Bob as a Mentor at Cornell (and later at Fermilab)

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Cornell Timeline with Bob

- Autumn of 1981 – Bob was assigned as my faculty advisor upon starting my graduate studies at Cornell.
- First year studies in1981/82 – Suffered through 510 Lab, the only required graduate course for physics (that was also Bob's pride and joy) and a literal right of passage.
- Summer of 1982 – I asked Bob if he would be my thesis advisor in accelerator physics. Worked for Bob that summer and started in earnest the following summer.
- April 1986 – I departed Cornell after finishing my thesis research, while waiting for Bob to change each page of my draft thesis into red-colored modern art.

Post-Cornell Timeline with Bob

- ~1988 – Bob comes to Fermilab to work on Tevatron Collider emittance growth, beam instrumentation, and to help expand and finish my thesis.
- June 21 to July 2, 1993 – Bob, Jacob Flanz of Mass. Gen. Hospital, and I teach the first USPAS laboratory class at MIT Bates. I serve on Bob's program committee.
- 1994 to 1995 – Bob is program chair of the 1995 PAC, and I am on his committee. Bob initiated electronic paper submission and proceedings publishing.
- 2000 to 2001 – Bob helps me (and PAC2001 and APS DPB) with gaining IEEE electronic publishing permission.
- 2002 to 2003 – Bob is conference chair of the 2003 PAC, and I am on his program committee.

Accelerator Physics Training at Cornell

- When it came to accelerator physics education, Bob emphasized a formula:
  - Translation of physics theory into simulations
  - Implementation of existing beam diagnostics as simulation outputs
  - If existing beam diagnostics were inadequate, innovate new detectors and/or processing hardware/software
  - Use of simulations as predictions for accelerator experiments
  - If simulations were too slow to run enough particles or turns or terms, improve the simulations through the development of better algorithms, computer hardware, or acquire access to better computers.
  - Publish scientifically significant papers : comparison of theory with experiments using simulations as the bridge

Computer simulation is a tool for studying beam stability which complements theoretical and experimental work, and in the case of future storage rings it can play the role of experimental observations.

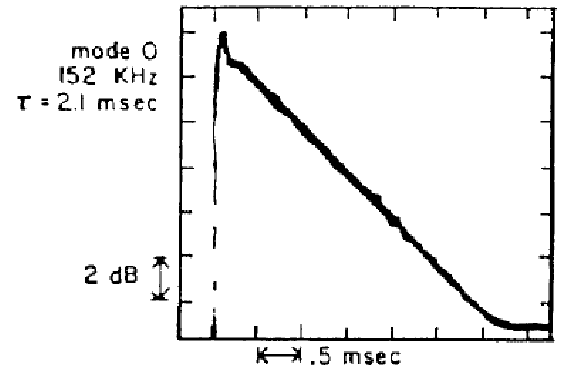
Beam Instability Simulations

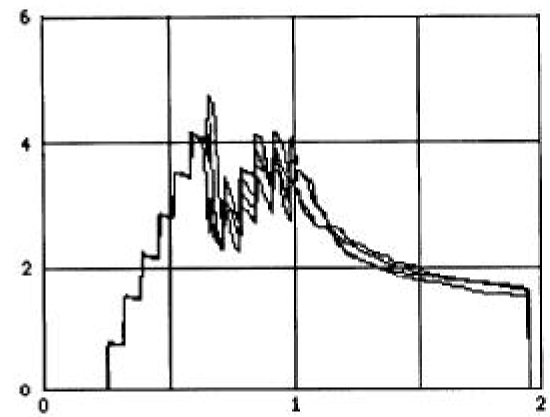
- My first summer working for Bob involved learning to run his single beam stability simulation program. He applied his program to CESR, PEP, and PETRA.
- Bob had a graduate student Bob Meller at this time. Because of their effect on operations, the CESR staff was diligently working on instability problems. In typical fashion, the entire laboratory was involved.
- References
  - R.H. Siemann, "Computer Simulation Studies of Single Beam Stability", IEEE Trans. Nucl. Sci., Vol. NS-30, No. 4, 2373 (1983).
  - D. Rice, et. al., "Single Bunch Current Dependent Phenomena in CESR", IEEE Trans. Nucl. Sci., Vol. NS-28, No. 3, 2446 (1981).
  - J. Seeman, et. al., "A Single Beam Multibunch Instability at CESR", IEEE Trans. Nucl. Sci., Vol. NS-28, No. 3, 2561 (1981)

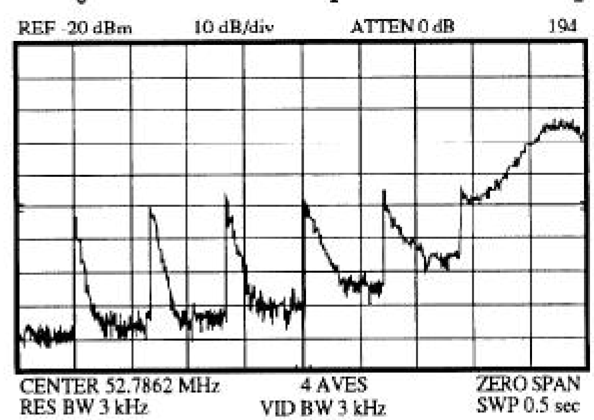
Continued Instabilities

- This work at Cornell, and the expertise derived from it, greatly influenced the careers of those involved, including Bob's. It even influenced later work at Fermilab.
- References

  - L.E. Sakazaki, et. al., “”Anomalous,” Nonlinearly Current-Dependent Damping in CESR”, IEEE Trans. Nucl. Sci., Vol. NS-32, No. 5, 2353 (1985).
  - R. Siemann, “Theory, Simulation and Observation of Beams in Storage Rings”, USPAS Lecture (1988).
  - G. Jackson, “Measurement of the Resistive Wall Instability in the Fermilab Main Ring”, Proc. U.S. Part. Acc. Conf., 1755 (1991).





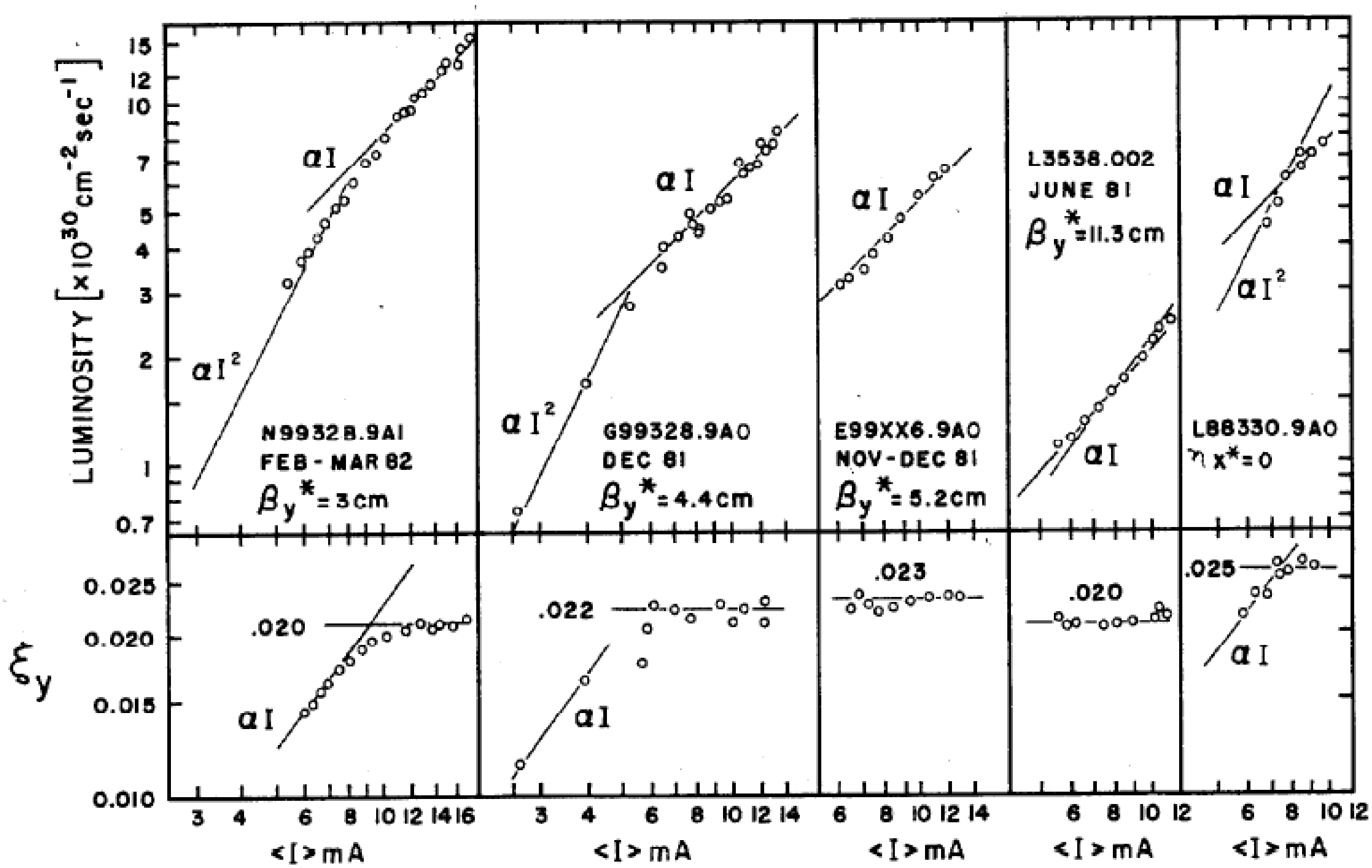


Early Beam-Beam Studies

- When Bob and I started discussing the topic of my thesis research in 1983, John Seeman had already made the key experimental observations that set the direction of future research (see the next slide). Theoretical studies of electron-positron limitations had already started.
- These studies, along with Bob's instability simulation program, served as the starting point for my thesis.
- References

  - R.E. Meller and R.H. Siemann, “Coherent Normal Modes of Colliding Beams”, IEEE Trans. Nucl. Sci., Vol. NS-28, No. 3, 2431 (1981).
  - J. Seeman, et. al., “Observation of the Beam-Beam Limit in CESR”, IEEE Trans. Nucl. Sci., Vol. NS-30, No. 4, 2033 (1983).
  - S.G. Peggs, “Beam-Beam Synchrobetatron Resonances”, IEEE Trans. Nucl. Sci., Vol. NS-30, No. 4, 2457 (1983).

Experimental Beam-Beam Evidence

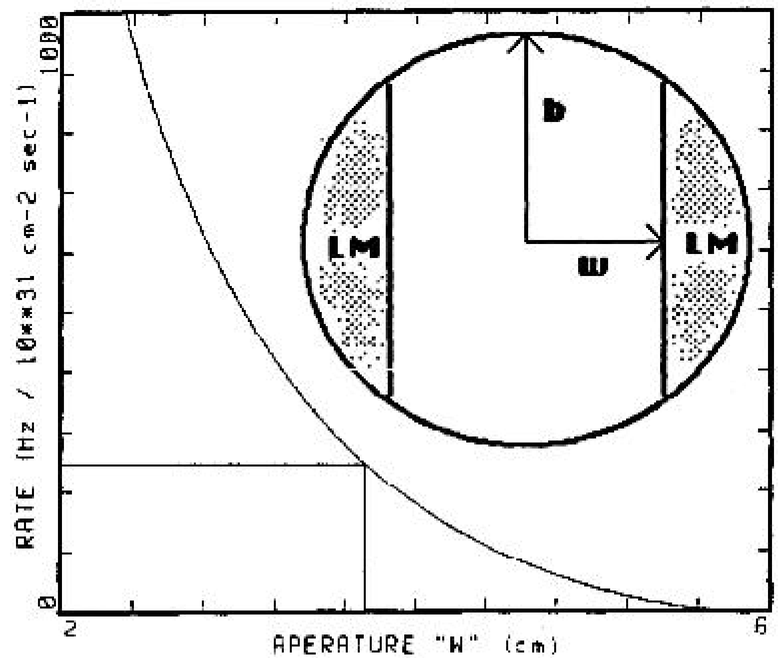


Bob's Simulation Expertise

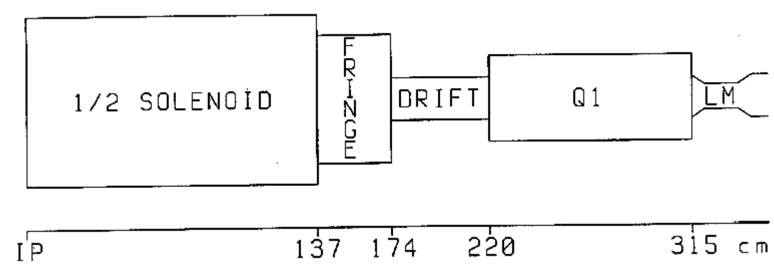
- Bob's instability simulation employed many innovative numerical techniques that were incorporated into my beam-beam simulations:
  - Digital filters to simulate beam detectors
  - Random number generators for a variety of probability distributions
  - Time to frequency domain transforms
  - Hermite polynomial expansions to simulate irregular bunch shapes
- He encouraged me to significantly improve the error function calculations drawn from Dick Talman's work.
- Understanding that correctly simulating beam size with random number excitations to simulate synchrotron radiation, we:
  - Used number theory to build faster uniform random number generators
  - Built a wire-wrapped PDP-11 memory-plane board that was a dedicated random number generator.

Beam Detector Improvements

- Bob believed that part of the job of an accelerator physicist was to design and build the instrumentation needed to understand the physics at work in an accelerator. He supported my need for faster (higher counting rate) luminosity monitors in the CLEO detector.

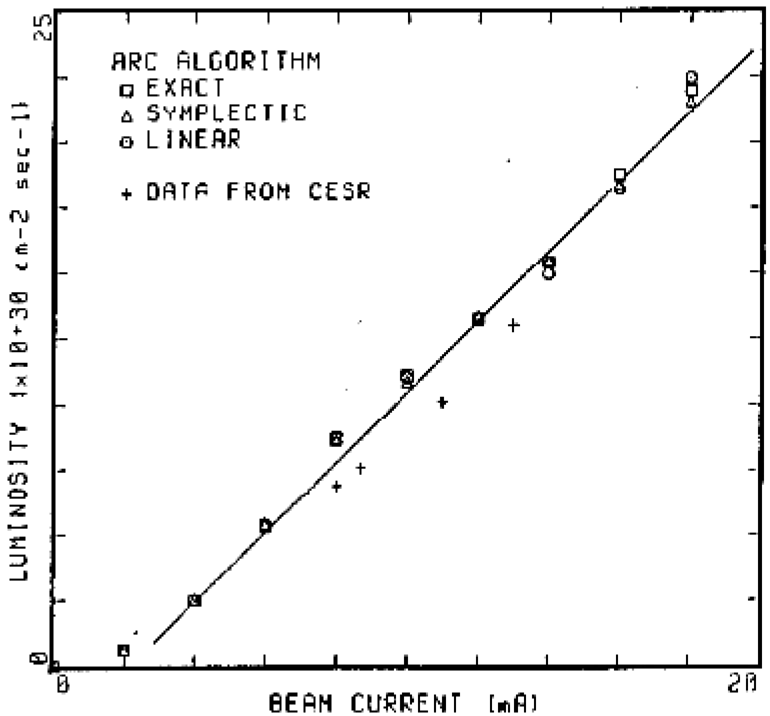


- References
  - G.P. Jackson and S.W. Herb, "Description of a High Rate Luminosity Monitor Installed at CESR", IEEE Trans. Nucl. Sci., Vol. NS-32, No. 5, 1925 (1985).



Predictions and Measurements

- The most stable period of CESR operations, with the least amount of competition for accelerator access, was the shift from 4am to noon. Though it was virtually impossible to arrive at the lab before Bob or leave after him, he eventually let me handle these shifts solo.

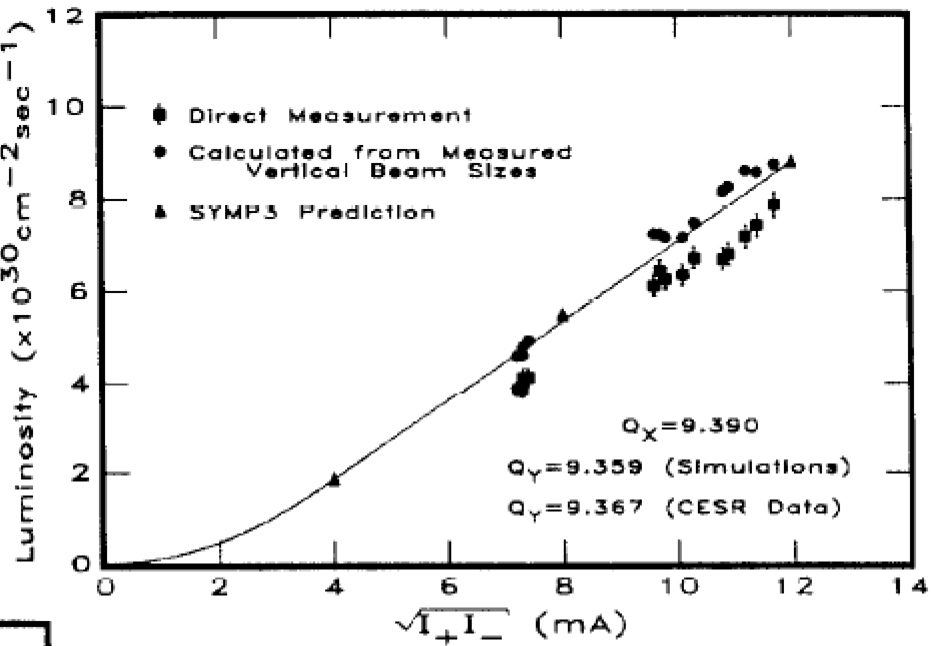


Note that the simulation was performed 3 different ways, with symplectic mapping algorithms provided by David Rubin.

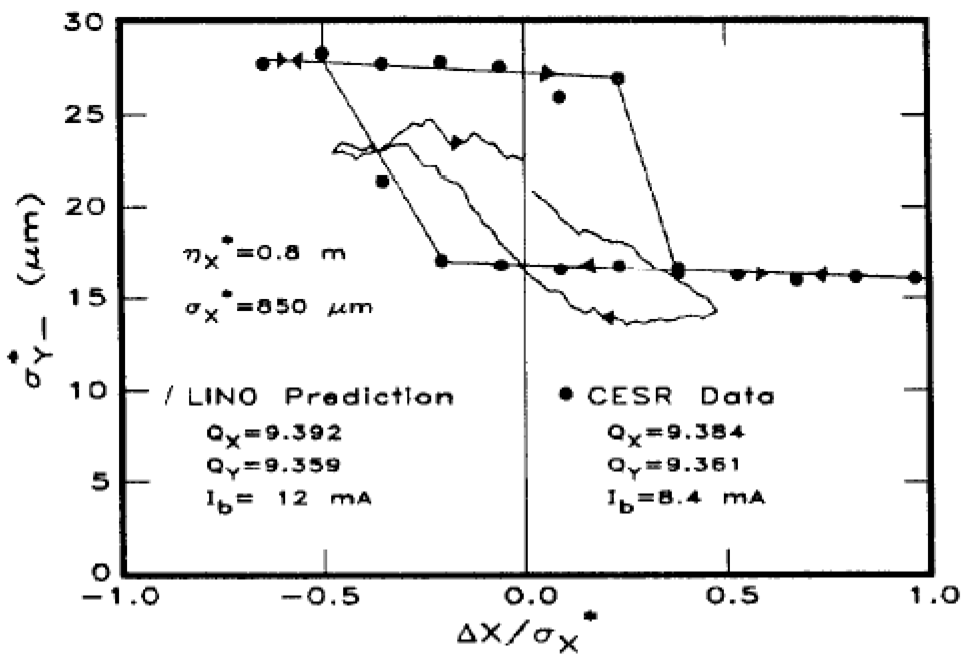
G.P. Jackson and R.H. Siemann, "A Computer Simulation Study of e+e- Storage Ring Performance as a Function of Sextupole Distribution", IEEE Trans. Nucl. Sci., Vol. NS-32, No. 5, 2541 (1985).

More Comparisons

Vertical size growth with beam current.



Flip-Flop Effect



G.P. Jackson and R.H. Siemann, "Comparison between the Simulated and Measured Luminosity Performance of CESR", Proc. U.S. Part. Acc. Conf., 1011 (1987).

Better Beam Height Measurements

- In addition to the CLEO and CUSB high energy physics experiments at the south and north interaction regions, there was also the CHESS synchrotron light facility operating in the CESR tunnel.
- Bob launched us into a measurement of vertical beam height using very hard x-rays measured by crystal collimators in CHESS. Rotating these collimators, not only could the beam size be determined, but also beam divergence. This was an independent measurement of the CESR beta function and the vertical emittance.
- References

  – G. Jackson, R. Siemann, and D. Mills, "Vertical Emittance Measurements of the CESR Electron Beam using Synchrotron Radiation", Proc. 12th International Conf. on High Energy Accelerators, Fermilab (1983), pg. 217.

Thinking in the Frequency Domain

- Probably the single most important technique I learned from Bob was the ability to think simultaneously in the time and frequency domain.
- At one point we were worried about synchrobetatron coupling via beam-beam interactions that were off-center longitudinally in the “hour-glass” vertical mini-beta.
- Filling CESR with a single electron and positron bunch of equal intensity, and plugging well surveyed beam position buttons on either side of the mini-beta into a spectrum analyzer, measurements of the frequency modulation yielded highly precise crossing-point positions with respect to the mini-beta quadrupoles.
- In the end we did not have to move the CESR RF cavities to correct the collision point.

Bob's Sabbatical at Fermilab

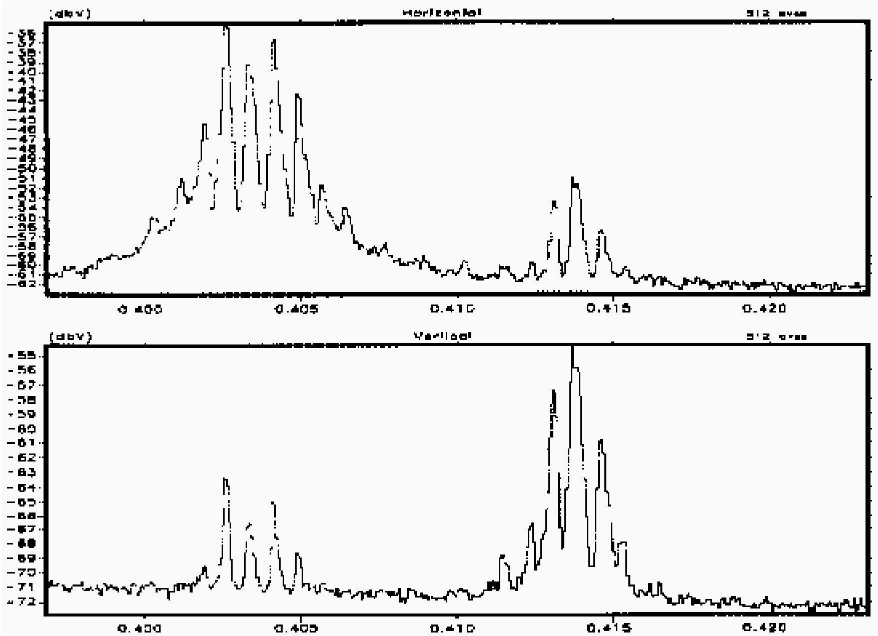
- Bob was very excited by all of the opportunities to learn new aspects of accelerator physics in hadron machines. We worked on instrumentation and machine studies diagnosing instabilities in the Main Ring and Tevatron.
- At the same time, Bob was involved with the SSC. While some of this time led to fulfilling diversions, such as the E778 experiment, much of that duty involved distasteful political incidents that caused Bob to recoil from similar positions in the future and to focus even more narrowly on students and accelerator physics.
- The "second-class citizenship" of Fermilab accelerator physicists also influenced the manner in which Bob later moved to Stanford/SLAC.

Schottky Receivers

- One of the novel differences between hadrons and electrons is the lack of oscillation damping. This allows one to measure Schottky betatron and synchrotron oscillation signals.
- References
  – D. Martin, et. al., "A Schottky Receiver for Non-Perturbative Tune Monitoring in the Tevatron", Proc. U.S. Part. Acc. Conf., 1483 (1989).
  – D. Martin, et. al., "A Resonant Beam Detector for Tevatron Tune Monitoring", Proc. U.S. Part. Acc. Conf., 1486 (1989).
  – P.J. Chou, et. al., "A Transverse Tune Monitor for the Fermilab Main Ring", Proc. U.S. Part. Acc. Conf., 2479 (1995).

Tevatron Transverse Emittance Growth

- The measured betatron signals were far too large on the Schottky detectors to be due to Schottky signals. They were in fact driven coherent oscillations.
- Bob’s role in this work was central to improving Tevatron operations to today’s 300x design luminosity.



- G. Jackson, et. al., "Luminosity Lifetime in the Tevatron", Proc. of the European Part. Acc. Conf., Rome, 556 (1988).
-G. Jackson and S. Mane, "Studies and Calculations of Transverse Emittance Growth in Proton Storage Rings", Nucl. Instr. and Methods in Phys. Research A276, 8 (1989).

Finding the Dominant Source of Tevatron Emittance Growth

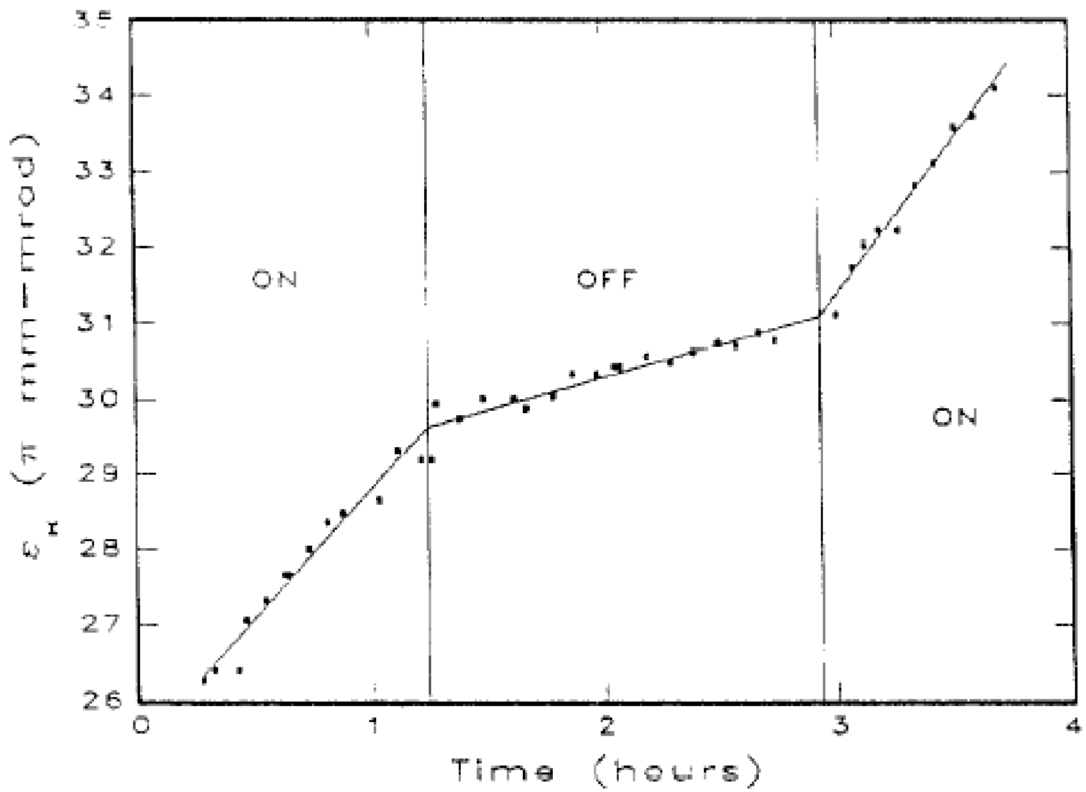
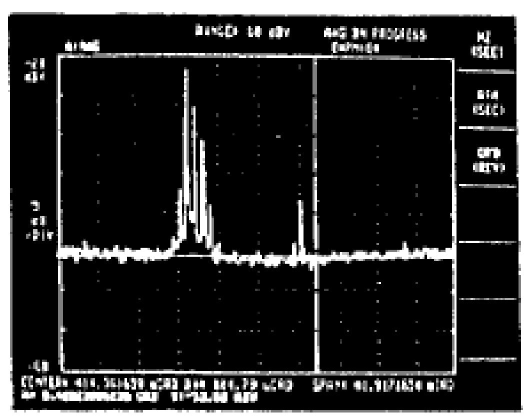
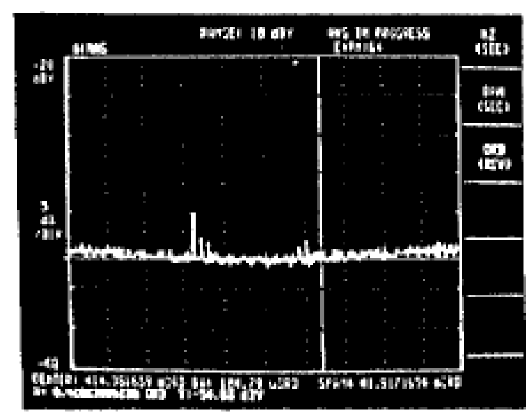


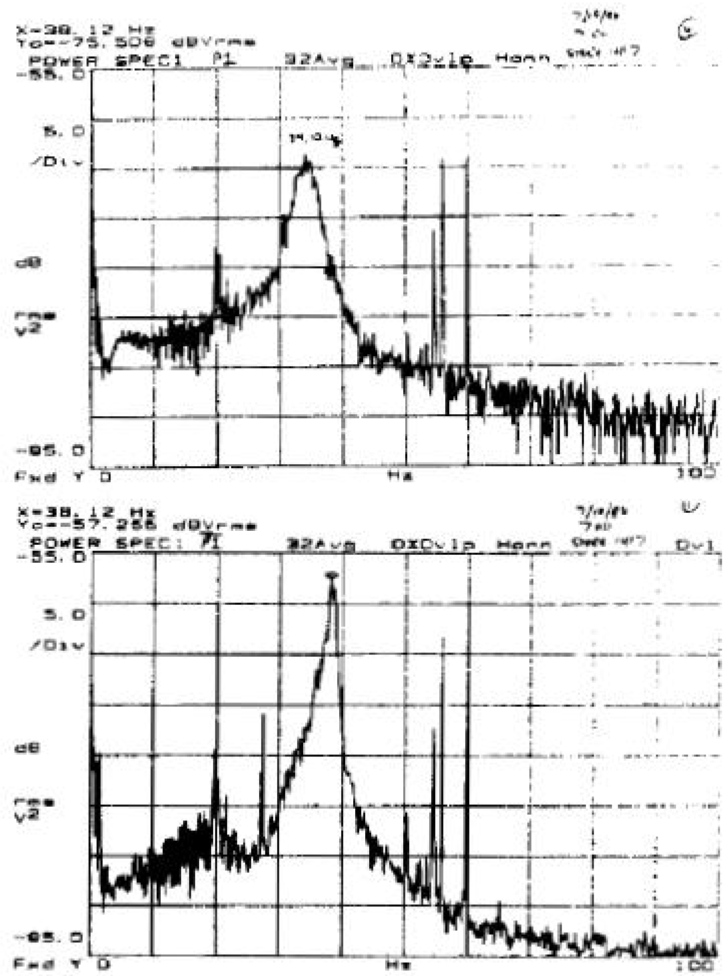
Figure 1: Horizontal emittance as a function of time while the antiproton abort kicker is on and off.





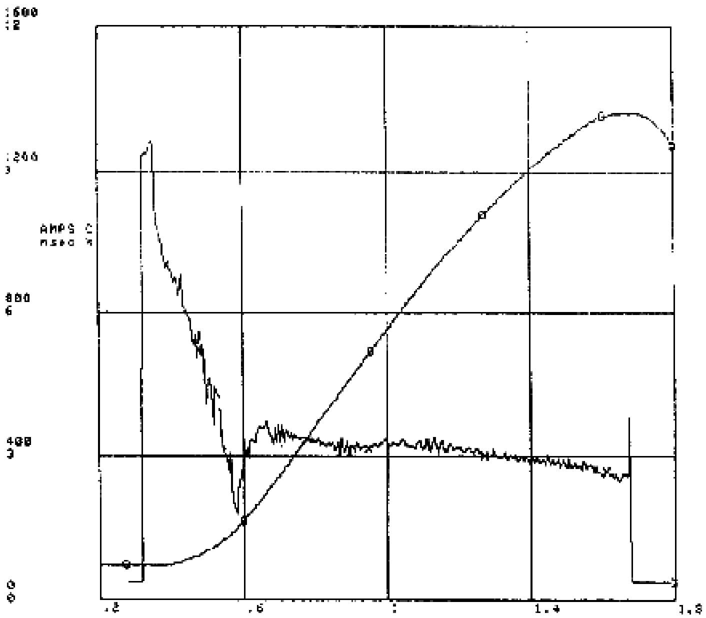
Tevatron Longitudinal Damping

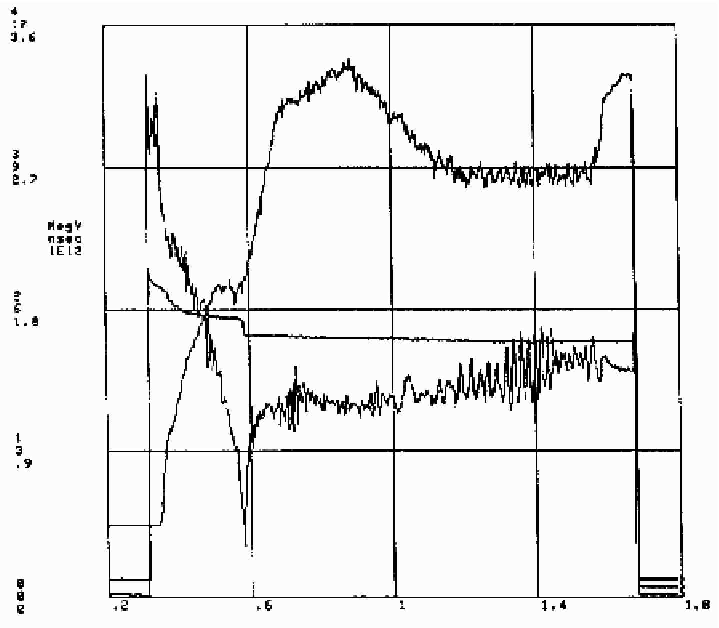
- Proton (top) and antiproton (bottom) synchrotron tune spectra during collisions are shown to the right.
- When only protons are in the Tevatron, there was an longitudinal instability.
- The loop noise in the damping system was found to drive emittance growth if left on during stores.
- References
  - Q.A. Kerns, et. al., “Longitudinal Damping in the Tevatron Collider”, Proc. U.S. Part. Acc. Conf., 1882 (1989).



Main Ring Bunch Spreader

- Since the Main Ring had a longitudinal instability which was difficult to diagnose, a bunch spreader was installed to grow the longitudinal emittance of the beam.
- References
  - G. Jackson and T. Ieiri, “Stimulated Longitudinal Emittance Growth in the Main Ring”, Proc. U.S. Part. Acc. Conf., 863 (1989).





Real Time Bunch Length Monitor

- In order to tune the bunch spreader and to diagnose longitudinal instabilities, Bob suggested new processing electronics for existing longitudinal beam detectors based on the frequency domain.
- Until this point, a diode/resistor/capacitor circuit was used to measure the peak voltage, which the computer normalized with DC beam current, in order to synthesize a signal that was proportional to the bunch length.
- Bob suggested monitoring a RF harmonic of the beam signal, taking the logarithm of that signal with an Analog Devices chip, and then taking the square root with another Analog Devices chip. The entire chain had a 10kHz bandwidth.

Next Generation Bunch Length Monitor

- Taking Bob's advice, we took this method to the next step and subtracted the logarithm of the third RF harmonic of the beam signal from the logarithm of the beam signal at the RF frequency itself using heterodyne electronics to match the changing RF frequency up the Main Ring acceleration ramp.
- These two matched arms of the electronics provided a 10kHz bandwidth bunch length signal to the control system that did not need to be normalized or calibrated.
- References

  – T. Ieiri, R. Gonzalez, and G. Jackson, "A Main Ring Bunch Length Monitor by Detecting Two Frequency Components of the Beam", Proc. 7th Symposium on Acc. Sci. and Tech., Osaka, Japan (1989), pg. 367.

SSC Nonlinear Beam Dynamics

- By my memory, Alex Chao knows a lot more about the beginnings of E778 than I do. My version of the story is that there was a review down at the SSC which Bob was chairing, and the SSC staff were presenting calculations of beam lifetime using simulations and employing terms such as “smear” and “shmear”. At some point the question arose as to whether anyone really knew what they were doing: hence the formation of the E778 experiment at Fermilab.

NONLINEAR DYNAMICS EXPERIMENT IN THE TEVATRON

N.Merminga, D. Edwards, D. Finley, R. Gerig, N. Gelfand, M. Harrison, R. Johnson, M. Syphers
*Fermi National Accelerator Laboratory,*Batavia, IL 60510*
R. Meller, R. Siemann, R. Talman
Newman Laboratory of Nuclear Studies, Cornell University, Ithaca, NY 14853 U.S.A.
P. Morton
Stanford Linear Accelerator Center, Stanford, CA 94305 U.S.A.
A. Chao, T. Chen, D. Johnson, S. Peggs, J. Peterson, C. Saltmarsh, L. Schachinger
SSC Central Design Group, Berkeley, CA 94720 U.S.A.

Sample E778 Result

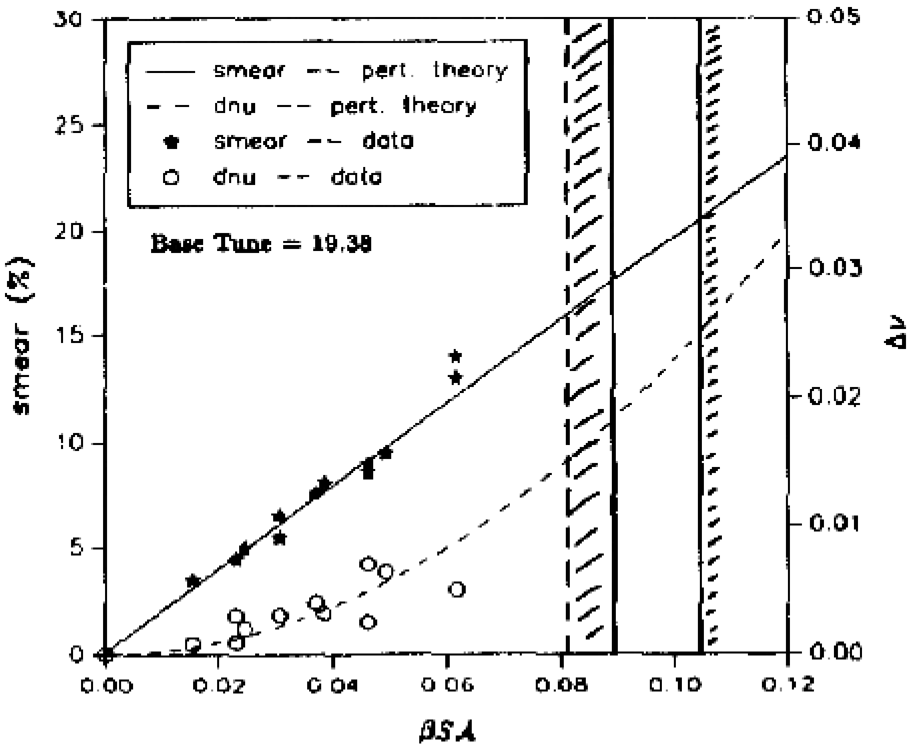
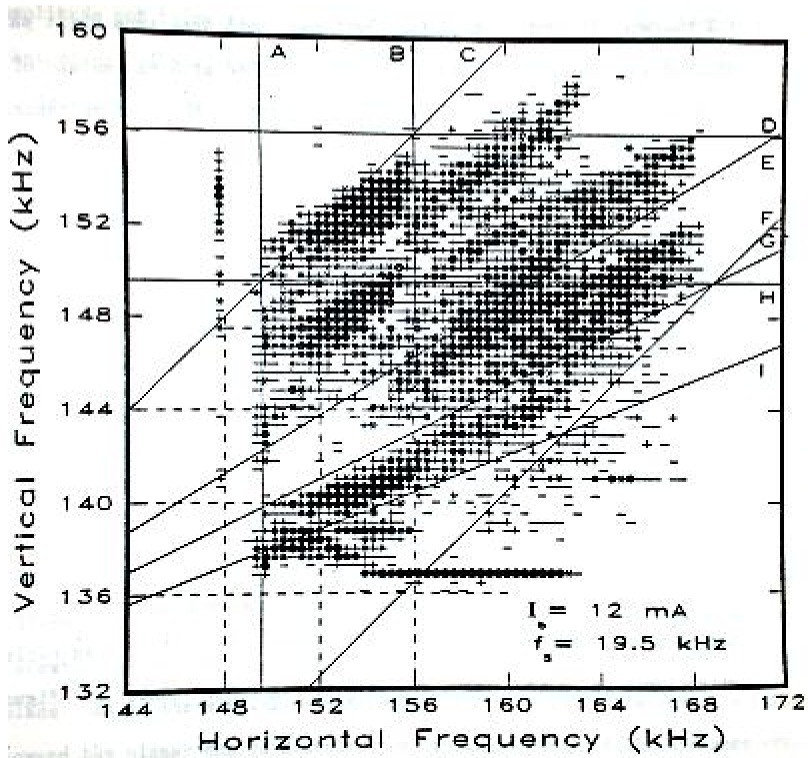


Figure 2: Smear, tuneshift, measured and calculated dynamic aperture plotted as functions of the product of the sextupole strength, the particle's amplitude and the beta function at the observation point. Data points are measured values; curves are predictions.

- The experiment took place, though in a very unusual fashion …
- References
  - N. Merminga, et. al., "Nonlinear Dynamics Experiment in the Tevatron", Proc. U.S. Part. Acc. Conf., 1429 (1989).
  - A.W. Chao, et. al., "Experimental Investigation of Nonlinear Dynamics in the Fermilab Tevatron", Phys. Rev. Lett. P.2752 (12/12/88).

Finishing My Thesis

- The work Bob and I did on Schottky detectors and emittance growth diagnosis led to dramatic improvements in our visualization and interpretation of our e+e- beam-beam simulation results.
- During this entire period Bob steadily trashed my thesis drafts, and I diligently rewrote them. Finally, on the fourth iteration, the thesis (and his sabbatical) were done.



Bob’s Return to Cornell

- Bob returned to Cornell to continue working with students:
  - CBN 88-1: “A Simulation Study of Radiation Treatment with a Quadrupole Beam-Beam Kick” by R. Siemann and S. Krishnagopal
  - CBN 88-2: “Linear Beam-Beam Force“ by R. Siemann, S. Krishnagopal
  - CBN 88-8: “Synchrotron Radiation in Simulations” by S. Krishnogopal and R. Siemann
  - CBN 89-2: “Synchrotron Radiation in Simulations – II” by R. Siemann
  - CBN 89-3: “Simulation of Round Beams” by S. Krishnagopal and R. Siemann
  - CBN 89-4: “Simulations of Electron-Positron Storage Rings” by R. Siemann
  - CBN 89-6: “Cavity Dissipation Dependence on Beam Pipe Radius” by S. Krishnagopal and R. Siemann
  - CBN 90-2: “A Comparison of Flat Beams With Round” by S. Krishnagopal and R. Siemann
  - CBN 91-6: “Resonances in the Beam-Beam Interaction Due to a Finite Crossing Angle” by D. Sagan, R. Siemann and S. Krishnagopal (EPAC90)
  - CBN 91-18: “Nearly Equal beta* at CLEO” by P. Bagley , M. Billing, S. Krishnagopal, D. Rubin, R.Siemann and J. Welch (PAC91)

Concluding Remarks

- Bob started out as my Cornell student advisor, became my thesis advisor, transformed into a colleague, and over the years remained a role model and friend.
- When I heard that Bob had passed, I found myself profoundly effected.
- I grew up in a farming community, and my parents ran the local gas station and auto repair shop. I was the first person in my family to finish college. Though my parents and I were always close, they really did not understand my life as a physicist.
- I now realize that when I strived to make someone proud of my career, that person was Bob. I will always value his role in my life, and be thankful to the Siemann family for sharing him with me.