Damping Ring EDR WP4: Instrumentation & Diagnostics

- RDR Wrap-up
- Towards the EDR…
- R&D Example: BPM Read-out System
- Summary

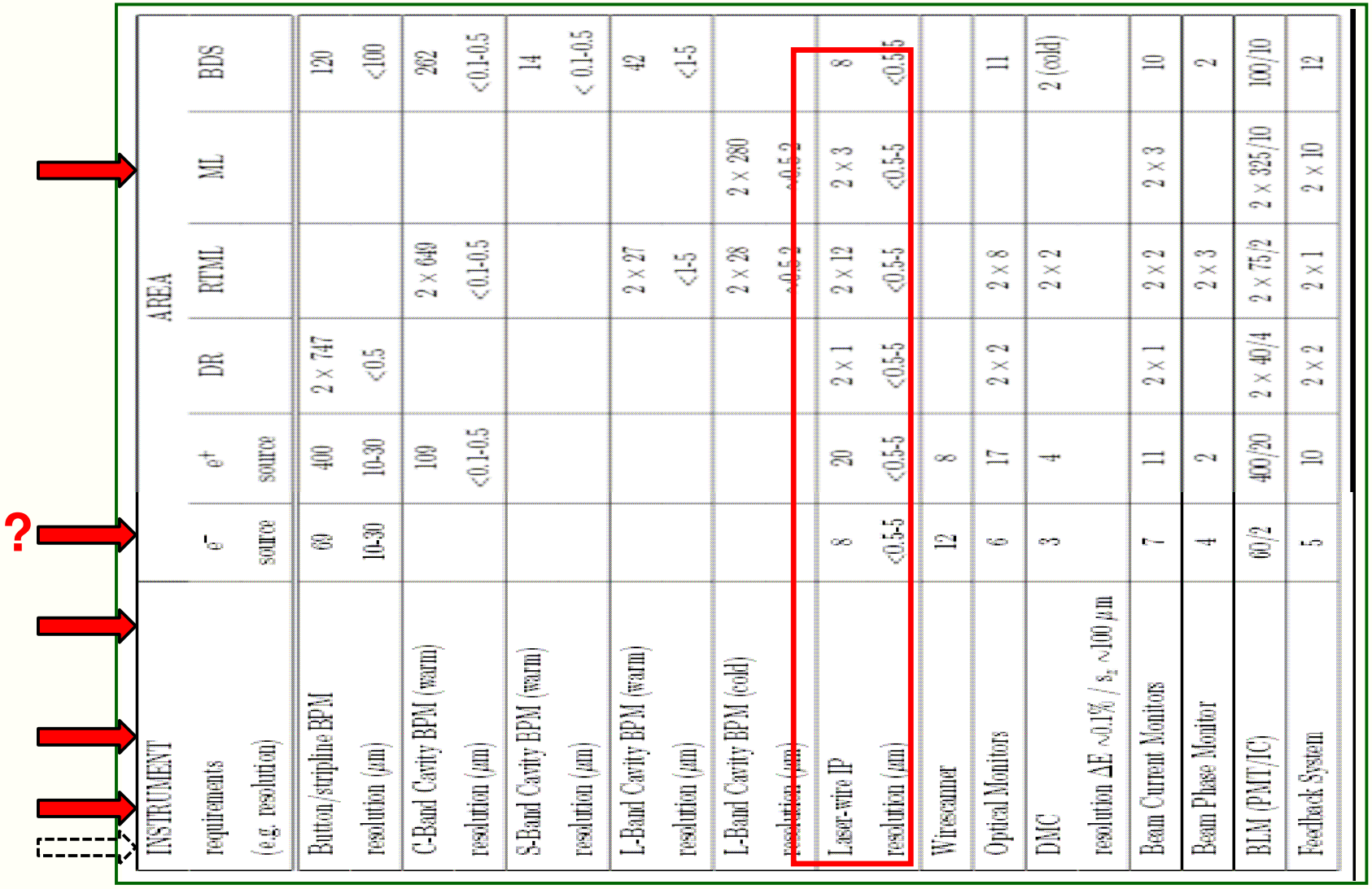
Manfred Wendt

(Fermilab)

Past Activities

- **BCD/RDR Instrumentation Group:**
  - Marc Ross, Phil Burrows, Junji Urakawa, Hans Braun, Manfred Wendt, Graham Blair, Steve Smith, and many others.
- **BCD:**
  - Focus on mission critical beam instrumentation systems, i.e. beam orbit, emittance, bunch length, and machine protection
  - Summarize R&D status of ongoing developments, particular high resolution cavity BPMs.
  - Define requirements for these core instrumentation systems.
- **RDR**
  - Define and count the core set of beam instruments, and the fundamental requirements.
  - Establish a comprehensive parametric spreadsheet, along areas and instruments for a complete cost analyzes.

RDR Instrumentation Summary

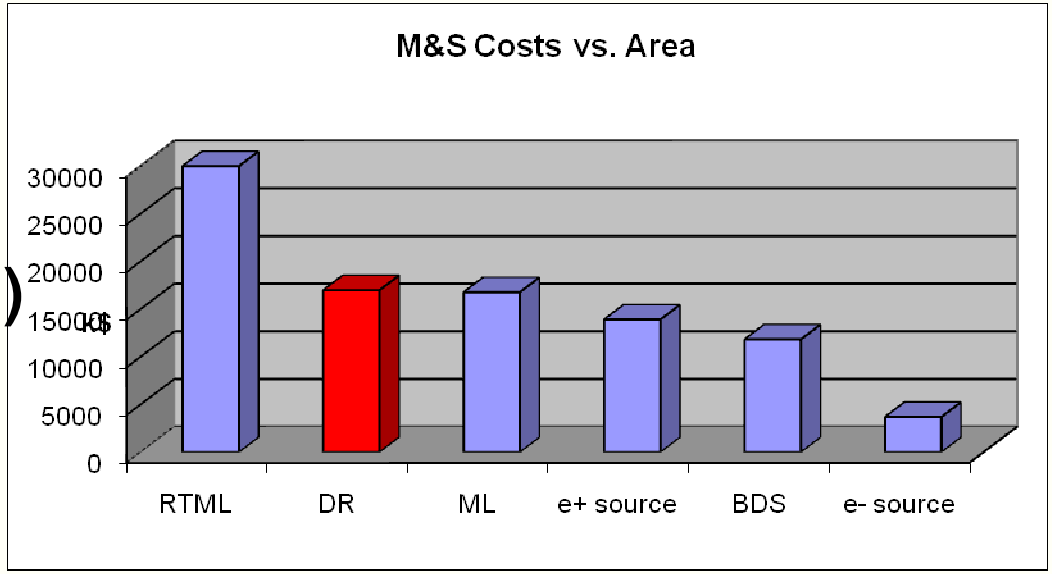


INSTRUMENT	AREA						
	e^-	e^+	DR	RTML	ML	BDS	
requirements	source	source					
(e.g. resolution)							
Button/stripline BPM	60	400	2 x 747			120	
resolution (μm)	10-30	10-30	<0.5			<100	
C-Band Cavity BPM (warm)		100		2 x 640		262	
resolution (μm)		<0.1-0.5		<0.1-0.5		<0.1-0.5	
S-Band Cavity BPM (warm)						14	
resolution (μm)						< 0.1-0.5	
L-Band Cavity BPM (warm)				2 x 27		42	
resolution (μm)				<1-5		<1-5	
L-Band Cavity BPM (cold)				2 x 26	2 x 280		
resolution (μm)				<0.5-2	<0.5-2		
Laser-wire IP	8	20	2 x 1	2 x 12	2 x 3	8	
resolution (μm)	<0.5-5	<0.5-5	<0.5-5	<0.5-5	<0.5-5	<0.5-5	
Wirescanner	12	8					
Optical Monitors	6	17	2 x 2	2 x 8		11	
DMC	3	4		2 x 2		2 (old)	
resolution ΔE ~0.1% / s_z ~100 μm							
Beam Current Monitors	7	11	2 x 1	2 x 2	2 x 3	10	
Beam Phase Monitor	4	2		2 x 3		2	
BLM (PMT/IC)	60/2	40/20	2 x 40/4	2 x 75/2	2 x 325/10	100/10	
Feedback System	5	10	2 x 2	2 x 1	2 x 10	12	

?

RDR Costing

- **Beam Instrumentation:**
  - Pickup detectors (mostly vacuum components), e.g. BPMs, toroids, screen monitors, WCMs, F-Cups, etc., also BLMs
  - Read-out, control, timing, and other common hard- and software, NOT: racks, PS, CPU, control interface, etc.
  - Cables, connectors, patch panels, etc.
  - Complex integrated instruments, e.g. Laser-wire, DMC, FB, etc.
- **Cost drivers: BPMs and Laser-wires**
- **Total costs: (no IP instrumentation)**
  - ~93 M$ (ILCU) M&S
  - ~257 manyears (FTE)



RDR Costing Spreadsheet

# of areas	BEAM INSTRUMENT	FUNCTION	COMPONENT	Material & Services				Manpower	
WBS				Unit Cost ($, k$)	Qty	Cost (%)	Cost (k$)	Manyears	Manyears (%)
2	**Total**					**0.182228**	**16967.11**	**30.694535**	**0.119652809**
3.1	**Button BPM**	**beam (bunch) position (TBT and NB)**		**9.9**	**747**	**0.871722**	**7395.3**	**10.1739724**	**0.662917512**
3.1.1			Vacuum mechanics	3000	1		3	0.00509424	
3.1.2			RF feedthrough	100	4		0.4	0.0001442	
3.1.3			DR Coaxial cable (1/2")	625	4		2.5	0.00066912	
3.1.4			Analog frontend	2000	1		2	0.00509424	
3.1.5			Digitizer (4 ch)	2000	1		2	0.00261797	
3.2	**Laserwire (IP)**	**tr. beam size (emittance)**		**447.7206**	**1**	**0.052775**	**447.7206**	**1.09411765**	**0.071290713**
3.2.1			soft- and firmware	50000	0.029412		1.470588	0.41176471	
3.2.2			Laser	360000	0.5		180	0.18235294	
3.2.3			laser power	50000	0.5		25	0.01617647	
3.2.4			laser controls	40000	0.5		20	0.09117647	
3.2.5			laser cables	2000	0.5		1	0.02058824	
3.2.6			laser room	30000	0.5		15	0.01029412	
3.2.7			laser cooling	4000	0.5		2	0.00882353	
3.2.8			transport (500 ft seg)	100000	0.5		50	0.06470588	
3.2.9			transport controls	10000	0.5		5	0.00735294	
3.2.10			transport cables	5000	0.5		2.5	0.01176471	
3.2.11			IP	100000	1		100	0.12058824	
3.2.12			IP controller	40000	1		40	0.06176471	
3.2.13			IP cables	2000	1		2	0.00441176	
3.2.14			Detector	5000	0.5		2.5	0.06176471	
3.2.15			detector controls	2000	0.5		1	0.00882353	
3.2.16			detector cables	500	0.5		0.25	0.01176471	
3.3	**X Sync light**	**tr. beam size (emittance)**		**115.9645**	**1**	**0.013669**	**115.9645**	**0.55842105**	**0.036385699**
3.3.1			soft- and firmware	15000	0.052632		0.789474	0.15789474	
3.3.2			port	25000	1		25	0.21315789	
3.3.3			port controls	2000	1		2	0.00789474	
3.3.4			port cables	225	1		0.225	0.00631579	
3.3.5			transport	80000	1		80	0.10789474	
3.3.6			transport controls	4000	1		4	0.01315789	
3.3.7			transport cables	225	1		0.225	0.01157895	
3.3.8			imager	2000	1		2	0.02368421	
3.3.9			imager controls	1500	1		1.5	0.01315789	
3.3.10			imager cables	225	1		0.225	0.00368421	
3.5	**Streak Camera**	**bunch length**		**280**	**1**	**0.033005**	**280**	**1.15**	**0.074931906**
3.6	**Toroid**	**beam (bunch) current**		**10.125**	**1**	**0.001193**	**10.125**	**0.5096453**	**0.03320756**
3.7	**BLM - ion chamber**	**machine protection**		**14.25**	**4**	**0.006719**	**57**	**0.25**	**0.016289545**
3.8	**BLM - PMT - discrete IC**	**machine protection**		**1.6625**	**40**	**0.007839**	**66.5**	**0.11111111**	**0.007239798**

EDR DR WP4 Deliverables & EOIs

- **DR Instrumentation deliverables:**
  - **Specify, design, development, testing of mission critical, DR unique beam instrumentation systems (e.g. BPMs, fast orbit FB, sync light monitors, etc.), to measure important beam parameters, establish the required beam quality, and stabilize the beam.**
  - **Provide information on BLMs (MPS), and other "standard" instrumentation, e.g. toroids, streak camera, etc. (no R&D needed).**
- **DR Instrumentation EOIs:**
  - **Cornell University (Mark Palmer): 2.7 FTE, 410 k$; transverse beam profile (sync light, bunch by bunch).**
  - **Fermilab (Manfred Wendt): 1.5 FTE, 75+++ k$; BPMs (at AFT DR) [with major contributions(!) from SLAC (Tonee Smith, Justin May, Doug McCormick)]**
  - **KEK (Junji Urakawa): 2 FTE, 100 k$; ATF DR instrumentation**
  - **LBNL (Alan Jackson): 0.2 FTE, ?; ?**
  - **IHEP (Jie Gao): ?, ?; ?**

First Steps…

- **Collecting Information:**
  - Refine the DR beam instrumentation needs (laser-wire, fast orbit FB?), requirements and specifications, listed in the RDR.
  - Summarize and document ALL DR beam instrumentation requirements and input technical details from other WPs.
- **WP Collaboration Setup**
  - Evaluate WP contributions:
    Who is going to do what parts of the instrumentation WP.
  - Partition the WP, e.g. BPM pickup design (incl. wake potential), read-out system, fast orbit FB, optical monitors, BLMs, etc.
  - Setup (regular?) meetings.
- **Start / Continue R&D Activities at the Test Facilities:**
  - ATF (KEK/Fermilab/SLAC): DR BPM upgrade.
  - Cornell: synchrotron light beam profile monitoring.

DR Instrumentation Specifics

- **ILC DR is a 3rd generation-like light source, but very large (HERA-e size) storage ring:**
  - **Operation and some beam parameters (bunch spacing) are fundamental different to the other ILC accelerator areas.**
  - **Single tunnel issues:**
    - **BPMs: single cable length vs. tunnel electronics (HA).**
    - **Other distributed systems: quad-BPM position encoders, BLMs & MPS, magnet interlock systems, temperature measurements, etc.**
    - **Tunnel layout with area refuges may help for electronics racks(?!).**
    - **Non-distributed instrumentation (toroids, sync light, laser-wire, streak camera, etc.) to be located along the main alcove sections.**
  - **Refine instrumentation needs and requirements, e.g. for:**

?

    - **Laser-wire**
    - **Fast orbit feedback, based on the BPM system with low-latency DAQ**
    - **Quad-BPM position encoders**

DR Instrumentation Specifics (cont.)

- **BPM system and it's operation:**
  - High resolution narrowband mode (~1 kHz BW & notch filters).
  - Turn-by-turn broadband mode (some 100 kHz BW).
  - Bunch-by-bunch or single bunch operation is NOT foreseen!?
  - Need to discuss injection/ejection orbit measurements & FB needs!
  - Specify requirements at nominal operation & during commissioning
  - Need vacuum chamber cross-section layout for button BPM design, → estimation of transfer impedance, position characteristic and wake potential (beam impedance).
  - BPMs need a online calibration system.
- **Beam intensity and profile measurements need to time resolve each bunch**
  - Broadband toroids, fast sync light signal processing.
  - Timing, trigger & clock signals; time stamping and data acquisition.

WP4 Information Exchange

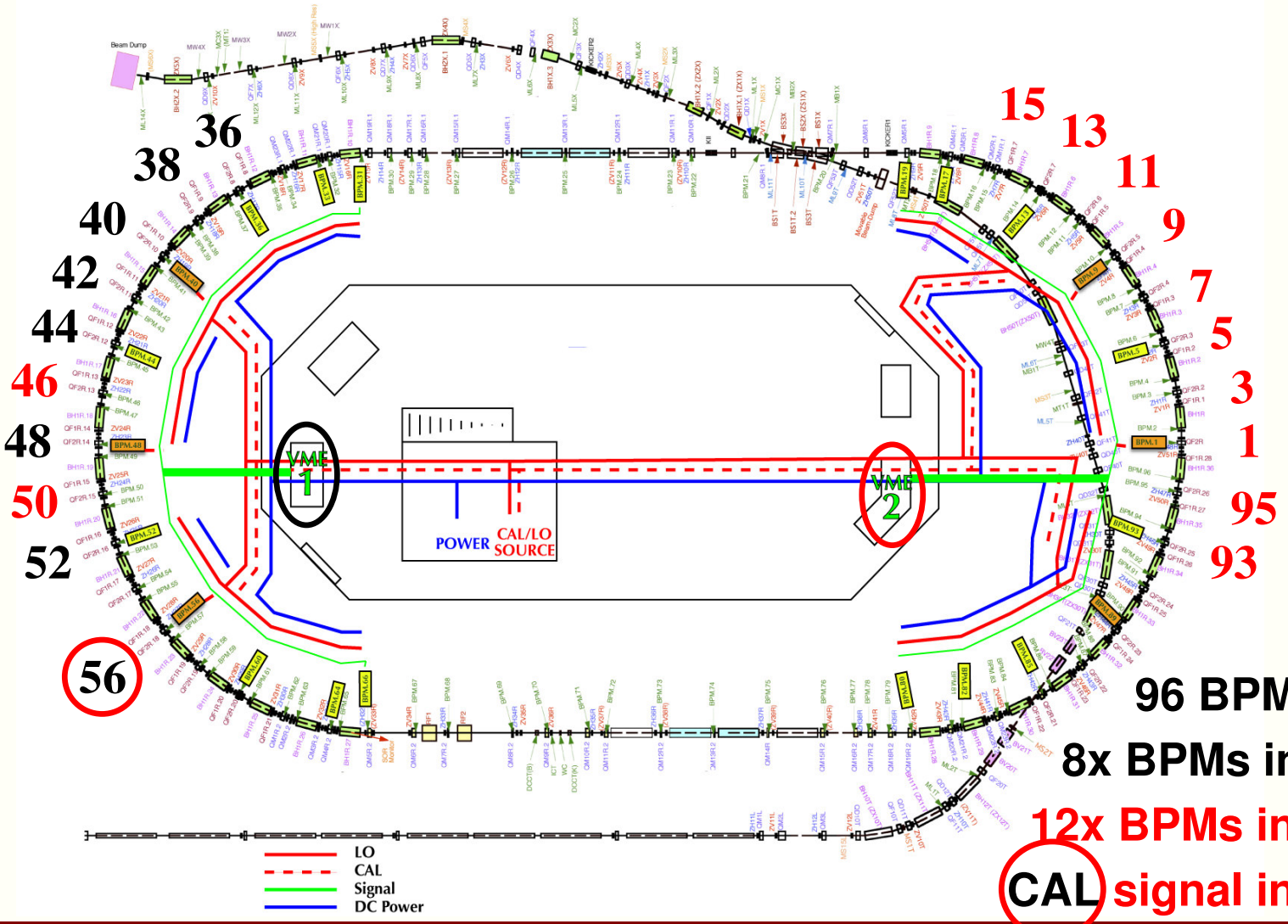
- ***Instrumentation and Diagnostics WP4*** **needs information from:**
  - **Orbit, Optics WP2 (requirements)**
  - **Magnets WP11 (encoders)**
  - **System Integration WP12**
  - **Vacuum System WP13 (beam pipe details)**
  - **Conv. Facilities (global) (rack locations)**

- ***Instrumentation and Diagnostics WP4*** **provides information for:**
  - **Orbit, Optics WP2**
  - **Impedance & Instab. WP5**
  - **System Integration WP12**
  - **Vacuum System WP13**
  - **(Injection & Ejection WP14)**

ATF DR BPM R&D

- **ILC damping ring R&D at KEK's Accelerator Test Facility (ATF):**
  - **Investigation of the beam damping process (damping wiggler, minimization of the damping time, etc.)**
  - **Goal: generation and extraction of a low emittance beam (ε_{vert} < 2 pm) at the nominal ILC bunch charge.**
- **A major tool for low emittance optimization: a high resolution BPM system**
  - **Optimization of the closed-orbit, beam-based alignment (BBA) studies to investigate BPM offsets and calibration.**
  - **Correction of non-linear field effects, i.e. coupling, chromaticity,…**
  - **Fast global orbit feedback(?)**
  - **Necessary: a state-or-the-art BPM system, utilizing**
    - **a broadband turn-by-turn mode (< 10 μm resolution)**
    - **a narrowband mode with high resolution (~100 nm range)**
- **Successful "global" (KEK/SLAC/Fermilab) ILC R&D collaboration, initiated by Marc Ross!**

ATF DR BPM R&D (cont.)



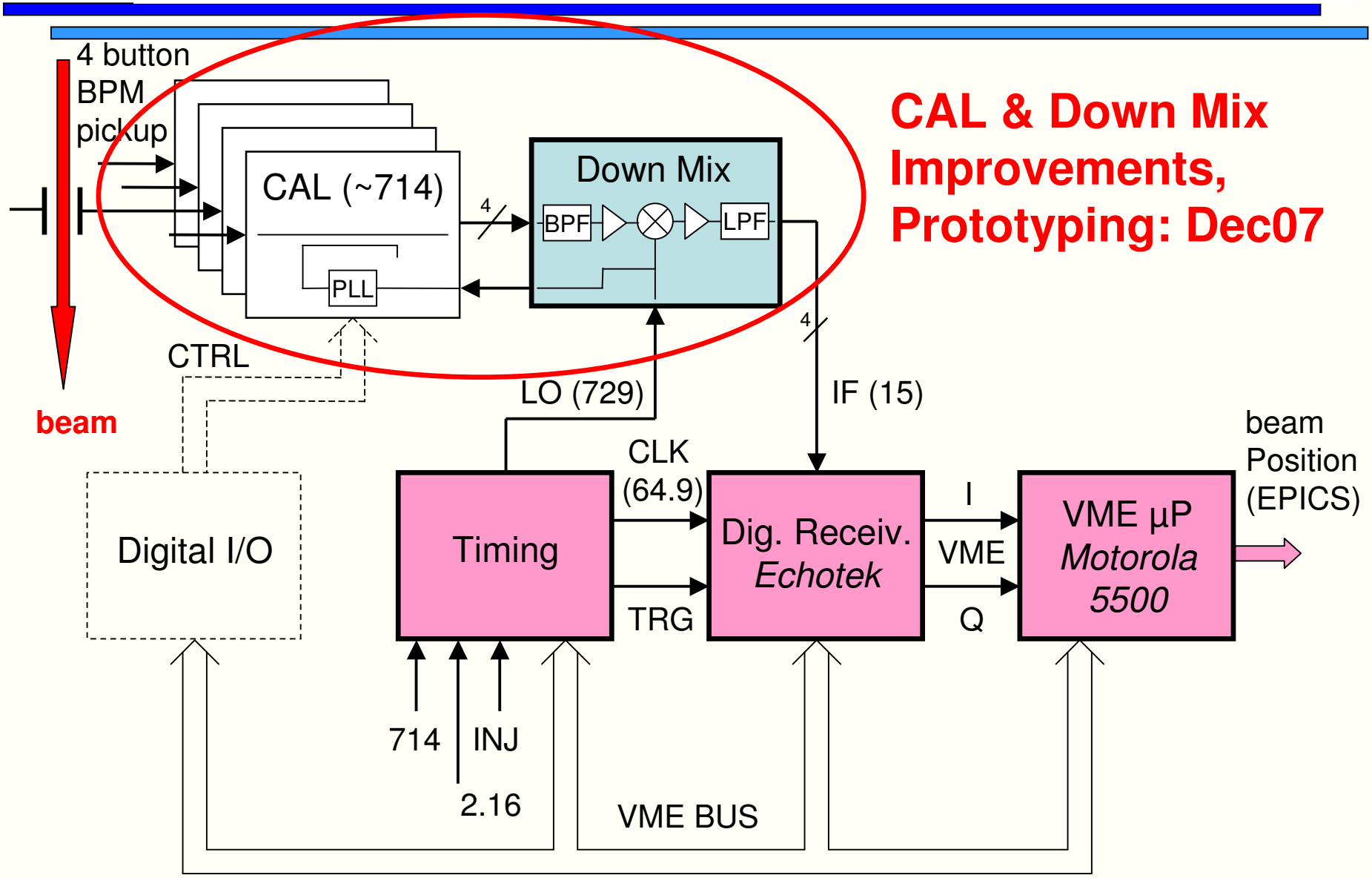
96 BPMs total:

8x BPMs in Feb07

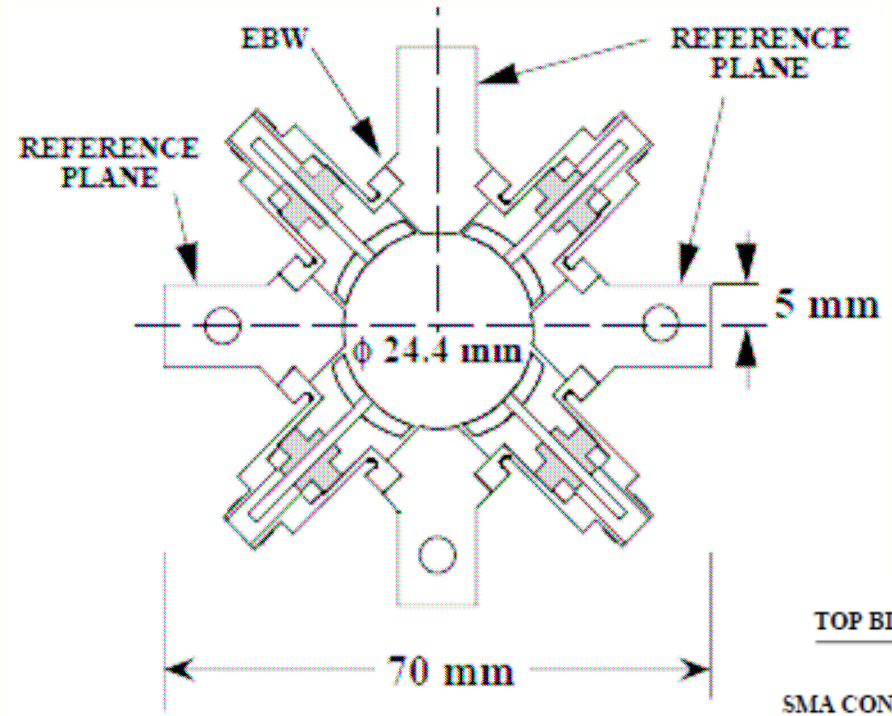
12x BPMs in May07

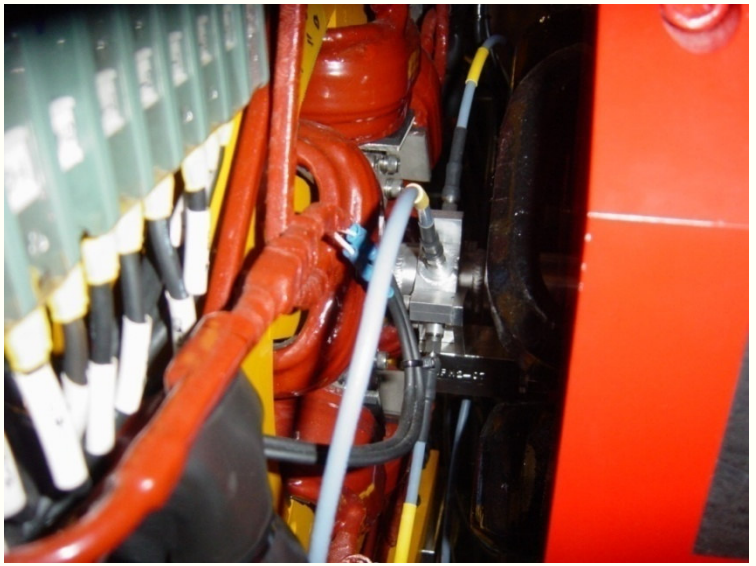
CAL signal in May07

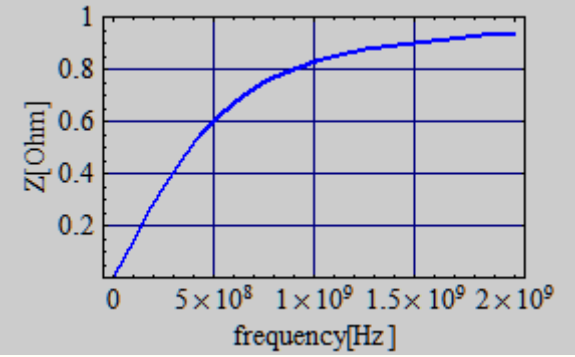
ATF DR BPM R&D (cont.)



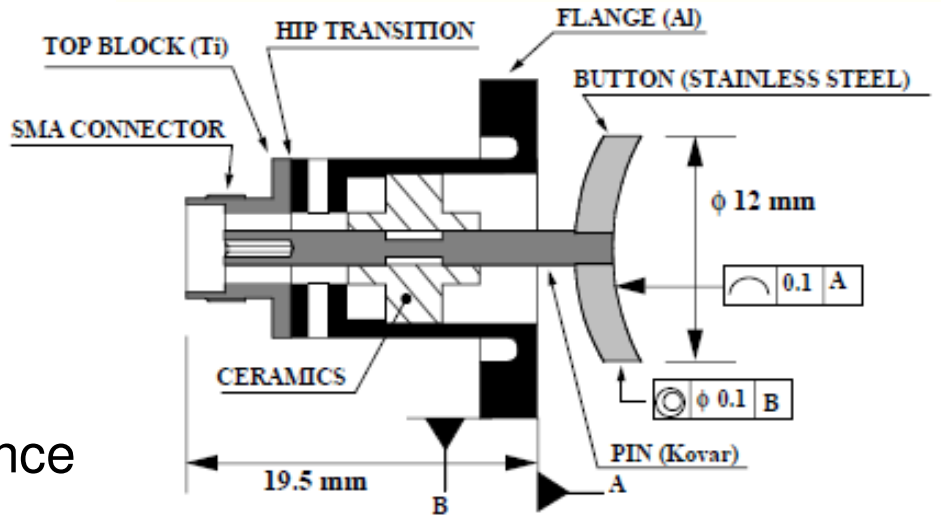
ATF DR BPM R&D (cont.)





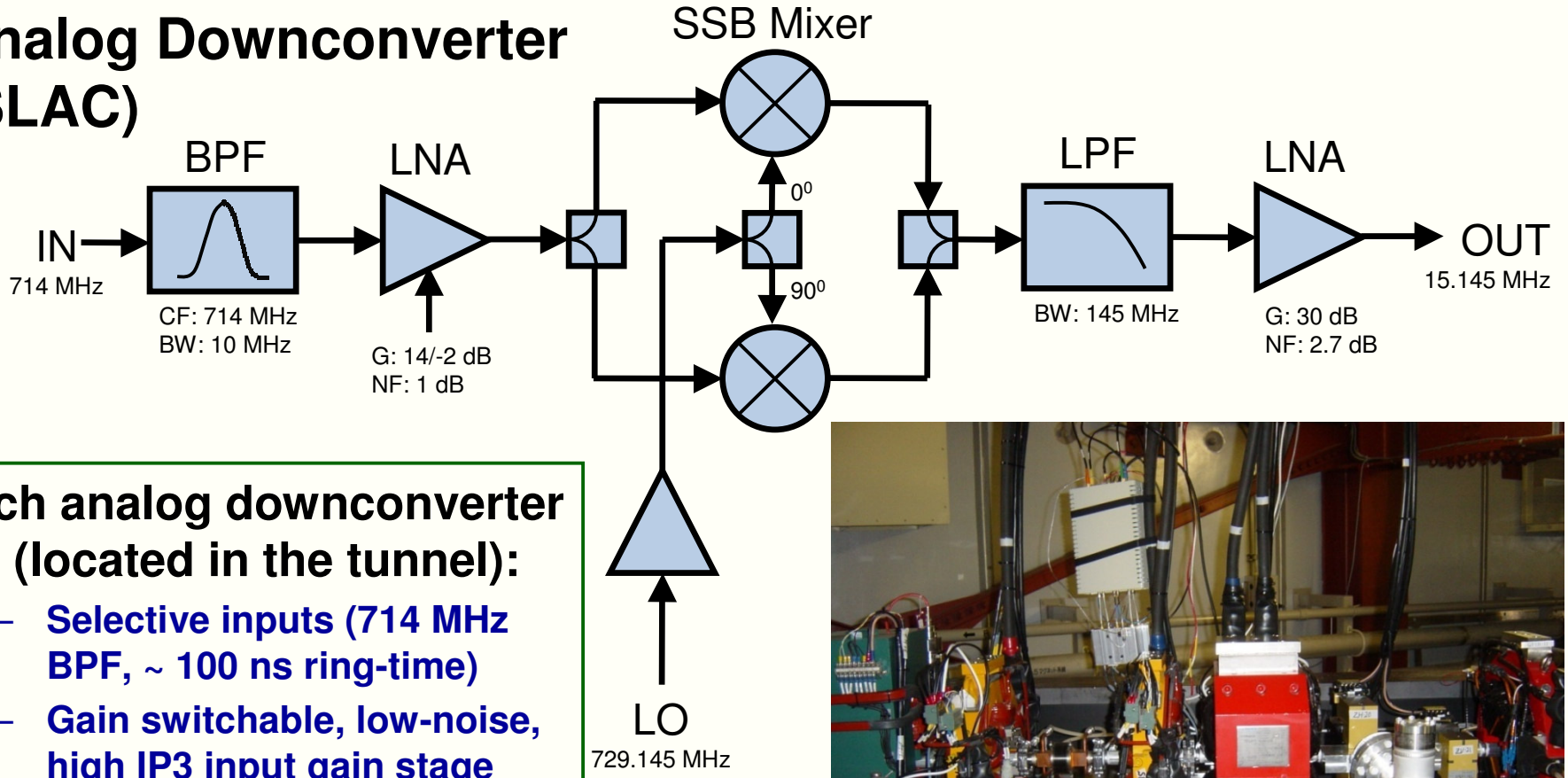


Button: transfer impedance



ATF DR BPM R&D (cont.)

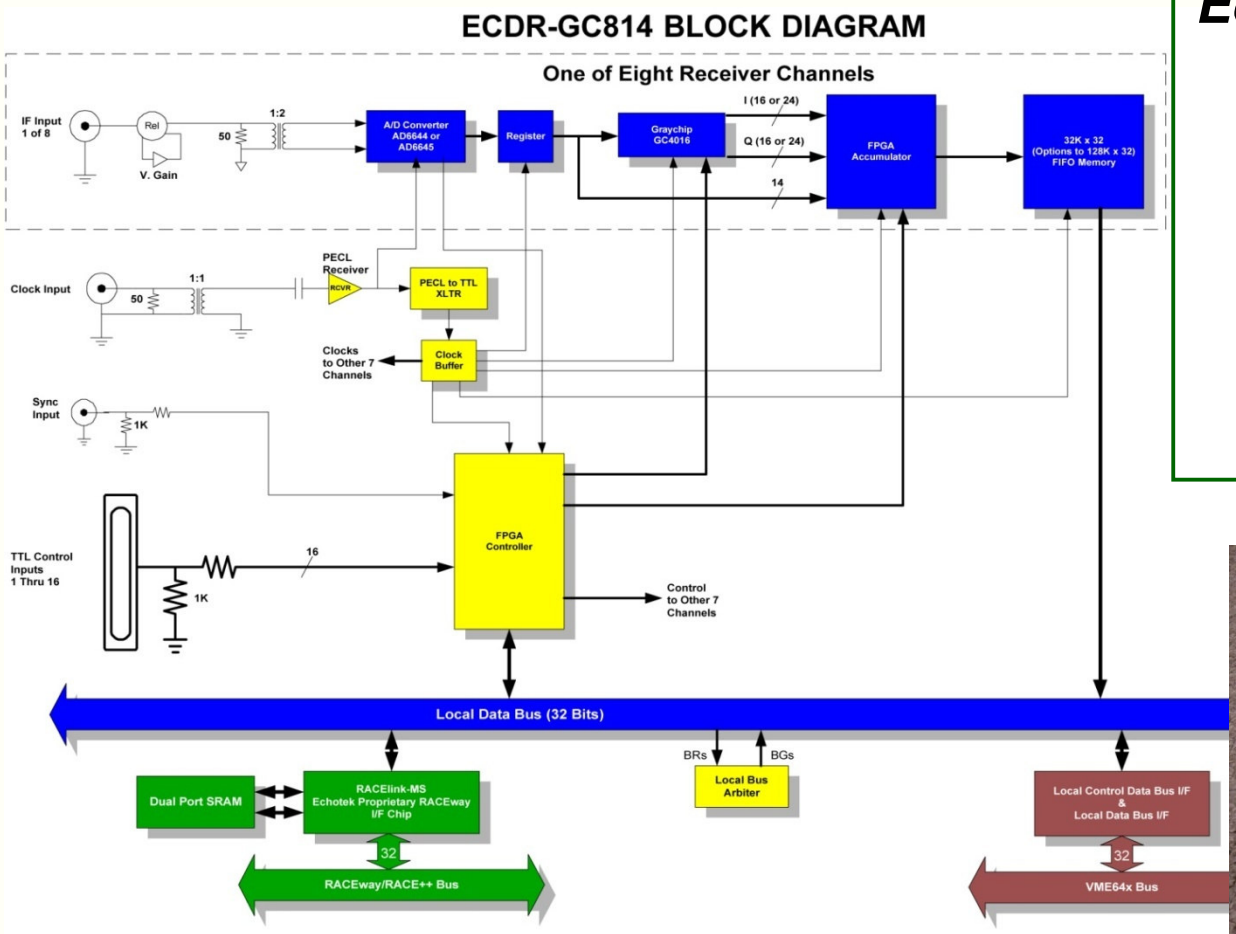
Analog Downconverter (SLAC)



4-ch analog downconverter (located in the tunnel):

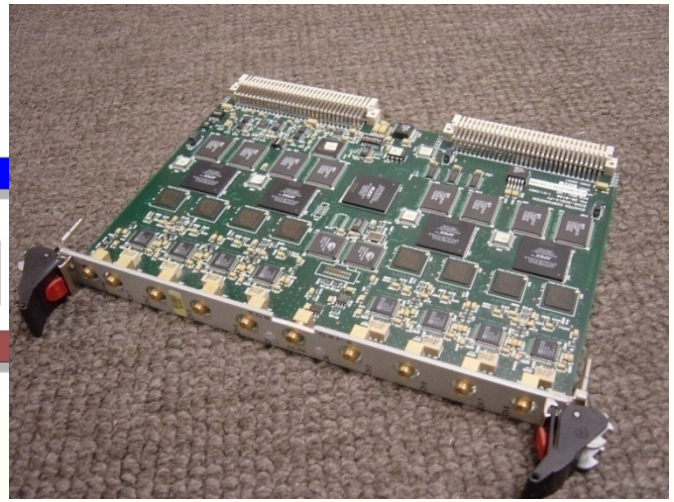
- Selective inputs (714 MHz BPF, ~ 100 ns ring-time)
- Gain switchable, low-noise, high IP3 input gain stage
- Image rejection (SSB) mixer
- 15.1 MHz high gain IF stage

ATF DR BPM R&D (cont.)

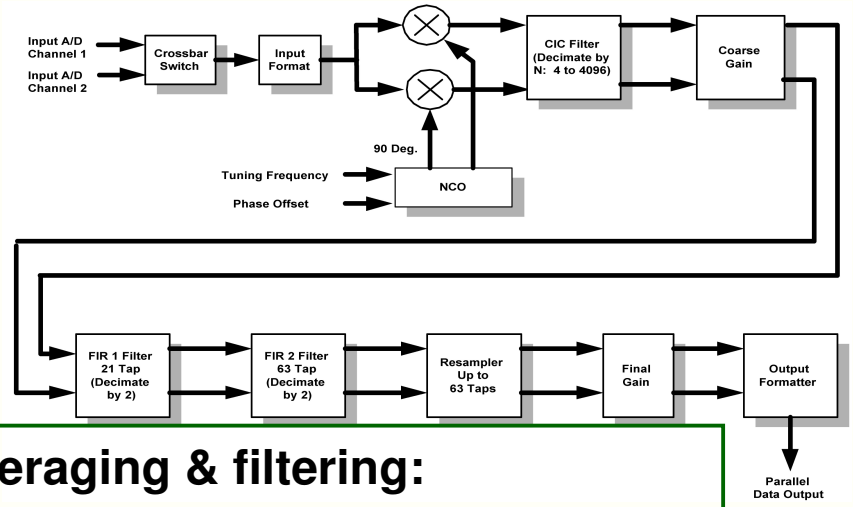


***Echotek* digital receiver:**

- **8-ch VME 64x module**
- **Analog Devices 14-bit 105 MS/s AD6645**
- **Each channel: *Texas Instruments* 4-ch GC4016 "*Graychip*" digital downconverter**



ATF DR BPM R&D (cont.)



Graychip digital downconverter:

- 4 independent channels per ADC
- NCO set to f_{IF} = 15.145 MHz (downconvert to DC baseband)
- ADC clock set to 32 samples per revolution: $f_{CLK} = 32 * f_{rev} = 69.2$ MHz
- Decimation and filtering for the broad- and narrowband operation, using CIC and FIR digital filters

Averaging & filtering:

- 5-stage CIC, dec 4…4096
- 21-tap CFIR, dec 2 (or 1)
- 63-tap PFIR, dec 2

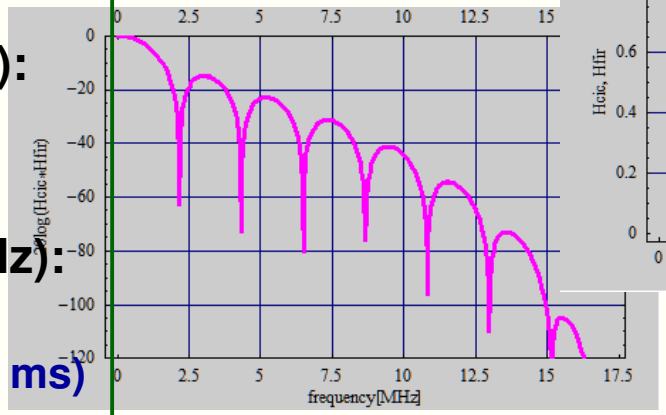
Wideband Mode (BW ~ 1 MHz):

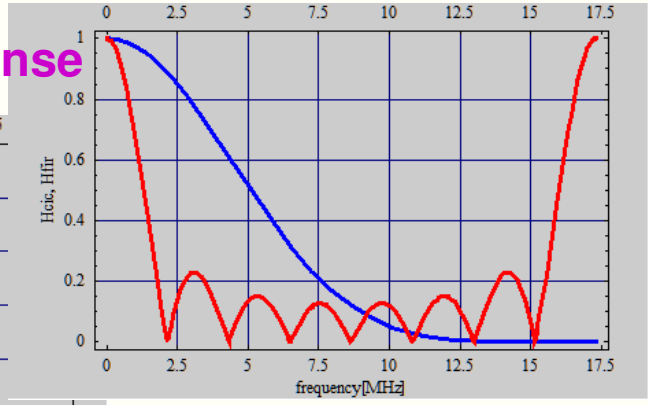
- total decimation: 8
- 8-tap running ave. FIRs

Narrowband Mode (BW ~ 1 kHz):

- total decimation: 10988, t_{dec}: 158.7 μs, 1280 pt (~ 200 ms)
- 21 & 63-tap RRC FIRs

WB mode magnitude response



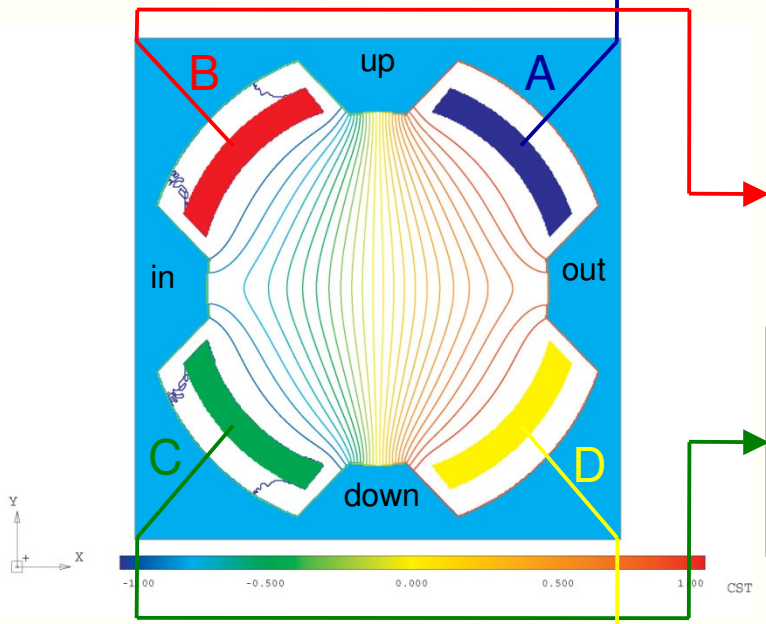


WB CIC response

WB FIR response

ATF DR BPM R&D (cont.)

Magnitude-based processing of 4 separate BPM signals



Down Mix A
BPF
LPF

Down Mix B
BPF
LPF

Down Mix C
BPF
LPF

Down Mix D
BPF
LPF

*"Echotek" d*igital signal processing:

$$\phi_H = \frac{(A+D)-(B+C)}{A+B+C+D}$$

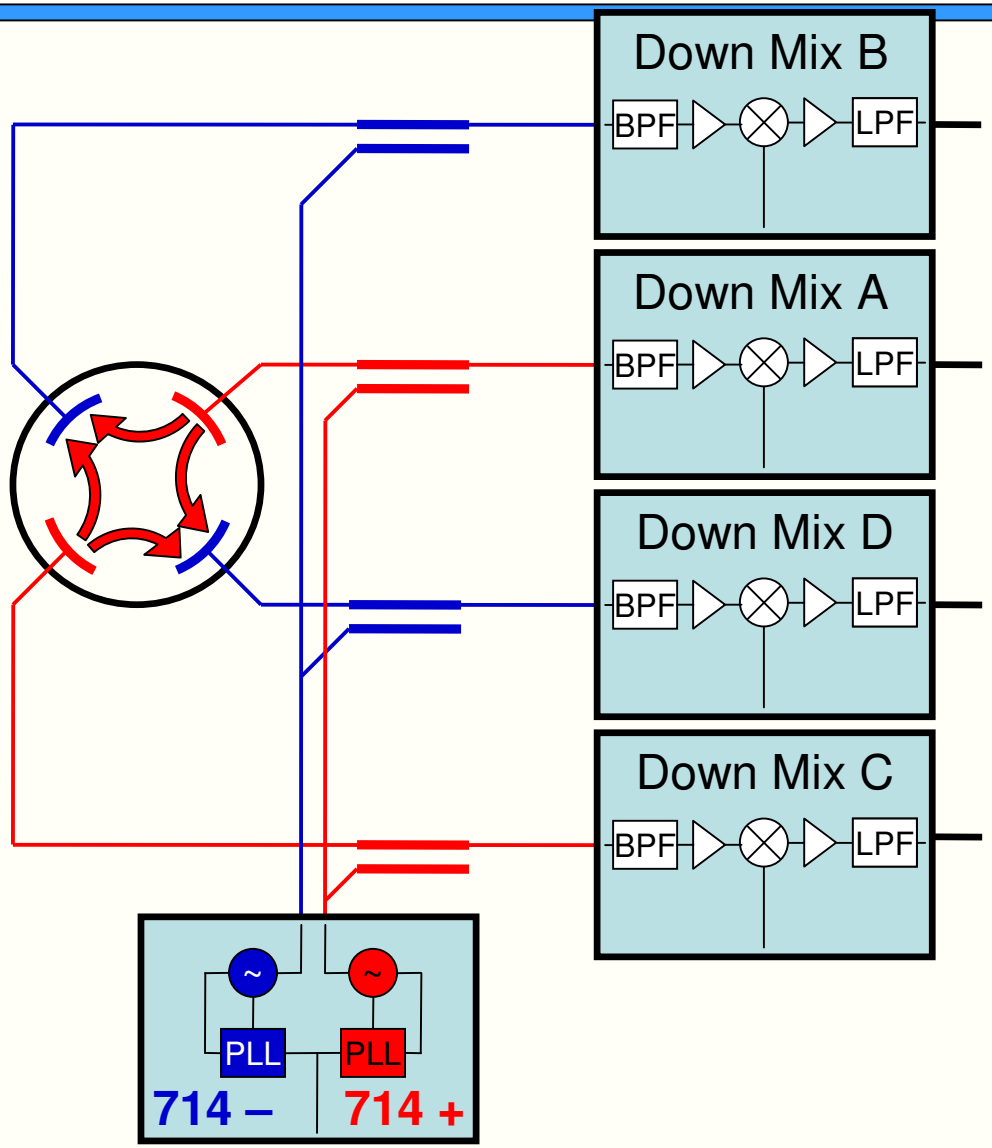
$$\phi_V = \frac{(A+B)-(C+D)}{A+B+C+D}$$

1D polynomial fit:

$$Pos\,[mm] = 9.35\phi + 1.00\phi^3 + 7.79\phi^5$$

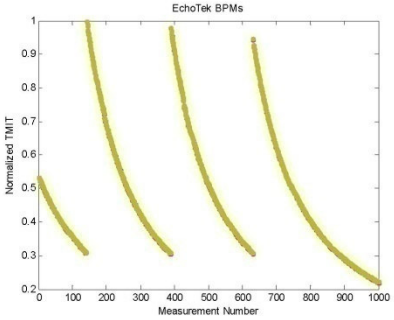
0.1 dB gain error ≡
27 µm offset error !

ATF DR BPM R&D (cont.)



- **2 calibration tones:**
  - **714 + ε MHz**
  - **714 – ε MHz**
  - **In passband of the downconverter**
  - **Coupling through the button BPM**
- **On-line calibration**
  - **In presents of beam signals**
  - **Available only in narrowband mode**
  - **Using separate *Graychip* channels**

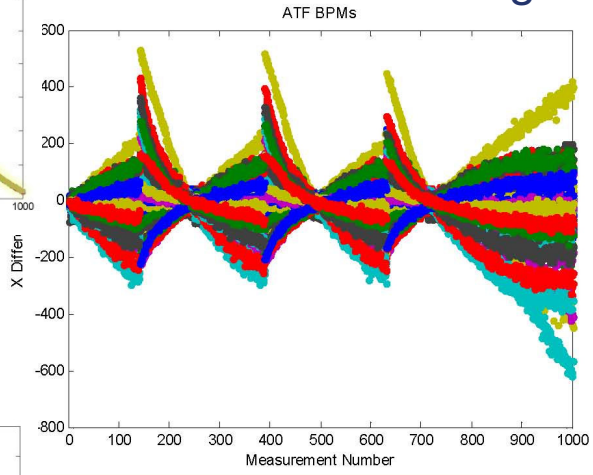
ATF DR BPM R&D (results)

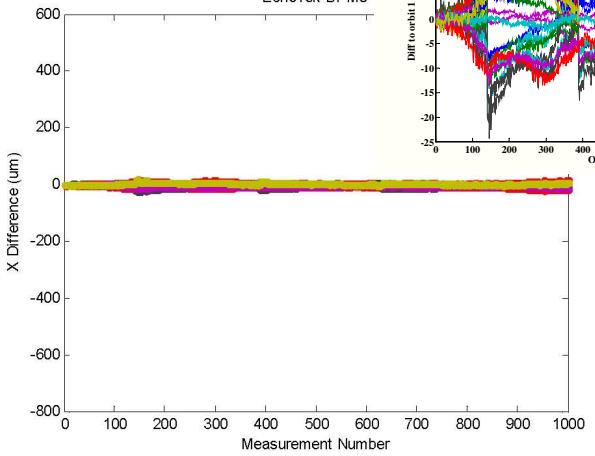


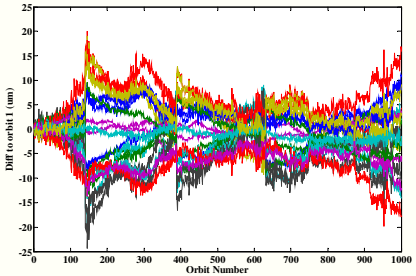
Normalized intensities

Horizontal Position

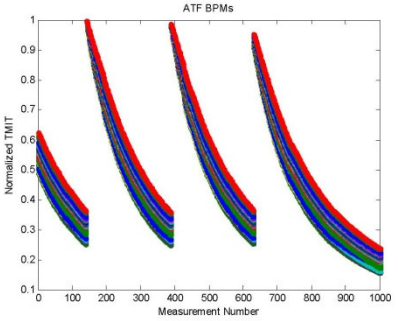
Plot range: +600/-800 µm





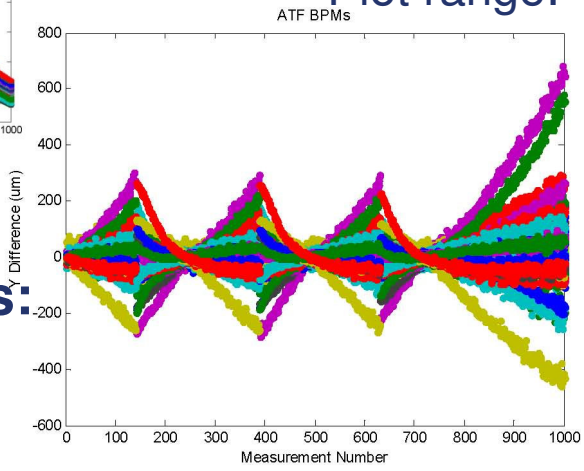


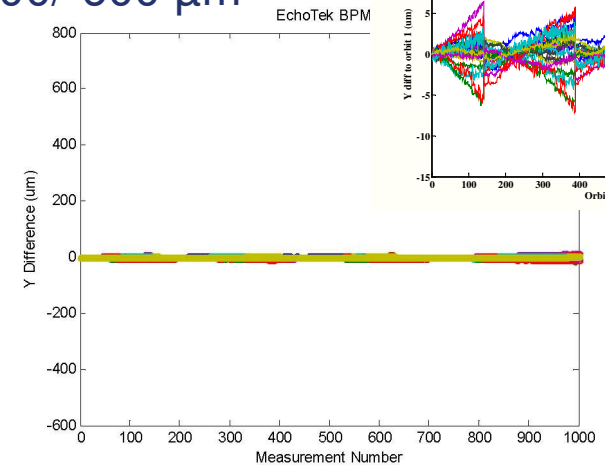
Plot range: ± 25 µm

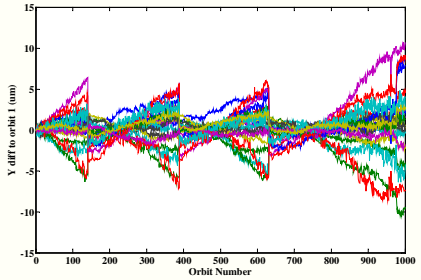


Vertical Position

Plot range: +800/-600 µm







Plot range: ±15 µm

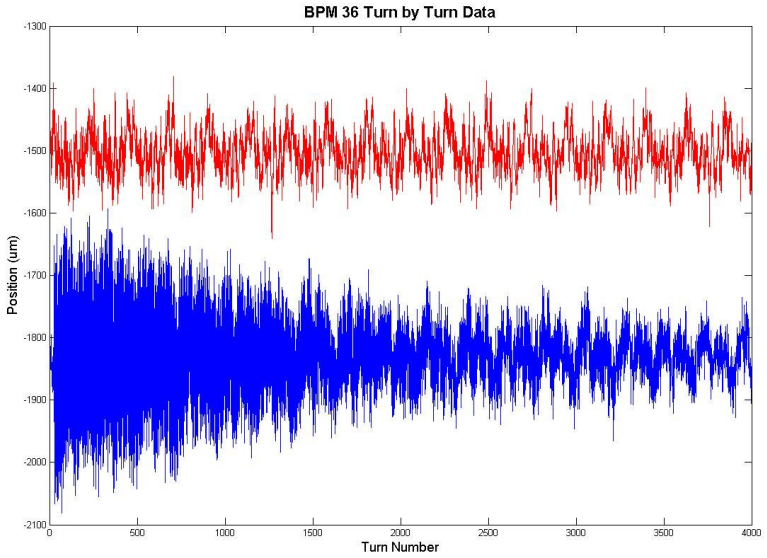
Scrubbed mode studies: Intensity dependence

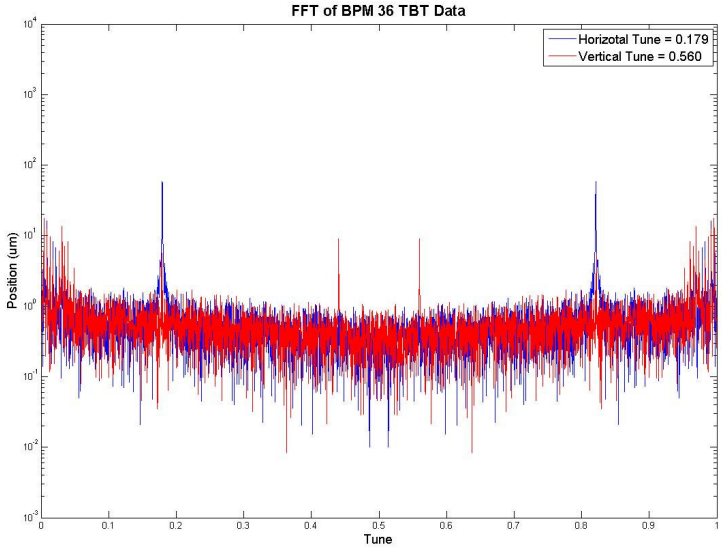
ATF DR BPM R&D (results)

BBA results (070227, 070302)

Y BBA (um)	ET	+/-	ATF	+/-	dET	dATF
QF2R.10	343.38	6.44	15.15	17.10		
	316.49	34.40	-105.14	174.00	26.9	120.3
QF2R.11	112.68	2.99	300.89	55.70		
	107.87	5.16	-89.69	165.00	4.8	390.6
QF2R.12	-72.69	5.07	-172.12	85.70		
	-91.84	14.20	-798.00	2040.0	19.2	625.9
QF2R.13	-188.03	1.19	-177.83	323.00		
	-174.37	37.20	-82.01	54.50	13.7	95.8

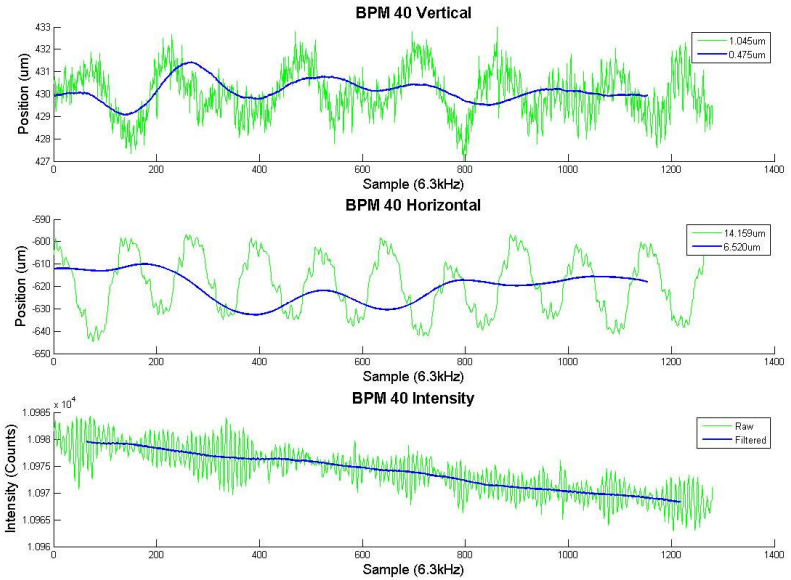
ATF DR BPM R&D (TBT results)

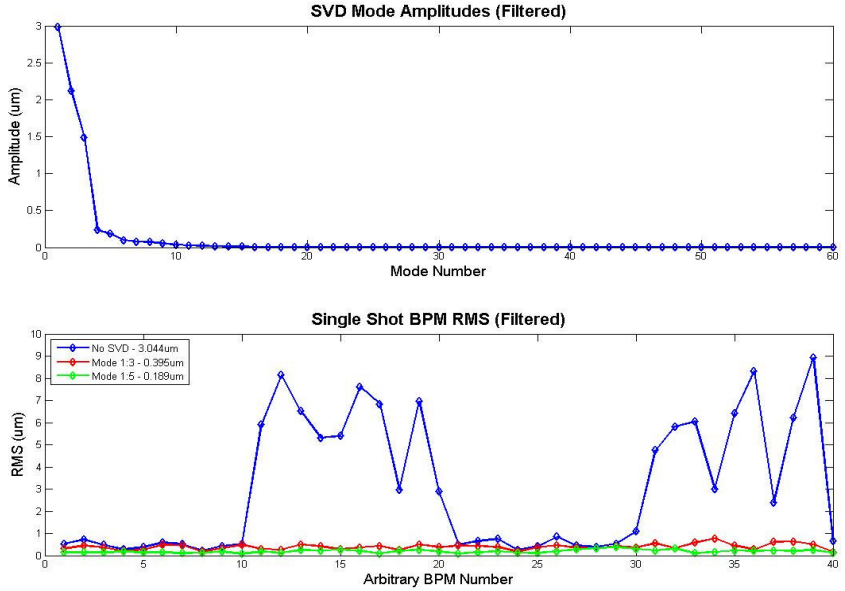




- **Turn-by-Turn data BPM #36 (pinger: On)**
- **Identifying hor. and vert. tune lines (387 kHz, 1.212 Mhz) as well as sync. tune lines (n x 9.7 kHz).**
- **Observed short time, broadband TBT resolution: few μm!**

ATF DR BPM R&D (NB results)

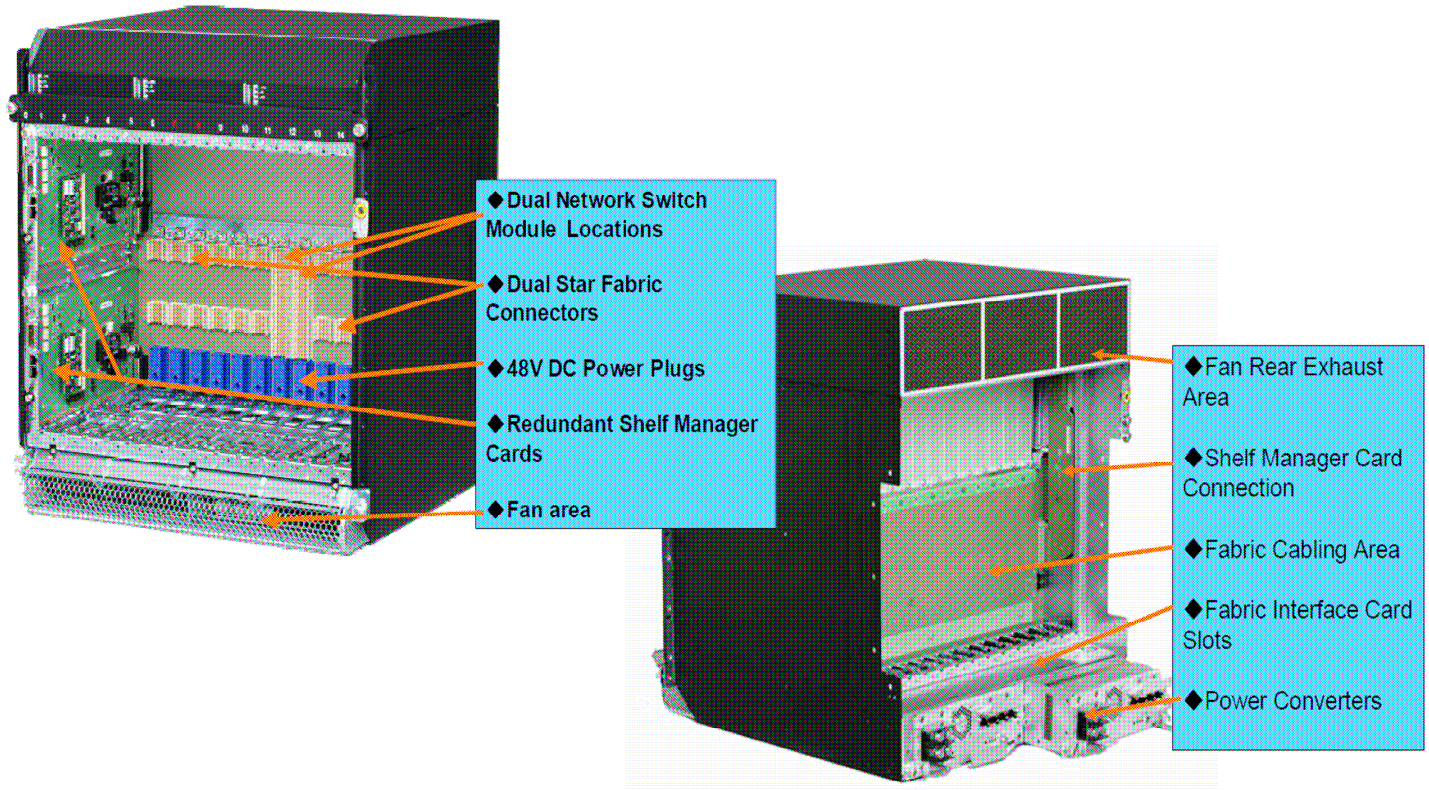




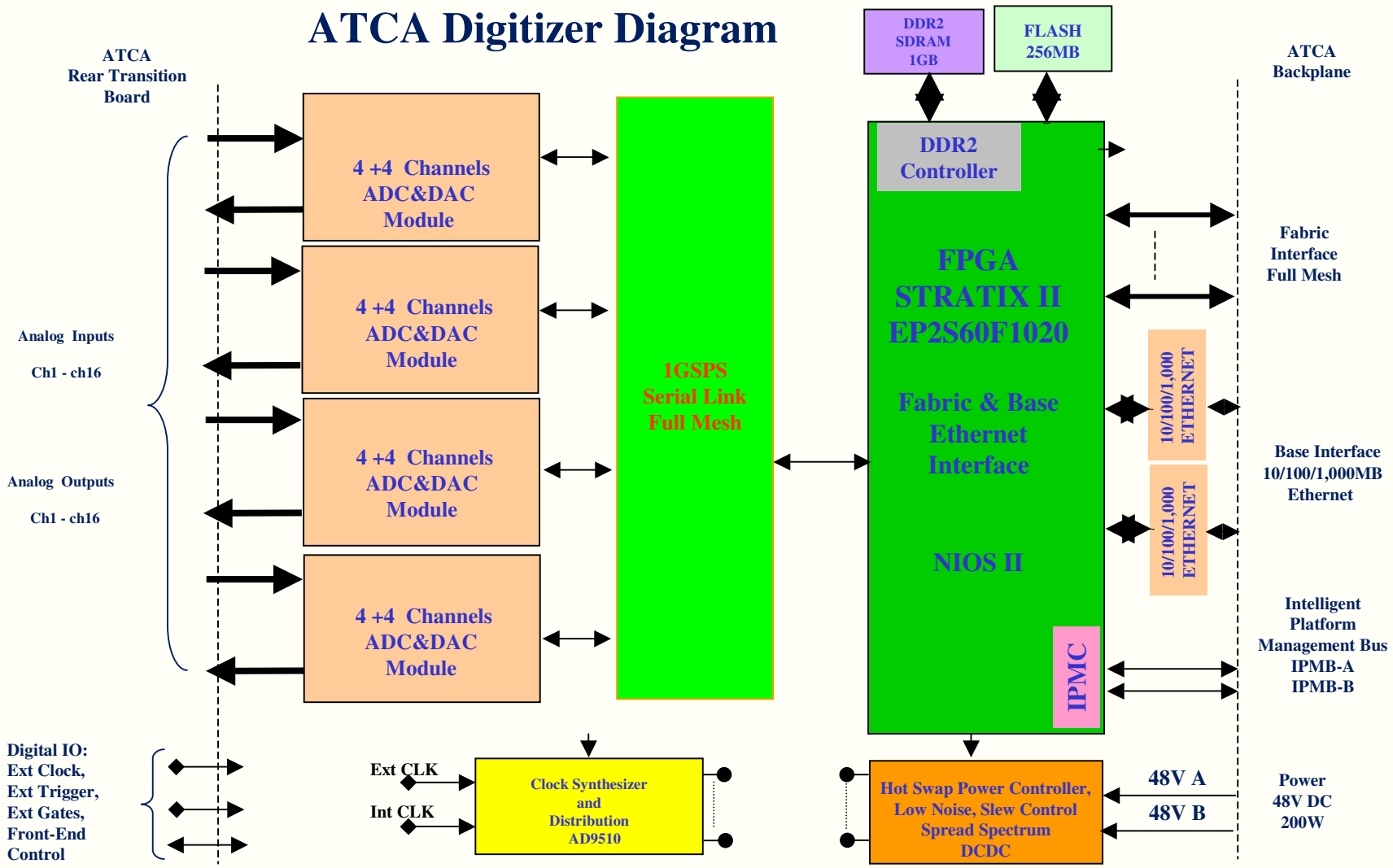
- Data filtered by 126 tap box to average and remove 50Hz
- Observe strong orbit motion in the horizontal plane!
- Remove the motion to find "real" BPM resolution
  - 400 to 200 nm range (preliminary!)
  - 30 nm using CAL tone signal!

ATCA Digitizer R&D

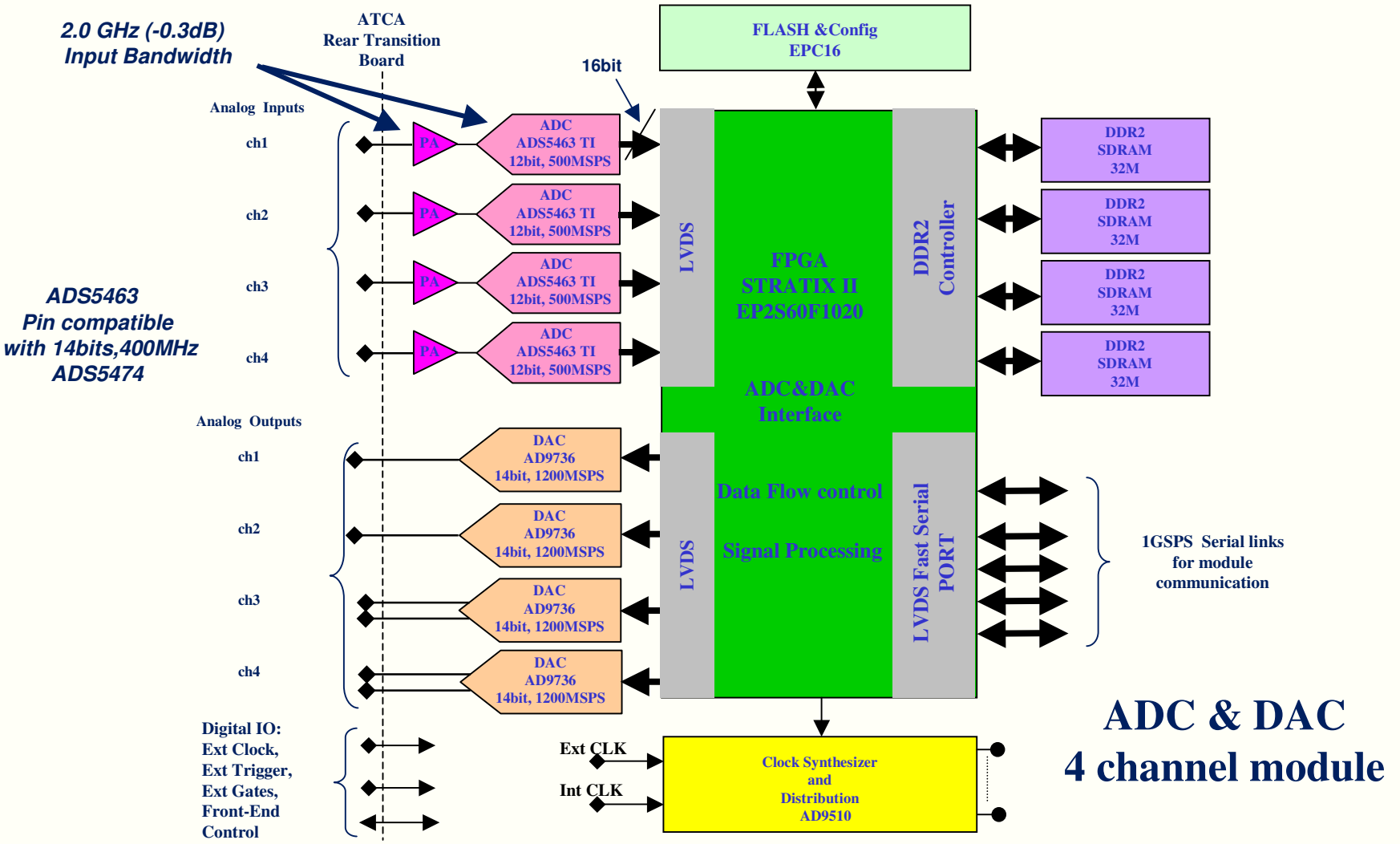
- **ATCA chosen as standard ILC HA electronics platform.**
- **General purpose, high-end digitizer for instrumentation.**



ATCA Digitizer R&D (cont.)

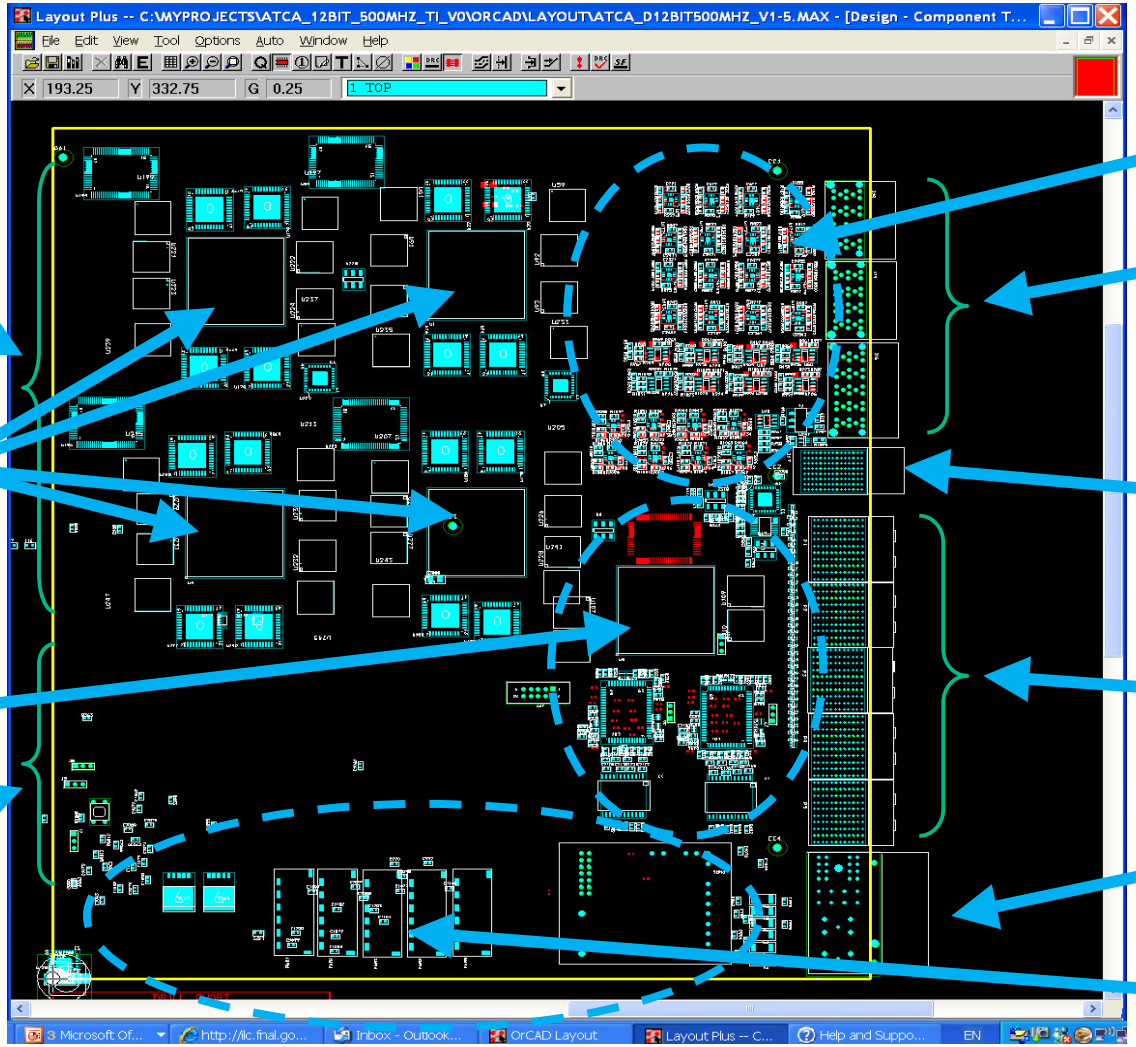


ATCA Digitizer R&D (cont.)



ATCA Digitizer R&D (cont.)

Digitizer Layout (in progress)



No Signals Connectors on Front!

4 Identical ADC&DAC Modules

Fabric & Base Modules

LED Indicators And JTAG Connector for service

Preamp & Drivers

Zone3:
Analog Inputs - 16
Ext Clock Input - 1
Ext Sync Input - 1
Analog Outputs – 8
26 Coax (HARTING)

Zone3:
Analog Outputs - 8
Digital In/Out - 16
Diff Pair

Zone2:
Fabric & Base
16 @ 4xLinks

Zone1:
Power Connector
dual - 48VDC

DCDC Converters

Summary Instrumentation WP4

- **Major instrumentation R&D activities are underway:**
  - **Integrated BPM system, including read-out hardware, signal processing, data acquisition, calibration, etc., AND beam studies! (KEK/Fermilab/SLAC).**
  - **Bunch-by-bunch transverse beam profile monitoring based on synchrotron light (Cornell) – details will follow.**
- **Needs, requirements and specifications for most DR beam instrumentation systems have to be refined.**
- **WP management has to be established**
  - **WP partition, tasks have to be described in details.**
  - **Collaboration contributions have to be formalized (by 11/9/07).**
  - **Communication (regular meetings?), links and information exchange with other DR WPs.**
  - **Documentation (ILC document server, EDMS).**