SIMULATIONS FOR GAMMAS IN CEPA (PYRAMIDAL AND PLANAR ARRAYS FOR THE ENDCAP) IN PHOSWICH CONFIGURATION

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1. PYRAMIDAL CEPA

Motivation:
The idea is to simulate as a first step the interaction between gammas and an array of pyramids that can be considered as the beginning of the end-cap design. Furthermore, the idea is to buy this array to be used in nuclear experiments and compare the experimental results with the ones obtain in Montecarlo simulations.

We have studied:

- Energy detection efficiency
- Photopeak efficiency (normalized to the total launched) and photopeak to total efficiency (E<90 % Eincident, E<80 % Eincident)(normalized to the ones detected)
- Photopeak efficiency and photopeak to total efficiency (Only counting the number of events in the photopeak)

Parameters of the simulation:

Geometry:
Array of 3x3 pyramidal-like phoswich detectors. Each of them with a square at the entrance face (side:49.9 cm) and a square at the exit side (side:80 cm). The diagonal side of each pyramid is 10.2 cm long (the symmetry axis is 10 cm long). Each individual detector is comprised of a LaBr3 crsytal 4 cm long optically coupled to a LaCl3 crystal 6 cm long. The volume of the detector is of 256.5cm3=9x28.5 cm3.

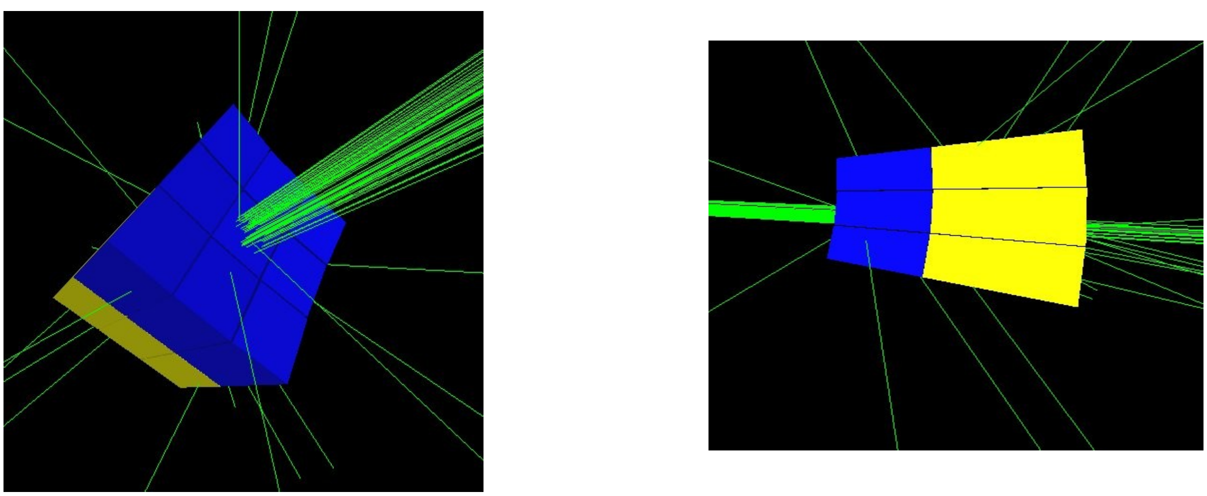

Figure 1:Detail of the geometry proposed and the dispersion of the gammas (10 MeV) that impacted in the central crystal

Primary Generator:

Gammas of energies ranging from 0.5 MeV to 20 MeV have been generated at a distance of 38 cm from the entrance face. They are directed towards the detector along the z-axis but with an aperture of 0.754 º so that they cover a circle of 2r=1 cm.

Physics:

Livermore low energy electromagnetic physics for gammas and electrons. It can be used too for Standard Physics for positrons and protons.

Results

Energy Efficiencies as a function of the energy of the gammas launched.

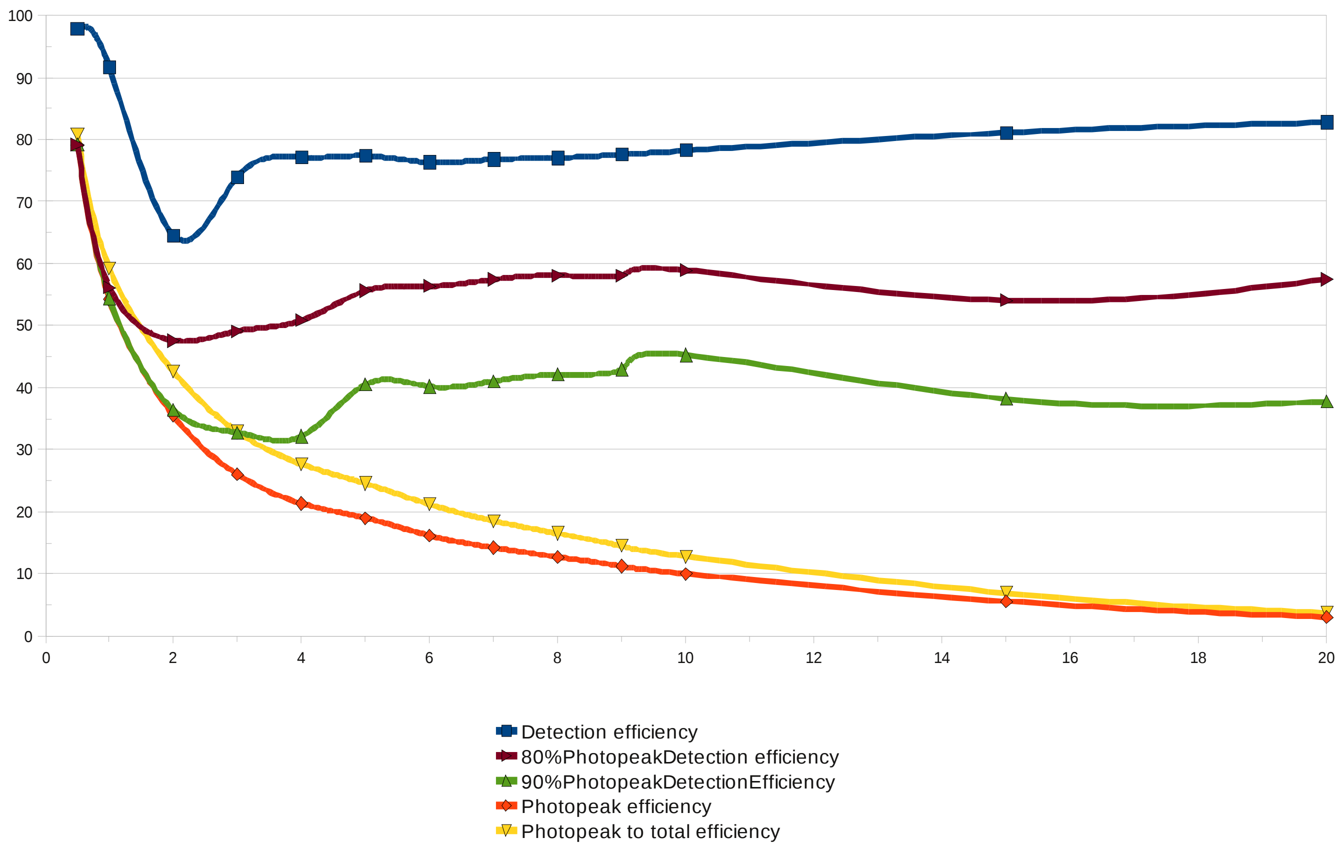

Figure 2: Blue:Detection efficiency E(10 MeV)=78%, E(20 MeV)=82%. Purple: Photopeak efficiency calculated as 80% incident energy. E(10 MeV)=59%, E(20 MeV)=58%. Green: Photopeak efficiency calculated as 90% incident energy E(10 MeV)=45%, E(20 MeV)=37%. Red: Photopeak efficiency considered as an accurate sum of number of events in the photopeak (using histogram of energy) and normalized to the total of gammas launched E(10 MeV)=10%, E(20 MeV)=3%. Yellow: The same as in the red curve but normalized to the total of gammas detected for each energy (E(10 MeV)=13%,E(20 MeV)=3%).

Discussion:

We can see 2 valleys of energy when we take in account the Compton effect (green, purple and blue curves). The first one is from 2 – 6 MeV and is owed to the 511 KeV, single and double escape and high photopeak contribution. The second one is owed to the LaCl contribution, that is very high for high energy gammas (a parabolic shape owed from 10-20 MeV to the statistical intrinsic contribution of the LaCl). In this last case there is much Compton contribution and the tendency of the curves is owed to the variation of the Comtpon effect with energy in the LaCl crystal.

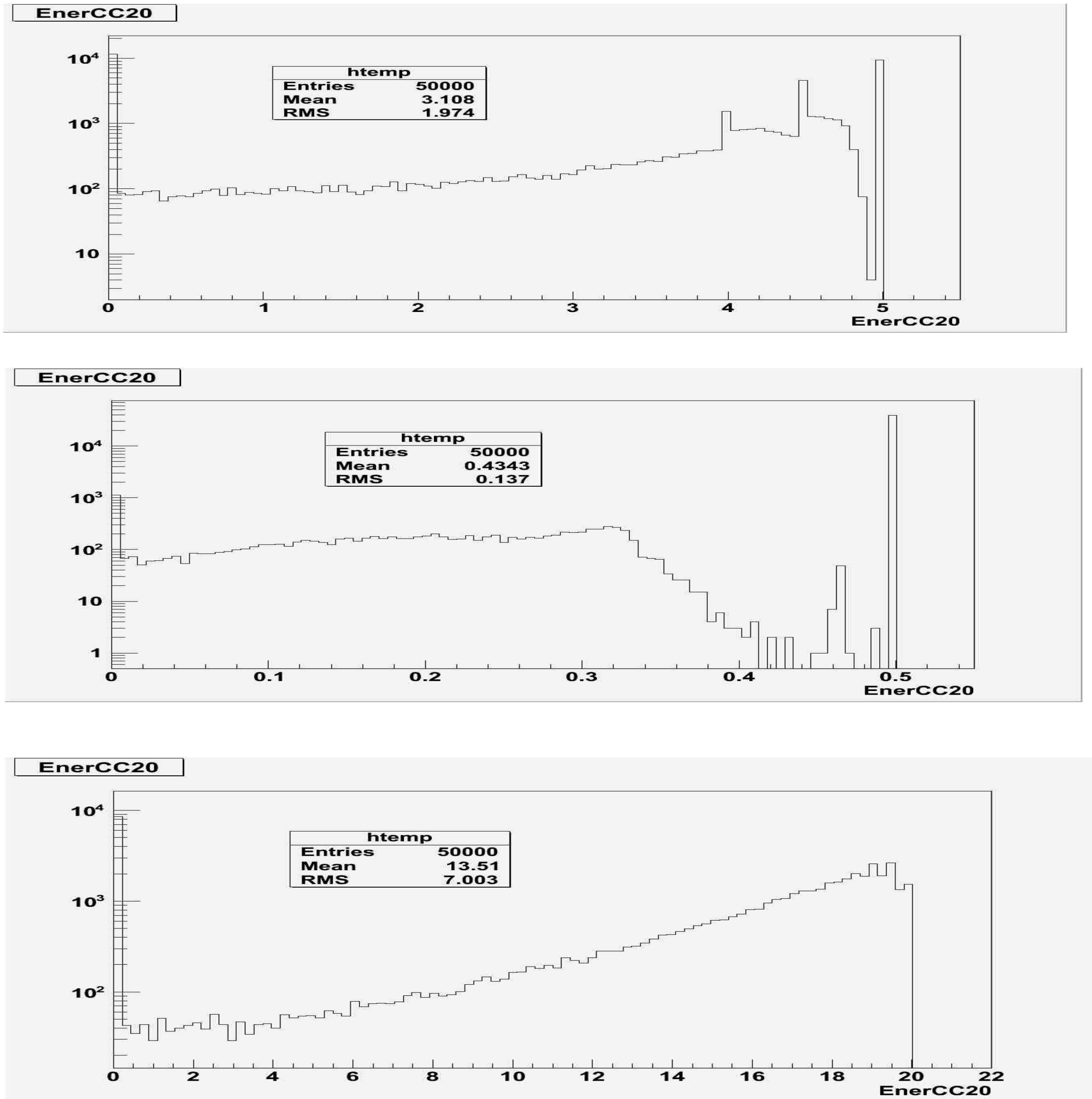

Figure 3: Spectra used for counting the number of events in the photopeak and for E>90%Eincident in the histogram (root command:htemp->integral(bin1,bin2)). We can see the high contribution of photopeak for low energies gammas and the low contribution of photopeak (high contribution of Compton effect) for high energy gammas.a)5 MeV b)500 KeV c)20 MeV

Energy	Photopeak(%Eincidente)
0.5	80.00%
1	92.00%
2	93.00%
3	97.33%
4	97.50%
5	98.20%
6	98.50%
7	98.57%
8	98.75%
9	99.33%
10	99.40%
15	99.63%
20	99.65%

Table 1: Percentage of E incident for the photopeak contribution. This means that if we take in account the photopeak as E>90%Eincident only the 500 KeV and 1 MeV incident gamma energies are 100 % photopeak contribution. In the other cases Comtpon effect, single and double escape, energy gap between Comtpon effect and photoelectric effect and Photopeak contribution play an important role in the sum for efficiencies calculi.

The red and yellow curves have been calculated using the percentages of incident energy contributions to the photopeak (and not 80 or 90 %) which are shown in Figure 4. In these curves there is not Compton effect (this means neither single nor double escape) and as a result of this there is not energy valley (2-6 MeV).

The 90% Eincident is used in simulations of real experiments

The yellow and red efficiency curves (calculated only as pure photopeak contribution) are very similar to the ones calculated by St. Gobain using Montecarlo Method for LaBr cylindrical crystals (very similar volume).

Future aims:

- Study the energy distribution of gammas in the space (calorimeter contribution). This 3D-histograme has already been obtained by E-Nacher. It shows that most of energy is deposited in the crystal. CEPA can be used then as a gamma calorimeter but we do not know yet if phoswich configuration is useful. With this graph we are able to know the best geometrical dimensions of the CEPA (it looks that the best one is for 4 cm height and 20 cm long). This study is better that the one of tracking the gammas.
- Study the spatial distribution of gammas (gamma spectroscopy). This 3D-histograme was obtained by E.Nacher and shows the difference from Protons spatial distribution (gammas interact much less in the crystal).
- To see the relevance of the phoswich configuration we need to study the first hit of the gammas in the first crystal and their post-photopeak contribution in any other part inside the detector. This study has already been performed with planar arrays.
- Compare these curves with CsI crystals and see which one has higher efficiency.

PLANAR ARRAY CEPA

Motivation:

The motivation is the same as in the pyramidal CEPA , however this time we want to know how much the efficiency changes with the increase of the number of crystals (width and depth).

We compare different planar arrays with area dimensions of 2.5 cm x 2.5 cm for each crystal.

We want to know the efficiency for the optimum geometrical phoswich configuration as planar array that is chosen according to the 3D gamma energy distribution studied by E.Nacher (4x4x20 cm).

In this geometrical option we have done the following efficiencies studies:

- Energy detection efficiency
- Photopeak efficiency and photopeak to total effciency
- FirsHit in first crystal and Photo-peak inside any other point of the crystal (it is called Photoelectric Efficiency to first Hit -normalized to the total number of gammas launched-) and Photo-peak to Total in the First Block Efficiency (the same but normalized to the number of gammas detected).

Parameters of the simulation:

Geometry:

Array of ***5x5, 10x10 and 20x20 phoswich planar array*** detectors. Each of them is a rectangular prism of a square base (side:2.5 cm) at top and at the bottom. Each individual detector is comprised of a LaBr3 crsytal 4 cm long optically coupled to a LaCl3 crystal 6 cm long and surrounded by a Teflon layer of 250 um. The volume of the detector 5x5 is of 25 x 2.5 x 2.5 x 10 =1562.5 cm3, the one of 10x10 is 6250 cm3 and the one of 20x20 is 25000 cm3. We have studied too the configuration of a planar array of 20x20x2.5x2.5x20 (4LaBr+16LaCl)cm of depth (Volume=50000cm3).

Case 1: 5x5x2.5x2.5x(4LaBr+6LaCl)

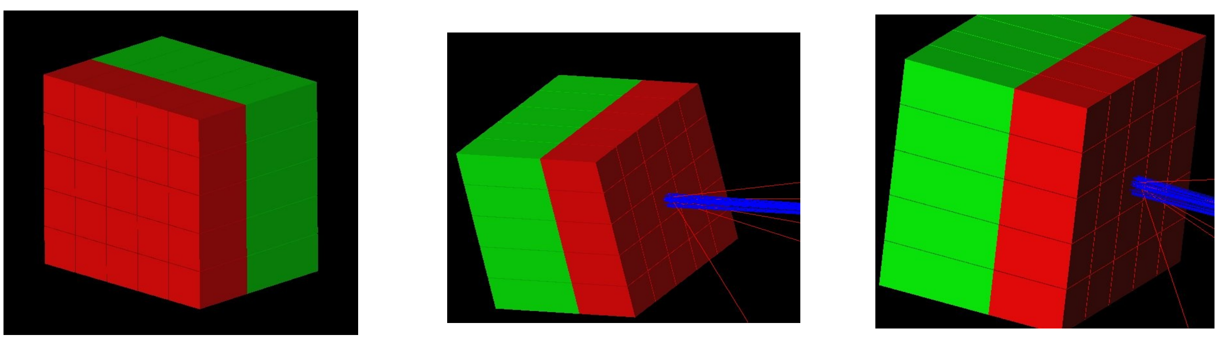

Figure 1:Detail of the geometry proposed and the dispersion of the gammas (10 MeV) that impacted in the central crystal of the planar array

Primary Generator:

Gammas of energies ranging from 0.5 MeV to 20 MeV have been generated at a distance of 30 cm from the entrance face. They are directed towards the detector along the z-axis but with an aperture of 0.754 º so that they cover a circle of 2r=1 cm.

Physics:

Livermore low energy electromagnetic physics for gammas and electrons. It can be used too for Standard Physics for positrons and protons.

Results:
Energy Efficiencies as a function of the energy of the gammas launched.

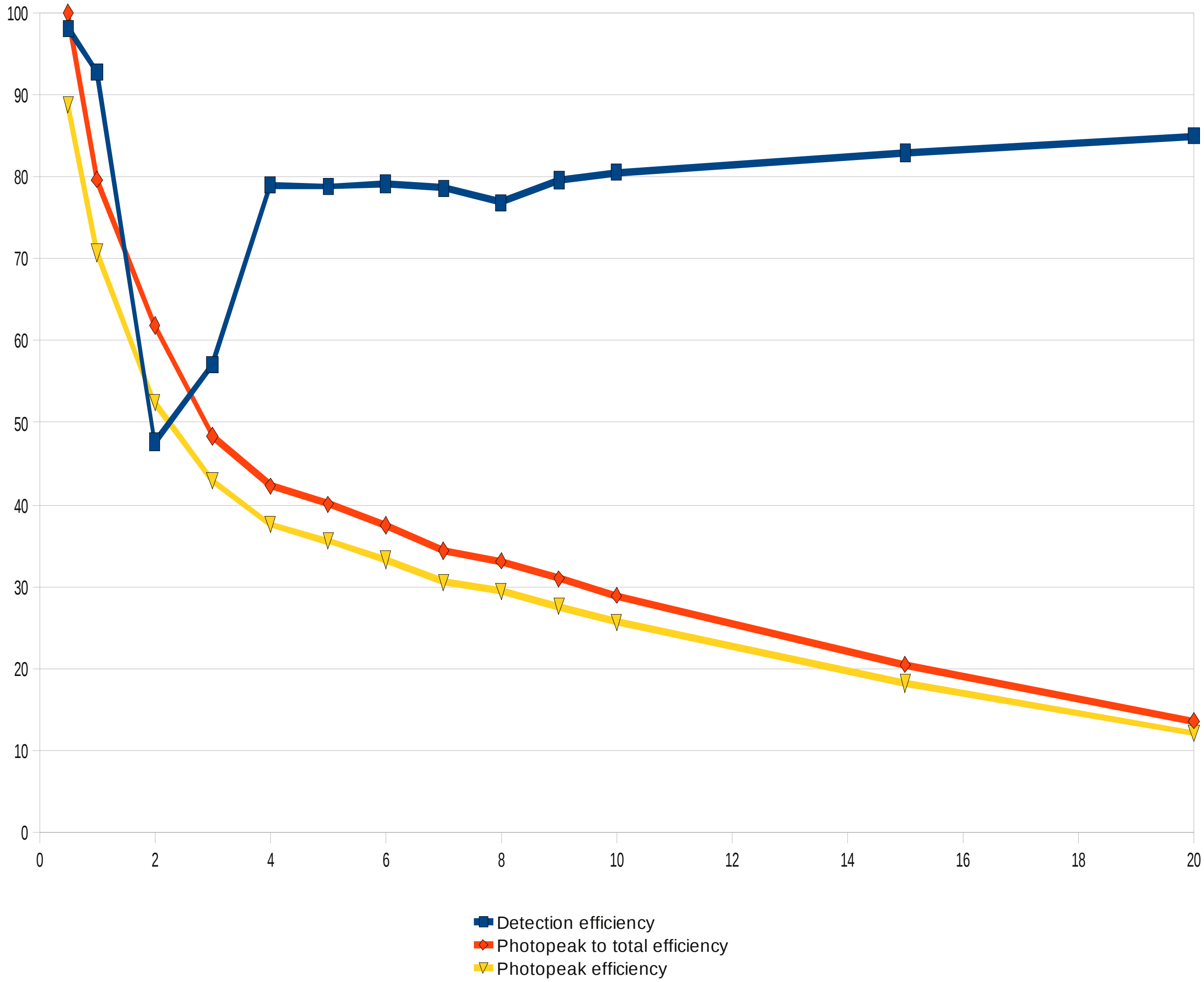

Figure 2: Detection efficiency, photopeak and photopeak to total efficiencies for a planar array of 5x5 cm and LaBr4cm+LaCl6 cm=10 cm height. Ered(10 MeV)=29%, Ered(20 MeV)=15%. Eyellow(10 MeV)=27 %, Eyellow(20 MeV)=12%. Eblue(10 MeV)=80 %. Eblue(20 MeV)=85 %.

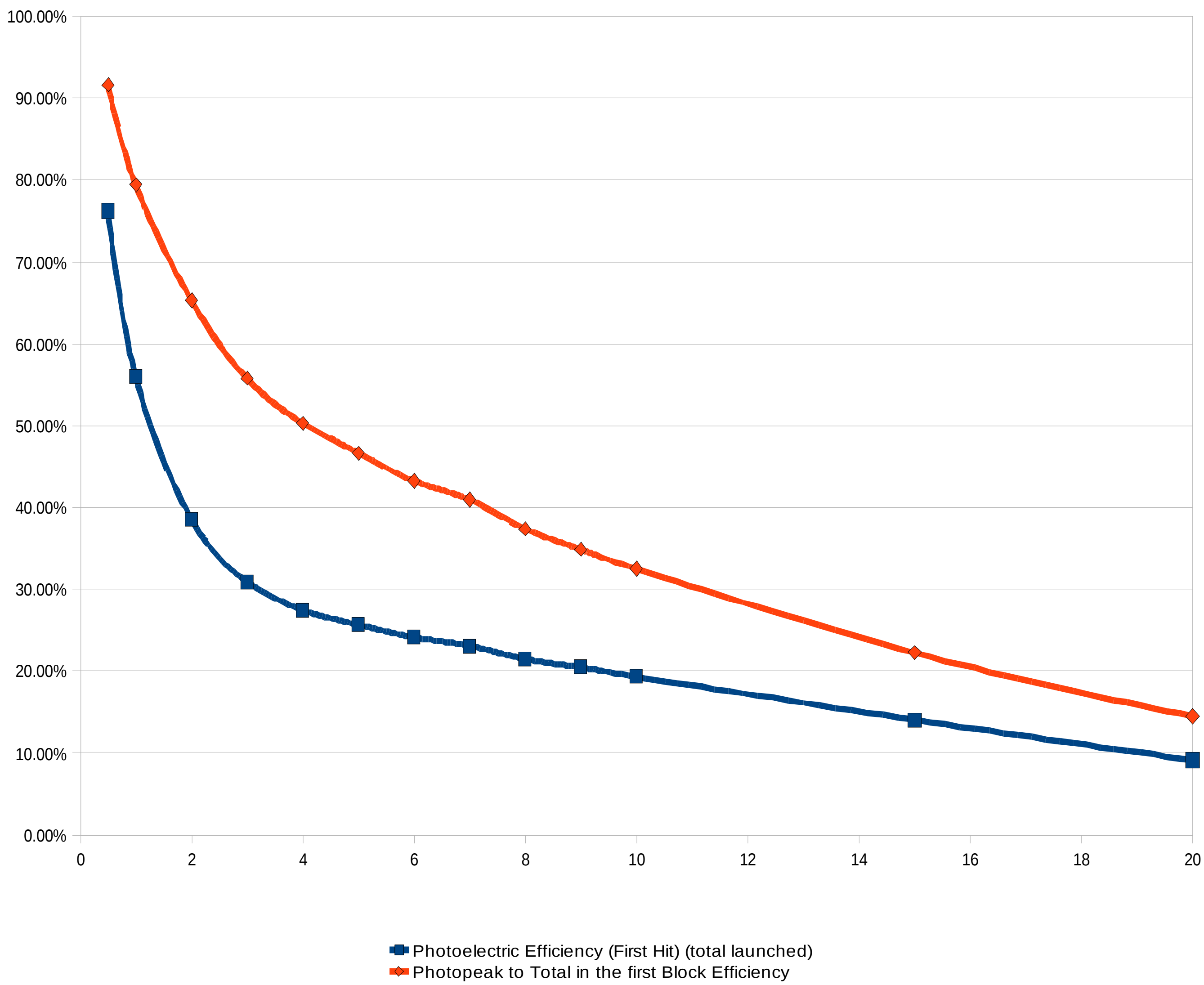

Figure 3: Efficiency for events that touch the first crystal and after contribute to the photopeak in anywhere of the crystal (Photoelectric Efficiency (first crystal) and Photopeak to Total in the first Block Efficiency) for a planar array of 5x5 cm and LaBr4cm+LaCl6 cm=10 cm height. Ered(10 MeV)=33%, Ered(20 MeV)=15%. Eblue(10 MeV)=20 % Eblue(10 MeV)=20 %.

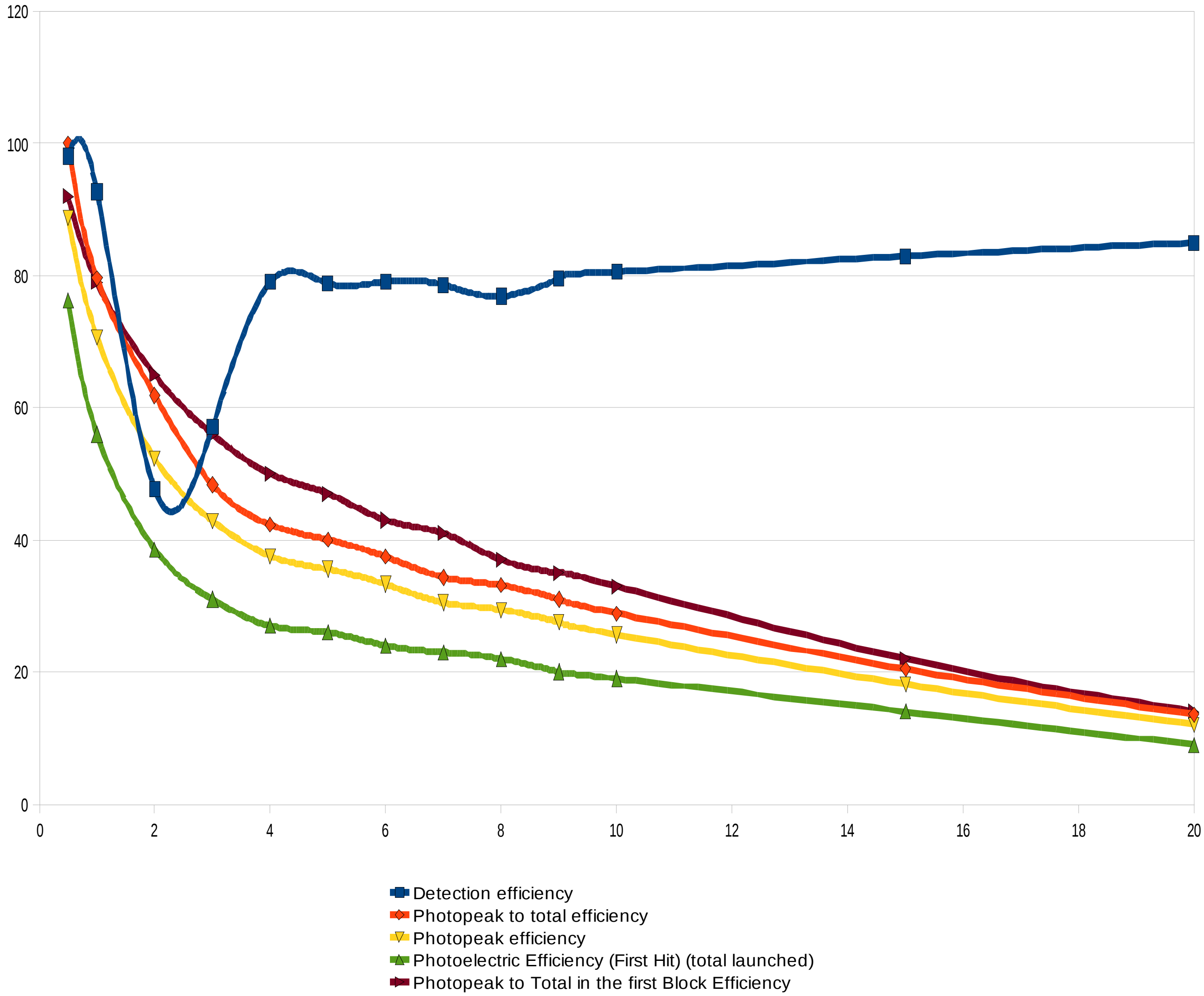

Figure 4: Comparison of previous efficiencies described: Detection (blue), Photopeak (yellow) and Photopeak to total(red), Photopeak-FirstHit (green) and Photopeak-FirstHit (purple) to Total efficiencies for a planar array of 5x5 cm and LaBr4cm+LaCl6 cm=10 cm height.

E (green)	E (green)	E (yellow)	E (yellow)	E(red)	E(red)	E(purple)	E(purple)
20 MeV	10 MeV	20 MeV	10 MeV	20 MeV	10 MeV	20 MeV	10 MeV
9.15%	19.34%	12.00%	25.00%	14.00%	29.00%	14.48%	32.41%

This means that the efficiencies for events that give the first hit in the first crystal and after contribute to the photopeak at any point inside the detector and normalized to the ones that give the first hit are the highest ones, so we can manage this efficiency as it is useful to calculate the photopeak efficiency of the detector.

We are only taking in account the events that contribute a 100 % to the photopeak, according to the table 1 but not the ones that are a 90% of the incident energy. If we took in account these ones the efficiency would be higher.

Case 2: 10x10x2.5x2.5x(4LaBr+6LaCl)

Same geometry, primary generator and physics is the same as in case 1.

Results:
We have obtained results for the different efficiencies studied: First hit in the first crystal and photoelectric effect anywhere inside normalized to total launched and to total detected..

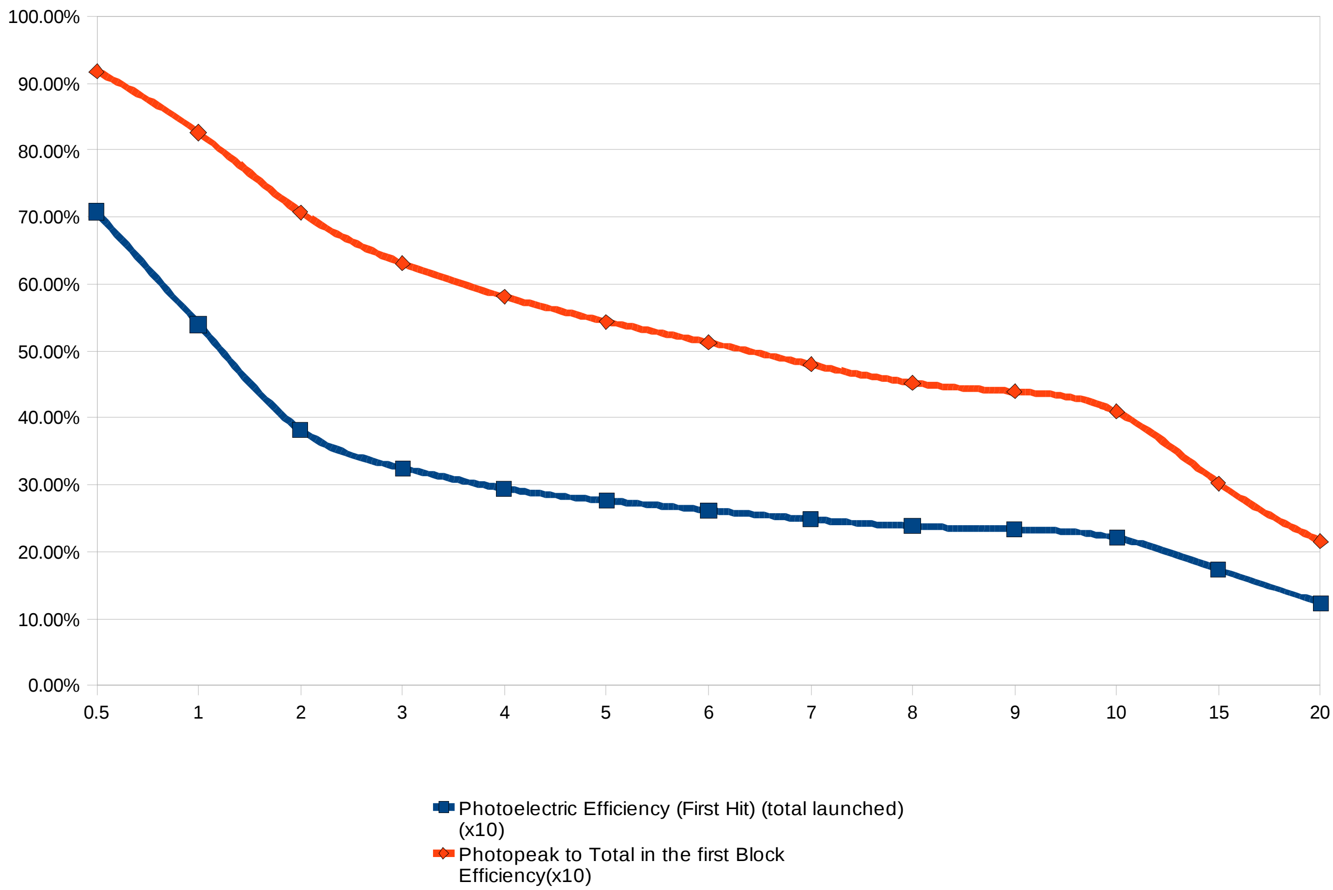

Figure 5: Efficiency for events that have the first hit in the first crystal and after contribute to the photopeak anywhere inside the arrray. Blue (normalized to total launched) E(10 MeV)=23%, E(20 MeV)=12%. Red(normalized to total detected) E(10 MeV)=43%, E(20 MeV)=22%.

The efficiencies firsh-hit--first-crystal-photopeak-anywhere-inside for an array of 10x10 are twice the value of the ones for an array of 5x5.

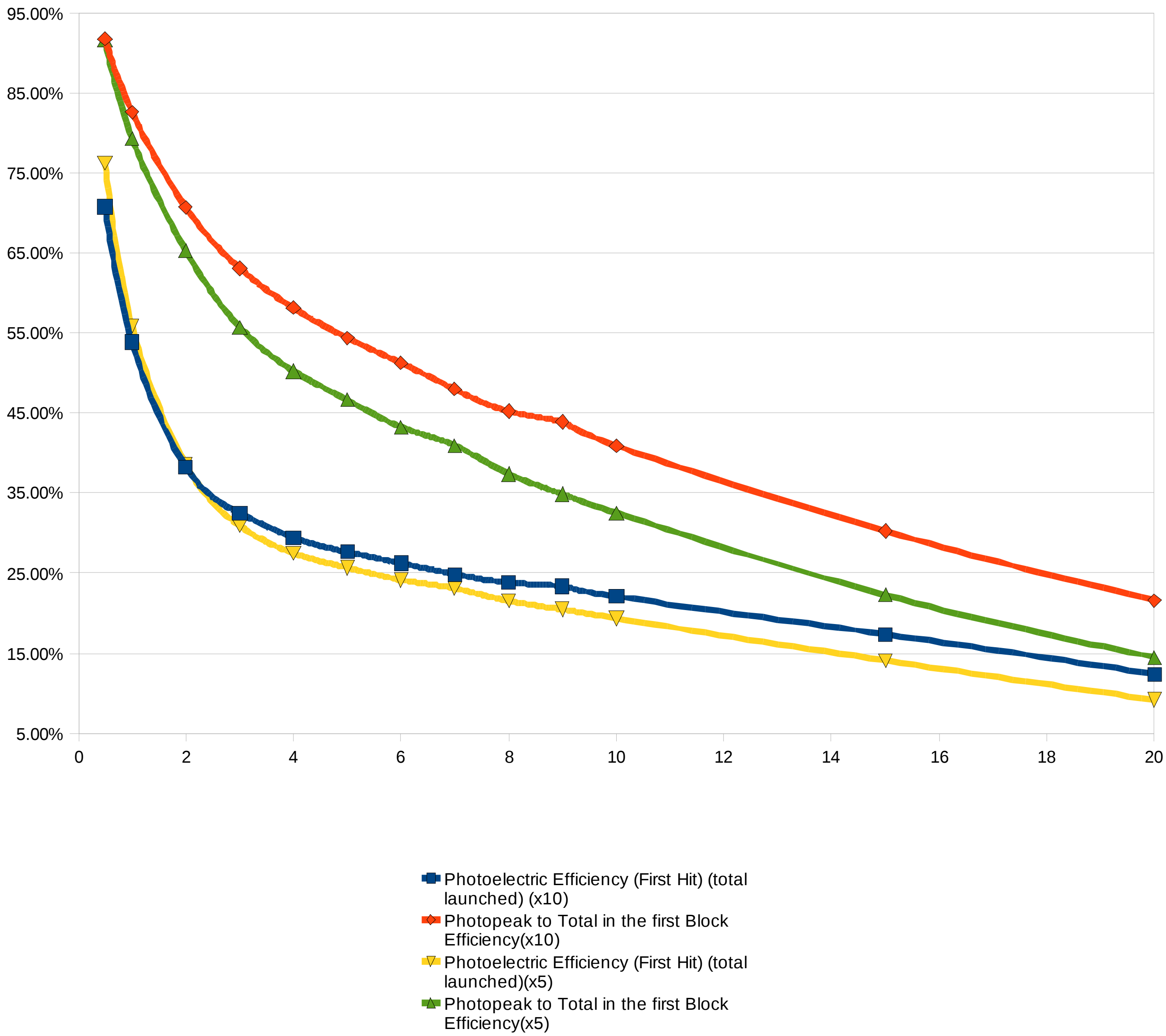

Figure 6: Comparison of efficiencies for events that have the first hit in the first crystal and after contribute to the photopeak anywhere inside the arrray in the case of arrays of 5x5 and 10x10. We can see the great difference between the arrays 10x10 and the arrays of 5x5.

Case 3: 20x20x2.5x2.5x(4LaBr+6LaCl)

Same geometry, primary generator and physics is the same as in case 1.

Results:
We have obtained results for the different efficiencies studied: First hit in the first crystal and photoelectric effect anywhere inside normalized to total launched and to total detected..

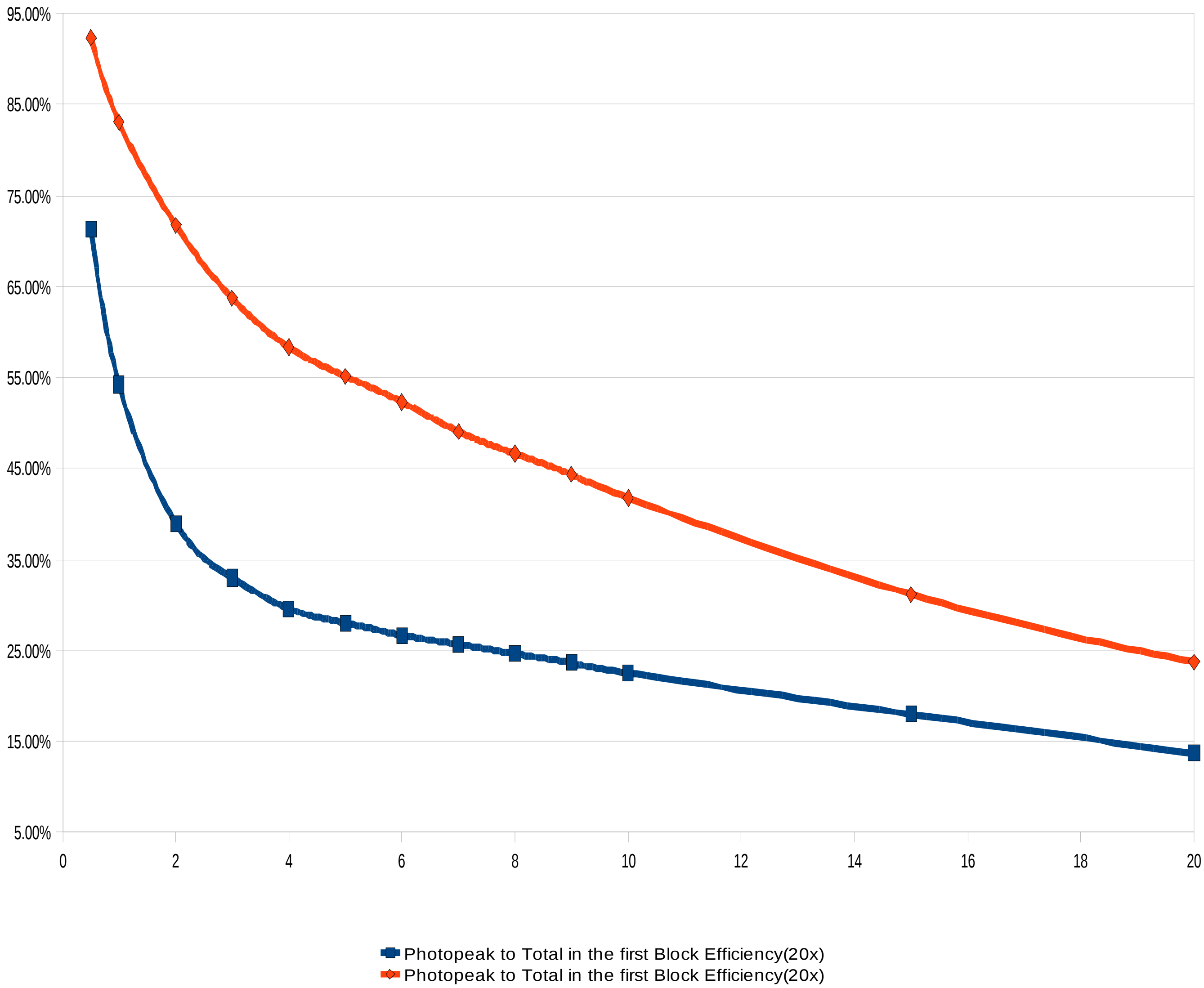

Figure 7: Efficiency for events that have the first hit in the first crystal and after contribute to the photopeak anywhere inside the arrray. Blue (normalized to total launched) E(10 MeV)=23%, E(20 MeV)=12%. Red(normalized to total detected) E(10 MeV)=43%, E(20 MeV)=24%.

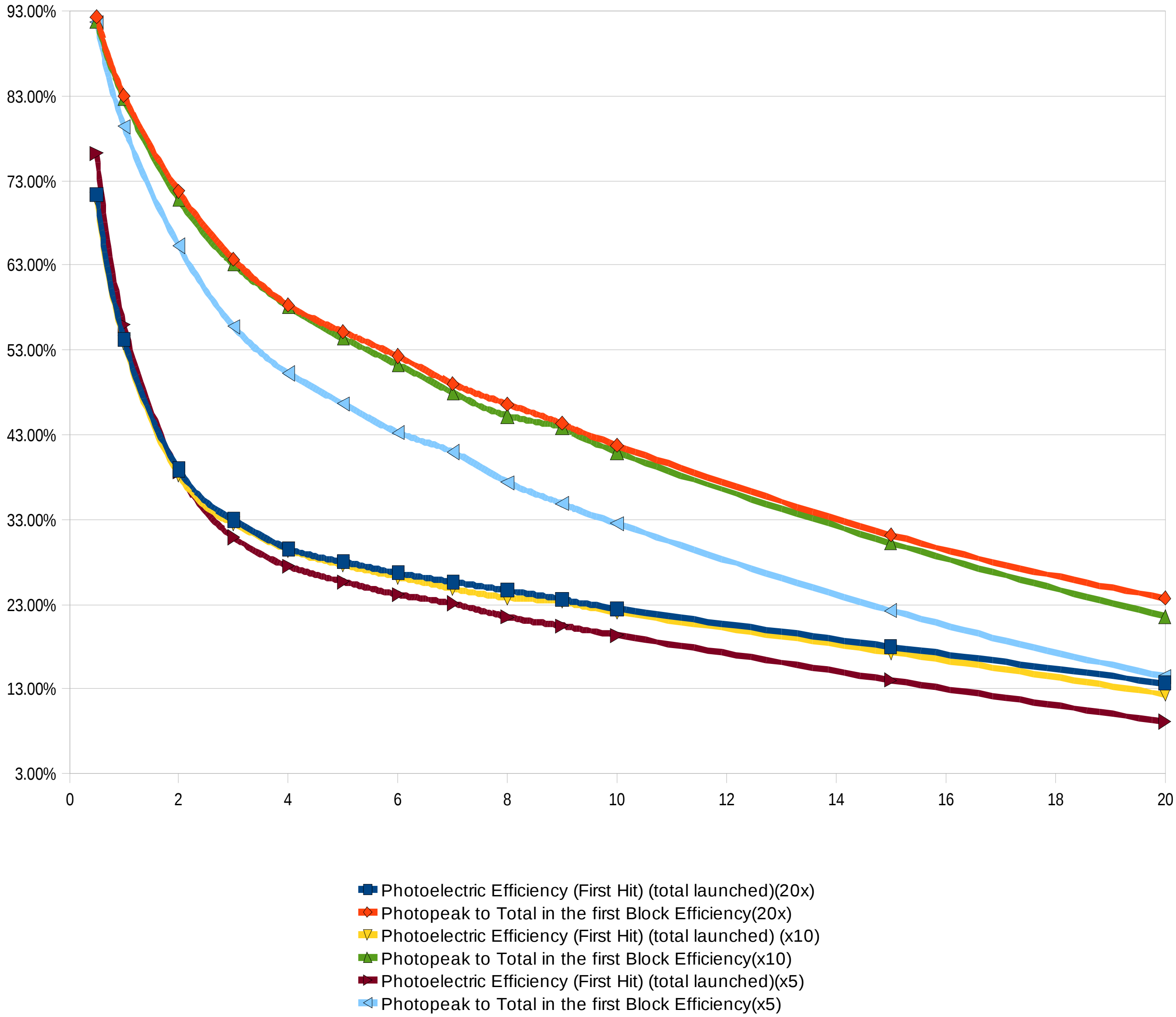

Figure 8: Comparison of efficiencies for events that have the first hit in the first crystal and after contribute to the photopeak anywhere inside the arrray in the case of arrays of 10x10 and 20x20. There is no meaningful difference between 10x10 and 20x20 arrays.

Case 4: 20x20x2.5x2.5x(4LaBr+16LaCl)

Same geometry but the depth (20cm) , primary generator and physics is the same as in case 3.

Results:
We have obtained results for the different efficiencies studied: First hit in the first crystal and photoelectric effect anywhere inside the detecto normalized to total launched and to total detected.

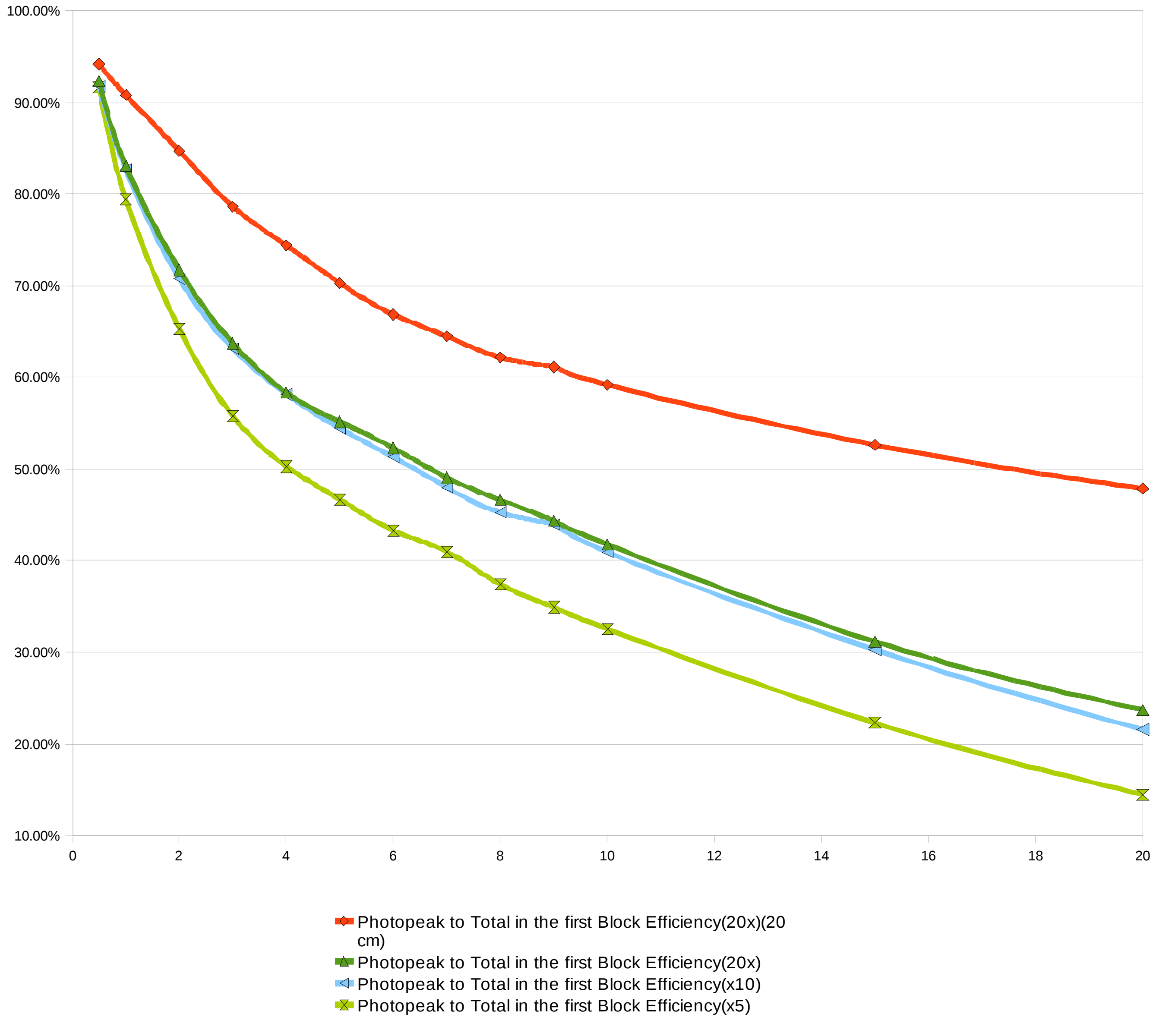

Figure 9: Comparison of efficiencies for events that have the **first hit in the first crystal** and after contribute to the **photopeak** anywhere inside the arrray in the case of arrays of 5x5, 10x10, 20x20 and 20x20 (20 cm). Efficiency now is higher because of the depth parameter (20 cm) (red). Ered (20MeV)=48%. **Ered(10 MeV)=59%**. The normalization is over the total number of events detected.

Discussion:

As we can see from previous results the depth parameter is the one that more affects for the study of photopeak efficiencies (number of counts in the photopeak) when launching gammas very focused on the center of the planar array. The other dimensions (X and Y direction) are relevant when transversal area increases from 5x5 (156.25 cm2) to 10x10 (625 cm2) though this increase stops here (there is no raise in efficiency from 10x10 to 20x20 (2500 cm2).

We consider then a good solution planar arrays of crystals of **10x10x(4+16 cm)** when studying efficiencies for events that have the **first hit in the first crystal** and after contribute to the **photopeak** anywhere inside the array. We achieve for **10 MeV** a **60% of photopeak efficiency** (counting the **number of events in the photopeak** according to the Table 1 and using the total of events detected for each energy as a normalization parameter).

However, as we want to simulate real nuclear experiments we must think about an increase of width in the photopeaks (owed to the finite resolution of the crystals and the electronics) and overlaps between photopeaks (gamma cascades) and Compton effects. Because of that we are going to suppose that the photopeak efficiency is a 90% of the incident energy and not only owed to the sum of counts in an ideal histogram of energy.

Case 5: Detection efficiencies for the previous arrays of crystals (5x5,10x10,20x20, 20x20(20 cm) and photopeak efficiencies considering the photopeak as the 90% of incident energy

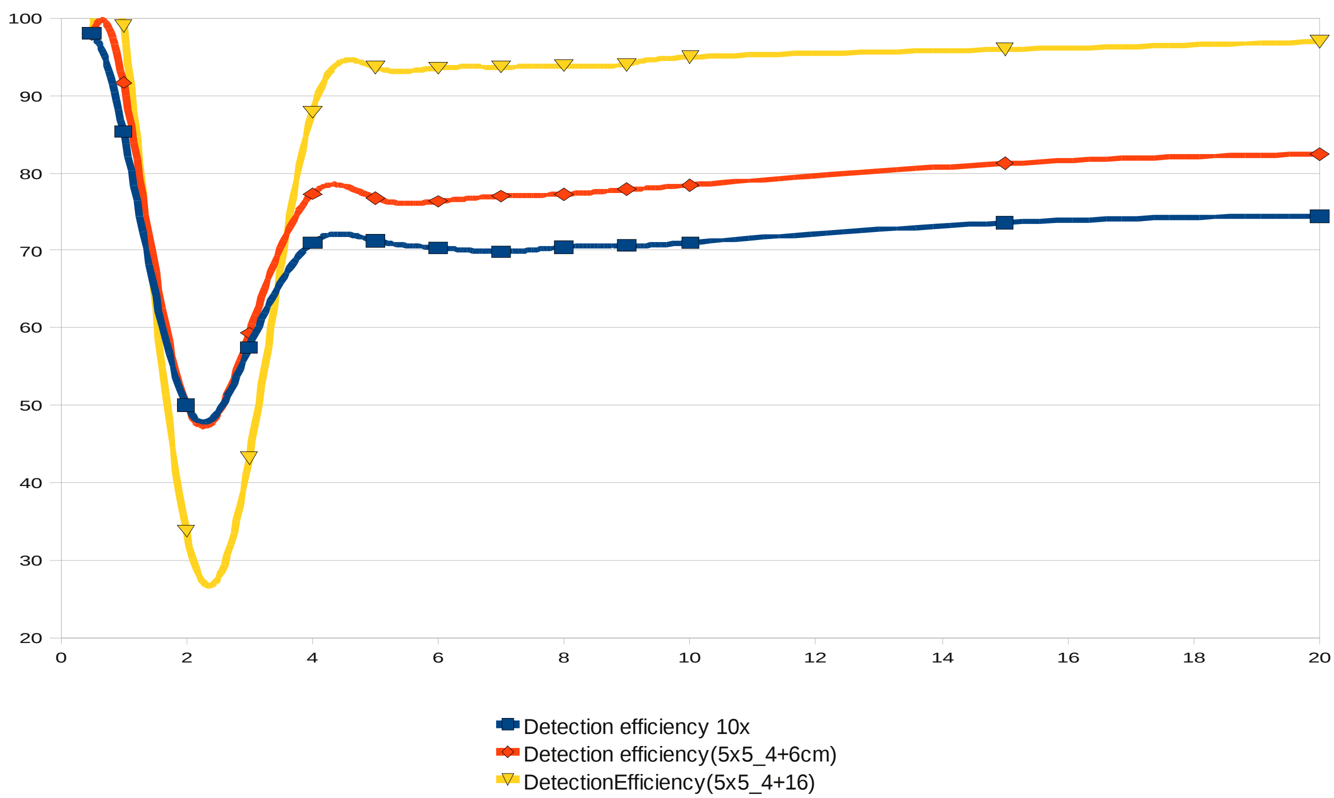

Figure 10. Energy Detection Efficiency for planar arrays of 10x10 (4+6 cm)(blue), 5x5 (4+6 cm)(red) and 5x5(4+16 cm) (yellow). Eyellow (10 MeV)=95% , Eyellow (20 MeV)=97%. Ered(10 MeV)=78%, Ered(20 MeV)=82%. Eblue(10 MeV)=71%. Eblue(20 MeV)=74%. **We must check these results.**

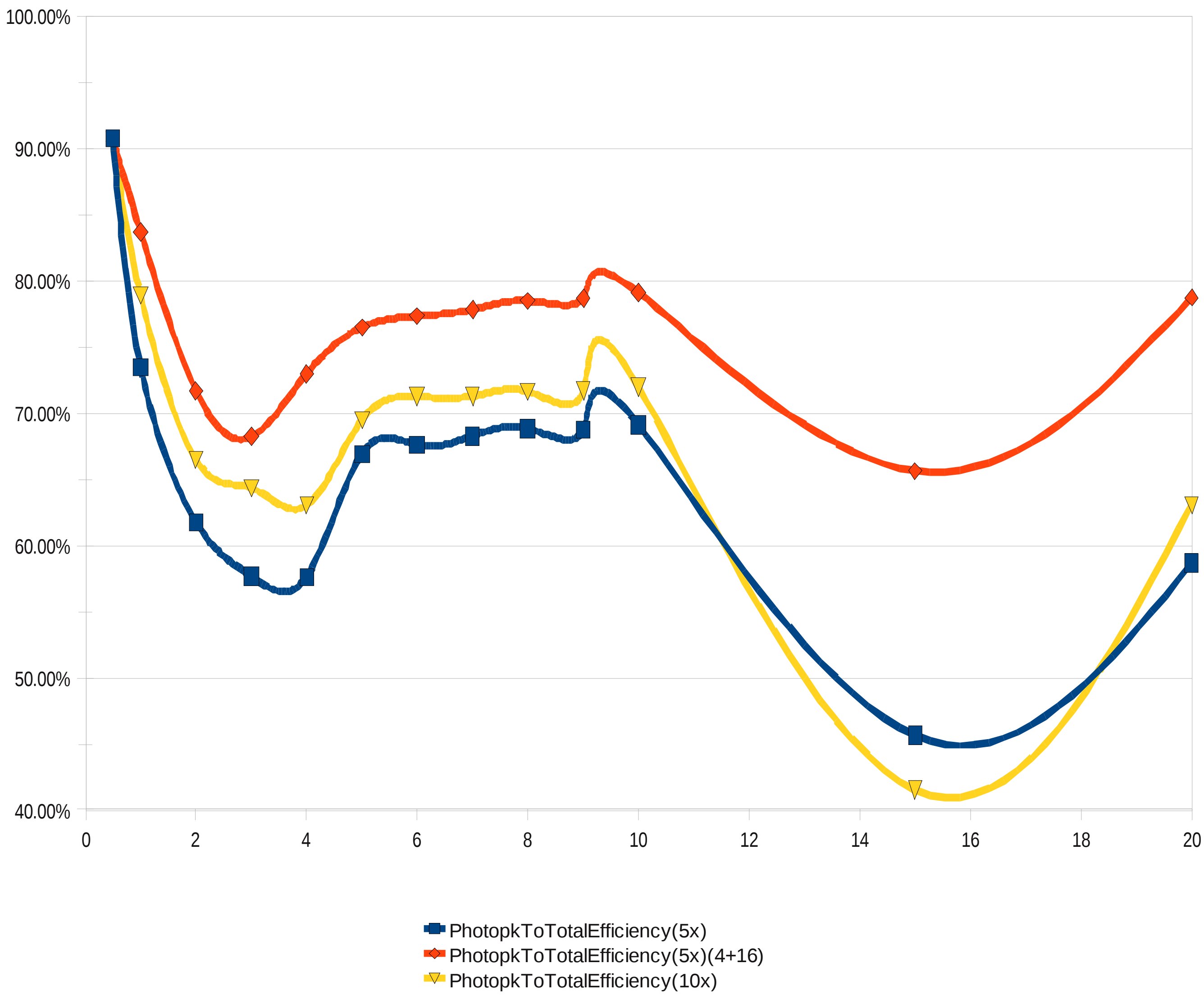

Figure 11. Efficiencies for events that have the **first hit in the first crystal** and after contribute to the **photopeak** anywhere inside the arrray in the case of planar arrays of 10x10 (4+6 cm)(yellow), 5x5 (4+6 cm)(blue) and 5x5(4+16 cm) (red). Eyellow (10 MeV)=75% , Eyellow (20 MeV)=63%. Ered(10 MeV)=82%, Ered(20 MeV)=78%. Eblue(10 MeV)=72%. Eblue(20 MeV)=59%. We must check these results.

Discussion:

The depth parameter in arrays plays again an important role too when we study the energy efficiency and the efficiency for events that have the first hit in the first crystal and after contribute to the photopeak anywhere inside the arrray. However the X-Y dimension is not so relevant: arrays of 5x5 and 10x10 have very similar efficiencies.

The second valley of energy is owed to the LaCl contribution for high energies.

We have obtained a very high total energy detection efficiency and photopeak efficiency for arrays of **5x5x(20cm=4+16 cm)** (Edetection(10 MeV)=95% and Ephotpeak(10 MeV)=82%). Good result!! It coincides with the study 3D energetic distribution of E. Nacher where the optimum geometry is 2x2x20 cm3.