Metody eksperymentalne badania podstawowych własności scyntylatorów

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Outline

1. Introduction – non-proportionality vs intrinsic resolution.
2. Influence of long Decay modes on intrinsic resolution.
3. Compton Coincidence Technique (CCT):
    - history,
    - description of method,
    - results of measurements.
4. Non-proportionality of fast and slow decay components.

Energy resolution of scintillators – statistical term with PMT readout

N – number of photoelectrons,

ε – the variance of PMT gain.

$$\delta_{st} = 2.355 \times 1/N^{1/2} \times (1 + \varepsilon)^{1/2}$$

P. Dorenbos / Nuclear Instruments and Methods in Physics Research A 486 (2002) 208–213

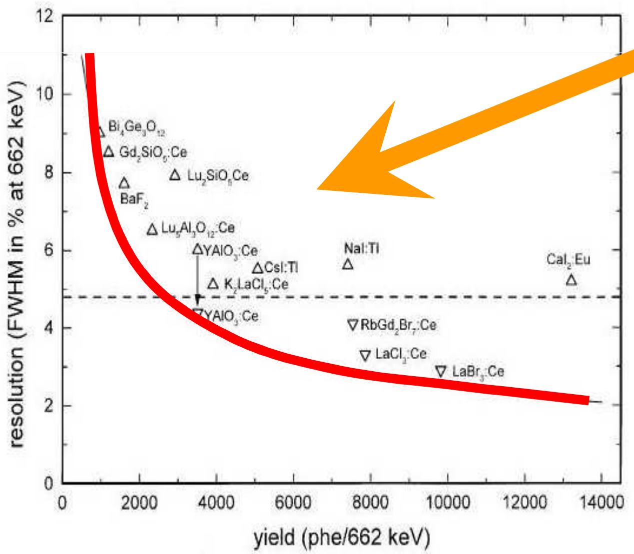


Fig. 3. Energy resolution at 662 keV gamma energy as a function of photoelectron yield in photomultiplier tubes. Data below the dashed line is from the past 6 years.

there is something that makes things worse...

$$(\Delta E/E)^2 = (\delta_{st})^2 + (\delta_{int})^2$$

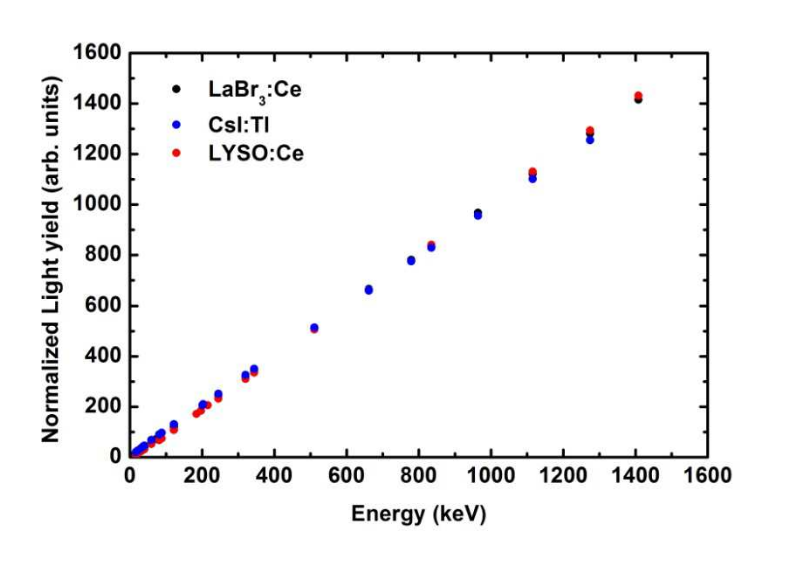
δ_{st} – photodetector statistical contribution

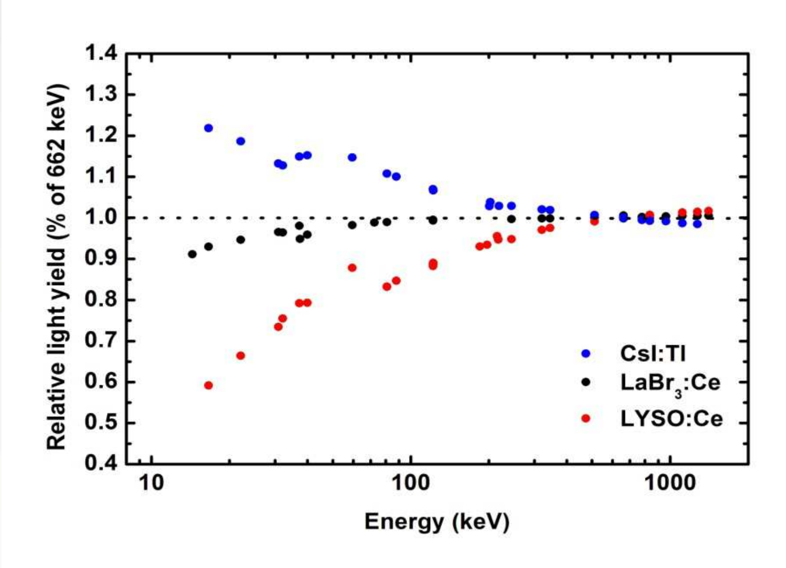
δ_{int} – intrinsic resolution of the crystal

Non-proprtionality and intrinsic resolution

Is scintillator response to the deposited energy linear?

Lets plot LY per energy unit (dLY/dE) and normalize at 662 keV





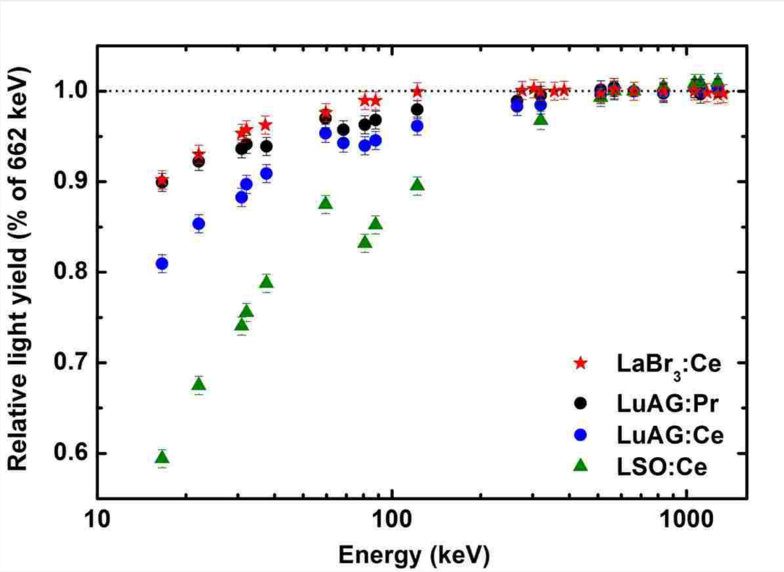
Plotting LY vs Energy looks so, but...

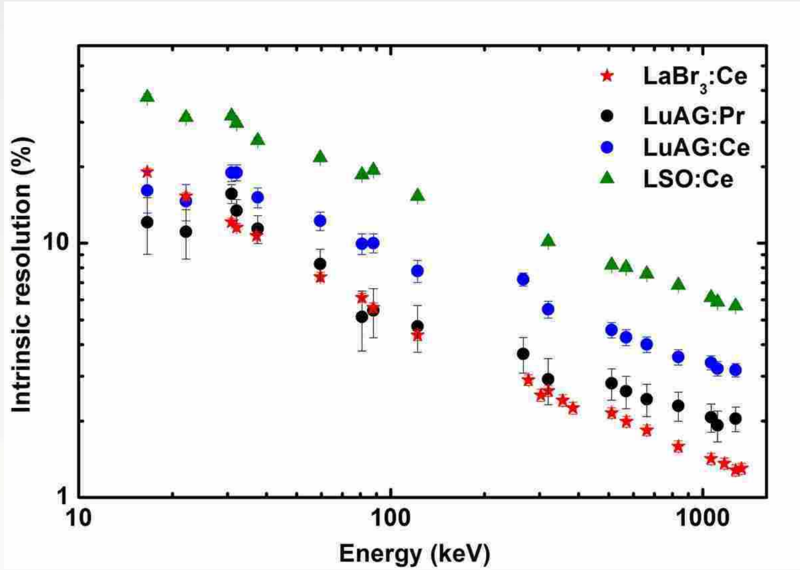
...plotting dLY/dE in logE scale allows for zooming low-energy range and shows the entire energy range on plot

Scintillation efficiency is changing with deposited energy → non-proportionality of Light Yield

Non-proprtionality and intrinsic resolution

Non-proportionality:
LuAG:Ce vs. LSO:Ce – the host crystal is decisive
LuAG:Pr vs. LuAG:Ce – the influence of doping agent





Gamma-ray absorption process is very complex – it produces a cascade of low-energy electrons of different scintillation efficiency
The intrinsic resolution follows the non-proportionality:
LSO:Ce – LuAG:Ce – LuAG:Pr – $LaBr_3$:Ce

L. Swiderski et al.,
Scintillation Properties of Praseodymium Doped LuAG Scintillator Compared to Cerium Doped LuAG, LSO and $LaBr_3$
IEEE Trans. Nucl. Sci. 56 (2009) 2499

Non-proportionality and energy resolution vs. slow decay components

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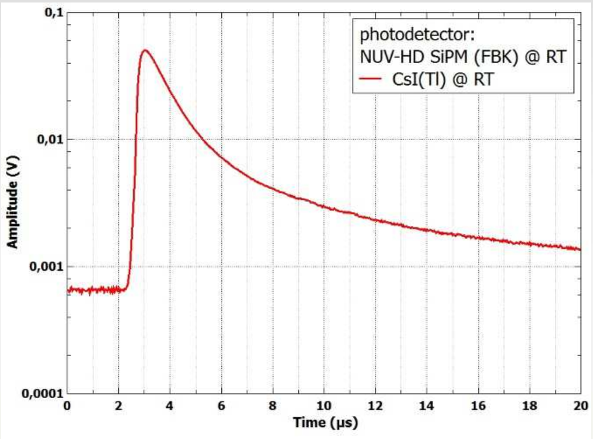
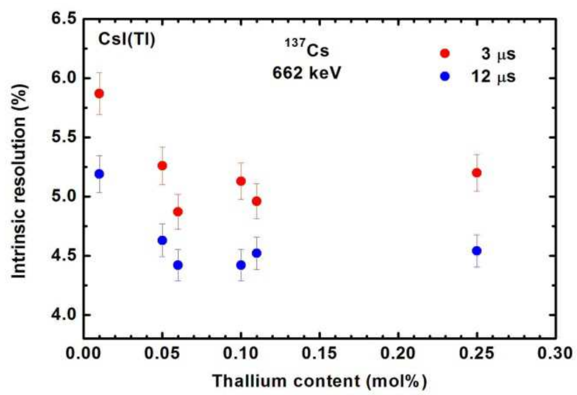
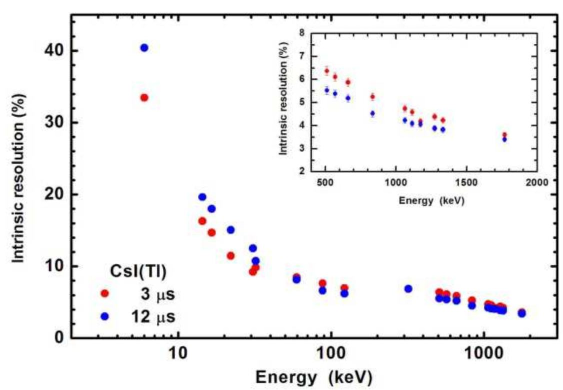
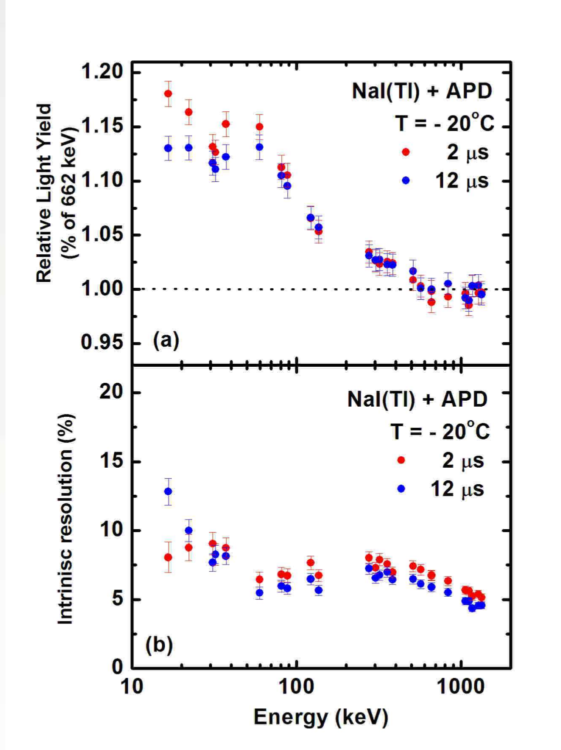
L. Swiderski et al.,
Non-proportionality and Energy Resolution of NaI(Tl) at Wide Temperature Range (-40°C to +23°C)
IEEE Trans. Nucl. Sci. 54 (2007) 1372



Integration of long decay modes improves intrinsic resolution







A. Syntfeld-Każuch et al.,
Non-proportionality and Energy Resolution of CsI(Tl)
IEEE Trans. Nucl. Sci. 54 (2007) 1836

Observed in:
CsI(Tl), CsI(Na), NaI(Tl), ZnSe(Te)

Non-proportionality and energy resolution vs. slow decay components

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$$(\Delta E/E)^2 = \delta^2_{stat} + \delta^2_{intr}$$

shaping time	3 μs	12 μs	
light yield (phe/MeV)	4500 ± 300	5600 ± 400	20 % more light
statistical contribution	4.53 (9) %	4.05 (9) %	
energy resolution	5.15 (7) %	5.07 (7) %	
intrinsic resolution	2.5 (3) %	3.0 (3) %	← ???

Non-proportionality and energy resolution vs. slow decay components

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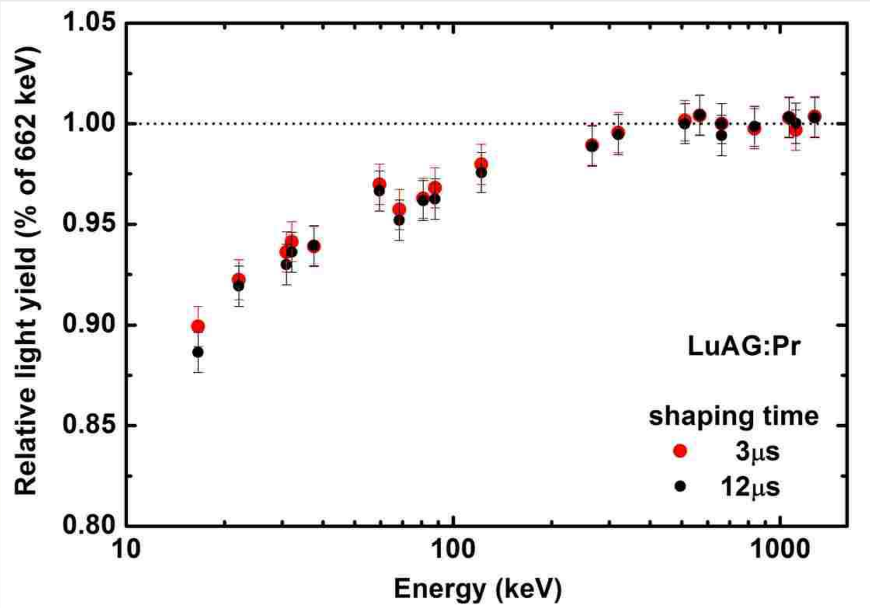
No difference in non-proportionality measured at 3 μs and 12 μs



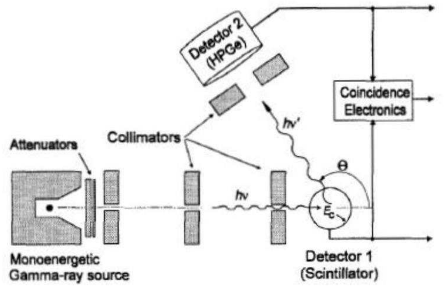
Long decay component of different origin than in *alkali iodides*

Integration of slow components in LuAG:Pr does NOT improve non-proportionality

L. Swiderski et al.,
Light Yield Non-proportionality and Energy Resolution of Praseodymium Doped LuAG Scintillator
IEEE Trans. Nucl. Sci. 56 (2009) 934

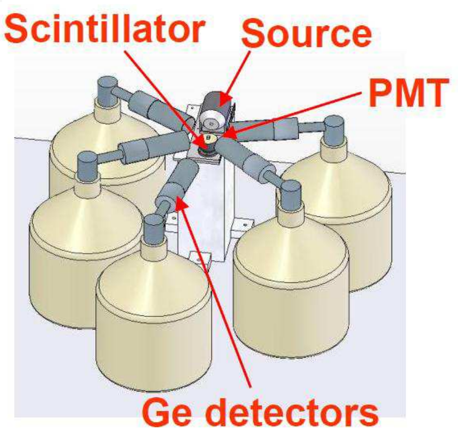
Compton Coincidence Technique

John Valentine et al. in ~1995



$E_C = h\nu - h\nu'$ or

$E_e = E_\gamma - E_{HPGe}$



Nuclear Instruments and Methods in Physics Research A 615 (2010) 182–187

Design and performance of a Compton-coincidence system for measuring non-proportionality of new scintillators

P.B. Ugorowski *, M.J. Harrison, D.S. McGregor

Mechanical and Nuclear Engineering Department, 3002 Rathbone Hall, Kansas State University, Manhattan, KS 66506, USA

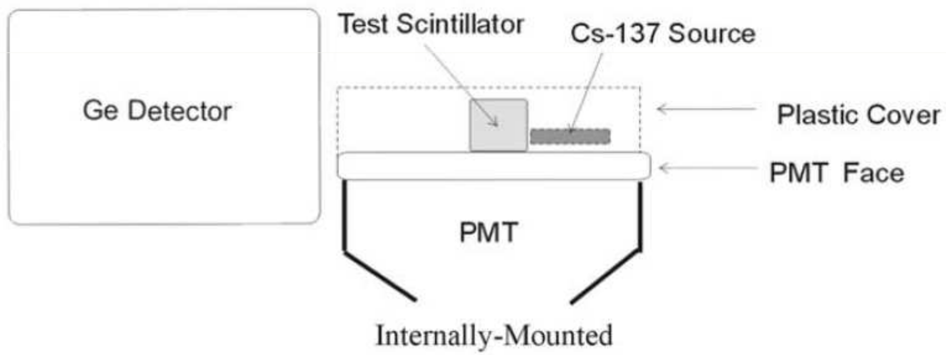


Fig. 9. A configuration for collecting data for scattering angles up to about 40°. The solid angle intercepted by the small scintillator crystal is maximized by placing the ^{137}Cs source as close as possible to the scintillator.

Scintillator Light Yield Non-proportionality Characterization Instrument (SLYNCI) W. Choong (LLNL) et al. in ~2008

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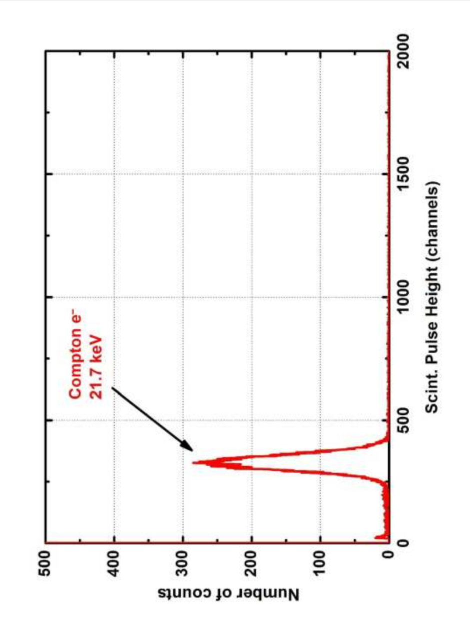
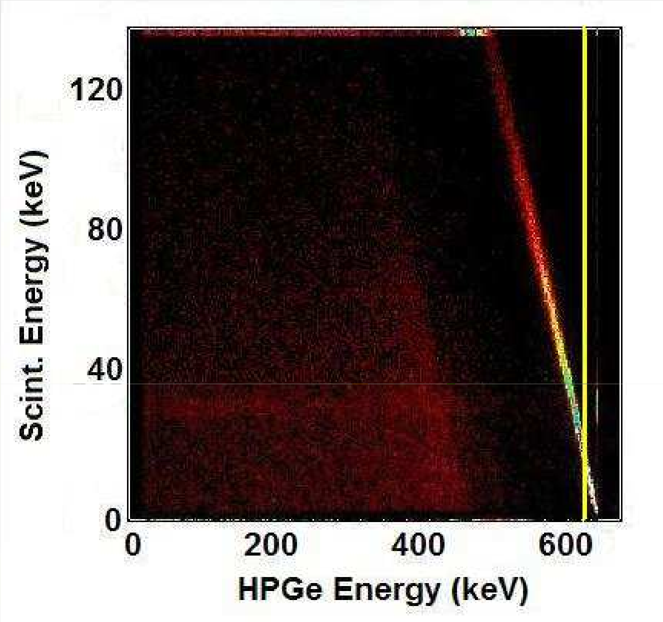
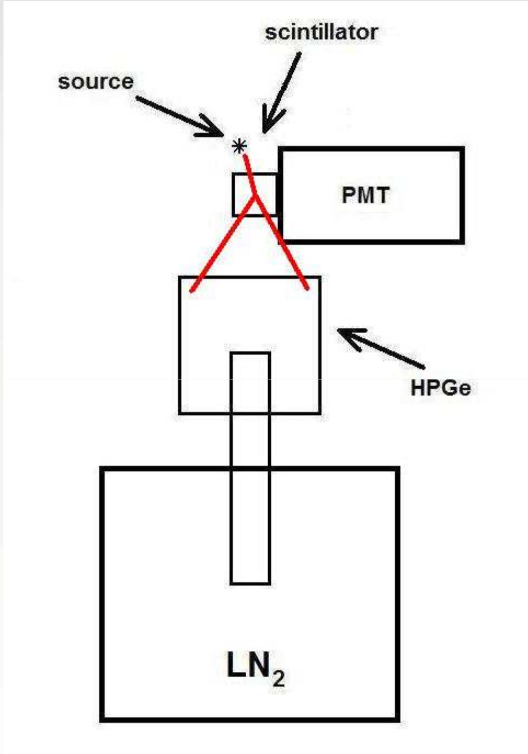
Compton Coincidence Technique







$E_0 = E_{scint} + E_{HPGe}$

close geometry: ~ 1- 6 cm
large solid angle: ≤ 90º
weak sources: ~ 10 - 30 uCi

Compton Coincidence Technique

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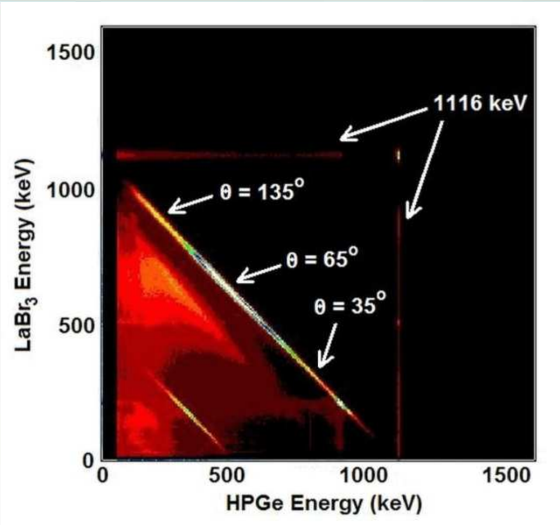
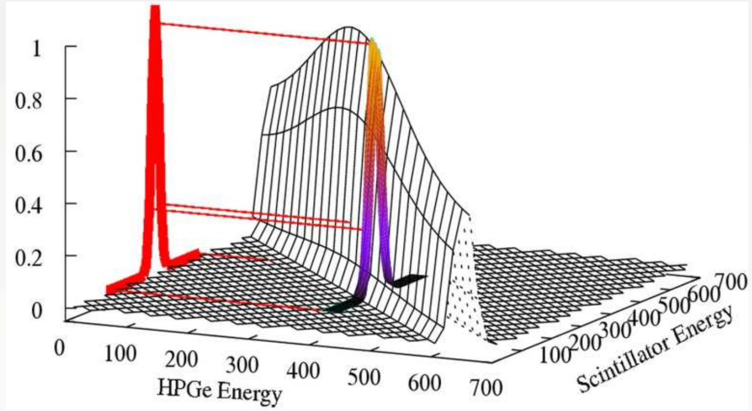
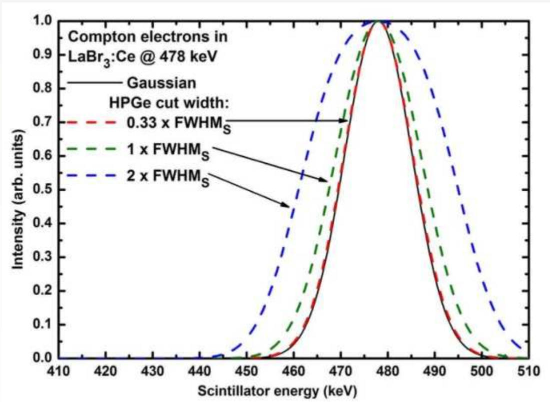


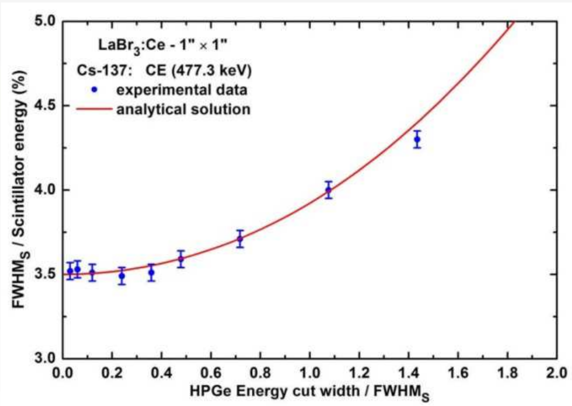
The diagonal is given by a 2-D Gaussian-like function

$$F(E_S, E_{Ge}; E_0, \sigma, N) = \frac{N}{\sqrt{2\pi\sigma_S^2}} \times e^{-\frac{1}{2}\left(\frac{(E_{Ge}-E_0)+E_S}{\sqrt{2}\times\sigma}\right)^2}$$

The solution allows to predict the influence of the cut width on the energy resolution







L. Swiderski et al.
Non-Proportionality of Electron Response and Energy Resolution of Compton Electrons in Scintillators
IEEE TNS 59 (2012) 222

$$f(E_S; E_0, E_{Ge1}, E_{Ge2}, \sigma, N) \sim \mathrm{erf}\left(\frac{aE_S + E_{Ge2} - E_0}{b\sigma}\right) - \mathrm{erf}\left(\frac{aE_S + E_{Ge1} - E_0}{b\sigma}\right)$$

CCT
Crystal characterization tool

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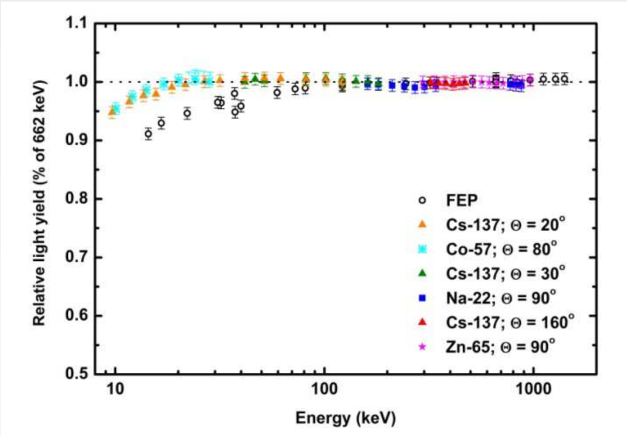
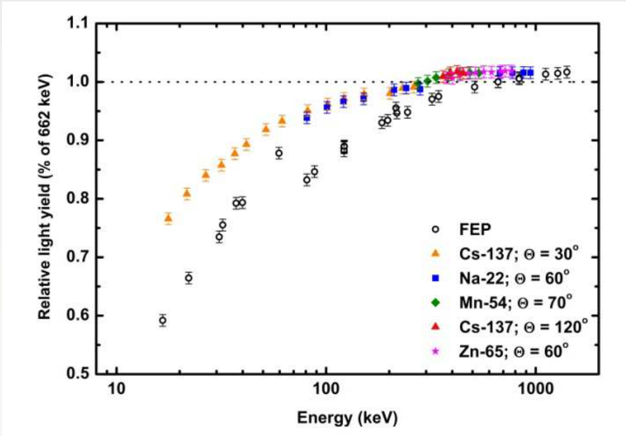
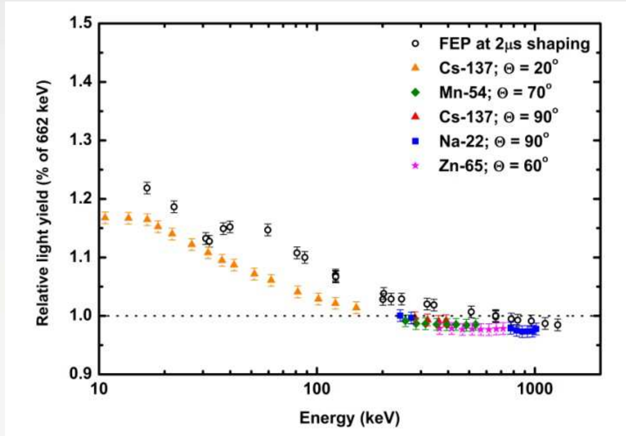
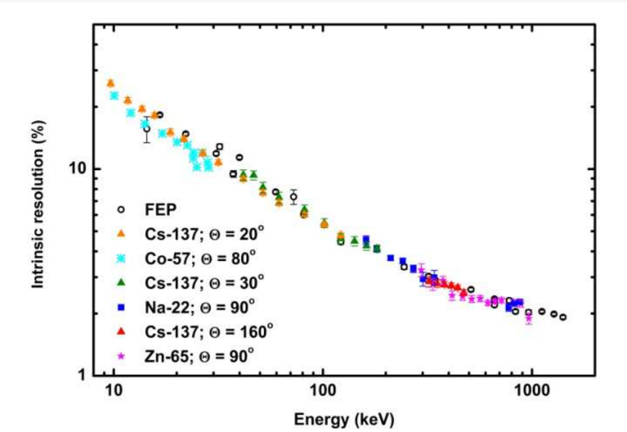
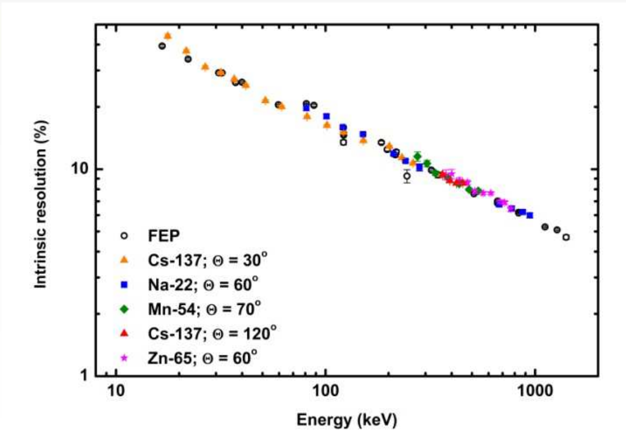
$LaBr_3$:Ce | LYSO:Ce | CsI:Tl

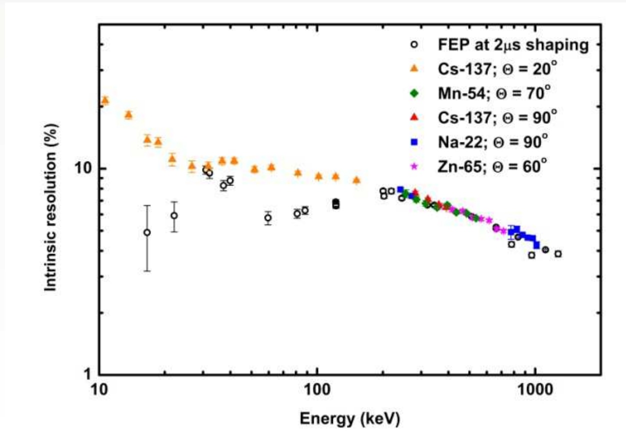






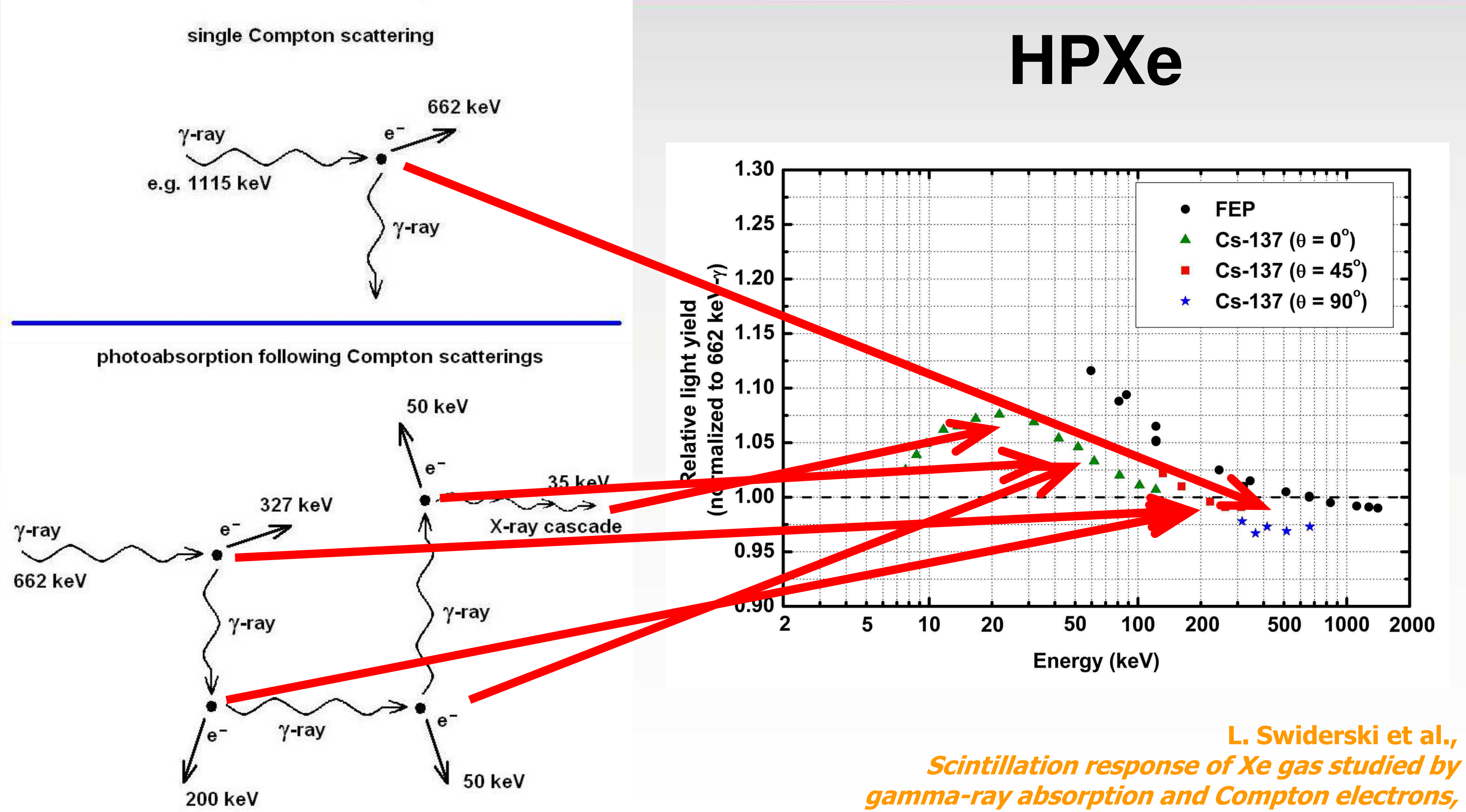






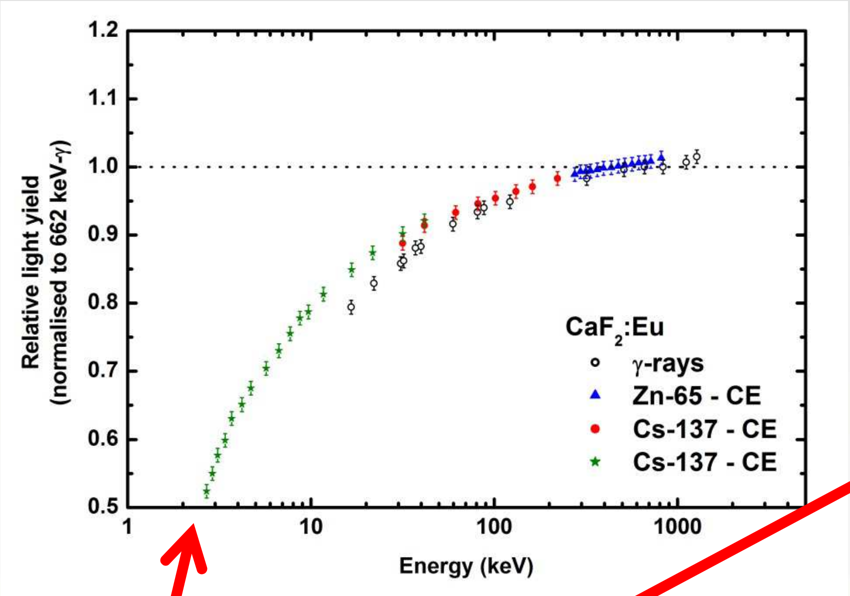
Compton vs. gamma response

HPXe

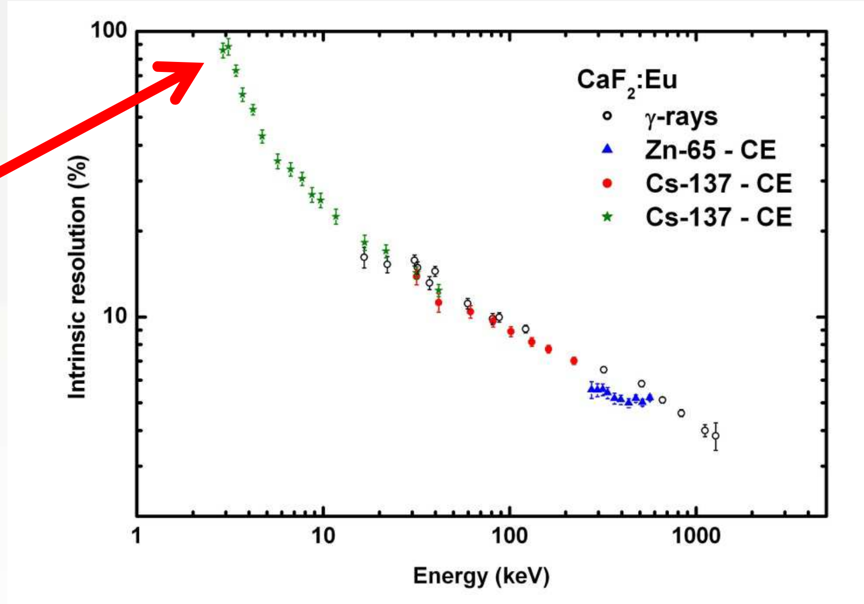


L. Swiderski et al., *Scintillation response of Xe gas studied by gamma-ray absorption and Compton electrons*, JINST 10 (2015) P07003

CCT
Low Z scintillators



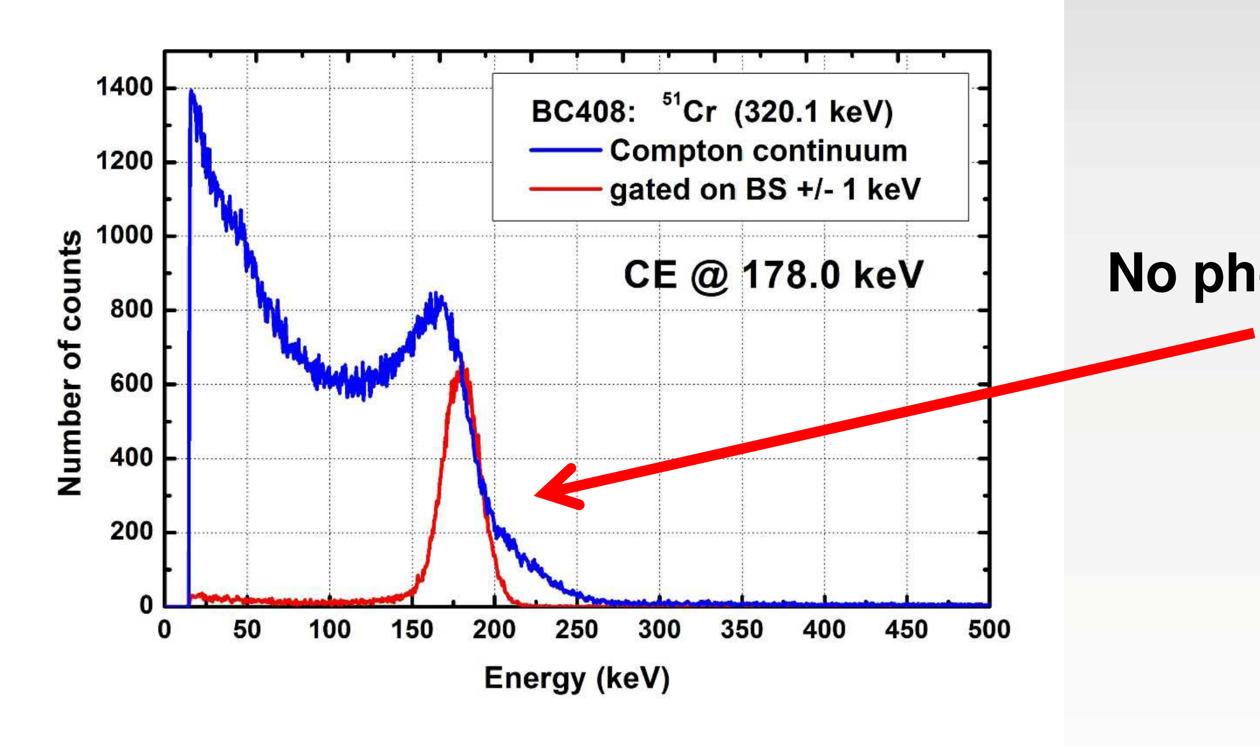
CaF_2:Eu – 1″×1″
(Schott AG)
LY = 7200 phe/MeV
dE/E = 6.5% @ 662 keV



3 keV
(11 phe)
Θ = 5º

L. Swiderski et al.,
Electron response of some low-Z scintillators in wide energy range
JINST 7 (2012) P06011

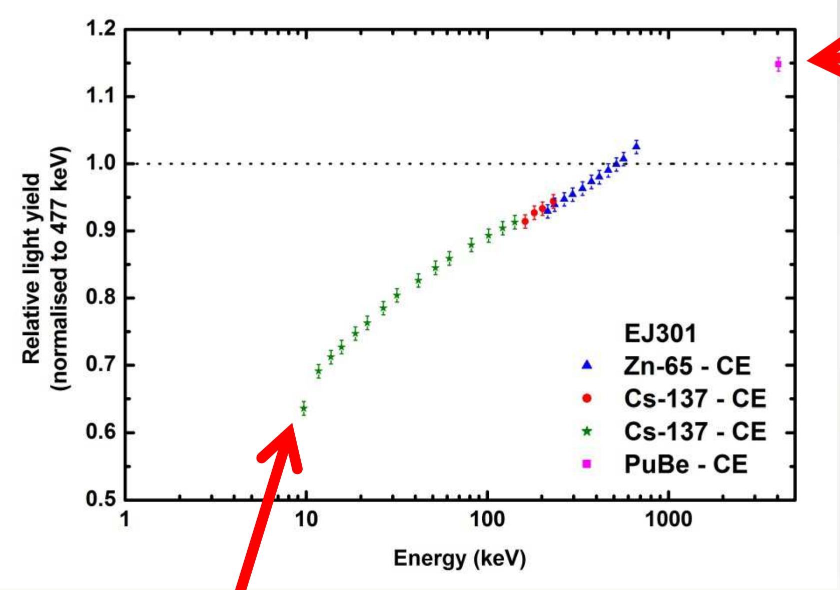
CCT
Organic scintillators



No photopeak efficiency ???

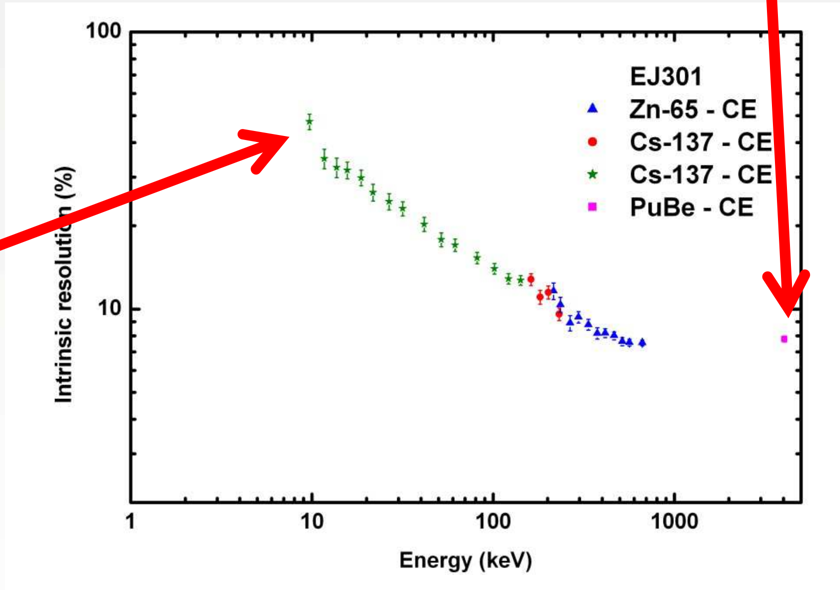
CCT allows for scanning the Light Yield and Energy Resolution of scintillators in the energy range between several keV and several MeV.

CCT
Organic scintillators



4050 keV

EJ301 – 2″×2″
(Scionix/Eljen Tech.)
LY = 2800 phe/MeV
dE/E = 9.4% @ 662 keV



10 keV
(17 phe)
Θ = 9º

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Electron response of some low-Z scintillators in wide energy range
JINST 7 (2012) P06011

CCT: reference detector HPGe → $LaBr_3$

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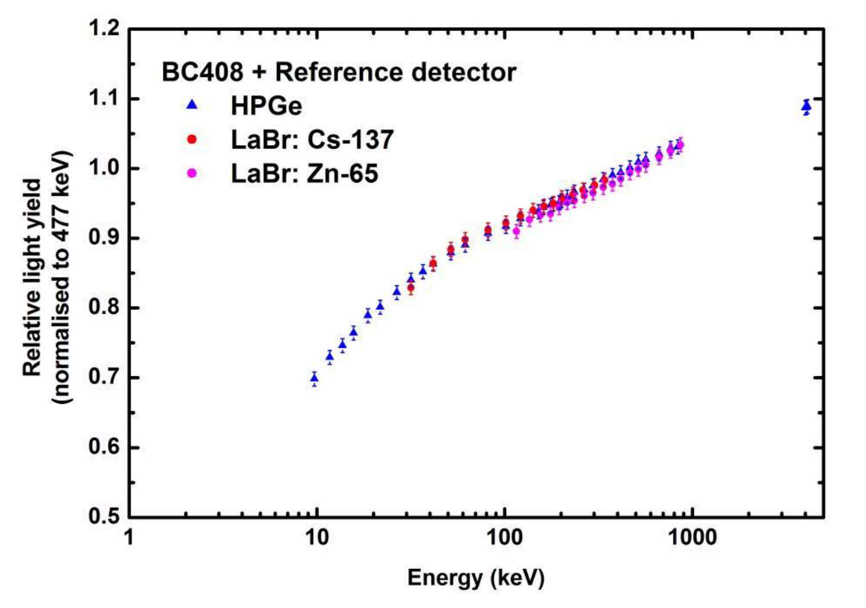
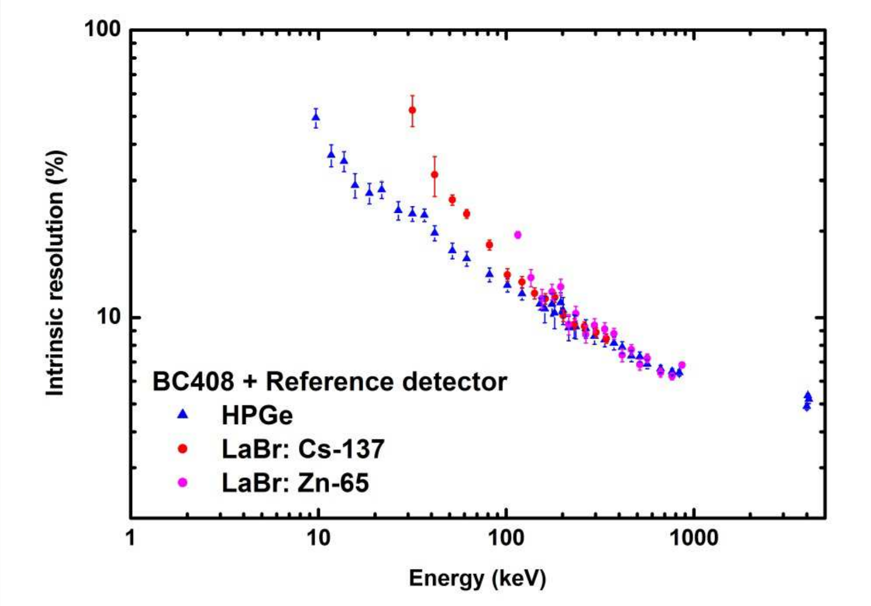


Try a scintillator!
(e.g. 1″×1″ $LaBr_3$)



@ 662 keV
HPGe: dE = 1.8 keV
$LaBr_3$: dE = 22 keV

L. Swiderski et al.,
Electron response of some low-Z scintillators in wide energy range
JINST 7 (2012) P06011

CCT
HPXe detector

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

COOPERATION

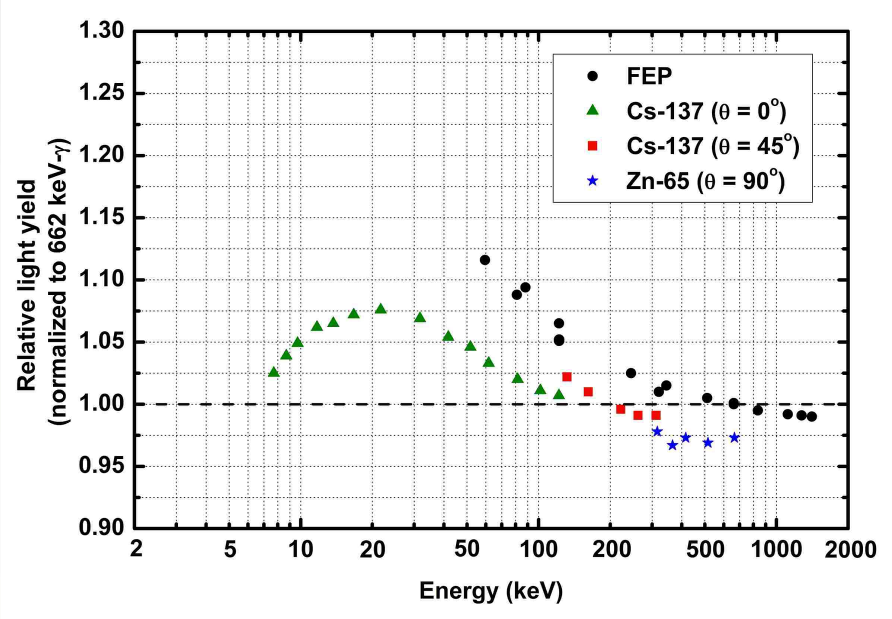
modes SNM

arktis
RADIATION DETECTORS

Preliminary tests of High Pressure Xe detector at optimization phase:

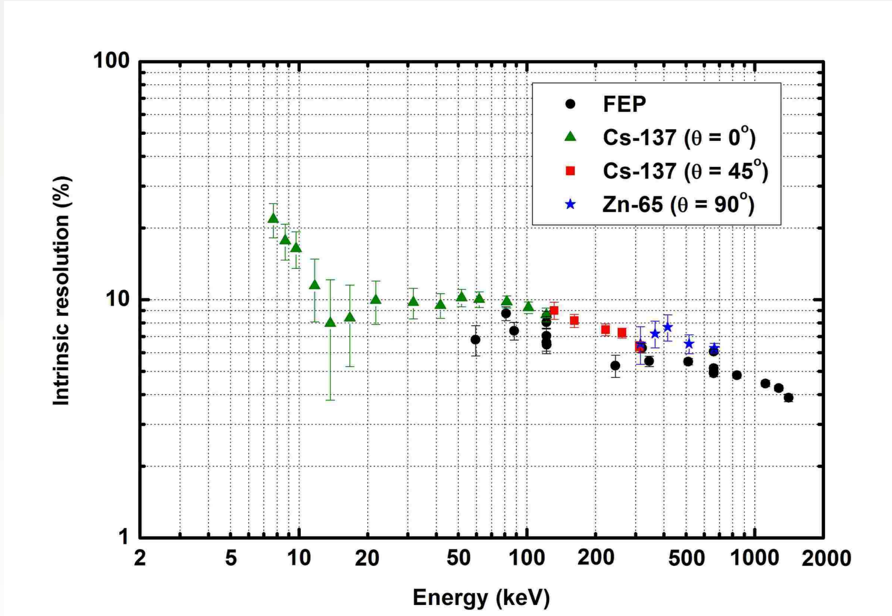
Titanium wall:	2.5 mm
Xe pressure:	50 bar
Xe density:	0.45 g/cm^3
3” PMT readout:	2×R6233-100
Photoelectron Yield:	3700 phe/MeV

L. Swiderski et al.,
Scintillation response of Xe gas studied by gamma-ray absorption and Compton electrons,
JINST 10 (2015) P07003



The electron response is shifted down with respect to gamma absorption curve due to large number of Compton events in case of absorption.

The intrinsic resolutution is the same when measured with gamma-rays or Compton electrons.



L. Swiderski et al.,
Scintillation response of Xe gas studied by gamma-ray absorption and Compton electrons,
JINST 10 (2015) P07003

Non-proportionality of fast and slow decay components

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1062 IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 55, NO. 3, JUNE 2008

Energy Resolution of Scintillation Detectors—New Observations

M. Moszyński, *Fellow, IEEE*, A. Nassalski, *Member, IEEE*, A. Syntfeld-Każuch, *Member, IEEE*, L. Świderski, *Member, IEEE*, and T. Szczęśniak, *Member, IEEE*

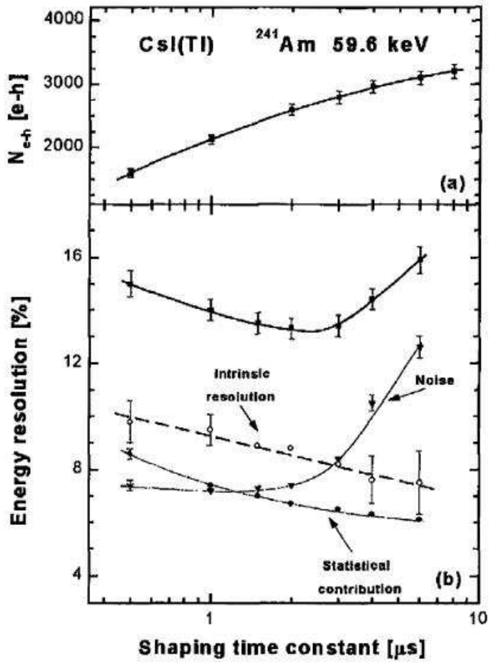
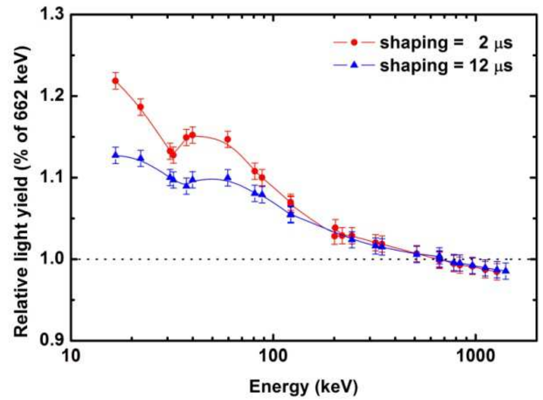
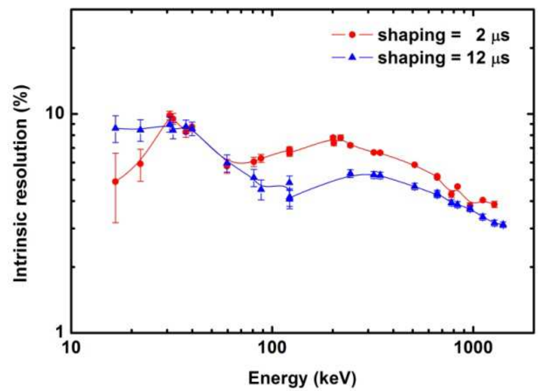


Fig. 1. (a) Number of e-h pairs measured with CsI(Tl) crystal for 59.6 keV γ-rays versus shaping time constant. (b) Energy resolution measured for 59.6 keV γ-rays versus shaping time constant. The thin continuous lines show the noise and the statistical contributions. The dashed line presents the intrinsic resolution determined from (1). Following [17].

Extended pulse integration
↓
Reduced non-proportionality of light yield
↓
Improved intrinsic resolution





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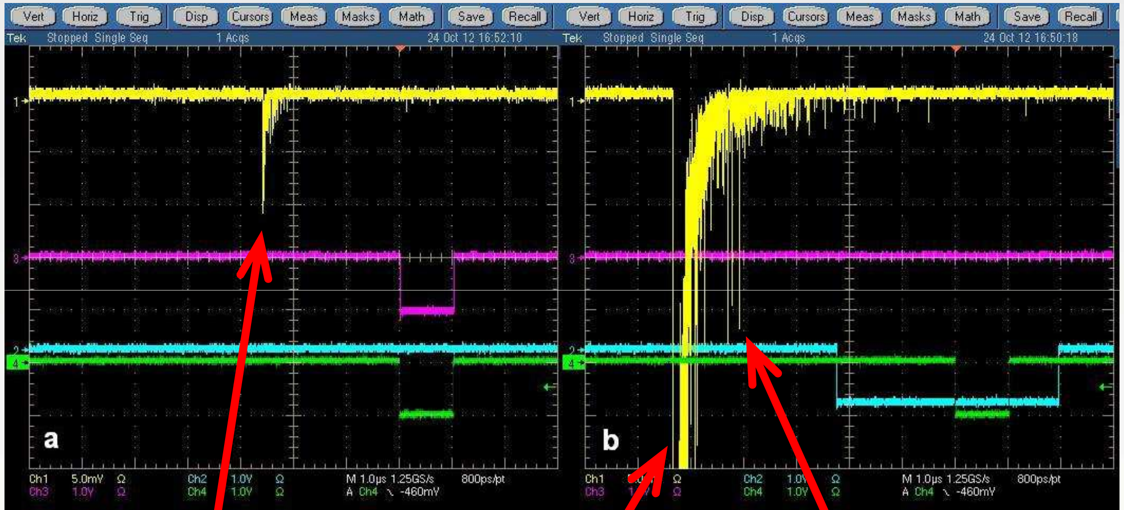
Non-proportionality of fast and slow decay components

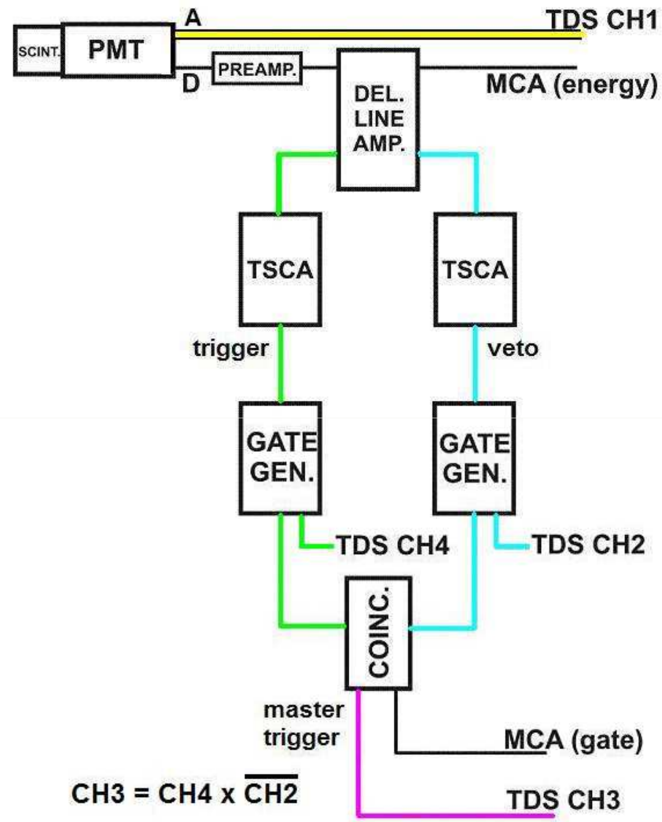
Problem to solve: afterpulses triggering scope



Need to block large pulses!

Trigger set for low energy deposits (~10 – 20 keV)

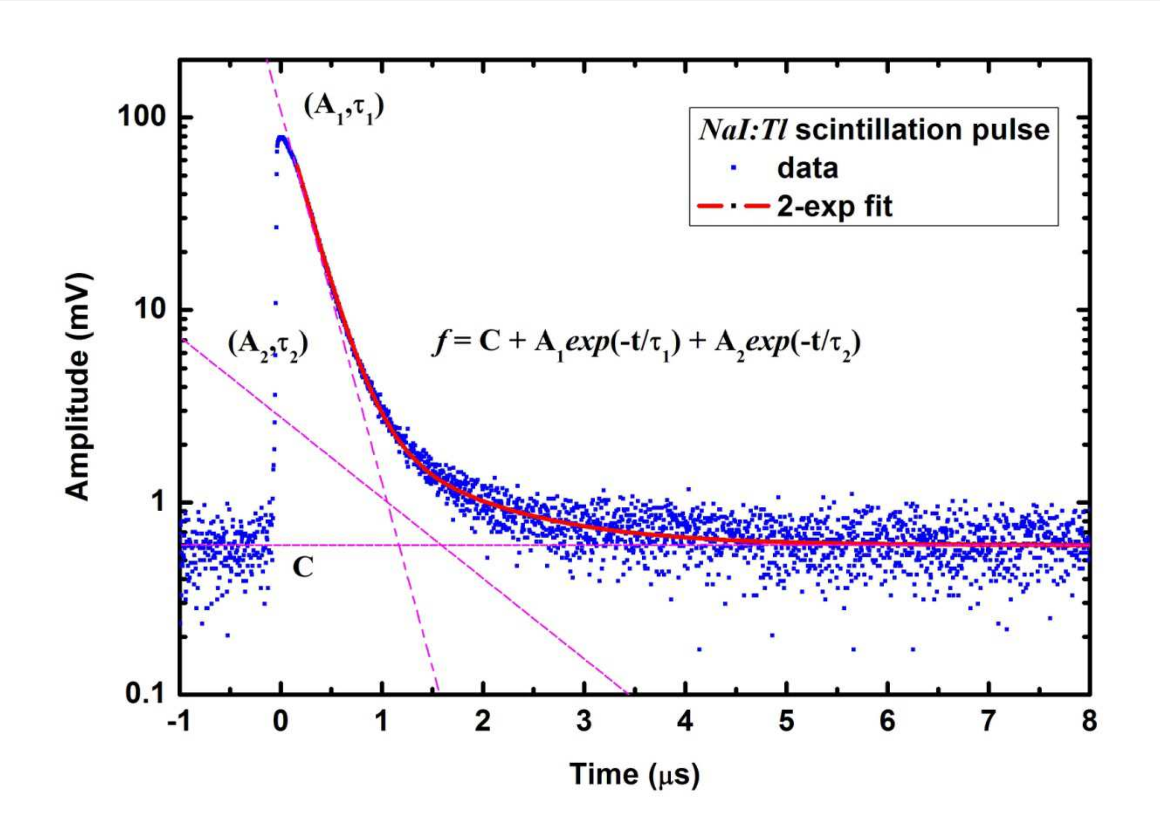
Afterpulse following large pulse produce event trigger



L. Swiderski et al., *Measuring the scintillation decay time for different energy deposits in NaI:Tl, LSO:Ce and $CeBr_3$ scintillators* Nucl. Instrum. Meth. A749 (2014) 68

Non-proportionality of fast and slow decay components

Fast and slow decay mode in NaI:Tl



$I_{fast} \approx 90\%$
$\tau_{fast} \approx 0.23\ \mu s$

$I_{slow} \approx 10\%$
$\tau_{slow} \approx 1\ \mu s$

$I_1(E) = A_1 \times \tau_1$

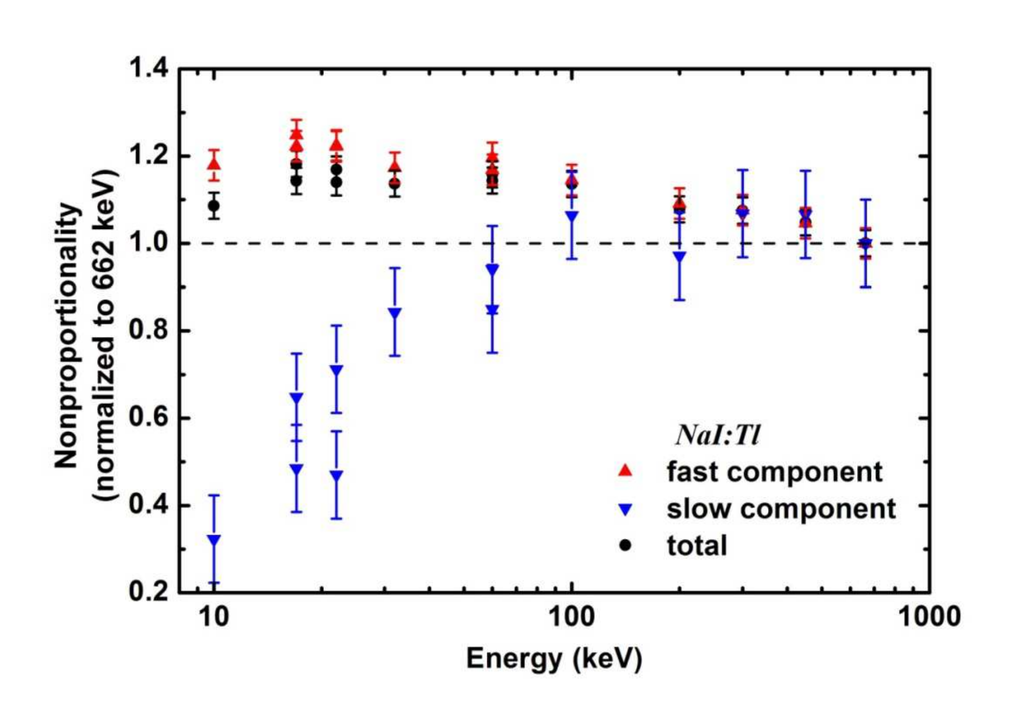
$I_2(E) = A_2 \times \tau_2$

$NP_1(E) = I_1(E) / I_1(662)$ $NP_2(E) = I_2(E) / I_2(662)$

L. Swiderski et al.,
Measuring the scintillation decay time for different energy deposits in NaI:Tl, LSO:Ce and $CeBr_3$ scintillators
Nucl. Instrum. Meth. A749 (2014) 68

Non-proportionality of fast and slow decay components

Non-proportionality of fast decay component has the same shape as typical for alkali iodides (maximum at ~20 keV).

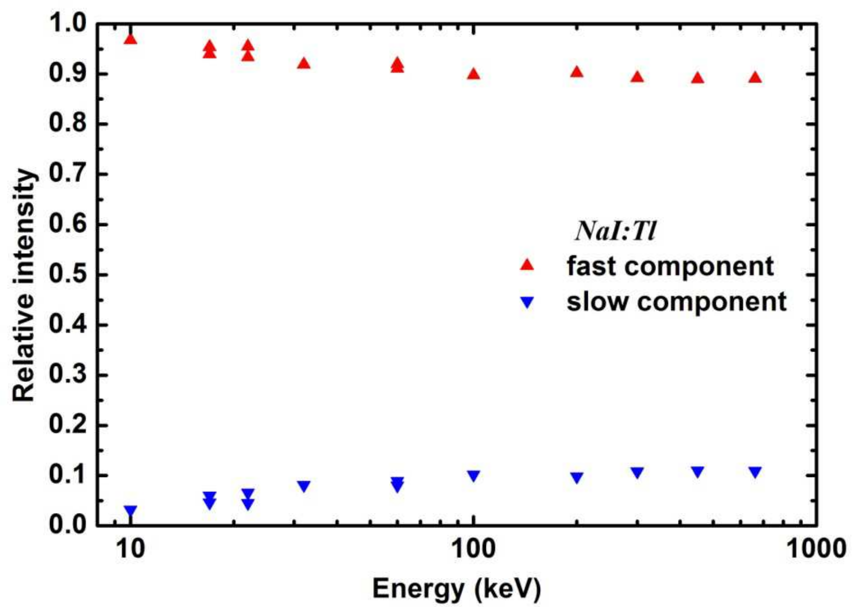


Taking into account information carried by both components reduces the non-proportionality of NaI:Tl.

Long decay component shows non-proportional response typical to oxide scintillators (monotonically decreasing at low energy).

L. Swiderski et al., *Measuring the scintillation decay time for different energy deposits in NaI:Tl, LSO:Ce and $CeBr_3$ scintillators* Nucl. Instrum. Meth. A749 (2014) 68

Relative intensity of fast and slow decay component in NaI:Tl changes with energy deposited in the scintillator.



1246 IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 55, NO. 3, JUNE 2008

Light Pulse Shape Dependence on γ-Ray Energy in CsI(Tl)

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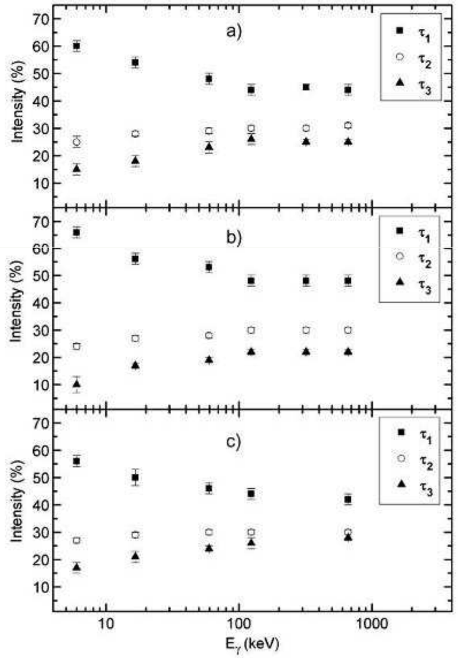

Fig. 4. Relative intensities of the light components as measured for a) CsI(Tl) 0.01 m/o, b) CsI(Tl) 0.06 m/o, and c) CsI(Tl) 0.25 m/o.

L. Swiderski et al.,
Measuring the scintillation decay time for different energy deposits in NaI:Tl, LSO:Ce and $CeBr_3$ scintillators
Nucl. Instrum. Meth. A749 (2014) 68

The same effect observed earlier in CsI:Tl crystal (measured with different experimental technique!).

Summary (CCT)

1. The energy resolution of scintillators is strongly correlated with non-proportionality of their response.

2. Compton Coincidence Technique (CCT) is a powerful tool that can be used for characterization of electron response for various types of scintillation materials, like:
   - single crystals (e.g. $LaBr_3$, LYSO, CsI:Tl)
   - low Z scintillators (e.g. CaF_2)
   - organic scintillators (e.g. EJ301, BC408)
   - gas scintillators (e.g. HPXe).

3. In contrast to gamma-ray absorption measurements, CCT provides continuous-like electron response and allows avoiding limitations related with the former technique.

Summary
(NP of decay components)

1. Non-proportionality of fast and slow decay components can be resolved by fitting the scintillation pulses at various energies deposited in the scintillator.

2. The information about the decay components non-proportionality can be used for „scintillator engineering" – modifying the non-proportionality by varying the intensity of different scintillation decay modes.

Thank you
for attention!