CORNELL UNIVERSITY LEPP

LABORATORY FOR ELEMENTARY-PARTICLE PHYSICS

Experience with CESR Operations

M. Billing

For the
30th Advanced ICFA Beam Dynamics Workshop
on High Luminosity e+ e- Colliders

October 13-16, 2003
Stanford, California

Configuration of the Accelerators

CESR (4.7 - 5.6 GeV)

Functioning as a collider since 1979

Installed a Mini-Beta Insert in 1981

Installed Pretzel with 3 trains of 1 bunch in 1982

Installed a Micro-Beta Insert in 1986

Initial operation with 7 trains of 1 bunch in 1987

Operated with a Crossing Angle and 9 trains of bunches in 1994

Operation with 9 trains of 5 bunches in 2000

Installed Super-conducting IR Quads in 2001

CESR-C (1.88 GeV)

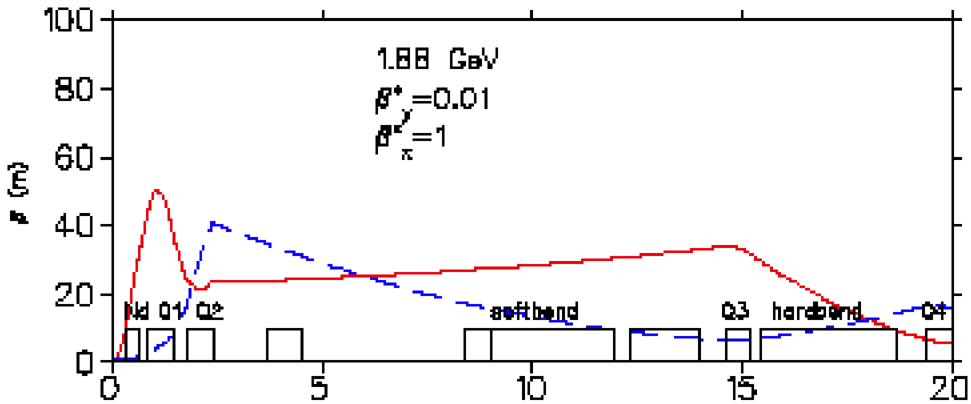
Began initial operation in 2002

Installed first 6 Superconducting Wigglers for Summer 2003 Run

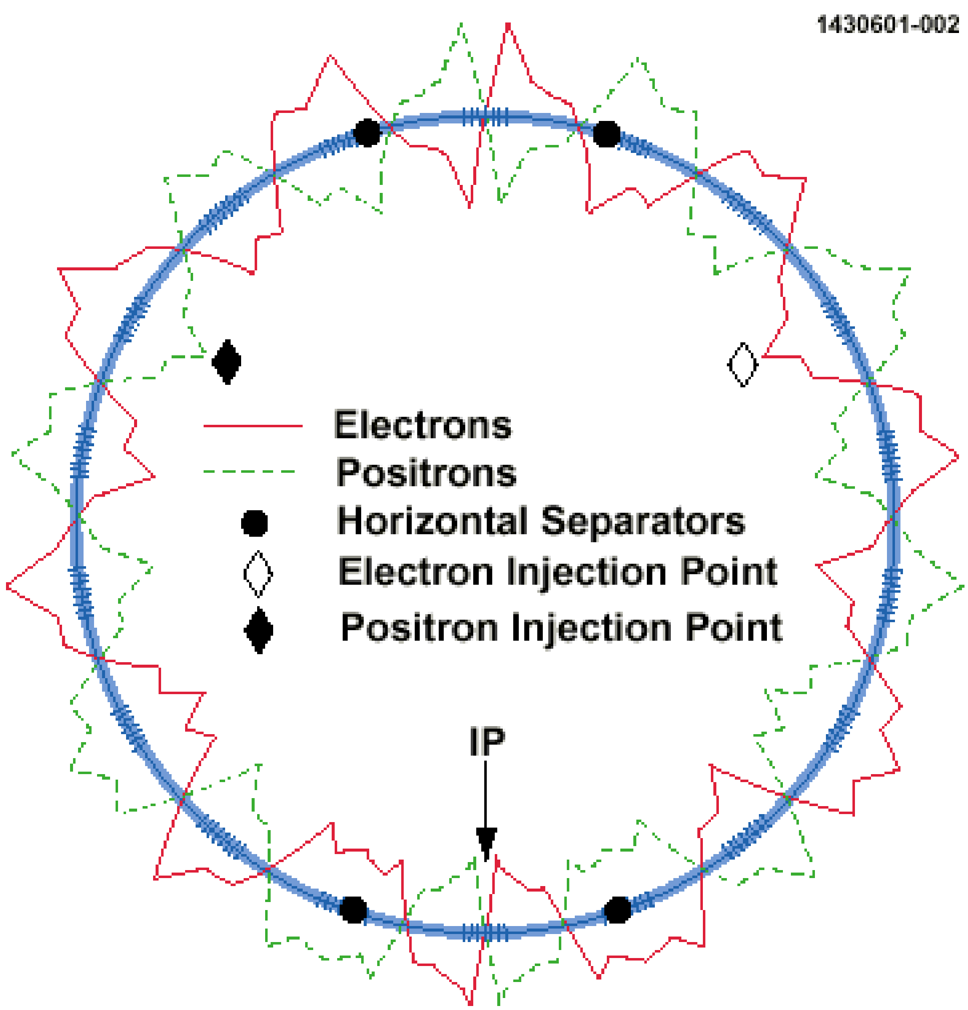
Will install Remaining Wigglers in Spring of 2004

CESR-C Configuration

SCIR: 2 PM & 4 SC Quads
± 3.5 mr Crossing Angle



RF: 4 SC RF Cavities
Bunch Distribution: 7or 8 trains of 3 or 4 bunches



Injector

Linac (60Hz)

- 8 Accelerator sections
- => 300 MeV electrons; max 30 bunches
- Positron target after 4 sections
- => 200 MeV positrons; max 16 bunches

Synchrotron (60Hz)

- 8 msec acceleration to CESR Energy

CESR-C Injection

- Top off e+ after dumping e- beam
- Fill e- from 0 mA

Accelerator Operations

Control Room

- Designed for a Single Operator
- Room for several accelerator physicists during MS
- Two Control Alcoves

Personnel

- Operator
  - Maintains Injector, Fills and Collides beams in CESR
  - Oversees tunnel access and adherence to tunnel safety procedures
- Director of Operations
  - Oversees operations
  - In charge of Accelerator Schedule
  - Deployment of Support Personnel
- Machine Studies Coordinator
  - In charge of MS Scheduling of tasks
- Accelerator Physicists
  - Participate in Machine Studies typically weekly

Details of Operations

Fill-by-fill (Operator)

- Top off e+
- Inject e-
- Collide beams - Start Run
- Make tuning adjustments as needed
- End Run - Scrape out e-

Weekly

- One shift of Tunnel Access
- 2-9 Shifts of MS
- Remainder is either HEP or Dedicated Synch Light

Running Periods (CESR-C)

- Combination of HEP (2/3) & X-ray Physics (1/3)
- 2-3 three week down periods / year
- Occasional long down periods for major upgrades

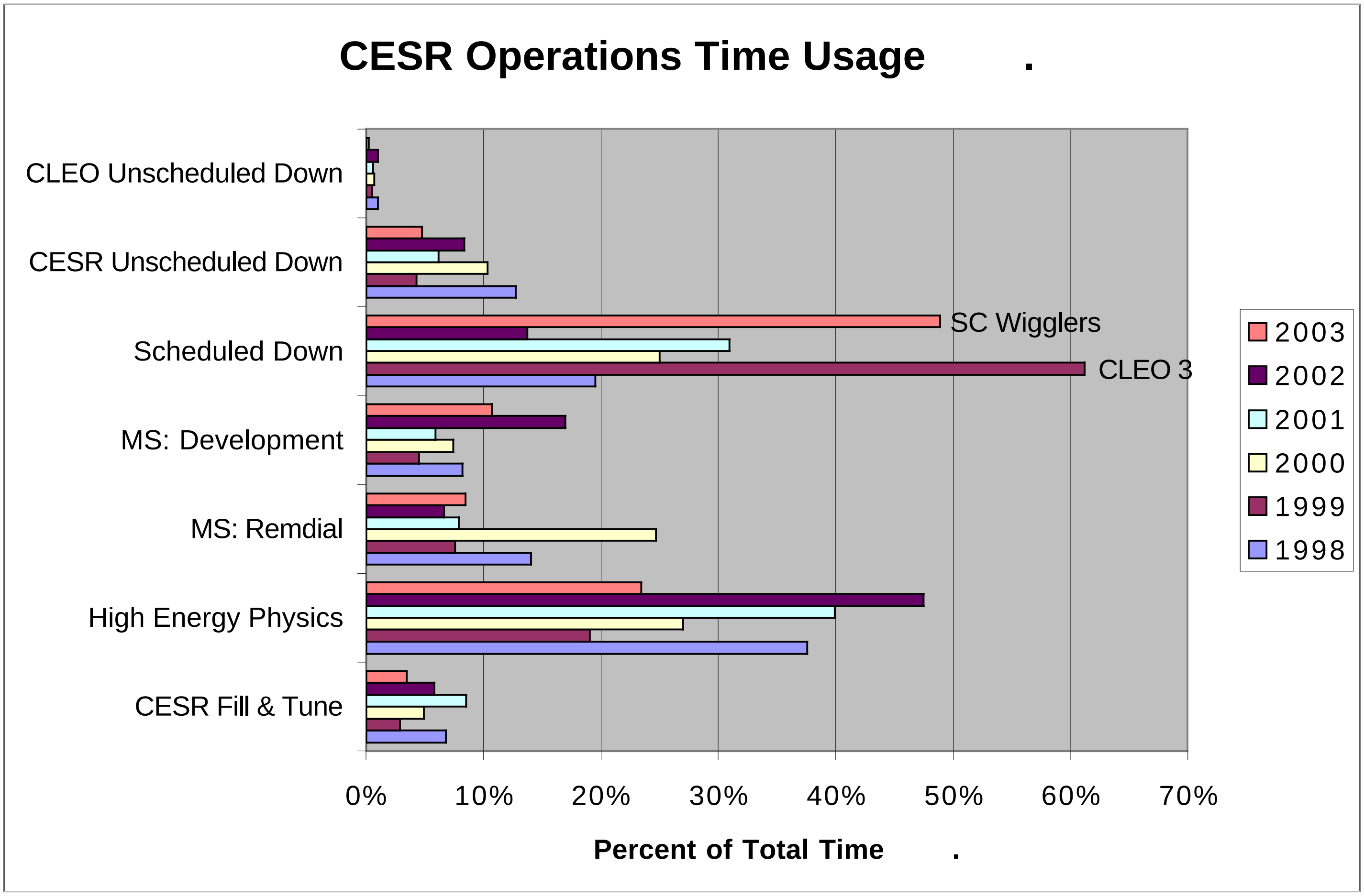
Reliability

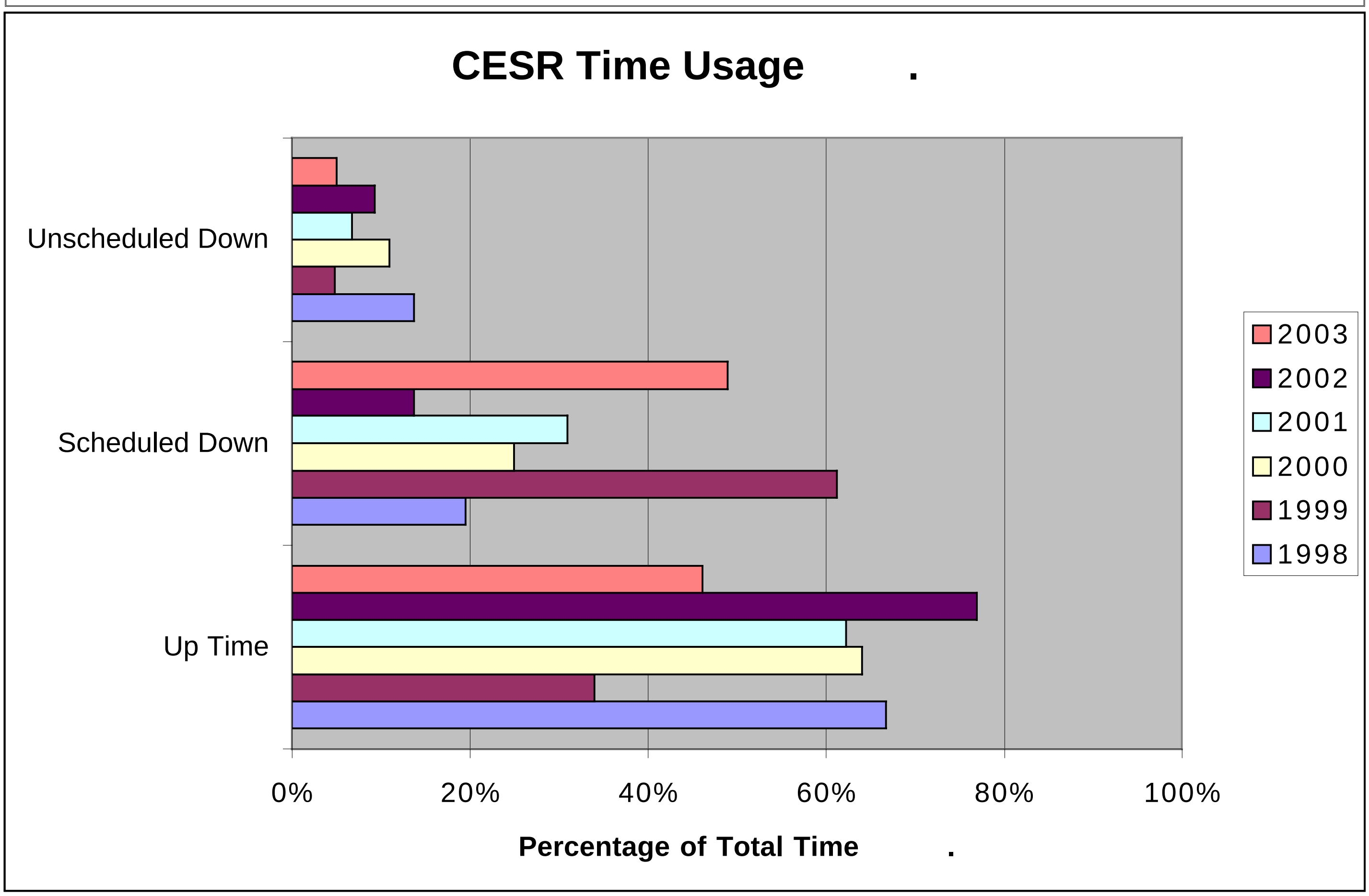
Definition of Terms

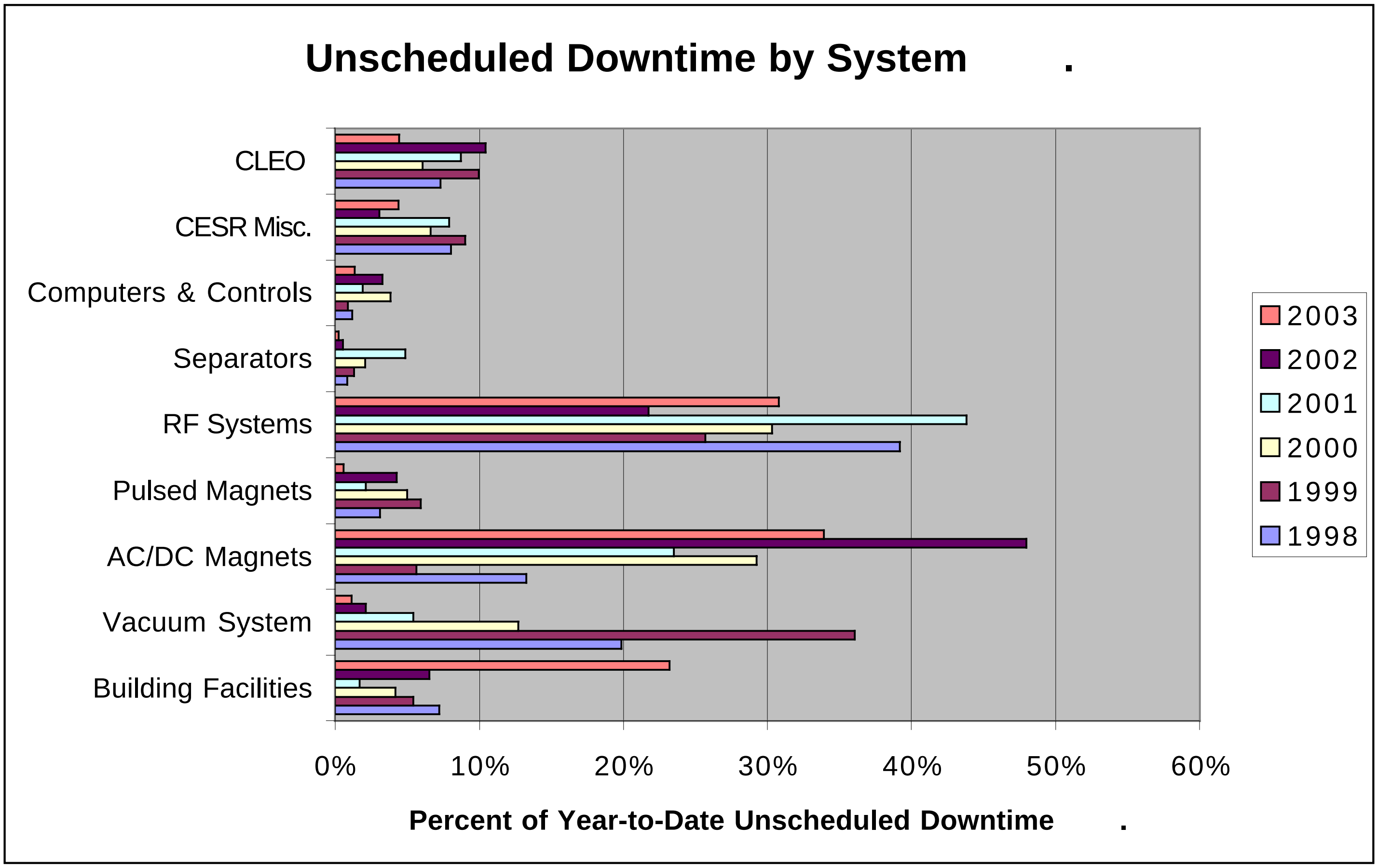
- CESR Fill & Tune - Injection & Tuning after Colliding
- High Energy Physics - HEP Run Start to Stop
- MS: Remedial - Machine Studies to Correct Operating Conditions
- MS: Development - Machine Studies for Longer Range Projects
- Scheduled Down - as stated
- CESR Unscheduled Down - Accelerator Downtime
- CLEO Unscheduled Down - Experimenter Downtime

Unscheduled Down Time:

- Building Facilities - includes power outages
- Vacuum Systems - all accelerator vacuum systems
- AC/DC Magnets - all accelerator guide, focusing, and transfer magnets
- Pulsed Magnets - injection & extraction magnets
- RF Systems - all RF systems
- Separators - H & V CESR separators
- Computers & Controls - includes software
- CESR Misc. - all else
- Cleo Unscheduled Down - for CLEO & CHESS


CESR Operations Time Usage .
CLEO Unscheduled Down
CESR Unscheduled Down
Scheduled Down
MS: Development
MS: Remdial
High Energy Physics
CESR Fill & Tune
SC Wigglers
CLEO 3
2003
2002
2001
2000
1999
1998
0%
10%
20%
30%
40%
50%
60%
70%
Percent of Total Time .


CESR Time Usage .
Unscheduled Down
Scheduled Down
Up Time
2003
2002
2001
2000
1999
1998
0%
20%
40%
60%
80%
100%
Percentage of Total Time .



Recent History

Magnet System Failures

Major failure has been radiation damage to CESR quadrupole & skew quadrupole coils (being replaced)

RF System Failures

CESR RF - poor welds in one ACCEL SRF cavity

Linac RF - Klystron replacements

Vacuum System

Leak in SR crotch during high current running

New SC Wigglers

Doing very well

Diagnosing Faults & Fault Recovery

Detecting Static Faults in Conditions

Weekly Characterization of CESR Conditions (1 hr)
- Tunes and Orbits in all conditions
- Phase, Coupling & Dispersion measurement
- Positions of SC IR Quads & Cryostats
- Worst magnet regulation errors (histograms)
- Whats_wrong - output from diagnostic program

Optics - Phase & Coupling Measurement - see below

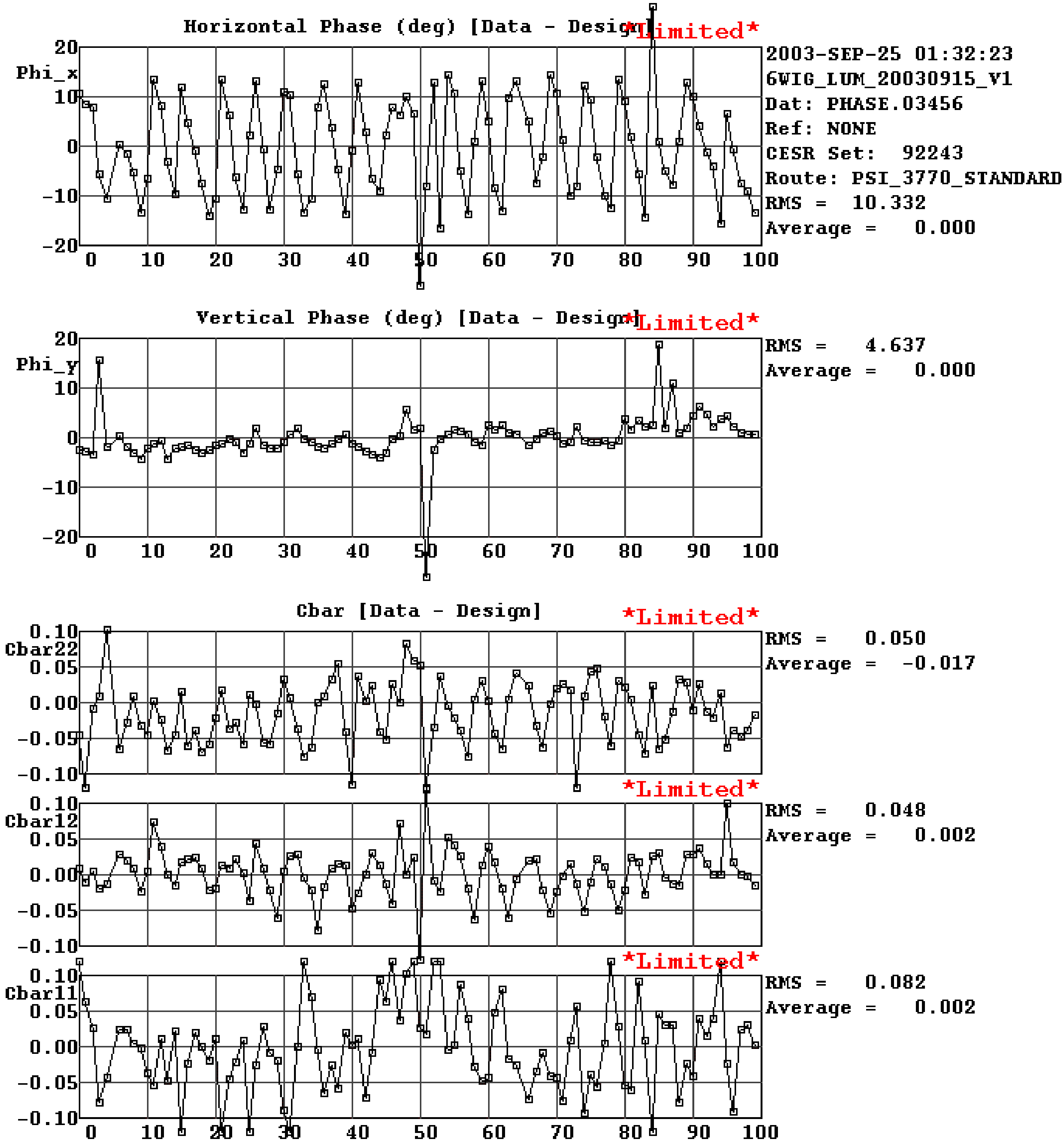
Whats_Wrong
- Simple program invoked to find obvious errors

Logged Data
- Data recorded once per minute

Hardware Testing Programs
- e.g. CESR Quadrupole current intercalibration
- or CESR RF phase balancing

CESRV
- Software which models the accelerator
- e.g. Detecting the movement of SCIR positioning CAM (moves IR Quad locations transversely)
- Caused by power outage & a mechanical stop that slipped

Data: HEPCSR - Seps Off



Betatron Phase Advance Error &
Coupling Matrix Error

Auto Charactization (Including Whats_wrong)

```
                25-Sep-2003 01:05:10
        Auto Characterization : [cesr.machmeas]auto_char
                                        Shifter(s) map jac
**************************************************
 Lattice = 6WIG_LUM_20030915_V1
 type = STANDARD         energy = PSI_3770   sen1 =    0.00
 Set    BIGGRP  POSCSR  ELCSR   ELTOLUM POSTOP  COLLIDE SCIR    HEP     CESR_RF SCWIG
 Num     92120   92236   92242   88244   88248   91933   92186   92243   92116   89942
 Orb         0       0       0       0       0       0       0       0       0       0
**************************************************
```

IRQP IR Quad sheet

tune_char

Chopstat FFT1 FFT2 FFT3

Time1 Time2 Time3

Hist1 Hist2 Hist3

Synch freq (1 bunch), is 36.00 kHz

E+ poscsr phase: 3454

E+ poscsr eta: 244

E+ HEP phase: 3456

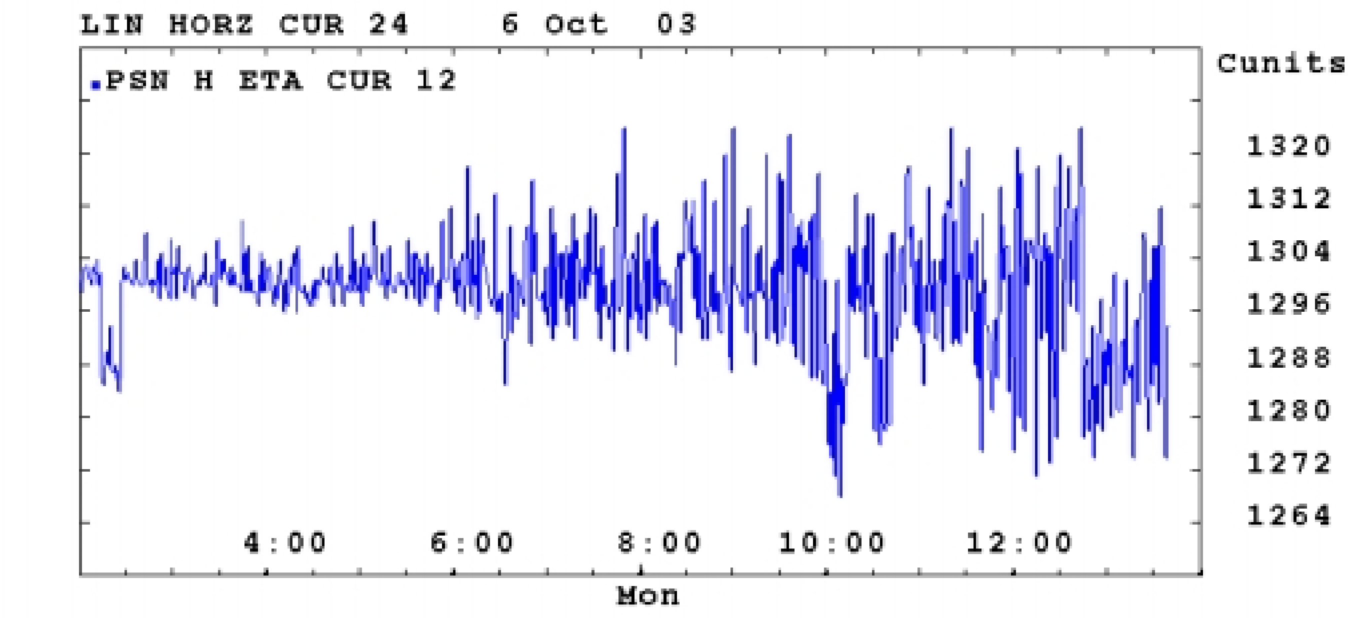
E+ HEP eta: 245

Set	#	e+ ma	V+H seps	Tunes horz	Tunes vert	Chromaticity Horz	Chromaticity Vert	butns	Gif
POSCSR	92236	4.66	off	202.2	223.3	0.9	-1.3	94189	orbit
ELCSR	92242	4.58	off	197.2	239.1	-1.1	-1.5	94190	orbit
HEP	92243	4.42	off	200.5	235.2	-4.1	0.0	94191	orbit
POSCSR	92236	3.62	off	201.7	224.2	1.1	-1.3	94192	orbit
ELCSR	92242	3.56	on	205.7	242.7	0.2	-2.6	94193	orbit
HEP	92243	3.46	on	207.0	237.5	-2.4	-0.8	94194	orbit

whats_wrong

```
 CSR XFR TIME rep rate not at 60 hz.
   - Problem with element Labelled >>>> BEAMKILL REPRATE <<<<
 SCIR SKQUCUR    3  SCIR SK QUAD 02E   No Voltage to test    -1.4   1229
 EXF SEPT CUR    3  EXF PULSE SEPTUM   No Readback to test    2047    433
 EXF BUMP HV     1  E- BUMPER HV 26E  Readback not equal to old    160    136
 EXF BUMP HV     5  E- BUMPER HV 36E  Readback not equal to old    135    118
 EXF BUMP HV     7  E- BMP MASTER HV  Readback not equal to old    136    118

 clr PCI semaphore #           60
```

Winlog Data Plot

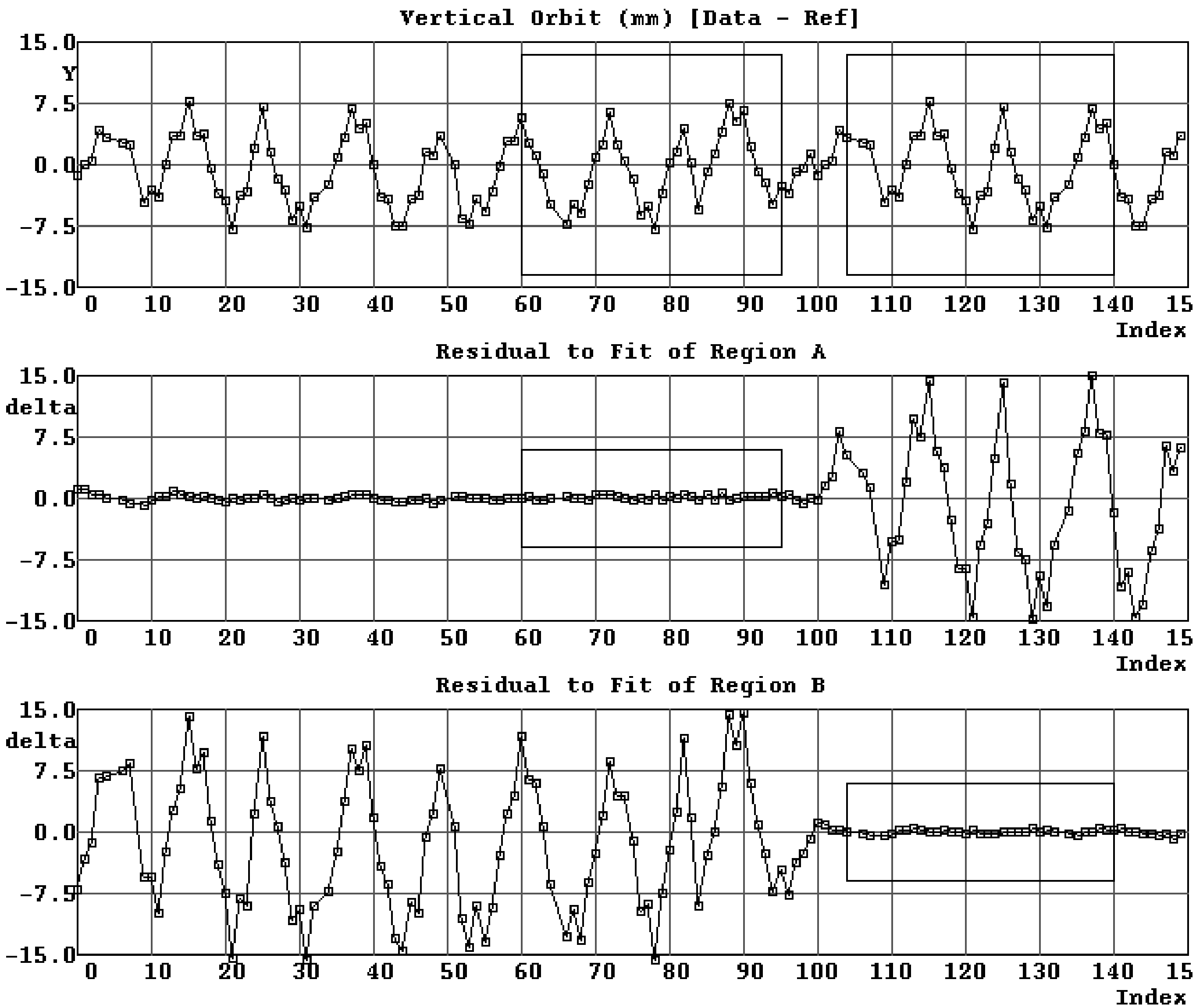


Plot of Positron Snout (Linac transport line) Bending Magnet current

Shows unstable behaviour

CESRV Orbit Fit

y wave analysis for 94123 - 94059



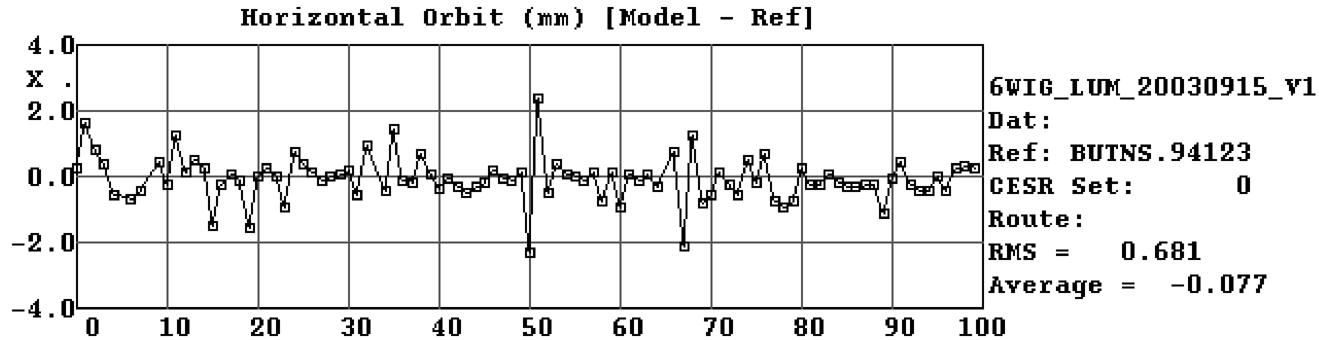

```
A Region Sig/A:    0.018
B Region Sig/A:    0.013
Kick    Sig_K/K:   0.008      Sig_phi:    0.008

Kick: delta_Y' * sqrt(beta)  [urad * sqrt(m)]
After Det#       Kick      phi_Y
          99   -2541.22    58.674
         100    2541.22     1.546
```

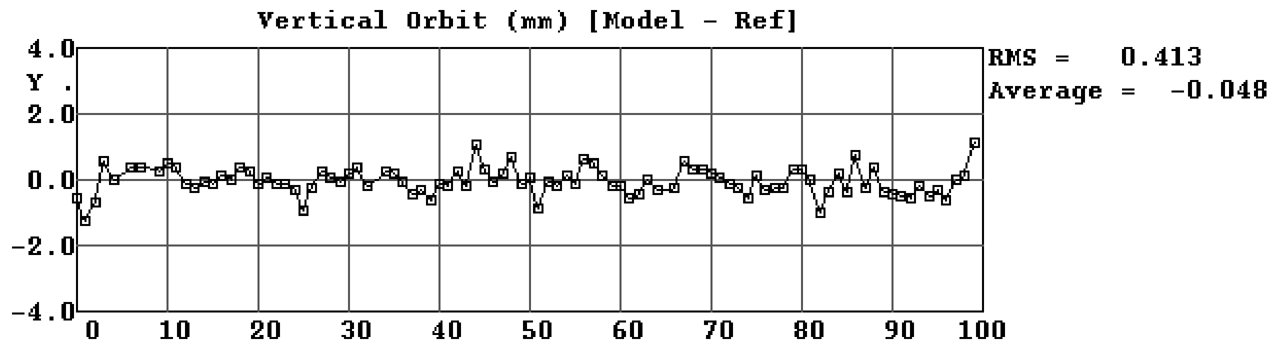
```
24-Sep-03 01:49:57
6WIG_LUM_20030915_V1
U:[CESR.ORBIT.BUT.94]
Dat: BUTNS.94123
Ref: BUTNS.94059
CESR Set:   92152

IX_A1, IX_A2:   60   95
IX_B1, IX_B2: 104 140
```

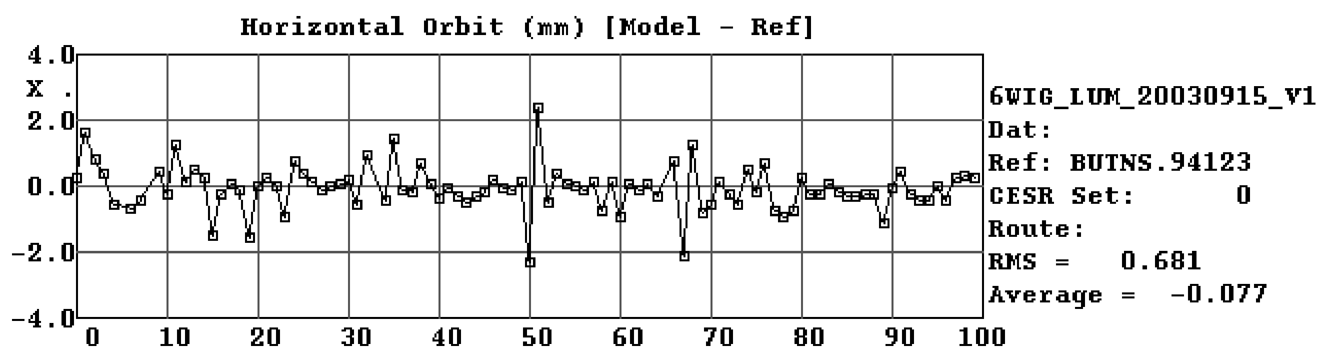
Free Betatron Wave Analysis
Finds single dipole error in IR

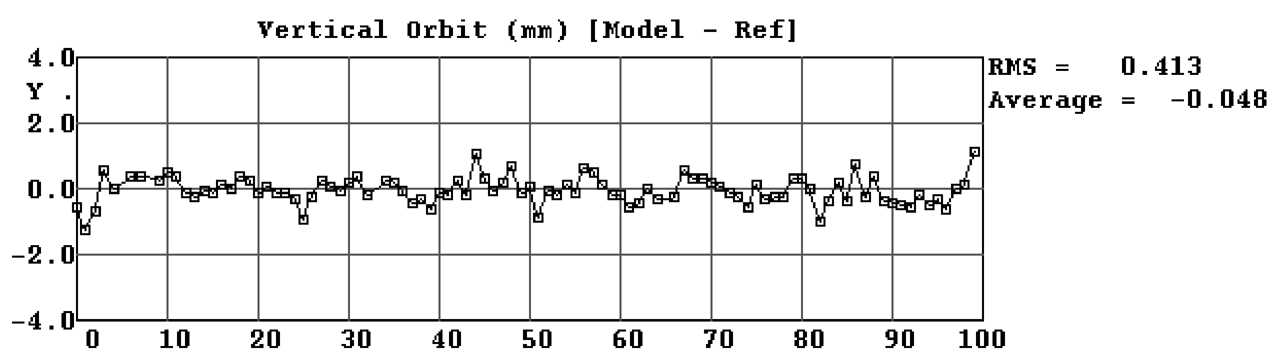
Measurement of Orbit Error <u>Minus</u> Orbit from Motion of IR Cryostat Positioning CAM

Difference between the measured orbit and one computed for a 706 um change in CAM 3 (on the West.)









Shows good agreement with diagnosis that 1 (of 10) CAM's slipped during a power outage

Detecting Intermittent Faults or Single Events

Event Watch

- Program, which reads 100-200 predetermined elements at a 10 Hz rate
- Writes data to disk on a Trigger
- Trigger can be a person or some preset transition of one or more elements

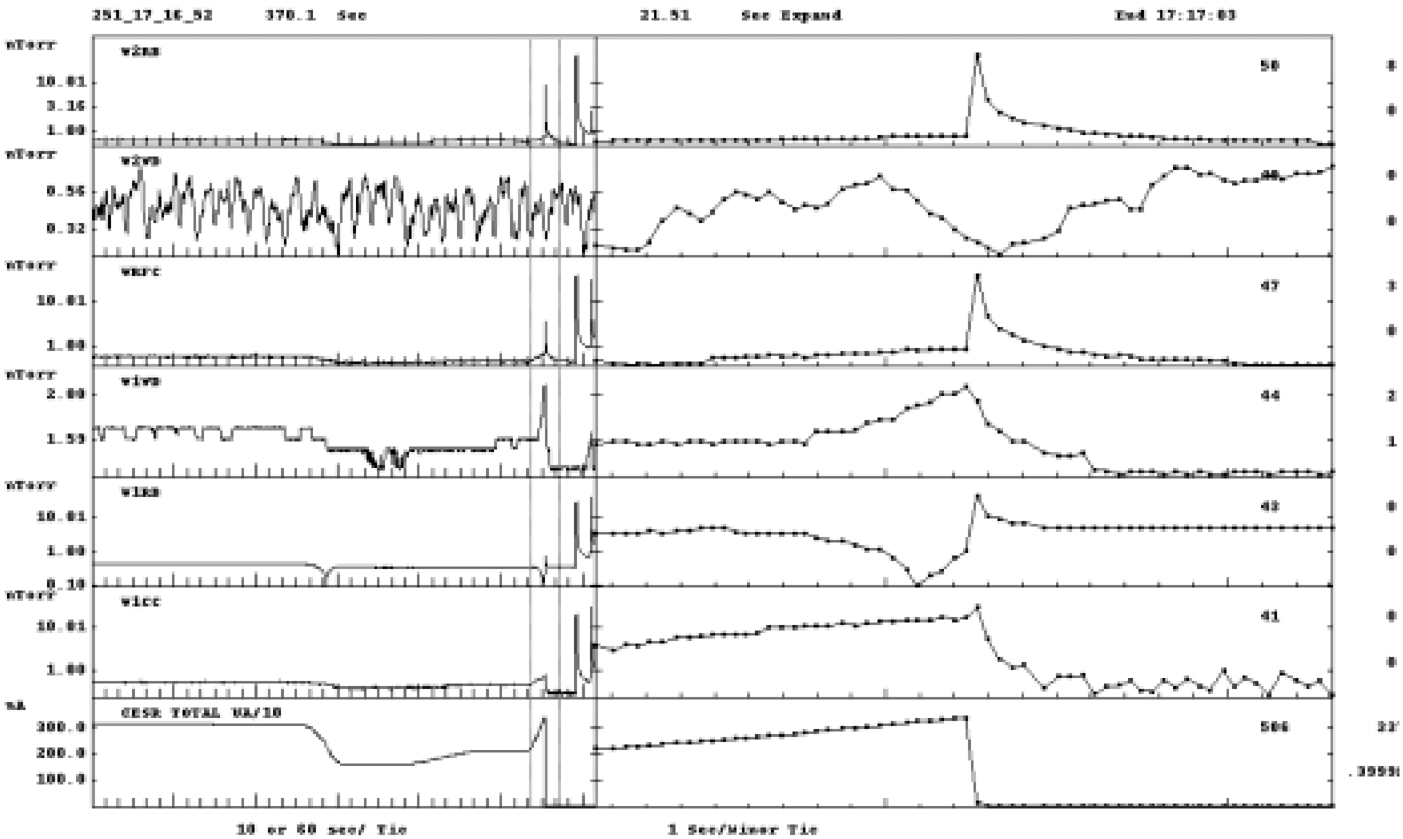
Beamloss

- Program reads fast latching (1 usec) counters
- Counters tell which of ~ 20 signals tripped first
  - -e.g. RF vacuum, RF Arc, Separator Trip, Beam Loss

Comet Diagnostic System

- Multiple channels of fast digitizing (200 nsec) ADC's
- Record for 1 to several thousand turns
- Include: RF Forward & Reflected Power, RF Phase, X & Y Beam Positions, Beam Currents, Feedback System Forward Powers
- Records transient behavior before a beam loss

Event Watch



Beam Trip caused by Vacuum Burst near SC RF cavity

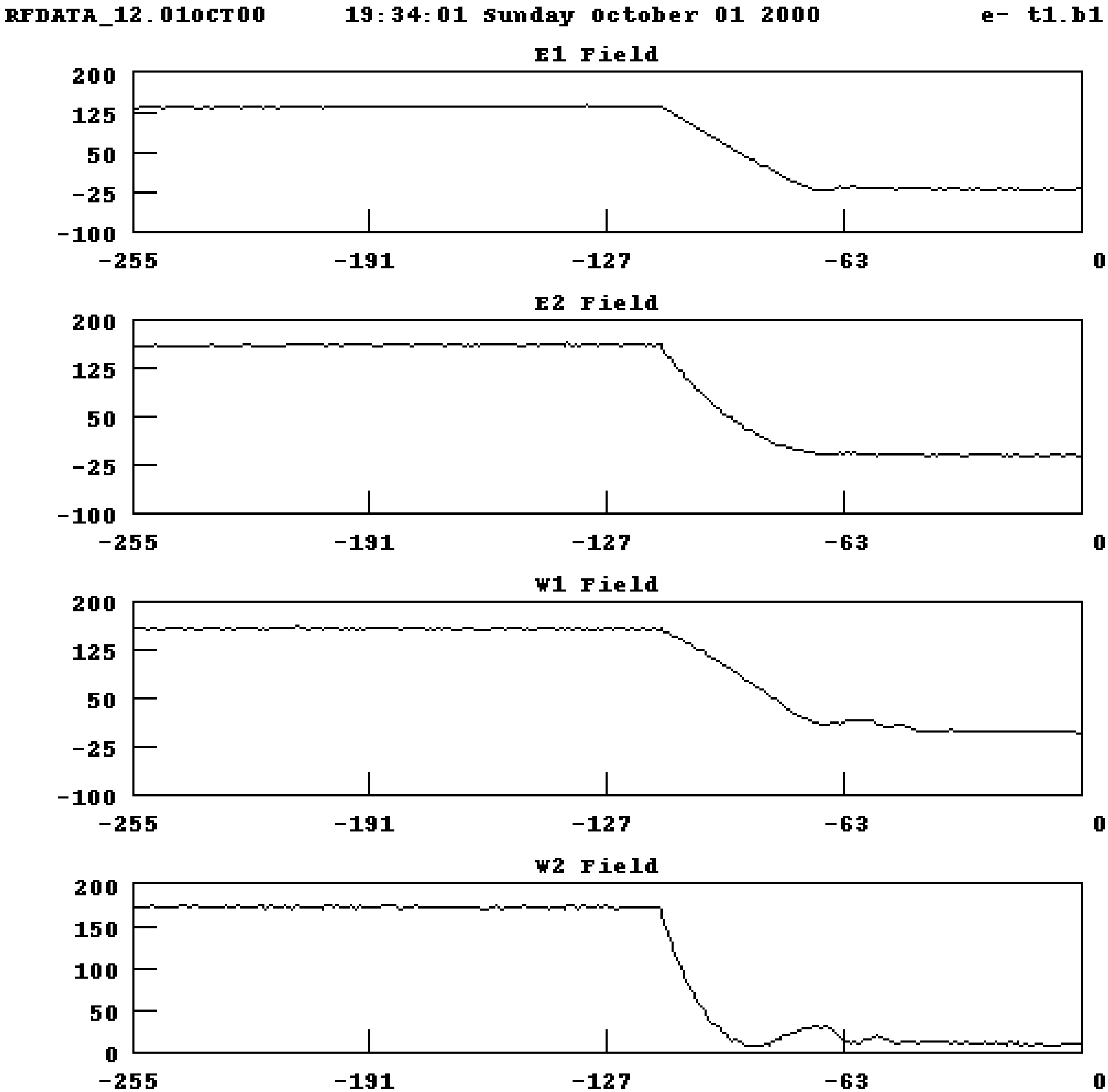
Beamloss

```
2003-10-09 10:19:09 Thursday, entry 7

Subject(s): Beam Loss

Other Info:
Witnesses: DJK
CESR Fill Number 282.04
Beamloss Time: 10:16:28  9 Oct 2003
COMET File Number 4
Beam Currents:    DCCT: 373 -> 0   e+: 199 -> 0   e-: 179 -> 0
CESR Conditions: ELCSR (before), ELCSR (after) 153 minutes left in run
EGGLOG (10:16:54) says W1 QUENCH DETEC
Beam Motion: H rms   Vrms     fh     amp     fv     amp     fs     amp
 e+             3     17      -       -      -       -      -       -
 e-             2      4      -       -   230.8     6.4   18.8     1.2
```

Semi-automatic entry into electronic logbook

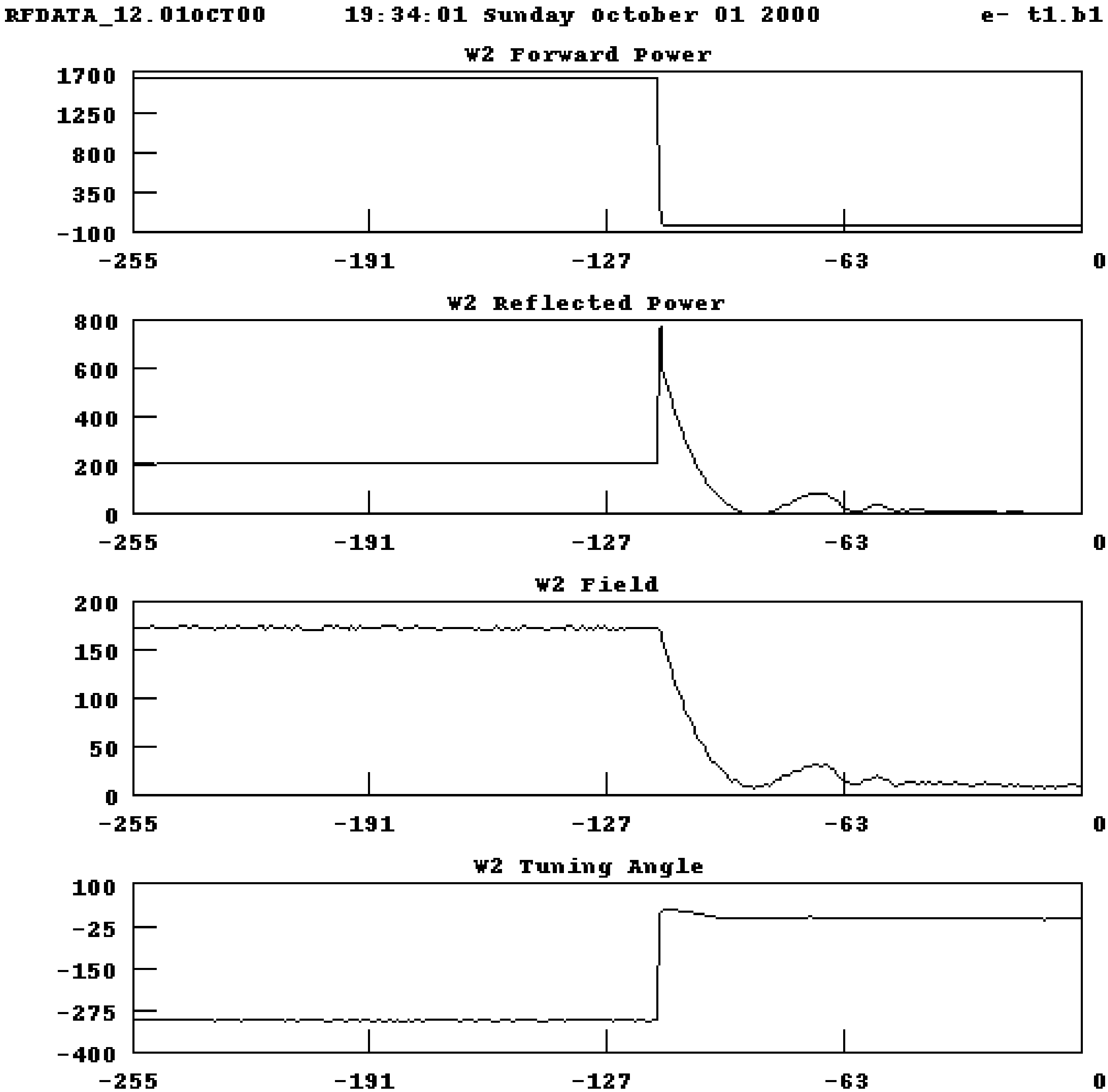
Describes beam dump due to W1 RF Cavity Quench

Comet Diagnostic System



W2 SC RF Field Tripped

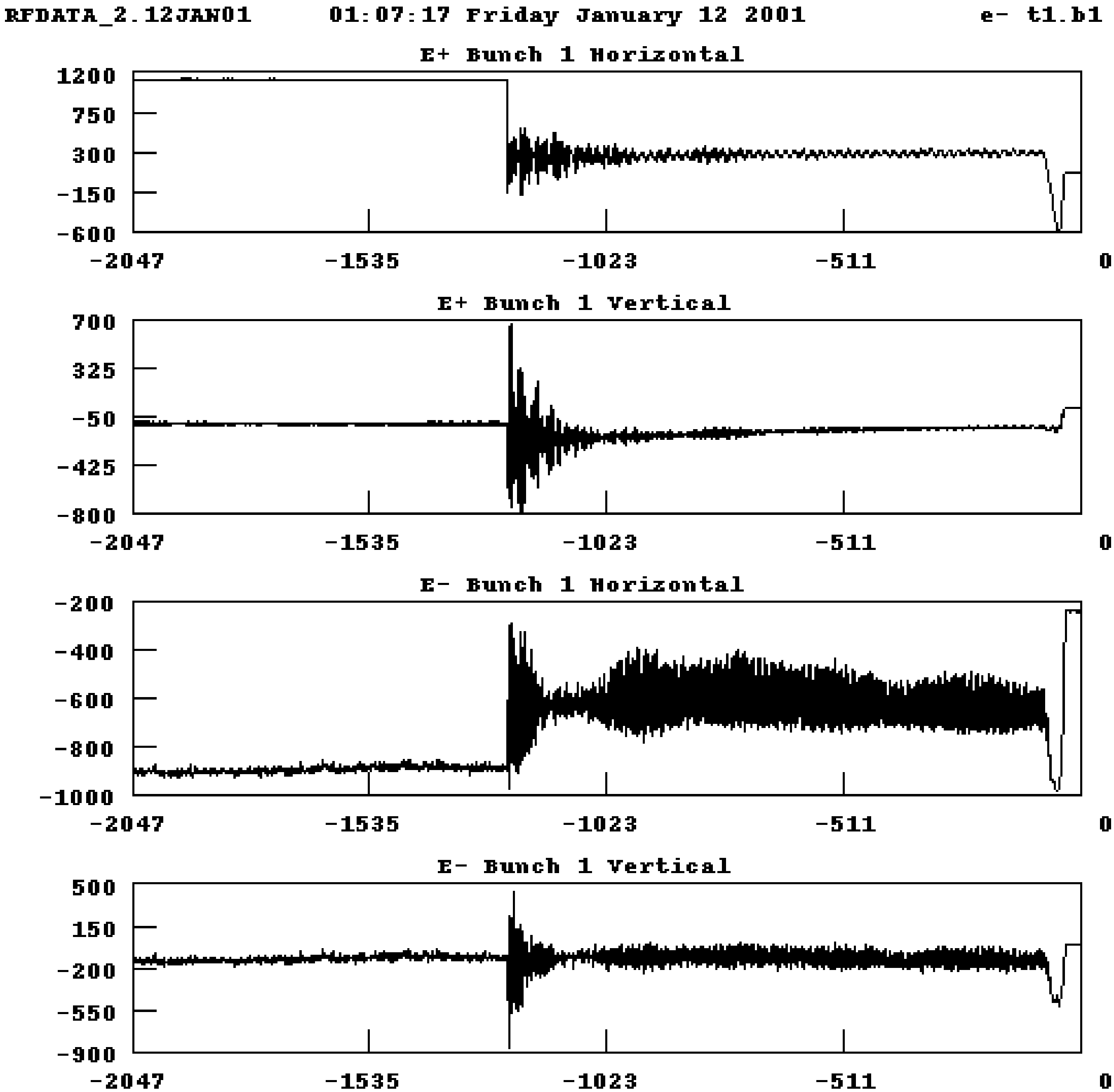
Comet Diagnostic System



Beam Dump - RF Turns Off & Beam spirals to hit inside of vacuum chamber

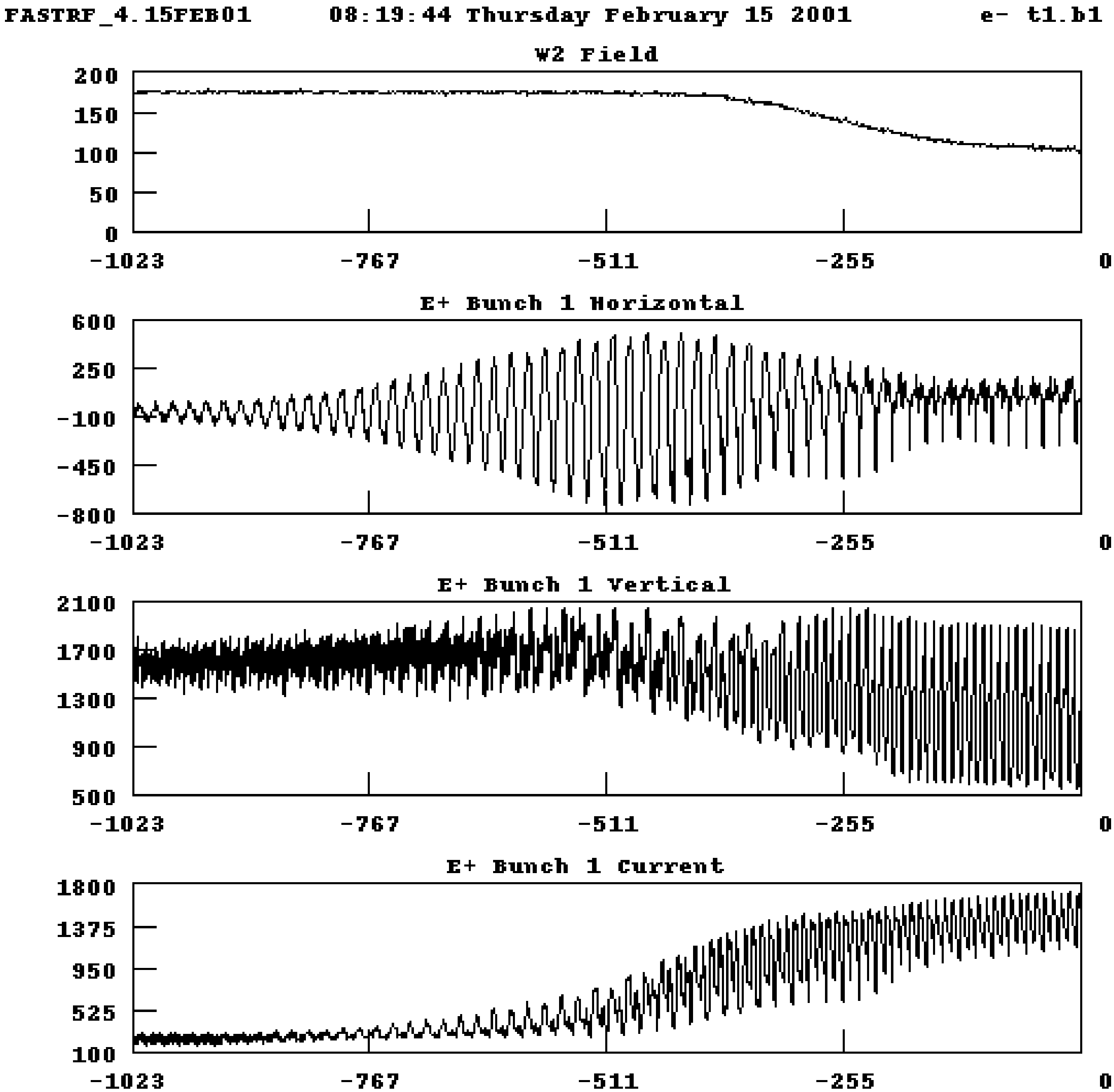
Causes Beam Induced RF Power as seen in the Reflected Power Signal (no Quench)

Comet Diagnostic System



Horizontal Separator Trip causing beam to become unstable horizontally

Comet Diagnostic System



Positron beam became unstable longitudinally causing beam loss

Injecting Beams Into CESR

Online Tools for Diagnosing Poor Injection Performance

GOAL: Isolate the process where performance is poor

- Scope Interface with coax multiplexed inputs
  - Pulsed Injection Element Waveforms quickly displayed on Oscilloscope in Control Room
- Online Displays to allow operator to tune
  - Linac BPM's: x, y, intensity - many selectable displays
  - (Synchrotron Beam is on dedicated scope)
  - Total Synchrotron charge accelerated
  - Capture rate and efficiency into CESR
  - CESR Currents & Fill rate bunch-by-bunch & Total Current
- Linac & Synchrotron Beams are tuned before being needed

Tools for Remediation of Injection into CESR

Position Monitor Viewed by Dedicated Oscilloscope

- Observe injected bunch(es) & dump beam at end of injection cycle or after 60 injection cycles
- Allows for larger tuning corrections

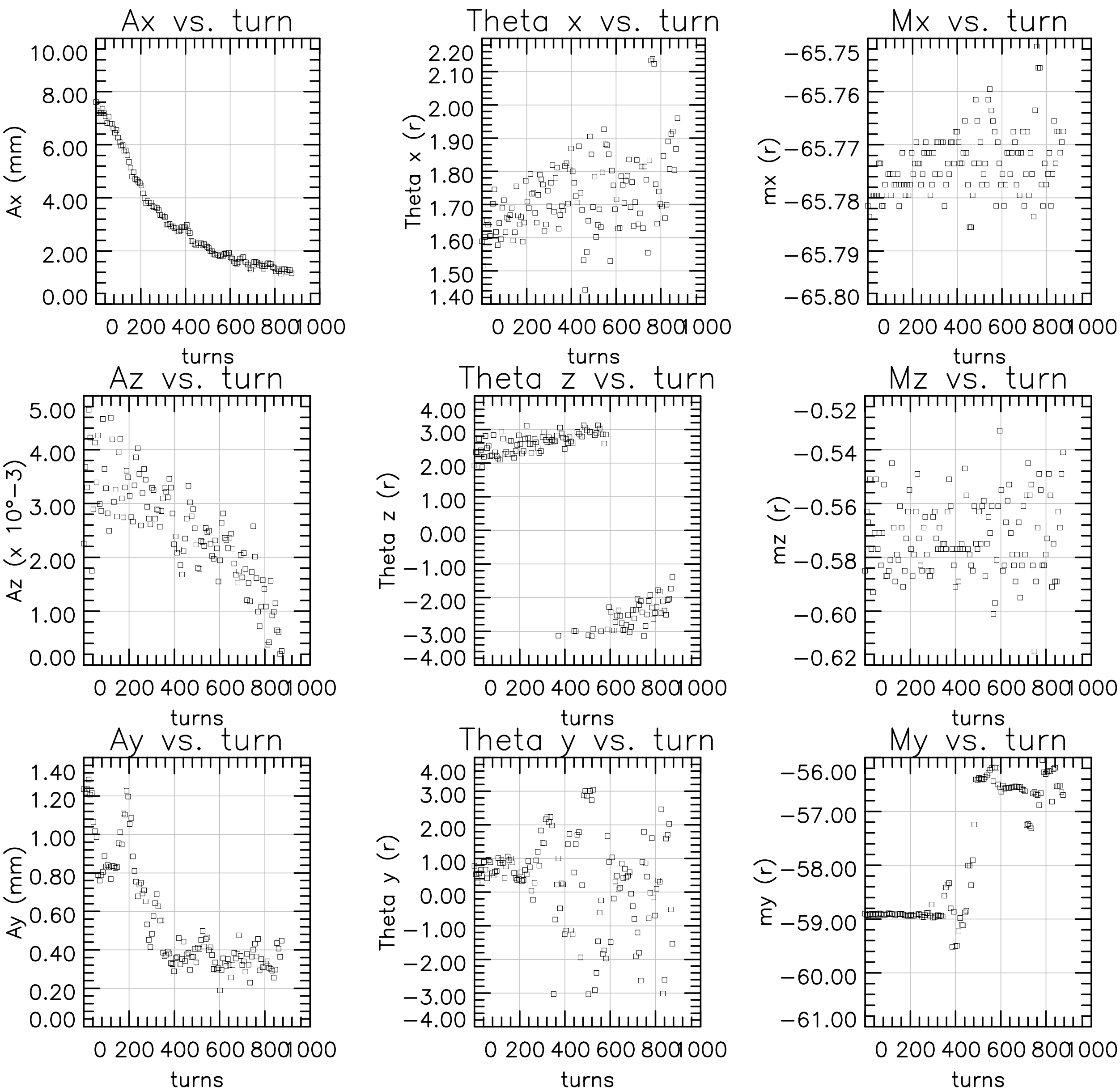
Injection Procedure

- Online Document
- Step-by-step process, which correlates flags, signals or monitors with the appropriate control elements
- References programs or other useful tools

Injection Trajectory Fitting

- Uses 1000 turns of BPM data for 1/10 of ring
- Can fit either injected or stored bunch
- Assumes design transport between BPM's
- (Ignores coupling)
- Allows tunes to be free parameters
- Fits a 42 turn window, moved in 7 turn steps
- Project amplitudes and phases back to injection point

=> Amplitudes, phases and tunes in x, y and energy



Plots of fits of the injected beam trajectory

Condition	Amplitude		
	Horizontal	Vertical	Longitudinal
Injected Electrons with Pulsed Bumper and Pinger Magnets	7.4 ± 0.7 mm	1.3 ± 0.1 mm	4.7 ± 0.2 x 10^{-3}
Stored Electrons with Pulsed Bumper Magnets	1.6 ± 0.3 mm	0.17 ± 0.02 mm	0.1 ± 0.1 x 10^{-3}
Stored Electrons with Pulsed Pinger Magnet	3.5 ± 0.3 mm	0.39 ± 0.05 mm	0.2 ± 0.1 x 10^{-3}

Results of Several Fits of Each type of Trajectory

Amplitudes represent the Oscillation Amplitude present after pulsing the injection elements

Reasonably consistent results

(Errors are estimated)

Characterizing Optics for Injection

Aside

Injection of e- against Stored e+ & Pretzels
complicates the situation for CESR

=> New look at injection into CESR

Basic Analysis Strategy

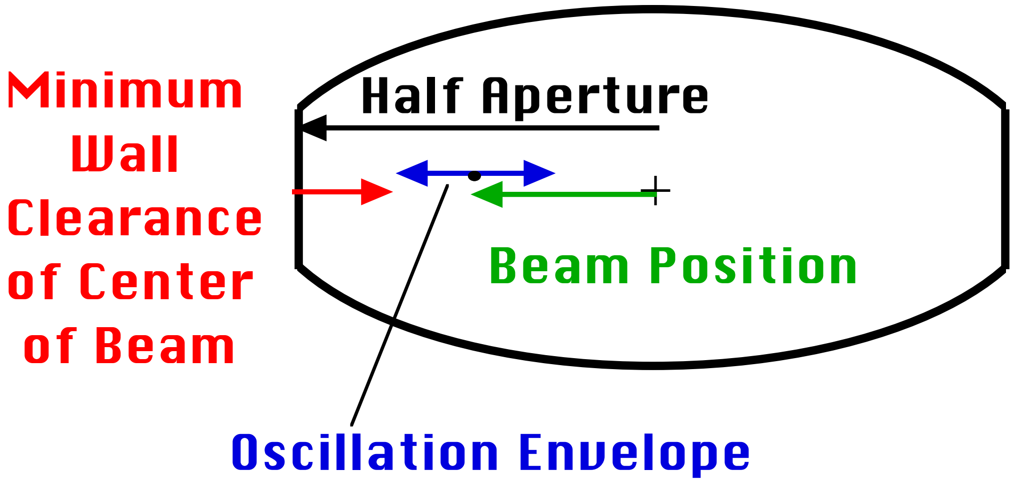
1. Examine only the Position of Center of the Beam

2. If beam undergoes oscillation from injection transient, then determine Amplitude of oscillation

3. If both betatron & energy oscillations are present, determine each amplitude

4. Assume that all phases of the oscillations will occur at every point in the ring before significant (radiation) damping occurs

=> Project the oscillation amplitudes around ring & ADD them together => Oscillation Envelope

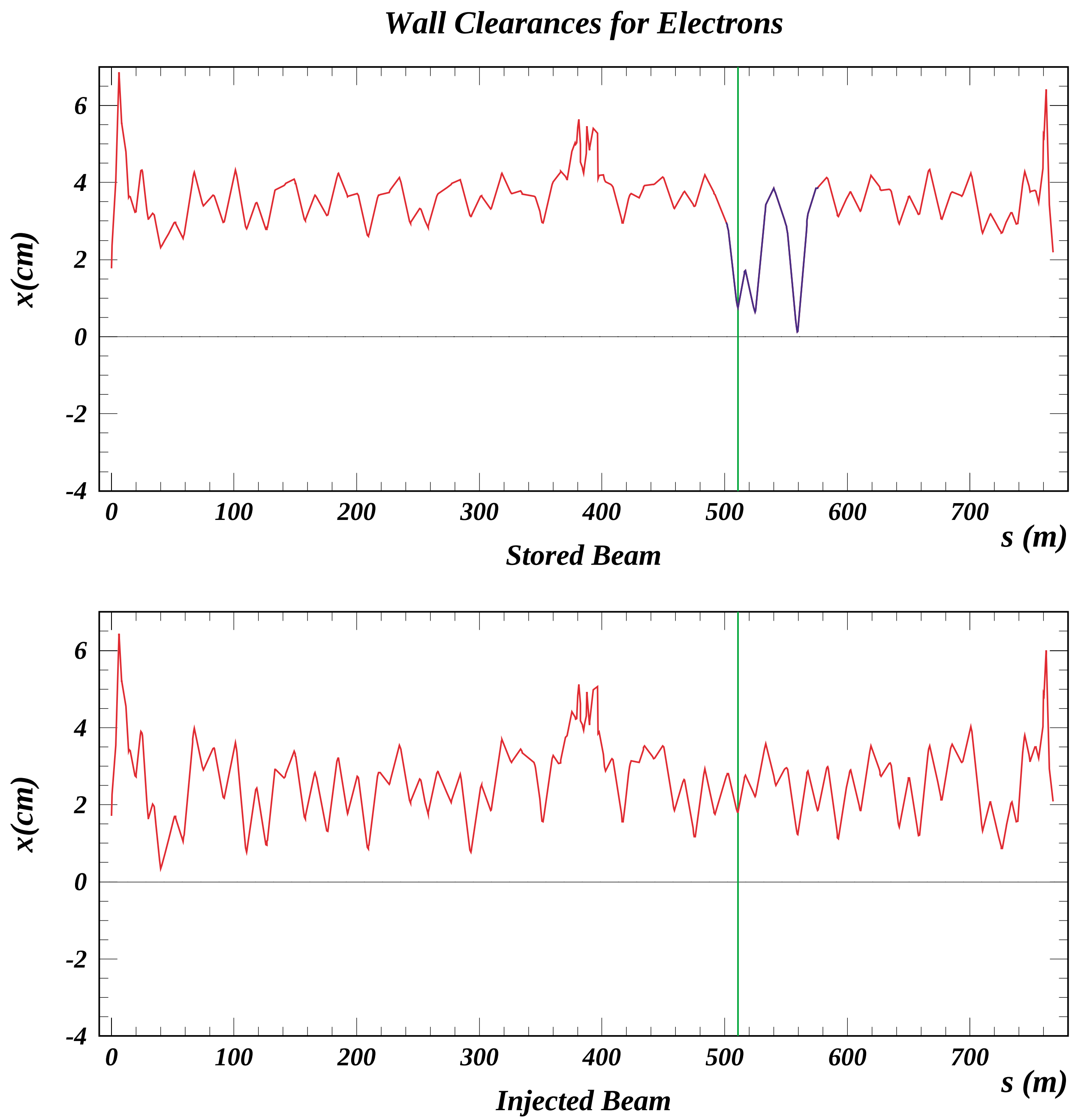


5. Determine any static or transient closed orbit distortion for stored beam or injected beam => Beam Position

Minimum Wall Clearance of Center of Beam =
Half Aperture - Beam Position - Oscillation Amplitude

Determine similar result for Clearance to Other Beam

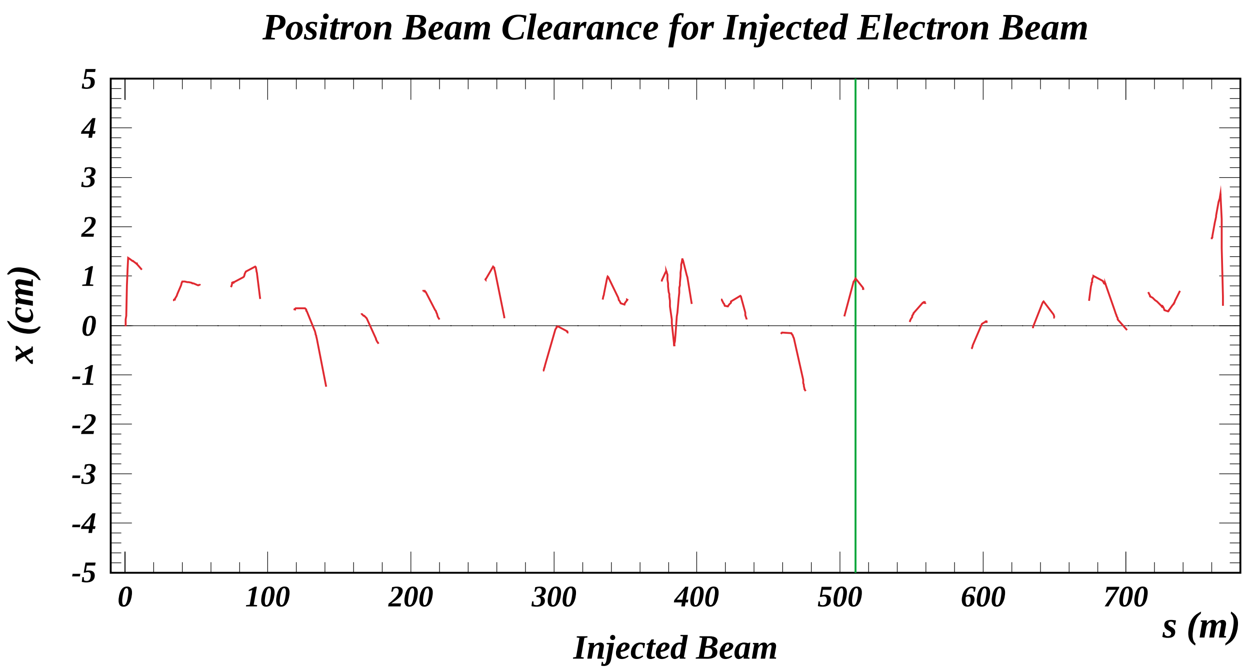
If Clearances are positive, this is the space for the particles in the beam



Wall clearances for Stored and Injected electron beams around CESR.

The section of the stored electron wall clearance plot, which is in blue, represents the reduced clearance due to the pulsed bump.

The vertical green line marks the injection point.



Clearance between the stored positron beam and the injected electrons.

Plot shows only regions in the ring near the locations where the injected electrons encounter trains of positrons bunches.

Plot shows that, UNLESS something else is done, the Injected Electrons will Pass through the core of the Stored Positron beam

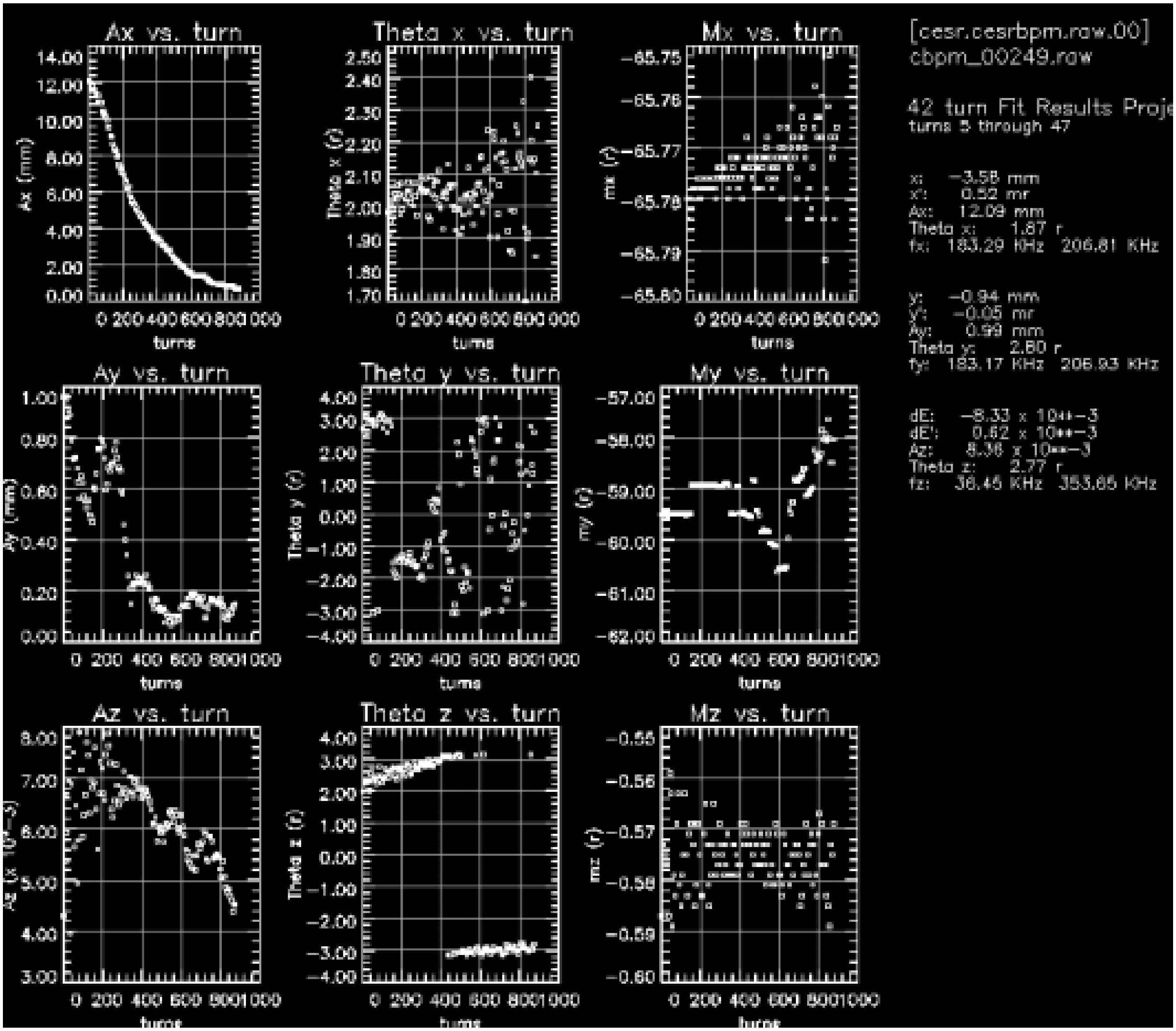
Real Result:

Preceding Example modeled a real set of conditions

Conditions did not inject to very high currents

Conditions required H-V coupling to inject at all => Raise Pretzel separation => Injected electrons barely clear core of positron beam

Conclusion so far : Conditions with more designed wall clearance inject better than those with less



Injection Trajectory Fits