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

Goal

Characterization of the angular distributions at the photosensor plane of the ND-GAr TPC, to consider the use of light concentrators (e.g. Winston cones) to maximize the collection efficiency while reducing the area covered by SiPM (therefore reducing also the optical noise).

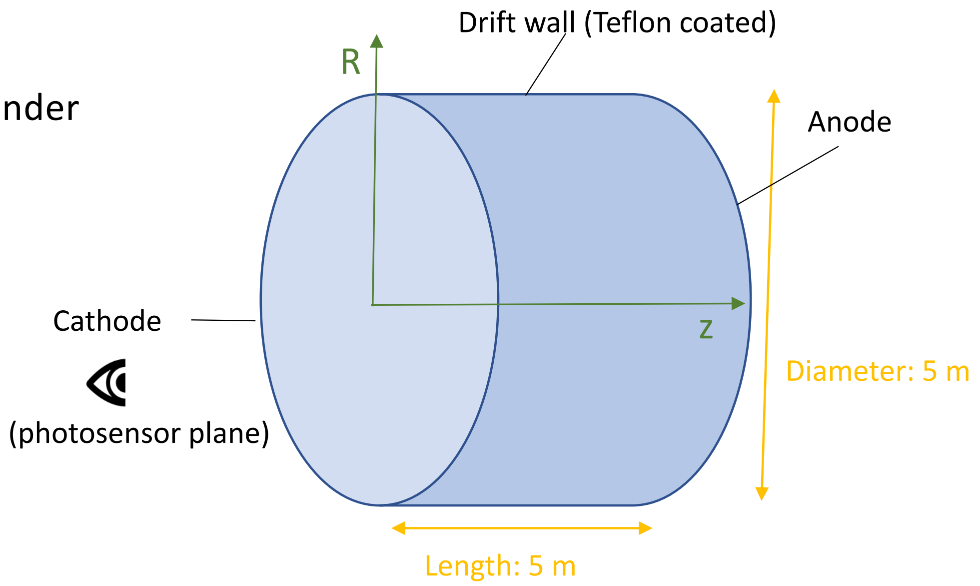
Outlook

- GEANT4 framework
- Collection efficiency vs source position
- Angular distribution at the photosensor plane vs source position

GEANT4 framework

Geometry: plain cylinder

Ar/CF4(99/1)
P = 10 bar
T = 298 K



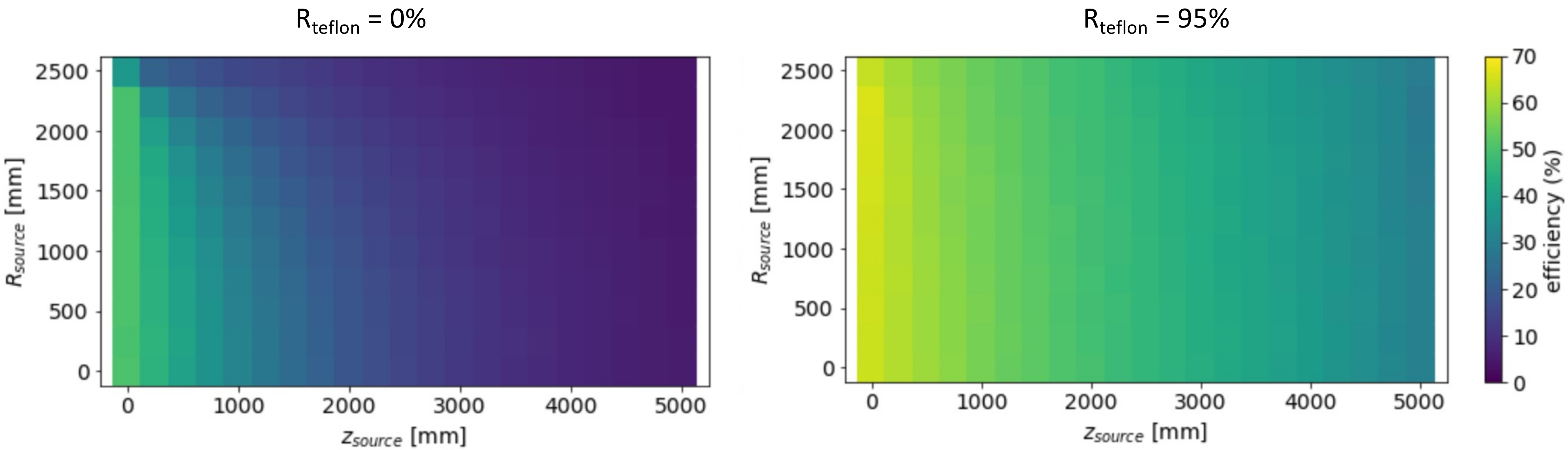
Reflectivities:

- R_{anode} = 0%
- $R_{cathode}$ = 0%
- R_{teflon} @650 nm = 95%

(only diffuse component)

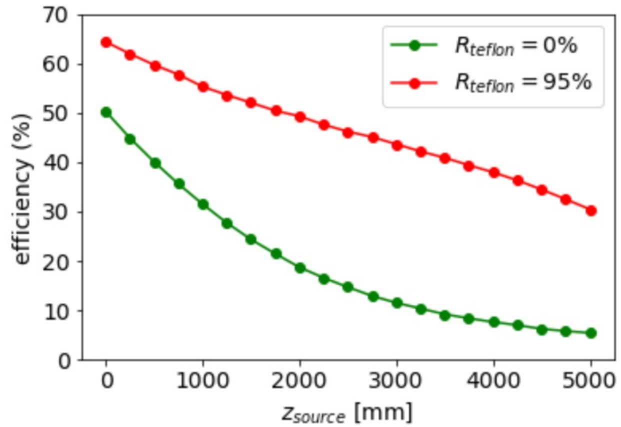
Primary particles: optical photons (interact with surface materials)
λ = 650 nm (CF4 emission)
isotropic emission

Collection efficiency as a function of source position (z_{source}, R_{source})



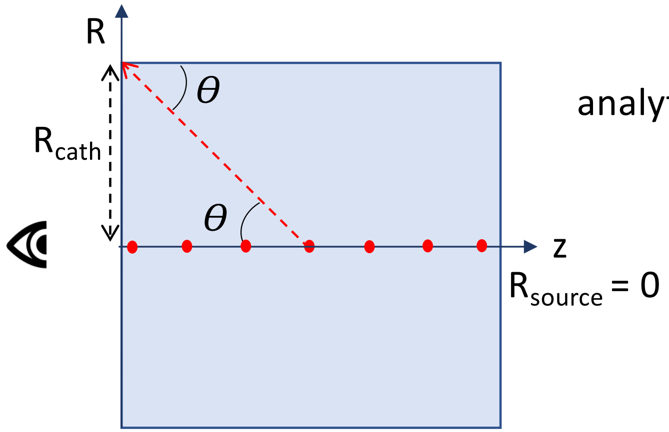
Observations:

- For R_{teflon} = 0% only direct light is collected while for R_{teflon} = 95% direct + reflected light is collected.
- Collection efficiency decays with z_{source} , as solid angle decreases. For R_{teflon} = 95% decay is flatter due to contribution of reflected light.
- For a given z_{source} → collection efficiency with R_{source} constant within few % (except for R_{teflon} = 0% and z_{source} < 2000 mm)



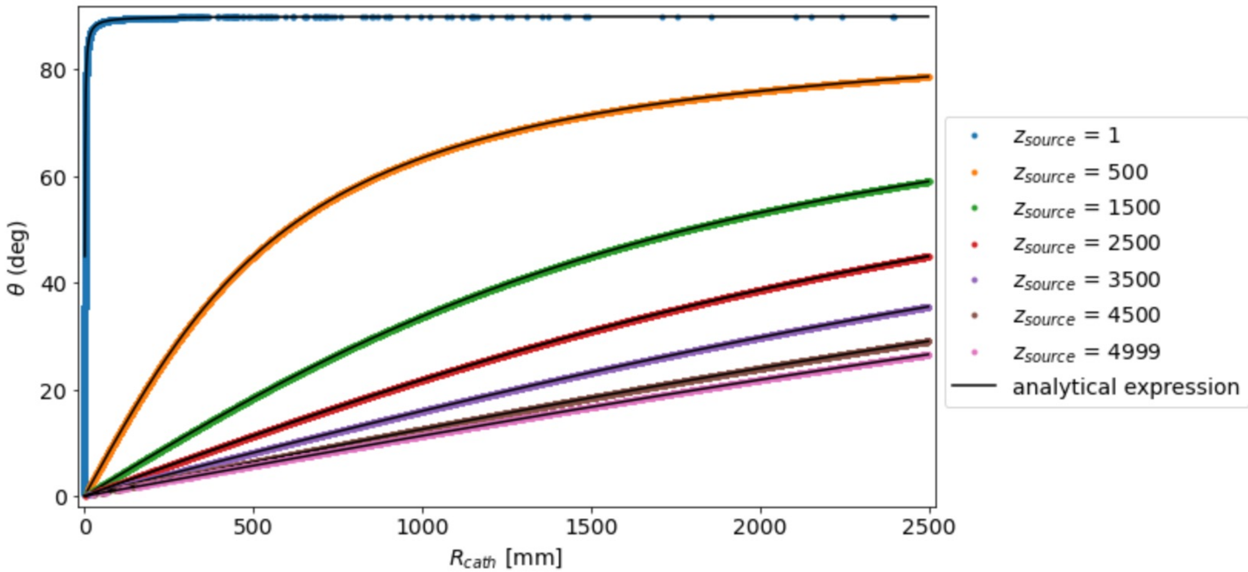
Angular distribution at the photosensor plane

Study for source positions along z
for R_{teflon} = 0%
(only direct light from source)



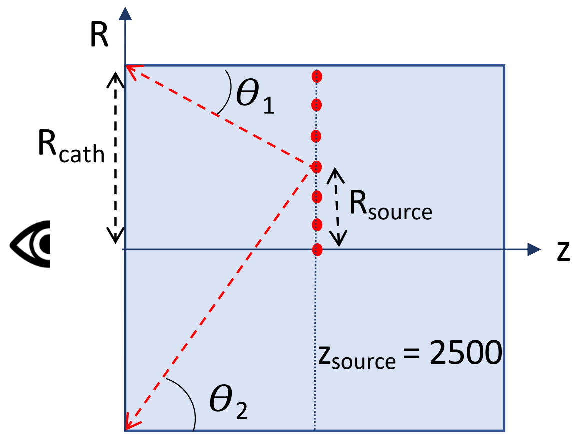
analytical expression for the incident angle

$$\theta = atan\left(\frac{R_{cath}}{z_{source}}\right)$$



Angular distribution at the photosensor plane

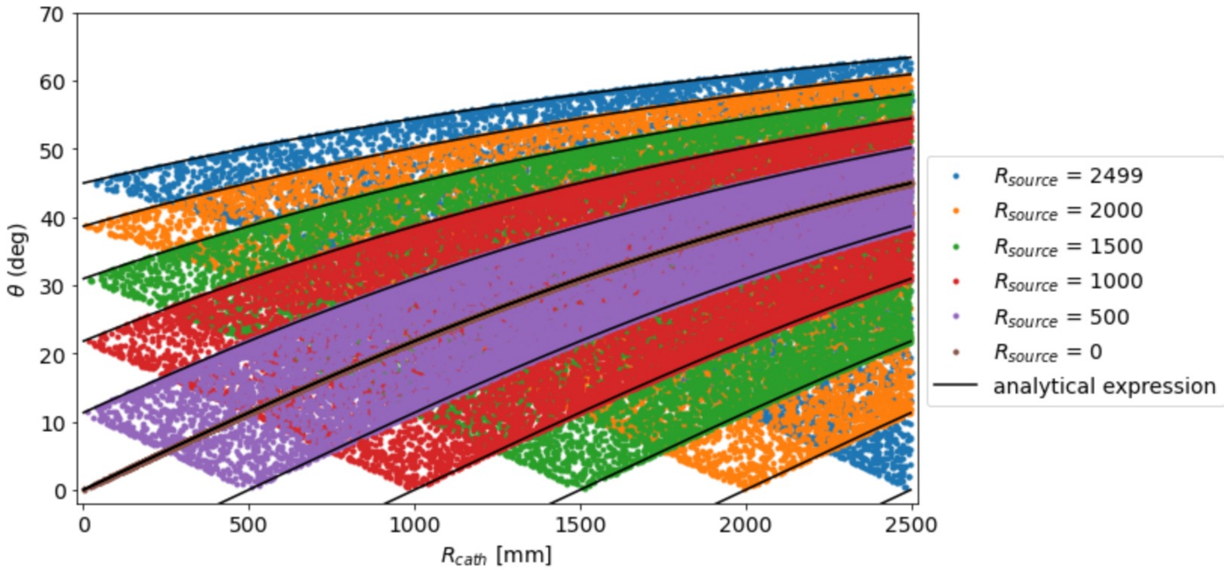
Study for source positions along R
for R_{teflon} = 0%
(only direct light from source)



analytical expression for the incident angle

$$\theta_1 = atan\left(\frac{R_{cath} - R_{source}}{z_{source}}\right)$$

$$\theta_2 = atan\left(\frac{R_{cath} + R_{source}}{z_{source}}\right)$$

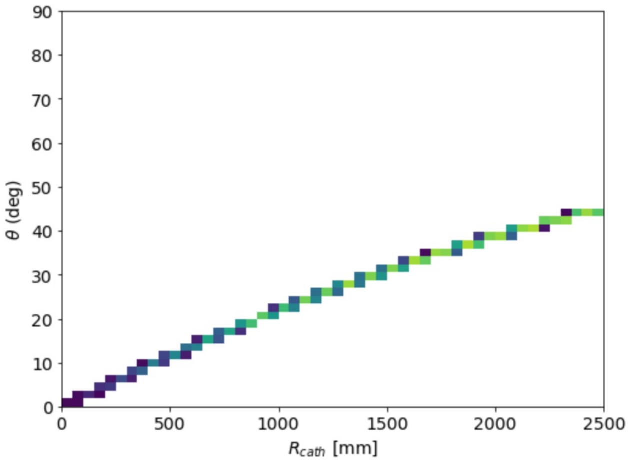


Observations:

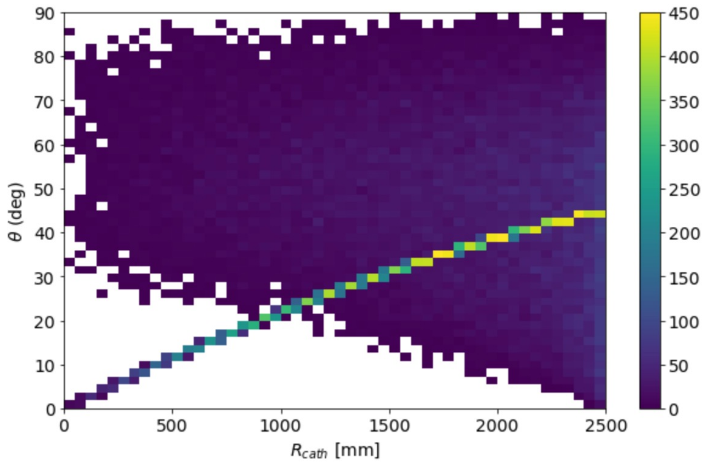
- θ = 0° only for R_{cath} = R_{source}

Angular distribution at the photosensor plane: contribution from reflected light

R_{teflon} = 0%
(only direct light from source)



R_{teflon} = 95%
(direct light from source + reflected light at drift wall)



Example for
(z_{source}, R_{source}) = (2500,0)

Observations:

- Reflected light on top-right region

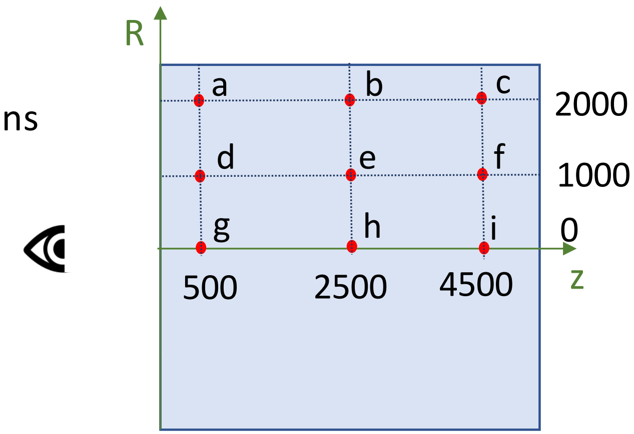
→ for large R_{cath} (i.e. closer to reflective surface of drift wall) all incident angles are possible
→ for small R_{cath} only large incident angles

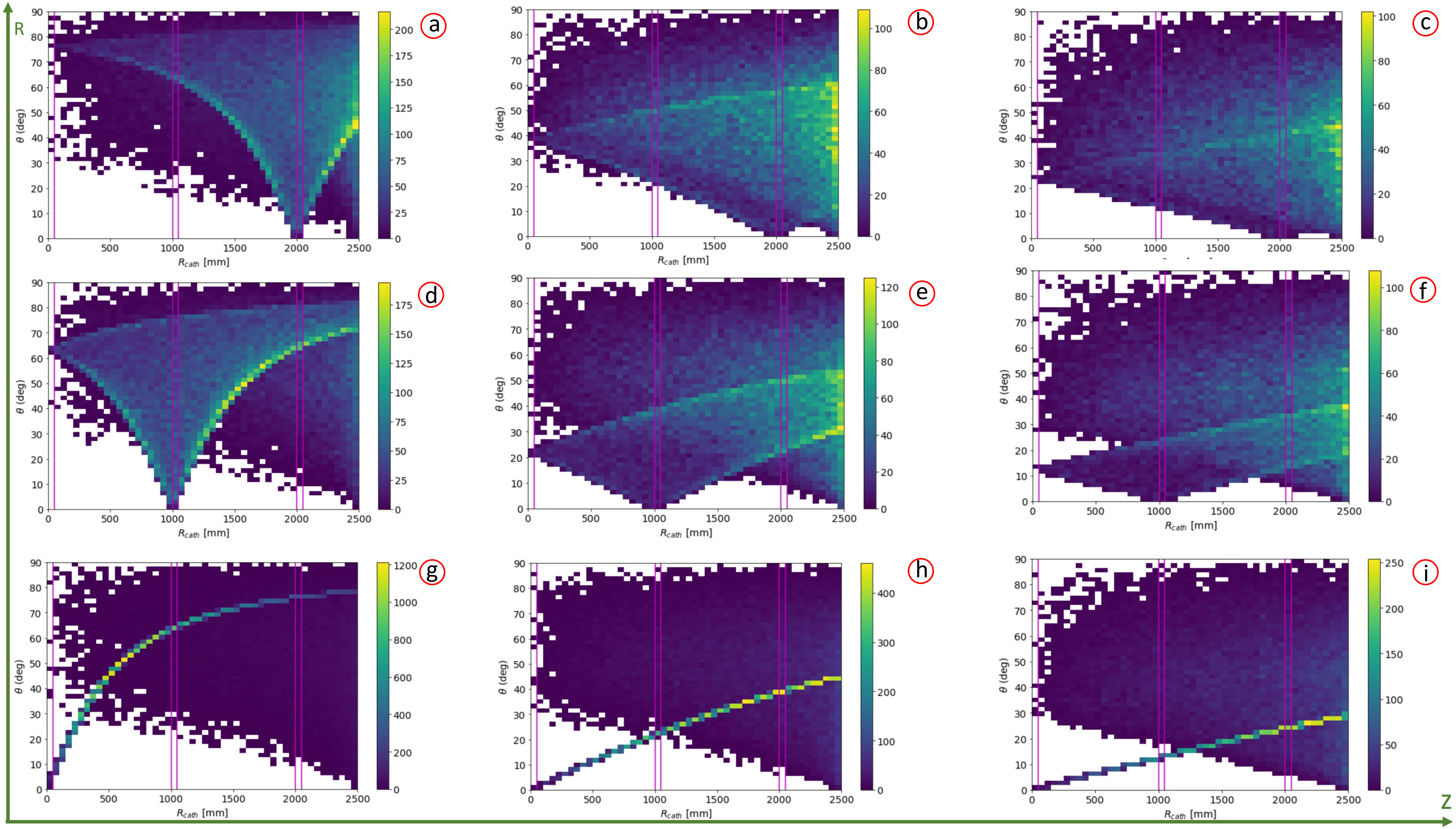
- Intuitively, if we would implement an anode with $R_{anode} \neq 0$, reflected light would extend to bottom-left region

Angular distribution at the cathode: contribution from reflected light

Study for different source positions

for R_{teflon} = 95%
(direct + reflected light)

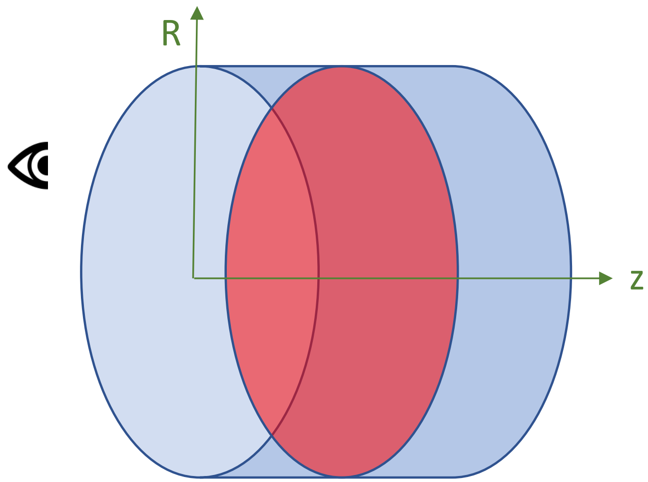




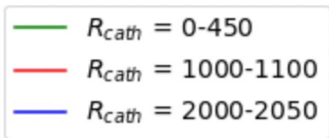
R
Z
a
b
c
d
e
f
g
h
i
θ (deg)
R_{cath} [mm]

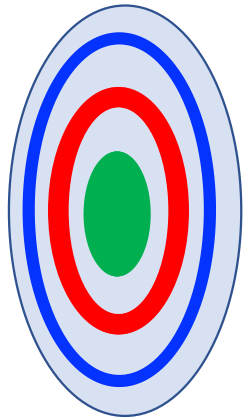
Angular distribution at the photosensor plane

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

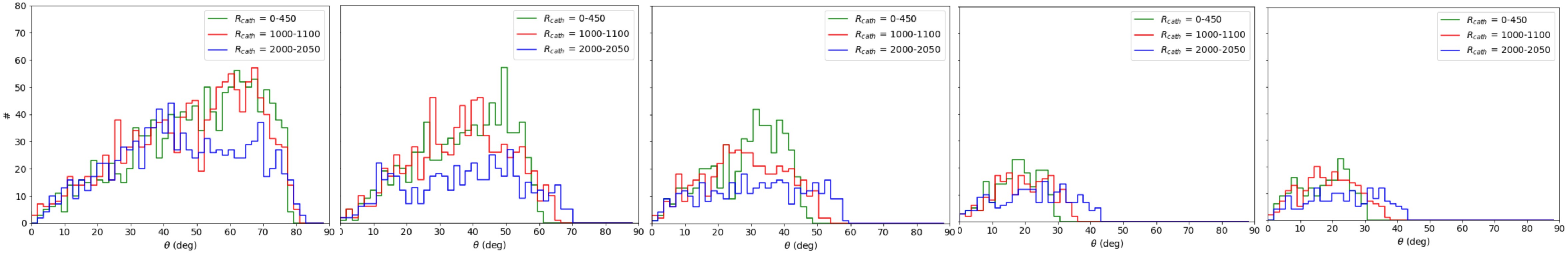




For R_{teflon} = 0% (only direct light)

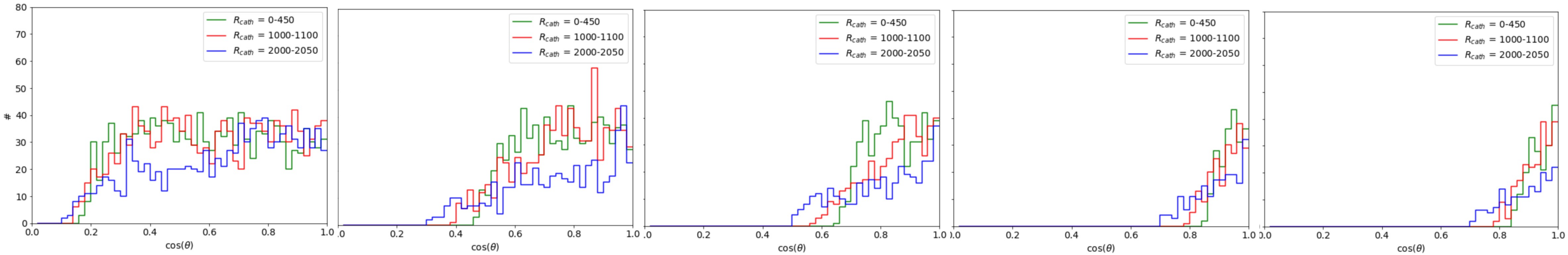
Distribution in θ

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



Distribution in cos(θ)

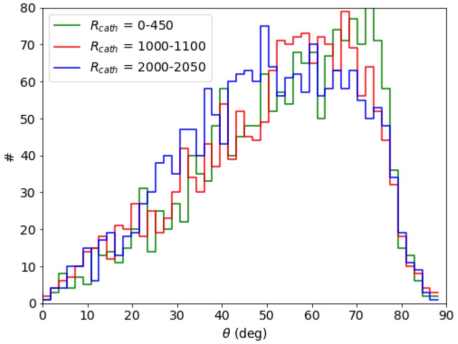
z_{source} = 500 z_{source} = 1500 z_{source} = 2500 z_{source} = 3500 z_{source} = 4500



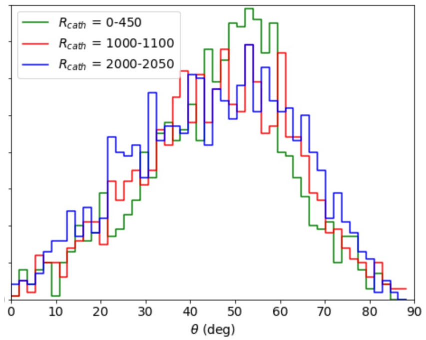
For R_{teflon} = 95% (direct + reflected light)

Distribution in θ

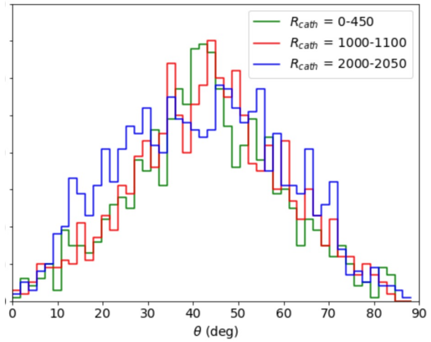
z_{source} = 500



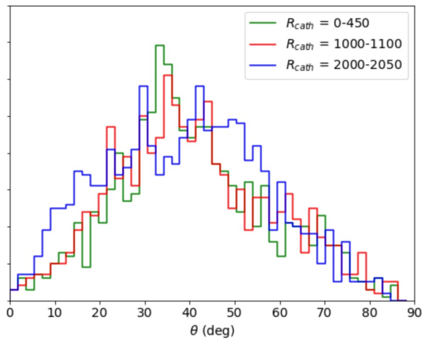
z_{source} = 1500



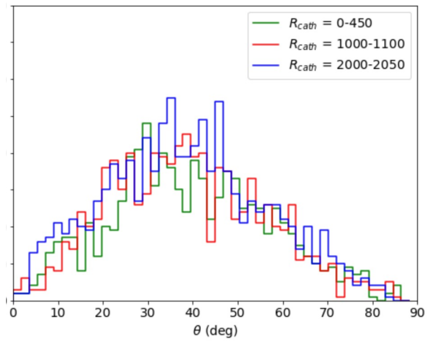
z_{source} = 2500



z_{source} = 3500

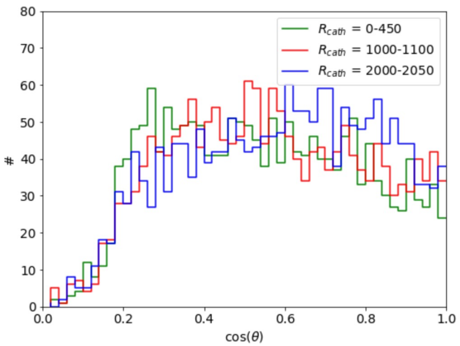


z_{source} = 4500

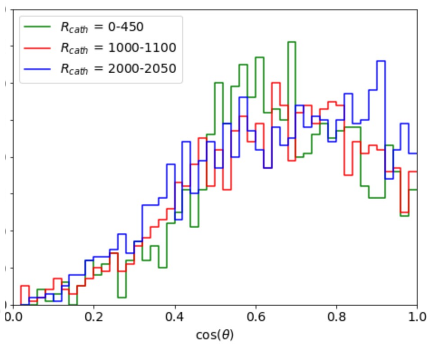


Distribution in cos(θ)

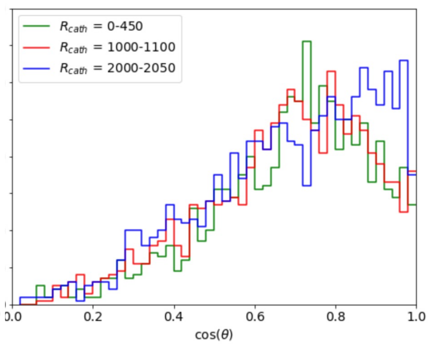
z_{source} = 500



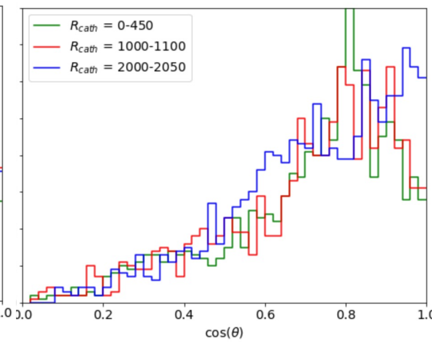
z_{source} = 1500



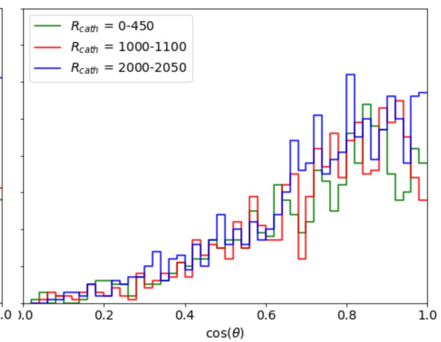
z_{source} = 2500



z_{source} = 3500



z_{source} = 4500



Observations:

- Small z_{source} values: almost homogeneous distribution in $\cos(\theta)$ → difficult to collect in Winston cones
- Large z_{source} values: narrower distribution of incident photons → a light concentrator could be used to reduce the area covered by SiPM (therefore reducing also the optical noise).

→ This (a priori intuitive) result could had been anticipated for direct light but was not obvious in the presence of reflected light. However, multiple reflections also cause a bias towards tracks close to the vertical, and the effect becomes dominant far from the cathode (where direct light is small). Only about half of the solid angle (compared to the isotropic) is filled, that gives some hope for a factor ~2 reduction of the SiPM area (if considering only Liouville theorem).

- Similar distributions with R_{cath} → Winston cones of the same geometry for the full readout plane?. Identical Fresnel lenses at the windows?.

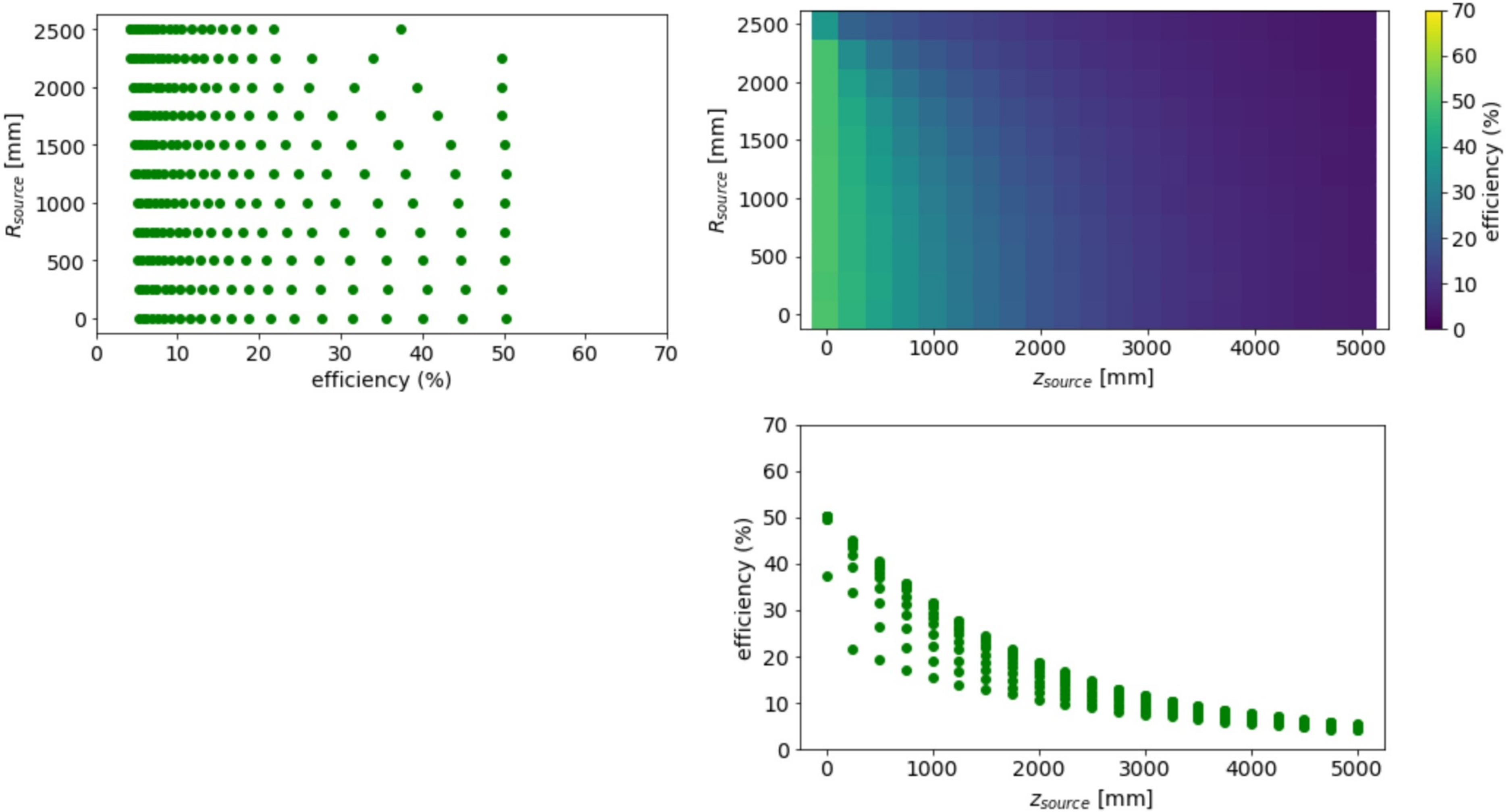
- Optimizing for far distances is interesting, as losing light for close distances is less problematic (more uniform response??).

- Next: evaluate the impact of a Winston cone with simple arguments. Consider a reflective aluminum-based GEM at the anode.

Extra slides

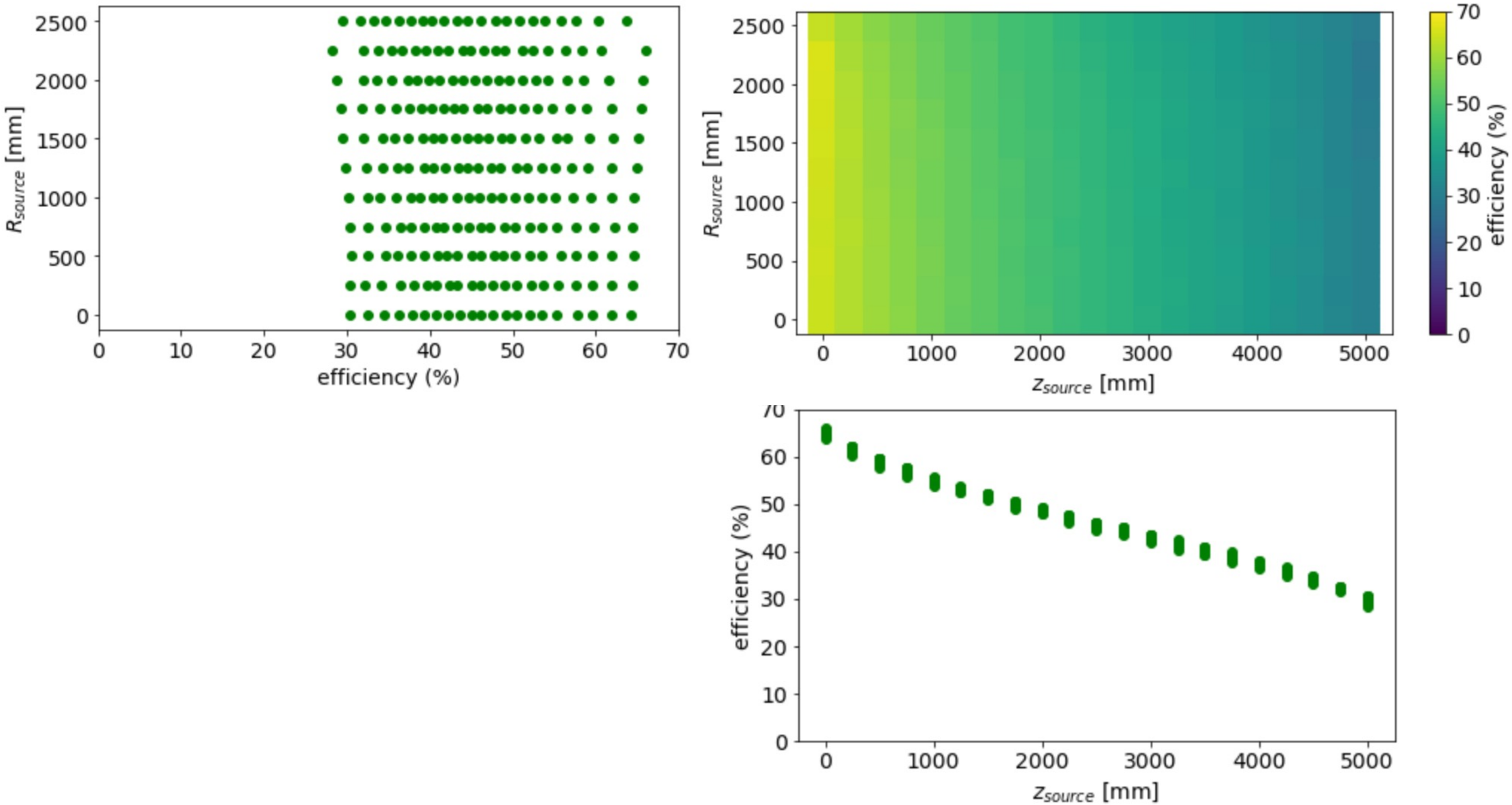
Collection efficiency as a function of source position (z_{source}, R_{source})

Reflectivity teflon = 0



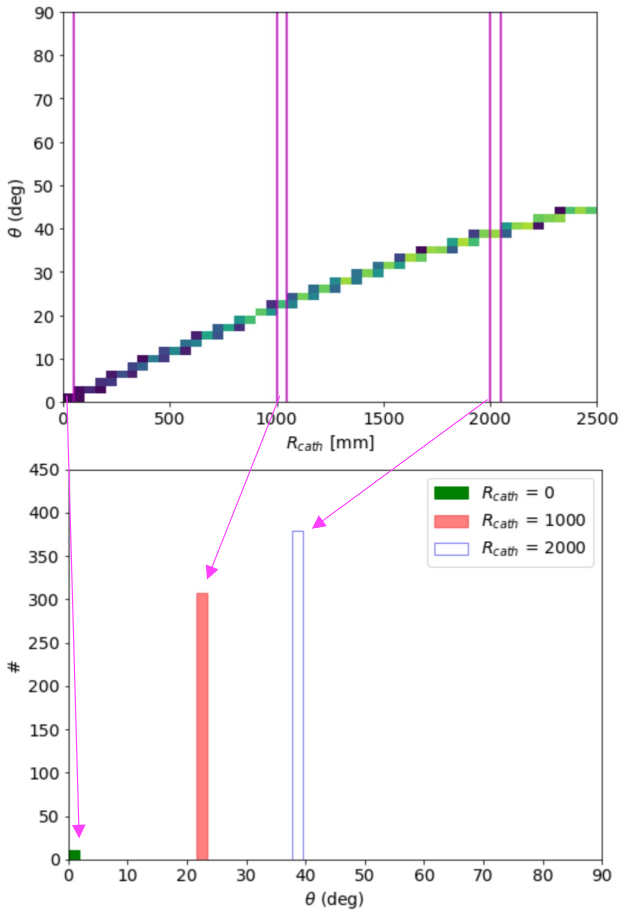
Collection efficiency as a function of source position (z_{source}, R_{source})

Reflectivity teflon = nominal

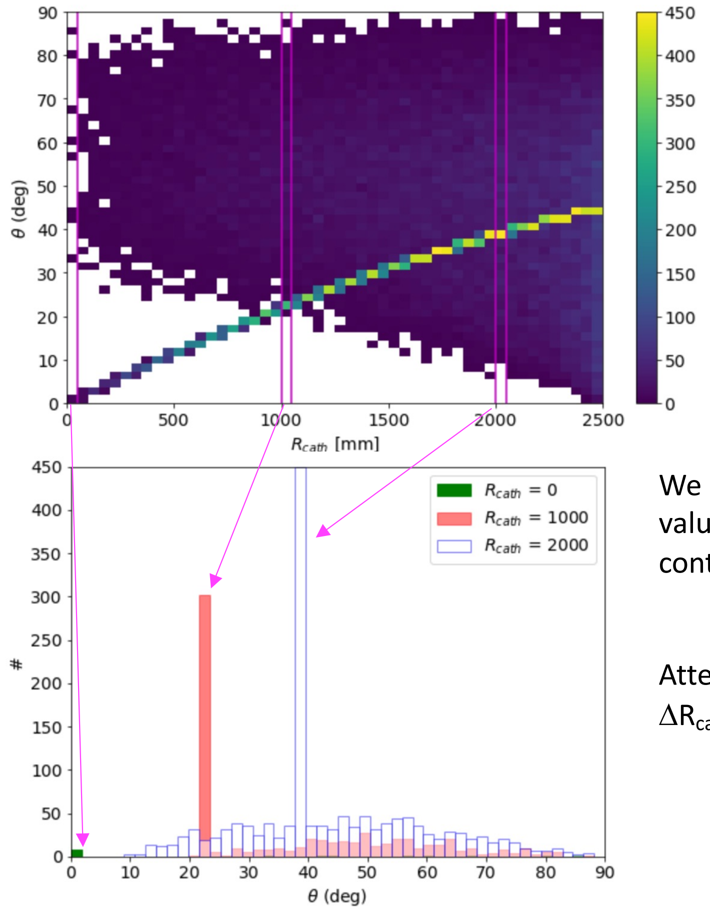


Angular distribution at the cathode: contribution from reflected light

R_{teflon} = 0%
(only direct light from source)



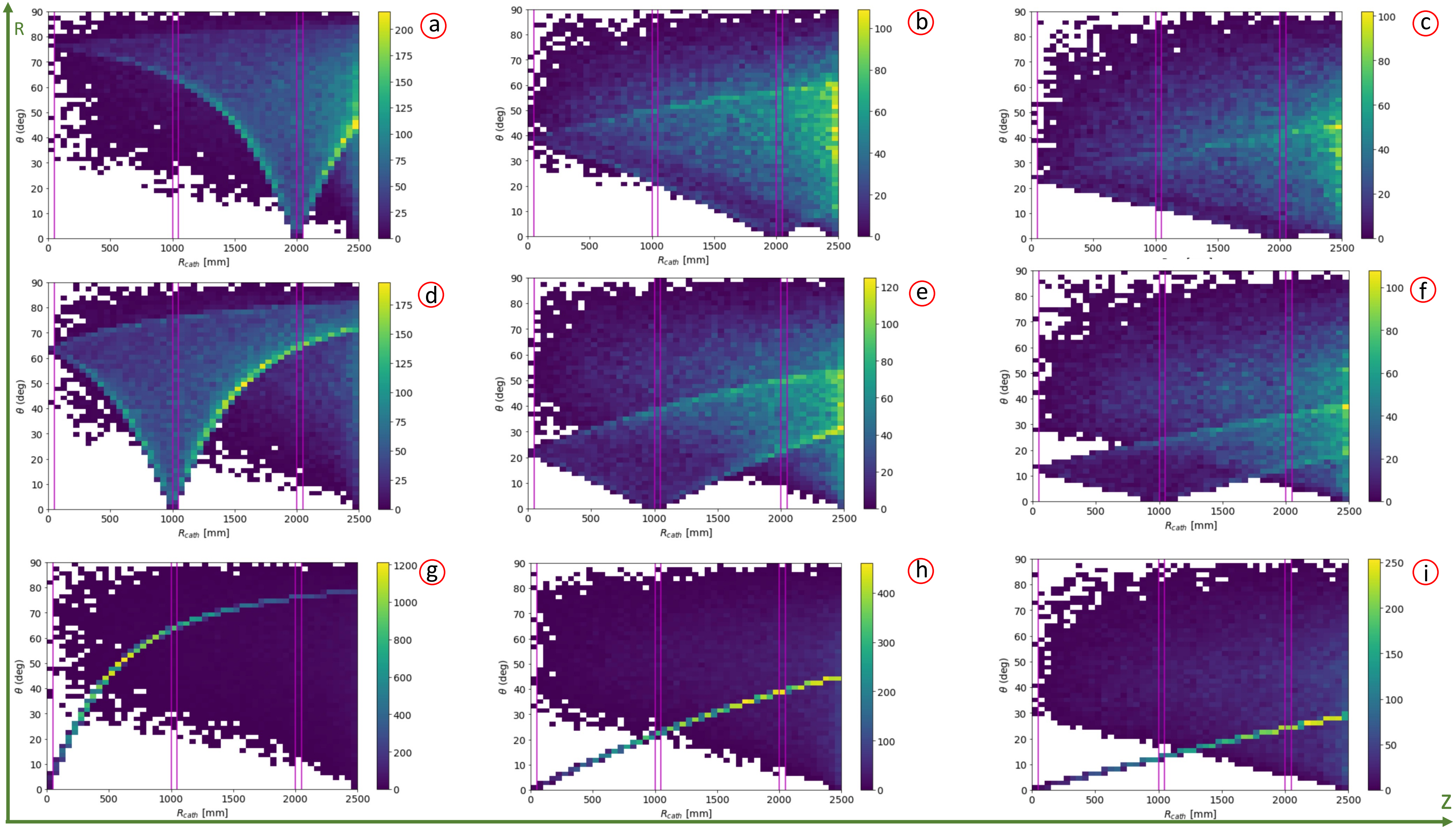
R_{teflon} = 95%
(direct light from source + reflected light at drift wall)



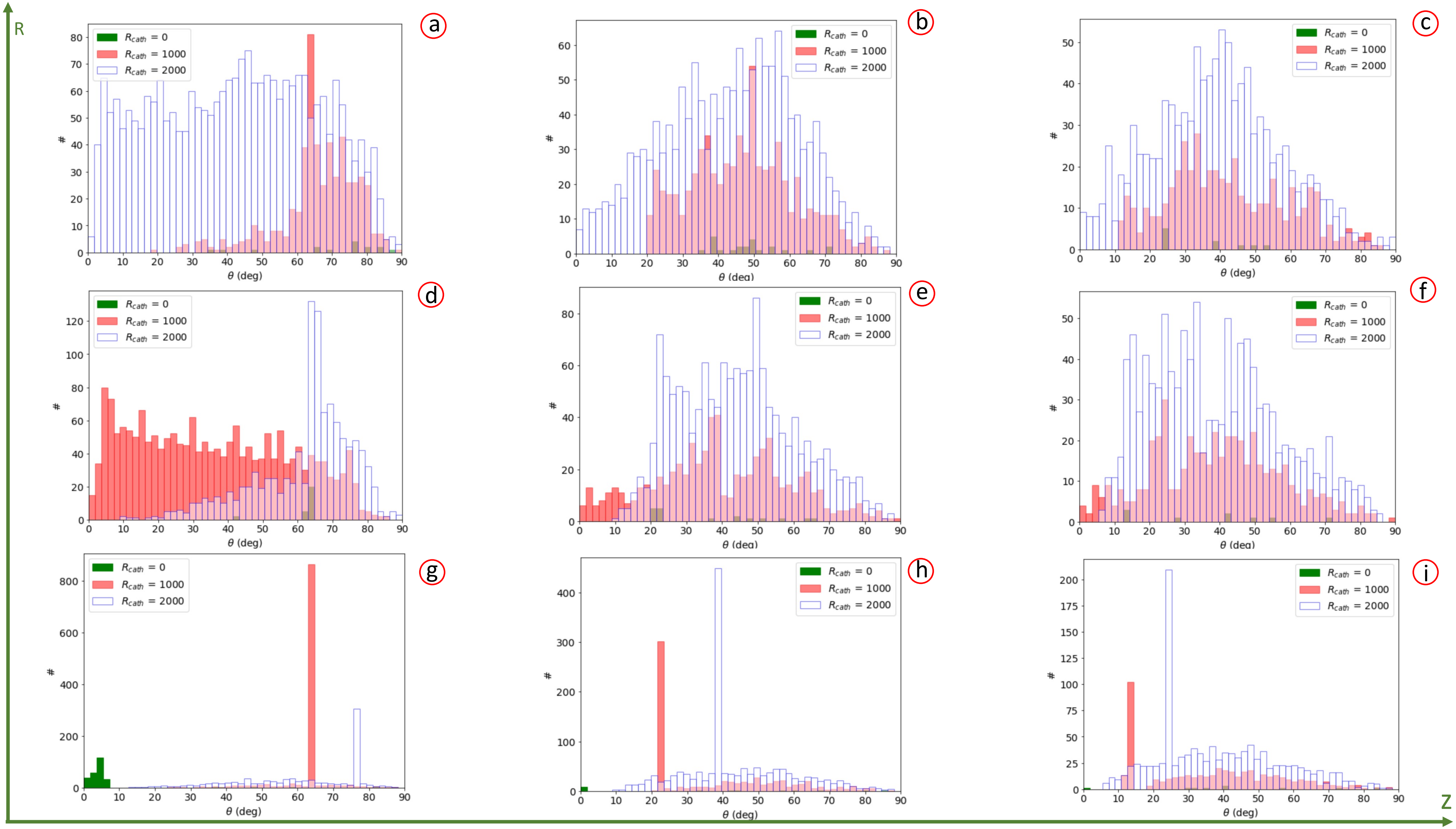
Example for (z_{source} , R_{source}) = (0,0)

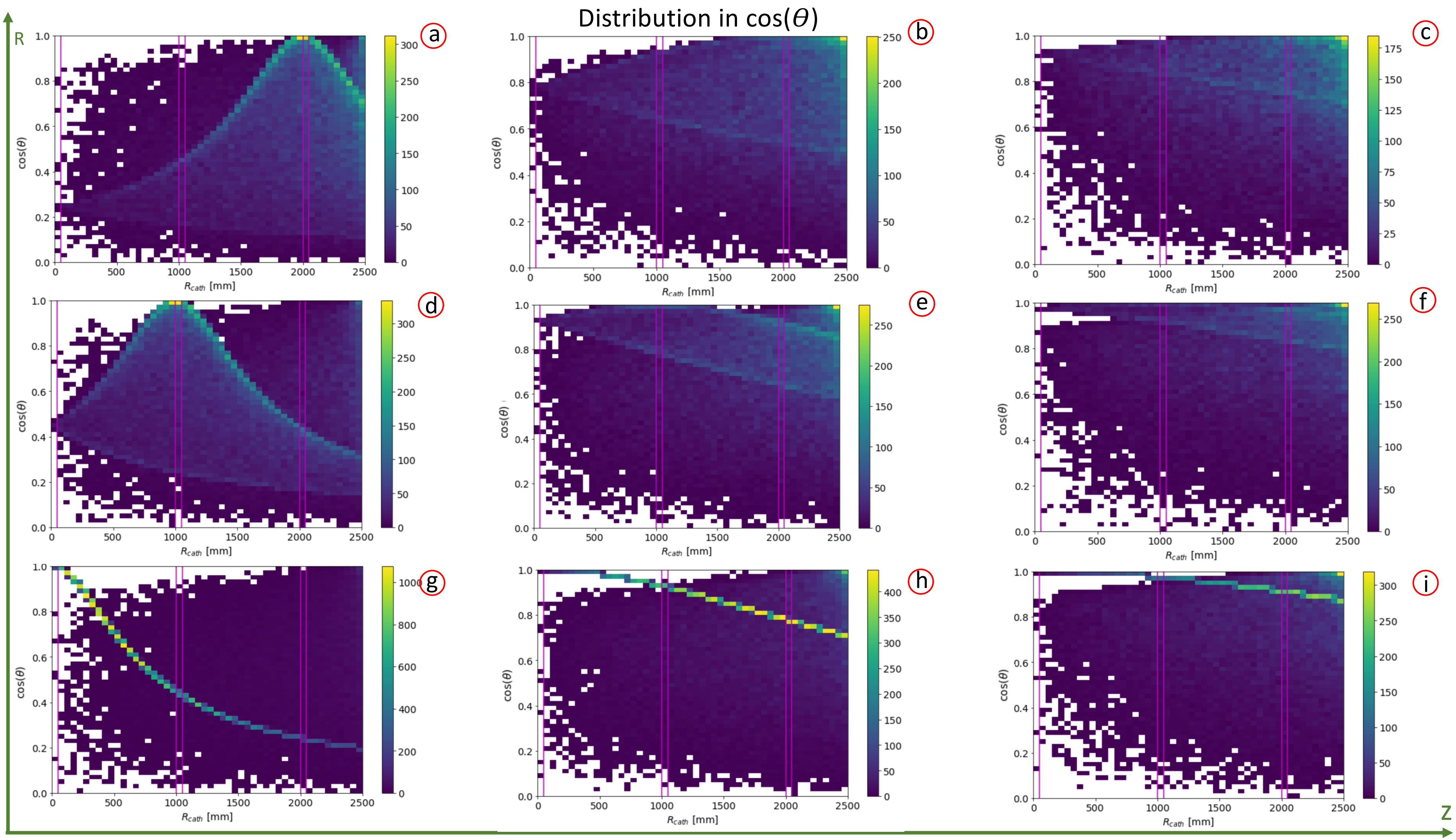
We do a 1D histogram for 3 different values of the R_{cath} to quantify contribution from reflected light

Attention!
ΔR_{cath} = 50 mm → different ring areas

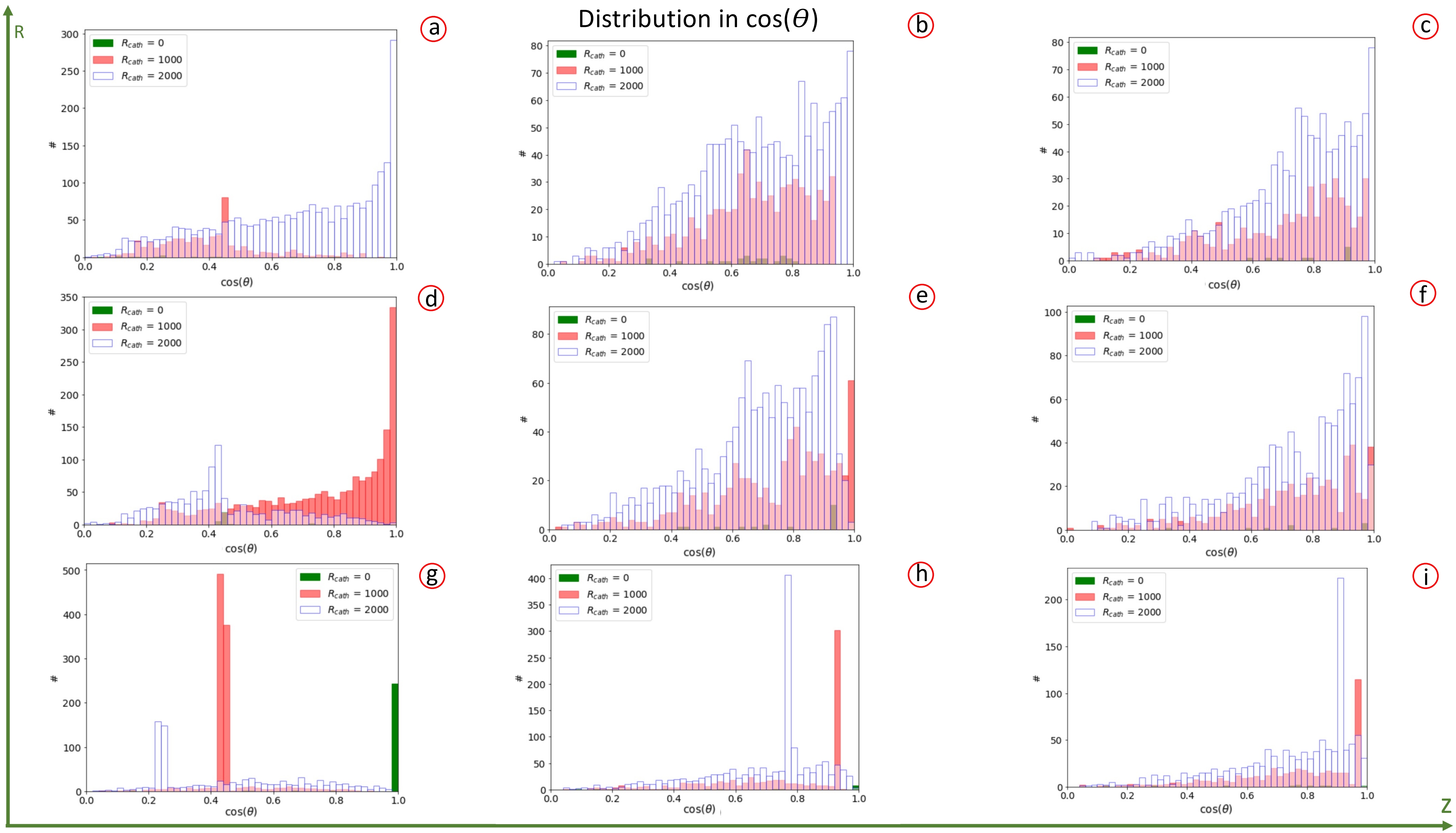


R
Z
a
b
c
d
e
f
g
h
i
θ (deg)
R_{cath} [mm]


R
Z
a
b
c
d
e
f
g
h
i
R_{cath} = 0
R_{cath} = 1000
R_{cath} = 2000
#
θ (deg)



Distribution in cos(θ)
R
Z
a
b
c
d
e
f
g
h
i
cos(θ)
R_{cath} [mm]



Distribution in cos(θ)
R
Z
a
b
c
d
e
f
g
h
i
R_{cath} = 0
R_{cath} = 1000
R_{cath} = 2000
cos(θ)
#