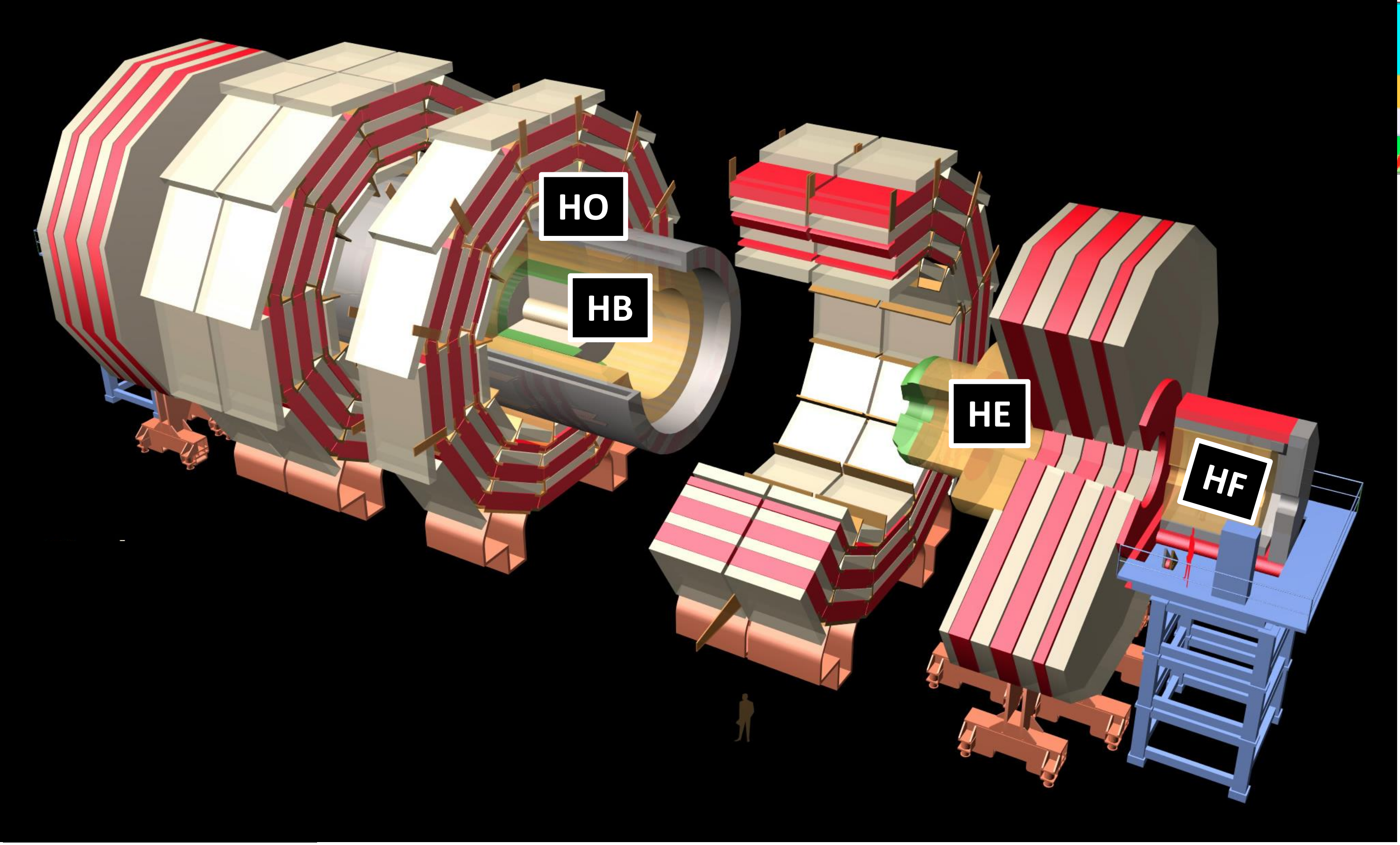


CMS HCAL Phase1* Upgrade

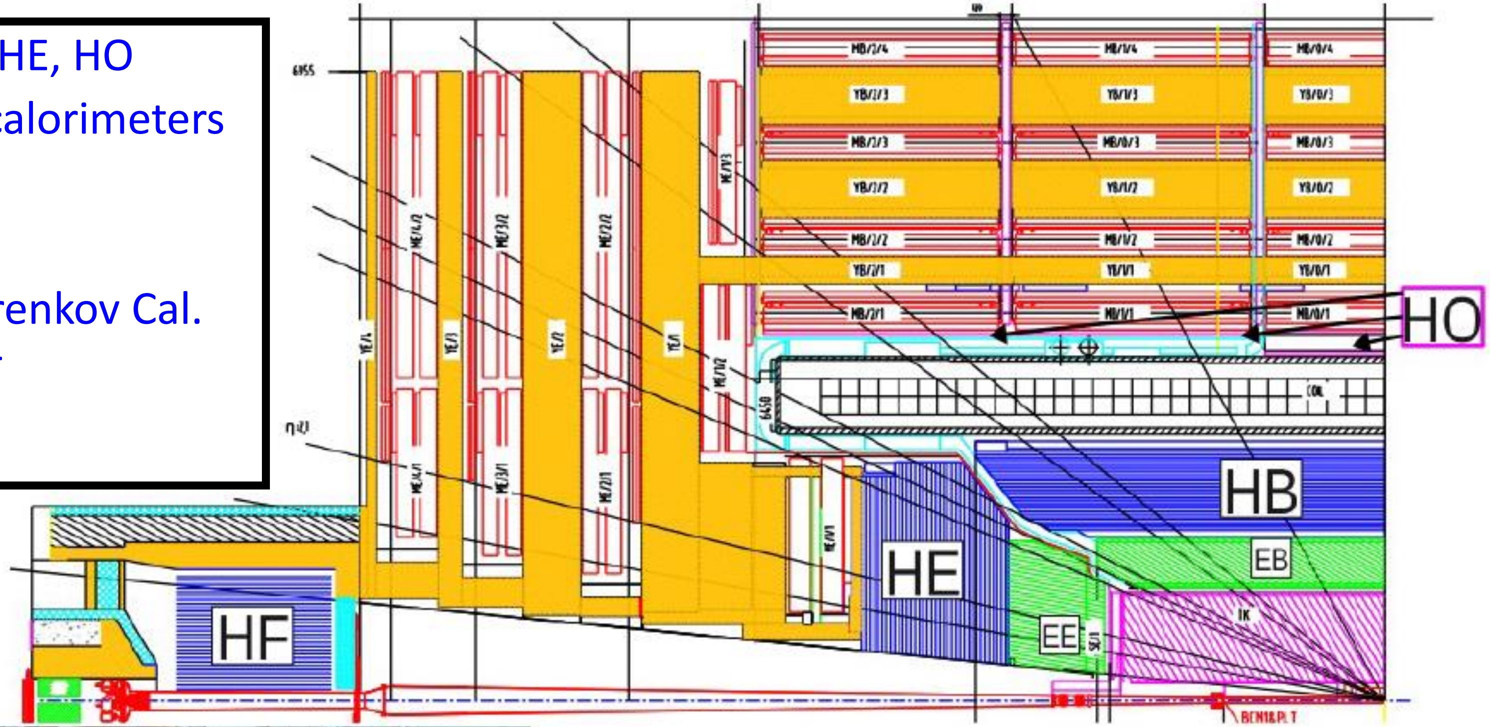
Gilvan A. Alves – CBPF/Rio

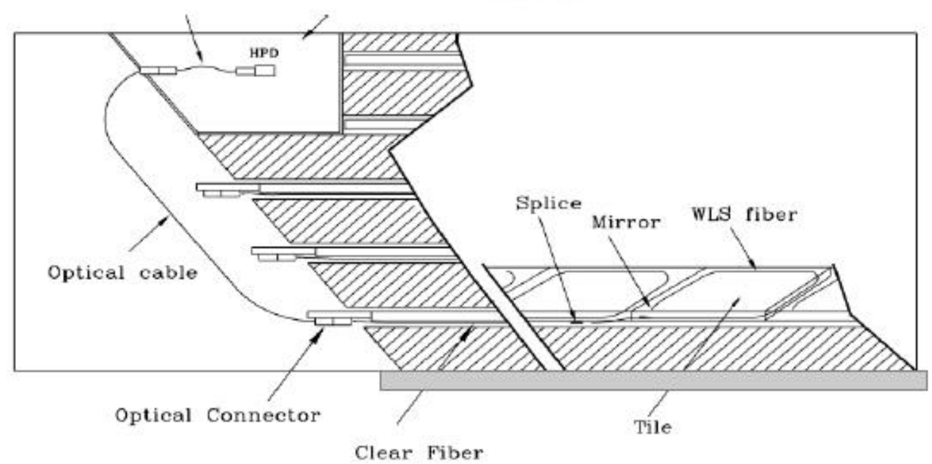
For the CMS Collaboration

*for phase2 and other see Tiziano's talk

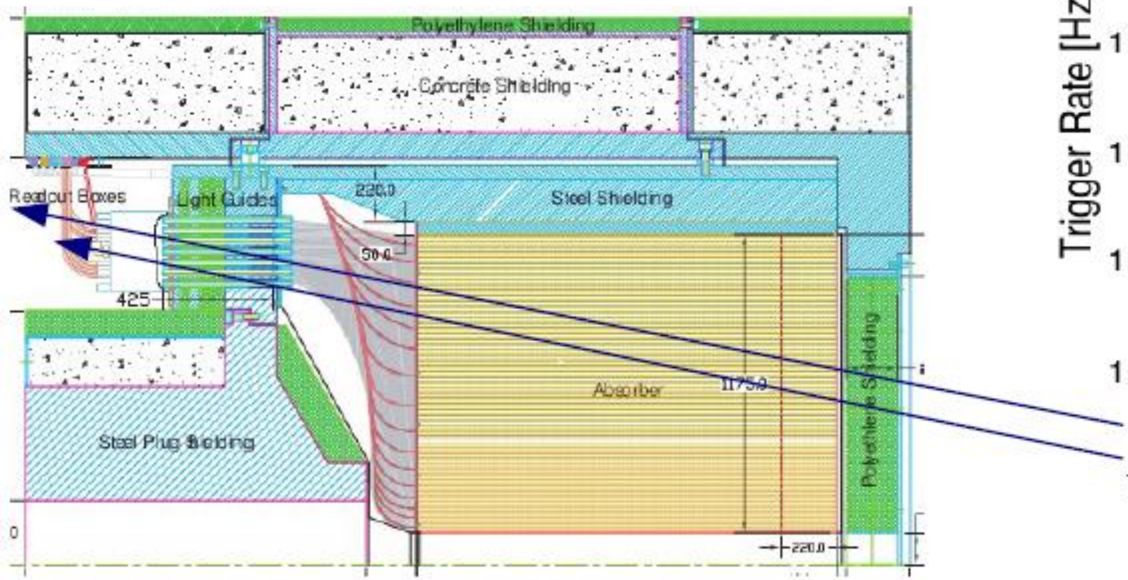
The CMS Hadron Calorimeters

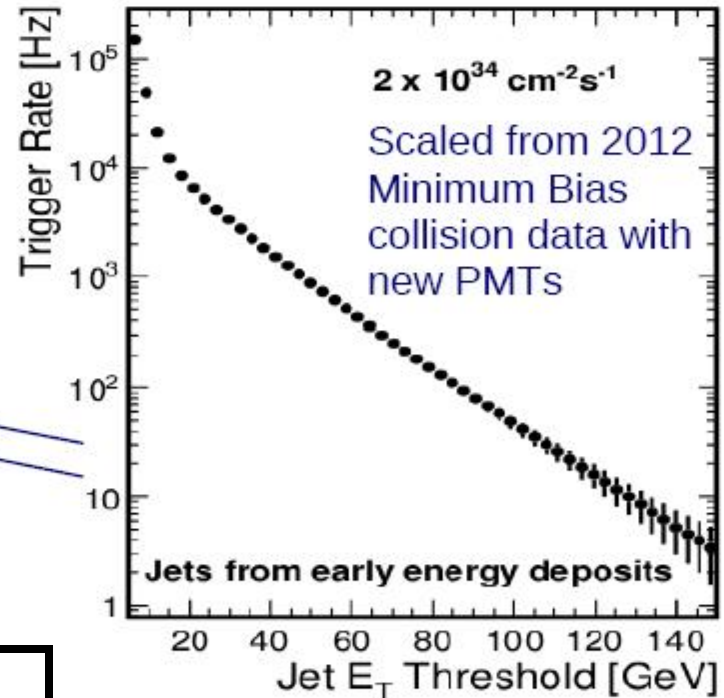
- HB, HE, HO
  Tile calorimeters
  HPD
- HF
  Cherenkov Cal.
  PMT



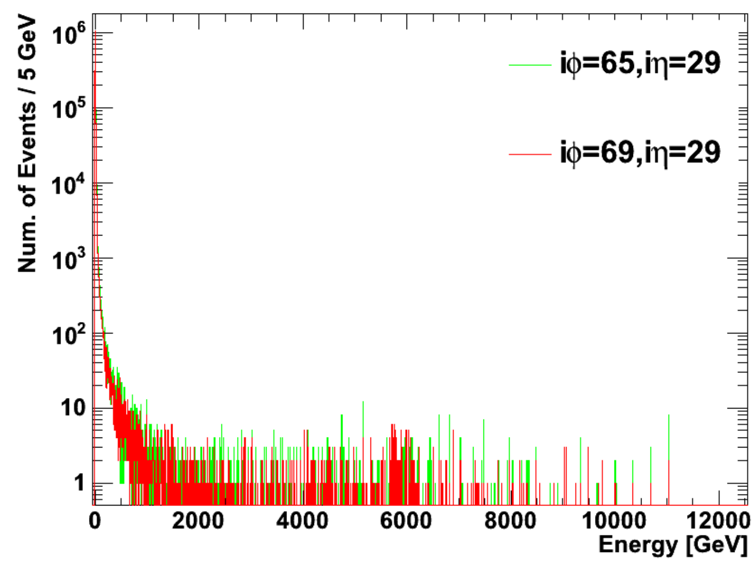


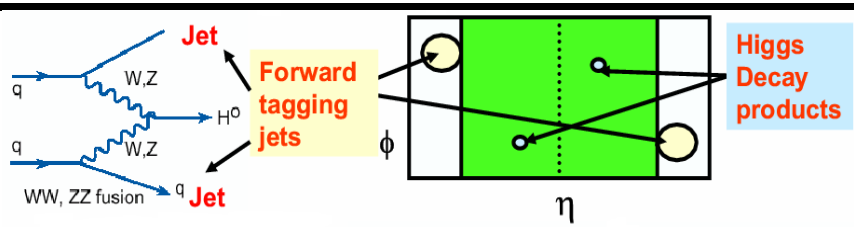
Why Upgrade? HF





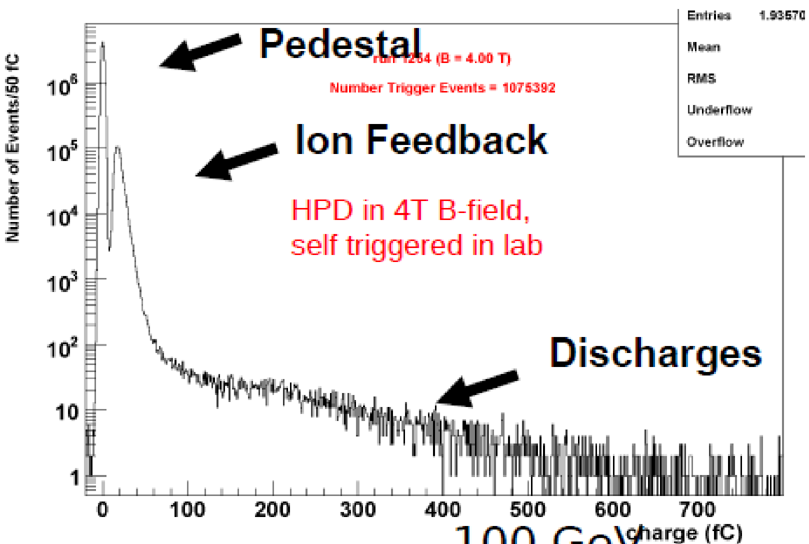
- Identified problems
  - Direct hits on HF PMT generate huge signals
  - OOT energy deposits generate fake signals
  - It only gets worse with pileup and 25ns
- Keep the performance in high pileup 25ns
  - VBF Higgs, MET

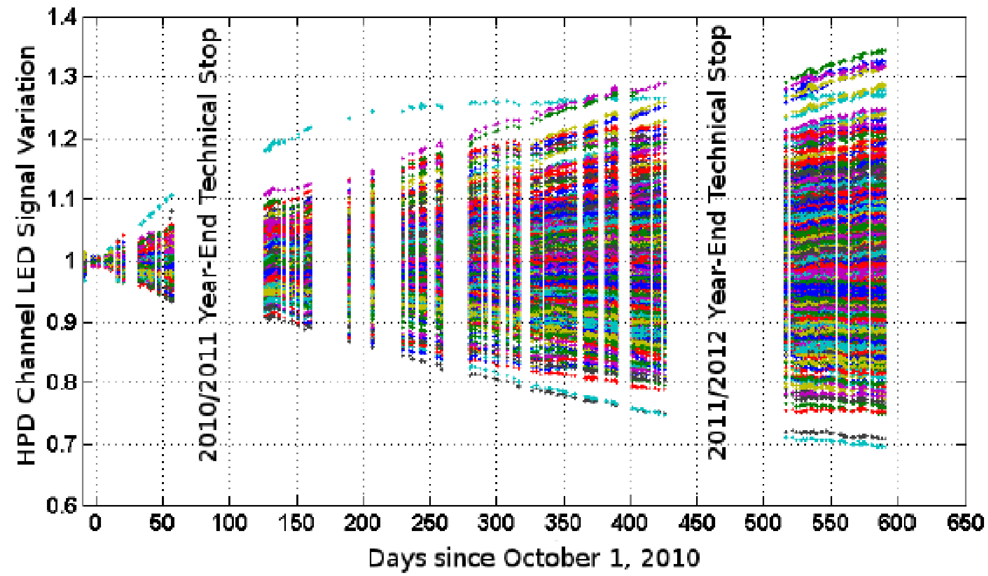




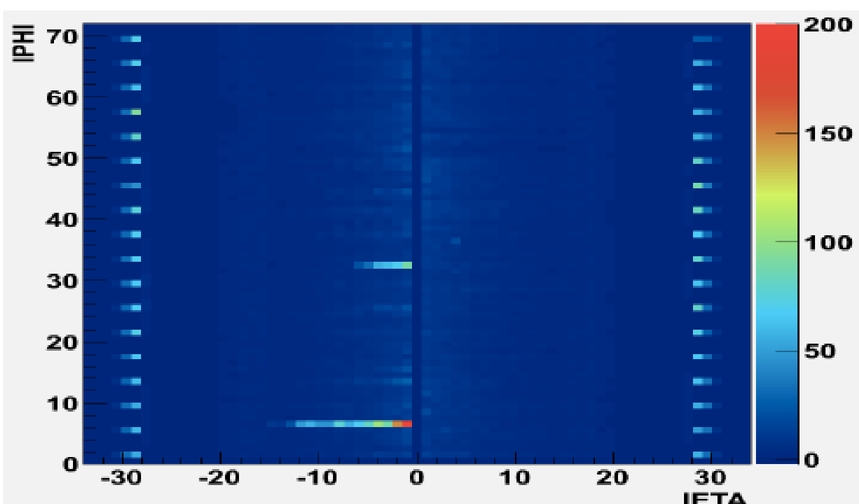
Why Upgrade? HB/HE/HO

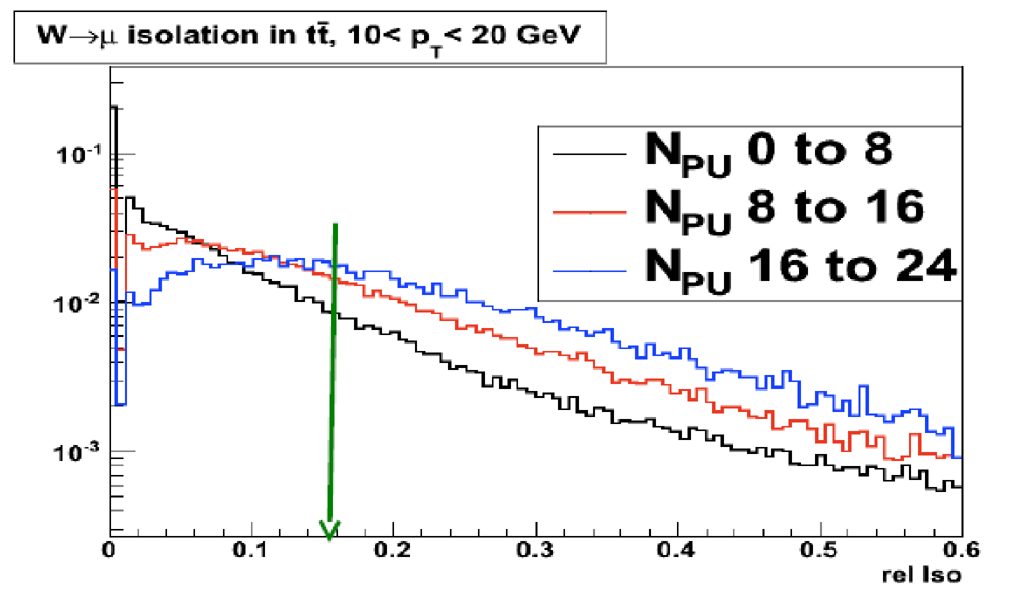
HPDs discharge regularly
(this is a good/typical HPD).



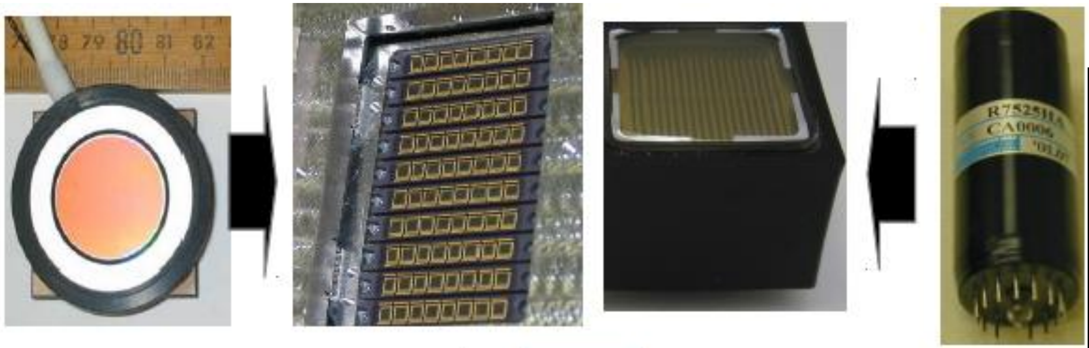


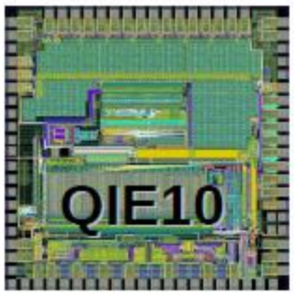
100 GeV

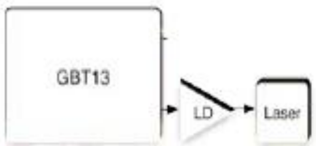




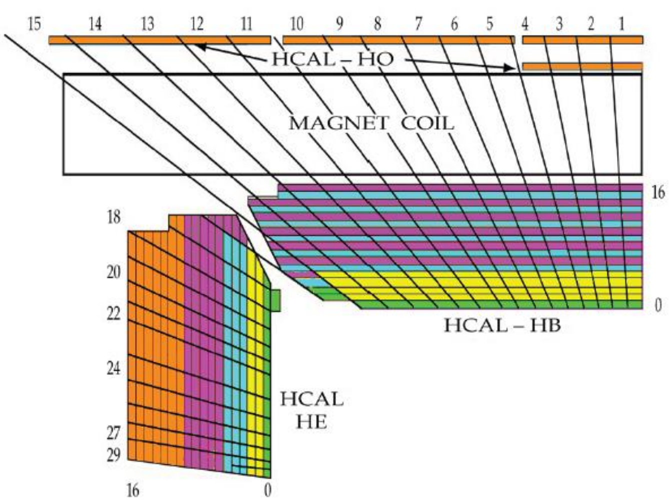
Upgrade in a Nutshell





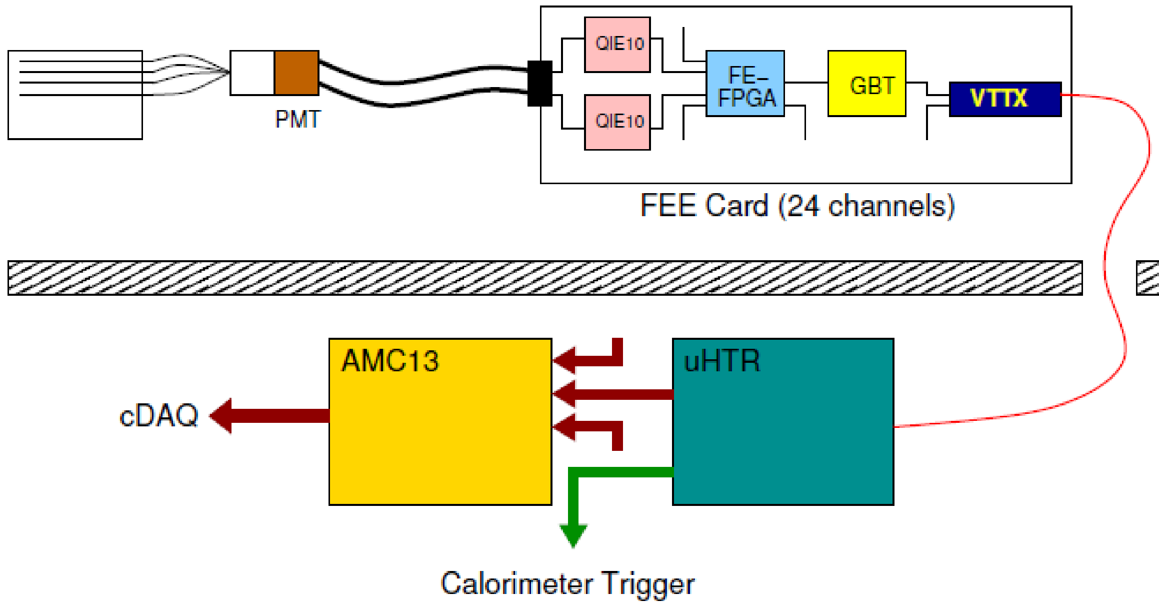


- Main Idea
  - Replace phototransducers to reduce noise and improve performance
  - Take advantage of new technologies to increase granularity (PFlow), add TDC information (pileup), etc.
  - Use as much common components as possible
  - Back-end installed and commissioned in parallel with CMS operations before F.E.

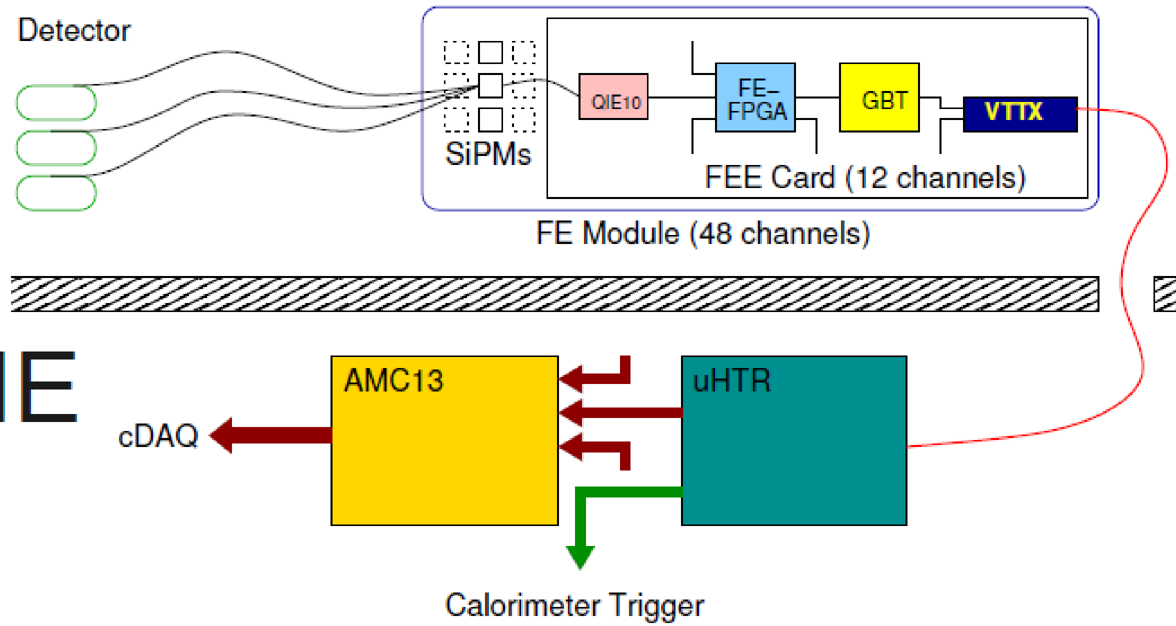


Upgrade in a Nutshell

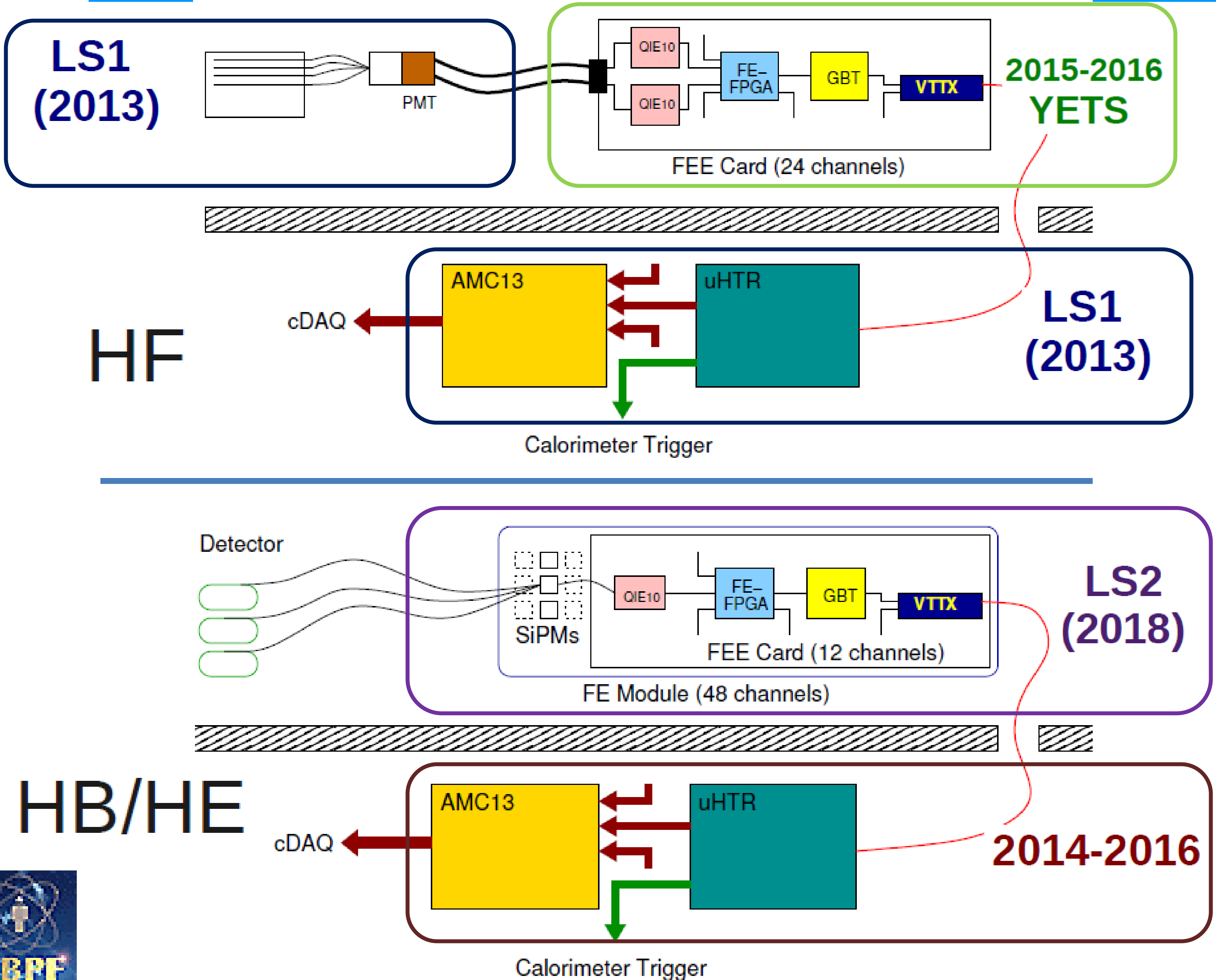
HF



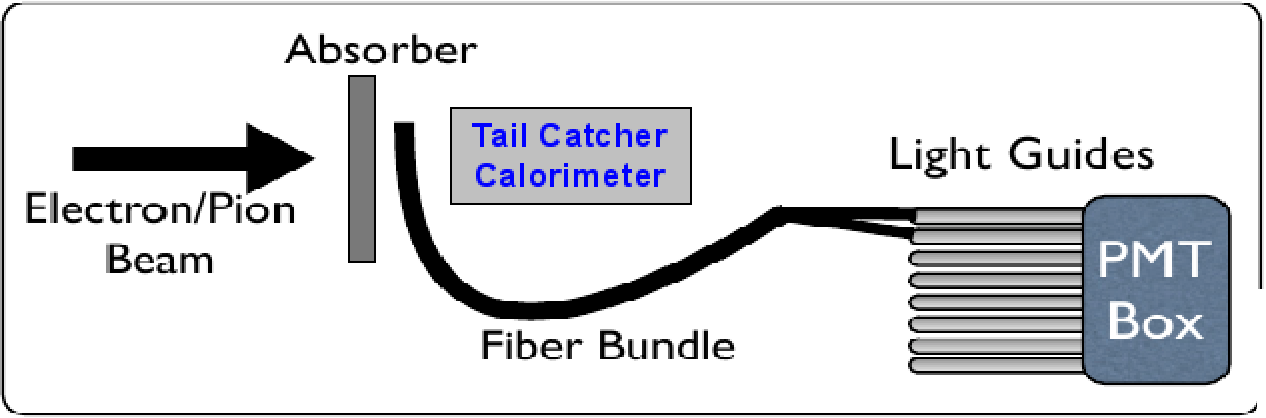
HB/HE

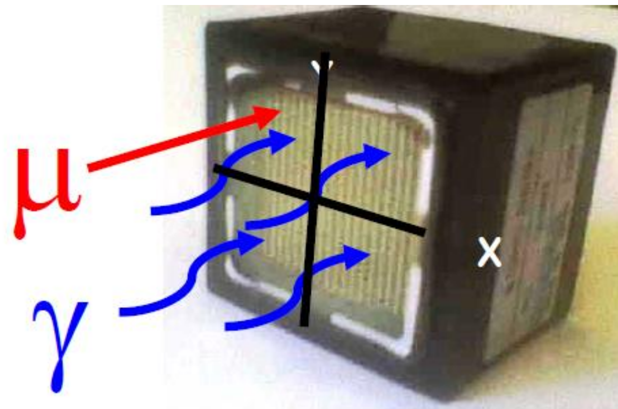


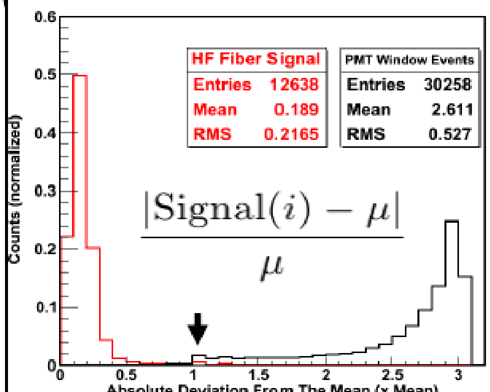
Upgrade Schedule



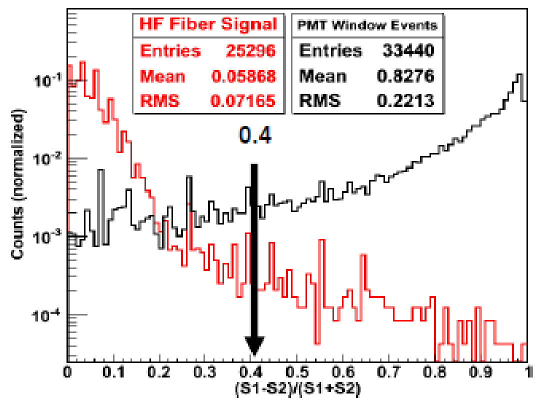
HF MAPMT







4 ch

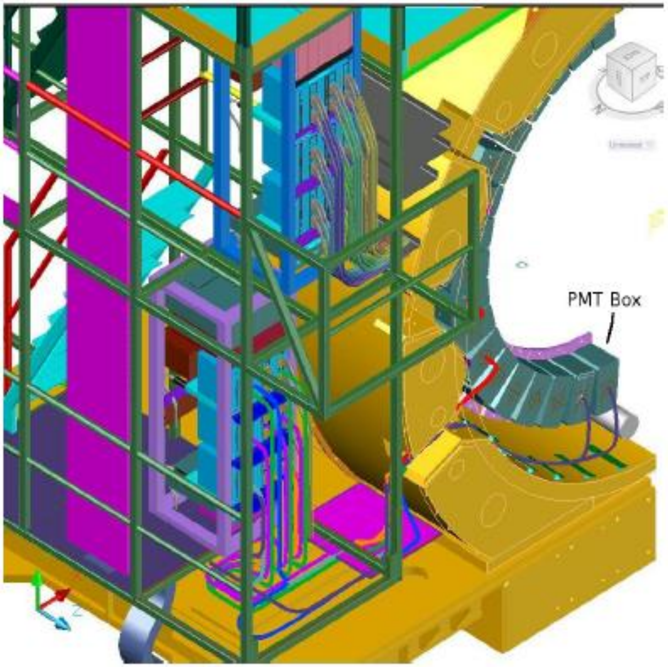


2 ch – M4

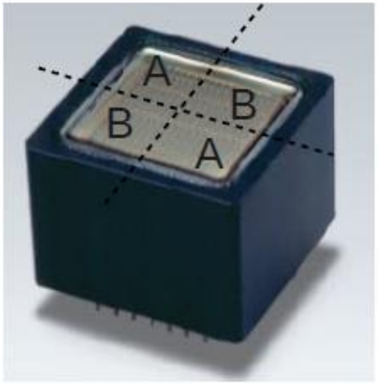
TB 2011 Data

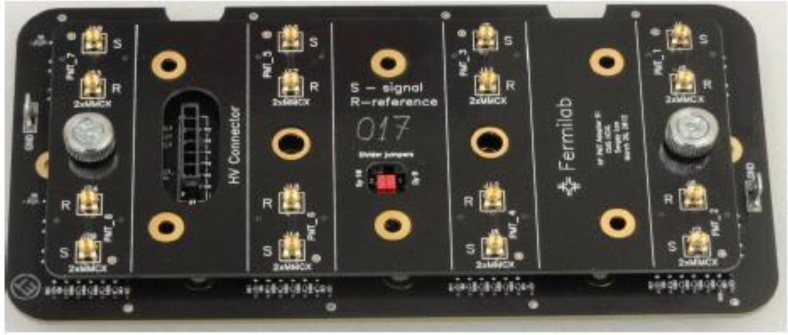
Muon Data
Pure Background

HF work in LS1

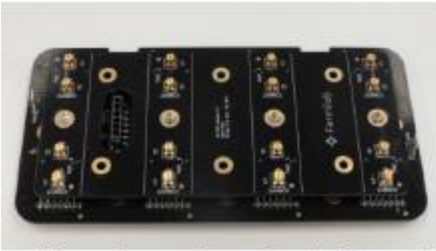


- Multianode phototubes will be installed during LS1 (2013/4)
  - During 2015, all four anodes will be ganged together and used with existing electronics
  - After upgrade, dual anode readout will be available
- Dual-anode analog signal cables planned for installation in LS1 as well to simplify upgrade installation process





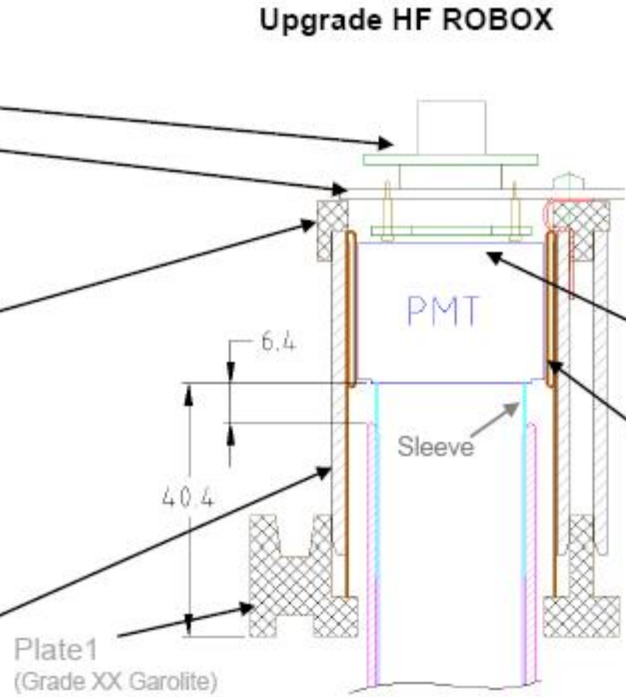
Components of the Upgrade HF ROBOX



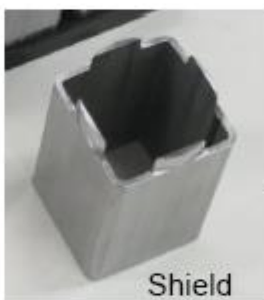
Base board + adapter board

New signal connectors and/or connector support

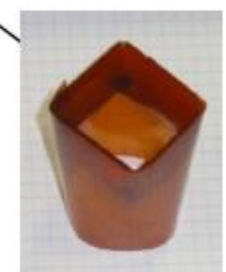
Plate2 (G-10)



PMT + socket



Shield

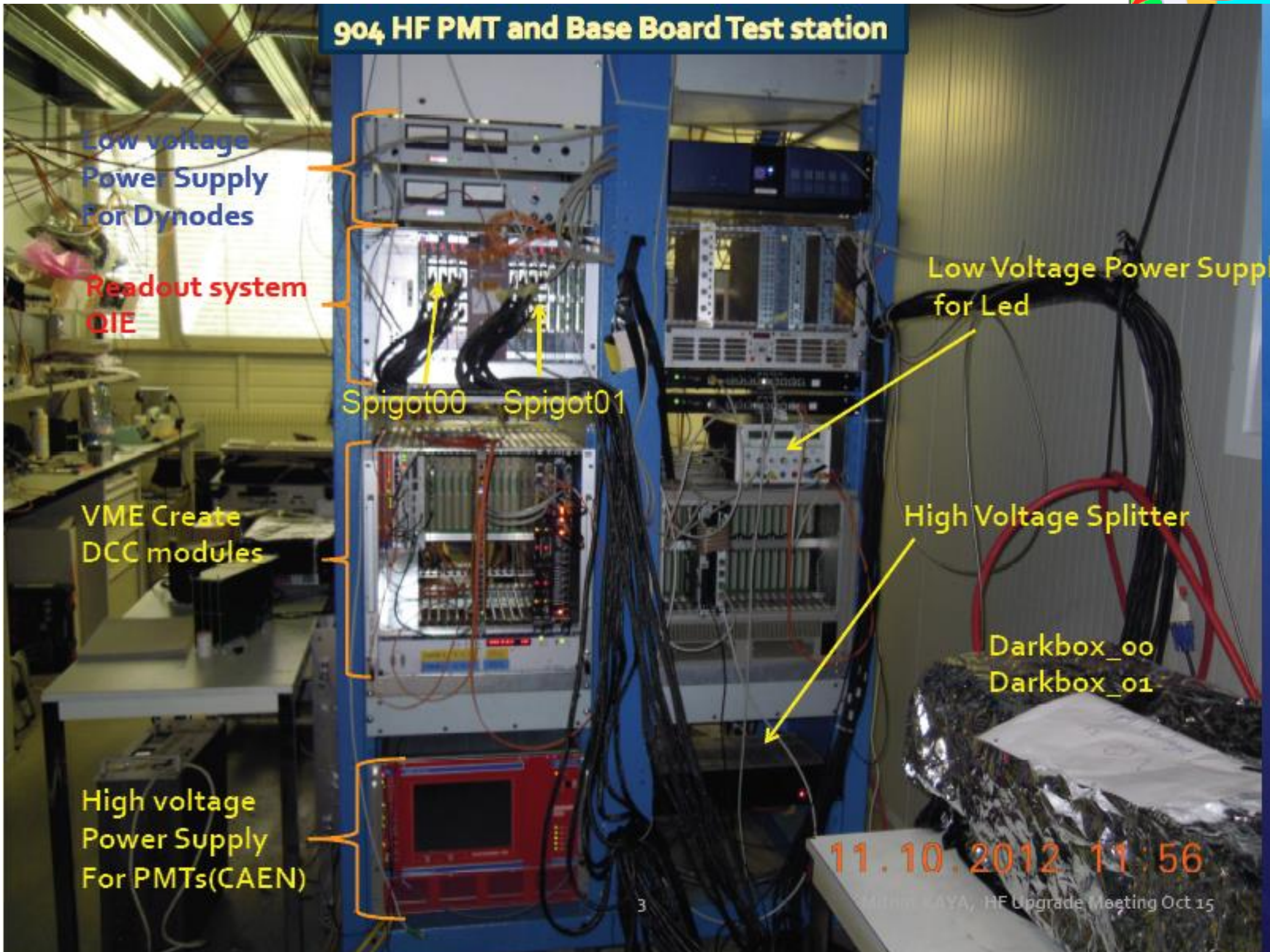


Kapton insulator

18

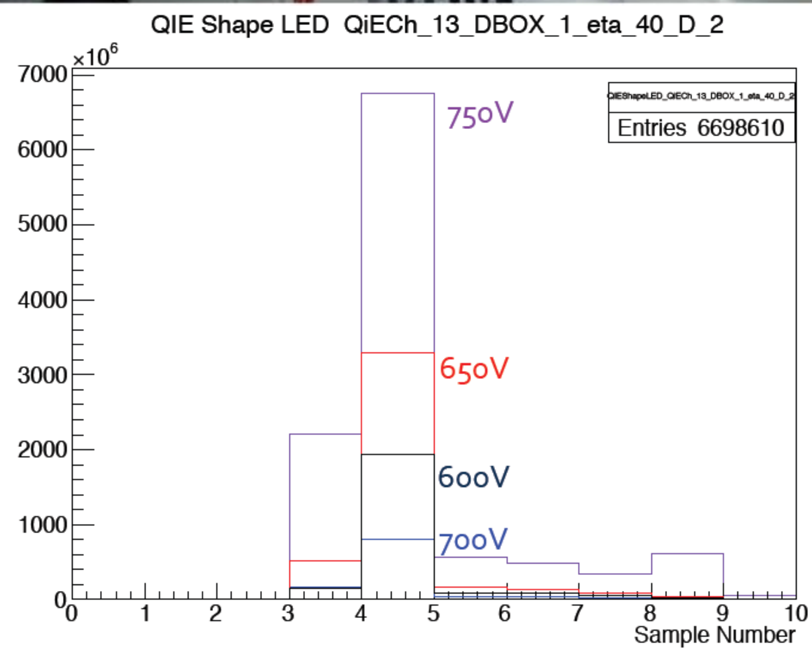
- Components being shipped from Iowa
- All MAPMT at CERN
- 100% Base boards + adapters

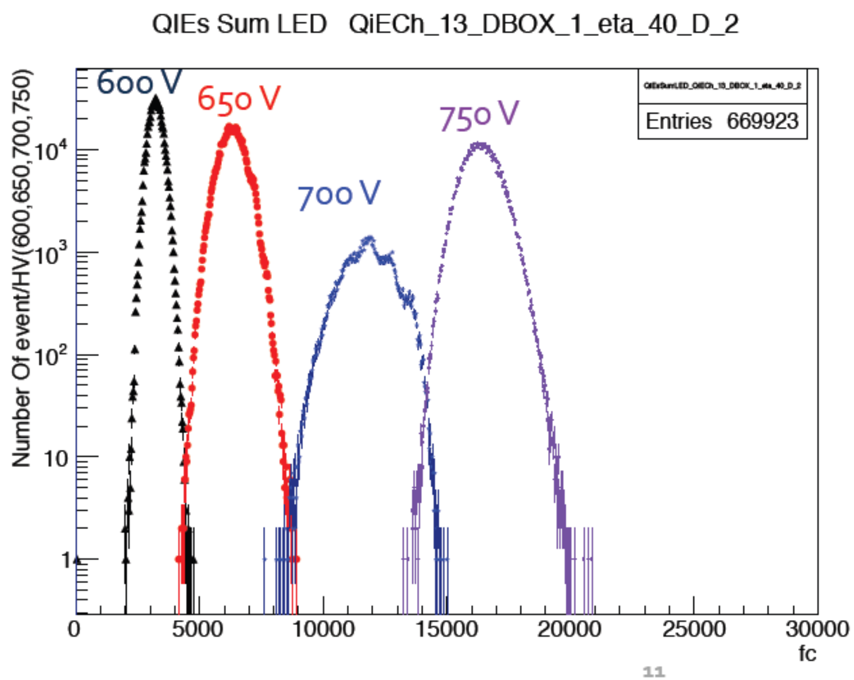
All HF MAPMTs delivered and tested



HF MAPMTs Tests @B904

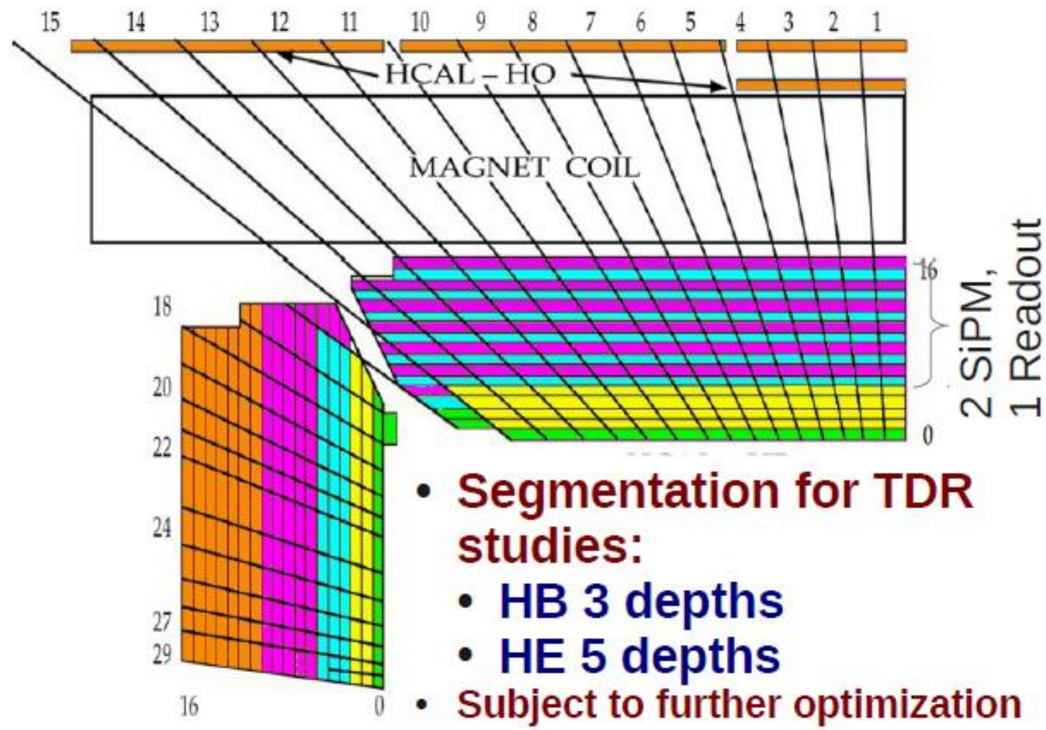
- Pedestal distributions
- LED spectrums
- SPE
- QIE shapes



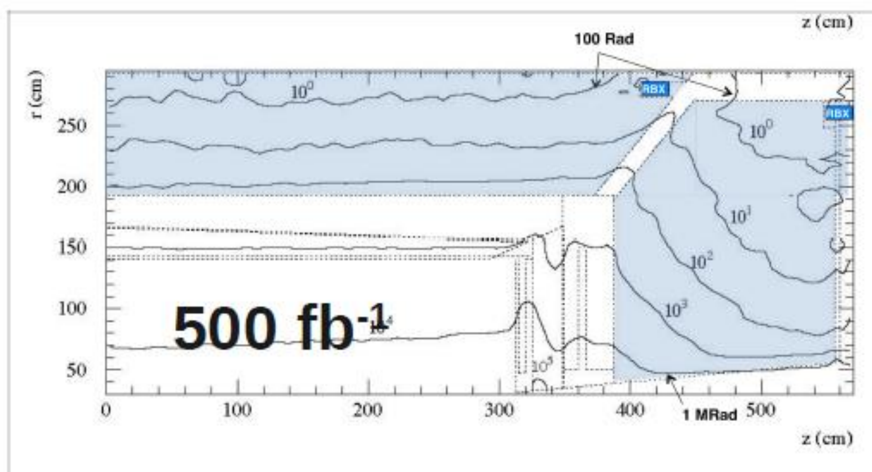


Depth Segmentation

- Impact of segmentation on Upgrade particle-flow methods for separating hadronic clusters
- Longitudinal isolation of electrons and muons
- Uniform energy density for hadron showers as a function of readout depth, thus providing uniform SiPM signal magnitude across depths
- Minimization of resolution degradation due to radiation damage to scintillators and WLS fibers
- Number of readouts (power/cooling/volume limits)

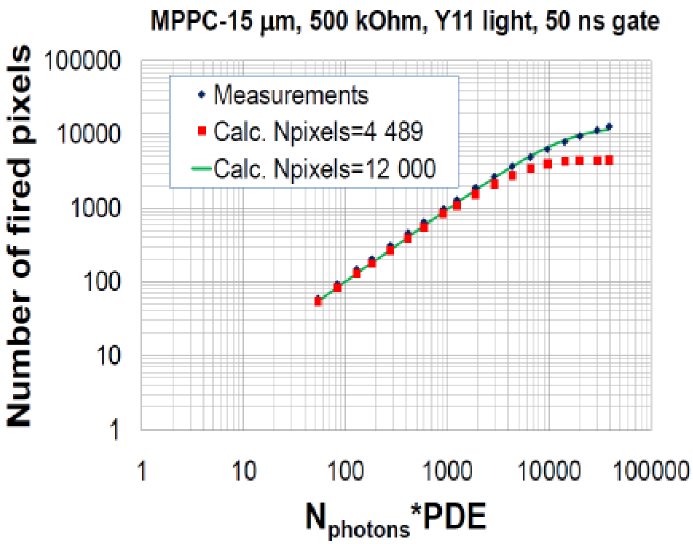


- **Segmentation for TDR studies:**
  - **HB 3 depths**
  - **HE 5 depths**
- **Subject to further optimization**

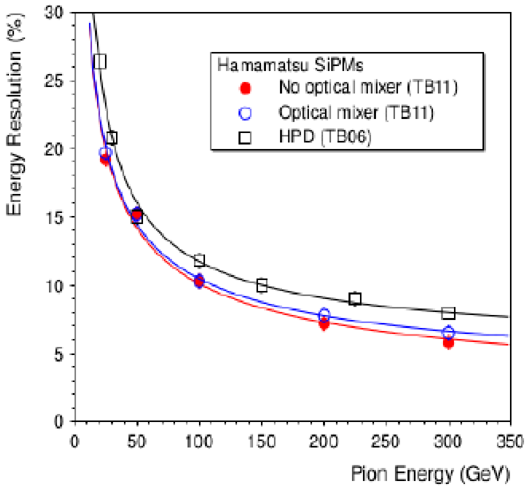


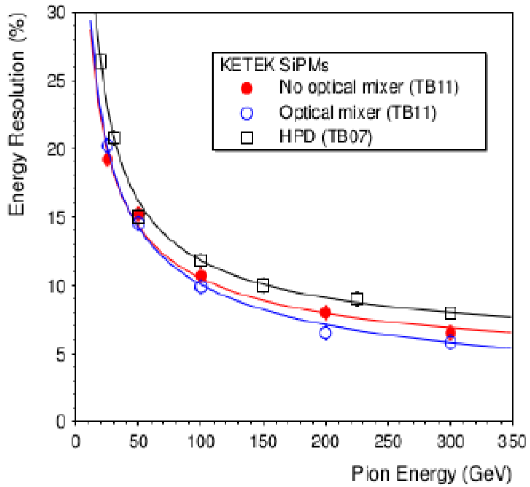
SiPM R&D

- Extensive simulation and R&D program (bench and testbeam) has identified the crucial parameters for SiPM performance in an LHC calorimeter
  - Particularly relevant result: importance of micropixel recovery time
- Specifications developed and two vendors have produced devices which match well



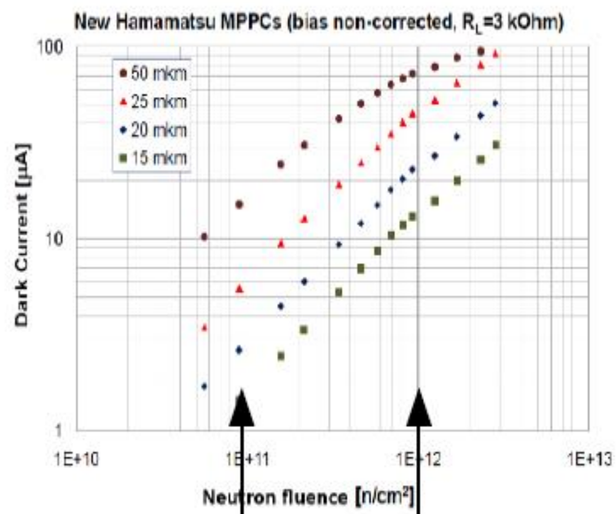
Parameter	Spec Value	Hamamatsu 15 μm 500 kΩ	[a]KETEK 20 μm 400 kΩ	[a,b]KETEK 15 μm 500 kΩ
Size	2.2 mm^2 or 2.5 mm round	2.2X2.2	2.2X2.2	2.2X2.2
Gain	6×10^4	2×10^5	9×10^5	5×10^5
Effective number pixels (per device)	> 20K per device	58K	12K	44K
Recovery Time RC	< 10 ns	4 ns	29 ns	8 ns
PDE at 515 nm	> 15%	18%	21%	12%
Leakage Current (after 2E12 n)	< 200 μA	120 μA	900 μA	388 μA
Fractional Gain X PDE (after 2E12 n)	> 65%	80%	80%	85%
ENF	< 1.4	1.3	1.2	1.1
Optical Cross Talk	< 15%	15%	15%	10%
Neutron noise sensitivity	NO	yes	no	no
Bias Voltage	< 100 V	75 V	25 V	29 V
Operating temp	22°C	22°C	22°C	22°C
Temperature Dependence	< 5% per °C	4%	1%	1.5%

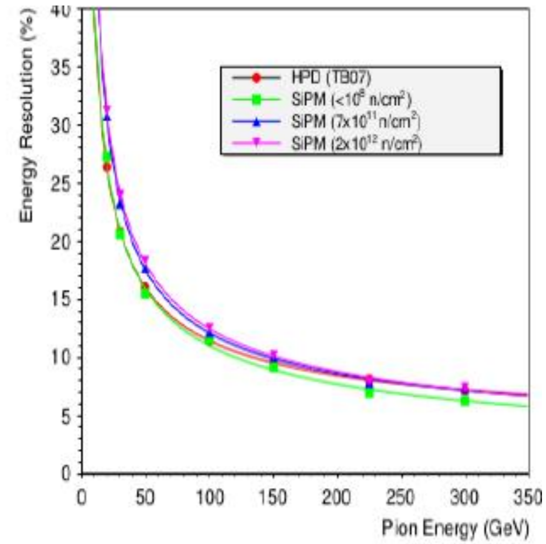




SiPM Radiation Studies

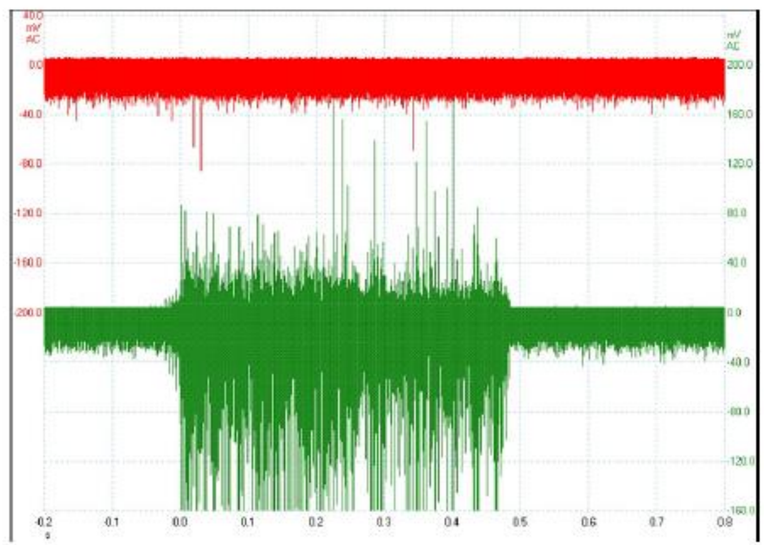
- Studies of SiPM devices carried out in CERN IRRAD facilities and neutron-damaged devices used for testbeam studies
  - Resolution effects of increased leakage current are acceptable up to 3000 /fb
- Single-event effects are minimal in SiPM devices, except for anomalous effect seen in Hamamatsu devices
  - Breaking news: newest R&D devices from HPK appear to have solved this effect





HE RBX 3000 fb^{-1}

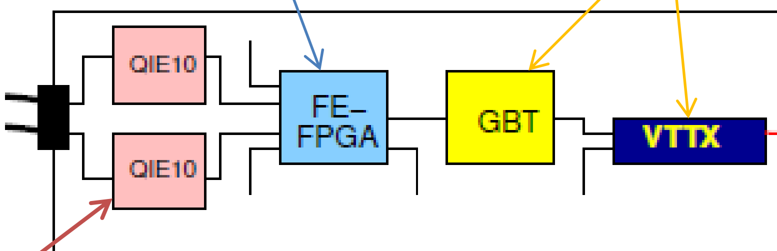
HB RBX 3000 fb^{-1} (10^{12} n/cm^2)



Front-End Electronics

Front-End FPGA
- Commercial radiation-tolerant FLASH-based FPGA (ProASIC3E)
- Provides data alignment/formatting
- Pulse-length measurement from discriminator output

4.8 Gbps data link
- CERN Project
- Runs in both FEC and 8b10b modes
- Existing multimode fiber plant capable for 4.8 Gbps data transfer



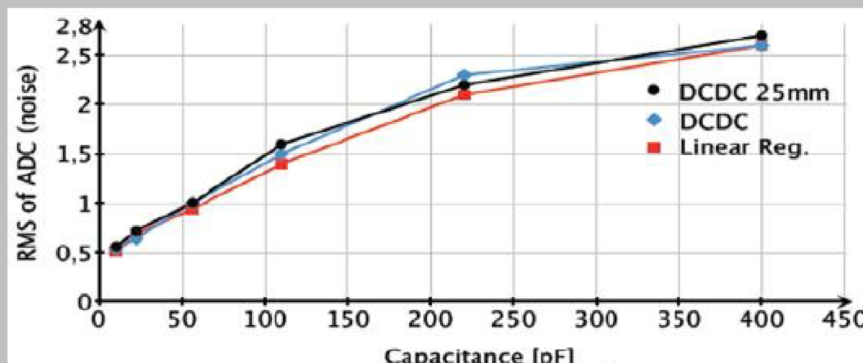
FEE Card (24 channels)

Link Status
- Full GBPTX ASIC sent for fab Aug 2012
- Other link parts complete, production beginning 2013

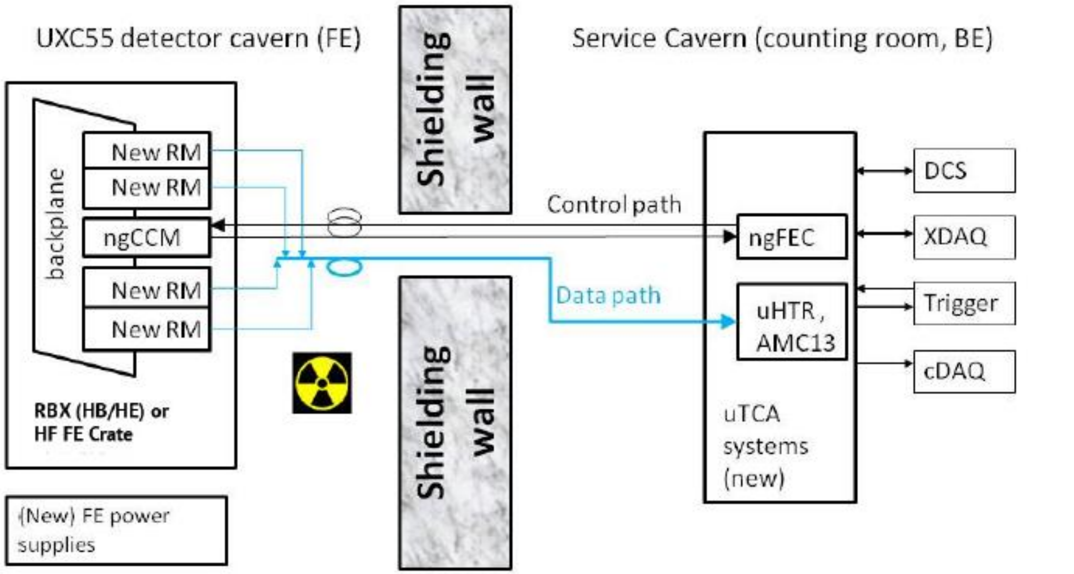
Charge-Integrating ADC
- Dynamic range of 10^5 encoded into piecewise-linear 8-bit code
- TDC capability (500 ps resolution)
- Built-in pulse-injection
- 0.35 µm SiGe AMS process

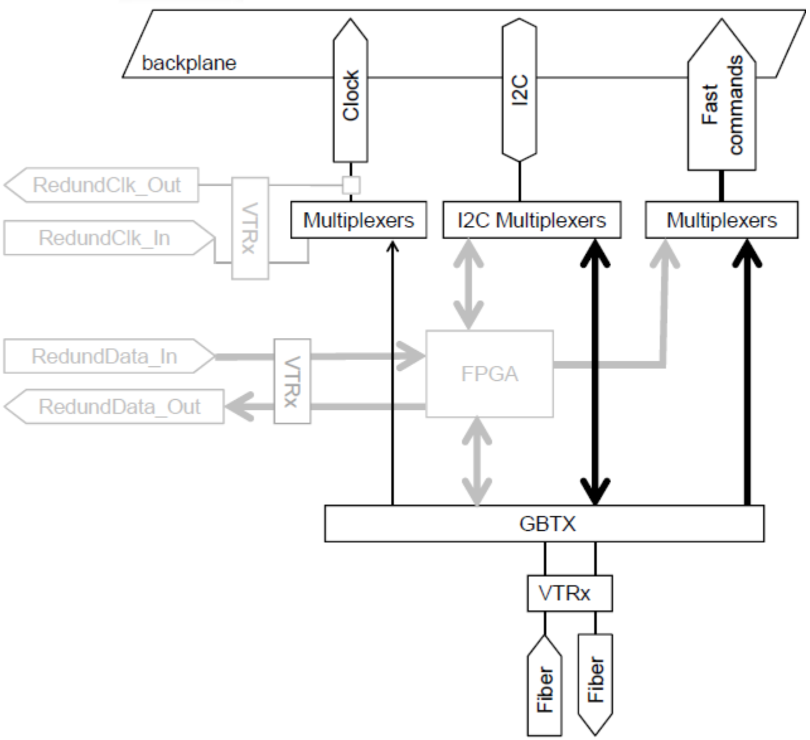
QIE10 Status
- ADC fully demonstrated
- Full HF version with TDC to be submitted in November

DC/DC power converters based on CERN design



Front-End control module - ngCCM

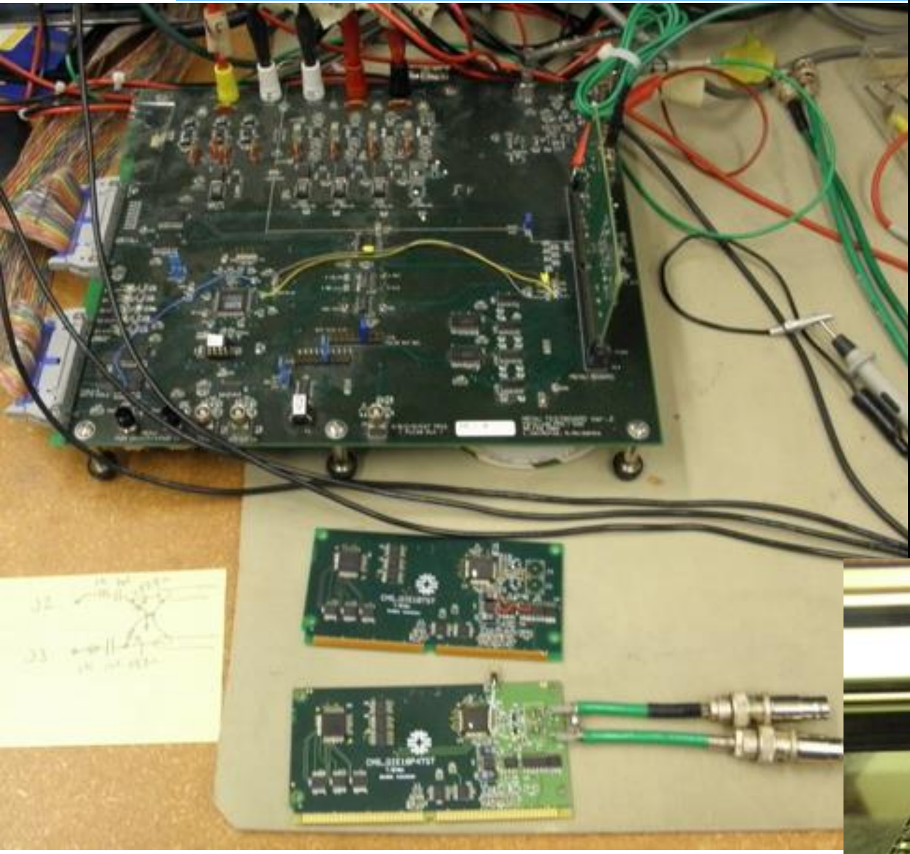


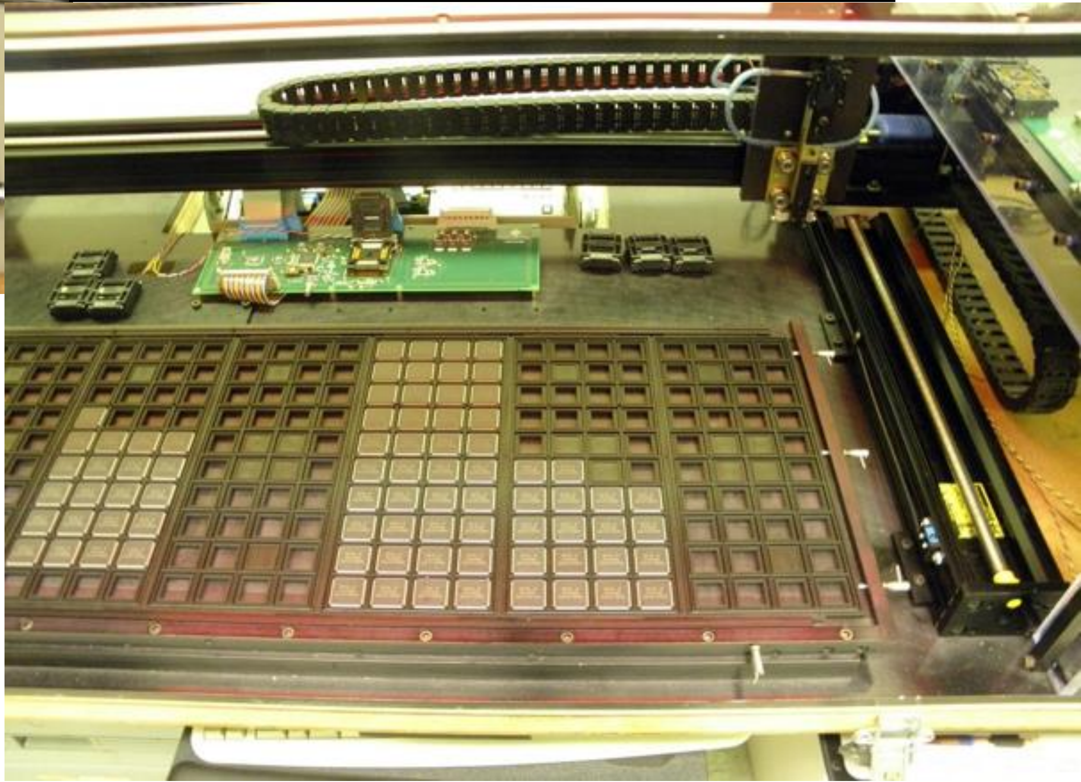


- Requirements
  - Good quality clock
  - Orbit signal for data sync (QIERESET)
  - Warning-test-enabled signal for calibration
  - I2C communication for GBTX, QIE10 and FE-FPGA config.
  - Robustness → neighbor ngCCM can take control in case of failure

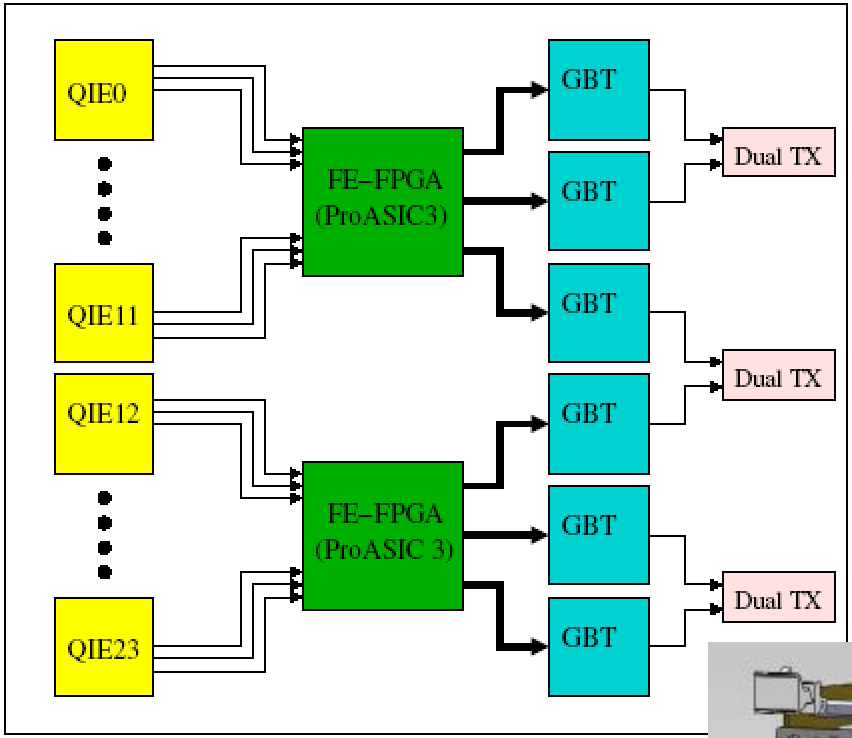
QIE10 Testing

- Test stand @Fermilab
  - Prototype test P3 & P4 tested individually
  - Feedback to chip designer
  - No major problems detected
  - QIE10.P5 available soon
  - Robotic tester can be modified for QIE10 production tests

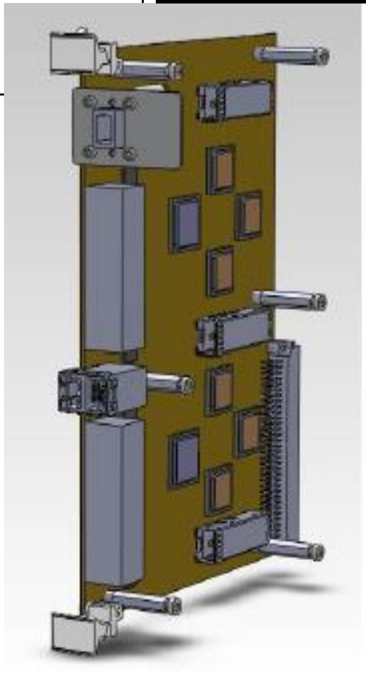


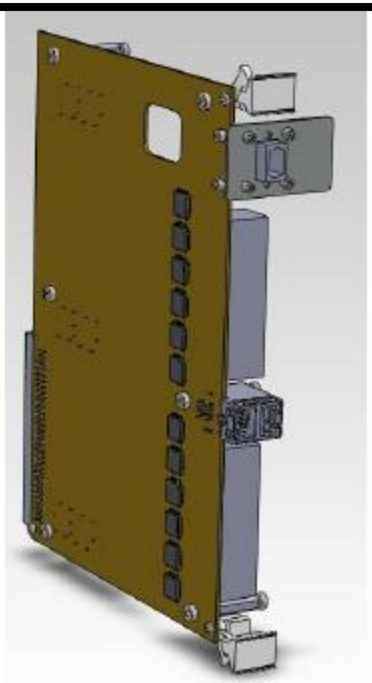


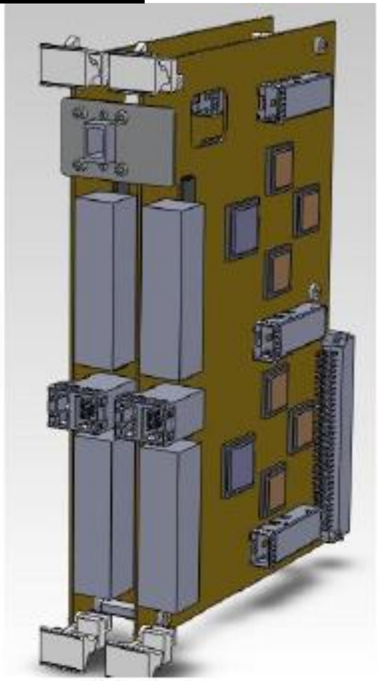
HF FE Card



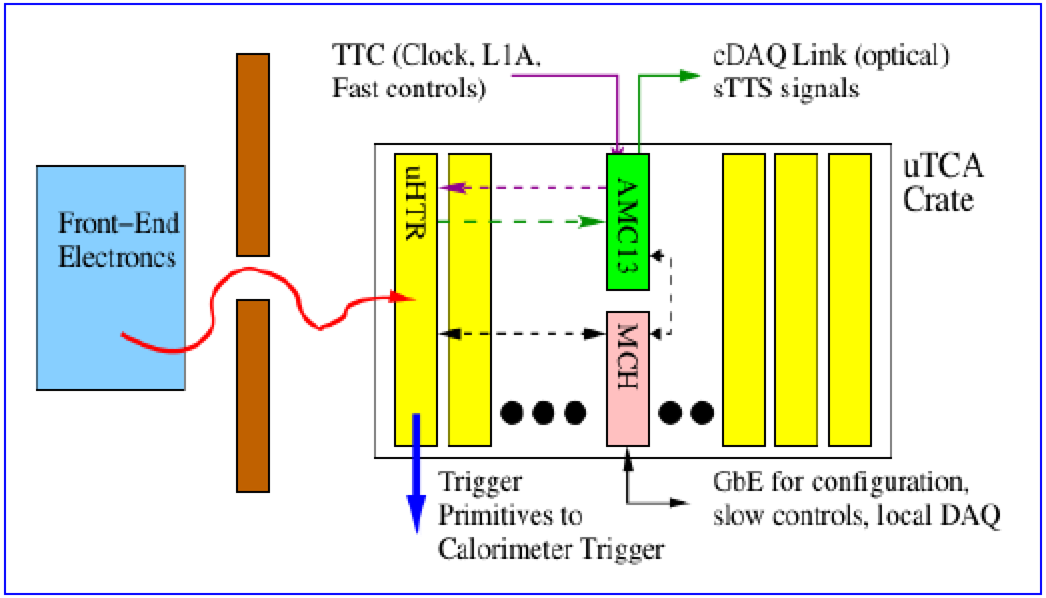
- Conceptual design exists
  - Cards will be combined for mechanical strength
  - Falling edge TDC
  - Work on prototype can begin when QIE10-p5 certified
  - Could use FPGA 8b10b link in early prototypes if GBTX not available

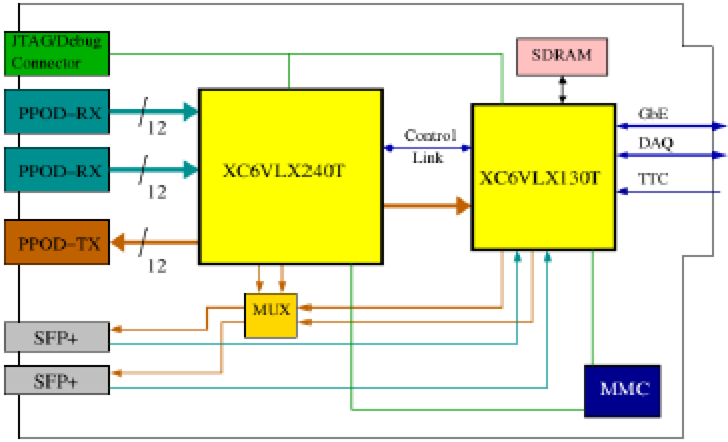


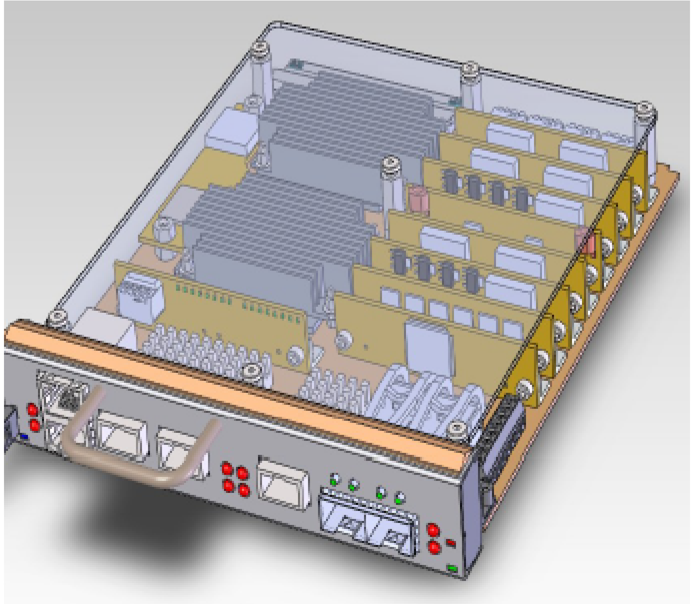




Back-End Electronics



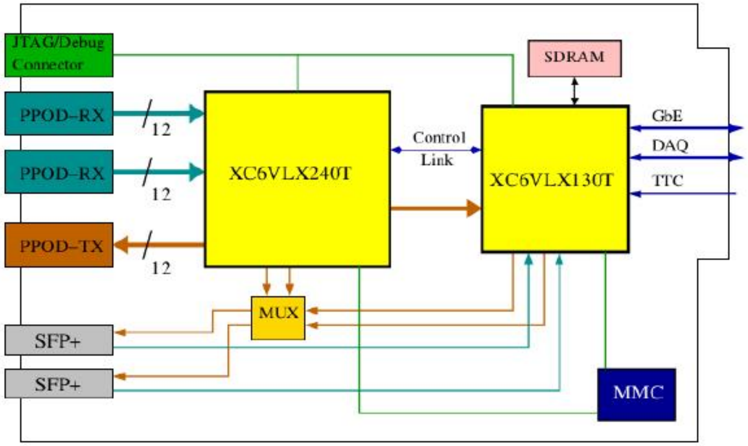


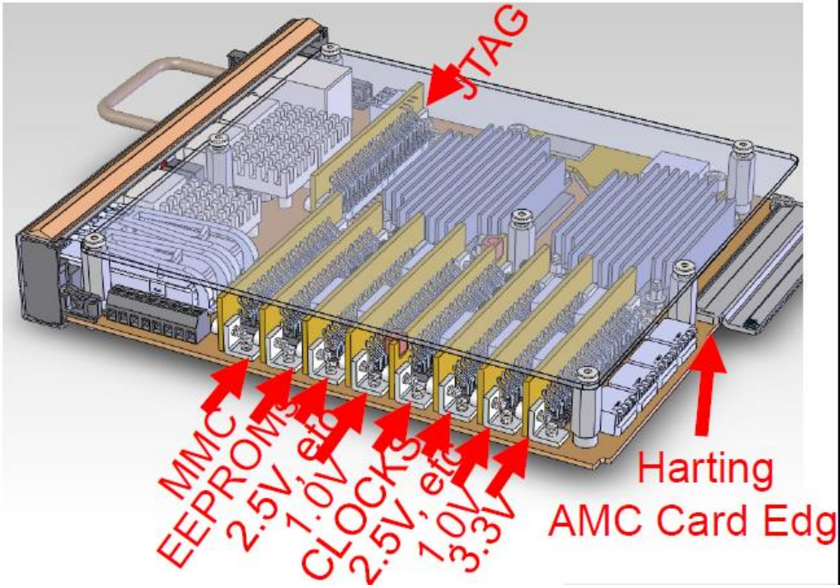


- Backend based on uTCA electronics standard
  - Simpler long-term maintenance
- Parallel-optic transmitters and receivers tested for 100m fiber distances, good sensitivity
- R&D is well-advanced

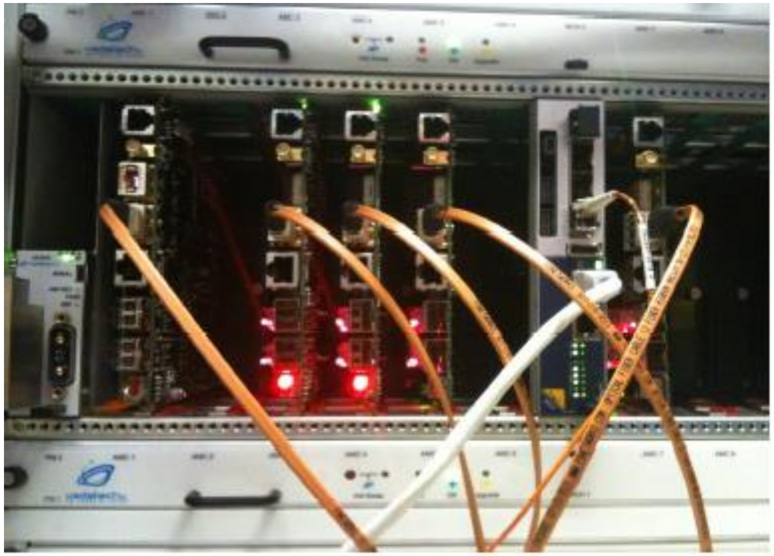
Final uHTR Development

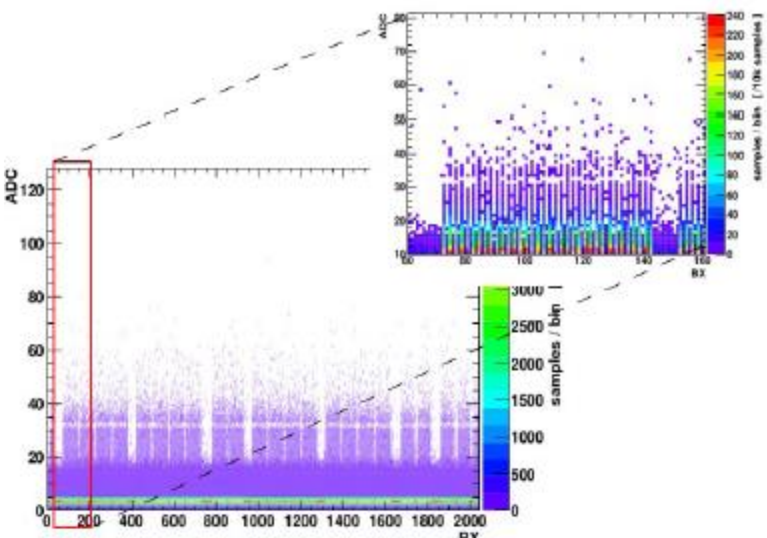
- Current mCTR2 cards in use at P5 are “half-scale” R&D prototypes
- Final uHTR will support 24 input fibers, more FPGA resources for trigger and lumi
- Top-level design is complete, construction based on modular subassemblies
  - Power, clocks, MMC, MMC, JTAG
    - Workhorse of parasitic testing program



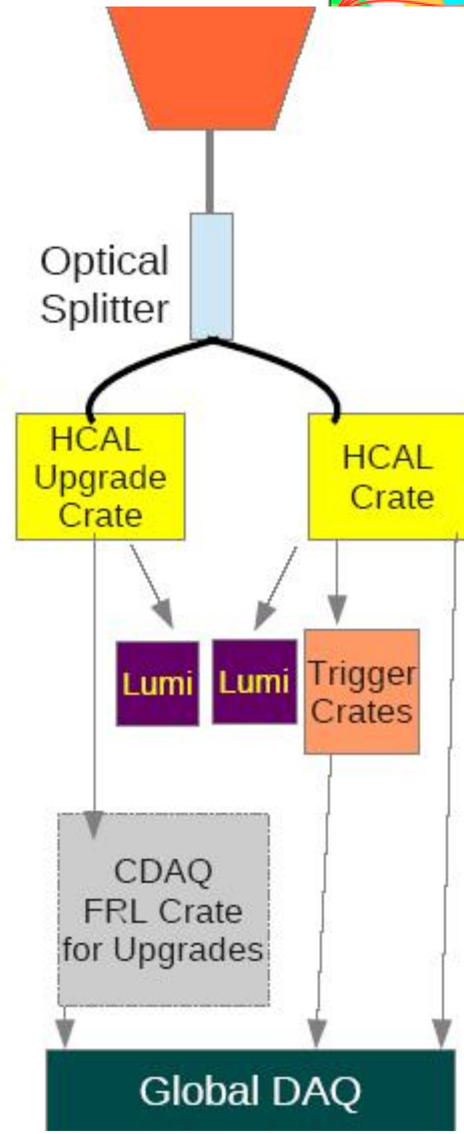


Parasitic Testing



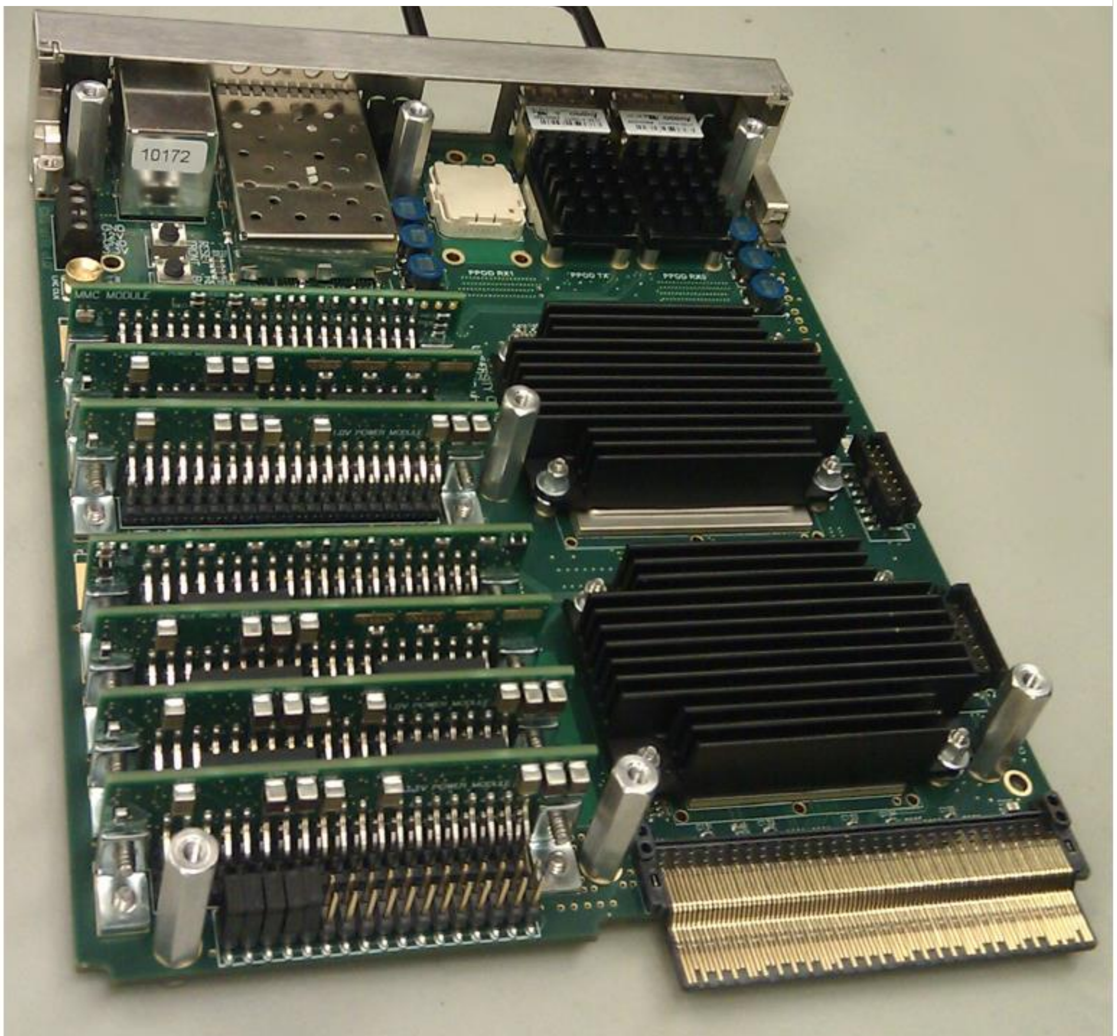


- Passive optical splitter divides signal from current HCAL detector (40° HB-/HE-/HF-)
- Prototype testing and firmware development
  - Link alignment and stability
  - DAQ
  - Luminosity data acquisition system
- Program ongoing



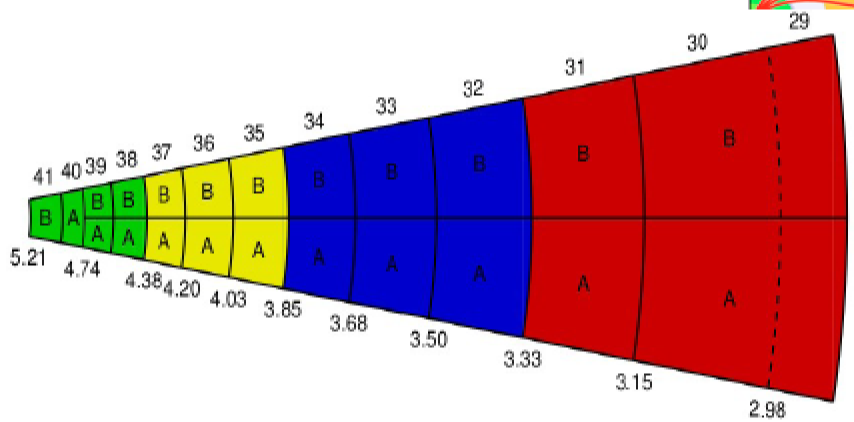
uHTR

- Two modules were in hands last month.
- Tests (bench/HI beam) and firmware development since then.



Trigger Primitive Improvements

- When coupled with upgrades in the calorimeter trigger, the HCAL upgrades will provide significant trigger improvements
  - Better granularity and uniformity, particularly in HF

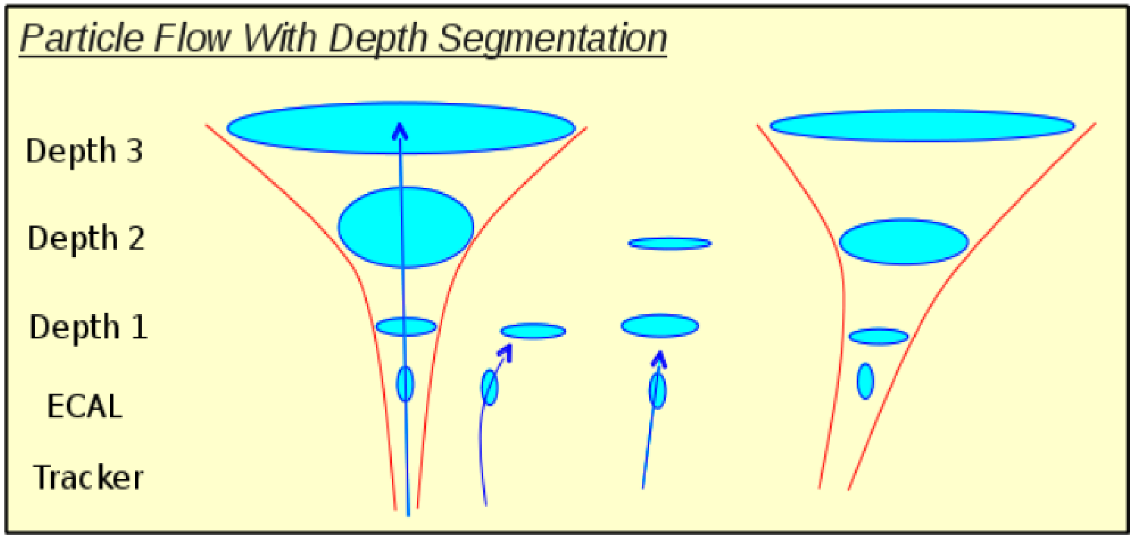


- Flags to identify particular interesting features in data
  - Most-energy-in-first-layer : lepton isolation/id at high pileup
  - Energy-late (from TDC) : long-lived particle searches
  - MIP-in-first-layer : isolated-track HCAL calibration trigger
  - MIP-in-deep-layers : muon id/isolation requirement
- Performance of these improvements will be studied in the context of the L1 Upgrade TDR

$\|\eta\|$	Current HCAL+RCT	Upgrade HCAL+CT
0-1.74	0.348×0.348 (4×4)	0.174×0.174 (2×2)
1.74-2.17	0.432×0.348 (4×2)	0.210×0.174 (2×2)
2.17-3.00	0.828×0.348 (4×2)	0.174×0.174 (1×2)
3.00-5.00	0.522×0.348 (3×2)	0.174×0.174 (1×1)

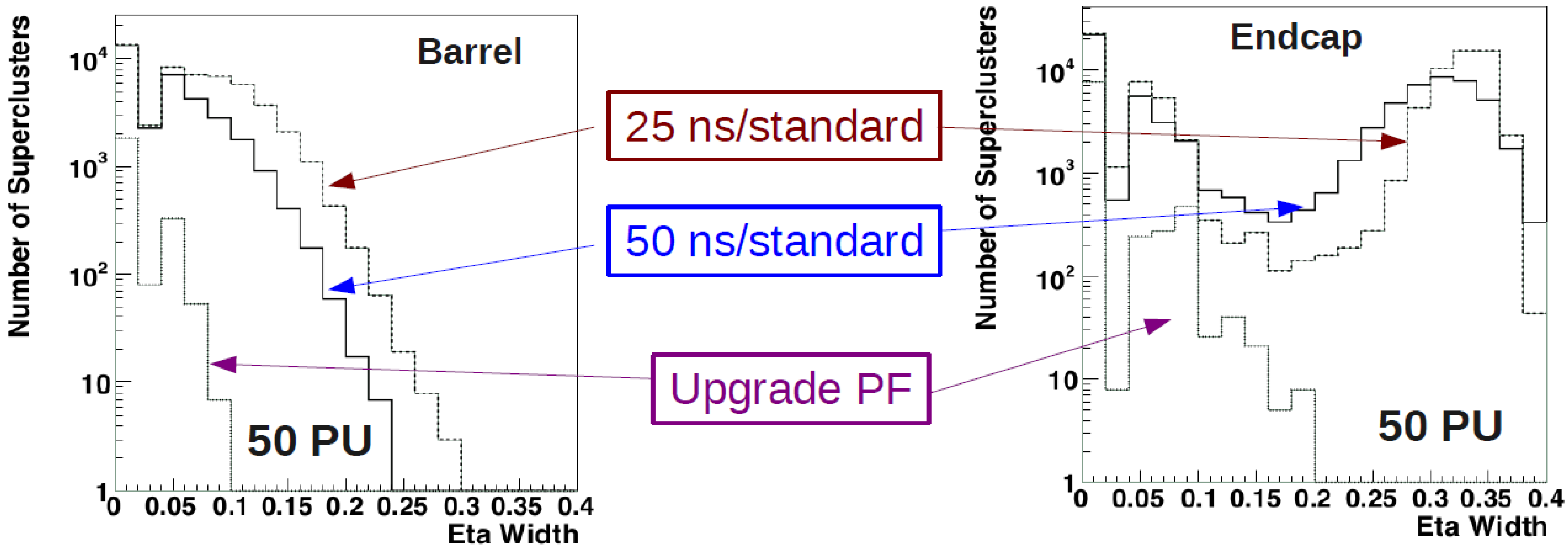
Improvement in jet-finding primitive uniformity

Performance of Phase1 Upgrades



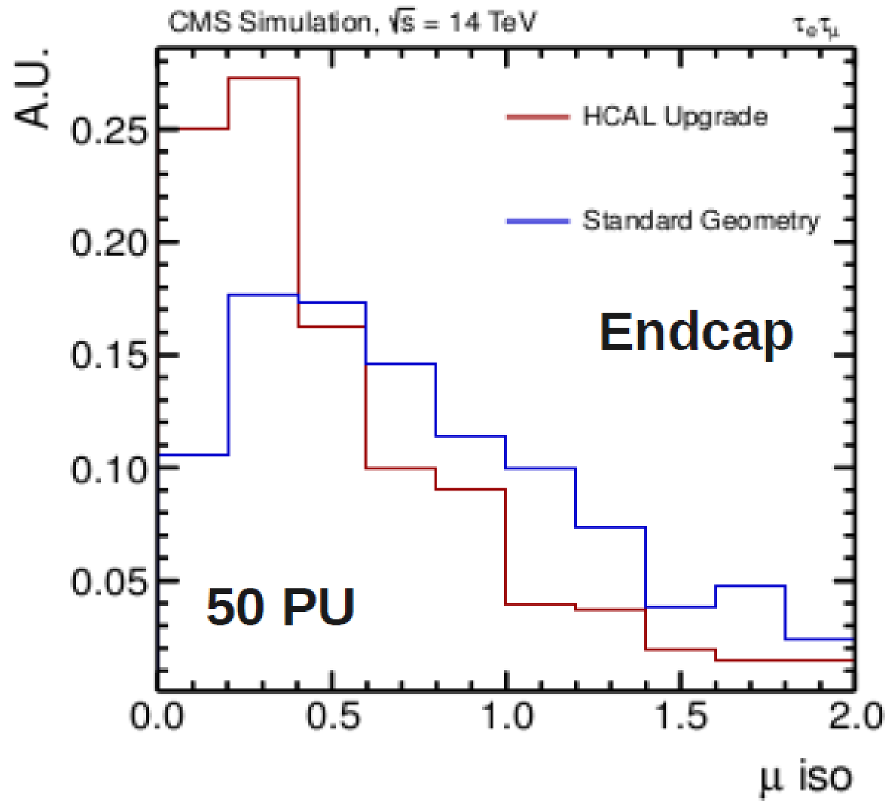
Hadronic showers spread out with increasing depth

- With a single-depth readout, pileup energy will be pulled into a charged hadron cluster or true energy will be left out and labeled as a neutral hadron
- With multidepth readout, clusters can remain bounded and natural



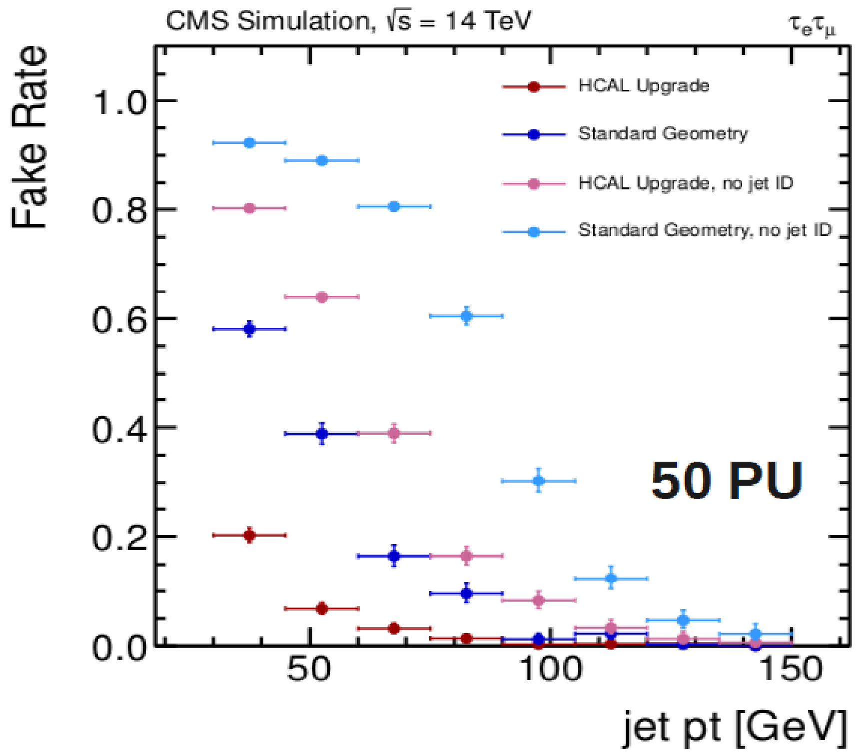
Physics Analysis VBF H→ττ

- Analysis channel signature
  $pp \rightarrow Hjj \rightarrow \tau\tau jj \rightarrow e\mu jj$
- Require isolated leptons
  - One with p_T>20 GeV, one with p_T>10 GeV
- Require two VBF tagging jets
  - p_T > 30 GeV, opposite hemispheres, no jets in gap between VBF jets, m_{jj} > 600 GeV
- Isolation cuts tuned to provide same efficiency as current reference analysis performed at 8 TeV and current LHC luminosity

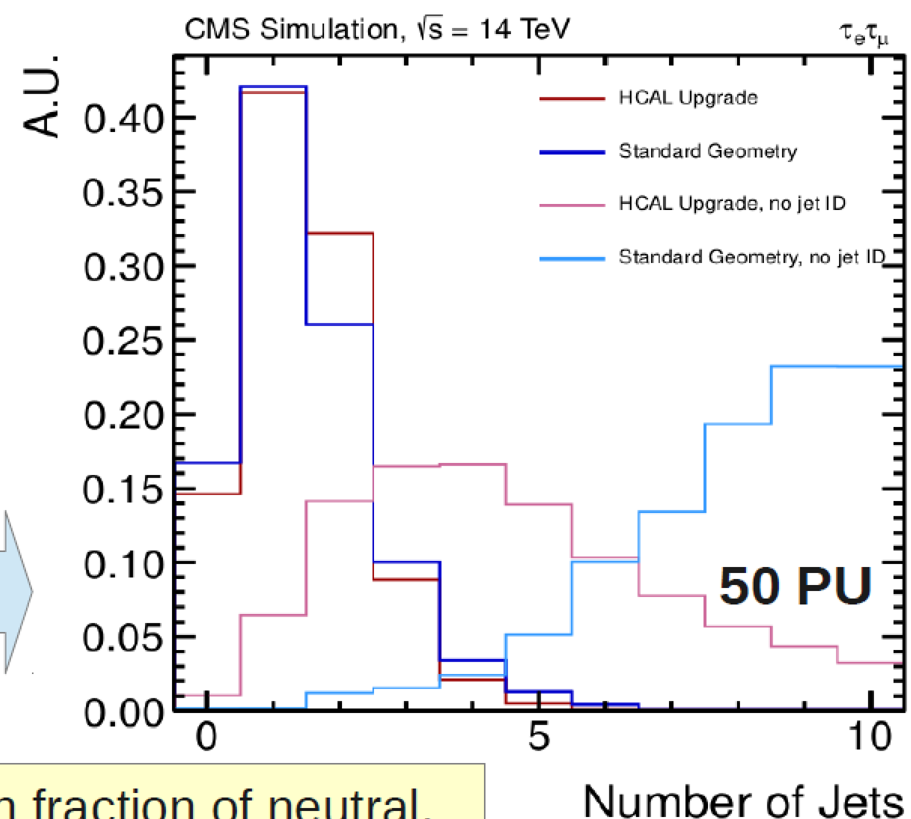


$$I_{\rm rel} = \frac{\sum p_{\rm T}(\text{charged}) + \max\left(\sum E_T(\text{neutral}) + \sum E_T(\text{photon}) - \Delta\beta, 0\right)}{p_{\rm T}(\mu \text{ or } e)}$$

Physics Analysis VBF H→ττ



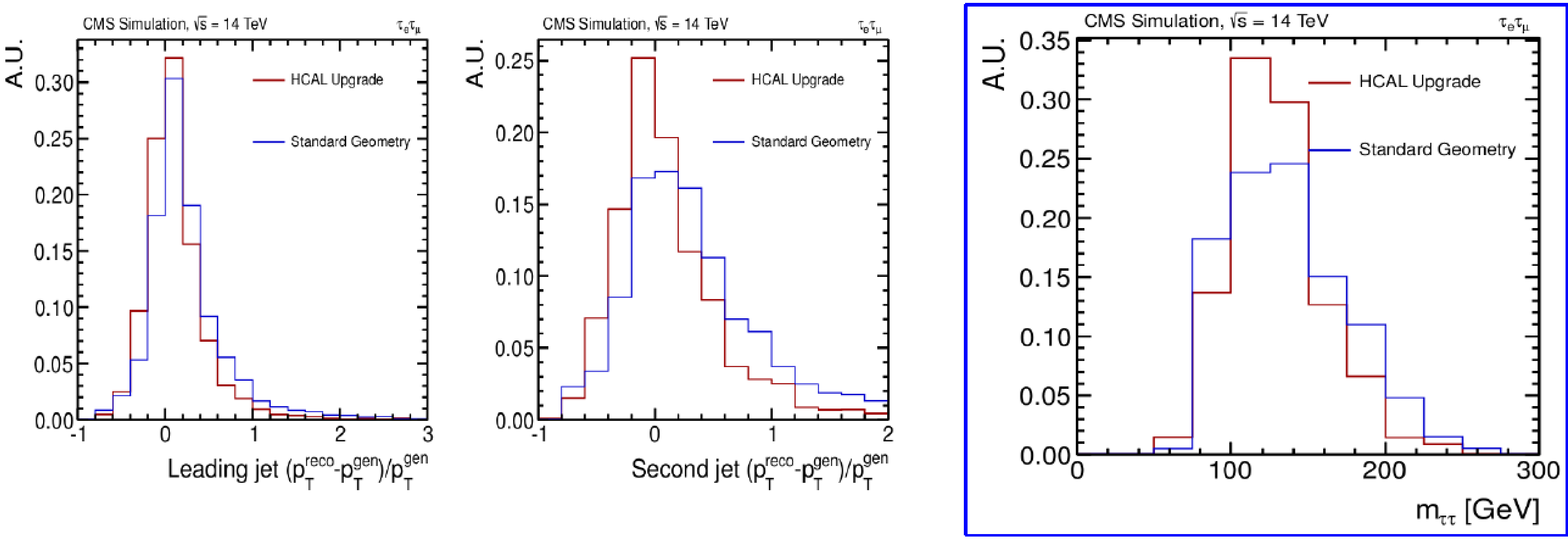
Significant reduction in jet fake rate, as defined as fraction of reconstructed jets not matched to generator jets



Efficiency of identifying true tag jets is improved, without increase in fake jets

Jet ID from multivariate selection based on fraction of neutral, charged components, comparison of track, jet momentum

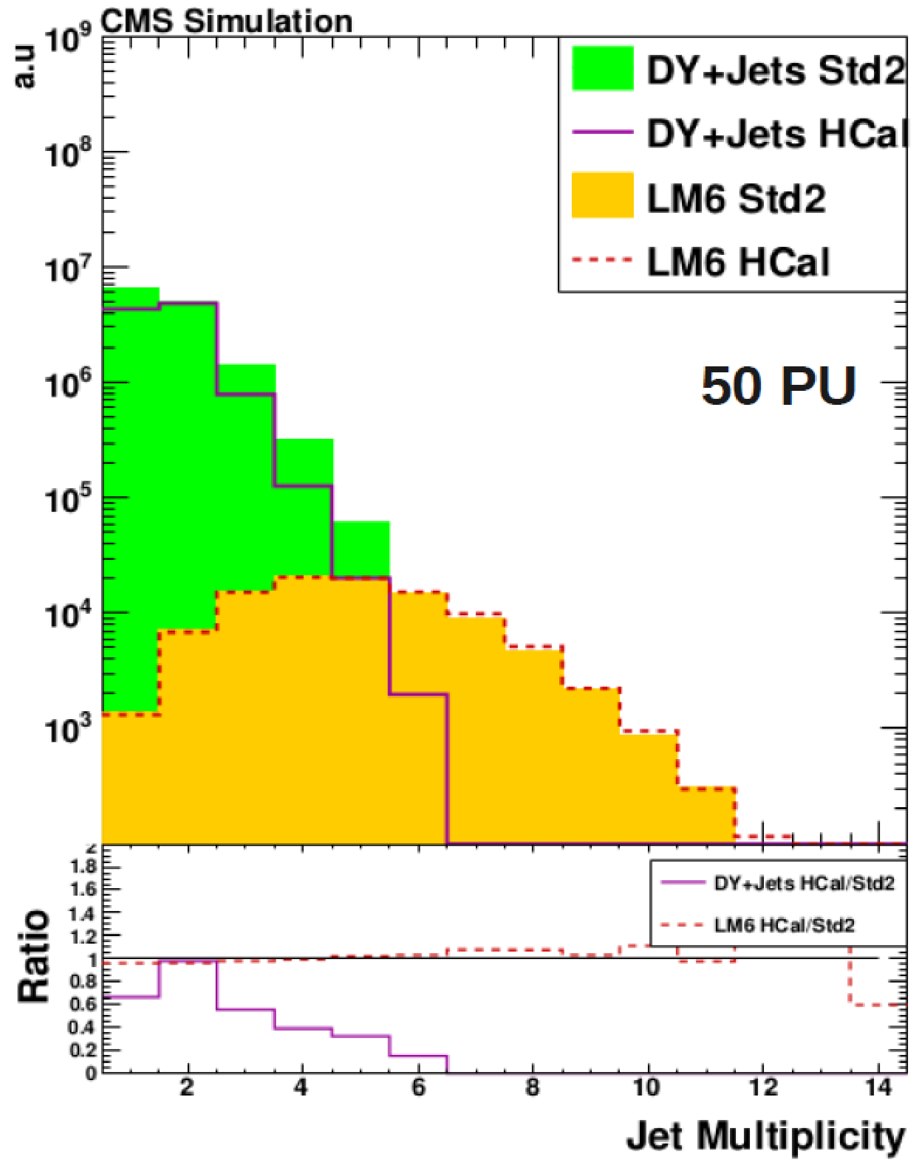
Physics Analysis VBF H→ττ



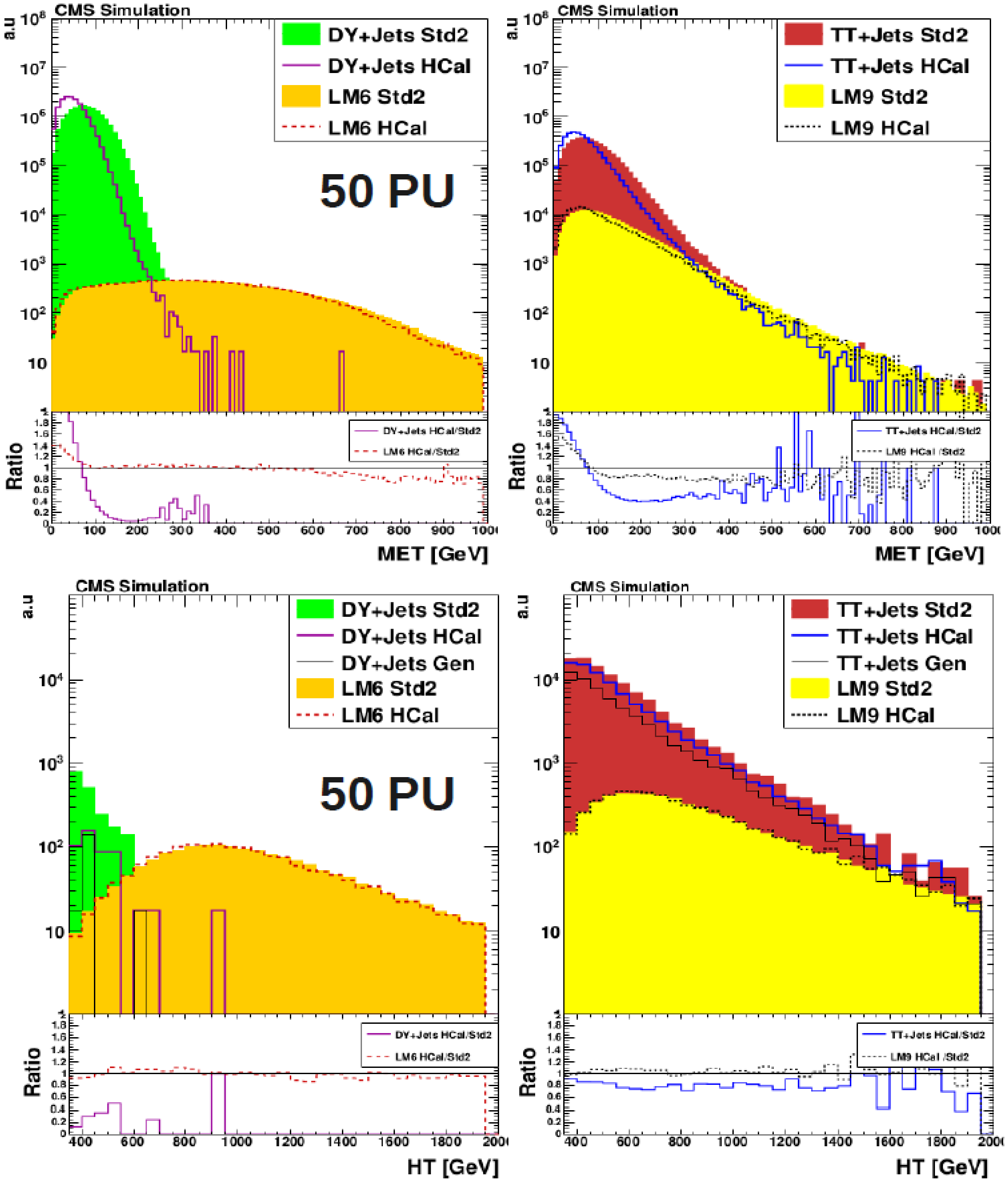
- Significantly-improved jet p_T resolution, particularly for lower p_T jets
- Improved jet and MET resolution allows 25% improvement in $m_{\tau\tau}$ resolution, as determined by multivariate likelihood technique
- Total efficiency improvement from upgrades: factor of 2.5 (4.5% → 11%)
  - Full improvements from particle flow upgrades not yet folded in

Physics Analysis SUSY

- Search for SUSY in events with a muon, jets, and significant MET
- Selection
  - An isolated muon with p_T > 20 GeV
  - At least four central (|η|<2.4) jets with p_T>40 GeV
  - MET > 60 GeV
- Final analysis variable is the scalar sum of the jet p_T (H_T)



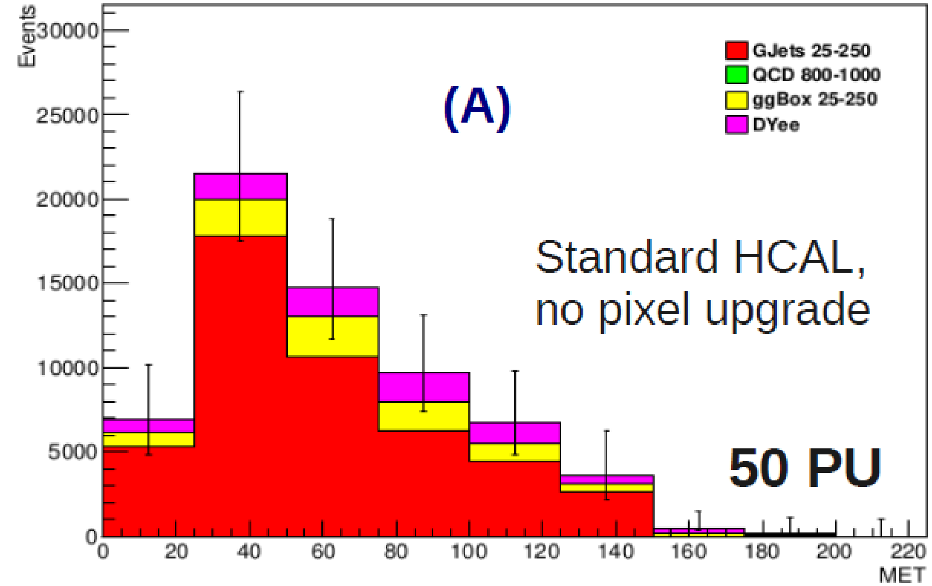
Physics Analysis SUSY

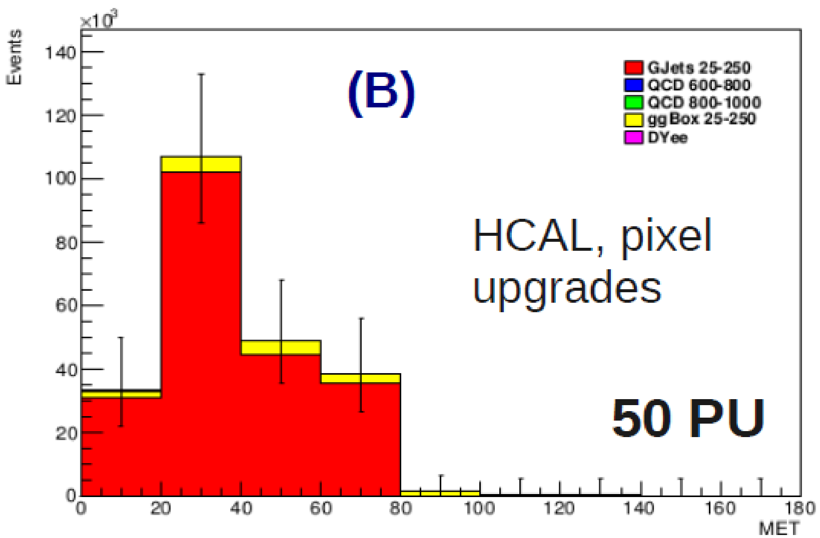


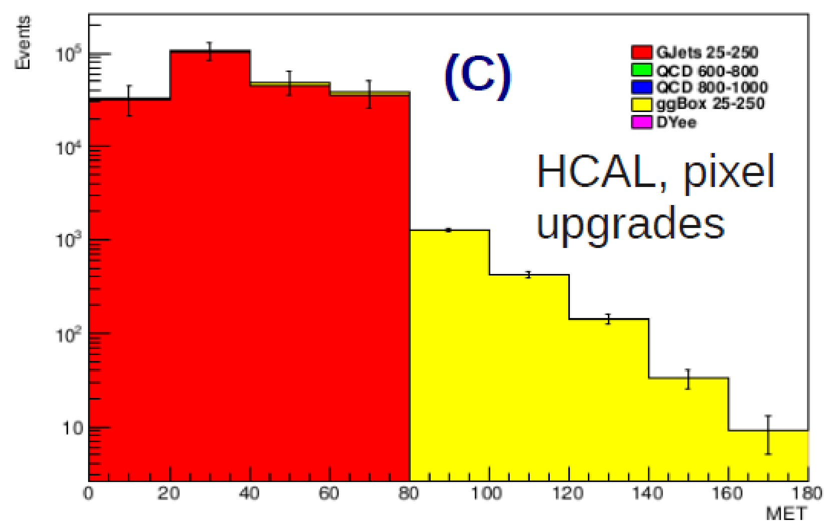
- Fake MET significantly reduced without affecting true MET in signal events
- Improved H_T distributions as well
  - tt+jets distribution closer to generator-level H_T
- S/B ratio improved by ~50% at high H_T
  - Full particle-flow improvements not yet folded in

Physics Analysis SUSY $\gamma\gamma$ + MET

- SUSY signature with very different kinematics from μ+j+MET (no selection for real jets), thus tests improvement on MET-fakes from pileup
  - From (A) to (B), pixel upgrade suppresses DY (pink)
  - From (A) to (B), HCAL upgrade suppresses high MET tail
  - High MET Tail detail in (C)

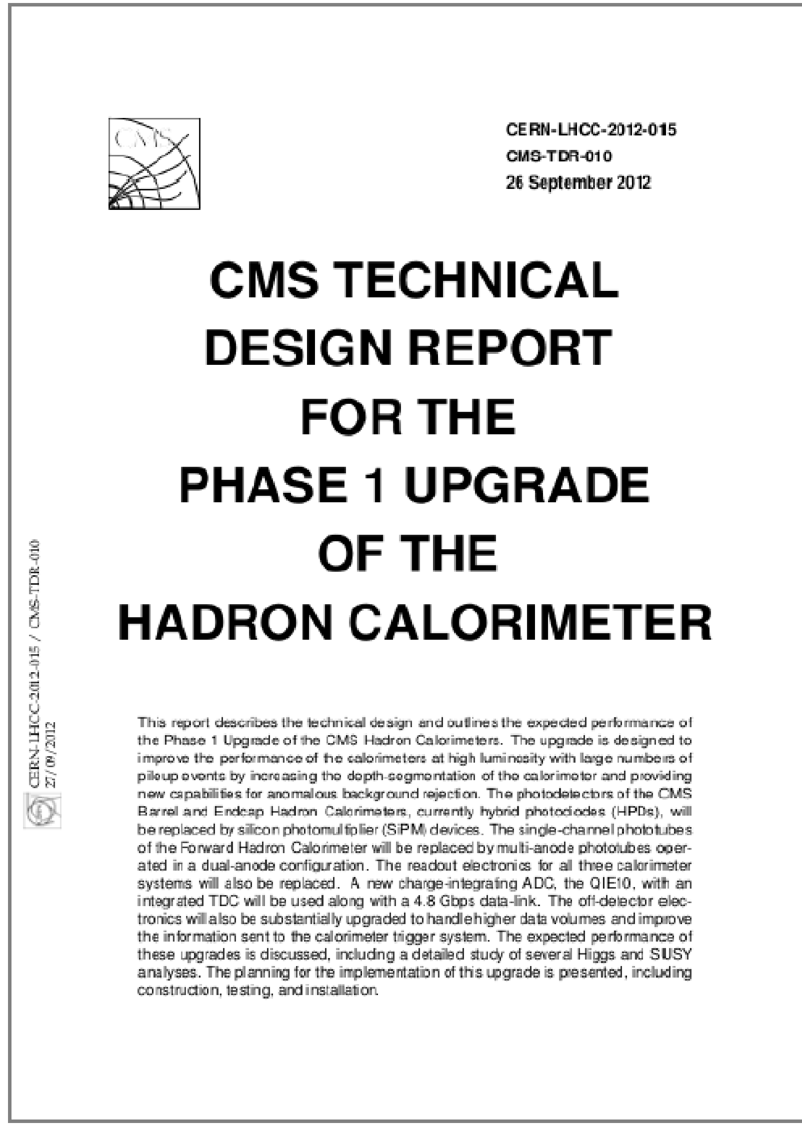






HCAL TDR

- TDR now fully public, uploaded to CDS
  - CMS-TDR-10
  - CERN-LHCC-2012-015
  - https://cdsweb.cern.ch/record/1481837
- Cover design under preparation, printing will occur later this year
- Presented to LHCC September 24/25
  - Very positive feedback ("extremely complete documentation", "strong case for upgrade")
  - Formal positive statement sent to RRB



CERN-LHCC-2012-015
CMS-TDR-010
26 September 2012

CMS TECHNICAL DESIGN REPORT FOR THE PHASE 1 UPGRADE OF THE HADRON CALORIMETER

This report describes the technical design and outlines the expected performance of the Phase 1 Upgrade of the CMS Hadron Calorimeters. The upgrade is designed to improve the performance of the calorimeters at high luminosity with large numbers of pileup events by increasing the depth segmentation of the calorimeter and providing new capabilities for anomalous background rejection. The photodetectors of the CMS Barrel and Endcap Hadron Calorimeters, currently hybrid photodiodes (HPDs), will be replaced by silicon photomultiplier (SiPM) devices. The single-channel phototubes of the Forward Hadron Calorimeter will be replaced by multi-anode phototubes operated in a dual-anode configuration. The readout electronics for all three calorimeter systems will also be replaced. A new charge-integrating ADC, the QIE10, with an integrated TDC will be used along with a 4.8 Gbps data-link. The off-detector electronics will also be substantially upgraded to handle higher data volumes and improve the information sent to the calorimeter trigger system. The expected performance of these upgrades is discussed, including a detailed study of several Higgs and SUSY analyses. The planning for the implementation of this upgrade is presented, including construction, testing, and installation.

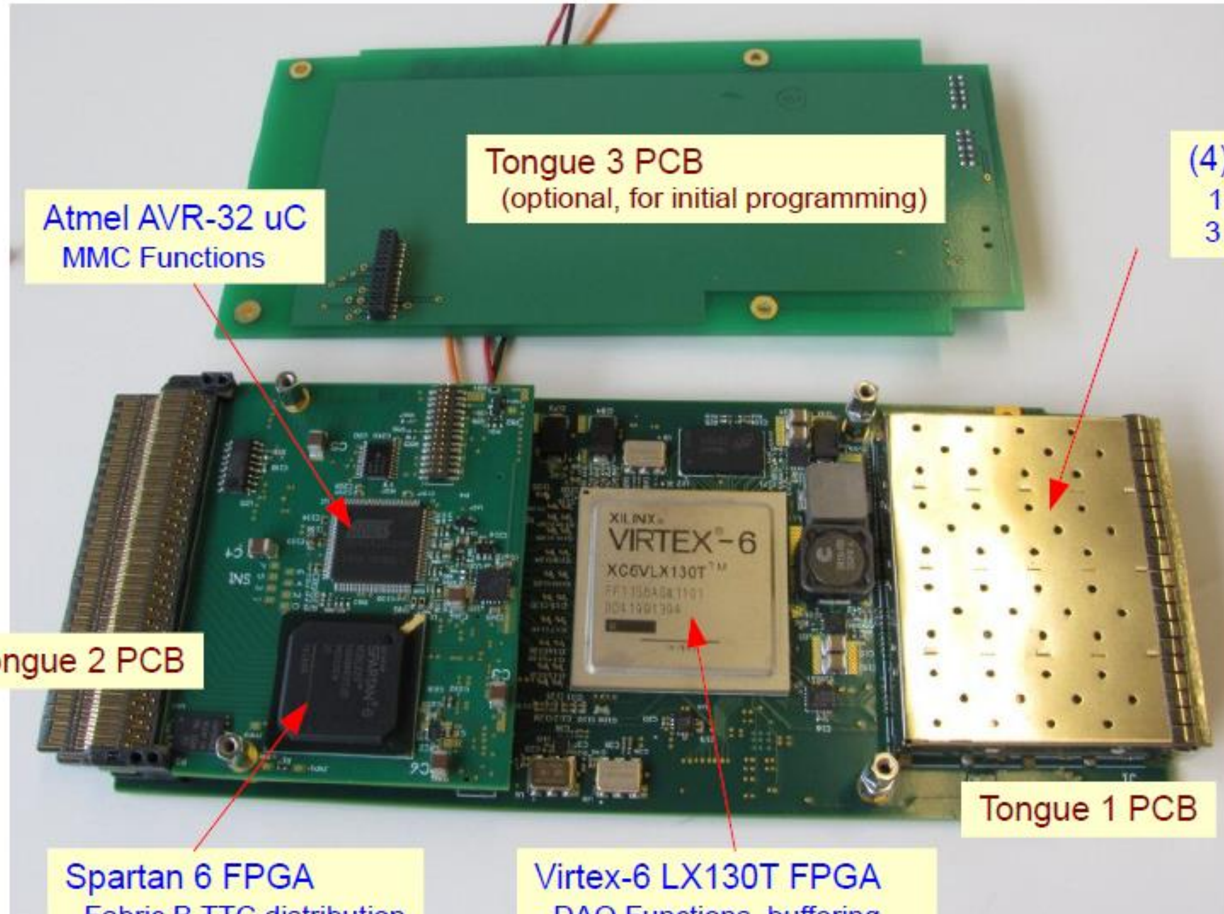
CERN-LHCC-2012-015 / CMS-TDR-010
27/09/2012

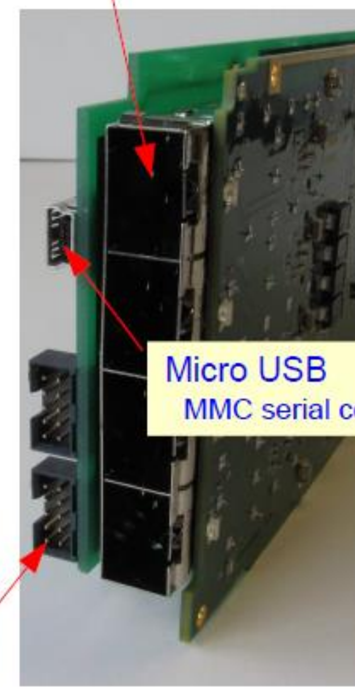
Summary

- Phase 1 Upgrade greatly improves the performance of HCAL in particular in High Pileup environment
- TDR was presented to the LHCC with very positive feedback
- Progress is being made in different areas
- We are on right track

Back-up

AMC13 Rev 1 Hardware





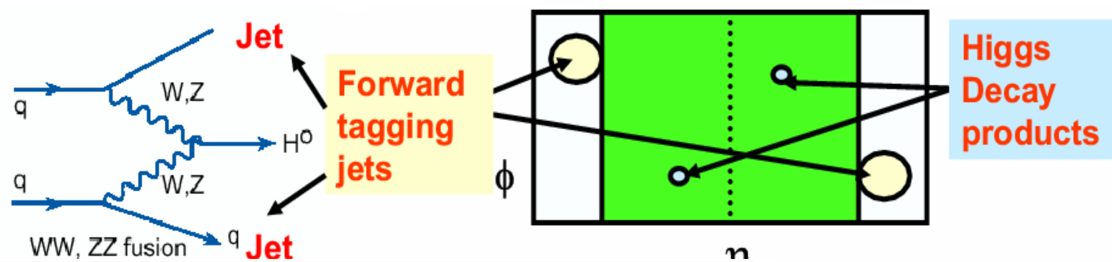
AMC13 Status

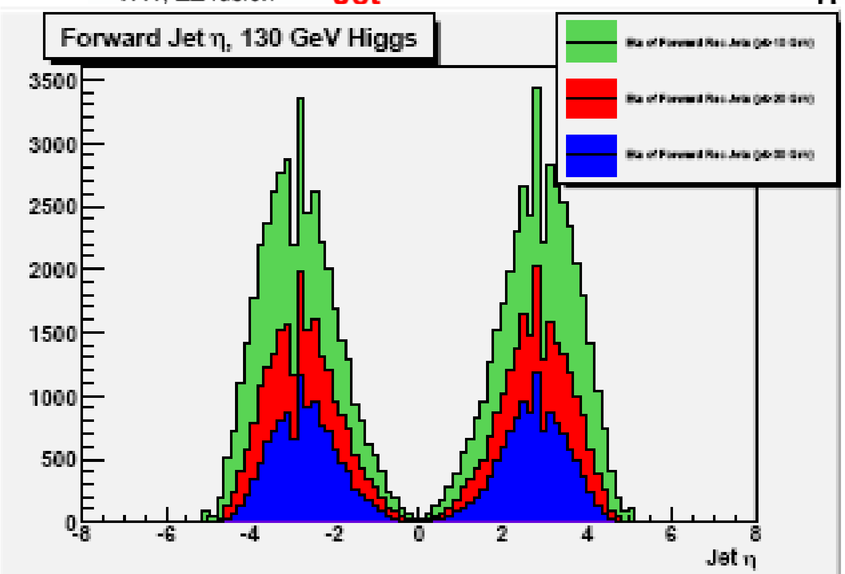
- Rev 1 boards produced (qty ~ 15)
  - Working in various test stands including at P5
  - Successful LED and Laser runs taken:
    RBX → Splitter → mCTR2 → AMC13 → xDAQ
    (using local DAQ)
  - CDAQ link is a work in progress but should be done soon
  - *These boards would function for HF readout*
- Production board design almost complete...
- Software ported to uHAL library (CMS standard)!

AMC13 Rev 2 Changes

- Virtex 6 to Kintex 7 for 10G link support
  - Requested by CDAQ for compatibility with COTS receivers
- Two-way GbE switch removed, GbE to Spartan chip only
  - (Never used Virtex GbE option)
- SDRAM size increased from 128MB to 512MB
  speed to 800MHz DDR (1600MT/s * 16 bits)
  - Now holds 2k HCAL event fragments
- Add 2 pins to T1-T2 board connector for additional power
- Minor changes to clocking to support use in upgraded TTC system (details still under discussion)

Previous study -- Importance of Forward Jets in VBF Higgs search (qqH $\rightarrow \tau\,\tau \rightarrow$leptons($\mu$ or e)





The qqH signal includes forward jets which are not present in many prominent background signals.

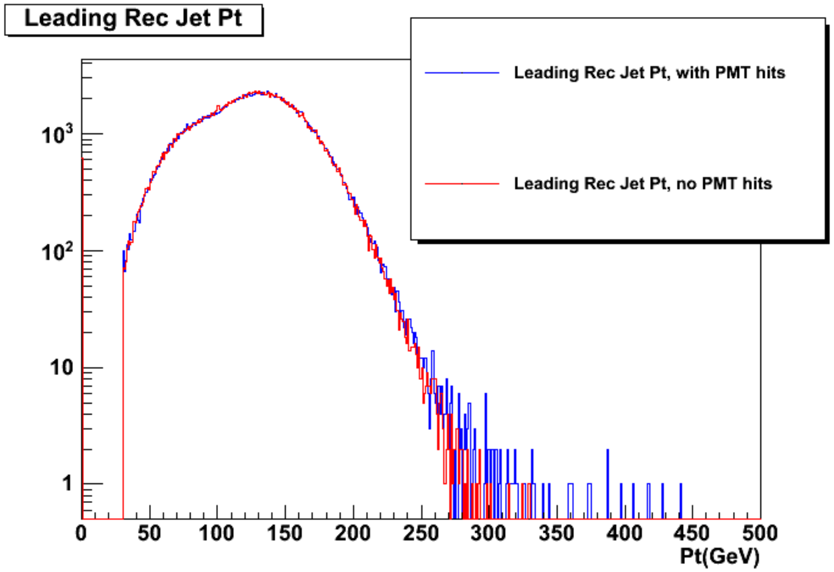
- → 2/3 of signal would be lost without HF coverage
- **Since many signal jets have η>3.0, HF is essential in the VBF Higgs search**

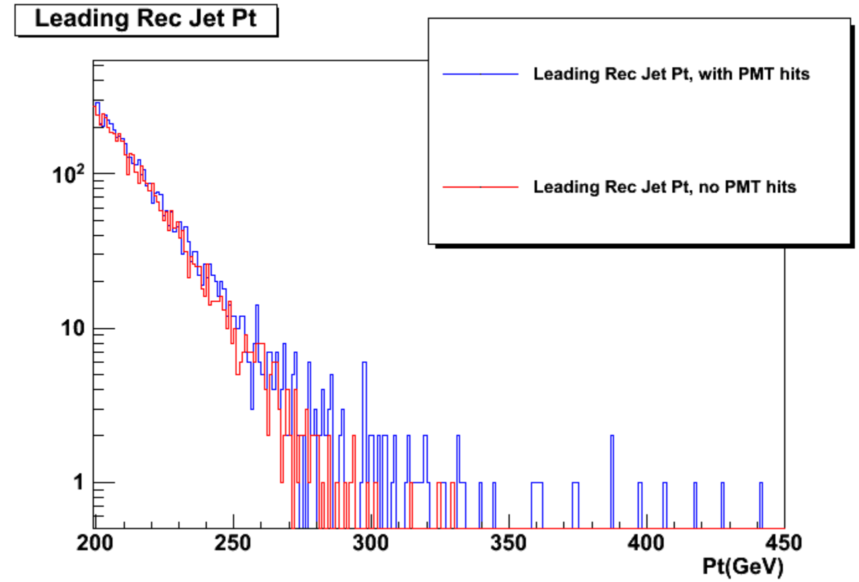
	Total Jet Pairs above threshold	At Least one Jet with $\|\eta\|$>3 (% of total)
10 GeV cut (green)	41785	32571 (78%)
20 GeV cut (red)	22252	16143 (73%)
30 GeV cut (blue)	11858	7992 (67%)

Previous study -- Impact of HF PMT hits on QCD jets (using PMT simulation)

Pt of leading jet (in HF) shows increase in hi-pt tail when PMT hits included --- pt>250 increased by 68%

Anthony Moeller

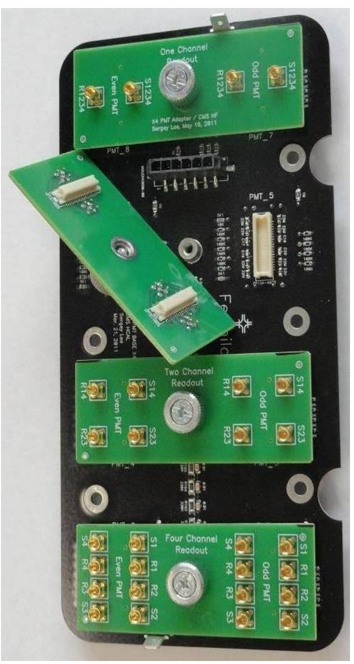




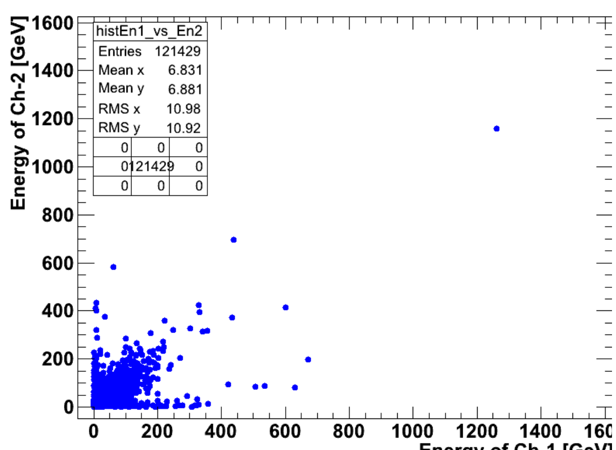
- Blue line is for events reconstructed with PMT hits, red line is for same events reconstructed without PMT hits.
- Right plot contains the same information as the left plot but zoomed in on the tail.
- Extra HF jets from QCD will lead to increased background to VBF Higgs search
  - Update this study to quantify difference between 2- and 4-anode

HF Multianode PMTs

- HF replacement PMTs have thinner windows, metal cases, and multiple anodes : tubes will be installed in LS1
- All will help reduce impact of charged particles passing through the PMTs, as will the TDC capability of QIE10.Multianode techniques have been tested with both P5 and testbeam data
- Multianode and TDC capabilities require upgraded electronics
- Choice between 2-anode or 4-anode readout will be important as a cost driver and for engineering complexity



Without Clean-up



With Clean-up