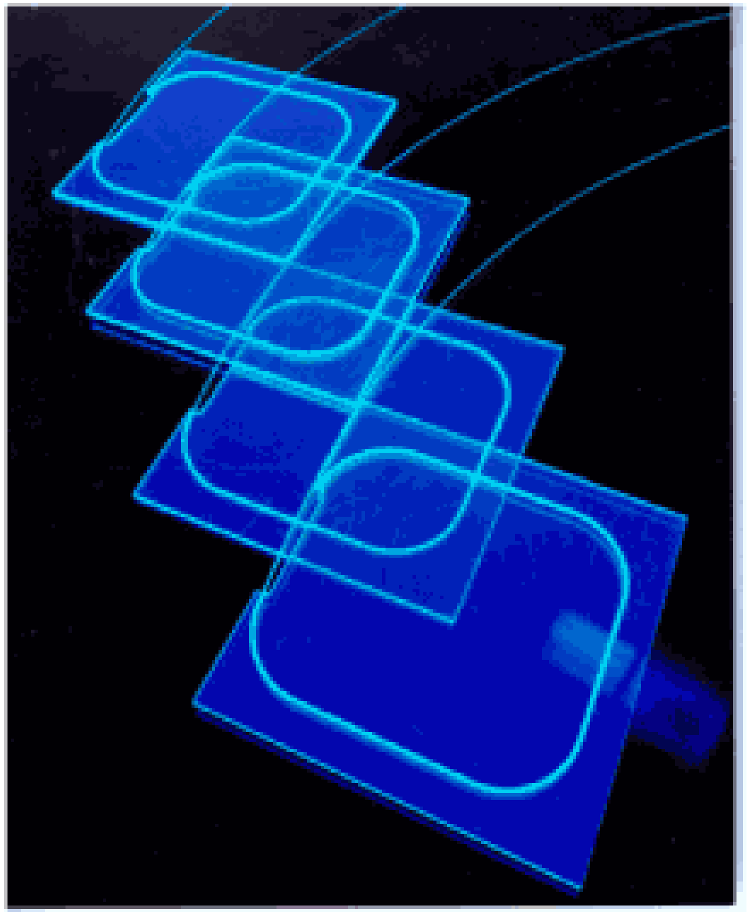
CMS Hadronic Endcap Calorimeter Upgrade Studies

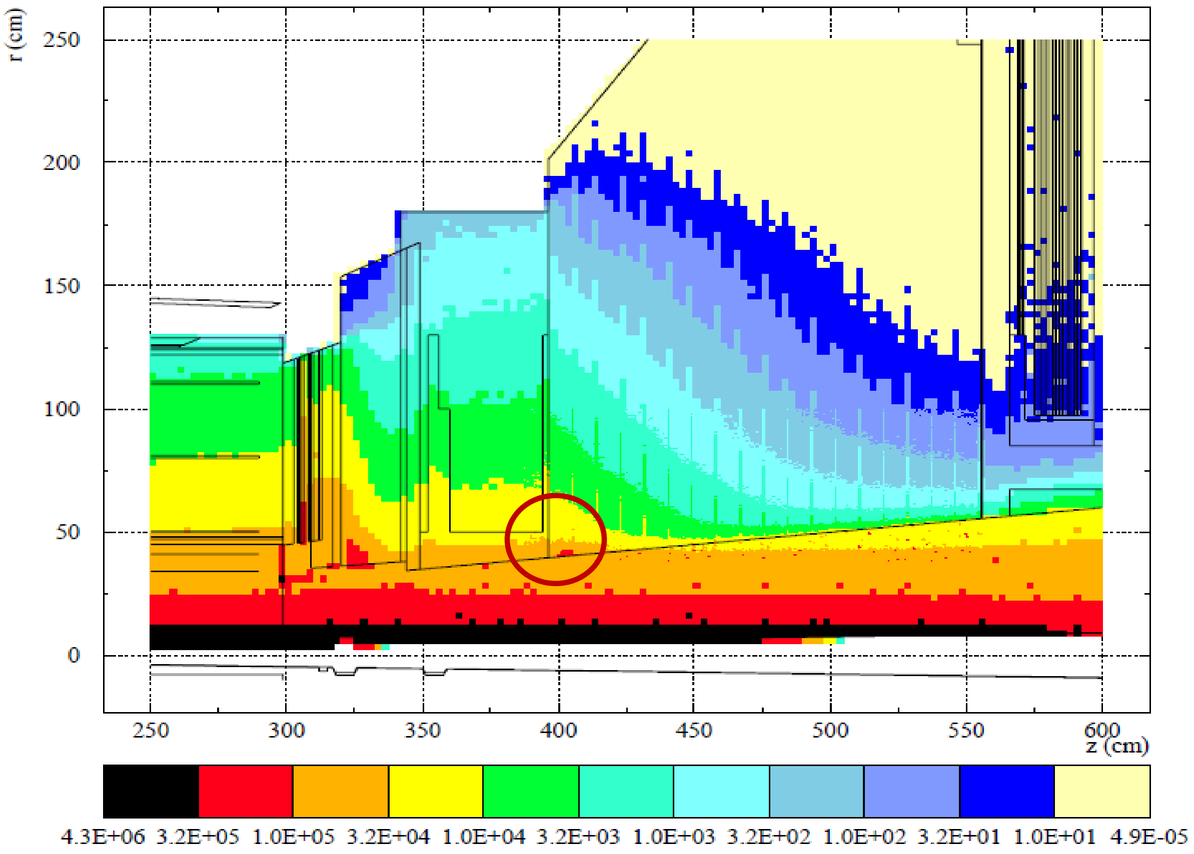
Current Design: “Scintillators”



- Megatiles of large scintillator sheets divided into components. They are inserted into 9mm thick spaces between absorbers.
- Light emission from tiles wavelength: λ=410-425 nm.
- Signal collected with wavelength shifting fibers absorbs blue, emit at λ=490 nm
- For the barrel and endcap detectors, the photosensors are hybrid photodiodes (HPDs) are used.

FLUKA Simulations

Simulation studies show that the scintillators are not going to be radiation hard for high Luminosity LHC runs.



Outline

We are proposing to replace HE scintillators with quartz plates for high luminosity LHC runs.

- **0^{th} Phase of R&D**
  - Show that Quartz is Radiation Hard
- **1^{st} Phase of R&D**
  - Cherenkov Light Collection from Quartz Plate
  - Tests of WLS fiber Embedded Quartz Plate Calorimeter
- **2^{nd} Phase of R&D**
  - Light enhancement tools: ZnO, PTP
  - Tests of PTP Deposited Quartz Plate Calorimeter
- **3^{rd} Phase of R&D**
  - Alternative readout options: SiPM
  - Radiation Hard WLS Fiber options

Quartz Radiation Damage Studies

We tested more than 10 different types of quartz with electron, proton and neutron irradiation. Polymicro quartz core, quartz clad fiber with a polyamide buffer looks promising.

Electron Irradiation Tests:

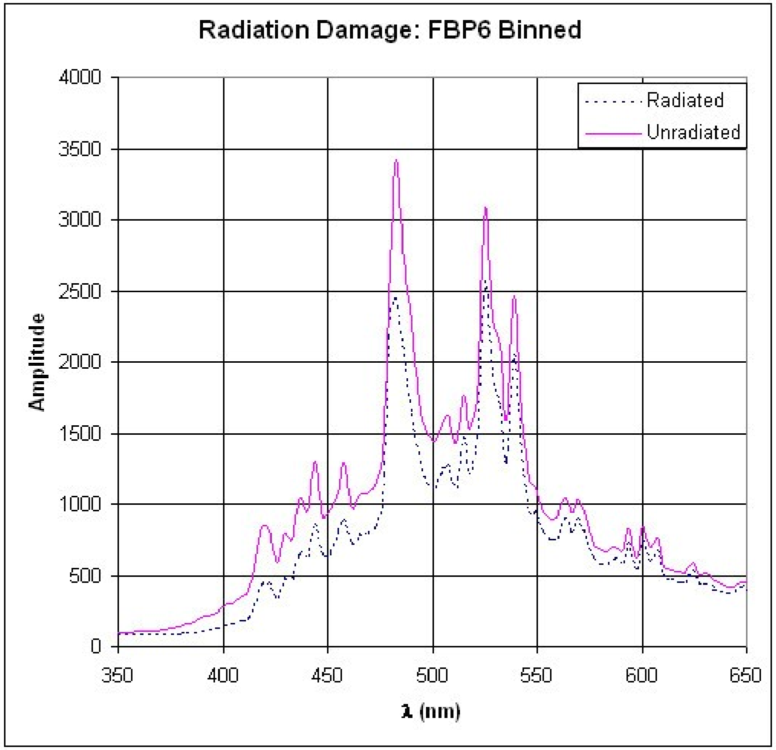
Dumanoglu *et al.* "Radiation-hardness studies of high OH content quartz fibres irradiated with 500 MeV electrons" **Nucl. Instr. Meth. A 490 (2002) 444-455**

Proton Irradiation Tests:

Cankocak *et al.* "Radiation-hardness measurements of high OH content quartz fibres irradiated with 24 GeV protons up to 1.25 Grad"
Nucl. Instr. and Meth. A 585 (2008) 20–27

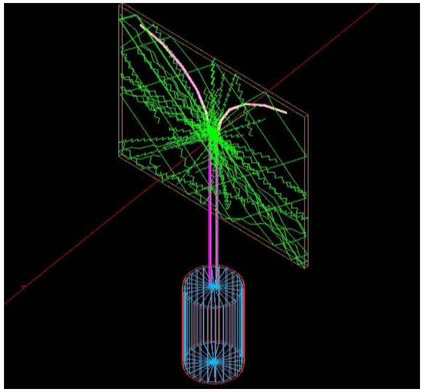
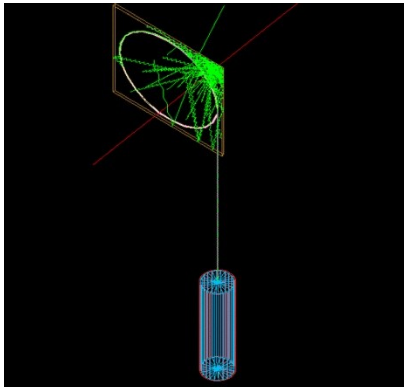
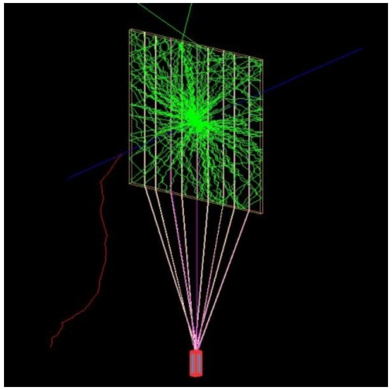
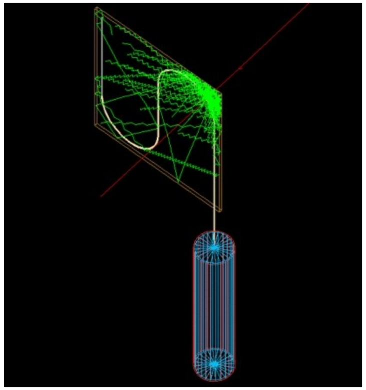
Neutron and Gamma Irradiation Tests:

U. Akgun *et al.* "Radiation Damage in Quartz Fibers Exposed to Energetic Neutrons", **in preparation**



Cherenkov Light Collection in Quartz

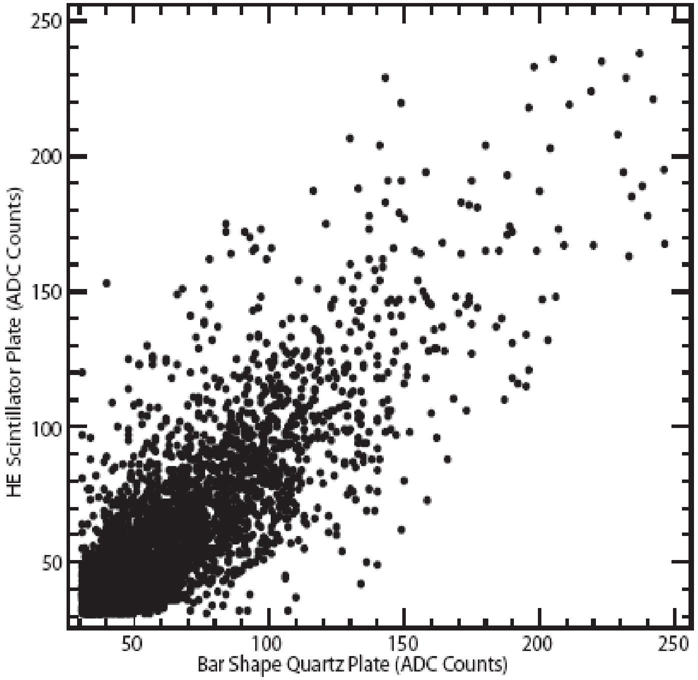
- Good : Quartz is radiation hard.
- Bad : We have to collect cerenkov photons. Very little light !! At fixed angle.
- Strategy: Go deep in UV to collect Cerenkov photons.
- We did R&D studies on
  - WLS fiber geometry
    - Cerenkov light collection, uniformity, and efficiency
  - Wrapping material reflectivity tests, Aluminum, Tyvek, HEM, Mylar.

WLS Fibers in Quartz

We showed that Cherenkov light collection inside the quartz is feasible with UV absorbing WLS fibers.

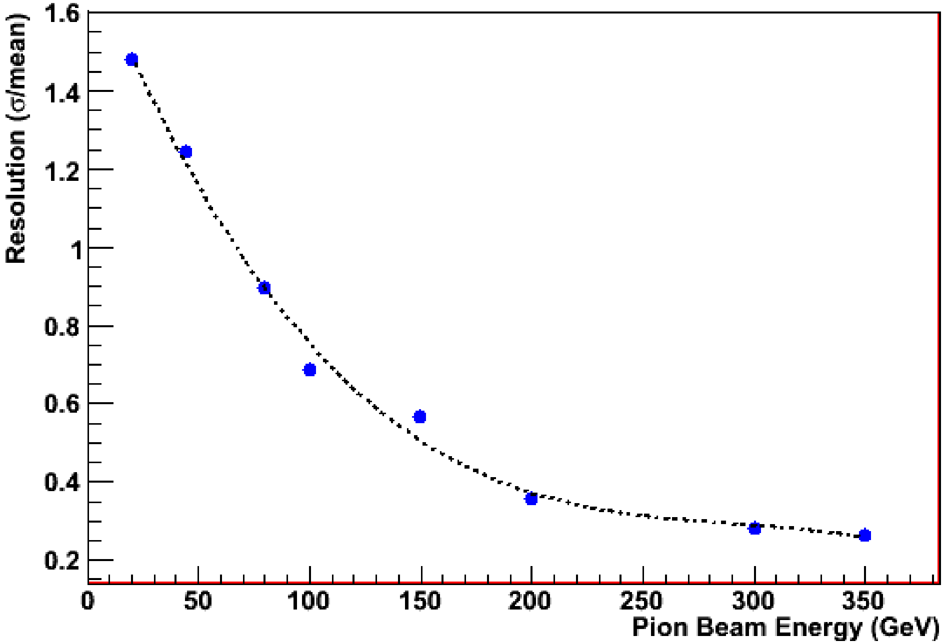
F. Duru *et al.* "CMS Hadronic EndCap Calorimeter Upgrade Studies for SLHC - Cerenkov Light Collection from Quartz Plates" , **IEEE Transactions on Nuclear Science, Vol 55, Issue 2, 734-740, 2008.**



QPCAL with WLS Fibers

We built and tested "WLS Fiber Embedded Quartz Plate Calorimeter Prototype"

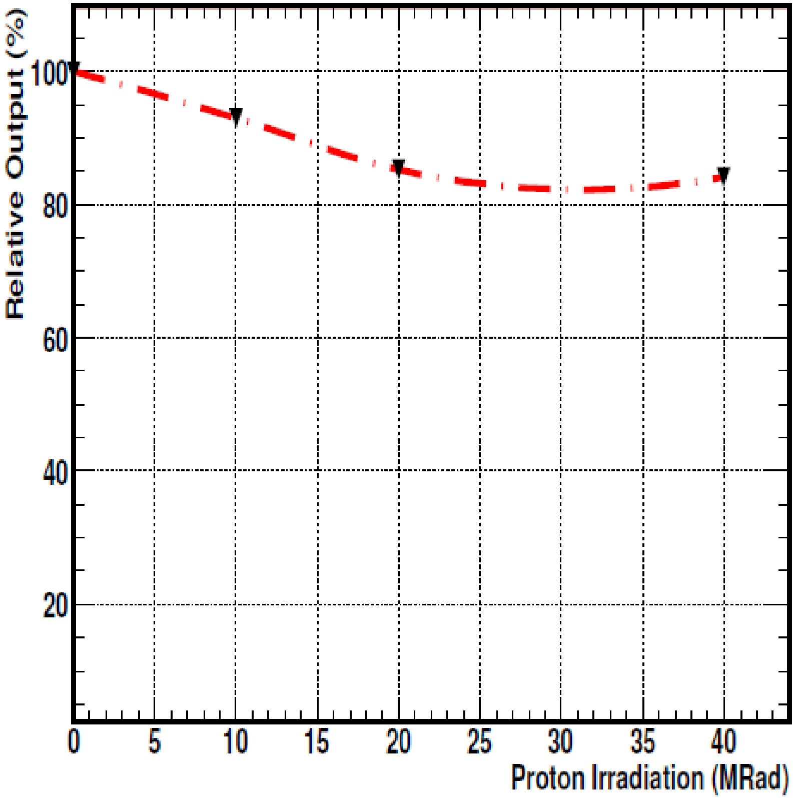
U. Akgun *et al.,* "Quartz Plate Calorimeter as SLHC Upgrade to CMS Hadronic Endcap Calorimeters", **XIII International Conference on Calorimetry in High Energy Physics, CALOR 2008, Pavio, Italy, May 2008, J.Phys.Conf.Ser.160:012015, 2009**

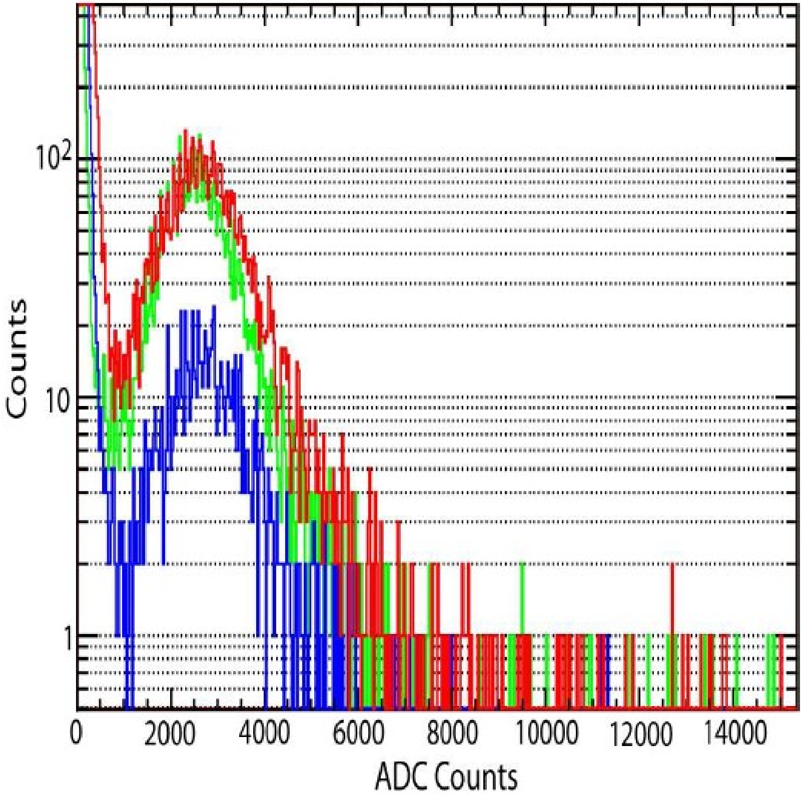


Radiation Hard Wavelength Shifters

Since the WLS fibers are not radiation hard, we tried radiation hard light enhancement tools (pTp, and ZnO) with quartz.

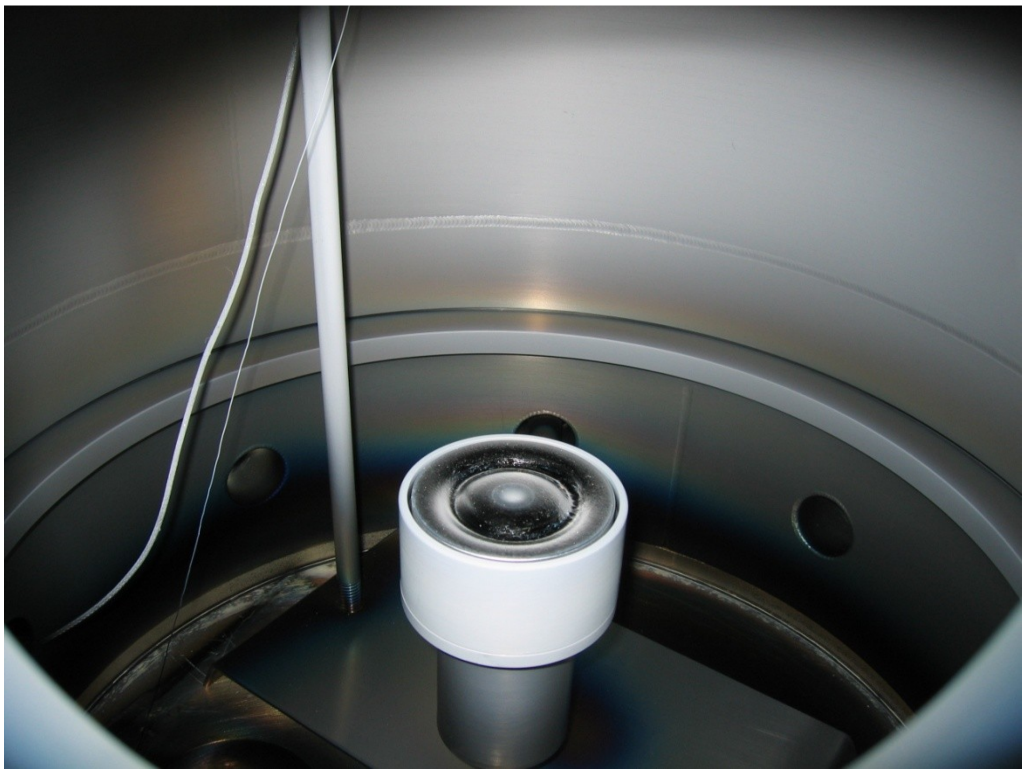
U. Akgun *et al.*, "P-Terphenyl Deposited Quartz Plate Calorimeter Prototype", IEEE Nuclear Science Symposium Conference, Dresden, Germany, 19-25 October 2008





Covering Quartz Plates with pTp and ZnO

We evaporated PTP and RF sputtered ZnO over quartz plates

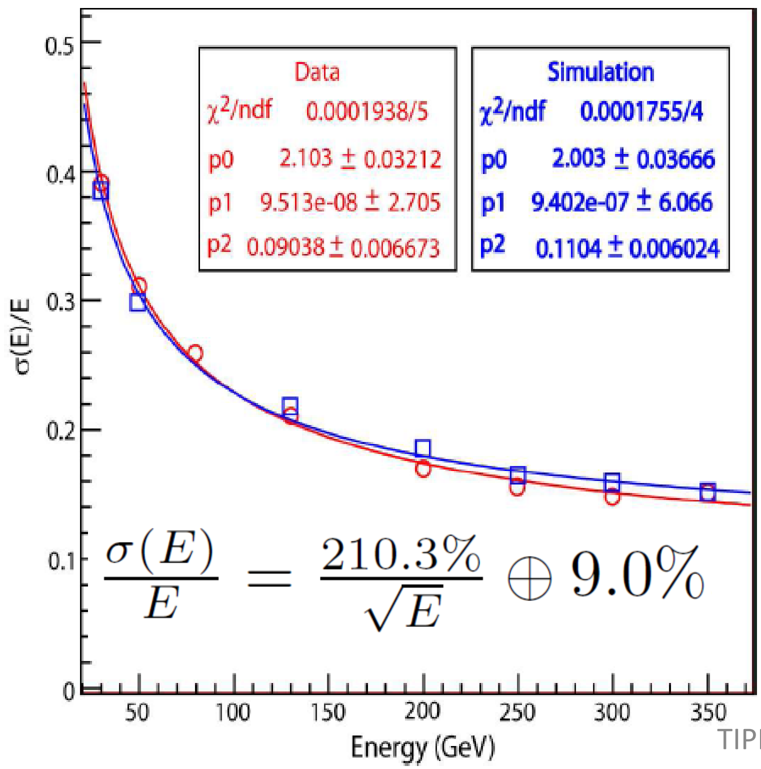


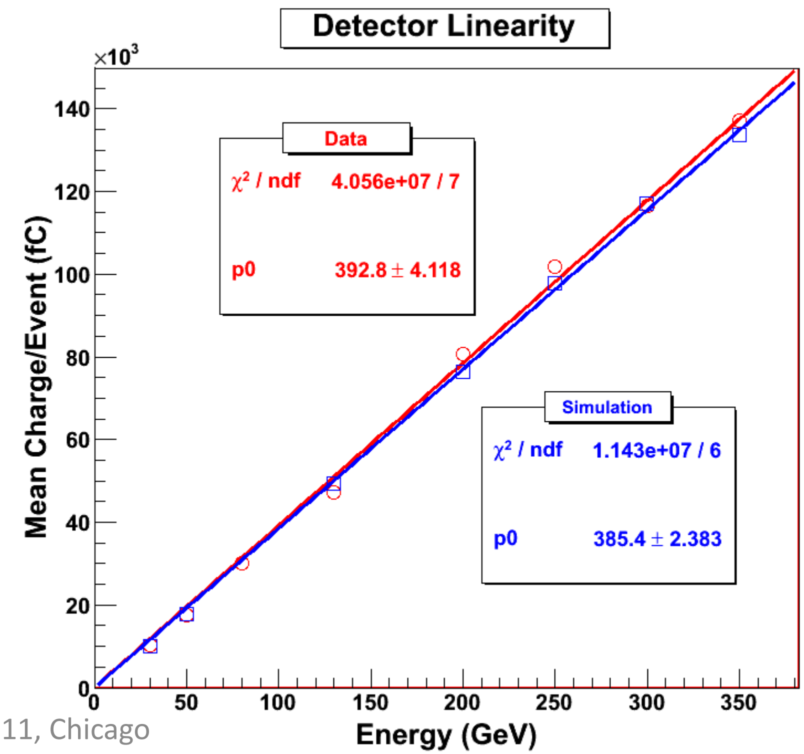
QPCAL with pTp

We built and tested "PTP Deposited Quartz Plate Calorimeter"

U. Akgun *et al.* "CMS Hadronic Calorimeter Upgrade Studies - P-Terphenyl Deposited Quartz Plate Calorimeter Prototype ", **APS 2009, Denver, CO, USA, May 2009**

B. Bilki *et al.* "CMS Hadron Endcap Calorimeter Upgrade Studies For Super-LHC", **CALOR 2010, Beijing, China, May 2010**

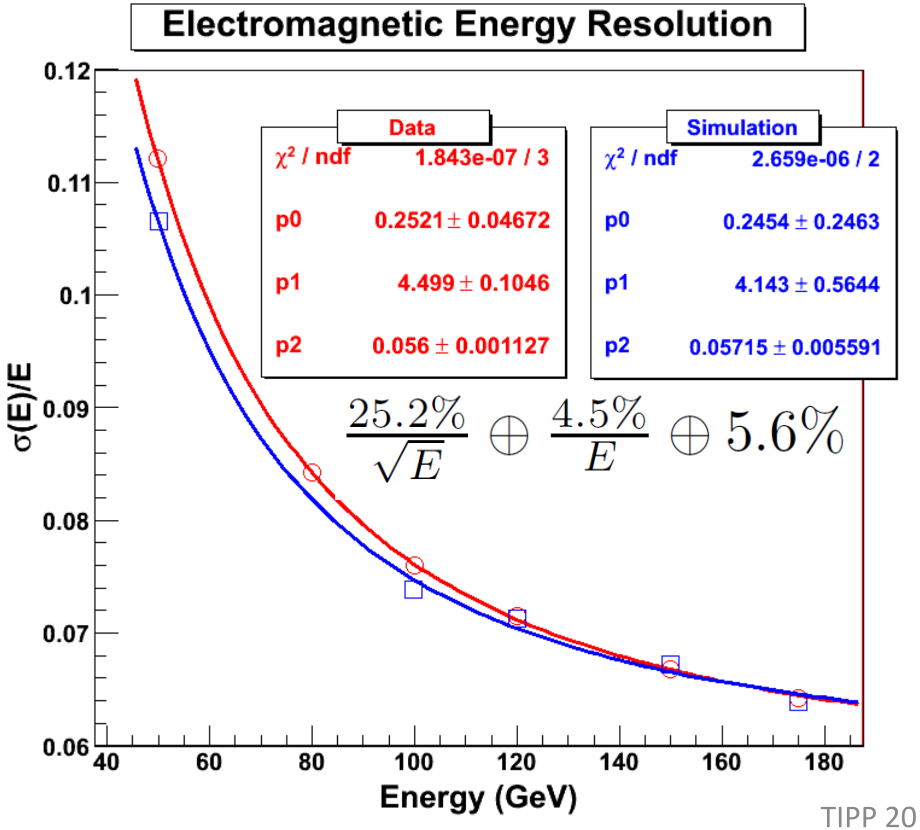


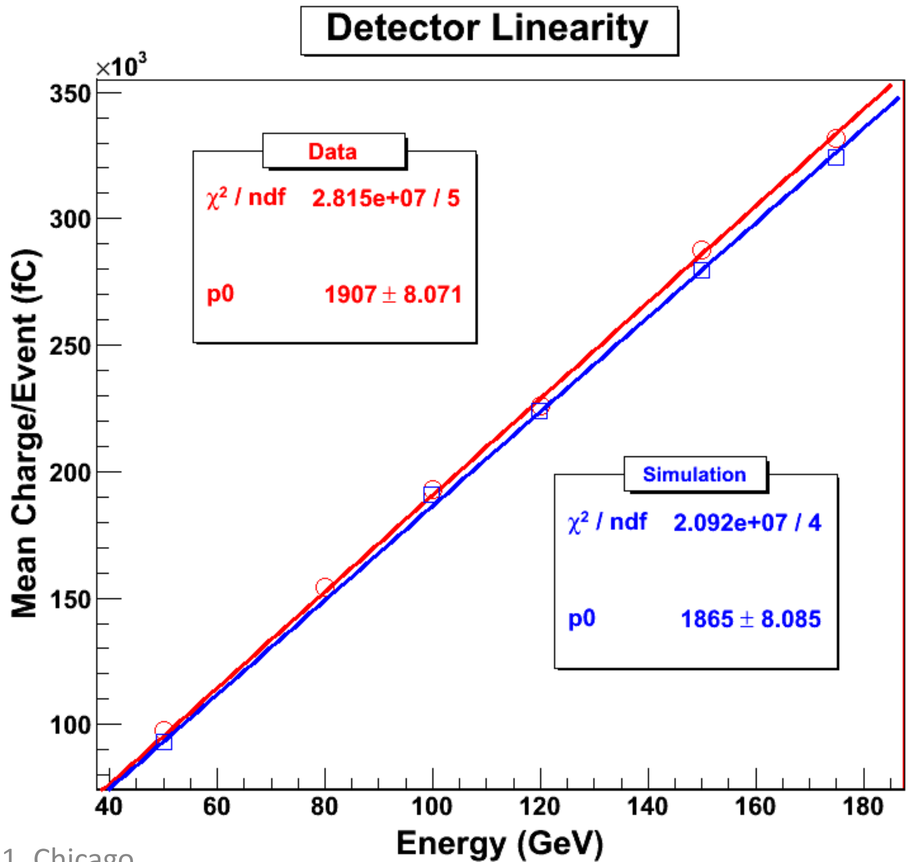


QPCAL with pTp – EM Mode

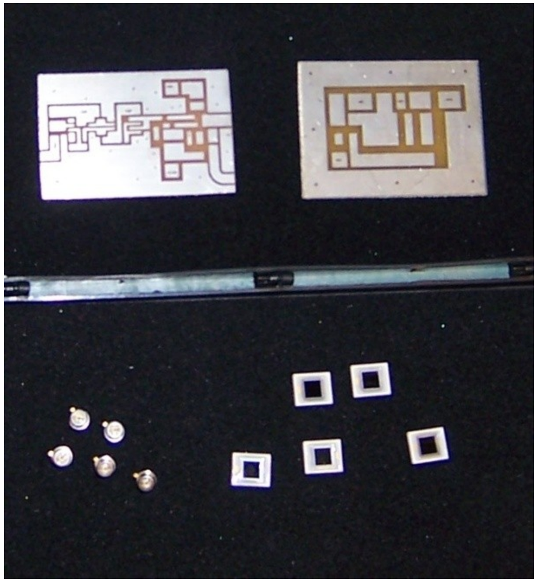
We can use combination as radiation hard CMS Endcap Calorimeter (EE + HE).

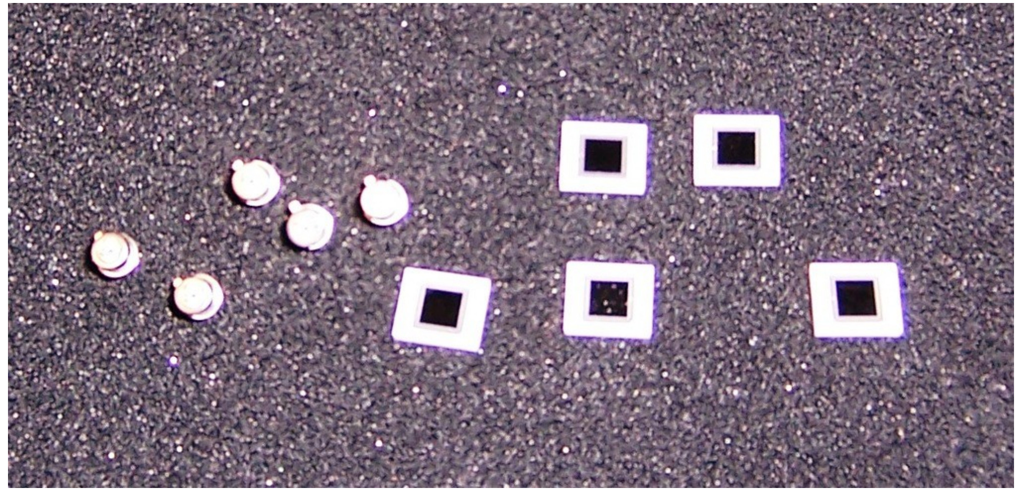
U. Akgun *et al.* "CMS Hadronic Endcap Calorimeter Upgrade Studies for SLHC P-Terphenyl Deposited Quartz Plate Calorimeter Prototype''
IEEE Transactions on Nuclear Science, Volume 57, Issue 2, 754-759, 2010

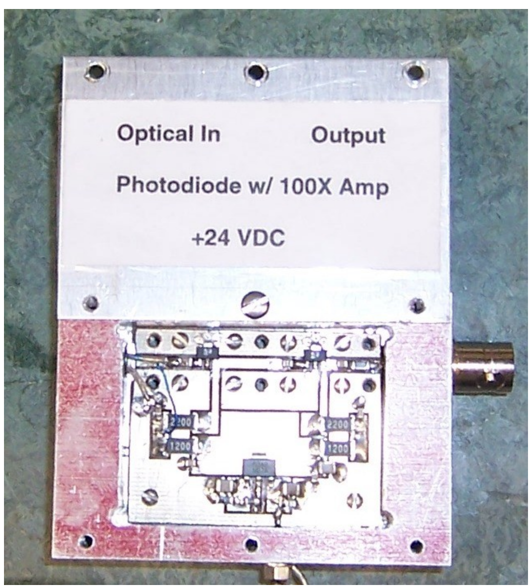




New Readout Options







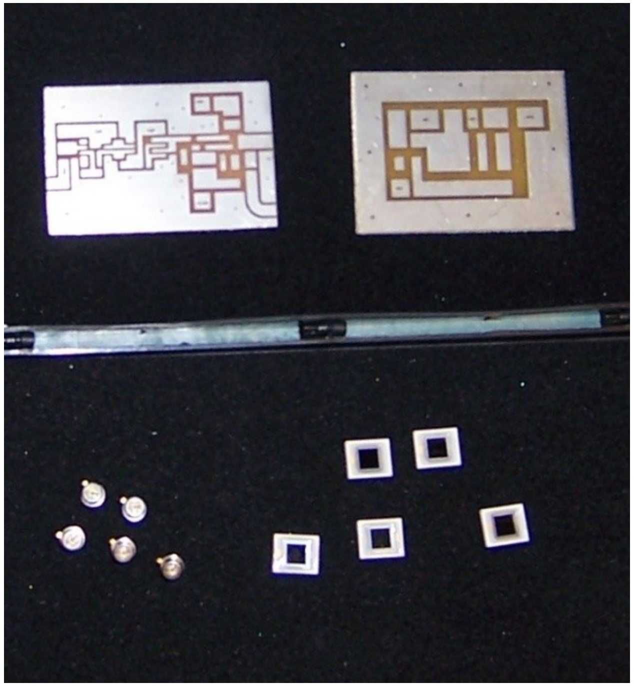
We tested;
*) Hamamatsu S8141 APDs (CMS ECAL APDs).
The circuits have been build at Iowa. These APDs are known to be radiation hard; *NIM A504, 44-47 (2003)*

*) Hamamatsu APDs: S5343, and S8664-10K
*) PIN diodes; Hamamatsu S5973 and S5973-02
*) Si PMTs

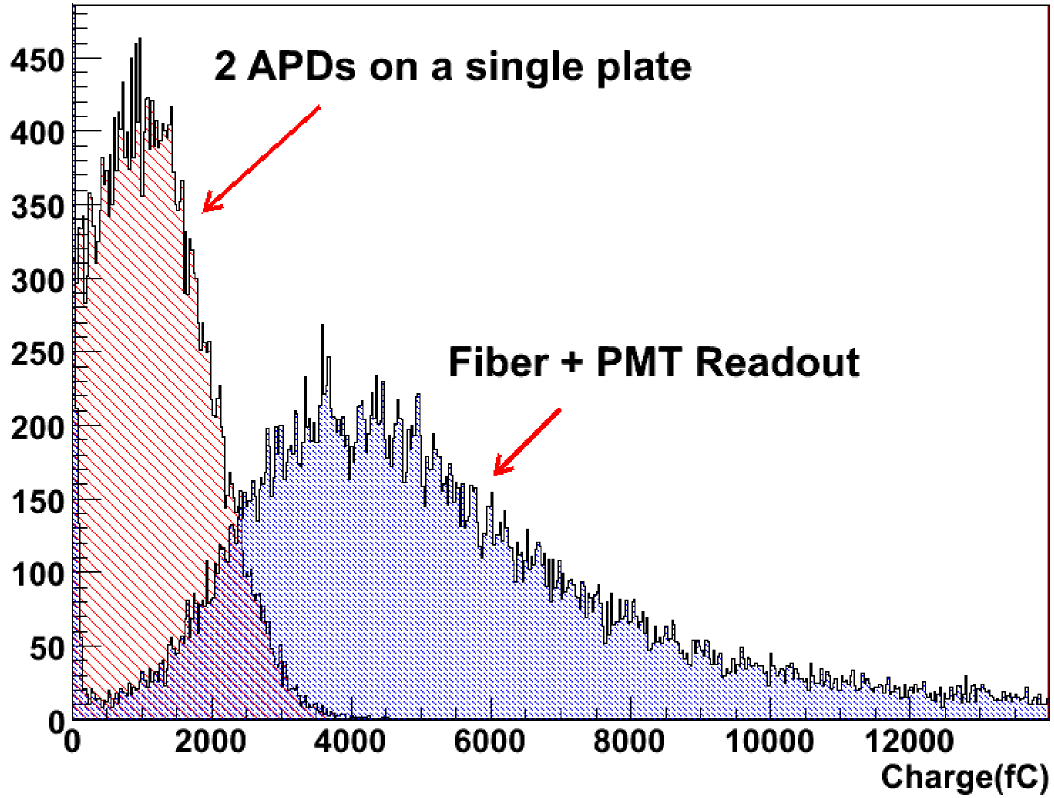
Alternative Readout

We constructed and tested alternative readout options from pTp deposited quartz plates: APD, SiPM, PIN diode.

They are not very effective and most importantly, the APD and SiPMs are not radiation hard enough for us.

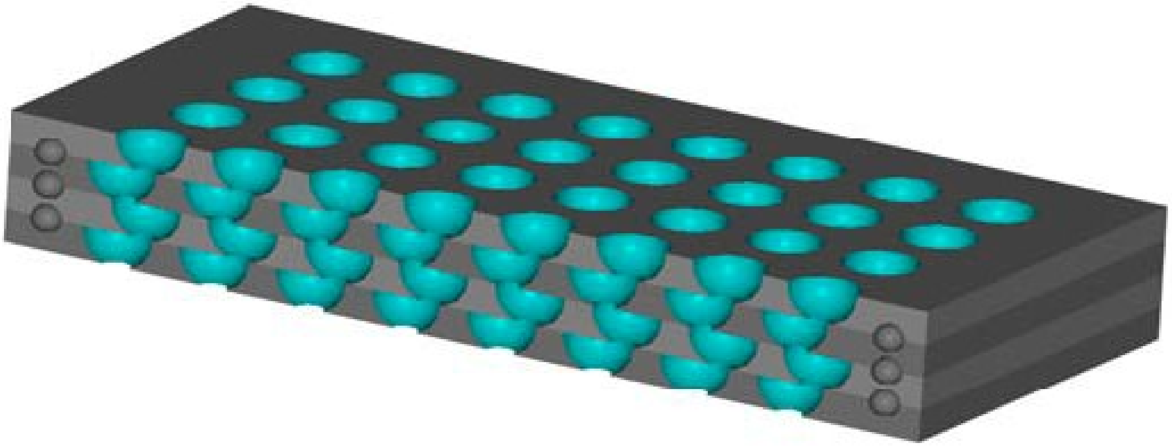


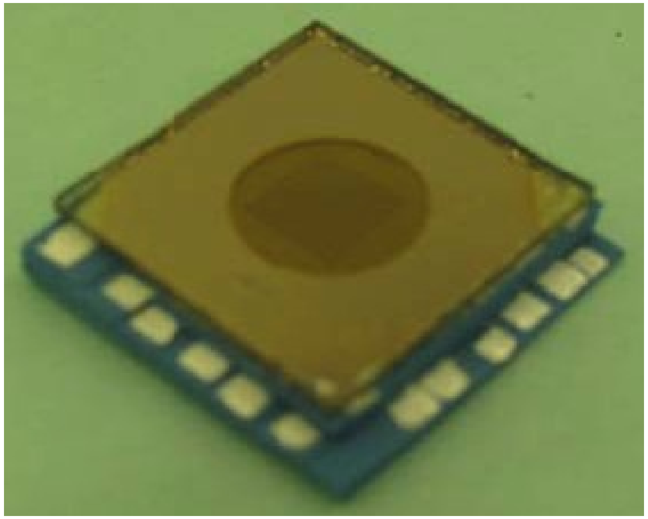
New Readout Options



We have tested ECAL APDs as a readout option. 2 APD connected to plain quartz Plate yields almost 4 times less light than fiber+PMT combination.

Microchannel PMT





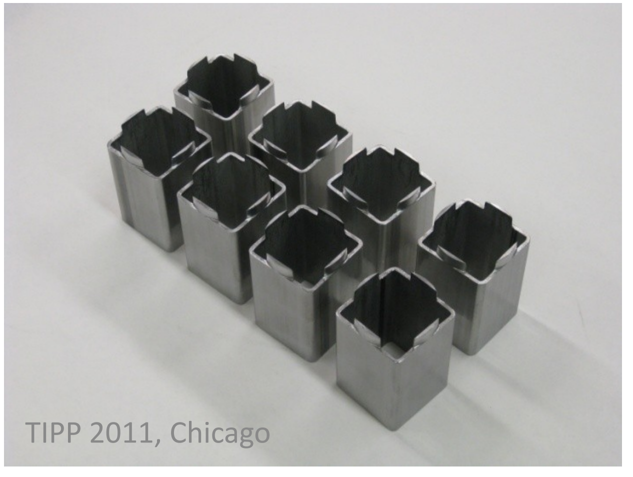
- Fast response time, high gain, small size, robust construction, power efficiency, wide bandwidth, **radiation hardness**, and low cost.

- 8 stage device is assembled from micro-machined dynodes which exhibits a gain of up to 2-4 per stage on single stage.

- The total thickness is less than 5 mm. 8x4 pixel micro-dynode array is shown

New Hamamatsu PMTs

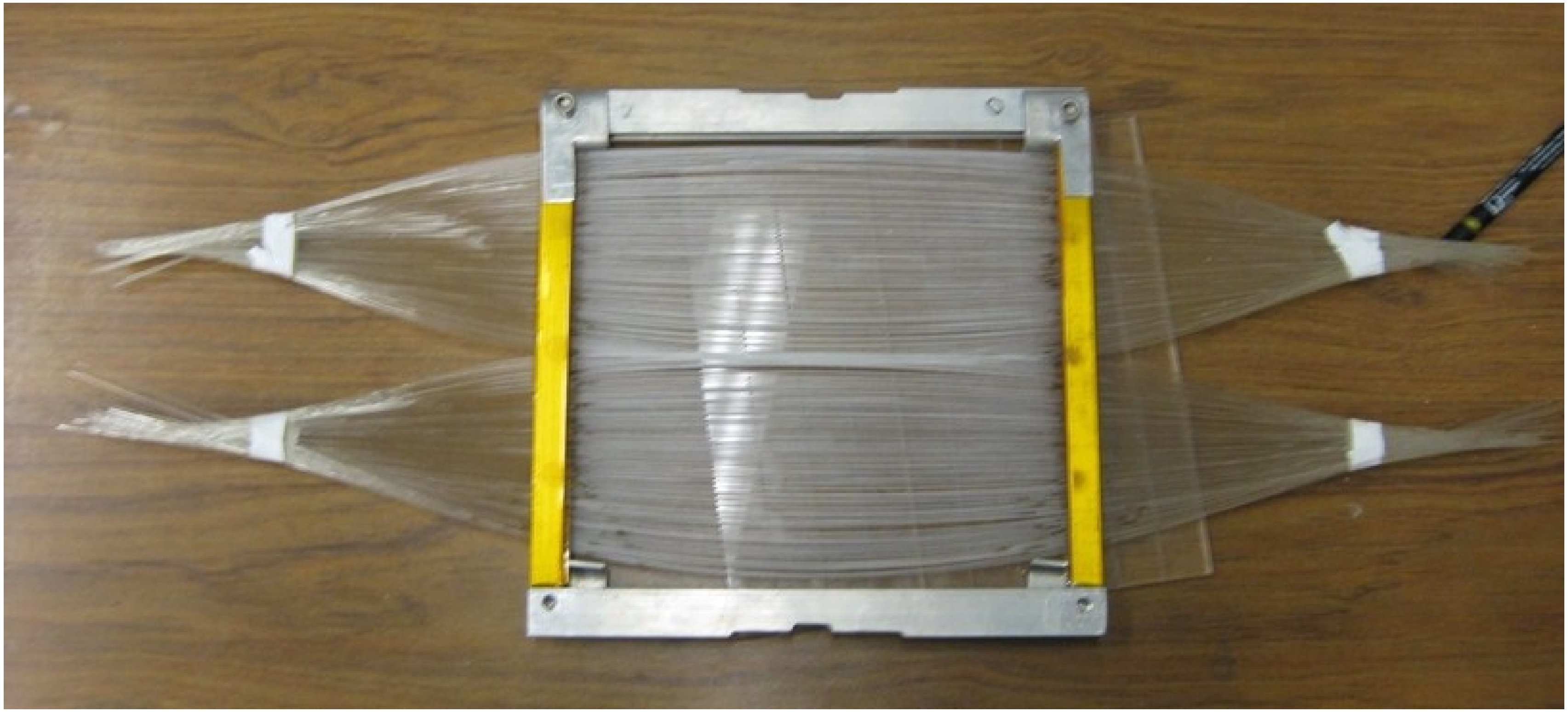
- During our HF Upgrade studies we extensively tested Hamamatsu 7600 series.
- Ultra Bialkali will make them better than any other option.
- Mashed architecture makes it B field hard. With no shielding it deviates only 2.5% at 200 Gauss.
- We also built mu shileds for these PMTs. They'll function in much higher B Fields.
- ***"Study of Various Photomultiplier Tubes with Muon Beams And Cerenkov Light Produced in Electron Showers"***, CMS NOTE 2010-003, Journal of Instrumentation 5 P06002, 2010



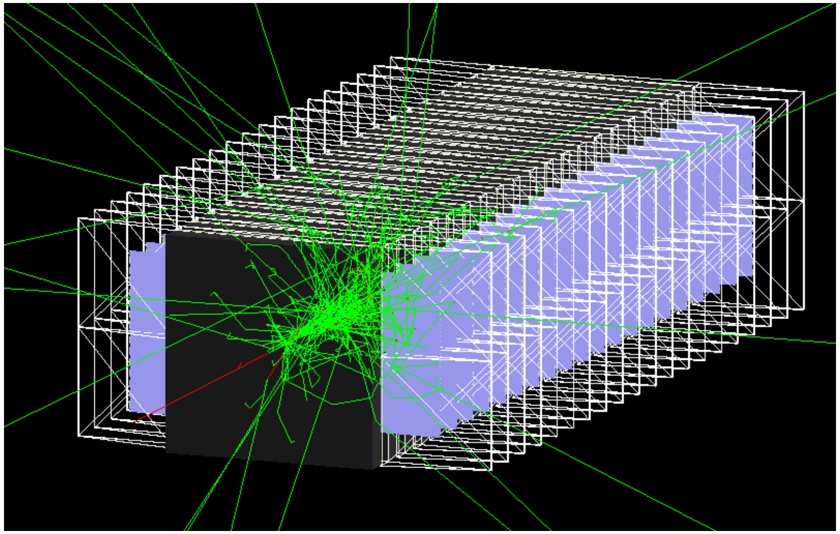
Radiation Hard WLS Fiber

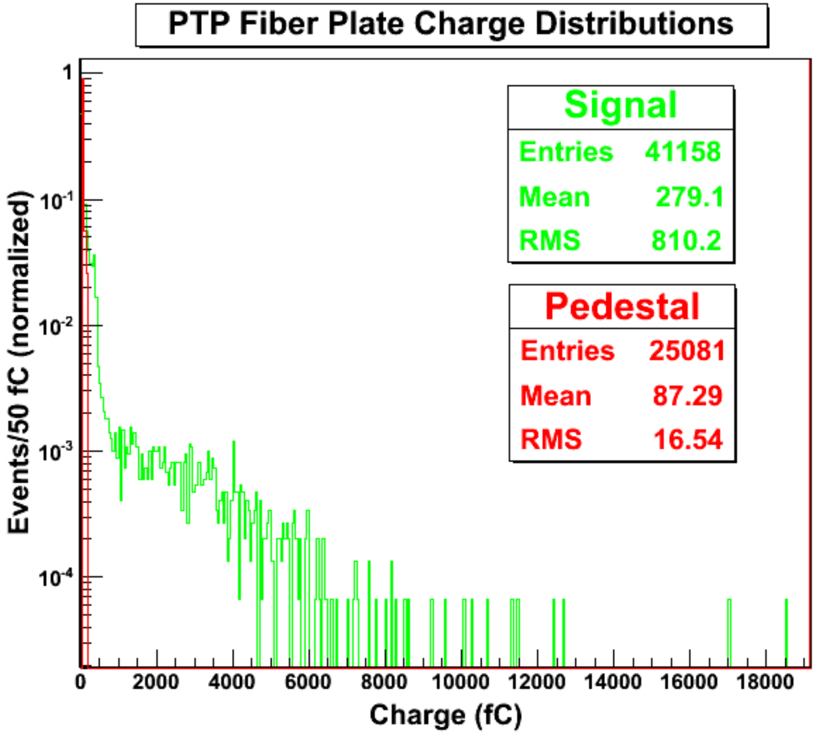
We Develop Radiation Hard Wavelength Shifing Fibers: Quartz fibers with PTP/ZnO covered core.

We built a radiation hard WLS fiber prototype. Deposited pTp on the stripped region, on both face. Then the whole ribbon will be sandwiched between quartz plates.



Radiation Hard WLS Fiber





We prepared a "homemade" rad-hard WLS fiber. We stripped the plastic cladding from QP fibers for "middle 20 cm" portion of 60 cm fibers.
This unit was tested with 80 GeV electron shower. The red line show the pedestal.
With a very simple prototype we collected substantial signal.

We try to optimize the model using Geant4 simulations.

HE Upgrade Plans

- We have two “viable” options for HE Upgrade, these can also be applied to EE region with 2 cm absorber thickness.

- Will read signal from PTP deposited plate, directly.
  - This will require radiation hard detector: Hamamatsu 7600 series, or multi channel PMT
  - The current technology of APD and SiPM is NOT enough.

- Will use WLS fibers
  - This requires rad-hard WLS fiber, which DOES not exist.
  - We built a primitive prototype with PTP, it is promising. Need R&D on PTP, ZnO deposition on quartz fibers. Sapphire fiber is another option.