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Electron Beam Diagnostics for SPX

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E-Beam diagnostics for SPX: scope and goals

INSIDE SPX ZONE, from crab cavities No. 1 (CC1) to CC2:

(1) Position e-beam through cavities at right time and on right orbit:

- (1A) Transverse beam centroid position (BPM)
- (1B) Beam arrival time (RF phase detectors)

(2) Position e-beam through 7-ID on right orbit

- (2A) Beam position and angle (BPM)

(3) Measure the effect of the crab cavities (7-BM or 8-BM):

- (3A) RF tilt meter for large tilt
- (3B) Optical tilt meter / bunch imager (visualizing tilt, phase, density distribution, HOM effect, etc.)
- (3C) Additional beam loss monitors (BLM)

OUTSIDE SPX ZONE

(4) Minimize the residual effect of the crab cavities:

- (4A) RF tilt meters for small tilt. Two locations, 90-degrees apart in ϕ_y.
- (4B) Synchronized measurements of beam centroid motion and beam size change in S35
- (4C) Multiple vertical emittance monitors

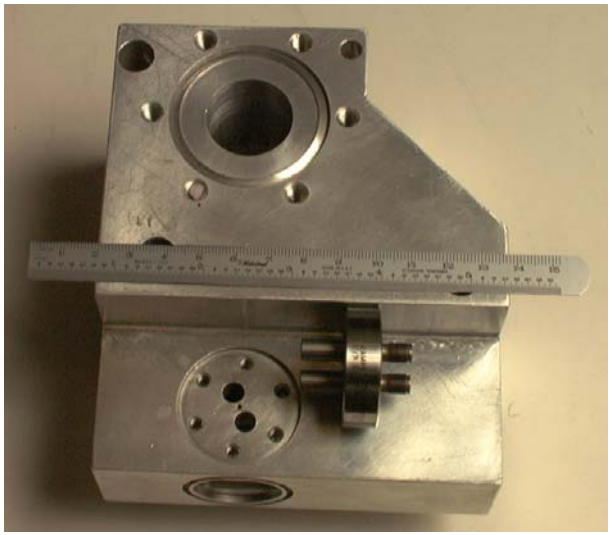
(1A & 2A) RF BPM: Transverse centroid measurements

Requirements (to be confirmed in PRD)

- Maintain ***absolute*** orbit in the deflecting cavities within ±50 μm
- Maintain orbit in the straight section within ±10 μm and ±1 μrad, in 200 Hz BW.

RF BPM enhancement:

- Two RF BPMs mounted on the same girder as the cryomodules, one upstream and one downstream, on room-temperature chambers, where/whenever practical.
- 7-ID uses normal ID mini-buttons.
- Libera Brilliance/Brilliance+.



(1B) S-Band phase detector: beam arrival time

Requirements (PRD)

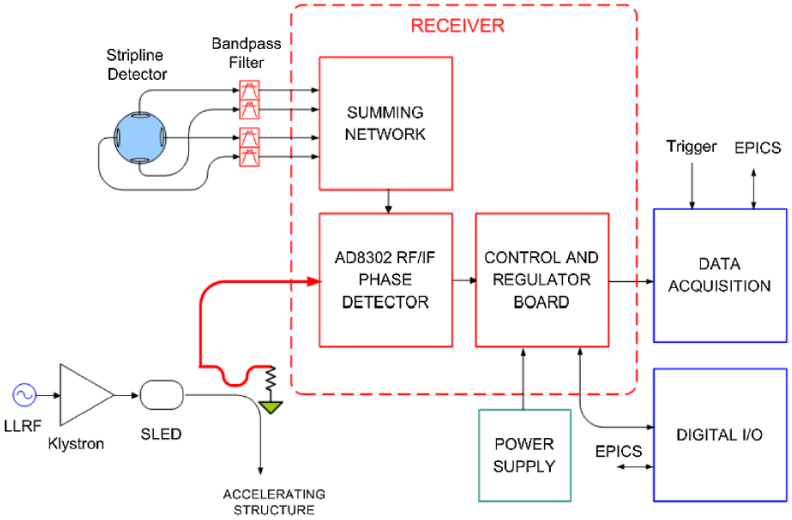
- Measure relative phase of electron bunch vs. Crab Cavity No. 1
- Accuracy requirements: 7˚ (~7 ps).

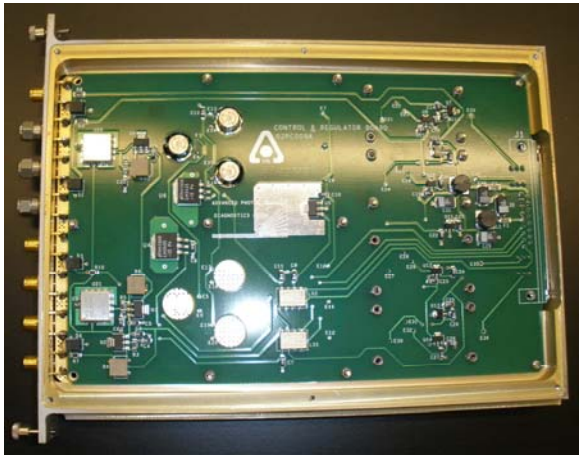
Plan

- Similar to phase detector used in APS LINAC
- Operate at 2815 MHz

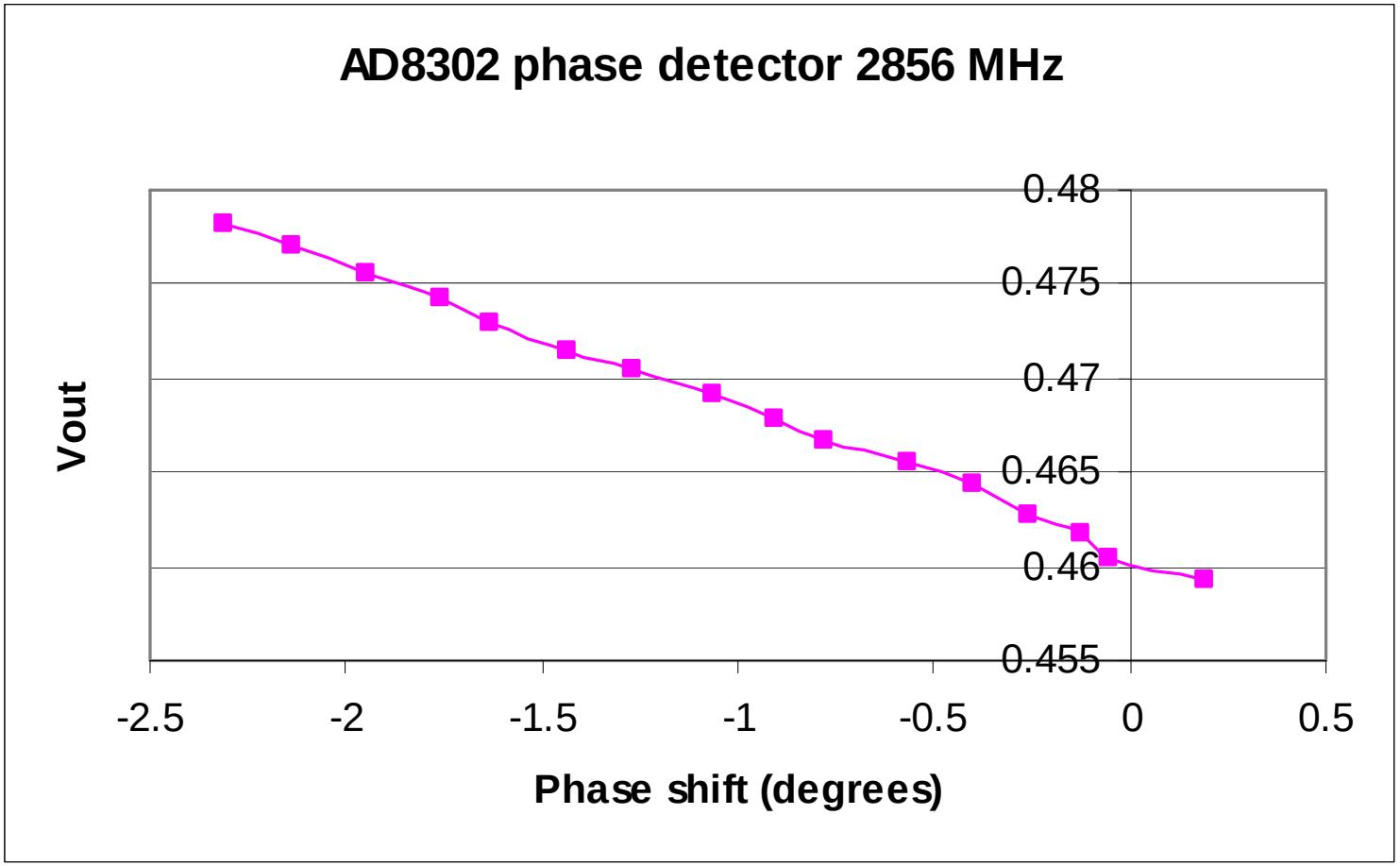
Issues

- Timing drift through long transport cables





APS-LINAC RF to beam phase detector



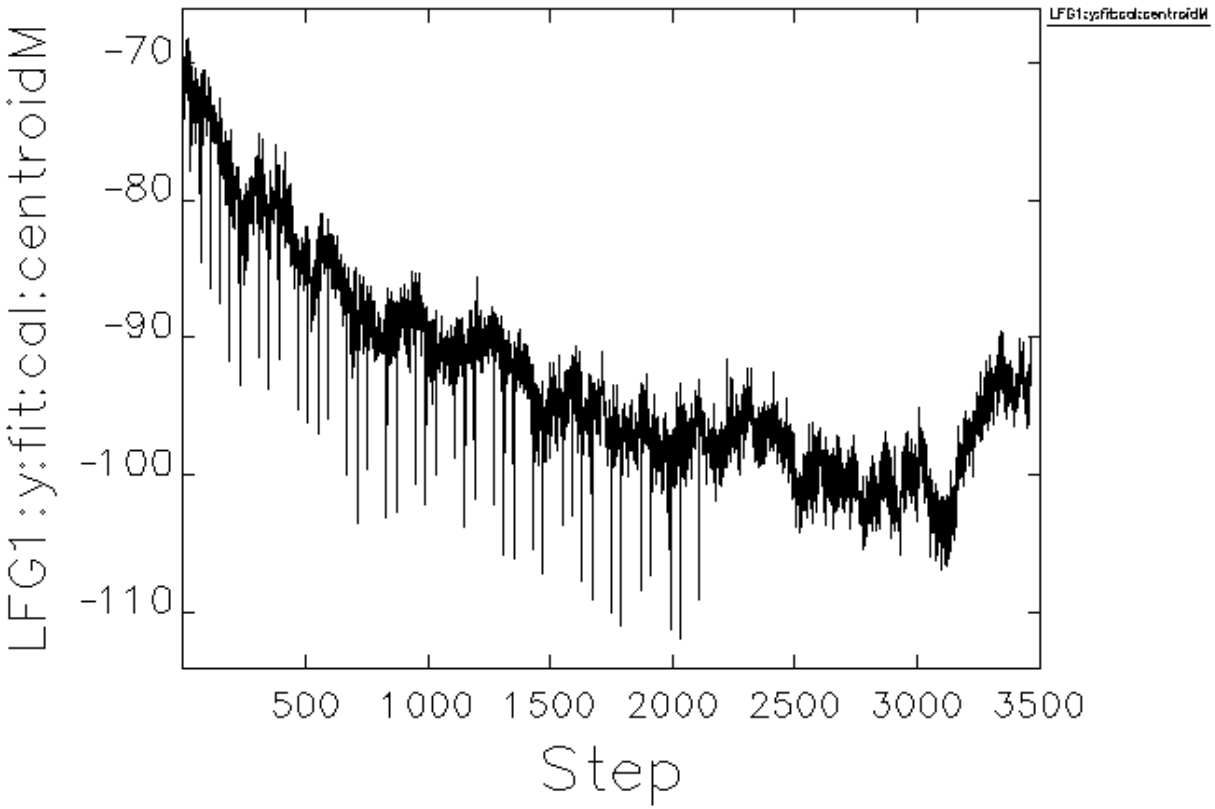
Achieved resolution: 0.1 – 0.2 degrees, or 100 – 200 fs.

Streak camera measured longitudinal centroid in 4 hours (18:00 – 24:00, 11/29/2006)

Centroid data taken at 4 sec/step. Average of two adjacent bunches.

Observation: RMS jitter ~ 1 ps. Drift ~ 30 ps over 4 hours

Question: How much of it is from temperature change of timing cable (25 m Heliax)?



(3A & 4A) RF tilt monitor (R & D)

Hardware candidate:

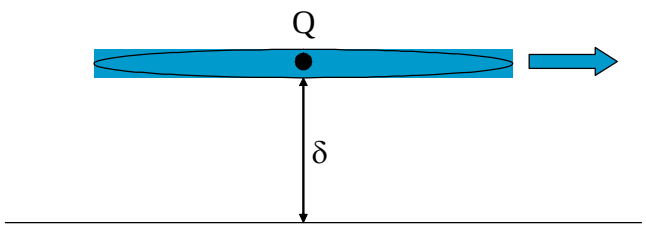
- Cavity BPM (proposed and demonstrated in SLAC & ATF)
- Striplines, button BPM?
- Low-energy electron beam???

Main Idea:

- Total BPM signal is the superposition of RF signals from all electrons. For tilted bunch, phase and amplitude of the signal is a function of displacement and tilt.
- Use appropriate signal processing electronics to sort out the displacement and tilt information

Cavity BPM response to two macro particle beam

From Steve Smith (SLAC), NLC Snowmass 2001

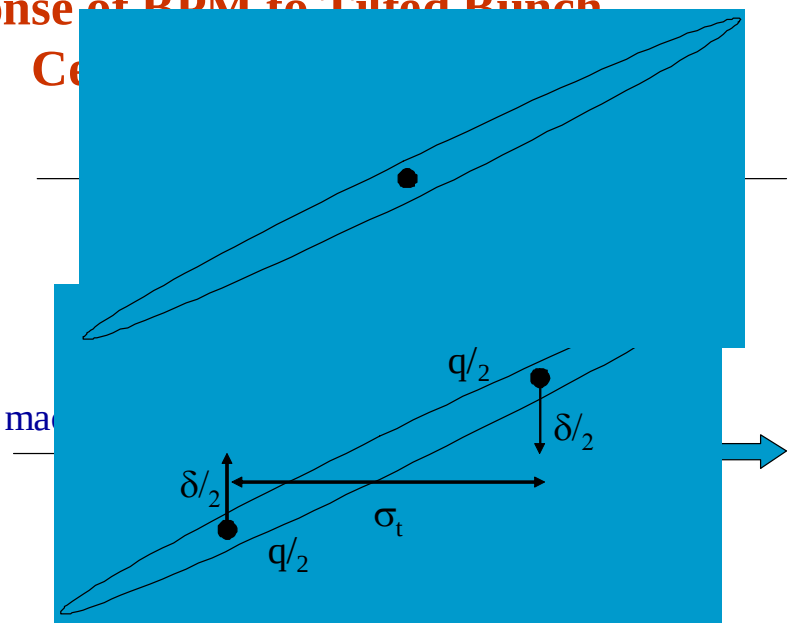


$$V(t) = aq\delta\sin(\omega t)$$

Response of BPM to Tilted Bunch

Ce

Treat as pair of ma

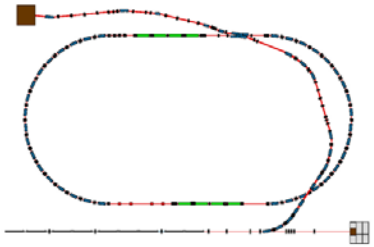


$$V(t) = a\frac{q}{2}\frac{\delta}{2}\sin\omega(t-\frac{\sigma_t}{2}) - a\frac{q}{2}\frac{\delta}{2}\sin\omega(t+\frac{\sigma_t}{2}) = \frac{a\delta q}{2}\cos\omega t\sin\frac{\omega\sigma_t}{2}$$

- Tilt signal is in *quadrature* to displacement. It can be enhanced for cavity wavelength comparable with the bunch length.
- Button BPM signal will also be affected by the bunch tilt. It can be extracted with similar signal processing.

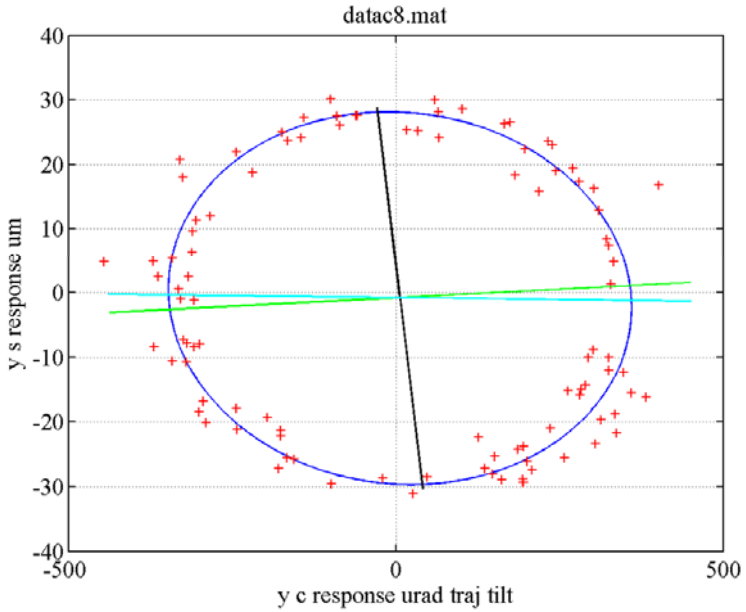
Cavity BPM tilt monitor test at the ATF

From Marc Ross (SLAC/ATF), KEK-SLAC ISG9 Meeting 12/2002



Deflection cavity on

- I/Q cavity response with deflection cavity at full voltage
- Axes show directions of pure displacement (black) and pure angle (bluish) (green is 90 from pure displacement)
  - Tilter motion is not quite orthogonal
- Ellipticity is the ellipse aspect ratio (*jiyouou*)
- This plot shows equivalent 'angle trajectory'

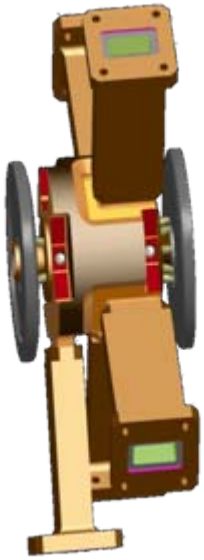


11.12.02 *ISG 9 at KEK* Marc Ross/SLAC 17

Demonstrated sensitivity < 0.2 mrad. Suitable for monitor residual effect outside SPX. How to measure large bunch tilt inside the SPX zone?

Candidate tilt monitor hardware

Hardware: LCLS cavity BPM… or APS LINAC S-band stripline

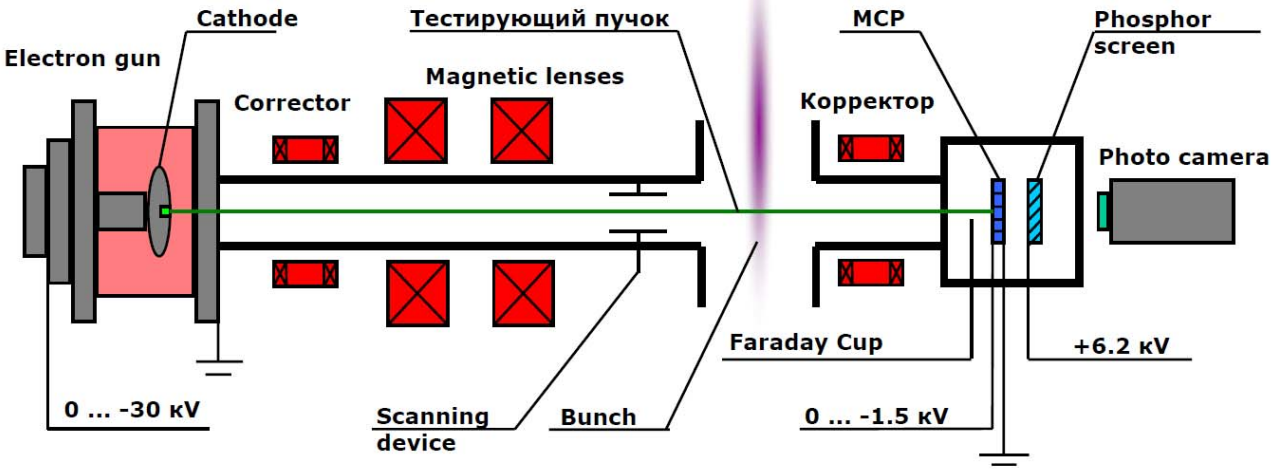


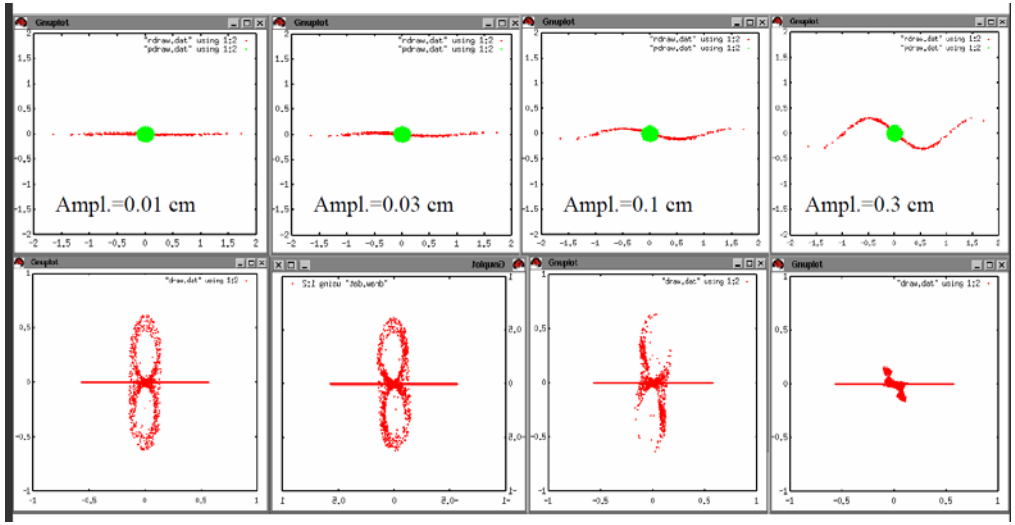
Other signals

Tune line intensity
Transverse dipole cavity signal power
Low-energy electron e-beam diagnostics

Low-energy electron beam profile monitor

P. Lagachev, et. al., BINP, RUPAC 2006, Novosibirsk



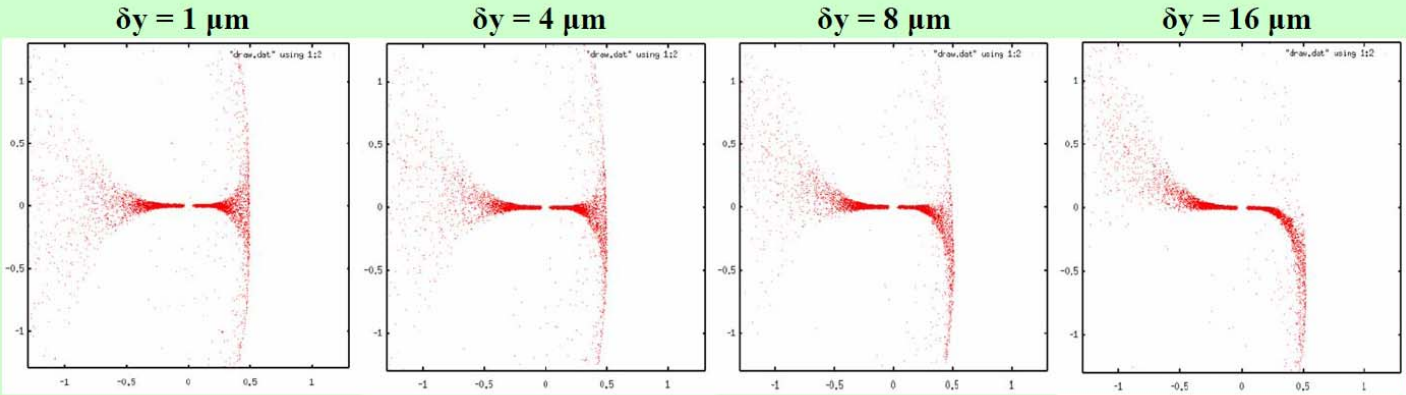


Low-energy electron beam profile monitor (continued)

EBP for ILC bunch tilt control

This mode of operation was successfully tested at S-band linac of VEPP-5 injector complex for the bunch length of 4 mm and 0.5mm transverse size

Simulation for typical ILC bunch parameters



Screen images for increasing amplitude of the bunch tilt δy.
the bunch head is δy up at $+\sigma_z$ and the tail is δy down at $-\sigma_z$

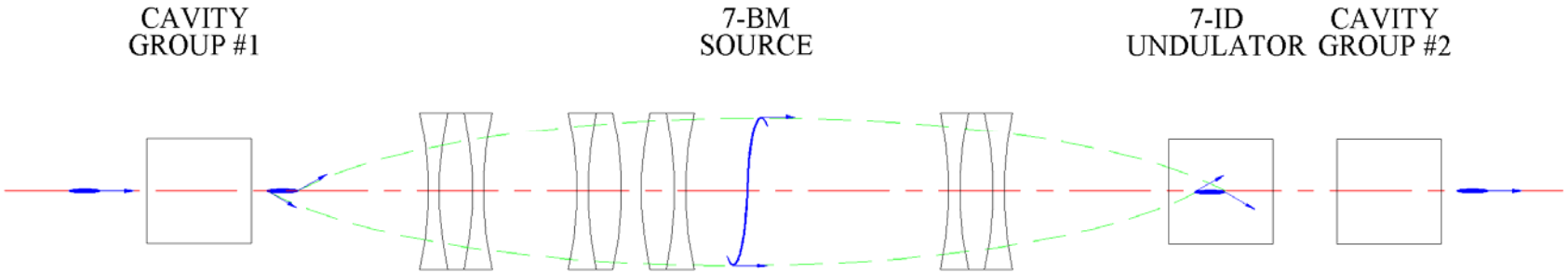
The asymmetry monotonically increase with increase of beam tilt

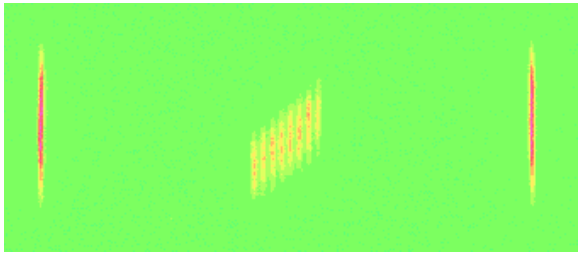
ILC bunch parameters: $\sigma_z = 0.1$ mm, $\sigma_x = \sigma_y = 10$ μm, $N = 0.7*10^{10}$

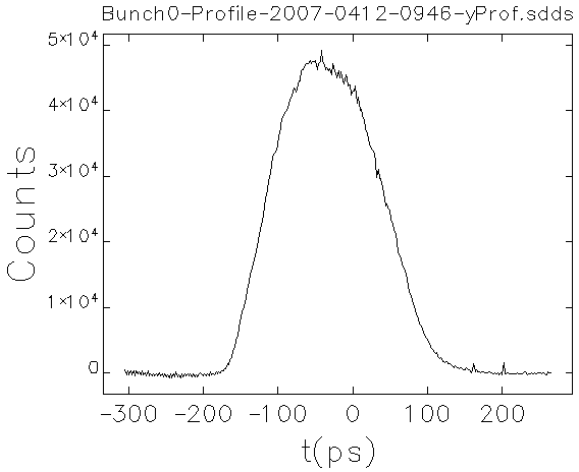
EBP: 200 keV, pulsed 2 mA, probe beam diameter in the interaction region is about 0.05 mm.
About 6000 electrons in the vicinity of ILC bunch.

P. Lagachev, et. al., BINP, RUPAC 2006, Novosibirsk

(3B) X-ray imaging (7-BM or 8-BM): vertical bunch profiles

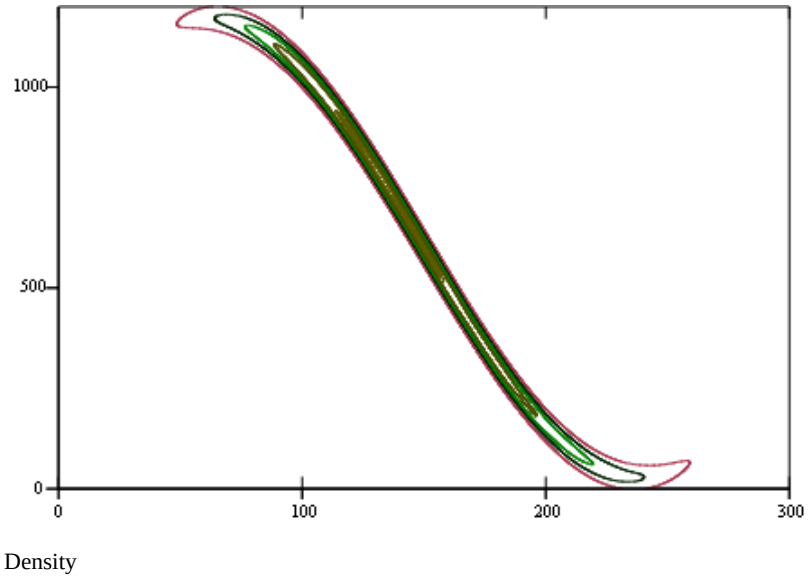






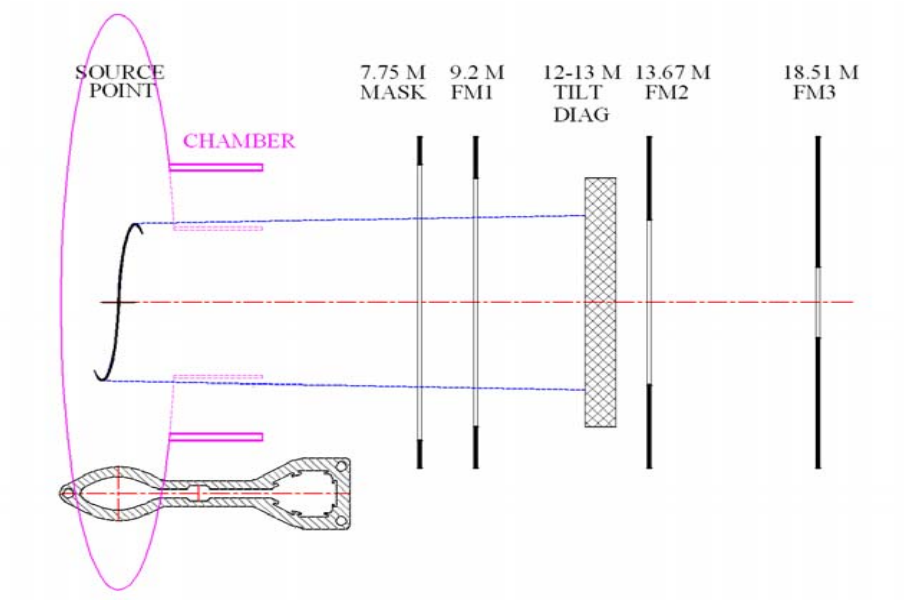
Bunch pattern / Super bunch profile

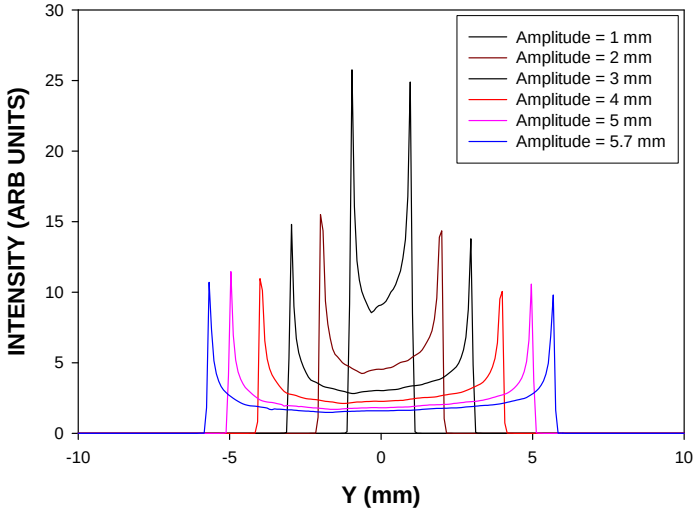
$$\left[\frac{dt}{dy}\right]_{y=0} \approx 10\,ps/mm \quad @\ 4\ \mathrm{MV}$$

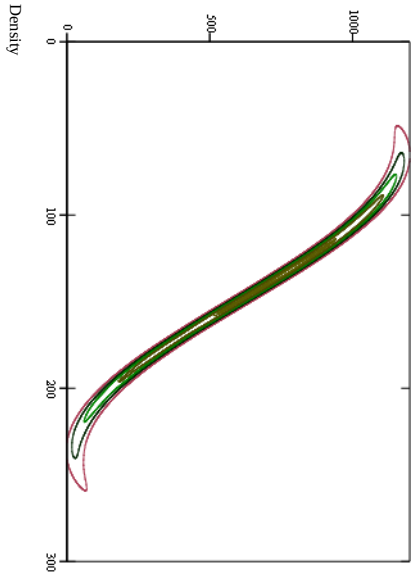


Side view of the super bunch in 7-BM

Beam information obtained from optical tilt monitor







Special BM chamber (Girder 5) required!

Time-averaged image / profile information:

- Total tilt ➔ Vertical beam size;
- RF Phase ➔ Vertical beam centroid;
- Horizontal RF field (-30 dB) ➔ Image become wiggly or fuzzy on the screen;
- HOM with vertical component (? dB) ➔ additional modulations in the profile;

Optical tilt monitor time-resolved modes

Time-resolved image / profile information:

- Gated camera ➔ Single bunch, single-pass image with bunch phase, tilt, HOM distortions, etc.
- Fast digital camera ➔ Up to many kHz frame rate
- TCSPC scanner ➔ Average bunch-by-bunch vertical profile

Need information on SPX for relevant simulations

- Twiss parameters at Cavity No. 1 and 7-BM source point

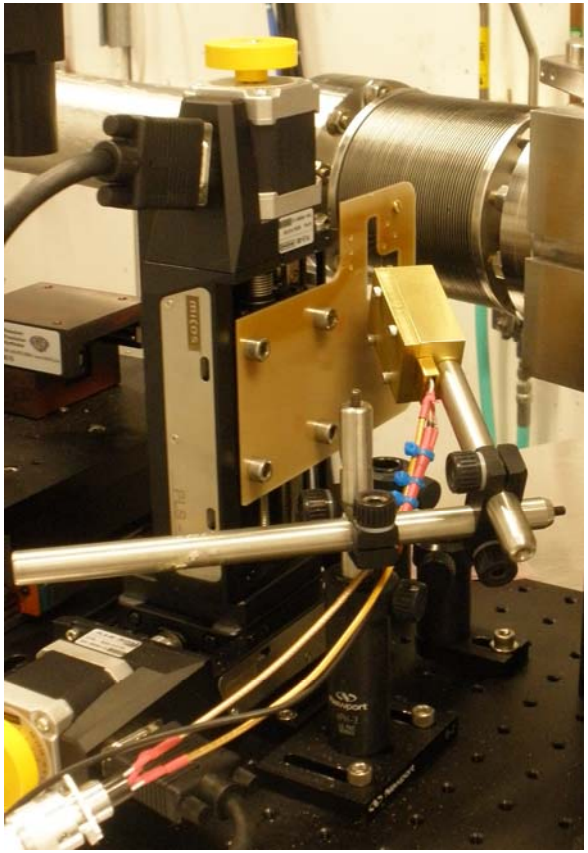
$40 K (analog) - $80K (digital)

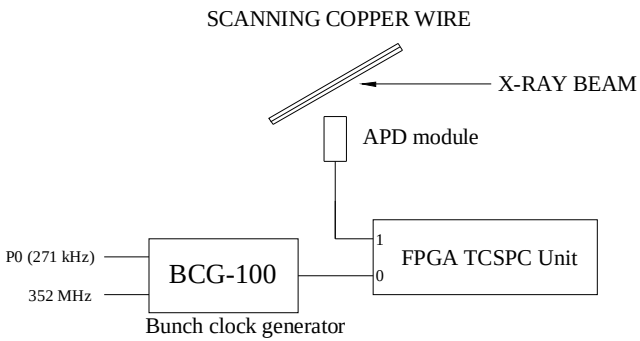
$3K - $4K

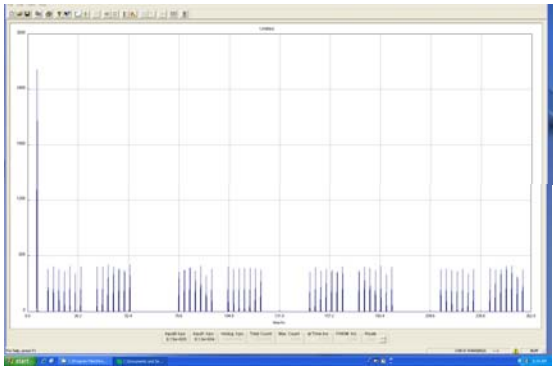
Sample TCSPC data at undulator ID-35

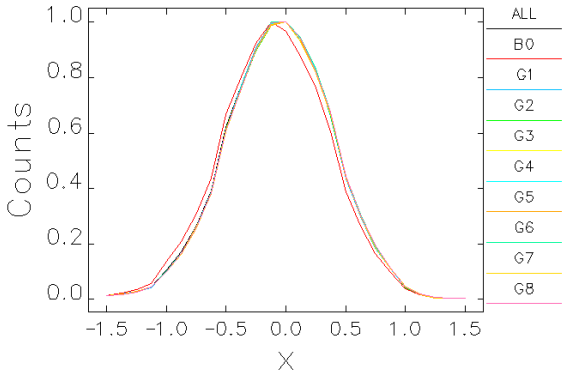
Time-correlated single photon counting (TCSPC)

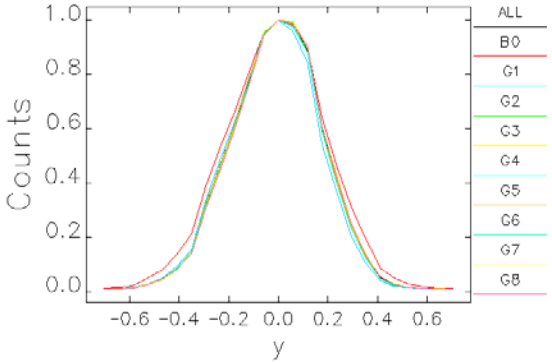
- Wire/slits scanner to provide spatial information
- TCSPC to provide timing information
- Computer sort out average bunch-by-bunch profiles











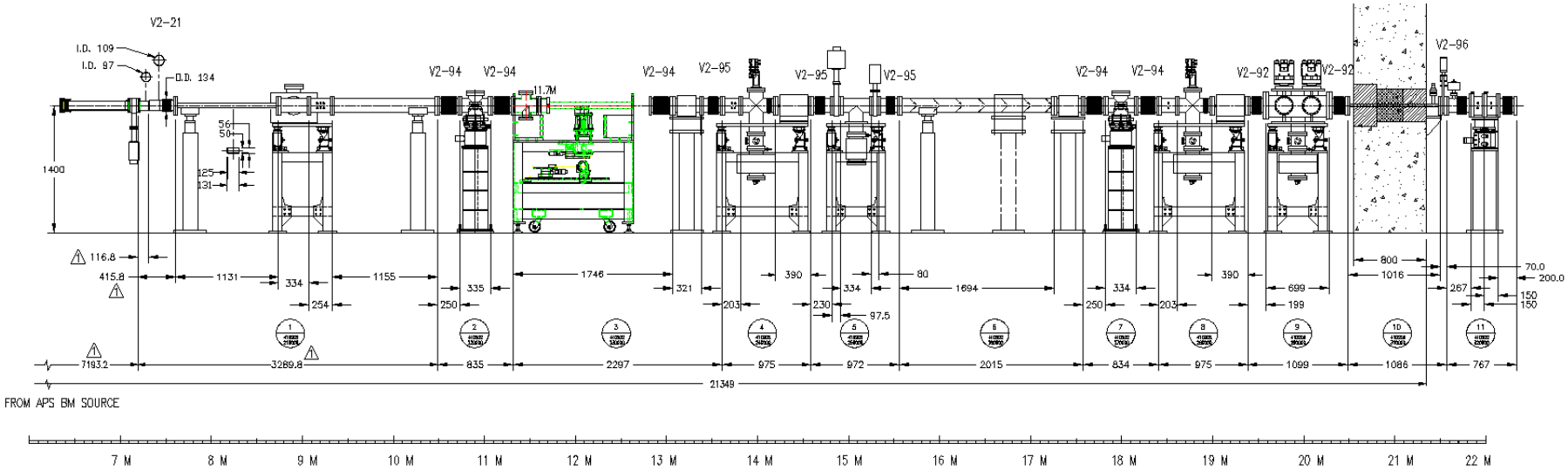
In the hybrid mode, the 16-mA bunch travels at different trajectory and has a different radiation spectrum from other bunches.

Where do we put the diagnostics?

Discussion with 7-BM users (XSD) in 2007:

- The 7-BM user beamline use 2 mrad x-ray fan outboard of the 7-BM axis.
- Tilt diagnostics uses 2 mrad x-ray fan on inboard side of 7-BM.
- Reserve space for second tilt monitor line or visible synchrotron radiation.

To do now: revisit the plan with XSD and finalize it ASAP.



(3C) Beam loss monitors inside and downstream of SPX

Present electron beam losses

- > 95% beam losses are from stored beam, Touschek scattering, etc.
- < 5% are from injections
- More than 40% of all losses occur at Sector 4 ID chamber

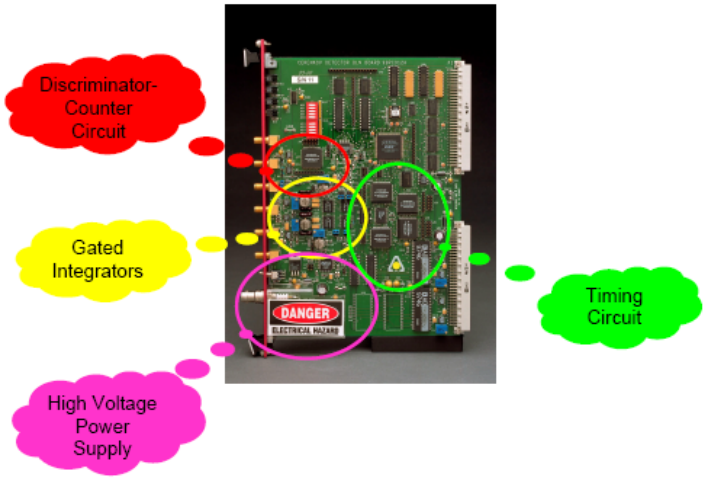
Operations of SPX will change electron loss patterns around the ring

- Losses in the superconducting cavity needs to be monitored
- Losses downstream of the SPX needs to be characterized

Plan for new BLM

- Cherenkov detector similar to those we are currently using.
- FPGA-based signal processor

Cerenkov Detector VME board.



(4B) Residual effect photon diagnostics (S35+)

Synchronized measurements

When SPX operates properly, the disturbance to electron beam is low outside of SPX. Synchronized (lock-in) experiment enhances the signal-to-noise ratio:

- Modulate deflection cavity voltage / phase / others in 1 – 200 Hz
- Measure the beam size / centroid change synchronously in Sector 35 at several times of modulation frequency.
- The narrow band width suppress the measurement noise significantly
- The amplitude of modulation may be so small that some routine measurements can be performed during user runs without user being aware of them
- If proven to be robust, feedback may be implemented based on these measurements

Other improvements

- Improve resolution of beam size measurements
- Increase bandwidth of beam centroid measurements

Additional vertical emittance monitors

Motivation:

- SPX X-ray pulse length is sensitive to the vertical emittance of the electron beam
- Multiple monitors distributed around ring improve sped and reliability of the optimization procedure that minimizes the coupling

Basic approach:

- Use the high energy component of the bend magnet x-rays spectrum to perform in-air measurements in unused bend magnet beamlines.
- ESRF (Kees Scheidt) high-energy x-ray monitor is to be evaluated. Other approach will be studied.

Summary

Diagnostics to implement with source development:

- RF BPM upgrade is crucial in maintaining / controlling electron beam trajectory during SPX operation.
- RF phase detector measures bunch arrival time.
- RF tilt monitor measures the chirp/tilt inside and outside of the SPX.
- Optical diagnostics measures x-ray beam vertical profile, extracting information of electron phase, tilt angle and other information about the transverse deflection cavity operations.

Diagnostics to monitor residual effects

- Sensitive rf tilt monitors and synchronized x-ray photon measurements outside of the SPX will be used to minimize the impact of SPX on other users around the ring.

Accelerator design information needed for simulations

- Twiss parameters at cavities / tilt monitors

Important Questions/Concerns – What Are They?

Does vertical deflection make the x-ray beam hit the vacuum chamber?

- Who is performing synchrotron radiation ray tracing?
- Will the existing vacuum chambers be heated by X-Ray radiation in 7-BM and 8-BM? If so, a number of questions naturally follow:
- Who is modifying the vacuum chambers to allow beam to pass freely?
- Do we need new absorbers in the storage ring chambers to intercept the x-rays?
- How does the modification change the microwave properties of the chamber? What are their impacts on beam stability? What are their impacts on the RFBPM performance?
- What are the machine protection requirements for chambers?
- Do we need additional BPLD to constrain the orbit? Do we need new detectors for BPLD?
- What are other MPS needs/requirements, RF, Cryo …
- The list goes on…