Plan to upgrade the ALS to Top-off Injection

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Advanced Light Source

Outline

Introduction and Motivation

Determining user requirements

Radiation Issues

Status of the Project

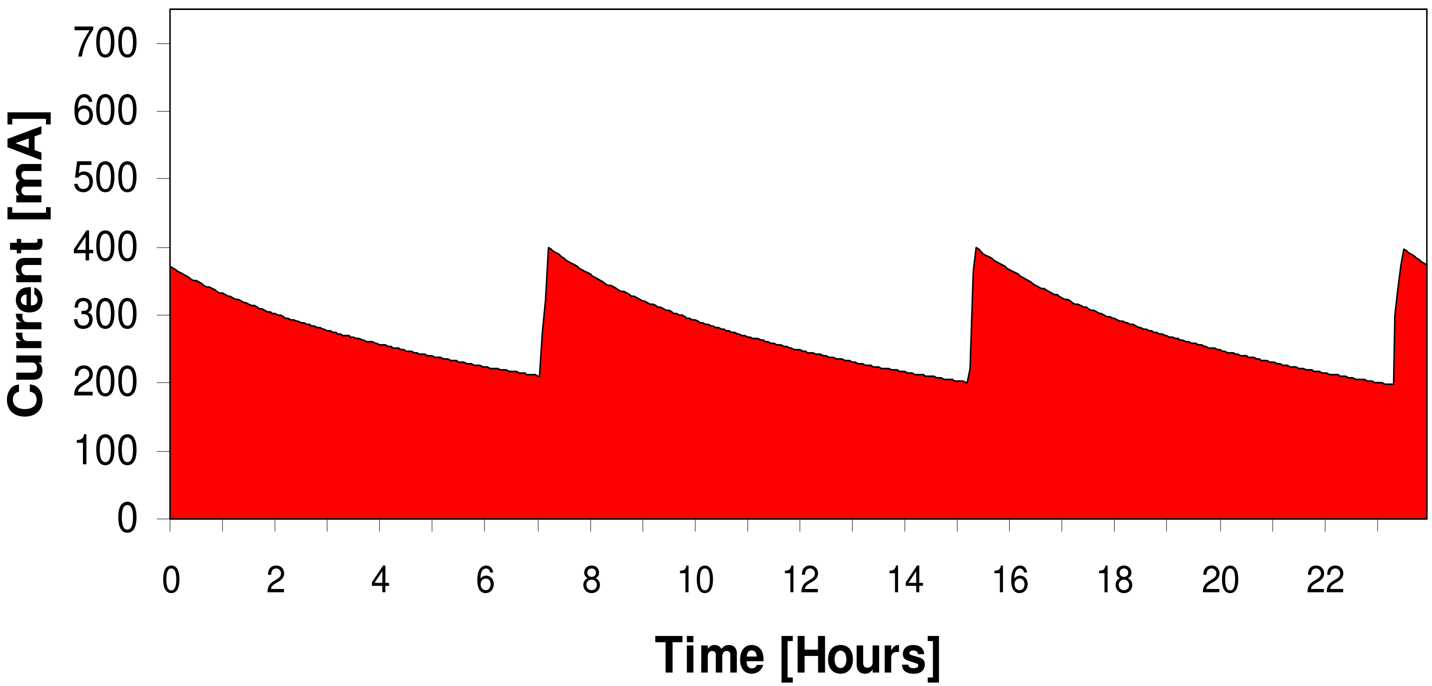
Future Plans

Present brightness limitation – beam lifetime

Brightness increases are possible by :

- **Increasing the time averaged beam current**
- **Reducing the beam size**
- **Reducing the insertion device gap**

These changes would result in unacceptably small beam lifetimes



Beam loss is caused by intrabeam scattering

- **Currently the fill the ring 3 times daily to 400mA and decays down to 200mA in 8 hours (with time averaged current of 250mA)**

Continuous Top-off Injection

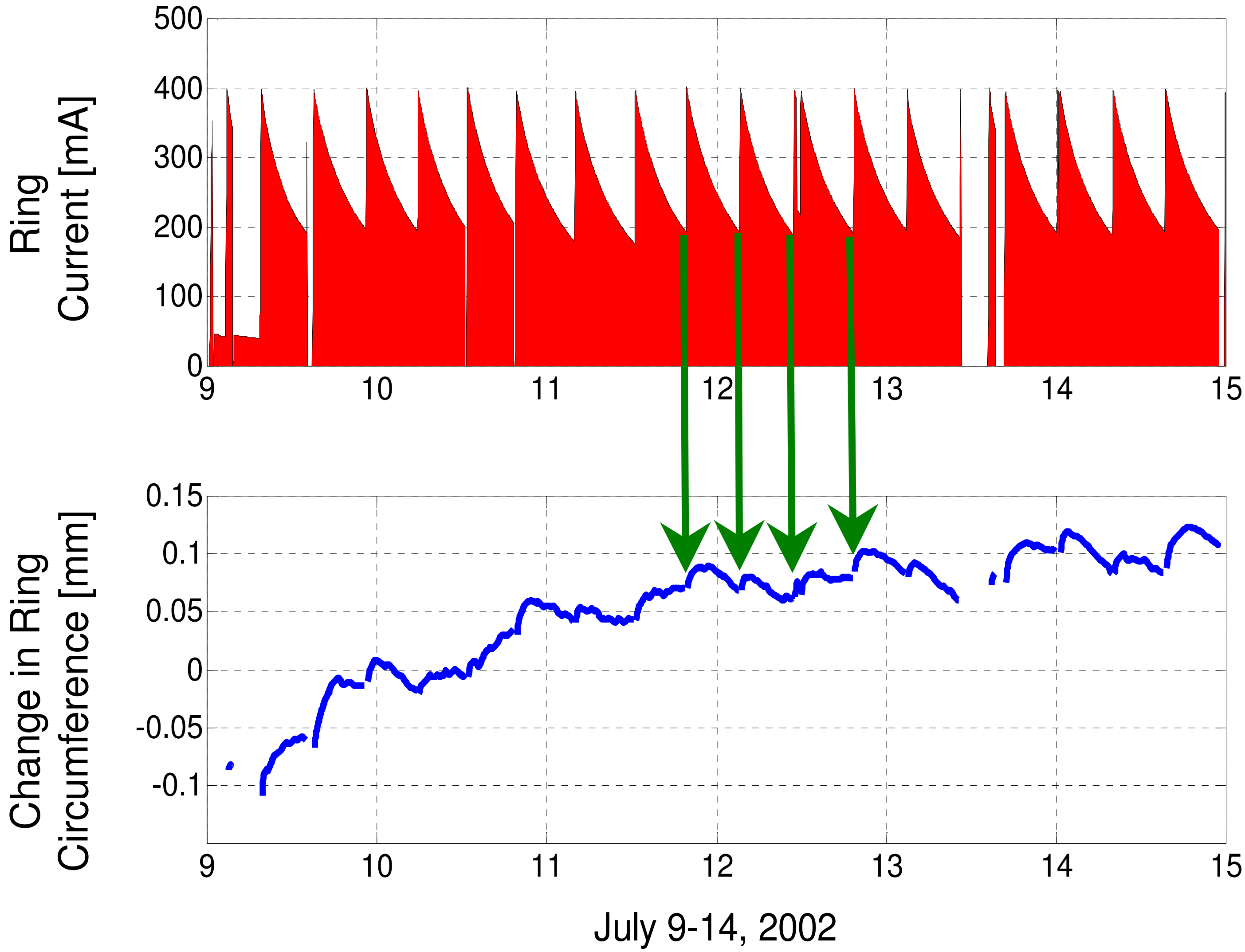
The lifetime limitation can be mitigated through continually filling the ring → top-off injection

- **Top-off mode is routinely used at the Advanced Photon Source (APS), the Swiss Light Source (SLS) and SPRING-8**

Added benefit

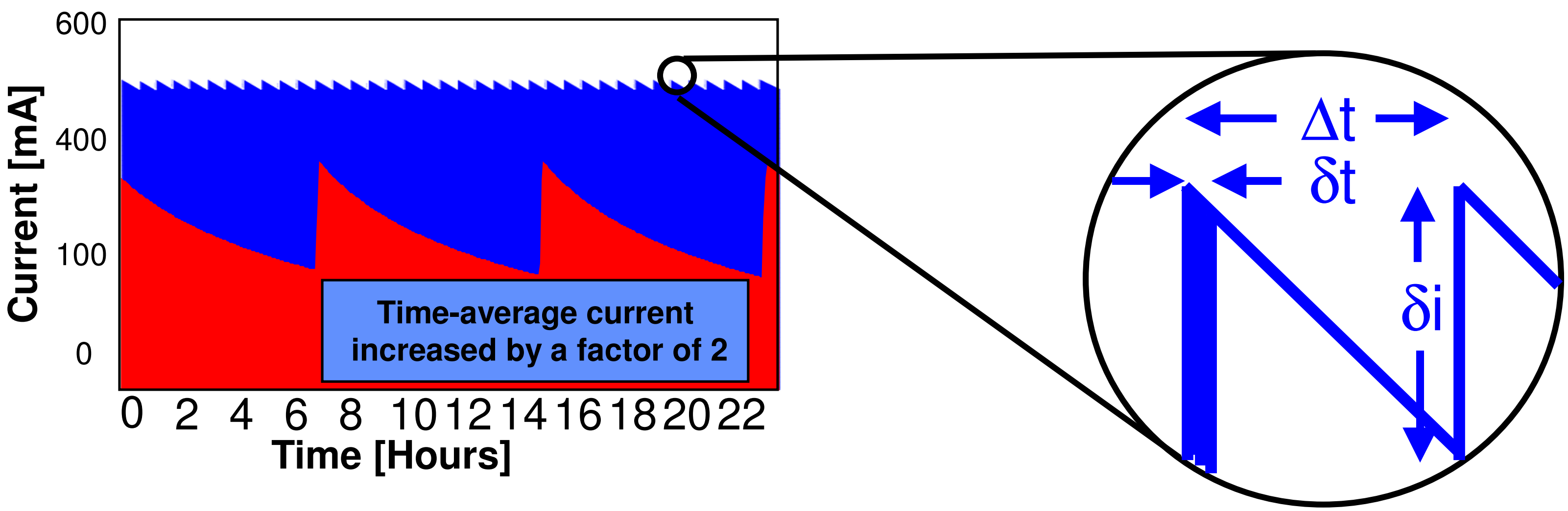
- **Operating at constant current improves thermal stability**

Weekly variations in circumference



Top-off operation

Top-off the current at 500 mA



coupling	δi	Δt	ε_v	σ_h	σ_v	$\sigma`_h$	$\sigma`_v$
Operational 03	1.5mA	72.0s	150×10^{-12}	298µm	23µm	22µrad	6µrad
Intermediate	**1.5mA**	**32.0s**	**20×10^{-12}**	**298µm**	**8µm**	**22µrad**	**3µrad**
Smallest Ever	1.5mA	14.4s	5×10^{-12}	298µm	4µm	22µrad	1µrad

Top-off opens the door to large increases in brightness

Larger beam currents

- **Increase the time averaged current by a factor of 2 from 250mA → 500mA**
  - **Top-off injection**

Smaller beamsizes

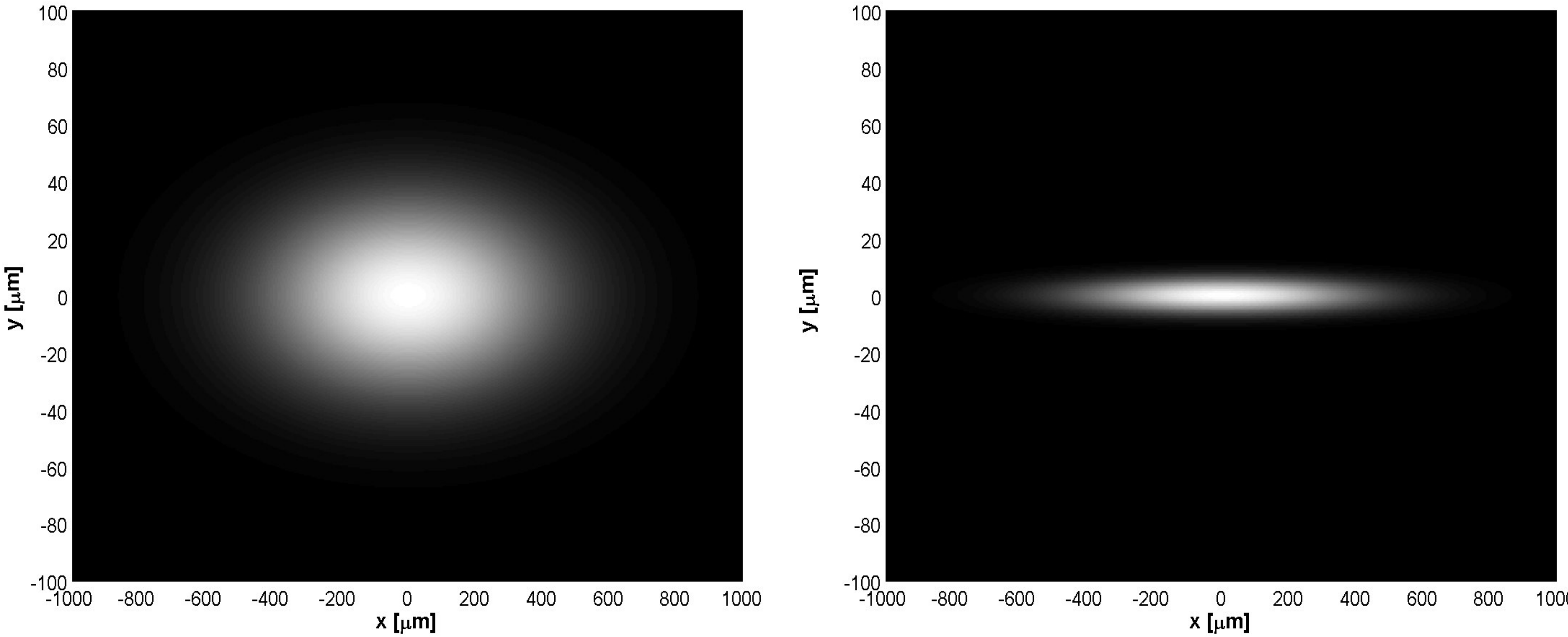
- **Reduce the vertical beamsize by a factor of 3**
  - **Reducing the emittance by a factor of 15 from 0.15nmrad → 0.02 nmrad.**
  - **Reduce the vertical beta-function by 1.5 from 3.6m to 2.25m**

Smaller gap insertion devices

- **Reduce the vacuum gap from 9mm → 5mm**

Smaller vertical beamsizes

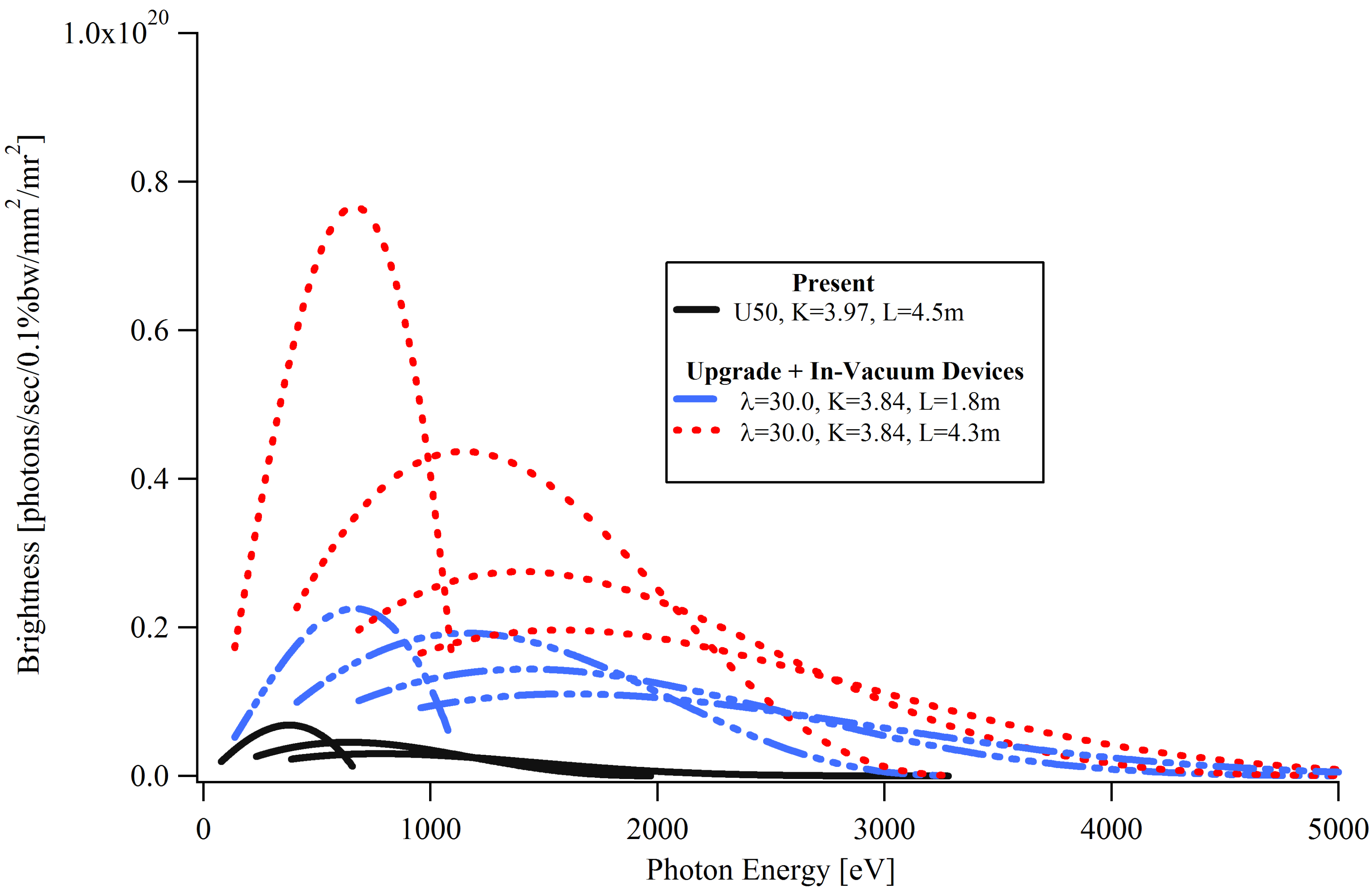
Achieved 5 pm-rad vertical emittance in accelerator studies



Present vertical beamsize **Low coupling beamsize**

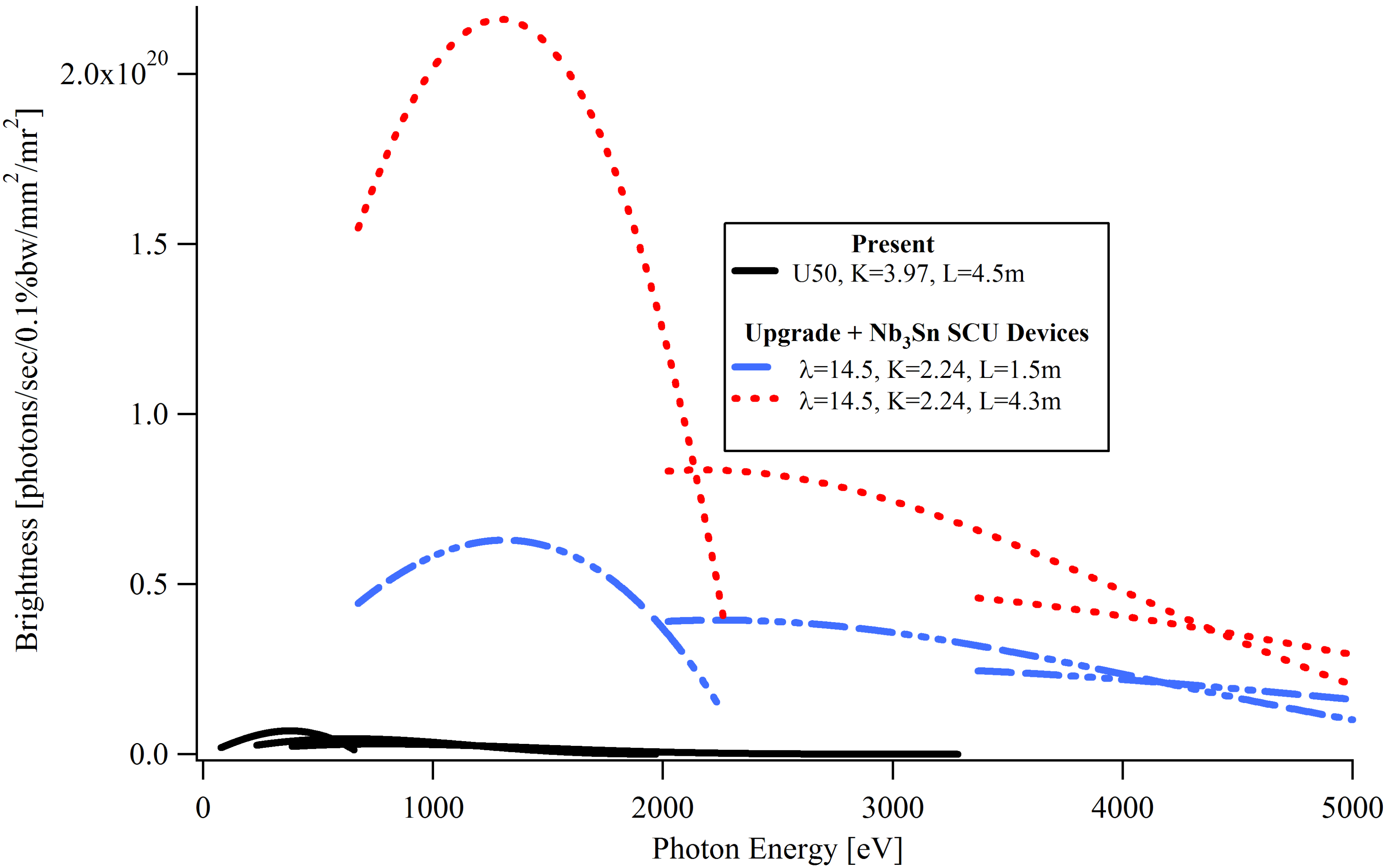
Brightness Now and After Upgrade

In-vacuum ID's

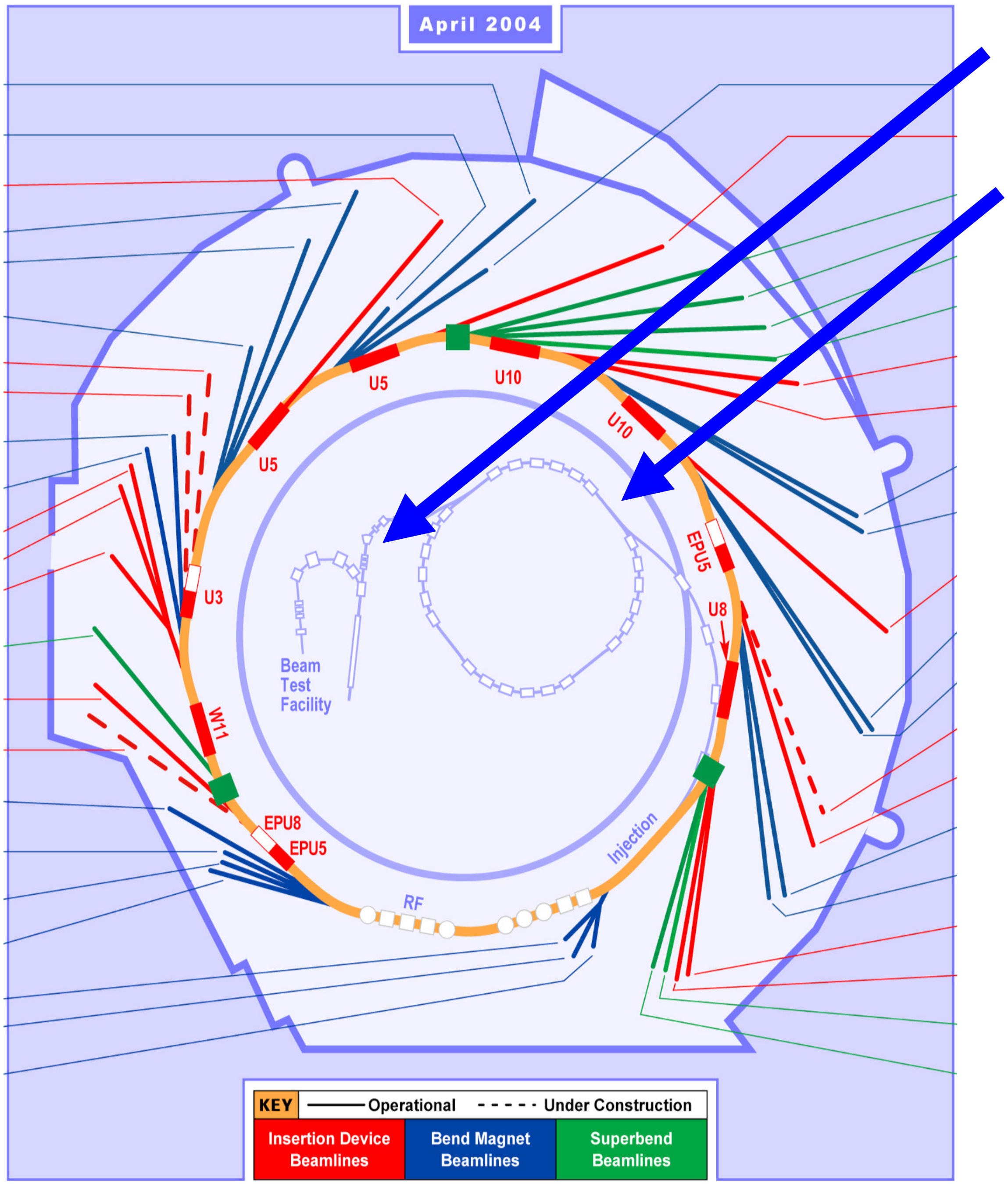


Brightness Now and After Upgrade

Superconducting ID



What is required to operate at Top-off



50 MeV Linac

1.5 GeV Booster

- Upgrade to a full-energy injector
  - Need to increase the booster and transfer line to 1.9 GeV
- Inject with beamline shutters open

Injection tests – determine user requirements

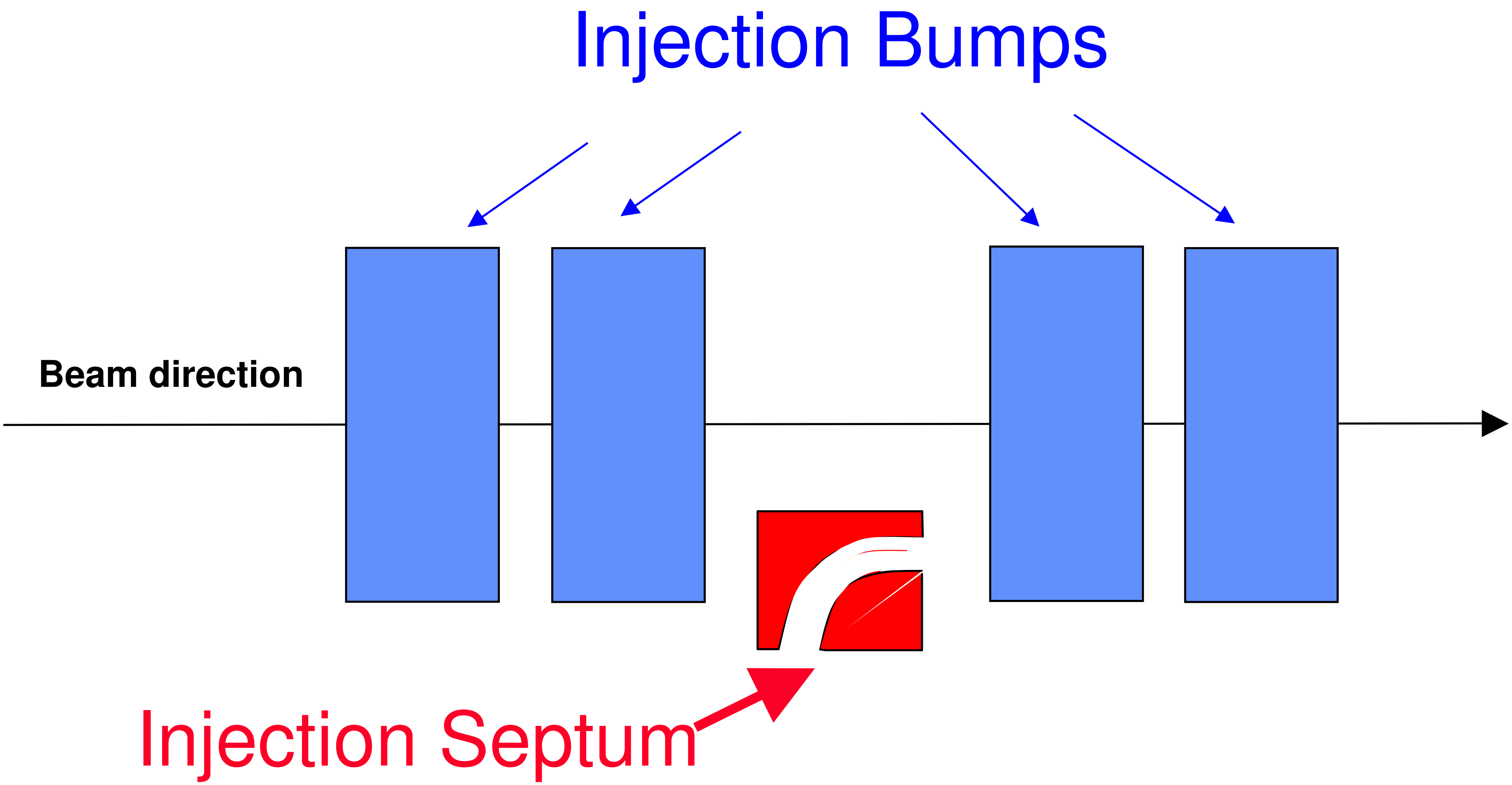
Purpose

- Evaluate the impact of the present injection process on various types of user experiments
  - Identify issues and mitigate potential problems
  - Help define the scope of the project

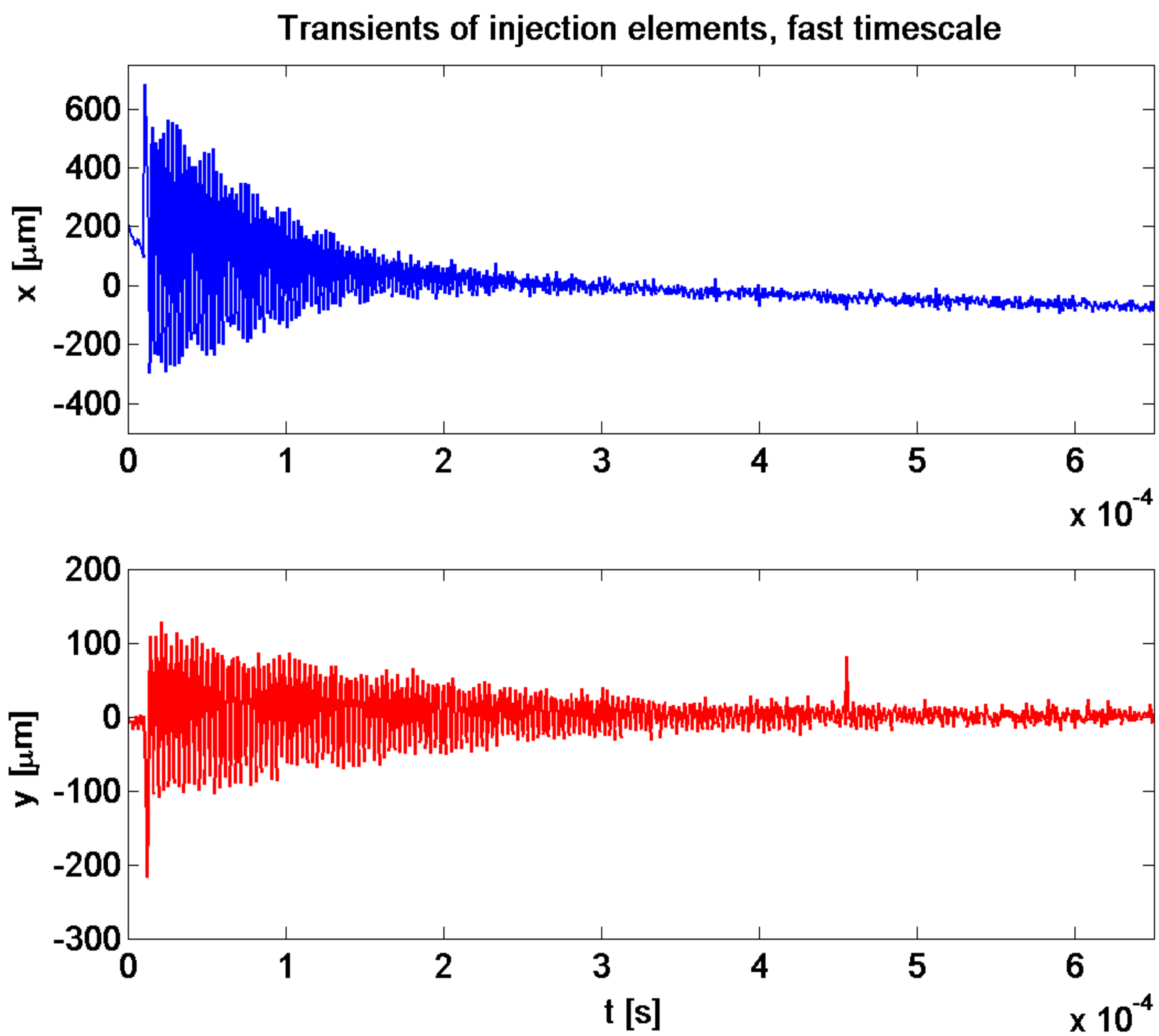
Issues that were addressed

- Allowable change in current when topping up
- Allowable orbit disturbance during injection
  - Amount and duration
  - Is gating an option?
- Inject equally spaced in time or current drop
  - Inject one pulse or several pulses (burst mode)
- Two bunch mode and camshaft beam cleaning

Injection Elements in Straight 1



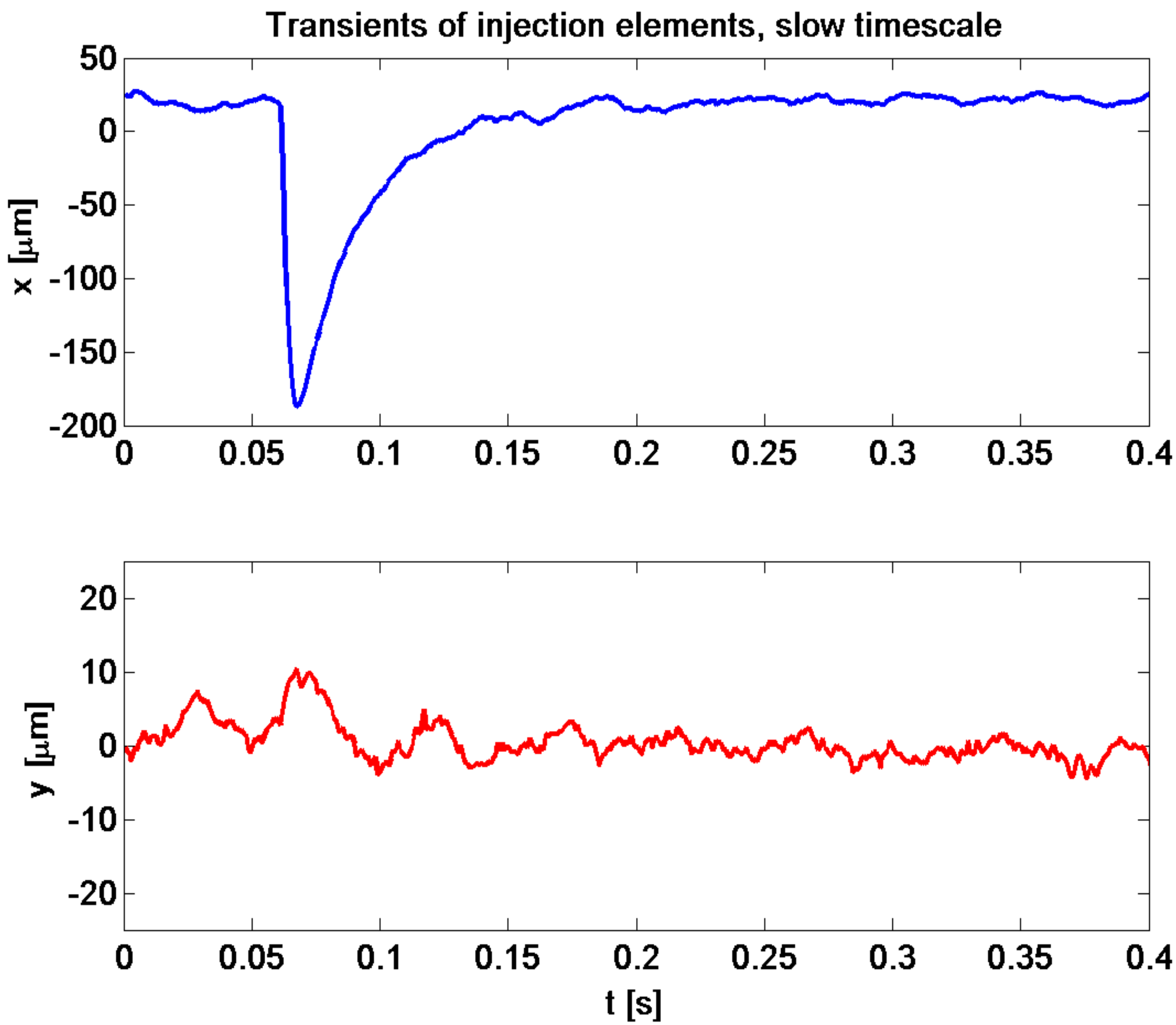
Effect of the Bumps



RMS Beam sizes are 300 by 8 microns

Transverse feedback system reduces the time of the transients

Effect of the Septum



Effects of the inj. bumps and septa

Experimentalists

M. Martin (1.4), A.T. Young and E. Arenholz (4.0), David Kilcoyne (5.3.2), E. Gullikson (6.3.2), Eli Rotenberg (7.0), A. Scholl (7.3), J. Holton (8.3.1), J. Bozek (10.0), M. Marcus (10.3.2), T. Tyliszczak (11.0), K. Goldberg (12.0)

Three measurement dates	→ Participating Beamlines
December 7, 2003	→ 5.3.2, 11.0
January 26, 2004	→ 1.4, 4.0, 5.3.2, 7.0, 7.3 (PEEM), 8.3.1, 10.3.2, 10.0, 11.0
April 19, 2004	→ 1.4, 4.0, 6.3.2, 11.0.2, 12.0

Meeting on February 13, 2004

Summarize the results of the December 7, 2003 and January 26, 2004 measurements

David Attwood, John Bozek, Erik Gullikson, James Holton, Zahid Hussain, David Kilcoyne, Mark Le Gros Dennis Lindle, Alastair MacDowell, Mathew Marcus, Howard Padmore, Andreas Scholl, Christoph Steier, Tony Warwick, Tony Young

Presentation to the UEC on March 2, 2004

Injection Tests for Top Off 19 April 2004

Three test conditions were run, with various beam lines looking at the effects:

Condition 1 normal operation.

Condition 2 injection bumps and septa pulsing every 30 seconds.

Condition 3 injection bumps only, every 30 seconds.

Best estimate is that the injection for top-off will be approximately every 30 seconds. The septum magnets are known to leak field and affect the position of the stored beam, if this problem is solved then condition 3 will best represent top-off operation.

No beam was actually injected during these tests. Observed variations in experiment count rates are due to transient distortions of the closed orbit.

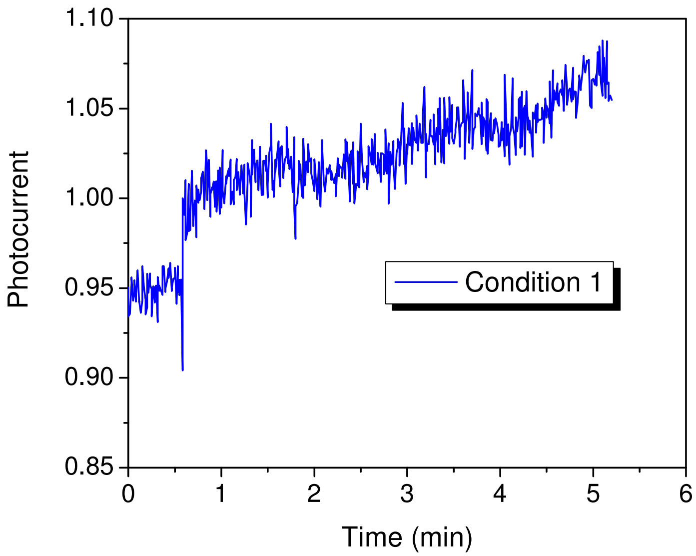
Beam lines 10.3.2 microXAS, saw no effects.

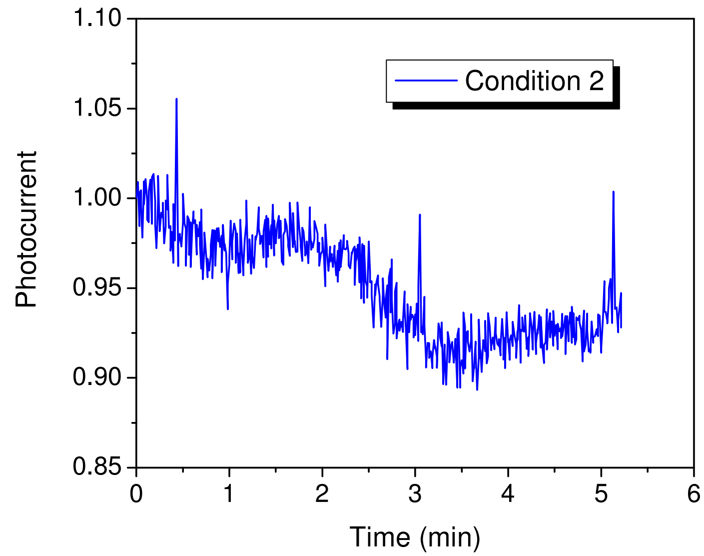
Beam lines 4.0 and 6.3.2 monitored the beam line flux and saw counting glitches under condition 2 that may be due to injection transients.

Beam line 1.4 (FT IR spectroscopy) saw definite glitches during instrument scanning under conditions 2 and 3.

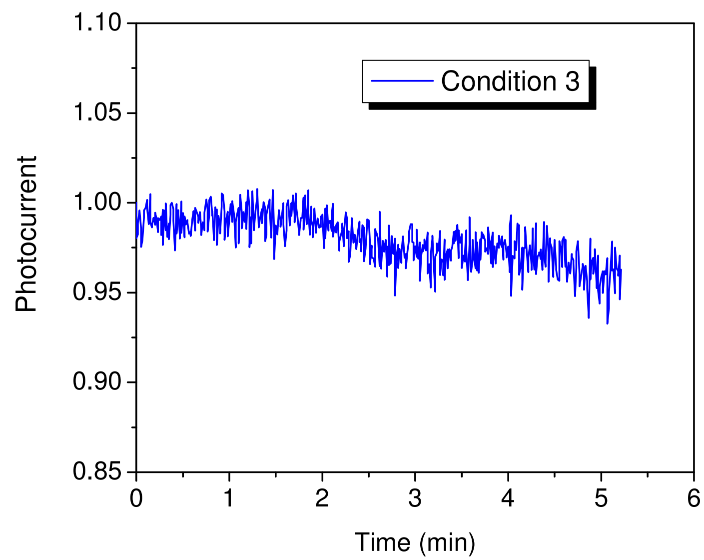
Beam line 11.0.2 (STXM) saw definite glitches during instrument scanning under condition 2.

Top off Mode Tests: BL 6.3.2





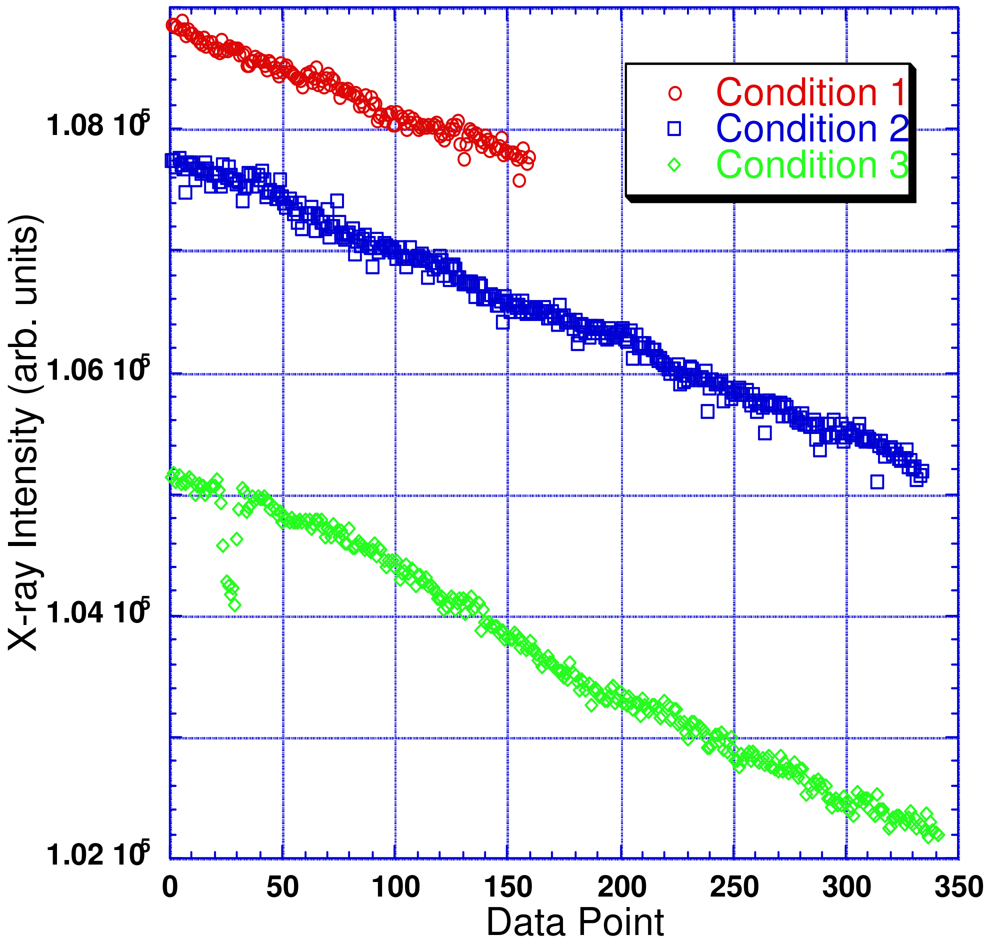
Signal measured after vertical slit offset in X by 160 microns from the center of the beam in the endstation. One point every 0.6 sec.



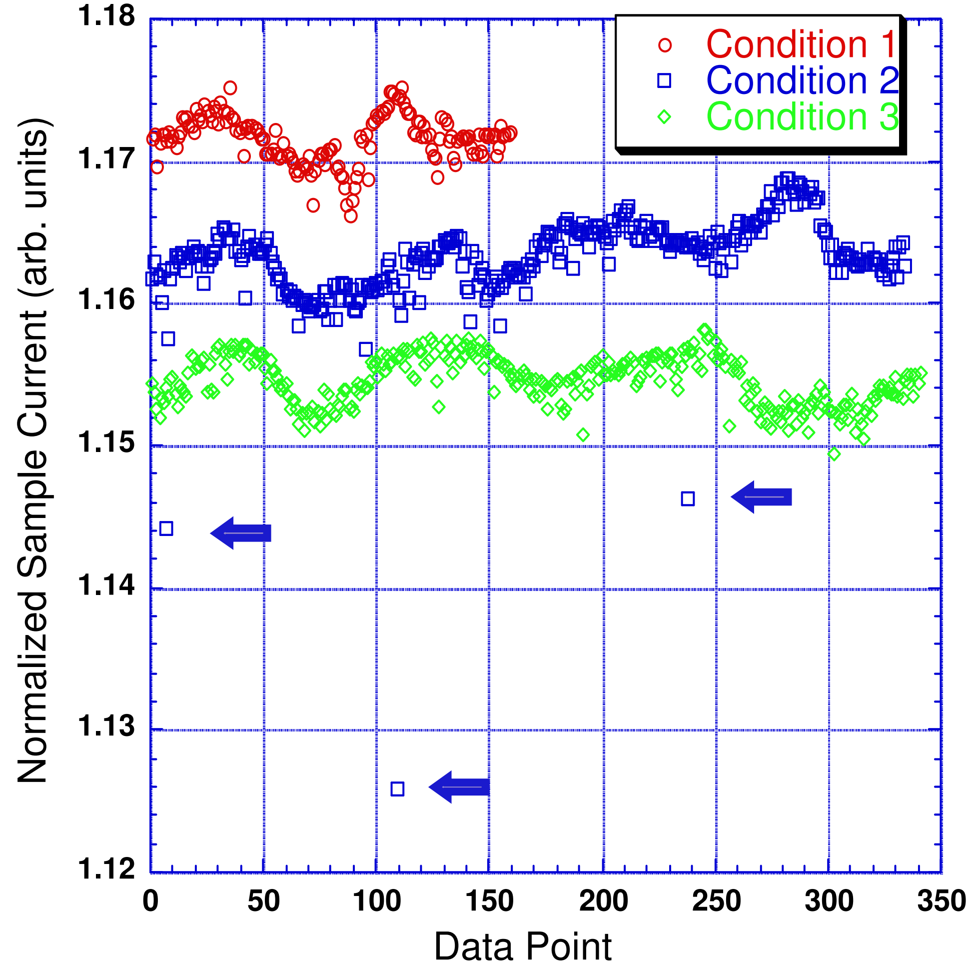
Erik Gullikson

Beamline 4.0.2

Intensity Monitor



Normalized Absorption

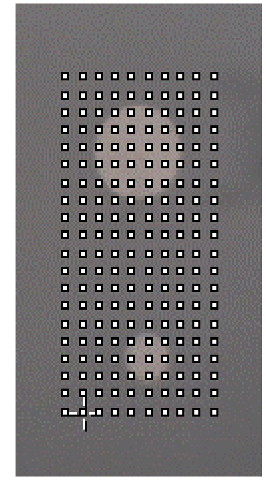


- Absorption measured at Cu L_3 peak at 932 eV, 1 sec avg, every 3.75 sec
- Condition 2 Intensity is somewhat noisier
- Condition 2 Absorption shows several large deviations, indicative of a small photon energy shift, and consistent with an average injection period of 32.4 sec
- Actual injection time data is not available

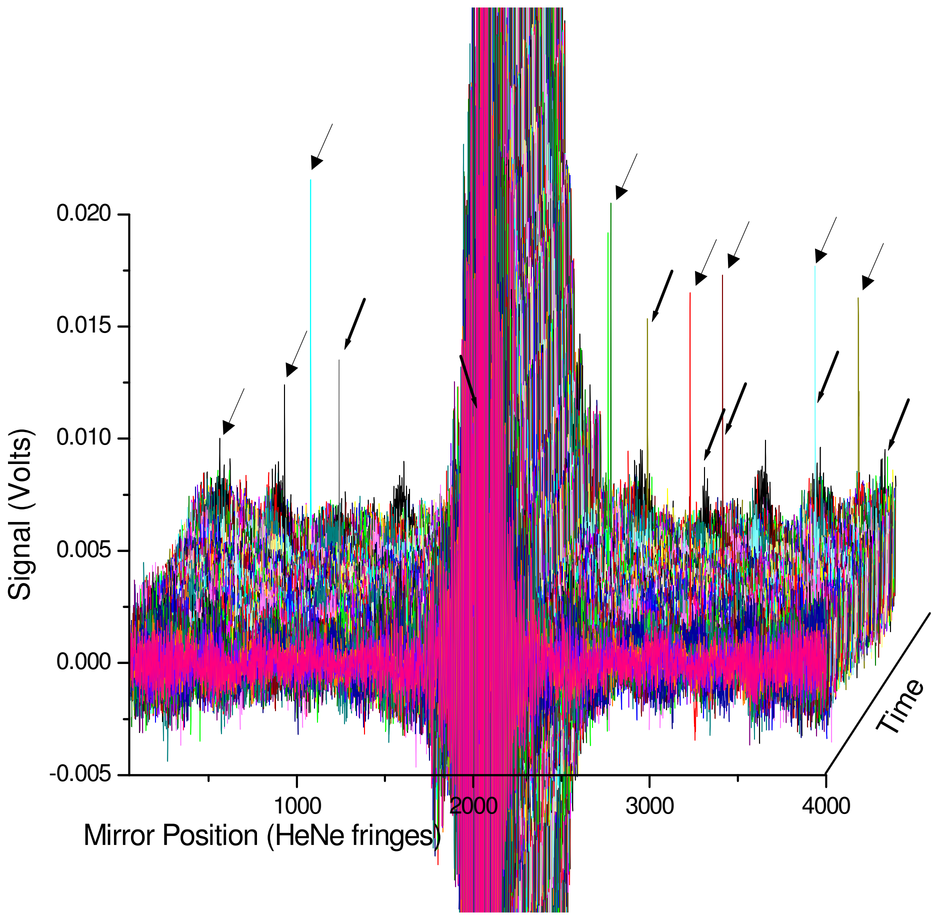
BL1.4.3

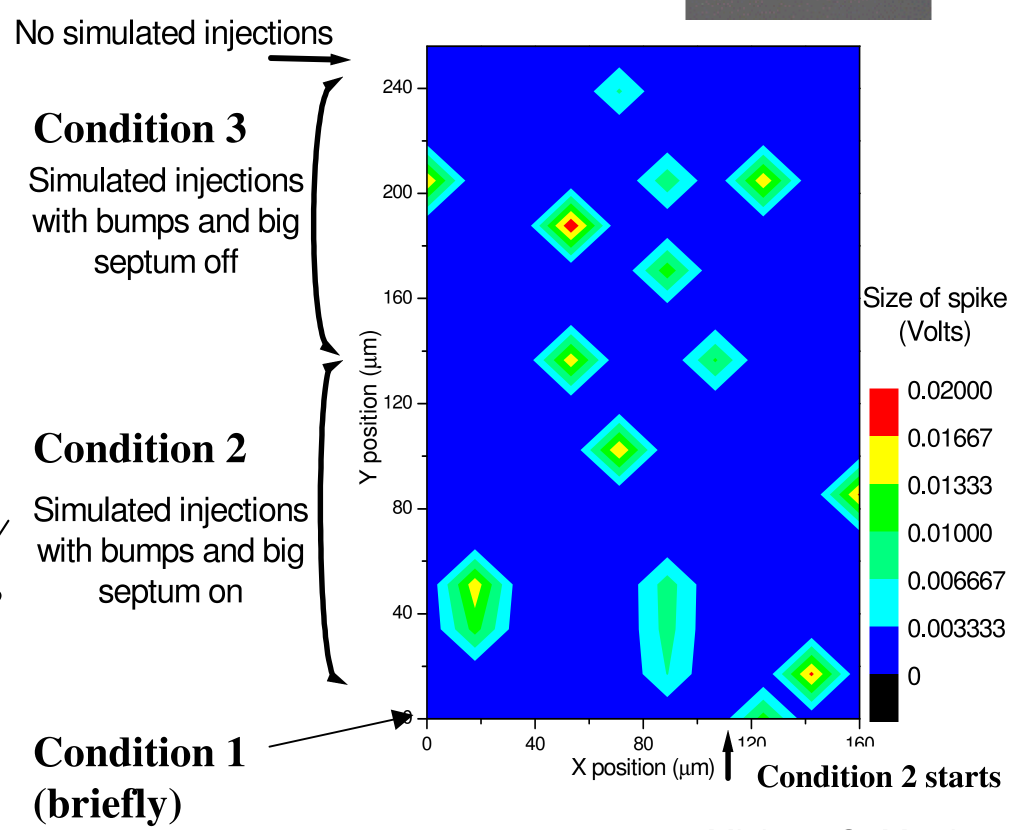
Summary:

- Simulated injections every ~30 seconds.
- I performed a “typical” mapping experiment, 32 averages (11.7 seconds) per point, + 7.5 seconds of dead time moving sample stage to next point. 160 total spectra during mapping test.

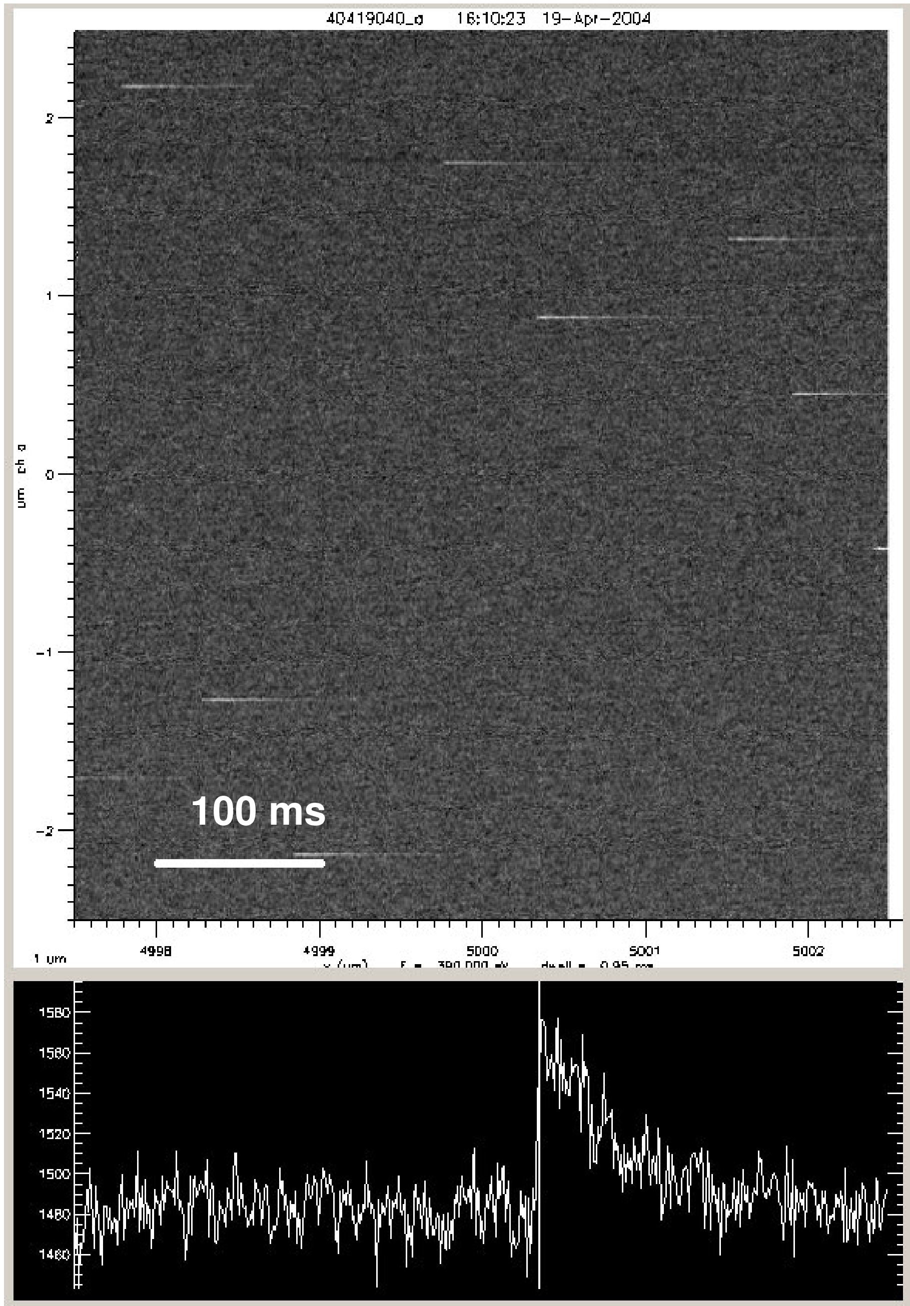


I see “spikes” in a number of scans throughout the test map:





BL11.0.2



During this test the sensitivity of the STXM 11.0.2 was much smaller then during the previous test (Dec 03).
Figure shows the influence of the injection (condition 2) - about 5 % of the signal for about 200 ms.
During condition 3 – the perturbation was within the noise level for 0.1, 0.2 and 1ms/pt image acquisition at 2 energies (1^{st} and 3^{rd} EPU harmonic).
Spectra acquisition at the exit slit (testing the beamline not STXM) did not show any significant perturbation.

Tolek Tyliszczak

Injection Tests for Top Off   Dec/Jan 03/04

Seven test conditions were run, with various beam lines looking at the effects:
Condition 1 40mA no bumps or septa
Condition 2 bumps on and septa on, pulsing at 1Hz
Condition 3 feed-back H=off V=on
Condition 4 feed-back H=off V=off
Condition 5 400mA feed-back H=on V=off
Condition 6 400mA feed-back slow-orbit=off
Condition 7 bumps on and septa off

This is the original set of tests and the conclusions are similar to those drawn in April 04. The STXM tests were more sensitive on this occasion and definite glitches were apparent even with the septa turned off.

No beam was actually injected during these tests. Observed variations in experiment count rates are due to transient distortions of the closed orbit.

Beam lines 10.3.2 microXAS, 7.0 photoemission, 7.3.3 PEEM and 8.3.1 PX, saw no effects.

Beam lines 4.0 monitored the beam line flux and saw counting glitches under condition 2 that may be due to injection transients.

Beam line 1.4 (FT IR spectroscopy) saw definite glitches during instrument scanning under conditions 2 through 5.

Beam line 11.0.2 (STXM) saw definite glitches during instrument scanning under conditions 2 through 6, with greatly reduced transients under condition 7. Beam line 5.3.2 (STXM) saw the same, with variations depending on the feedback configuration.

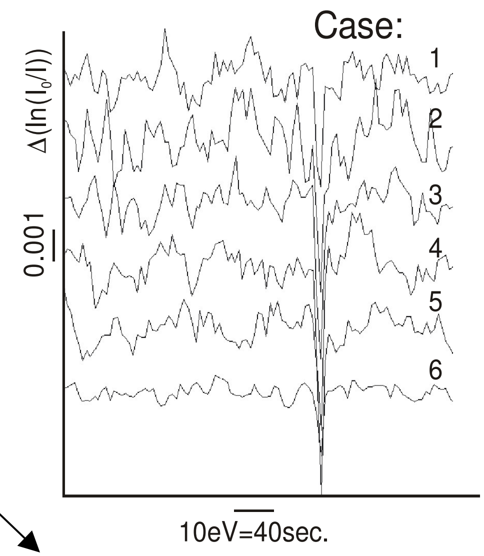
Top-up tests: 10.3.2 Jan 04

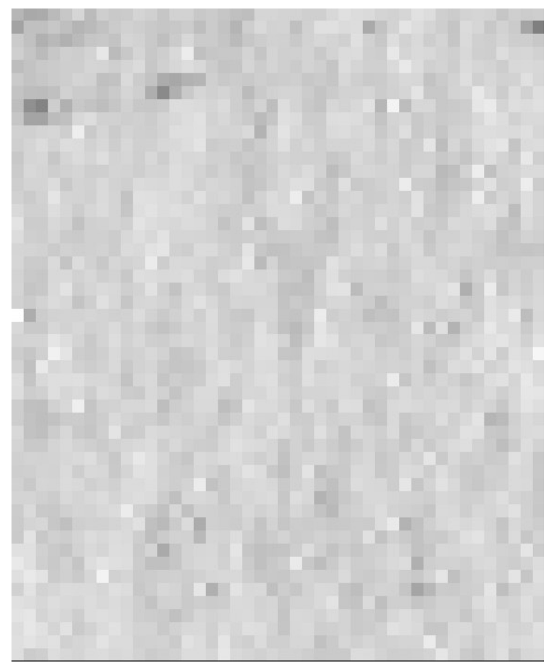
We cannot see any effect here

Experiments:

1. EXAFS on Ni foil starting at 9keV, transmission and fluorescence
2. Mapping on same Ni foil.

Executive summary: Nothing happened!





Cautions:

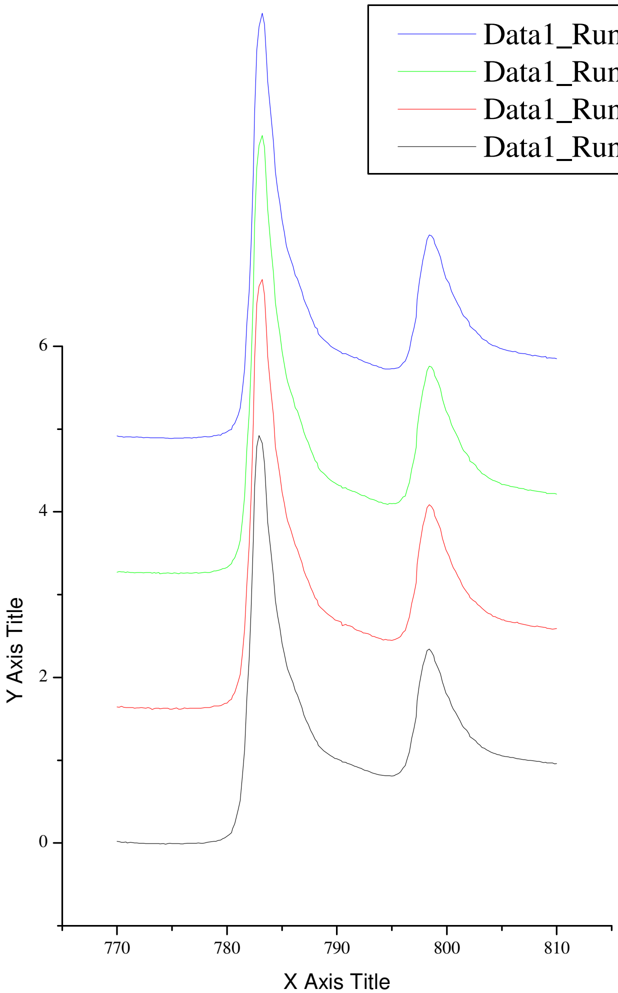
EXAFS: Count time was 4 sec/pt, so each point had the same number of blips, so even if blips affected the signal, we wouldn't see it. Real life: 30sec between blips; so a blip every 3-8 points.

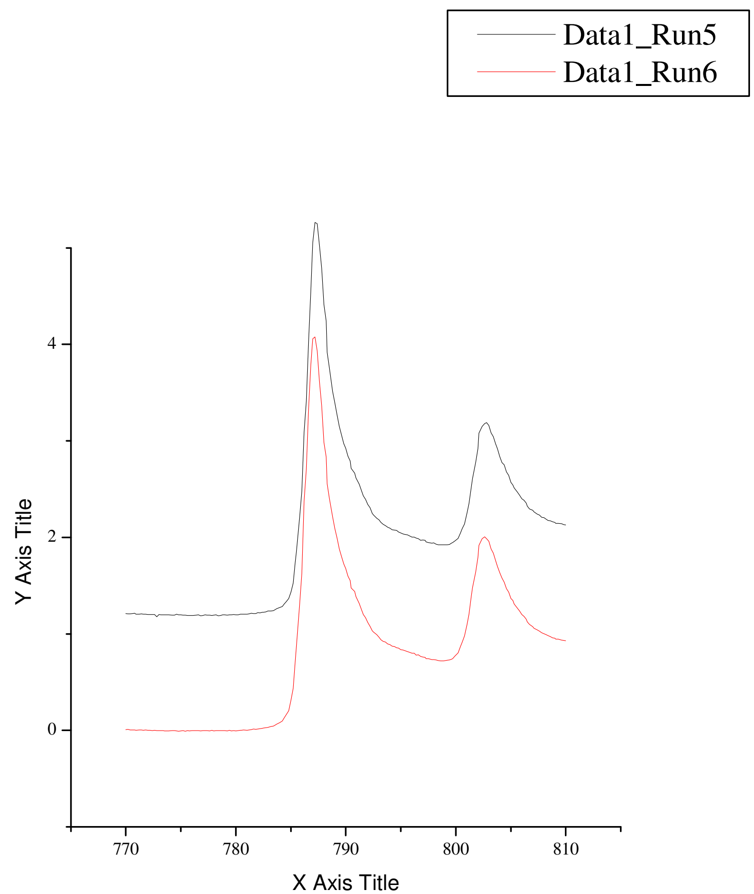
Mapping: Sample was inhomogeneous, which could have hidden the blips. Blips would have been 1-pixel excursions, several/line.

Top-up tests: 7.3.3 Jan 04

We cannot see any effect here

Typical Co NEXAFS spectra measured with PEEM-2 on 30x30 μm^2 area
Exposure time per point: 2s





No increase in noise is apparent.

PX data in top-off mode, beam line 8.3

We cannot see any effect here

case	exposure	R_{merge}	R_{anom}	I/sd	Patt	FOM	FOMDM	CC
1	1.00	4.3%	4.6%	29.0	6.77	0.274	0.746	0.4800
2	1.02	4.1%	4.6%	29.5	5.65	0.280	0.673	0.4958
3	1.04	4.3%	4.6%	27.7	6.10	0.267	0.729	0.4955
4	1.05	4.2%	4.6%	28.4	6.19	0.268	0.661	0.4704
5	0.10	4.8%	4.6%	26.3	5.97	0.270	0.751	0.4735
5a	0.90	4.2%	4.5%	29.2	5.71	0.278	0.671	0.4735
6	0.11	4.7%	4.6%	26.8	7.06	0.268	0.665	0.5036
6a	0.93	4.2%	4.5%	29.6	5.72	0.284	0.701	0.4982

All data sets had the same dose: $2x10^6$ Ph/um^2

the “a” data sets used an Al attenuator to normalize the exposure time

Exposure: the shutter-open time used for 100 images

Rmerge: standard error of equivalent diffraction spot intensities

Ranom: difference between Friedel mates

I/sd: signal-to-noise ration

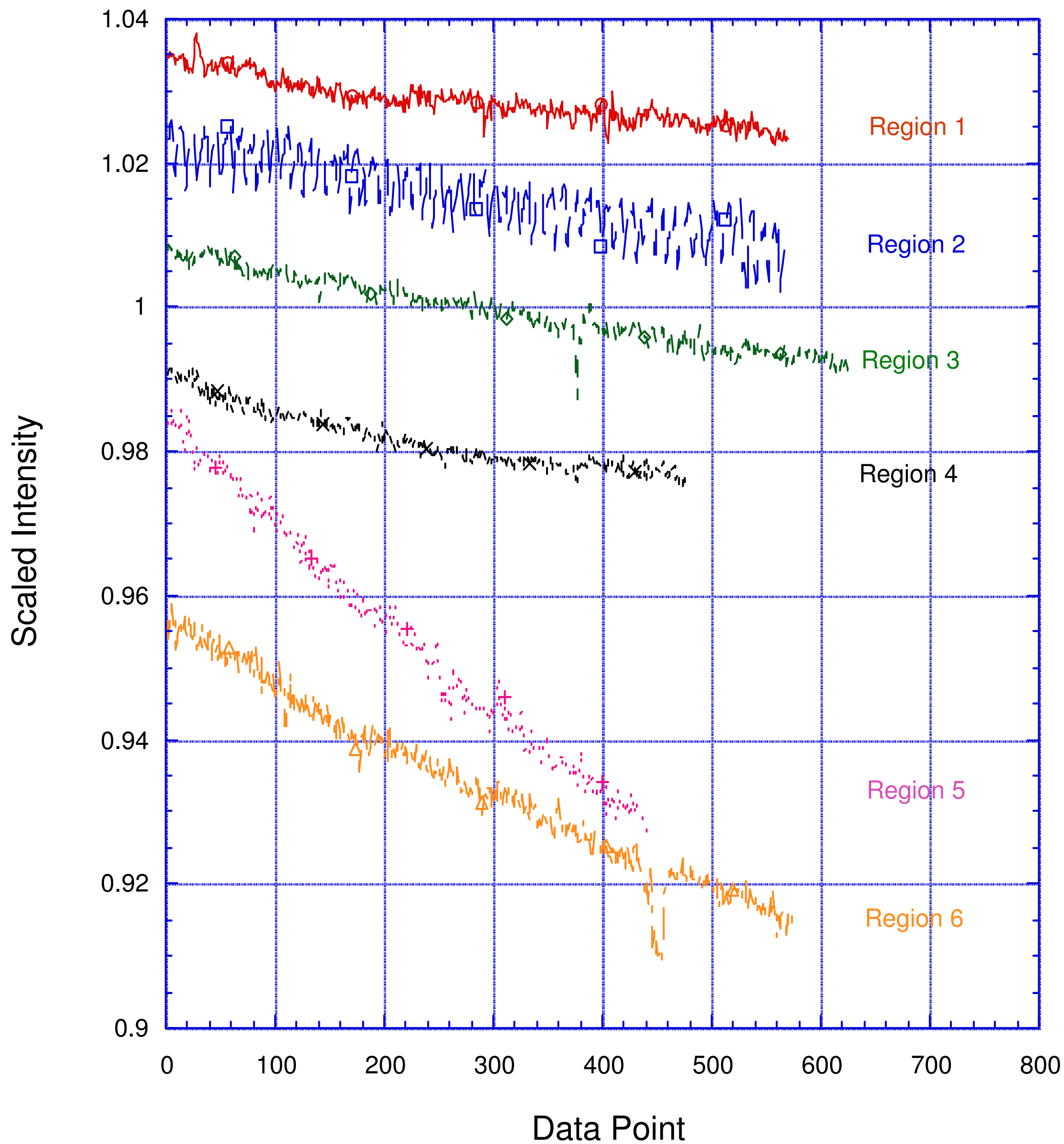
Patt: height/sigma for non-origin Patterson peak

FOM: estimated cosine of phase error

FOMDM: FOM after density modification

CC: correlation coefficient of experimental map to model

Top Off Mode Injection Test: BL 4.0 1/26/04



'condition 2' = septum-on we can see intensity fluctuations

Intensity of the x-rays was determined by measuring the photo-current from a gold mesh

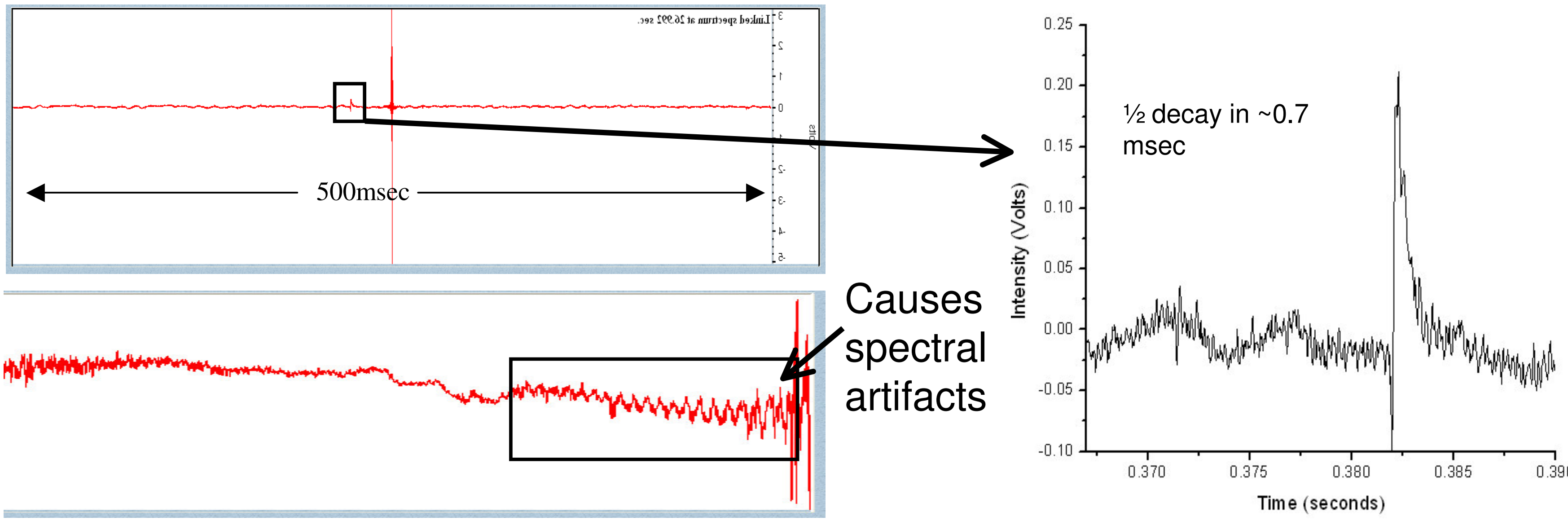
Each data point was integrated for 1 second using a picoammeter and a V/F converter

Each region (condition) was scaled to unity and offset for clarity

Top-Off Tests, BL1.4.3 - Jan 26, 2004

Summary:

In conditions 2-5 (injection septum and/or bumps on) we observed brief signal glitches in measured interferograms. Not seen in conditions 1 or 6 (no injection).



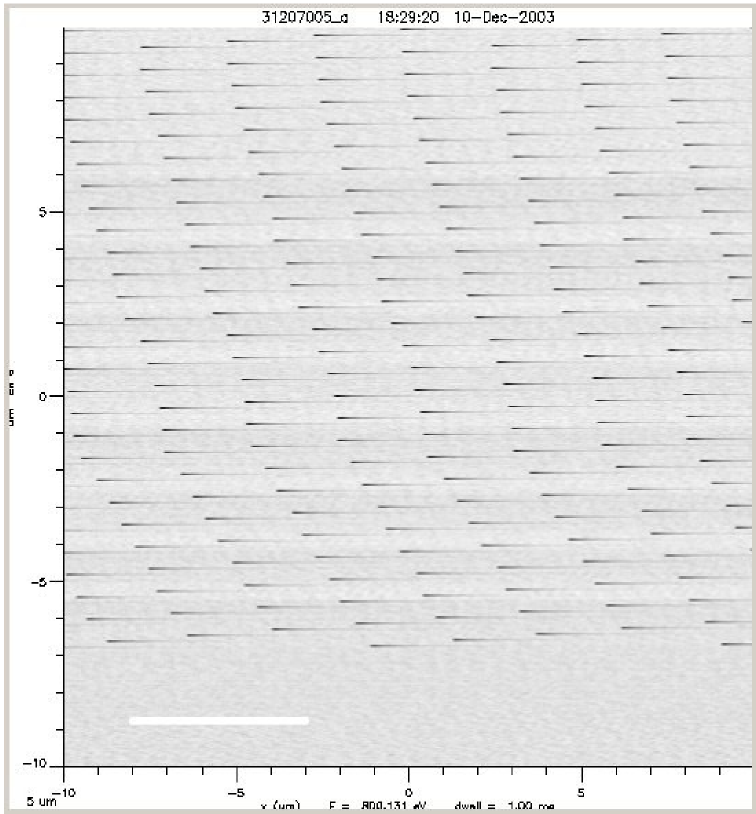
- The typical user averages many spectra, so this will “wash out” into worse Signal to Noise.

- Or we should look for a way to have the software/hardware reject scans when the injection bumps are on.

Condition	Current	S/N
1	40	1470
2	38.3	1243
3	37.6	956
4	36.9	1108
5	387	3467
6	370	3662

“Injection” test 7 Dec 2003

Recorded STXM images



Condition 6 feed-back slow-orbit=off

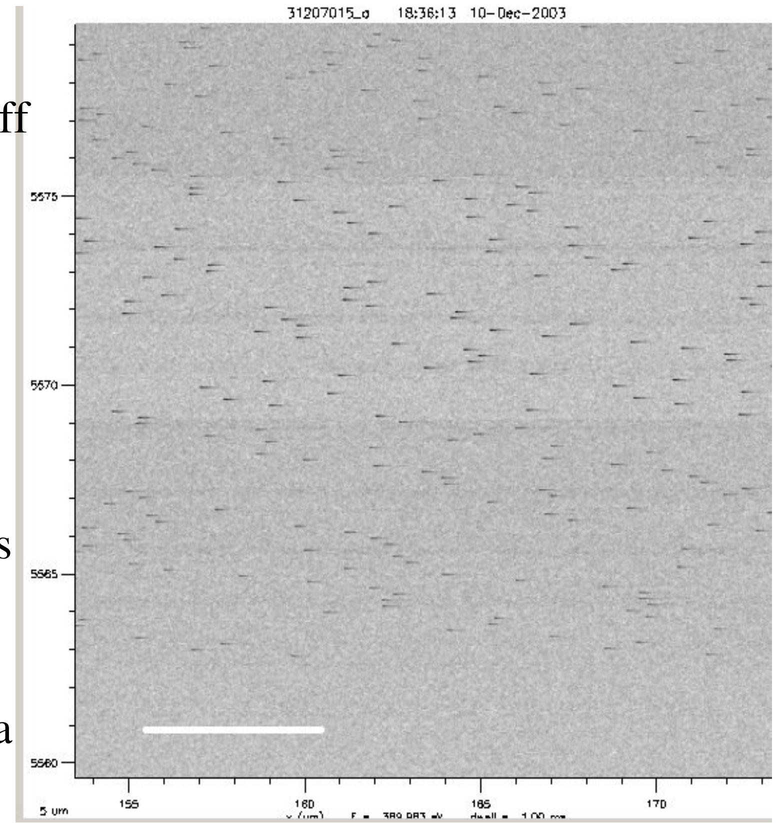
Condition 5 feed-back H=on V=off

Condition 4 feed-back H=off V=off

Condition 3 feed-back H=off V=on

Condition 2 bumps and septa on

Condition 1 No bumps or septa



STXM 11.0.2

Undulator, entrance slit-less beam line designed with in-sensitivity to vertical beam motion, sensitive to horizontal beam motion.

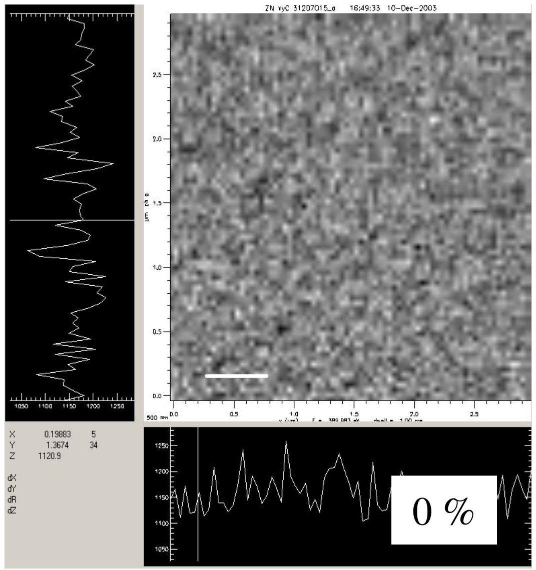
Horizontal scale is 500 ms

STXM 5.3.2

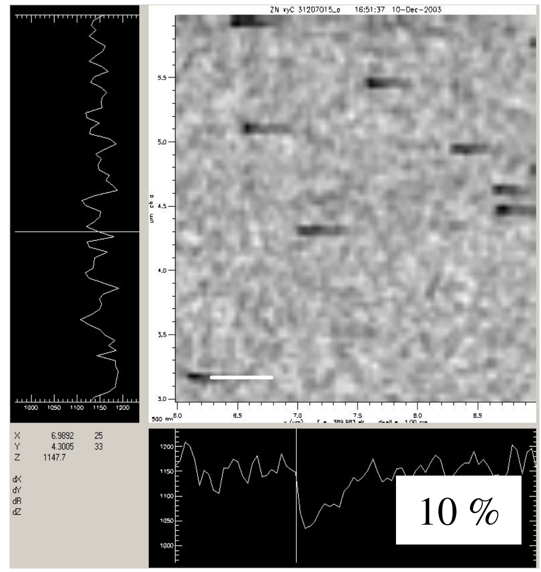
Bend magnet, collecting part of the fan, sensitive to vertical beam motion.

“Injection” tests 7Dec 2003 STXM 5.3.2

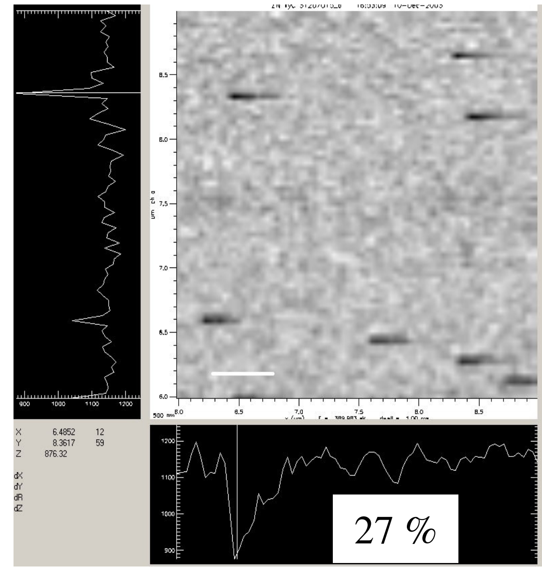
Condition 1
No bumps or septa



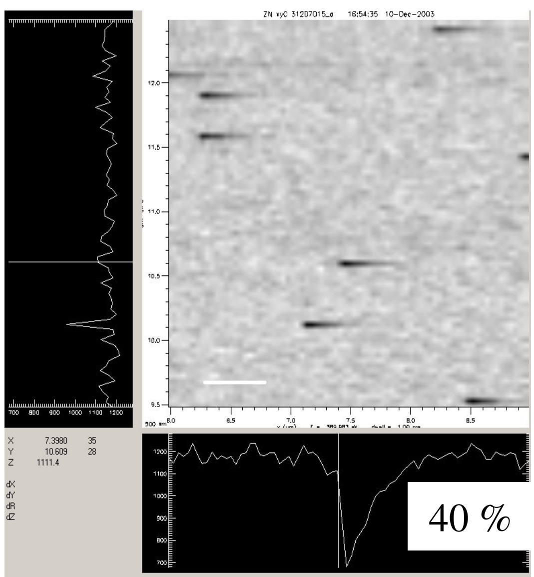
Condition 2 bumps
and septa on



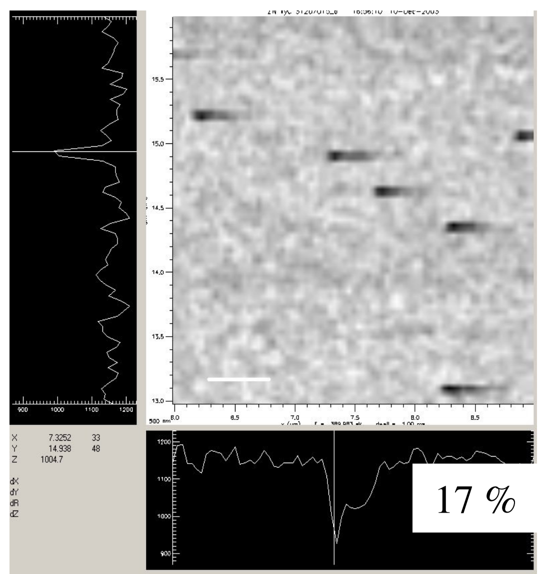
Condition 3 feed-
back H=off V=on



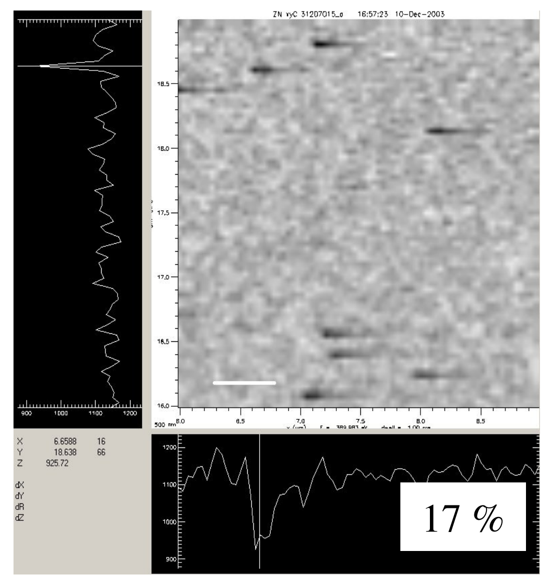
Condition 4 feed-
back H=off V=off



Condition 5 feed-
back H=on V=off



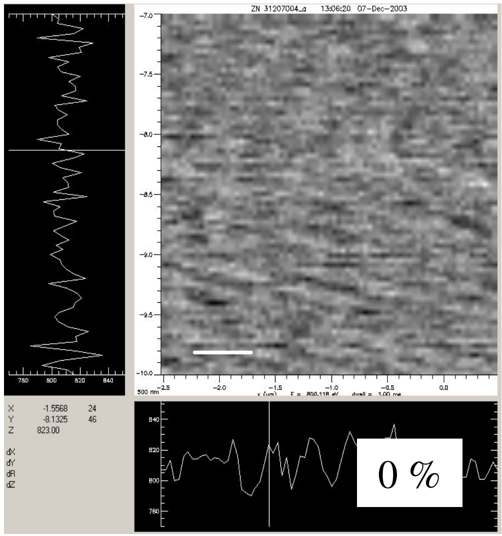
Condition 6 feed-
back slow-orbit=off



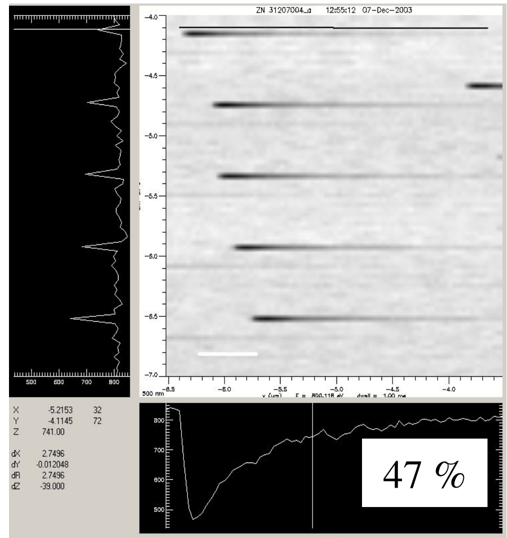
Horizontal scale is 75 ms

“Injection” tests 7Dec 2003 STXM 11.0.2 zoom-in

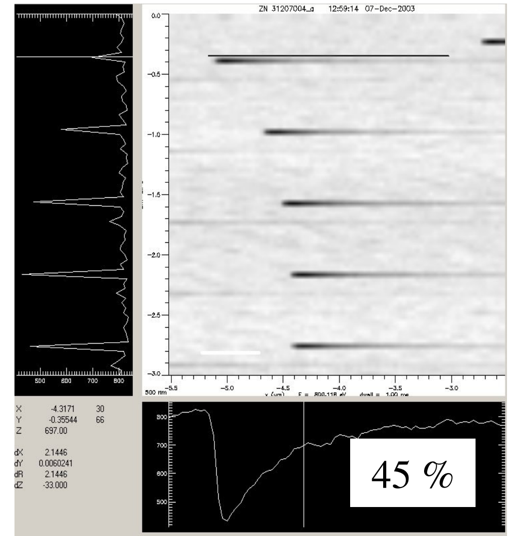
Condition 1
No bumps or septa



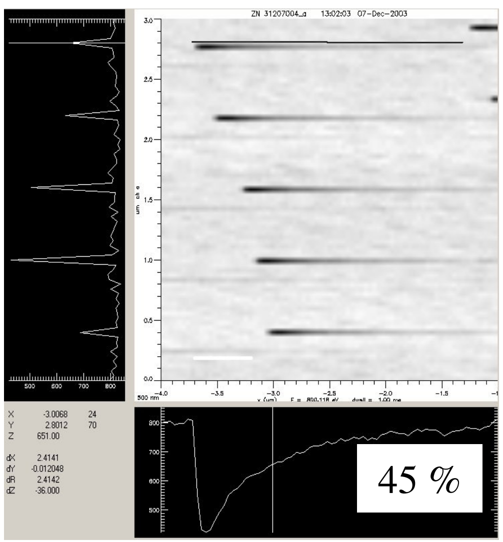
Condition 2 bumps
and septa on



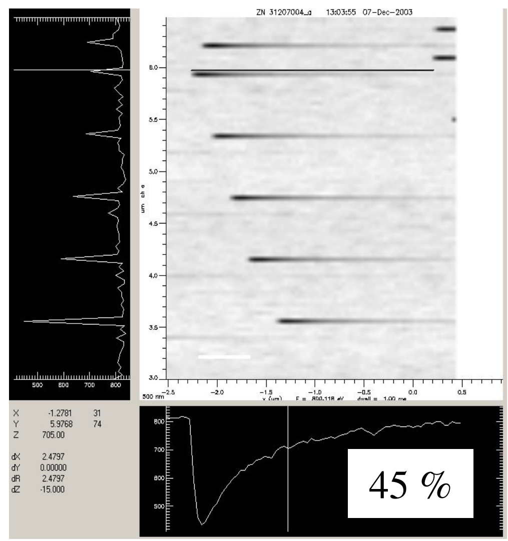
Condition 3 feed-
back H=off V=on



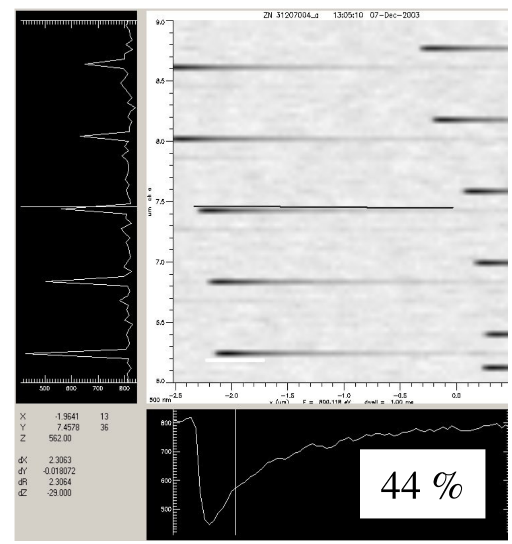
Condition 4 feed-
back H=off V=off



Condition 5 feed-
back H=on V=off



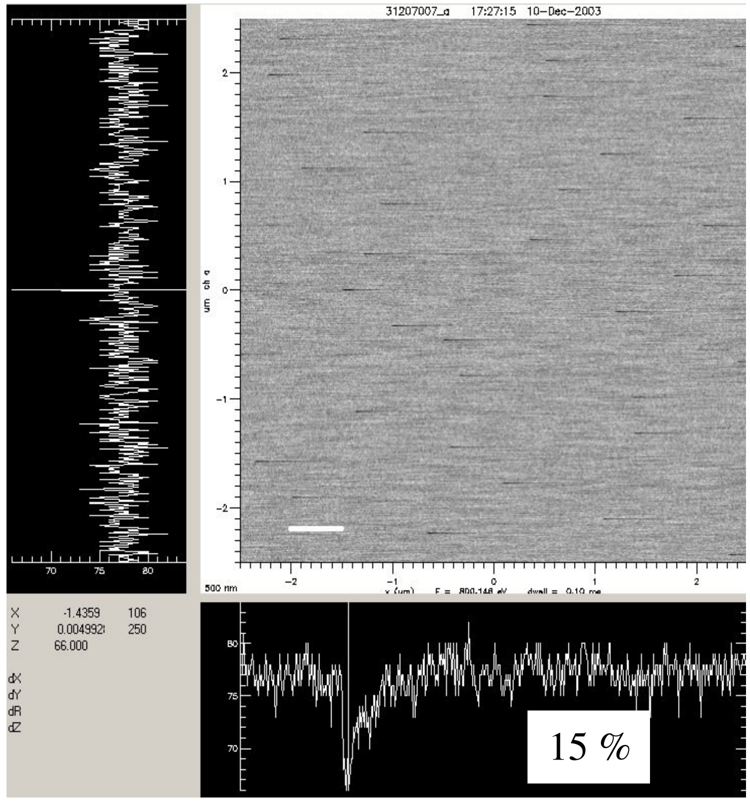
Condition 6 feed-
back slow-orbit=off



Horizontal scale is 75 ms

Second “Injection” test 7 Dec 2003 STXM 11.0.2
Septum magnet turned off

Recorded image



Horizontal scale is 60 ms

Summary of injection tests

Summary

- Most experiments did not see the injection transients
- The most sensitive experimental techniques were microscopes with short integration times – in particular STXM (5.3.2 and 11.0.2), IR (1.4.3)
  - For these techniques gating may be the only option
- Beamline 4.0 also sensitive to the Septum
  - Planned improvements in the Septum should be sufficient

Other issues addressed

- Those requiring gating would like “single shot” injection
- Users not very sensitive to bunch-to-bunch current variations
- Users would like to incorporate injection bunch cleaning in the booster in order to have cleaner camshaft and 2-bunch top-off operation

Difference between present operation and Top-off

Present Operation	After Top-Off
• Injection at 1.5 GeV and then ramp	• Full energy injection (1.9 GeV)
• Injection period every 2 to 8 hours — 1 Hz injection for 4 minutes • From 200 to 400 mA	• Injection period about every 30 seconds — 1 pulse • From 498.5 to 500 mA
• Average beam current is 250 mA	• Average beam current is 500 mA
• Photon shutters are closed during injection	• Photon shutters remain open during injection
• Lifetime is 8 hours at 400 mA	• Lifetime is about 3 hours at 500 mA

Time between fills

If the lifetime is limited by Touschek scattering

Beam lifetime (dI/dt) is proportional to total current and inversely proportional to the beamsize

$$\frac{\Delta I}{\Delta T} \alpha \frac{I^2}{\sigma_y}$$

So in the case of a maximum acceptable ΔI

$$\Delta T \, \alpha \frac{\sigma_y}{I^2} \Delta I$$

So in the case of maximum acceptable ΔI/I

$$\Delta T \, \alpha \frac{\sigma_y}{I} \frac{\Delta I}{I}$$

Time between fills

In the Touschek lifetime regime $$\Delta T = \tau_i \left(\frac{\Delta I}{I_f} \right)$$

$$\text{if } \tau_i = 8\,\text{hours} : \Delta T = 8\left(\frac{400-200}{200} \right) = 8\,\text{hours}$$

Nominal case is 1.5 mA about every 30 seconds

Note : in 8 hours the amount of injected beam current = 1440mA compared with 200 mA in present operation!

Lifetime is still important even in Top-off

Radiation Issues with Top-off

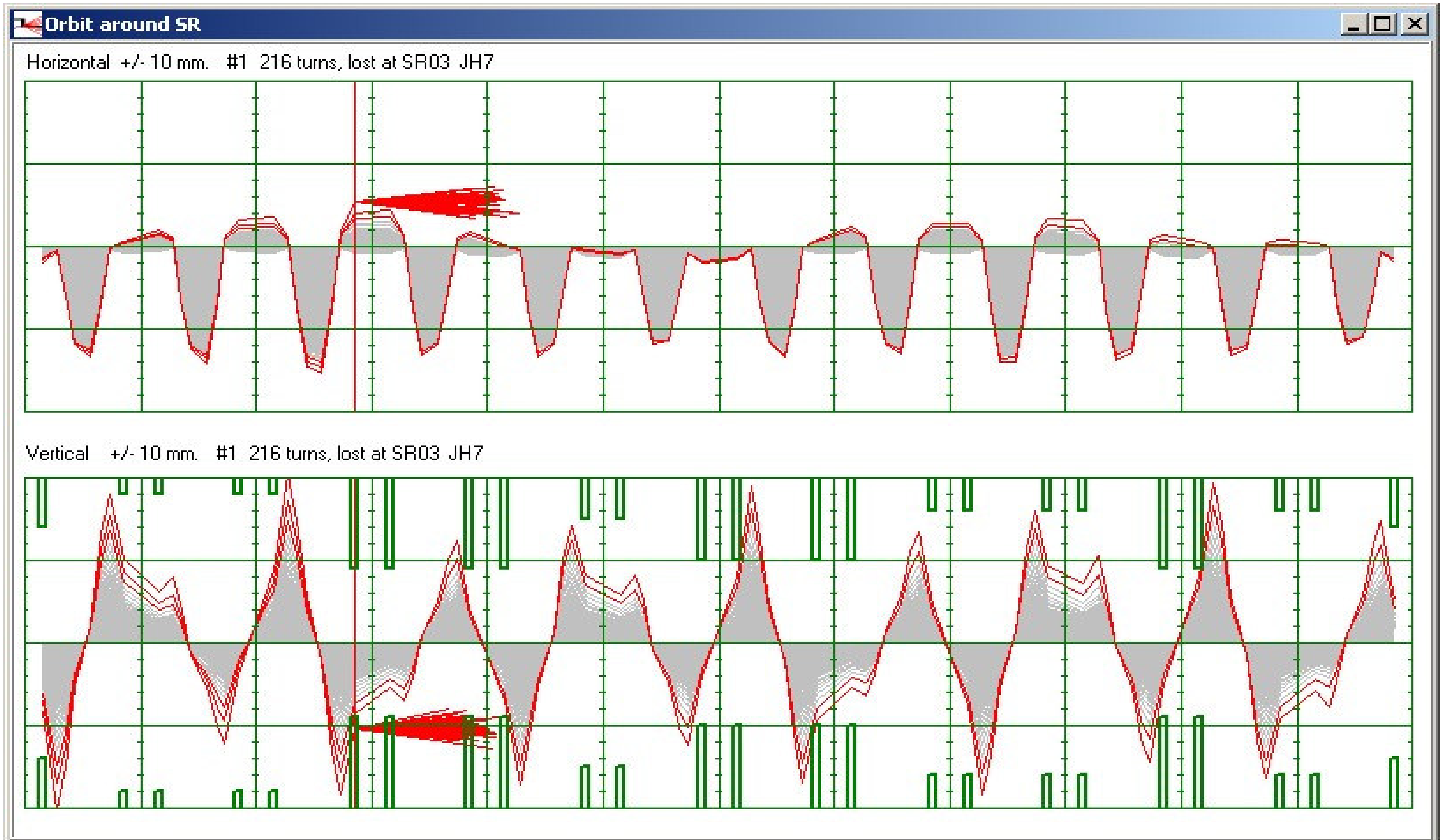
Three aspects of Top-off operation may effect radiation levels

1. **Shorter beam lifetimes and higher currents ➔ higher stored beam loss rates**
2. **Beam dumps will occur on average at higher beam currents**
3. **Injection with the personnel safety shutters (PSS) open**

Need to mitigate the effects of all three

Beam loss after a beam trip

Beam gets lost vertically on the narrow gap chamber



Install collimators to control location of particle loss

Injection with shutters open

Two issues

1. **Injected electrons potentially going down the beamline**
2. **Increased Bremsstrahlung from injected electrons scattering in the storage ring**

Electrons down the beam pipe

Two issues

1. Electrons going down the beamline

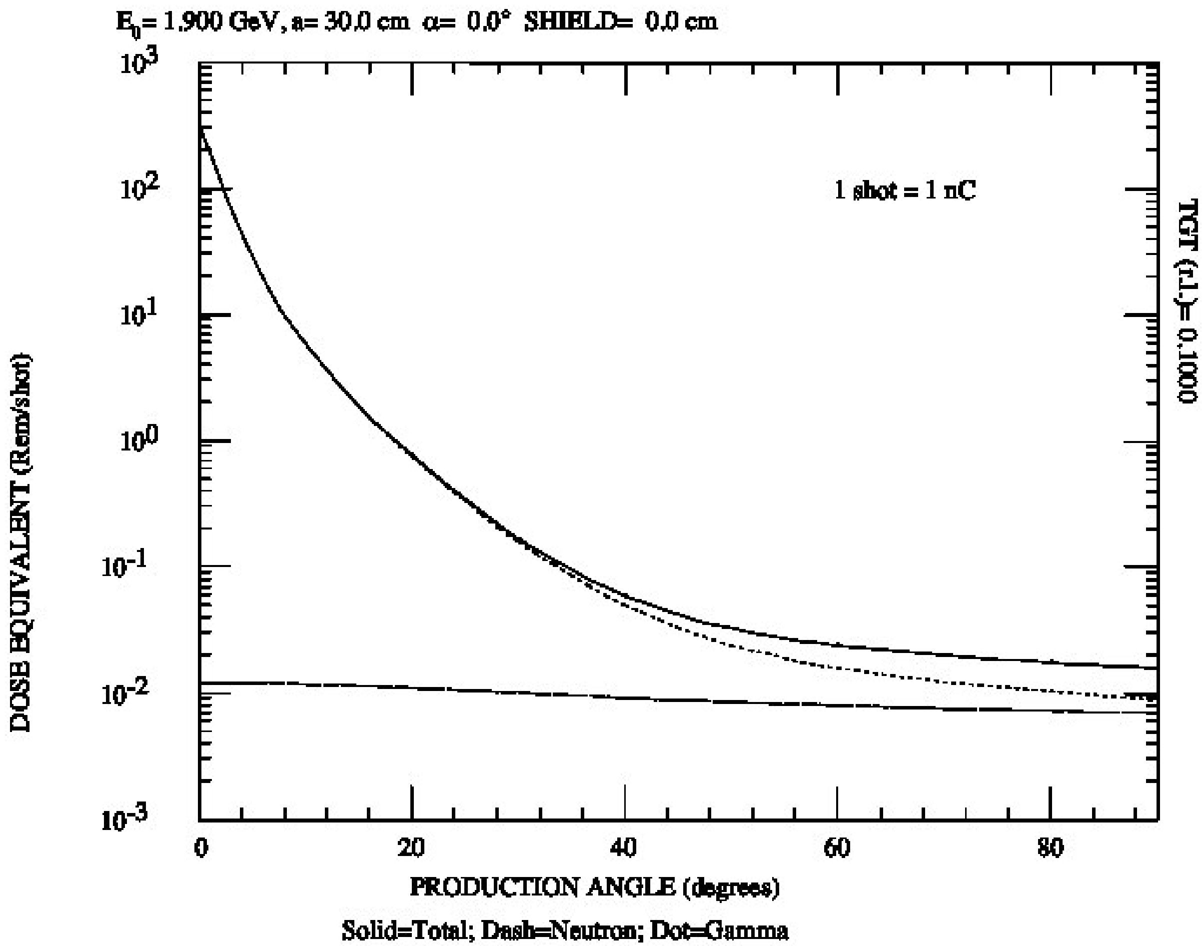
- **When the PSS are opened, injected electrons can go down the beam pipe if the storage ring lattice is severely mistuned**
- **If electrons go down the beam pipe they will collide with the first optic and generate radiation**
- **However the necessary degree of mistuning precludes storing beam in the storage ring**

➔ Solution for preventing electrons from going down the beam pipe is to interlock on stored beam current

- **This is the standard solution at labs currently doing top-off**
- **Our simulations show that it is a viable method for us**

Calculation of dose from electrons

Neutron and gamma dose rate at 30 cm from a single 1 nC 1.9 GeV e- bunch. Angle is measured with respect to incident beam direction.



Electrons down the beam pipe

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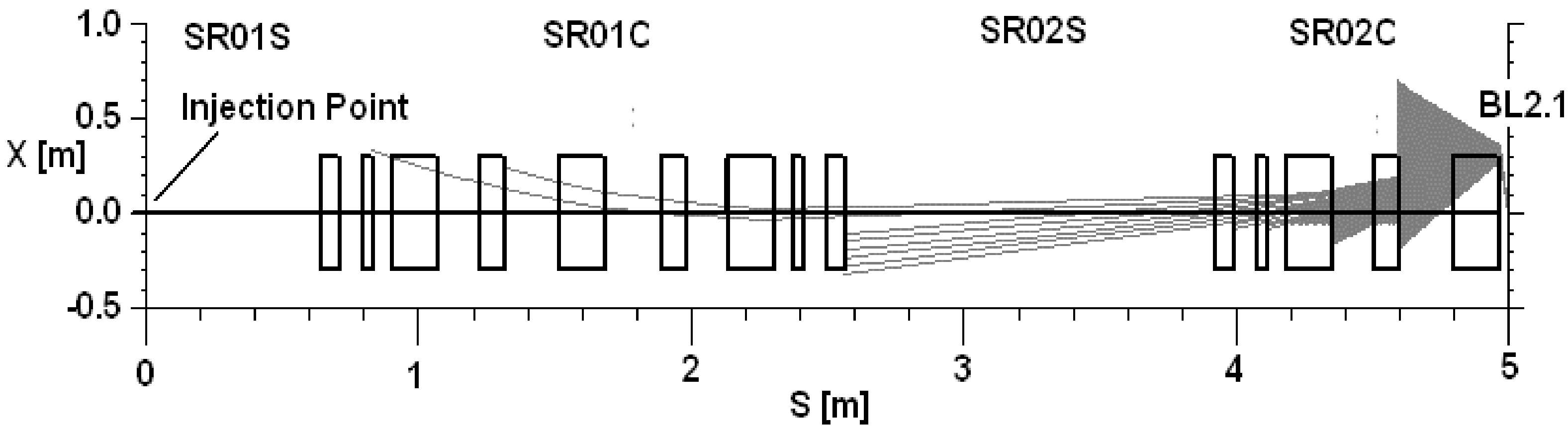
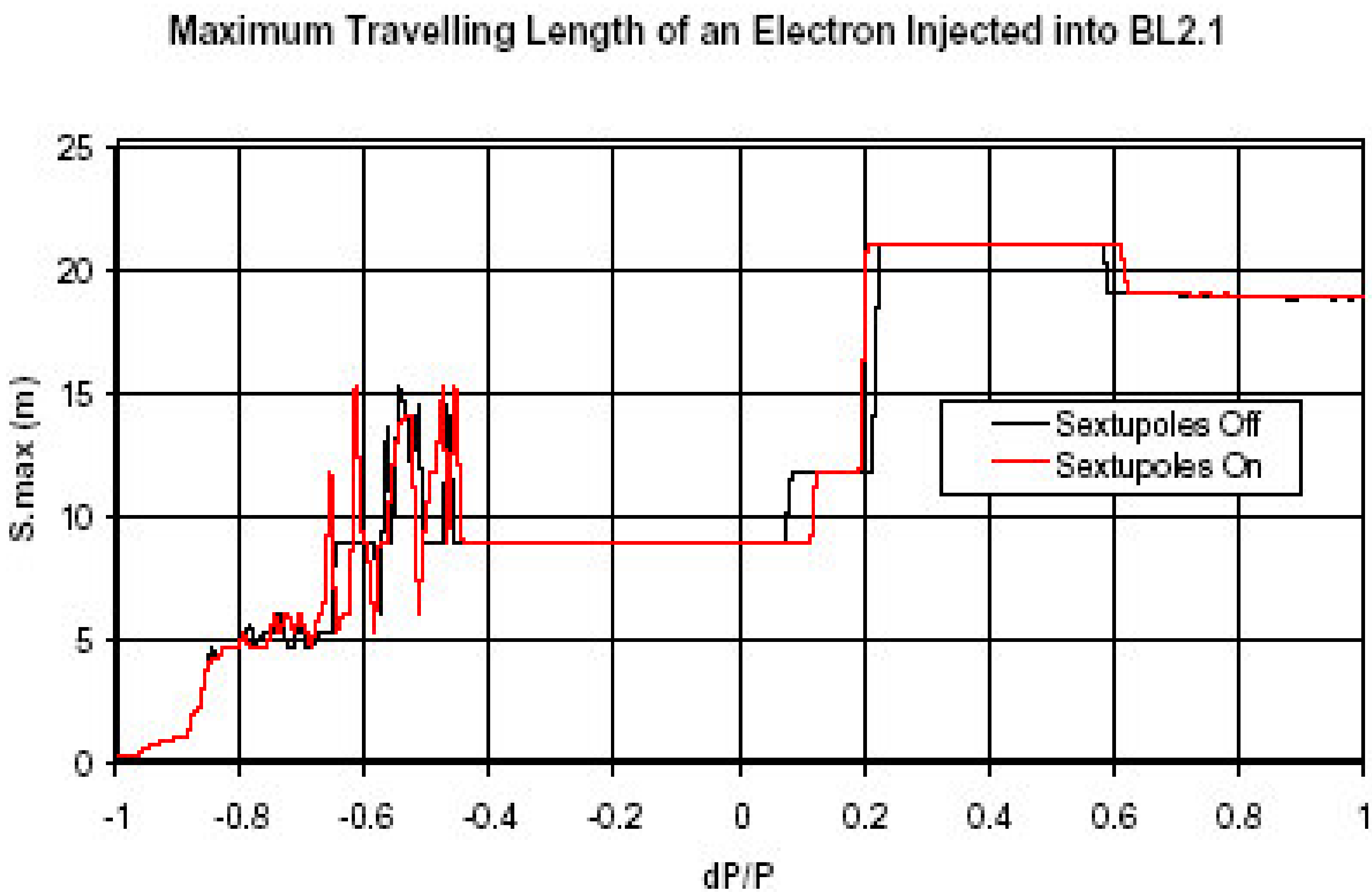
Can electrons go down the beampipe



Result


Maximum Travelling Length of an Electron Injected into BL2.1
S.max (m)
25
20
15
10
5
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
dP/P
Sextupoles Off
Sextupoles On

Injection with shutters open

Increased Bremsstrahlung from injected electrons scattering in the storage ring

- Do not know how large the Bremsstrahlung levels are under this condition
- Need to measure
- Potentially need to test schemes for reduced levels

- Final solution may include permanent scrapers in the injection line will include shutter interlock on radiation monitors

Scope of the project

1. **Fast pulsed elements**
   - **Magnets are all okay at 1.9 GeV**
     - **Booster, extraction kicker and septum**
     - **Storage ring injection bumps and septum**
   - **Power supplies**
     - **Septum**
       - **Reduced the injection transients by going to a full sine excitation of the thick septum**
     - **Bumps**
       - **Moved the injection septum closer to the stored beam**
       - **May upgrade the pulser to improve injection transients**
2. **Booster and transfer line elements**
   - **All magnets are capable of 1.9 GeV operation**
   - **Power supplies need to be replaced for the Bend, Quads, and Sextupoles**
   - **Increase the power to the RF**

Scope of the project

3. Utility Requirements
    - Will not need to upgrade the utilities
        - Reduction in the maximum injection rate from 1 to 0.5 Hz
- Bunch cleaning will be performed in the booster rather than in the storage ring
    - Similar to ESRF and SPRING-8
- Insert collimators in the transfer line and the storage ring to minimize losses near insertion devices and beam lines
- May install synchrotron radiation monitors in the booster to storage ring transfer line.
    - Similar to ESRF

Future Plans and Summary

- Completing a full cost, scope, and schedule for the upgrade
- Plan to upgrade to full energy injection in the next two years
- Plan to upgrade to top-off within 3 years

When completed Top-off will allow significant improvements in the performance of the ALS