ALTERNATIVES TO HE-3 FOR NEUTRON DETECTORS

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Trends, Challenges, and Opportunities

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Germanys organization for applied research
~ 2.3 billion € budget
staff of 25.000 in 72 institutes

Fraunhofer Institute for Technological Trend Analysis INT

Nuclear Security Policy and Detection Techniques

- Non-destructive measurement techniques for the detection and identification of radioactive and nuclear material
- Design and operation of mobile measurement systems
- Support and advice of national and international security authorities
- Theoretical and experimental research on nuclear proliferation and verification

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Helium-3: Applications

Neutron Detection

- Helium-3 is the gold standard for neutron detection
  - High cross section (5330 barn)
  - Good gamma rejection (~ 1 Gy/h)
  - Simple and robust design of detectors
  - Non-toxic

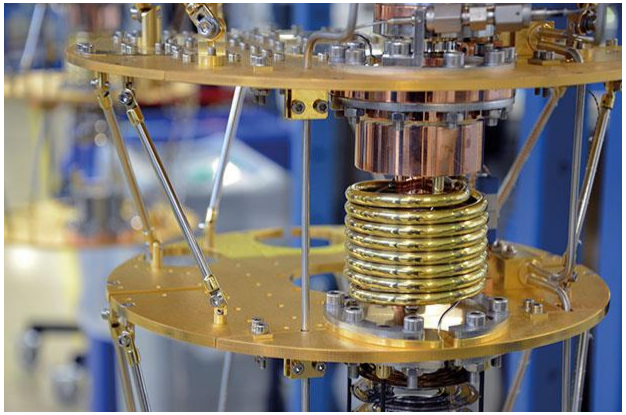
- But the increase in He-3 price can make its use prohibitive

- No single alternative for every detection requirement

Helium-3: Applications

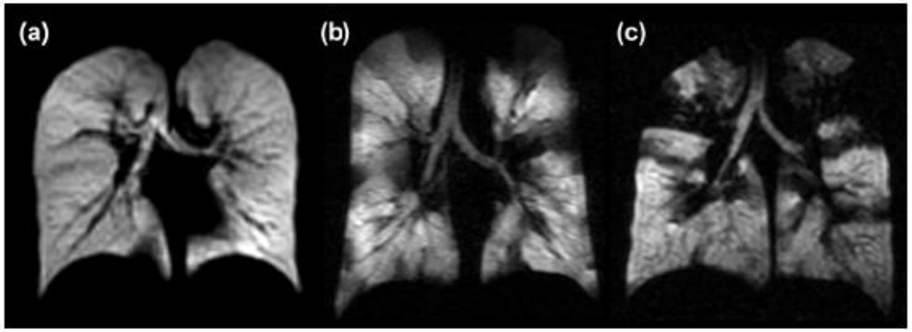
Other Applications

- Low temperature physics (~ 10 mK)
  - Condensed Matter
  - Quantum computers
  - BEC, …



Oxford Cryophysics

- NMR-Imaging using hyperpolarized He-3



Kai Ruppert 2014 *Rep. Prog. Phys.* **77** 116701

- Neutron Spin Polarizers (Neutron Polarization Analysis)

Helium-3: Source

- Main supply is decay of tritium from (US) nuclear weapons
  - Ca. 8000 l per year, demand ~ 60.000 l
  - Increased demand for homeland security (RPM)
  - Price increase from ca. 100 US$ per liter to 2000 US$ (2010)

- Other Sources:
  - Nuclear Reactors
    - Special absorber rods (TPBARs) in LWR
    - H-3 accumulates in moderator tank in HWR
  - Natural Gas (main supply of Helium-4)

Helium-3: Alternatives

Isotop	He-3	Li-6	B-10	Nat-Cd	nat-Gd
Cross section	5330 barn	940 barn	3836 barn	2500 barn	49000 barn
Reaction	^{3}He(n,p)t	^{6}Li(n,a)t	^{10}B(n,a)^{7}Li	Cd(n,g)	Gd(n,g)
Q	764 keV	4.78 MeV	2.79 MeV	8,42 MeV	8.05 MeV
		Li Glass	BF_3	Cd-loaded Plastic	Gd-loaded Plastic
		Li Fiber	Boron lined	Cd-loaded Scintillator	Gd-loaded Scintillator
		LiF/ZnS:Ag		Cd-Coating	Gd-Coating
		Elpasolites			

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Alternatives: Boron-10

- Boron trifluoride (BF_3)
  - Corrosive & toxic
  - Established & robust technology, same as He-3
  - High bias voltage limits pressure

- Boron lined (straw) detectors
  - Short range of products -> thin coating
  - Multiple staws per tube -> increase gamma sensitivity
  - Commercially available

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Alternatives: Lithium-6

- LiF/ZnS:Ag
  - ZnS Scintillator with ^{6}LiF-converter
  - Neutron/Gamma discrimination via pulse shape analysis
  - Commercial modules including electronics available

- Elpasolites scintillators
  - Anorganic scintillators, simultanous neutron & gamma detection
    - CLYC: Cs_2LiYCl_6
    - CLLB: $Cs_2LiLaBr_6$
    - CLLC: $Cs_2LiLaCl_6$
    - …
- **Large quantities of enrichted Li-6 itself raise a proliferation concern**

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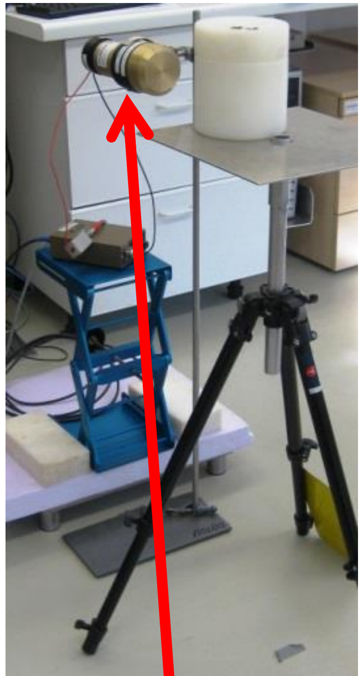
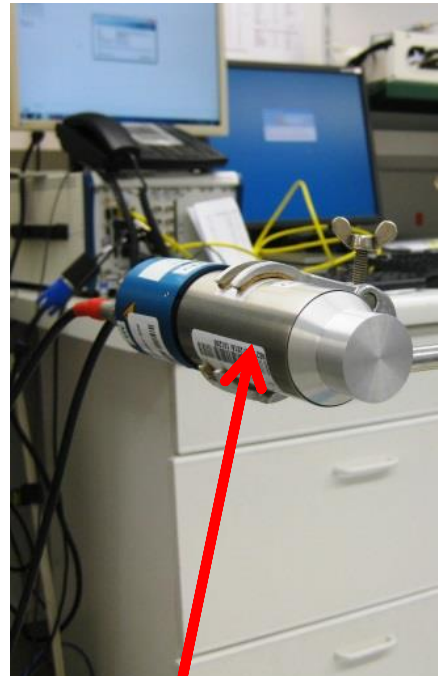
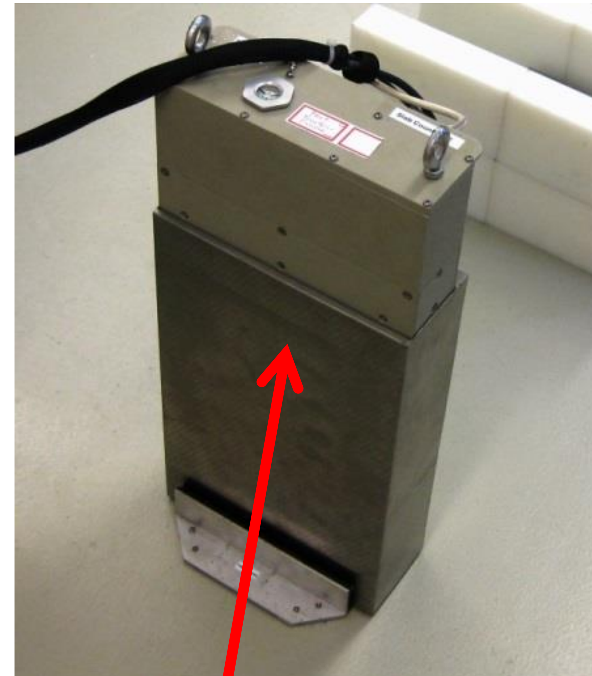
Overview of Detection Systems







N-Blades (SYMETRICA)
LiF/ZnS

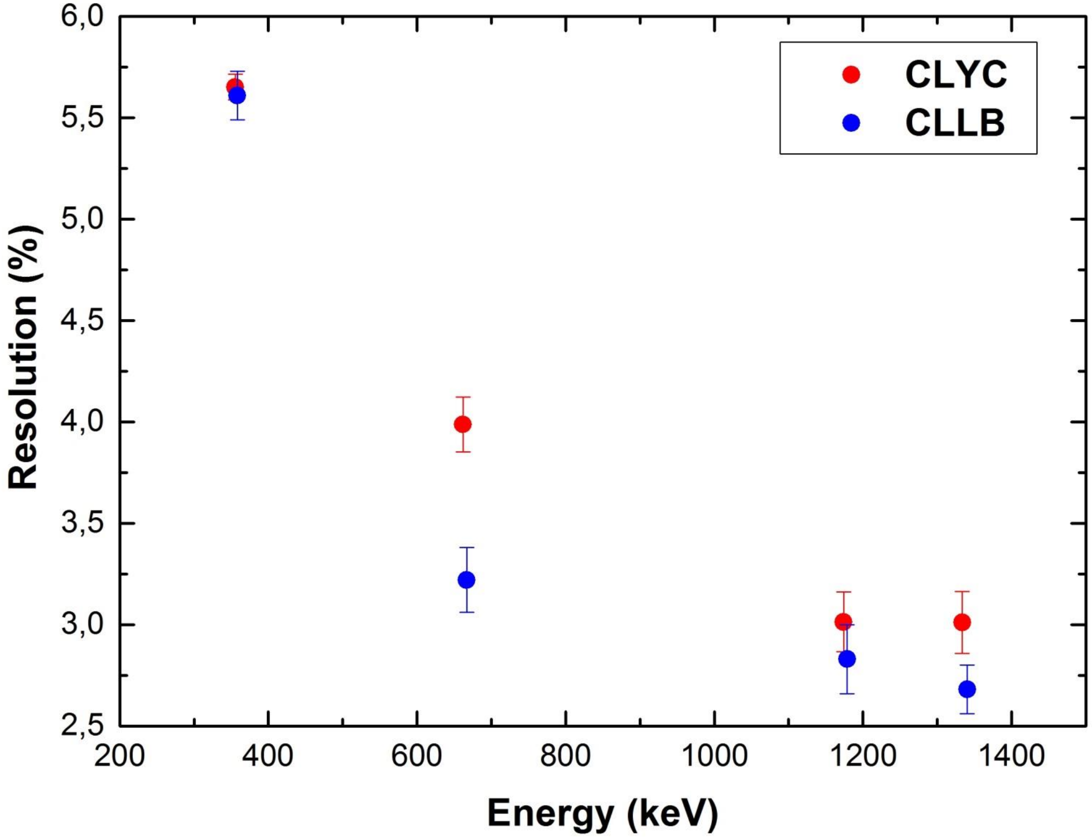
CLYC (RMD)
Li-enriched

CLLB (GCT)
Li-nat

Slab-Counter (CANBERRA)
He-3 technology

CLYC

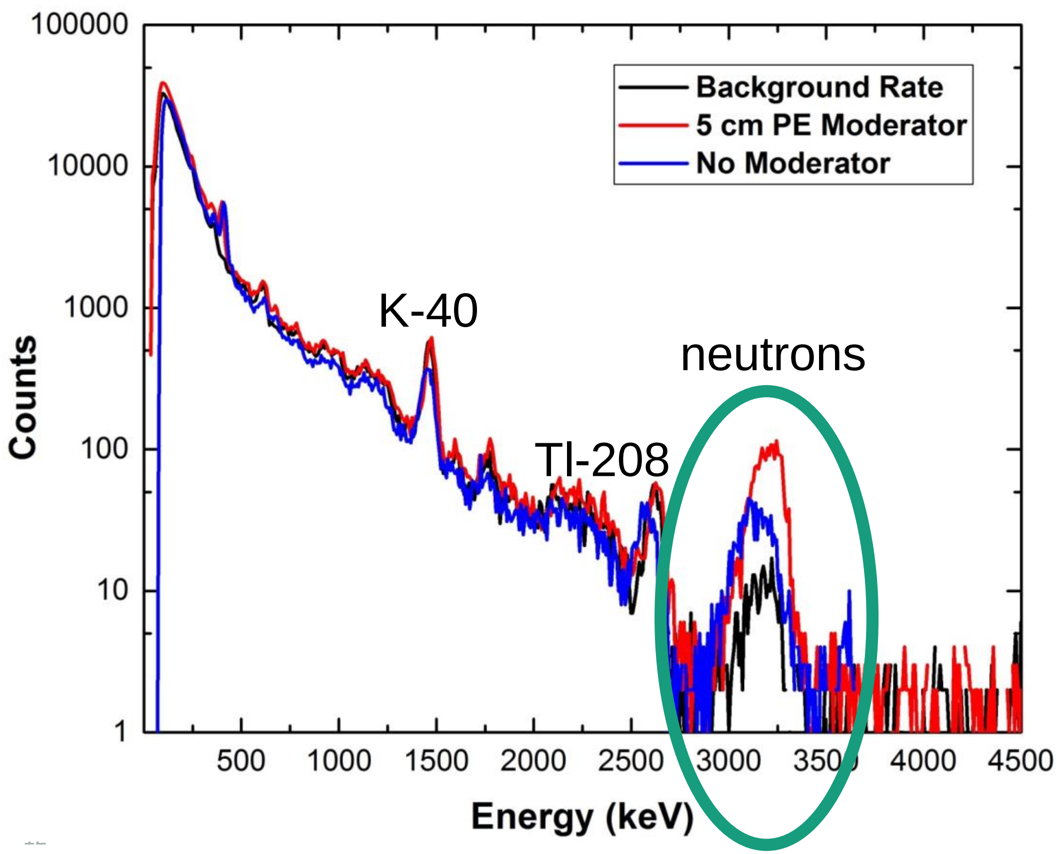
- 2" x 2" Crystal of Cs_2LiYCl_6
- Enriched to 90% Li-6
- Resolution better than NaI
  ~ 4% @ 662 keV



- Data aquisition with conventional NIM electronics
- Ba-133, Cs-137 and Co-60

CLYC

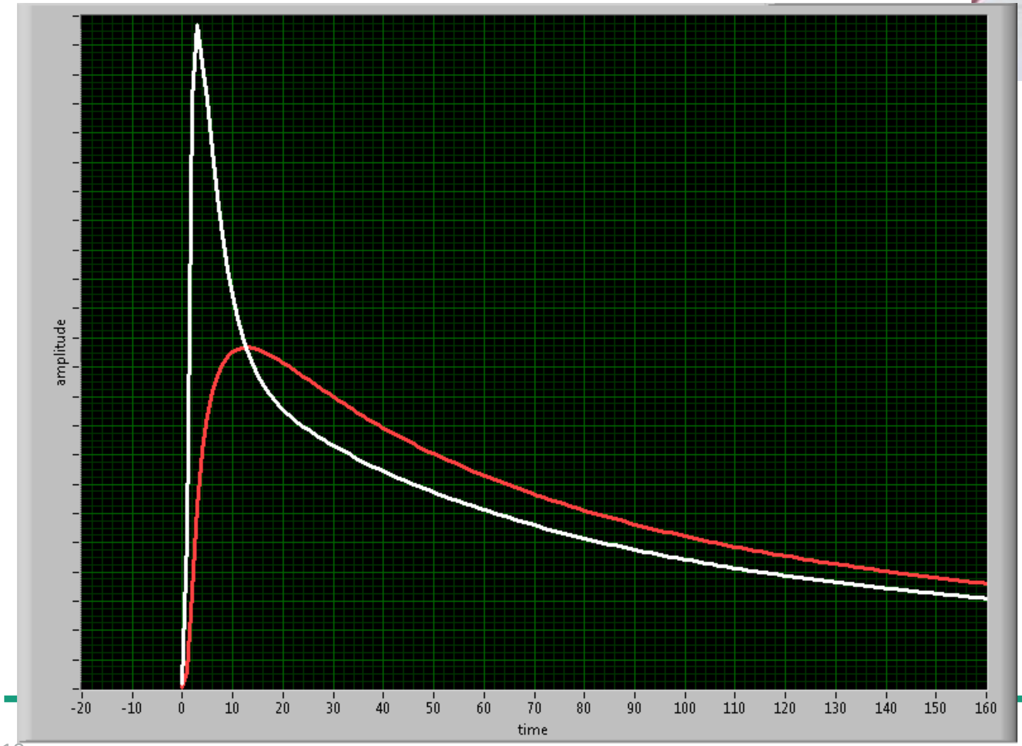
- 2" x 2" Crystal of Cs_2LiYCl_6
- Neutron Signal at γ-equivalent energy of 3.3 MeV



- Data aquisition with conventional NIM electronics
- Cf-252 neutron source

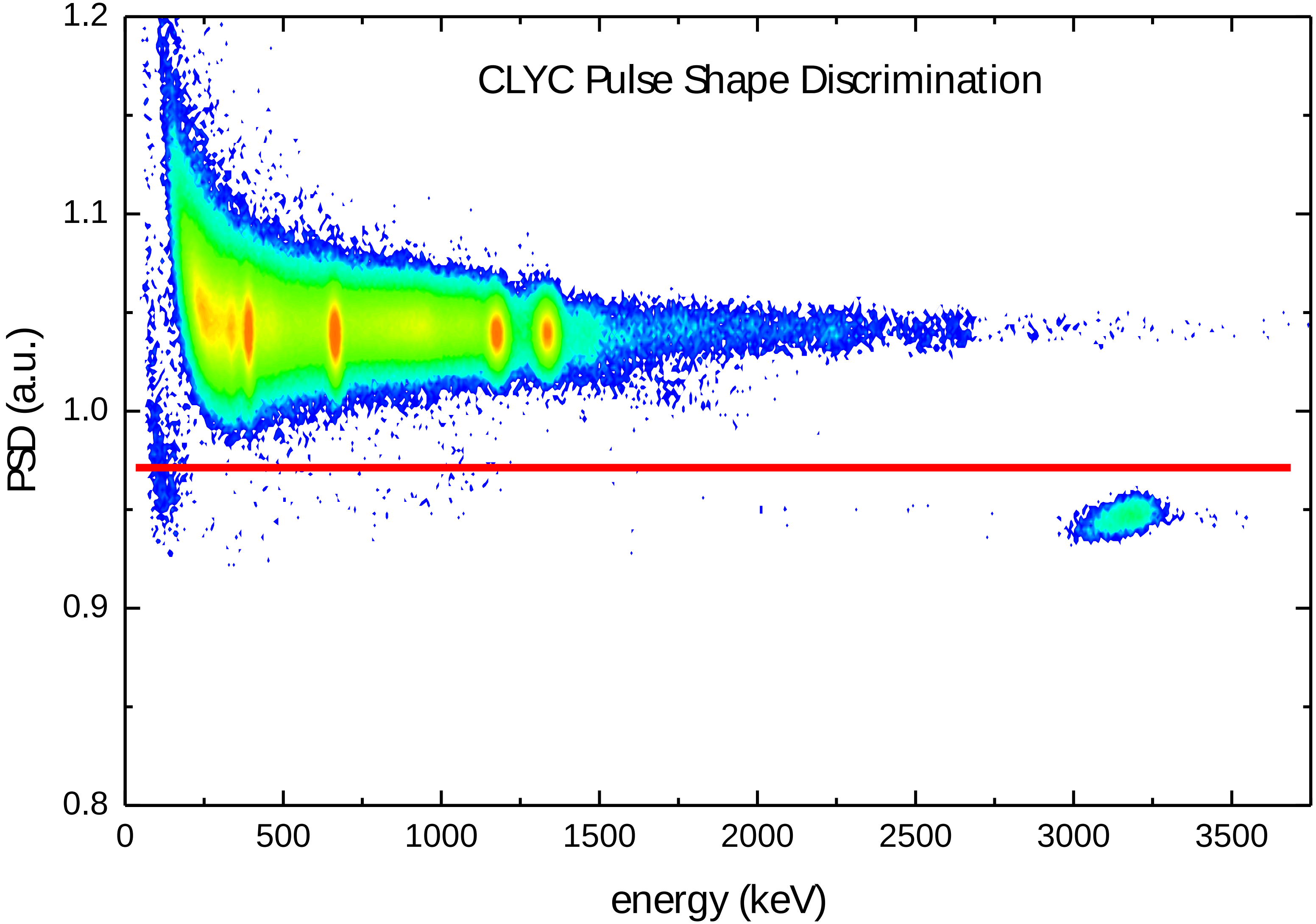
CLYC

- 2“ x 2“ Crystal of Cs_2LiYCl_6
- Neutron Signal at γ-equivalent energy of 3.3 MeV
- Different shapes for gamma and neutron signals



- Data Aquisition with National Instrument PXI System
- PXIe-5122 digitizer and PXIe-7966 FPGA

CLYC: Pulse shape discrimination



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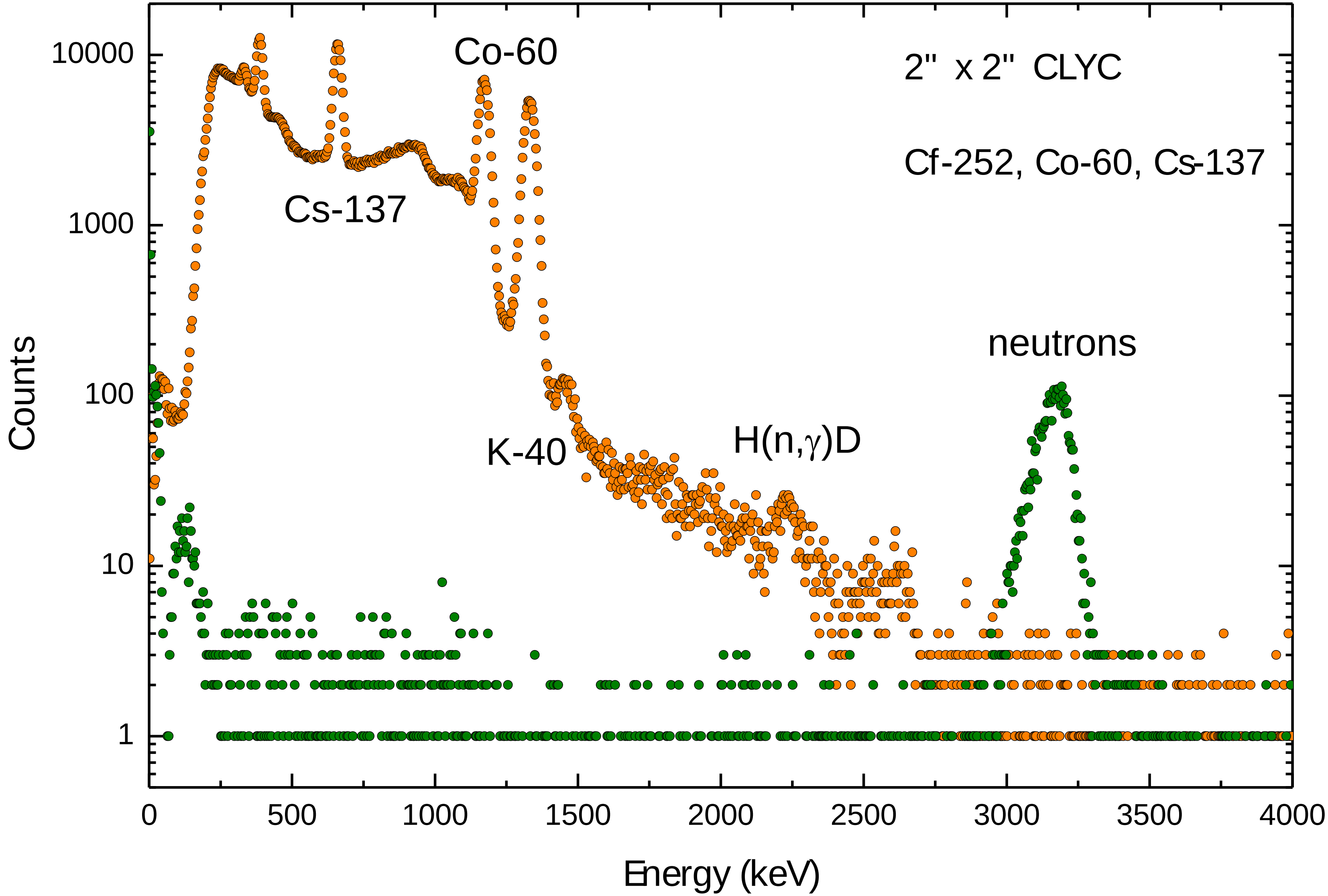
CLYC: Pulse shape discrimination



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Conclusions

- Helium-3 based detectors too expensive for comprehensive use

- Alternatives exists and more are on the horizon
  - Not every technology is suitable for every use case
  - Gamma rejection / Sensitivity / Hazards / Robustness …

- CLYC
  - Energy resolution: 4 % at 662 keV
  - Neutron signal above most gamma lines
  - Pulse shape analysis possible
  - Simultaneous detection of gamma and neutrons

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