NEDA (NEutron Detector Array)

J.J. Valiente Dobon (LNL-INFN)

on behalf of the NEDA collaboration

Organization

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

GANIL Liason: M. Tripon (GANIL)

Steering committee:

-B. Wadsworth (U. of York)

-N. Erduram (U. of Istanbul)

-L. Sttugge (IRES – Strasbodurg)

-J. Nyberg (U. of Uppsala)

-M. Palacz (U. of Warsaw)

-A. Gadea (IFIC - Valencia)

FP7-INFRASTRUCTURES-2007-1

SPIRAL2 PREPARATORY PHASE

FIRB

FUTURO IN RICERCA (MIUR)

Members of the collaboration:

U. of Ankara (Turkey), COPIN (Poland), CSIC-IFIC (Spain), Daresbury Laboratory (U.K.), GANIL (France), U. of Istanbul (Turkey), INFN (Italy), IRES (France), U. of Nidge (Turkey), U. of Uppsala (Sweeden), U. of York (U.K.) and *Kolkata, India (under discussion)*

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, EXOGAM2 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: EXOGAM2, GALILEO, PARIS, AGATA, FAZIA, GASPARD, DIAMANT, DESCANT, FARCOS, RIPEN, Neutron spectroscopy at DESIR, MONSTER, NEUTROMANIA, ...).
    - *Responsible: P. Bednarczyk*

Collaboration meetings

- Three collaboration meetings, where the physics, simulations and electronics have been discussed as well as the synergies with other detectors/projects such us: AGATA, GALILEO, EXOGAM2, PARIS, FARCOS, DESCANT, MONSTER, NEUTROMANIA, etc
  - Kick off meeting - Warsaw 5/10/2007
  - Collaboration meeting - Istanbul 18/6/2009
  - Collaboration meeting - Valencia 3/10/2010

Physics with NEDA

NEDA will address the physics of neutron-rich as well as neutron deficient nuclei, mainly in conjunction with gamma-ray detectors 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, GANIL, Stockholm, York)
  - Coulomb Energy Differences in isobaric multiplets: T=0 versus T=1 states (Warsaw, LNL, GANIL, York)
  - Coulomb Energy Differences and Nuclear Shapes (York, Padova, GANIL)
  - Low-lying collective modes in proton rich nuclei (Valencia, Krakow, Istanbul, Milano, LNL)
- **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)

Proton Pygmy Dipole resonance

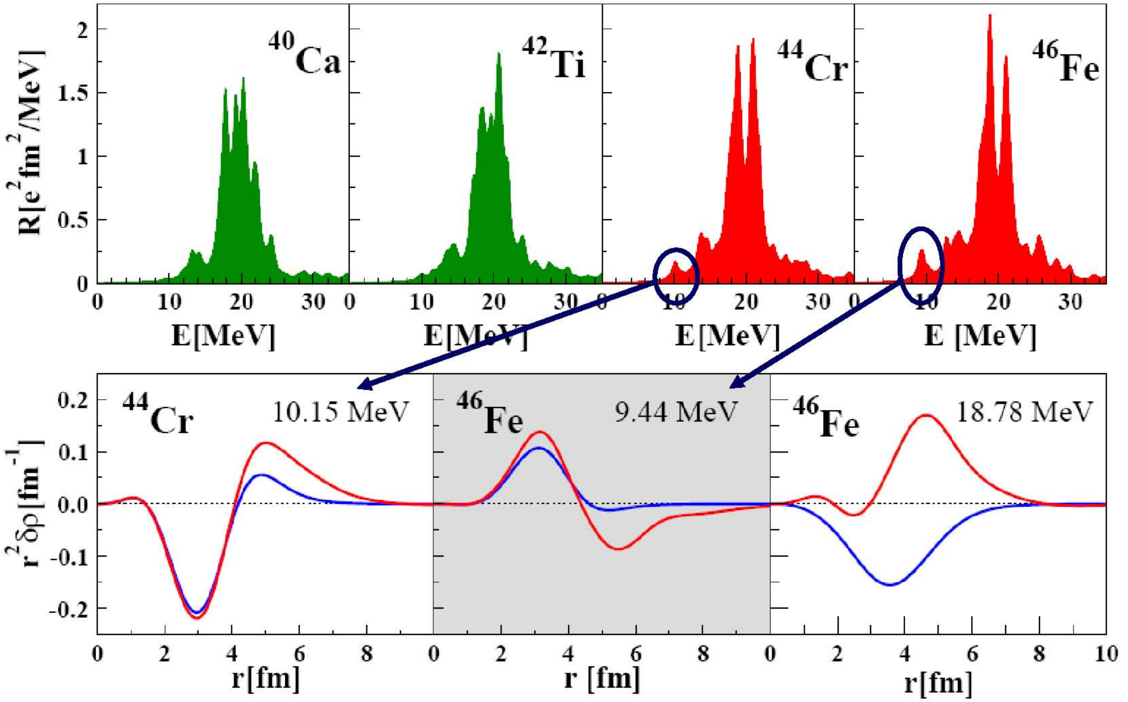
PARIS + NEDA

Low-lying collective modes in proton rich nuclei

Evolution of low-lying E1 strength in proton-rich nuclei

Paar, Vretenar, Ring, Phys. Rev. Lett. 94, 182501 (2005)

RHB+RQRPA isovector dipole strength distribution in the N=20 isotones.
DD-ME1 effective interaction + Gogny pairing.



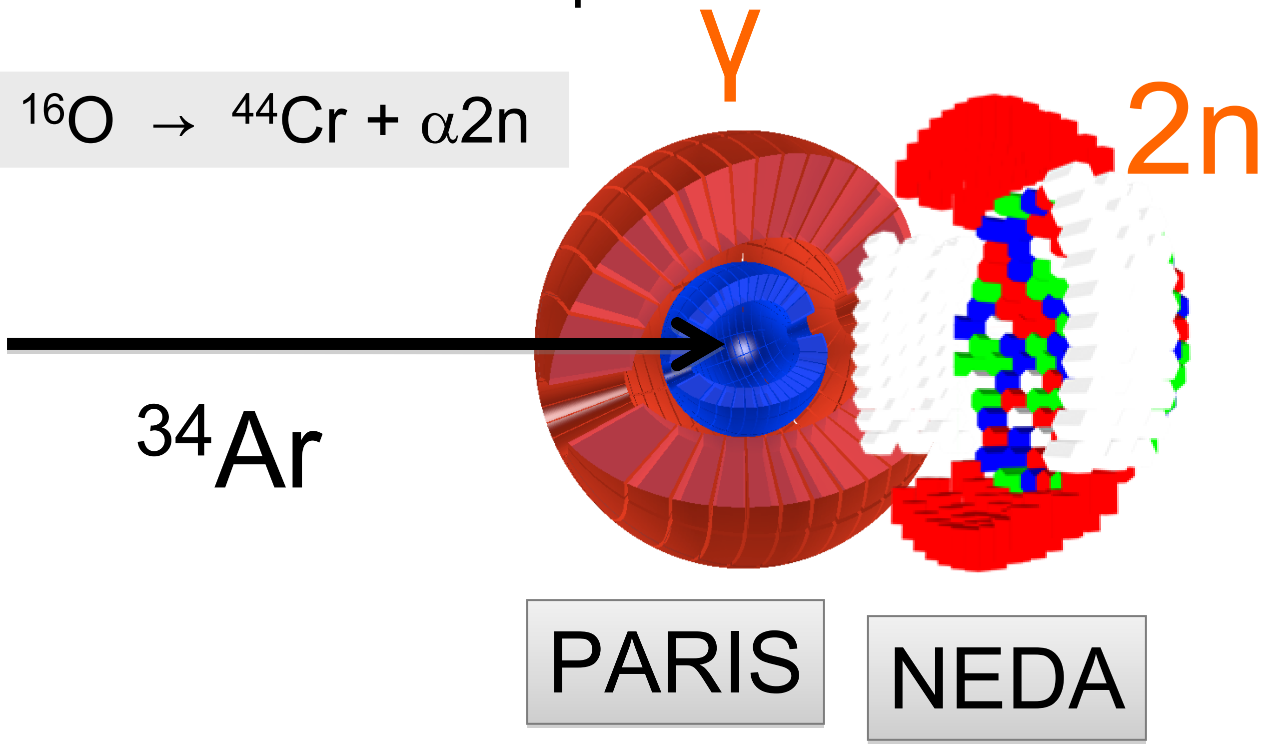
N=20

Transition densities

Experiment PARIS + NEDA

Proton pygmy dipole states develop in light and medium mass proton-rich: ^{44}Cr

$^{34}Ar + ^{16}O \rightarrow ^{44}Cr + \alpha 2n$



The p and n transition densities show that the PDR states correspond to the oscillation of the proton excess against and approximately isospin saturated core.

NEDA+PARIS experiment

Spiral2

Light and N=Z RIB at SPIRAL 2

Rough Estimation of Yields (Examples)

Courtesy M. Lewitowicz

RI Beam	Reaction	Production method	Yield (min. - max.) in pps
^{6}He	$^{9}Be(n,\alpha)^{6}He$	ISOL	5×10^{7} - 10^{12}
^{11}C	$^{14}N(p,\alpha)^{11}C$	ISOL	10^{7} - 3×10^{11}
^{15}O	$^{15}N(d,2n)^{15}O$	ISOL	3×10^{7} - 10^{10}
^{18}Ne	$^{19}F(p,2n)^{18}Ne$	ISOL	6×10^{6} - 7×10^{9}
^{34}Ar	$^{35}Cl(p,2n)^{34}Ar$	ISOL	2×10^{6} - 2×10^{8}
^{56}Ni	$^{58}Ni(p,p2n)^{56}Ni$	Batch mode	2×10^{4} - 10^{8}
^{58}Cu	$^{58}Ni(p,n)^{58}Cu$	Batch mode	10^{4} - 10^{8}
^{80}Zn	$^{24}Mg+^{58}Ni$	In-flight	$< 3\times10^{4}$

The reaction to study the Pigmy resonance in ^{44}Cr

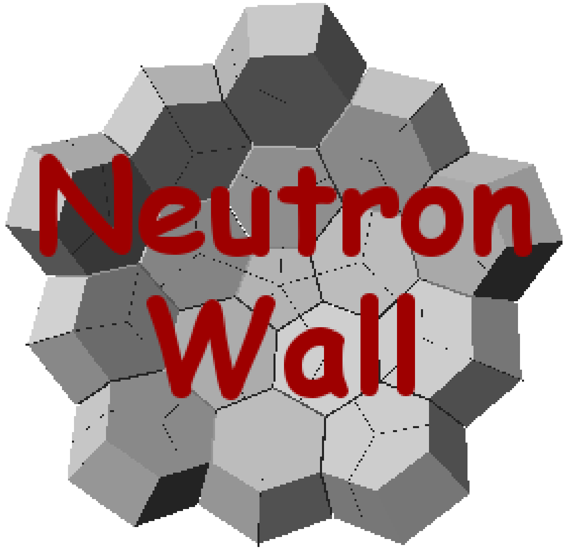
$$^{34}Ar + ^{16}O \rightarrow ^{44}Cr + \alpha 2n \quad (^{34}Ar\ 10^{8}\ pps)$$

Problem definition

-NEDA: Neutron detector to be used coupled to AGATA/GALILEO/EXOGAM2/PARIS

-Previous experience with the NWall (BC501) currently at GANIL

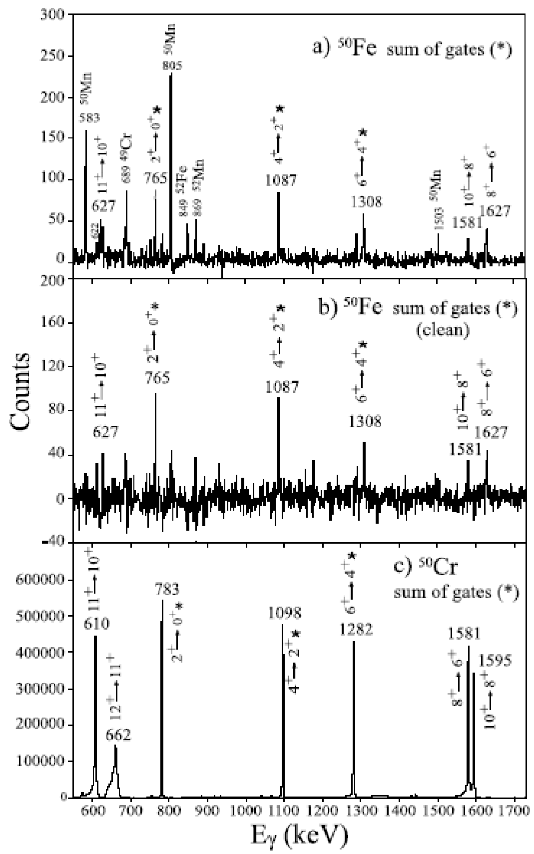
- -High efficiency 25% for one neutron.
- -Relatively good gamma/neutron discrimination.
- -Problems with cross talk.
- -Low efficiency for 2n (1-2%).
- -Analogic electronics.



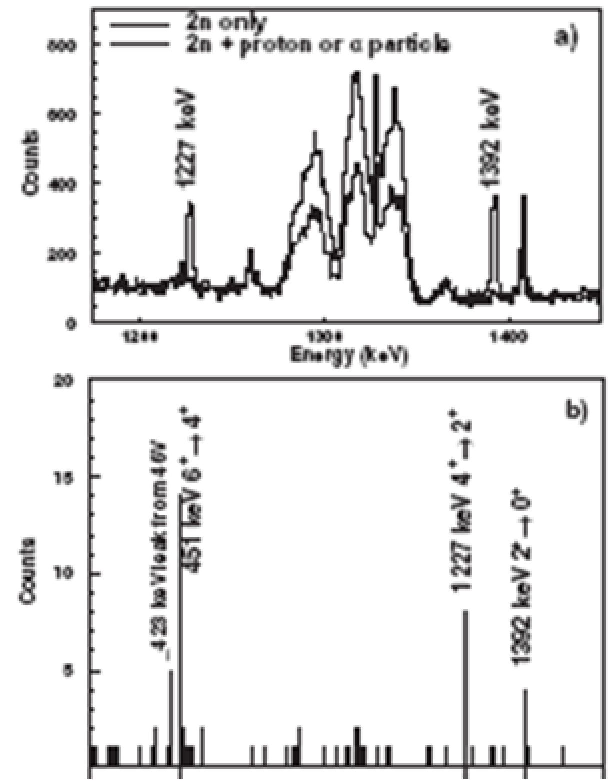
Neutron Wall: N=Z-2

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

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



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



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

Strategy of NEDA

-Optimization of the geometry: unitary cell size, spherical, planar, zig-zag, granularity, distance, versatility.

-FEE: GTS integrated in the motherboard and FADC in a mezzanine. Fully compatible with other gamma-ray arrays.

-Possible use of the deuterated scintillator BC537

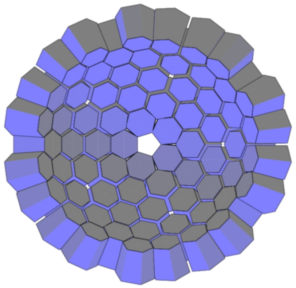
  -Pulse height seems to be proportional to incident neutron energy (reported by DESCANT collaboration)

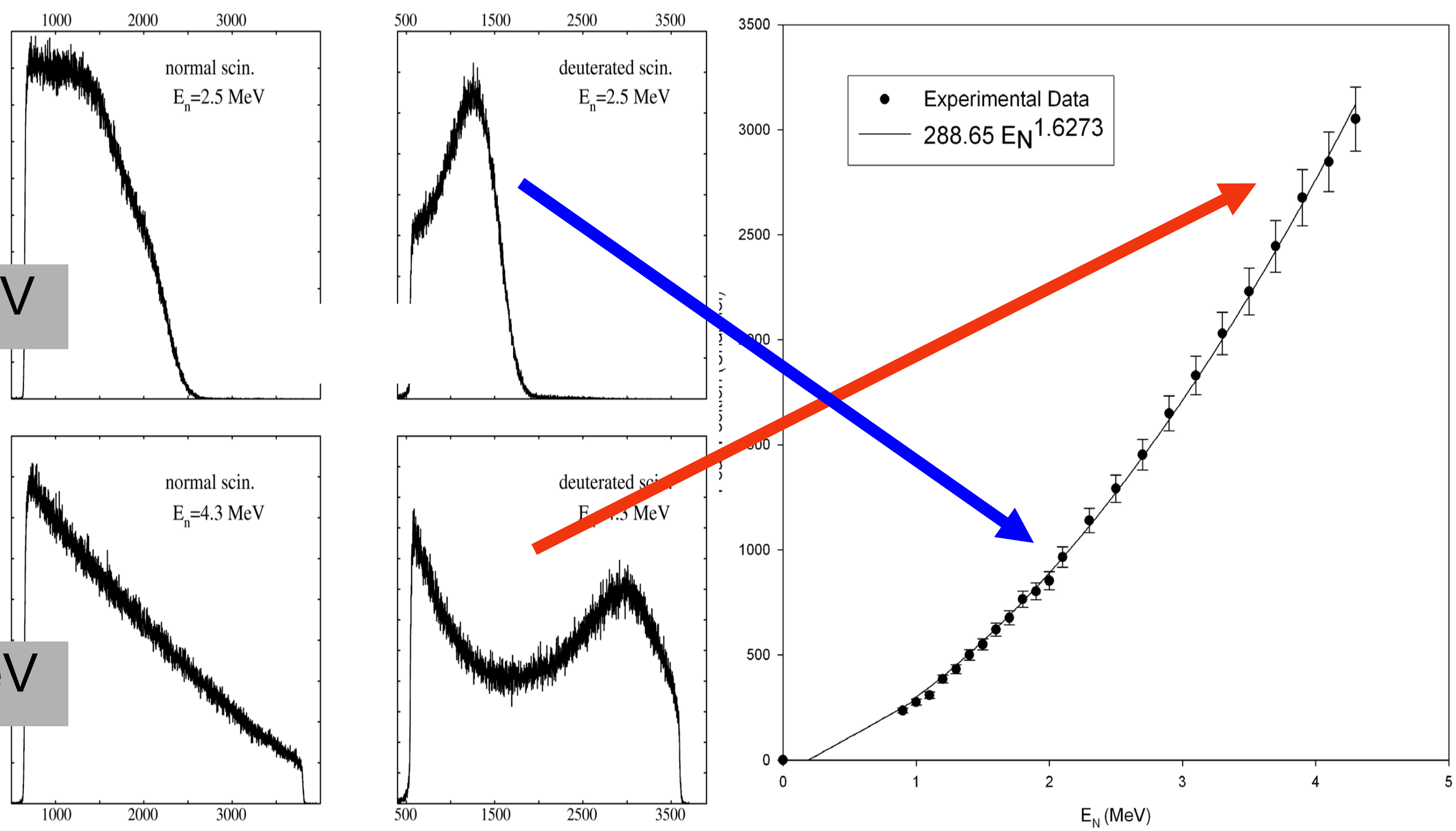
  -Provides another method of determinig neutron energy beyond TOF

  -Can lead to a better discrimination of high multiplicity neutron events and scattered events.

-New solid scintillators ➔ Lawrence Livermore National Laboratory

BC501 vs. BC537 response

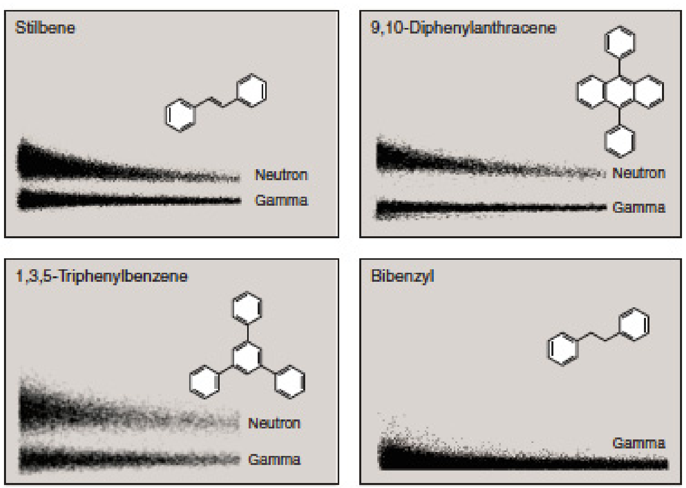




Courtesy of P. Garrett, University of Guelph.

Solid scintillators 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.



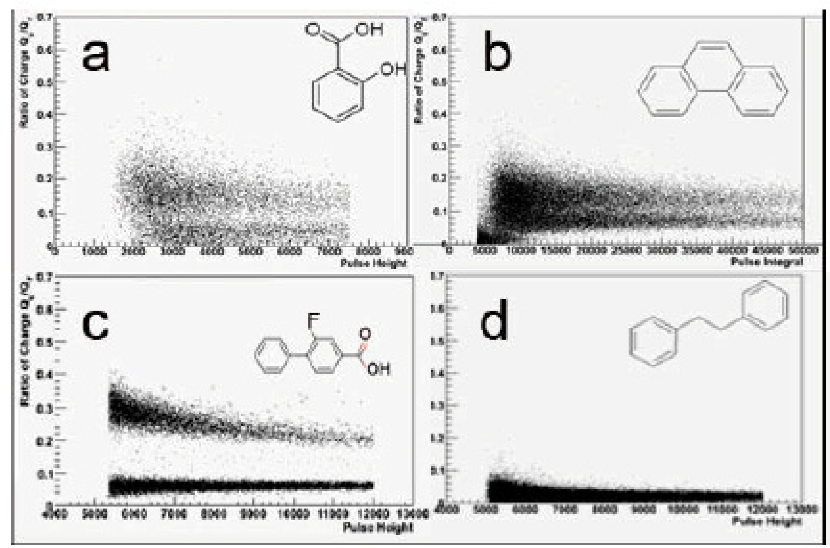
Neutron detection with single crystal organic scintillators

Natalia P. Zaitseva*, Jason Newby, Sebastien Hamel, Leslie Carman, Michelle Faust, Vincenzo Lordi, Nerine J. Cherepy, Wolfgang Stoeffl, and Stephen A. Payne

Lawrence Livermore National Laboratory, Livermore, CA

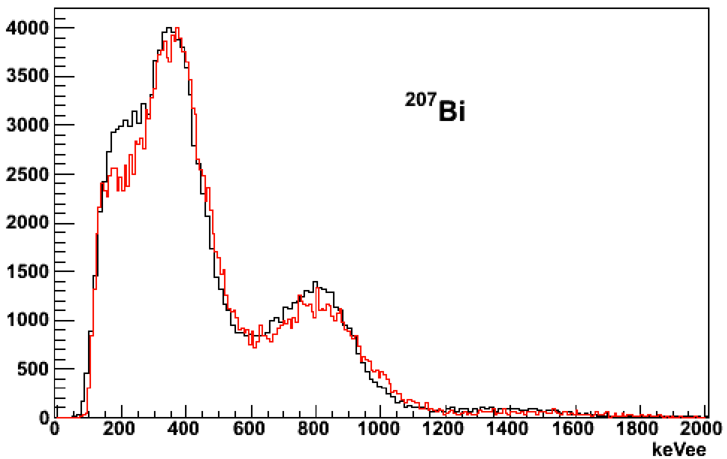
ABSRACT

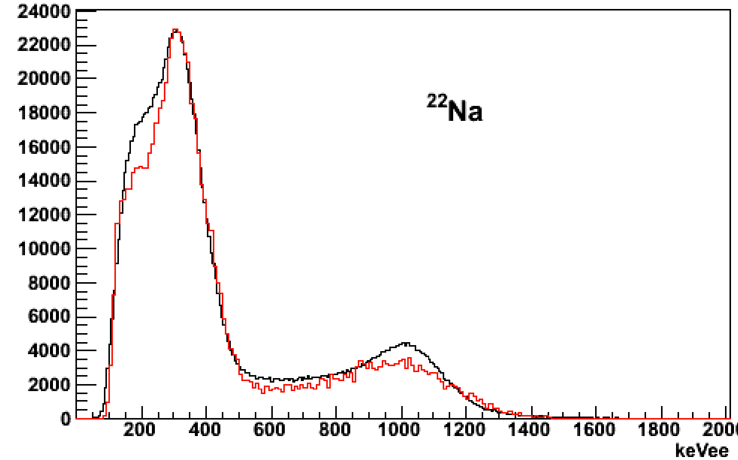
Detection of high-energy neutrons in the presence of gamma radiation background utilizes pulse-shape discrimination (PSD) phenomena in organics studied previously only with limited number of materials, mostly liquid scintillators and single crystal stilbene. The current paper presents the results obtained with broader varieties of luminescent organic single crystals. The studies involve experimental tools of crystal growth and material characterization in combination with the advanced computer modeling, with the final goal of better understanding the relevance between the nature of the organic materials and their PSD properties. Special consideration is given to the factors that may diminish or even completely obscure the PSD properties in scintillating crystals. Among such factors are molecular and crystallographic structures that determine exchange coupling and exciton mobility in organic materials and the impurity effect discussed on the examples of trans-stilbene, bibenzyl, 9,10-diphenylanthracene and diphenylacetylene.

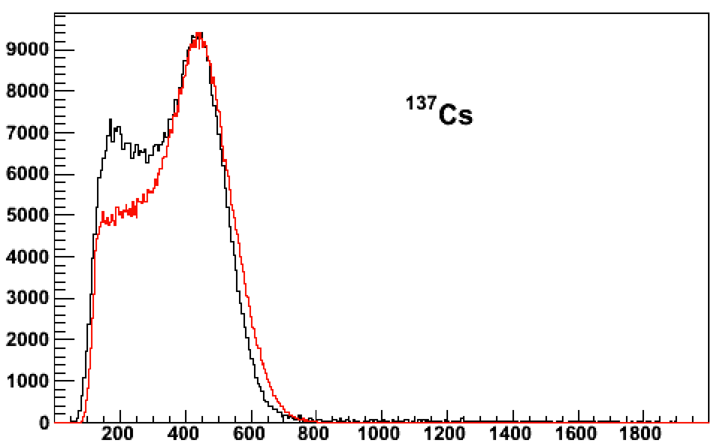


Simulations for NEDA

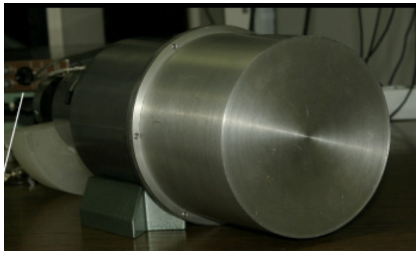
Large work has been performed to validate the GEANT4 simulations + light production





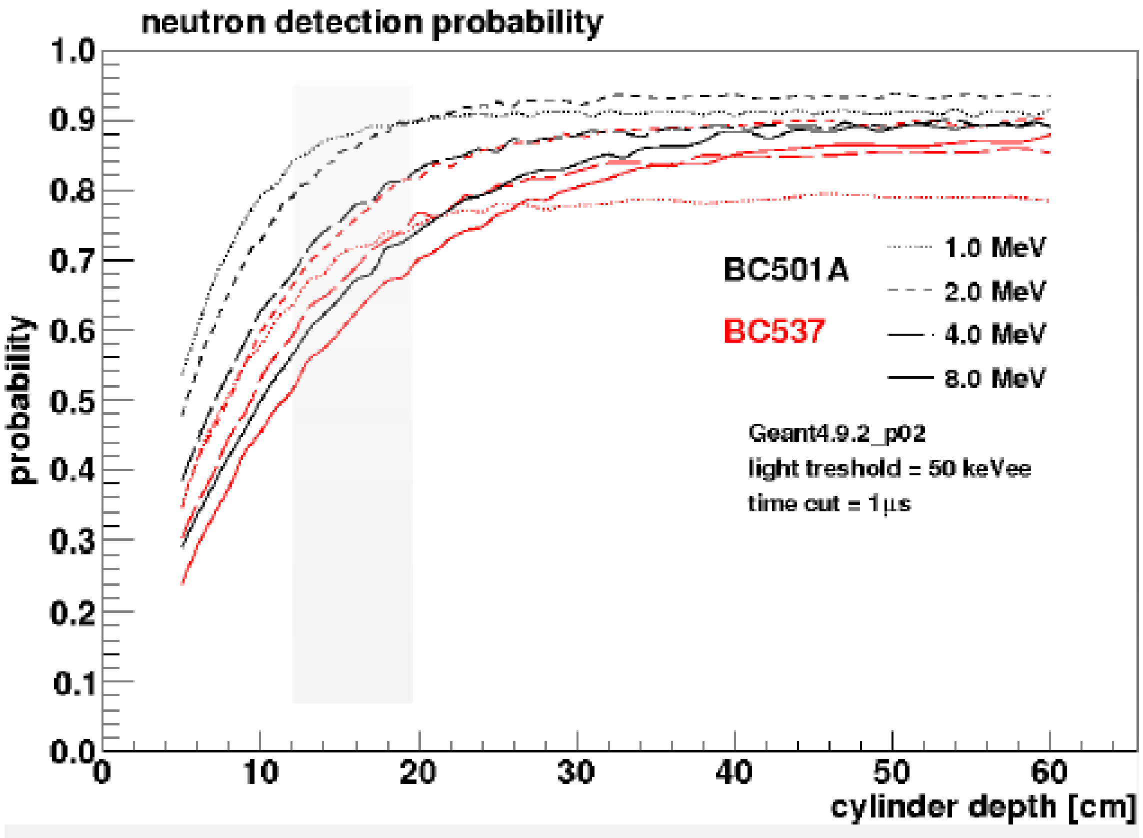


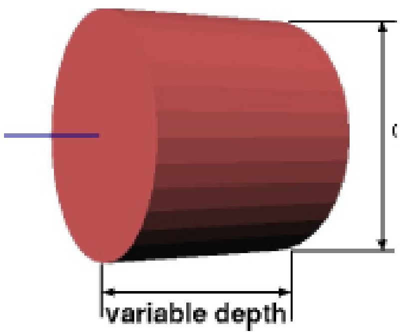
CAEN digitizer 250Mhz, 12bit



BC501A

Unitary cell dimensions





Definition of the unitary cell dimensions: depth=20cm, diameter=5”

Geometries

There are two possible main geometries, either spherical or planar.

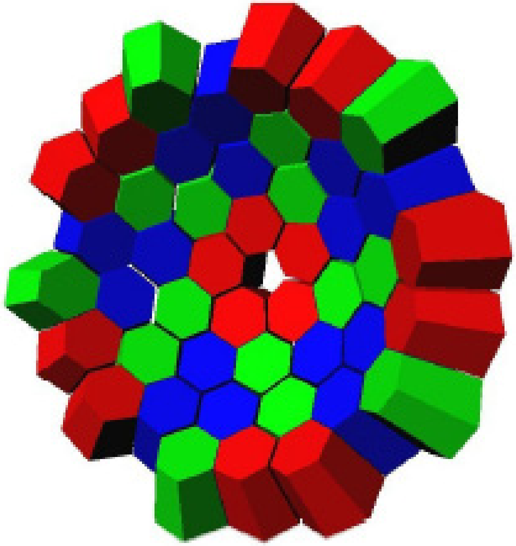
•The spherical geometry presents the full symmetry.

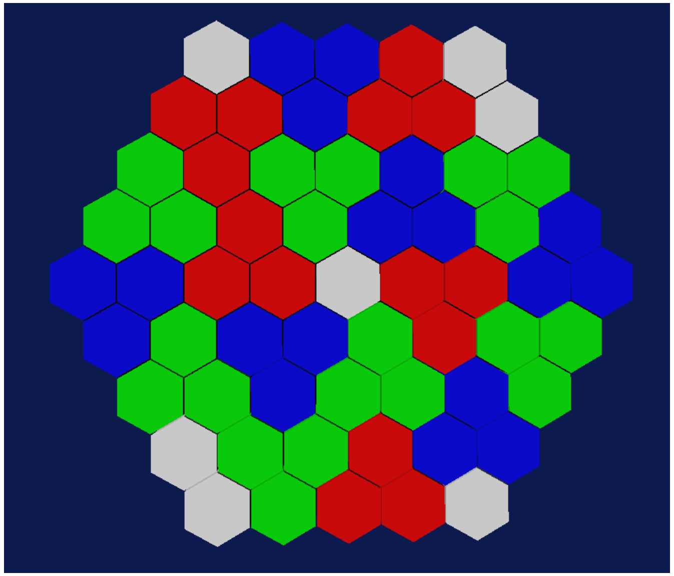
•The planar has some advantages, than the spherical does not present.

-Flexibility – different arrangements of the detectors, e.g. zig-zag

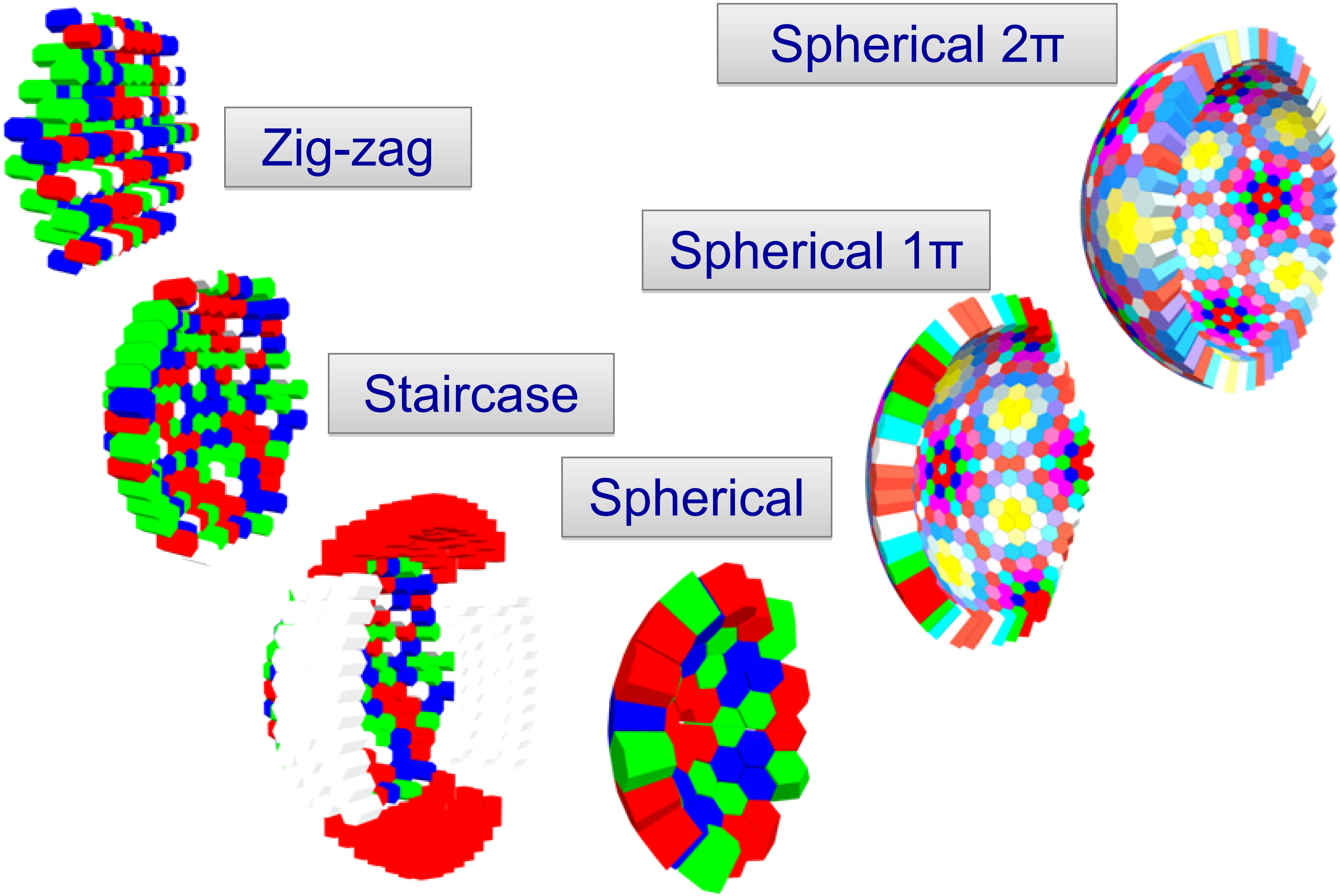
-Different focal posistions (500cm, 1000cm, 2000cm)

-Budget issues

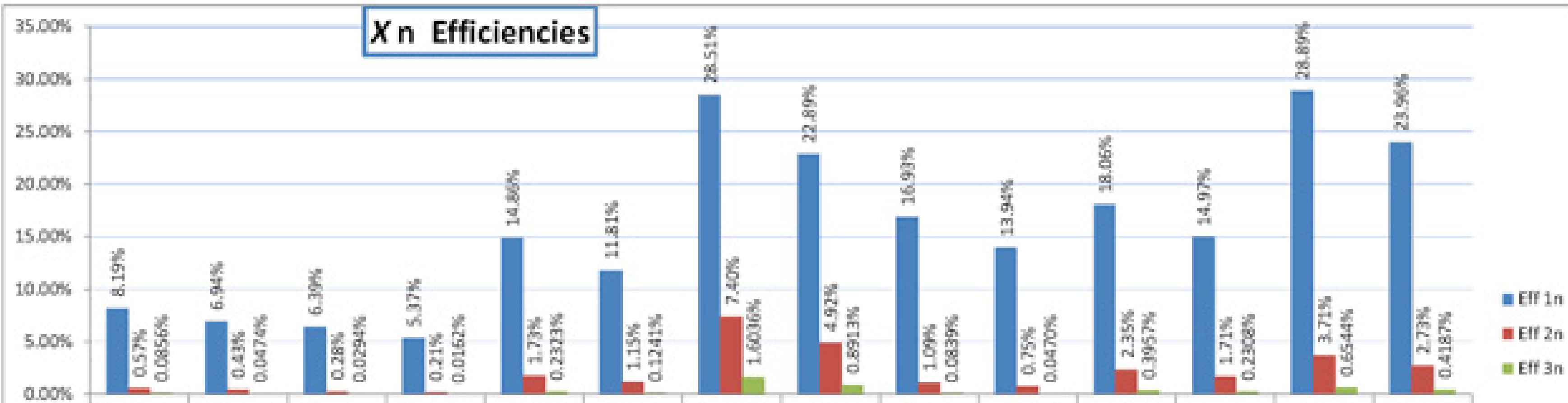




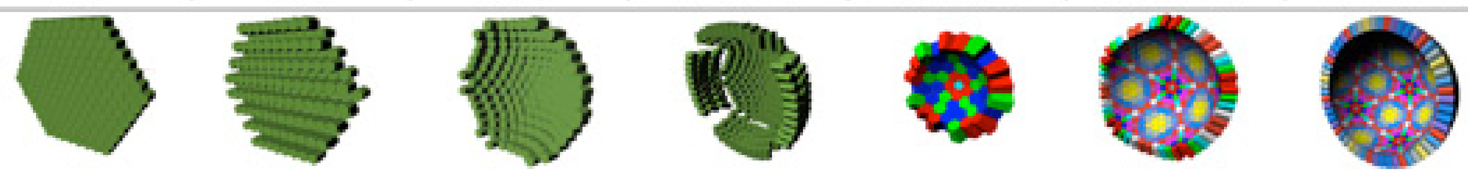
Different NEDA geometries



Performances of various geometries



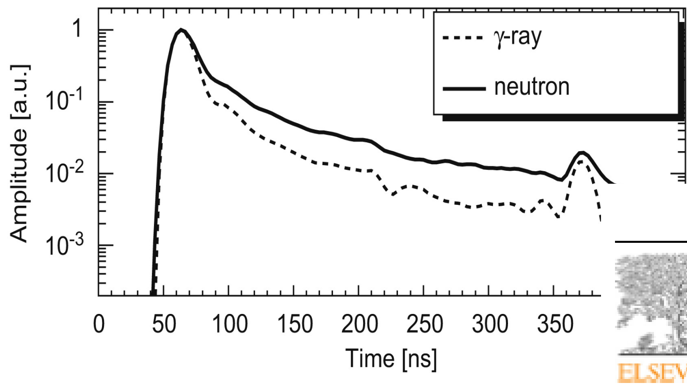
M	BC501A	BC537	BC501A	BC537	BC501A	BC537	BC501A	BC537	BC501A	BC537	BC501A	BC537	BC501A	BC537
Ω	0.6		0.6		1		2		1		1		2	
AV	3		3		3		3		4.5		2		2	
V	507		507		489		1065		202.5		652		1212	
N	169		169		163		355		45		326		606	
R	1m		1m		1m		1m		0.5 m		1m		1m	
	Planar		Zigzag		Staircase		Staircase 2pi		Spherical N180		Spherical 1m1pi		Spherical 1m2pi	



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

Discriminating neutron/gamma



Nuclear Instruments and Methods in Physics Research A 594 (2008) 79–89

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

Digital pulse-shape discrimination of fast neutrons and γ rays

P.-A. Söderström *, J. Nyberg, R. Wolters

Department of Physics and Astronomy, Uppsala University, SE-75121 Uppsala, Sweden

Nuclear Instruments and Methods in Physics Research A ▮ (▮▮▮) ▮▮–▮▮

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Nuclear Instruments and Methods in Physics Research A

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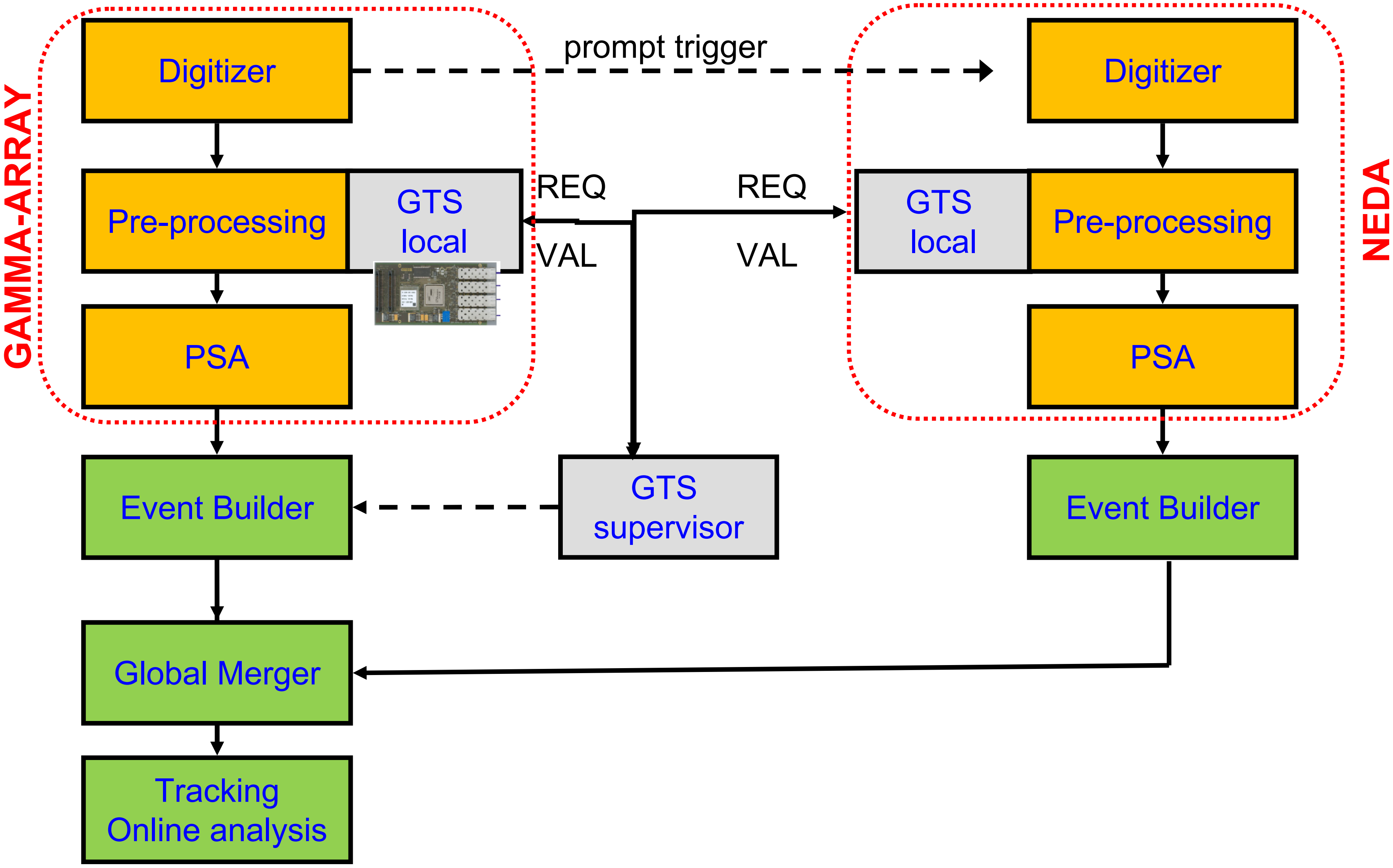
An artificial neural network based neutron–gamma discrimination and pile-up rejection framework for the BC-501 liquid scintillation detector

E. Ronchi *, P.-A. Söderström, J. Nyberg, E. Andersson Sundén, S. Conroy, G. Ericsson, C. Hellesen, M. Gatu Johnson, M. Weiszflog

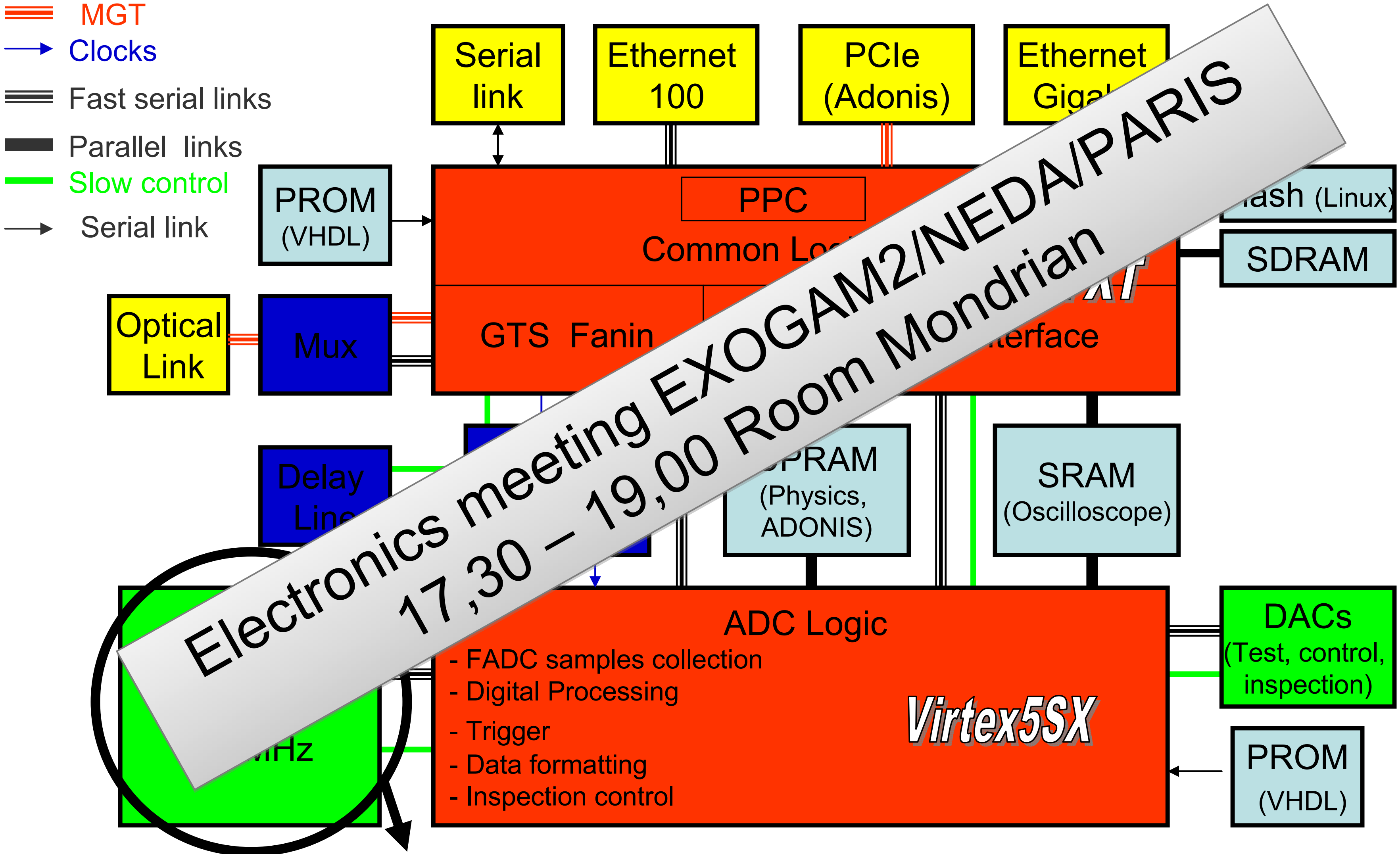
Department of Physics and Astronomy, SE-75120 Uppsala, Sweden

Applying an artificial neural network can increase the quality even further

NEDA coupled to AGATA/EXOGAM2



Digital electronics: EXOGAM2-NEDA



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

Phases of NEDA

The current development on new materials and readout systems for neutron detection makes necessary to build NEDA in four different phases:

- Phase 0: Upgrade of Neutron Wall with digital electronics.
- Phase 1: R&D on new material and light readout systems for a highly segmented neutron detector array.
- Phase 3: Construction of a limited size Demonstrator
- Phase 4: Final construction of NEDA

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 BC536 – 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€

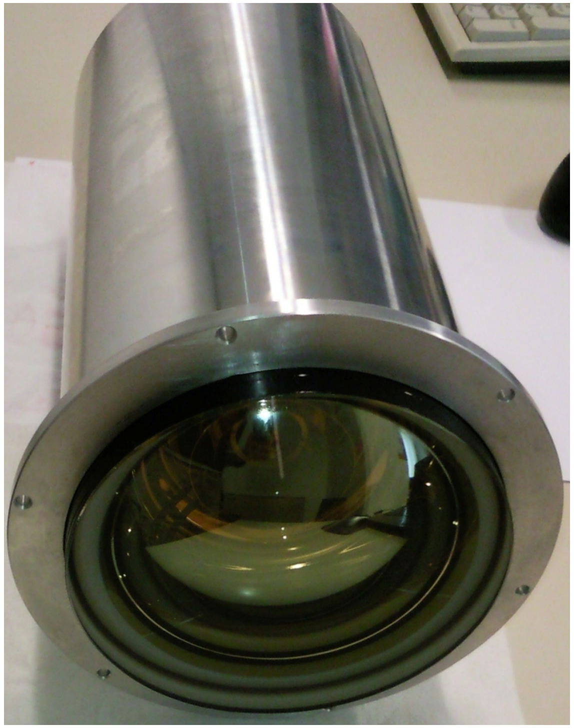
Summary

- 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 detectors arrays like AGATA, GALILEO, EXOGAM2 and PARIS.*
- Optimal geometry
- Currently bought BC537 and BC501A commercial detectors to test:
  - cross talk
  - light production
  - FADC – frecuency and number of bits
  - PSA – neutron-gamma discrimination
- Test of SPMPlus from York in BC537 and BC501A
- Development of electronics in synergy with EXOGAM2
- Steering Committee decision on the final geometry for NEDA
- Steering Committee decision on the liquid scintillator to be used
- Steering Committee phases of NEDA

BC501A and BC537 detectors

Currently bought commercial detectors from Saint Gobain

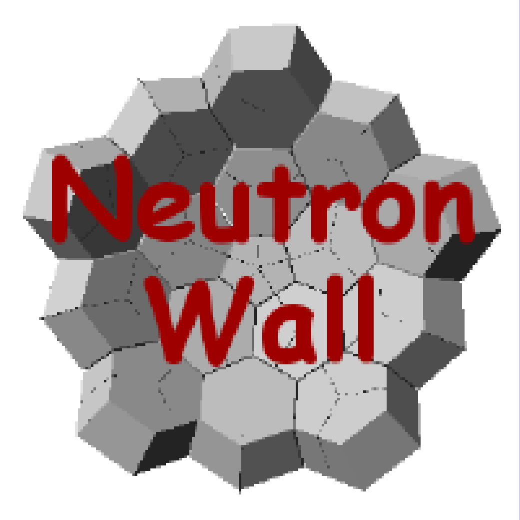
- Two detectors 5”x5” BC537
- Two detectors 5”x5” BC501A

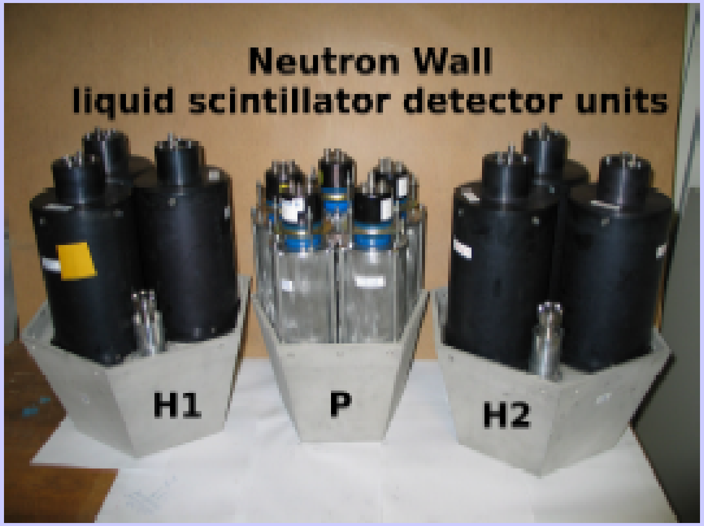


Characterization of the detectors.

Neutron Wall

- Closely packed ~1π neutron detector array of 50 liquid scintillator detectors (BC-501A)
- Neutron energy range: ~500 keV to ~10 MeV
- Built for the EUROBALL spectrometer 1995-97
- Owned by the European Gamma-Ray Spectroscopy Pool





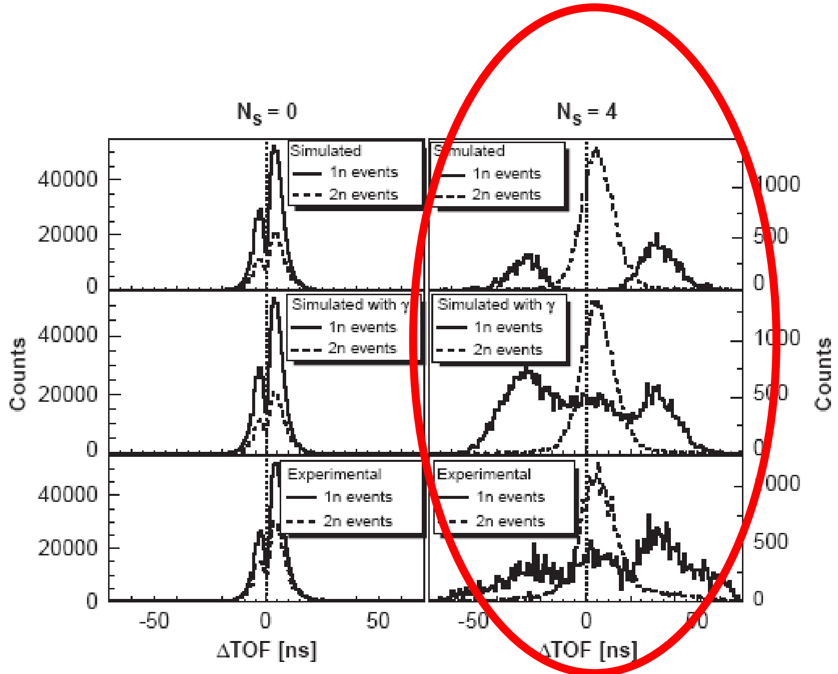
- 50 detector elements, ~15 cm thick
- 150 liter liquid scintillator (BC-501A)
- Distance target to detector front face = 51 cm
- Neutron-gamma discrimination: analog ZCO technique

Neutron Wall

- Experiments performed at EUROBALL/LNL, EUROBALL/IReS, EXOGAM/GANIL
- Used together with charged particle detector arrays (EUCLIDES, DIAMANT,...)

- GANIL homebase since 2005
- Four experimental campaigns at GANIL with EXOGAM and other detectors

Cross talk – low 2n cross section



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

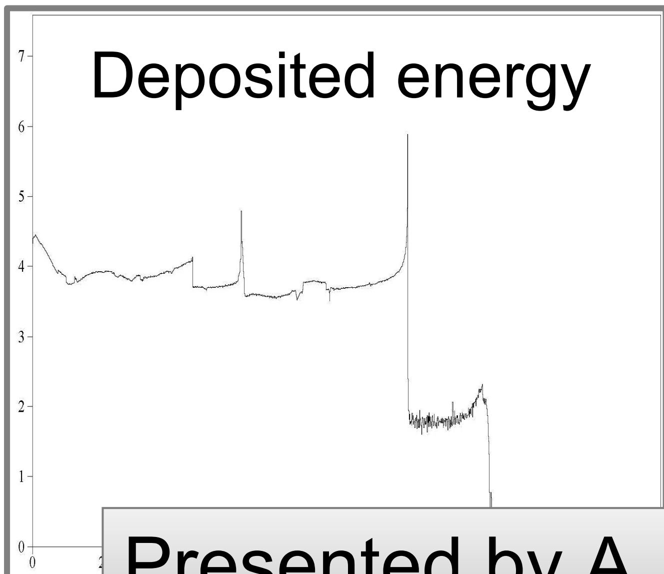
- High cross talk between neighboring detectors
- It is not possible to differenciate between 2n real events or just 1n scattered.
- Therefore neighbouring detectors are dismiss in the analysis and the efficiency decreases to 1-2%.

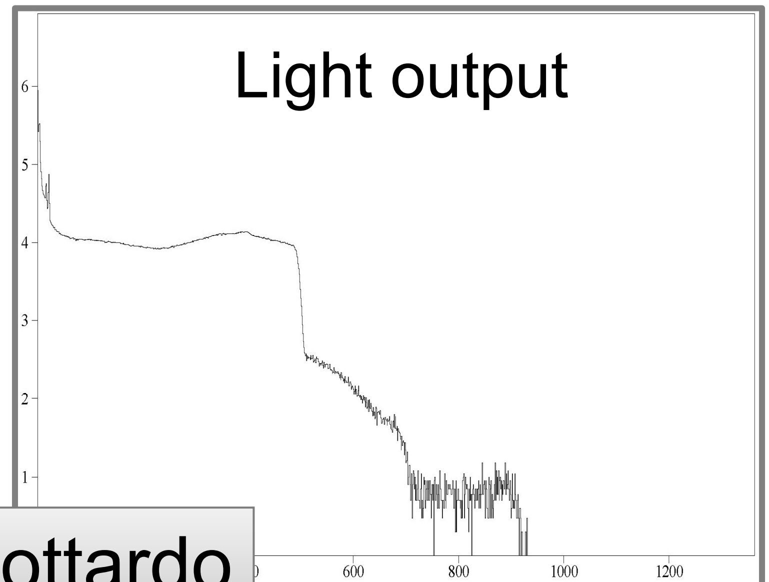
Possible to improve 2n efficiency using TOF among detectors

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

Light output of liquid scintillator

- The light-output L is usually given in MeVee: the particle energy required to generate 1 MeVee of light is defined as 1 MeV for fast electrons
- L is generally less for heavier particles such as protons, deuterons, alphas, beryllium, carbon…
- Therefore, the light output L in a certain path *dx* is a function of the deposited energy E in *dx:* L(E)





Presented by A. Gottardo

Dekempeneer et Liskien NIM A 256 (1987) 489-498