Geant4 study for geometry of quartz fiber luminometer at CMS HL-LHC

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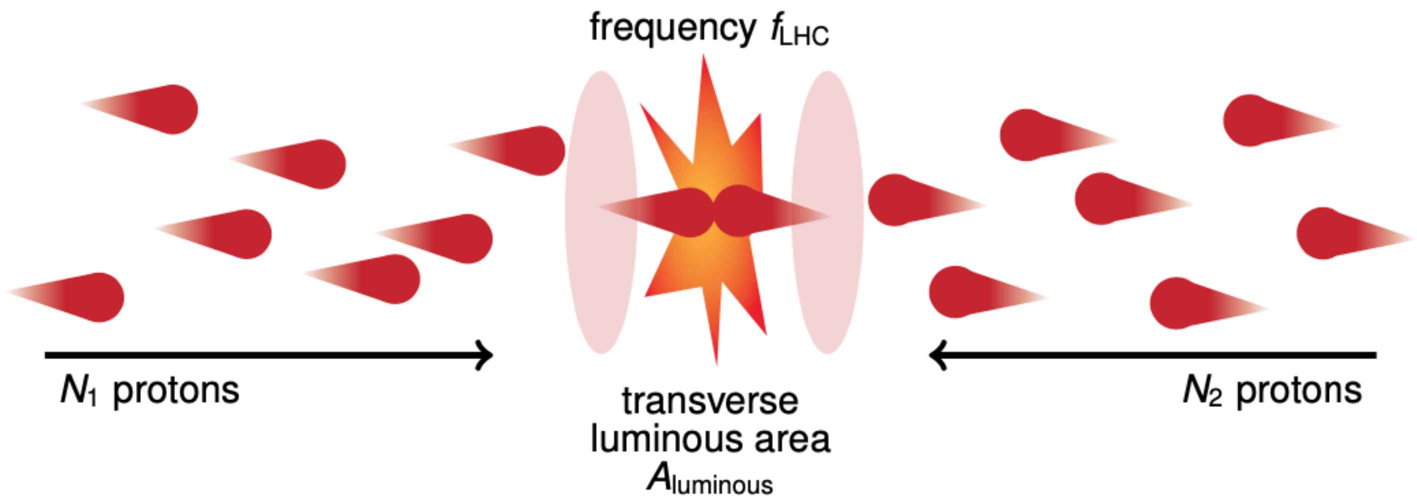
Outline

- Introduction
- CMS Detector
- Luminometers
- Quartz fiber calorimeters (QFC)
- Simulation studies and results
- Summary

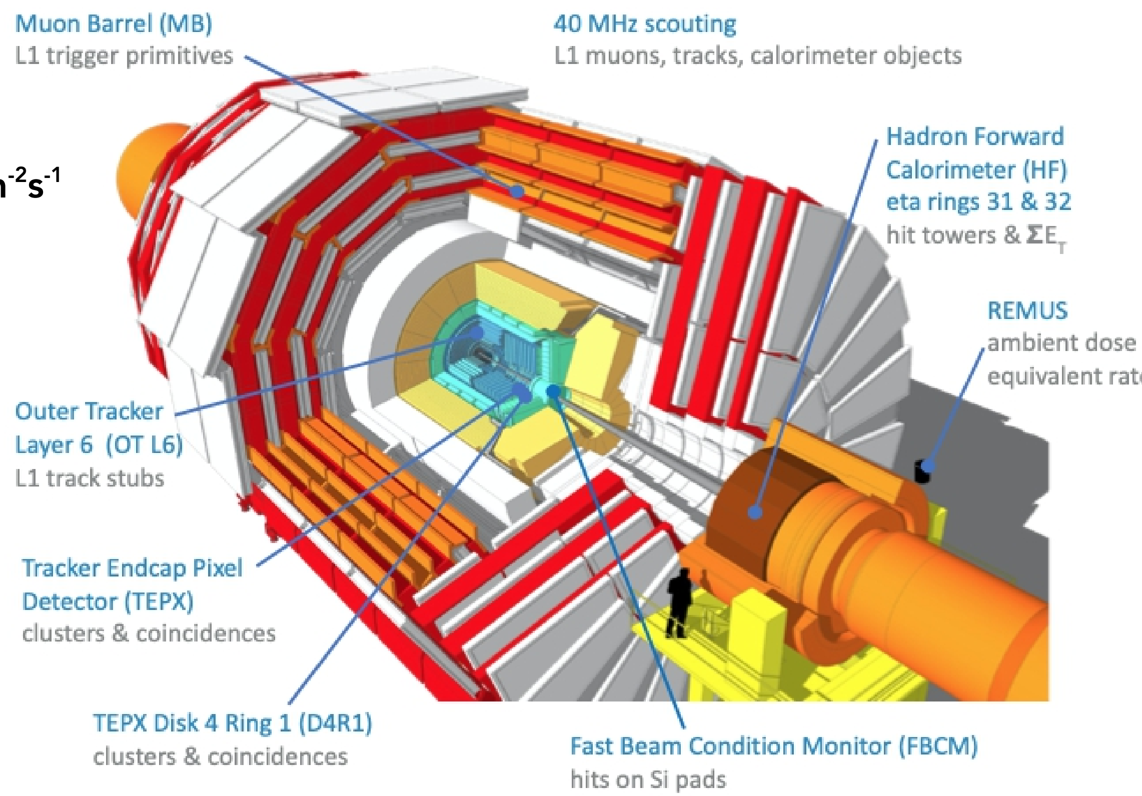
Introduction

- **Luminosity (L):**
  - **Measure of the collision rate in a collider experiment:** $\frac{dN}{dt}(pp \to X) = \mathcal{L} \cdot \sigma(pp \to X)$
  - **A precise knowledge of the integrated luminosity of a collision data set is a crucial requirement for precision cross section measurements.**
  - **Determination with the beam parameters:** $\mathcal{L} = \frac{N_1 N_2 f_{LHC}}{A_{luminous}}$



CMS detector

- High Luminosity-LHC period (scheduled in 2027)
  - instantaneous luminosity of $5x10^{34}$ $cm^{-2}s^{-1}$
  - with an average pileup of 140
  - a maximum performance scenario of $7.5x10^{34}$ $cm^{-2}s^{-1}$
  - an average of 200 interactions per bunch crossing
  - Precise measurement of the luminosity is key to the physics program of the HL-LHC:
    - it is one of the dominant syst.unc.



CMS DETECTOR

Total weight	: 14,000 tonnes
Overall diameter	: 15.0 m
Overall length	: 28.7 m
Magnetic field	: 3.8 T

Luminometers

- Luminosity measurements rely on the precise determination of event rates observed within the acceptance of a given detector (luminometer).

- In the CMS experiment, two-step strategy to measure the integrated luminosity of its collision data set

  - 1st method relies on counting hits (or events). Here the luminosity per bunch (L_B) expressed as:

$$L_B = -\frac{ln(1-f) \cdot f_{rev}}{\sigma_{vis}}$$

    - where σ_{vis} is the visible cross section, f_{rev} is the LHC machine revolution frequency.

  - 2nd method is integration of rate measurement
    - normalization with σ_{vis} to obtain the integrated luminosity.

Luminometer design

- In order to measure luminosity a quartz fiber based luminometer (QFL) is being developped by the Turkish-Russian Collaboration.
- Cherenkov radiation generation and transport in the quartz fibers is the basis of luminosity measurements
- The basic idea is to find the proportionality coefficient between the luminosity and the signal
- The signal is generated by a module consisting of a small converter/multiplier, a quartz fiber bundle and a photodetector

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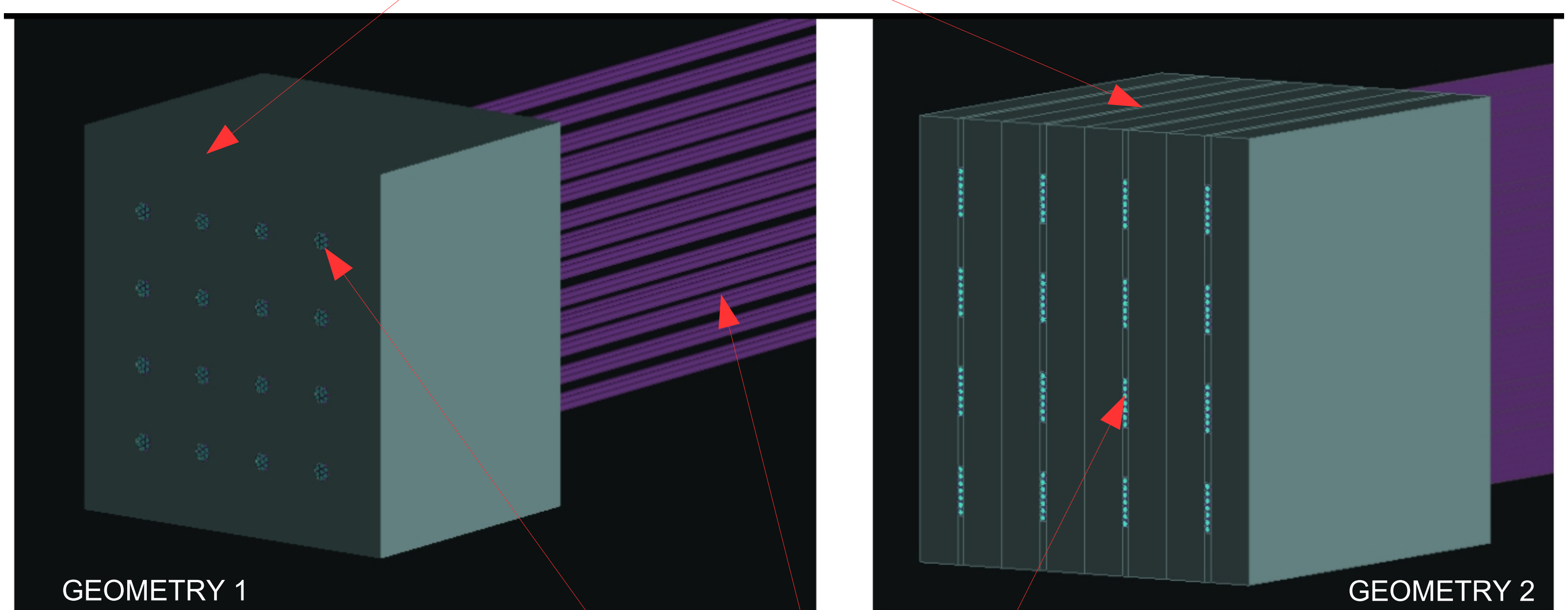
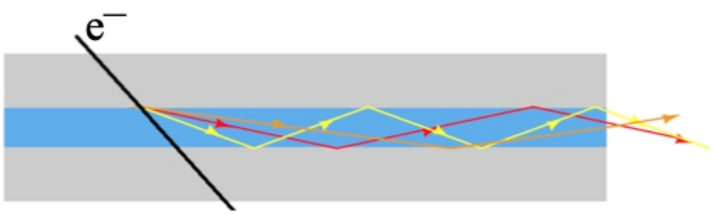


- Photodetectors are placed at the end of the fibers!

Principle of quartz fiber calorimeters

- The quartz fiber calorimeters:
  - sampling calorimeters.
  - absorber is made of dense material such as copper, iron, lead or tungsten
  - the sensitive medium is composed of quartz fibers.
- The incident particles interact with the calorimeter's absorber and initiate showers.
- The charged particles of the shower traversing the optical fibers produce Cherenkov photons, which are guided along the fibers and are collected by photomultipliers.

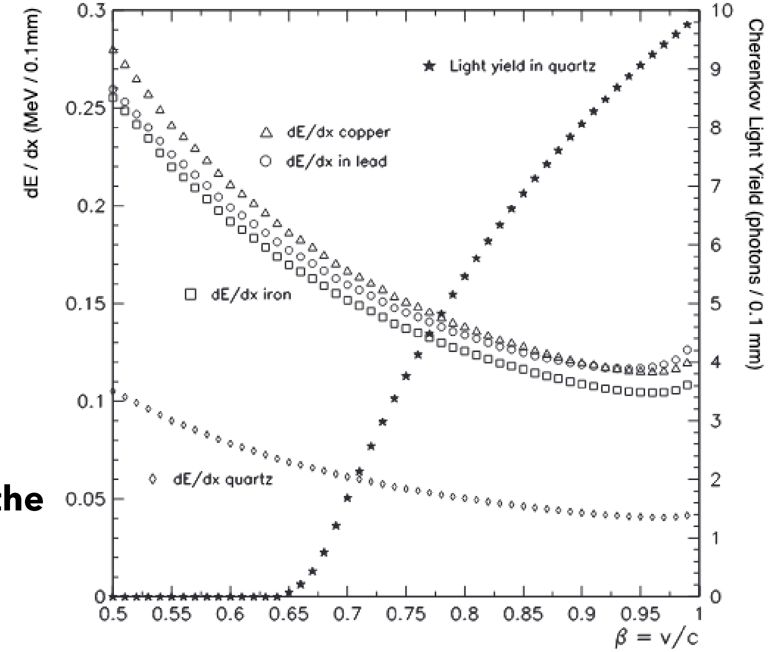
- Production of Cherenkov radiation occurs when a charged particle travels in a medium with velocity higher than the velocity of light in that medium.



▸ **Cherenkov radiation generation and transportation to the photodetector by quartz fibers**

$$\beta > \beta_{threshold} = \frac{1}{n} \Rightarrow \cos\theta_c = \frac{1}{n\beta}$$

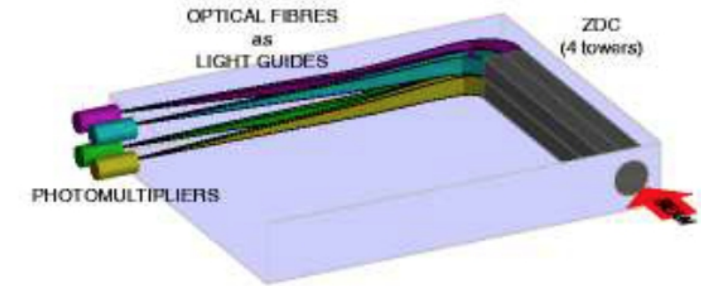
arXiv:physics/0412123 [physics.ins-det]



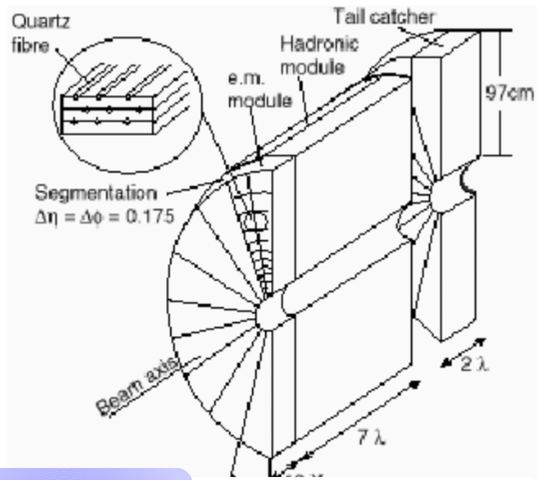
Quartz fiber calorimeters

- main advantages:
  - radiation hardness (high dose ~1 Grad or more)
  - fast response (< 10 nsec)
  - compact detector dimensions, since the transverse size of the visible shower is very narrow.

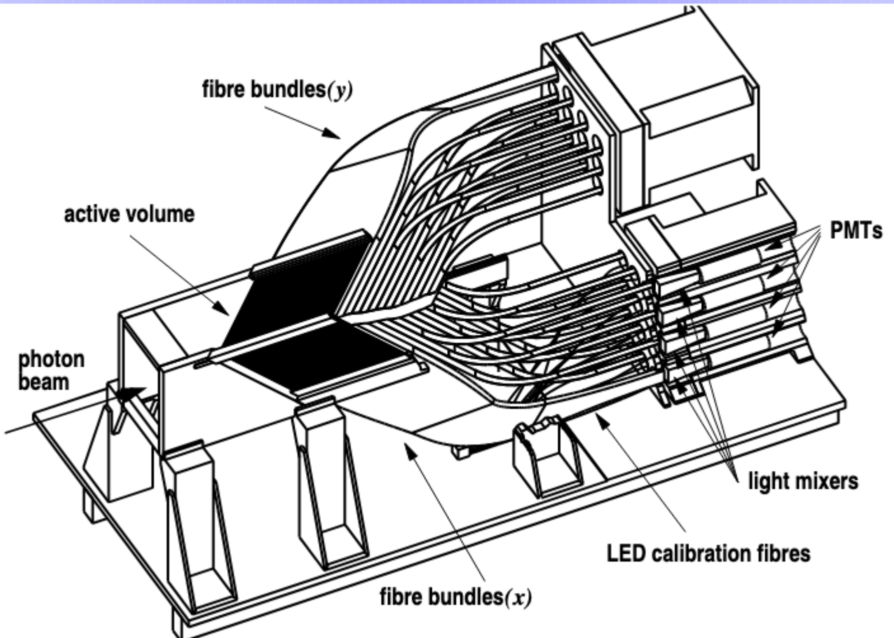
Zero Degree calorimeter for the NA50 experiment



CMS Very Forward calorimeter

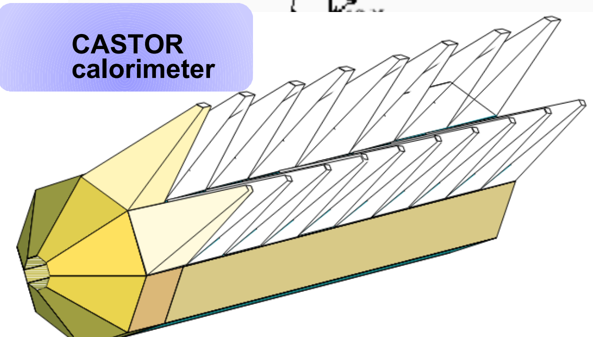


Very Forward Electromagnetic calorimeter for the H1 experiment.



arXiv:physics/0412123 [physics.ins-det]

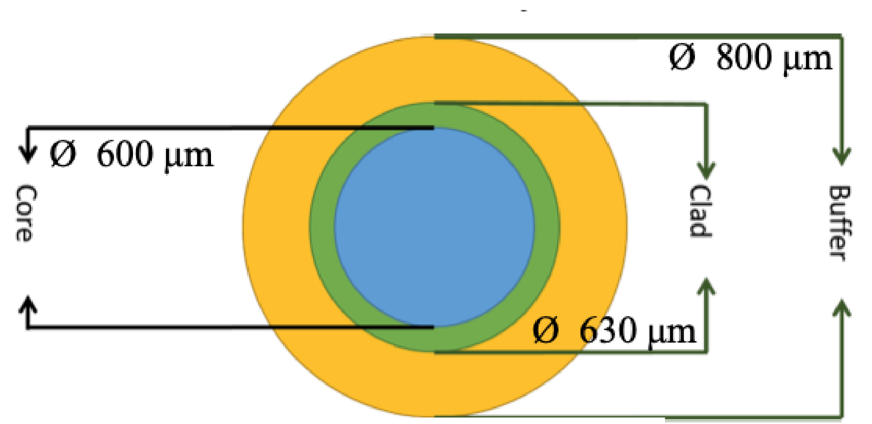
CASTOR calorimeter

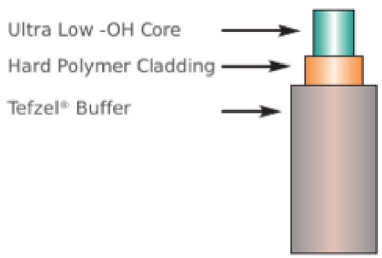


Geant4 simulation

- Quartz fibers (QF)
  - the corner stones of the project
  - consist of three physical volumes in simulation, each a cylinder
  - Each layer has its own optical and material properties
  - Optical properties such as refractive indices and absorption lengths are added to Geant4.
  - Information about SiO_2 for the core, Polyethylene for the cladding and $C_4H_4F_4$ for the buffer is obtained from the manufacturer.

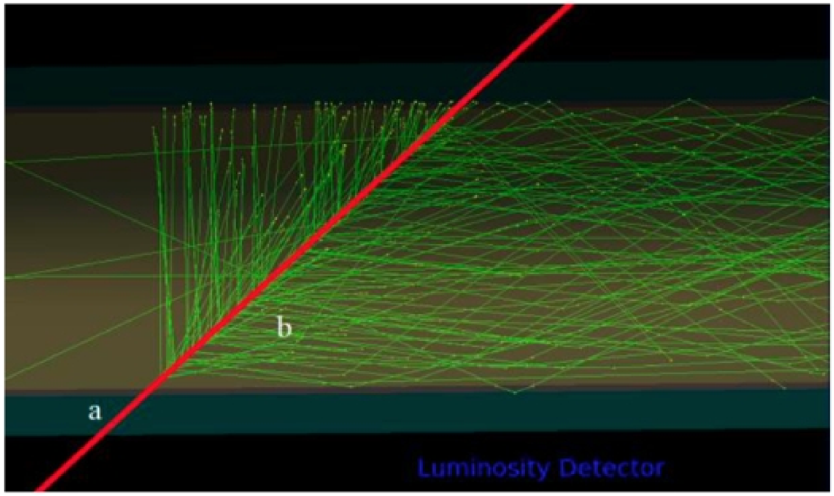
Cross-section of the fiber
(blue – core, green – cladding (clad), yellow – buffer)

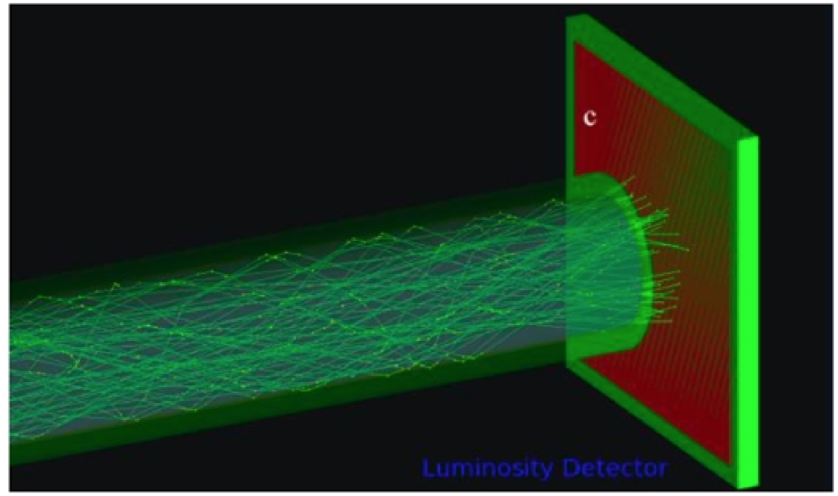




The fibers used are Quartz-PolyClad fibers produced by Molex

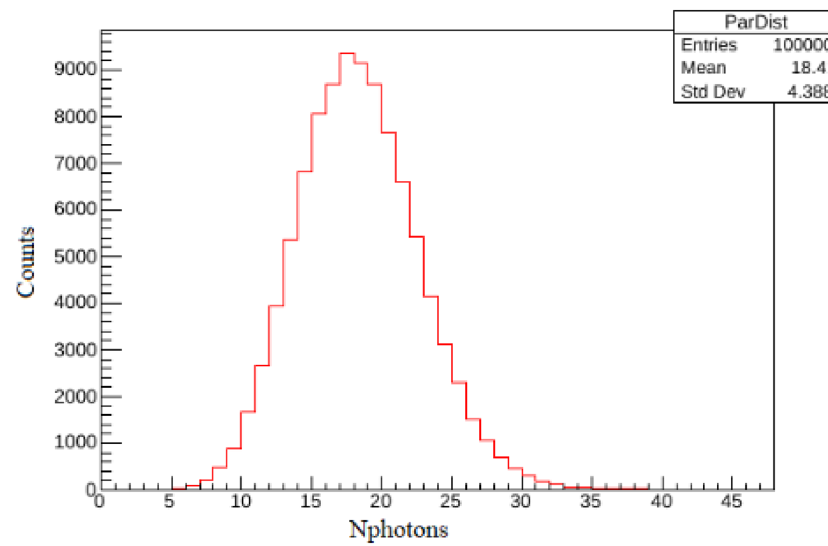
Results





- Event visualization :
  - Red track (a) electron (left figure),
  - green tracks (b) optical photons (left figure)
  - end of the fiber with a detecting volume (red (c) active area of the detecting volume (top right figure)

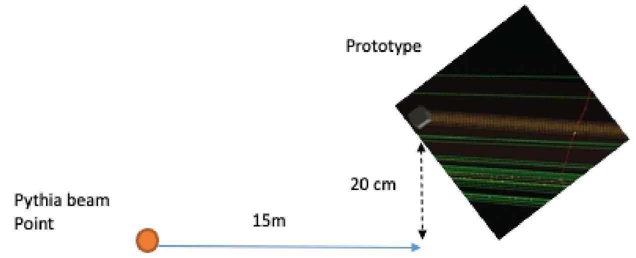
- A 'particle gun' used for creating events with electrons with the energy of 100 GeV hitting the fiber with momentum at $\theta = 45°$ relative to the axis of the fiber.

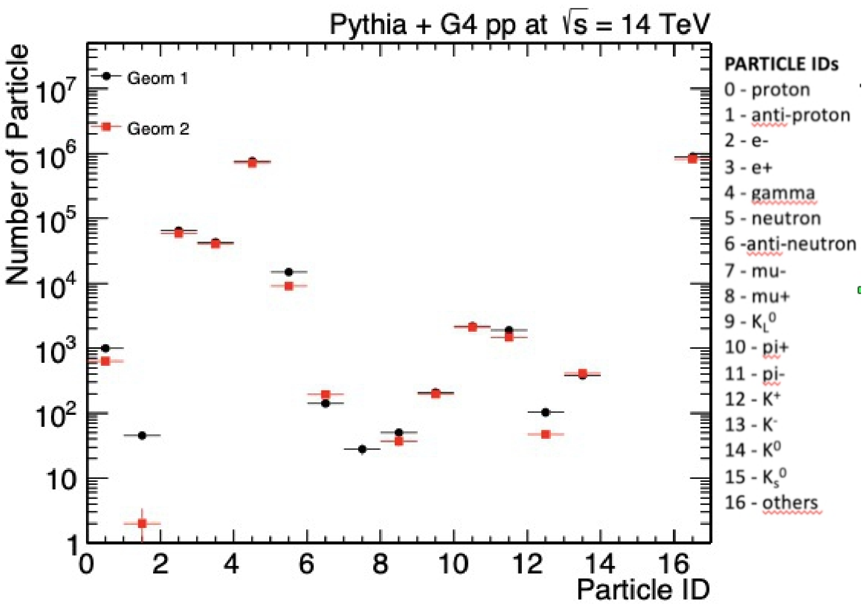


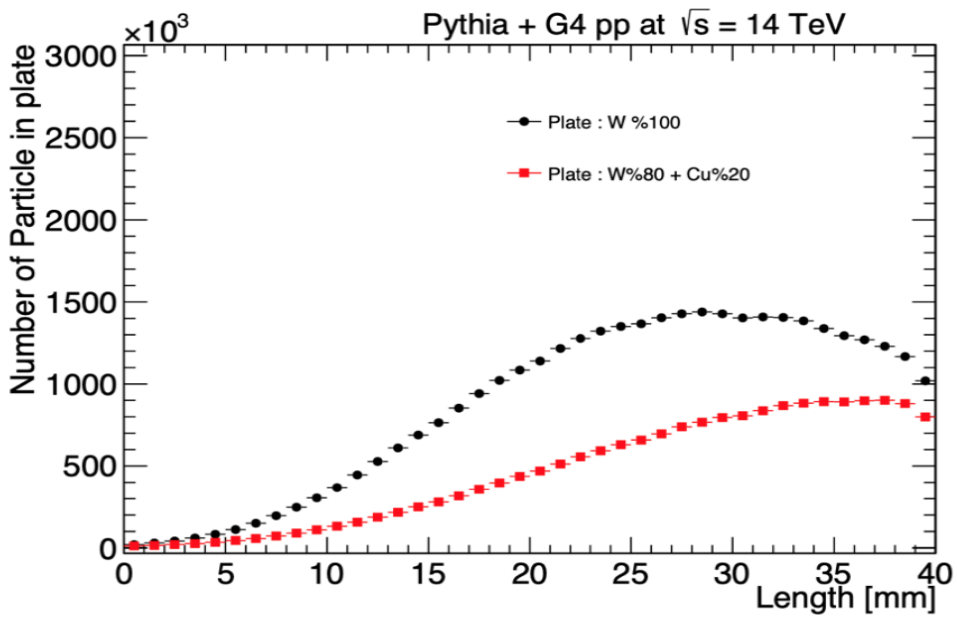
the number of photons that reached the end of the fiber

Results

- Properties used in the GEANT4 Simulation:
  - 8 Plates with each 5x5cm (Tungsten%80+CU%20), width d = 0.5cm
  - 112 Fibers (r=0.06 cm, Quartz Fiber)





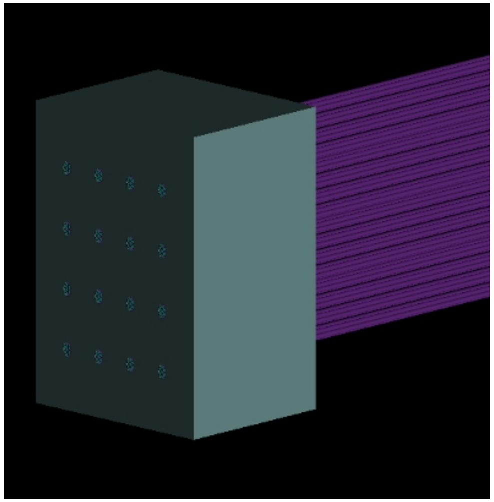


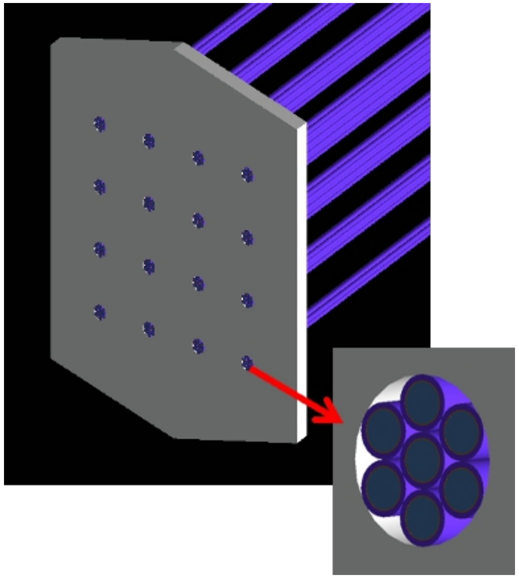
- Distribution of particles hitting to prototype

- Number of the particles generated in tungsten (black) and tungsten+copper (red) plates

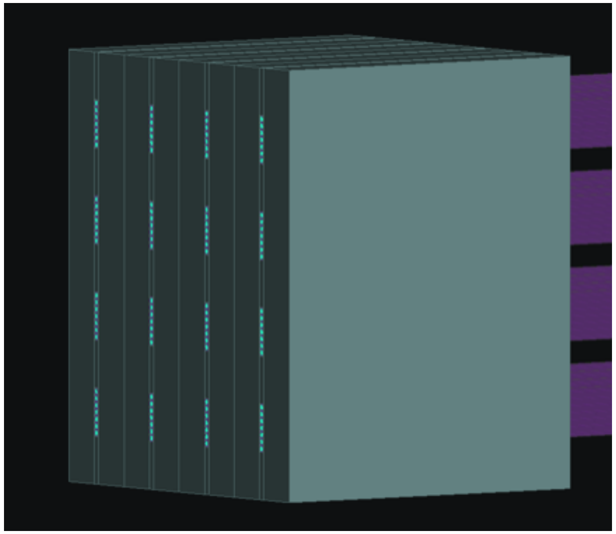
Geometry designs: detailed view

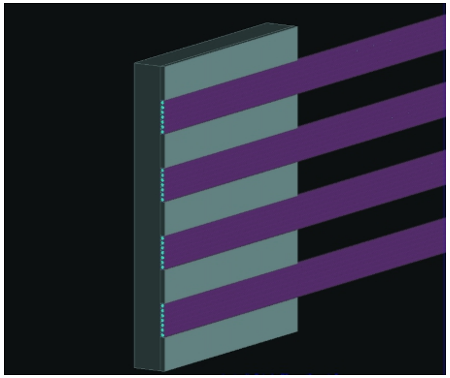
GEOMETRY 1

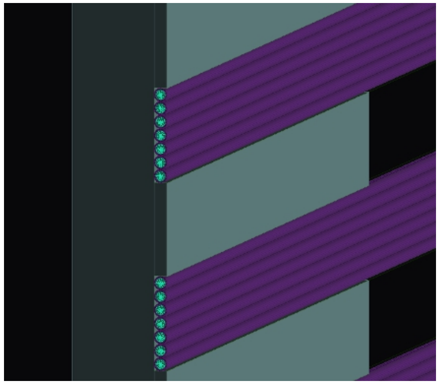




GEOMETRY 2

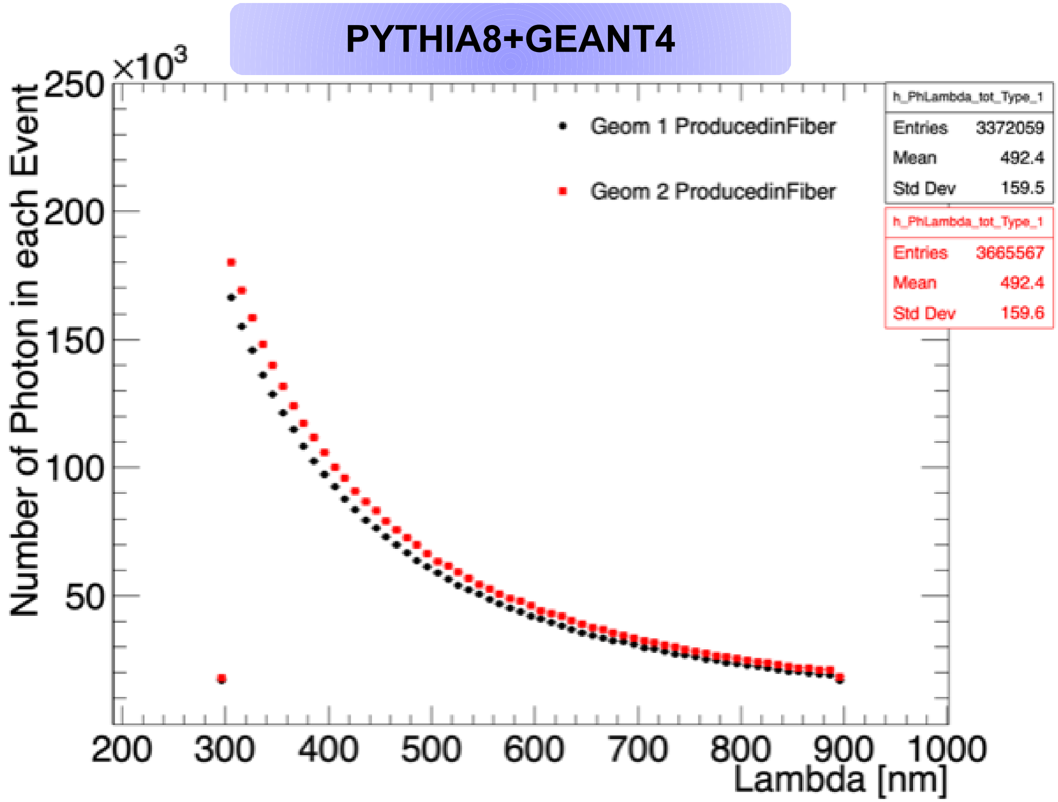






Cherenkov photons vs. wavelength

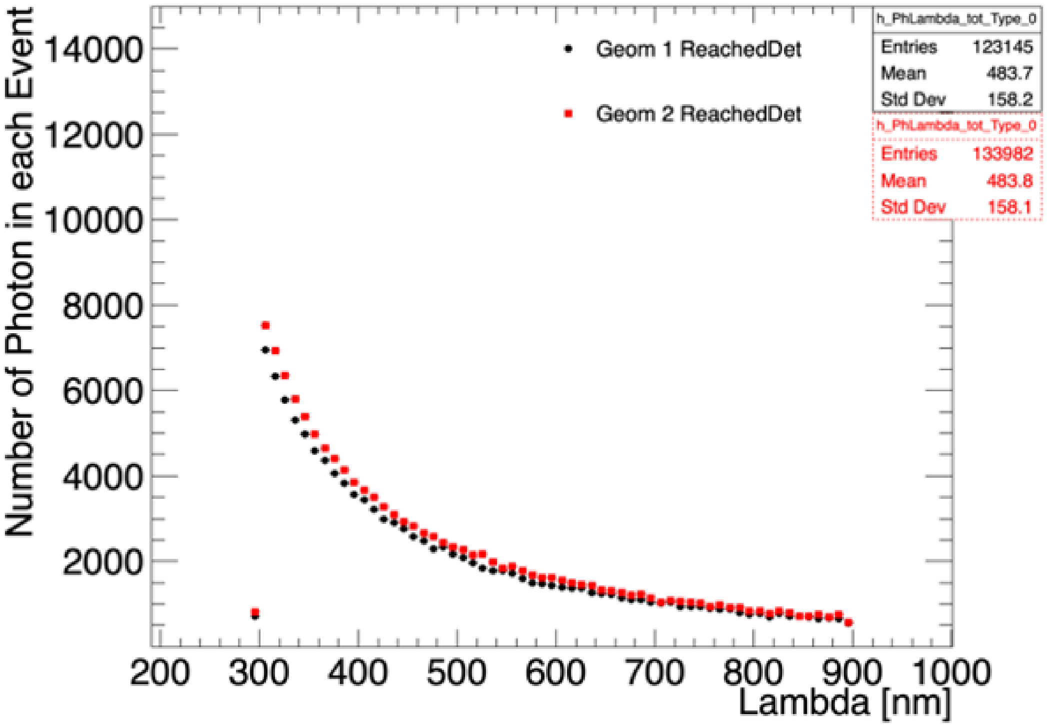
- Comparison of two geometries for Cherenkov photons produced in fibers
  - Geometry 1 (black) and Geometry 2 (red)
- Number of photons in each event vs. wavelength distribution is shown.



Cherenkov photons vs. wavelength

- Comparison of two geometries for Cherenkov photons reached at the detector
  - Geometry 1 (black) and Geometry 2 (red)
- Number of photons in each event vs. wavelength distribution is shown.

PYTHIA8+GEANT4



Summary

- An overview of the luminometer project for luminosity measurements under the extreme conditions of the CMS HL- LHC has been presented

- Detailed Pythia8+Geant4 simulation has shown for two geometry designs

  - Obtained results show a compete understanding of the optical behaviour in a fiber
  - Design optimization studies are on going.
  - Plan to test the prototype with test beam.

Acknowledgments

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Thank you for your attention!

BACKUP