SLAC Proposal for PX RF Systems

Chris Adolphsen

SLAC Interests in PX L-band RF System

- Modulator charging supply – develop 80% main for multiple modulators plus 20% individual supplies
- Modulators – Marx alternative and baseline modifications
- Klystrons – Multi-beam klystron long-term testing (Toshiba, CPI, ..) and sheet beam and other alternatives
- RF Distribution System – adapt version being developed for NML cryomodules
- Intra-pulse amplitude and phase shifter – develop less expensive version
- LLRF – develop control algorithms based on FLASH experience (but probably not hardware)
- Couplers – see earlier talk

XFEL High Power RF Status

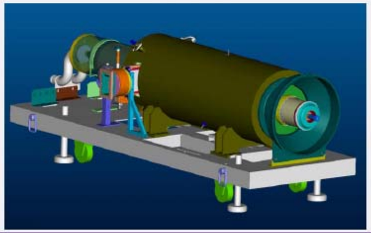
S. Choroba

RF High Power Source

Horizontal MBK prototypes

- Horizontal versions of MBKs by all 3 vendors are under construction (THALES, TOSHIBA, CPI)
- First klystron has been tested at DESY (Toshiba, December 07 to February 08)

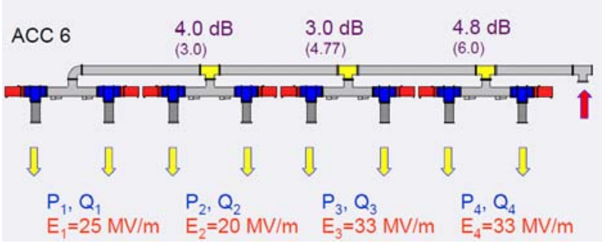
THALES TH1802



TOSHIBA E3736H

- #6 passed acceptance test at Thales, passed acceptance test at DESY
- (10MW, η=61%)
- #7 passed acceptance test at Thales, passed acceptance test at DESY
- (10.5MW on matched load, η=62%)

- 1 TOSHIBA E3736 at DESY
  - 10.4MW, 1.5ms, 10Hz, 66%
  - 750h, ~80% at full power
  - will be used at the modulator test stand in Zeuthen

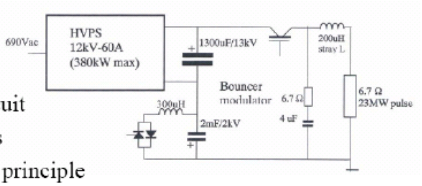


Modulator

Qualification of additional vendors

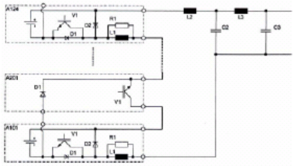
Bouncer Modulator by Imtech/Vonk

- Bouncer Type, as specified by DESY
  - 12kV HVPS
  - Bouncer 300uH/4.6kA
- 7st IGCT main switch
- Digital Regulation Circuit
- Analog In- and Outputs
- Well known and tested principle
- delivery time: 12 month

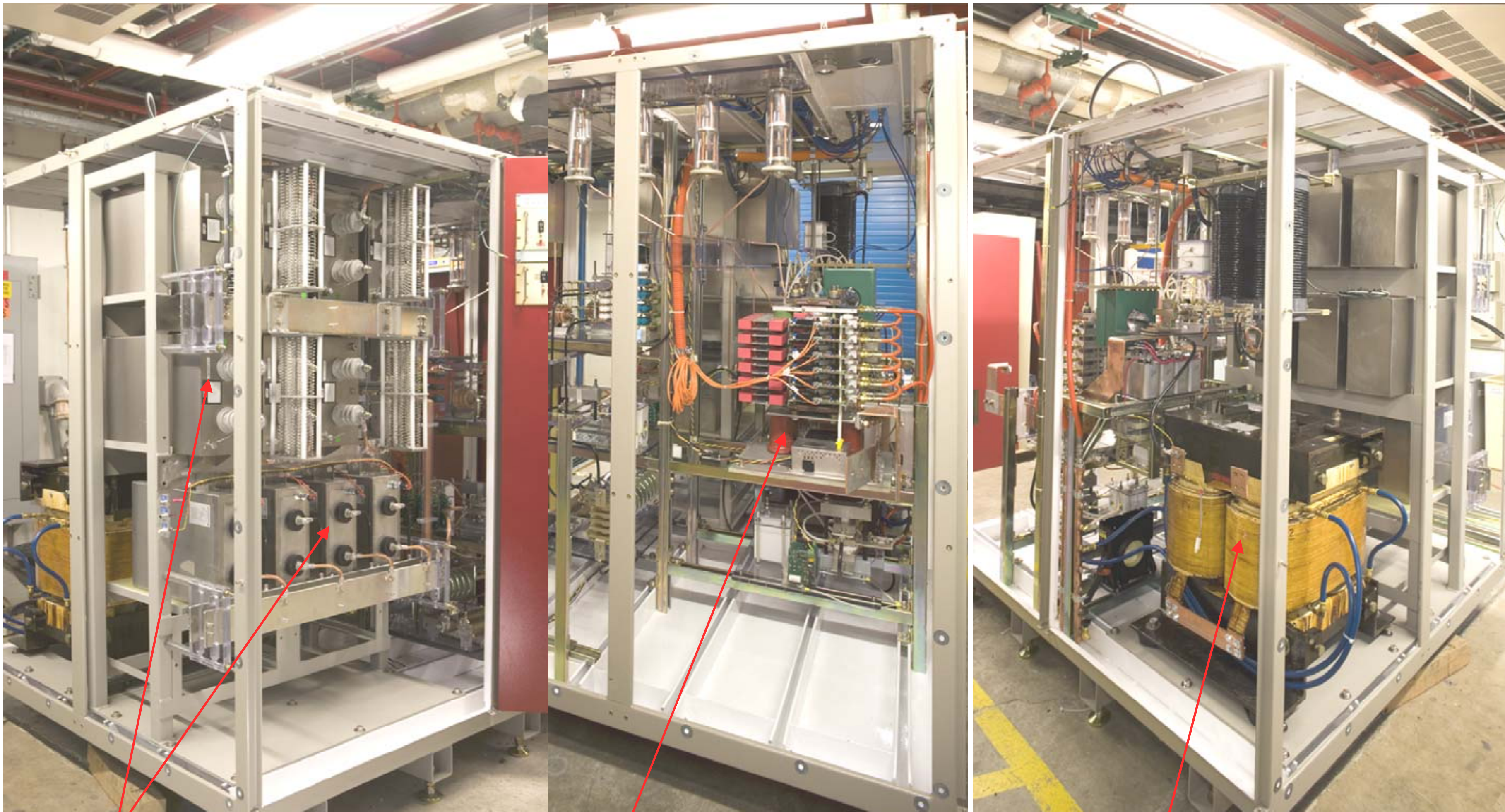


PSM Modulator by Thomson BM

- Different Type:
  - 12kV/2kA w. transformer
  - Pulse Width Modulation
  - 24 switching stages in series
  - FPGA based control
  - 2 stages for redundancy
- Slew rate and pulse shape controllable
- detailed description available, principle already successfully tested (worldwide, i.e. W7/X)
- delivery time: 14 month



FNAL Pulse Transformer Modulator Layout



Capacitor Banks

NEW! IGBT Redundant Switch

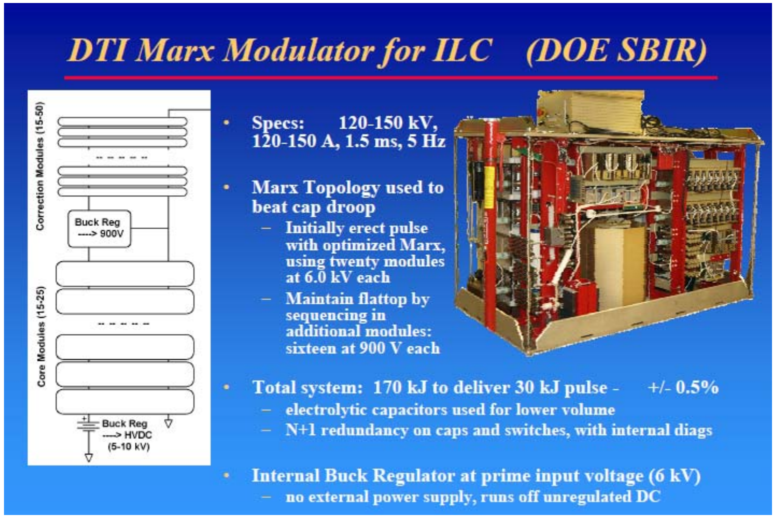
Bouncer Choke

Development Status of the ILC Marx Modulator

Craig Burkhart

P1-Marx Status

- Developmental Testing in B015 Completed
  - Operational Testing
    - Full voltage (120 kV), current (140 A) and pulse length (1.6 mS) witl coarse flattening
    - Full PRF (5 Hz)
    - Near full power (135 kW), load limit ~100 kW, HVPS limit ~120 kW
    - Several shifts without intervention
  - Arc-down Testing (Simulated Klystron Arc)
  - Integrated into “Sealed” Enclosure
- Install in L-Band Test Station in ESB for Extended Life Tests
  - Marx Control System Upgrades: EPICS interface
  - L-band Test Stand Interlocks and Control
- Improve Output Voltage Regulation to ±0.5%
  - Vernier Regulator



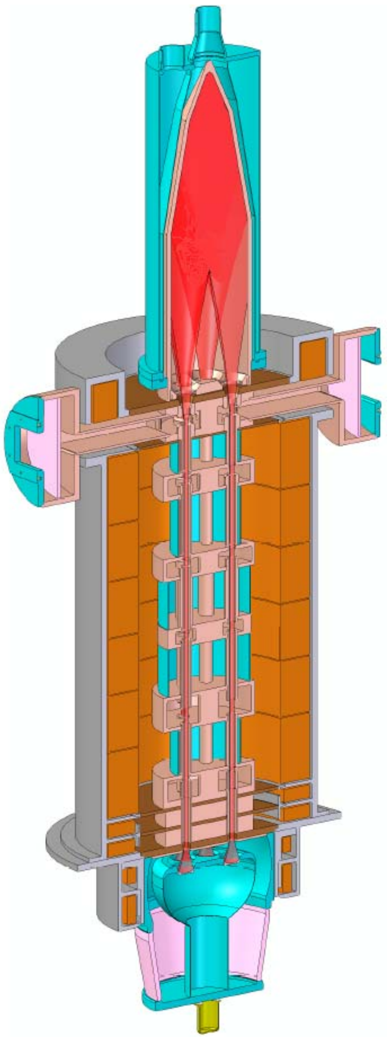
Normal Operational Testing

- Coarse Pulse Flattening
  - 16 Cells: 11 prompt, 5 delayed
  - 0.86 kΩ water load
- Efficiency Measurement
  - Total power efficiency: 97%
  - Usable (RF) efficiency: 92%

Marx Program Status Summary

- SLAC P1-Marx
  - Developmental Testing: Complete
  - Initial ESB Operation: 11/08
  - Integration into L-Band Station: Early ’09
  - Output Regulation (±0.5%): 3/09
- SBIRs
  - Complete ’09
  - Hardware to SLAC: FY10
- SLAC P2-Marx
  - Initial Design/Components Ordered: 12/09
  - 1st Cell Assembly & Testing: FY09-Q2&3
  - Multi-Cell Testing: FY09-Q4
  - Final Design/Components Ordered: FY10-Q1
  - Cell Assembly: FY10-Q2
  - Modulator Testing: FY10-Q3&Q4

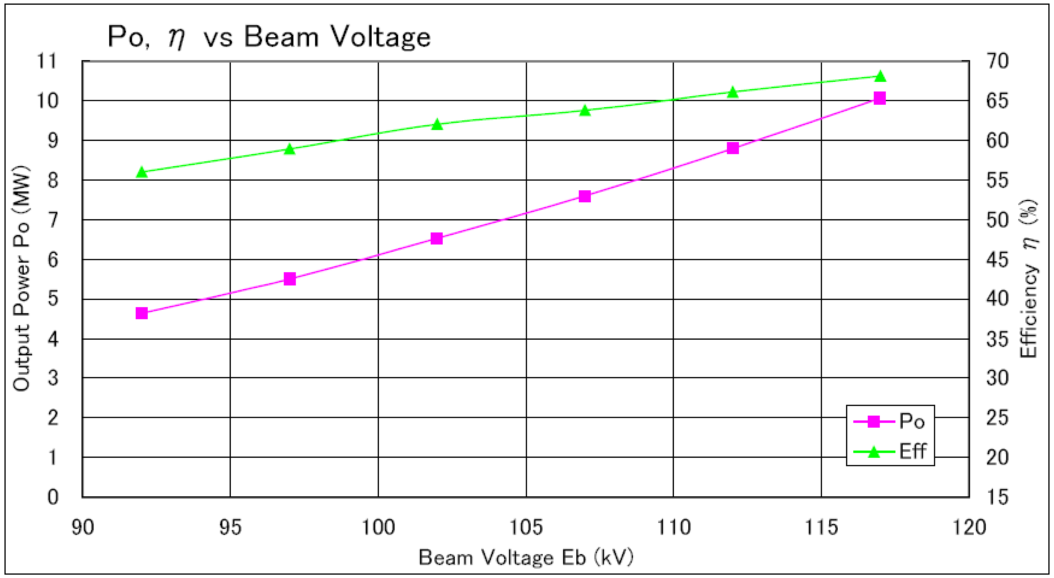
SLAC/KEK Toshiba 10 MW MBK

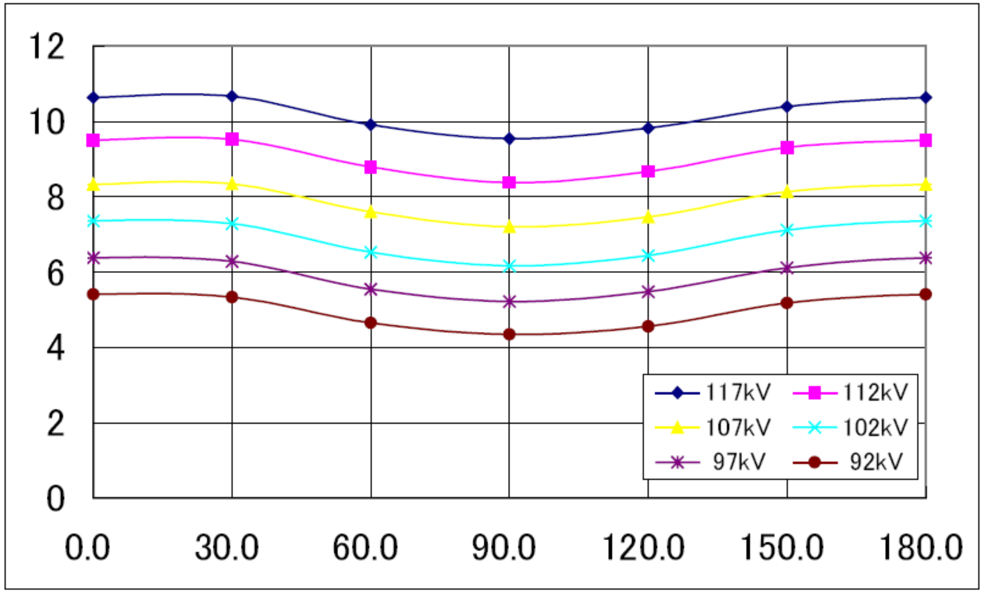


6-Beam
Gun

Test Results at Toshiba

Efficiency and Output Power -vs- Beam Voltage

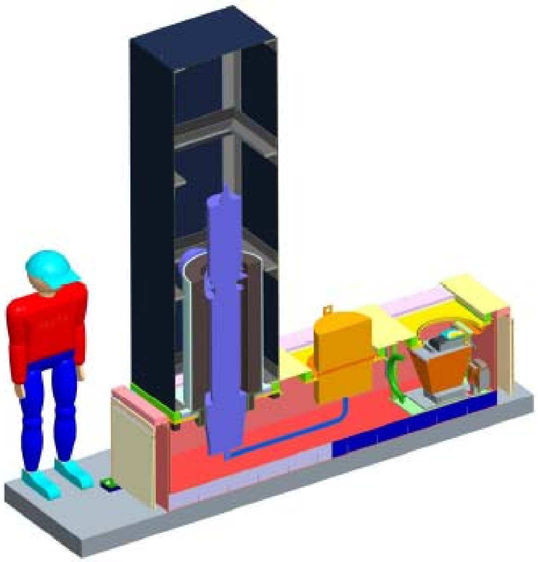


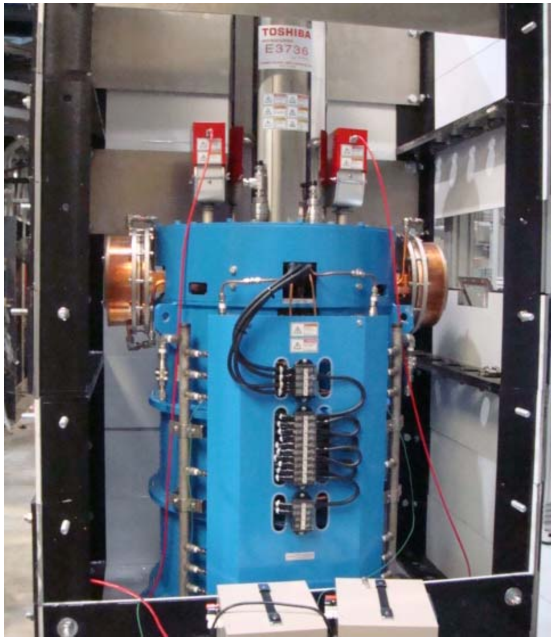


Effect of a Mismatch (VSWR = 1.2): Output Power -vs- Phase of Mismatch

New Station Nearing Completion

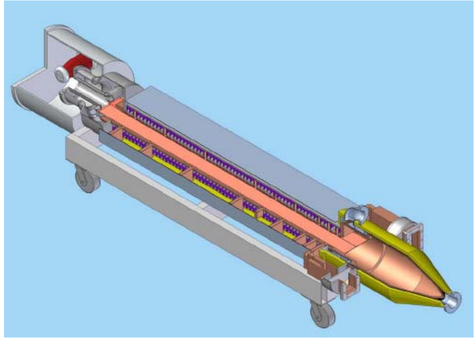
- In early 2009, the Marx Modulator will be used to power the 10 MW Toshiba MBK for long-term evaluation.
- Built oil tank to support the MBK, a water load, and a filament PS transformer.
- Water load can dissipate the full output power of the modulator in the absence of a klystron





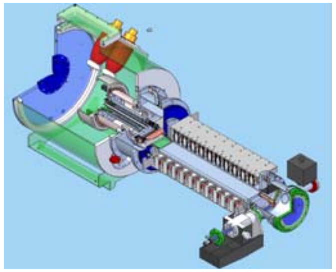
LSBK Development Status

Erik Jongewaard



LSBK Program Plan

- Build a flexible beam test diode to verify 3-D gun simulations.
  - Beam profile measurement capability for electrostatic and magnetic focusing cases
  - Modular design to allow quick modifications and component changes
- In parallel develop a klystron to be fabricated immediately after the beam test diode.



Beam, RF and Interaction Status

- Electron gun:
  - Simulations complete
- Beam Transport:
  - 3D magnetics design complete for diode
  - Klystron magnetics in progress
- RF circuit:
  - Cavity loading design complete
- RF-Beam Interaction:
  - TE mode discovered, studies underway for suppression

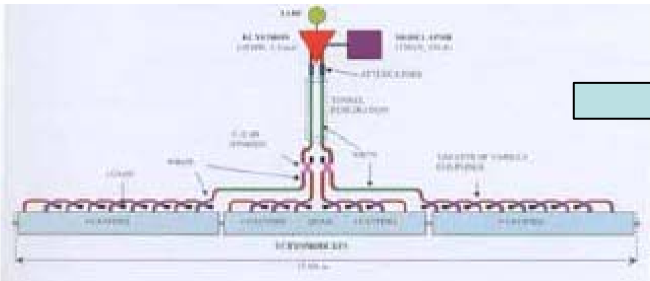
Mechanical Design Status

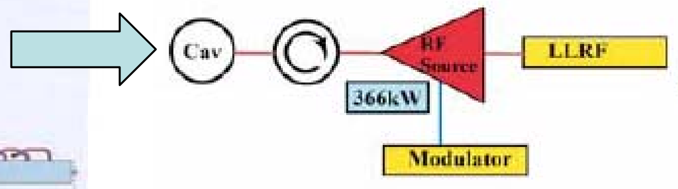
- Electron gun:
  - Three cathodes in house
  - FE machining in progress
  - Assembly beginning
- Anode assembly:
  - Brazed assemblies in final machining
- Beam diagnostic:
  - Sub assembly brazing complete
  - Assembly of vacuum chamber beginning
- Klystron design on hold for TE mode resolution

Distributed RF Source (DRFS) Scheme

One Klystron feeds power to a few cavities.

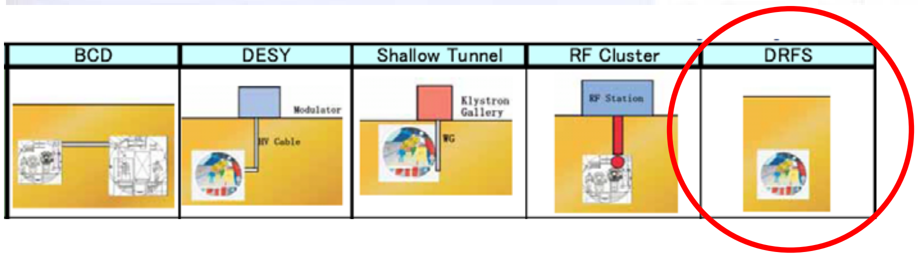
S Fukuda

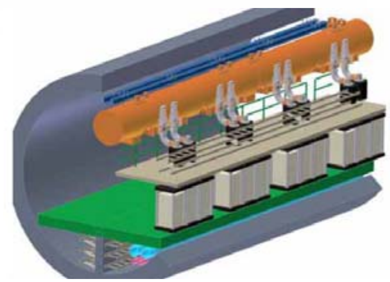


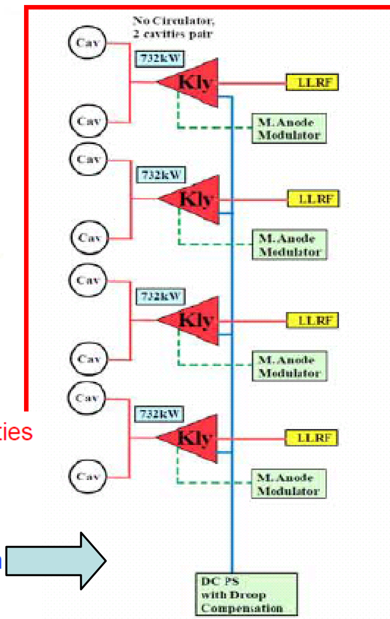


Total amount

X 26 X 650 =16900







There are several merits in DRFS.

- **Complete single tunnel scheme and simple configuration. (Cost benefit is expected)**
- **Klystron failure doesn't give a serious effect to beam operation since failures are scattered. (cf. BCD, RF Cluster)**
- **Adoption of MAK leads to the cheap HLRF system and introduction of power handling is possible for klystron.**
- **Direct connecting of about 60kV to klystron eliminates pulse transformer and use of huge insulation oil.**
- **LLRF control is easy and vector sum of 2 cavities are better than BCD plan.**
- **By coupling two cavities with same performance, circulators are possibly eliminated.**
- **There are lots of advantages for the operation and control.**

Likely Plan

- Circulator elimination by power feeding to 2 cavities from one klystron. Output power is 732kW.
- Modulated Anode Klystron (MAK) is adopted.
- Anode modulation pulser does not need the high power and cost efficient pulser is manufactured.
- DC Power Supply is common for 26 cavities and voltage drop during the pulse is compensated with appropriate circuits at the level that LLRF can feed back.

Cost estimates being made

HLRF Interlock Module and ATCA* Platform R&D Plan

Ray Larsen

Summary Status & Plans

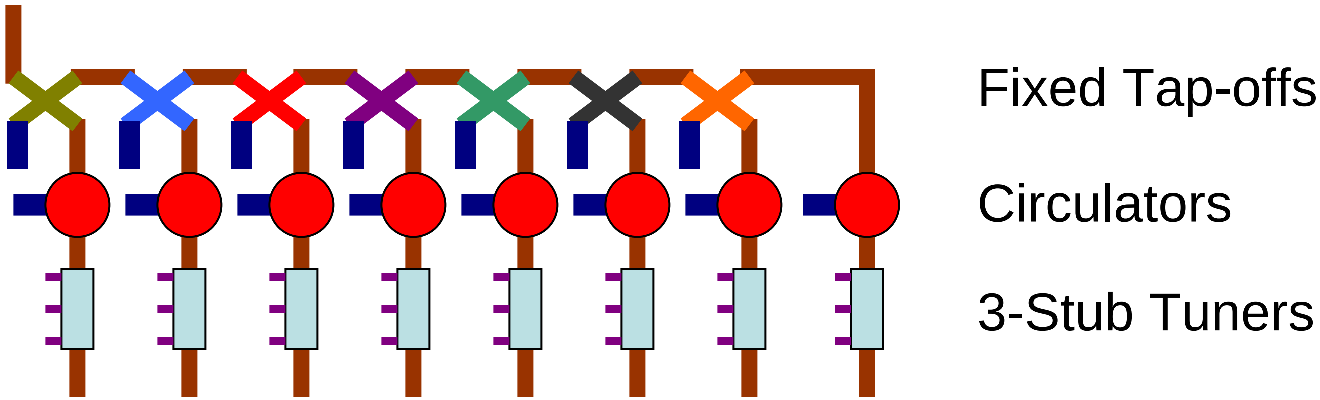
- VME Interlock System
  - F3 FPGA based test stand interlock system in test, hardware installation continuing, interlock software nearing completion
- VME-ATCA Adapter
  - Board loading underway; will need IPMI, driver software development to complete
  - Reference design for future AMC carrier board
  - Future: Implement ATCA adapter version of test stand interlocks
- AMC's in MicroTCA promising for future controls upgrade
  - Commercial AMC, IP products can perform most SLAC linac controls functions
  - Collaborating with DESY to get fast ADC Firmware
  - Plan initial experimental tests in FY 09
- *Future:*
  - *Port controls designs directly to generic AMC FPGA modules with front-end plug-in options*
  - *optimize use of xTCA infrastructure over more payload modules*

**Advanced Telecom Computing Architecture*

Fast Fault Finder

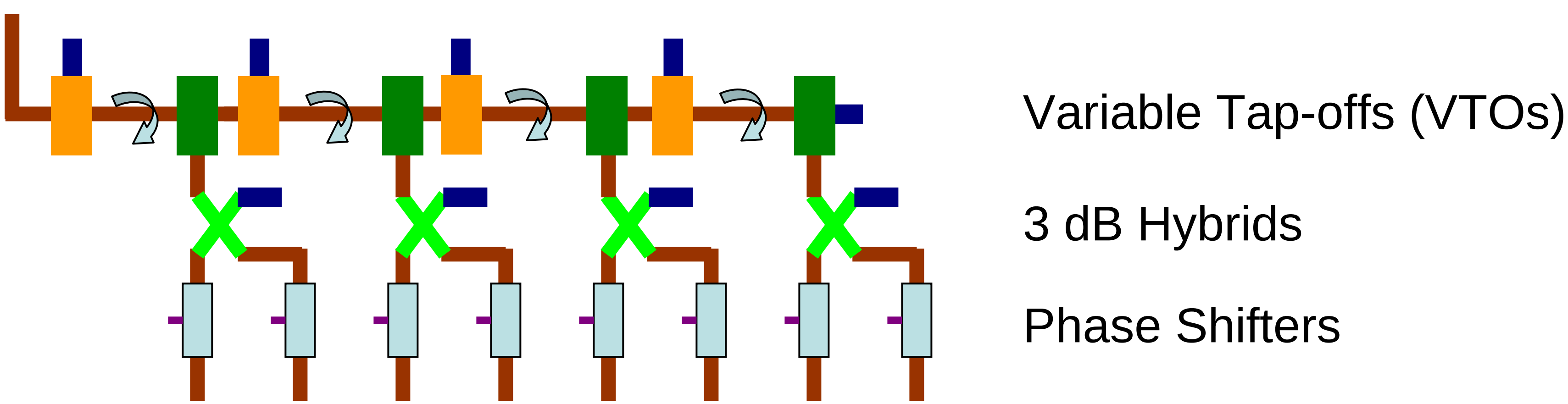
- Replaces PLC and NIM logic to protect klystron (the modulator has its own interlock system)
- All signals, fast (e.g., rf or light) or slow (e.g., flow or PS current), are pre-conditioned to the same voltage range and sampled by a 20 MHz, 12 bit ADC and sent to a FPGA to generate fast (< 1 us) or slow (< 1 ms) fault signals based on high/low thresholds of individual channels or channel differences.
- Currently, four VME boards (4 fast, 10 slow channels each) are being tested.

ILC Baseline RF Distribution System

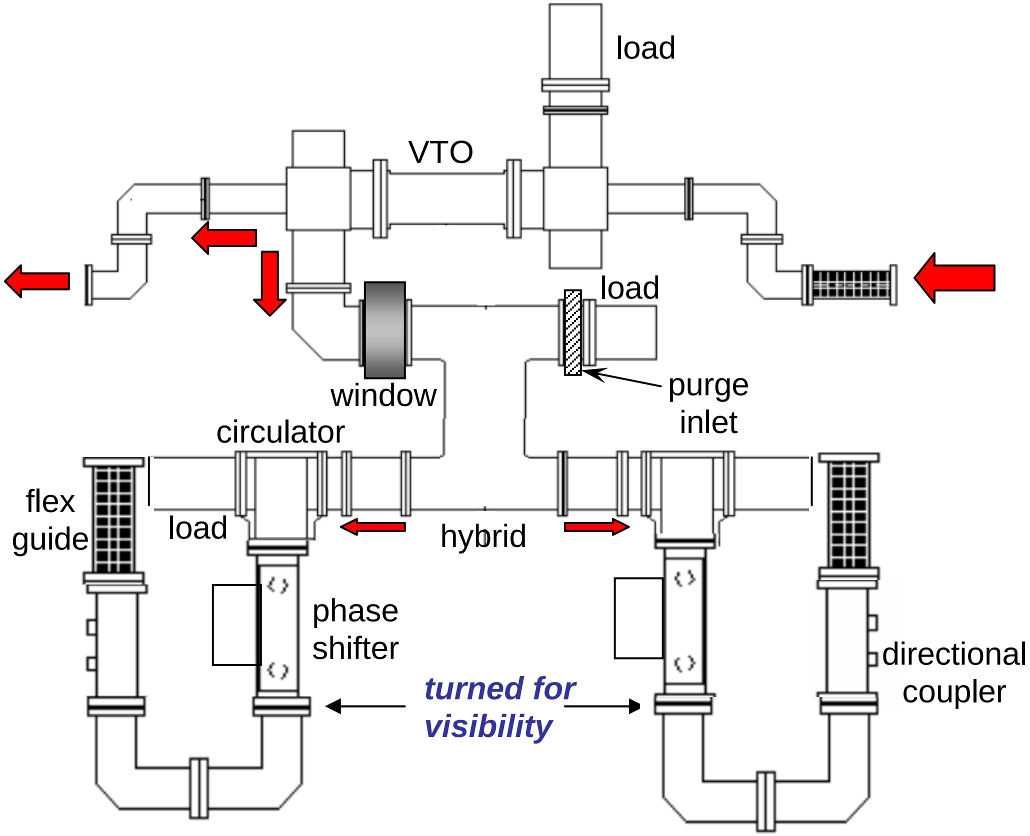


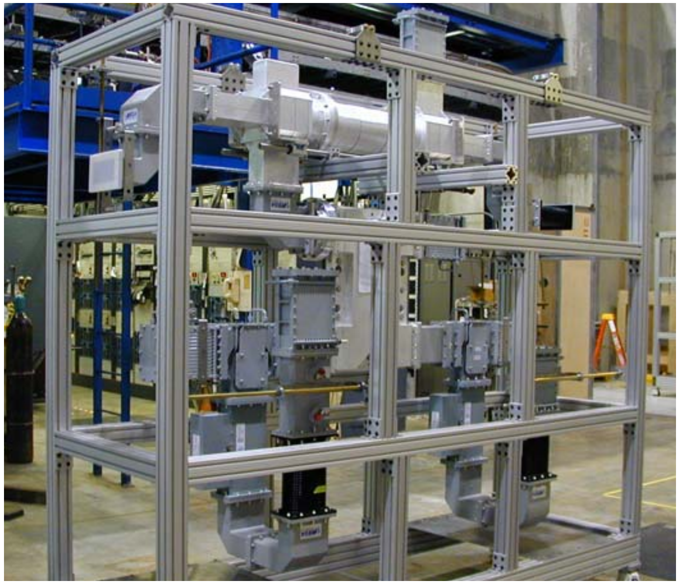
ILC Alternative RF Distribution System

Currently Building This Version for FNAL Cryomodules



Modular 2-Cavity PDS Unit for 1st FNAL CM





BENEFITS OVER LINEAR BCD:

- fewer types of splitters (2 vs. 9)
- power division adjustable by pairs (VTO)
- permits elimination of circulators (hybrid)

First (of 4) 2-cavity unit for ILCTA@NML CM-1 tested and delivered to Fermilab.
The other three are about to be high-power tested and shipped.

Christopher Nantista

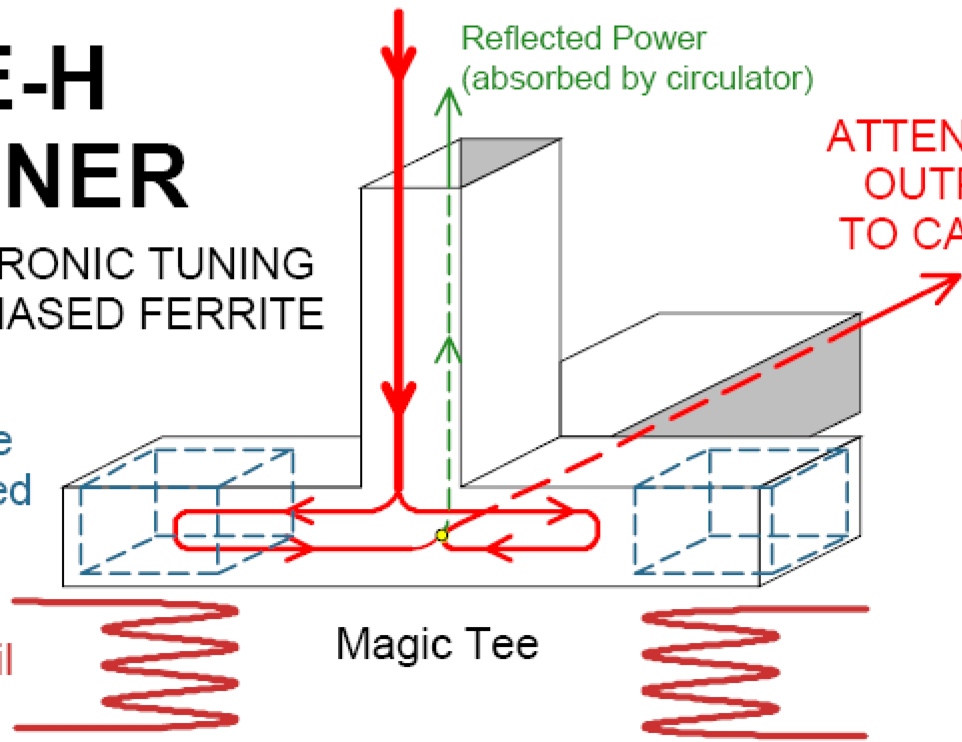
ELECTRONICALLY ADJUSTABLE E-H TUNER

Attractive Price
Quote from AFT

(<< Klystron)

E-H TUNER

ELECTRONIC TUNING
WITH BIASED FERRITE



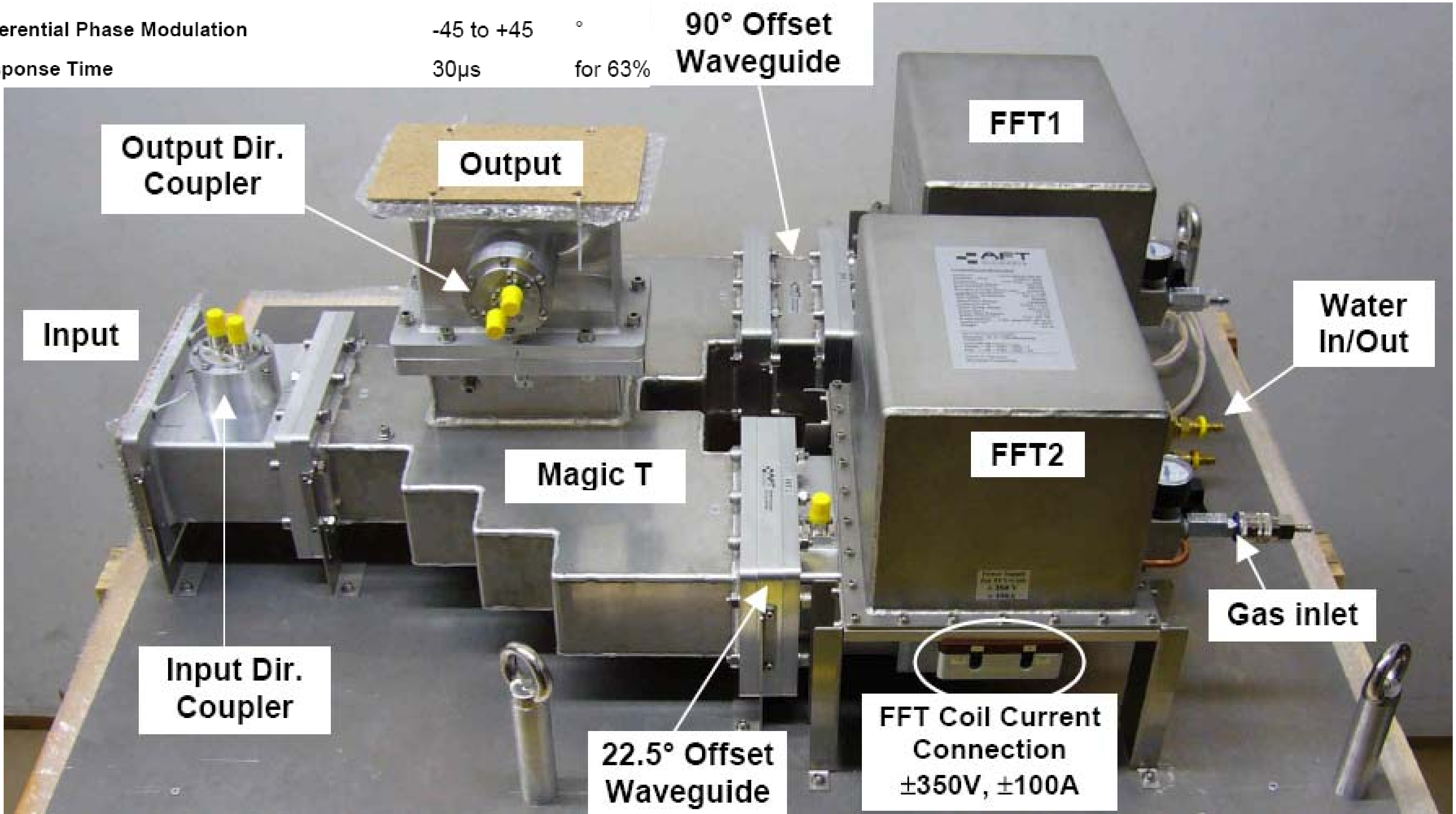
FERRITE LOADED SHORTED STUBS CHANGE ELECTRICAL LENGTH DEPENDING ON DC MAGNETIC BIAS.

TWO COILS PROVIDE INDEPENDENT ***PHASE AND AMPLITUDE*** CONTROL OF CAVITIES

AFT E/H Tuner Prototype

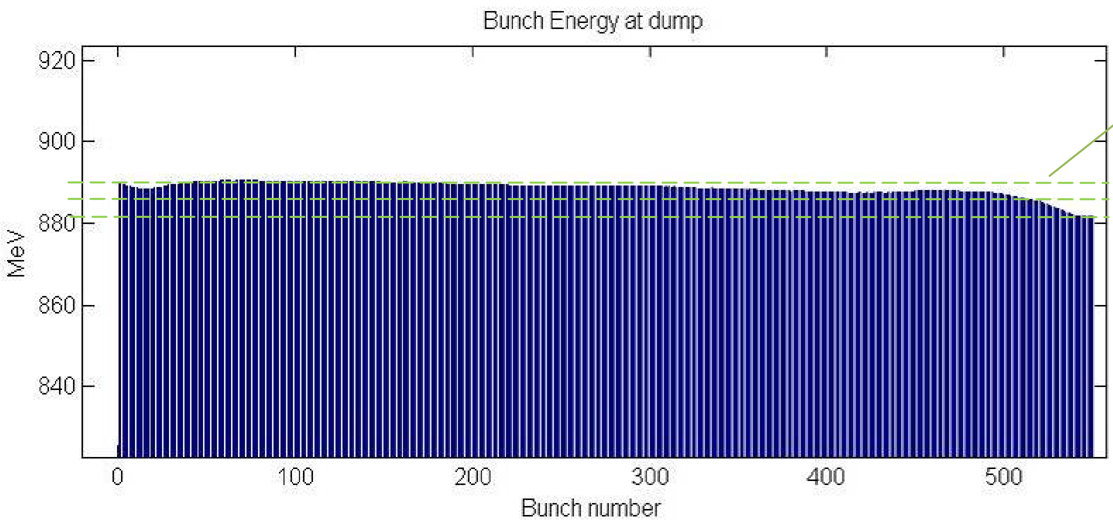
Minimum Insertion Loss	< 0.2	dB
Amplitude Modulation	0 to -3dB	dB
Insertion Loss Modulation	0.2 to 3.2	dB
Differential Phase Modulation	-45 to +45	°
Response Time	30µs	for 63%

Cost Each in Quantity Estimated to be 30 k$ (WG) + 15 k$ (PS) + Second 8 k$ Circulator

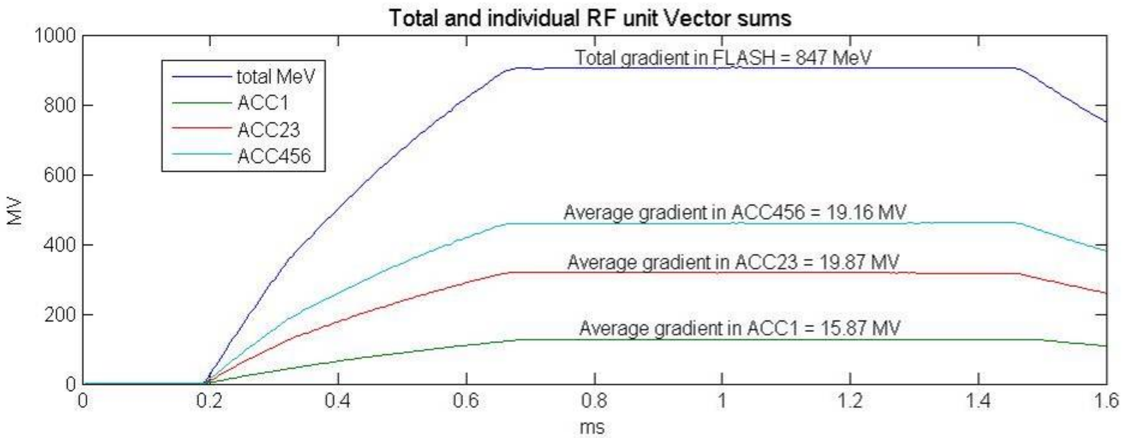


TTF/FLASH 9mA Experiment
Recent Machine Studies and Results

John Carwardine, Gustavo Cancelo, Nick Walker



10 MeV over 550 bunches
(~1%)
(~4 MeV over 1st 500)



Stable operation with 450 bunches
- Several hours of data
- Currently under analysis

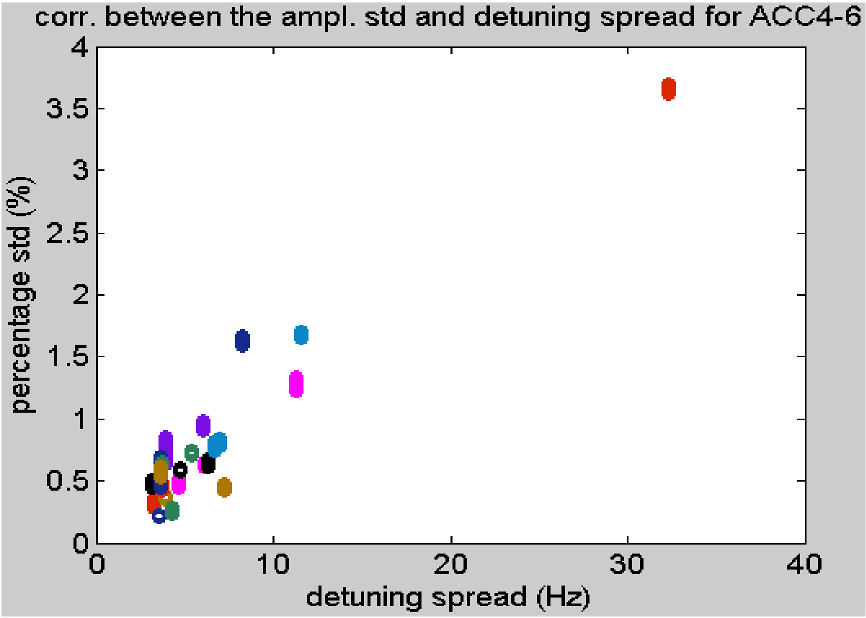
Long bunch trains (~2.5 nC/bunch)
- 550 bunches at 1MHz
- 300 bunches at 500KHz
- 890 MeV linac energy

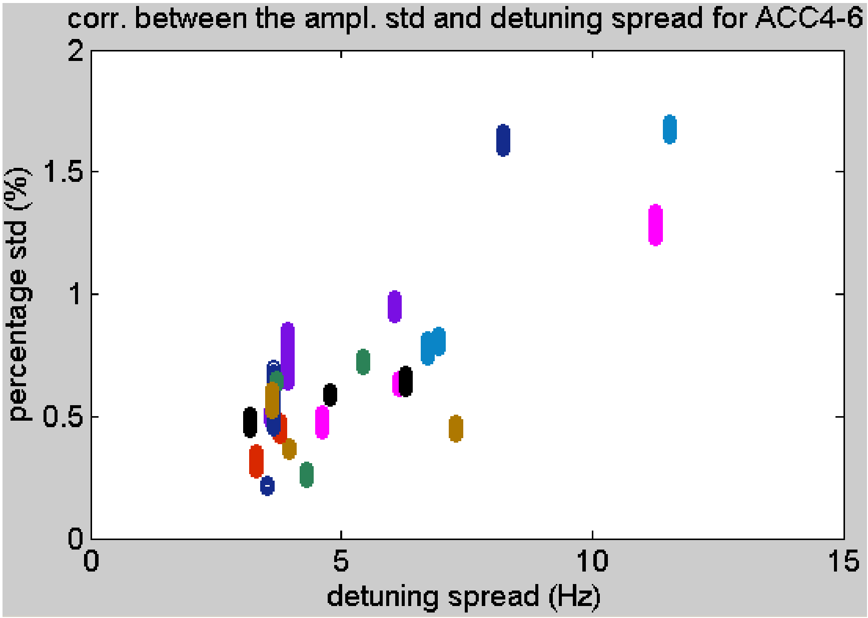
All modules (RF) running with 800us flat-top and 1GeV total

Increase from 450 to 550 bunches eventually caused vacuum event

FLASH Beam-OFF Cavity Probe Signal Analysis

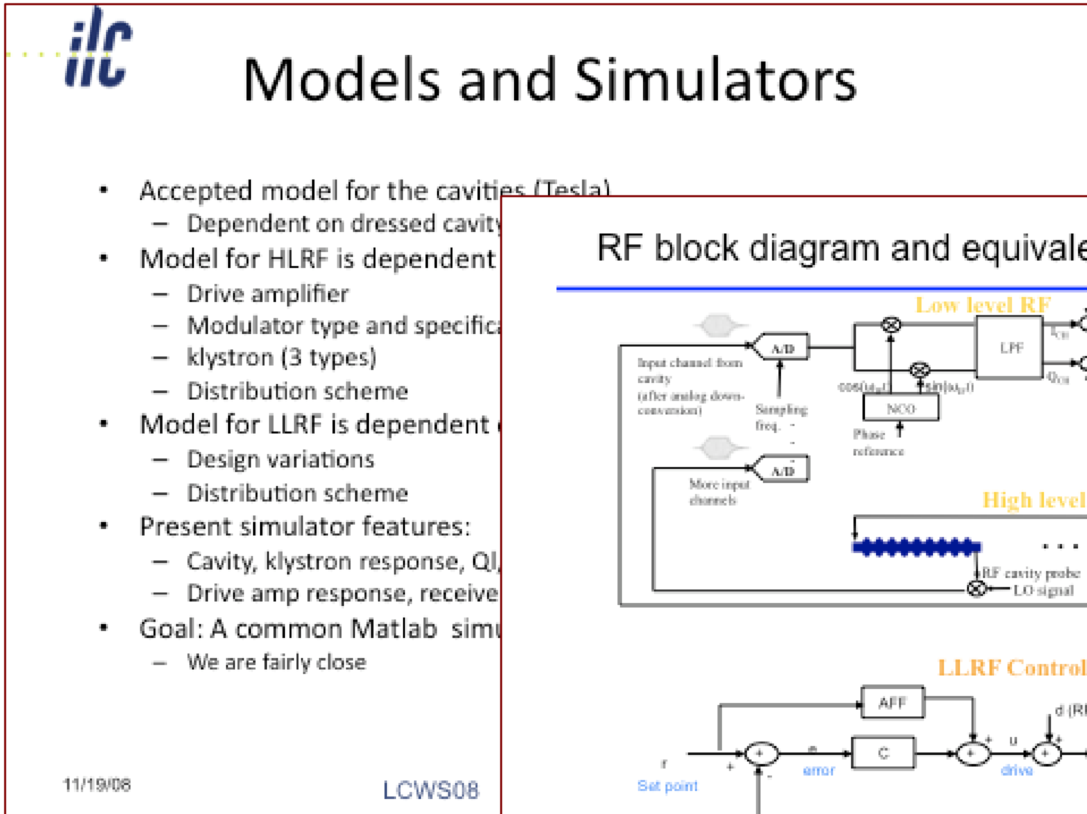
Correlation of Jitter Amplitude RMS & Detuning RMS
for the 24 Cavities in ACC 4-6





RF Control Models & Simulators
(Goal: A Common Matlab Model)

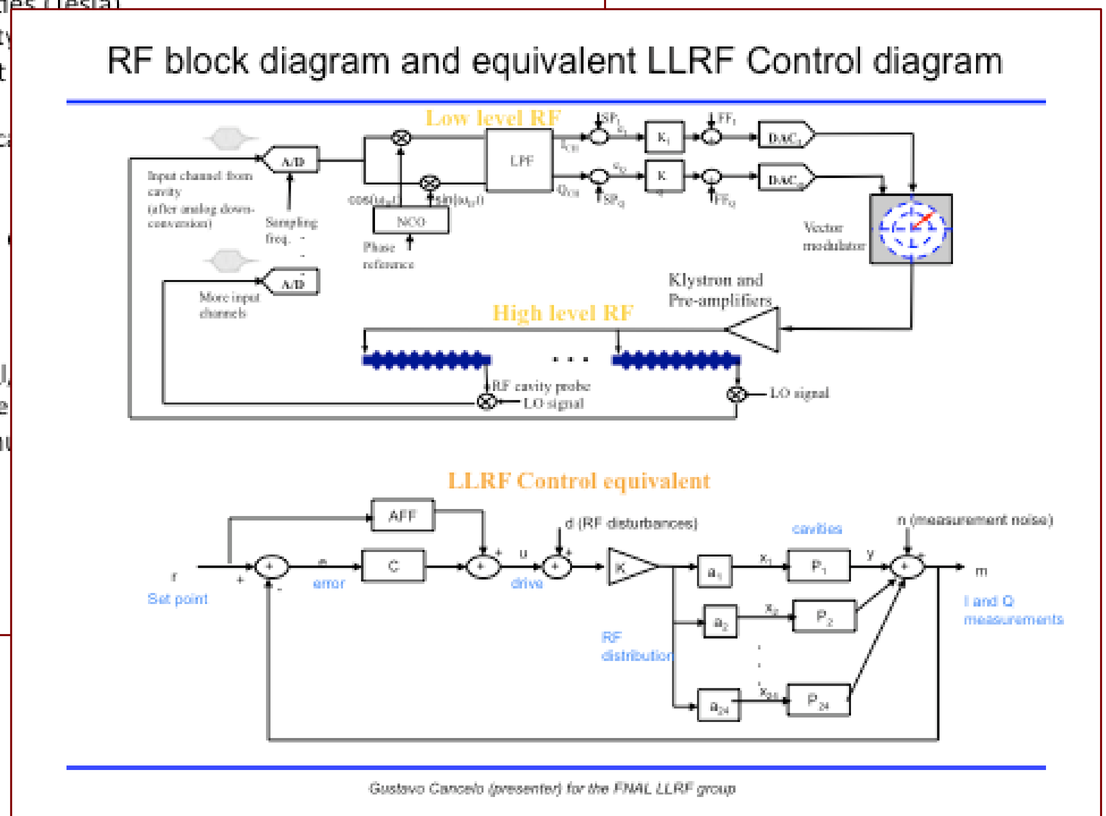
Gustavo Cancelo
Brian Chase



Models and Simulators

- Accepted model for the cavities (Tesla)
  - Dependent on dressed cavity
- Model for HLRF is dependent
  - Drive amplifier
  - Modulator type and specific
  - klystron (3 types)
  - Distribution scheme
- Model for LLRF is dependent
  - Design variations
  - Distribution scheme
- Present simulator features:
  - Cavity, klystron response, QI,
  - Drive amp response, receive
- Goal: A common Matlab simu
  - We are fairly close

11/19/08 LCWS08



RF block diagram and equivalent LLRF Control diagram

Gustavo Cancelo (presenter) for the FNAL LLRF group

Elements of a PX RF System R&D Program

- Continue ILC efforts on ACD modulators, klystrons and rf distribution systems
- Do long term testing of baseline klystrons (acquire CPI version ?) in parallel with XFEL mod/kly test and industrialization program
- Assess implications of doubling pulse length and pulse rate on rf sources
- Develop affordable fast phase/amplitude shifter for the low energy end of the linac (full linac ?). Also measure power limits of rf distribution components.
- Examine other rf source possibilities (e.g. one source per cavity) that are not driven by large scale of ILC and that may have higher average power capabilities
- Better understand the implications of the beta < 1 proton beam for the cavity gradient regulation
- Increase efforts on understanding cavity perturbations in FLASH and the control algorithms required to keep the beam energy stable.