NEDA: NEutron Detector Array for Spectroscopy Studies

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On behalf of the NEDA collaboration

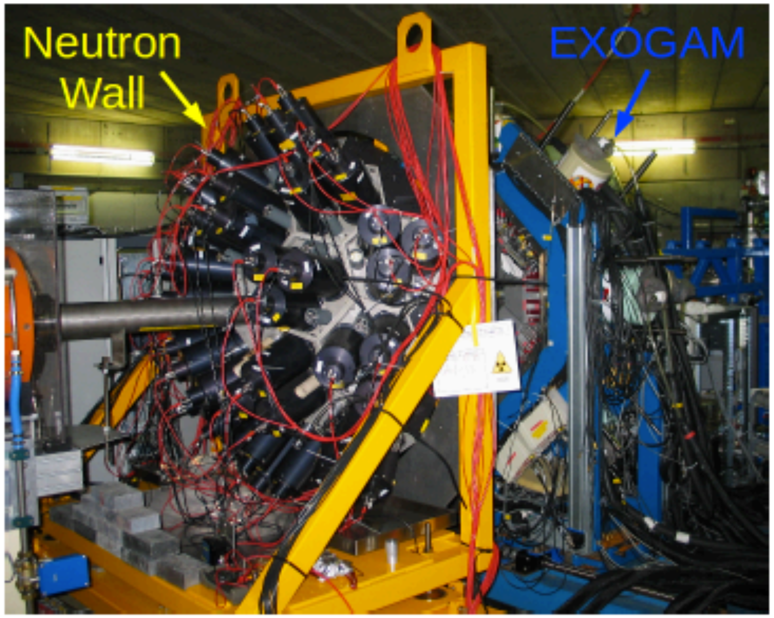
Nuclear Structure Physics with Advanced Gamma-Detector Arrays

Padova, June 10 -12, 2013

Neutron Wall

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

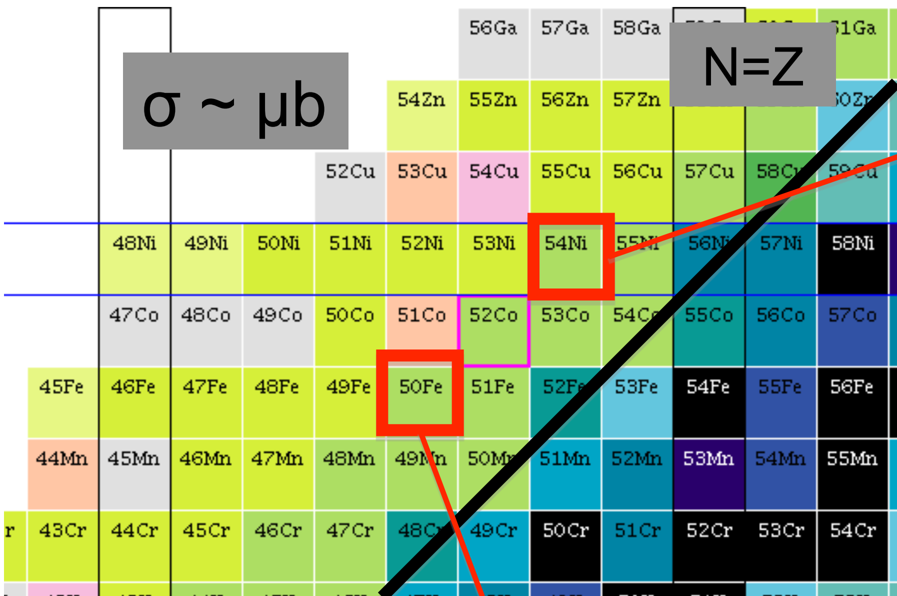
Combined with charged particle detector arrays (EUCLIDES, DIAMANT, CUP, ...).



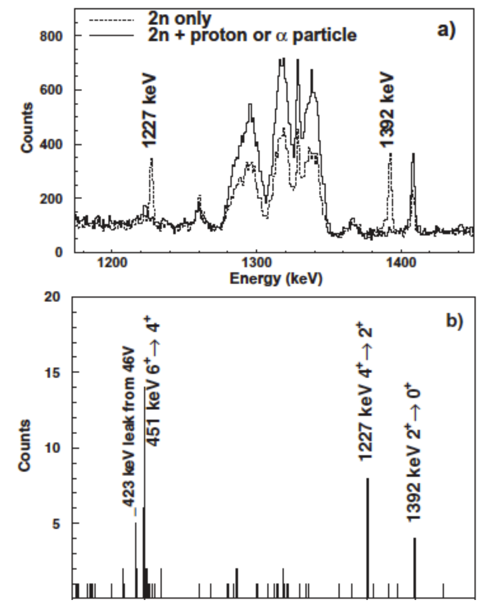
GANIL home base since 2005.

Four experimental campaigns at GANIL with EXOGAM + DIAMANT and other detectors

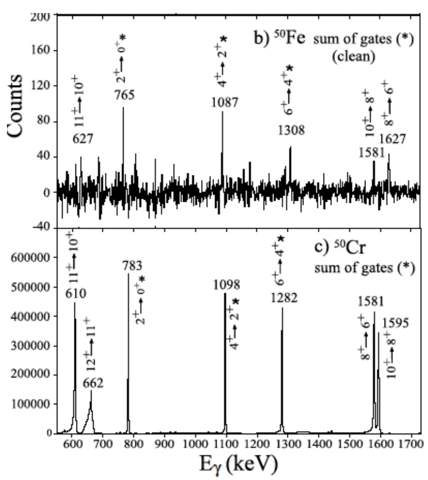
Neutron Wall: N=Z-2



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



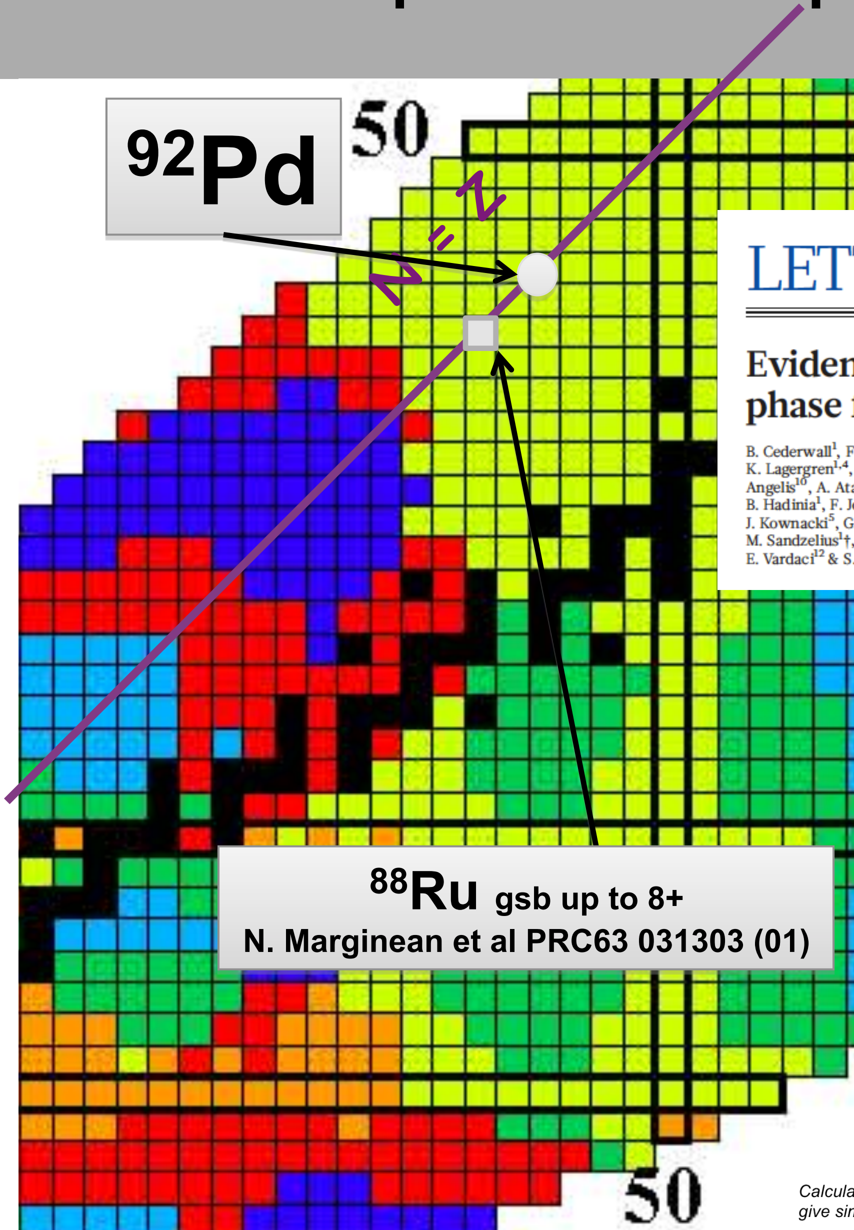
A. Gadea et al., PRL97, 152501 (2006)



^{28}Si(^{28}Si,2nα)^{50}Fe

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

In beam spectroscopy of ^{92}Pd



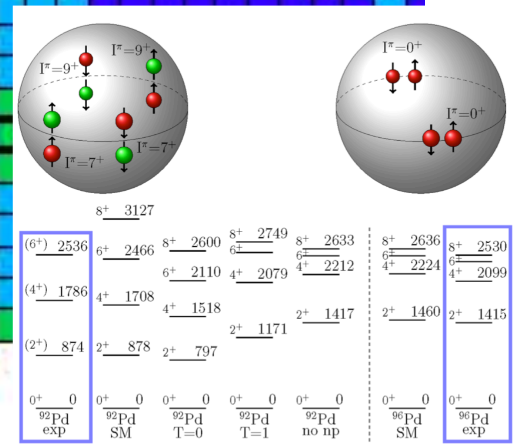
LETTER

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]

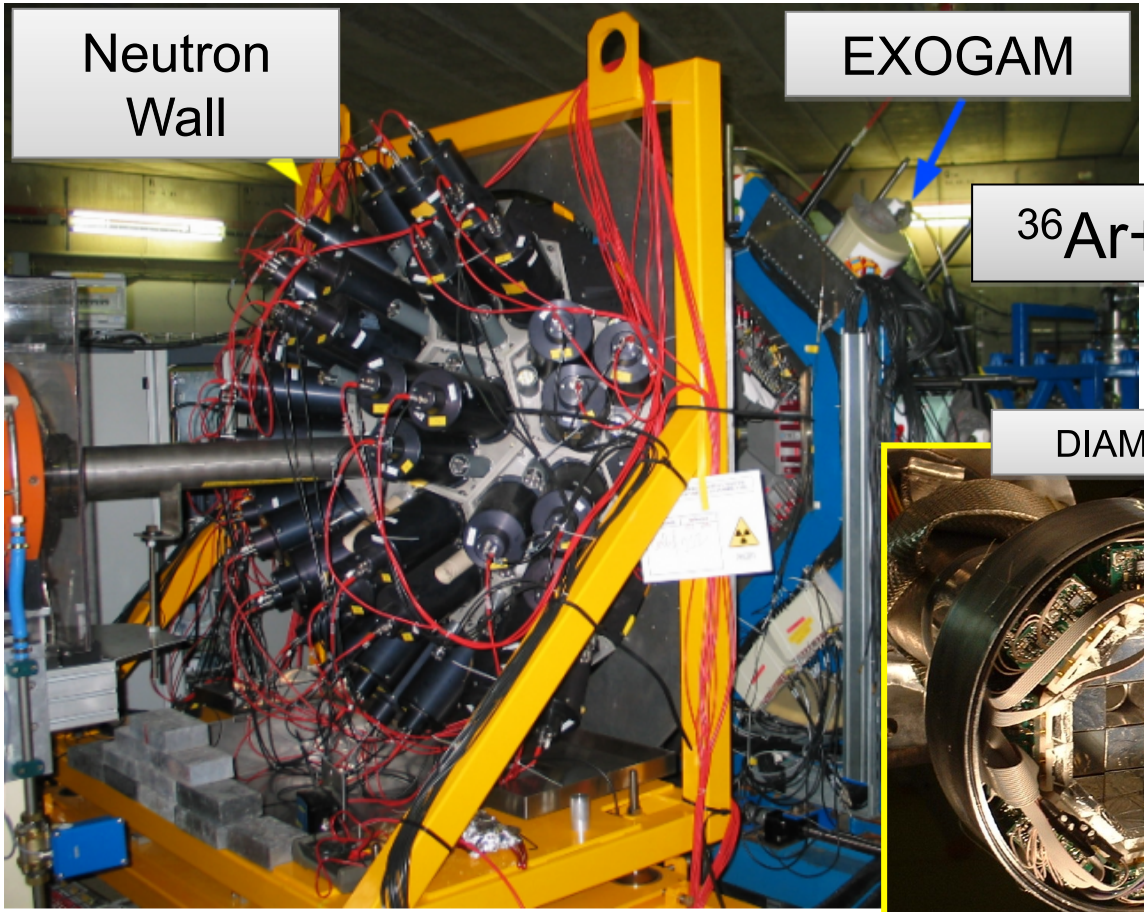
Nature vol. 469 (2011)



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

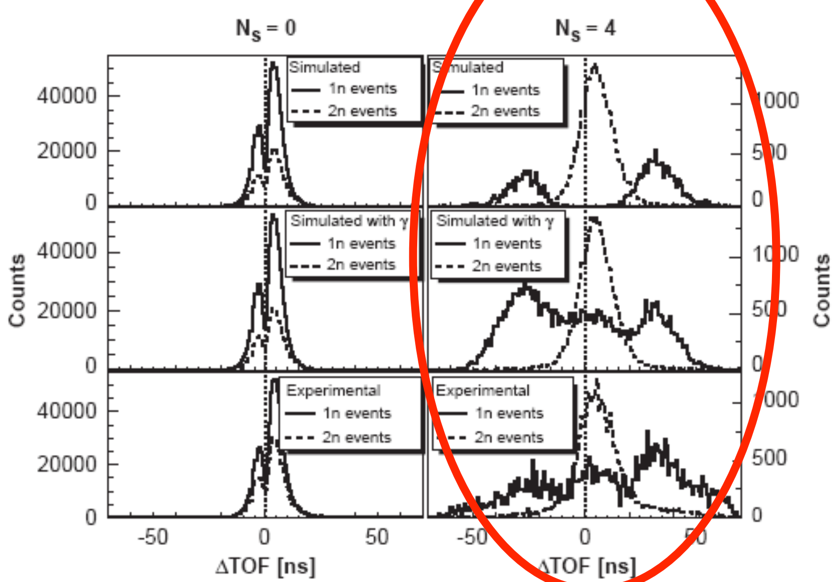
Experimental approach



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

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

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 dismiss in the analysis and the efficiency decreases 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.

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**: ε(1n) ≈ 40% (20-25%), ε(2n) ≈ 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 be an ancillary detector of AGATA and gamma-ray arrays such GALILEO, EXOGAM2, PARIS, etc. It will address the physics of neutron-rich as well as neutron-deficient nuclei.

- **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)

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

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]

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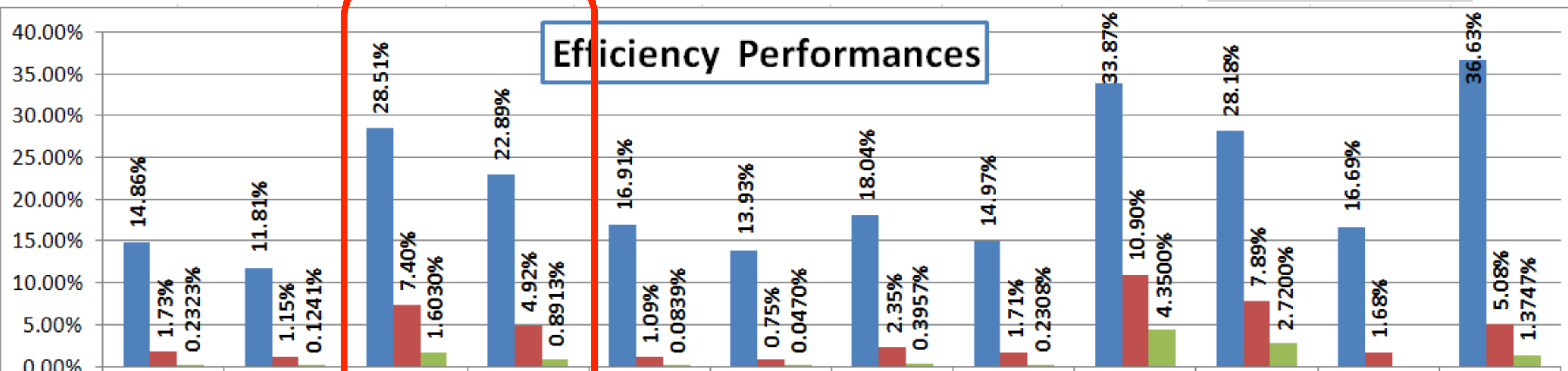
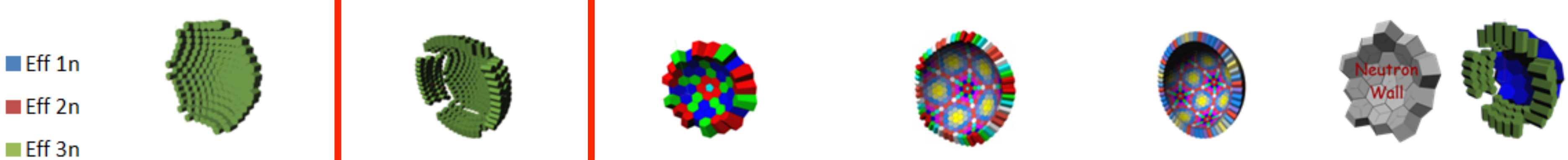
G. Jaworski et al., NIM A 673 (2012) 64-72

Overview: Efficiency & geometries

^{252}Cf



M	BC501A	BC537	BC501A	BC537	BC501A	BC537	BC501A	BC537	BC501A	BC537	BC501A	BC501A
Ω	0.92		1.88		1		1		2		1	~2
AV	3		3		4.5		2		2		3.2 / 1.1	3 / 3.2 / 1.1
V	489		1065		202.5		652		1212		149.5	317.5
N	163		355		45		326		606		50	56 + 50
R	1m		1m		0.5 m		1m		1m		0.51 m	0.5 m
	Staircase		Staircase 2pi		Spherical N180		Spherical 1m1pi		Spherical 1m2pi		Nwall	NEDA + NW

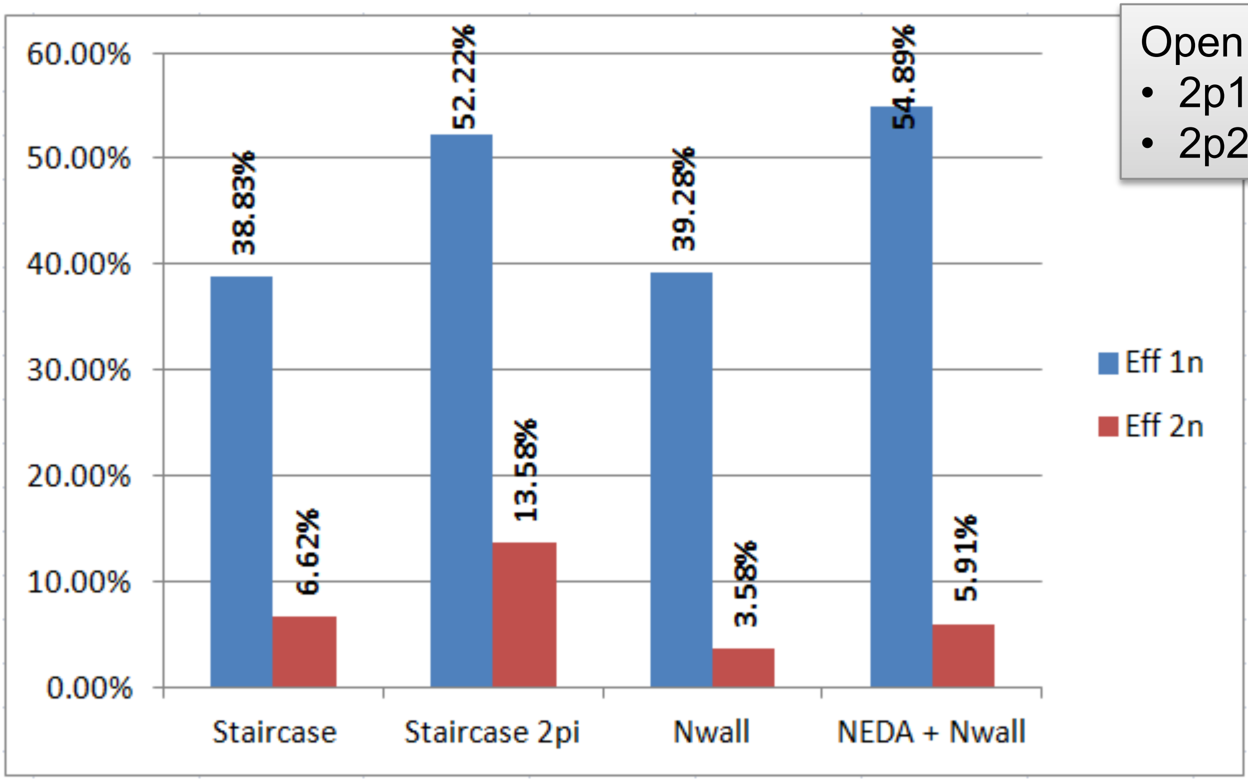


Overview: Efficiency & geometries

$^{58}Ni + ^{56}Fe$

E_{lab} = 220 MeV

Open channels:
- 2p1n
- 2p2n



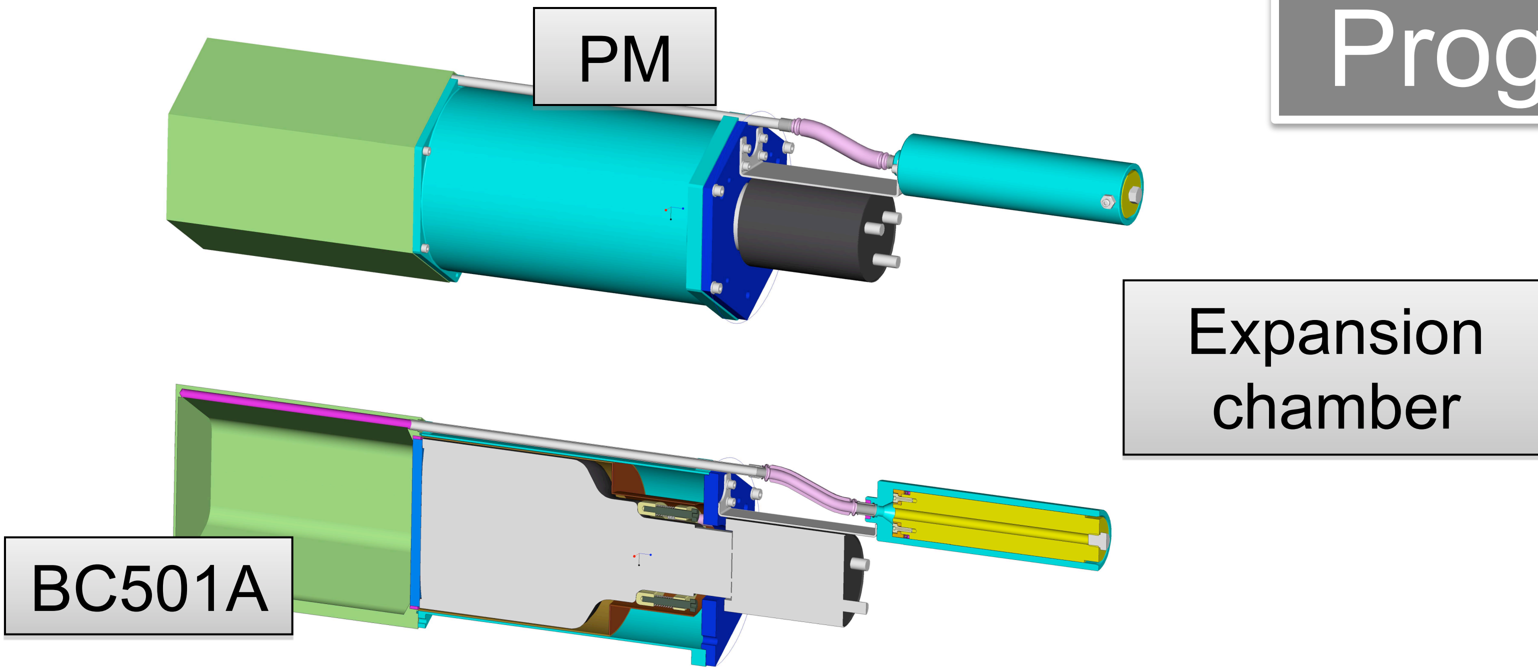
Event generator by A. Di Nitto, using PACE2_Na97

The code is still being developed

Design of the NEDA cells

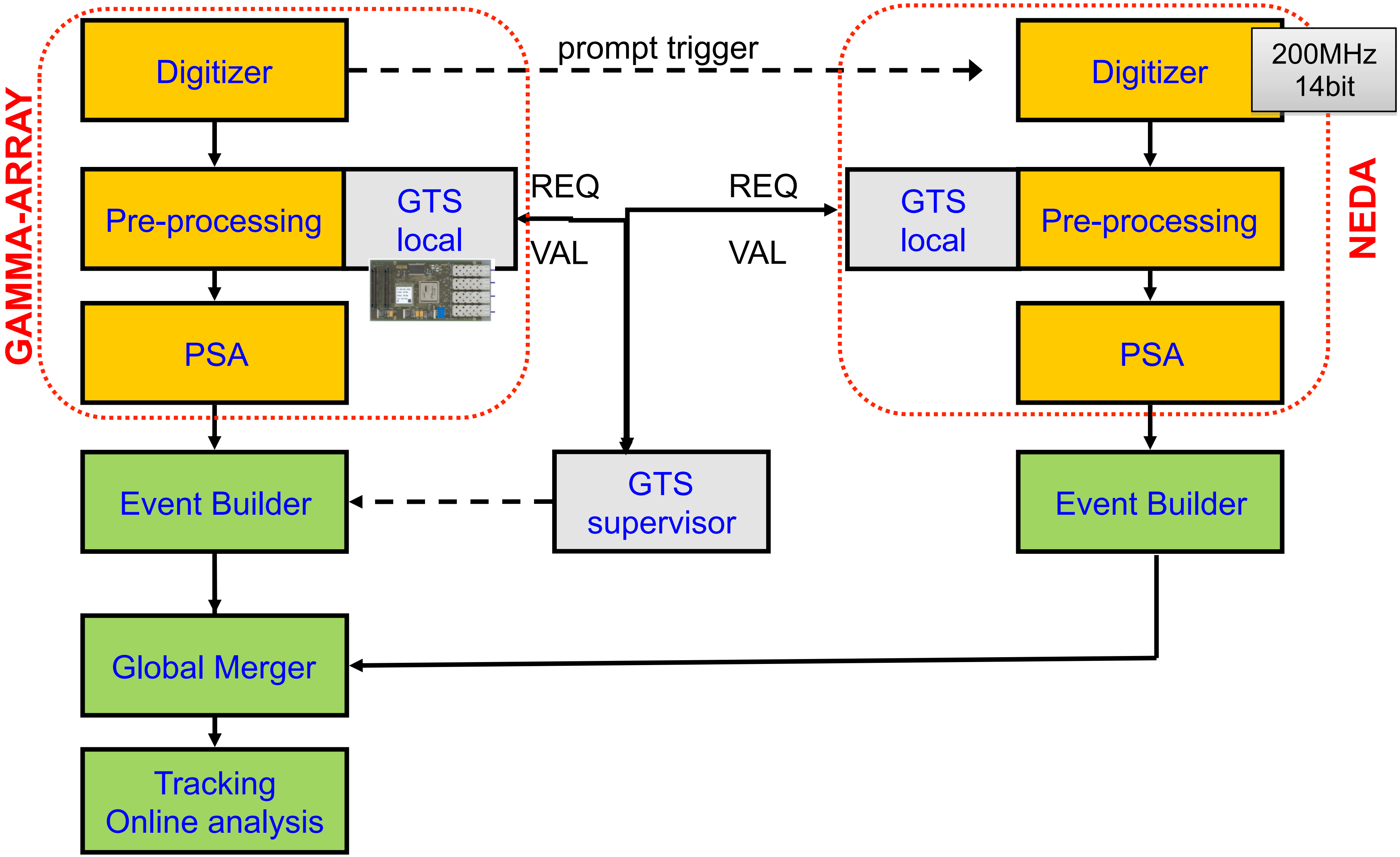
Self production

Design in Progress

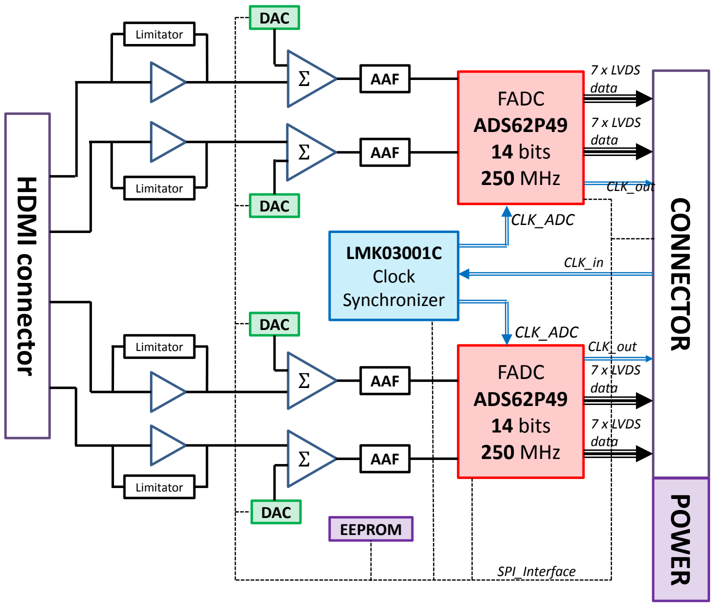


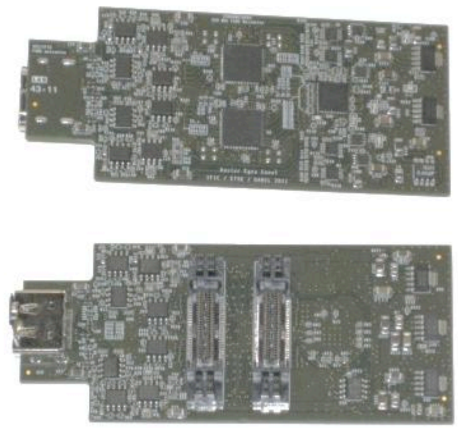
The prototype has been designed to be as much compact and economic as possible. The hexagonal cell is ~3L volume with a side-to-side distance of 146 mm designed in Al alloy 2011 (inner distance is 133 mm), 20 cm tall. The case fits 1mm mu-metal shield.

NEDA coupled to GALILEO/AGATA/EXOGAM2/PARIS



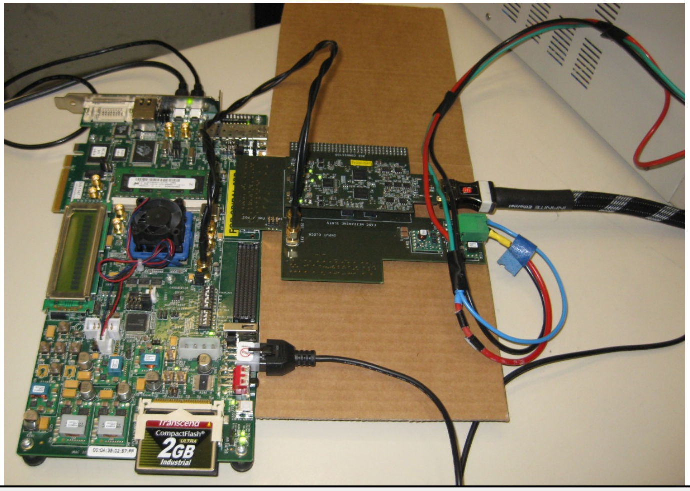
Design of FADC for NEDA/EXOGAM2



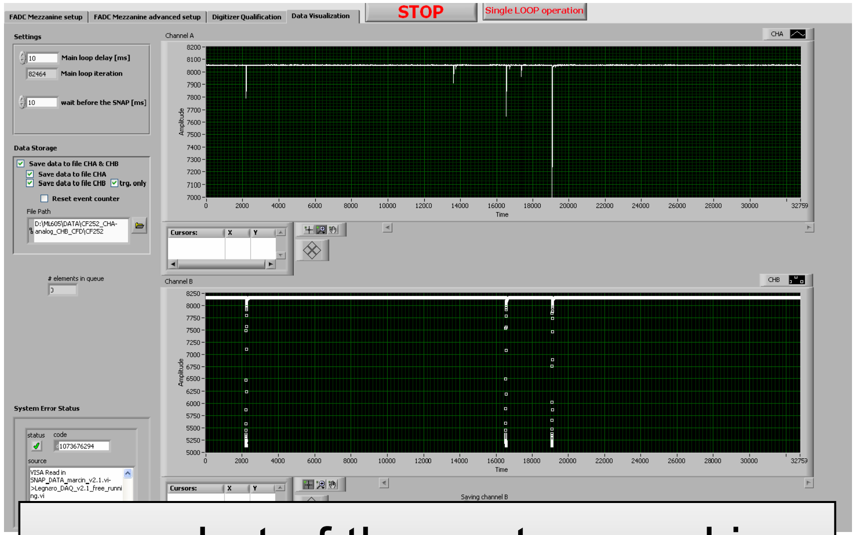


The FADC uses the ADS62P49 flash ADC, sampled by a low-jitter clock cleaner LMK03001C and a full differential analog stage based on the AD8139 amplifier driving the signal in an optimal way. An HDMI cable will be used to transfer the signals from the detector to the FADC.

Tests of the FADC for NEDA/EXOGAM2



A test bench has been designed



snapshot of the system working with a real detector.

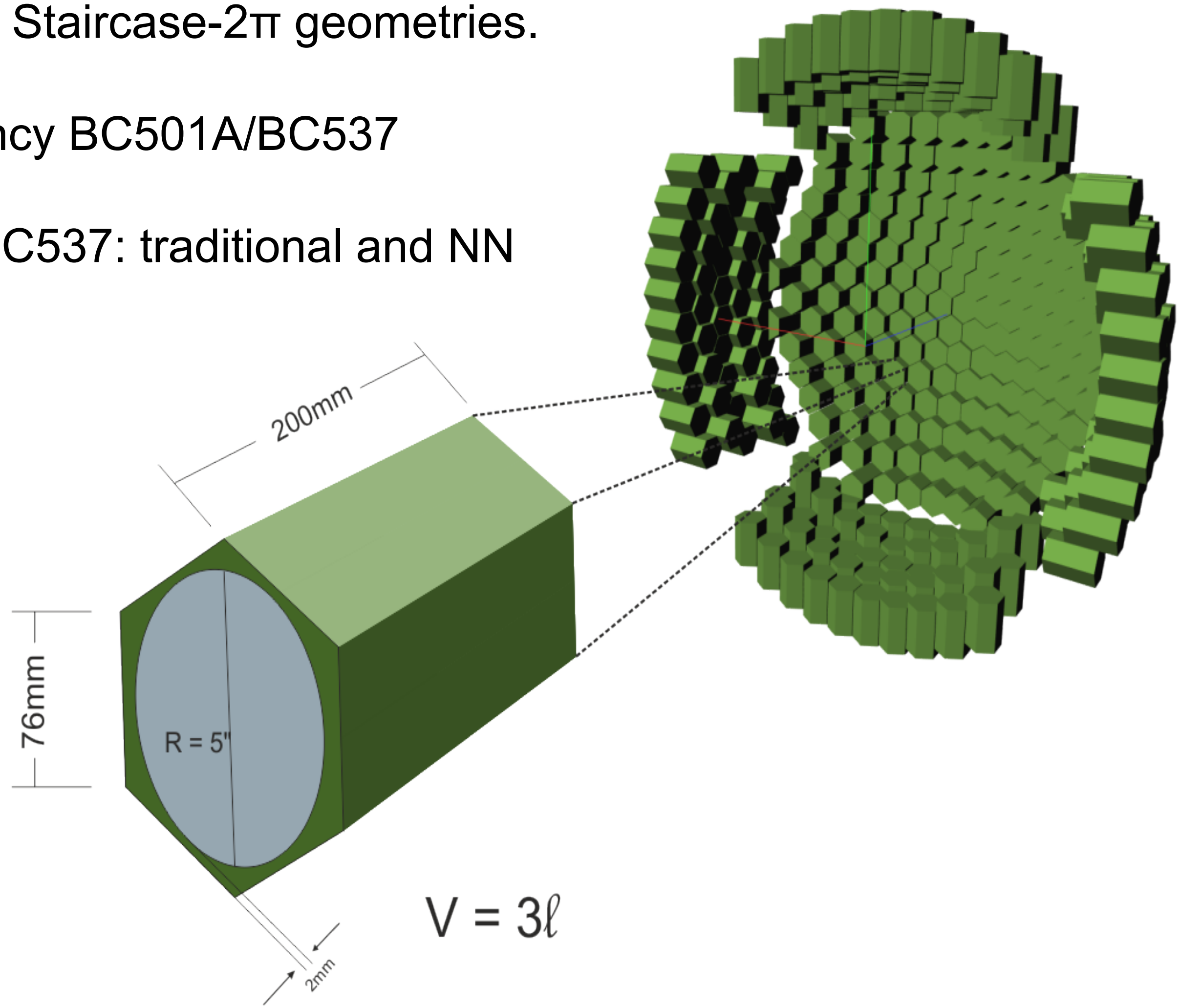
Measurements, such as timing and gamma-neutron discrimination have been performed at LNL in december 2012 using a Cf source.

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

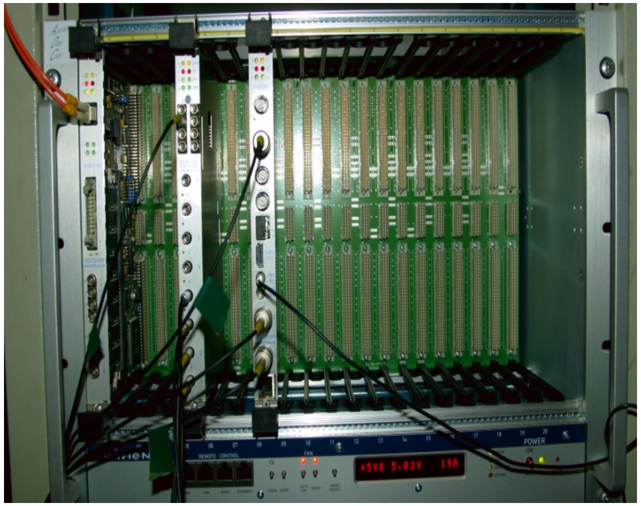


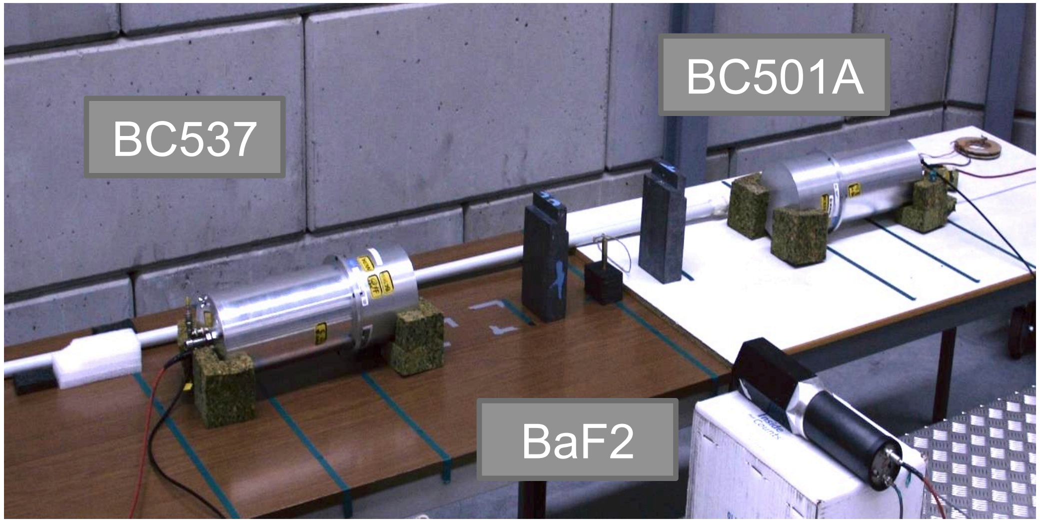
NEDA test setup

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

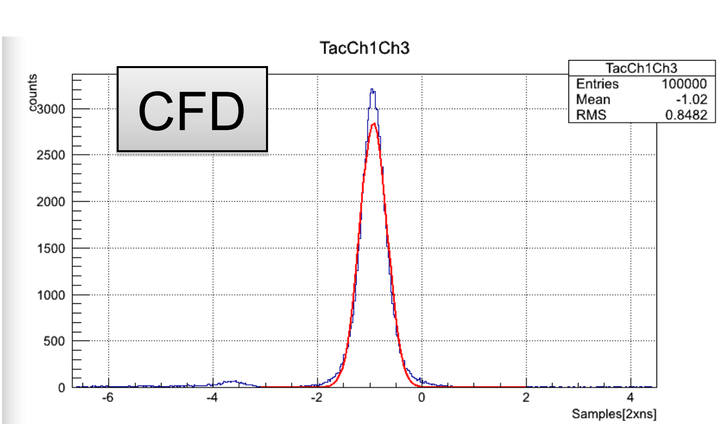


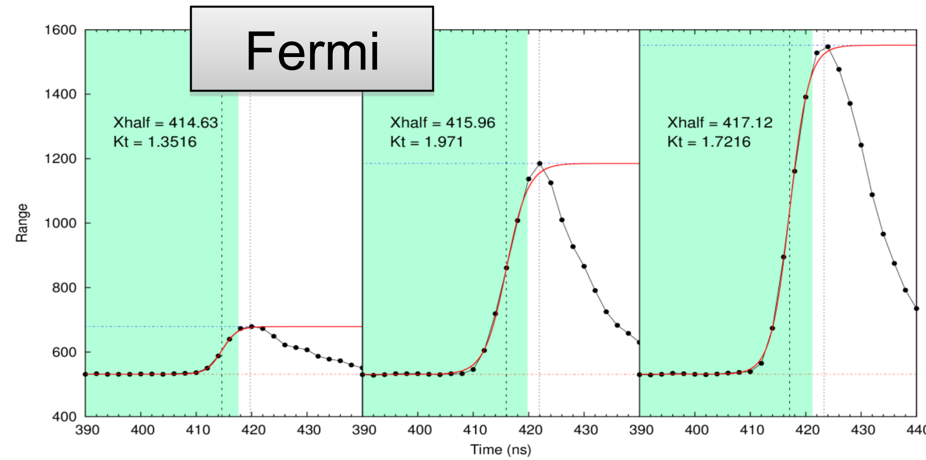


Tests: Preliminary timing 500–200MHz

We are currently working on two different algorithms for digital timing:

- CFD (Constant Fraction Method) method with a cubic interpolation of the ZCO (Zero Cross Over)
- fit of the rising time with a Fermi-like function.





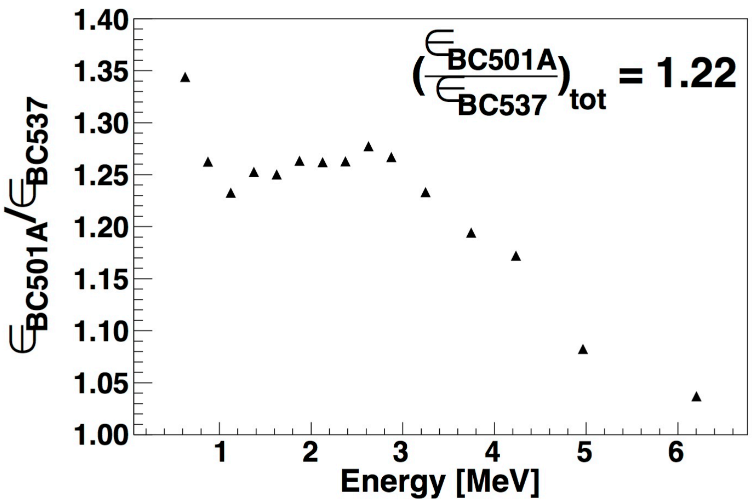
FWHM = 1.23 for CFD at 500 MHz.
FWHM = 2.03 for CFD at 200 MHz.

FWHM = 1.32 for CFD at 500 MHz.
FWHM = to be done at 200 MHz but very promising

The time resolution is obtained for the SuperBialkalyne PMT with a ^{60}Co source and for two frequencies 500 MHz (the nominal) and 200 MHz (final NEDA one)

Tests: Relative efficiency BC501/BC537

Originally two types of liquid scintillator: BC501A (proton-based) or BC537 (deuteron-based) were considered for NEDA. The proton-based scintillator is successfully used in existing neutron detection arrays like Neutron Wall. **Currently NEDA will be done with BC501A**



Preliminary relative neutron detection efficiency of two scintillators as a function of incoming neutron energy. In general proton-based scintillator is 22% more efficient.

Tests: Preliminary Cross-Talk Performance

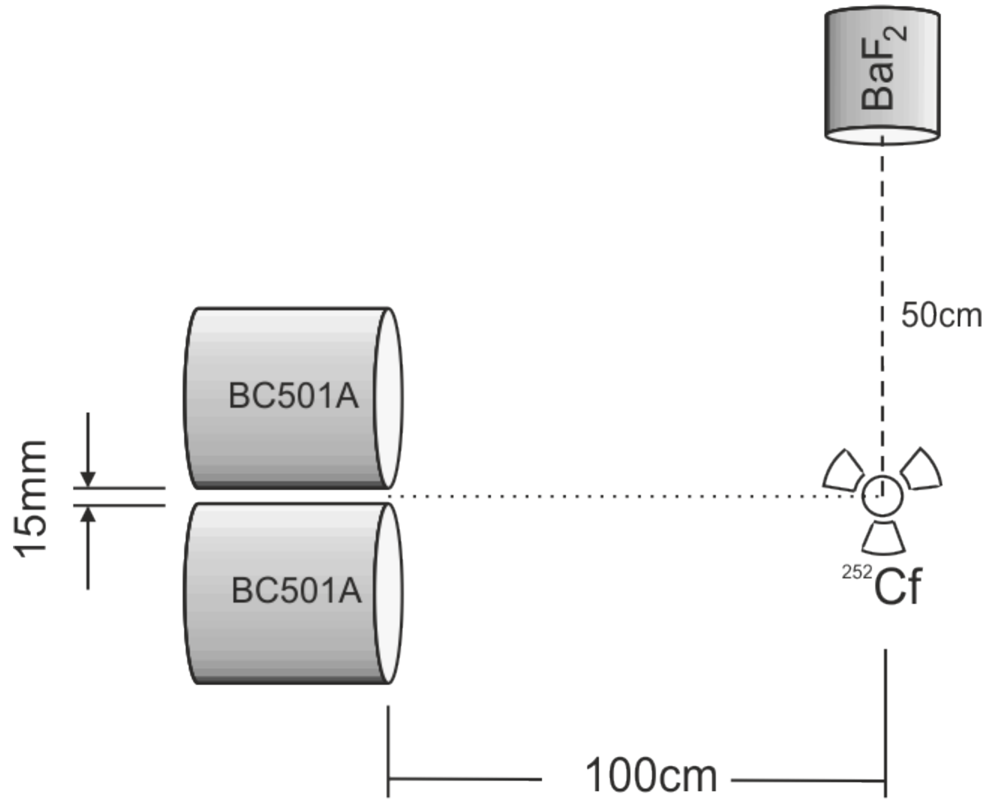
Preliminary

A_2 : Number of events fired both detectors
$A_{\geq 1}$: Number of events fired at least one detector

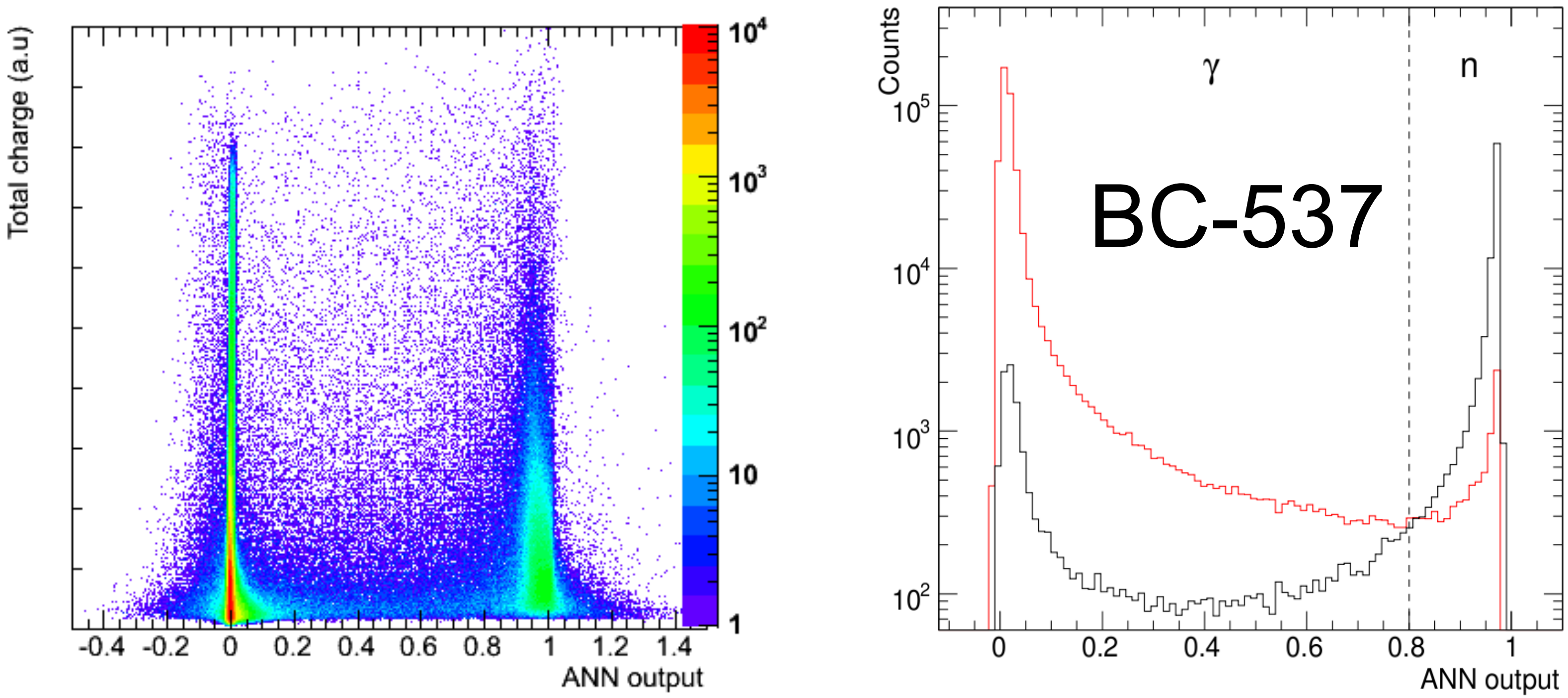
Cross-talk probability :

$$P_{1n \to 2n} = \frac{A_2}{A_{\geq 1}}$$

Electronics	X-talk
Analog	4.5 ‰
Digital	4.01 ‰



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

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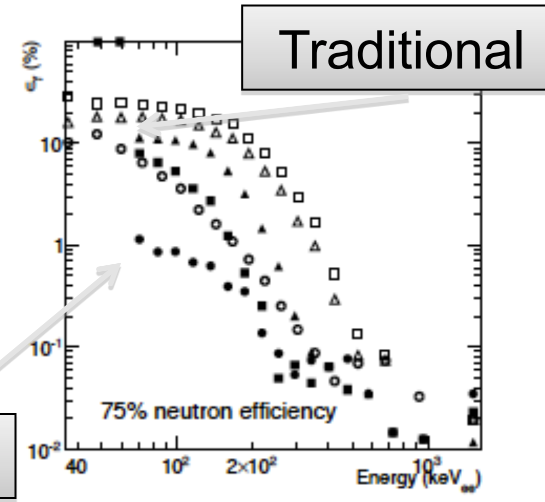
Abstract

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

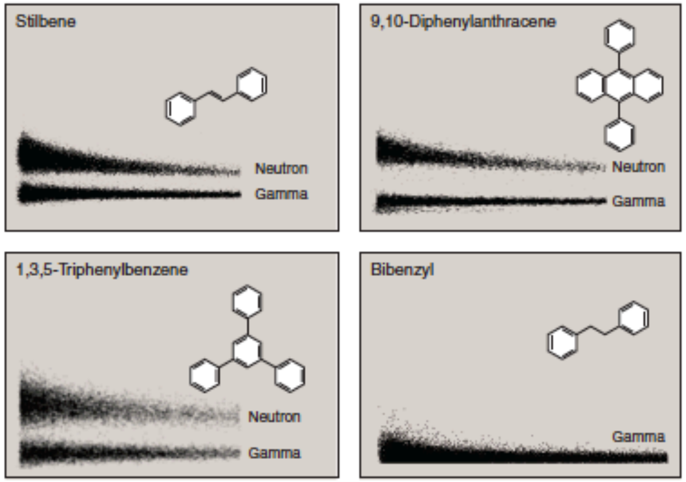
Pulse shape discrimination for NEDA



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

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

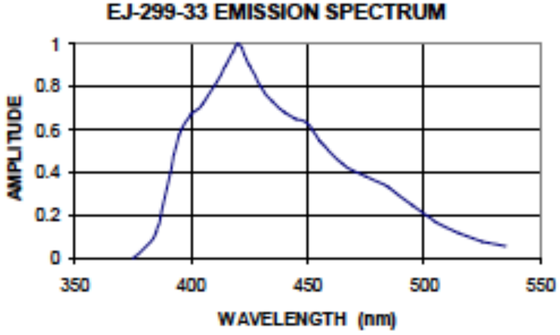
This revolutionary plastic scintillator possesses pulse shape discrimination properties enabling the separation of gamma and fast neutron signals on the basis of their timing characteristics using conventional PSD electronics systems. It is, at this time, still under development in regard to optimized 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>:

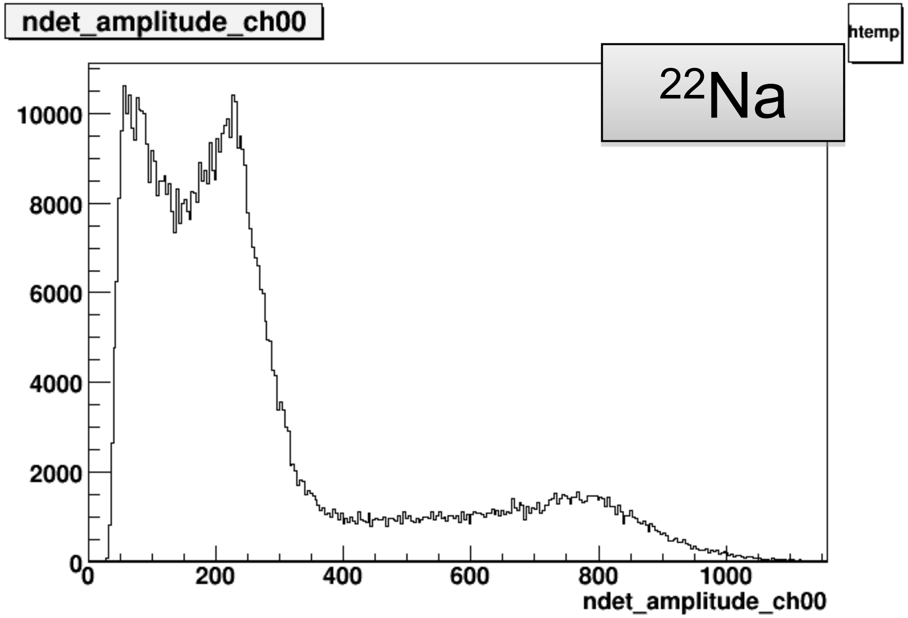
Light Output, % Anthracene	56
Scintillation Efficiency, photons/1 MeV e^-	8,600
Wavelength of Max. Emission, nm	420
No. of H Atoms per cm^3, x 10^{22}	5.13
No. of C Atoms per cm^3, x 10^{22}	4.86
No. of Electrons per cm^3, x 10^{23}	3.55
Density, g/cc:	1.08

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.



Tests of new material at LNL EJ299

The new scintillator EJ299 3''x3'' is being tested at LNL. It was provided by SCIONIX with a ETL PMT already mounted.



Preliminary results are obtained that for the moment are kept confidential

Collaboration

J. Agramunt Ros, G. de Angelis, M. Clement, G. de France, A. Di Nitto, J. Egea, N. Erduran, S. Erturk, E. Farnea, A. Gadea, V. Gonzalez, T. Hüyük, G. Jaworski, J. Nyberg, M. Palacz, B. Roeder, P.-A. Söderström, E. Sanchis, R. Tarnowski, A. Triossi, R. Wadsworth, J.J.Valiente Dobon

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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 being constructed
- Development of electronics in synergy 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
- Test of new materials EJ299-33
- Creating a community of young gamma spectroscopists with experience on neutron detection.

Thank you for your attention!