Advances on the Development of the Detection System of the C-BORD's Rapidly Relocatable Tagged Neutron Inspection System

European H2020 C-BORD project

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Outline

- C-BORD Project
- Rapidly Relocatable Tagged Neutron Inspection System (RRTNIS)
- RRTNIS detection module (γ-scintillator detectors, electronics based on digitizers and DAQ system)
  - Detectors assembly and characterization
  - DAQ and electronic tests
- Conclusions and future

C-BORD Project

effective Container inspection at BORDer control points

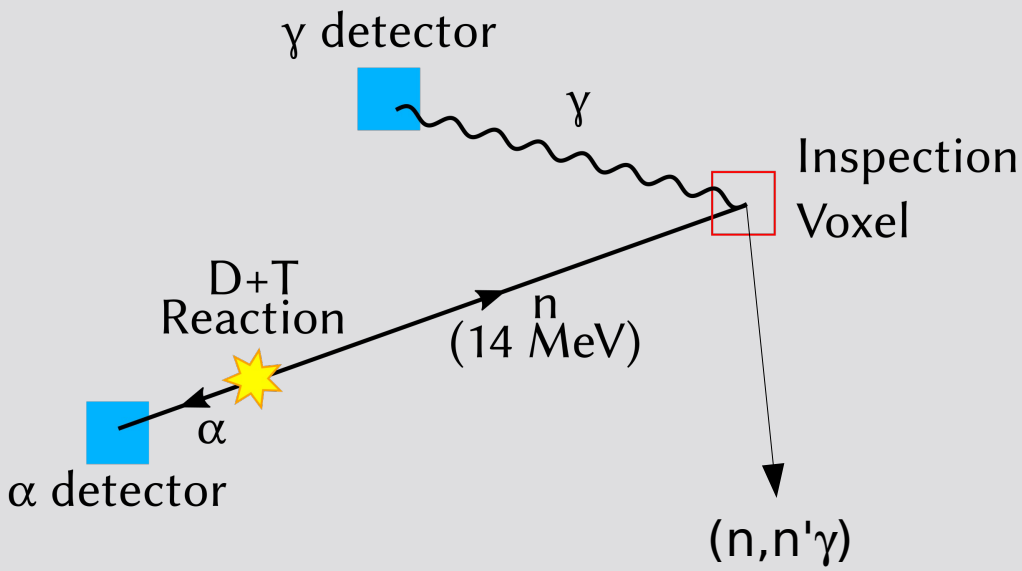
C-BORD Project

- Container security is an important factor in all borders, and efficient NII (non-intrusive inspection) of containers is critical
- The most effective array of screening technologies should be selected: the C-BORD Toolbox
- C-BORD develops five technologies to enable next generation container NII at EU sea and land borders:
  Advanced Radiation Management / Next Generation Cargo X-Ray / Tagged Neutron Inspection / Photofission / Evaporation Based Detection
- Other WP → Assessment,
  framework for end users, etc.

RRTNIS

Rapidly Relocatable Tagged Neutron Inspection System

Tagged Neutron Inspection Technique

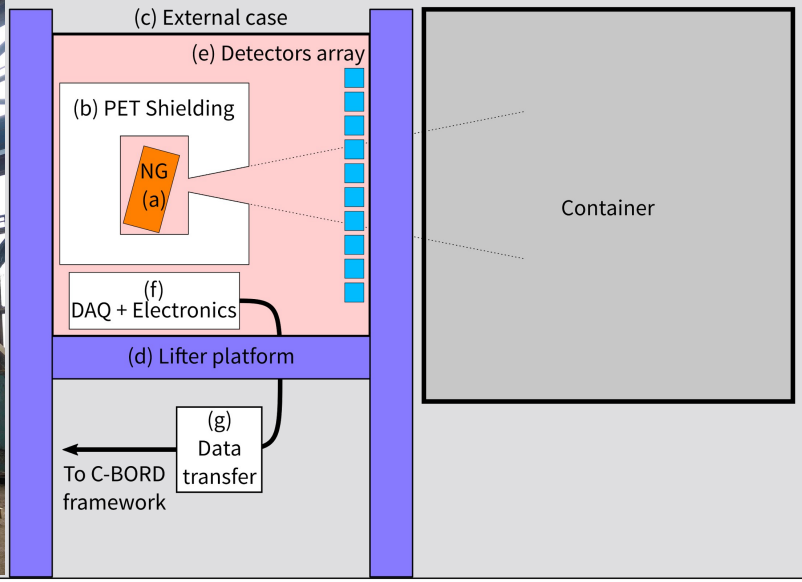


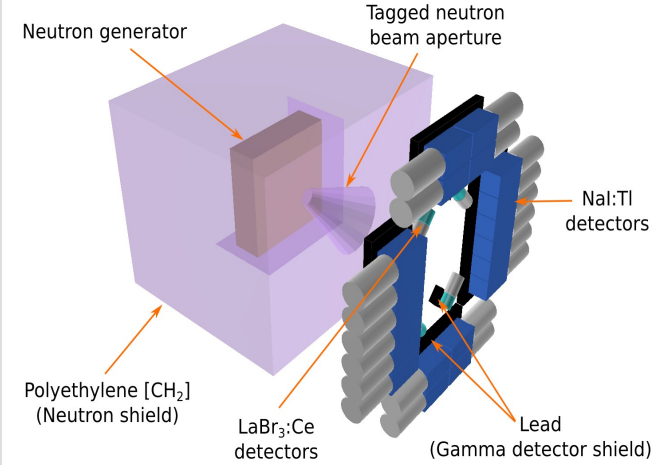
- Fast neutrons (14 MeV) from:
  $D + T \rightarrow \alpha + n$
- The collinear α tags the n
- Voxel selection is given by time-of-flight (ToF) and the α direction
- The γ spectrum at selected ToF depends on the voxel material

RRTNIS Design

- RRTNIS is fully contained in a movable casing
- γ detectors are in a back-scattering configuration
- The whole system is moved to select the inspection voxel (2nd—line system)

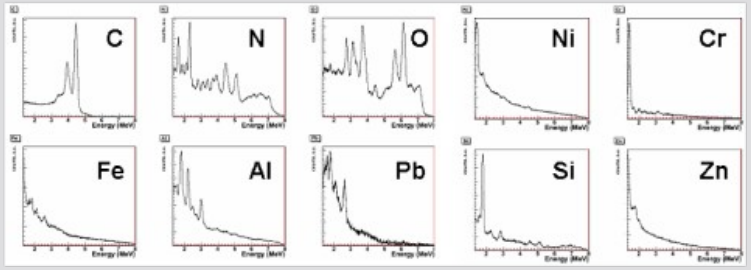
SIDE VIEW



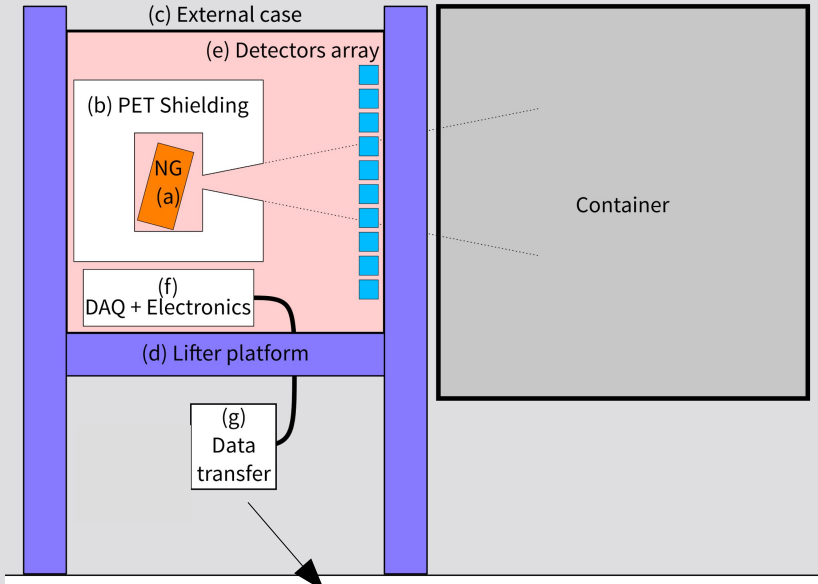


RRTNIS Design

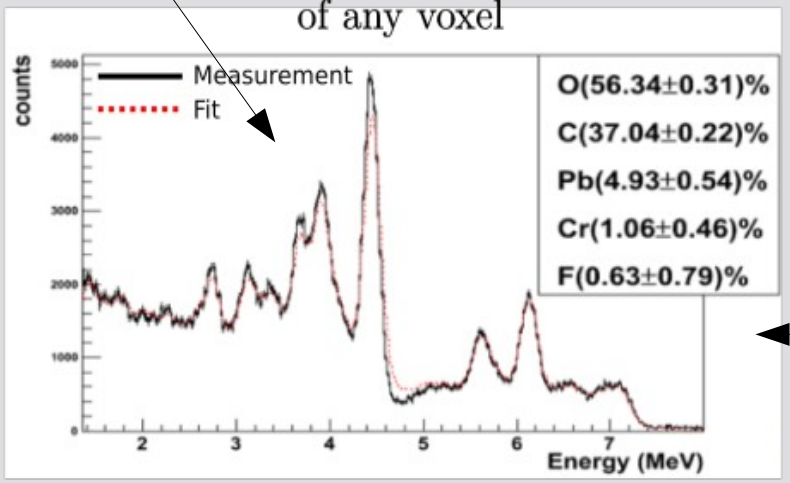
Elementary gamma signature database



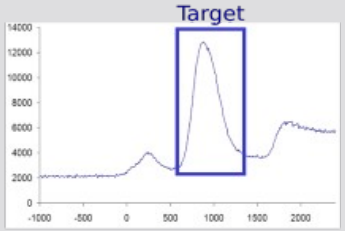
SIDE VIEW



γ energy spectrum of any voxel



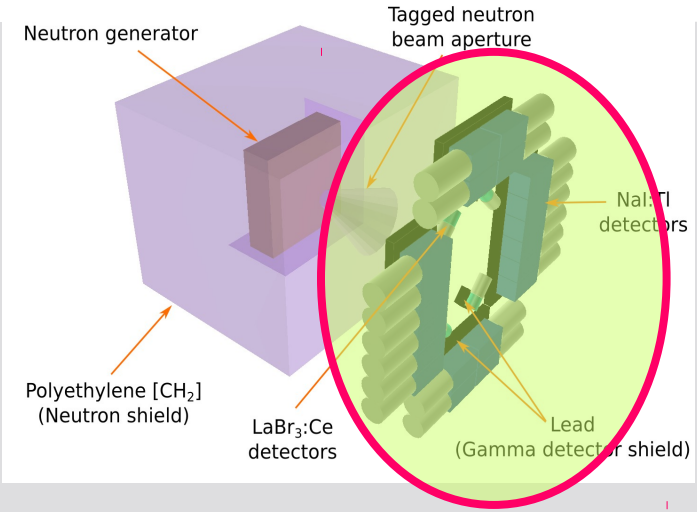
Neutron time of flight spectrum



⇓

Distance traveled

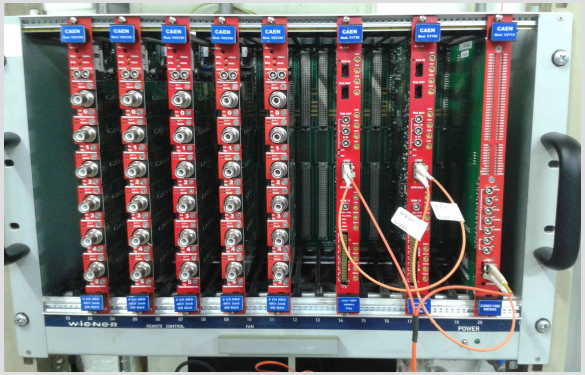
RRTNIS Detection Module

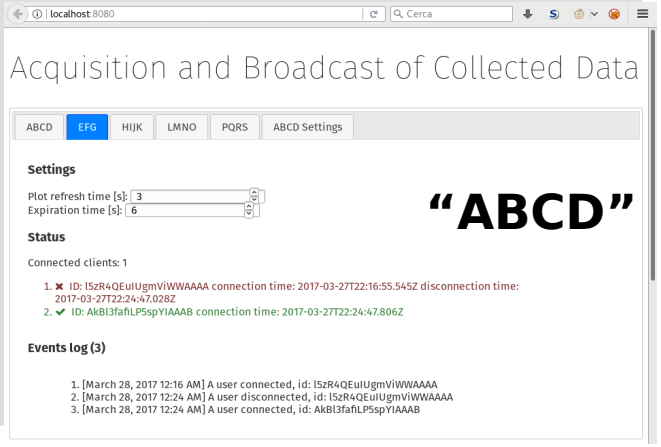


- Detectors:
  - 20 large-sized (5” x 5” x 10”) NaI(Tl) EURITRACK project
  - 4 $LaBr_3$(Ce), 3” x 3” scintillators
- Electronics
  - 2 VME CAEN V1730 Digitizers, 16 ch, 14 bit, 500 MS/s
  - 5 VME CAEN V6533 HV supply. 6 ch (NEG) 4kV/3mA
  - 1 VME Optical Controller Bridge

NaI(Tl)

$LaBr_3$(Ce)





RRTNIS Detection Module

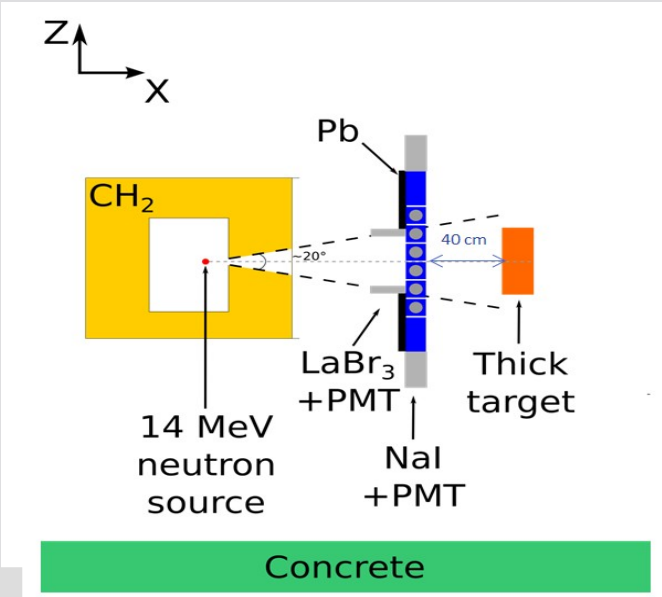
Requirements:

- Good energy resolution, 7-8% @662keV
  - Elemental identification (C, N, O, S, As, etc.)
- Good time resolution 2 ns (Thres=1MeV). NaI(Tl) are slow scintillators.
  - ~ Tens of cm voxel

Monte Carlo estimations (MCNP6); CEA-Cadarache (France)

- - Neutron generator: 5 x 10^7 n/s "worse case scenario"
  - NaI(Tl) → 100 -150 kHz each
  - $LaBr_3$(Ce) → 10 -20 kHz each

Linearity and high rate stability!!!



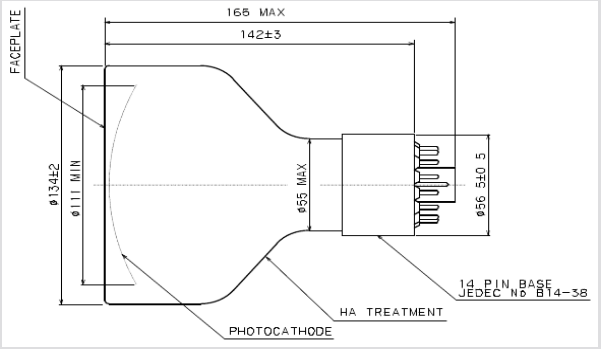
Gamma Detector Tests

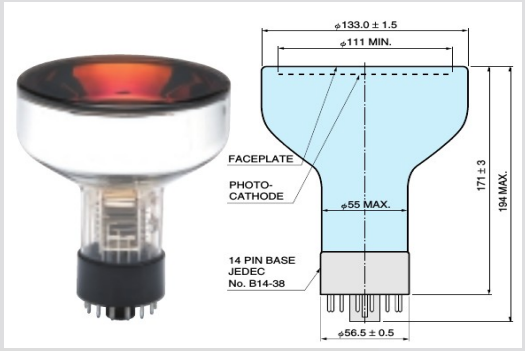
RRTNIS Detection Module

5” Photomultipliers:

Existing EURITRACK PMT

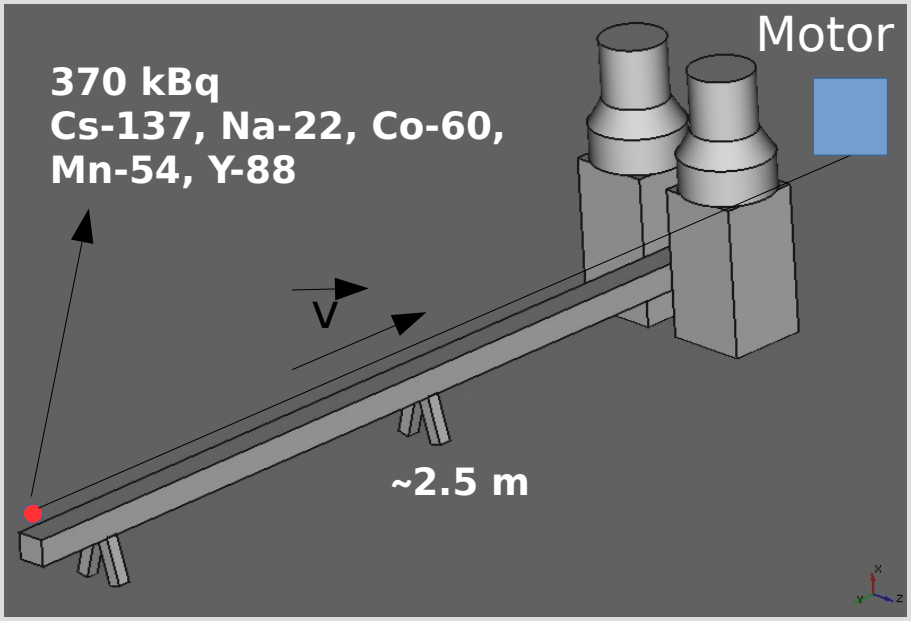
	PMT			
	ET 9390B	Hamamatsu R877-100	Hamamatsu R11833-100HA	XP4512
photocathode	bialkali	bialkali	bialkali	bialkali
spectral range (nm)	300-630	300-650	300-650	290-630
active diameter (mm)	115	111	111	110
luminous sensitivity (microA/lm)	75	90	105	70
QE (%)	28	35	35	24
nominal anode sensitivity (A/lm)	50	40	50	70
gain at nominal	7×10^5	4.4×10^5	2×10^5	2×10^7
dark current typ (nA)	1	10	8	90
rise time (ns)	13	20	4	2,5
transit time (ns)	60	115	49	49

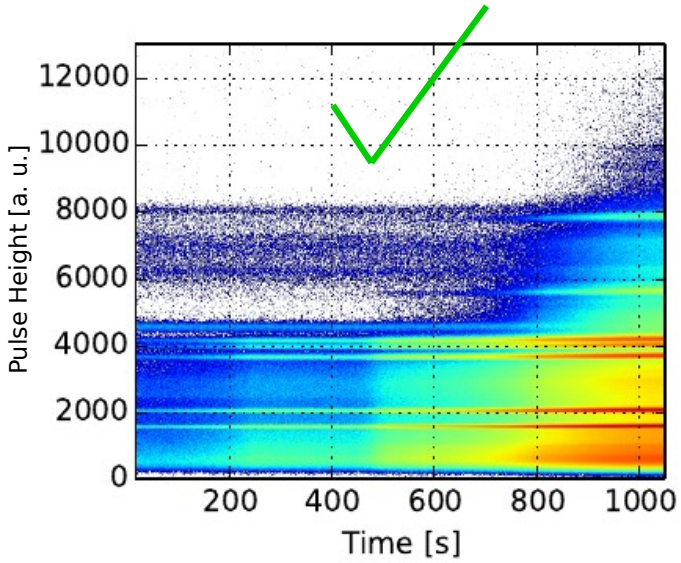


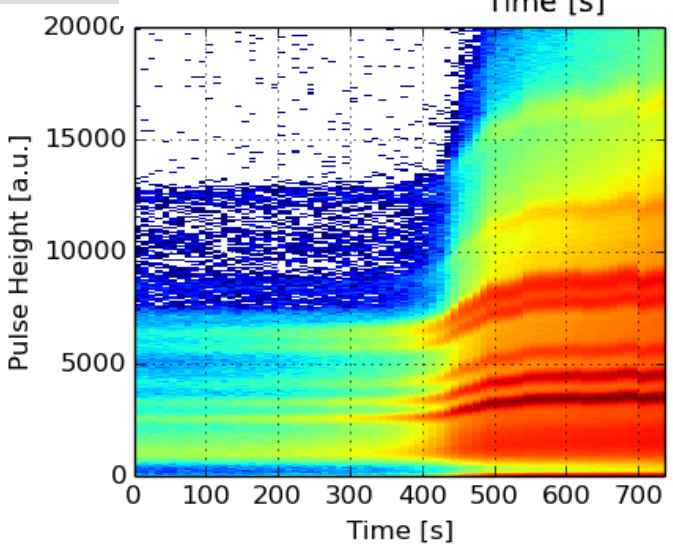


Experimental set-up 1
Detector characterization

- High counting rate tests
  - Energy resolution measurements
  - Stability → Gain shift

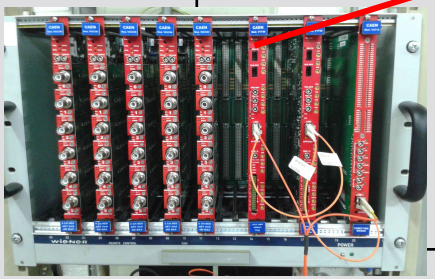


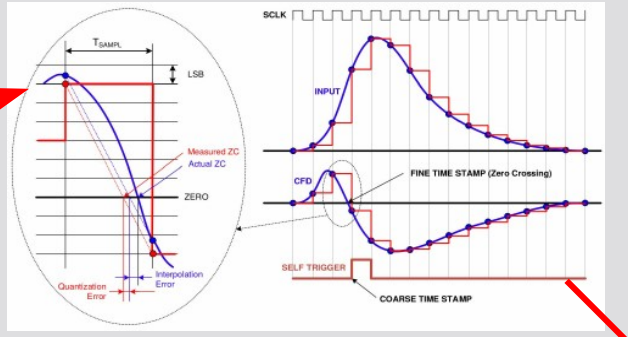




Experimental set-up 2
Detector characterization

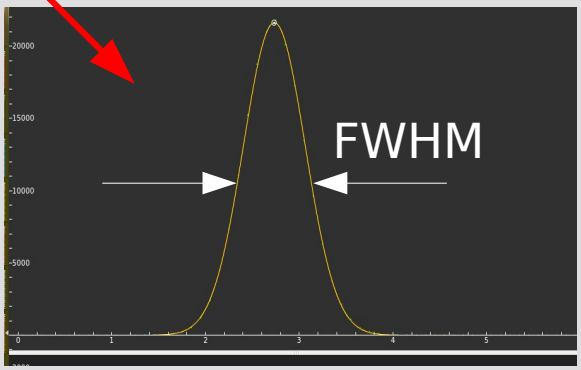
- Time resolution
  - Coincidence measurements with Na-22 and Co-60





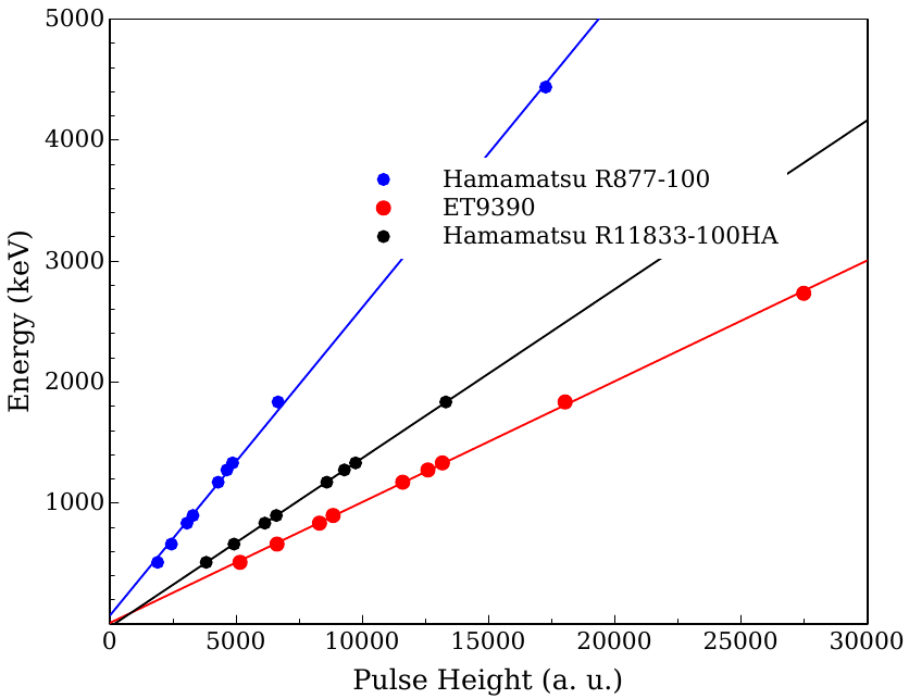
- A new firmware for the V1730 with an embedded Constant Fraction Discriminator
- CFD(t) = F * V(t) – V(t – D)
- F and D must be optimized

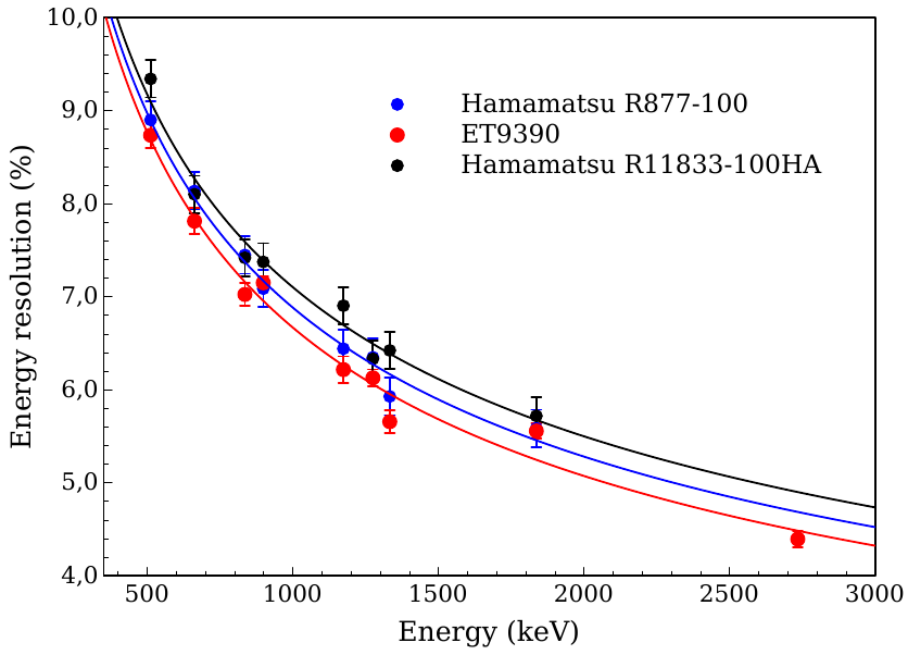
Time Spectrum



Results
NaI(Tl) characterization

- **NaI(Tl) detectors: energy resolution**





- **NaI(Tl) detectors: Time resolution** → **Na-22 coin.**

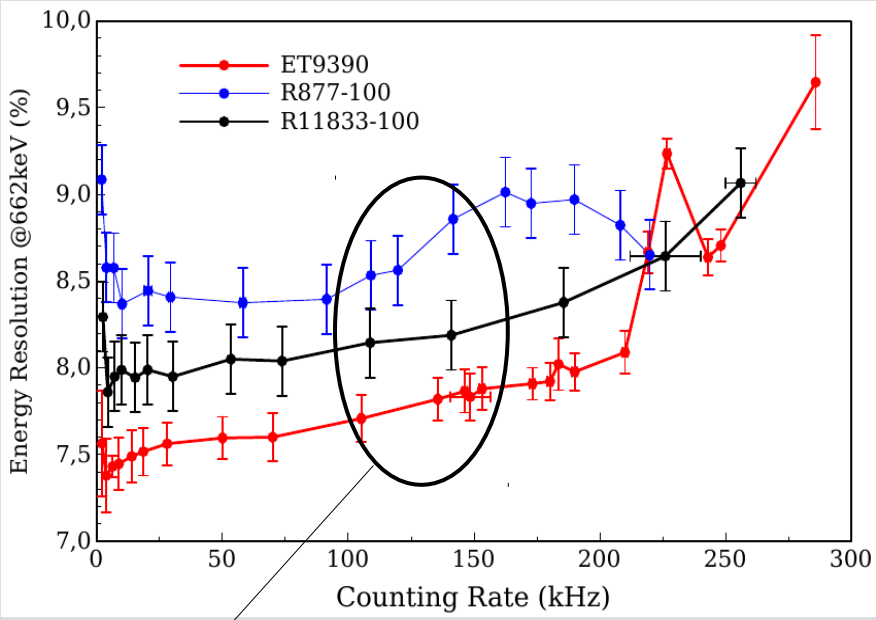
ET9398 → (3.9 ± 0.2) ns

R877-100 → (3.5 ± 0.1) ns

R11833-100HA → (2.5 ± 0.1) ns

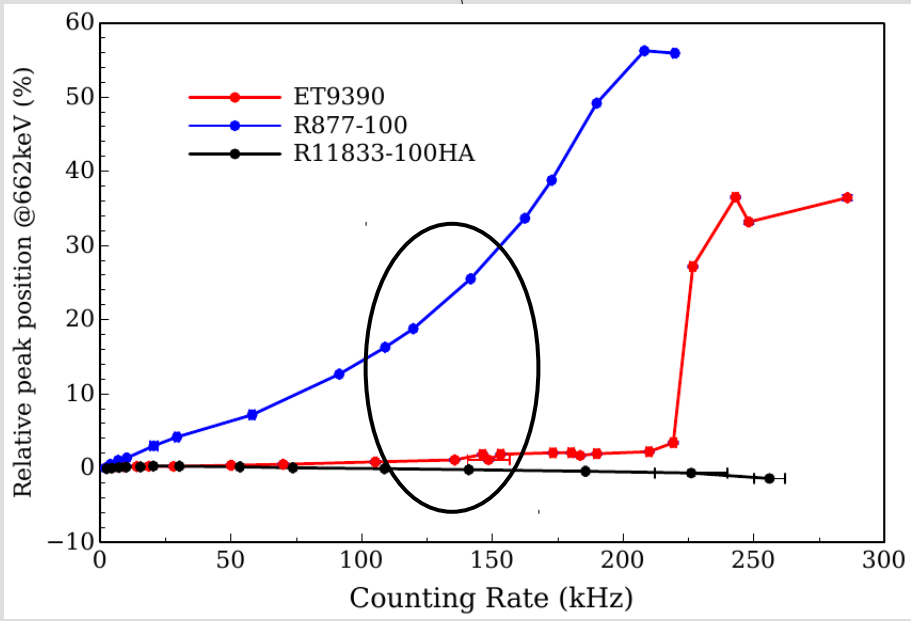
Results
NaI(Tl) characterization

- **NaI(Tl) detectors: High counting rates**



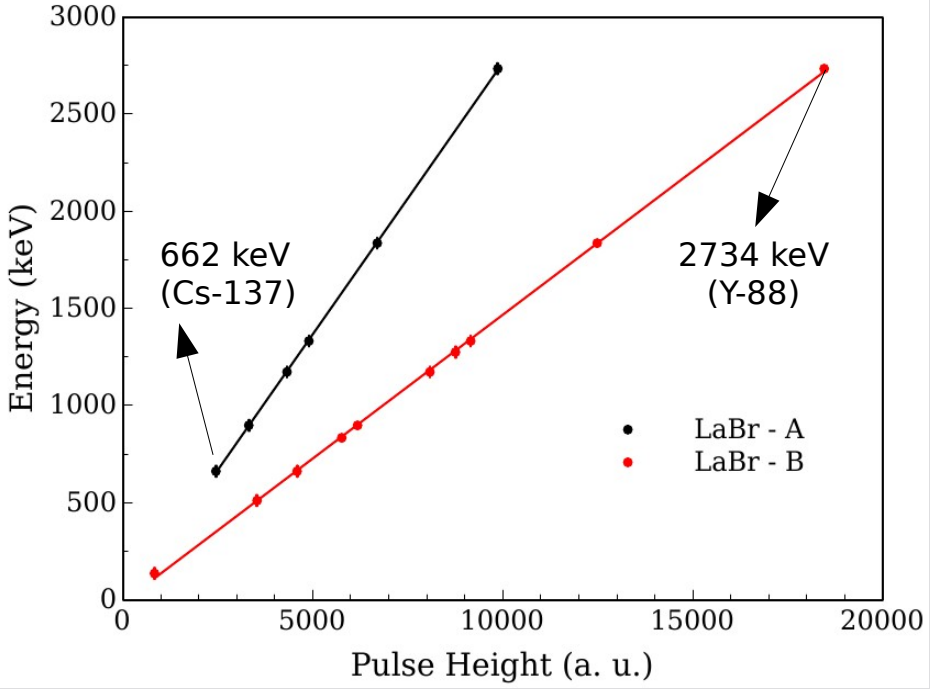
Energy Resolution

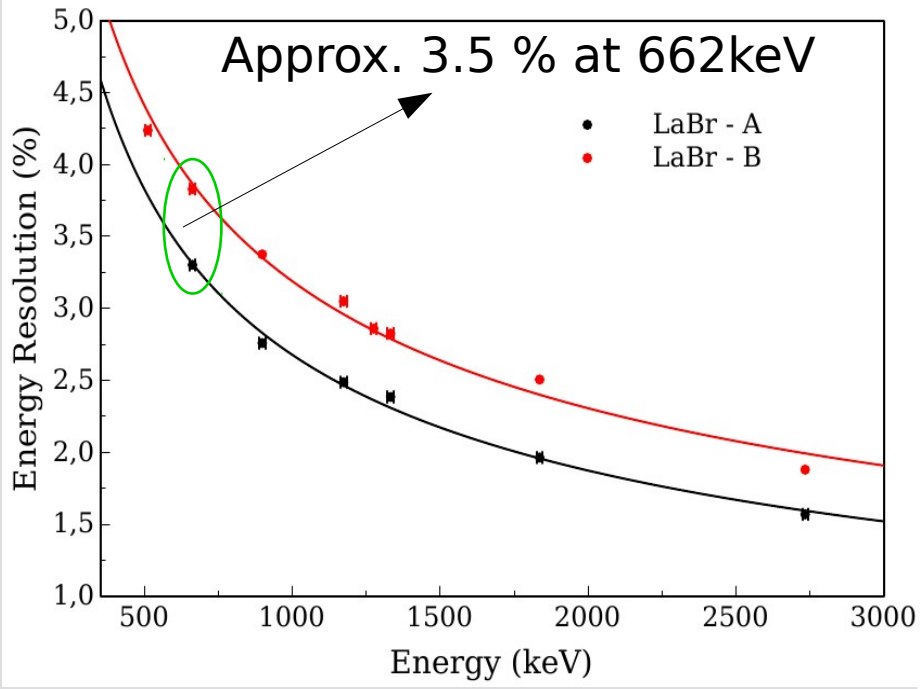
Gain stability



Results
$LaBr_3(Ce)$ characterization

- Coupled to a 3.5” R10233-100 Hamamatsu PMT
- Linearity and energy resolution

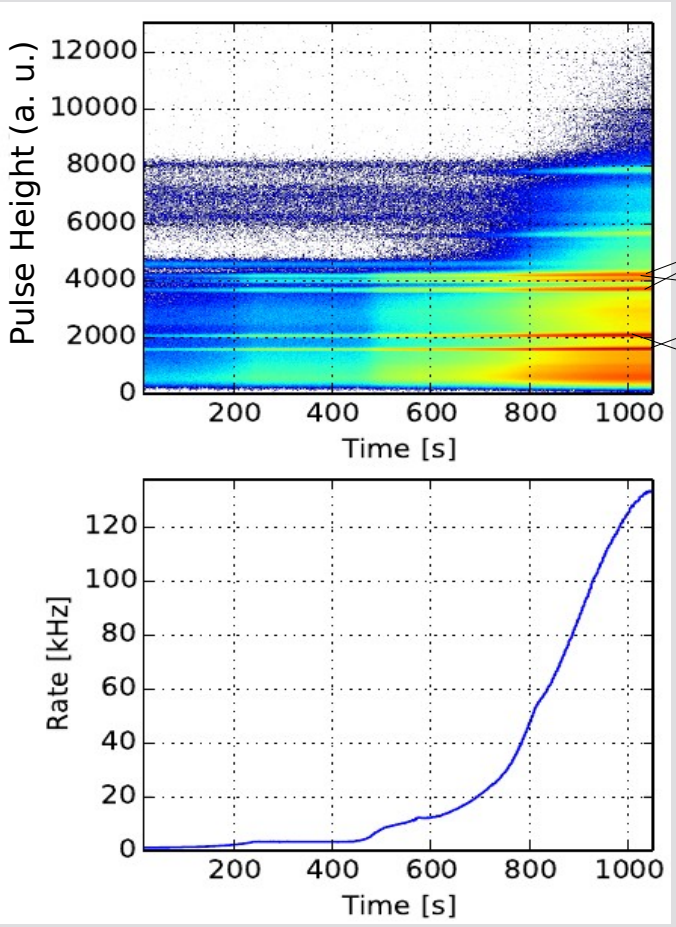




- Time resolutions were estimated to be (0.50 ± 0.02) ns

Results
$LaBr_3(Ce)$ characterization

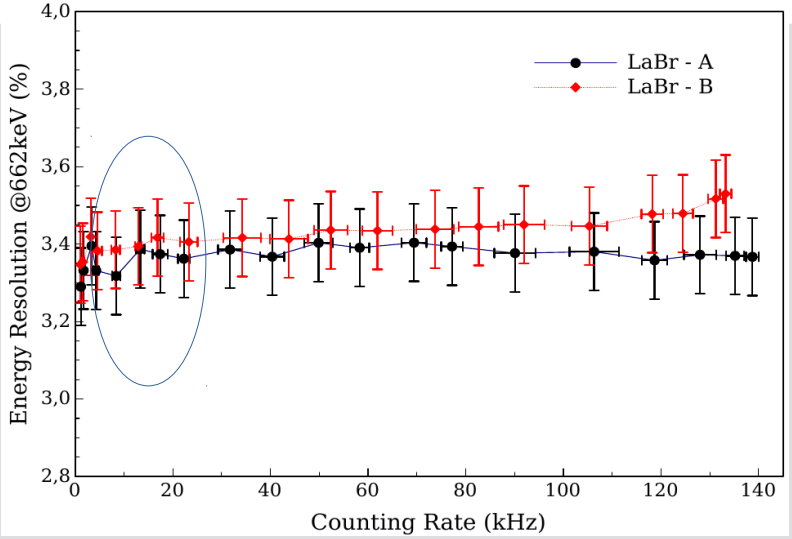
- High couting rates

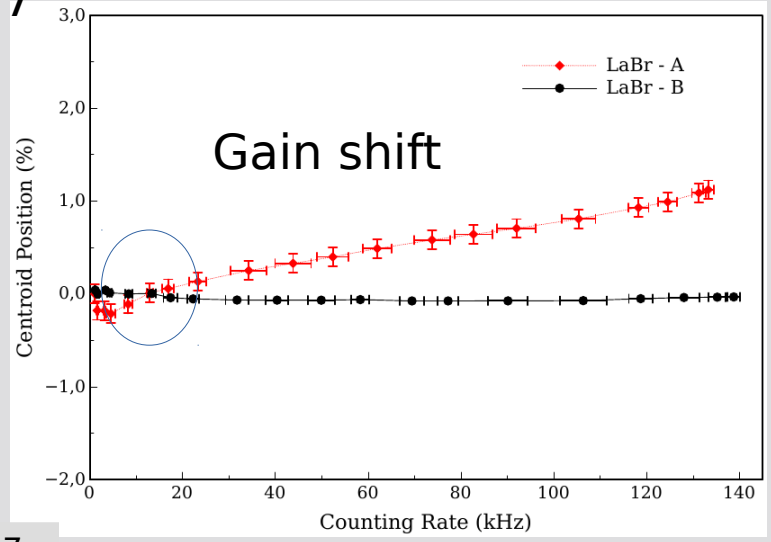


Co-60

Na-22

Cs-137

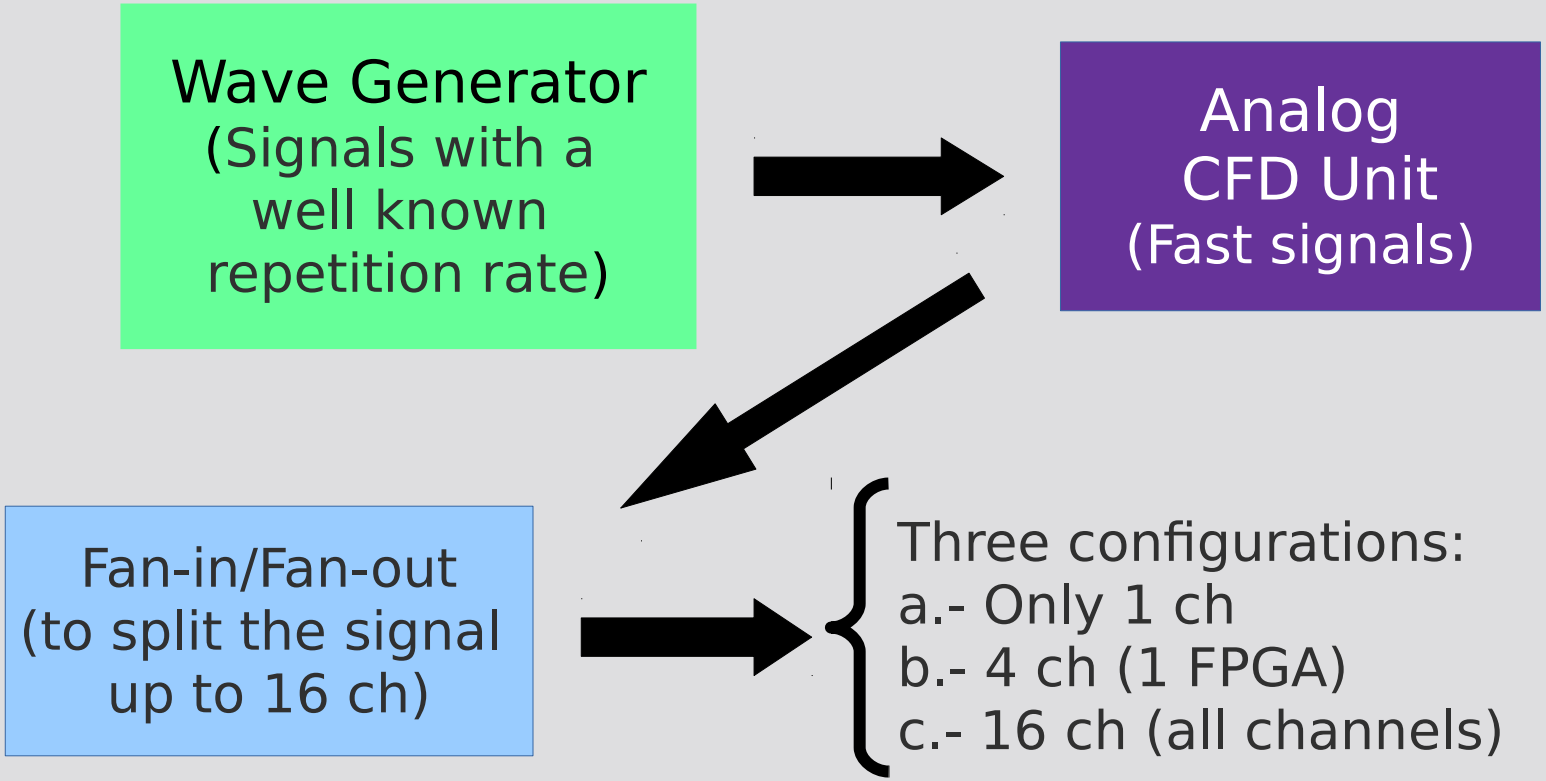




Electronics & DAQ

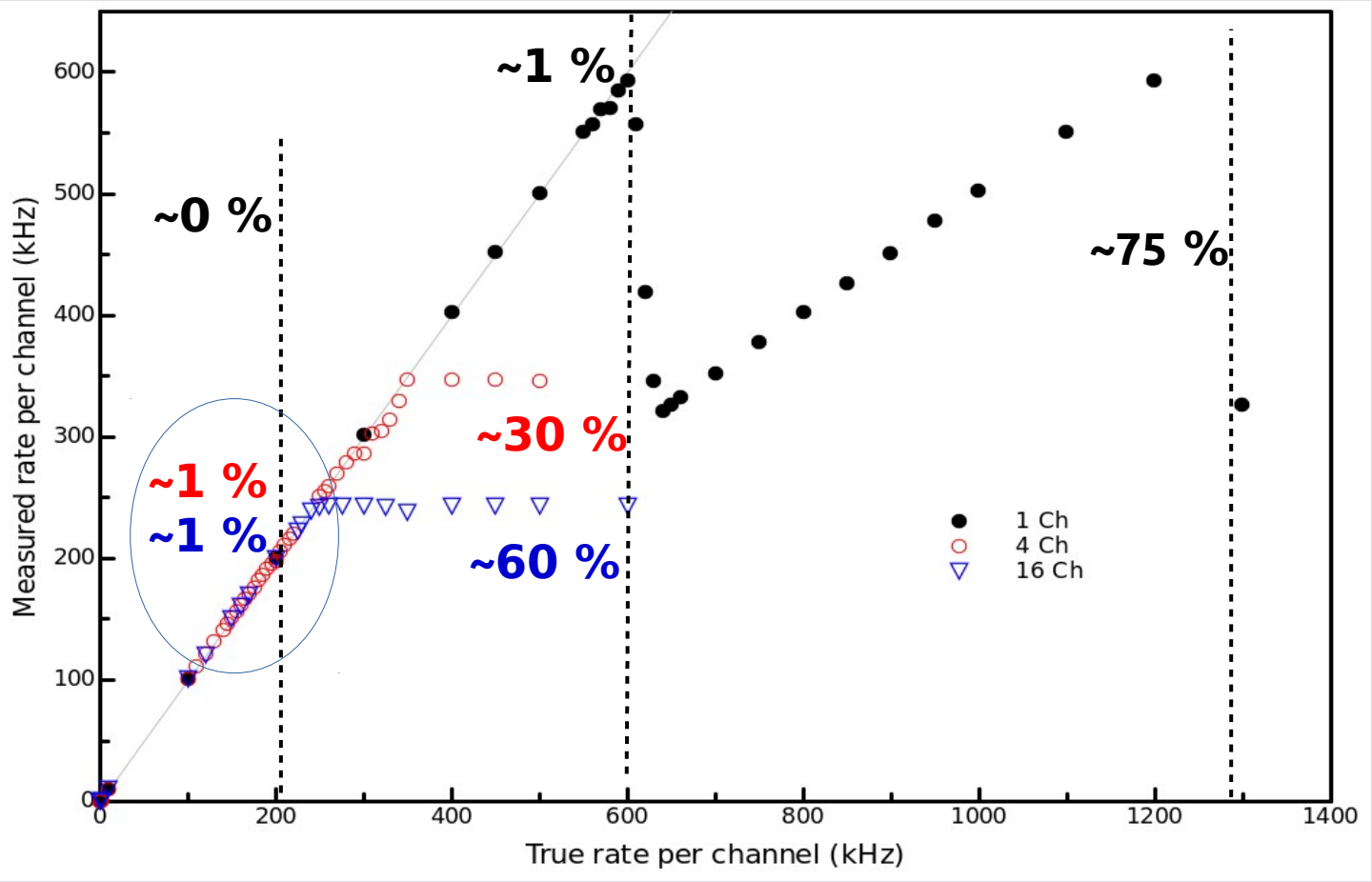
Experimental set-up
DAQ and Electronics tests

- Dead time of the DAQ vs counting rate ?
  - V1730 CAEN Digitizer, 16 ch → 1 FPGA/4 ch



Results
DAQ and Electronics tests

- Dead time estimations



Conclusions and future

- Three 5” PMTs were studied in order to refurbish the NaI(Tl) detectors used in the EURITRACK project
  - Requirements were achived by R11833-100HA (C)
    - Energy resolution: ~ 7 - 8 %; @662keV
    - Time resolution: ~ 2 ns; Thres=1 MeV
    - Excellent linearity
    - Gain shift < 1 % up to 200 kHz

- Two new 3” x 3” $LaBr_3$(Ce) were assembled (coupled to a R10233-100 PMT)
    - Energy resolution: ~ 3.5 %; @662keV
    - Time resolution: ~ 0.5 ns
    - Excellent linearity
    - No gain shift up to 140 kHz

Conclusions and future

- Electronics and DAQ system
  - 1% of dead time at 200 kHz / digitizer channel
  - 60 % of dead time at 500 kHz / digitizer channel

- Next steps:

  - Two integration test (laboratory) → 2nd semester 2017
    - JRC-ISPRA (Italy), CEA-Saclay (France)

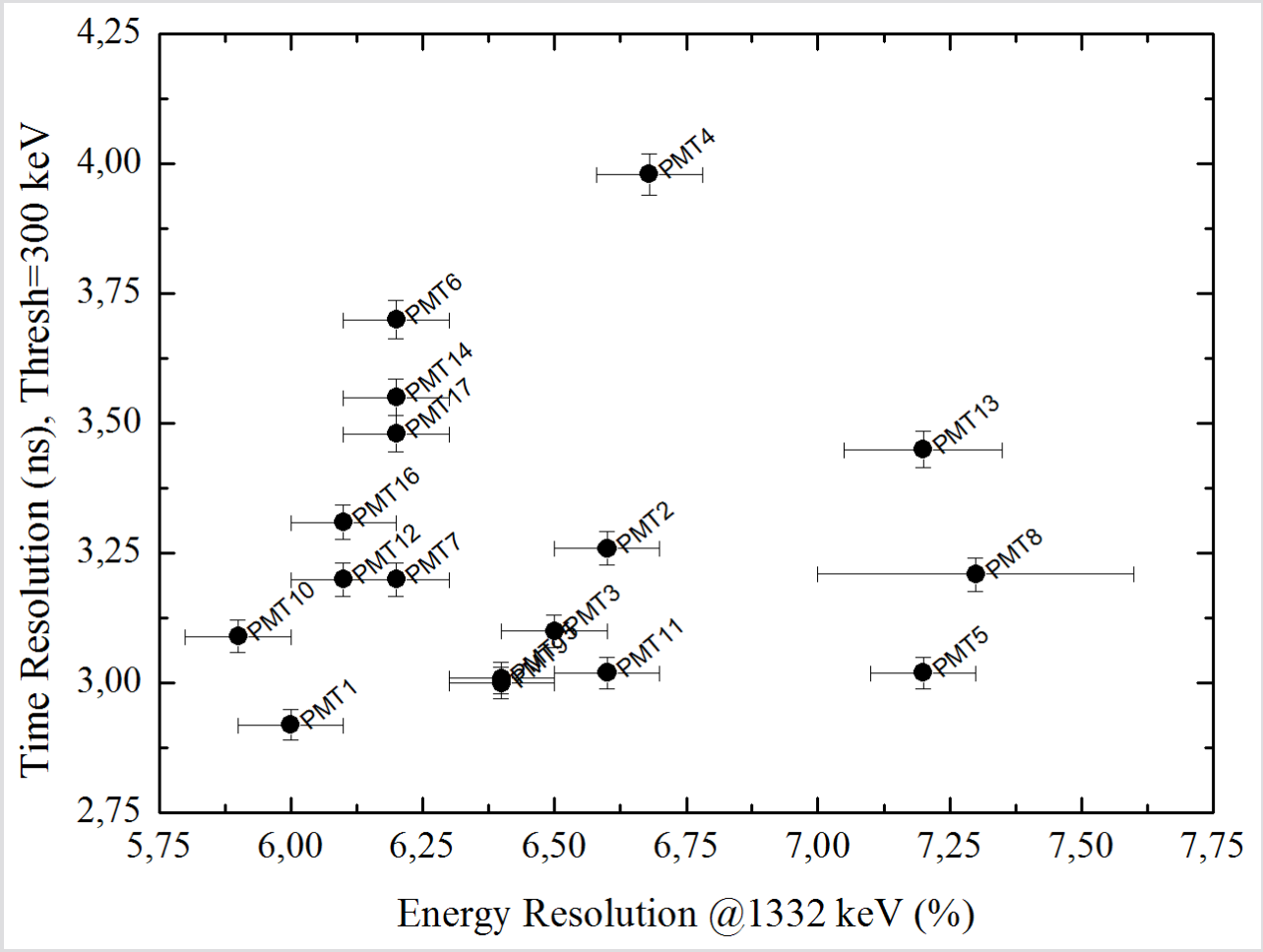
  - Live field trials will show proof of capabilities: two cases under real conditions at different border control points will be performed in 2018
    - Gdanks (Poland)
    - Rotterdam (Holland)

Thank You!

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653323. This text reflects only the author's views and the Commission is not liable for any use that may be made of the information contained therein.

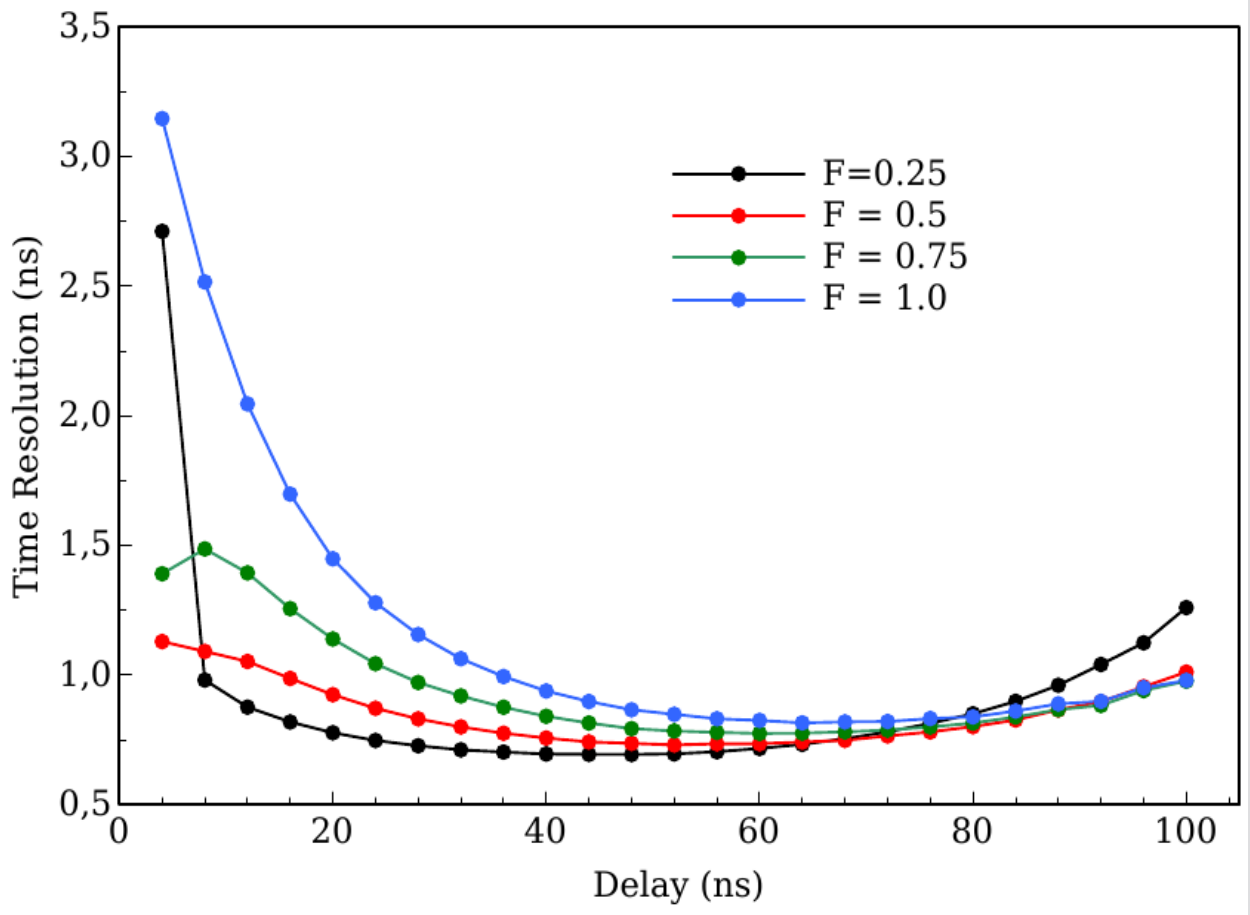
Back-up slides

Time Resolution vs Energy Resolution

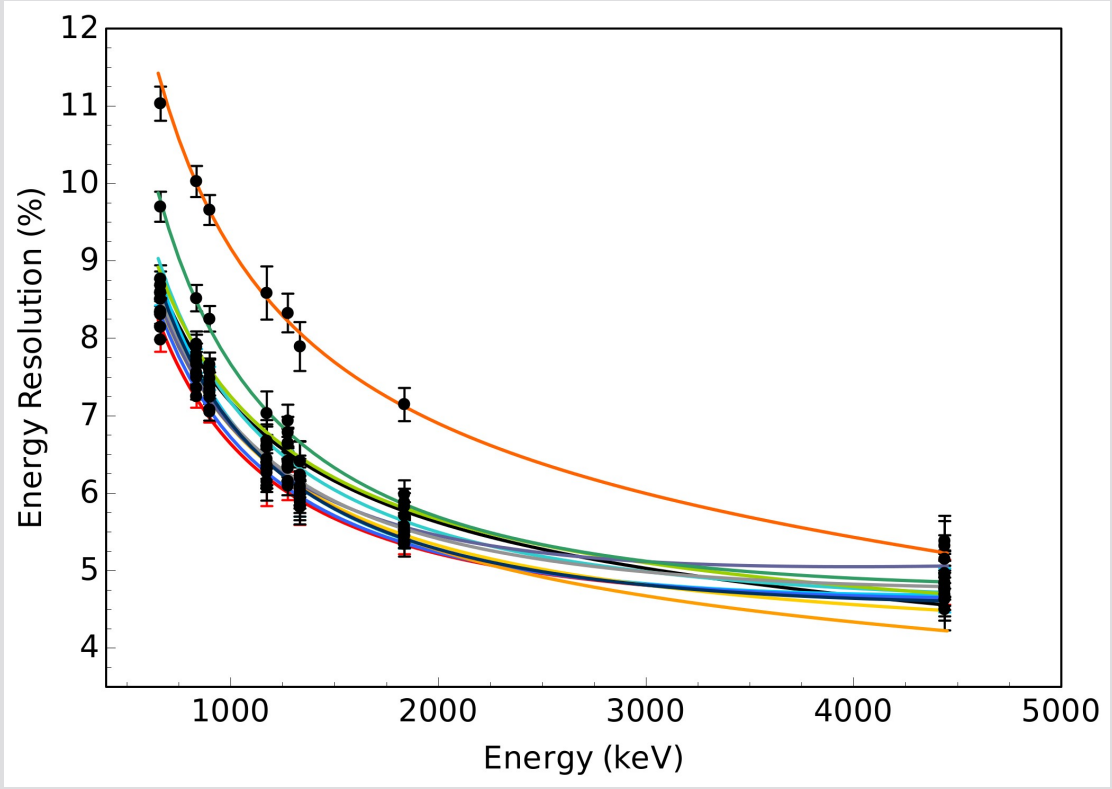


- Thr: 300 keV
- E: 1332 keV

Fraction and Delay LaBr scintillators



Energy Resolution



- 20 detectors characterized.
- Energy resolution: 5% to 10%

Threat	Description	Chemical formula	Chemical formula of simulant
Hexogen (RDX)	Explosive	$C_3H_6N_6O_6$	$Si_3C_3H_6N_6O_6$
TNT	Explosive	$C_7H_5N_3O_6$	$C_7H_6N_3O_6$
TATP	Explosive	$C_9H_{18}O_6$	$C_9H_{16,9}O_6$
Cocaine	Drug	$C_{17}H_{21}NO_4$	$C_{17}H_{21}NO_4$
Heroin	Drug	$C_{21}H_{23}NO_5$	$C_{21}H_{23}NO_5$
Yperite	Chemical warfare	$C_4H_8Cl_2S$	$C_4H_{8,2\text{-}8,4}Cl_2SNa_2$
Tetranitromethane	Liquid explosive	$C(NO_2)_4$	$Fe_{4/9}C_{4/3}(NO_2)_4H_{32/3}$
peroxide methylethylketone	Liquid explosive	$C_8H_{18}O_6$	$C_8H_{12}O_6$
Nitromethane	Liquid explosive	CH_3NO_2	$Fe_{1/3}CH_{5/2}NO_2$
Ethyleneglycol dinitrate	Liquid explosive	$(CH_2ONO_2)_2$	$FeCH_{5/2}NO_3$