Beam-induced EMI and detector electronics

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Beam RF effects at Colliders

SLC

Problem with EMI for SLD's VXD3 Vertex Detector

- Loss of lock between front end boards and DAQ boards (100% of beam passing !)
- Errors (sometimes) in decoding of "fast" commands, sent by means of 60 MHz clock phase modulation
- Solved with 10 μsec blanking around beamtime – front end boards ignore commands during this period

PEP-II

Heating of beamline components near IR due to High-order Modes (HOMs)

- S. Ecklund et al., *High Order Mode Heating Observations in the PEP-II IR*, SLAC-PUB-9372 (2002).
- A. Novokhatski and S. Weathersby, *RF Modes in the PEP-II Shielded Vertex Bellows,* SLAC-PUB-9952 (2003).
- Heating of button BPMs, sensitive to 7GHz HOM, causes BPMs to fall out

HERA

Beampipe heating and beam-gas backgrounds

- HOM-heating related to short positron bunch length

UA1

Initial beam pipe at IP too thin

- not enough skin depths for higher beam rf harmonics

Beam RF effects at ILC IR?

	SLC	PEP-II e^+	ILC
Electrons/Bunch, Q	4.0×10^{10}	5.0×10^{10}	2.0×10^{10}
Bunch Length, σ_Z	1 mm	12 mm	0.3 mm
Bunch Spacing	8 ms	4.2 ns	337 ns
Average Current	7 nA	1.7 A	50 μA
$(Q/\sigma_Z)^2$ relative	92	1	256

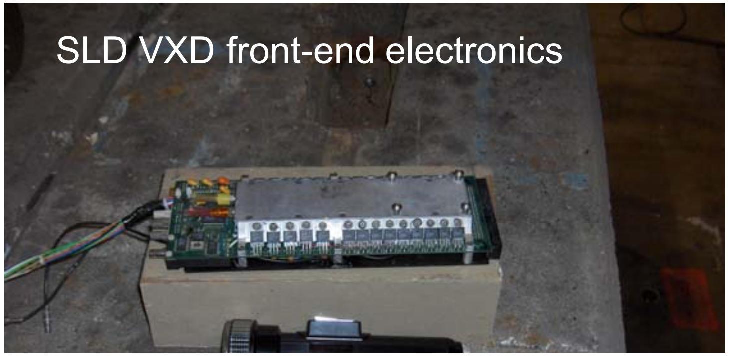
PEP-II experience

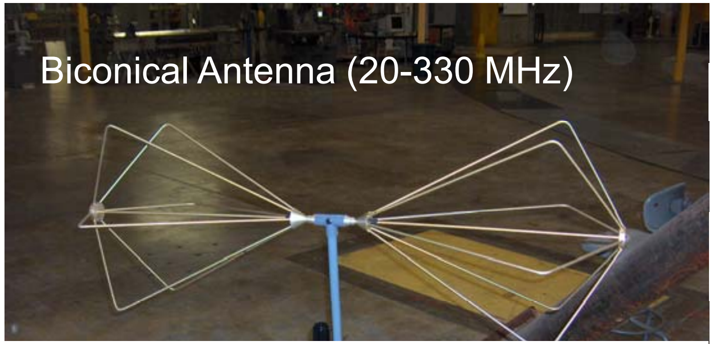
- HOM heating scales as $(Q/\sigma_Z)^2$
  - same scaling for EMI affecting detector electronics?
  - does scaling extend to mm and sub-mm bunch lengths?
  - need a cavity of suitable dimensions to excite
- IR geometry (aperture transitions, BPMs) has similar complexity as for ILC
- VXD and other readout systems ok for EMI in signal processing

ILC Considerations

- HOM heating ok because of small average beam current
- EMI affecting Signal Processing and DAQ? Impact on Detector Design and Signal Processing Architecture?
- ➢ ***EMI Standards needed for Accelerator and Detector in IR region***

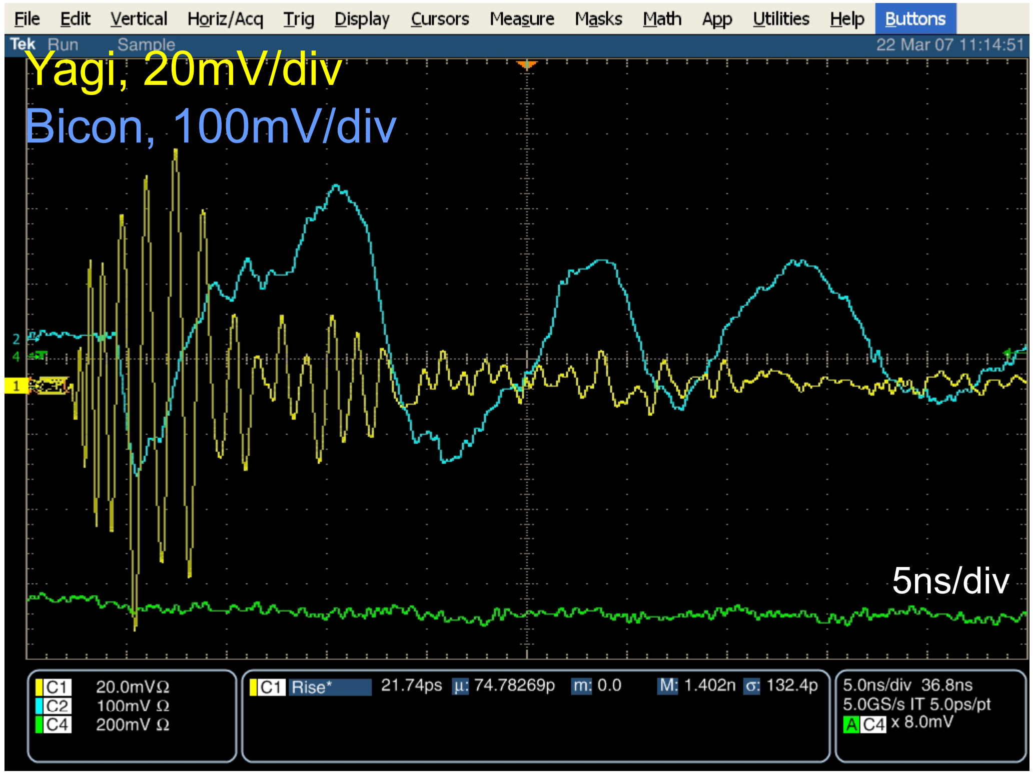
EMI Studies at SLAC ESA

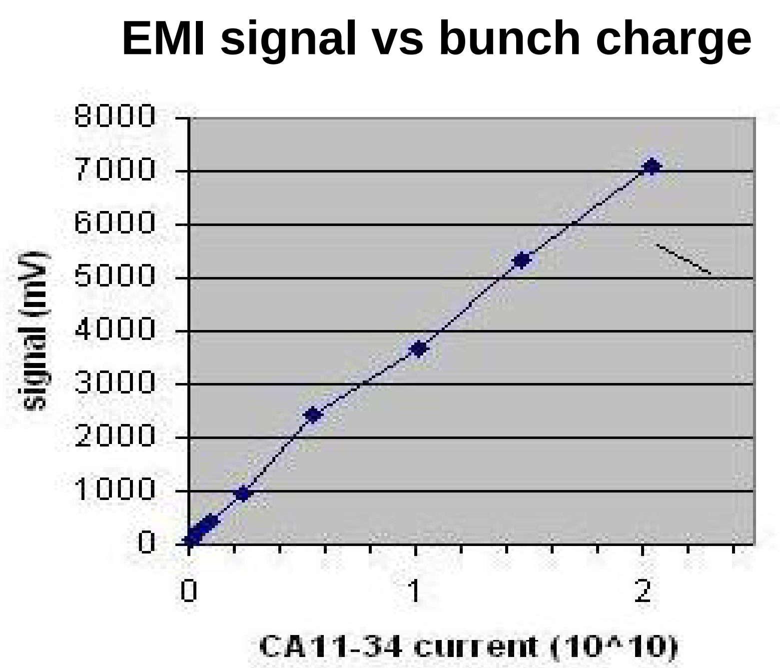




- EM fields within the beam pipe are contained by the small skin depth.
- But dielectric gaps emit EM radiation out of the beam pipe.
- Common “gaps” are camera windows, BPM feedthroughs, toroid gaps, etc.

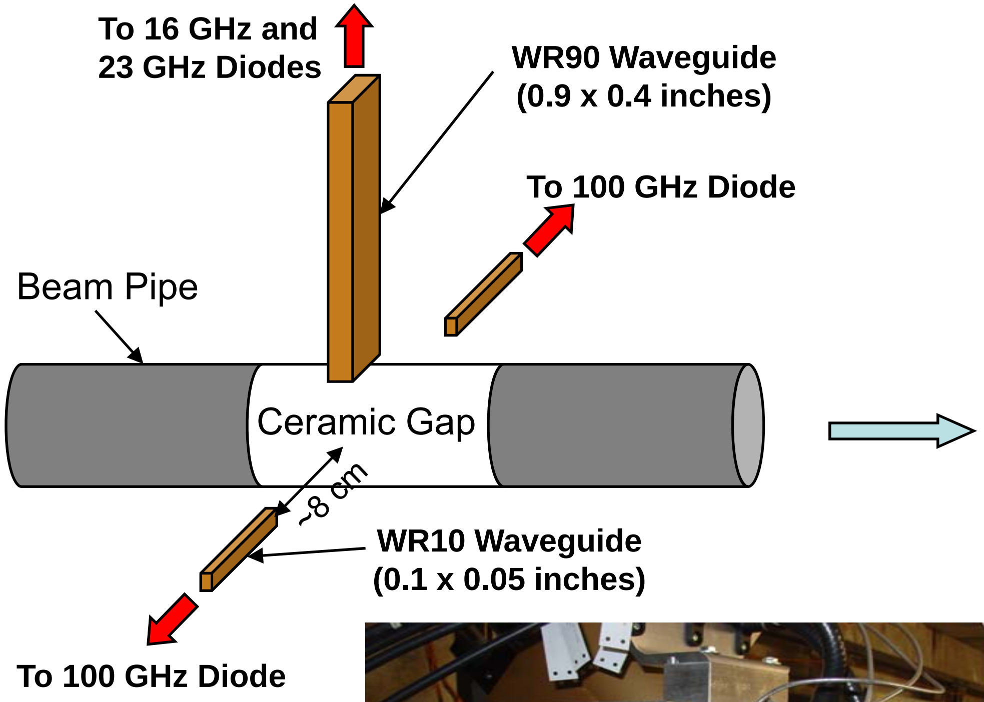
EMI Measurements near ceramic gap

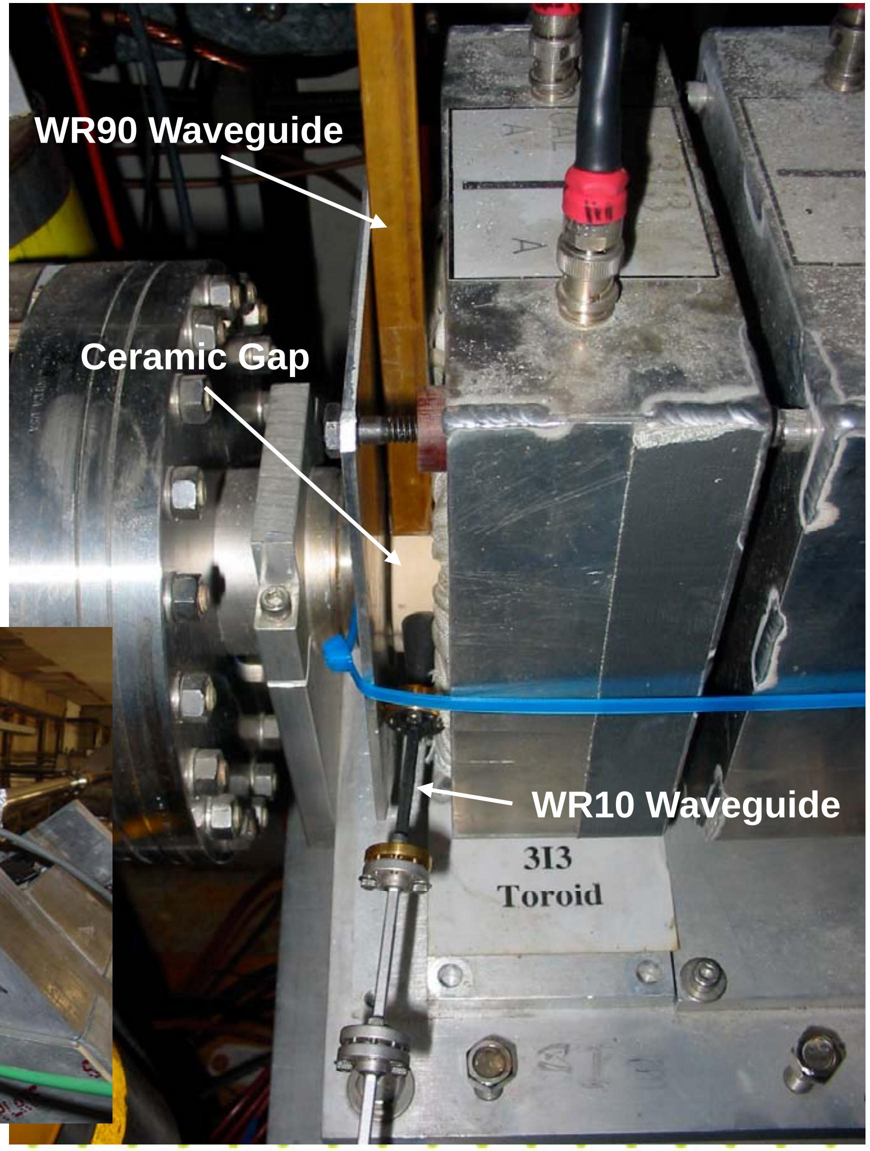


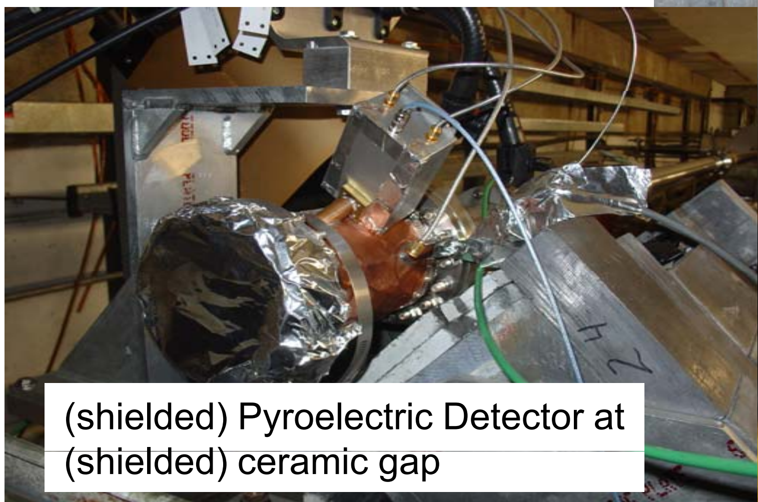


- Antennas placed near (~1 m) gaps observed EMI up to ~20 V/m.
- Pulse shapes are very stable over widely varying beam conditions, indicating they are determined by the geometry of beam line elements.
- Pulse amplitudes varied in proportion to the bunch charge but were independent of the bunch length. Observe ~1/r dependence on distance from gap.

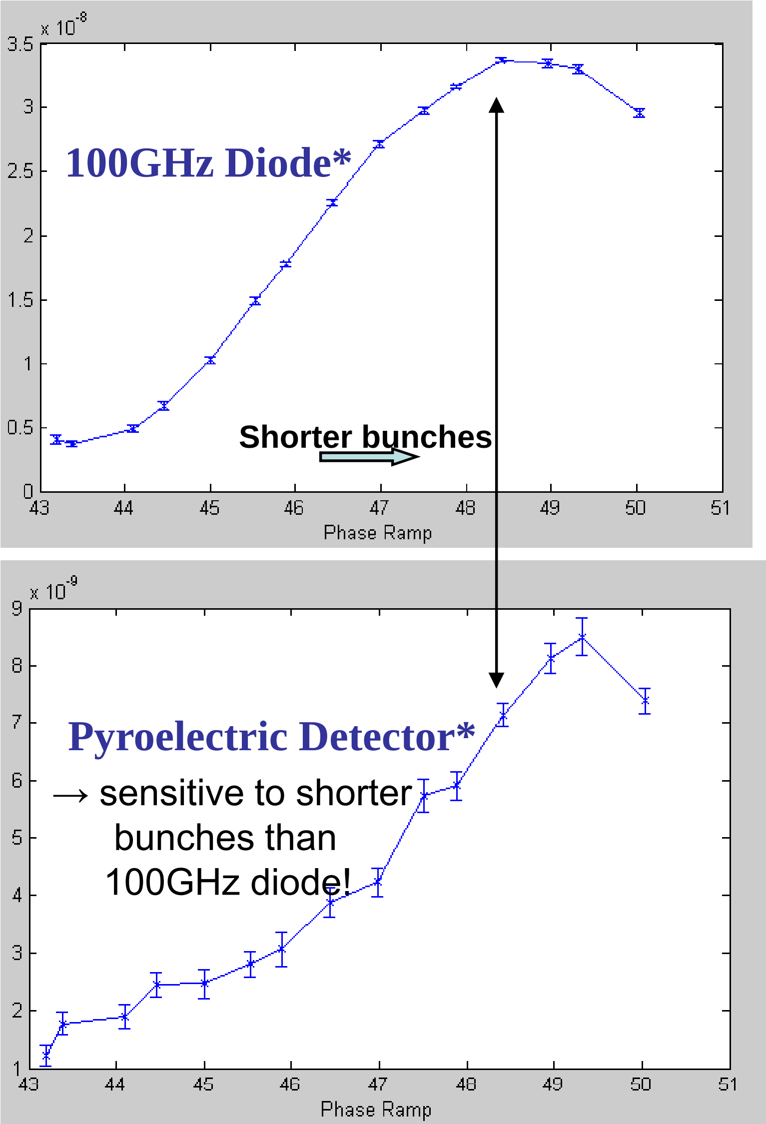
RF Bunch Length Detectors in ESA





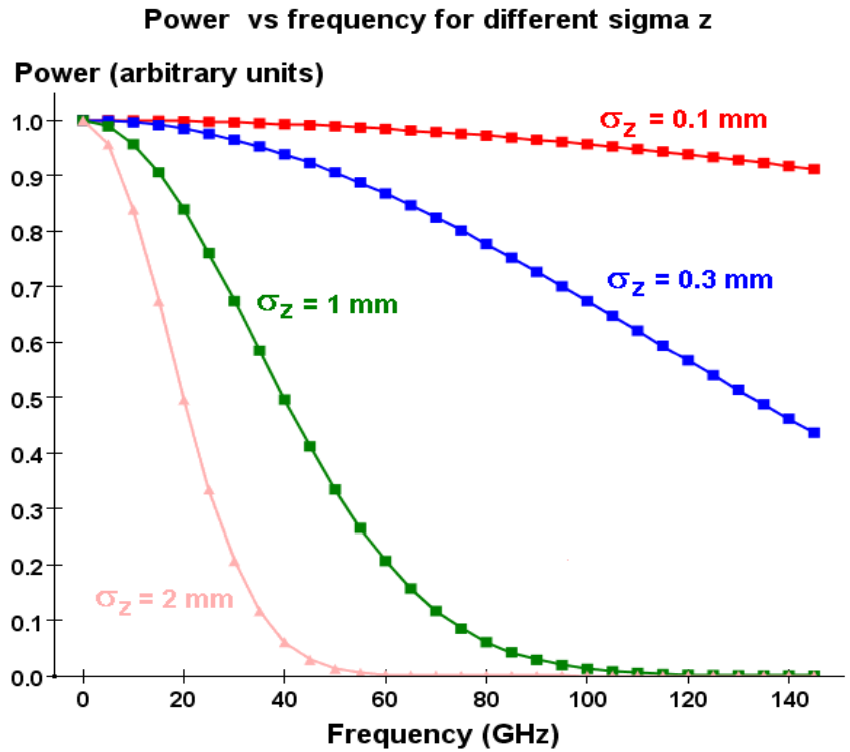


Bunch Length Measurements vs Linac rf Phase



Radiated Power Spectrum at Ceramic Gap

$$P(\omega) \propto Q^2 \cdot \exp\left(-\frac{\omega^2 \sigma_z^2}{c^2}\right)$$



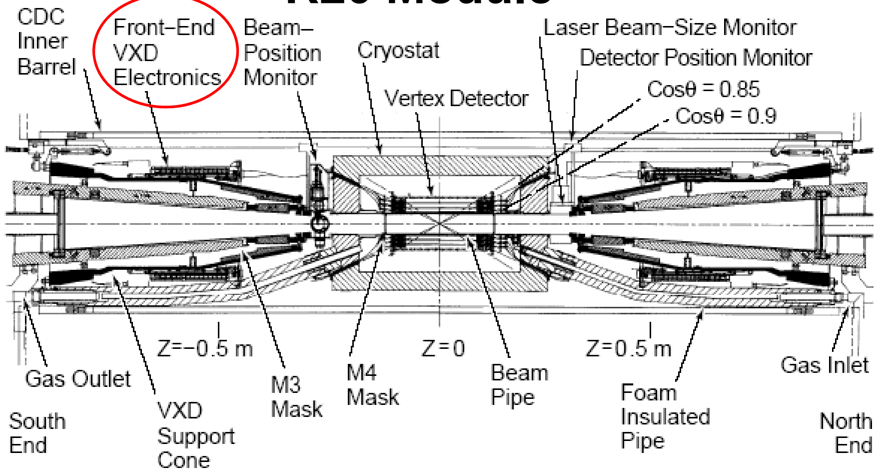
From our observations:

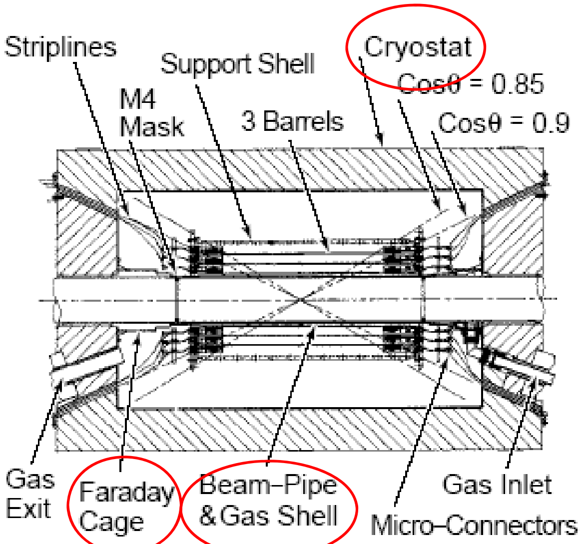
23GHz Diode was insensitive to bunch length

(phase ramp determines relative timing of beam wrt accelerator rf)

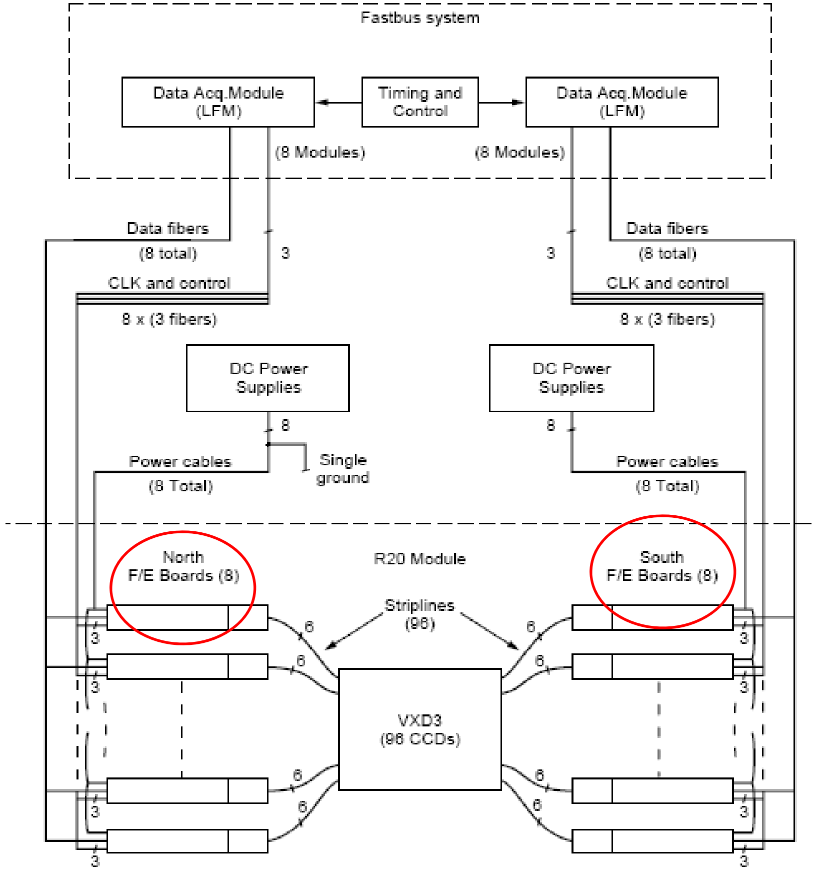
SLD Vertex Detector

R20 Module

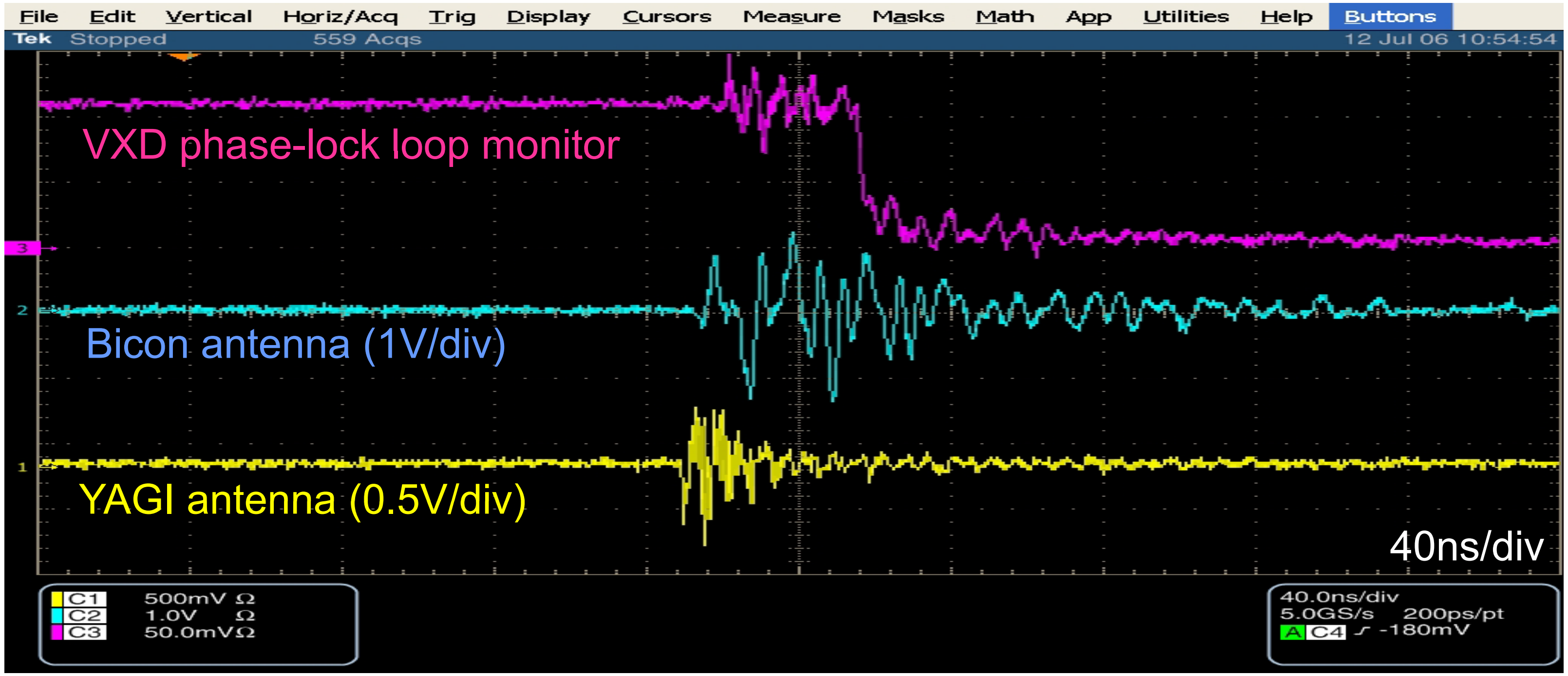




Electronics



SLD VXD electronics studies



→ VXD front-end electronics placed near ceramic gap. When exposed to sufficient EMI the phase-lock loop monitor signal drops.

- Phase lock loop lost lock on about 85% of beam crossings when the module was at location where antenna observed ~20 V/m (YAGI measurement on 2.5GHz bandwidth scope)
- Phase lock loop lost lock failure rate drops to 5% at ~1 V/m signal from antenna.

VXD electronics failures: observations

EMI Shielding Tests, July 2006

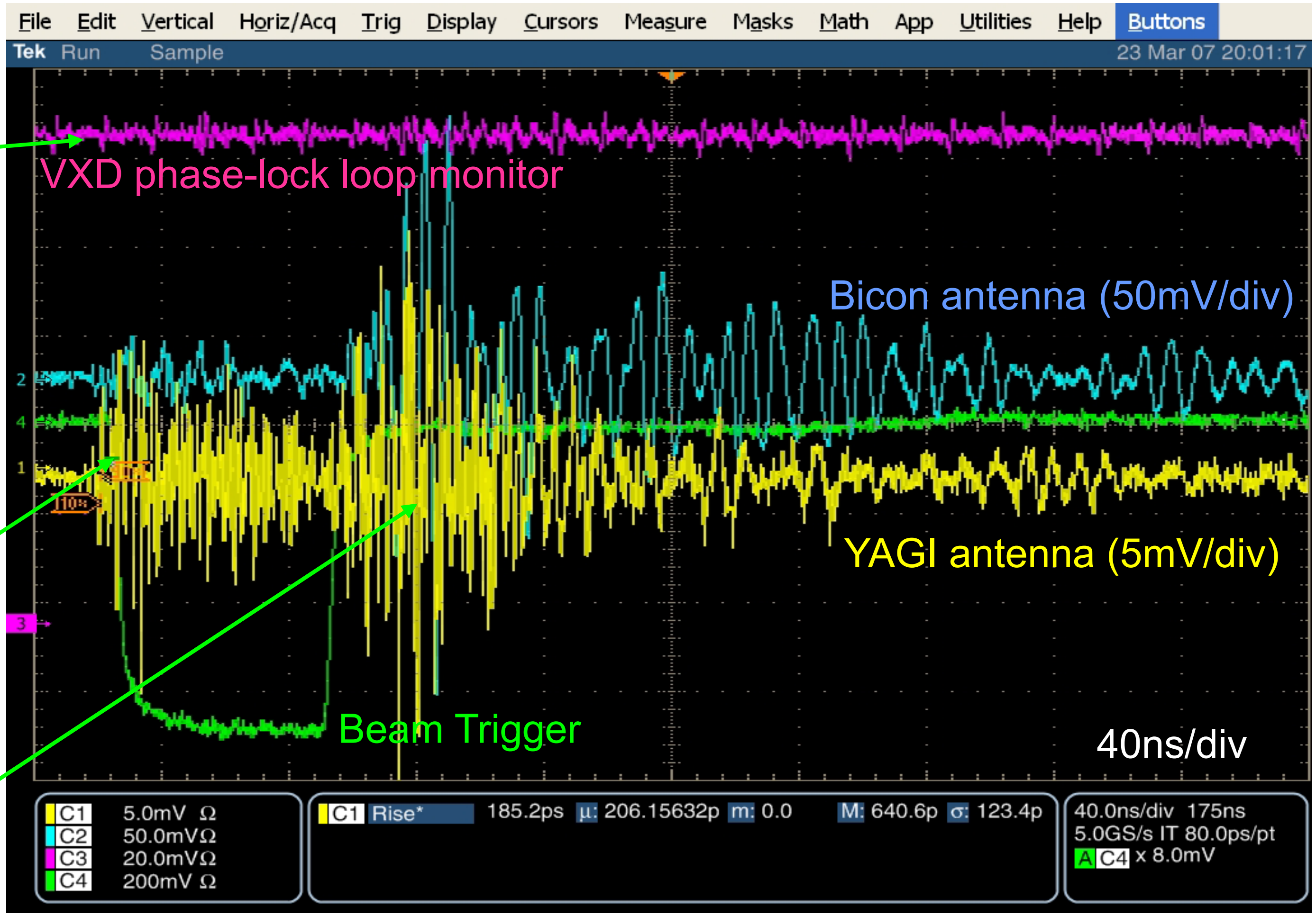
- Placing just the VXD board inside an aluminum foil shielded box stopped the failures.
- Covering the gap also stopped failures.
  - ➢ failures not due to ground loops or EMI on power/signal cables
  - ➢ failures are due to EMI emitted by gap
  - ➢ what frequencies are important?

EMI Shielding Tests, March 2007

- A single layer of common 5mil aluminum foil was placed over the ceramic gap and clamped at both ends to provide an image current path.
- The antenna signal amplitude was reduced by >x10. (We could not say if it disappeared completely because of upstream signal pickup)
- The aluminum foil gap cover stopped VXD failures.
- A 1 cm x 1 cm hole in the gap foil cover emitted enough EMI to cause about 50% VXD failure rate at ~1m distance. (With no foil rate would be 100% at this distance.)
- There was no failure with a 0.6 cm x 0.6 cm hole.

Antenna Signals, gap covered with Al foil

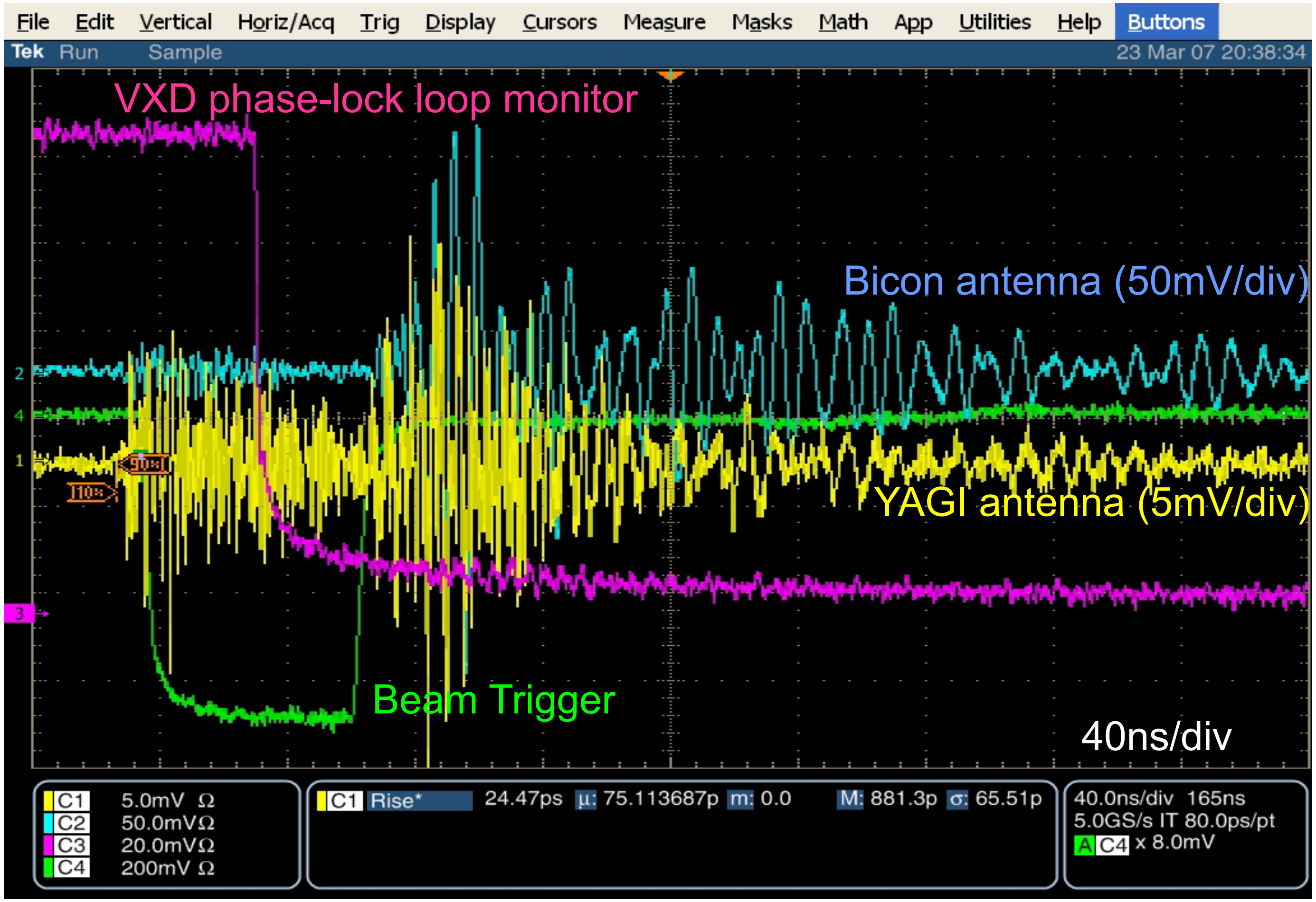
no failures



EMI from upstream gaps

EMI from gaps (toroids, …) downstream

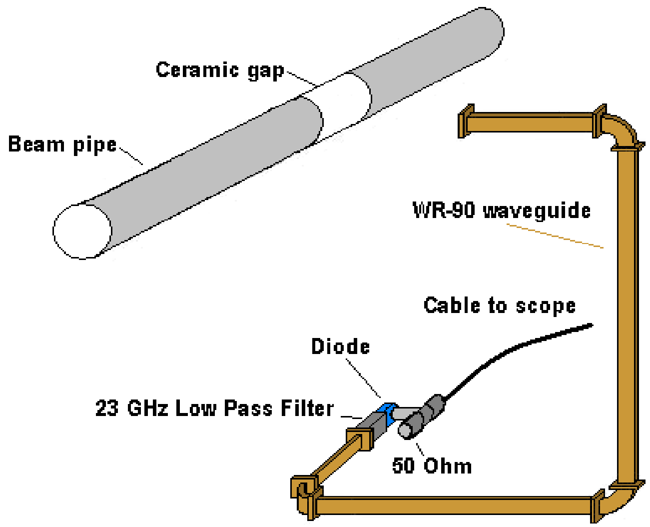
Antenna Signals, $1cm^2$ gap in foil



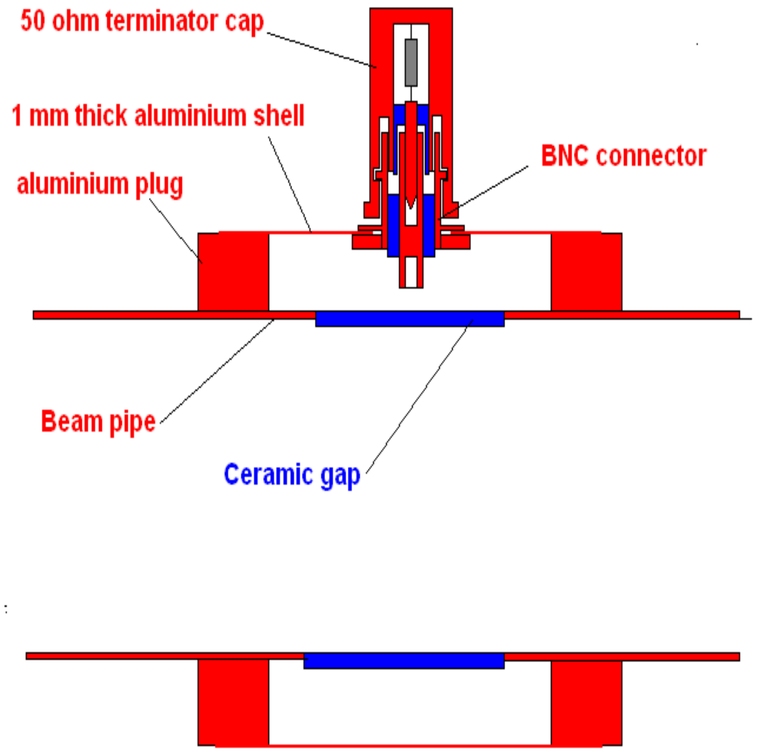
→ observe VXD electronics failure, but little change in antenna signals

→ indicates VXD electronics sensitive to EMI at higher frequencies than seen by YAGI; dimensions indicate sensitivity at ~30GHz

July 2007 run- setup

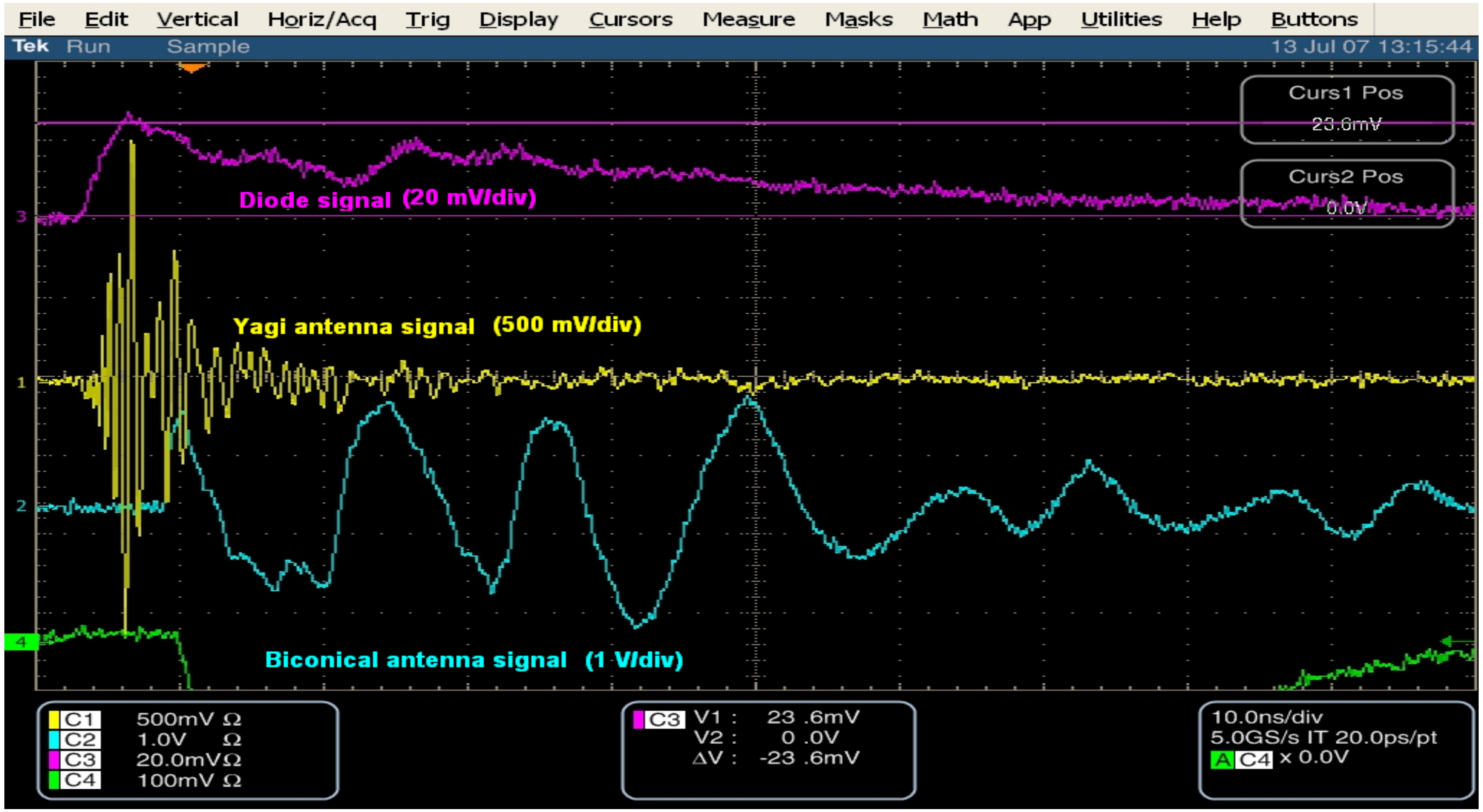


20 GHz diode setup for EMI measurements. The gap was either open, or covered with aluminum foil, or covered with “clamshell” shown on next picture



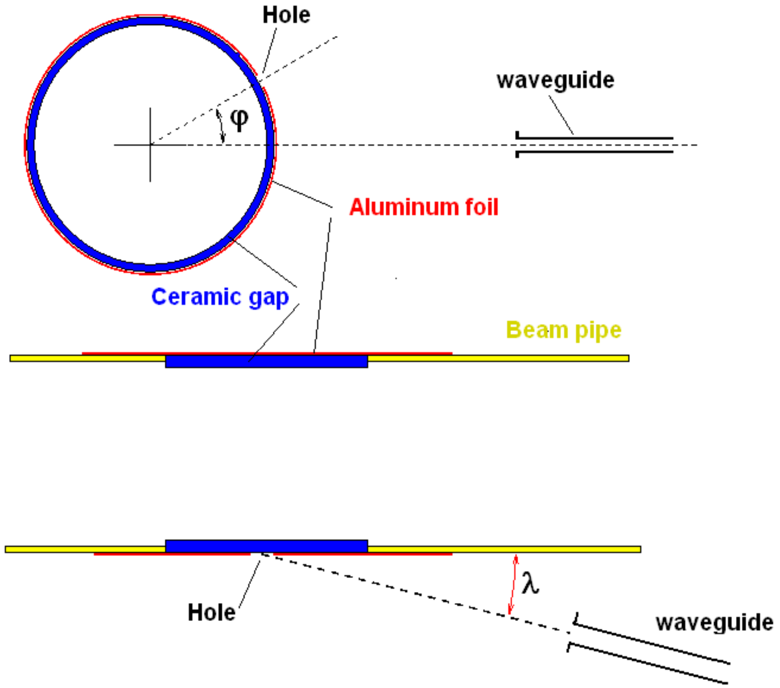
Cross section of beam pipe with gap covered with “clamshell” with BNC connector. Red color is metal, blue – insulator.

Experiment with 20 HGz diode



Here is the signal from diode (as well as from antennas) for uncovered ceramic gap. The diode signal from gap covered with aluminum foil with 1cm x 1cm hole was only 2 times smaller! The signal, leaking from BNC connector capped by 50 ohm terminator was about 1 mV.

Angle dependence



- With uncovered ceramic gap we observed strong dependence of the diode signal on polar angle λ – at 30º signal was 6 time larger than at 90º .
- With gap covered with foil, having small (1cm x 1cm) hole, there was strong φ dependence – signal dropped almost to 0 at φ=90º, but very weak λ dependence – in fact, signal now had maximum at λ=90º .

EMI leaking through connector

- With BNC connector inserted in the hole in "clamshell" (as shown on slide 14), the signal from diode still was seen (at 1.4 mV level). Surprisingly, this signal did not change when connector was capped with 50 ohm terminator, though terminator body is all metal.
- However, wrapping connector with aluminum foil eliminated signal.

Electronics was sensitive to EMI leaking from connector !

- When VXD3 electronics board was placed close to terminated BNC connector, it still failed pretty often (about 80% of beam passing). However, wrapping connector with foil stopped failure completely !

Conclusions

- EMI can be the problem for electronics, if proper care is not taken
- EMI can escape from beam pipe through very small holes
- Careful covering of all such holes with metal shield can stop EMI.
- RF connectors penetrating beam pipe may be the source of EMI.
- Standards need to be developed for stray RF field limits and electronics sensitivity to it

Future plans

- We want to try to reproduce failure by exposing VXD board to RF field from controllable source (generator).
- We want to check if “good” RF connector will not leak EMI.
- We want to check if EMI is not leaking through coaxial cables.
- It would be interesting to investigate higher frequency (100 GHz and beyond?) EMI.