Diagnostics for SuperB

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SuperB Mini-workshop, Jesus College, Oxford

May/17-19/2011

Introduction

- In the SuperB project, two trains of ~900 (maybe, in a second phase, up to 1800) electron and positron bunches will collide at the IP (Interaction Point) to achieve a foreseen extremely high luminosity (10**36 cm-2 s-1)
- The collision scheme is based on ultra low emittance, and the beam vertical dimension specifications are of the order of 36 nm at the IP
- Given these two points, of course *diagnostic systems* have fundamental importance to have a perfect beam-beam overlap and to achieve the very ambitious luminosity goal, and need to be carefully evaluated
- In addition, to maintain stable collisions along the bunch train, SuperB diagnostics must include powerful and multiple *feedback systems,* with different characteristics and features
- A short discussion is carried on in the following slides

SuperB parameter:

version Sep/28/10

(Bold: computed values)		V12		V13		V14	
Parameter	Units	HER (e+)	LER (e-)	HER (e+)	LER (e-)	HER (e+)	LER (e-)
LUMINOSITY	$cm^{-2}\ s^{-1}$	**1.00E+36**		**1.10E+36**		**1.11E+36**	
Energy	GeV	6.7	4.18	6.7	4.18	6.7	4.18
Circumference	m	1258.4		1263.5		1159.5	
X-Angle (full)	mrad	66		60		60	
β_x @ IP	cm	2.6	3.2	2.6	3.2	2.6	3.2
β_y @ IP	cm	0.0253	0.0205	0.0253	0.0205	0.0253	0.0205
Coupling (full current)	%	0.25	0.25	0.25	0.25	0.25	0.25
Emittance x (without IBS)	nm	1.97	1.82	2.09	1.93	1.90	1.82
Emittance x (with IBS)	nm	2.07	2.37	2.19	2.51	2.00	2.37
Emittance y	pm	**5.17**	**5.92**	**5.49**	**6.27**	**4.99**	**5.92**
Bunch length (zero current)	mm	4.69	4.29	4.8	4.4	4.53	4.29
Bunch length (full current)	mm	5	5	5	5	5	5
Beam current	mA	1892	2447	**1930**	2470	1892	2447
Buckets distance	#	2		2		2	
Buckets distance	ns	4.20		4.20		4.20	
Ion gap	%	2		2		2	
RF frequency	Hz	4.76E+08		4.76E+08		4.76E+08	
Revolution frequency	Hz	**2.38E+05**		**2.37E+05**		**2.59E+05**	
Harmonic number	#	**1998**		**2006**		**1841**	
Number of bunches	#	**978**		**982**		**901**	
N. Particle/bunch	#	**5.08E+10**	**6.56E+10**	**5.18E+10**	**6.63E+10**	**5.08E+10**	**6.57E+10**
σ_x @ IP	microns	**7.334**	**8.701**	**7.554**	**8.960**	**7.202**	**8.701**
σ_y @ IP	microns	**0.036**	**0.035**	**0.037**	**0.036**	**0.036**	**0.035**
$\sigma_{x'}$ @ IP	microrad	**282.1**	**271.9**	**290.5**	**280.0**	**277.0**	**271.9**
$\sigma_{y'}$ @ IP	microrad	**143.0**	**169.9**	**147.3**	**174.9**	**140.4**	**169.9**
Piwinski angle	rad	**22.50**	**18.96**	**19.86**	**16.74**	**20.83**	**17.24**
σ_x effective	microns	**165.22**	**165.29**	**150.24**	**150.31**	**150.22**	**150.30**
Σ_x	microns	**11.379**		**11.719**		**11.295**	
Σ_y	microns	**0.050**		**0.052**		**0.050**	
Σ_x effective	microns	**233.35**		**212.13**		**212.13**	
Hourglass reduction factor		0.950		0.950		0.950	
Tune shift x		**0.0021**	**0.0033**	**0.0026**	**0.0040**	**0.0026**	**0.0040**
Tune shift y		**0.0989**	**0.0955**	**0.1067**	**0.1041**	**0.1089**	**0.1070**
Longitudinal damping time	msec	13.4	20.3	13.6	20.6	11.6	20.3
Energy Loss/turn	MeV	2.11	0.865	2.08	0.88	2.24	0.865
Momentum compaction		4.36E-04	4.05E-04	4.69E-04	4.35E-04	4.60E-04	4.05E-04
Energy spread (zero current)	dE/E	6.31E-04	6.68E-04	6.30E-04	6.68E-04	6.52E-04	6.68E-04
Energy spread (full current)	dE/E	6.43E-04	7.34E-04	6.43E-04	7.34E-04	6.64E-04	7.34E-04
CM energy spread	dE/E	**5.00E-04**		**5.00E-04**		**5.11E-04**	
Energy acceptance	dE/E	0.01	0.01	0.01	0.01	0.01	0.01
SR power loss	MW	**3.99**	**2.12**	**4.01**	**2.17**	**4.24**	**2.12**
Touschek lifetime	min	33	16	33	16	33	16
Luminosity lifetime	min	**4.81**	**6.22**	**4.48**	**5.73**	**3.99**	**5.16**
Total lifetime	min	**4.20**	**4.48**	**3.94**	**4.22**	**3.56**	**3.90**
RF Wall Plug Power (SR only)	MW	**12.22**		**12.38**		**12.71**	
Total RF Wall Plug Power	MW	17.08					

SuperB Diagnostics design general approach

DAFNE diagnostics manpower is really small, so system designs need to be addressed pragmatically. I consider two design approaches:

- "Standard" Diagnostics

- Systems needing little or no R&D
- It is possible to use PEP-II or DAFNE systems, and eventually from other accelerators (LHC,KEK, ?)
- It is possible to buy *turnkey systems* when sold by spin-off or commercial companies

- "Non-Standard" Diagnostics

- Systems needing big R&D efforts
- It is convenient (or necessary) looking for *collaborations* with other Institutes, National Laboratory, Research Centers
- It could be necessary an adequate time to achieve state-of-art solutions

Alan Fisher in two talks has discussed many diagnostics topics for SuperB focusing on several difficult issues

SuperB

SLAC
NATIONAL ACCELERATOR LABORATORY

Overview of SuperB Diagnostics

Alan Fisher
SLAC National Accelerator Laboratory

SuperB General Meeting
Annecy
2010 March 16 to 19

SuperB

SLAC
NATIONAL ACCELERATOR LABORATORY

Measuring Beam Sizes in SuperB

Alan Fisher
SLAC National Accelerator Laboratory

SuperB General Meeting
Isola d'Elba
2010 May 31 to June 4

Diagnostics for SuperB [Alan Fisher,Annecy,10-03-17]

- Monitors:
  - Beam position
  - Beam profiles
  - Beam loss
  - Tunes
  - Total current
  - Bunch current
  - Luminosity
  - Polarization (LER)
- Measure/tweak in collision:
  - Coupling
  - Chromaticity
  - Phase advance
- Feedbacks:
  - Orbit
  - Luminosity *(=> Dither fb !)*
  - Tune
  - Transverse motion
  - Longitudinal motion
- Too much for 25 minutes
- Some are in other talks.
- Others are similar to PEP-II.
- I will concentrate on a few difficult issues.

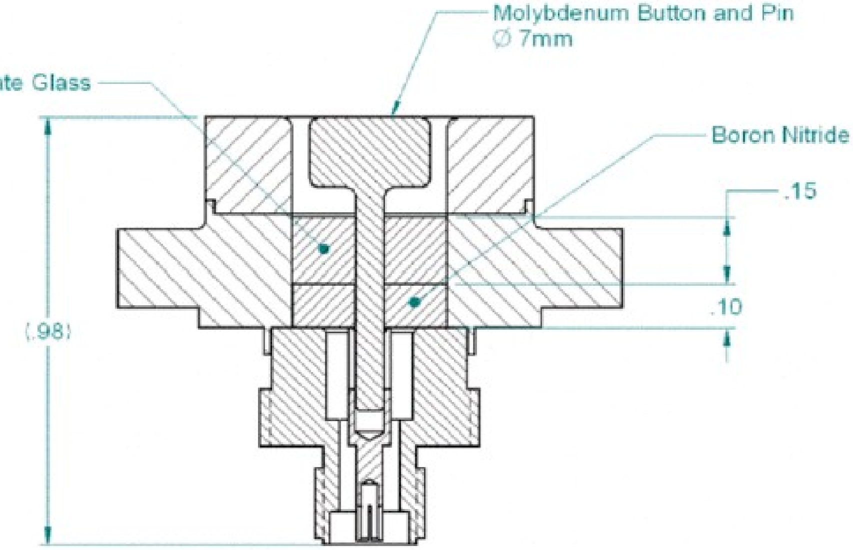
Other necessary diagnostic systems

- diagnostics for injection
- kickers (including abort kickers)
- timing systems
- vacuum monitors
- flags / scrapers
- ???
-
- In conclusion: there is a *long to-do list* and we have a long series of *decisions* to take
- In the following slides the most critical subsystems are discussed

BPM Button Issues

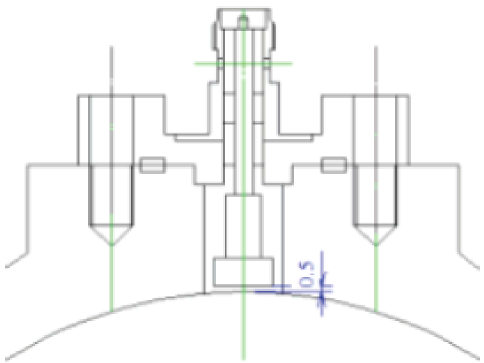
- Two existing button designs should work for SuperB:
  - 7-mm redesigned PEP-II buttons
  - 6-mm test buttons developed for SuperKEKB
  - Detailed modeling needed to choose
- BPM thermal motion
  - With $\sigma y \approx 10$ µm, what is the tolerance?
  - Can we lock the buttons securely to the quadrupoles? To the floor?
  - Measure button position? Relative to what?
  - Distortion or roll of BPM chamber (coupling)?
- Buttons near the IP
  - Crossing angle allows buttons closer to the IP than in PEP-II (72 cm)
  - Buttons in cryostat of superconducting IP quads?
    - Special design?

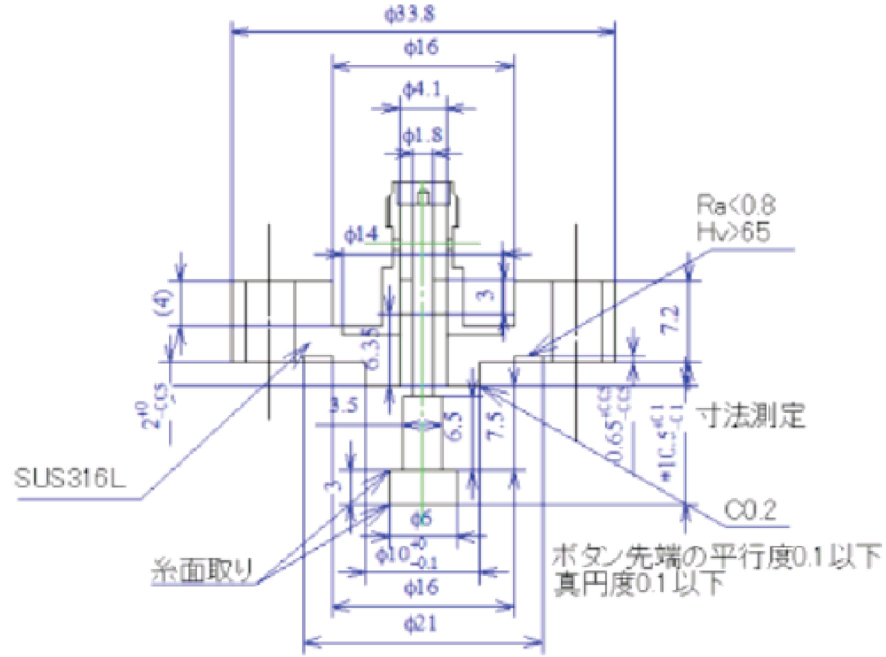
BPM Buttons: Upgraded PEP-II Design



- 7 mm diameter
- Button and center conductor made of single Mo piece
- Insulated by borosilicate glass and boron nitride
- Made by Kaman

BPM Buttons: SuperKEKB Design



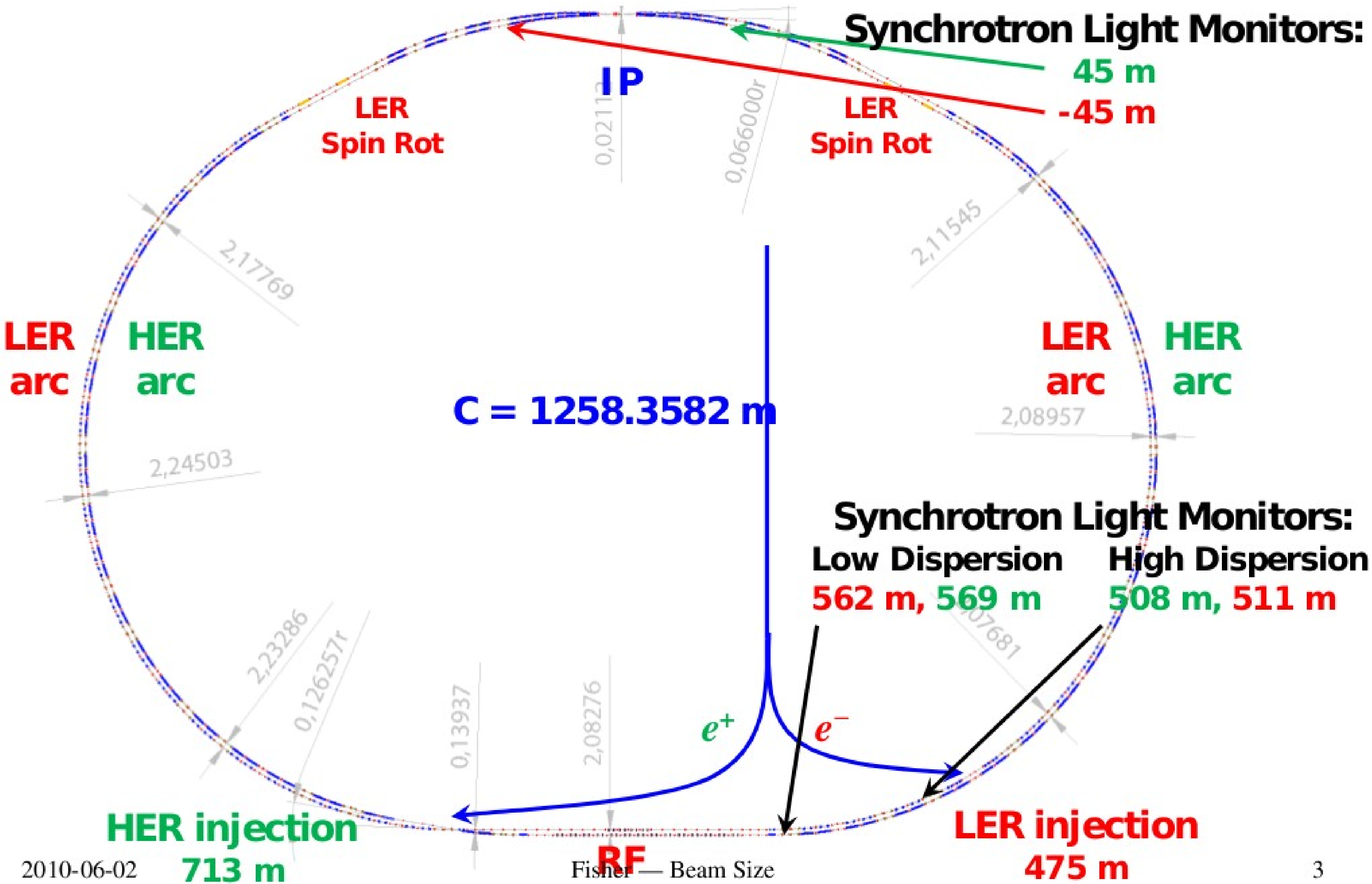


- 6 mm diameter
- Glass insulator for a lower dielectric constant
  - Fewer high-frequency resonances
- Several test versions made in collaboration with Kyocera

Synchrotron-Light Monitors: Locations

- Locations with high and low dispersion for each ring
  - Measure both to get emittance and energy spread
  - Stay outside the coupled region near the IP
- Source point at low dispersion:
  - In arc at a point with large β_y
  - HER and LER points 7 m apart: allows sharing a hutch
- Source points at high dispersion:
  - Arc location with comparable β_y are available
    - HER and LER can again share a hutch, ~50 m from low-dispersion point
  - Or 45 m from IP:
    - β_y is much higher than in arc
    - Outboard of coupling correction
    - But HER and LER points are on opposite sides of IP: can't share a hutch

Proposed SLM Locations



Visible Light: Null in Vertical Polarization

- Angular emission pattern of vertically polarized emission
  - Two lobes, above and below the horizontal plane, with *opposite* polarization (due to symmetry)
- Perfect cancellation at the image of a point source
  - Some light above and below (diffraction)
- But for a nonzero beam size:
  - Sources at different heights have their nulls at different heights
  - Contrast is reduced as size increases
- Developed by Andersson and Chubar at MAX-Lab in Sweden
  - Swiss Light Source has demonstrated resolution of 1 μm at $\varepsilon_y = 2.8$ pm

SLS Measurements with Low *y* Emittance

SLS has reported a vertical emittance of 2.8 pm (±0.4 pm)

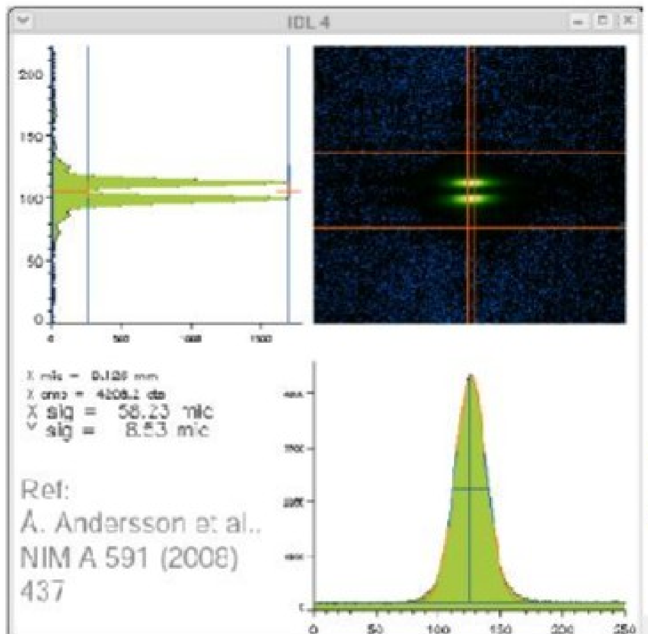
SR - Emittance (Sigma) Coupling Monitor

The coupling correction procedure is similar to the one used at Diamond.

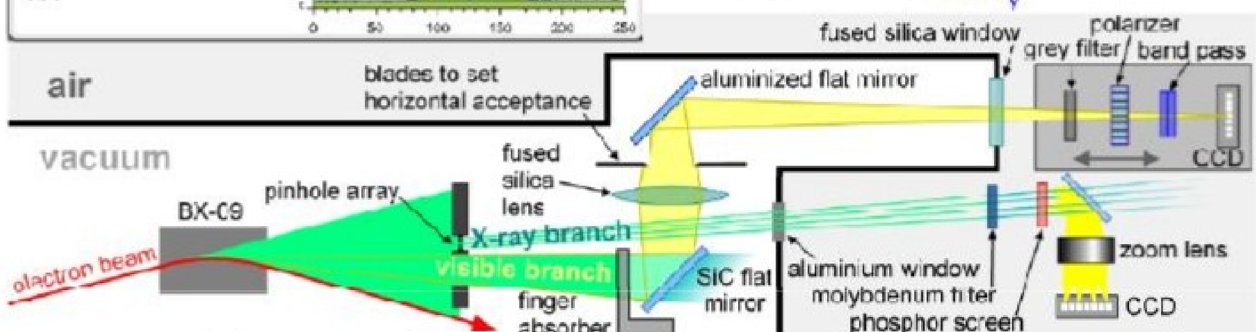
But less skew quadrupoles and separated dispersion free regions

High precision emittance measurement with the “emittance monitor”

Resolution of 1 um



- An important instrument for optics correction: the beam size monitor
  - ➢ vertically polarized, near-UV (384 nm) synchrotron light
  - ➢ better resolution than X-ray pinhole array monitor
  - ⇨ control of coupling
  - ⇨ optimization of Touschek lifetime → T/σ_y !



Courtesy SLS

Conclusions: Beam Profiles

- Visible light
  - Beams are too small for forming a direct image
  - Null in the vertical polarization looks promising (only for vertical size)
  - Horizontal size can be measured with an interferometer
  - Both give size, but not profile
  - Visible beamline needed for longitudinal profiling with a streak camera
- X rays
  - Pinhole will work near IP and may work in arcs.
  - X-ray zone plates may be best for sizes and profiles
    - But thermal distortion of the x-ray mirror must be controlled
- Lasers
  - Expensive but with good resolution
  - Measurements require multiple shots to scan beam across laser

Multiple feedback systems to maintain stable collisions

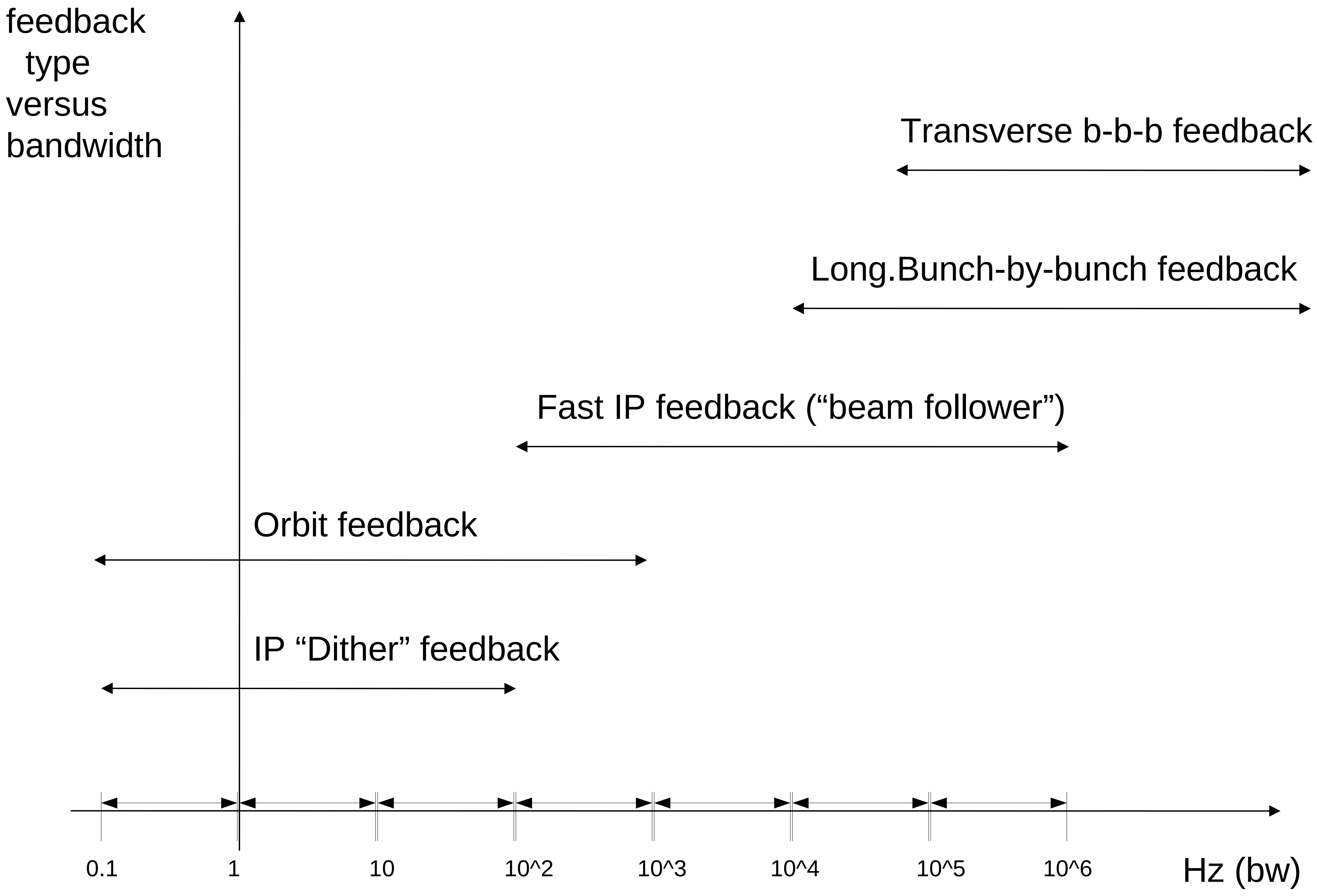
a) *Betatron and synchrotron bunch–by-bunch feedback systems*: these are used to maintain under control the transverse and longitudinal bunch-by-bunch motions (kicking each bunch every turn in V, H, and L planes)

b) *Tune feedback*

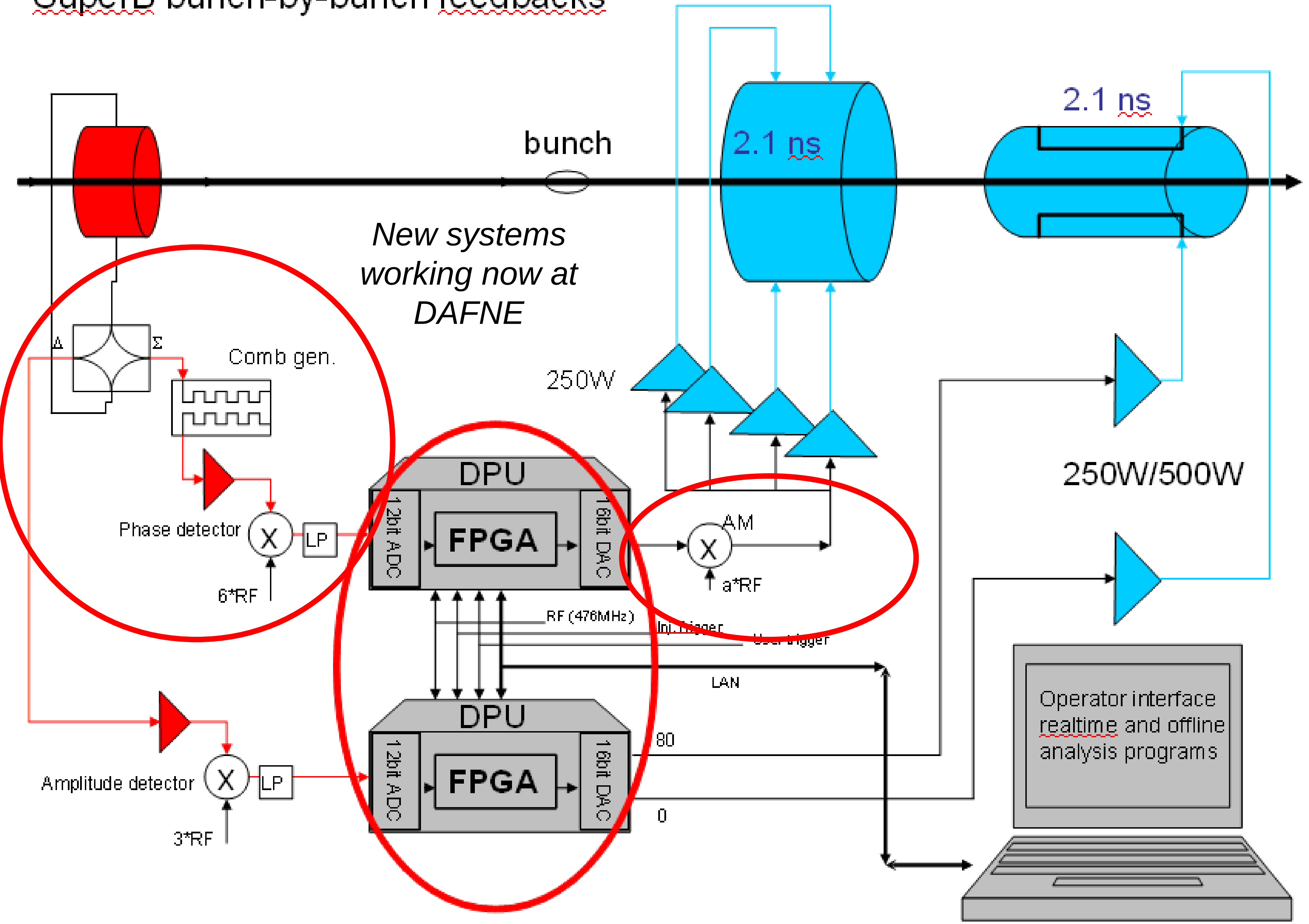
c) *Orbit feedback* (Libera or Libera–like based): it takes as reference a “golden orbit” for each ring and applies corrections using the “regular” corrector magnets

d) *IP “dither” feedback (or luminosity feedback)*: it should use 8 air-core coil correctors to generate orbit-bumps in 3 dimension (in just one of the two rings) being based on the Luminosity monitor real-time data

e) *Fast IP feedback* or feedforward (“beam-follower”): this system, inspired to FONT project, is under study.


feedback
type
versus
bandwidth
Transverse b-b-b feedback
Long.Bunch-by-bunch feedback
Fast IP feedback (“beam follower”)
Orbit feedback
IP “Dither” feedback
0.1
1
10
10^2
10^3
10^4
10^5
10^6
Hz (bw)

SuperB bunch-by-bunch feedbacks



Core of the bunch-by-bunch feedback system is the iGp (Digital processing Unit), at the begin developed in collaboration with KEK and SLAC. Now iGp it has been upgraded from the previous 8-bit version that was derived from the longitudinal bunch-by-bunch feedback designed in the 90's by SLAC/LNF/LBL for PEPii,Dafne,ALS

The iGp12 is very similar to the previous version of iGp but it uses 12bit A-to-D and D-to-A conversion to have a bigger dynamic range as well as many new powerful features.

- Software is upward compatible with the previous feedback versions
- The front panel offers almost the same functionality: differential or single-end ADC input, timing & trigger (there is one more external trigger), differential DAC output and status LED

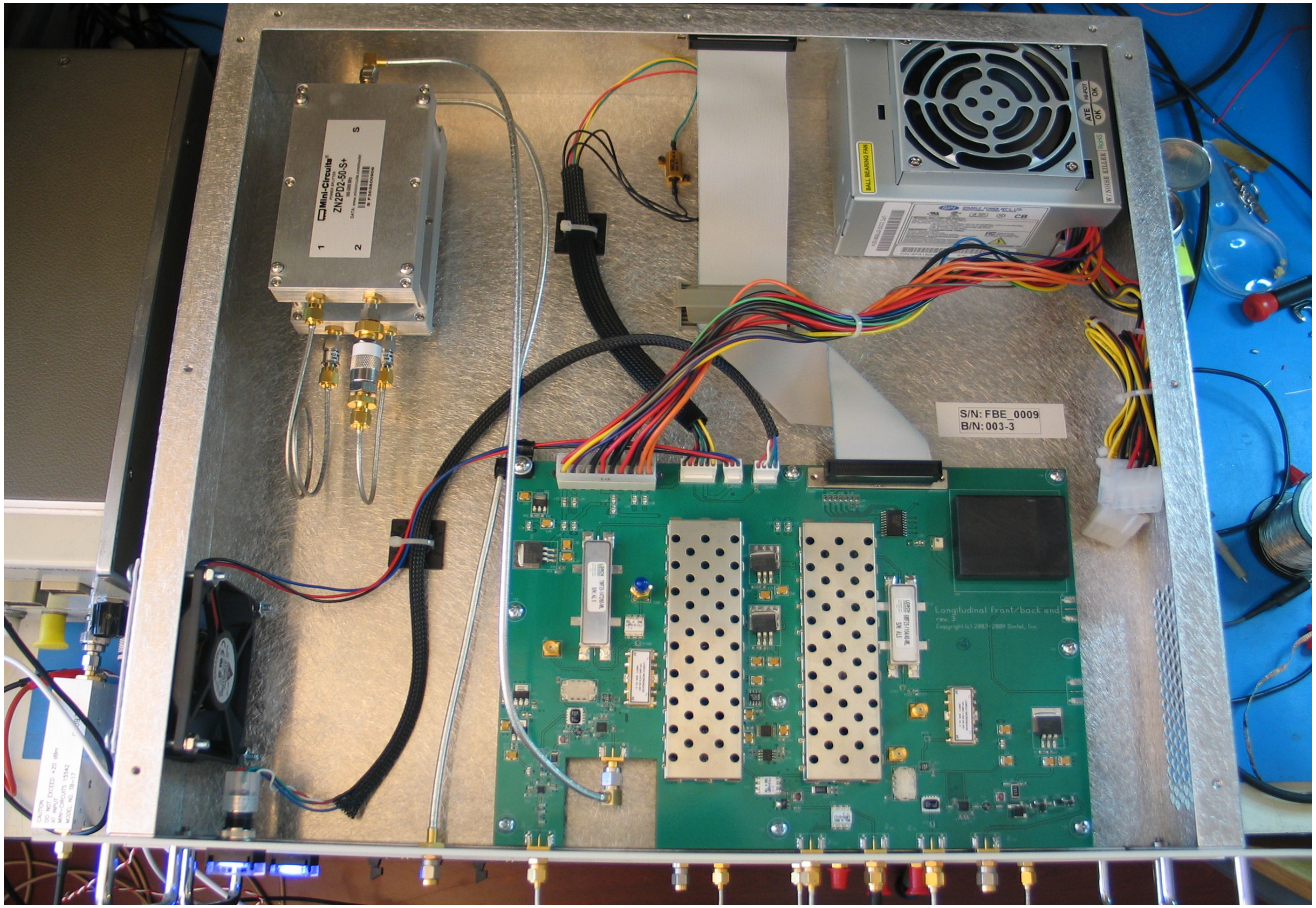
Longitudinal front end / back end analog module

Very simple and compact front panel:

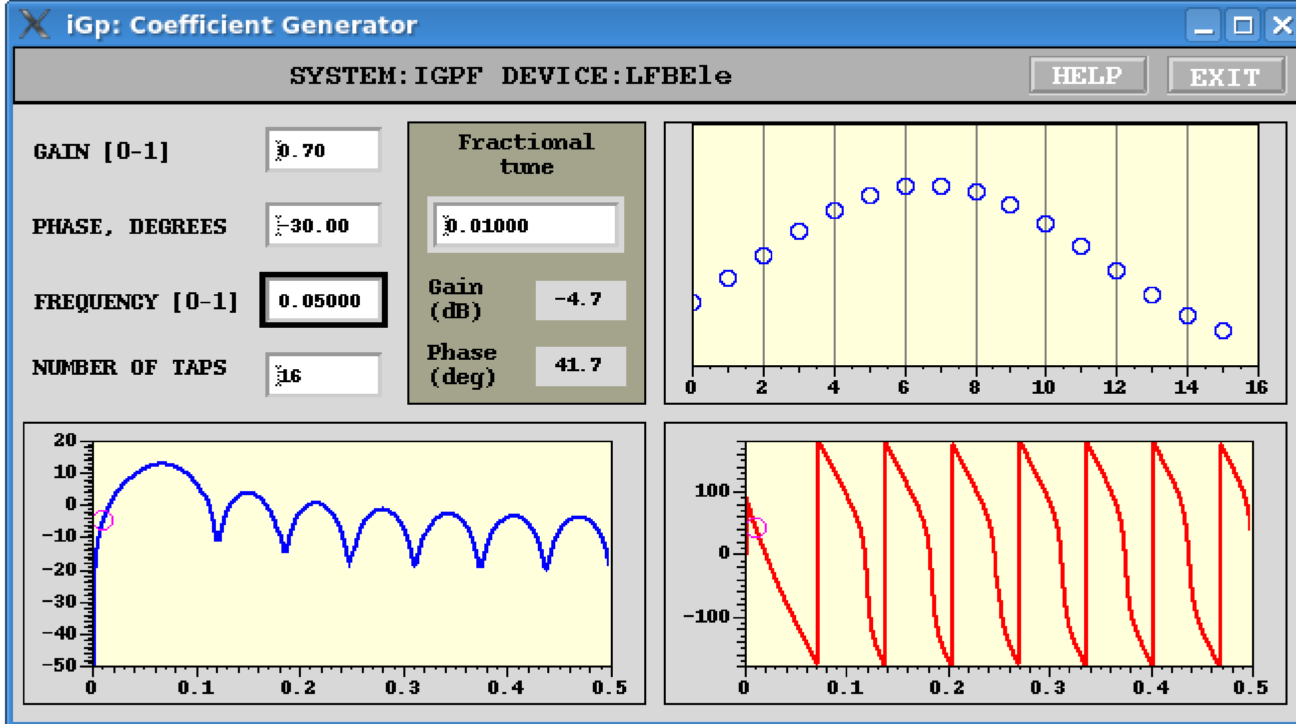
- analog front end input and output
- RF clock in and out
- analog back end signal input and output

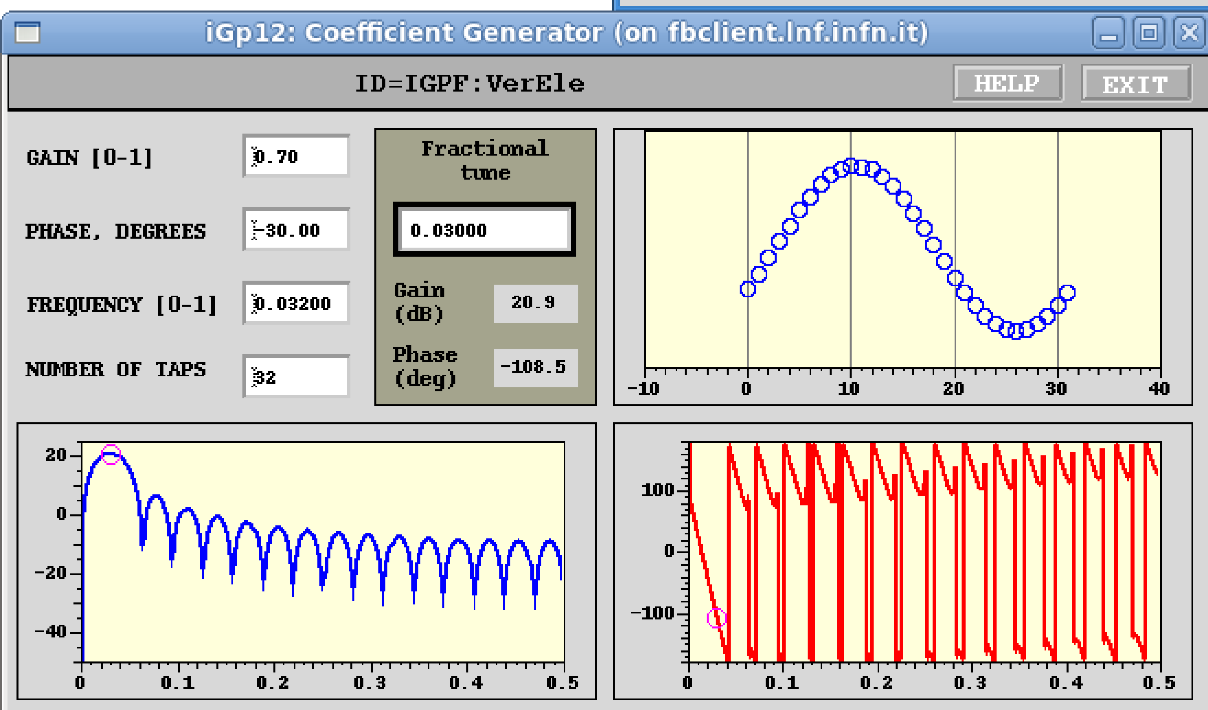
In rear panel: power supply and 68-pin signal cable used as bus for command & data from/to iGp unit

A look to FE/BE unit inside: two taps comb filter @ 4*RF (four taps @ 6*RF for the previous system) - no more QPSK in backend – just amplitude modulation



A larger (32) number of FIR filter taps is necessary in case of low frequencies motions; downsampling factor >1 (i.e. longitudinal feedback) can be set easily

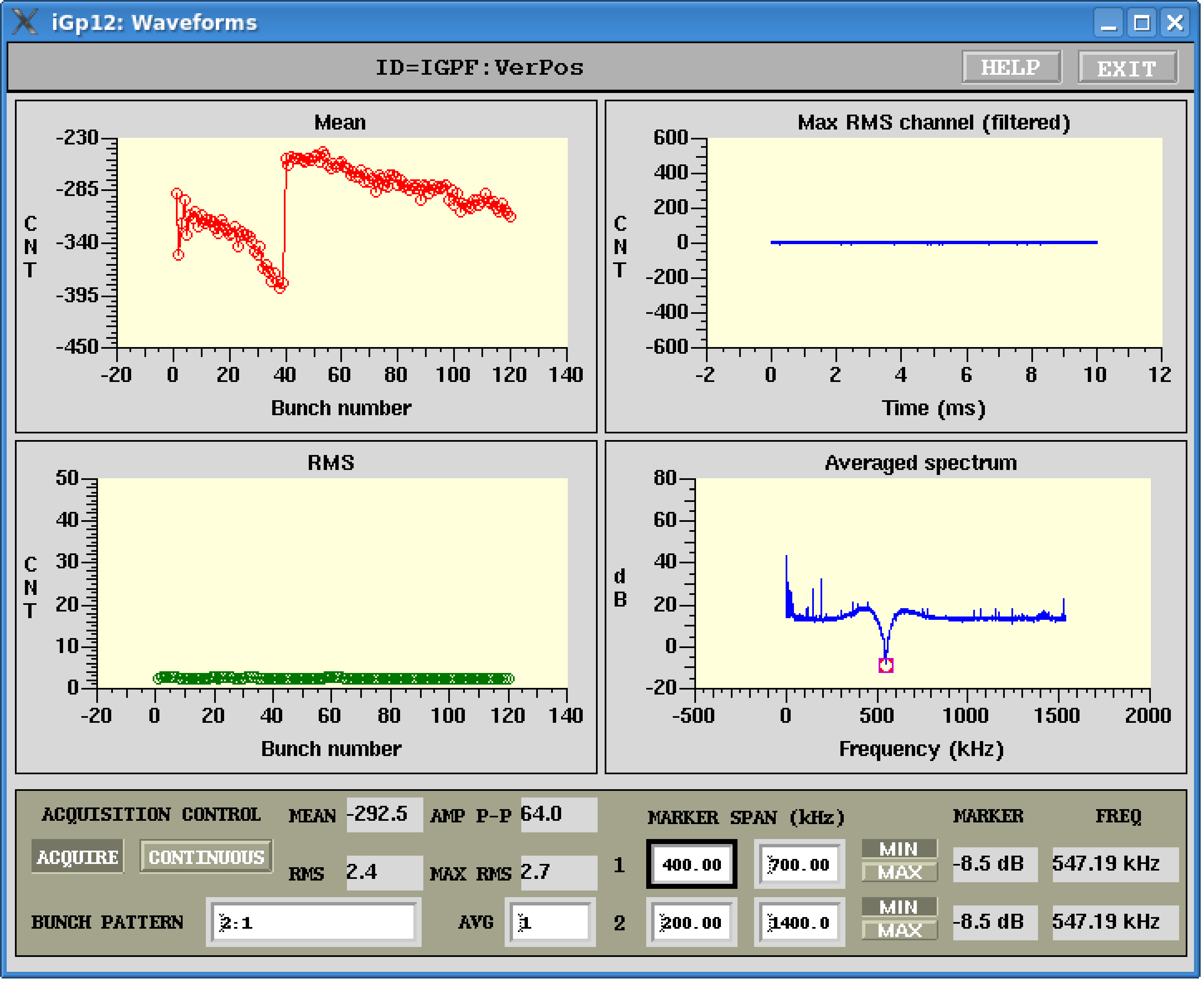




up: Filter with 16 taps (iGp8)

left: Filter with 32 taps (iGp12)

It is possible that for SuperB synchrotron feedbacks even more taps will be necessary [64 or 128] in base at the specifications



The iGp12 performance are clearly better than the previous system

The bunch pattern selection can be used (by a dedicated external program) to plot the bunch-by-bunch tune spread and the gap transient

Beam diagnostics

Tune Monitor and Tune Feedback

- PEP-II used downconversion in a mixer, followed by:
  - A spectrum analyzer
  - A phase-locked loop, with single-frequency excitation and detection by a lock-in amplifier
- Both should be good for SuperB
- Direct Diode Detection (or “barbeque”, for Baseband Q), now used for LHC protons, is very sensitive
  - Can measure the tune of a single bunch without driving the beam.
- Tune feedback
  - Tune spectrum in collision is too wide for a single value
  - Need a “pilot” (noncolliding) bunch
    - Unstable when colliding tune is just above 0.5
    - Must shake the pilot to raise its tune above the half integer

Orbit feedback based on “*Libera*” or *Libera*-like system

a) Probably the choice will be for the same system (by Instrumentation Technology) used in DIAMOND

b) Implemented in many circular light sources but, if I remember well, still not in a collider (two rings with a common Interaction Region)

c) It should have ~2k bandwidth (acquisition at 10kHz)

d) ~10 micron stability/sensitivity (maybe less)

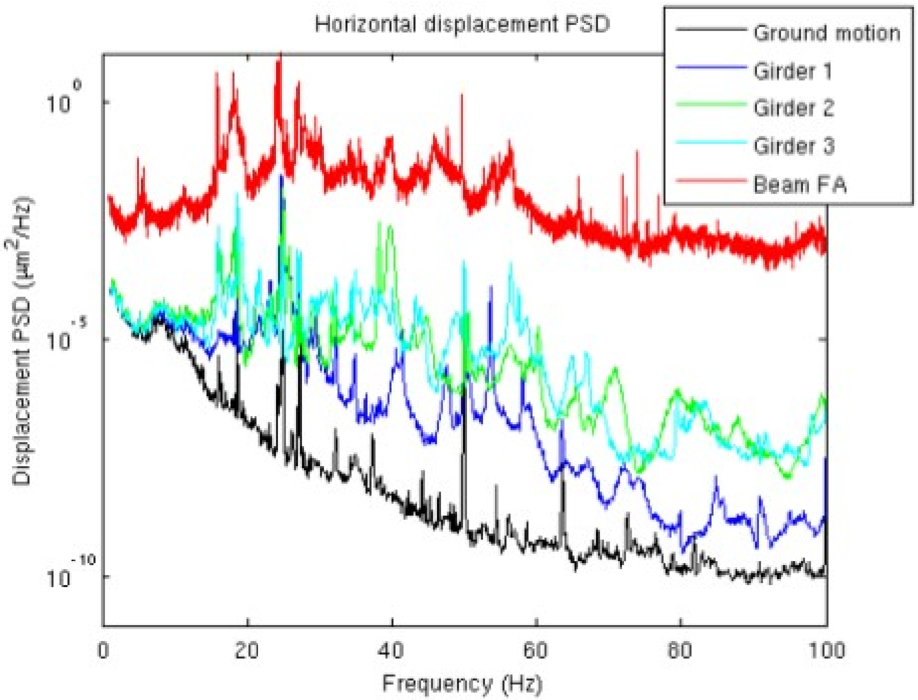
e) Strategy: in each ring the feedback operates to move orbit toward the reference orbit applying command to the “regular” correctors

f) At the IP (that is a common part of the vacuum chamber) it is necessary to avoid unstable situations or conflicts between the two orbit feedback systems

Libera BPM Processors

- Commercial product from Instrumentation Technologies
- Integrates BPM processing with networking for fast orbit feedback
- Used by many light sources
  - Share codes and architecture
- Specifications
  - Turn by turn: 2 µm
  - Orbit feedback data at 10 kHz: 0.25 µm
- ADC clock frequency near 117 MHz: Use 119 MHz = fRF/4
- Front-end filter at 19 MHz
  - Cannot see individual bunches turn by turn ←
  - Bunch positions are smeared together over ~20 ns

The Purpose of Global FOFB



- Global FOFB: Global fast orbit feedback
- To decrease the beam emittance
- To stabilize the beam in Storage Ring
- Disturbances:
  - Mechanical vibrations
  - Vacuum pumps
  - Ground motion
  - Electrical power lines
  - Etc.

- Courtesy of Guenther Rehm, Diamond, Libera Workshop 2007

FOFB Principle & Topology

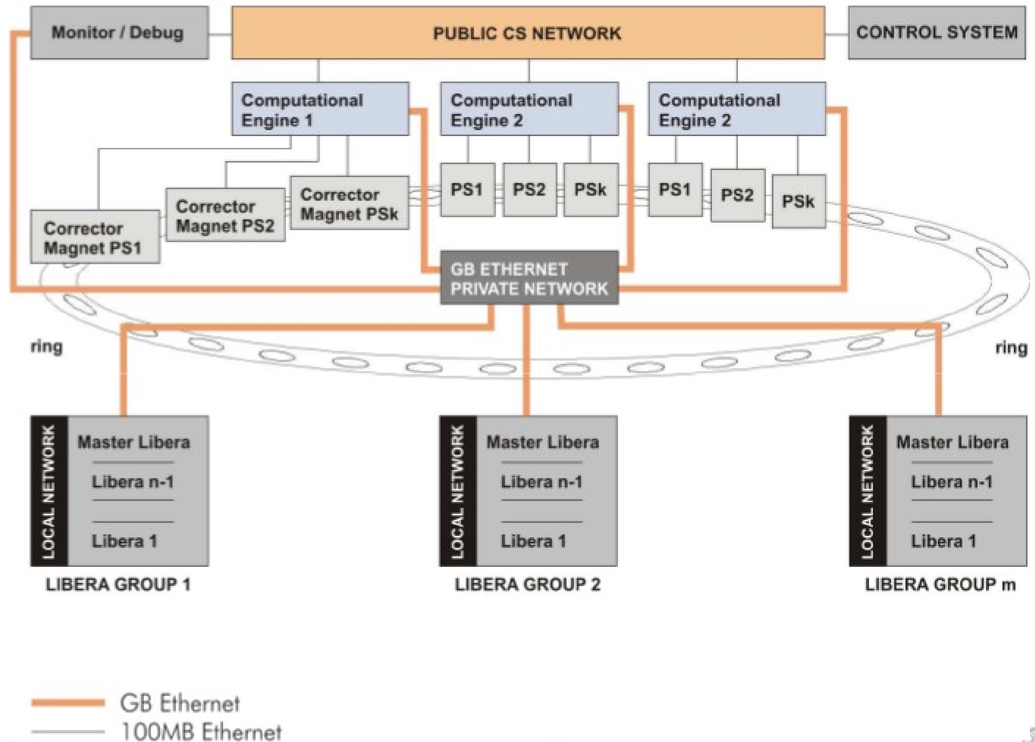
$$\begin{bmatrix} m_1 \\ m_2 \\ m_3 \\ \square \\ m_k \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & \square & r_{1n} \\ r_{21} & r_{22} & r_{23} & \square & r_{2n} \\ \square & \square & \square & \square & \square \\ r_{k1} & r_{k2} & r_{k3} & \square & r_{kn} \end{bmatrix}^{-1} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \square \\ x_n \end{bmatrix}$$

- Multiple BPM devices (x)
- Multiple magnet correctors (m)

- Interdependency – One magnet correction influences the position of the beam at virtually all BPM positions.
- Response matrix R

- Global FOFB

Libera Grouping & GbE



Comment➔ necessary budget for Libera is not a trivial problem: in fact considering a unit every 5 meters would give a total of 240 units x 2 rings x 10k euro = 4.8 M euro !!!

PERFORMANCE AND FUTURE DEVELOPMENT OF THE DIAMOND FAST ORBIT FEEDBACK SYSTEM

M. G. Abbott, J. A. Dobbing, M. T. Heron, G. Rehm, J. Rowland, I. S. Uzun, Diamond Light Source, Oxfordshire, U.K. S. Duncan, University of Oxford, Oxfordshire, U.K

INTRODUCTION

The Fast Orbit Feedback (FOFB) system on the Diamond Light Source storage ring began routine operation in July 2007. It achieves integrated beam stability, up to 100 Hz, of X < 1.0 µm and Y < 0.4 µm, at primary eBPMs, which are well within the required 10% RMS beam dimensions. The FOFB implementation has been refined during this operational period to improve stability and to cope with anomalous behaviour in eBPMs and the communications network.

While the FOFB meets the current requirements it is recognised that the system needs to be further developed to meet increasing demands on beam stability arising from smaller vertical beam sizes, higher sensitivity beamlines and additional sources of beam motion.

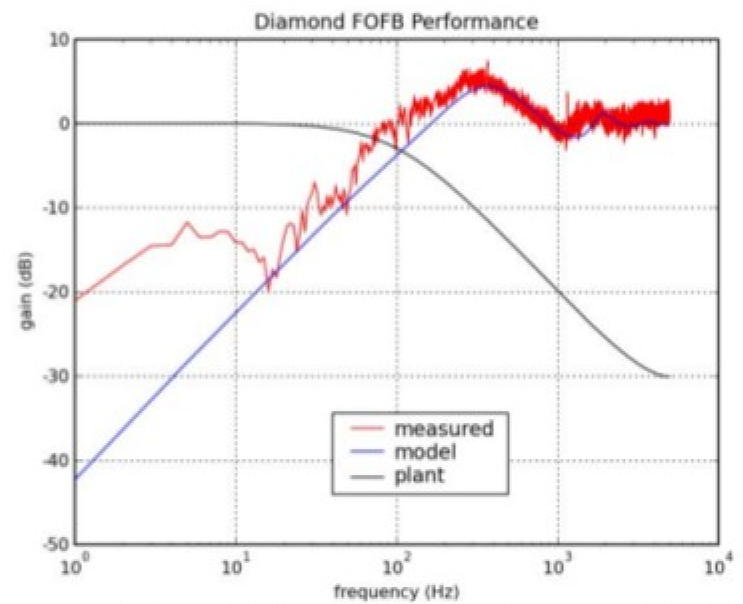


Figure 3: Theoretical and measured suppression in the vertical plane. Below 10 Hz is noise dominated in the measured data.

IP “Dither” (Luminosity) feedback

I. The IP “Dither” feedback system was designed for PEP-II and uses dedicated corrector magnets and a luminosity signal to optimize the overlap of colliding beams at the interaction point.

II. The luminosity signal comes from a real time luminosity detector (to be evaluated).

III. One beam (the low-energy positron beam?) is steered through the IP to maximize the signal from the detector.

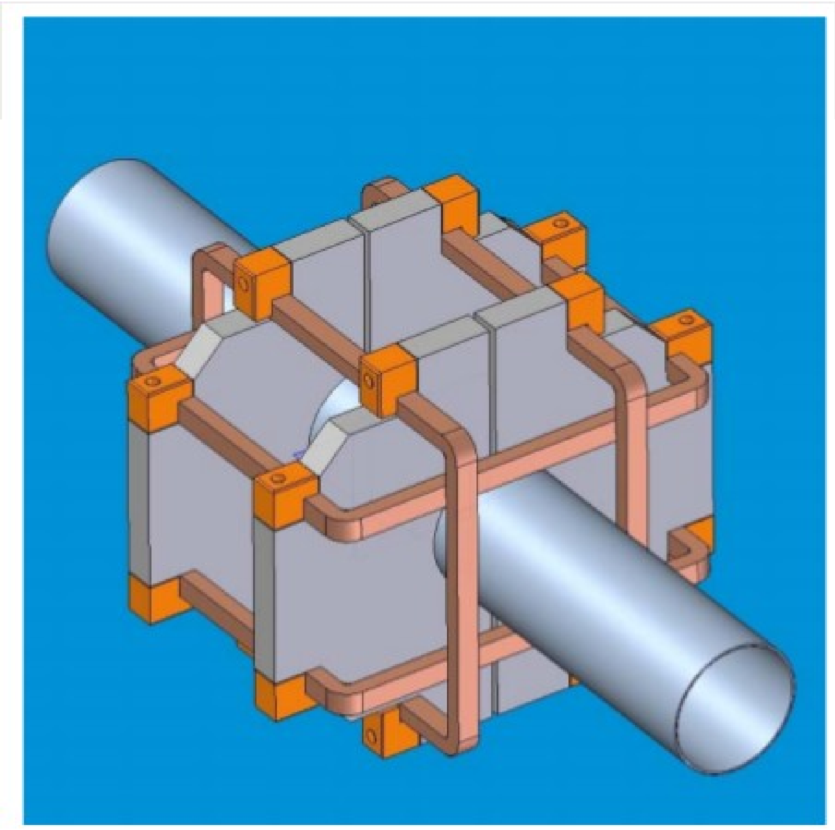
IV. The other beam (the high-energy beam ?), is driven with small dither motions to allow luminosity detection of best beam overlap.

V. The dither and applied corrections occur in three directions: horizontal, vertical, and vertical angle.

VI. The original PEP-II design allowed for dither amplitudes of up to 40 microns horizontal, 5 microns vertical, and 0.1 mrad in vertical angle.

VII. Relative to the IP, the dither coils in PEP-II were at ±29 meters and ±48 meters, with a horizontal and vertical pair at each location.

Horizontal and vertical pairs of Helmholtz air-core coils were used in PEP-II at four locations surrounding the IP, on vacuum chambers with thin stainless-steel walls to allow for rapid field penetration.



- The air-core coils had 48 turns producing less than 20W rms when driven at 100 Hz.
- The coils were installed on stainless-steel beam chambers for effective penetration of the time-dependent field.
- In PEP-II the chambers at 29 m were octagonal and the ones at 48m round, so small phase delays were introduced to synchronize the dithers and close the bumps.
- The installation at 48 meters is depicted in the figure.

Proceedings of EPAC 2006, Edinburgh, Scotland THPCH100

NEW FAST DITHER SYSTEM FOR PEP-II*

S. Gierman†, S. Ecklund, R.C. Field, A.S. Fisher, K. Krauter, E. Miller, M. Petree, P. Grossberg, K.G. Sonnad, N. Spencer, M.K. Sullivan, K.K. Underwood, U. Wienands,
SLAC, Menlo Park, CA 94025, U.S.A.

Proceedings of PAC07, Albuquerque, New Mexico, USA FRPMS066

COMMISSIONING THE FAST LUMINOSITY DITHER FOR PEP-II*

A.S. Fisher#, S. Ecklund, R.C. Field, S. Gierman, P. Grossberg, K. Krauter, E. Miller, M. Petree, K.G. Sonnad†, N. Spencer, M.K. Sullivan, K.K. Underwood, and U. Wienands
Stanford Linear Accelerator Center, Stanford, CA 94309, USA

SLAC SuperB

Fast Luminosity Feedback

Super-B
2-13-09

Kirk Bertsche

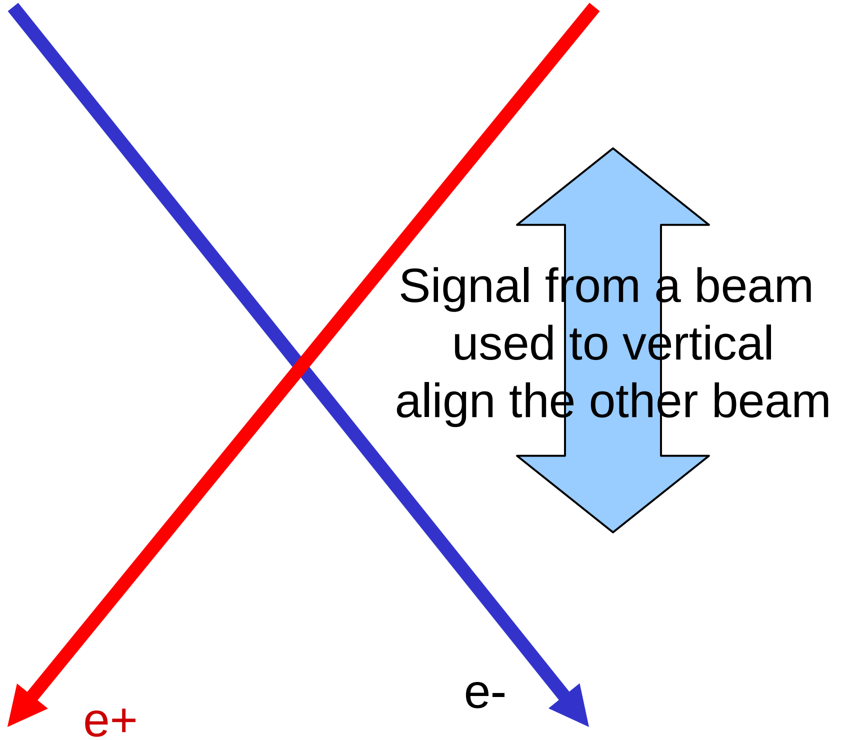
Contributes presented
at EPAC'06 and PAC'07.
An updated version
at the VIII SuperB General
Meeting by Kirk Bertsche
(Orsay, Febrary 2009)

Luminosity Feedback

- PEP-II dithered LER position and angle against HER
  - Initially dithered x, y, and y' sequentially, in steps
  - Later simultaneously, with small sinusoidal drive at 3 frequencies
  - Rate limited to 1 Hz by software magnet controls
  - Often ran at 0.3 Hz to use smaller dithers
- Integrate luminosity feedback with orbit feedback !!!
  - Avoids having orbit feedback “fix” the luminosity dither
    - Especially in x, which the BPMs will see

Fast IP feedback or feedforward ("beam-follower")

- This design is freely inspired to the FONT project (by P. Burrows)
- Design and specification are in very preliminary stage
- The feedback should take the vertical position of the first and second beam and moves vertically the second beam for a better overlapping in the Interaction Point



Fast IP feedback or feedforward ("beam-follower")

- Why another feedback ?
- Many reasons:
  - The betatron and synchrotron bunch-by-bunch feedback work as band pass filter and cannot do almost anything about slow motions
  - Luminosity and orbit feedbacks can work at 100Hz and 1kHz
  - There are corrector magnet transition phases that can produce losses of luminosity
  - The Fast IP feedback should be able to make a beam able to overlap the other beam as a vertical follower for the necessary short period of time
  - What about horizontal and angle ? Also these options in principle could be considered

Fast IP feedback or feedforward ("beam-follower")

Tentative specifications and algorithm

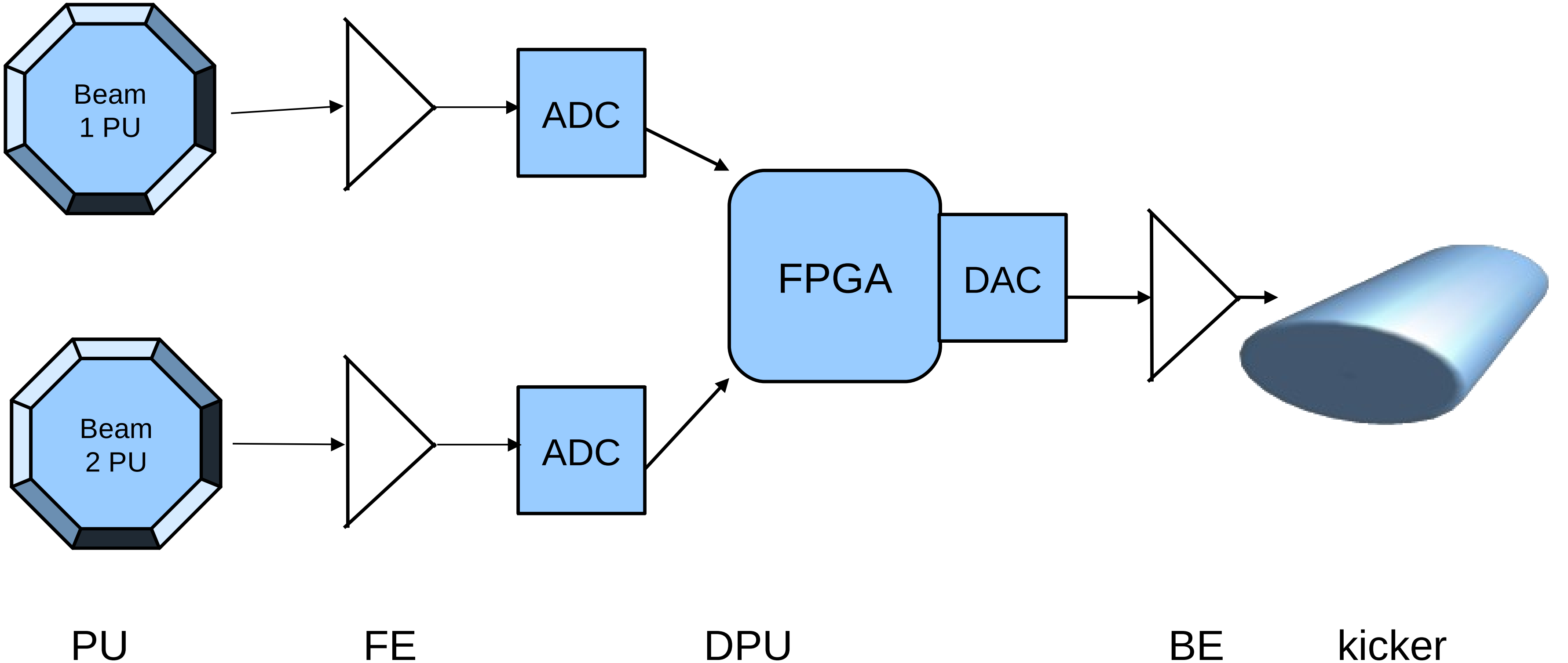
- Propagation delay: ~150ns
- It should be able to acquire position signals with a precision better than 36 nm from the first and the second beam
- It should compare the two signals (avoiding noise problems) and generate a correction signal to be applied to the second beam that have to be overlapped to the first beam
- Bandwidth: at least up to revolution frequency, better if up to 1MHz
- Great noise immunity is fundamental
- Dynamic range: the feedback should work at least between 10 nm and ± 10 μm, so the minimum is 60dB, better if >70dB
- It should be based on FPGA to be extremely flexible and to give possibility to try different feedback transfer functions & algorithms
- Powerful software to monitor and change parameters in real time
- Should it work only in the vertical planes ?

Fast IP feedback or feedforward ("beam-follower")

Parts under study that could be used for implementation:

- ML605 by Xilinx with the last Virtex-6 FPGA
- ADS 5474 (Analog-to-digital converter) by Texas Instruments:
    * 400-MSPS Sample Rate
    * 14-Bit Resolution, 11.2-Bits ENOB
    * 1.4-GHz Input Bandwidth
    * SFDR = 80 dBc at 230 MHz and 400 MSPS
    * SNR = 69.8 dBFS at 230 MHz and 400 MSPS
    * 2.2-Vpp Differential Input Voltage
    * LVDS-Compatible Outputs
- MAX 5891 by Maxim: 16-Bit, 600Msps, High-Dynamic-Performance DAC with LVDS Inputs

Fast IP feedback
R&D activity: schematic plot



Simulations are necessary to find an algorithm with good noise immunity

Conclusions

To achieve the Superb luminosity specifications a perfect real-time overlap of the two beams is necessary.

- Some of the diagnostic systems are crucial to achieve the luminosity goal
- Many different feedback systems are under study
- In particular all the systems that we are considering should cooperate to achieve the challenging luminosity goals giving a perfect beam-beam overlap
- An upgraded version of the betatron and synchrotron bunch-by-bunch feedbacks are working very well in the DAFNE main rings this year
- Orbit feedback and luminosity feedback should be implemented taking in mind the previous experiences
- The Fast IP feedback is in a preliminary specification phase
- Nevertheless we should go carefully in depth to understand possible unstable behaviors made by real-time conflicts between the different systems
- Collaborations are in progress with Institutes, National Laboratory and Companies for R&D, specification, design, fabrication and test