Top-off Upgrade: What and Why

Christoph A Steier
Advanced Light Source

Accelerator Physics Group
July 12, 2006

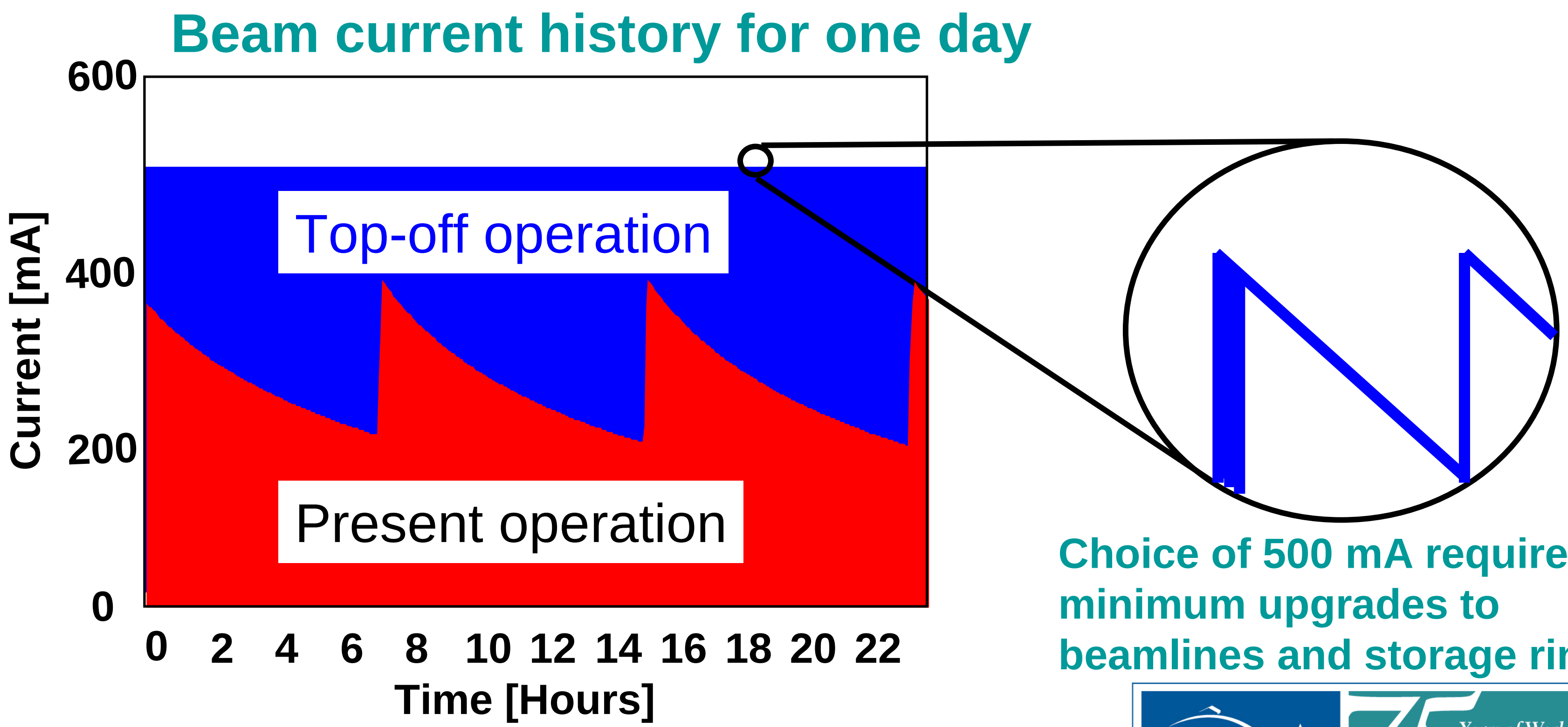
LAWRENCE BERKELEY NATIONAL LABORATORY

Outline

- Top-off
  - Why
  - What needs to be done: Overview
  - Project Management Structure
  - Status
- Technical System
  - System by system listing what we plan to do (already did) and short motivation why
- Schedule/Future Plans
  - Fall shutdown
  - Next year

What is Top-off operation of the ALS?

Top-off operation is quasi-continuous injection into the storage ring



Choice of 500 mA requires minimum upgrades to beamlines and storage ring

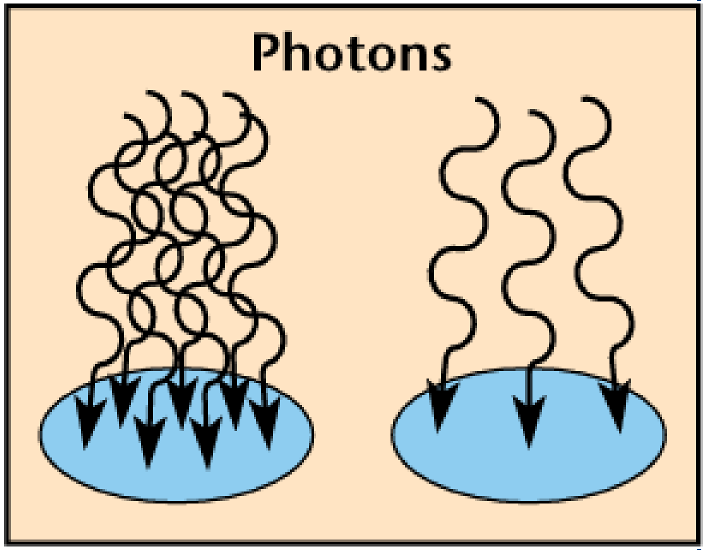
Motivations for Top-off

- Increased Brightness
  - 2x higher time average current
  - Smaller vertical emittance (0.25x)
  - Smaller undulator gaps
    - First two changes would result in unacceptably short lifetimes without top-off
- Better (thermal) stability
  - Accelerator (thermal)
  - Beam diagnostics (current dependence)
  - Beamline optics (especially bend magnet/wiggler beamlines, but also undulators)

What is Brightness ?

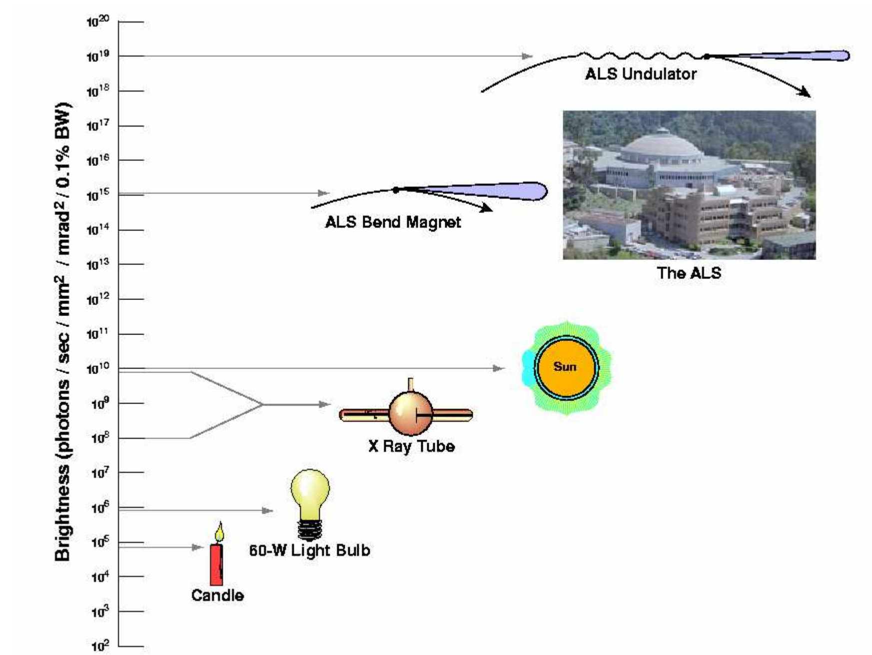
- The brightness of light is defined as the number of photons emitted (within some bandwidth) normalized by the emission area and the emission solid angle
$\Rightarrow$ the smaller the source and the more parallel the beam, the higher the brightness

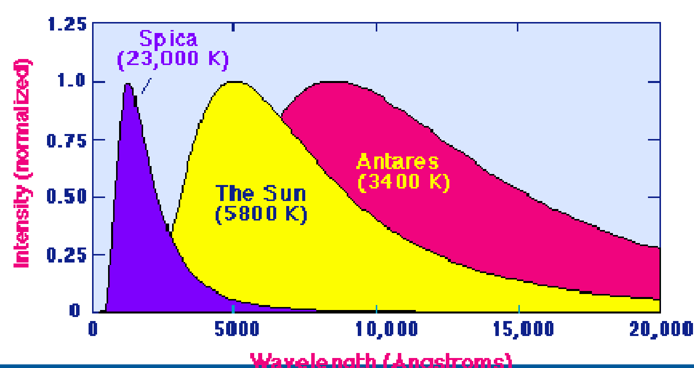
- Total radiated power of the Sun is a thousand * a billion * a billion times greater than the ALS, but the radius of the Sun is about 100 times bigger than earth, whereas the ALS beam is about as small as a hair (100 μm) and the emission solid angle of the sun is 4π (about 13 rad^2) compared to a hundredth of a millionth rad^2 for the ALS (area*solid angle factor is about 10^{35}!!!)

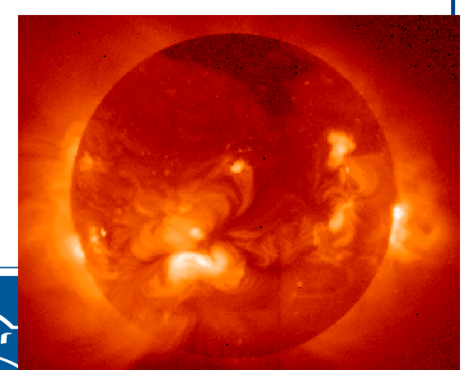


Comparing the Sun and the ALS further

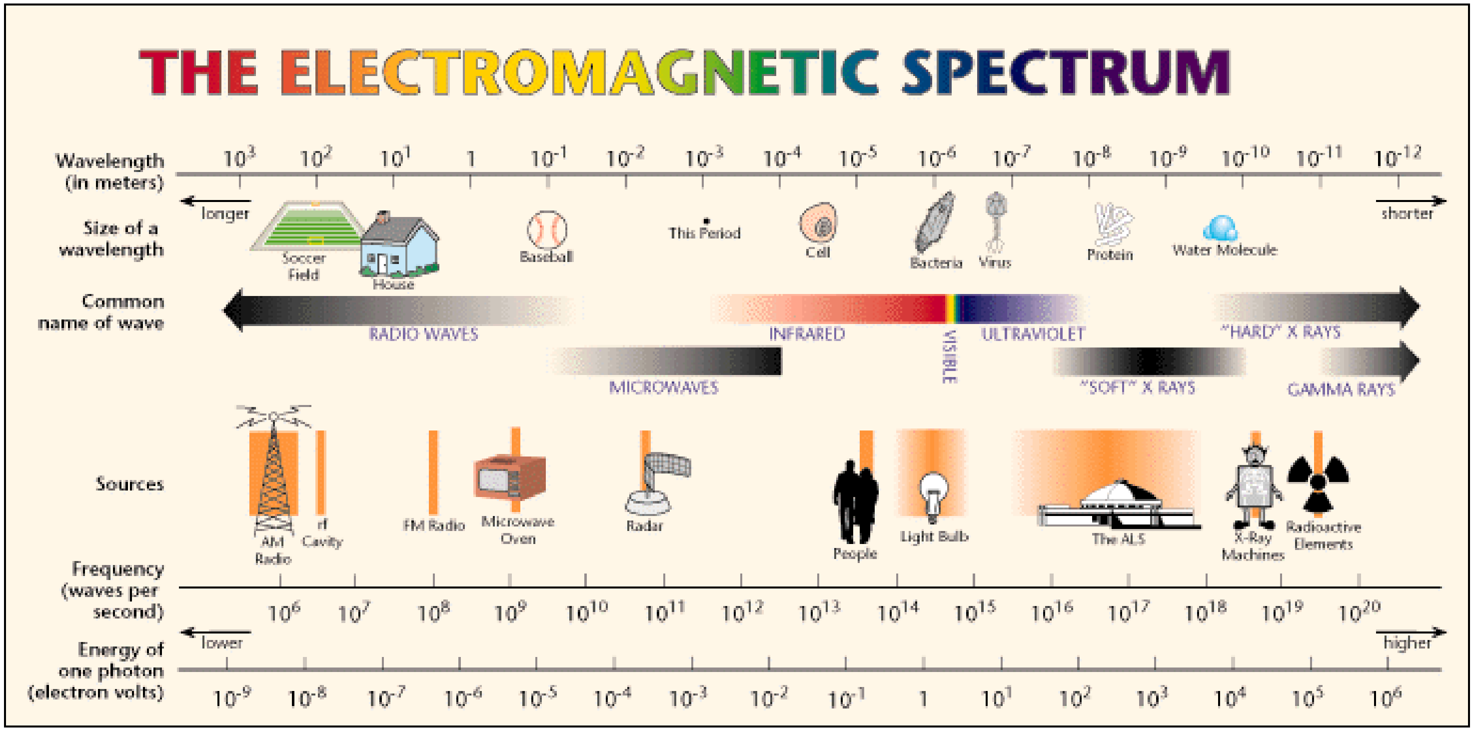
- **ALS (and other synchrotron light sources worldwide) are much brighter than the Sun**
- **Spectrum of the Sun: ‘black body radiation’ given by surface temperature (5800 K) + absorption lines + some harder UV and x-rays (mostly absorbed in atmosphere)**
- **ALS covers broad spectrum, peak in VUV and soft x-ray (all electromagnetic radiation is called light by physicists, not just the visible light) → undulators**







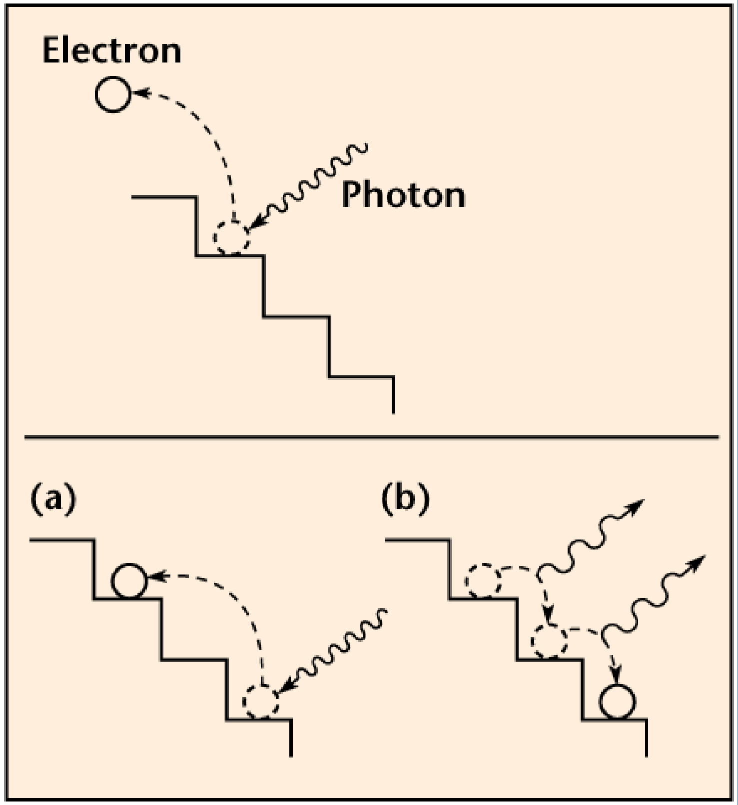
Why Experiments Require High Brightness?

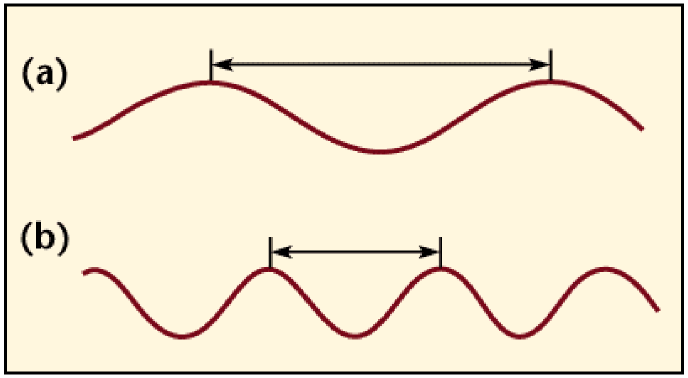


- **Samples studied at the ALS are small (protein crystals, cells, structures on computer hard disk surfaces, atomic beams, …); detectors have limited acceptance; smaller beams enable higher precision experiments; coherence; …**
- **Wavelength and energy of ALS light suited for wide range of systems and structures**

Why do we use soft x-rays for experiments?

- **Three main reasons:**
  - **Wavelength of light has to be of the order of objects to study (distance of atoms, molecules,…) → ALS covers about 0.1 nm to several μm**
  - **Probing the electronic structure requires the right energy**
  - **X-rays can penetrate matter, can probe surface as well as bulk**





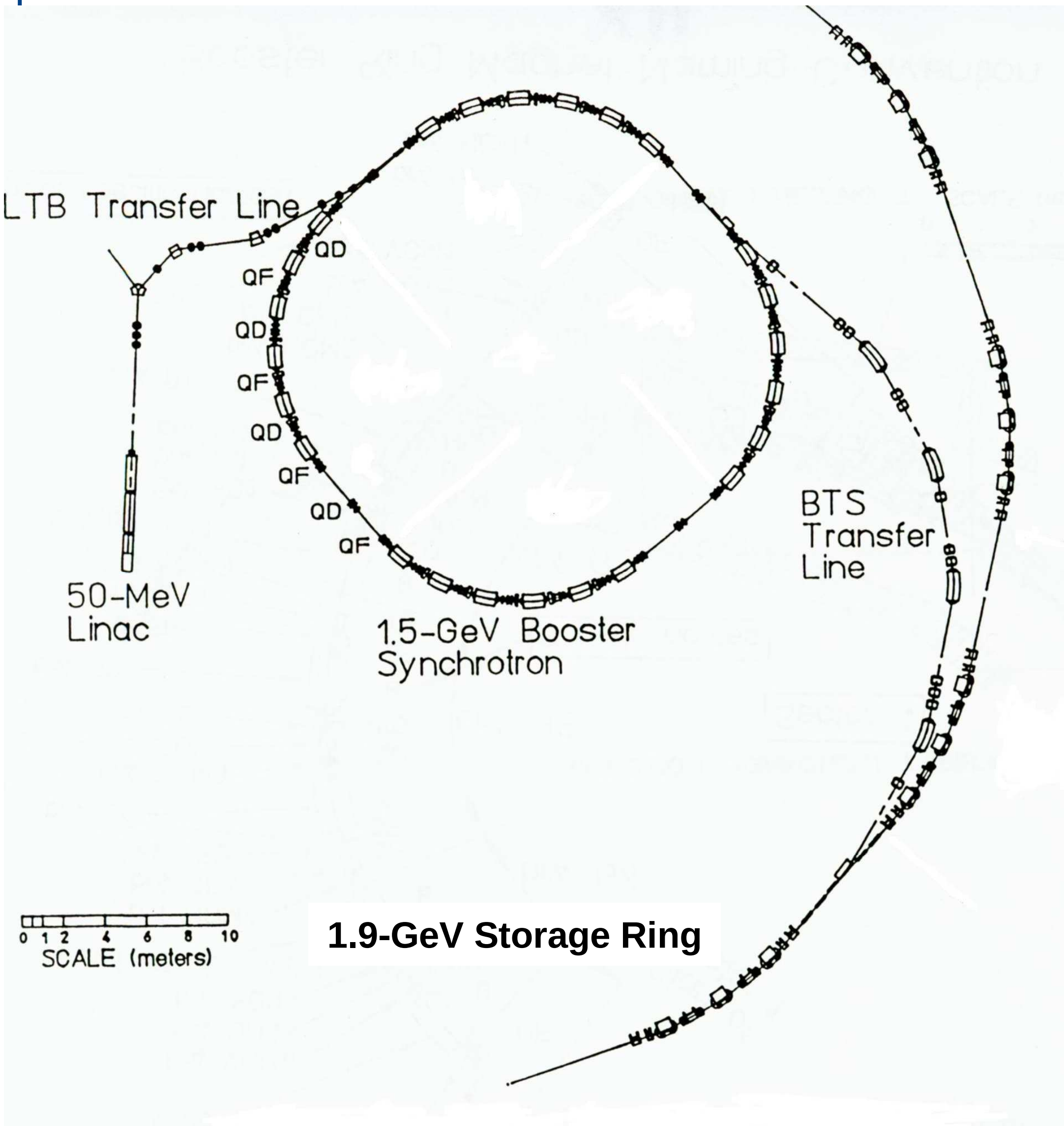
LAWRENCE BERKELEY NATIONAL LABORATORY

(Reduced) Scope of the Top-off Upgrade

- Upgrade injector to enable full energy injection
- Improve diagnostics and other existing systems where necessary for reliability
- Upgrade radiation safety system to allow injection with shutters open
- Minimize injection transients to reasonable levels and provide a gating signal
- Migrate to higher current and smaller vertical beamsizes
- Transition to Top-off with minimal negative impact to users
- Delayed/dropped bunch cleaning in booster

Berkeley Lab 75 Years of World-Class Science 1931-2006

Upgrade injector for full energy injection



- **New booster+BTS DC Power Supplies and Controls**
- **Upgrade of the booster RF system (e.g. power)**
- **Modifications of the Pulsed Magnets and Supplies**
- **Timing System, Controls, Diagnostics**
- **User Gating Signal**
- **Radiation Interlocks, Collimators, …**

Organization Chart

ALS top-off upgrade

- David Robin — *Project Leader*; Christoph Steier — *Project Manager*
  - Rick Donahue — *Radiation Safety*
  - Steve Rossi — *Project Controls*
  - Tony Warwick — *User Requirements*
  - Rob Duarte — *Mechanical Engineering*
  - Walter Barry — *Electrical Engineering*
    - Ken Baptiste — *RF*
    - Mike Fahmie — *Power Supplies and Timing*
    - Bob Mueller — *Interlocks*
    - Fernando Sannibale — *Diagnostics*
    - Greg Stover — *Pulsed Magnets*
  - Chris Timossi — *Controls*
  - Christoph Steier — *Accelerator Physics*

Status of Top-off Project

- Conceptual Design Review of the Project in November 2004, CDR in December 2004
- Received funding in March 2005
- Testing of Pulsed Magnet Systems 2005/2006
- Finished Design work on major systems 2006
- Long Lead Items ordered, several delivered
- Radiation Safety Studies/System Design
- In house fabrication of smaller systems 2006

Work breakdown structure (level 3)

1.1 Project Management
1.2 Top Off Documentation
- 1.2.1 User Requirements
- 1.2.2 Specification
- 1.2.3 CDR

1.3 Linac
- 1.3.1 EDI
- 1.3.2 Beam Loading Compensation
- 1.3.3 Diagnostics

1.4 Booster
- 1.4.1 Power Supplies
- 1.4.2 Thin Septum Magnet
- 1.4.3 Thick Septum Magnet
- 1.4.4 Kicker Magnet
- 1.4.5 RF
- 1.4.6 Diagnostics
- 1.4.7 Bump Magnets

1.5 BTS
- 1.5.1 EDI
- 1.5.2 Diagnostics
- 1.5.3 Beam Stopper for Injection Tune-Up
- 1.5.4 B1-B4 bend power supplies

1.6 Storage Ring
- 1.6.1 Bump Magnets
- 1.6.2 Thin Septum Magnet
- 1.6.3 Thick Septum Magnet
- 1.6.4 Radiation Protection
- 1.6.6 Diagnostics

1.7 Controls and Timing
- 1.7.1 User Gating Signal
- 1.7.2 Linac and Booster Timing
- 1.7.3 Controls
- 1.7.4 RF Controls

1.8 Commissioning
- 1.8.1 Pre-commissioning
- 1.8.2 Commissioning/Startup

Where can you look up infos?

- http://als.lbl.gov/als_physics/csteier/top_off/
  - Cost estimate is detailed and includes all work
  - CDR gives overview of the project, motivation, …
  - Monthly progress reports tell about where we are and what problems we face
  - Schedule (not quite up to date)
  - Risk analysis (not quite up to date)
  - Change order log
  - …

LAWRENCE BERKELEY NATIONAL LABORATORY

Project Management, …

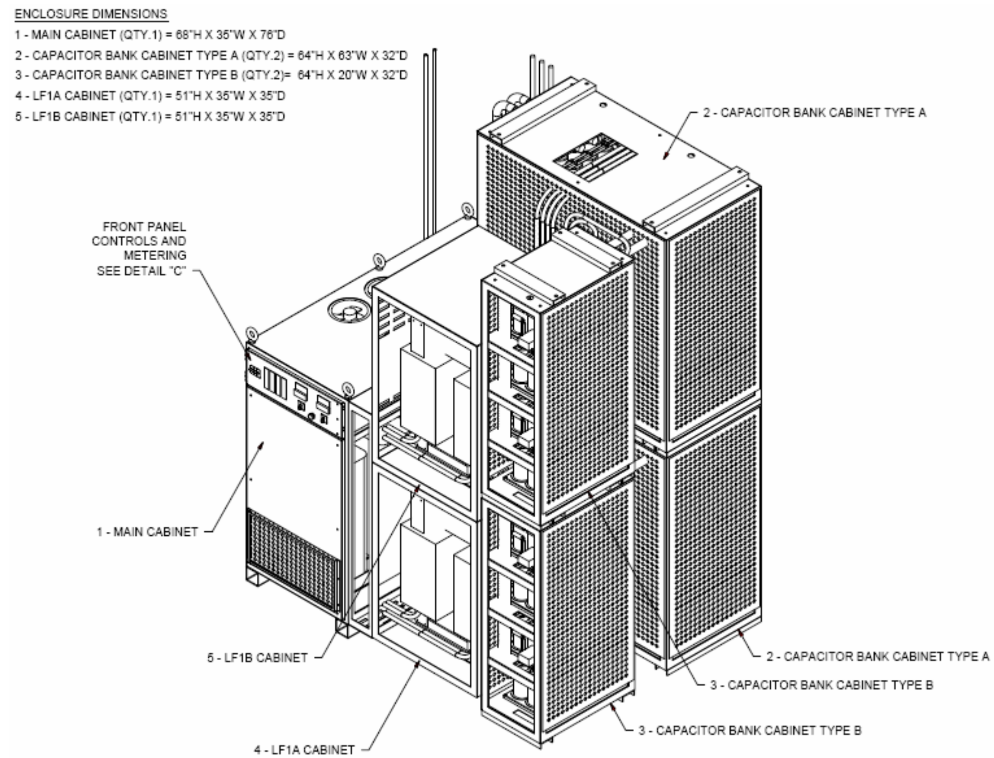
- I will not talk about project management part – I am still learning on the job … ☺
- If you have any questions, concerns, suggestions, all of us always have an open ear
- Scope of Documentation and LINAC upgrades turned out to be minimal – will not cover either (at the moment nothing remains to be done)

Booster

- All magnets turned out to be sufficient for higher energy
- Power supplies are not!
  - New Bend Magnet Supply
  - New QF+QD supplies
  - Sextupole power supplies turned out to be sufficient!
  - New controls for all supplies (including sextupoles and correctors) -> Controls section
    - Replace multiplying DACs
  - New timing system
- New RF transmitter, HVPS, cavity window, waveguides, …
- Pulsed Magnets
  - Charging supplies, pulsers, cooling
- Tune Measurement System

Power Supplies

- **Bend, QF, QD manufactured by IE Power**
- **Bend with capacitor bank**
- **All with switch mode technology**
- **Analog input is only backup, primary control is fully digital**



Lawrence Berkeley National Laboratory

New Booster RF system

- New transmitter is IOT based
- Delivered last week – test installation under way

LAWRENCE BERKELEY NATIONAL LABORATORY

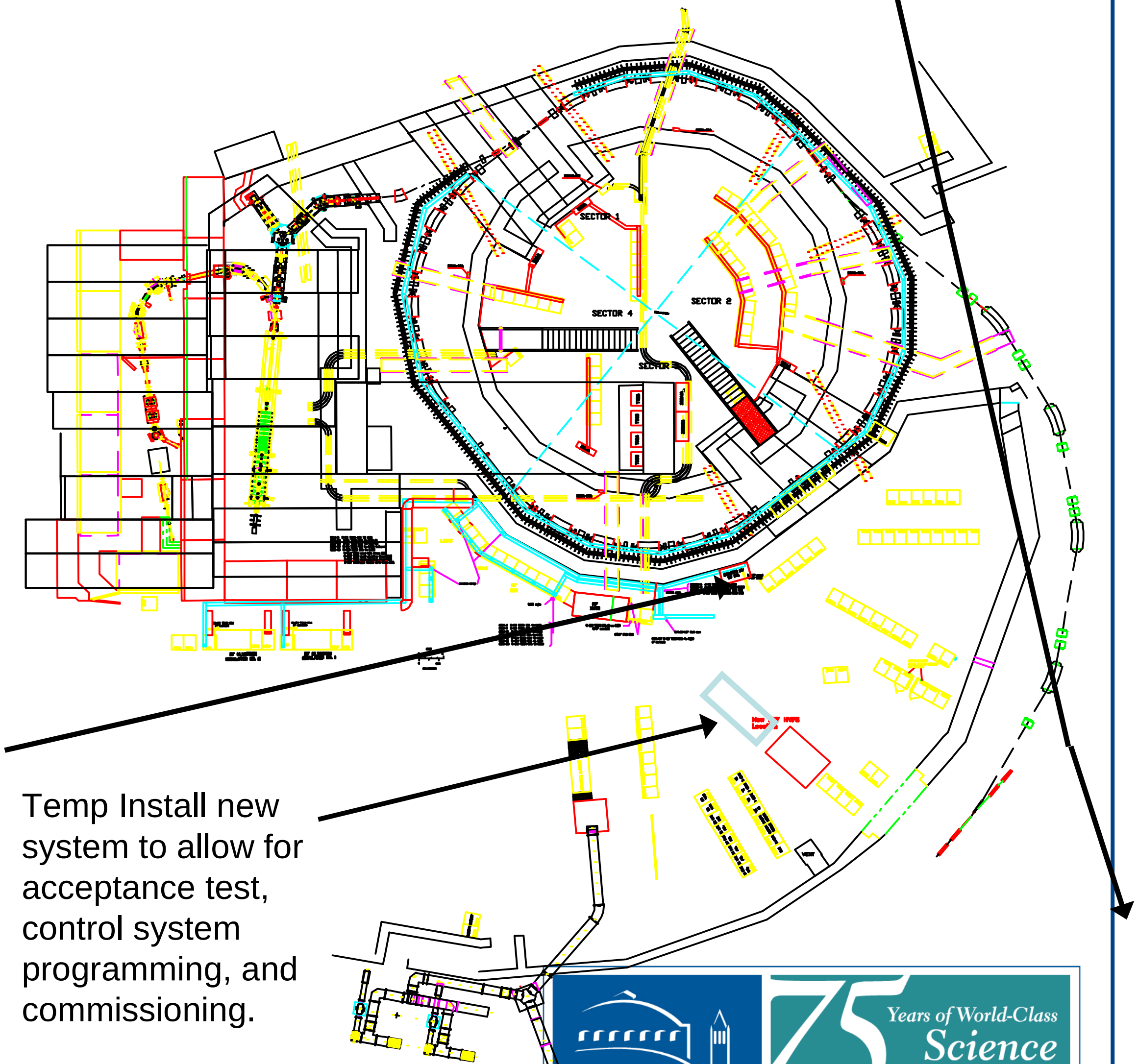
BERKELEY LAB

75 Years of World-Class Science 1931-2006

HVPS Location

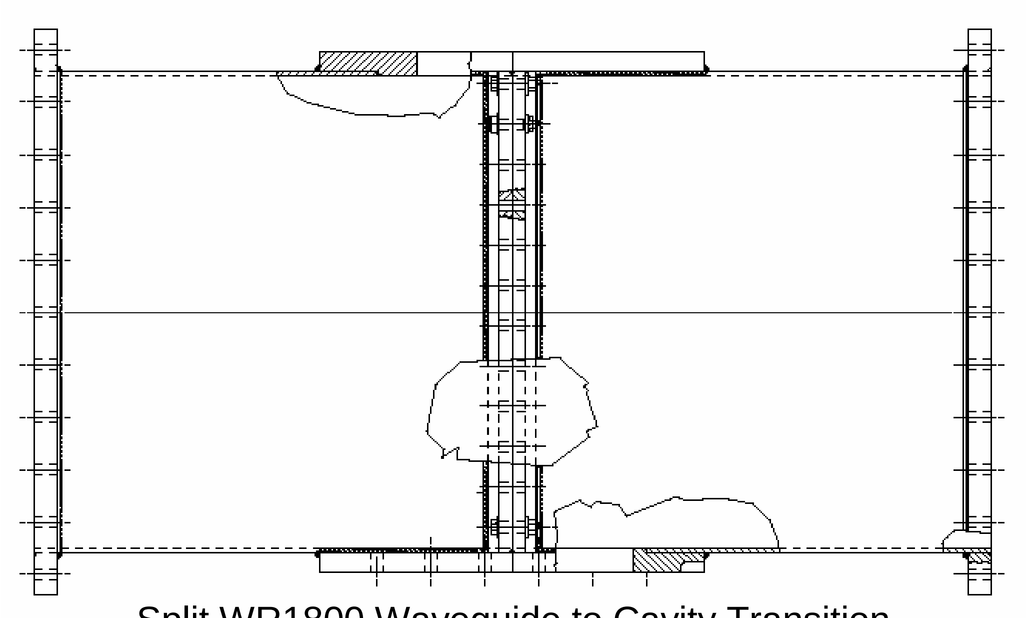
New HVPS Location

Existing HVPS Location



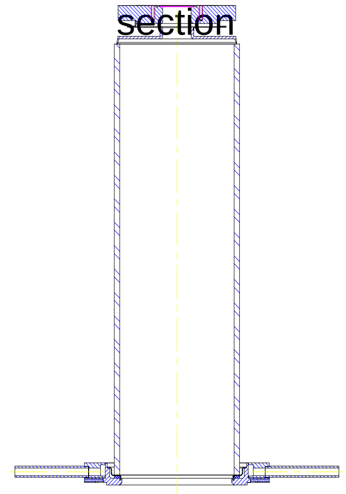
Temp Install new system to allow for acceptance test, control system programming, and commissioning.

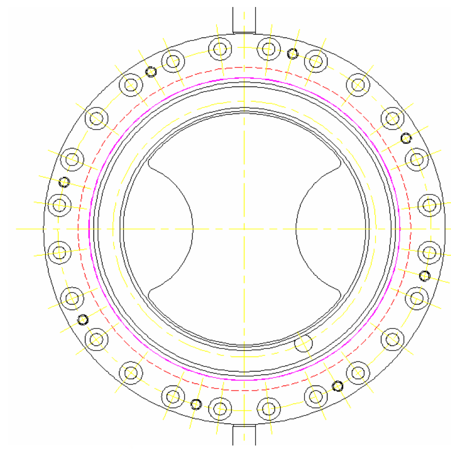
RF Cavity Power Coupler Window



Split WR1800 Waveguide to Cavity Transition

Window Cross-section





Iris Flange Profile

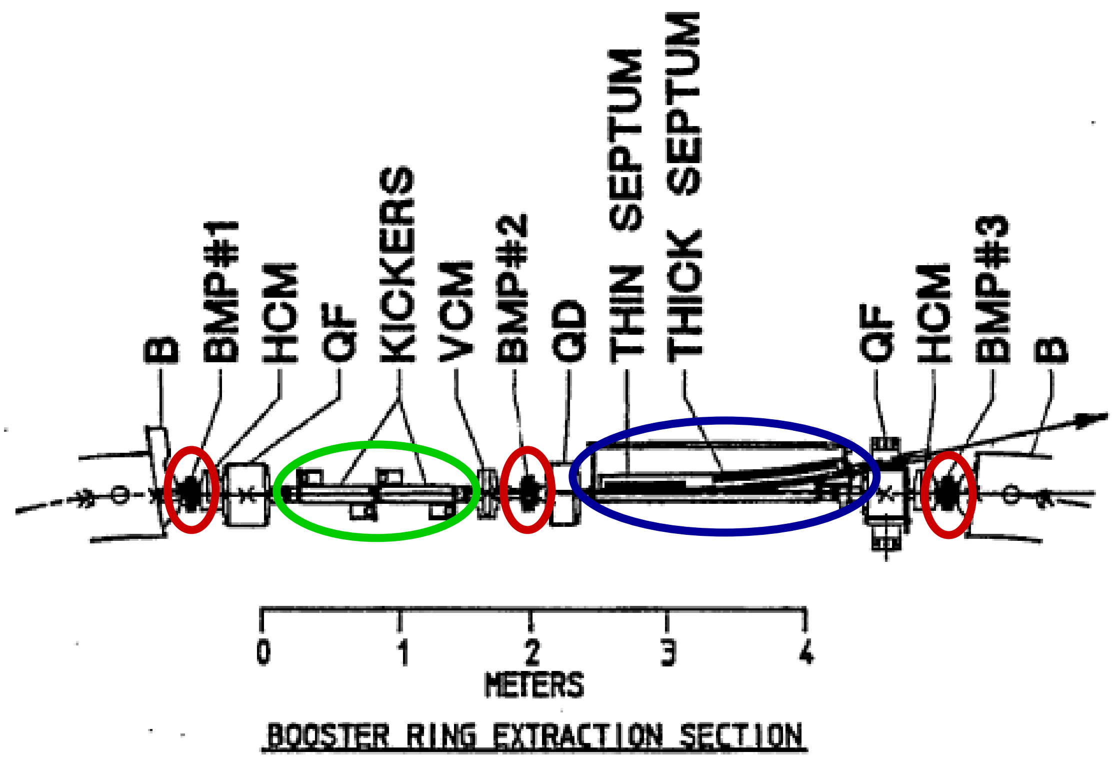
β: 1 to 3.2

Current Design:

- 2 in SRRF operating at 43kW CW
- 1 repaired fully tested spare
- Manufacture, TiN coating & test to 66KW CW at LBNL

Manufacture 2 more windows of this type for Booster RF

Extraction magnet layout



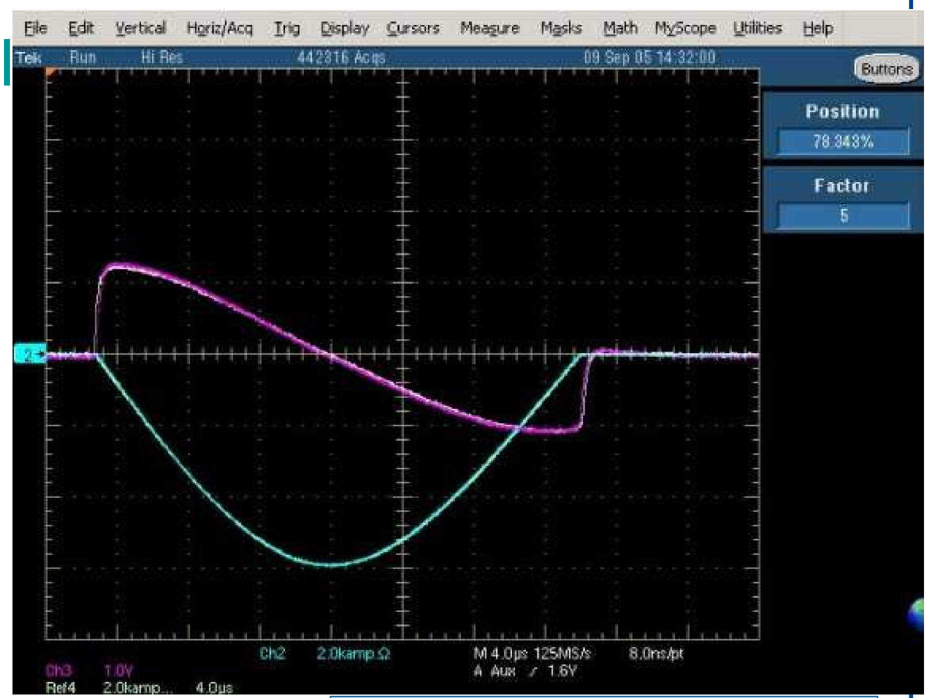
Booster extraction magnets:

3 booster bumps, 4 booster extraction kickers

And the 'thin' septum and 'thick' septum

Tests of the Pulsed Magnet Systems

- Successfully tested each of the Pulsed Magnets at full energy



Thin Septum Test Setup

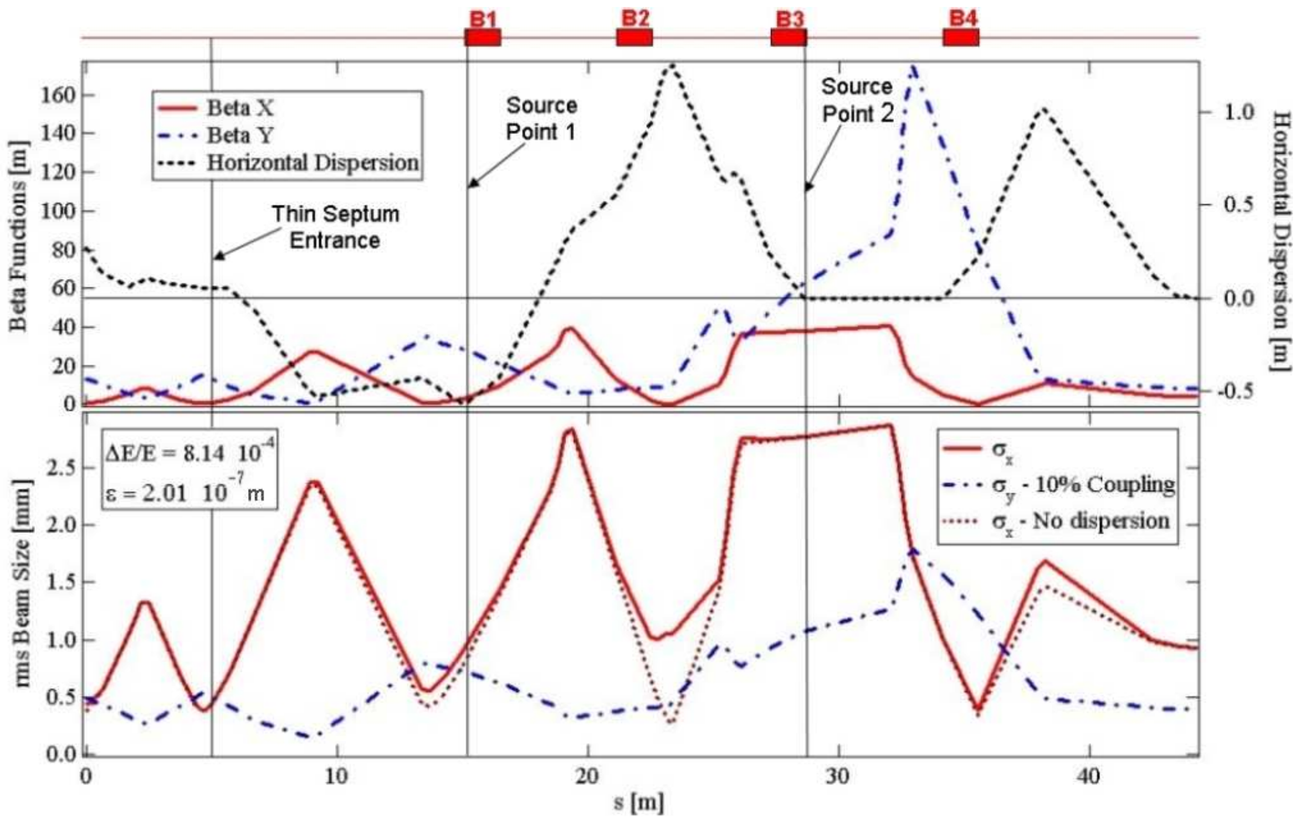
BTS

- All magnets turned out to be sufficient for higher energy
- Power supplies again are not!
  - New B1-B4 power supplies
- New SR monitor diagnostics (off B1)
- Two pairs of horizontal collimators (radiation protection)

Power Supplies

- 4 BTS B1-B4 power supplies are build by alpha-scientific
- Conventional SCR technology, similar footprint to existing supplies
- Control however will be digital as well, details are still being worked out

BTS Synchrotron Radiation Monitors



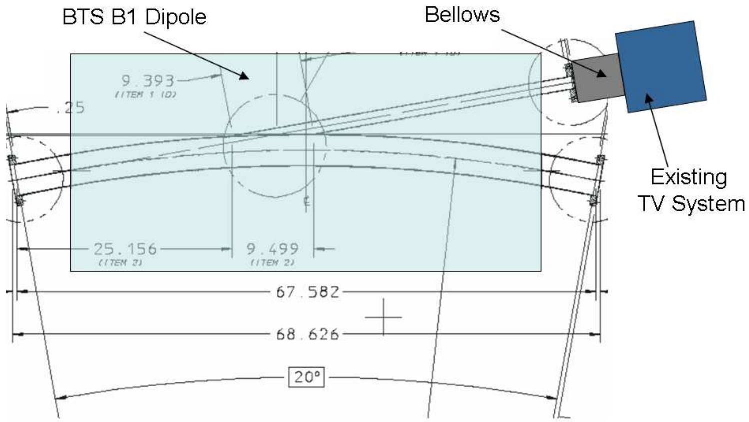
Source at B1: "high" dispersion

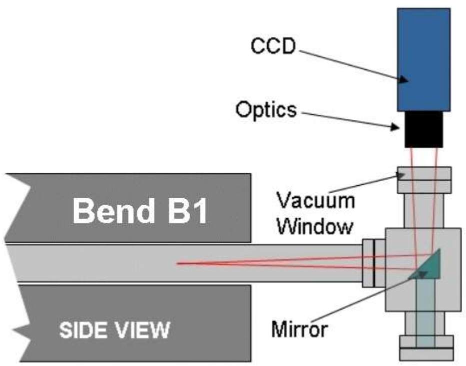
Source at B3: "zero" dispersion

Single glance check of the injector status

Both use standard CCDs

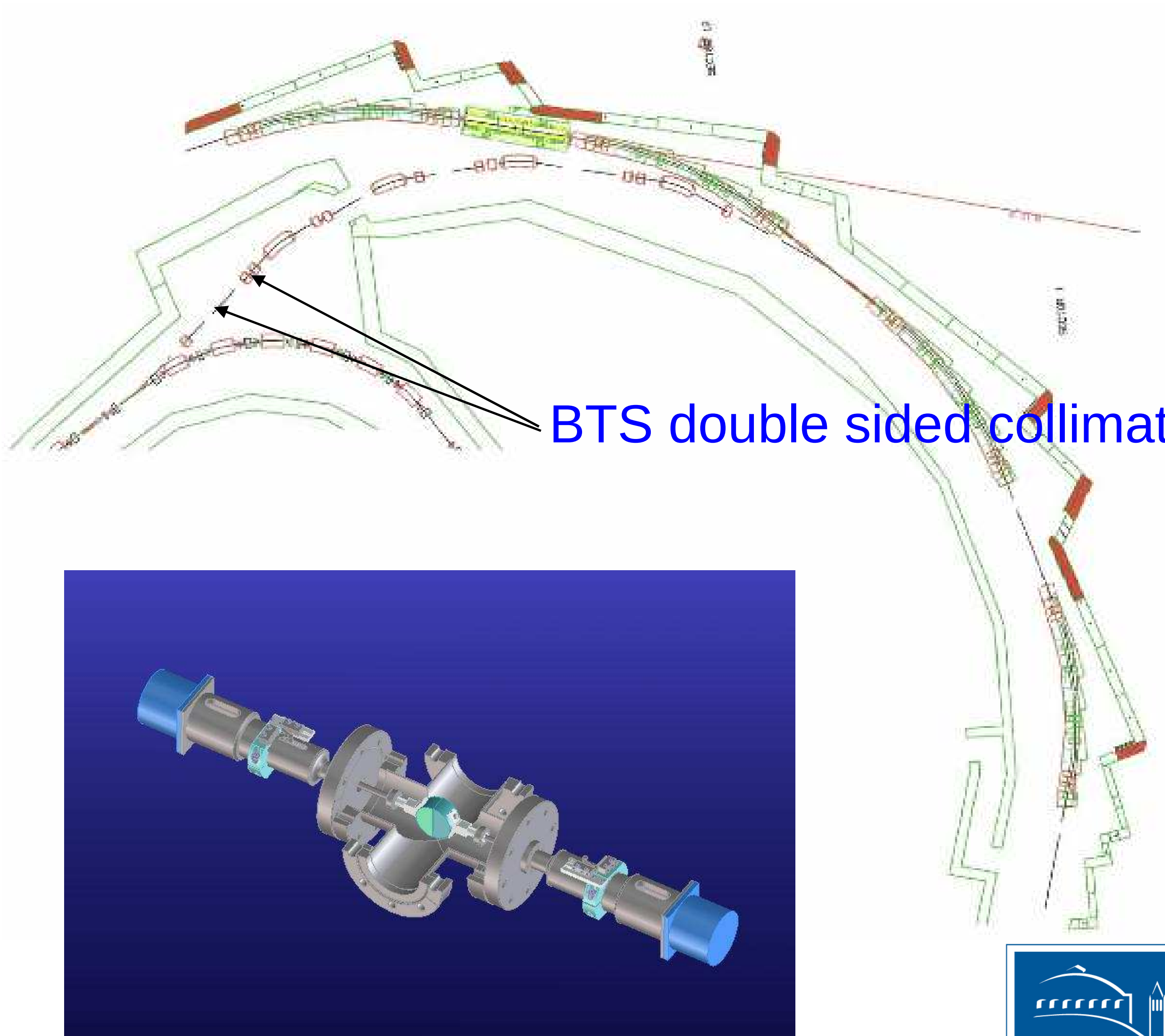
SRM @ B1 BTS Bending Magnet





Photons per beam passage (between 250 – 700 nm)	~ 1.3×10^{8}	Horizontal acceptance (total chamber aperture)	~ 18 [mrad]
Energy deposited in the mirror per passage (whole SR spectrum)	~ 8.0×10^{-7} [J]	Minimum vertical acceptance (total)	10 [mrad]
Bunch charge (1.5 mA in the Storage Ring)	9.84×10^{-10} [C]	Mirror angle	45 [deg]

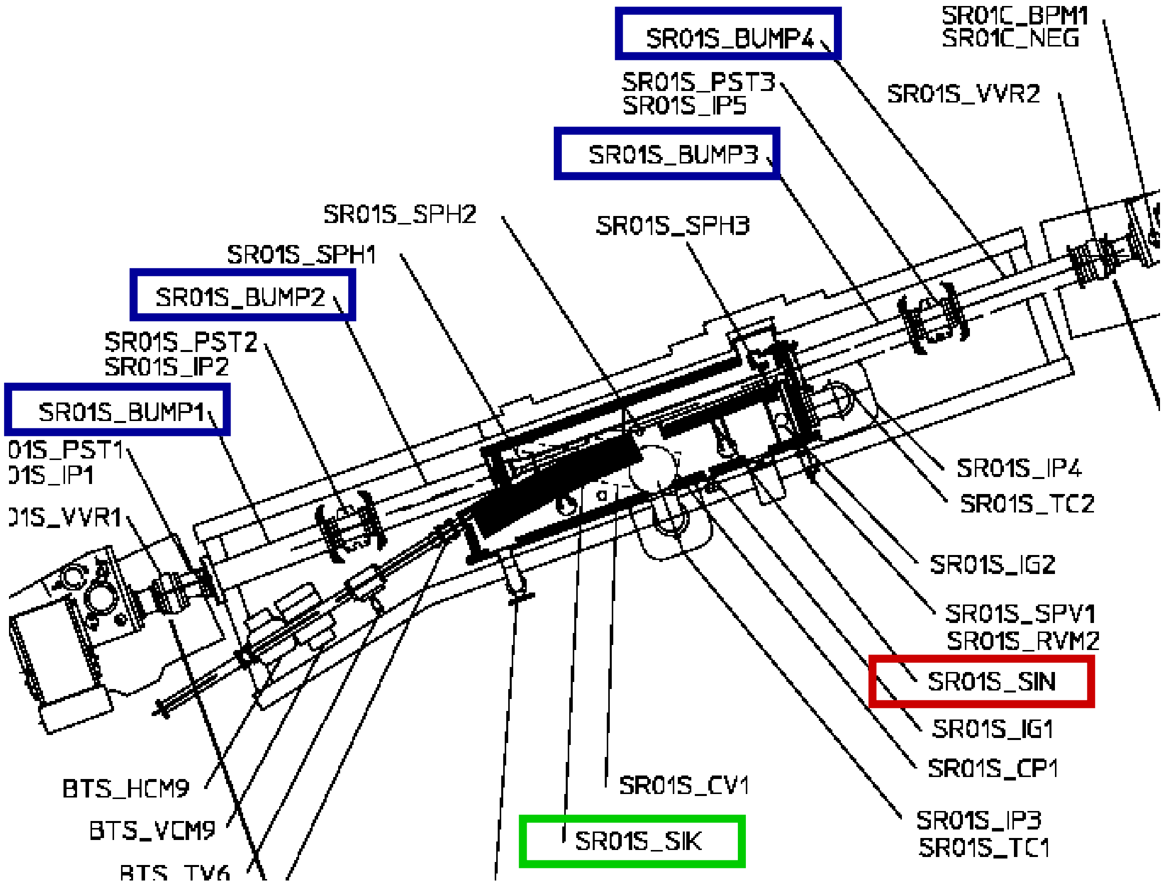
Requires replacement of the flag with a mirror. Nothing more!


BTS double sided collimators

Storage Ring

- Pulsed Magnets
  - Bumps are OK
  - Septa as in Booster
    - In addition full sine thick septum pulser
- Radiation Safety
  - Fill interlock
  - Beamline Radiation Monitor Interlocks
  - Energy Matching
  - Jackson Hole Scrapers
- Bunch Cleaning
- Fill structure monitor

Injection magnets layout



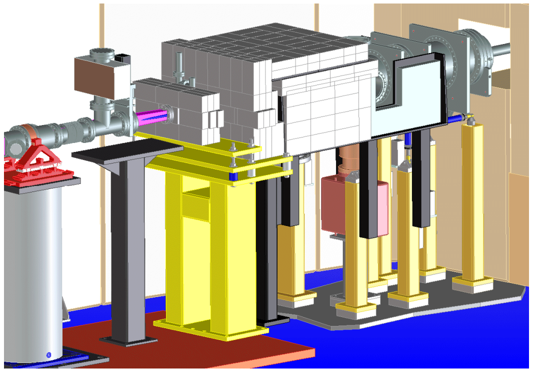
Upgrading our Radiation Protection Systems

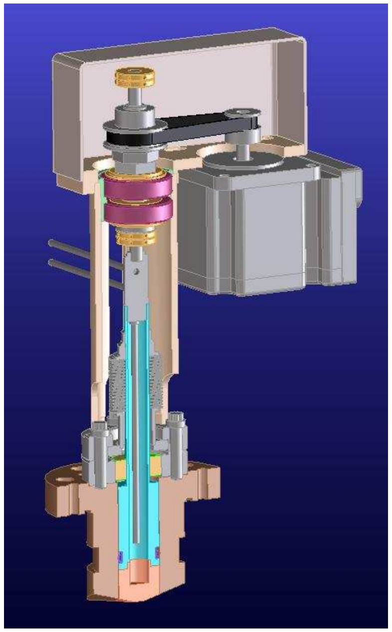
Changes in operation after Top-Off

- Injection with the personnel safety shutters open
- Higher stored beam losses
- Injection with undulators closed

The radiation protection systems (interlocks, collimation, local shielding) will be upgraded to ensure safe operation with Top-off

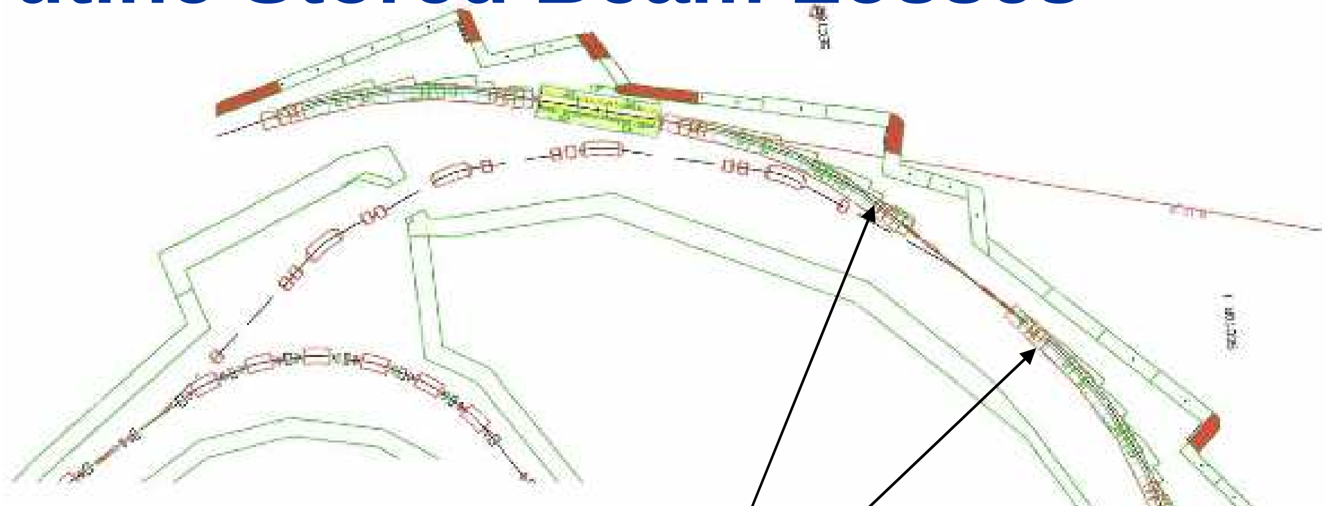
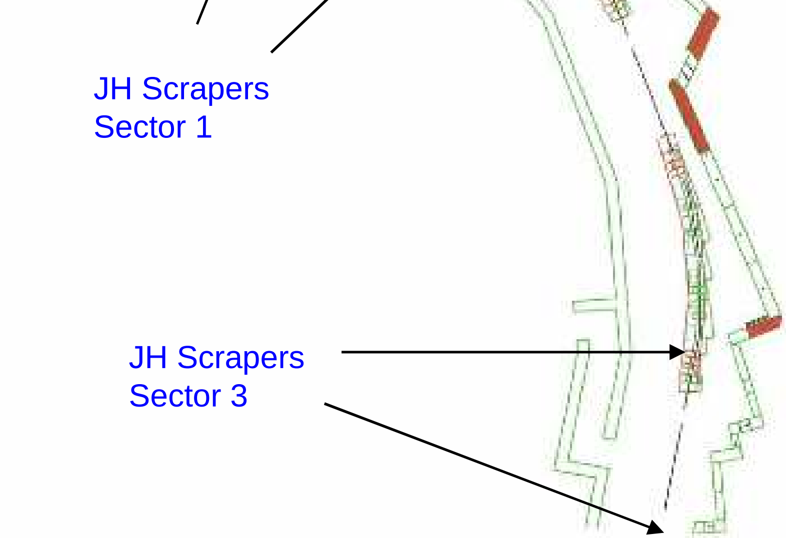
Upgrading our Radiation Protection Systems



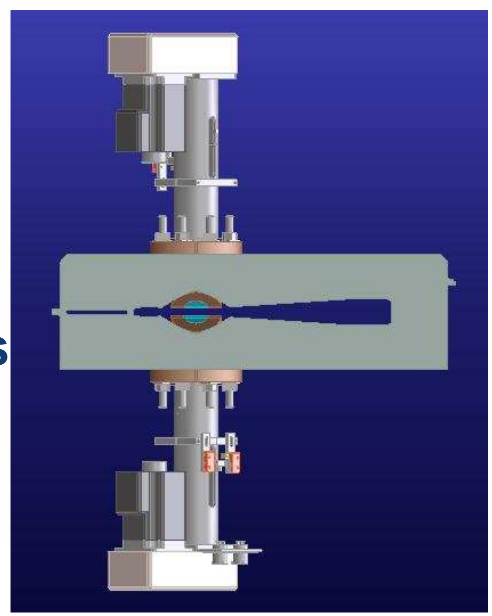


- Extensive testing on beamline 4.0
  (already tested 1.5 GeV top-off with beamline 4.0 open)
- Working closely with DOE
- (External) Review in Winter 06/07
- ALS Safety Analysis Document (SAD) will be modified

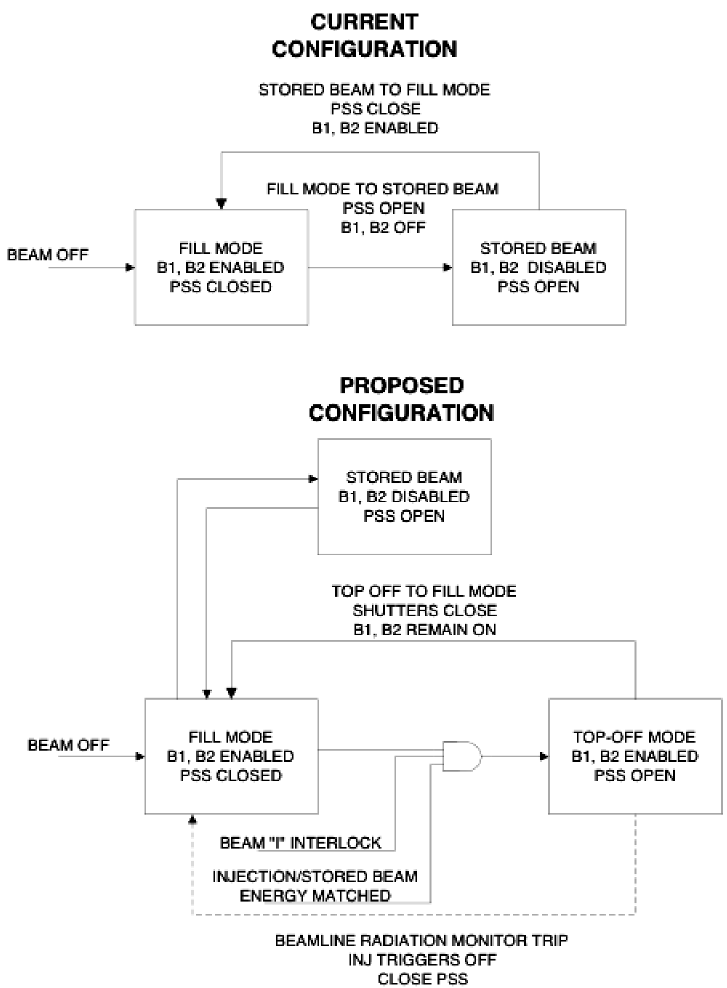
Routine Stored Beam Losses

- **New scrapers localize losses away from beamline source points and undulators**
- **Installed+work very well**



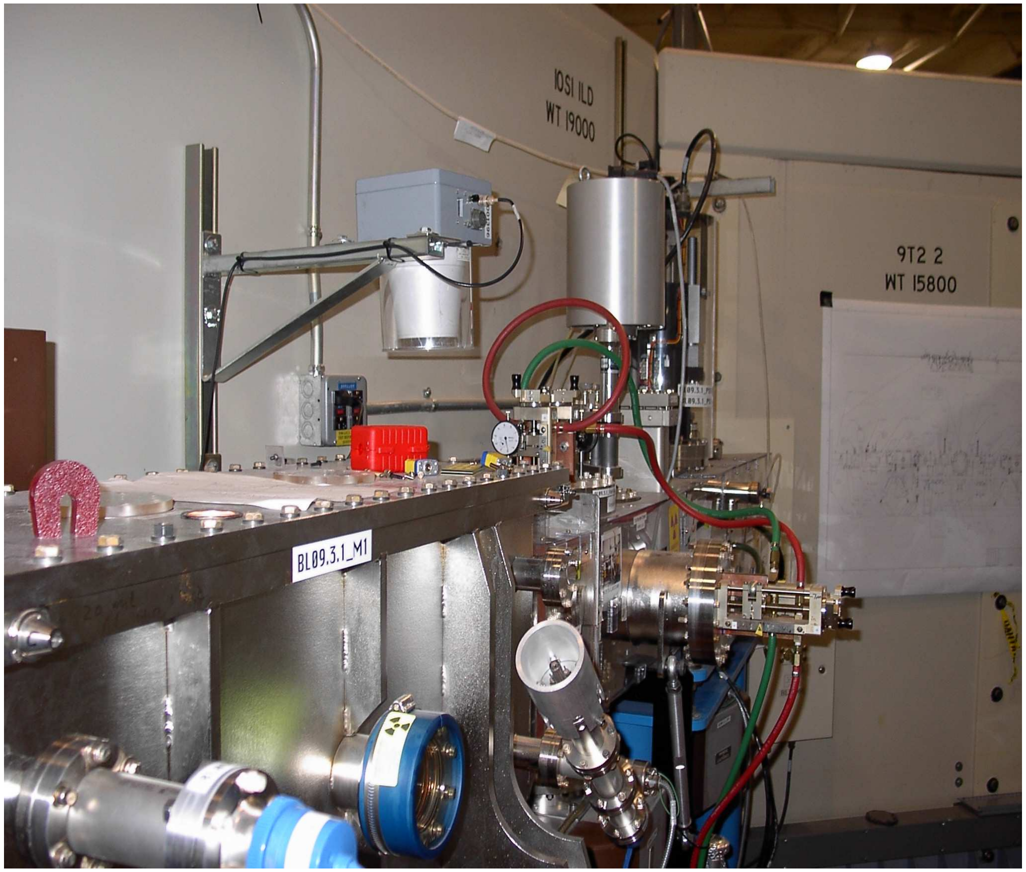
Interlock Changes



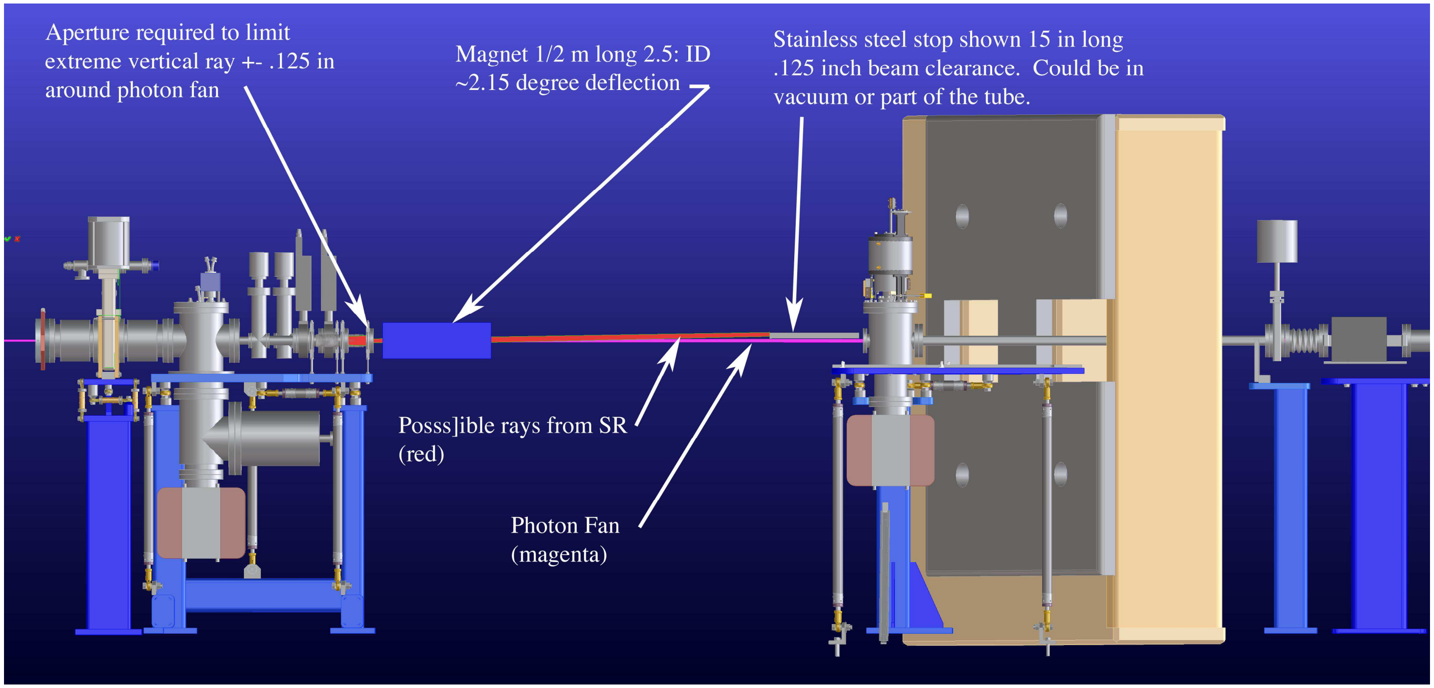
- **Injection will only be allowed with shutters open if**
  - **There is stored beam**
  - **The energy of the injected beam matches the stored beam**
- **Additionally we will have active interlocked monitors on beamlines**

Beamline Interlocked Monitors

- Monitors have been installed on beamline frontends for years
- So far only used for monitoring
- Will be interlocked (safety gain independent of top-off)
- New electronics, new monitoring applications, tested saturation behavior



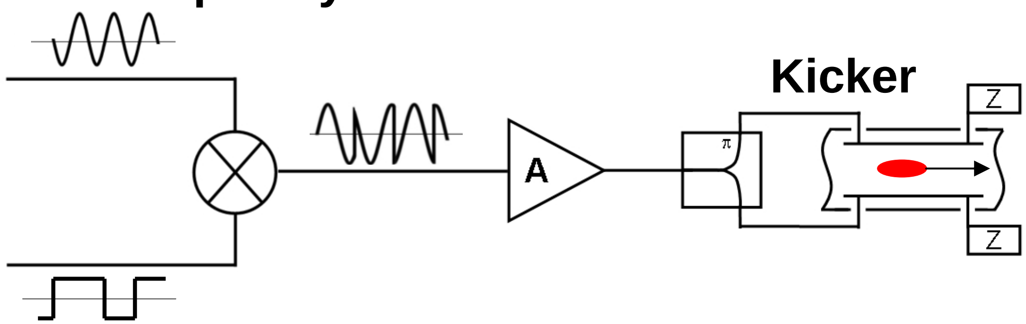
Fallback Solution



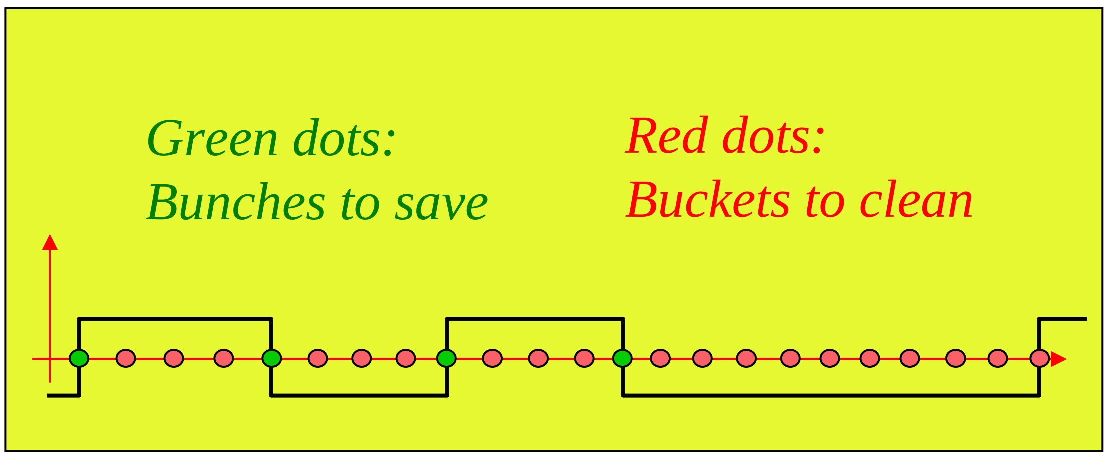
- **If all our efforts to demonstrate that apertures protect injected beam down photon beamlines with stored beam should fail**
  - **Fallback solution is to add permanent magnets on (subset) of frontends (x.3 beamlines ?)**

The New Cleaning Technique

Sinusoid at Vertical Betatron Frequency



Pseudo-square wave

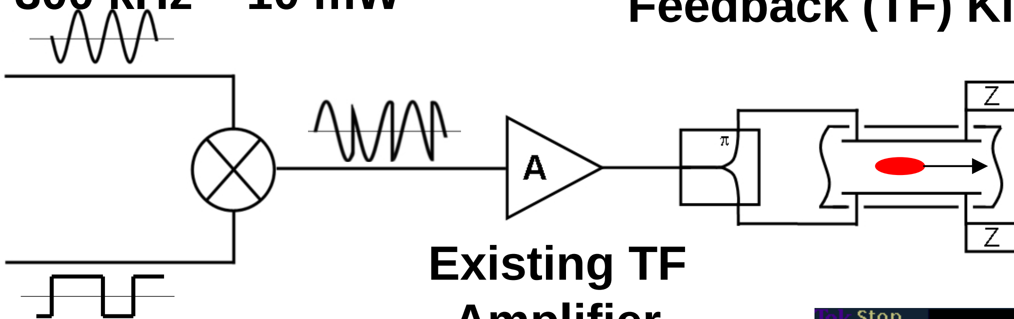


H. Suzuki, *et al*., NIM A **444** (2000) 515-533.

Our Implementation

Existing Sinusoidal Generator
300 kHz – 10 mW

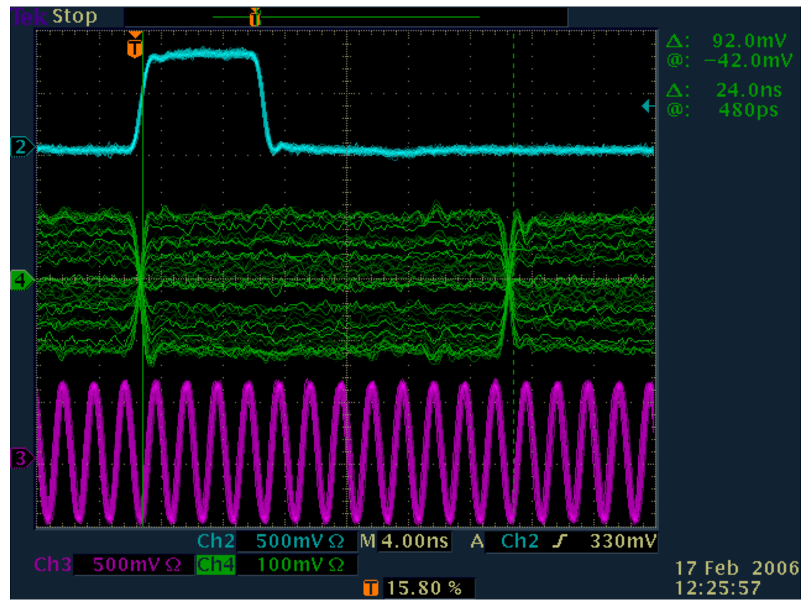
Existing Transverse Feedback (TF) Kicker (Stripline Type)



No scraper required!

New FPGA General Purpose Board ~ 500 MHz BW

Existing TF Amplifier ~ 150 W 250 MHz BW

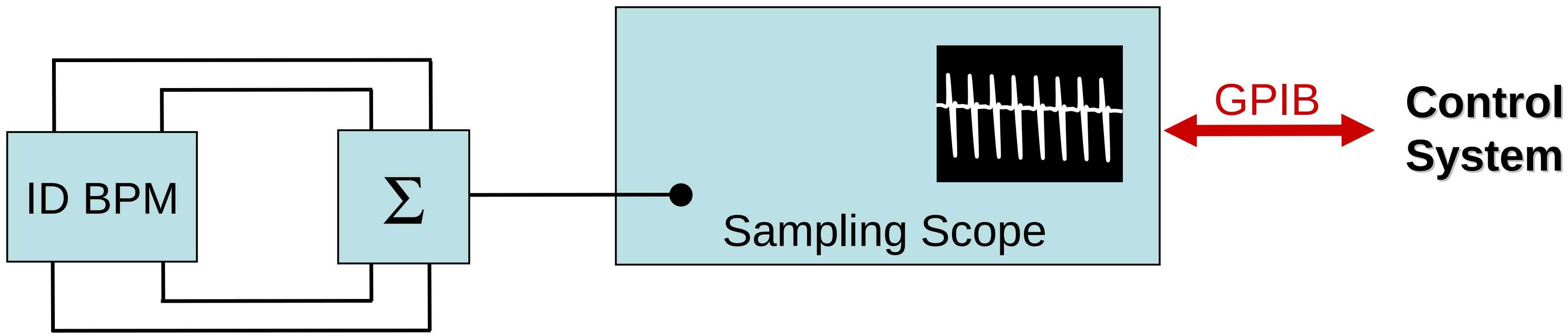


Multi-purpose board (W. Barry, M. Chin, J. Weber):

- B-Factory transverse feedback
- ALS Control System CPUs
- Arbitrary function generator

Very large bandwidth, no timing drift, very reliable, easy to program, …

Storage Ring
Bunch by Bunch Current Monitor



- **Upgrade of the existing system:**
  - **Use of a “cleaner” signal from an ID BPM**
  - **Dedicated oscilloscope**
  - **Development of a new high level application**

Controls and Timing

- New main power supplies (booster+BTS) are digital
  - New controls via network
- Need to update controls of other ramping magnets (and RF amplitude)
  - miniIOC
  - Modify multiplying DACs
- Need to control PLC of RF transmitter
- Control of stepper motors (scrapers, collimators)
  - Several new IOCs and controllers
- Need new master timing system (more flexibility) + controls interface
- User gating signal

Commissioning

- This time startup+commissioning will center on booster (+BTS)
- Hope to start just after Thanksgiving
- Will start without beam (power supplies and controls tests)
- Later with beam, but first just in booster
  - Can continue work in storage ring for a while (HOM dampers, BPM buttons, …)

Shutdown+Commissioning Schedule

Oct-06	1	2	3	4	5	6	7	8	9 (Users Mtg)	10 (Users Mtg)	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	Su	M	T	W	Th	F	S	Su	M	T	W	Th	F	S	Su	M	T	W	Th	F	S	Su	M	T	W	Th	F	S	Su	M	T
0000-0800		AP	I							AP						IT	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
0800-1600		M	I						AP							I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
1600-2400		I	S/T						AP							I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I

Nov-06	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	W	Th	F	S	Su	M	T	W	Th	F	S	Su	M	T	W	Th	F	S	Su	M	T	W	Th	F	S	Su	M	T	W	Th
0000-0800	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	H	H	X	X	S/T	S/T	S/T	S/T
0800-1600	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	H	H	X	X	S/T	S/T	S/T	S/T
1600-2400	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	H	H	X	X	S/T	S/T	S/T	S/T

Dec-06	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	F	S	Su	M	T	W	Th	F	S	Su	M	T	W	Th	F	S	Su	M	T	W	Th	F	S	Su	M	T	W	Th	F	S	Su
0000-0800	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	BLC	BLC	BLC	X	X	H	H	H	H	H	X	X
0800-1600	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	BLC	BLC	BLC	X	X	H	H	H	H	H	X	X
1600-2400	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	S/T	BLC	BLC	BLC	X	X	H	H	H	H	H	X	X

Jan-07	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	M	T	W	Th	F	S	Su	M	T	W	Th	F	S	Su	M	T	W	Th	F	S	Su	M	T	W	Th	F	S	Su	M	T	W
0000-0800	H	X	MS						AP						H	IT							AP						IT	I	
0800-1600	H	M	AP	BLC				AP							H	M						AP						AP	M	I	
1600-2400	H	S/T	AP	BLC				AP							H	S/T						AP						MS	I	S/T	

Berkeley Lab
75 Years of World-Class Science 1931-2006

LAWRENCE BERKELEY NATIONAL LABORATORY

Future (Top-off) Plans

- Extended shutdown will be in Fall 2006
  - Starts just after User meeting (middle of October), commissioning November+December
- Plan to operate with full-energy injection immediately following the shutdown
- Will slowly migrate to full top-off operation during the following six to nine months
- Move to 500 mA and smaller emittances within 2007 (maybe intermediate steps based on user responses, …)