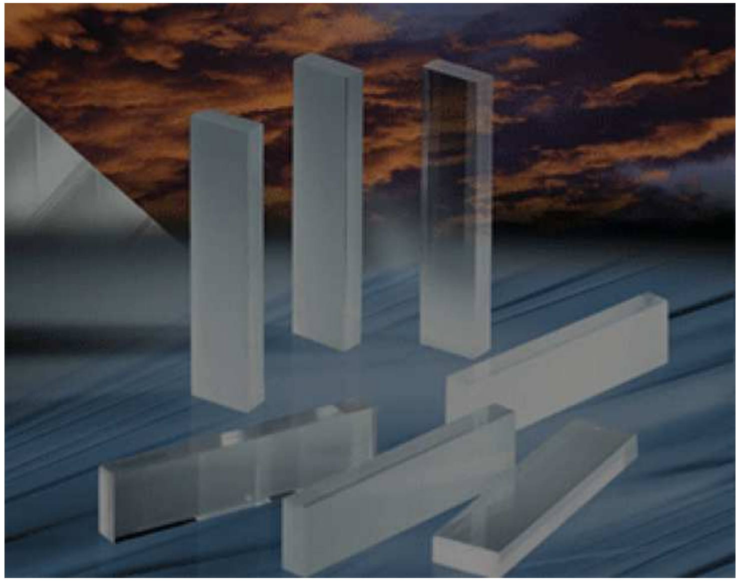
Nagroda IEEE NPSS im. Prof. Glenna Knolla



czyli moja przygoda z detektorami scyntylacyjnymi

Marek Moszyński
Narodowe Centrum Badań Jądrowych, Świerk

2018 Glenn Knoll Radiation Instrumentation Outstanding Achievement Award of the IEEE Nuclear and Plasma Science Society

„For outstanding contribution to the modern scintillation detectors in application to physics, medicine and homeland security”

Zakończenie ceremonii wręczenia nagrody na konferencji IEEE w Sydney.
M.M. razem z Stefanem Ritt z PSI, Villigen, prezydentem IEEE NPSS i
Prof. Chiarą Guazzoni z Politecnico di Milano, przewodniczącą komisji nagród

IEEE – Institute of Electric and Electronics Engineers jest największym na świecie stowarzyszeniem zawodowym zrzeszającym ponad **423 tysięcy członków z ponad 160 krajów**. IEEE powstało w 1963 roku z połączenia **American Institute of Electrical Engineers (utworzony w 1884 roku) i Institute of Radio Engineers (od 1912 roku).**

IEEE NPSS – IEEE Nuclear and Plasma Science Society jest międzynarodowym tematycznym stowarzyszeniem w IEEE z ponad **3000 naukowców i inżynierów z całego świata**. IEEE NPSS powstało w 1947 r. jako amerykańskie stowarzyszenie należące do IEEE. NPSS organizuje kilka światowych konferencji naukowych, wydaje ważne periodyki naukowe. **Organizator Nuclear Science Symposium and Medical Imaging Conference –** pierwotnie w USA, obecnie w różnych krajach na świecie.

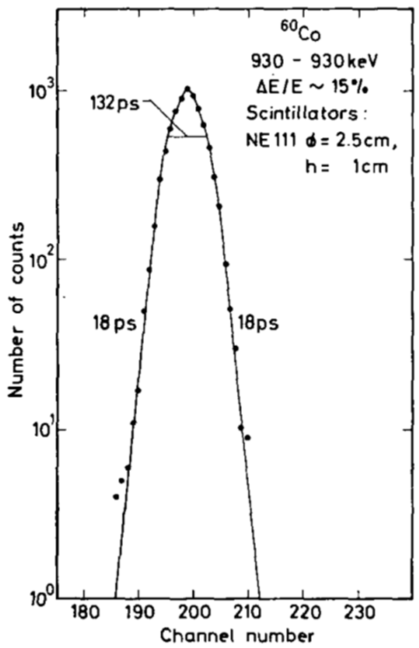
Outline

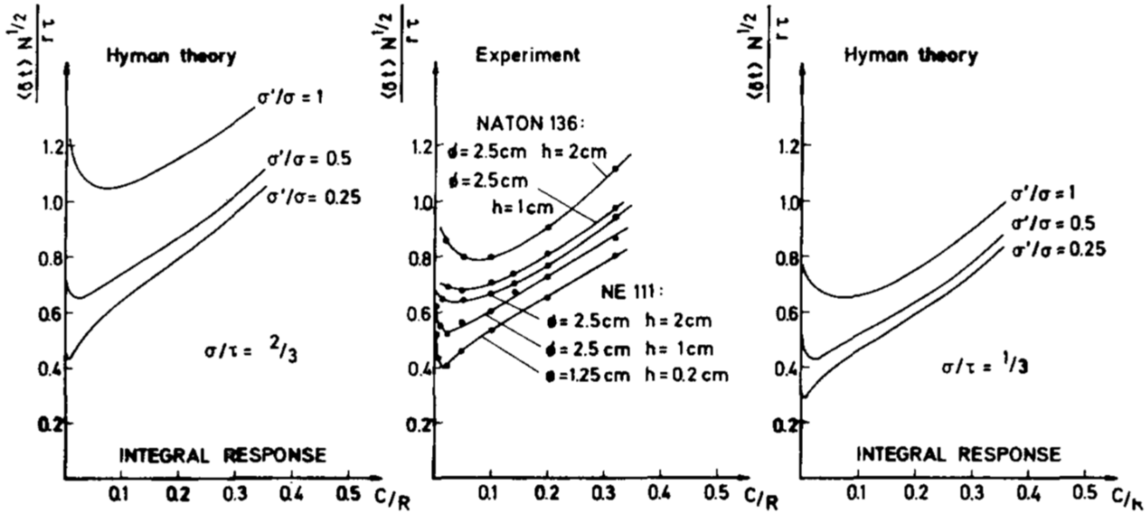
My talk will consist of three parts, the most representative for my activity:

- Fast timing in nuclear structure physics and nuclear medicine (PET)
- Energy resolution and non-proportionality of scintillator response
- Neutron detection

The first 20 years
Fast timing with scintillation detectors

- **Timing with plastic scintillators in application to live time measurements of nuclear states, Aarhus University, Denmark, 1969**





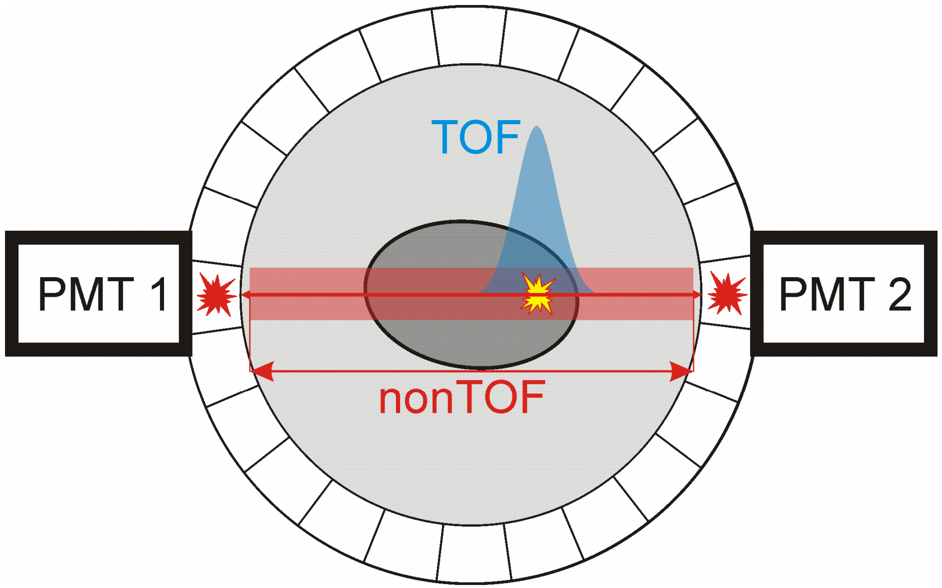
PMT,
σ' – time jitter

Scintillator

PMT

B.Bengtson and M.M., NIM 81(1970)109 – **98 citations**

Time-of-flight PET



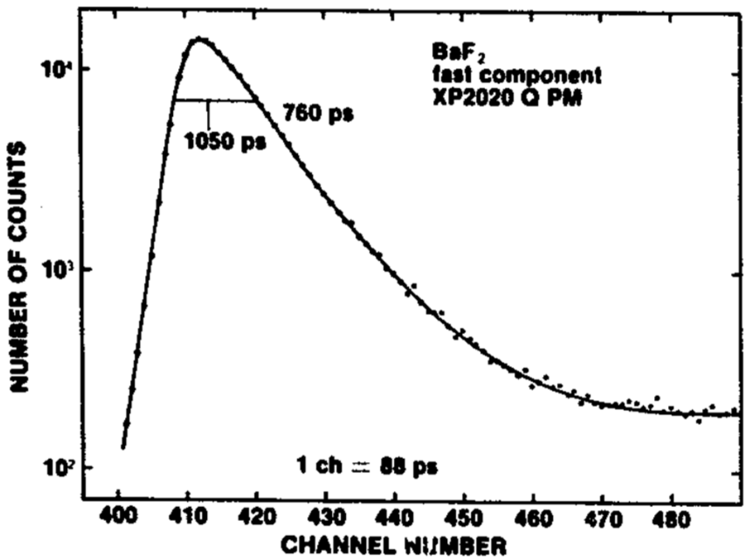
III World Congress on Biology and Nuclear Medicine is planned in 1982 in Paris

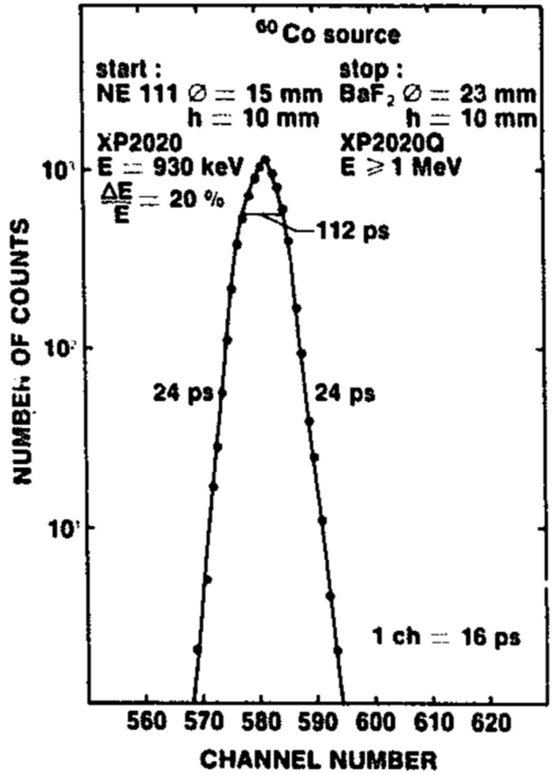
1979 CENG – LETI, Grenoble proposes the development of the first TOF PET.

They have got algorithms to improve an image due to TOF information, but it was lack of a good scintillator to get at least 500 – 700 ps at FWHM.
Plastic – very low detection efficiency!!
NaI(Tl) – too poor time resolution

Fast timing with scintillation detectors

- CsF and BaF2, the first fast inorganic scintillators in the TOF PET – LETI, Grenoble, 1980-82
- The first TOF-PET

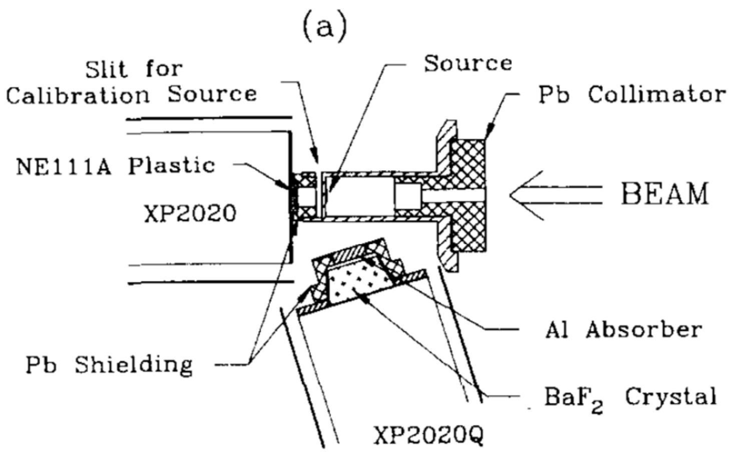


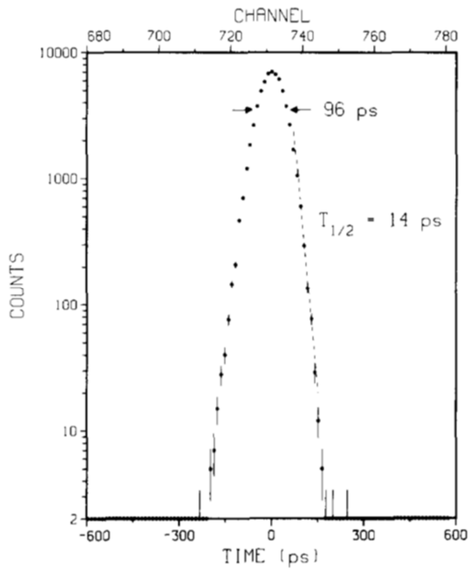


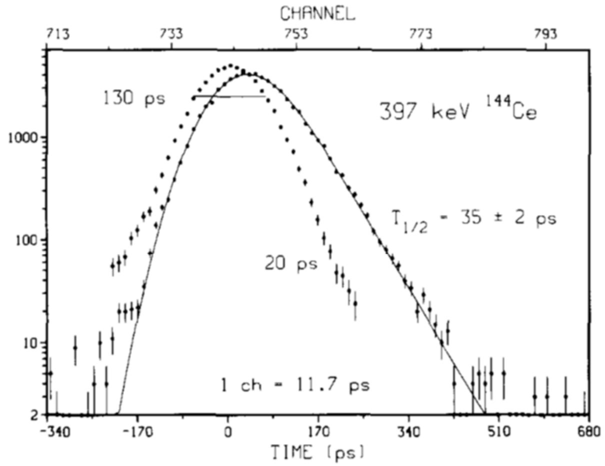
M. Laval, M.M. et al., NIM, 206(1983)169 – 380 cytowań

Fast timing with scintillation detectors

- A method of picosecond half lives measurements of nuclear states at BNL, H. Mach and M.M. 1987- 89





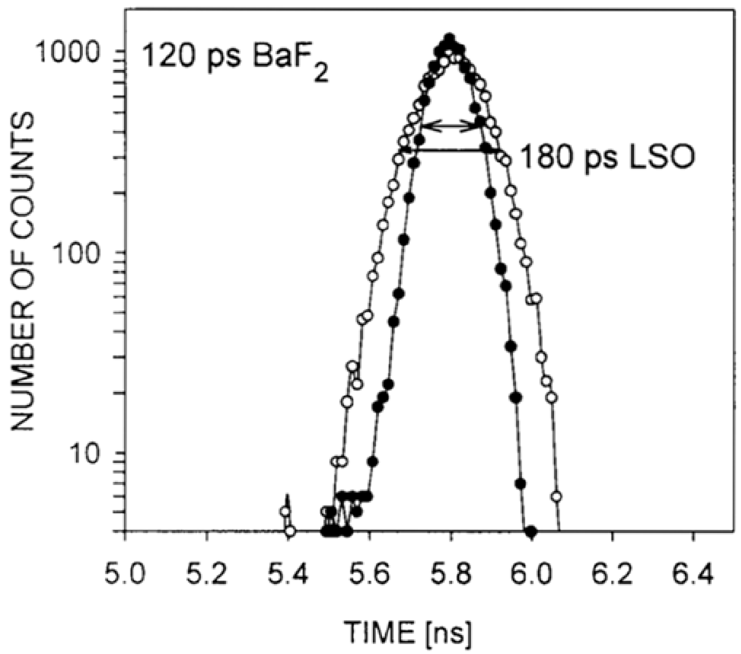


M.M. and H. Mach NIM, A277(1989)407
H. Mach, R. Gill, M.M. , NIM, A280(1989)49
280 cytowań

The method is used at present by groups of Cologne, Madrid, Surrey Guildford in UK, CERN, Grenoble, Warsaw, etc

The next decades
study of new scintillators

- YAG:Ce, YAP:Ce, LSO:Ce, LuAP:Ce, $LaBr_3$, LGSO, LSO:Ce:Ca, LuAG:Pr, LuAG:Ce, CWO, CaWO, LiCAF, GAGG, $CeBr_3$, plastic scintillators with PSD capability and others

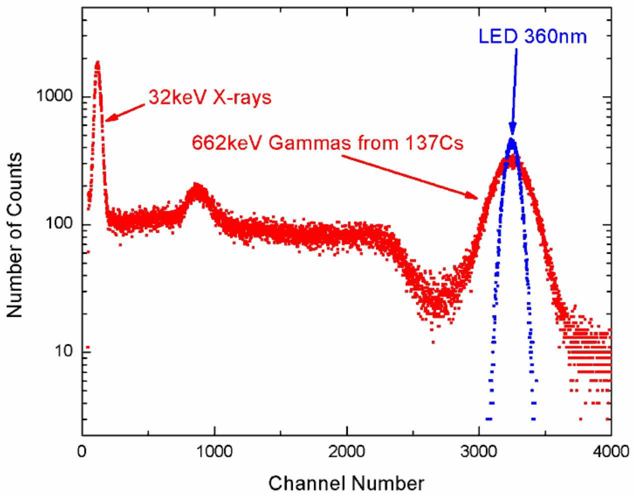


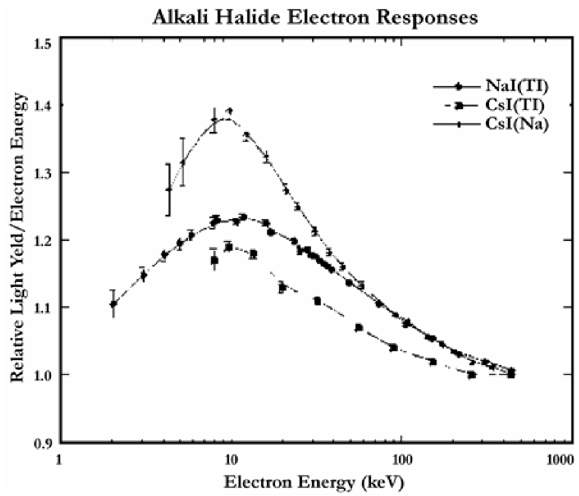
T. Ludziejewski, M. Moszyński, et al., IEEE TNS 42(1995)328: - **56 cytowań**

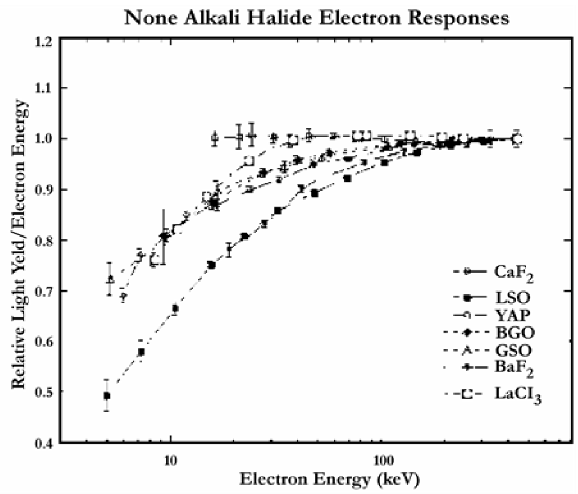
„The potential advantages of LSO crystal in positron emission tomography were pointed out earlier. The presented results of the time resolution study seems to suggest that the time-of-flight PET to be possible with LSO crystals.”

Energy resolution, Non-proportionality

Intrinsic resolution of scintillators → Non-proportionality is a fundamental limitation of energy resolution!







Competitive centers:

Berkeley, CA

Livermore, CA

Idaho Lab

Homeland security

Richland, WA

Homeland security

Energy resolution, Non-proportionality
1998-2018

1998 – a proportional response of YAP:Ce scintillator is reflected in the lowest intrinsic resolution – Maciek Kapusta et al.

2002 – 2004 – scattering of secondary electrons (δ-rays) is dominating component of intrinsic resolution

1999 – 2013 – influence of slow components of light pulses on non-proportionality and intrinsic resolution (halide crystals)

2002 – 2008 – undoped NaI and CsI scintillators, influence of accidental impurities on intrinsic resolution and non-proportionality

2007 – 2008 – correlation of „afterglow" and intrinsic resolution

2008 – deterioration of energy resolution by slow components of the light pulses

2010-2011 – Energy resolution and non-proportionality of Compton electrons

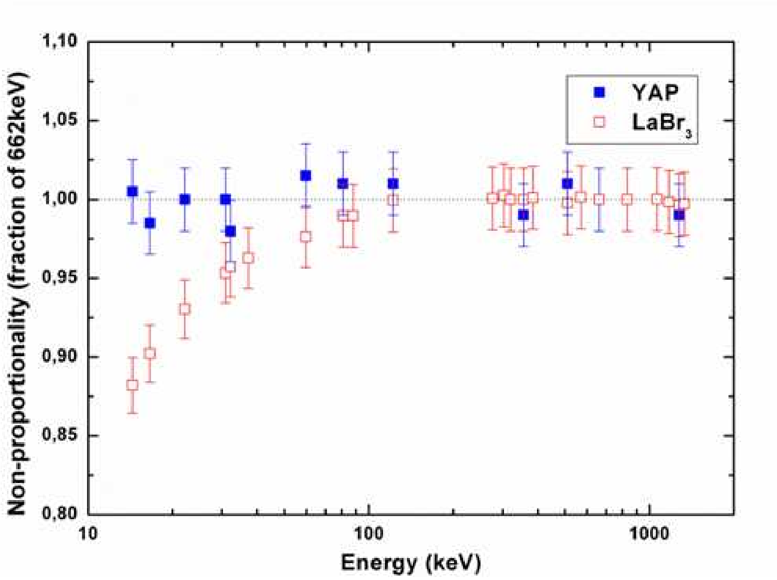
2012 – Świerk vs. Berkeley and Livermore: electron scattering or Landau fluctuations

2013 – The first test of nonproportionality of a Xe gas scintillator

2014 – 2018 – nonproportionality of separate components of the light pulses

Results: **about 65 papers, 7 invited talks, 5 review papers, >2100 citations**

YAP:Ce



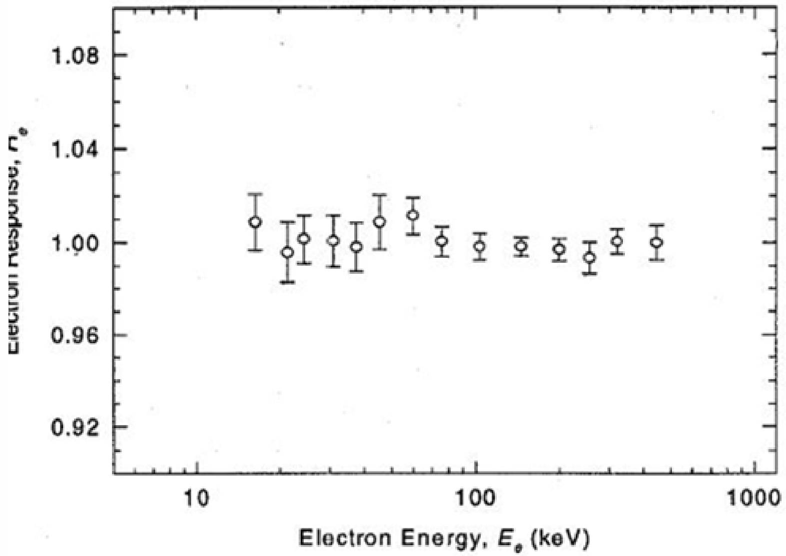
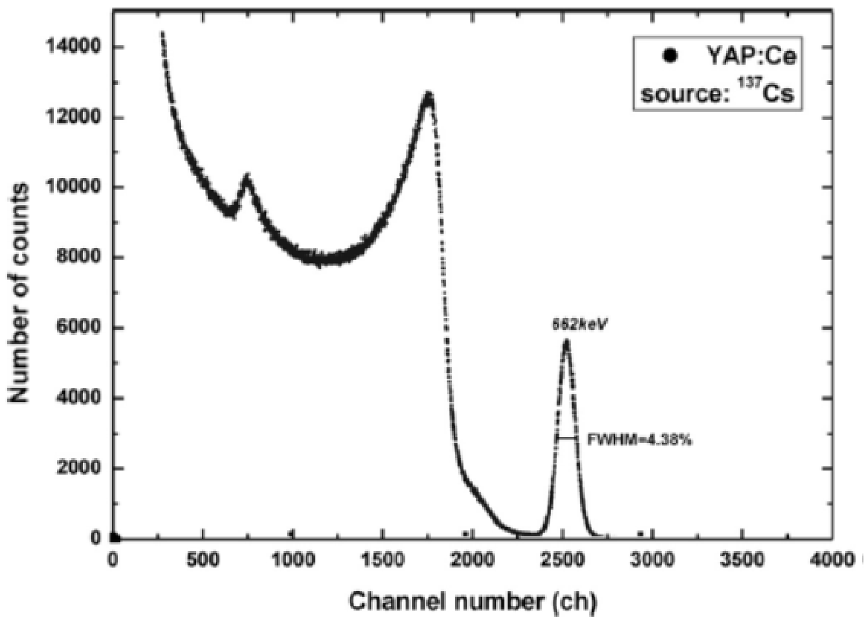


Figure 7: YAP electron response $R_e(=L/E_e)$ measured using the CCT. Data are normalized to unity at 445 keV.



IEEE TNS 45 (1998) 456 – W. Mengesha et al.

NIM A421 (1999) 610 – M. Kapusta et al.

YAP: δ_{int} = (1.3 ± 0.5)%

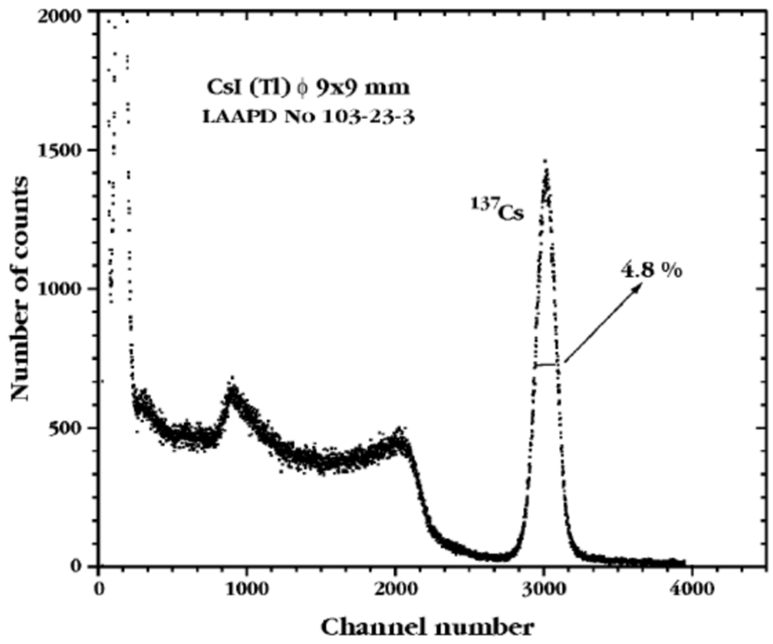
Intrinsic resolution correlated with (non)proportionality 16 keV < Eγ < 1 MeV

73 citations

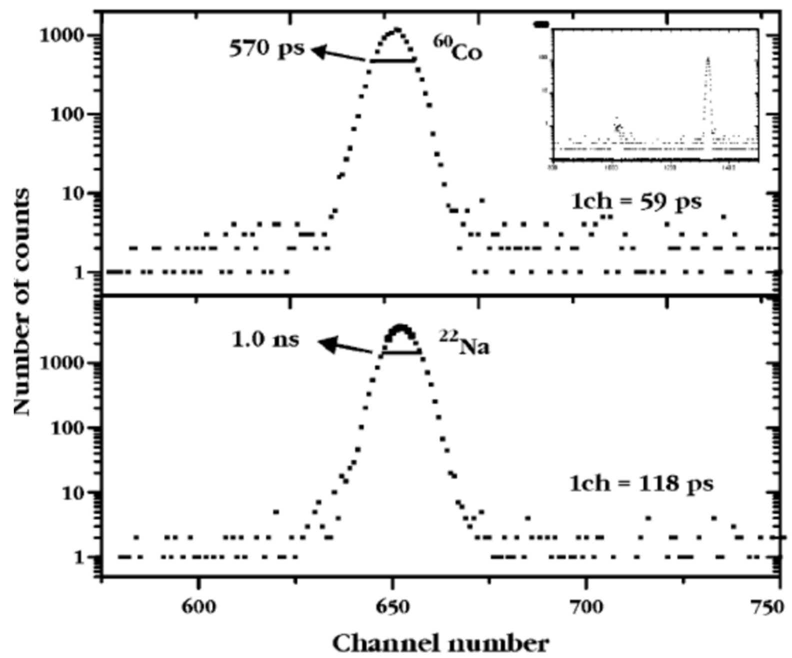
Avalanche photodiodes

Collaboration with Advanced Photonix, Inc. USA – Marek Szawłowski

Large Area Avalanche Photodiodes – Ø16 mm



In gamma spectroscopy with scintillators

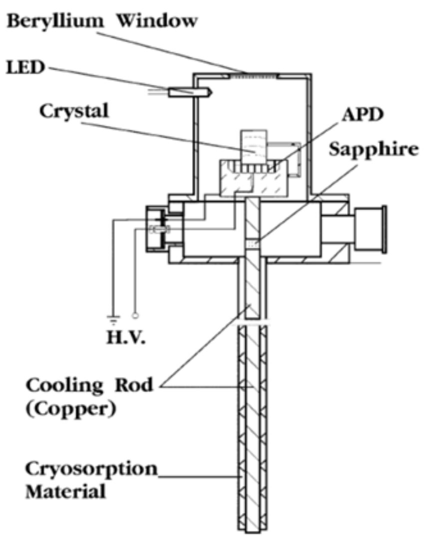


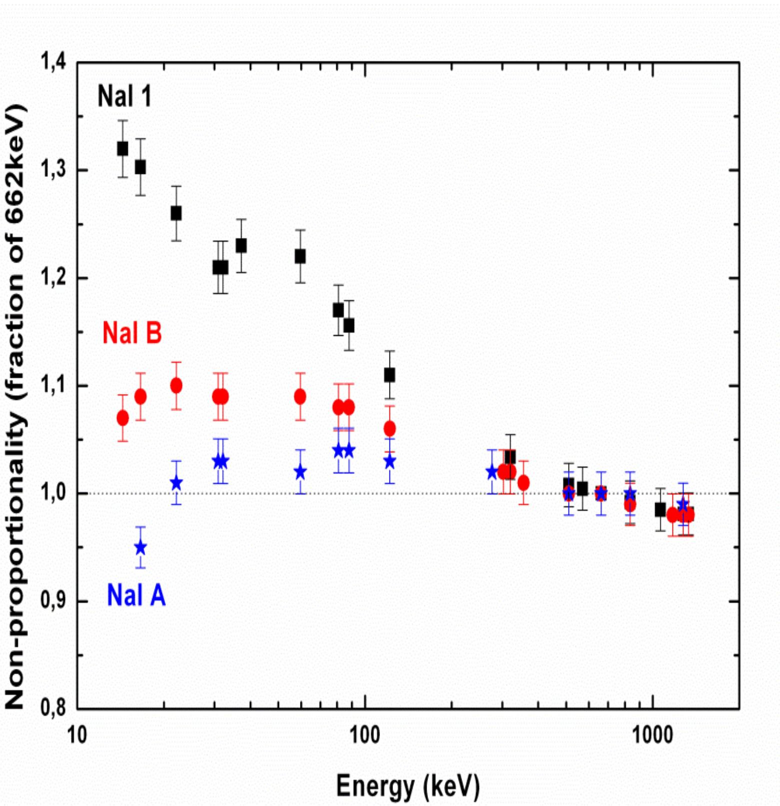
In fast timing with LSO scintillator

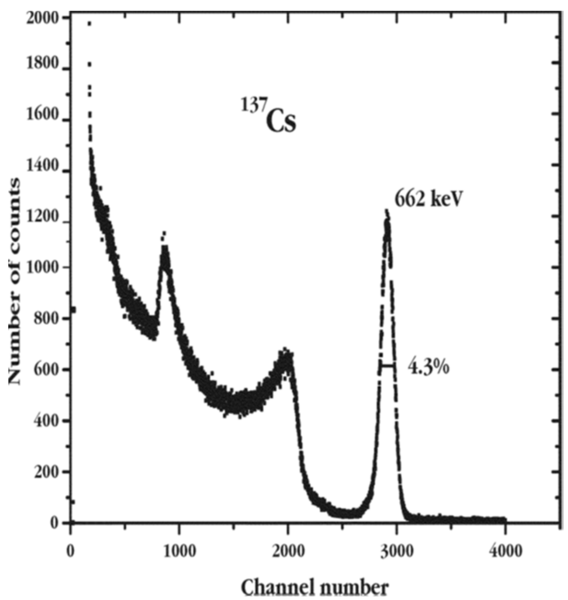
25 papers, about 840 citations

M.M. et al., NIM A485(2002)504–521 – 90 citations

APD at liquid nitrogen temperature





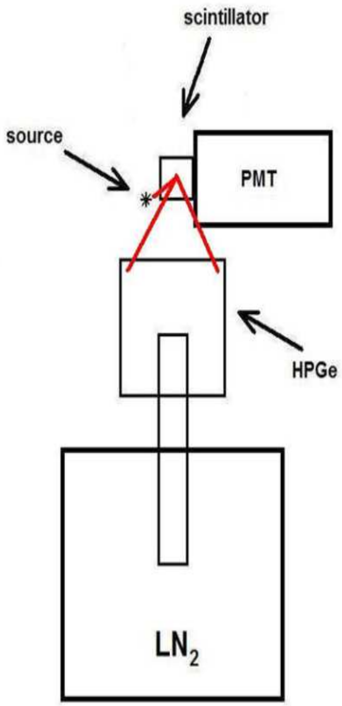


APD of Advanced Photonix,
Test of crystals:
undoped NaI and CsI, BGO, CWO, LSO, CeF_3 and others

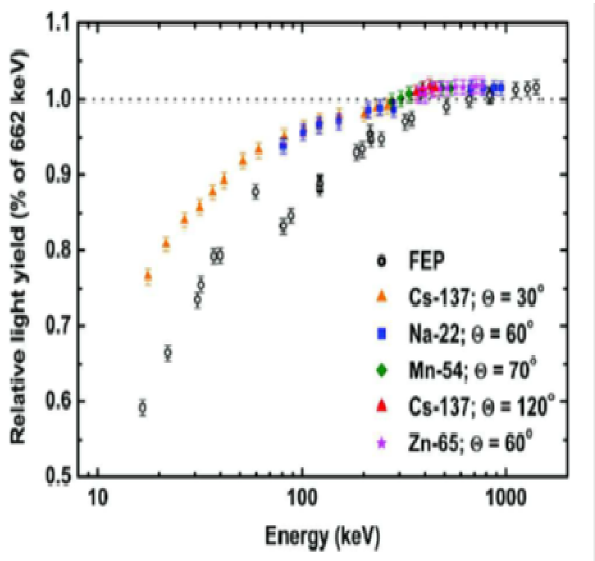
„The results suggest that **a selective doping of pure crystals or a co-doping** of other crystals may reduce the non-proportionality resulting in an improvement of the energy resolution."

11 papers – 354 citations

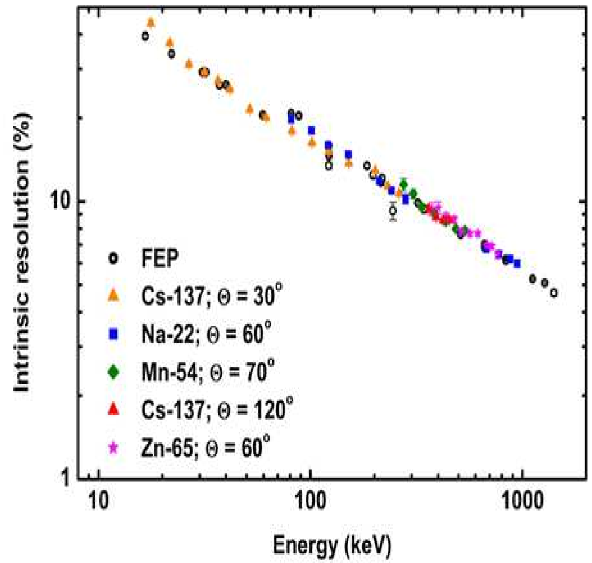
Nonproportionality and energy resolution of Compton electrons



L. Swiderski, et al., TNS, 59(2012)22



Nonproportionality of LSO for Compton electrons
and full energy peaks. Curves are normalized to 662 keV full energy peak of Cs-137.



Intrinsic resolution of Compton and full energy events vs energy.

Intrinsic resolution is created by secondary electrons.

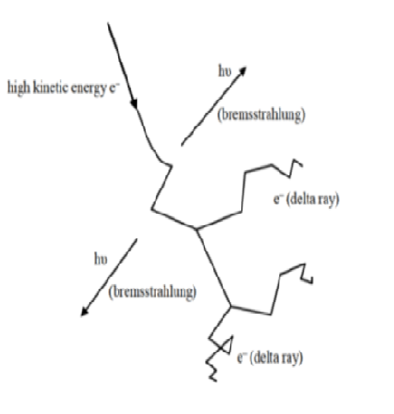
What is the origin of the contribution of the secondary electrons to the intrinsic resolution of the scintillators?

According to Steve Payne and Bill Moses (Livermore and Berkeley), the Landau fluctuations are responsible for the intrinsic resolution of scintillators.
see S. Payne et al., „Nonproportionality of Scintillator Detectors: Theory and Experiment. II.”, IEEE TNS vol. 58, no. 6, pp. 3392, 2011

According to Świerk group the dominating process is related to the scattering of secondary electrons (produced by γ-rays).
See M.M. et al., NIMA, A805(2016)25

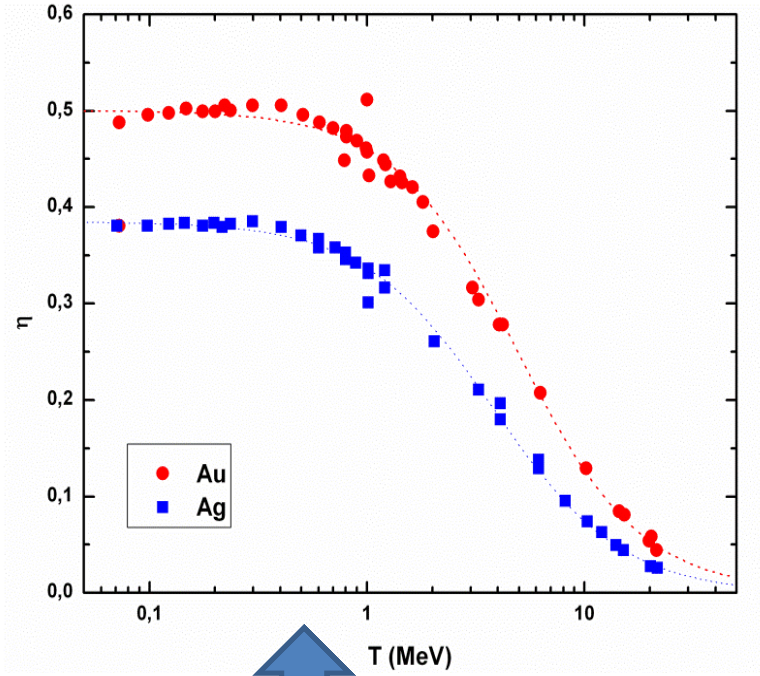
Oakland, Cal

Electrons in matter:

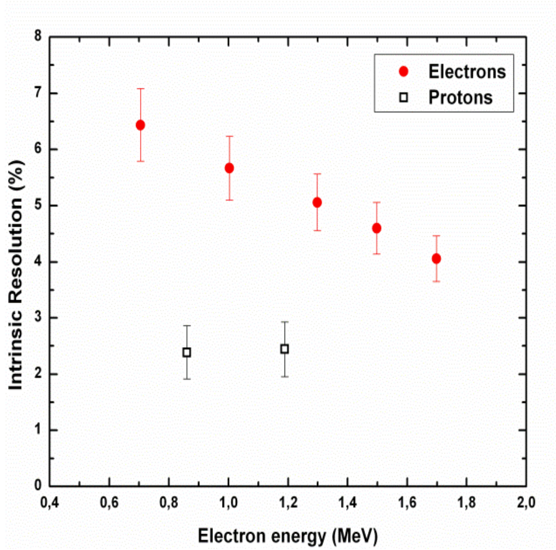


Life history of a fast electron

Electrons often undergo large angle deflections loosing a large part of energy and producing δ-rays

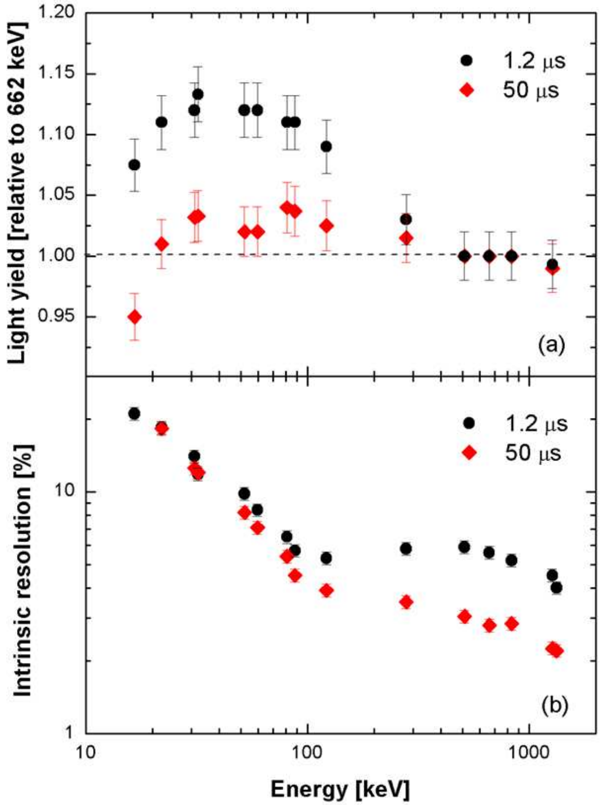


Backscattering of electrons
T. Tabata, et al.,NIM, 94(1971)509

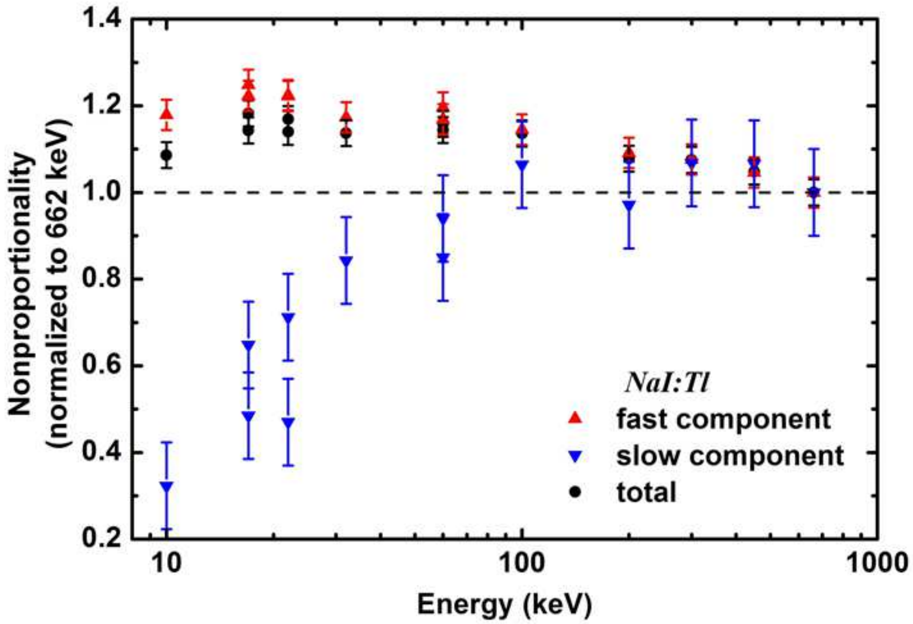


Intrinsic resolution measured with protons and electrons
TNS 55 (2008) 3717 – H.H. Vo et al.

Slow components of the light pulses and energy resolution



M.M. et al., NIM A505, 2003



L. Swiderski et al. NIM A 749 (2014) 68

A. Syntfeld-Każuch et al., IEEE NSS 2014

Z. Mianowska et al., NIM, A914(2019)165

Collaboration with:

Wake Forest University, North Caroline

Kharkov, Ukraine

Invited paper to the special issue of NIM A dedicated to the memory of Prof. Glenn Knoll

Nuclear Instruments and Methods in Physics Research A 805 (2016) 25–35

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

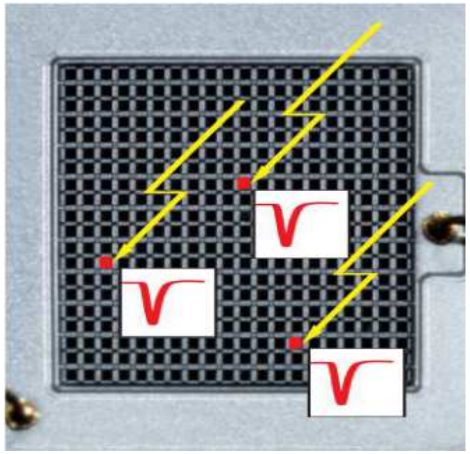
ELSEVIER

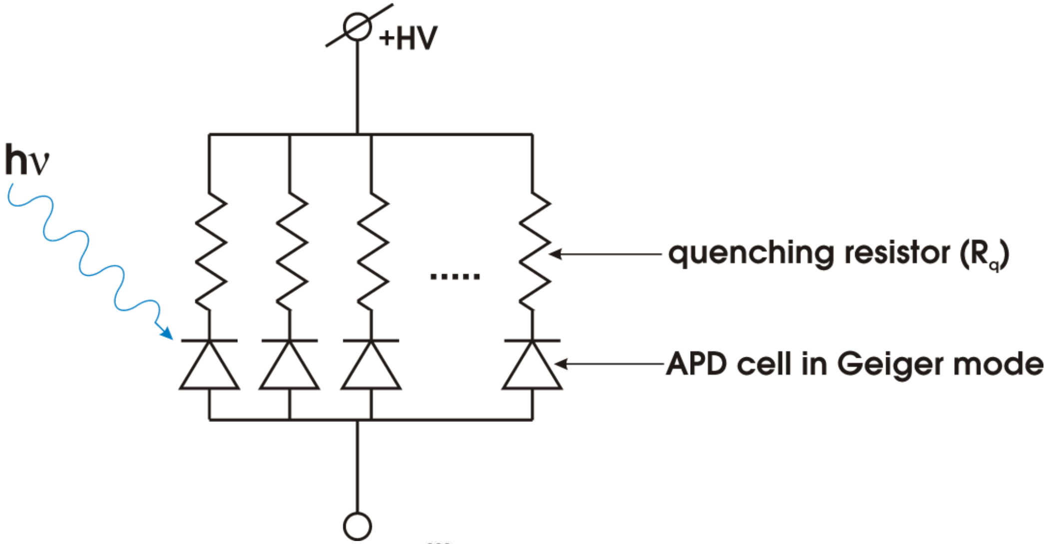
Energy resolution of scintillation detectors

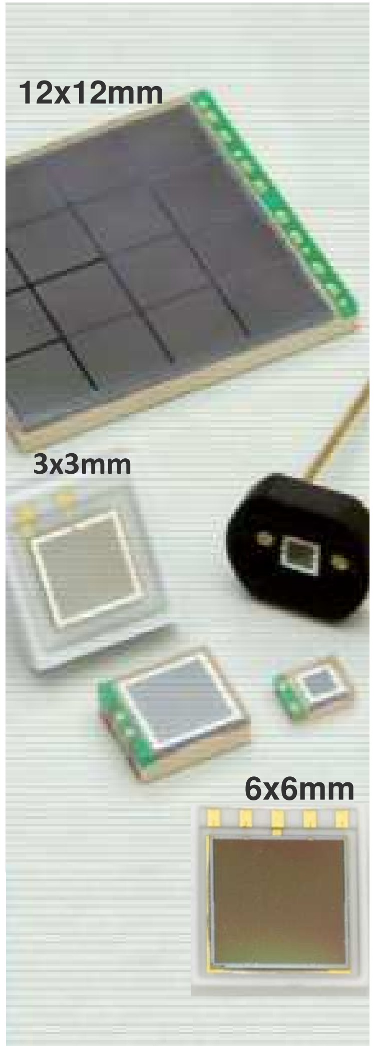
M. Moszyński *, A. Syntfeld-Każuch, L. Swiderski, M. Grodzicka, J. Iwanowska, P. Sibczyński, T. Szczęśniak

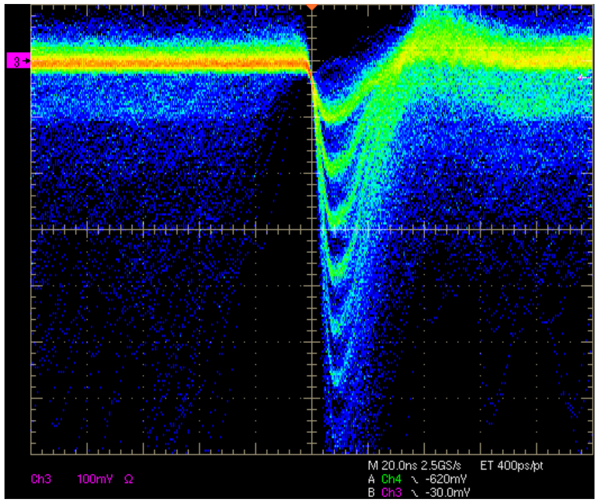
National Centre for Nuclear Research, A. Sołtana 7, 05-400 Otwock-Świerk, Poland

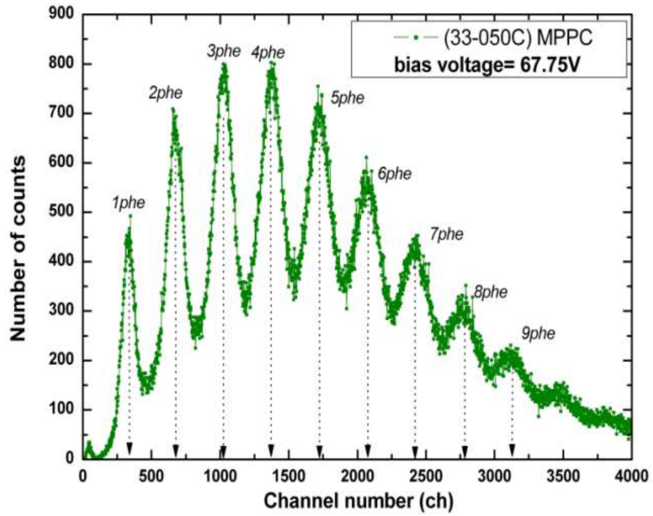
SiPMs in gamma spectroscopy with scintillators









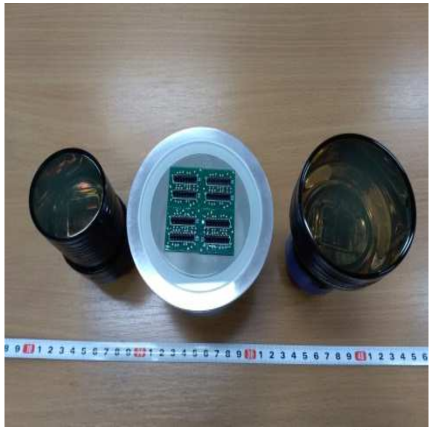


SiPMs in gamma spectroscopy with scintillators

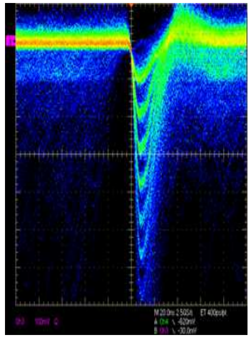
- Characterization of 3x3mm, up to 50 x 50 mm MPPC Array in scintillation spectroscopy
- >15 papers in JINST, NIM A and IEEE TNS
- M. Grodzicka, M. Moszyński, T. Szczęśniak, Monografia: Radiation Detectors for Medical Imaging. **Rozdział: Silicon photomultipliers in detectors for nuclear medicine**, CRC Press, USA(2016)

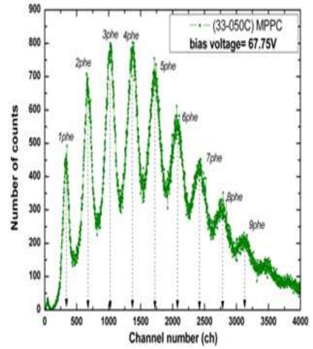
2014 Martyna Grodzicka – *PhD thesis:* „Silicon Photomultipliers in Gamma Spectrometry with Scintillators”.
2018 Martyna Grodzicka – nagroda NCBJ

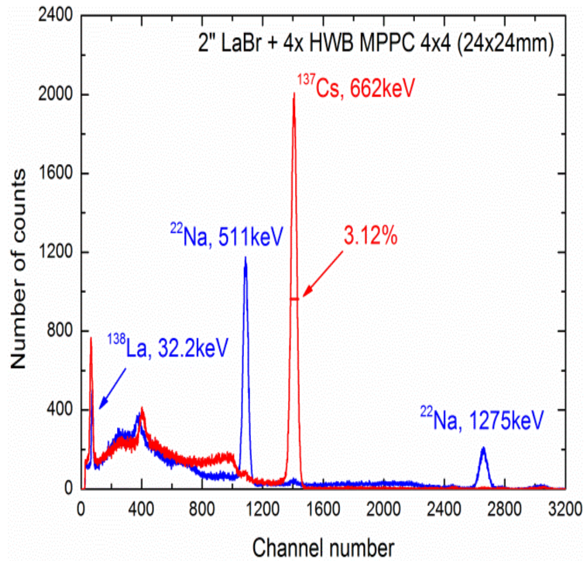
Tomek Szczęśniak – large LaBr3 and NaI(Tl)



3”x3” NaI(Tl) and MPPC array 8% energy res.







Invited paper to the special issue of NIM A addressed to SiPM applications

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Silicon photomultipliers in gamma spectroscopy with scintillators

M. Grodzicka-Kobylka, M. Moszyński *, T. Szczęśniak

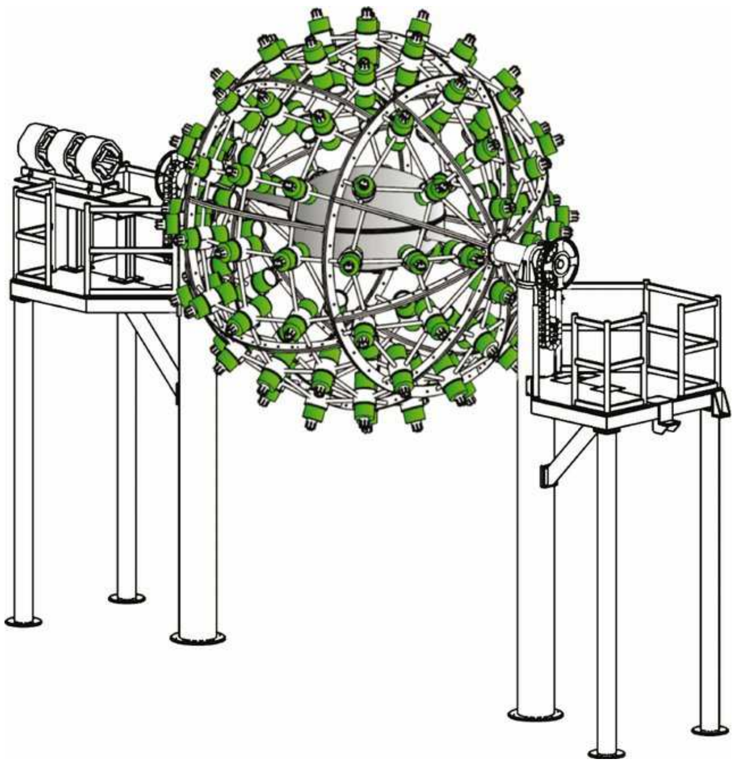
National Centre for Nuclear Research, A. Soltana 7, 05-400 Otwock-Świerk, Poland

Detekcja neutronów

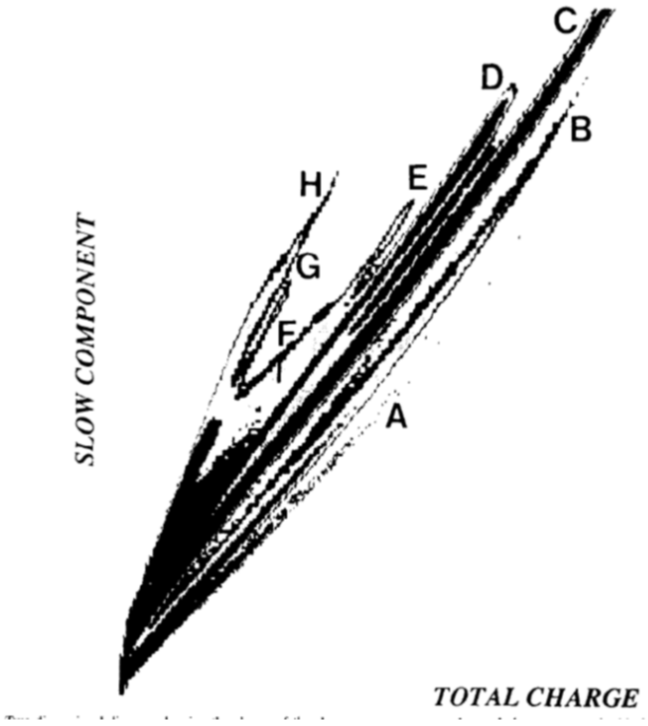
- 1962 – praca magisterska
- 1987 - Ściana neutronowa w NORDBALLu
- 1990 – 1992 DEMON – CRN Strasburg
- 1994 – 2000 Ściana neutronowa w EUROBALLu
- Od 2007 – detekcja neutronów w TJ3
    - Ł. Świderski ciekłe scyntylatory z B-10
    - Asia Iwanowska – PhD
    - matryce SiPM w detekcji neutronów – M. Grodzicka
- Od 2012 – NEDA

French – Belgian DEMON arrangement

Demon detector:
BC501A Ø16 cm x 20 cm at XP45212B



M.M., et al., NIM, A317(1992)262
M.M., et al., NIM, A343(1994)563
and more…



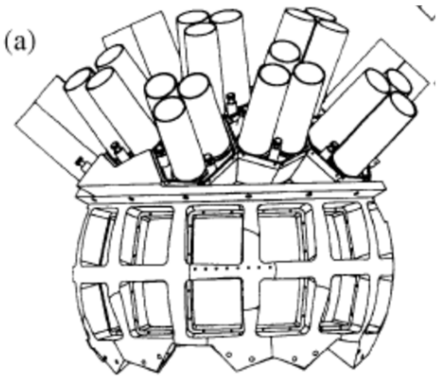
Response to 56 MeV neutrons

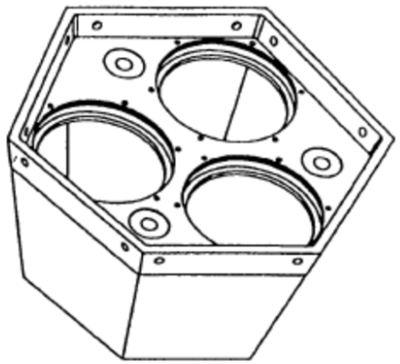
A – gamma rays, B – protons, not fully stopped
C – recoil protons, D – Deuterons
E – Tritons, F – Tritons and alphas
G – 3He, H – alpha particles

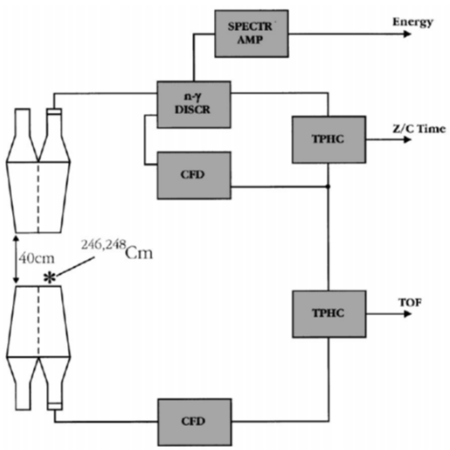
Nuclear structure physics– EUROBALL

Neutron wall - Darmstadt, Goteborg, Stockholm, Legnaro, Strasbourg, Świerk

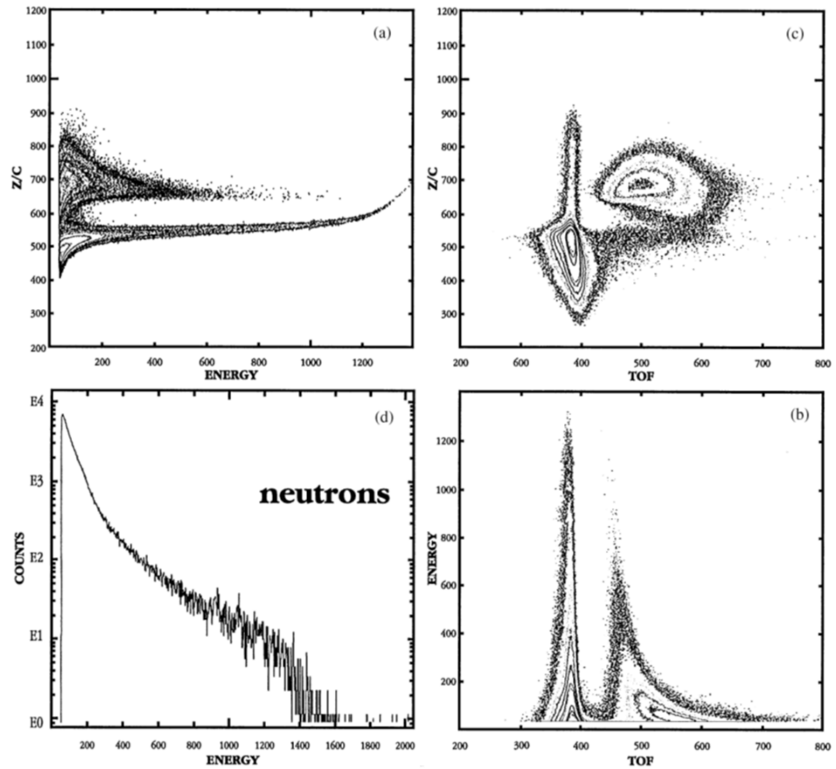
Oe. Skeppstedt… M. Moszyński, Z. Sujkowski, D. Wolski, M. Kapusta…
“The EUROBALL neutron wall – design and performance tests of neutron detectors”
Nucl. Instr. and Meth., A421(1999)531. - **107 cytowań**





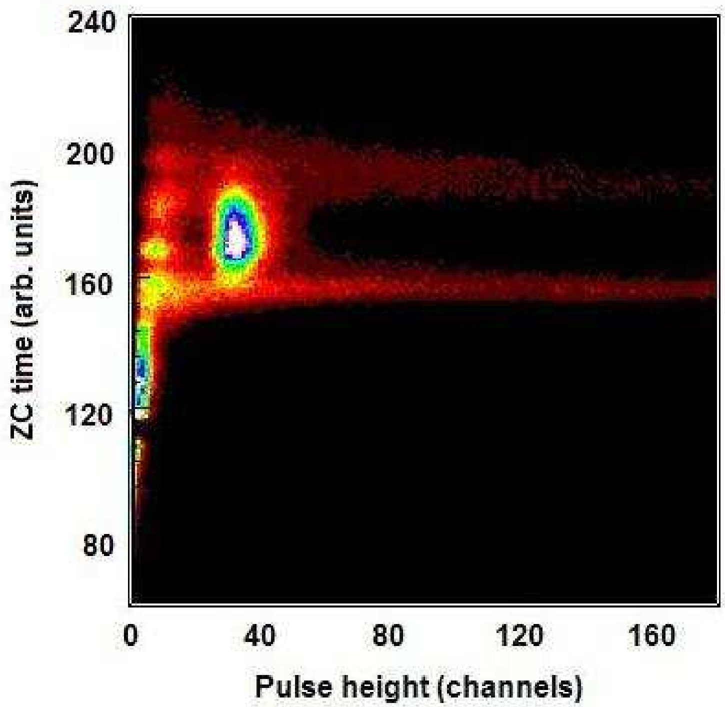


Volume 3 x 3.23 l

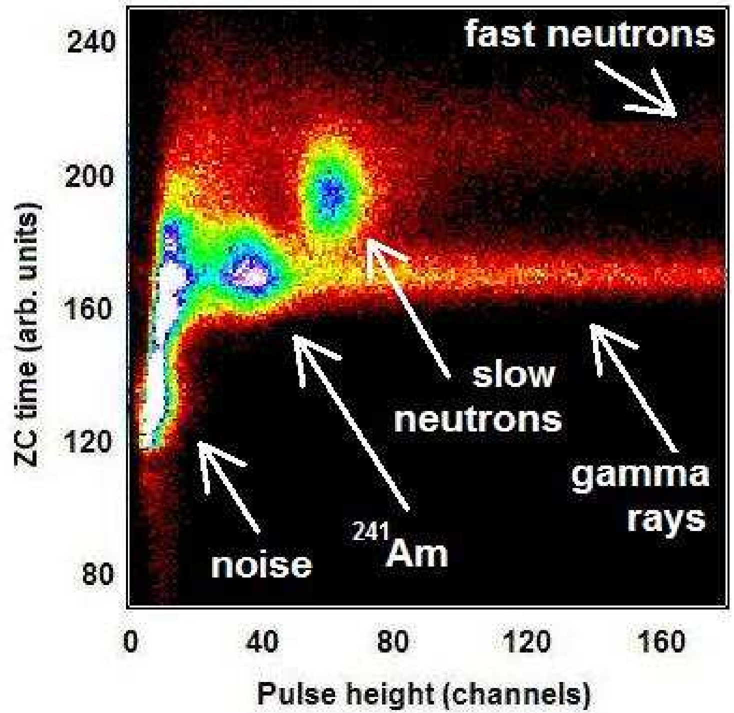


Fast and thermal neutron detection in liquid scintillators

n/γ discrimination in B-10 loaded liquid scintillators



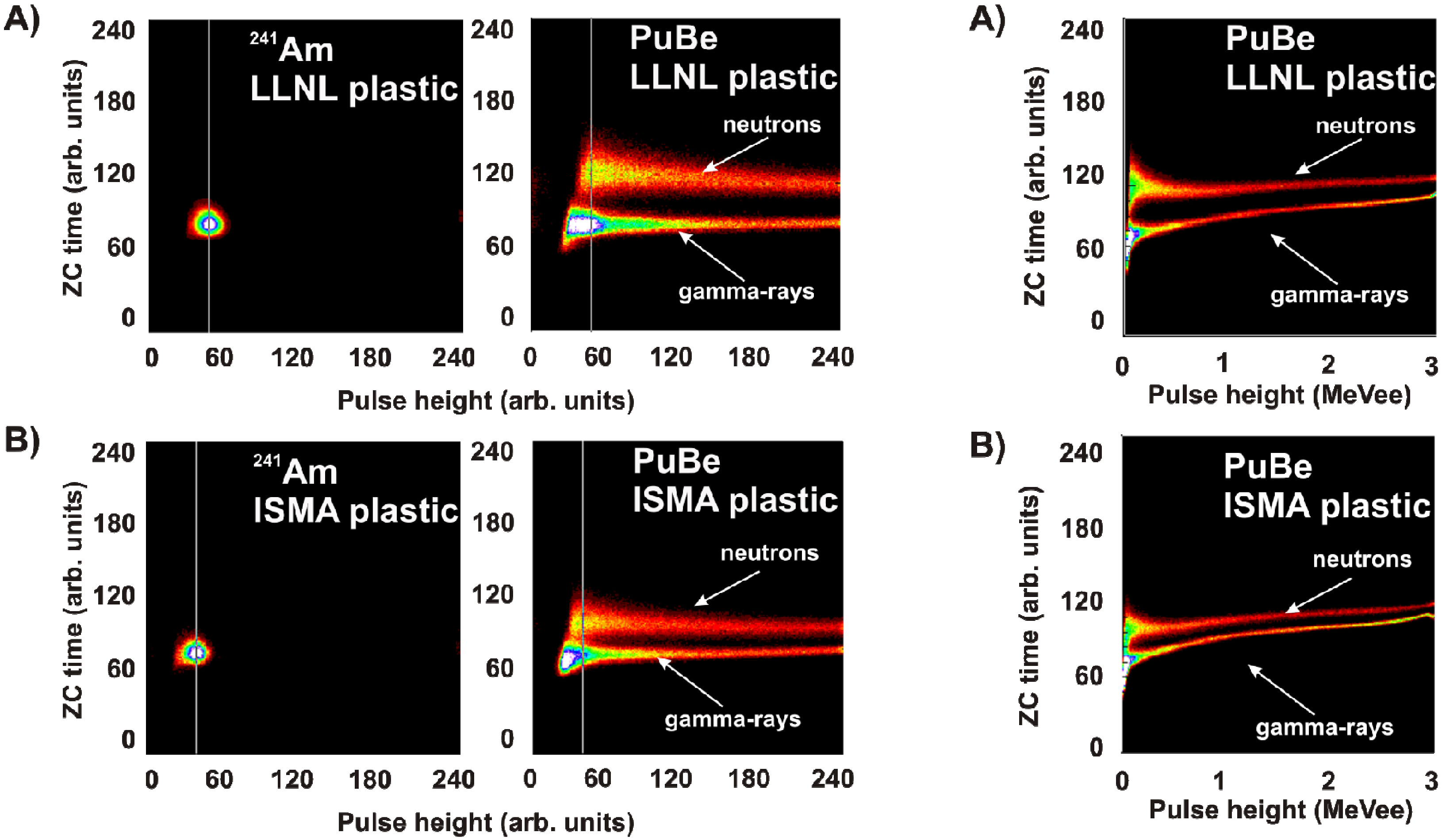
BC523A2 – n/γ discrimination



A 2D plot of ZC time vs. pulse height measured with **EJ309B5** under irradiation of Pu-Be and ^{241}Am.

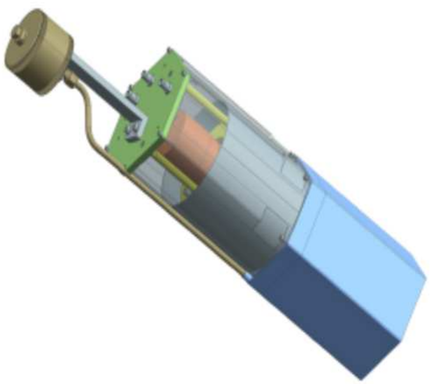
L. Swiderski, et al., IEEE TNS – 3 papers, NIM A – 1 paper, osiągnięcie IPJ w 2010

Neutron/gamma discrimination in plastics

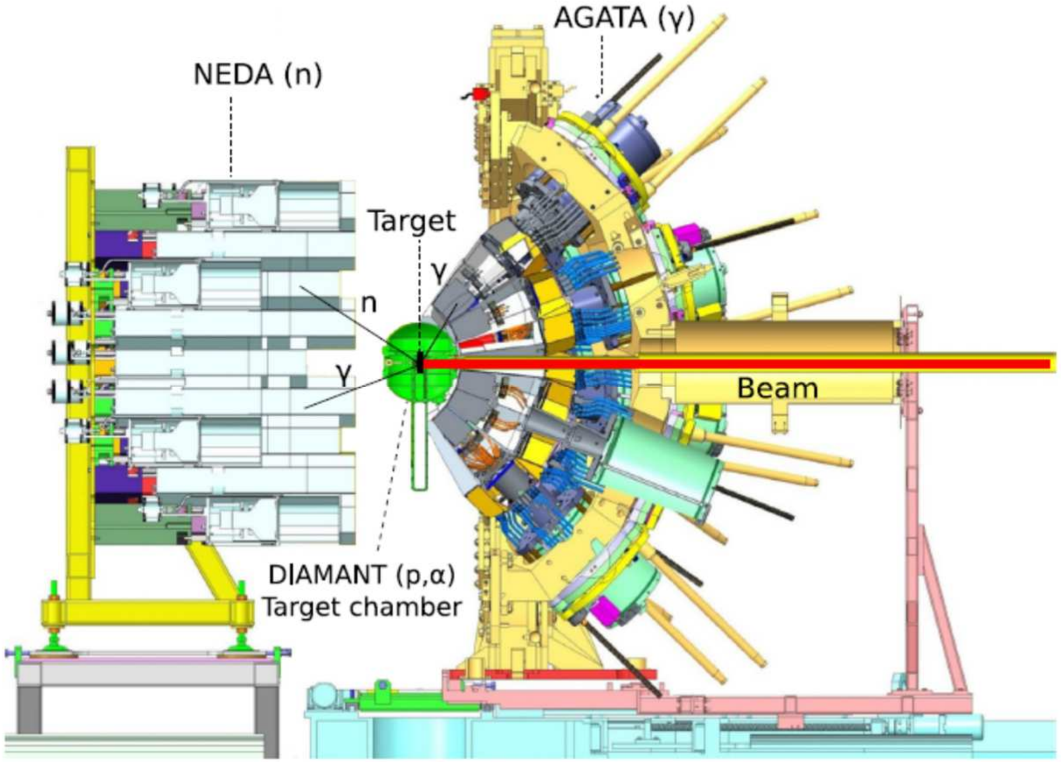


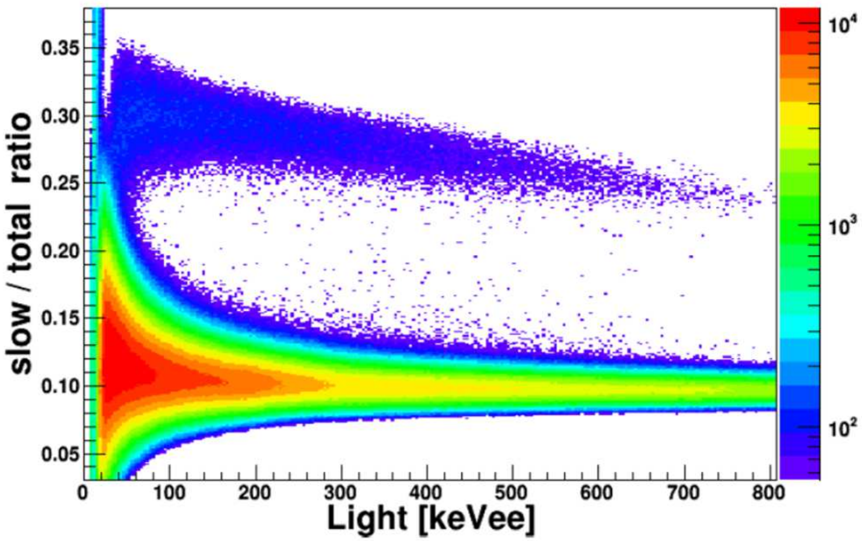
See Asia Iwanowska, „The comparative studies of neutron detectors in the crisis of 3He supply", PhD thesis 2016

NEDA



3.15 liters of EJ301 liquid





Planowane 331 detektorów, wykonane i stosowane 50 detektorów. Aktywne dzielniki opracowane przez Darka Wolskiego i dostarczone w ramach małego kontraktu (ok. 15000 €).

Granty, kontrakty…

- Granty KBN – x 5 | 1993 – 2005 | ok.. 180 kUSD
- Grant stosowany KBN – x1 | 2007 – 2009 | ok.. 500 kUSD

- MAEA + SPUB – 2 x 3 lata | 2004 – 2010 | ok.. 370 kUSD

- Kontrakty:

- Photonis, Francja	2002 – 2008	200 k€
- Target/IcX/FLIR, Niemcy	2004 – 2012	310 k€
- Photonis Materials, Szkocja	2003	10 k€
- IKF Julich, Niemcy	2002 – 2004	85 k€
- ADIT, USA	2015	13 kUS$
- Legnaro, Włochy	2015	15 k€

- Granty UE

- BioCare + SPUB	2004 – 2008	150 k€ + 400 kPLN
- EURITRACK + SPUB	2004 – 2008	150 k€ + 440 kPLN
- MODES + SPUB	2012 – 2014	290 k€
- TAWARA + SPUB	2014 – 2016	390 k€
- C-bord	2015 – 2018	

- COST | 2010 – 2014

- Grant „CEMENT” – RaM-ScaN | 2014 – 2016 | 4020/2625 kPLN
- AiD | 2009 – 2013 | ok. 80 MPLN
- Detektory CdTe(Mn), grant IFPAN | 2018 – 2020 | ok. 2 MPLN

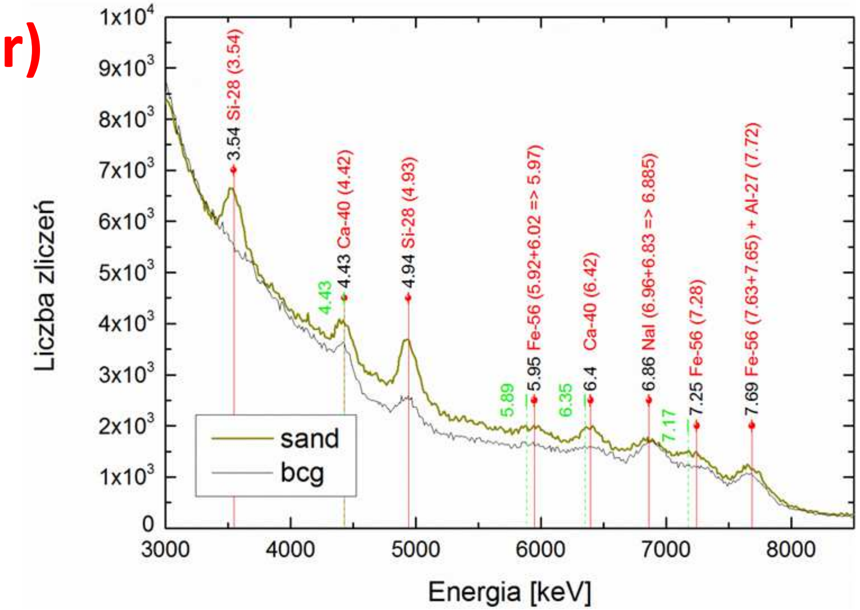
RaM-ScaN (Raw Material ScaNner)

W laboratorium

Próbka

Detektory

Generator neutronów



Kopalnia „Folwark” zasilająca cementownię Górażdże

Brawo Tomek Szczęśniak!!

Publikacje, cytowania

- Publikacje powyżej 300,
  głównie Nucl. Instr. Meth., IEEE Trans. Nucl. Sci.

- Suma cytowań – ok. 7300, WEB of Science

- Średnie cytowanie w ostatnich 10 latach – ok. 400/rok

- Czynnik H = 43

Doktoraty po 1990

- 1998 – Marcin Balcerzyk
  Nowe materiały scyntylacyjne do detekcji i spektrometrii promieniowania γ

- 2005 – Maciek Kapusta
  Detektory scyntylacyjne dla pozytonowej emisyjnej tomografii komputerowej oparte o matryce fotodiod lawinowych

- 2009 – Antek Nassalski
  Wspólny detektor do tomografii pozytonowej i rentgenowskiej

- 2012 – Tomek Szczesniak
  Optimization of detectors for time-of-flight PET

- 2014 – Martyna Grodzicka
  Study of silicon photomultipliers in gamma spectrometry with scintillators

- 2015 – Asia Iwanowska
  The comparative study of neutron detectors in the crisis of He-3 supply

Nagrody, wyróżnienia

- 1982 – M.M. et al — Von Hevesy Prize at III World Congress of Nuclear Medicine and Biology, Paris, 1982
- **2000 – M.M.** — **IEEE/NPSS – Merit Award**
- 2000 – M.M. — Nucl. Instr. Meth. A – Member of Advisory Editorial Board
- **2005 – M.M.** — **IEEE Fellow**
- 2006 – M.M. — Editor in JINST
- 2007 – M.M. — nagroda Ministra Nauki i Szkolnictwa Wyższego w kategorii badania na rzecz rozwoju gospodarki
- 2007 – EURITRACK — Nagroda Trophy senatu Republiki Francuskiej
- **2018 – M.M.** — **IEEE/NPSS – Glenn Knoll Award**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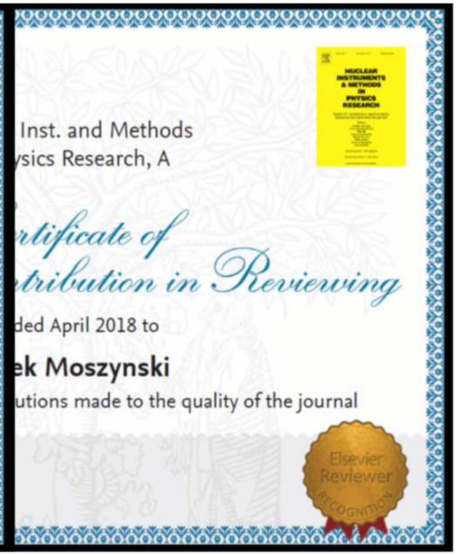
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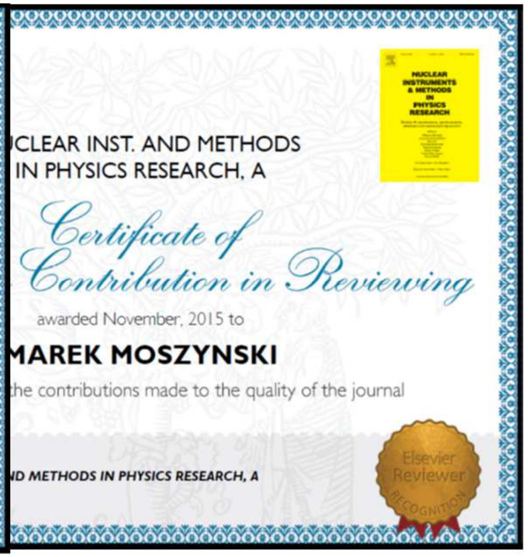
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Prof. Glenn Knoll wręcza nagrodę Merit Award na konferencji IEEE NSS-MIC 2000 w Lyonie

Prof. Seweryński, minister NiSzW wręcza nagrodę Ministra – 2007 r

Nagroda Senatu Republiki Francuskiej dla twórców EURITRACK'a – 2007

Serdeczne podziękowania dla licznych naszych partnerów i przyjaciół w Kraju i różnych laboratoriach na świecie!!!

Ale specjalne podziękowania kieruję do środowiska fizyki jądrowej w Świerku i na Hożej, które nauczyły mnie znaczenia publikacji i były tryggerem w dalszej mojej karierze.