

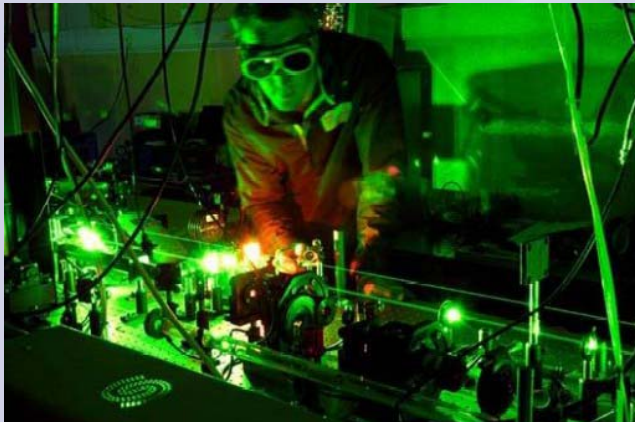
Beam Diagnostics at Diamond Light Source

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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?



01/04/2009

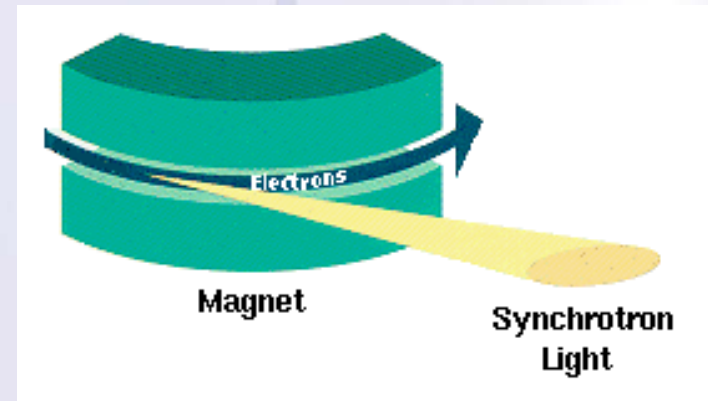
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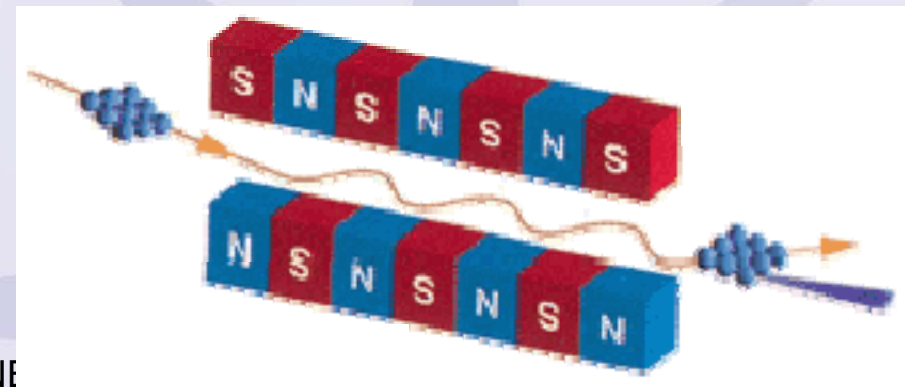
How Is Synchrotron Light Produced?

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



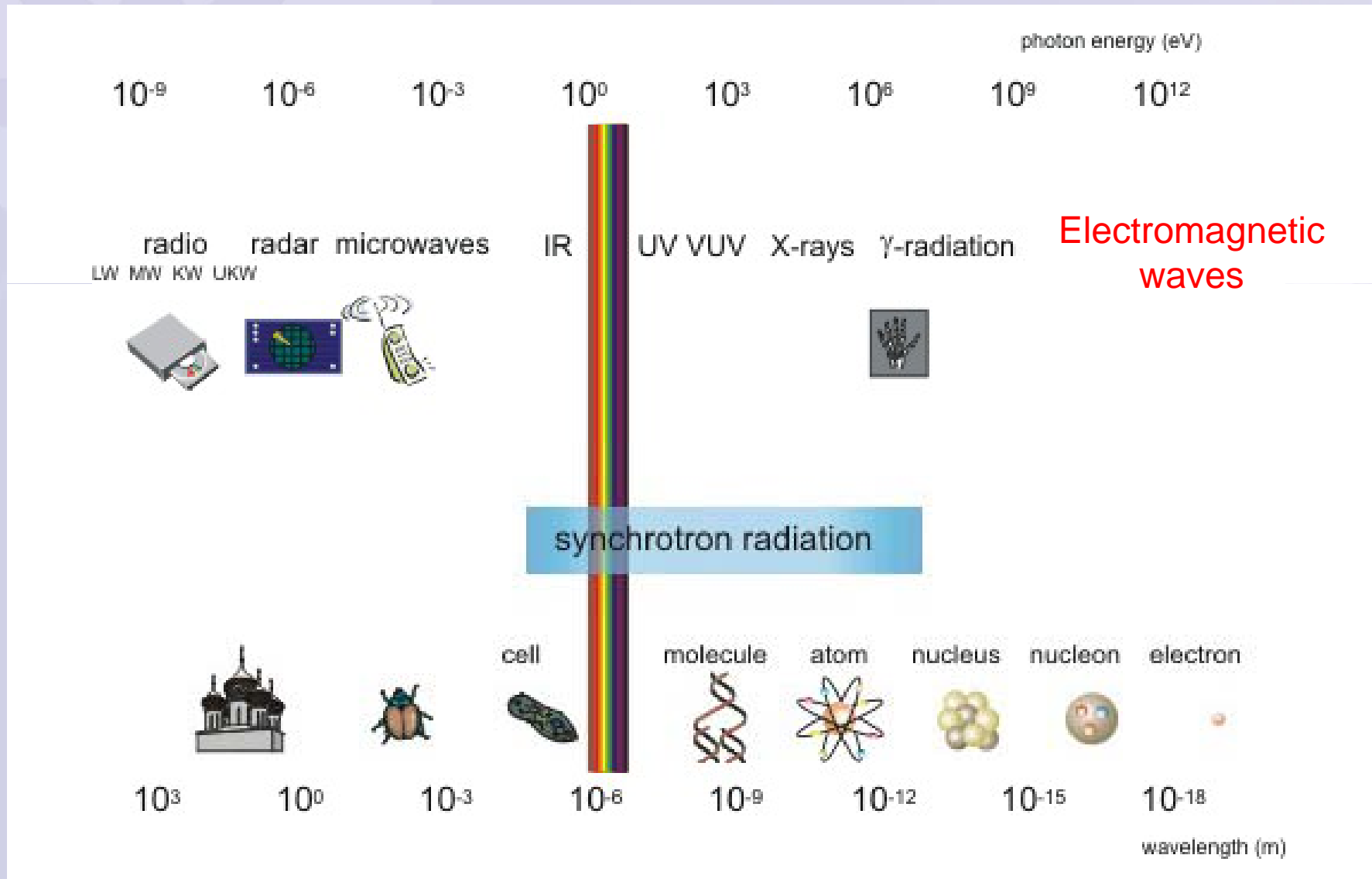
multiple bends in an "undulator" or "wiggler" magnet give higher intensity and more directed radiation



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

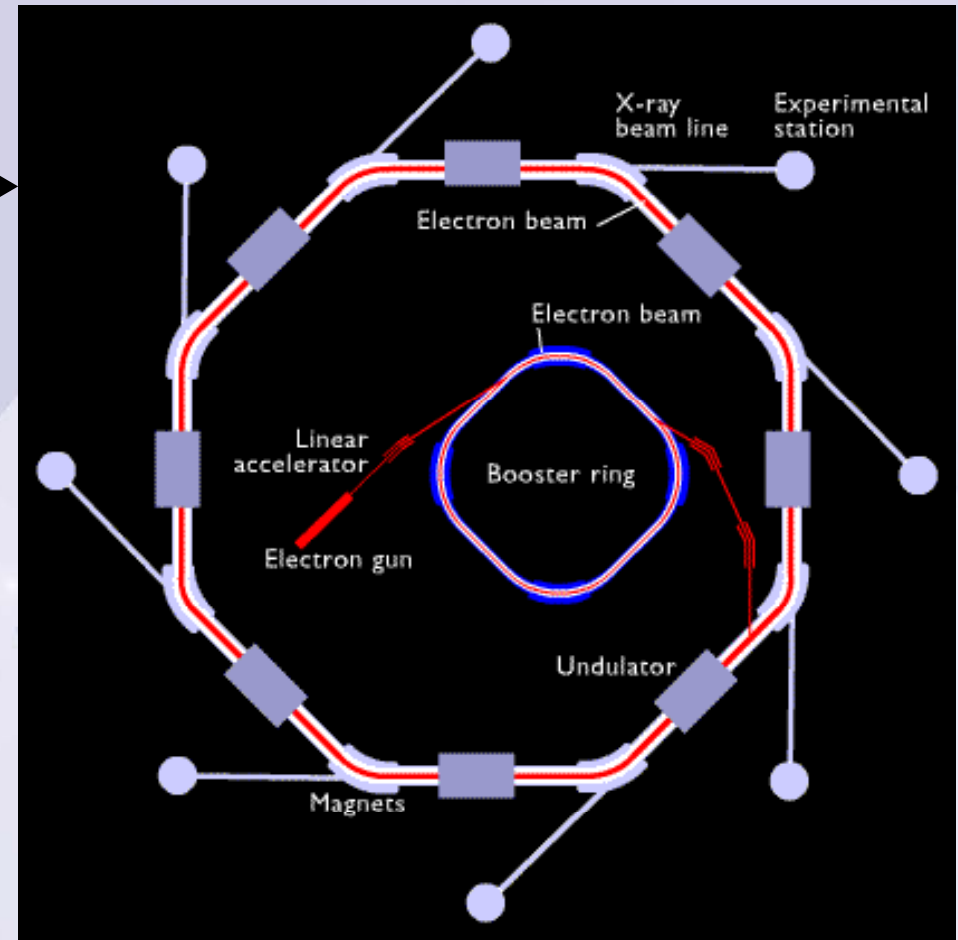
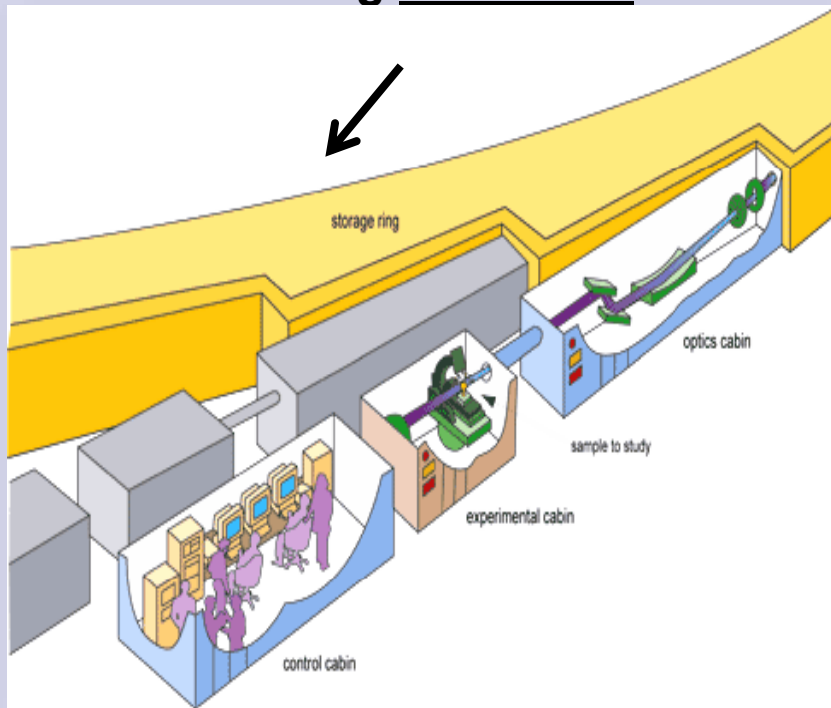


Diagnostics

Layout of a 3G Light Source

A beam of electrons is accelerated in a LINAC, further accelerated in a booster synchrotron, then accumulated in a storage ring. →

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



Layout of Diamond

100 MeV Linac

3 GeV Booster

C = 158.4 m

3 GeV Storage Ring

C = 562.6 m

Experimental Hall
and Beamlines

office
building

technical
plant

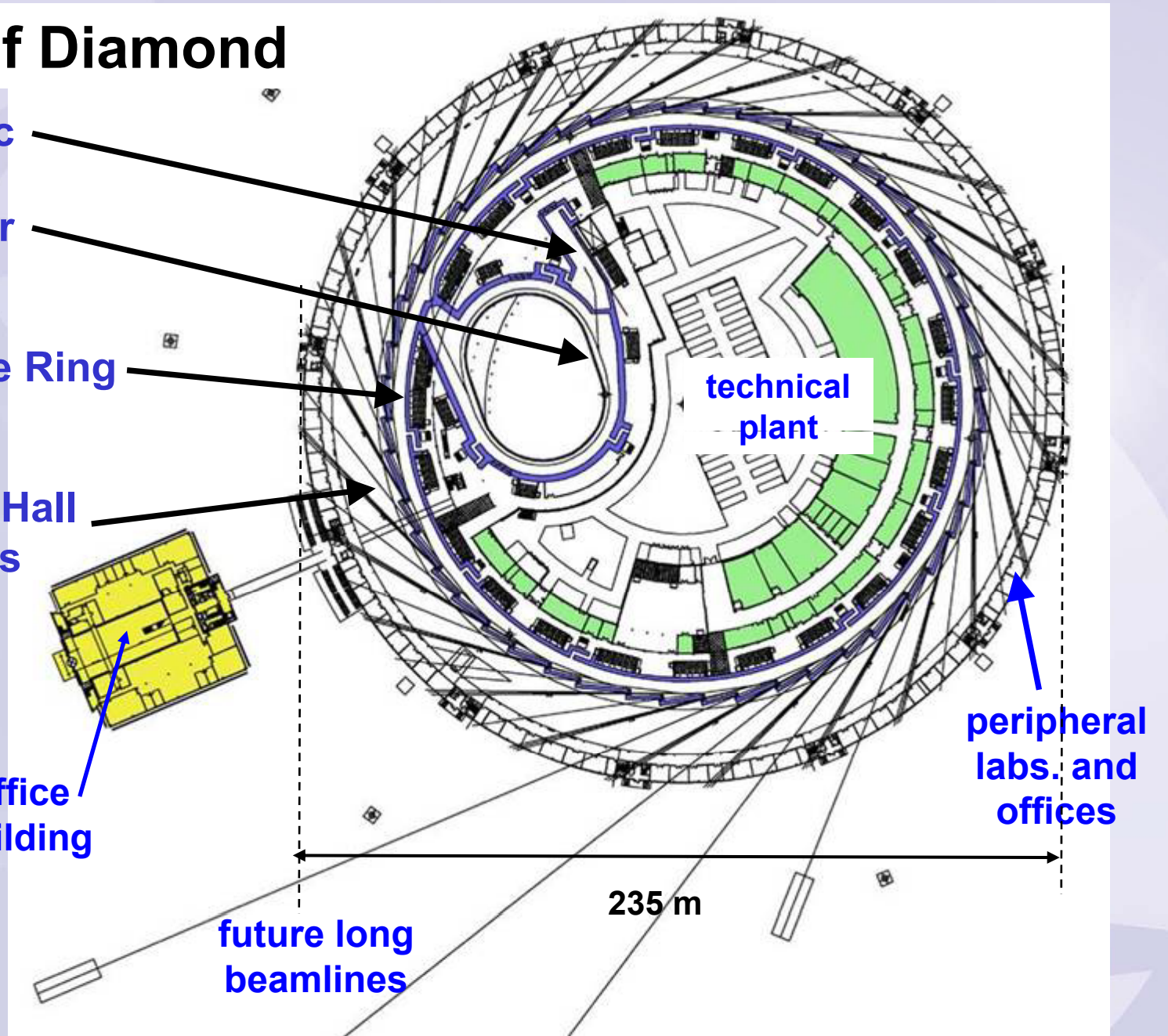
peripheral
labs and
offices

235 m

future long
beamlines

Diagnostics

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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*	$2 \cdot 10^{20}$
Peak brightness* (1Å)	10^{19}

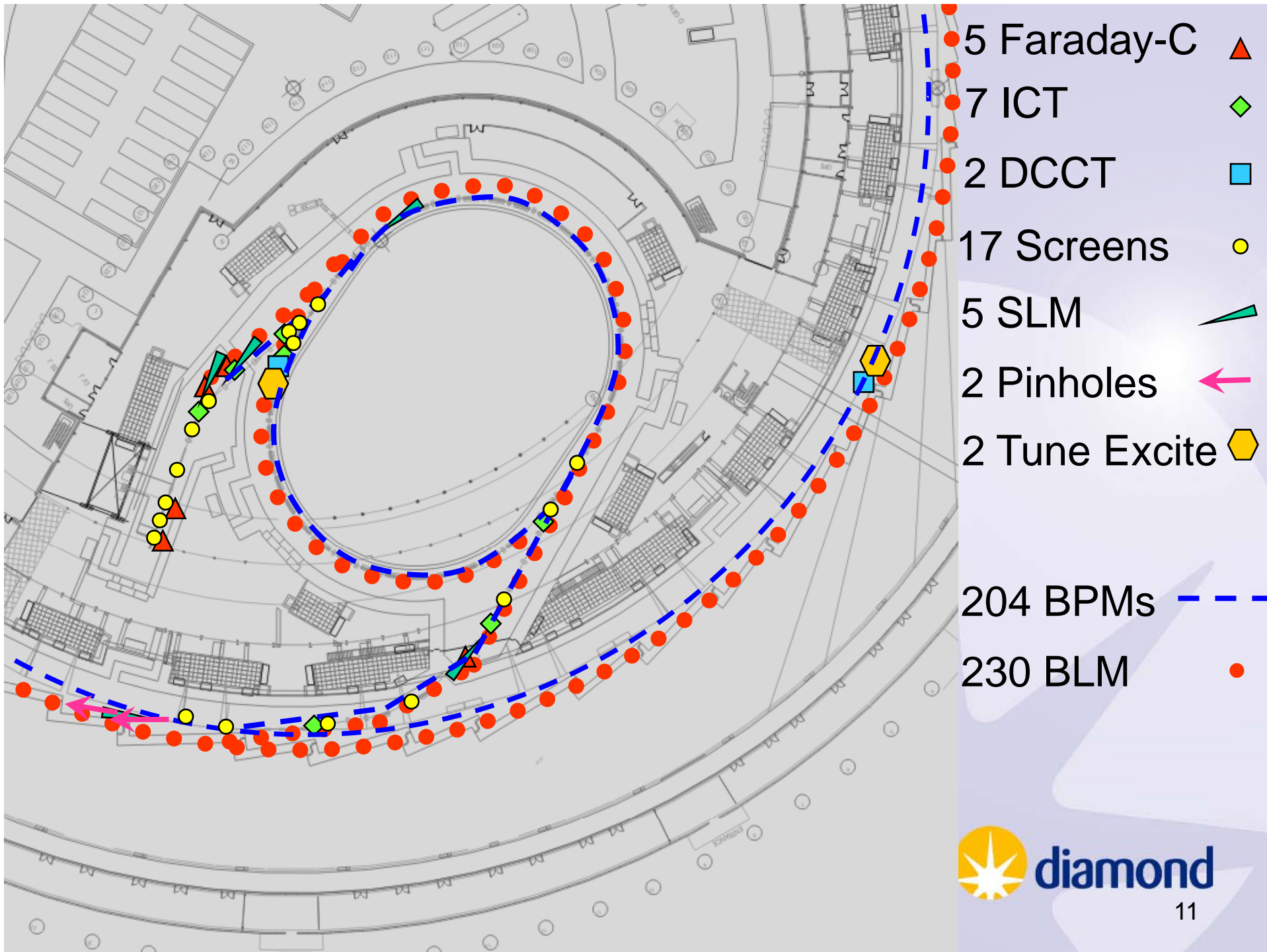
* photons/s/mrad²/mm²/0.1%bw
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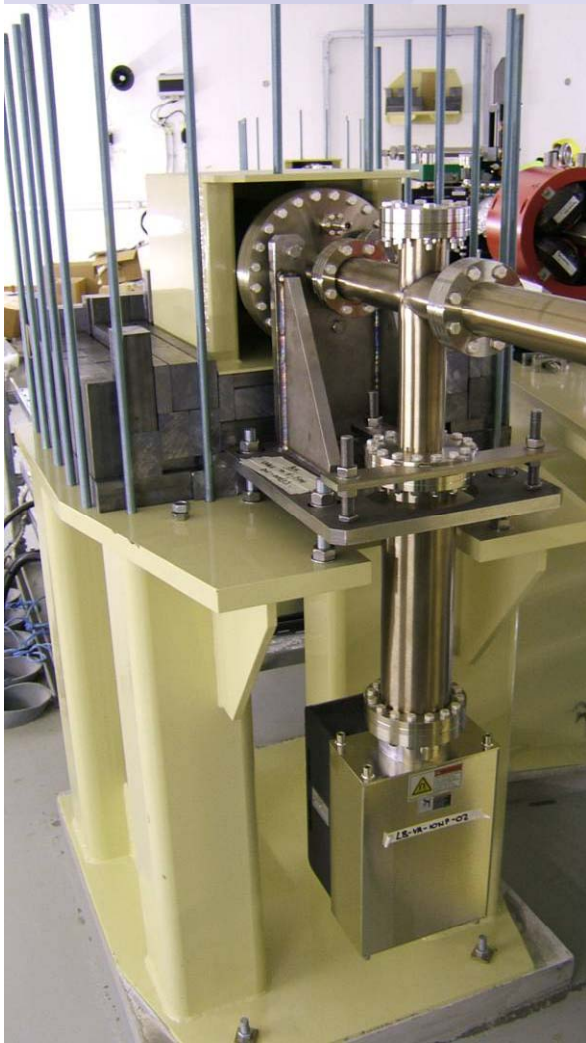


Diagnostics Requirements

- Track charge through 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



Faraday Cups, WCMs, ICTs



LTB FC



LINAC
FC

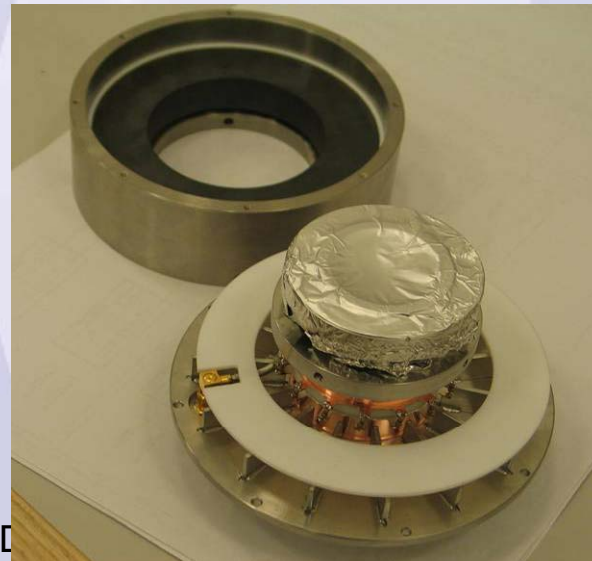
1st D



ICT and electronics

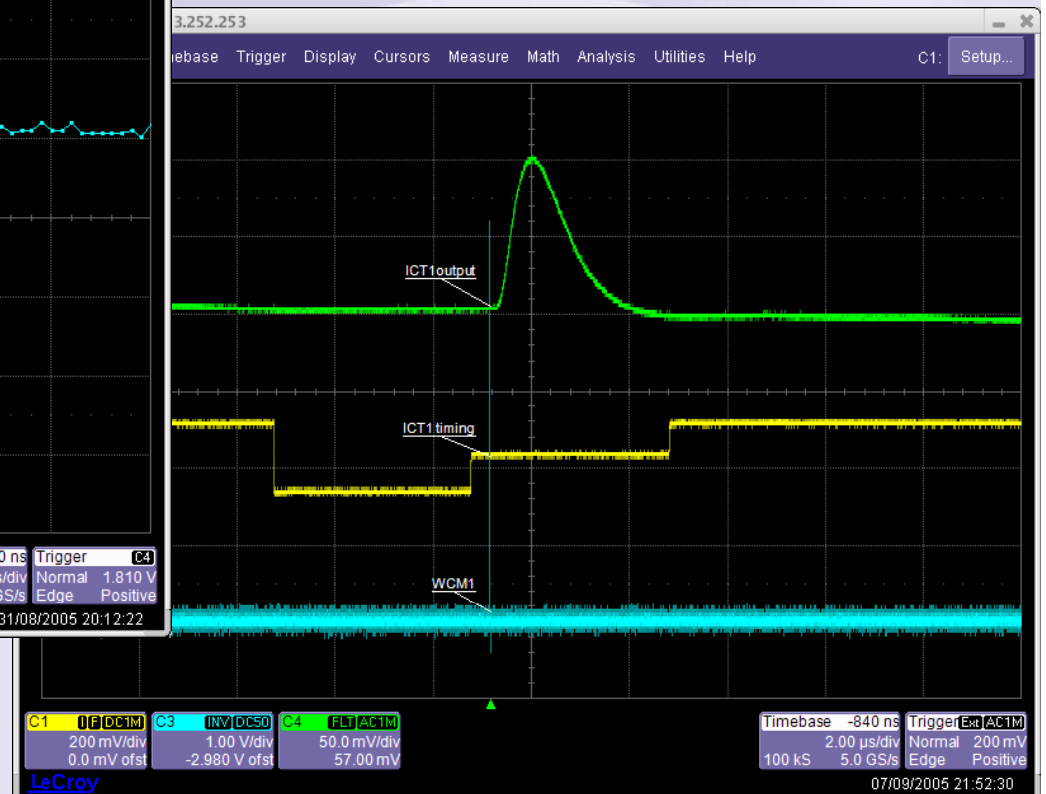
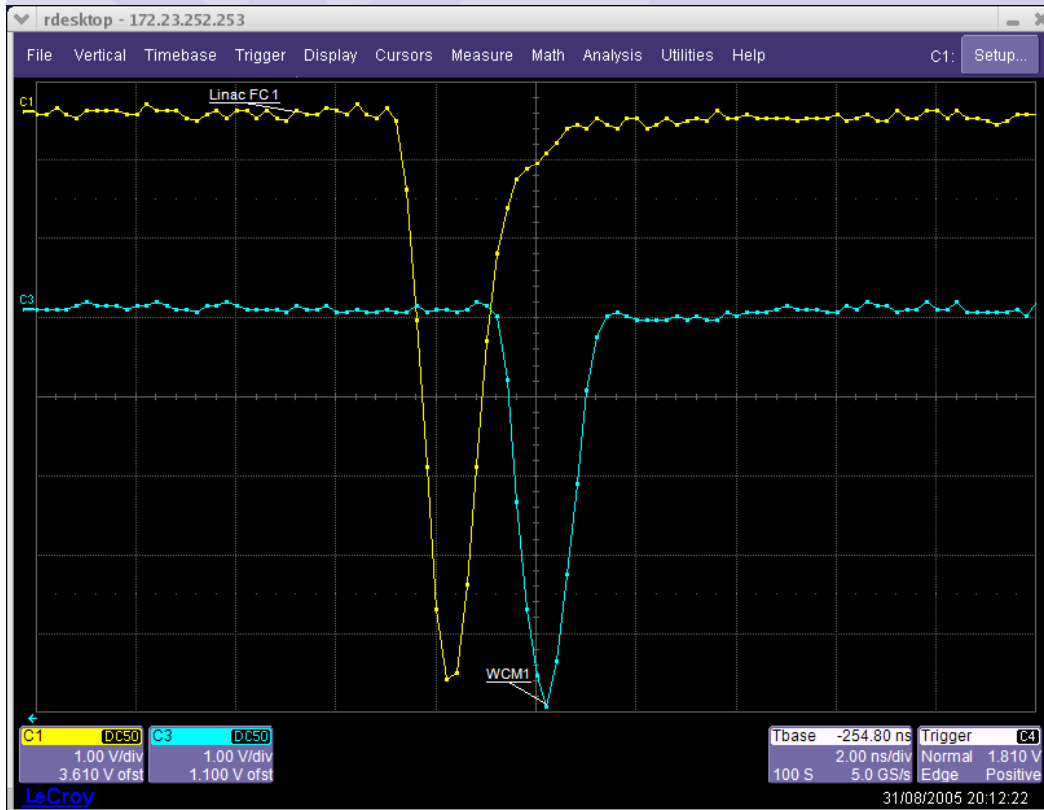


ICT shield



WCM for LINAC, LTB, BTS

The first bunches on WCM and ICT



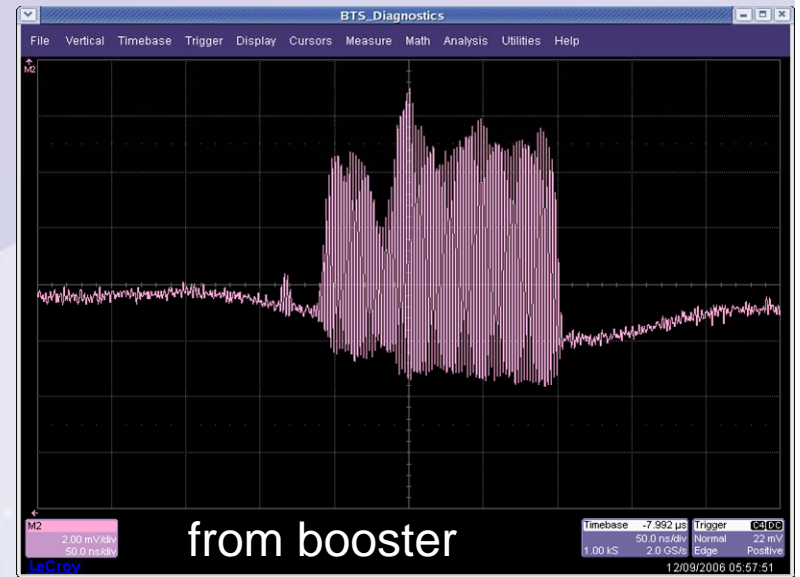
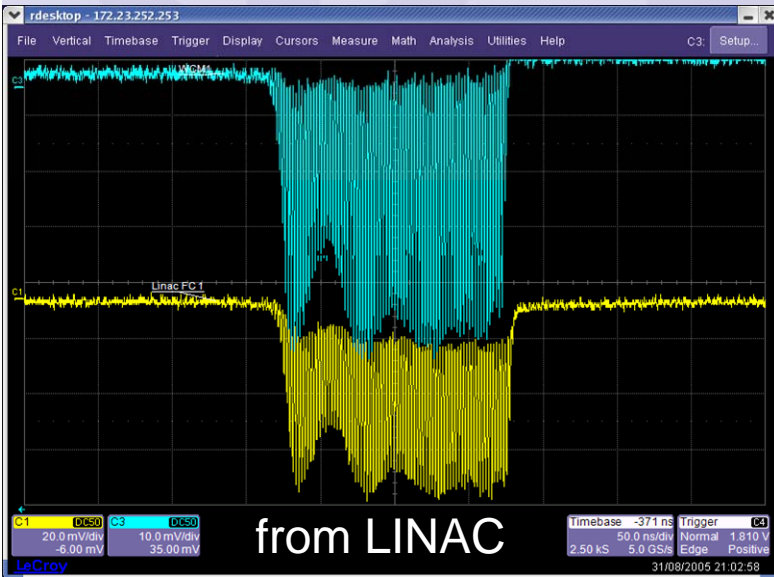
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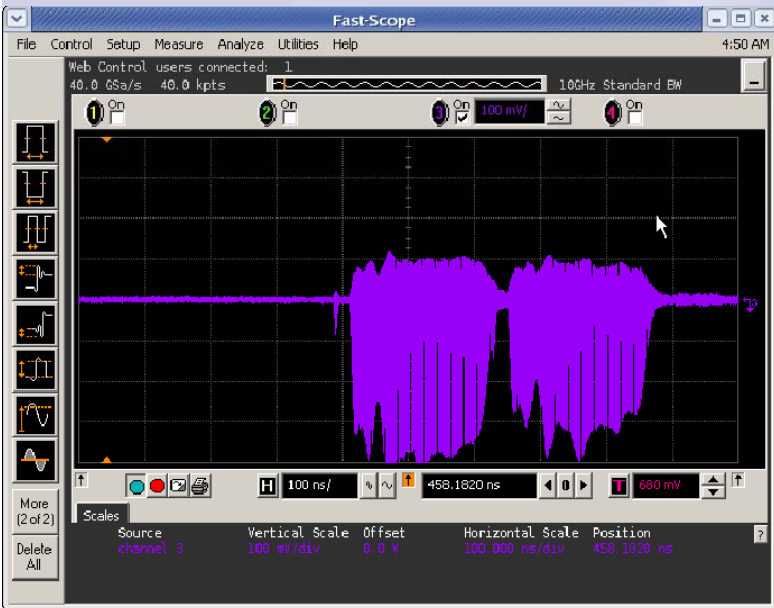


Bunch Charge and Train Structure

WCMs in transfer paths

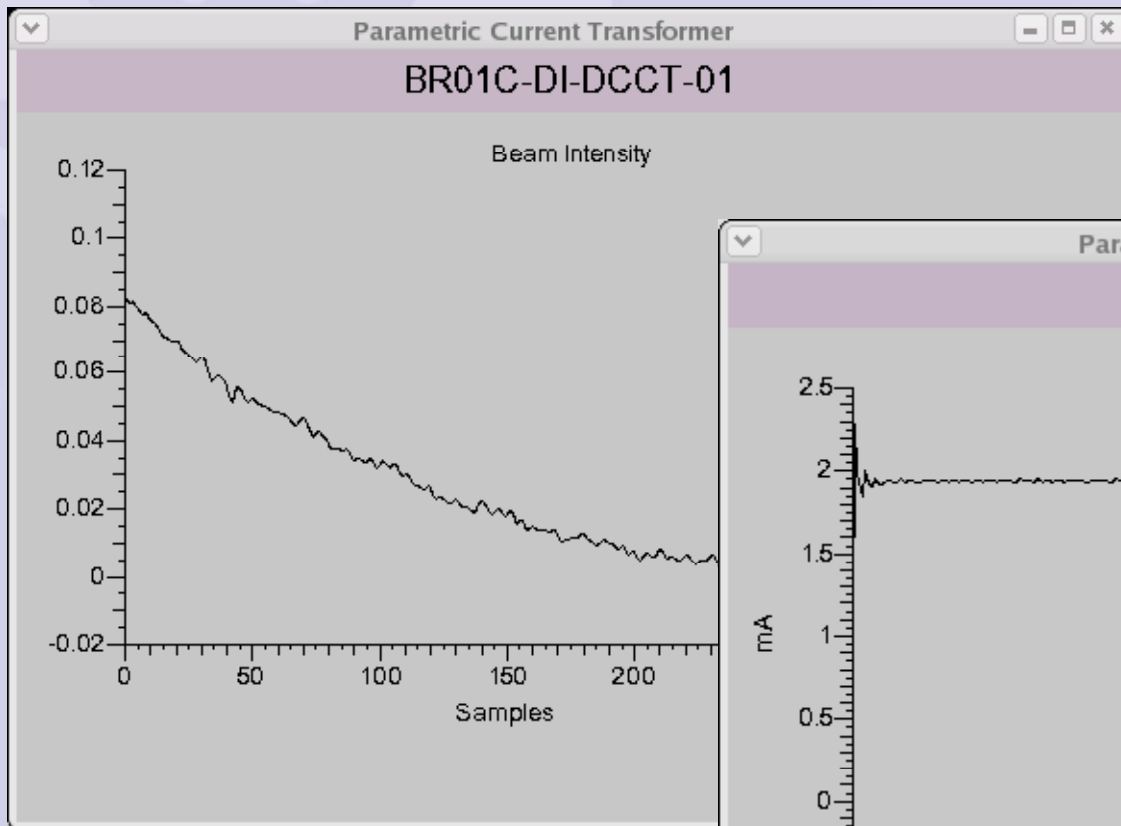


Button in SR

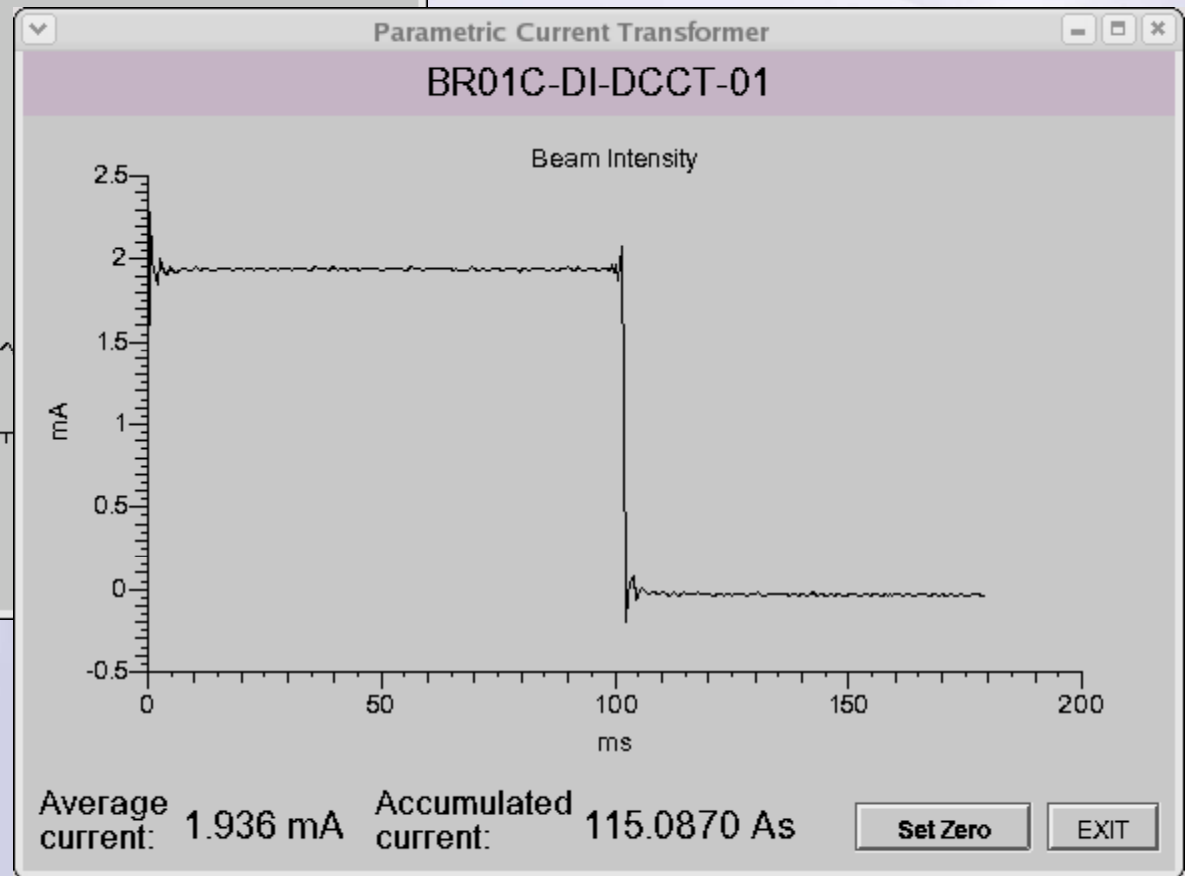


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Booster Current on DCCT



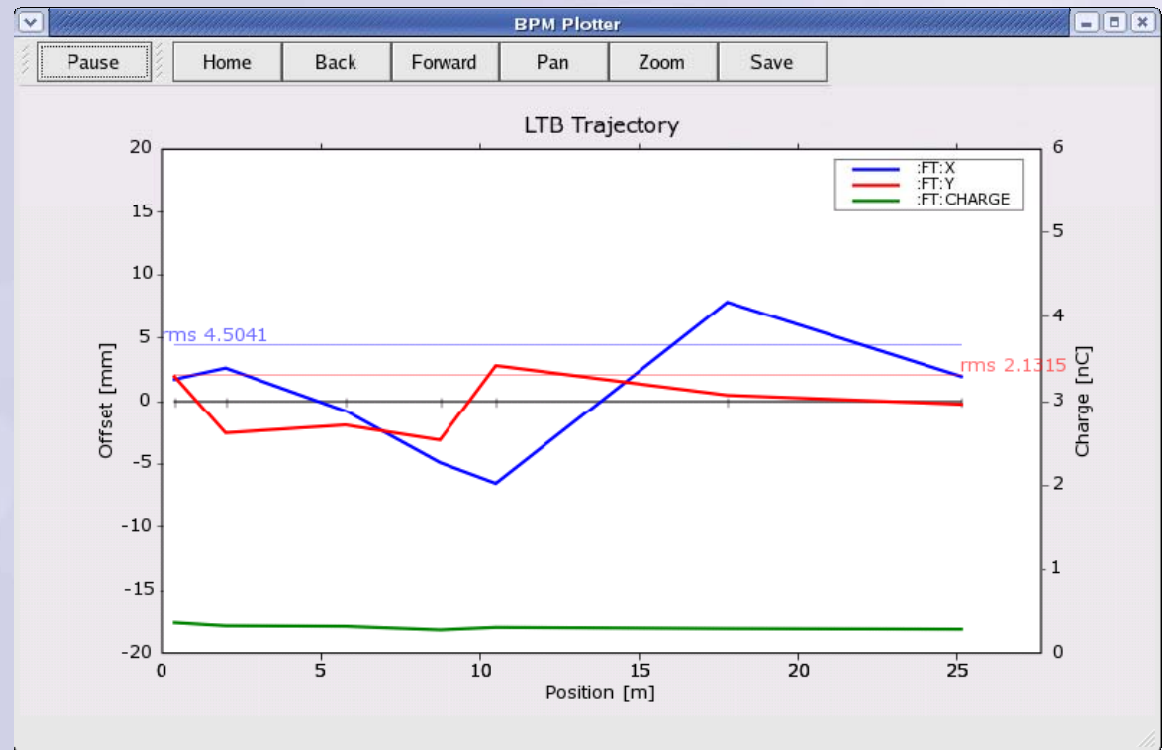
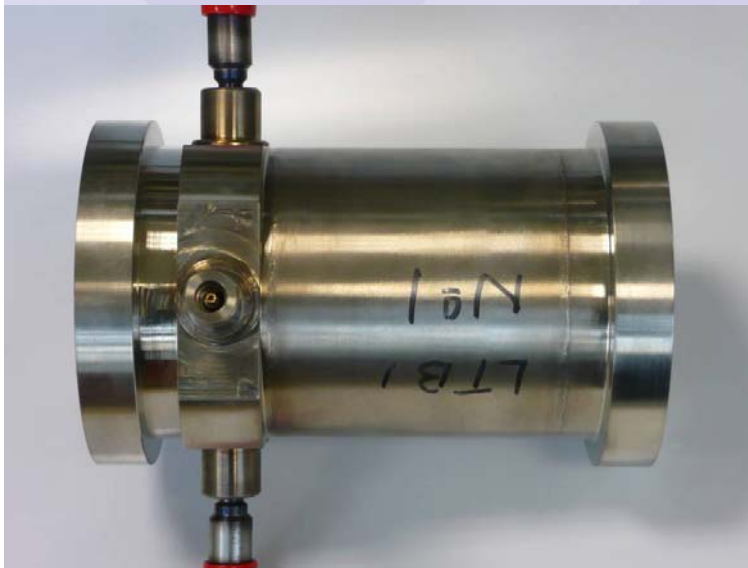
First measurement



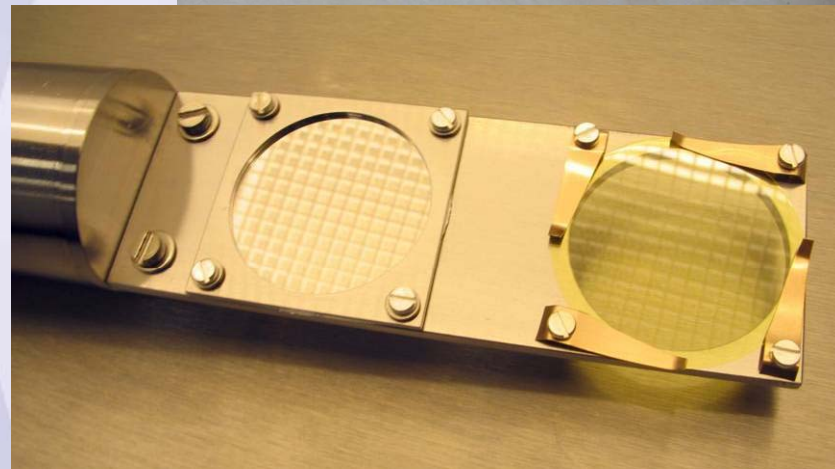
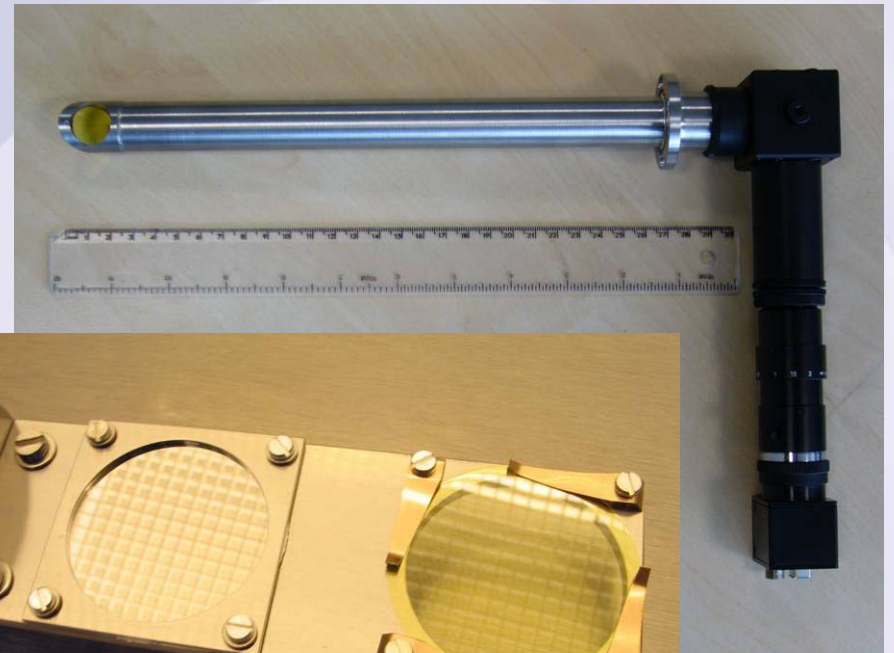
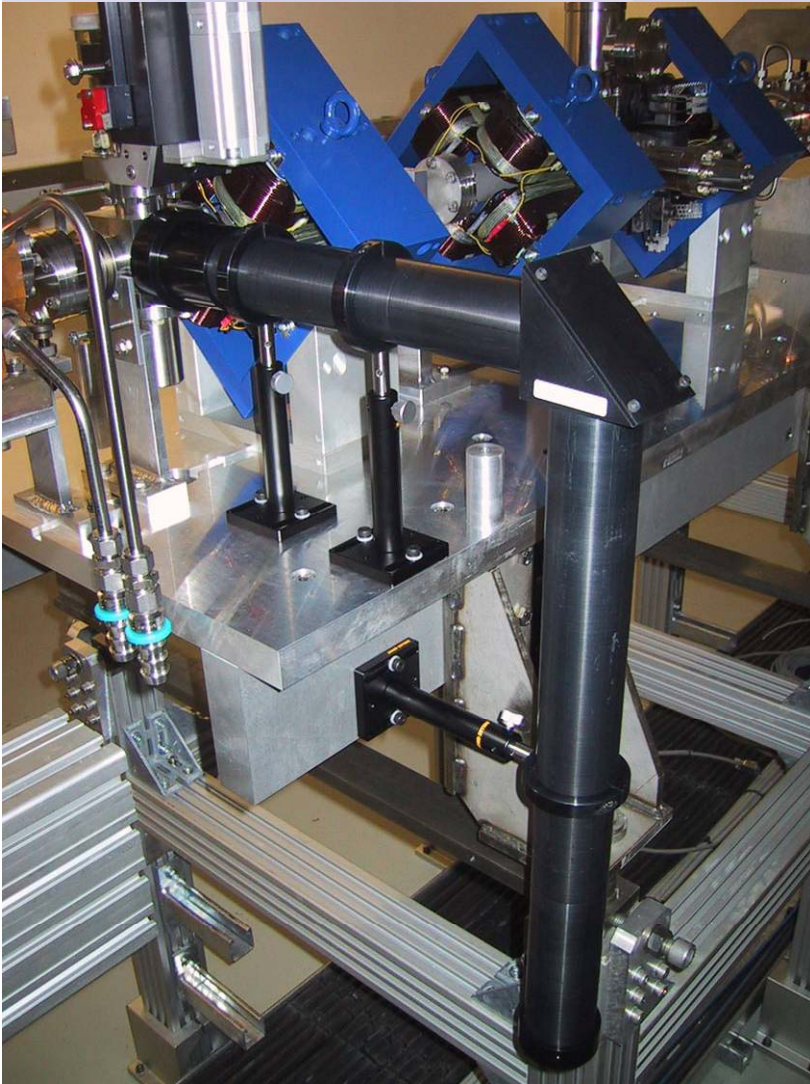
Later with extraction after 100ms

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Strip Line BPM Pickups in Transfer Paths

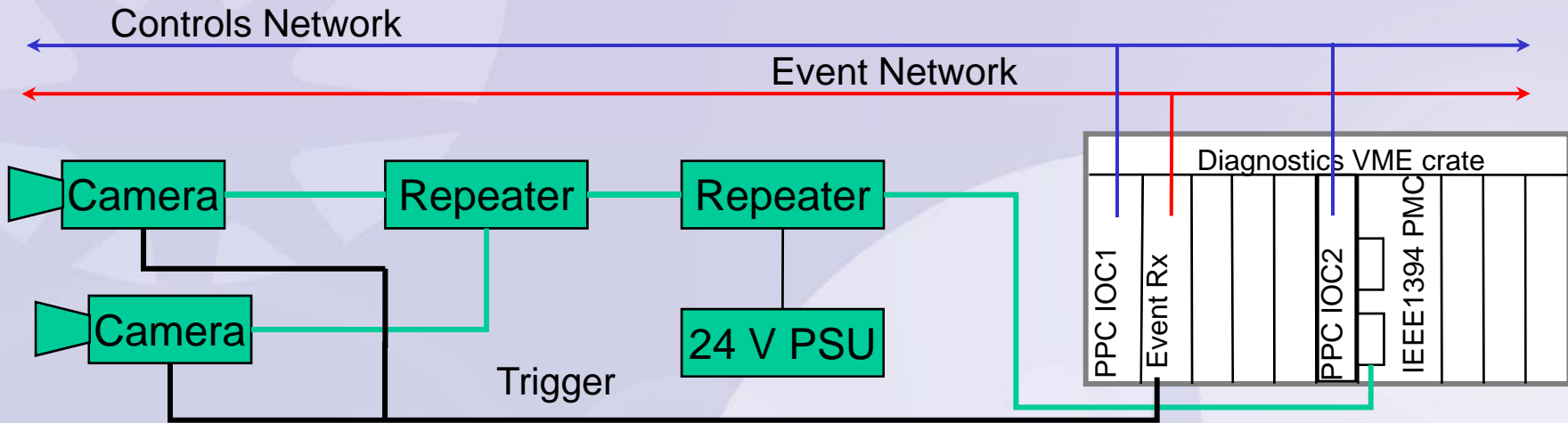


Screens and Optics



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IEEE1394 Cameras



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EDM Camera Display

Diagnosics Camera SR01C-DI-DCAM-02

SR01C-DI-YAG-02 and SR01C-DI-DCAM-02

Camera Image

11.25 mm

0.00 mm

-11.25 mm

-15.00 mm 0.00 mm 15.00 mm

Camera Status

Enable **Enabled**

Camera Controls

Gain: **245**

Exposure: **1479**

1 Frames/s: **1.7**

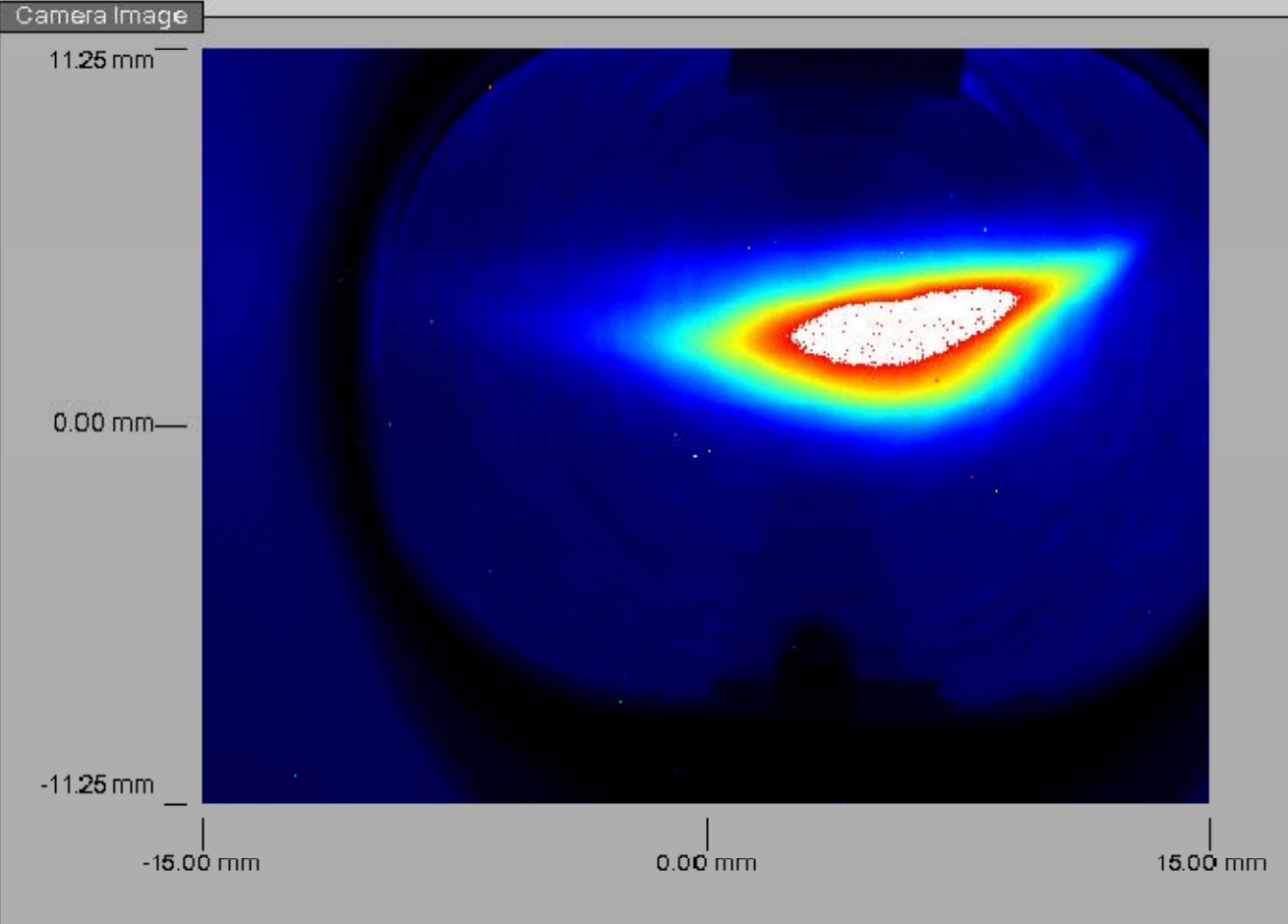
Digital Zoom and Pan

1/2 1/1 Width: **1024**

Horizontal centre: **512**

Vertical centre: **384**

Camera Config Position Info Grey Scale Show Grid EXIT



The image shows a software interface for an EDM camera. The main window displays a circular field of view with a central bright spot, likely representing the EDM process. The spot is surrounded by a color gradient from blue to red to yellow. The interface includes a title bar, a main display area with a coordinate system, and several control panels on the right and bottom. The right panel contains 'Camera Status' (Enabled), 'Camera Controls' (Gain: 245, Exposure: 1479, Frames/s: 1.7), and 'Digital Zoom and Pan' (Zoom: 1/2, Width: 1024, Horizontal centre: 512, Vertical centre: 384). The bottom panel has buttons for 'Camera Config', 'Position Info', 'Grey Scale', 'Show Grid', and 'EXIT'.

Precisely Triggered Acquisition

Diagnosics Camera BR03C-DI-DCAM-01

BR03C-DI-OTR-02 and BR03C-DI-DCAM-01

Camera Image

11.25 mm

0.00 mm

-11.25 mm

-15.00 mm 0.00 mm 15.00 mm

kicked beam before main septum

beam in booster during ramp

edge of screen

Camera Status

Enable Enabled

BR03C-DI-OTR-02 Control

OTR in

Out OTR

Camera Controls

Gain: 1537

Exposure: 1

1 Frames/s: 5.0

Digital Zoom and Pan

1/2 1/1 Width: 1024

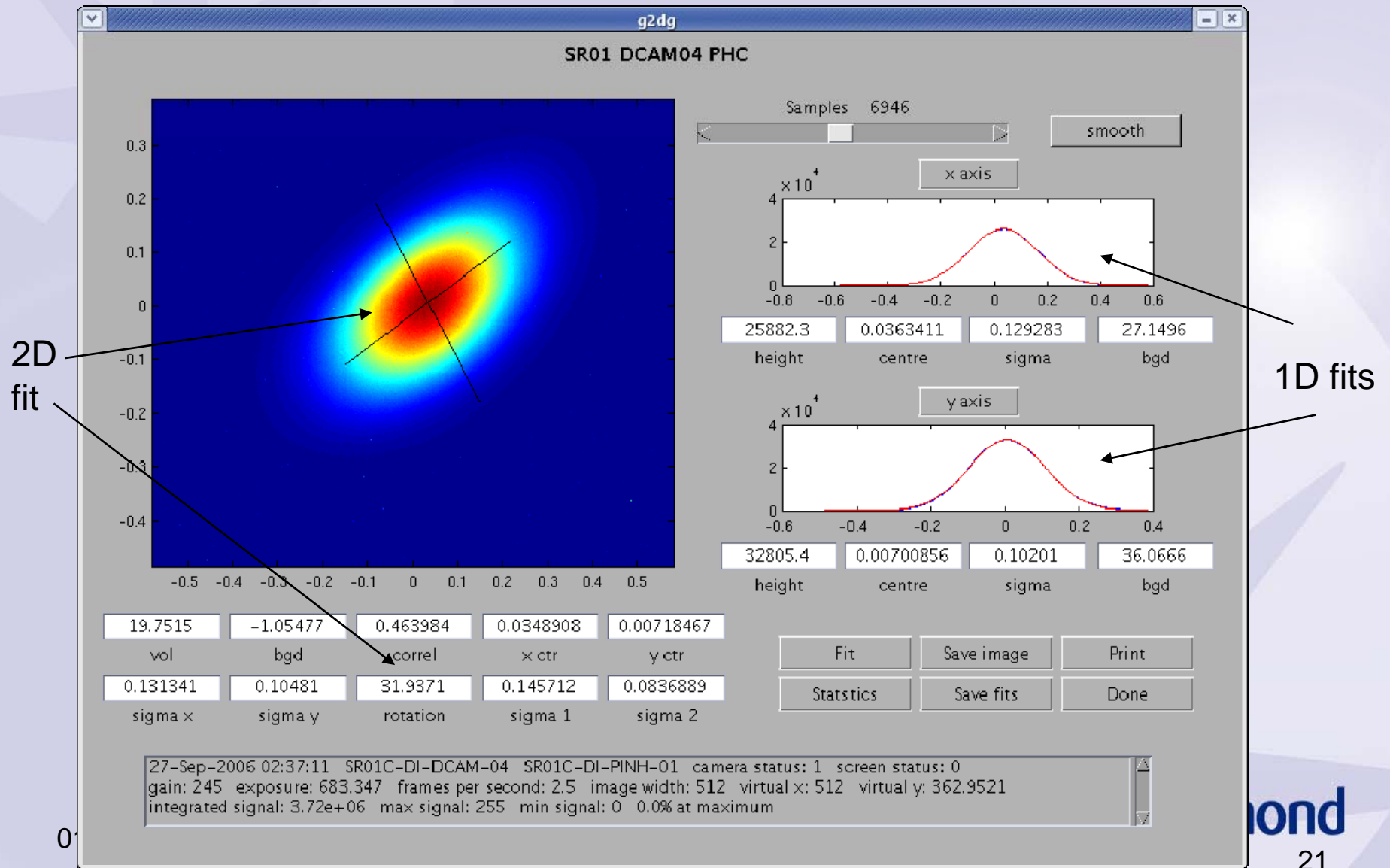
Horizontal centre: 585

Vertical centre: 384

Camera Config Position Info Grey Scale Show Grid Grid Size 100 EXIT

The screenshot displays a software interface for a diagnostics camera. The main window, titled 'Diagnosics Camera BR03C-DI-DCAM-01', shows a camera image of a beam spot. The image is overlaid with a coordinate system with vertical axis labels at 11.25 mm, 0.00 mm, and -11.25 mm, and horizontal axis labels at -15.00 mm, 0.00 mm, and 15.00 mm. A bright blue and yellow beam spot is visible, with a dashed white oval around it labeled 'beam in booster during ramp'. An arrow points to the spot from the text 'kicked beam before main septum'. Another arrow points to the right edge of the image from the text 'edge of screen'. To the right of the image are three control panels: 'Camera Status' with an 'Enable' button and 'Enabled' text; 'BR03C-DI-OTR-02 Control' with an 'OTR in' label and 'Out' and 'OTR' buttons; and 'Camera Controls' with sliders for 'Gain: 1537', 'Exposure: 1', and 'Frames/s: 5.0'. Below the image are buttons for 'Camera Config', 'Position Info', 'Grey Scale', 'Show Grid', 'Grid Size 100', and 'EXIT'.

Image Analysis



Orbit Stability Requirements in 3rd Generation Light Sources

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

$$\Delta x < 0.1 \cdot \sigma_x$$

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

$$\Delta y < 0.1 \cdot \sigma_y$$

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

For Diamond nominal optics (at short straight sections)

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

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

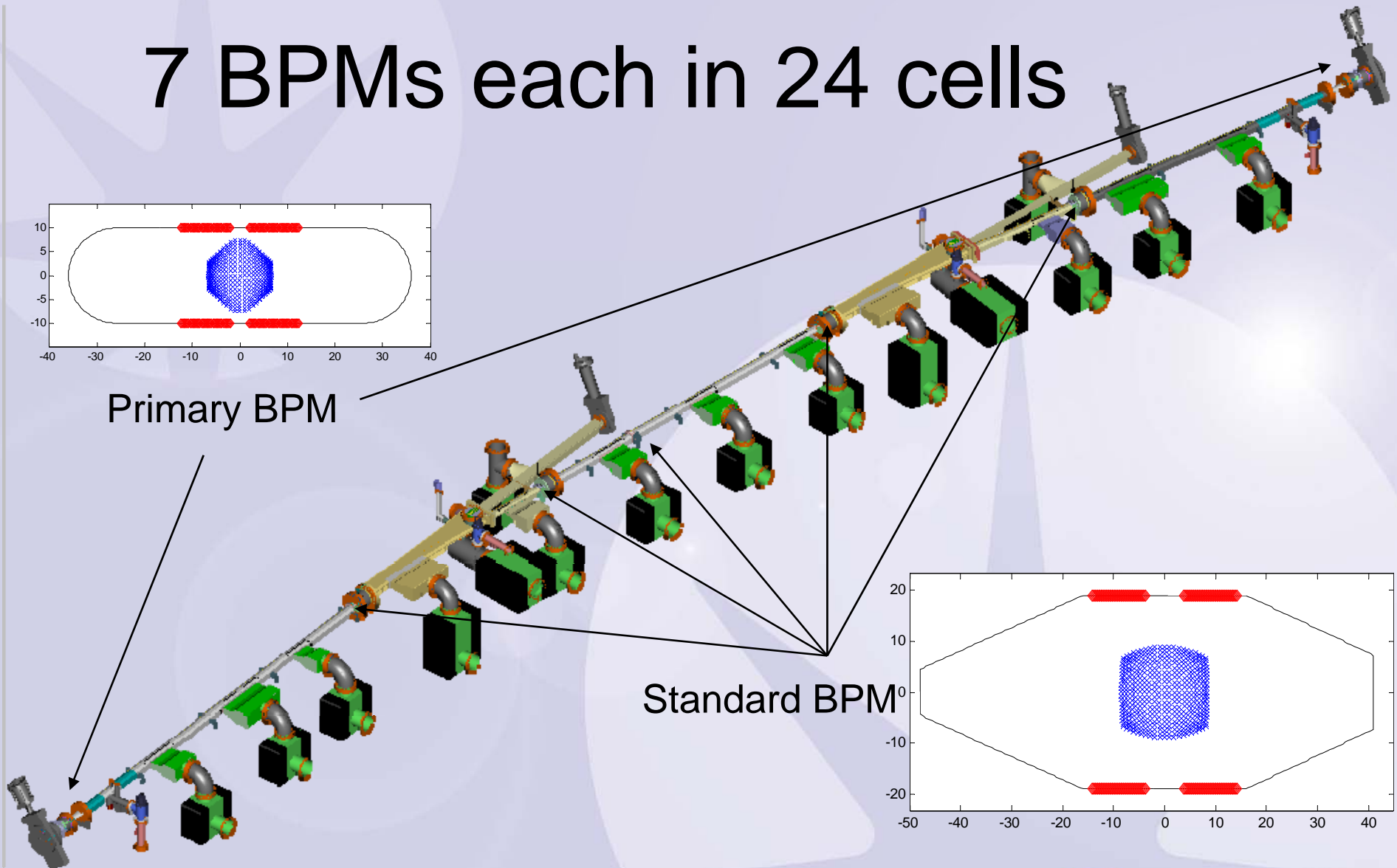
Motivation and Challenges

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

Correct as fast as possible

Minimise or remove from correction

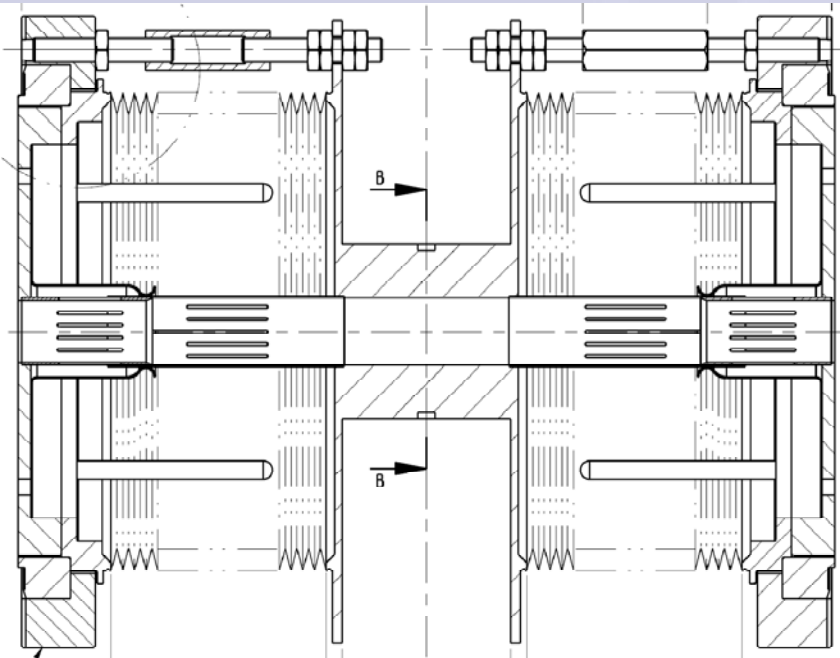
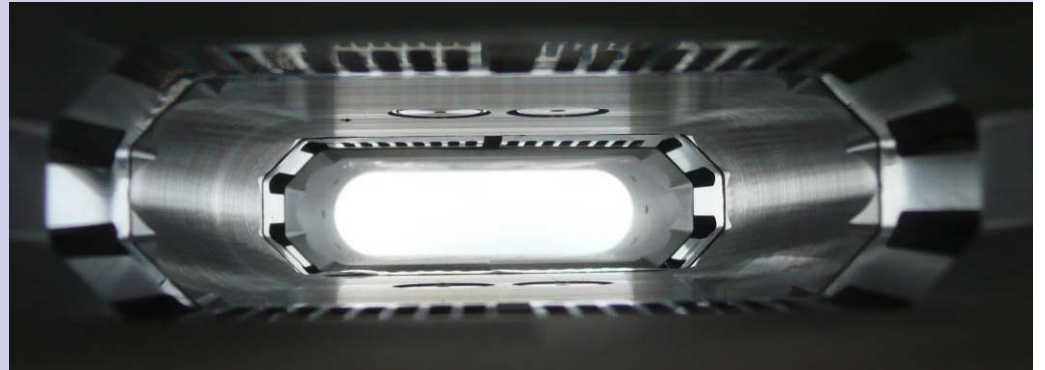
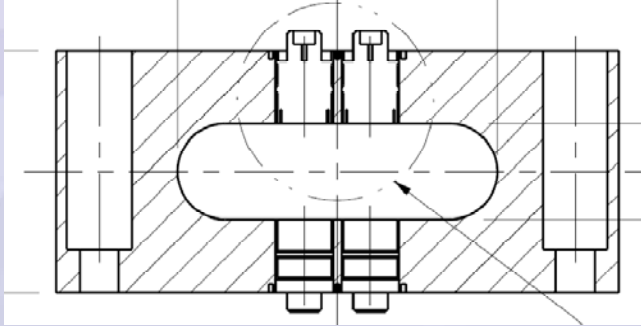
7 BPMs each in 24 cells



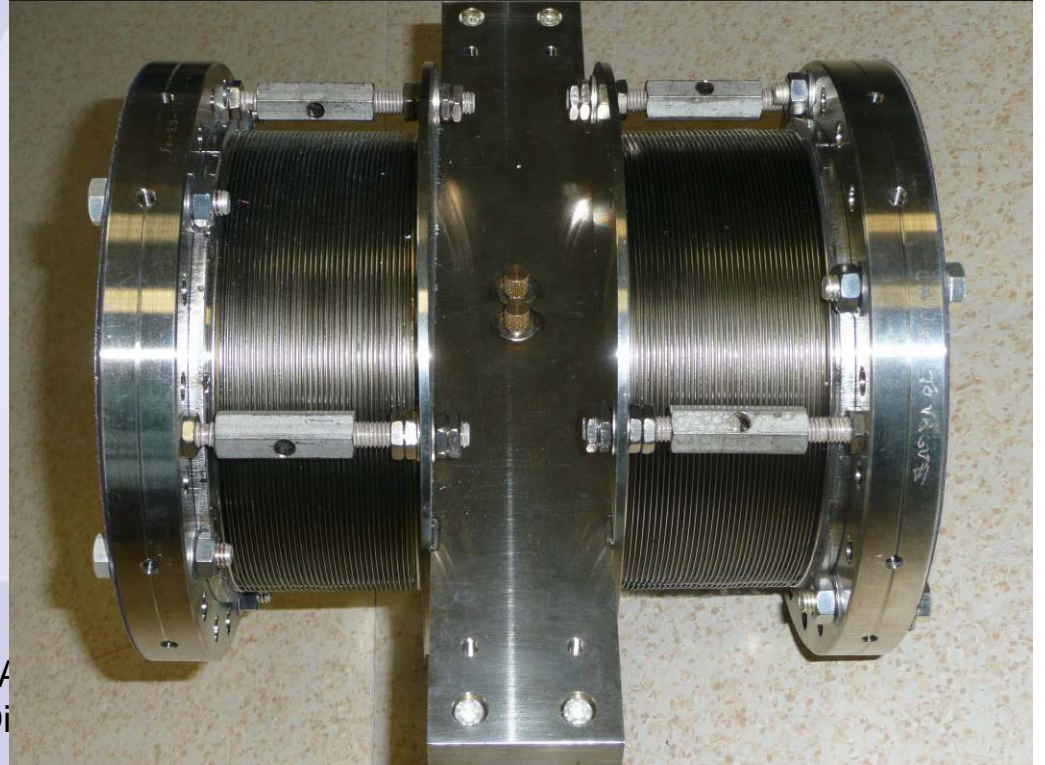
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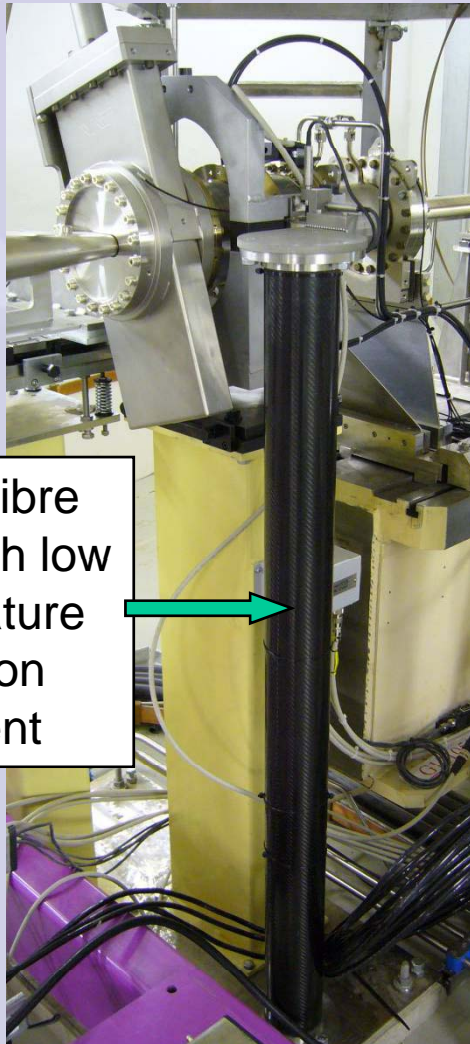
Button Pickup



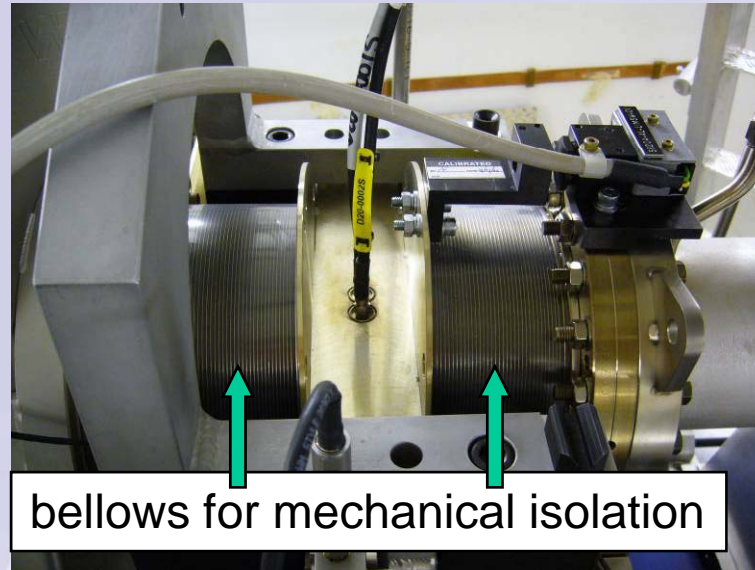
ITA
Di



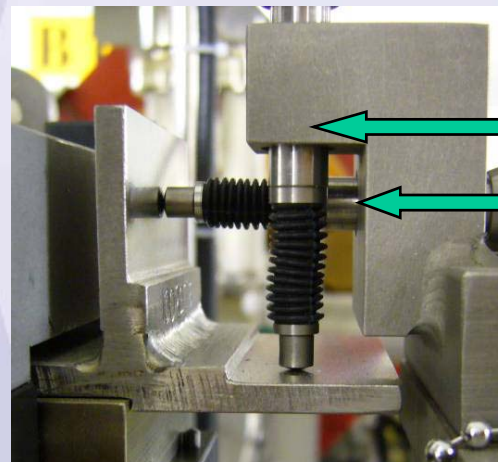
Primary BPM with reference pillar



carbon fibre pillar with low temperature expansion coefficient



bellows for mechanical isolation

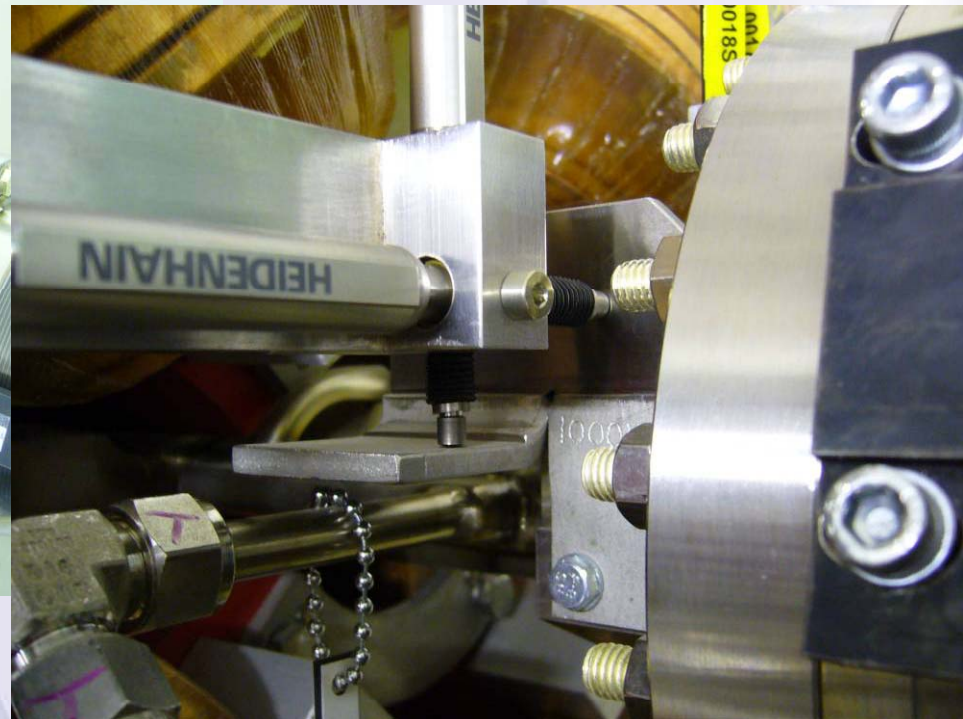
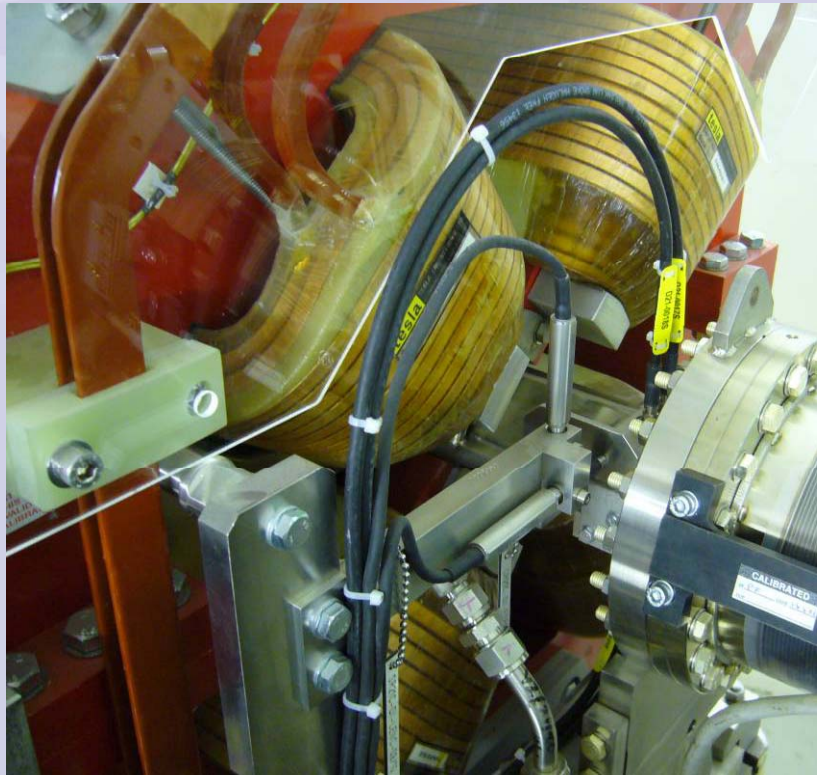


length gauges sense H/V position with 0.5um resolution

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Standard BPM near Quad

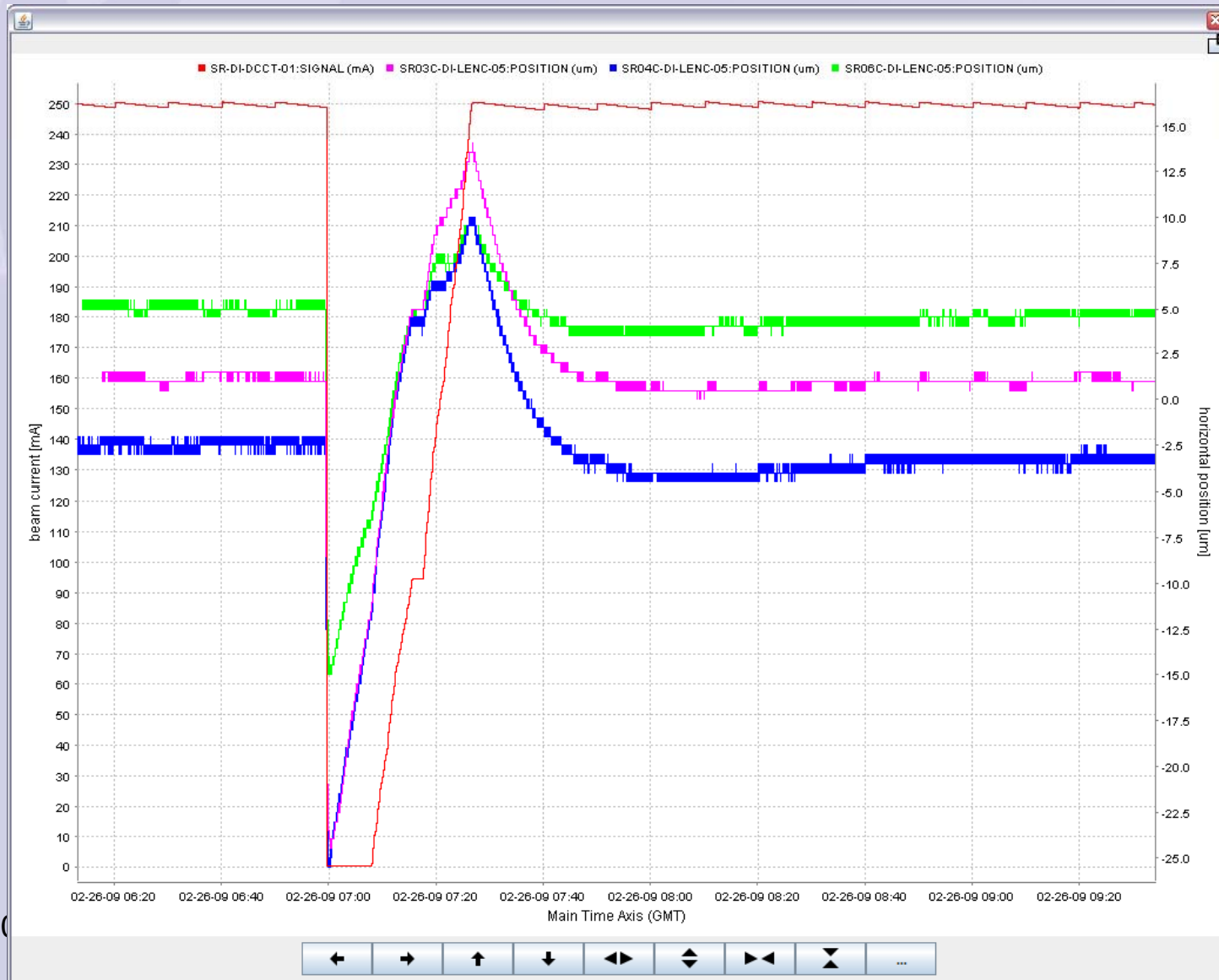


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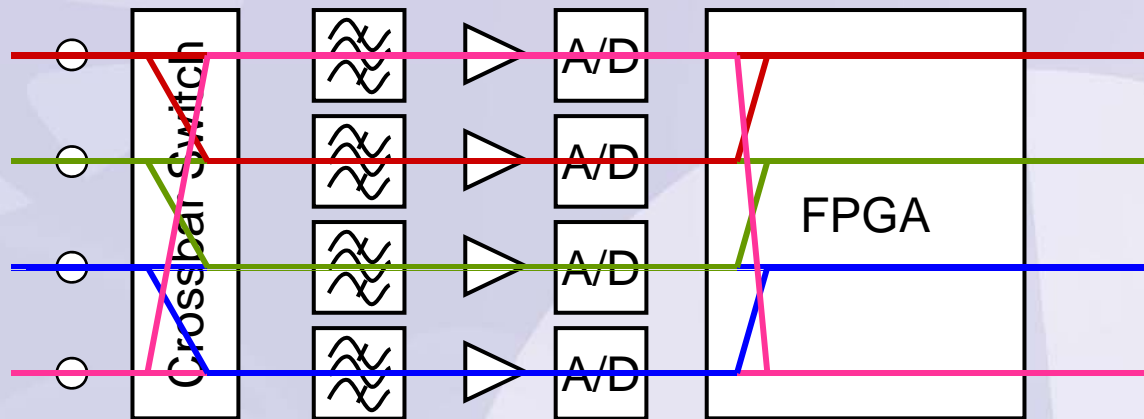
Some BPMs move after beam loss



01/04/20

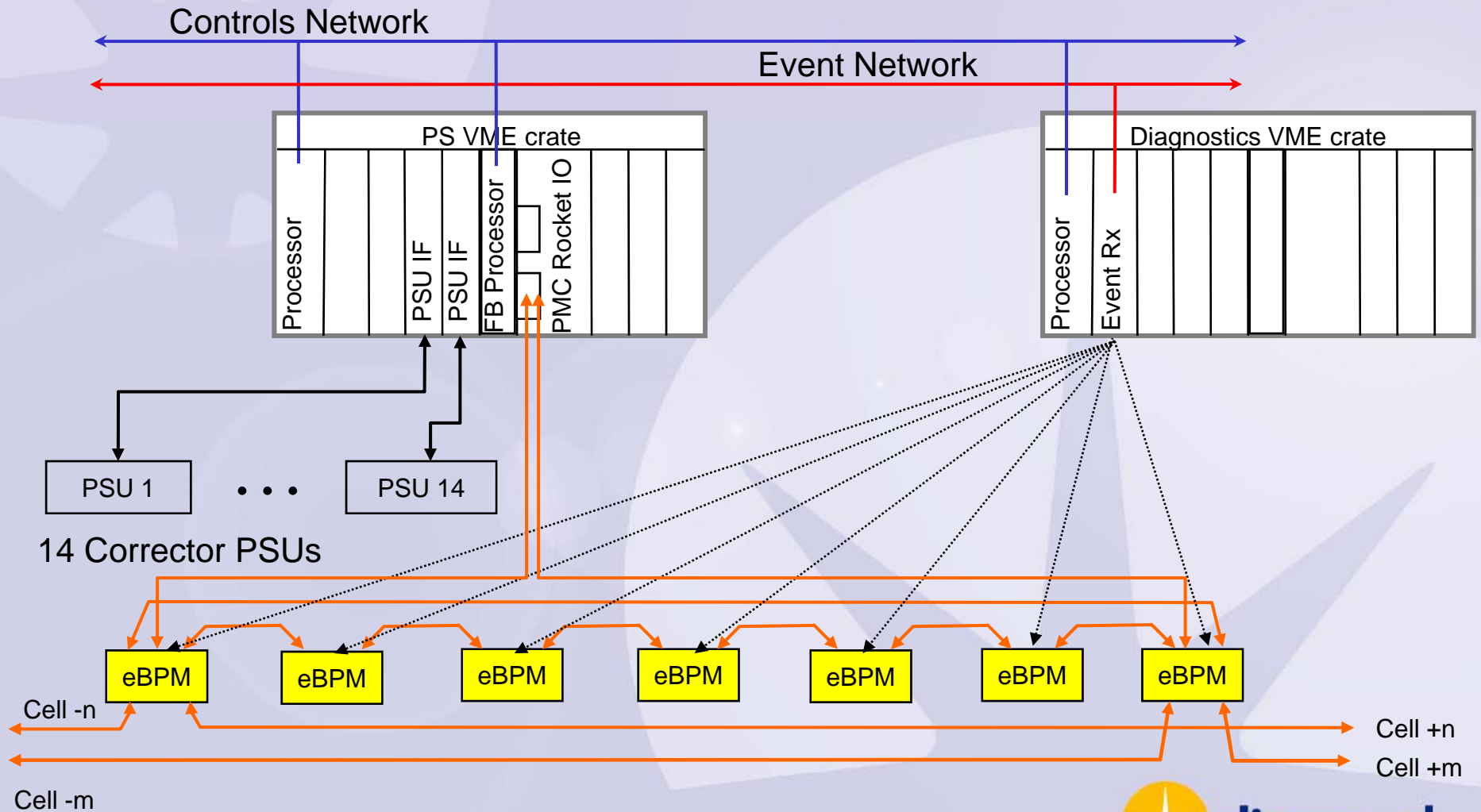
ond

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

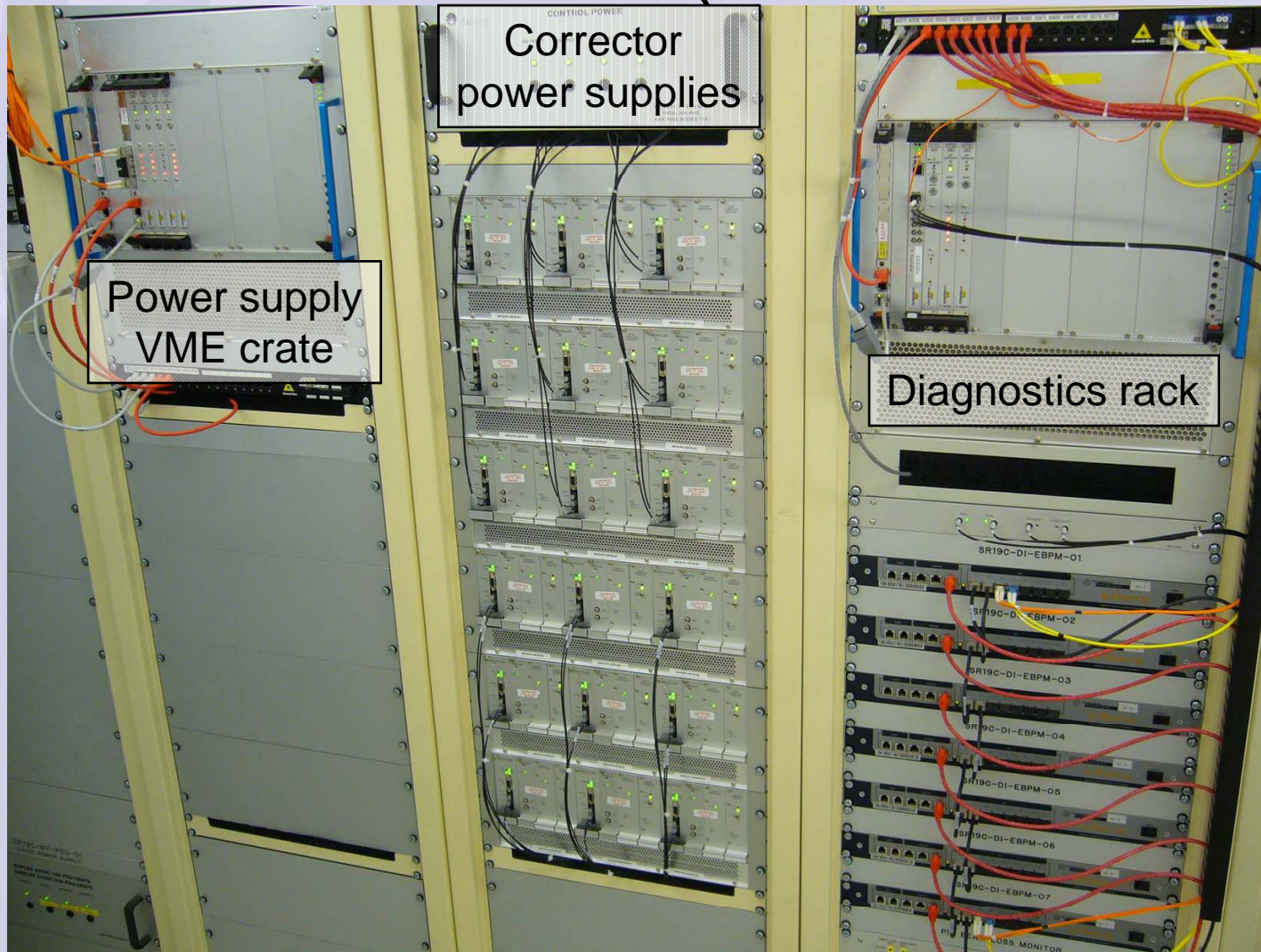


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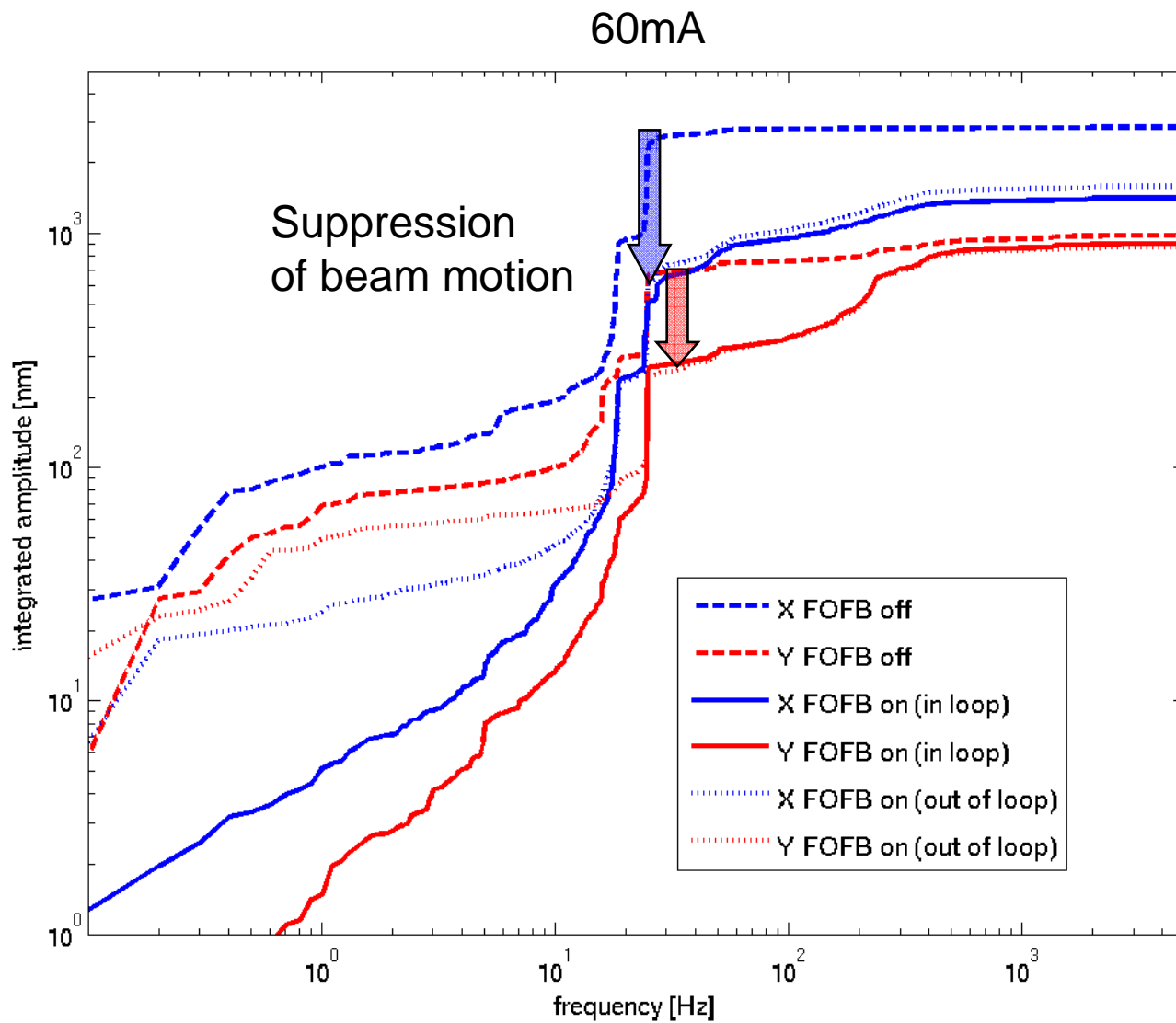
FOFB Installation (one of 24 cells)



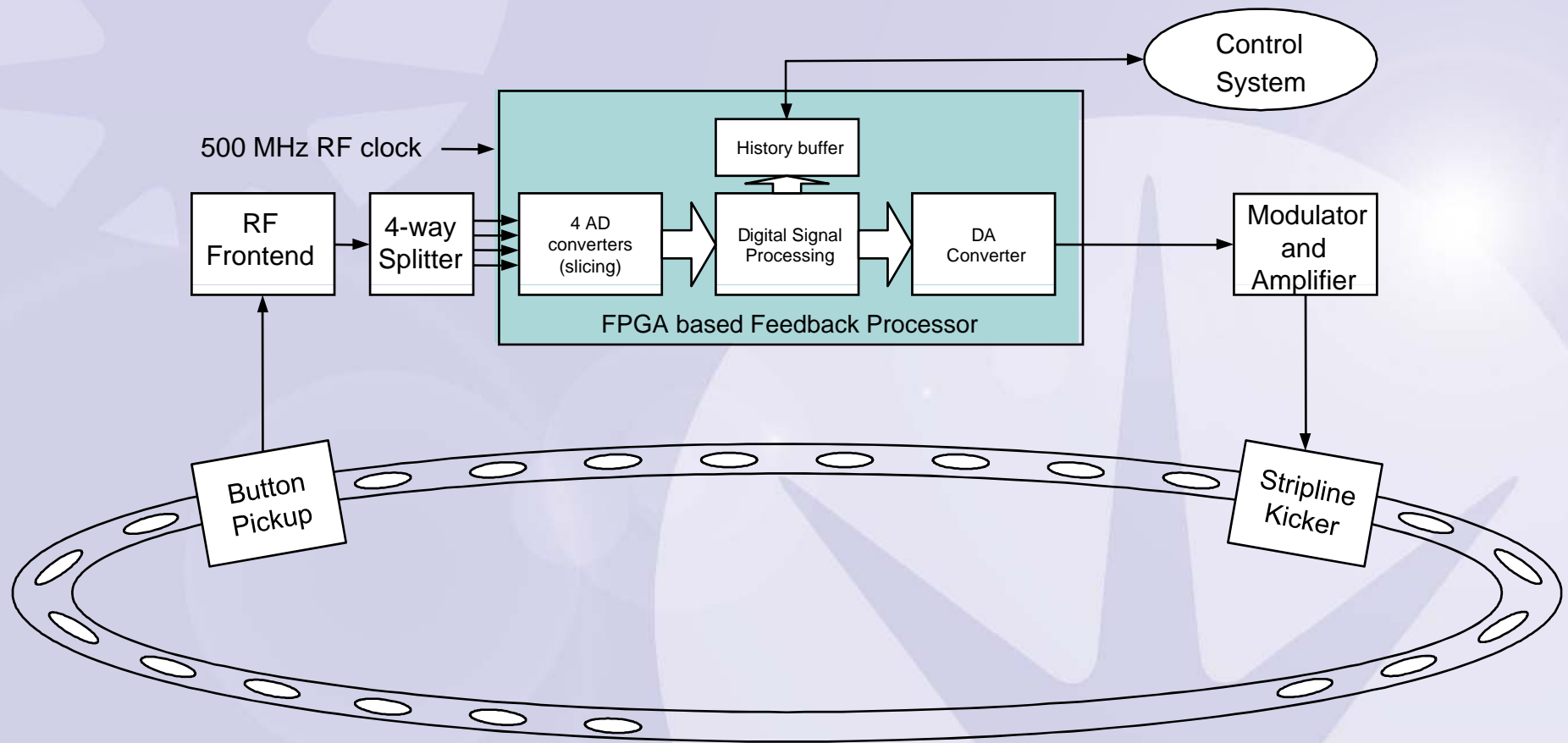
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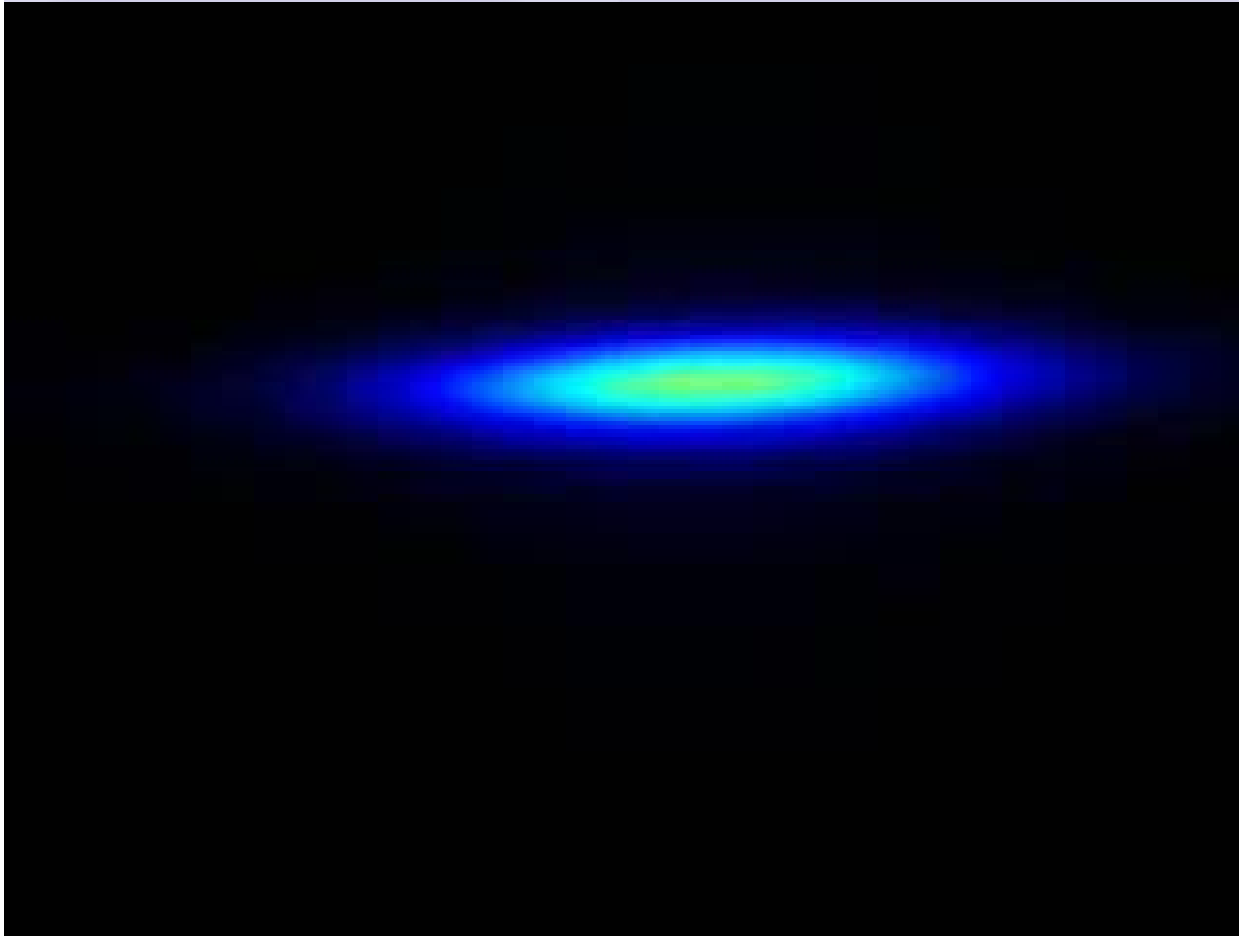
FOFB Performance



Transverse Bunch-by-Bunch Feedback



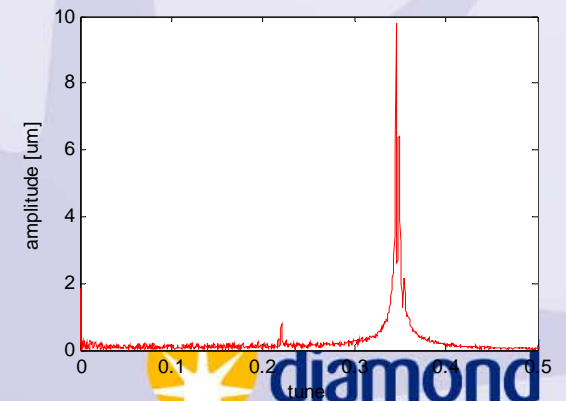
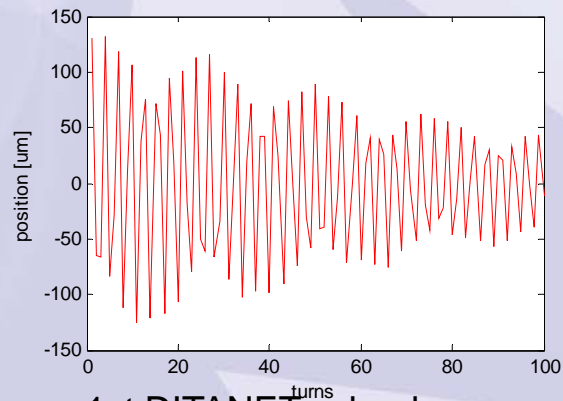
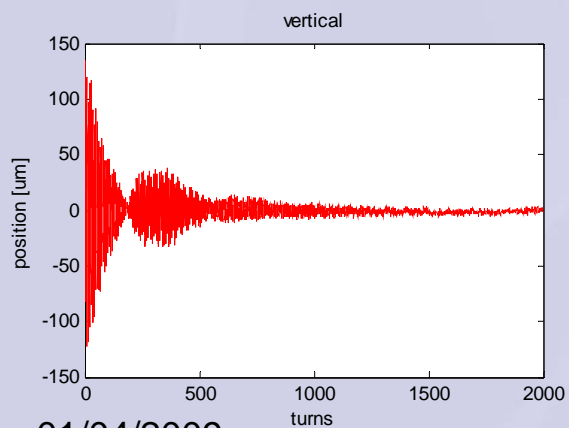
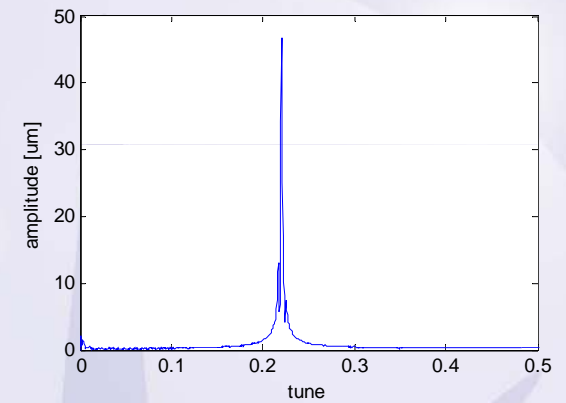
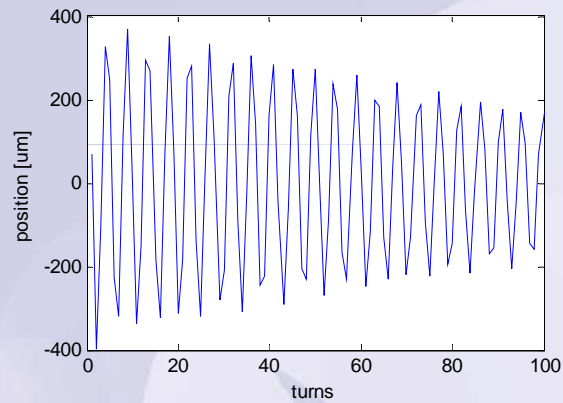
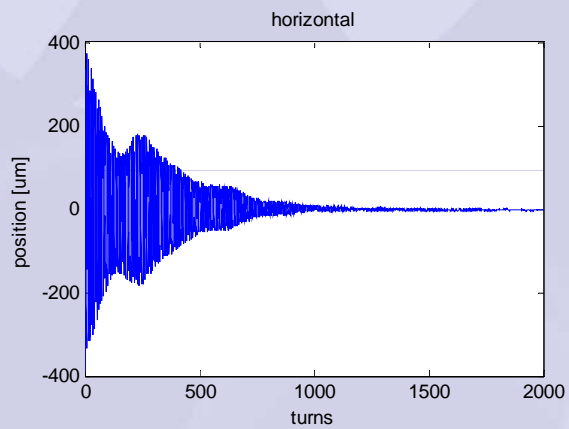
Bunch-by-Bunch Feedback in Action



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

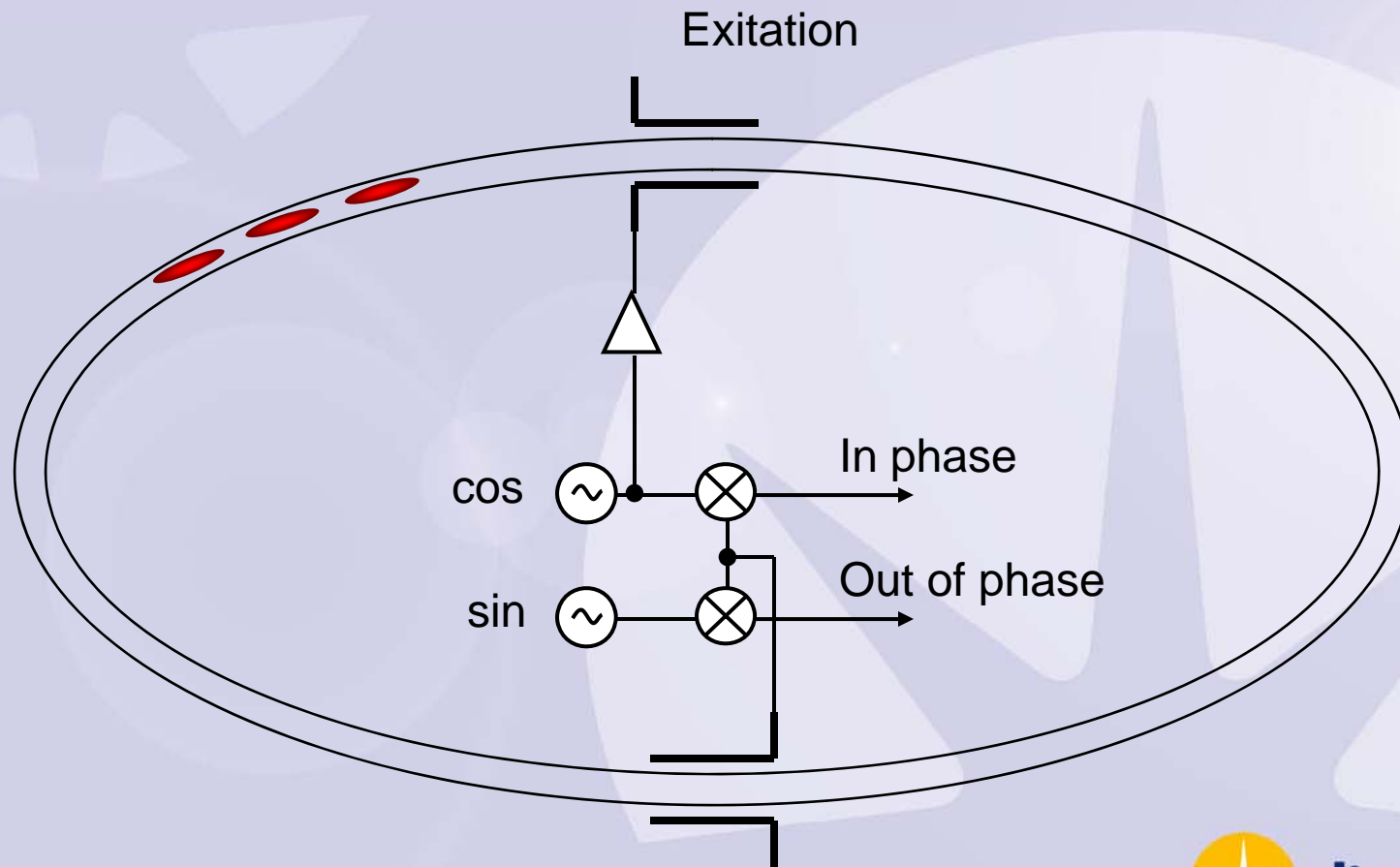


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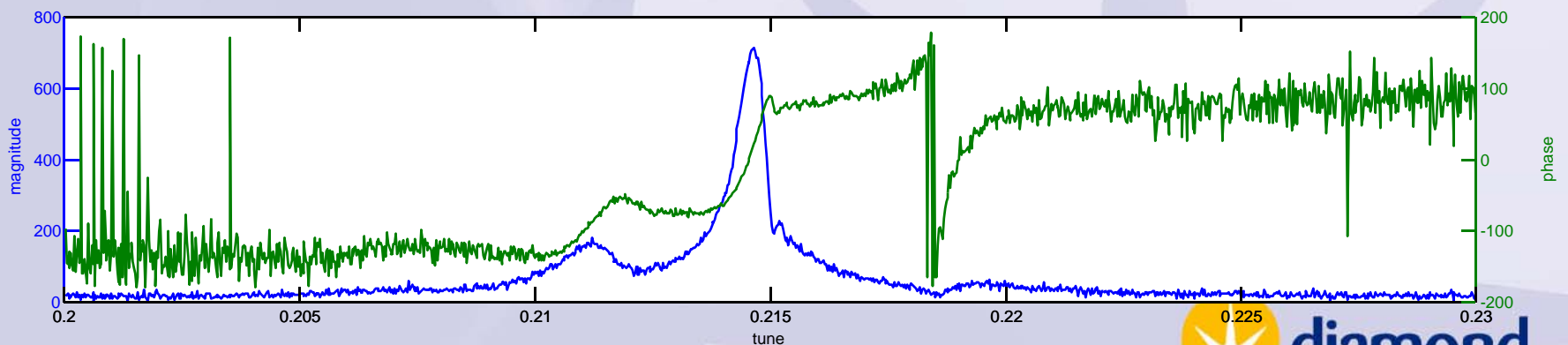
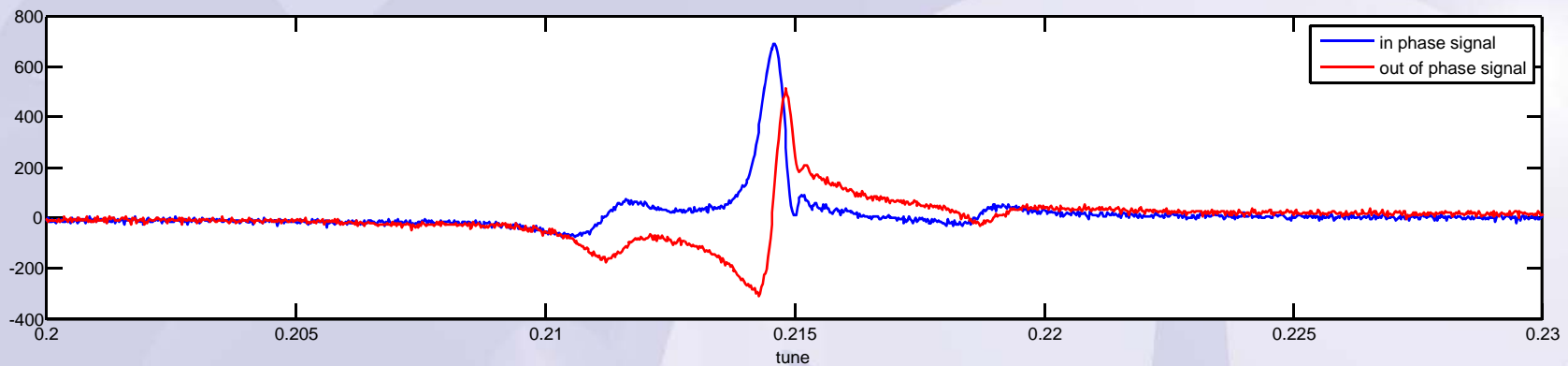
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More Elegant Tune Measurement: Harmonic Excitation and Detection



Amplitude and Phase of Beam Response to Swept Sine Excitation



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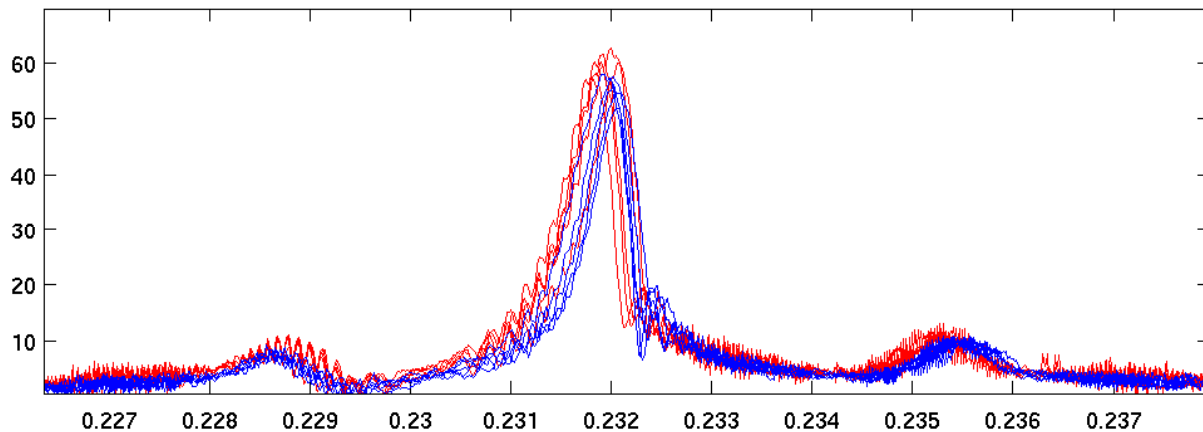
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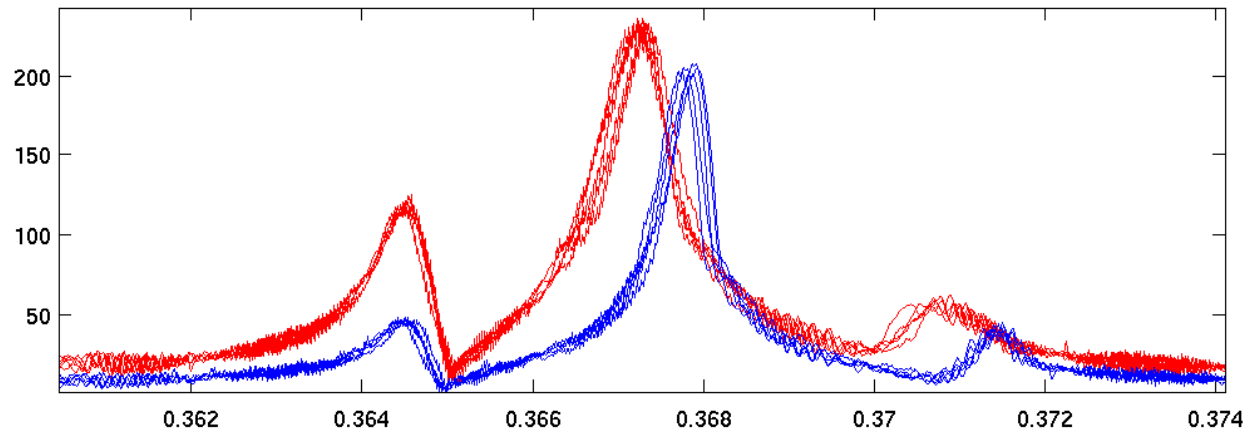
Tune Measurement of Individual Bunches

- 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

horizontal tune: red=bunch264=0.62nC blue=bunch268=0.32nC



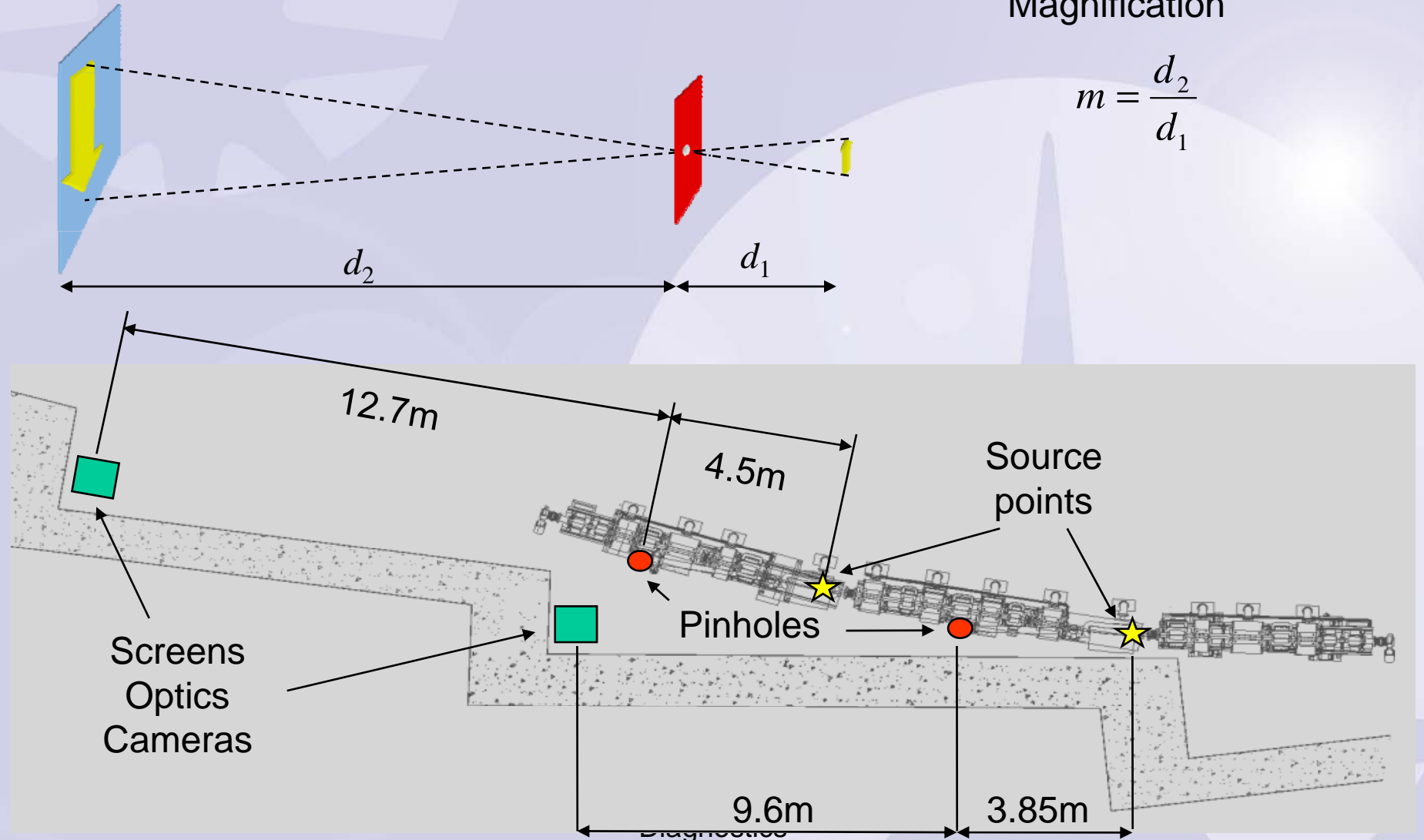
vertical tune: red=bunch264=0.62nC blue=bunch268=0.32nC



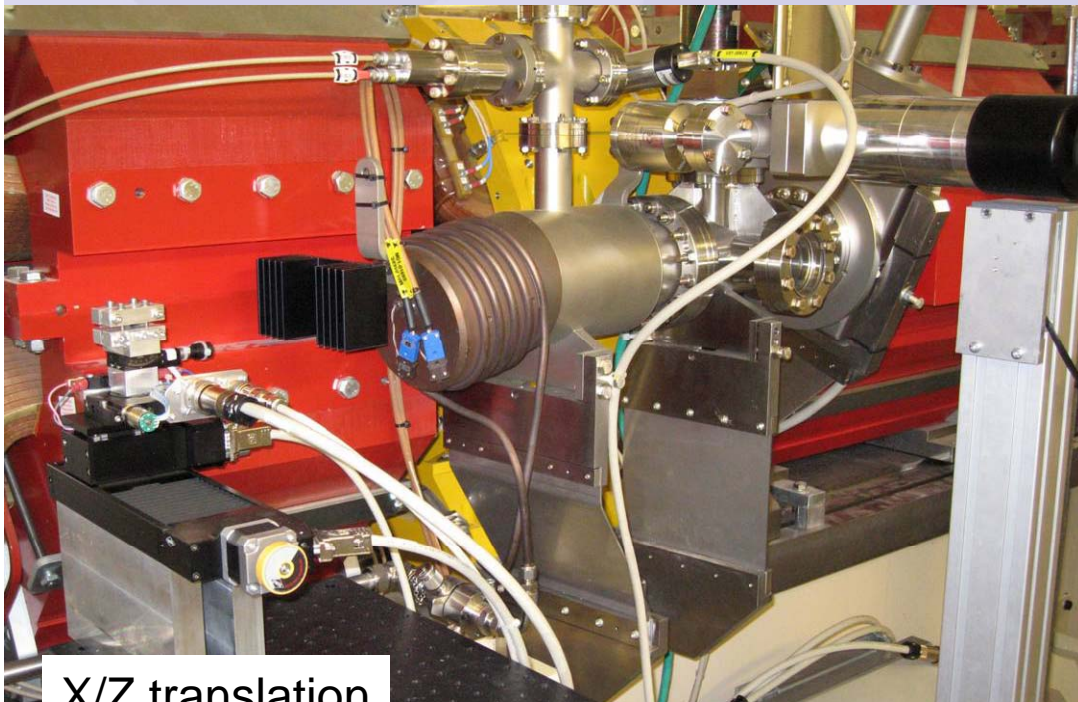
X-ray Pinhole Cameras

Magnification

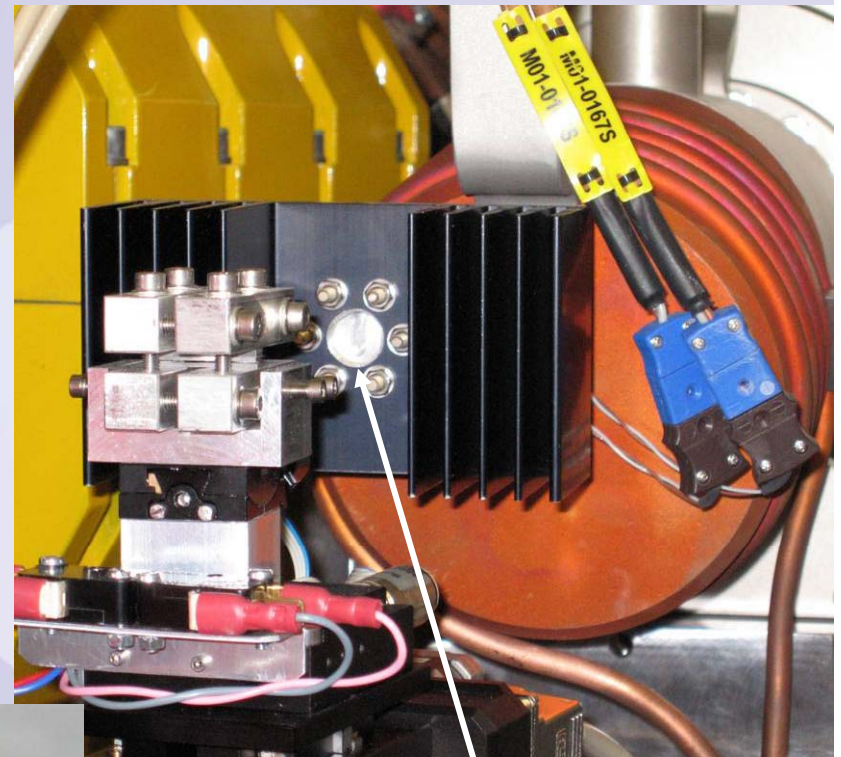
$$m = \frac{d_2}{d_1}$$



Modified Beam Port Absorbers and Pinholes

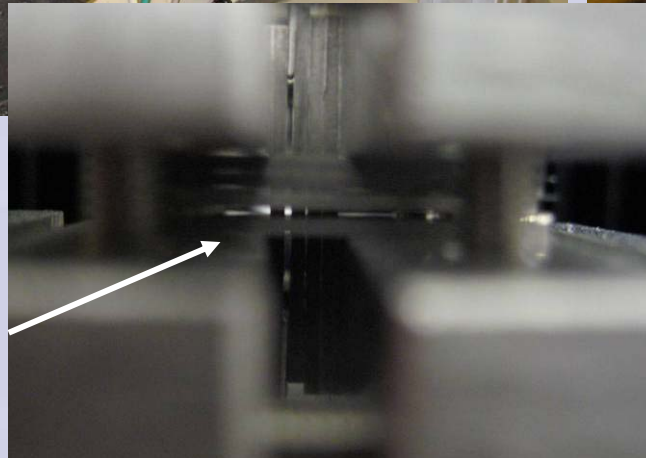


X/Z translation
and rotation



Aluminium/Steel
explosion bonded
flange as window

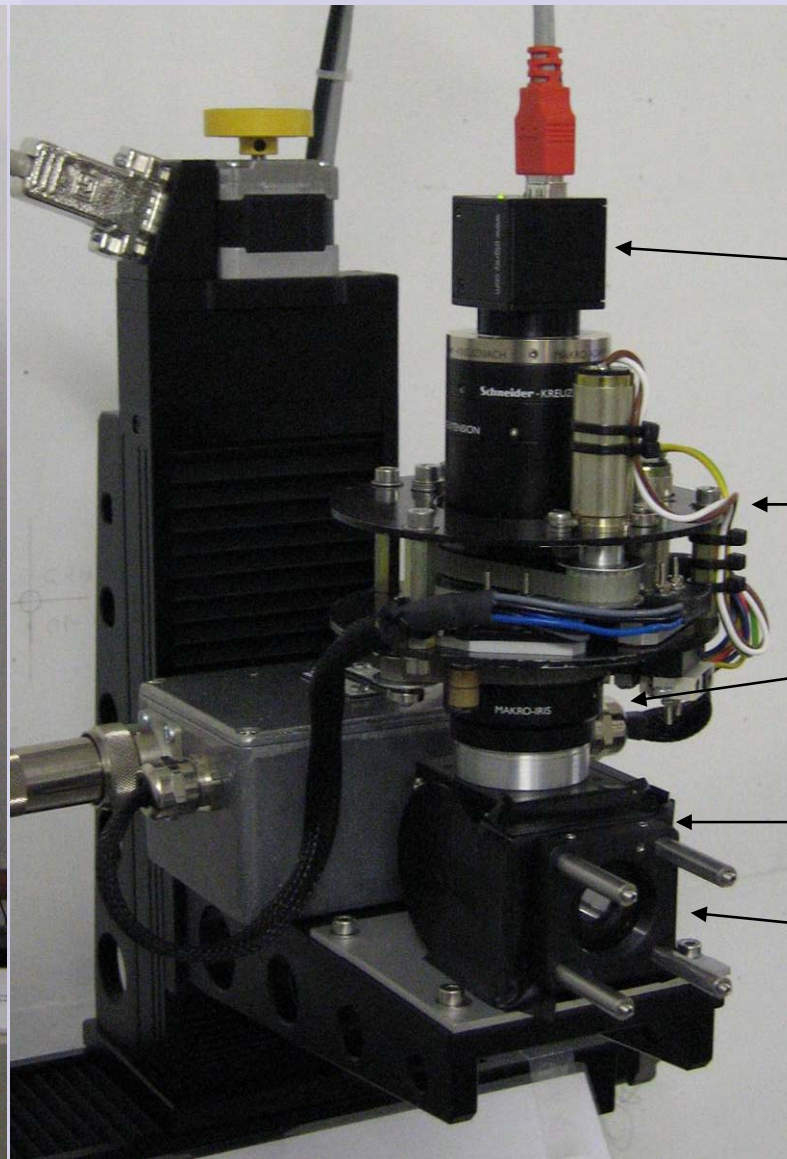
2 stacks of 4 slabs
5mm*1mm*30mm
with 0.1mm spacers



Pinhole Screens and Optics



Do not touch!
Fragile
Danger!
Motors are remote
controlled and can
move at any time
without warning.



1024x768 camera
4.65um pixel

focus and iris
remote control

50mm macro lens
magnification 1:1

mirror

CdWO₄ screen

Pinhole Image Analysis

Pinhole image ID1

176 190 71.7684

74.4369 27.4592 rotation

Skew quads on

Panel

load image load image

load pinh01 store active load pinh02

fit ID1 pinhole_data fit BM1

vol	213.3811	x ctr	-0.4478	sigma 1	0.062116	0.17021	1	35295.8355	4	1.9378e-09
height	2.0872	y ctr	-0.0056456	sigma 2	0.014483	rotation angle	2	0.035142	5	59
							3	5.321e-07	6	2

Results: BM1

vol	224.4163	x ctr	-0.041946	sigma 1	0.04549	-0.043545	1	8187.9259	4	3.0359e-10
height	1.3169	y ctr	-0.06015	sigma 2	0.016091	rotation angle	2	0.063868	5	32
							3	3.1516e-06	6	2

elapsed time 1.2495

flag 2

emittance and energy spread

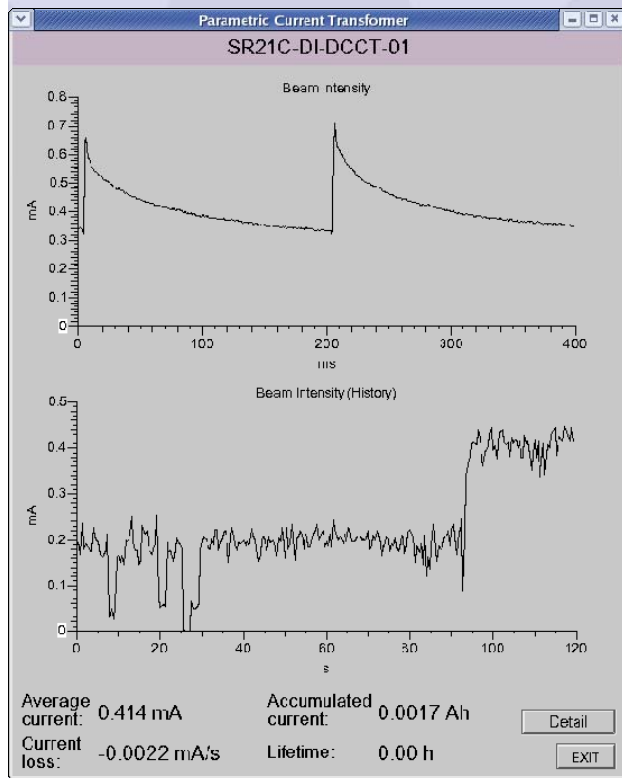
solve emittance Static Text

eval energy spread Static Text

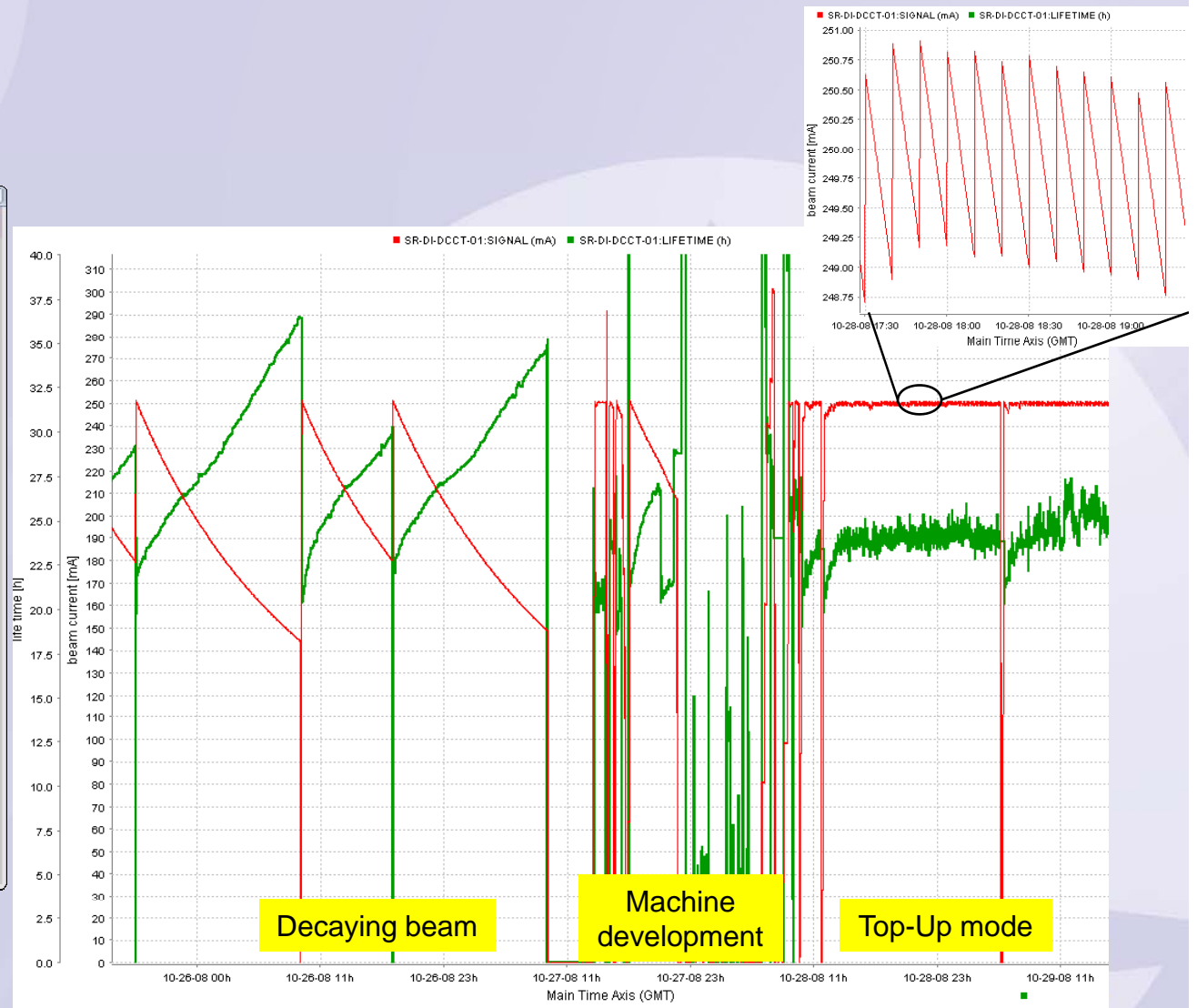
quit

nd
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Storage Ring DCCT

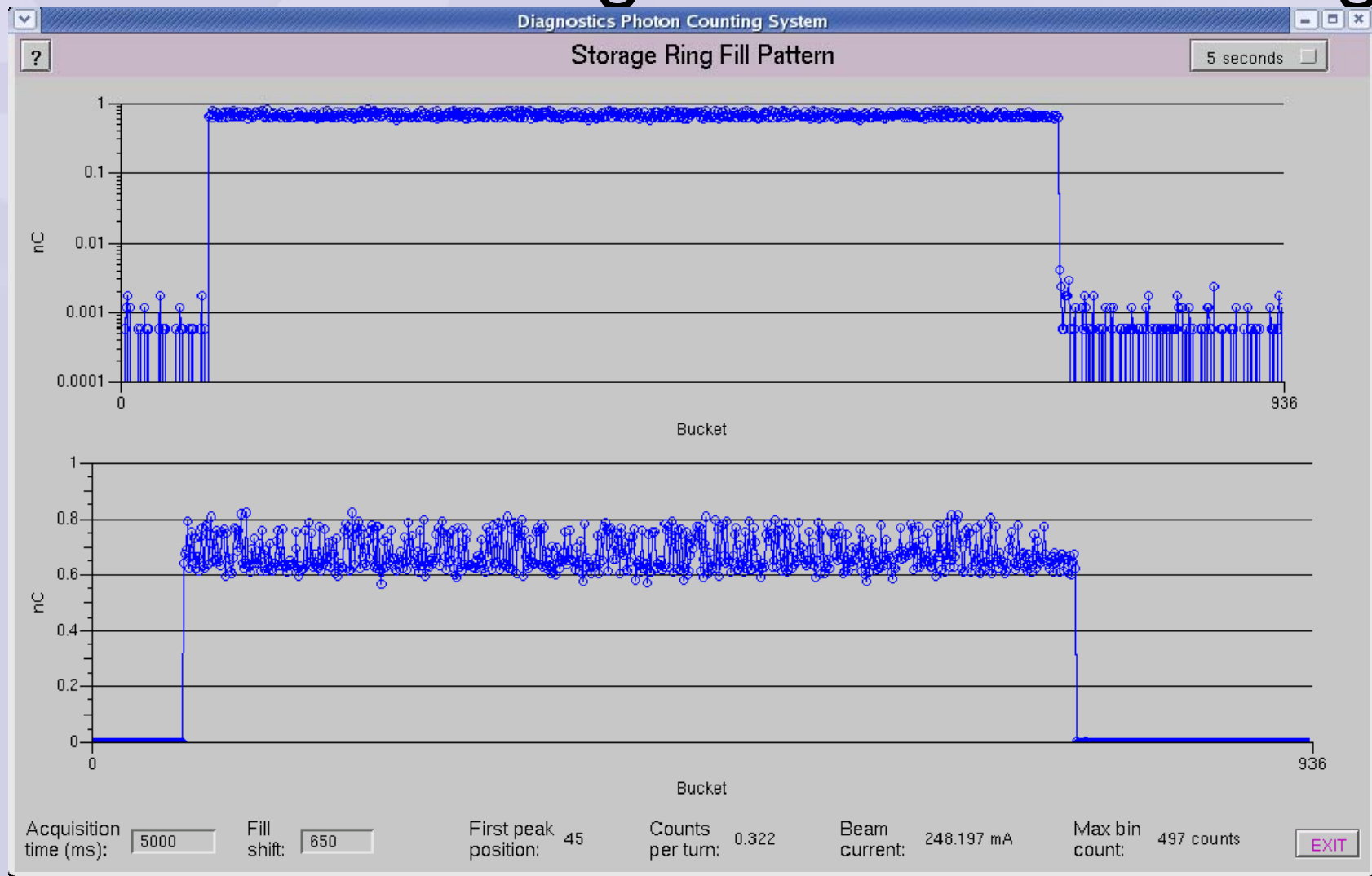


First accumulation of stored current at Diamond
01/04/2009



Diagnostics
Stored current and life time

Fill Pattern Measurement by Time Correlated Single Photon Counting



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Thank you for your attention!



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1st DITANET school on
Diagnostics



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