A Simple Monte Carlo to understand Cerenkov photons propagation and light collection in a single crystal equipped with two PMs

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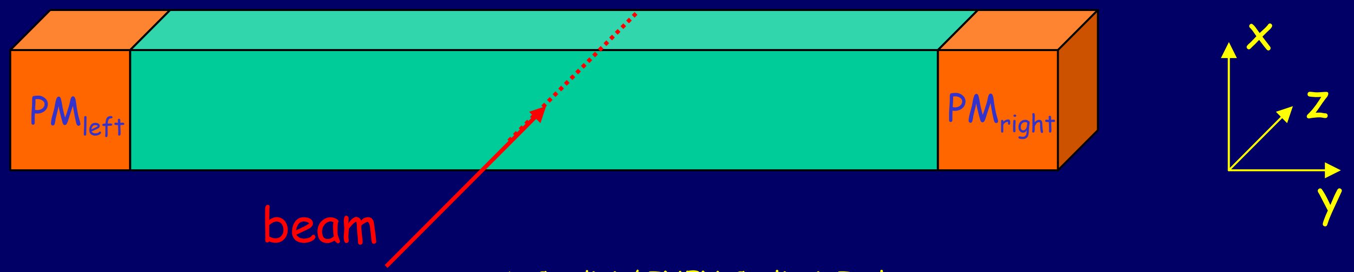
Motivation of this work

Understand:

- the asymmetry plot shown by the Cosenza group on the web page http://www.cs.infn.it/DREAM/contrib/cosenza.html
- how photons propagates in a crystal with n=2.2
- how to improve light collection without loosing asymmetry
- have some real fun while building LHC experiments

The Toy MC

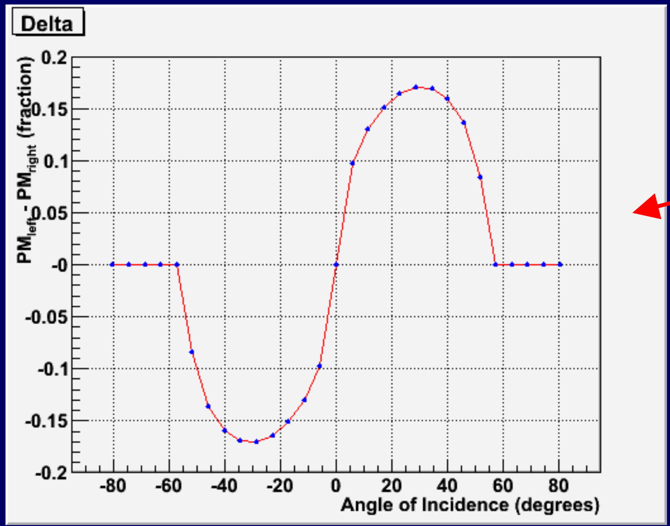
- A short C code (today), easy to debug and modify
- Crystal of parallelepipedic shape of size 22x180x22 mm^3 respectively in x,y,z, centered at (0,0,0) and index of refraction n_{cry} = 2.2
- Beam (MIP) moves along z when impinging at zero degree with the crystal, and can rotate in plane yz (positive θ for counterclock-wise around x)
- Photons are produced randomly along the particle path inside the crystal at the Cerenkov angle (number of photons does not depend on path length)
- Photons are tracked until they exit the crystal after a certain number of internal reflections. All sides are facing air (n_{air} = 1) or there is a silicon contact between crystal and light detectors (n_{sil} = 1.43)
- If the photons exit the crystal from the 4 larger sides they are lost, otherwise they are (always!) collected by light detectors (eff=1)
- No other effects included

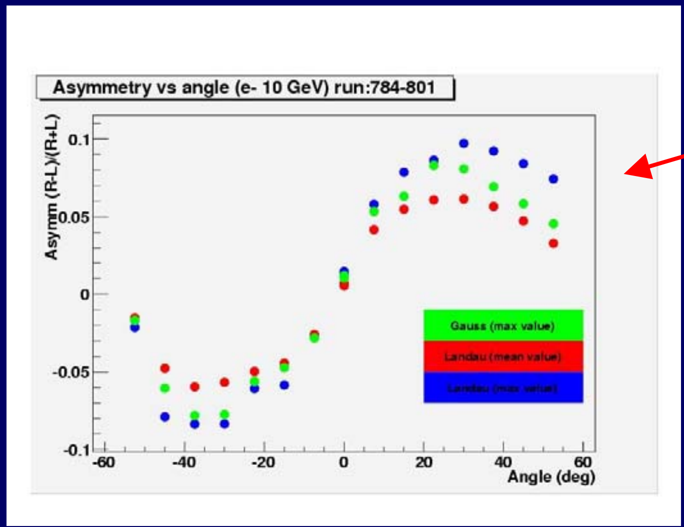


Simulation #1

- Only Cerenkov light is produced along the incident particle path and according to Cerenkov light emission formula
- All sides are facing Air (n_{air} = 1)
- All photons exiting sides are lost (fully absorbed)
- Non-optimal coupling between crystal and PM (air)

PM1 vs. PM2: asymmetry and difference



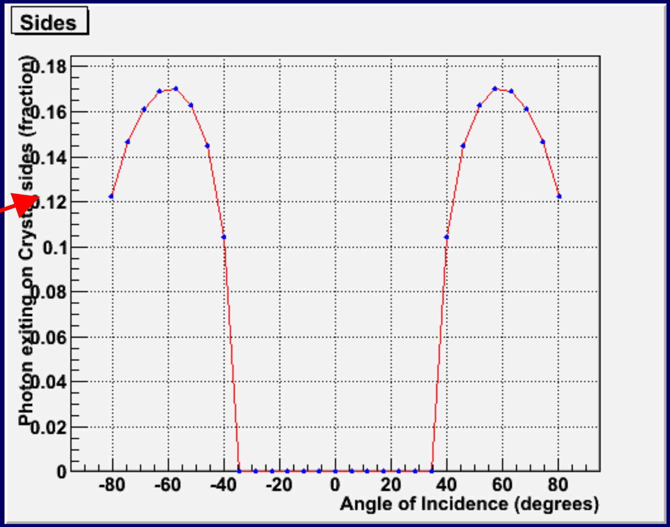


- Difference in collected light is plot vs. beam incidence angle
- Cerenkov light is collected ONLY on one PM depending on the incidence angle
- This is similar to the plot shown by the Cosenza group

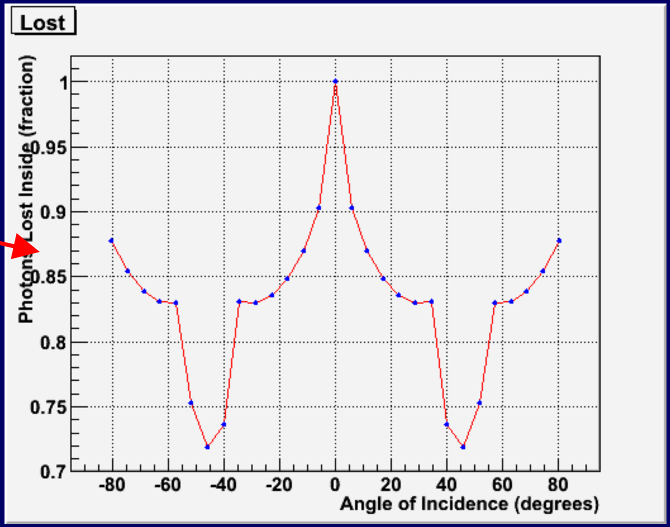
TRUE GEOMETRIC EFFECT arising from Cerenkov light characteristics

Photons exiting sides and trapped inside

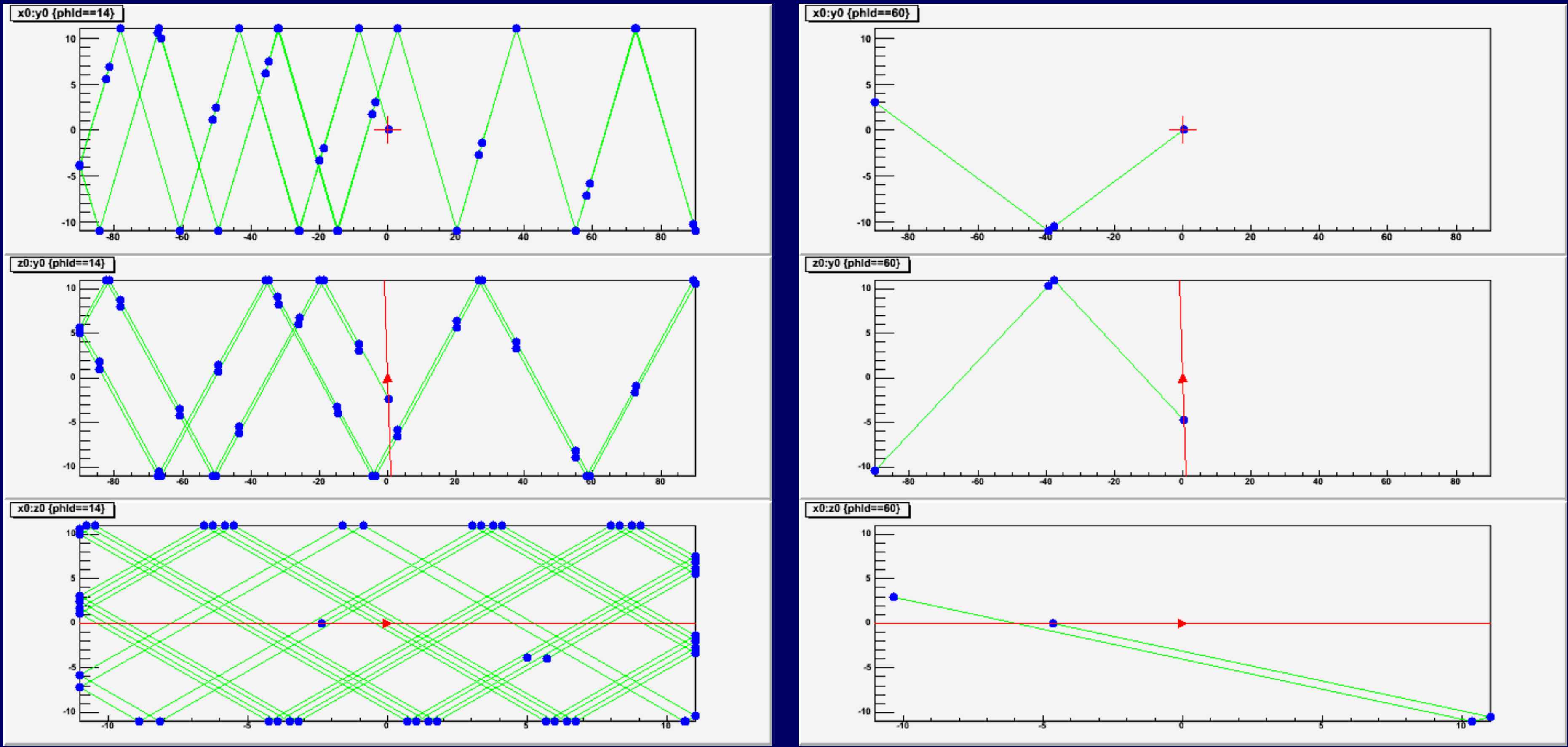
- Fraction of light exiting from the 4 sides not readout by photomultipliers



- Total fraction of light NOT exiting the crystal



Photon path – 3 projections

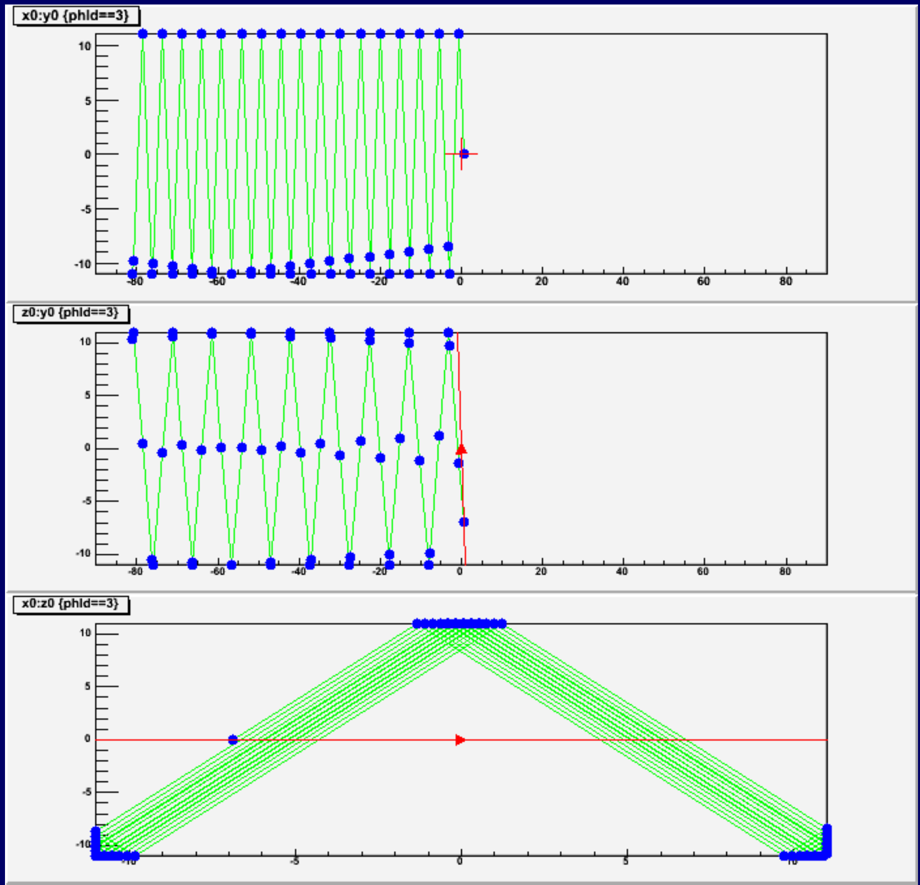


Cerenkov photon not exiting the crystal and stopped (absorbed) after 100 reflections

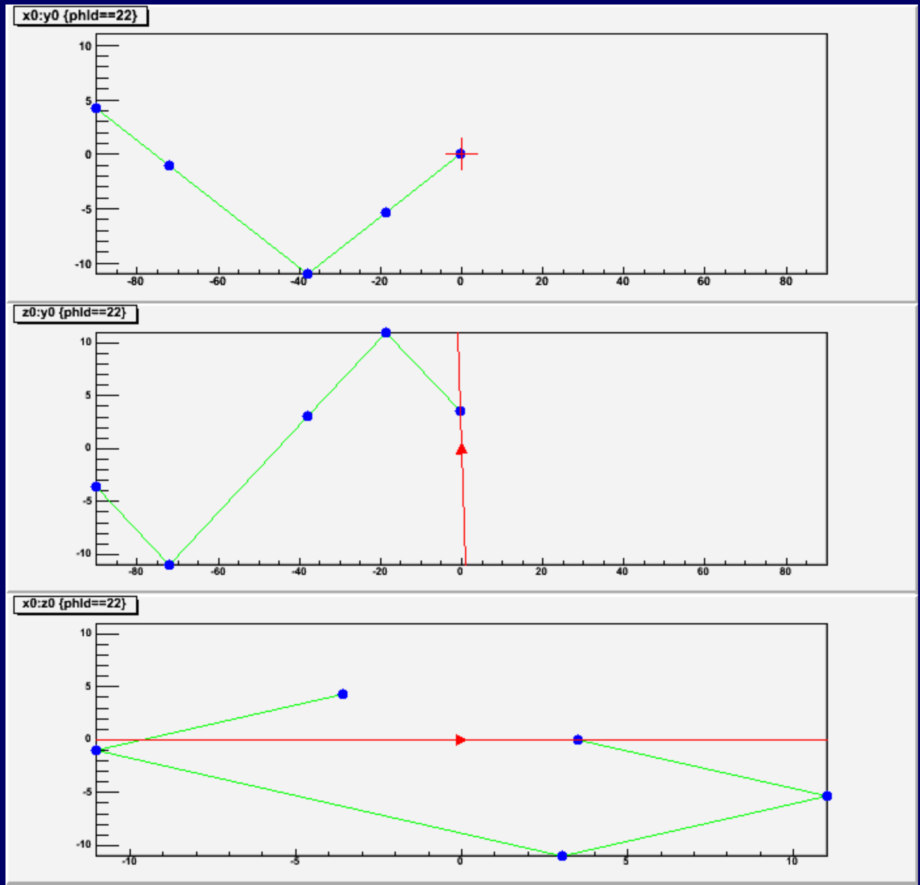
Cerenkov photon exiting the crystal on the left side after 2 reflections

For both photons θ = 0.1 rad

Photon path – 3 projections



Cerenkov photon not exiting the crystal and stopped (absorbed) after 100 reflections

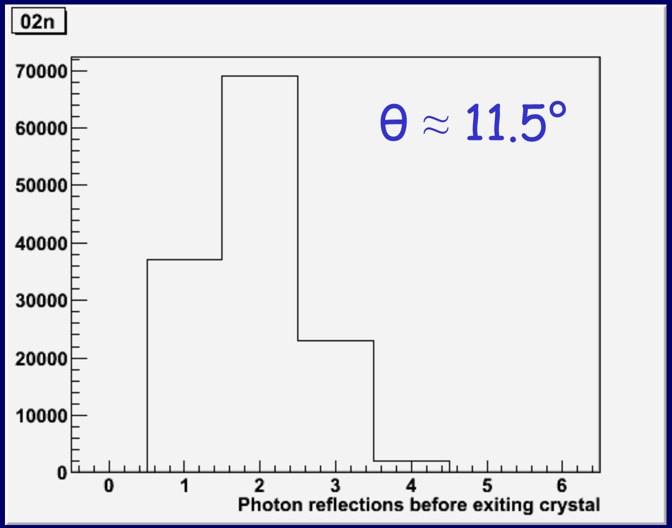


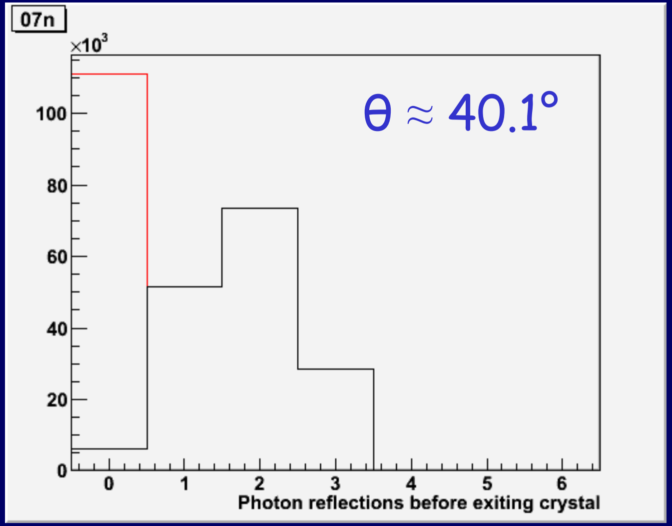
Cerenkov photon exiting the crystal on the left side after 3 reflections

For both photons $\theta = 0.1$ rad

Number of reflections before exiting

- Before exiting, how many reflections do photons make? (Purpose: evaluate if there is the need to include some bulk absorption or not in this simulation)
  - The shape of the histogram of number of reflections depends on the particle incidence angle θ
  - The maximum number of reflection for a photon that will exit the crystal somewhere was found never to exceed 4 (at least for the configurations studied)
  - In the simulation it was assumed that if a photon does not exit after 100 reflections it is lost inside (but not needed, really)



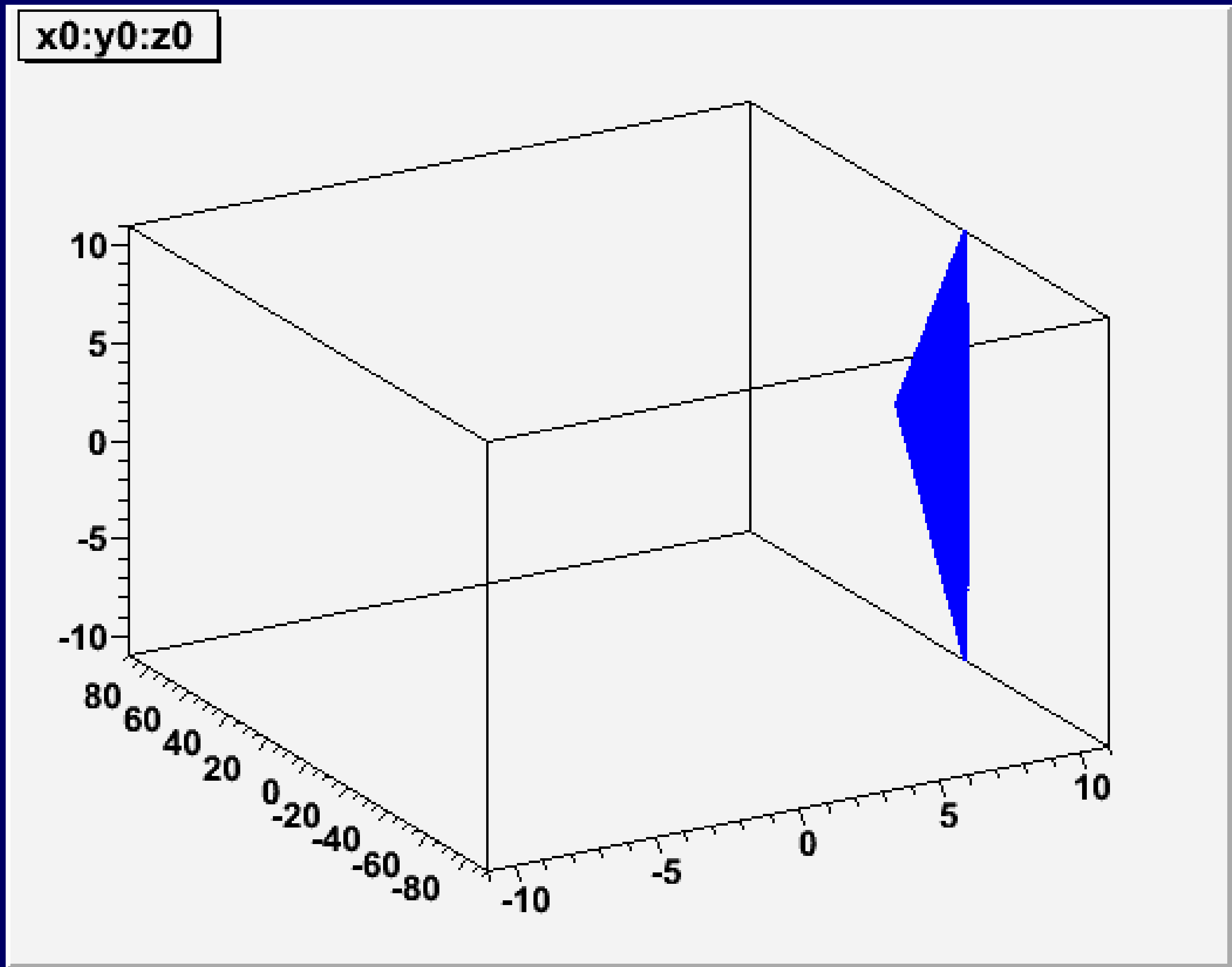


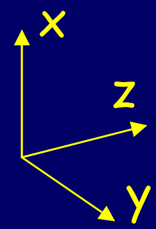
Black line: # refl. for photons reaching PMs
Red line: # refl. for photons not reaching PMs

No need to include bulk absorption...

Photon Exit point vs. Reflections

(Main Purpose: learn ROOT...)





Photon exit point on crystal faces for a particle path with angle 0.1 radians, increasing by 0.1 radians at each click (last is 1.0 radians)

Color indicate the number of reflections a photon makes before exiting:

Blue	no refl.
Green	1
Yellow	2
Red	3
Pink	4

What about scintillation light?

- Just to understand how much scintillating light could be extracted from such a crystal in this configuration I replaced the Cerenkov angular distribution with an isotropic one

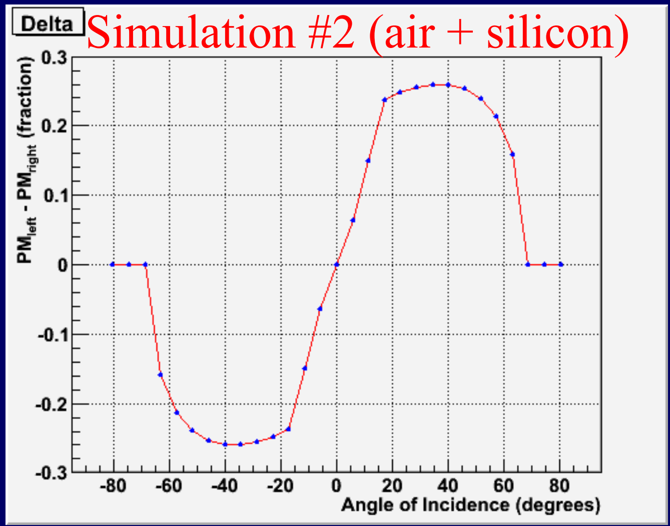
- This is what I learnt:

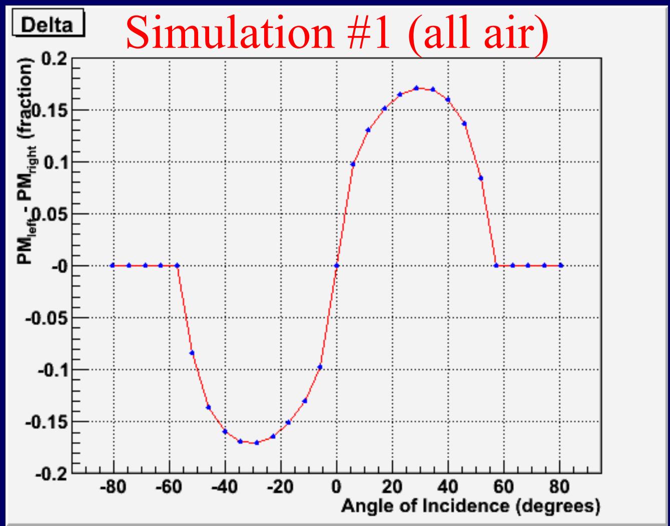
    - Obviously there is no asymmetry in light collection between the two equipped crystal sides
    - ~11% of the light produced is collected on the two PMs
    - ~22% of the light exits on the other sides
    - The rest (~67%) is trapped inside the crystal due to internal reflections

Simulation #2

- Only Cerenkov light is produced along the incident particle path and according to Cerenkov light emission formula
- All large sides are facing Air (n_{air} = 1), the two small sides are facing a silicon interface
- All photons exiting sides are lost (fully absorbed)
- Silicon-pad coupling (n_{sil} = 1.43) between crystal and PM (this should help to recover some light)

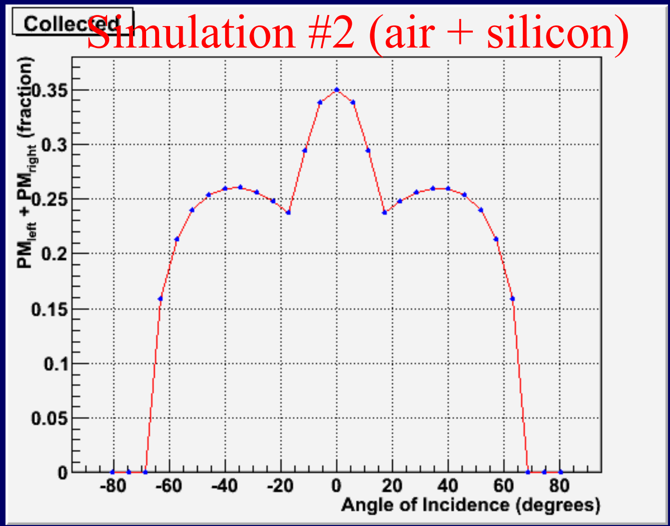
PM1 vs. PM2: difference

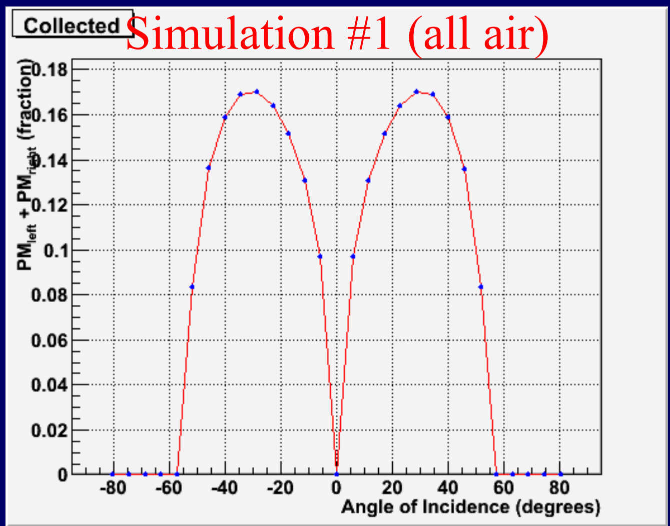




- When a silicon "adapter" is inserted between the crystal and the PM the following things happen:
  - More Cerenkov light reaches the PMs (from ~17% to ~25% at the peak)
  - The maximum is at slightly higher θ values (was ~30°, now ~35°)
  - At very small angles (<20°) Cerenkov light is collected on both PMs, this slightly reduces asymmetry for such small angles

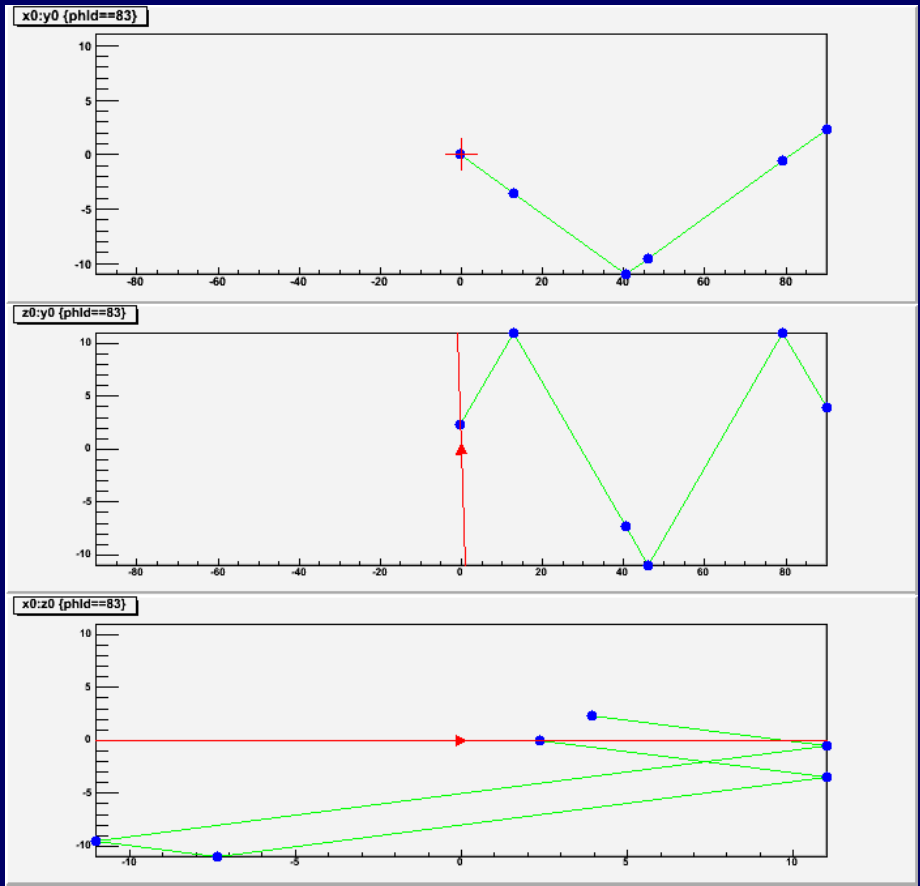
PM1 + PM2: all light collected



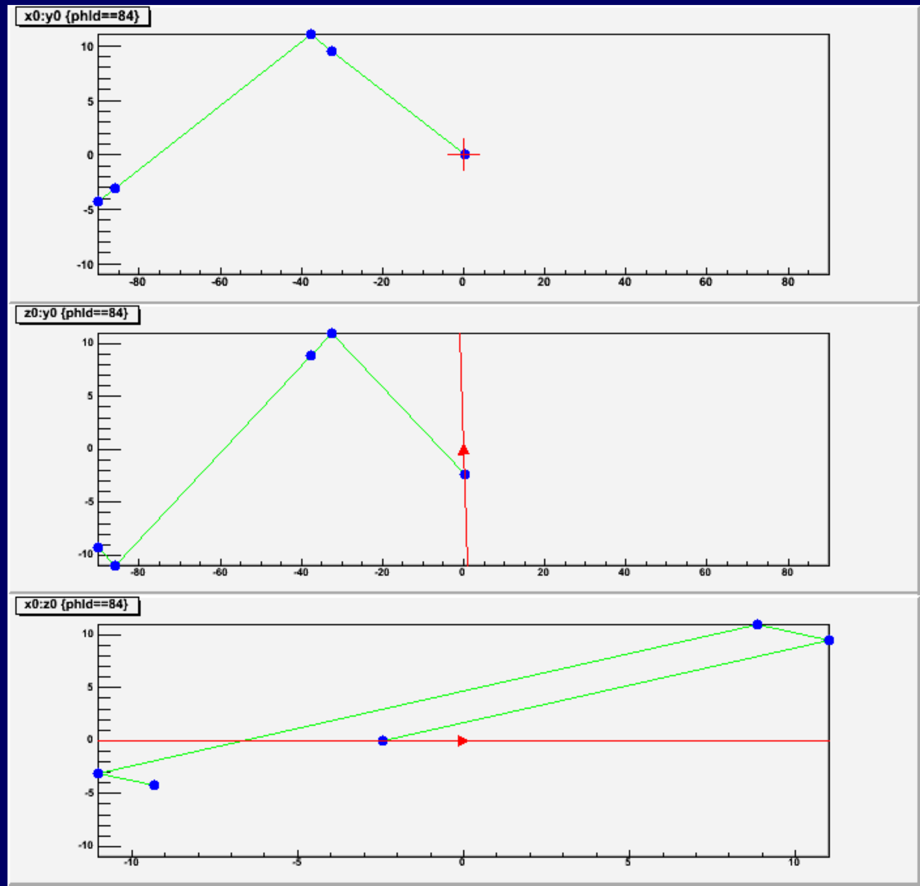


- The reduction is asymmetry can be seen in the plot of total collected light vs. incidence angle:
  - At 0° light is collected on both sides ➔ no asymmetry
  - While increasing angle asymmetry increases and then reaches again 1 (all Cerenkov light on one PM only) for angles of about 15°-20°

Photon path – 3 projections



Cerenkov photon exiting the crystal on the RIGHT side after 4 reflections



Cerenkov photon exiting the crystal on the LEFT side after 3 reflections

For both photons $\theta = 0.1$ rad

What about scintillation light?

- What happens in the case of air + silicon pads?
  - No asymmetry in light collection between the two equipped crystal sides
  - ~24% of the light produced is collected on the two PMs
  - ~22% of the light exits on the other sides
  - The rest (~54%) is trapped inside the crystal due to internal reflections

Some Conclusions (1)

- Asymmetry distribution vs. angle in the single crystal case, evaluated using a simple MC, is similar to the one found in real life
- Cerenkov photons produced for a defined angle of incidence reach only ONE photomultiplier, or they exit on not-equipped crystal side or they are internally absorbed (infinite reflections)
- Choice of surface treatment: no need of mirror treatment on the long sides, this will NOT increase the number of photons collected on PMs (such photons will not have the right angle to exit on the crystal faces equipped with PMs). Diffusion treatment of long surfaces will obviously increase light collected by PMs but will not increase asymmetry. Probably the best solution is a fully absorbing treatment.
- Total number of internal reflections for photons exiting the crystal somewhere never exceeds 4, or the photon is internally trapped (at least for this crystal size)

Some Conclusions (2)

- When a silicon "adapter" is used, more Cerenkov light is collected (from ~17% to ~26% at peak)
- However at small angles (<15°-20°) asymmetry is smaller, Cerenkov photons can reach both PMs
- Photons can do more reflections before they are collected (at least 5 reflections were occasionally observed for such a crystal)