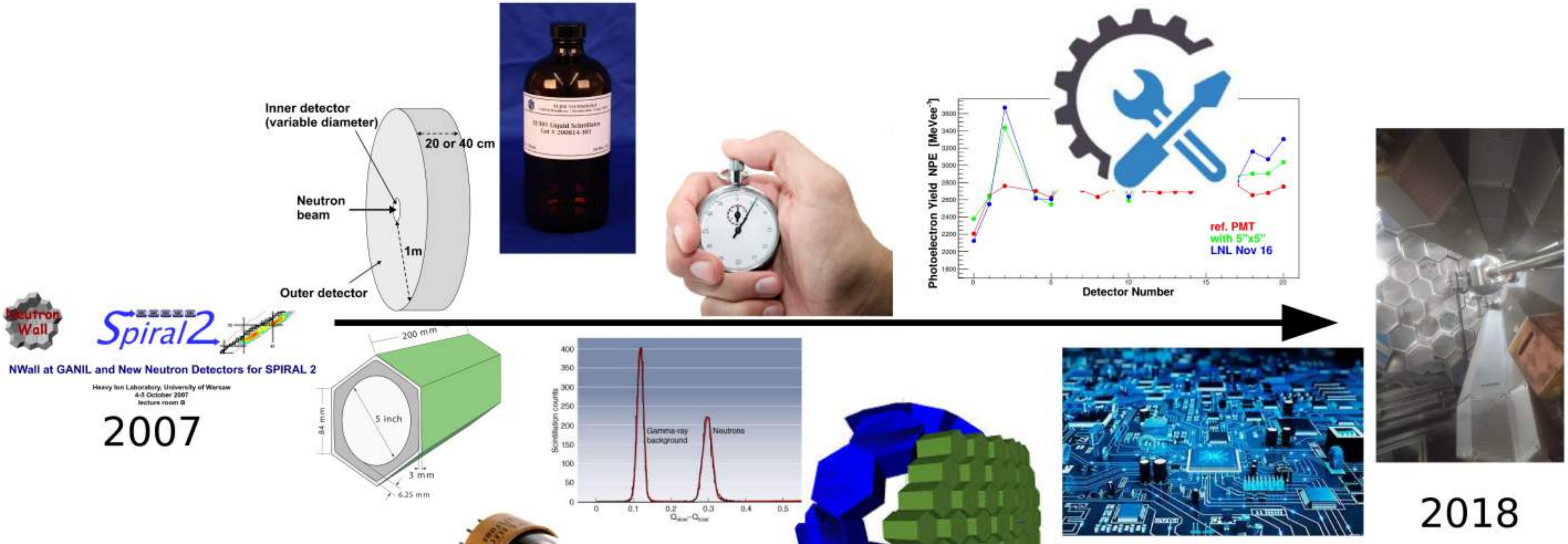
12 lat projektu – od koncepcji do pierwszej serii eksperymentów ze spektrometrem AGATA

Grzegorz Jaworski, ŚLCJ UW

Warszawa, 30 maja 2019

Plan prezentacji

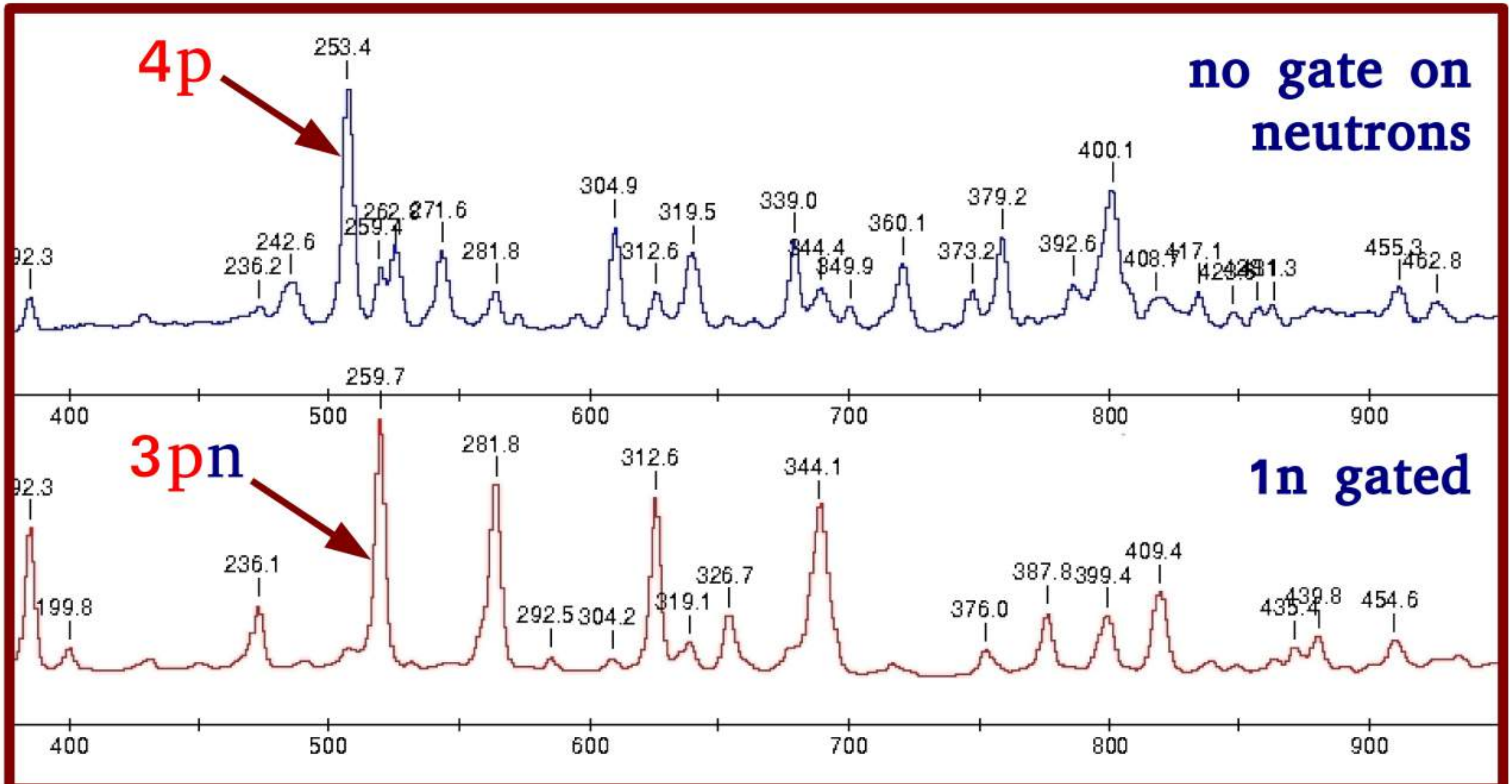
→ Dlaczego (nowy) filtr krotności neutronów?



→ Podsumowanie

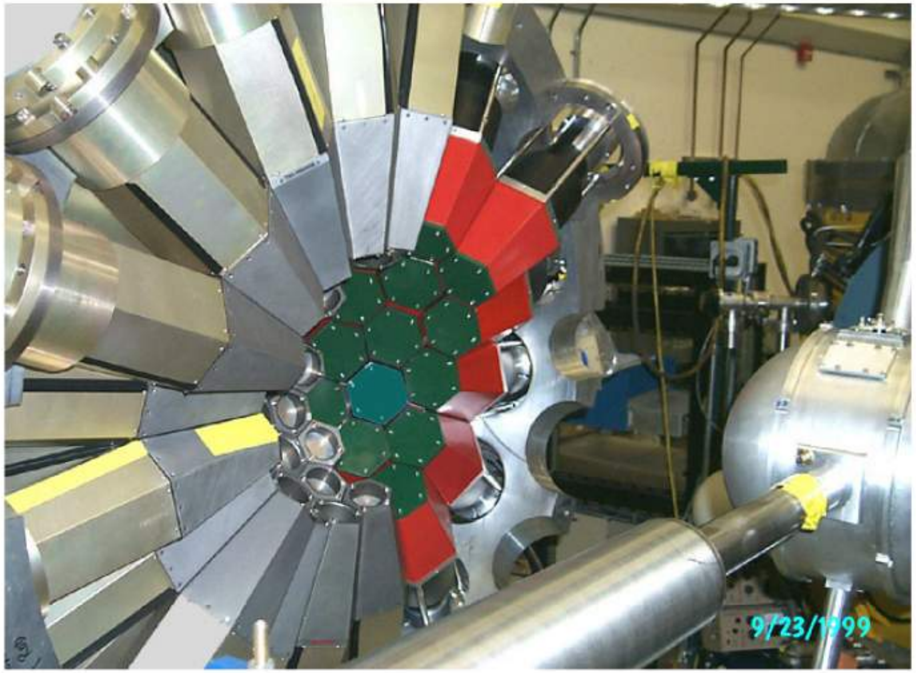
n selection

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



n selection

Neutron Wall



Neutron Shell

Neutron Wall

→ Constructed 1995-1997 for EUROBALL

→ New dedicated electronics

→ Experimental campaings:

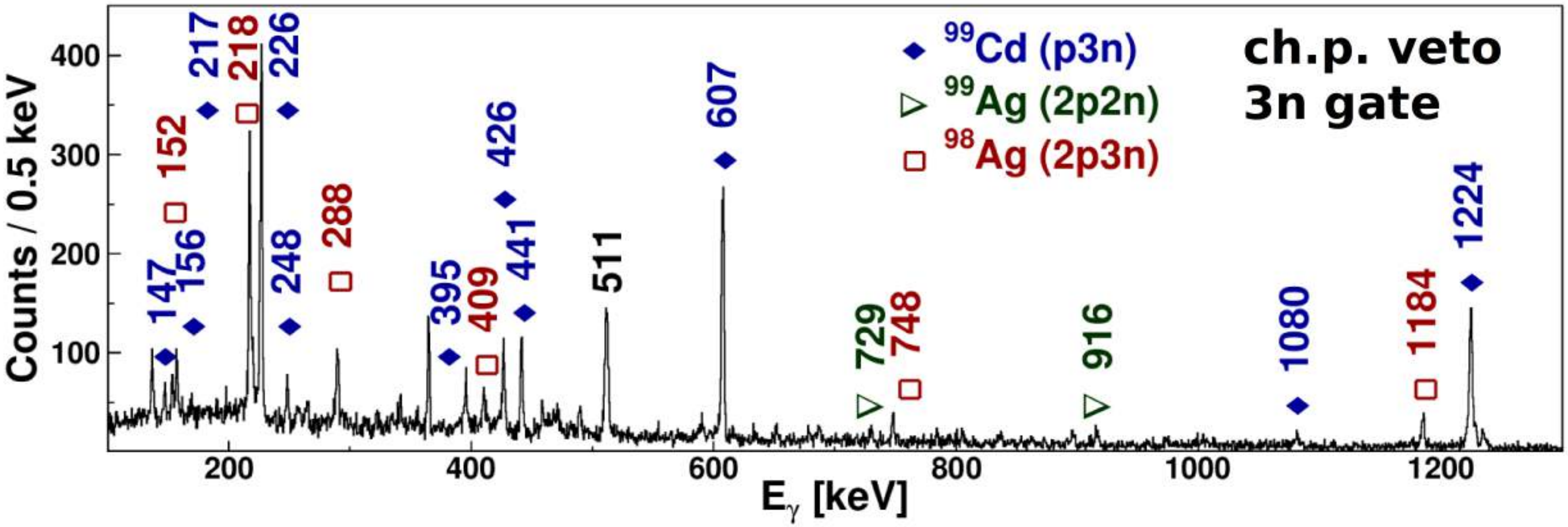
- EUROBALL @ LNL – 1998
- EUROBALL @ IReS – 2001-2003
- EXOGAM @ GANIL – 2005-2014
- GALILEO @ LNL – 2015-2017

Ö. Skeppstedt et al,. NIM A421 (1999) 531
J. Ljungvall et al., NIM A528(2004)741

→ ~40 papers and still counting,
Mostly along N=Z, approaching ^{100}Sn

Why a new array?

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



^{100}In not observed, but observation only a matter of statistics.
20x statistics: → a year with EXOGAM + NWall

2007 Decision: New array

→ Goal: develop a neutron detector array to be used with AGATA, GALILEO, EXOGAM2, PARIS, EAGLE, etc. for experiments with high intensity stable and radioactive ion beams (SPES, SPIRAL2, ...), able to filter out the channels with neutron emission from overwhelming background of 0n channels.

→ Requirements:

- excellent neutron-gamma discrimination (NGD);
- good timing;
- superior 1n/2n/3n/... discrimination;
- capability to run at high counting rates;
- be versatile (energy resolution for reaction studies);
- cope with large neutron multiplicities (reactions with neutron-rich RIBs).

2007 Decision: New array

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- excellent neutron-gamma discrimination (NGD);
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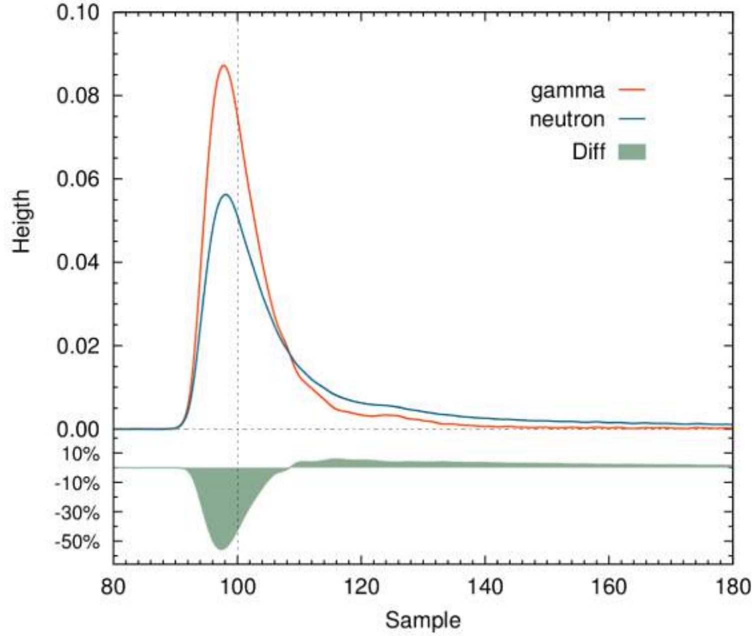
- cope with large neutron multiplicities (reactions with neutron-rich RIBs).



2007 Decision: New array

→ Requirements:
- excellent neutron-gamma discrimination (NGD);
- good timing;
- superior 1n/2n/3n/... discrimination;
- capability to run at high counting rates;
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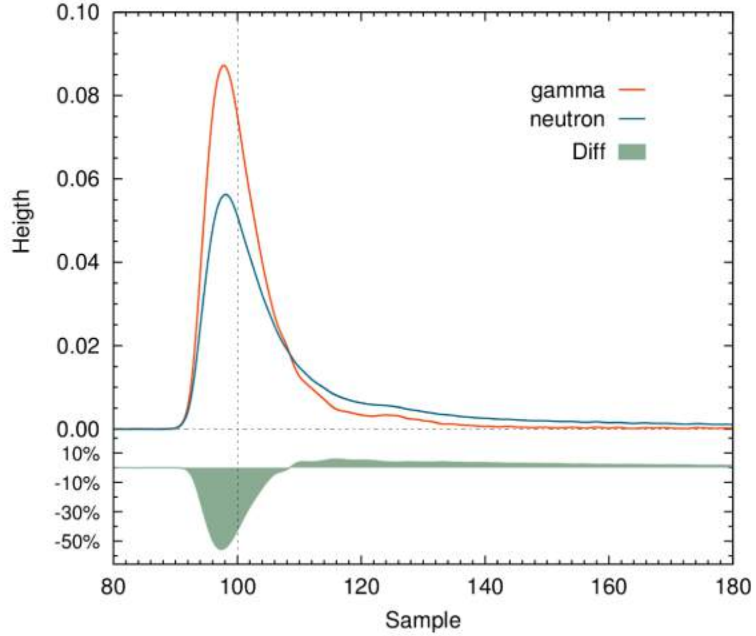
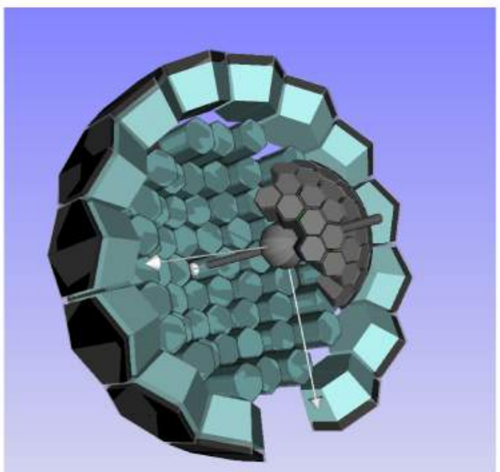


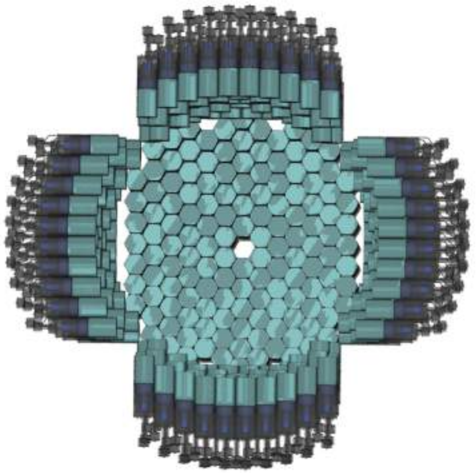
Want the best quality → do it yourself!

Properties now and in the future



NEDA+NW+AGATA

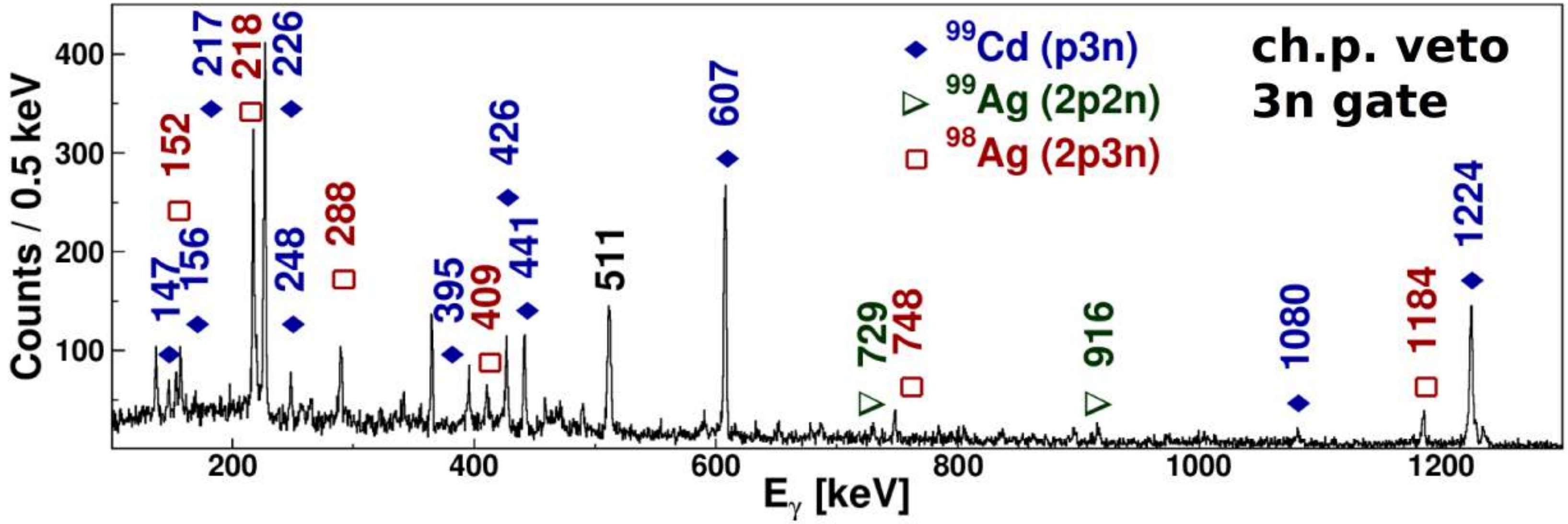
	2018	NW	2028
ε(1n)	30.0%	20%	40.5%
ε(2n)	3.5%	1-2%	11.5%
ε(3n)	0.5%	0.1%	3.7%



NEDA 2Π

Why a new array?

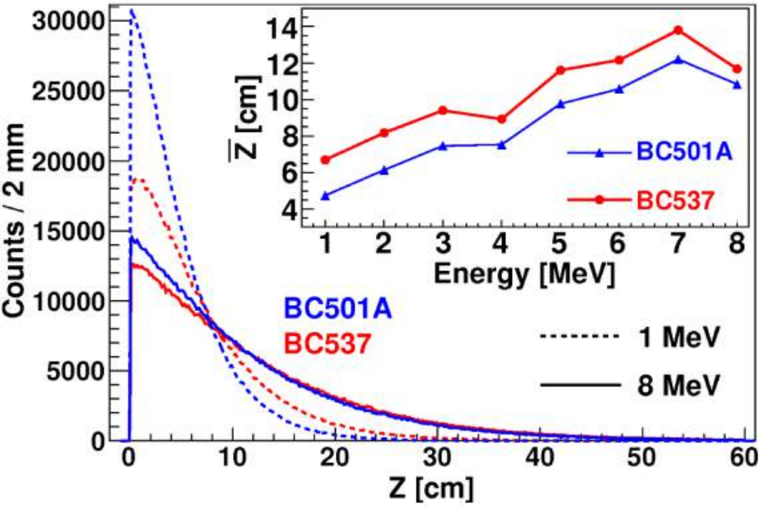
An example:
Attempt to study ^{100}In – 1ν 1π^{-1} outside ^{100}Sn
3n evaporation channel – the only 3n case with NWall (+ EUROBALL)

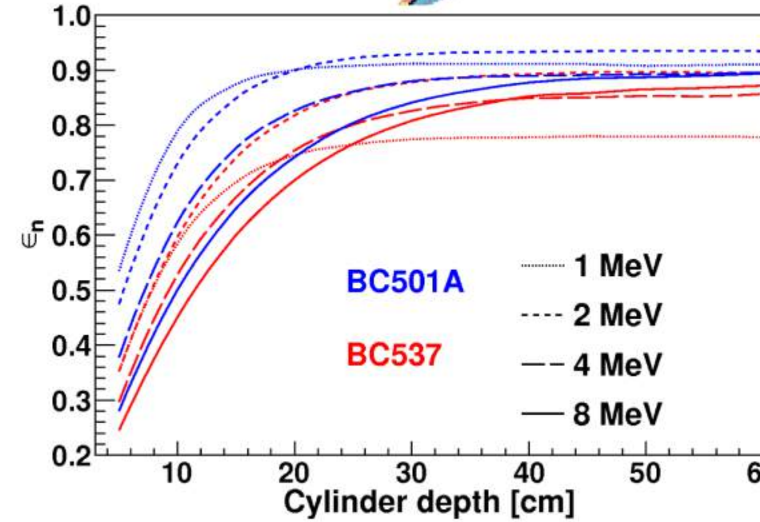


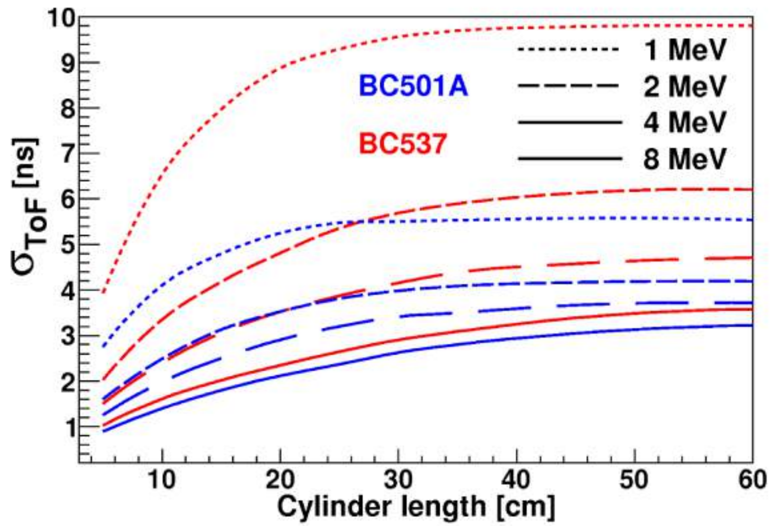
^{100}In not observed, but observation only a matter of statistics.
20x statistics: → a year with EXOGAM + NWall
→ 1 week with AGATA + NEDA

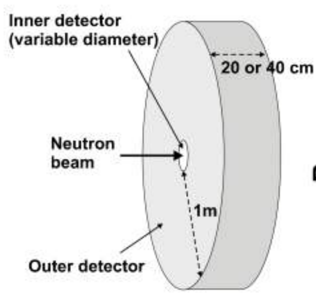
Other crucial nuclei accessible in 3n evap. channels, including ^{101}Sn.

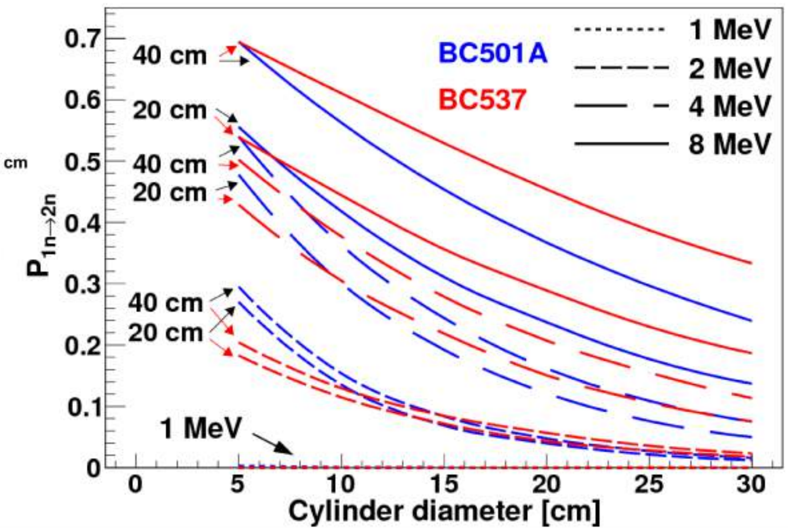
Single cell


Counts / 2 mm
Z [cm]
BC501A
BC537
1 MeV
8 MeV
Z̄ [cm]
Energy [MeV]
BC501A
BC537


ϵ_n
Cylinder depth [cm]
BC501A
BC537
1 MeV
2 MeV
4 MeV
8 MeV

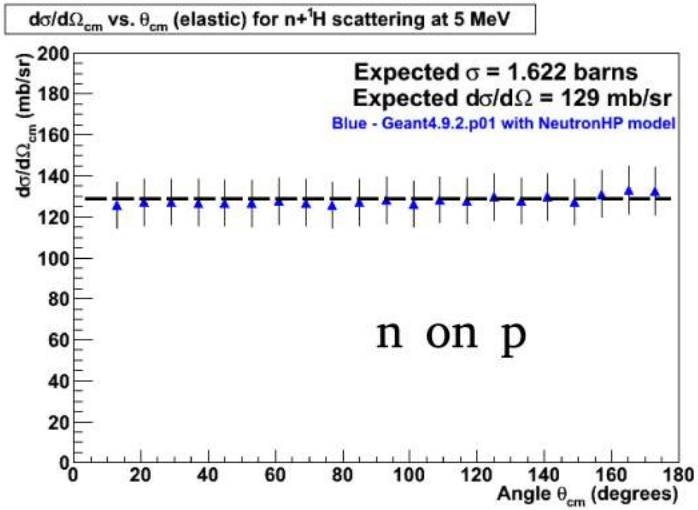

σ_{ToF} [ns]
Cylinder length [cm]
BC501A
BC537
1 MeV
2 MeV
4 MeV
8 MeV

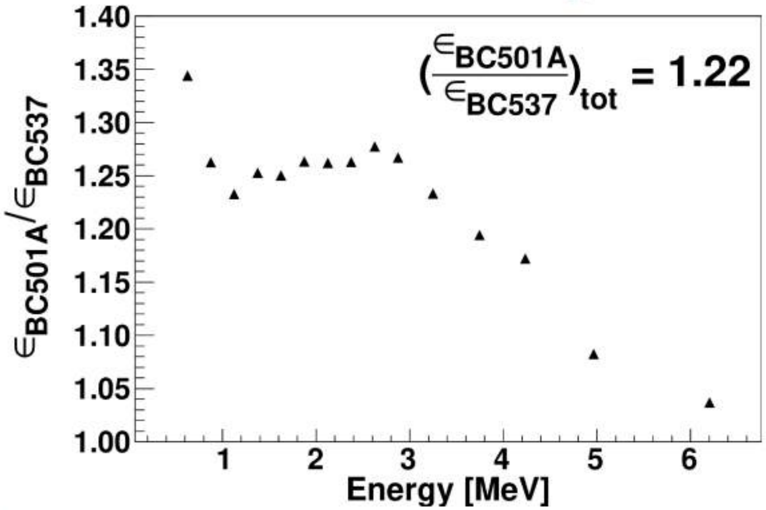

Inner detector
(variable diameter)
20 or 40 cm
Neutron
beam
1m
Outer detector


$P_{1n \to 2n}$
Cylinder diameter [cm]
BC501A
BC537
1 MeV
2 MeV
4 MeV
8 MeV
40 cm
20 cm
40 cm
20 cm
40 cm
20 cm
1 MeV

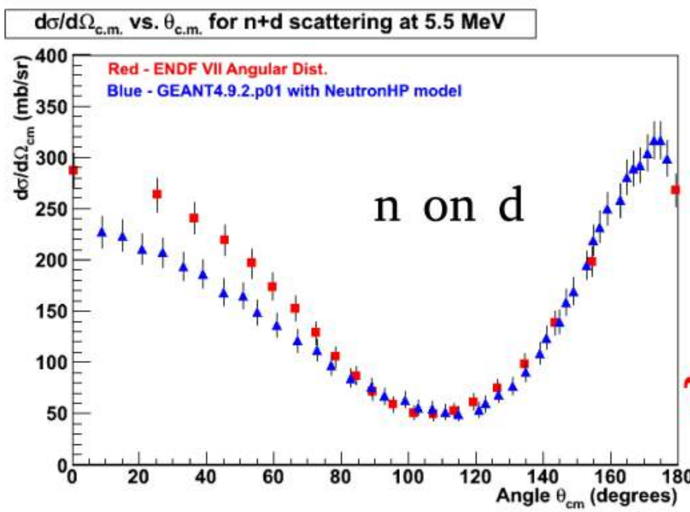
Scintillator

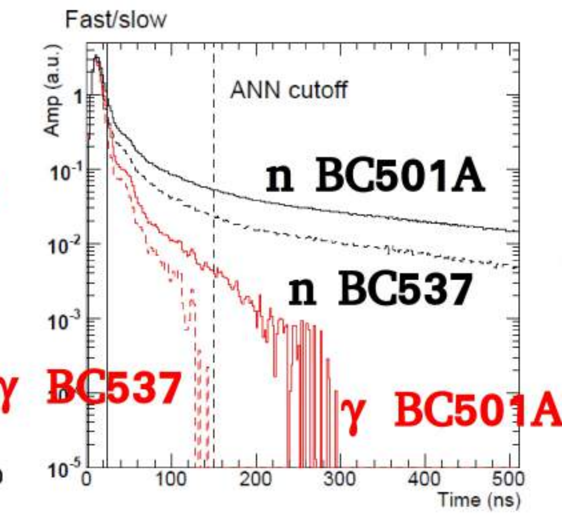
? BC501A / BC537 / EJ299 / ... ?

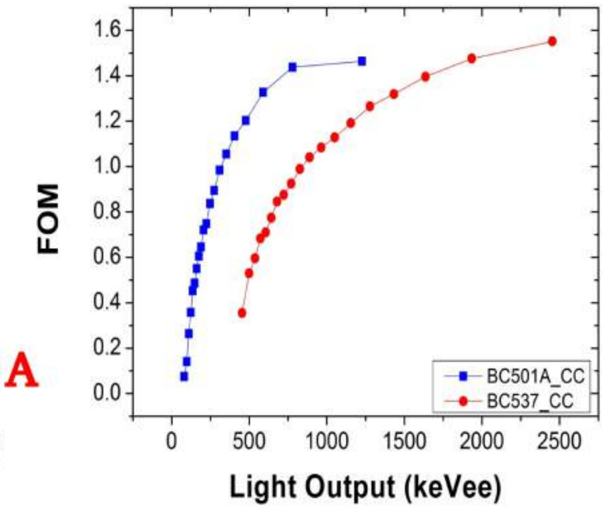




preliminary







Single cell

Nuclear Instruments and Methods in Physics Research A 673 (2012) 64–72

Contents lists available at SciVerse ScienceDirect

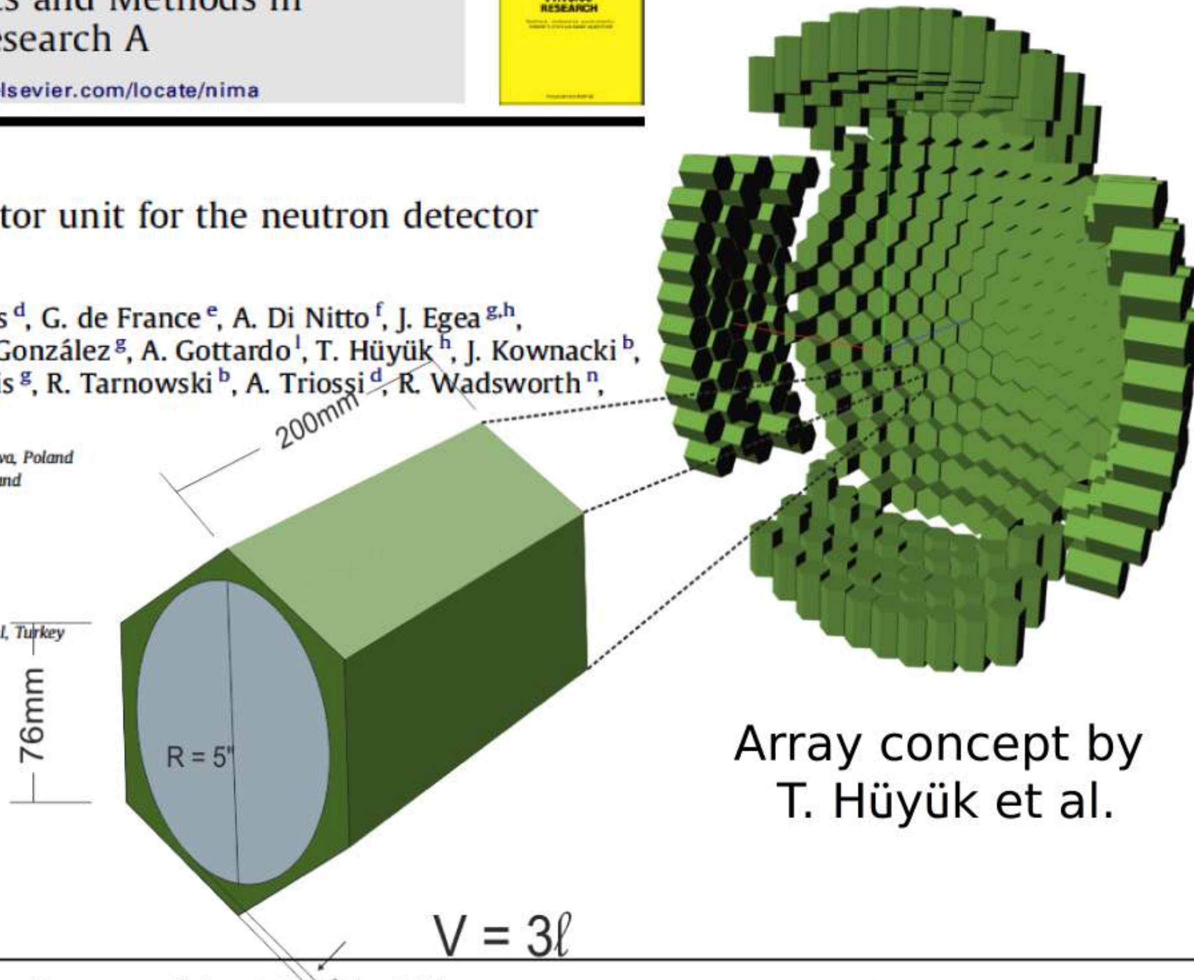
Nuclear Instruments and Methods in Physics Research A

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

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

G. Jaworski [a,b], M. Palacz [b,*], J. Nyberg [c], G. de Angelis [d], G. de France [e], A. Di Nitto [f], J. Egea [g,h], M.N. Erduran [i], S. Ertürk [j], E. Farnea [k], A. Gadea [h], V. González [g], A. Gottardo [l], T. Hüyük [h], J. Kownacki [b], A. Pipidis [d], B. Roeder [m], P.-A. Söderström [c], E. Sanchis [g], R. Tarnowski [b], A. Triossi [d], R. Wadsworth [n], J.J. Valiente Dobon [d]

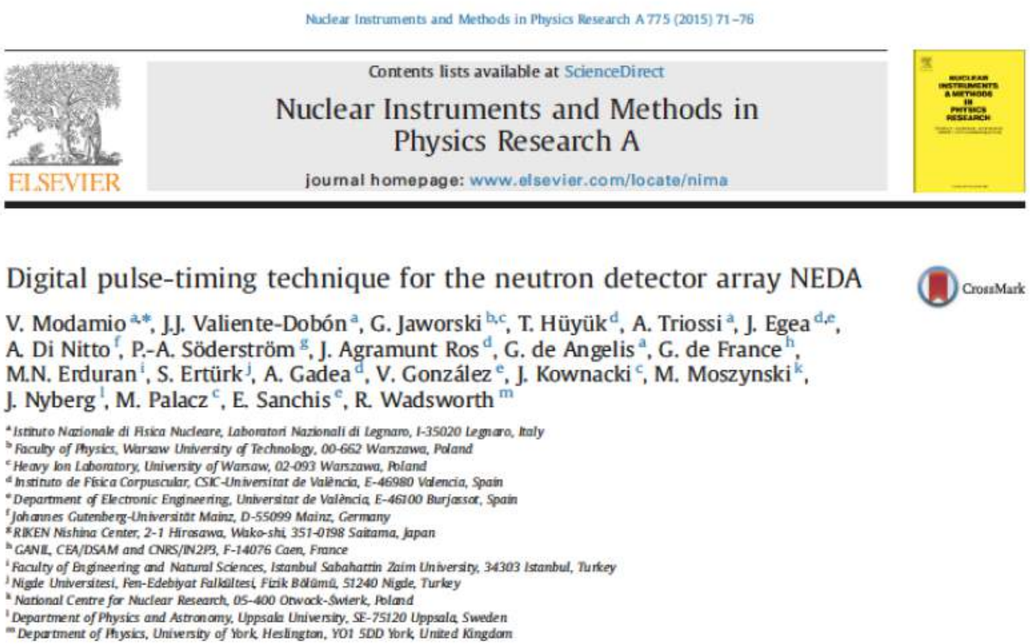
[a] Faculty of Physics, Warsaw University of Technology, ul. Koszykowa 75, 00-662 Warszawa, Poland
[b] Heavy Ion Laboratory, University of Warsaw, ul. Pasteura 5A, PL 02-093 Warszawa, Poland
[c] Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden
[d] INFN, Laboratori Nazionali di Legnaro, Legnaro, Italy
[e] GANIL, Caen, France
[f] INFN Sezione di Napoli, Napoli, Italy
[g] Department of Electronic Engineering, University of Valencia, Burjassot (Valencia), Spain
[h] IFIC-CSIC, University of Valencia, Valencia, Spain
[i] Faculty of Engineering and Natural Sciences, Istanbul Sabahattin Zaim University Istanbul, Turkey
[j] Nigde Universitesi, Fen-Edebiyat Falkültesi, Fizik Bölümü, Nigde, Turkey
[k] INFN Sezione di Padova, Padua, 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



Array concept by T. Hüyük et al.

Timing

Digital timing algorithm for various 5” PMTs



Nuclear Instruments and Methods in Physics Research A 775 (2015) 71–76

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

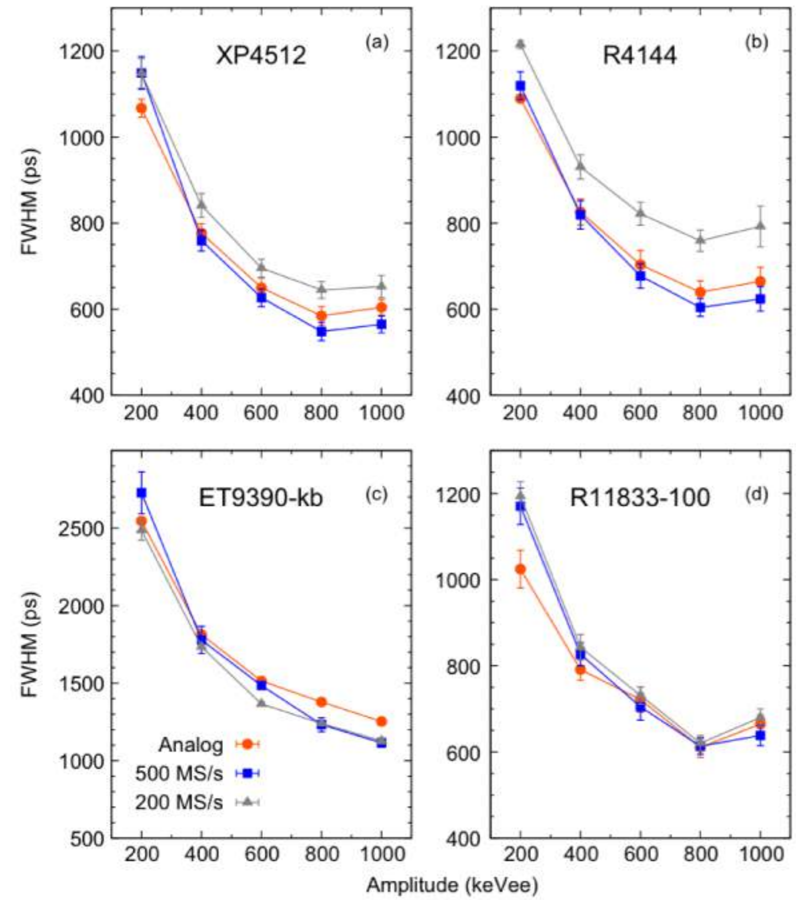
journal homepage: www.elsevier.com/locate/nima

ELSEVIER

Digital pulse-timing technique for the neutron detector array NEDA

V. Modamio [a,*], J.J. Valiente-Dobón [a], G. Jaworski [b,c], T. Hüyük [d], A. Triossi [a], J. Egea [d,e], A. Di Nitto [f], P.-A. Söderström [g], J. Agramunt Ros [d], G. de Angelis [a], G. de France [h], M.N. Erduran [i], S. Ertürk [j], A. Gadea [d], V. González [e], J. Kownacki [c], M. Moszynski [k], J. Nyberg [l], M. Palacz [c], E. Sanchis [e], R. Wadsworth [m]

[a] Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro, I-35020 Legnaro, Italy
[b] Faculty of Physics, Warsaw University of Technology, 00-662 Warszawa, Poland
[c] Heavy Ion Laboratory, University of Warsaw, 02-093 Warszawa, Poland
[d] Instituto de Física Corpuscular, CSIC-Universitat de València, E-46980 Valencia, Spain
[e] Department of Electronic Engineering, Universitat de València, E-46100 Burjassot, Spain
[f] Johannes Gutenberg-Universität Mainz, D-55099 Mainz, Germany
[g] RIKEN Nishina Center, 2-1 Hirosawa, Wako-shi, 351-0198 Saitama, Japan
[h] GANIL, CEA/DSAM and CNRS/IN2P3, F-14076 Caen, France
[i] Faculty of Engineering and Natural Sciences, Istanbul Sabahattin Zaim University, 34303 Istanbul, Turkey
[j] Nigde Universitesi, Fen-Edebiyat Falkültesi, Fizik Bölümü, 51240 Nigde, Turkey
[k] National Centre for Nuclear Research, 05-400 Otwock-Świerk, Poland
[l] Department of Physics and Astronomy, Uppsala University, SE-75120 Uppsala, Sweden
[m] Department of Physics, University of York, Heslington, YO1 5DD York, United Kingdom



PMT tests for best timing for NEDA

NGD

NEDA

Digital PSA algorithm for various 5" PMTs

Nuclear Instruments and Methods in Physics Research A 767 (2014) 83–91

Contents lists available at ScienceDirect

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Nuclear Instruments and Methods in Physics Research A

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

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

X.L. Luo [a,b,*], V. Modamio [c], J. Nyberg [b], J.J. Valiente-Dobón [c], Q. Nishada [b], G. de Angelis [c], J. Agramunt [d], F.J. Egea [d,e], M.N. Erduran [f], S. Ertürk [g], G. de France [h], A. Gadea [d], V. González [e], T. Hüyük [d], G. Jaworski [i,j], M. Moszyński [j,k], A. Di Nitto [l], M. Palacz [j], P.-A. Söderström [m], E. Sanchis [e], A. Triossi [c], R. Wadsworth [n]

[a] Department of Instrument Science and Technology, College of Mechatronics and Automation, National University of Defense Technology, Changsha, China
[b] Department of Physics and Astronomy, Uppsala University, SE-75120 Uppsala, Sweden
[c] INFN, Laboratori Nazionali di Legnaro, I-35020 Legnaro, Padova, Italy
[d] IFIC-CSIC, University of Valencia, Valencia, Spain
[e] Department of Electronic Engineering, University of Valencia, E-46071 Valencia, Spain
[f] Faculty of Engineering and Natural Sciences, Istanbul Sabahattin Zaim University, Istanbul, Turkey
[g] Nigde Universitesi, Fen-Edebiyat Falkültesi, Fizik Bölümü, Nigde, Turkey
[h] GANIL, CEA/DSAM and CNRS/IN2P3, Bd Henri Becquerel, BP 55027, F-14076 Caen Cedex 05, France
[i] Faculty of Physics, Warsaw University of Technology, ul. Koszykowa 75, 00-662 Warszawa, Poland
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[k] National Centre for Nuclear Research, A. Soltana 7, PL 05-400 Otwock-Swierk, Poland
[l] Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany
[m] RIKEN Nishina Center, 2-1 Hirosawa, Wako-shi, Saitama 351-0198, Japan
[n] Department of Physics, University of York, Heslington, York YO10 5DD, UK

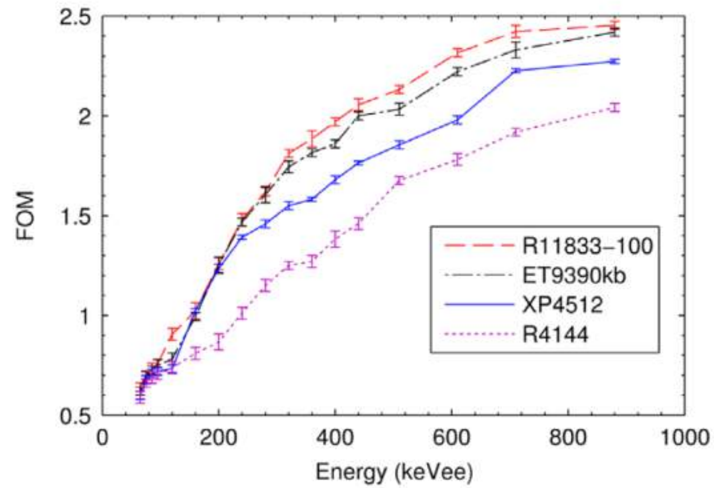
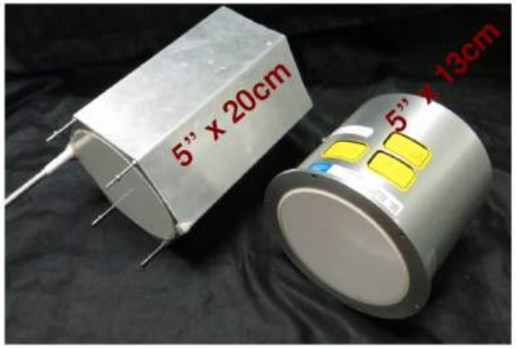
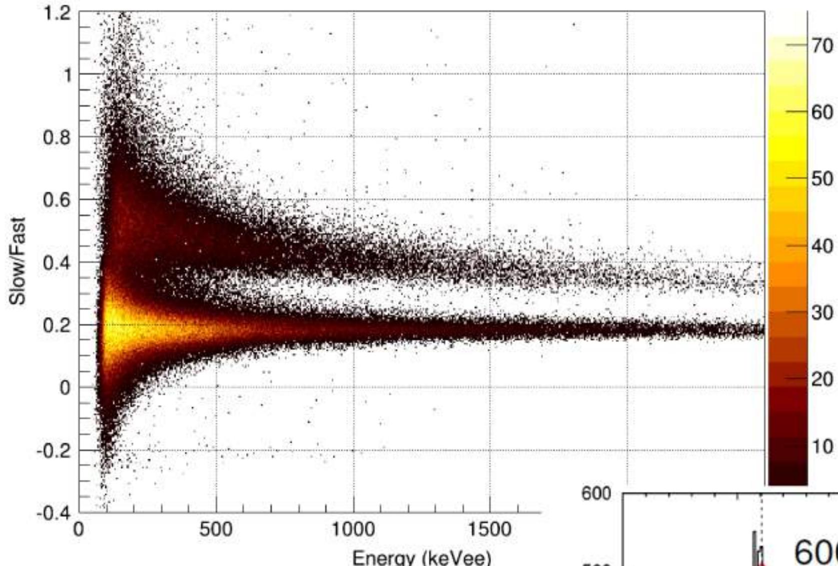


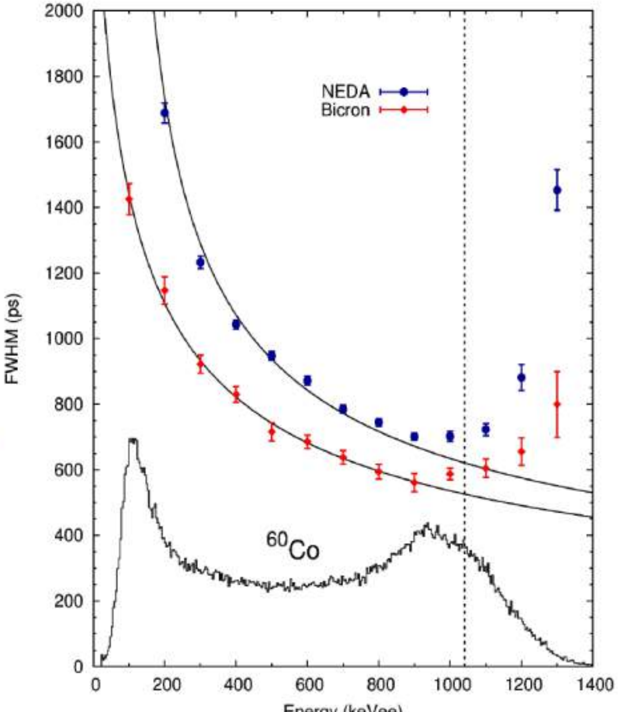
Fig. 10. FOM values of the IRT method for PMT ET9390kb, R11833-100, XP4512, and R4144 as a function of energy window (the widths of the windows are 10, 40, and 100 keVee in energy regions of 50–100, 100–500, and 500–1000 keVee, respectively).

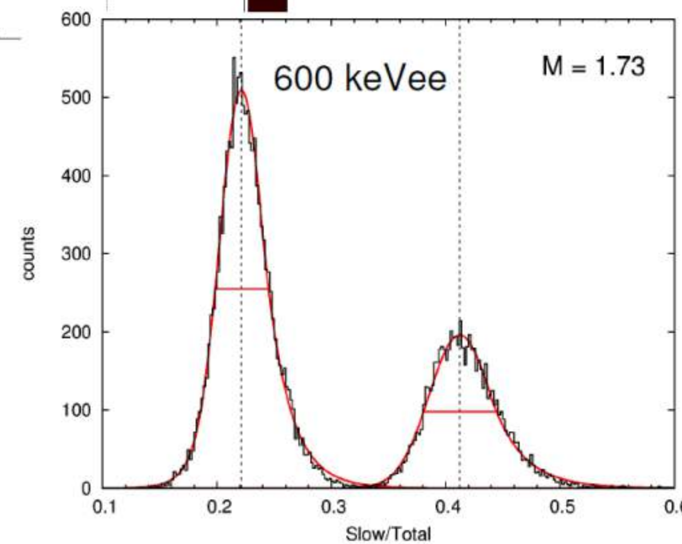
PMT tests for best NGD for NEDA

Prototype


5'' x 20cm
5'' x 13cm

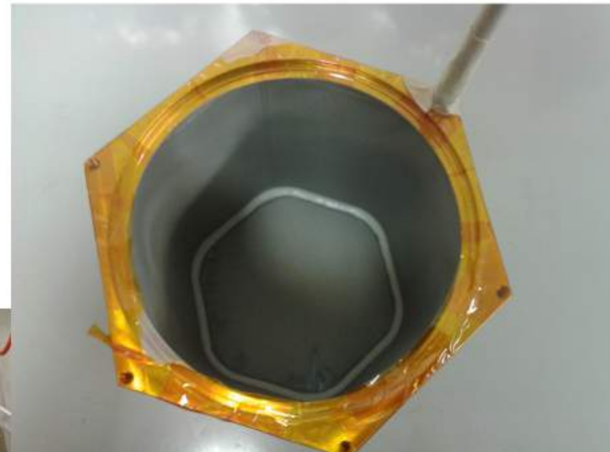

Slow/Fast
Energy (keVee)


NEDA
Bicron
^{60}Co
FWHM (ps)
Energy (keVee)


600 keVee
M = 1.73
counts
Slow/Total

Detector production

5" 5mm BK7 glass



TorrSeal

Etching

EJ520 TiO_2 paint

Detector production

NEDA

Filling with EJ301 & bubbling

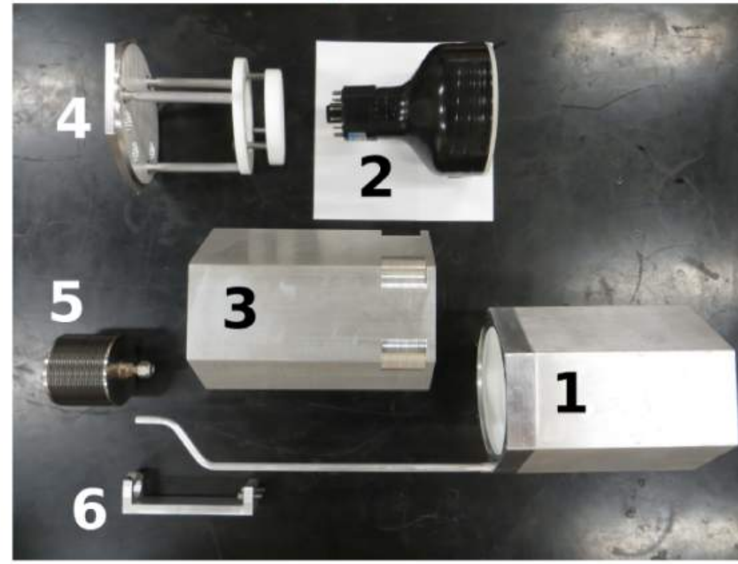
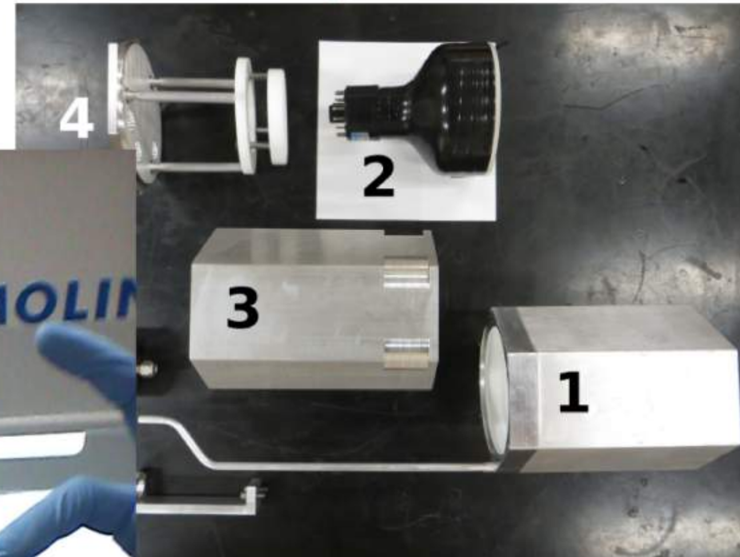


Fig. 1. Elements used for the construction of the NEDA detector: detector cell, with extension pipe (1); PMT (2); PMT housing (3); PMT pusher (4); the bellow (5) and the support for the bellow (6).

→ Expansion bellow – $\Delta T = 40$ K;
→ SBA R11833-100HA 5’’ PMT (32% Q.E.);
→ custom transistorized VD provided by Świerk;
→ mu-metal shielding (1 mm).

Detector production

Filling with EJ301 & bubbling



ments used for the construction of the NEDA detector:
ll, with extension pipe (1); PMT (2); PMT housing (3);
er (4); the bellow (5) and the support for the bellow (6).

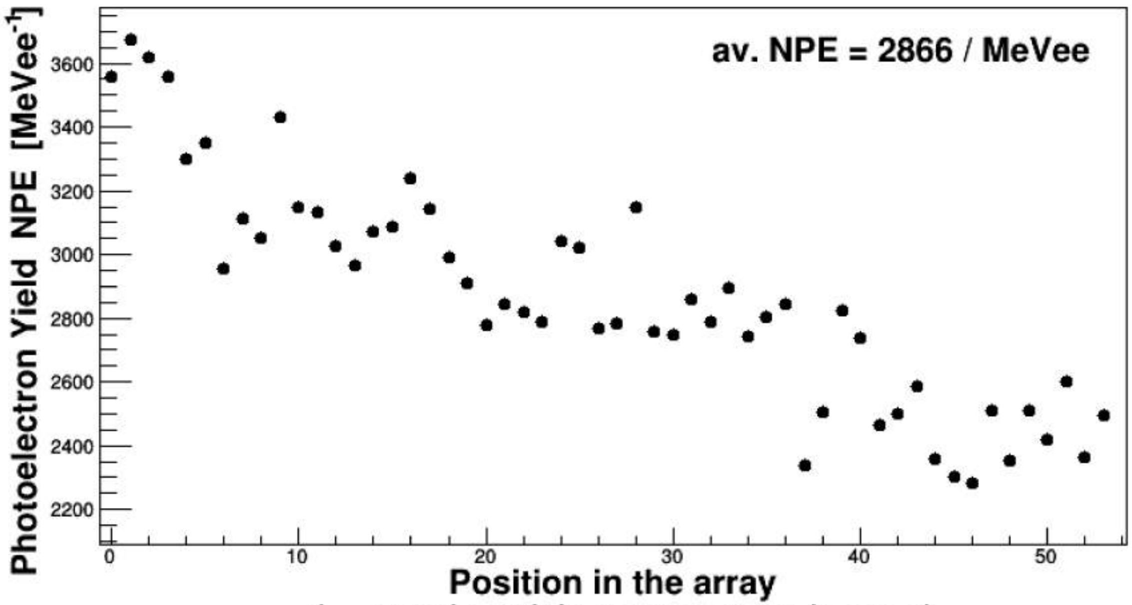
w – ΔT = 40 K;

HA 5" PMT (32% Q.E.);

→ custom transistorized VD provided by Świerk;

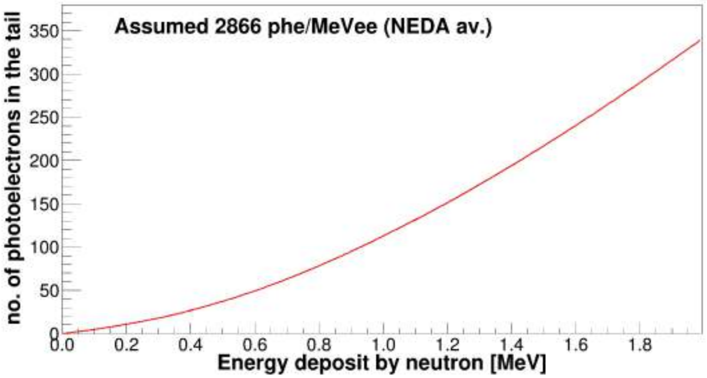
→ mu-metal shielding (1 mm).

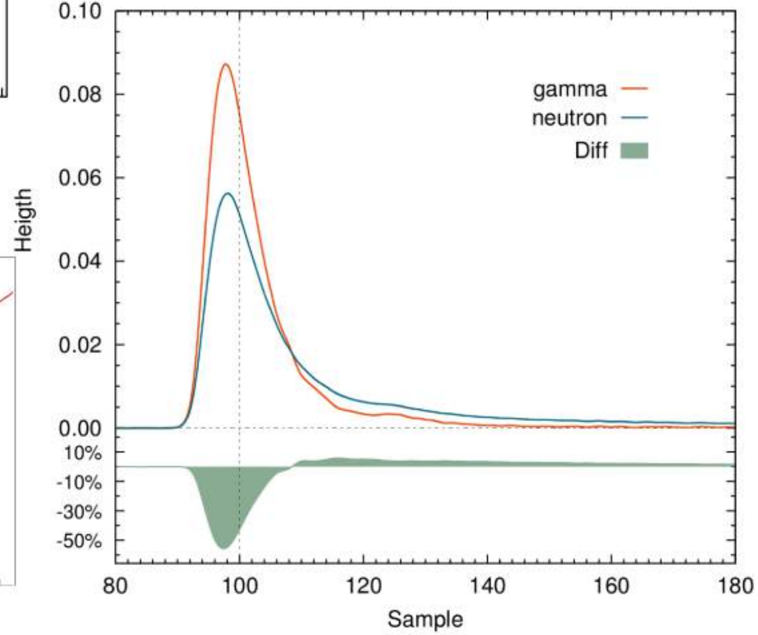
Light output



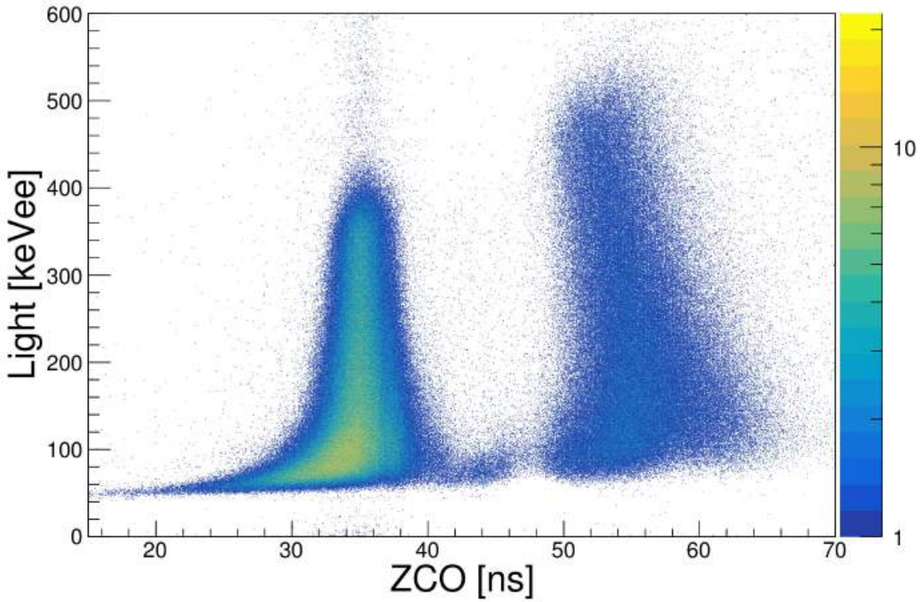
(~ angle with respect to beam)

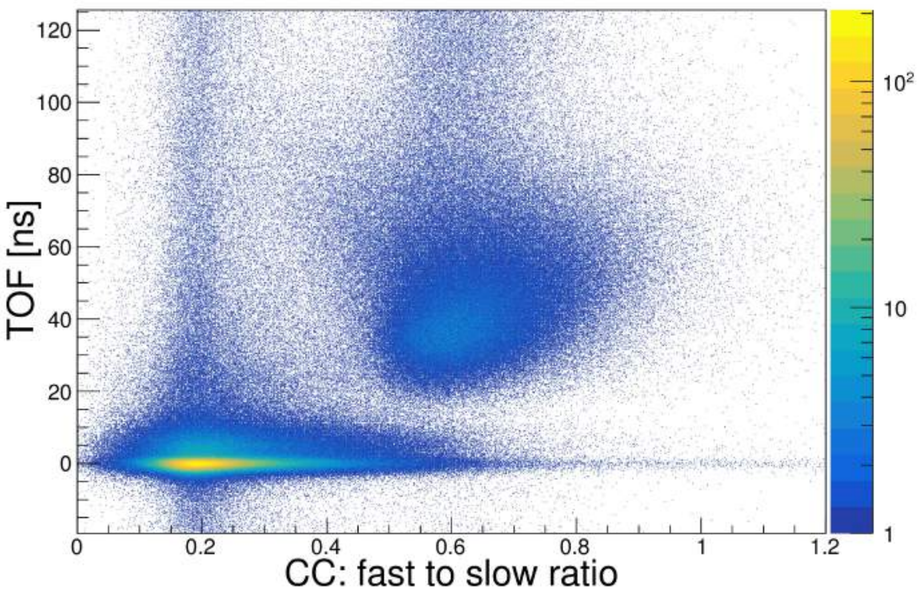
Compare to NWall:
~1300 new 1998
472 av. Jan. 2018





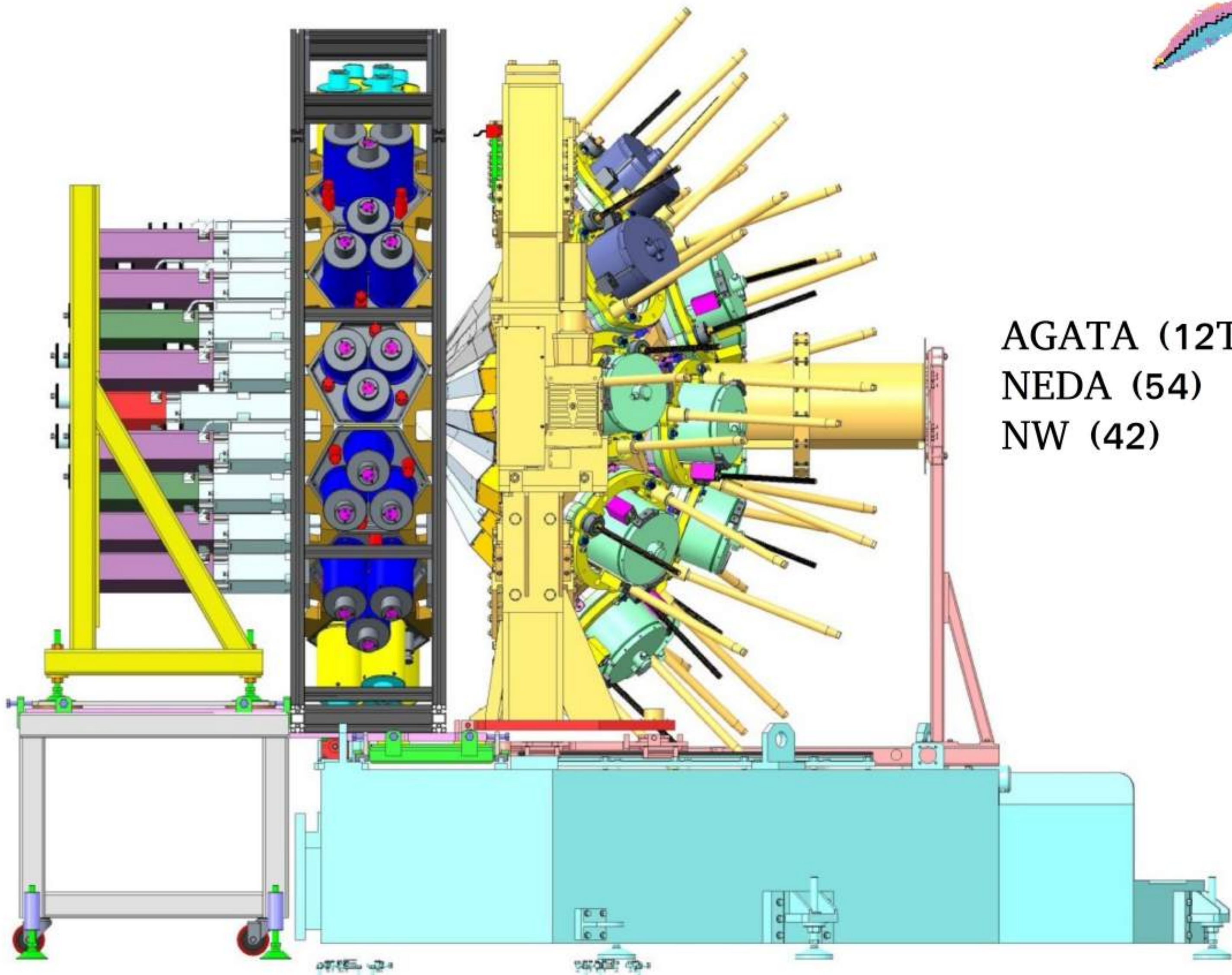
Characterisation





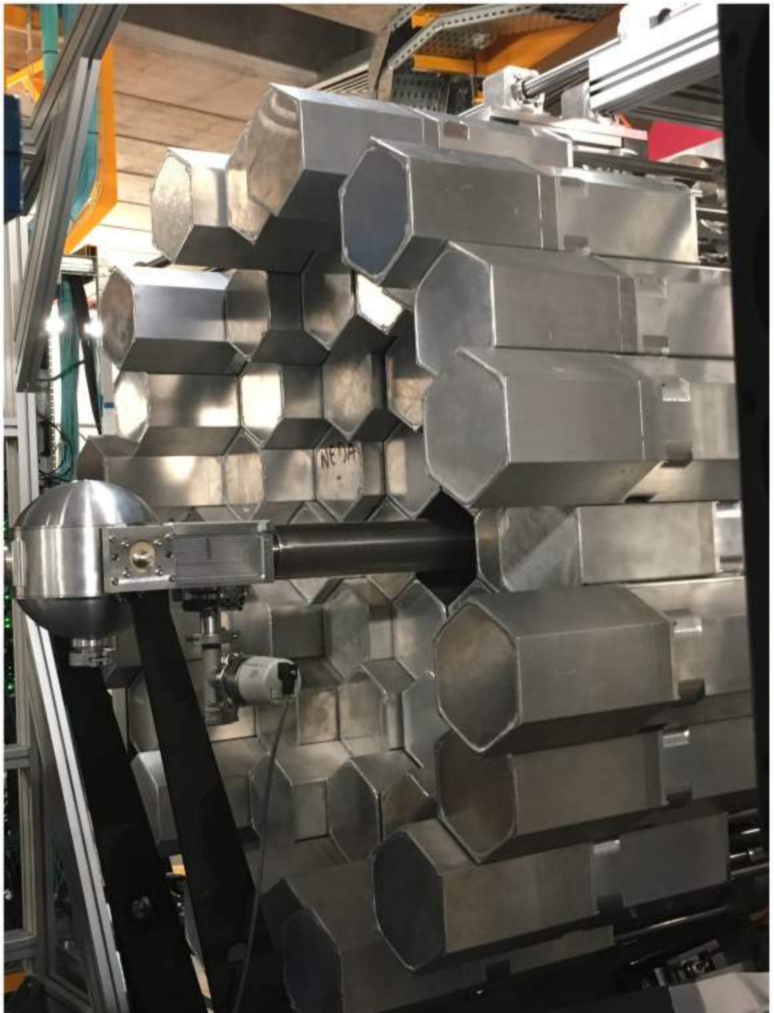
NEDA #21

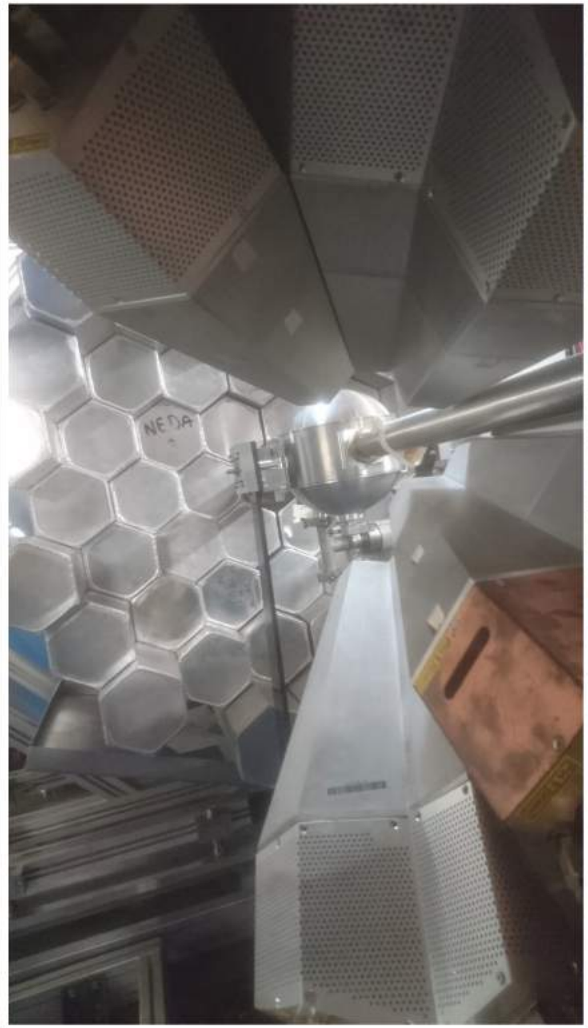
GANIL 2018: AGATA + NEDA

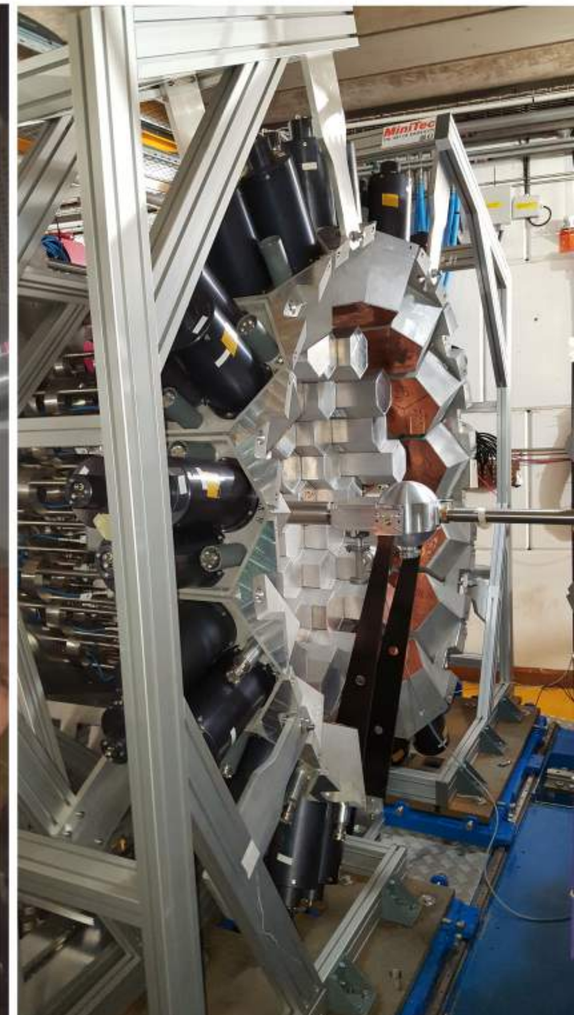


AGATA (12TC) @ 145 mm
NEDA (54) @ 510 mm
NW (42) @ 650 mm

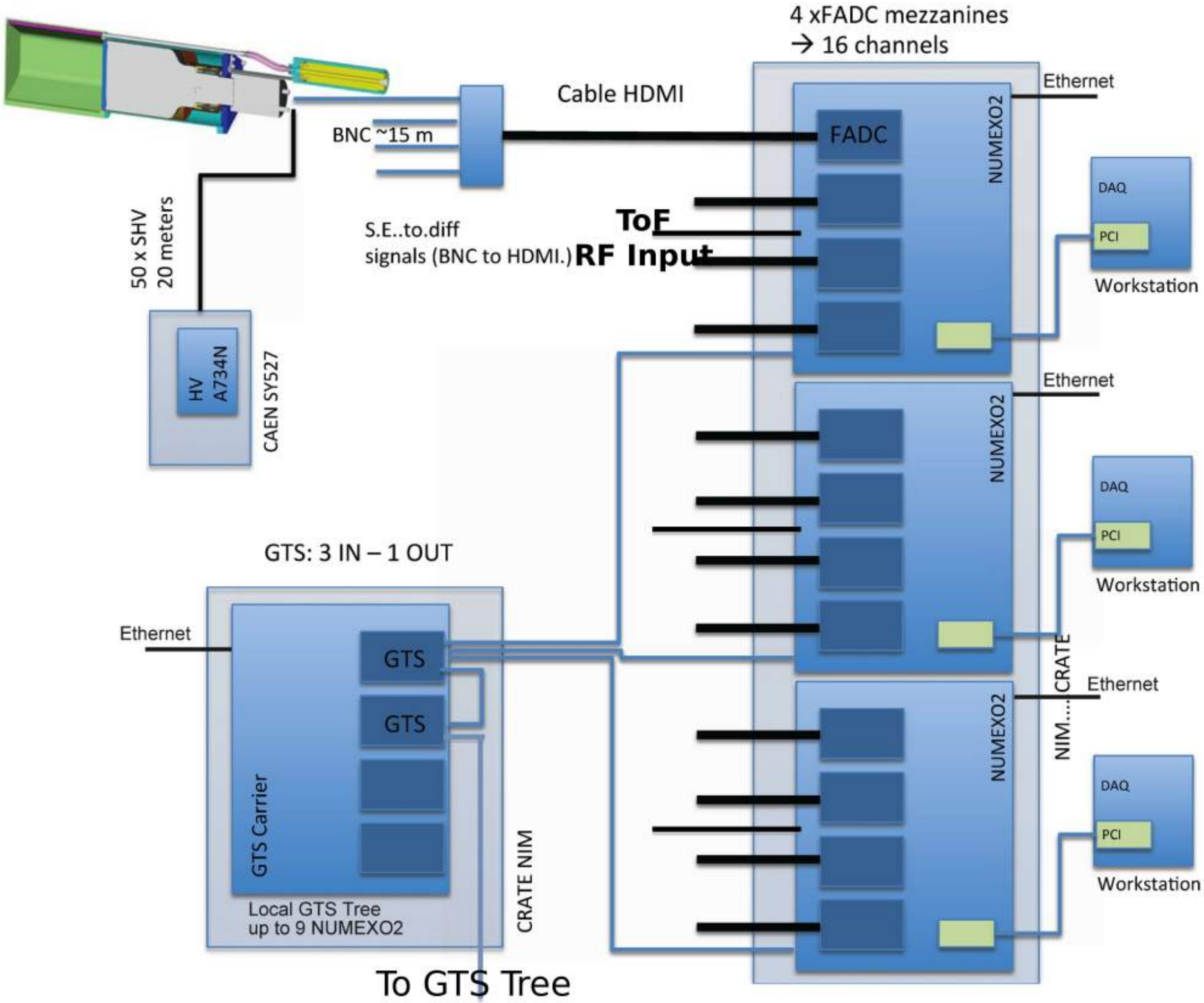
GANIL 2018: AGATA + NEDA







Electronics

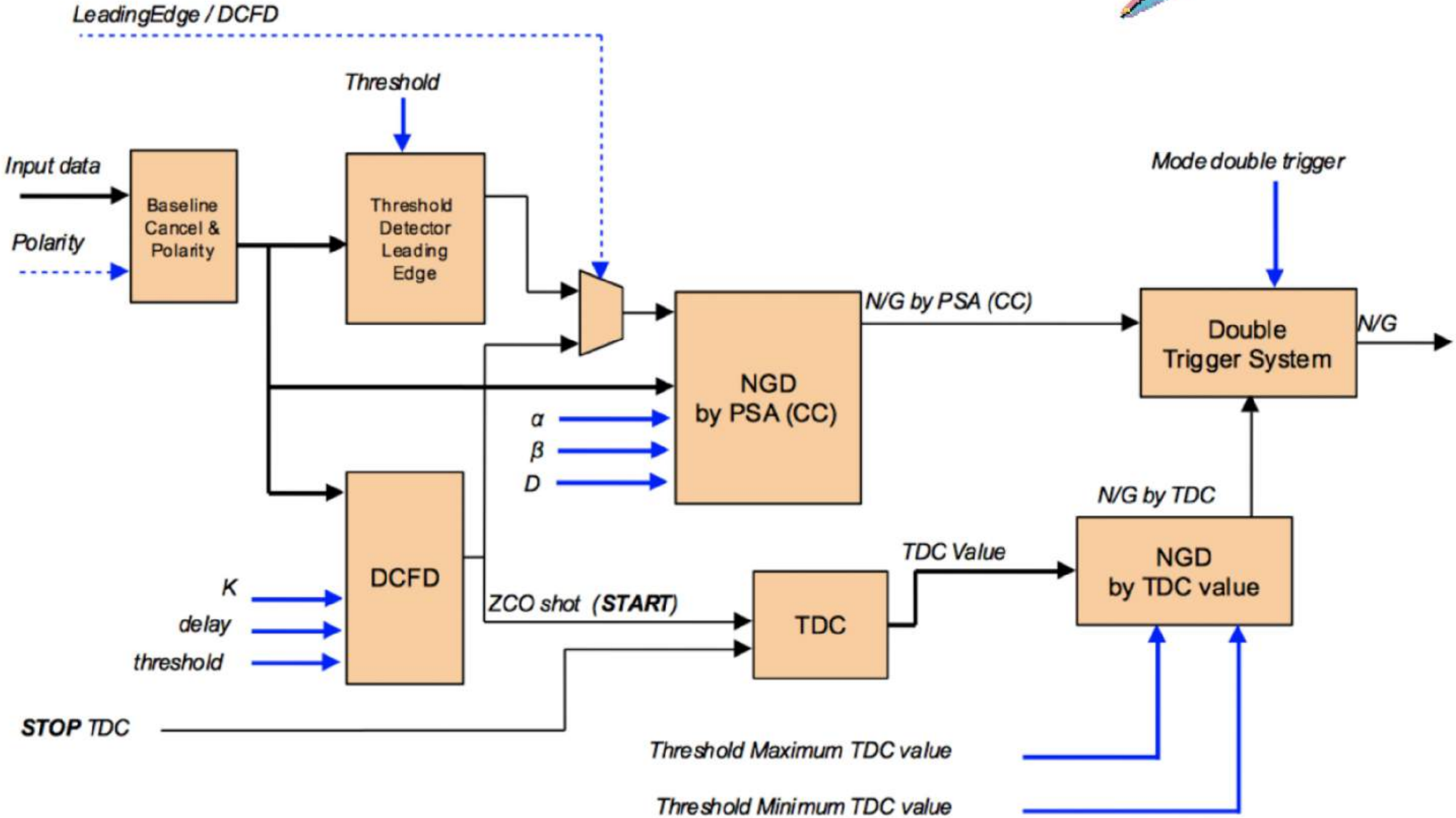


Electronics

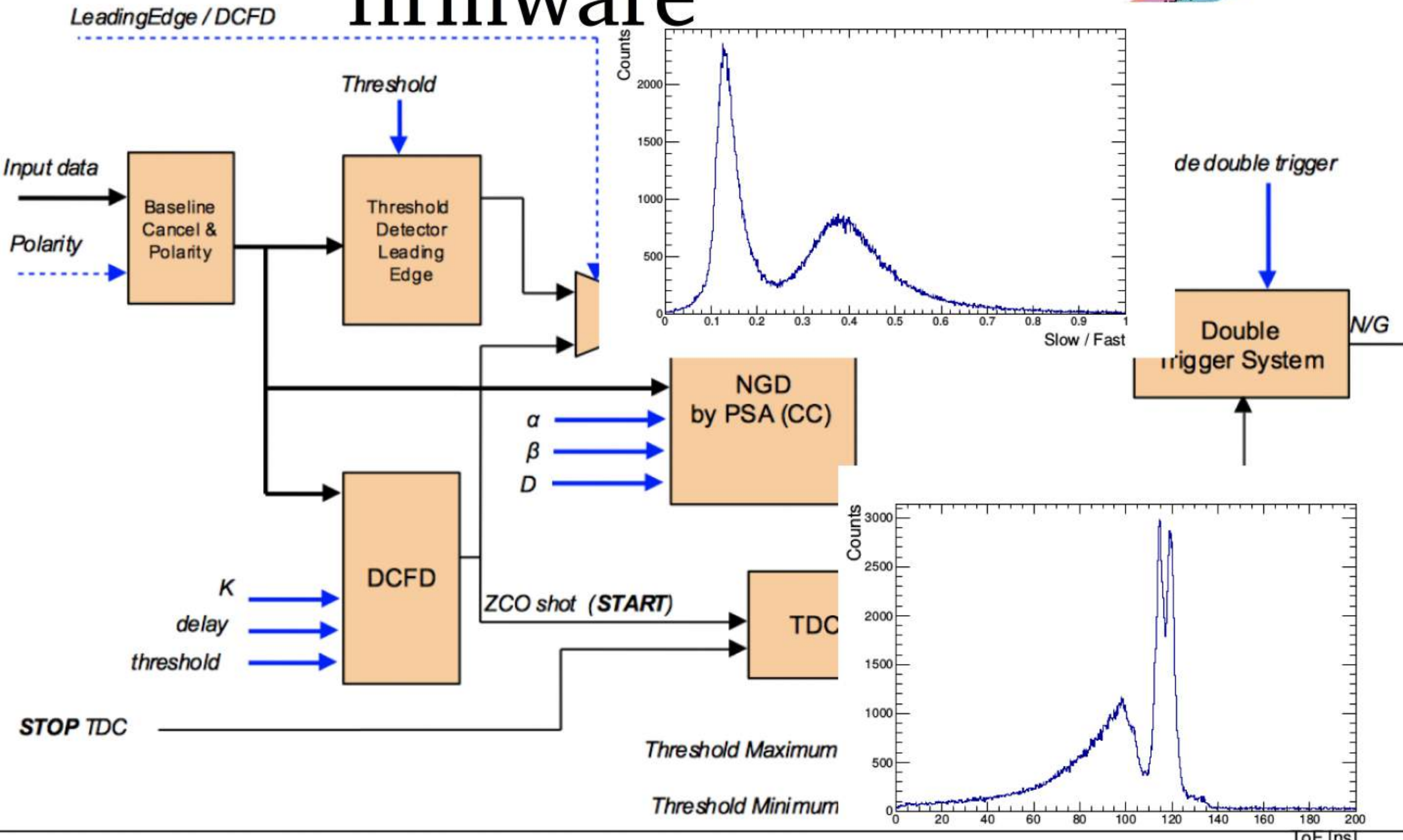
NUMEXO2 Digitizers :

- 200 MHz, 14 bit (11.3 enob)
- 16 channels NIM modules :
  - 4 differential channels / mezzanine
  - 4 mezzanines / board
  - HDMI inputs
- Programmable FPGAs :
  - Signal processing: Xillinx Virtex6
  - Time-stamping & Readout: Xillinx Virtex5
- Readout :
  - Ethernet (⇒ DIAMANT)
  - Optical Fiber (⇒ NEDA)
- GTS leaf implementation

The NEDA Virtex6 firmware

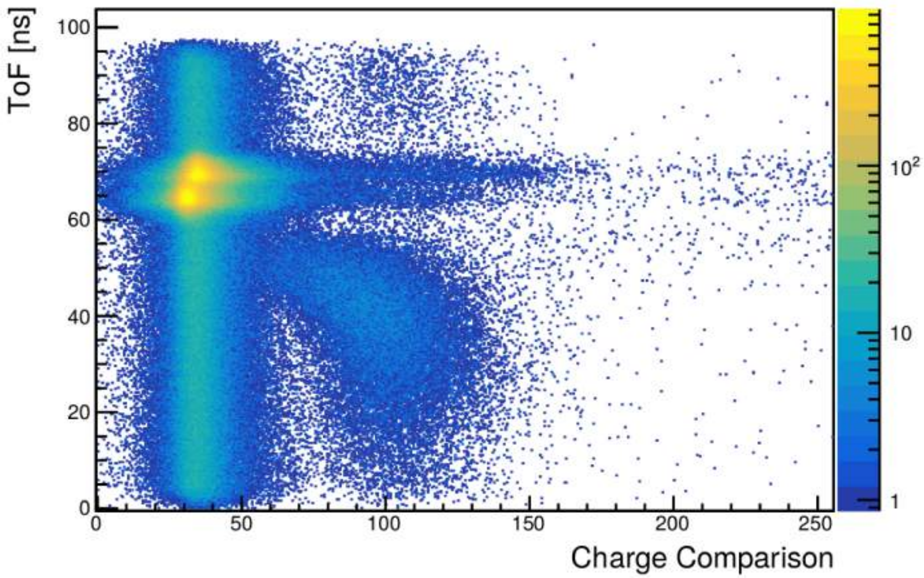


The NEDA Virtex6 firmware

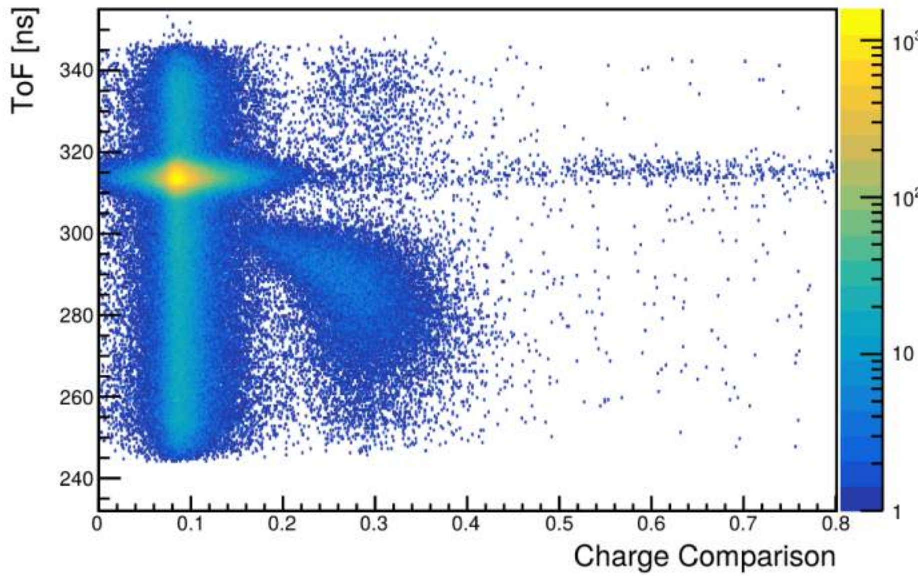


Digital NGD online

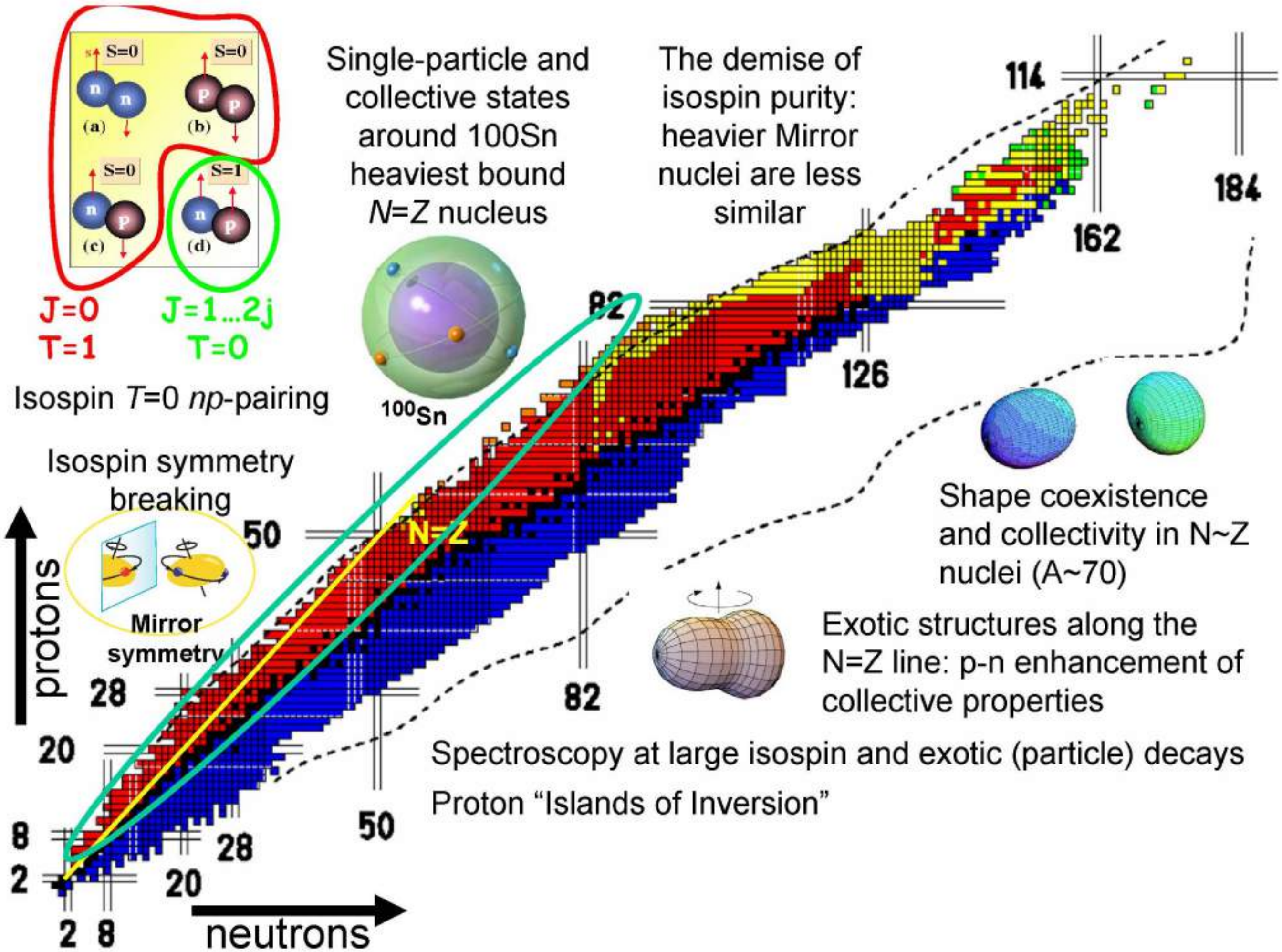
NEDA FPGA



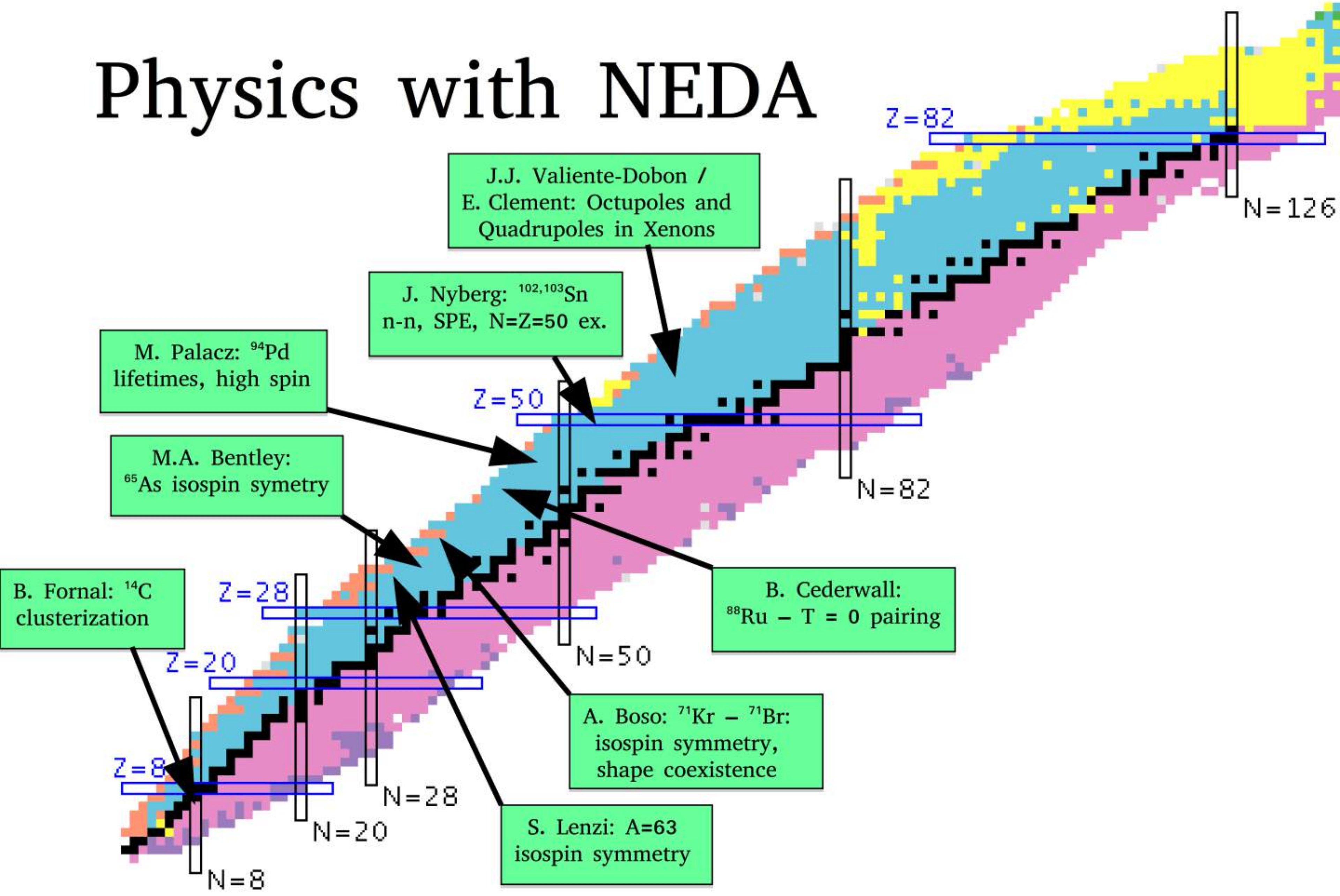
NEDA Post-PSA



Physics with NEDA



Physics with NEDA



GANIL 2018: AGATA + NEDA

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 $g^{n}_{9/2}$ 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.

√ – 976 h of the beam (122 UT)

E703: ^{102,103}Sn

NEDA

J. Nyberg, M. Palacz, A. Ataç et al.

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

^{58}Cr(^{58}Ni, 1α2n)^{102}Sn, σ~0.002 mb

^{50}Cr(^{58}Ni, 1α1n)^{103}Sn,

^{102}Sn

Indirect information on excited states in ^{100}Sn by studying:

9^- states — core excited 3- phonon coupled to 6+ in ^{102}Sn, $\nu(g_{7/2}h_{11/2})$

8+, 10+ — 2+,4+ core excited coupled to 6+ in ^{102}Sn state

5+, $6+_2$ — $\nu(d_{5/2}\ g_{7/2})$ matrix elements

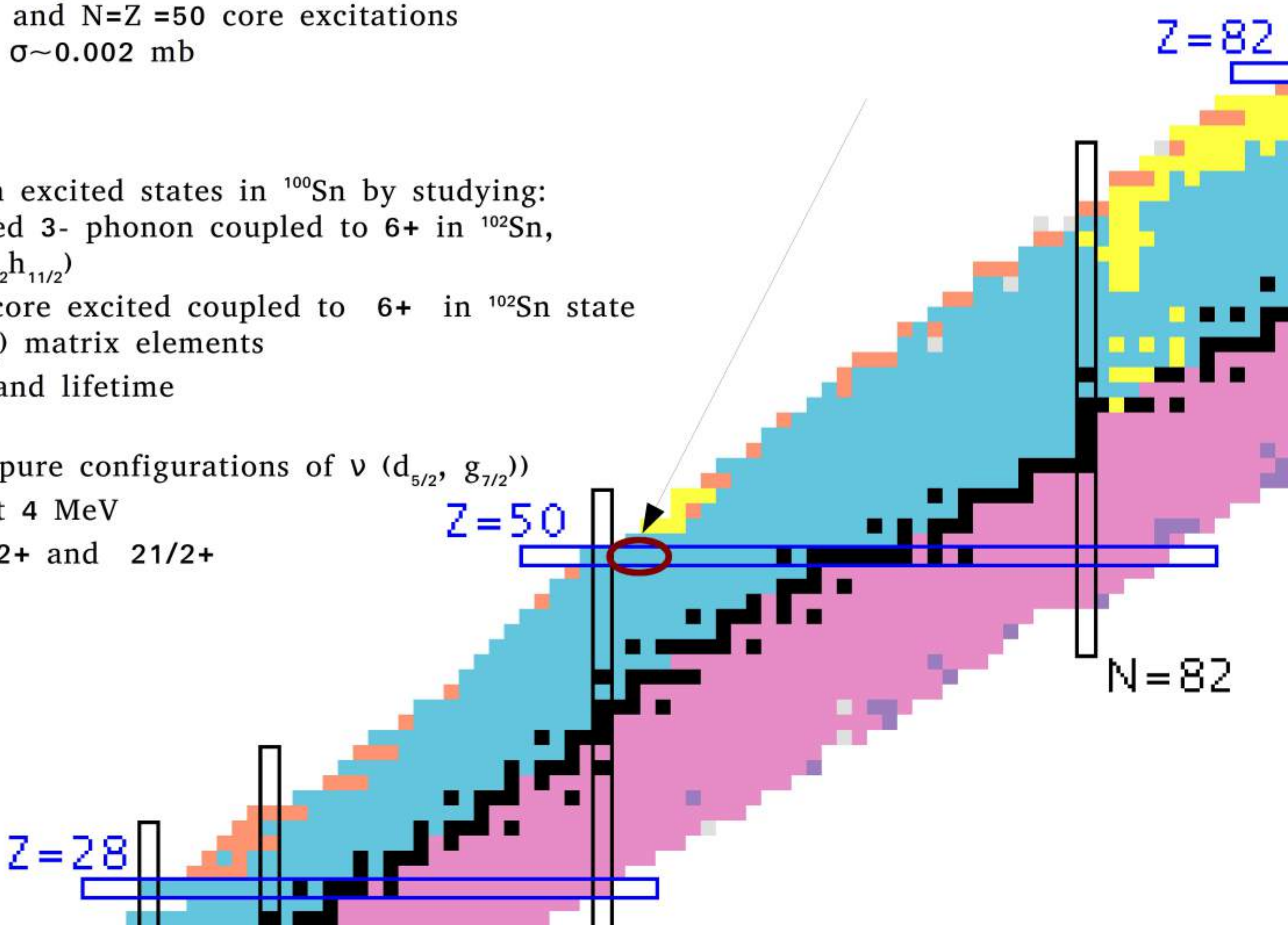
$6+_1$ — decay and lifetime

^{103}Sn

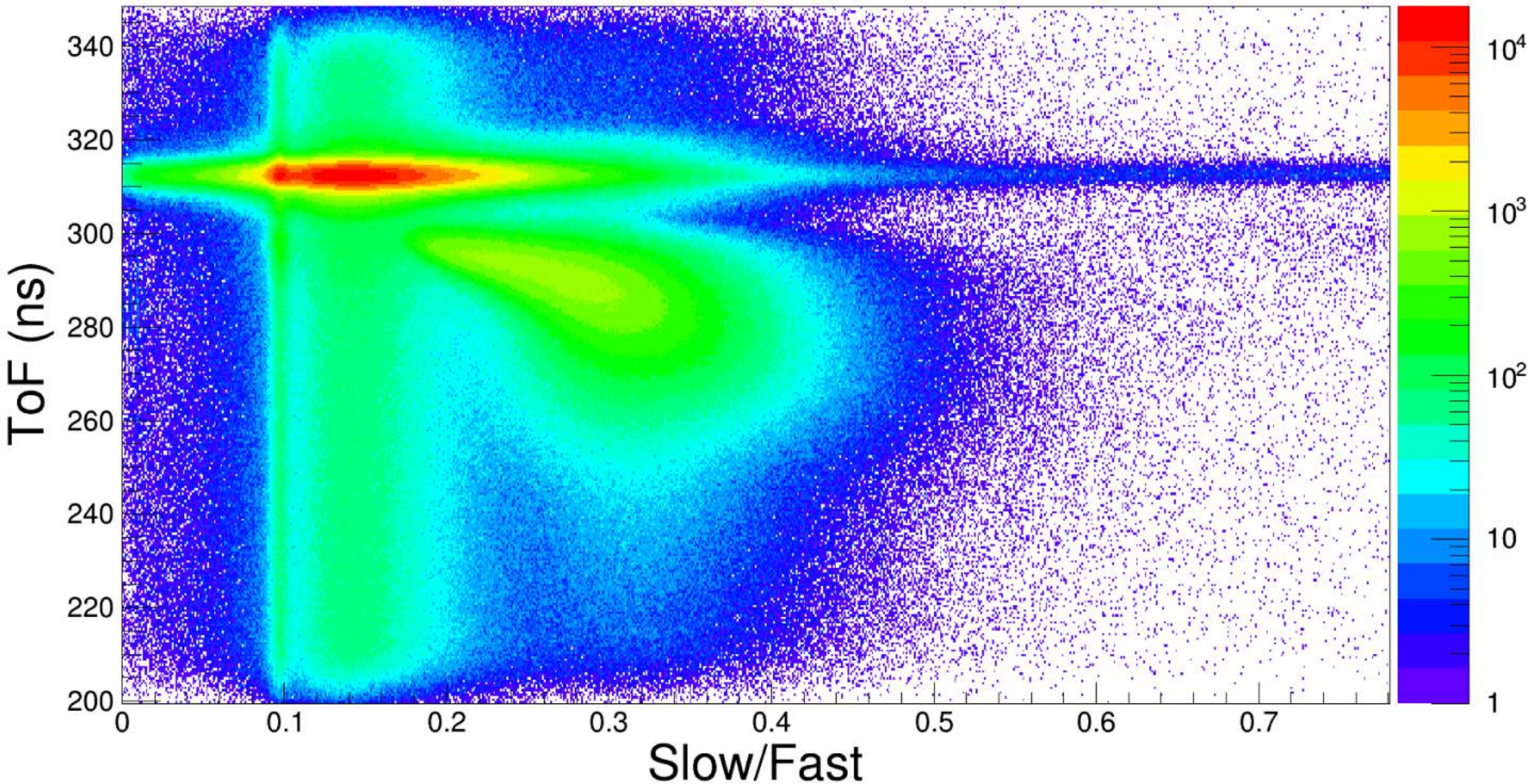
17/2+ , 15/2+ (very pure configurations of $\nu\ (d_{5/2},\ g_{7/2})$)

$\nu h_{11/2}$ states at about 4 MeV

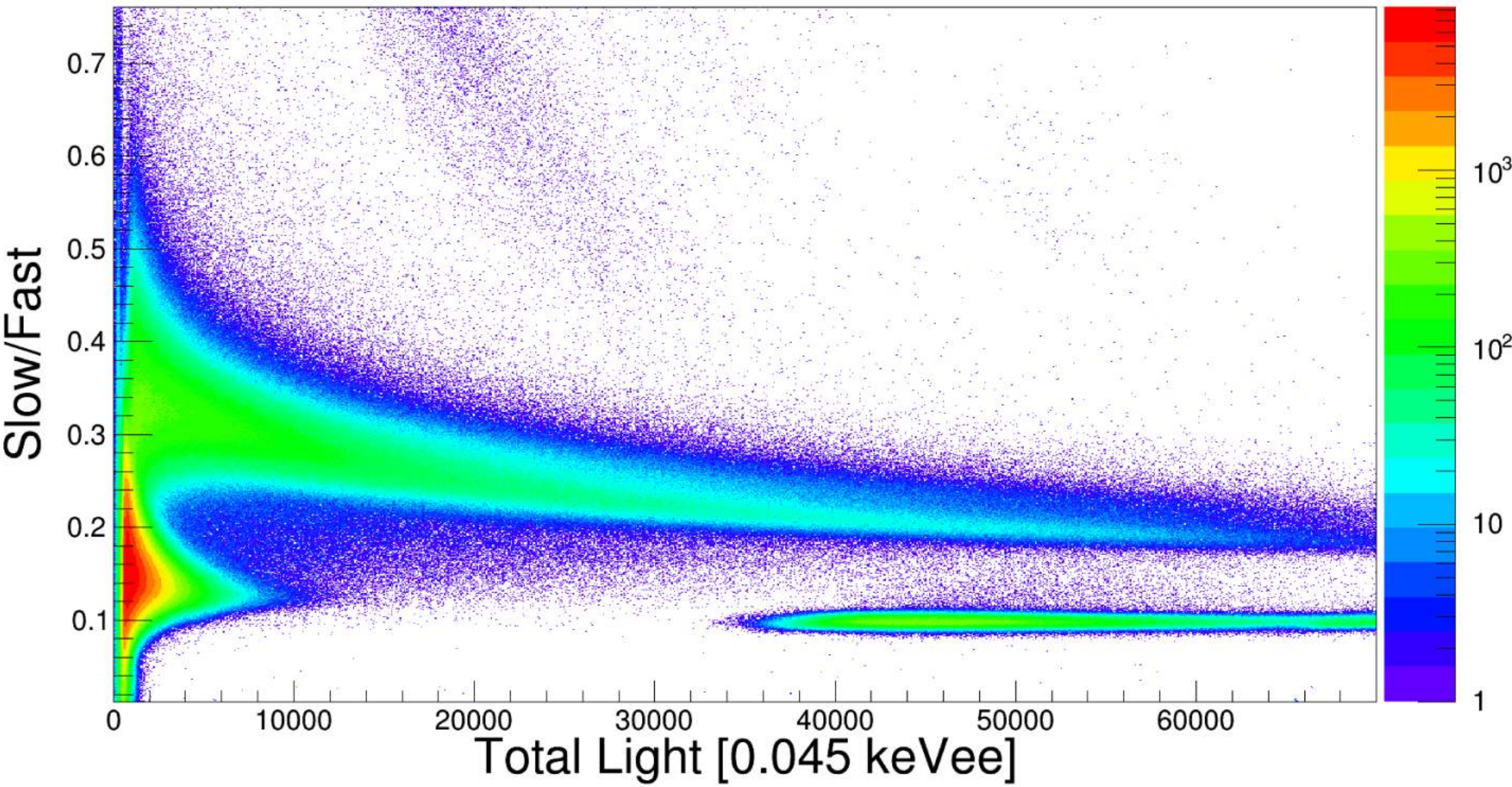
core excited states 19/2+ and 21/2+ to verify Z=50 gap



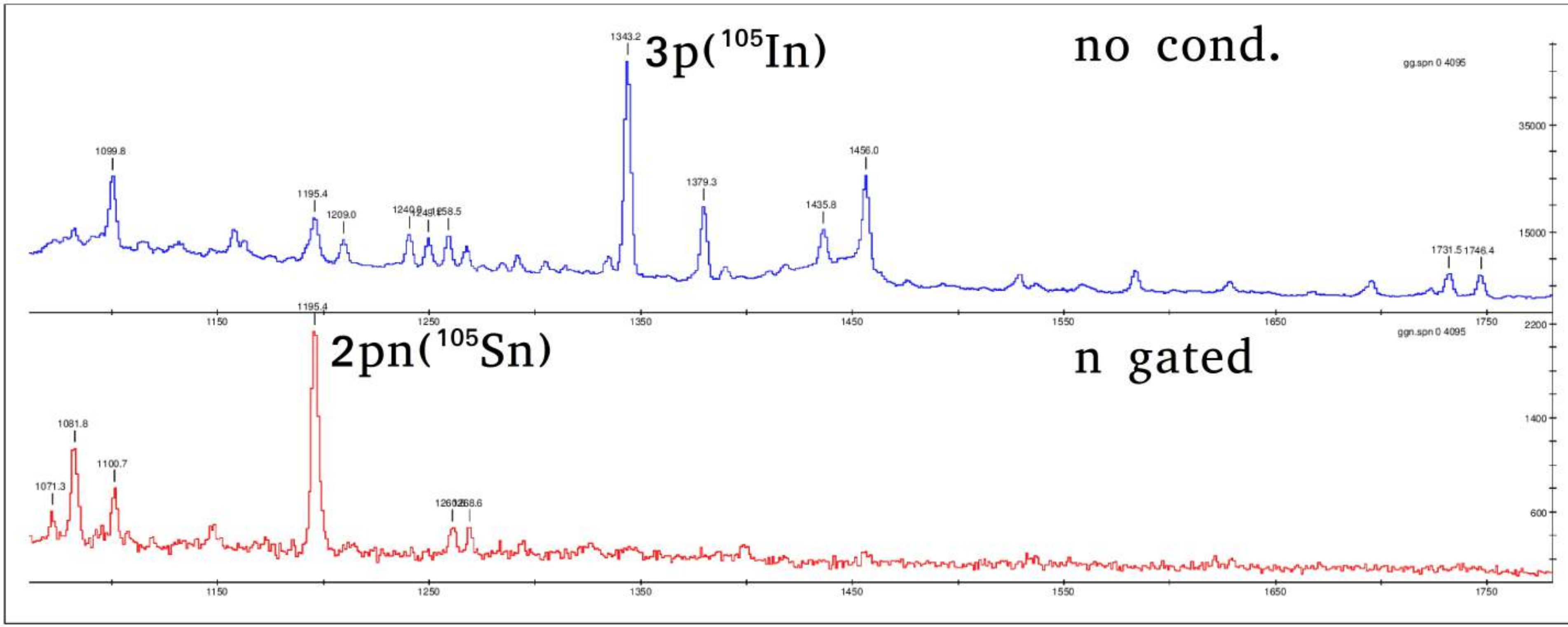
Neutron-gamma discrimination



Neutron-gamma discrimination



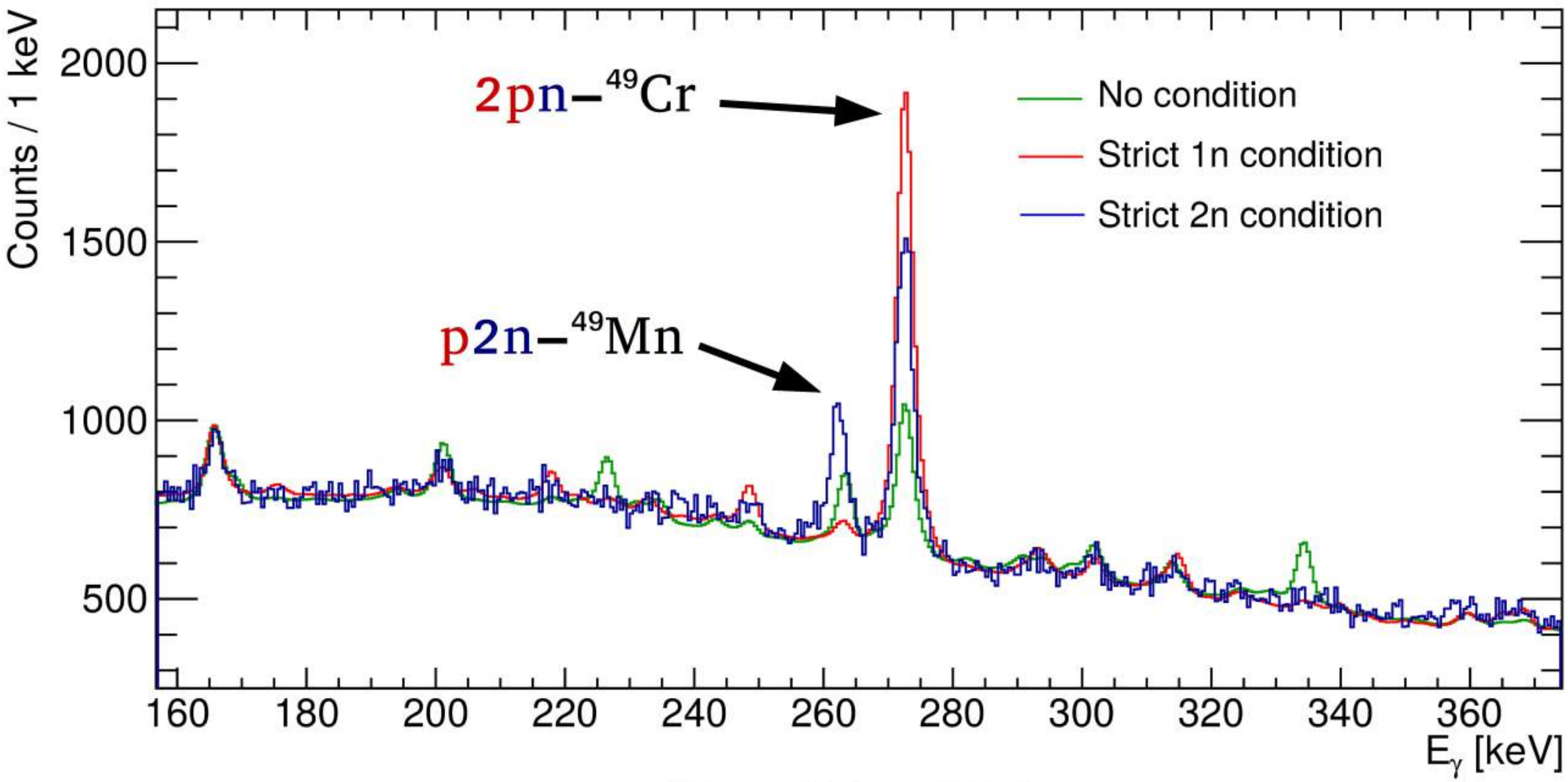
neutron gating



E_γ [keV]

$^{58}Ni + ^{50}Cr \rightarrow ^{108}Te^*$

n multiplicity selection



$^{36}Ar + ^{16}O \rightarrow ^{52}Fe^*$

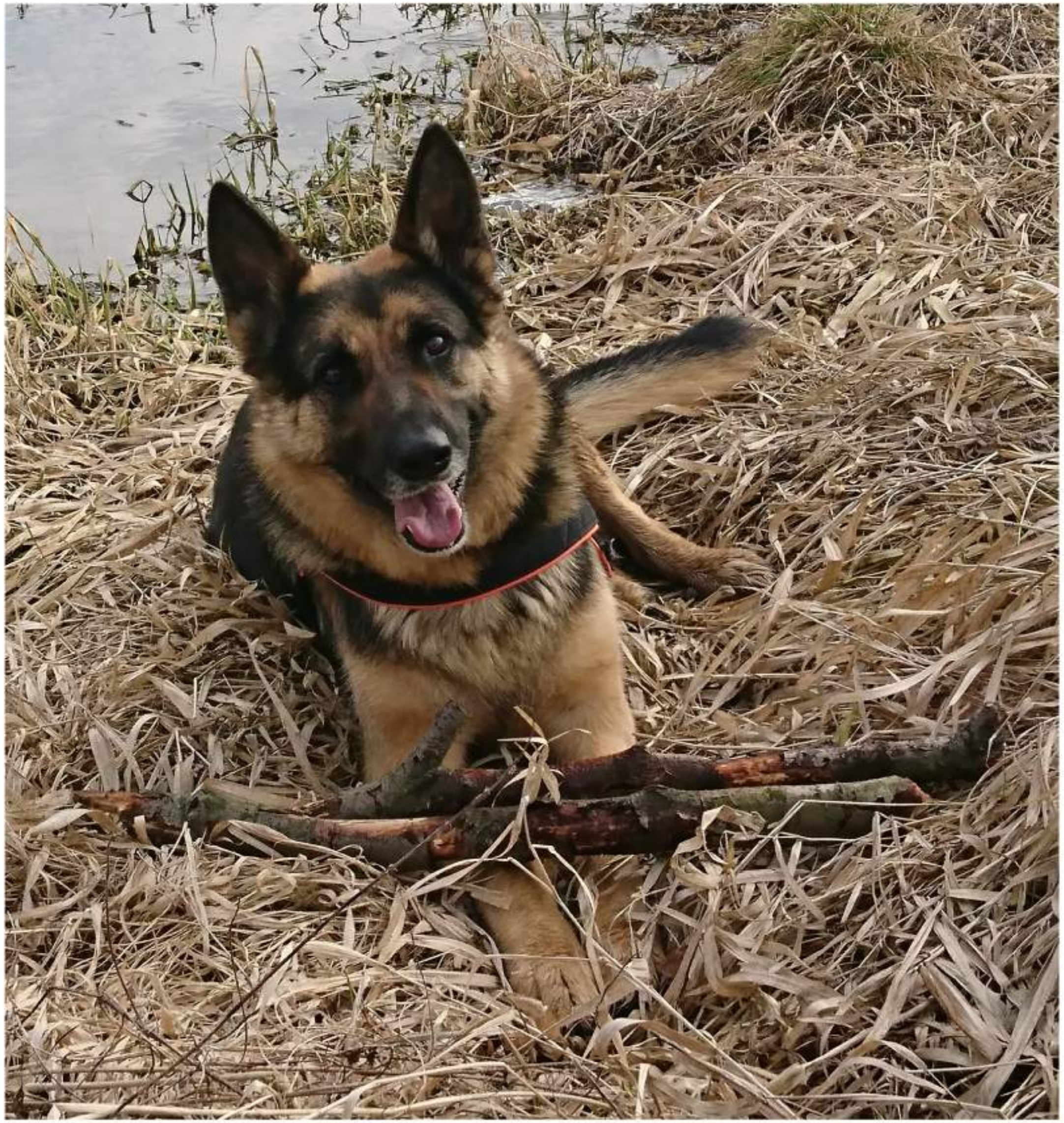
Collaboration

A. Goasduff, F.J. Egea, V. Modamio, T. Hüyük, A. Triossi, M. Jastrząb, P.-A. Söderström, S. Carturan, G. de Angelis, G. De France, N. Erduran, A. Gadea, M. Moszyński, J. Nyberg, M. Palacz, J. Valiente, R. Wadsworth, R. Aliaga, C. Aufranc, M. Bézard, G. Beaulieu, P. Bednarczyk, E. Bisiato, A. Boujrad, I. Burrows, P. Cocconi, G. Colucci, D. Conventi, M. Cordwell, S. Coudert, J.M. Deltoro, A. Di Nitto, L. Ducroux, T. Dupasquier, S. Ertürk, X. Fabian, V. González, A. Grant, K. Hadyńska-Klęk, A. Illana-Sisson, M. L. Jurado-Gomez, M. Kogimtzis, I. Lazarus, L. Legeard, J. Ljungvall, A. Maj, G. Pasqualato, A. Raggio, D. Ralet, N. Redon, F. Saillant, E. Sanchis, M. Scarcioffolo, M. Siciliano, D. Testov, O. Stezowski, M. Tripon, I. Zanon & GJ

It's good for you!

Summary

- Versatile neutron detector to be used alone or to be coupled to γ-ray arrays and charged particle detectors.
- High performance neutron multiplicity filter based on the liquid scintillator EJ301 with excellent neutron-gamma discrimination capabilities.
- The first campaign of physics – NEDA coupled to AGATA@ GANIL with stable beams performed in 2018 – fusion evaporation reactions along N=Z.
- Reach data-set collected for five experiments and data analyses are ongoing, so far on the very basic level.
- Versetile – insreased potenciality tagging neutrons in transfer reactions (3He,n), (d,n); nTOF and neutron spectroscopy.
- End point not known...



Dziękuję za uwagę!