First look at the angular distributions at the photosensor plane of ND-GAr

Continuation from 21/04/22

https://indico.fnal.gov/event/54203/contributions/239655/attachments/154287/200407/angular_distribution.pdf

Goal

Optimize the TPC design to maximize the light collection at the photosensor plane.

- Study the effect of different reflectors
- Characterize the angular distributions, to consider the use of light concentrators (e.g. Winston cones) and reduce the area covered by SiPM (therefore reducing also the optical noise and cost).

What was already presented

- GEANT4 framework
- Collection efficiency vs. source position w/o reflective drift wall
    - ➢ decays with z_{source} , as solid angle decreases. For R_{wall} = 95% decay is flatter, and up to 40% more light is collected, due to contribution from reflected light
    - ➢ constant with R_{source} within few %

- Angular distribution at the photosensor plane for point-like source
    - <u>direct light</u>: analytical expressions derived for $\theta(z_{source}, R_{source}, R_{cath})$
    - <u>reflected light</u>:
        - ➢ only photons with large incident angles collected at center of photosensor
        - ➢ explore the idea of implementing a reflective anode to enhance light collection
        - ➢ explore the idea of using ESR (instead of Teflon) and the impact of specular reflection

- Angular distribution at the photosensor plane for disks at different z_{source}
    - ➢ ~1/2 of the solid angle is filled for large z_{source} values (~ isotropic for small z_{source})
      → could a light concentrator be used to reduce the area covered by SiPM?
    - ➢ similar angular distributions with R_{cath} → identical light collector for the full readout plane
    - ➢ evaluate the impact of a Winston cone as light collector

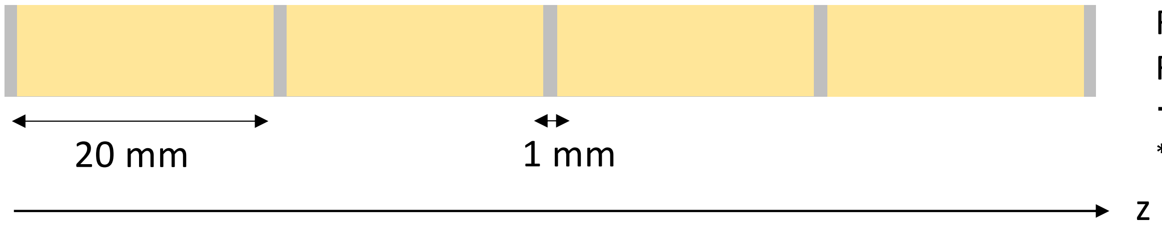
Overview

- Compare reflectors (ESR vs. Teflon) and include field cage effect
- Include aluminized GEM at the anode
  - Collection efficiency with effect from field cage and aluminized GEM at the anode
  - Angular distribution with effect from field cage and aluminized GEM at the anode

- First considerations on the use of a light collector: Winston Cones

Compare reflectors and include field cage effect

Geometry 1: teflon reflector + aluminum field shapers

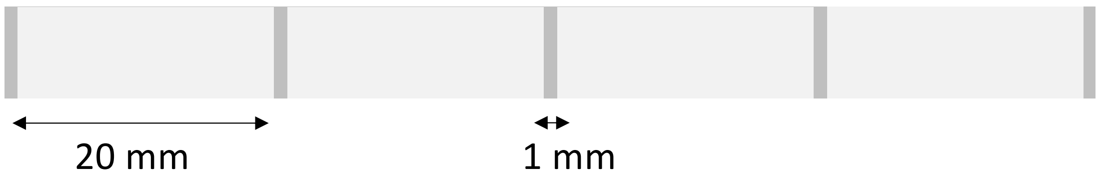


Occupancy of field shapers in wall = 5%
with the assumed lengths → 238 field shapers along TPC

R_{Al} = 85% (diffuse) [1]
R_{tef} = 95% (diffuse) [2, 3]
→ effective* reflectivity: R_{wall} = 94.5% (diffuse)
*consider homogeneous material in simulation, for simplicity

Reminder: λ = 650 nm (peak emission CF_4)

Geometry 2: Enhanced Specular Reflector film (ESR) + aluminum field shapers



R_{Al} = 85% (diffuse) [1]
R_{ESR} = 98% (specular) [4, 5]
→ effective reflectivity: R_{wall} = 97.3% (specular)

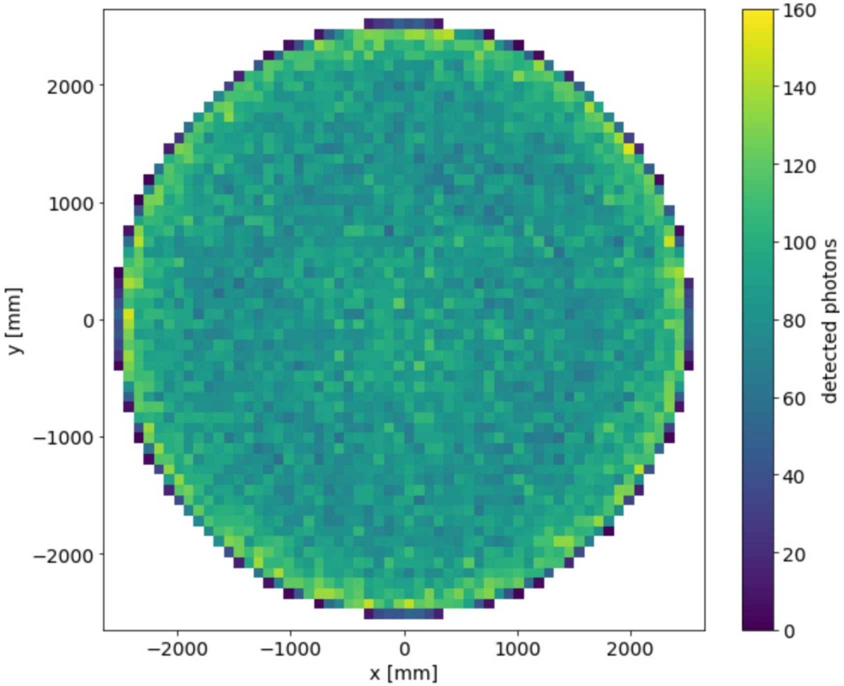
Other elements that may affect the effective reflectivity could be considered as well (e.g. gas tubes, laser calibration system), with present estimates ~3% of the field-cage area

[1] V. Pozzobon et al. / Biotechnology Reports 25 (2020) e00399
[2] C. Silva *et al*. "Reflectance of Polytetrafluoroethylene (PTFE) for Xenon Scintillation Light", *J. Appl. Phys.* 107 (2010) 064902
[3] S. Ghosh *et al.* "Dependence of polytetrafluoroethylene reflectance on thickness at visible and ultraviolet wavelengths in air", arXiv:2007.06626v1
[4] https://www.digikey.com/en/pdf/3/3m/3m-vikuiti-enhanced-specular-reflector-esr
[5] https://resources.perkinelmer.com/lab-solutions/resources/docs/FAR_Measurement-of-Enhanced-Specular-Reflector-Films-Using-LAMBDA-1050-and-URA-Accessory-012190_01.pdf

Compare reflectors: light distribution at photosensor plane

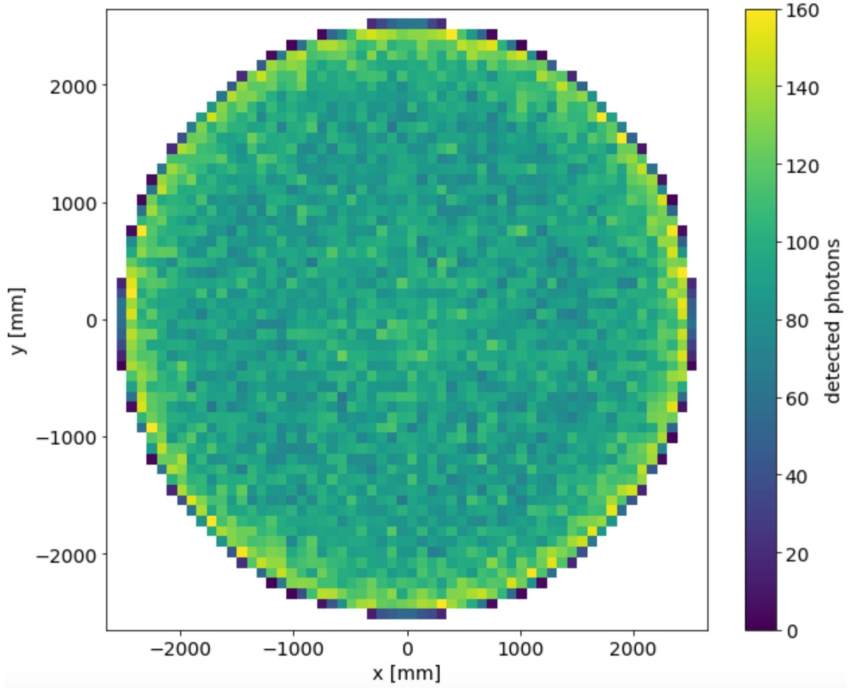
Evaluation of pattern formation in the photosensor plane (a possibility mentioned during last meeting)

5×10^5 photons launched from point-like source at (z_{source}, R_{source} = 2500, 0)



Geometry 1: teflon reflector + aluminum field shapers

R_{wall} = 94.5% (diffuse)



Geometry 2: ESR+ aluminum field shapers

R_{wall} = 97.3% (specular)

Include aluminized GEM at the anode

GEM design from ALICE [6-8]

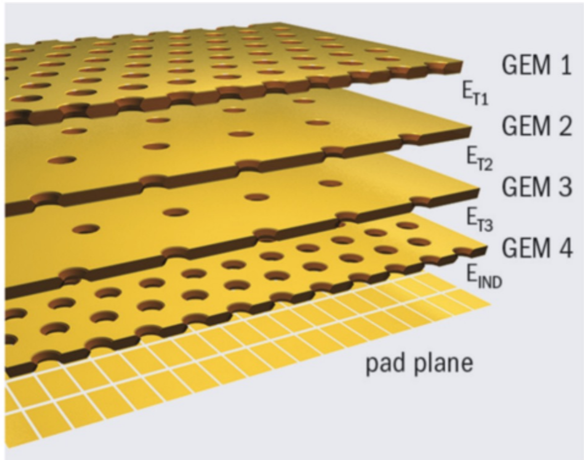
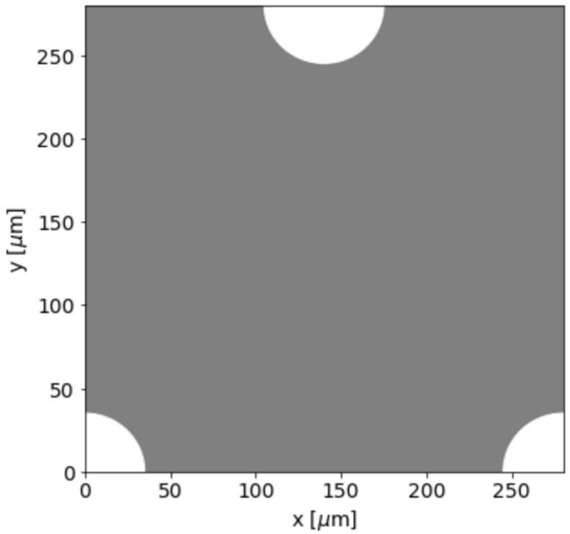


Fig.1: Schematic view of a stack of four large-size GEM foils as employed for the upgrade of the ALICE TPC

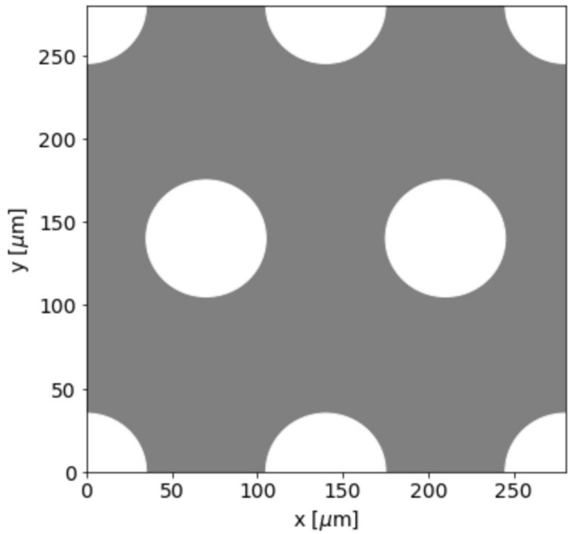
large-pitch GEM



Hole diameter = 70 μm
Hole pitch = 280 μm

→ Hole occupancy = 4.9% of total area
→ effective reflectivity of the anode plane: R_{anode} = 80.8% (diffuse)

standard-pitch GEM



Hole diameter = 70 μm
Hole pitch = 140 μm

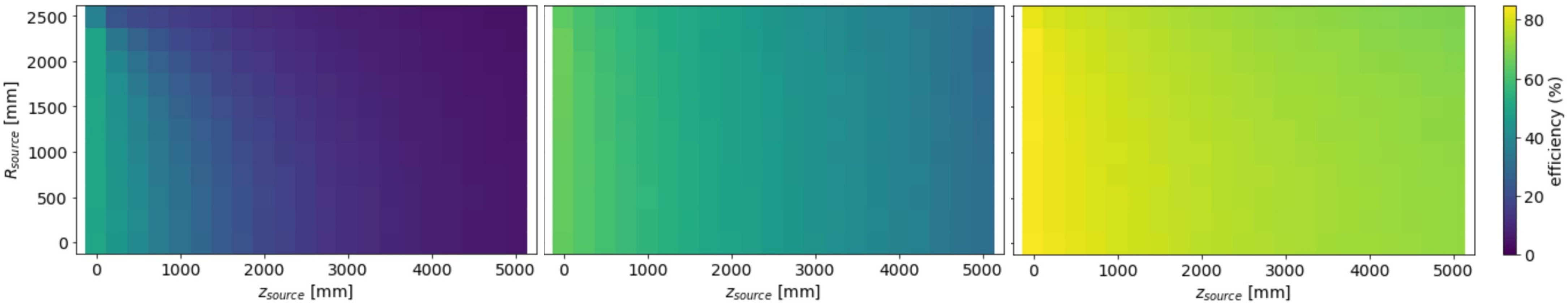
→ Hole occupancy = 19.6% of total area
→ effective reflectivity of the anode plane: R_{anode} = 68.3% (diffuse)

Assume aluminum electrode (R_{Al} = 85%, diffuse):

[6] https://indico.cern.ch/event/676702/contributions/2817159/
[7] https://www.ph.nat.tum.de/denseandstrange/research/current-projects/gem-tpc-upgrade-project-at-alice/
[8] https://arxiv.org/pdf/2012.09518.pdf

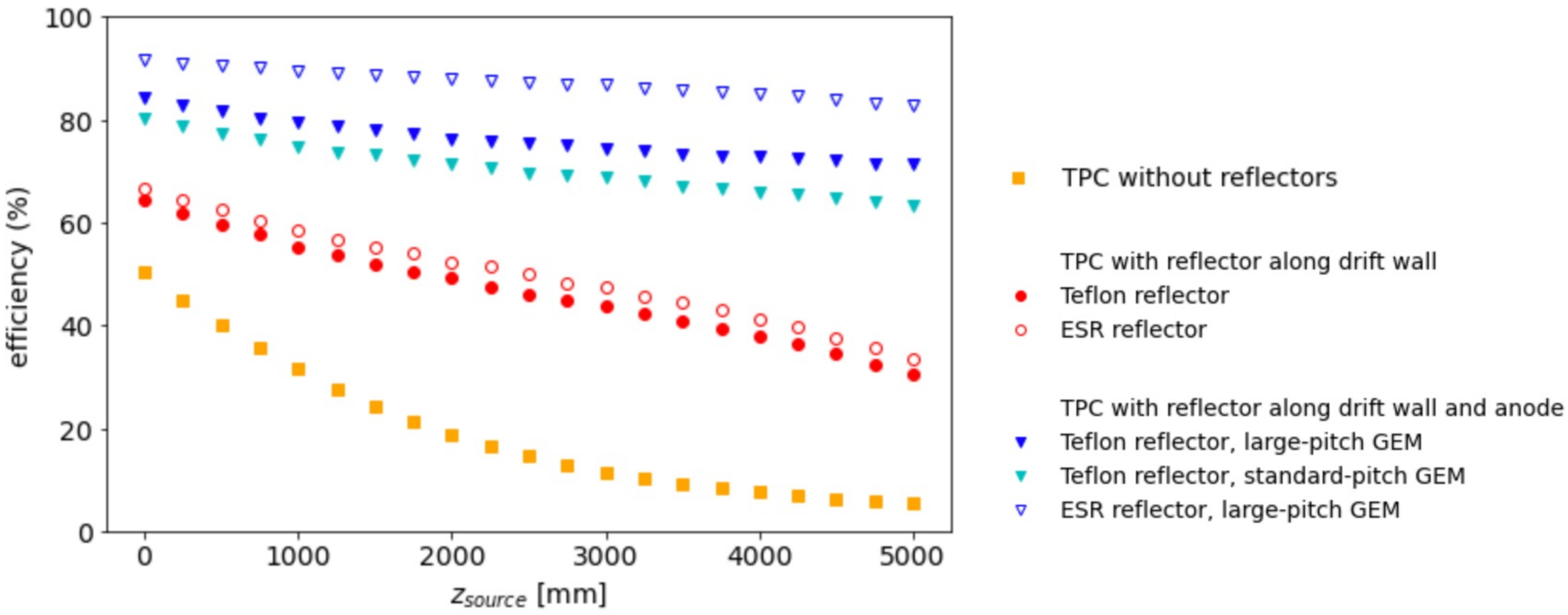
Collection efficiency with effect from field cage and aluminized GEM at the anode

TPC without reflectors | covering drift wall with Teflon | + covering anode GEM with aluminum



R_{wall} = 0%, R_{anode} = 0% | R_{wall} = 94.5%, R_{anode} = 0% | R_{wall} = 94.5%, R_{anode} = 80.8%

Collection efficiency with effect from field cage and aluminized GEM at the anode



Observations:

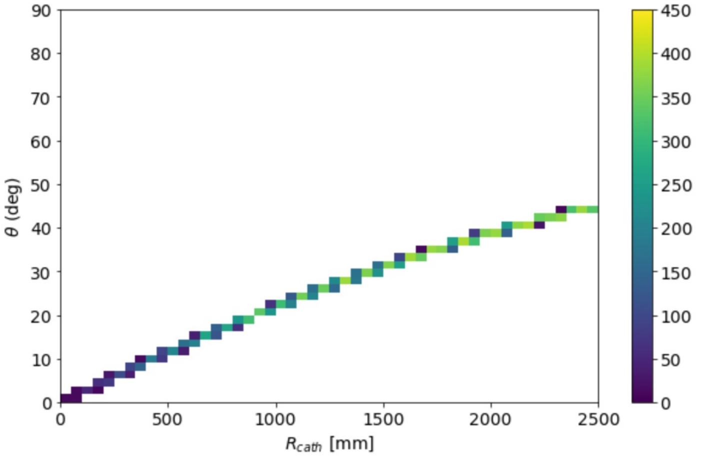
- Collection efficiency decays with z_{source} , as solid angle decreases
- The decay is flatter the larger the contribution of reflected light

Angular distribution with teflon-based field cage and aluminized GEM at the anode

Example for point-like source at $(z_{source}, R_{source}) = (2500,0)$

TPC without reflectors

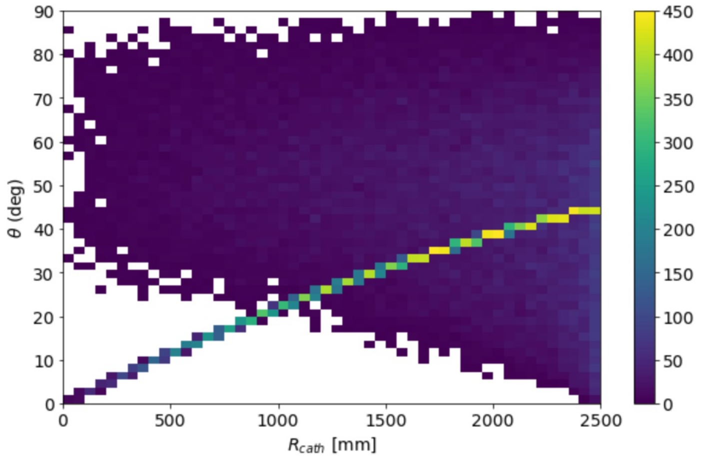
$R_{wall} = 0\%$, $R_{anode} = 0\%$



Only direct light reaches the photosensor plane, there is no reflected light

cover drift wall with Teflon

$R_{wall} = 94.5\%$, $R_{anode} = 0\%$



Direct light

+

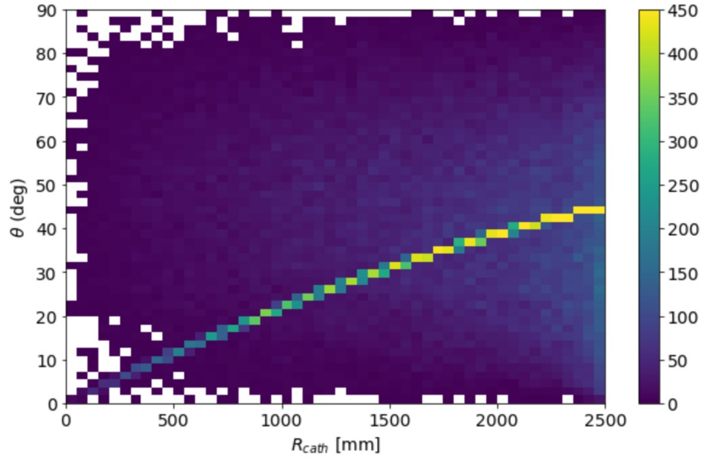
Reflected light on top-right region

→ for large R_{cath} (i.e. closer to reflective surface of drift wall) all incident angles are possible

→ for small R_{cath} mainly large incident angles

+ include aluminized GEM

$R_{wall} = 94.5\%$, $R_{anode} = 80.8\%$



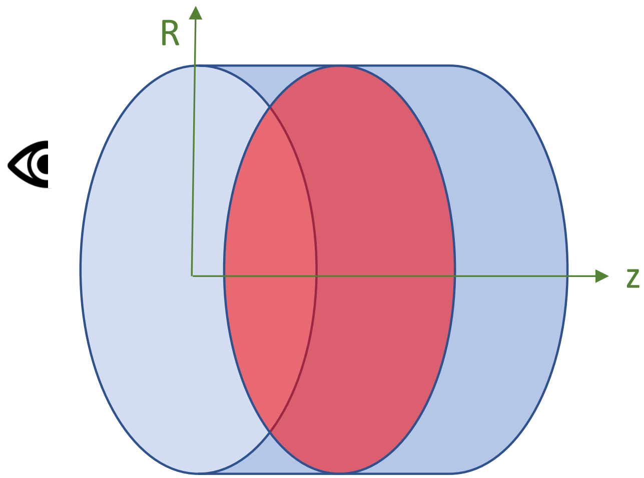
Direct light

+

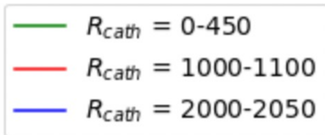
Reflected light extends to bottom-left region → photons reflected at anode can reach central areas of the photosensor plane perpendicular to it (i.e. with small incident angles)

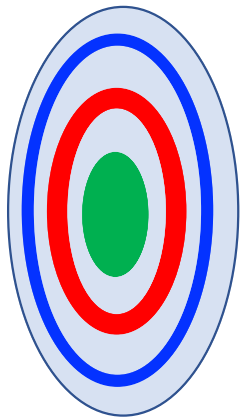
Angular distribution at the photosensor plane

As we had previously seen that for a given z_{source} the collection efficiency with R_{source} is constant within few % and the angular distribution of the reflected light is similar for all source points → we study a source distributed homogeneously over a disk for different z positions



Use cathode areas of same area to compare total number of incident photons

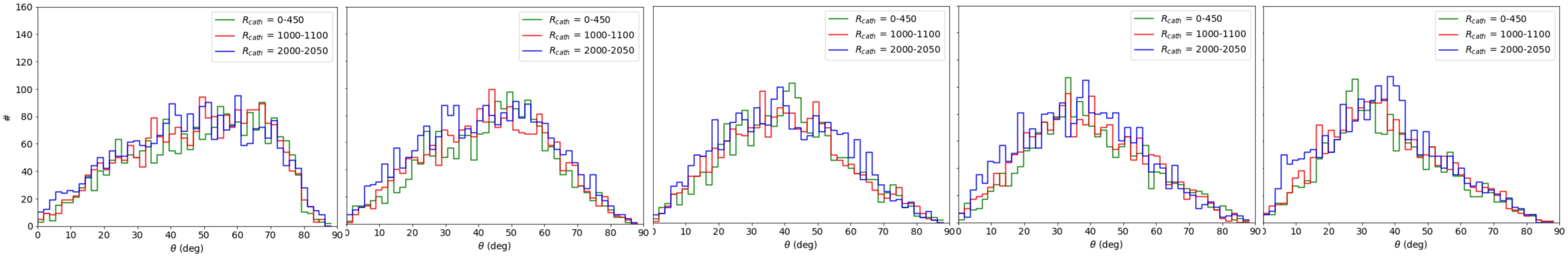




For R_{wall} = 94.5% and R_{anode} = 80.8%

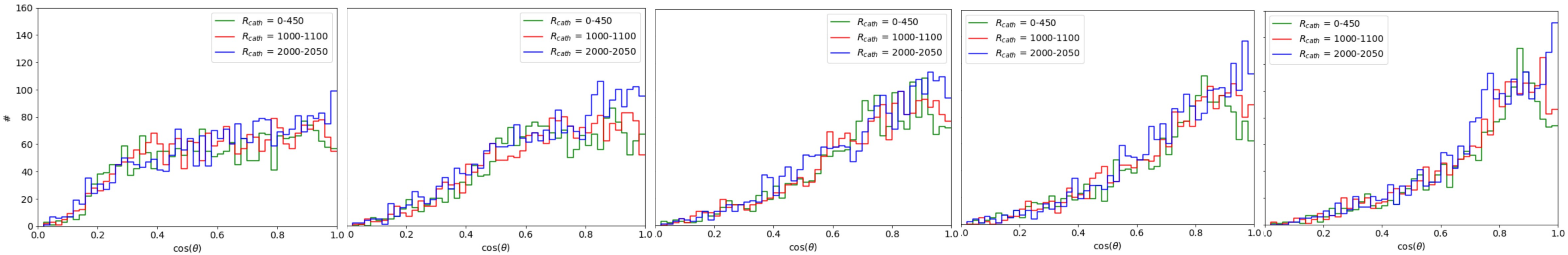
Distribution in θ

z_{source} = 500 z_{source} = 1500 z_{source} = 2500 z_{source} = 3500 z_{source} = 4500



Distribution in cos(θ)

z_{source} = 500 z_{source} = 1500 z_{source} = 2500 z_{source} = 3500 z_{source} = 4500



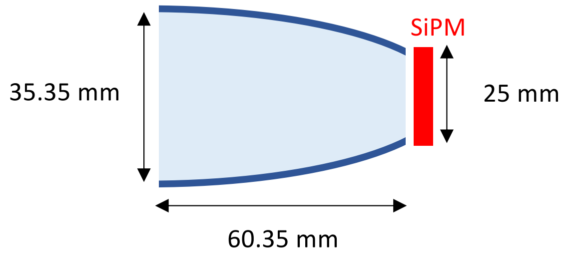
First considerations on the use of a light collector: Winston Cones

Winston cones (a.k.a. compound parabolic concentrator) is a non-imaging light collector consisting of a truncated parabolic reflector

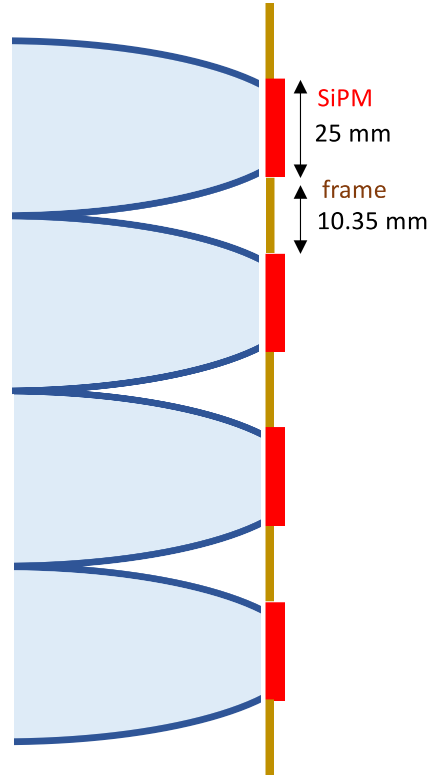
Possible specifications:

Spectral range	550 – 750 nm	CF_4 emission peak at 650 nm
Geometry	empty shell	coating with specular reflectivity > 90%
	crystal	largest optical transmission possible
Exit area	25 x 25 mm (square)	defined by SiPM area
Entrance area	35.35 x 35.35 mm (square?)	to have a concentration factor C = entrance area/exit area = 2
Cut-off angle (θ_c)	45°	$\sin(\theta_c)$ = exit side/entrance side
Length (L)	60.35 mm	L = (exit side + entrance side)/$\tan(\theta_c)$

Scheme of a cone (side view, not to scale)



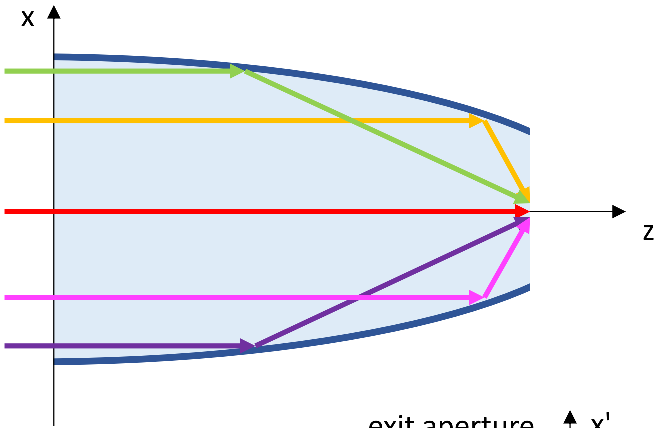
Scheme of cone arrangement (side view, not to scale)



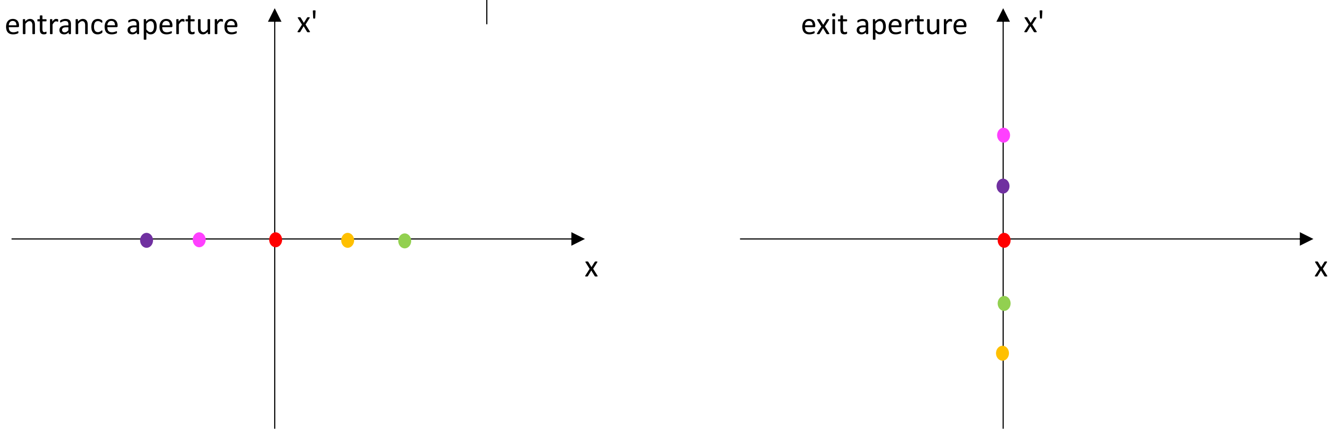
Liouville theorem

Conservation of the phase-space area (x, x’), (y, y’) at entrance and exit aperture of Winston cone

The simplest example:

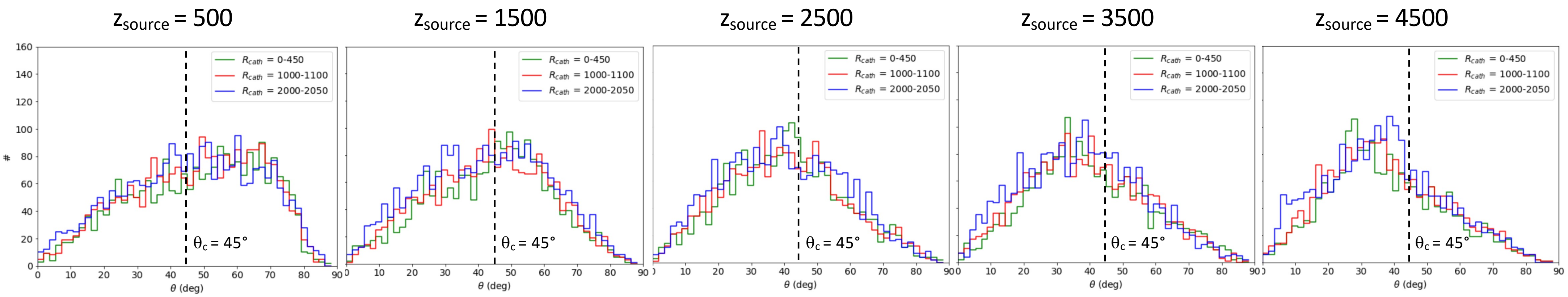


However, an accurate simulation (e.g. using Zemax), including real geometry (materials, paraboloid with square section?) and optical aberrations should eventually be done

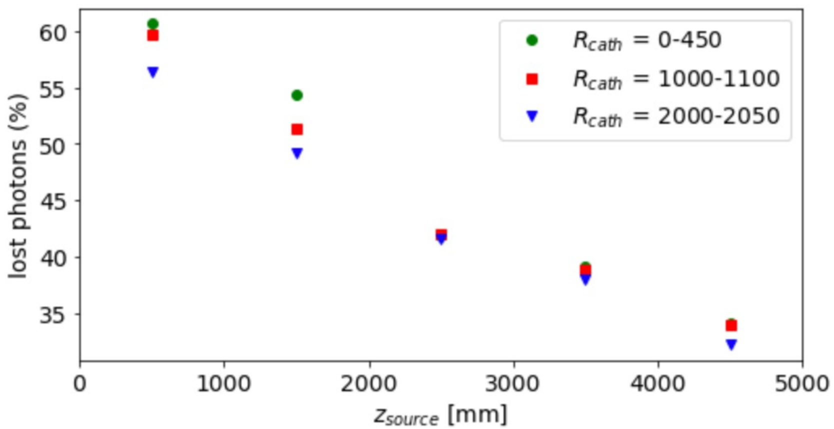


Light collection using Winston Cones

Distribution in θ, for R_{wall} = 95% and R_{anode} = 80.8%



photons collected by Winston cones only when $\theta < \theta_c$



~60% losses close to the cathode is probably a loss we cannot afford… not promising solution so far…

Extra slides

Compare reflectors: light distribution at photosensor plane

Light generated from source isotropically
Any point at cathode can be reached from direct and reflected photons
No inner structure implemented that could collimate light

Surface reflectivity implemented as specular spike in GEANT4

--> No pattern formation observed …