Diamond Light Source

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ICALEPCS 2007

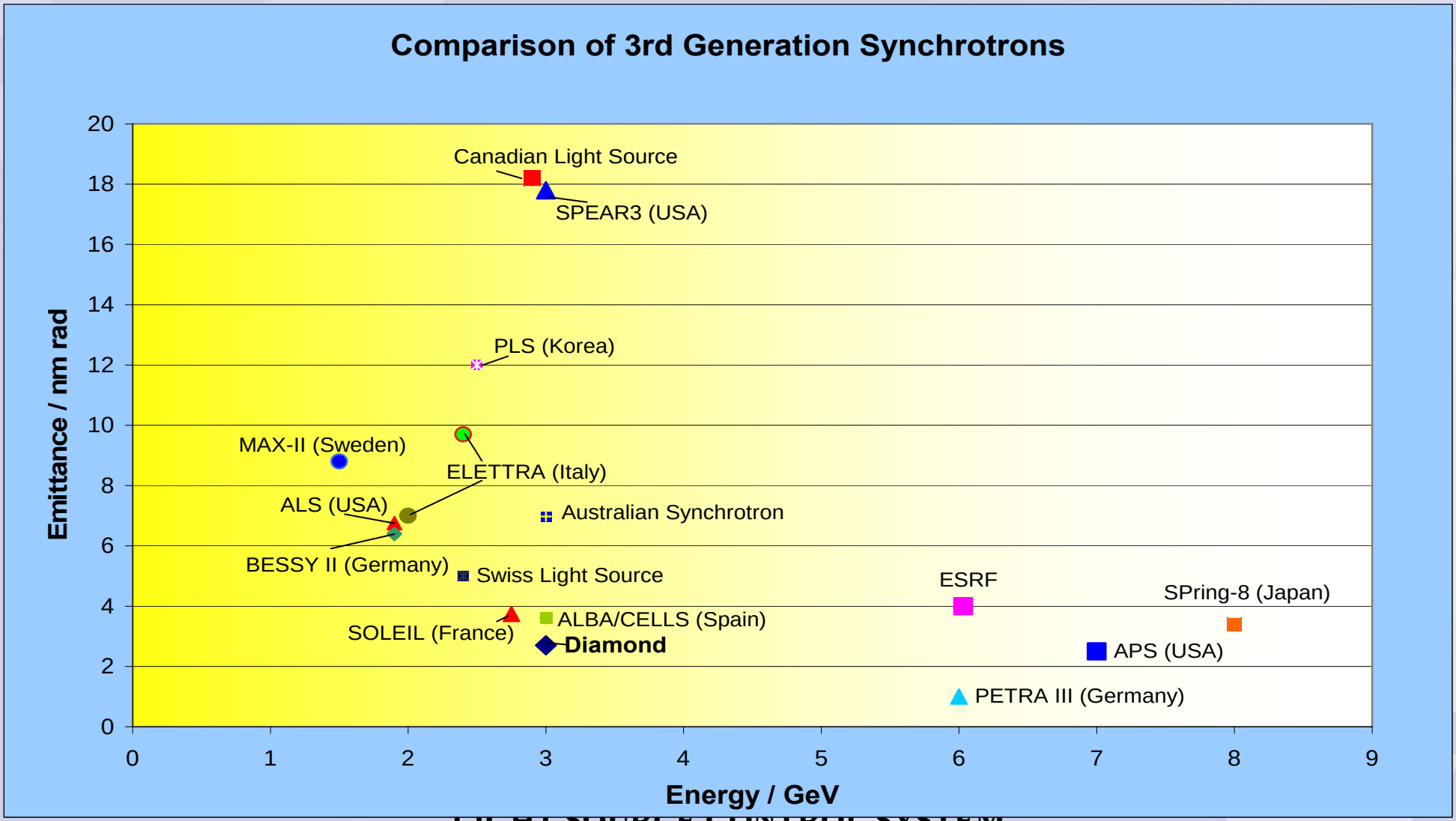
IMPLEMENTATION, COMMISSIONING AND CURRENT STATUS OF THE DIAMOND LIGHT SOURCE CONTROL SYSTEM

Content of Talk

- Introduction to Diamond
- Implementation of the Control System
- Commissioning
- Current Status
- Developments
- Conclusion

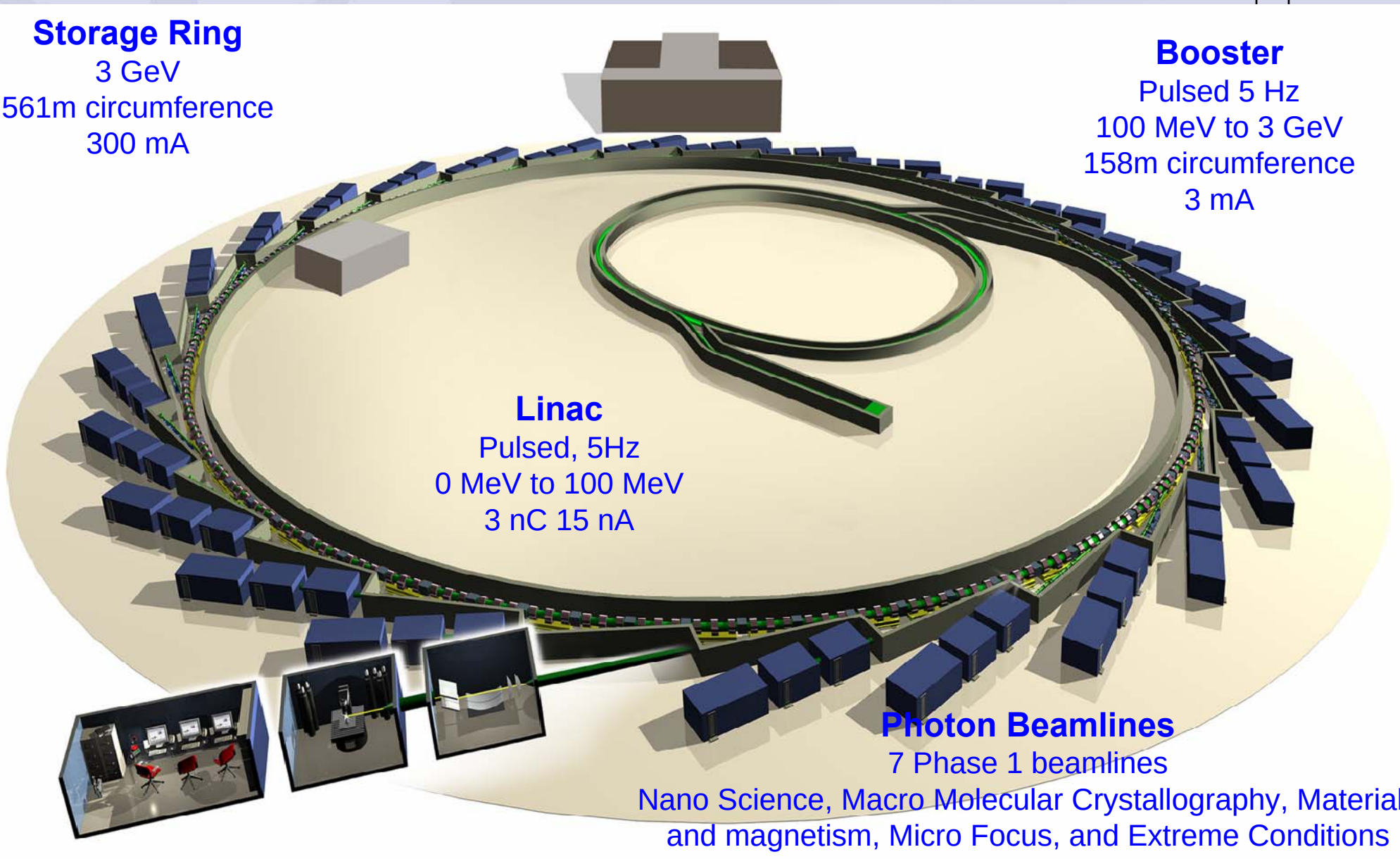
Introduction: Diamond

Diamond is a new Medium Energy, 3rd Generation Synchrotron Light Source



Introduction: Diamond

EPICS



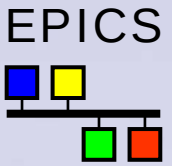
Storage Ring
3 GeV
561m circumference
300 mA

Booster
Pulsed 5 Hz
100 MeV to 3 GeV
158m circumference
3 mA

Linac
Pulsed, 5Hz
0 MeV to 100 MeV
3 nC 15 nA

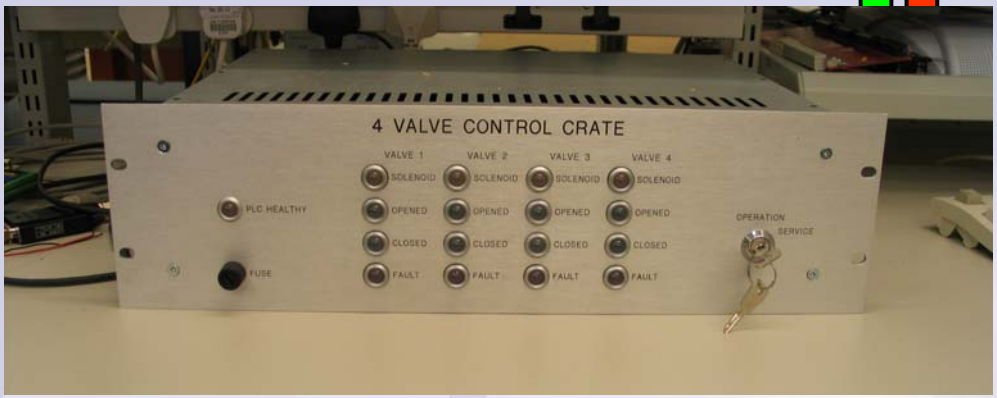
Photon Beamlines
7 Phase 1 beamlines
Nano Science, Macro Molecular Crystallography, Materials and magnetism, Micro Focus, and Extreme Conditions

Implementation: Control System Structure



- Control system applied across the 3 accelerators, photon Beamlines and experiment stations
- Based on EPICS
- Uses PCs running Linux for Clients, Development and Servers
- Most equipment Interfaces is VME 64x running VxWorks
  - Exception Libera eBPMs
- Two layer structure interconnected with GBit switched network
- Partitioned, vertically by technical Area ie Diagnostics, PSUs etc and by geographical location ie Cell of SR
  - Result in ~290 embedded VME systems

Implementation: Programmable Logic Controllers



- Programmable Logic Controllers (PLCs) are used below the IOCs for process control and interlocking applications
- Evaluated a number of solutions. Selected

See Poster TPPB42 by S Lay

  - Omron CJ1 for low end applications
  - Siemens S7 for high end applications
- Designed standard products for Vacuum Valve Control and Interlocking, and for Machine Protection by encapsulating Omron PLCs in 19” crates
  - Will help to manage obsolescence
  - Provided for efficient on site installation and commissioning

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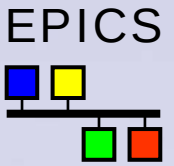
Implementation: Turn-key Systems

- Specified high level controls requirements for turn-key systems, but not detail functionality
- Defined constraints
  - Warned suppliers this is how we intend to do procure systems, with controls included
  - Use DLS preferred hardware, will be free issued
  - Comply with DLS naming convention, Application Development Environment and HMI requirements
- Support
  - Offered EPICS training before tender, and/or when contract placed
  - List of companies who they could sub contract controls to
  - We free issued DLS development environment
    - Linux, VxWorks, EPICS base, EPICS tools, Support module and Examples
  - Provide support during the contract.
- Systems
  - Linac RF, Booster RF, SR LLRF, SR RF amplifier, SR Girder alignment, PM IDs, SC MPW, Beamline optics, Beamline Monos
- Suppliers include
  - Accel, Thales Broadcast , CryoEletra, MicroMech Systems, Budker, Oxford Danfysik, CosyLab, Observatory Sciences, and IDT

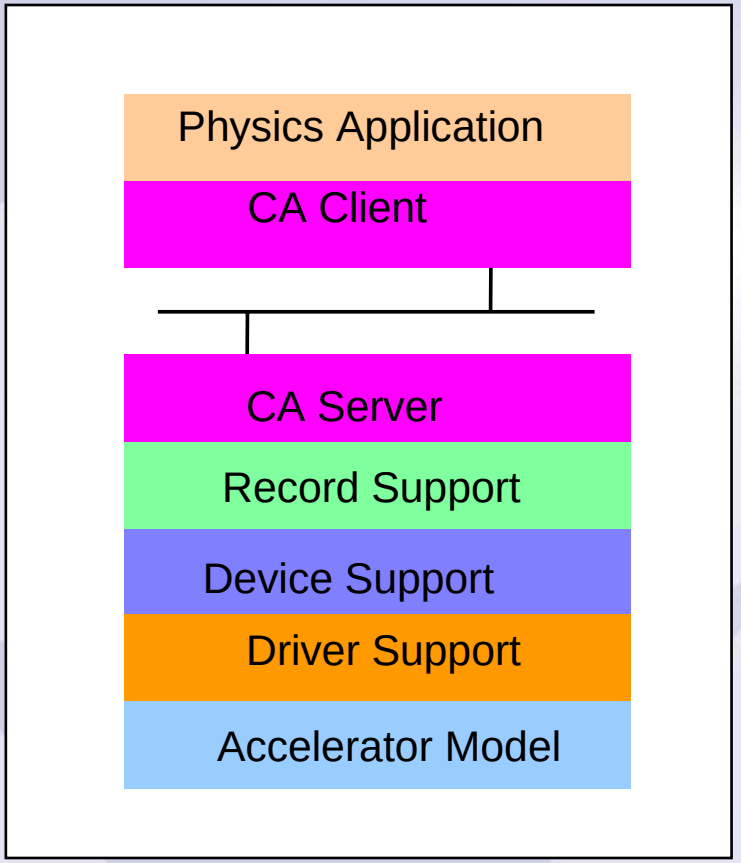
Implementation: Simulation Systems



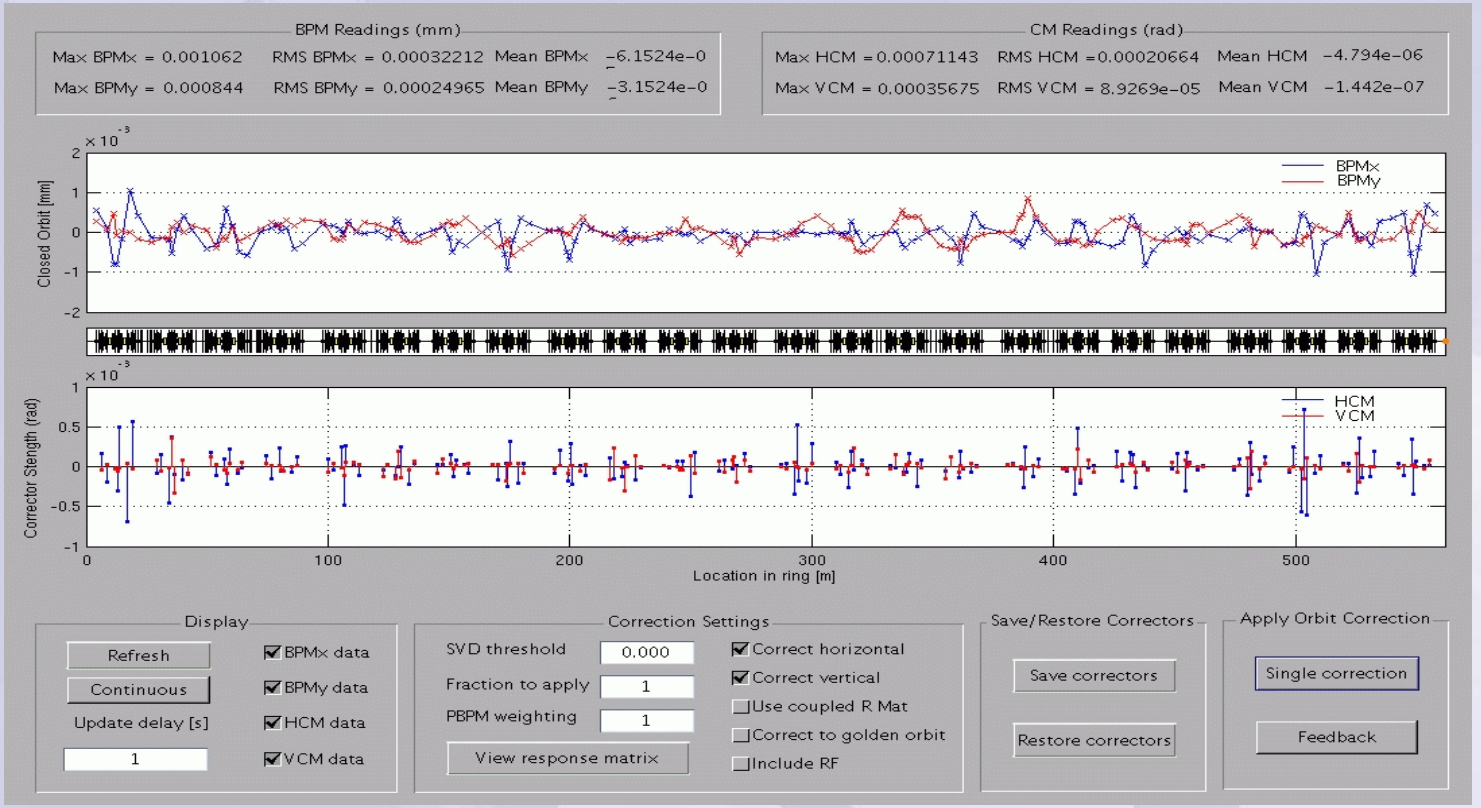
- For major systems (PSUs, Diagnostics, MPS, Vacuum Girder alignment, Front ends, IDs, Linac PSS) simulations were built
- Use simulation records under the real record interface
  - Maintain the same application interface in name and PV functionality
- Ran on the same hardware 12 x MVME5500s (350k PVs).
- Set up one Console, the application Launcher, and applications
  - Invited Operation and Technical Group to "Come See" and review
- In **Oct 2004** we had first release of simulations and applications for most Technical systems
  - NOT Timing or all eBPM functionality or Beamlines

Implementation: Virtual Accelerator

- A virtual accelerator was implemented to give simulation of the machine though the intended PV interface.
- This was realised by developing EPICS device support to interface to the model implemented with the TRACY-2 libraries.
- For physics tools the Accelerator Toolkit for Matlab is being used.
- Valuable for debugging Middle Layer interface for AT



Implementation: Physics Tools



- Use Matlab applications Accelerator ToolBox
  - Used on ALS, SPEAR III, CLS, Soleil and others
  - Developed Middlelayer to give abstract machine interface
- Use Matlab for analysis applications and general scripting

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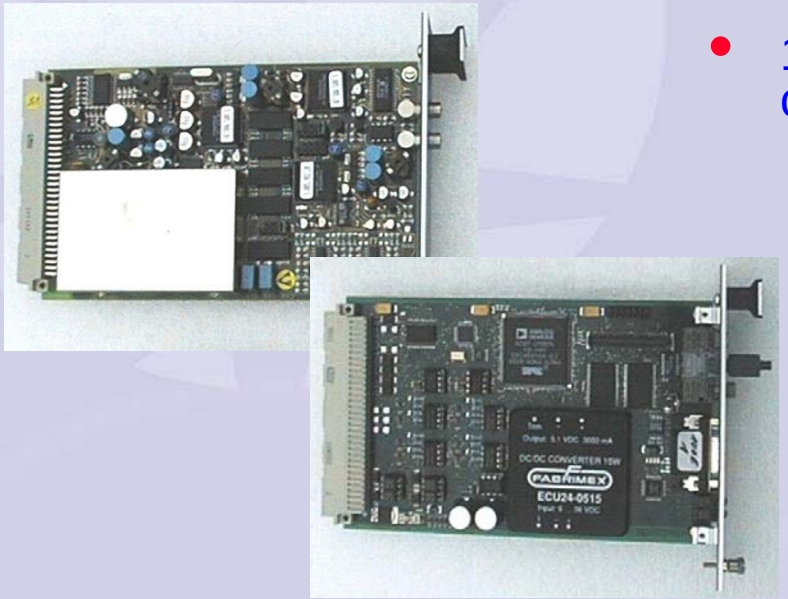
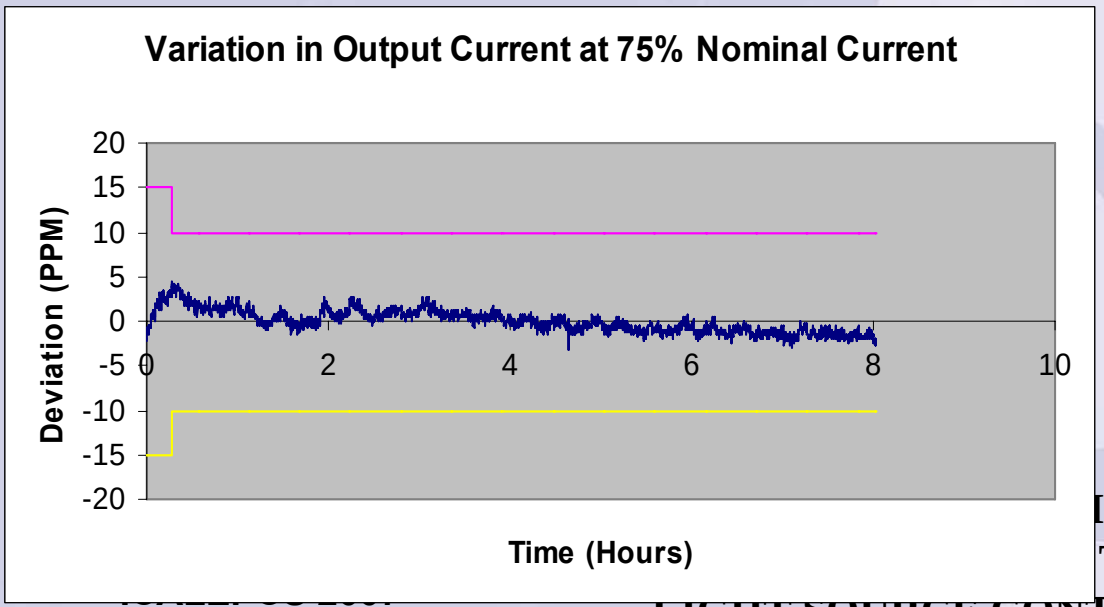
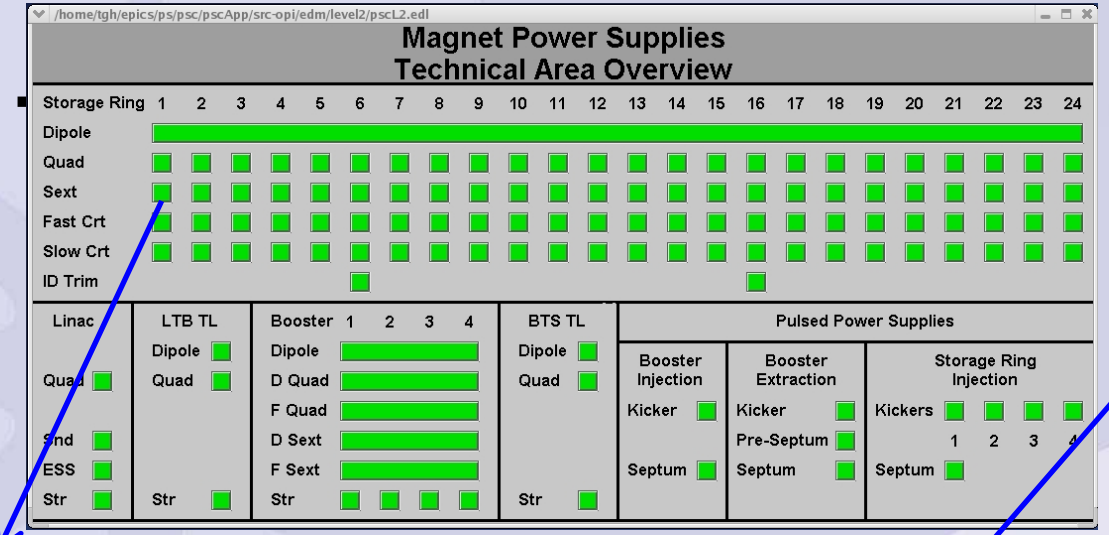
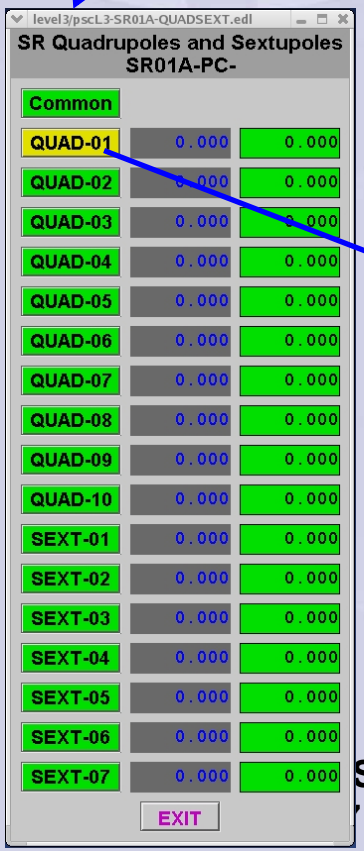
Implementation: PSUs

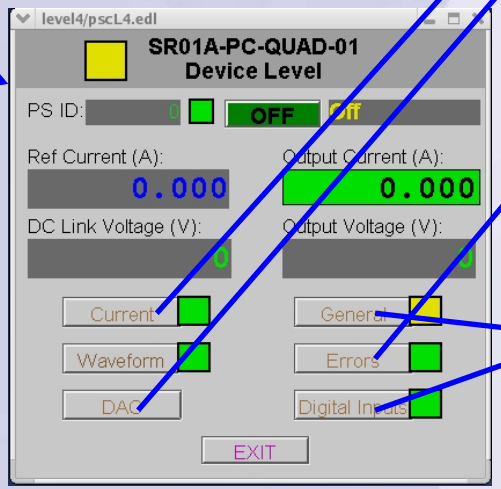


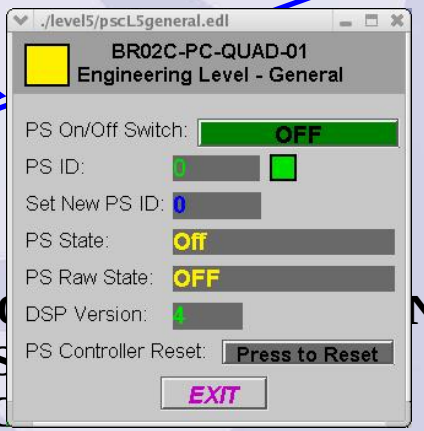
- 1200 PSUs all controlled by the Digital PSU controller
  - Same control interface to all DC and pulse PSUs
  - N +1 Redundancy in large and medium converters
  - DSP based regulation
  - Good resolution 3ppm
  - Good stability < 10ppm over hours.
  - PSC functionality developed for different PSU types both state machine and signal processing for regulation
  - PSC interface using point to point serial over FO to IP modules in VME crates

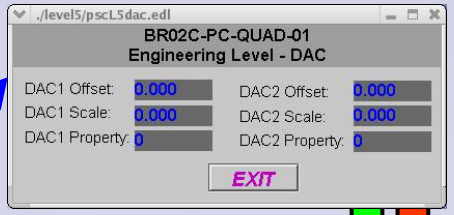


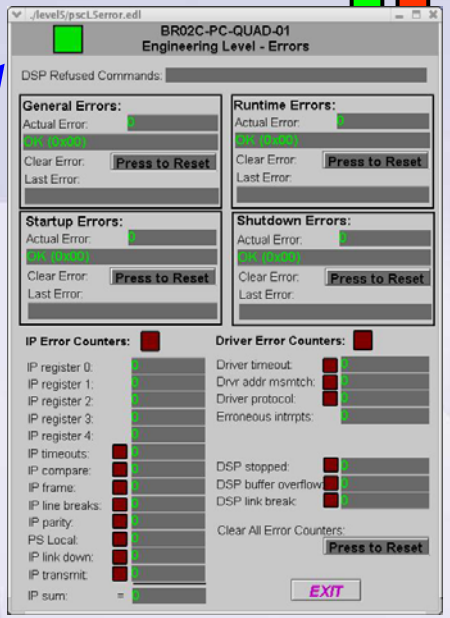


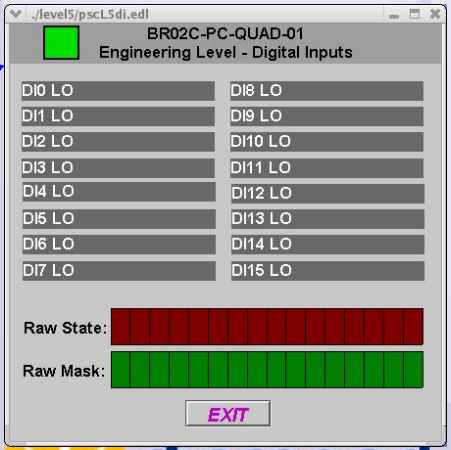












Source

IMPLEMENTATION, C ND
CURRENT STATUS
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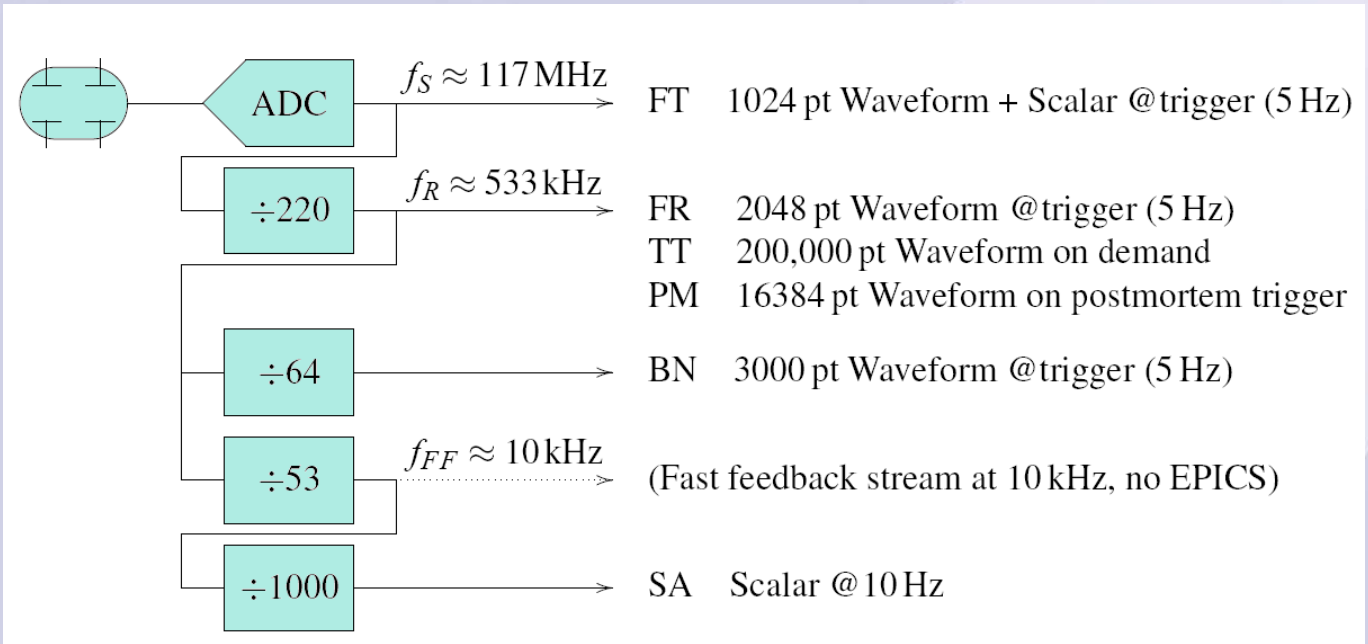
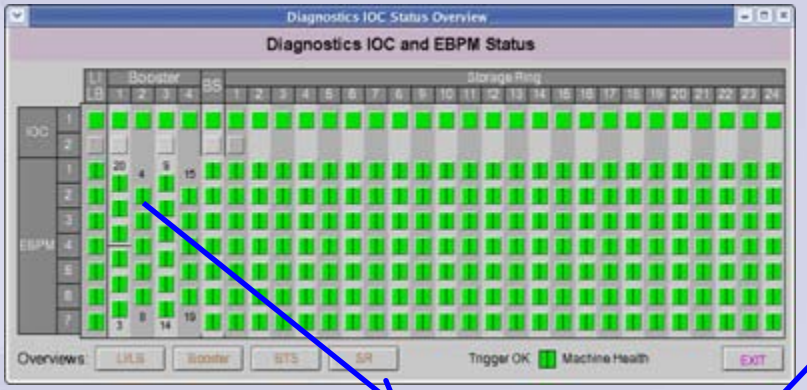
Implementation: Diagnostics

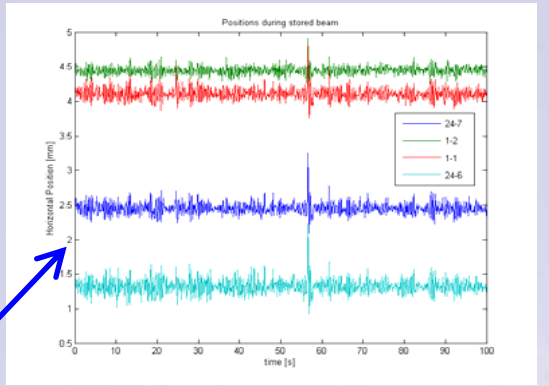
Electron Beam Position Monitors

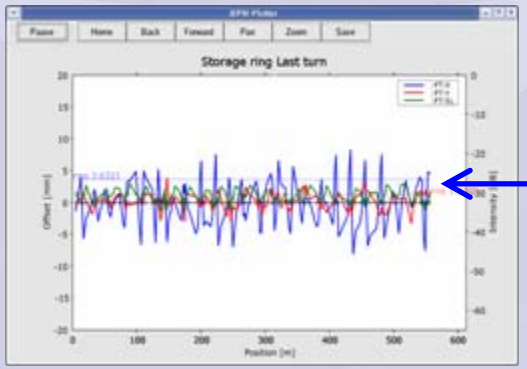
- 207 EBPMS using Libera EBPM detectors from Instrumentation Technology (I-Tech) Linac to SR
- EPICS server running on Libera box

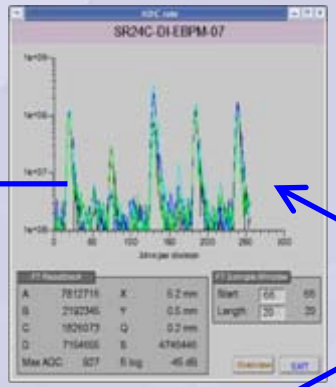


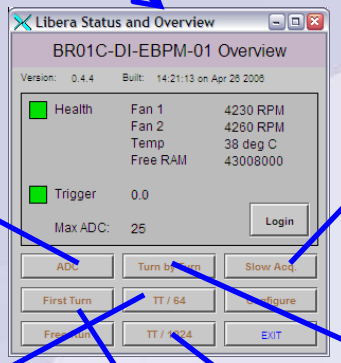
- Linux OS
- ARM processor
- Timing from event system

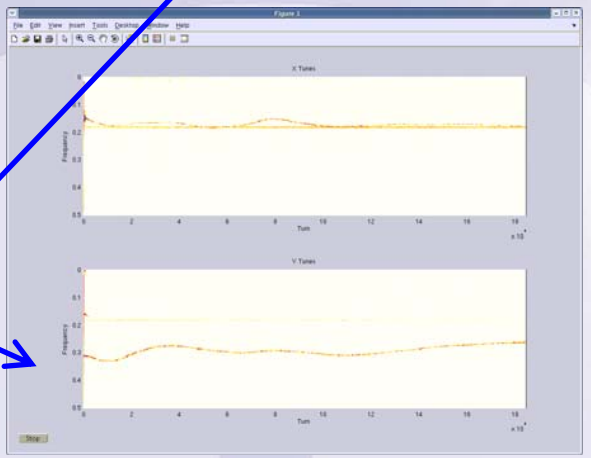


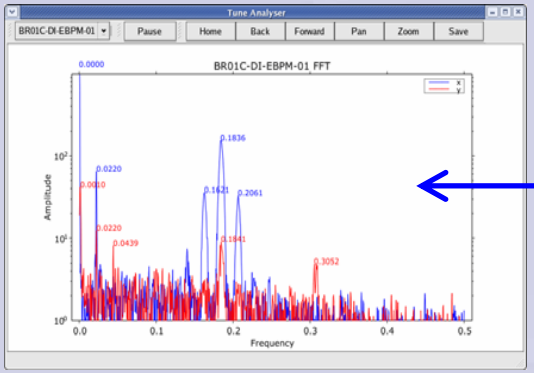


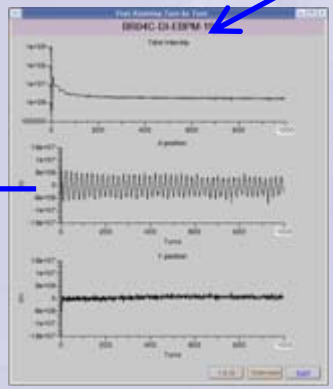


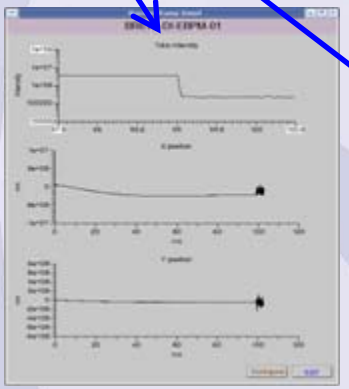


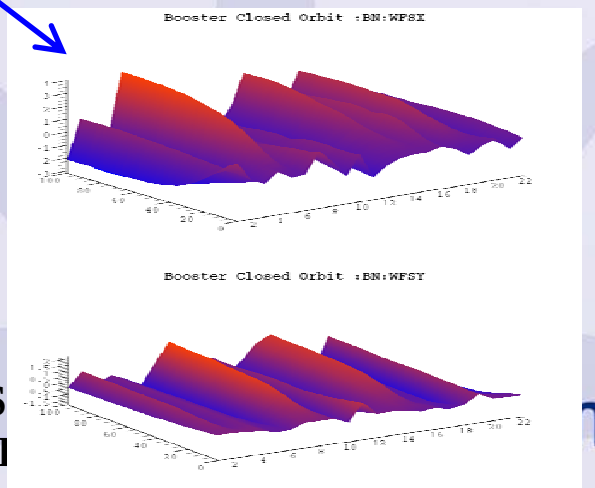












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IMPLEMENTATION, COMMISS
CURRENT STATUS OF THE I
LIGHT SOURCE CONTROL SYSTEM

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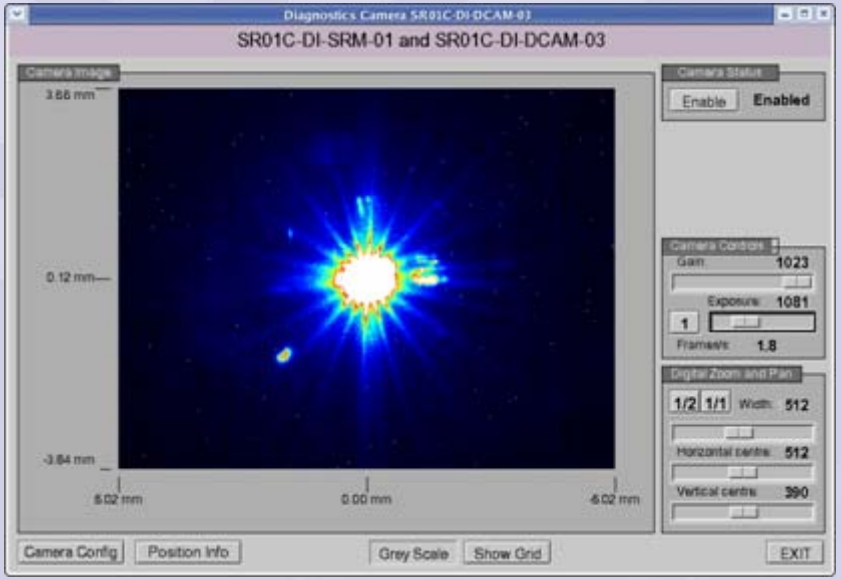
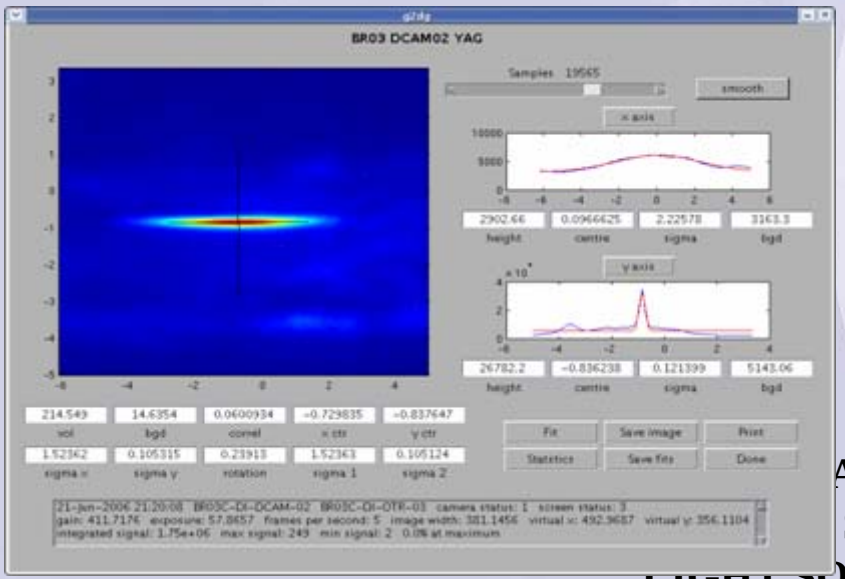
Implementation: Diagnostics

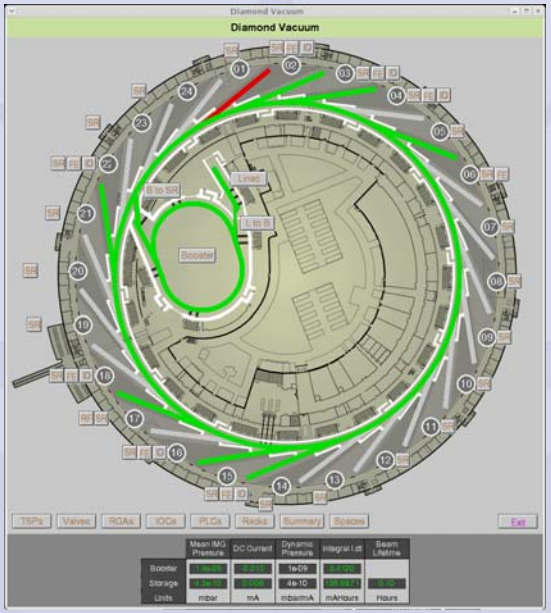


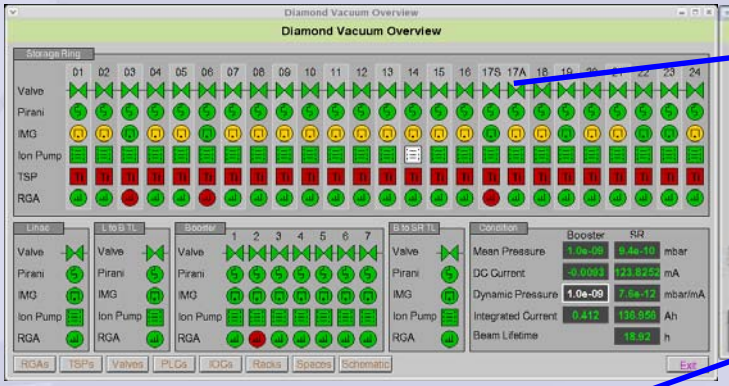


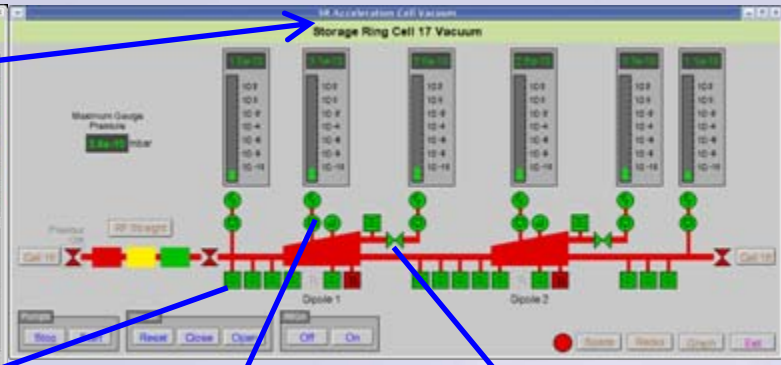
- PointGrey Flea 1024x768 cameras with IEEE1394 interface.
  - Triggered by injection cycle 5Hz
  - Interface in to PMC 1394 interface on VxWork systems.
  - Video over Channel Access.
- Applied Linac, Transfer lines, injection into Booster and SR, SR Pin hole and beamlines
- Applications
  - Use 2d Widget in EDM with false colour for visualisation
  - Matlab for fitting energy spread, and emmitance.

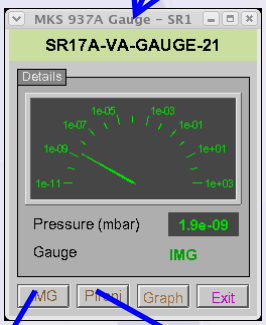
Implementation: Vacuum

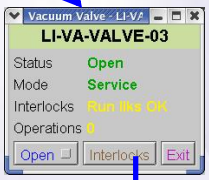
- 528 Gauges MKS937A Interfaced through serial connections
- 624 Ion pumps and 60 TSPs controlled by MPCs from Gamma Vacuum, interfaced through serial connections
- 139 vacuum valves controlled through PLC based valve control units
  - PLC encapsulated in crate to create standard products, which manage obsolescence and simplify rack build
- RGAs integrated into CS
- Use Streams to define comms protocol with "printf and scanf" like rules

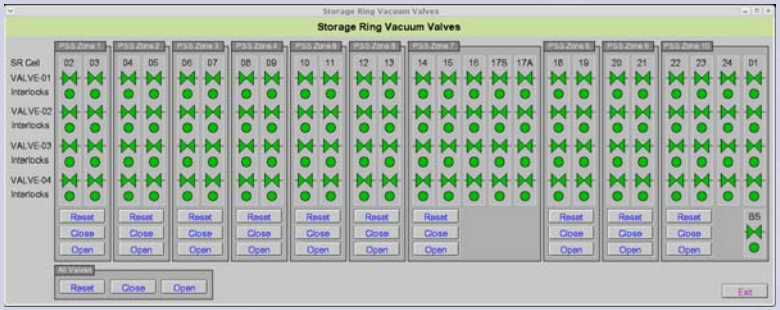


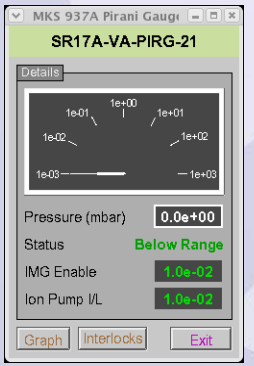


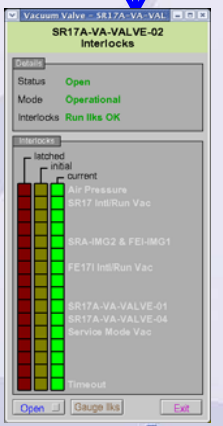


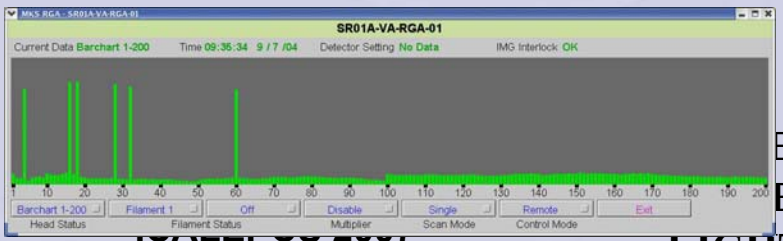












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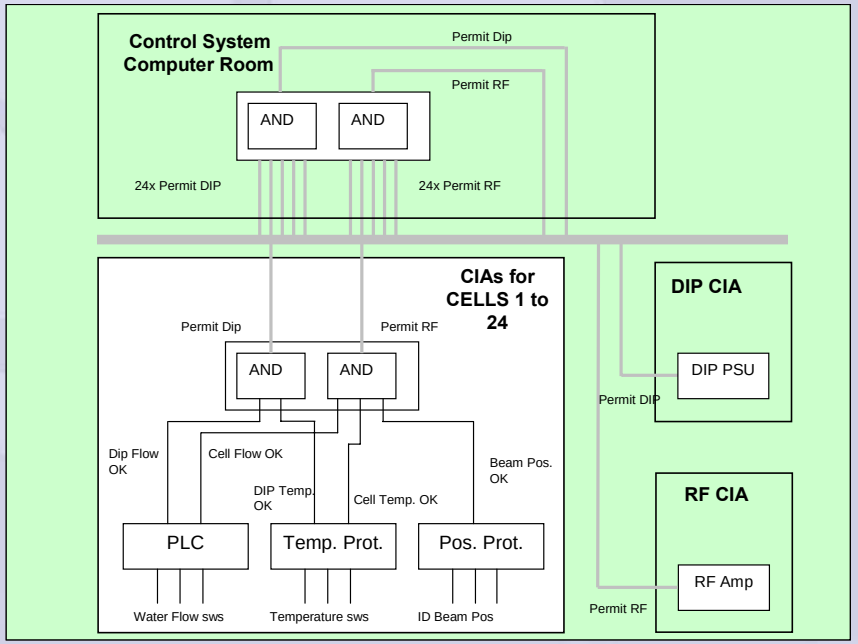
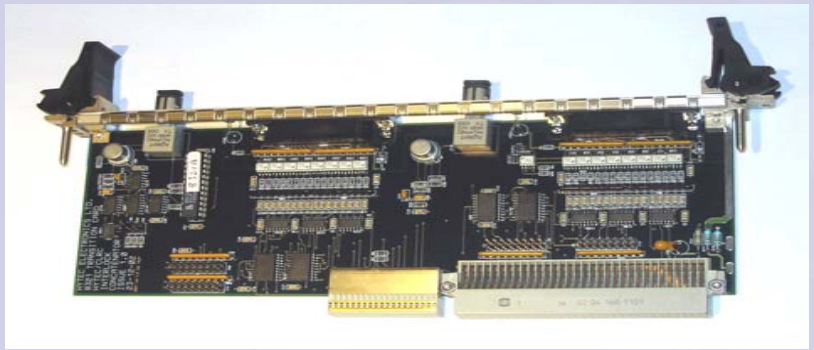
diamond

Implementation: Machine Protection System

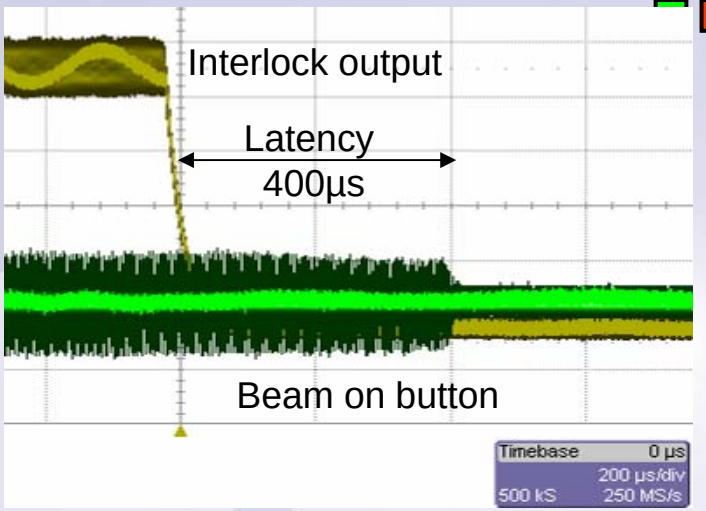




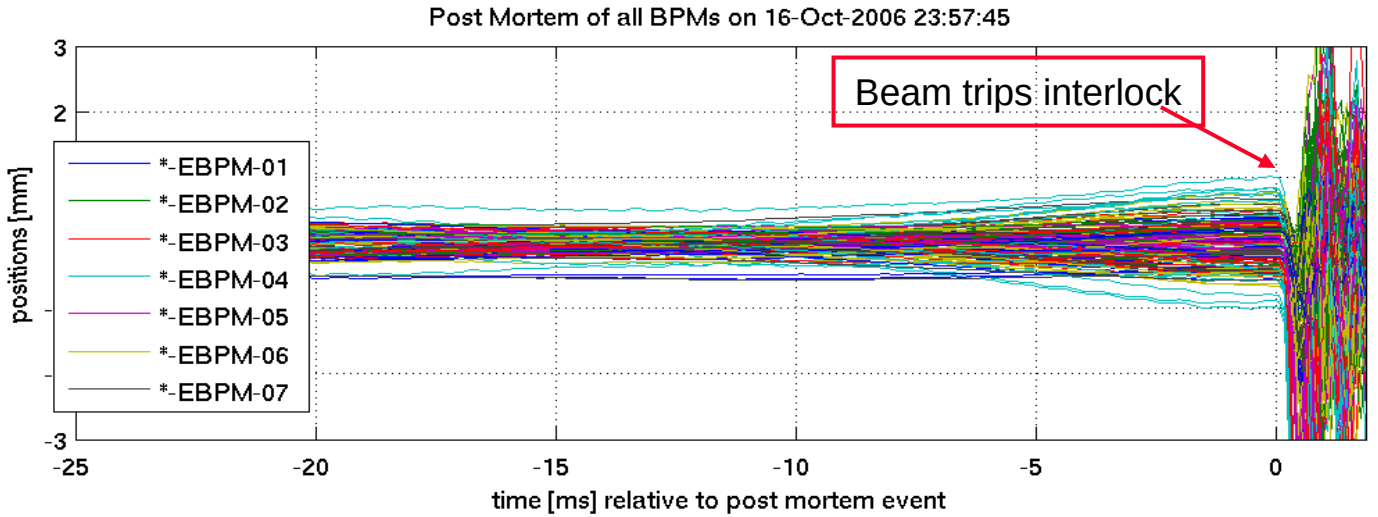
- Machine Protection System manages interlocks on a global basis to protect components from damage loss of cooling obstructions in beam path Mis-steering of the beam.
- Protection circuits
  - Storage Ring two; Vessel and Dipole
  - Booster four; Vessel, Dipole, FQuad and DQuad
- Uses a 5MHz pulse stream over Fibre Optic to TX the Interlock. No encoding, defined fail to safe and propagation delay.
- DLS modules realised as VME64 Transition boards monitored by EPICS
- Use FO infrastructure provided by the Network contract
- Water flow etc monitored by PLC sub system which feed into Local MPS module

Implementation: MPS Fast Orbit Interlock

- Limit of ±1mm in X and Y around BBA centres
- All 168 EBPMs connected into MPS
- MPS drops RF and sends post mortem event
- Total latency 600 µs (200usec eBPM 400usec MPS) from beam movement to beam dump
- PM buffer records 15000 turns before and 1000 turns after MPS on all BPMs



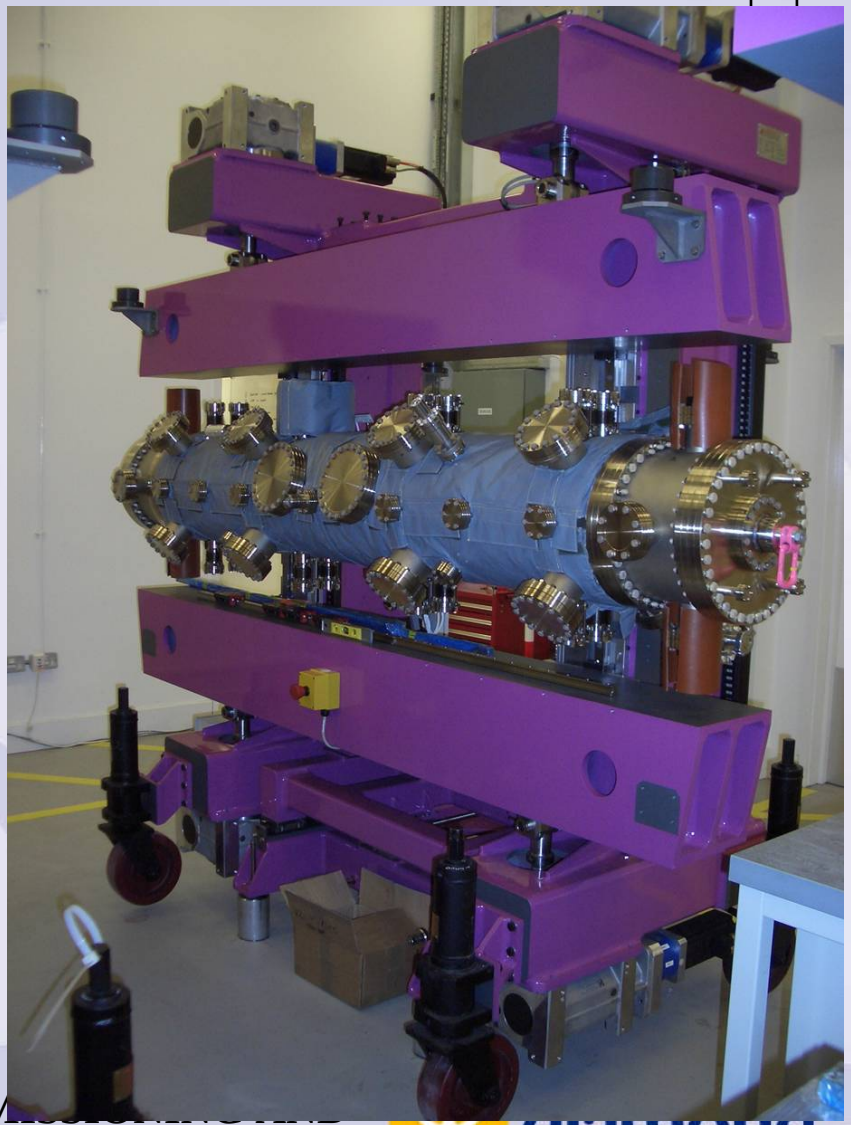
Time delay MPS IP to Beam Dump



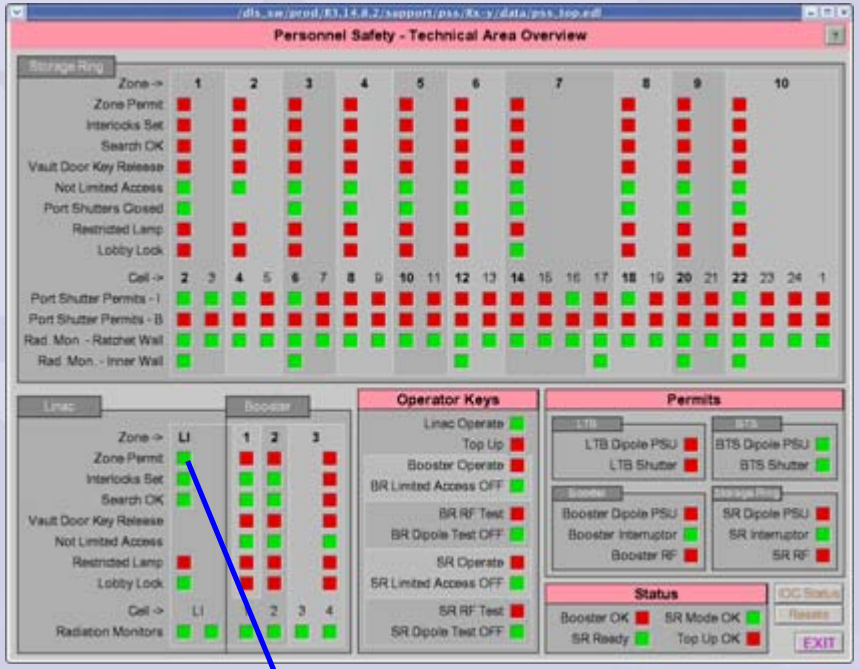
Post Mortem Buffer triggered from MPS

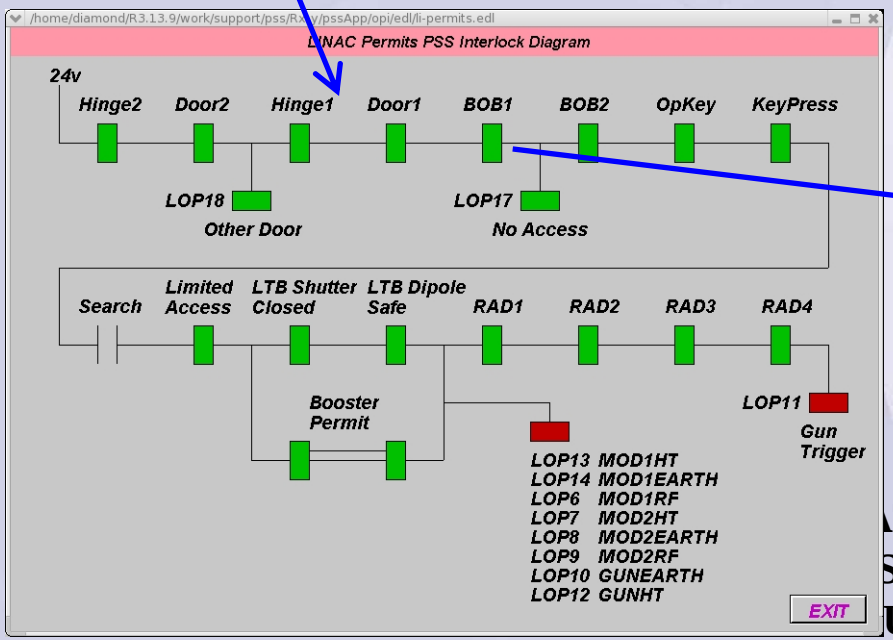
Implementation: Insertion Devices

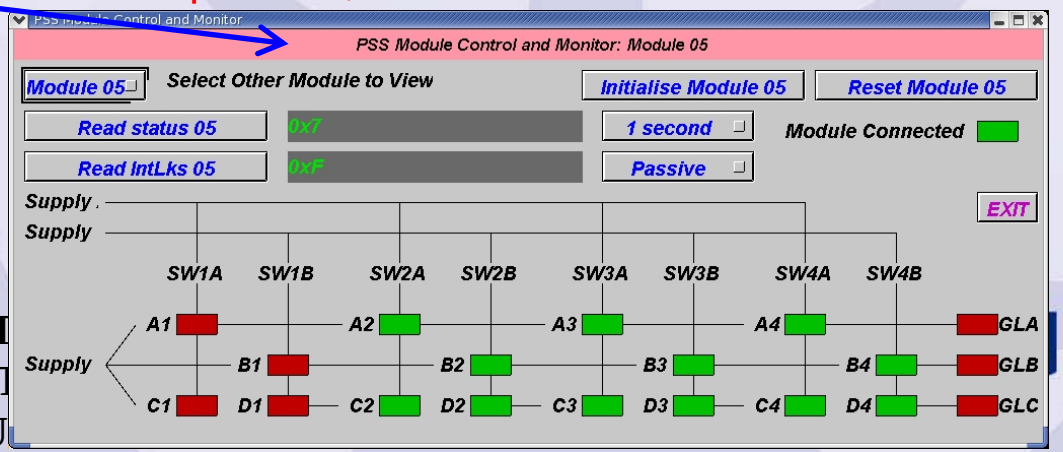
- Common motion Control System for all permanent magnet IDs
  - In-Vacuum and Ex-Vacuum
- 6 axis motion control
  - Each beam has two independent jacks requiring synchronization
  - On Apple type device each beam has Phase change of magnet arrays
- Motion
  - Resolution < 1um
  - Repeatability < 10um
- PLC protection subsystem
  - Manages interlock from Limit switches and Delta between encoders and from tilts sensors.
- Includes
  - Vacuum control where required
  - DC Power supplies with Feed-forward for Integral field correction



Implementation: Personnel Safety System



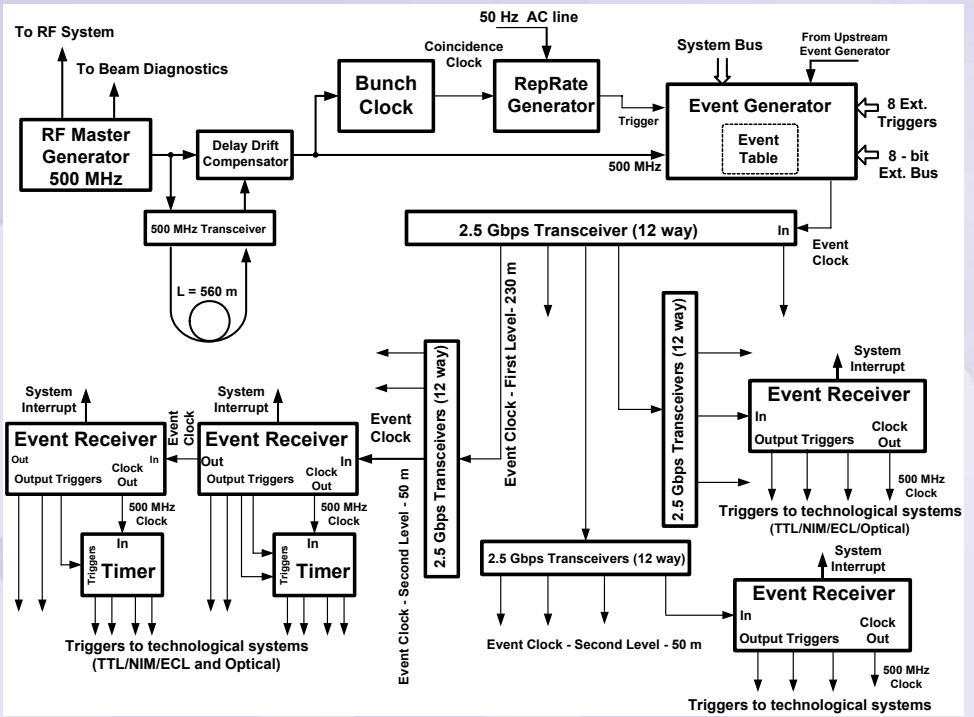




- Designed against a methodology compliant with IEC61508
  - Risk Analysis gave SIL2 requirement
  - Failure mode analysis to verify
- Realised as a dual guard-line with logic implemented in relays
  - Based on design applied to SRS at Daresbury and ESRF
- CS monitors the PSS system plays no part in logic
  - Checks for Single bit errors, generate alarms.
  - Compile statistics on searches, shutter operation, etc to validate the model

Implementation: Timing System

- Timing system based on APS/SLS event system
  - Redesigned to remove obsolescence and improve performance
- Used for all accelerator and for beamline timing
- Structured as Event Generator which distributes timing events to Receivers which decode these and provide additional control
  - Hardware signals, Interrupts or EPICS Events
  - EVRs as VME and PMC modules
- Event resolution 8nsec,
  - Jitter stability < 10psec VME EVRs and ~20psec PMC EVRs
  - Maintain phase across locations by equal fibre length



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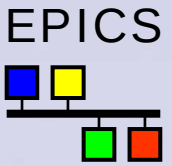
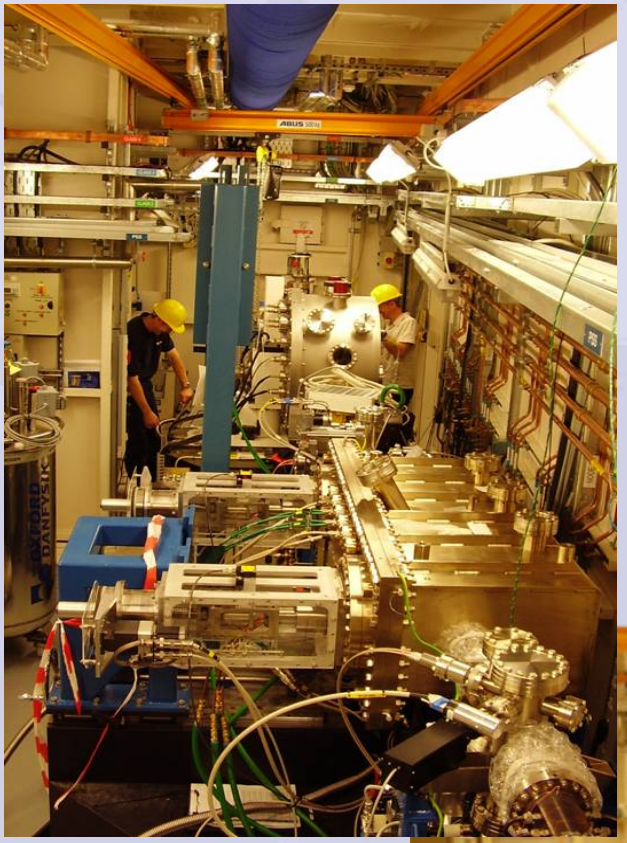
IMPLEMENTATION, COMMISSIONING AND CURRENT STATUS OF THE DIAMOND LIGHT SOURCE CONTROL SYSTEM

Implementation: SR RF System



- SR RF Amplifiers
  - Turn-key solution complete with EPICS controls
- SR Cavities
  - Accel delivery PLC based low level control which DLS intergrated
- SR Drive Amplifiers
  - Integrate though serial interface
- SR LLRF
  - Turn key solution including EPICS based controls
- SR RF Cryogenic refrigeration plant
  - Standalone SCADA system
  - Uses Siemens S7 PLC will look to integrate key data post 2007/ 2008

Implementation: Beamline Controls

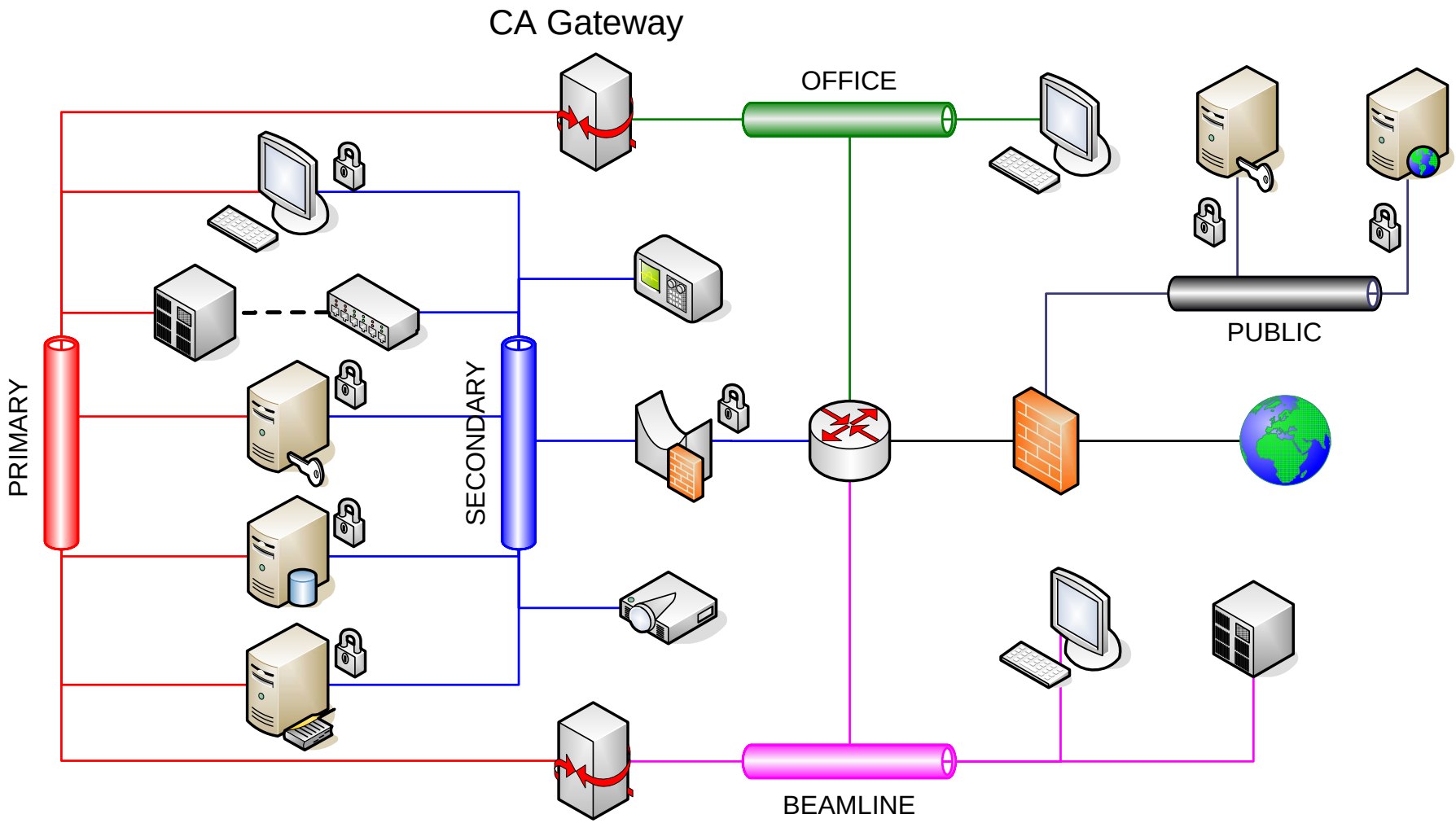


- Typical 100axis of steppers per BL and some servo motors.
  - Primarily through Delta Tau PMAC controller with UMAC sub crate
  - Other motion in Newport XPS notably Newport Diffractometers
  - Development of EPICS Motor Record
- Includes all vacuum instrumentation, diagnostics and some detectors
- Use the Generic Data Acquisition application for science functionality and data taking

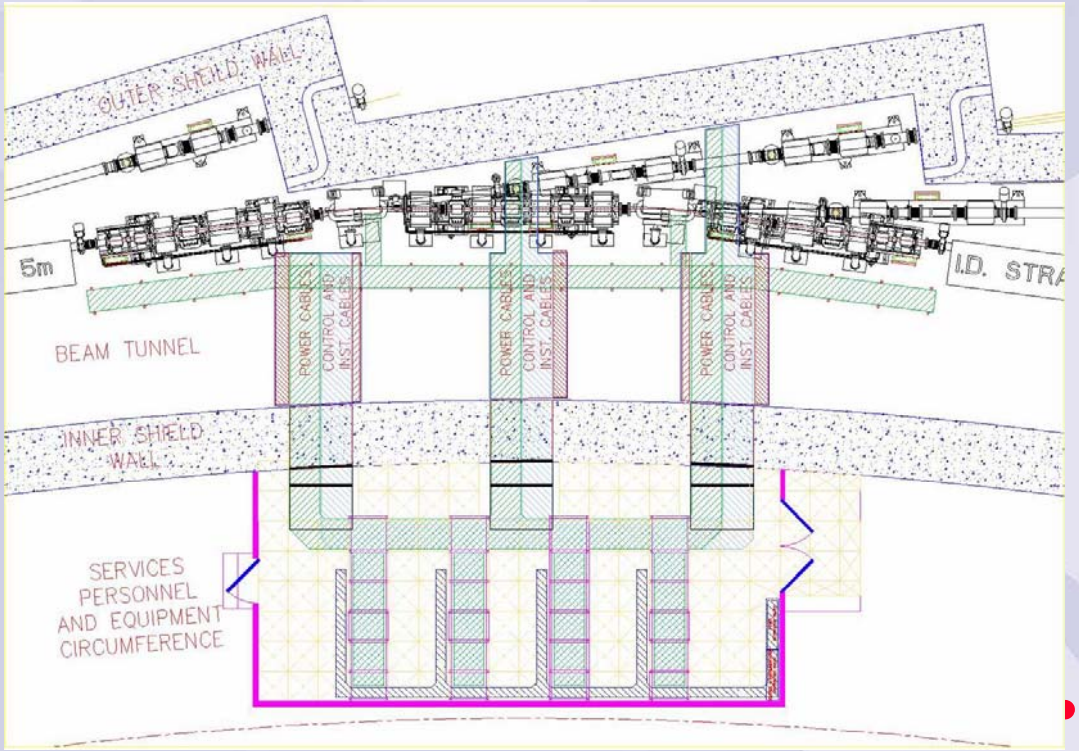
See Poster TPPA10 by N Rees

Implementation: Network Structure

EPICS



Implementation: Control Instrumentation Areas (CIA)



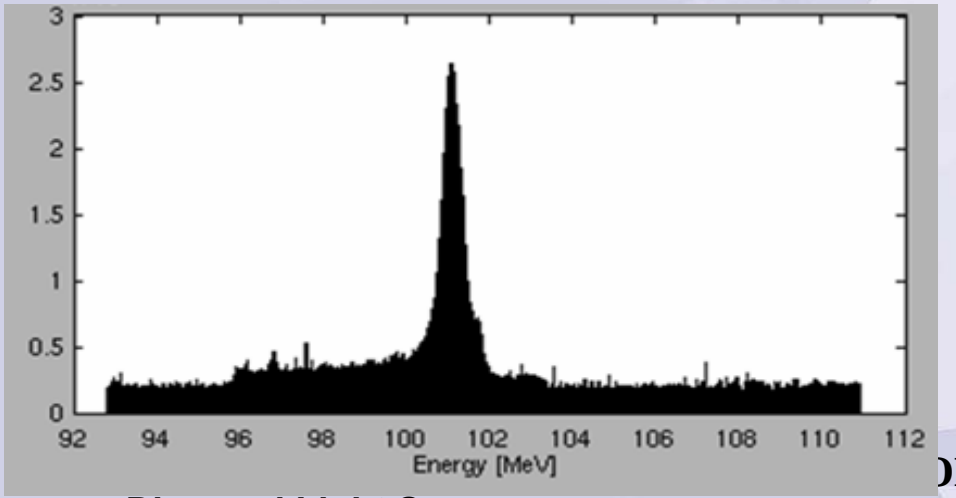
- CIAs house instrumentation racks and provide
  - A clean, temperature controlled environment
  - Manage cooling of racks
  - Define cable routes and labyrinths into accelerator enclosures
  - Smoke detection
  - All Cables are Segregate by class, are LSZH and are on aneathe plane.
  - Minimum Inter CIA Copper connections
- 1 Linac, 4 for Booster, 24 for SR, 4 for misc and 1 per beamlines


SR23C-MP-RACK-01
MACHINE PROTECTION SYSTEM CONTROL RACK
SR23C-MP-PLC-01
MACHINE PROTECTION PLC
SR23C-DI-RACK-02

Commissioning: Commissioning……..

- Control System Commissioning
  - Linac and Booster during 2005
  - Storage Ring Jan to April 2006
    - 2 cells per week
    - Coordinating multiple activities in the tunnel
  - Beamlines 2005 on
- Beam Commissioning
  - Linac Booster 2005 and 2006
  - April 2006 technical systems required for SR first beam commissioned
  - **But building not finished and no cooling water**
  - Only “out of hours”, Night and weekend commissioning with beam
  - Ongoing Installation of Cooling, Frontends
- Booster and Storage Ring Beam commissioning in 2 phases
  - 1St Phase 700MeV
  - 2nd Phase 3GeV

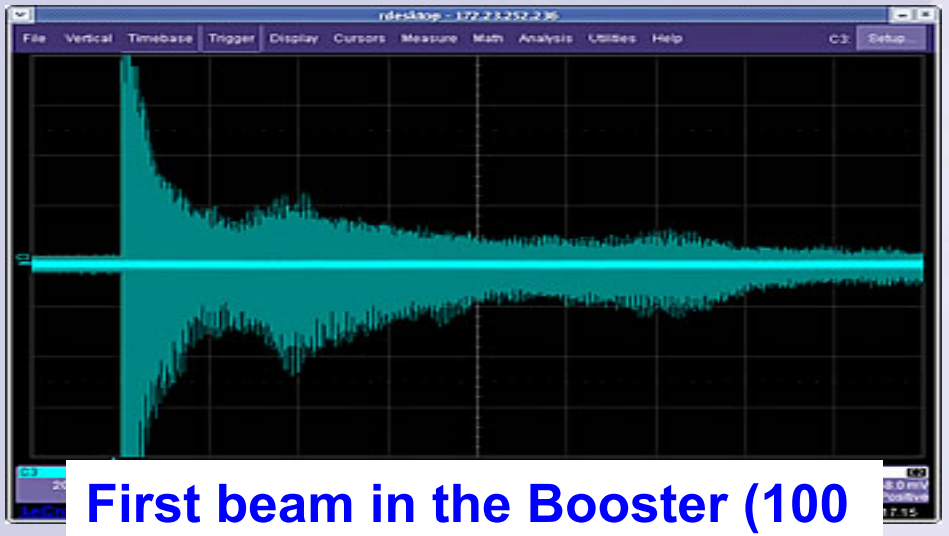
Commissioning: Linac



- Installation complete: Aug. 3rd 2005
- 1st beam from gun: Aug. 31st 2005
- 1st 100 MeV beam: Sep. 7th 2005
- Acceptance test mid-Oct. 2005
- Control System
  - Temporary Cu Network
  - Local Timing Generator
  - Booting IOC of development servers
  - Temporary Control Room

Commissioning: Booster

Booster installation completed	December 2005
First injection into booster from LTB	December 22nd 2005
Capture of beam by booster RF	February 2006
Acceleration to 700 MeV	March 3rd 2006
First extraction from booster at 700 MeV	April 4th 2006
First 700 MeV injection into storage ring	May 2006
3 GeV extracted	June 2006



First beam in the Booster (100 MeV, no RF) Dec. 21st 2005

- Control System
  - Operational network and servers were installed
  - Timing EVG installed and timing distributed signal distributed over computer network
  - 2nd temporary Control Room a Booster CIA

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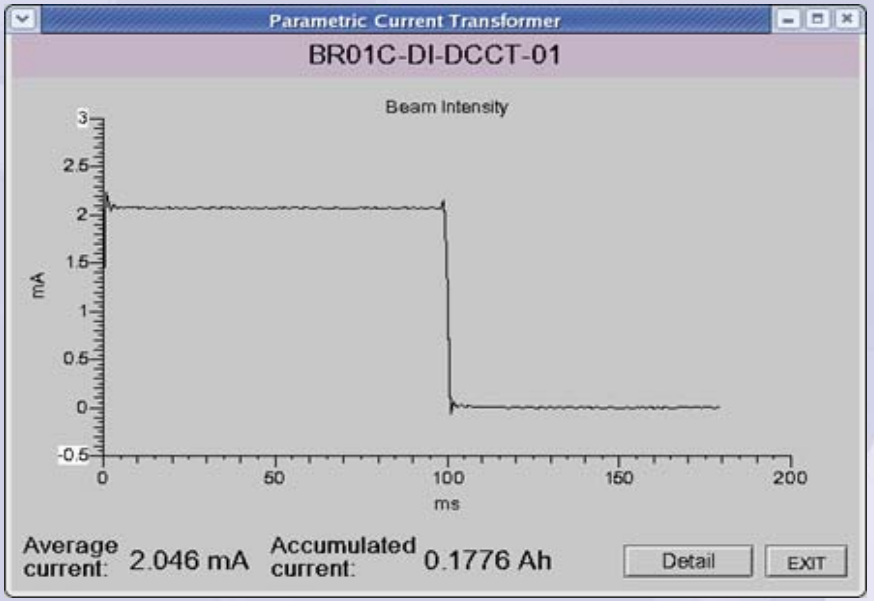
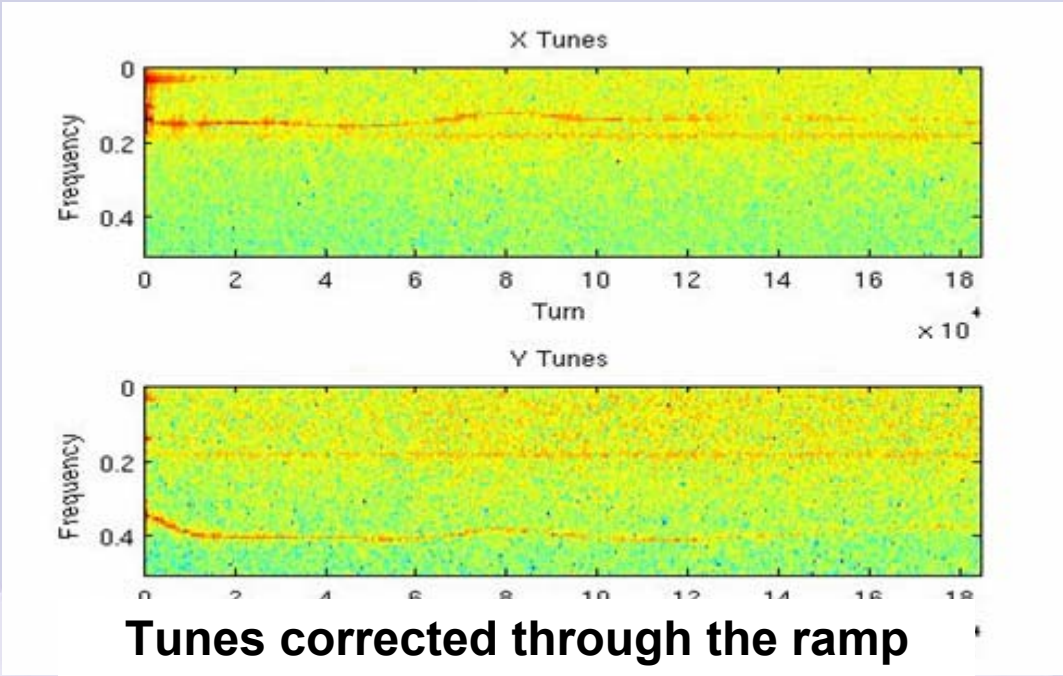
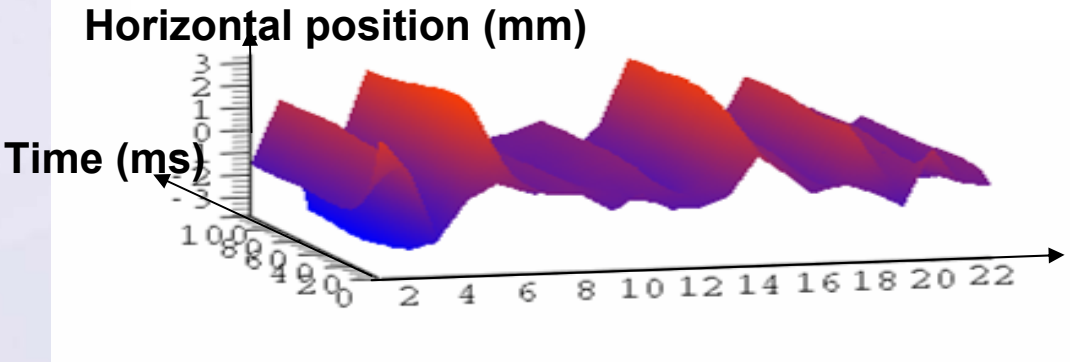
Commissioning: Booster @ 3 GeV June 2006

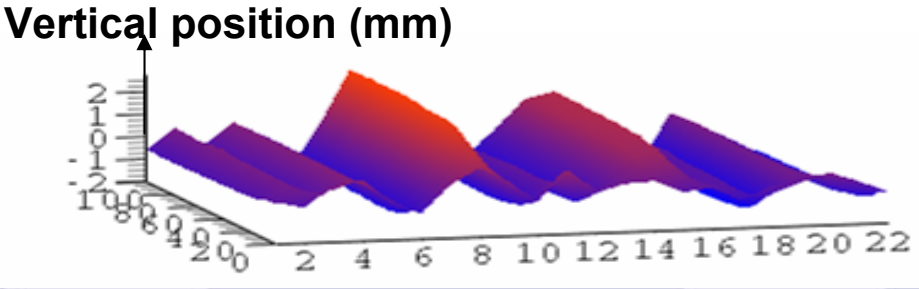


2 mA typical, with ~ 70 % transfer efficiency from before injection to after extraction.



Tunes corrected through the ramp





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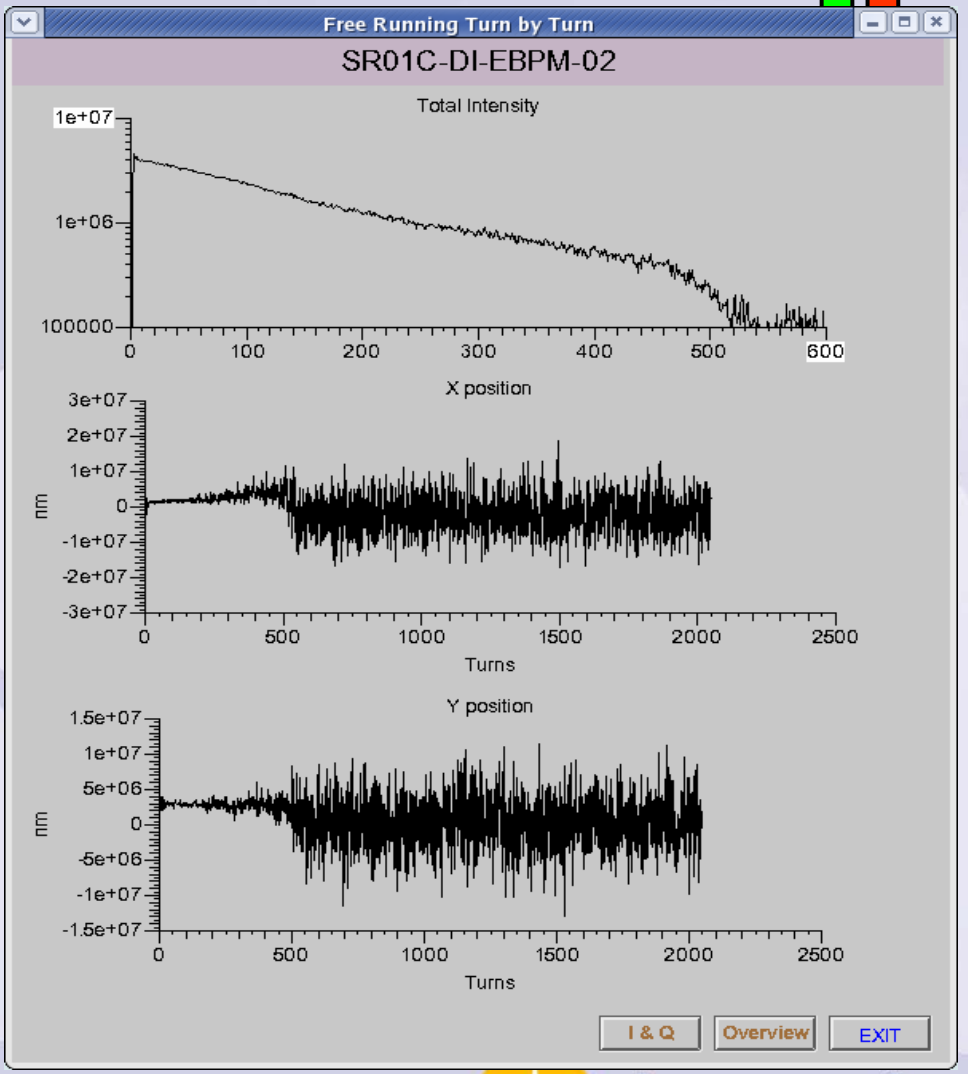
Commissioning: Diamond Control Room

- Installed network and Diamond control room available March 2006
- Ten dual screen Linux consoles, connected to Primary and Secondary networks
  - Secondary network gives site access to non Operational critical services ie Scopes etc
- Only hardwired signals are PSS Permits

Commissioning: SR @ 700 MeV



- 1St beam,1 Turn on 5th May 2006
- Limited by a Quad with incorrect polarity

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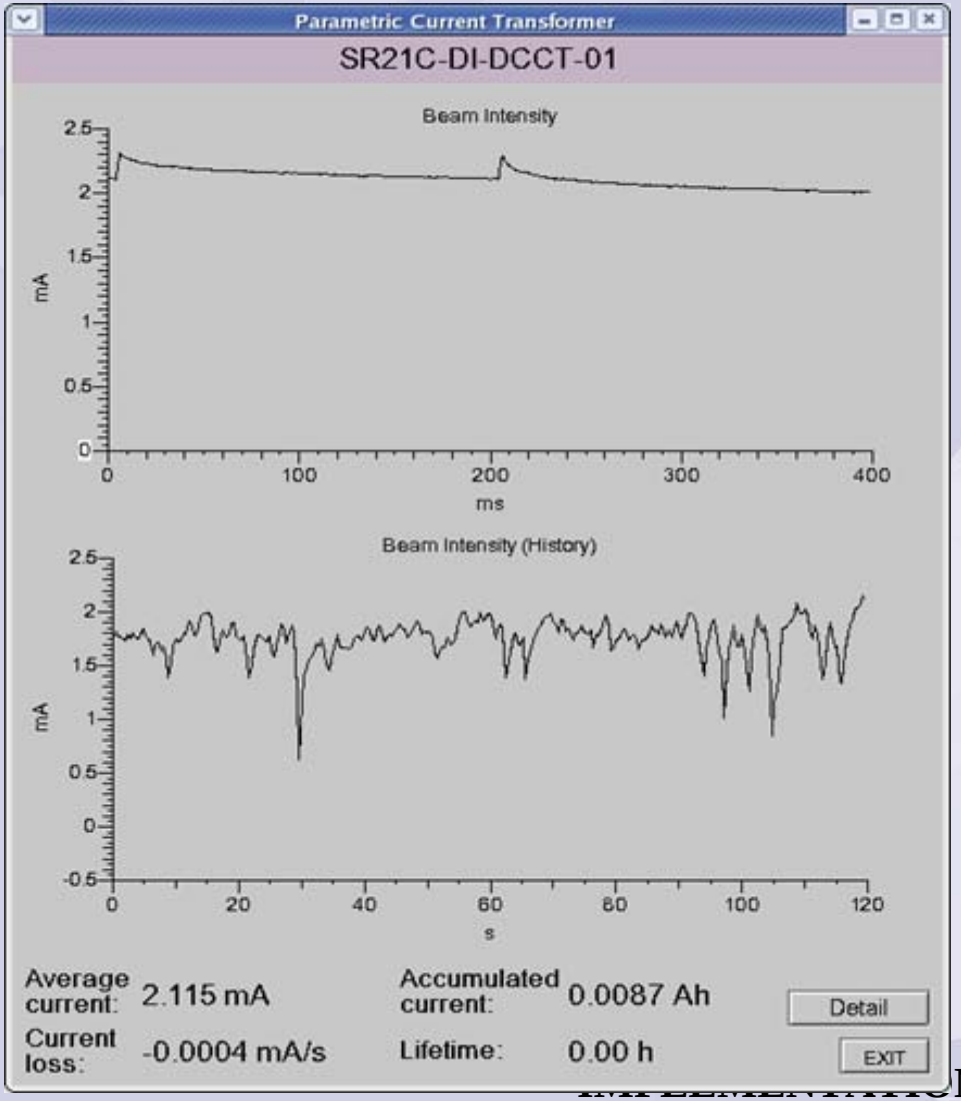
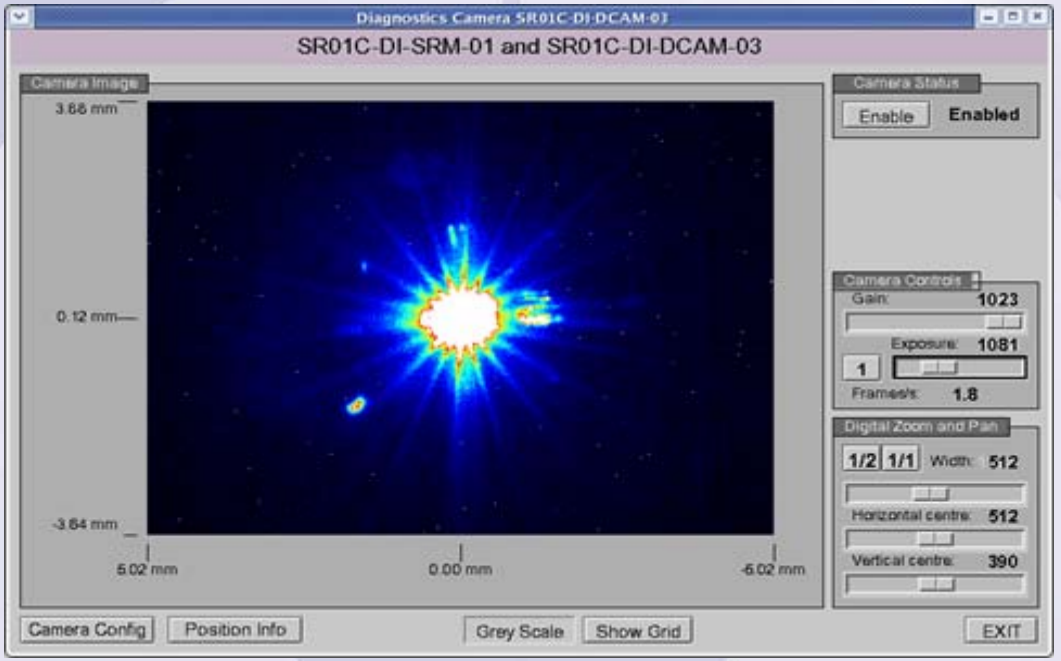
Commissioning: SR @ 700 MeV



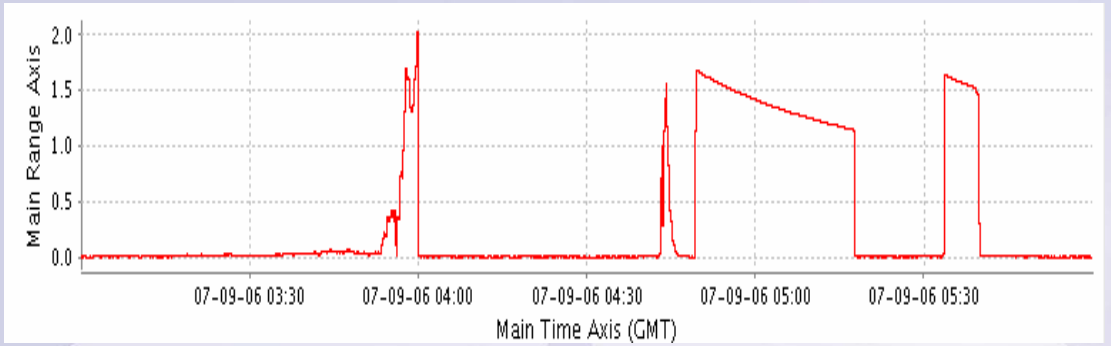
> 2 mA accumulated

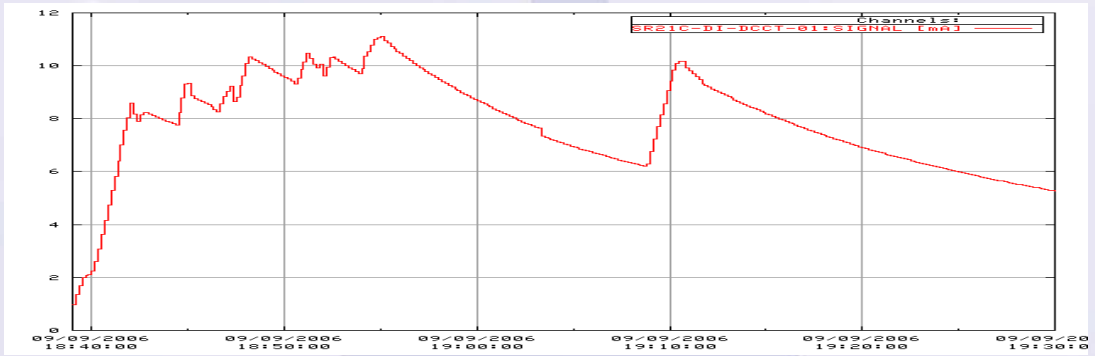


SR visible on SLM

Commissioning: SR @ 3GeV

- Sep. 4th/5th – 5 turns, no correctors !
- Sep. 5th/6th – 120 turns, no RF on
- Sep. 6th/7th – RF on .. 2 mA stored;
- 2mA limit since absorber water flow interlocks not commissioned
- Sep. 9th – 10 mA
- 10mA limited since orbit interlock not commissioned
- Sep. 25th – 25 mA
- Oct. 2nd – 60 mA
- Oct. 10th – 90 mA





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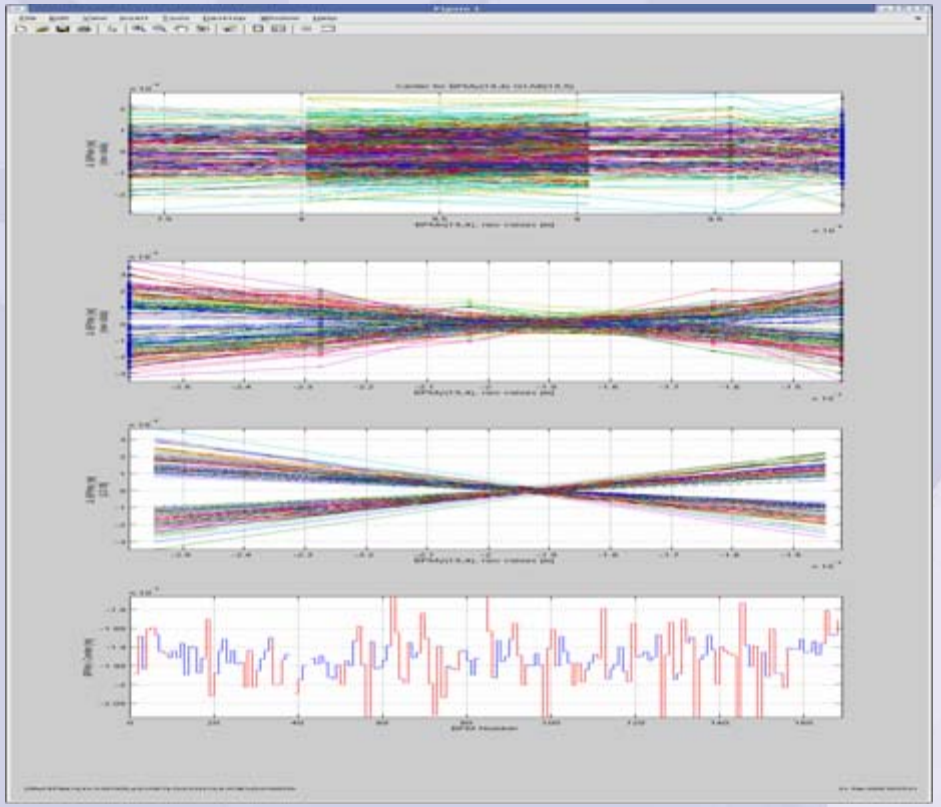
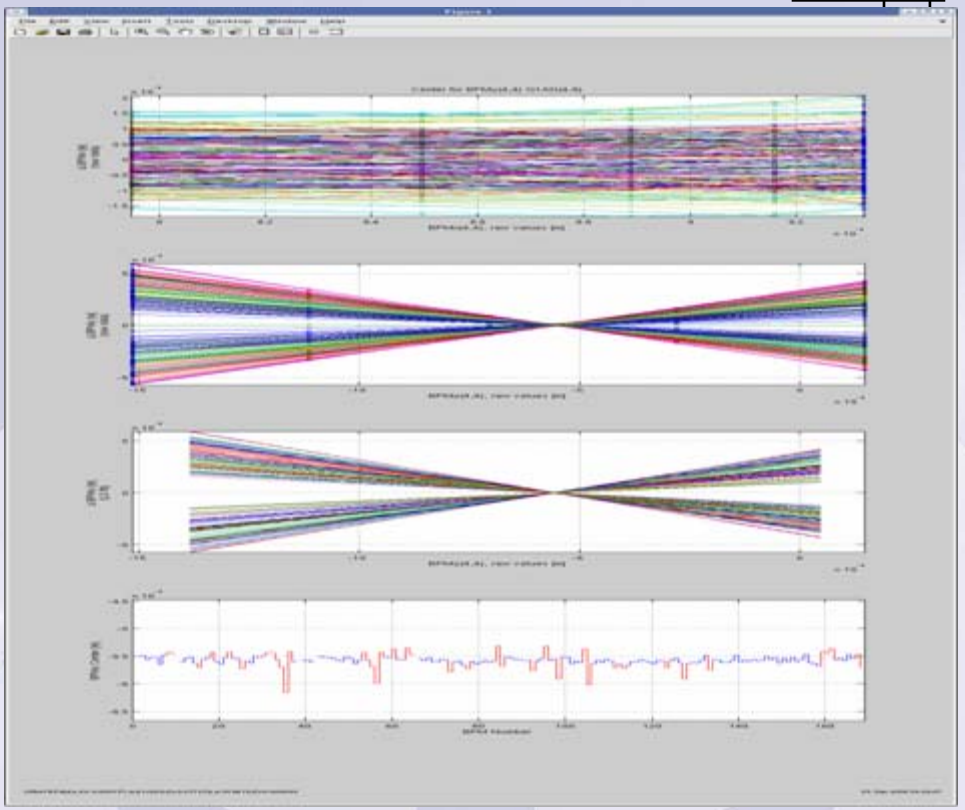
Commissioning: SR @ 3 GeV



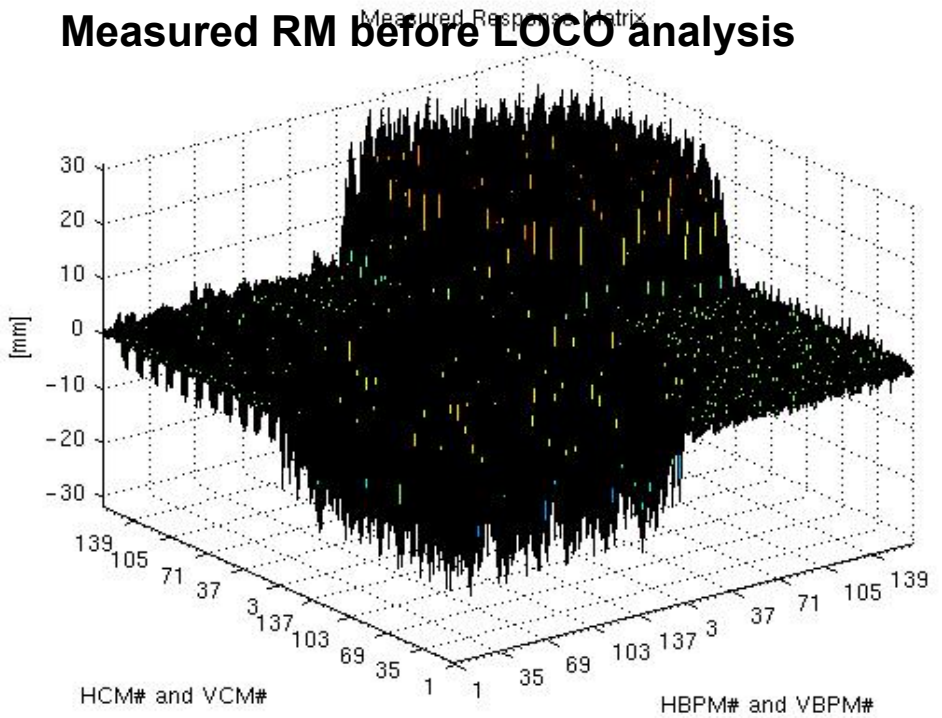


- Poor correction of closed orbit,
- Initial BBA measurement very noisy but offsets applied and subsequent measurement much cleaner
- Three BBA runs to establish BPM centres carried out, which improved orbit

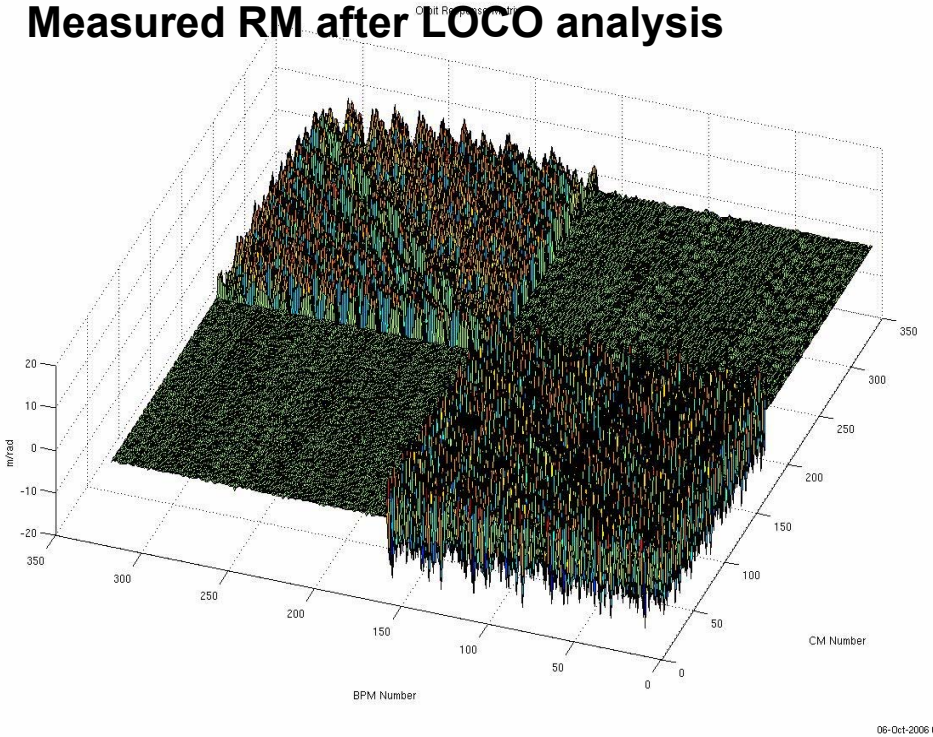
Commissioning: SR @ 3 GeV

EPICS

Measured RM before LOCO analysis



Measured RM after LOCO analysis



- LOCO Measurement and correction applied to optics
- Initial Beta Beat 40%, was reduced in iterations to about 2%
- Measured RM much cleaner

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IMPLEMENTATION, COMMISSIONING AND CURRENT STATUS OF THE DIAMOND LIGHT SOURCE CONTROL SYSTEM

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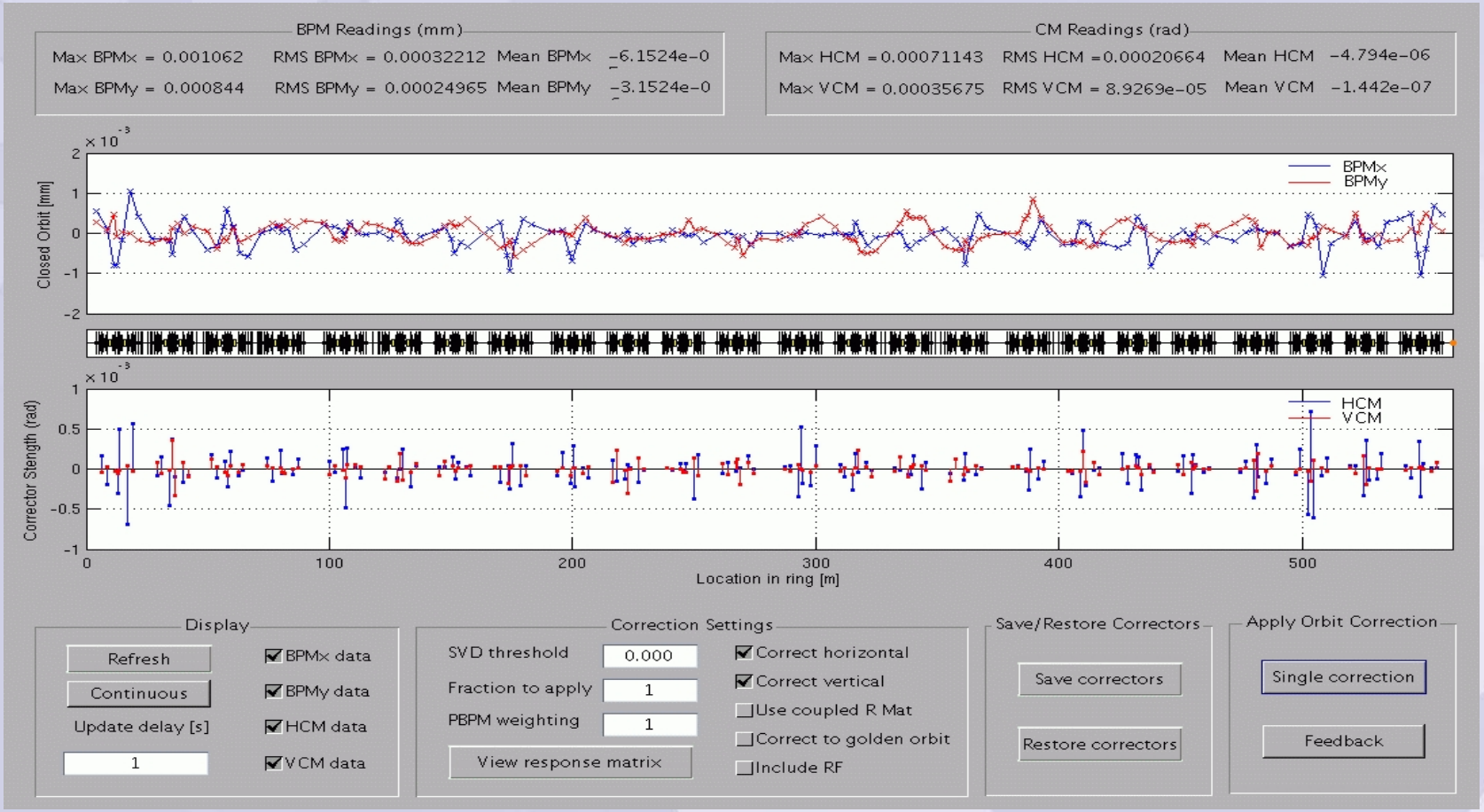
Commissioning: SR @ 3 GeV



- SR orbit corrected to < 1um
- Slow orbit FB run in AT application

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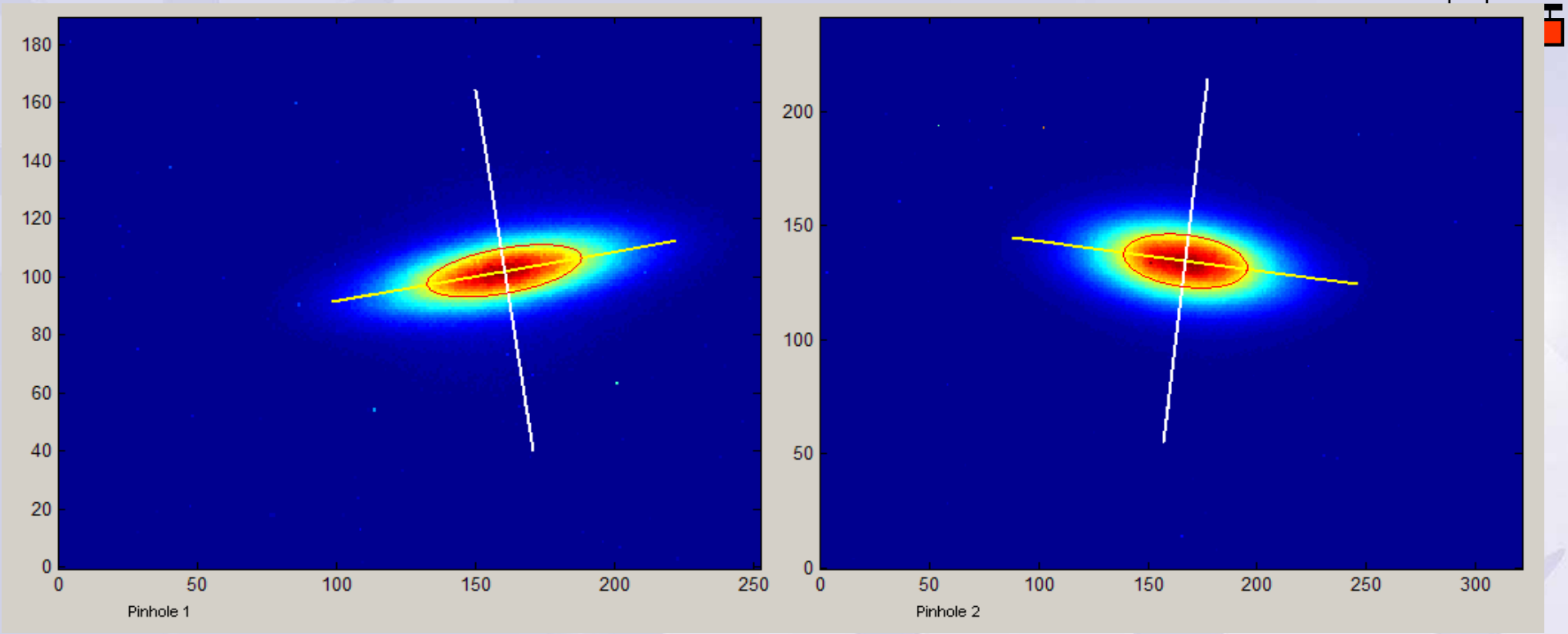
Commissioning: SR @ 3 GeV



Pinhole camera #1	nominal:	Pinhole camera #2	nominal:
sigma-x = 56 μm	52 μm	sigma-x = 47 μm	45 μm
sigma-y = 14.5 μm	25 μm	sigma-y = 19 μm	25 μm

Best fit: emittance 3.2 nm, energy spread 0.014%, coupling 0.4%

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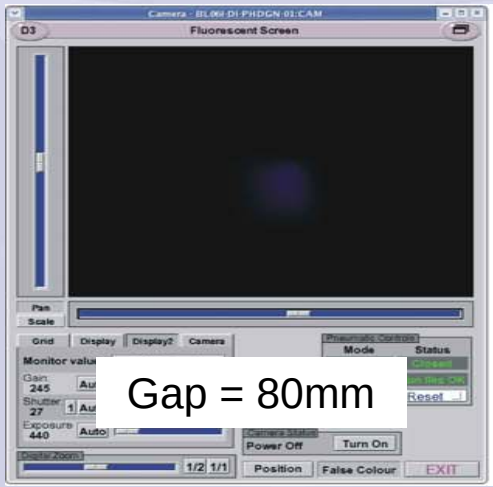
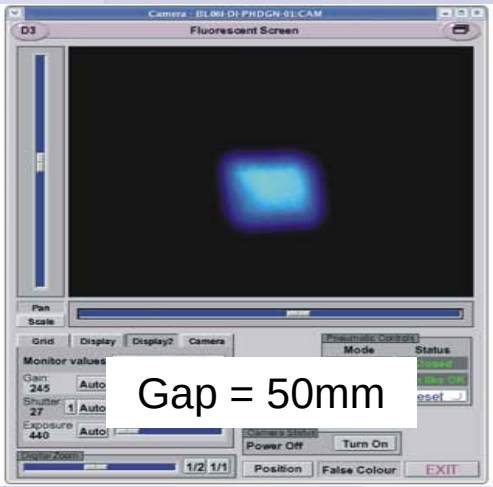
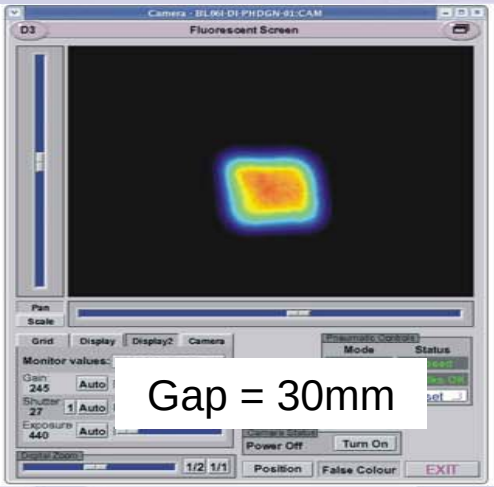
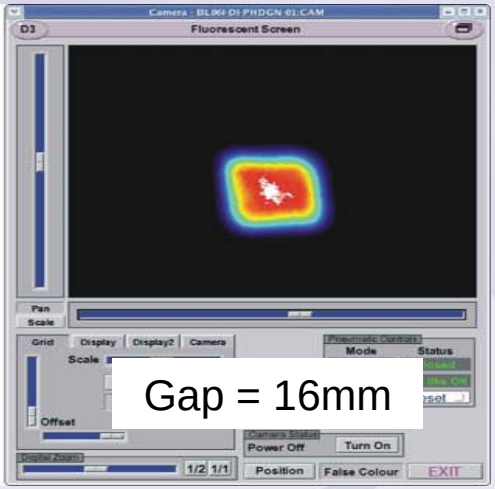
Commissioning: First X-Rays on Beamline I06









BL Fluorescent screen intensity changing as the HU64 ID gap is closed.
The white beam slits (which are square) are set to ~3mm x 3mm.

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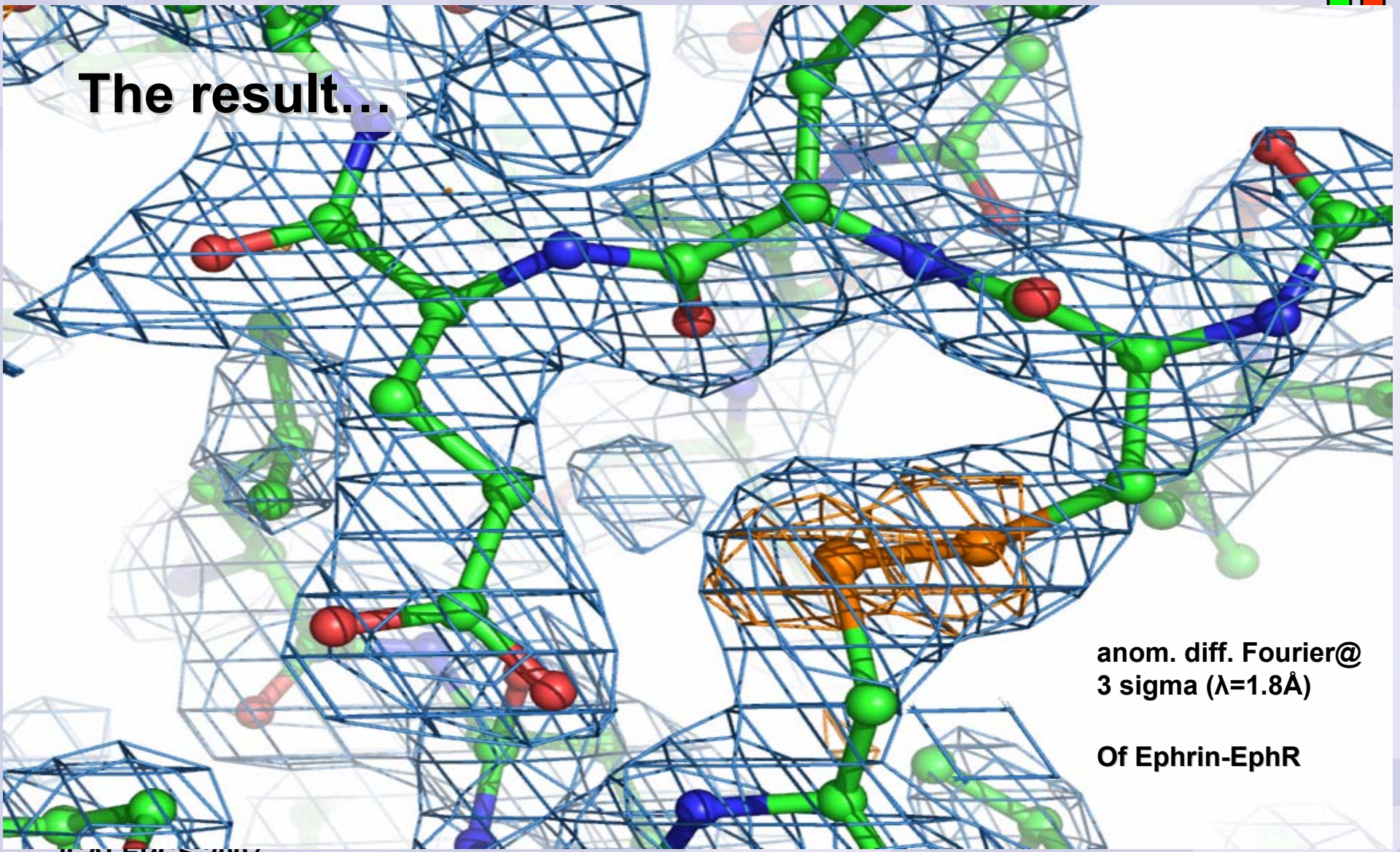
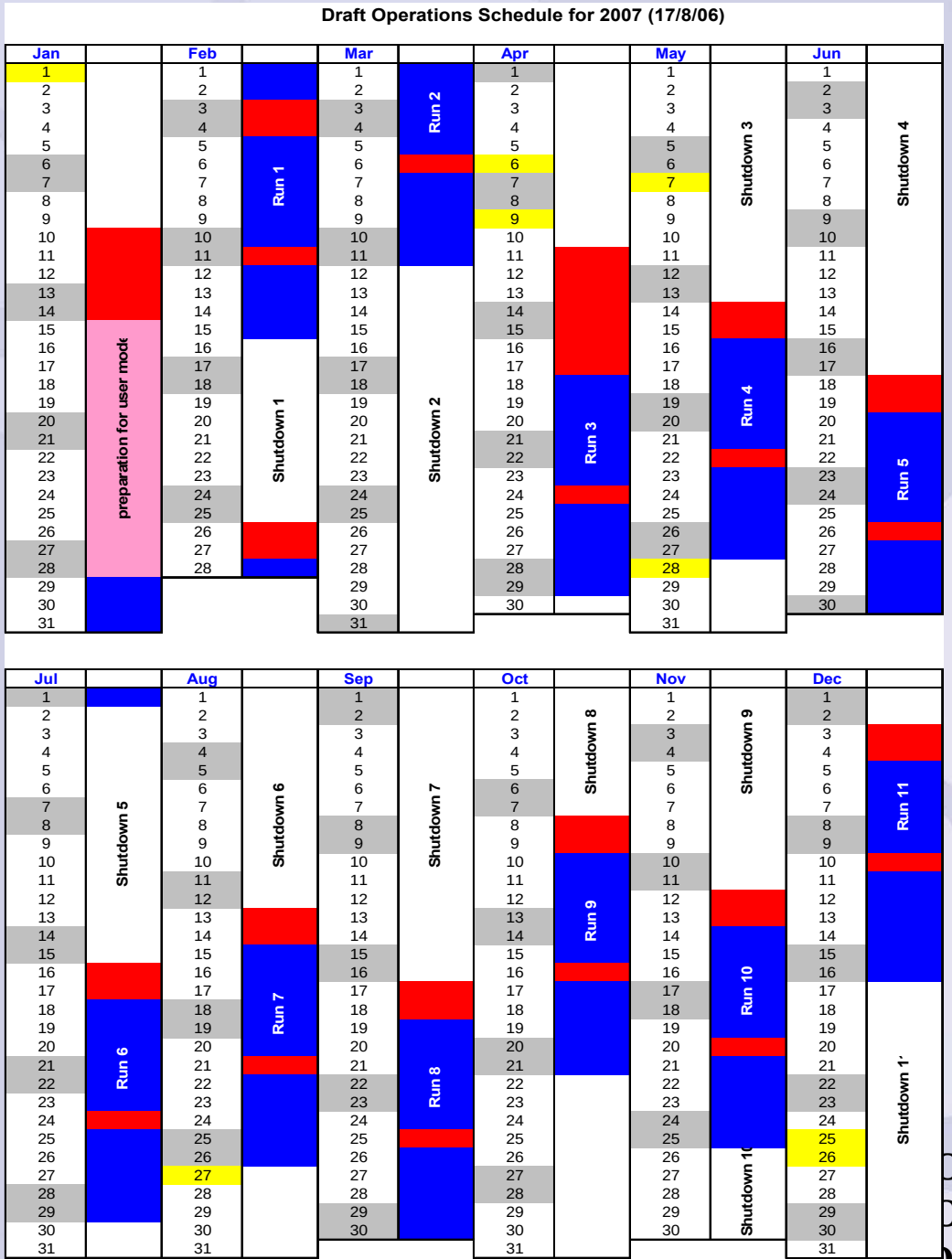
Commissioning: First data from Macro-Molecular Beamline





Status: Operational Schedule 2007/2008

EPICS

- 11 Runs of ~ 2 weeks
- 3000Hrs of Beamline Mode
- Shutdowns 1½ - 4 weeks, for maintenance and installation:
  - 2nd RF cavity
  - ID6 module 2, ID11, ID24
  - FEs 11, 16, 19, 23, 24

Machine Physics

User beam

Shutdown

diamond

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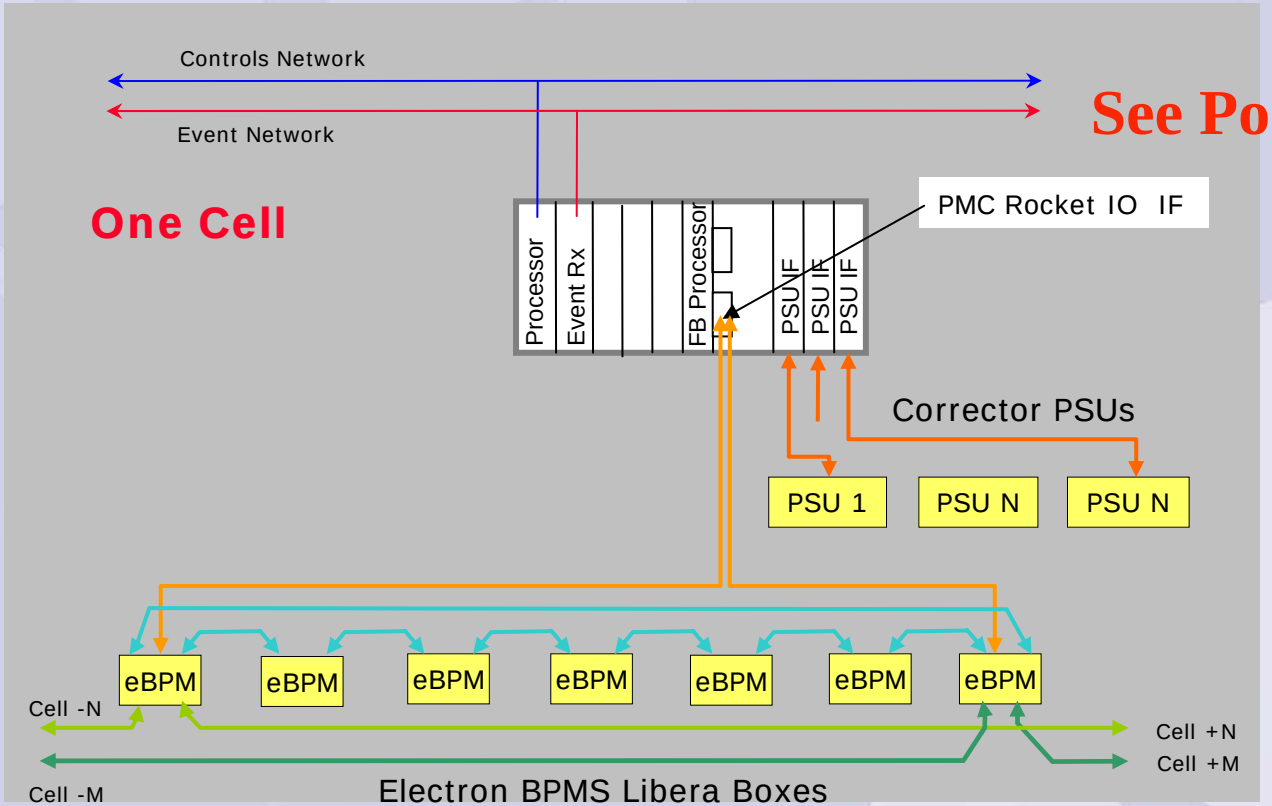
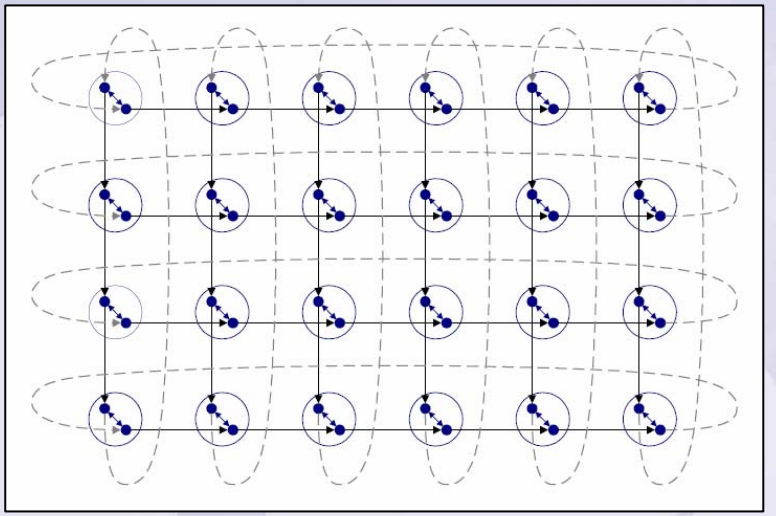
Developments: Fast Beam Position Feedback



See Poster RPPA10 J Rowland



- Fast beam position feedback system is structured such that all eBPM data is moved to 24 computation nodes, one per cell, to carry out FB calculations for a subset of steerers
- Data transport is realised by interconnecting Libera and compute nodes as a 2D torus
  - Gives resilience to multiple failures of BPM boxes, fibres and Bit errors
- Apply correction using IMC in corrector space

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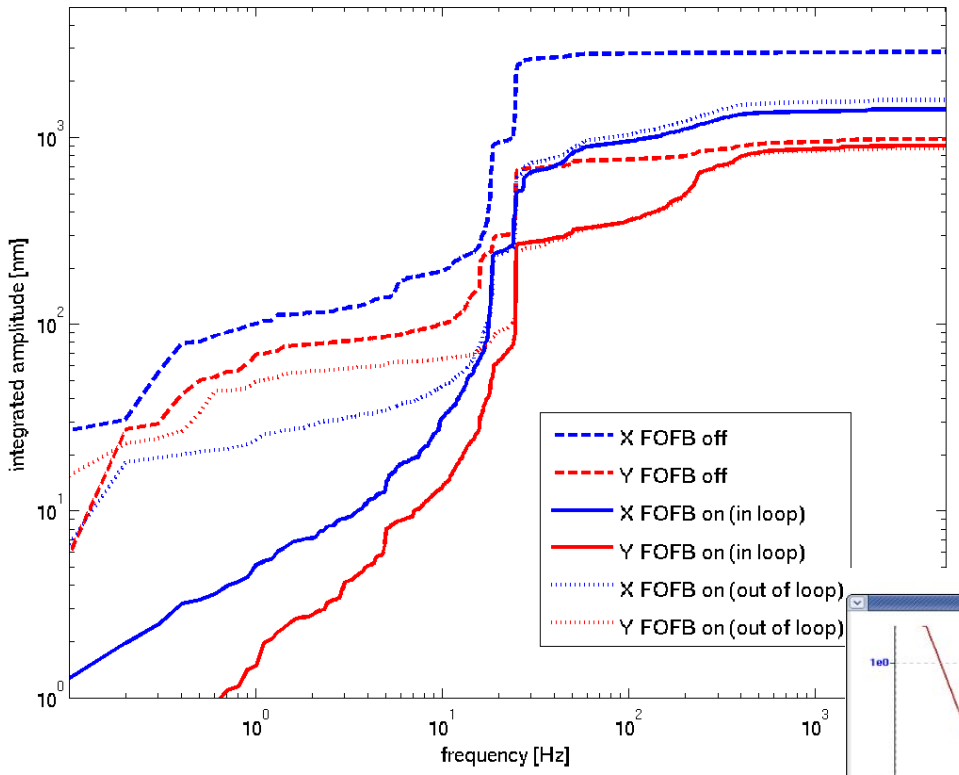
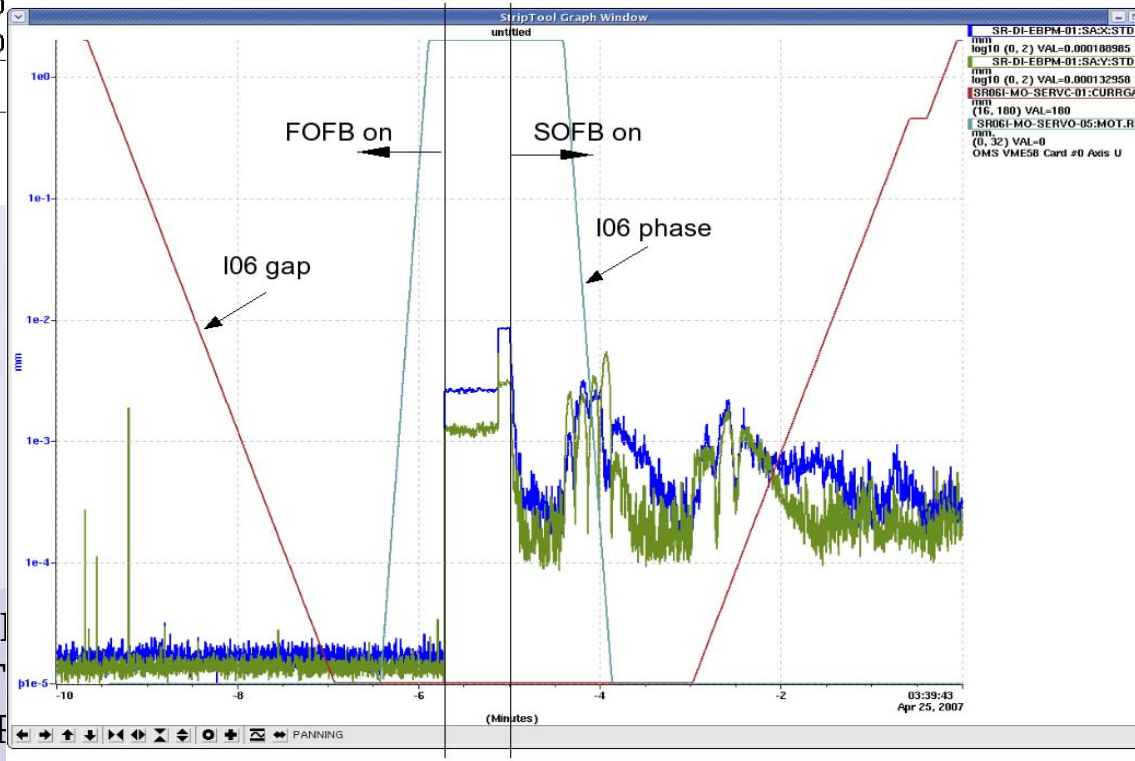
Developments: FOFB Results



Integrated orbit amplitude with FOFB On and Off



Orbit Stability with FOFB and SOFB On to I06 Gap change and Phase change

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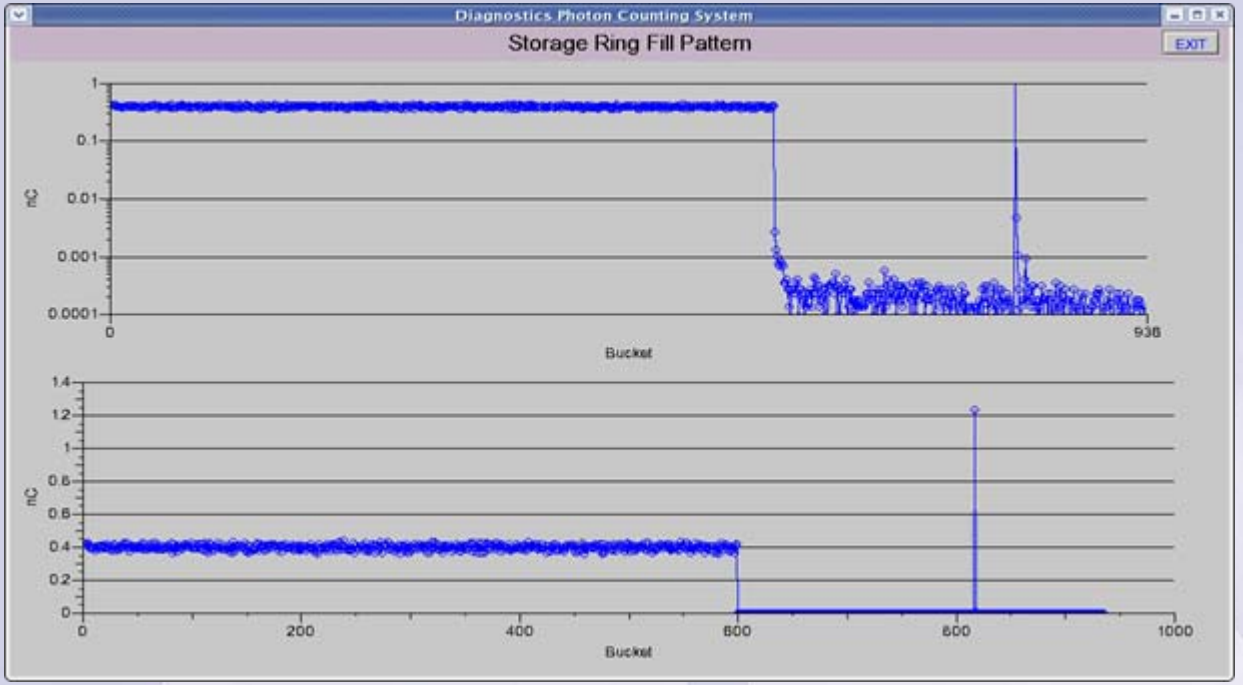
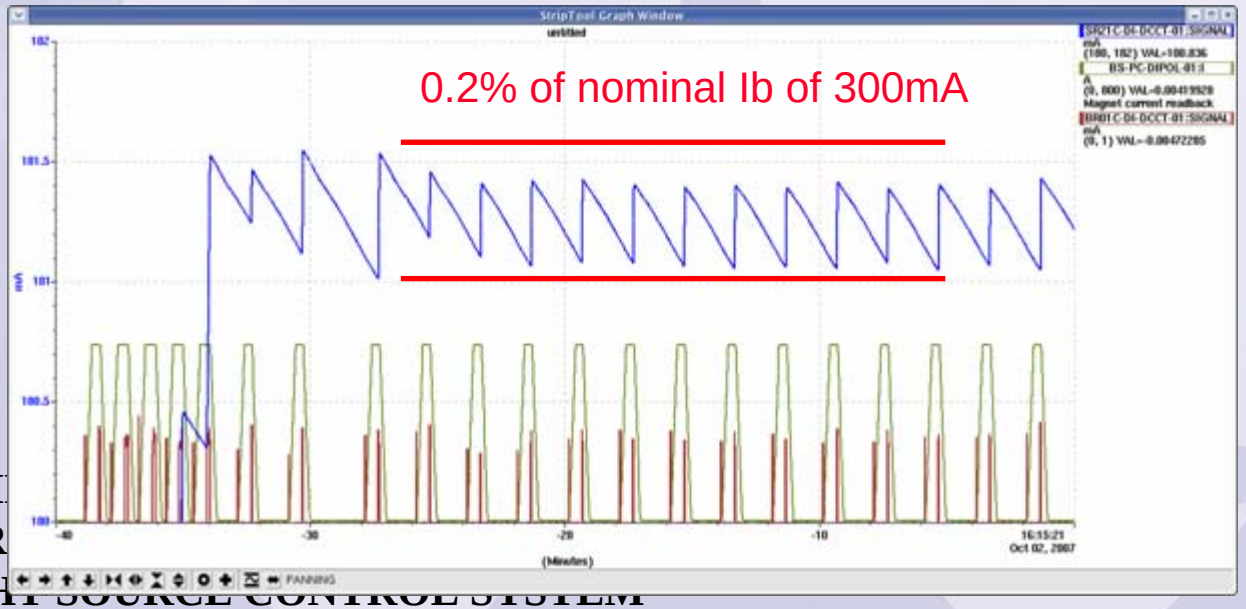
Developments: Top-up Operation

- Arbitrary fill patterns and maintain them with periodic
- Move to Top-up operation
  - Injection every 2mins with photon shutters open
  - PSS functionality approved
  - Control application implemented
  - Work on failure mode analysis and safety case continues





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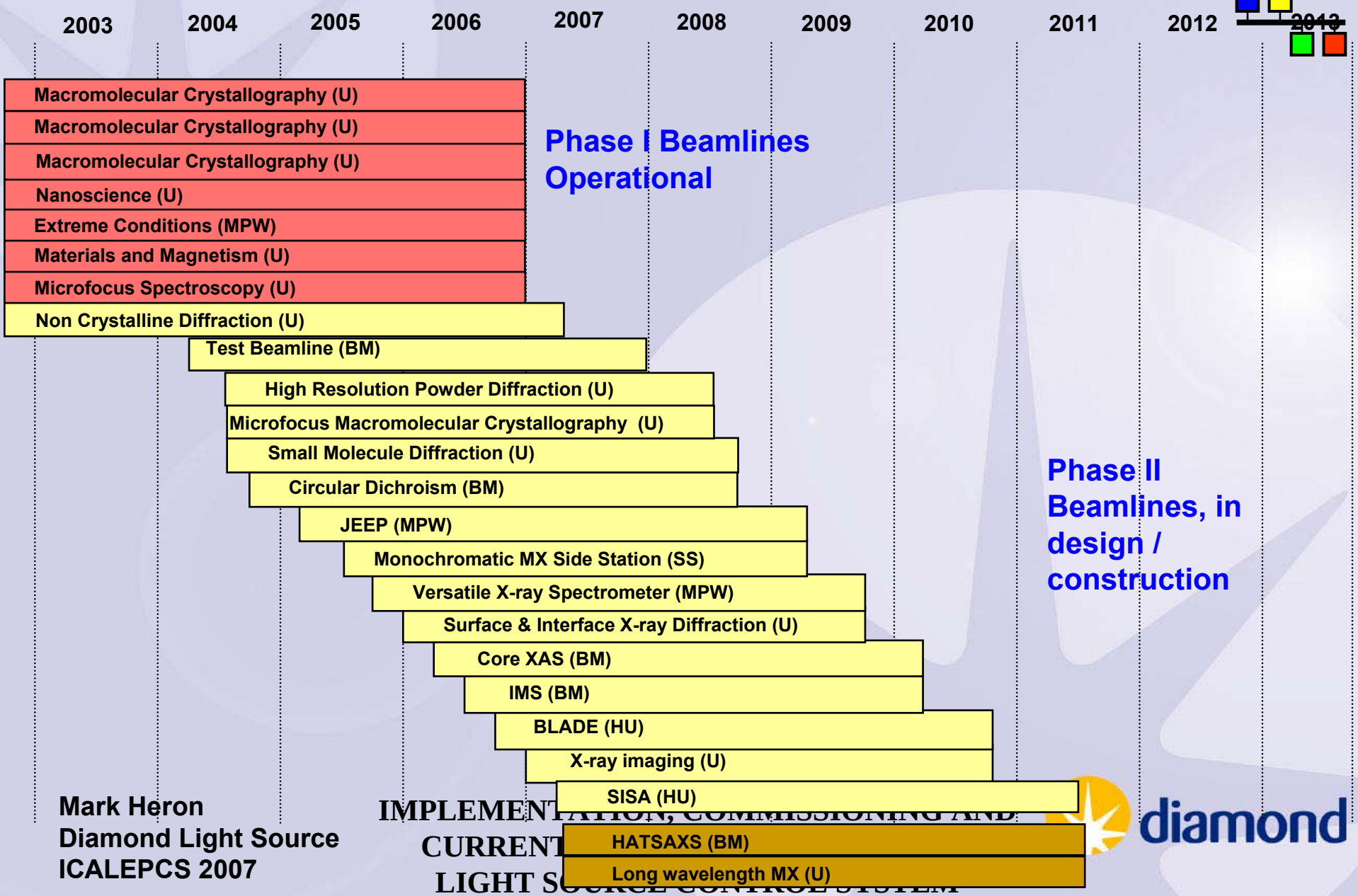
Developments: Phase 2 Beamlines 2008-2011



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IMPLEMENTATION, COMMISSIONING AND CURRENT LIGHT SOURCE CONTROL SYSTEM

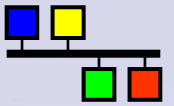
diamond

Conclusion

- The control system for Diamond met its requirement
  - Notably functionality, availability and stability
- Real benefits from technical and geographical division of the control system
  - Little disruption of an already commissioned system by other systems being commissioned
  - Larger number of smaller systems makes commissioning easier and more effective
  - The ability to commission systems off-site and integrate with virtually zero overhead was particularly valuable for turn systems.
- Use of modular design, reuse of code and implementation by configuration made for a robust system design
  - Vertical tests and simulation early in the design process gave high levels of confidence in the final application software

Acknowledgement

- This is the work of many people. Including Diamond Control Systems Group, Pete Owens at Daresbury Lab, Steve Hunt, and others.
- It builds on the work of many others, particularly in their contribution to EPICS



Thank You For Your Attention.

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IMPLEMENTATION, COMMISSIONING AND CURRENT STATUS OF THE DIAMOND LIGHT SOURCE CONTROL SYSTEM