Status of the NEDA (NEutron Detector Array) project

A.Gadea (IFIC, Valencia)

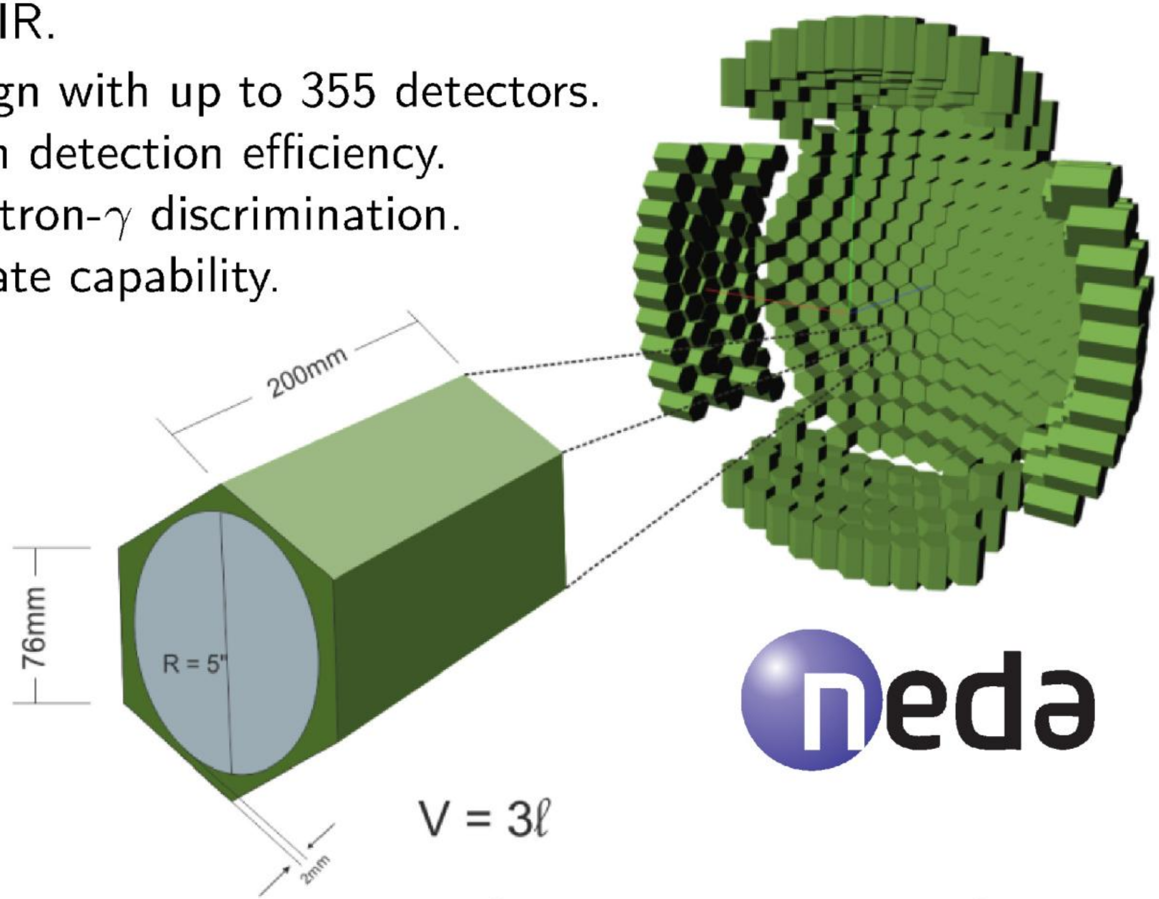
on behalf of the NEDA collaboration

Compact high-efficiency neutron detector array to be coupled with large Ge arrays as AGATA.
NEDA R&D largely financed by SPIRAL2PP

EGAN2014, GSI Darmstadt 23rd -26th June 2014

The NEDA (NEutron Detector Array)

- 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-γ discrimination.
- High count-rate capability.



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

Neutron Wall

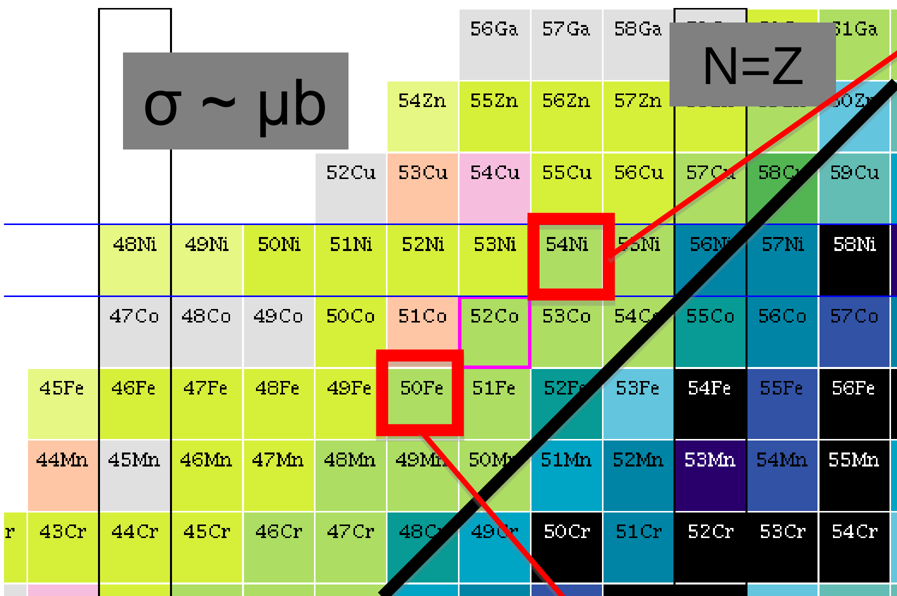
The Neutron Detector Array for EUROBALL

Experiments performed with EUROBALL at LNL in 1998, at IReS in 2001-2003 and at GANIL with EXOGAM since 2005. Coupled with LCP detectors as EUCLIDES, DIAMANT, CUP…

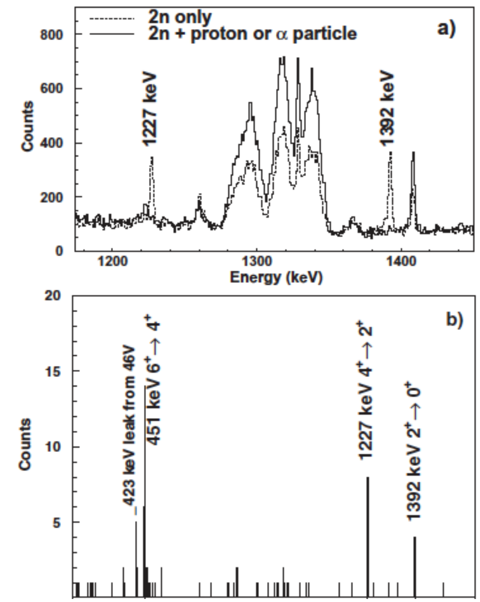
GANIL is the home base of Neutron-Wall since 2005
4 experimental campaigns performed at GANIL with EXOGAM DIAMANT, and other detectors.

Neutron Wall: N=Z-2

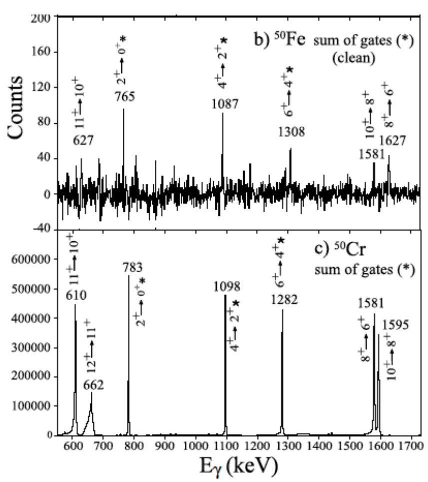
$^{24}Mg(^{32}S,2n)^{54}Ni$



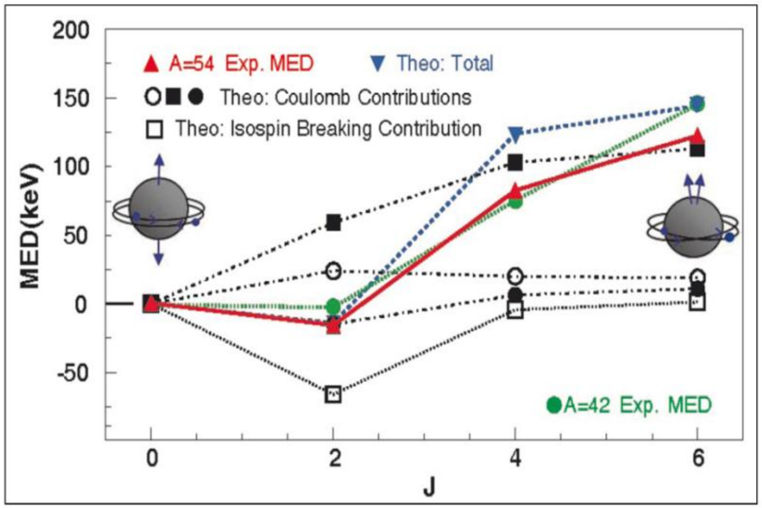
A. Gadea et al.
PRL97, 15250
(2006)



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

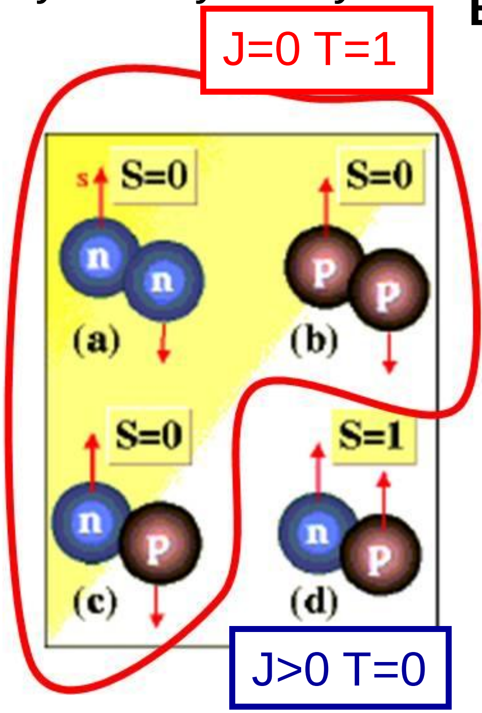


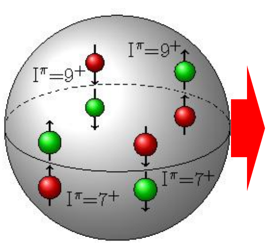
S. Lenzi et al.,
PRL87,
122501 (2001)



Isoscalar (T=0) proton-neutron pairing

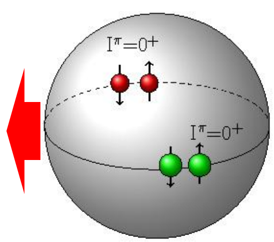
The Spin-Isospin symmetry family





T=0 pair Condensate

T=1 pair Condensate



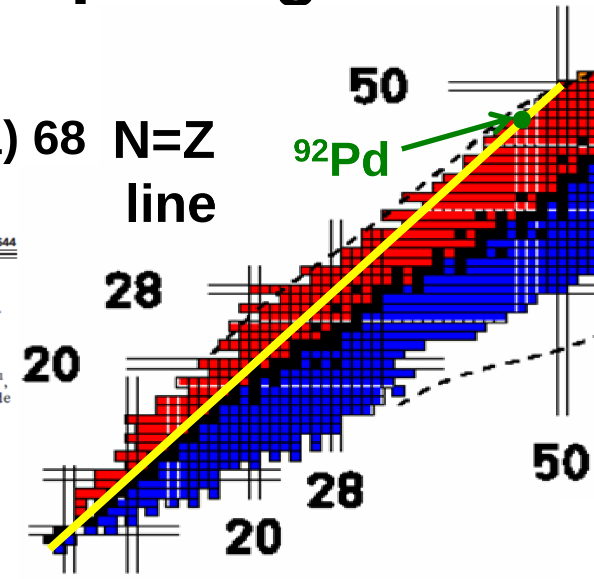
B. Cederwall et al., Nature 469 (2011) 68

LETTER

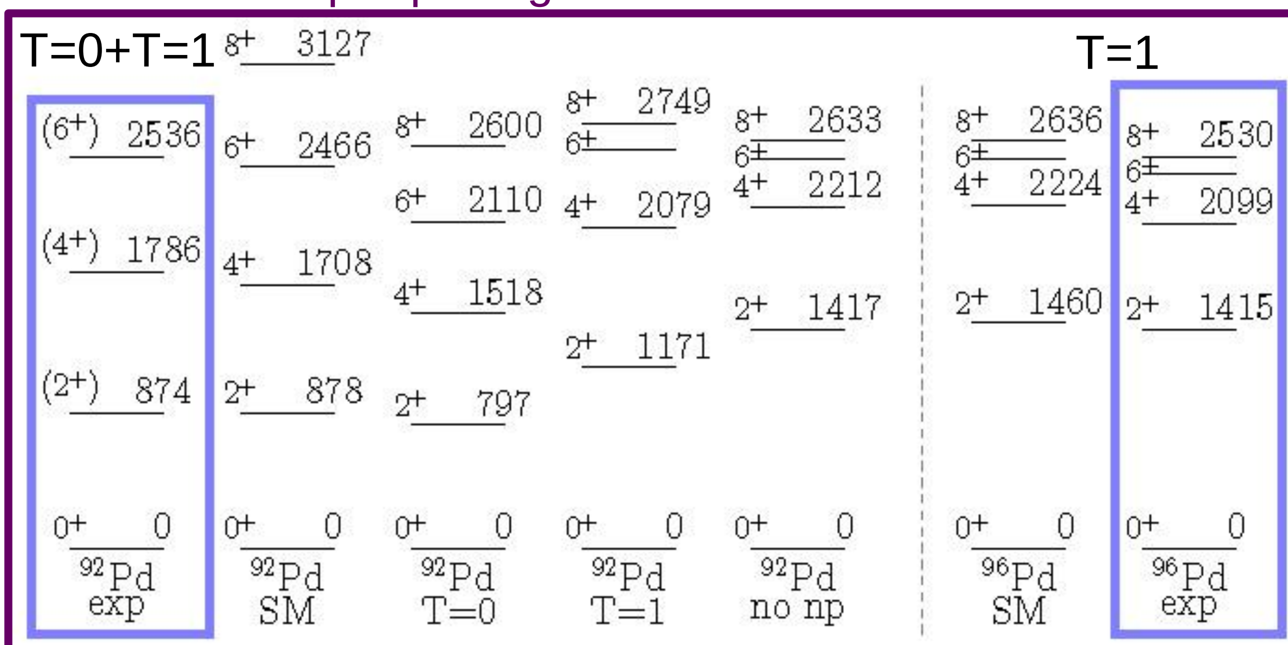
doi:10.1038/nature09644

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

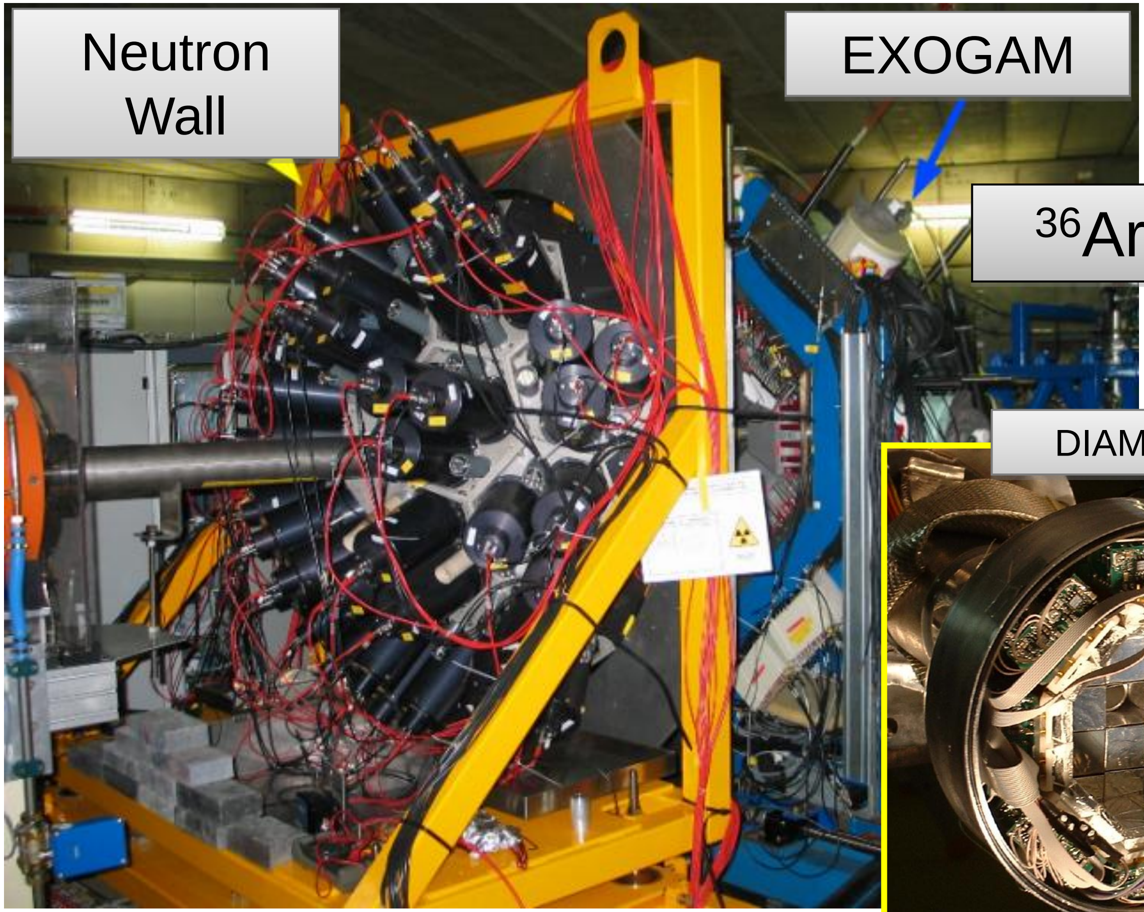
B. Cederwall[1], F. Ghazi Moradi[1], T. Bäck[1], A. Johnson[1], J. Blomqvist[1], E. Clément[2], G. de France[2], R. Wadsworth[3], K. Andgren[1], K. Lagergren[1,4], A. Dijon[2], G. Jaworski[5,6], R. Liotta[1], C. Qi[1], B. M. Nyakó[7], J. Nyberg[8], M. Palacz[5], H. Al-Azri[3], A. Algora[9], G. de Angelis[10], 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]



Effects of p-n pairing in Structure: T=0 needed in SM



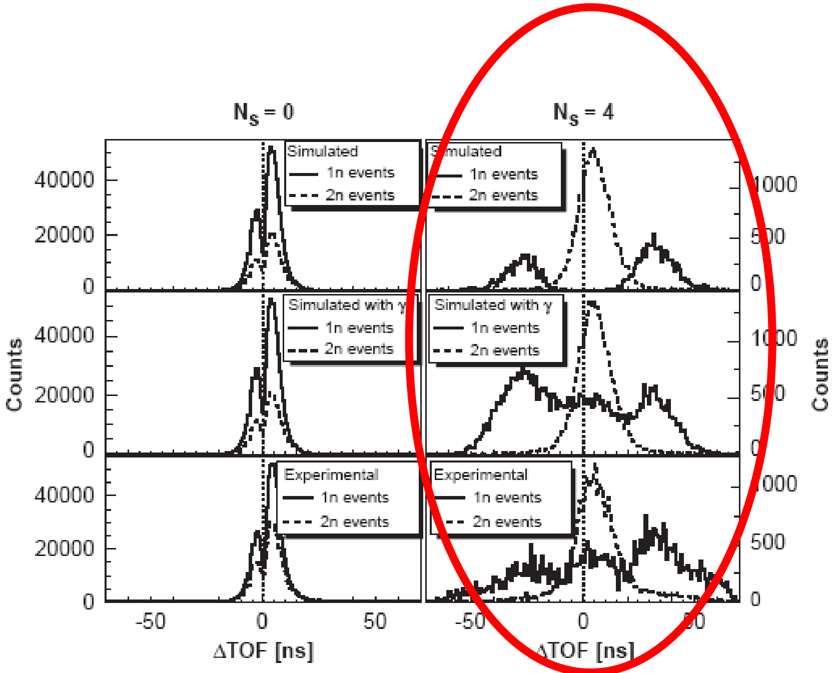
Experimental approach



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

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

Cross talk → limits 2n efficiency & selectivity



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 improve discrimination between real 2n events and scattered neutrons → Increase of the 2n efficiency.

NEDA Physics Case

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, Valencia)
  - 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)

NEDA Organization

Management Board
J.J.Valiente Dobon (projectmanager), N.Erduran, G.deFrance, A.Gadea, M.Moszynski, J.Nyberg, M.Palacz, D.Tonev, R.Wadsworth. M. Tripon (GANIL Liason)

WorkingGroups

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

Institutions/Institutes
Bulgaria: INRNE, **France:** GANIL, **Italy:** INFN
Poland: Warsaw University, HIL, IFJ-PAN Cracow, COPIN
Spain: IFIC, CSIC, University of Valencia, MINECO
Sweden: Uppsala University
Turkey: TUBITAK, TAEK
United Kingdom: York University

MoU (4 years) march 2012 signed by Bulgaria, France, Turkey, Poland, Sweden, United Kingdom, Italy and Spain

Aim and strategy of the NEDA design

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

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.

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

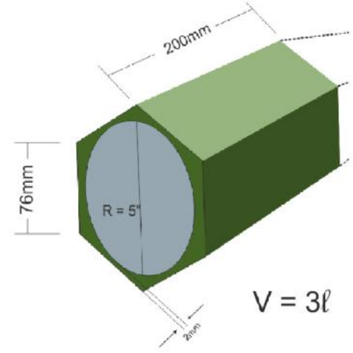
Nuclear Instruments and Methods in Physics Research A

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

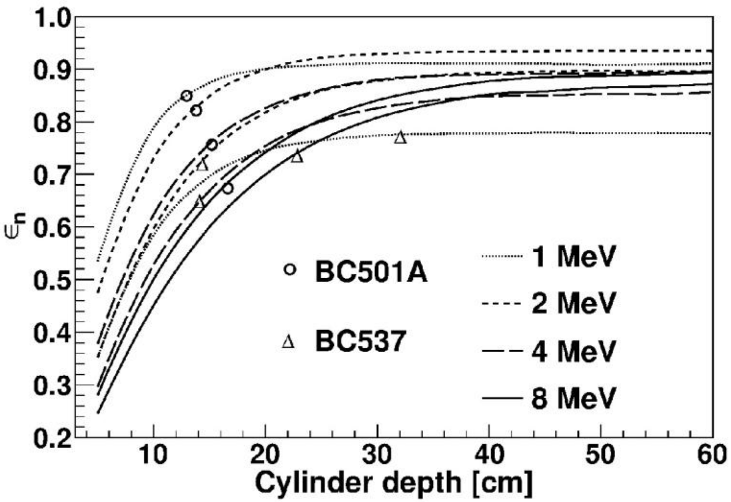
Monte Carlo simulation of a single detector unit for the neutron detector array NEDA

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]

[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 A673 (2012) 64.



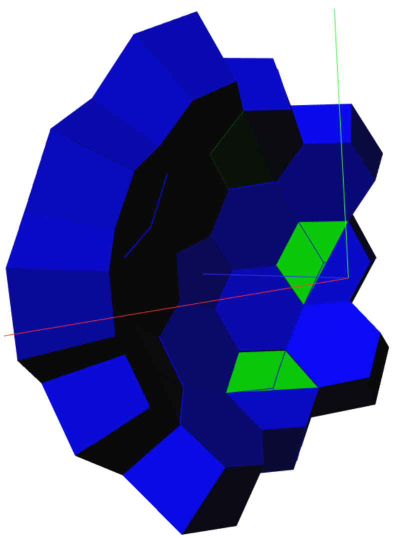
BC501A: ^{1}H, BC537: ^{2}H (deuterated)

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

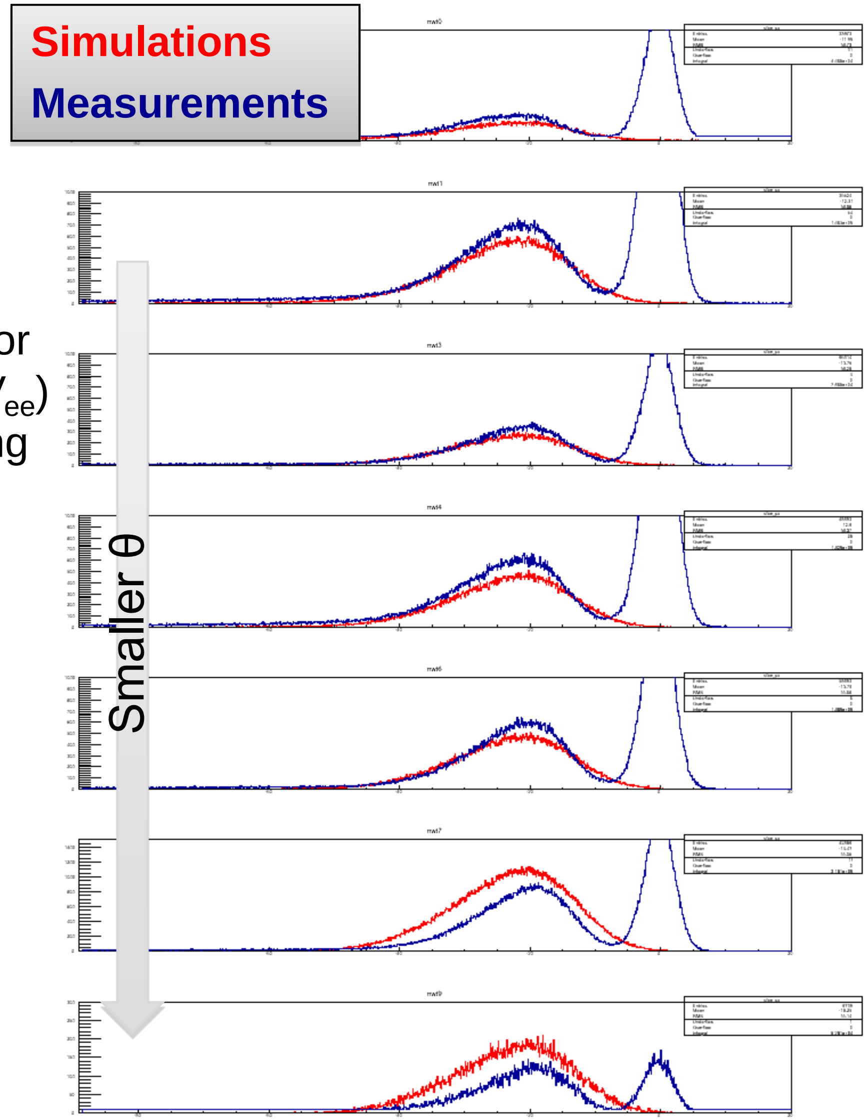
Simulations: a realistic event generator

A. Di Nitto contribution this afternoon

• All neutron channels were considered Lilita Monte Carlo HF Code.
• Experimental threshold energies were set separately to each detector in the simulations ($E_{thr\ (avg)}$=150keV$_{ee}$)
• Model parameters need fine tuning in the calculations



^{58}Ni (220 MeV) ^{56}Fe



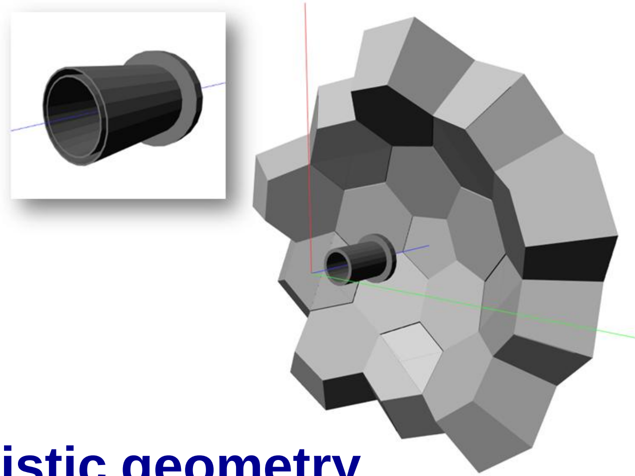

Facoltà di Scienze Matematiche, Fisiche e Naturali
Corso di Laurea in Fisica
Anno Accademico 2011/2012
Tesi di Laurea
Studio dei coefficienti di trasmissione per l'evaporazione di neutroni e protoni da nucleo composto


Università degli Studi di Napoli "Federico II"
Facoltà di Scienze Matematiche, Fisiche e Naturali
Corso di Laurea in Fisica
Anno Accademico 2011/2012
Tesi di Laurea
Studio della configurazione 2π dell'array NEDA attraverso simulazioni Monte Carlo di reazioni di fusione-evaporazione

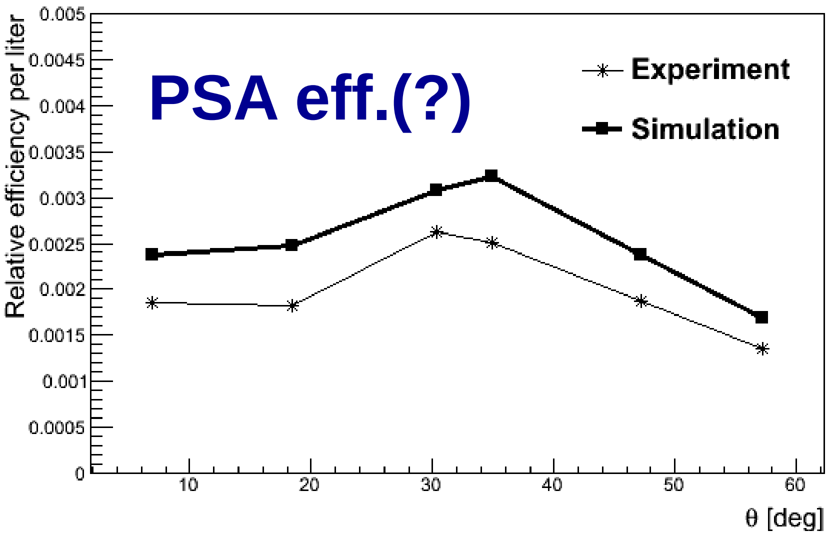
T.Hüyük, A. Di Nitto et al., to be submitted

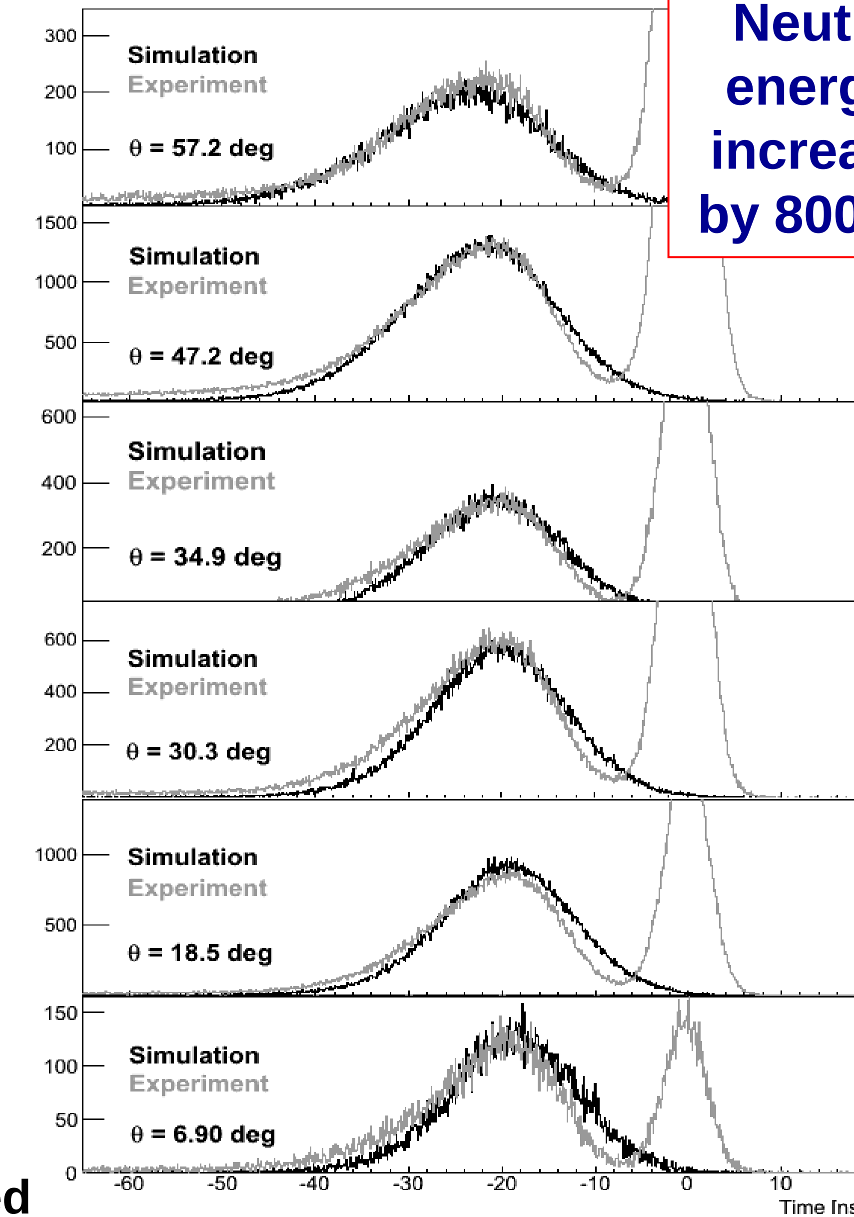
Simulations: a realistic event generator

^{58}Ni (220 MeV) ^{56}Fe



Realistic geometry





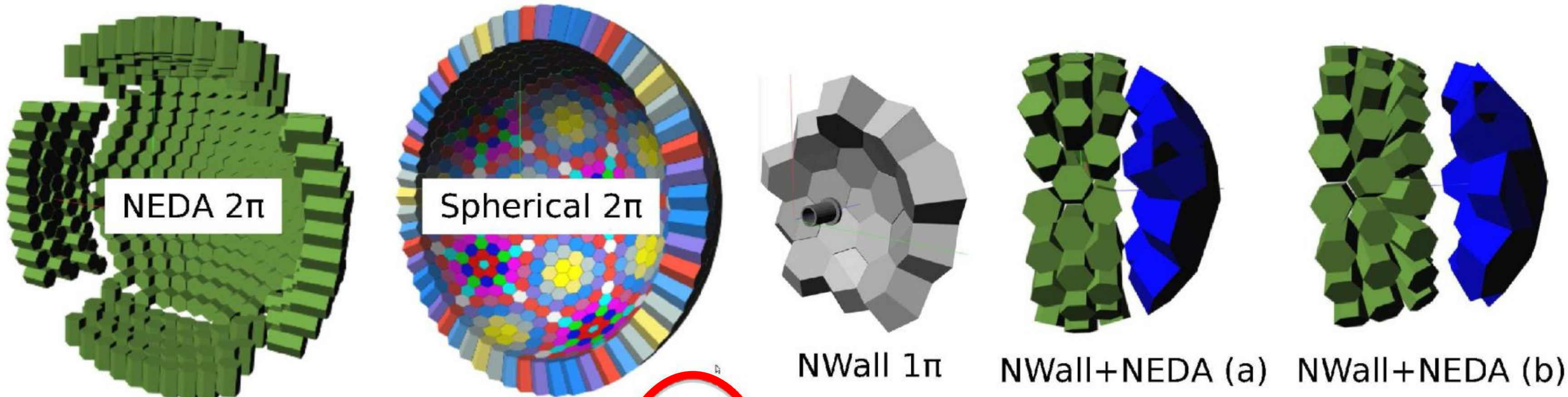
Neutron energies increased by 800 keV

T.Hüyük, A. Di Nitto et al., to be submitted

Overview efficiency geometries

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

Geometry	Solid angle (*s.r.*)	Avg. cell volume (*l*)	Total Volume (*l*)	Granularity	Distance to target (*m*)
NEDA 2π	1.87π	3.23	1065	331	1.0
Spherical 2π	$\sim 2\pi$	2	1212	606	1.0
Neutron Wall	$\sim \pi$	3.23	145	50	0.5
Neutron Wall + NEDA (a)	1.85π	3.23	293.6	96	0.5
Neutron Wall + NEDA (b)	1.32π	3.23	306.5	100	0.5 and 0.75



Geometry	Material	ε_{1n} (%)	ε_{2n} (%)	ε_{3n} (%)
NEDA 2π	BC501A	35.94	7.66	2.81
Spherical 2π	BC501A	43.66	10.92	5.55
Neutron Wall	BC501A	25.99	1.07	0.30
NW + NEDA (a)	BC501A	31.85	3.15	0.55
NW + NEDA (b)	BC501A	26.42	2.44	0.30

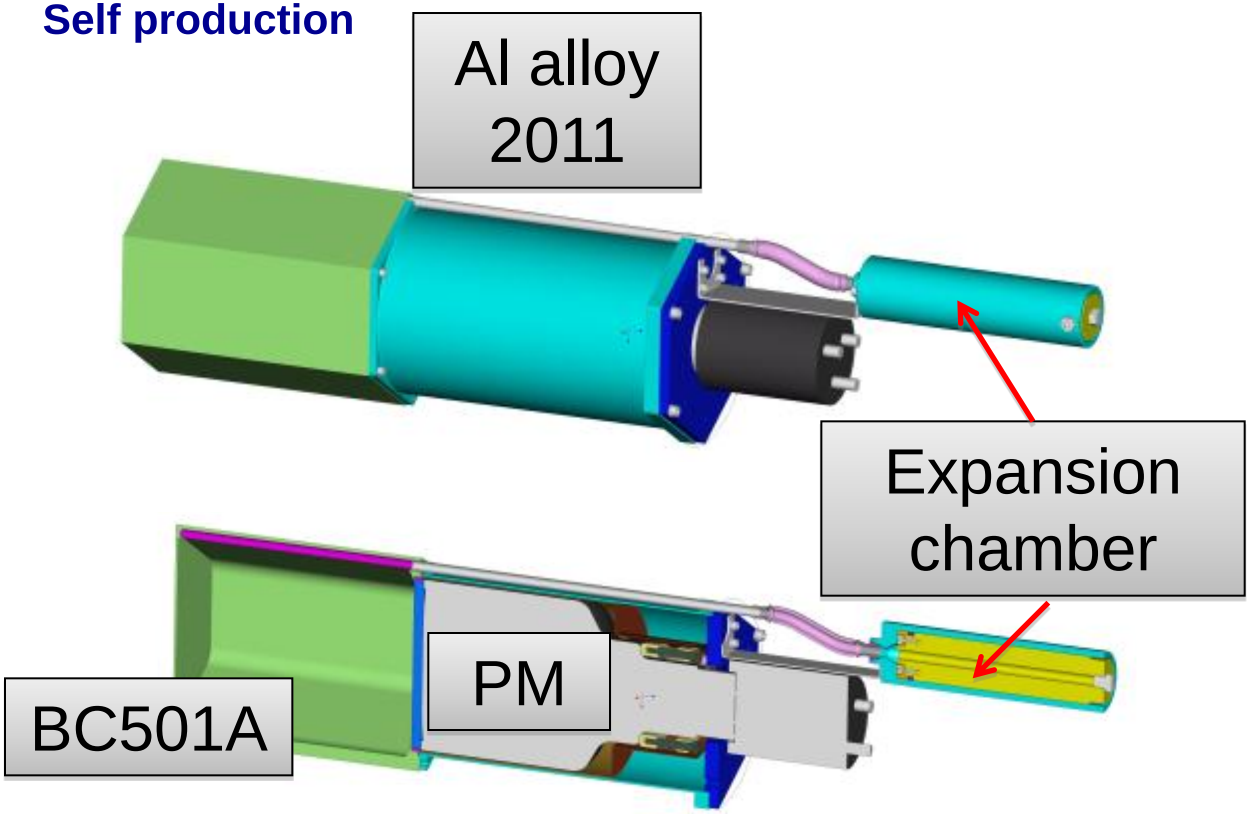
Clean 2n efficiency:
[NEDA 2π] ≃7.5∗[NWall]
[NWall+NEDA (b)] ≃3.3∗[NWall]

Preliminary results

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

Design of NEDA Cells

Self production

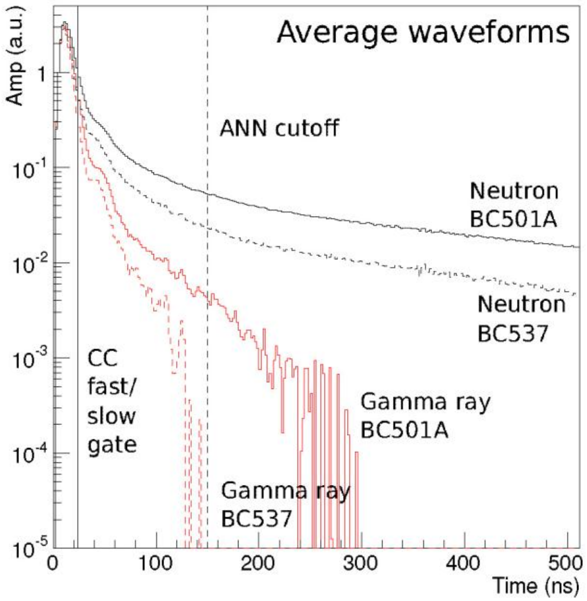


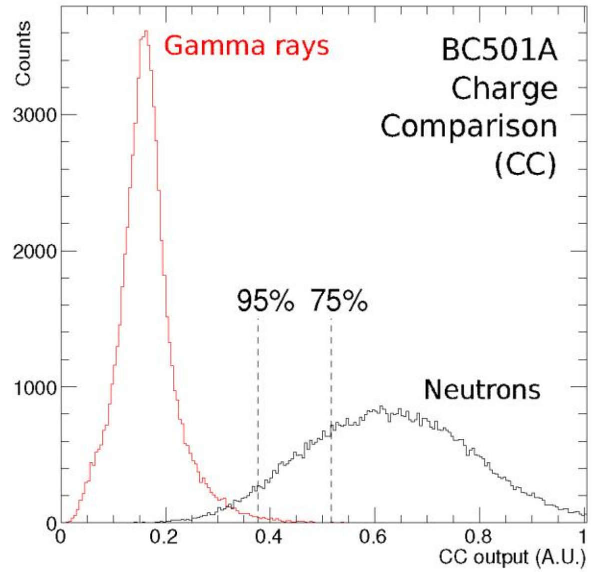
First three prototype cells (Feb. 2014)

Prototype 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 μ-metal shield.
First prototype ready to be filled with liquid and to be tested.

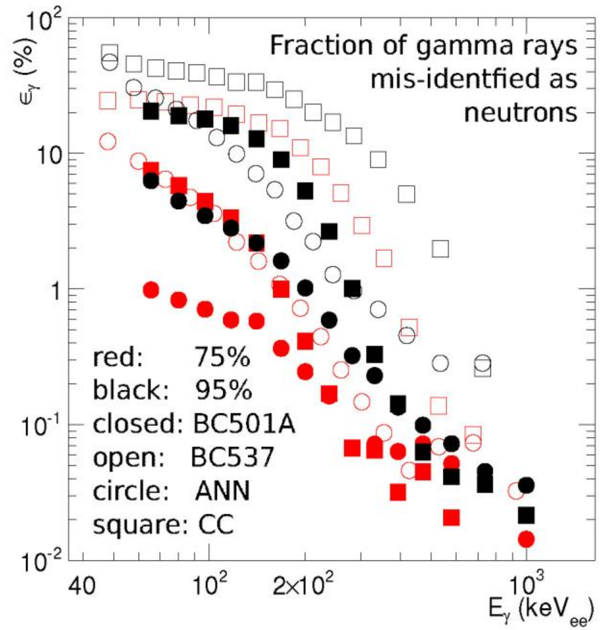
Digital Neutron-Gamma PSA

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





Preliminary results



Conclusions:

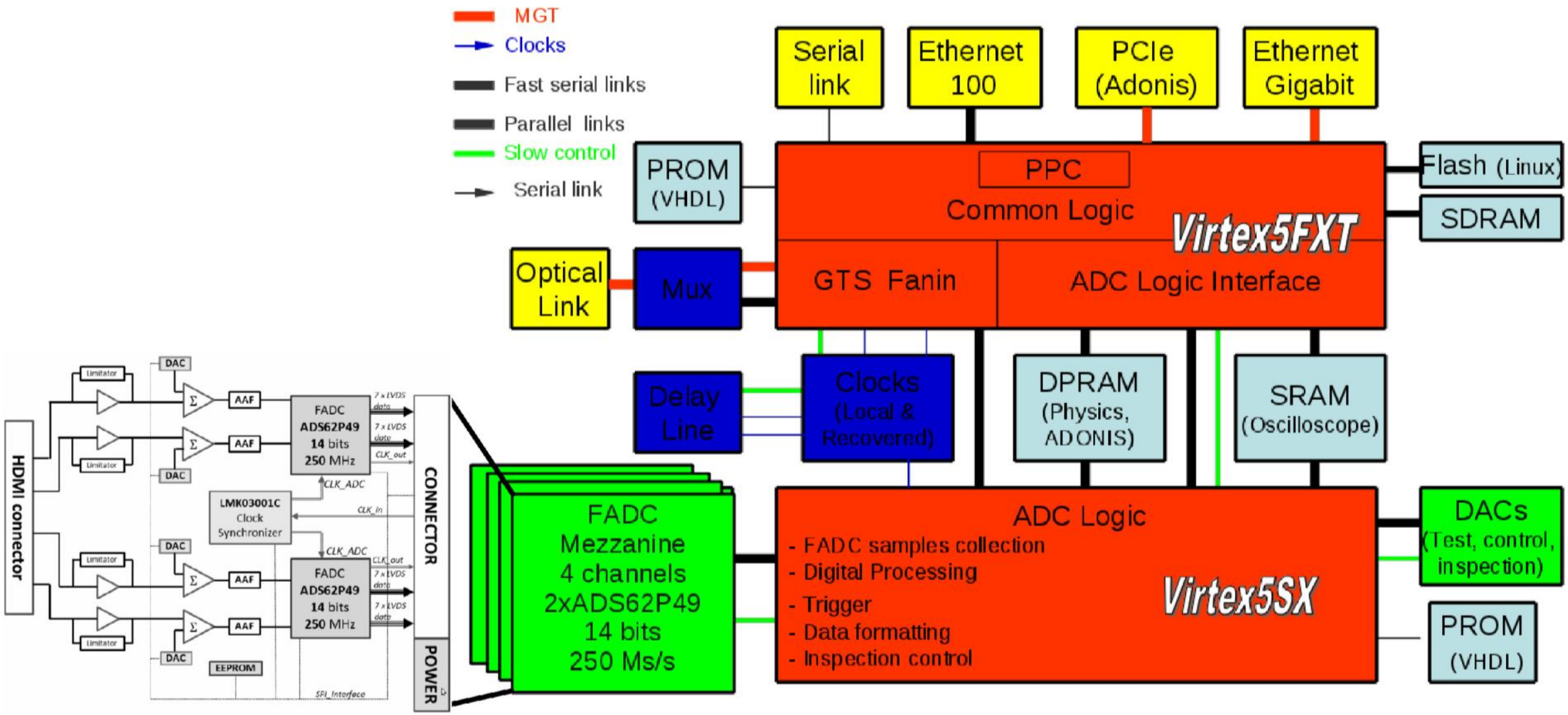
- BC501A is better than BC537.
- ANN is better than CC.

Digital PSA feasible

P.-A. Söderström et al., LNL Ann. Rep. (2011) 66 and to be submitted to NIMA.
(see also P.-A. Söderström, et al., NIM A594 (2008) 79)

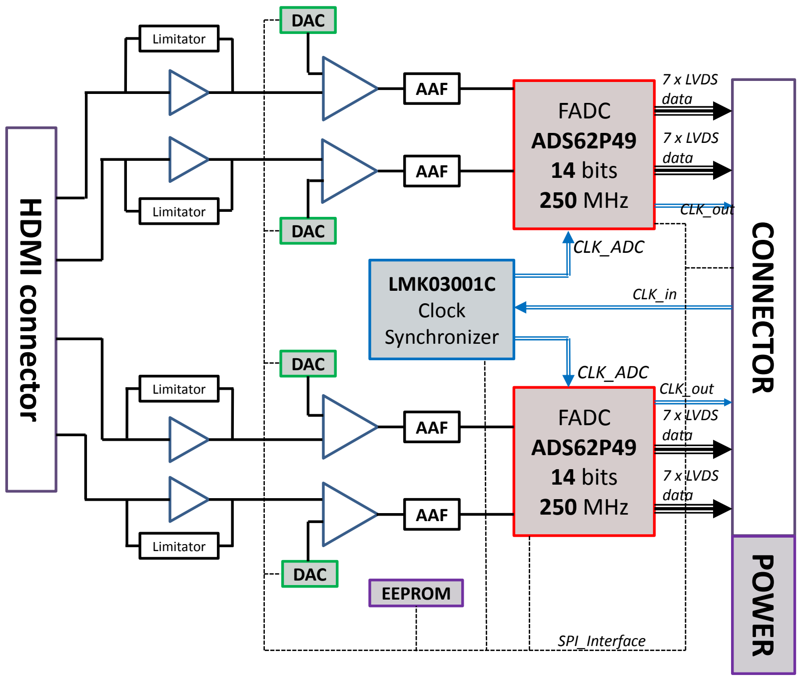
NEDA Digital Front-End Electronics

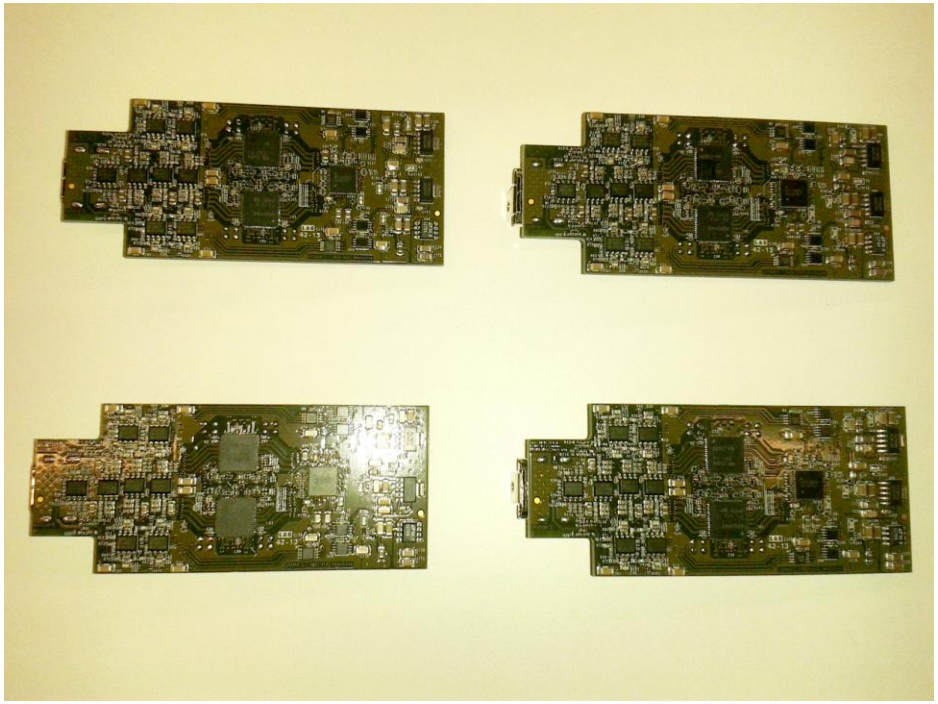
NUMEXO2 (EXOGAM2): 16 channels NIM unit, 4 mezzanine cards each with four 200-250 MS/s, 14 bits FADCs
Design & test of Mezzanine cards performed by IFIC and ETSE University of Valencia, GANIL.
NUMEXO2 is fully compatible with AGATA (GTS, timestamp, readout, etc.
Possible Synergies with PARIS



Production of the cards ready in 2014

Design of the 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, with high band width, will be used to transfer the signals from the detector to the FADC.

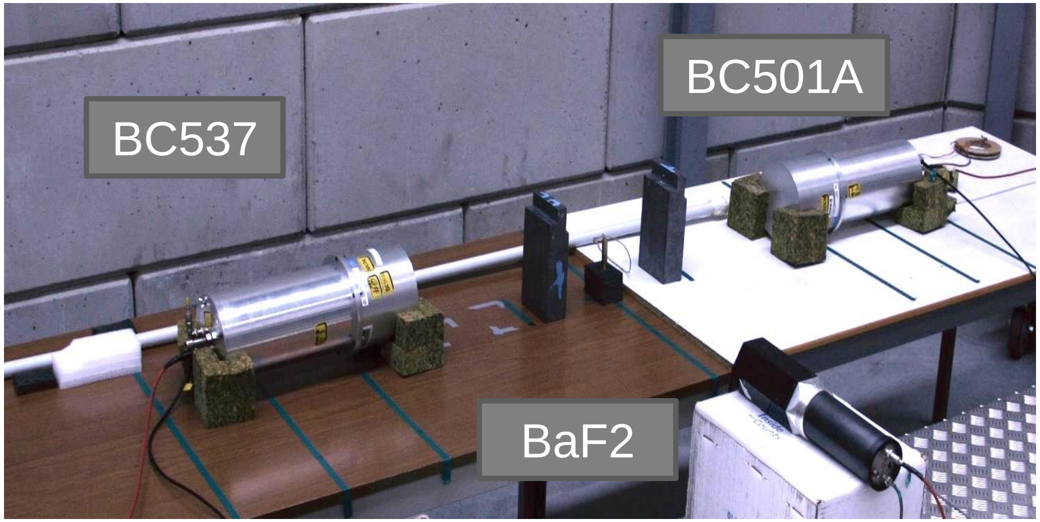
NEDA Test Setup at LNL

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

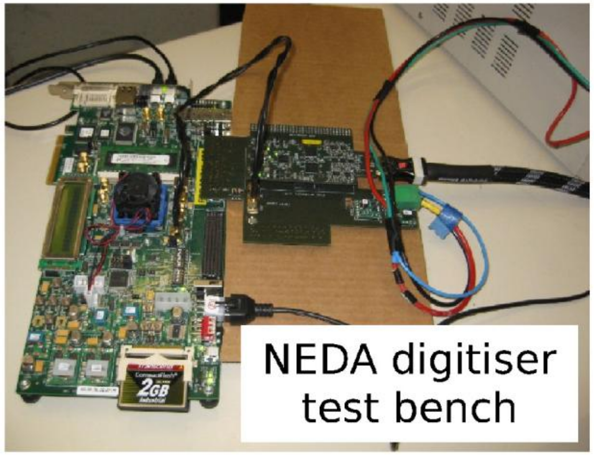
- 2 x BC501A (5” x 5” cylindrical prototype detector)
- 2 x BC537 (5” x 5” cylindrical prototype detector)
- SIS3302 100 MS/s, 16 bits 8 ch. digitizer (analog setup)
- SIS3350 500 MS/s, 12 bits 4 ch. Digitizer
- NEDA 200 MS/s FADC prototype
- DAQ by IFIC, (J. Agramunt)

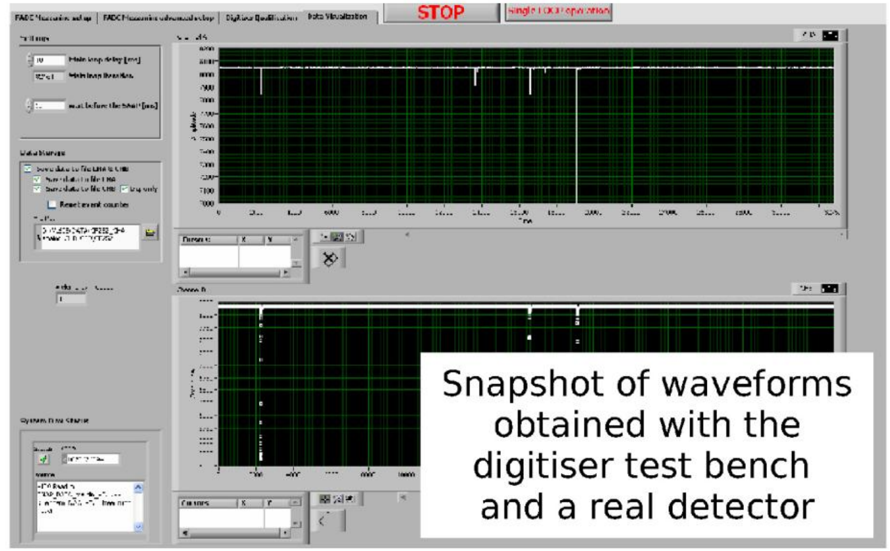
Aiming to test:

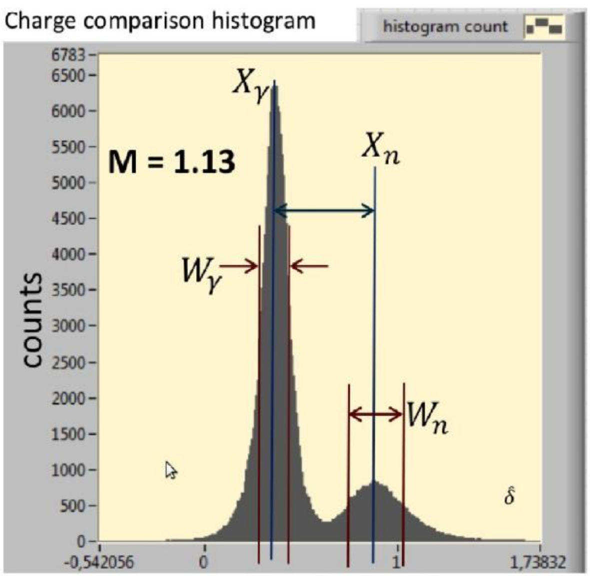
- Digital PSA
- Relative efficiency performance
- Cross-talk between the detectors
- Timing



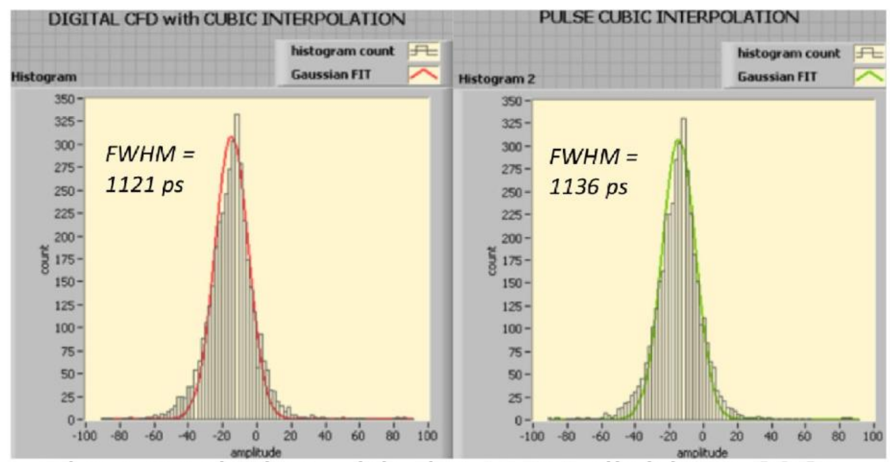
Tests of the FADC for NEDA/EXOGAM2







Neutron-gamma discrimination with the NEDA digitiser. 252Cf source, 5"x5" BC501A detector, Charge Comparison method.

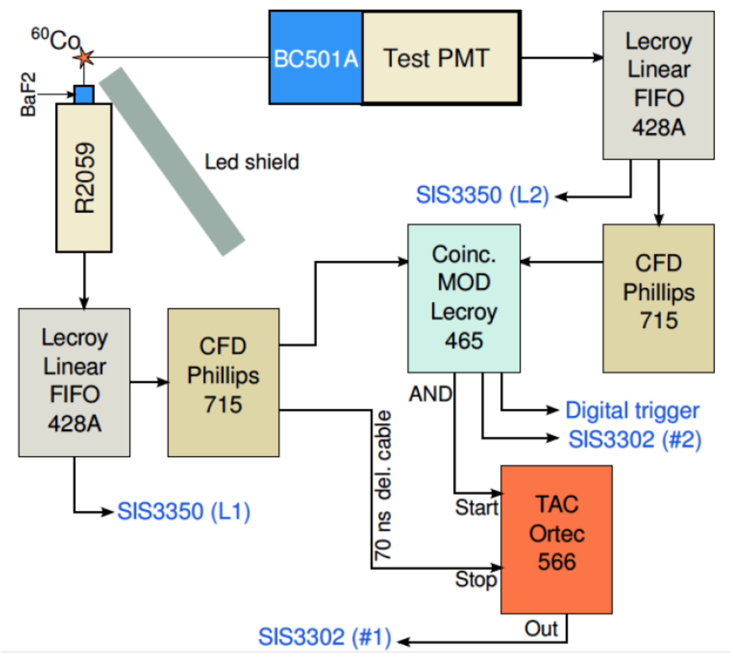


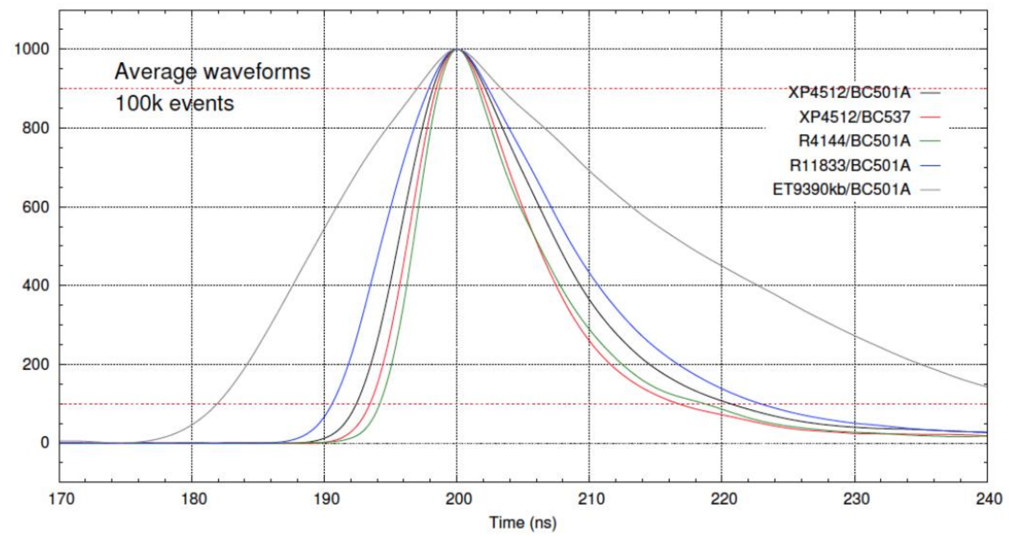
Time resolution with the NEDA digitiser. 60Co source, two 5"x5" BC501A detectors, digital CFD

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

Digital Pulse-Timing Techniques

Algorithm for digital timing for various Photomultipliers (fast to slow HQE 5'')



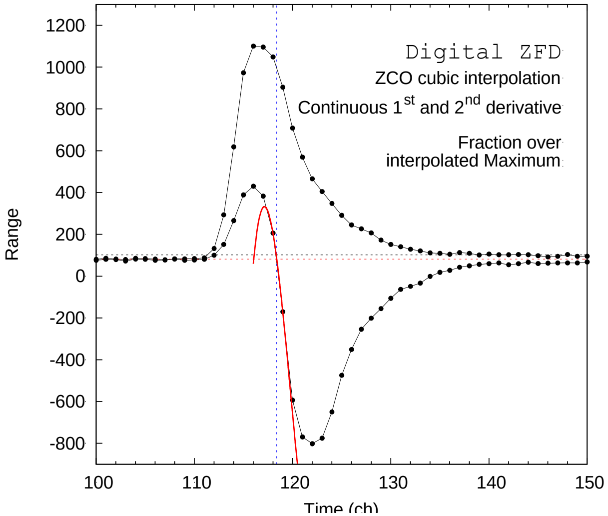


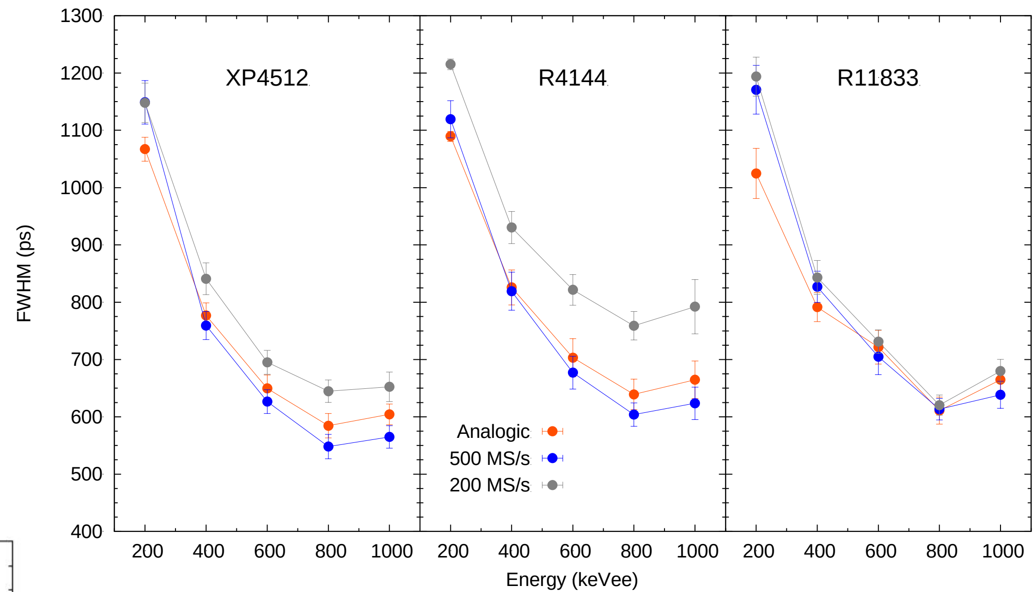
The time resolution is obtained with a ^{60}Co source and for two frequencies 500 MHz (the nominal) and 200 MHz (final NEDA one)

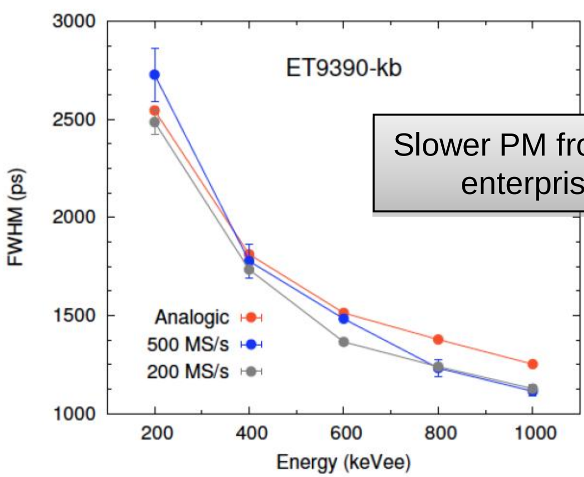
Timing 500–200MHz – Various PM 5”

Algorithm for digital timing:

- CFD (Constant Fraction Method) method with a cubic interpolation of the ZCO (Zero Cross Over) with threshold continuous in the first and second derivative







Slower PM from ETL enterprises

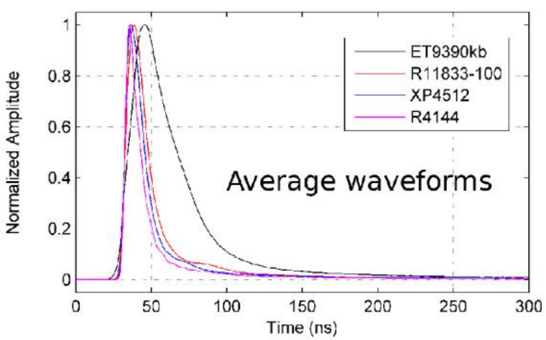
Table 2: Results for all the PMTs measured with R2059/BaF2 as reference.

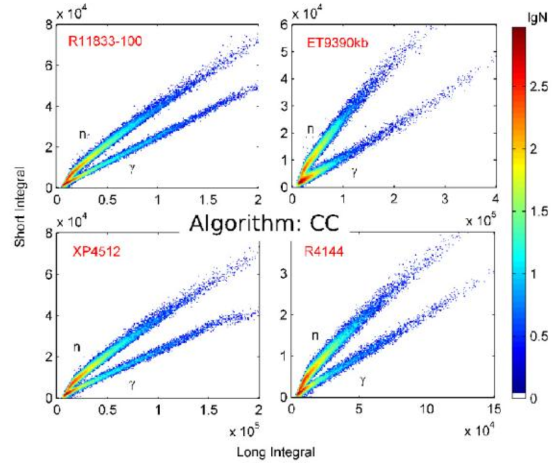
			Time resolution FWHM (ps)		
Detector	Risetime (ns)	Nphe (MeV^{-1})	Analogic	500 MS/s	200 MS/s
XP4512(D0P3)	4.9(5)	1330(70)	690(30)	660(30)	740(30)
XP4512(D1P1)	4.4(4)	970(50)	660(30)	660(40)	730(30)
R4144	3.8(4)	–	750(30)	710(30)	870(30)
R11833	6.3(8)	1830(90)	743(13)	730(20)	760(20)
ET9390-kb	13.5(15)	1550(50)	1470(20)	1330(30)	1360(20)
D0P3-D1P1			1006(30)		

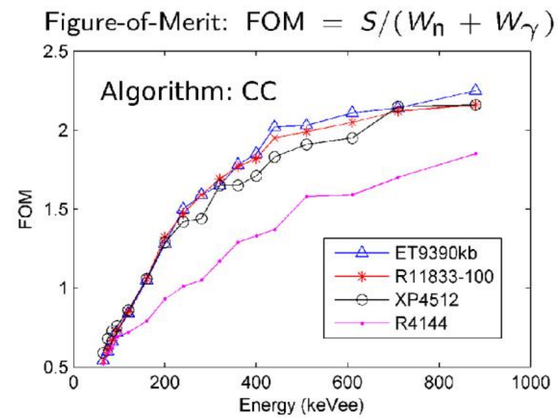
PMT test for Optimal γ-n Discrimination

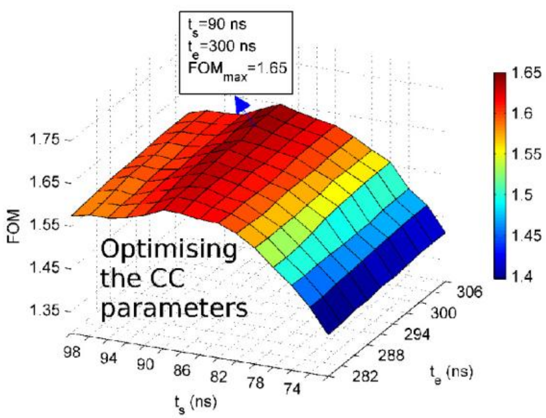
PMT model	R4144	XP4512	ET9390-kb	R11833-100
Type	fast	fast	spectroscopy	fast
QE_{max}[%]	22	24	28	35
NPE/MeV	950(60)	1350(70)	1800(90)	2070(100)

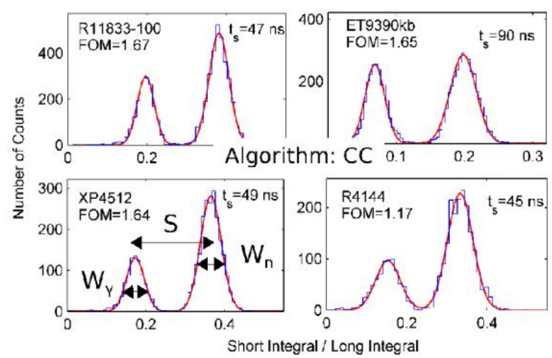
PSA algorithms: CC and IRT (Integrated Rise Time). 500 MS/s. Preliminary results.











Conclusions:

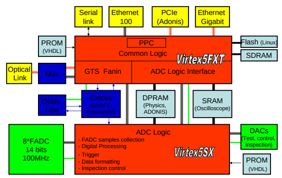
- R11833-100, ET9390-kb, XP4512 give similar FOM values.
- Similar results with IRT.
- PMT for NEDA: R11833-100 (better time resolution).

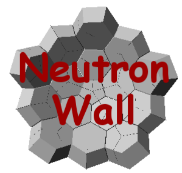
X.L. Luo et al., LNL Ann. Rep. (2013) and submitted to NIMA

Phases of NEDA

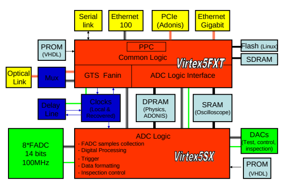
NEDA will be built in four different phases:

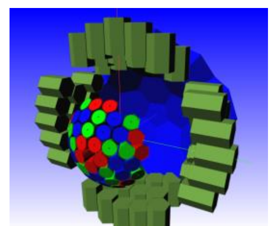
- Phase 0: Upgrade of Neutron Wall with digital electronics.





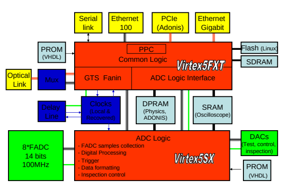
- Phase 1: Construction of NEDA det. combined with NW

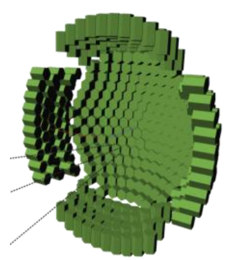




MoU 2015

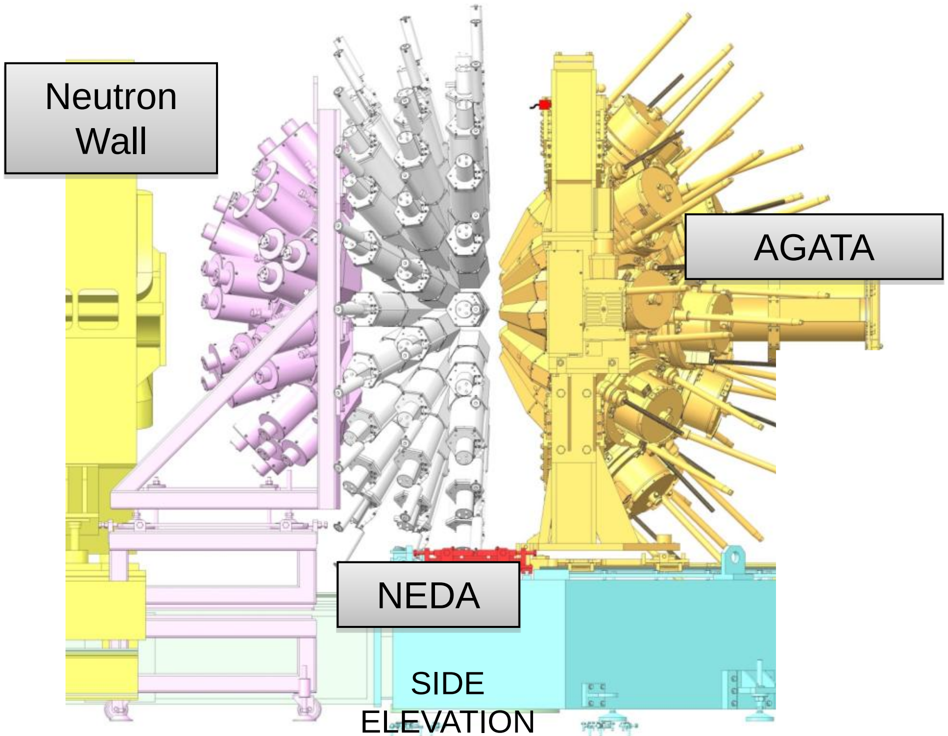
- Phase 2: Final construction of NEDA 2π – 355 detectors



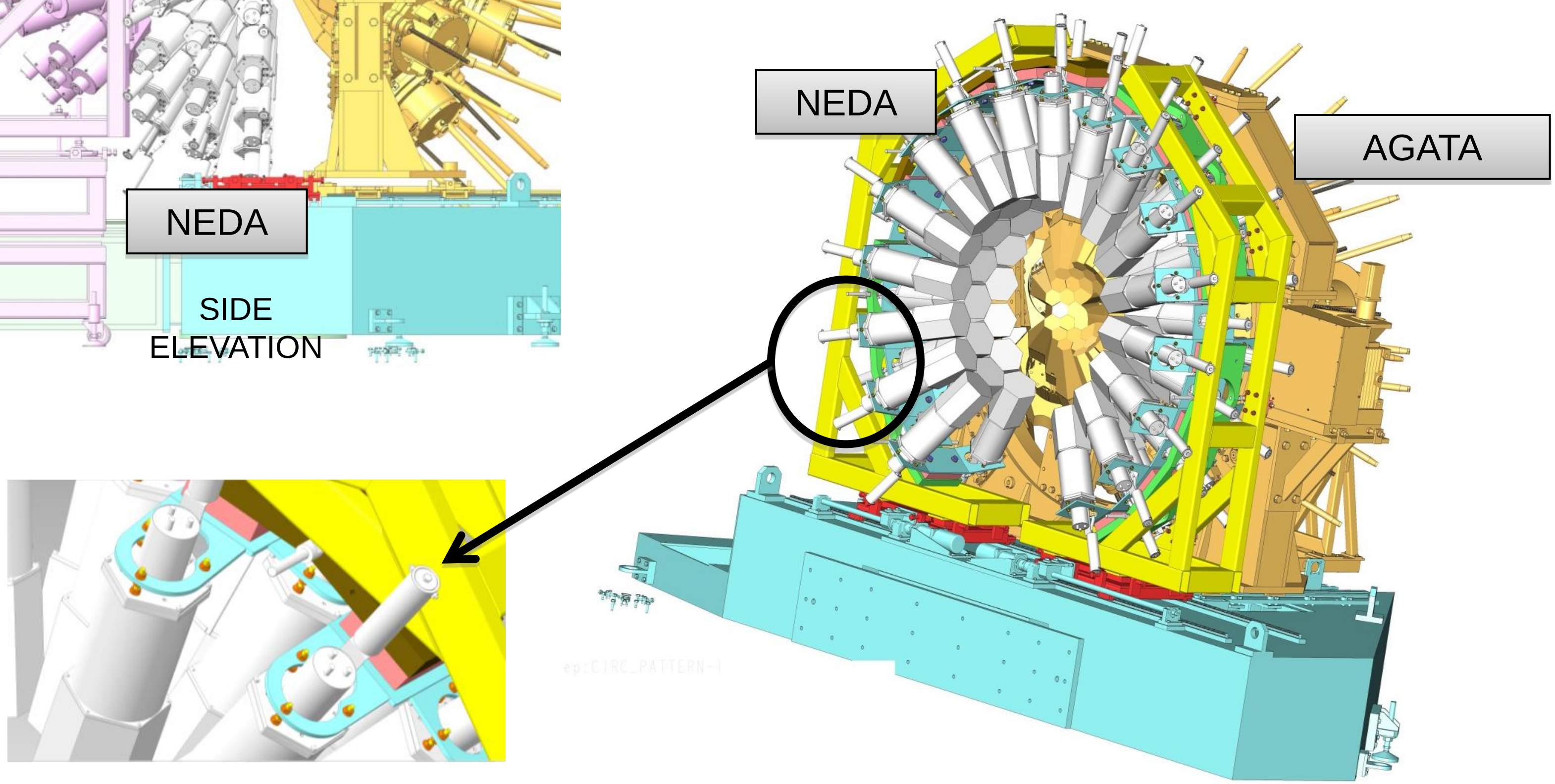


- Phase 3: R&D on new material and light readout systems for a highly segmented neutron detector array.

NEDA holding structure AGATA@GANIL



In this very first phase it will be possible to place up to 45 detectors in addition to the Neutron Wall.



Summary

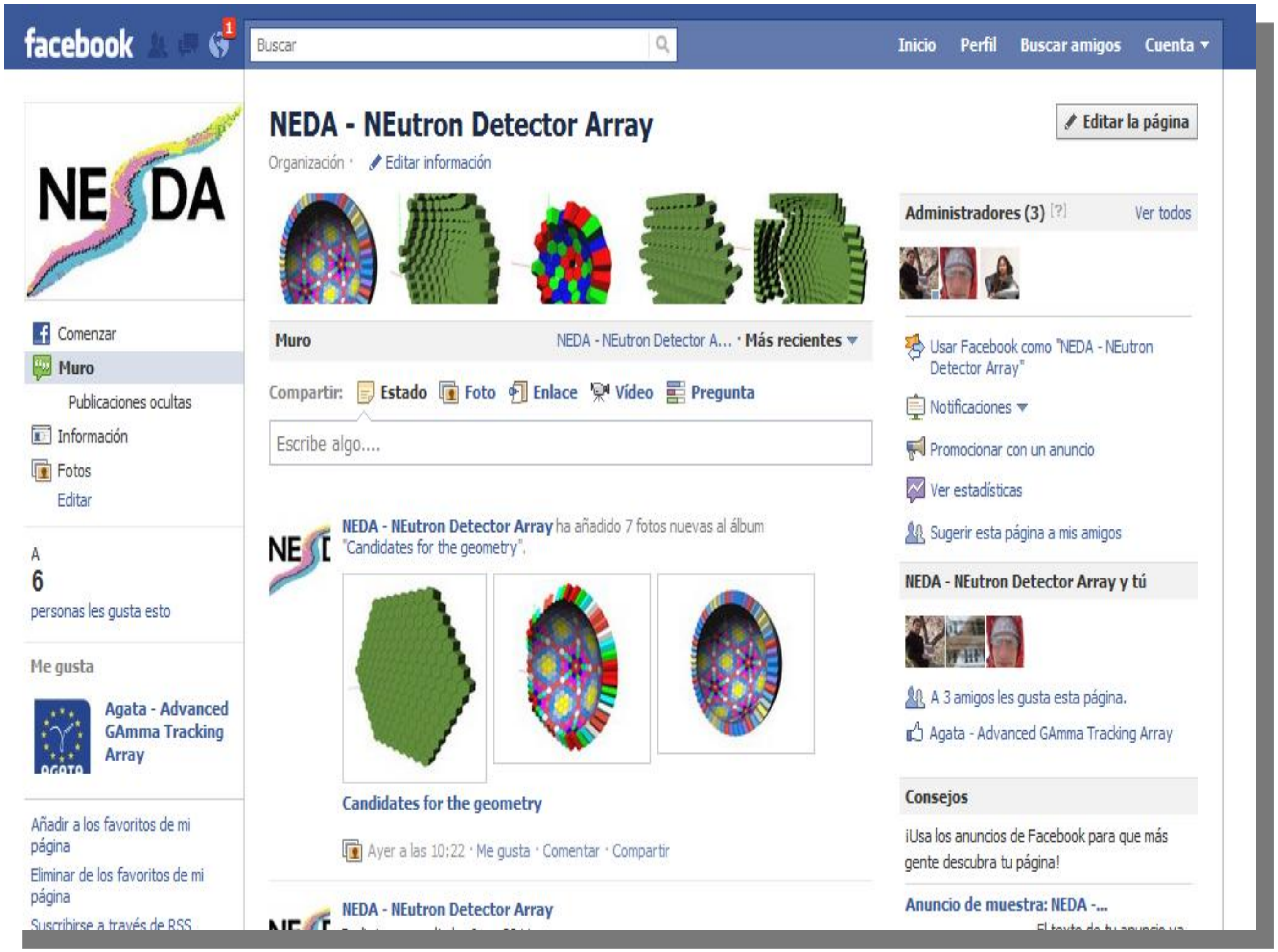
NEDA will be a neutron detector to address the *physics of neutron-rich as well as neutron-deficient nuclei, mainly in conjunction with gamma-ray detector arrays like AGATA, GALILEO, EXOGAM2 and PARIS.*

- Exhaustive simulations and work on an event generator.
- Design and construction of the first NEDA prototype
- Development of electronics in synergy with EXOGAM2 and PARIS
- Design test and mass production of the FADC
- NEDA will be built in phases: MoU signed March 2012 until 2015.
- NEDA will be coupled to the NW+AGATA at the AGATA GANIL phase, later LNL …
- Strong synergies with other neutron communities: MONSTER, DESIR, NEULAND, DESCANT
- R&D Neutron potition resolution and new materials
- Creating a community of young gamma spectroscopists with experience on neutron detection. So far the R&D phase will make part of two PhD thesis and one tesis magistrale.

NEDA youngsters

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

To be updated visit us on Facebook



http://agata03.ific.uv.es/boceto01/nedahome.htm

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.