Beam induced EMI and detector electronics

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The problem

- Since the advent of short bunch length colliders in the 70s, the effect of beam induced EMI on proximate detector electronics has been a worry.
- There have a been a few cases where it may have played a role.
- There have been some limited and inconclusive efforts at exploring the problem
- But it is a difficult situation to study.

Beam induced EMI

- EMI = ElectroMagnetic Interfence in the form of RF radiation.
- E&M theory predicts a moving bunch charge creates dynamic EM fields.
- In the proximity of matter (eg, accelerator beam pipe elements), these fields are complex in structure.

Calculating EMI

- In principle Maxwell's equations give a complete description of EMI for any situation.
- In practice, both analytic calculations and even computer beam codes are very complex and difficult to use to understand a realistic beam line situation.
- They can however provide a crude understanding of phenomena.

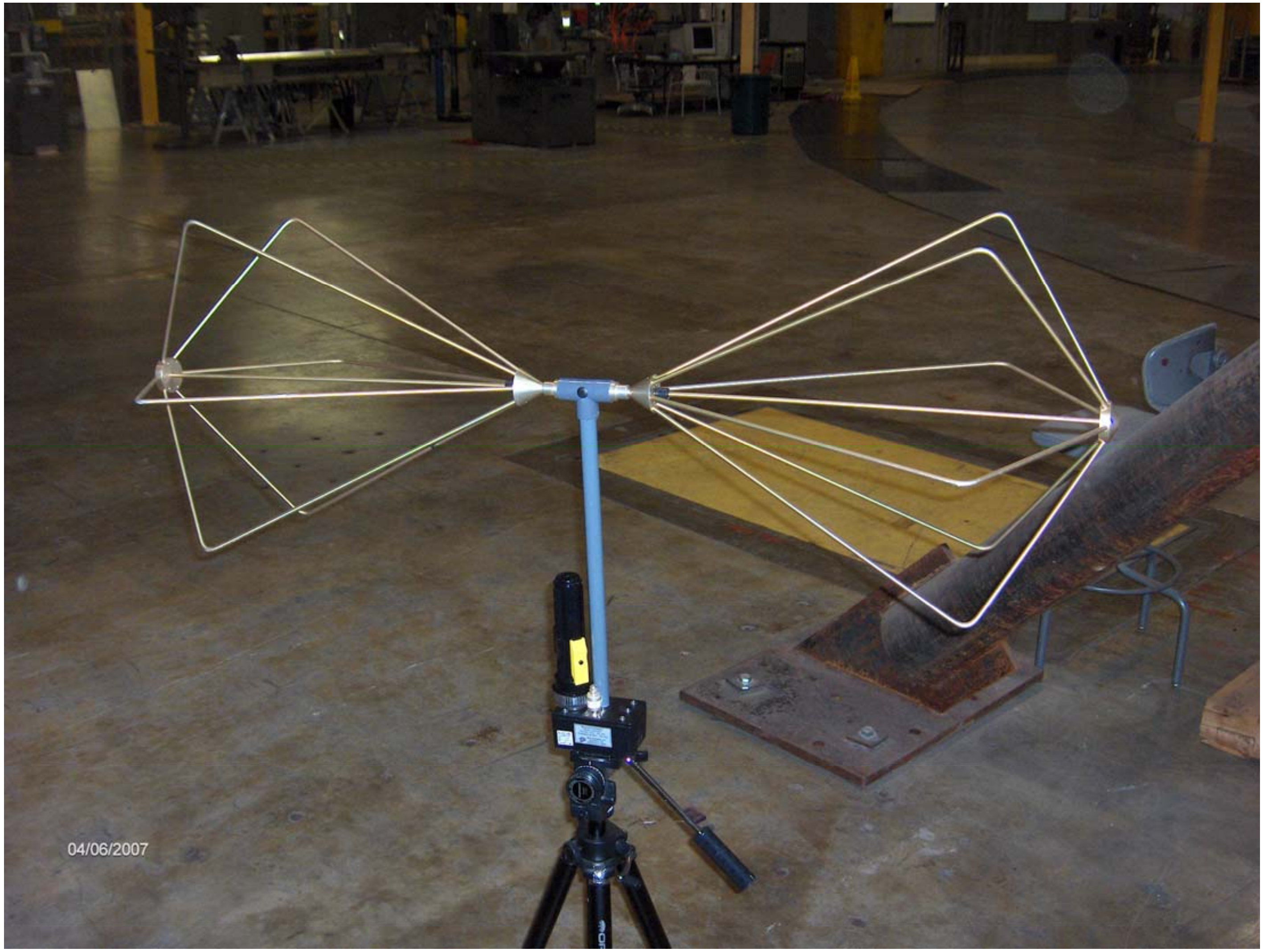
Measuring EMI

- In principle it is possible to measure beam induced EMI.
- In practice giving a complete characterization is challenging.
- The RF frequency range of potential interest covers many orders of magnitude.
- Individual antennas have limited range.
- Scopes have limited resolution.

The tools used at SLAC ESA

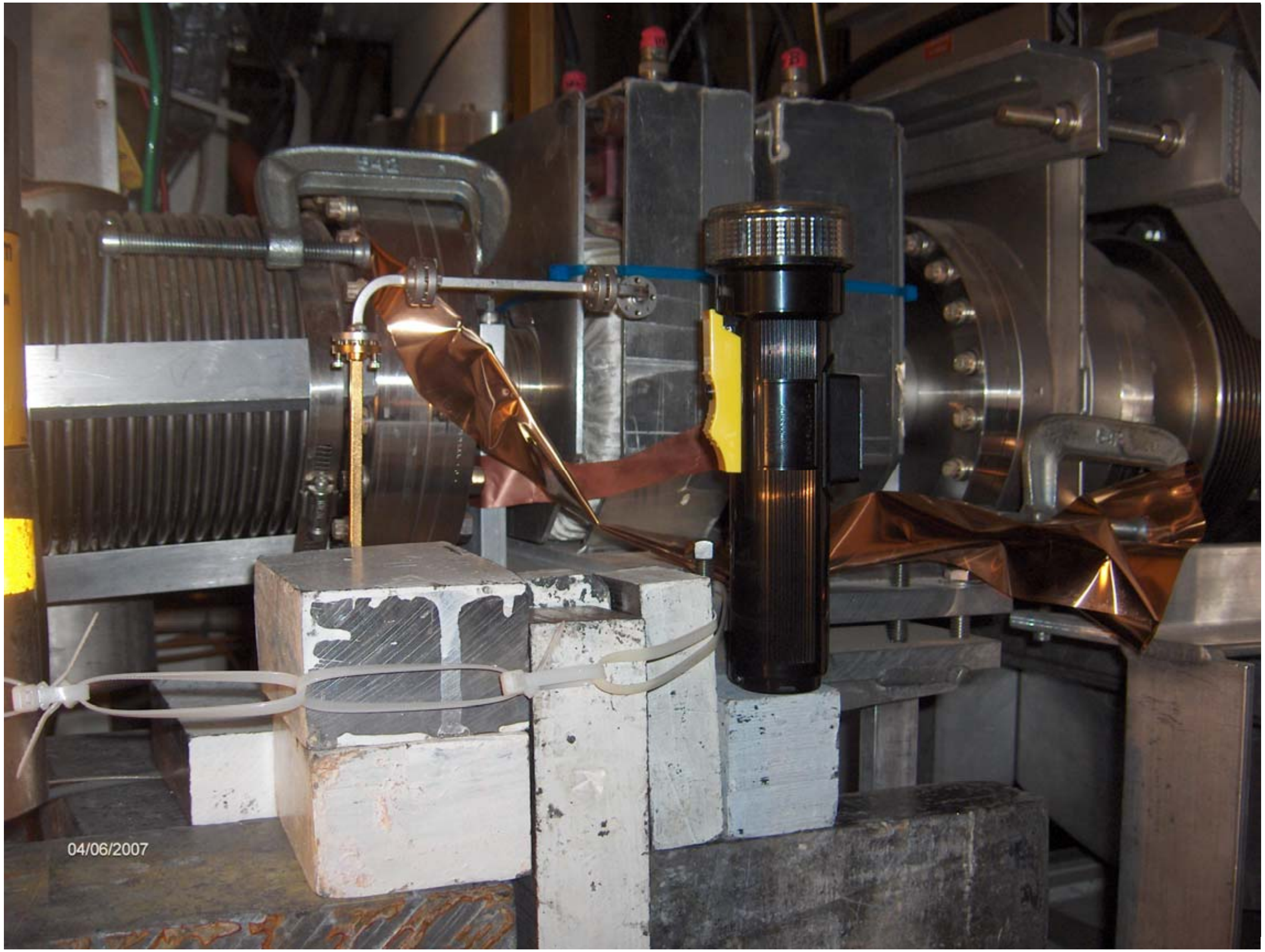
- Two RF antennas sensitive in the high MHz to very low GHz range.
- An HP digital scope with resolution in the very low GHz range.
- A few specially designed narrow band pass antenna for 30GHz, 100GHz and 300GHz.
- An electronics module from the SLD Vertex detector that may have suffered from EMI during the run at SLC.

Biconical antenna



Yagi antenna

RF horn antenna

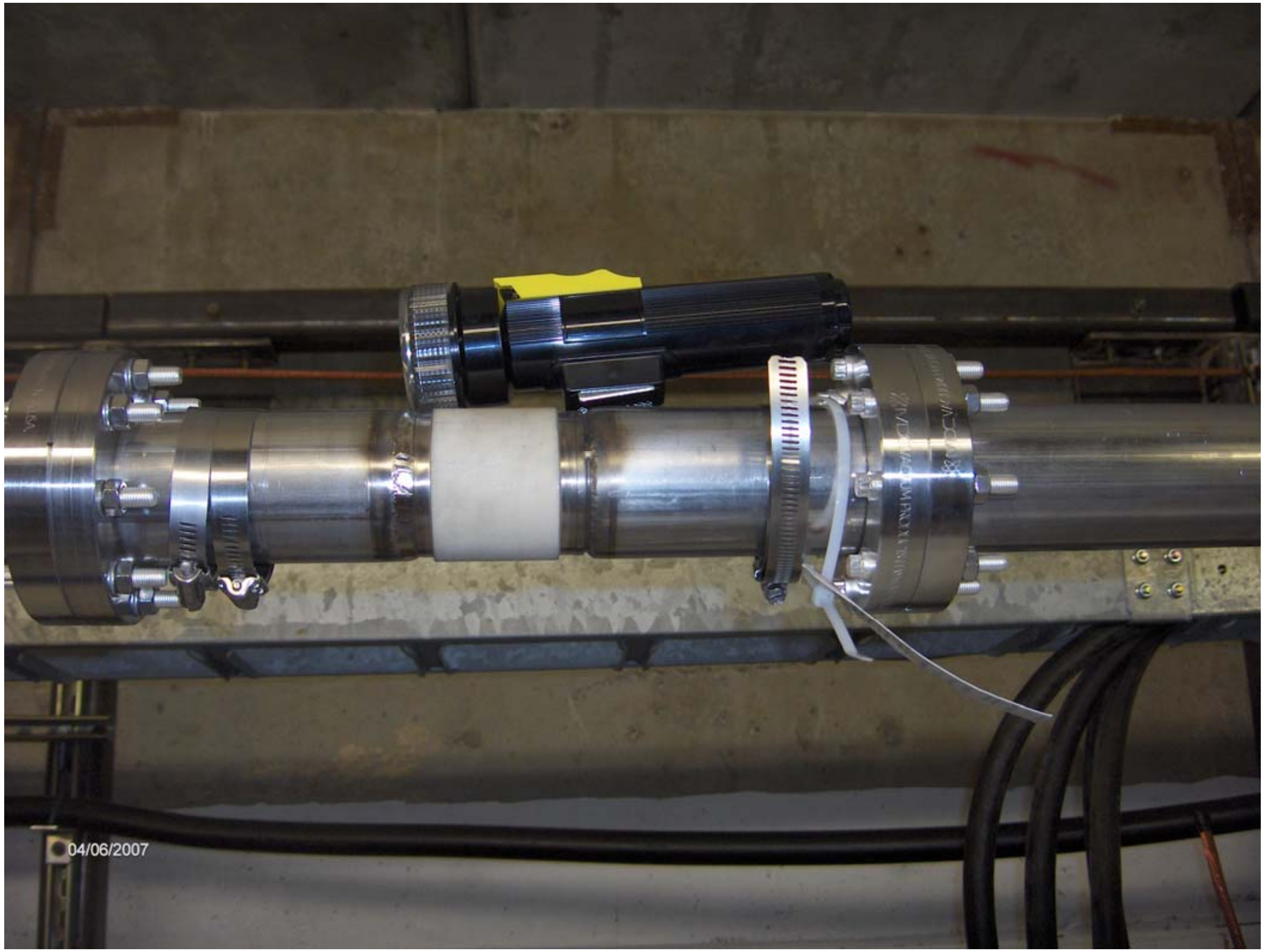


SLD VXD electronics board

Beam line EMI emitting “gaps”

- EM fields within the (conducting) beam pipe are contained by the small skin depth.
- However, any dielectric gap can emit EM radiation out of the beam pipe.
- Common “gaps” are camera windows, BPM feedthroughs, toroid gaps, etc.

Ceramic gap



The ESA beam line

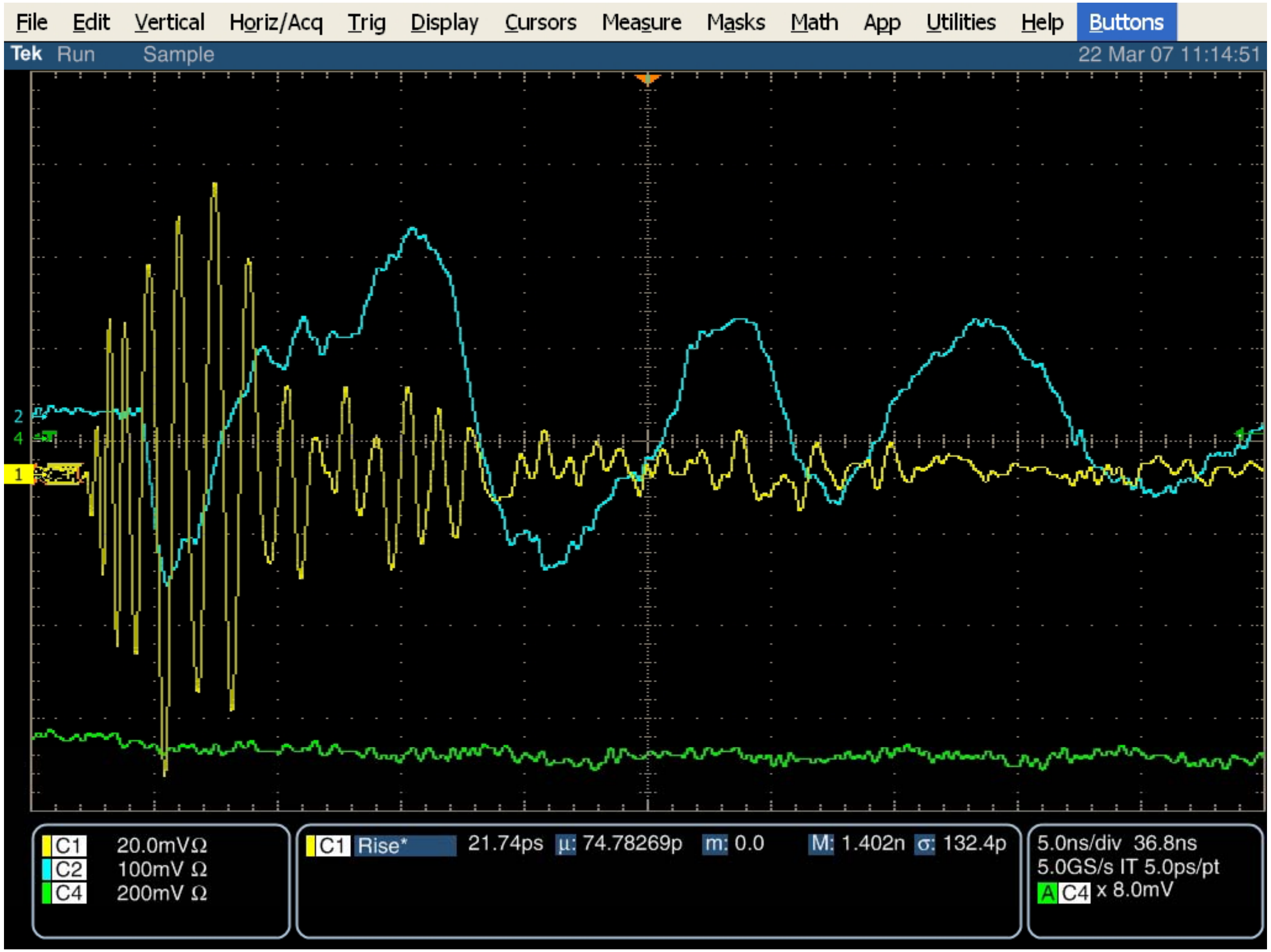
- The SLAC ESA ILC program consists of approximately nine independent test beam experiments, including the EMI study.
- There have been three runs of about 2.5 weeks each.
- Beam time has been shared between the different projects.
- Unlike the others the EMI project requires frequent accesses to rearrange resources.
- In the last run EMI had 13 accesses.

Beam line

Observed EMI in ESA

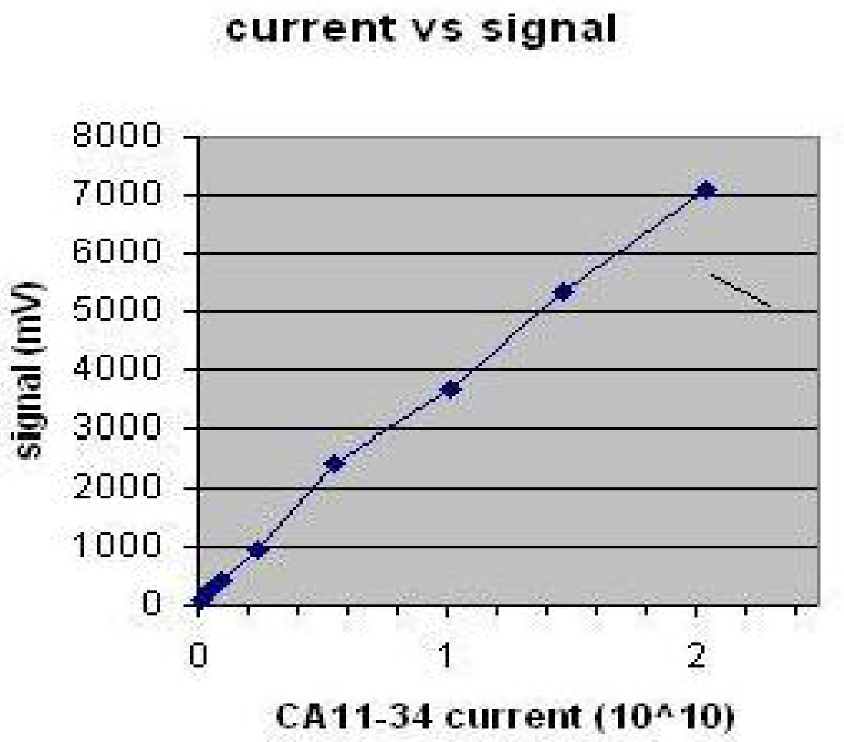
- Antennas placed near (~1 m) gaps observed pulses of EMI in the high MHz range with strengths up to ~20 V/m.
- The pulse shapes are very stable over widely varying beam conditions indicating they are determined by the geometry of the beam line elements.
- The pulse amplitudes varied in proportion to the bunch charge but were independent of the bunch length.

Pulse shape (yagi, bicon)



Data: E vs charge

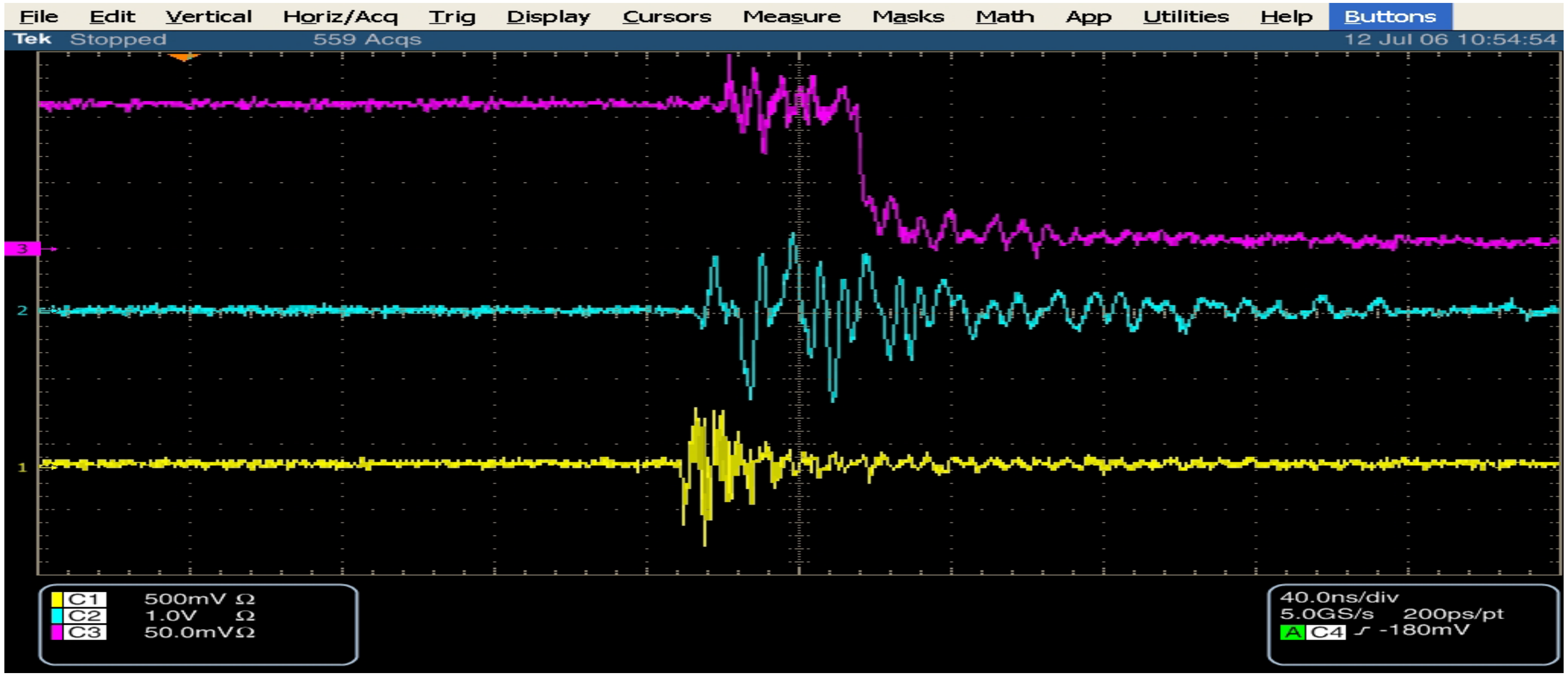
- Plot shows linear relation as predicted.



VXD electronics results

- One vertex detector readout module from SLD was placed near the beam line.
- A “ready” signal was monitored that had been an indicator of momentary board failure during SLC running.
- When exposed to sufficient EMI the ready signal dropped.

VXD phase lock loop drops



Top trace: VXD board phase-lock loop signal

Other traces: the two EMI antennas.

Time offsets are due to cable length differences.

Was “airborne” EMI the culprit?

- Or was it image current coupling, ground faults, etc?
- The rate of failure declined as VXD was moved further away from the source and antennas confirmed the EMI amplitude declined.
- Placing just the VXD board inside an aluminum foil shielded box stopped the failures.
- Covering the gap also stopped failures.

VXD failure rate vs EMI strength

- The VXD module phase lock loop lost lock on about 85% of beam crossing when the module was exposed to ~20 V/m of EMI.
- The VXD module lost lock about 5% when exposed to ~1 V/m of EMI.
- That was what we thought we learned from run in May of 2006. However, 2007 run has shown, that signal seen in antennas is not the signal, causing failure

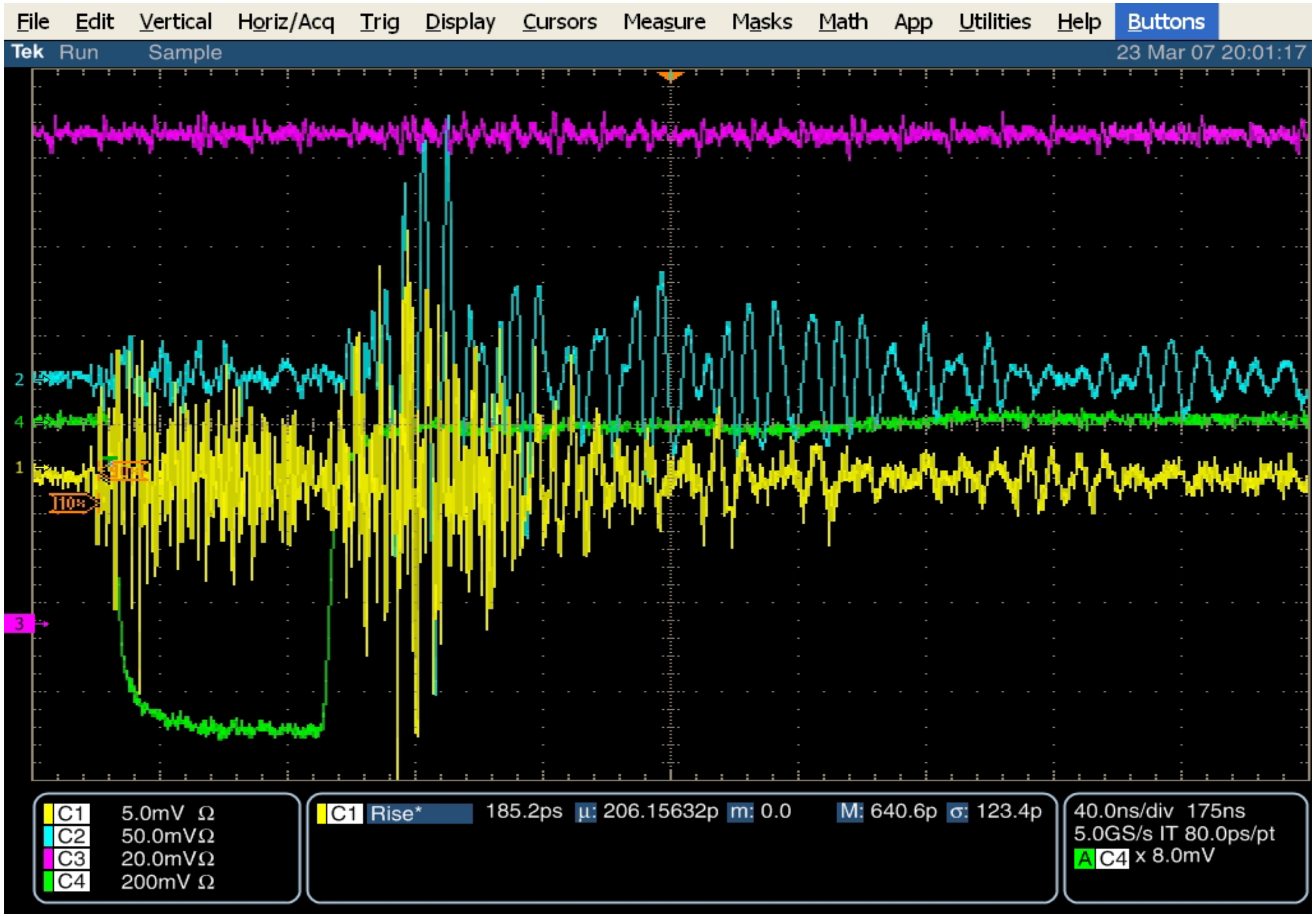
Recent shielding experiments

- 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 signal amplitude was reduced by >x10.
- EMI from upstream sources limited the resolution.

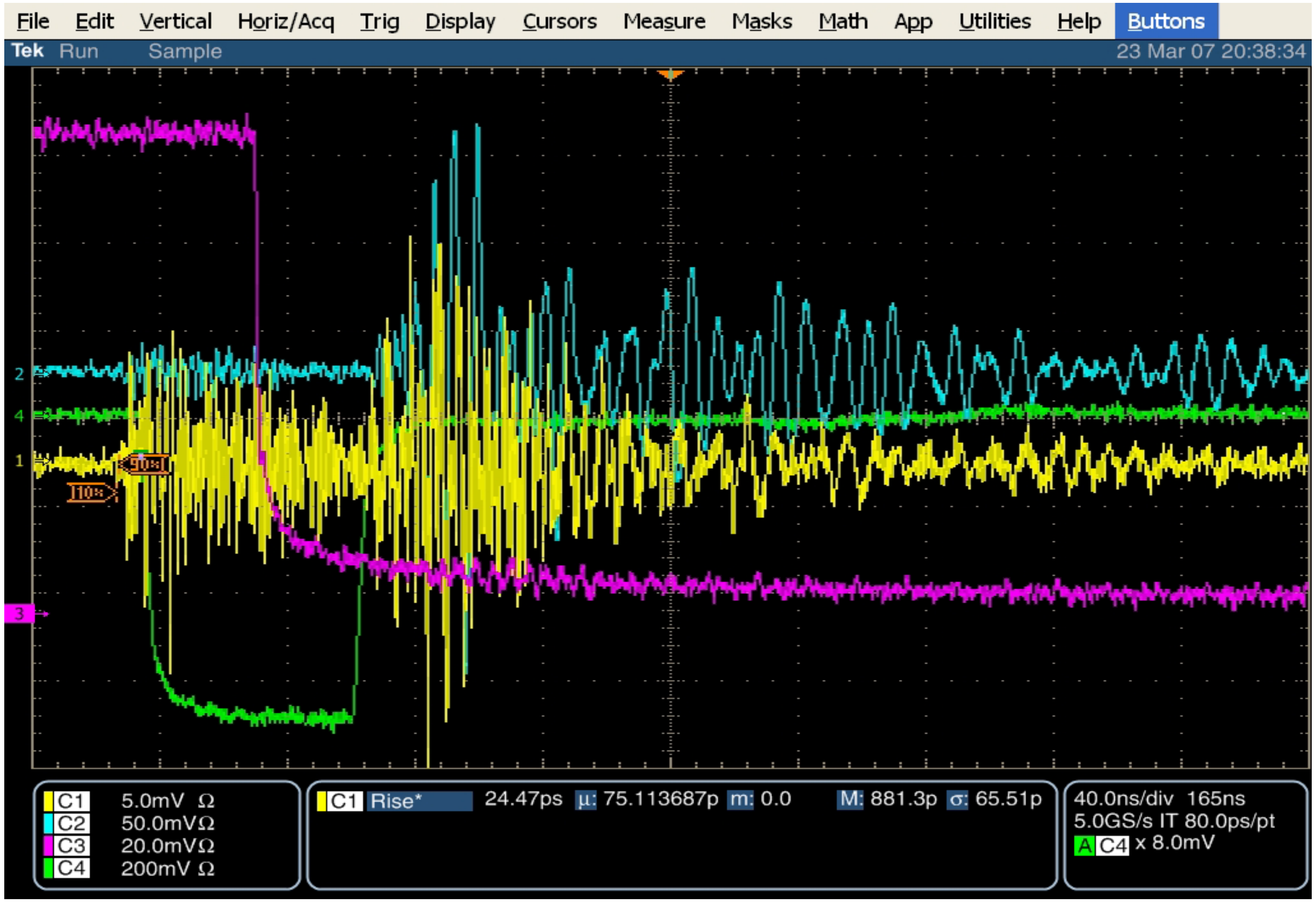
Shielding and VXD

- 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.

Antennas signals with gap covered with foil



Failure with 1 cm^2 hole in foil



Hole results interpretations

- Did the larger hole induce failure because it emitted an overall stronger EMI signal?
- Did the larger hole induce failure because it emitted a stronger signal at a lower wavelength?
- If the latter is true then the hole dimensions suggests ~30GHz is a critical frequency for VXD.

What have we learned?

- Results so far suggest that significant amounts of EMI can be common at short bunch length accelerators.
- To observe all EMI signals, very high frequency antennas and registration system required.
- Electronics operations can be disrupted by very high frequency signals (not seen with antenna/scope)
- Such signals can be generated whenever small (~1 cm^2) hole is present in the beam pipe.
- There have been very few instances where EMI was suspected of being a problem for electronics over 30+ years. So EMI sensitivity is the feature of specific electronics design.

Next steps

- Which of the two “hole” interpretations is correct?
- Explore counter-intuitive observation that partial shielding increased EMI???
- Explore methods of shielding beam line emission sources for use at ILC.
- Try to understand why VXD is failing to avoid a similar problem at ILC.