Overview of ILCTA Instrumentation Activities

– Status June 2006 and future plans –

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Contents

Diagnostics (non beam-based)

- RF protection interlock system.

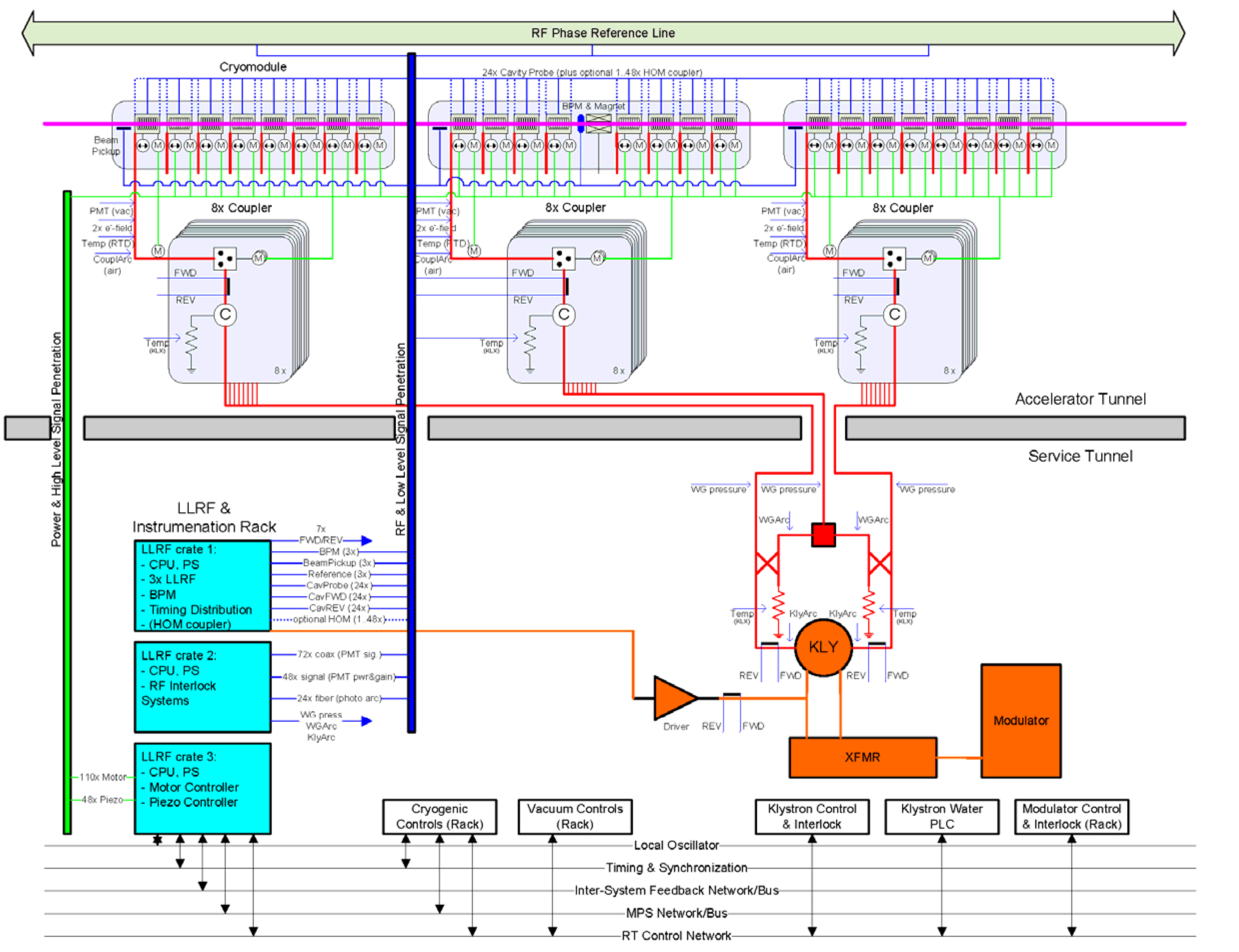
Basic Beam Instrumentation

- Read-out systems for BPM's, toroids, phase monitors, etc.
- Cold cavity-BPM development

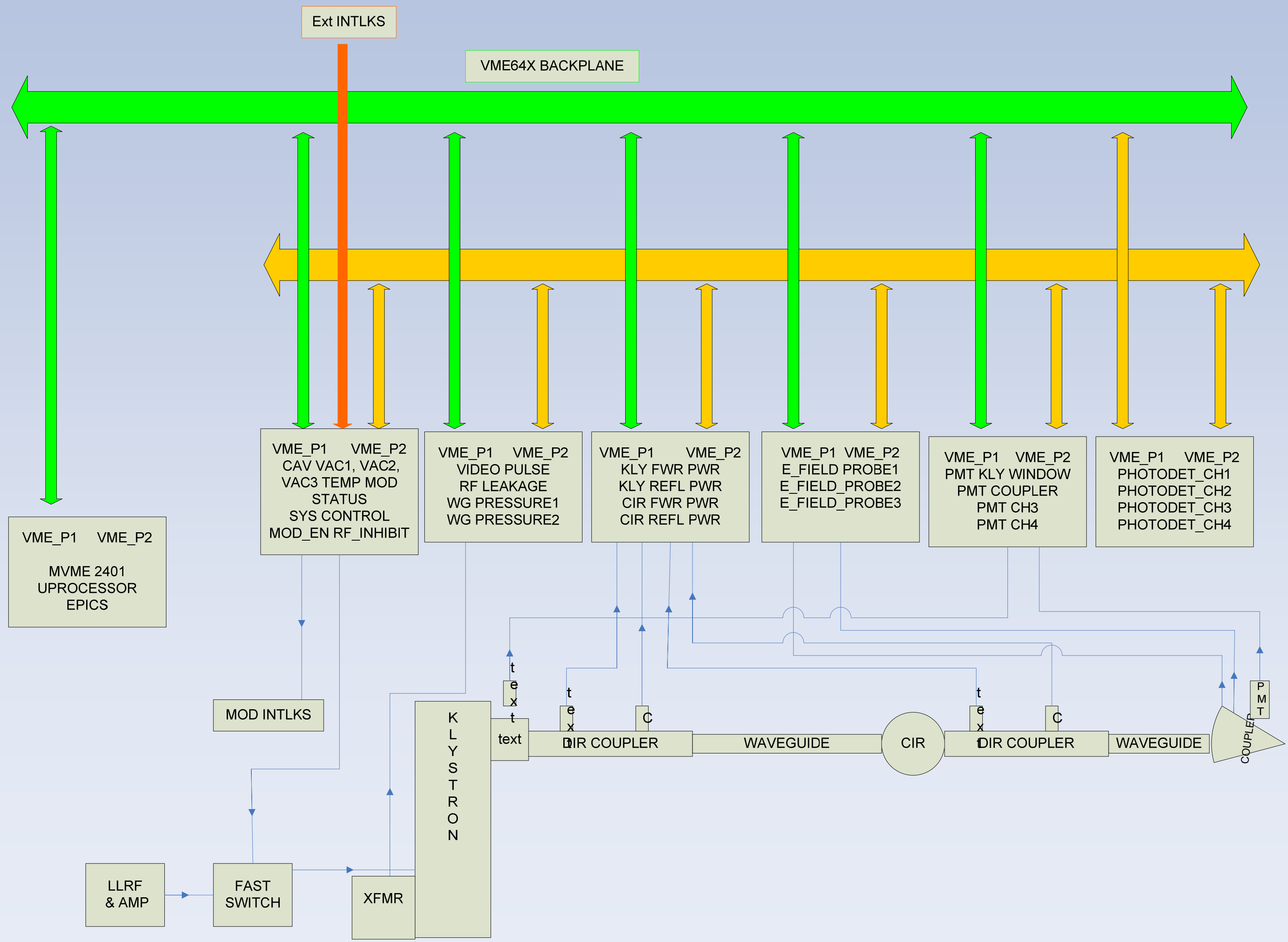
Advanced Beam Instrumentation

- HOM coupler signal monitoring.
- OTR interferometry for transverse beam size (emittance) and beam energy measurements.
- NIU activities on advance beam instrumentation.

International Linear Collider at Fermilab

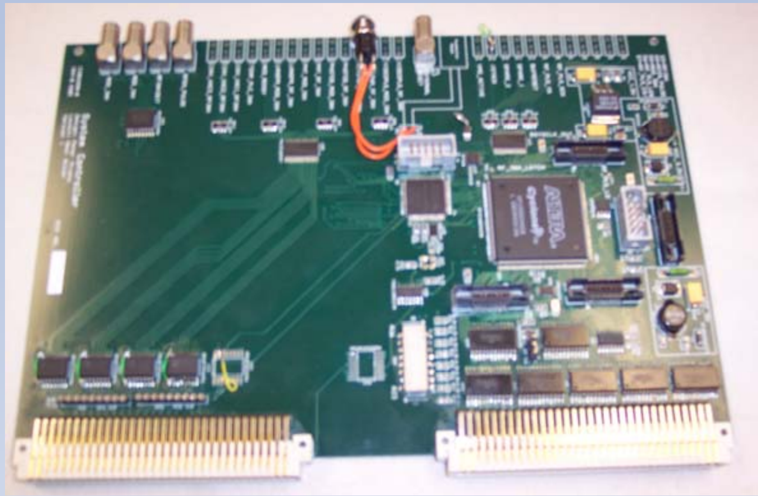


HIGH INTENSITY PROTON SOURCE AND SMTF RF INTERLOCKS



RF Protection Interlock System

- Signal Monitoring:
  - Klystron (forward and reflected power, window arcs with PMT)
  - Coupler (PMT photodiode based arc detection, and field emission detection, ceramic window temperature measurement)
  - Cavity (PMT and photodiode based arc detection, vacuum control)
- Normal operation: Permit to LLRF when MOD. ON
- Trip Detection: within 1..2 μs: remove LLRF permit!
- all 6 interlock boards are assembled and tested:
  - System Control, performs as designed
  - Forward/reflected power, performs as designed
  - Photodetector, PMT, Field Emmission brds: Perform as Designed
  - Video pulse, Performs as Designed
- The system is at SMTF to be tested with new Klystron


System Control


Forward/Reflected Power

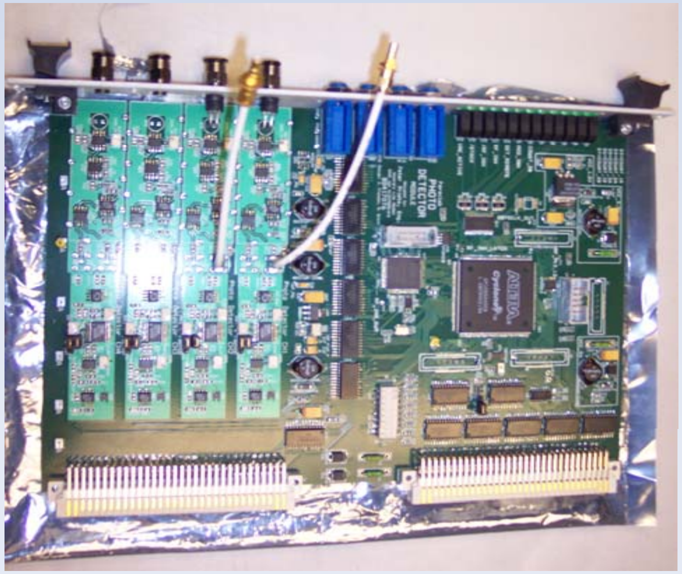
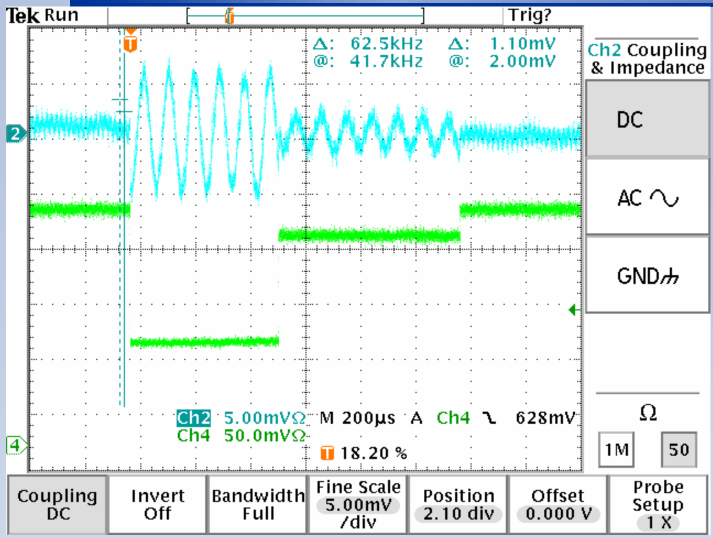
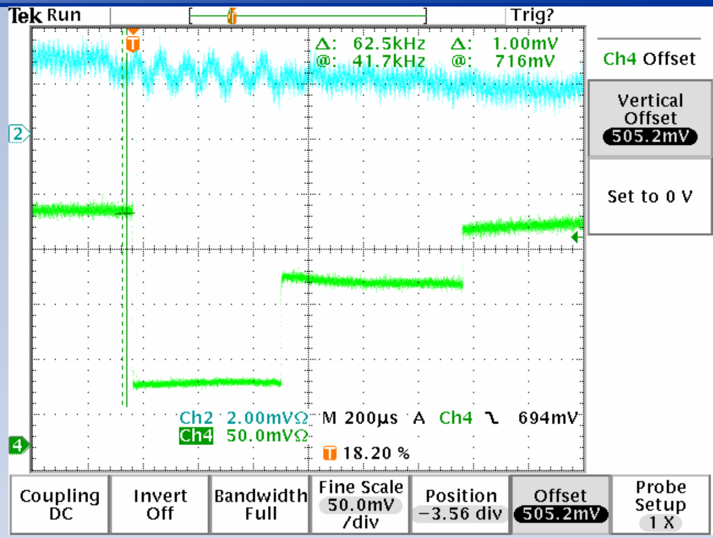


Photo Detector

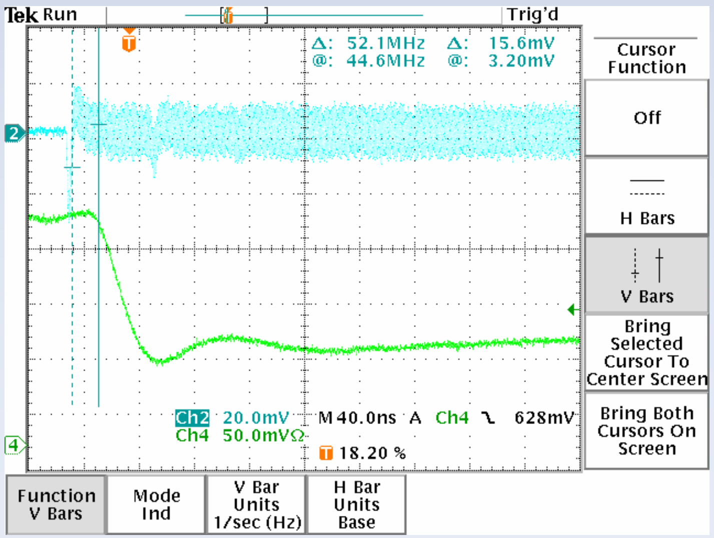

Video Pulse



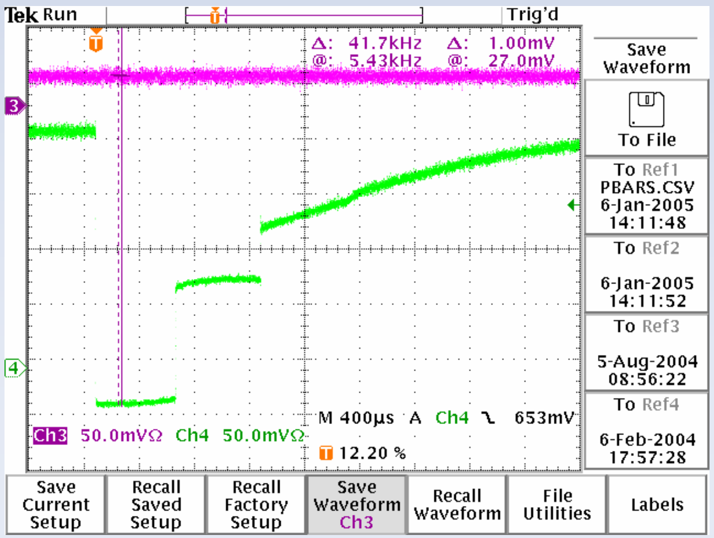
Forward power 200 kW, undersampled



Reflected power 200 kW

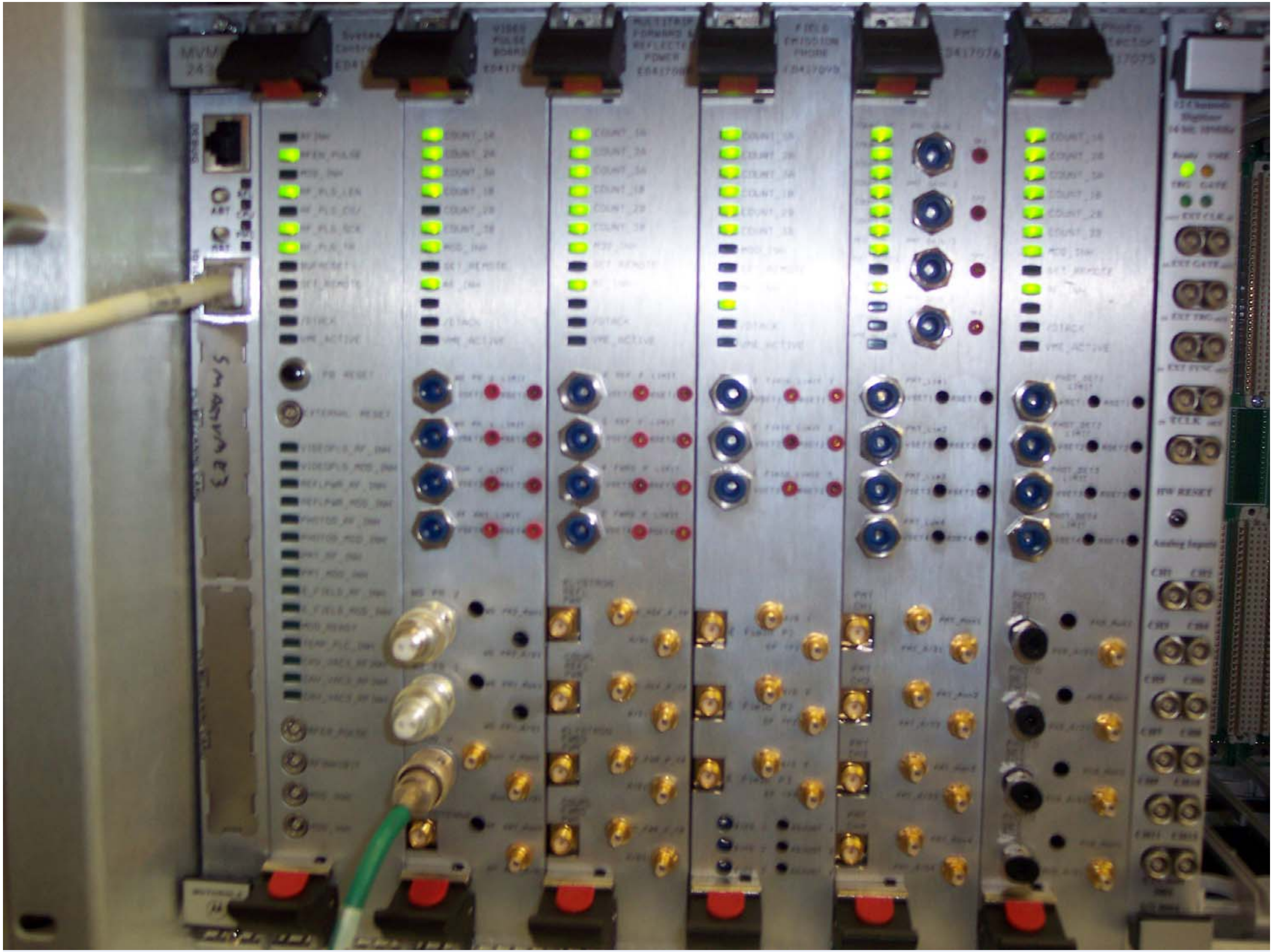


59.1 ns detection time!



Ch-to-Ch cross-talk measurement


I.R.M.


HW RESET
Analog Inputs

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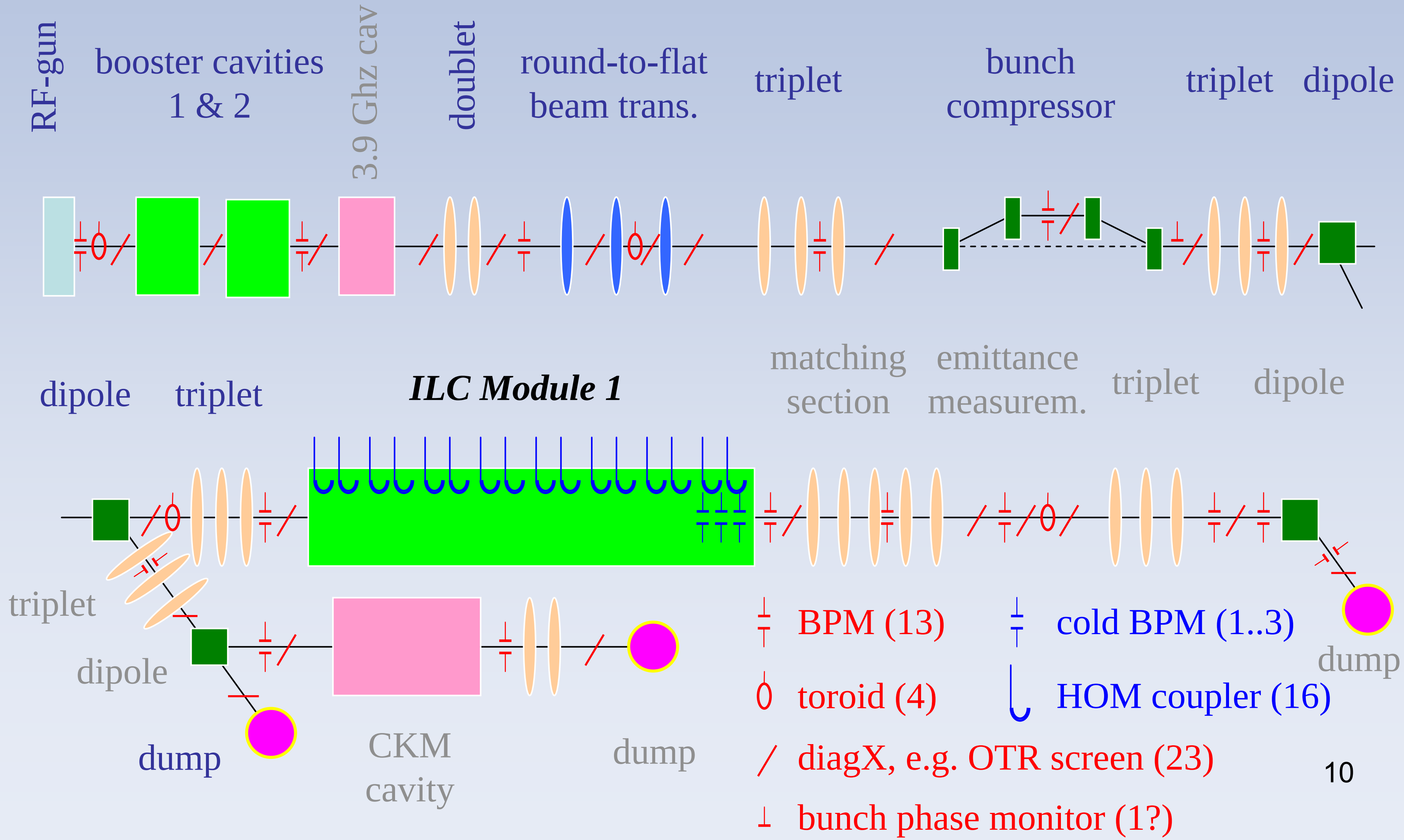
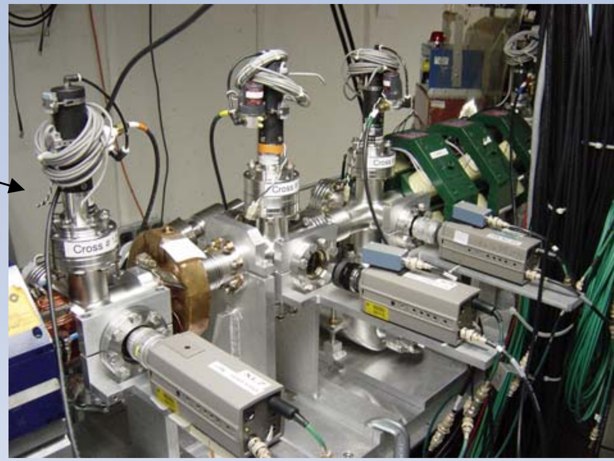
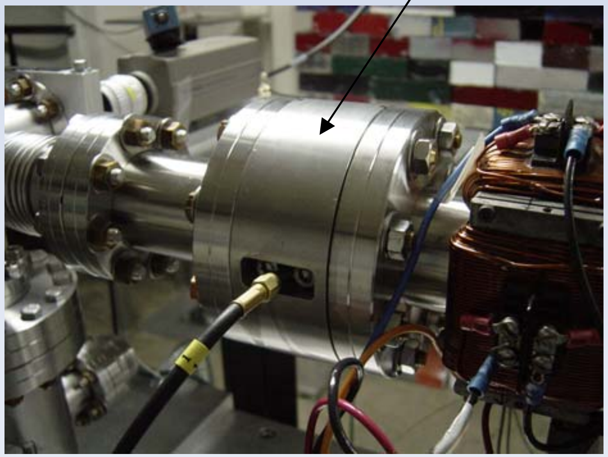
ILCTA Basic Beam Instrumentation

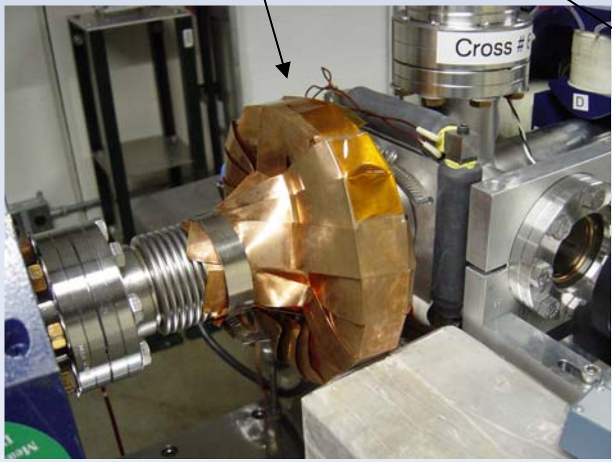


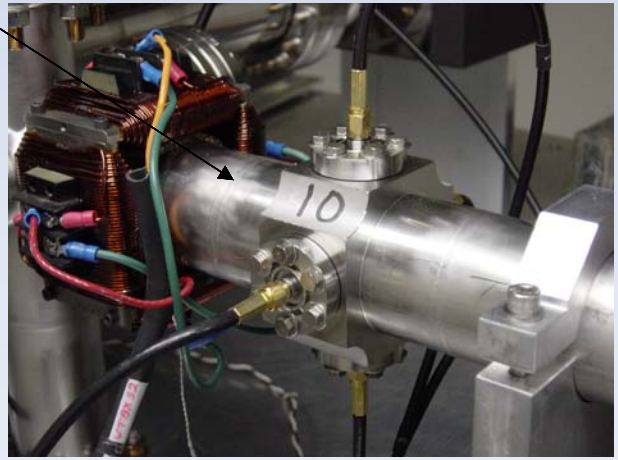
Recycle Photoinjector vacuum parts

- Diagnostic crosses (flags) with screens, F-cup, etc. (15+5)
- Button BPM's (11)
- Toroidal transformers (4)
- Bunch phase pickup (1)







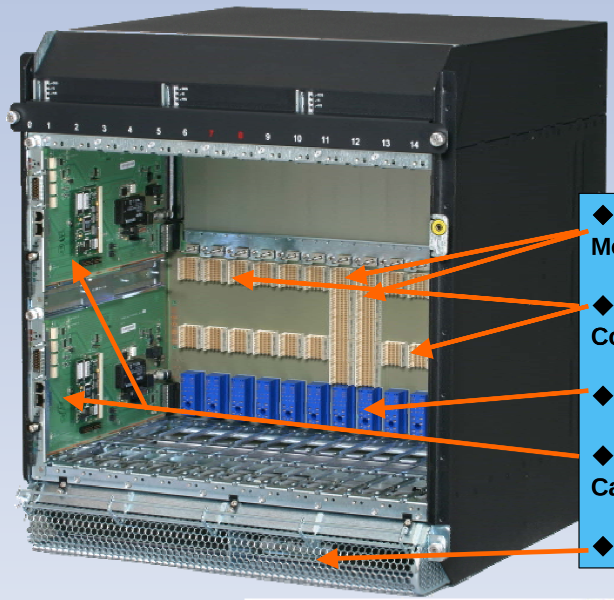


Digitizer Board Development

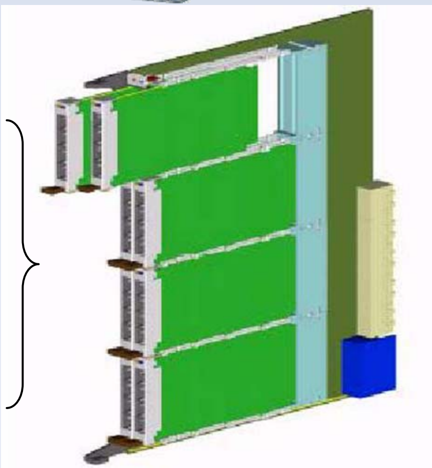
- We (soon!) need read-out electronics for
  - 13+ Button-style BPM's (~ 1 GHz analog BW, > 12 bit resolution, "high" sample rate)
  - 1..3 Cavity BPM's (~ 200 MHz analog BW, 14 bit)
  - 4+ Toroidal transformers (~ 200 MHz analog BW, 14 bit)
  - More digitizer needs for bunch phase and HOM signals…
- Signal processing mainly in the digital domain.
- General purpose multi-channel digitizer (ADC/DAC) board, minimum analog signal processing.
- HA-friendly environment, e.g. ATCA
- Acceptance from the ILC controls&instrumentation community

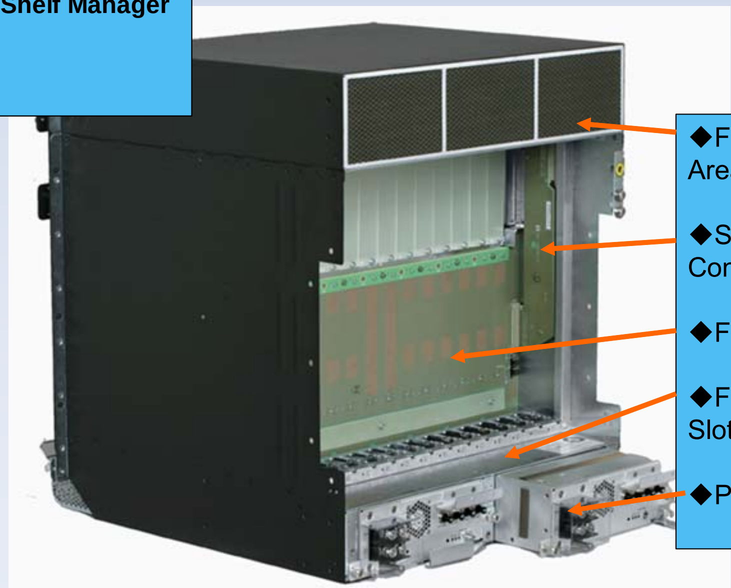
High Availability ATCA Platform

- 2 Control & 12 Applications slots
- Up to 200 W/module at 45ºC ambient, 2.8KW Shelf
- Redundant speed controlled DC fans

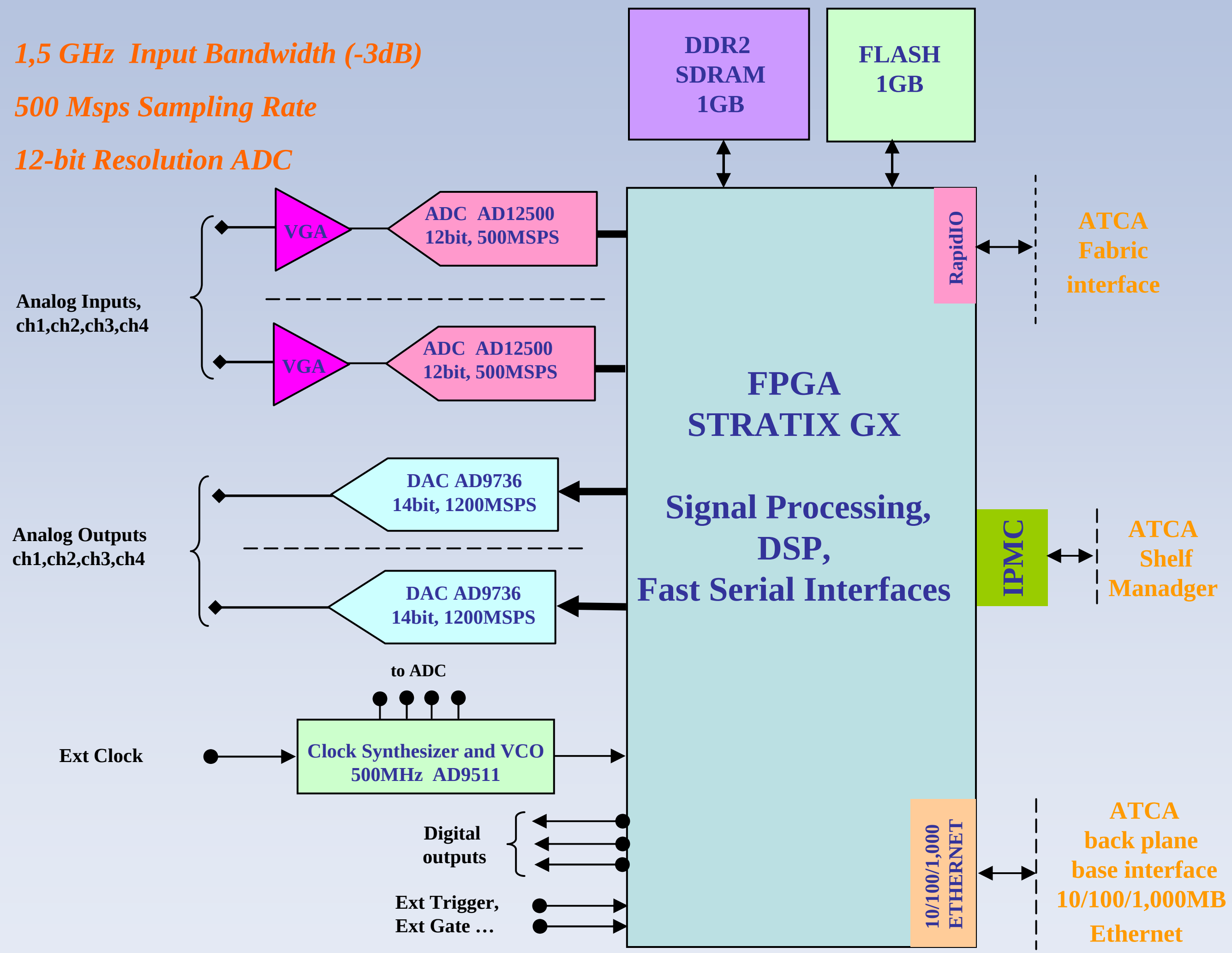


Mezzanine Card Option
3x7inch Hot Swappable
Up to 8/Mbrd

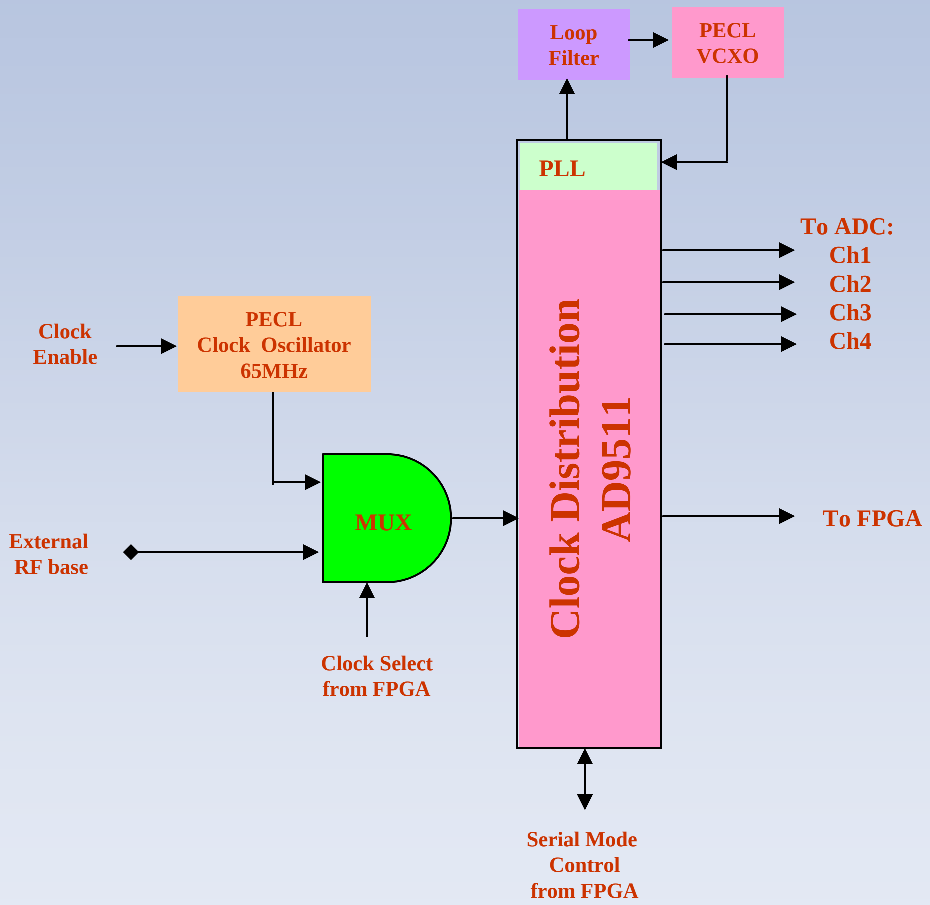




- ✓ *1,5 GHz Input Bandwidth (-3dB)*
- ✓ *500 Msps Sampling Rate*
- ✓ *12-bit Resolution ADC*



ILC Instrumentation Proposal 4 channels 12bit 500MHz DIGITIZER based on ATCA
A.Semenov

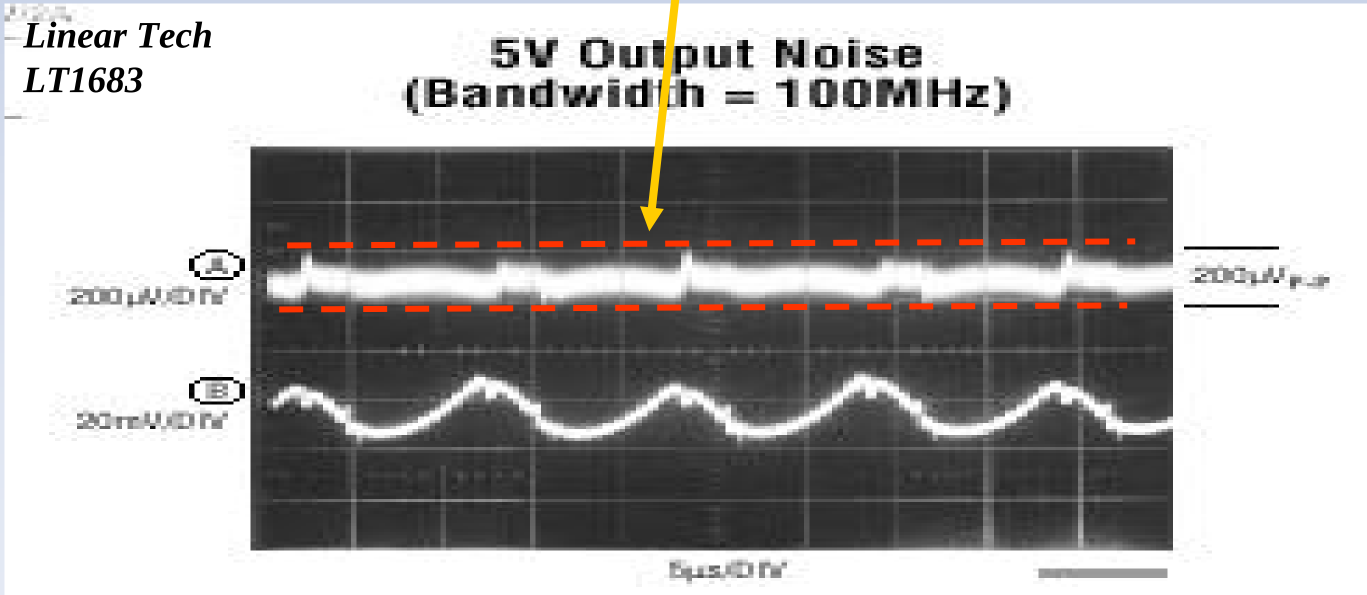


- ✓ *Low output jitter ~0.5 ps RMS*
- ✓ *Input reference frequencies to 250MHz*
- ✓ *1.2 GHz clock distribution*
- ✓ *Programmable divider for each output*
- ✓ *Fine delay adjust for one LVDS output*
- ✓ *Serial mode control port*

How to reduce EMI from ATCA – 48V DC-DC Power Converters?

- ✓ *Slew Rate Controlled MOSFET Switches?!*

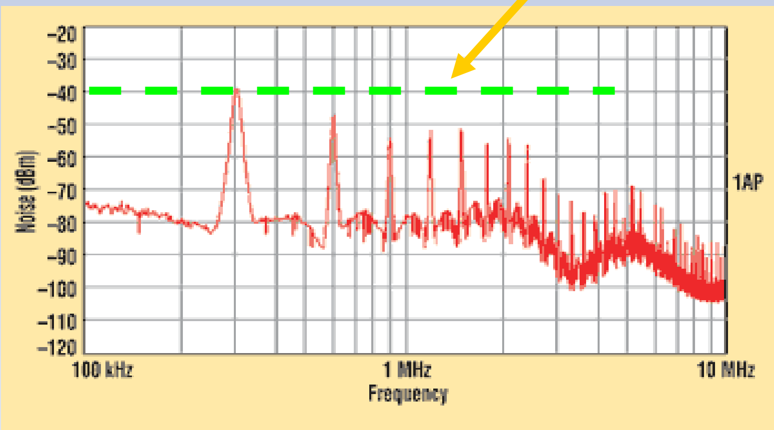
40 dB reduction
~ 200µV !

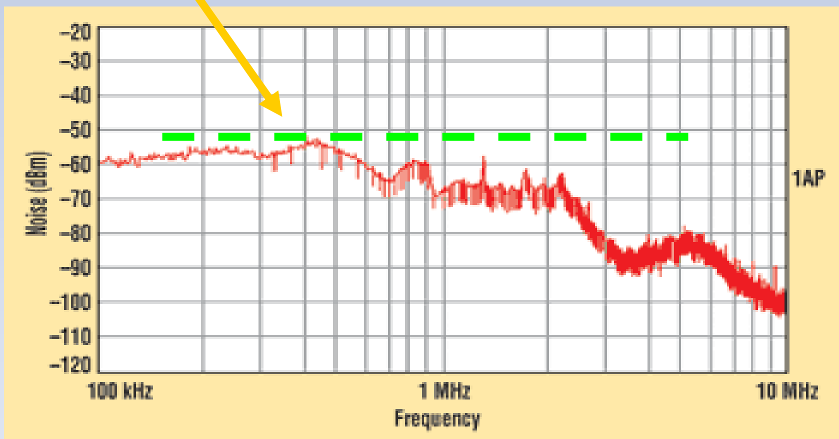


How to reduce EMI from ATCA – 48V DC-DC Power Converters?

✓ *Spread-Spectrum Clock for DC-DC ?!*

40 dBm vs 55 dBm





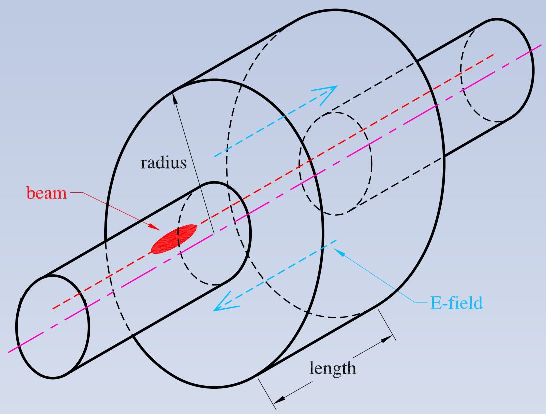
Output spectra demonstrate that a conventional fixed-frequency clock produces considerably more noise than does the spread-spectrum technique.

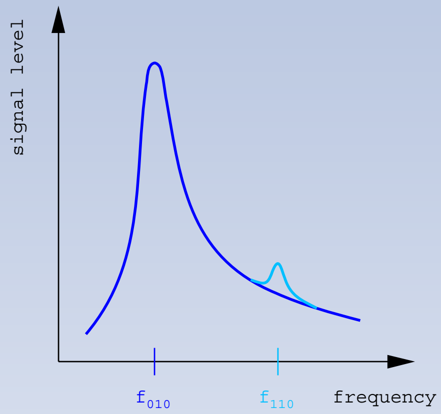
➢ ***In General Spread-Spectrum Technique for the Digitizer Reference Clock could also help to reduce EMI up to 20 dB…***

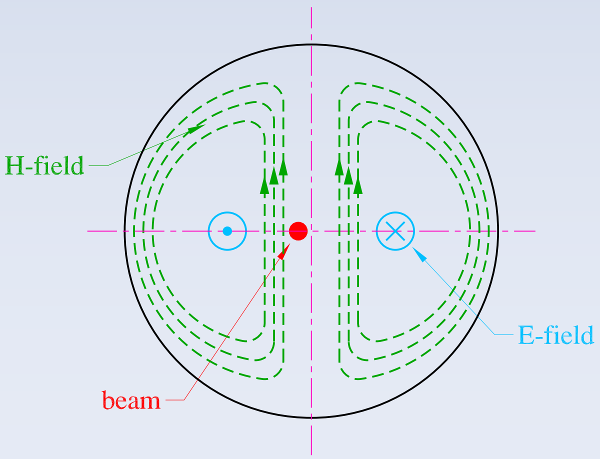
Cold BPM Requirements and Issues

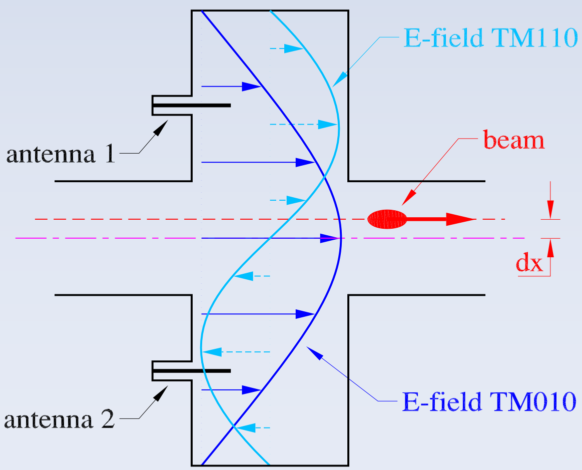
- BPM location in the cryostat, at the SC-quad
  - Real estate: ~ 170 mm length, 78 mm beam pipe diameter.
  - Cryogenic environment (~ 4 K)
  - Cleanroom class 100 certification (SC-cavities nearby!)
  - UHV certification
- < 1 μm single bunch resolution,
  i.e. measurement (integration) time < 300 ns.
- < 200 μm error between electrical BPM center and magnetic center of the quad.
- Related issues:
  - RF signal feedthroughs.
  - Cabling in the cryostat
  - Read-out System

Cold Cavity BPM Development









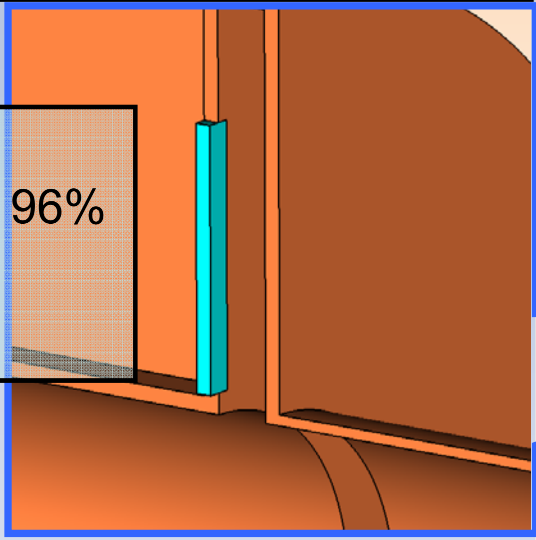
Problems with simple "Pill-Box" Cavity BPM's

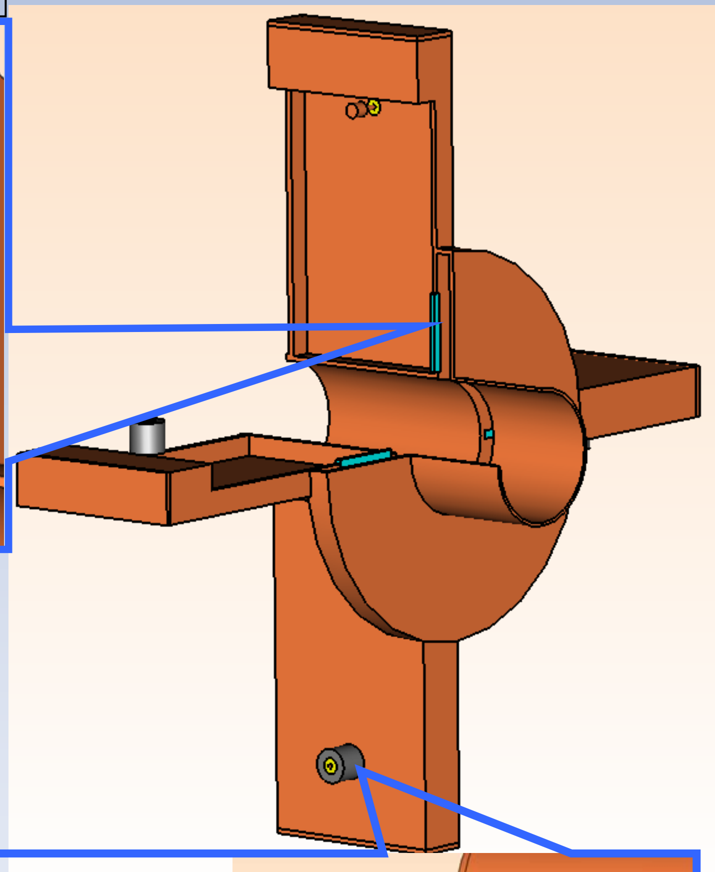
- TM_{010} monopole common mode (CM)
- Cross-talk (xy-axes, polarization)
- Transient response (single-bunch measurements)
- Wake-potential (heat-load, BBU)
- Cryogenic and cleanroom requirements

- Waveguide-loaded pillbox with slot coupling.
- Dimensioning for f_{010} and f_{110} symmetric to f_{RF},
  f_{RF} = 1.3 GHz, $f_{010} \approx$ 1.1 GHz, $f_{110} \approx$ 1.5 GHz.
- Dipole- and monopole ports, no reference cavity for intensity signal normalization and signal phase (sign).
- $Q_{load} \approx 600$
  (~ 10 % cross-talk at 300 ns bunch-to-bunch spacing).
- Minimization of the X-Y cross-talk (isolation).
- Simple (cleanable) mechanics.
- Iteration of EM-simulations for optimizing all dimensions.
- Vacuum/cryo tests of the ceramic slot window.
- Copper model for bench measurements.

Ceramic windows in coupling slots

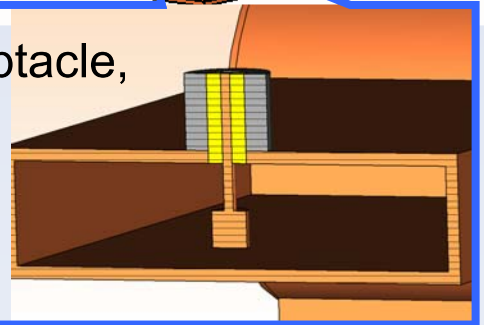
Window –
Ceramic brick of alumina 96%
$\varepsilon_r \approx 9.4$
Size: the same as slot

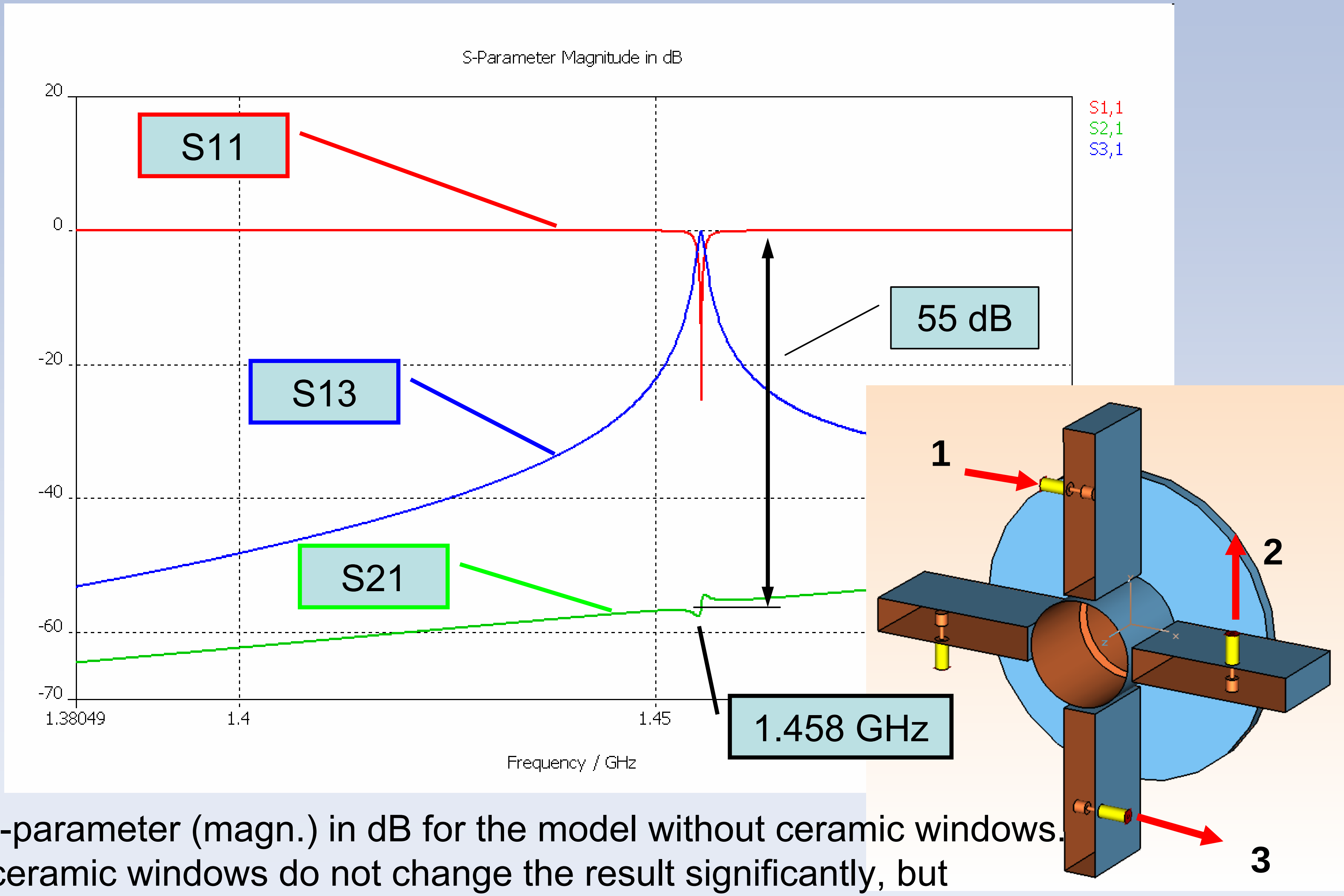




Frequency, GHz	1.46
Loaded Q	~ 600
Beam pipe radius, mm	39
Cell radius, mm	114
Cell gap, mm	10
Waveguide, mm	122x110x25
Coupling slot, mm	47x5x3

N type receptacle,
50 Ohm,
D=9.75 mm
d=3.05 mm

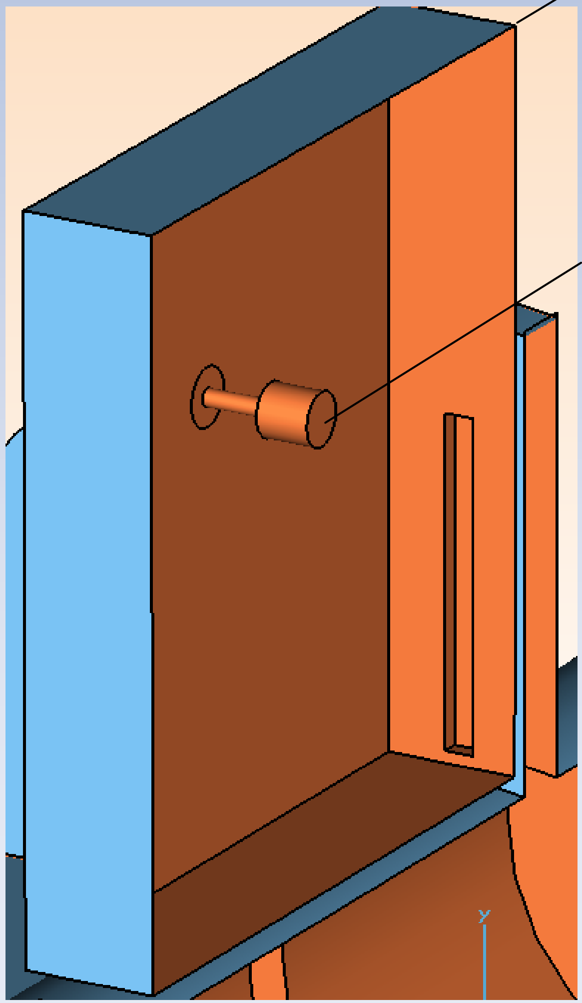




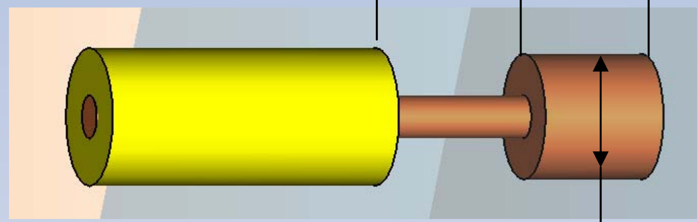
S-parameter (magn.) in dB for the model without ceramic windows.
(ceramic windows do not change the result significantly, but increase MWS’s simulation time much)

Pick-up dimensions

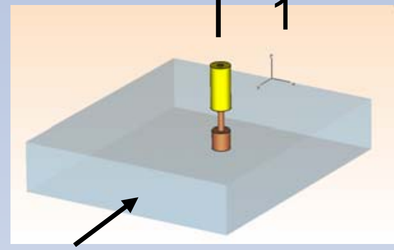
47.03.mm

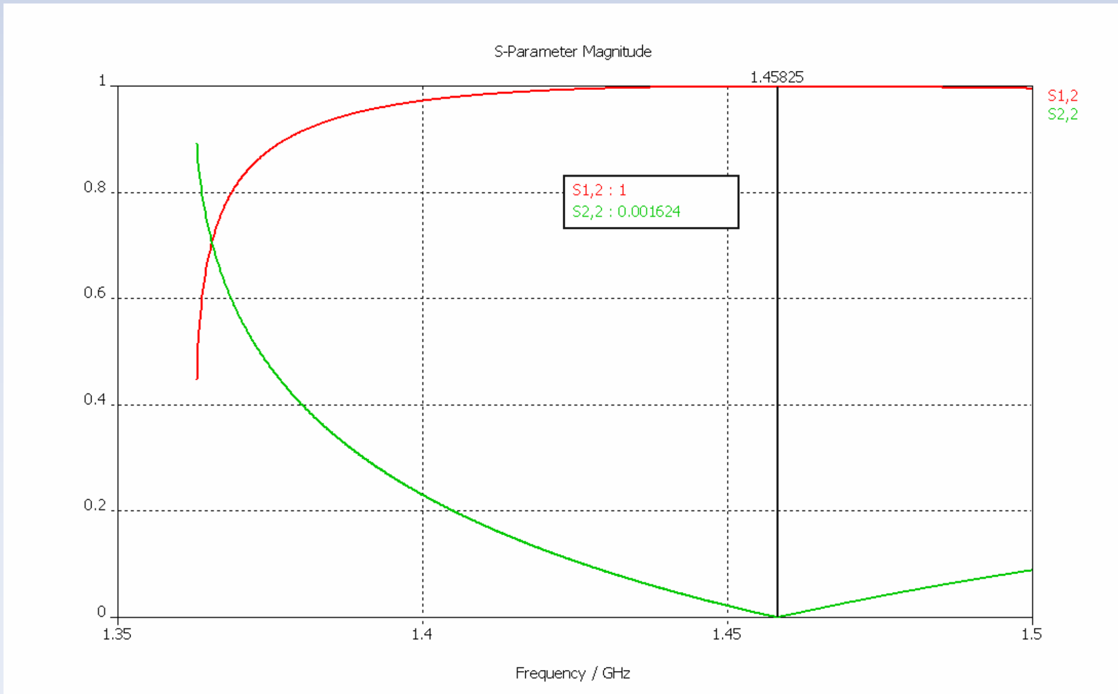


11.13 mm 8.9 mm



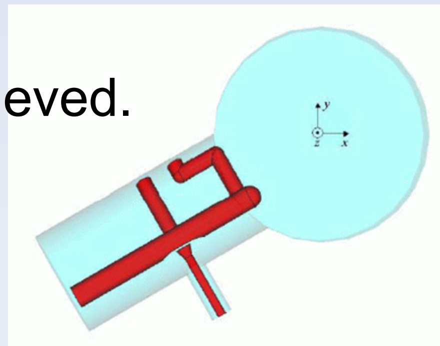
Diam. 4.46 mm

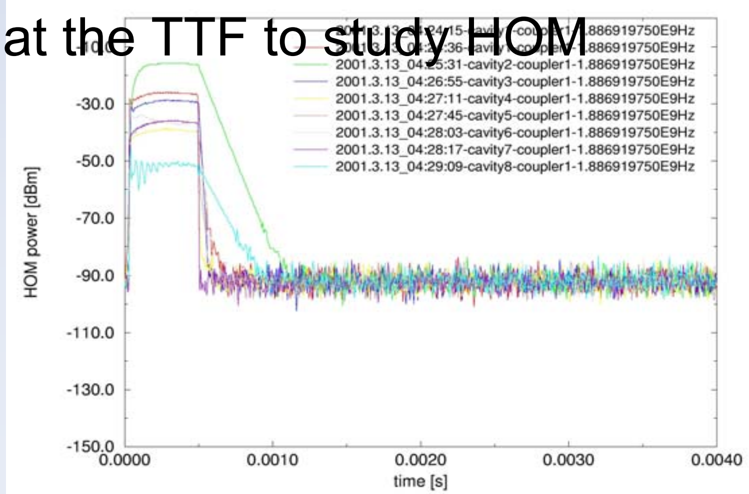




Accelerating Cavity HOM Coupler Signals

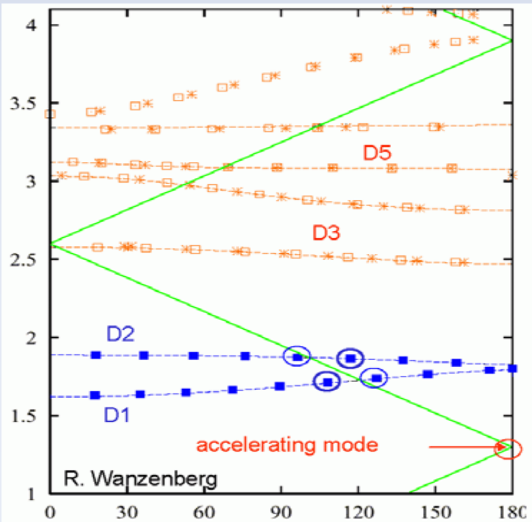
- In addition to the fundamental accelerating mode, superconducting cavities support additional higher frequency modes, e.g. beam excited
  - Monopole modes: Sensitive to beam intensity
  - Dipole modes: Sensitive to beam intensity x beam displacement
- The SC cavities in the Tesla Test Facility (DESY), (and the proposed ILC) are equipped with couplers to damp higher order modes
  - Each cavity has 2 couplers, one at each end, at a relative angle of 115 deg.
  - The signals from these couplers can provide information on the cavity shapes (non-uniformity), and on the beam orbit through the cavity (misalignment).
- There have been several experimental runs at the TTF to study HOM signals produced by single bunch beam.
- A position resolution of 1…10 ❍m could be achieved.

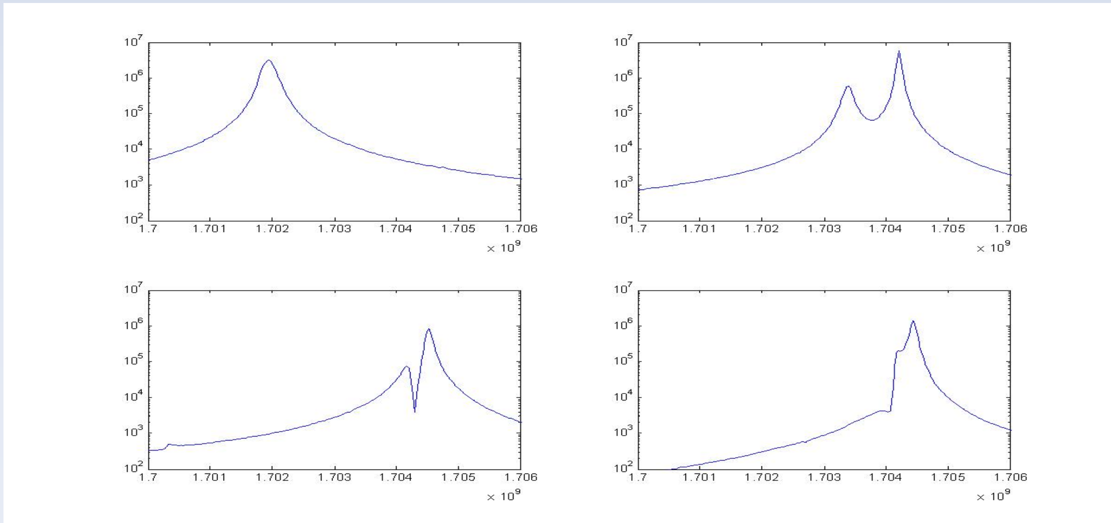




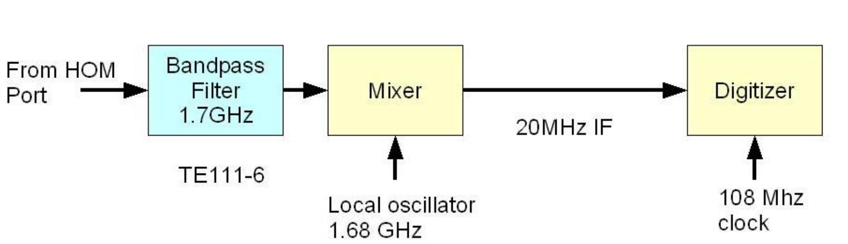
Which Dipole Mode for Analysis?

- Near "speed of light" modes have strongest coupling: $TE_{111\_6,7}$, $TM_{110\_4,5}$
- For the HOM analysis, the TE_{111_6} as mode was selected
  - This is approximately the strongest mode
- Dipole modes have 2 orthogonal polarizations. For some modes, the separation is less than a line width, and the modes must be distinguished by the relative signals at the 2 couplers.
- The modes are unique to each individual cavity

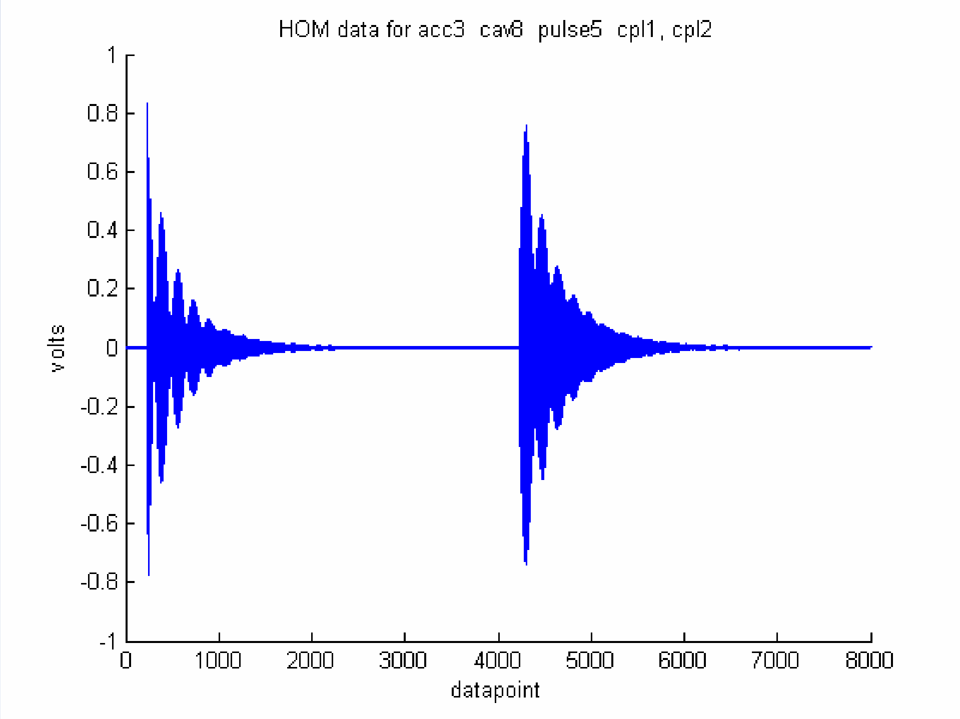




HOM Signal Processing (SLAC)



- Custom electronics are used to filter and downmix the HOM signals which are then digitized at 108Mhz



- The graphs shows the raw digitized coupler output from a single bunch pulse

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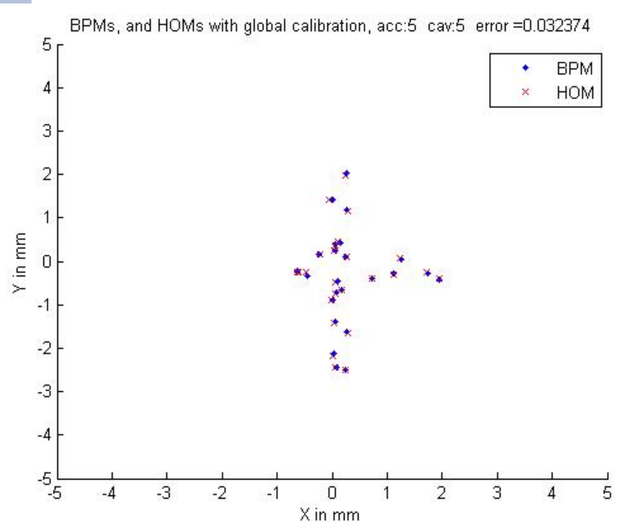
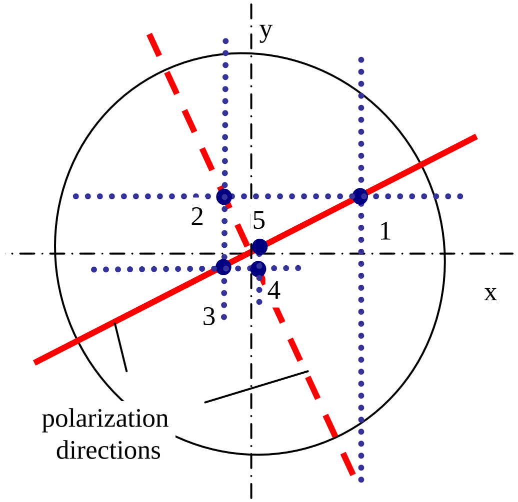
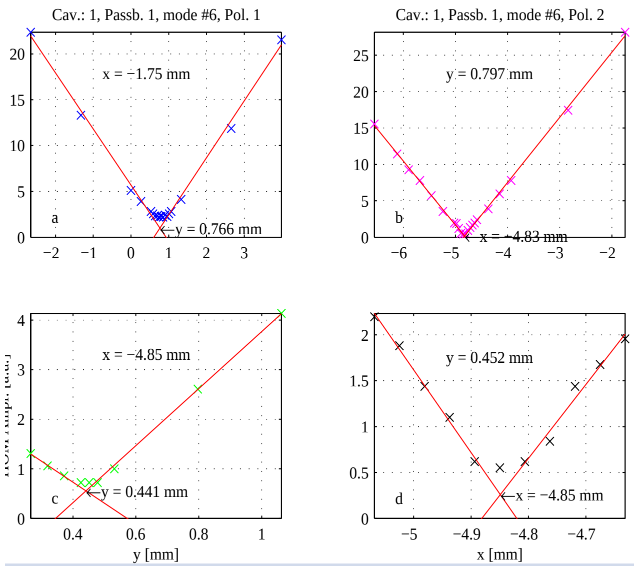
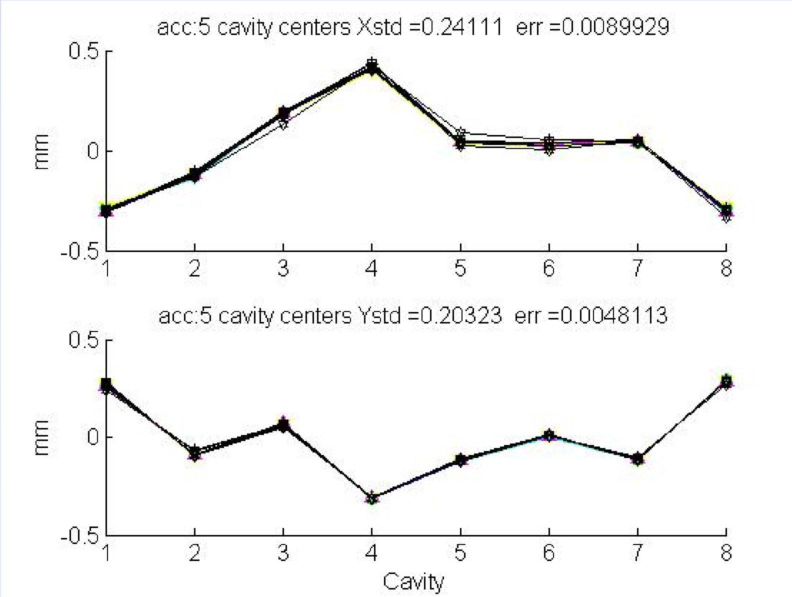








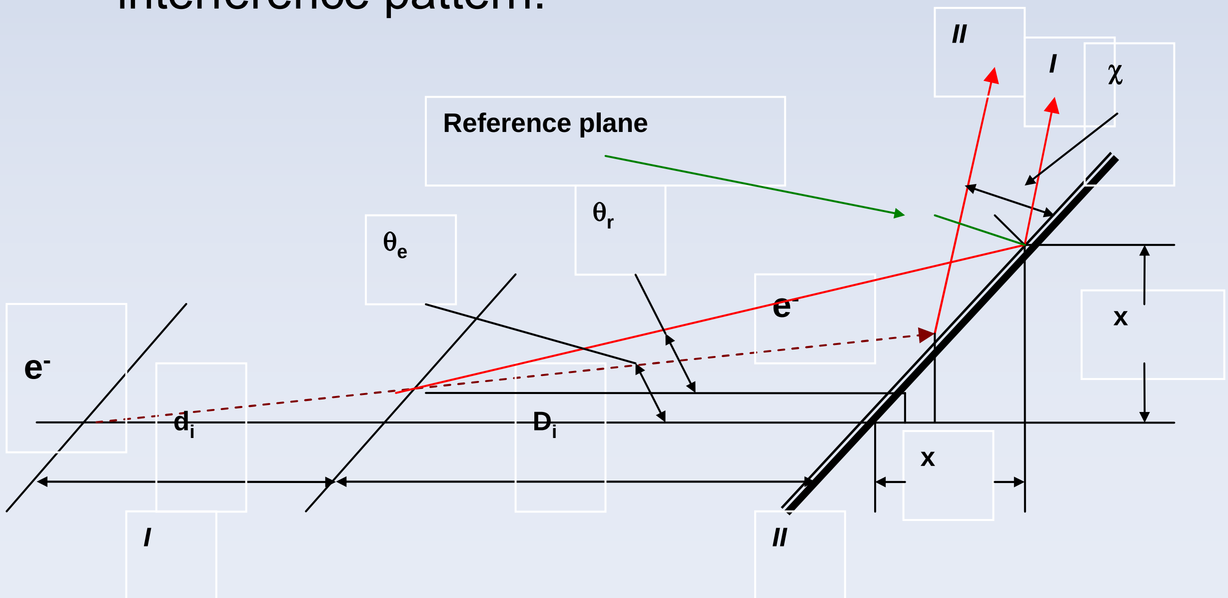
- After calibrating the HOM signals against the BPM signals, the HOMs provide beam position information at each cavity.
- This can be used to provide relative alignment data on each cavity within a cryomodule!

Fermilab HOM Activities

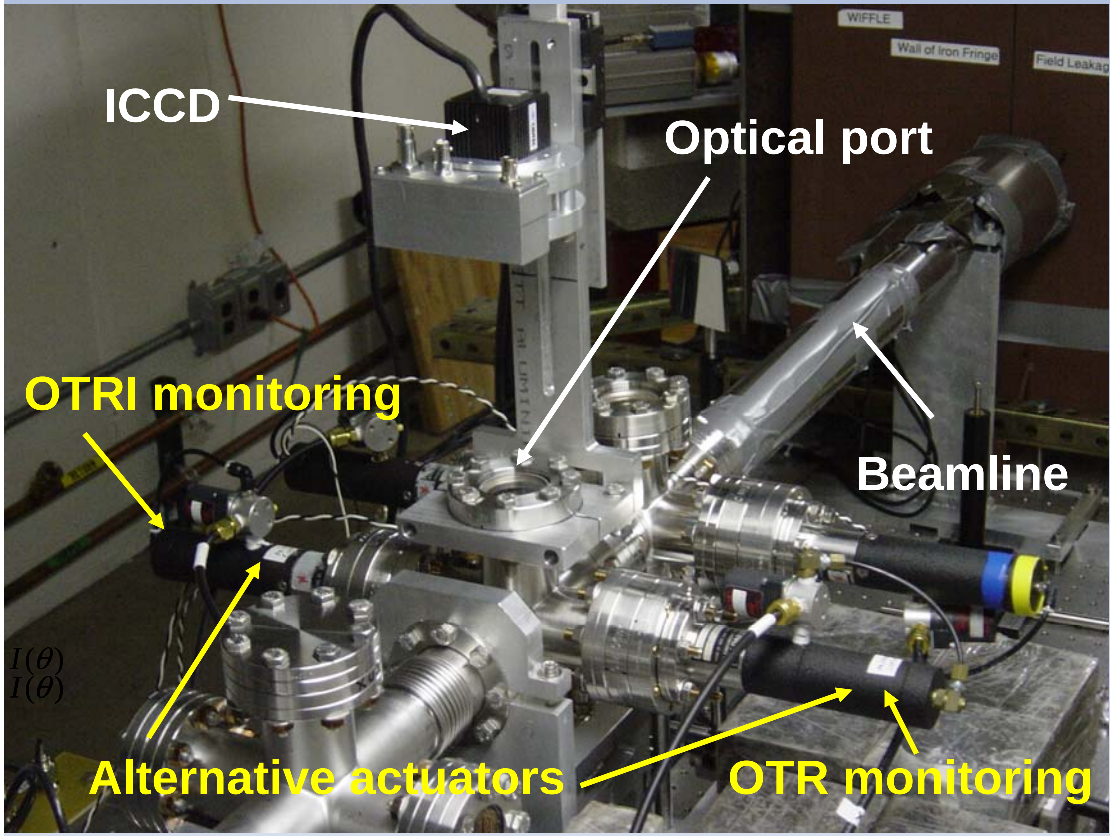
- Involved in several software projects
  - DAQ software to collect calibration data
    - Requires sweeping beam in x, x’, y, y’ at each cavity
  - Offline software to analyze data using SVD and determine calibration for each cavity
- Developing FPGA based calibration implementation in the front-end using custom digitizer board developed at FNAL
  - Plan to test implementation during August study

Optical Transition Radiation Interferometry

- Charged particles passing through the boundary of two medias of different ϵ_r (dielectric permeability) generate Transition Radiation (TR).
- Relativistic particles generate a broad TR spectrum, ranging into the optical spectrum (OTR). OTR monitors are used for transverse beam profile measurements.
- A beam passing two thin foils, allows the measurement of additional beam parameters (energy, energy spread, angles), derived from the OTR interference pattern.



OTRI setup with 45^0 inclination of the mica films to the beam axis. Thickness of the first film is magnified; the second film is mirror-reflecting; d is the film thickness, D is distance between films.



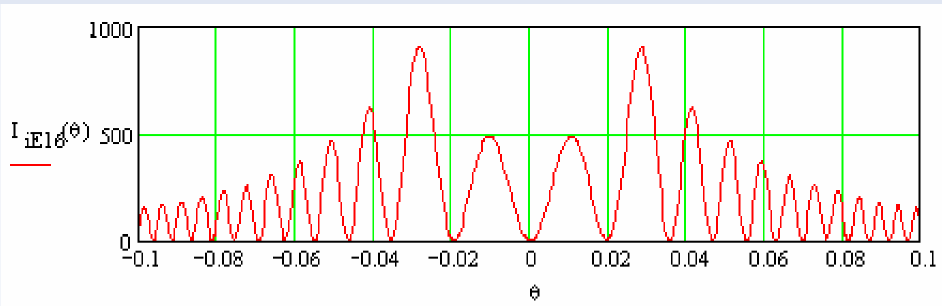
OTRI setup mounted on the Photoinjector beamline

For such setup the main contributions in the interference pattern give the forward OTR wave generated on ***I*** (transparent) film and the backward OTR wave generated on the ***II*** (mirror-reflecting) film. Intensity in each wave is proportional to $I(\theta)$.

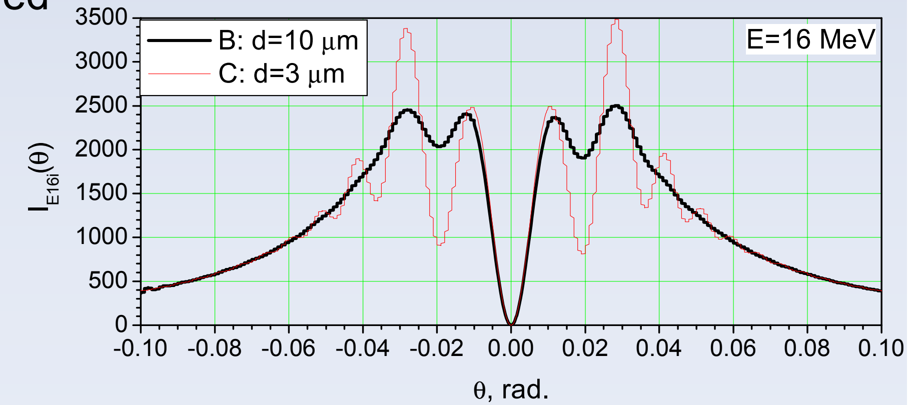
Here: $I(\theta) \sim \dfrac{\sin^2(\theta)}{\left[1-\beta^2\cos^2(\theta)\right]^2}$

Simulation of the interference pattern in wide energy range was done for A0 Photoinjector and R&D ILC program.

Calculated interference pattern profile for non scattered electrons having energy of 16 MeV at λ = 0.632 μm, d=10 μm, D= 1 mm is shown in following figure:



Calculated interference pattern for the beam energy of 16 MeV considering scattering of the beam in the foil at the wavelength of 0.632 μm ± 0.005 μm is presented below:



ILC-related instrumentation at NIU: overview

The Beam Physics and Astrophysics Group (BGAP) is currently building an in-house lab for multiple purposes, in particular to develop and test charged-particle diagnostics.

The lab will incorporate a ~5 MeV e- source from ANL and eventually the e- beam will be accelerated to higher energy. The beam will be used to do preliminary test before testing the diagnostics elsewhere (e.g. FNAL or ANL).

Current status (June 2006):

•Remodeling of first laser room (including new AC temp. control) finished and fs laser Ti:Sapphire + optics expected by the end of this month

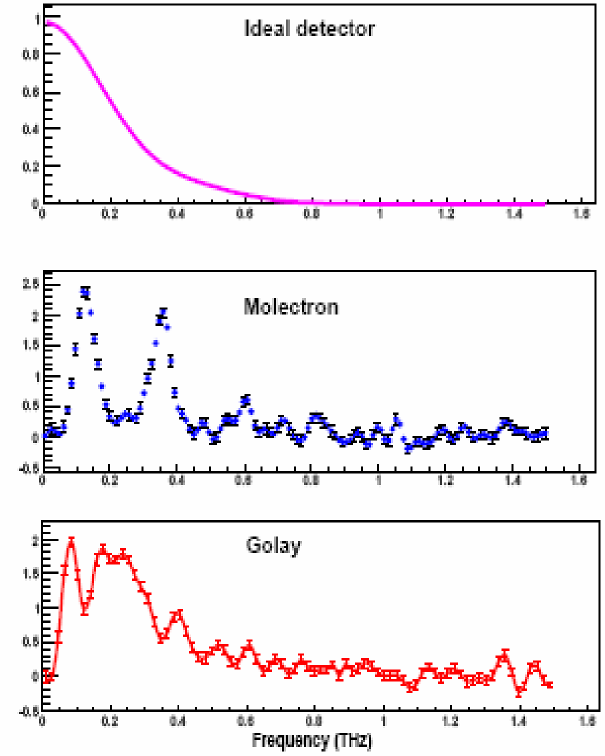
•The Ti:Sapphire laser will be used this summer to produce THz radiation via optical rectification.

Bunch length measurements/monitors

•At FNPL, NIU-team has worked on trying to understand limitation of CTR-based bunch length measurement for sub-mm bunchlength (comparable to ILC)

•Currently developing a new technique to measure and correct the response function of the CTR interferometer used at FNPL using a THz beam at NIU

Sub-mm wavelength Response of various detector



•Next step is a single shot bunch monitor (that measures the spectrum of the coherent radiation being emitted)

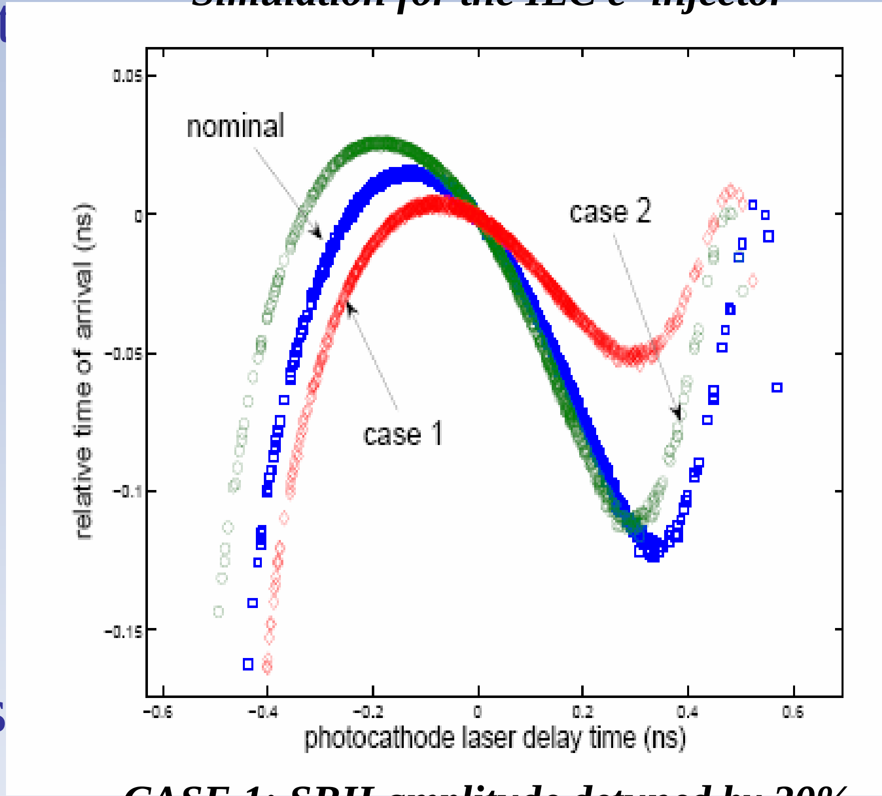
Phase map pattern-recognition for e-/e+ ILC injectors (NIU-ANL-FNAL collaboration)

•Based on an method developed at CEBAF accelerator (Krafft *et al.*)

•Modulation of certain system impact the time of flight in different ways

•A measurement of longitudinal transfer map might indicate what parameter in the bunching process is detuned

Simulation for the ILC e- injector



CASE 1: SBH amplitude detuned by 20%
CASE2: phase of SBH drifted by 20 deg

•Applicable for tuning/monitoring the longitudinal dynamics of both e- and e+ injectors

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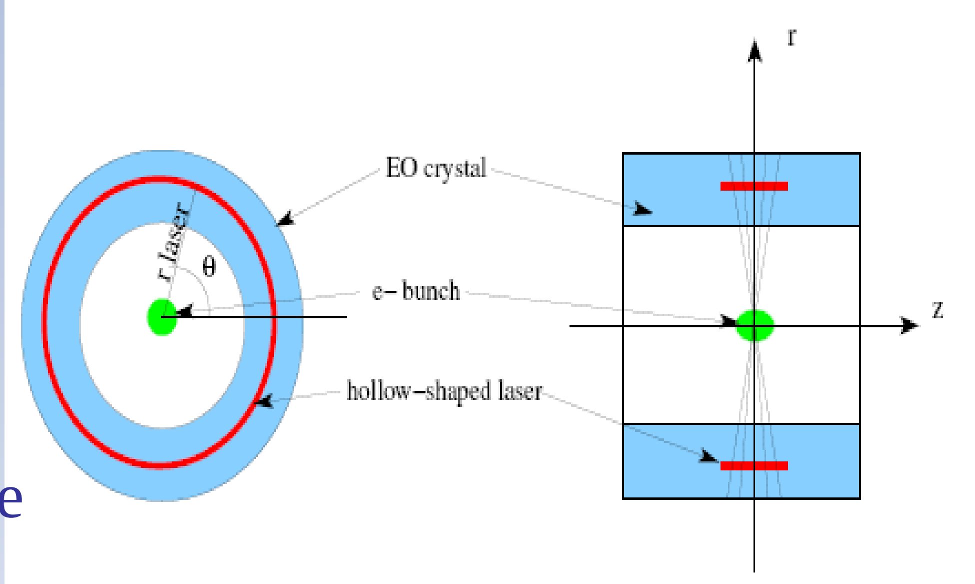
Time-transverse correlation monitor for e-/e+ linacs (NIU-ANL collaboration)

•Based on electro-optical effect.

•First version will be an optical equivalent of an electromagnetic beam position monitor.

•Basic idea is to measure both the time and radial dependence of the radial E-field associated to the moving bunch.

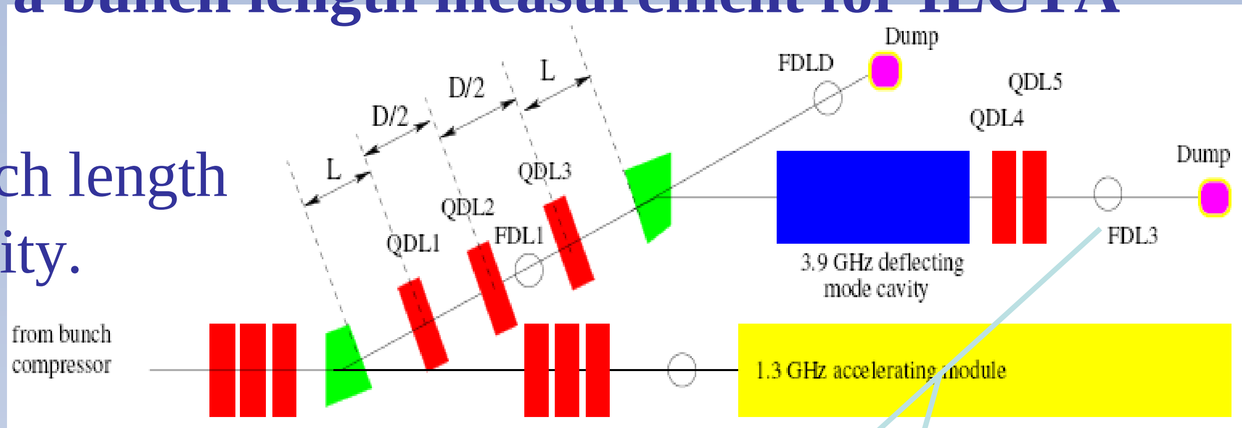


Concept for the EO sampling measurement of correlation between time and transverse position

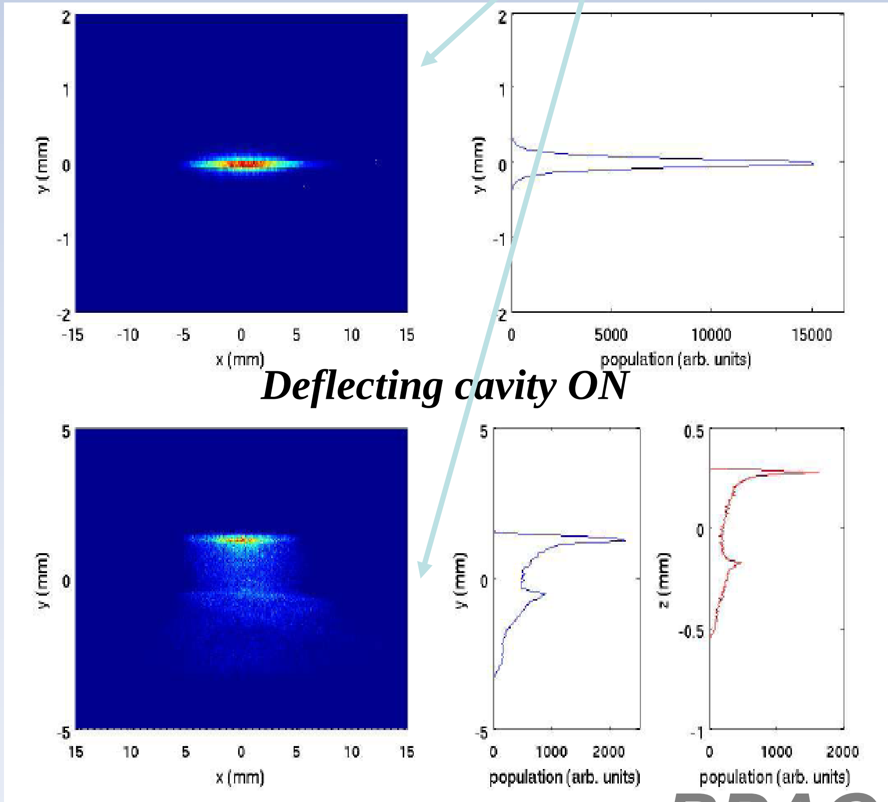
•This monitor should be helpful in diagnosing/curing "banana effects" in e-/e+ bunches. Could in principle work at any energy and is non interceptive.

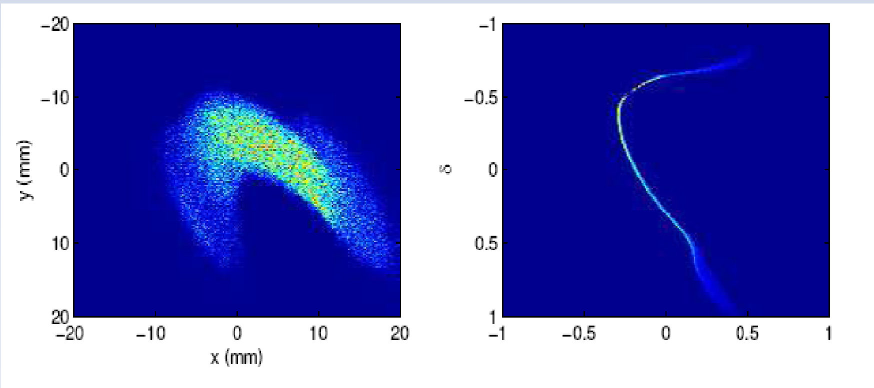
Simulation/design of a bunch length measurement for ILCTA

- Measurement of bunch length using a deflecting cavity.
- Longitudinal phase space correlation measurement
- Slice emittance measurement



Deflecting cavity OFF





Left: beam sport on FDL3 with dispersion
Right: initial longitudinal phase space

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