Experiences from First Top-Off Injection At The Stanford Synchrotron Radiation Lightsource

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Overview

- Introduction to SSRL
- Introduction to "Top-Off"
- Studies in Preparation for Top-Off
- Safety System
- First Tests
- SSRL Improvements
- New Tests
- Conclusions and Path Forward

Introduction to SSRL

“Stanford Synchrotron Radiation Lightsource”

- Evolved from
  high-energy physics synchrotron “SPEAR”
- Twice upgraded, now:
  - Storage ring SPEAR3
  - Fed by 10 Hz Linac (to 150 MeV), Booster (to 3 GeV)
  - Connected with BTS line (Booster-To-SPEAR)
- 3 GeV, 100 mA with typically 1 W injection
  usually three times a day fill from ~85 mA to 100 mA
- Going to 500 mA this year, later up to 5 W injection
- Currently 13 beamlines with 27 stations

Introduction to SSRL (cont.)

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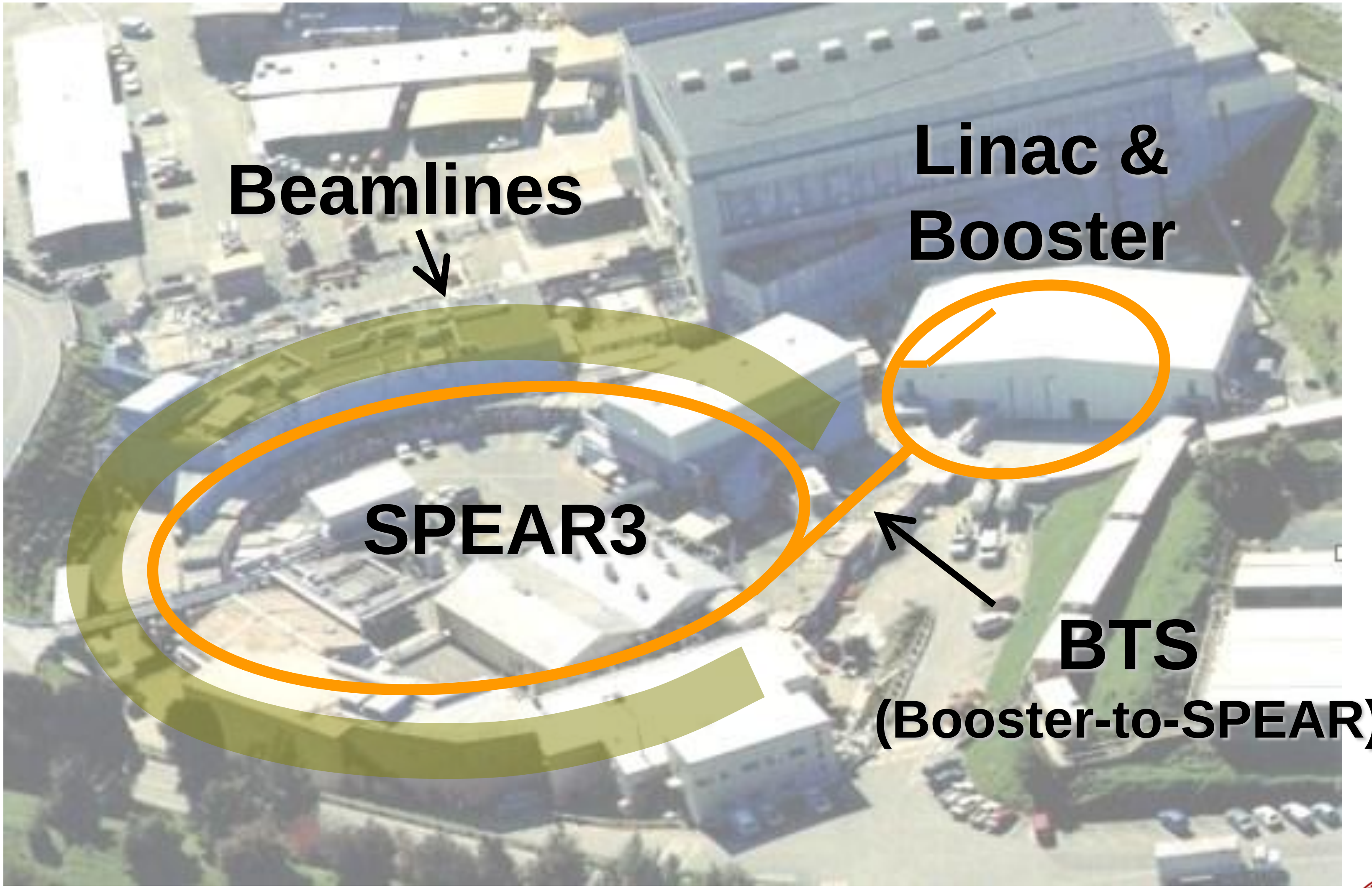


Top-off, Top-Up, etc.

So far: Injection stoppers (IS) closed while filling storage ring

→ no worries about electrons and Bremsstrahlung reaching BL during injection

→ but temperature changes (→alignment) affect optical components: o.k. now, but not desired at higher currents

Top-Off: Filling storage ring while injection stoppers open

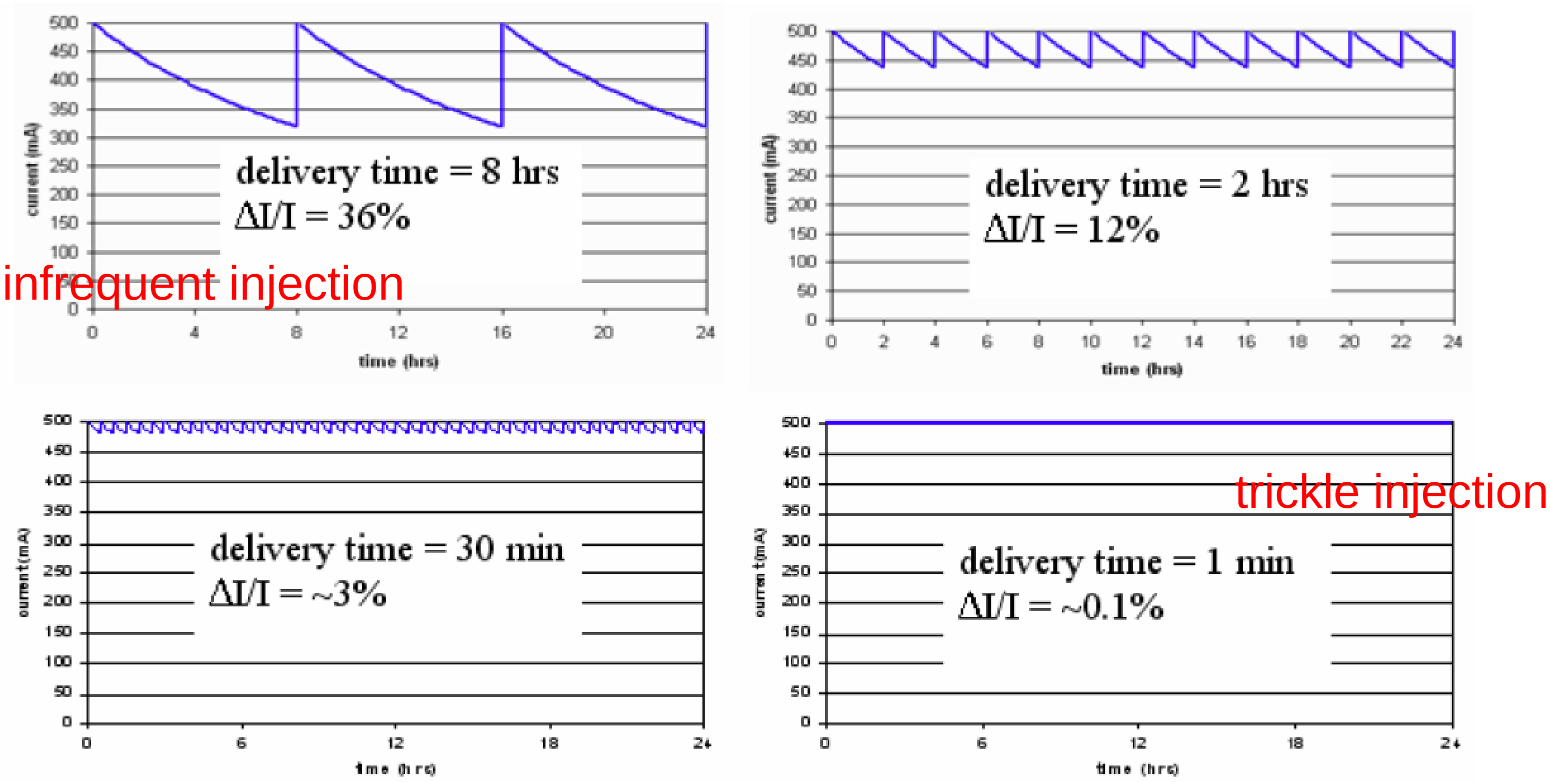
– "Infrequent injection": 3+ times a day

impractical unless IS stay open

– "Trickle injection": up to once every minute ← injector stays on, must stay tuned, high instantaneous charge

At other facilities "top-off" called "top-up"

Top-off, Top-Up, etc. (cont.)



Q = 5 A hr: Higher beam currents → shorter lifetime → higher losses

SSRL Ray Trace Studies

Beam chamber apertures and magnets constrain where beam can go

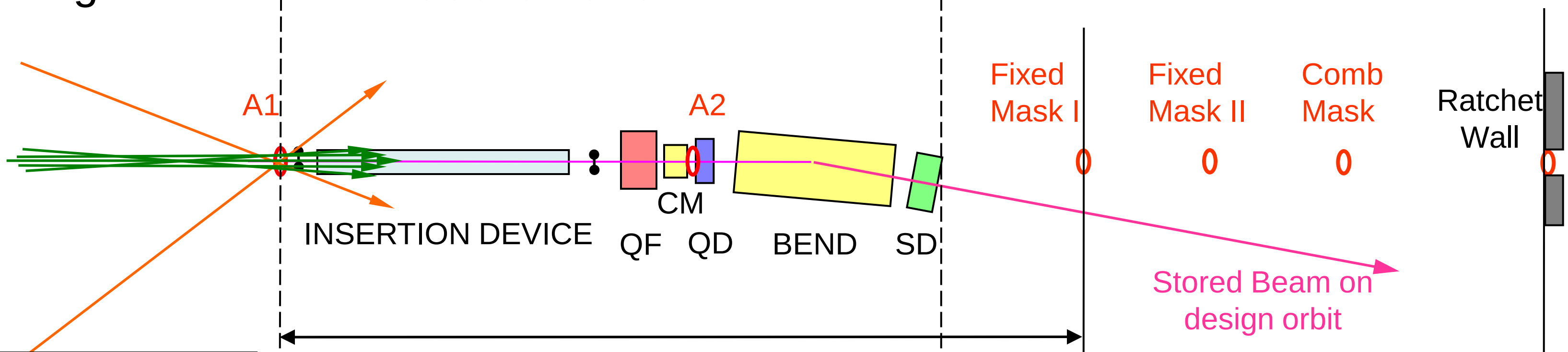
Studies by SSRL (with LBNL) to answer:

- How far towards beamline can injected beam travel with which magnet settings?
- Which magnet settings prevent beam from going past safe endpoints?

Safety Systems designed to keep beam within safe endpoints

SSRL Ray Trace Studies (cont.)

Incoming Beam | Section of SPEAR | Beamline



Region for trajectory simulations

Start Point

Safe Endpoint

Assume all positions and angles are possible

No distinction between stored beam, injected beam on the 1st turn, and injected on subsequent turns

Energy error

Magnetic field in all elements

ID – insertion device + trim coils
BEND – dipole magnet
QF – focusing quadrupole
QD – defocusing quadrupole
CM – horiz. corrector magnet
SD – defocusing sextupole

SPEAR Apertures
Vacuum Chamber
Radiation Masks

No magnetic field

Straight line trajectories

Beamline Apertures
Vacuum Chamber
Radiation Masks

Thanks to A.Terebilo, SSRL

Radiological Considerations

(1) Long-term dose from normal operation:

Additional radiation from:

- forward-angle Bremsstrahlung from injected beam at apertures
- higher beam currents

Based on estimated loss rates: within 1 mSv (100 mrem) per 1000 hr limit

(2) Radiation dose due to mis-steered beam

Within bounds of safety systems,
but such serious mis-steering expected only very rarely

Safety system defines "safety endpoint" that electrons cannot pass

Simulations → up to 22 mSv/h (2.2 rem/h at 5 W) for dipole lines,
~20% less for ID lines – always radiation monitors in place

(3) Radiation due mis-steering with full safety system failure

Should never happen; VERY UNLIKELY; requires several serious failures

Simulations → dose rate high, up to 3.3 Sv/h (330 rem/h) at 5 W for dipole lines, up to 0.13 Sv/h (13 rem/h) for ID lines
but per event (<1 s) 0.74 mSv (74 mrem) with radiation monitors in place

Top-Off Safety Systems

Beam Containment System (BCS):

- Stored Current Interlock: top-off only for >50 mA
- Apertures: may not be modified without approval
- Magnet Power Supply Interlocks: monitoring both current and voltage
- Clearing Magnets: along dipole beamlines (no space for permanent magnets)
- Dose Rate Interlock: radiation monitors tripping at 0.02 mSv/h (2 mrem/h)

Non-BCS Systems:

- Daily Dose Interlock: rad. monitors allow max. 0.01 mSv (1 mrem) per day
- Charge Loss Interlock: allow only certain # e- lost each day
- Additional: Machine protection interlocks and software warnings (tight limits)

First Tests

- April to July 2008
- Interlocked BSOICs next to hutch
- Floor cleared, most data read out remotely:
  - Beam Shut-Off Ion Chambers (BSOIC) SLAC-built
  - Beamline Radiation Monitors HPI 6030/6012
- Access restricted:
  - No access during tuning
  - Electronic “chirping” dosimeters
  - Handheld dose meters

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Beam Conditions for Tests

- High-efficiency injection

(1 W injection, ~60-80% injection efficiency)

- Low-efficiency injection due to BTS mis-tuning

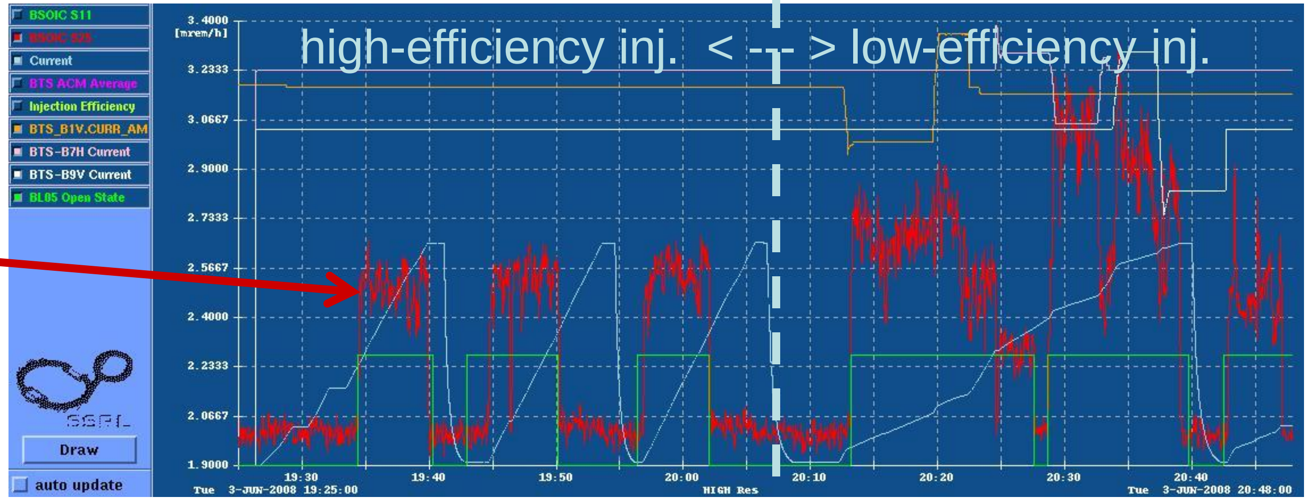
(1 W, ~30-50% injection efficiency)
Losses inside SPEAR ring at apertures

- Zero-efficiency injection

similar results

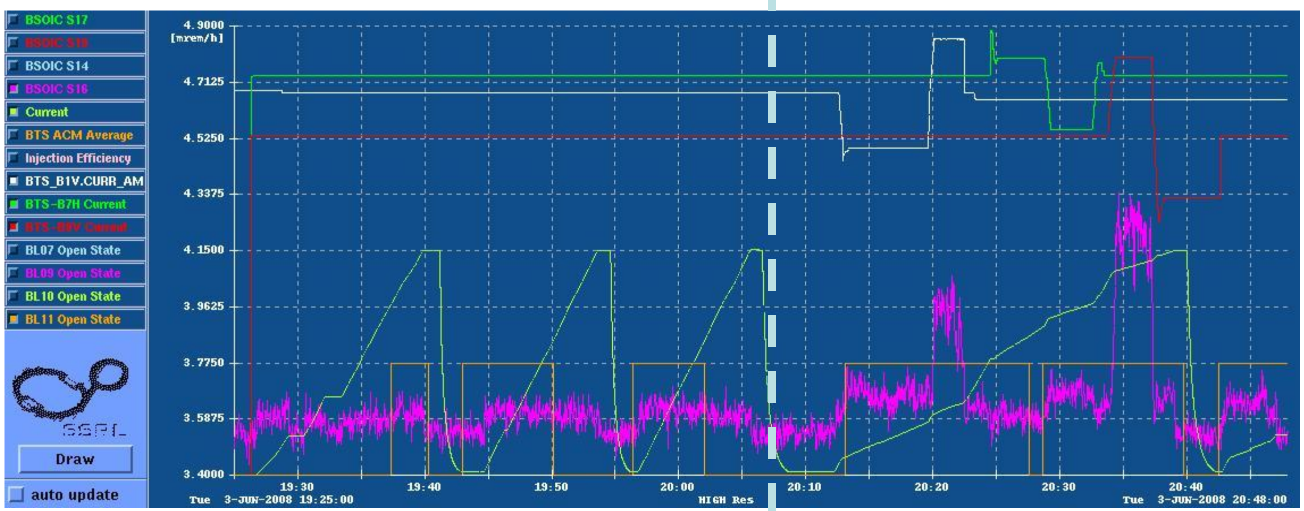
(1 W,   0% injection efficiency)
All of injected beam lost in ring due to “bump” at beamline
(orbit moved towards edge of aperture)

Measurements with Old Injection



BL5
5 microSv/h
(0.5 mrem/h)
already at
high-efficiency
injection

11 microSv/h
(1.1 mrem/h)



injection
current
throughout
0.16 0.04 nA

BL11
radiation only
at inefficient
injection

7 microSv/h
(0.7 mrem/h)

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Measurements with Old Inj. (cont.)

Three "types" of beamlines were found:

1. BL 4, 5:
   Extra radiation seen during both
   high-efficiency injection, up to 18.5 microSv/h (1.85 mrem/h)
   and low-efficiency injection, up to 30 microSv/h (3 mrem/h)
2. BL 10, 11:
   No extra radiation seen during high-efficiency injection,
   but during low-efficiency injection, up to 16 microSv/h (1.6 mrem/h)
3. BL 1, 2, 6, 7, 9:
   No or very little, < 1 microSv/h (< 0.1 mrem/h), extra radiation
   seen during high- or low-efficiency injection

BL 8, 12, 13, 14: Ray trace studies not yet approved; BLs not tested

Dose Extrapolations - Old Injection

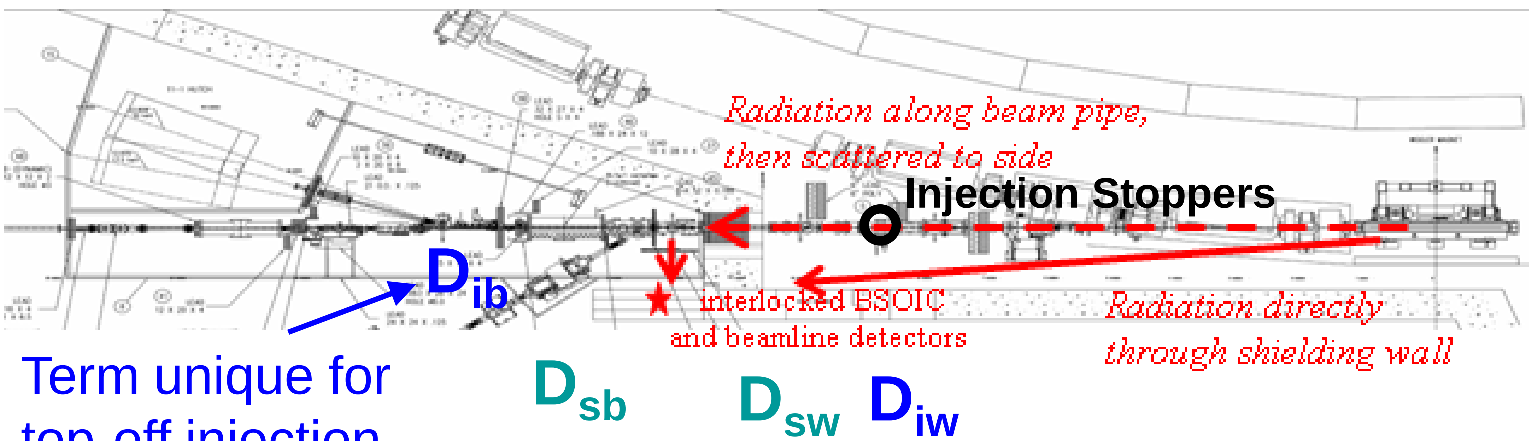
Extrapolations based on measurements & operation scenarios

- No issues for any BL at 100 mA top-off operation

BL	100 mA Infrequent Total dose	
	microSv/1000h	mrem/1000h
BL 1	0	0
BL 2	4	0.4
BL 4	110	11
BL 5	190	19
BL 6	14	1.4
BL 7	10	1
BL 8	Ray trace study not yet approved, BL not tested	
BL 9	3	0.3
BL 10	80	8
BL 11	80	8
BL 12	Ray trace study not yet approved, BL not tested	
BL 13	Ray trace study not yet approved, BL not tested	

Dose Components

Radiation from stored beam (s), injected beam (i), traveling through wall (w), through beam pipe (b)



Dose Extrapolations - Old Injection

Dose components at 500 mA trickle injection

D_{ib} high for BL 4, 5, 10

D_{sb} high for BL 4, 5, 11

lower with new injection

	Dose components at 500 mA trickle injection in mSv/1000h and mrem/1000h									
BL	D_{ib}		D_{iw}		D_{sb}		D_{sw}		Total	
BL 1	0	0	0	0	0	0	0.01	1	0.01	1
BL 2	0	0	0	0	0	0	0.1	10	0.10	10
BL 4	0.93	93	0.02	2	1.32	132	0.06	6	2.33	233
BL 5	2.34	234	0.14	14	1.07	107	0.06	6	3.62	362
BL 6	0.05	5	0.05	5	0.18	18	0.02	2	0.30	30
BL 7	0.05	5	0	0	0	0	0.18	18	0.23	23
BL 8	Ray trace study not yet approved, BL not tested									
BL 9	0	0	0	0	0.08	8	0	0	0.08	8
BL 10	0.94	94	0.01	1	0.32	32	0	0	1.27	127
BL 11	0.15	15	0.04	4	1.66	166	0.08	8	1.93	193
BL 12	Ray trace study not yet approved, BL not tested									
BL 13	Ray trace study not yet approved, BL not tested									

Stored beam dose measured with GM/BF_3 detector

Requires additional shielding for higher currents

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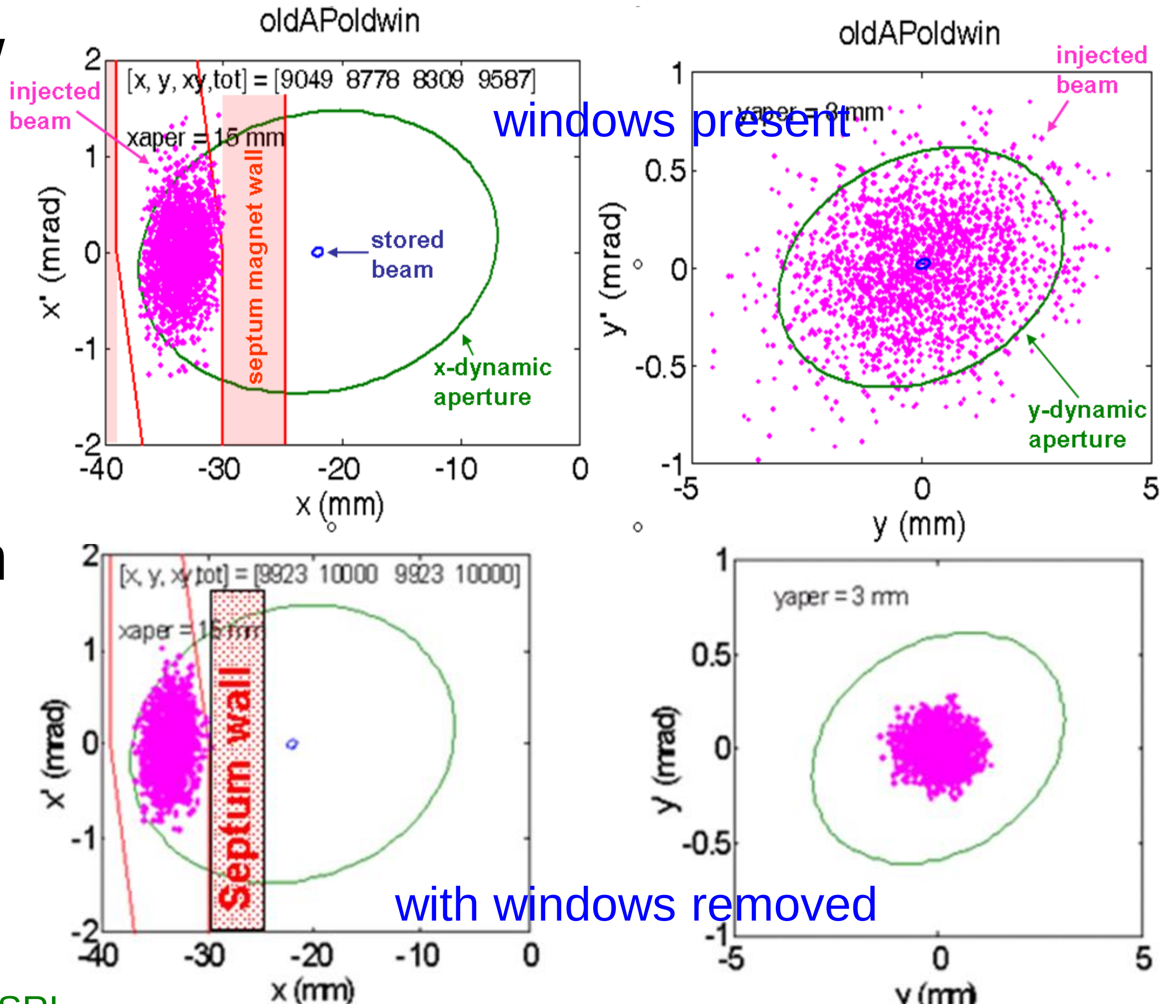
SSRL Improvements to Injection

Injection system was adequate up to now;
top-off raised the bar, and SSRL responded

- Studied changes in x, y, x’, y’, energy, timing, optics of injected beam
- New diagnostics added
- Better control of trajectory and optics (computer monitoring, frequent checks)
- Removal of windows in BTS line:
  Now one vacuum system from Linac to SPEAR

SSRL Improvements to Injection (cont.)

- Simulations show big improvement
  - very clear in y and y' distributions of injected beam
  - injection efficiency 83% → 99% in simulation
- Similar simulation for optics
- Measured radiation doses went down



Thanks to J.Safranek, X.Huang, SSRL

Measurements with New Injection

- Repeat with improved injected beam (fall 2008)
- Measurements during high-efficiency injection

The four worst BLs before! →

BL 4:	1.2	microSv/h	0.12	mrem/h
BL 5:	1.6	microSv/h	0.16	mrem/h
BL 10,11:	0	microSv/h	0	mrem/h

Dose rates about 10 times lower than before!

Worst 1.6 microSv/h (0.16 mrem/h) extrapolated to 1000 hour/year:

D_{ib} = 5 microSv (0.5 mrem) for 100 mA infrequent injection
56 microSv (5.6 mrem) for 500 mA infrequent injection
92 microSv (9.2 mrem) for 500 mA trickle injection

(was 2.34 mSv or 234 mrem before)

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Dose Extrapolations - New Injection

Dose components at 500 mA trickle injection

D_{ib} now low!

No effects on D_{sb} (to be improved by shielding; reduction to 1/10 for higher current operation)

	Dose components at 500 mA trickle injection in mSv/1000h and mrem/1000h									
BL	D_{ib}		D_{iw}		D_{sb}		D_{sw}		Total	
BL 1										
BL 2										
BL 4	0.07	7	0.02	2	1.32	132	0.06	6	1.47	147
BL 5	0.09	9	0.14	14	1.07	107	0.06	6	1.36	136
BL 6										
BL 7										
BL 8	Ray trace study not yet approved, BL not tested									
BL 9										
BL 10	0	0	0.01	1	0.32	32	0	0	0.33	33
BL 11	0	0	0.04	4	1.66	166	0.08	8	1.78	178
BL 12	Ray trace study not yet approved, BL not tested									
BL 13	Ray trace study not yet approved, BL not tested									

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Measurements with New Inj. (cont.)

- Injection with low efficiency

BL4:	1.2 microSv/h	0.12 mrem/h
BL5:	4.8 microSv/h	0.48 mrem/h
BL10:	0.9 microSv/h	0.09 mrem/h
BL11:	0.6 microSv/h	0.06 mrem/h

Again lower dose rates than before

Worst 4.8 microSv/h extrapolated to 1000 hour/year

D_{ib} = 2.8 mSv (280 mrem) at 500 mA trickle injection

(50 min to reach 100 mA)

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Summary of Test & Path Forward

- Tests taught us:
  - Improved injection well enough even for 500 mA trickle injection
  - No long-term dose rate concerns for 100 mA (June 2009)
- More beamlines will be added over time
- For top-off up to 200 mA (July 2009)
  - Warning system for injection beam lattice and optics
  - Daily Dose Interlock
  - Charge Loss Interlock
- For > 200 mA (stored beam issue) (Fall 2009)
  - Additional shielding for BL4, 5 and 11
  - Mitigation systems for BL thermal damage issues
- Review for trickle charge injection (beyond 2009) & injector upgrade (>1.5 W)

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Conclusions

- Tests very interesting:
  higher dose rates measured than expected
- SSRL was able to improve injection system
- With improvements top-off o.k. even
  for 500 mA trickle injection
- Stored-current dose needs to be addressed for >200 mA
- Top-off will start soon, later going to higher currents