From Neutron Wall towards NEDA

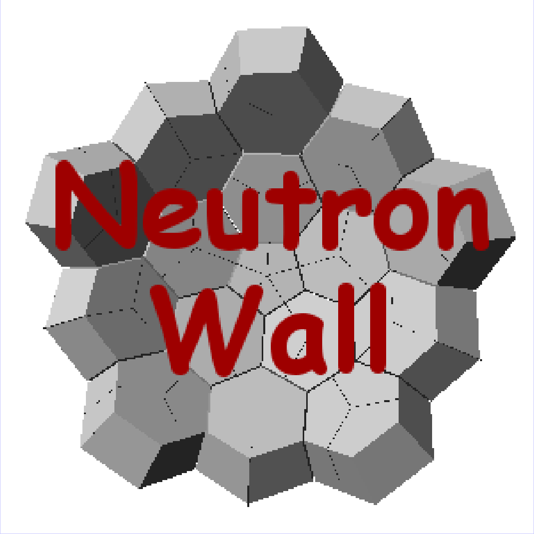
GANIL Scientific Council Meeting, GANIL, 2009-10-22

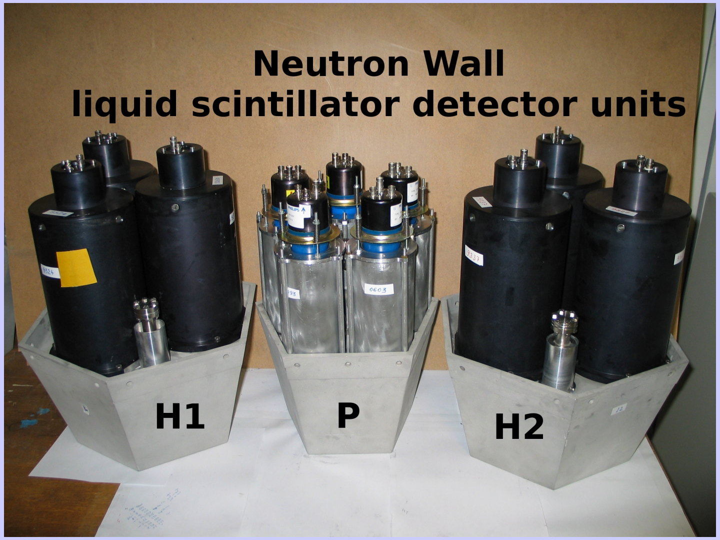
Johan Nyberg (Uppsala University)

on behalf of the Neutron Wall and NEDA collaborations

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

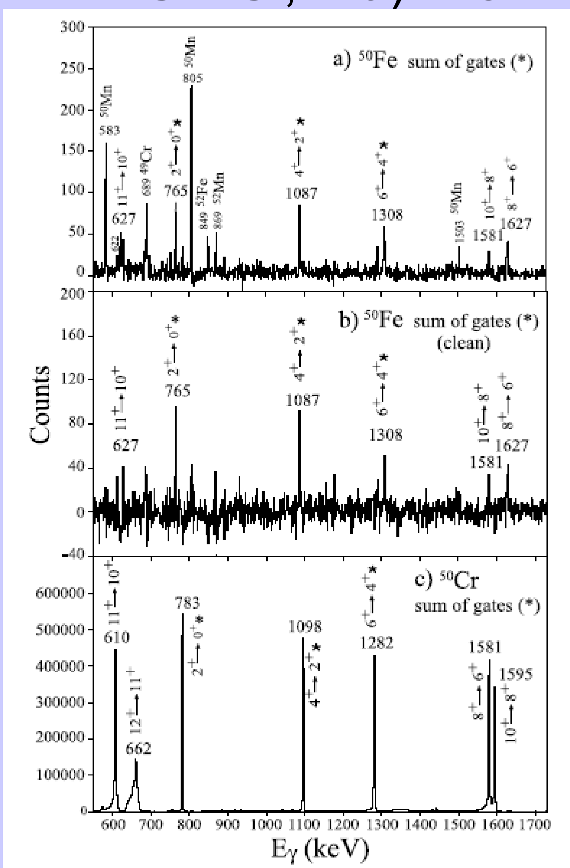
- Experiments performed at EUROBALL/LNL, EUROBALL/IReS, EXOGAM/GANIL
- Used together with charged particle detector arrays (EUCLIDES, DIAMANT,...)

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

Neutron Wall results at EUROBALL

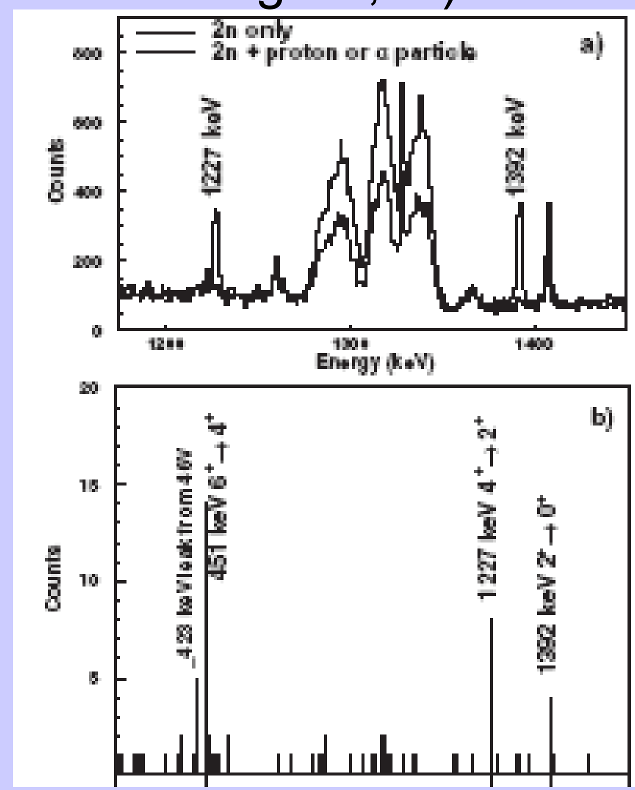
First observation of excited states in N=Z–2 nuclei ^{50}Fe, ^{54}Ni

^{28}Si(^{28}Si,2nα)^{50}Fe



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

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



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

Neutron Wall results at GANIL

First experiment with a radioactive ion beam

Cover figure of PRL Vol 101, Nr 3:

1n and 2n Transfer With the Borromean Nucleus 6He Near the Coulomb Barrier

A. Chatterjee, A. Navin et al., PRL101 032701 (2008)

NEDA Organization

- New neutron detector array under development within SPIRAL2 Preparatory Phase (WP5 Task 5.8)
- Spokeperson: J.J. Valiente Dobon (LNL-INFN)
- GANIL liason: M. Tripon (GANIL)
- Steering committee:
  - R. Wadsworth (University of York)
  - N. Erduran (Istanbul University)
  - L. Stuttgé (IPHC – Strasbourg)
  - J. Nyberg (Uppsala University)
  - M. Palacz (HIL, Warsaw University)
  - A. Gadea (IFIC – Valencia)
- Participating institutes: INFN, CNRS, COPIN, GSI, AU, IFIC, IU, KTH, UU, UY,... (open for new ones)

NEDA working groups

- **Detector characteristics:** report on physics of interest, this will help to define the detector specifications
  - *Responsible: R. Wadsworth*
- **Geometry:** make a full study of the geometry to optimize efficiency, reduce cross-talk, etc; comparison of different simulation codes: Geant4, MCNP-X; simulate effects of other detectors, neutron scattering,...
  - *Responsible: M. Palacz*
- **Explore new materials:** solid scintillators, deuterated liquid scintillators
  - *Responsible: L. Stuttgé*
- **Electronics:** fast sampling ADCs, commercial, EXOGAM-like electronics, Avalanche Photo Diodes,...
  - *Responsible: A. Gadea*
- **Pulse-shape analysis:** simulations of pulse shapes, development of PSA algorithms,...
  - *Responsible: J. Nyberg*
- **Synergies other detectors:** EXOGAM2, AGATA, PARIS, FAZIA, GASPARD, DIAMANT, DESCANT, DESPEC, NEUTROMANIA,...
  - *Responsible: P. Bednarczyk*

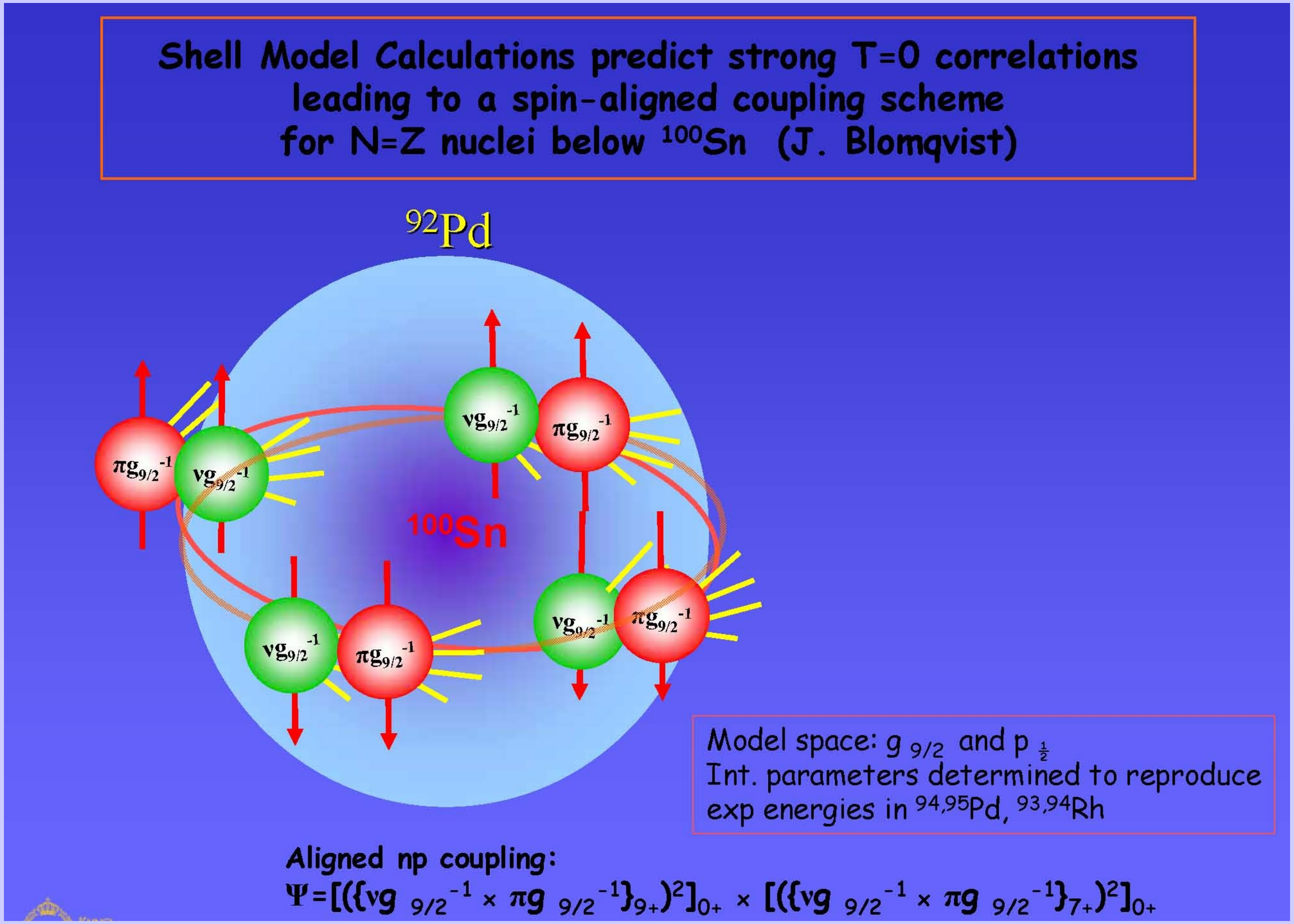
Physics with NEDA

- **Nuclear Structure**
  - Probe of T=0 correlations in N=Z nuclei: The structure beyond ^{92}Pd
  - Coulomb Energy Differences in isobaric multiplets: T=0 versus T=1 states
  - Coulomb Energy Differences and nuclear shapes
  - Low-lying collective modes in proton-rich nuclei
- **Nuclear Astrophysics**
  - Element abundances in the Inhomogeneous Big Bang Model
  - Isospin effects on the symmetry energy and stellar collapse
- **Nuclear Reactions**
  - Level densities of neutron rich nuclei
  - Fission dynamics of neutron-rich intermediate fissility systems

First day experiment

NEDA + EXOGAM2 + AGATA

Nuclear structure N=Z beyond ^{92}Pd: ^{96}Cd, etc.



Second day experiment

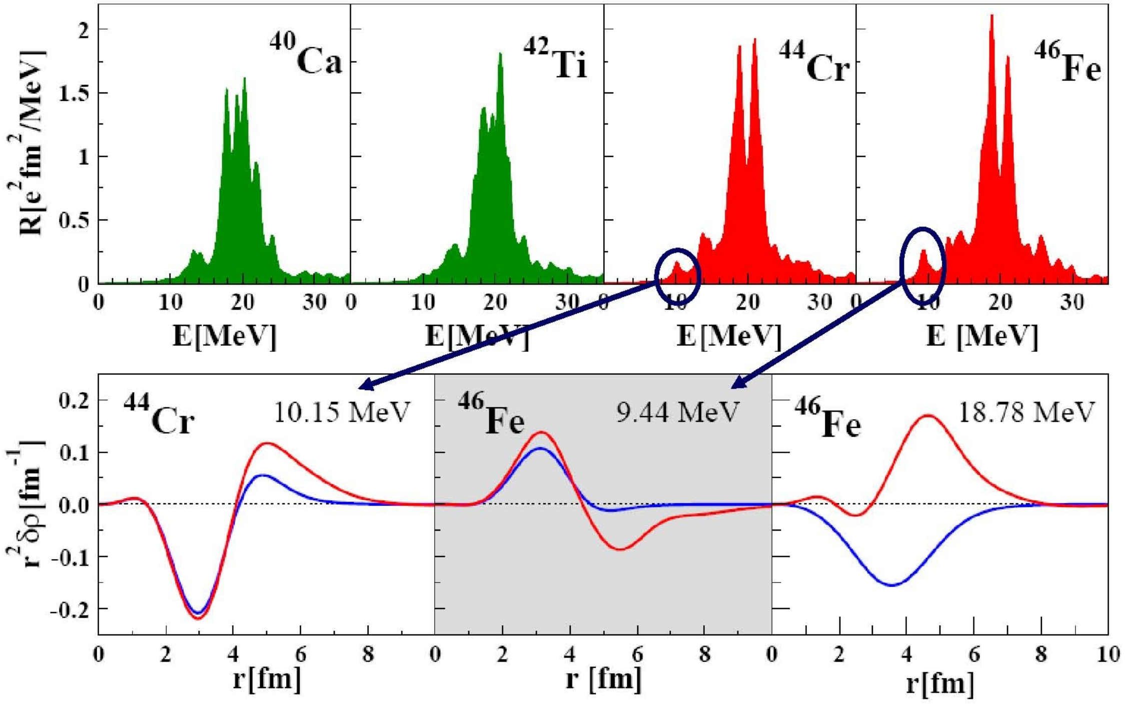
NEDA+PARIS

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

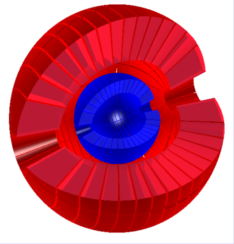
NEDA+PARIS experiment

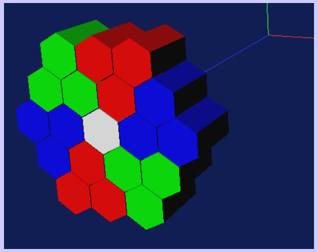
Courtesy M. Lewitowicz

Light and N=Z RIB at SPIRAL 2

Rough Estimation of Yields (Examples)

RI Beam	Reaction	Production method	Yield (min. - max.) in pps
^{6}He	^{9}Be(n,α)^{6}He	ISOL	5×10^{7} - 10^{12}
^{11}C	^{14}N(p,α)^{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}
^{60}Zn	^{24}Mg+^{58}Ni	In-flight	< 3×10^{4}



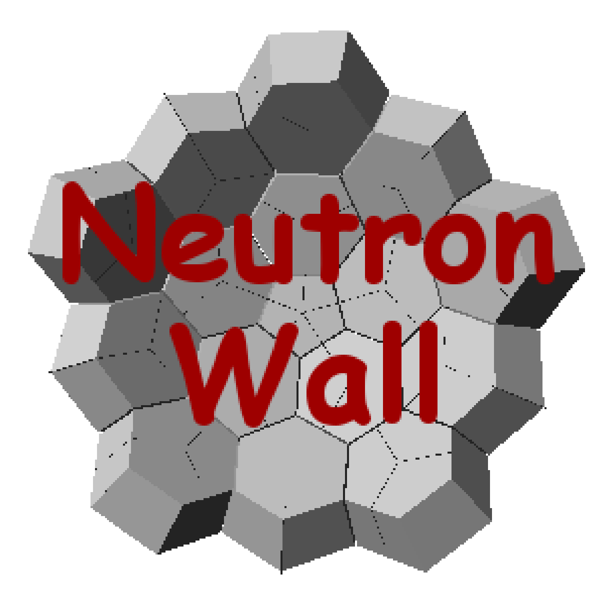


The reaction to study the Pigmy resonance in ^{44}Cr

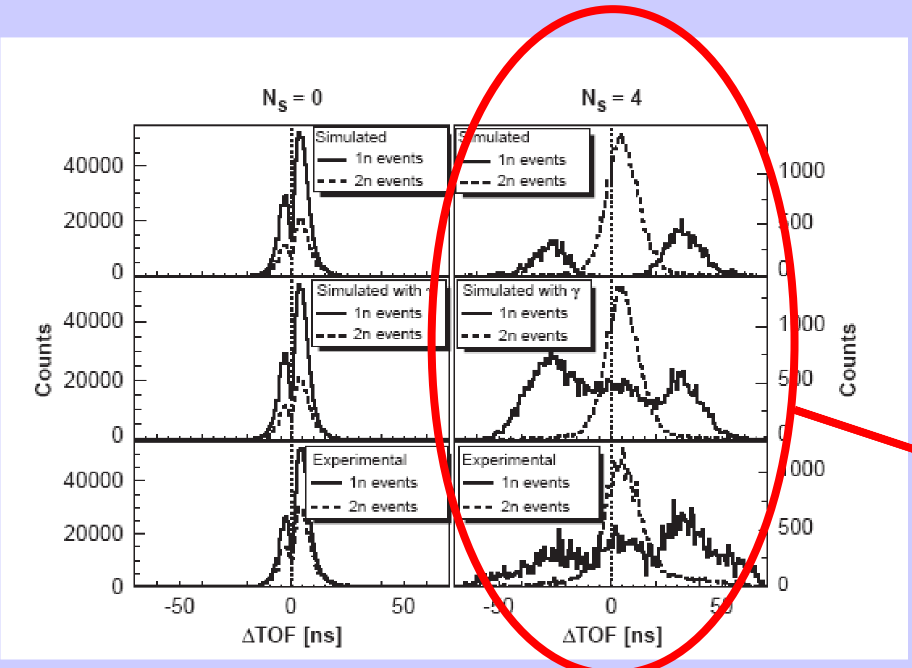
^{34}Ar + ^{16}O $\rightarrow$ ^{44}Cr + α2n (^{34}Ar 10^{8} pps)

Problem definition

- Neutron detectors to be used primarily for reaction channel tagging (determination of number of emitted neutrons) coupled to AGATA, EXOGAM2, PARIS
- If requested available also for neutron spectroscopy experiments
- Previous experience with the Neutron Wall:
  - High efficiency ~25% for detection of one neutron
  - Good neutron-gamma discrimination
  - Low efficiency for detection of two (~1-2%) or more neutrons due to problem with cross talk (scattering of neutrons)



The cross-talk problem



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

- Large probability of cross talk between neutron detectors (7 % in Neutron Wall)
- 2n reaction cross sections much smaller than 1n → most events with 2 detected neutrons are due to scattered 1n
- Methods of rejecting scattered neutrons: neighbour rejection, TOF difference
- 2n efficiency achieved by Neutron Wall: 1-2 %

One of the important aims of NEDA is to improve the discrimination of scattered neutrons without loosing the precious real 2n events → increased 2n efficiency

Strategy of NEDA

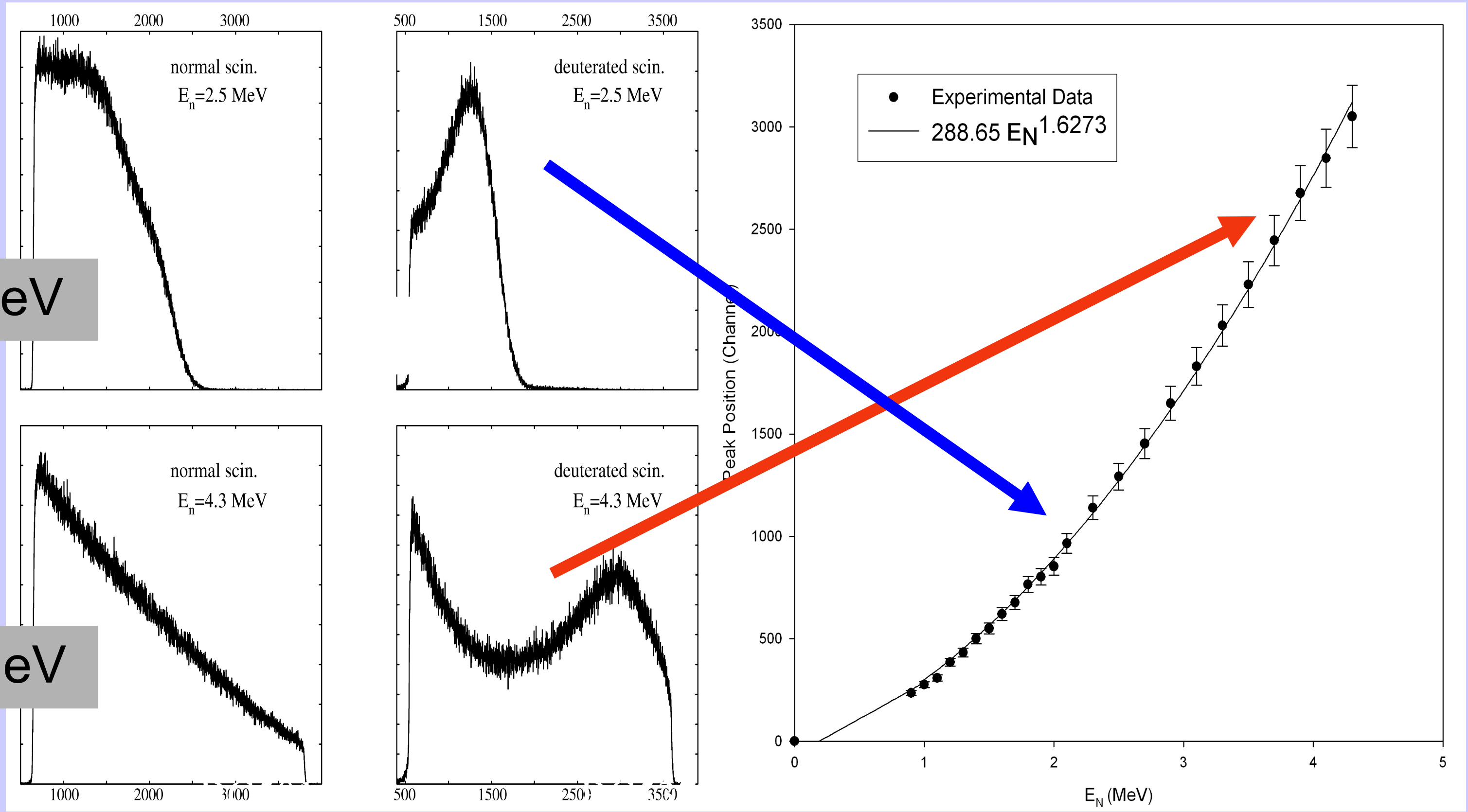
- Combine neutron TOF with energy deposited in the detector to discriminate 1n scattered events from the real 2n reaction channels
- Use of deuterated scintillator, e.g. BC-537:
  - Better detector response than normal (^{1}H based) liquid
  - Provides another method than TOF to determine the neutron energy
  - Correlating TOF with deposited neutron energy may lead to a better discrimination of high-multiplicity neutron events and scattered events
  - Possibly better neutron-gamma discrimination, since more events are at higher energies

BC-501A versus BC-537 response

BC-501A (^1H) BC-537 (^2H)

E_n = 2.5 MeV

E_n = 4.3 MeV



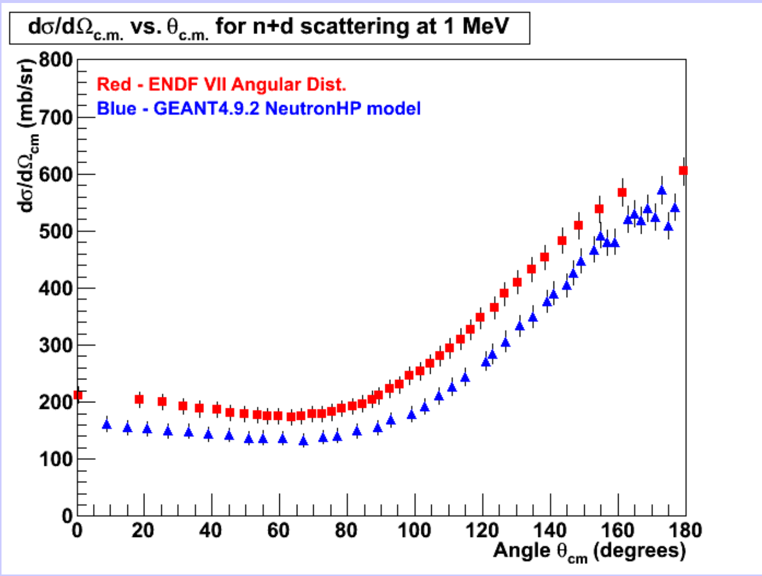
Courtesy of P. Garrett University of Guelph

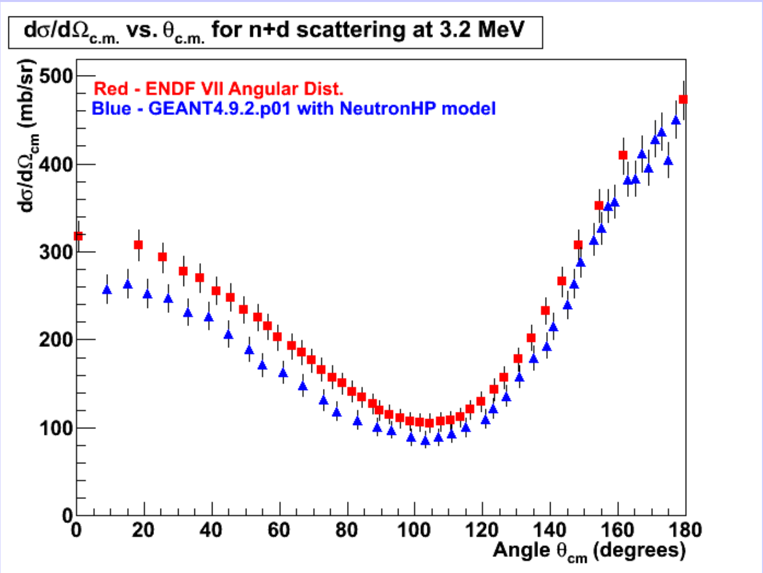
Validation of Geant4 simulations

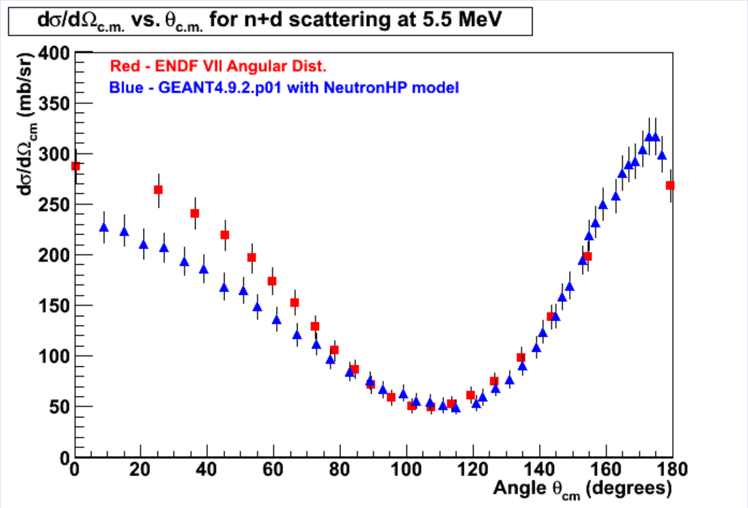
- Neutron HP model in Geant4.9.2.p01 (March 2009) much improved comparing to earlier versions
- Total cross sections and angular distributions for elastic scattering on p, d, and ^{12}C reasonable
- Correct (high-energy) gamma-ray lines produced
- Inelastic interactions not fully validated yet:
  - Wrong kinematics (angular distributions?) in the $^{12}C(n,\alpha)^{9}Be$ reaction
  - Important reactions still missing, e.g. $^{12}C(n,n')3\alpha$

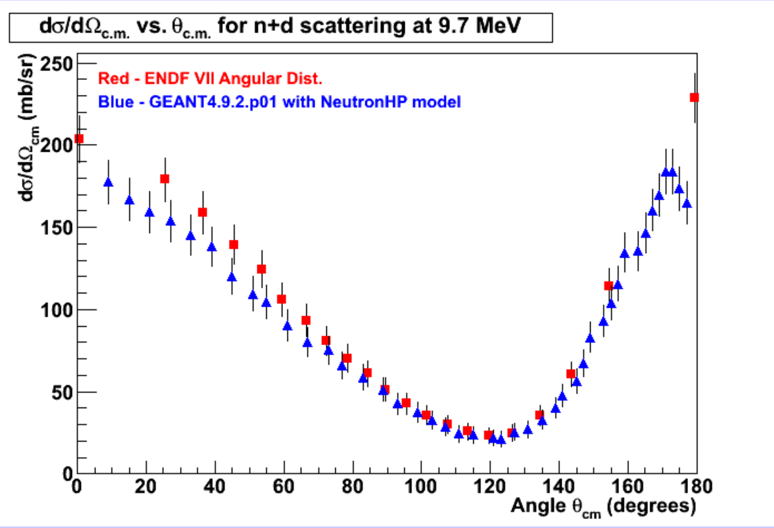
Existing defficiencies are not significant in the energy range of interest for NEDA (100 keV-10 MeV)

σ(θ) elastic neutron scattering on d





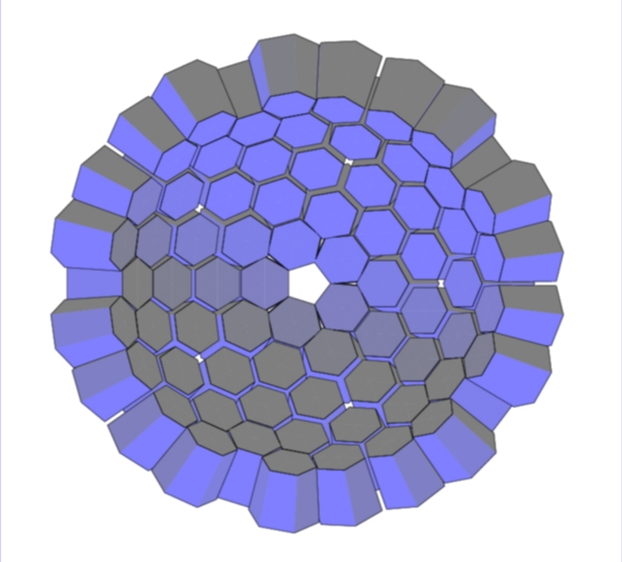




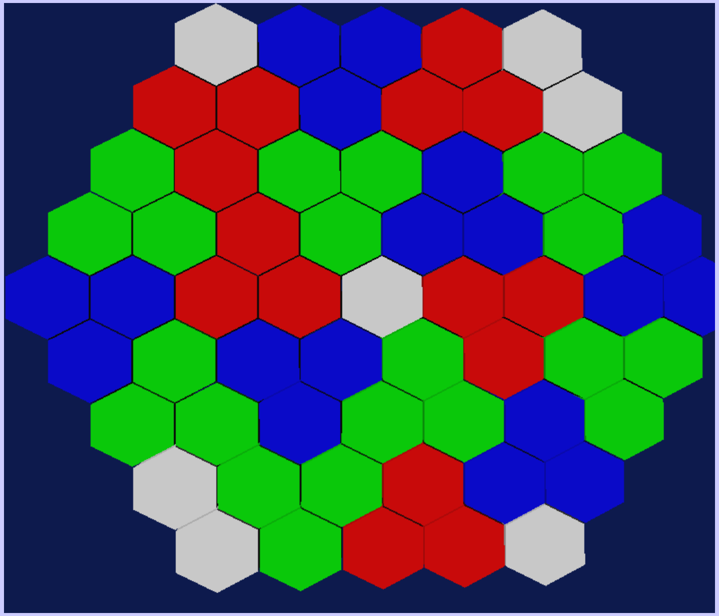
By Brian Roeder

Geometries

- Two possible geometries are considered: spherical, planar
- Planar geometry has some advantages:
  - Flexibility - different possible arrangements of the detectors
  - Different focal positions (500 cm, 1000 cm, 2000 cm)

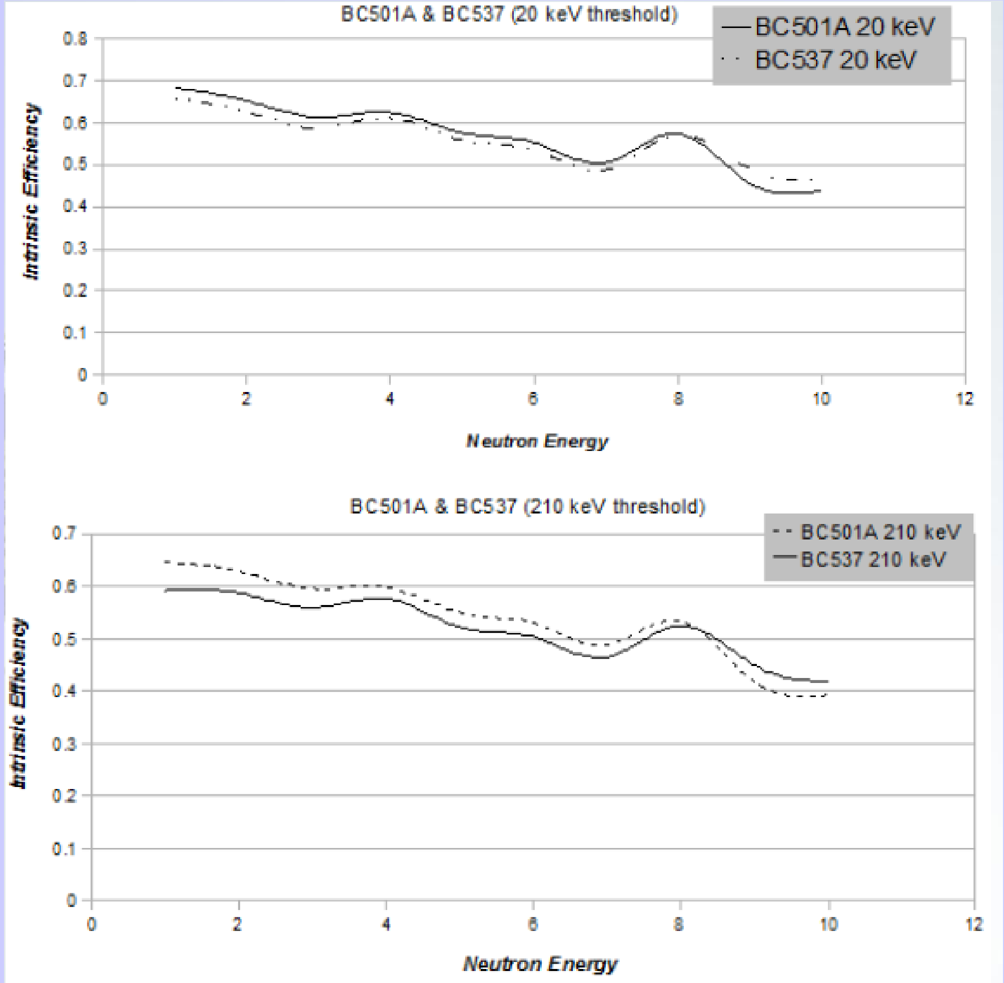


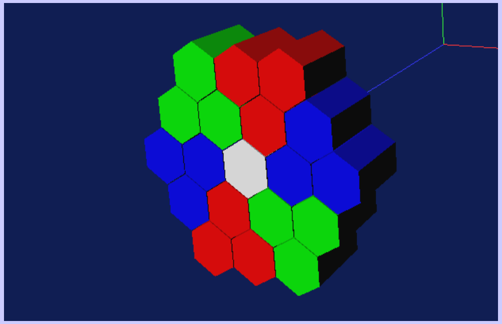
DESCANT geometry

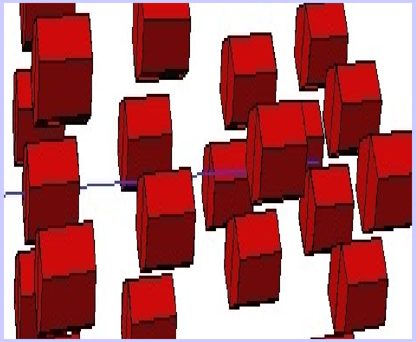


NEDA planar geometry

Neutron efficiency planar geometry





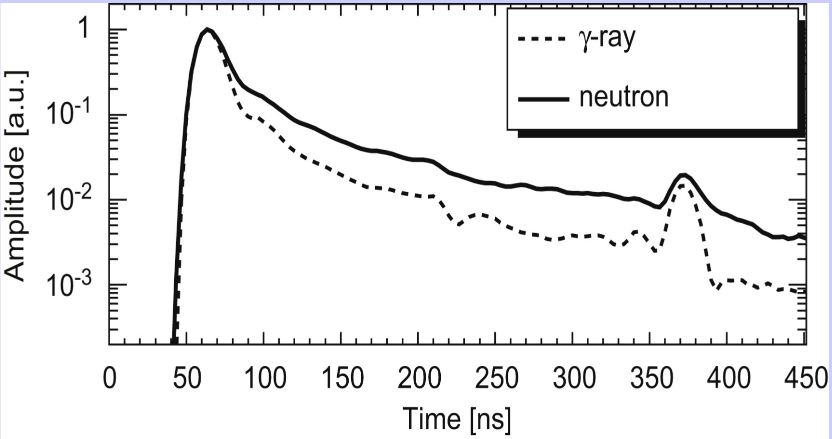


Versatility of the planar

- 2.5 mm Al encapsulation
- 159 mm depth
- .60 mm side length

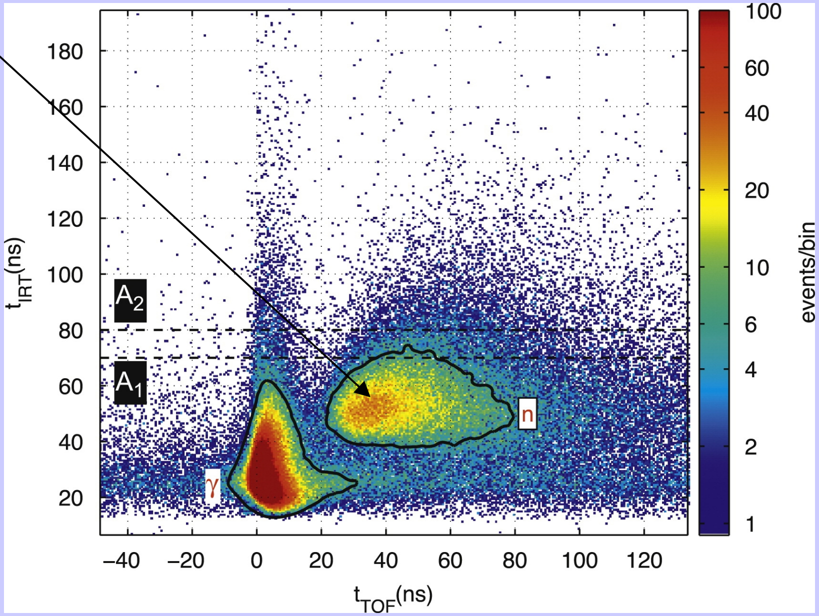
Efficiency of NEDA with 61 hexagonal detectors ~30 %

Neutron-gamma discrimination



Pulse shapes from the detector differs between neutrons and gamma rays

neutrons

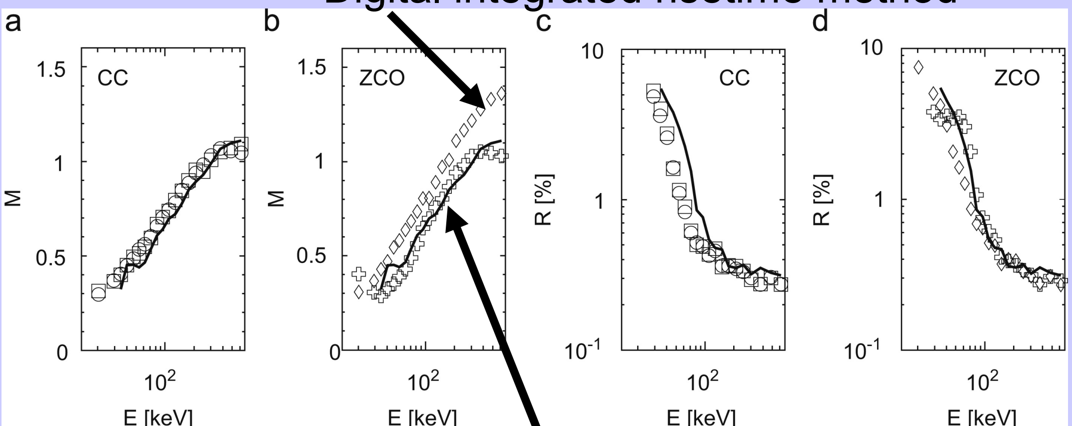


Neutron-gamma discrimination is usually done by combining pulse-shape analysis and TOF measurement

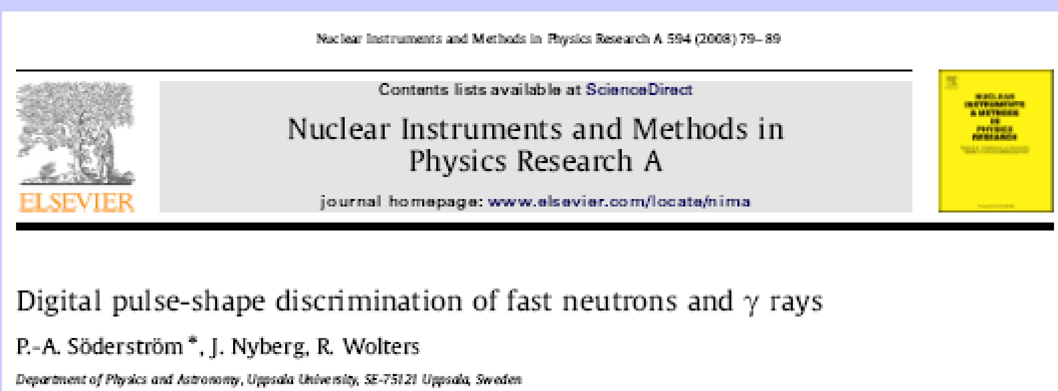
Digital methods of PSA

- Use fast sampling ADC to digitize detector waveform
- Different PSA algorithms tested

Digital integrated risetime method



Analog zero-crossover method



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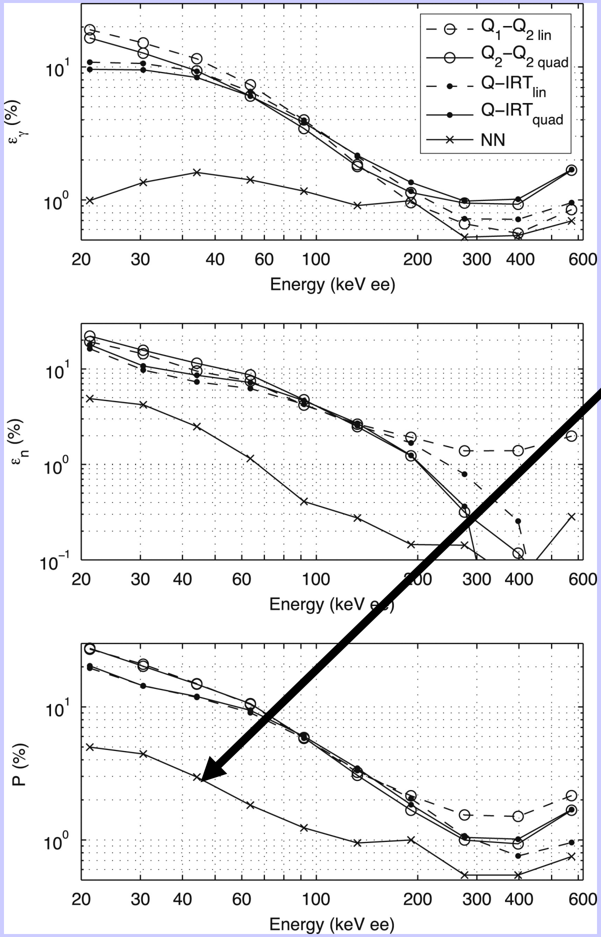
journal homepage: www.elsevier.com/locate/nima

Digital pulse-shape discrimination of fast neutrons and γ rays

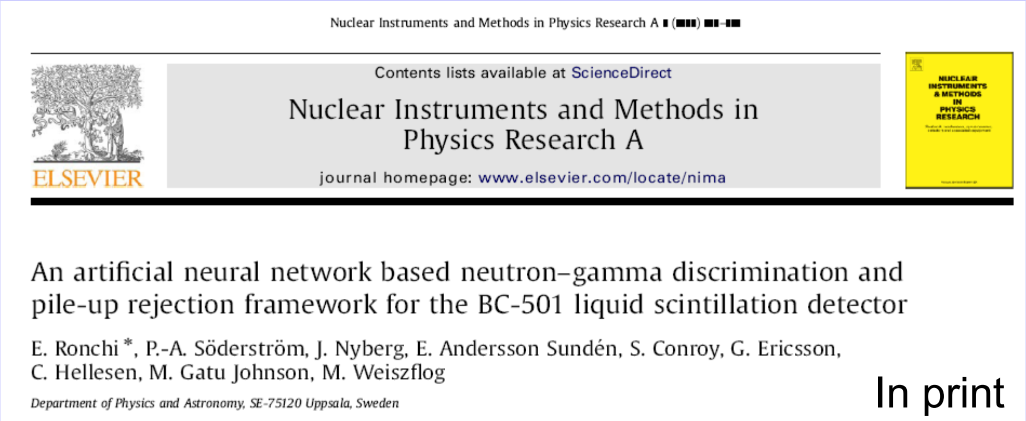
P.-A. Söderström *, J. Nyberg, R. Wolters
Department of Physics and Astronomy, Uppsala University, SE-75121 Uppsala, Sweden

Achieved as good or better neutron-gamma discrimination with a digital system compared to an analog system

Neutron-gamma discrimination with Neural Networks



Applying an artificial neural network can increase the quality even further



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

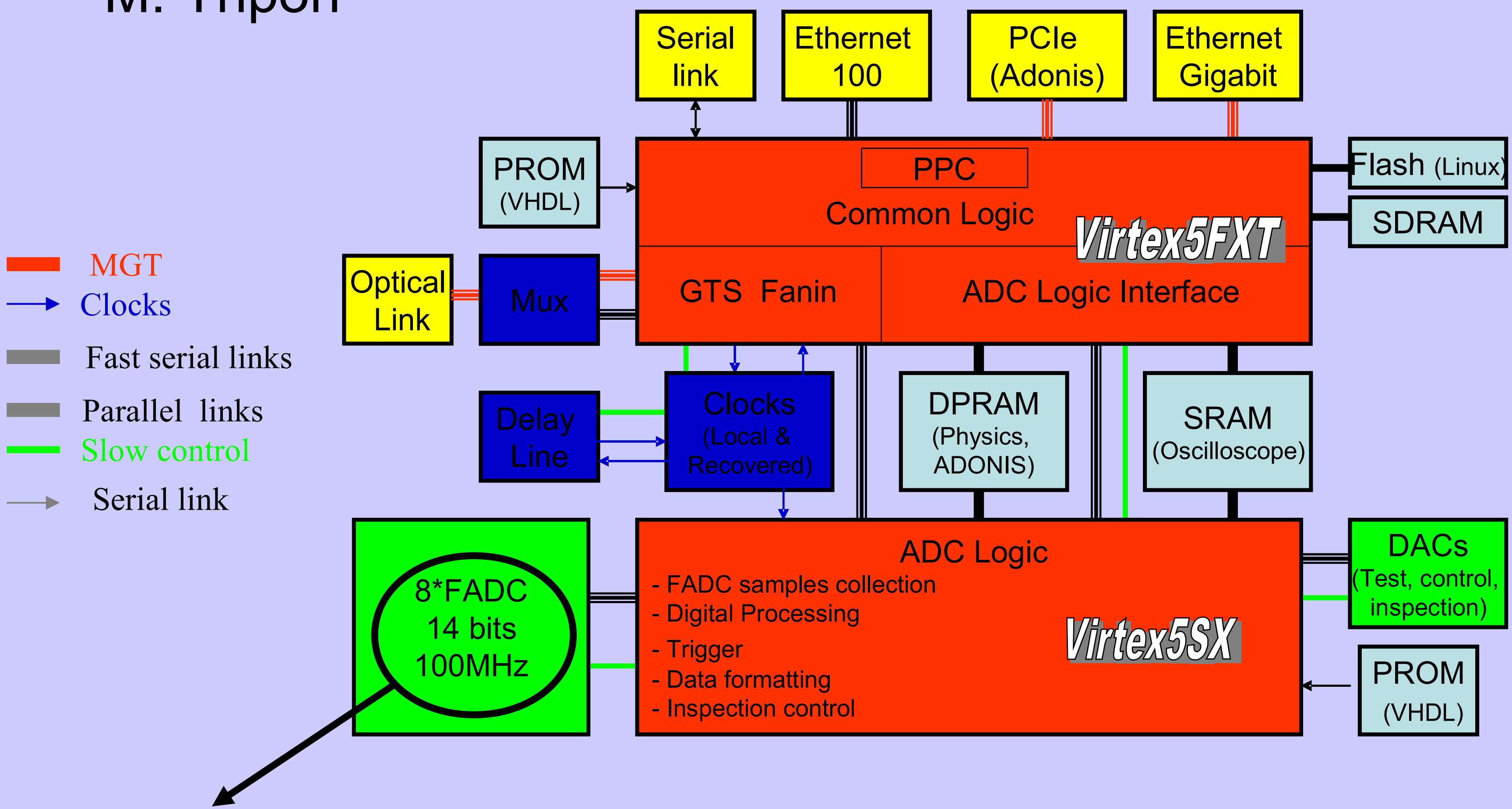
E. Ronchi *, P.-A. Söderström, J. Nyberg, E. Andersson Sundén, S. Conroy, G. Ericsson, C. Hellesen, M. Gatu Johnson, M. Weiszflog

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

In print

Electronics for NEDA: EXOGAM2 style

M. Tripon



Basic hardware difference between EXOGAM2 and NEDA is the higher sampling frequency of the FADC (NEDA needs ≥250 MS/s)

Electronics for NEDA

Other alternatives for FADC system:

- Commercial
- Hardware developed within Faster project by LPC-Caen
- ...

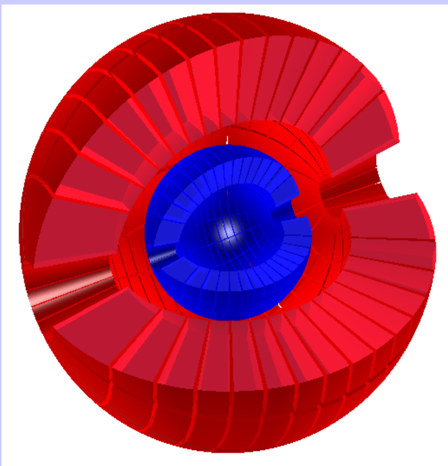
Alternatives to photo-multiplier tubes:

- Super bi-alkali PMT with larger quantum efficiency (Hamamatsu)
- Avalanche photo diodes (Hamamatsu, SensL)
- Silicon photo multiplier

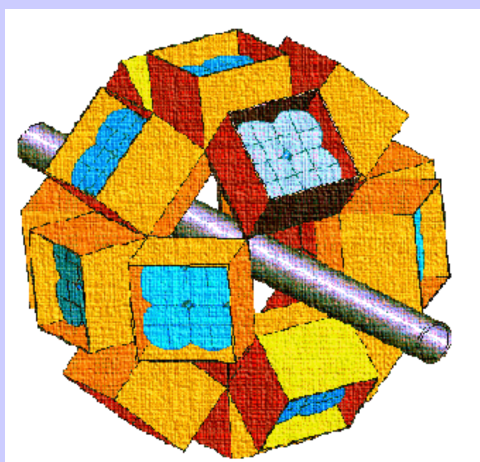
Time scale

Task	2008	2009				2010		
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Validation GEANT4 neutorn simulations								
Geometry definition								
Digital algorithms for PSA								
Detector prototype								
Test prototype								
Electronics								
Negotiations MoU								
MoU signature								

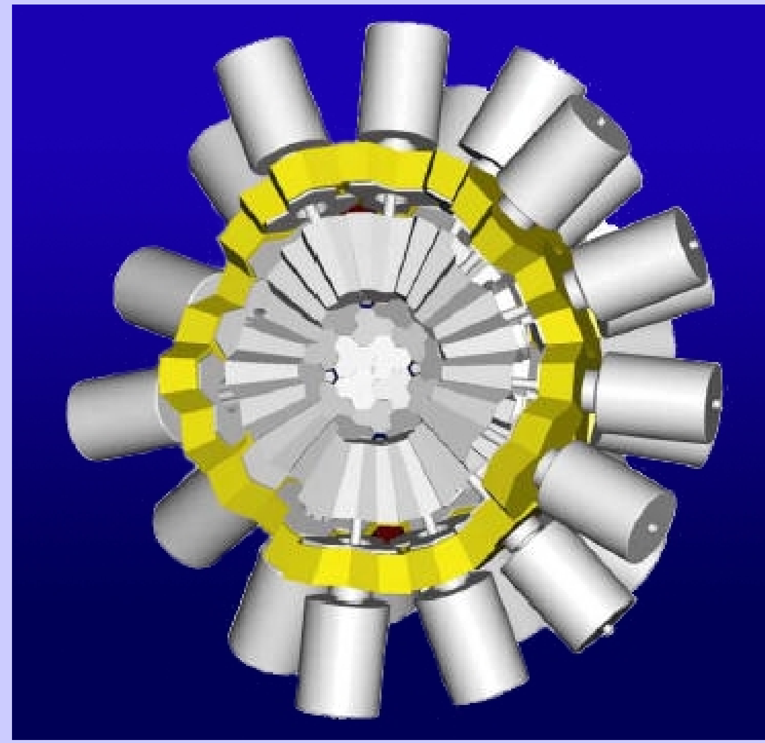
Synergies



PARIS



EXOGAM array



ADVANCED GAMMA TRACKING ARRAY

Summary and future work

Summary:

- One of the main tasks is to improve the efficiency for 2n reaction channels – will test deuterated liquid scintillator
- Validated simulatons – realistic results for BC-501A and BC-537
- Digital PSA methods for neutron-gamma discrimination – promising results in particular with Neural Networks

Near future work:

- Currently buying BC-501A and BC-537 commercial detectors to test
  - cross talk
  - light production
  - PSA
- Buying FADC system for tests
- Test of APDs, SiPMs
- Continue simulations of geometry and light production

END

Acknowledgement:

J.J Valiente Dobon and G. de Angelis for most of the slides