SUMMARY OF PRESENT ABS SYSTEMS

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Abstract

The session on present ABS Systems is summarized. A variety of systems have been created, but there are many common elements, including algorithms, operational challenges, and goals. Similarities and differences between the systems are noted, and highlights of various talks are described.

1. INTRODUCTION

The session on present ABS systems included nine talks, reporting on existing automated systems from several laboratories around the world. There is a wide variation in complexity and sophistication among the different systems. Limited hardware and software resources are a common situation, and the sophistication of automated systems is necessarily matched to local requirements. Key goals of the packages include providing more reproducible beam conditions, reducing tuning time, and optimizing luminosity. Higher order tuning packages are used in several facilities. In several facilities, the controls history shows a trend of increasing levels of automation in response to increasingly demanding requirements.

At present, common algorithms and needs are addressed among the labs, but common software among multiple projects is not typical. In many cases, different experiments at the same site use diverse controls interfaces, resulting in duplication of software effort and increased complexity for users. An effort to standardize algorithms as well as software and human interfaces could be of benefit for many facilities. The COCU package is a positive step towards this goal, providing a machine-independent correction package with a choice of algorithms which has been used at several different experiments.

Automated steering packages have common challenges, such as recognising and eliminating unreasonable beam position monitors (BPMs), and enhancing numerical stability and robustness. Decisions must be made about number and placement of measurement and control devices. A common operational strategy is to limit the number of correctors, and to minimize their strength. Difficulties with coupling or crosstalk between horizontal and vertical planes, or between separate beamlines or beams are addressed. Several projects have encountered questions of compensating for hysteresis and nonlinearities of correction devices.

A common question for controls designers is choice of the location at which the beam position is stabilized. At Jefferson lab, there is a proposal to introduce “virtual monitors” to allow choice of the stabilization point, in addition to providing a tool for improved numerical stability. For the SLC feedback system, a similar function is provided by movable “fit points”, which can be placed at any modeled location in the accelerator, including component locations and arbitrary marker points.

Response-based matrix methods are typical. Singular Value Decomposition (SVD) and Micado algorithms are widely used. In some cases, model-driven matrices are adequate, but for many experiments a measurement of the response matrix is required. In discussions at the workshop, there was general agreement that when measured methods are used, it is advisable to study any discrepancies between the measurements and the model to gain a better understanding of the machine and to improve the model.

Steering packages are typically available under user control, with an application run on demand, and an opportunity for users to review proposed corrections before making a decision to implement or reject changes. Users have an opportunity to select a range for steering, and devices to be included or excluded. Many systems allow a choice of several steering algorithms, and some provide a selection of packages with varying levels of automation.

Time scales range from high bandwidth feedback systems, to once-a-day tuning packages, to once-a-year procedures. Hardware considerations frequently limit the bandwidth for control, including controls architecture and magnet response limitations. Some fully automated systems require minimal operator intervention, while others involve more substantial user control and interaction. There is a trend towards improved controls response time and additional feedback systems as experiments mature. Feedback algorithms include PID control, state space formalism, as well as simple response algorithms.

Oracle databases are common, although they are not typically used for real-time information. There are also file-driven configurations, and several types of real-time databases. A variety of control system hardware and architectures is seen; in many cases the systems use "vintage" hardware that is no longer state-of-the-art, since technology is changing rapidly and many control systems are long-lived.

2. Automated Tuning and Feedback Systems at the SLC

Pantaleo Raimondi spoke about some of the tuning and steering packages which have contributed to the success of the latest SLC run at SLAC. The luminosity for the 1997-1998 run was substantially increased over previous runs, due in large part to improvements in tuning and optimization procedures.

In the linac, a two-beam dispersion free steering algorithm was used successfully. This takes advantage of information from electron and positron beams traveling down the same beamline, since imposing the same orbit on both beams is equivalent to minimizing the dispersion. The algorithm uses Singular Value Decomposition to fix the orbit while minimizing the corrector strengths.

A stronger focusing lattice and weaker BNS profile also contributed towards minimizing emittance in the linac. An automated, generalized optimization package facilitated adjustment of emittance bumps in the linac as well as other parameters. Finally, an automated, reliable subbooster phasing method was developed for the linac, to help maintain a stable, well-understood energy profile. Figure 1 shows a graphical display of the "dithering" phase measurement. The subbooster phase is moved up and down by a small amount, with repeated measurements of the energy taken at each point. The results of a cosine fit of the energy versus phase are used to determine the desired phase setting.

Emittance control in the arc sections was improved by a new orbit centering technique which minimized wakefield effects. Improved emittance measurements in the final focus facilitated minimization of synchrotron radiation growth. These new procedures resulted in the smallest emittances ever seen in the final focus of the SLC.

Feedback systems are used in every major region of the SLC to control parameters such as intensity, steering and energy as well as higher-order control. State space feedback algorithms are used, with Kalman filters and Linear Quadratic Gaussian regulators. A specialized algorithm is used to damp beam noise at and near the Nyquist frequency of 60 Hz. A fully-automated optimization feedback system uses subtolerance excitation, or "dithering" techniques to maximize luminosity by adjusting final focus parameters and averaging luminosity monitor readings over many pulses. The optimization system provides substantially improved resolution over the previous method, which involved manual scans and user interaction. The new method results in improved reproducibility and luminosity, as well as freeing operators for other tuning. The optimization feedback is also used as a high resolution measurement device for manual tuning of higher order aberrations. As a result of these new tuning procedures, the final focus is effectively corrected up to the third order.

The SLC experience has shown that improved online applications, feedbacks and software diagnostics are of great benefit for complex and challenging machines.

3. ABS at the PS Division

Michel Martini reported on automated steering and tuning procedures for the PS complex at CERN. The goal for the PS complex is to provide high brightness beams for colliders. This is accomplished by minimizing beam emittance blow up and particle losses. Steering and matching are performed for the PS

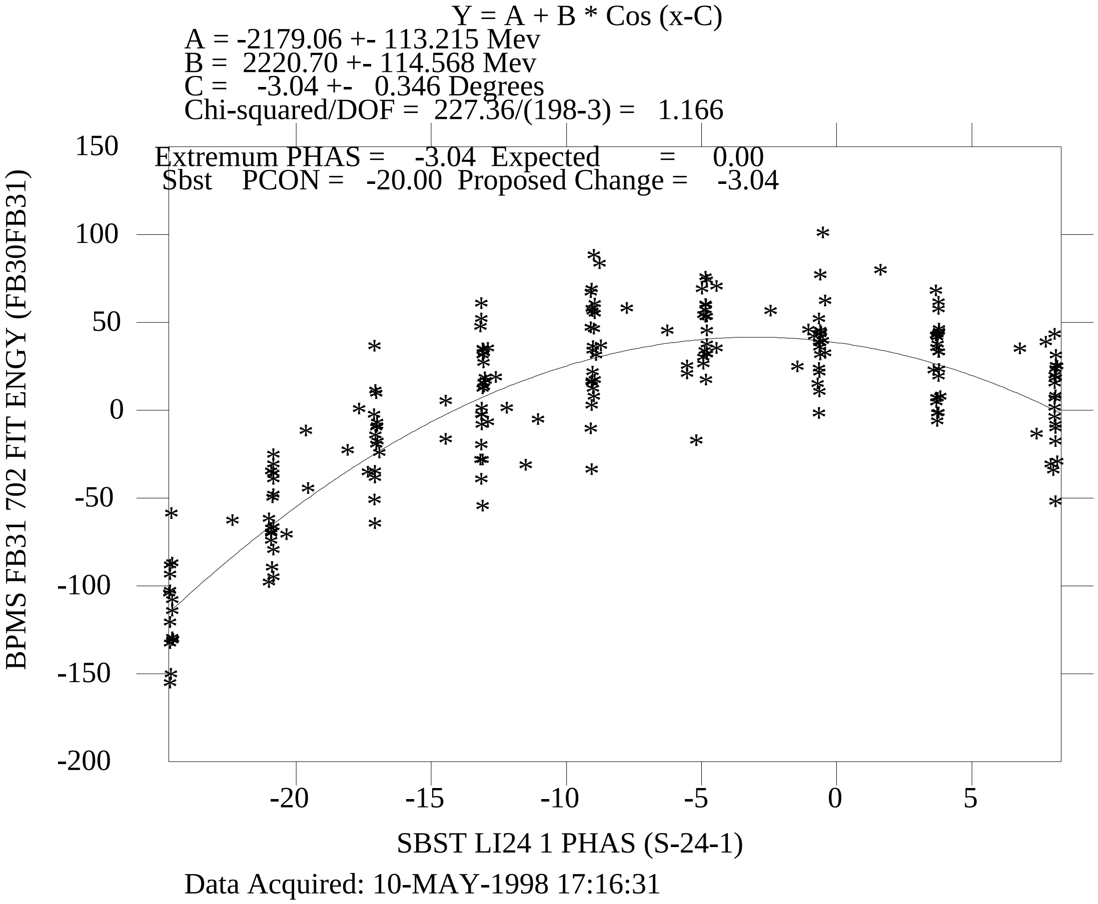


Fig. 1: Subbooster phasing procedure in the SLC

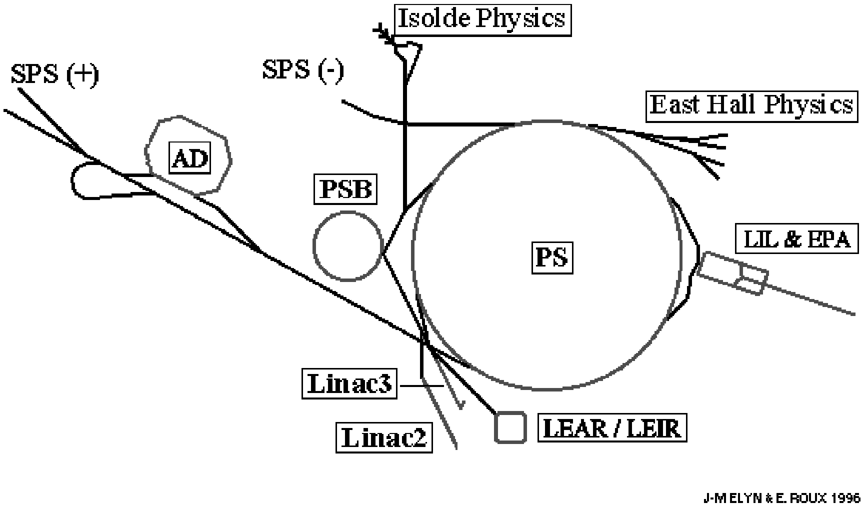


Fig. 2: The CERN PS complex.

and associated transfer lines. The Micado solver is used. The PS systems are more fully described in a later section. A view of the facility and associated beamlines is shown in figure 2.

4. ABS at CRYRING

Ansgar Simonsson of MSL reported on some of the tuning techniques used at CRYRING, an atomic physics facility in Stockholm, Sweden.

Feedback for the electron ion source is used to control the anode voltage, improving stability for the beam energy and the current. In the injection line, a beam centering procedure varies a quadrupole, and determines that the beam is centered if the spot does not move on an inserted screen, adjusting steering elements as needed. This manual procedure will be replaced with an automated Labview system.

Of interest to many at the workshop was an intensity optimization system, with a “stupid but indefatigable” virtual operator. A Pascal optimization program varies parameters up and down, keeping changes that result in increased intensity. The concept and some system benefits are similar to the SLC optimization feedback: the system is faster than a human, and it still works when a human is distracted.

5. Beam Steering and Control at DAFNE

Catia Milardi described techniques and results for trajectory control of the DAFNE facility at Frascati. Commissioning has been completed and orbit control systems are working well. DAFNE is a double-ring F-factory, with circulating electron and positron beams. The transfer line includes 23 beam position monitors, and the trajectory correction is used to optimize the beam current transmitted to the rings. VME is used for controls in the transfer line and in the rings.

In the rings, the closed orbit correction system must manage challenges due to cross-talk between the electron and positron rings, and between the rings and transfer line. The correction system must optimize the coupling and control the positions of the beams at the interaction points. Local closed bumps are used for collision control. Vertical tuning is particularly important due to the beam dimensions, and

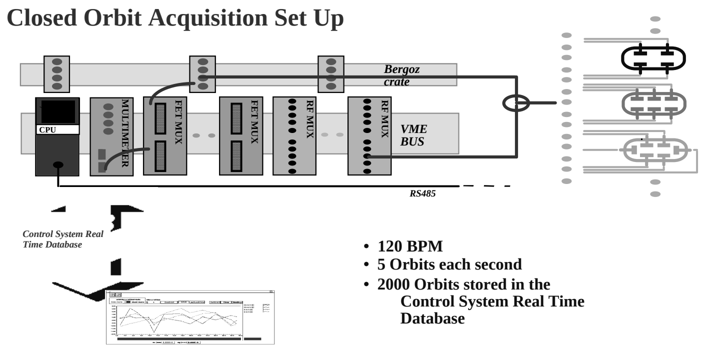


Fig. 3: Architecture of DAFNE Closed Orbit Acquisition System

fine tuning is accomplished using a luminosity monitor.

A schematic of the system used for the closed orbit acquistion is shown in figure 3. The BPMs are multiplexed, and the acquisition system runs at 5 Hz. Several algorithms for closed orbit correction have been tried, including best corrector, harmonic method, and orbit decomposition eigenvector methods. The response matrix is measured, and is independent from the model or from corrector calibrations. In the future, more work will be done to use the response matrix measurements in DAFNE modeling. Figure 4 shows a comparison of the closed orbit before and after correction.

At the interaction point, in addition to bringing the beams into collision, the synchronization is tuned by making small adjustments to the RF cavity phase. Beam coupling is controlled with skew quadrupoles, and the beam lifetime is enhanced by proper tuning. A novel arc lattice is used, with a Bending-Wiggler-Bending (BWB) configuration. This has resulted in decreased damping times and better emittance tunability.

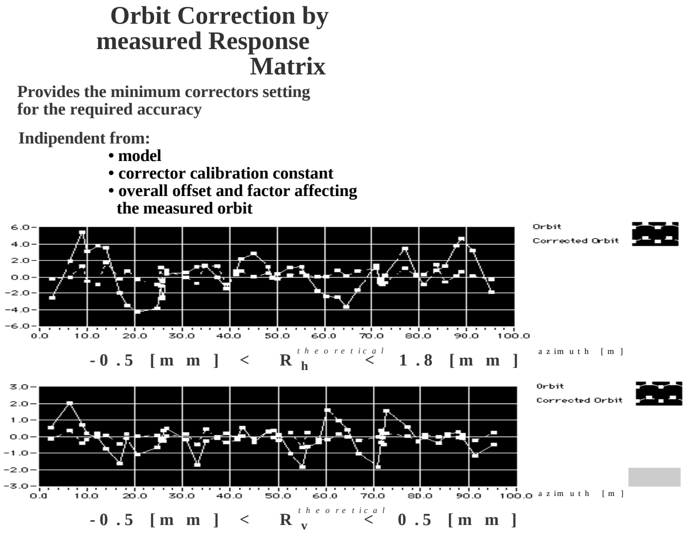
6. Online Beamline Centering at PSI

Automated systems for beam position monitoring and control at PSI were described by Thomas Blumer. Several accelerator facilities are supported, including a meson factory, spallation neutron source, proton therapy and irradiation areas, as well as an injector with many different particles. Good controls are needed due to the very high intensity beams which require good stability, and the strong dependency of the beam characteristics on intensity.

The controls hardware architecture includes VME, CAMAC, ethernet, and Alpha/Vax, HP and SUN workstations. Software architecture includes a message-based communications system. Oracle databases are used to store device information, while ASCII files are used to store program configurations. A graphical user interface enables viewing of results and modification of control parameters. Several applications are provided for both open and closed loop control of beam position and intensity parameters, and for measurement of beam characteristics. A generalized PID-based feedback controller is used to stabilize a two-by-two system, with a repetition rate of 3 Hz. Stabilization is effective at the beam position monitor locations, although alternatives are being studied.

7. Automatic Beam Tuning at Ganil

Automated tuning packages at Ganil were described by A. Savalle. Systems have been developed for transverse matching, beam centering and achromaticity. Tuning for the cyclotrons and associated transfer lines can take 24 hours. Automated systems speed up tuning, optimize beam parameters, and improve



Orbit Correction by measured Response Matrix

Provides the minimum correctors setting for the required accuracy

Indipendent from:
- model
- corrector calibration constant
- overall offset and factor affecting the measured orbit

Fig. 4: Results of DAFNE Closed Orbit System

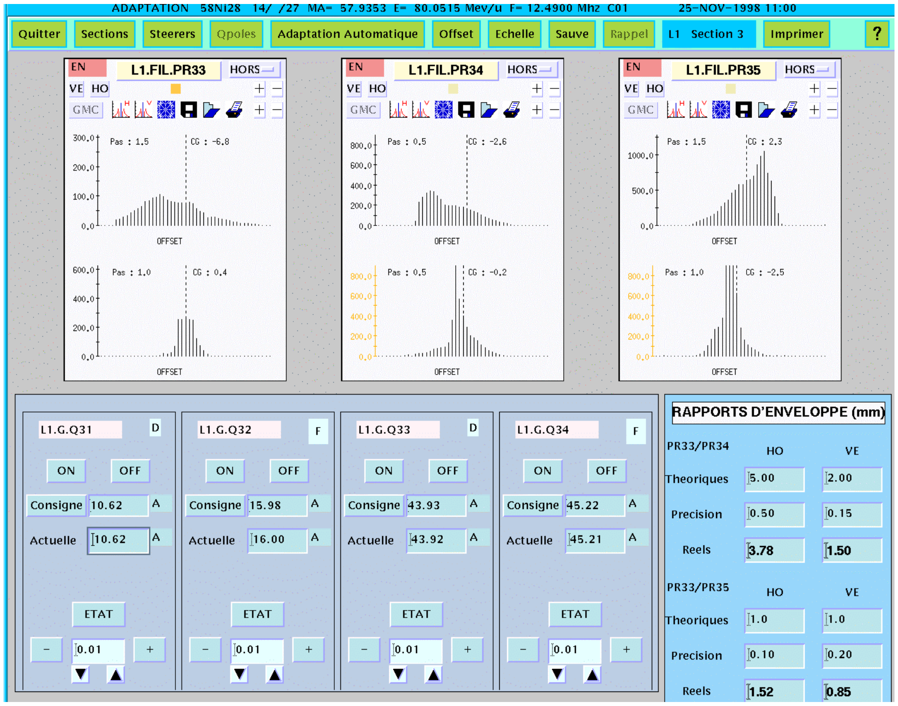
reproducibility. Figure 5 shows a user interface display for the system. The betatron matching system has been operational since 1997, and has been faster and more reliable than the previous manual method. Beam sizes are measured with profile monitors, and an online beam optics calculation is used to optimize the beam transfer matrix. The automatic beam centering system uses profile monitors to measure the beam center, and a least squares fit is performed to determine corrections which center the beam while minimizing corrector values. Noise on the profile monitor measurements is a limitation for both the matching and centering packages. An additional package was developed to decorrelate the transverse and longitudinal planes, resulting in fully achromatic beam in the matching section by optimizing quadrupole settings. Initial tests are encouraging.

8. ABS at the SPS and LEP

Joerg Wenninger reported on automated systems for SPS and LEP, which are large circular accelerators at CERN. Much of the steering software for the two machines is common, even though the two machines have very different operational goals. SPS orbit control has simpler requirements, and is mainly concerned with minimizing beam losses, while LEP is concerned with optimizing the vertical orbit for maximum luminosity and polarization. As a result, most of the developments have been geared towards the requirements of LEP.

The COCU orbit correction package is used, in combination with a main user interface and display dataviewer. A user interface display for the LEP orbit control is shown in figure 6. The dataviewer and COCU are identical for both machines. COCU is a machine independent package which supports a variety of correction algorithms. It was developed at CERN for SPS and LEP, but has been adopted at several other facilities.

For SPS, the twiss parameters are stored in an Oracle database, and other machine parameters and data are stored in files. Global MICADO corrections are used, in addition to local bumps and other corrections. All orbit correctors for the two machines are based on modeling parameters, without using measured response matrices.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Consigne (A)	10.62	15.98	43.93	45.22
Actuelle (A)	10.62	16.00	43.92	45.21
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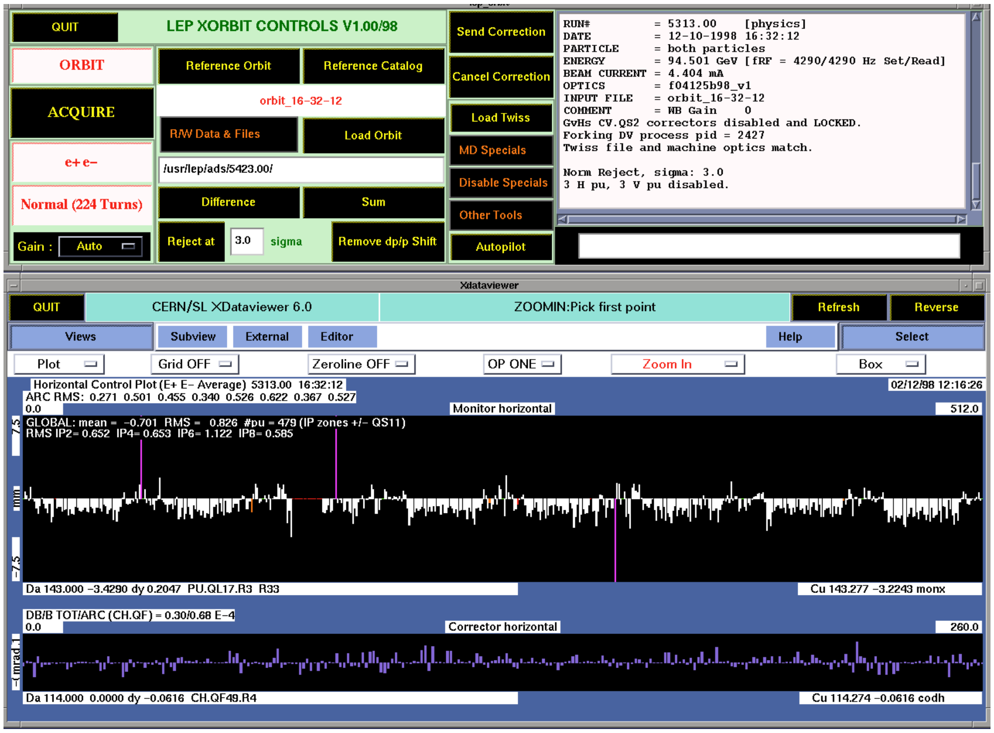
RAPPORTS D'ENVELOPPE (mm)

PR33/PR34	HO	VE
Theoriques	5.00	2.00
Precision	0.50	0.15
Reels	3.78	1.50

PR33/PR35	HO	VE
Theoriques	1.0	1.0
Precision	0.10	0.20
Reels	1.52	0.85

Fig. 5: User Interface for Ganil Automated Tuning



orbit_16-32-12

/usr/lep/ads/5423.00/

3.0

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RUN#         = 5313.00    [physics]
DATE         = 12-10-1998 16:32:12
PARTICLE     = both particles
ENERGY       = 94.501 GeV [fRF = 4290/4290 Hz Set/Read]
BEAM CURRENT = 4.404 mA
OPTICS       = f04125b98_v1
INPUT FILE   = orbit_16-32-12
COMMENT      = WB Gain    0
GvHs CV.QS2 correctors disabled and LOCKED.
Forking DV process pid = 2427
Twiss file and machine optics match.

Norm Reject, sigma: 3.0
3 H pu, 3 V pu disabled.
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Horizontal Control Plot (E+ E- Average) 5313.00 16:32:12
ARC RMS: 0.271 0.501 0.455 0.340 0.526 0.622 0.367 0.527
0.0
02/12/98 12:16:26
512.0
GLOBAL: mean = -0.701 RMS = 0.826 #pu = 479 (IP zones +/- QS11)
RMS IP2= 0.652 IP4= 0.653 IP6= 1.122 IP8= 0.585
Da 143.000 -3.4290 dy 0.2047 PU.QL17.R3 R33
Cu 143.277 -3.2243 monx
DB/B TOT/ARC (CH.QF) = 0.30/0.68 E-4
0.0
260.0
Da 114.000 0.0000 dy -0.0616 CH.QF49.R4
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Fig. 6: User Interface For LEP Orbit Control

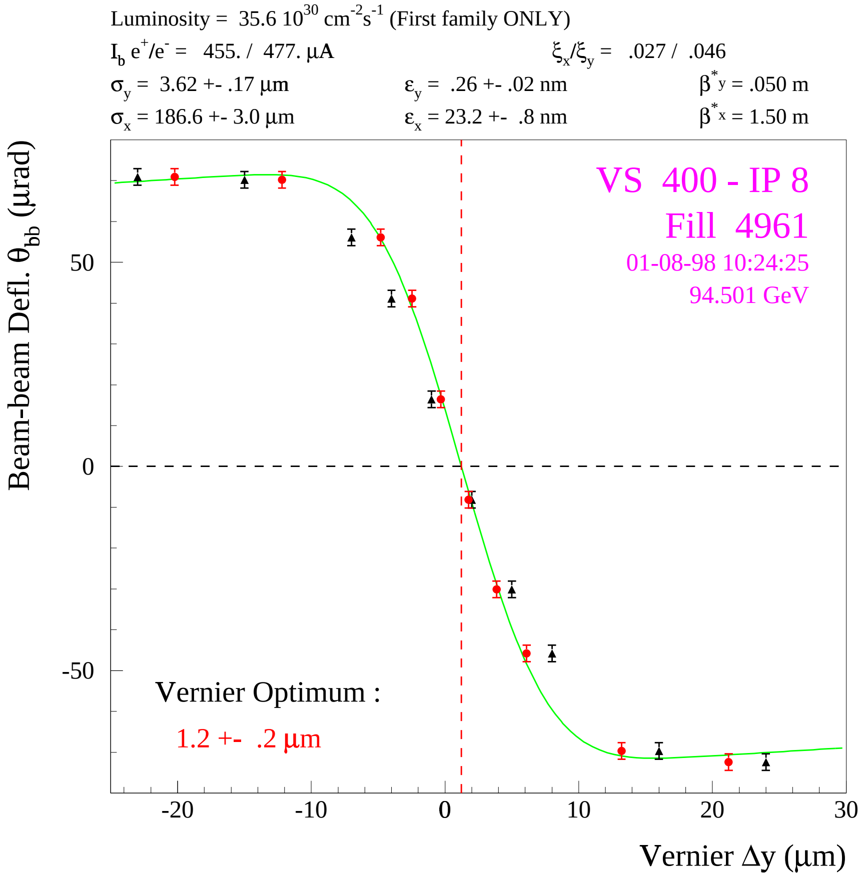

Fig. 7: Interaction Point Collision Control at LEP

At LEP, all hardware and modeling parameters are stored in an Oracle database, with orbits updated to the database every 40 seconds. MICADO is the most popular algorithm. Golden orbits are found through an empirical tuning process, but tests using SVD for orbit and dispersion correction looked promising, and a more complete implementation is planned for 1999. An autopilot application maintains the orbit, with corrections every 2 minutes. A Hydrostatic Levelling System was installed around the quadrupoles to monitor movement associated with orbit drifts. At the interaction point, the vertical beam collisions are adjusted with electrostatic separators. Local separator bumps are scanned to find the optimal setting, based on luminosity monitor and deflection measurements. Figure 7 shows a display of the beam-beam deflection as a function of separation.

Automated beam steering has been essential for the operation of SPS and LEP. The implementation of Dispersion Free Steering for LEP is planned for 1999.

9. Orbit Correction Methods - Basic Formulation, Current Application at Jefferson Lab, and Future Possibilities

Yu-Chiu Chao presented an overview of orbit correction methods which are applicable to CEBAF and to other facilities. A summary of general challenges encountered in orbit correction at any facility was included, along with symptoms, sources and possibilities for solutions. An example depicted in figure 8 shows a situation in which there are not enough monitors to correctly detect an orbit excursion. An optimization program was used to identify optimal locations to add monitors in order to improve the orbit

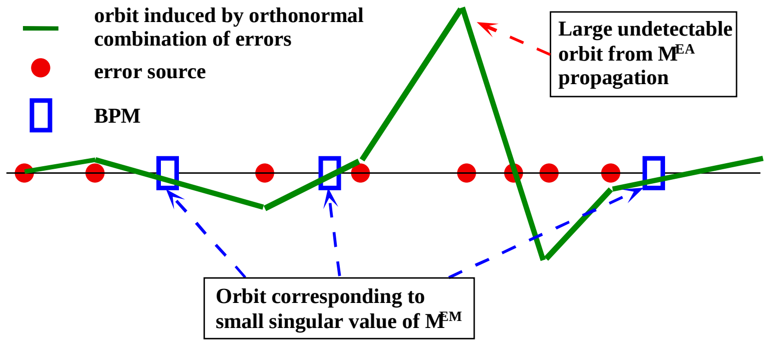

Fig. 8: Monitor Deficiency Detection and Elimination from Jefferson Lab

detection. The program also identified redundant correctors, which had resulted in excessive correction and poor reproducibility. In order to improve response singularies and other numerical problems, Chao proposes a Virtual Monitor algorithm, which is capable of controlling the orbit at an arbitrary location. Further information about these techniques is provided in a later section.

10. Automated Beam Position Control in the ESRF Storage Ring

Laurent Farvacque described two independent systems which are used for automated orbit correction at ESRF. The goal is to stabilize the beam to 10% of the beam size in both the horizontal and vertical planes. A periodic automated orbit correction system performs a correction every 30 seconds to control medium and long-term effects, and a global position feedback system regulates short term effects. Singular Value Decomposition (SVD) is used. Figure 9 shows the optical functions in the ring.

The response matrix is augumented to include additional effects: adjustment of the RF frequency acting on the orbit through the dispersion, and keeping the sum of the correctors constant so that the energy of the particles is constant. Results for measured response matrices were compared to the model, with good agreement as shown in figure 10. Limiting the number of eigenvectors reduces the sensitivity to BPM drifts by a factor of 2, minimizing emittance growth. The automated correction system requires specific beam and BPM conditions, in order to ensure the reliability of the calculations.

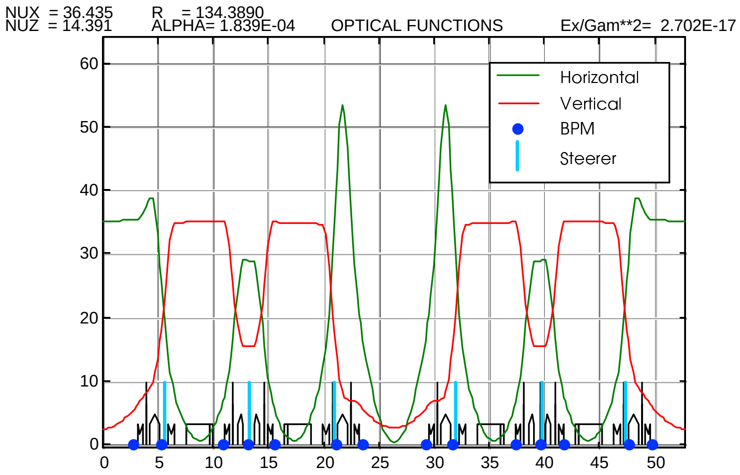

Fig. 9: Orbit Correction System at ESRF

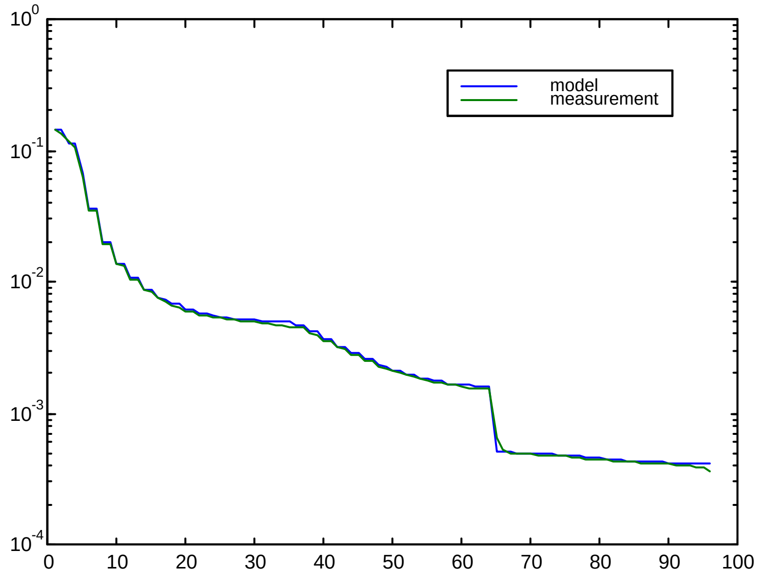

Fig. 10: Comparison of Measurement and Modeled Response Matrix at ESRF