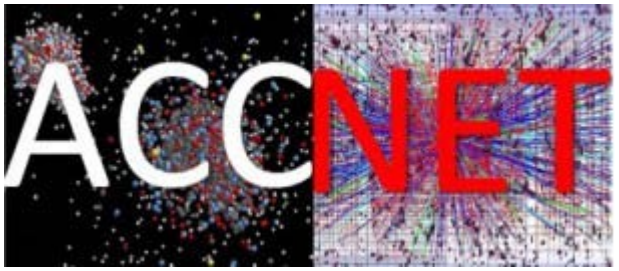
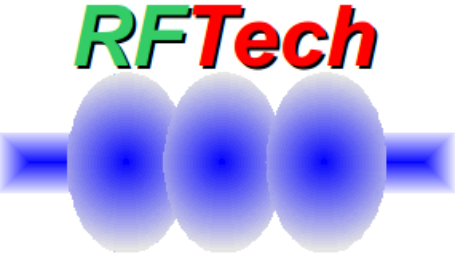
µTCA architecture for HEP instrumentation

Mariusz Grecki, for the LLRF team





EuCARD4th RFTech meeting, Annecy, 26.03.2013

Agenda

- FLASH and XFEL
- LLRF Control
  - Requirements
  - Development
- uTCA for Physics (uTCA.4) LLRF Control System
  - System architecture
  - Hardware
  - Firmware & Software
- Summary

FLASH

Free-electron LASer in Hamburg

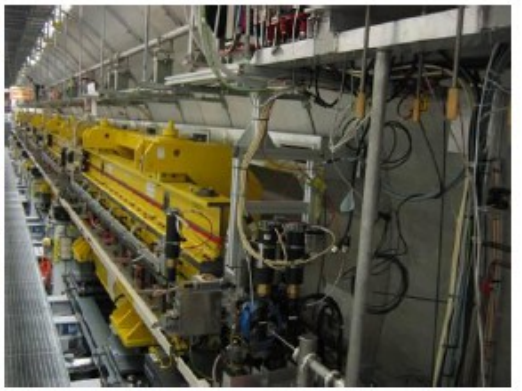
- Single-pass high-gain SASE FEL

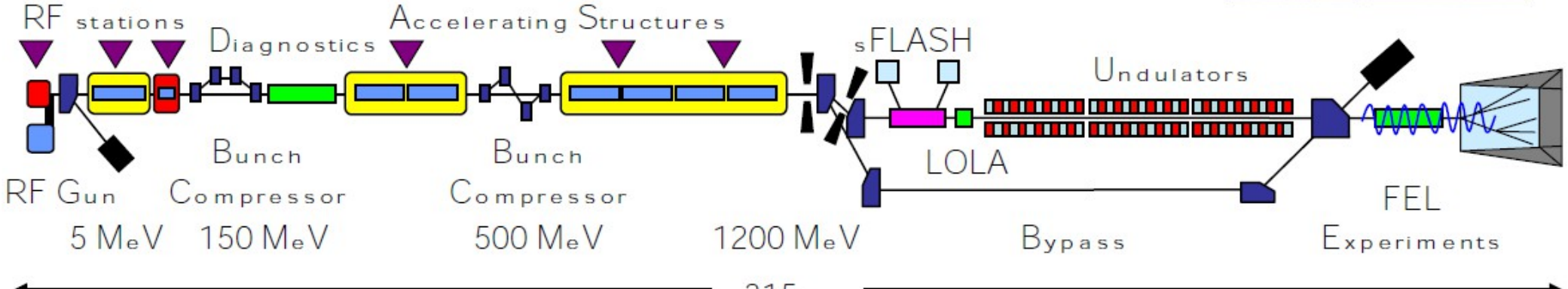
  SASE = self-amplified spontaneous emission

- Photon wavelength range from vacuum ultraviolet to soft x-rays
- Free-electron laser user facility since summer 2005
  - 1st period: Jun 2005 – Mar 2007
  - 2nd period: Nov 2007 – Aug 2009
  - 3rd period: Sep 2010 – Sep 2011
  - 4th period: Feb 2012 – Feb 2013
- FLASH is also a test bench for the European XFEL and the International Linear Collider (ILC)
- FLASH II, a second undulator beam line is in preparation, FLASH III and next are planned

FLASH







RF stations
Diagnostics
Accelerating Structures
sFLASH
Undulators
Bunch
Compressor
Bunch
Compressor
LOLA
RF Gun
5 MeV
150 MeV
500 MeV
1200 MeV
Bypass
FEL
Experiments
315 m




XFEL

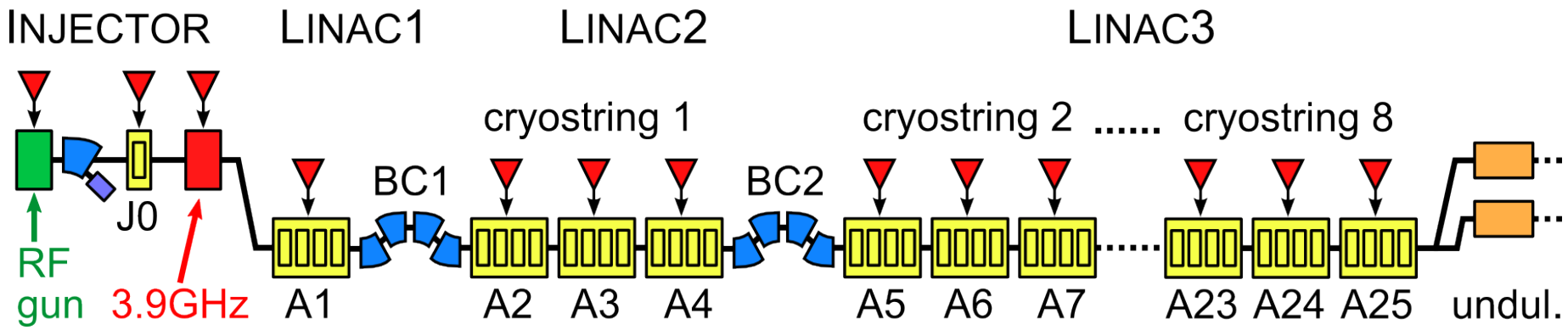
European X-Ray Free-Electron Laser

- Energy for 0.1nm wavelength 17.5 GeV
- Klystron peak power 5.2 MW
- RF pulse length 1.4 ms
- Beam pulse length 0.65ms
- Repetition rate 10 Hz
- Maximum average beam power 600 kW
- Bunch charge 1 nC
- Bunch peak current 5 kA
- Energy spread (slice) at undulator 1 MeV

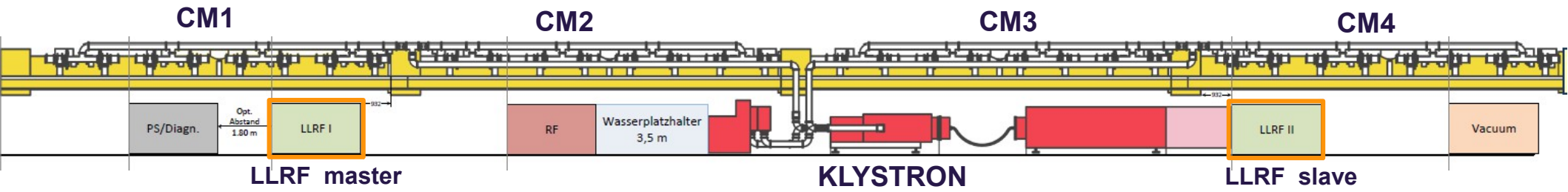
The European XFEL

- XFEL: European X-ray Free-Electron Laser
- Pulsed, superconducting LINAC (17.5 GeV)
- TESLA 1.3 GHz RF cavities
- First beam: Dec 2015

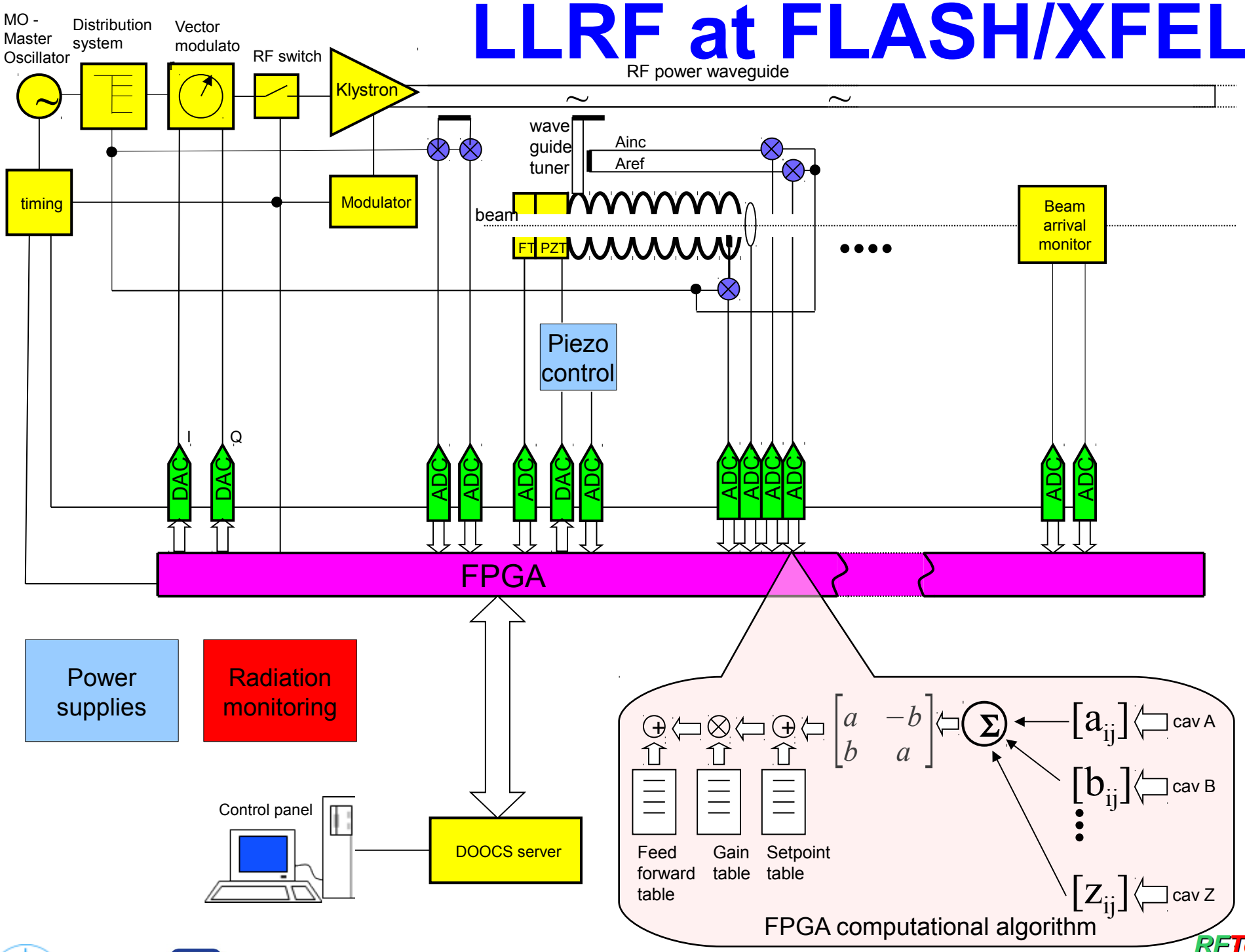
The European XFEL



- 808 superconducting 1.3 GHz TESLA RF cavities
- 101 cryomodules (8 cavities)
- 25 RF stations (4 cryomodules)
- **1 LLRF system / RF station (i.e. per klystron)**



LLRF at FLASH/XFEL



LLRF Control Requirements

- Maintain Phase and Amplitude of the accelerating field within given tolerances to accelerate a charged particle beam (e.g. XFEL: 0.01% for amplitude and 0.01 deg. for phase)
- Minimimize Power needed for control
- RF system must be reproducible, reliable, operable, and well understood.
- Other performance goals
  - build-in diagnostics for calibration of gradient and phase, cavity detuning, etc.
  - provide exception handling capabilities
  - meet performance goals over wide range of
  - operating parameters

Old hardware platform

- DSP C67 (2002)
  - 1x C67 DSP for up to 32 cavities
  - 8x Gigalink Interface (4x8ADC, DAC)
  - 1 MHz sampling, 4 microsecond latency

Current hardware platform

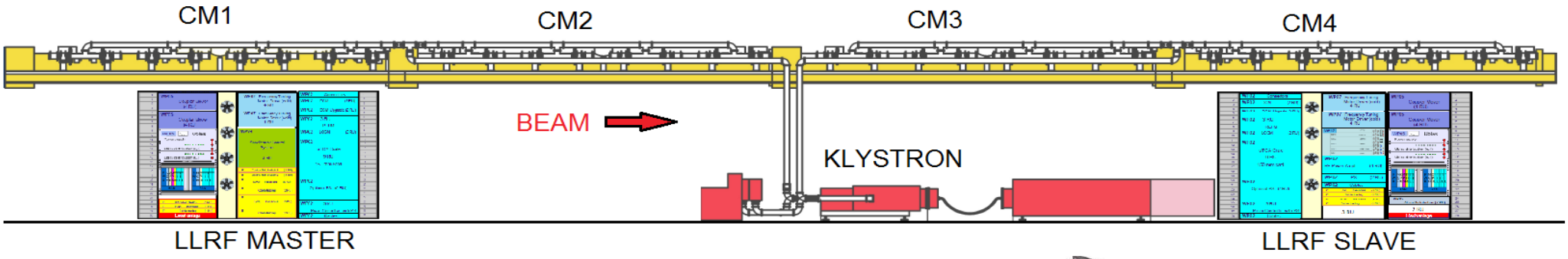
SimconDSP

- VME interface
- 10xADC, 8xDAC
- Xilinx Virtex II Pro (20/30/50), PowerPC
- DSP, Tiger Sharc
- 2 opto gigalinks
- Ethernet

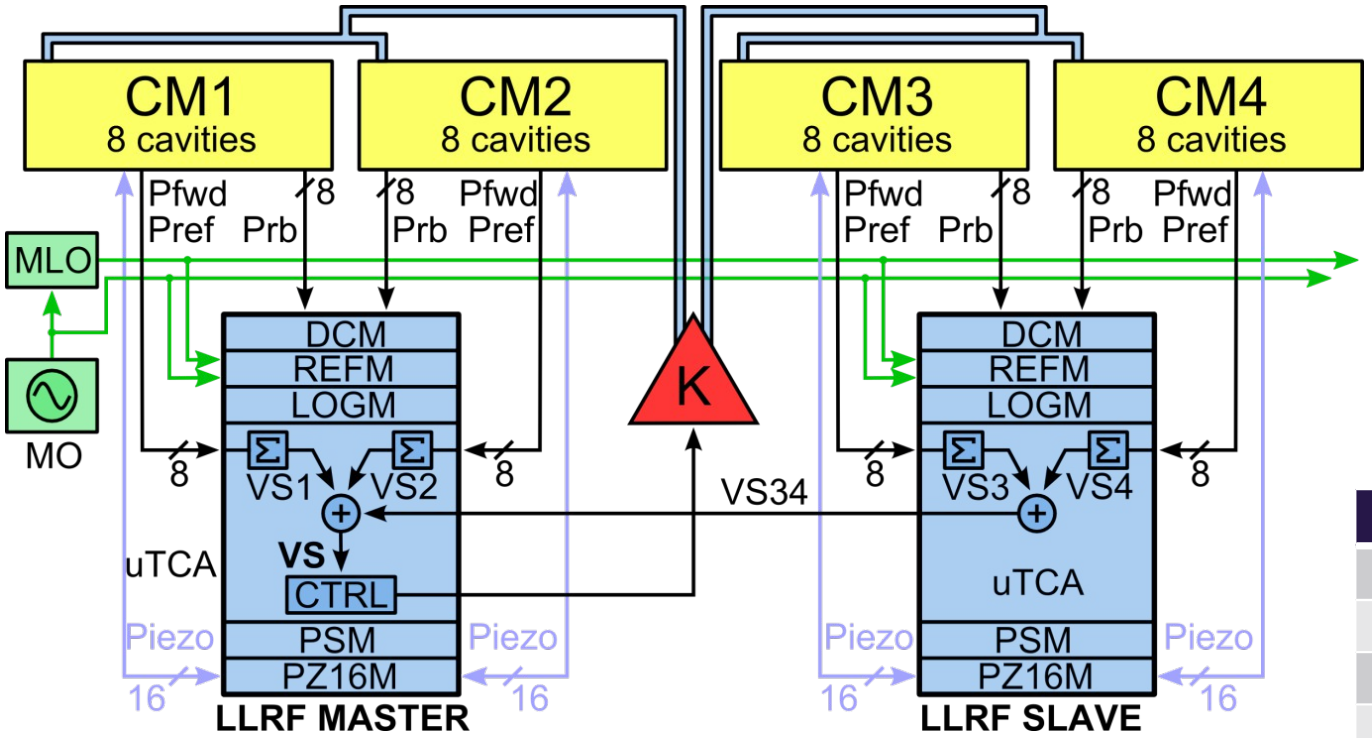
MTCA.4 history at DESY

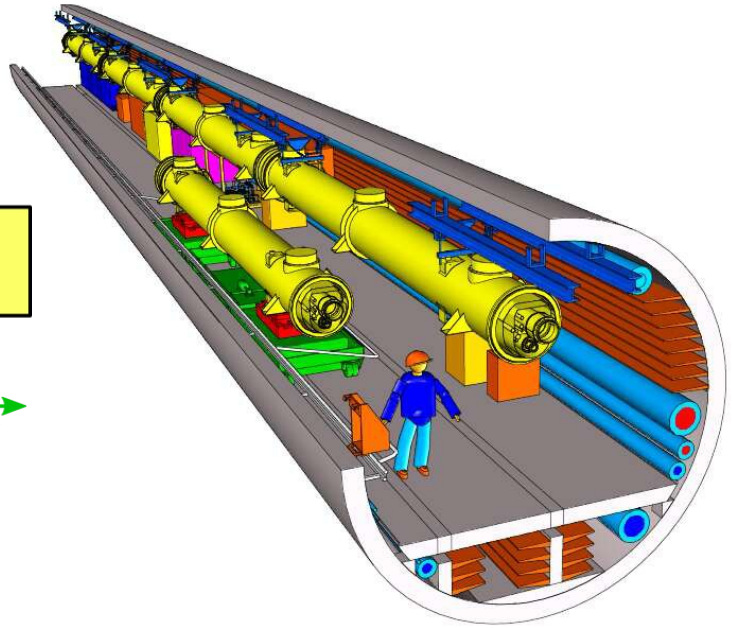
- 2007 decision to use xTCA as standard platform for XFEL
- 2009 narrowed down to MTCA ("xTCA for Physics" formed)
- 2010 decision to migrate LLRF from ATCA to MTCA.4
  - development of the platform and various modules

LLRF at XFEL



RF station: semi-distributed LLRF system

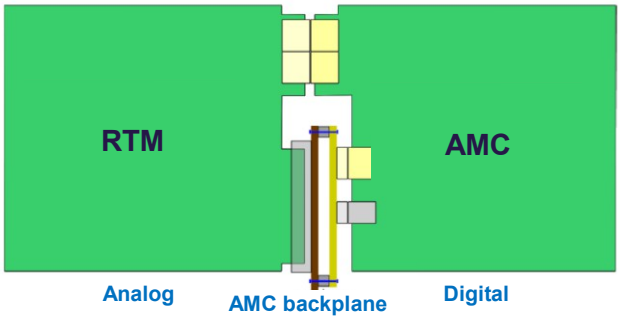


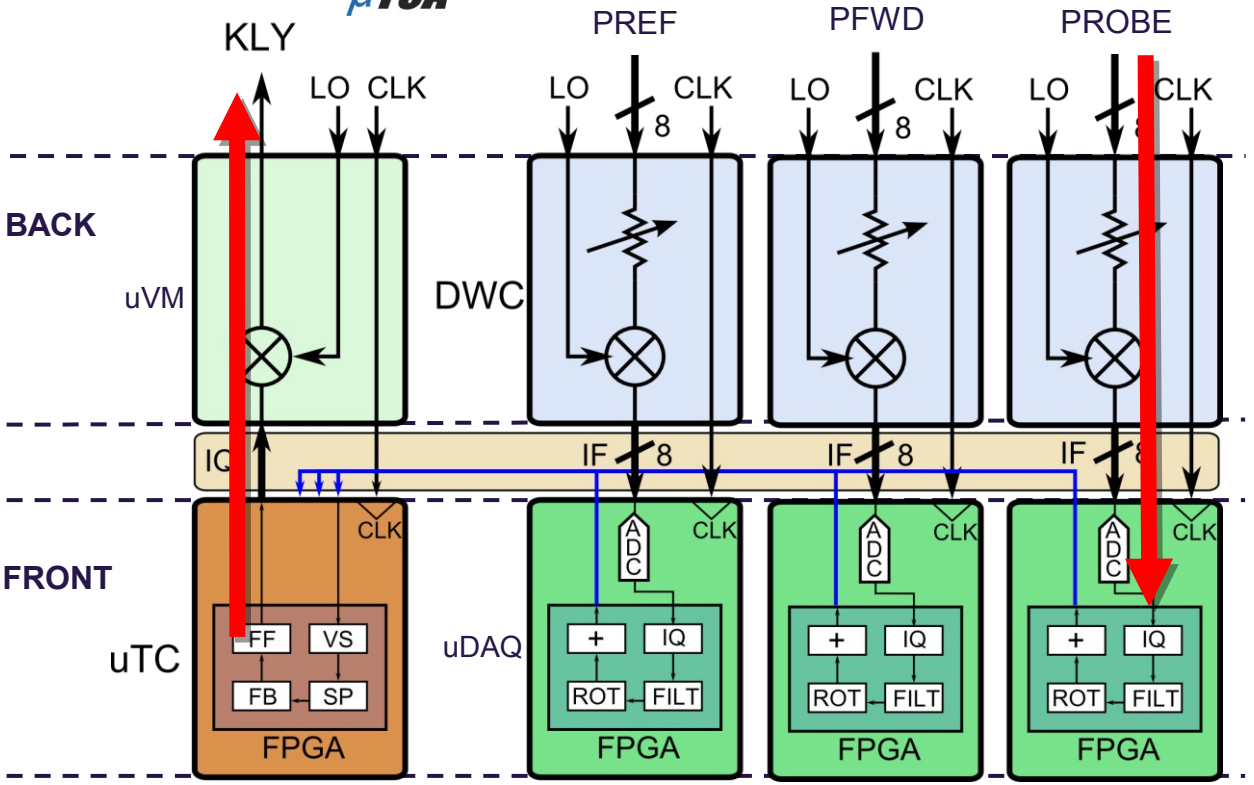


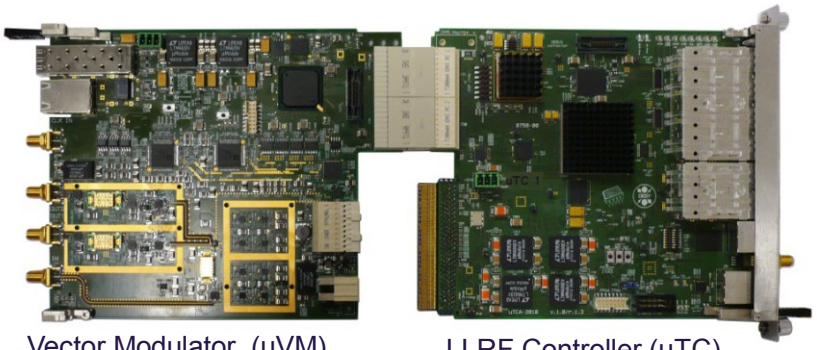
Section	Rack space	Redundancy
Gun, I1, 3H1	16U	Full
Linac 1	28U	Full
Linac 2	28U	No
Linac 3	28U	No

uTCA LLRF System

- AMC: Advanced Mezzanine Card
- RTM: Rear Transition Module
- 12 slots, hot swap
- Redundant power supply

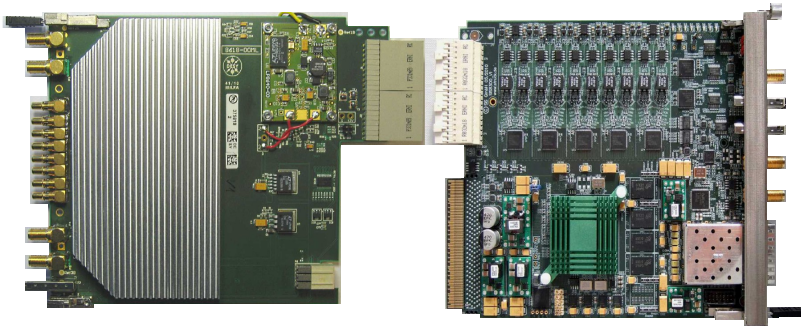






Vector Modulator (uVM)

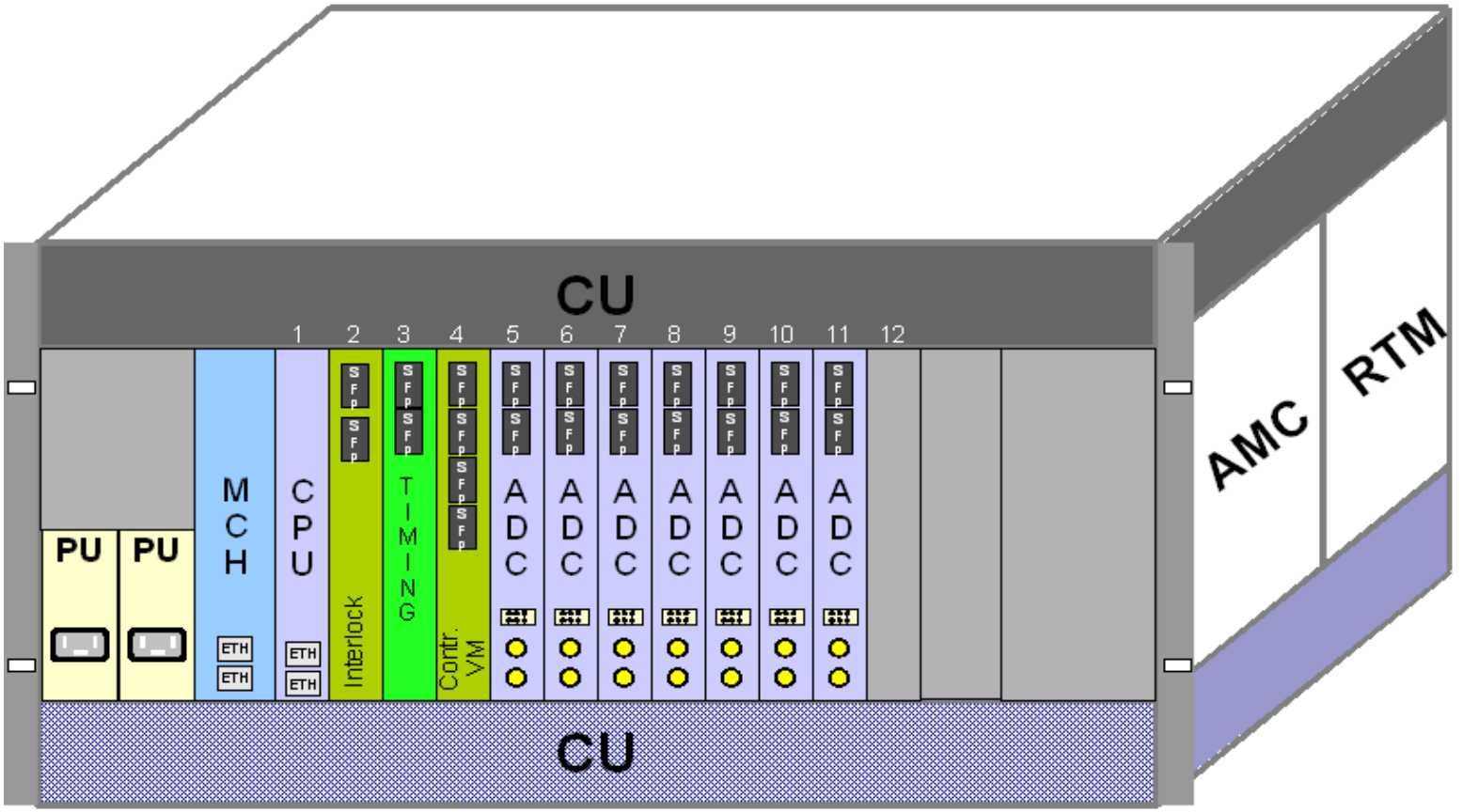
LLRF Controller (uTC)

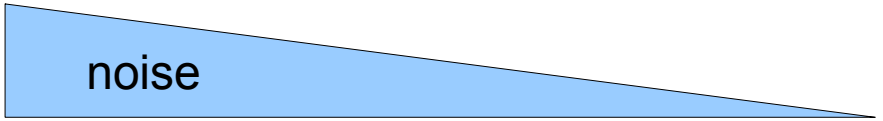


Down Converter (DWC)

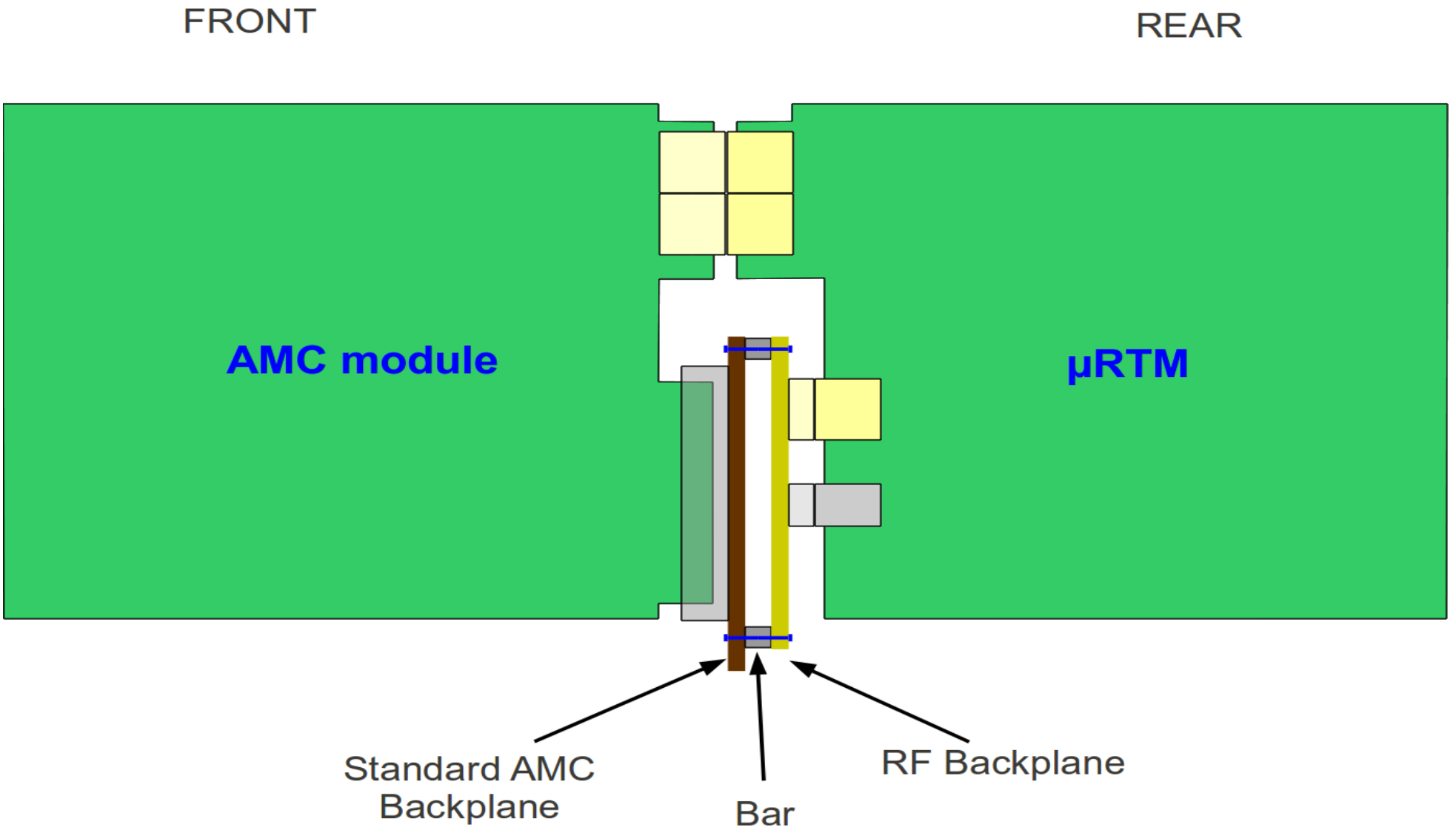
Digitizer (uDAQ)

xTCA Crate for LLRF – front view

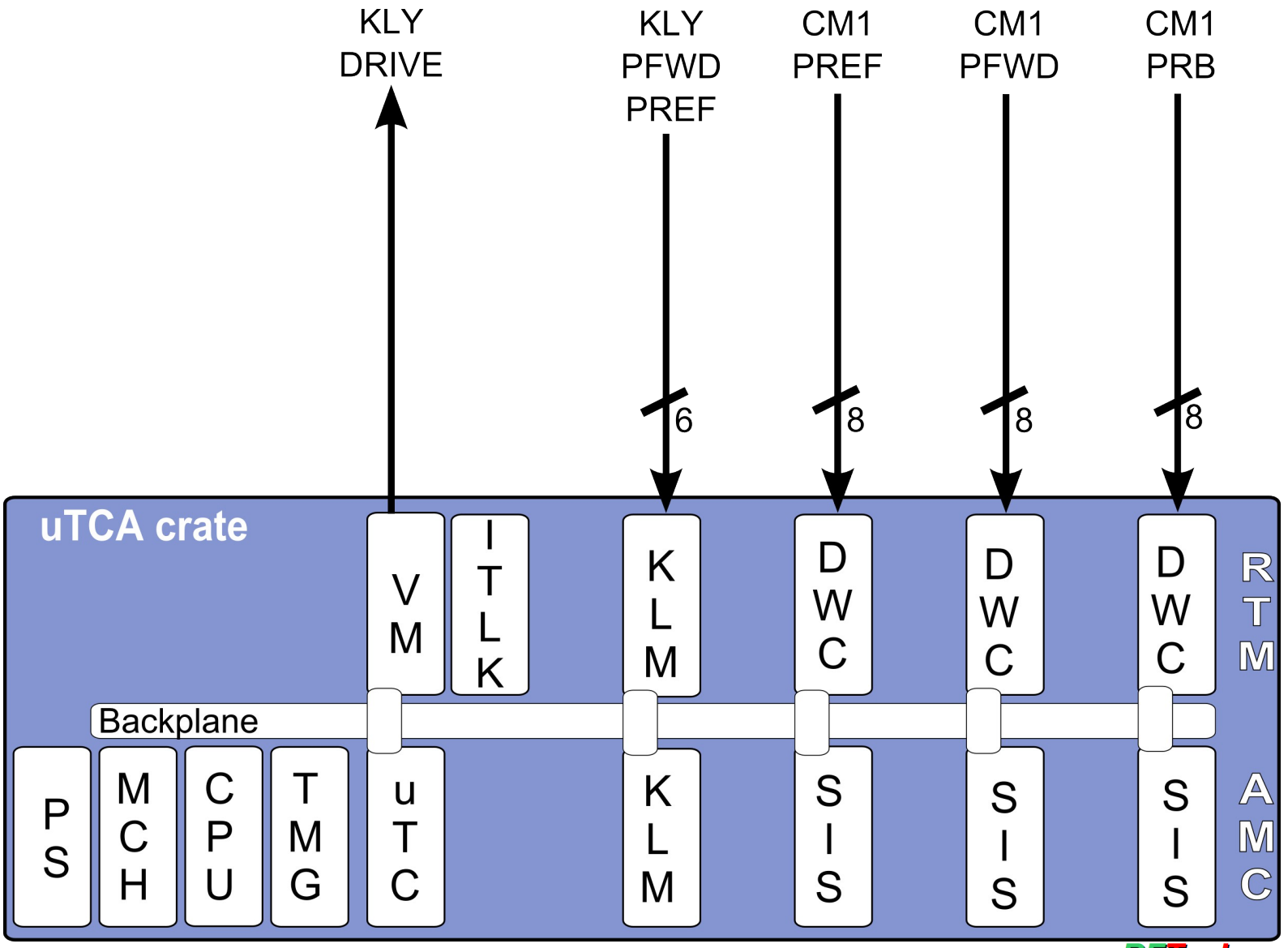




xTCA Crate – RF backplane

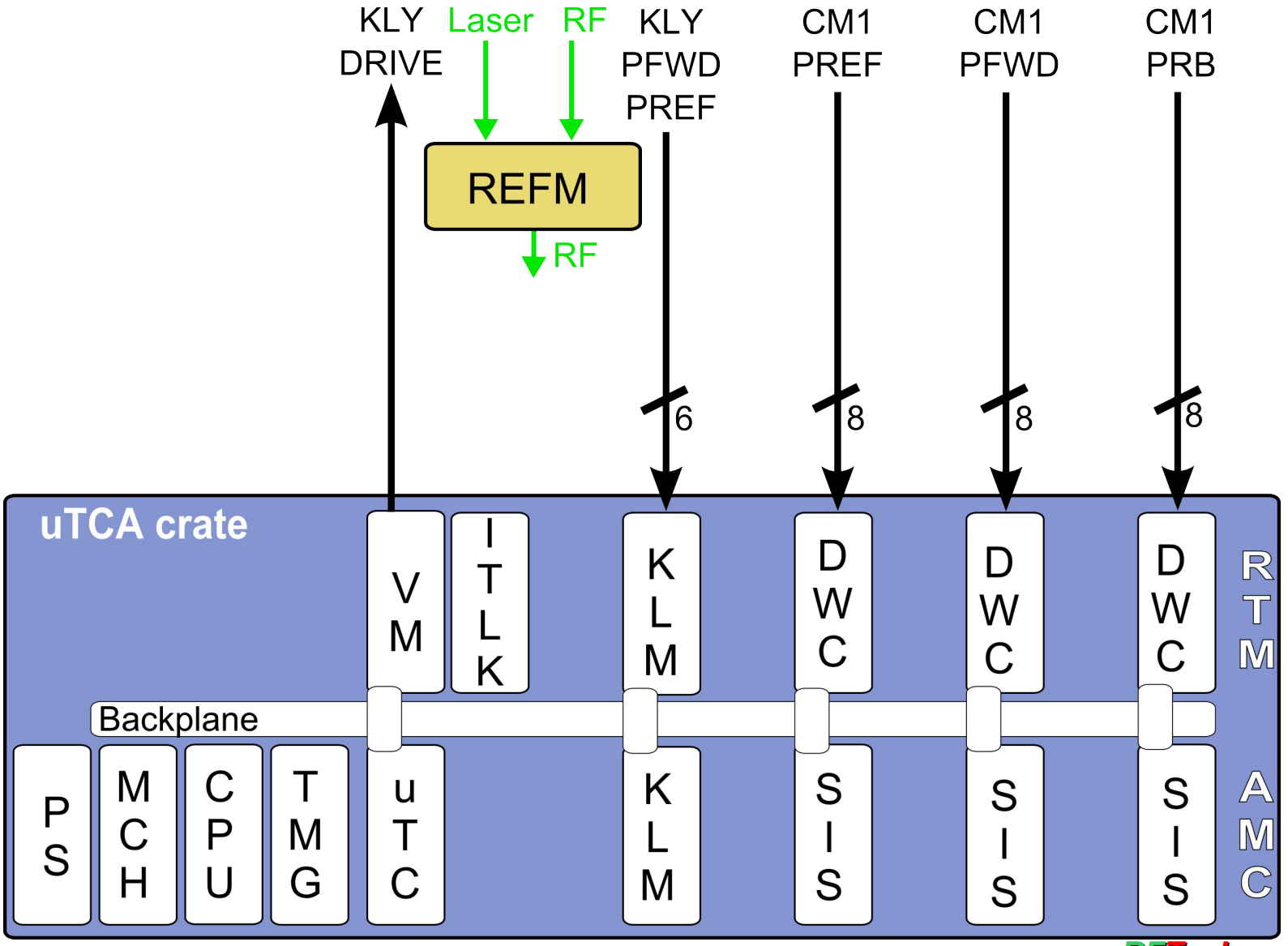


LLRF System Architecture



LLRF System Architecture

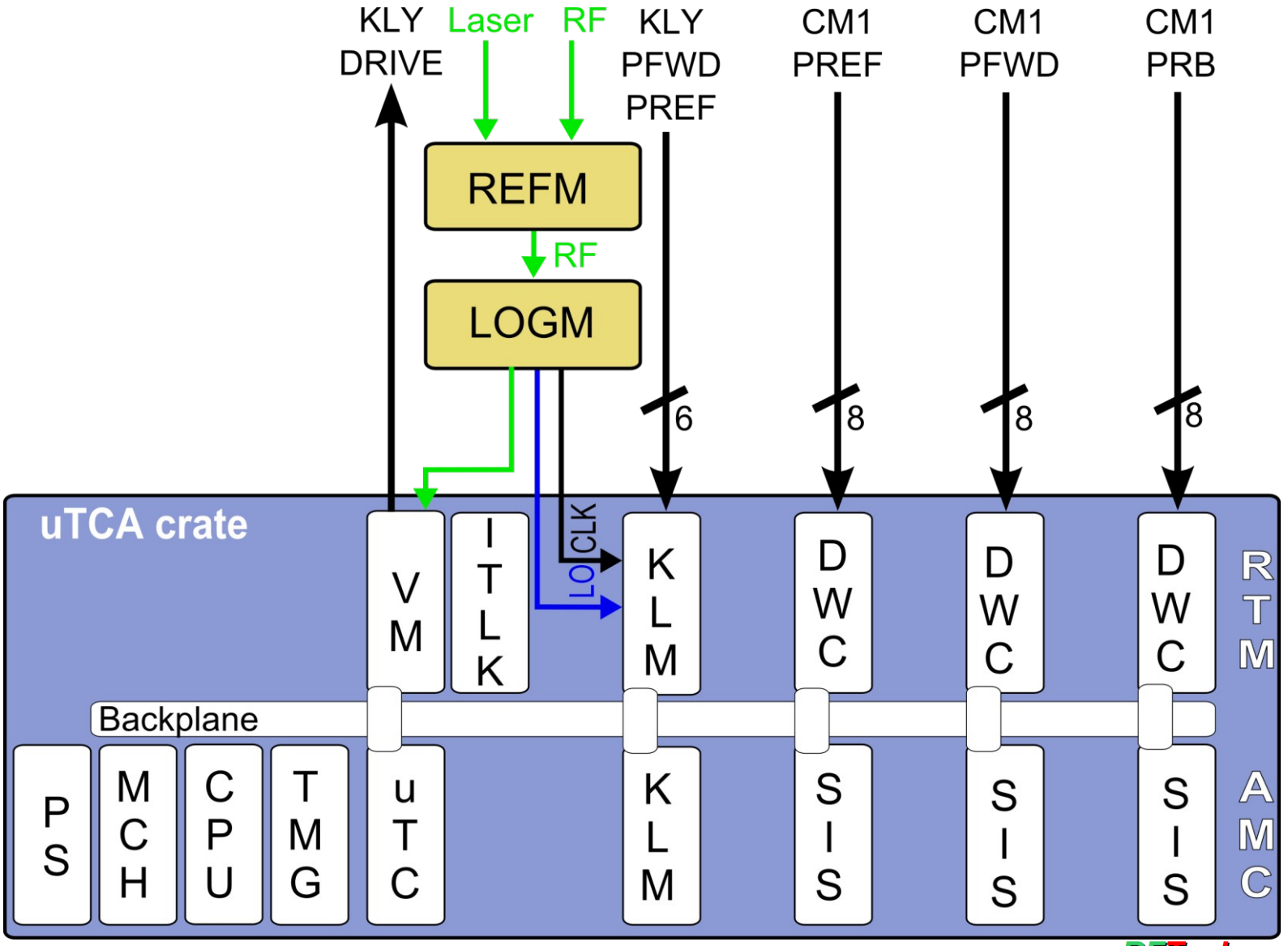
REFM
RF Reference Module



LLRF System Architecture

REFM
RF Reference Module

LOGM
Local Oscillator
Generation Module

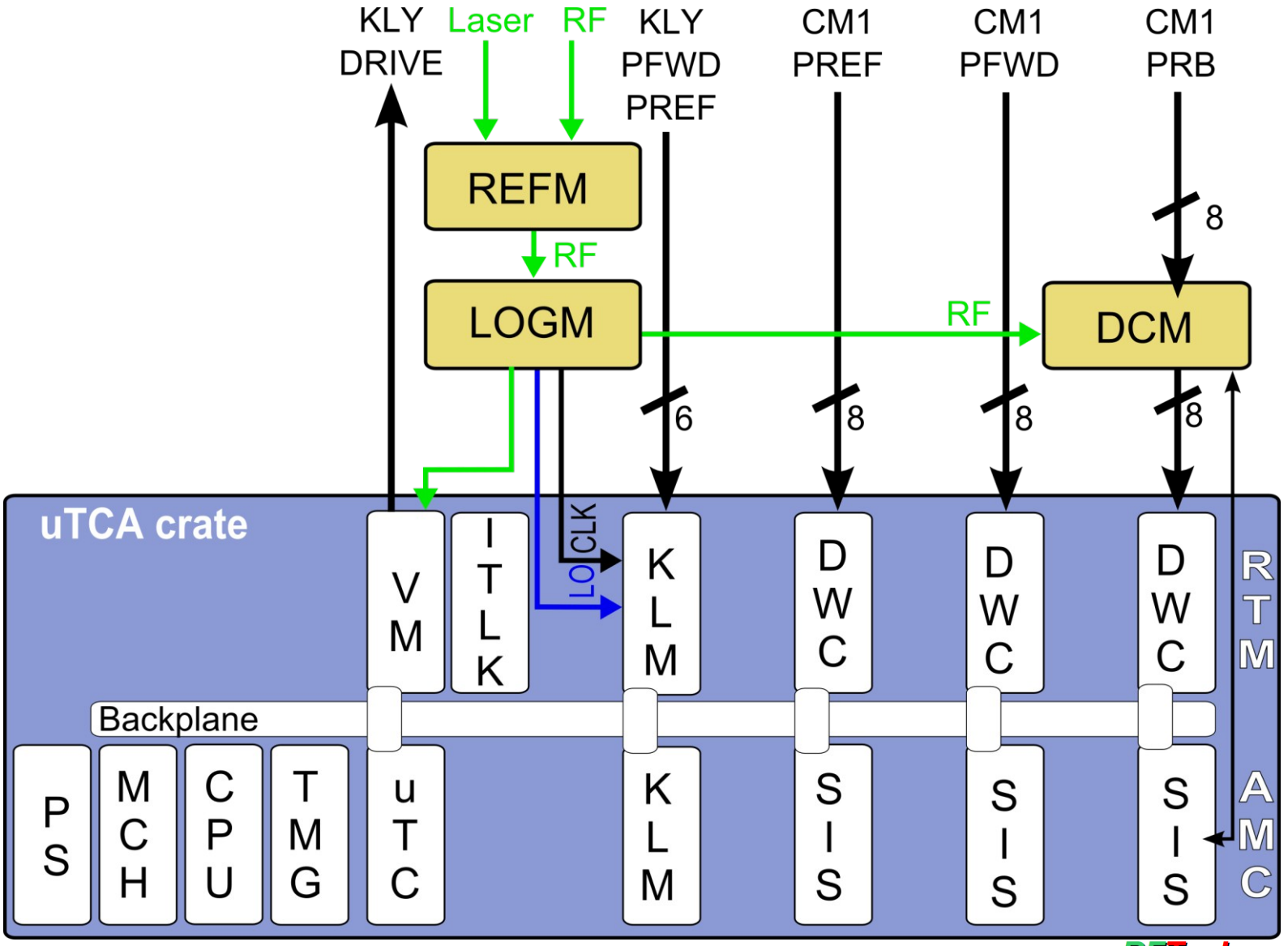


LLRF System Architecture

REFM
RF Reference Module

LOGM
Local Oscillator Generation Module

DCM
Drift Compensation Module



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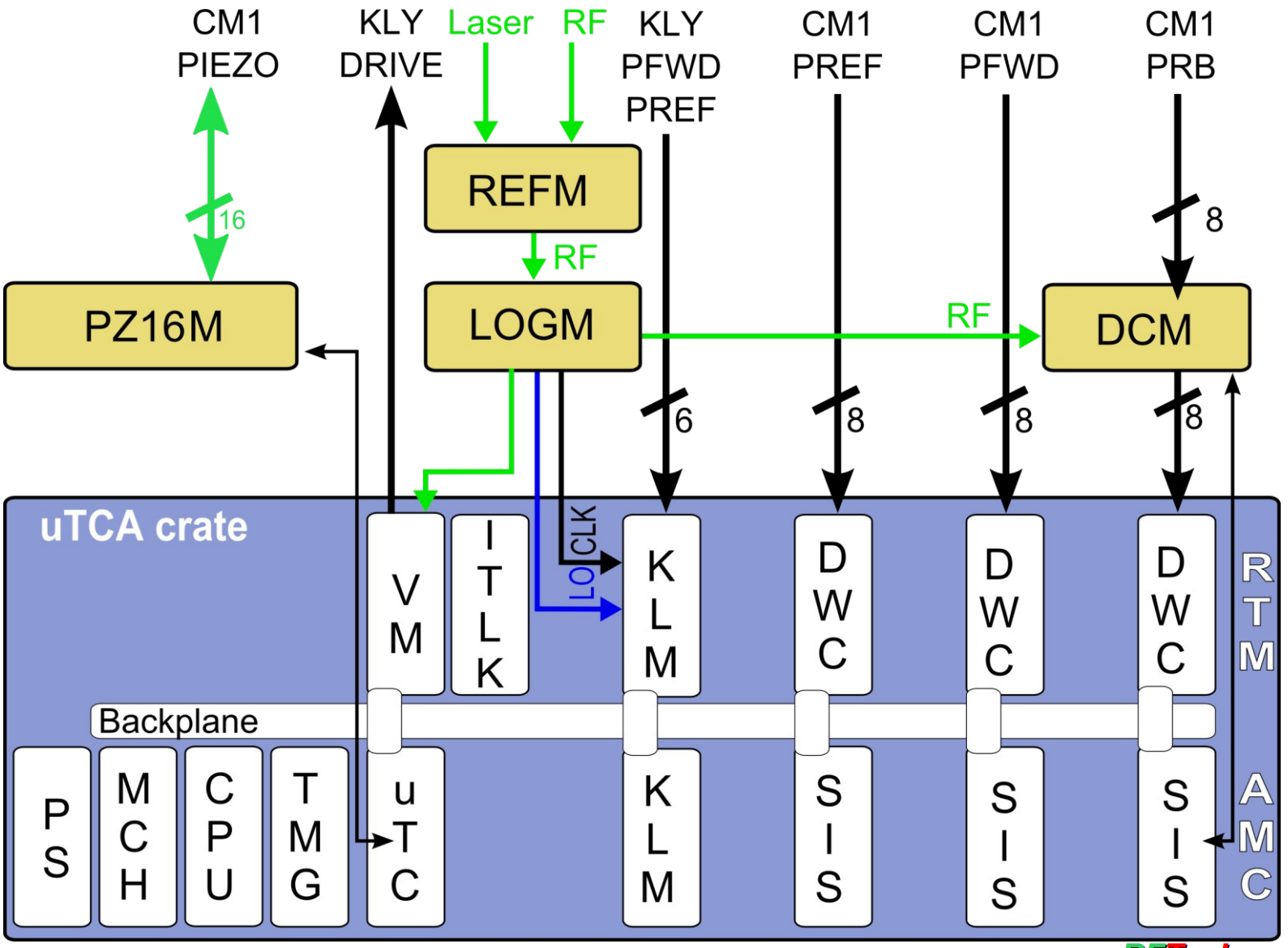
Drift Compensation Module

PZ16M
Piezo Driver Module



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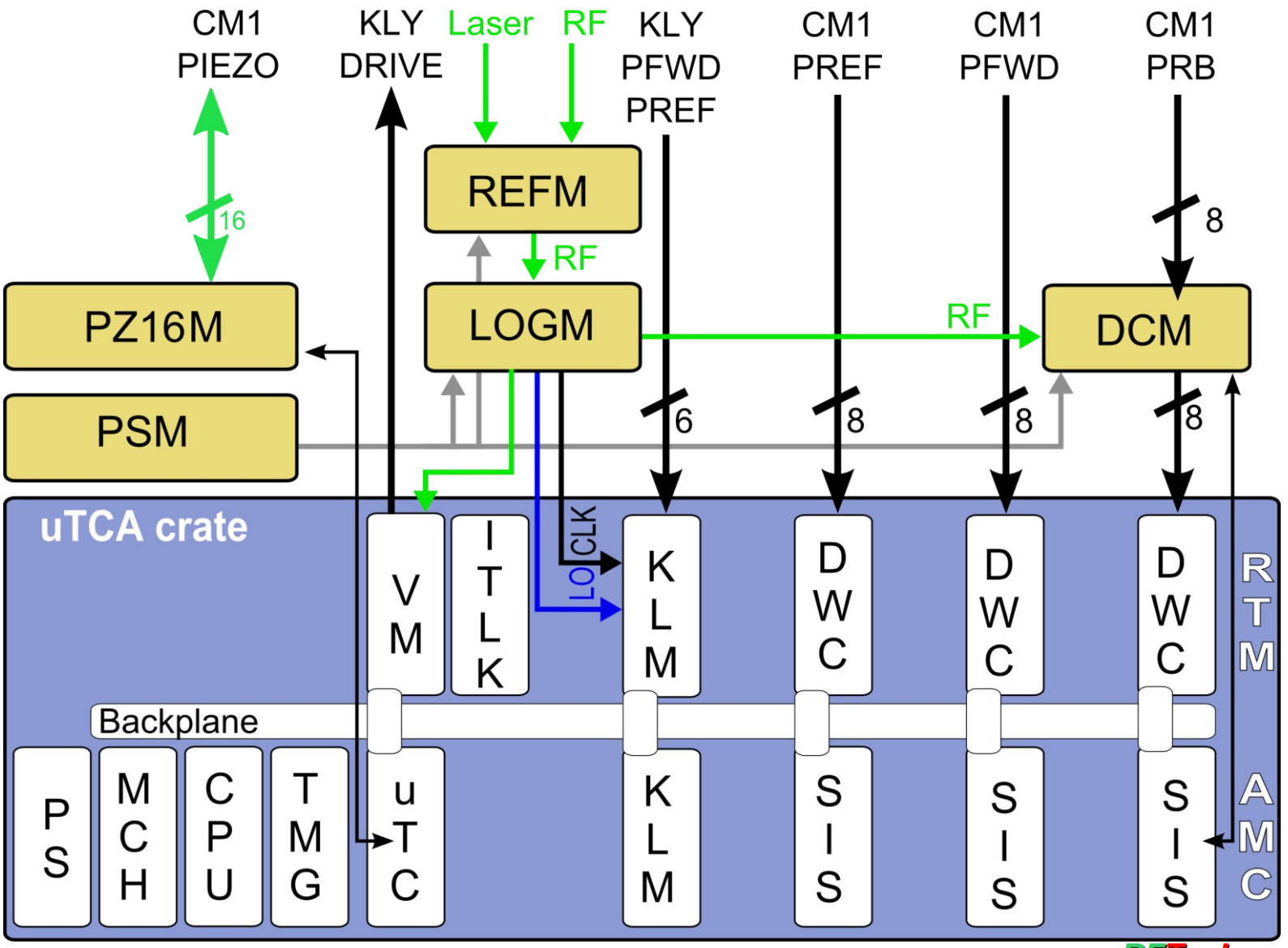
PSM
Power Supply Module



LLRF System Architecture

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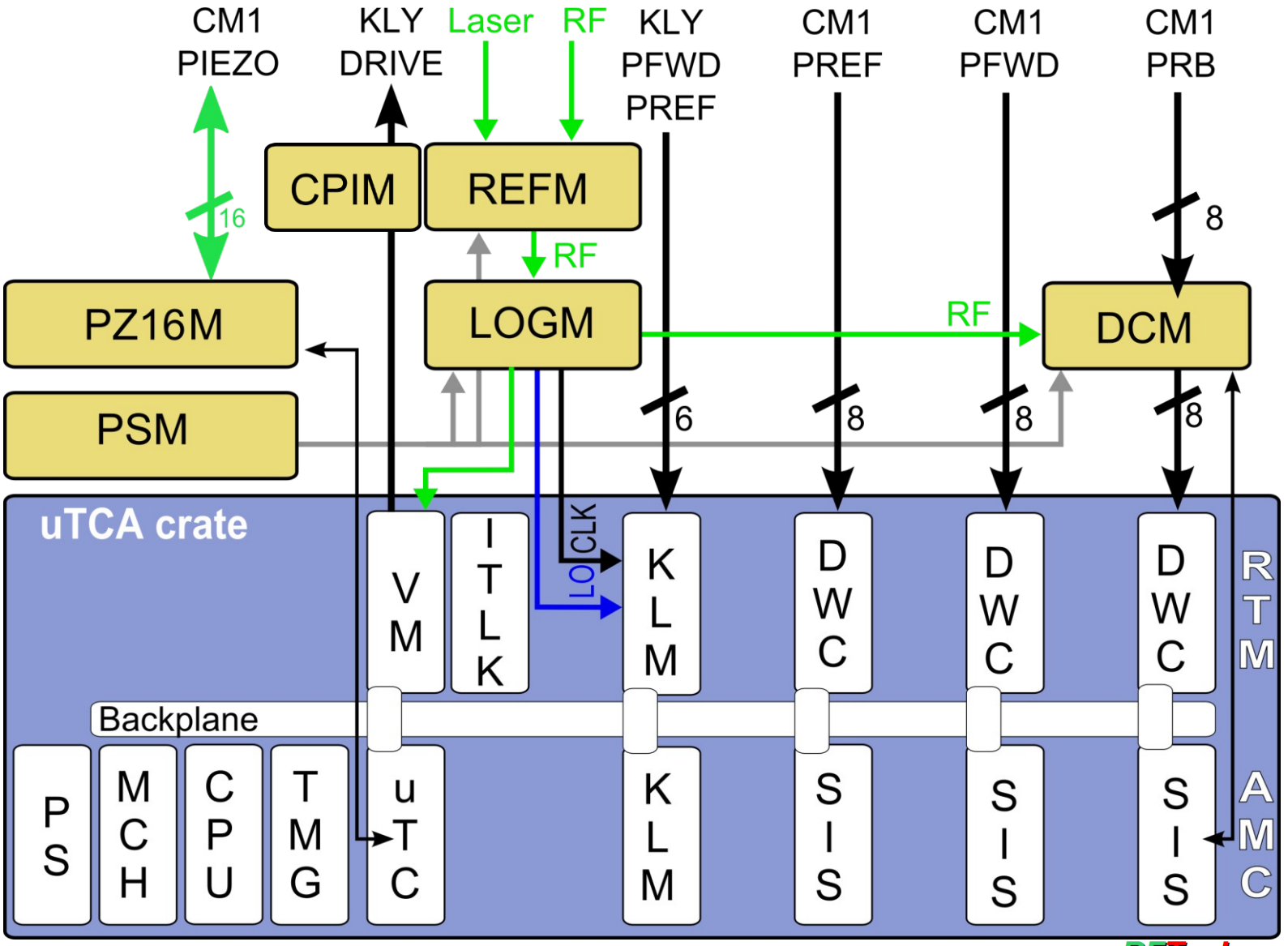
CPIM
Coupler Processing interlock Module



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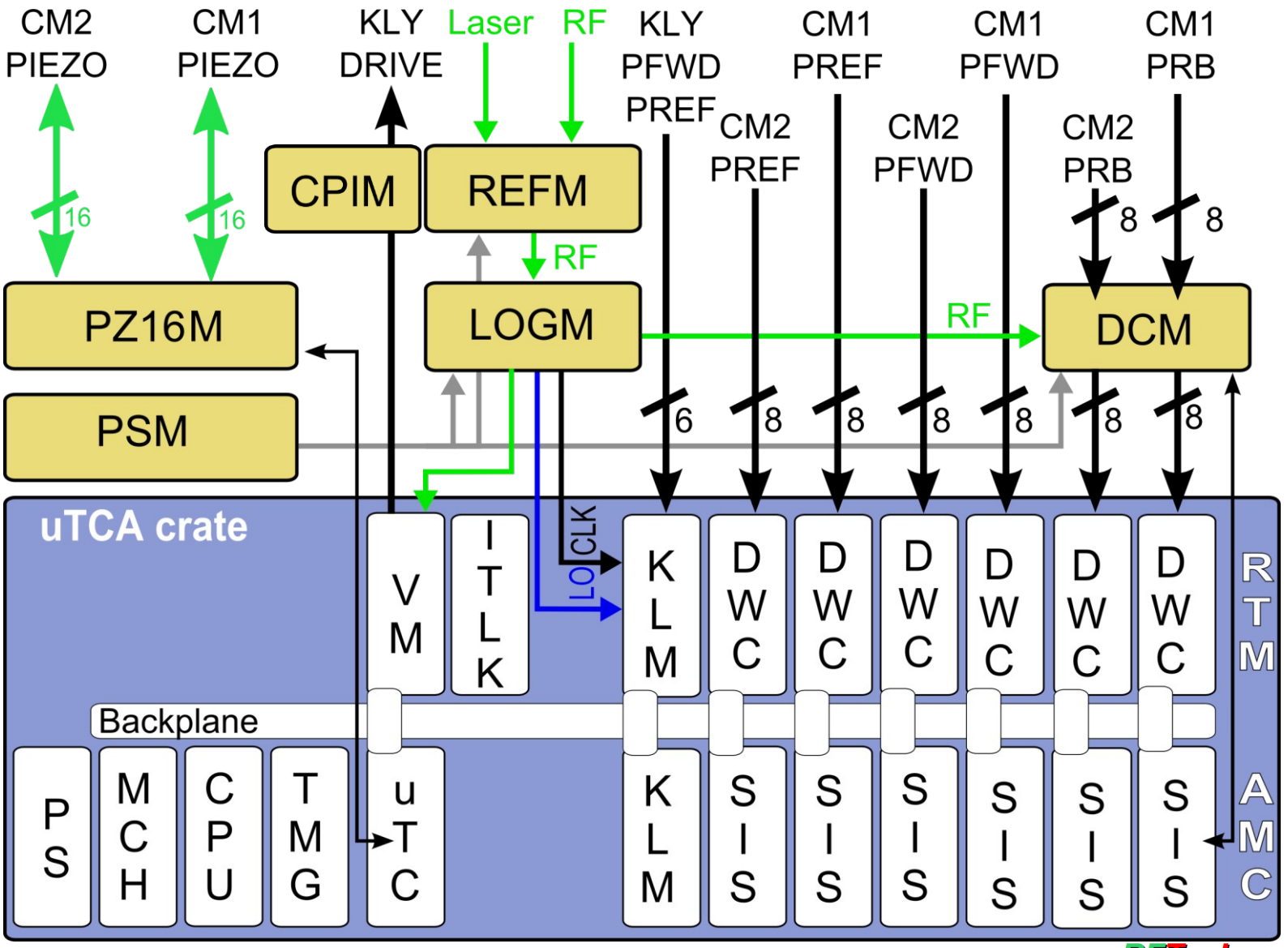
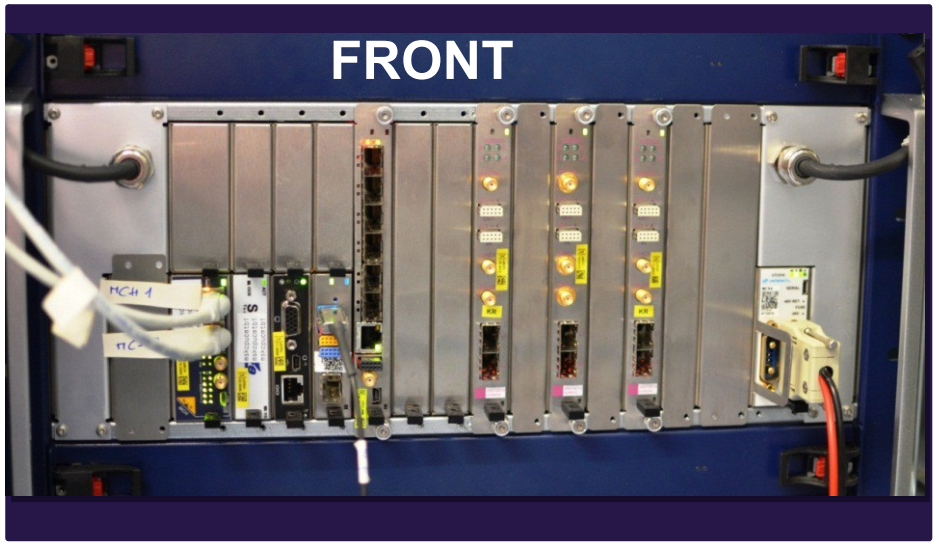
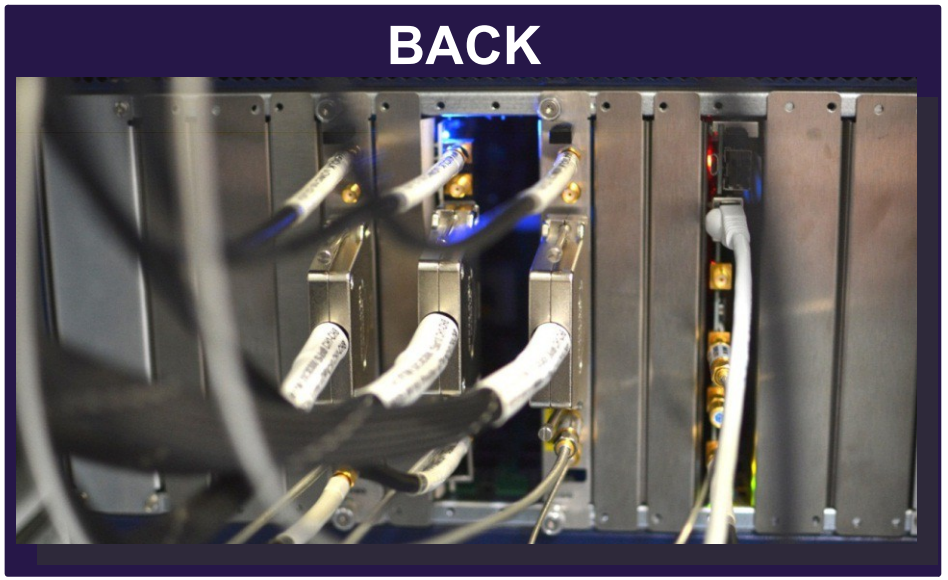
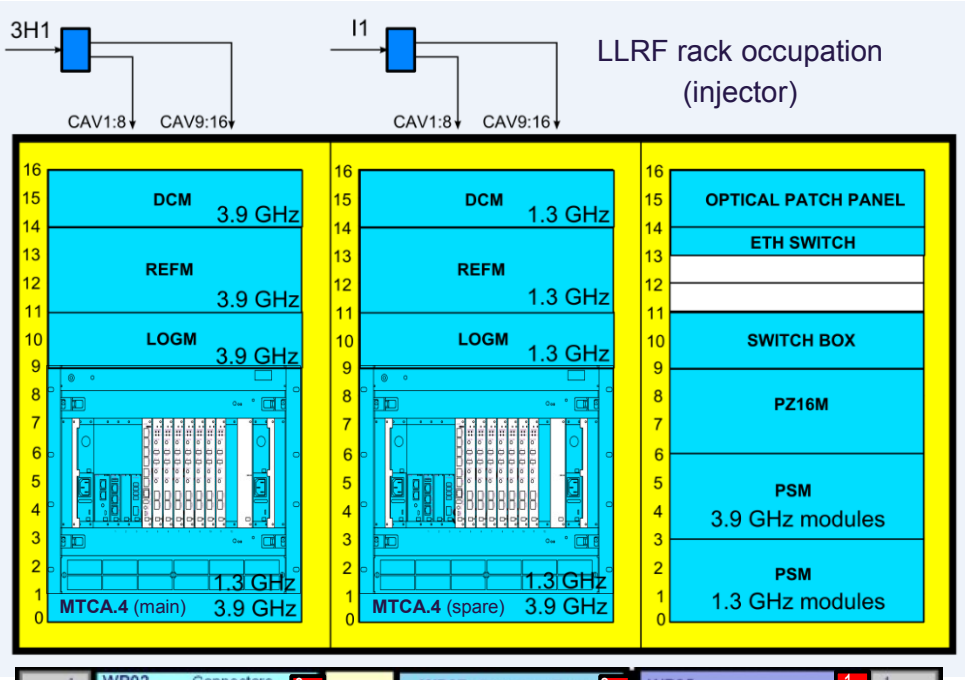


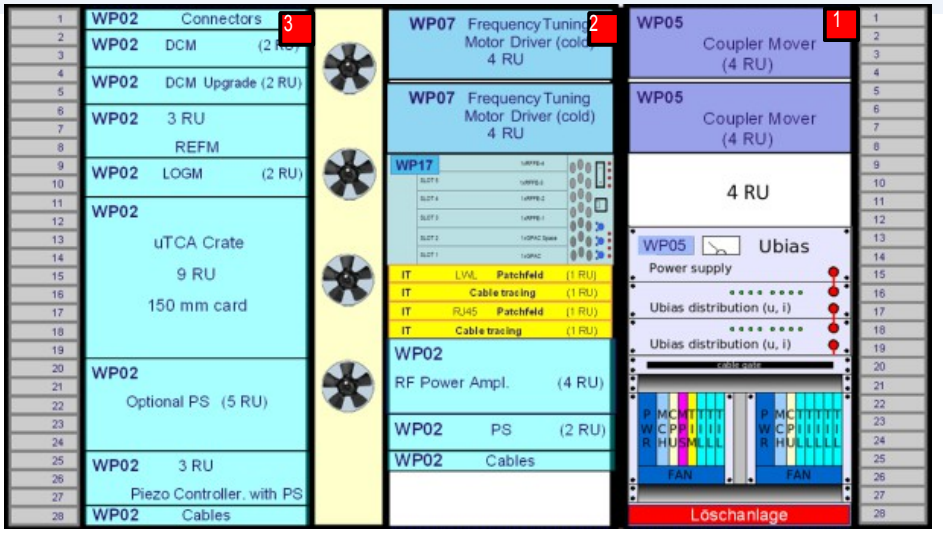
LLRF System Architecture





MTCA.4 crate

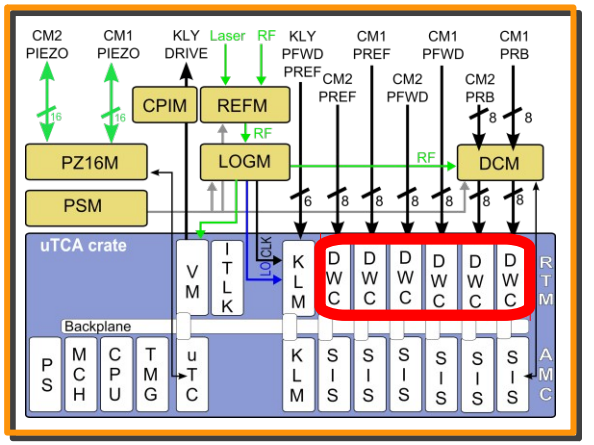


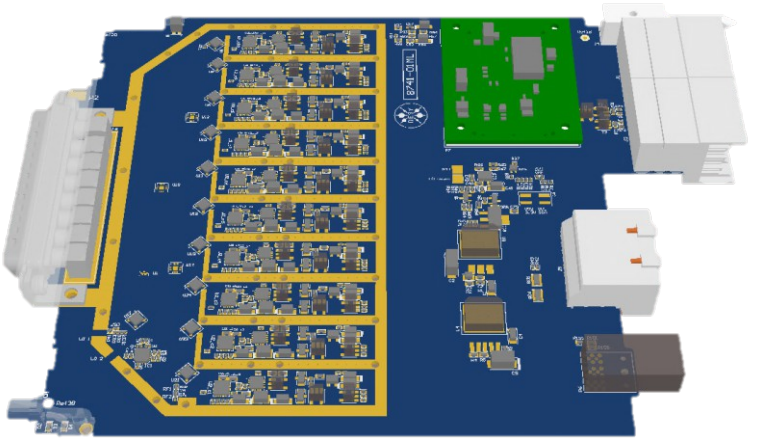


LLRF rack occupation (main linac)

Hardware

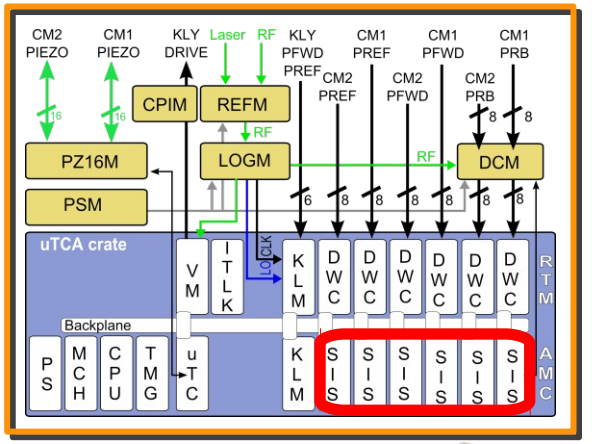
- **uDWC**: MTCA.4 Down-Converters
  - uDWC previous version in operation (FLASH/CMTB/REGAE/AMTF)
  - uDWC version 2.1 passed all tests (final version: 2.2)
  - Mass production scheduled for Spring ‘13
  - Test stand for quality control ready



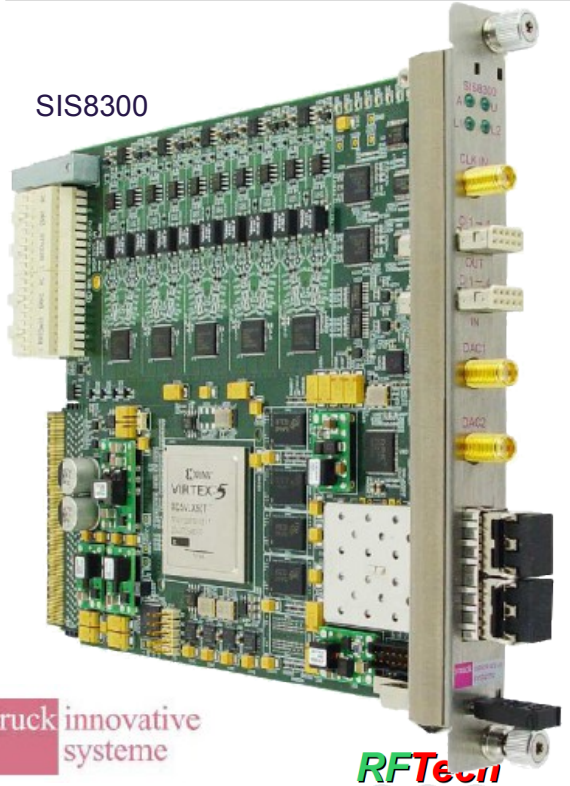


Hardware

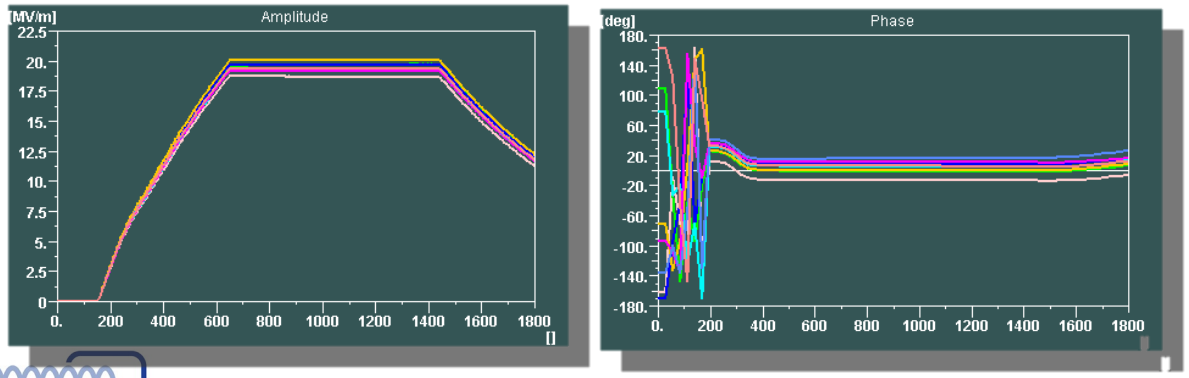
- **uDAQ**: MTCA.4 Digitizer board
  - First version in use (FLASH, CMTB, …)
  - Redesign with more resources and standalone capability (ex. single cavity)
  - New version ready end of ’12
  - Firmware redesign to match new FPGA
  - Pre-series is curently tested tested



SIS8300



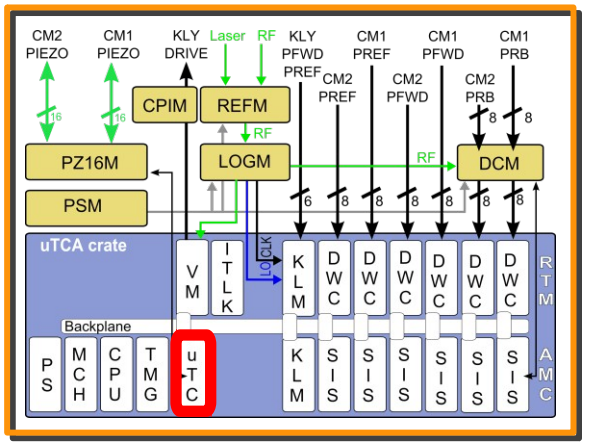
uDAQ running at FLASH

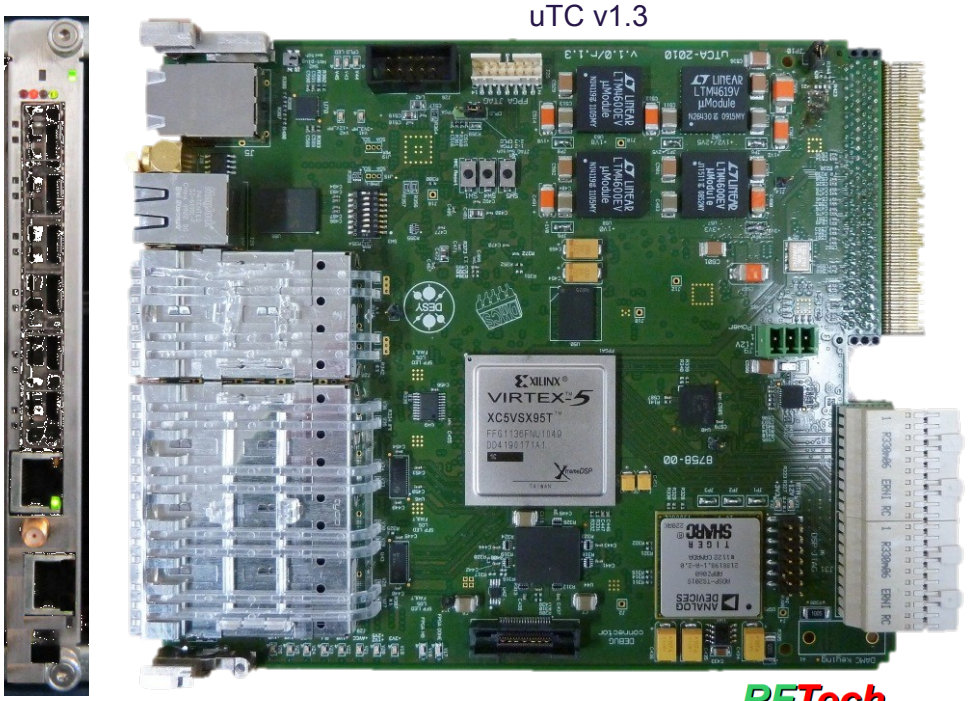


struck innovative systeme

Hardware

- **uTC**: MTCA.4 LLRF Controller
  - First version in use (FLASH, CMTB, …)
  - Redesign with more resources, faster processing and more connectivity
  - New version ready early ’13
  - Firmware redesign to match new FPGA
  - Mass production: Spring’13

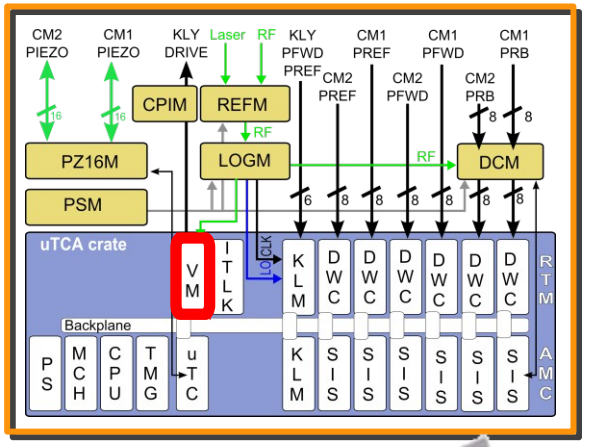




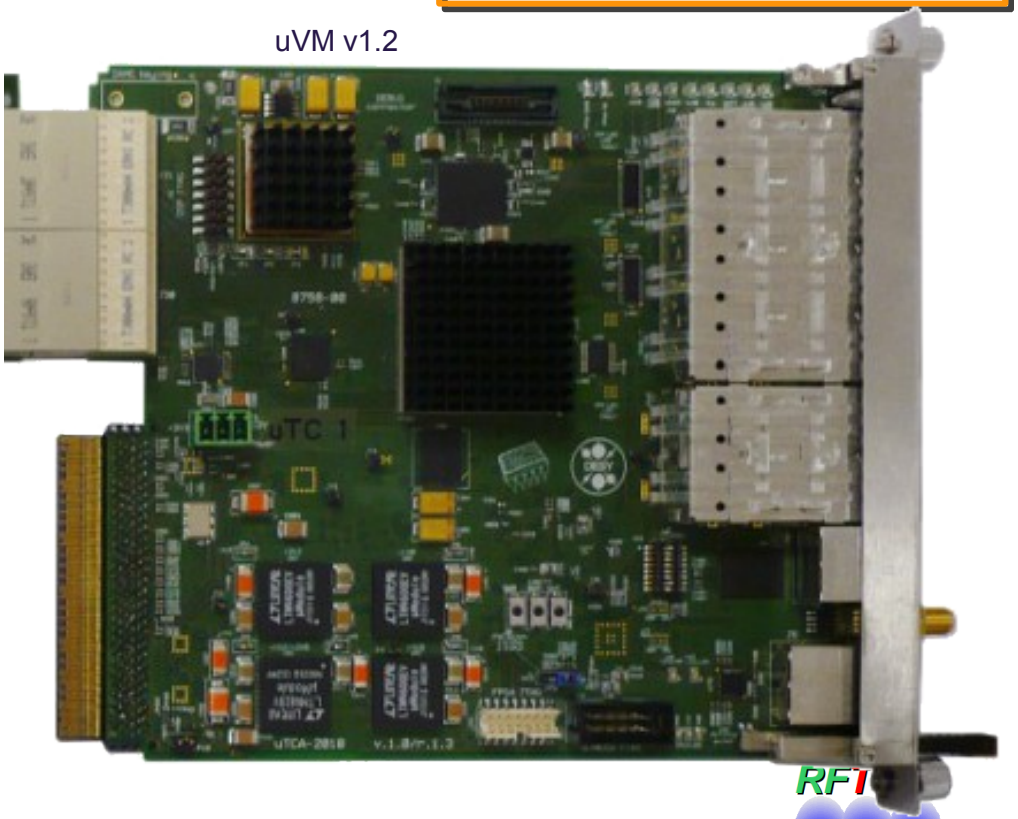
- new design with Kintex VII
- suited for photon diagnostics

Hardware

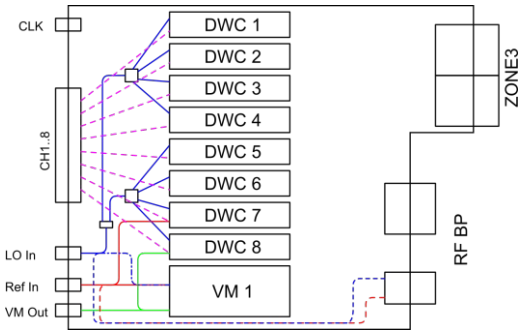
- **uVM**: MTCA.4 Vector Modulator
  - Version 1.2 in use (FLASH, CMTB, …)
  - Latest version (2.0) currently under tests
  - Mass production: Fall'13
  - New "combo" board design underway (uDWC + uVM)
  - Standalone version (single cavity)
  - Production this year



uVM v1.2

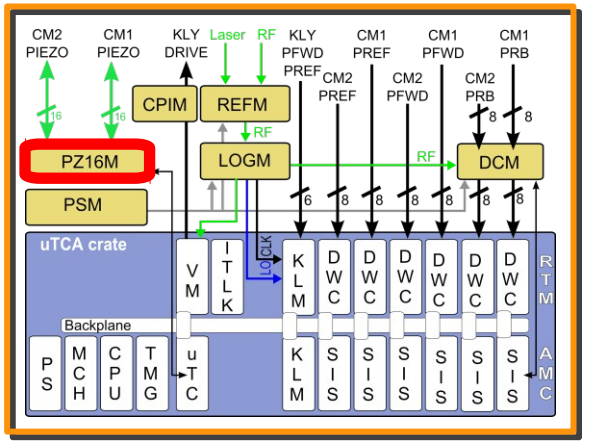


uDWC_VM



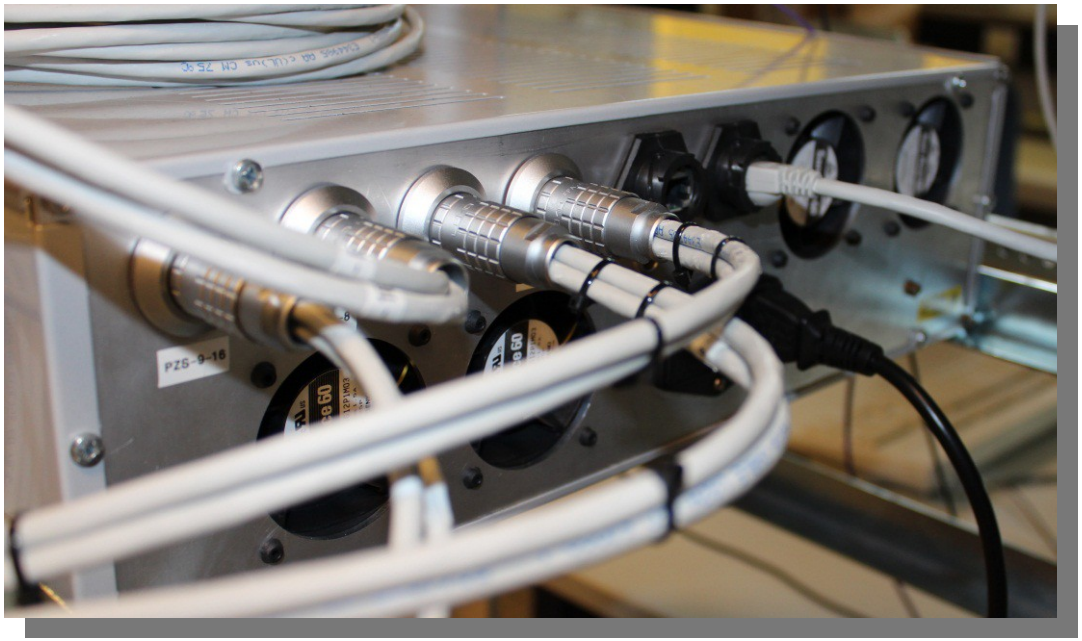
Hardware

- **PZ16M**: Piezo Driver Module
  - Prototypes in use at FLASH/CMTB/AMTF
  - 10x pre-series orders to I-Tech
  - Rest of prod. scheduled for Summer ‘13



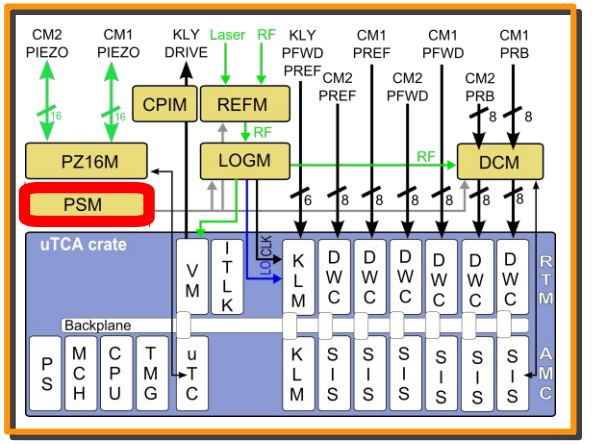
PZ16M prototype (front)

PZ16M prototype (rear)

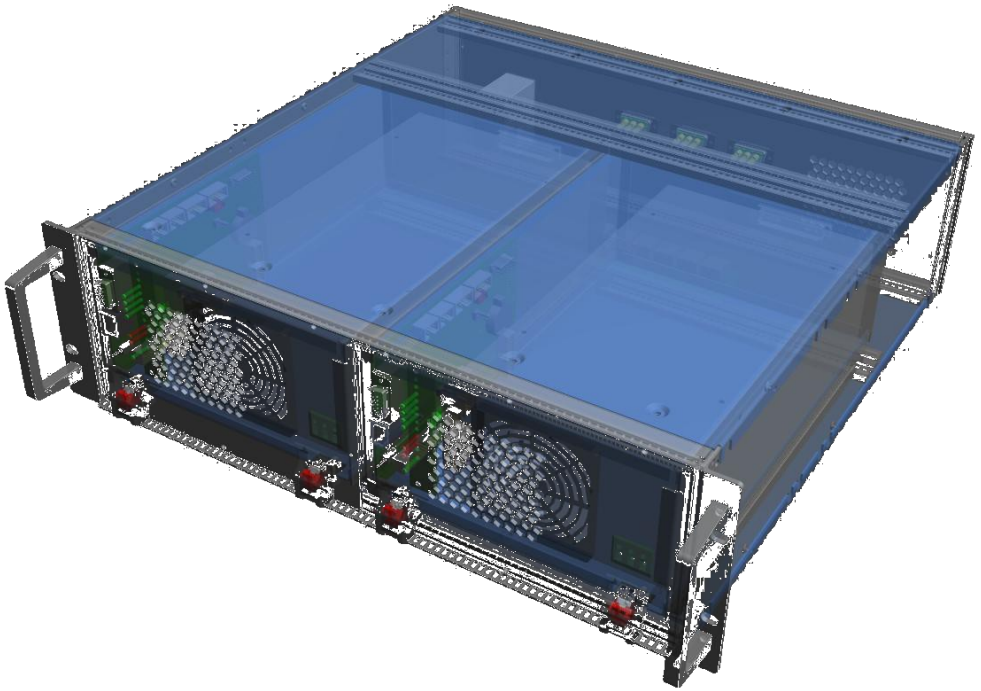


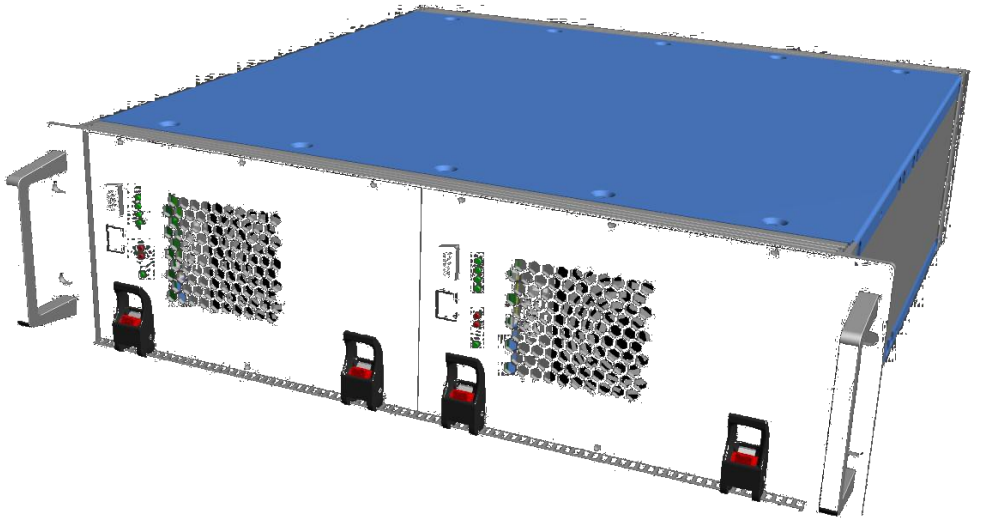
Hardware

- **PSM**: Power Supply Module
  - 2 competing vendors (ELMA and Wiener)
  - First prototypes in tests



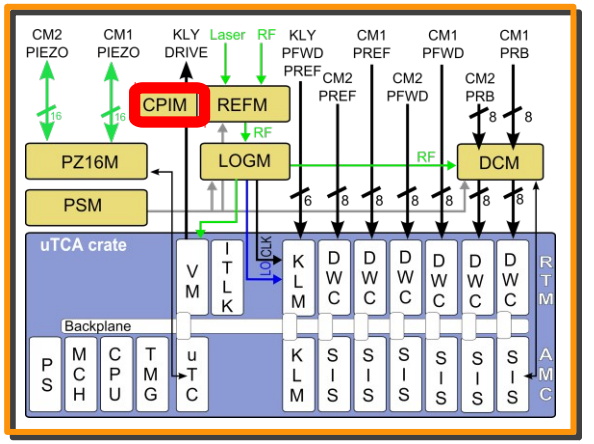
ELMA prototype



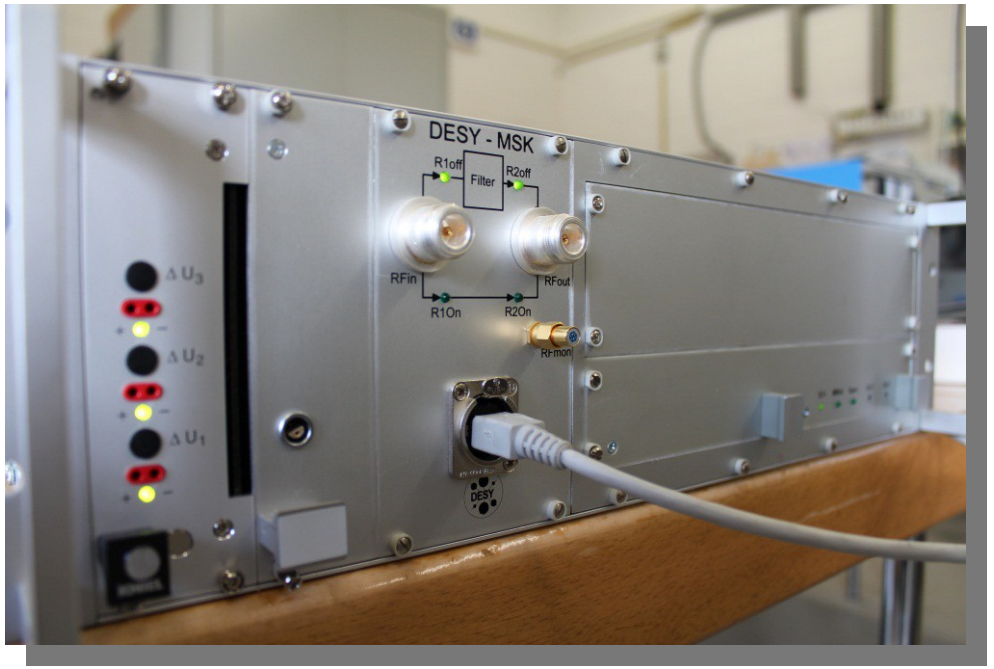


Hardware

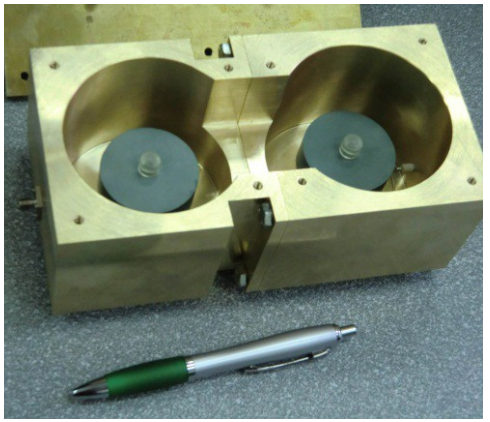
- **CPIM**: Coupler Processing Interlock Module
  - 2 prototypes ready (CMTB, AMTF)
  - Software and GUI ready
  - Mass production launched (30 units)

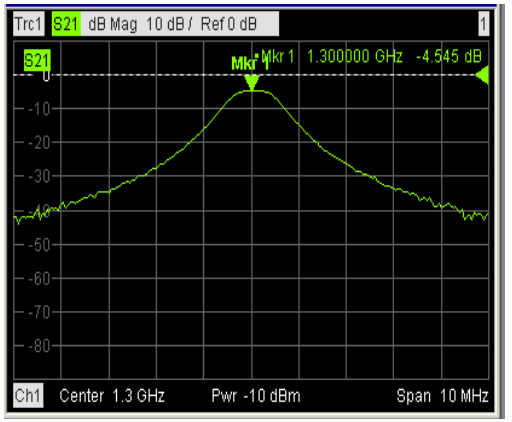


CPIM (prototype)



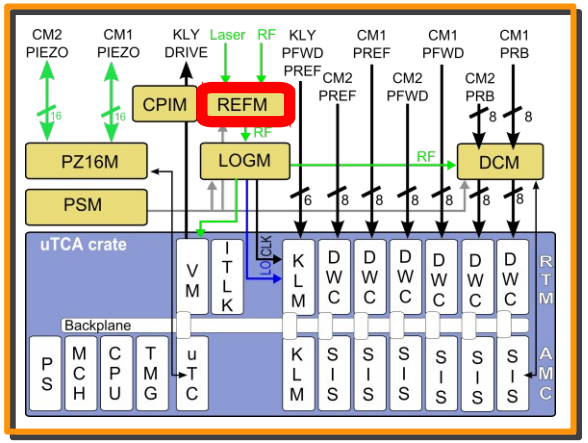
RF filter



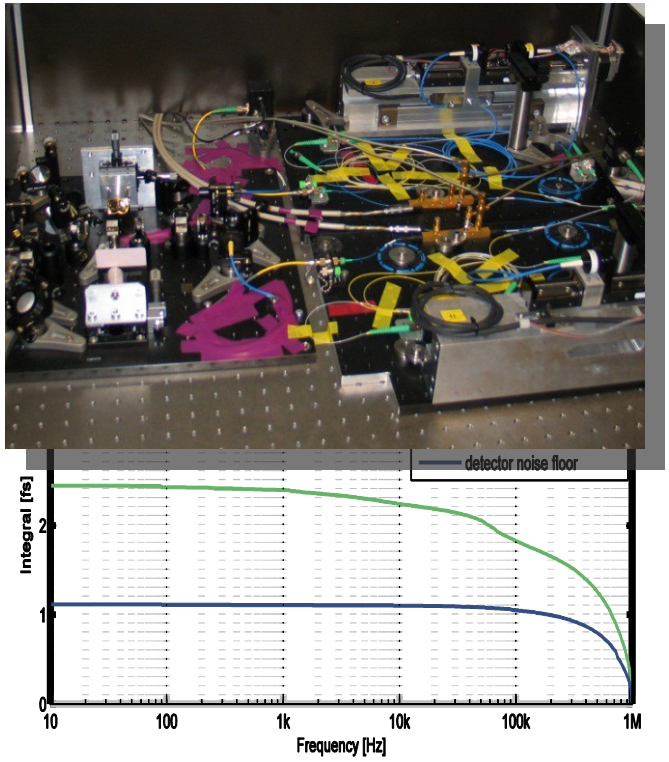


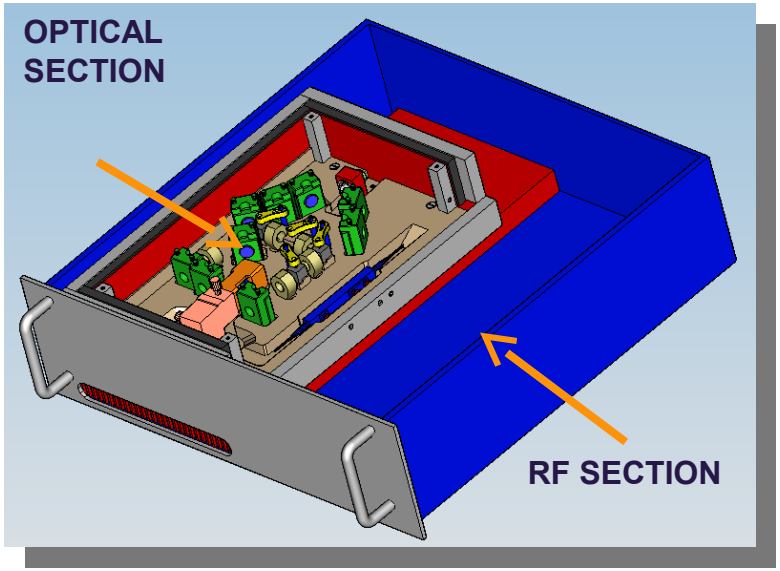
Hardware

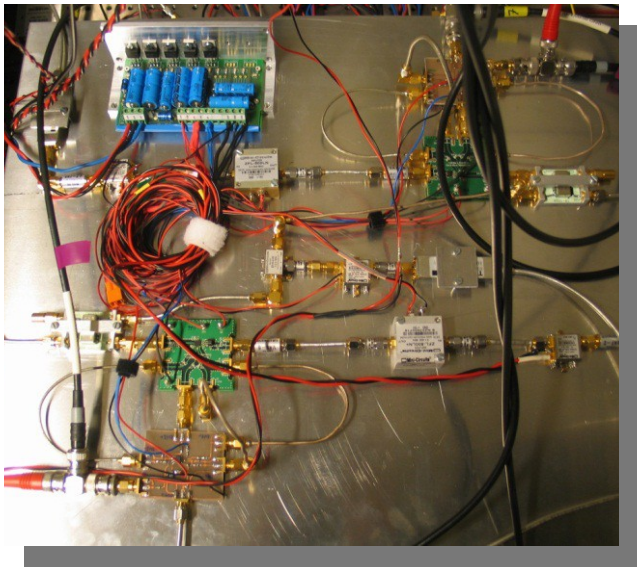
- **REFM**: REFerence Module
  - First version ready mid this year
  - First results: DESY highlight (2.5 fs jitter)



Optical (Mach-Zehnder interferometer)



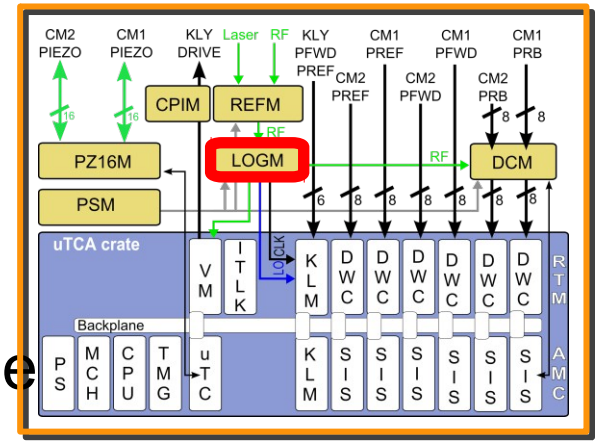




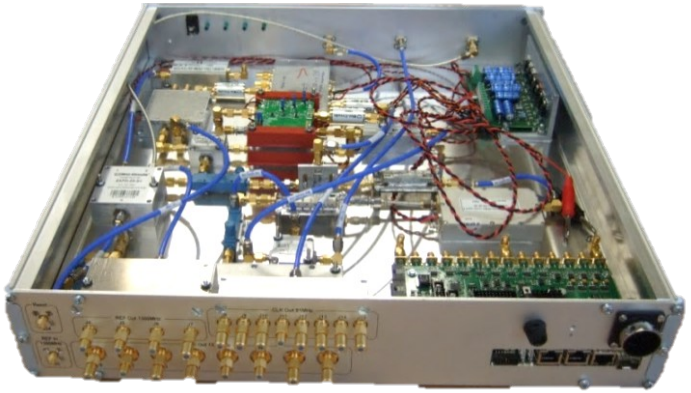
RF (PCB ready early '13)

Hardware

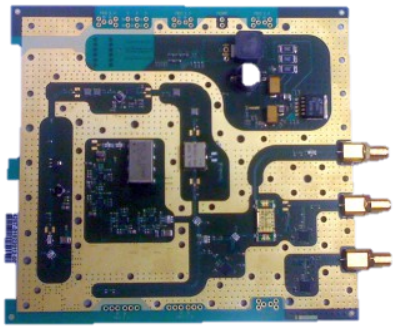
- **LOGM**: Local Oscillator Generation Module
  - Prototypes in use at FLASH/CMTB/AMTF
  - New PCB version ready in Fall this year
  - 1st MTCA.4 version uLOG expected Summe

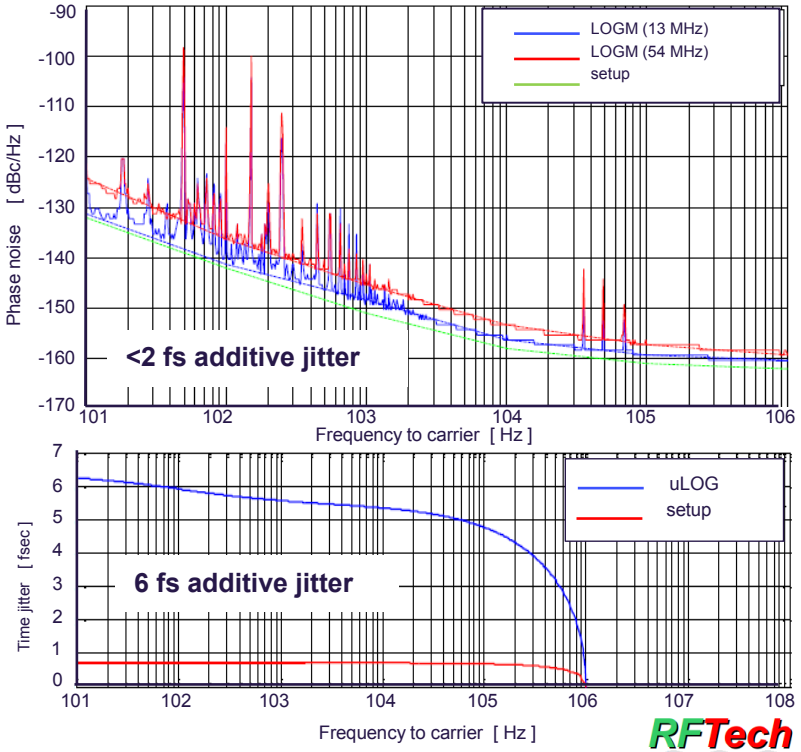


LOGM prototype



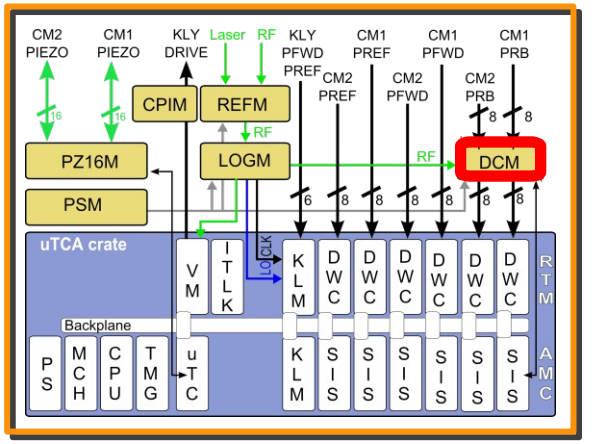
uLOG
(compact LO generation)

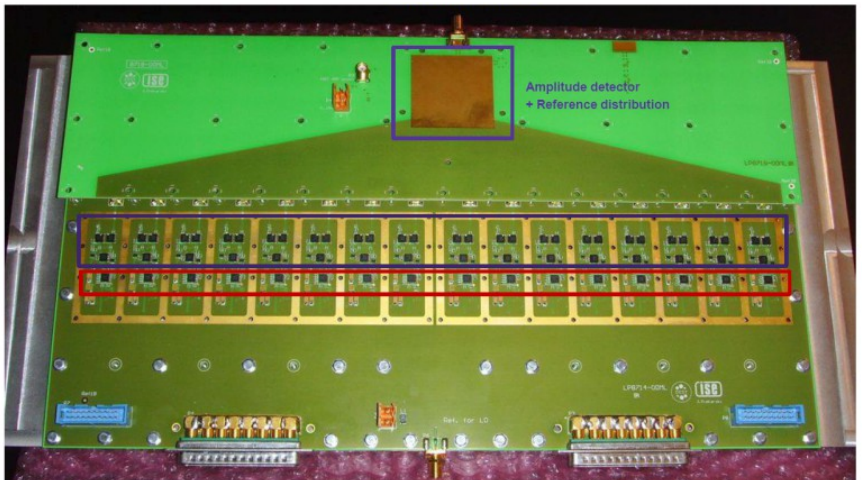




Hardware

- **DCM**: Drift Compensation Module
  - Prototype in use at CMTB
  - Goal reached
  - Could be improved by factor 2-3
  - New version after test results (early ‘13)
  - Firmware under development

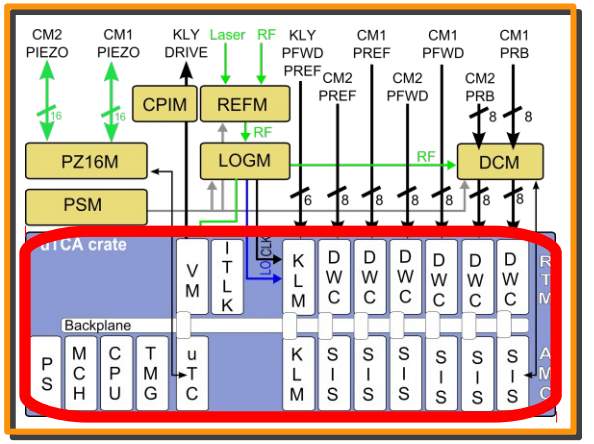




DCM (first prototype)

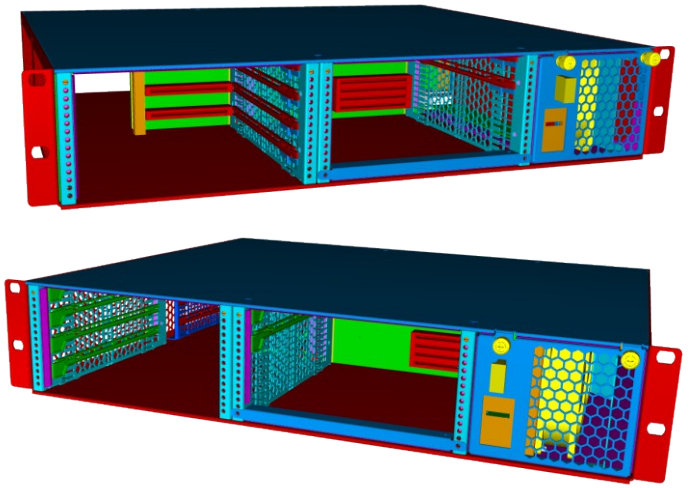
Hardware

- **MTCA.4 crate**
  - 2 vendors: ELMA and SCHROFF
    - Redesign to optimize air-flow
  - Many use in lab operations (FLASH / CMTB / REGAE / AMTF)
  - Smaller form factor design



ELMA MTCA.4 crate

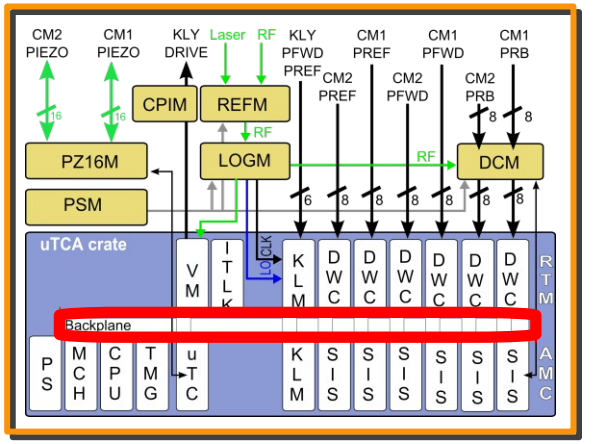
SCHROFF MTCA.4 crate

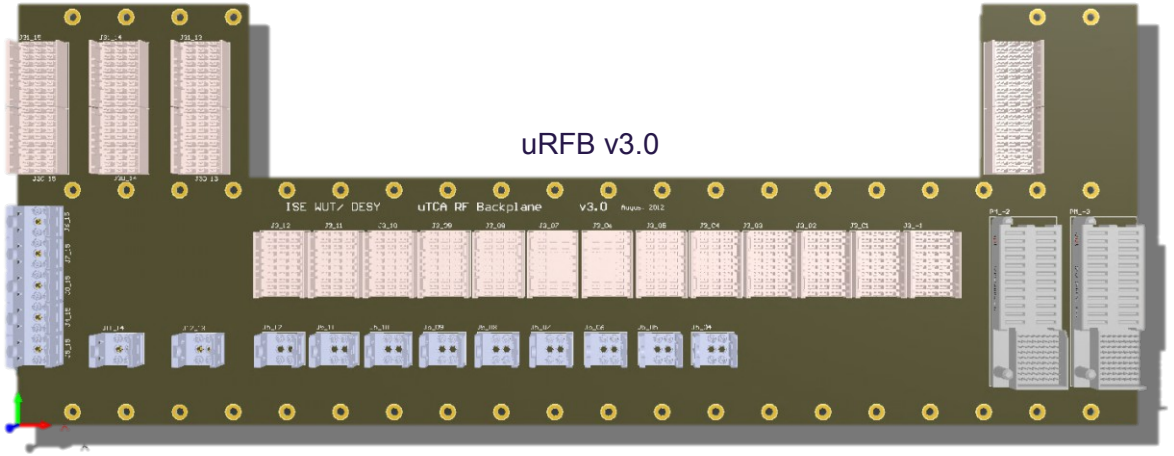


SCHROFF 2U MTCA.4 crate

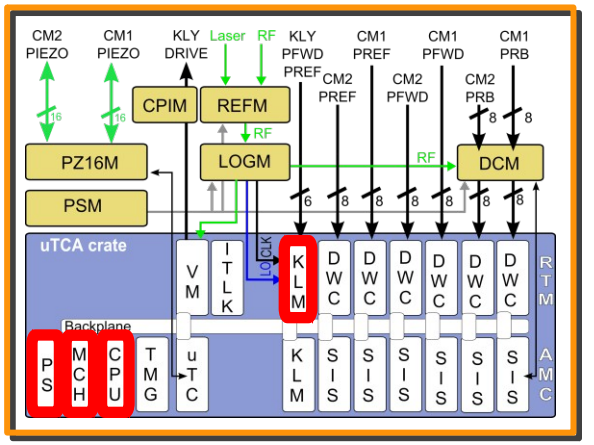
Hardware

- **uRFB**: MTCA.4 RF backplane
  - Several prototypes successfully tested
  - PCB ready end of Nov.'12
  - Full integration with uLOG Spring'13
  - Mass production Summer'13





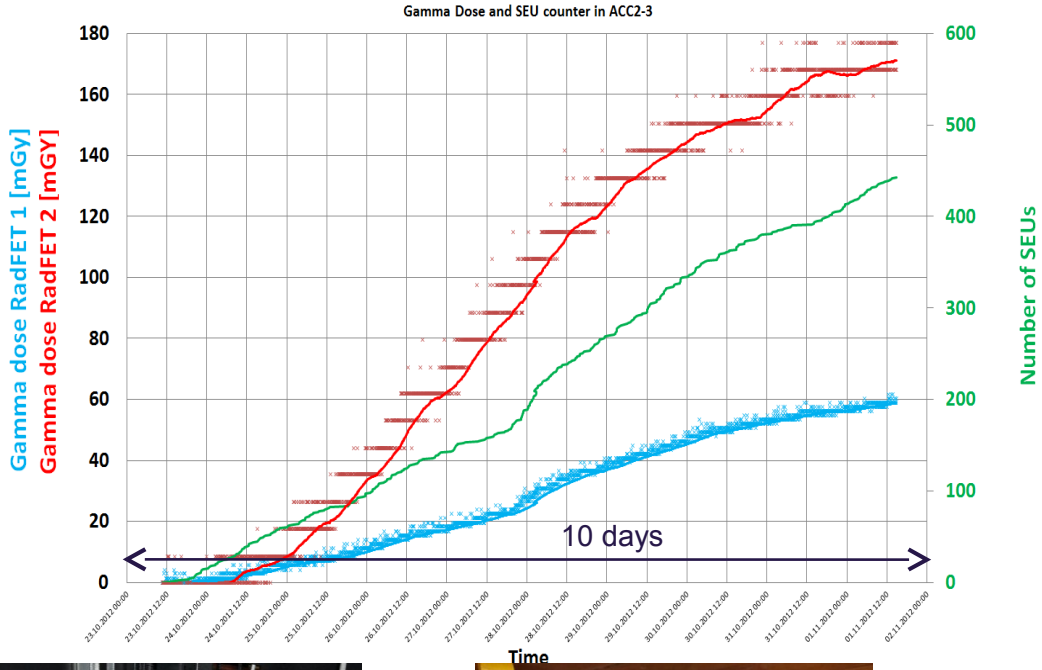
HARDWARE

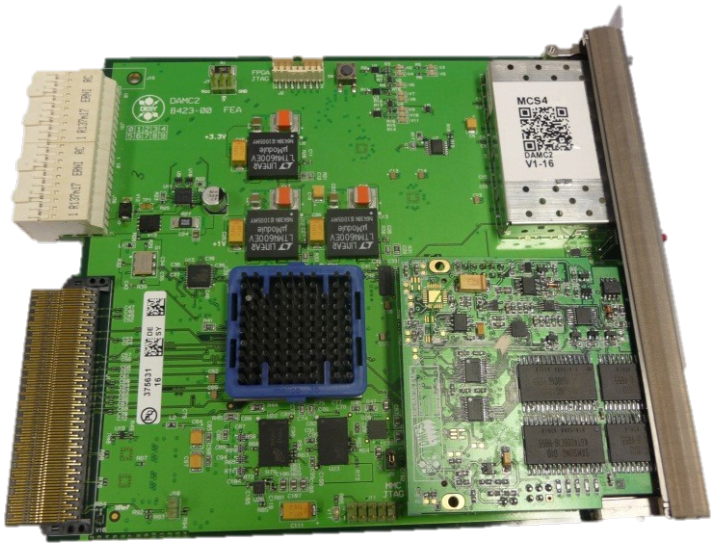


- **other MTCA.4 boards**
  - MCH: MTCA.4 controller hub
    - redesign with NAT, double width (Dec.'12)
    - new concept for RTM MCH (Spring'13)
  - CPU: MTCA.4 CPU + HDD
    - latest version (Concurrent) under test
  - uPS: MTCA.4 power supply
    - long delays from vendors (power management issues), **critical path**
    - overheating issues
  - uDS800: MTCA.4 fast ADC for KLM & HOM
    - AMC prototype ready early'13
    - specific RTMs for Klystron Lifetime Management and HOM

Hardware

- **FMC RadMon**
  - ACC1 and ACC23 racks
  - Shielding with closed doors
    - 0.45 mGy / h
    - 2 SEU / h
  - Expected radiation
    - **1 SEU / day / board**

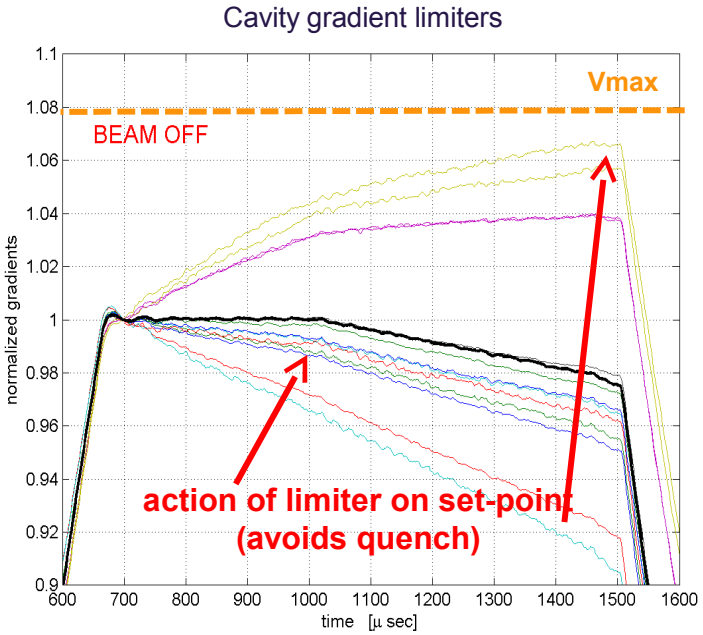


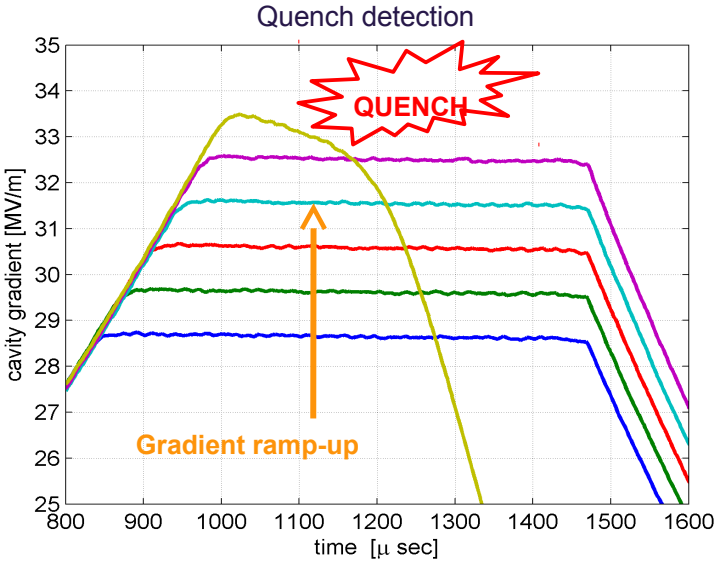


DAMC02 carrier with FMC RadMon

Firmware & Software

- On-going development
  - Test when we can / where we can
    - FLASH (when time)
    - CMTB (when module)
    - REGAE (warm cavity)
- New tools development
  - Implemented and tested at FLASH
  - Automation
    - QL, piezo
  - Machine protection
    - cavity gradient limiters (Vcav < Vmax)
    - quench detection (crucial for cryo)
    - klystron lifetime management

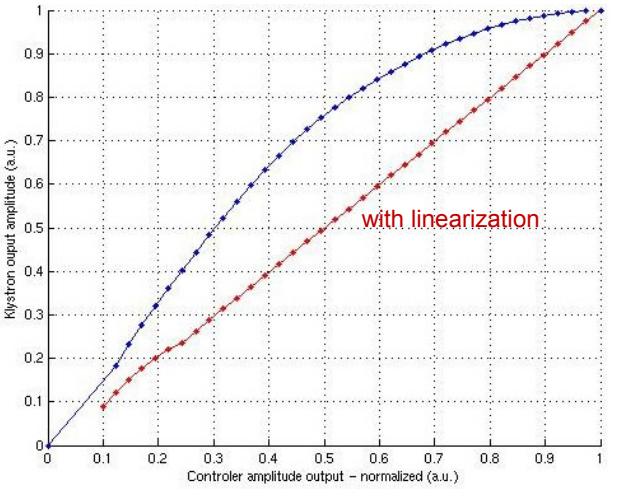




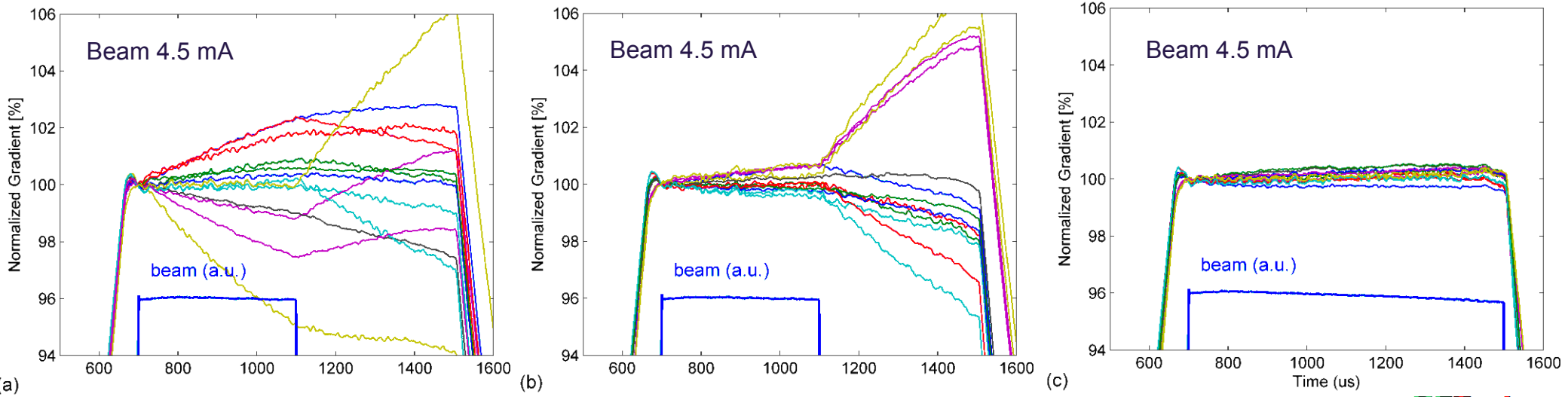
Firmware & Software

- New operation strategies implemented and validated during ILC 9mA studies
  - Klystron linearization
  - Compensating beam induced gradient tilts with motorized cavity couplers (QL)

Klystron Linearization



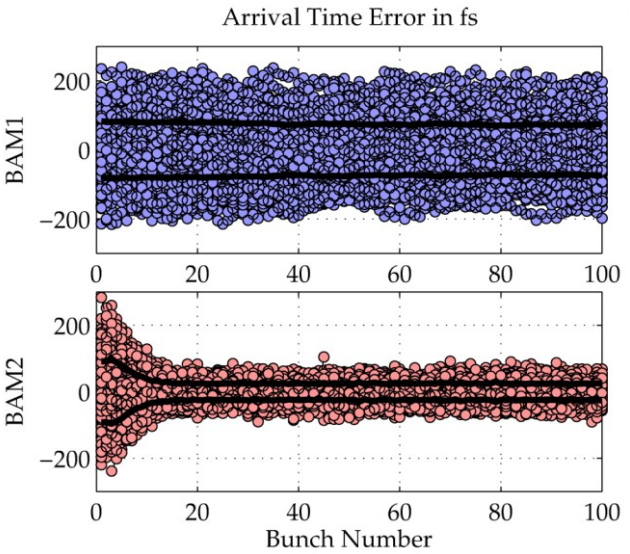
Flattening gradients with QL

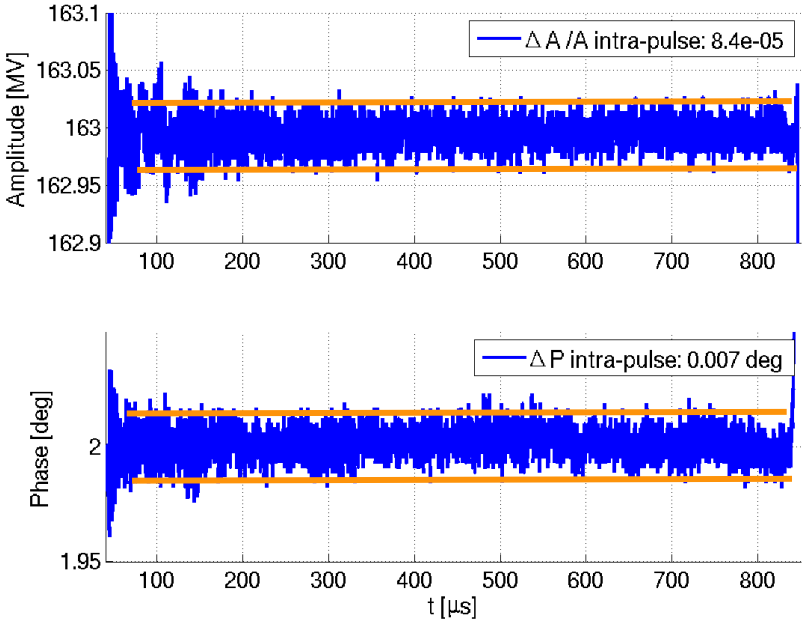


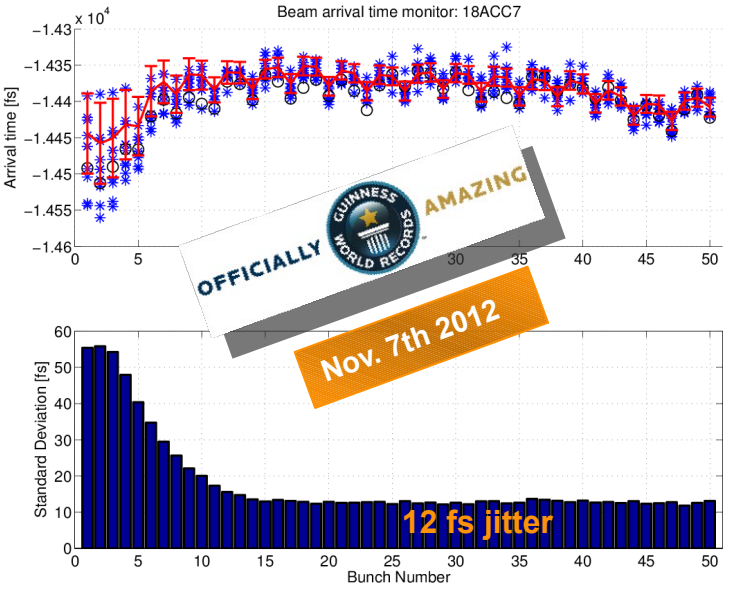
Firmware & Software

- Improvement of LLRF control performance
  - Beam-based feedback (tested at FLASH)
    - factor of 3 improvement in arrival time jitter
  - Cavity fundamental modes (tested at FLASH)
    - detection & filtering of 8π/9 and 7π/9 modes
  - ΔA/A < 9x10-5 , Δϕ < 0.008 deg. achieved

Beam-based feedback

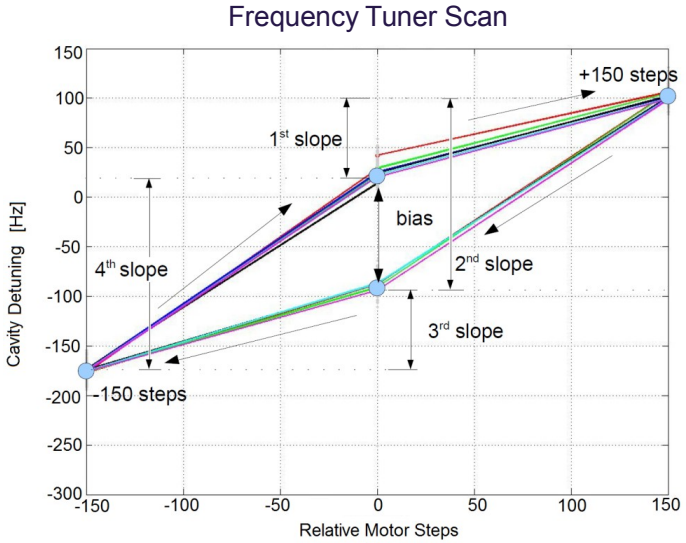


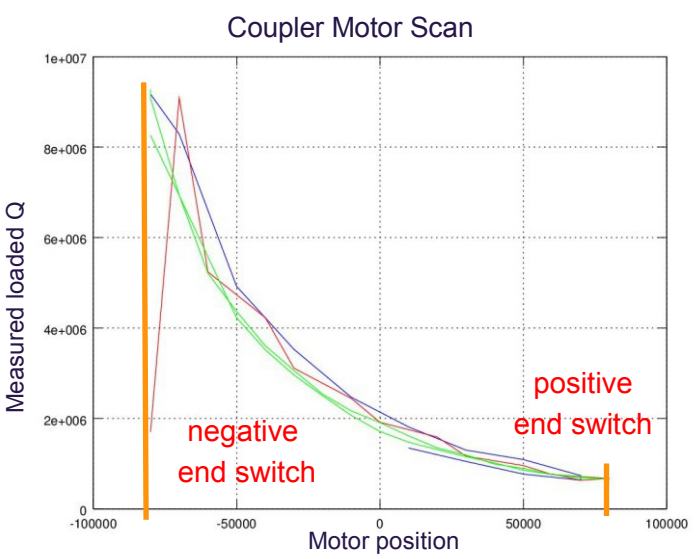


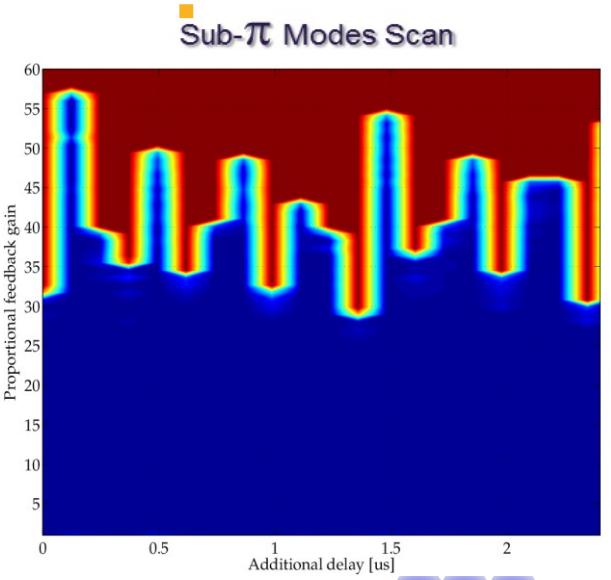


Firmware & Software

- AMTF **LLRF Test Suite** to characterize:
  - cavity piezos (sensor/actuator)
  - cavity frequency tuner
  - cavity coupling motor
  - cavity quench profile
  - cavity fundamental modes
  - cryomodule performance under nominal operation







Summary

- thanks to EU support (EuCARD/RFTech) the strong collaboration was organized
- xTCA extension for instrumentation has been proposed (hardware manufacturers has started components design and production)
- the new LLRF system has been developed using the xTCA architecture
- the prototype system has been initially tested at FLASH and CMTB with very good results (performance improvements)
- permanent FLASH installation is in progress

Acknowledgment

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- Gerth Christopher
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- Hacker Kirsten
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- Rutkowski Igor
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- Szczepanski Bartlomiej
- Szewinski Jaroslaw
- Tarnowski Szymon
- Weddig Henning-Christof
- Wendland Bibiane
- Wierba Woyciech
- Yang Bin
- Zembala Lukasz
- Zukocinski Mateusz

Collaborators:

Industry partners:

LLRF System Description

REFM
RF Reference Module

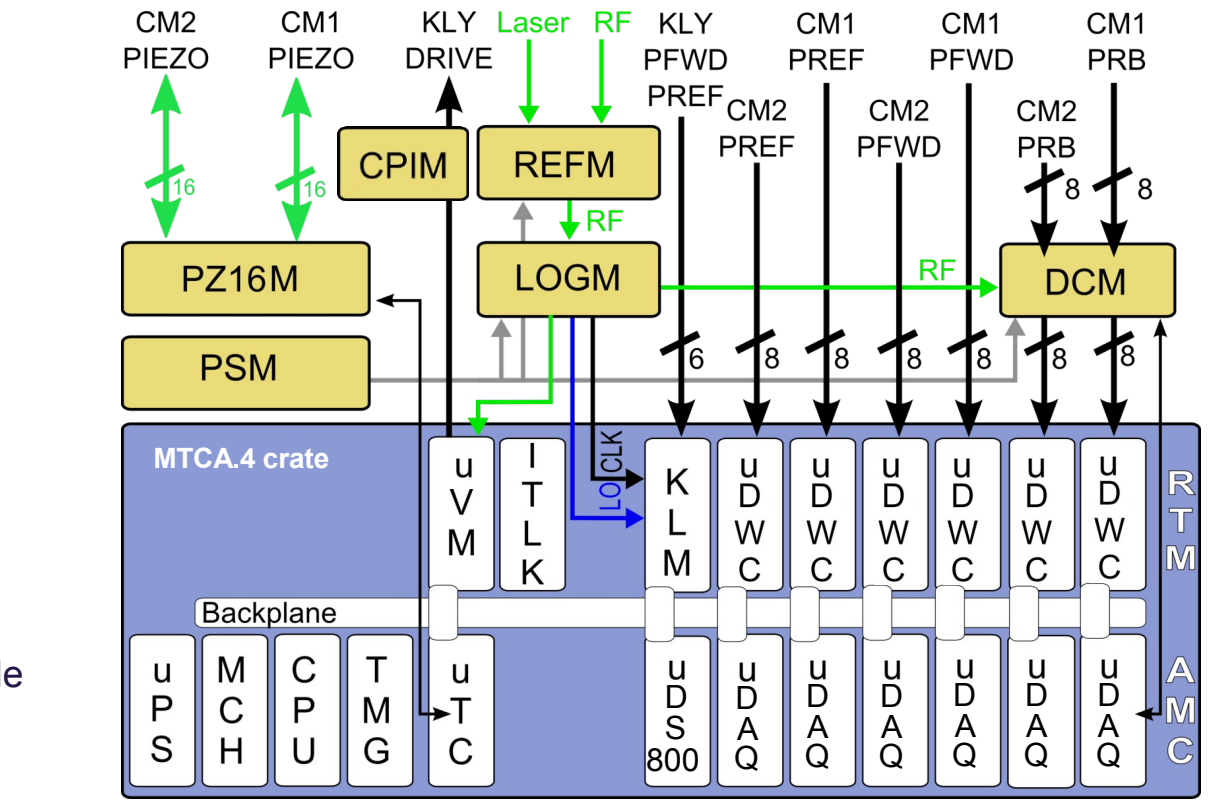
LOGM
Local Oscillator Generation Module

DCM
Drift Compensation Module

PZ16M
Piezo Driver Module

PSM
Power Supply Module

CPIM
Coupler Processing interlock Module



RTM Rear Transition Module
AMC Advanced Mezzanine Card

uPS Power Supply

MCH Management and Control Hub

CPU Computing Unit

TMG Timing

uTC Control board

uDS800 Fast ADC

uDAQ Digitizer board

uVM Vector Modulator

ITLK Interlock

KLM Klystron Lifetime Management

uDWC Down converter