R3B simulation for CALIFA in Phoswich configuration

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Outline

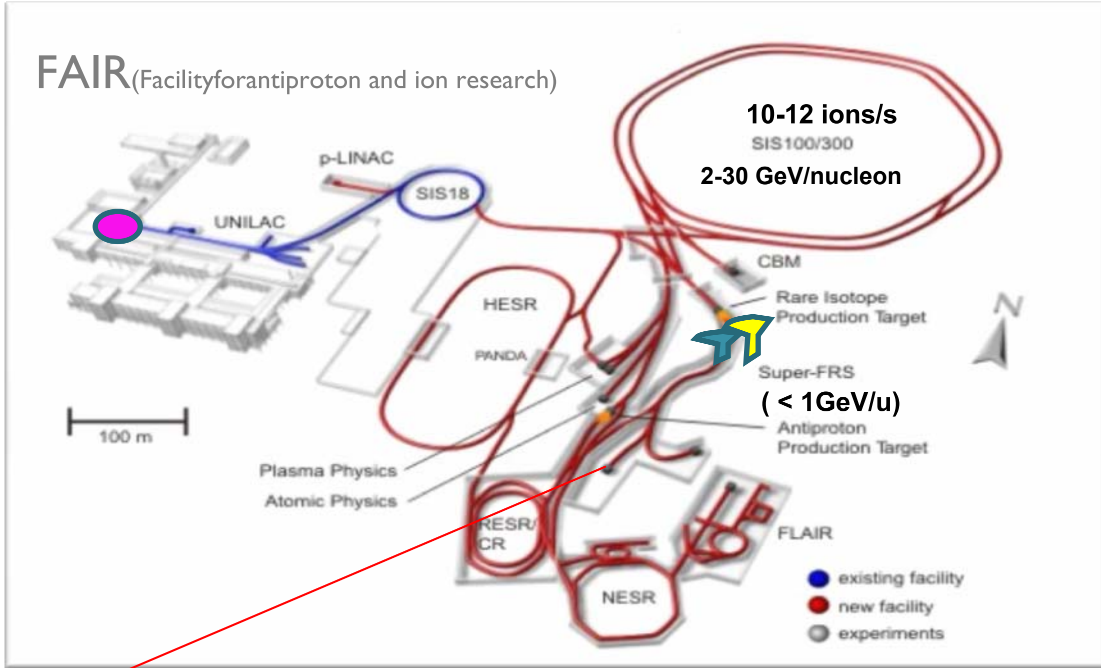
Introduction
- FAIR at GSI (Germany)
- R3B Experiment

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

Towardsanend-cap configuration using Geant4
- Choice of crystal length. How long 2nd crystal?
- Energy transfer to neighboring crystals. Array 3x3 energies studies
- Simulations with arrays of 25x25
- Best geometrical possibilities for the end-cap

Conclussions and future aims

FAIR (Facility for Antiproton and Ion Research)

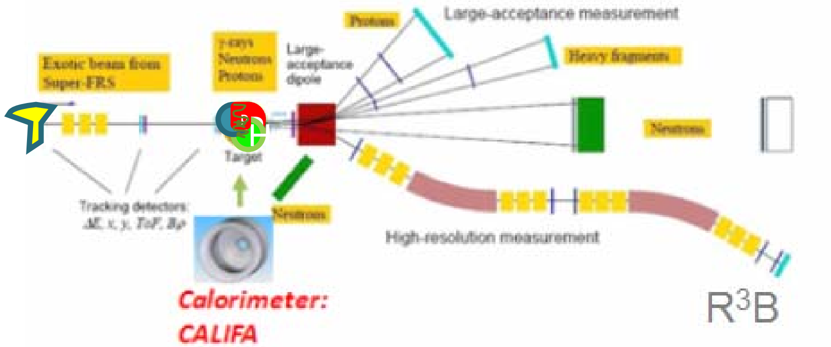


Pillar of Fair: Program centered on the exotic radioactive beams delivered from the Super - FRS

NUSTAR
(planned experiments folowing the FRS)

R3B project: a fixed Target Experiment within NUSTAR

R^{3}B

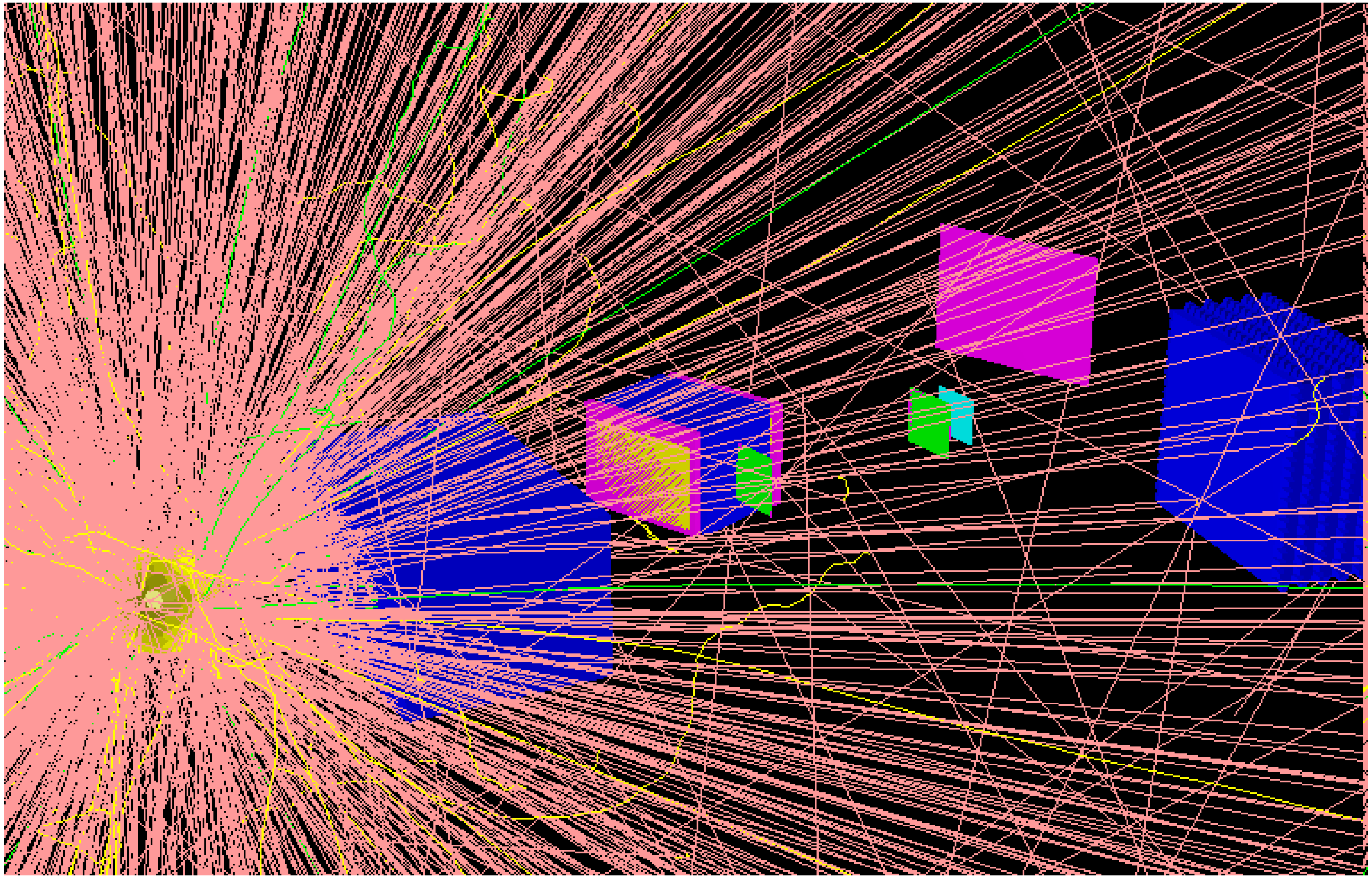


NUSTAR
(Nuclear STructure, and Astrophysics Research)

Benefits from the super-FRS beams (0.32 GeV/u)with the characteristics inherent to the inflight production method.

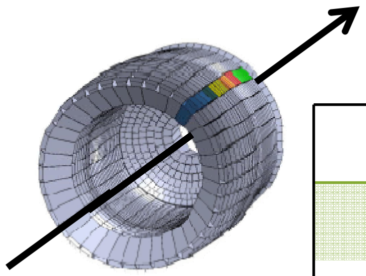
Many detectors that allows to identify the fragments from the beam delivered by the FRS and determine the momentum before and after the reaction in the target, the same as to detect the decay products.

The R3B Set-up in FAIR simulated with R3BRoot



CALIFA's Requirements

(**CAL**orimeter for **I**n-**F**light gamm**A** 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	3-5 % $\left(\frac{\Delta E}{E}\right)$
Calorimeter for high energy light charged particles	Up to 300 MeV in Labsystem
Good light charged particle energy resolution	< 3 % $\left(\frac{\Delta E_p}{E_p}\right)$

***Prime mission:* measure γ (50 keV – 25 MeV) with optimal energy resolution (ideally < 5%)**

R³B Calorimeter Collaboration:

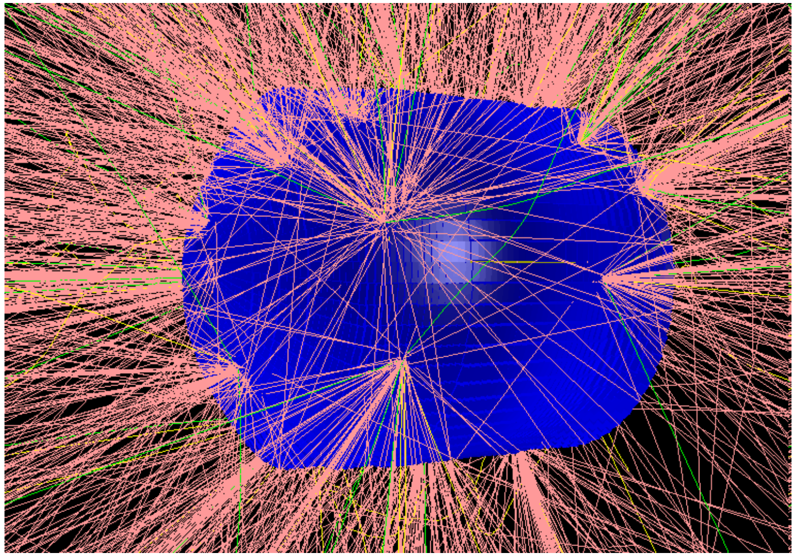
USC (Spain), LUND (Sweden), IEM (Spain), GSI (Germany), Chalmers (Sweden), Daresbury (UK), Univ. Complutense (Spain), KTH Stockholm (Sweden), IPN Orsay (France), JINR (Russia), TUD (Germany), TUM (Germany)

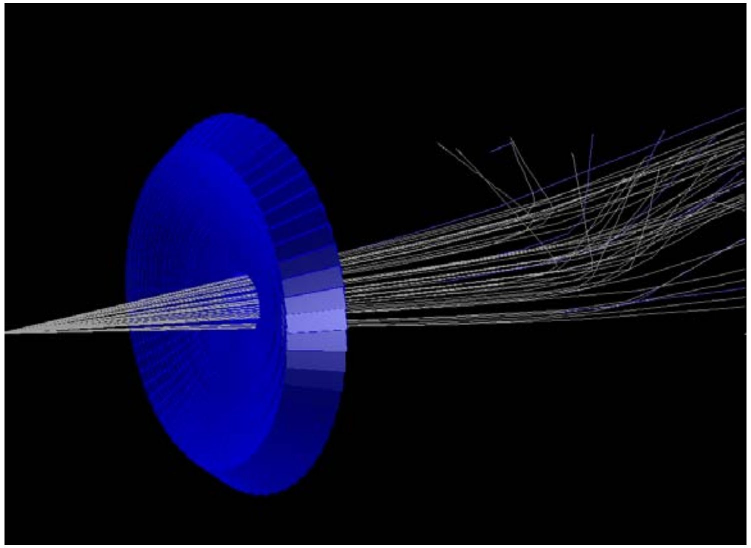
CALIFA's Structure

Based on angular distribution of emitted γ-rays and its corresponding Doppler shift which is more important for low than for high polar angles **(because of γ rays sources are moving with relativistic energies).**

◦**Barrel:** Region from ~40° up to 130° in polar angles with 45% of gammas rays emitted in this direction

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





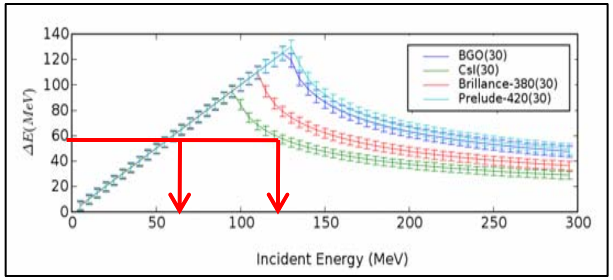
This region, particularly between 20-40º is extremely complex because it concentrates a large fraction of the gamma emitted. Also the Doppler shift boosts the energy to 1.5-2.5 times its value.

Design features: minimum set, reduction of empty space and gammas escaping

Forward endcap: Phoswich

- **Design of CALIFA's forward endcap.** CALIFA has to record:
  - **γ-rays in the energy region 50 keV - 25MeV (emitted by a moving source)**
  - **Protons up to 300 MeV in Lab system**

- The length of the cristals should be selected according to the detection efficiency at different energies
- Our suggestion: two **scintillator** crystals layers **in a phoswich configuration** with only one common readout (crystals must be optically compatibles).
- The LaBr and LaCl have both very good energy resolution (3-4% for 662 keV gammas and exhibit high light ouput (32+63 phot/keV)).
  - For **protons**: useful for particle telescope ΔE/E identification: solve ambiguity



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

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

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

Experimental tests

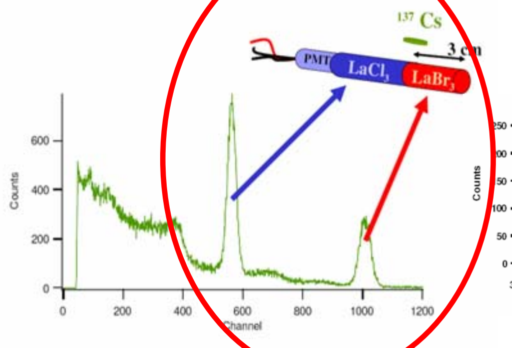
- Phoswich: $LaBr_3$ (3 cm) + $LaCl_3$ (5 cm)

ST. GOBAIN PHOSWICH

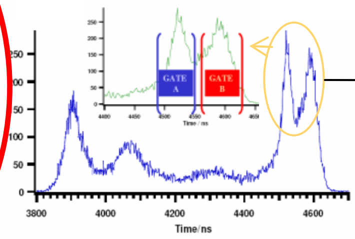
HAMAMATSU R5380 PMT

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

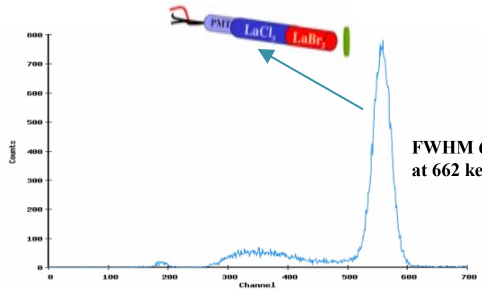
PHOSWICH ENERGY SPECTRUM



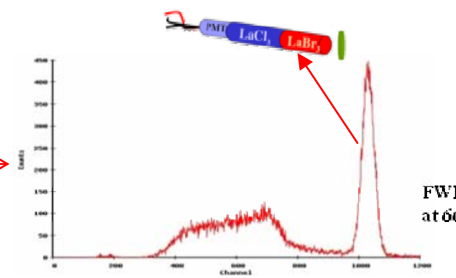
TEMPORAL SPECTRUM



ENERGY SPECTRUM WITH GATE A

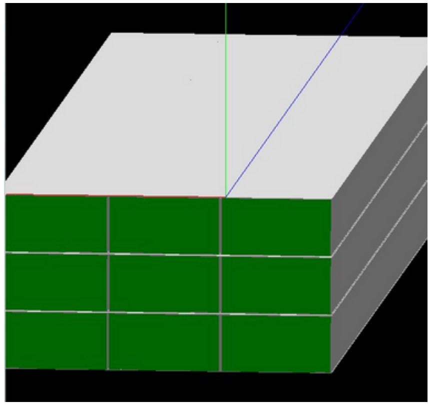


ENERGY SPECTRUM WITH GATE B

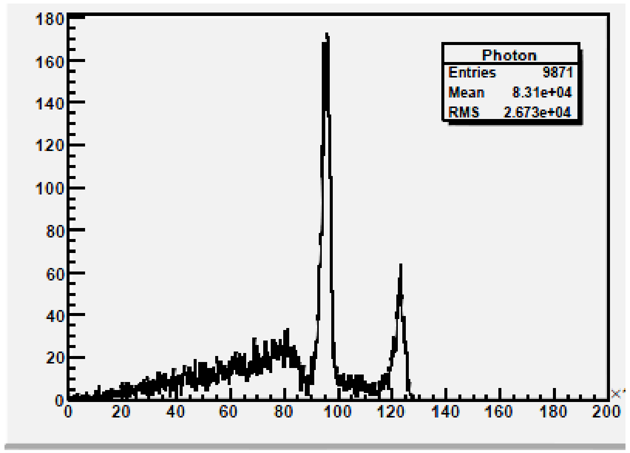


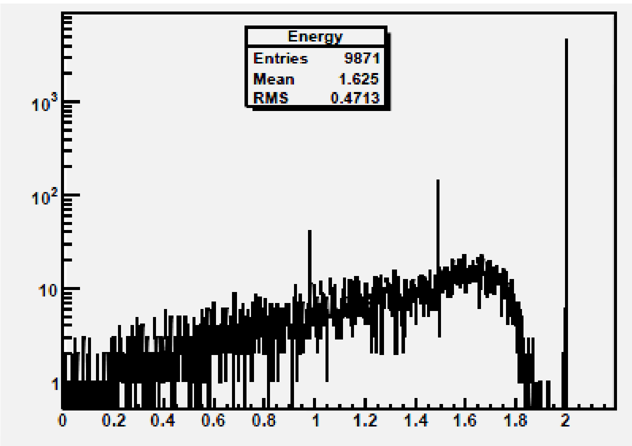
M.Turrión

Simulations results for the scintillation experimental tests



Array 3x3 Phoswich configuration
Geant 4: 10.000 gamas, 2 MeV
Distance: 30 cm and radius of the beam: 2 cm. Coverage of tefflon.



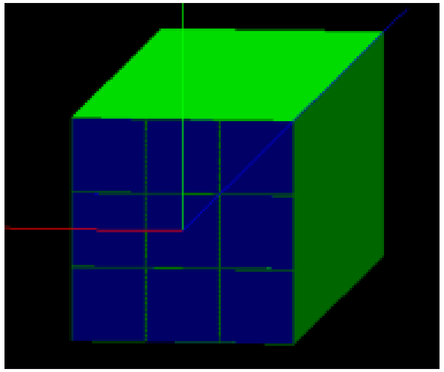


Crystals optimization: ***simulations***

- Reasons for Geant4 simulation:
  - Search for the best material and size of each crystal
  - Analysis of energy transfer to the neighboring crystals: compromise between the number of crystals, the dead volume, the detection efficiency and the cost.
  - This analysis is very important for electronic components and for reconstruction of initial energy summing different signals.

First configuration analyzed is:

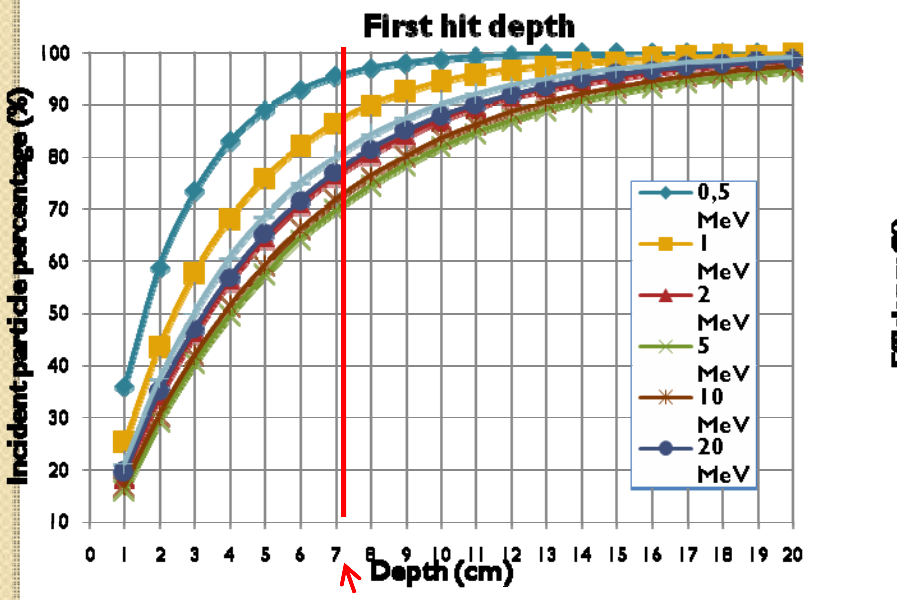
- **$LaBr_3$ in a 3x3 array.**
- **20x20 mm² frontal surface of each crystal**
- **Total energy deposited (9 crystals)**
- **Gamma-rays from 500 keV up to 30 MeV**
- **Incidence on central crystal**
- **Radius of the beam: 2 cm**
- **Distance source-detector: 30 cm**



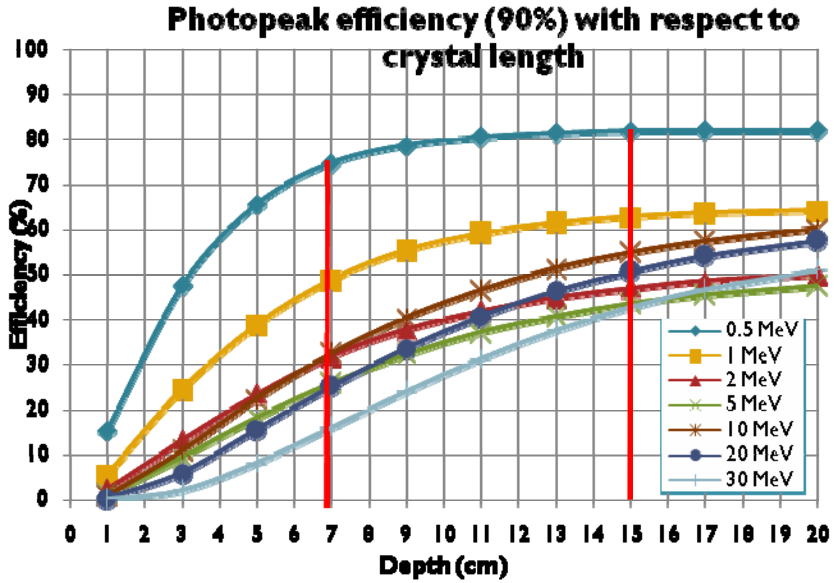
First crystal length and length of the second crystal

1. Studying first interaction depth for LaBr3:

2. Studying Photopeak efficiency
How long must be the second crystal?



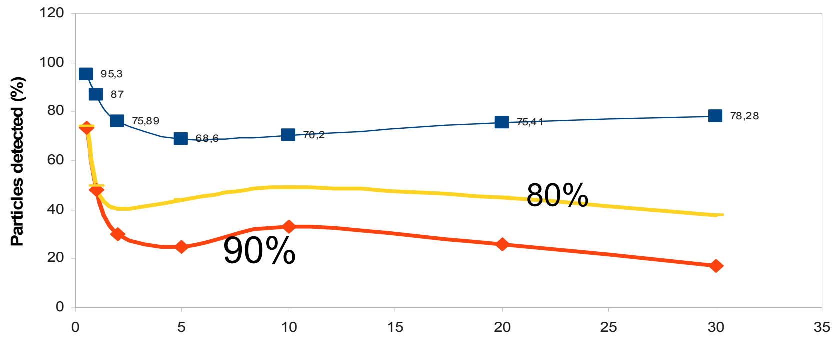
With 7 cm length we get 70% (at least) incident particles have been detected. Probably is a good election for first crystal length



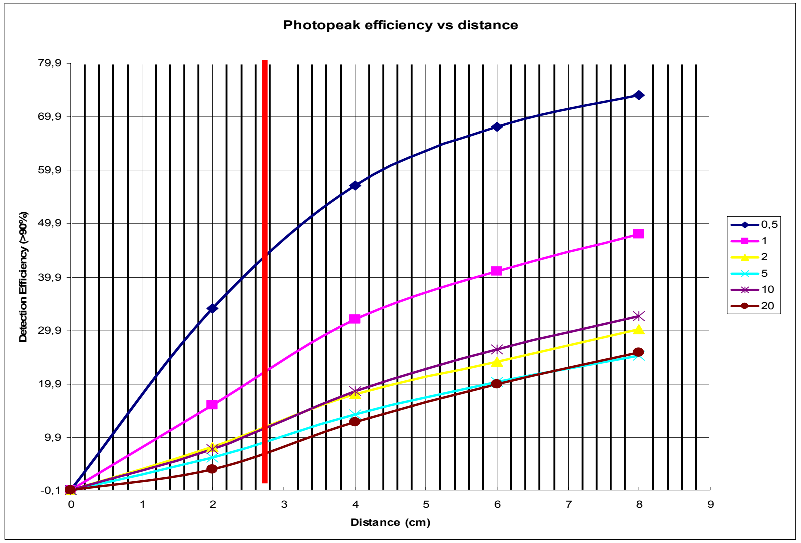
From 15 cm of $LaBr_3$ practically efficiency don´t improve: a hint about total phoswich length

New efficiencies for Phoswich configuration

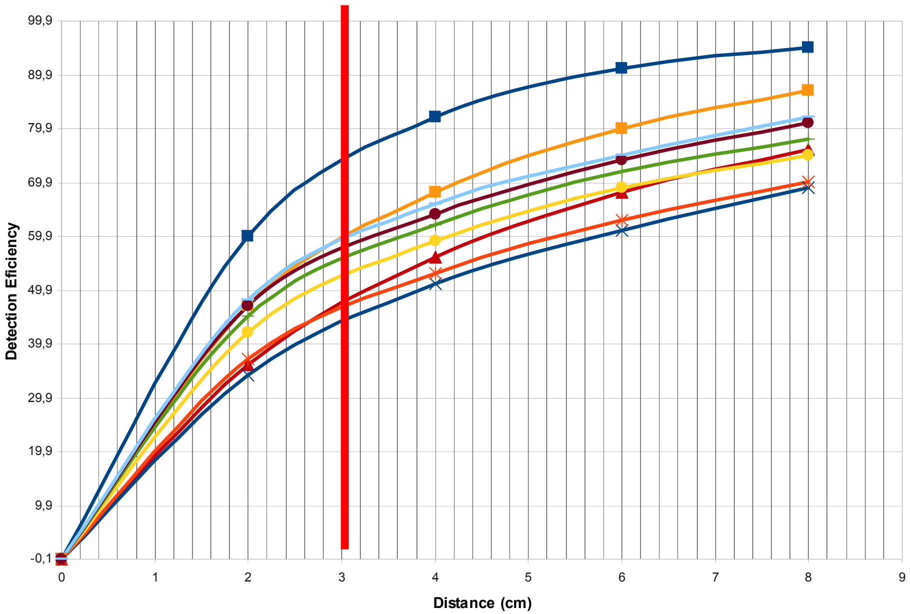
Array 3x3, 15x29x(3+5), Phoswich



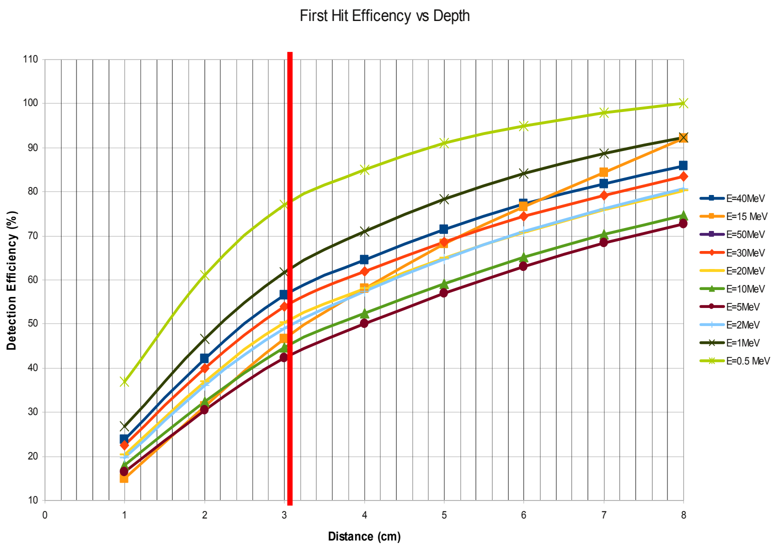
Detection efficiency vs Energy



Photopeak efficiency vs distance

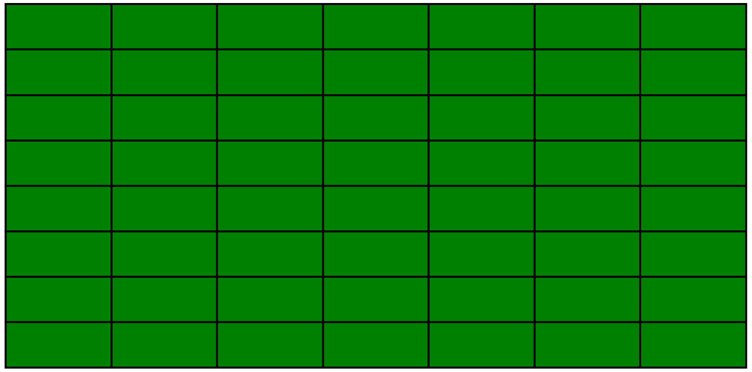


Detection efficiency vs distance



First hit vs distance

Energy transfer to neighboring cristals

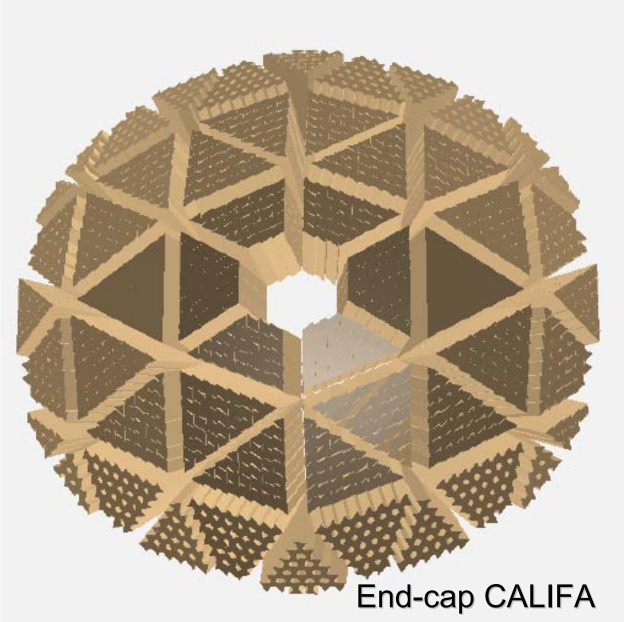


Array 25x25
Phoswich config
Angular resolution: 3.5º

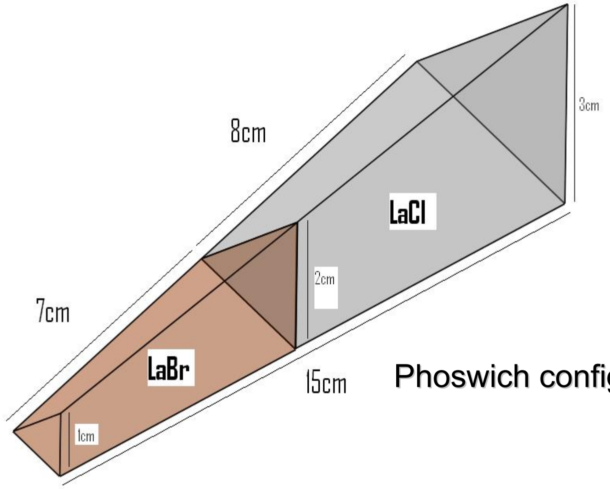
Possible geometry end-cap

Different geometries proposed for the forward-end cap CALIFA

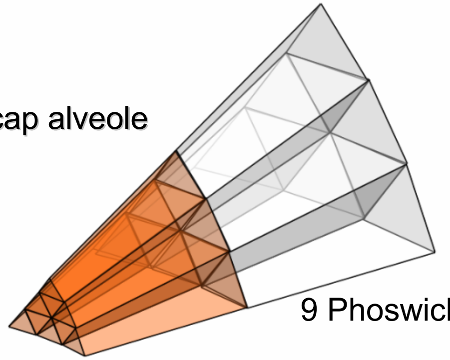
Triangular Prisms



End-cap CALIFA



Phoswich configuration



End-cap alveole

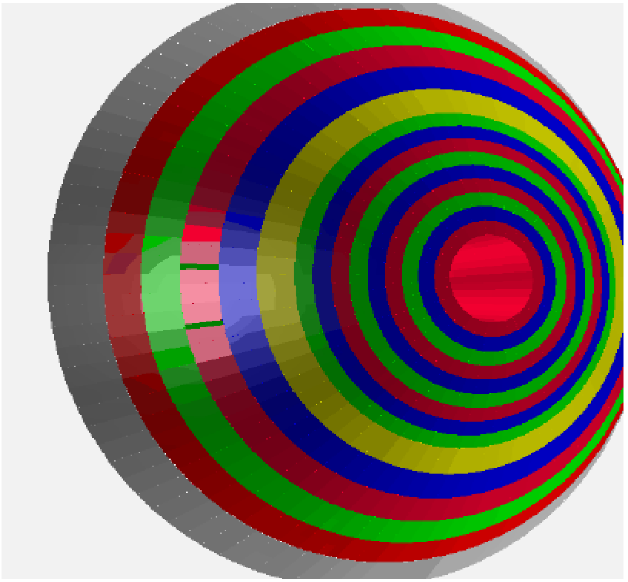
9 Phoswich crystals

Θ=2º	Volume (cm3)	Weight	Number of Crystals
LaBr	6.74	35 g	1
LaCl	21.41	80g	1
Alveole	280	1 kg	9

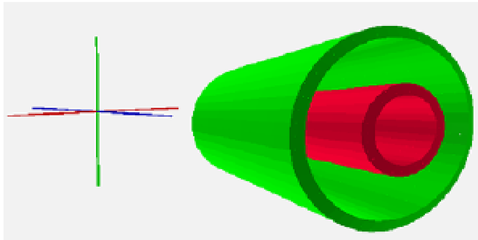
Characterisitcs of an alveole

Different geometries proposed for the forward-end cap CALIFA

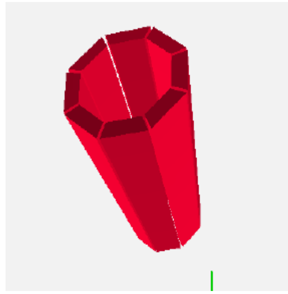
Trapezoidal Prisms: a very good candidate

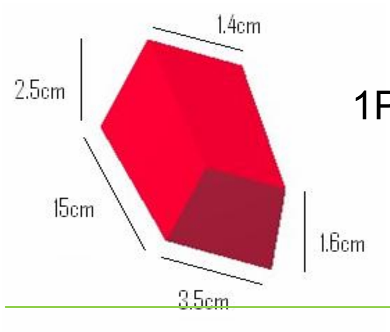


End-cap CALIFA



Different rings





1Phoswich crystal

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

Summary

- we have studied possible end-cap configuration for the CALIFA
- end-cap: Phoswich, two crystals 7(LaBr) + 8 [cm](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.

Future work

- Perform simulations with protons
- Study energy effiencies for different geometries proposed
- Implementation other codes like LITRANI for creation and propagation of scintillation photons to obtain realistic spectra with energy resolution of crystals. May be the BPM is a good choice.
- SimulateR3B experiments .

That'sall

Thank you for your attention!!!