HCAL Phase-1 upgrades and tt+γ cross section measurement

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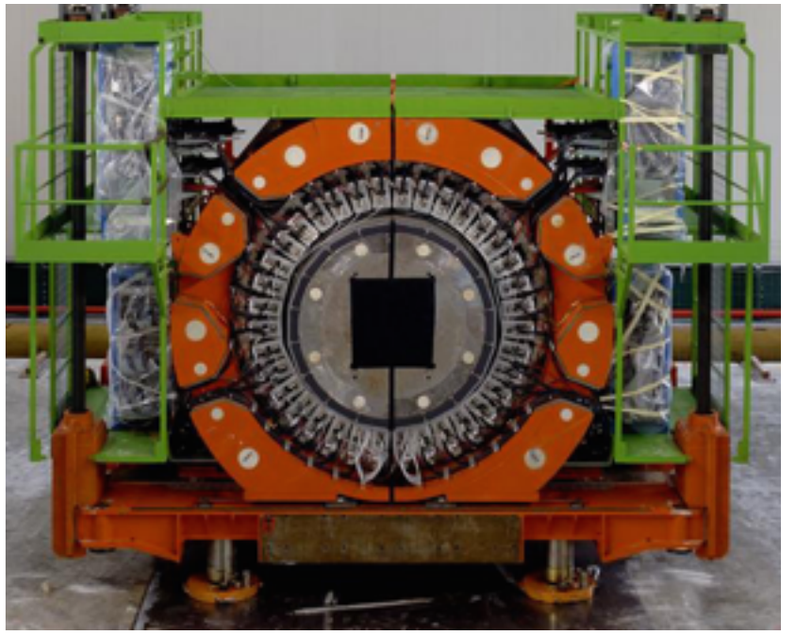
High Tech with a Human Touch™

CMS

Compact Muon Solenoid

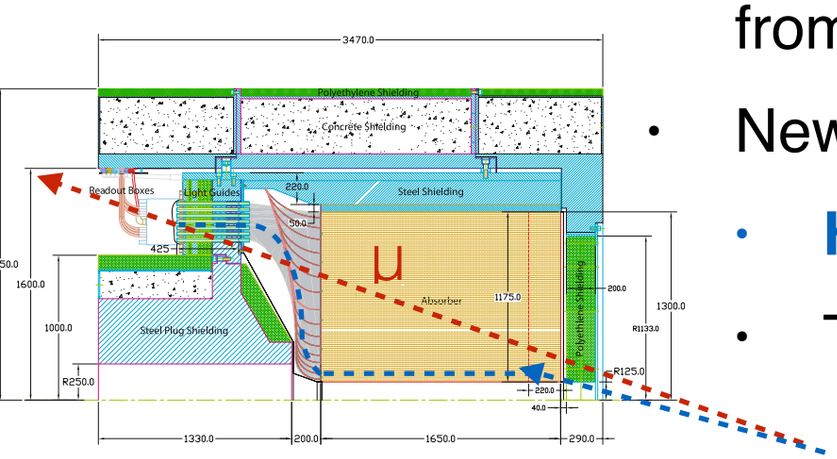
Outline

- Phase 1 upgrades for HCAL front end electronics
  - HF phase-1 upgrades:
    - Testing of all QIE cards before installation, commissioning of the detector after installation
  - Calibration of QIE channels for HF, HE, and HB upgrades
  - Working with many US and international institutions:
    - **Alabama, Baylor**, Bogazici, **Brown**, CBPF, Cukurova, DESY, **Florida Institute of Technology, Fermilab**, Istanbul Tech, **Iowa, Maryland, Minnesota**, Moscow State, **Princeton, Rutgers, UC Riverside**, Universidade do Estado do Rio de Janeiro, **Virginia**



- Measurement of ttgamma production cross section at 8 TeV
  - Florida Institute of Technology & Kansas State University

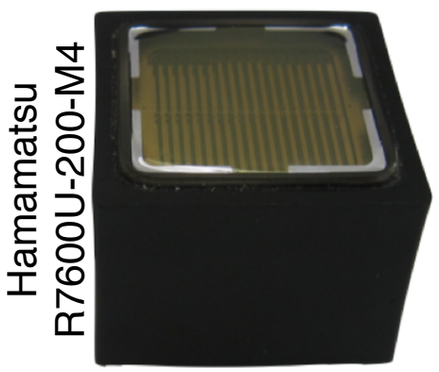
HF Phase-1 Upgrade



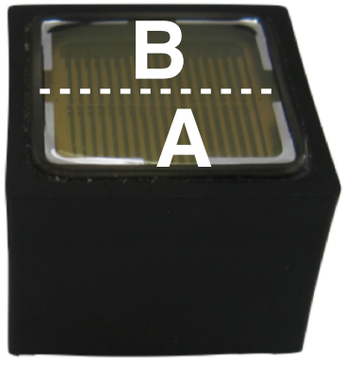
- Goal: Reduce noise from anomalous hits from particles hitting the PMT
- New PMT's installed during LS1
  - **Hamamatsu R7600U-200-M4**
  - Thinner window, multi-anode

Old PMT

New PMT



- During 2016-17 EYETS:
  - Rework PMT boxes to allow dual-anode readout of PMTs
  - Upgrade Front-end electronics

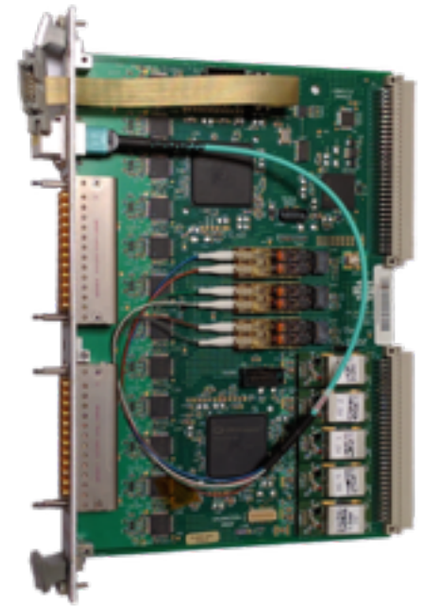


Asymmetry between anodes can be used to reject anomalous hits

New FE electronics:

- Doubles number of channels
- QIE10 chip
  - 8-bit ADC
  - 6-bit TDC

Pulse arrival time can be used to reject anomalous hits



Front End Testing and Installation

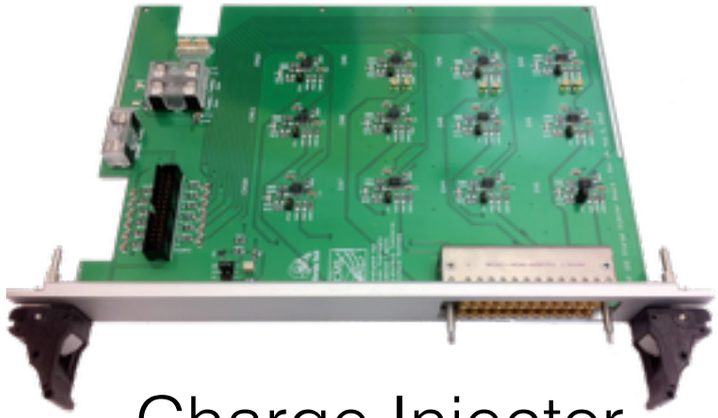
- All upgrade electronics were tested at CERN before installation during summer/fall of last year
  - Full testing of individual QIE cards
  - Calibration of QIE response
  - Burn-in of full system
- Installation of full system (144 QIE cards) on the detector this past winter

Burn-in at b904 at CERN

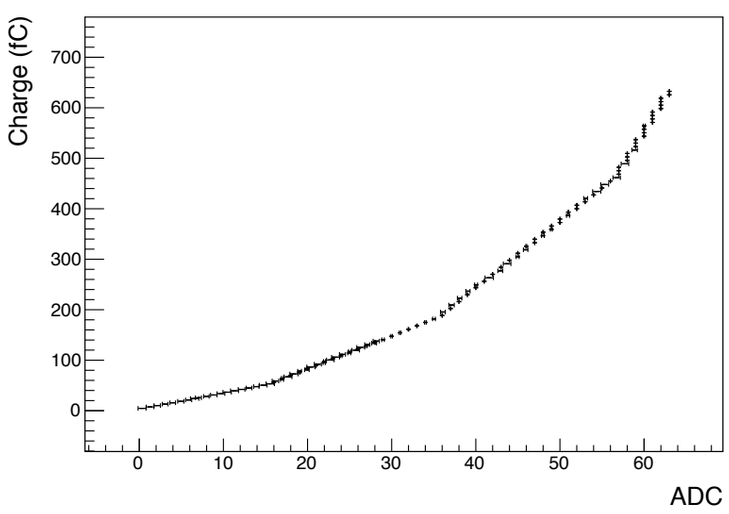
Quadrant installed on detector

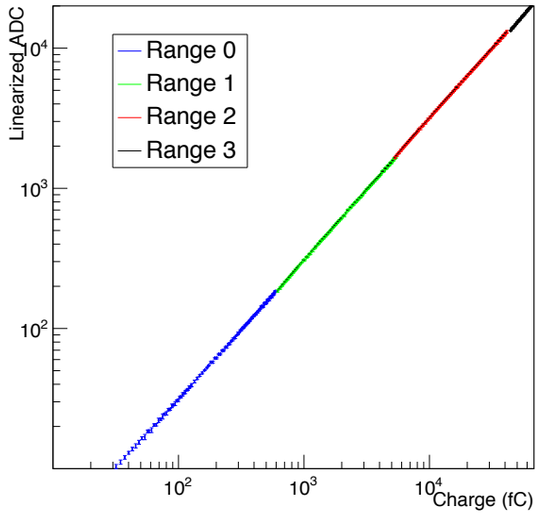
Calibration of QIE Cards

- FIT has taken the responsibility for the calibration of QIE chips used in the phase-1 upgrade (HF, HE, & HB)
- Goal is to precisely measure response of the QIE chip to different levels of input charge
- Designed and built external charge injector to inject DC current into QIE cards
  - Can measure ADC response of QIE cards at large range of injected charge
  - Configurable through 16-bit USB-controlled DAC
  - Provides fC level control over the amount of charge input into the QIE
- Individually calibrate all QIE channels
- Same calibration also performed for HE, and will be done on HB



Charge Injector





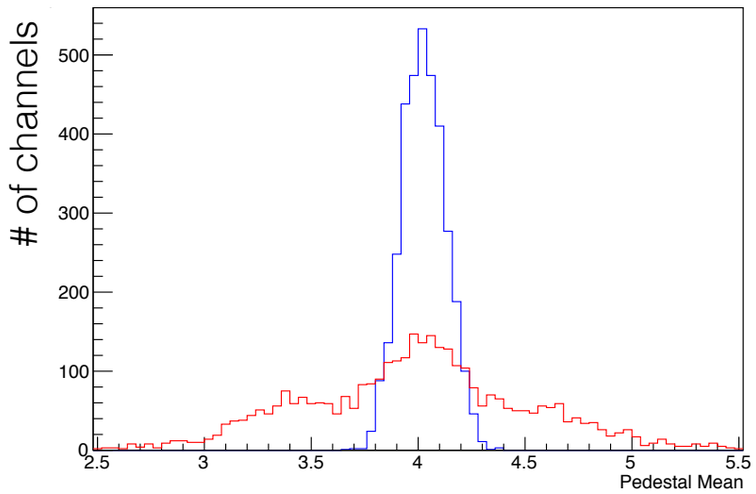
QIE10's being calibrated

Charge Injectors

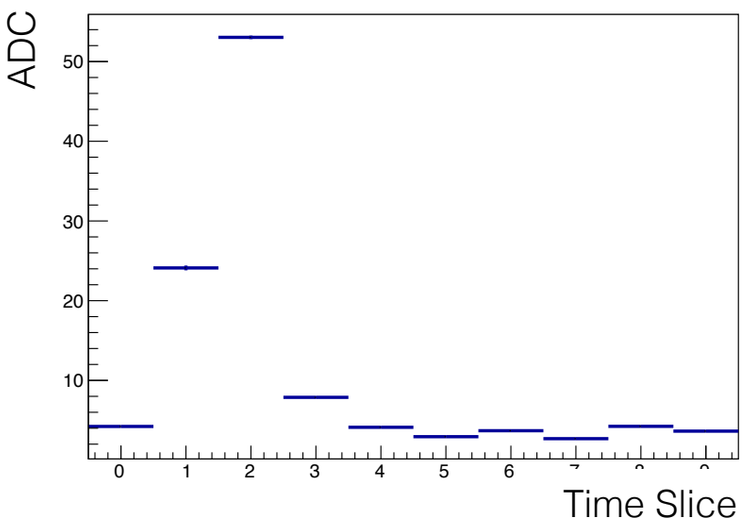
HF Commissioning

- After installation of electronics, full suite of tests performed to ensure everything works properly
  - Measuring pedestal levels and noise
  - Injecting charge with LED's and Laser pulses to measure response and timing of the system
  - Cobalt-60 sourcing: running radioactive source through tubes in detector and measuring the response

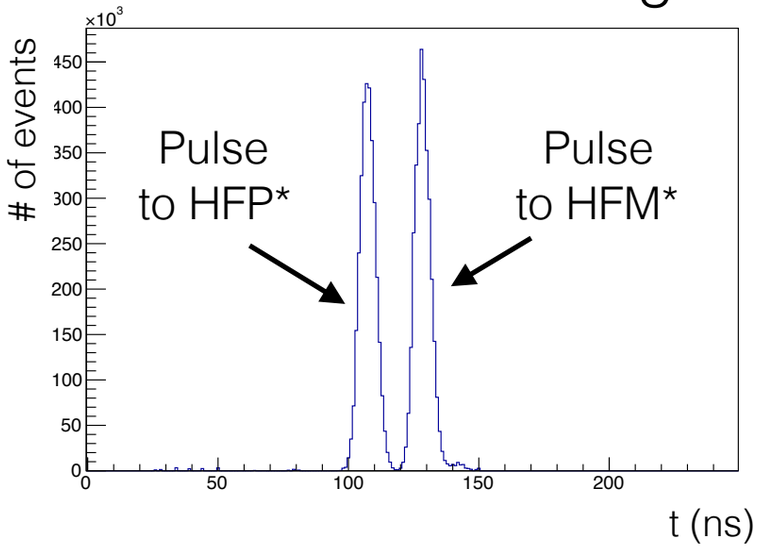
Pedestal Tuning



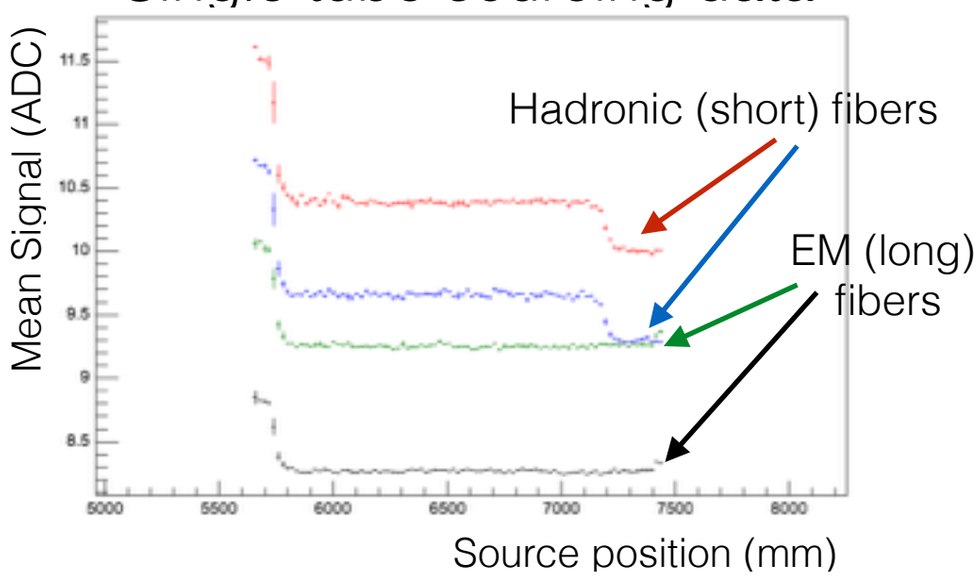
Laser Pulse



Laser Pulse Timing



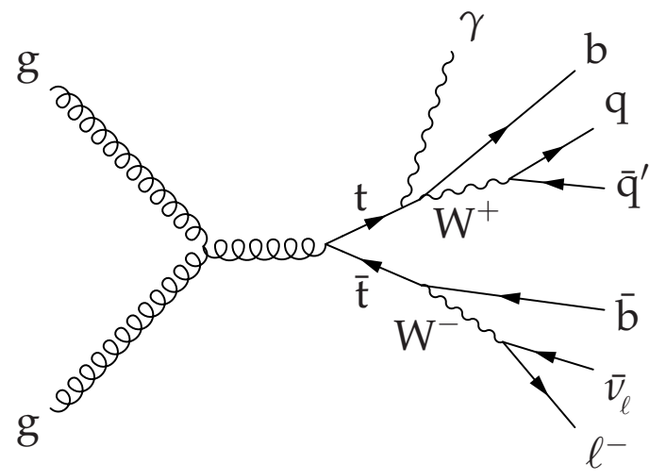
Single tube sourcing data

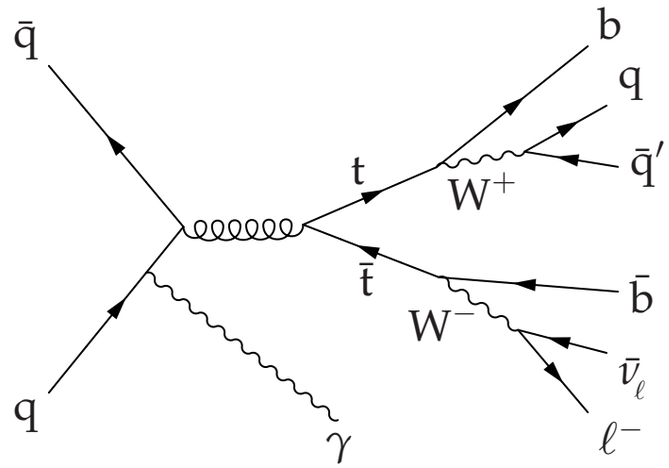


* Different laser fiber lengths to HFP and HFM

tt+γ Cross Section Measurement

- Measurements of top quark production cross sections and couplings provide import checks of the SM
  - Any deviations from the precise predictions of the SM can be an indication of BSM physics (anomalous dipole moments, exotic quarks, etc.)
- Measurement of tt+γ cross section
  - Probes the electromagnetic coupling of the top quark
  - Using 8 TeV data, 19.7 fb-1 of data collected in 2012
  - Measurement performed in the l+jets final state
- Signal is a top pair decaying into either an electron or muon, jets, MET, and an isolated photon
- Backgrounds fall into two main categories:
  - Top events with a fake photon coming from misidentified electrons or jets (tt)
  - Non-top events with real photons (W+γ or Z+γ)

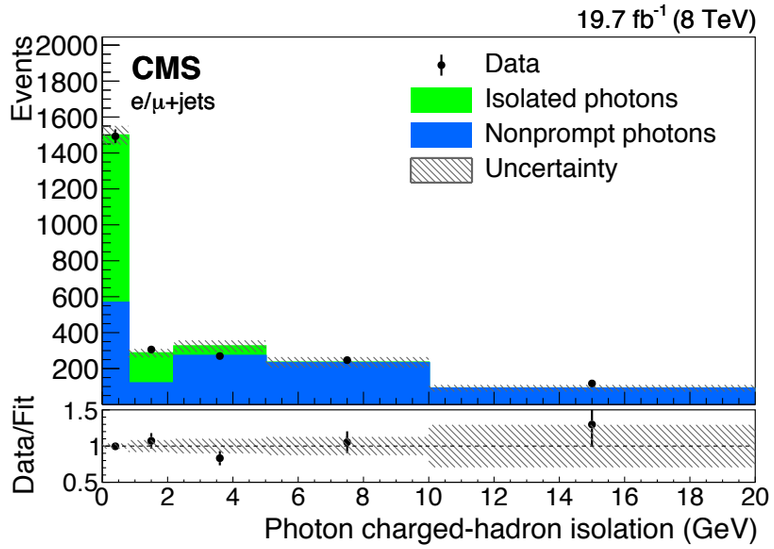




*** Submitted to JHEP, arxiv:1706.08128**

tt+γ Cross Section Measurement

- Background categories estimated individually
  - Using photon isolation variable to separate real from fake photons
  - M3 variable reconstructs hadronically decaying top, separates top pair events from
  - Combine the information about the rates of each of the two background categories in a likelihood function



$$\chi^2(SF_{t\bar{t}+\gamma}, SF_{V+\gamma}, SF_{jet\to\gamma}) = \frac{(\pi_{e\gamma}^{\text{data}} - \pi_{e\gamma}^{\text{MC}})^2}{\sigma_{\pi_{e\gamma}}^2} + \frac{(\pi_{t\bar{t}}^{\text{data}} - \pi_{t\bar{t}}^{\text{MC}})^2}{\sigma_{\pi_{t\bar{t}}}^2} + \frac{(N^{\text{data}} - N^{\text{MC}})^2}{\sigma_N^2}$$

Category	$\sigma_{t\bar{t}+\gamma}^{\text{fid}}$ (fb)	$\sigma_{t\bar{t}+\gamma} \times \mathcal{B}$ (fb)
e+jets	138 ± 45	582 ± 187
μ+jets	115 ± 32	453 ± 124
Combination	127 ± 27	515 ± 108
Theory	–	$592 \pm 71\ (\text{scales}) \pm 30\ (\text{PDFs})$

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Summary

- HCAL Upgrades:
  - Phase-1 upgrades of the HF electronics were completed during the EYETS this past winter
    - Took leading role in the testing and installation, as well as the calibration of both HF & HE
  - Plan to continue with calibration of HB here at the LPC next year, as well as contributing to research into phase-2 upgrade

- Top quark measurements:
  - We performed measurement of tt+γ cross section at 8 TeV in the l+jets final state
  - Continuing this work at 13 TeV, with the plan to extend the analysis to also perform differential measurement of the cross section