NEDA (NEutron Detector Array)

M. Nizamettin Erduran, ISZU

on behalf of NEDA collaboration

NEDENSAA NuPNET Meeting 20-22 February 2013 San Biagio Resort Acireale - Italy

Aim of NEDA

- Develop a neutron detector array to be used with AGATA, EXOGAM2, GALILEO, PARIS, etc., for experiments with high intensity stable and radioactive ions beams at SPES, SPIRAL2 and at other facilities.

The array should have:

Increased neutron detection efficiency compared to

Neutron Wall:

ε(1n) ≈ 40% (20-25%), ε(2n) ≈ 6% (1-3%).

ε(3n) ≈ 1% (0.1 %)

Excellent neutron-gamma discrimination.

Superiour 1n/2n/3n discrimination.

Capability to run at much higher count rates than the Neutron Wall.

Cope with large neutron multiplicities in reactions with neutron-rich RIBs.

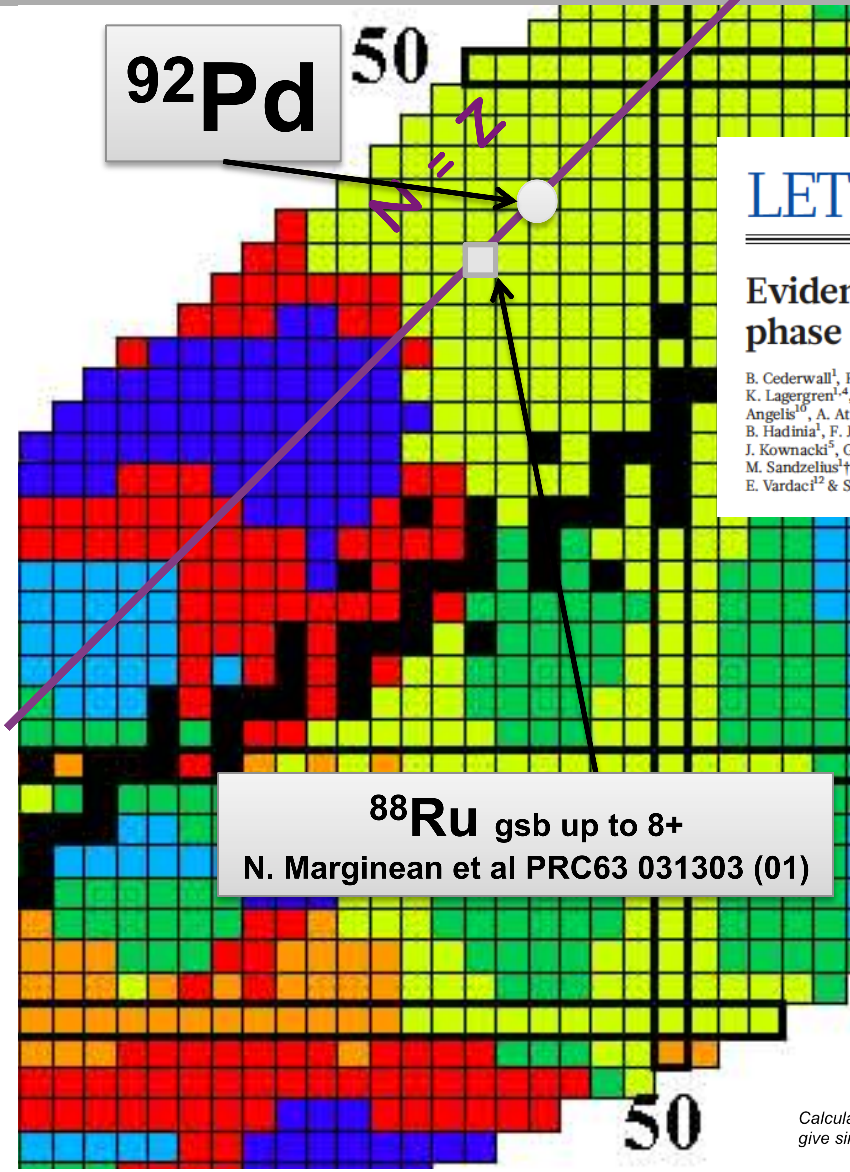
Improved neutron energy resolution for reaction studies.

Is it worth the effort ?

ε(1n) ≈ 40% (20-25%), ε(2n) ≈ 6% (1-3%).
ε(3n) ≈ 1% (0.1 %)

- The primary application of NEDA is to act as neutron multiplicity filter in γ-ray fusion-evaporation studies of very neutron deficient nuclei, close to N=Z
  - probe of T=0 correlations (like ^{92}Pd)
  - ^{100}Sn region: SPE, nucleon-nucleon interactions and core excitations
  - Coulomb Energy Differences in isobaric multiplets, T=0 vs. T=1 states
  - Low-lying collective modes (proton pygmy dipole resonance, ^{34}Ar+^{16}O → ^{44}Cr+α2n, with PARIS)
- The power of the new neutron detector can be especially demonstrated in studies in which detection of 2 or more neutrons is required

In beam spectroscopy of ^{92}Pd



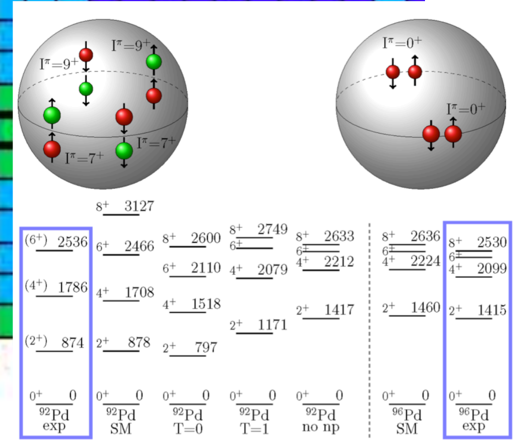
LETTER

doi:10.1038/nature09644

Evidence for a spin-aligned neutron–proton paired phase from the level structure of ^{92}Pd

B. Cederwall[1], F. Ghazi Moradi[1], T. Bäck[1], A. Johnson[1], J. Blomqvist[1], E. Clément[2], G. de France[2], R. Wadsworth[3], K. Andgren[1], K. Lagergren[1,4], A. Dijon[2], G. Jaworski[5,6], R. Liotta[1], C. Qi[1], B. M. Nyakó[7], J. Nyberg[8], M. Palacz[5], H. Al-Azri[3], A. Algora[9], G. de Angelis[10], A. Ataç[11], S. Bhattacharyya[2]†, T. Brock[3], J. R. Brown[3], P. Davies[3], A. Di Nitto[12], Zs. Dombrádi[7], A. Gadea[9], J. Gál[7], B. Hadinia[1], F. Johnston-Theasby[3], P. Joshi[3], K. Juhász[13], R. Julin[14], A. Jungclaus[15], G. Kalinka[7], S. O. Kara[11], A. Khaplanov[1], J. Kownacki[5], G. La Rana[12], S. M. Lenzi[16], J. Molnár[7], R. Moro[12], D. R. Napoli[10], B. S. Nara Singh[3], A. Persson[1], F. Recchia[16], M. Sandzelius[1]†, J.-N. Scheurer[17], G. Sletten[18], D. Sohler[7], P.-A. Söderström[8], M. J. Taylor[3], J. Timár[7], J. J. Valiente-Dobón[10], E. Vardaci[12] & S. Williams[19]

Nature vol. 469 (2011)



Shell model calculations by J. Blomqvist et al.

Calculations done in several model spaces,:i.e., 0g9/2, 0g9/2-1p1/2 and 0g9/2-1p1/2-0f5/2-1p3/2 which all give similar results . Int. parameters determined to reproduce exp energies in ^{94,95}Pd, ^{93,94}Rh

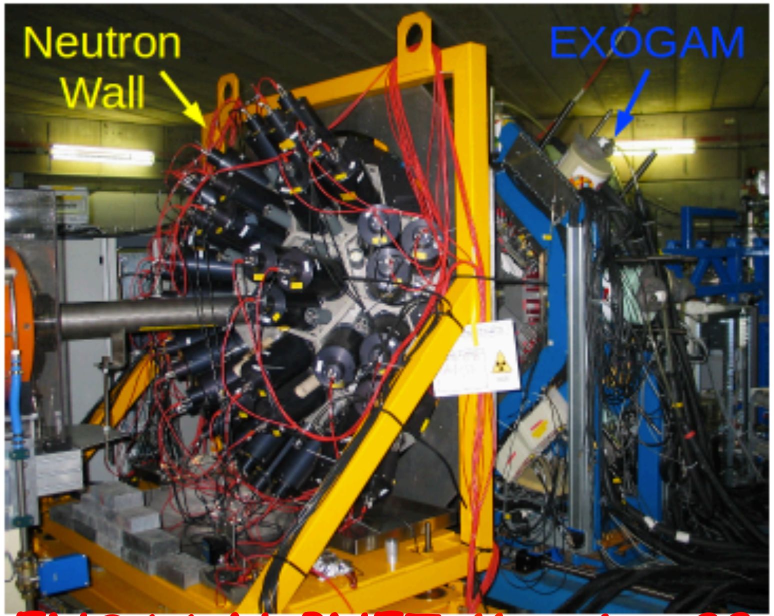
Strategy of NEDA

- Optimise size of detector units, distance to target, geometry of the array, . . .
- Investigate other detector materials than ordinary liquid scintillator.
- Adopt digital electronics which is fully compatible with AGATA, GALILEO, EXOGAM2, PARIS . . .
- Develop advanced on-line and off-line algorithms for neutron-gamma discrimination, neutron scattering rejection, pile-up rejection/recovery.

Neutron Wall

Experiments performed with EUROBALL at LNL (1998) and at IReS (2001-2003), and with EXOGAM at GANIL (2005-).

Combined with charged particle detector arrays (EUCLIDES, DIAMANT, CUP, . . .).

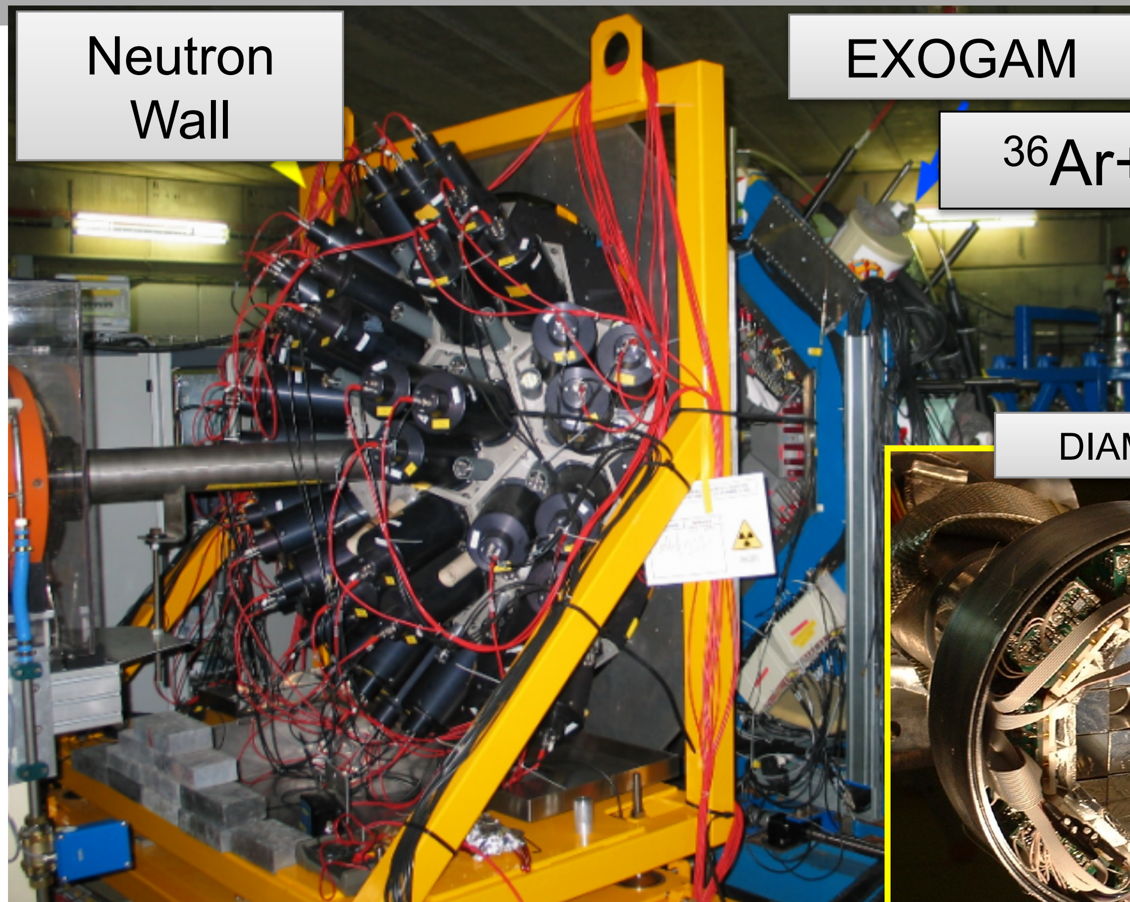


GANIL home base since 2005.

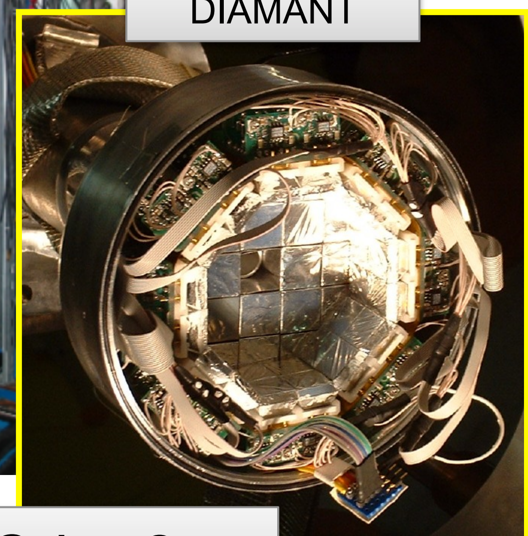
Four experimental campaigns at GANIL with EXOGAM + DIAMANT and other detectors (2005-2009).

Next cam[...] periments):

Experimental approach

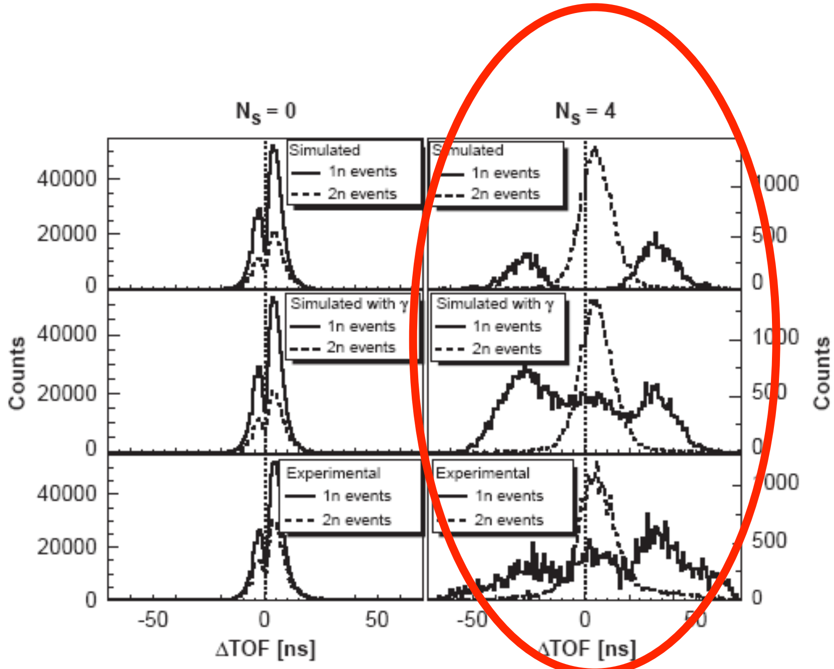


$^{36}Ar + ^{58}Ni \rightarrow ^{92}Pd + 2n$



$^{40}Ca + ^{58}Ni \rightarrow ^{98}Cd^{*} \rightarrow ^{96}Cd + 2n$

Cross talk – low 2n cross section



J. Ljungvall et al., NIMA528 471 (2004)

- High cross talk between neighboring detectors
- It is not possible to differenciate between 2n real events or just 1n scattered.
- Therefore neighbouring detectors are dismissed in the analysis and the efficiency decreases down to 1-2%.

Possible to improve 2n efficiency using TOF among detectors

One aim of NEDA is to be able to distinguish between real 2n events and scattered neutrons → Increase of the 2n efficiency.

Organization of NEDA

Spokesperson: J.J. Valiente Dobon (LNL-INFN)

GANIL Liason: M. Tripon (GANIL)

Management board:

-B. Wadsworth (U. of York)

-N. Erduran (Istanbul Sabahattin Zaim U.)

-G. De France (GANIL)

-J. Nyberg (U. of Uppsala)

-M. Palacz (U. of Warsaw)

-A. Gadea (IFIC - Valencia)

-D. Tonev (INRNE – Bulgaria)

FP7-INFRASTRUCTURES-2007-1

SPIRAL2 PREPARATORY PHASE

FIRB (2008)

FUTURO IN RICERCA (MIUR)

MoU (4 years) signed in march 2012 by Bulgaria, France, Turkey, Poland, Sweden, United Kingdom.

To be signed by: Italy and Spain

Parties of the collaboration

Parties

- **Bulgaria:** Institute for Nuclear Research and Nuclear Energy (INRNE)
- **France:** GANIL
- **Italy:** Istituto Nazionale di Fisica Nucleare (INFN)
- **Poland:** Consortium of Polish Governmental and Public Institutions (COPIN)
- **Spain:** Conselleria d'Educació, Generalitat Valenciana/Secretaría de Estado de Investigación, Desarrollo e Innovación/Ministerio de Economía y Competitividad/Centro Superior de Investigaciones Cientificas (CSIC)/ Universidad de Valencia/Istituto de Física Corpuscular (IFIC)
- **Sweden:** Uppsala University
- **Turkey:** The Scientific and Technological Research Council of Turkey (TUBITAK)/ Turkish Atomic Energy Authority (TAEK)
- **United Kingdom:** York University

Simulations: Single cell unit

Detailed study of GEANT4 simulations for a single detector of NEDA.

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

ELSEVIER

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

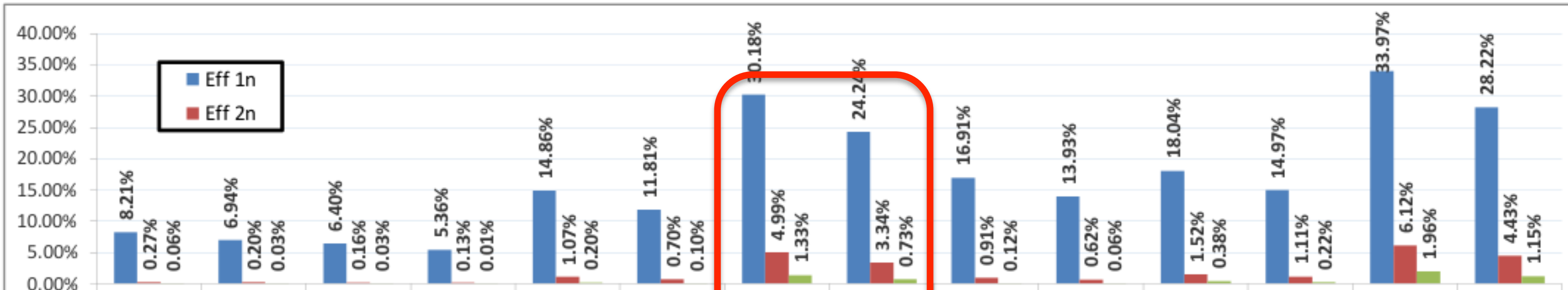
Monte Carlo simulation of a single detector unit for the neutron detector array NEDA

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

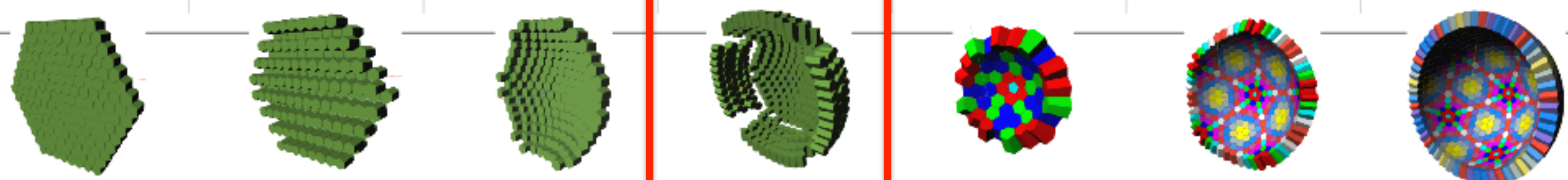
[a] Faculty of Physics, Warsaw University of Technology, ul. Koszykowa 75, 00-662 Warszawa, Poland
[b] Heavy Ion Laboratory, University of Warsaw, ul. Pasteura 5A, PL 02-093 Warszawa, Poland
[c] Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden
[d] INFN, Laboratori Nazionali di Legnaro, Legnaro, Italy
[e] GANIL, Caen, France
[f] INFN Sezione di Napoli, Napoli, Italy
[g] Department of Electronic Engineering, University of Valencia, Burjassot (Valencia), Spain
[h] IFIC-CSIC, University of Valencia, Valencia, Spain
[i] Faculty of Engineering and Natural Sciences, Istanbul Sabahattin Zaim University Istanbul, Turkey
[j] Nigde Universitesi, Fen-Edebiyat Falkültesi, Fizik Bölümü, Nigde, Turkey
[k] INFN Sezione di Padova, Padua, Italy
[l] Padova University, Padua, Italy
[m] LPC-Caen, ENSICAEN, IN2P3/CNRS et Université de Caen, Caen, France
[n] Department of Physics, University of York, York, United Kingdom

G. Jaworski et al., NIM A 673 (2012) 64-72

Overview efficiency geometries



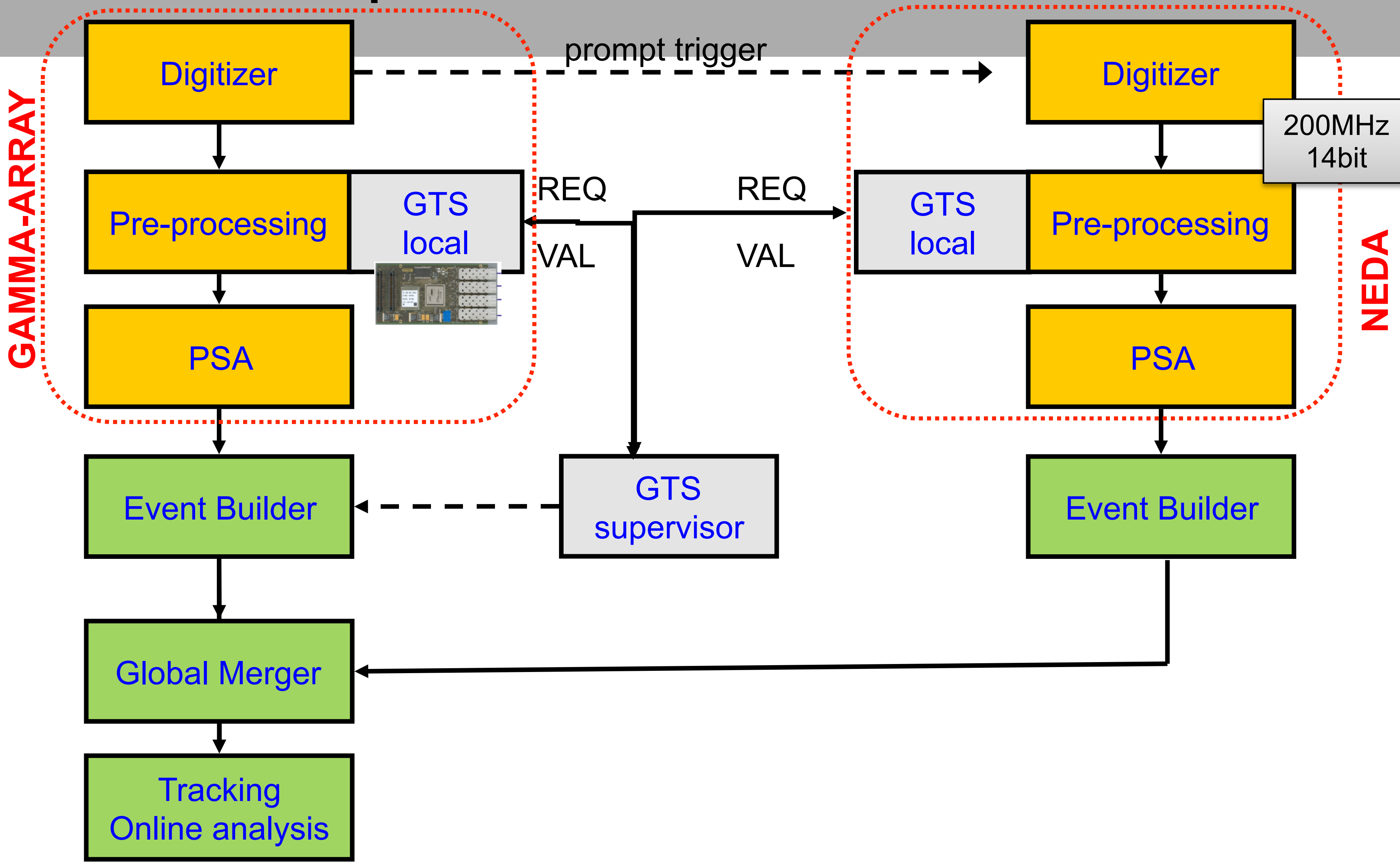
M	BC501A / BC537	BC501A / BC537	BC501A / BC537	BC501A / BC537	BC501A / BC537	BC501A / BC537	BC501A / BC537
Ω	0.52	0.45	0.92	1.88	1.00	1.00	2.00
AV	3	3	3	3	4.5	2	2
V	507	507	489	1065	202.5	652	1212
N	169	169	163	355	45	326	606
R	1m	1m	1m	1m	0.5 m	1m	1m



R Distance from the origin / Radius (meter)
N Granularity (Number of modules)
V Total Volume (liter)
AV Average Volume (liter)
Ω Solid angle coverage (π)
M Material

Simulated neutron source: Cf-252
Depth of the detectors: 20 cm
Neutrons were shot in 2π solid angle
1E+7 statistics have been recorded

NEDA coupled to GALILEO/AGATA/EXOGAM2/PARIS

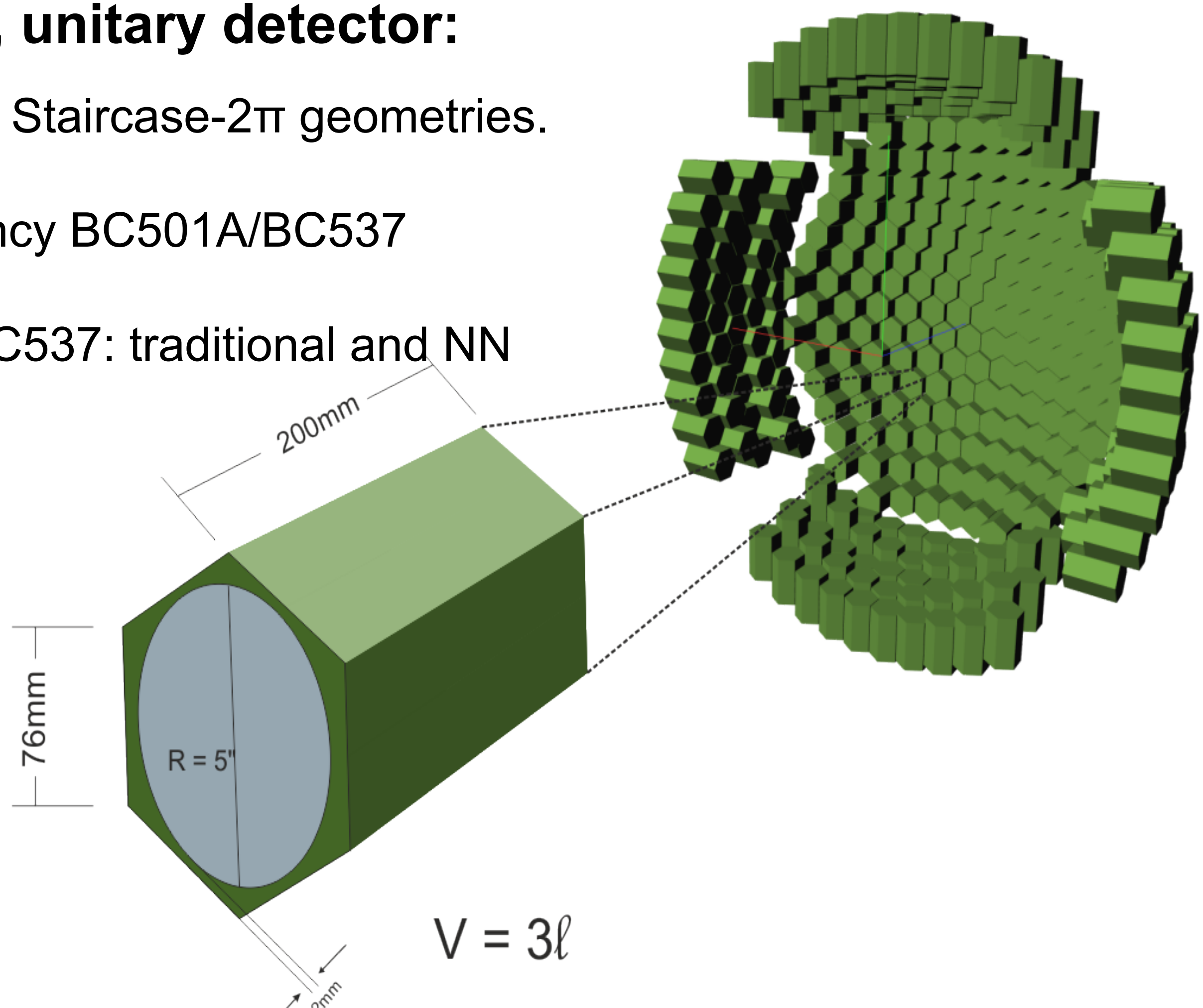


Tests at LNL BC501/BC537

Starting point, unitary detector:

- One unit cell → Staircase-2π geometries.

- Relative efficiency BC501A/BC537
- Timing
- PSA BC501A/BC537: traditional and NN

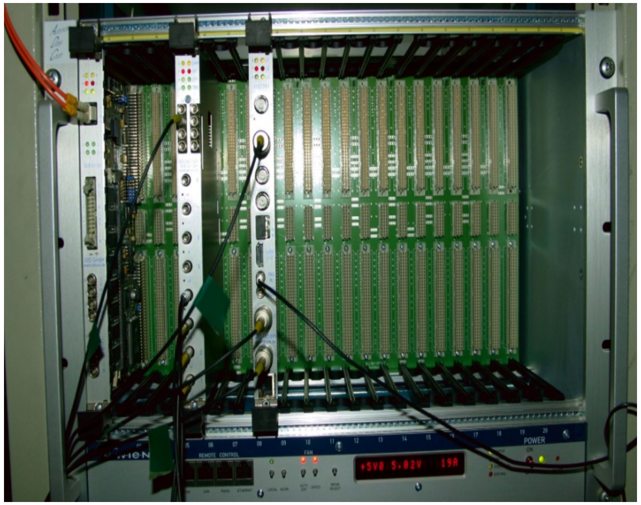


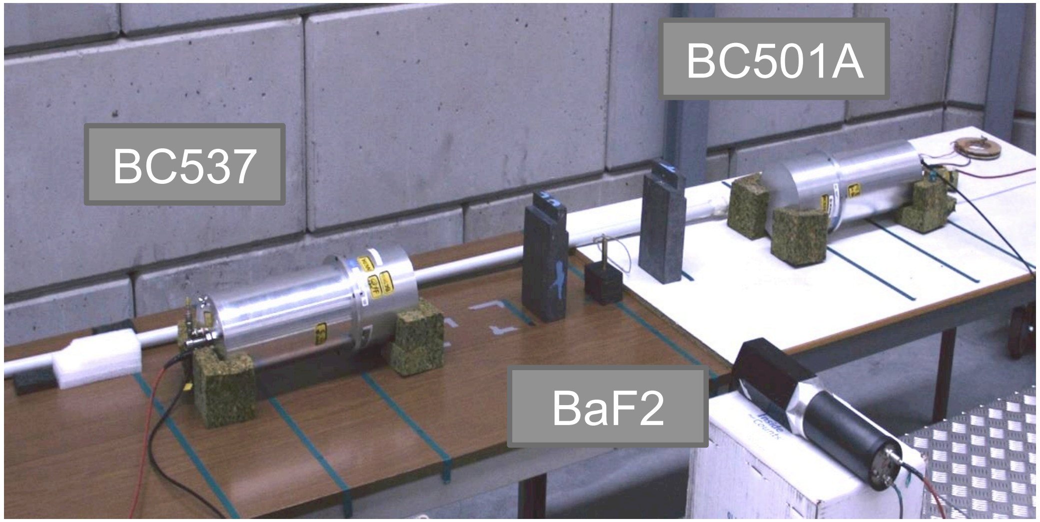
NEDA test setup

The tests are being performed at LNL with the following instrumentation:

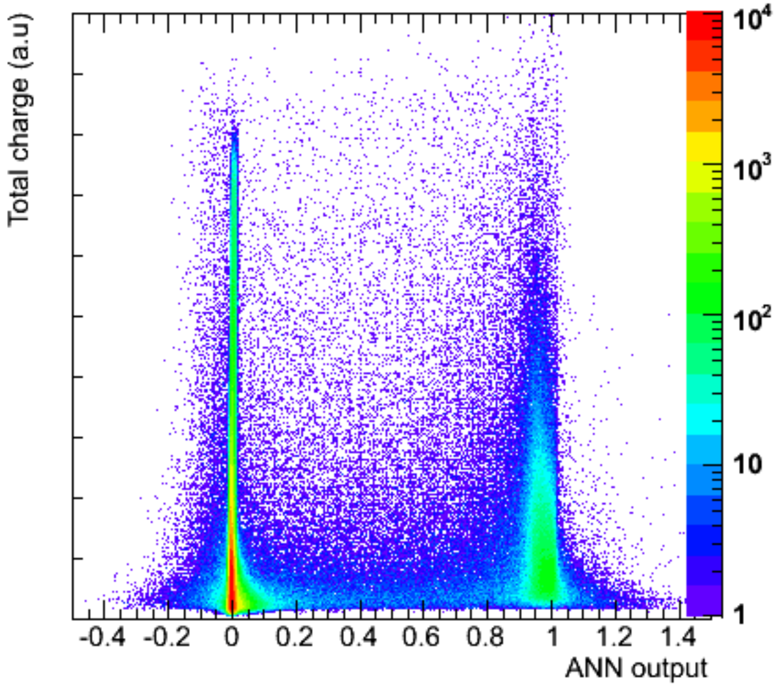
- 2 x BC501A (5” x 5” cylindrical prototype detector)
- 2 x BC537 (5” x 5” cylindrical prototype detector)
- SIS3302 100 MS/s, 16 bits 8 ch. digitizer (analog setup)
- SIS3350 500 MS/s, 12 bits 4 ch. digitizer
- DAQ by IFIC, J. Agramunt

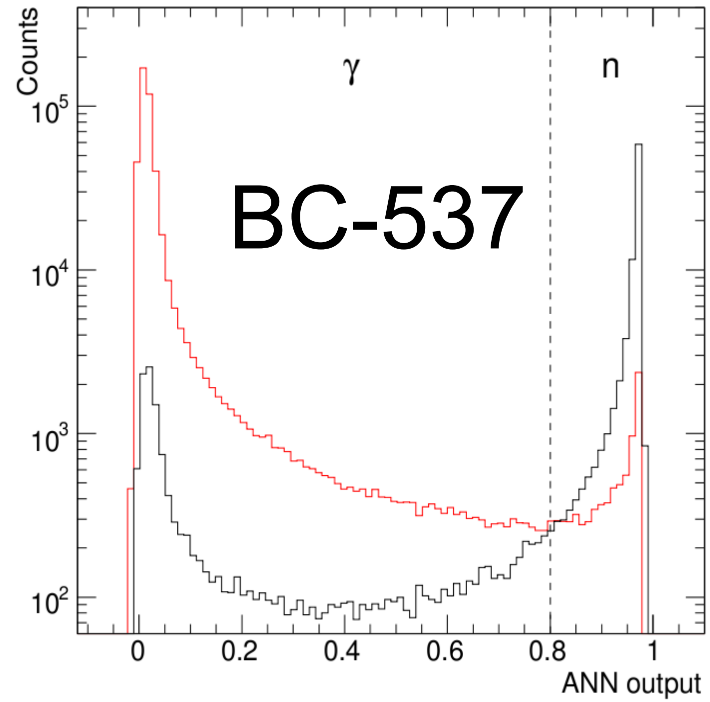
- Digital PSA
- Relative efficiency performance
- Cross-talk between the detectors





NEDA test: PSA Neural Network





Full advantage of digital electronics can be obtained using artificial neural networks to perform pulse-shape discrimination. This method is currently being investigated both for BC537 and BC501A.

+ Optimal discrimination over a large energy range
- Slower implementation limits counting rate

Tests: PSA NN BC501 vs. BC537

Pulse-shape discrimination between neutrons and γ rays in the liquid scintillators BC-501A and BC-537

P.-A. Söderström[a,b,*], A. Di Nitto[c], T. Hüyük[d], G. Jaworski[e,f,g], A. Pipidis[g], J. J. Valiente Dobón[g,*], J. Nyberg[a], M. Palacz[f], G. de Angelis[g], J. Agramunt-Ros[d], G. de France[h], J. Egea[i,d], M.N. Erduran[j], S. Ertürk[k], A. Gadea[d], V. González[i], J. Kownacki[f], E. Sanchis[i], A. Triossi[g], R. Wadsworth[l], et al.

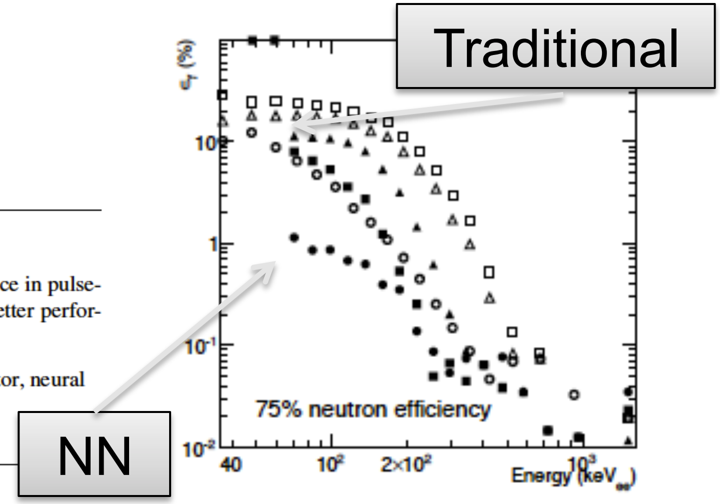
[a] *Department of Physics and Astronomy, Uppsala University, SE-75120 Uppsala, Sweden*
[b] *RIKEN Nishina Center, 2-1 Hirosawa, Wako-shi, Saitama 351-0198, Japan*
[c] *INFN Sezione di Napoli, I-80126 Napoli, Italy*
[d] *Instituto de Física Corpuscular, CSIC-Universidad de Valencia, E-46071 Valencia, Spain*
[e] *Faculty of Physics, Warsaw University of Technology, ul. Koszykowa 75, 00-662 Warszawa, Poland*
[f] *Heavy Ion Laboratory, University of Warsaw, ul. Pasteura 5A, 02-093 Warszawa, Poland*
[g] *Laboratori Nazionali di Legnaro dell'INFN, I-35020 Legnaro (Padova), Italy*
[h] *GANIL, CEA/DSAM and CNRS/IN2P3, Bd Henri Becquerel, BP 55027, F-14076 Caen Cedex 05, Francee*
[i] *Department of Electronic Engineering, Universidad de Valencia, E-46071 Valencia, Spain*
[j] *Faculty of Engineering and Natural Sciences, Istanbul Sabahattin Zaim University Istanbul, Turkey*
[k] *Nigde Universitesi, Fen-Edebiyat Falkültesi, Fizik Bölümü, Nigde, Turkey*
[l] *Department of Physics, University of York, Heslington, York, YO10 5DD, UK*

Abstract

A comparison between the two liquid scintillators BC-501A and BC-537, with respect to their performance in pulse-shape discrimination between neutrons and γ-ray, have been carried out. The results obtained show a better performance of the BC-501A scintillator, which can be explained by the larger light yield compared to BC-537.

Keywords: BC-501A, BC-537, digital pulse-shape discrimination, fast-neutron detection, liquid scintillator, neural networks
PACS: 29.40.Mc, 29.85.Ca

Pulse shape discrimination for NEDA

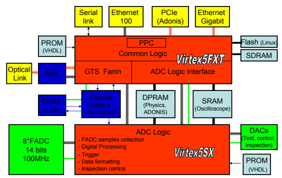


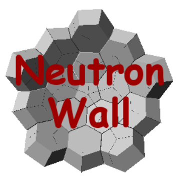
P.A. Soderstrom et al., to be submitted NIM A

Phases of NEDA

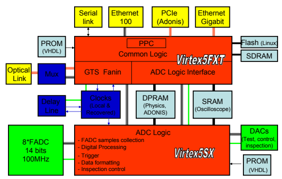
NEDA will be built in four different phases:

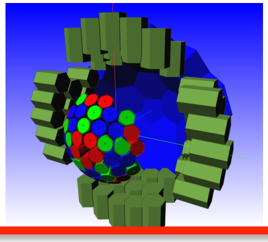
- Phase 0: Upgrade of Neutron Wall with digital electronics.





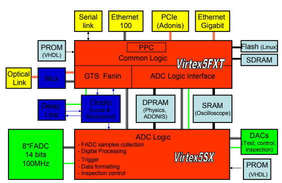
- Phase 1: Construction of 90 NEDA det. combined with NW

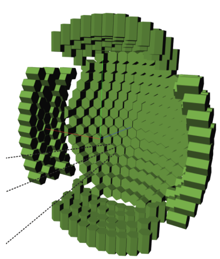




MoU

- Phase 2: Final construction of NEDA 2π – 355 detectors





- Phase 3: R&D on new material and light readout systems for a highly segmented neutron detector array.

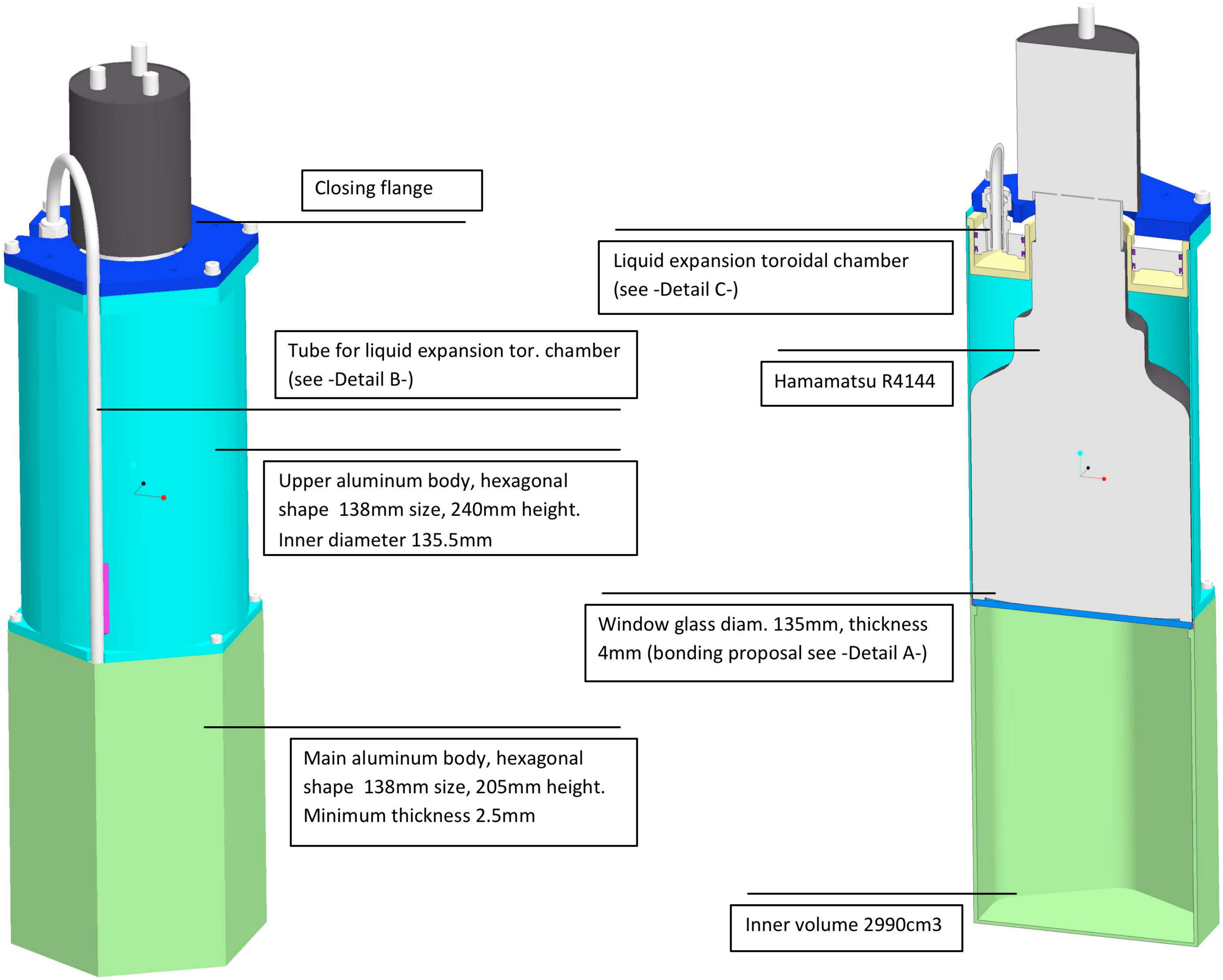
Summary

- NEDA will be a neutron detector to address the *physics of neutron-rich as well as neutron-deficient nuclei, mainly in conjunction with gamma-ray detector arrays like AGATA, GALILEO, EXOGAM2 and PARIS.*
- Exhaustive simulations (G. Jaworski et al. NIM 673 (2012) 64-72)
- Design of the first NEDA prototype, currently is being constructed
- Development of electronics in Synergie with EXOGAM2 and PARIS
- Design of the FADC and tests
- Tests BC537 and BC501A (Relative efficiency, Timing, PSA)
- NEDA will be built in phases: MoU signed March 2012.
- NEDA will be coupled to the NW+AGATA at the AGATA GANIL phase
- Strong synergies with other neutron communities: MONSTER, DESIR, NEULAND
- Creating a community of young gamma spectroscopists with experience on neutron detection.

THANKS…

Preliminary design NEDA cell

Self production



Commitment INFN capital investment

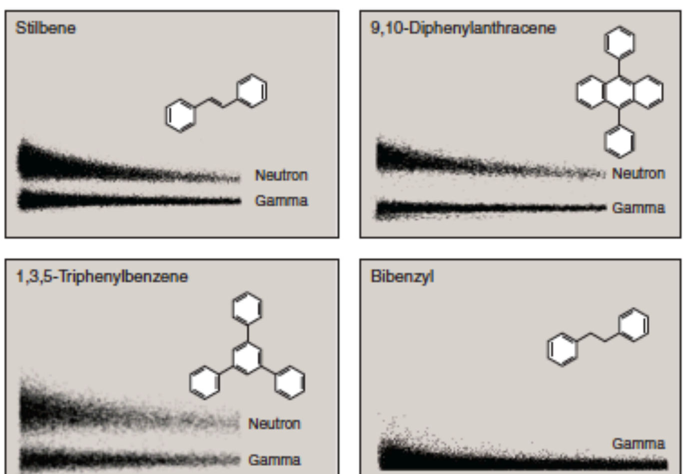
Total capital investment commited for the NEDA construction period from January 2012 to December 2015 is ~ 400 keuro

<u>Commitment for INFN 2013-2015 for 3 years → 80 keuro</u>

Divided among: LNL (GAMMA), LNS/Sezione di Catania (EXOCHIM) and Sezione Napoli (NUCL-EX)
Request within GAMMA ~ 30 keuro in 3 years
GAMMA request for 2013 ~ 8 keuro

New materials for neutron detection

In the 1990s, Natalia Zaitseva developed a rapid-growth technique for producing very large crystals in record-shattering time. She now leads a team that grows organic crystals for use in fast-neutron detectors.



EJ-299-33 PSD PLASTIC SCINTILLATOR
PROVISIONAL DATA SHEET

This revolutionary plastic scintillator possesses pulse shape discrimination properties enabling the separation of gamma and fast neutron signals on the basis of their timing characteristics using conventional PSD electronics systems. It is, at this time, still under development in regard to optimized composition and manufacturing procedures. Cylinders up 51mm diameter x 76mm long have been manufactured.

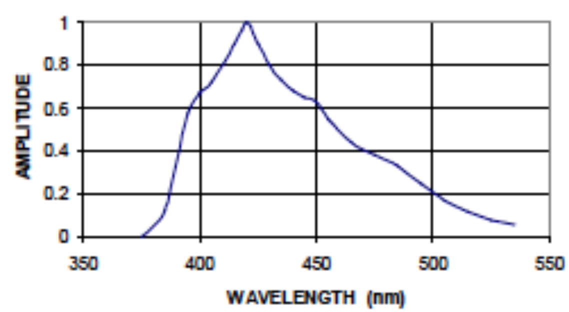
The following physical properties are representative of the more successful formulas.

<u>Physical and Scintillation Constants</u>:

Light Output, % Anthracene	56
Scintillation Efficiency, photons/1 MeV e^-	8,600
Wavelength of Max. Emission, nm	420
No. of H Atoms per cm^3, x 10^{22}	5.13
No. of C Atoms per cm^3, x 10^{22}	4.86
No. of Electrons per cm^3, x 10^{23}	3.55
Density, g/cc:	1.08

Chemical Compatibility: Is attacked by aromatic solvents, chlorinated solvents, ketones, solvent bonding cements, etc. It is stable in water, dilute acids and alkalis, lower alcohols and silicone greases. It is safe to use most epoxies and "super glues" with EJ-299-33.

EJ-299-33 EMISSION SPECTRUM



Cost for NEDA – Phase 1 and 2

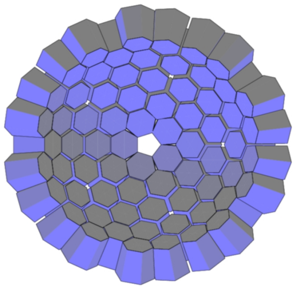
MoU

Capital costs for *NEDA*

Cost (k€)	2009-2011	2012-2015	Full NEDA
Detectors			
Unitary cell	12.5[(1)]	1.0 x 90	1.0 x 355
Voltage Divider + Photo Multiplier		2.0 x 90	2.0 x 355
Electronics	15[(2)]		
ADC mezzanines (4 channel)	20[(3)]	0.6 x 25	0.6 x 89
Carrier (16 channel)		5.0 x 7	5.0 x 23
GTS/LINCO2	1.7 x 9[(4)]	3	13
Data acquisition			
Computing nodes (each serves 32 mezzanines)		2.5 x 2	2.5 x 8
Others			
Mechanics		50	50
HDMI cables/Optical Fibers		4	15
TOTAL	62.8	382	1331.4

(1) This amount corresponds to two different prototypes, based on two different liquid scintillators, BC501A and BC537 (deuterated).
(2) This amount corresponds to commercial digital electronics for the test of the detectors.
(3) This amount corresponds to the R&D of the Flash ADC mezzanines.
(4) Already purchased by GANIL.

BC501 vs. BC537 response



DESCANT

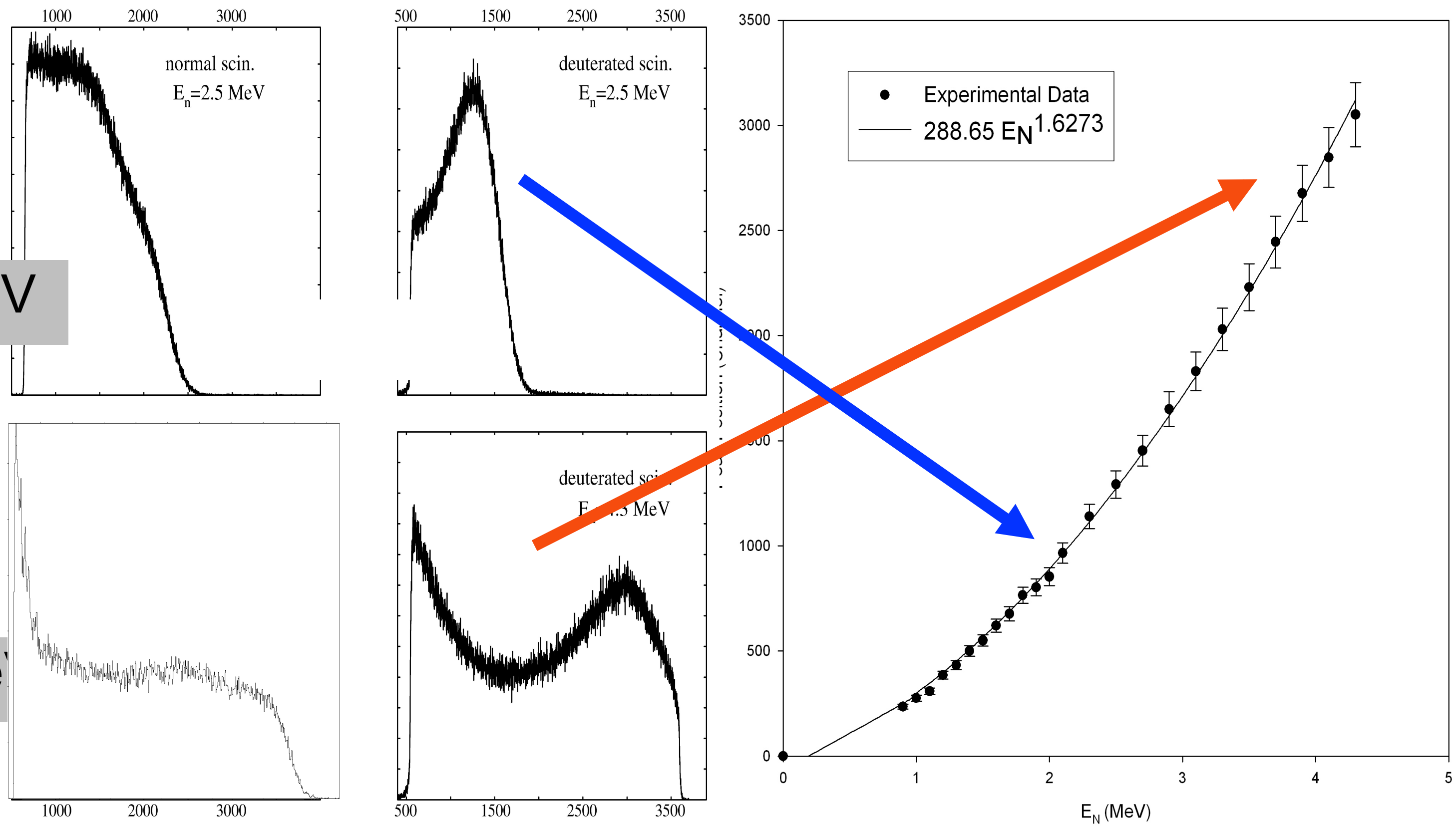
E_n = 2.5 MeV

E_n = 4.3 Me

BC501

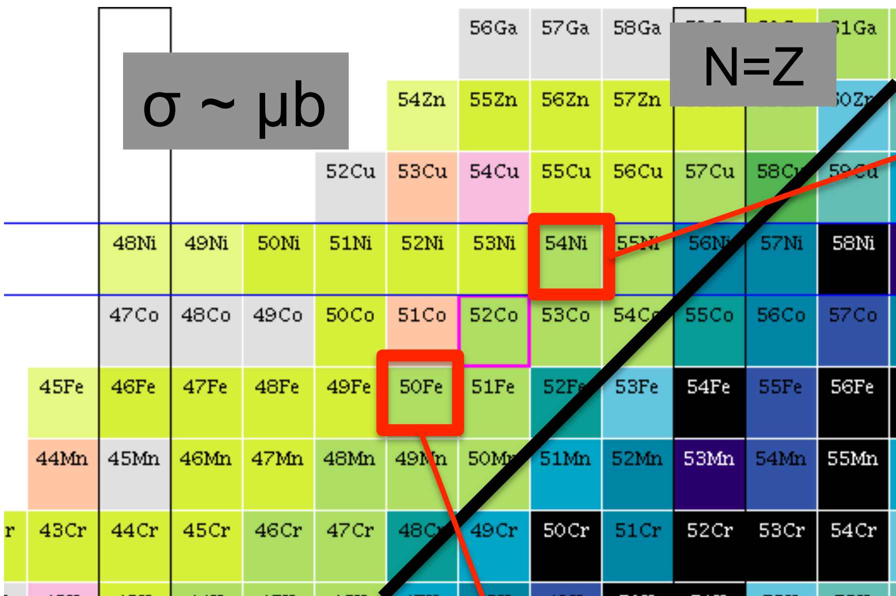
BC537

Depth 2.5cm

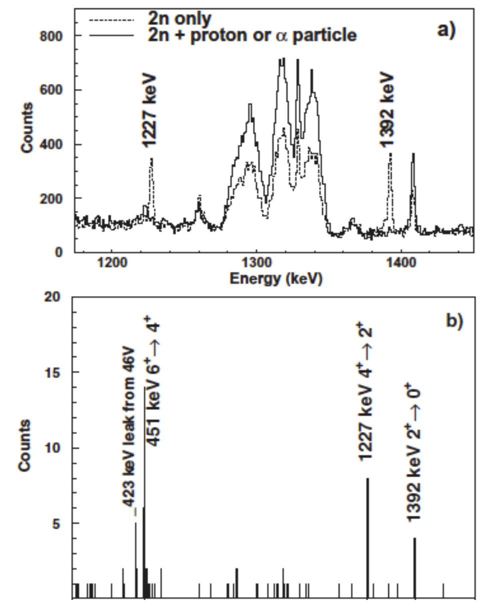


Courtesy of P. Garrett, University of Guelph.

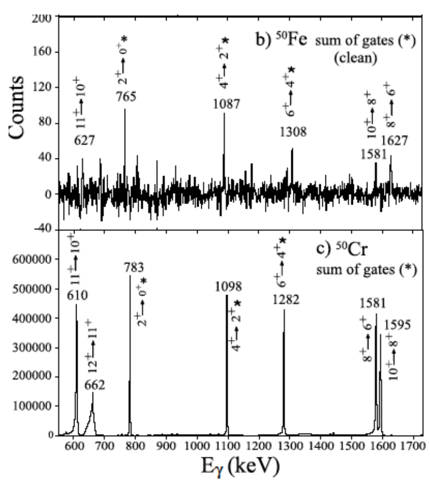
Neutron Wall: N=Z-2



$^{24}Mg(^{32}S,2n)^{54}Ni$



A. Gadea et al., PRL97, 152501 (2006)



$^{28}Si(^{28}Si,2n\alpha)^{50}Fe$

S. Lenzi et al., PRL87, 122501 (2001)

Aim and strategy of NEDA

Aim

- Develop a neutron detector array to be used with GALILEO, AGATA, EXOGAM2, PARIS, etc., for experiments with high intensity stable and radioactive ions beams

The array should have:

- Increased neutron detection efficiency compared to Neutron Wall: $\varepsilon(1n) \approx 40\%$ (20-25%), $\varepsilon(2n) \approx 6\%$ (1-2%).
- Excellent neutron-gamma discrimination.
- Capability to run at much higher count rates than with the Neutron Wall.
- Cope with large neutron multiplicities in reactions with neutron-rich RIBs.
- Improved neutron energy resolution for reaction studies.

Strategy

- Optimise size of detector units, distance to target, geometry of the array, . . .
- Investigate other detector materials than ordinary liquid scintillator.
- Adopt digital electronics which are fully compatible with AGATA, GALILEO, EXOGAM2, PARIS . . .
- Develop advanced on-line and off-line algorithms for neutron-gamma discrimination, neutron scattering rejection.

Physics with NEDA

NEDA will address the physics of neutron-rich as well as neutron-deficient nuclei, mainly in conjunction with gamma-ray detector arrays like GALILEO, AGATA, EXOGAM2 and PARIS.

- **Nuclear Structure**
  - Probe of the T=0 correlations in N=Z nuclei: the structure beyond ^{92}Pd (Uppsala, LNL, Padova, GANIL, Stockholm, York)
  - Coulomb Energy Differences in isobaric multiplets: T=0 versus T=1 states (Warsaw, LNL, Padova, GANIL, York)
  - Coulomb Energy Differences and Nuclear Shapes (York, Padova, GANIL)
  - Low-lying collective modes in proton rich nuclei (Valencia, Krakow, Istanbul, Milano, LNL, Padova)
- **Nuclear Astrophysics**
  - Element abundances in the Inhomogeneous Big Bang Model (Weizmann, Soreq, LNS, Sez. Catania, GANIL)
  - Isospin effects on the symmetry energy and stellar collapse (Naples, Debrecen, LNL, LNS, Sez. Catania, Florence)
- **Nuclear Reactions**
  - Level densities of neutron-rich nuclei (Naples, LNL, LNS, Sez. Catania, Florence)
  - Fission dynamics of neutron-rich intermediate fissility systems (Naples, Debrecen, LNL, LNS, Sez. Catania, GANIL)