

# The NEDA Project: Status and Perspectives

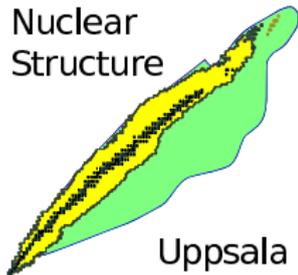
Johan Nyberg

For the NEDA Collaboration

Division of Nuclear Physics  
Department of Physics and Astronomy  
Uppsala University

2014-05-27

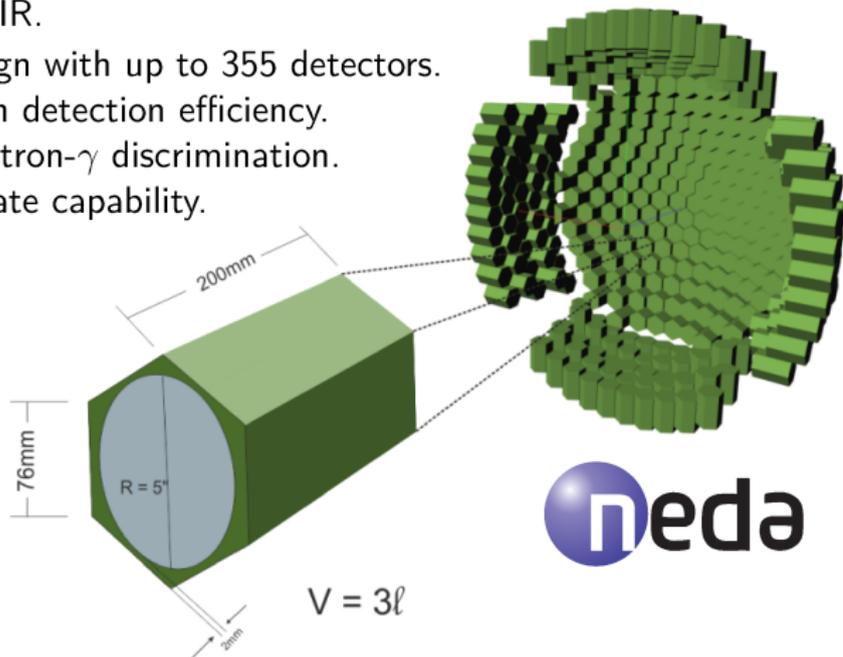
Nuclear  
Structure



UPPSALA  
UNIVERSITET

# What is NEDA?

- Neutron detector array for experiments at SPIRAL2/GANIL, SPES/LNL, NUSTAR/FAIR.
- Modular design with up to 355 detectors.
- Large neutron detection efficiency.
- Excellent neutron- $\gamma$  discrimination.
- High count-rate capability.



- Primary use: reaction channel identification by detection of  $\geq 2$  neutrons in studies of exotic proton-rich nuclei produced in fusion evaporation reactions.

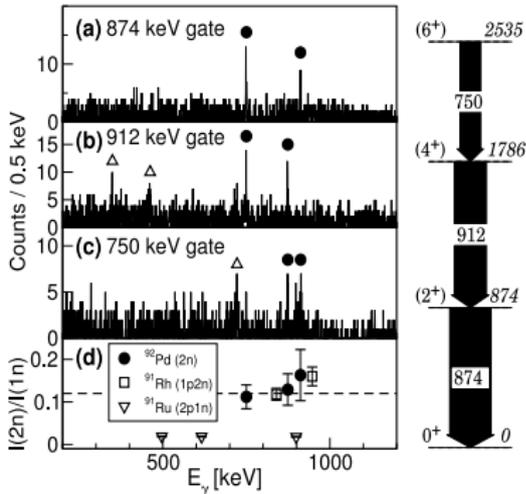
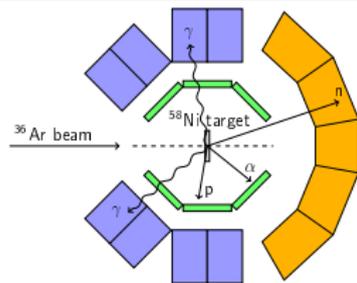
# $^{92}\text{Pd}$ experiment at GANIL

Experiment at GANIL (2009).

EXOGEN + DIAMANT + Neutron Wall (50 liq. scint.).

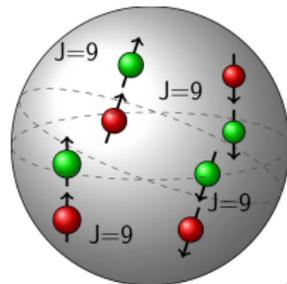
$^{36}\text{Ar}$  (111 MeV) +  $^{58}\text{Ni}$  →  $^{92}\text{Pd}$  + 2 n.

Cross section:  $\sigma_{\text{fus}} \sim 0.2$  b,  $\sigma_{^{92}\text{Pd}} \sim 1\mu\text{b}$ .



First observation of excited states in  $^{92}\text{Pd}$ .  
Approximately equidistant energy levels.

Valence neutrons and protons couple pairwise to  $S = 1, T = 0$  in the ground and first excited states of  $^{92}\text{Pd}$ .



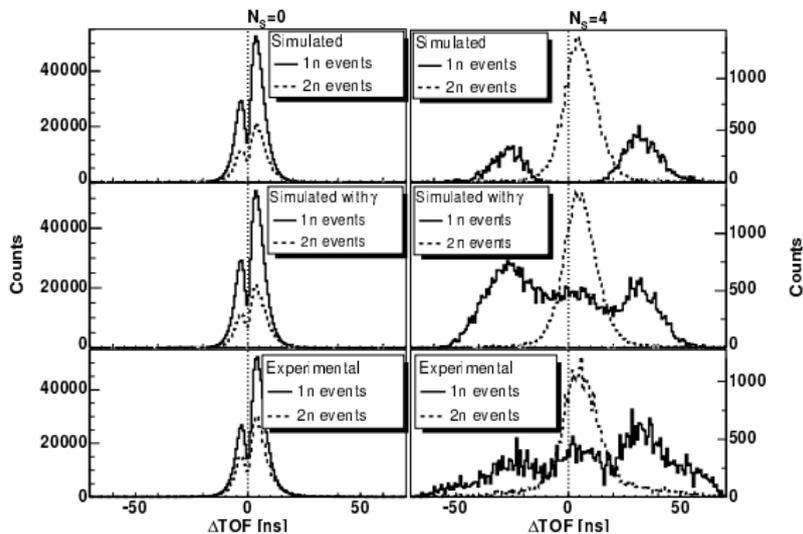
B. Cederwall, F. Ghazi Moradi et al., Nature 469 (2011) 68

Approved GANIL experiment:  $^{96}\text{Cd}$  (Oct 2014). Spokepersons: B. Cederwall, G. de France, R. Wadsworth.

# Neutron Scattering Problem

NWall: probability of 1 neutron giving a signal in 2 or more detectors  $\simeq 10\%$ .

Serious problem in searches for weakly populated  $\geq 2n$  reaction channels: scattered neutrons from much stronger  $1n$  channels are mis-identified as being due to  $2n$ ,  $3n$ , ... channels.



J. Ljungvall et al. NIM A528 (2004) 741.

Methods to detect scattered neutrons:

- Neighbor rejection.
- $\Delta TOF$ . J.Cederkäll et al. NIM A385(1997)166.

$\Rightarrow$  "Clean"  $2n$  efficiency reduced by factor 3 to 5 compared to  $\epsilon_{1n}^2$ .

Note: small amounts of  $\gamma$  rays mis-identified as neutrons reduces dramatically the quality of the  $\Delta TOF$  based neutron scattering reduction.

# NEDA Physics Cases

NEDA will address the physics of neutron-rich and neutron-deficient nuclei, mainly in conjunction with  $\gamma$ -ray detector arrays like AGATA, GALILEO, EXOGAM2 and PARIS. Brief list of physics ideas:

- Nuclear Structure:

- Probe  $T = 0$  correlations in  $N = Z$  nuclei: the structure beyond  $^{92}\text{Pd}$  (GANIL, LNL, Stockholm, Uppsala, York).
- Coulomb Energy Differences in isobaric multiplets:  $T = 0$  versus  $T = 1$  states (GANIL, LNL, Warsaw, York).
- Coulomb Energy Differences and Nuclear Shapes (GANIL, Padova, York).
- Low-lying collective modes in proton-rich nuclei (Istanbul, Krakow, Milano, LNL, Valencia).

- Nuclear Astrophysics:

- Element abundances in the in-homogeneous Big Bang Model (GANIL, LNS, Soreq, Weizmann).
- Isospin effects on the symmetry energy and stellar collapse (Debrecen, Florence, LNL, LNS, Naples).

- Nuclear Reactions:

- Level densities of neutron-rich nuclei (Florence, LNL, LNS, Naples).
- Fission dynamics of neutron-rich intermediate fissility systems (Debrecen, GANIL, LNL, LNS, Naples).

# NEDA Organisation

## Management Board

J.J. Valiente Dobon (project manager), N. Erduran, G. de France, A. Gadea, M. Moszynski, J. Nyberg, M. Palacz, D. Tonev, R. Wadsworth.

## Working Groups

- Physics
- Simulations and conceptual design
- Front-end electronics and DAQ
- Pulse-shape analysis
- New detector materials
- Synergies with other detectors

## Collaborating Countries

Bulgaria, France, Italy, Poland, Spain, Sweden, Turkey, UK.

## MoU for the Development Phase 2012-2015

Signed by Bulgaria, France, Italy, Poland, Sweden, Turkey, UK.

# GEANT4 Simulations: Optimal Size of NEDA Cells

Nuclear Instruments and Methods in Physics Research A 673 (2012) 64–72



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Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in  
Physics Research A

journal homepage: [www.elsevier.com/locate/nima](http://www.elsevier.com/locate/nima)



## Monte Carlo simulation of a single detector unit for the neutron detector array NEDA

G. Jaworski<sup>a,b</sup>, M. Palacz<sup>b,\*</sup>, J. Nyberg<sup>c</sup>, G. de Angelis<sup>d</sup>, G. de France<sup>e</sup>, A. Di Nitto<sup>f</sup>, J. Egea<sup>g,h</sup>, M.N. Erduran<sup>i</sup>, S. Ertürk<sup>j</sup>, E. Farnea<sup>k</sup>, A. Gadea<sup>h</sup>, V. González<sup>g</sup>, A. Gottardo<sup>l</sup>, T. Hüyük<sup>h</sup>, J. Kownacki<sup>b</sup>, A. Pipidis<sup>d</sup>, B. Roeder<sup>m</sup>, P.-A. Söderström<sup>c</sup>, E. Sanchis<sup>g</sup>, R. Tarnowski<sup>b</sup>, A. Triossi<sup>d</sup>, R. Wadsworth<sup>n</sup>, J.J. Valiente Dobon<sup>d</sup>

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<sup>e</sup> GANIL, Caen, France

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<sup>g</sup> Department of Electronic Engineering, University of Valencia, Burjassot (Valencia) Spain

<sup>h</sup> IFIC-CSIC, University of Valencia, Valencia, Spain

<sup>i</sup> Faculty of Engineering and Natural Sciences, Istanbul Sabahattin Zaim University Istanbul, Turkey

<sup>j</sup> Niğde Üniversitesi, Fen-Edebiyat Fakültesi, Fizik Bölümü, Niğde, Turkey

<sup>k</sup> INFN Sezione di Padova, Padova, Italy

<sup>l</sup> Padova University, Padova, Italy

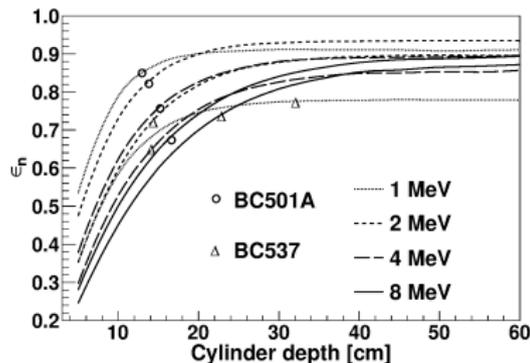
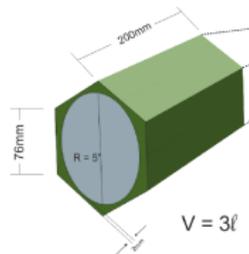
<sup>m</sup> LPC-Caen, ENSICAEN, IN2P3/CNRS et Université de Caen, Caen, France

<sup>n</sup> Department of Physics, University of York, York, United Kingdom

G. Jaworski et al., NIM A673 (2012) 64.

BC501A:  $^1\text{H}$ , BC537:  $^2\text{H}$  (deuterated)

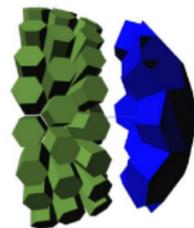
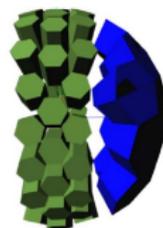
Dimensions: length=20 cm, diameter=12.7 cm (5 inch), volume=3  $\ell$ . BC501A better.



# GEANT4 Simulations: Conceptual Design

Aim: optimise 1n, 2n & 3n efficiencies and minimise cross-talk.

Geometry	Solid angle ( <i>s.r.</i> )	Avg. cell volume ( <i>l</i> )	Total Volume ( <i>l</i> )	Granularity	Distance to target ( <i>m</i> )
NEDA $2\pi$	$1.88\pi$	3	1065	355	1.0
Spherical $2\pi$	$\sim 2\pi$	2	1212	606	1.0
Neutron Wall	$\sim \pi$	3	145	50	0.5
Neutron Wall + NEDA (a)	$1.85\pi$	3	287	96	0.5
Neutron Wall + NEDA (b)	$1.32\pi$	3	300	100	0.5 and 0.75



NWall 1 $\pi$

NWall+NEDA (a) NWall+NEDA (b)

Geometry	Material	$\epsilon_{1n}$ (%)	$\epsilon_{2n}$ (%)	$\epsilon_{3n}$ (%)
NEDA $2\pi$	BC501A	47.35	10.27	3.71
Spherical $2\pi$	BC501A	55.33	13.84	7.03
Neutron Wall	BC501A	32.94	1.36	0.38
NW + NEDA (a)	BC501A	41.25	3.85	0.58
NW + NEDA (b)	BC501A	34.29	4.51	0.79

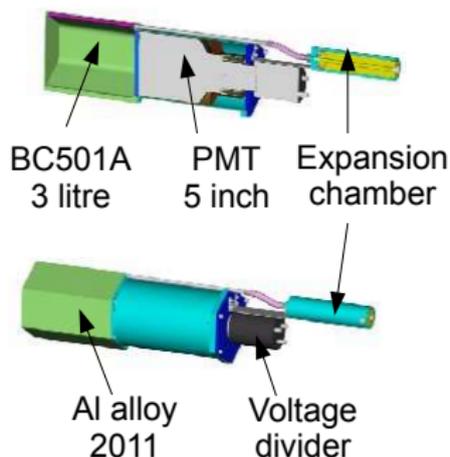
Clean 2n efficiency:  
 [NEDA  $2\pi$ ]  $\approx 7.5 \times$  [NWall]  
 [NWall+NEDA (b)]  $\approx 3.3 \times$  [NWall]

Preliminary results

T. Hüyük (IFIC-Valencia) et al., LNL Ann. Rep. (2013) and to be submitted to NIMA.

# Design and Construction of NEDA Cells

Self production. Prototype designed and built at LNL (V. Modamio et al.).



First three prototype cells  
(Feb 2014)

Prototype designed to be as compact and economic as possible.

Hexagonal cell designed in Al alloy 2011. Case fits 1 mm  $\mu$ -metal shield.

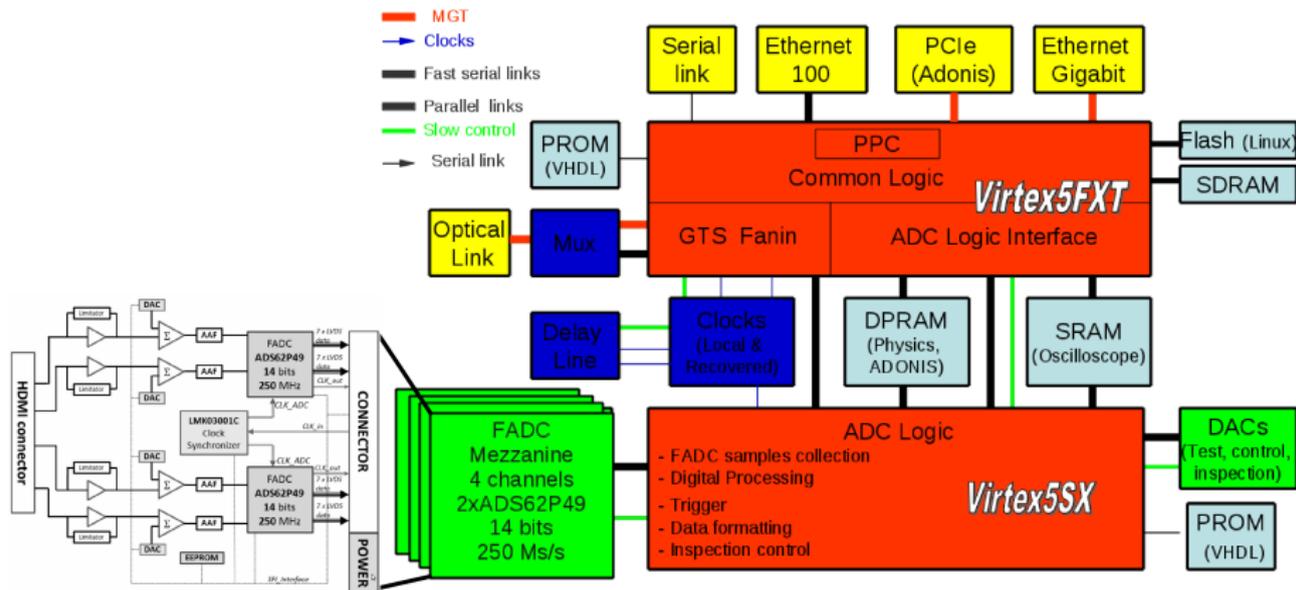
Dimension:  $V \approx 3\ell$ ,  $L = 200$  mm, diam. (side-to-side)  $d_o = 146$  mm,  $d_i = 133$  mm.

First prototype ready to be filled with liquid and to be tested.

# Electronics: NEDA Digitiser

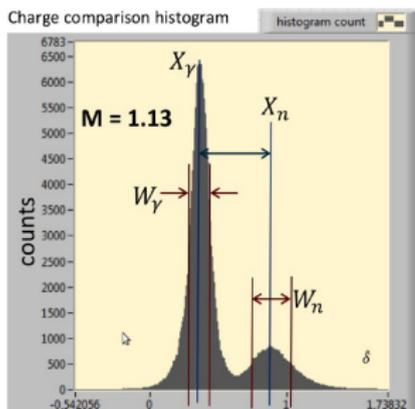
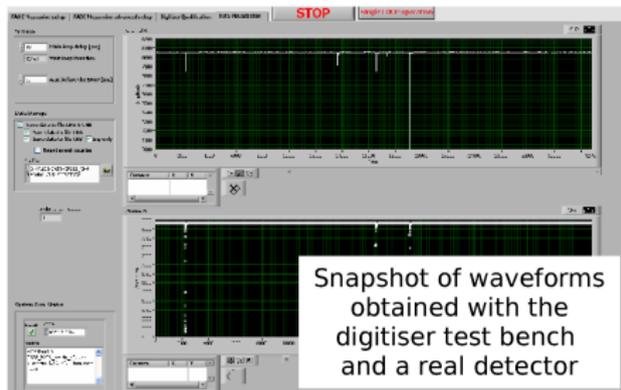
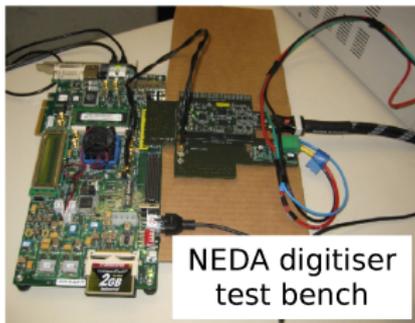
NUMEXO2 (EXOGAM2): 16 channel NIM unit, 4 mezzanine cards, each with four 200-250 MS/s, 14 bit FADCs.

Design & tests of mezz. cards by IFIC-Valencia, LNL, GANIL, F.J. Egea et al.  
NUMEXO2 is fully compatible with AGATA (GTS, timestamping, readout, etc.).  
Synergies with PARIS.

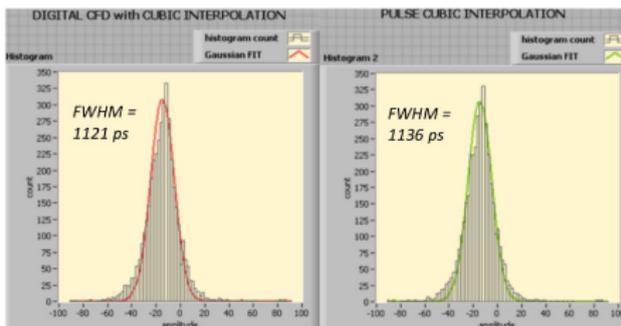


Prototypes ready and tested. Production of cards from 2014.

# NEDA/EXOAM2 Digitiser Tests



Neutron-gamma discrimination with the NEDA digitiser.  $^{252}\text{Cf}$  source,  $5'' \times 5''$  BC501A detector, Charge Comparison method.



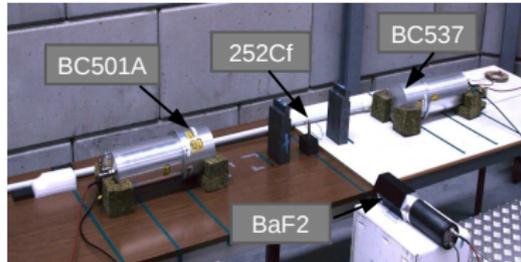
Time resolution with the NEDA digitiser.  $^{60}\text{Co}$  source, two  $5'' \times 5''$  BC501A detectors, digital CFD

F.J. Egea et al., IEEE TNS 60 (2013) 3526; LNL Ann. Rep. (2013); Subm. to IEEE RTC, Nara Japan (2014).

# NEDA Tests at LNL

## Instrumentation:

- Neutron source:  $^{252}\text{Cf}$  ( $\approx 2$  MBq).
- Detectors:
  - $2 \times \text{BC501A}$  ( $\text{C}_8\text{H}_{10}$ ), cyl. 5"  $\times$  5"
  - $2 \times \text{BC537}$  ( $\text{C}_6\text{D}_6$ ), cyl. 5"  $\times$  5"
  - $\text{BaF}_2$  for time reference, cyl. 2"  $\times$  2"
- Photomultiplier tubes:  
fast: XP4512, R4144, R11833-100  
spectroscopy type: ET9390-kb



- Digitisers:
  - SIS3302 8 ch, 100 MS/s, 16 bits
  - SIS3350 4 ch, 500 MS/s, 14 bits
  - Caen DT5720, 250 MS/s, 12 bits
  - NEDA digitiser, 200 MS/s, 14 bits



- DAQ: VME-based by J. Agramunt (IFIC-Valencia)

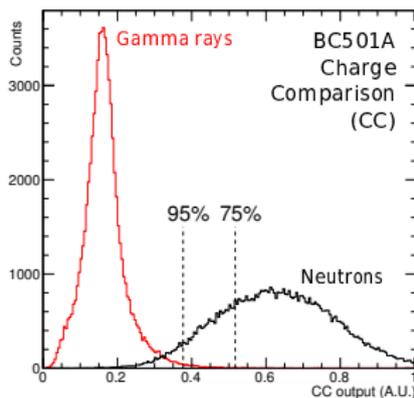
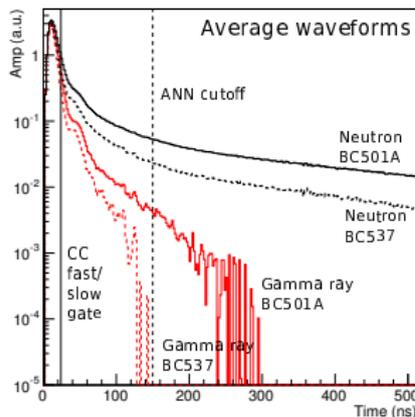
## Performed tests:

- Neutron-gamma discrimination.
- Neutron efficiency.
- Neutron scattering.
- Digital pulse-timing
- Tests to find optimal PMT for NEDA.
- High count rate tests (pile-up).

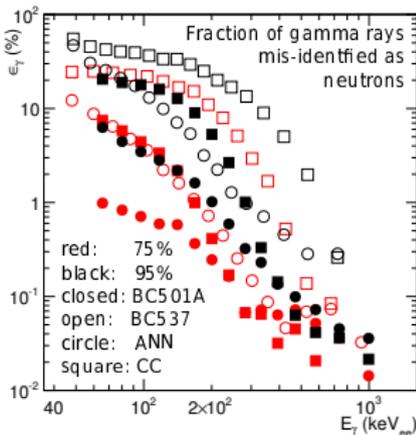
Analysis in progress ...

# Neutron-gamma Discrimination with BC501A, BC537

PSA algorithms: Charge Comparison (CC), Artificial Neural Network (ANN).



## Preliminary results



## Conclusions:

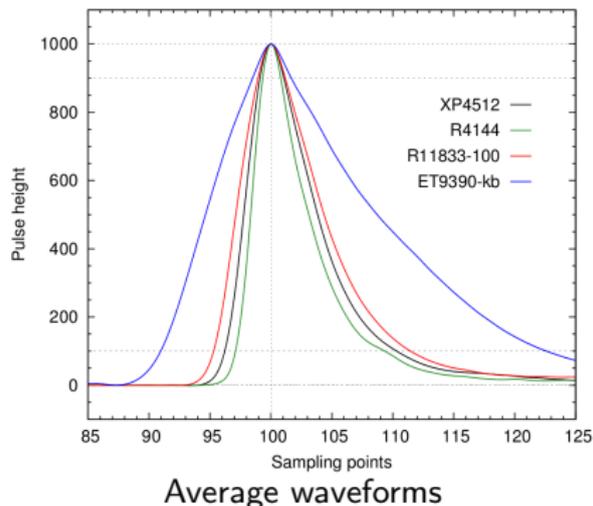
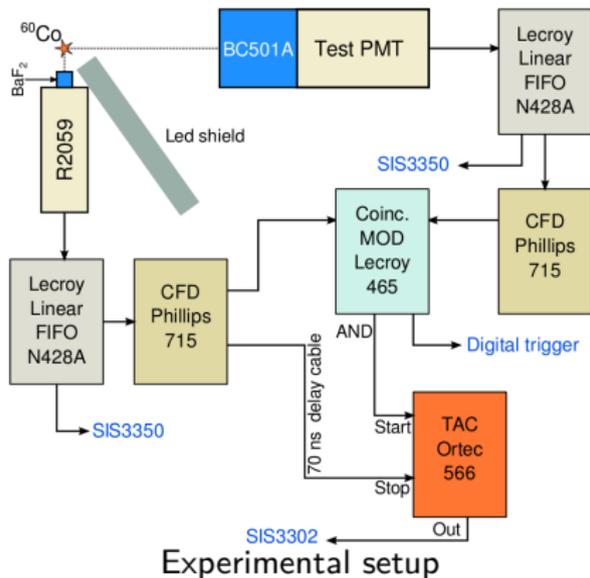
- BC501A is better than BC537.
- ANN is better than CC.

P.-A. Söderström et al., LNL Ann. Rep. (2011) 66 and to be submitted to NIMA.

# Digital Pulse-Timing Techniques

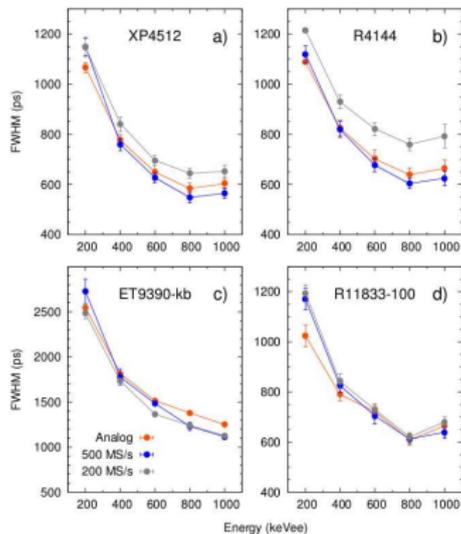
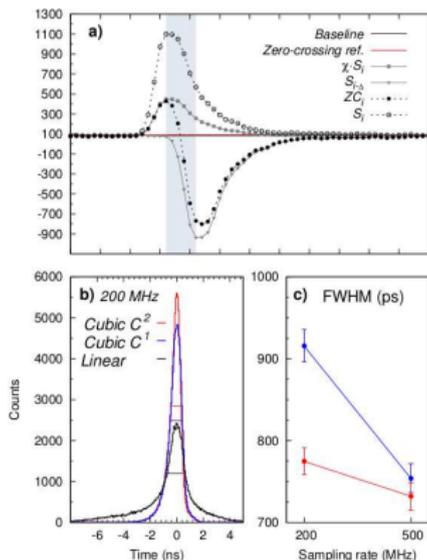
Development and tests of new digital CFD algorithm, with zero crossing obtained by cubic interpolation, continuous up to second derivative.

Tests with four different 5 inch PMTs (3×fast, 1×spectroscopy) and at sampling rates 200 MS/s and 500 MS/s.



V. Modamio et al., LNL Ann. Rep. (2012) 77 and to be submitted to NIMA.

# Digital Pulse-Timing Techniques



PMT	Risetime (ns)	$S_{pc}$ ( $\mu\text{A}/\text{Im}$ )	$N_{phe}$ ( $\text{MeV}^{-1}$ )	Analog	Time resolution FWHM (ps)	
					500 MS/s	200 MS/s
XP4512	4.9(4)	10.6	1330(70)	690(30)	660(30)	740(30)
R4144	3.8(3)	10.2	950(60)	750(30)	710(30)	870(30)
R11833-100	6.3(7)	13.5	1830(90)	743(13)	730(20)	760(20)
ET9390-kb	13.5(13)	12.0	1550(50)	1470(20)	1330(30)	1360(20)

**Conclusion:** comparable time resolutions for all three measurements: analogue and digital at 200 MS/s 500 MS/s. Preliminary results. V. Modamio et al., LNL Ann. Rep. (2012) 77 and to be subm. to NIMA.

# PMT Tests for Optimal Neutron-Gamma Discrimination

PMT model	R4144	XP4512	ET9390-kb	R11833-100
Type	fast	fast	spectroscopy	fast
QE <sub>max</sub> [%]	22	24	28	35
NPE/MeV	950(60)	1350(70)	1800(90)	2070(100)

PSA algorithms: CC and IRT (Integrated Rise Time). 500 MS/s. Preliminary results.

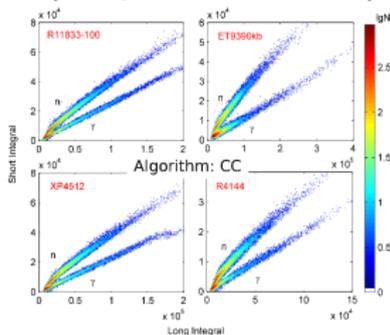
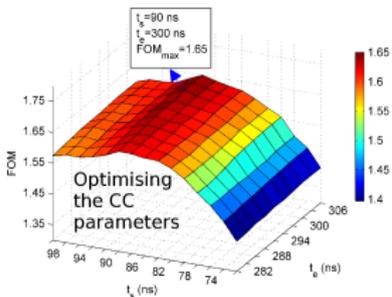
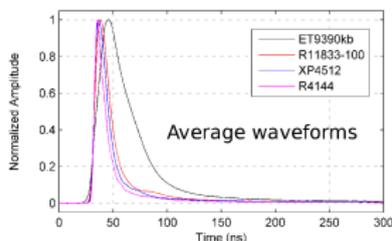
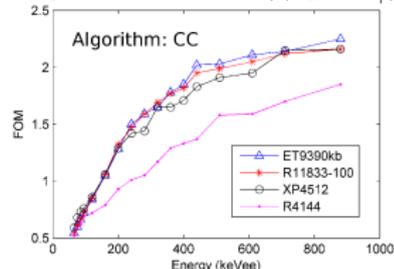
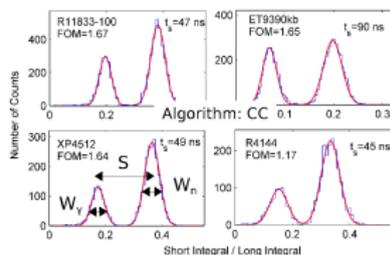


Figure-of-Merit:  $FOM = S / (W_n + W_\gamma)$



Conclusions:

- R11833-100, ET9390-kb, XP4512 give similar FOM values.
- Similar results with IRT.
- PMT for NEDA: R11833-100 (better time resolution).



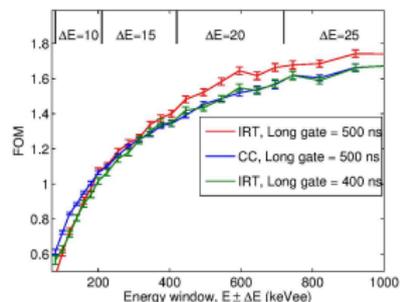
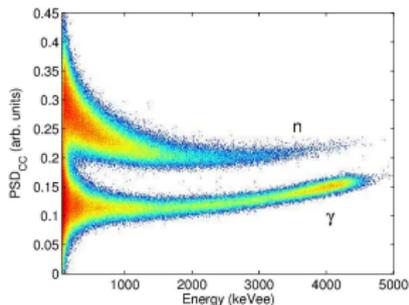
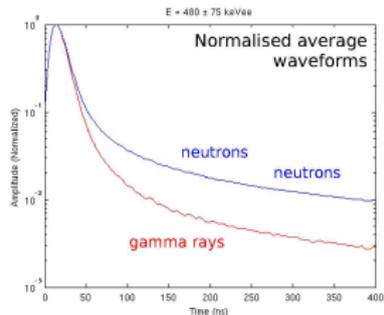
L. Xiaoliang et al., LNL Ann. Rep. (2013) and to be subm. to NIMA.

# New Detector Materials

New solid plastic scint. with NGD capabilities. N. Zaitseva et al., NIM A668 (2012) 88. Tests performed at NCBJ Swierk, Poland. Neutron source: Pu-Be. Detector: 3" × 3" EJ399-33 (ELJEN/SCIONIX). PMTs: 3" ET9821, 5" ET9390-kb. Digitiser: Caen DT5720 (250 MS/s, 12 bit). Preliminary results.



EJ299-33



## Conclusions:

- Not yet quite as good FOM as with the best liquid scintillator.
- New versions of the EJ299 on the market (soon/now?).
- Very promising technology and new developments will be followed closely by NEDA...

Q. Nishada et al., Master Thesis, Uppsala Univ. (in prep.); LNL Ann. Rep. (2013); to be subm. to NIMA.

# NEDA Phases and Future Campaigns

## Phases

- 0 Upgrade of Neutron Wall to use digital electronics (NUMEXO2).
- 1 Construction of a  $1\pi$  NEDA array, may be combined with Neutron Wall to cover  $2\pi$ .
- 2 Construction of the full  $2\pi$  NEDA array.

## Future Campaigns

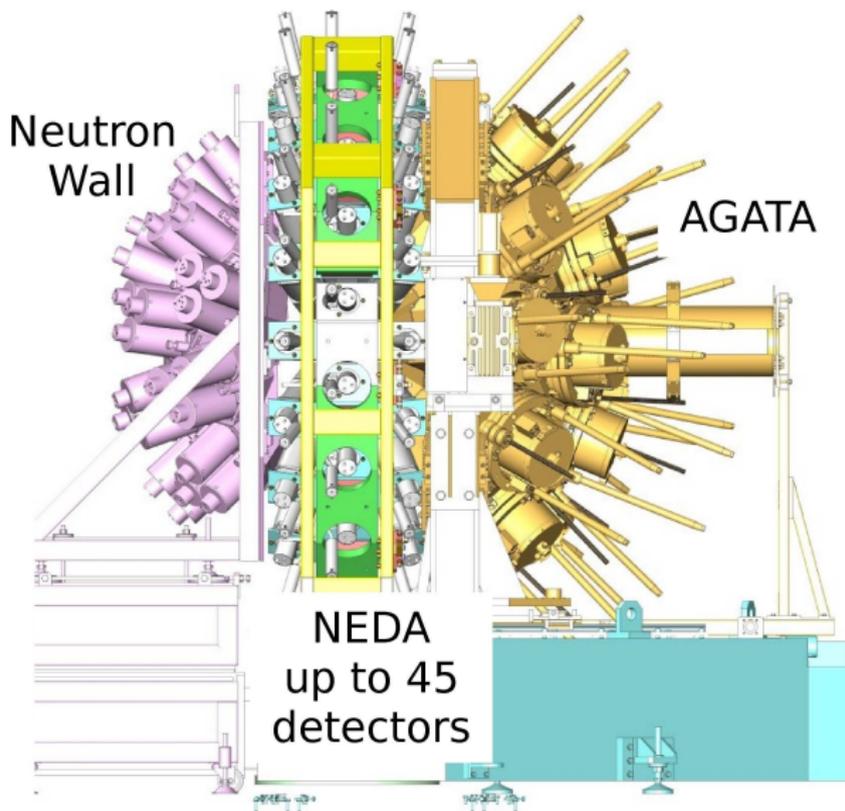
### Decided:

- 2015 Neutron WALL + GALILEO at LNL.
- 2016 AGATA campaign at GANIL. Neutron WALL (50 detectors) + NEDA (up to 45 detectors) with new NEDA electronics. 18 Lols.

### Preliminary plans:

- 2017+ NEDA at SPIRAL2, NEDA at SPES ( $\beta$ -decay station), NEDA+HISPEC at NUSTAR/FAIR, ...

# Neutron Wall + NEDA + AGATA at GANIL



# Acknowledgments

J. Agramunt Ros, F.J. Egea, M.N. Erduran, S. Ertürk, G. de Angelis, G. de France, A. Di Nitto, A. Gadea, V. Gonzalez, T. Hüyük, M. Jastrzab, G. Jaworski, J. Kownacki, V. Modamio, M. Moszynski, Q. Nishada, M. Palacz, E. Sanchis, P.-A. Söderström, D. Tonev, M. Tripon, A. Triossi, J.J. Valiente Dobon, R. Wadsworth, L. Xiaoliang, and the NEDA Collaboration.



Thank you for your attention