Grześ Jaworski

on behalf of NEDA collaboration

NUSPIN Kick-off, San Servolo, June 30th, 2016
Outline

→ Why neutron multiplicity filter and why to build a new one?

→ Let's start from scratch (howto)
  • single cell;
  • scintillator;
  • full geometry;
  • PMT;
  • timing;
  • NGD;
  • electronics;
  • NEDA + NW @ GANIL geometry;
  • production (ongoing);
  • final characteristics (todo).

→ Physics with NEDA
  • GANIL 2018
Accessing \( N=Z \)
n selection

EXOGAM experiment: $^{58}$Ni (240 MeV) + $^{54}$Fe

4p

3pn

no gate on neutrons

1n gated
Why not NW?

An example:
Attempt to study $^{100}\text{In} - 1\nu 1\pi^{-1}$ outside $^{100}\text{Sn}$
3n evaporation channel – the only 3n case with NWall (+ EUROBALL)

$^{100}\text{In}$ not observed, but observation only a matter of statistics.
10x statistics: $\rightarrow \frac{1}{2}$ a a year with EXOGAM + NWall,
$\rightarrow$ 2-3 weeks with EXOGAM + NEDA.

Other crucial nuclei accessible in 3n evap. channels, including $^{101}\text{Sn}$. 
Single cell

Counts / 2 mm

Energy [MeV]

Z [cm]

BC501A
BC537

1 MeV
2 MeV
4 MeV
8 MeV

NEDA - G. Jaworski - San Servolo, June 30th, 2016
Single cell

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

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a Faculty of Physics, Warsaw University of Technology, ul. Koszykowa 75, 00-662 Warsaw, Poland
b Heavy Ion Laboratory, University of Warsaw, ul. Pasteura 5A, PL 02-093 Warsaw, Poland
c INFN, Laboratori Nazionali di Legnaro, Legnaro, Italy
d CENBG, Saclay, France
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* Institute for Nuclear Physics, Saclay, France
i Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden
j Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden
k INFN Sezione di Padova, Padova, 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

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Scintillator

$\frac{d\sigma}{d\Omega_{\text{cm}}}$ vs. $\theta_{\text{cm}}$ (elastic) for n+p scattering at 5 MeV

Expected $\sigma = 1.622$ barns
Expected $\frac{d\sigma}{d\Omega} = 129$ mb/sr
Blue - Geant4.9.2.p01 with NeutronHP model

Light Output (keVee)

Fast/slow

ANN cutoff

n BC501A

n BC537

$\gamma$ BC537

$\gamma$ BC501A

NEDA - G. Jaworski - San Servolo, June 30th, 2016
### Full geometry

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<th>M</th>
<th>Eff 1n</th>
<th>Eff 2n</th>
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<td>BCS01A</td>
<td>8.21%</td>
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<td>28.22%</td>
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### Parameters

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<td>R</td>
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<td>N</td>
<td>Granularity (Number of modules)</td>
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<td>V</td>
<td>Total Volume (liter)</td>
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<tr>
<td>AV</td>
<td>Average Volume (liter)</td>
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<td>Ω</td>
<td>Solid angle coverage (π)</td>
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<td>M</td>
<td>Material</td>
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### Notes

- Simulated neutron source: CI-252
- Depth of the detectors: 20 cm
- Neutrons were shot in 2π solid angle
- 1*10^7 statistics have been recorded

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NEDA - G. Jaworski - San Servolo, June 30^{th}, 2016
Digital timing algorithm for various 5” PMTs

PMT tests for best timing for NEDA
NGD

Digital PSA algorithm for various 5” PMTs

Test of digital neutron–gamma discrimination with four different photomultiplier tubes for the NEutron Detector Array (NEDA)


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3 INP, Laboratori Nazionali di Legnaro, F-35032 Legnaro, Padova, Italy
4 IFIC-CSIC, University of Valencia, Valencia, Spain
5 Department of Electronic Engineering, University of Valencia, E-46071 Valencia, Spain
6 Faculty of Engineering and Natural Sciences, Istanbul Sabahattin Zaim University, Istanbul, Turkey
7 Ngāi University, Rarotonga, Cook Islands, New Zealand
8 CAHE, CEA/DAM and CNRS/IN2P3, Bâtiment Borex, BP 55227, F-14076 Caen Cedex 05, France
9 Faculty of Physics, Warsaw University of Technology, ul. Koszykowa 75, 00-662 Warsaw, Poland
10 Heavy Ion Laboratory, University of Warsaw, ul. Pasteura 5A, 02-093 Warsaw, Poland
11 National Centre for Nuclear Research, A. Sołtana 7, PL 05-400 Otwock-Swierk, Poland
12 Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany
13 KEK Nihiwa Center, 2-1 Higashikita, Minato-ku, Tokyo 115-0003, Japan
14 Department of Physics, University of York, Heslington, York YO10 5DD, UK

Fig. 10. FOM values of the IRT method for PMT ET9390kb, R11833-100, XP4512, and R4144 as a function of energy window (the widths of the windows are 10, 40, and 100 keVee in energy regions of 50–100, 100–500, and 500–1000 keVee, respectively).

PMT tests for best NGD for NEDA

NEDA - G. Jaworski - San Servolo, June 30th, 2016
Electronics

→ NUMEXO2 board
→ GTS on board
→ GTS logic trigger tree
→ 200 MHz, 14 b (11.3 enob)
Mezzanines FADC

Figure 20: Global electronics layout for 48 NEDA detectors
Conceptual design of the early implementation of the NEutron Detector Array (NEDA) with AGATA

Table 4. One-, two- and three-neutron efficiencies obtained from simulations of a fusion-evaporation reaction $^{58}\text{Ni} + ^{56}\text{Fe}$ at 220 MeV for the different detector configurations. Errors quoted are statistical.

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<tr>
<th>Geometry</th>
<th>$\varepsilon_1n$ [%]</th>
<th>$\varepsilon_2n$ [%]</th>
<th>$\varepsilon_3n$ [%]</th>
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<td>Neutron Wall (NW)</td>
<td>26.00 (5)</td>
<td>3.93 (10)</td>
<td>0.55 (14)</td>
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<tr>
<td>NEDA + NW</td>
<td>28.70 (5)</td>
<td>6.37 (11)</td>
<td>1.66 (12)</td>
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<tr>
<td>NEDA + NW-ring</td>
<td>31.30 (5)</td>
<td>7.62 (11)</td>
<td>1.89 (11)</td>
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</table>
Conceptual design of the early implementation of the Neutron Detector Array (NEDA) with AGATA by Tayfun Heyök et al.

<table>
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<th>[%]</th>
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<td>3.93 (10)</td>
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<td>300 (5)</td>
<td>6.37 (11)</td>
<td>1.66 (12)</td>
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<tr>
<td>400 (5)</td>
<td>7.62 (11)</td>
<td>1.89 (11)</td>
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</table>
Prototype

NEDA - G. Jaworski - San Servolo, June 30th, 2016
Construction

Self production among collaboration, using:

→ Detector vessels and PMT housings are made by welding flanges to hexagonal profiles
→ EJ520 TiO$_2$ paint; TorrSeal; 5” 5mm BK7 glass
→ Expansion bellow – $\Delta T = 40$ K.
→ EJ301 (BC501) liquid scintillator

→ SBA R11833-100HA 5” PMT (32% Q.E.)
→ custom transistorized VD provided by Świerk
→ mu-metal shielding (1 mm)
→ NUMEXO2
→ Single ended to differential converter (progress)
→ Array structure (under design)
→ cables (some have, some testing)
Etching & Gluing corners
Painting & glass sealing
Mounting bellow, checking leakage
Filling and bubbling
Mounting and testing
Construction

NEDA

NWall

Quality starts from the initial signal.

NEDA - G. Jaworski - San Servolo, June 30\textsuperscript{th}, 2016
Construction
Construction
GANIL 2018: AGATA + NEDA

AGATA @ 145 mm
NEDA @ 510 mm
NW @ 650 mm
Physics with NEDA

- Single-particle and collective states around 100Sn heaviest bound $N=Z$ nucleus
- The demise of isospin purity: heavier Mirror nuclei are less similar
- Shape coexistence and collectivity in $N-Z$ nuclei ($A \approx 70$)
- Exotic structures along the $N=Z$ line: p-n enhancement of collective properties
- Spectroscopy at large isospin and exotic (particle) decays
- Proton "Islands of Inversion"

Isospin $T=0$ np-pairing
Isospin symmetry breaking
Mirror symmetry

$J=0$  
$T=1$

$J=1...2j$  
$T=0$
Physics with NEDA

J.J. Valiente-Dobon / E. Clement: Octupoles and Quadrupoles in Xenons

M.A. Bentley: \( ^{65}\text{As} \)

M. Palacz: \( ^{94}\text{Pd} \) lifetimes, high spin

A. Boso: \(^{71}\text{Kr} - ^{71}\text{Br}: \) isospin symmetry, shape coexistence

B. Cederwall: \(^{88}\text{Ru} - T = 0 \) pairing

J. Nyberg: \(^{102,103}\text{Sn} \) n-n, SPE, \( N=Z=50 \) ex.

S. Lenzi: \( A=63 \) isospin symmetry

B. Fornal: \(^{14}\text{C} \) clusterization
M. Bentley: In beam gamma-proton coincidence spectroscopy in $^{65}$As – isospin symmetry at the limits of proton binding.

A. Boso: Isospin symmetry breaking and shape coexistence in mirror nuclei $^{71}$Kr – $^{71}$Br.

B. Cederwall: Search for isoscalar pairing in $^{88}$Ru.

B. Fornal, S. Leoni & M. Ciemała: Gamma decay from near-threshold states in $^{14}$C: a probe of clusterization phenomena in open quantum systems.

S. Lenzi: Effects of Isospin Symmetry Breaking in the A=63 mirror nuclei.

J. Nyberg: Studies of excited states in $^{102,103}$Sn to deduce two-body neutron interactions, single-particle energies and $N = Z = 50$ core excitations.

M. Palacz: Purity of the $g_{9/2}$ configuration based on lifetime measurements and energies of excited states in $^{94}$Pd.

J.J. Valiente Dobon & E. Clément: Shell evolution of neutron-deficient Xe isotopes: Octupole and Quadrupole Correlations above $^{100}$Sn.
RIB: n tagging in transfer reactions

Lifetime measurements

Reachable via
(d,n)
(³He,n)
(⁴He,n)

26.3 ns
13.0 ns
10.8 ps


NEDA - G. Jaworski - San Servolo, June 30th, 2016
Summary

• Versatile neutron detector to be coupled to γ-ray arrays and charged particle detectors.

• High performance neutron multiplicity filter based on the liquid scintillator EJ301 with good neutron-gamma discrimination capabilities.

• The first campaign of physics will be NEDA coupled to AGATA@ GANIL with stable beams in 2018:
  – Fusion evaporation reactions along N=Z.

• Potentiality with future RIB: transfer reactions (3He,n), (d,n); plunger measurements (access to transition probabilities).

• The work continues.... (we will further invest in R&D of new materials and techniques to improve the neutron detection eff., discrimination, ...).
Collaboration


It's good for you!
Backup slides follow
Efficiency of a single NEDA detector

- thr. on light: 50 keVee
- 100 keVee
- 150 keVee

Neutron energy [MeV]

abs. eff. (x 1e-3)
Fig. 2. Digitized waveforms averaged over $10^5$ events for the four 5 in. PMTs coupled to a cylindrical 5 in. by 5 in. BC501A. The sampling frequency of the digitizer was 500 MS/s. The waveforms were normalized to a pulse height of 1000 and time aligned at the maximum of the signal. Dashed lines are drawn at 10%, 90%, at the maximum and at the baseline of the waveform to guide the eye.
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: \( \varepsilon(1n) \approx 40\% \ (20\%-25\%), \varepsilon(2n) \approx 6\% \ (1\%-3\%), \varepsilon(3n) \approx 1\% \ (0.1\%) \)

→ Excellent neutron-gamma discrimination.
→ Superior 1n/2n/3n discrimination.
→ Capability to run at much higher count rates than current arrays.
→ Cope with large neutron multiplicities in reactions with neutron-rich RIBs.
→ Improved neutron energy resolution for reaction studies.
Is it worth the effort?

\[ \varepsilon(1n) \approx 40\% \ (20-25\%), \ \varepsilon(2n) \approx 6\% \ (1-3\%). \]
\[ \varepsilon(3n) \approx 1\% \ (0.1 \%) \]

- The primary application of NEDA is to act as neutron multiplicity filter in \( \gamma \)-ray fusion-evaporation studies of very neutron deficient nuclei, close to \( N=Z \)
  - probe of \( T=0 \) correlations (like \( ^{92}\text{Pd} \))
  - \( ^{100}\text{Sn} \) 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, \( ^{34}\text{Ar}+^{16}\text{O} \rightarrow ^{44}\text{Cr}+\alpha 2n, \text{with PARIS} \))

- The power of the new neutron detector can be especially demonstrated in studies in which detection of 2 or more neutrons is required
Tests of NEDA prototype detectors

- 5x5 inch cylinders
- BC501A and BC537 – 2 of each type
- Photonis XP4512
- Struck SIS3350 (500 MHz, 12 bit)
- VME-based DAQ system by J. Agramunt-Ros
- BaF$_2$ for time reference
NEDA tests: digital neutron/$\gamma$ discrimination

P.-A. Söderström (RIKEN, Nishina, Japan; Uppsala University, Uppsala, Sweden)

Figure of merit: $\epsilon_\gamma = \text{fraction of } \gamma \text{ rays mis-identified as neutrons.}$

Shown in plots:
- $y$-axis: $\epsilon_\gamma = \text{fraction of } \gamma \text{ rays identified as neutrons.}$
- $x$-axis: energy deposited in the detector in units of keV$_{ee}$ (keV electron-equivalent).
- Top (bottom) figure: 75% (95%) of the neutrons remain after neutron-gamma discrimination.
- Filled (open) symbols: BC501A (BC537)
- Digital neutron-$\gamma$ discrimination methods:
  - Circles: Artificial neural network
  - Triangles: Integrated rise-time
  - Squares: Charge-comparison

Conclusions:
- ANN is best in particular at small energies.
- BC501A is better than BC537.
Conclusions on deuterated vs proton-based scintillator

→ better light to energy correlation for deuterated scintillator only for small detectors – not NEDA case.

Proton-based BC501A:

→ gives more light;
→ has higher efficiency;
→ has better time resolution;
→ has better n/\gamma discrimination;
→ has smaller scattering probability (p_{1n->2n});
→ is much less expensive.

NEDA decided to use standard proton based scintillator
Design of a NEDA detector

ϕ = 127 mm - PMT diameter
L = 200 mm - length

drawings by Nicola Lollo
Phases of NEDA

- Phase 0: Upgrade of NWall electronics (going digital)
- Phase 1: Construction of $1\pi$ array, combined with NWall
- Phase 2: Final construction of $2\pi$ array, 355 detectors
- Phase 3: R&D on new material and light readout systems for a highly segmented neutron detector array.

MoU (4 years) signed in March 2012
Phases 0 to 2 (90 detectors)

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Estimated cost phase 0 to 2: ~ 0.5 MEuro
full NEDA ~ 1.3 MEuro
Summary and outlook

→ NEDA will be a neutron detector array to address the physics of neutron-rich and neutron-defficient nuclei in conjunction with γ-ray arrays like EXOGAM2, AGATA, GALILEO, PARIS.

→ Geant4 simulations:
  • model validated;
  • optimal size of detector units: 20 cm length, 5" diameter;
  • BC501A better then BC537 for our needs;
  • conceptual design: staircase geometry, 2Π, r = 1.0 m, 355 units.

→ experimental tests BC501A and BC537: proton based better: efficiency, NGD.
→ self production of the cells.
→ development of electronics in synergy with EXOGAM2 and PARIS.
→ NEDA will be built in phases: MoU signed in March 2012.

→ work on digital PSD, multiplicity identification and timing algorithms in progress.
→ mechanical design of detector units in progress.
Organization of NEDA

Spokesperson: J.J.V.D. (LNL-INFN)
GANIL Liason: M. Tripon (GANIL)
Management board:
- B. Wadsworth (U. of York)
- N. Erduram (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
FUTURO IN RICERCA (MIUR)
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 Científicas (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
NEutron DEtector developments for Nuclear Structure, Astrophysics and Applications (NEDENSAA)

- Three years project
- Eight countries (Bulgaria, Finland, France, Germany, Italy, Spain, Sweden, Turkey)
- MONSTER, NEULAND, n-detector DESIR, NEDA, Neutromania, ...

Kick-off meeting 15th-17th February – Madrid.

Next meeting – Catania February 20th to 22nd 2013
Working groups

• **Detector characteristics** (Physics interests of NEDA to define the detector specifications).
  - *Responsible: B. Wadsworth*

• **Geometry** (Make a full study of geometry to determine (materials) efficiency, reduce cross-talk, ... Comparison between different codes: Geant4, MCNP-X. Simulate effect of other ancillaries, neutron scattering.).
  - *Responsible: M. Palacz*

• **Study New Materials** (Exploring new materials, solid scintillators, deuterated liquid scintillators).
  - *Responsible: L. Stuttgé*

• **Digital Electronics** (Flash ADCs, GTS, NUMEXO electronics, ..)
  - *Responsible: A. Gadea*

• **PSA** (Pulse shapes analysis, PSA algorithms, ...).
  - *Responsible: J. Nyberg*

• **Synergies other detectors** (Detectors that can be considered in synergy with NEDA: AGATA, EXOGAM2, GALILEO, PARIS, AGATA, FAZIA, GASPARD, DIAMANT, DESCANT, FARCOS, RIPEN, Neutron spectroscopy at DESIR, MONSTER, NEUTROMANIA, ...).
  - *Responsible: P. Bednarczyk*
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 campaign (two experiments): GANIL 2012.
NEDA will 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.

- **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, GANIL)
  - Isospin effects on the symmetry energy and stellar collapse (Naples, Debrecen, LNL, Florence)

- **Nuclear Reactions**
  - Level densities of neutron-rich nuclei (Naples, LNL, Florence)
  - Fission dynamics of neutron-rich intermediate fissility systems (Naples, Debrecen, LNL, GANIL)
NEDA coupled to AGATA/GALILEO/EXOGAM2/PARIS

1. Digitizer
2. Pre-processing
3. PSA
4. Event Builder
5. Global Merger
6. Tracking
7. Online analysis

8. Digitizer
9. Pre-processing
10. PSA
11. Event Builder

GTS local

prompt trigger

REQ VAL

GTS supervisor

REQ VAL

NEDA

GAMMA-ARRAY
Digital electronics: EXOGAM2-NEDA-PARIS

NUMEXO2

[Diagram of a digital electronics system including components such as Virtex5FXT and Virtex5SX, with various interfaces and connections labeled.]
FADC Mezzanine
X. Egea and A. Gadea (IFIC, CSIC, Valencia)

- 4-channel acquisition with a sampling rate of 250 Msps and 14-bit resolution.
- Use of a PLL for jitter cleaning and clock synchronization.
- 6 W power consumption at 250 MHz.
- Possibility to use a variable offset by using a 16-bit digital-to-analog converter.
- Includes 2 QFS-026-04.75-LD-PC4 connectors, and through them, differential signals, control lines and power lines are transmitted by using the same connector.
- Includes an HDMI PCB receptacle, which will link the front-end electronics with the FADC mezzanine.
- 10 layers have been used in order to make possible this design by using high-speed layout techniques.
- The FADC follows an easy and straightforward placement and routing. Besides, symmetry has been provided in order to make an easier design.
- The board dimensions fit on the NIM standard, where 4 of these will be inserted into the crate. (42mm wide + 98.5 mm long)
- Most of the QFS lines are linked to the Virtex 6.
- It has been used a SPI control for all the devices.
HDMI NEDA Cable results

X. Egea (IFIC, CSIC, Valencia) & M. Tripón (GANIL)

- Several tests have been applied to different cables in order to test their performance.
- Among them we may mention the bandwidth, crosstalk, impedance and reflections, and EMC (electromagnetic compatibility).
- On the picture on the left it is shown the **HDMI cable**.
- The HDMI 1.4 version, including a double shield, makes an important improvement against high-voltage peaks.

- Top \(\rightarrow\) (From left to right): Crosstalk, reflections and EMC measurements.
- Bottom \(\rightarrow\) Bandwidth
- The HDMI 1.4 has a big stiffness and it might be a little bit problematic mechanically.
Tests at LNL BC501/BC537

- One unit cell $\rightarrow$ Staircase-$2\pi$ geometries.
- Relative efficiency BC501A/BC537
- Timing
- PSA BC501A/BC537: traditional and NN
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
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

Monday and Thursday talk by G. Jaworski
In beam test with the NW

- First in-beam waveform taking (two weeks ago @GANIL)
- 124 MeV $^{40}\text{Ca}$ onto $^{58}\text{Ni}$ 6 mg/cm² and $^{12}\text{C}$ 0.5 mg/cm²
- PSA algorithms
- MATACQ digitizer, 1GS/s, 14 bit
With current technological status …

• Three main options:
  – 200 detectors BC501A – PM readout – Digital electronics
    • Total cost: 600K€ (BC501A) + 200K€(Elec.) + 40K€ (mechanics) = 840 K€
  – 200 detectors BC537 – PM readout – Digital electronics
    • Total cost: 2000K€ (BC537) + 200K€(Elec.) + 40K€ (mechanics) = 2240 K€
  – Upgrade Neutron Wall - Phase 0 (Digital electronics)
    • Total cost (50 channels) = 40K€
NEDA test: PSA Charge Comparison

\[ M = \frac{|X_\gamma - X_n|}{W_\gamma + W_n}. \]
Interactions of neutrons in the scintillator

![Diagram showing neutron interactions in BC501A and BC537 scintillators.](image)
**Neutron - gamma discrimination**

Liquid scintillators give a difference in signal pulse shapes for neutrons and gamma rays:

- neutrons (recoiling protons) - slow light component ($\tau \sim 300$ ns)
- $\gamma$ rays (electrons) - fast light component ($\tau \sim 3$ ns)

Pulse shape combined with TOF gives with $\gamma$-ray as neutron interpretation probability $\sim 0.1\%$.

Present NWAll: pulse shape discrimination analog. NEDA will use digital techniques.
$1n/2n/3n$ discrimination

$\varepsilon_{2n} \approx 2\%$

$P_{1n \rightarrow 2n} \approx 4 \times 10^{-4}$

J. Ljungvall et al. NIM A528 (2004) 741
Validation of the simulations

Detector and radioactive source

<table>
<thead>
<tr>
<th>Efficiency (%)</th>
<th>Exp.</th>
<th>Sim.</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORDBALL:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{137}$Cs $\gamma$ rays, 50 cm</td>
<td>0.30(1)</td>
<td>0.285(1)</td>
</tr>
<tr>
<td>$^{252}$Cf neutrons, 51 cm</td>
<td>0.174(9)</td>
<td>0.241(2)</td>
</tr>
<tr>
<td>Cylindrical:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{252}$Cf neutrons, 5 cm</td>
<td>6.1(3)</td>
<td>6.64(2)</td>
</tr>
</tbody>
</table>
Geant 4 simulations

Light output for 2 MeV neutrons
Instrumental response function included

Light to energy dependence

![Graph showing light output for 2 MeV neutrons with instrumental response function included.](image_url)

G. Jaworski et al. NIM A673 (2012) 64
Geant 4 simulations

Neutron detection efficiency

![Graph showing neutron detection efficiency vs neutron energy for BC501A and BC537.](image)
Tests of NEDA prototype detectors

$^{252}$Cf neutron energy distribution
Transverse position of the sig. interaction

Light output for 10 MeV neutrons
An instrumental response function not included

Influence of the 100 ns detection time limit on the p(1n→2n).
Preliminary time line of NEDA

2016
Production of NEDA

2017
NEDA/AGATA@GANIL

2018
CERN Shutdown

2019
NEDA SPES

2020
HIE-ISOLDE

2021
HIE-ISOLDE

2022
HISPEC

2023
LNS?

2024

2025

2026

2027

2028

2029

2030