# Optimization of light collection from crystal scintillators

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# Light output and energy resolution in the light channel of cryogenic scintillating bolometers are requested:

1) to achieve low energy threshold (most important for dark matter experiments)
2) to improve particle discrimination (both for DM and $2\beta$ experiments)
3) to improve energy resolution in the heat channel ($2\beta$ experiments)
4) to discriminate random coinciding $2\beta2\nu$ events [1], [2]

[1] D.M. Chernyak et al., Eur. Phys. J. C 72 (2012) 1989
[2] D.M. Chernyak et al., Eur. Phys. J. C 74 (2014) 2913.

# Aims of investigation

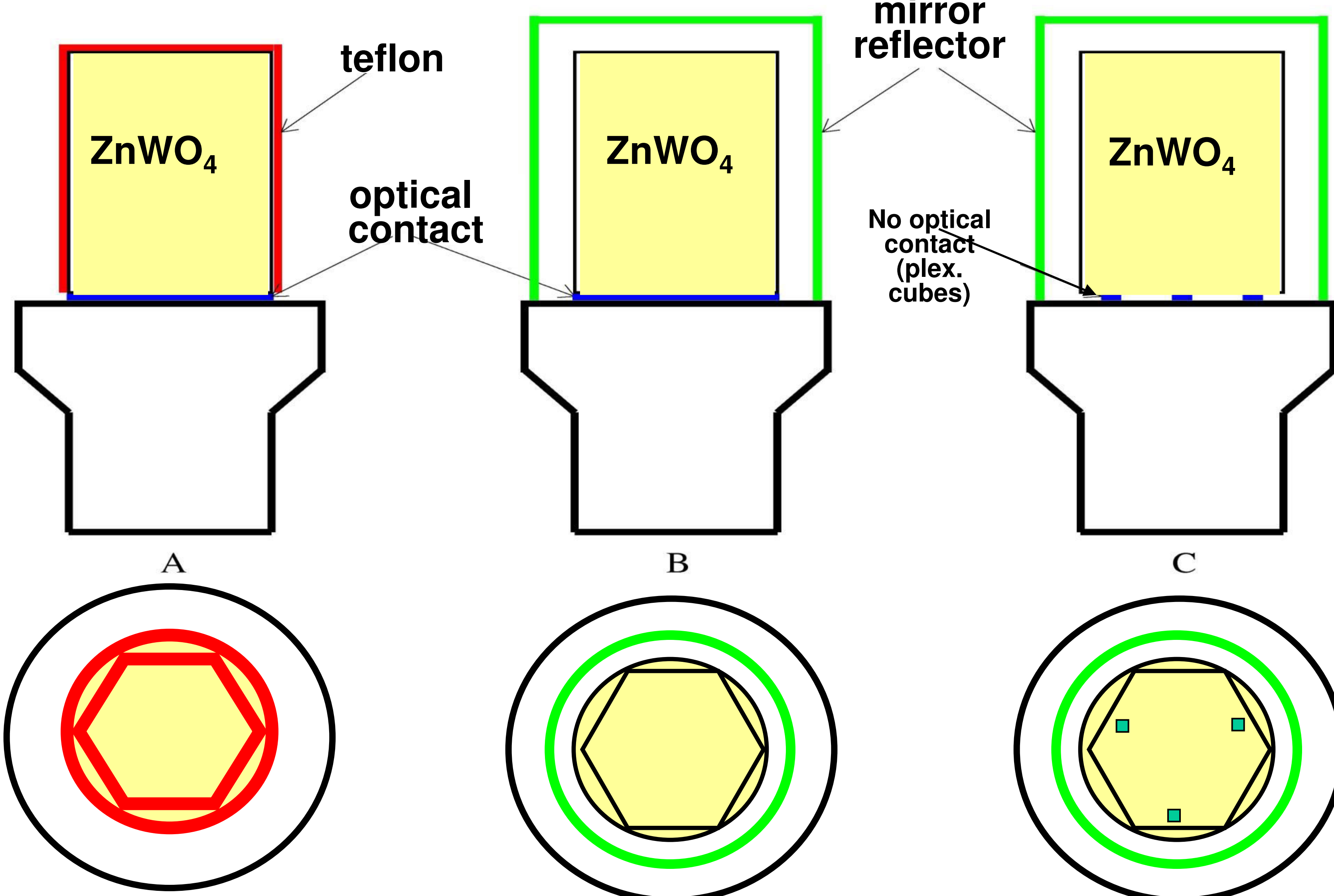
- Optimisation of light collection conditions from crystal scintillators (first of all, for cryogenic experiments)

  Influence on energy resolution and light collection:

  - shape of crystal (hexagonal, cylindrical)
  - surface (polished, diffused)
  - type and  shape of reflector
  - presence of optical contact with photo-detector

- Experimental data for development of Monte Carlo simulation of light collection in scintillation detectors

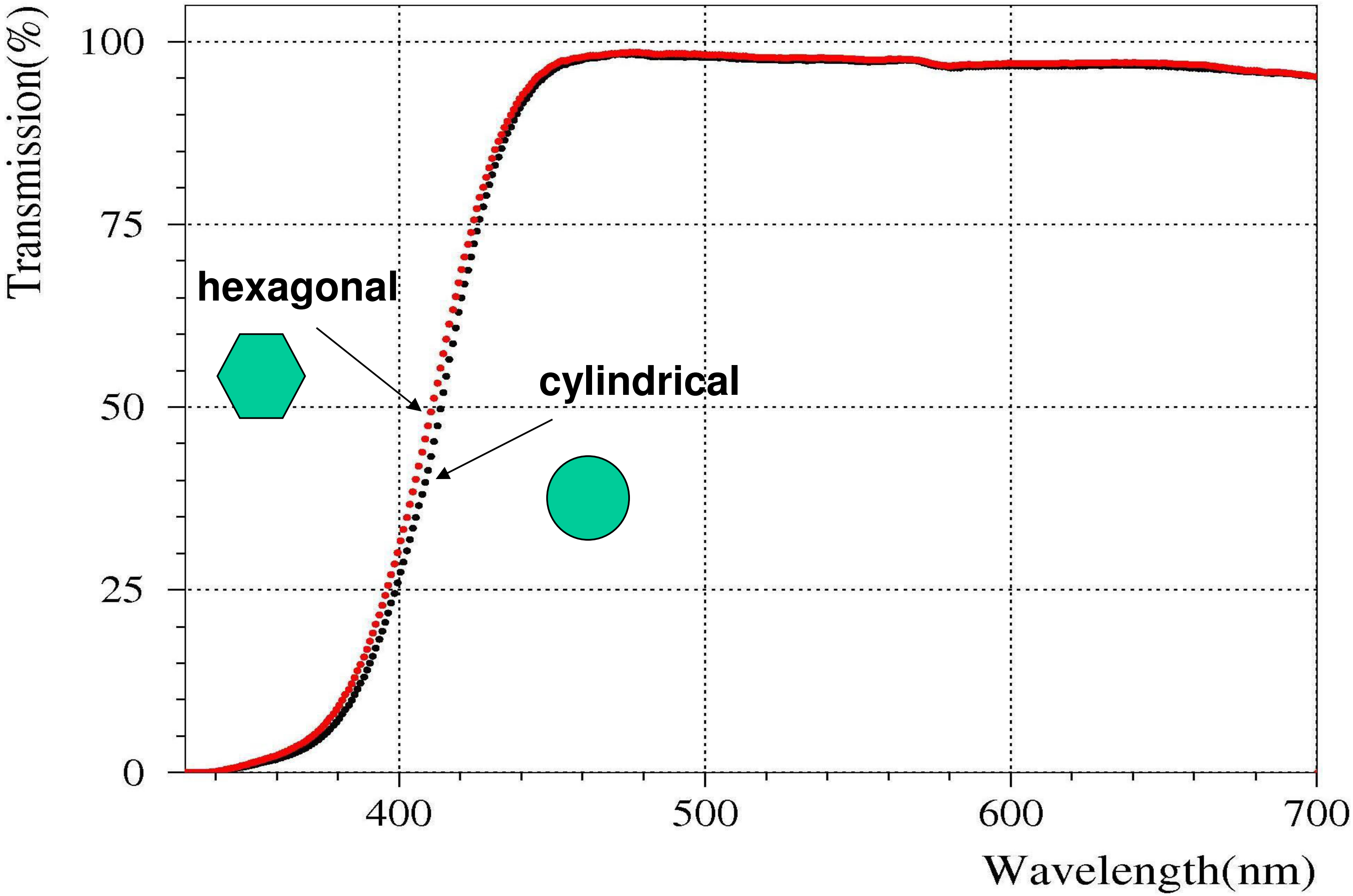
# Conditions of measurements




**Crystal scintillation surface :**

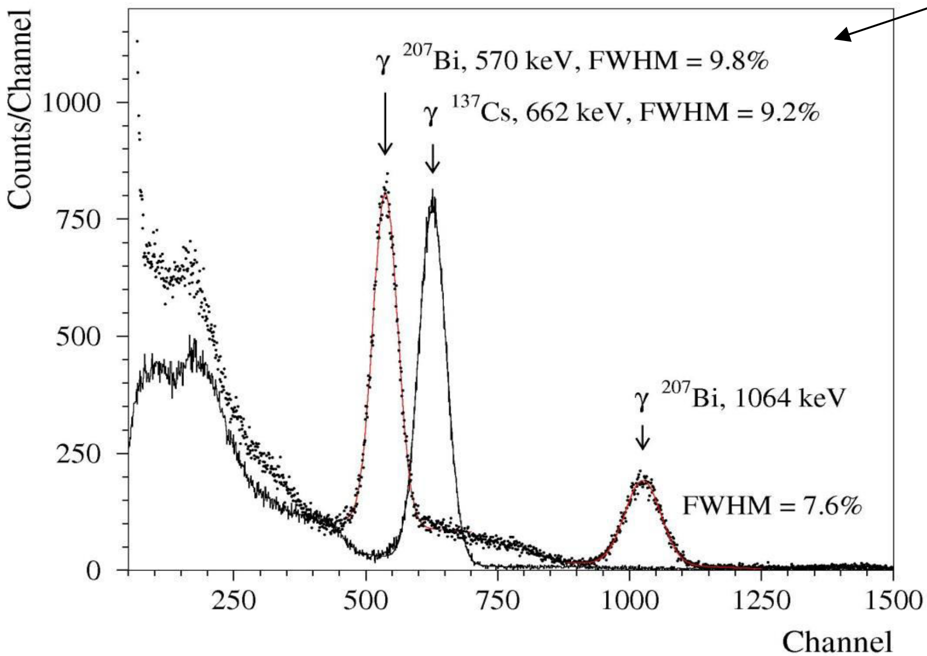
1. all surface polished; 2. side surface diffused;
3. side and top surfaces diffused; 4. all surface diffused.

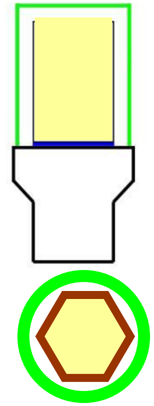
# Identity of the $ZnWO_4$ crystal optical properties



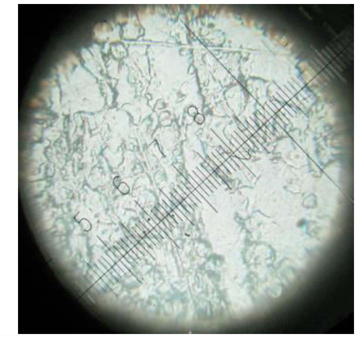

**The measurement were peformed with a thin (2 mm) $ZnWO_4$ plate in the spectrophotometer reference beam**

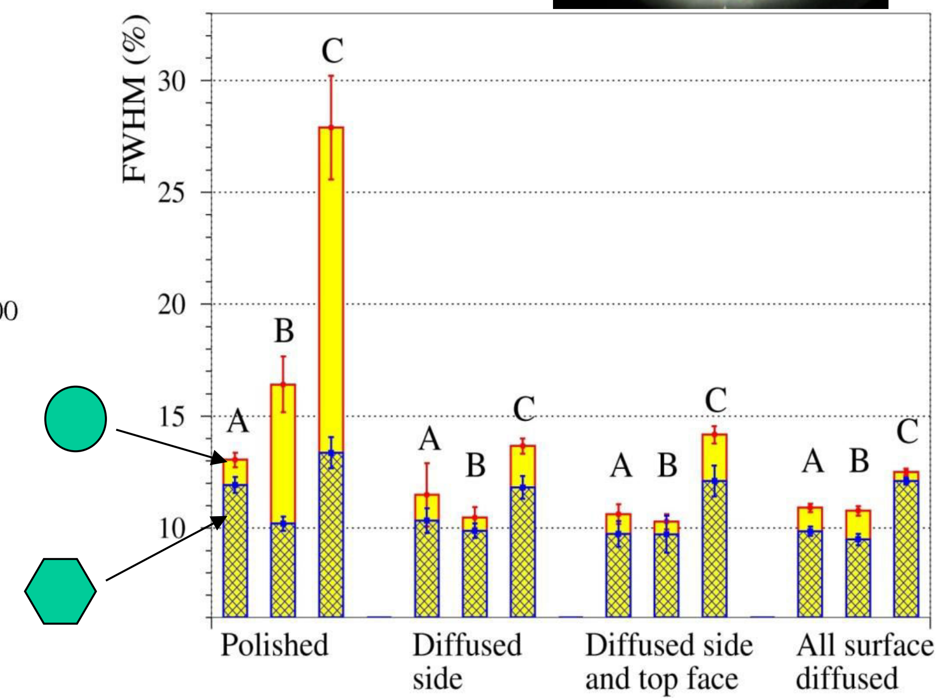
# Energy resolution



**Micro-photograph of $ZnWO_4$ diffused surface**



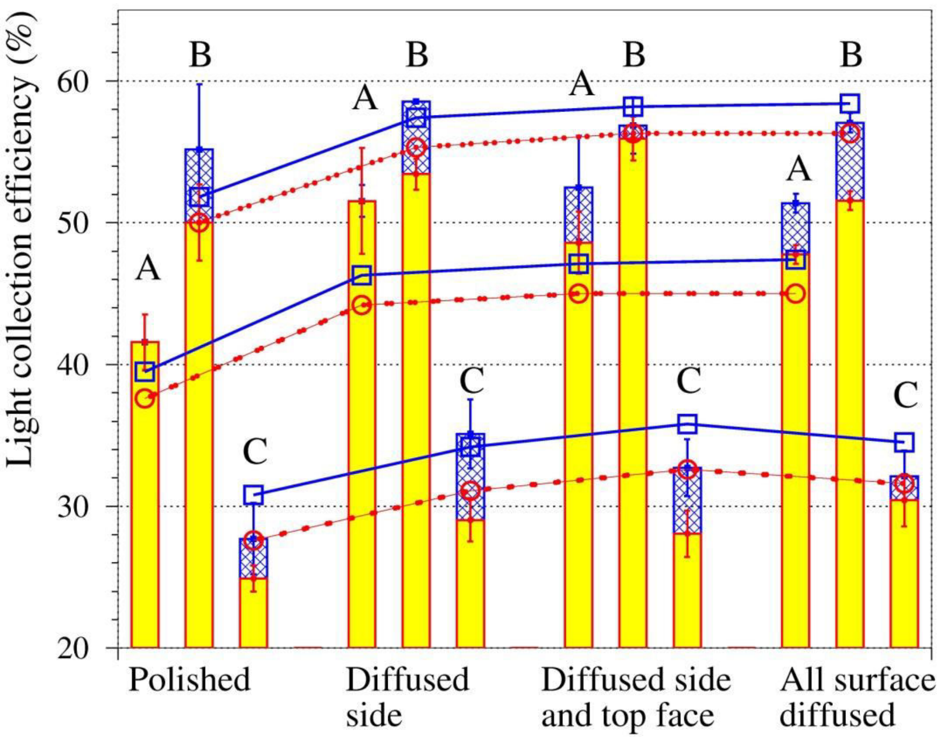



Hexagonal form and diffused surface of crystal increase of light collection efficiency and the energy resolution

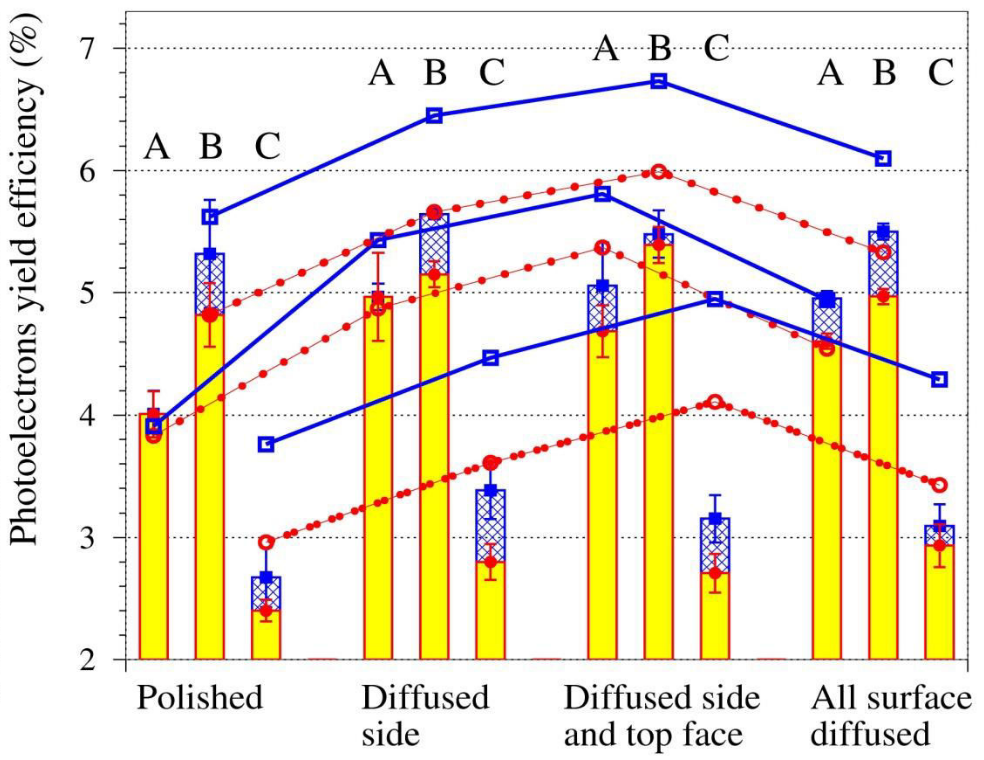
**F.A.Danevich, et al. NIMA 744(2014)41-47.**

# Simulation using ZEMAX and Geant4

## ZEMAX



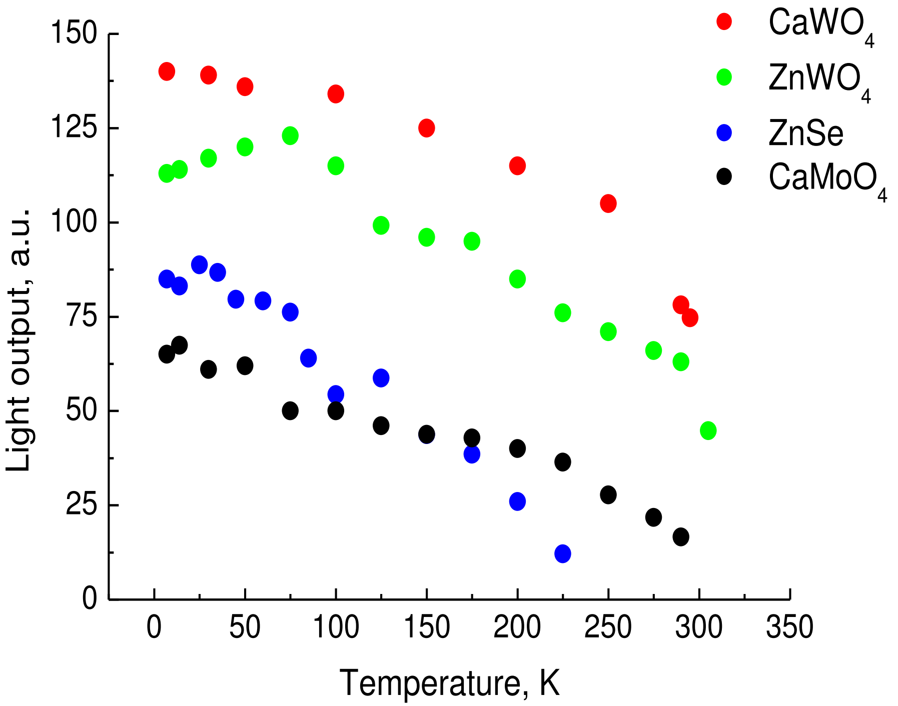

## Geant4




F.A.Danevich, et al. NIMA 744(2014)41-47.

# Measurements with $CaWO_4$ crystal scintillators

- **High light output at low temperature**
- **Much lower optical anisotropy**
- **Presence of $^{40}Ca$, $^{48}Ca$, $^{180}W$ and $^{186}W$ 2β candidates ($^{180}W$ is of especial interest thanks to a possibility of resonant neutrinoless double electron capture [1])**
- **Used now in the CRESST dark matter experiment [2], to be used in the EURECA project [3]**
- **similar properties to $CaMoO_4$, $CdWO_4$, $ZnWO_4$, $ZnMoO_4$, $LiMoO_4$, ZnSe promising scintillators for double β experiments**

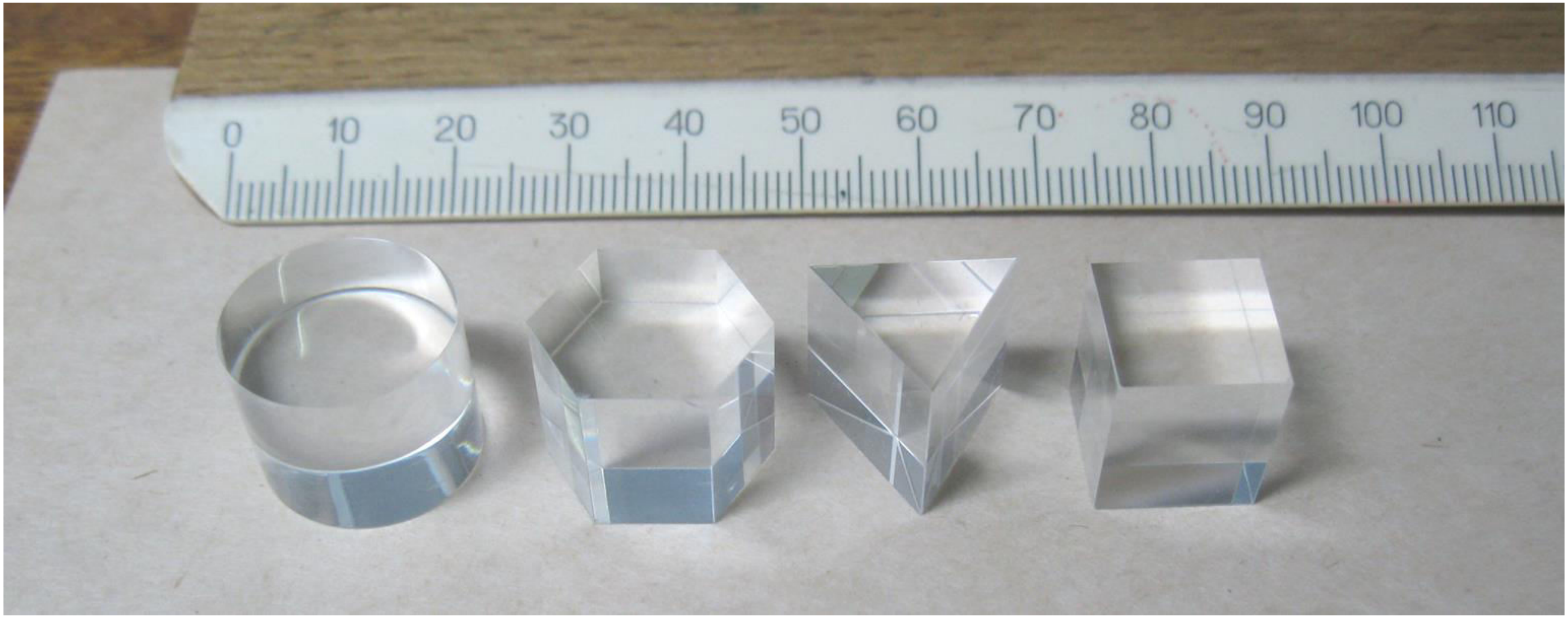




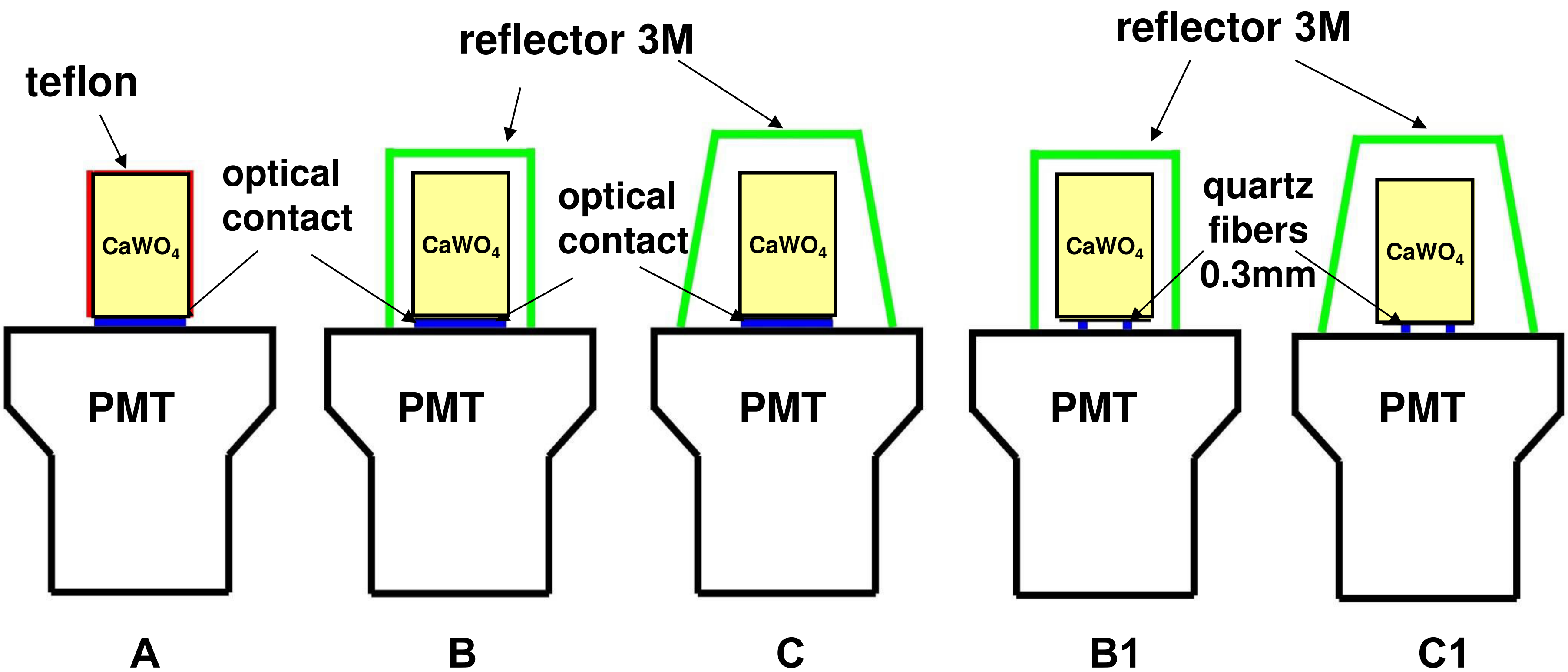
[1] see, e.g., M.I. Krivoruchenko et al., NPA 859 (2011) 140.
[2] G. Angloher et al., Eur. Phys. J. C 72 (2012). 1971-22.
[3] G. Anglohen et al., Phys. of the Dark Universe 3 (2014) 41-74.

# $CaWO_4$ crystal samples

**Four $CaWO_4$ samples (cilinder ∅ 17.5×15 mm and prisms with diagonal 17.5×15 mm) were produced from one crystal**



# Conditions of measurements

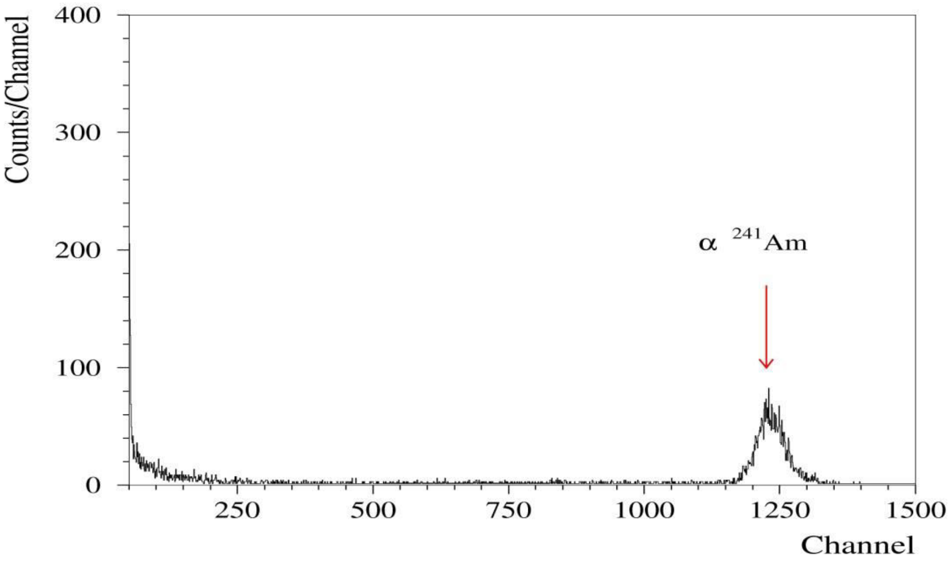


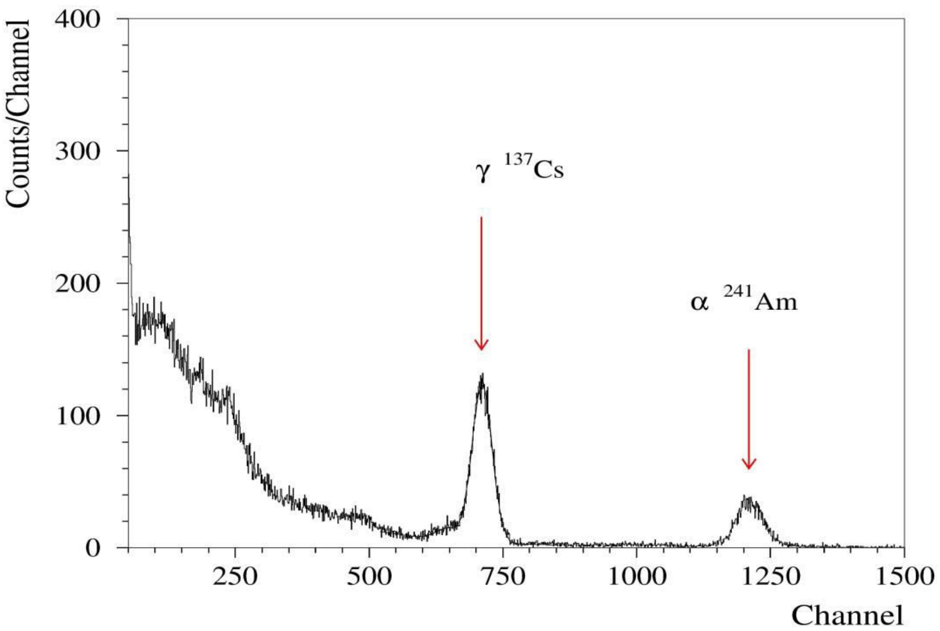

**Crystal scintillation surface :**

**1. all surface polished; 2. side surface diffused;**

**3. side and top surfaces diffused; 4. all surface diffused.**

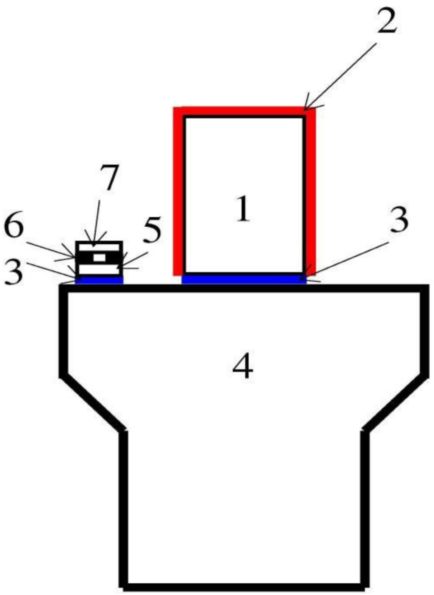
# Experimental set-up



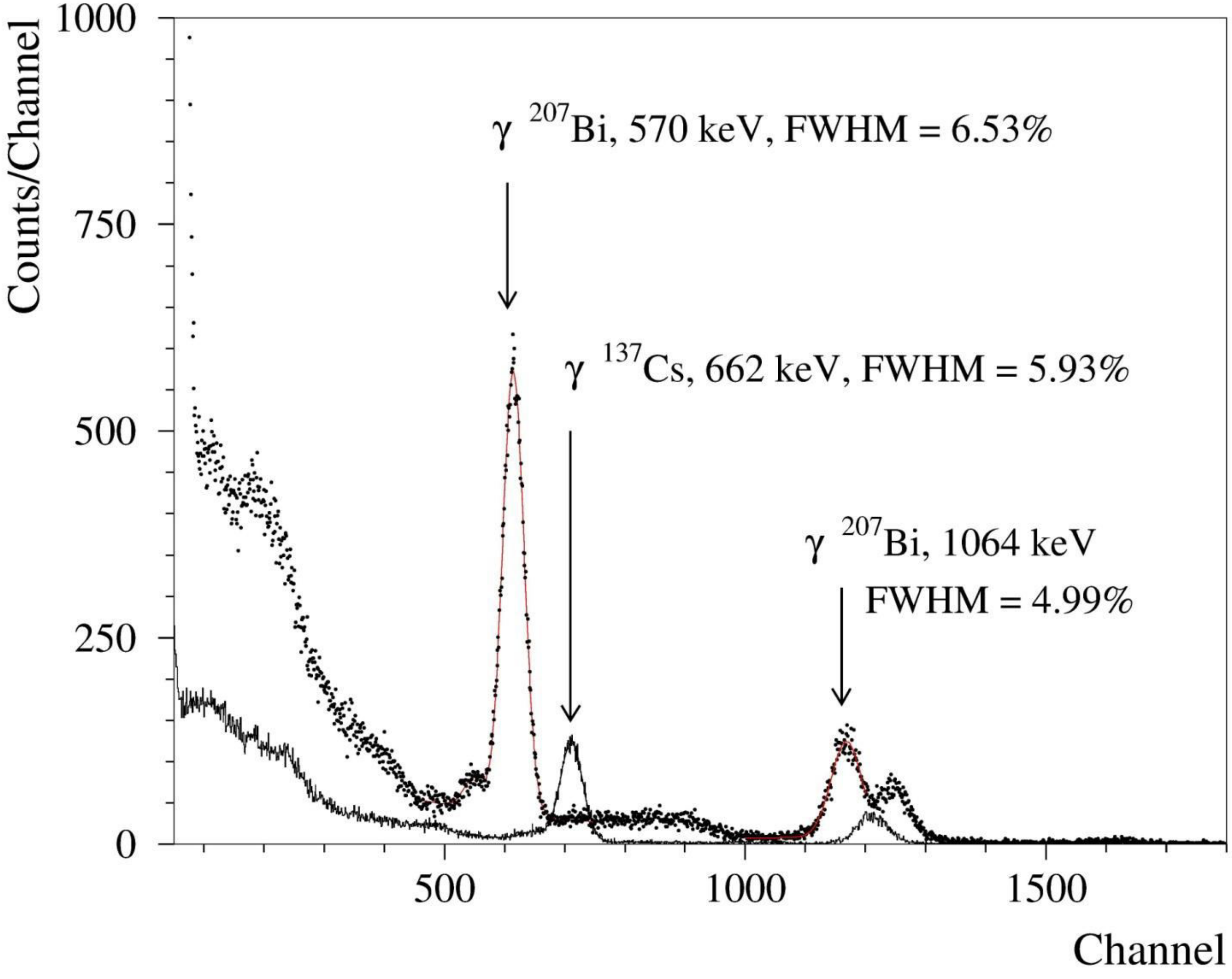

**Control of the set-up stability**

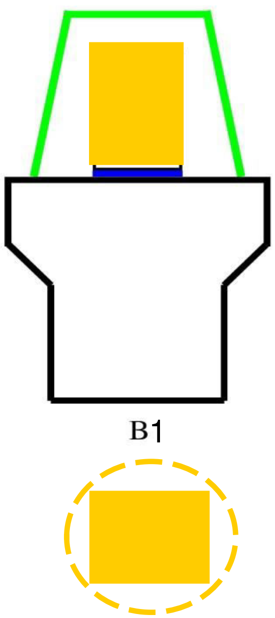
1. $CaWO_4$ crystal to be tested
2. Teflon reflector
3. optical contact
4. Photomultiplier
5. $CaWO_4$ crystal 5*5*1mm (used for the spectrometer stabilization)
6. collimator
7. $^{241}$Am $\alpha$ source



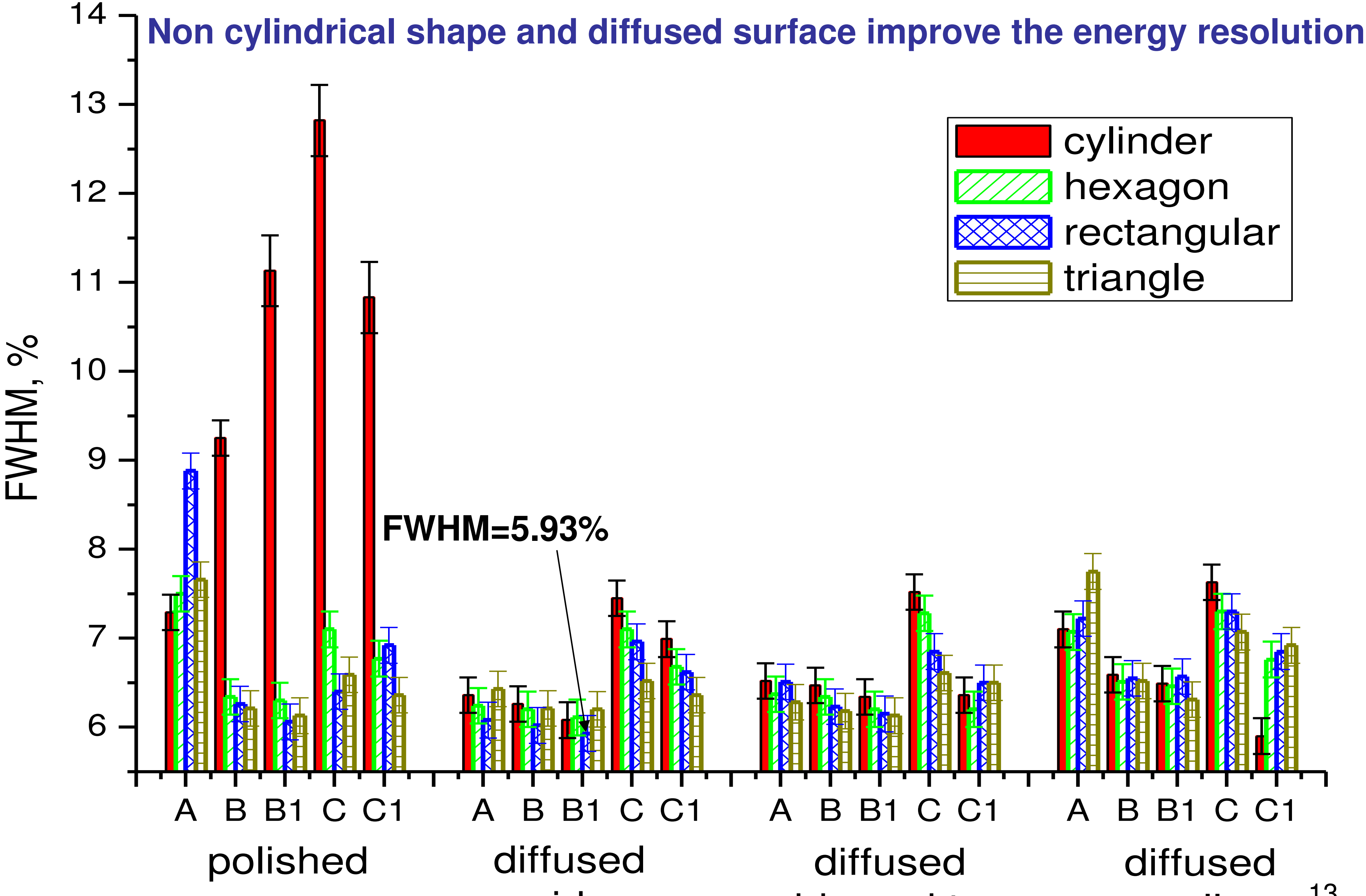

The gamma peaks position was controlled with an accuracy ~2%

# The best energy resolution
## (achieved with $CaWO_4$ for the first time)



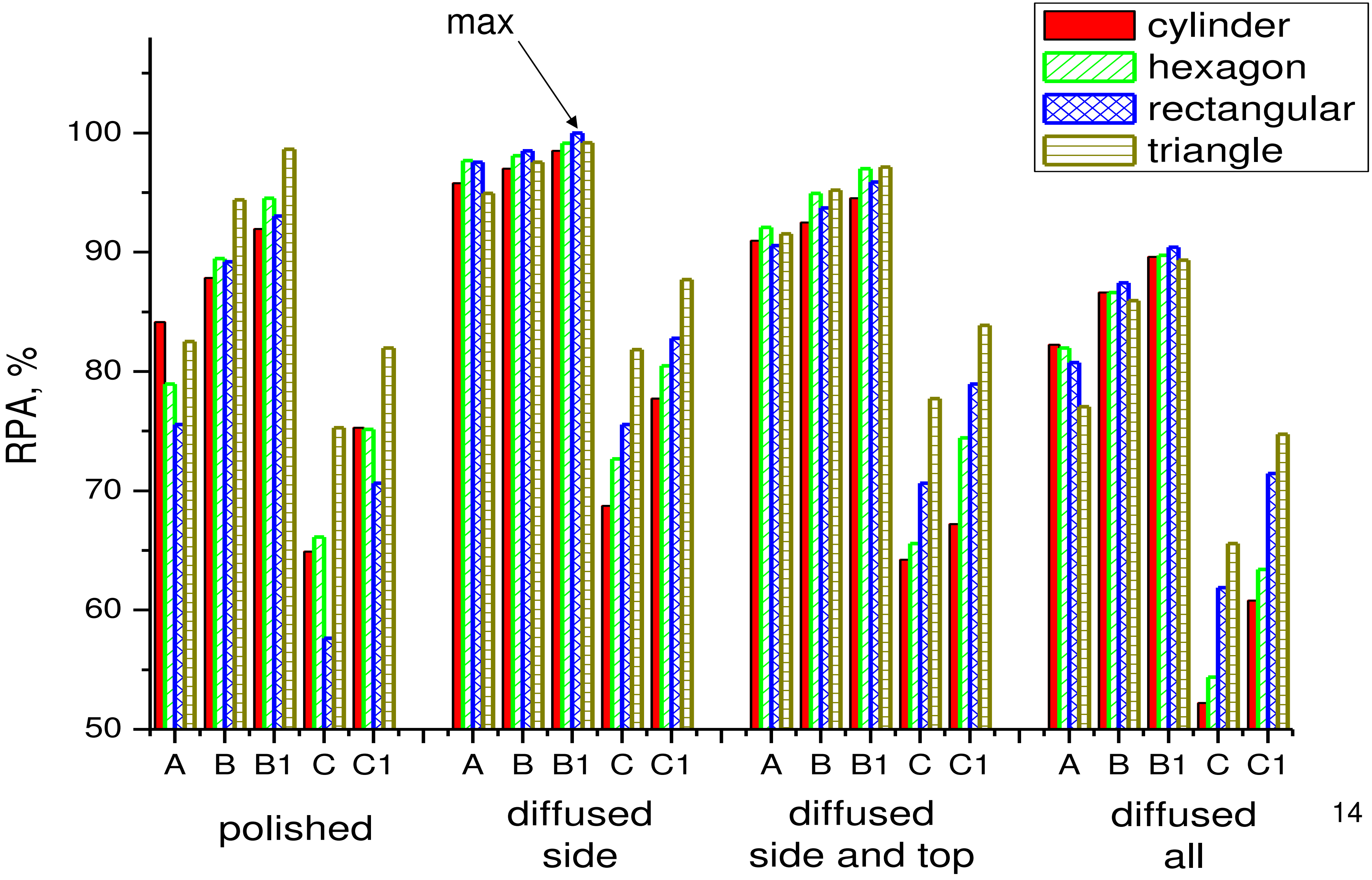



# Energy resolution

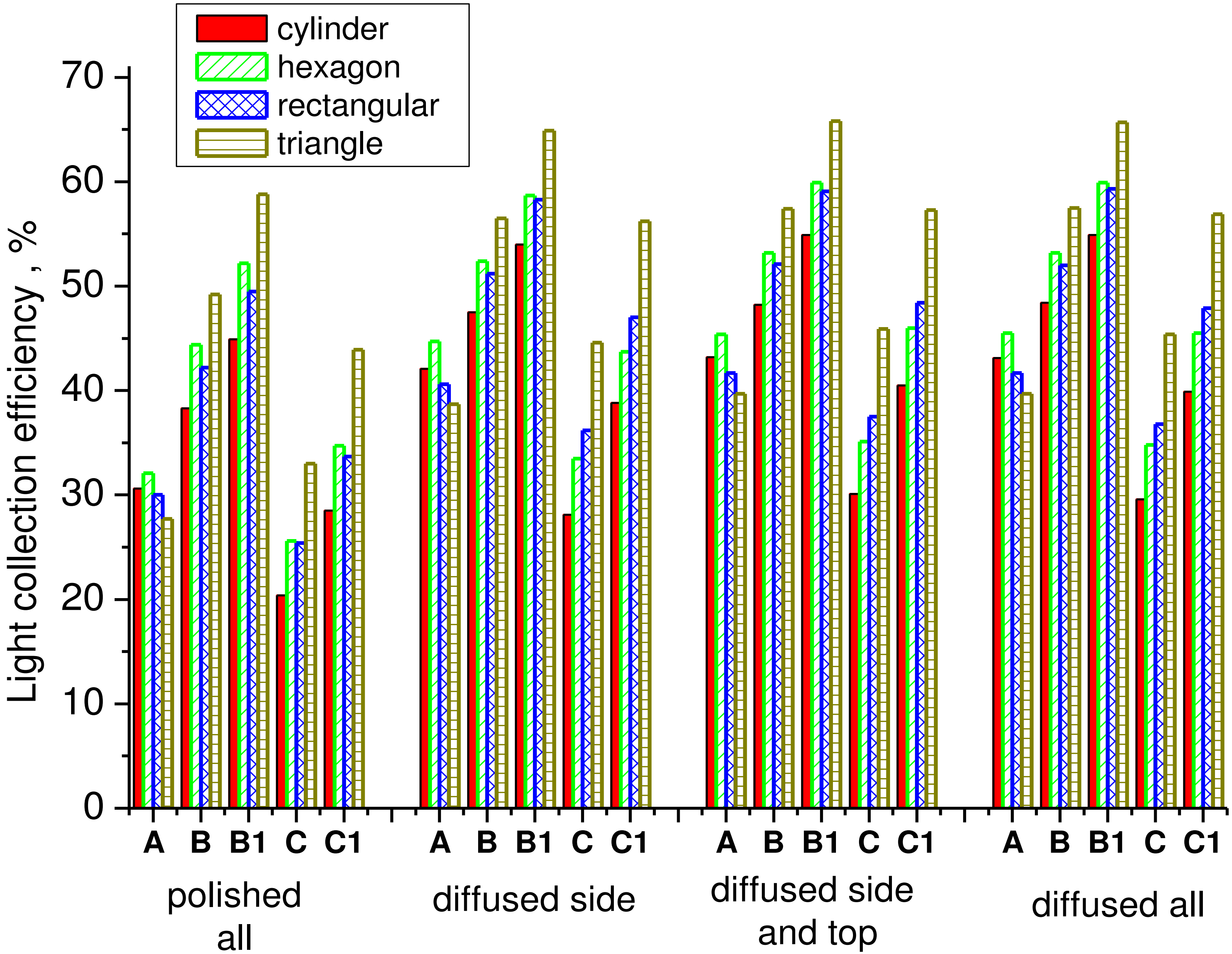


# Relative pulse amplitude

**Diffused surface and non cylindrical shape improve the light collection**



# Simulation using ZEMAX



# Simulation using ZEMAX, Geant4 and Litrani

The criterion of minimal standard deviation was calculated from experimental data to determine the best software package for simulation of light collection in scintillation detectors.

Standard deviation was calculated by the formula:

$$\psi = \sqrt{\sum_{i=1}^{n} \frac{(a_i - b_i)^2}{n \cdot (n-1)}},$$

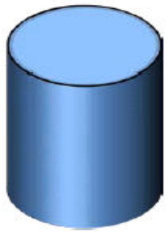
where $a_i$ – experimental data, $b_i$ – simulation data, $n$ number of degrees of freedom.

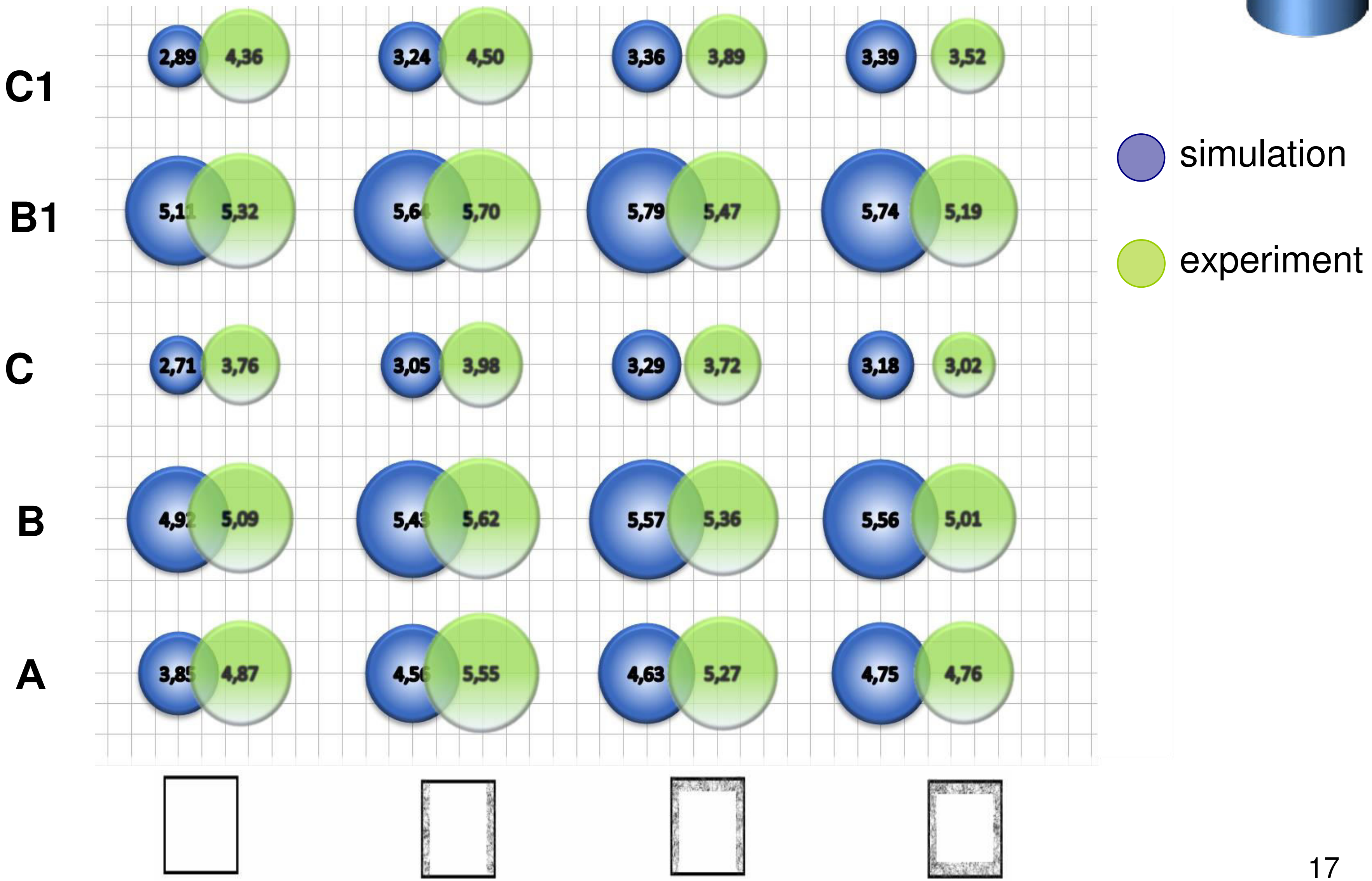
For software packages were received following values :

Geant4: ψ = 0,039; Zemax: ψ = 0,038; Litrani: ψ = 0,028.

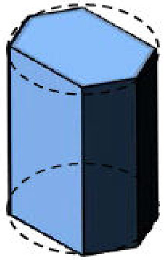
Litrani provides the best agreement with the experimental data.

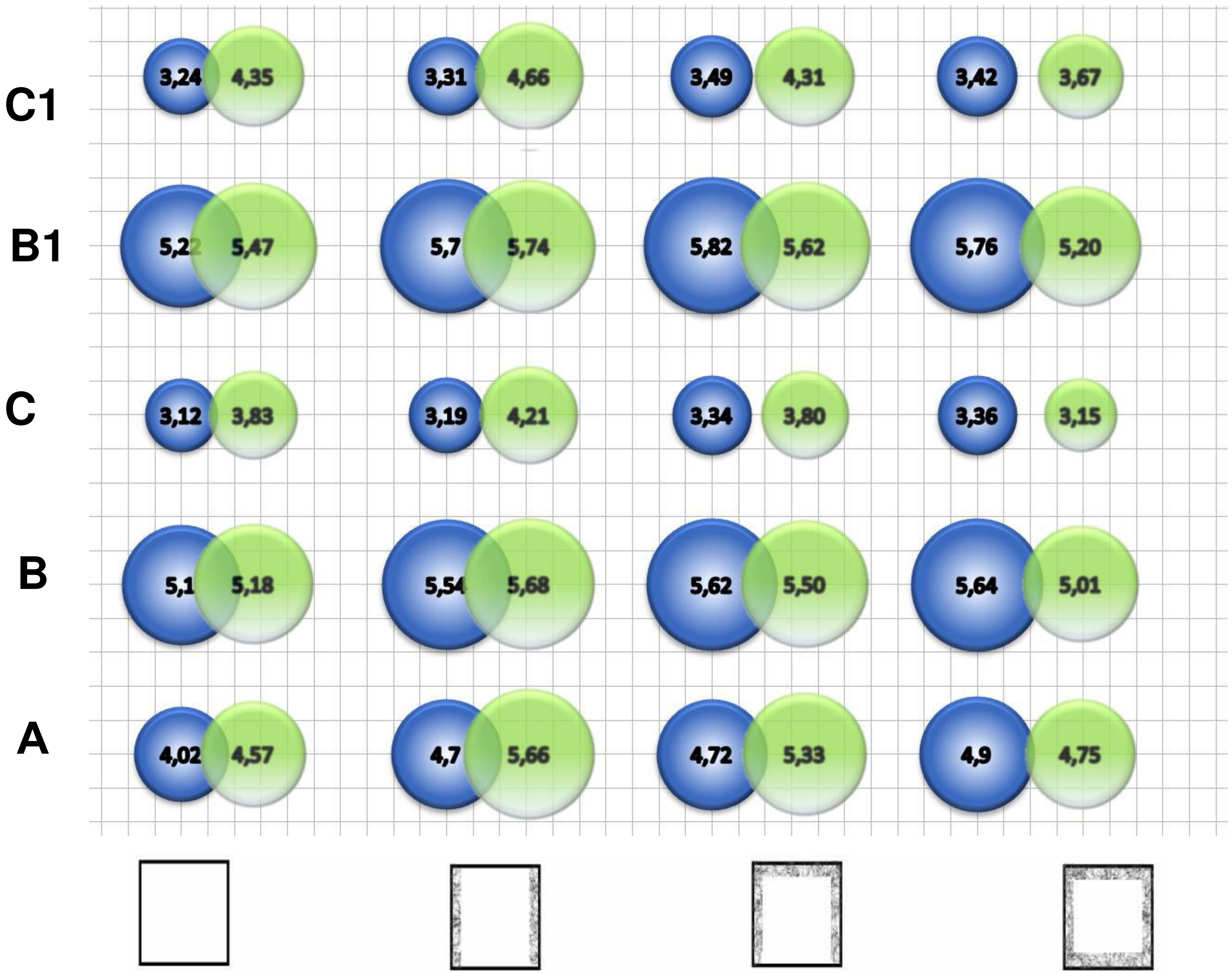
# Simulation using LITRANI



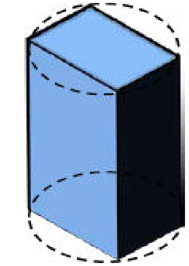


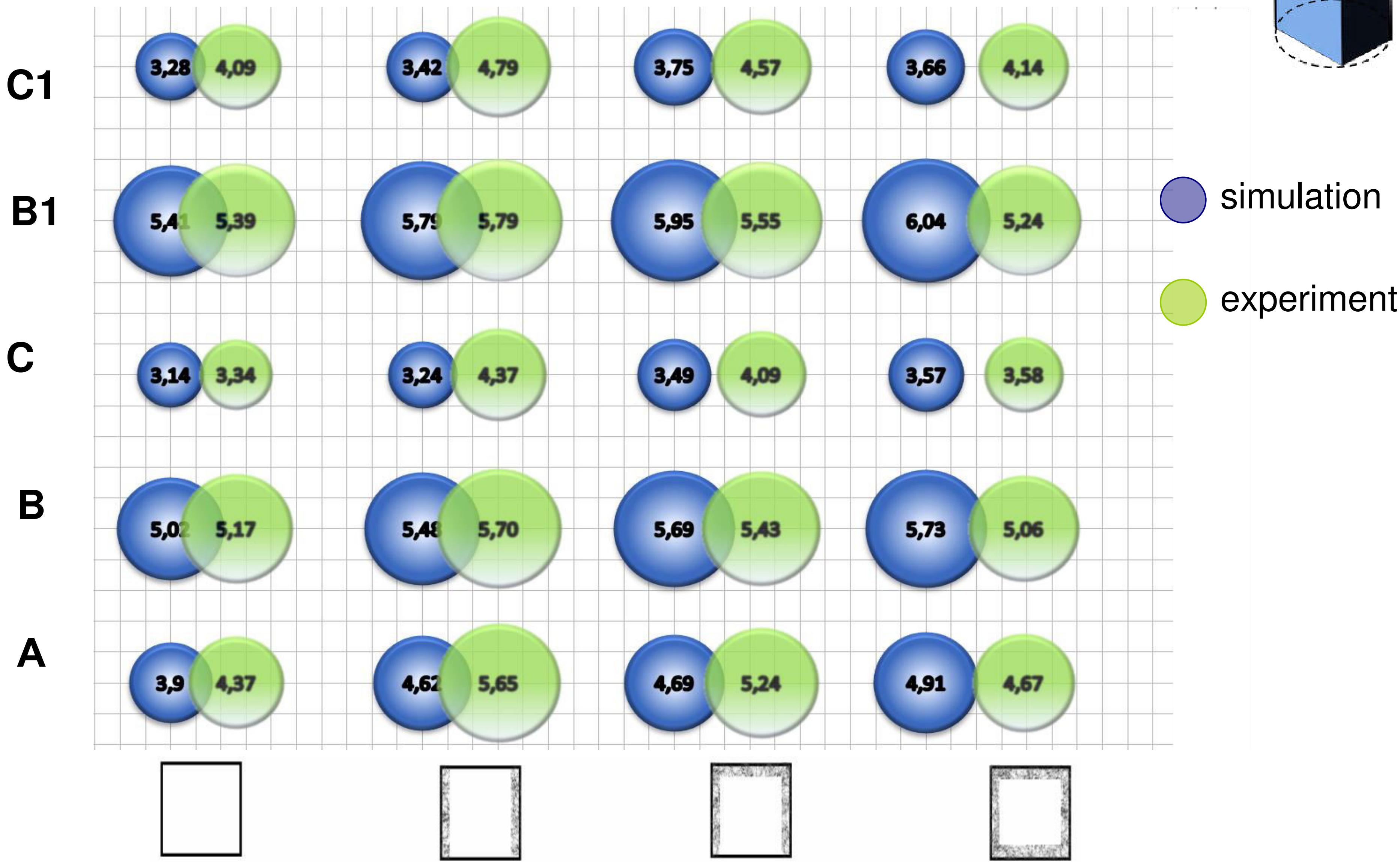
# Simulation using LITRANI



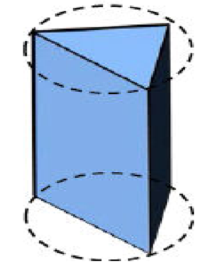


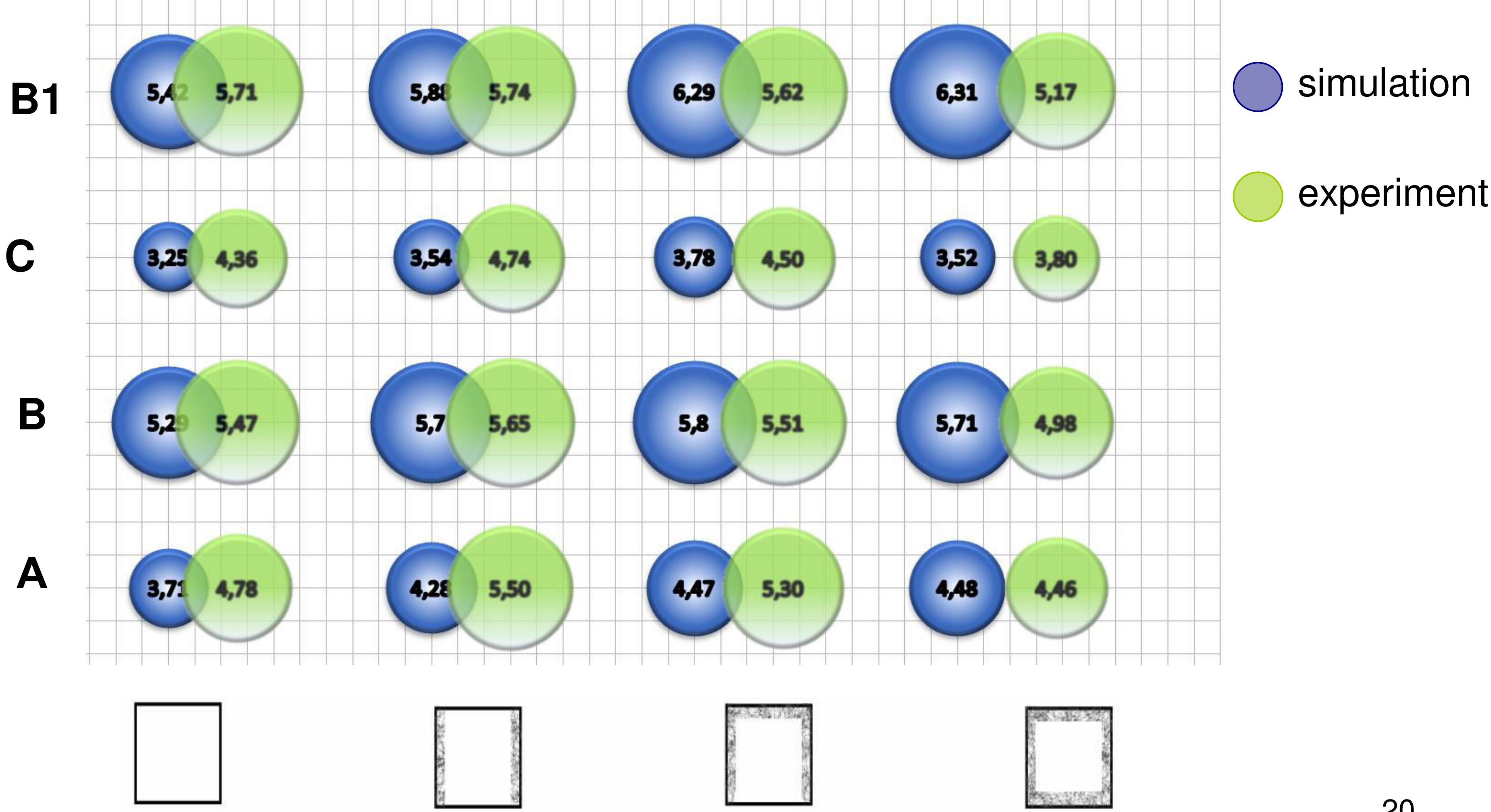
# Simulation using LITRANI





# Simulation using LITRANI





# Conclusions

- The highest energy resolution and relative pulse amplitude were obtained for cube crystal with diffused side and polished top surfaces, with truncated cone 3M reflector, in optical contact with photomultiplier;

- In measurement without optical contact (condition of **cryogenic scintillating bolometer**), the best relative pulse amplitude and energy resolution were obtained for triangle crystal with diffused side and polished top surfaces, surrounded by truncated cone 3M reflector;

- Results of simulations using Litrani, GEANT4 and ZEMAX packages are in a qualitative agreement with the results of measurements;

- Litrani provides the best agreement with the experimental data.