NEDA (NEutron Detector Array)

Marcin Palacz

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on behalf of the NEDA collaboration

and for the COPIGAL project

„Nuclear Structure Close to N=Z=50”
(G.de France/M. Palacz)

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:

ε(1n) ≈ 40% (20-25%), ε(2n) ≈ 6% (1-3%).

ε(3n) ≈ 1% (0.1 %)

Excellent neutron-gamma discrimination.

Superiour 1n/2n/3n discrimination.

Capability to run at much higher count rates than the Neutron Wall.

Cope with large neutron multiplicities in reactions with neutron-rich RIBs.

Improved neutron energy resolution for reaction studies.

Strategy of NEDA

- Optimise size of detector units, distance to target, geometry of the array, . . .
- Investigate other detector materials than ordinary liquid scintillator.
- Adopt digital electronics which is fully compatible with AGATA, GALILEO, EXOGAM2, PARIS . . .
- Develop advanced on-line and off-line algorithms for neutron-gamma discrimination, neutron scattering rejection, pile-up rejection/recovery.

Is it worth the effort ?

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

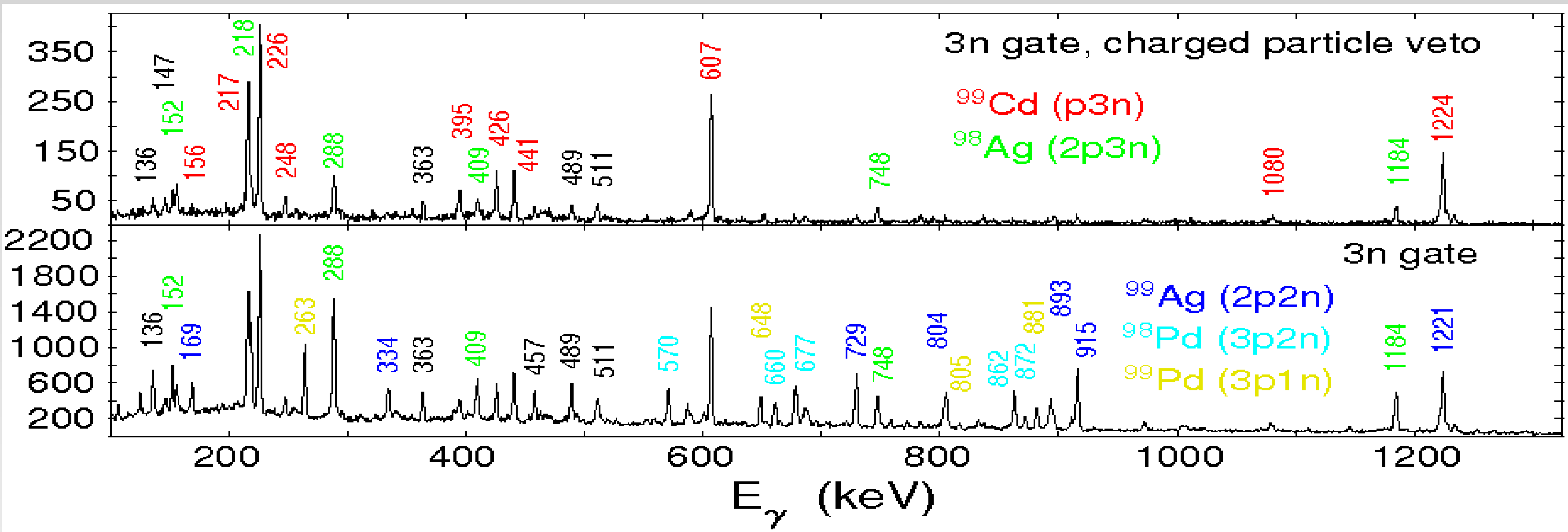
- The primary application of NEDA is to act as neutron multiplicity filter in γ-ray fusion-evaporation studies of very neutron deficient nuclei, close to N=Z
  - probe of T=0 correlations (like ^{92}Pd)
  - ^{100}Sn region: SPE, nucleon-nucleon interactions and core excitations
  - Coulomb Energy Differences in isobaric multiplets, T=0 vs. T=1 states
  - Low-lying collective modes (proton pygmy dipole resonance, $^{34}Ar + ^{16}O \rightarrow ^{44}Cr + \alpha 2n$, 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

Is it worth the effort ?

$\varepsilon(3n) \approx 1\%$ (0.1 %)

An example: attemp to study ^{100}In:

^{100}In : 1 neutron particle, 1 proton hole outside ^{100}Sn
3n evaporation channel - the only 3n case with NWall (+EUROBALL)



^{100}In not observed, but observation only a matter of statistics.
If 10 times larger statistics should be collected:
half a year beam time with EXOGAM+NWall,
2-3 weeks beam time with EXOGAM+NEDA

Many other crucial nuclei accessible in 3n evaporation channels, including ^{101}Sn.
Improving multiple neutron detection - easiest way to access such nuclei.

Organisation of NEDA

Spokesperson – Project Manager: J.J. Valiente Dobon (LNL-INFN)

GANIL Liason: M. Tripon (GANIL)

Steering committee - Management Board:

- B. Wadsworth (U. of York)
- N. Erduram (U. of Istanbul)
- G. De France (GANIL)
- J. Nyberg (U. of Uppsala)
- M. Palacz (U. of Warsaw)
- A. Gadea (IFIC – Valencia)
- D. Tonev (U. of Sofia)

Institutions:

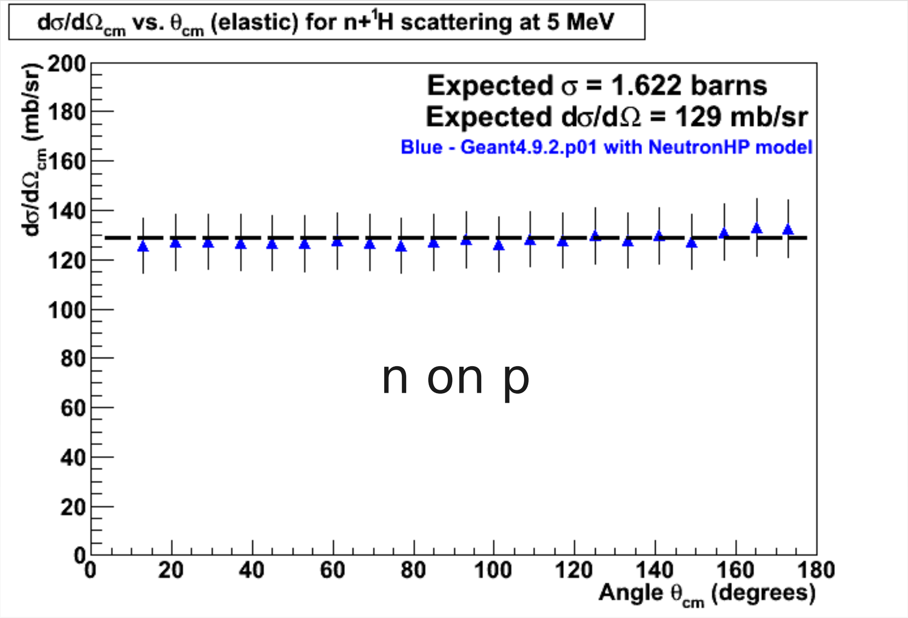
U. of Ankara (Turkey), COPIN (Poland), CSIC-IFIC (Spain), Daresbury Laboratory (U.K.), GANIL (France), U. of Istanbul (Turkey), INFN (Italy), IRES (France), U. of Nidge (Turkey), Uppsala U. (Sweden), U. of York (U.K.), U. of Sofia (Bulgaria)

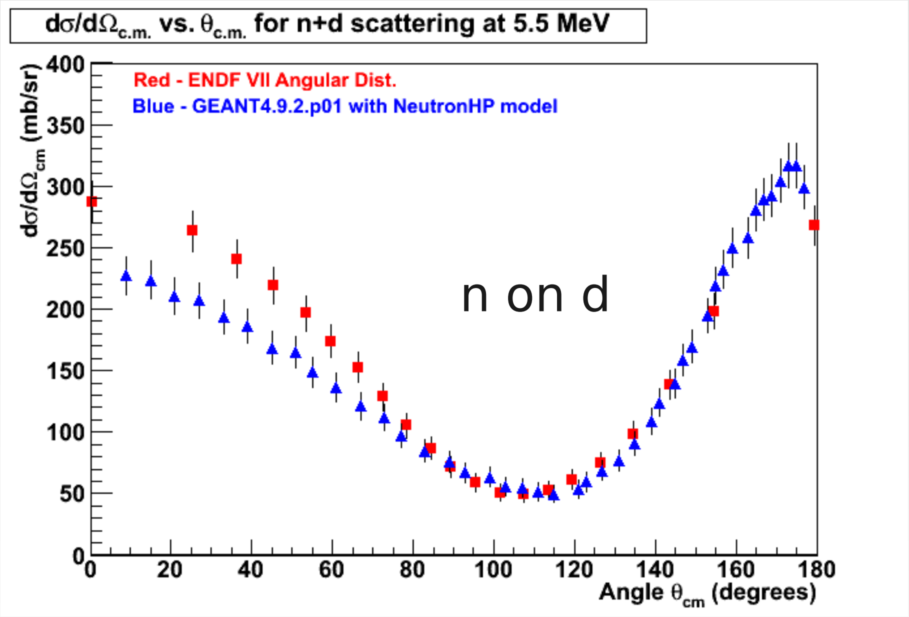
Organisation: working grops

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

New materials: deuterated scintillator ?

- Commonly used scintillator: C_8H_{10} (BC501A, NE213, BC501)
- Deuterated scintillator (C_6D_6 BC537): due to anisotropic scattering of n on d, may produce signals which are more correlated with the incoming neutron energy – could be used to improve multiple neutron discrimination.

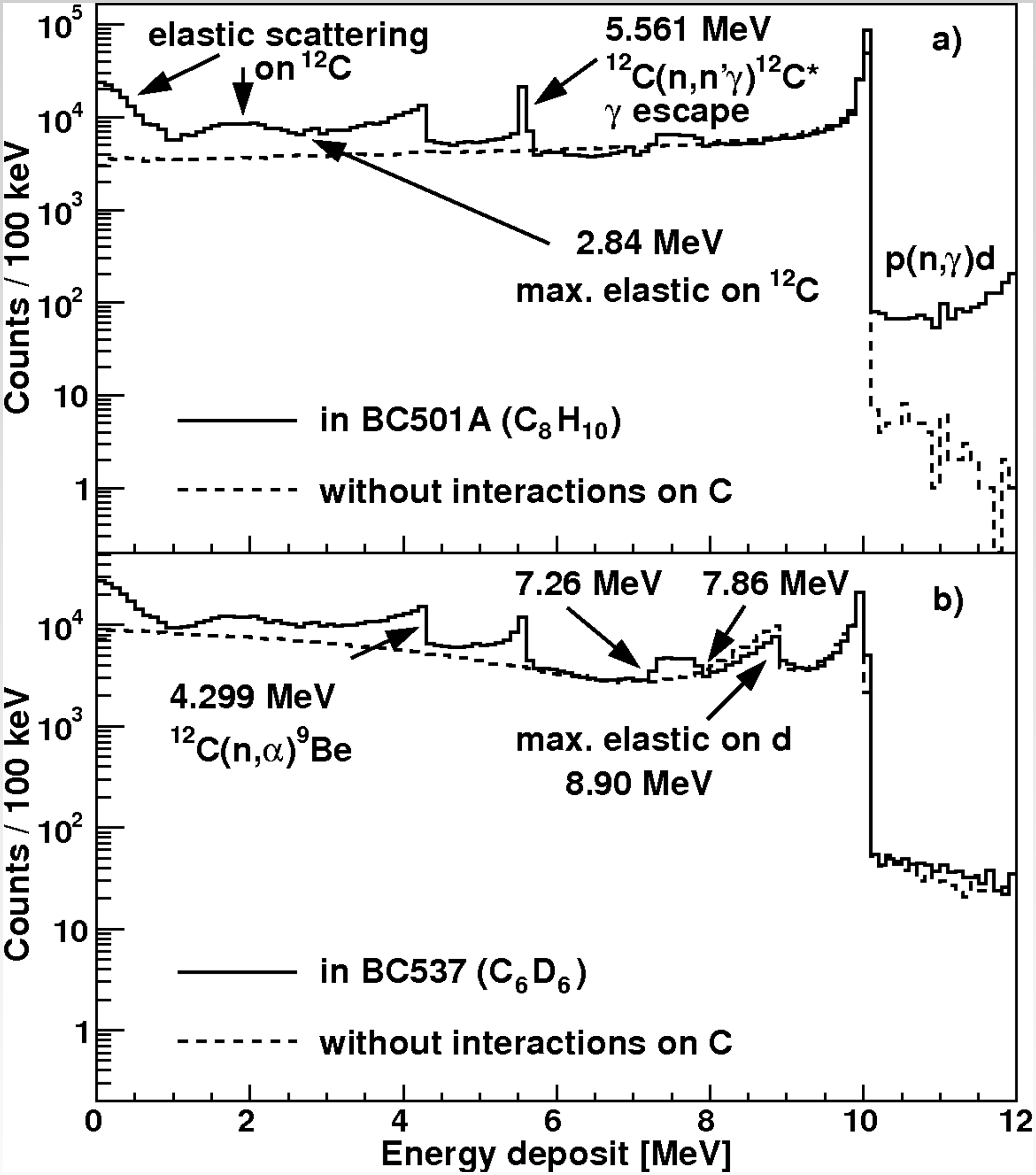


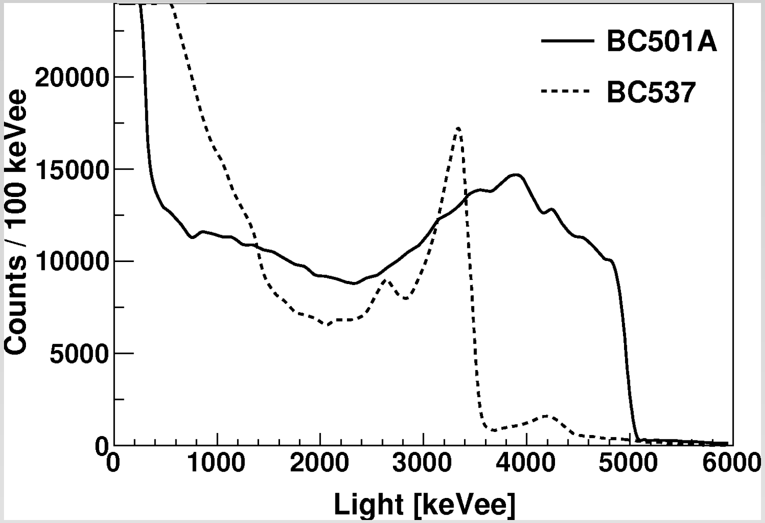


plots by B. Roeder

DESCANT (TRIUMF) decided to use deuterated scintillator (2007 ?) !

Interactions of neutrons in the scintillator





G.Jaworski et al. NIM A673 (2012) 64

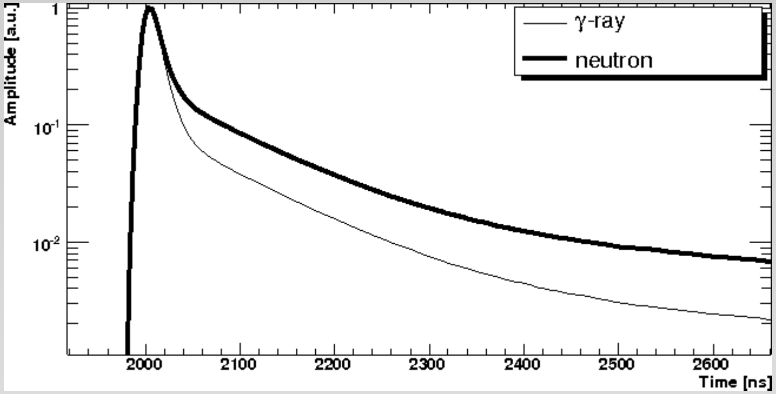
Neutron – gamma discrimination

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

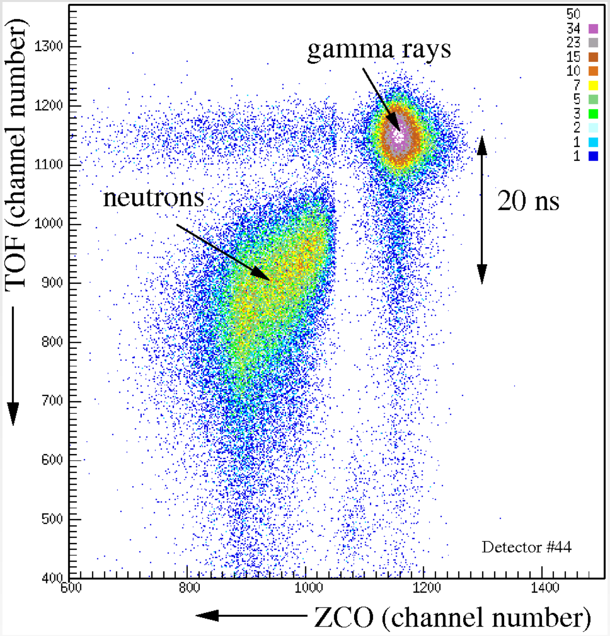
- neutrons (recoiling protons) - slow light component (τ~300 ns)
- γ rays (electrons) - fast light component (τ~3 ns)

Pulse shape combined with TOF gives w γ-ray as neutron interpretation probability ~0.1 %.

Present NWall: pulse shape discrimination analog.
NEDA will use digital techniques.



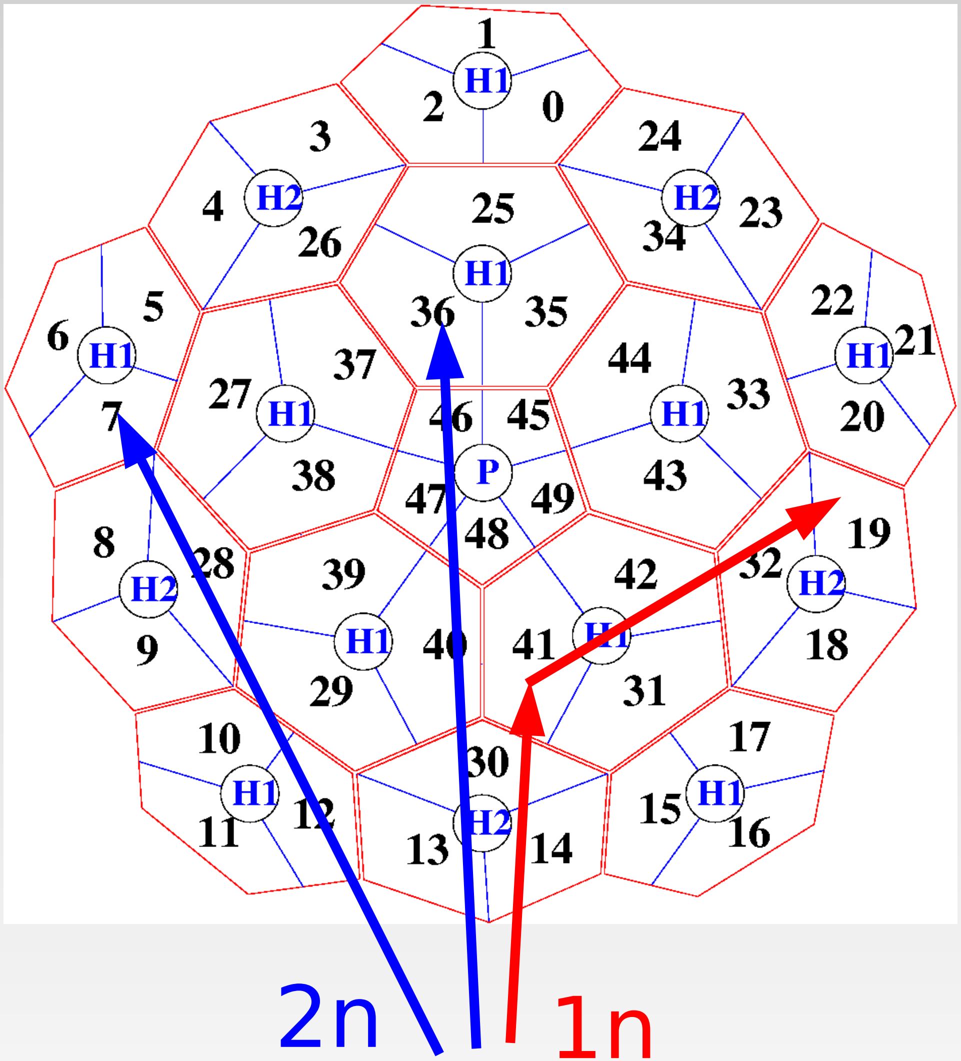
plot by P.-A. Soderstrom

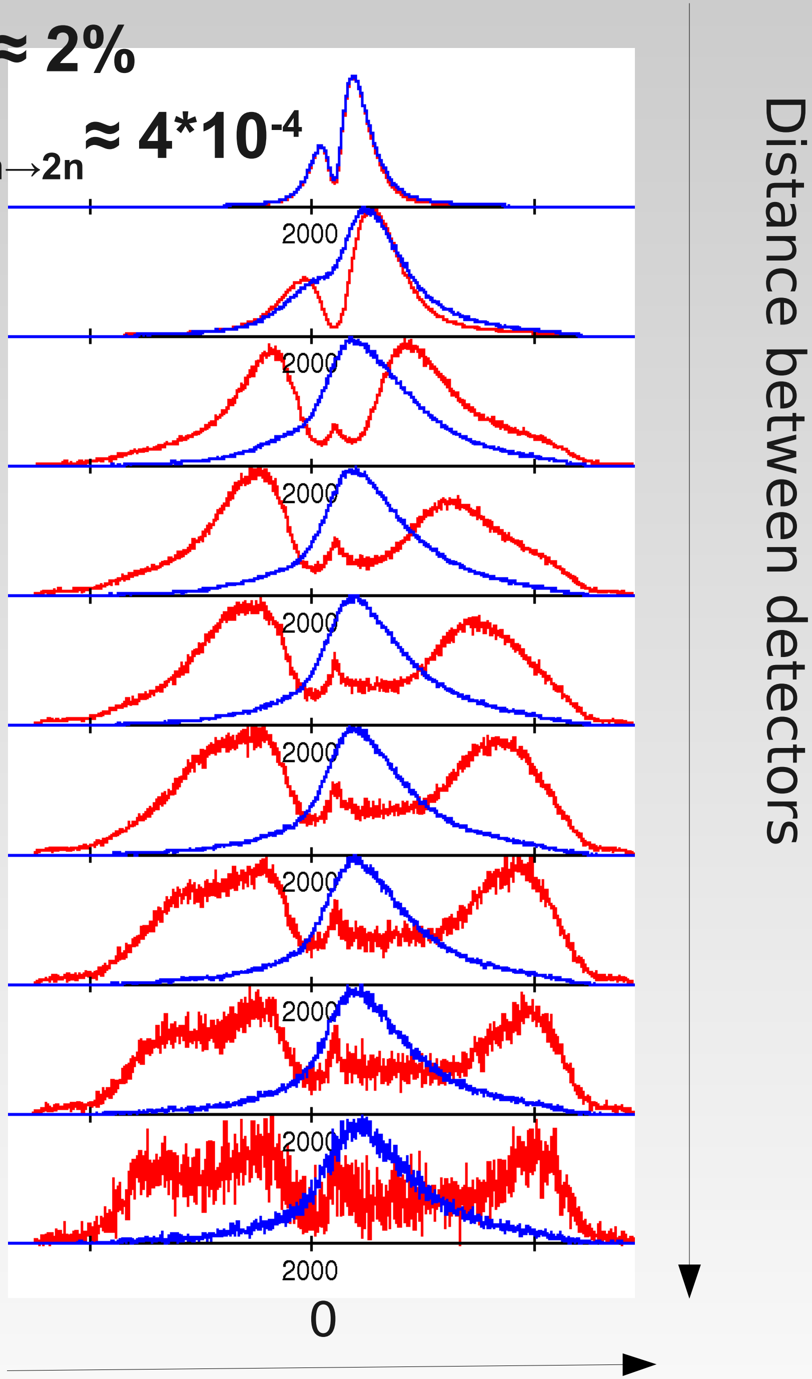


1n/2n/3n discrimination

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

$P_{1n \to 2n} \approx 4*10^{-4}$

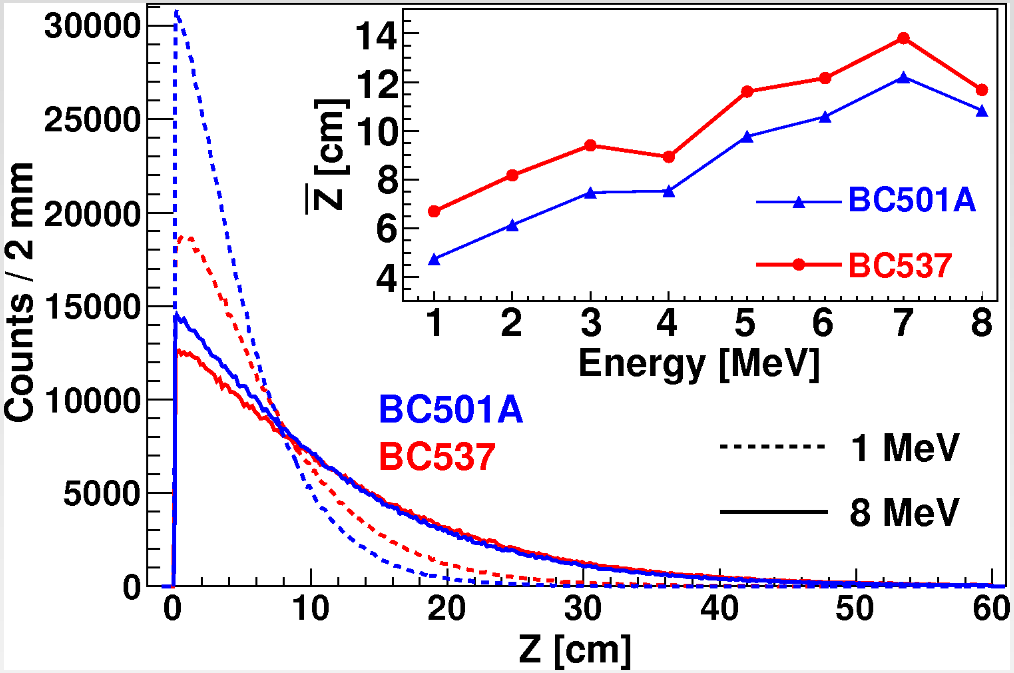




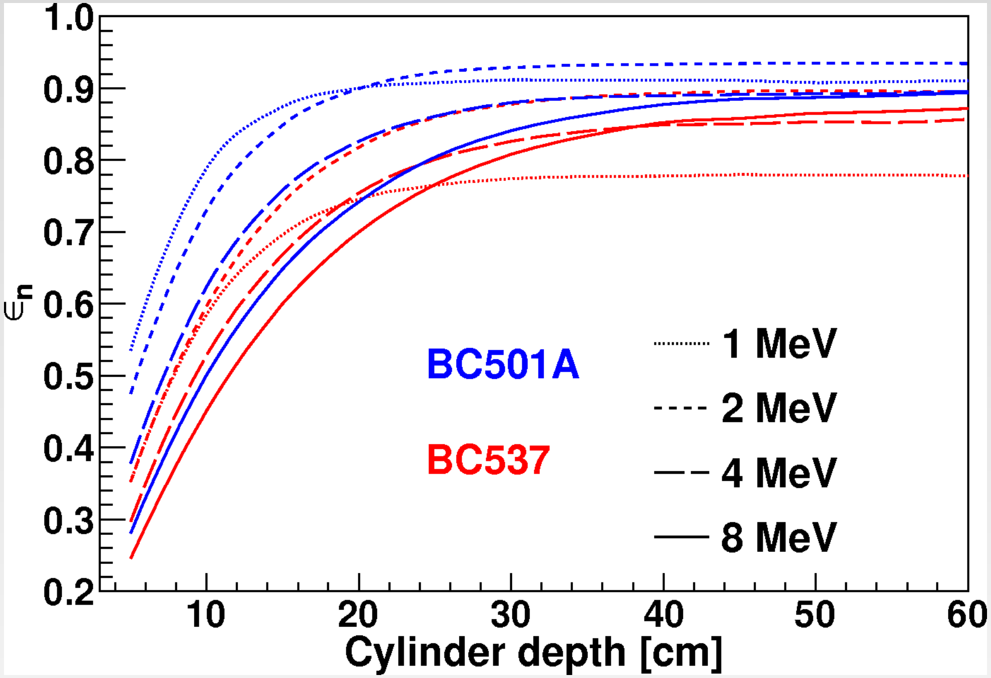
J. Ljungvall et al. NIM A528 (2004) 741

Evaluation of single detector size - length

Depth of the interaction – distribution and average



Neutron detection efficiency



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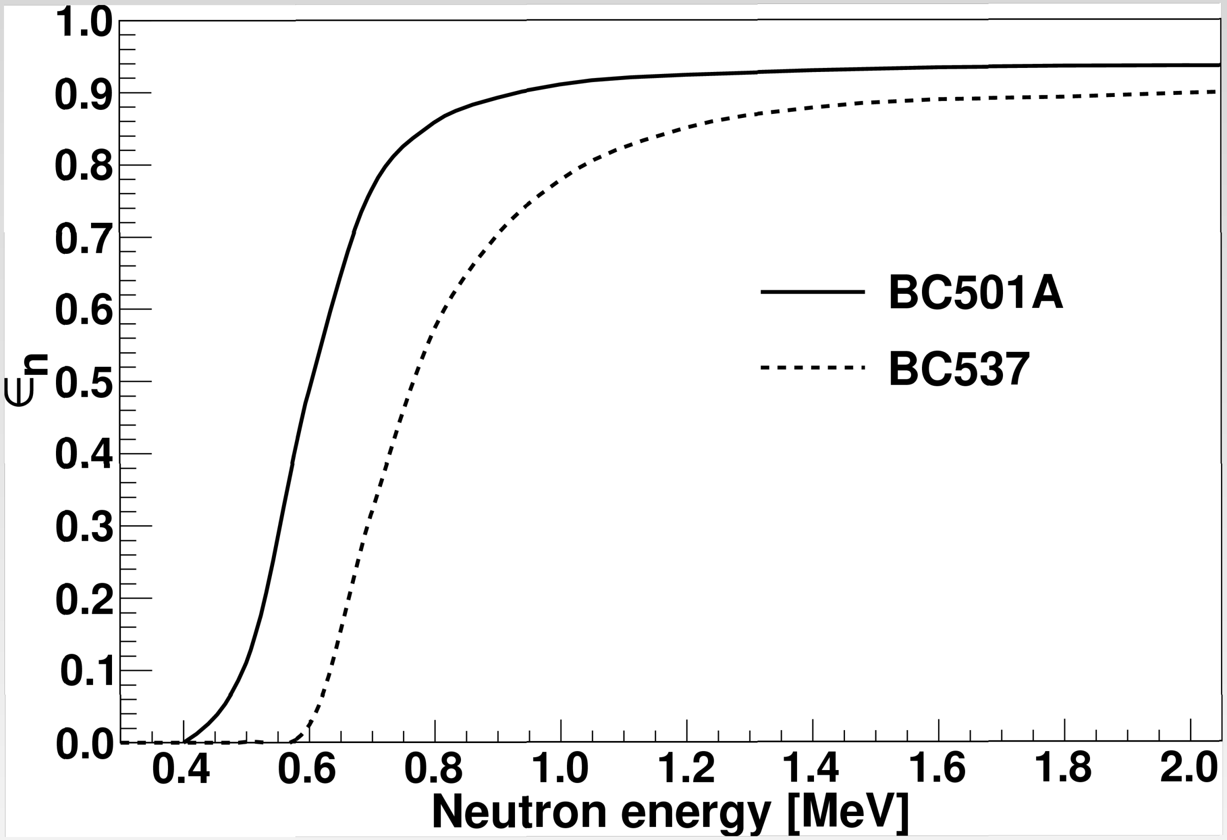
Efficiency at low neutron energy



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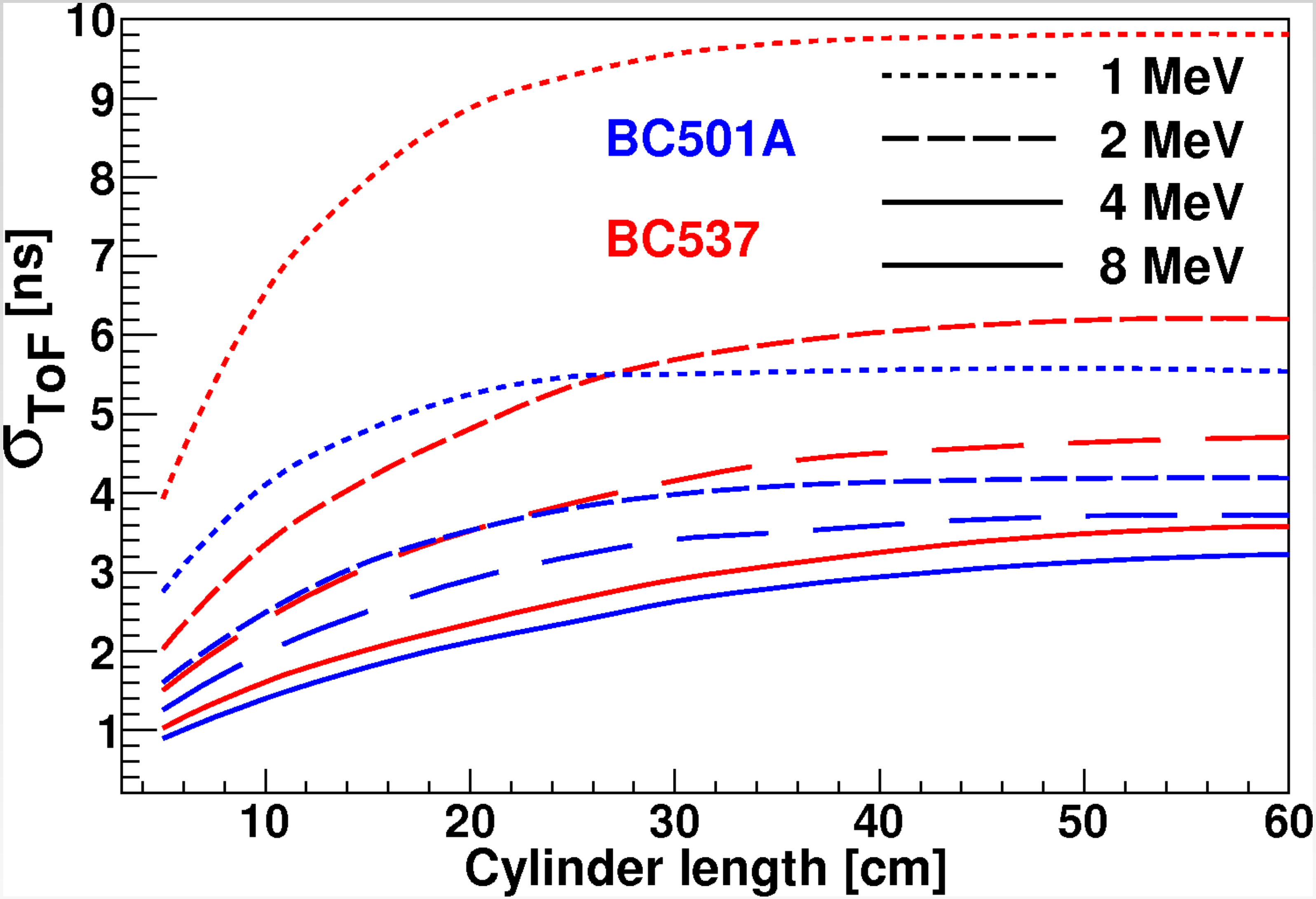
Time resolution

Time resolution due to variation of the interaction depth



σ_{int} = 1.5 ns

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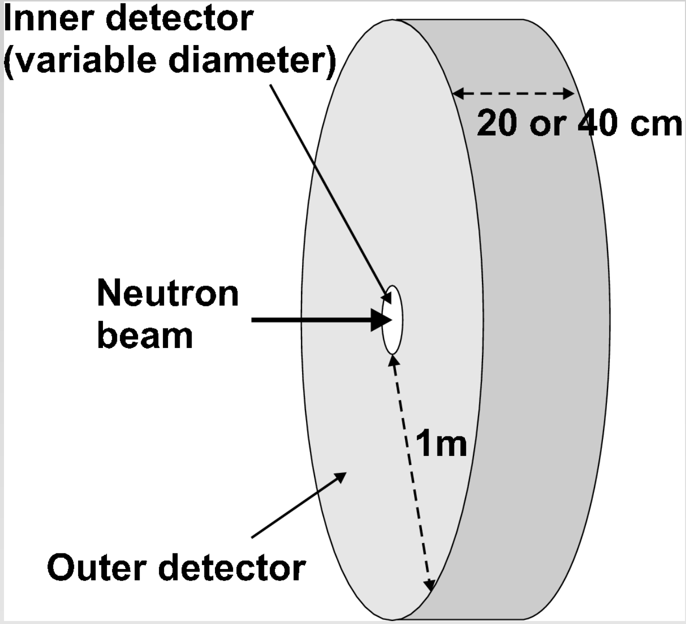
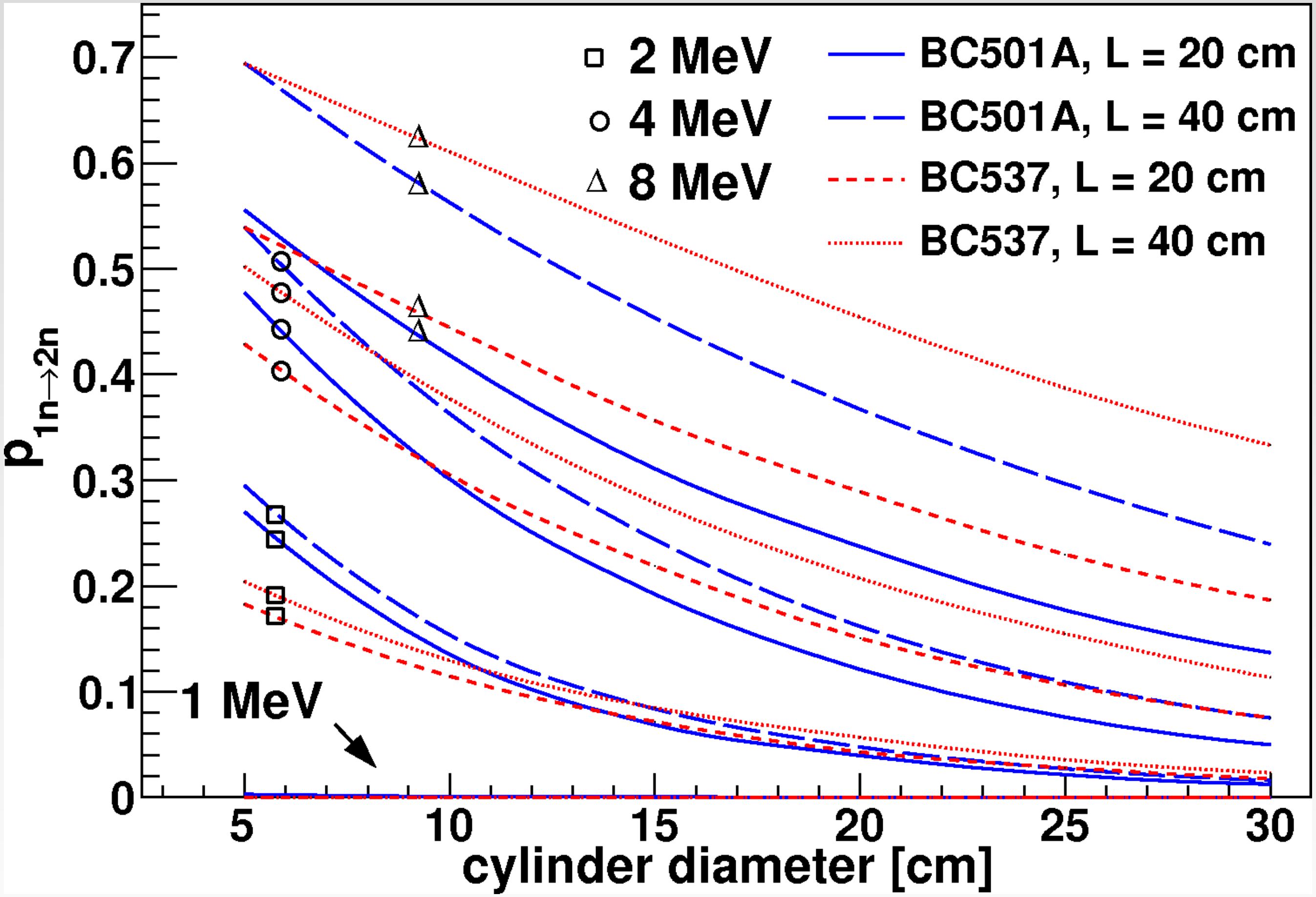
Evaluation of the detector diameter



Probability that one neutron
gives signals in two detectors



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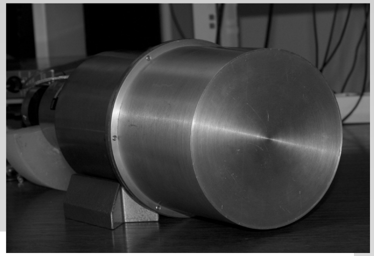
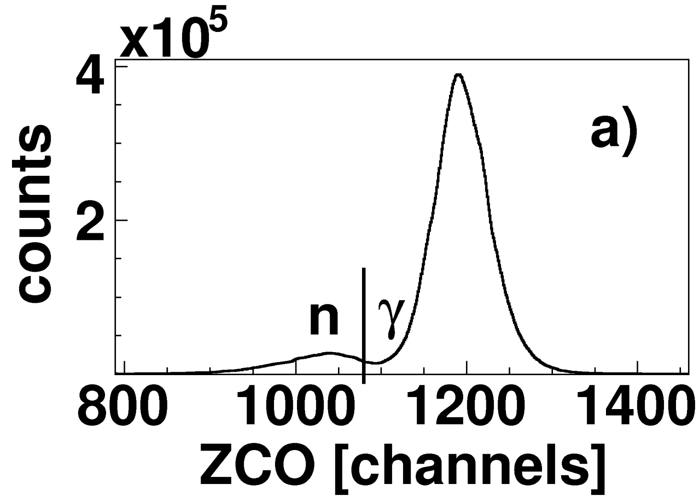
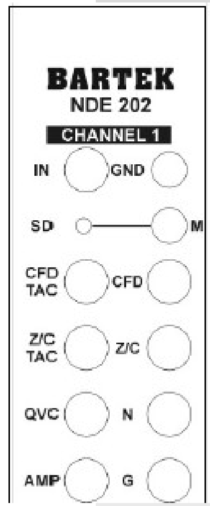
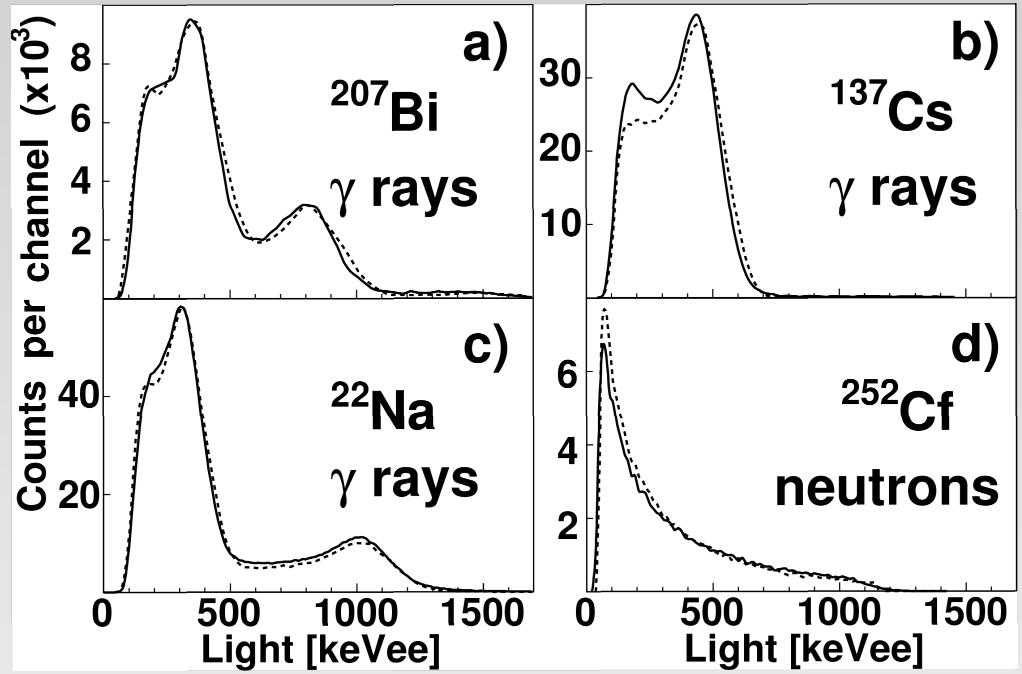
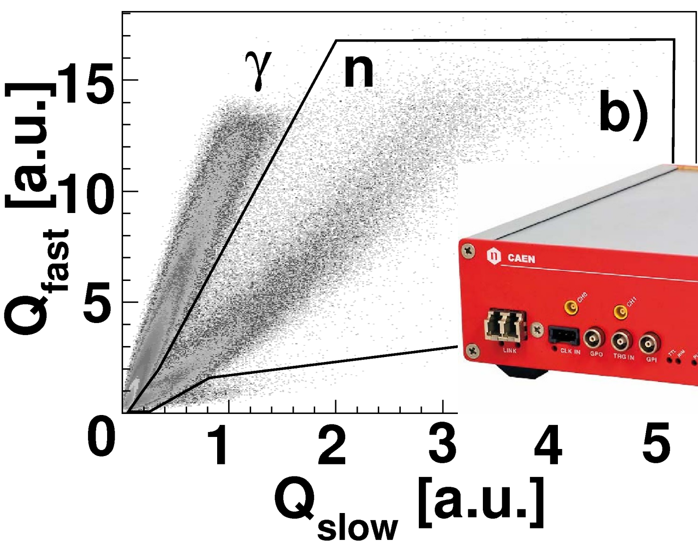
Validation of the simulations











	Efficiency (%) Absolute	
Detector and radioactive source	Exp.	Sim.
NORDBALL:		
^{137}Cs γ rays, 50 cm	0.30(1)	0.285(1)
^{252}Cf neutrons, 51 cm	0.174(9)	0.241(2)
Cylindrical:		
^{252}Cf neutrons, 5 cm	6.1(3)	6.64(2)

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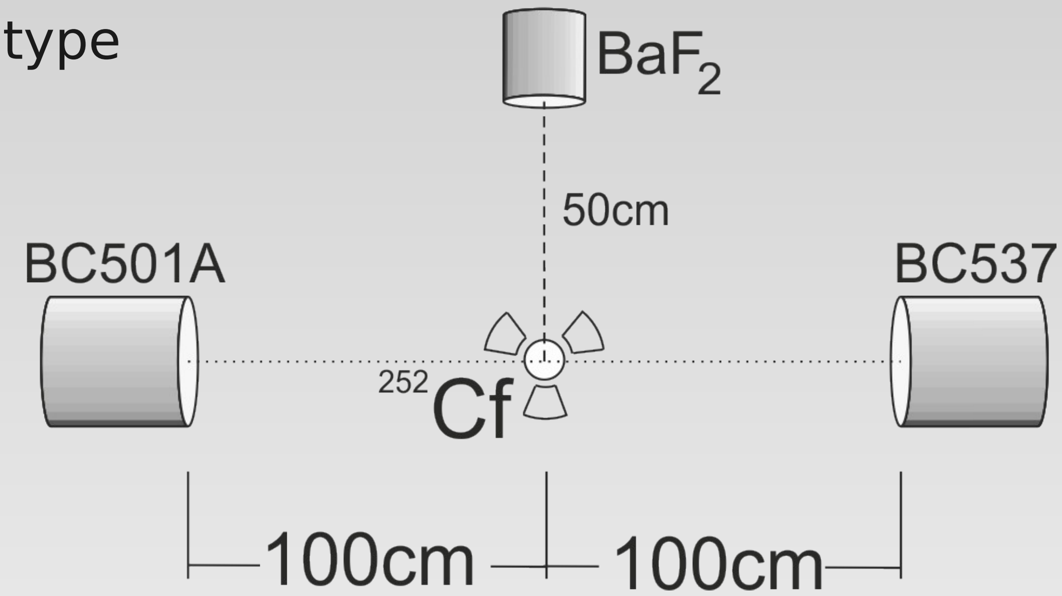
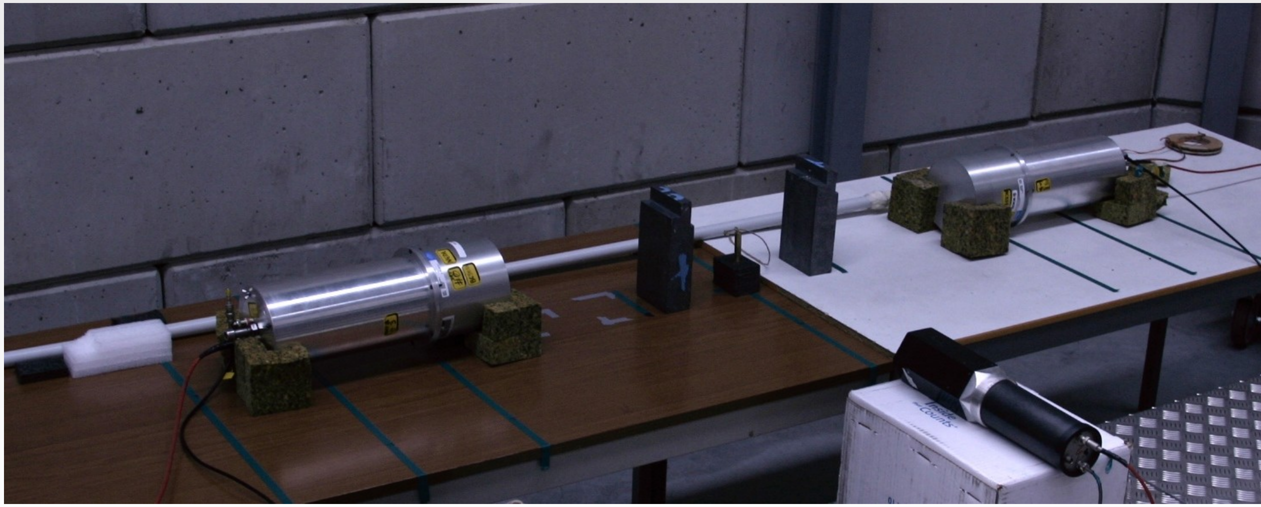
Tests of NEDA prototype detectors

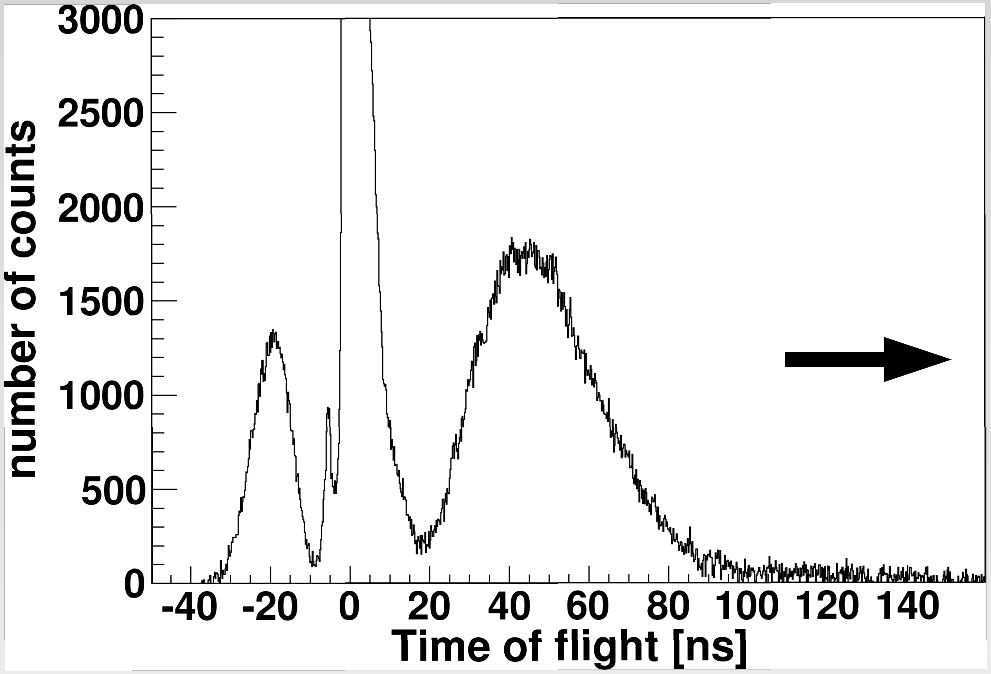
Legnaro

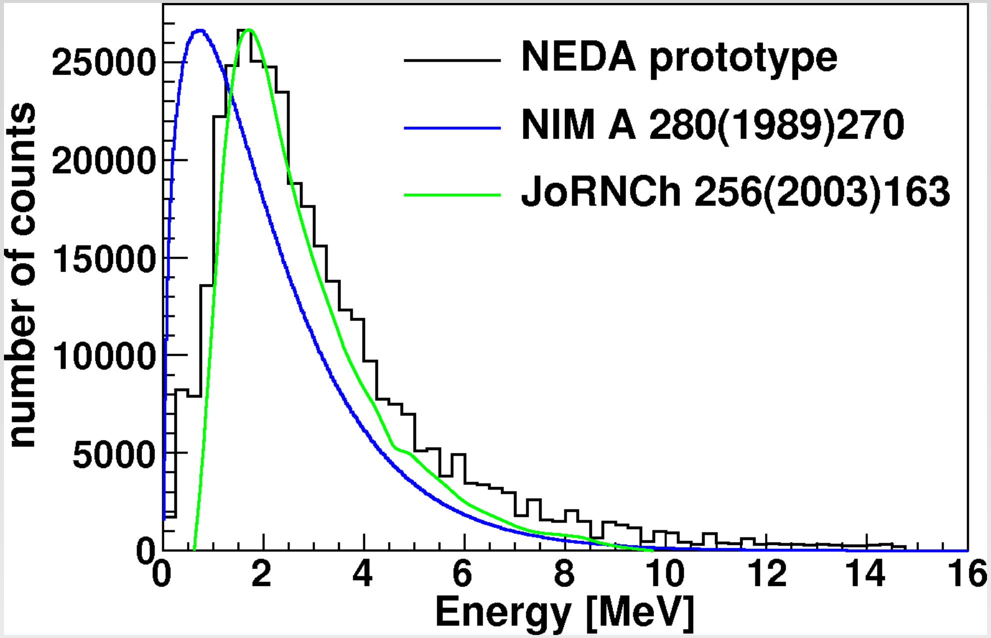
- 5 inch cylinders
- BC501A and BC537 – 2 of each type
- Photonis XP4512
- Struck SIS3350
  (500 MHz, 12 bit)
- VME-based DAQ system by
  J. Agramunt-Ros
- BaF_2 for time reference





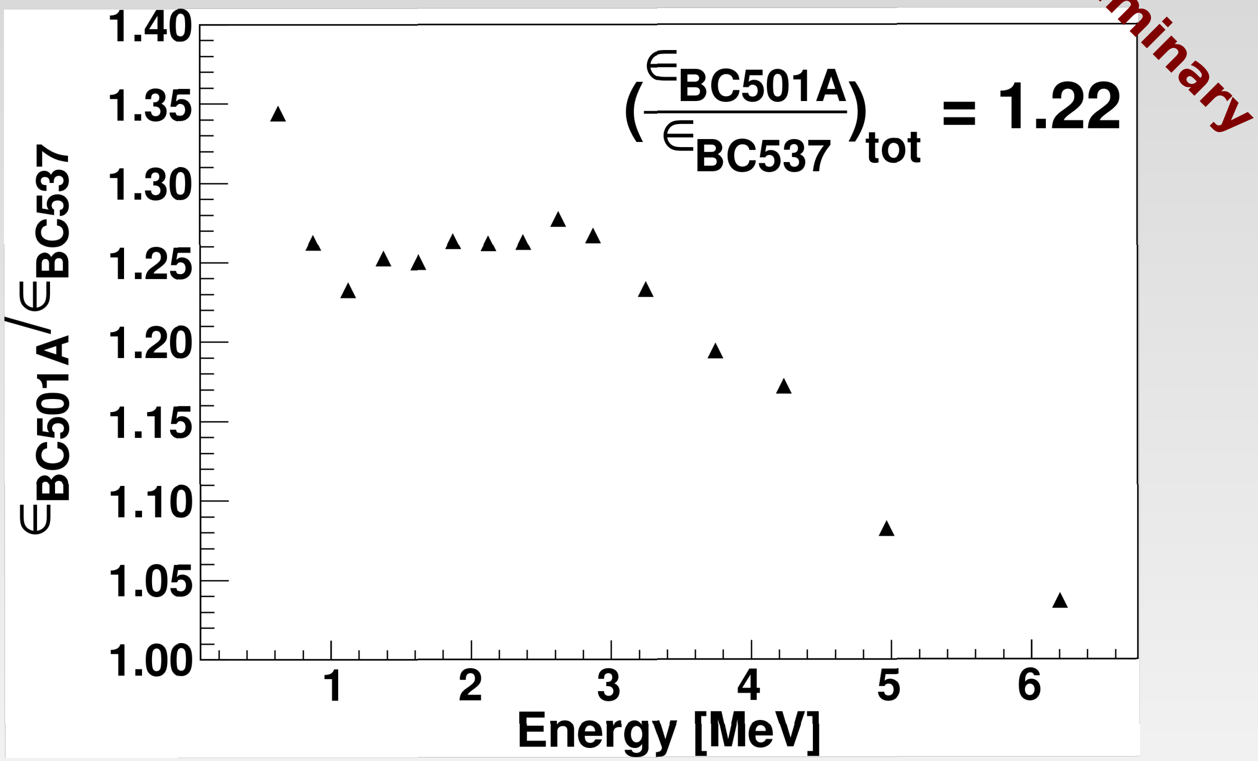
Evaluation of the test data





G.Jaworski, work in progress

Relative efficiency of the two scintillators (experimental)



G.Jaworski, work in progress

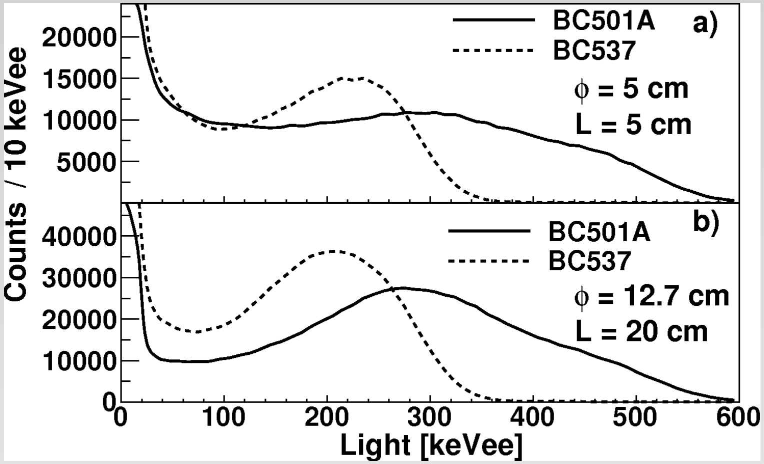
Further test data evaluation

- Light vs. neutron energy correlation
- Time resolution
- Pulse shape discrimination
- Scattering to another detector

Digitized NWall detectors' signals to be acquired also during the NWall comissioning experiment at GANIL 13-16 June (in coinc. with EXOGAM)

Deuterated scintillator ? Negative.

- *Deuterated scintillator:*
  - *correlation with E_n only for small detectors*



  - *less light, lower efficiency, worse time resolution, worse n/γ discrimination*

- *Observed differences between the two scintillators easily explained by the physical properties of the two materials (cross sections, amount of light produced in the interactions of n on p/d, relative content of C)*

Conclusions on single detector unit size

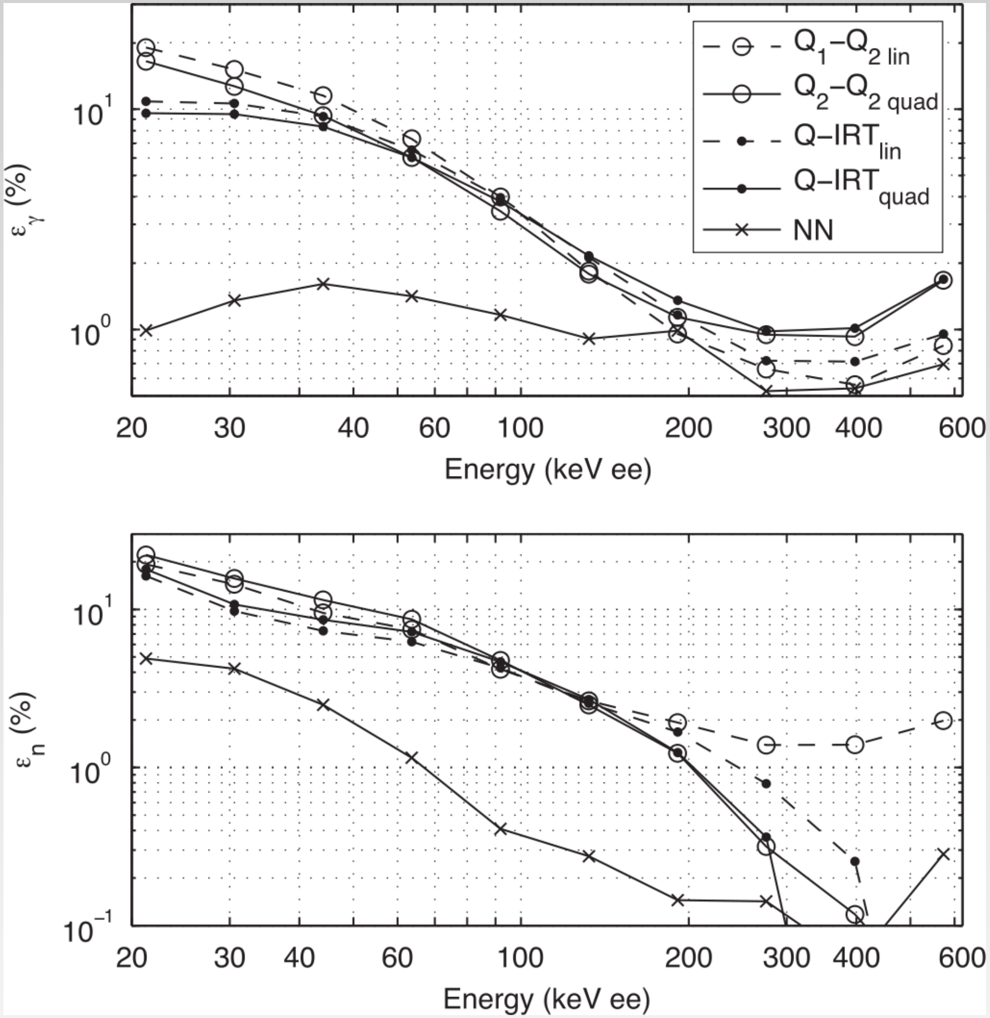
- **Length 20 cm** sufficient to detect most of the neutrons. Longer detectors – larger scattering to neighbours, worse time resolution
- **Diameter 5 inch** – limited by the size of commonly available PMT, no reason to reduce the diameter (and increasing the number of electronic channels)

Pulse shape discrimination

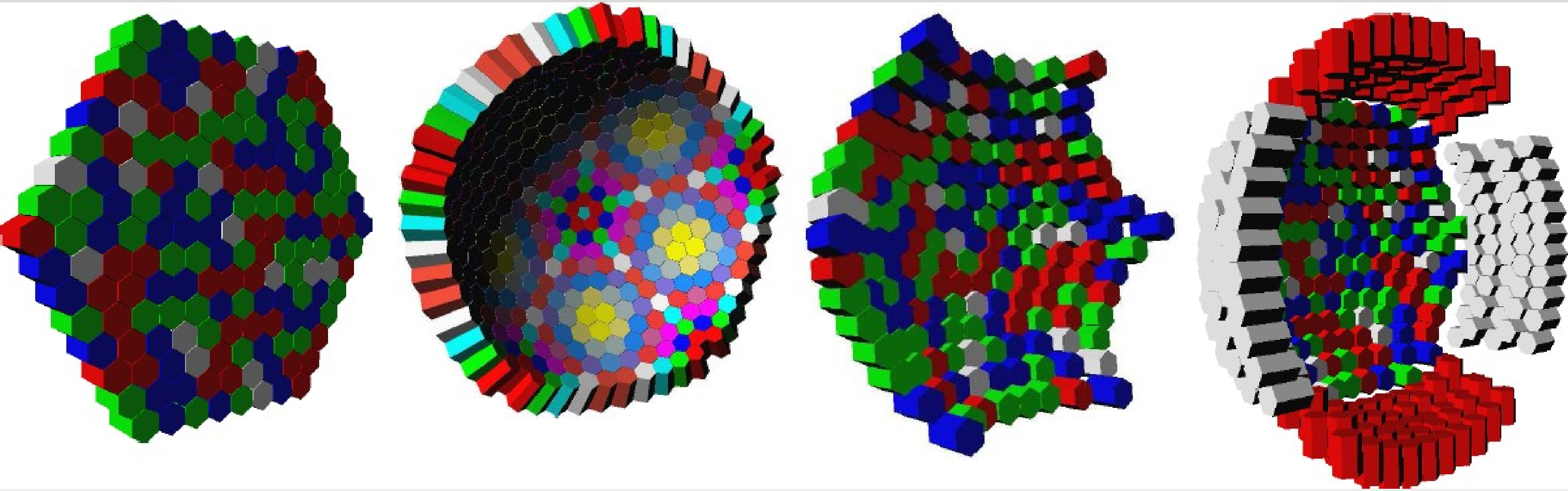
- Work in progress on digital implementation and tests of several neutron – γ-ray discrimination algorithms
- Very promising results obtained using an artificial neural network

E.Ronchi, P.-A.Söderström, J.Nyberg et al.
NIMA 610 (2009) 534

also
P.-A.Söderström, J.Nyberg, R.Wolters
NIMA 594 (2008) 79

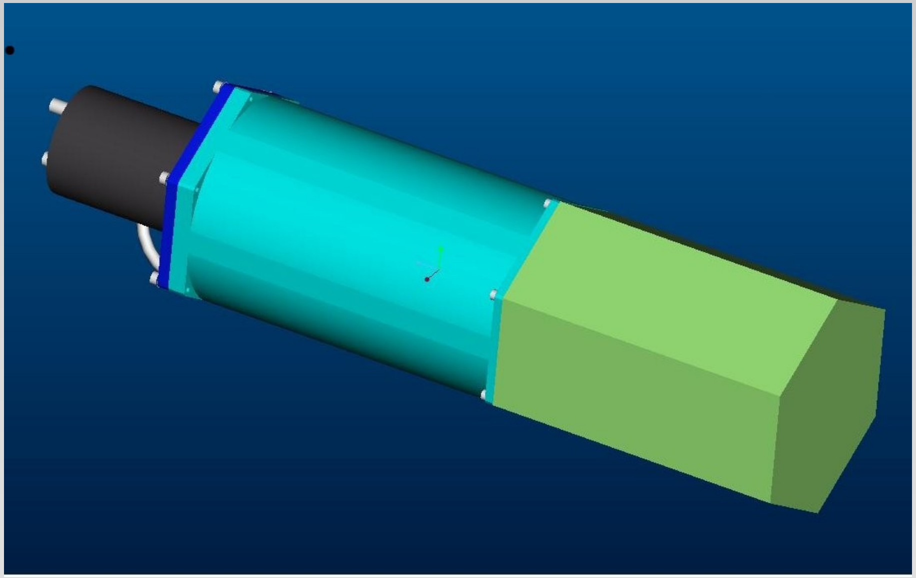


Geometries



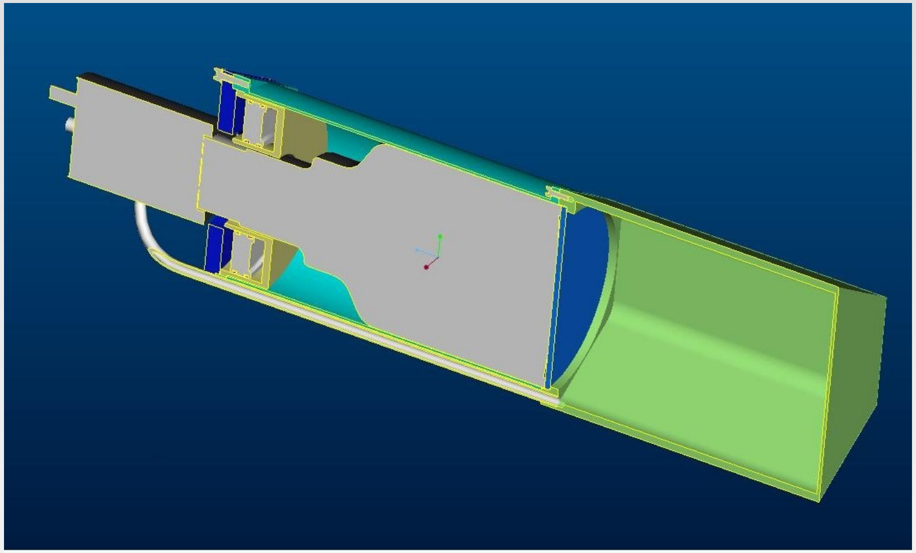
T. Hüyük et al

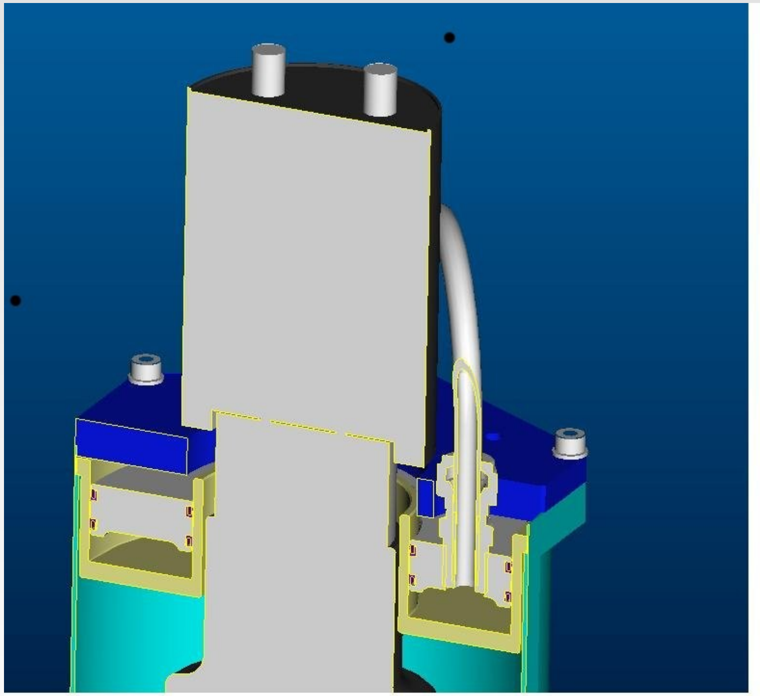
Design of a NEDA detector



ϕ = 127 mm - PMT diameter

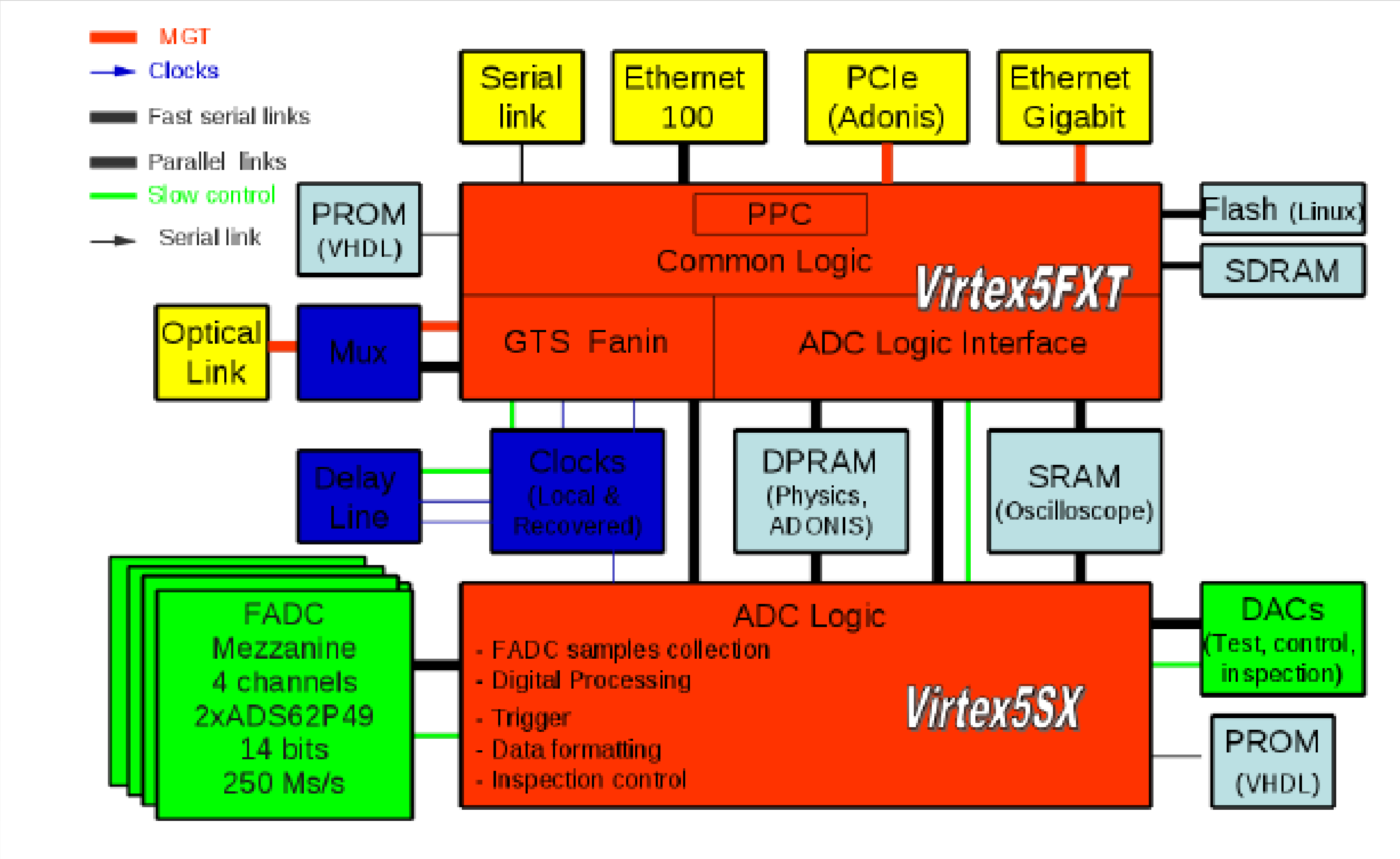
L = 200 mm - length





drawings by
Nicola Lollo

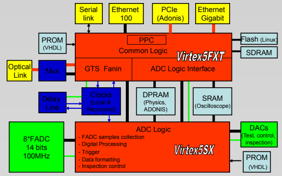
NUMEXO2

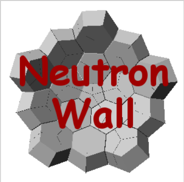


MGT
Clocks
Fast serial links
Parallel links
Slow control
Serial link
Serial link
Ethernet 100
PCIe (Adonis)
Ethernet Gigabit
PROM (VHDL)
PPC
Common Logic
Virtex5FXT
Flash (Linux)
SDRAM
Optical Link
Mux
GTS Fanin
ADC Logic Interface
Delay Line
Clocks (Local & Recovered)
DPRAM (Physics, ADONIS)
SRAM (Oscilloscope)
FADC Mezzanine 4 channels 2xADS62P49 14 bits 250 Ms/s
ADC Logic
- FADC samples collection
- Digital Processing
- Trigger
- Data formatting
- Inspection control
Virtex5SX
DACs (Test, control, inspection)
PROM (VHDL)

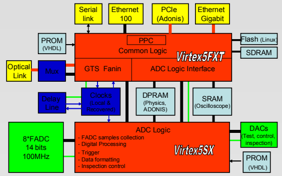
Phases of NEDA

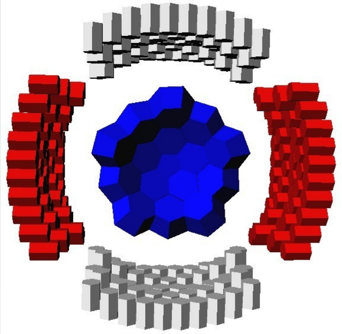
- Phase 0: Upgrade of NWall electronics (going digital)



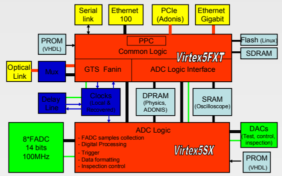


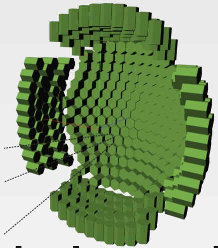
- Phase 1: Construction of 1π array, combined with NWall





- Phase 2: Final construction of 2π array, 355 detectors





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

Phases 0 to 2 (90 detectors)

	2012				2013				2014				2015			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Electronics																
Manufacturing Tests	■	■	■	■	■	■										
Mass Production							■									
Tests								■	■							
Detectors																
Design single det.	■	■	■	■												
Production single det.					■	■	■	■								
Test detectors									■	■	■	■				
Mechanics																
Design Mechanics			■	■												
Production Mechanics					■	■	■	■								
Voltage Dividers																
Design								■	■	■						
Production											■	■				
Tests													■	■		
Photo Multipliers																
Launch purchase					■	■	■	■								
Final Asembly													■	■	■	
General Tests															■	■

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

Summary

- BC501A (C_8H_{10}) scintillator will be used in NEDA
- Up to 355 identical detector units,
  "hexagonal", L=20 cm, PMT ϕ = 12.7 cm,
  with the default target-detector distance of 1m
- NUMEXO2 digitizer (EXOGAM, PARIS, ...)

  (first stage: upgrade of the NWall electronics)
- Work on digital PSD and timing algorithms in progress.
- Mechanical design of detector units in progress.