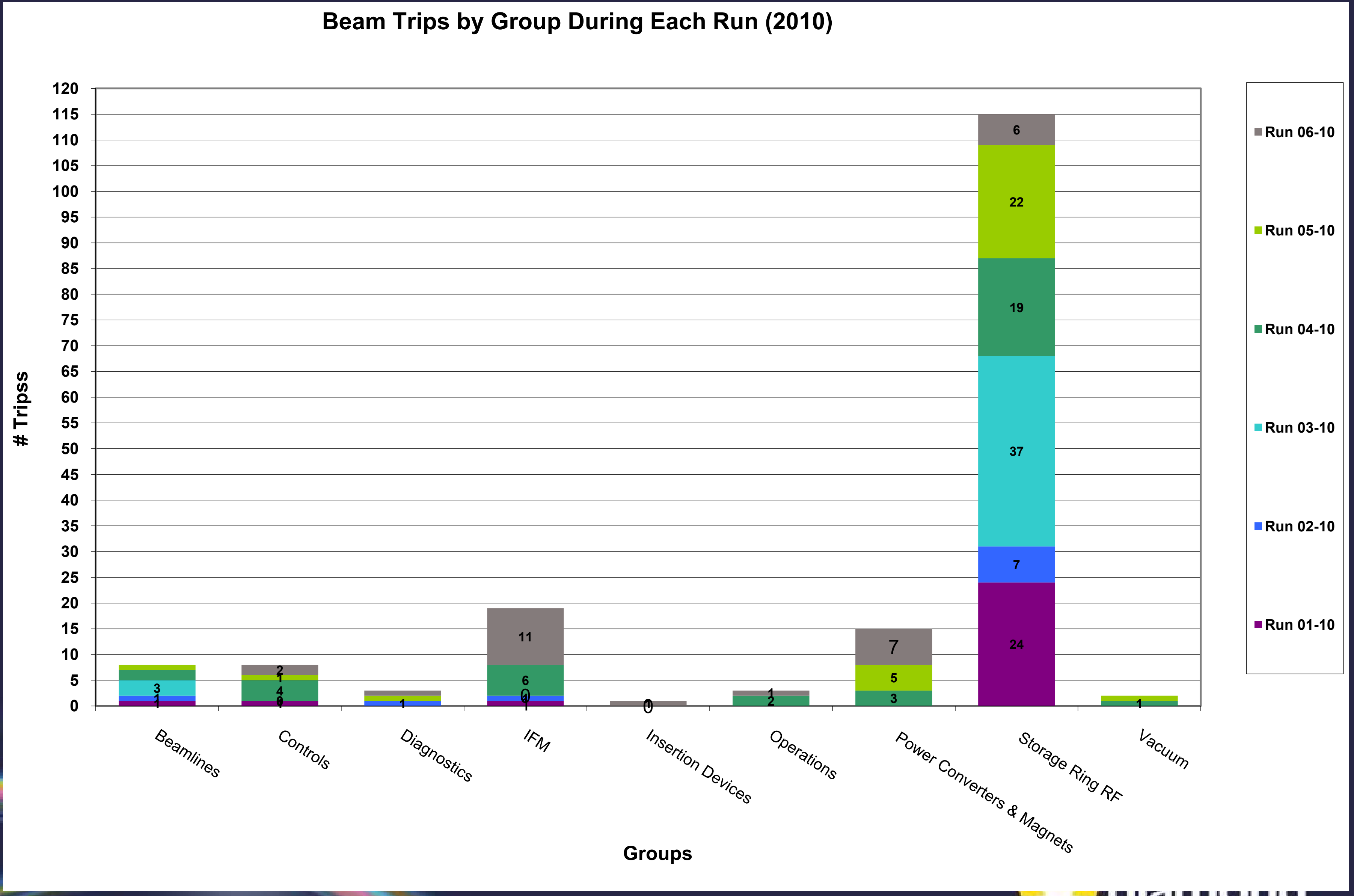
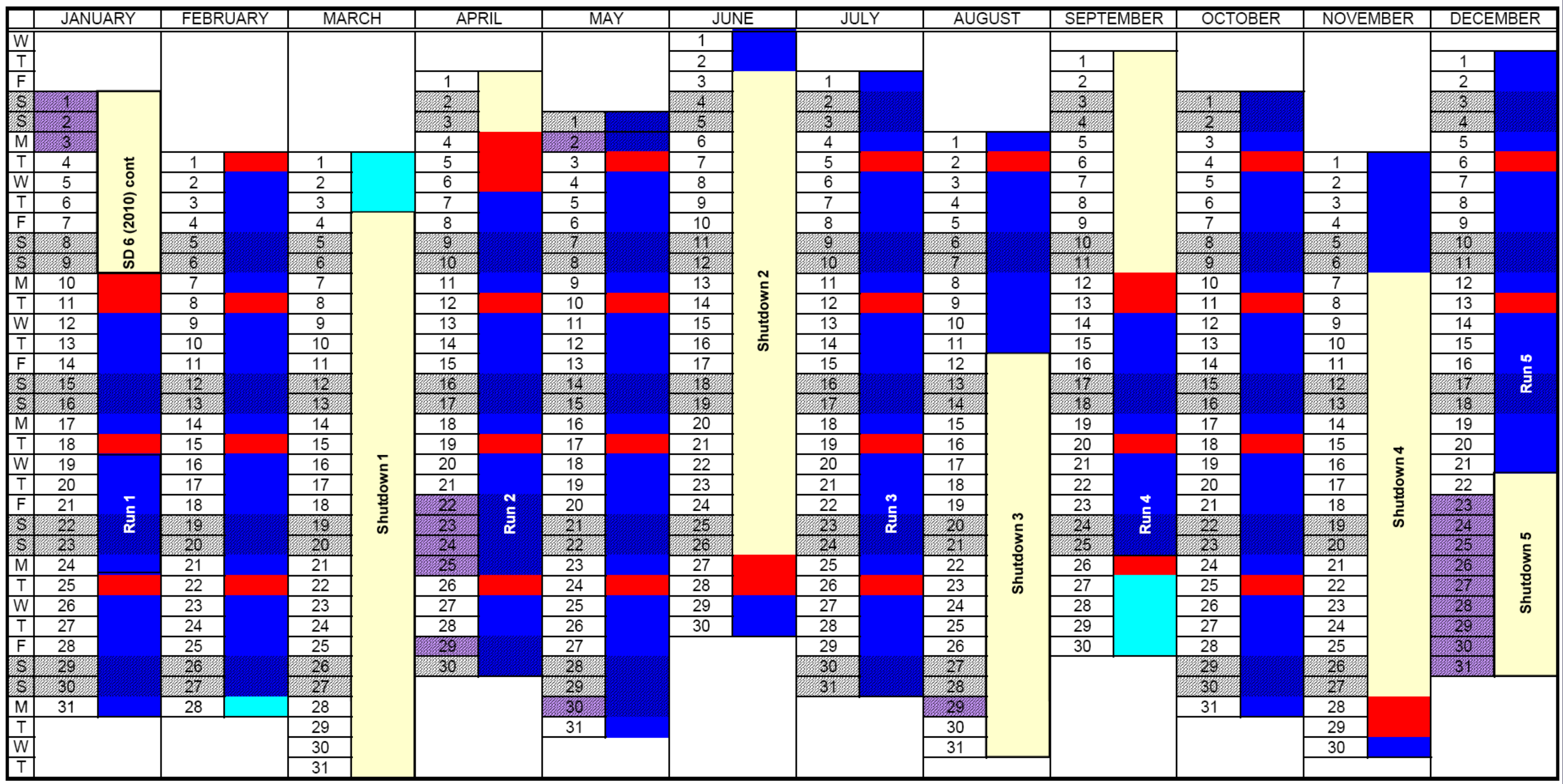
Operational reliability 2010



Operations calendar 2011



Main vacuum mechanical upgrades since initial build

- 6 of 72 girders replaced with new builds (Synchrotron Radiation (SR) aperture, magnetic lattice)
  - 1 x B22 IR beamline
  - 3 x I13 Double mini beta
  - 2 x I09 Double mini beta
- 21 front ends installed (17 ID, 4 BM)
- 18 of 22 insertion device straights installed
  - 12 in-vac undulator (including 1 cryo)
  - 9 NEG coated vessel for ex-vac ID
  - 2 superconducting multipole wiggler
- 20 (+ 2 in progress) beamlines installed
- Superconducting RF cavity exchanges and pumping improvements (to reduce hydrogen cryo-pumping in cavities thought to be linked to RF breakdown events)

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Main vacuum controls and equipment upgrades since initial build

- Many refinements to interlock system to reduce unwanted beam trips
- Permanent magnet filters fitted to prevent stray electrons affecting IMG gauges
- Some Piranis stop working in the presence of stored beam. Thought to be RF heating but not well understood. Pirani interlocks overridden
- Development of new fast valve control system
- Introduction of new ion pump controller
- Introduction of new cold cathode / Pirani gauge controller
- Improved RGA integration with EPICS

New girders and straight installation for I13

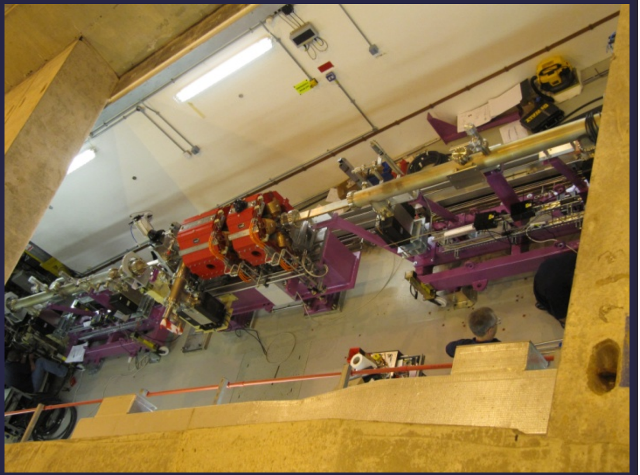
New vacuum string build, bakeout and integration on to girder

Old 8.3m straight

Straight vessels and girders removed

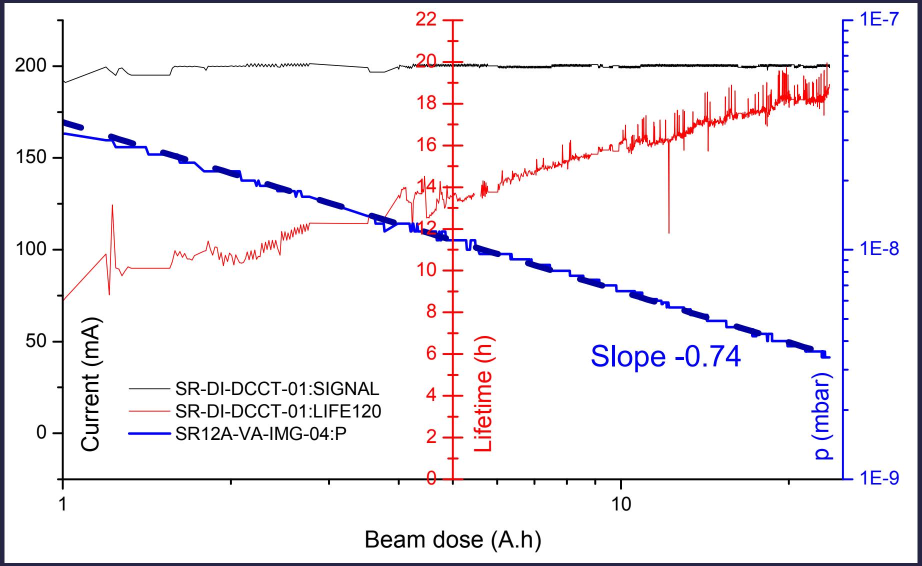
New girder lift

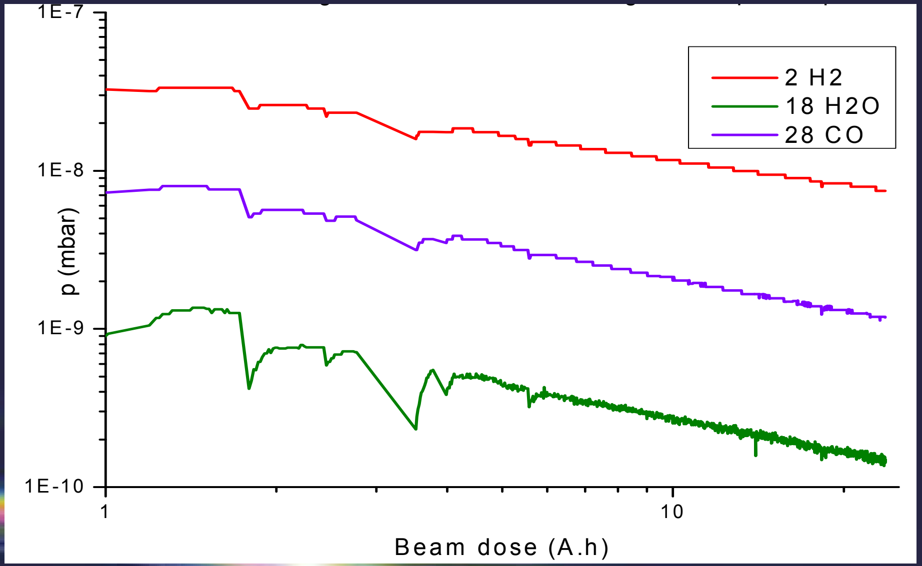
New girder installation



New 9.4m straight
with quadrupole magnets

Beam conditioning of new I13 girders and straight





Conditioning plots after girder swap Sept 2010

New 22m section of storage ring installed Sept 2010 (for beamline I13)

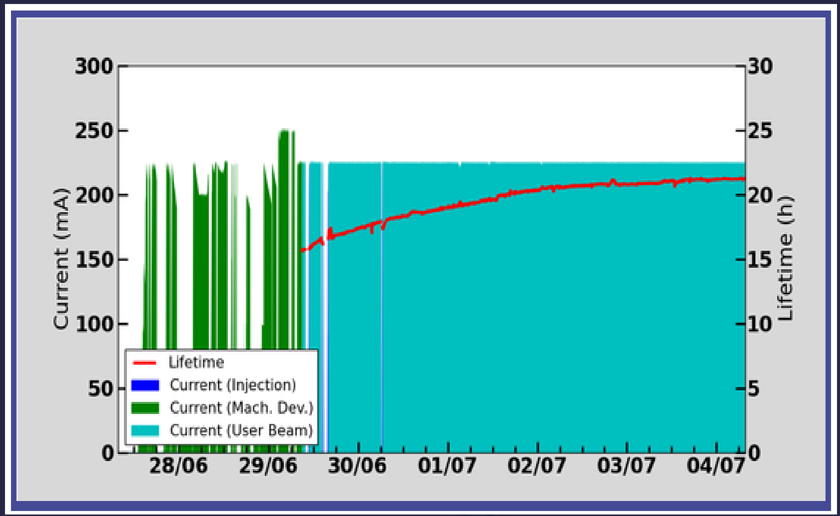
Beam conditioning at 200 mA

Main gases: H_2, CO, H_2O

Pressure rise due to PSD ~10^{-7} mbar

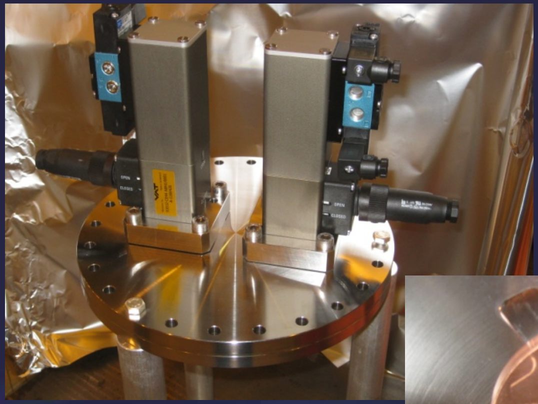
PSD yield (η) vs dose (Γ) follows:

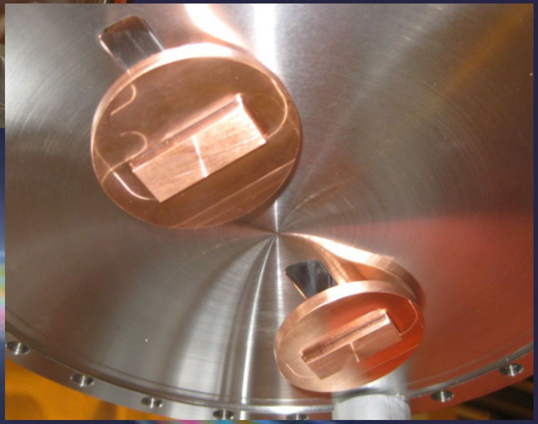
$$\eta \propto \Gamma^{-0.74}$$



Lifetime recovery after girder swap June 2011

Beamline I13 vacuum layout





- Complex beamline with two main branches (CO and IM)
- External vacuum duct
  - Two 150m long x-ray beam pipes 100 to 200 mm diameter
  - Windowless
  - Pumped from ends only (except during installation)
  - Differential pumping to achieve UHV ~5x10^{-9} mbar at both ends
  - Exposed to ambient temperature variation = outgassing rate variation
  - In-situ baked
- New design fast-closing mask to protect normal fast-closing valve from synchrotron radiation heating to give more vacuum protection options

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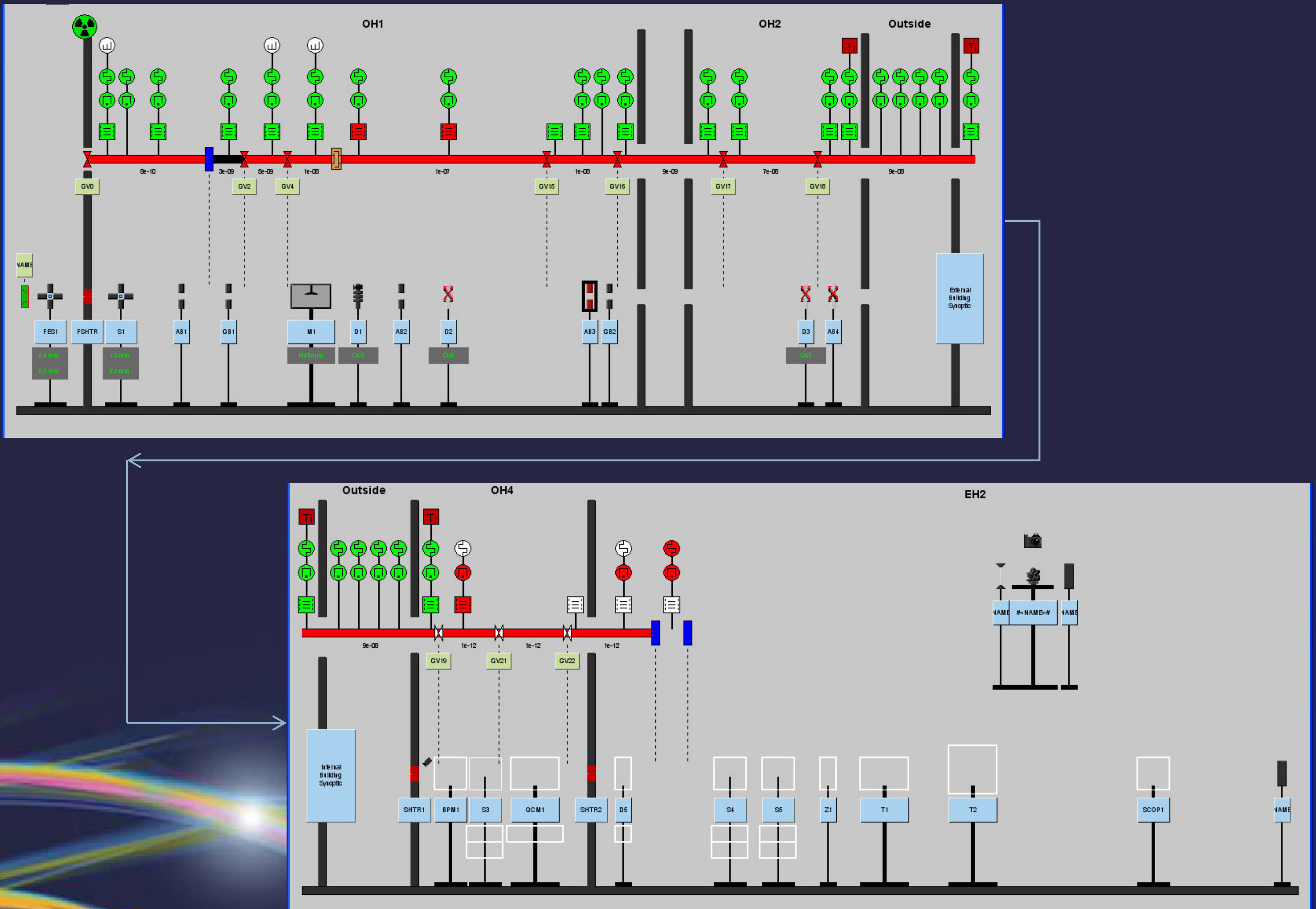
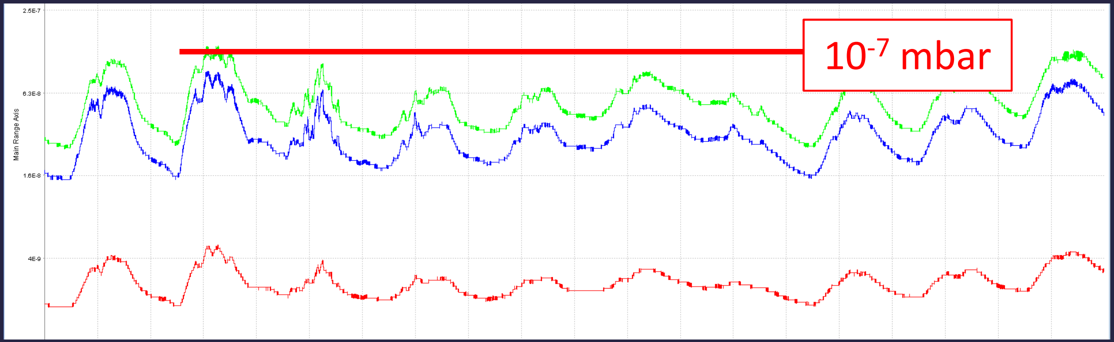
Beamline I13 schematic (CO branch only)

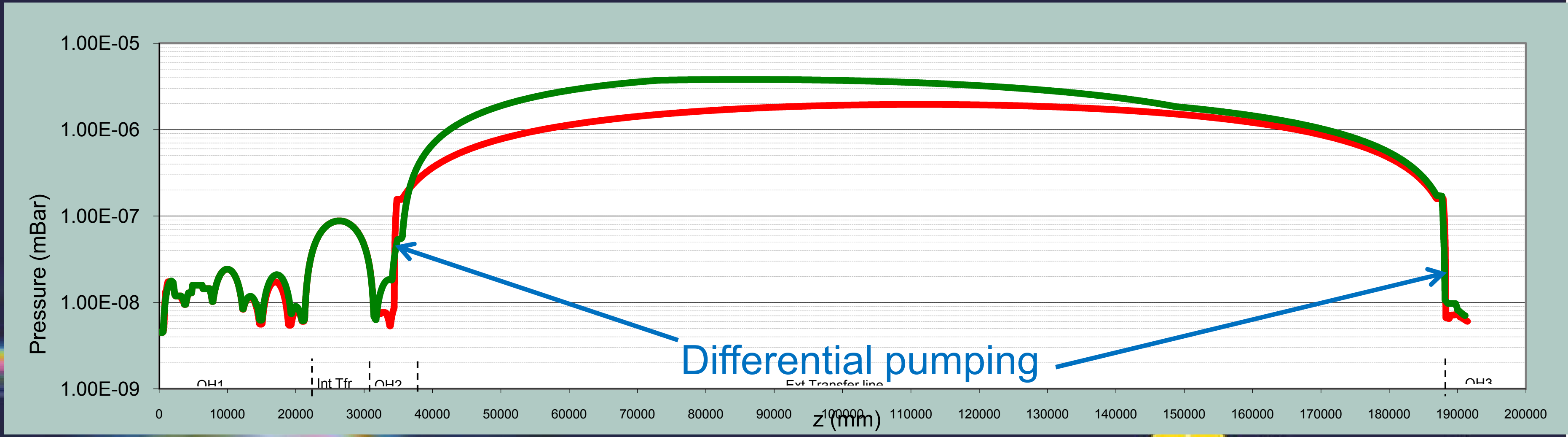


Beamline I13 external duct

Bakeout of external vacuum duct

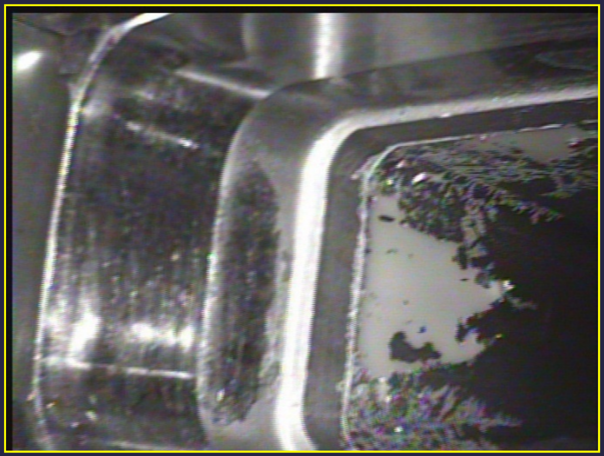


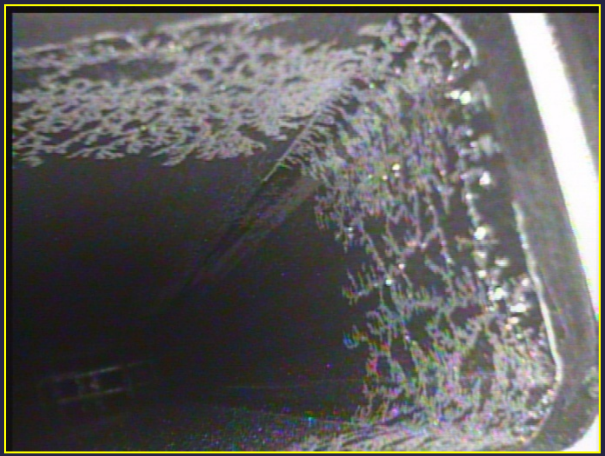
Measured pressure in external duct CO branch



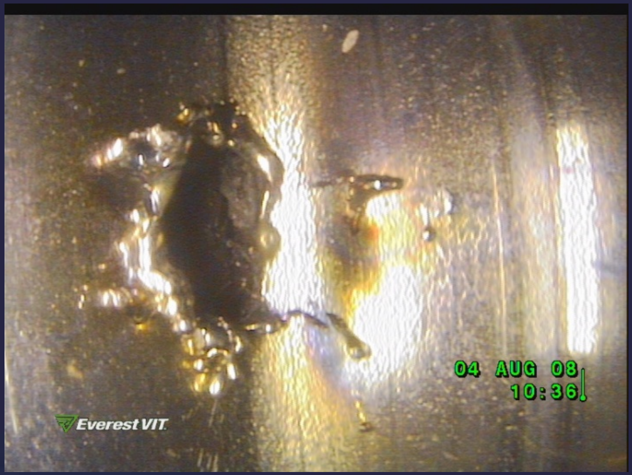
Calculated pressure in beamline (CO and IM branches)

Some accelerator component failures



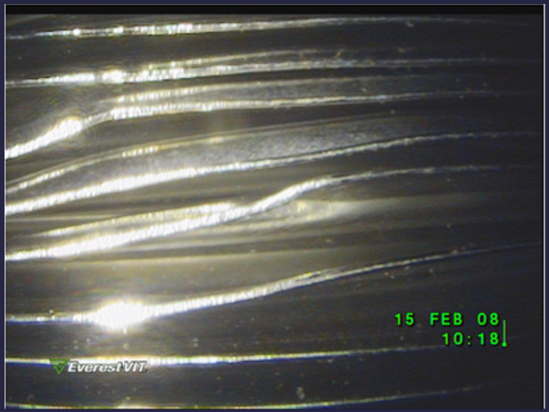


Titanium coating damage inside ceramic kicker vessel



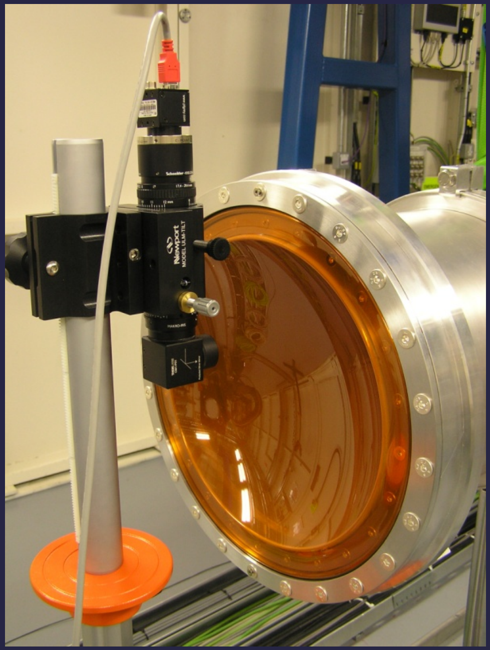
Electrical insulation failure caused melted hole in septum vacuum vessel (x2)

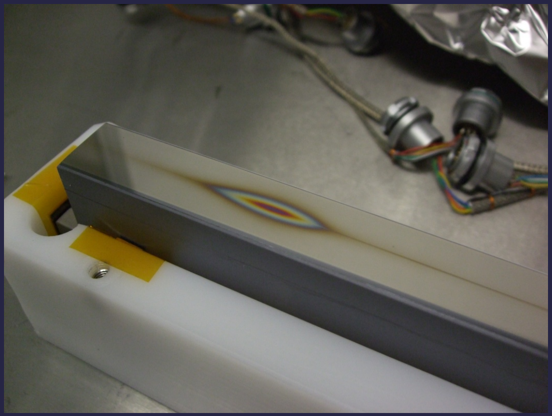
Some beamline vacuum issues



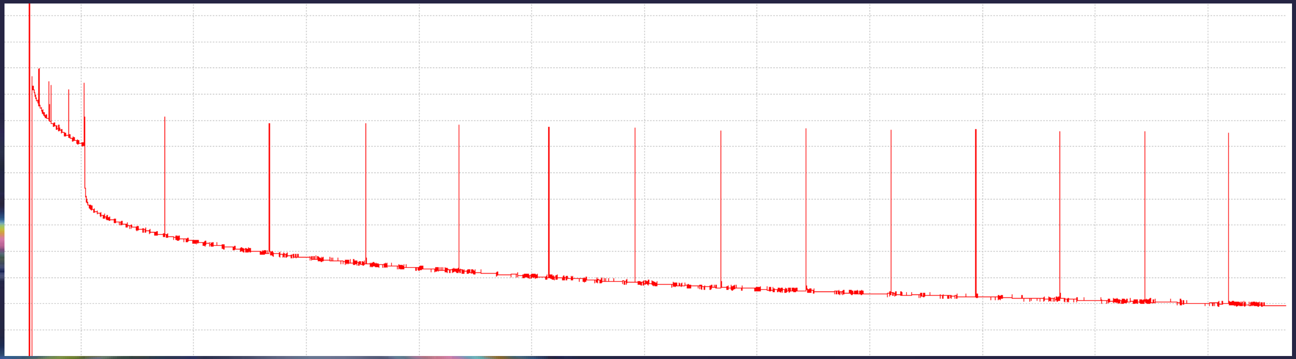
Failed shutter bellows after a few hundred cycles – mechanical design error (x4)

Broken window on beamline (x2)





Carbon deposition on x-ray optics



Pressure spikes from ferrofluidic vacuum seals

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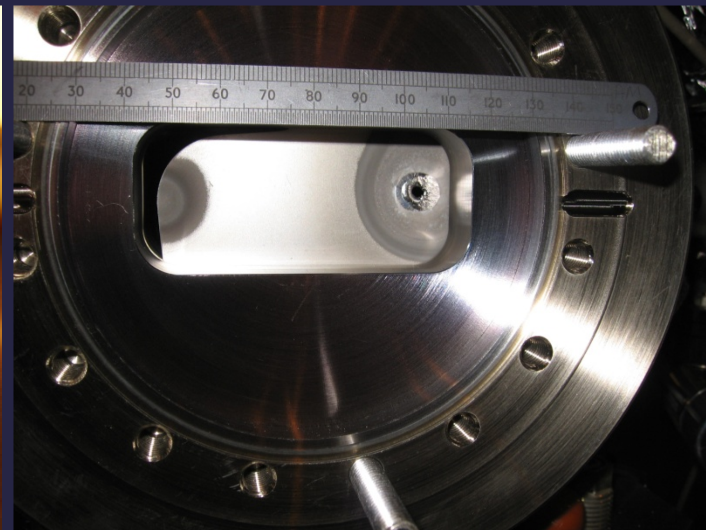
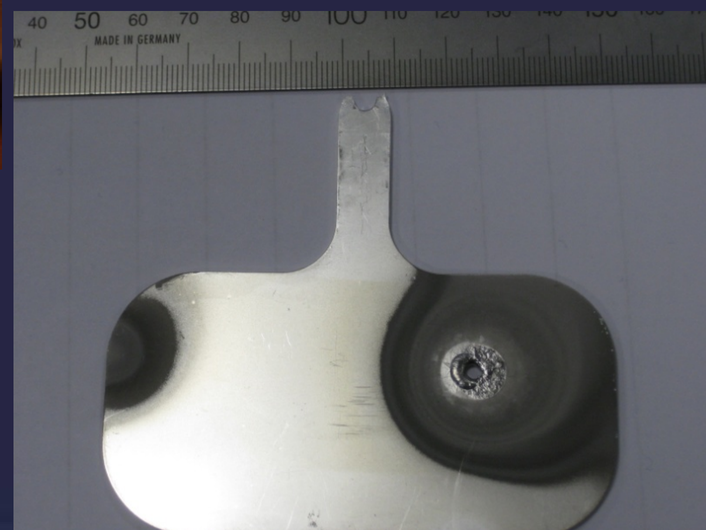
Synchrotron radiation heating damage

Melted LN2 pipe in monochromator due to undulator beam heating





Melted hole in fast closing vacuum valve titanium plate due to undulator beam

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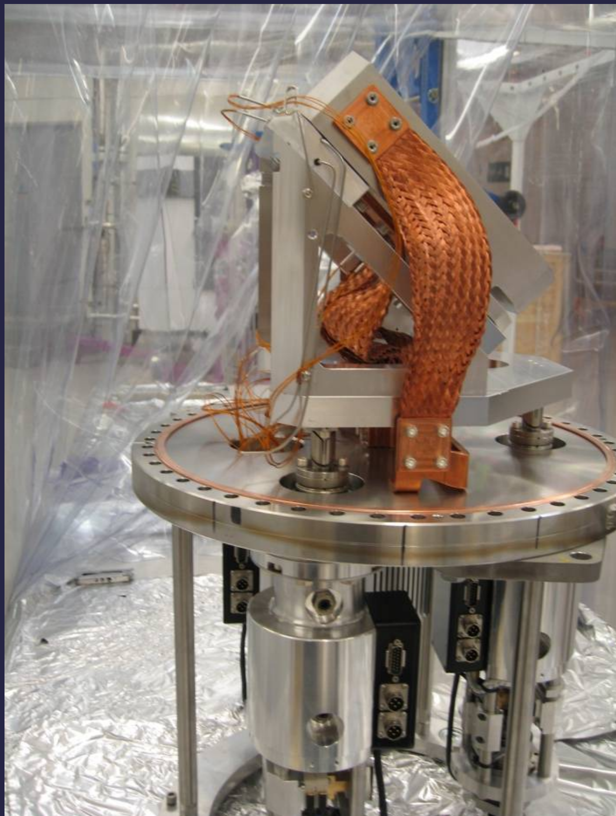
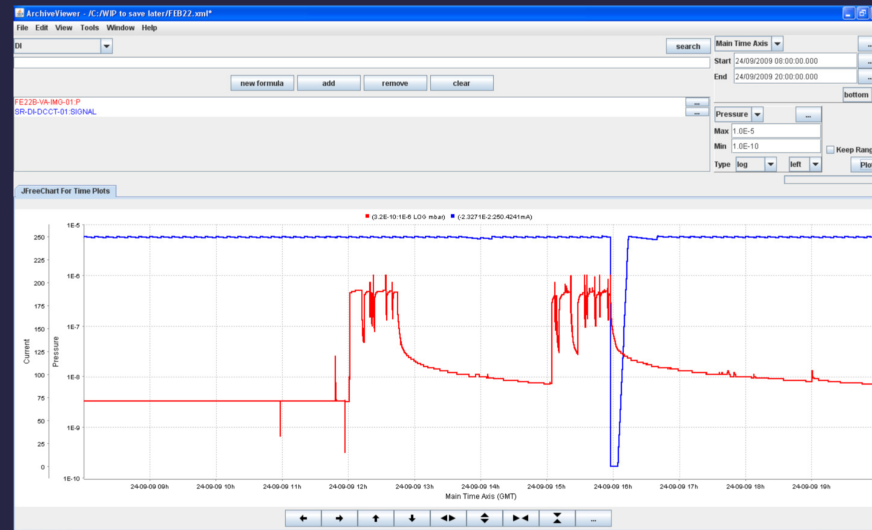
Kapton insulated wire problem

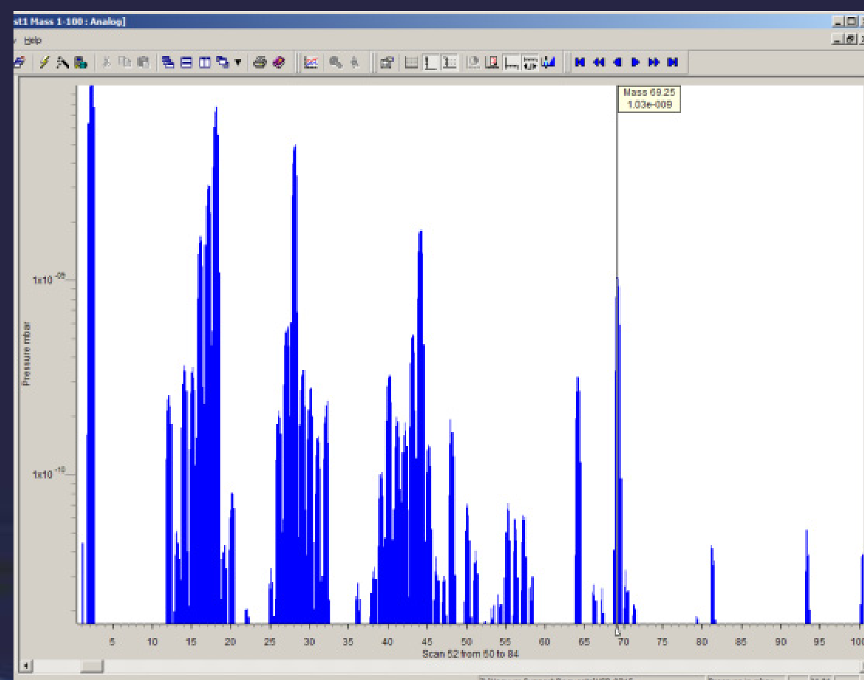


IR mirror and x-ray absorber in beamline B22



Pressure spikes trip interlock system

Beam on only



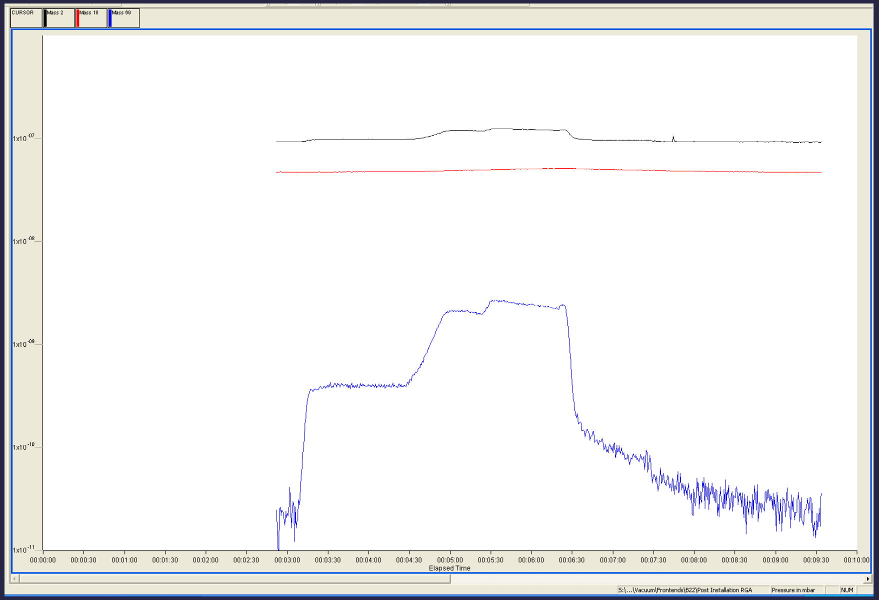
RGA

Mass 69

CF_3^+

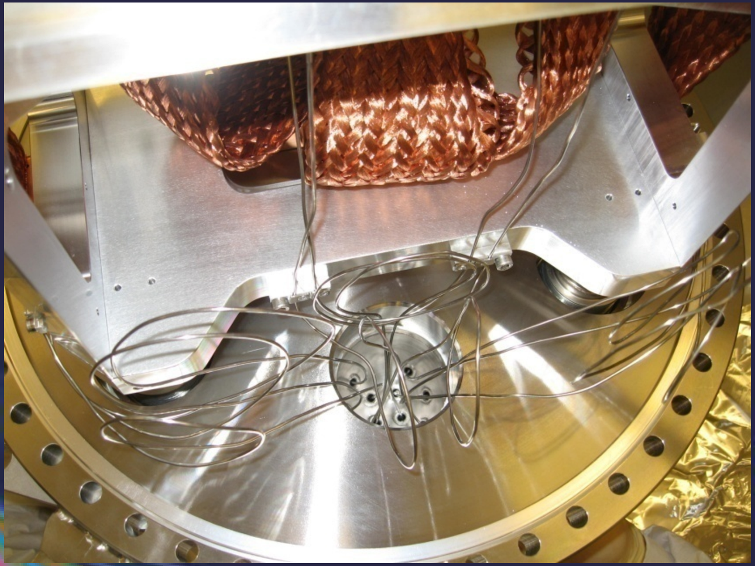
Kapton insulated wire problem

Kapton insulated wire contains unexpected FEP binder which breaks down due to scattered x-rays



CF_3^+ also seen with electron irradiation (5keV) in test system

Solution: remove Kapton insulated wire near strong x-ray beam absorber or scatterer



Multiple occurrences in different front ends and beamlines

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Future upgrades and challenges

- Complete phase 2 then phase 3 and beyond:
  - Complex beamlines
  - Complex vacuum experimental stations and detectors
  - 7.9 m long NEG vessel for I05?
  - “Superbend” dipole magnet?
  - Additional IDs in existing straights?
- Optimisation of vacuum interlock protection system: beamline protection vs machine reliability
- Maintain and improve supplier vacuum QA for beamlines and small quantities of vessels
- One-offs of complex vessels for spares and upgrades: manufacturers maybe unable or unwilling
- Obsolescence of equipment and spares
- Direct integration of RGA systems into EPICS (currently via Windows PC intermediate)
- Increase beam current to 500 mA

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Summary

- Diamond has a large and complex UHV system
- It is operating reliably to specification ($<10^{-9}$ mbar in the storage ring). The main residual gas is hydrogen
- Many small and medium size upgrades have been installed over the past 4 - 5 years
- A number of vacuum challenges had to be solved along the way
- The journey is not over yet and there will be more challenges to come

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Acknowledgements

- Diamond Technical Groups
  - Vacuum
  - Engineering
  - Controls
- Suppliers
- Other labs for helpful advice

Thank you