Biasing of Optical Photons in PWO Crystal

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Abstract

The influence of optical photon biasing in PWO crystal calorimeters on the mean number of the photons and the calorimeter resolution is discussed. Optical photon yield and contribution of Cerenkov radiation are simulated for electrons, protons and π^+ in the energy range 1-100 GeV.

1 Motivation

Generation of optical photons for simulation of calorimeters with light output significantly affects the simulation performance. In current GEANT4 calorimeter applications the optical photon generation (Cerenkov and scintillation) is not used. The reason is huge number of generated photons $\sim 10^5 - 10^6$ photons per 1 GeV of absorbed energy.

Biasing allows us to accelerate the simulation and predict better signal description. It influences however the calorimeter resolution. The limits of safe biasing are discussed.

PWO ($PbWO_4$) is popular material for electromagnetic calorimeters (CMS, ALICE). It is relatively weak scintillator ($\sim 0.3\%$) of NaI(Tl). Therefore the contribution of Cerenkov radiation is not small (10-15%).

2 Cerenkov radiation in uniaxial crystals

PWO is negative axial crystal ($n_o > n_e$), where $n_o \sim 2.284$ and $n_e \sim 2.194$ (at $\lambda = 500$ nm) are ordinary and extraordinary refractive indexes, respectively. The theory of Cerenkov radiation in uniaxial crystals was developed for general case when a charged particle moves at any angle ϑ relative to optical axis, in particular parallel or perpendicular to it. The Cerenkov radiation per unit trajectory length reads for these cases:

$$\frac{d\bar{N}_{\|}}{\hbar d\omega dx} = \frac{\alpha}{\hbar c}\left[1 - \frac{1}{n_o n_o \beta^2}\right] \leftarrow \frac{\alpha}{\hbar c}\left[1 - \frac{1}{n_o n_e(\vartheta)\beta^2}\right] \rightarrow \frac{d\bar{N}_{\perp}}{\hbar d\omega dx} = \frac{\alpha}{\hbar c}\left[1 - \frac{1}{n_o n_e \beta^2}\right],$$

where $\beta = v/c$ is the particle velocity. The extraordinary refractive index depends on direction relative (at the angle ϑ) to the optical axis:

$$n_e(\vartheta) = \sqrt{n_o^2 \cos^2\vartheta + n_e^2 \sin^2\vartheta}.$$

Then one can use as the first approximation the GEANT4 Cerenkov process for isotropic medium with the isotropic refractive index:

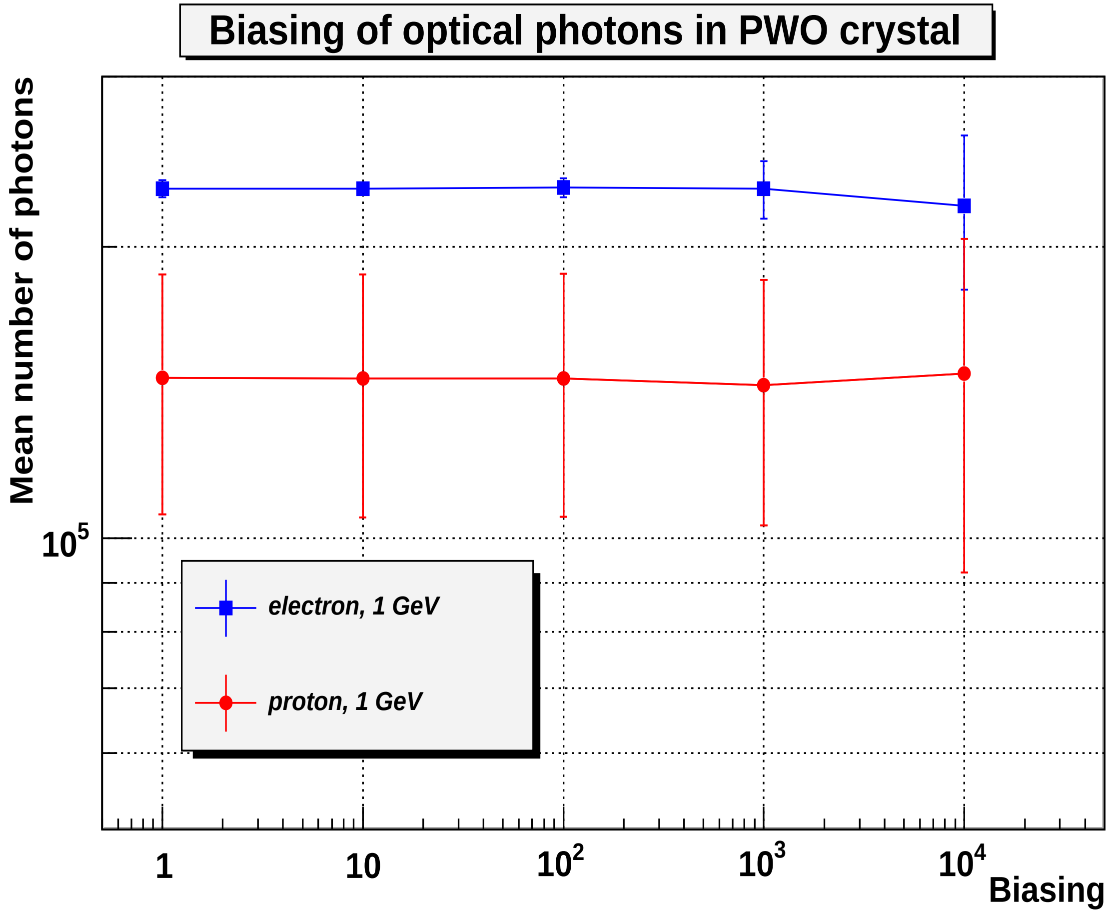
$$\langle \frac{d\bar{N}_{\vartheta}}{\hbar d\omega dx} \rangle = \frac{\alpha}{\hbar c}\left[1 - \langle \frac{1}{n_o n_e(\vartheta)\beta^2} \rangle\right], \quad \langle \frac{1}{n_e(\vartheta)} \rangle = \int \frac{d\Omega}{4\pi}\frac{1}{n(\vartheta)}, \quad \cos^2\theta = \langle \frac{1}{n_o n_e(\vartheta)\beta^2} \rangle.$$

3 PWO Geometry

The first set-up is 100 x 100 x 230 cubic cm PWO. Particles shoot it along Z-axis. Electrons, protons and π^+ (for comparison) were investigated in the energy range 1 - 100 GeV.

Photon generation cross-sections are biased (reduced), then GEANT4 supports the transport of reduced number of photons followed by detection of each photon with biased weight (increased).

More realistic geometry based on approximated ALICE PHOS crystal (18 x 2.2 x 2.2 cm^3) including boundary processes was simulated to reproduce the experimental data concerning the asymmetry of optical photon radiation in PWO.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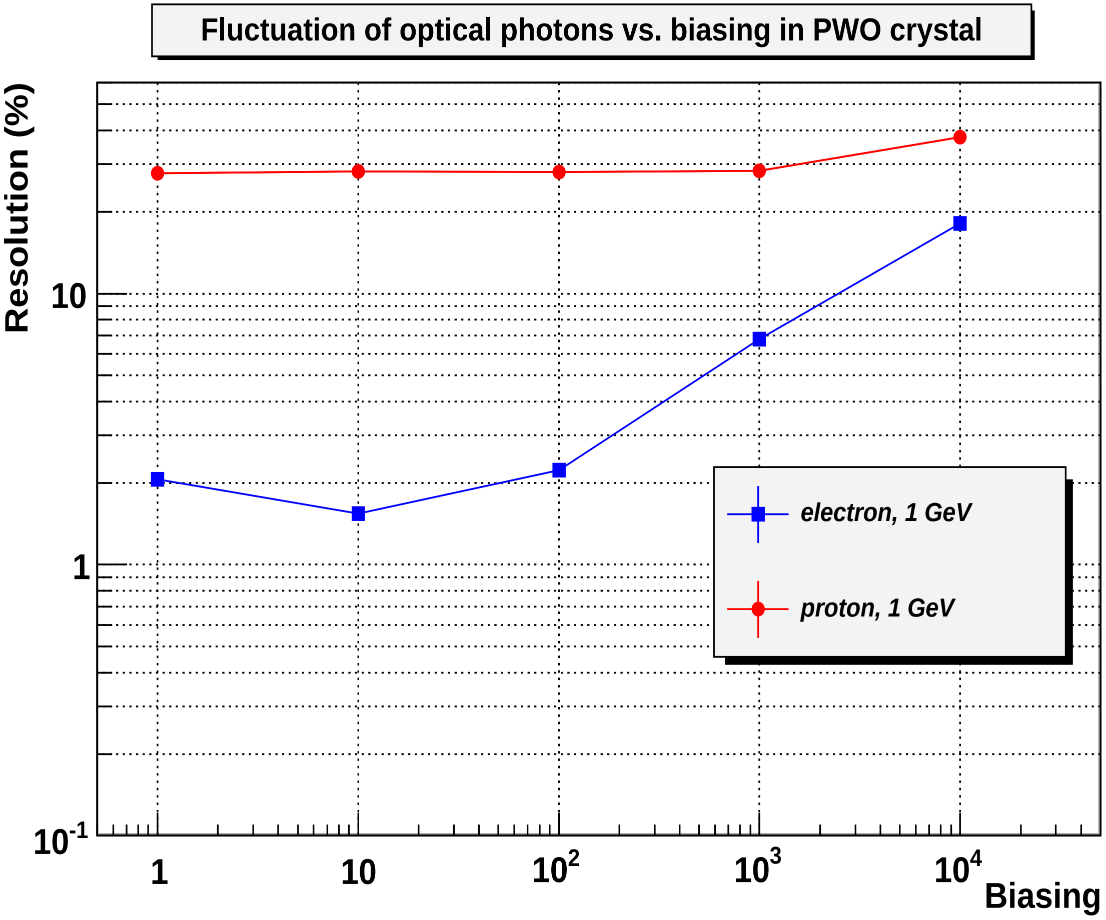
Mean number of photons
10^5
electron, 1 GeV
proton, 1 GeV
1
10
10^2
10^3
10^4
Biasing

Biasing of Optical Photons in PWO Crystal



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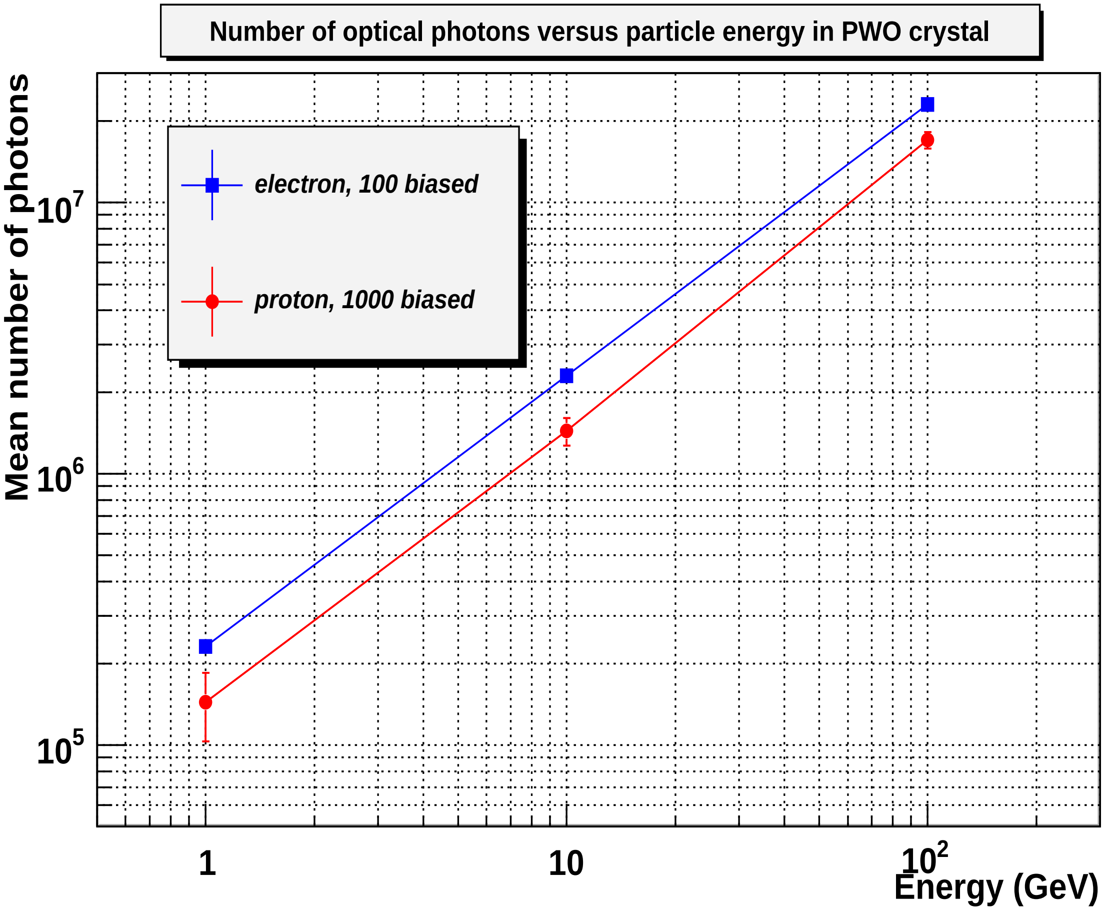

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The table of performance (s) for the cases of no photons and biased photons (1000 events of electrons and protons with the energy 1 GeV in PWO)

Physics list	no photons	bias = 100	no photons	bias = 1000
QGSP	85.47	192.3	31.06	37.2
QGSP_BERT	85.82	204.6	114.8	125
QGSP_BIC	87.64	243.9	129.8	137.9
QGSC	85.33	197.9	50.07	51.23
LHEP	85.8	197.3	32.7	41.5
FTFP	85.38	209.9	32.03	37.06

For QGSP_BERT the ratio for 10-100 GeV electrons bias=100/no-photons=1.8-1.9. For protons bias=1000 practically does not affect performance (less than 20%).

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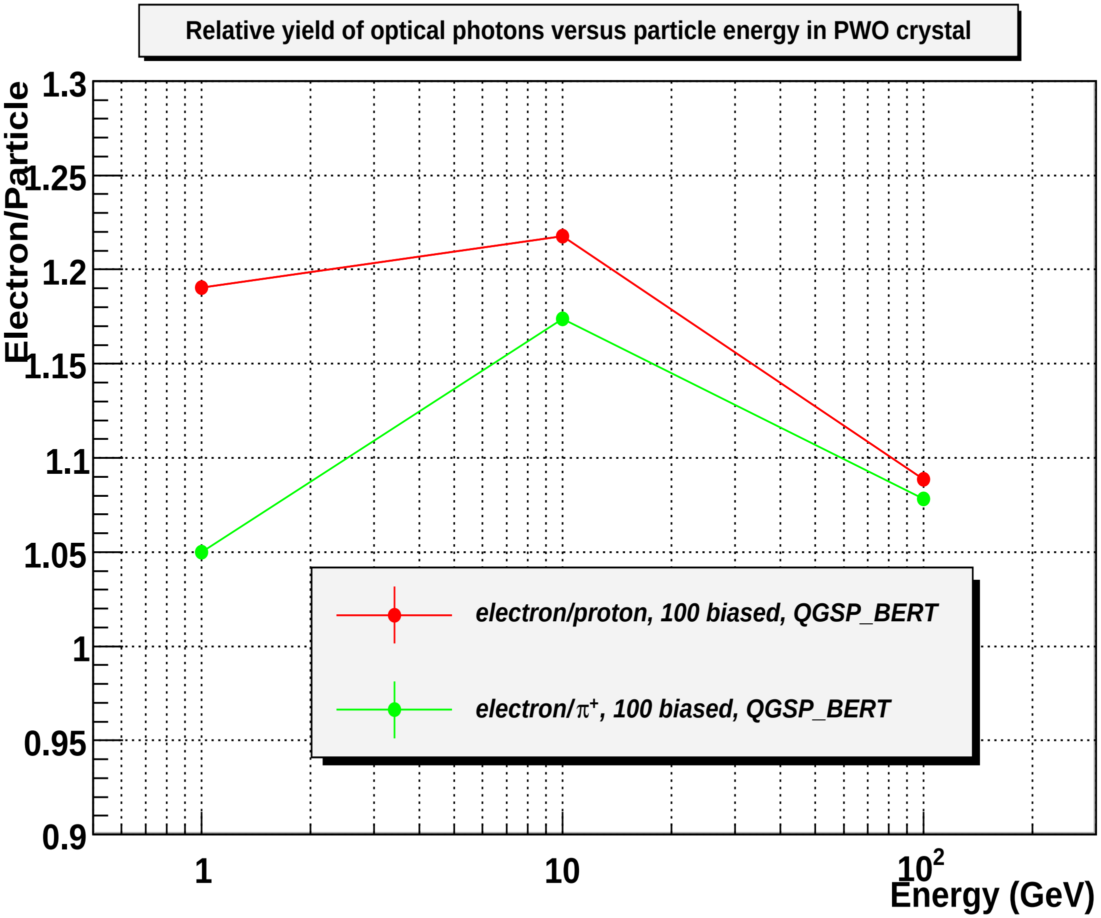

Relative photon yield of electron for different particles
(100 events of in PWO with bias = 100, QGSP_BERT)

Energy (GeV)	electron/proton	electron/π^+
1	1.1905	1.0501
10	1.2178	1.1739
100	1.0885	1.0783

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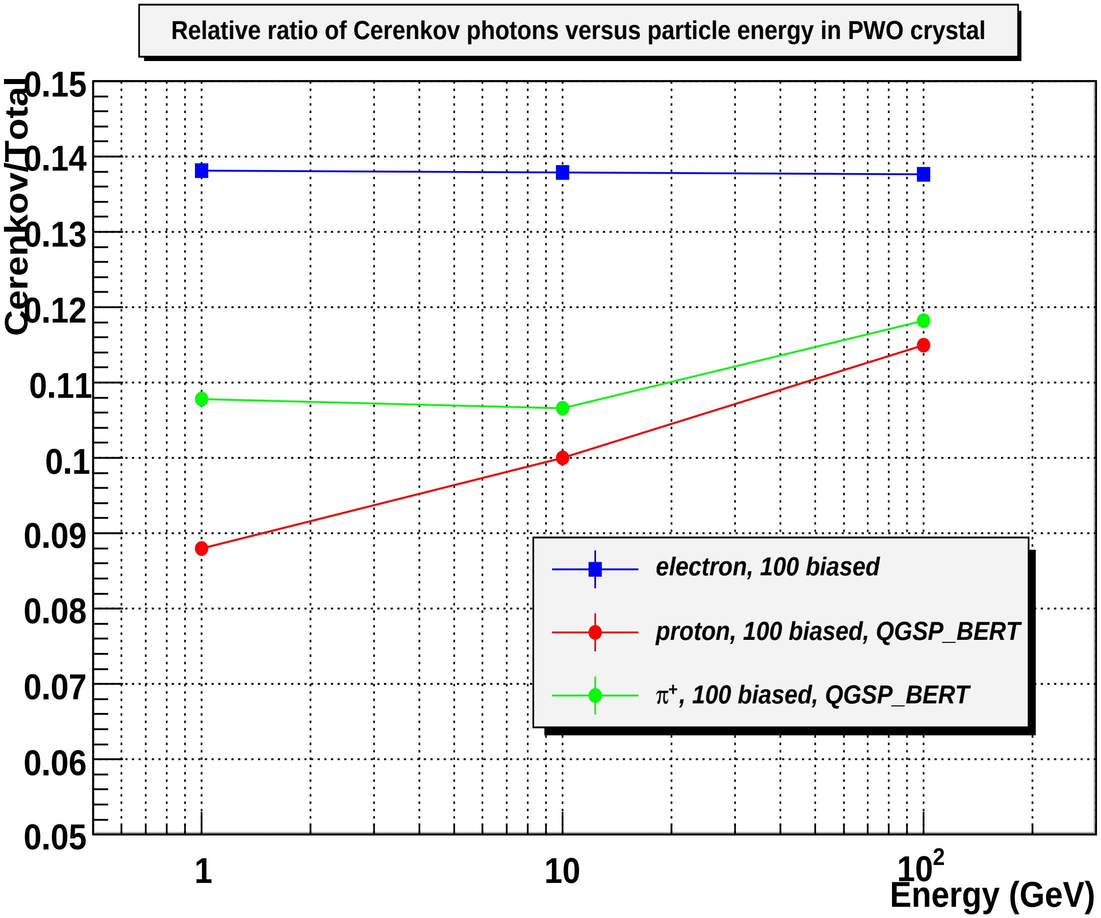

Ratio of Cherenkov to total photon numbers for different particles
(100 events of in PWO with bias = 100, QGSP_BERT)

Energy (GeV)	electron	proton	π^+
1	0.1381	0.088	0.1078
10	0.1379	0.100	0.1066
100	0.1376	0.115	0.1182

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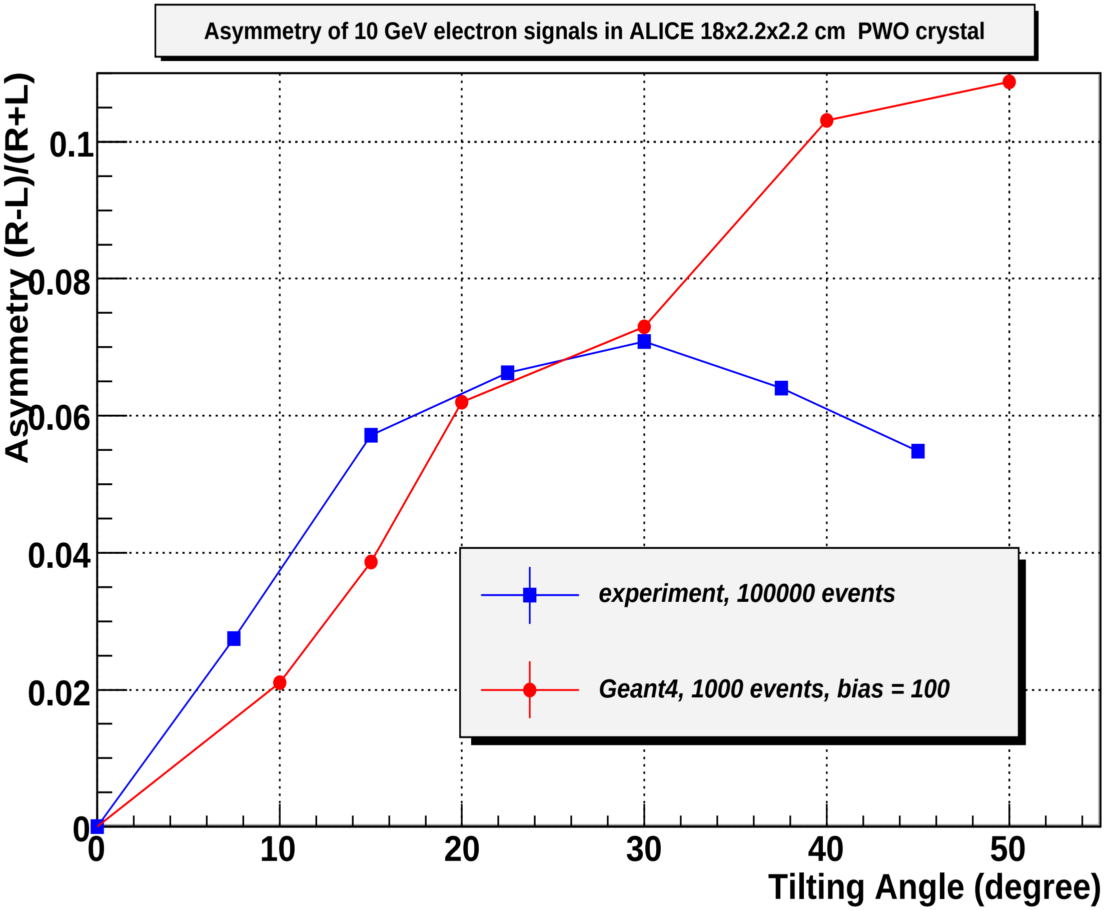

"PWO was loosely wrapped in 0.1 mm thick aluminized mylar, and installed in a light-tight box made of 3 mm thick aluminum." We are trying to find a model for that. (Shown: dielectric-metal, R=0.8.)

4 Summary and Conclusions

1. Optical photon biasing improves essentially the simulation performance of calorimeters with light output and makes it to be practical.
2. For hadron calorimeters the level of safe biasing is of order of 10^3, for electromagnetic calorimeters it is of the order of 10^2.
3. Relative yield of optical photons produced by electron versus other particles (calibration) depends on the particle and its energy.
4. Cerenkov radiation which contributes to the light signal of PWO crystal on the level of 8-15 % depending on particle and its energy.
5. Simulation of signal asymmetry in PWO requires precise knowledge of boundary conditions.