Neutron Wall and NEDA: Status and Perspectives

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Outline

- Neutron Wall
  - Description and status
  - Recent results
- NEDA
  - Aim and strategy
  - Organization and working groups
  - Physics with NEDA
  - Technical description and status
- Summary and outlook

Neutron Wall

Neutron detector array with $\simeq 1\pi$ solid angle

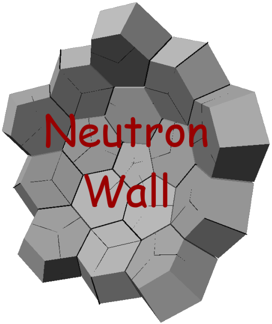
Built for the EUROBALL spectrometer 1995-97
(H. Grawe and Ö. Skeppstedt)

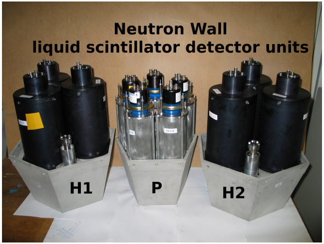
Financed by Sweden, UK, Germany, Poland

Owned by the European Gamma-Ray Spectroscopy Pool

50 liquid scintillator detectors (BC501A, 150 litre);
distance to target: 51 cm; detector thickness: $\simeq$ 15 cm

Neutron energy range: $\simeq$ 0.5 MeV to $\simeq$ 10 MeV





Neutron-gamma discrimination: pulse-shape analysis based on the zero-crossover (*ZCO*) technique (analogue electronics) combined with time-of-flight (*TOF*) measurement (need pulsed beam with time resolution *FWHM* $\lesssim$ 5 ns)

Neutron efficiency (symmetric fusion evaporation reaction): $\varepsilon_{1n} = 20\text{-}25\%$, $\varepsilon_{2n} = 1\text{-}3\%$

Neutron Wall experiments

Experiments performed with EUROBALL at LNL and IReS, EXOGAM at GANIL

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

GANIL home base since 2005

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

Next "campaign" (two experiments) at GANIL: 2012

Apply to the Gammapool for the use of the array

First experiments with radioactive beams

Two experiments with ^{6}He and ^{8}He beams at SPIRAL/GANIL

1n and 2n transfer with the Borromean nucleus ^{6}He near the Coulomb barrier, *A. Chatterjee, et al., Phys. Rev. Lett. 101 (2008) 032701*

Neutron correlations in ^{6}He viewed through nuclear break-up, *M. Assie et al., Eur. Phys. J. A 42 (2009) 441*

Reactions with the double-Borromean nucleus ^{8}He, *A. Lemasson et al., Phys. Rev. C 82 (2010) 044627*

Pair and single neutron transfer with Borromean ^{8}He, *A. Lemasson et al., Phys. Lett. B 697 (2011) 454*

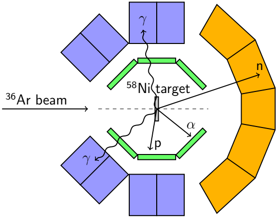
^{92}Pd experiment at GANIL

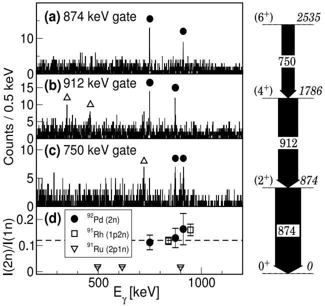
Experiment at GANIL (2009)

EXOGAM + DIAMANT + Neutron Wall

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

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

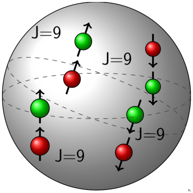




First observation of excited states in ^{92}Pd

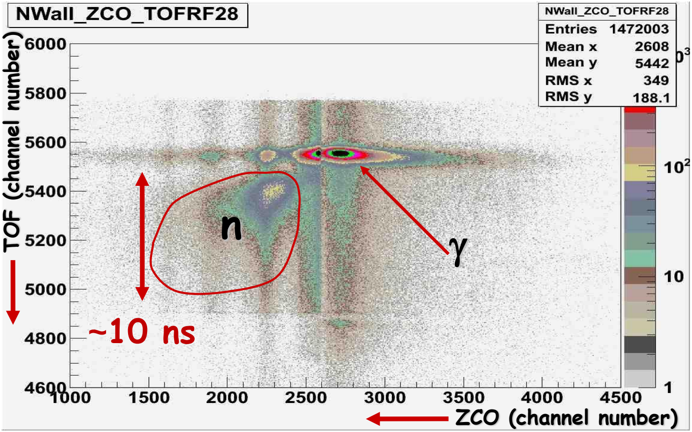
Approximately equidistant energy levels

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



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

Neutron-gamma discrimination



γ–neutron mis-identification probability ~ 0.12%

Farnaz Ghazi Moradi (KTH,Stockholm)

EGAN 2011

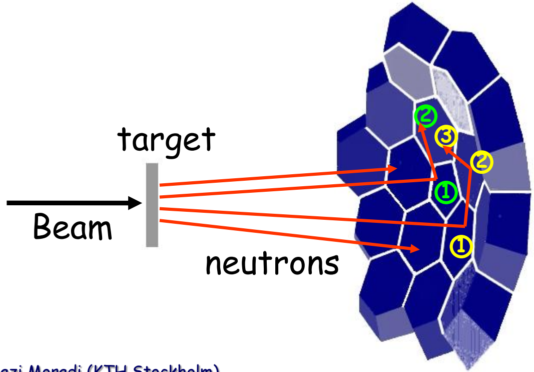
Identification of scattered neutrons

Correction of neutron multiplicity

For ^{91}Ru (2pn) the scattering probability of 1n neutron in 2n channel: 12%

Scattering of neutrons between adjacent detectors

Measuring ΔTOF for 2n events and 1n-scattered events



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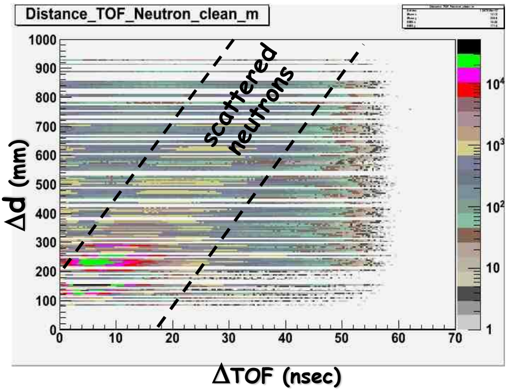
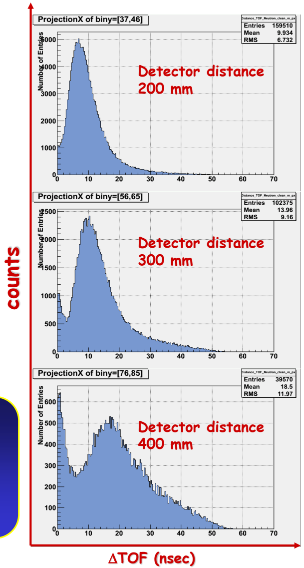




Rejection efficiency of 1n-scattered neutrons

for ^{91}Ru (2pn): 87%

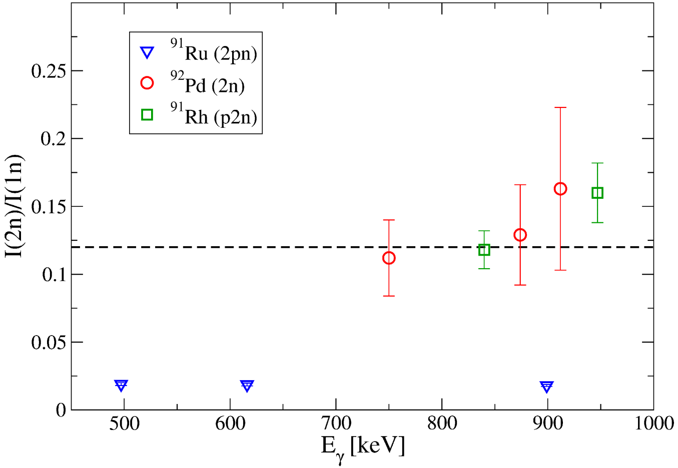
for ^{12}C(^{36}Ar, pn)^{46}V: 75%

and 73% of true 2n events are preserved.

Description of methods for neutron scattering rejection: *J. Ljungvall et al., NIM A 528 (2004) 741*

Farnaz Ghazi Moradi (KTH,Stockholm) **EGAN 2011**

Identification of γ rays in the 2n reaction channel



NEDA – Neutron Detector Array

Aim

- Develop and build a neutron detector array to be used with AGATA, EXOGAM2, etc. for experiments with high-intensity stable and radioactive ions beams at SPIRAL2, SPES, ...
- Excellent neutron-γ discrimination
- Increased efficiency to detect ≥ 2 neutrons: $\varepsilon_{2n} = 5\text{-}10\%$ (NW: 1-3%)
- 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

- Optimize size of detector units, distance to target, geometry of the array, ...
- Investigate other detector materials than ordinary liquid scintillator: deuterated liquid scintillator, solid scintillators
- Adopt digital electronics
- Develop advanced on-line and off-line algorithms for neutron-γ discrimination, neutron scattering rejection, pile-up rejection/recovery

Organization

Spokesperson

J.J. Valiente Dobon (LNL-INFN)

FP7-Infrastructures-2007-1
SPIRAL2 Preparatory Phase

GANIL liaison

M. Tripon (GANIL)

FIRB
Futuro In Ricerca (MIUR)

Steering committee

N. Erduran (Istanbul), A. Gadea (Valencia), J. Nyberg (Uppsala), M. Palacz (Warsaw), L. Stuttgé (Strasbourg), R. Wadsworth (York)

NEDA Collaboration

Ankara University (Turkey), COPIN (Poland), CSIC-IFIC (Spain), Daresbury Laboratory (UK), GANIL (France), Istanbul University (Turkey), INFN (Italy), IPHC (France), Nide University (Turkey), Uppsala University (Sweden), University of York (UK), Kolkata (India, under discussion)

Working groups

Detector characteristics and physics

Responsible: B. Wadsworth

Simulations and conceptual design

Responsible: M. Palacz

Study of new detector materials

Responsible: L. Stuttgé

Front-end electronics and DAQ

Responsible: A. Gadea

Pulse-shape analysis

Responsible: J. Nyberg

Synergies with other detectors

Responsible: P. Bednarczyk

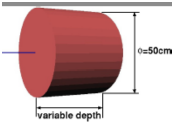
Physics with NEDA

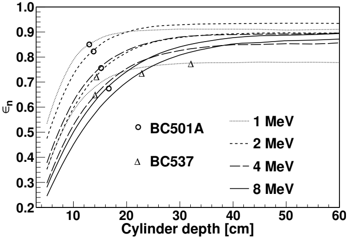
Studies of proton- and neutron-rich nuclei

- Nuclear Structure
  - Probe $T = 0$ correlations in $N = Z$ nuclei: the structure beyond ^{92}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, Soreq, Weizmann)
  - Isospin effects on the symmetry energy and stellar collapse (Debrecen, Florence, LNL, Naples)
- Nuclear Reactions
  - Level densities of neutron-rich nuclei (Florence, LNL, Naples)
  - Fission dynamics of neutron-rich intermediate fissility systems (Debrecen, GANIL, LNL, Naples)

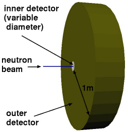
GEANT4 simulations, optimal size of detector units

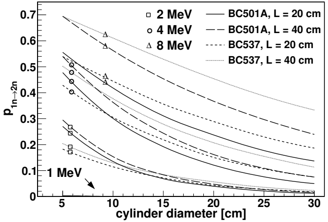
GEANT4 validated for simulations of interactions of fast neutrons with energies up to about 10 MeV in liquid scintillators





Optimal depth: $\simeq$ 20 cm





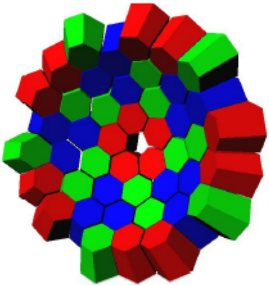
Optimal diameter: 5" (PMT)

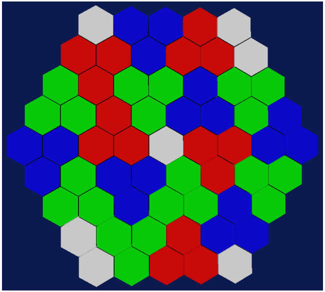
G. Jaworski et al., manuscript to be submitted to Nucl. Instr. Meth. A

Conceptual design and geometries of the NEDA array

Talk by T. Hüyük yesterday

Three possible geometries: spherical, staircase, planar





Spherical: allows easy coverage of $> 1\pi$ of the solid angle

Planar, staircase: flexibility regarding different arrangements of the detector (zigzag) and change of detector-target distance

New detector materials and light readout techniques

New detector materials

- Deuterated scintillator (BC537)
- Solid scintillators: IPHC Strasbourg (L. Stuttgé), LLNL, Dubna

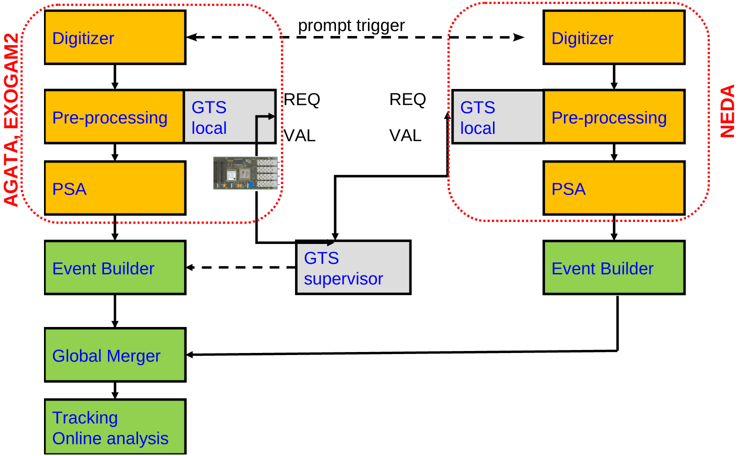
Novel light readout techniques

- Main aim
  - Larger quantum efficiency (QE) than ordinary PMTs ($\simeq 20\%$)
  - Position sensitivity
- Under evaluation
  - Super bi-alkali PMTs: QE up to $\simeq 40\%$
  - Avalanche Photo Diodes: QE up to $\simeq 80\%$, size few cm^2
  - Silicon PMs, size few cm^2

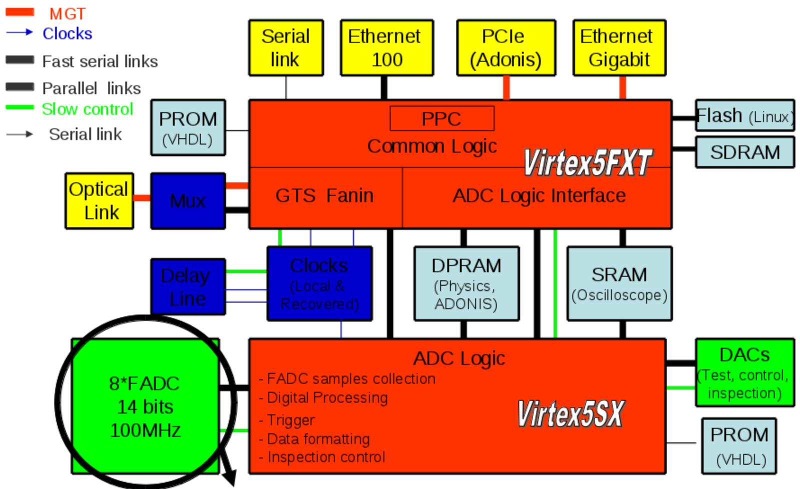
Front-end electronics and DAQ

Development at GANIL and IFIC Valencia

Fully compatible with EXOGAM2 and AGATA



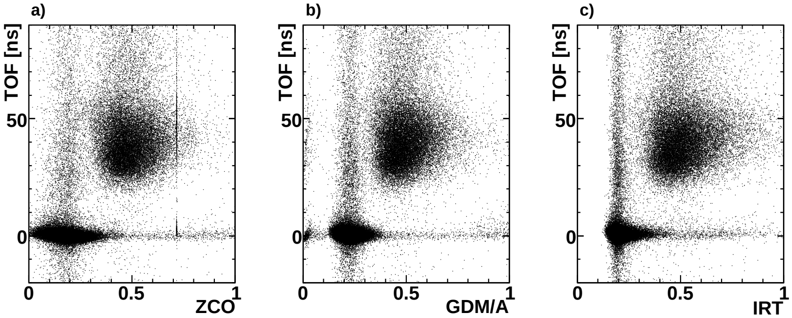
NEDA Digitiser



Basic diference EXOGAM2/NEDA is the ADC: 200-300 MHz 12-14bit

GANIL, Valencia

Pulse-shape analysis with digital electronics



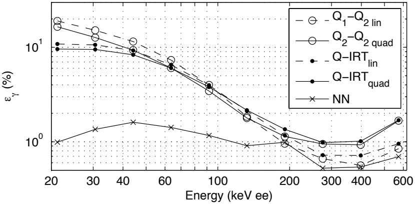
P.-A. Söderström et al., Nucl. Instr. Meth A 594 (2008) 79

Conclusions

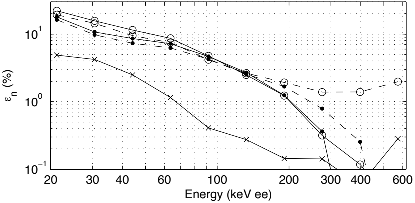
Digital PSA works as good or better than analogue *ZCO*
Digitiser: sampling frequency $\geq$200 MS/s, number of bits $\geq$12

Pulse-shape analysis with Artificial Neural Networks

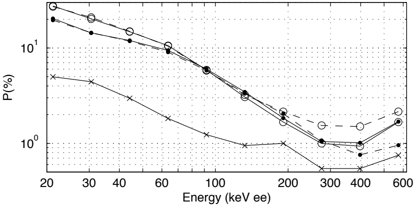
ϵ_γ = fraction of mis-interpreted γ rays



ϵ_n = fraction of mis-interpreted neutrons



$$P = \sqrt{\epsilon_\gamma^2 + \epsilon_n^2}$$



Conclusions

Better neutron-γ separation than with "standard" digital PSA methods in particular for small signals

E. Ronchi et al., Nucl. Instr. Meth A 610 (2009) 534

NEDA prototypes and tests

See talk by A. Pipidis yesterday

Detector prototypes

- Two BC501A cylindrical 5" $\times$ 5" (delivered)
- Two BC537 (deuterated) cylindrical 5" $\times$ 5" (delivered)

Light readout

- PMT: Hamamatsu R877-MOD (QE$=32\%$) (to be ordered)
- PMT: Hamamatsu R4144 (QE$<22\%$) (to be ordered)
- APD: Hamamatsu 1×2 cm^2 (delivered)
- SiPM: (York)

Digitiser for detector tests

- Caen DT5720 (4 chs, 250 MS/s, 12 bit) (delivered)
- Struck SIS3320-250 (8 chs, 250 MS/s, 12bit) (delivered)
- Struck (4 ch, 500 MS/s, 12 bit) (loan from IFIC)
- Struck (8 ch, 100 MS/s, 14 bit) (loan from IFIC)

Phases of NEDA

Phase 0

Upgrade of the Neutron Wall to use digital electronics

Phase 1

R&D on new detector materials and light readout systems for a highly segmented neutron detector array

Phase 2

Construction of the NEDA Demonstrator with a limited size

Phase 3

Construction of the full NEDA array

Summary and outlook

Neutron Wall

- Neutron Wall is alive and well
- Next "campaign" at GANIL 2012
- Apply for use of the array from the Gammapool

NEDA

- Next generation neutron detector array
- R&D phase in full progress
- Steering Committee decision on geometry, type of detector material, phases of NEDA in 2012

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Thank you

Acknowledgments to all members of the Neutron Wall and NEDA collaborations