CESRTA Low Emittance Tuning Instrumentation: x-ray Beam Size Monitor

xBSM group: (those who sit in the tunnel)
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plus infinite help from CESR and CHESS personnel

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x-ray Beam Size Monitor

Overview:

Measure beam size bunch-by-bunch for 4 ns bunch spacing (currently 14 ns)
2 products:

- LET tuning tool with rapid feedback of the beam size (height)
- measurements of beam size evolution as an indication of emittance growth

Non destructive measurement (except that we require a horizontal bump)
Both electron and positron sizes
Flexible Operation

- DC or fast readout
- with/without monochromator
- variety of optics

Previous Report:

An update of this project was previously given
November 2008, at ILC08, University of Illinois Chicago campus
by Walter Hopkins.

The November 2008 report included work with a preliminary diode array
and a beam line with an incomplete vacuum.

This report covers progress in running periods since November 2008.

2009-January-04 : 2009-February-01
2009-May-14 : 2009-June-12
2009-July-27 : 2009-August-26

x-ray Beam Size Monitor

2009-January : primary focus was hardware development at 2 GeV beam operation

installation if the D-line e^+ optics and vacuum system
including the diamond window
alignment including the detector and the beam pipe
detector controls shake-down
detector development and understanding
monochomator understanding
some initial tests of image sensitivity to controlled changes in the beam height

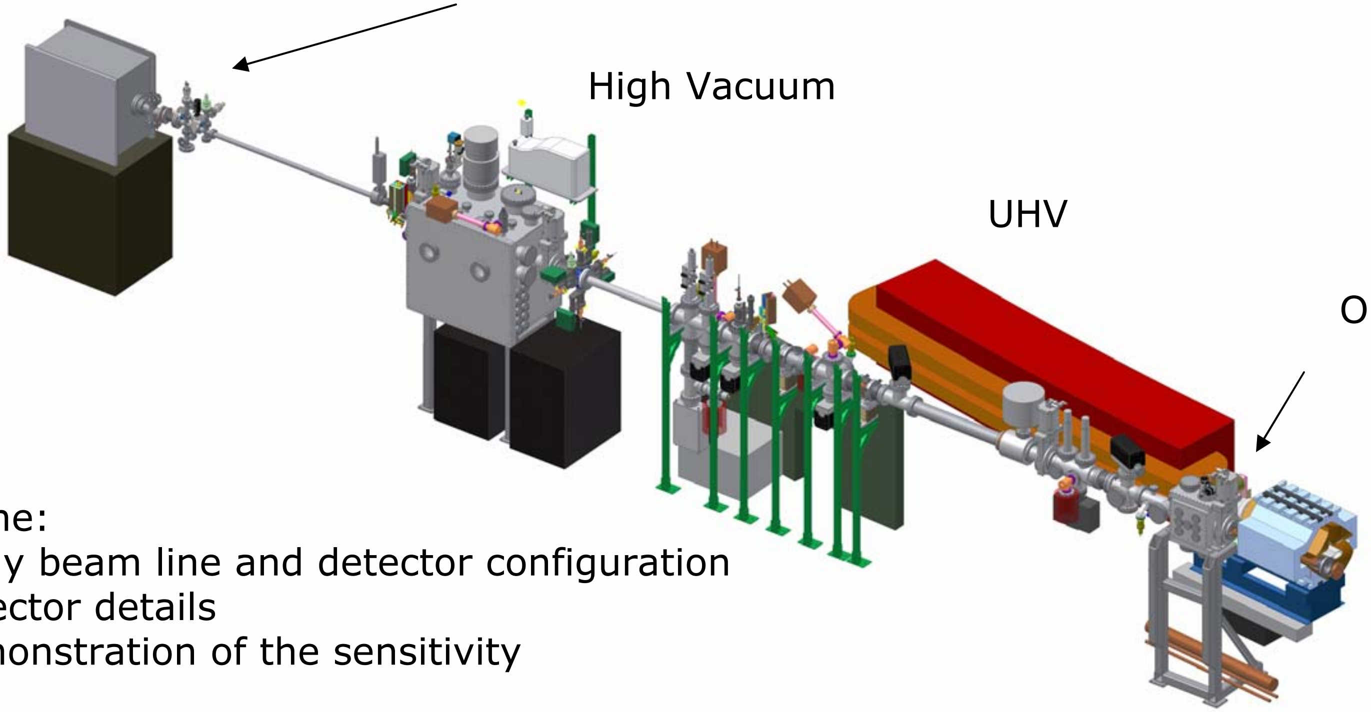
2009-May : primary focus was development of software tools at 2 GeV beam operation

revised detector mount
Low Emittance Tuning real-time support

2009-July : primary focus was 5 GeV operation and pin-hole optics

revised optics and optics mount
5 GeV beam operation/calibrations
Adaptation of the LET tuning tool to use the pin-hole optics
C-line e^- optics and vacuum system
software development of the emittance growth measurement (not discussed)

x-ray Beam Size Monitor

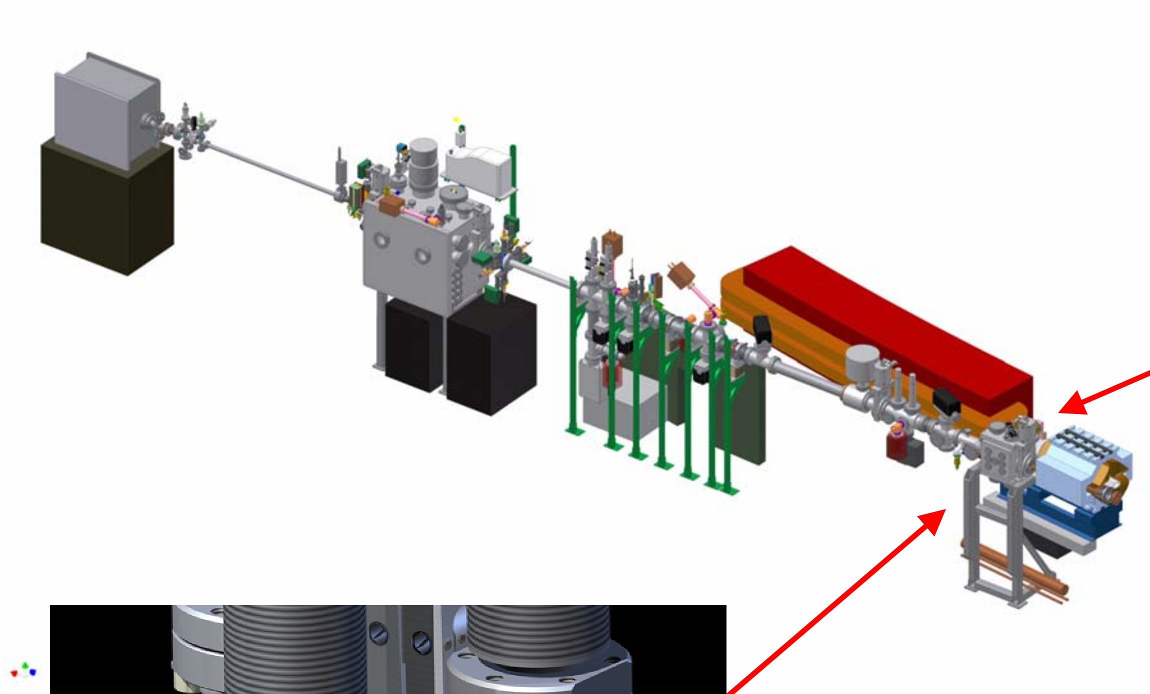


Outline:

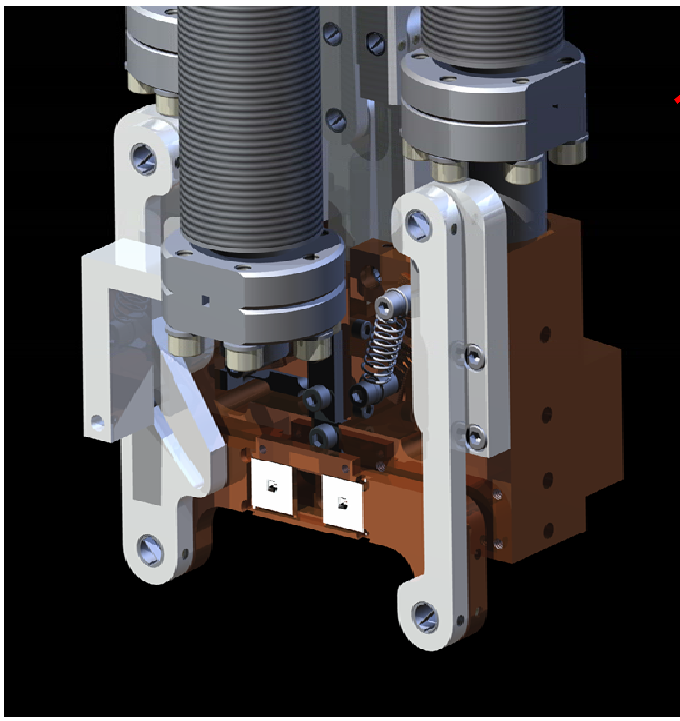
- x-ray beam line and detector configuration
- detector details
- demonstration of the sensitivity

- detector improvements for May 2009 run
- calibrations
- hurdles
- LET tool

- e- commissioning
- 5 GeV operation
- further use of the LET tool
- future



The x-ray optics assembly holds a chip with the optical elements.



There are provisions for multiple optics chips with various elements in each chip:
- square hole
- Coded Aperture (CA)
- Fresnel Zone Plate (FZP)

Each element has a gross size of about 1mm.

There is also a vertical-limiting adjustable slit that can be used as an optical element.

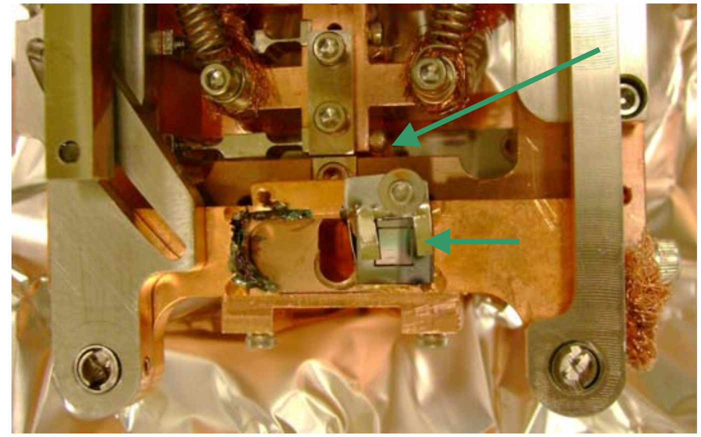
There have been two iterations of the optics assembly.

The current assembly (July run)

removes problems with the horizontal motion,

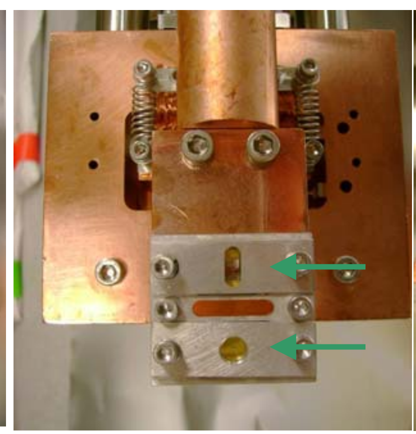
has both low energy (2 GeV) optics
(with FZP, CA, and hole)

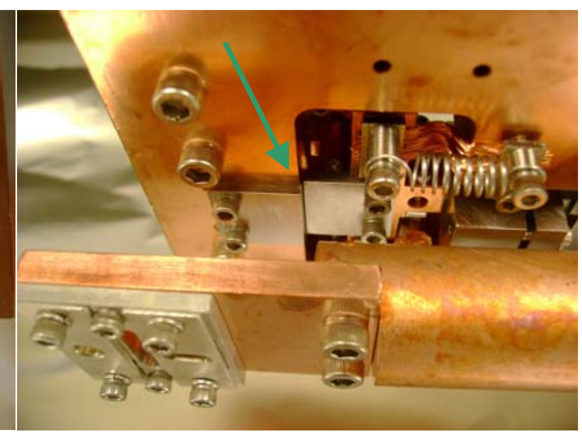
and high energy (5 GeV) optics
(with CA).



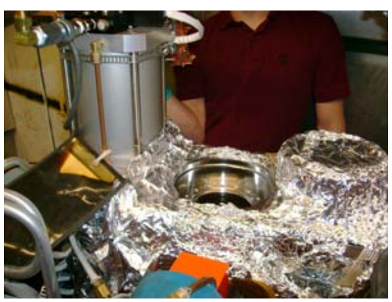
Optics assembly, January and May runs, 3 motions:
1) overall vertical motion selects position on chip
2) horizontal motion selects chip/hole selected
3) separate vertical motion selects vertical-limiting slit width

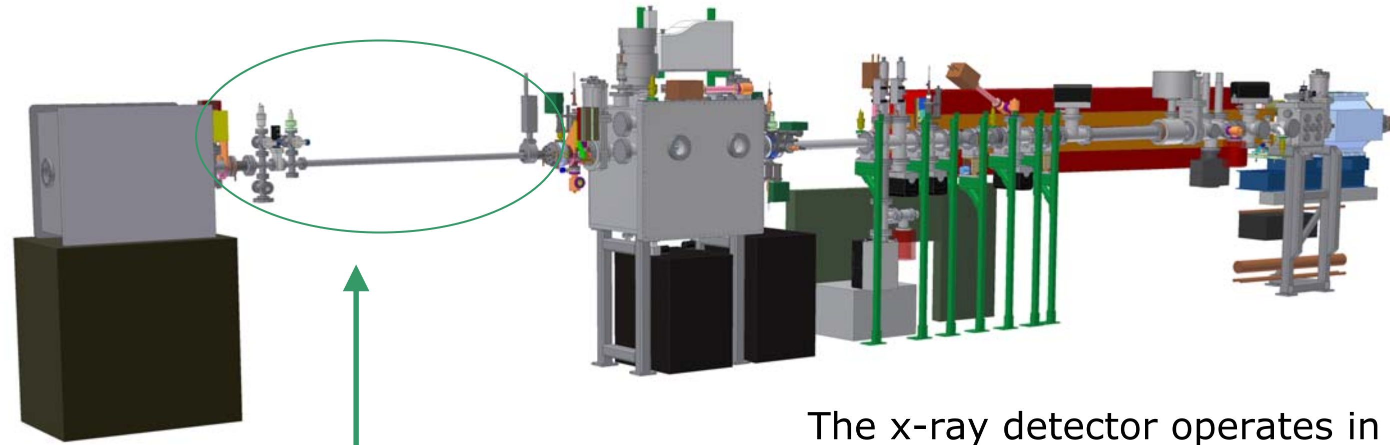
Optics assembly, July run, 3 motions:
1) vertical motion selects chip/hole, and position on chip
2) vertical motion selects location of
3) separate vertical motion selects vertical-limiting slit width

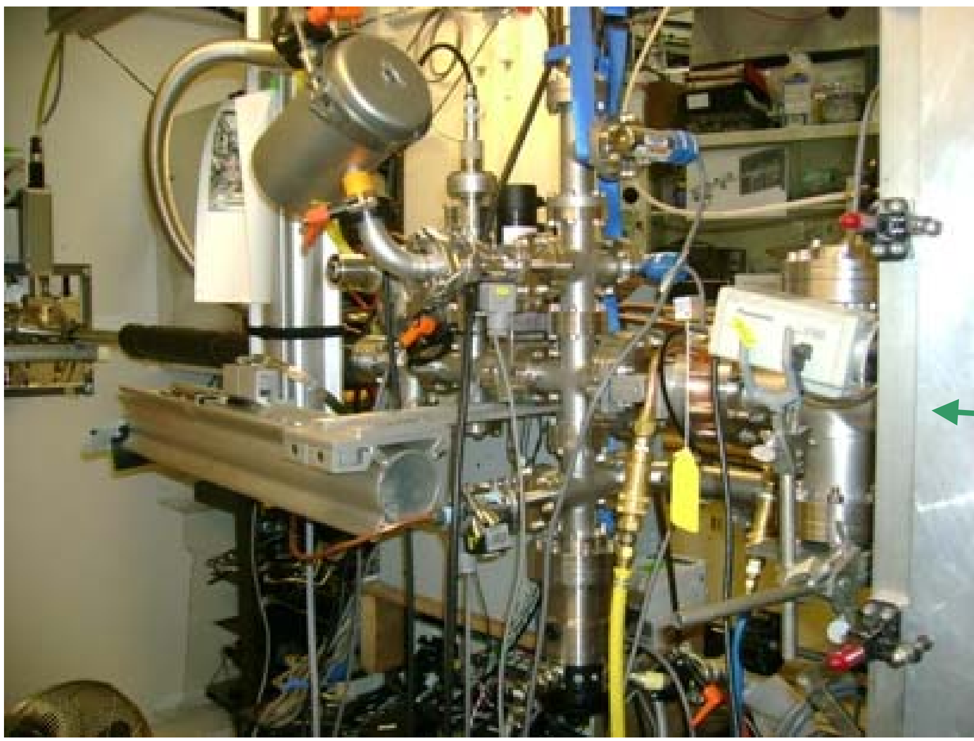




location in CESR





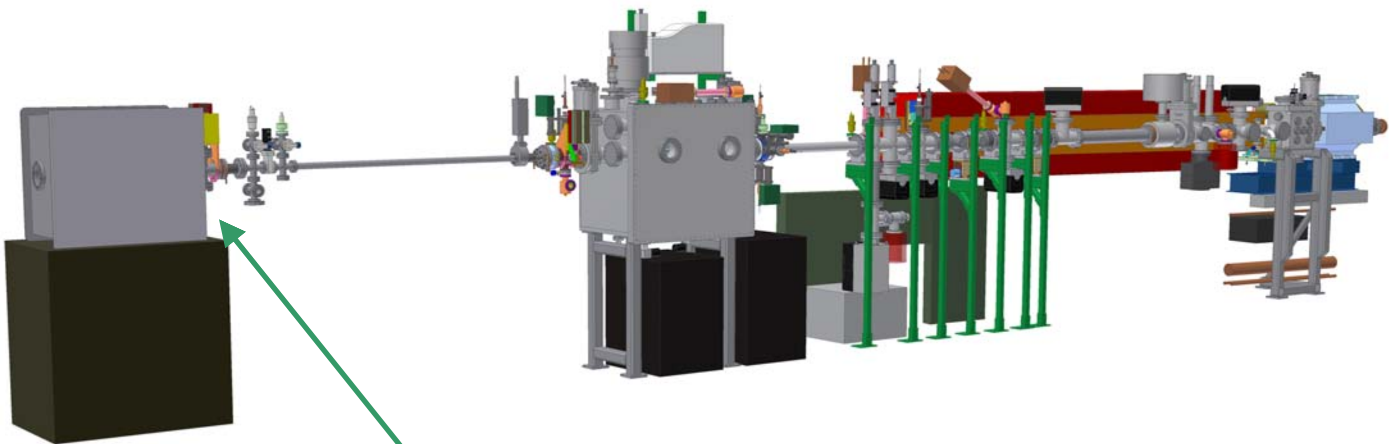


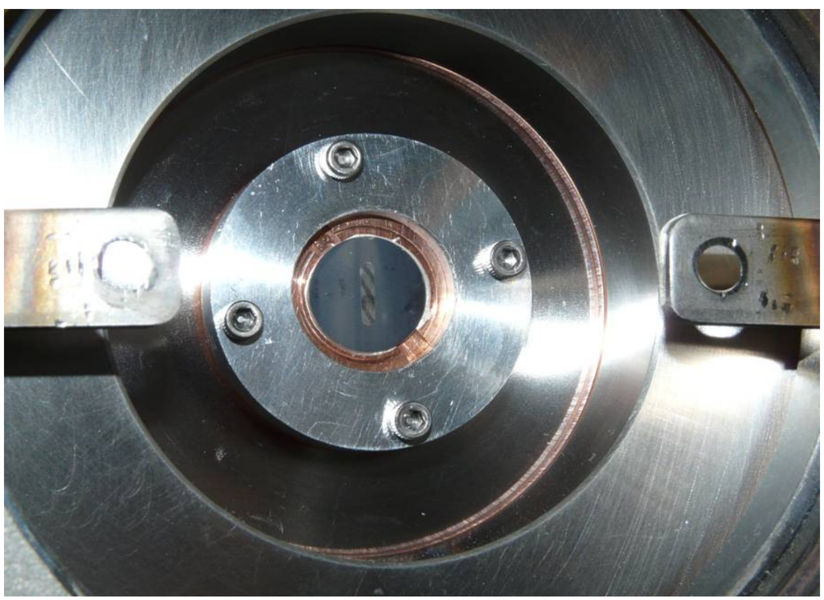
The x-ray detector operates in a vacuum, but must be isolated from the CESR vacuum to avoid contamination of CESR and allow quick turn-around access to the detector.

The detector vacuum (~0.5 Torr) is isolated from the x-ray line vacuum (~10^{-6} Torr) by a diamond window (next slide).

The pressure difference across the diamond window is controlled by the control system.

CESR is protected against catastrophic failure of the window by a gate valve.

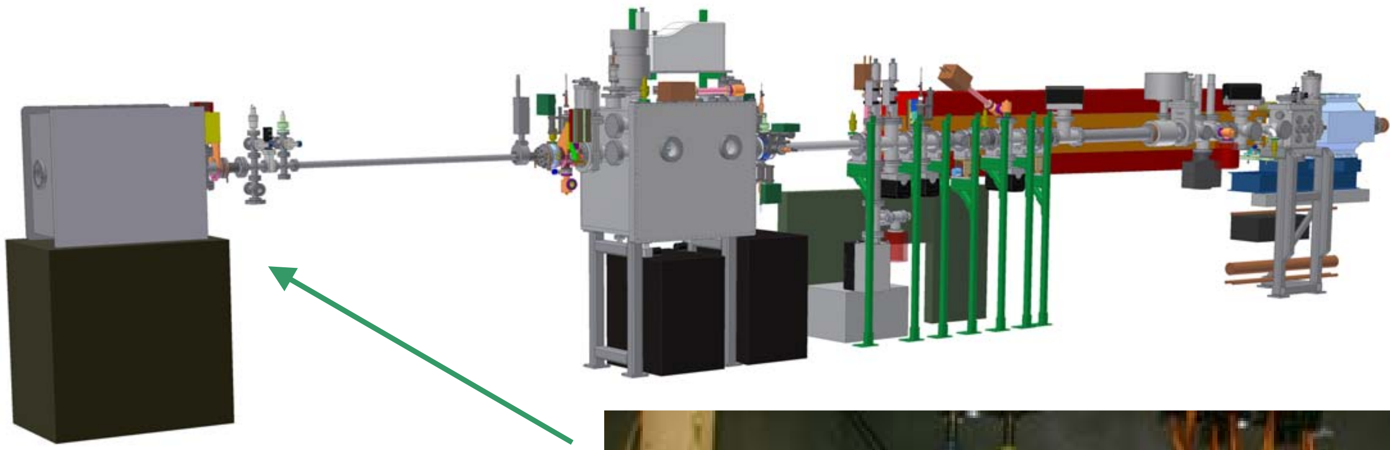


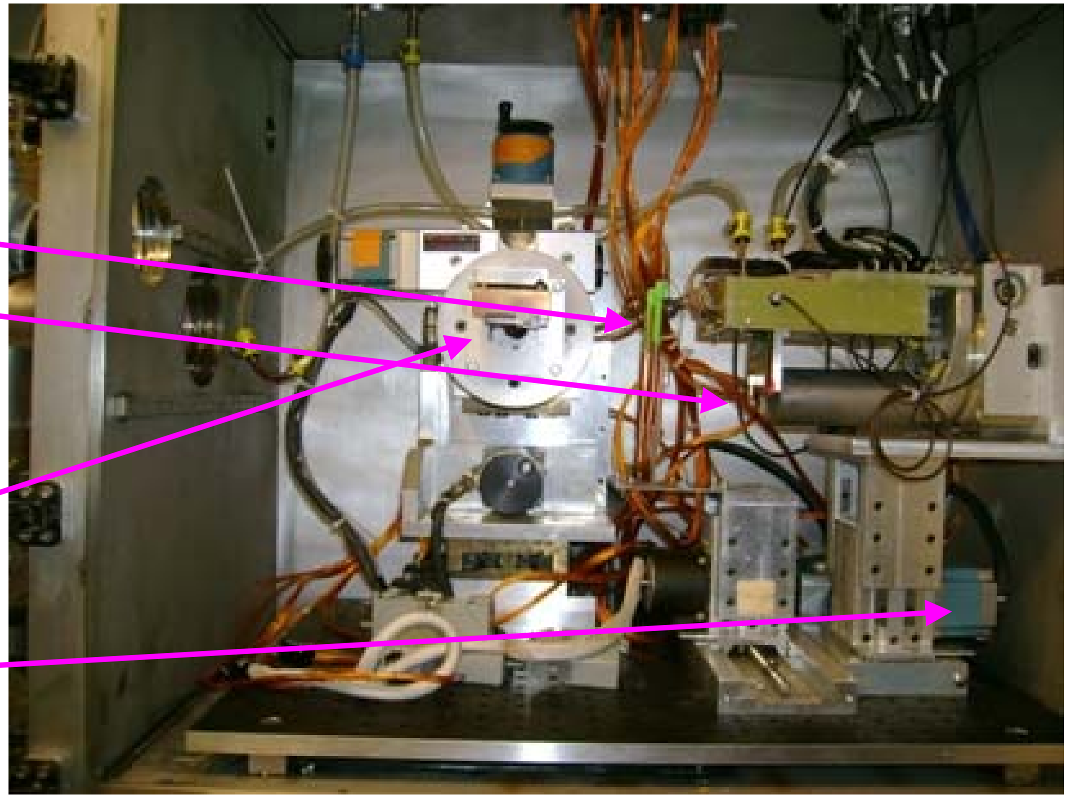


The thin (4um) diamond window separates
high quality CESR vacuum from the
low quality vacuum of the detector enclosure.

The window transmits 76% of the x-rays at
2.5keV, and is supported by a thick silicon
frame; the 4um membrane region is 2mm
(horizontal) x 6mm (vertical).

The window was fabricated by
Diamond Materials GmbH of Freiberg





The detector box contains

movable slits for calibration, and the

diode array detector and preamplifiers.

The monochomator is a silicon-tungsten multi-layer mirror.
X-ray energies are selected as a function of angle with 1.5% FWHM bandwidth.
This well matched the chromatic aberration of the 239 ring FZP.

All devices are motor controlled.

As this is in a vacuum, the amplifiers and monochromator are water-cooled.

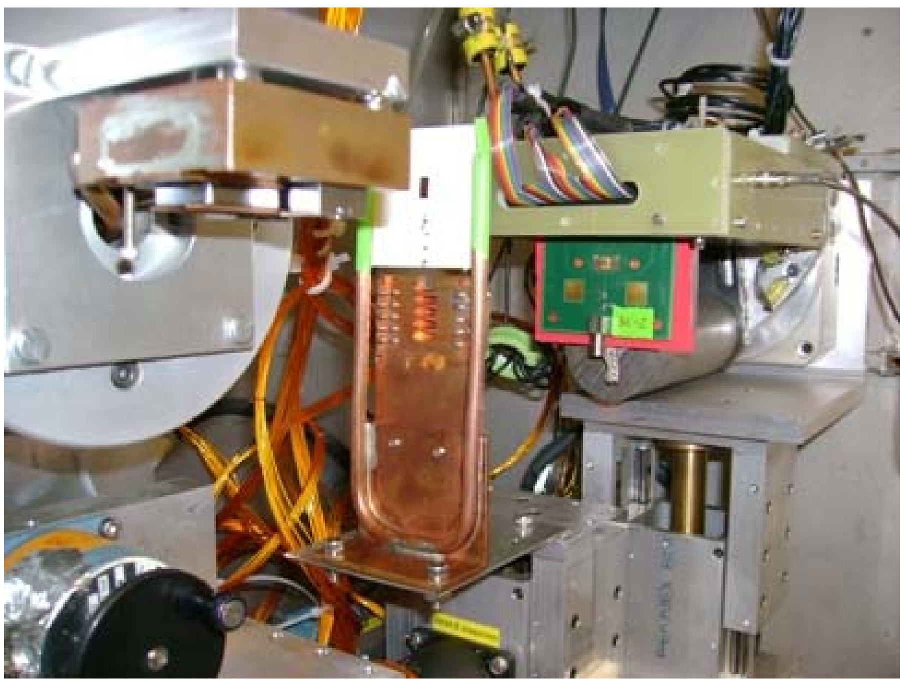
Detector:

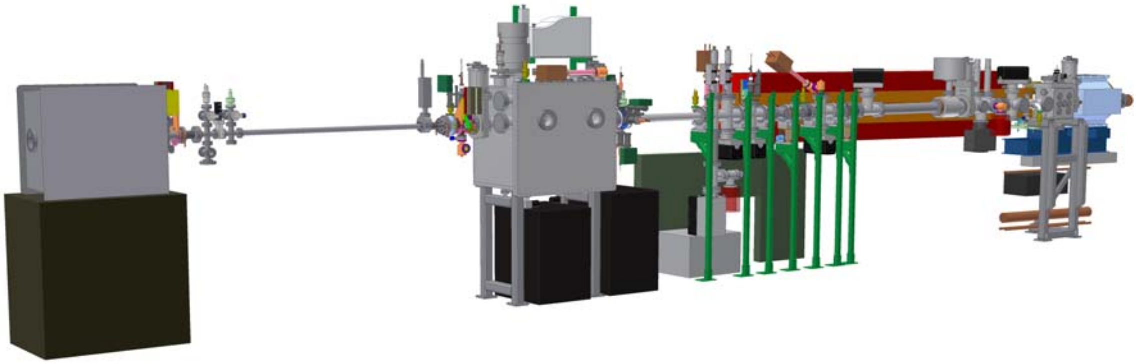
an array of ~ 64 diodes, InGaAs, manufactured by Fermionics Inc.,
50μm pitch (1.6mm coverage over 32 diodes),
400μm pixel width.

The InGaAs layer has thickness =3.5μm and absorbs 73% of photons at 2.5keV.

We instrument 32 contiguous diodes for the fast readout, a FADC with 14ns repetition rate.

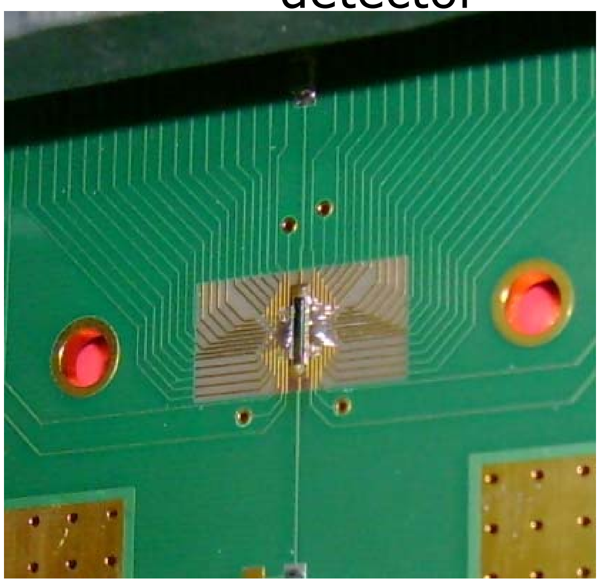
There are also 8 diodes connected for the “DC” readout.

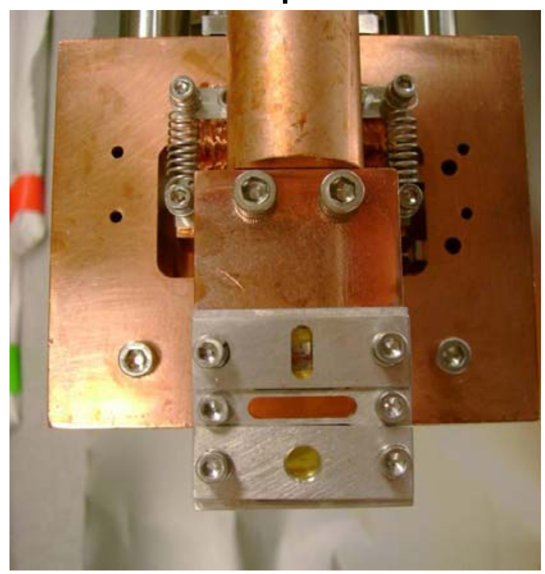




10.186m — 4.360m

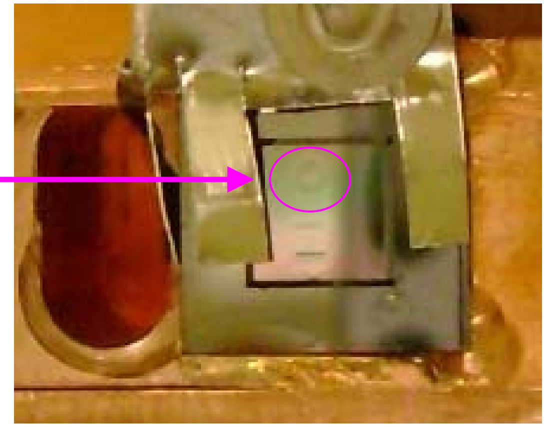
detector — optics — source





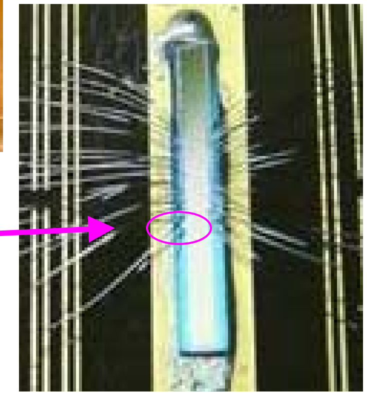
magnification: image/source size = 2.34

Demonstration of the response to beam height



The Fresnel Zone Plate is centered/fixed on the x-ray beam.

We use the "DC" readout.
There are 8 diodes that are connected to be available for the "DC" readout.

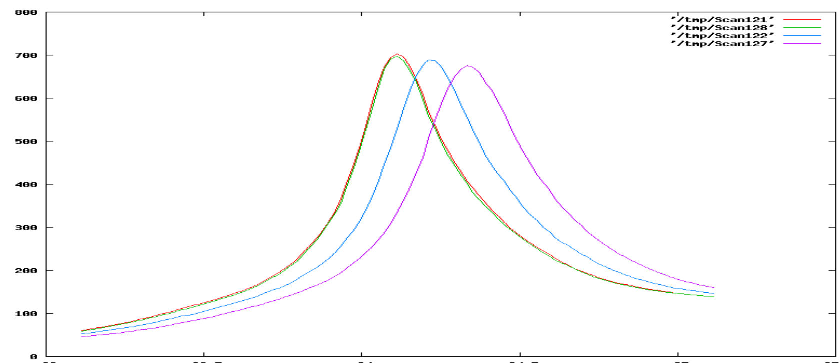


One of the 8 instrumented diodes is read directly through a pico-ammeter.

The ammeter output is collected, synchronized to the vertical motion of the detector stage.

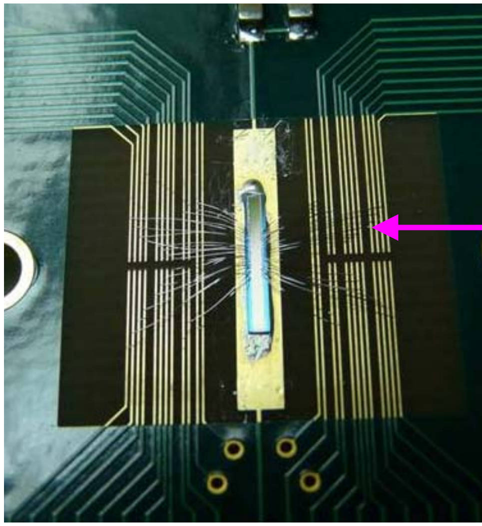
Thus, the single diode is swept through the x-ray image. We observe the diode current as a function of position.

Integration is ~0.1 sec, the step size is typically less than a diode pitch.



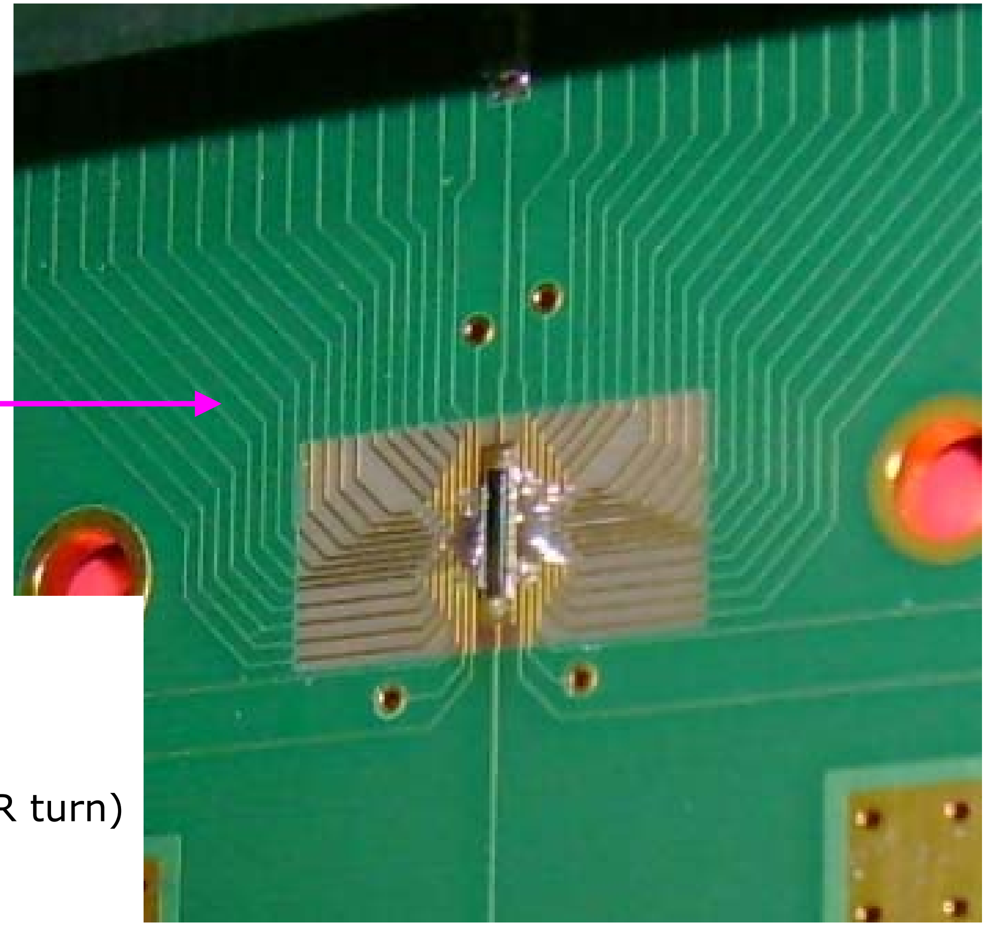
The plot shows the change in the FZP image for various applied tuning changes that are expected to change the beam height.
This demonstration is the main result of the January run.

this is a slow scan of 1 diode,
TADETZ, 2mm motion, FZP, no-mono
20090201



January

May



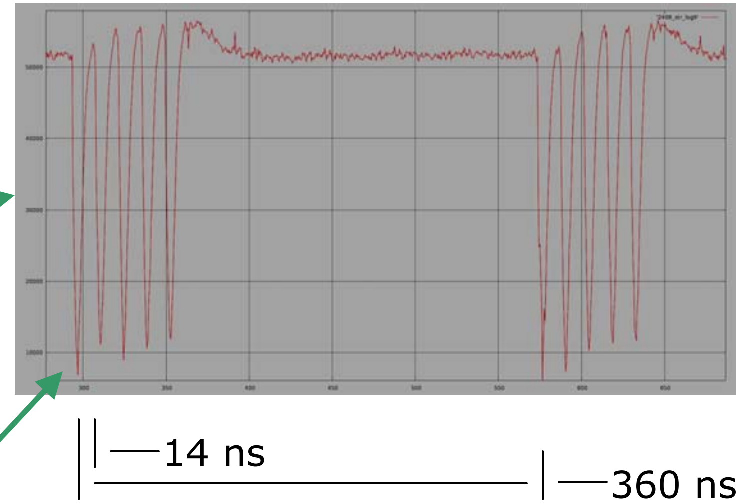
There were many detector developments
after the January run.

Fast readout (measurements in a single CESR turn)
requires pulse height measurements from
32 contiguous diode pixels.

Development of the fast readout in the
January run was limited by poor
wire-bonding efficiency (~25%).

The wire-bonding pattern was fixed for the May run
providing 100% efficiency.

Calibration of the Fast readout includes
synchronization of the readout to the beam,
mapping,
channel-to-channel PH calibration,
and signal shaping.

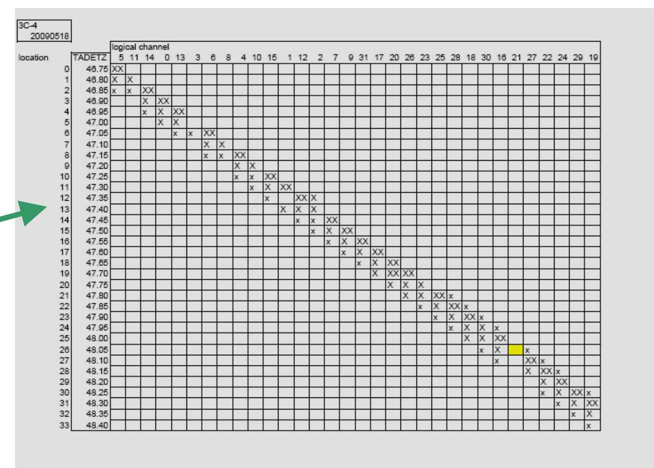


Here, we are looking at the digitized signal of one diode. This is the "storage oscilloscope mode".
The diode response is sampled at 0.5 ns.
(Individual measurements are separated by the turn time (2500ns) + 0.5 ns)

In the "single pass mode" the readout time is synchronized to the maximum diode response.

Determine the physical order of the logical channels.
Mapping was first mapping done "by hand".
(Use narrow focus FZP with monochromator.)

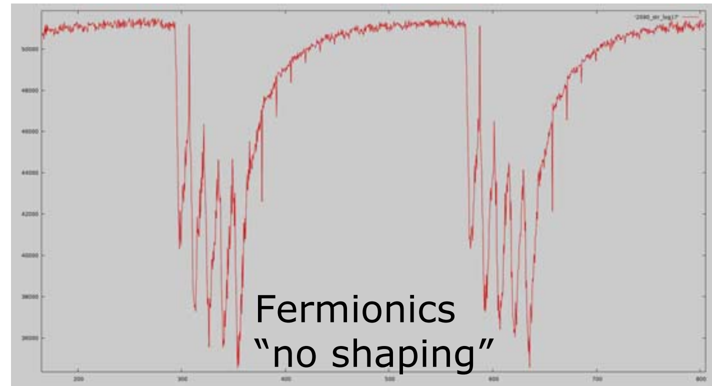
Observe the relative signal strength of the logical (electronics) readout channels w.r.t. the illuminated position.

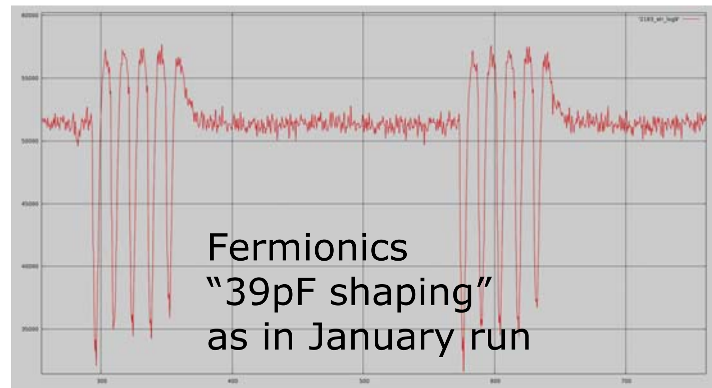


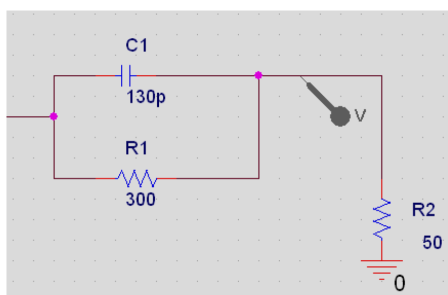
Mapping and channel-to-channel PH calibration is now automated;
four detector boards are mapped and certified.

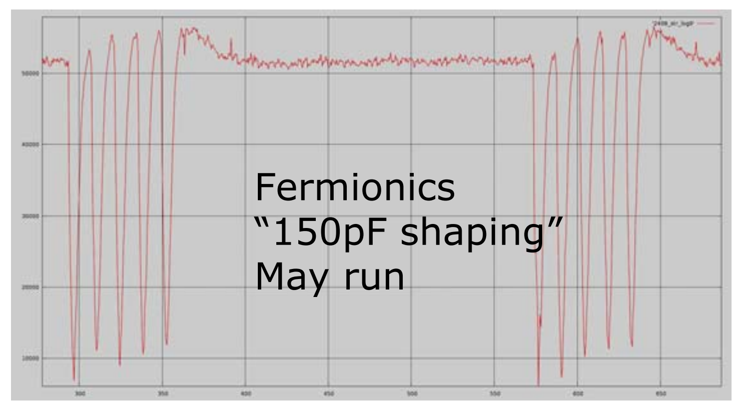
Emittance growth measurements,
and measurements of bunches spaced as close at 4ns,
require damping of the individual bunch signals
to limit the distortion of subsequent measurements.

During the May run, we optimized the signal shaping
as shown in the figures.





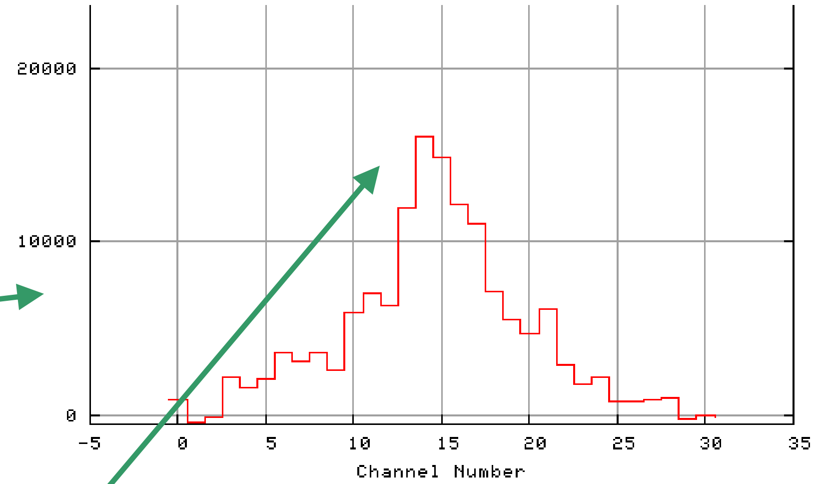




So,
 after synchronization,
 mapping,
 signal shaping, and
 pulse height calibration,

this is our "fast" readout.

The "fast" readout uses
 32 contiguous diodes,
 in a fixed position,
 instrumented with 14ns FADCs.

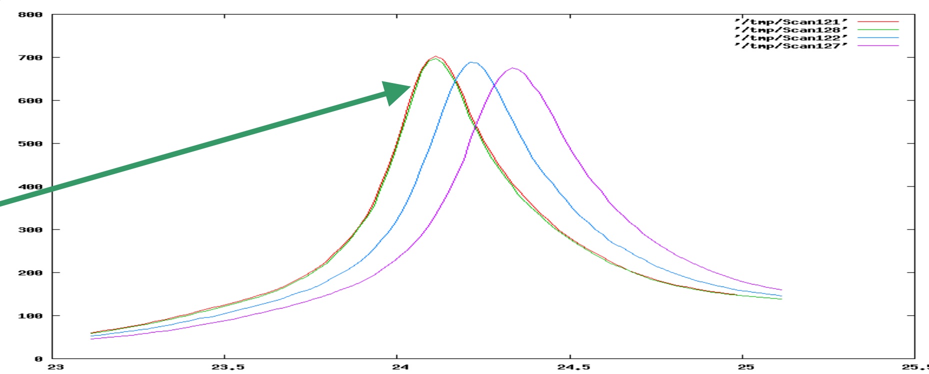


this is turn average response
32 diodes, FZP, monochromator,
20090525-2368

The image is observed
in the relative response of the 32 diodes

compares with the

earlier image observed
in scanning a single diode through the x-rays.



this is a slow scan of 1 diode,
TADETZ, 2mm motion, FZP, no-mono
20090201

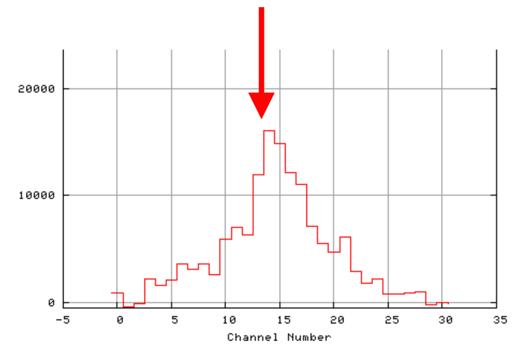
But, while use of the monochomator masks the chromatic aberration of the FZP (decreasing the image width, and improving the spatial resolution of the detector),

the **x-ray flux is too low to make single-turn measurements**. (Plot shown is turn averaged.)

We measured the number of photons reaching the detector
by comparing the mean and variation of the PH in the peak channel.

Using the FZP, monochromator, 1 bunch, 4.3ma beam.

The observed rate is about 1 photon/(ma of beam) at the peak.
(Multi-bunch measurements will require ~1-2 ma/bunch.



a turn-averaged response
32 diodes
FZP, monochromator

We investigated the use of white-beam.
The image will be a convolution of x-ray energies, with varying amount of defocus.

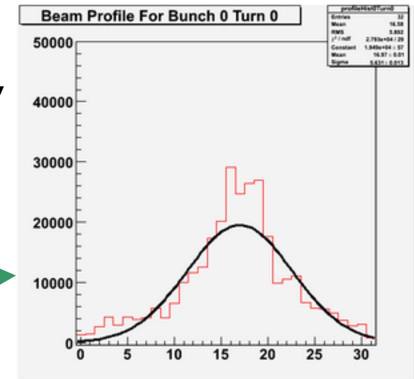
20090529: Using the "DC" readout, and a controlled increase in the beam size,
we compared the sensitivity of
white-beam measurements w.r.t. monochromatic beam,
Using FZP, monochrometer, FWHM changes from .21 to .25mm
FZP and white-beam, FWHM changes from .46 to .50mm.
The relative photon count, at the peak, is 114.

20090601: We verified that the fast readout shape matches the "DC" readout.
We can develop the measurement with white-beam.

20090601: FZP, white-beam measurements

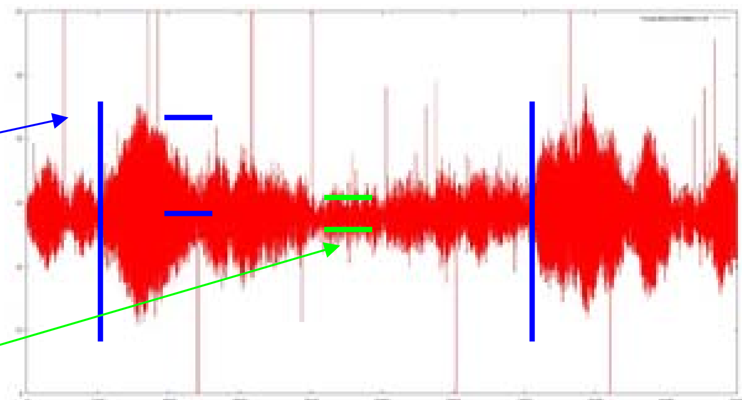
Measured the beam position and image size for 10000 consecutive turns, single bunch beam structure.

The measurement is based on fits to the image, as observed in a single turn, with the fast readout. (At this point, it is a simple gaussian fit.)



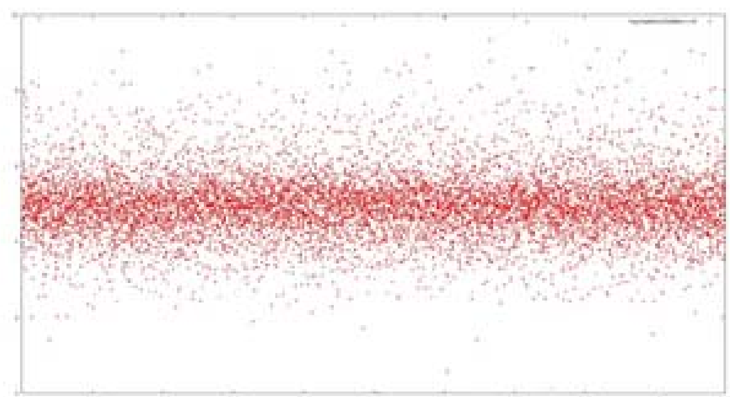
The history of the image **position** over 10,000 measurements, 0.0256 seconds, shows a disturbance initiated at 60 Hz, with image size amplitude of 150 µm.

The image position measurement accuracy is σ<35µm, as indicated by the narrowest part of the wave form.



The history of the image **size** does not show a correlation with the variation of the position. While the image has size, σ=250 µm, the variation of the image size is σ_σ ~ 35µm.

(Based on the slow diode measurements 20090531, we expect σ (image shape) =230 µm.)



This is the first time that we
have observed this position variation.

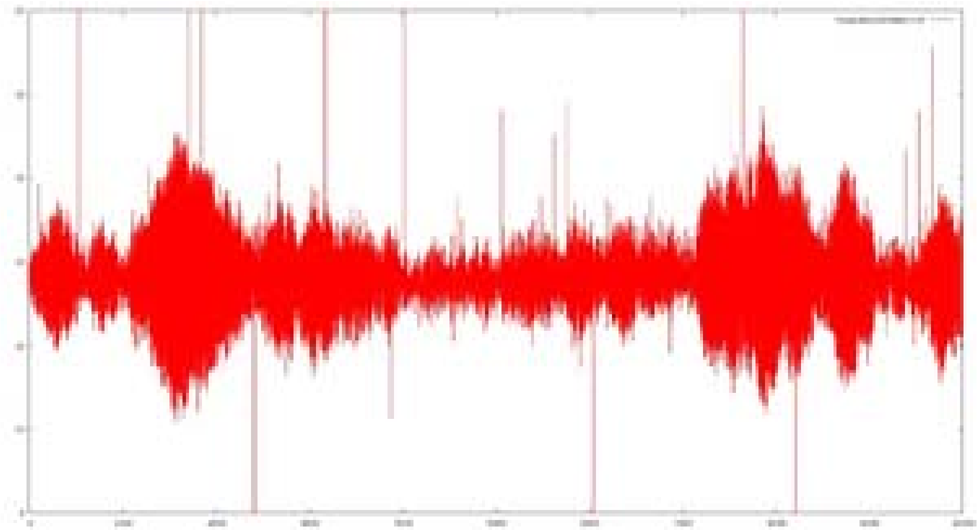
It creates a problem for averaging measurements from different turns, or comparing different turns, because the effect (150 μm, image) is
~larger than the effects we want to measure.

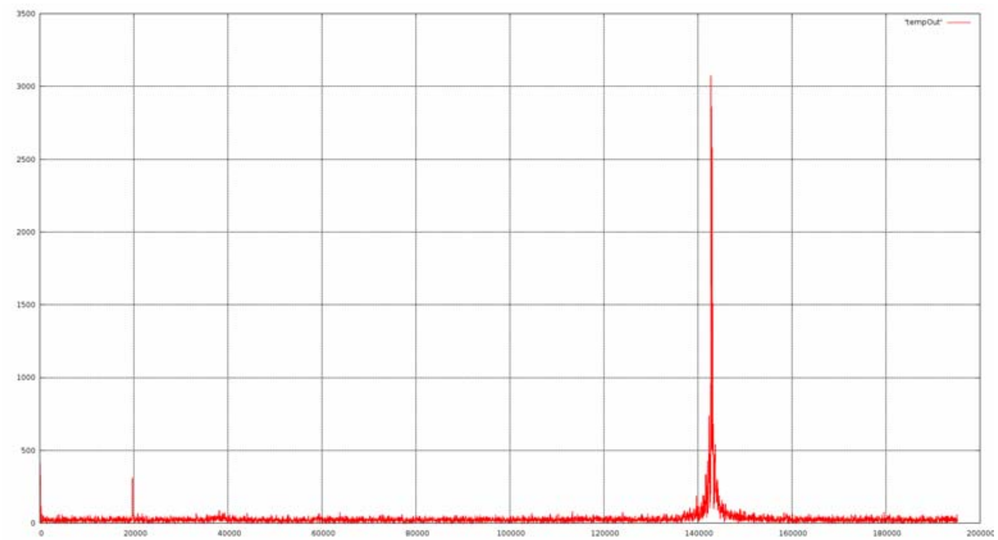
As described on the previous page,
the onset is 60 Hz.

A Fourier analysis of the position disturbance

reveals the betatron frequency
~142 kHz

and the synchrotron frequency
~20 kHz.

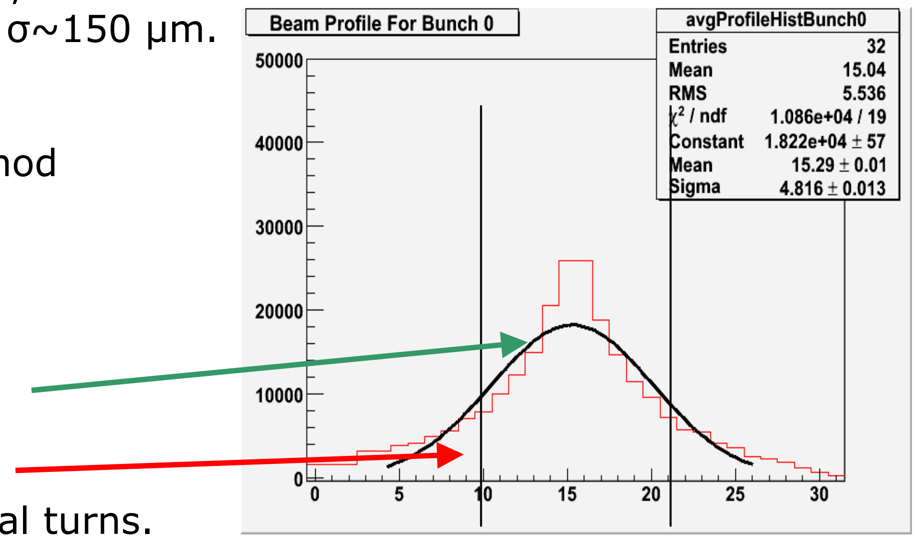




How do we go from here to a Low Emittance Tuning tool?

The "tuning tool" is a chart recorder readout of the beam size and position that gives feedback to the CESR tuner.

With white-beam, we have increased the x-ray flux to ~100 photons/(ma of beam) (which is still low), we have allowed an increase in the image width, and the beam position varies turn-by-turn with σ~150 μm.



We require a faster and stable calculation method for the "tuning tool" display.

Sum distributions from 100 turns.
Fit the sum to a gaussian,
then refit with 2nd iteration within ± 2σ.

With this, we define a window, FW=4σ, for determining center and RMS for individual turns.

(The window is the fixed for all turns.)

Beam positions are averaged over the 100 turns.

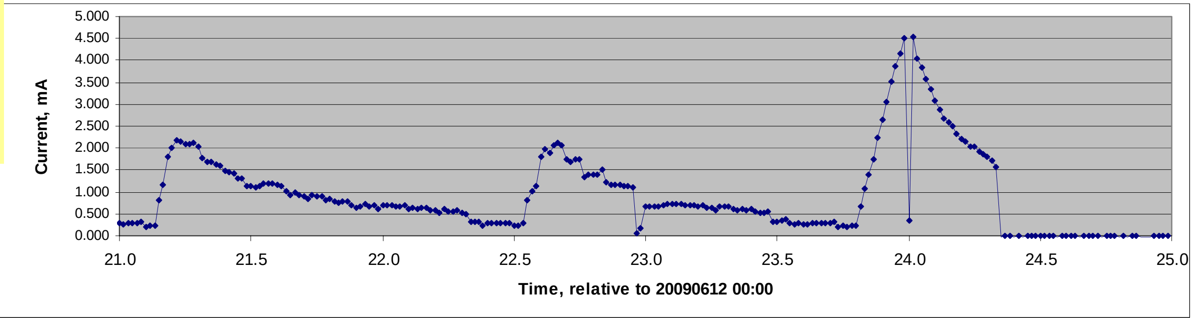
Beam sizes (the RMS), now de-convolved from the position, are averaged over the 100 turns.

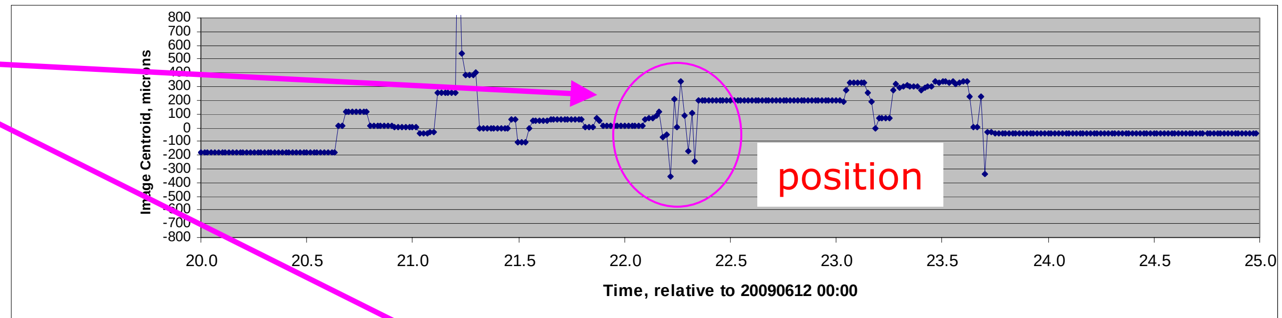
The stability of this procedure allows an update time of ~ 2 seconds.

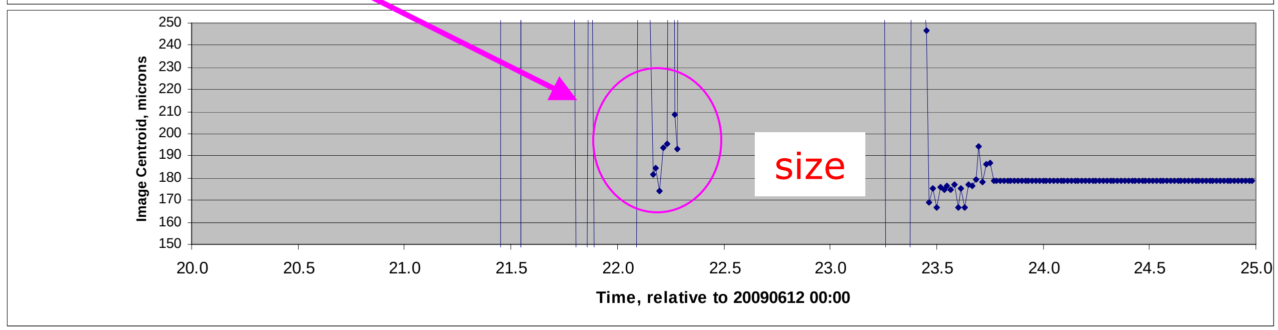
(The saved data is more coarse than during measurements.
There is a brief period with relevant saved data.)

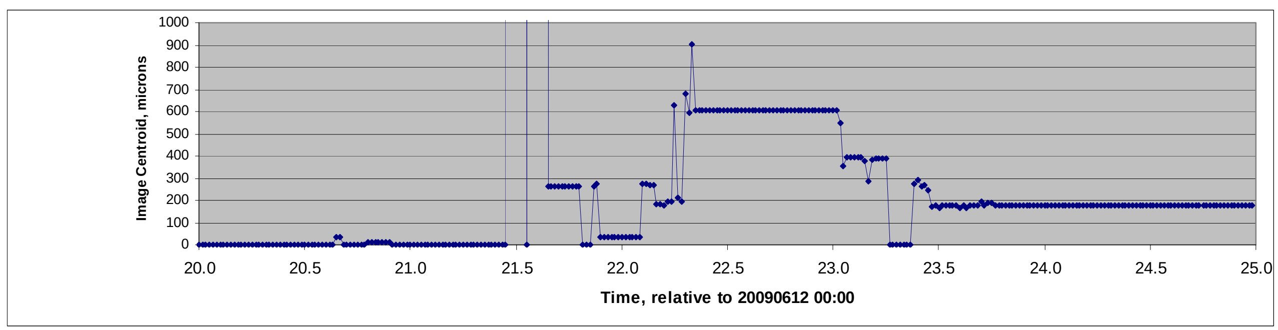
20090612, ~22:15

we varied βsing1	position μm	image size (σ) μm
0	118	175
100	60	185
300	-360	192
-100	210	190
-200	330	210









Beam position changes track earlier observations with the DC readout for the βsing1 tuning knob.

Scatter in the beam position and beam image size are both ~ ±10 μm.

The scatter in the beam size is improved relative to the single turn measurements by averaging.

Changes for the July Run

Significant changes during the July run:

commissioning of the electron line (Previous results are all with the e^+ line.)

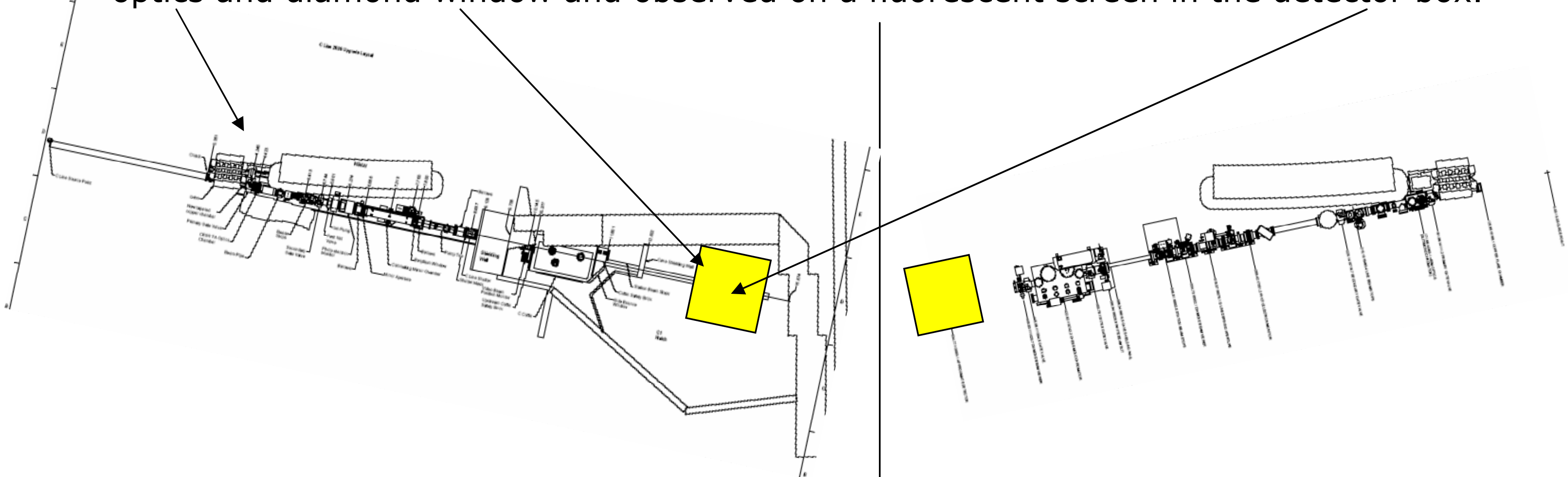
5 GeV operation and associated hardware changes

update of the LET tool

All C-line vacuum work/controls and construction of the detector box
were completed for the July run.

Components were processed in beam.

x-rays were brought through the
optics and diamond window and observed on a fluorescent screen in the detector box.



C-line, electrons

D-line, positrons

Further C-line development will wait until we have new 4ns electronics.

July run: 5 GeV optics

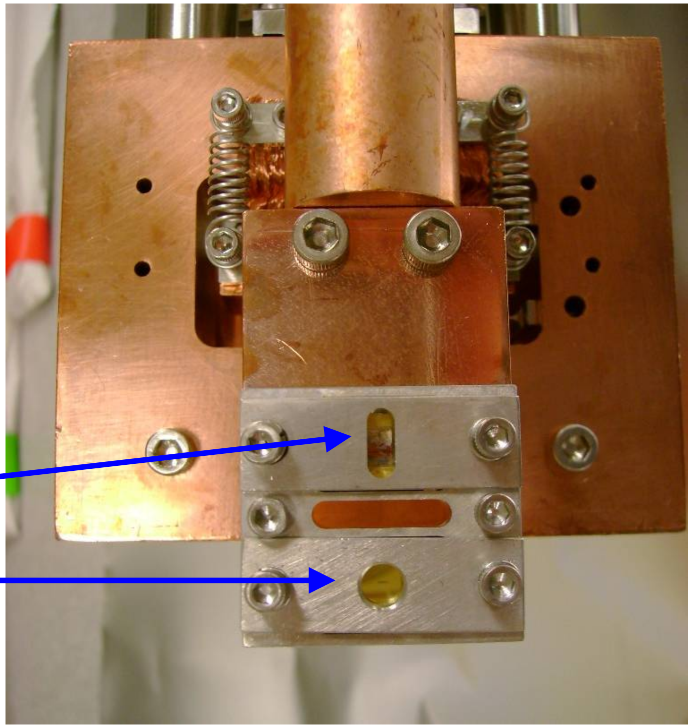
As shown on a previous slide,
the optics carrier was updated.

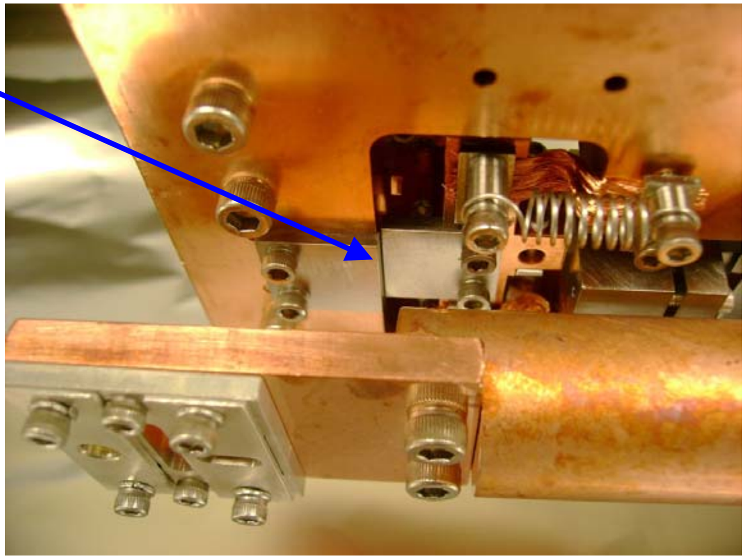
Provides smoother operation.

Provides the 2 GeV optics, well studied in the May run,
(Fresnel Zone Plate, Coded Aperture, hole).

Provides a 5 GeV capable Coded Aperture

Provides an precision adjustable slit
usable at any energy.



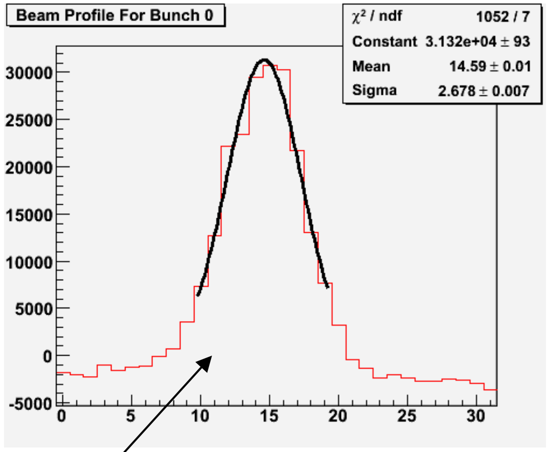


5 GeV running:

Time was invested understanding the

optics slit ("pinhole" for 1-dimesional measurements) and
5 Gev Coded Aperture,

calibrating the detector for 5 GeV beam.

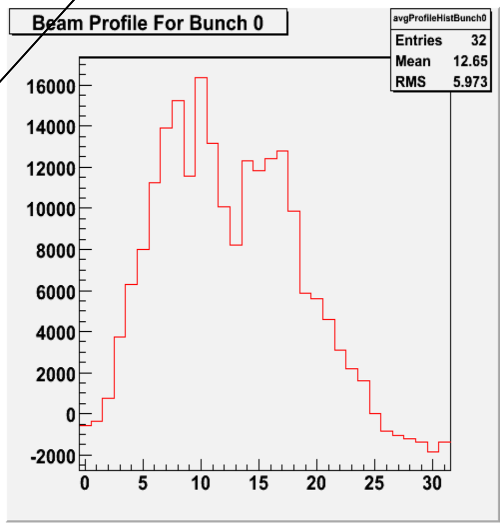


The pinhole size was optimized for the x-ray spectrum, finding the minimum resulting from the "shadow" and "diffraction" regimes.

We provided a measurement of the 5 GeV beam height.

$$\sigma_{beam} = \frac{\sqrt{\sigma_{image}^2 - \sigma_{pinhole}^2}}{m}$$

σ_{image} = 2.678 * 50 μm = 133 μm
$\sigma_{pinhole}$ = ~25 μm
m=magnification= 2.34
σ_{beam} = 57 μm



Corresponding CA image.

2 GeV running:

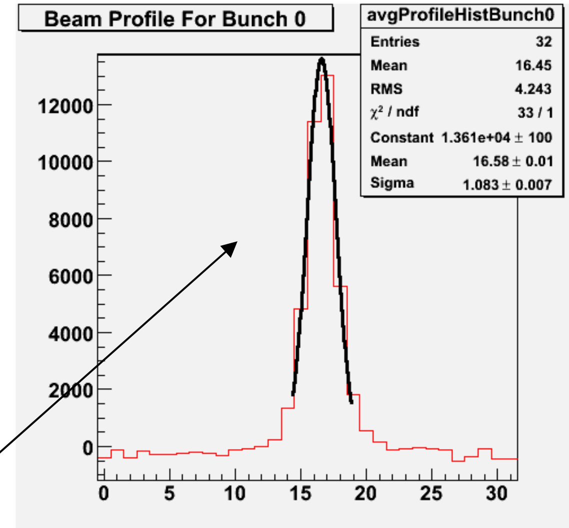
Time was invested understanding the optics slit ("pinhole" for 1-dimesional measurements).

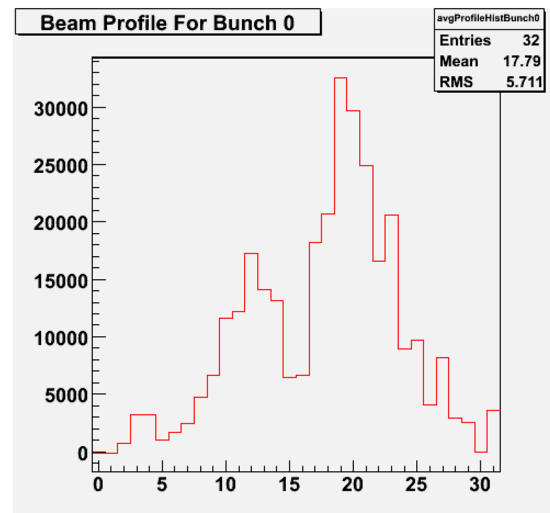
The pinhole provides the flux of the FZP,
without the chromatic aberration.

We made measurements of the 2 GeV beam height with the pinhole.

$$\sigma_{beam} = \frac{\sqrt{\sigma_{image}^2 - \sigma_{pinhole}^2}}{m}$$

σ_{image} = 1.083 * 50 μm = 54 μm
$\sigma_{pinhole}$ = ~25 μm
m=magnification= 2.34
σ_{beam} = 21 μm

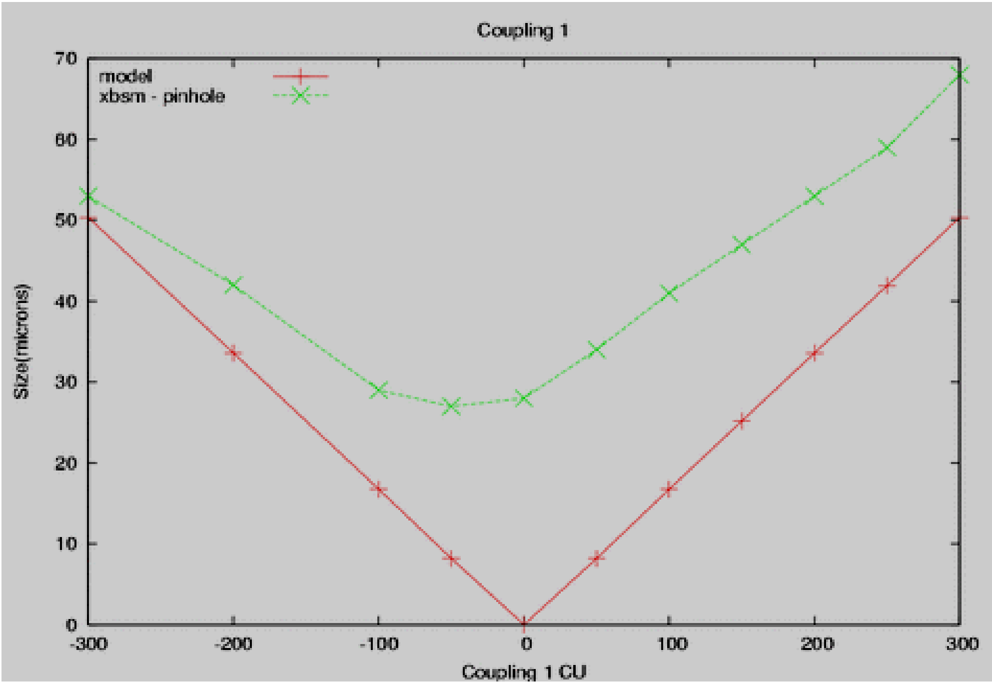




Adapted the LET tool to use the pinhole
(The LET tool was previously developed with the FZP).

Corresponding CA image:
17 μm beam size, run 3385.

2 GeV Low Emittance Tuning with Pinhole



(Probably saw this plot in the previous talk.)

Plot shows measured (green) and
theoretical (red) beam size.

The measured beam size is taken
from the chart recorder LET tool,
running with pinhole optics.

Previous description of the LET tool
showed
the beam moves and
there is limited range in the diode for this motion.
These results utilize the beam chaser
(feedback of the fit results to the diode vertical position motor).

The rounded shape of the measured beam size is
thought to be due to the finite size of the “pin hole”.
The theoretical beam size has no input minimum.

Low Emittance Tuning Status

Chart recorder LET tool runs with

at 2 GeV

Fresnel Zone Plate optics (requires careful fitting)
or
pinhole optics (some limitations at small beam size.)

At 5 GeV, the beam size is well matched to the pinhole.
(There are problems with limiting the x-ray flux that
will be addressed with a refined mask before the detector.)

We have experience with the Coded Apertures at both 2 GeV and 5 Gev
that will can be developed into a more precise measurement.

Future Plans

Upgrade electronics for 4 ns readout
   reduced noise
   variable gain to be able to read out 2, 4, 5 GeV with minimal physical flux reduction

Commission C-Line optics

Add fast read out to C-Line with 4 ns readout

Calibrate detectors for 4 and 5 GeV

Implement fitting of the Coded Aperture images