R3B simulation towards a CALIFA end-cap in Phoswich configuration

José Sánchez del Río Sáez
IEM – CSIC – Madrid

NUSTAR meeting Lund September 2010

Outline

Introduction
- Requirements as gamma and proton calorimeter
- Structure and design
- Forward endcap: Phoswich and experimental results

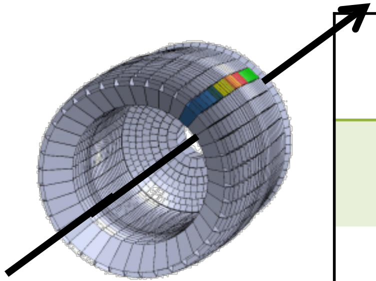
Towards an end-cap phoswich configuration using Geant4
- Choice of crystal length. How long 2nd crystal?
- Energy transfer to neighbouring crystals.
- Comparison of:
  - an array of 3x3 with array of 25x25 crystals

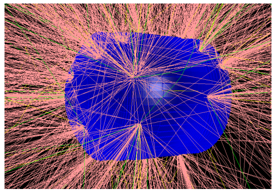
Optimal geometry for the end-cap

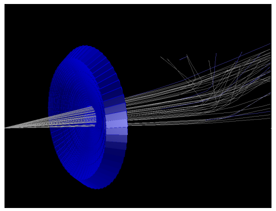
Conclussions and ongoing work

CALIFA Requirements

(CALorimeter for In-Flight gammA detection)







PROPERTIES	REQUIRED VALUES
Total absorption efficiency	80 % (up to E_γ= 15 MeV Labsystem)
γsum energy $\frac{\sigma(E_{sum})}{\langle E_{sum} \rangle}$	<10%
γmultiplicity $\frac{\sigma(N_\gamma)}{\langle N_\gamma \rangle}$	<10%
Good γenergy resolution	$\left(\frac{\Delta E}{E}\right)$ 3-5 %
Calorimeter for high energy light charged particles	Up to 300 MeV in Labsystem
Good light charged particle energy resolution	$\left(\frac{\Delta E_p}{E_p}\right)$ < 3 %

meassure γ (50 keV – 25 MeV) with optimal energy resolution (ideally < 5%)

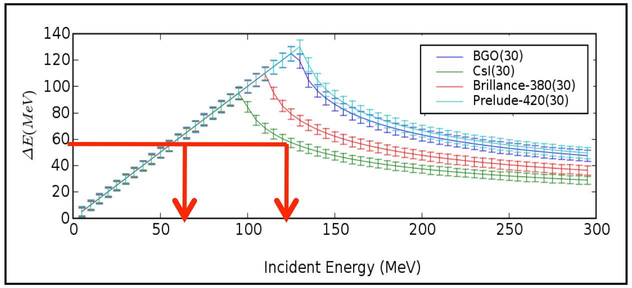
Barrel: Region from ~40º up to 130º in polar angles with 45% intensity

Forward endcap: From ~ 7º up to ~40º and concentrates 50% of the total gamma rays emitted by a moving source

Design features: few crystals, reduce dead volume and gammas escaping

Forward endcap: Phoswich

- **Design parameters**
  - **γ-rays in energy region 50 keV - 25MeV (emitted in flight)**
  - **Protons up to 300 MeV in Lab system**
- **Solution → two scintillator crystal layers in a phoswich configuration common readout (crystals must be optically compatibles).**
- **LaBr and LaCl have good energy resolution (3 % for 662 keV gammas and exhibit high light ouput (32+63 photons/keV)).**
  - **For protons: particle telescope ΔE/E identification: solve ambiguity**



$$-\frac{dE}{dx} = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \log \frac{2m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 \right]$$

Deposited energy by a charged particle in a material according to *Bethe-Bloch equation*

  - **For gammas: energy efficiency optimization at reduced cost**

Test Experimen: it works

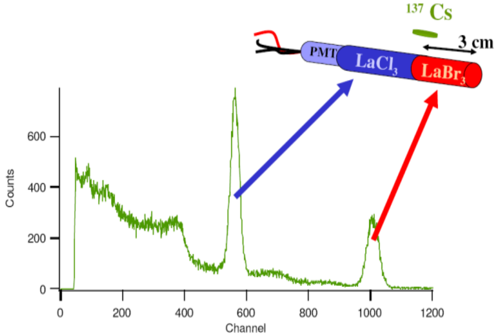
- Phoswich: LaBr3 (3 cm) + LaCl3 (5 cm)

ST. GOBAIN PHOSWICH

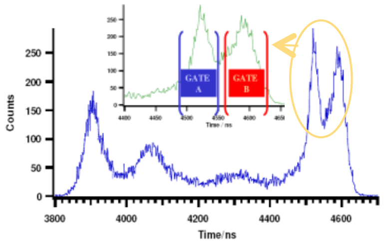
HAMAMATSU R5380 PMT

Material	EnergyResolution (at 662 keV) (%)	Light yield (photons/keVγ)	Decay time (ns)
$LaBr_3$	2.9	63	16
$LaCl_3$	3.8	49	28

PHOSWICH ENERGY SPECTRUM

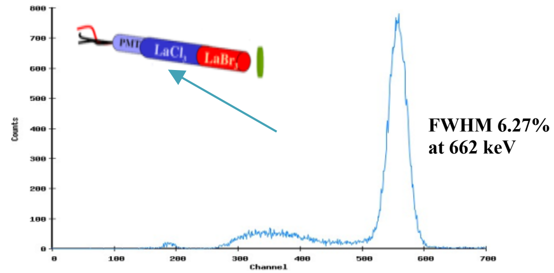


TEMPORAL SPECTRUM

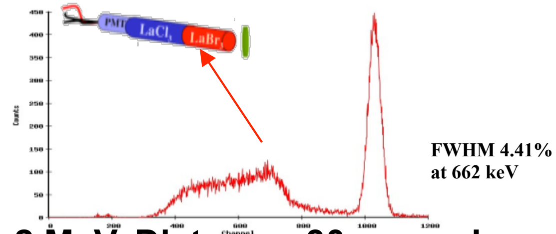


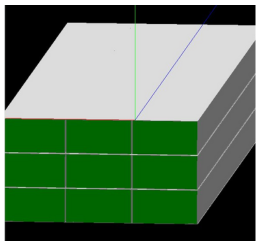
M.Turrión

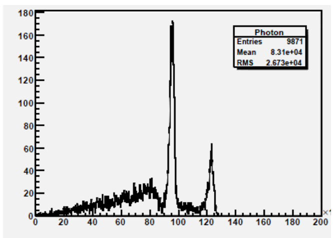
ENERGY SPECTRUM WITH GATE A

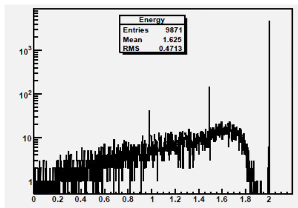


ENERGY SPECTRUM WITH GATE B









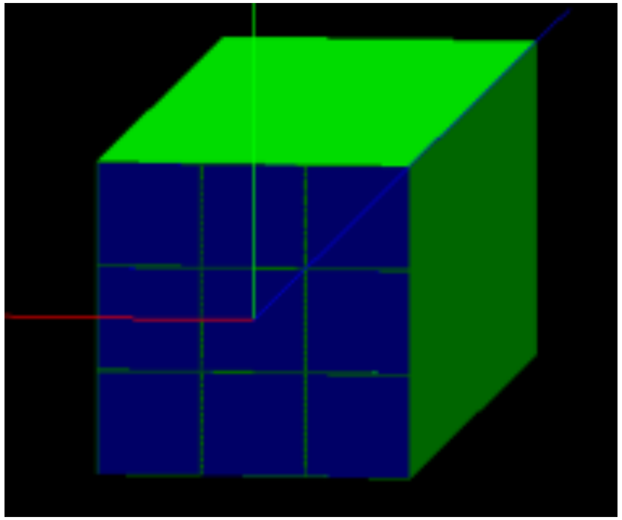
Simulation G4: Array 3x3 Phoswich configuration. 10.000 gamas, 2 MeV. Distance: 30 cm and radius of the beam: 2 cm. Individual crystals covered by tefflon.

Crystals optimization: G4 ***simulations***

- **Geant4 simulation:**
  - **Optimize size of each crystal in phoswich configuration**
  - **Analysis escape to neighbouring crystals: compromise between number of crystals, dead volume, detection efficiency and cost**

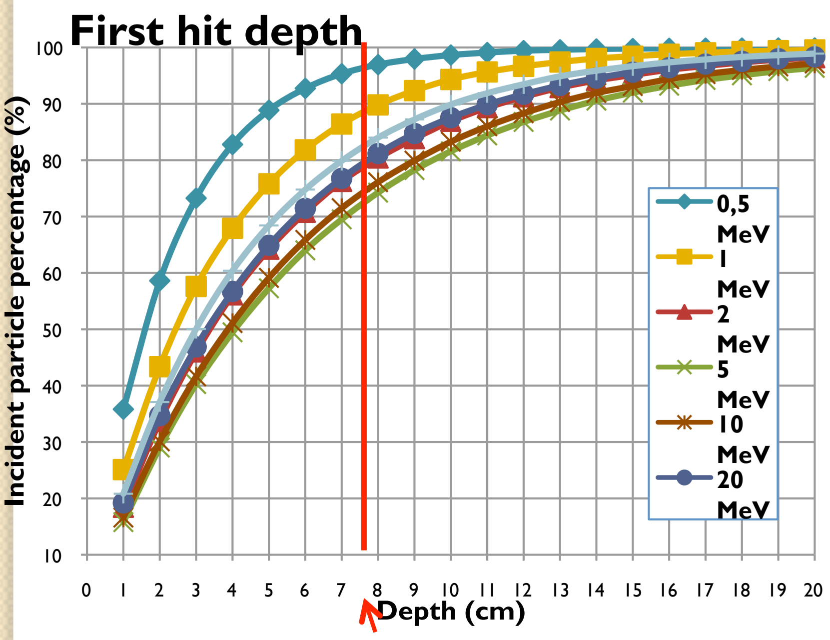
First configuration analyzed is:

- **$LaBr_3$ in a 3x3 array.**
- **20x20 mm^2 frontal surface of each crystal**
- **Total energy deposited (9 crystals)**
- **Gamma-rays from 500 keV up to 30 MeV**
- **Incidence on central crystal**
- **Radius of the beam: 2 cm**
- **Distance source-detector: 30 cm**



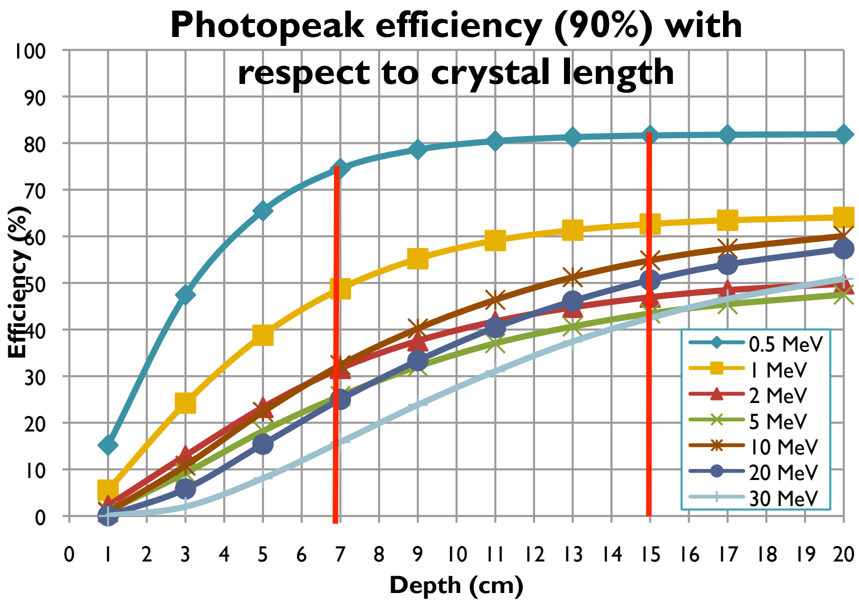
Optimize the Phoswich

interaction depth in LaBr



With 7 cm length we get 70% (at least) incident particles have been detected.
→ selection for length of first crystal

Photopeak efficiency vs crystal length



>15 cm of $LaBr_3$ practically efficiency doesn´t improve:
→ hint to total phoswich length

Let me remind you the aims…

A brief summary:

1. **Phoswich configuration: 7 cm LaBr + 8 cm LaCl**
2. **Problems associated to this length, → high cost & not optimized for protons**
3. **According to last point: we need further to optimize the length!!!**

How to proceed?

4. **Study different energy detection efficiencies of the planar arrays of phoswich crystals (3x3)**
5. **Same dimmensions of the existing PHOSWICH**
6. **To improve energy efficiency we will study the relevance when working as calorimeter → (arrays 25x25)**

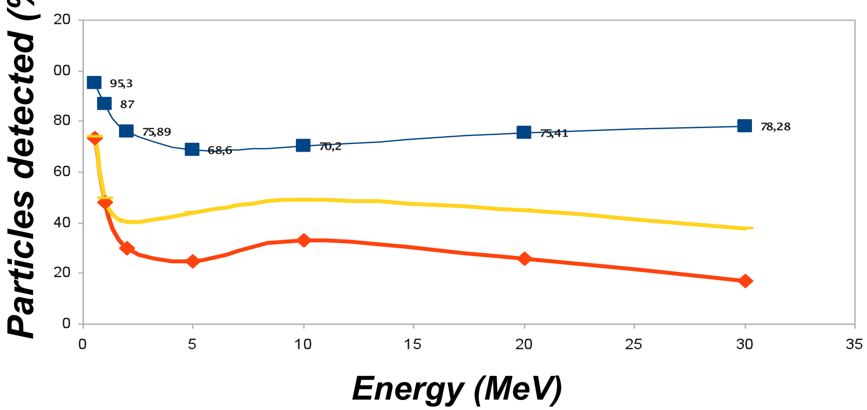
What to obtain?

8. **Recover the detection efficiency summing from neighbours**

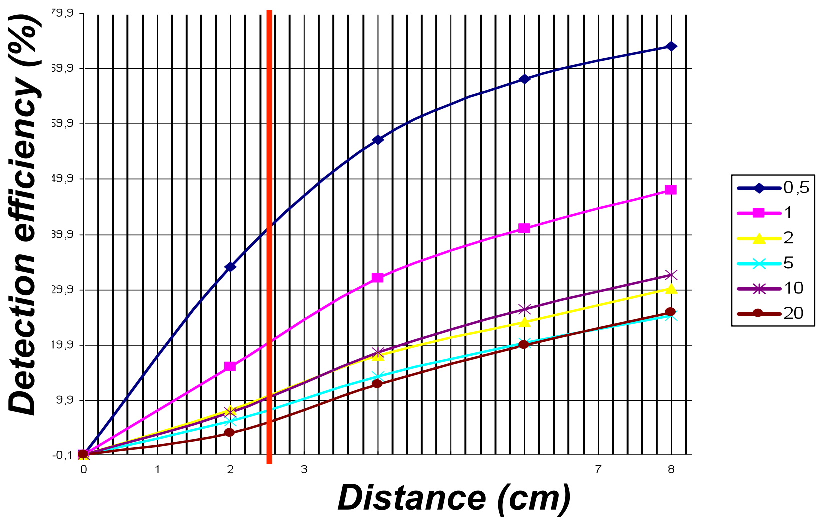
Single Phoswich 3+5 cm cathastrophy!!

Array 3x3, 15x29x(3+5), Phoswich

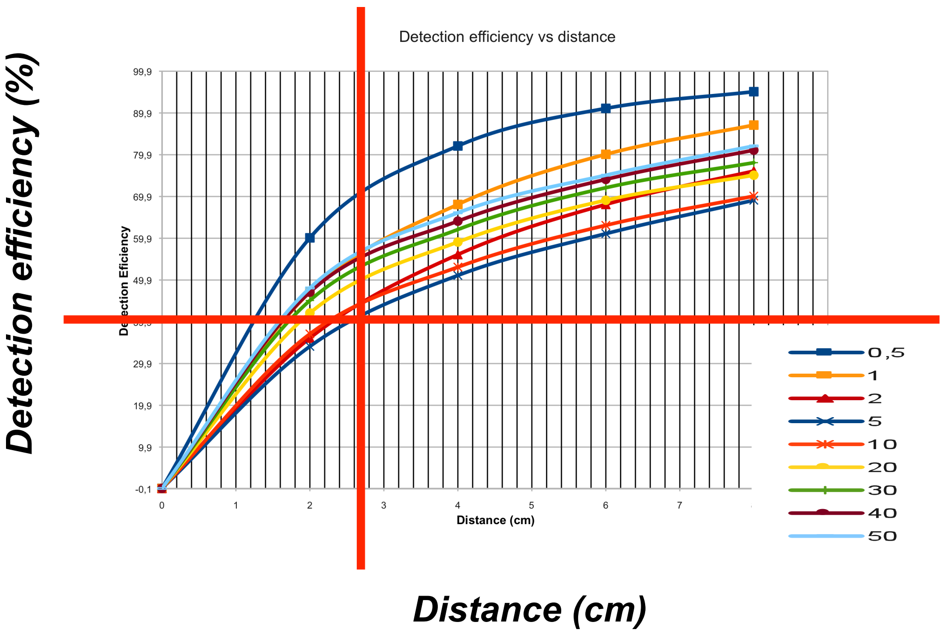
Detection efficiency vs Energy



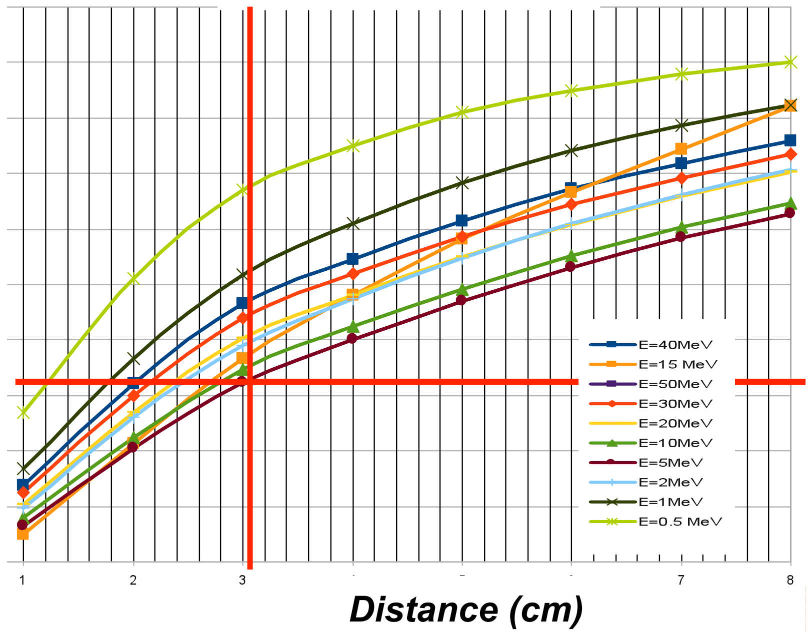
Photopeak efficiency vs distance



Detection efficiency vs distance



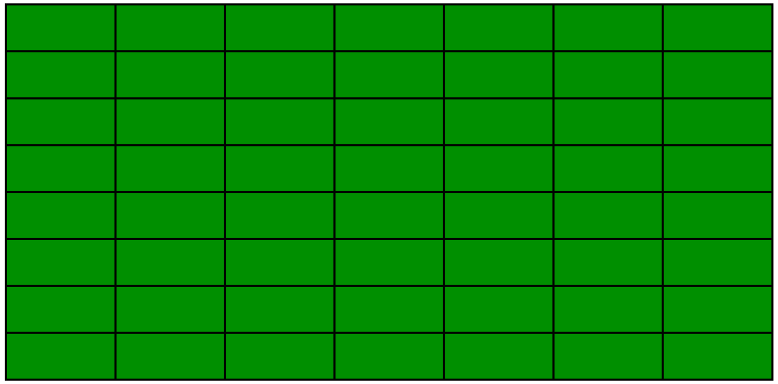
First hit vs distance



Escape to neighbouring crystals

Summing as calorimeter can one recover efficiency?

Simple test geometry



Planar Array **25x25**
Phoswich config
Angular resolution: 3.5º

Aims of this study:

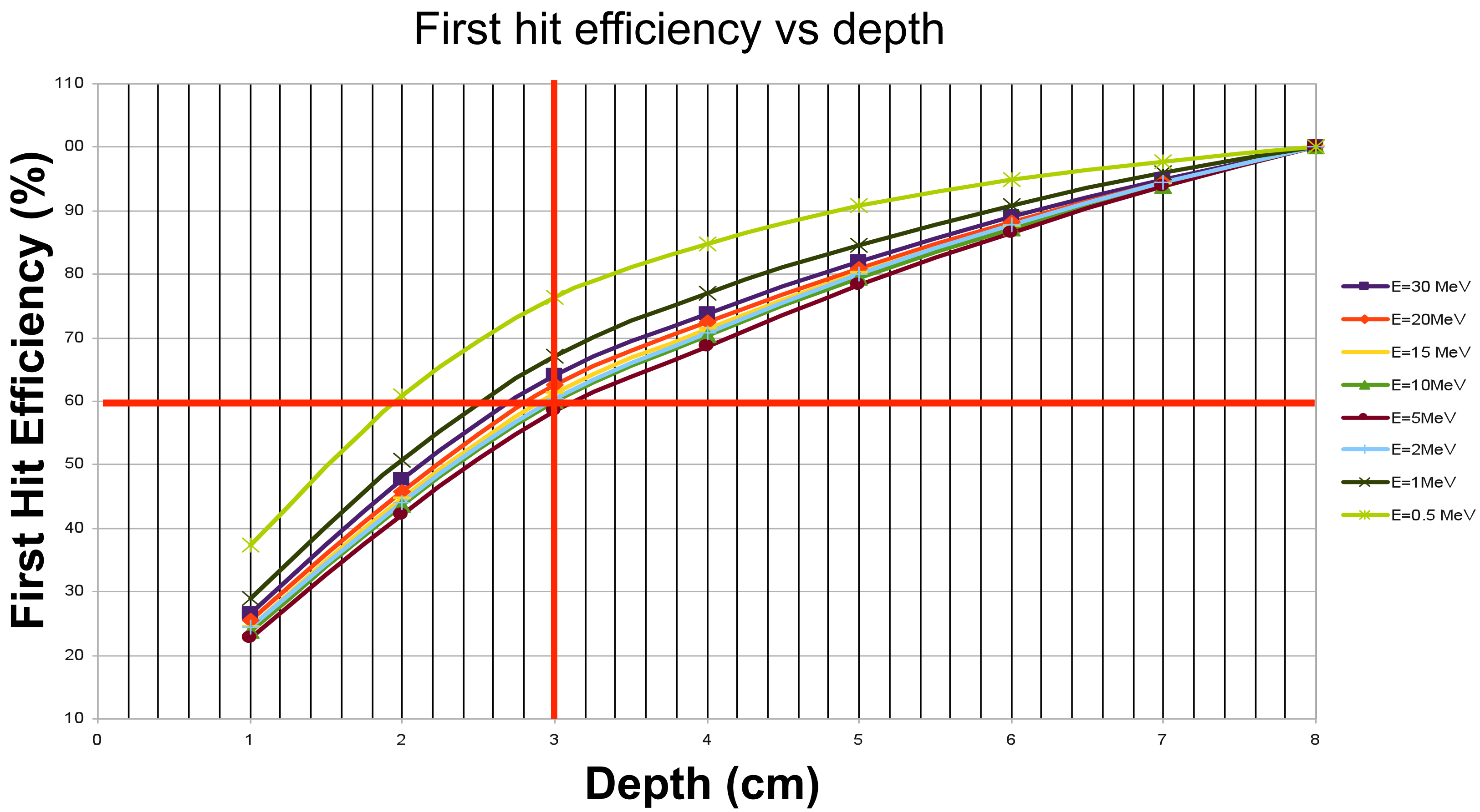
1. Study the same energetic efficiencies than in previous simulations

2. Compare them with previous results

3. Can be the planar array a possible geometry for the end-cap?

Energy transfer to neighbouring cristals

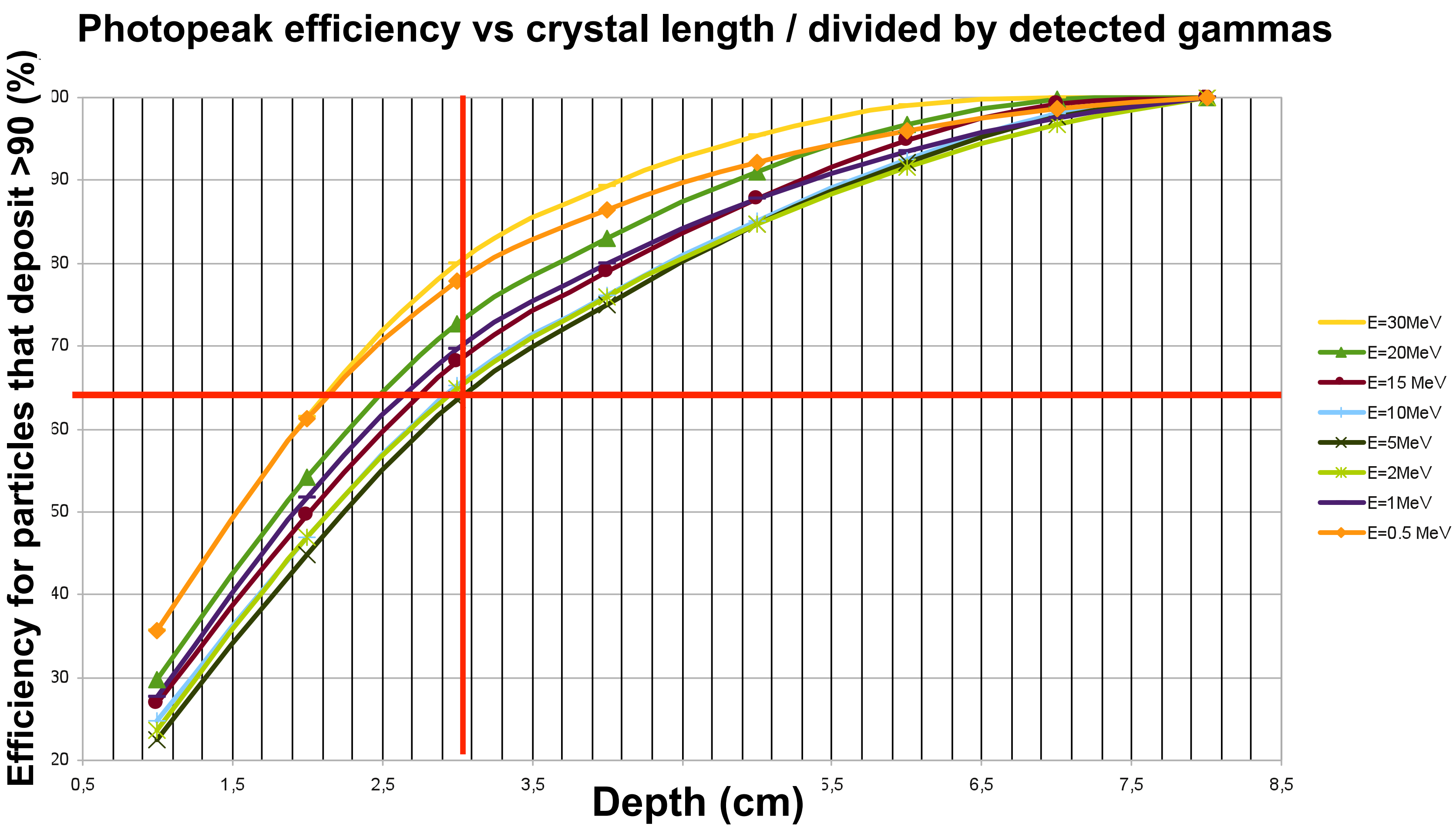
The planar array



The number of gammas that deposit energy per cm increases when counting escape to neighbours (60 %)

Energy transfer to neighbouring cristals

The planar array



The number of gammas that deposit more than 90 % of initial energy increases when summing the energy transfer to neighbours (65 %)

Energy transfer to neighbouring cristals

The planar array

Summary

The detection efficiency is recovered when summing energy deposited in neighbouring crystals.

Already with (LaBr:3cm+LaCl:5cm) one reaches 65% photopeak efficiency counting the gammas that have had any interaction in first 3cm!

A planar array of crystals as a wall is a possible option as “separate front detector”,
however, very critical which angle to switch from Barrell to Front wall

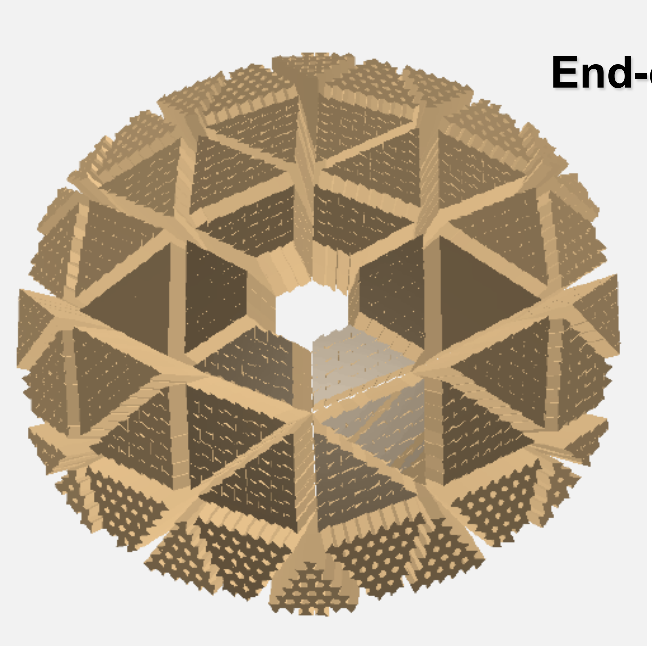
a) Easy to fabricate. Good anglular resolution and detection efficiency

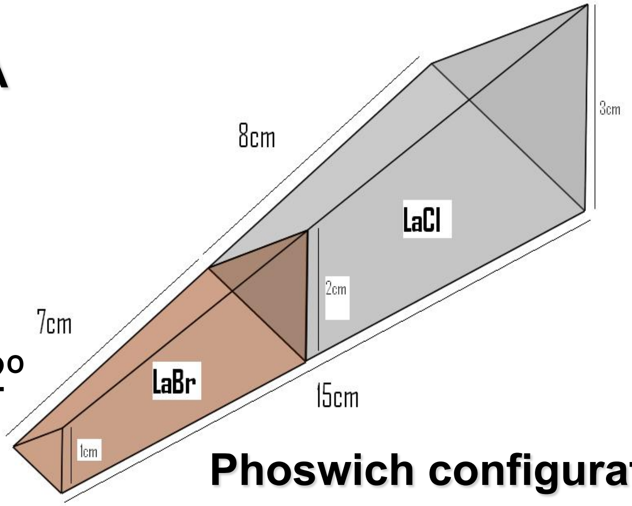
b) However, better to adapt “perfectly” to Barrell → rectangular prism crystals → to increase energy detection efficiency vs polar angle

geometries proposed for the forward-end cap CALIFA

Triangular Prisms

End-cap CALIFA



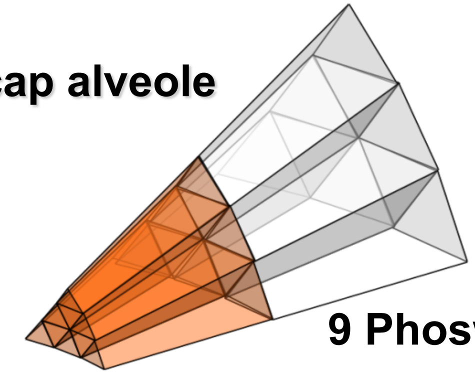


$\Theta = 2^o$

Phoswich configuration

	Volume (cm3)	Weight	# Crystal types
LaBr 6.74		35 g	1
LaCl 21.41		80g	1
Alveole 280		1 kg	9

End-cap alveole

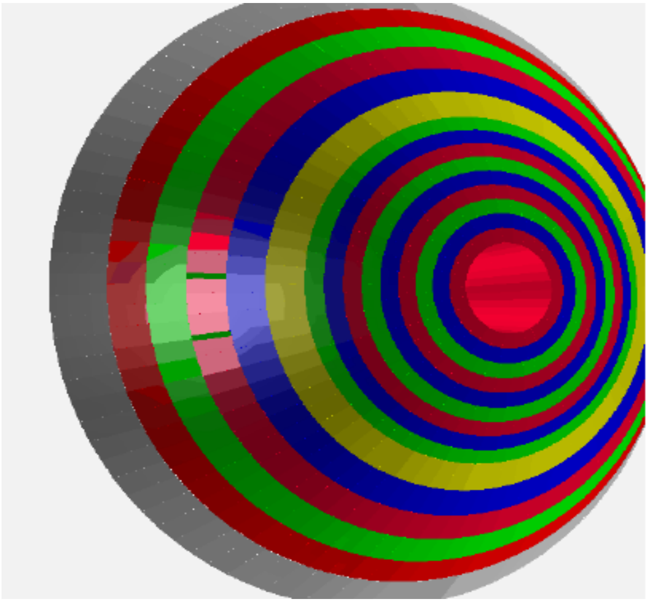


9 Phoswich crystals

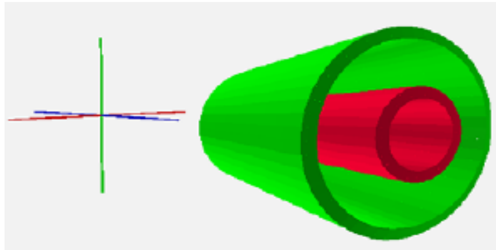
Characterisitcs of an alveole

Different geometries proposed for the forward-end cap CALIFA

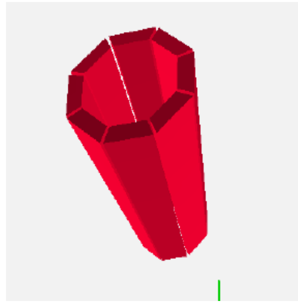
Irregular Rectangular Prisms: a very good candidate

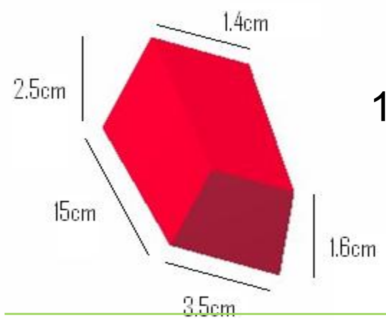


End-cap CALIFA



Different rings





1Phoswich crystal

Total # crystals	456	636	904
Total Weight (kg)	302	312	309
Number of rings	14	17	21
Number of alveoles	114	159	226
Angular resolution	3	2.5	2

Summary

- **Studdied possible end-cap configuration for CALIFA**
- **Phoswich, two crystals (LaBr) + (LaCl)might be an optimum solution**
- **reducing the length we lose efficiency though with neighbouring crystal we recuperate the good efficiency**
- **three possible CALIFA end-cap geometries proposed: planar, semi spherical using triangular or rectangular prisms.**

Ongoing work

- **The same optimization simulation but for protons**
- **Study angular, energy effiencies for the different geometries proposed**
- **Implementation LITRANI for creation and propagation of scintillation photons to obtain realistic spectra with energy resolution of crystals.**

Thank you for your attention

Thank you for your attention