Beam Instrumentation for Super-KEKB

J.W. Flanagan

KEKB Review

2004.2.17

Beam Instrumentation

- Beam Position Monitors
- Bunch-by-Bunch Feedback System
- Synchrotron Radiation Monitors
  - HER and LER SR Monitors
  - Damping Ring SR Monitor

Beam Position Monitors

- Performance of current COD BPM system is expected to be sufficient for Super-KEKB.
- Will use the same front-end electronics.
- Need some modifications to button electrodes to accommodate dynamic range of front-end at higher beam-currents.

KEKB BPMs

- Connector:
  - Ring BPMs use N-type connector.
  - However, slight changes in contact pressure have led to several tens of μm orbit measurement error.
  - Special male SMA connector feedthrough has been developed, successfully used near the IP.
  - This connector will be adopted for ring BPMs as well at Super-KEKB.

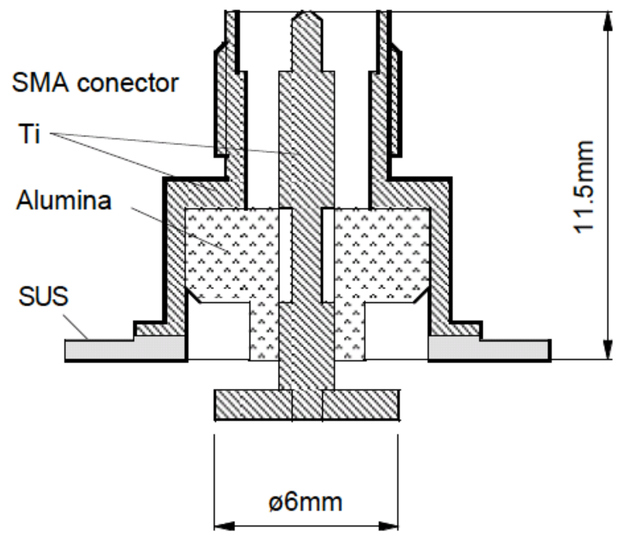
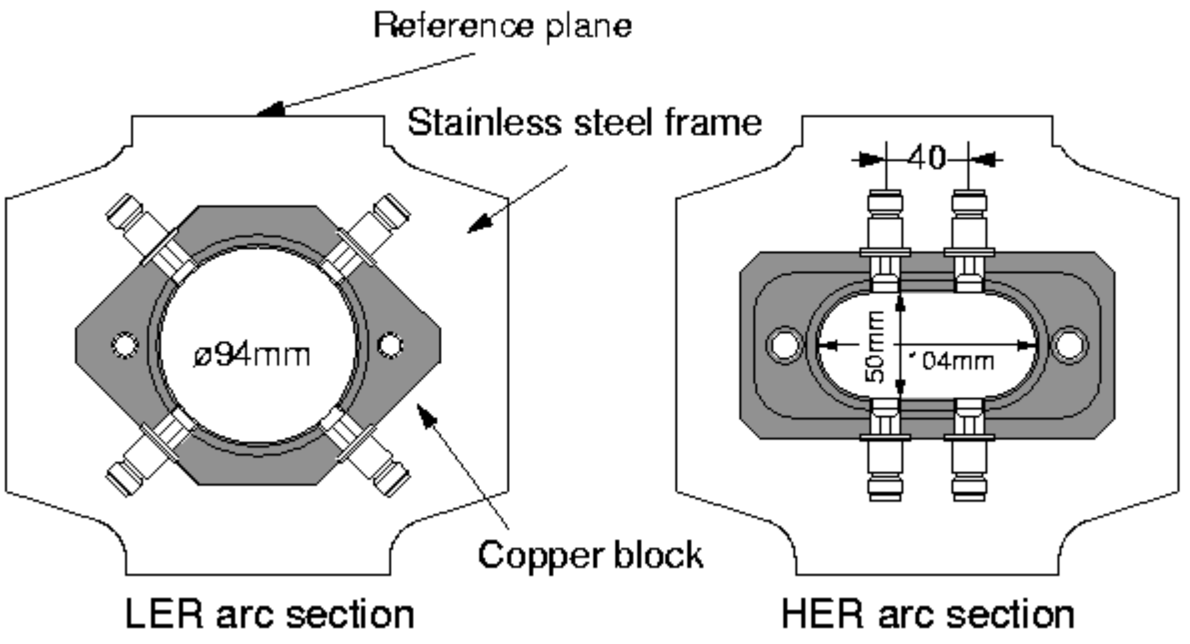


Figure 10.1: Feedthrough of the button electrode with a special SMA connector for KEKB.

KEKB BPMs

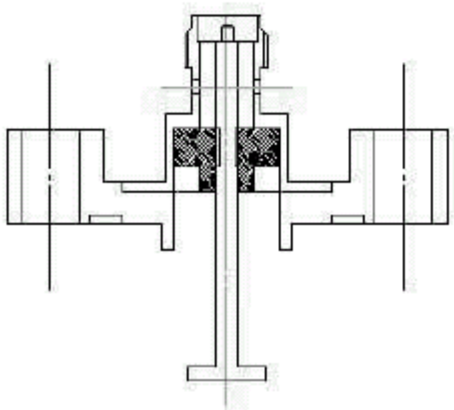
- Mounting:
  - Currently, electrodes are embedded in BPM blocks, which are electron-beam welded to the beam pipe and rigidly mounted next to each quadrupole magnet. Mapping was carried out before welding to beam pipe.

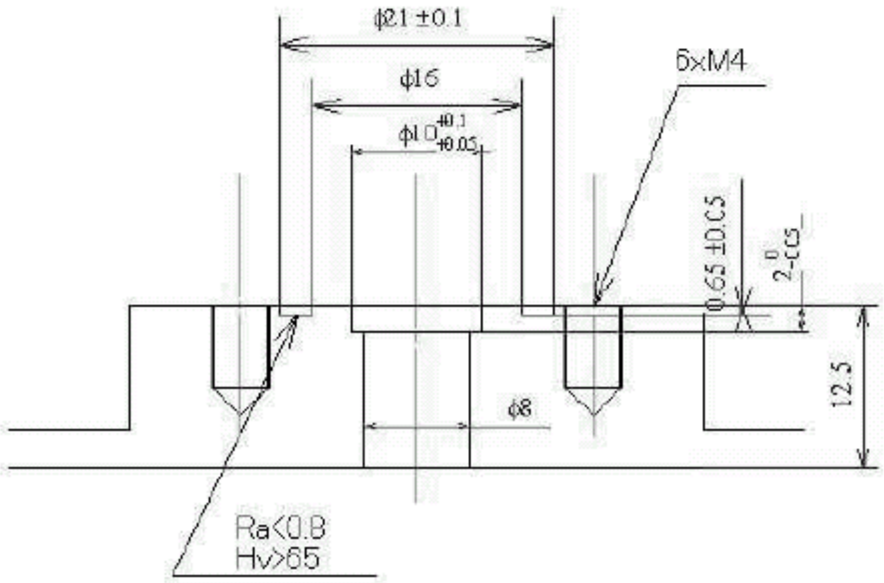


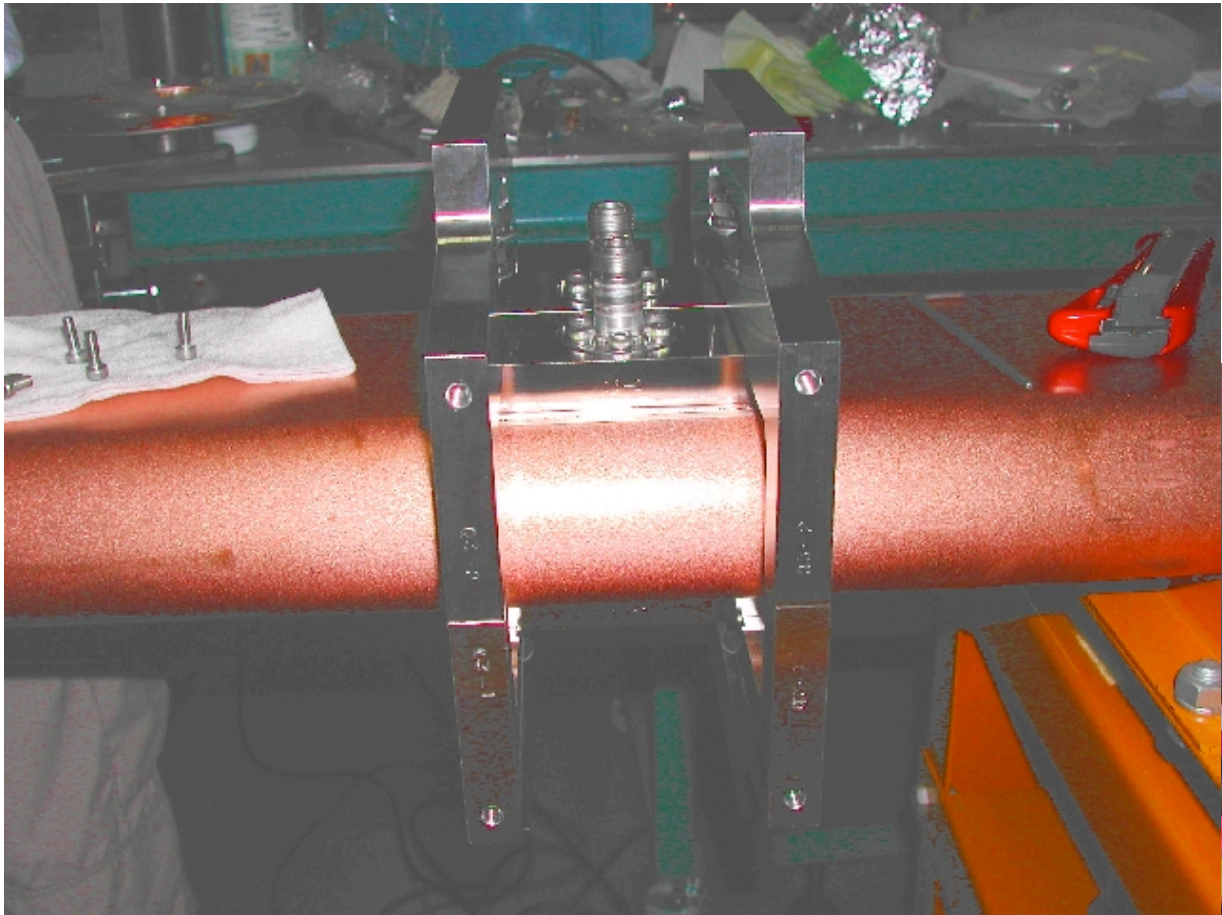
Super-KEKB BPMs

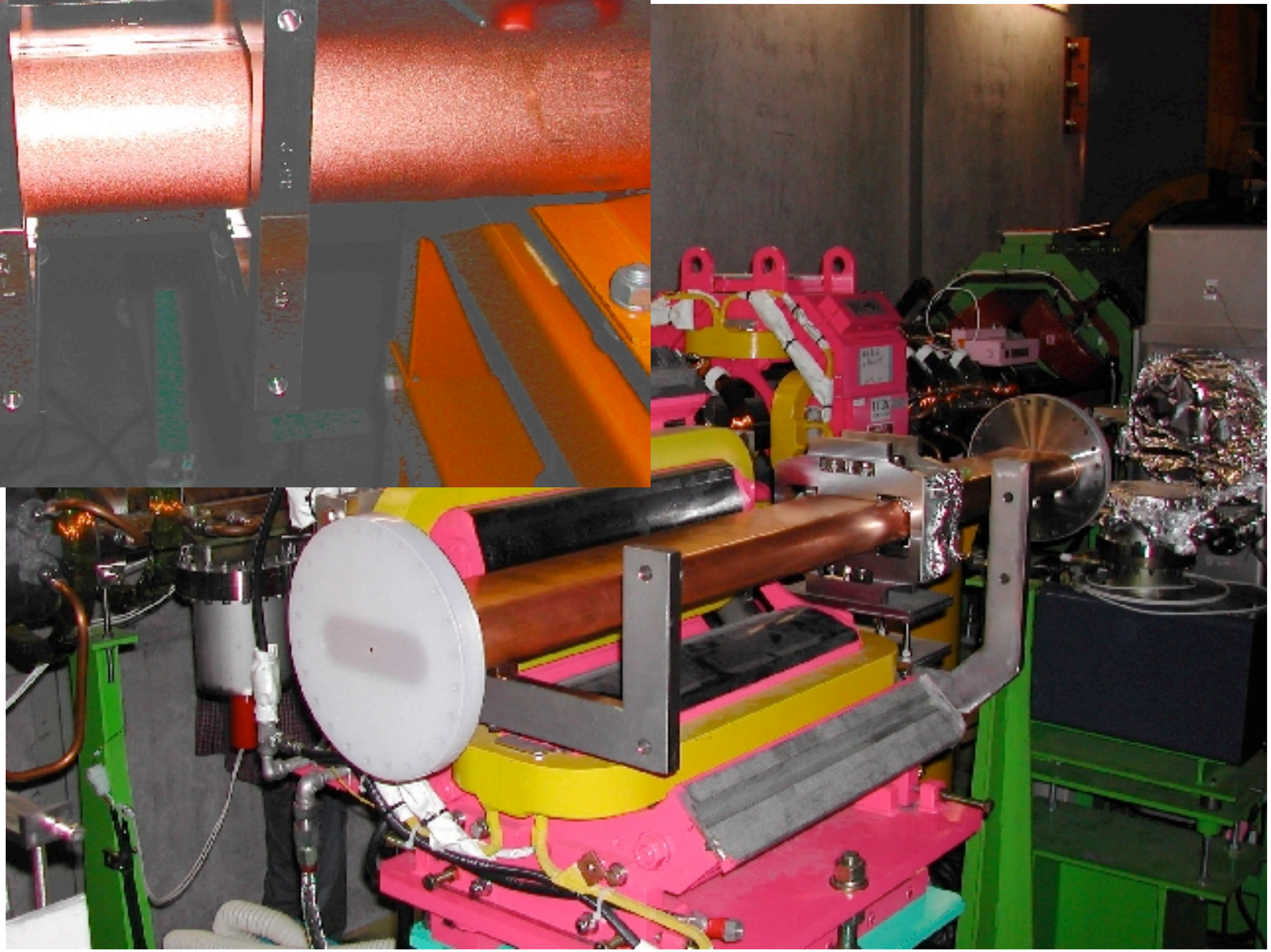
- Change to flange-mounted electrodes embedded in beam-pipe
  - Cheaper, shorter construction time, easy replacement.
  - Beam-based alignment has proven very reliable, so pre-installation mapping unnecessary.

- R&D: Ceramic -> low-permittivity (if successfully developed for FB BPMs)
  - Reduce heating from HOM losses in ceramic (may be needed for 3 mm bunch length).









Super-KEKB BPMs

- Ring electrodes
  - Diameter 12→6 mm
    - Reduce output voltage to 1/4 for high beam-current operation

	KEKB	SuperKEKB	Units
Beam current	2.6	9.4	A
Button	ϕ 12	ϕ 6	mm
Electrode output	0.798	1.17	W
Cable loss	0.789	1.16	W
Electronics input	0.009	0.009	W

- OCTPOS electrodes
  - Diameter 6→3 mm
    - To handle equivalent beam current of 13.5 A (sum of both beams)
  - Welded to beam pipe
    - not enough space for flange.

BPMs, cont.

- COD BPM
  - Due to new antechamber, HF cut-off frequency at ~700 MHz → Cannot continue direct detection at 1 GHz
    - 500→1000 MHz up-converter in front of detector
      - 2 ch x 240
- Single-Pass BPM
  - Increase from 30 -> 120 sets
- VXI/VME: MXI-1 -> MXI->2
  - Bus speed-up from 6 Mb/s→10 Mb/s
  - 7 x 20 locations

Super-KEKB BPMs

- Expected performance
  - Similar to that in KEKB, but higher minimum measurable beam current.

	Averaging detection	Single-pass detection
Detection frequency	509/1018 MHz	250 MHz
Measurable beam current	> 40 mA	0.1 – 30 mA/bunch
Resolution	A few μm	$> 100\mu$m
Measuring time	4 sec	Turn by turn
Bunch number	Multi bunch/single bunch	Single bunch

Bunch-by-Bunch Feedback

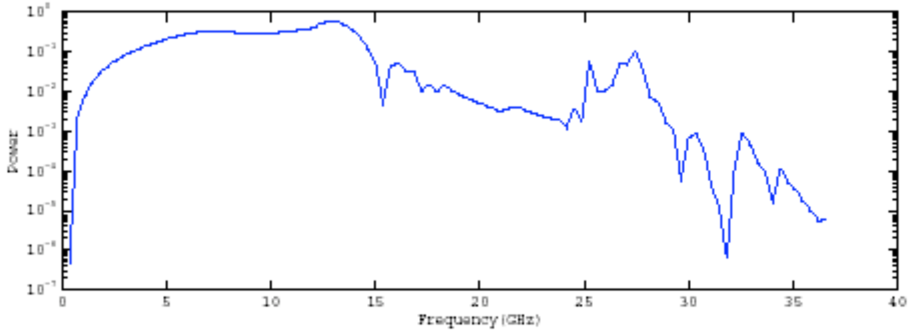
- Transverse feedback: design damping rate of 0.2 ms.
- Longitudinal feedback: design damping rate of 1 ms.

Feedback Hardware

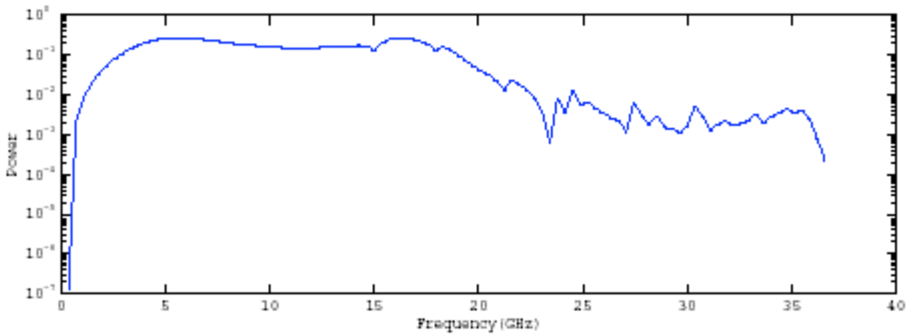
- Pickup electrode
  - Same basic design as OCTPOS pickups.
  - Reduced dielectric constant would reduce TE-mode trapping and improve higher frequency response
    - R&D necessary
  - Present pickup chamber same inner diameter as at present, with material, cooling and transition tapers modified for higher beam currents.

MAFIA simulation
σz = 3 mm

εr=9.8

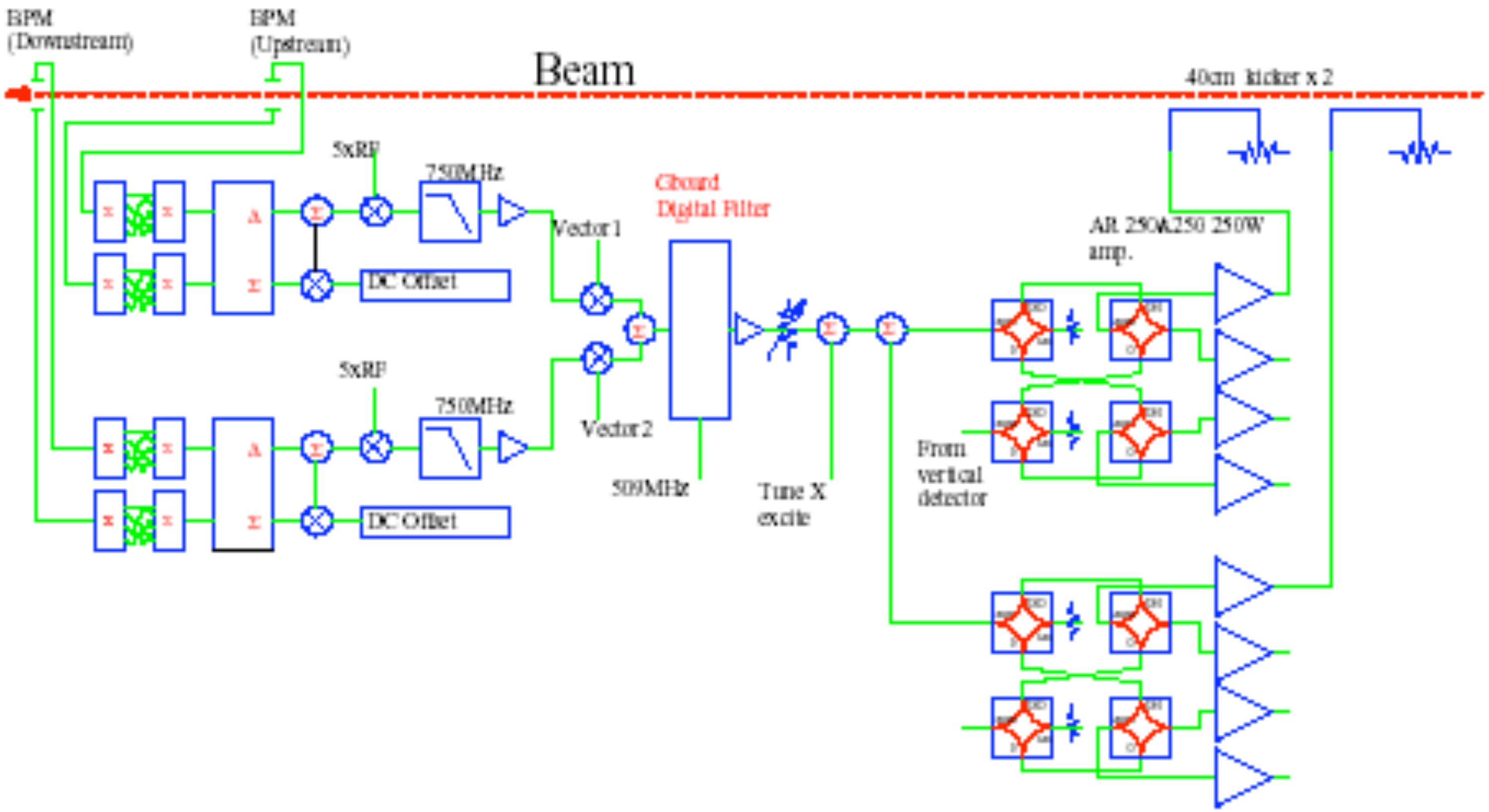


εr=4

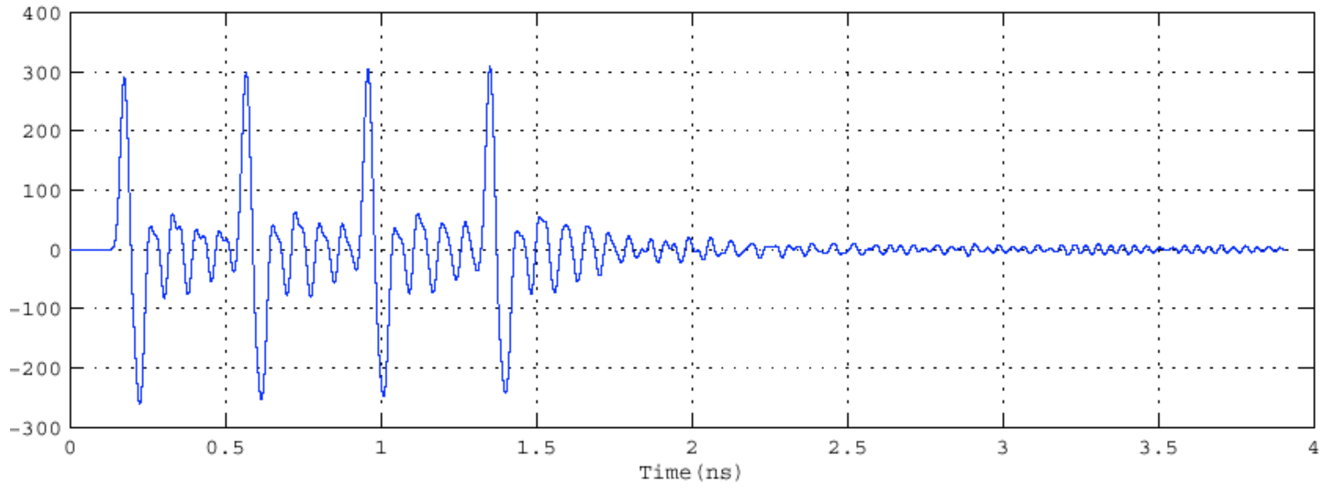


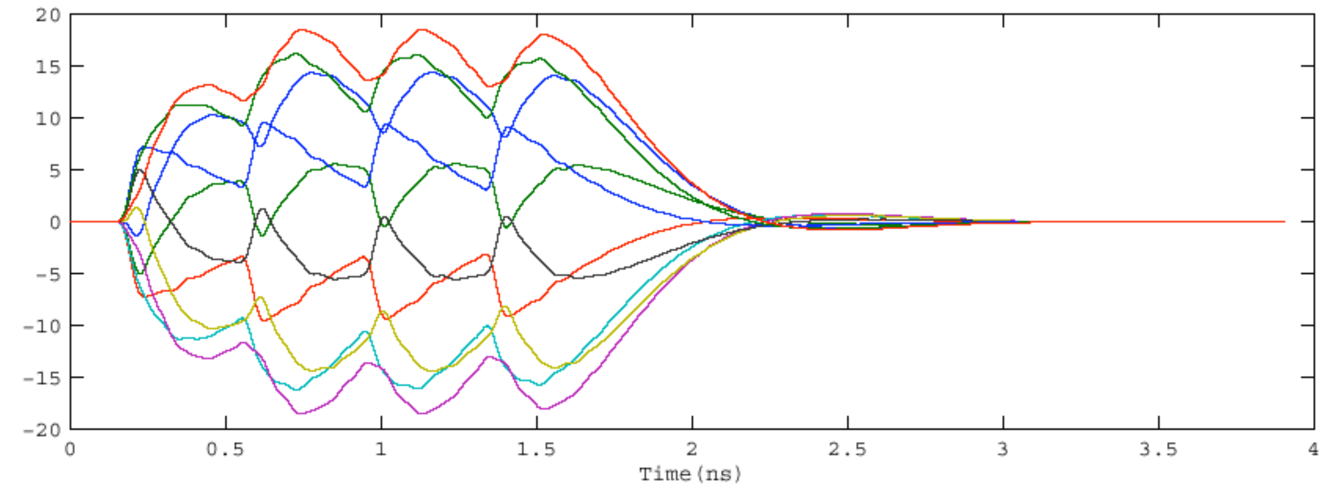
Feedback Hardware

- Front-end Circuit
  - Transverse largely same as at present, except for detection frequency
    - 2 GHz (4 x f_{RF}) → 2.5 GHz (5 x f_{RF}) for better inter-bunch isolation.
  - Automate slow-control of LO phase and DC offset tuning.
  - Longitudinal similar (uses sum signal to detect phase only).



Feedback Hardware

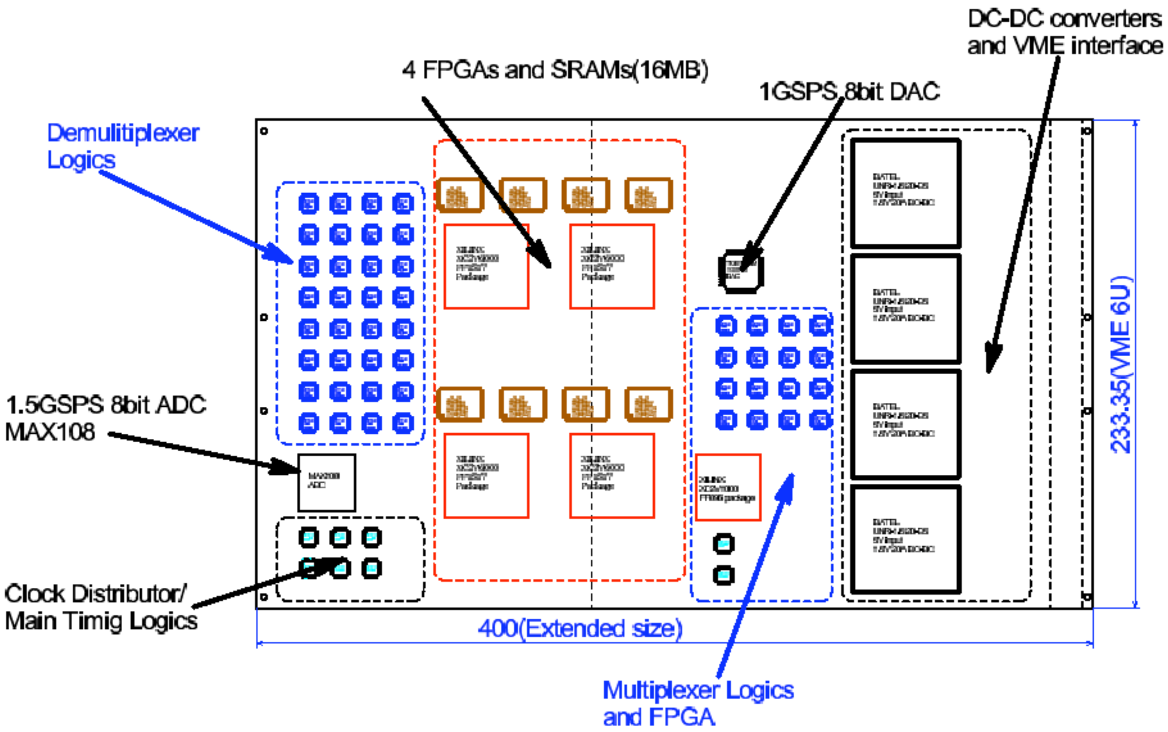




- Beam signal after 2.5 GHz BPF (upper) and detected signal (lower). Good flatness and isolation at 2 ns separation are seen.

Feedback Hardware

- Signal processing
  - Gboard: General-purpose feedback signal processor being developed by SLAC, KEK, INFN
  - Handle transverse, longitudinal FB and diagnostics
  - Support bunch spacings down to 0.66 ns, sampling at 1.5 GHz
  - Custom digital-filter algorithms possible.
  - Should give better noise reduction, beam diagnostics than present 2-tap FIR filter.



- Back-end electronics
  - Almost same as at present. Possibly add second transverse kicker system for larger FB range.

Feedback Hardware

- Power amplifiers and kickers
  - Need more reliable structure for transverse kickers, and durable attenuators for higher beam currents.
    - Loss factor of 0.11 V/pC at 7 mm bunch length, will worsen with 3-mm bunch length
  - Possible measures:
    - Supports with improved cooling for kicker plates using beryllia.
    - Flexible longitudinal supports with good DC connection and wideband response.
    - Step back radial plate position to chamber-wall
      - HOM dampers needed for trapped modes inside the kicker.
  - Longitudinal kicker: use DAΦNE-type low-Q-cavity kickers, with eight-port structure for high beam power. Better feed-throughs needed for frequency response.

Feedback Kicker

SR Monitors

- Problems experienced thus far:
  - Wall-current heating
    - Expanding/contracting stainless-steel beam pipe → mirror motion → Optical axis drift.
      - Corrected initially by optical-axis feedback.
      - Basically cured by changing stainless duct to copper.
  - SR heat loads
    - Mirror distortion
      - Measure, correct, calibrate

SR Monitors, cont.

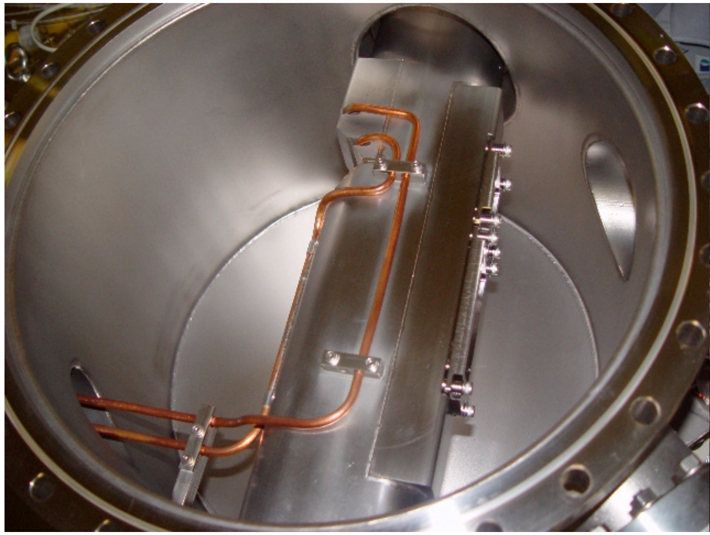
- Problems, cont.
  - Low light levels, especially in LER
    - Troublesome for single-bunch measurements (streak camera, gated camera, etc.)
    - Partial solution: reflective optics
      - Removes need for bandpass filters for imaging systems
      - Used with streak camera
        - » Enables bunch-length measurement at LER
        - » Still cannot resolve bunch shape or tilt very well, so would like to improve light levels before crab cavity commissioning in 2 years.

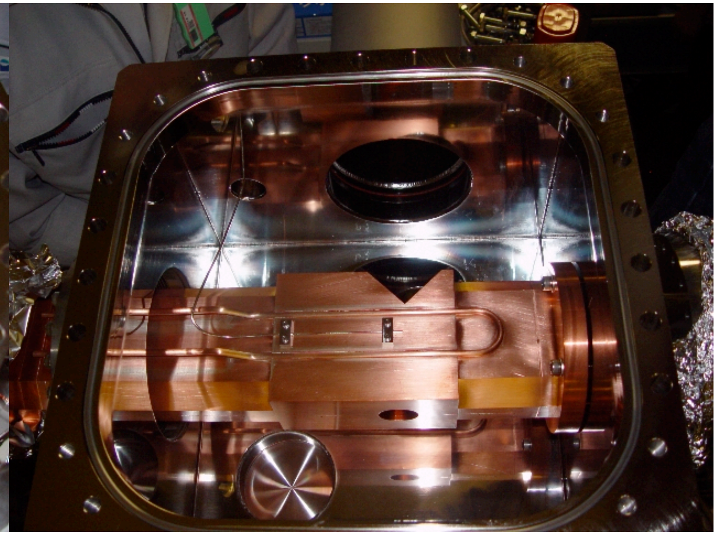
Hardware Improvements

- New SR extraction chambers
  - Beam-pipe section changed from stainless steel to copper, reducing resistive wall heating and improving stability of extraction mirror mount, and eliminating the need for optical axis feedback compensation with changing beam currents. Stable optical axis also makes study measurements much easier.

HER SR Monitor Extraction Chamber

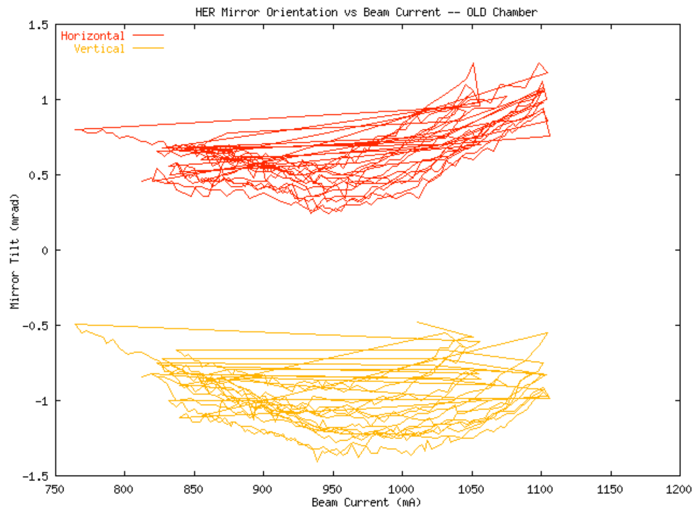
Wall current heating
•Old chamber:
>200°@ 700 mA
•New chamber:
<1°@ 1100 mA



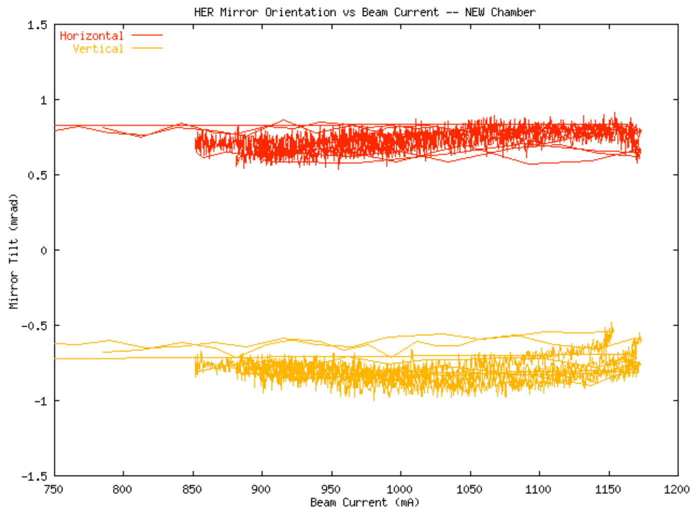


Estimated HOM leakage from extraction aperture (MAFIA simulation):
•Old chamber:
100-200 W @
1200 mA, 5.5 mm
•New Chamber:
50 W @
1200 mA, 5.5 mm

Old Chamber

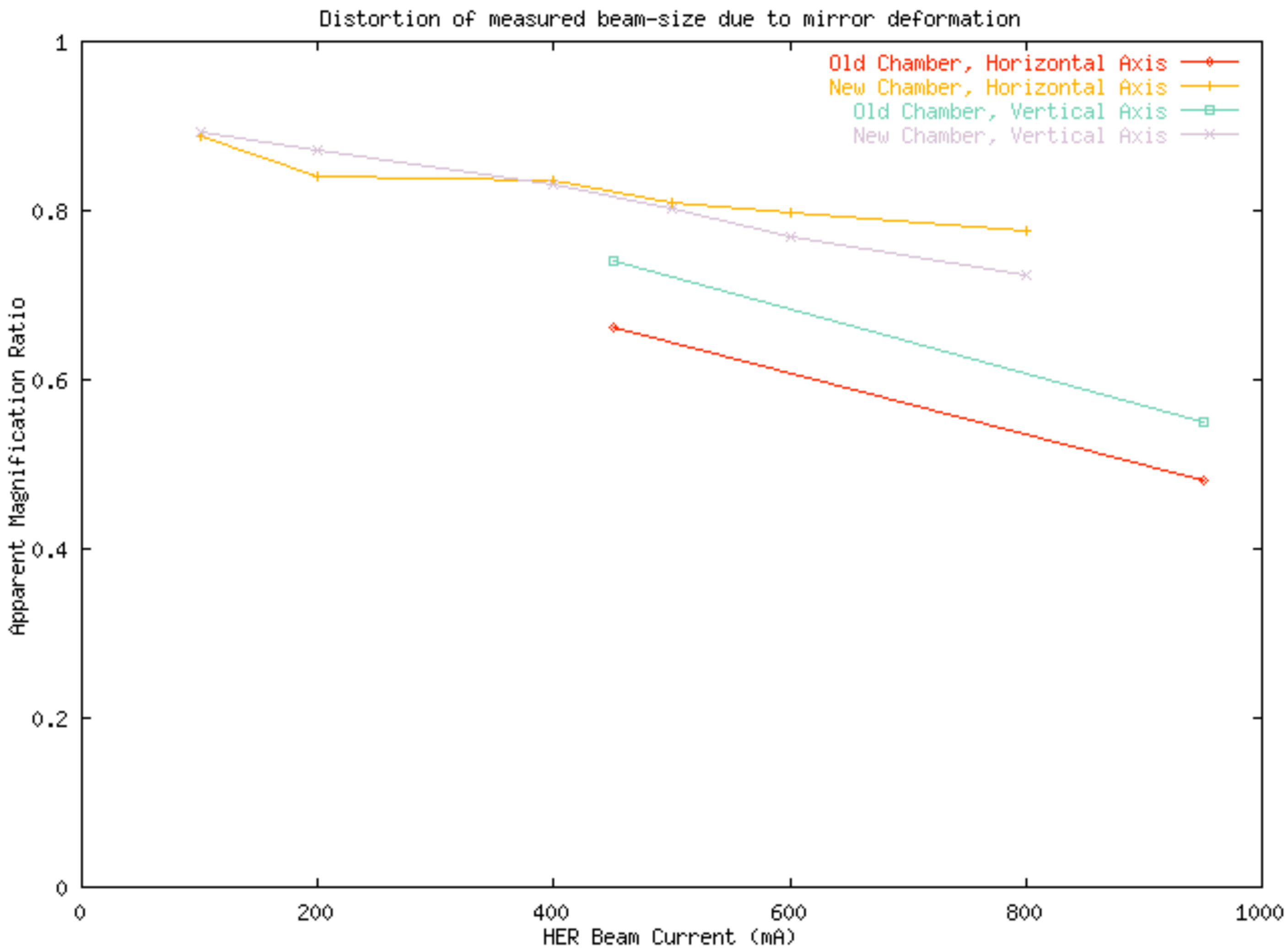


New Chamber



Mirror orientation drift with beam current reduced.
•Optical axis feedback no longer needed.

SR Monitor Mirror Heating



•Apparent beam-size distortion due to mirror heating with old and new chambers at HER.

  •Improved, but will need further improvement for higher beam currents.

SR Monitor Upgrade Plans for SuperKEKB

- Wall-current chamber heating issues
  - Old chamber: wall current heating a severe problem, solved by changing beam duct section from stainless steel to copper.
  - Calculations, which agree with current beam pipe measurements, suggest an 220-degree temperature rise at 9.4 A with 3-mm bunch length due to wall currents without cooling.
    - Extra cooling will be needed.

Bunch Spacing (buckets)	σ_z (mm)	I (A)	ΔT (°C) [Calculated]	ΔT (°C) [Measured]
4	6	1.4	1.7	1.7
4	6	9.4	78	
4	3	9.4	220	
1	3	9.4	55	

Beam-pipe heating with the current beam chamber design

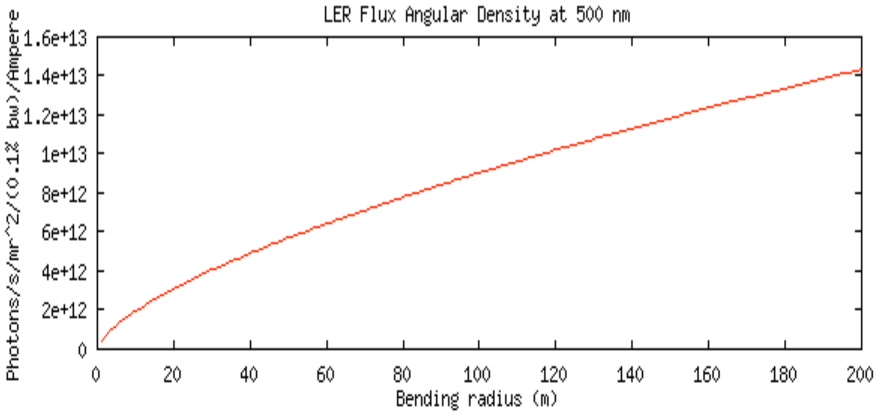
SR Monitor Upgrade Plans, cont.

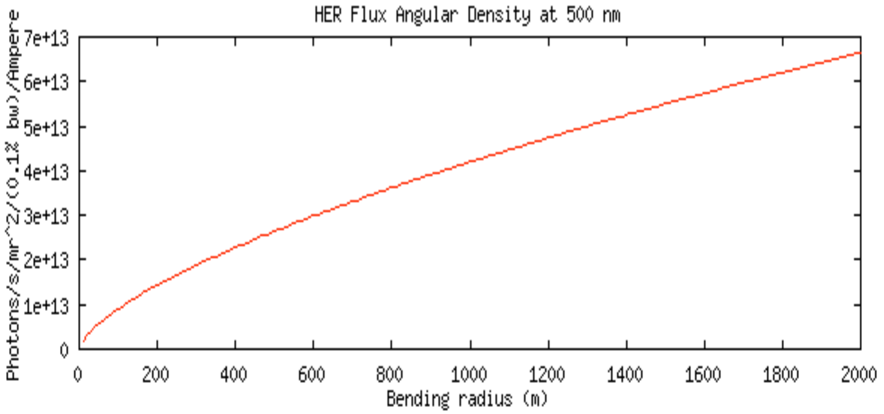
- SR heating:
  - Larger bending radius, longer core length magnet →higher λ_{crit}.
    - Increase visible light flux for single-bunch and low-current measurements.
    - Lower total incident SR power, reducing heat load on mirror and resulting deformation.
      - Currently, ~10% magnification drifts at 1.5 A in LER with new chamber.
    - Also increases visible light flux – desirable to help see effect of single crab cavity

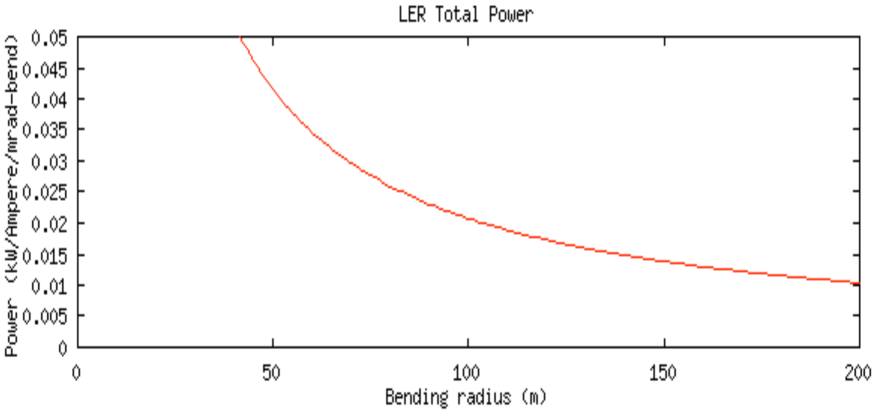
SR Source Bend Radius vs Flux Density at 500 nm and Total Power

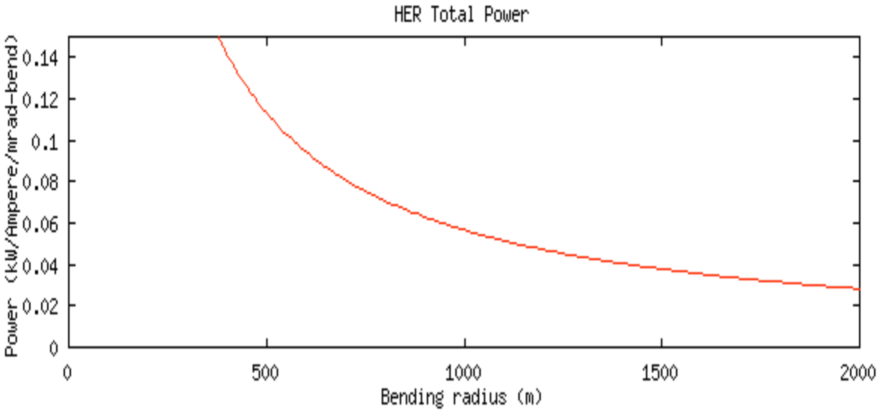
LER

HER





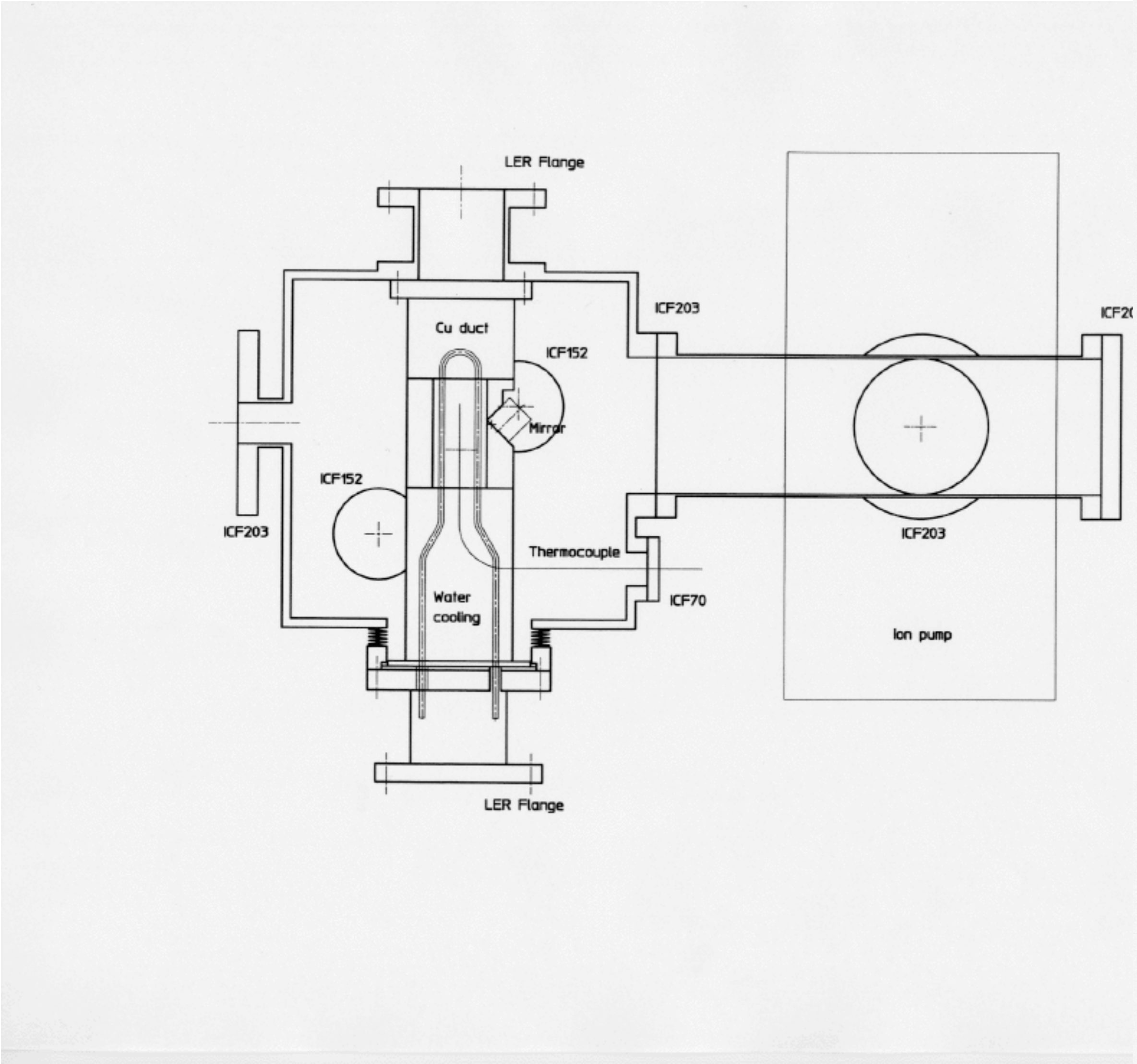


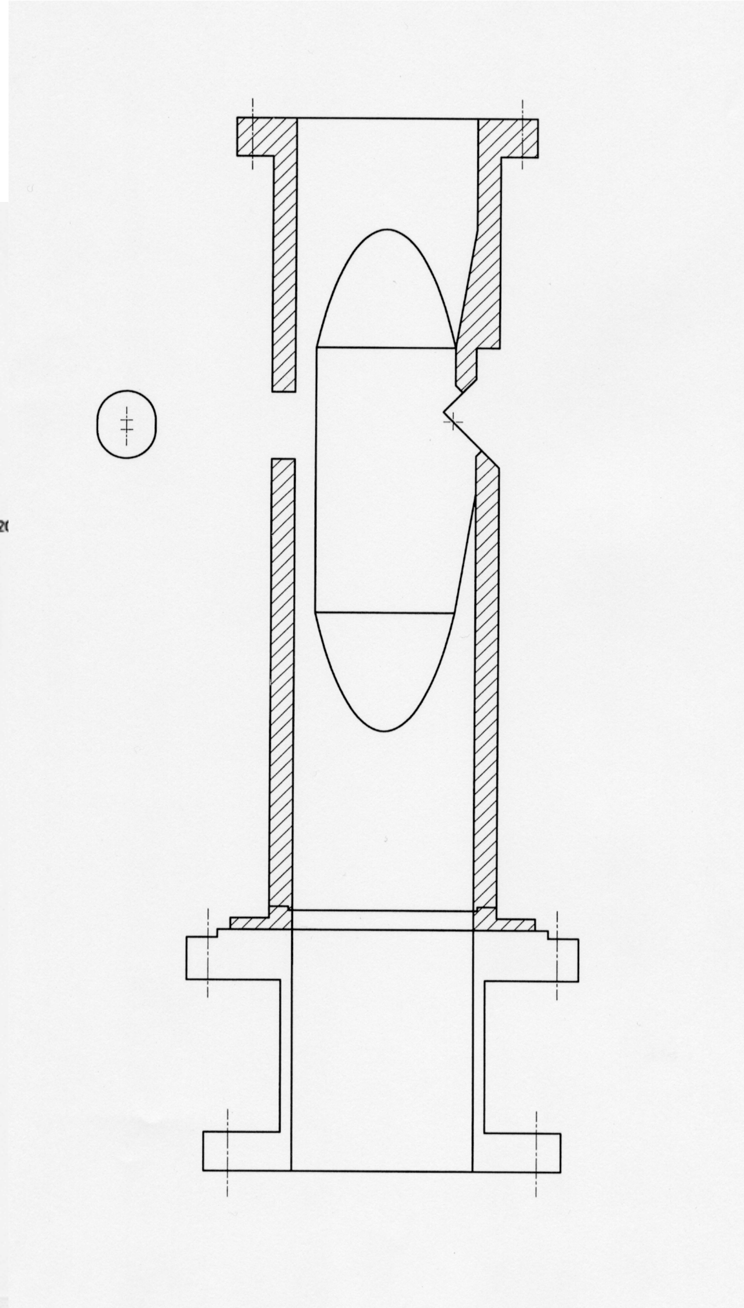


SR Monitor Upgrade Plans, cont.

- HOM
  - Some HOM leakage into outer chamber was also indicated by arcing of thermocouple leads. MAFIA simulations suggested reducing apertures would help. Current chamber design expects ~100 W at 2 A, with current 4-bucket spacing. At 9.4 A, with 1-bucket spacing, ~500 W would be expected. This needs to be measured, and possibly absorbers added outside the light-extraction aperture.

SR Extraction Chamber



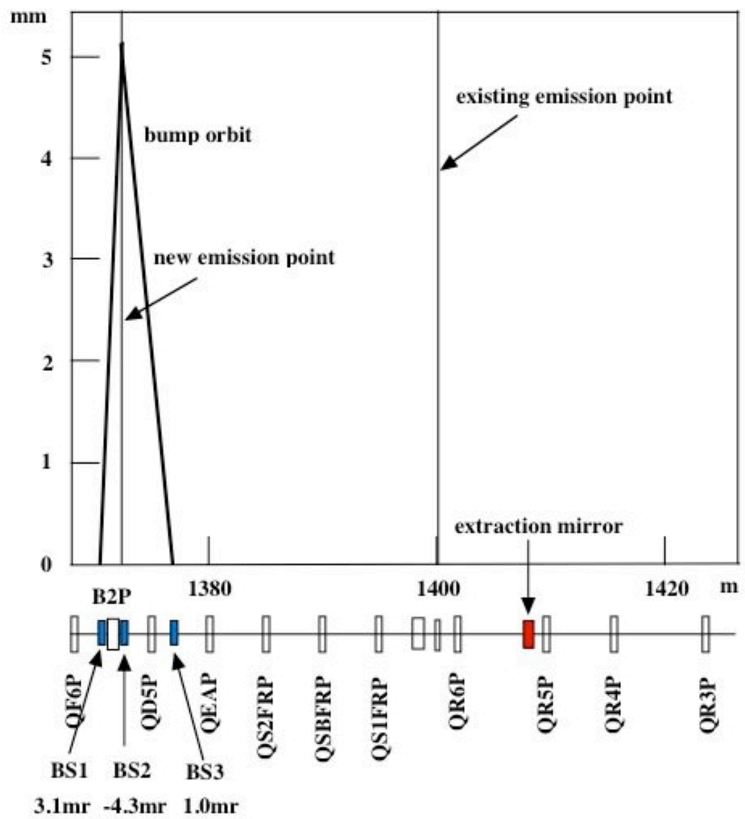


SR Monitor Upgrade Plans, cont.

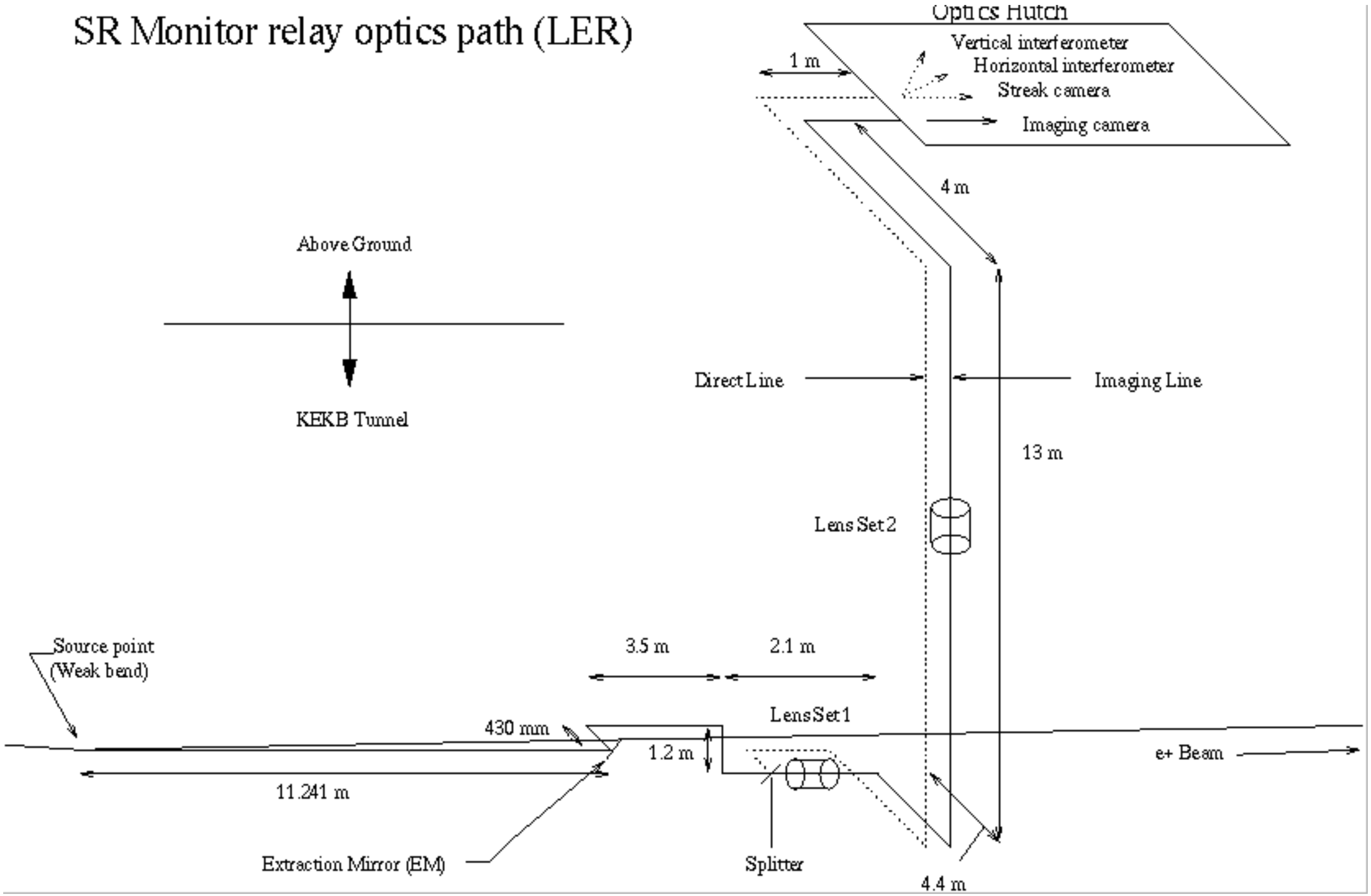
- Dynamic Beta Measurement/Compensation
  - Second monitor needed, ideally at 90 degree phase advance from current locations.
  - Candidate locations:
    - Weak bends (arc-section entrances, exits)
      - Relatively little disturbance to lattice, but requires new optics huts, and space for them
    - Arc sections near current locations
      - Can use existing huts, only need new optical transfer lines
      - Probably use a bump or chicane system to minimize disruption to optics

Second SR Monitor for Dynamic Beta Measurement

- Build a second SR source in each ring
- Using known phase advance between two locations, can measure the dynamic beta effect due to beam-beam collisions.
  - Correct beam size estimation at IP
  - More importantly, can monitor beam-beam parameters directly, in real-time.
  - Useful for luminosity tuning.
- Second source: create a local bump near current source
  - Minimize disturbance to lattice
  - Can use existing optics huts.



SR Monitor relay optics path (LER)



Damping Ring SR Monitor

		Units
Beam Energy	1	GeV
Field Strength	1.267	T
Bending Radius ρ	2.6	m
Critical Wavelength λ_{crit}	1.36	nm
Critical Energy E_{crit}	0.84	keV
β_x	1.56	m
β_y	6.25	m
η_x	0.2	m
ϵ	$1.23 \times 10^{-6} \rightarrow 1.22 \times 10^{-8}$	m
$\Delta E/E$	$6 \times 10^{-3} \rightarrow 5.5 \times 10^{-4}$	
σ_x	$1800 \rightarrow 176$	μm
σ_y	$2800 \rightarrow 280$	μm
Damping time	11.95	msec

Table 10.5: Damping Ring SR Source Characteristics

- Gated camera for imaging turn-by-turn bunch size damping.
  - Up to 4 bunches in ring at one time, at two different stages of damping.
  - Diffraction-limited resolution below 3% if optical line not too long (~10 m).

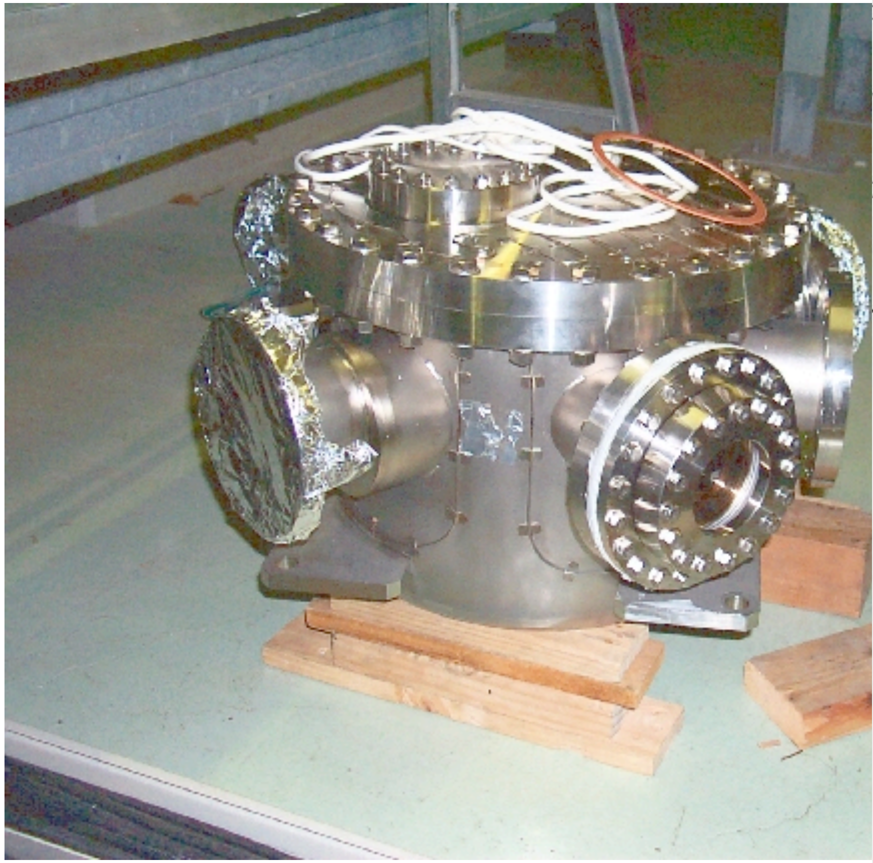
Summary

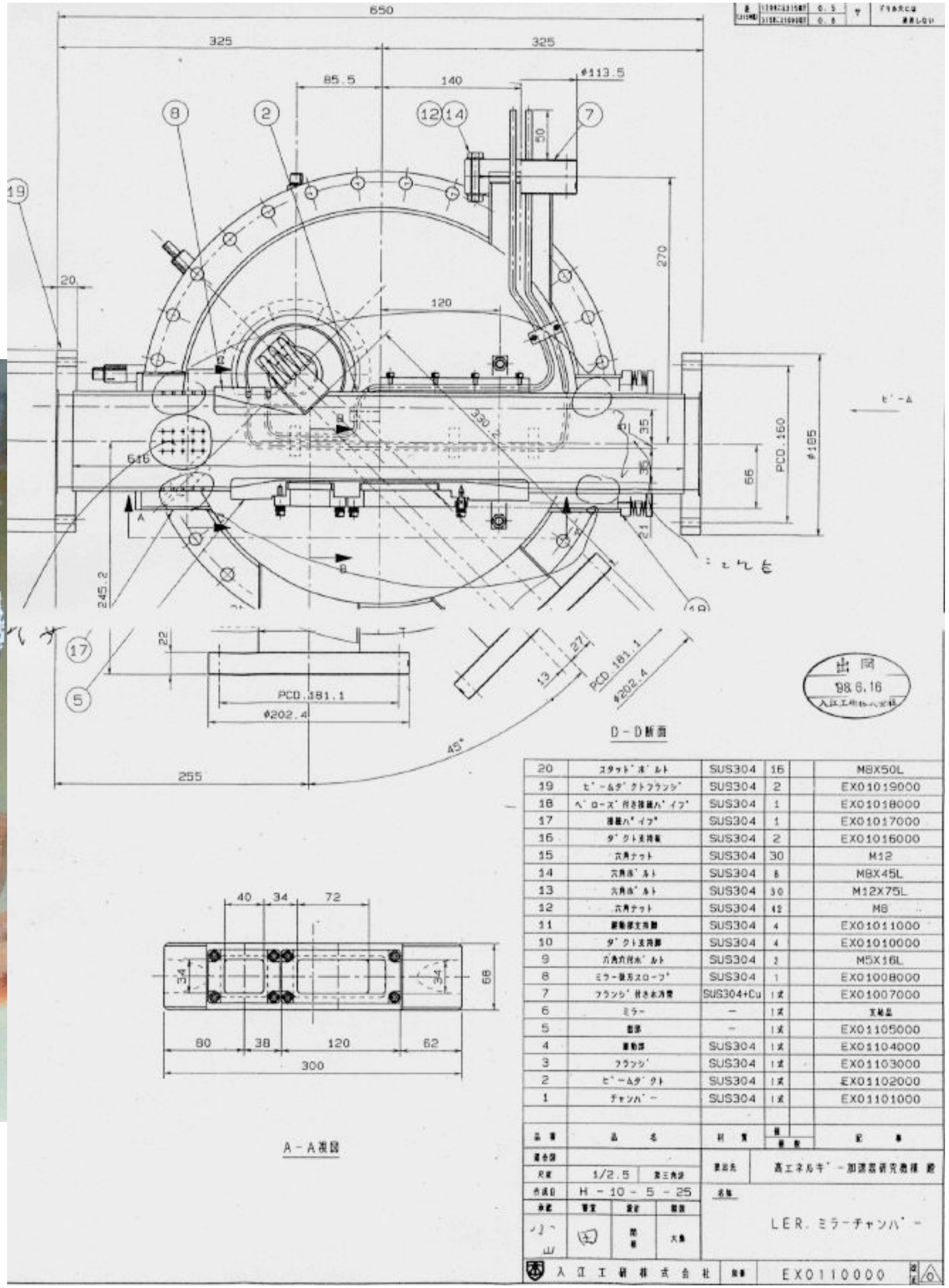
- BPMs:
  - New, smaller buttons
- Feedback:
  - Gboard
  - Longitudinal Feedback
- SR Monitors
  - More cooling of extraction chamber, longer bending-radius source bends
  - Second set of monitors for dynamic beta measurement
  - Gated camera for damping ring

Bunch-by-Bunch Feedback

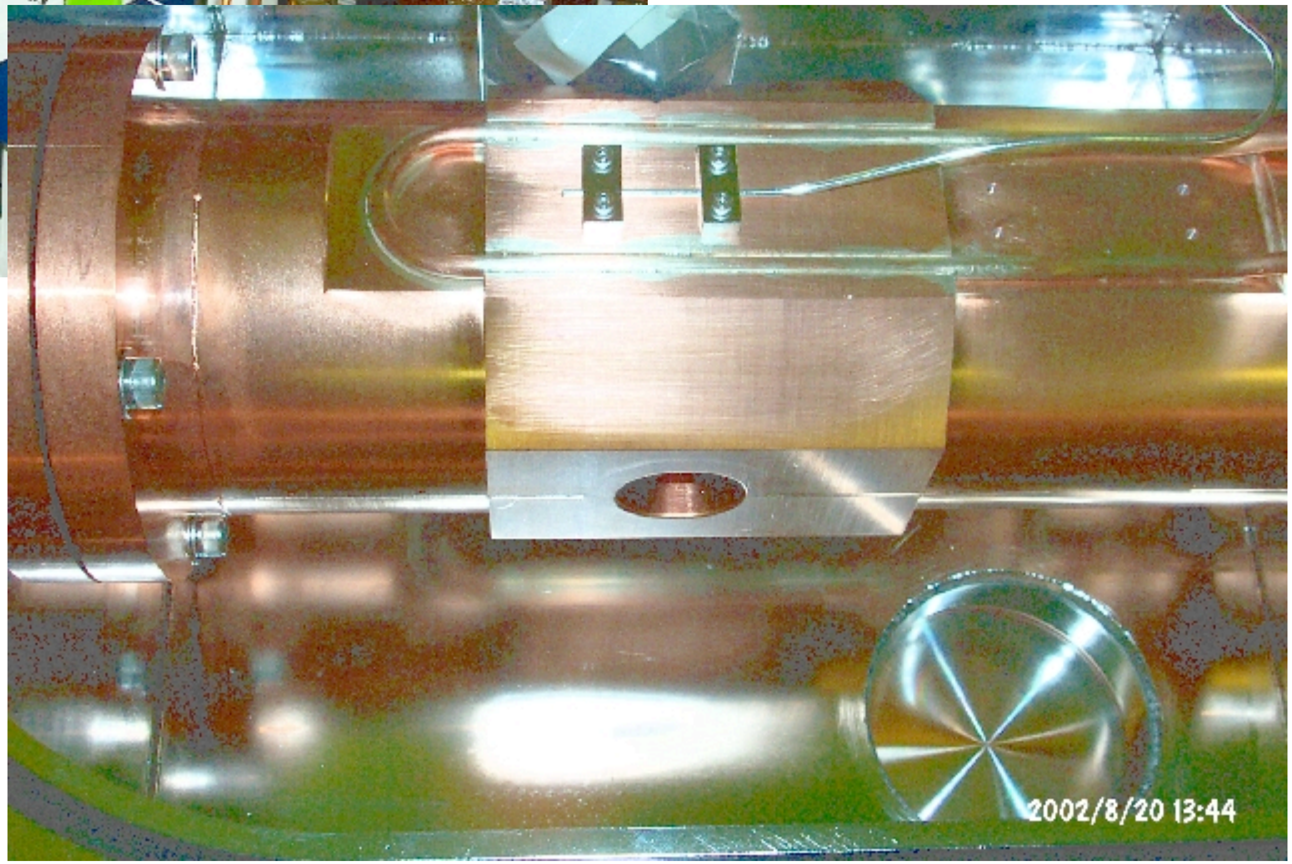
- New BPMs for higher beam currents.
- Transverse feedback similar to present design
  - Detection frequency 2.0 -> 2.5 GHz.
  - Automated LO phase and DC offset tuning.
  - Transverse kicker needs work to handle higher currents
    - Improved cooling, supports for kicker plates.
- Longitudinal feedback to handle ARES HOM and 0/Pi mode instability
  - Use DAϕNE-type (low-Q cavity) kicker.
  - QPSK modulation with center frequency 1145 MHz (2.25 x RF freq.)
- Digital FIR and memory board to be replaced by new GBoard under development at/with SLAC.
  - Low noise, high speed (1.5 GHz), with custom filtering functions possible.
  - Extensive beam diagnostics.

Old LER SR Extraction Chamber
1998 - 7/2002





New LER SR
Extraction
Chamber
8/2002 -



Beam-Pipe Temperature

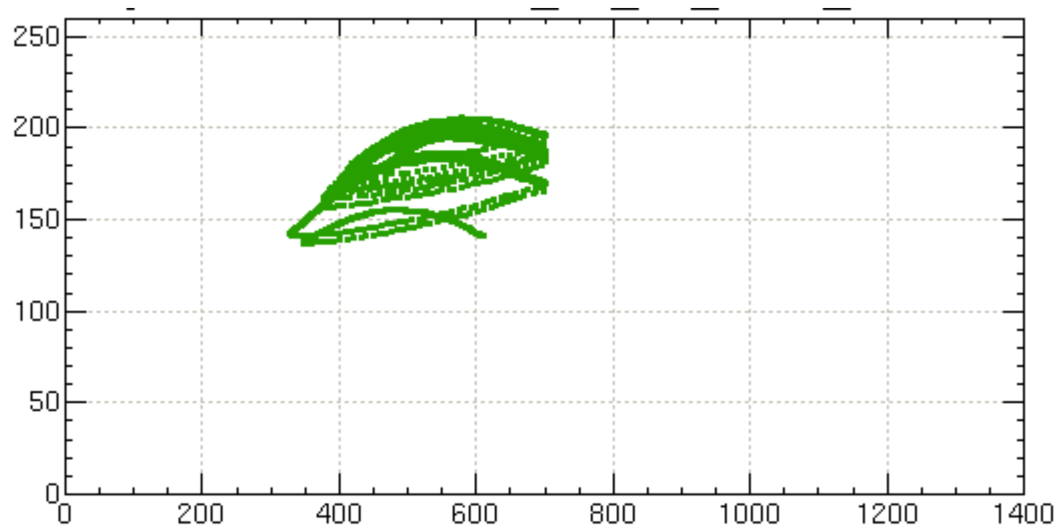
SUS: Resistive losses at

1 A → ~20 W → 100°/10cm

Cu: 1/40-1/50 of SUS

Old Chamber

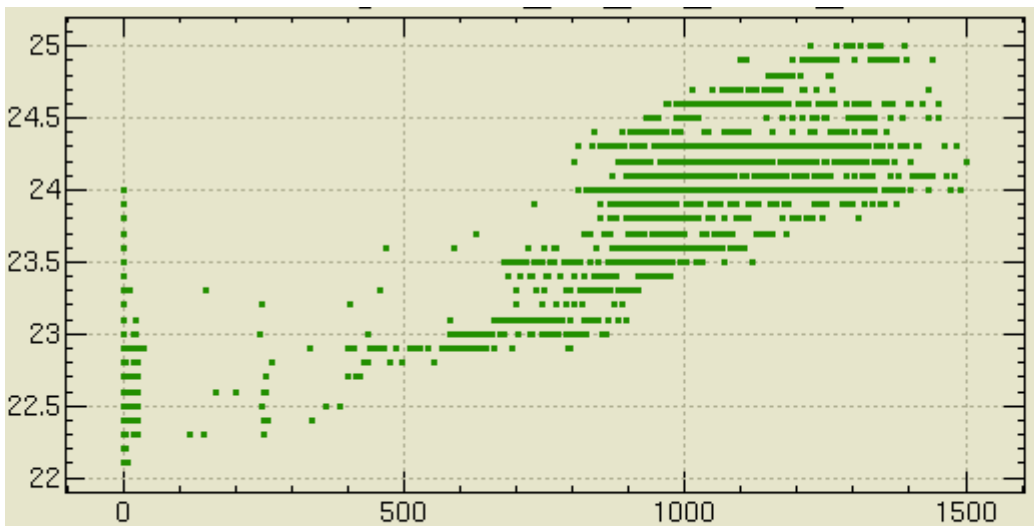
°C



LER Current (mA)

New Chamber

°C

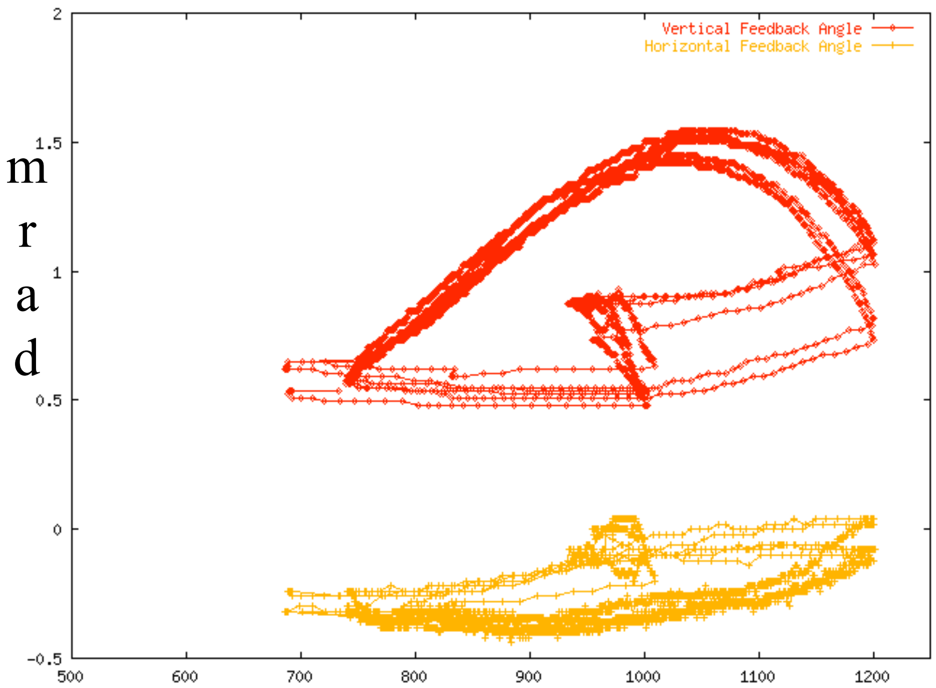


LER Current (mA)

Extraction Mirror Orientation

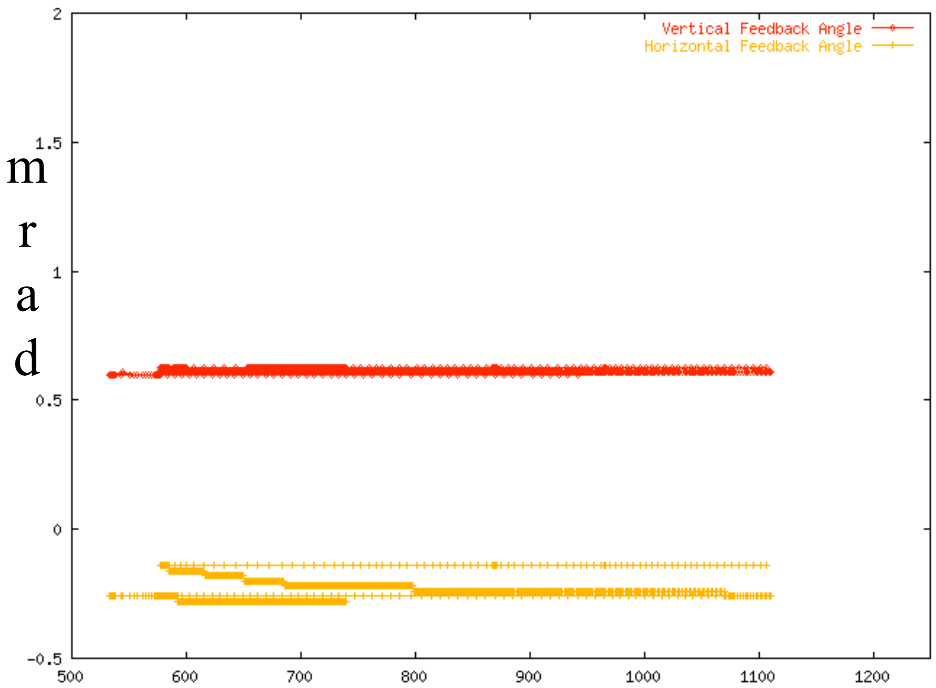
Optical-axis feedback compensation angles

Old Chamber



LER Current (mA)

New Chamber



LER Current (mA)

- Optical-axis feedback is now unnecessary, turned off in LER (expected to be unnecessary in HER as well)

Beam Loss Monitors

- KEKB
  - Originally: ~100 ionization chambers dispersed evenly around ring. Expensive and slow, but indestructible
  - Channels around masks replaced with PIN diodes for fast abort (few turns) to prevent excessive mask-head gouging. Cheap, periodic replacement needed.
- SuperKEKB
  - Probably move to all-PIN diode system, for reasons of speed. Rather than broad coverage (which hasn't proven necessary), aim for detailed monitoring of aperture-restricting locations (masks, IR, etc.).

DCCT

- Current design should be fine at higher currents.