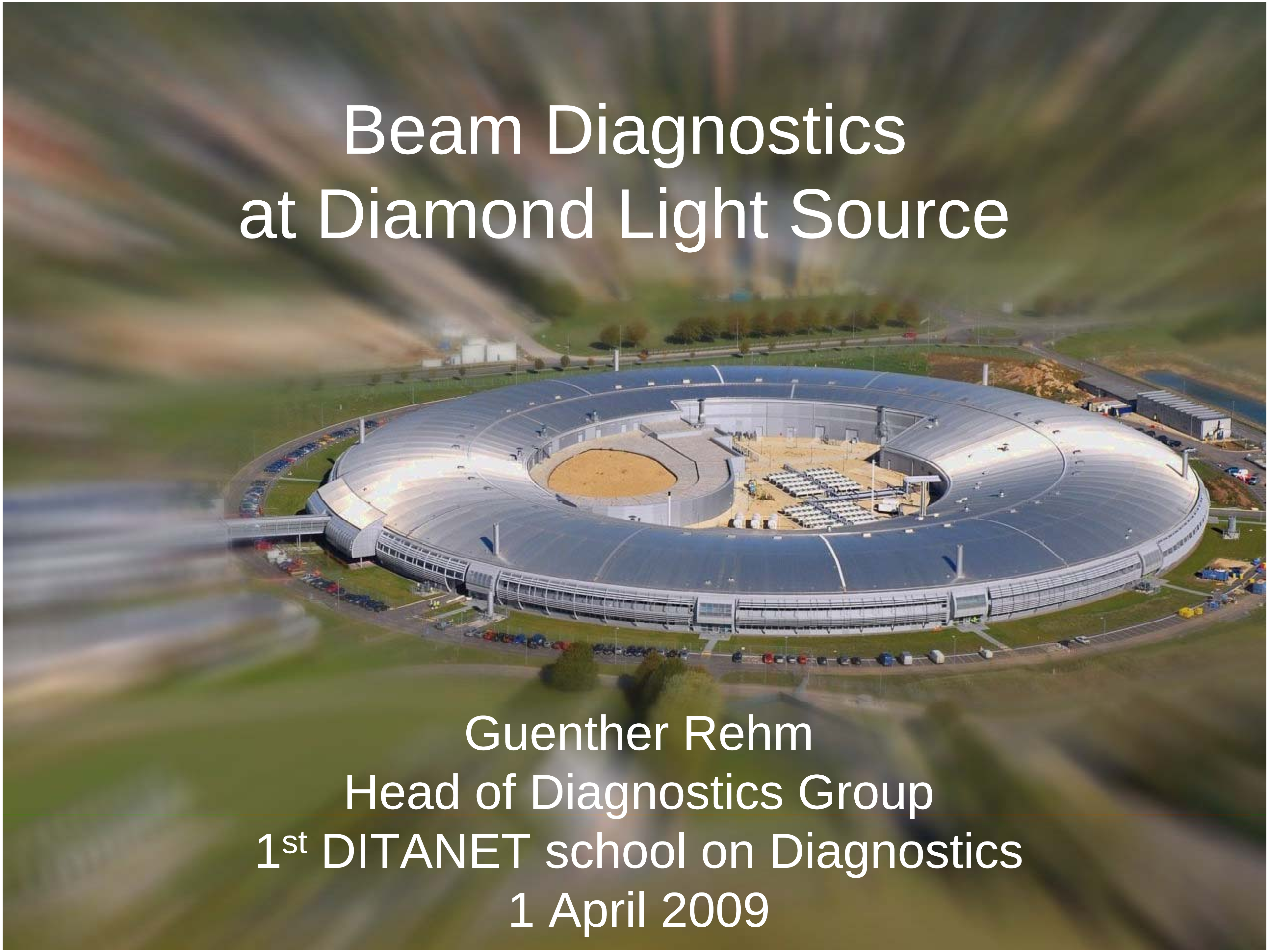


Beam Diagnostics at Diamond Light Source

Guenther Rehm
Head of Diagnostics Group

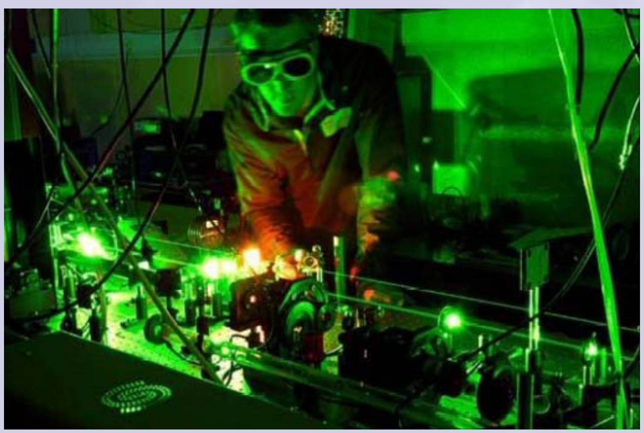
1st DITANET school on Diagnostics

1 April 2009

Outline

- What is a Light Source?
- Diagnostics Requirements for a Light Source
- Diagnostics in the Injector
- Diagnostics in the Storage Ring

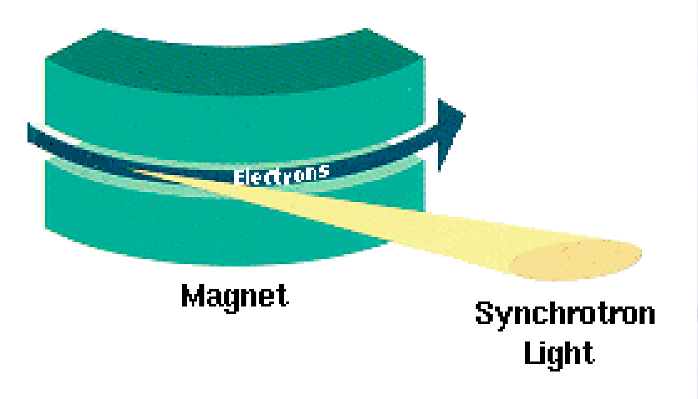
A Light Source?



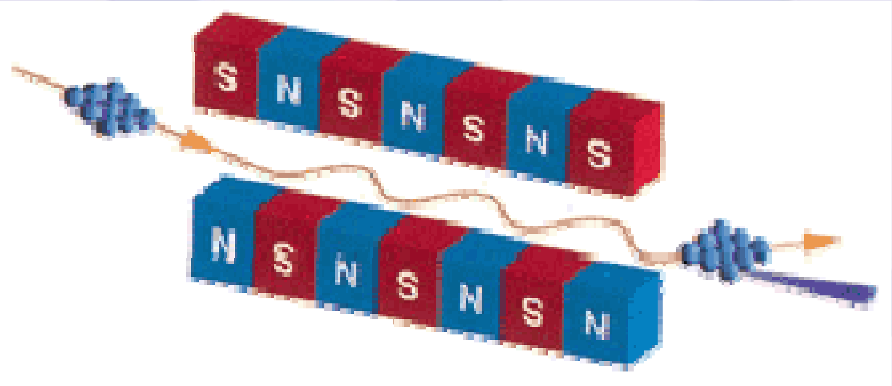
How Is Synchrotron Light Produced?

Synchrotron Light (or Radiation) is electromagnetic radiation emitted when a high energy beam of charged particles (electrons) is deflected by a magnetic field

a single bending magnet produces a wide fan of radiation



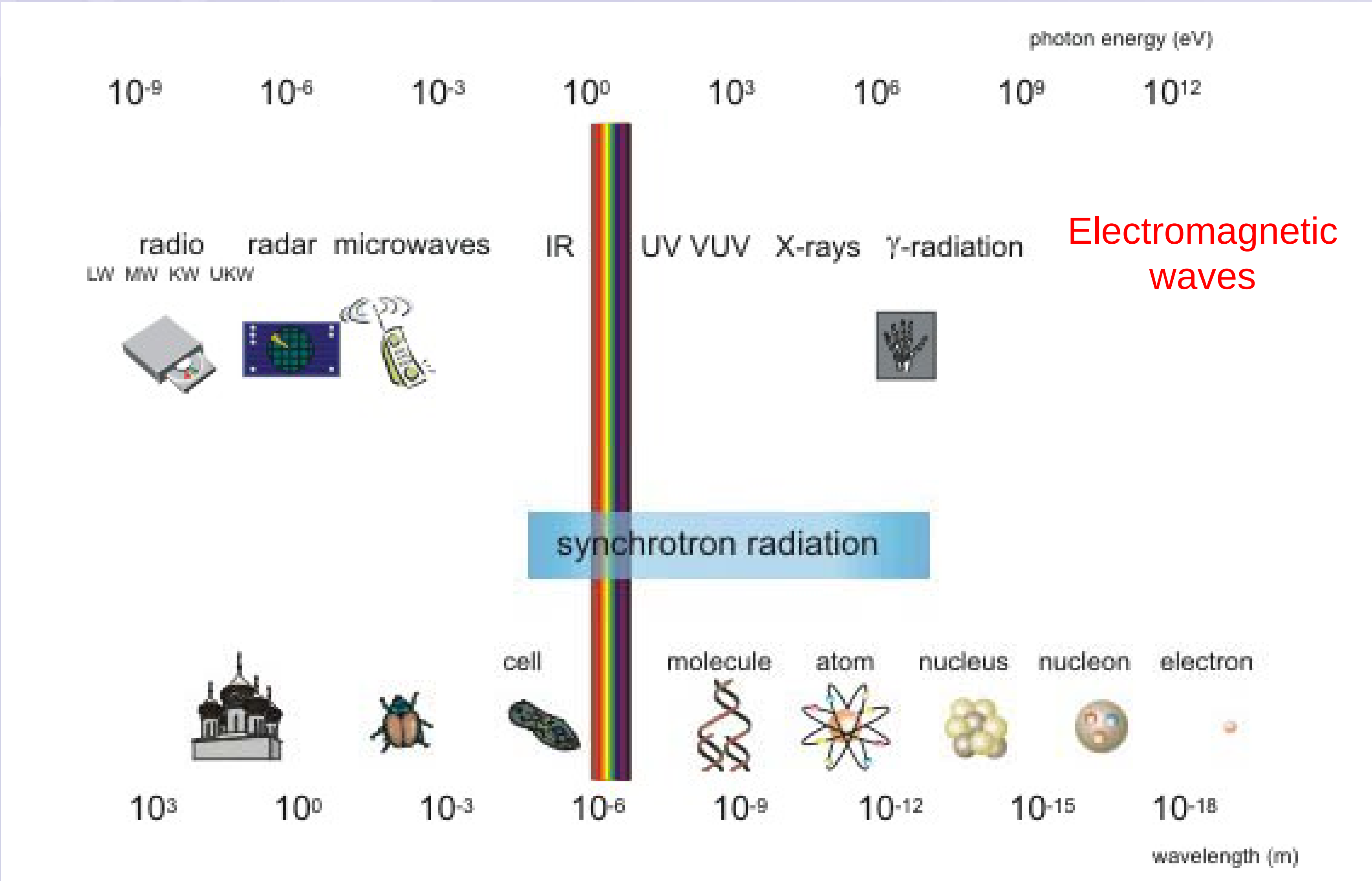
multiple bends in an "undulator" or "wiggler" magnet give higher intensity and more directed radiation



A Brief History of Synchrotron Light Sources :

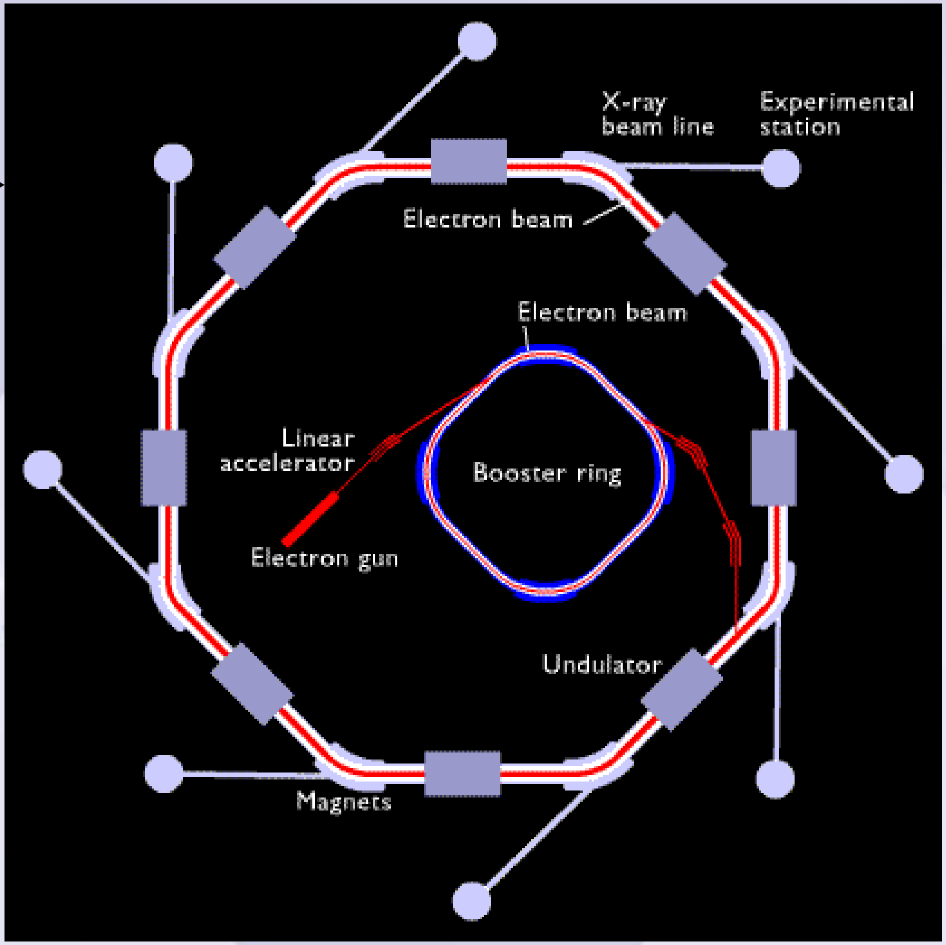
- **Discovery: 1947, General Electric 70 MeV synchrotron**
- **First use for experiments: 1956, Cornell 300 MeV synchrotron**
- **1st generation:**
  machines built for other purposes, mainly High Energy Physics
- **2nd generation:**
  purpose-built storage rings for production of synchrotron light
- **3rd generation:**
  higher brightness synchrotron light sources, using mainly 'insertion devices' (undulators and wigglers) as the X-ray sources
- **4th generation:**
  LINAC followed by 'Free Electron Laser', i.e. a series of undulators producing coherent synchrotron light of even higher peak brightness and shorter duration

SR and the Electromagnetic Spectrum

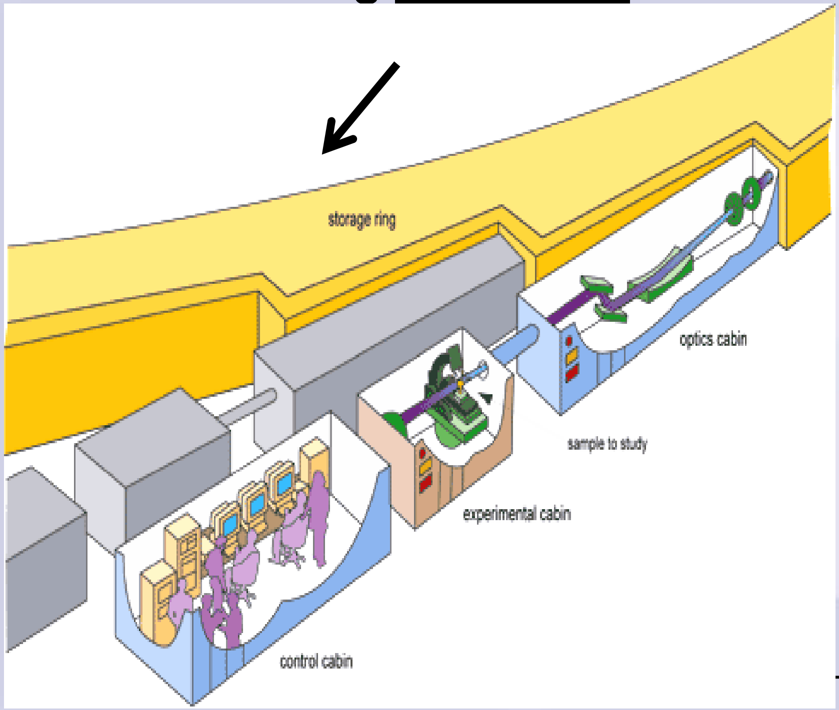


Layout of a 3G Light Source

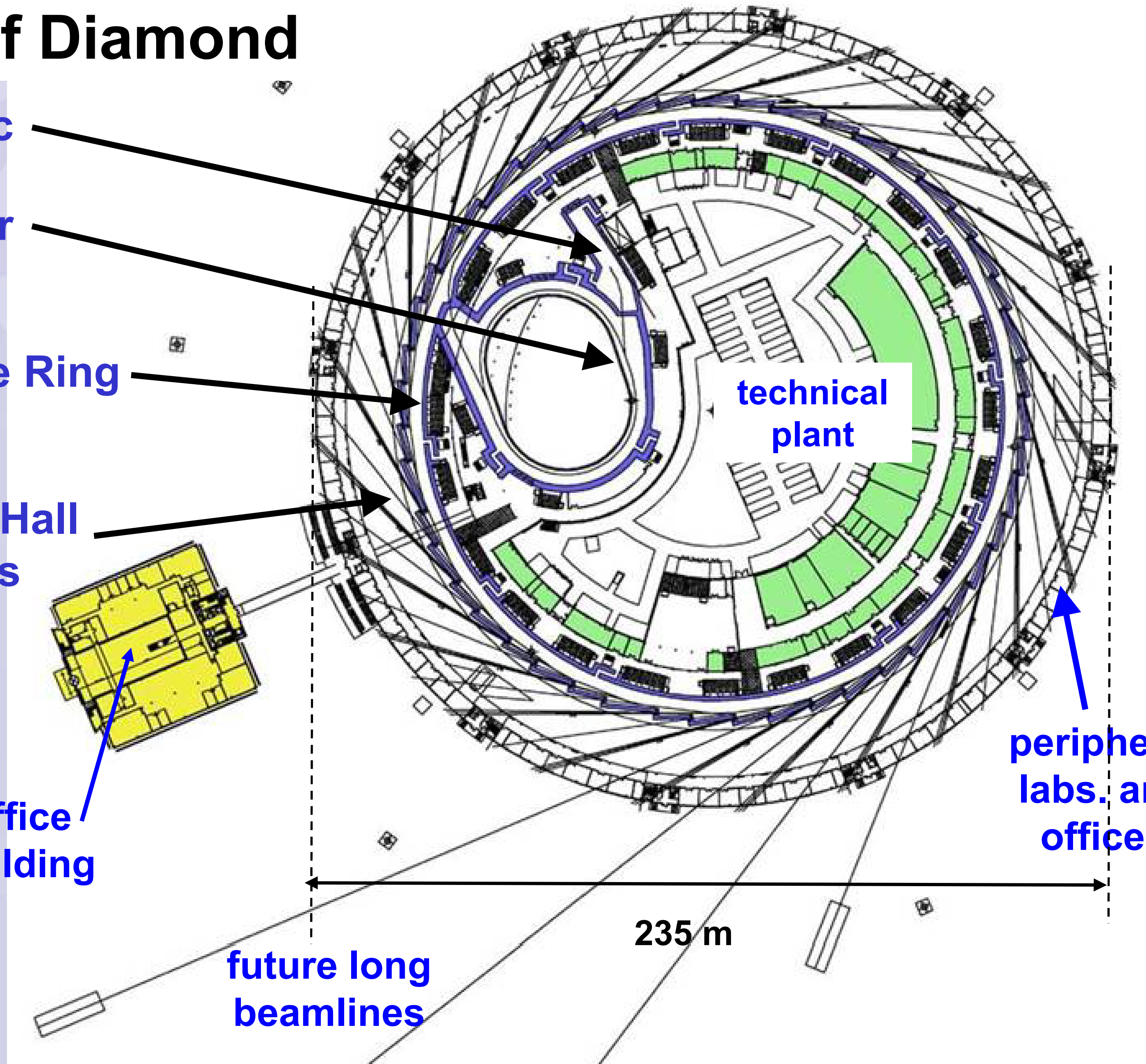
A beam of electrons is accelerated in a <u>LINAC</u>, further accelerated in a <u>booster synchrotron</u>, then accumulated in a <u>storage ring</u>.



The circulating electrons emit intense beams of synchrotron light that are sent along <u>beamlines</u> to the



Layout of Diamond



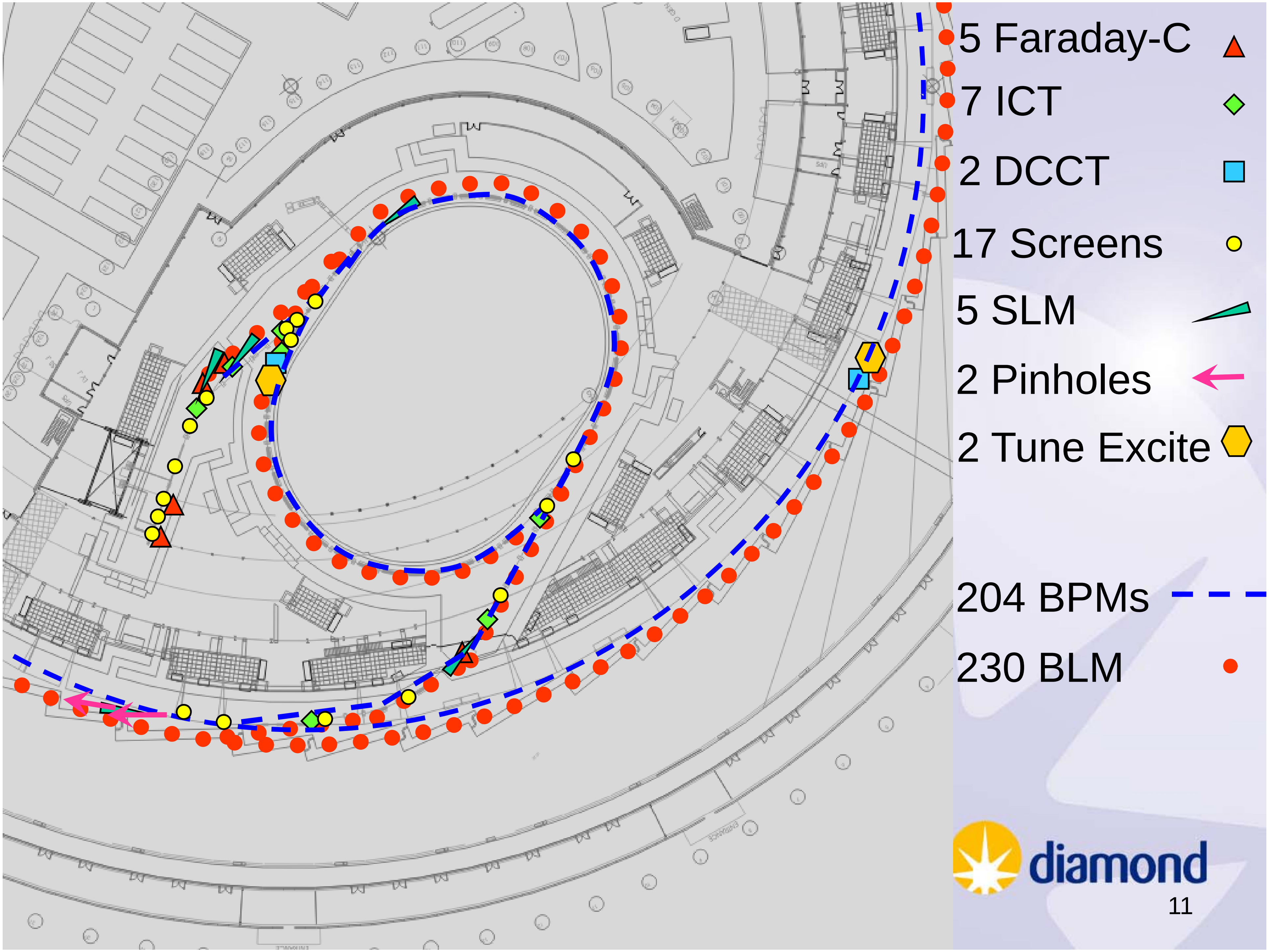
Key Parameters of Diamond

Electron Beam Energy	**3 GeV**
Storage ring circumference	**561.6 m**
Available space for Insertion Devices	**4x8m, 18x5m**
Beam current	**300 mA**
Emittance (hor., vert.) (nm rad)	**2.7, 0.03**
Minimum ID gap	**5 mm**
Electron beam sizes (hor., vert) (μm)	**123, 6**
Electron beam divergences (hor., vert)	**24, 4 μrad**
Peak brightness*	**$2*10^{20}$**
Peak brightness* (1Å)	**10^{19}**

* photons/s/mrad²/mm²/0.1%bw

Diagnostics Requirements

- Track charge trough Injector
  - Integrating Current Transformers, Faraday Cups and Wall Current Monitors
  - Stripline BPMs in transfer paths, buttons in booster
  - Screens / Cameras / Synchrotron Light Monitors
- Keep stored beam stable
  - Fast Global Orbit Feedback: Monitor beam position and correct orbit 10000 per second to sub-um
  - Transverse Bunch by Bunch Feedback: Monitor bunch motion and correct after each turn to damp coupled bunch instabilities
  - Measure betatron tunes without visibly disturbing beam
  - Monitor beam size, calculate emittance, coupling and energy spread
  - Measure stored current and bunch by bunch charge



5 Faraday-C
7 ICT
2 DCCT
17 Screens
5 SLM
2 Pinholes
2 Tune Excite
204 BPMs
230 BLM

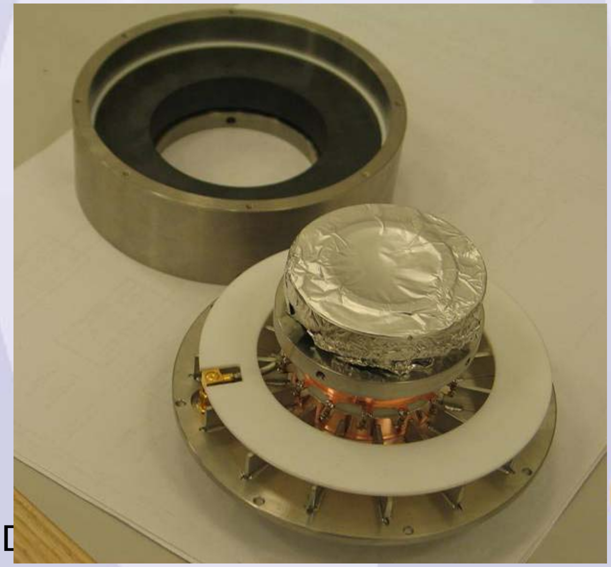
diamond

Faraday Cups, WCMs, ICTs

LTB FC

LINAC FC

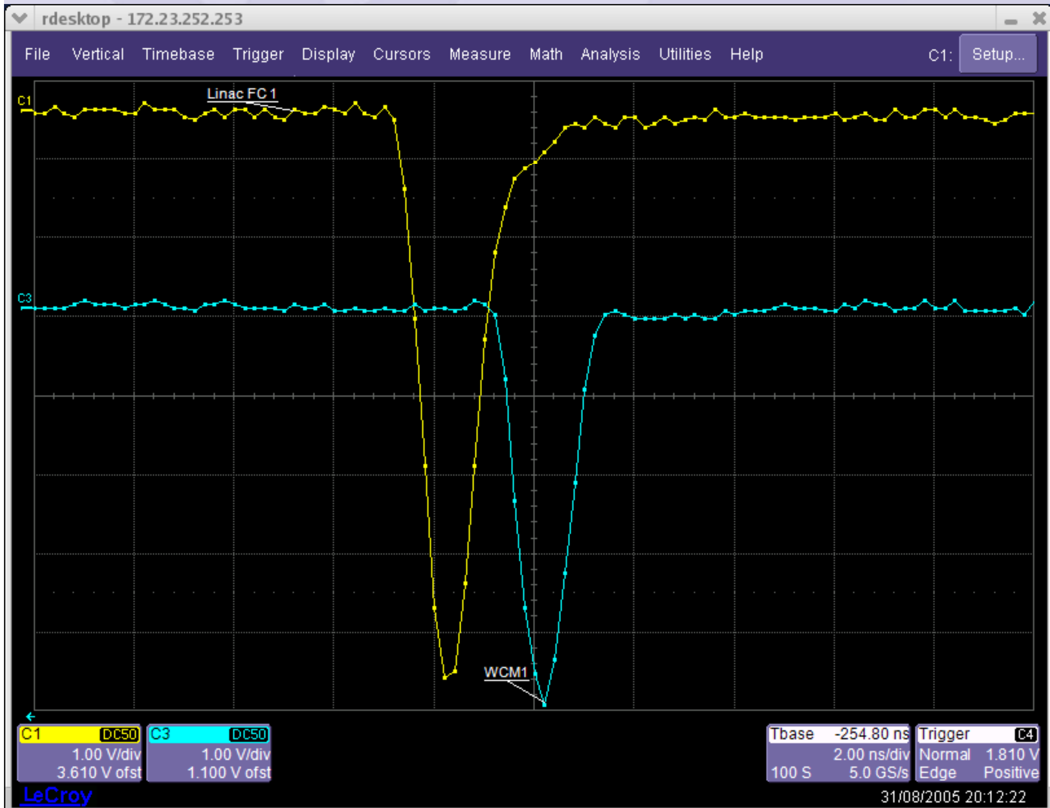
ICT and electronics

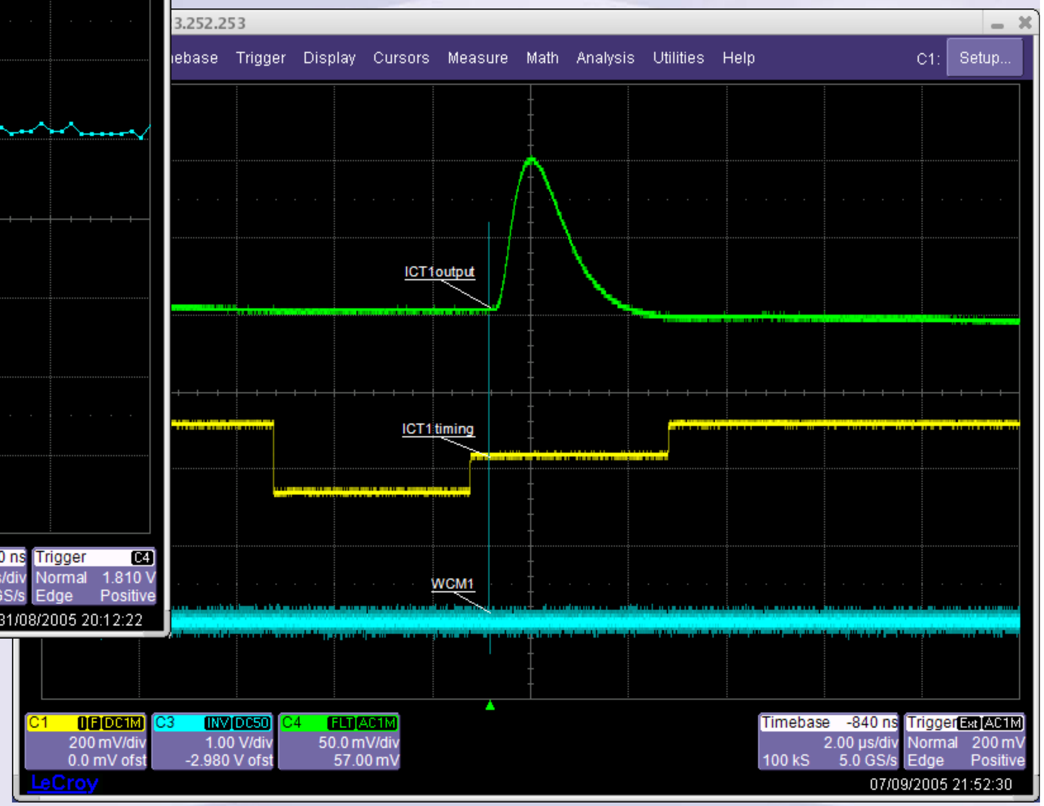


WCM for LINAC,LTB,BTS

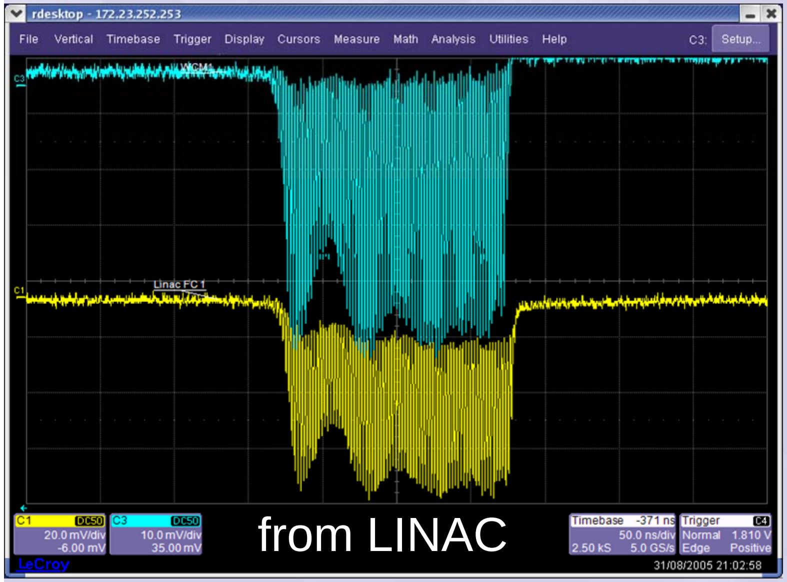
ICT shield

The first bunches on WCM and ICT

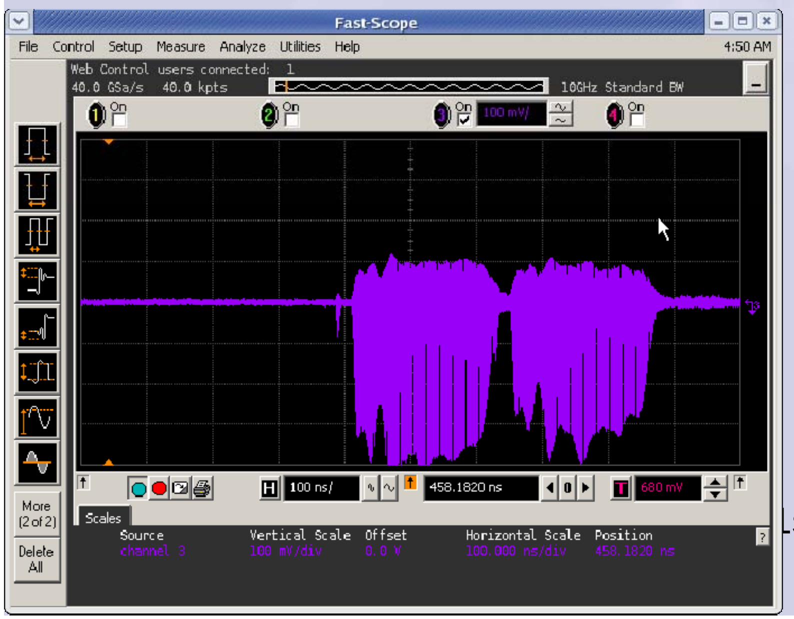




Bunch Charge and Train Structure

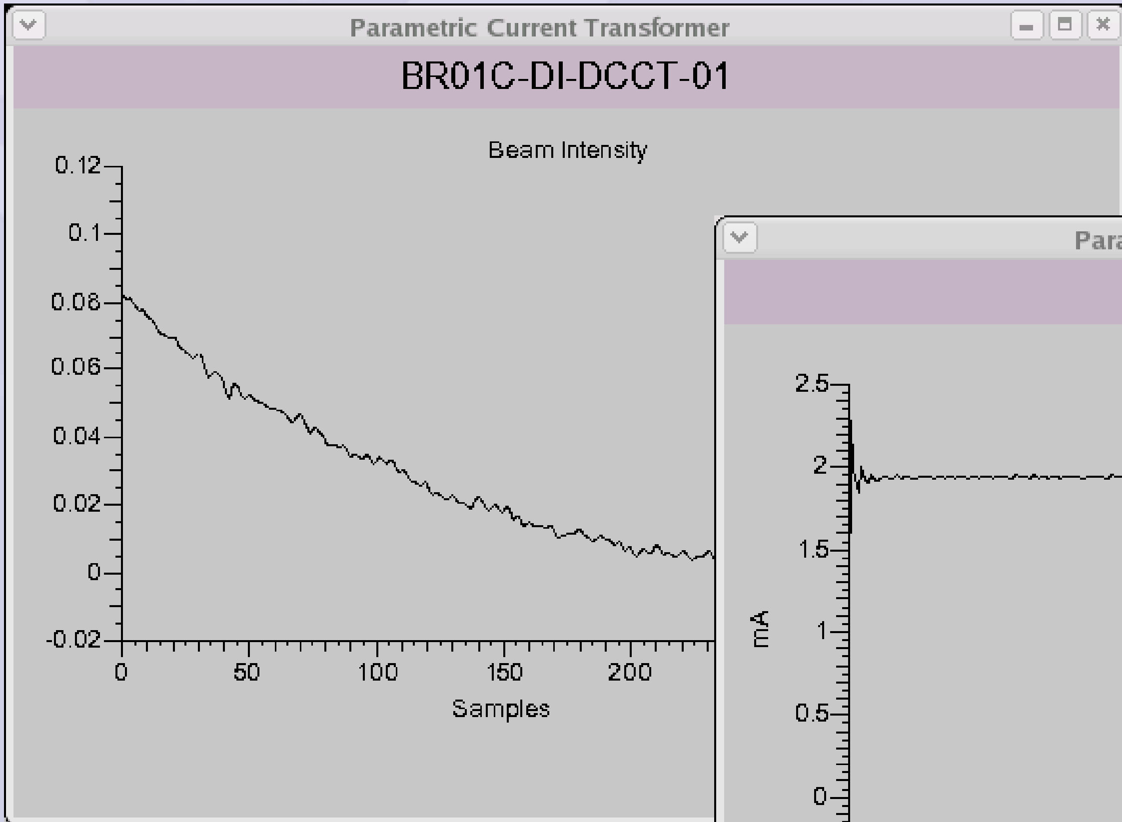


WCMs in transfer paths

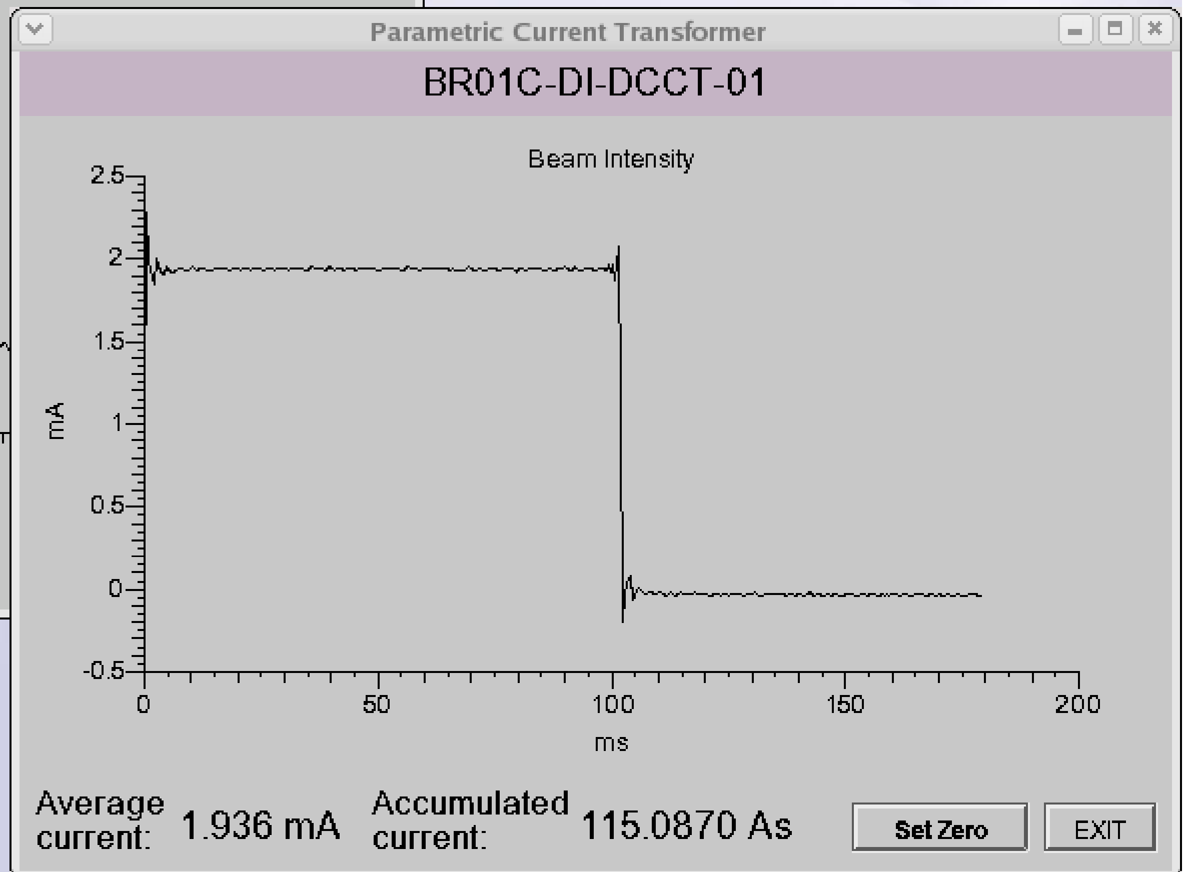


Button in SR

Booster Current on DCCT

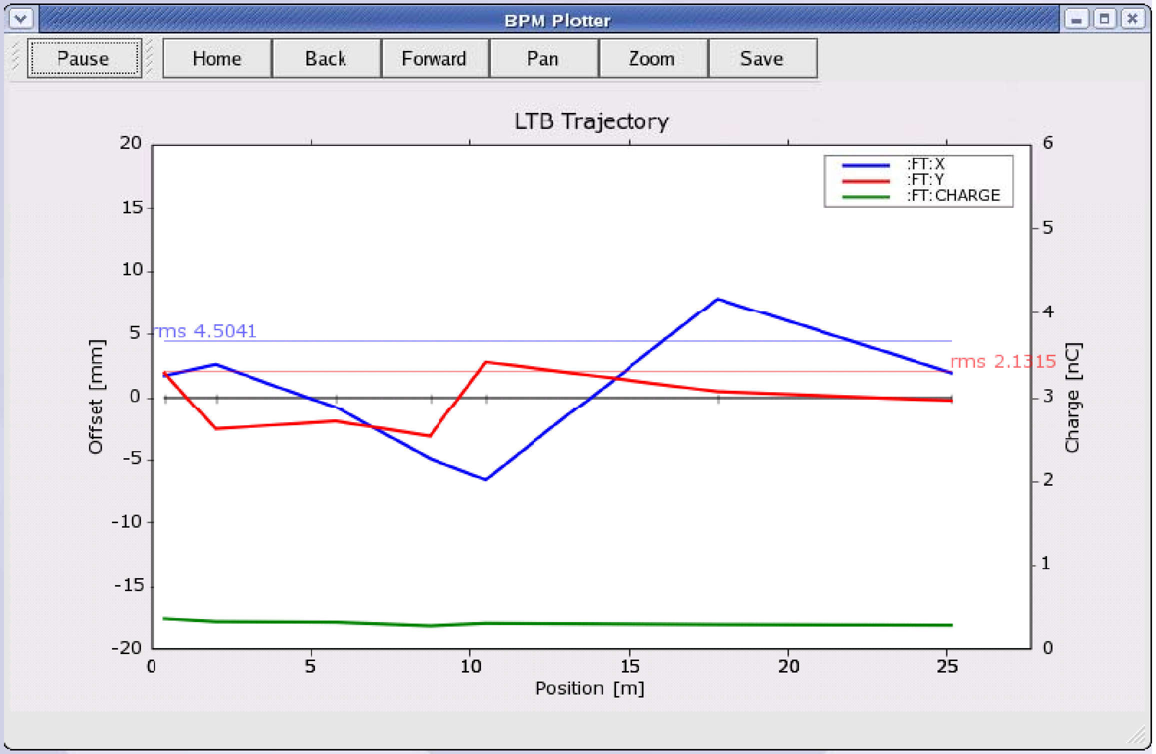


First measurement

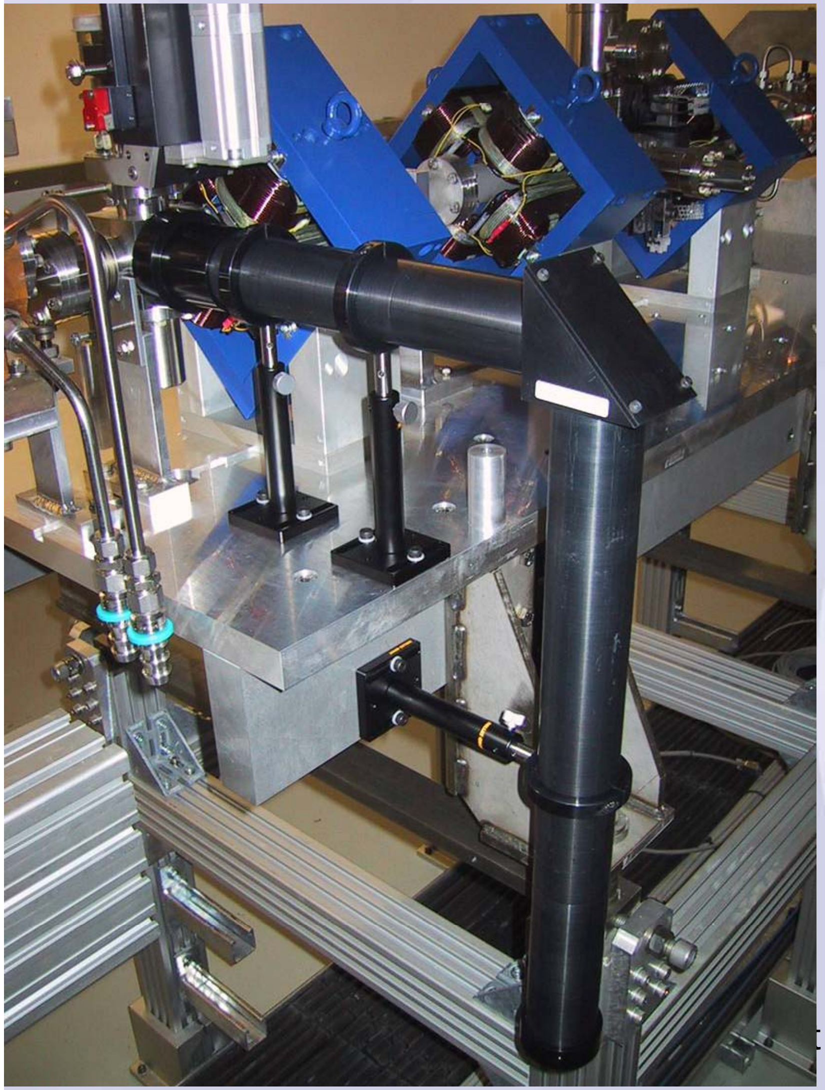


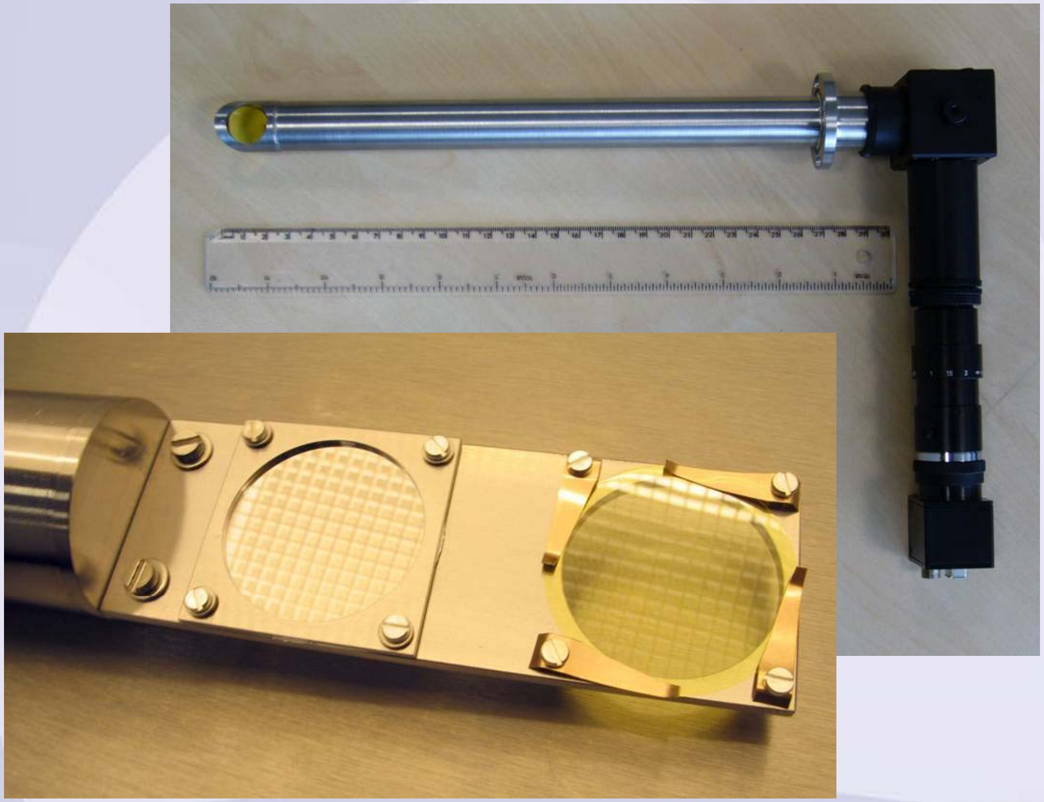
Later with extraction after 100ms

Strip Line BPM Pickups in Transfer Paths

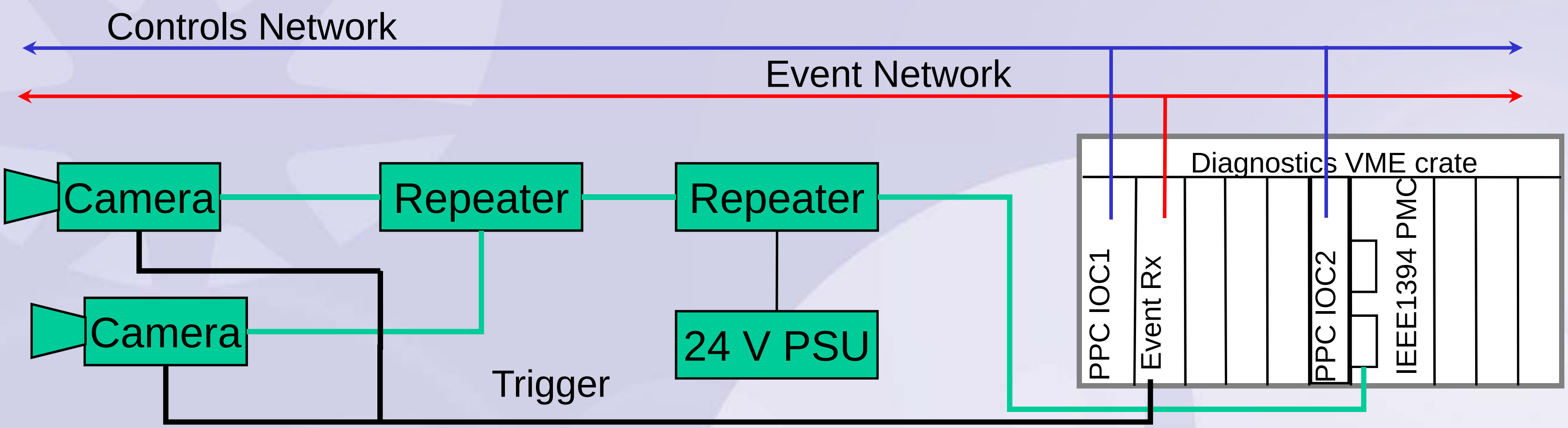


Screens and Optics

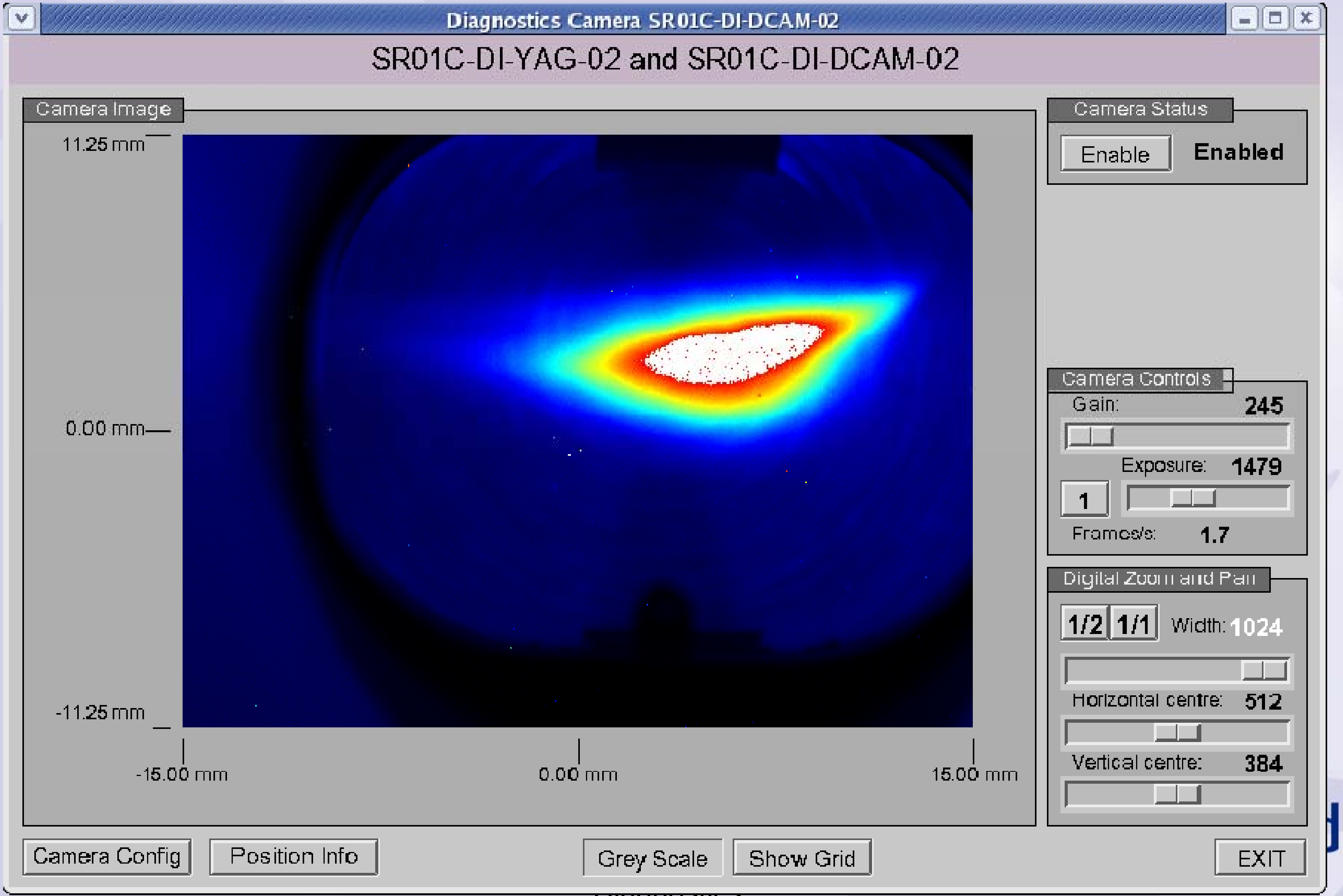




IEEE1394 Cameras



EDM Camera Display



Diagnostics

Precisely Triggered Acquisition

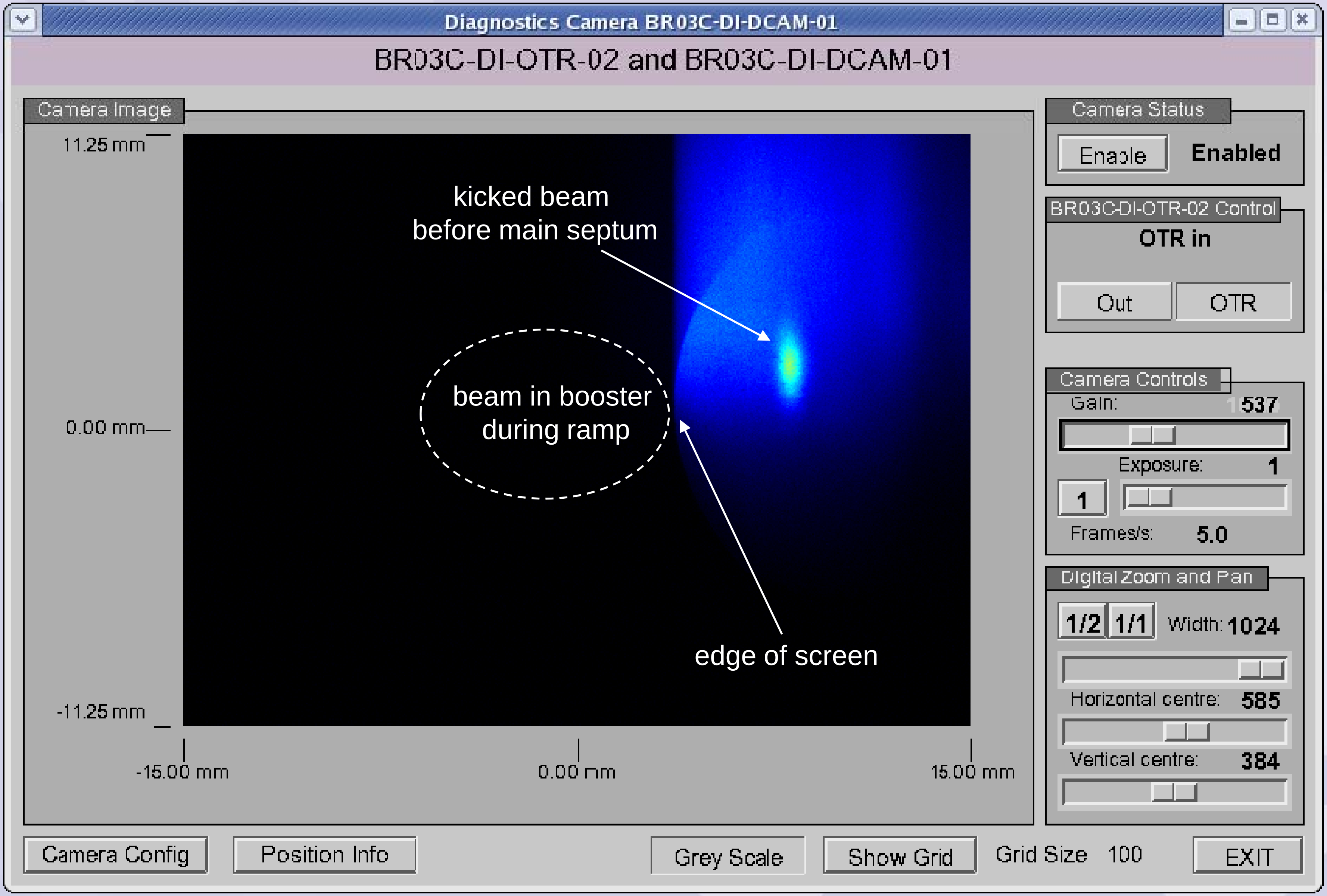
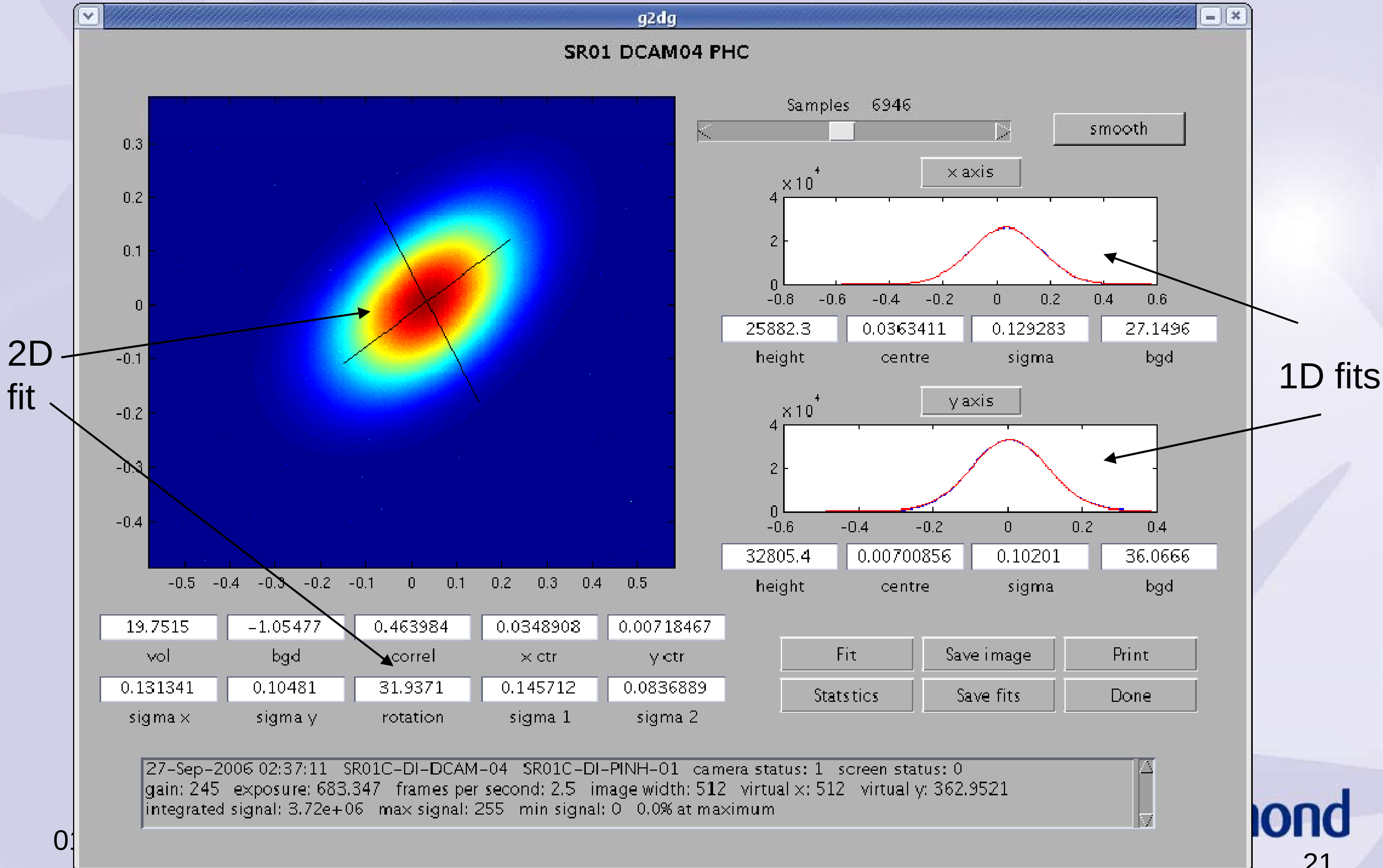


Image Analysis



Orbit Stability Requirements in 3rd Generation Light Sources

Beam stability should be better than 10% of the beam size

$$\Delta x < 0.1 \cdot \sigma_x \qquad \Delta x' < 0.1 \cdot \sigma_{x'}$$

$$\Delta y < 0.1 \cdot \sigma_y \qquad \Delta y' < 0.1 \cdot \sigma_{y'}$$

For Diamond nominal optics (at short straight sections)

$$\Delta x < 0.1 \cdot 123\,\mu m = 12.3\mu m \qquad \Delta x' < 0.1 \cdot 24\,\mu rad = 2.4\,\mu rad$$

$$\Delta y < 0.1 \cdot 6.4\,\mu m = 0.6\mu m \qquad \Delta y' < 0.1 \cdot 4\,\mu rad = 0.4\,\mu rad$$

Motivation and Challenges

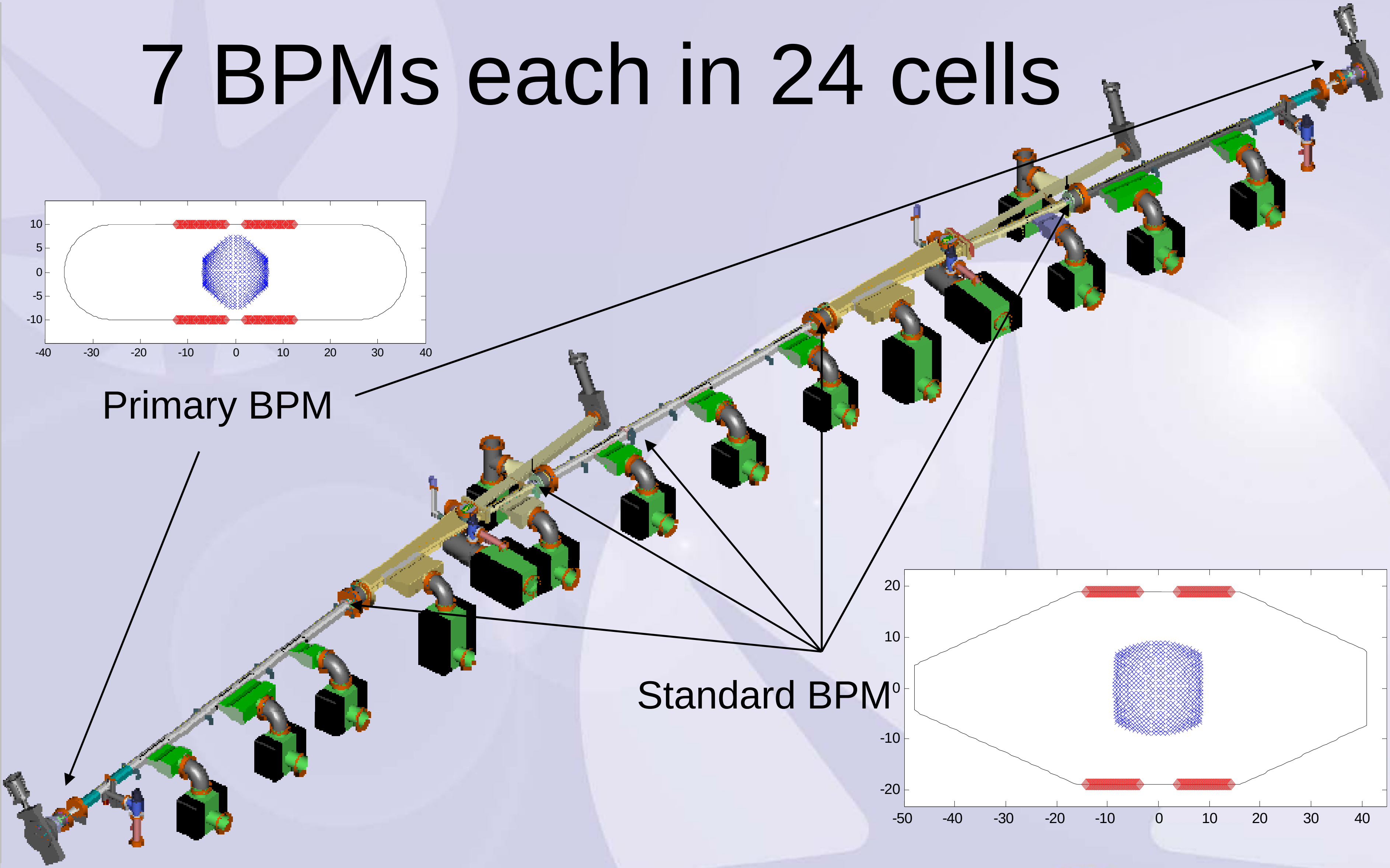
- Sources of beam motion:
  - Insertion devices not fully compensated, ID motion leads to orbit displacement
  - Ground vibrations amplified through girders
  - Magnet power supply drift
  - Vibrations from water cooling

Correct as fast as possible

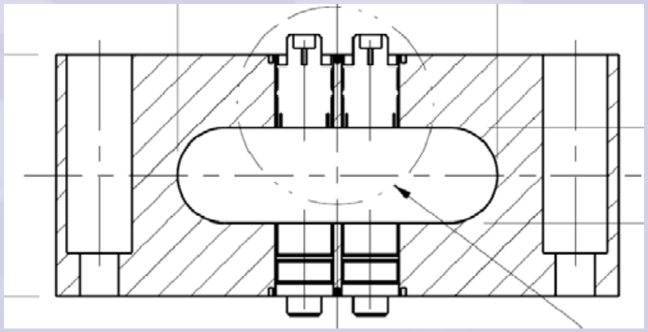
- Sources of errors in EBPM measurement:
  - Mechanical/electrical offsets
  - Noise
  - Beam current dependence
  - Pickup thermal motion

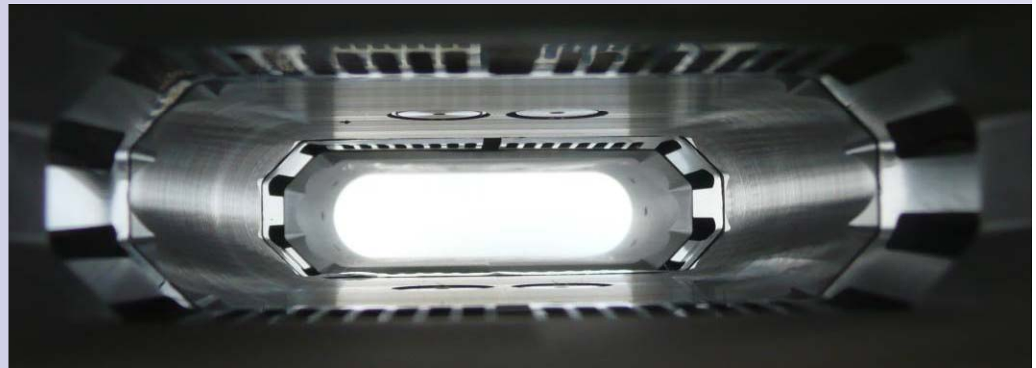
Minimise or remove from correction

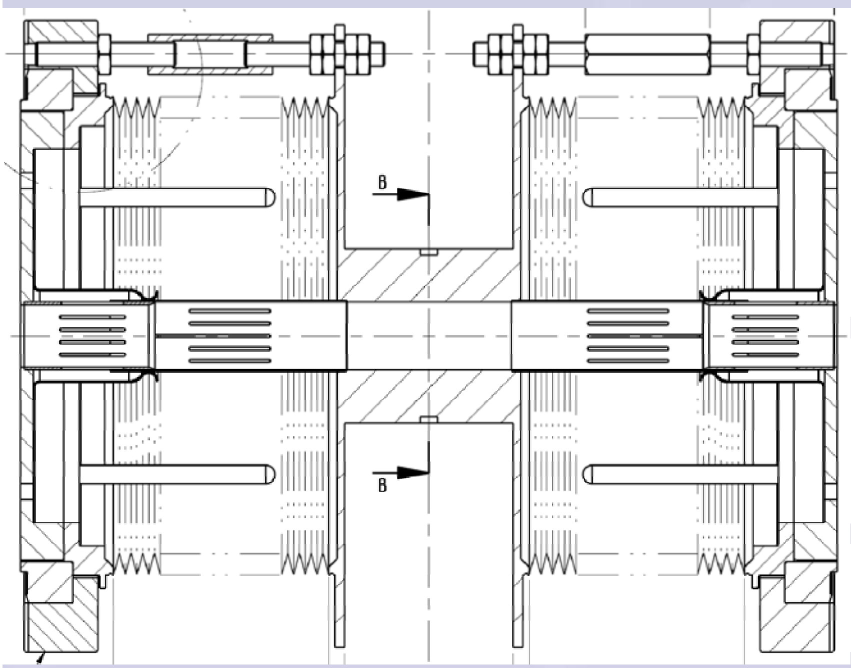
7 BPMs each in 24 cells

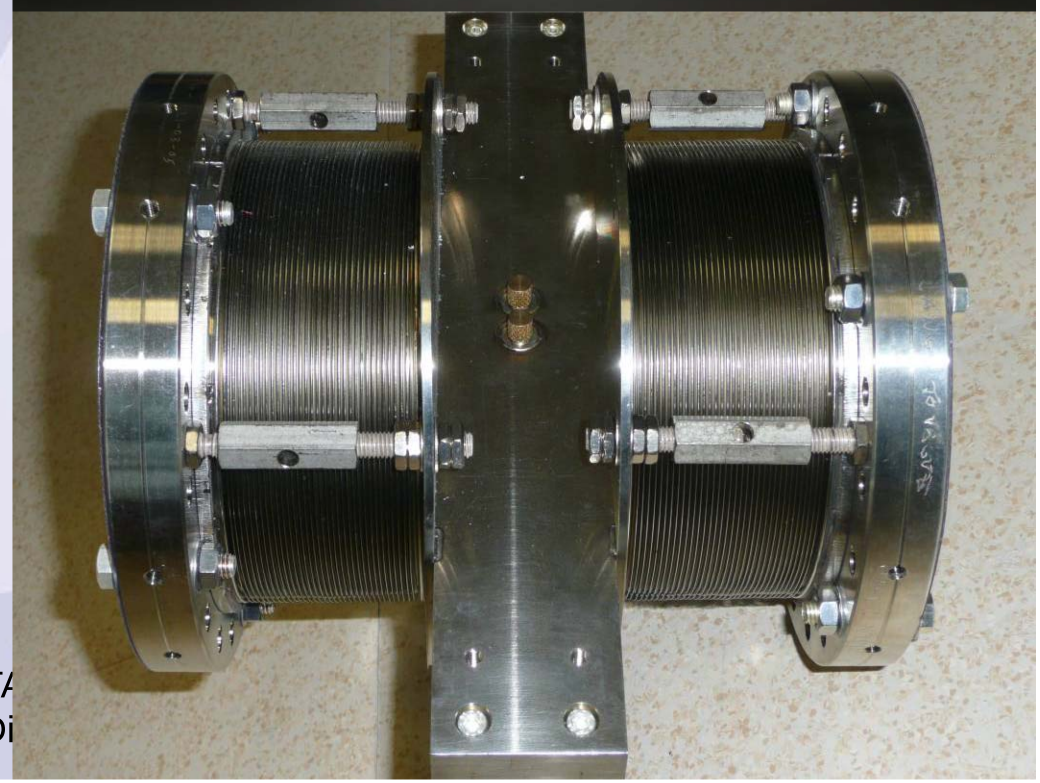


Button Pickup

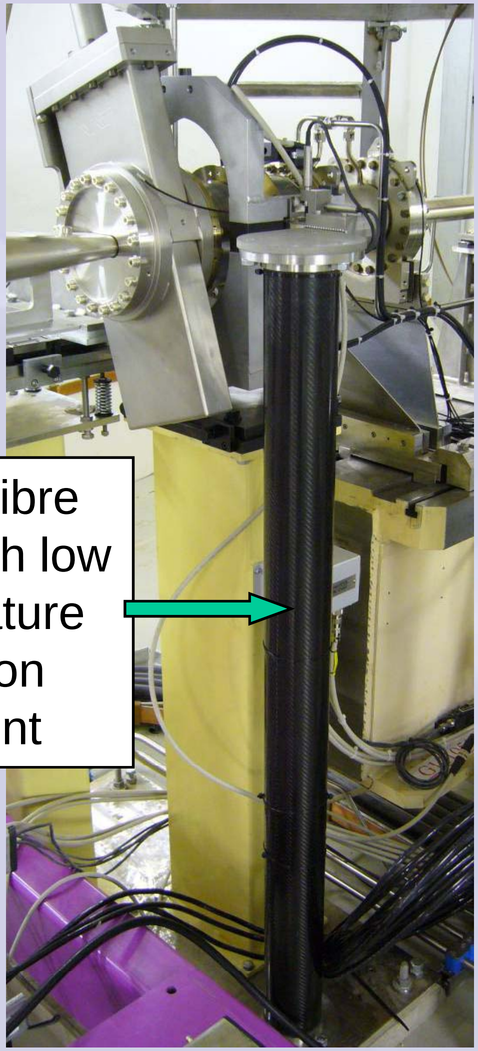




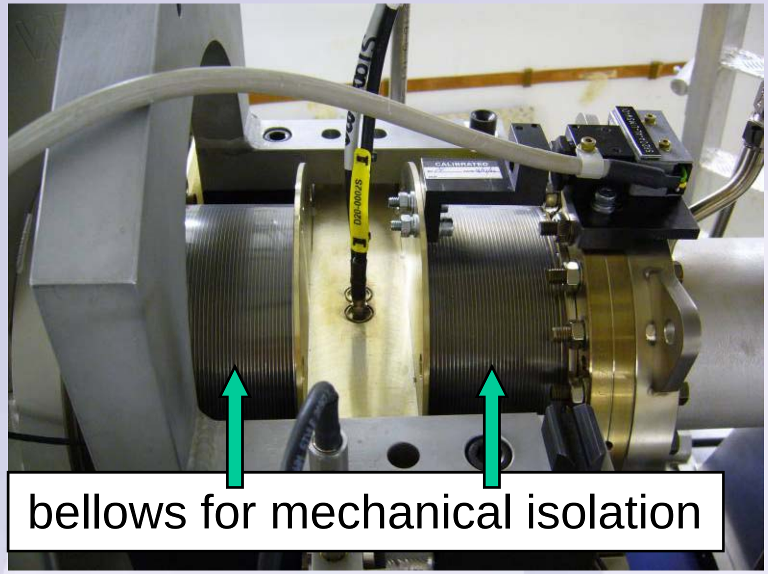




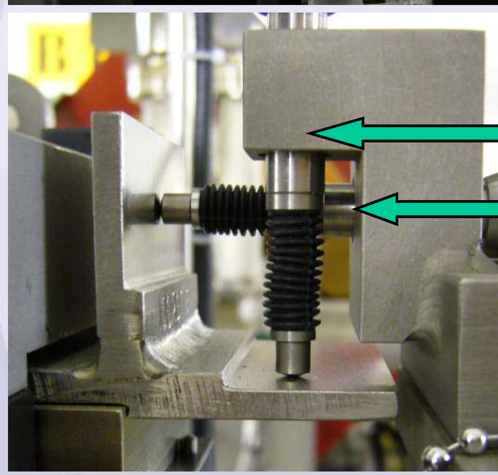
Primary BPM with reference pillar



carbon fibre pillar with low temperature expansion coefficient

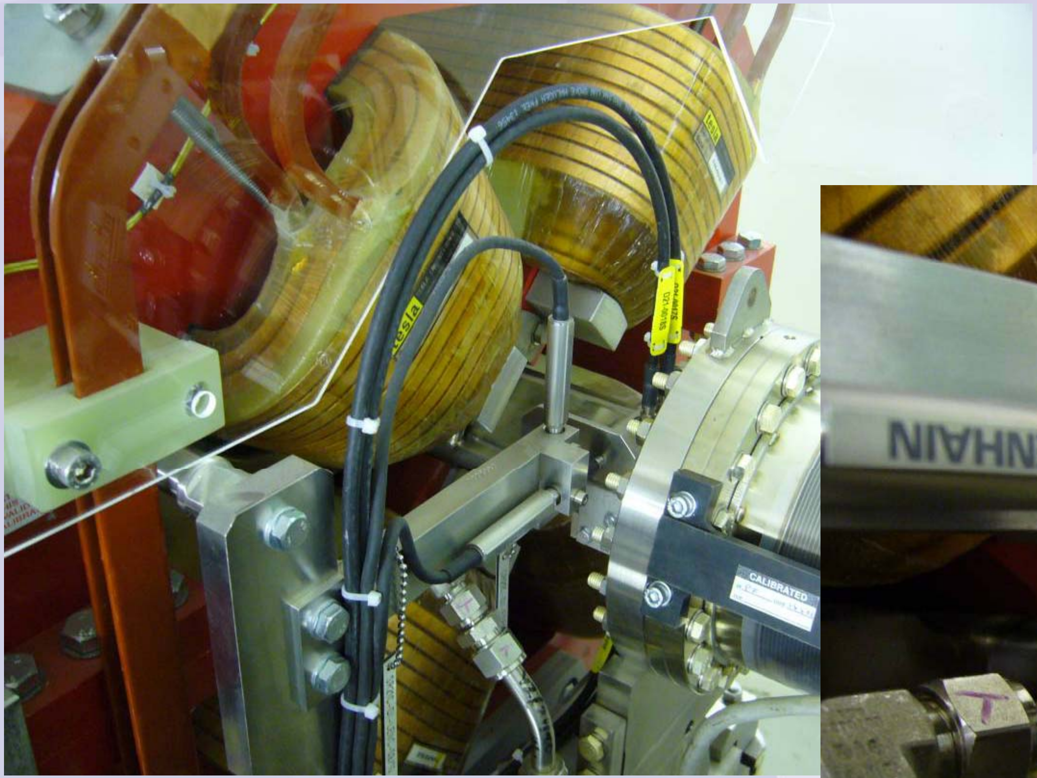


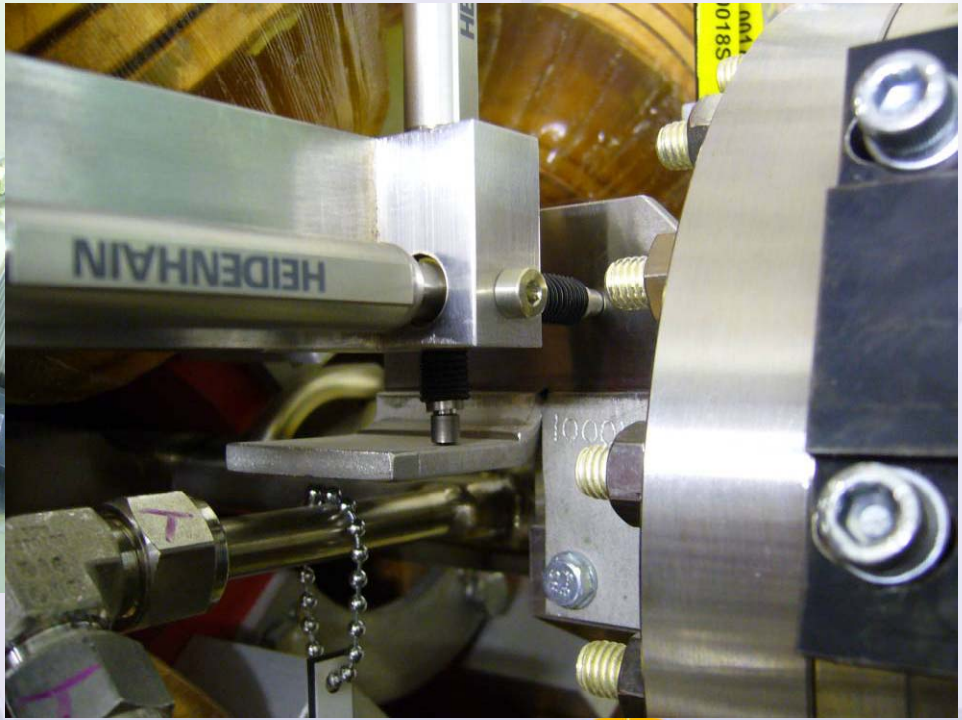
bellows for mechanical isolation



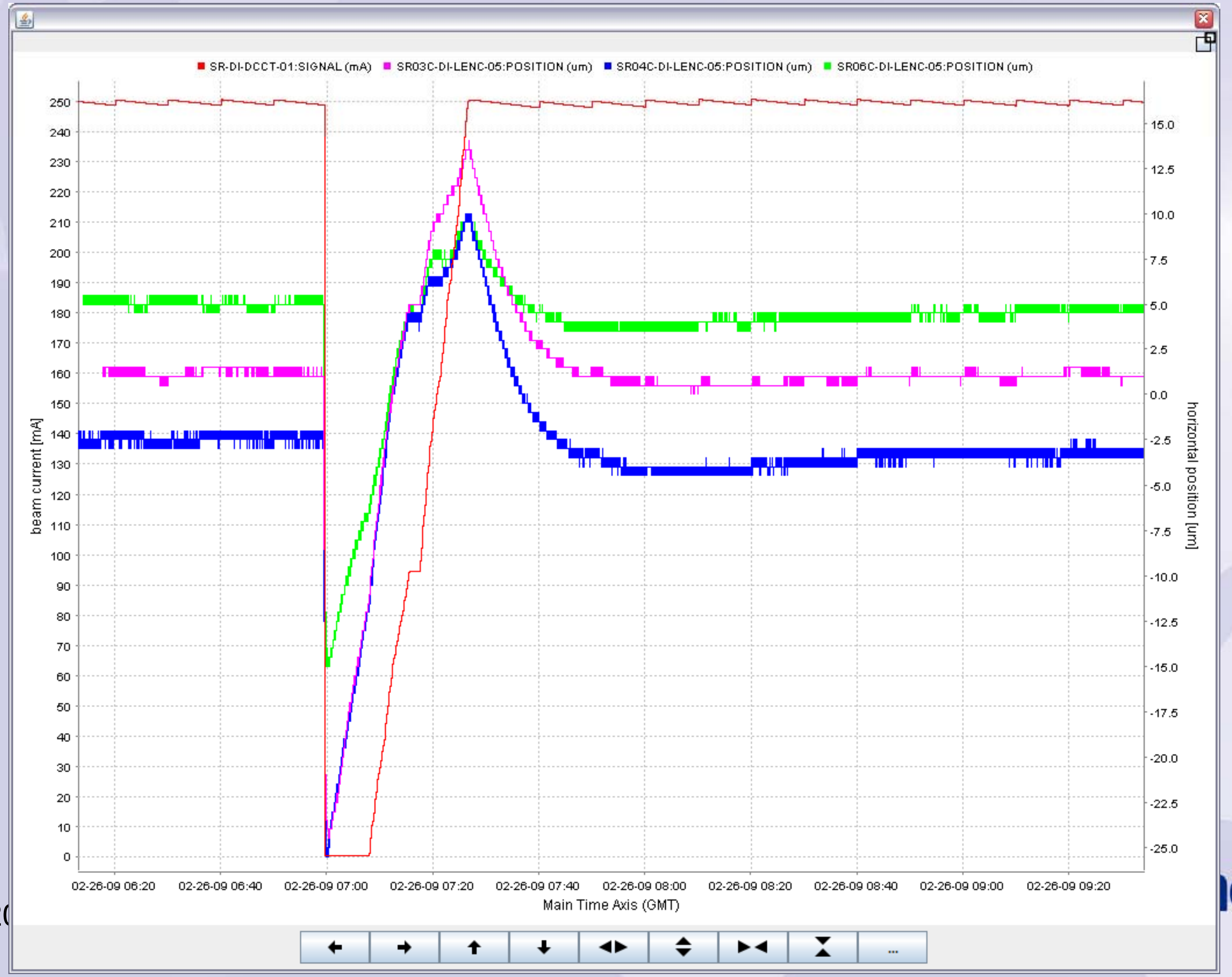
length gauges sense H/V position with 0.5um resolution

Standard BPM near Quad

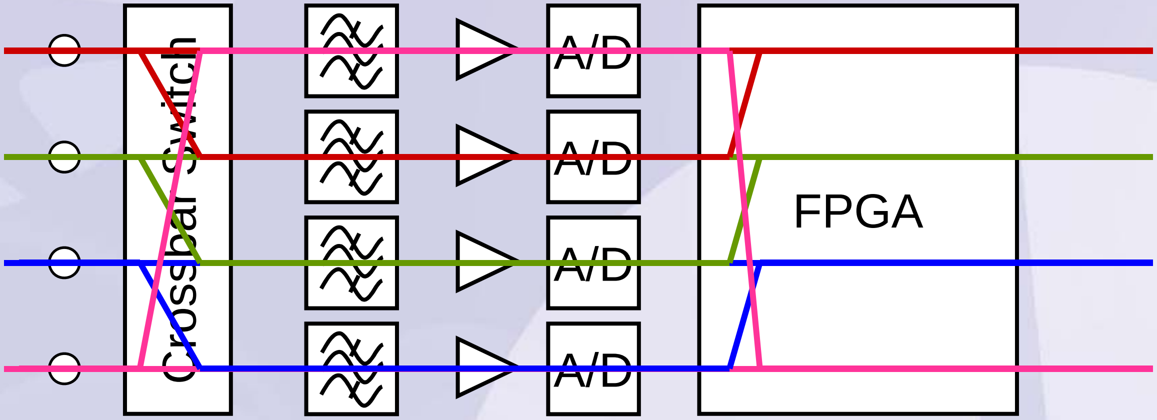




Some BPMs move after beam loss

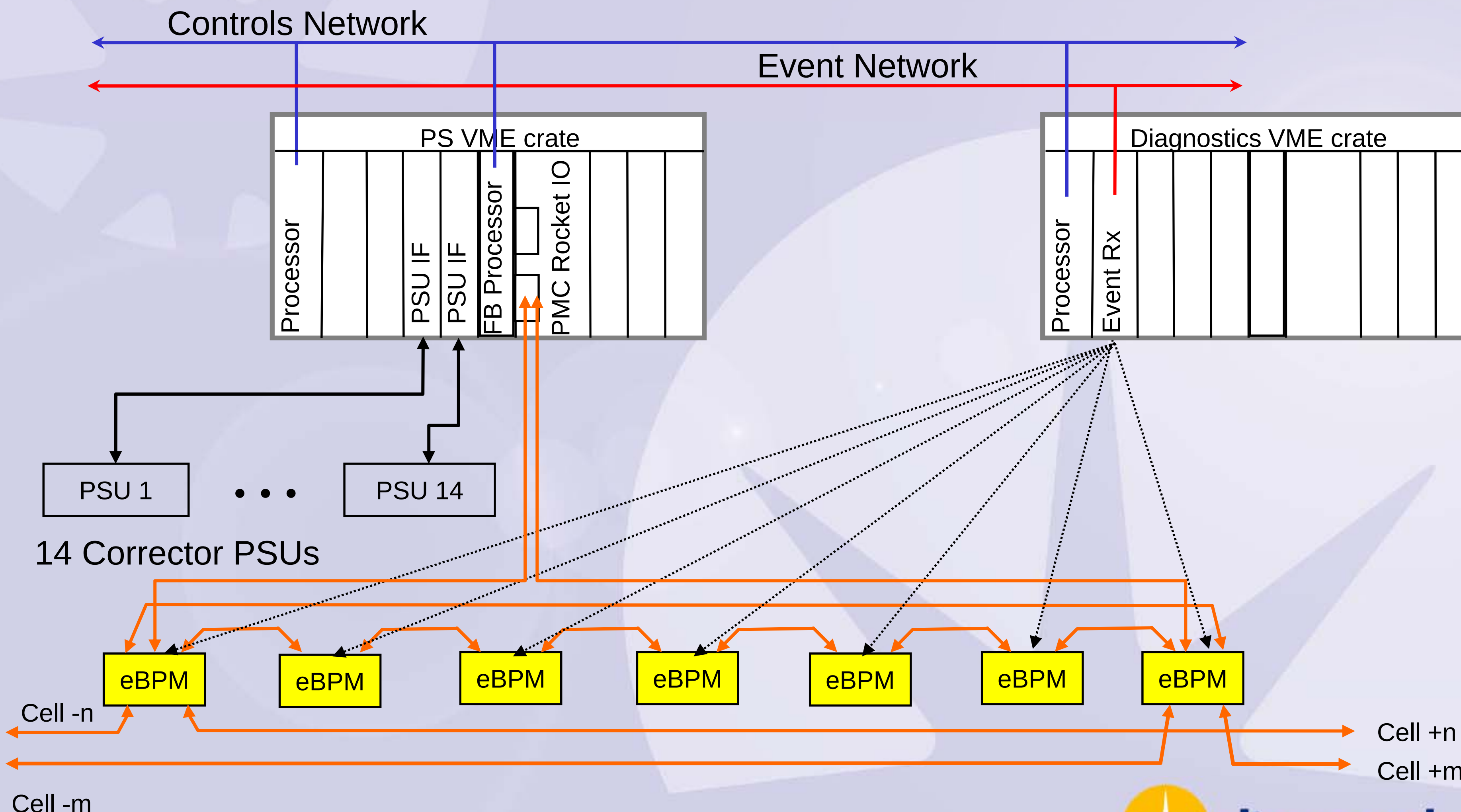


Multiplexing in BPM Electronics

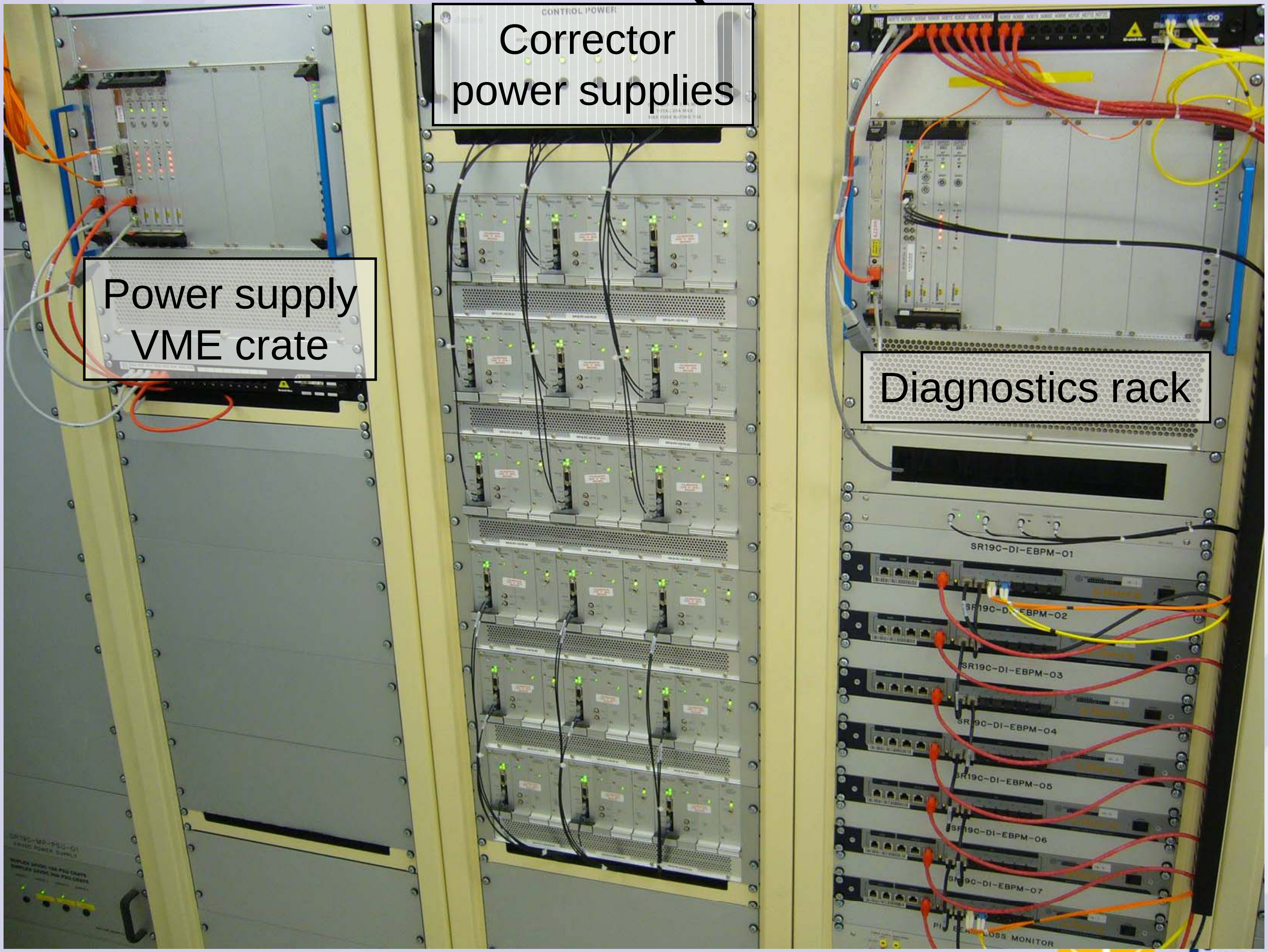


- **Crossbar switch** routes all four inputs through all processing channels in parallel, but **permutes routing**
- **After digitisation**, but before further filtering, the **permutation is reversed**
- By **averaging over 4 permutations**, any **differences/drifts** between the channels will be **removed** (each input will have been routed through each channel during the averaging period)
- By examining the changes in the outputs during permutation, the gains of the individual channels can be retrieved and then digitally equalised to reduce artefacts of switching

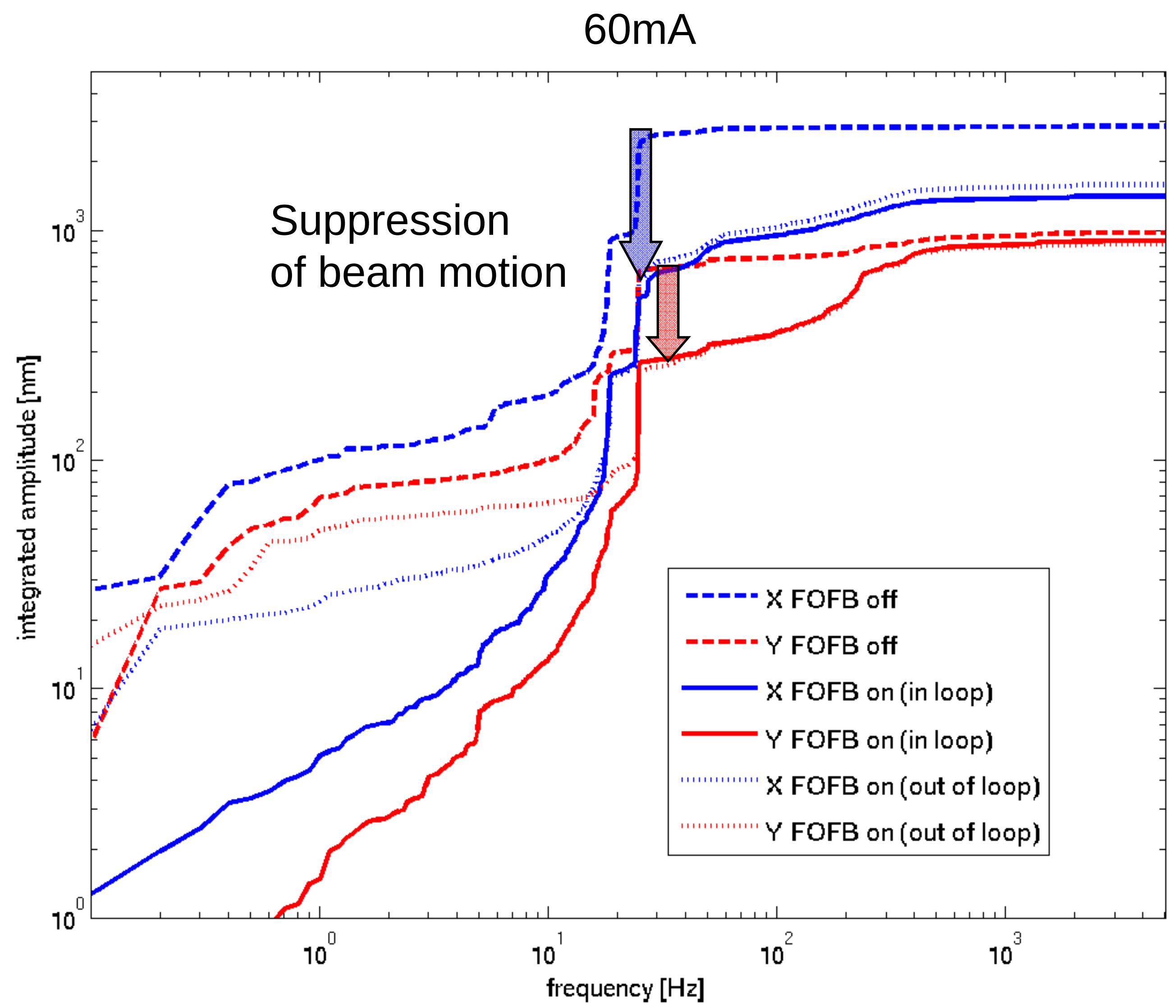
Fast Orbit Feedback



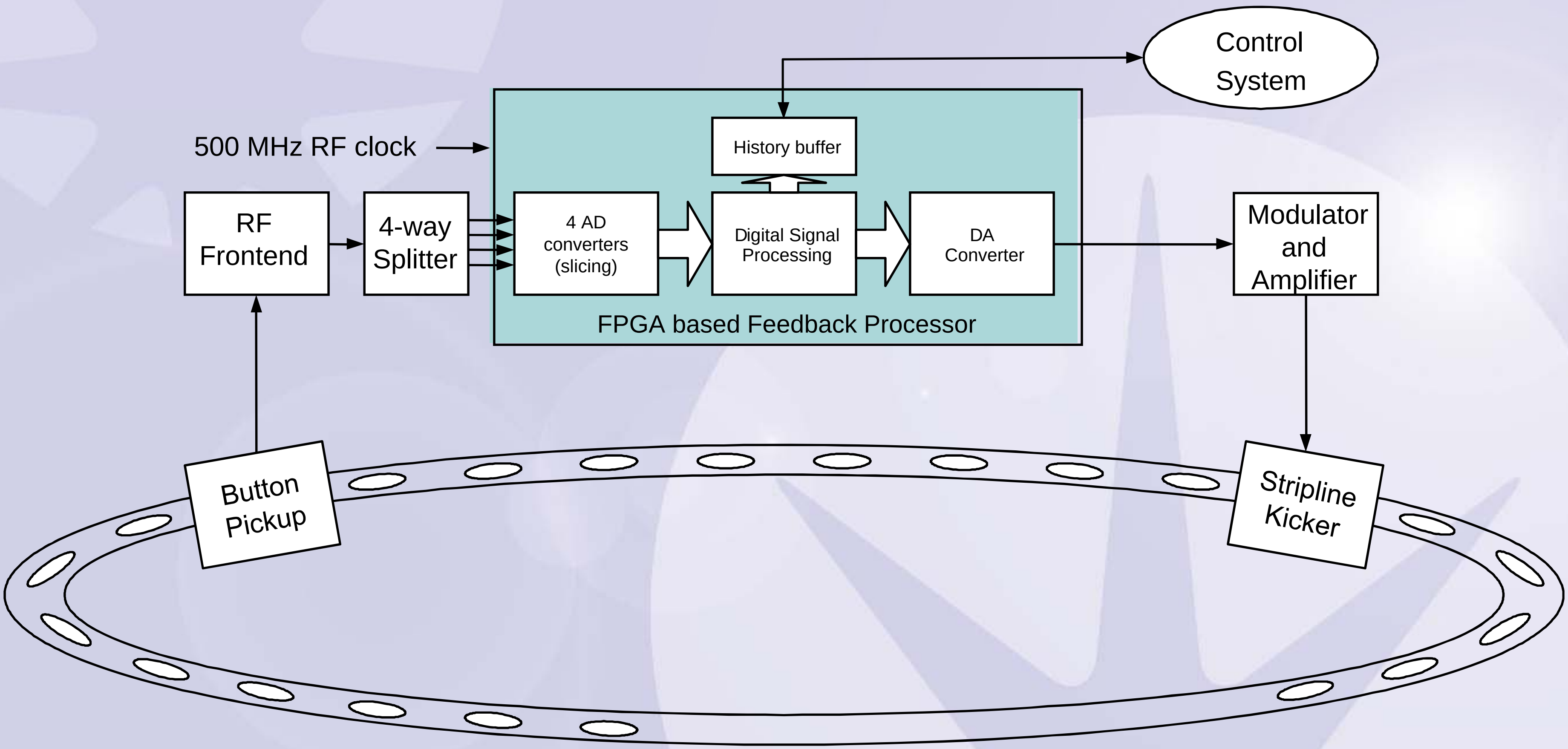
FOFB Installation (one of 24 cells)



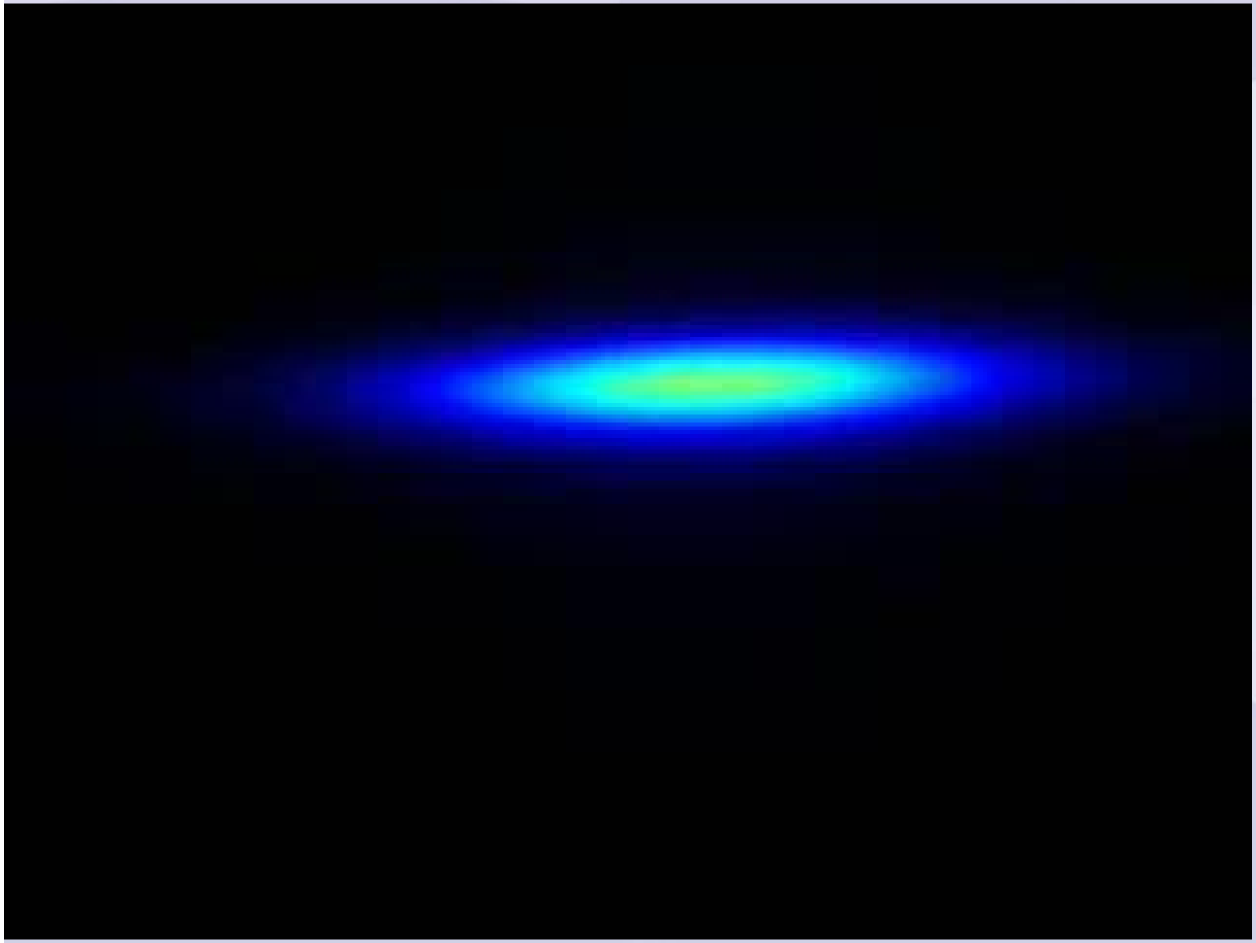
FOFB Performance



Transverse Bunch-by-Bunch Feedback



Bunch-by-Bunch Feedback in Action



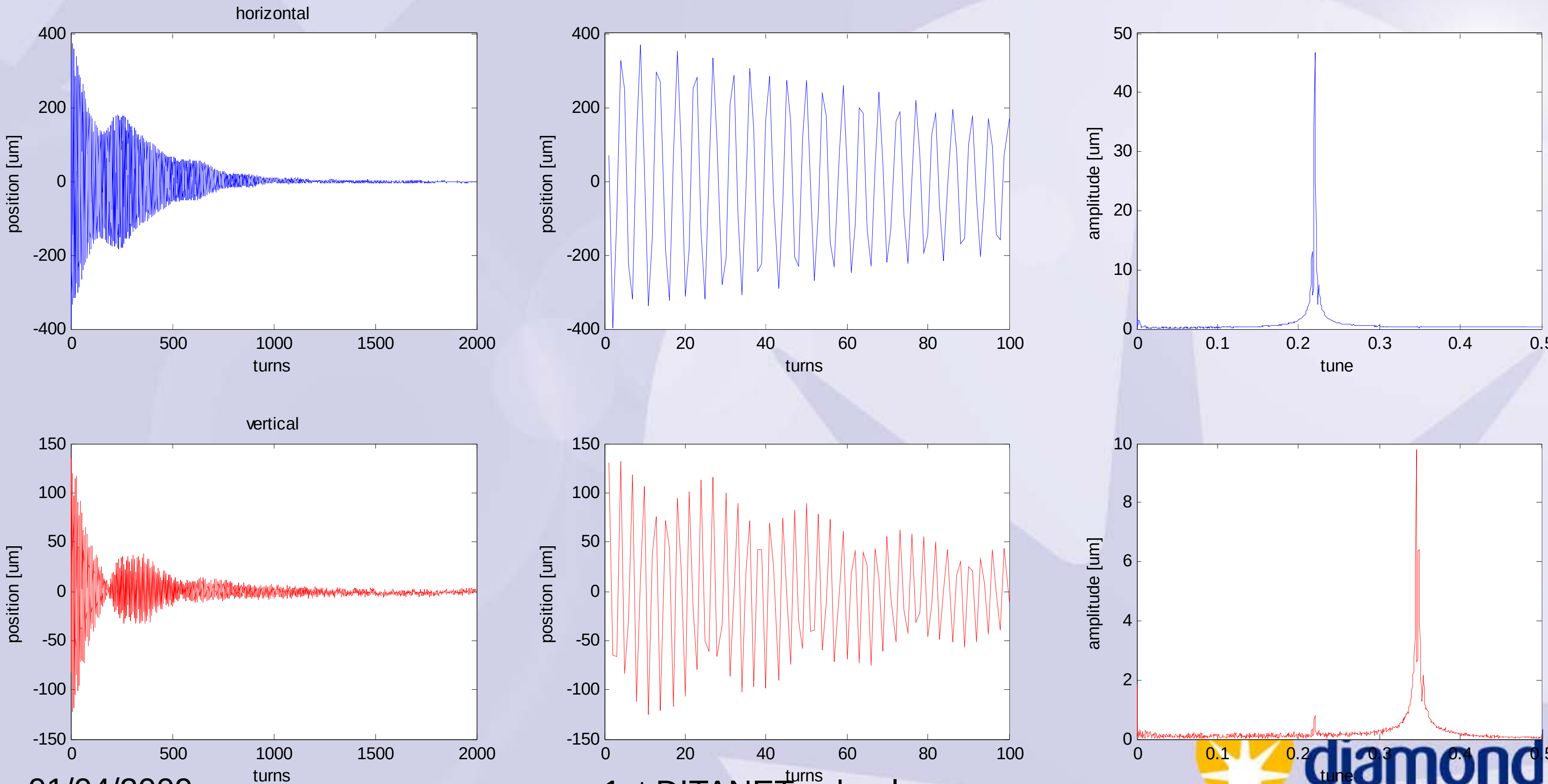
Beam artificially made unstable in both planes:

1) **no feedback**
   → **horizontally unstable**

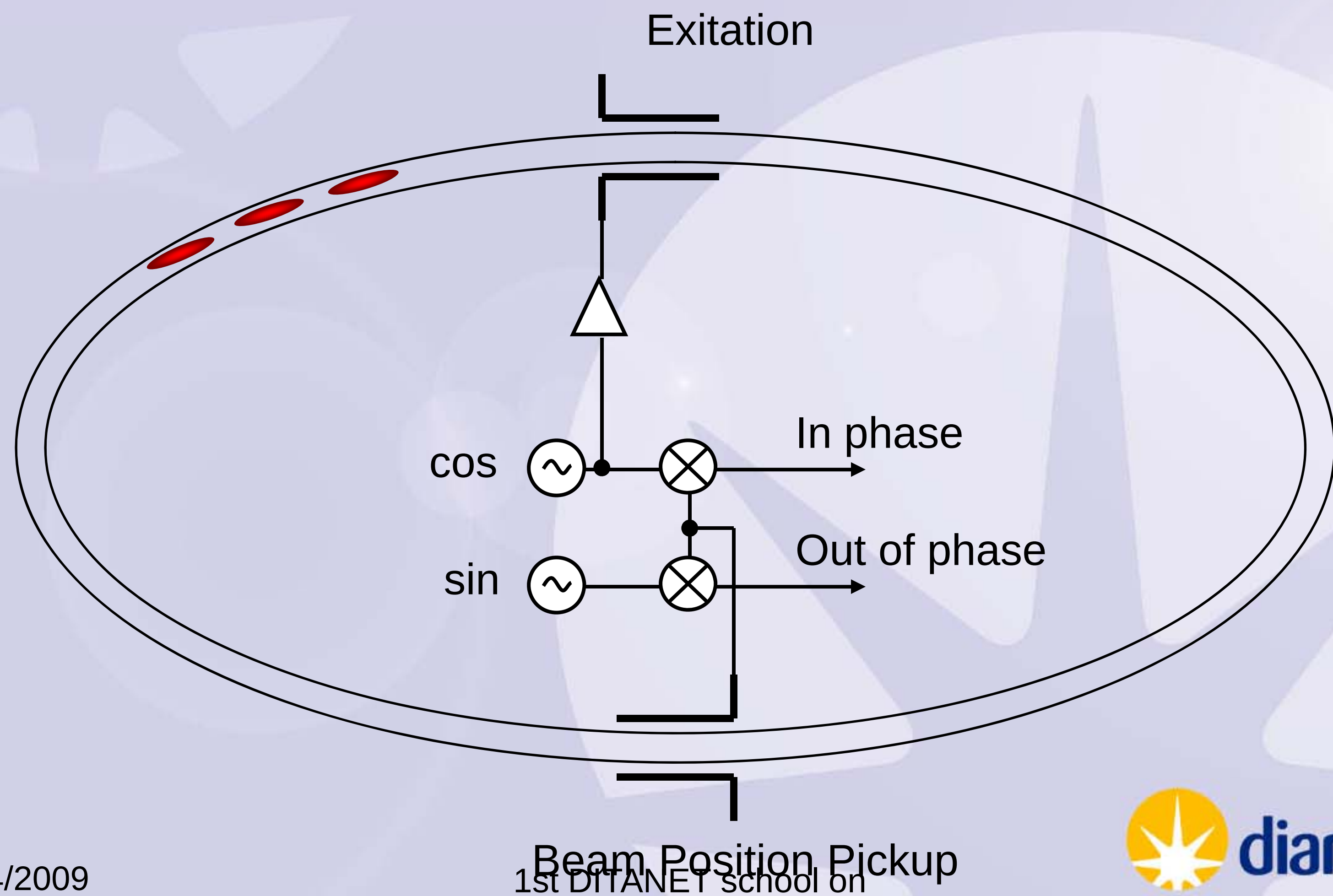
2) **feedback in horiz. plane only**
   → **vertically unstable**

3) **feedback in both planes**
   → **stable in both planes**

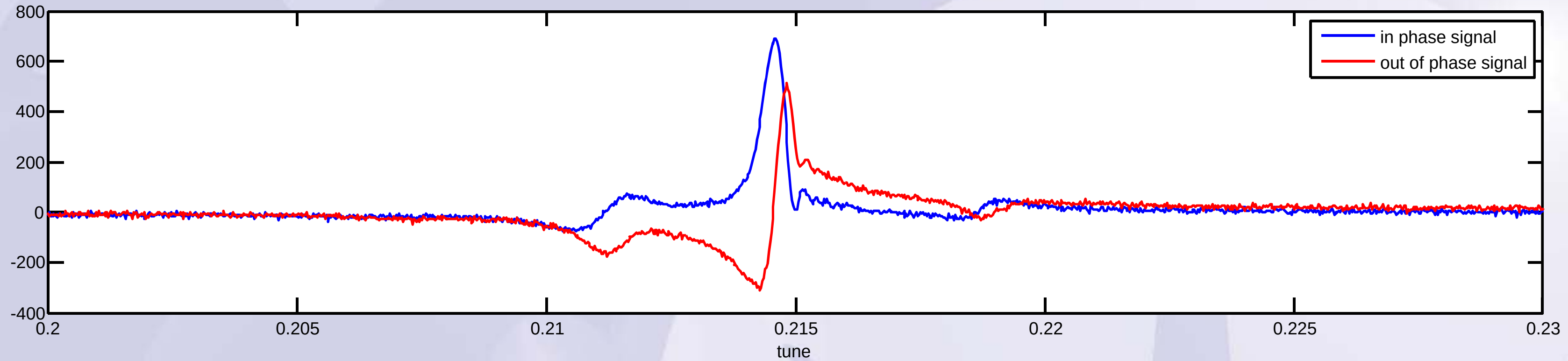
Tune Measurement: Kick and Fourier Transform

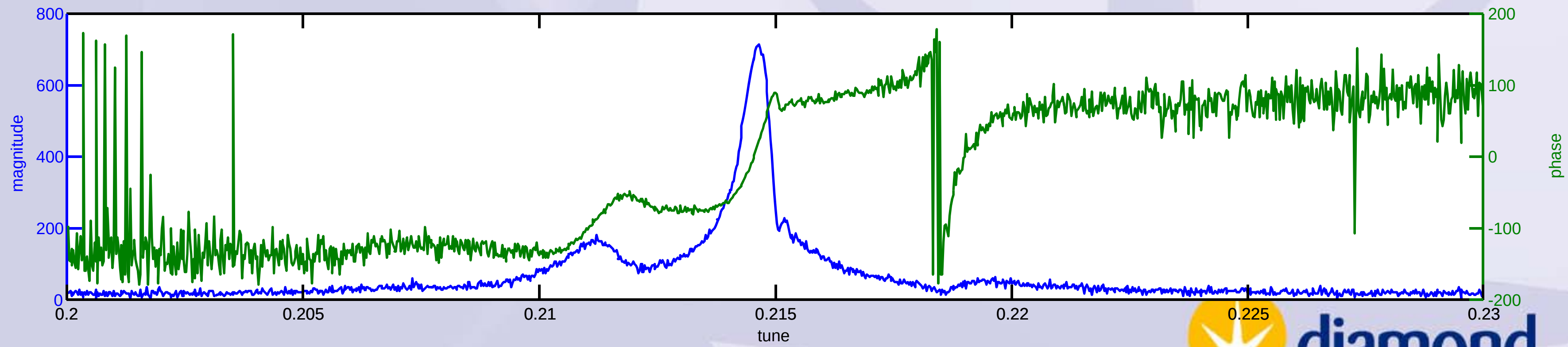


More Elegant Tune Measurement: Harmonic Excitation and Detection

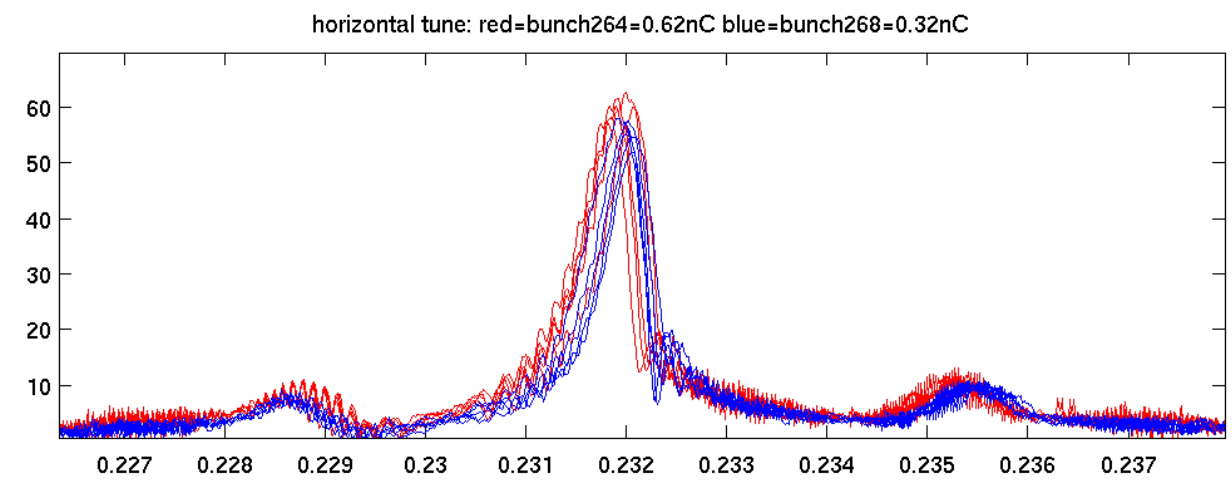


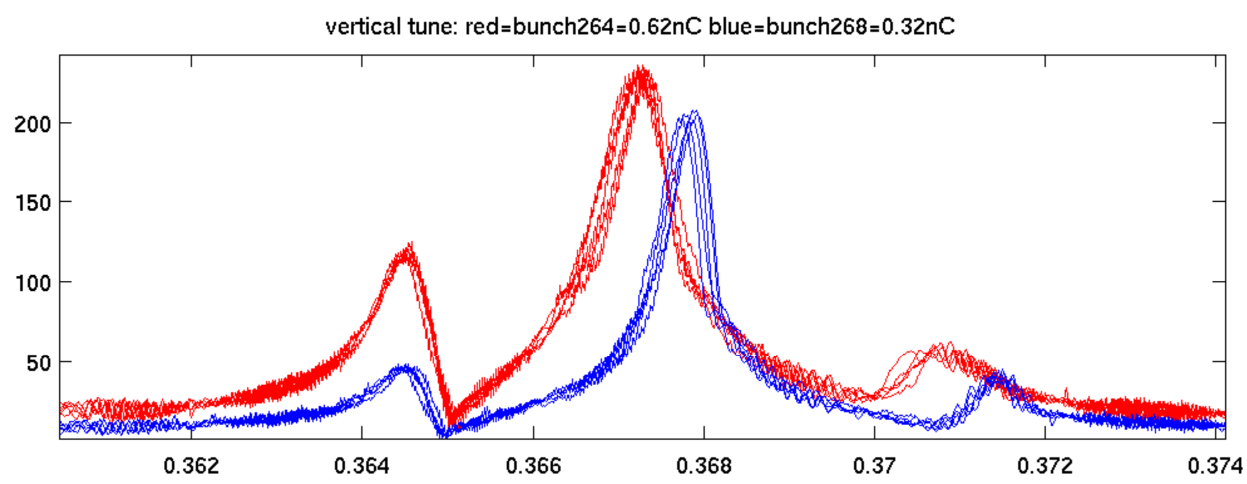
Amplitude and Phase of Beam Response to Swept Sine Excitation





Tune Measurement of Individual Bunches

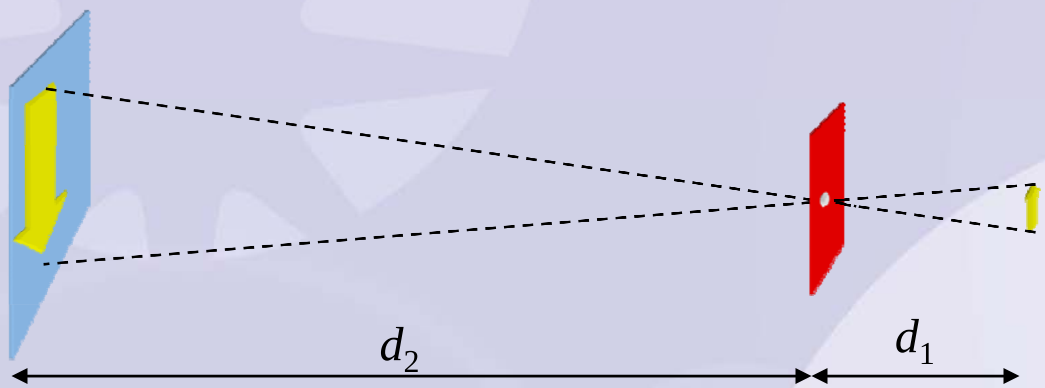




- Only one bunch is excited with swept sine wave
- Tune depends on charge per bunch
- Head-Tail mode leads to asymmetry of Synchrotron sidebands for larger charges

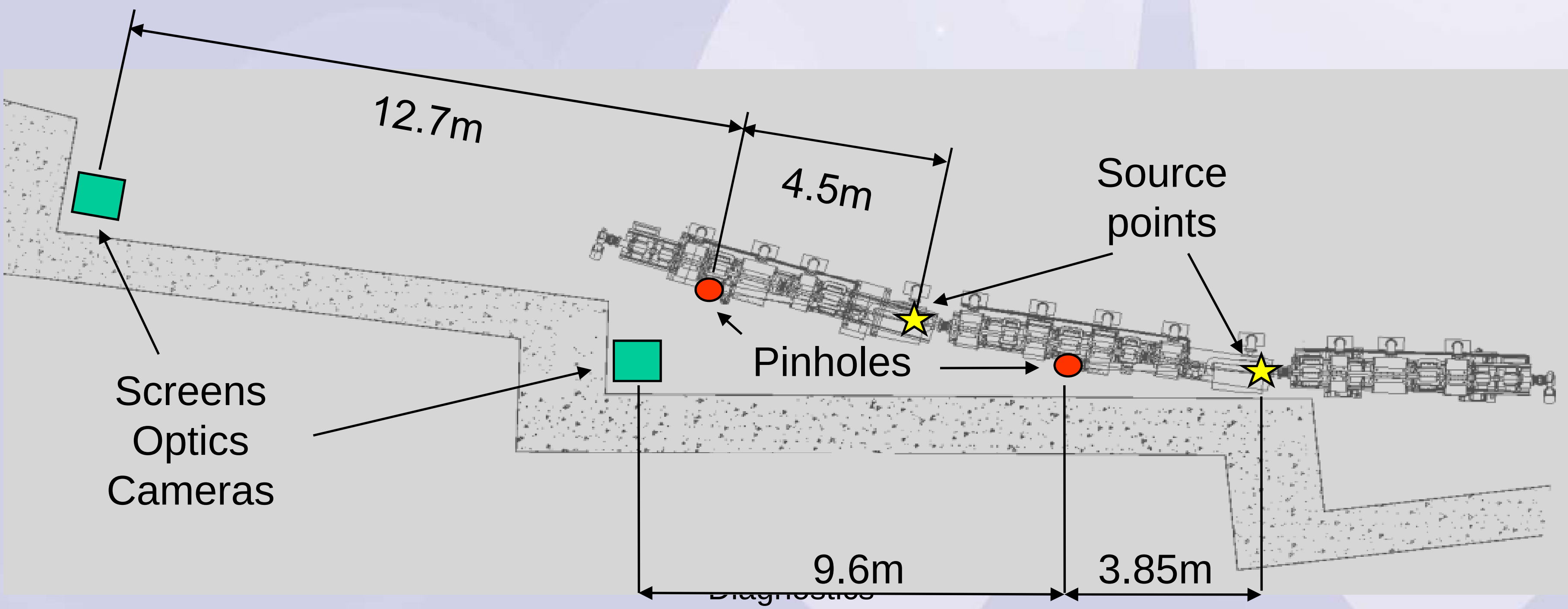
diamond

X-ray Pinhole Cameras

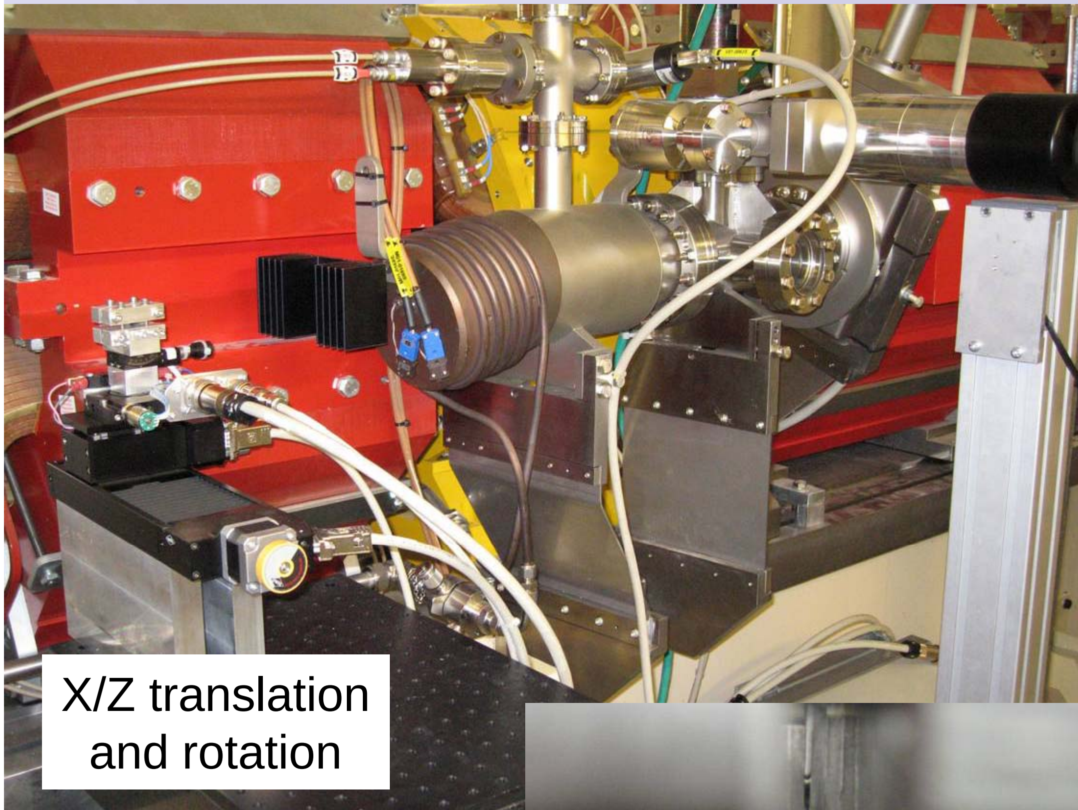


Magnification

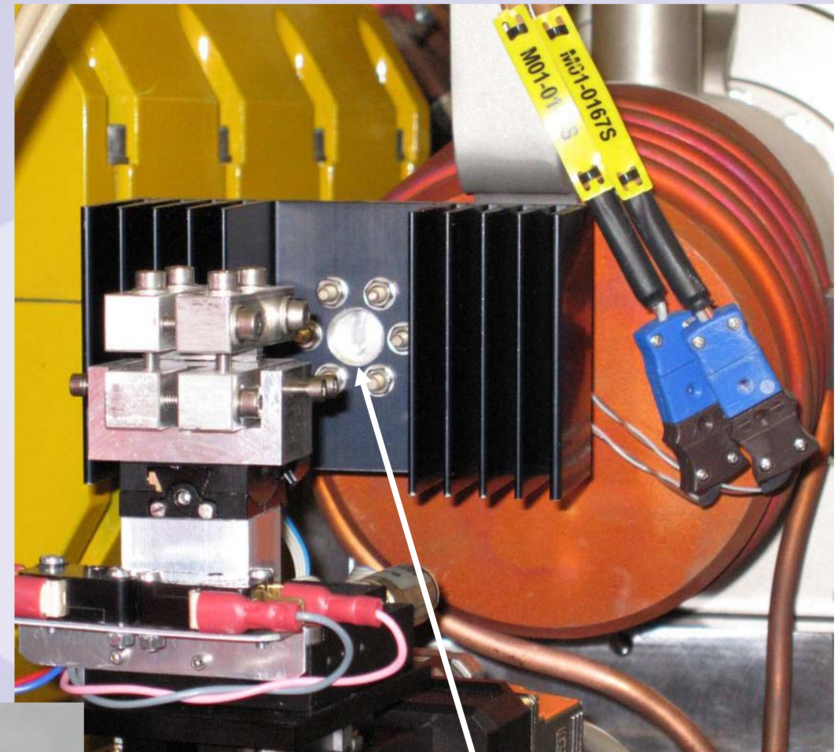
$$m = \frac{d_2}{d_1}$$



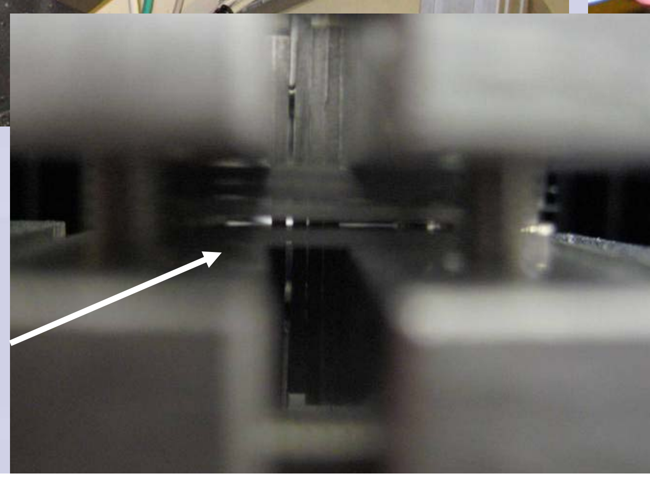
Modified Beam Port Absorbers and Pinholes



X/Z translation
and rotation

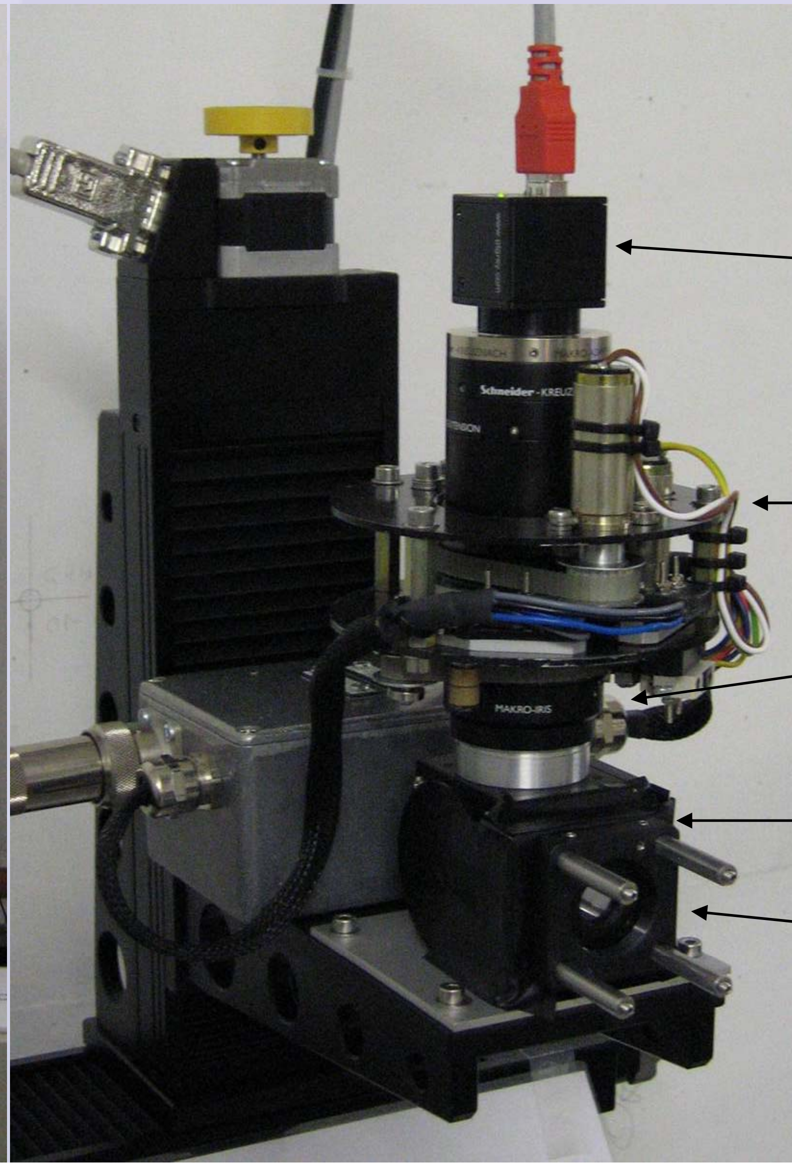


Aluminium/Steel
explosion bonded
flange as window



2 stacks of 4 slabs
5mm*1mm*30mm
with shims as spacers

Pinhole Screens and Optics



1024x768 camera
4.65um pixel

focus and iris
remote control

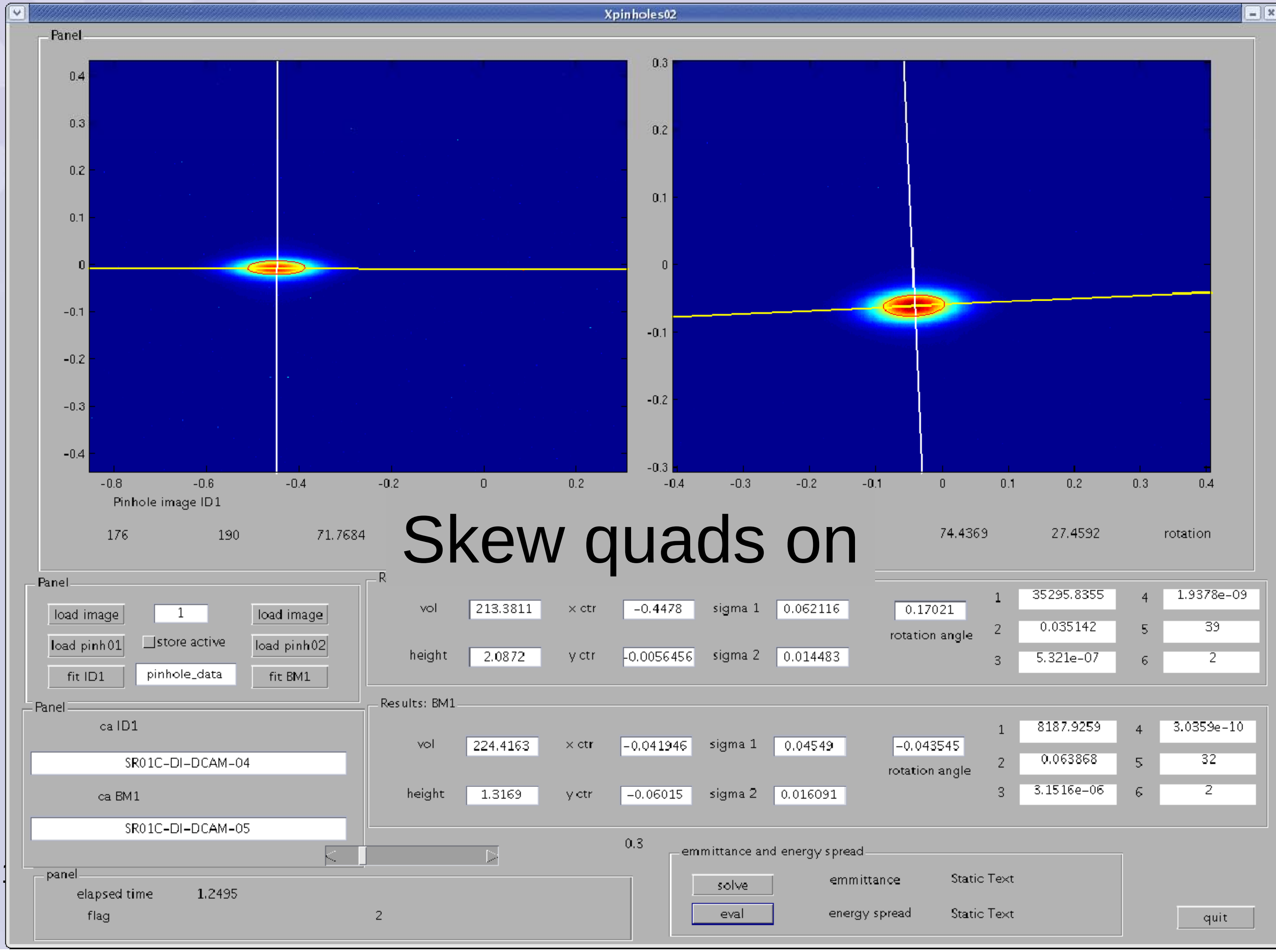
50mm macro lens
magnification 1:1

mirror

$CdWO_4$ screen

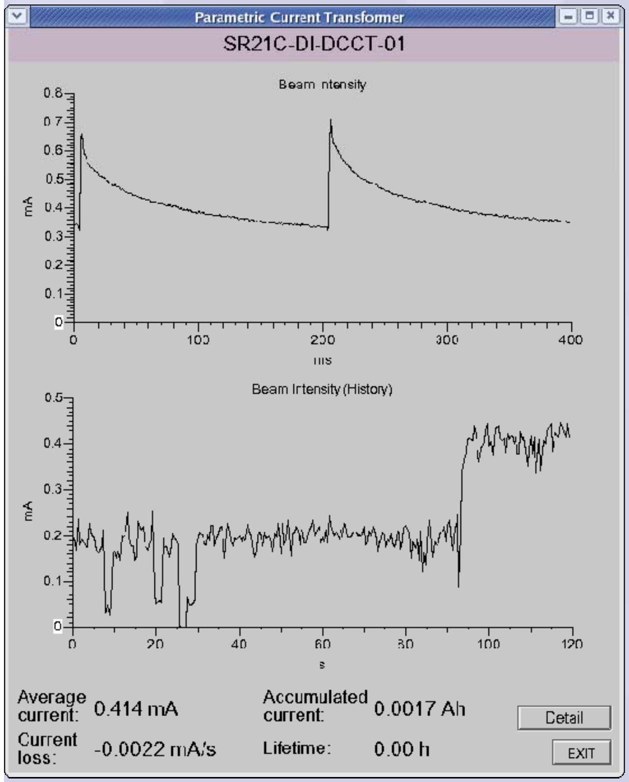
diamond

Pinhole Image Analysis

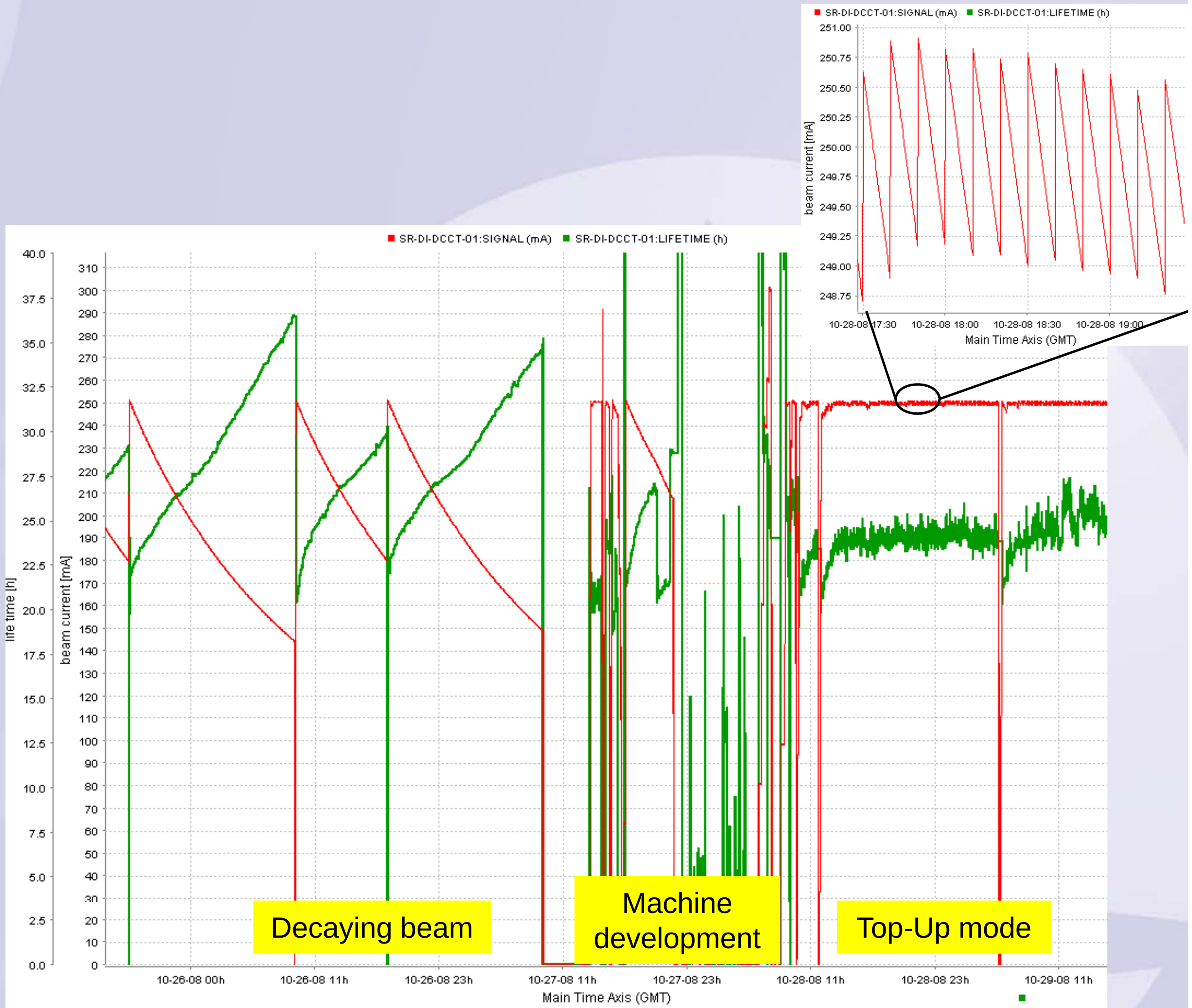


Skew quads on

Storage Ring DCCT

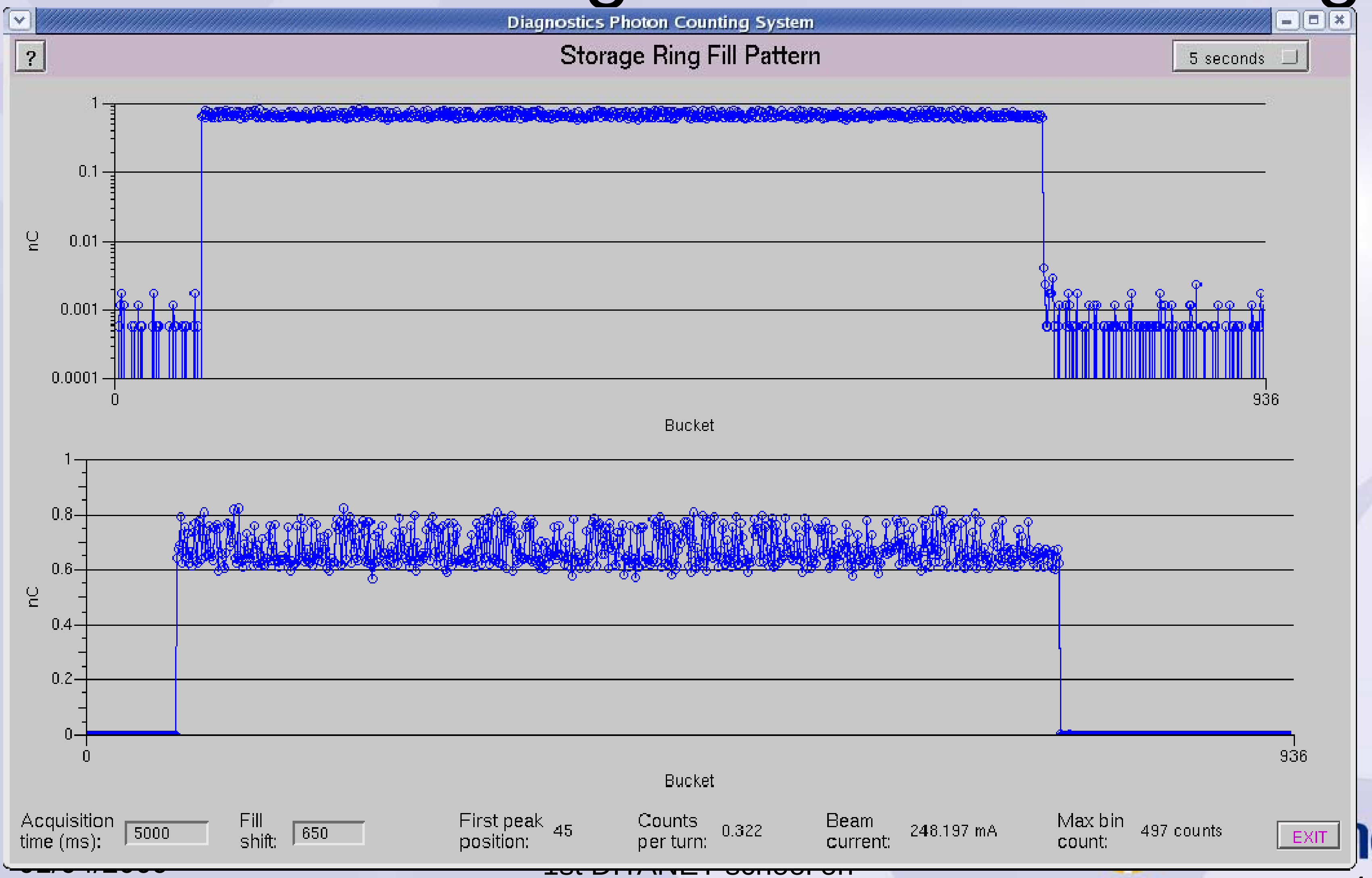


First accumulation of stored current at Diamond



Stored current and life time

Fill Pattern Measurement by Time Correlated Single Photon Counting



Acknowledgements

- Diagnostics: Alun Morgan, Cyrille Thomas, Chris Bloomer, Graham Cook
- Controls: Michael Abbott, Isa Uzun, James Rowland, Mark Heron
- Accelerator Physics: Ian Martin, Riccardo Bartolini
- Engineering: Nigel Hammond, Ron Godwin, Darren Simmons

Thank you for your attention!