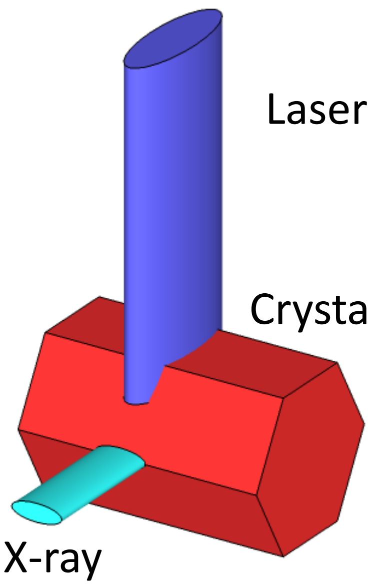
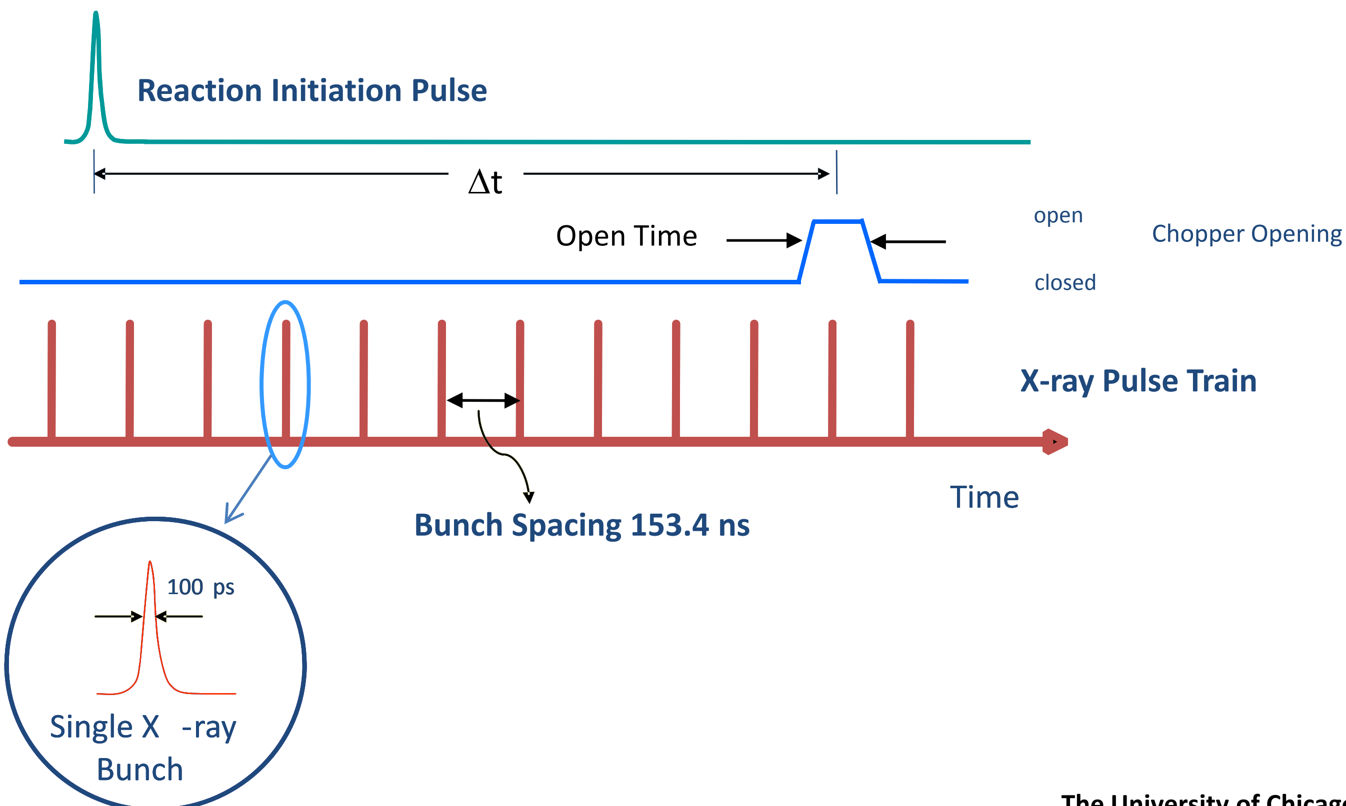
X-ray pulse isolation using synchronous beam choppers at BioCARS





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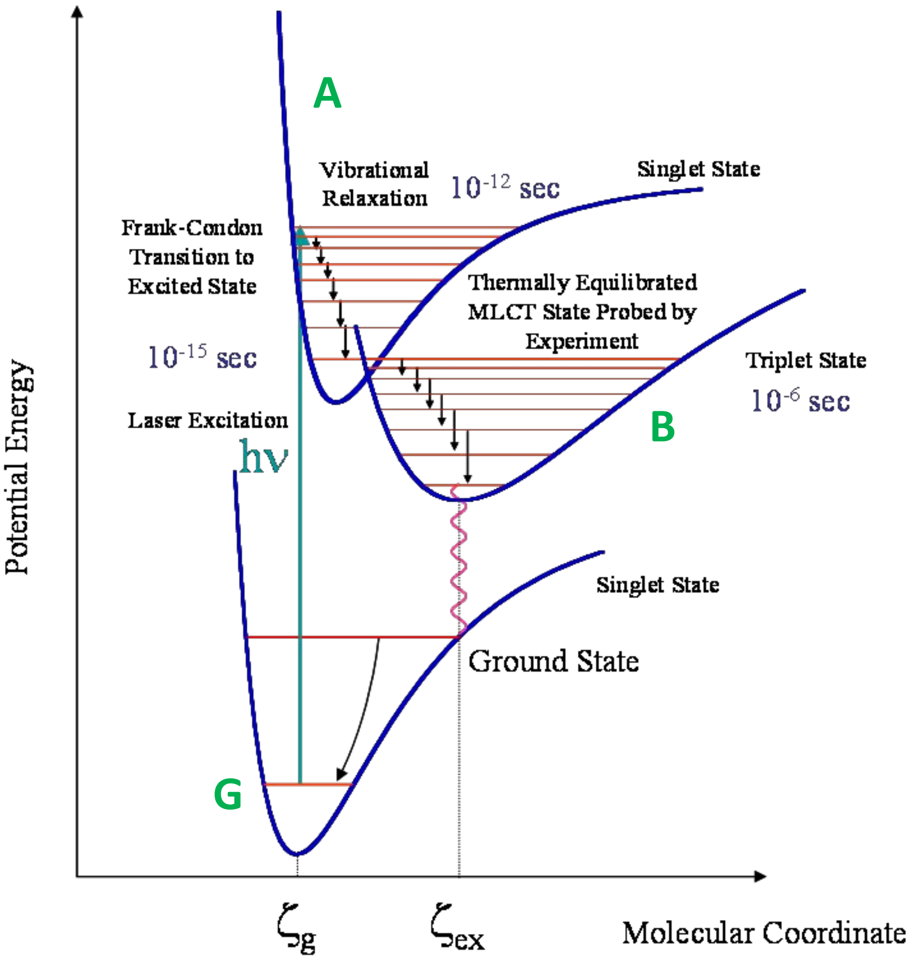
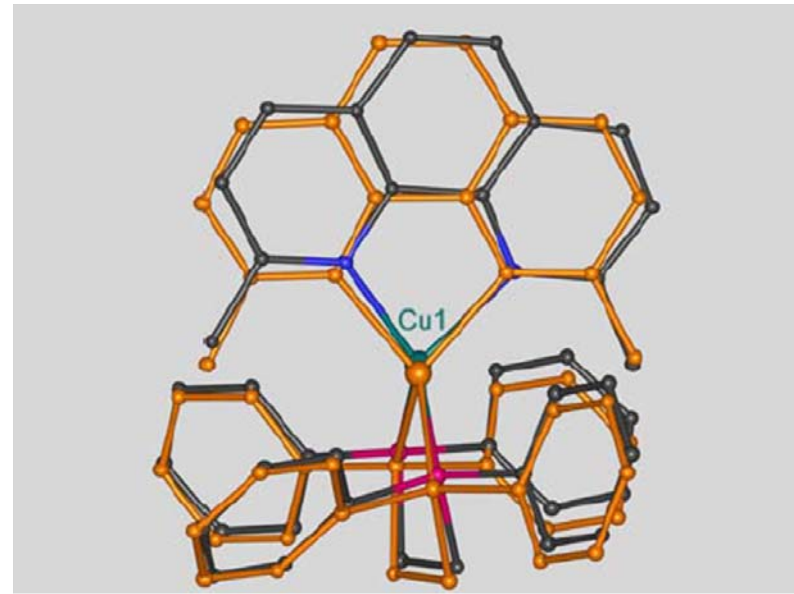
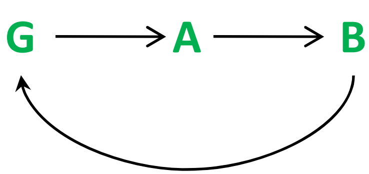
MTCT example of a possible system





By taking data with a series of pump-probe delays intermediate states can measured as a function of time.



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Why is an X-ray chopper necessary? Can’t you just use a fast detector?

- Fast point detectors and special area detectors can be gated to acquire only during exposure to a single pulse.
- Works for samples that are not susceptible to radiation damage.
- In 24-bunch mode, we can deliver 10^{10} photons per pulse at the sample corresponding to a time-average flux of [24/3.68μsec] x10^{10} or 6.5x10^{16} photons/sec
- This is roughly 500x hotter than the most intense monochromatic beam at the APS.
- For most biological and inorganic samples this beam is far too intense and will damage the crystal.

Additionally, with regard to an area detector ………..

- There are no large-area detectors in existence with sufficient time resolution and inter-frame rate
- Ideally we would want 100ps (or better) exposure with a 154 ns inter-frame rate.
- We can deposited 40,000 photons at 12 keV in 100 ps into a single 80x80μm^2 pixel
- Counting detectors such as the Pilatus will not work . We must have an integrating detector.

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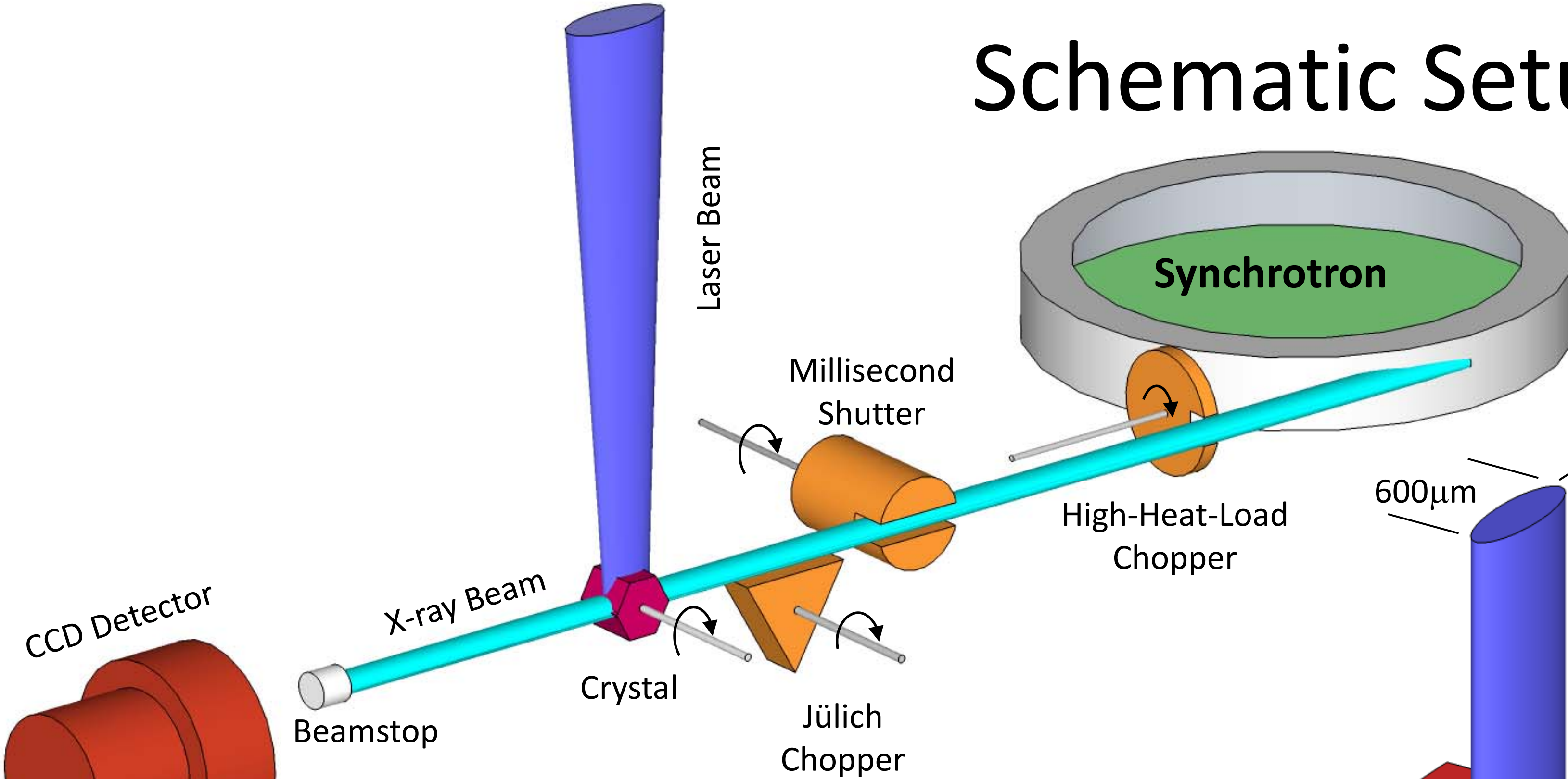
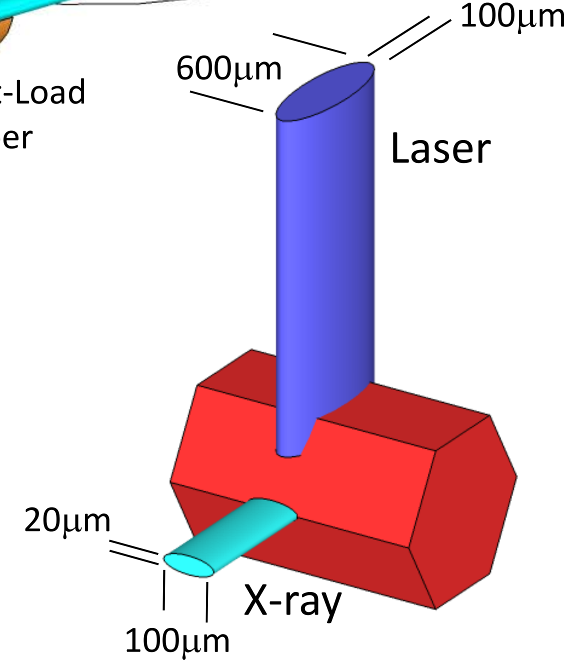
Schematic Setup





- Choppers are constantly rotating devices that are synchronized to the storage ring RF clock and “chop” the beam.

- The shutter open and close on demand, like the shutter on a camera to expose the CCD detector

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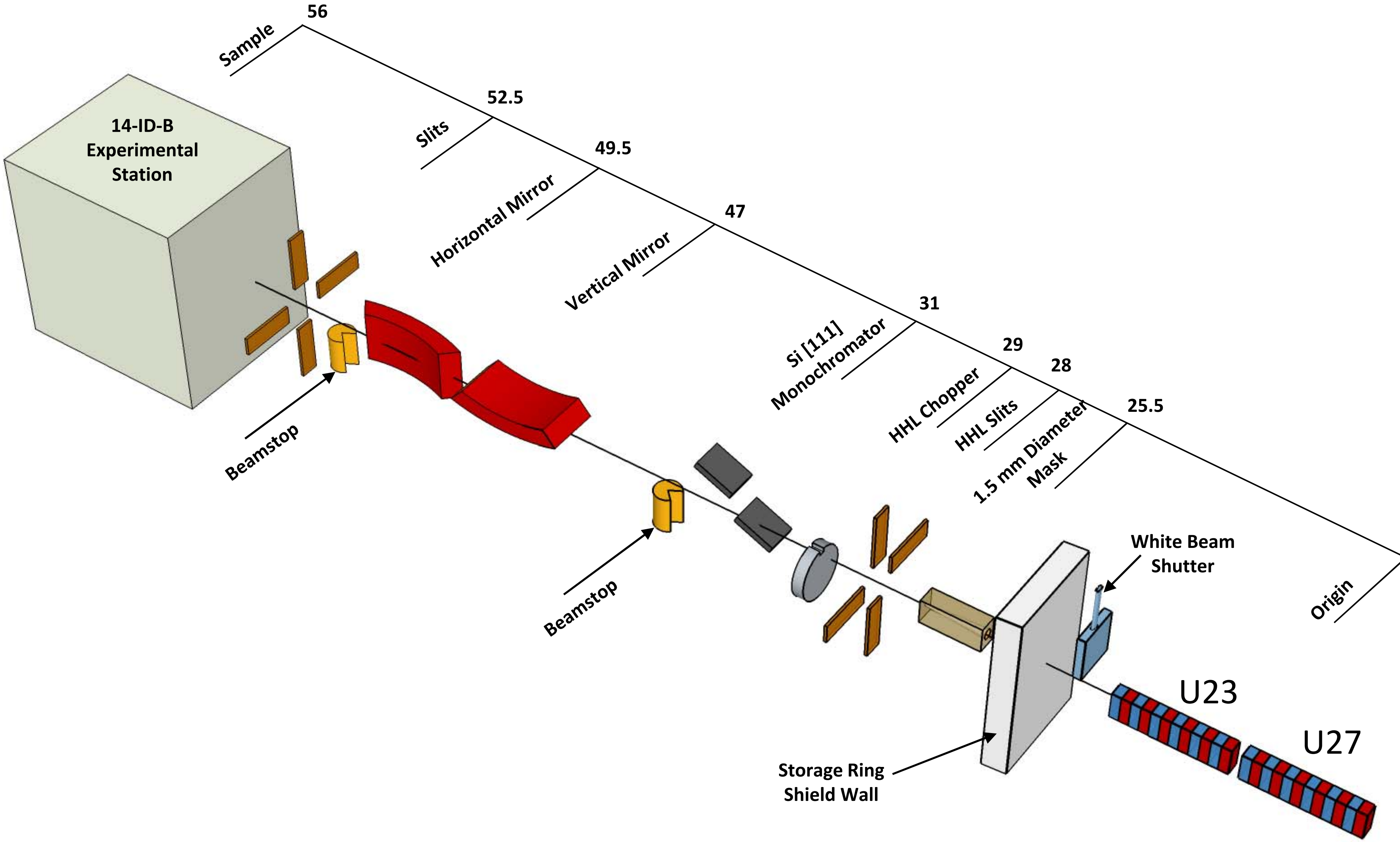

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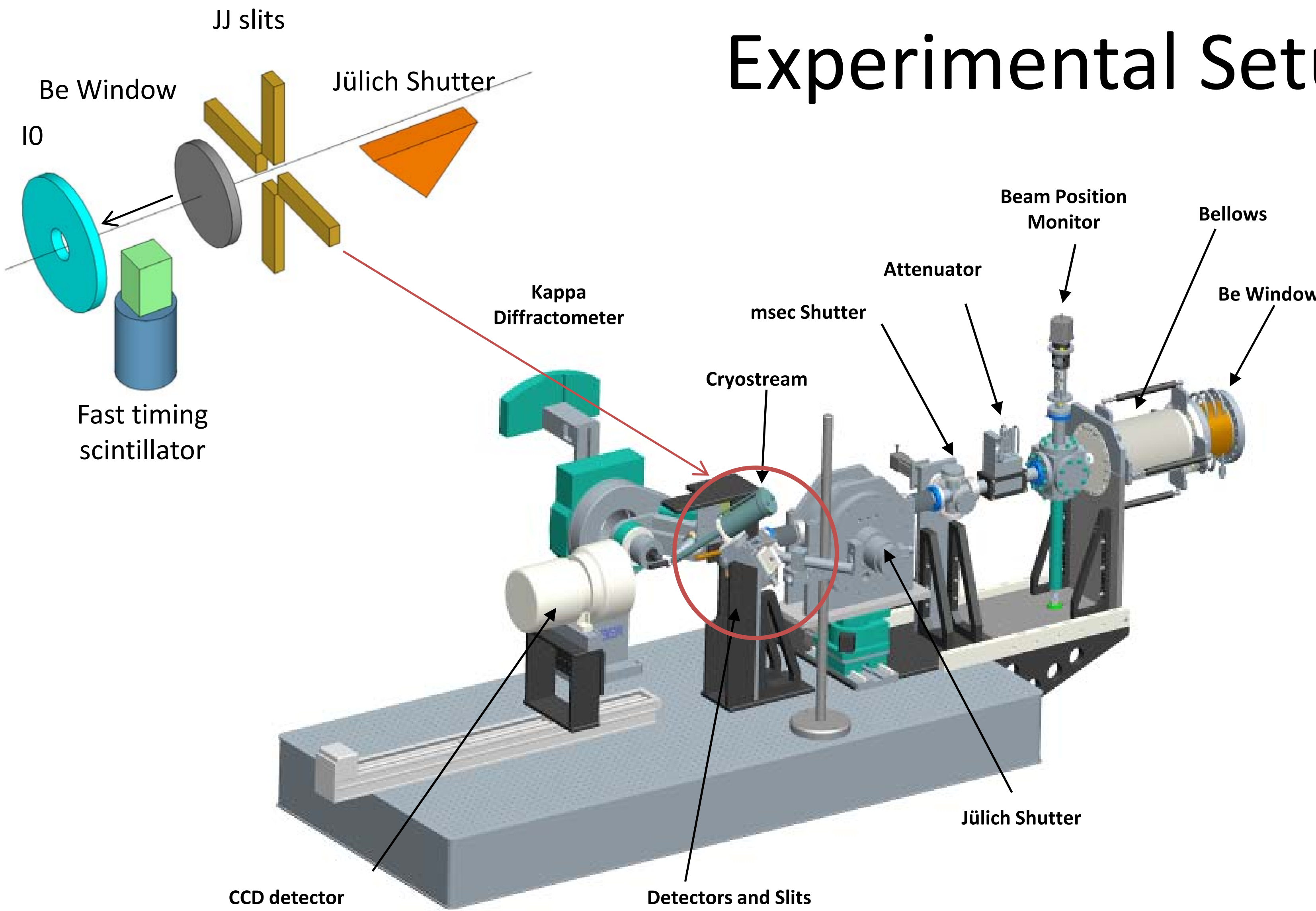
Experimental Setup



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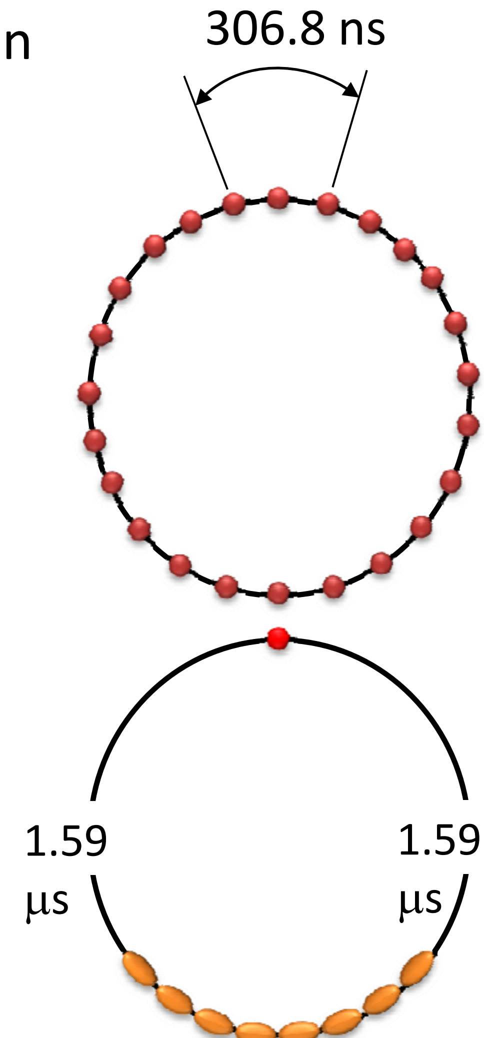
Important Chopper Parameters

Open time must be less than twice the time between consecutive bunches.

Frequency should match the laser rep rate.

Attenuation should be large for the desired operational energy range.



t_r=35ns

t_o=125ns

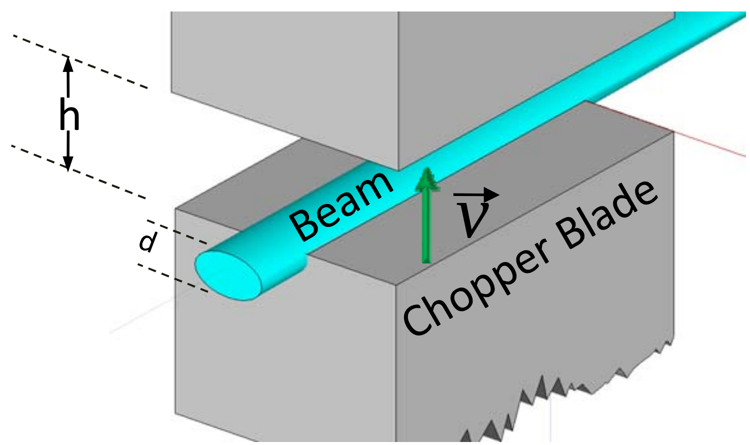
d=20μm

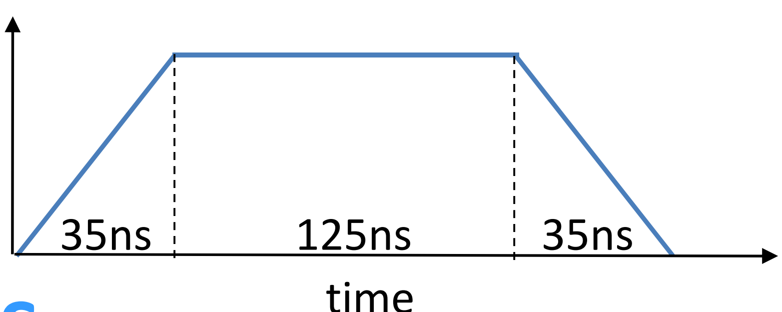
$v=d/t_r$=571.5 m/s

=1278.4 miles/h

(343 m/s speed of sound)

$h=vt_o$=71μm





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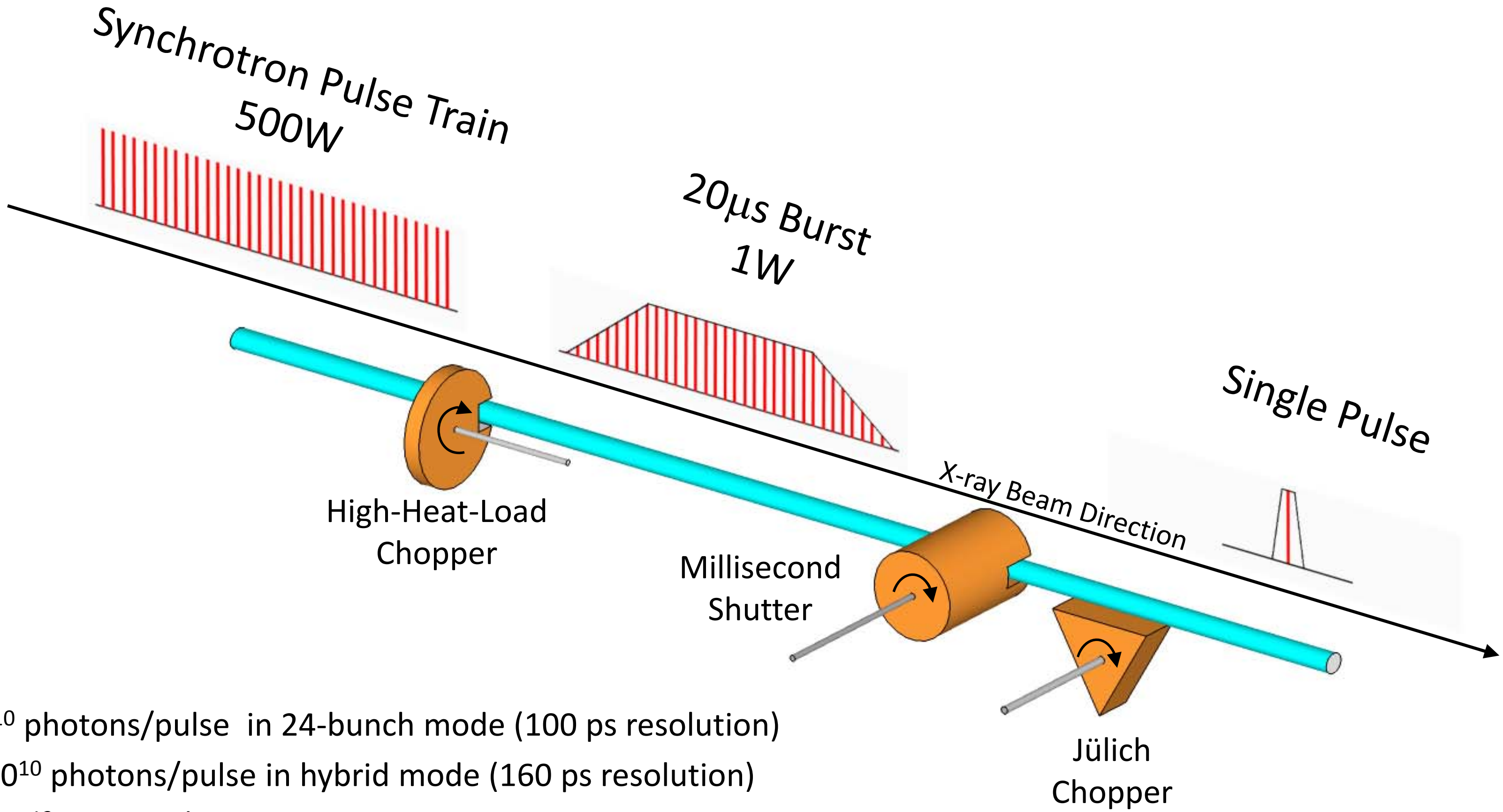
Shutter and Timing System



- 1×10^{10} photons/pulse in 24-bunch mode (100 ps resolution)
- 3.8×10^{10} photons/pulse in hybrid mode (160 ps resolution)
- LCLS 10^{12} photons/pulse (10 fs resolution)

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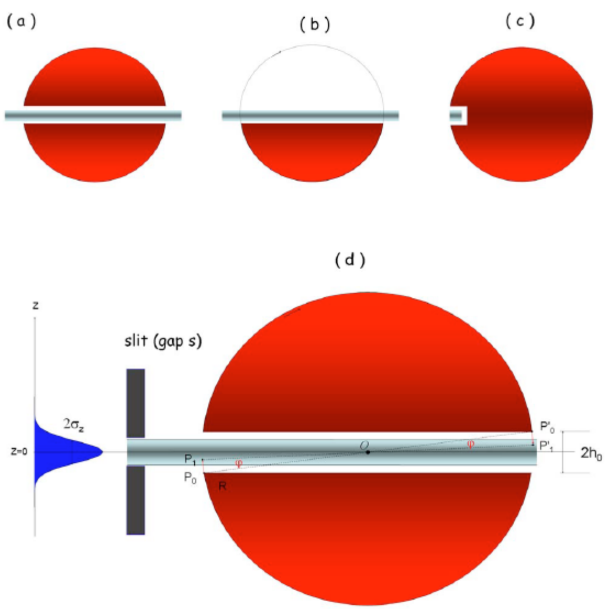
Gaussian beam model of transmitted intensity

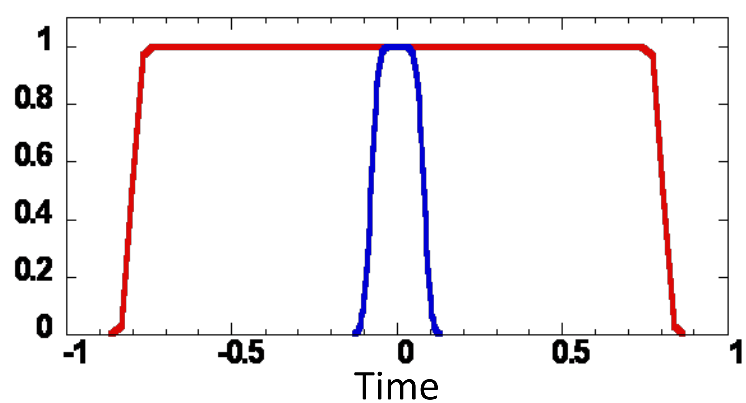
$$f(z) = \frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{z^2}{2\sigma^2}\right)$$

$$\upsilon = 2\pi f R$$



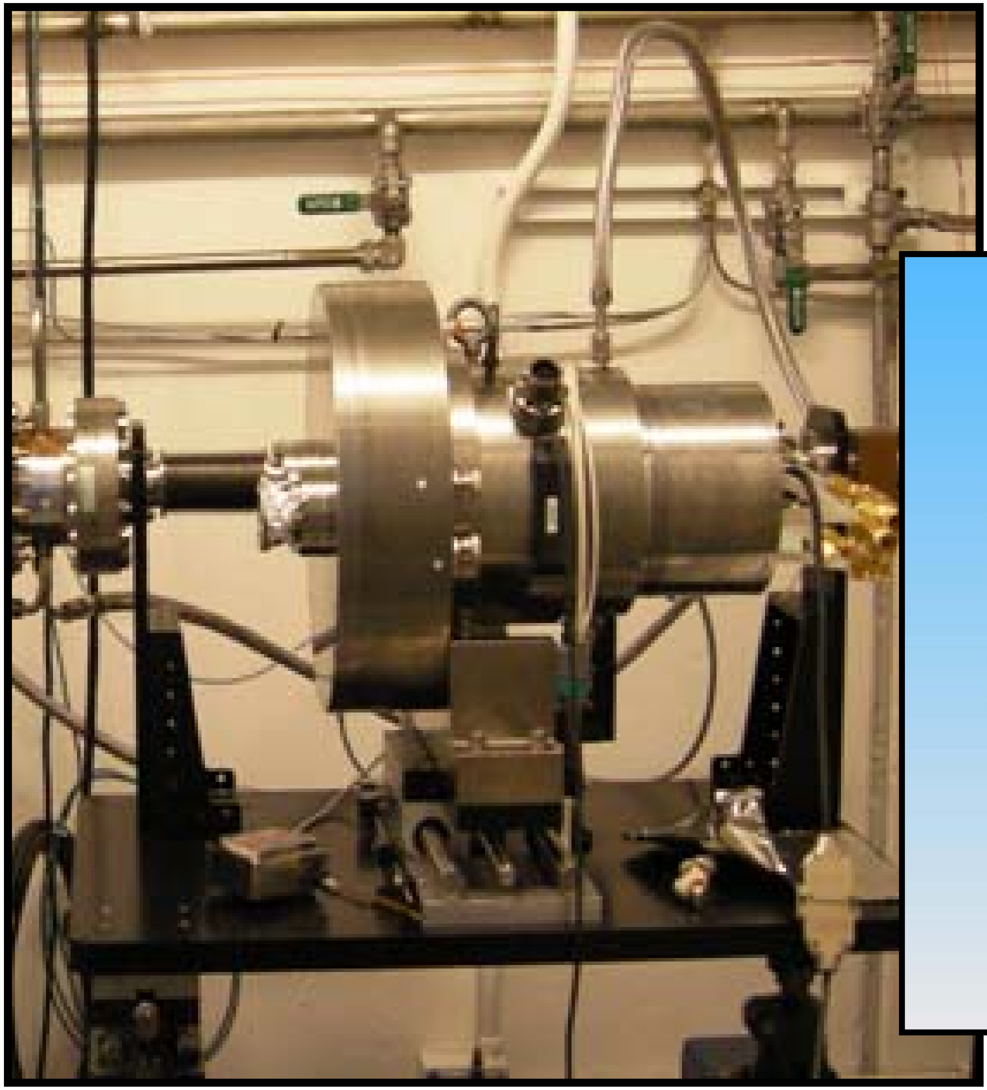
$$I(t) \cong \int_{-h(t)}^{h(t)} f(z)dz = \operatorname{erf}\left(\frac{h(t)}{\sqrt{2}\sigma}\right)$$

$$h(t) = h_0 - 2\pi f R|t|$$

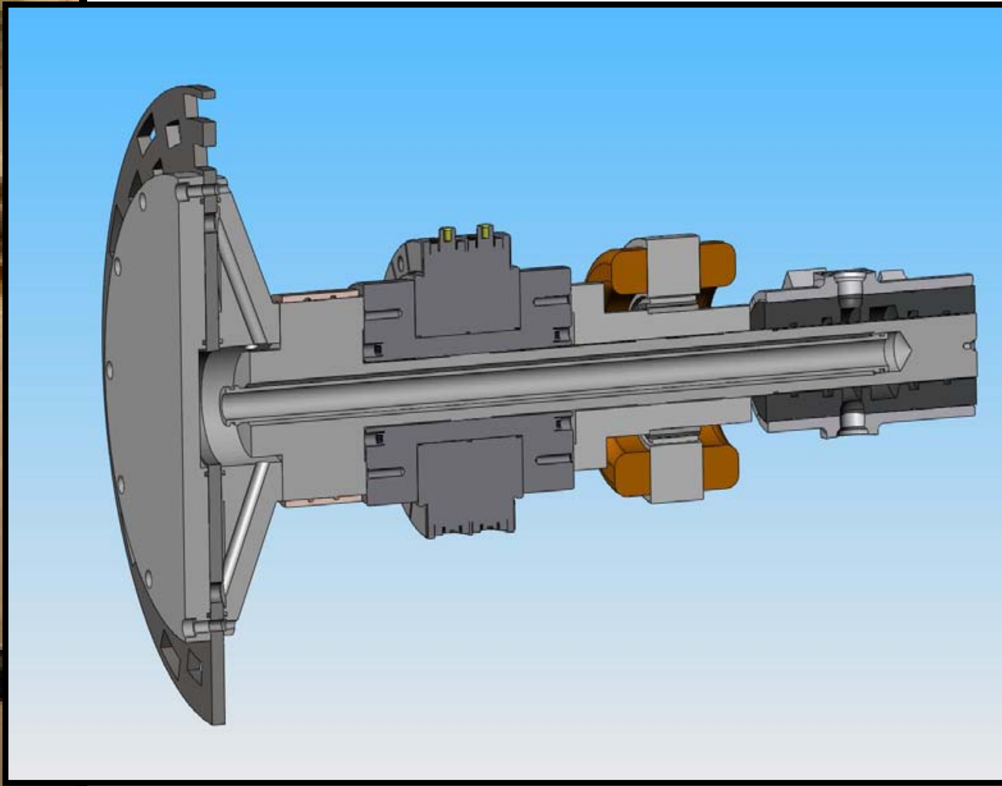


Marco Cammarata, *et al.,* Chopper system for time-resolved experiments with synchrotron radiation, REVIEW OF SCIENTIFIC INSTRUMENTS **80, 015101 2009**

High-heat-load chopper



- Air Bearing
- Water Cooled
- Vacuum Isolated
- Reduces downstream heat load



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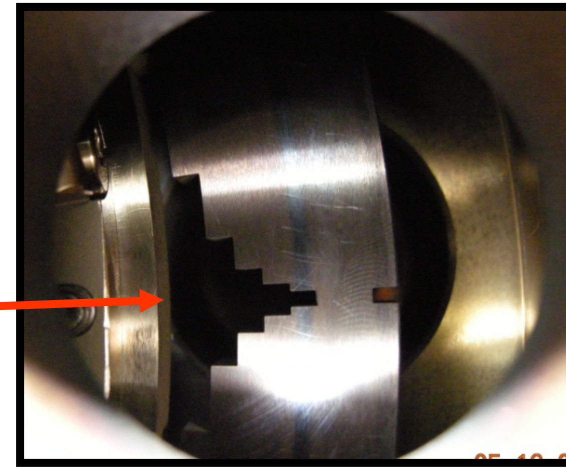
Professional Instruments Company
pico@airbearings.com

Rotor and slot arrangement

Stainless steel



- Nominal frequency 4980 rpm
- 83 Hz or 1kHz operation
- Temperature rise 16°C

Slot Width [mm]	Open Time [us]
48	789 (6.5%)
24	386 (3.3%)
12	189 (1.6 %)
6	92 (0.8%)
3	45 (0.4 %)
1.5	22 (0.2 %)

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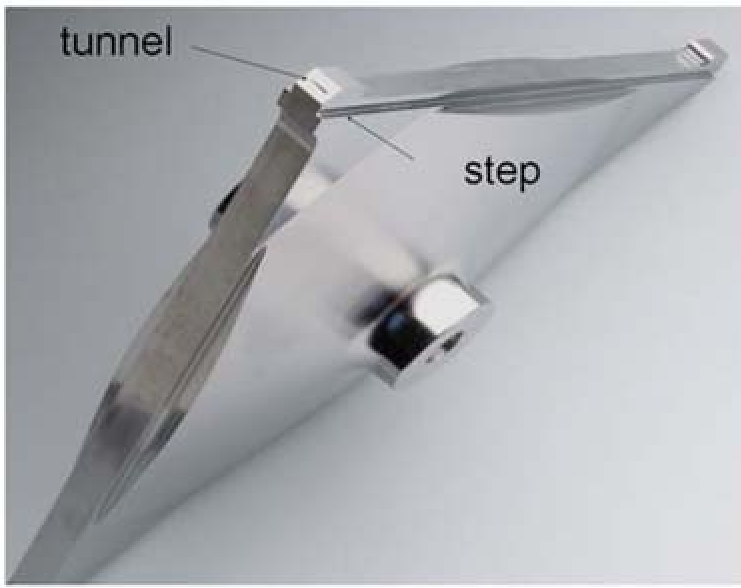
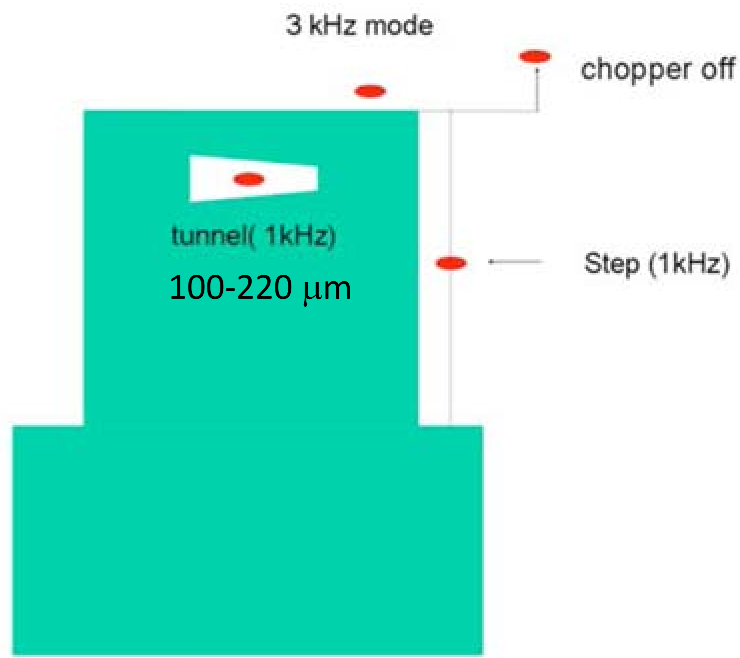
High-speed Jülich Chopper

JÜLICH
FORSCHUNGSZENTRUM

- f=59,220 rpm
- Tip speed ~ 600m/s
- Magnetic bearing
- Titanium Rotor





http://www.fz-juelich.de/zat/Chopperen/

- free of contact without friction
- no lubricant
- wear-free
- maintenance-free

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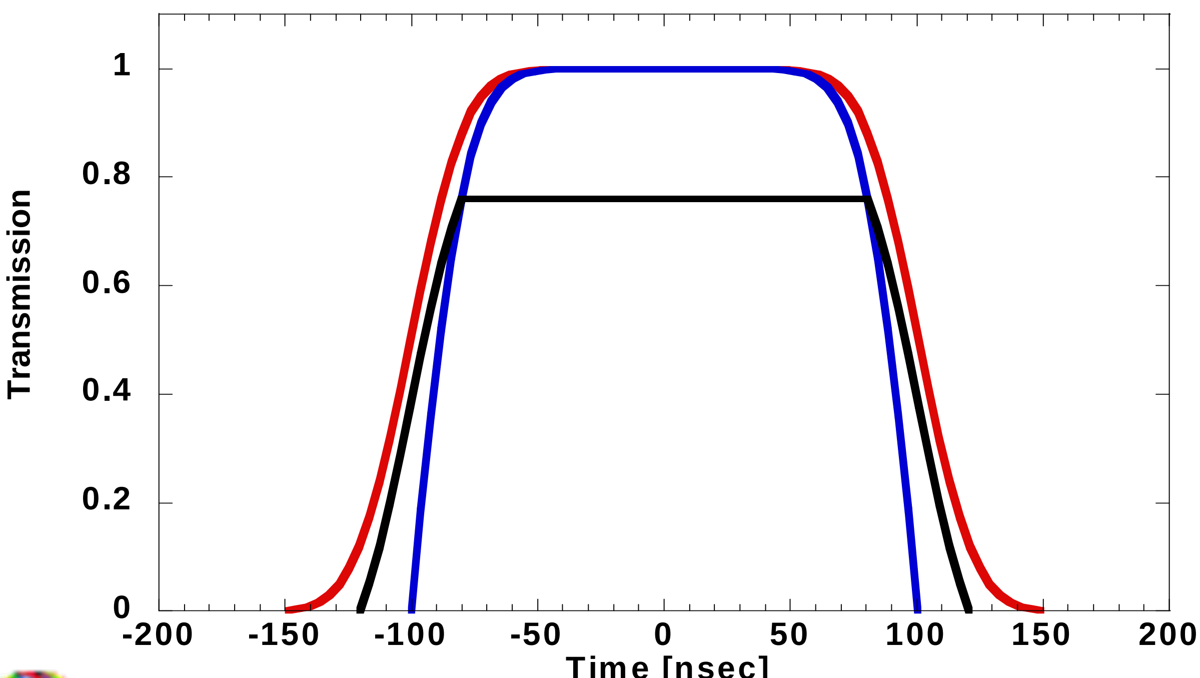
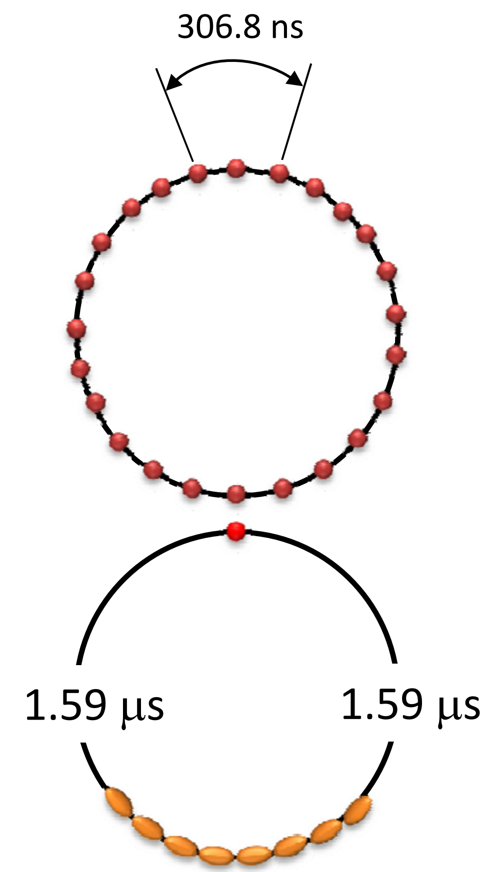
Transmission function for Jülich

- 100µm tunnel (blue)
- Tunnel-less (red)
- Tunnel-less 20 µm slits (black)

Using a 20 µm FWHM Gaussian function





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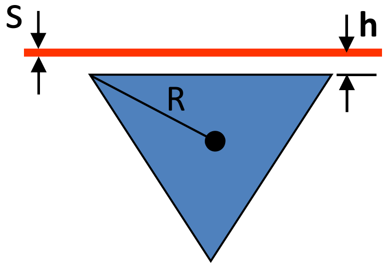
Fast Jülich Chopper



Height of beam above rotor determines open time

$$\Delta t_{\text{top}}(\text{tunnel-less}) = \frac{2h_0 - s}{\sqrt{3}\pi f R}$$

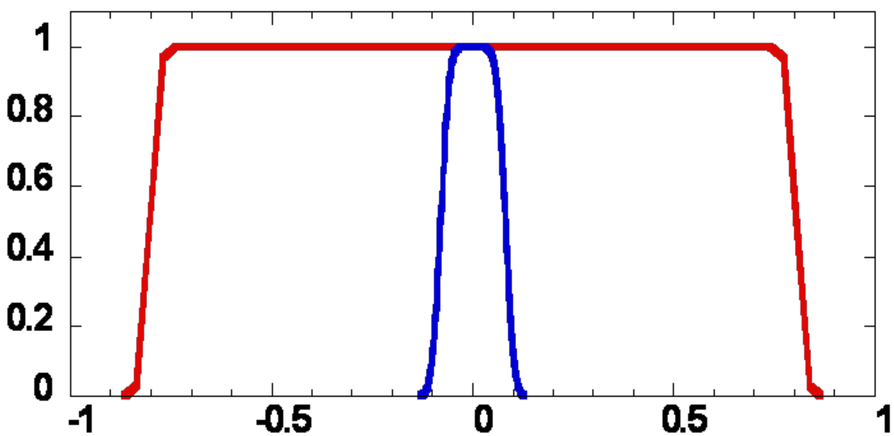
$$\Delta t_{\text{base}}(\text{tunnel-less}) = \frac{2h_0 + s}{\sqrt{3}\pi f R}.$$

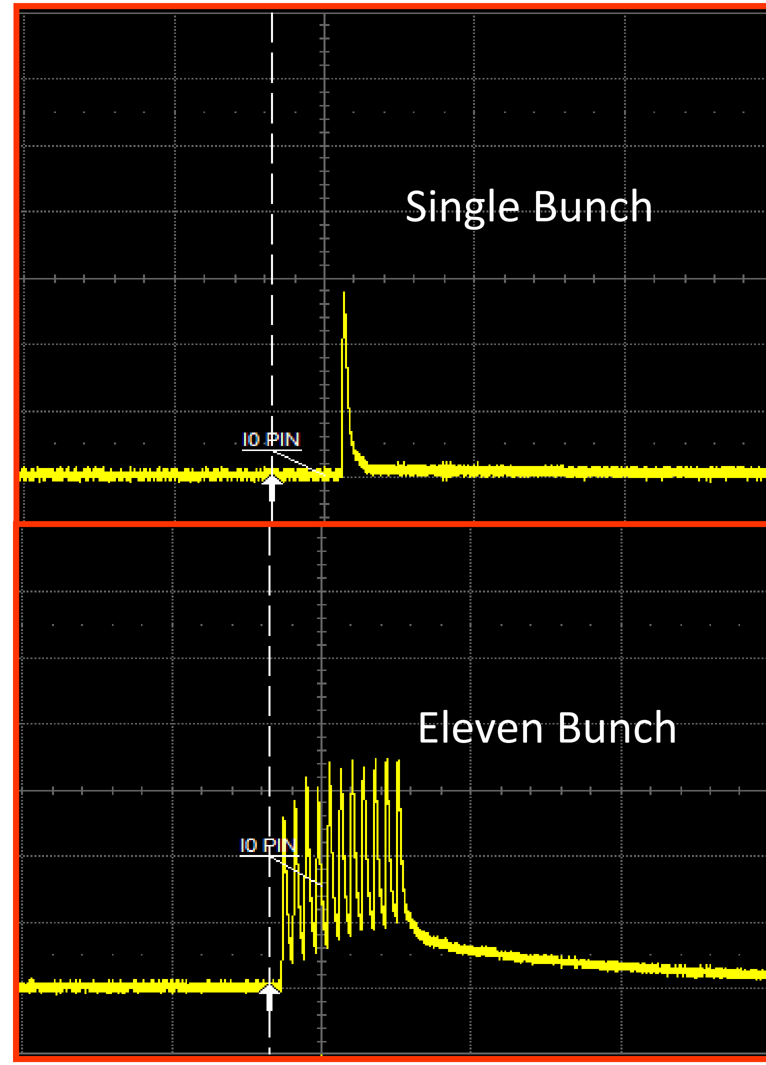
R = 96.8mm

f = 987 Hz

h = 25 μm

s = 40 μm





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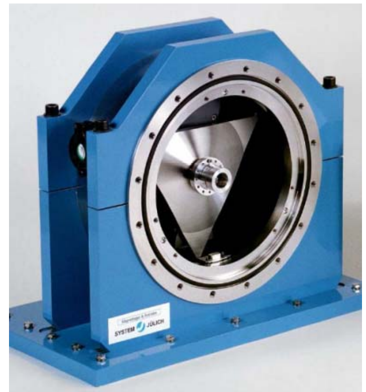
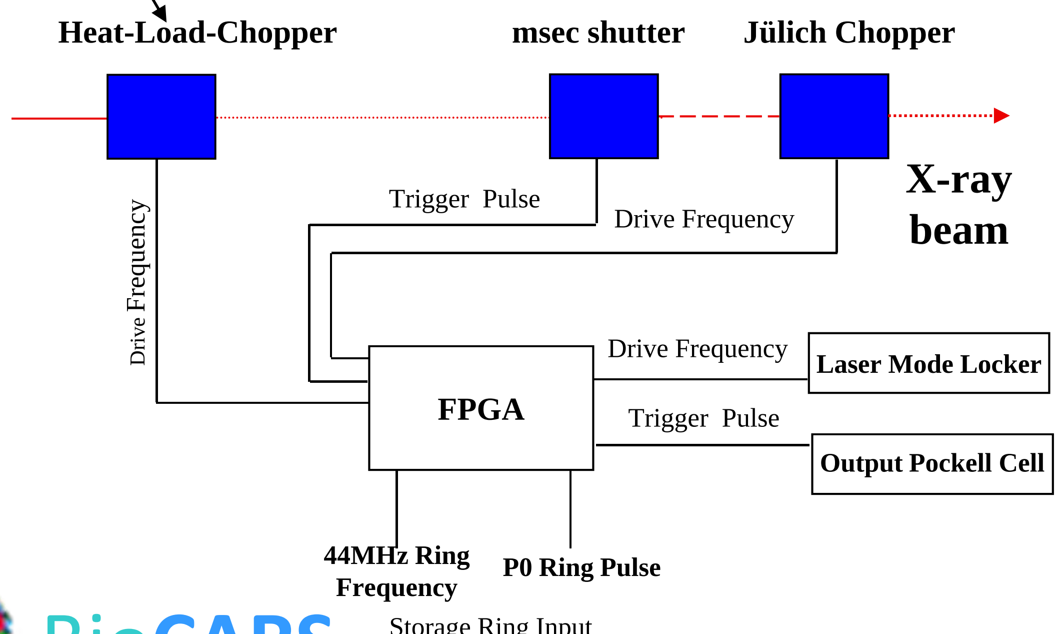
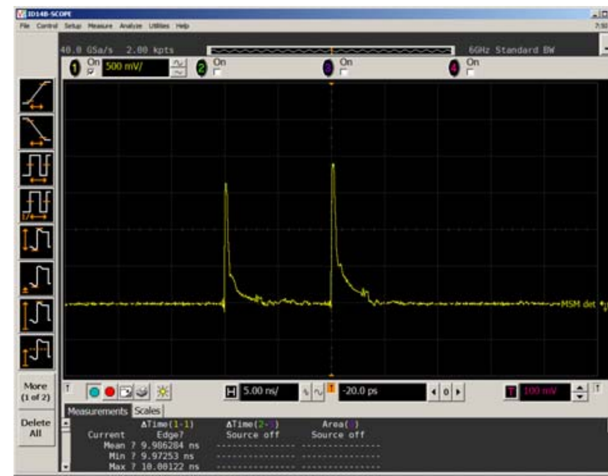
Shutter train and synchronization with the storage ring

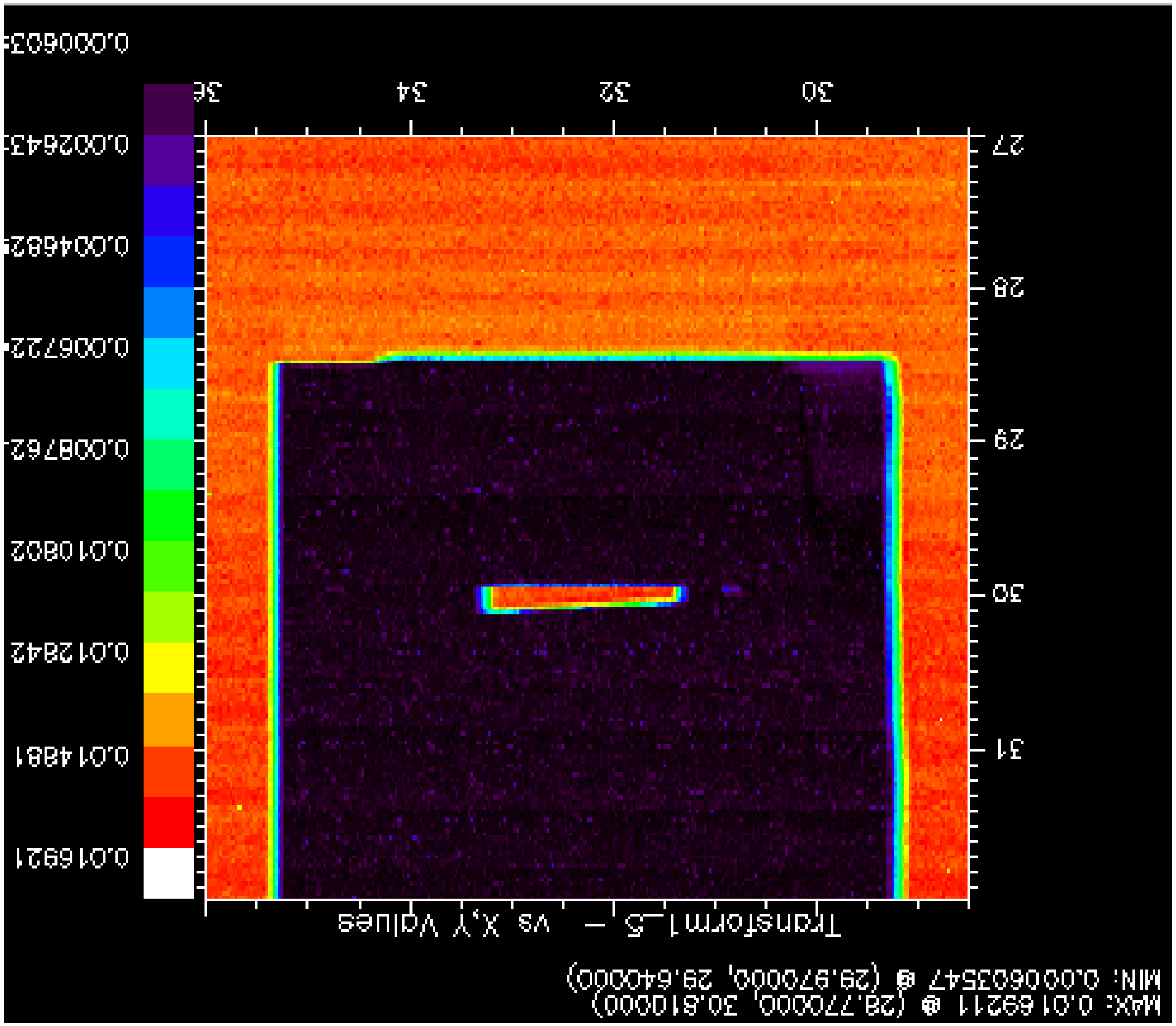




10ps RMS jitter in system



System Stability

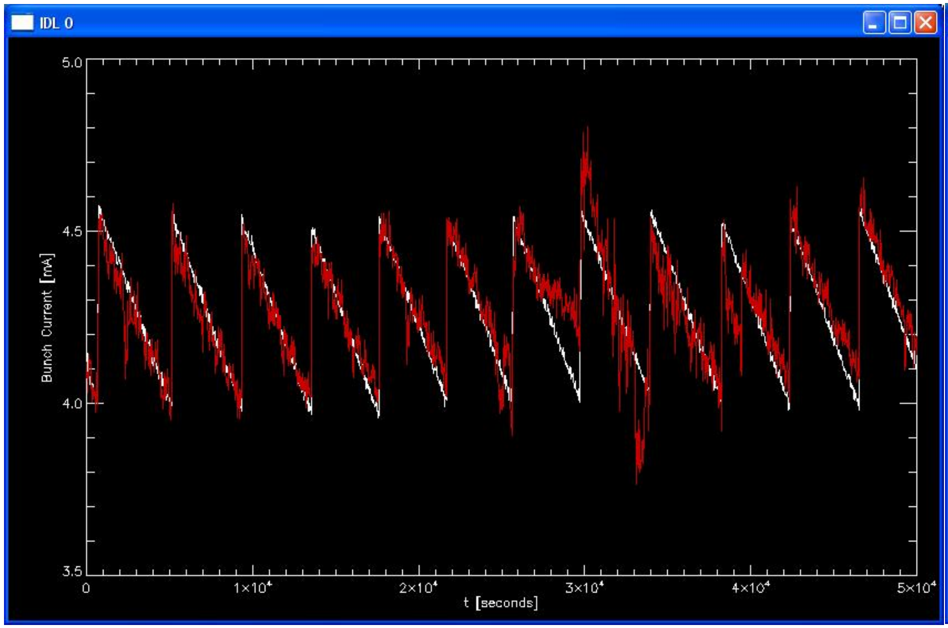


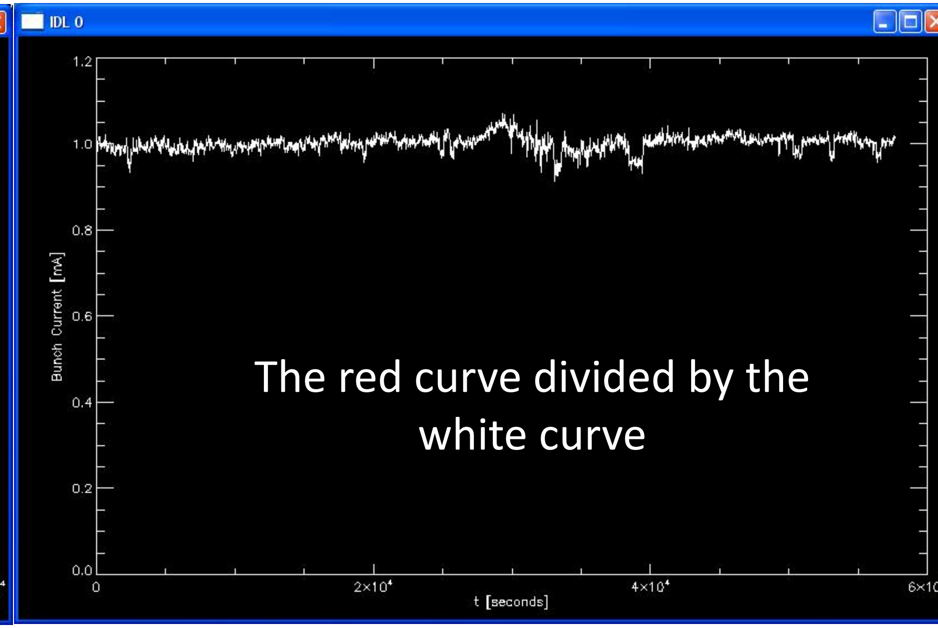
Position scan in x-y plane of the rotor tip taken while spinning

Tip speed ~ 600m/s

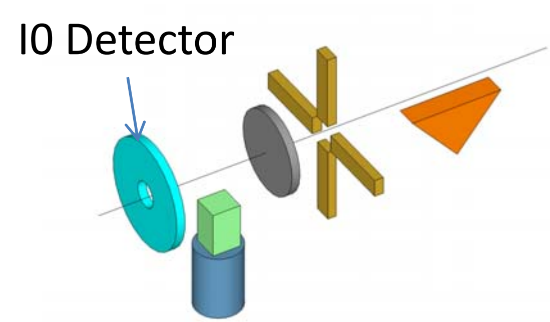
Since the only rotor tip moves 0.4μm during the transit time on the X-ray pulse, it can be considered stationary.

Ability to lock on to a single bunch in 24-bunch mode





- White curve is a plot of the APS PV for single bunch current.
- The red curve is a measure of the beam at the beamline using the I0 detector.



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