Geant4 quartz fiber simulations as part of luminometer development for CMS

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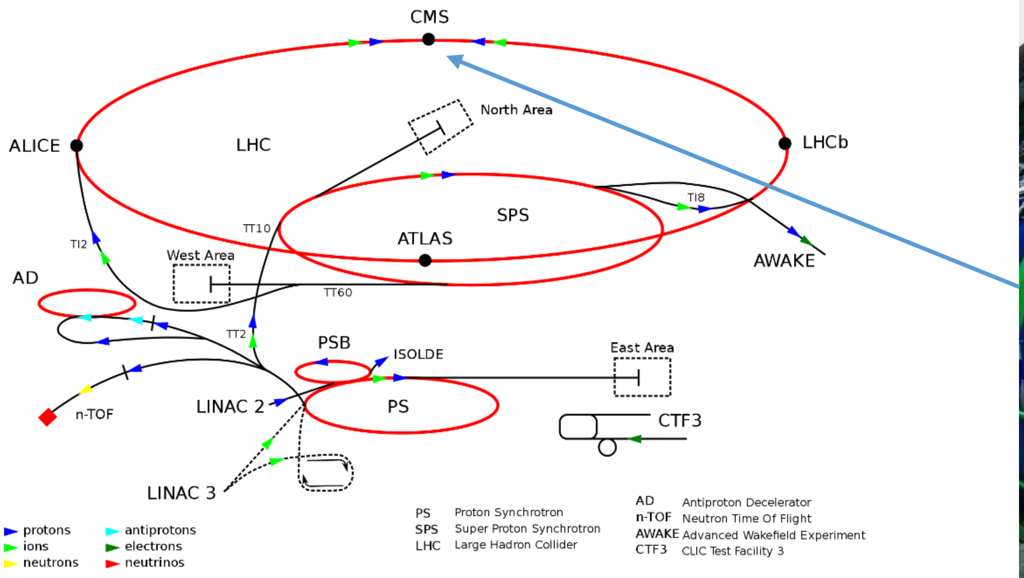
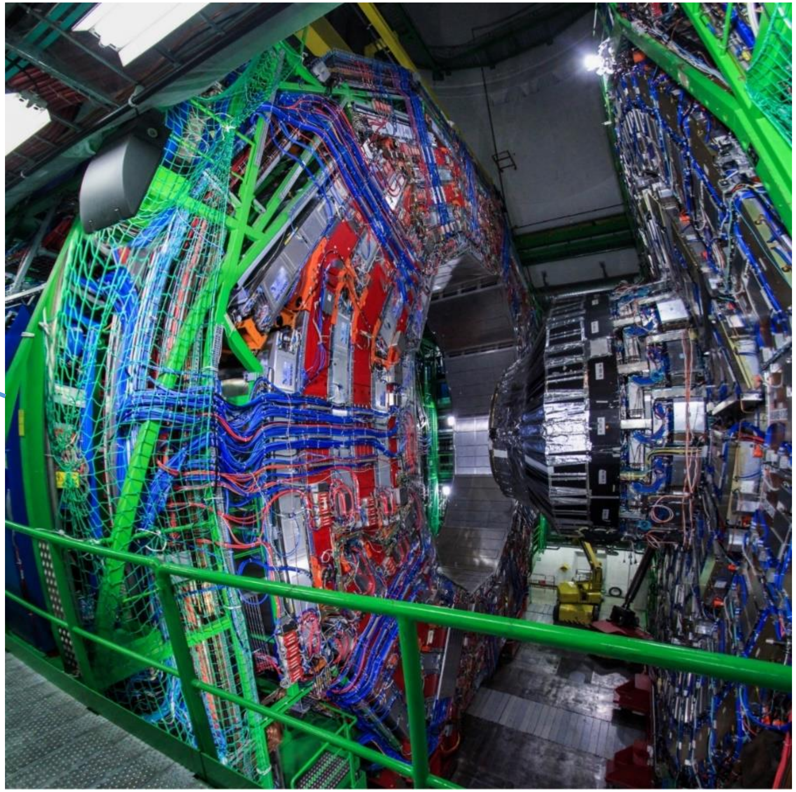
on behalf of the QFL development team

CMS experiment





CMS cavern, 100 m underground, November 2019

Luminosity

Integrated luminosity is the proportionality coefficient between the cross-section of an event (σ_p) and the total number of events of interest

$$N_p = \sigma_p \cdot \boldsymbol{L_{int}} \qquad \mathrm{fb}^{-1}$$

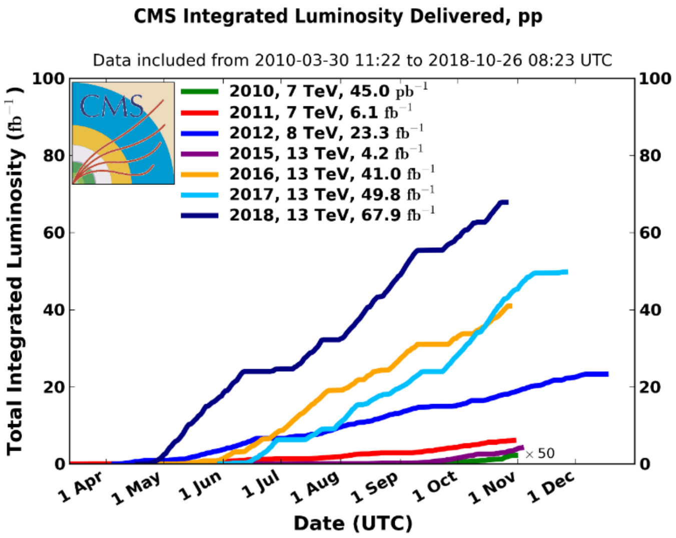
It is a key figure of merit of the collider's performance

However it contributes to the uncertainties:

Table 3: The measured inclusive fiducial cross sections in the dimuon and dielectron final states. The combined measurement is also shown. $\mathcal{B}$ is the $Z \to \ell\ell$ branching fraction.

Cross section	$\sigma\,\mathcal{B}$ [pb]							
$\sigma_{Z\to\mu\mu}$	694	$\pm$	6	(syst)	$\pm$	17	(lumi)
$\sigma_{Z\to ee}$	712	$\pm$	10	(syst)	$\pm$	18	(lumi)
$\sigma_{Z\to\ell\ell}$	699	$\pm$	5	(syst)	$\pm$	17	(lumi)

[arXiv: 1909.04133]



[https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults]

The main objective is to eliminate these error bars by measuring luminosity to the accuracy of ~ 1%!

Luminometer design

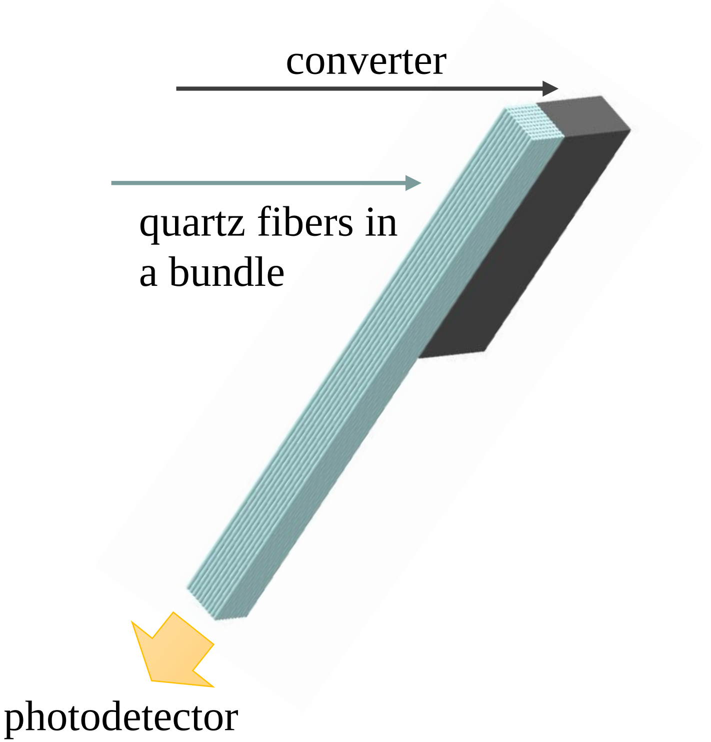
To measure luminosity a Ru-Tr collaboration is developing a quartz fiber based luminometer (QFL)

Cherenkov radiation generation and transport in the quartz fibers is the basis of luminosity measurements

The main idea is to find the proportionality coefficient between the luminosity and the signal

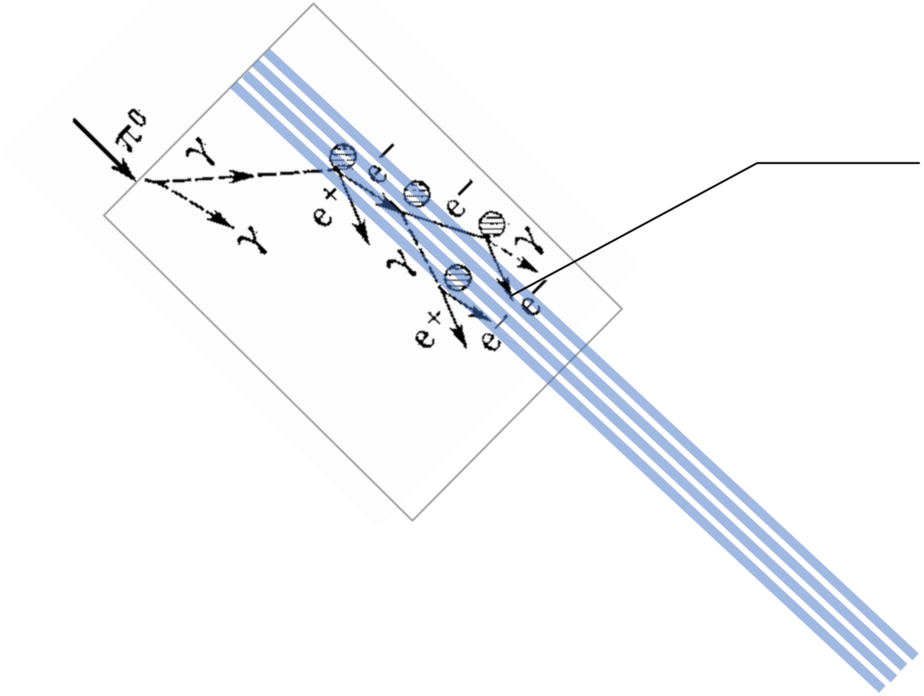
The signal is generated by a module consisting of a small **converter/multiplier**, a **quartz fiber bundle** and a **photodetector**

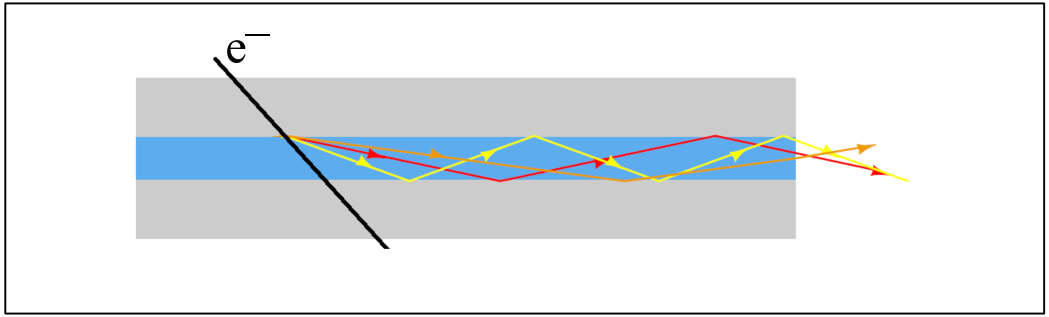
Quartz fibers allow to move the photodetector outside of the most damaging area



Luminometer operation

EM shower development from primary particles produced in the pp collision in the converter





Cherenkov radiation generation and transportation to the photodetector by quartz fibers

$$\cos\theta = \frac{1}{n\beta} \qquad \alpha \geq \alpha_{crit}$$

Geant4 simulation – geometry

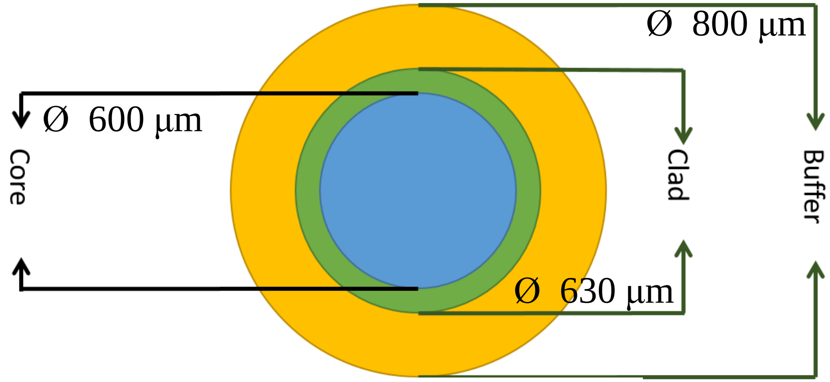
Quartz fibers are the corner stones of the project

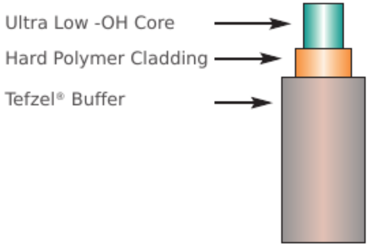
A comprehensive and accurate model of a single fiber is at the base of all future analysis

Quartz Fibers consist of three physical volumes in simulation, each a cylinder

Each layer has its own optical properties and material properties that are added in G4. Such as refractive indices, absorption lenght.

Thus, Geant4 simulation was brought to a level that can understand the optical behavior in a fiber.





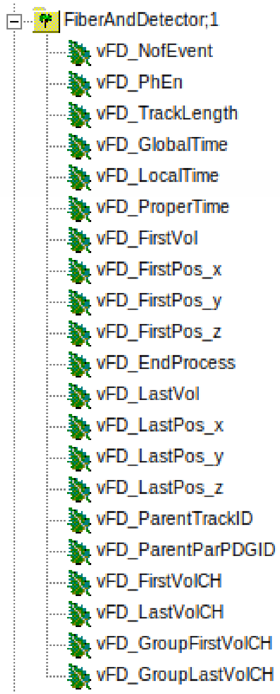
The fibers used are Quartz-PolyClad fibers produced by Molex

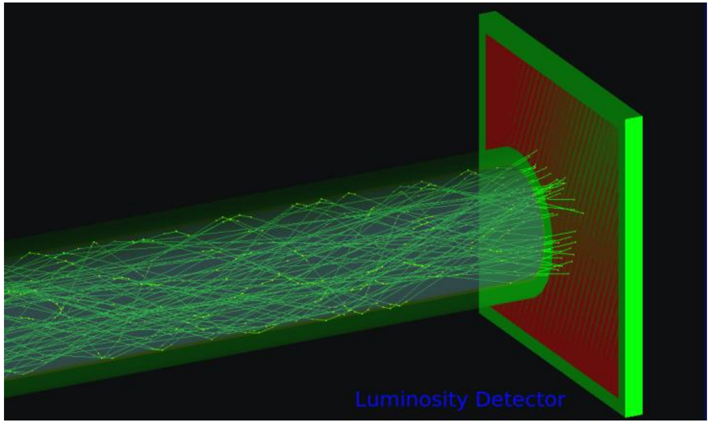
Geant4 simulation – method

All geometry objects and operations with them (rotation, union, subtraction, etc.) were written as methods to make the geometry very flexible

Custom methods were also written to collect all available data and send it to ROOT

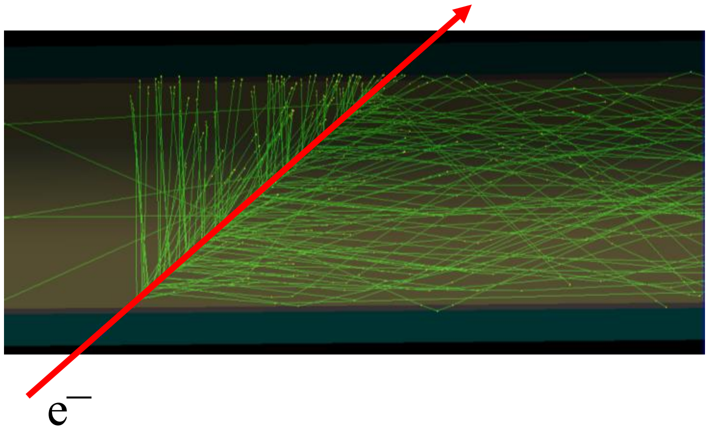
This allows to work with the number of particle hits, the number of photons created, etc.



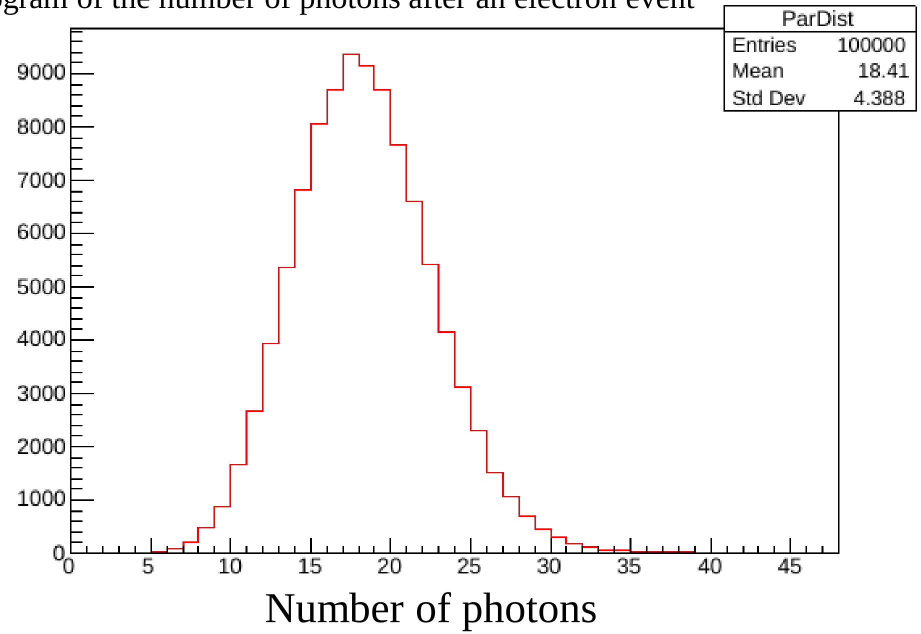


Geant4 simulation – results

A simulation with 100k primary electrons, 100 GeV, 45 degree angle



Histogram of the number of photons after an electron event



After recalculating the number of photons into the number of pixels using PDE of the SiPM it would be possible to verify the simulation with experimental data

Conclusion

1. The objective of the project and basic concepts like integrated luminosity were introduced

2. The conceptual design, main components and physics behind the signal generation were presented

3. Geant4 simulation geometry and methods were shown

4. The results obtained so far (once verified) will not only show a compete understanding of the optical behavior in a fiber, but will also be used in future simulations for optimization of the design

Acknowledgments

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Thank you for attention

If you have any questions don't hesitate to contact me

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