Development of simulation tools to realize an active Thomson Parabola

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Outline

I. Thomson Parabola ? Active ?

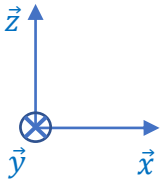
II. Simulation tools

1. EM simulation
2. Optical simulation
3. Fibers simulation

III. New design of TP

Thomson Parabola

- **Thomson Parabola (TP)** = Parallel magnetic & electrical field with **Imaging Plates (IPs) for the detection**
- Used for **qualitative & quantitative detection** of particules created in a plasma by a laser shot
- Very efficient to **discriminate ions but …**



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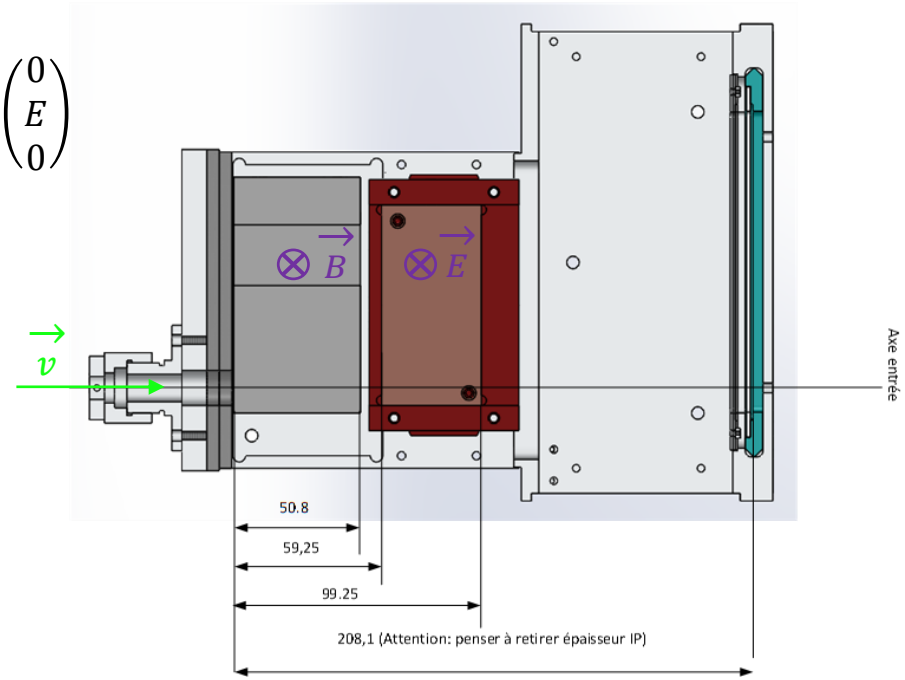

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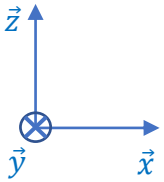

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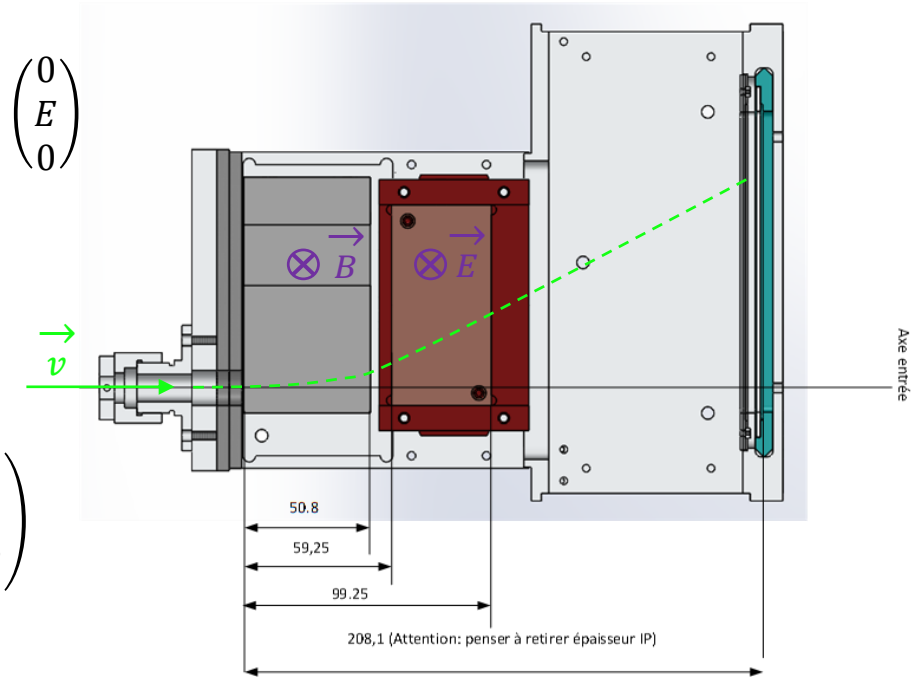

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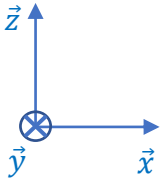

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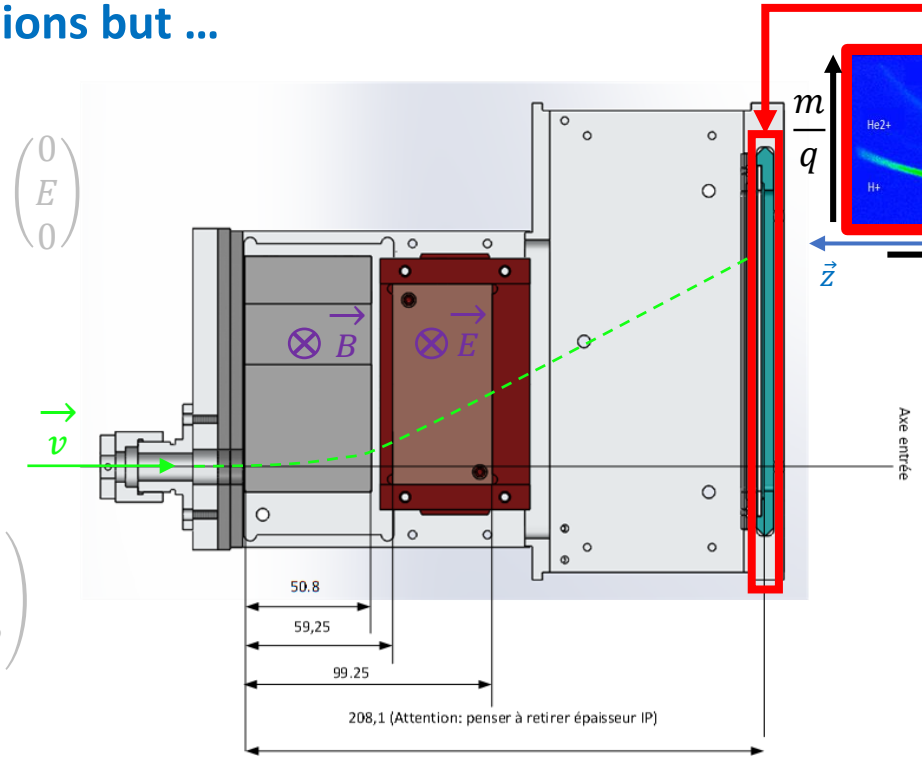

$$m\begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix} = \begin{pmatrix} 0 \\ qE \\ qvB \end{pmatrix} \Rightarrow \boxed{y = \frac{2mE}{qB^2L_{tot}^2}z^2}$$

Most simplified case

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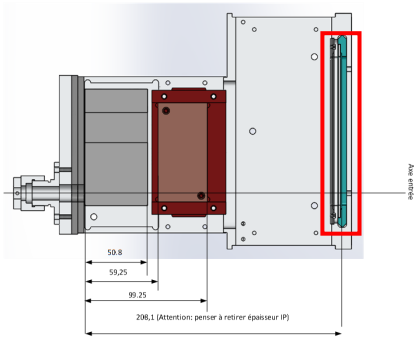
- … must be **read after the shot**
- Not possible to use IPs at **high laser repetition rates**
- **Realization of an Active Thomson Parabola** (RATP project with GPR Light)

- 2 detection scenarii to be tested :
  - Combination of **scintillators** imaged with **cameras (CCD, CMOS)**
  - ***CMOS detector*** *directly in focal plan of TP*



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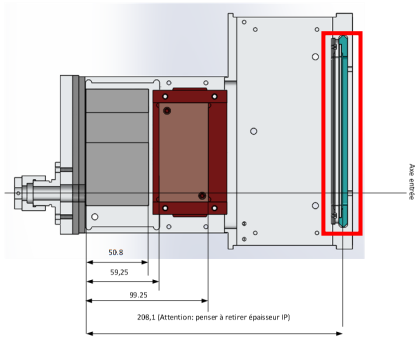

- Some questions to answer *:*
  - **What is the « perfect configuration » for a given experiment ?**
  - **What is the impact of the differents TP parameters ?**
  - **Is the light produced in the scintillator sufficient to be detected ?**
  - **Can we use the system in the experimental chamber (EMP, X flash) ?**

Simulation tools-EM

- Simulation of TP with GEANT4 software
  - EM part for tracking and energy deposition in detector
  - Optical part for tracking and detection of the scintillation (choice to activate or not)
  - Simulation of p^{+}, He^{1+} & He^{2+}

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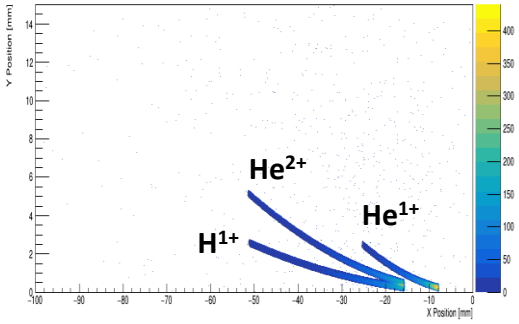

Simulation parameters :

$r_{pinhole}$ = 0.1 mm
B value = 0.6 T
E value = 630000 V/m
Magnet Length = 50 mm
Ecart plates D = 0 mm
Electric length = 40 mm
Distance plate/detector = 175 mm
L_{tot} = 265 mm
Sc length = 200 mm
Sc thickness = 0 mm
ZnS thickness = 0 mm
Optique ? : No

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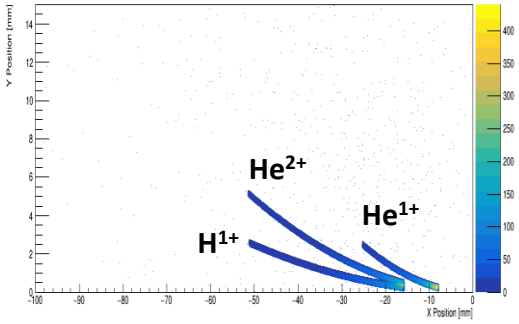

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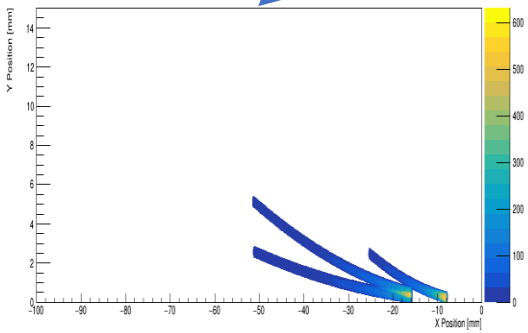
Entrance pinhole variation



$r_{pinhole}$ = 1.0 mm

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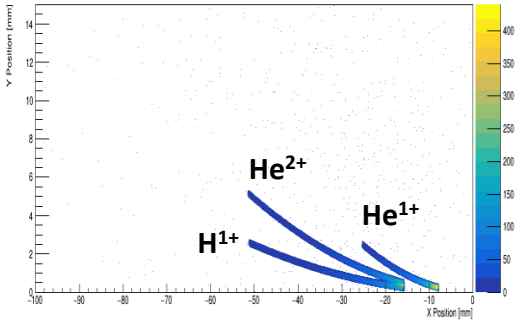
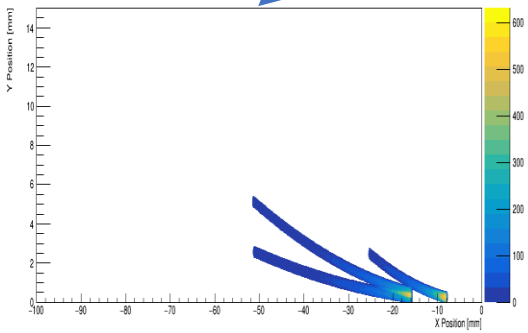
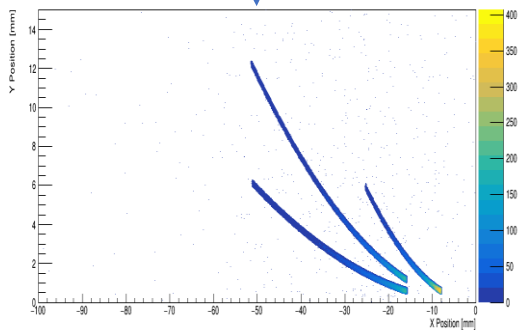


Entrance pinhole variation

E field variation





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E field = 1500 kV/m

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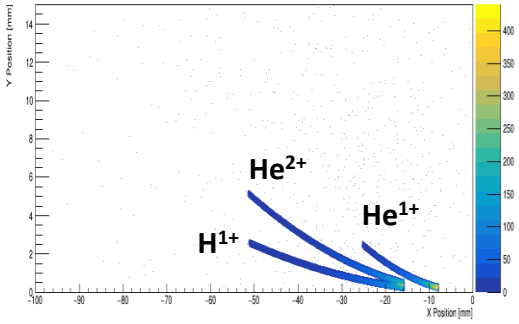

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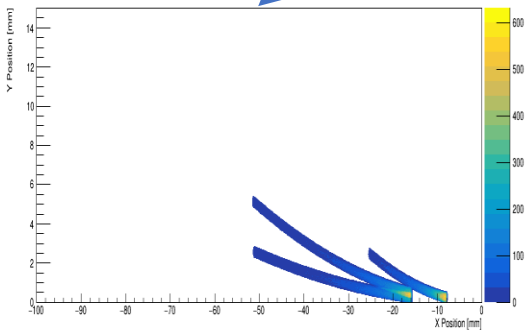
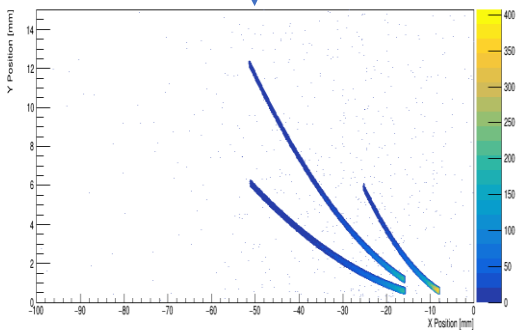
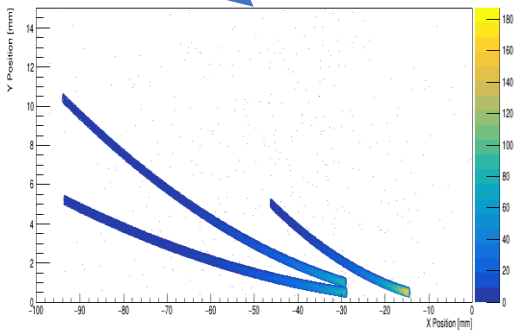
Entrance pinhole variation

E field variation

E Field/focal plan distance variation







$r_{pinhole}$ = 1.0 mm

E field = 1500 kV/m

Distance Ef/det = 140 cm

Simulation tools-Optical

- First study (Jan 22 -> May 22) with a scintillator in focal plan :
  - **Estimate if a CCD/CMOS camera directly in contact is possible**

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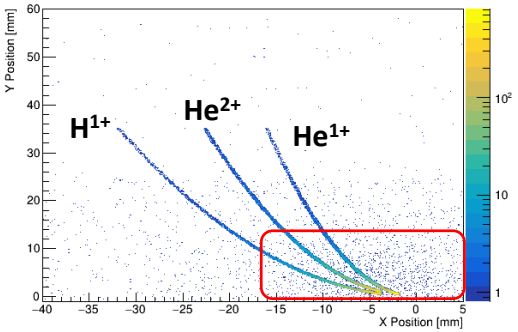
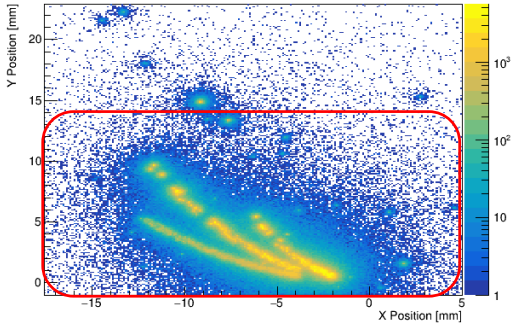
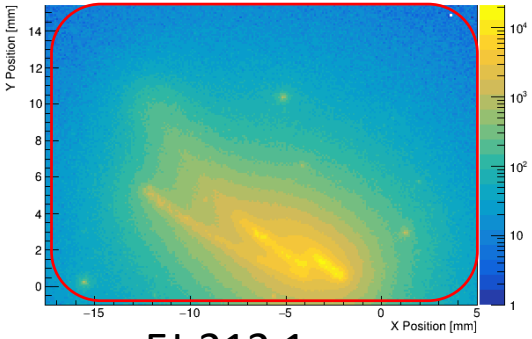
EJ 212



IP like



EJ-212 0,1 mm



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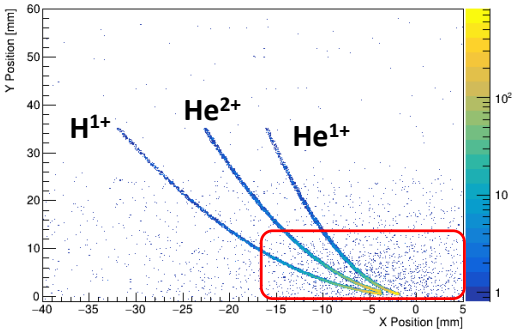
EJ 212



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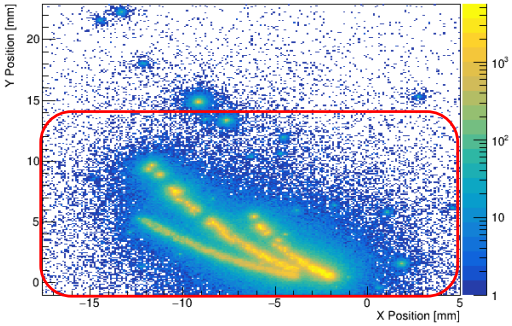
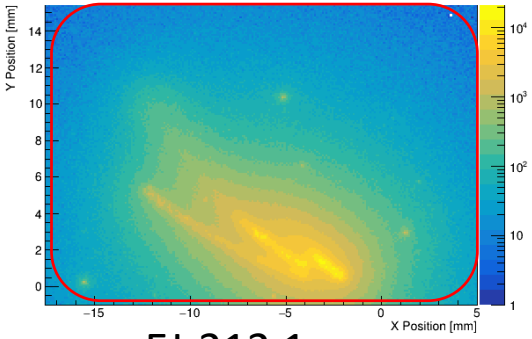


EJ-212 0,1 mm



EJ-212 1 mm

If thickness scintillator ↗
number of photons generated ↗

If thickness scintillator ↗
dispersion of photons ↗

Potential loss of information at high (all) and low energy (He^{n+})

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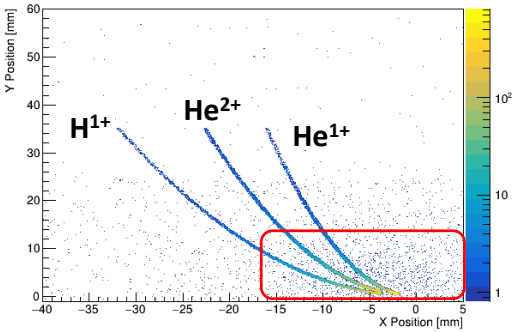

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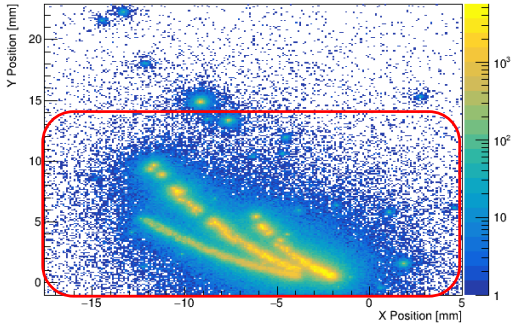
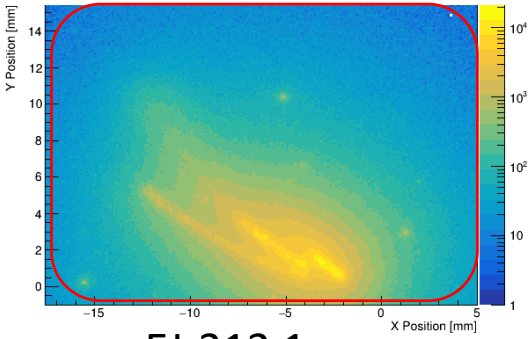


EJ-212 0,1 mm



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- Configuration possible but :
  - ⚠ Needs more investigations for optimization (additional energy from primary particle)
  - ⚠ Difficult to have a CCD/CMOS Camera with a large Field Of View (FOV)
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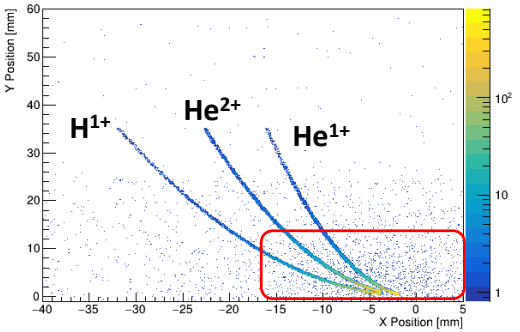

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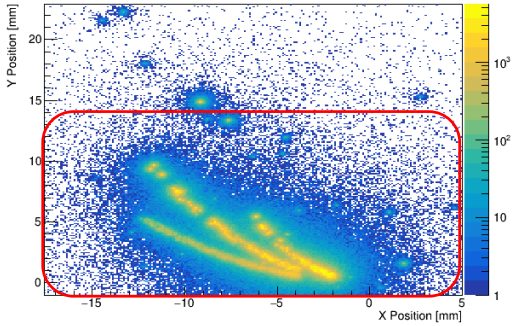

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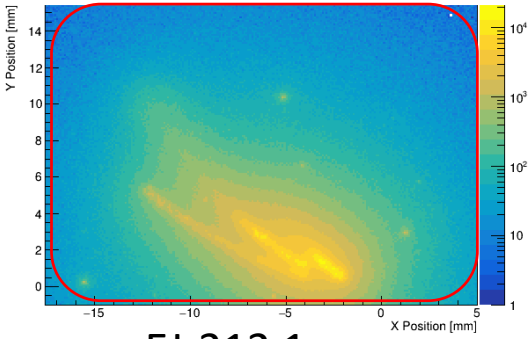

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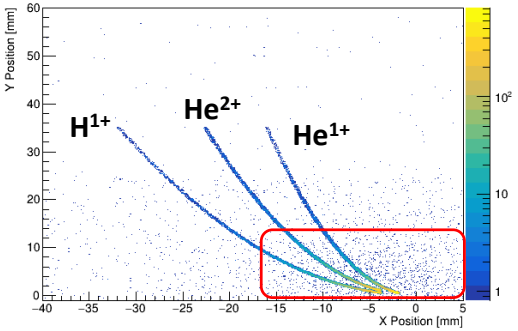

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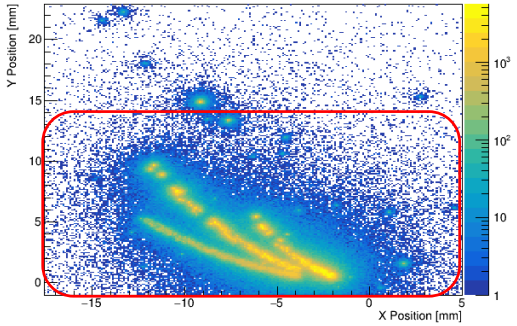

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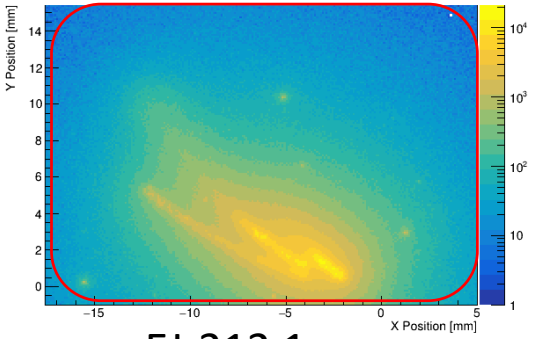

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    - 💡 **Simulation of fibers bunch**

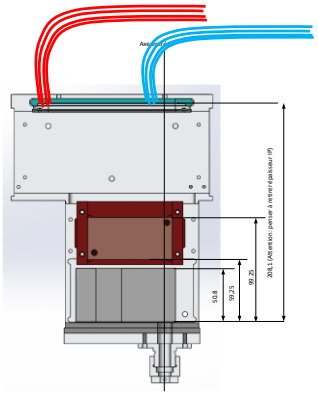
Simulation tools-Fibers

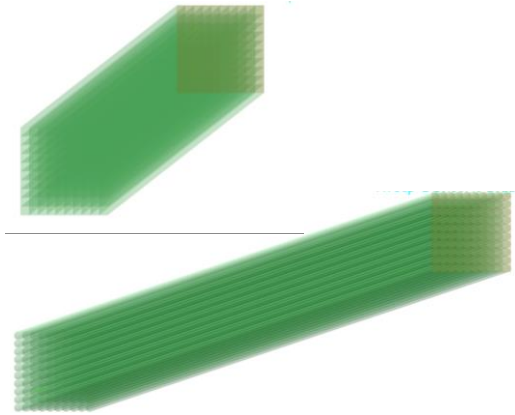
- Optical fiber simulation based on Kuraray geometries (LIQUIDO's fibers manufacturer)

- Try with parameterization for the bunch generation on the code
- Not conclusive -> loop generation
- Detector at the end of bunch

- Code automation with a config file

- Very long time of simulation !!!
  - 3,5 MeV proton on TP with optical photon tracking on fibers = **704s/event**
  - Necessary to improve !!!

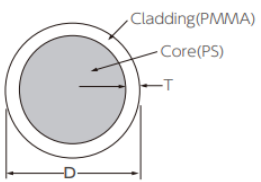
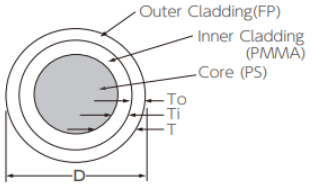
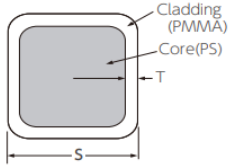




Materials

		Materials	Refractive index	Density (g/cm³)	No. of atom per cm³
Core		Polystylene(PS)	n_D=1.59	1.05	C: 4.9x10²² H: 4.9x10²²
Cladding	for single cladding inner for multi-cladding	Polymethylmethacrylate (PMMA)	n_D=1.49	1.19	C: 3.6x10²² H: 5.7x10²² O: 1.4x10²²
	outer for multi-cladding	Fluorinated polymer (FP)	n_D=1.42	1.43	

Cross-section and Cladding Thickness

	Single Cladding	Multi-Cladding (M)
Round Fiber (D)	 Cladding Thickness[1]: T=2% of D Numerical Aperture: NA=0.55 Trapping Efficiency : 3.1%	 Cladding Thickness[2]: T=2%(To)+2%(Ti) =4% of D Numerical Aperture : NA=0.72 Trapping Efficiency : 5.4%
Square Fiber (SQ)	 Cladding Thickness : T=2% of S Numerical Aperture : NA=0.55 Trapping Efficiency : 4.2%	Not available

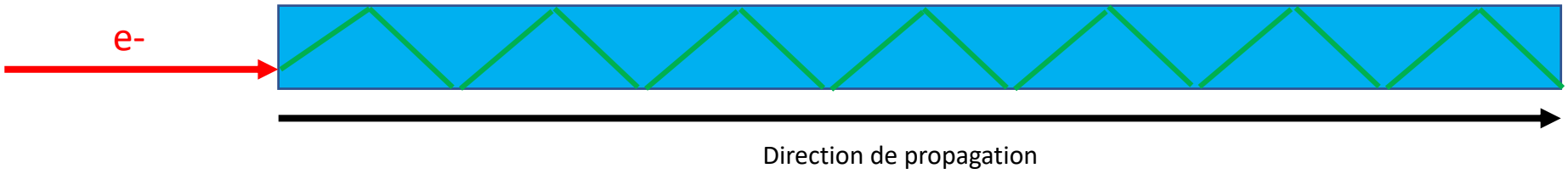
1) In some cases, cladding thickness T is 3% of D 2) In some cases, cladding thickness T is 6% of D. To and Ti are both 3% of D

```
37
38  #Fibers
39  Fiber_geometry 0 #0=round & 1=square
40  Fiber_multi_cladding 0 #0 or 1 to activate
41  Fiber_number_per_line 5
42  Fiber_space 0.001 mm
43  Fiber_width 1 mm
44  Fiber_cladding_ratio 0.02
45  Fiber_length 1. m
46
```

Simulation tools-Fibers

Assumptions for a fast optical transport simulation

- Best way is to let GEANT4 doing all the calculations
- Most CPU consumption is coming from the optical photon tracking
- Need to take care of several aspects : generation, reflections and absorption.



Simulation tools-Fibers

Assumptions for a fast optical transport simulation

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- Most CPU consumption is coming from the optical photon tracking
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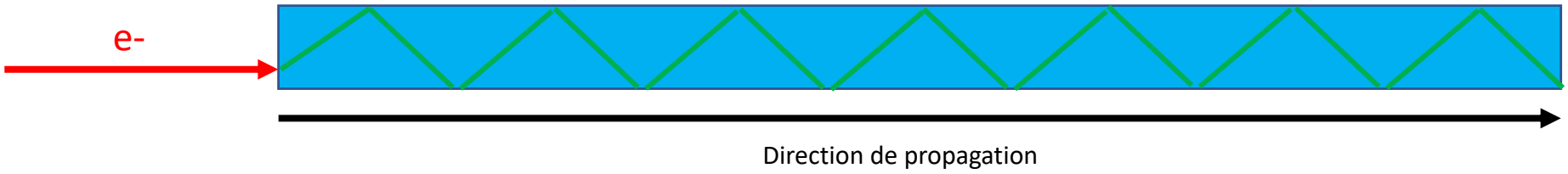
Assumptions from fiber characteristics

- An optical photon trapped inside the fiber will do multiple internal reflections up to be detected or absorbed.
- The angle of a photon at the interface of the fiber will remain the same during all the transport.
- Surface of core and cladding are perfectly polished.

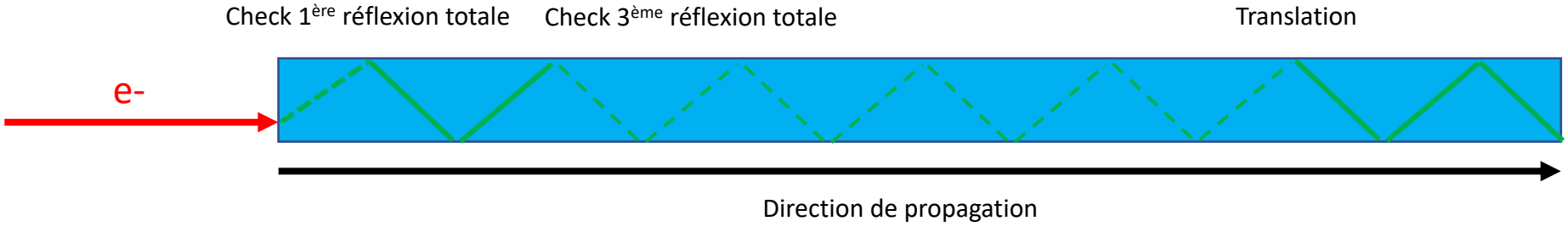


Simulation tools-Fibers

Idea of an algorithm for a fast optical photon transportation

- All the intermediates steps are not necessary for the simulation
- It's sufficient to know that an optical photon made some total internal reflections
- Probability of absorption can be calculated separately for each photon

- Possible to go to a fast photon transportation according to :
  - 1. FastSim algorithm activation if we have 2 internal total reflections
  - 2. Estimation of the final position acording to the tracking
  - 3. Absorption check after translation
  - 4. Track translation with modification of the attached tracking informations



Simulation tools-Fibers

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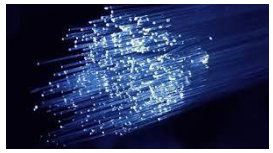
Time of simulation (proton 3,5 MeV):
- Without G4FAST : 704 s/event
- With G4FAST : 298 s/event

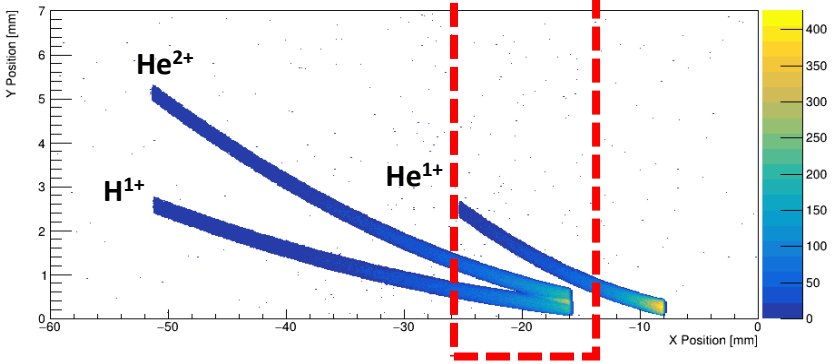
New design of TP

- Second study (May 22 -> ongoing) with a bunch of fibers in focal plan :
  - **Remote the detection of light outside the chamber**



FOV ORCA CAMERA

IP like

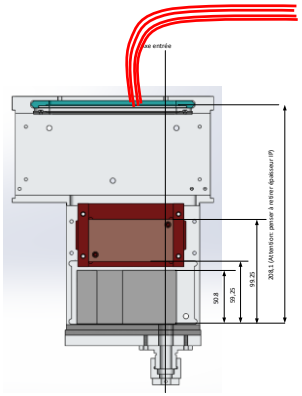


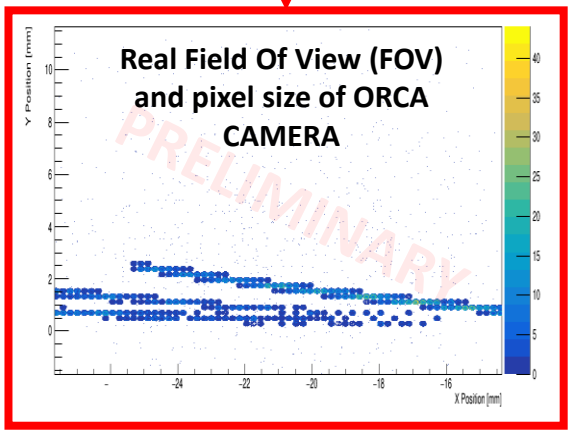
LP2IB config
1-10 MeV

Simulation parameters :

$r_{pinhole}$ = 0.1 mm
B value = 0.6 T
E value = 630000 V/m
Magnet Length = 50 mm
Ecart plates D = 0 mm
Electric length = 40 mm
Distance plate/detector = 175 mm
L_{tot} = 265 mm
Sc length = 200 mm
Sc thickness = 0 mm
ZnS thickness = 0 mm
Optique ? : No

Round bunch fibers





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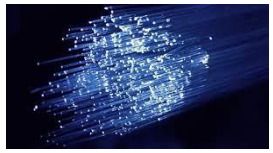
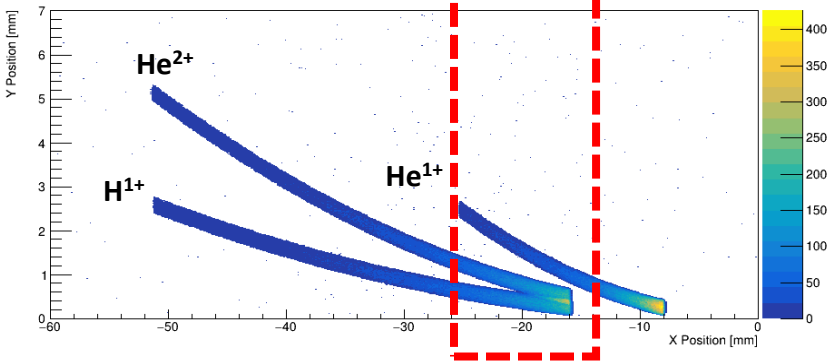


FOV ORCA CAMERA

IP like



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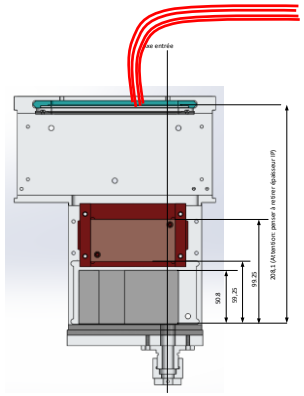

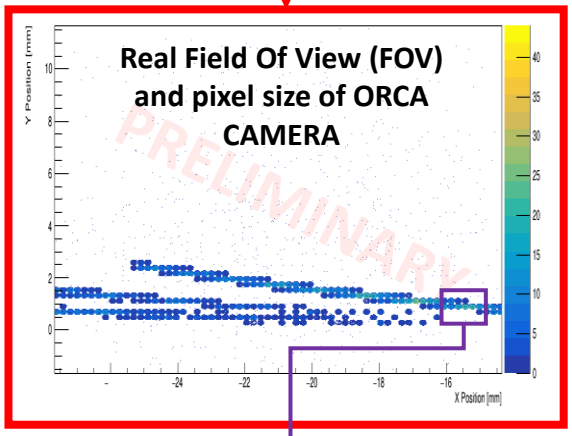

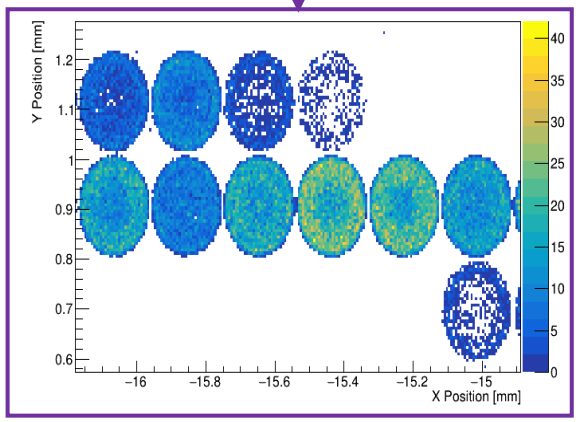

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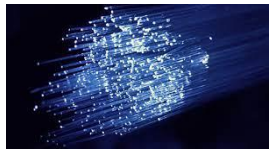

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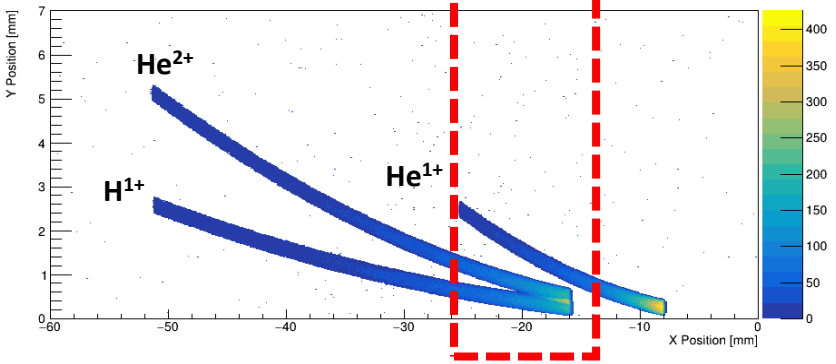
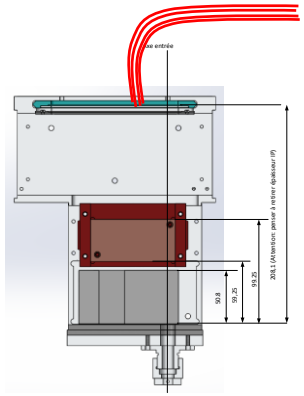
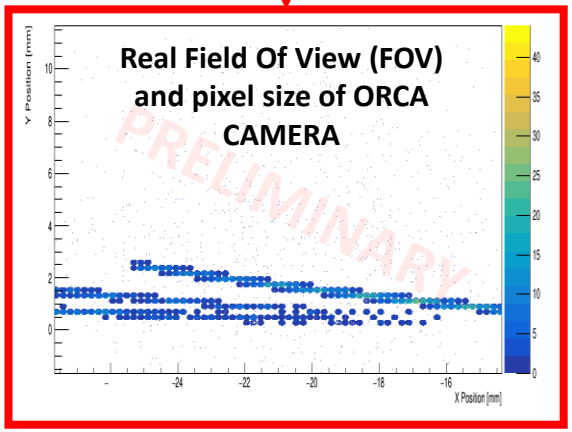


Round bunch fibers





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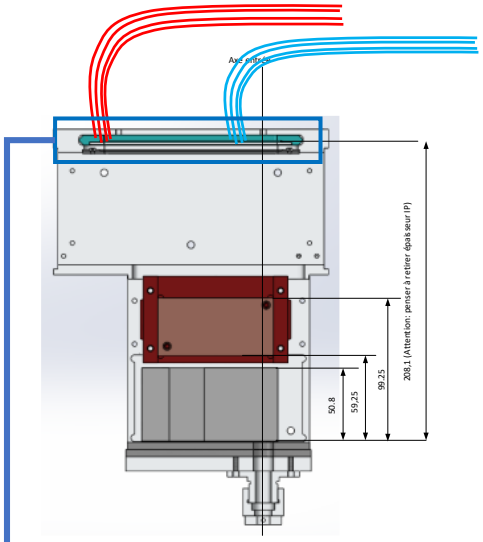
Optique ? : No

LP2IB config
1-10 MeV

Potential good solution solution to :

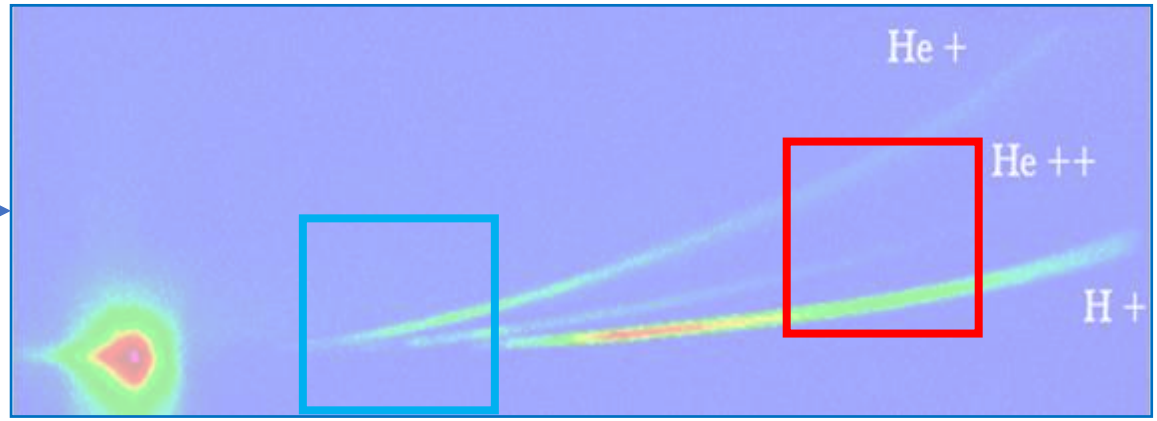
- **Maximise Nph/Edep without smearing due to ↗ scintillator thickness**
- **Avoid Flash X & EMP problem**
- **Be adaptative for multiple experiments**
- **Fiber pixel dependant on the fiber dimensions**

New design of TP



!!! If this configuration is the best solution !!!

- **Mechanical point of view :**
  - Adjustable for each TP configuration & type of experiments (plug and play solution)
  - Multizones with multiple cameras
  - Potential light shielding to take care and so on…
- **Instrumentation point of view :**
  - Custom-made CMOS detector (collaboration with IPHC Strasbourg)



Conclusions & perspectives

- Creation of a **simulation tool** for the **study of Thomson Parabola**
  - **Already in contact** with GSI and CLPU (LaserLAB collaboration)
  - **Feedback are really important** (especially for the optical simulation)
- **Feasibility of TP with scintillator possible**
  - Needs **optimization** and **complete characterization**

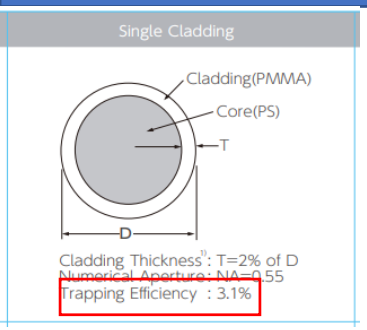
- Test also configuration with **CMOS directly in focal plan**
- Decide what is the **best configuration**
- **Tests** of this configuration **to follow**
- **TP production & validation** in 2023-2024

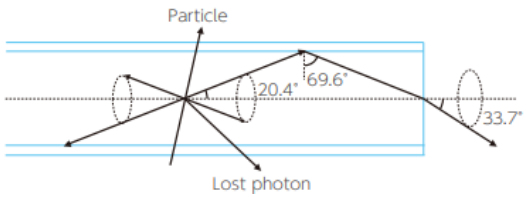
THANK YOU FOR YOUR ATTENTION

This study has received financial support from the French State in the framework of the Investments for the Future programme IdEx université de Bordeaux / GPR LIGHT

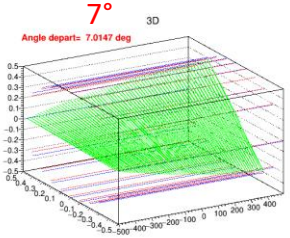
BACKUP

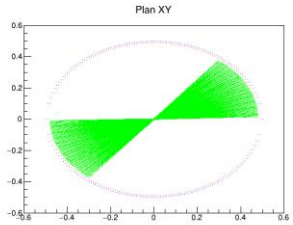
Rond single cladding

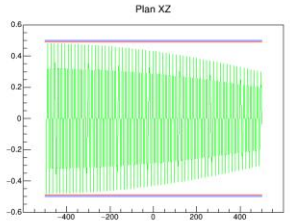


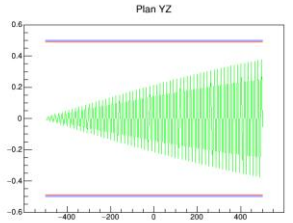


7°

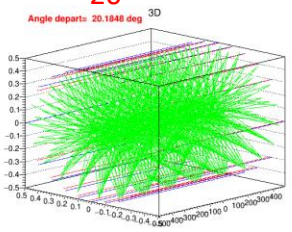


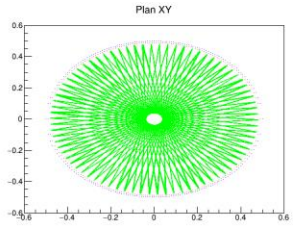


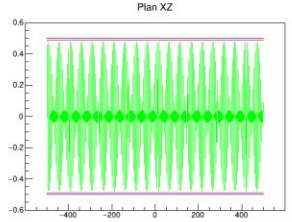


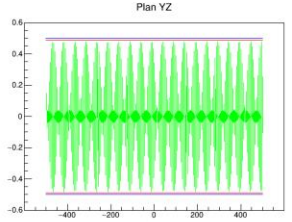


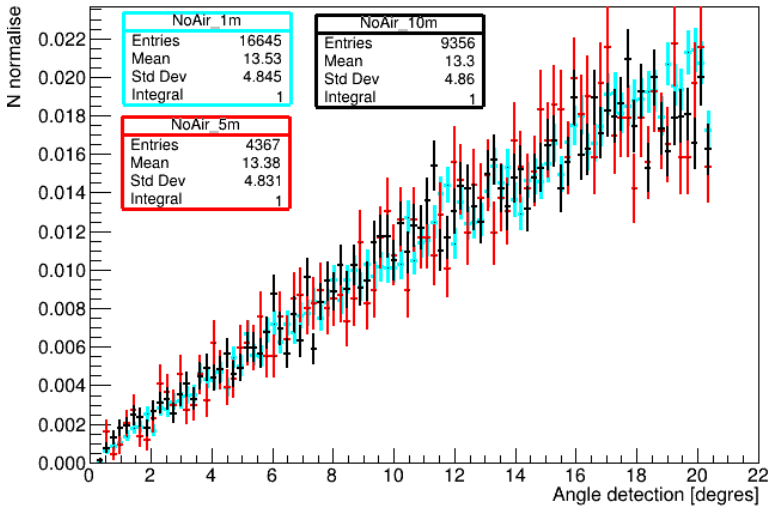
20°

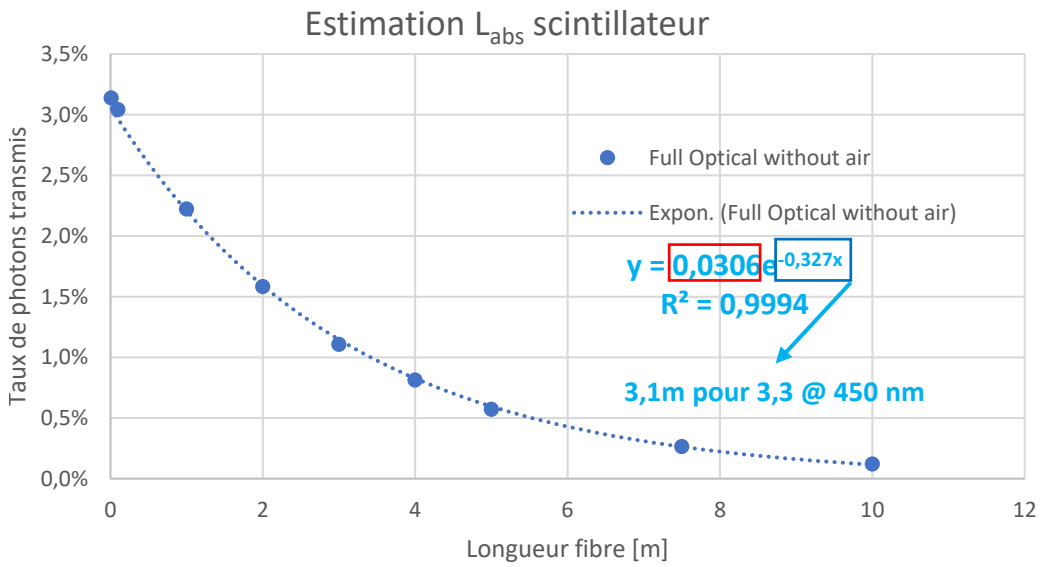




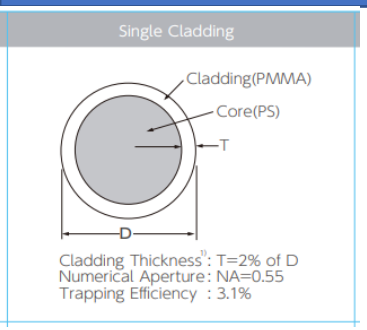


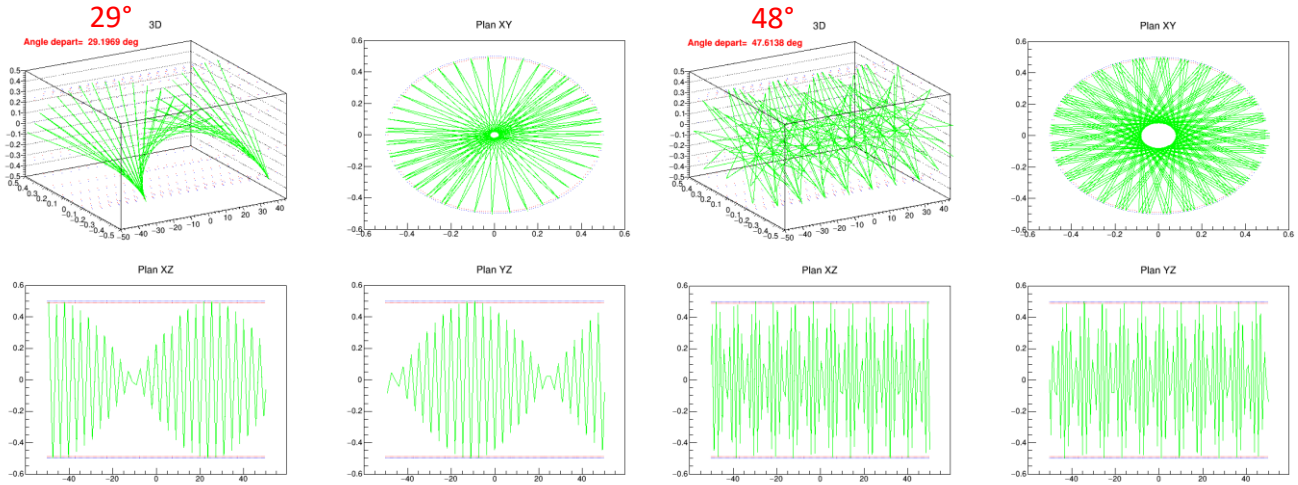


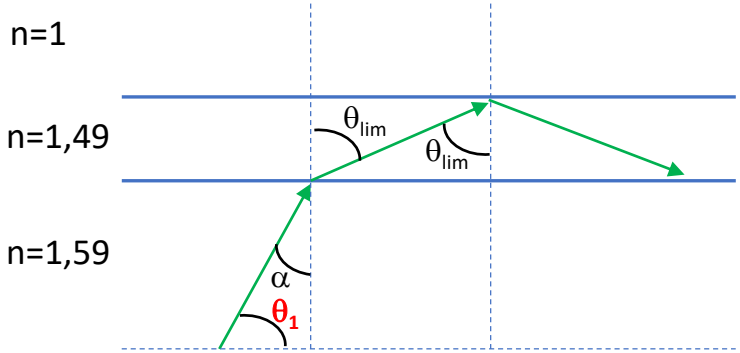




Rond single cladding



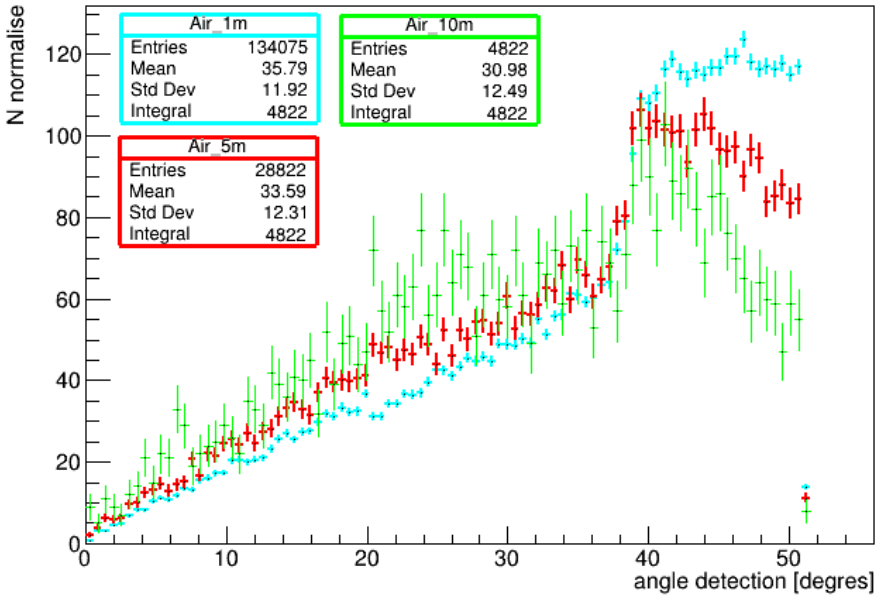




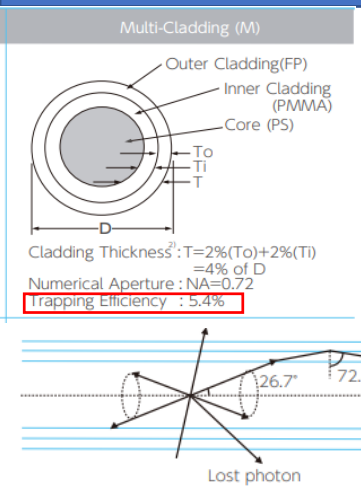
$$\theta_{lim} = \sin^{-1}\left(\frac{1}{1{,}49}\right) = 42{,}2°$$

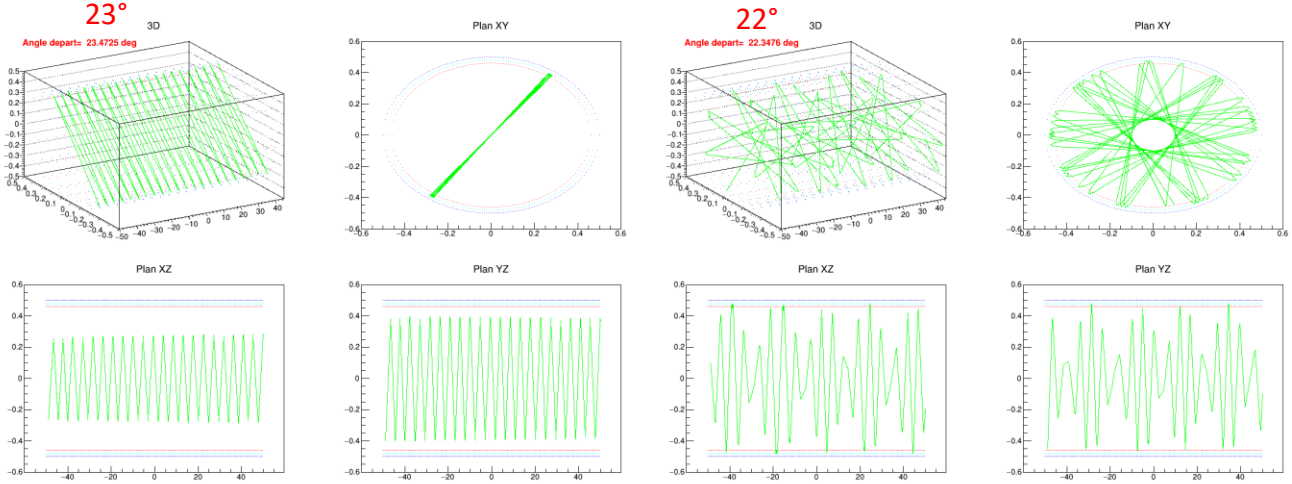
$$\alpha > \sin^{-1}\left(\frac{1{,}49}{1{,}59} \times \sin\theta_{lim}\right) = 39{,}0°$$

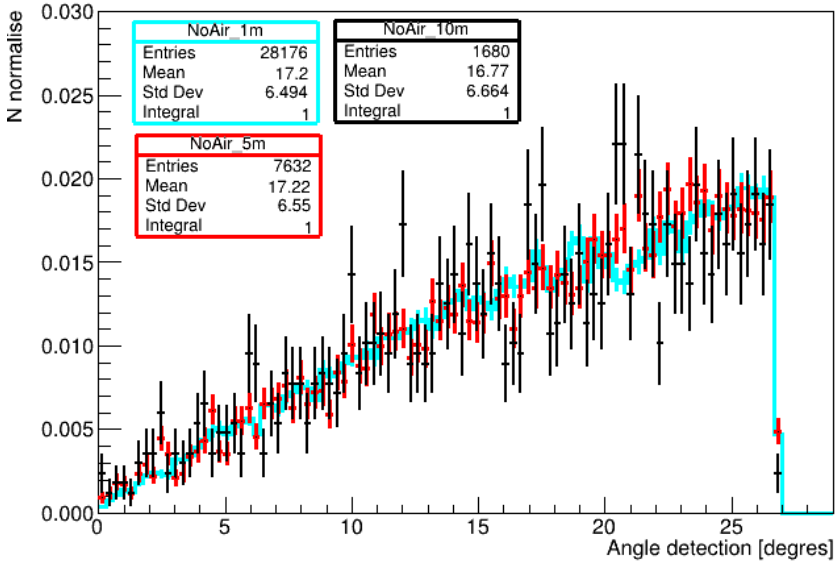
$$\boldsymbol{\theta_1 < 90 - \alpha = 51°}$$

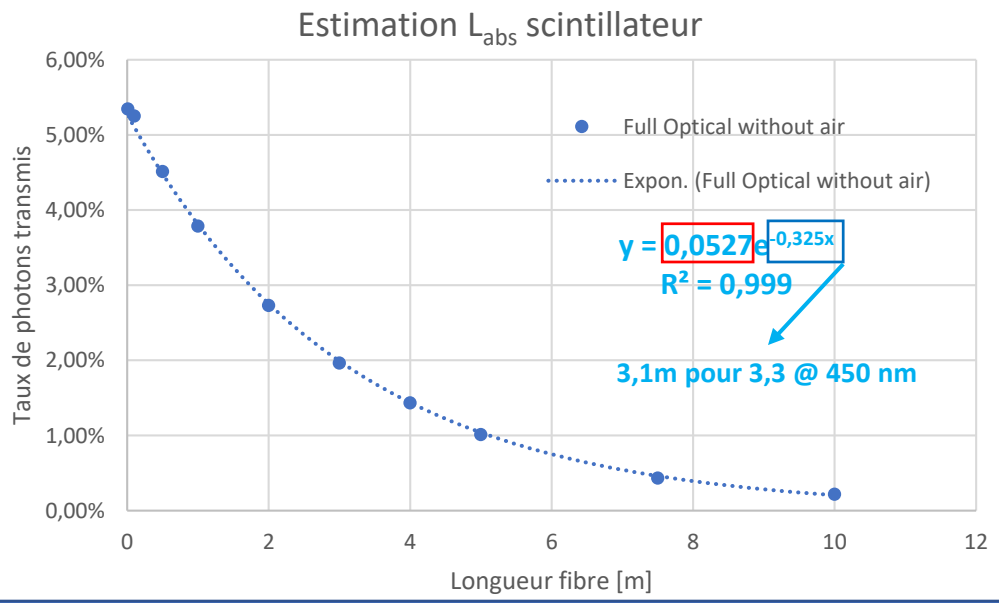


Rond multicladding









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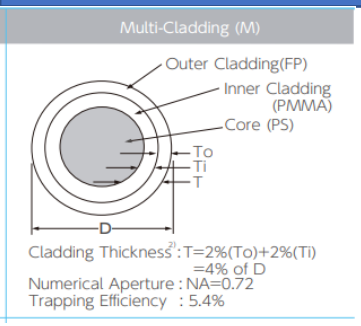
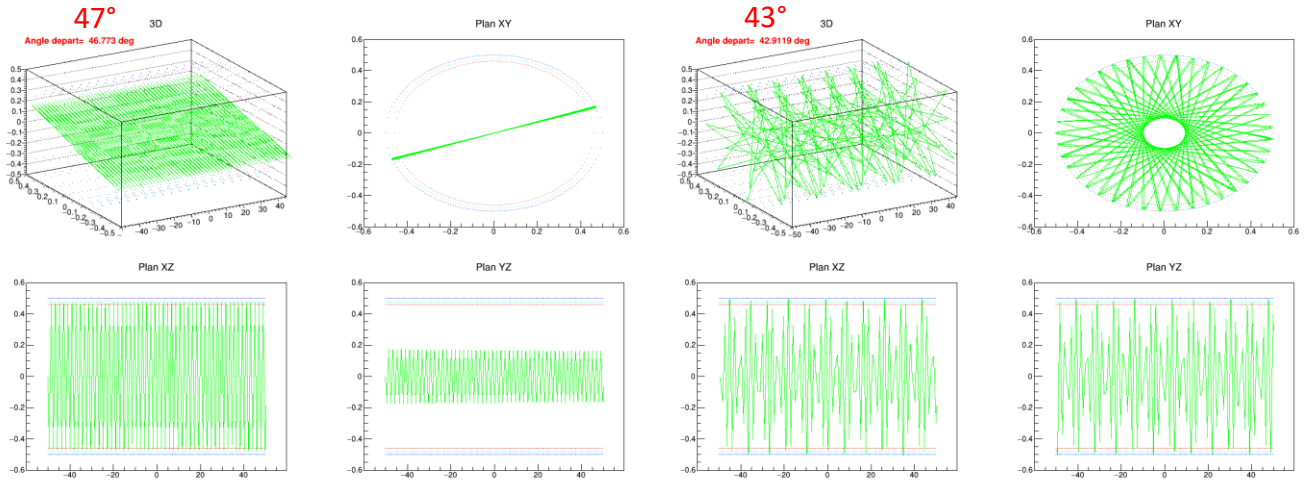


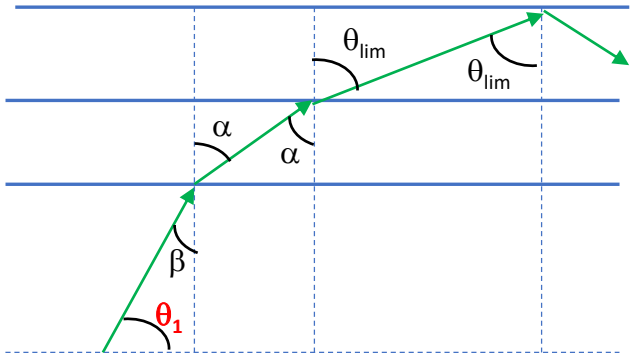


n=1

n=1,42

n=1,49

n=1,59

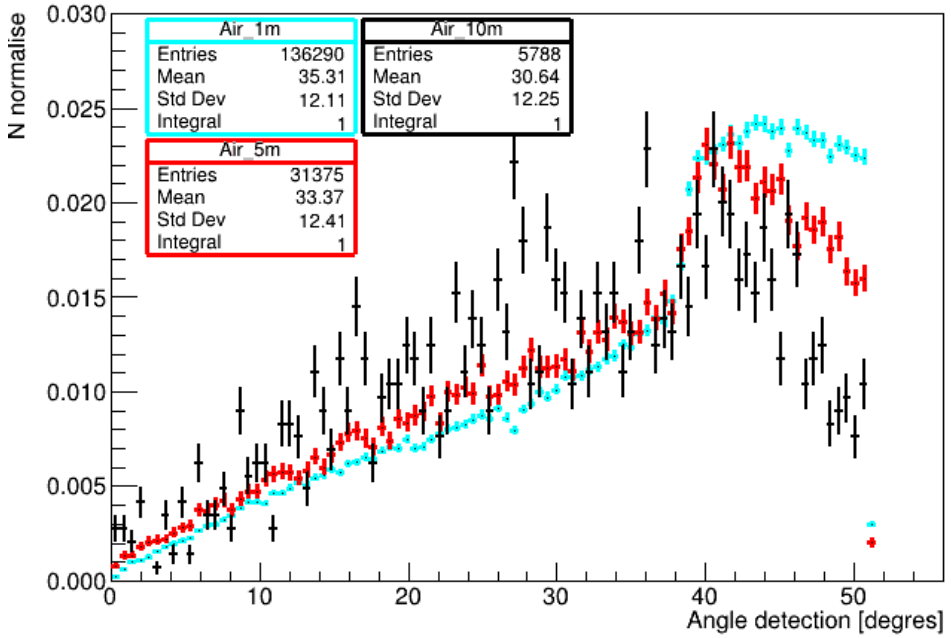


$$\theta_{lim} = \sin^{-1}\left(\frac{1}{1{,}42}\right) = 44{,}8°$$

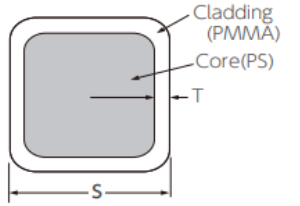
$$\alpha > \sin^{-1}\left(\frac{1{,}42}{1{,}49} \times \sin\theta_{lim}\right) = 42{,}2°$$

$$\beta > \sin^{-1}\left(\frac{1{,}49}{1{,}59} \times \sin\alpha\right) = 39{,}0°$$

$$\boldsymbol{\theta_1 < 90 - \alpha = 51°}$$

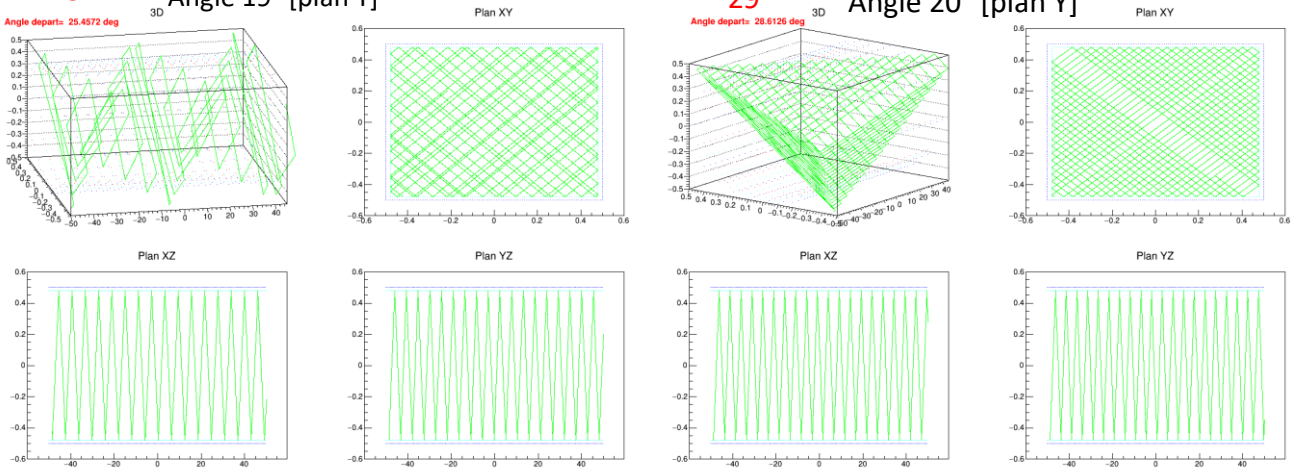


Carré single cladding

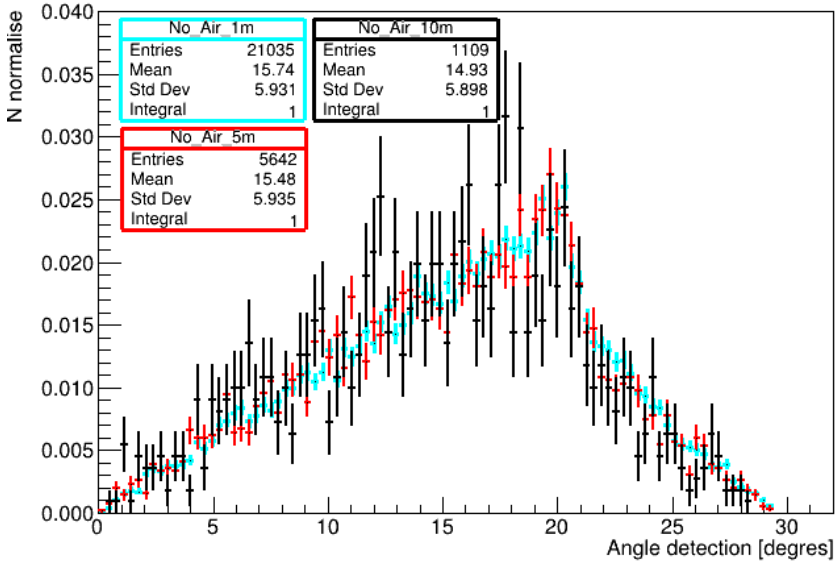


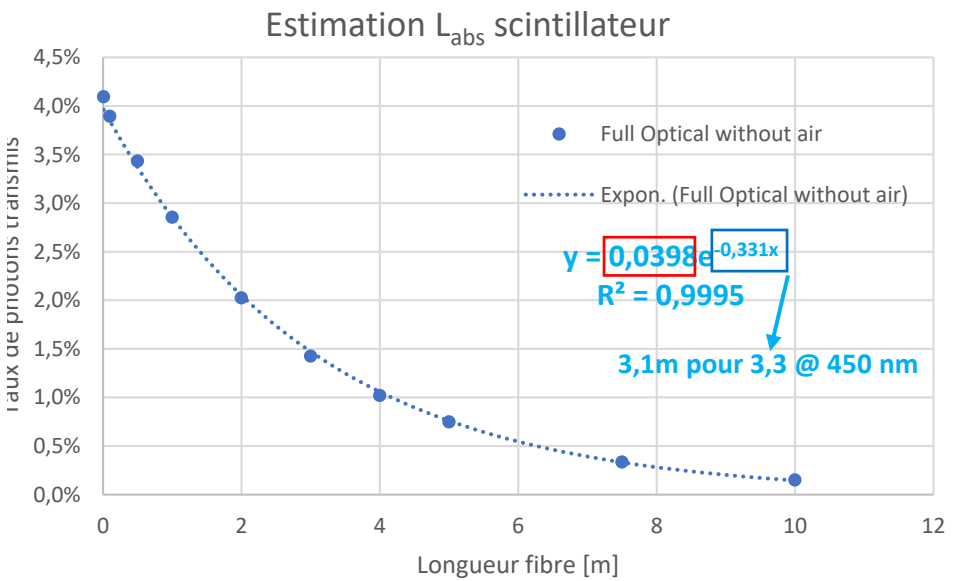
Cladding Thickness : T=2% of S
Numerical Aperture : NA=0.55
Trapping Efficiency : 4.2%

25°
Angle 16° [plan X]
Angle 19° [plan Y]

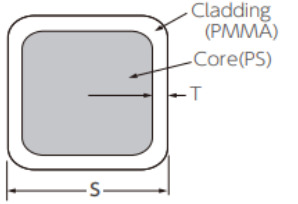


29°
Angle 20° [plan X]
Angle 20° [plan Y]



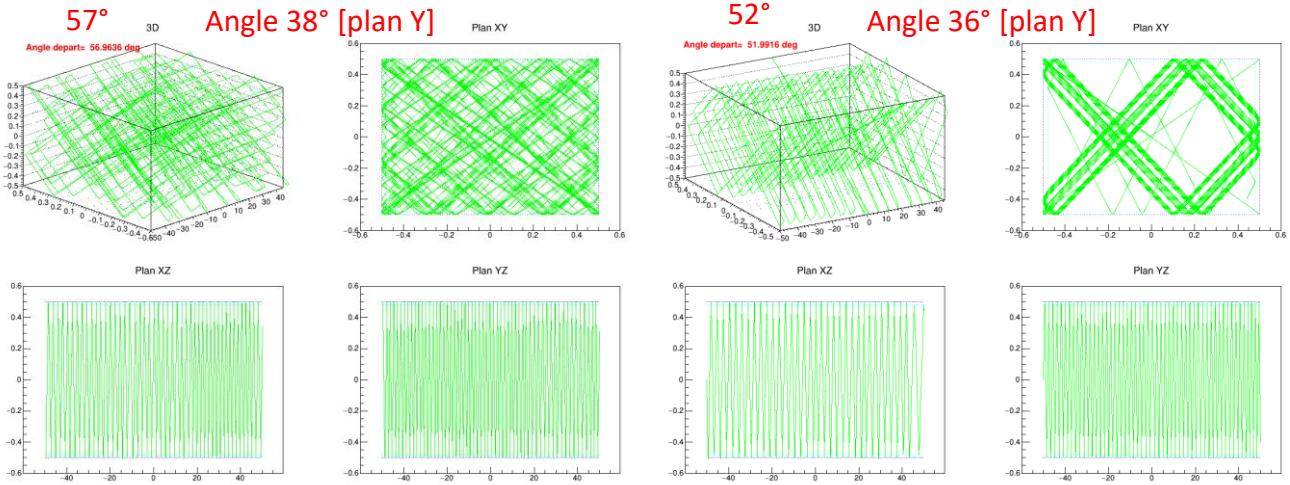


Carré single cladding



Cladding Thickness : T=2% of S
Numerical Aperture : NA=0.55
Trapping Efficiency : 4.2%

Angle 32° [plan X]
Angle 38° [plan Y]
57°

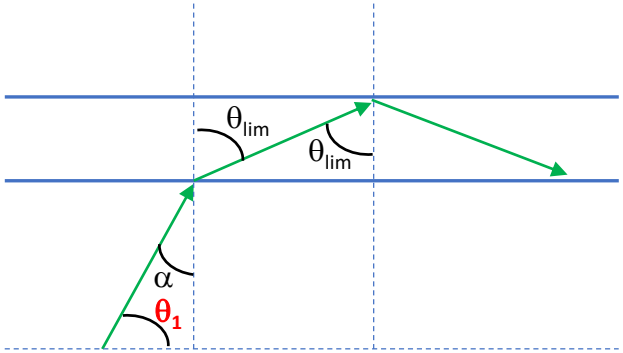


Angle 28° [plan X]
Angle 36° [plan Y]
52°

n=1

n=1,49

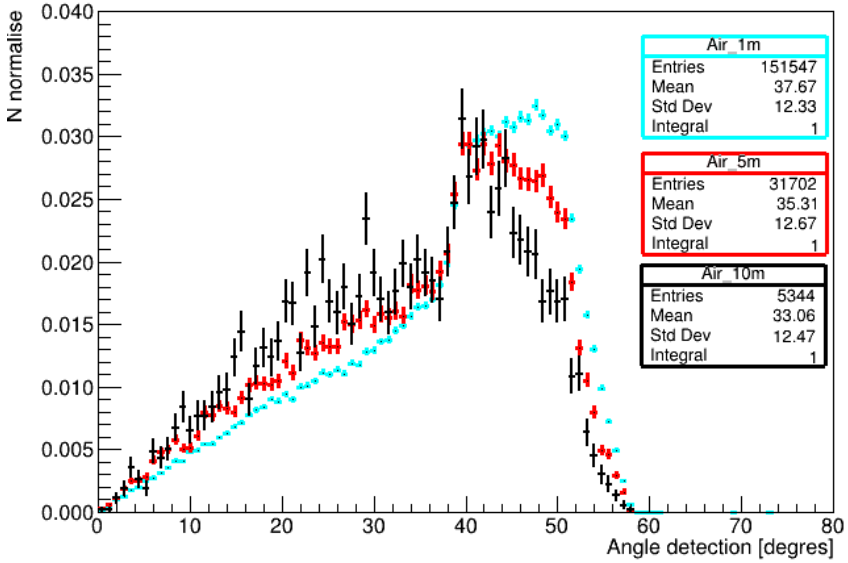
n=1,59



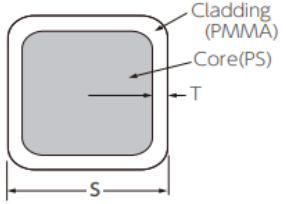
$$\theta_{lim} = \sin^{-1}\left(\frac{1}{1{,}49}\right) = 42{,}2°$$

$$\alpha > \sin^{-1}\left(\frac{1{,}49}{1{,}59} \times \sin\theta_{lim}\right) = 39{,}0°$$

$$\boldsymbol{\theta_1 < 90 - \alpha = 51°}$$



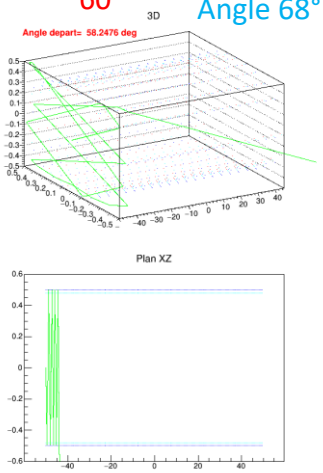
Carré single cladding



Cladding Thickness : T=2% of S
Numerical Aperture : NA=0.55
Trapping Efficiency : 4.2%

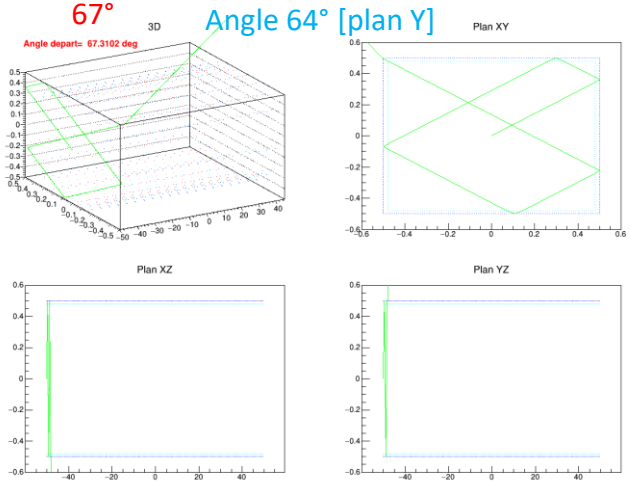
60°

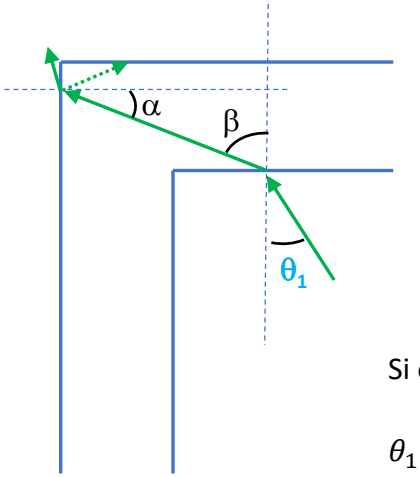
Angle 51° [plan X]
Angle 68° [plan Y]



67°

Angle 45° [plan X]
Angle 64° [plan Y]



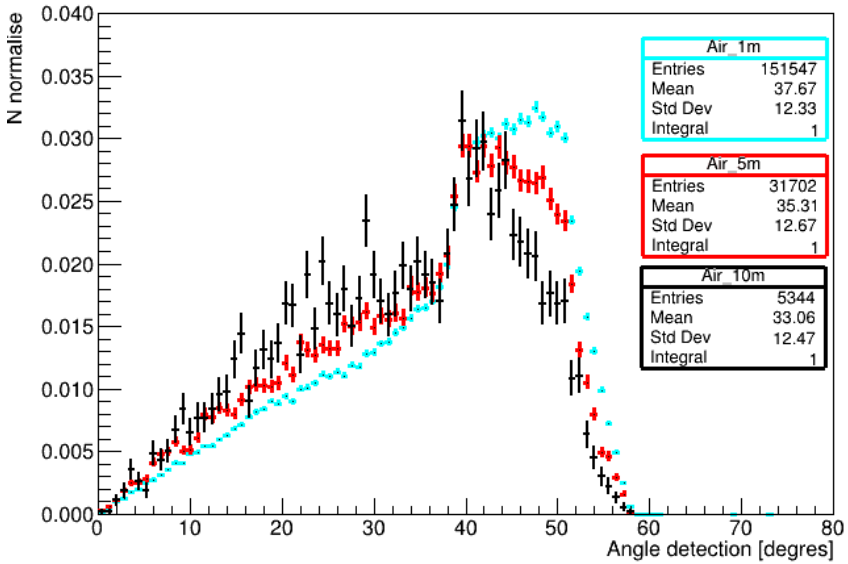


$$\theta_{lim} = \sin^{-1}\left(\frac{1}{1{,}49}\right) = 42{,}2°$$

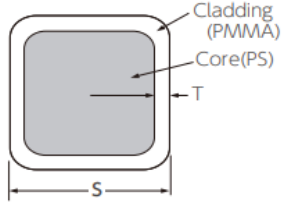
Si $\alpha > \theta_{lim}$ $\quad \beta < (90 - \alpha = 47{,}8°)$

$$\theta_1 < \left(\sin^{-1}\left(\frac{1{,}49}{1{,}59} \times \sin\beta\right) = 44{,}0°\right)$$

Réflexion totale au point A si et seulement si $\theta_1 < 44°$

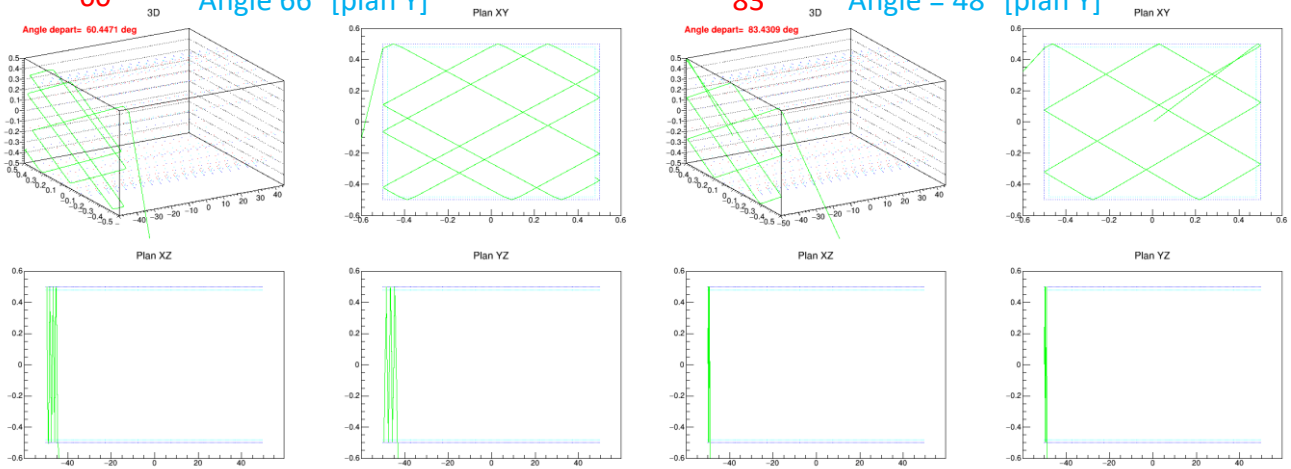


Carré single cladding

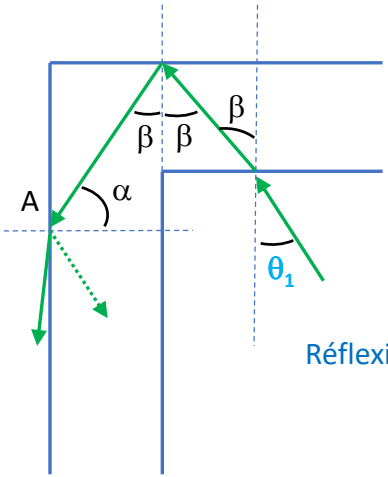


Cladding Thickness : T=2% of S
Numerical Aperture : NA=0.55
Trapping Efficiency : 4.2%

60° Angle 50° [plan X] Angle 66° [plan Y]



83° Angle = 43° [plan X] Angle = 48° [plan Y]



$$\theta_{lim} = \sin^{-1}\left(\frac{1}{1{,}49}\right) = 42{,}2°$$

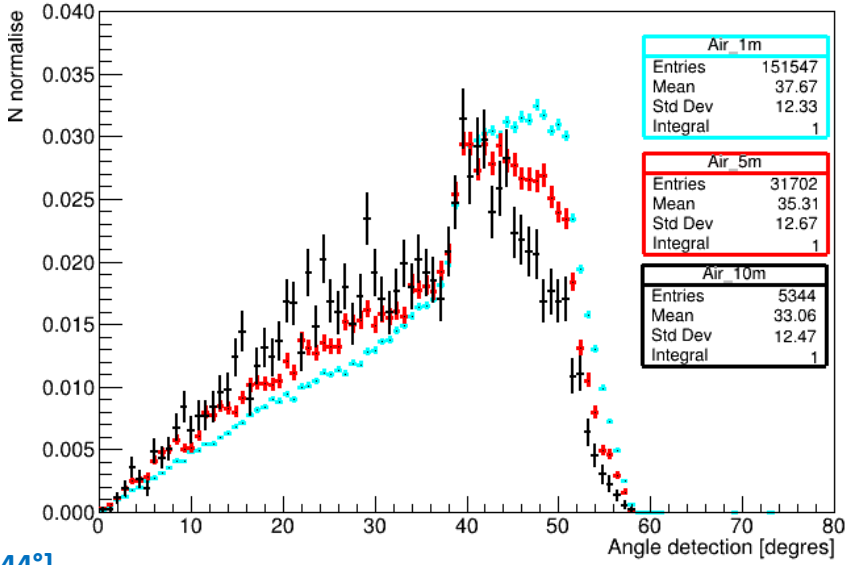
Si $\alpha > \theta_{lim}$ $\beta < (90 - \alpha = 47{,}8°)$

$$\theta_1 < \left(\sin^{-1}\left(\frac{1{,}49}{1{,}59} \times \sin\beta\right) = 44{,}0°\right)$$

Réflexion totale au point A si et seulement si $\theta_1 < 44°$

On doit également avoir $\beta > \theta_{lim}$

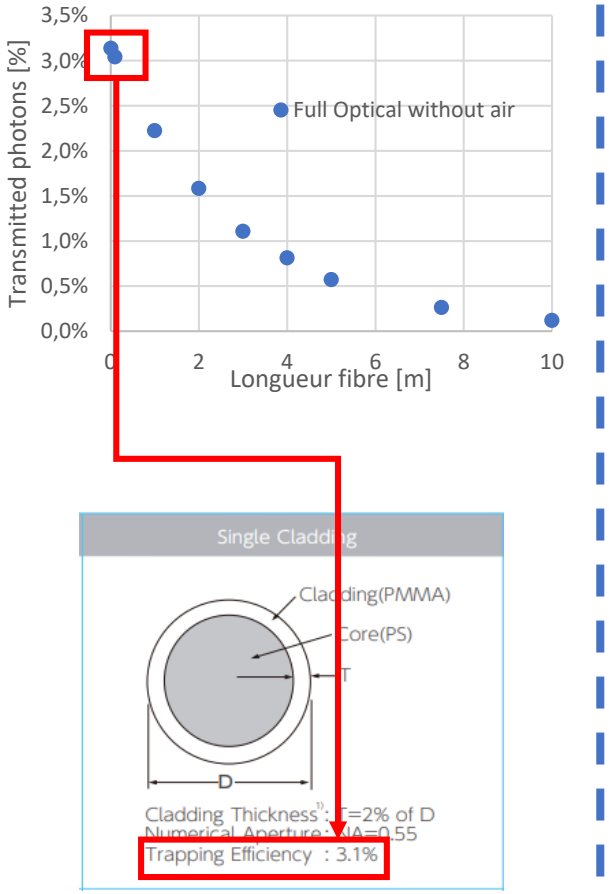
$$\theta_1 > \left(\sin^{-1}\left(\frac{1{,}49}{1{,}59} \times \sin\beta\right) = 39{,}0°\right)$$



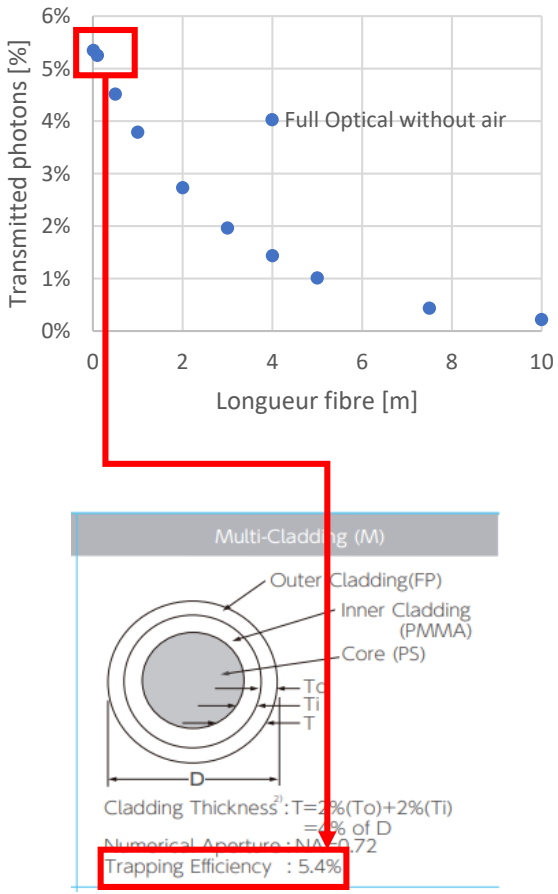
Réflexion totale au point A si et seulement si $\theta_1 \in$ [39° ; 44°]

Simulation tools-Fibers

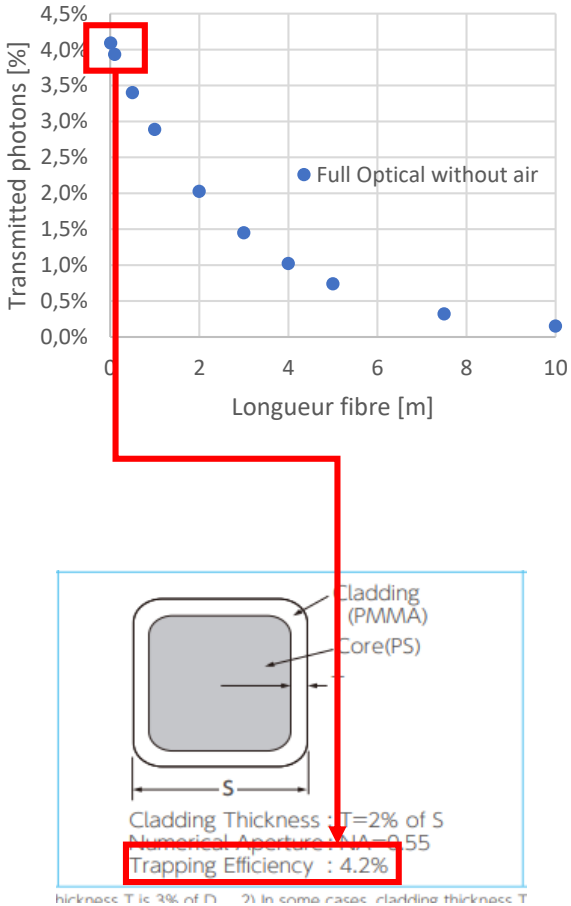
Round single cladding



Round multi-cladding

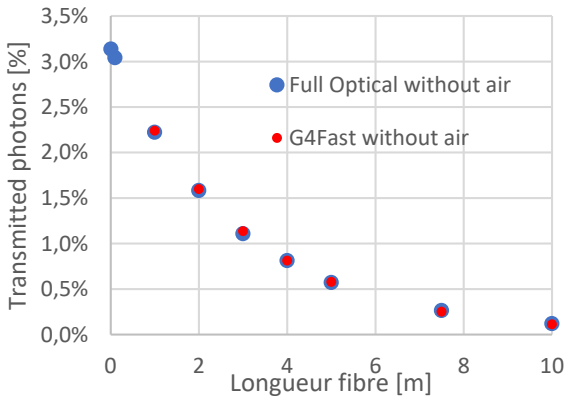


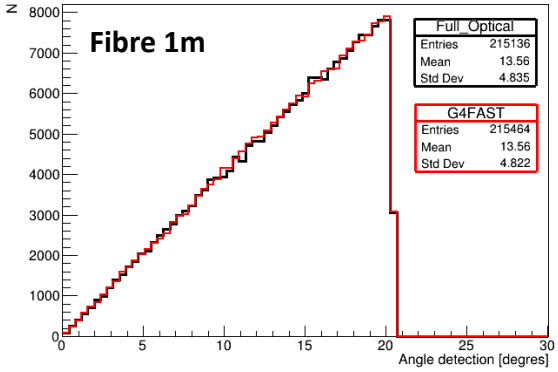
Square single cladding



Simulation tools-Fibers

Round single cladding

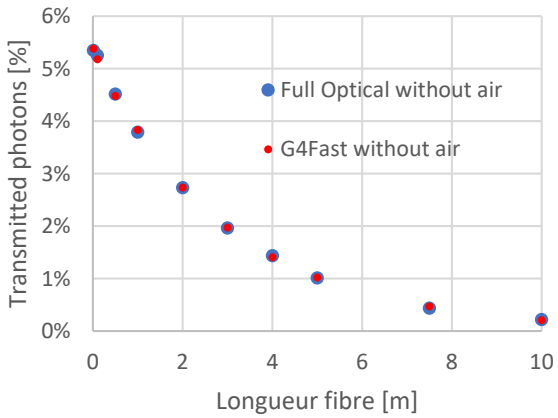


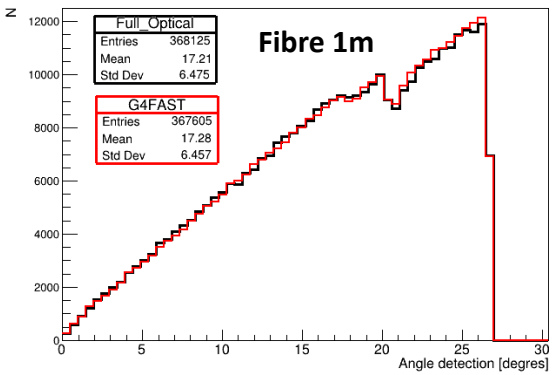


Full Optical : 358 events/s

G4FAST : 735 events/s

Round multi-cladding

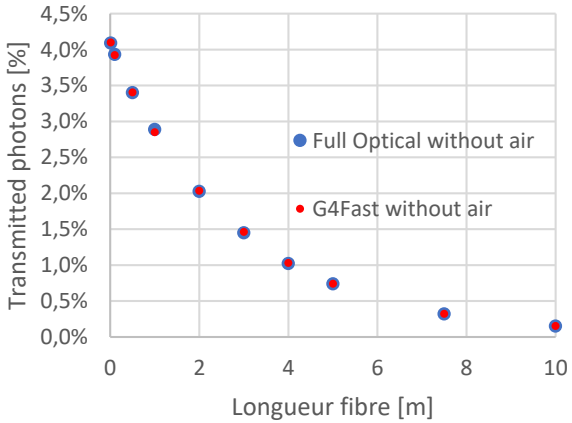


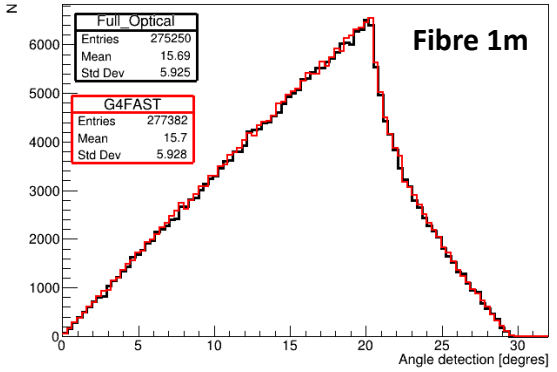


Full Optical : 145 events/s

G4FAST : 602 events/s

Square single cladding



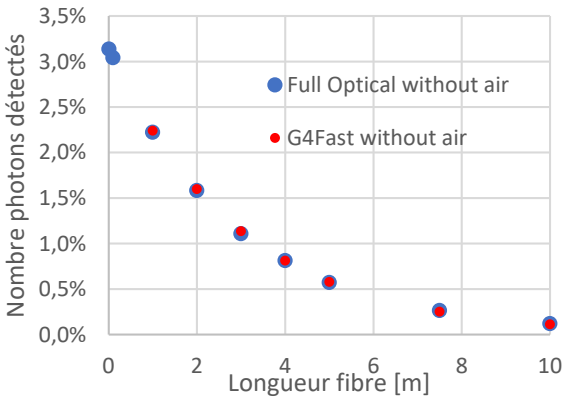


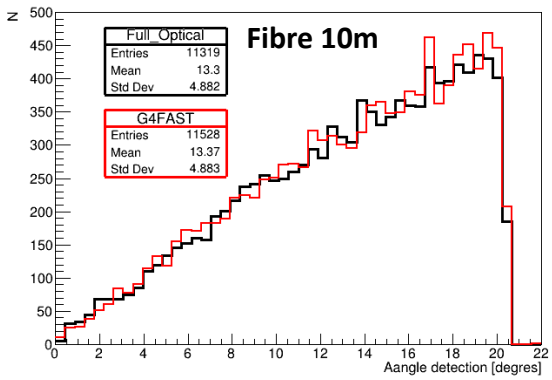
Full Optical : 244 events/s

G4FAST : 781 events/s

Simulation tools-Fibers

Round single cladding

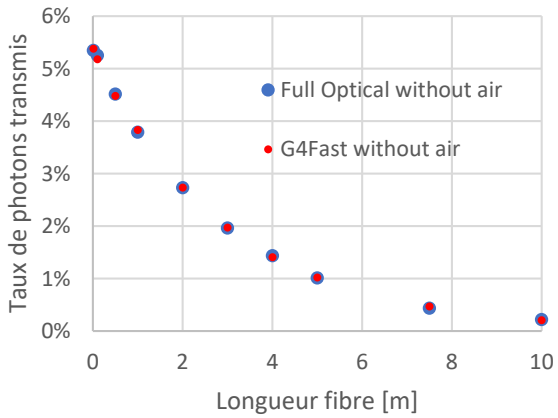


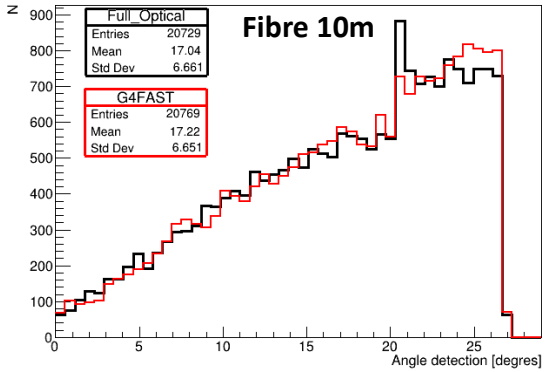


Full Optical : 78 events/s

G4FAST : 730 events/s

Round multi-cladding

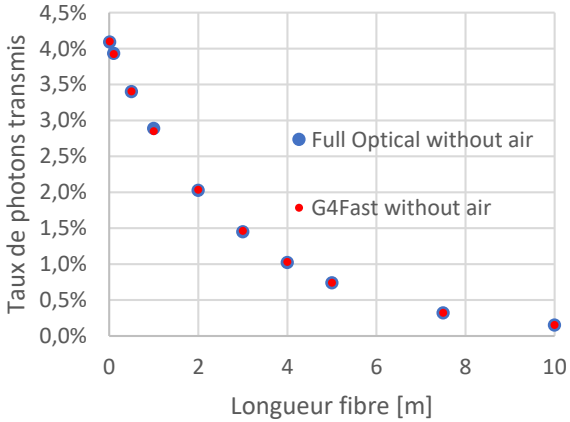


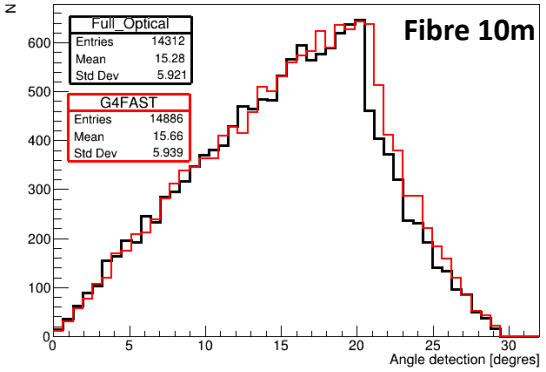


Full Optical : 48 events/s

G4FAST : 549 events/s

Square single cladding



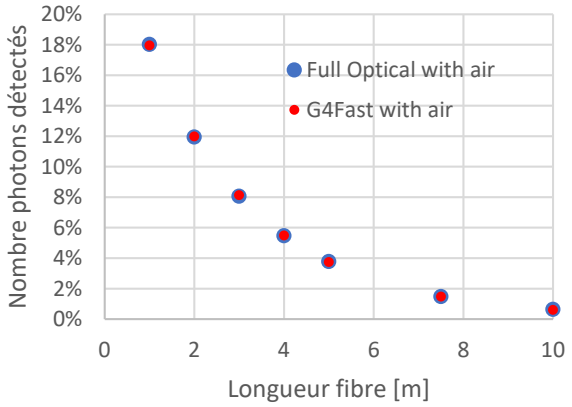


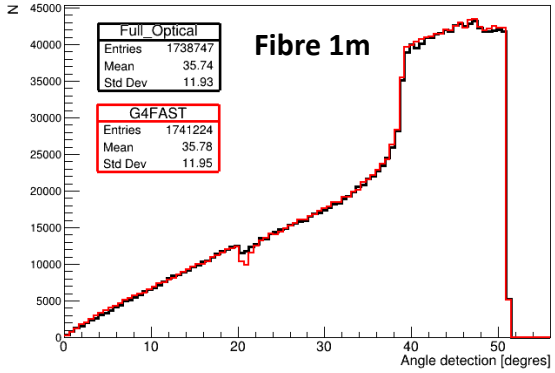
Full Optical : 93 events/s

G4FAST : 840 events/s

Simulation tools-Fibers

Round single cladding

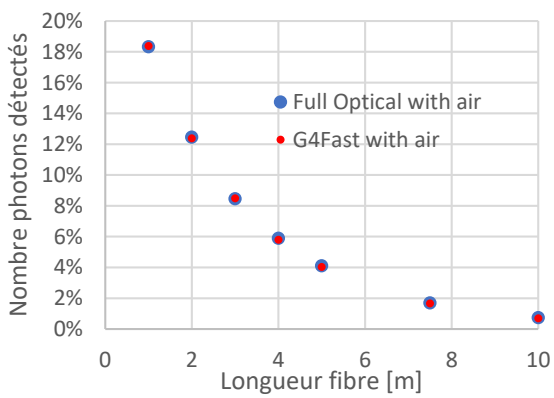


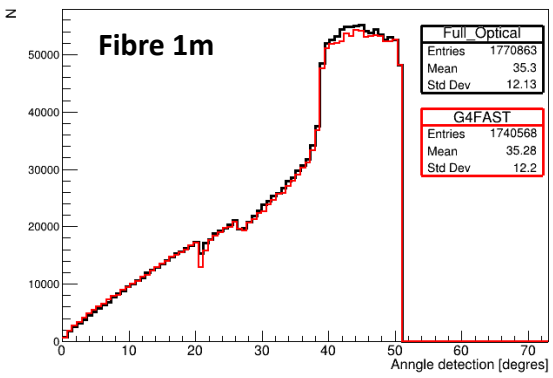


Full Optical : 12 events/s

G4FAST : 111 events/s

Round multi-cladding

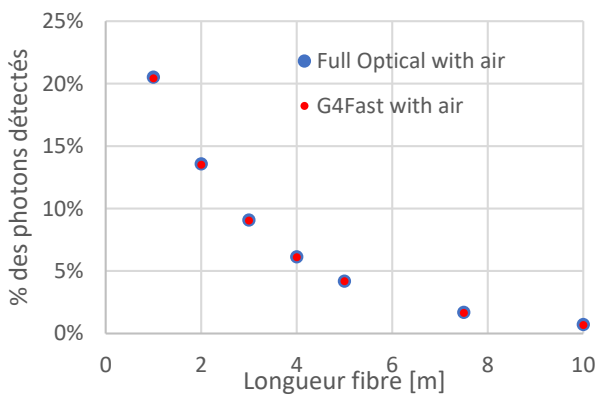


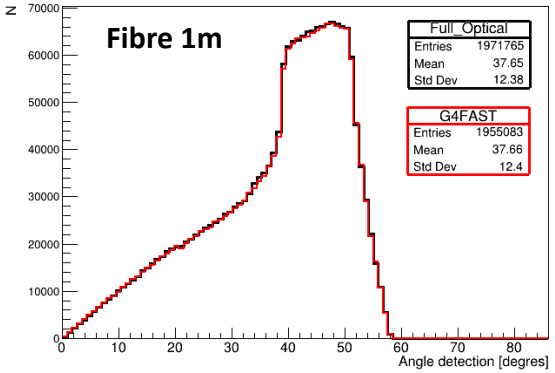


Full Optical : 8 events/s

G4FAST : 75 events/s

Square single cladding



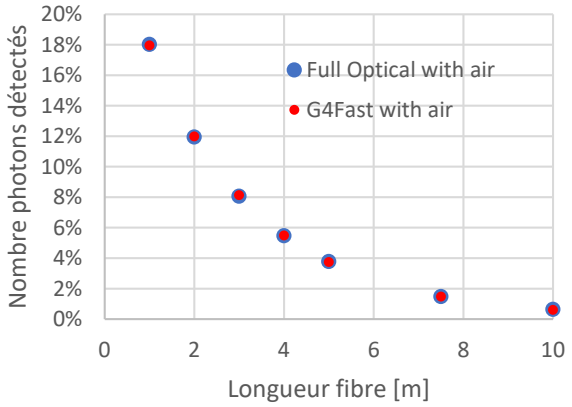


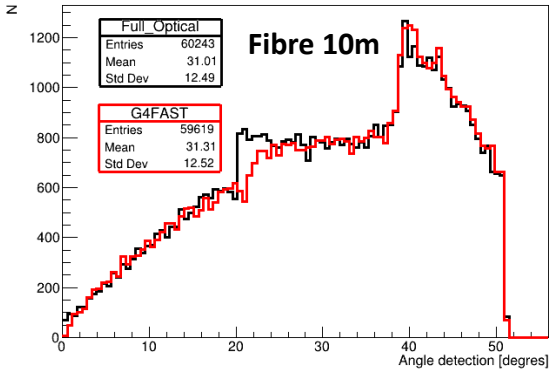
Full Optical : 8 events/s

G4FAST : 22 events/s

Simulation tools-Fibers

Round single cladding

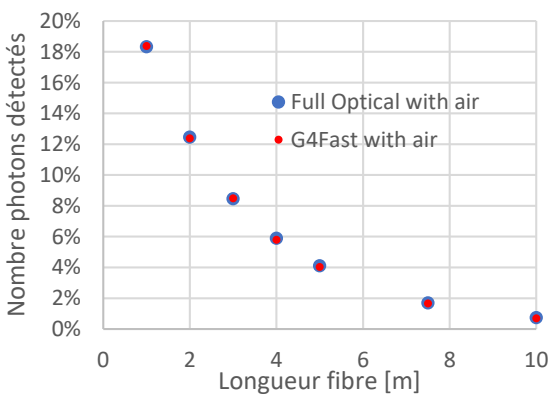


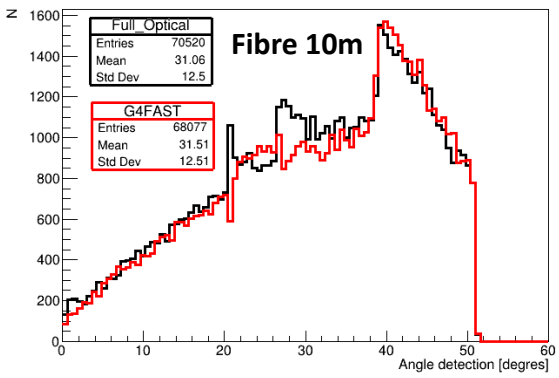


Full Optical : 4 events/s

G4FAST : 48 events/s

Round multi-cladding

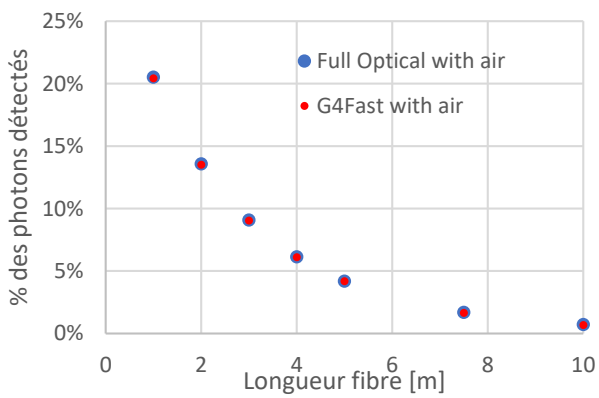


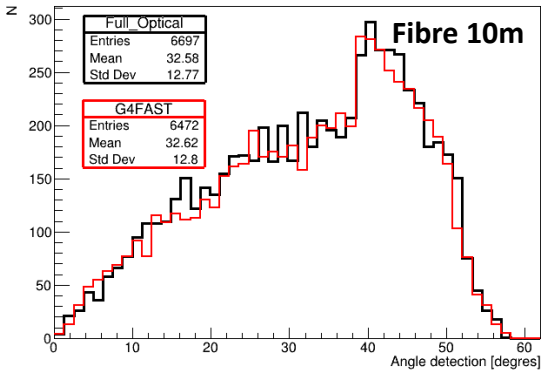


Full Optical : 3 events/s

G4FAST : 32 events/s

Square single cladding





Full Optical : 3 events/s

G4FAST : 10 events/s