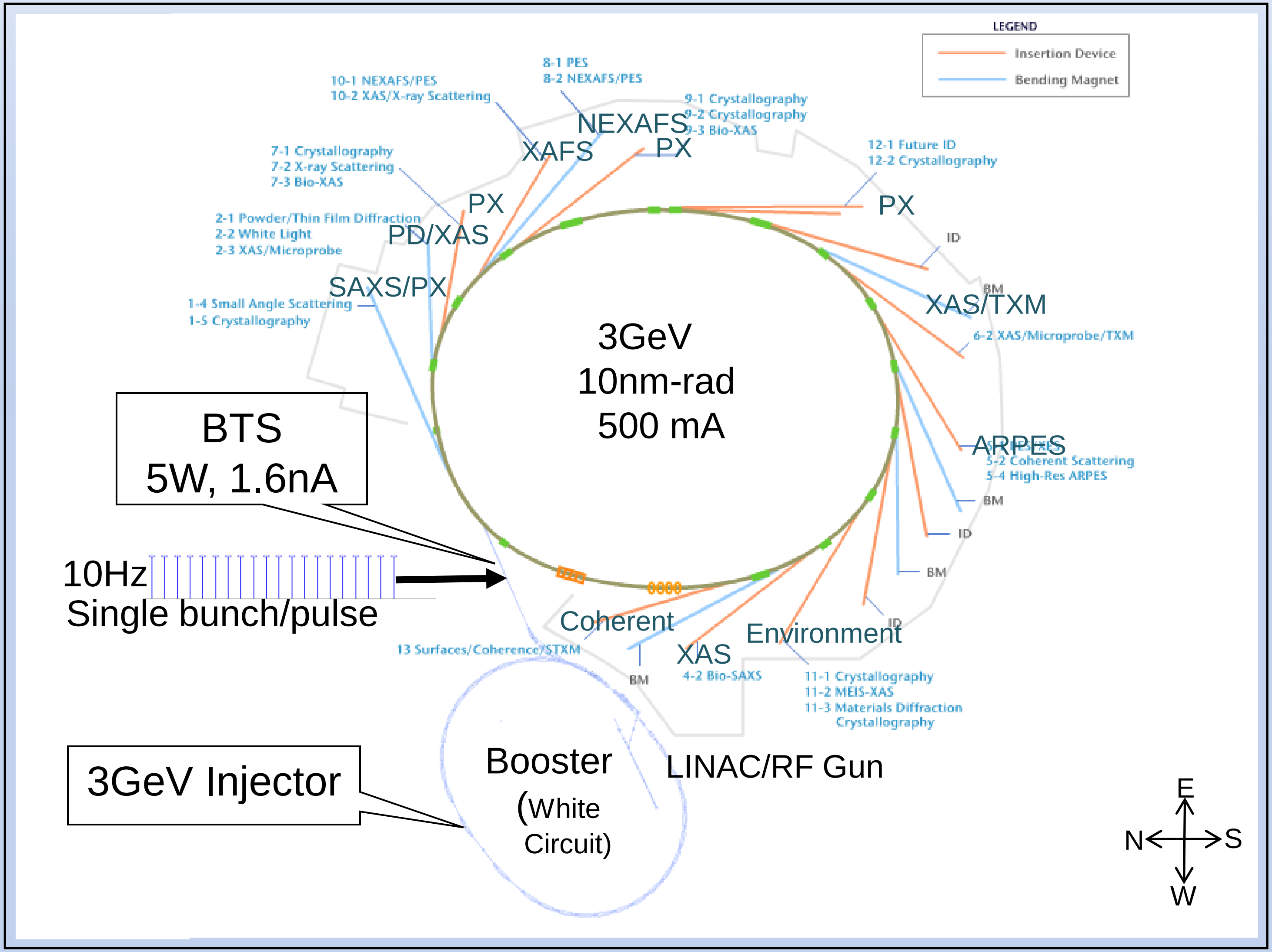
Top-Up Experience at SPEAR3

Contents

SPEAR3 Accelerator Complex



Top 'off' at SPEAR3

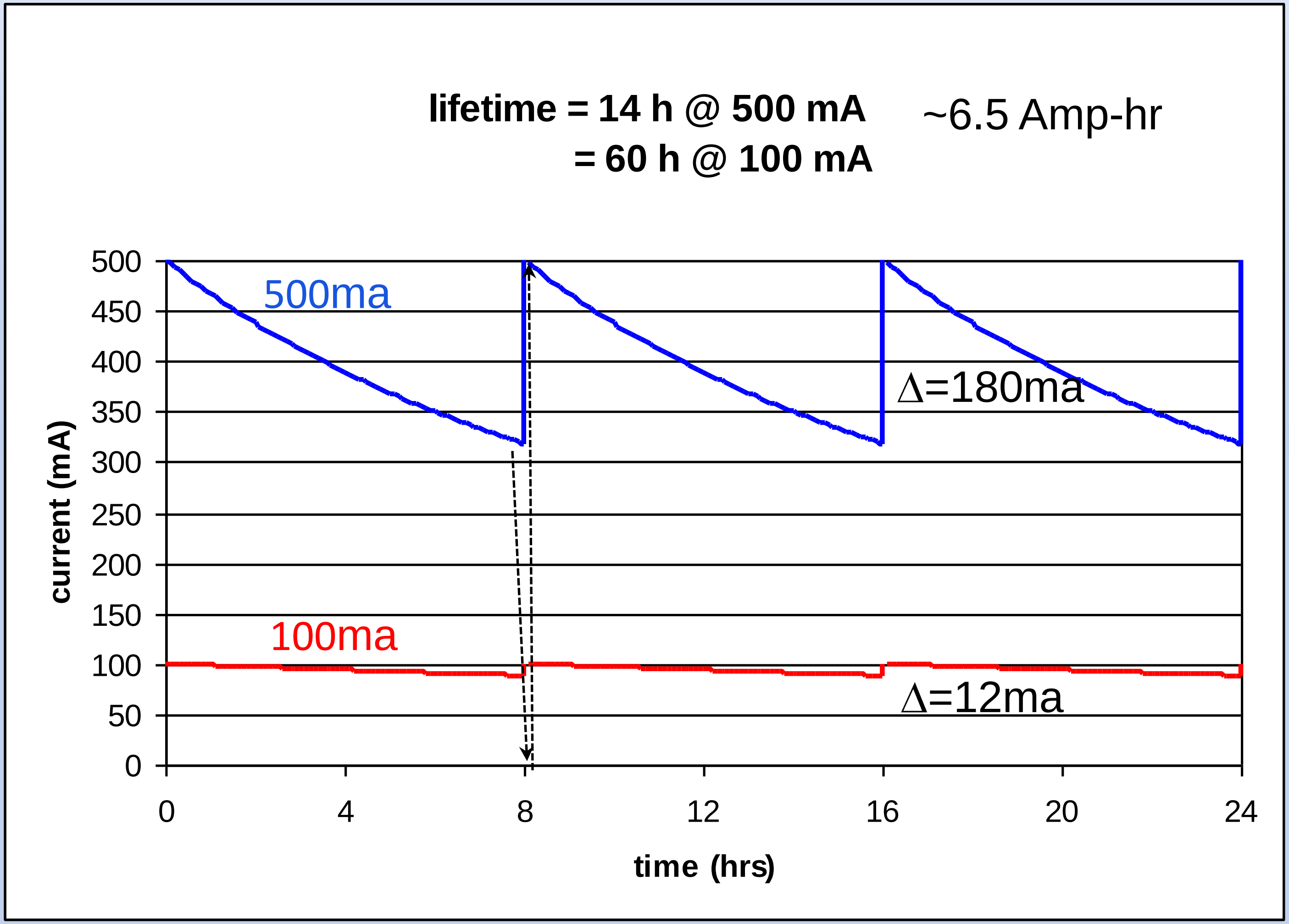
- o Rebuild SPEAR into SPEAR3 (1999-2003)
- o Operated at 100mA for ~6 years (beam line optics)
- o Recently increased to 200mA
- o Chamber components get hot at 500ma (450kW SR, impedance)
- o 500mA program suspended because of
  power load transient on beam line optics
- o Instead worked to top-off mode (beam decay mode, fill-on-fill)

RF system and vacuum chamber rated for 500ma

Present Status

- 13 exit ports taking SR (9 Insertion Device, 4 Dipole)
- 7 ID ports presently in ‘fill-on-fill’ open shutter mode
- 4 dipole beam lines open shutter injection by end of October 2009
- Last two ID shutters fill-on-fill by June 2010
- Trickle charge 2011

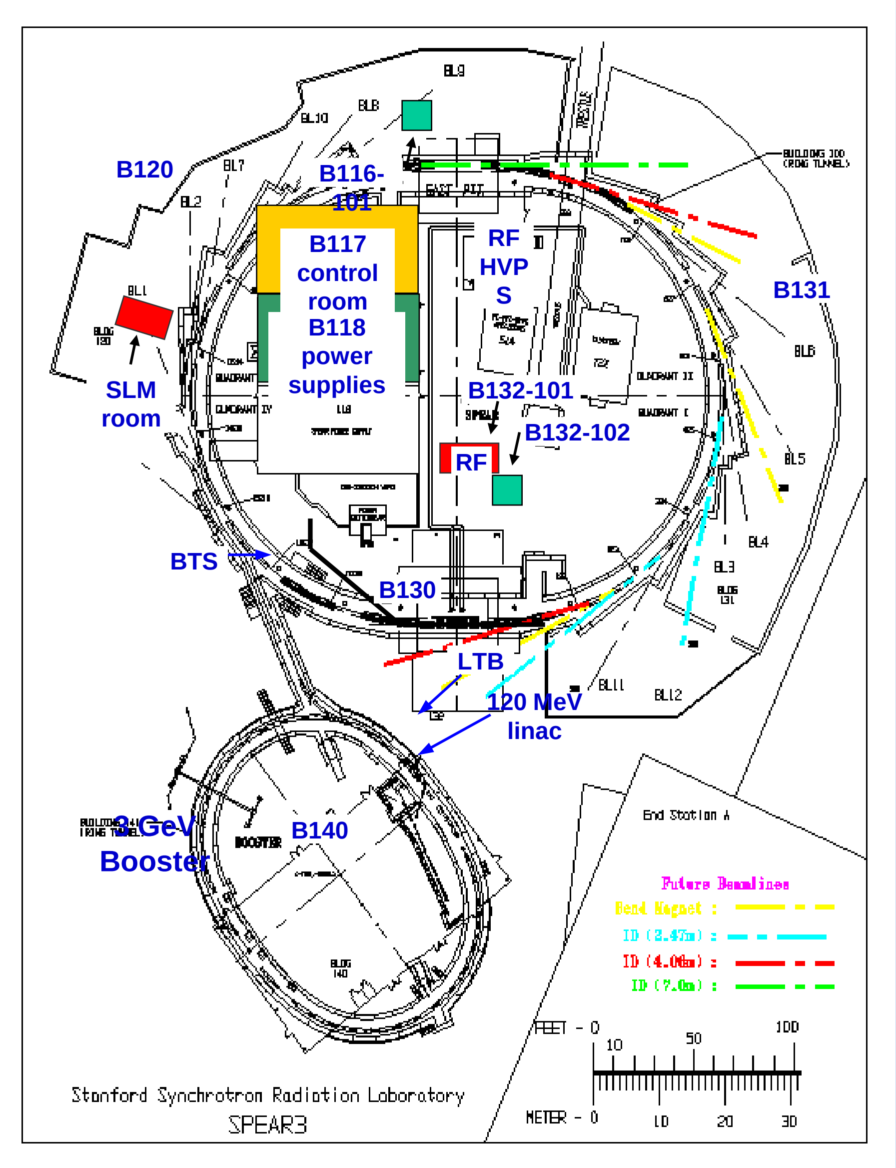
100mA and 500mA Operation



500mA Injection Scenarios

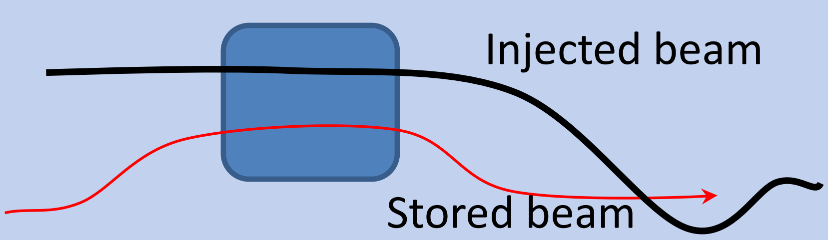
Hardware Upgrades

- **Gun**
  - o higher current
  - o stablize emission rate
  - o “laser-assisted” emission
- **Linac**
  - o restore 2nd klystron
    (higher energy, feedback)
  - o phase-lock linac and booster rf
- **Booster**
  - o improve capture with modified lattice
  - o improve orbit and tune monitors
  - o develop fast turn-on mode
- **BTS**
  - o eliminate vacuum windows (done)
  - o diagnostics
- **SPEAR**
  - o add shielding, interlocks
  - o improve kicker response
  - o transverse feedback
- **Beamlines**
  - o add shielding, interlocks
  - o timing

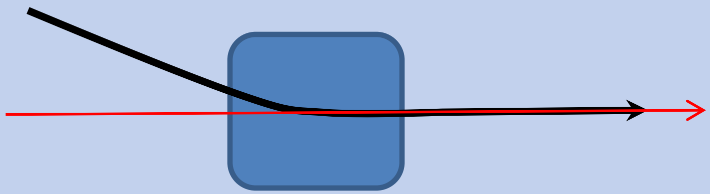


SPEAR3 Injection Notes

- Vertical Lambertson septum (booster outside ring)
  - operates DC, skew quadrupole added
- Three magnet bump
- ~15 mm amplitude, ~12mm separation
- Injection across three cells (sextupoles)
- Slotted stripline kickers (DELTA, low impedance)
- Transverse field dependence in K2



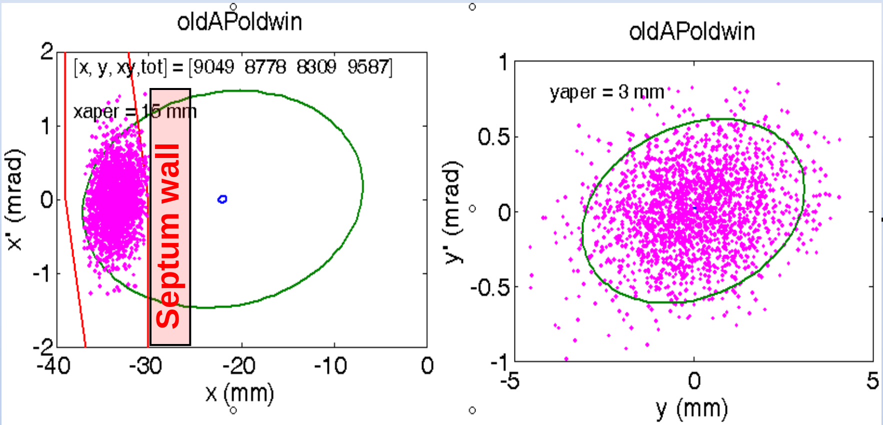
Plan view



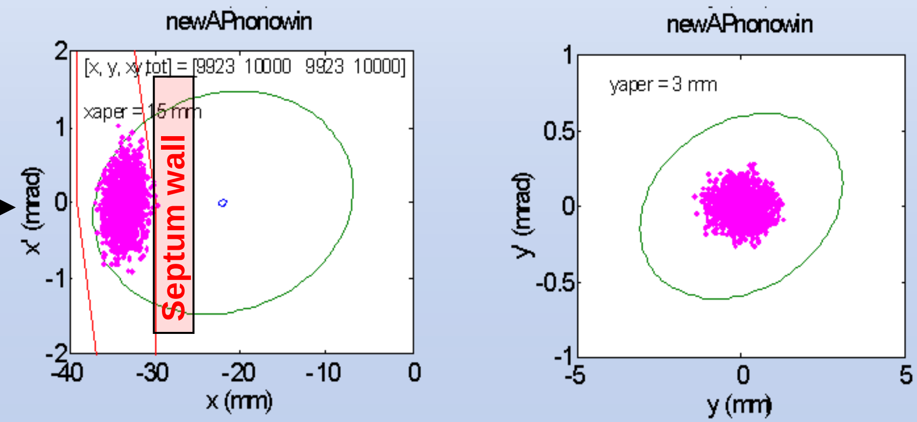
Elevation view

Hardware Upgrade: BTS Windows

With windows: ~20% beam loss



No windows: ~no loss

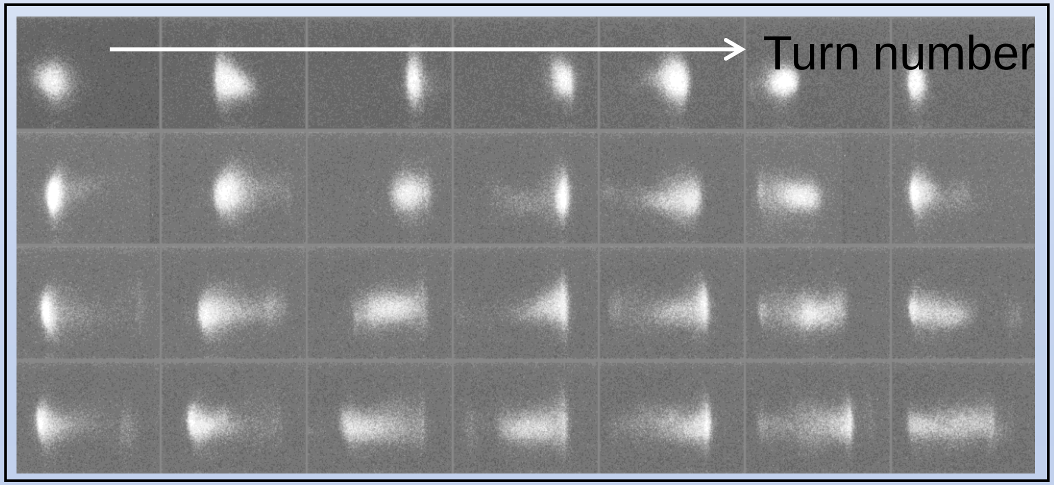


old BTS: rough vacuum + windows

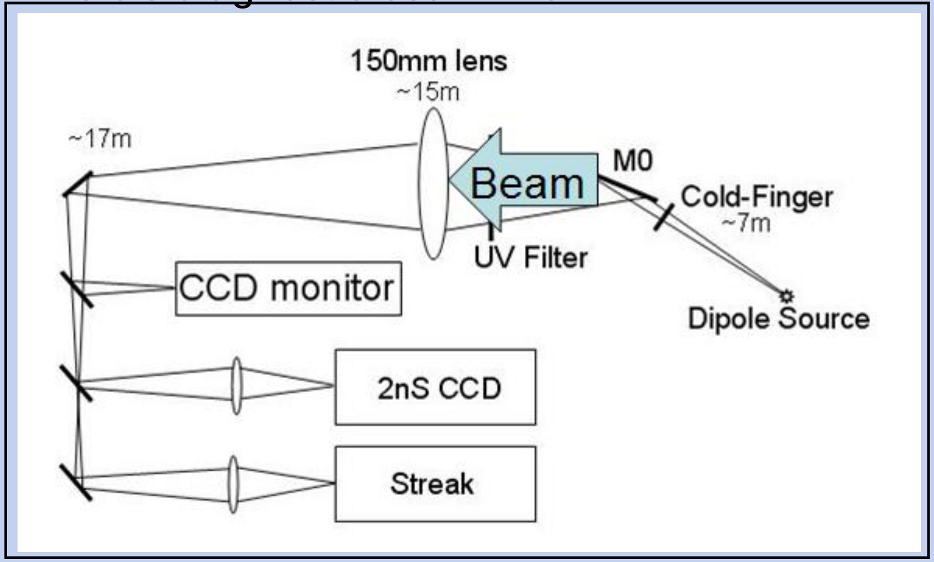
new BTS: high vacuum + no windows

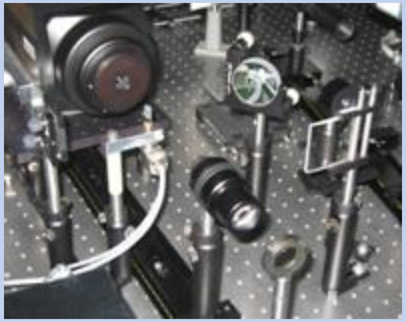
Huang & Safranek

Injected beam profile measurements



Visible diagnostic beam line

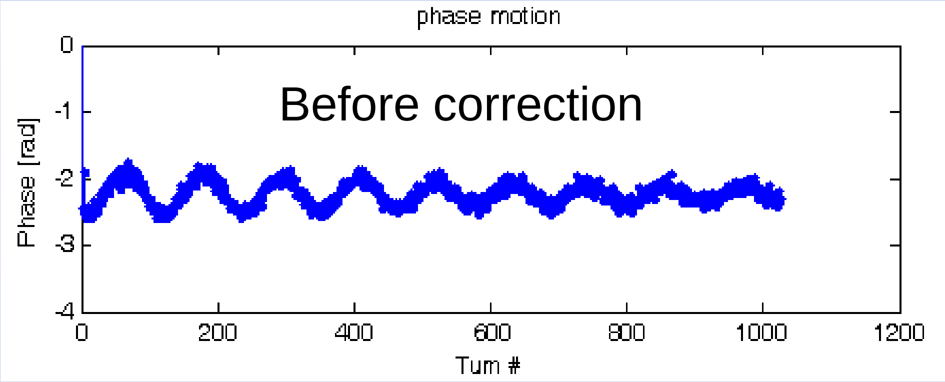


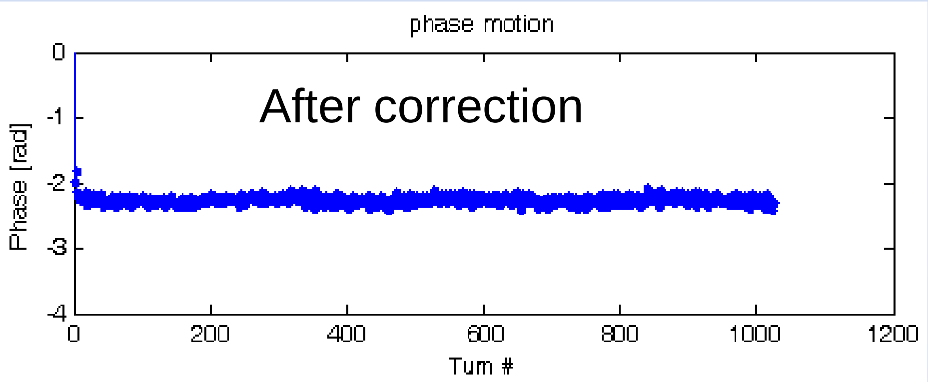


Movies…

Hardware upgrade: Injection Timing and Energy

- Synchrotron oscillations measured with turn-by-turn BPMs:



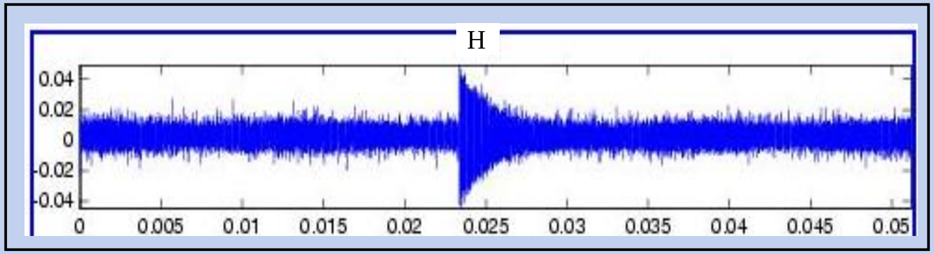


- Kickers set to dump injected beam each cycle
- Injection energy stable
- Injection time varies over hours
  - RF cable temperature
- Develop method to measure timing with stored beam

Huang, Safranek & Sebek

Hardware upgrade: Injection Bump Closure

- Kickers can interrupt data acquisition
  - o What is interruption sequence?
    - depends on current ripple, beam lifetime and charge/shot
    - bunch train filling needs new booster RF system
  - o Gated data acquisition



Single shot

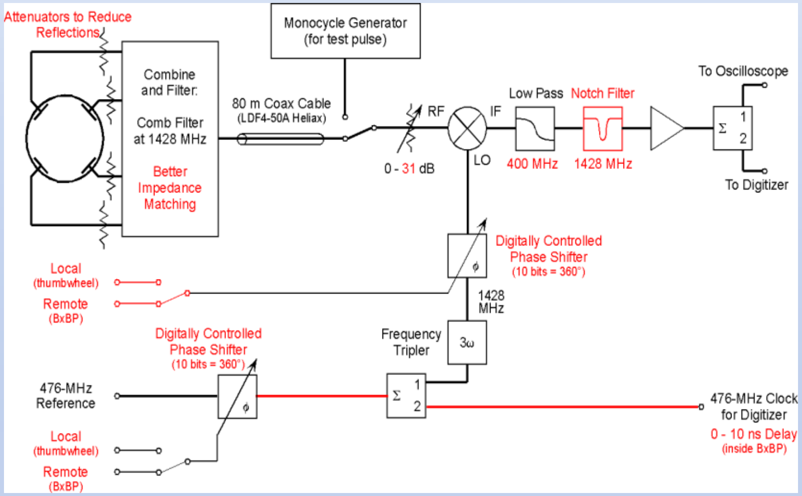
injection kicker transient = ~10 ms

(~0.1 ms with feedback)

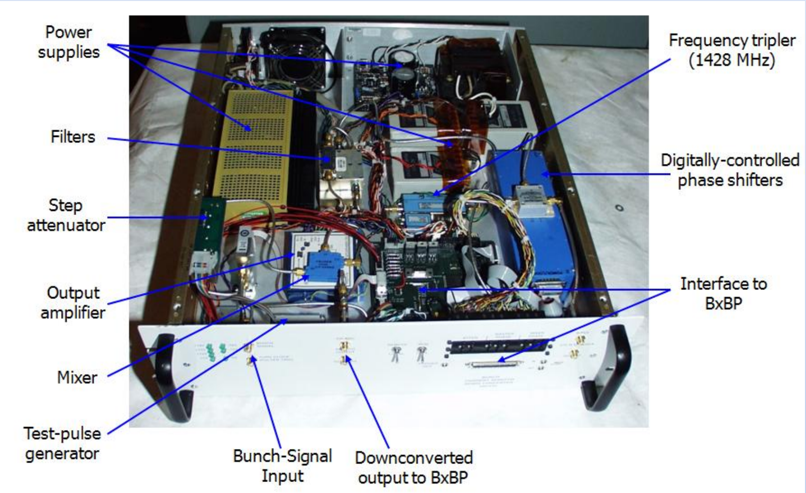
  - o Tests with beam lines ➔ no complaints
  - o Lots of work to match kicker waveforms

Hardware Upgrade: PEP-II Bunch Current Monitor

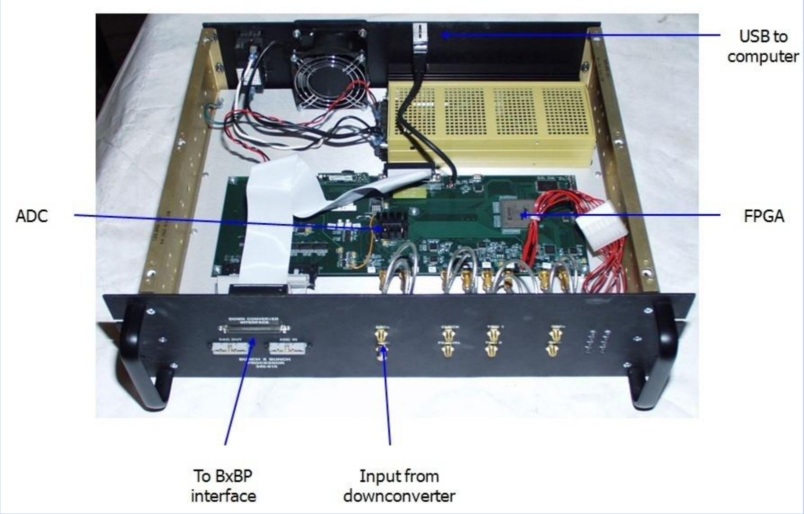
downconverter schematic



downconverter chassis



bunch-by-bunch processor chassis

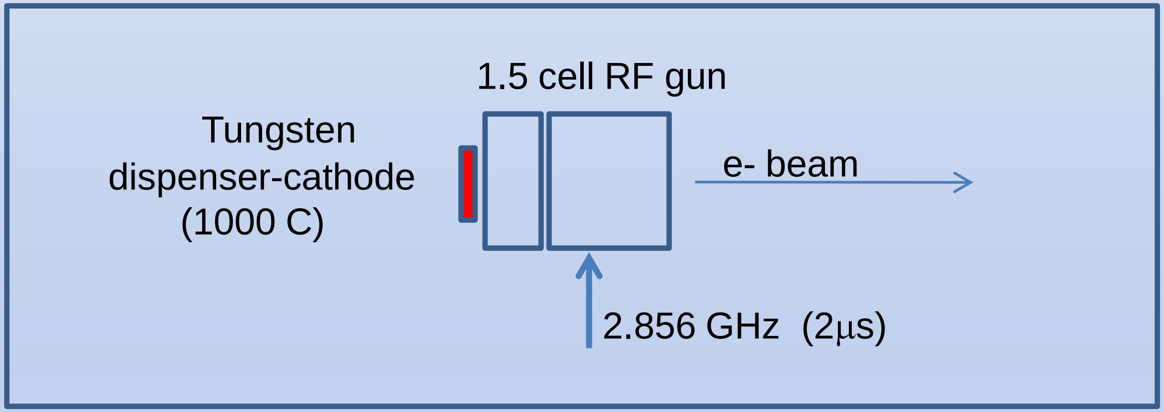


- visible APD (ASP)
- x-ray APD (CLS)

A.S.Fisher

Hardware Upgrade: Thermionic Cathode as a Photo-Emitter

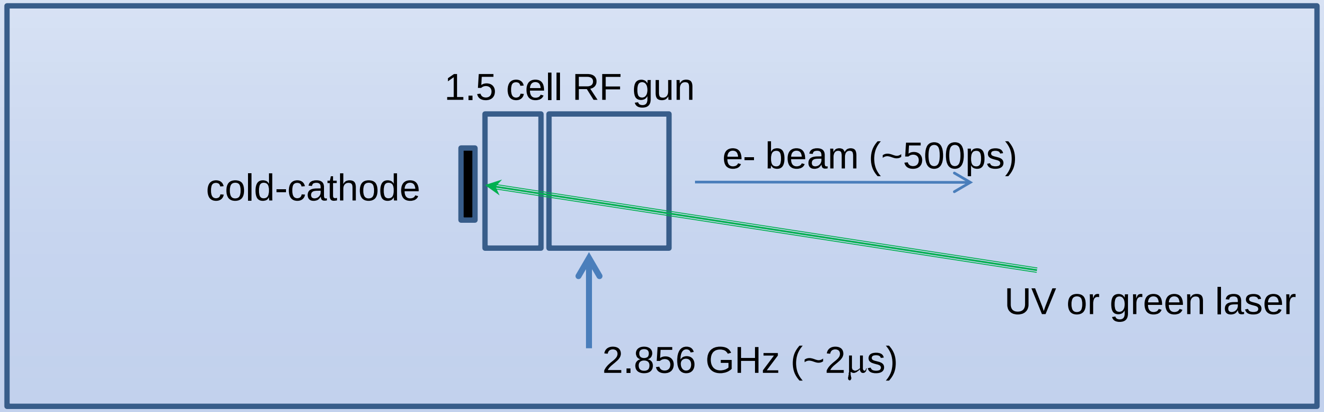
Nominal configuration

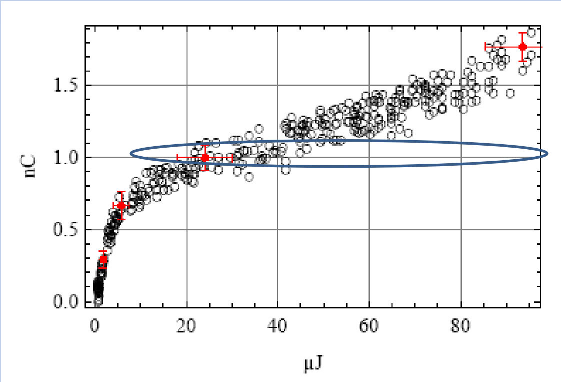


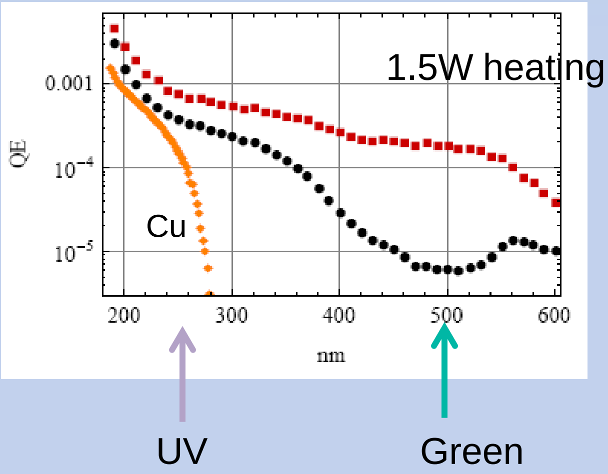
- ► S-band RF gun with thermionic cathode, alpha magnet, and chopper
- ► Most charge during the 2 *μs* RF pulse stopped at the chopper
- ► 5-6 S-band buckets pass into the linac, single booster bucket
- ► SPEAR3 single bunch injection, 10Hz presently ~50pC/shot

Photo-emission cathode (cont'd)

Laser-driven configuration







S.Gierman

► high singe-bunch charge for top-off
- reduce beam loading in linac
- eliminate cathode back bombardment
- eliminate chopper

Sara Thorin/MAXLab, EPAC'08
'Turning the thermionic gun into a photo injector has been very successful '

The Injected Beam Safety Dilemma

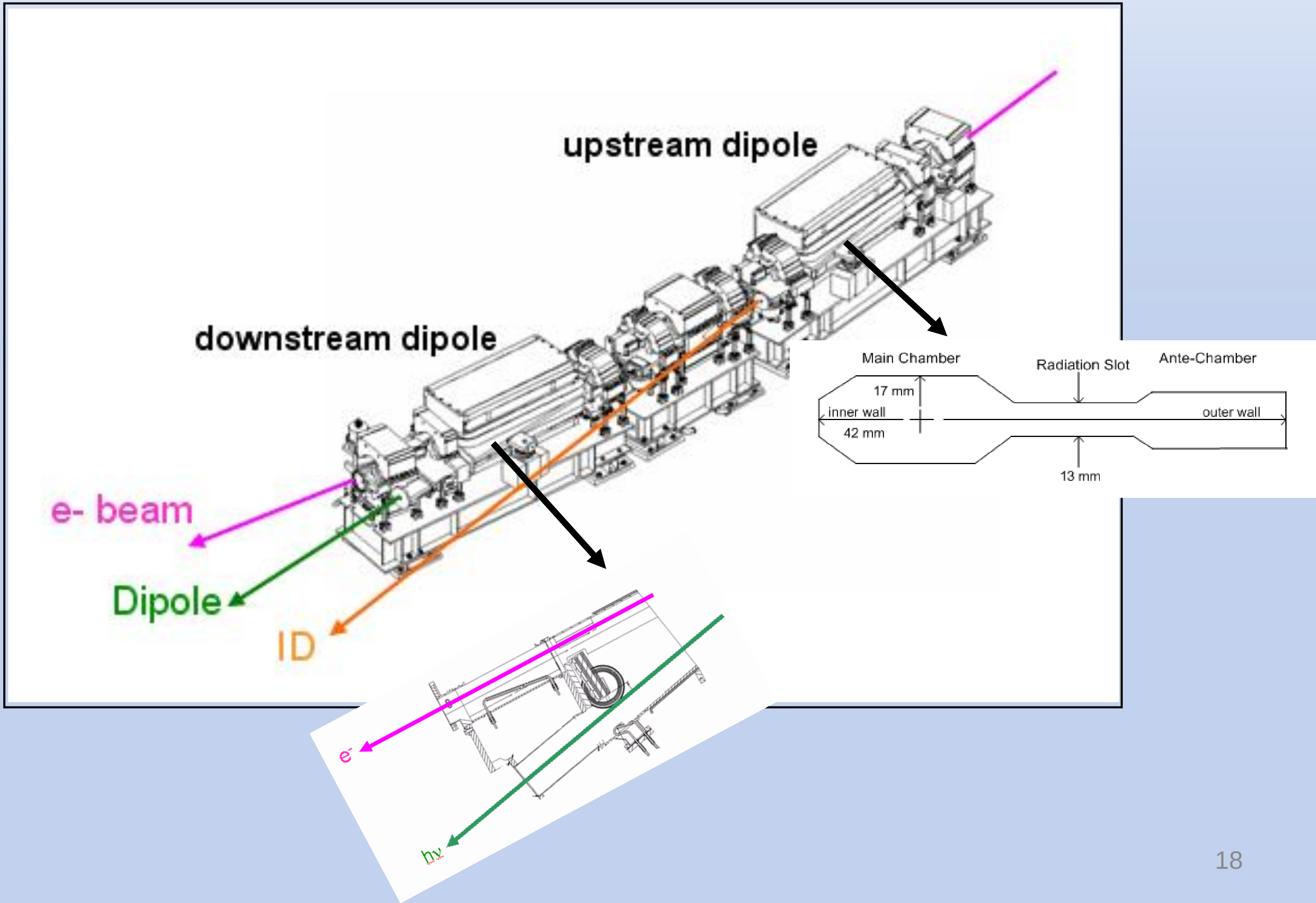
- Radiation Safety: the first hurdle
  - o AP studies to demonstrate injected beam can not escape shielding
  - o Many clever scenarios (dreams and zebras)
  - o BL shielding sufficient? (higher average current, more bremsstrahlung)
  - o PPS/BCS interlock modifications
  - o Do users wear badges?

- Efficient injection into main ring
  - o Injection time, charge/shot, repetition rate

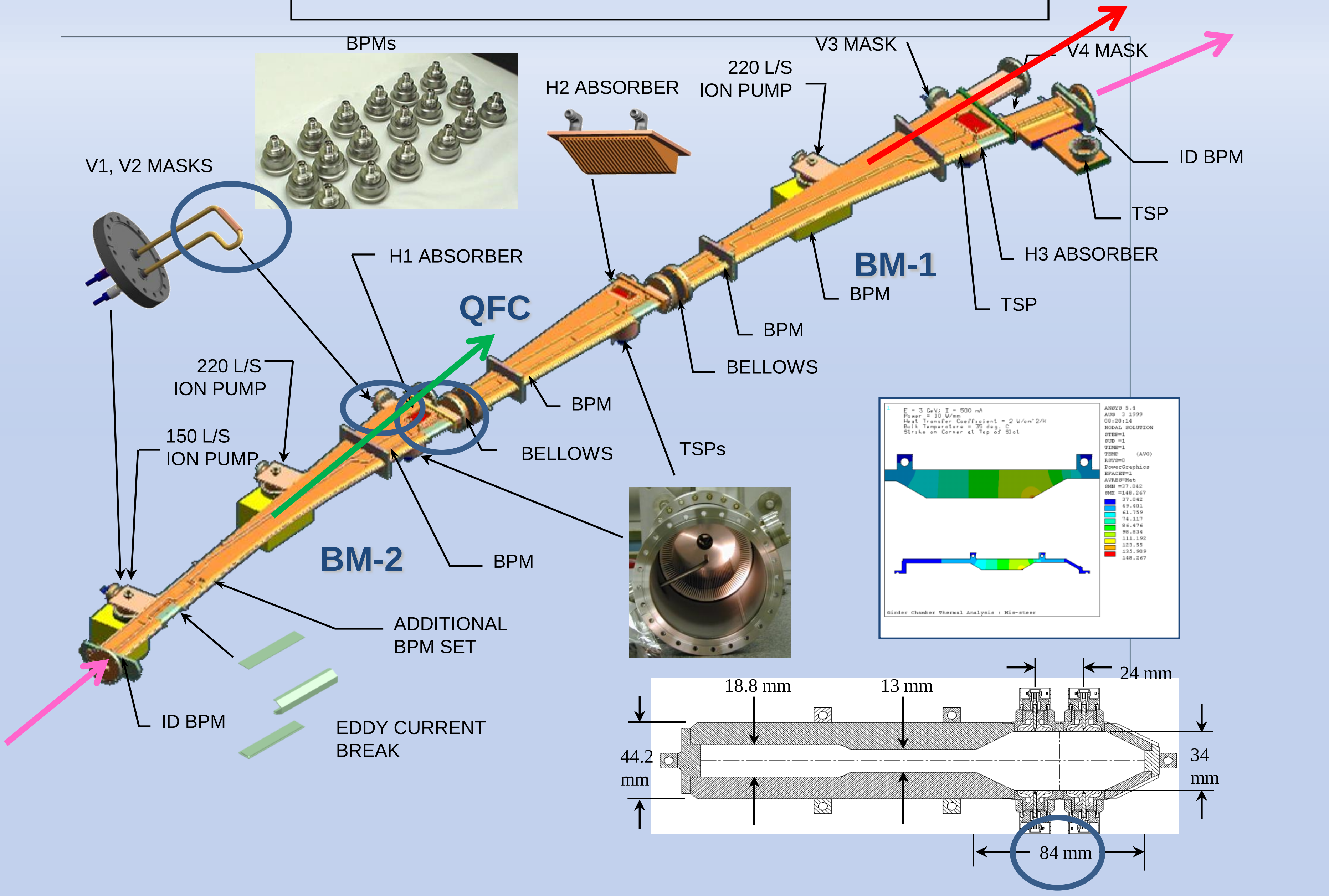
Safety is complicated!

Synchrotron Radiation Exit Ports

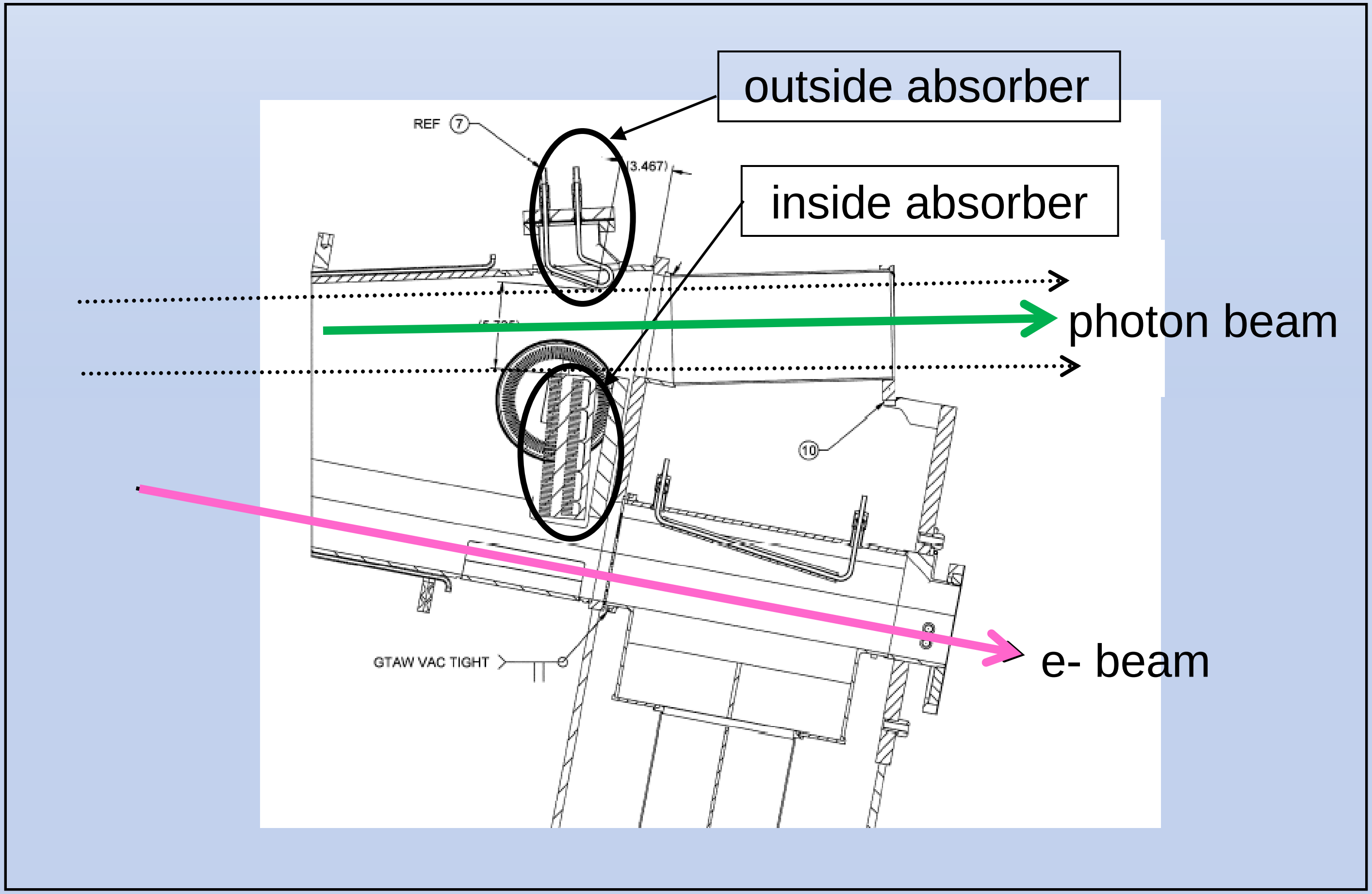
SPEAR3 DBA cell



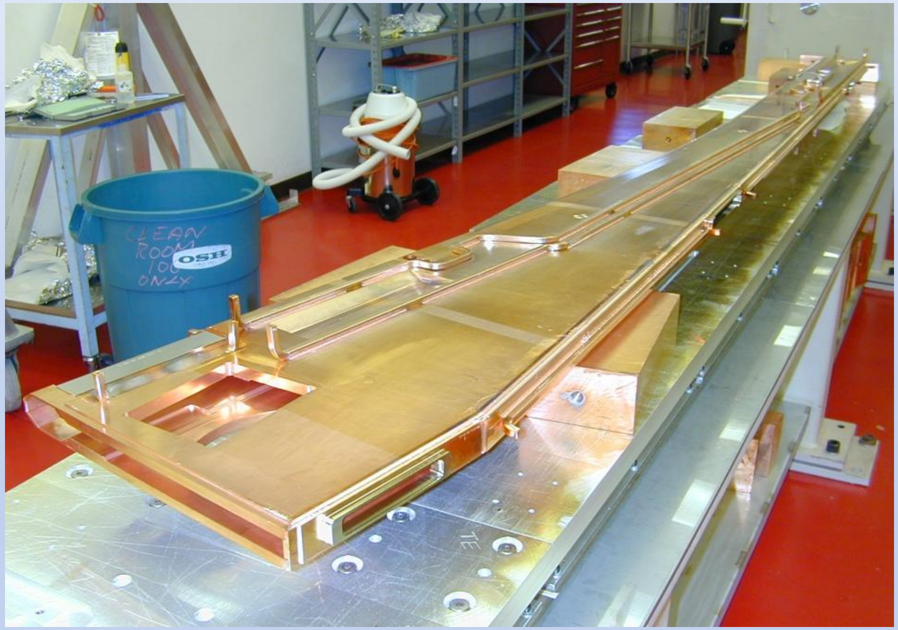
Vacuum Chamber Construction

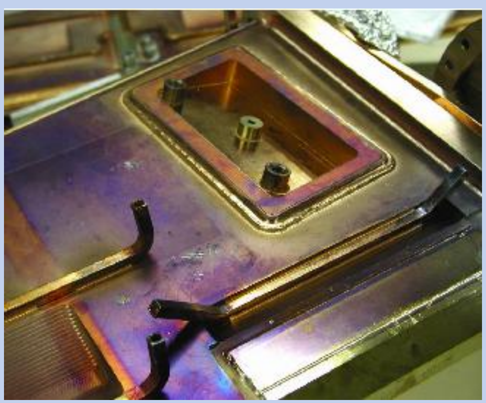


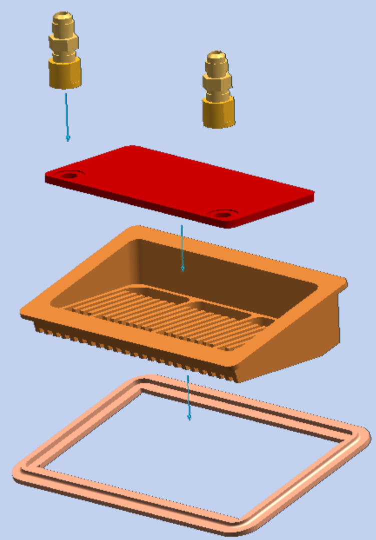
Photon Beam Exit Channel



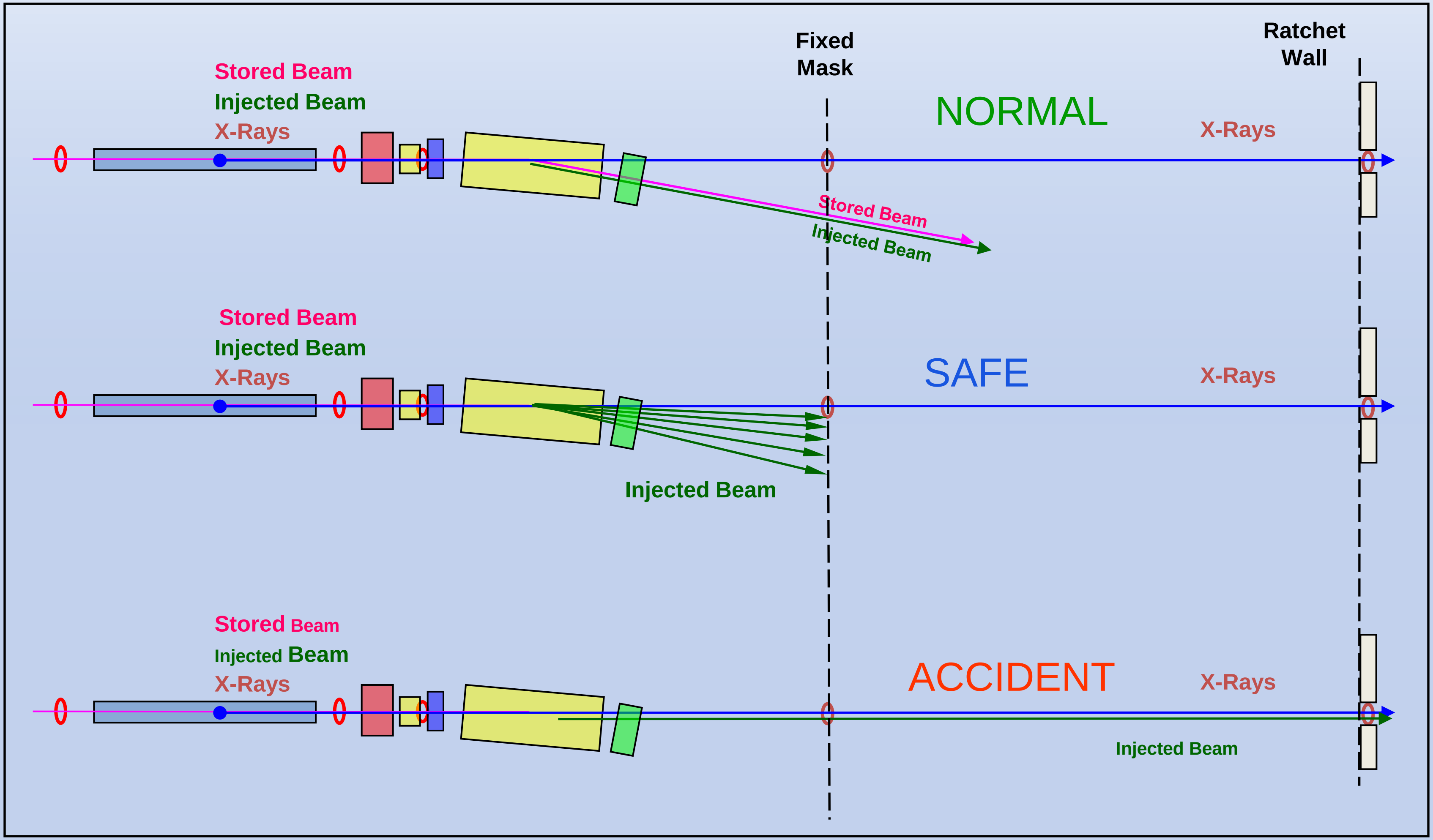
A Closer Look…



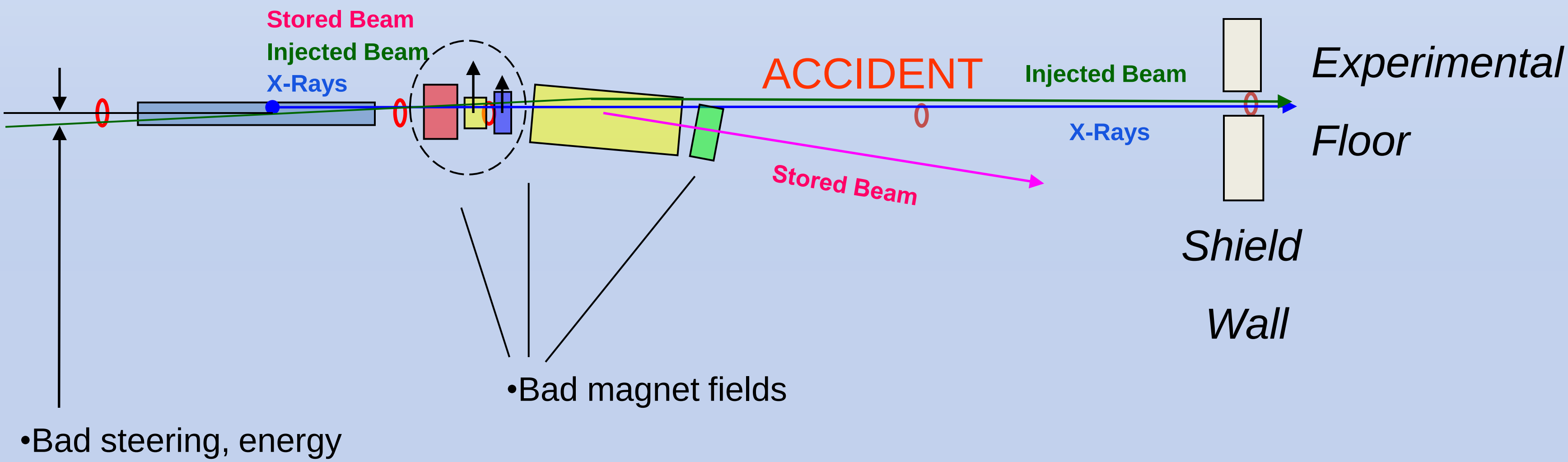




Top-Up with Safety Shutters Open



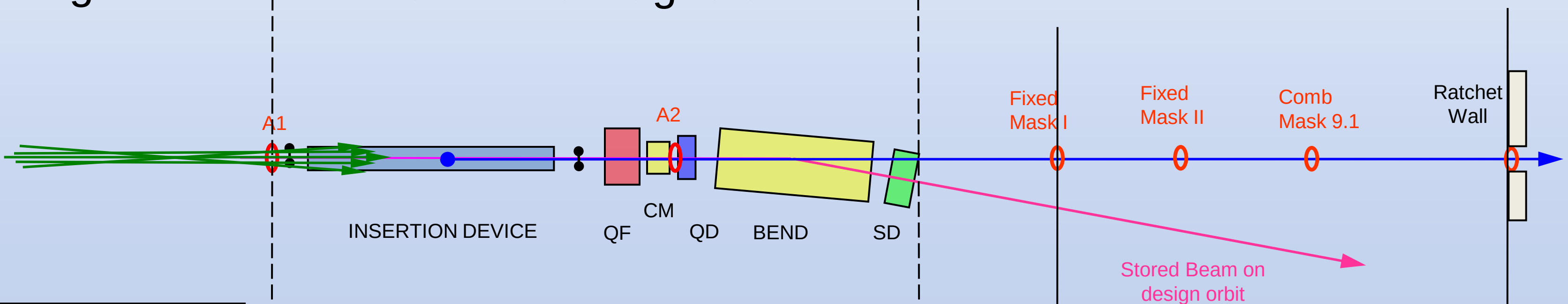
Is this a real possibility?



Simulation is necessary!

SSRL Approach to Calculations

Incoming Beam | SPEAR3 Magnets | Beamline

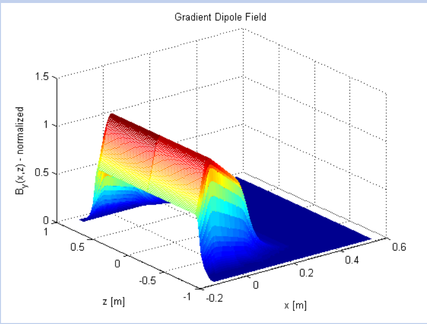


Field simulation region

Start Point

Safe Endpoint

- No assumptions about initial steering
- All physical positions and angles possible
- Energy errors!



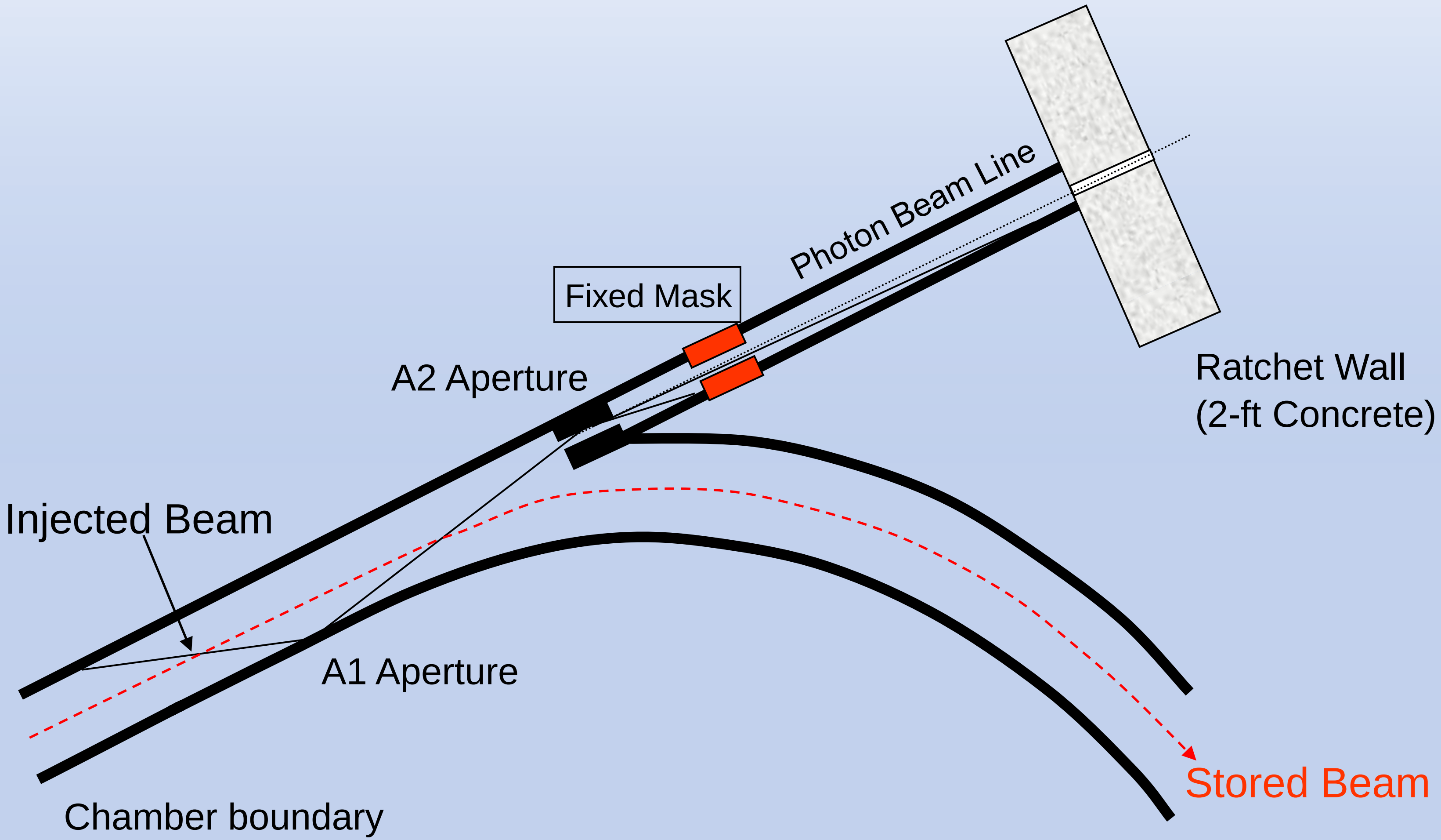
- Wide fringe fields

- No magnetic field
- Straight trajectories

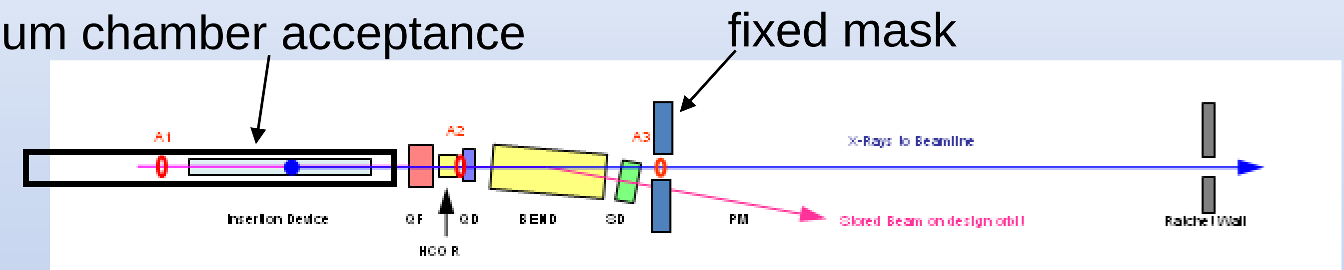
Beamline Apertures
Vacuum Chamber
Radiation Masks

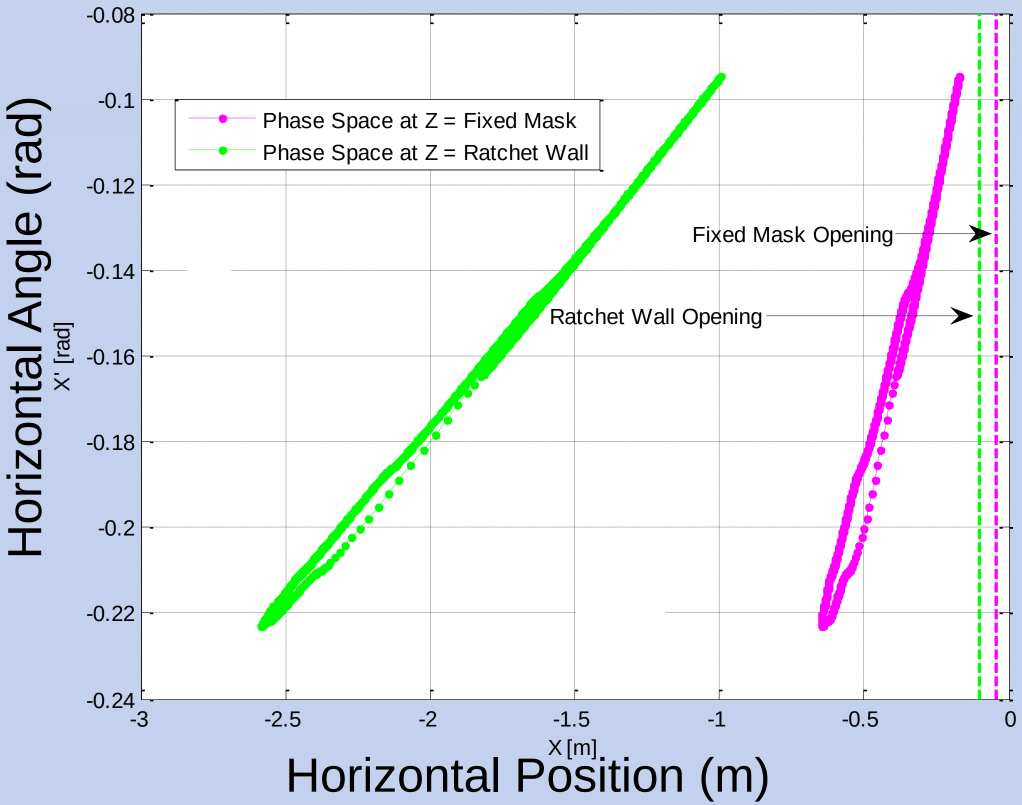
A.Terebilo

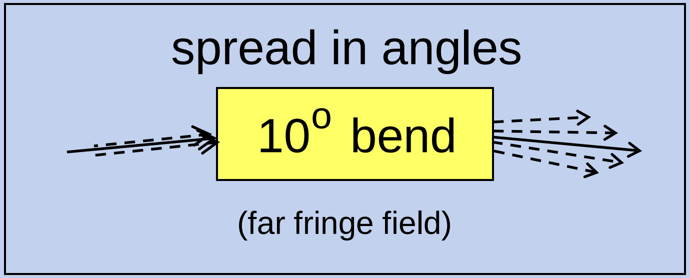
Forward Propagation Only



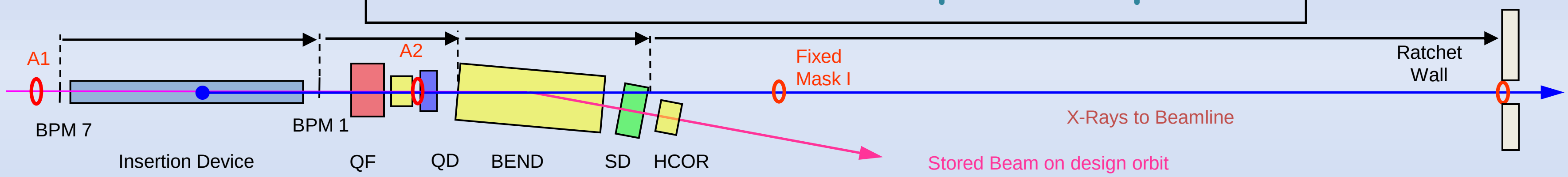
Trajectories in Phase Space

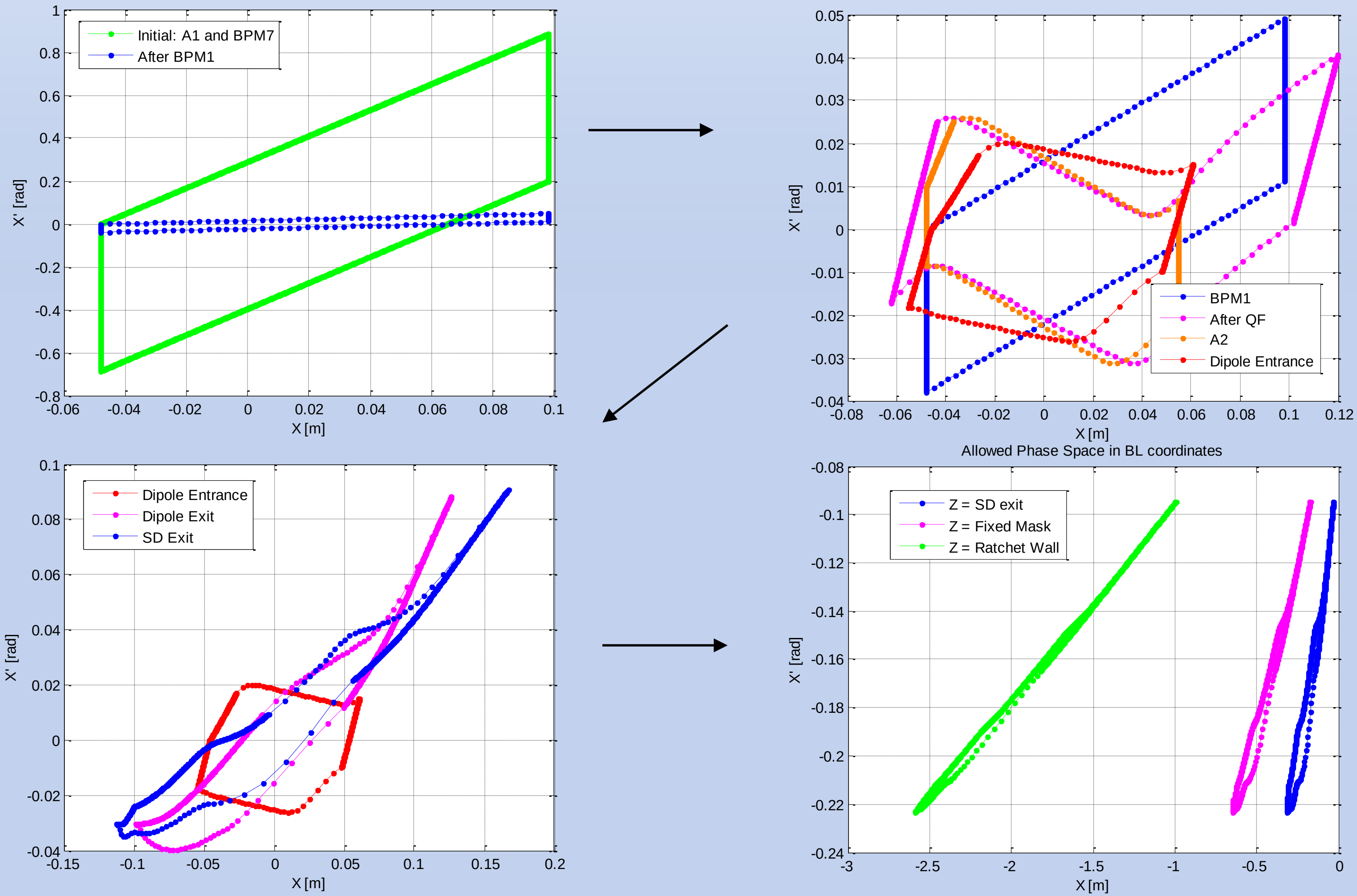




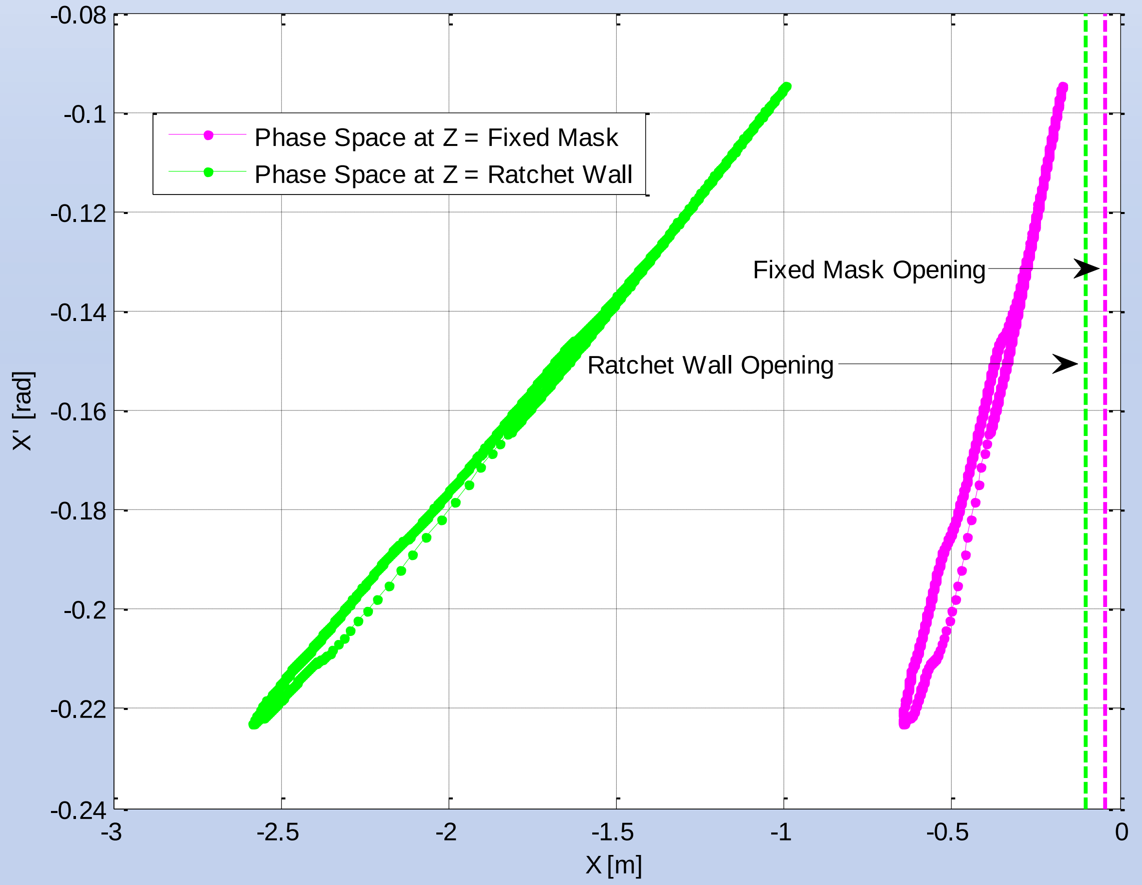


Evolution of allowed phase space

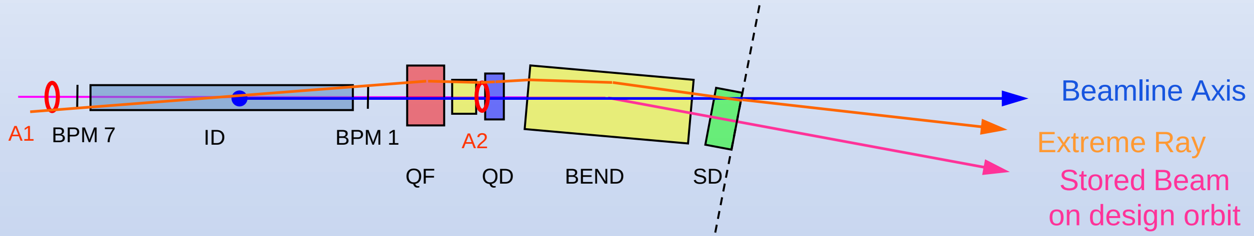


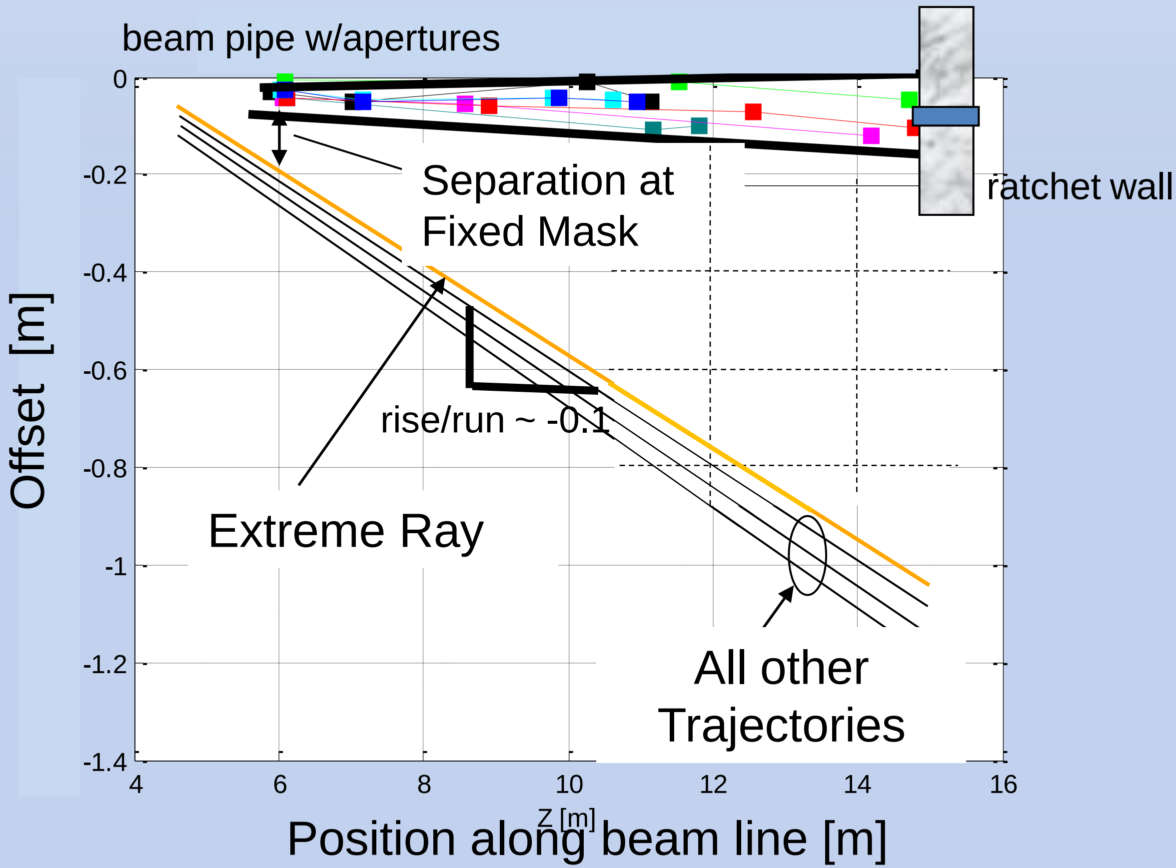


The Metric: Separation in Phase Space to Apertures



The Extreme Ray





Condition for 'Abnormal' Scenario

special SLAC interpretation

Large SPEAR3 magnet field error

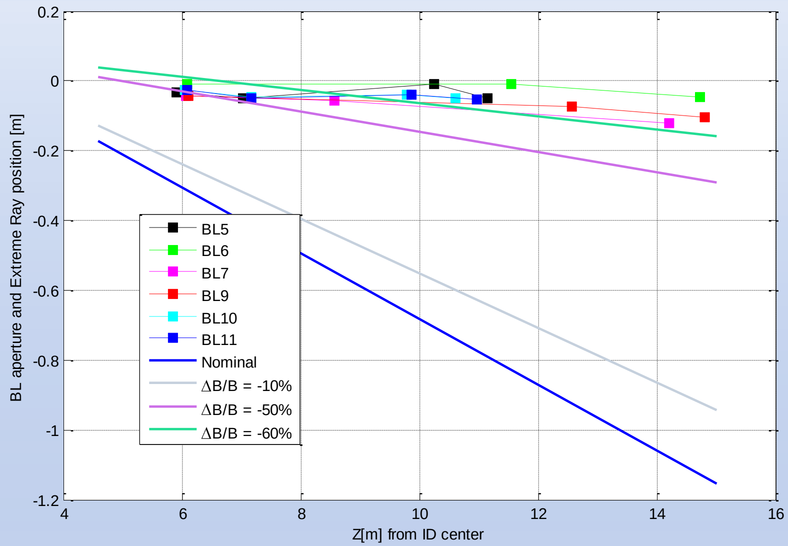
- and/or -

Large injected beam energy error

- AND -

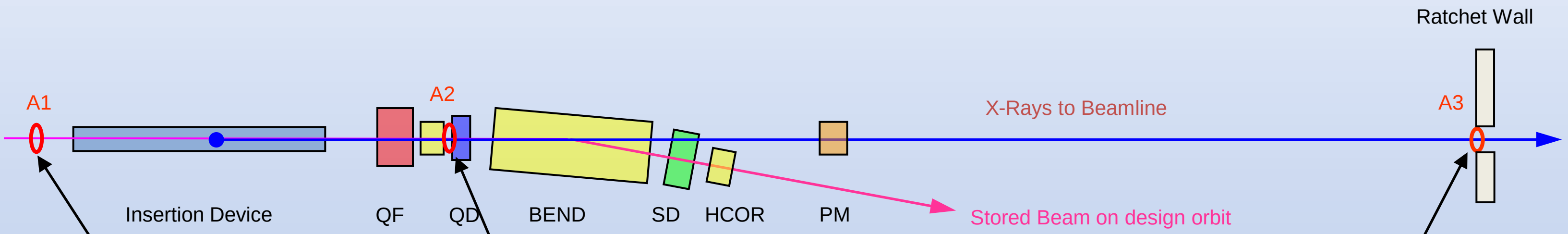
"extensive intentional steering"

Parameter Sensitivity



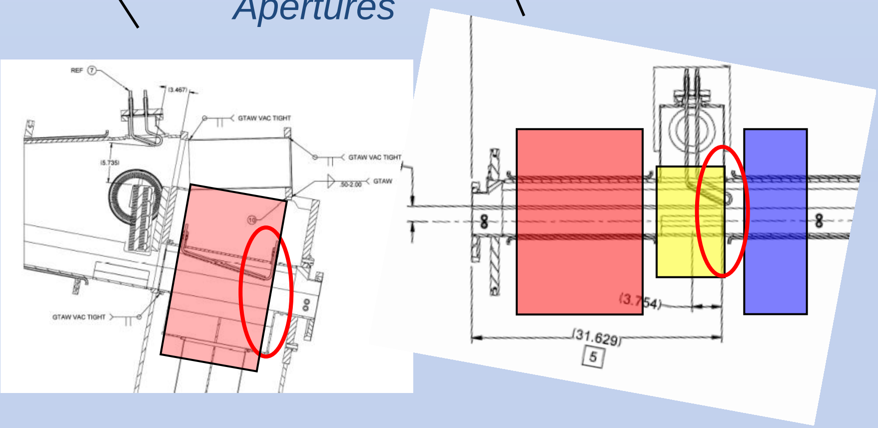
Parameter	To Pass Beyond Fixed Mask	To Pass Beyond Ratchet Wall	Target Value for Interlock Limit
$\Delta E_{INJ}/E_{SPEAR}$	+59%	+100%	+10%
ΔB/B	-48%	-60%	-1% (-10%)
ΔQF	-100%	Only with polarity reversed	-25%
ΔQD	+300%		55% (PS Limit)
HCOR	22 mrad	30 mrad	3mrad (2 x PS Limit)

Alignment of Apertures is Critical



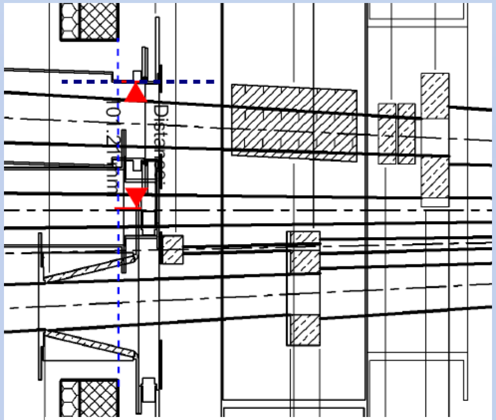
SPEAR Apertures

Beamline-Specific Aperture



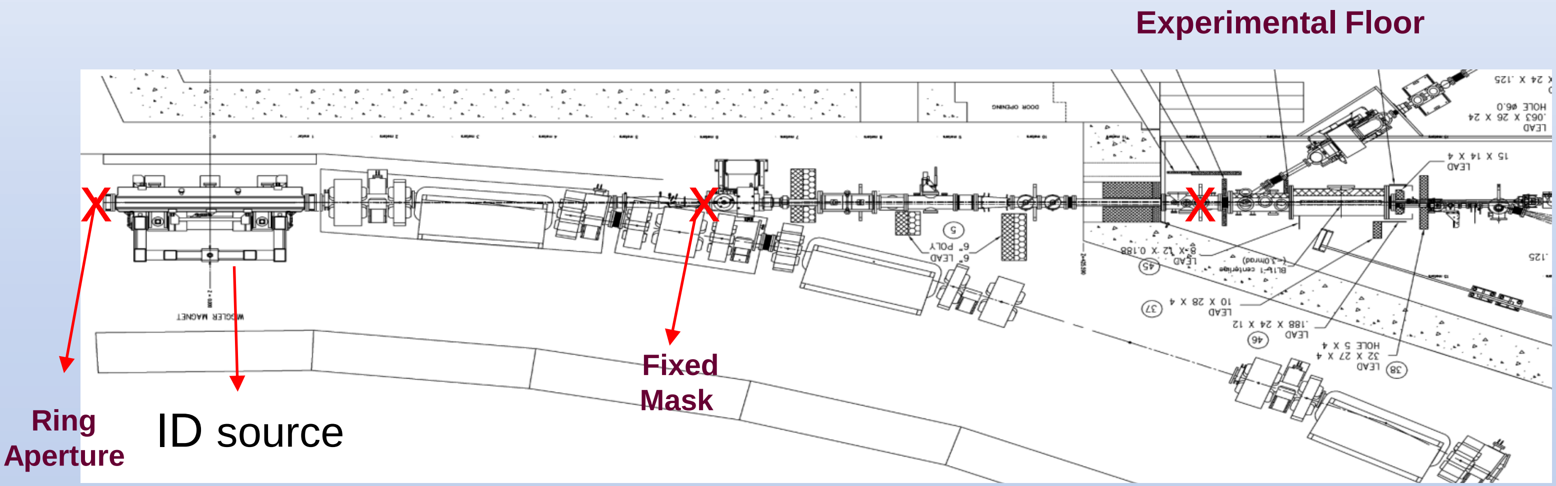
+60 / **-43** mm

+50 / -43 mm



BL9: +112 / **-101** mm

Mechanical Drawings & Tolerances

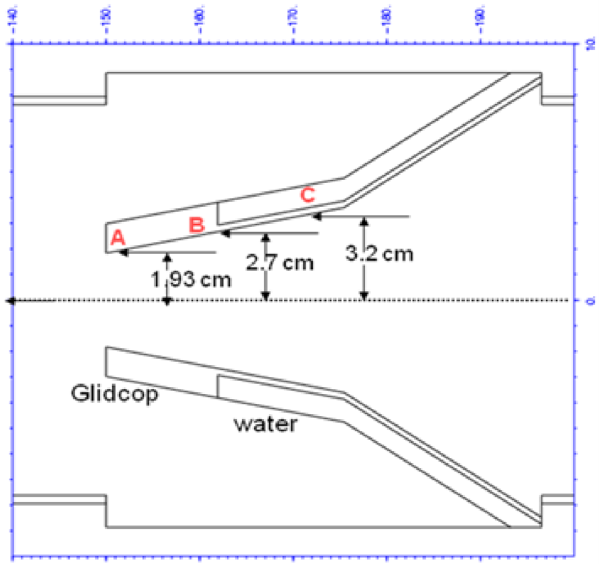


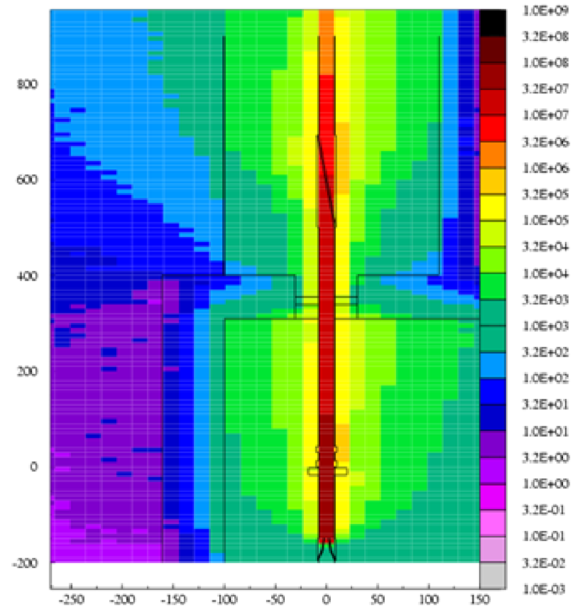
Documentation

Periodic checks

More documentation

Dose Calculations & Testing





3-GeV beam hits points A, B or C of fixed mask, the maximum dose rate outside optical hutch is 1, 0.1 or 0.03 rem/h/W.

Trajectory study shows uniform loss over fixed mask → 1.7 rem/h at 5 W

mis-steer and measure…

Bauer & Liu

'Hazard Mitigation'

Passive Systems

-Limiting apertures in transport line (BTS)

-Limiting apertures in SPEAR3 and beam lines

- Permanent magnets for dipole beam lines

Active Systems (Redundant Interlocks)

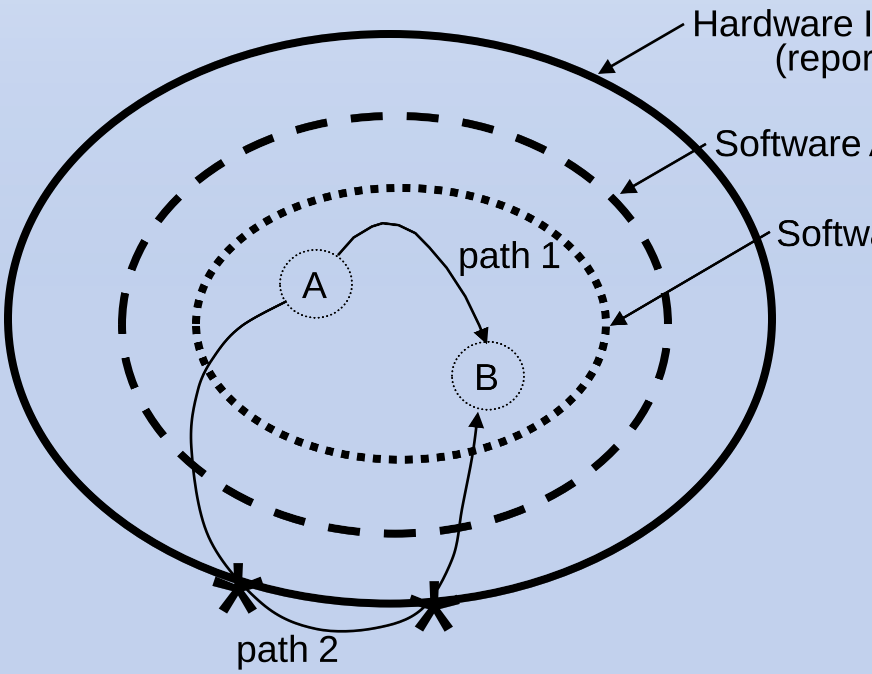
- Injection energy interlock
    - BTS dipole supply

- SPEAR3 magnet supplies

- Stored beam interlock

- Radiation detectors at each beam line

Interlock Hierarchy



A Rastafarian Logic Table

Top-Off injection fault table for SPEAR3 ID beam lines

	global BCS	Magnet BCS			Non-BCS			radiation monitors
Injected Beam Condition ↓	**TOSCI Intl'k**	**Inject Energy Intl'k**	**QF Error Intl'k**	**Dipole Intl'k**	**Injected Beam Steered**	**Power Supply Software Interlock**	**Orbit Intl'k (MPS)**	**BSOIC/ LION/ Rad Mons**
Accumulation	OK	OK	OK	OK	yes	OK	OK	OK
Beam lost before FM (safe)	OK*	OK	OK	OK	no	failed	OK*	Hazard not detected
Injected beam lost between FM and Ratchet Wall	OK*	BCS failure	OK	OK	no	failed	OK*	Hazard not detected
	OK*	OK	BCS failure	OK	no	failed	OK*	Hazard not detected
	OK*	OK	OK	BCS failure	no	failed	OK*	Hazard not detected
Injected Beam Lost past Ratchet Wall	BCS failure	OK	BCS failure	OK	no	failed	MPS failure	Hazard not detected
	BCS failure	OK	OK	BCS failure	no	failed	MPS failure	Hazard not detected
(Dipole Short)	BCS failure	OK	OK	BCS failure	yes	failed	MPS failure	Hazard not detected

* stored beam very unlikely

¥ local ray trace analysis requires E_{inj}>45% - not possible

NOTES: all BCS systems redundant (2x)
FM= Fixed Mask
SCI=Stored Current Interlock

Corbett & Schmerge

SPEAR3 Operating Sequence

1. Load operational lattice
- software check of PS readbacks

2. Inject to <20 mA (orbit interlock)

3. Start orbit feedback (few microns)

4. Inject to 50 mA – top-off permit

5. Open beam line injection stoppers

6. Fill 500 mA maximum (FOFB runs continuous)

7. Fill-on-fill or trickle charge

Top up vs. top off

Which definition?

top up *vb. (tr.,adv.) Brit.*

1. to raise the level of (a liquid, powder, etc.) in (a container), usually bringing it to the brim of the container:
top up the sugar in those bowls.

top off *vb.*

(*tr., adv.*) to finish or complete, esp. with some decisive action:
he topped off the affair by committing suicide.