CMS Hadron Endcap Calorimeter Upgrade Studies for Super-LHC

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CMS Hadron Endcap (HE) Calorimeters

- Coverage $1.3 < |\eta| < 3$
- Inserted into the ends of 4T magnet
- Mounted on the iron endcap yoke
- Brass absorber (~ 8 cm each layer)
- Megatiles of large scintillator sheets (4 mm SCSN81, 9 mm Bicron BC408 (for layer 0))
- Light emission from tiles: $\lambda=410-425$ nm
- Signal collected with wavelength shifting (WLS) fibers ($\lambda=490$ nm)
- Photosensors are hybrid photodiodes (HPDs)
LHC Upgrade

- The current design luminosity of the LHC is $10^{34}$ cm$^{-2}$ s$^{-1}$
- There are several proposed upgrade phases to the LHC
- In phase I the luminosity would be increased to $2 \times 10^{34}$ cm$^{-2}$ s$^{-1}$
- In phase II the luminosity would be further increased to $5-6 \times 10^{34}$ cm$^{-2}$ s$^{-1}$
- The time schedule for phase II calls for it to be performed in 2016
The “Problem” and the “Solution”

The Problem:
The plastic scintillator tiles currently employed by HE and their accompanying wavelength shifting fibers are radiation hard up to 2.5 MRad. The SLHC upgrade expects up to 16 MRad in HE.

The Solution:
Quartz plates would not be affected by high radiation.
Although the number of generated Čerenkov photons are at the level of 1% of the scintillators, the total light production can be increased with inorganic wavelength shifters.
Quartz Radiation Damage Studies

**Electron Irradiation Tests:**

**Proton Irradiation Tests:**

**Neutron and Gamma Irradiation Tests:**
U. Akgun et al. “Radiation Damage in Quartz Fibers Exposed to Energetic Neutrons”
*Submitted to IEEE Transactions on Nuclear Science.*
Wavelength Shifters

- Radiation hard
- Easy to coat the quartz with
- An effective light enhancement tool

Tested candidates:

**p-terphenyl (pTp)**

Evaporated in a vacuum chamber to be applied on quartz.

**ZnO:Ga (4%)**

RF sputtered on quartz (more expensive and delicate deposition process).

Evaporation and RF sputtering were performed in Fermilab and Iowa.

100K triggers. PMT gains normalized to the same value.
pTp Radiation Damage Tests

• Sr-90 activated scintillation light output of pTP samples before and after irradiation (Mississippi),

• The data was produced using protons from CERN and the Indiana Cyclotron Facility
QPCAL with pTp - Description

A calorimeter prototype with pTp coated quartz plates was built and tested in CERN H2 beamline.

The calorimeter stack consisted of 20 layers of pTp-coated quartz plates with size 15 cm x 15 cm x 5 mm.

7 cm (HAD) / 2 cm (EM) iron absorbers were placed in between the plates.

Readout was performed by Hamamatsu R7525 photomultiplier tubes (PMTs) from the 1-inch polished region on one side of the quartz plates.
Two different configurations, EM (2 cm absorber) and HAD (7 cm absorber) were tested with electrons (50, 80, 100, 120, 150, 175 GeV/c) and pions (30, 50, 80, 130, 200, 250, 300 GeV/c) respectively.

Trigger was provided with the coincidence of 14 cm x 14 cm, 4 cm x 4 cm and 2 cm x 2 cm scintillation counters.

Readout was performed by the HCAL QIE (charge integration and encoding) system.

Beamline elements were utilized during offline event selection.
QPCAL with pTp – Hadron Response

Longitudinal Shower Profile

Solid lines are GEANT4 simulation results. Simulation results are calibrated with the 80 GeV data on a layer-by-layer basis.
QPCAL with pTp – Hadron Response

Hadron Response Linearity

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QPCAL with pTp – EM Response

Longitudinal Shower Profile

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QPCAL with pTp – EM Response

EM Response Linearity

Calorimeter Resolution

$$\sigma(E) = \frac{26\%}{\sqrt{E}} \oplus \frac{4.5\%}{E} \oplus 5.6\%$$

Solid lines are GEANT4 simulation results. Simulation results are calibrated with the 80 GeV data on a layer-by-layer basis.
Radiation-Hard WLS Fibers

Radiation-hard wavelength shifting fibers have been developed in Iowa:

Quartz fibers with the core pTP coated.

Prototype: Deposited pTP on the stripped region (central 20 cm). Then the whole ribbon was sandwiched between quartz plates. Currently only two plates.
One unit was tested in 80 GeV electron shower at six radiation lengths depth. Results promising, technology still under development.

GEANT4 simulations are being performed to optimize the geometries and the WLS material.
Conclusions

The idea of a sampling calorimeter with pTp coated quartz plates as the active medium was tested. The light enhancement introduced by pTp was satisfactory with a hadronic energy resolution reaching \( \sim 15\% \).

Different geometries (quartz plate, quartz fiber) and readout techniques (PMTs, SiPMs, APDs, microchannel PMTs) are possible.

Such a calorimeter would respond to the radiation-hardness requirements of current detectors.