

# Muon-detector studies for CMS-Upgrade at SLHC

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CHIPP Winterschool 2010

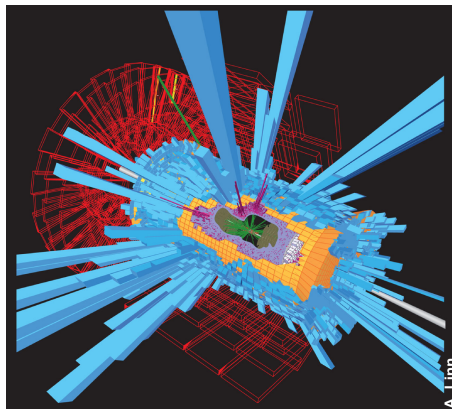
GEFÖRDERT VOM



Bundesministerium  
für Bildung  
und Forschung

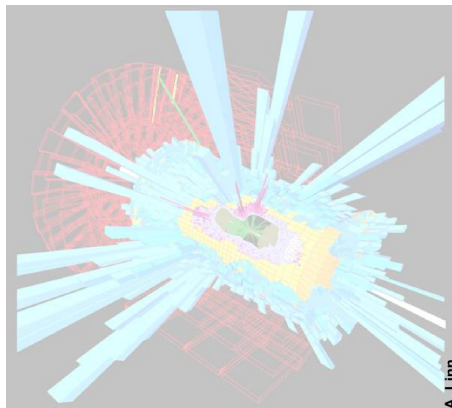
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# Outline

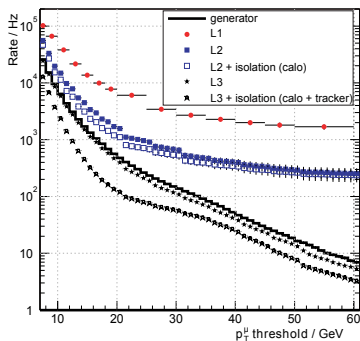
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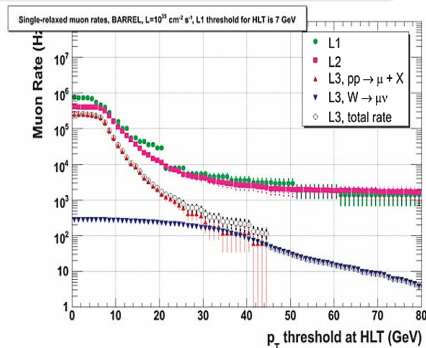
## Suggested SLHC-Upgrade:

- Increase of luminosity up to  $10^{35} \text{ cm}^{-2} \text{ s}^{-1}$  and  $\sim 400$  interactions per BX instead of 20
- Increase in muon rate by one order of magnitude

**CMS:** Wish to keep L1 Trigger-rate without  $p_T$ -threshold increase!



Lumi x 10



(Juan Alcaraz)

**PROPOSAL:** new detector component

**Muon Track fast Tag (MTT)**

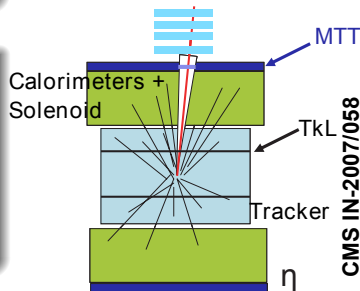
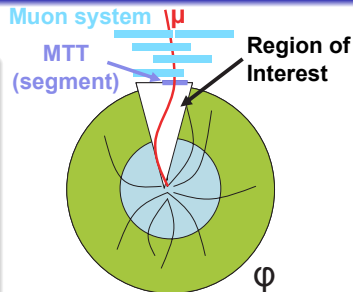
# "Muon Track fast Tag"

## MTT features

- Fast recognition of Muons at L1-Trigger.
- Combine with Tracker Information to allow better momentum resolution at L1.
- Help to dissolve ambiguities in the Muon system.
- Interplay with Tracker not elaborated yet.

## MTT requirements

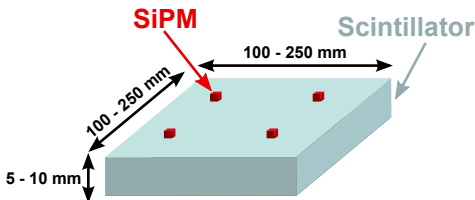
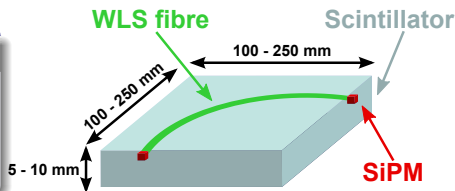
- compact: has to fit between Solenoid and Muon system
- inexpensive: 300 m<sup>2</sup> have to be covered
- fast: bunch crossing every 50 ns
- spatial resolution:  $\mathcal{O}(100 \text{ mm})$



# Ideas for the MTT

## Setup with WaveLengthShifting fibre

- Advantage: Good light yield
- Disadvantage: mechanical effort
- Time resolution  $\sim 10$  ns



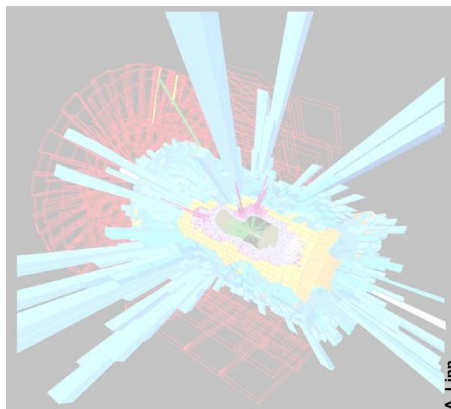
## Alternative: "direct readout"

- Advantage: simple construction
- Disadvantage: lower light yield
- Time resolution  $\sim 10$  ns

**Light yield and time resolution to be checked with GEANT4**

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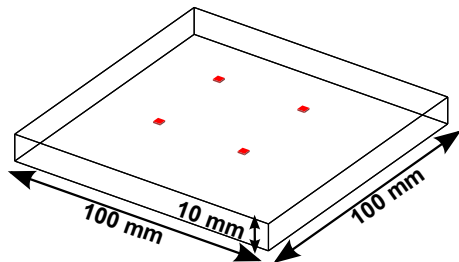
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# Simulation and visualisation with GEANT4

All relevant physical processes implemented:

- optical photon creation by scintillation and WLS process
- standard G4 propagation/tracking of optical photons
- surface boundary processes

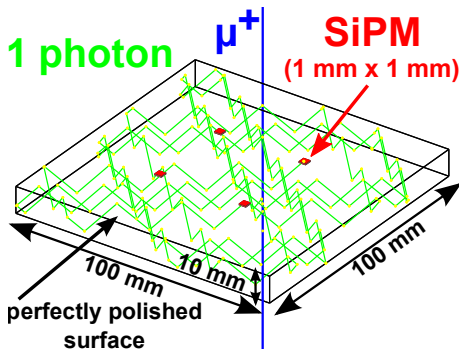


“direct readout”

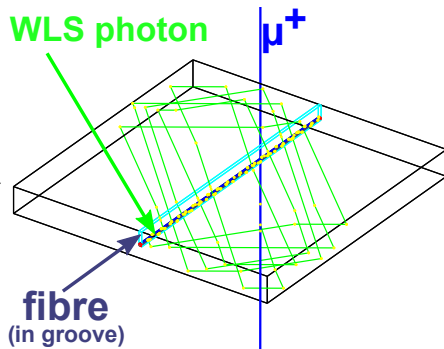
# Simulation and visualisation with GEANT4

All relevant physical processes implemented:

- optical photon creation by scintillation and WLS process
- standard G4 propagation/tracking of optical photons
- surface boundary processes



“direct readout”



“WLS readout”

# Simulation details

## Scintillator:

Using the properties of scintillator BC-404:

- Good light yield:  $\approx 8000 \gamma/\text{MeV}$
- Fast: decay time 1.8 ns
- Good attenuation length: 1.6 m

## SiPM:

Properties of Hamamatsu SiPMs (S10362-11-100C) implemented

- Especially photon detection efficiency (spectrum)

## WLS:

Properties of WLS fibre BCF-92 used:

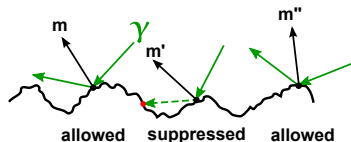
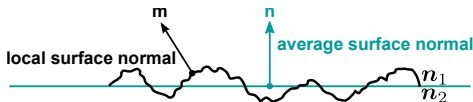
- Multi-cladding fibre with short decay time (2.7 ns)
- Fibre is positioned in groove and coupled with optical cement
- Optical properties of optical cement BC-600 implemented
- SiPMs are coupled directly onto the fibre ends

# Simulation of surface roughness

## Surface roughness in GEANT4

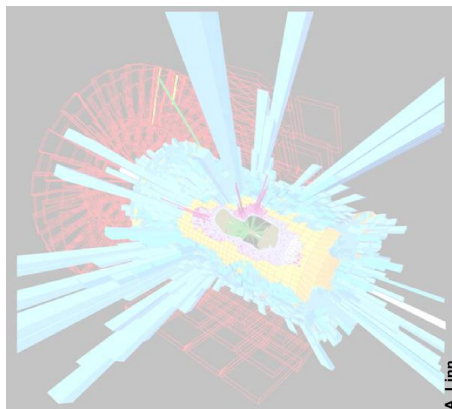
All simulations use the `UNIFIED` model implemented in GEANT4.  
(Nuc. Sci. Symp., 1996. Conf. Rec., IEEE, vol.2, TRI-PP-96-64)

- Reflection and refraction behaviour of photons considers (classical) electromagnetic and quantum mechanical effects.
- Several optical surface properties must be provided by the user.
- “Most important” parameters: refractive indices of both media and the width of the **distribution of the local surface normals** that is assumed to be Gaussian.



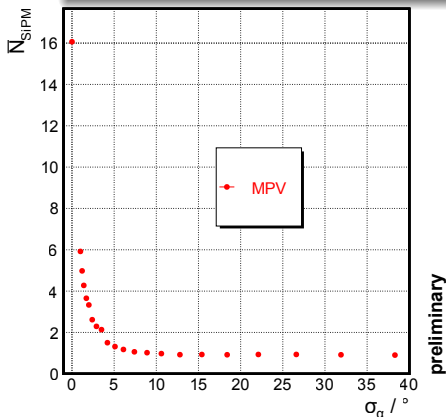
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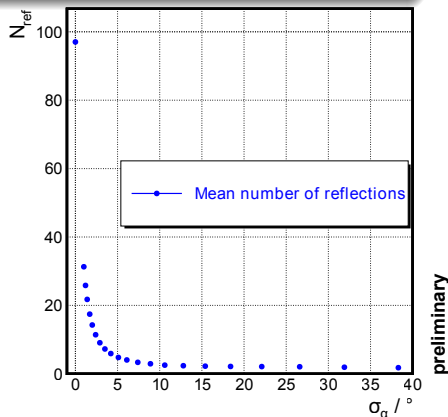


# Direct Readout

Study of photon yield against surface roughness parameterised by  $\sigma_\alpha$ .



**Photon yield at SiPM is very sensitive to surface roughness!**

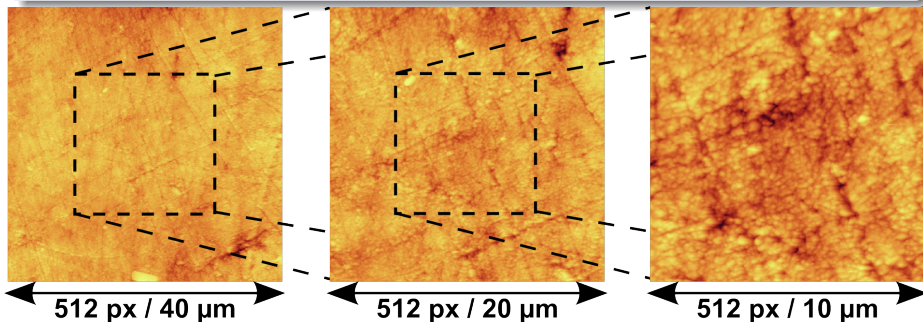


And: It is correlated with the number of reflections.

# Surface

Determination of surface roughness is recommended.

⇒ **AFM scan** of the scintillator surface! (2nd Phys. Inst. A Aachen)  
(Piece of scintillator polished by Aachen III A mechanics workshop.)

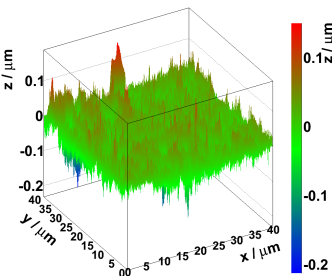


Scanned several areas with different resolutions and extracted the height and slope distribution of the surface.

Typical structures on the surface: small channels, larger rifts

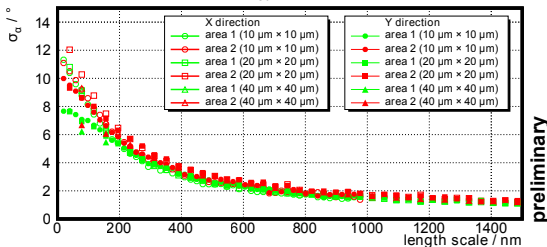
# Surface analysis

Analysing the surface in ROOT  $\Rightarrow$



- Different areas of the scintillator look very similar.
- Evaluate height and slope distribution at different length scales.
- Heights and slopes are approximately Gaussian distributed.
- In the relevant range (380 nm - 500 nm):  

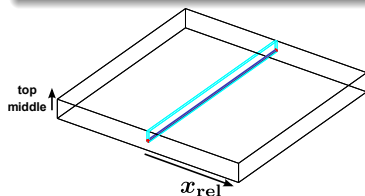
$$\sigma_\alpha \approx 2.0^\circ - 4.5^\circ$$



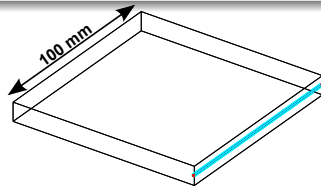
Roughness of the scintillator is not negligible

# WLS setups

## Different fibre positions

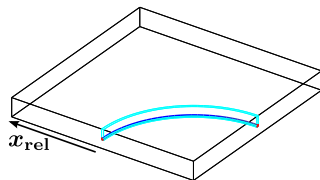


relative position:  $x_{\text{rel}} = 0$



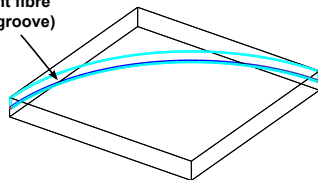
relative position:  $x_{\text{rel}} = 1$

## Different bending radii



relative radius:  
 $r_{\text{rel}} = 0.5 \hat{=} x_{\text{rel}} = 0$

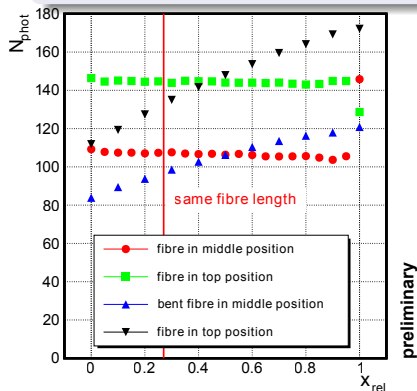
bent fibre  
(in groove)



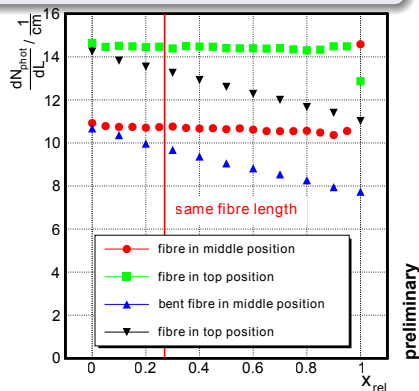
relative radius:  
 $r_{\text{rel}} = 1 \hat{=} x_{\text{rel}} = 1$

# Different fibre geometries

Comparing straight and bent fibre  
(with absorption in optical cement)



Absolute number of photons at SiPM by trend higher for bent fibre



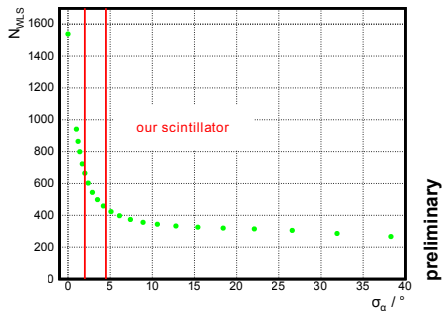
Number of photons per fiber length always worse for bent fibre

Focusing on straight fibre

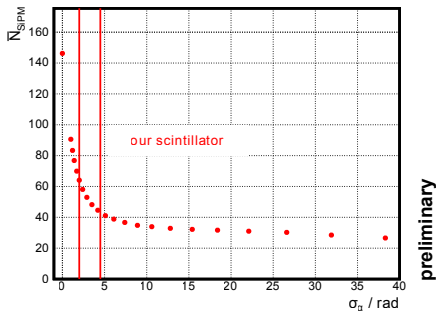
# Surface roughness with WLS fibre

Fibre in top position

Number of photons arriving at WLS



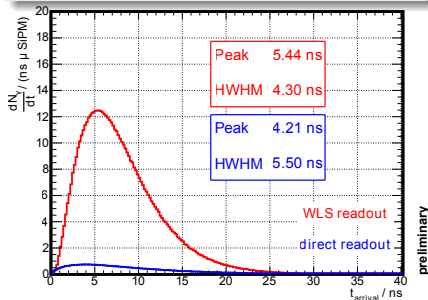
Mean number of photons at SiPM



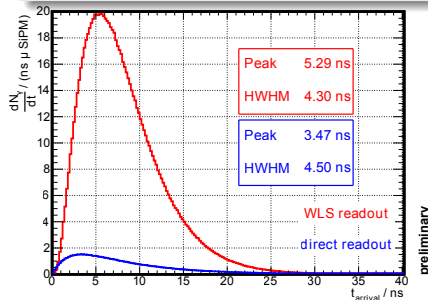
Surface roughness reduces dramatically both the number of photons arriving at the fibre and the number of photons hitting the SiPM.

# Timing for $100 \times 100 \times 10 \text{ mm}^3$ scintillator

Perfectly polished surface  
no reflector



Perfectly polished surface  
additional diffuse reflector (98 %)



Peak at  $\sim 3.5 - 5.5 \text{ ns}$ .

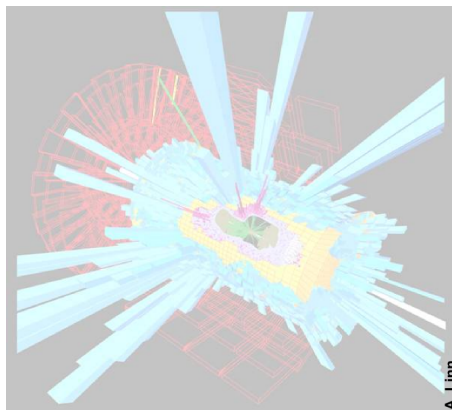
**Nearly all photons arrive within 20 ns**  
(Bunch crossings every 50 ns!)

Further considerations needed:

detection efficiency of the SiPMs, response (signal) of the SiPMs etc.

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# Outlook

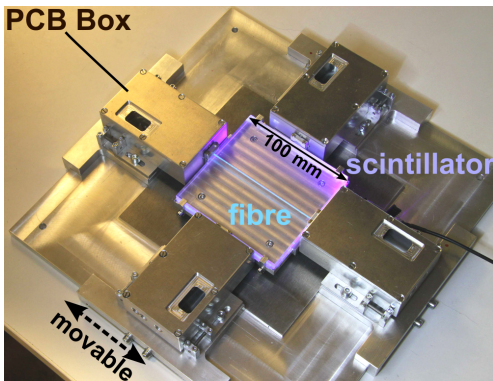
## Simulation:

- Simulation is in a mature status, allows a variety of geometries/setups.
- The reduced light yield due to the surface roughness makes the use of a reflector mandatory.
- Studying different reflector types: specular, diffuse with different reflectivities (typically  $< 98\%$ ).
- In reality, there is always a small airgap between scintillator and reflector and will be implemented in the simulation.

## Test setup:

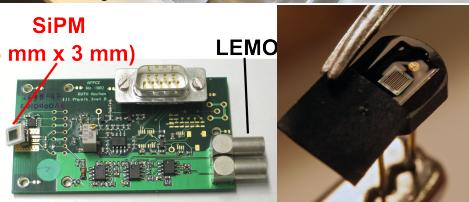
- Experimental setup is in preparation to compare simulation results to real data (especially photon yield at SiPM).
- Using materials as described before.

# Test setup



SiPM  
(3 mm x 3 mm)

LEMO



Preparation of systematic measurements:

- “Scintillator tray” with flexible readout possibilities capable to hold different scintillator setups (straight/bent fibre etc.)
- Frontend electronics with fine adjustment of SiPM voltage and amplification of the signal
- Different SiPM types:  
 $1 \times 1 \text{ mm}^2$ ,  $3 \times 3 \text{ mm}^2$   
coming soon:  $6 \times 6 \text{ mm}^2$   
(interesting for direct readout)

# Summary

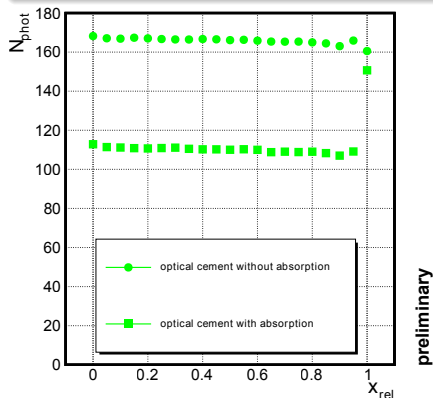
- SLHC-Upgrade implies considerable increase of single muon rate
- Improvement in Muon Trigger needed → new subdetector MTT
- Prototype simulations are very promising, especially with WLS readout
- Time and spatial resolution are in the right order of magnitude
- Further studies with different reflectors and scintillator geometries/sizes will be performed
- Light yield and timing need an extensive study with an experimental setup

Thank you for your attention

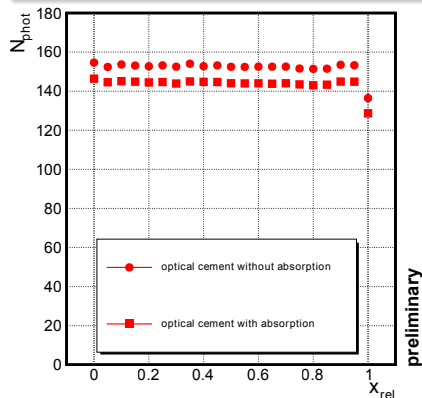
backup

# Absorption in Optical Cement (straight fibre)

straight fibre in middle position

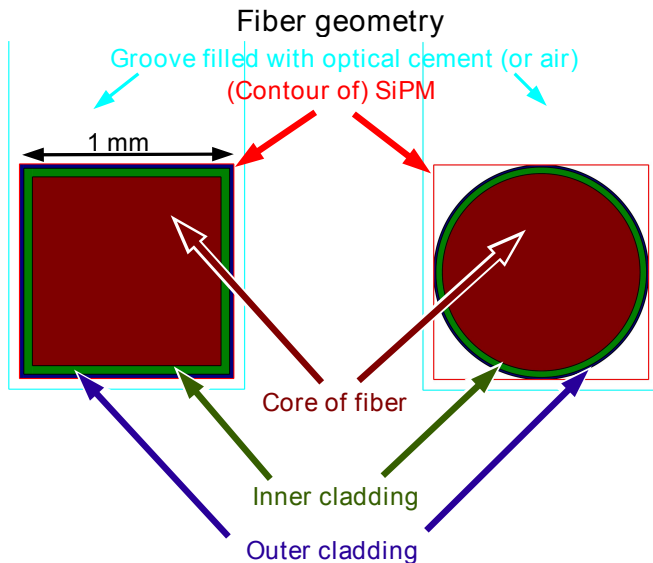


straight fibre in top position

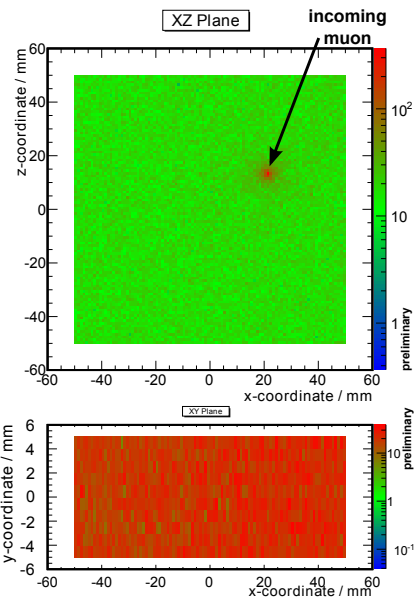


Absorption in optical cement reduces photon yield by up to 30 %.  
Losses are dominant when fibre is in deeper groove.  
Also: larger insensitive detector volume (cement is not scintillating).

# Fibre in groove



# Photons at the surface



Scintillator  $100 \times 100 \times 10 \text{ mm}^3$

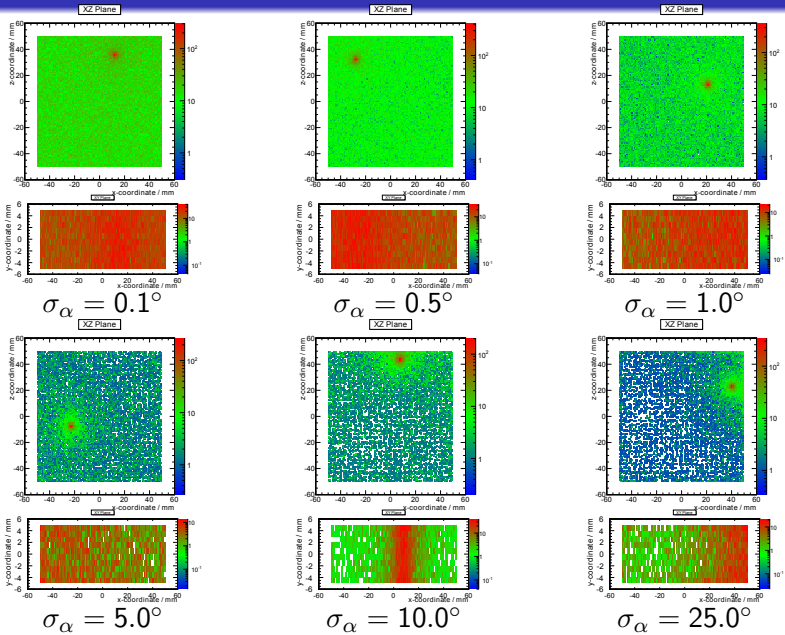
2 GeV Muons traversing perpendicular

Perfectly polished scintillator surface.  
Only total internal reflection possible.

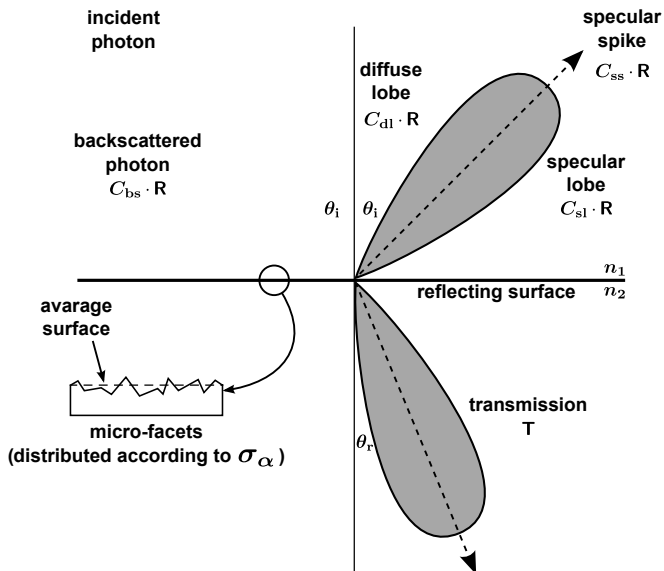
- Binning set to  $1 \text{ mm} \times 1 \text{ mm}$ .
- Photons touching the surface are “uniformly distributed”.
- Typically: 10-20 photons per  $\text{mm}^2$  expected.
- Only  $\lesssim 20 \%$  leaving the scintillator.
- Exception: Muon entrance point.

**Position of SiPMs not crucial**

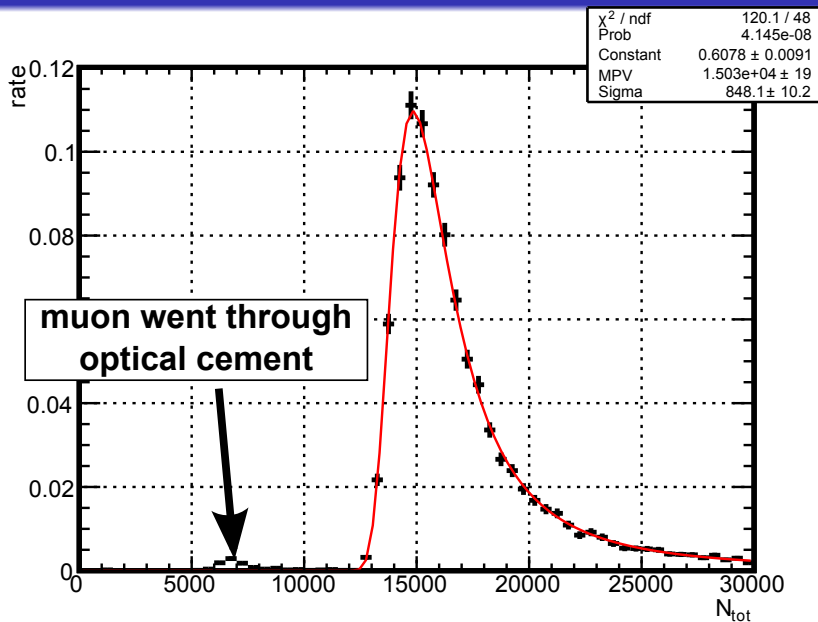
# Introducing angular smearing: Photon distributions



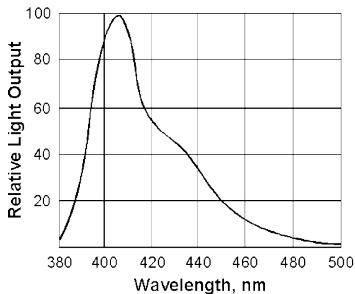
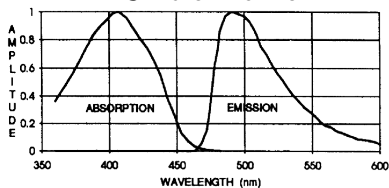
# Surface in the UNIFIED model



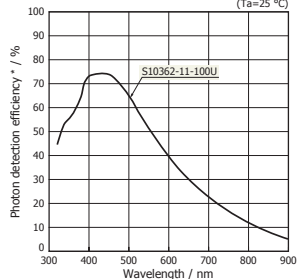
# Muon through cement



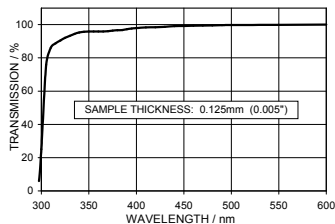
# Spectra

**BC-404****WLS fibre: BCF-92****SiPM: S10362-11-100C**

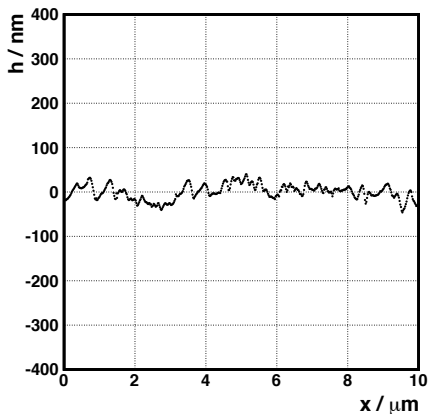
(Ta=25 °C)



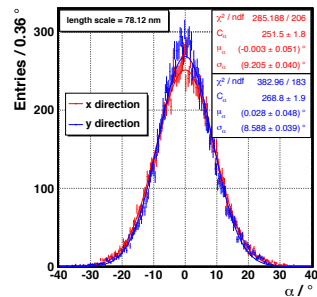
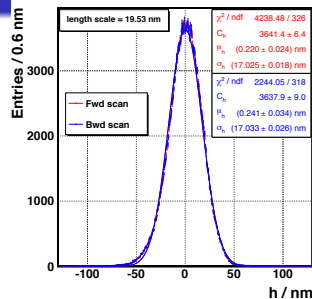
\* Photon detection efficiency includes effects of crosstalk and afterpulses.

**Optical Cement: EJ500**

## AFM



See also:  
 CMS-RI-TR-89-7 (Nayar, Ikeuchi, Kanade),  
 TRI-PP-96-64 (Levin, Moisan).



# CMS

