STUDY OF NUCLEAR PHYSICS METHODS OF IDENTIFICATION OF HIDDEN SUBSTANCES IN JINR

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02-7-1045-2002/2004 – JINR scientific long-term plan of subjects

Leaders: V.M. Bystritsky, M.G. Sapozhnikov

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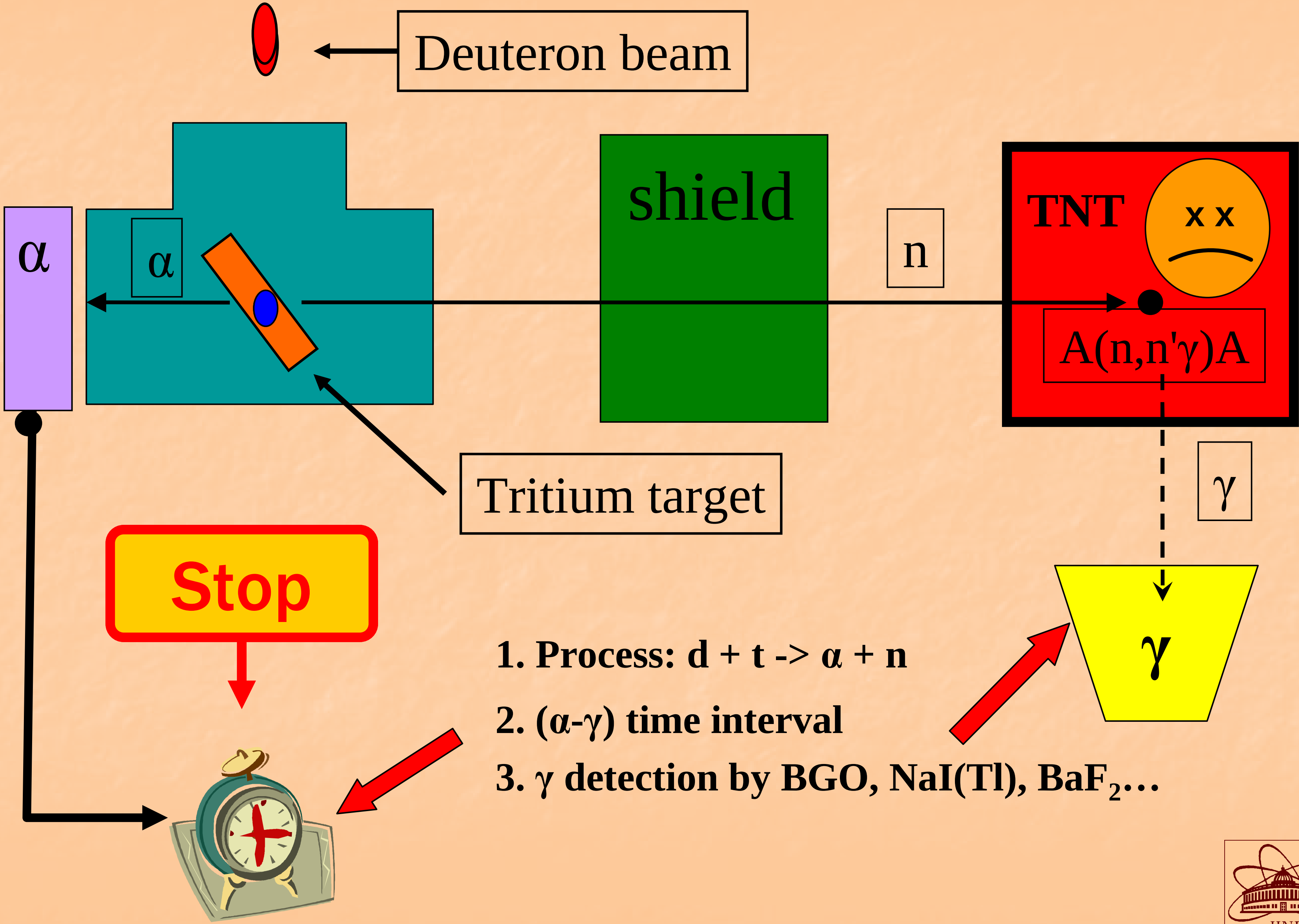
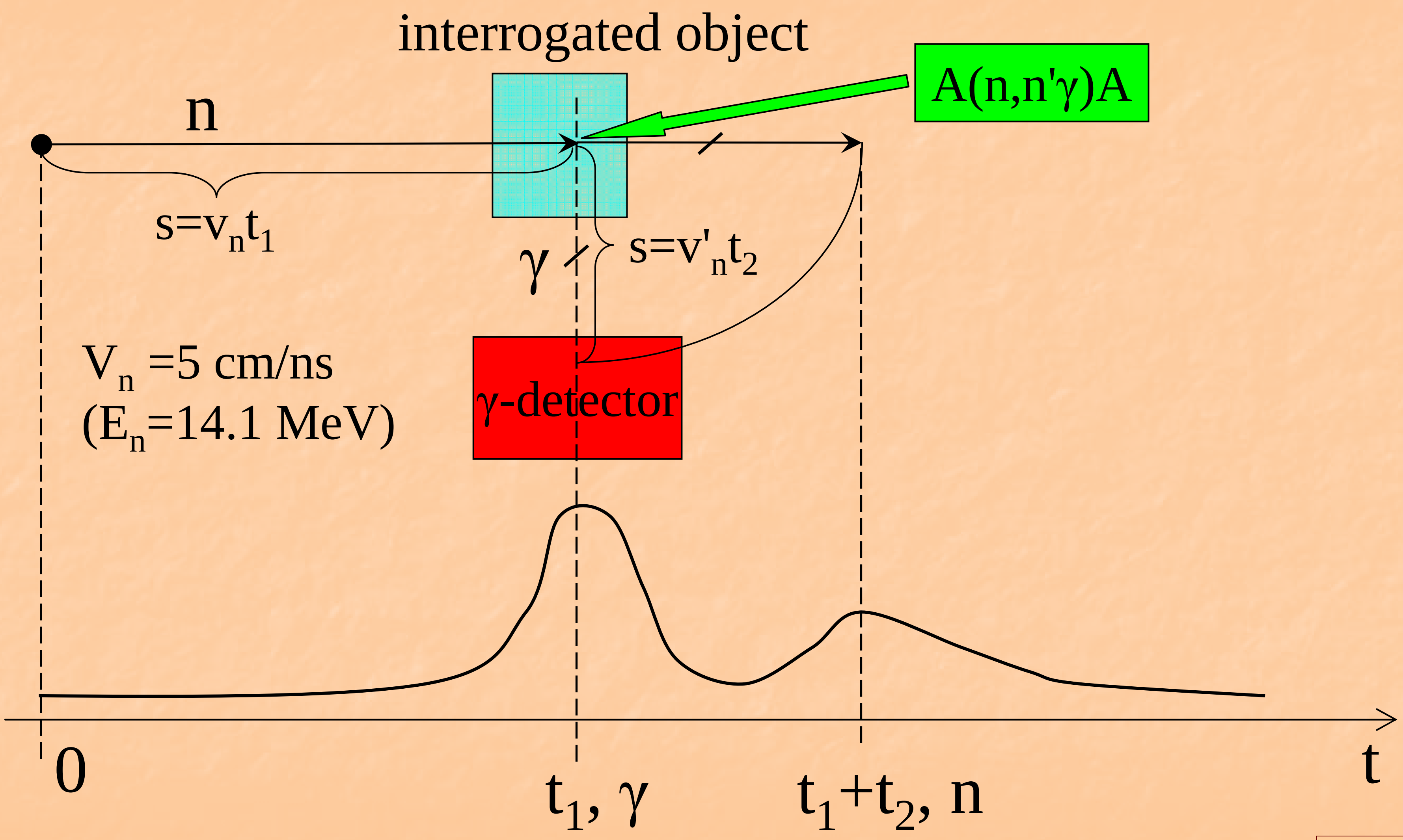
API method (Associated Particle Imaging method)



1. Process: d + t -> α + n
2. (α-γ) time interval
3. γ detection by BGO, NaI(Tl), BaF_2…

Time interval distribution ((α-γ) coincidences)



The main advantages of the API method

- Sensitivity to a chemical composition of an object
- 3D image of an object
- Penetration capability up to 1.5 meters
- The best conditions for identification of hidden substance (signal/background ratio is 200 times better)
- One-measurement tomography of an object

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Milestones (1999-2004)

- Po-Be source
- Van de Graaff accelerator
- Pumped portable neutron generator (PNG) with embedded plastic α-detector
- Sealed PNG with YAP (Ce) α-detector
- Sealed PNG with Si α-detector

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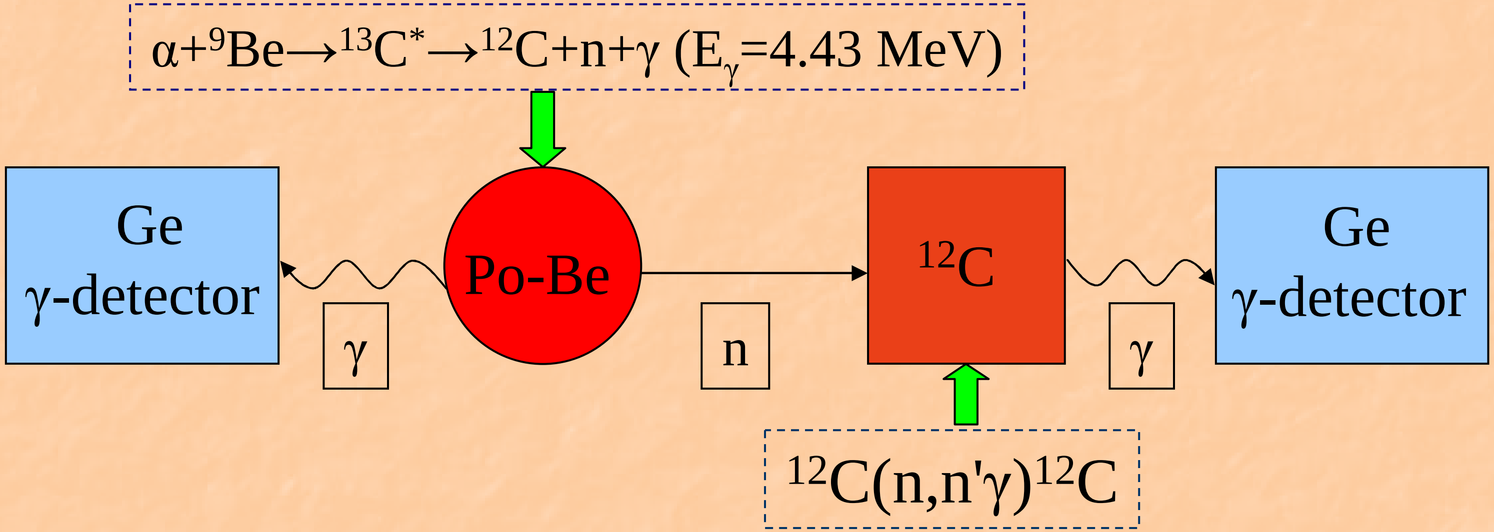
Milestone 1: Whether the API method works? (1999)

Impetus to study the API method in JINR – Rochester Conference on High Energy Physics, Vancouver



Observation of γγ coincidences

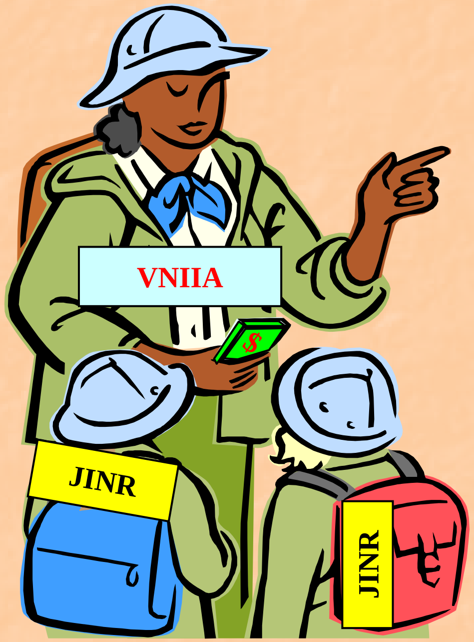
Conclusion: O.K.

Milestone 1: Whether the API method works? (1999)

Forward to light tops

Strategy and Tactics (2000)

Attempt to have a contract with VNIIA for design and construction of the sealed PNG with an embedded α-detector.



The indicated price
by VNIIA was very high.

<u>Our decision</u>: to study the API method using the Van de Graaff accelerator and in parallel to design and construction the pumped PNG by ourselves.

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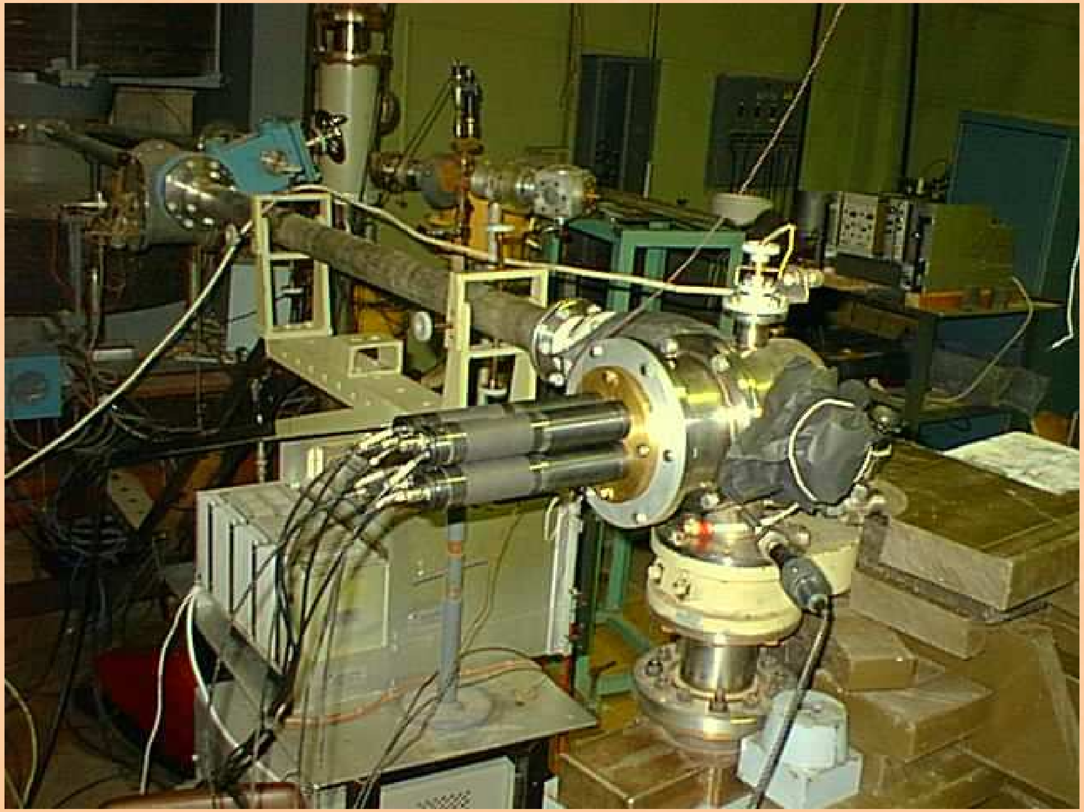
Milestone 2: Van de Graaf accelerator R&D 2000-2003



- The molecular ion beam D^+_2 .
- E= 450 keV per deuteron.
- I= 0.5 μA.
- 4 mm in diameter
- Tritium target (TiT_2)

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α- and γ- detectors

α-detector

- 4 pixels 1x1 cm^2 shielded by 7 μm Al foil at the distance of 75 mm from the target

γ-detector

- NaI(Tl) Ø 150 mm, h = 100 mm, $\Delta E/E_\gamma$=8% (E_γ = 1.33 MeV), $\Delta t(\alpha\text{-}\gamma)$ = 3.4 ns
- BGO, Ø 100 mm, h = 70 mm

Properties of different α-detectors based on BGO, GSO(Ce), LSO(Ce), YAP(Ce), ZnS(Ag), Si and Ga(As) were studied.

Conclusion: The YAP(Ce) crystal and the ion-implanted Si α-detector can be used in the sealed PNG

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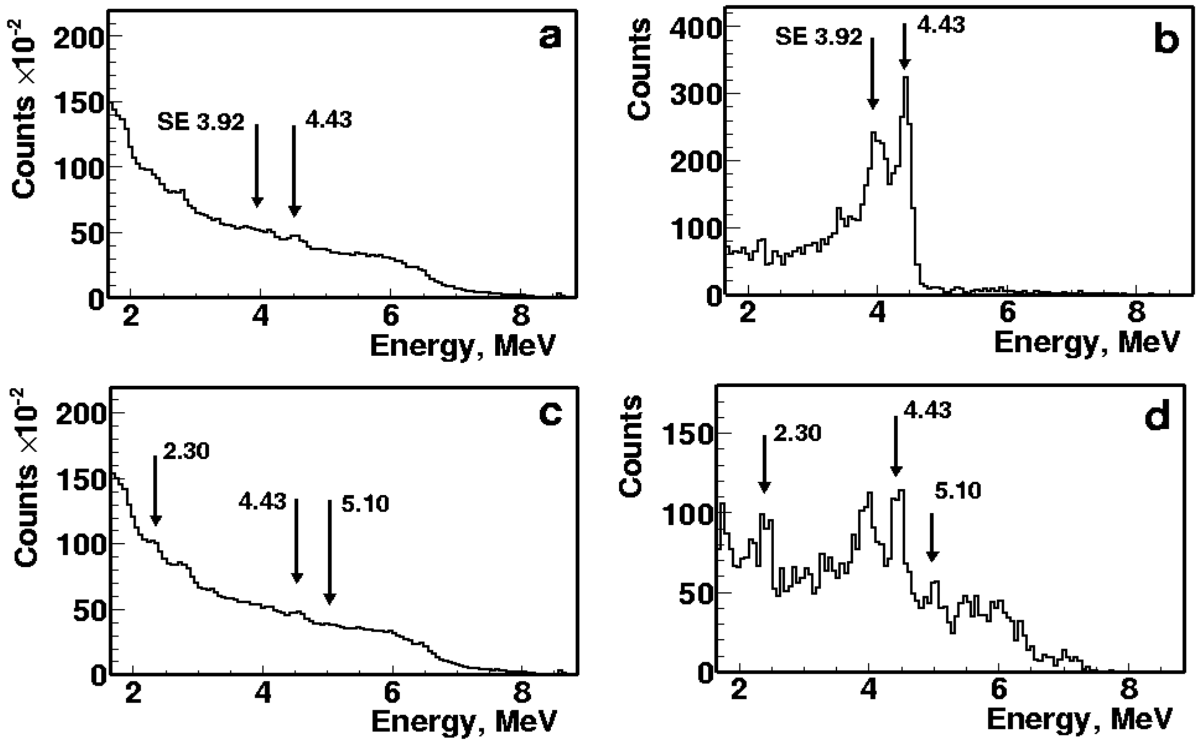
Reliability of hidden substance detection

$E_{\gamma}(^{12}C) = 4.43$ MeV, $E_{\gamma}(^{14}N) = 5.1$ MeV, $E_{\gamma}(^{16}O) = 6.13$ MeV

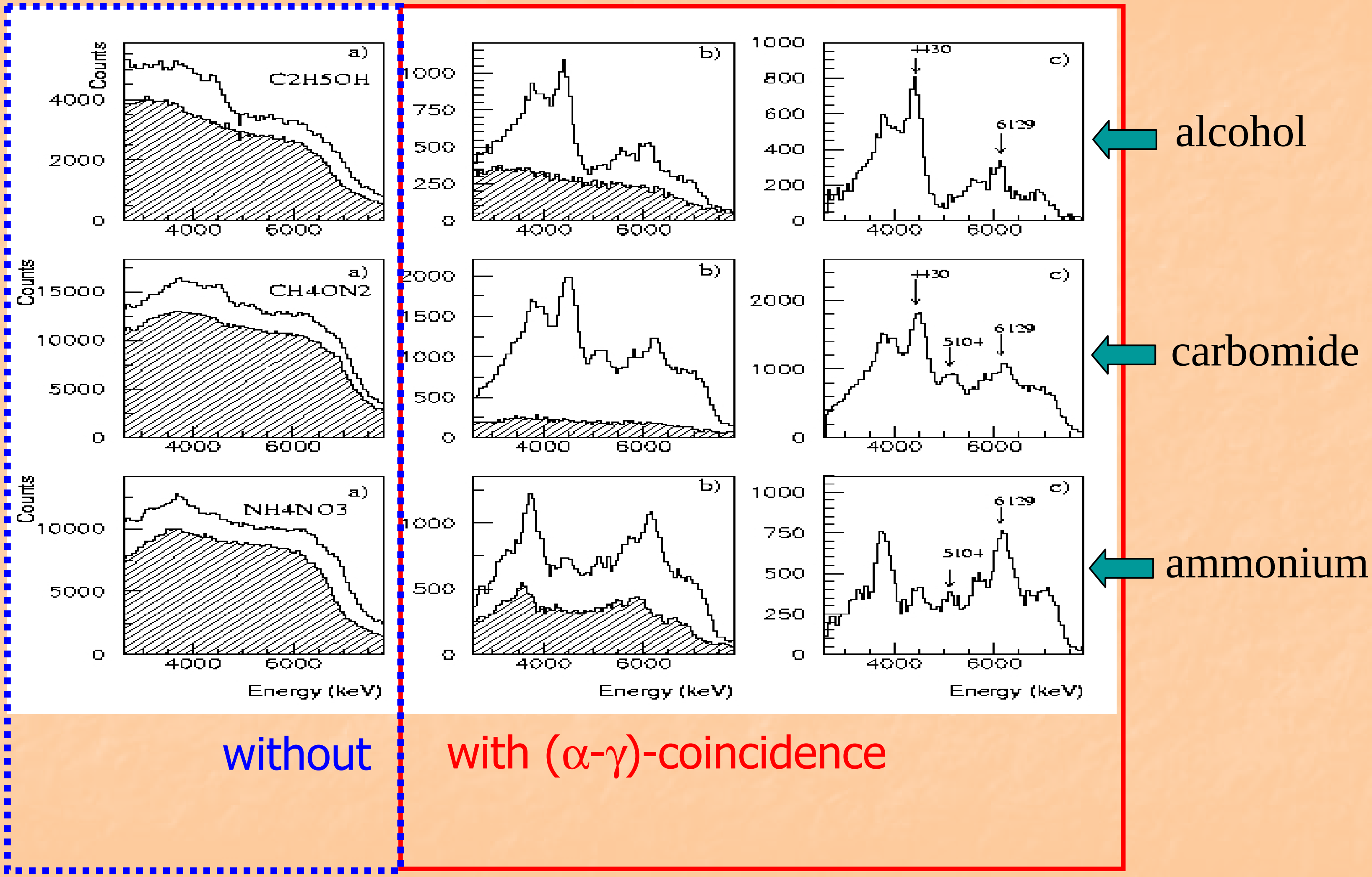


^{12}C

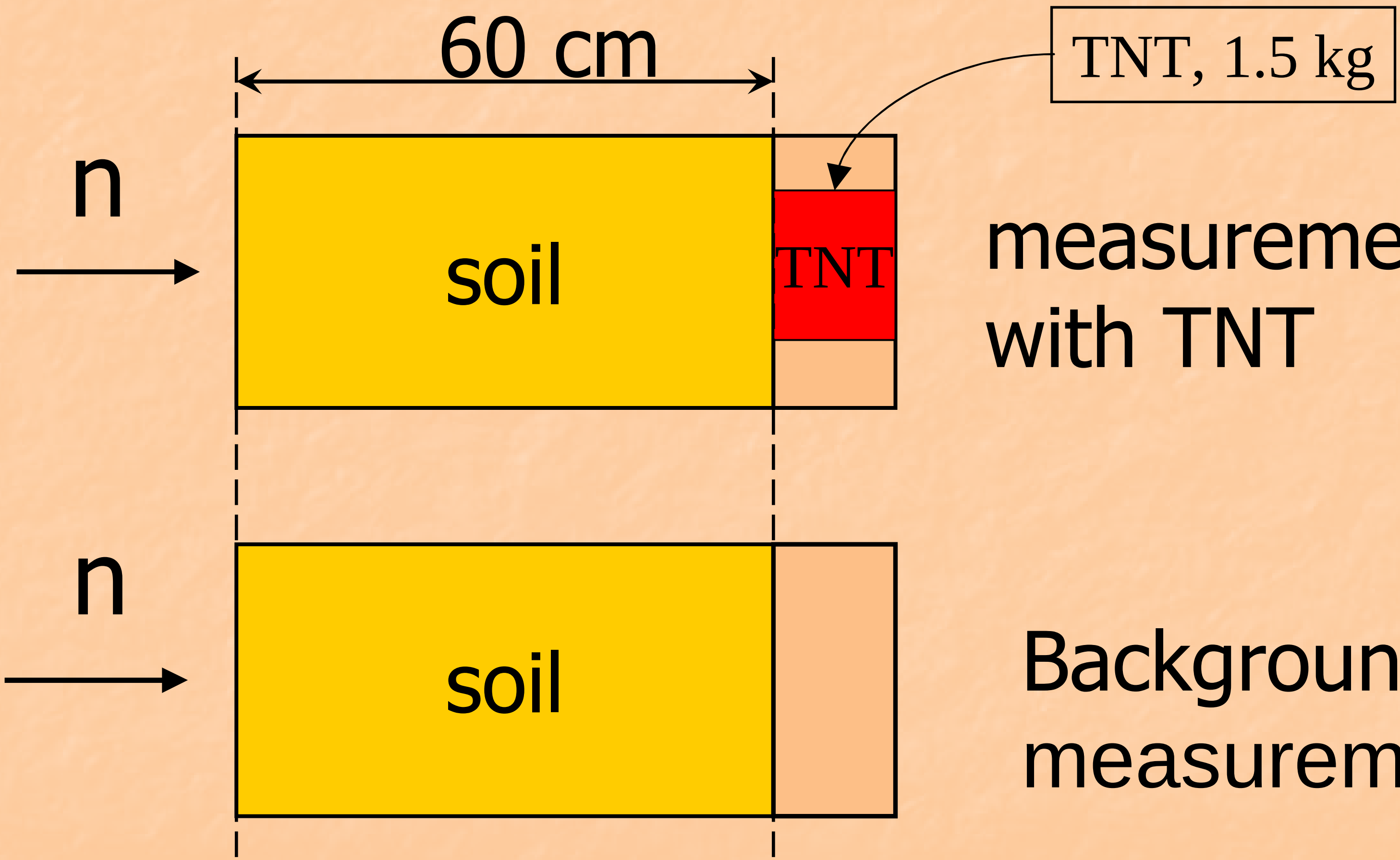
melamine ($C_3H_6N_6$)

Signal/background ratio is better than 200

Reliability of hidden substance identification



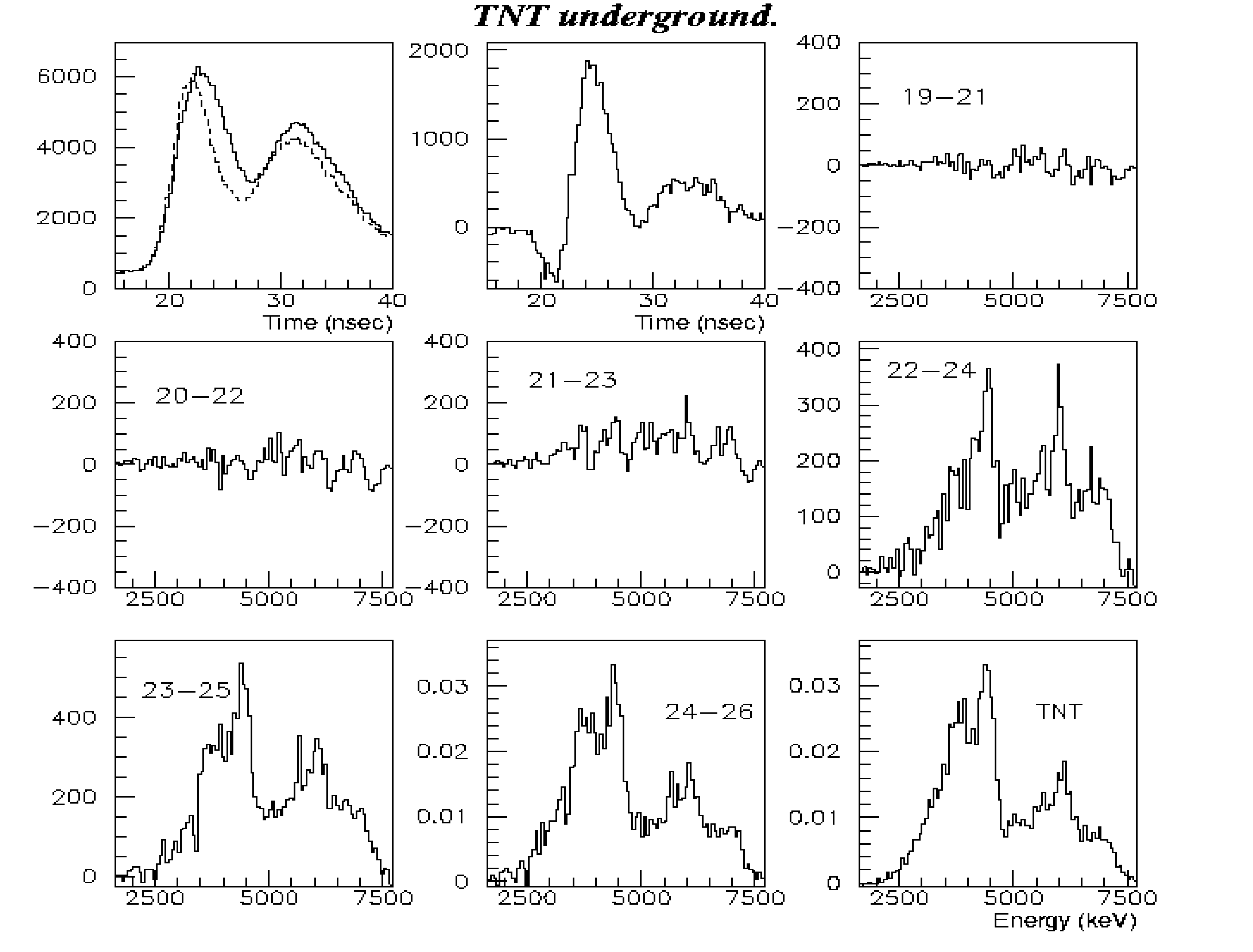
TNT shielded by a layer of soil



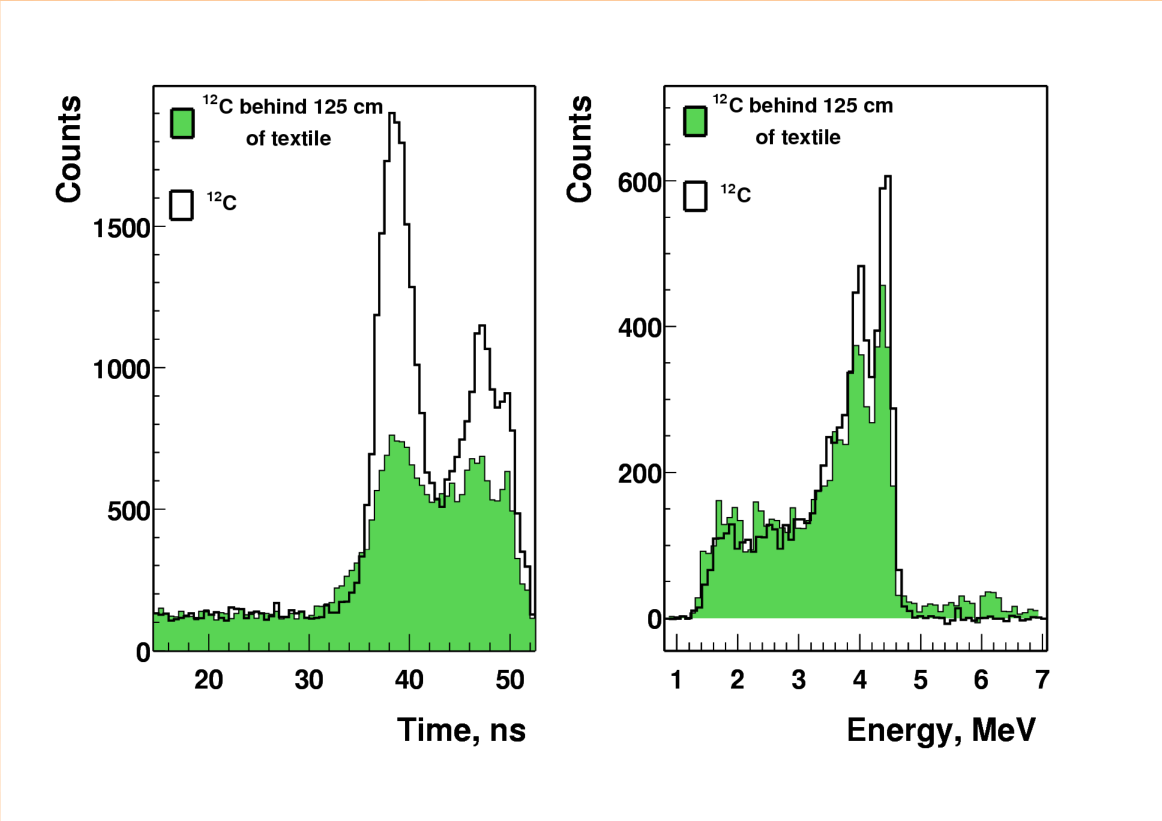
measurement with TNT

Background measurement

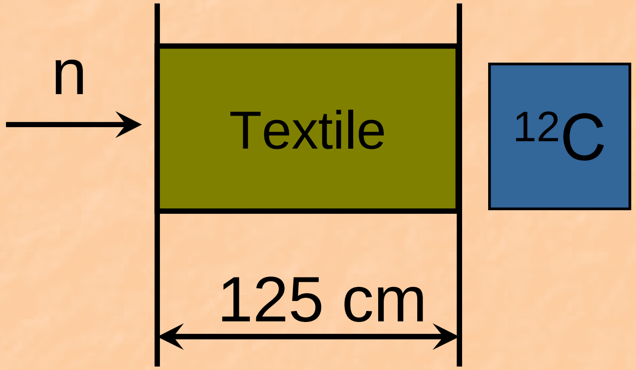
Time interval and energy distributions for TNT measurement



Screening of Carbon

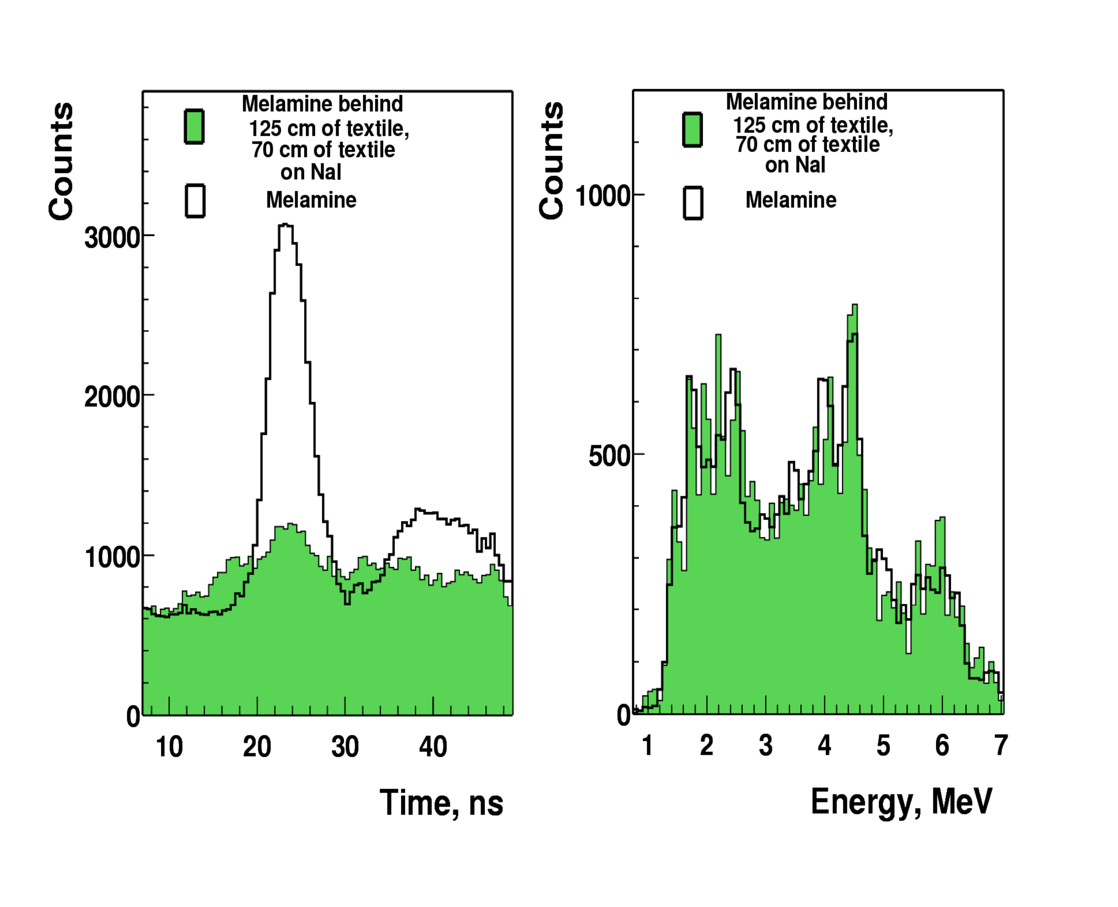


- Carbon shielded by 125 cm of a textile



- $I_n = 8 \cdot 10^7$ n/s
- $m(^{12}C) = 9$ kg
- Time of identification is $t \approx 10$ min

Screening of Melamine



- $I_n = 10^8$ n/s
- m = 10÷20 kg
- Time of identification: 10÷15 min

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Collaboration

The main results have been received in the collaboration JINR – SPC “Aspect” (Scientific Production Center “Aspect”, Dubna) – FCS RF (Federal Customs Service of the Russian Federation)

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Milestone 3: Pumped PNG (JINR)
2000 – 2001

$I_n = 10^7$ n/s, $I_d \approx 10$ μA

$I_{tot} \approx 70$ μA

Penning ion source

Disadvantage: Burn-out of tritium target

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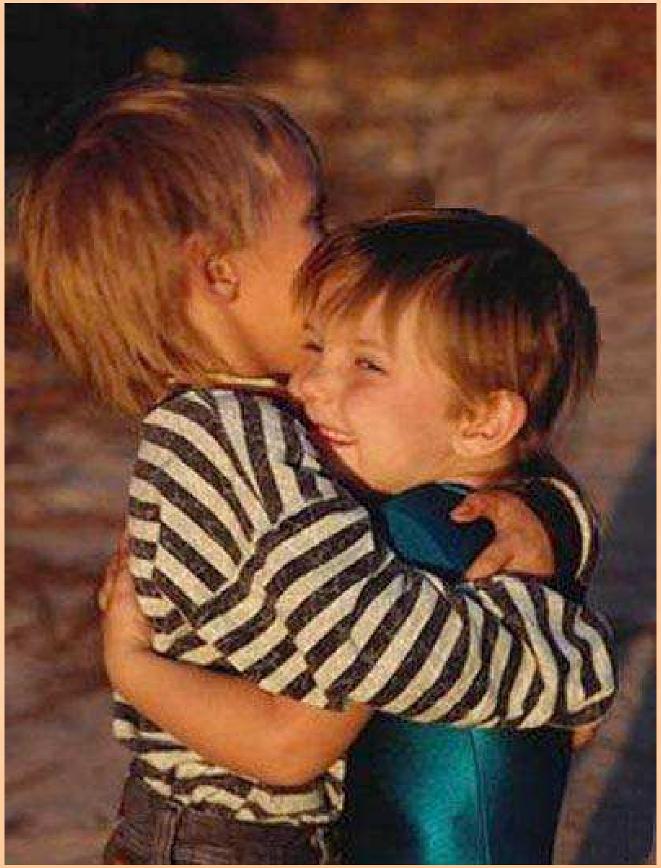
Milestone 4: Sealed PNG with YAP (Ce) α-detector

2002 – establishment of friendly relationship with VNIIA and beginning of the joint creative activity



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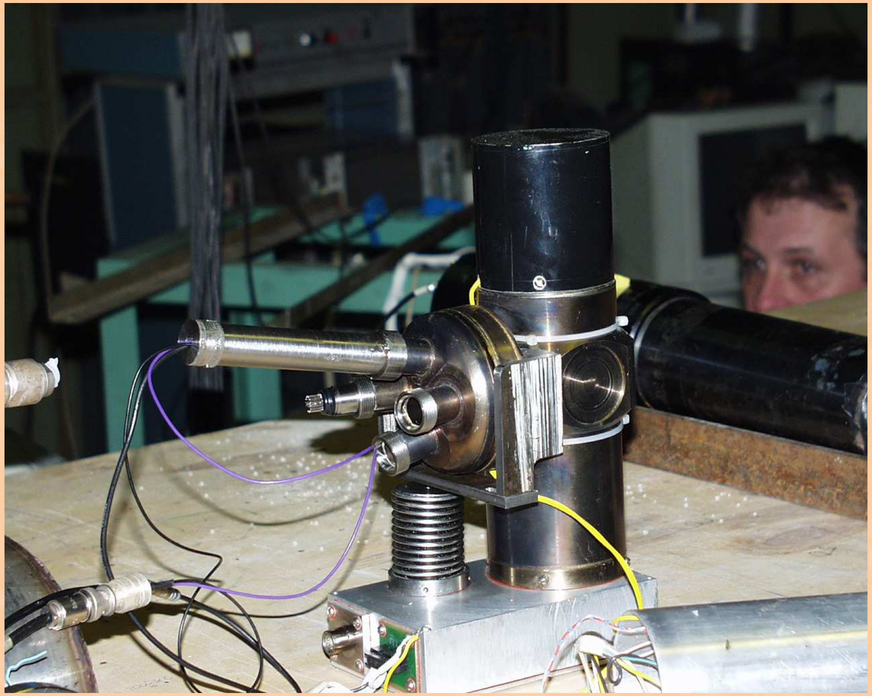
Milestone 4: Sealed PNG with YAP (Ce) α-detector



4 pixels of YAP(Ce) 10x10 mm^2,

d = 0.5 mm

Achieved intensity – $I_n = 5 \cdot 10^6$ n/c

Design and construction:

VNIIA – a neutron generator

JINR – α-detector

Problems: huge level of α detector background load

(electrons, bremsstrahlung)

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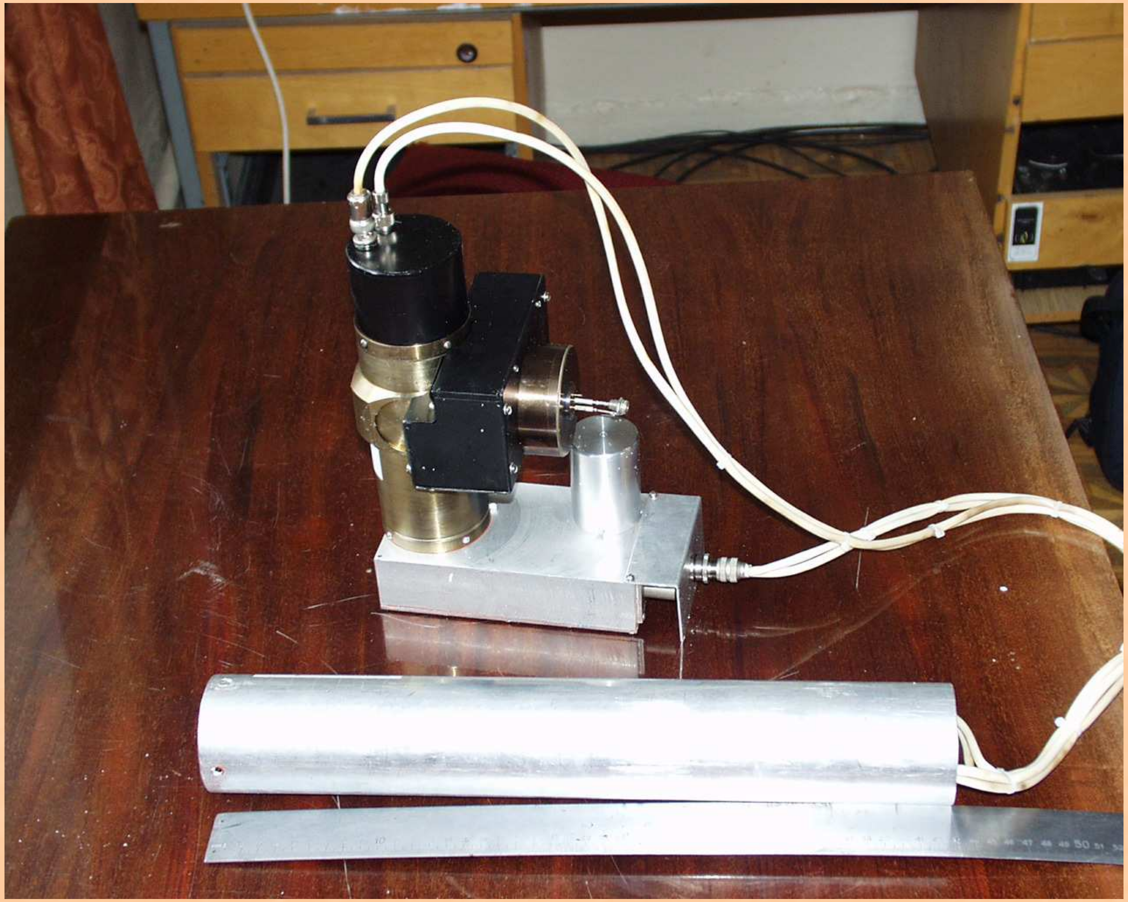
Milestone 5: Sealed PNG with silicon α-detector



- Codesign: VNIIA (neutron generator), JINR (α-detector)
- Achieved intensity - $I_n = 5 \cdot 10^7\ s^{-1}$
- 300 hours of operation (from starting to present time)

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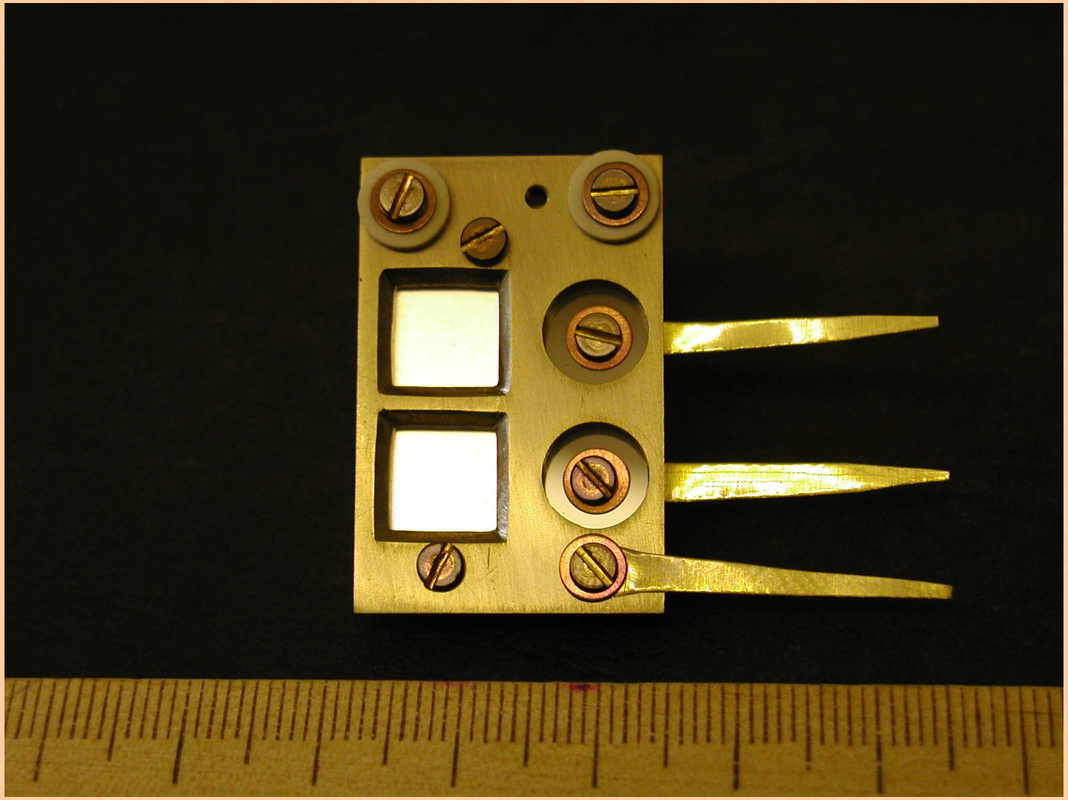
Si α-detector



- 2 cells
- 8x8 mm^2
- Silicon
- α-count ~ $(3 \div 4) \cdot 10^4$ s^{-1}

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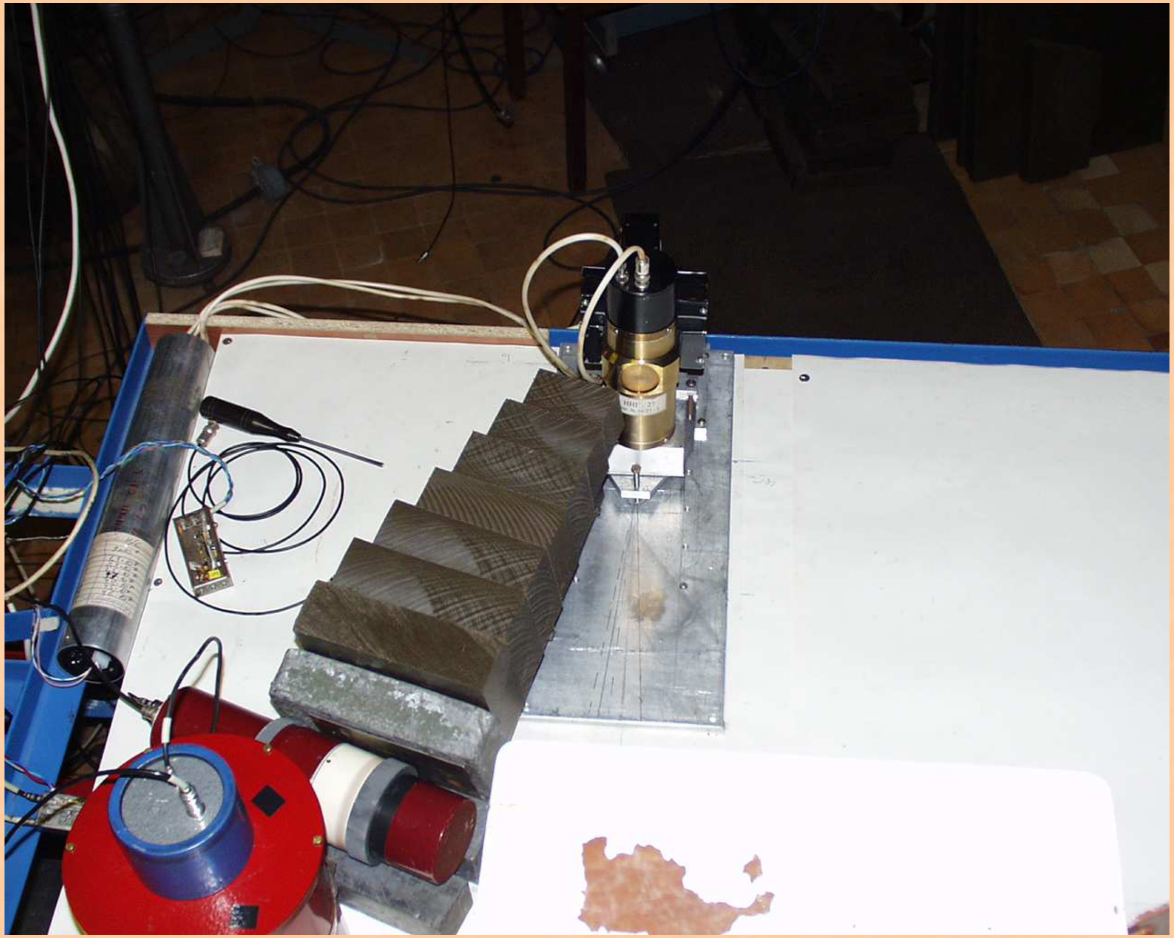
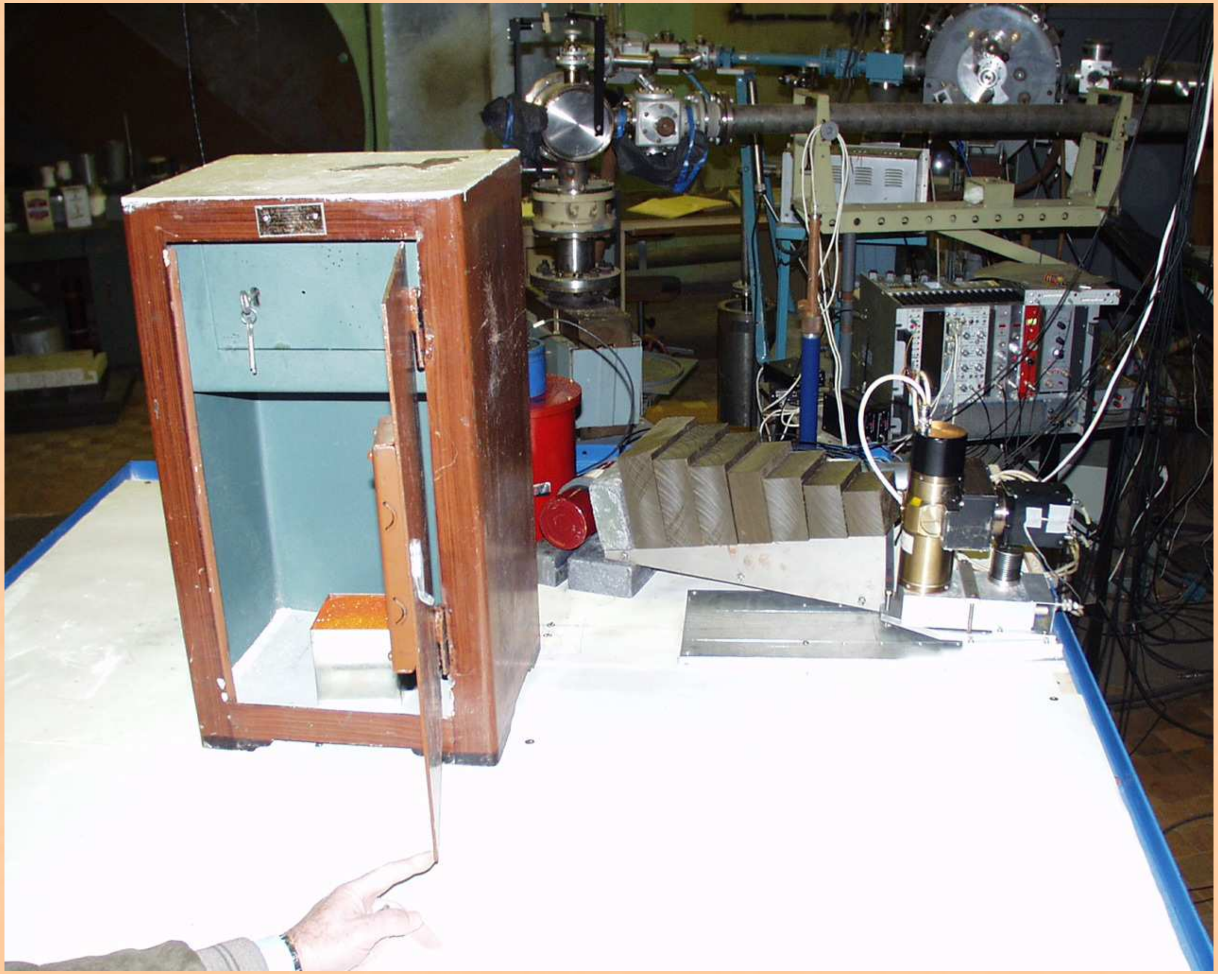
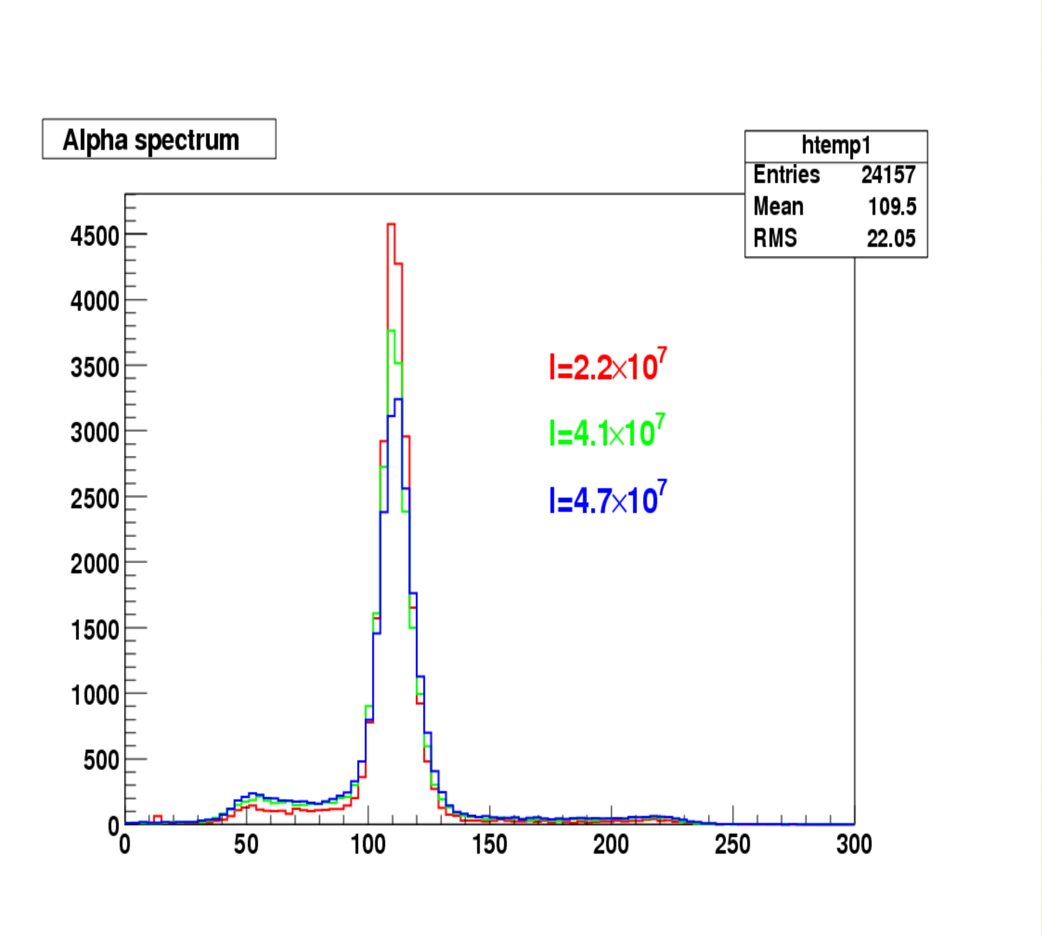
Experimental setup



Measurements

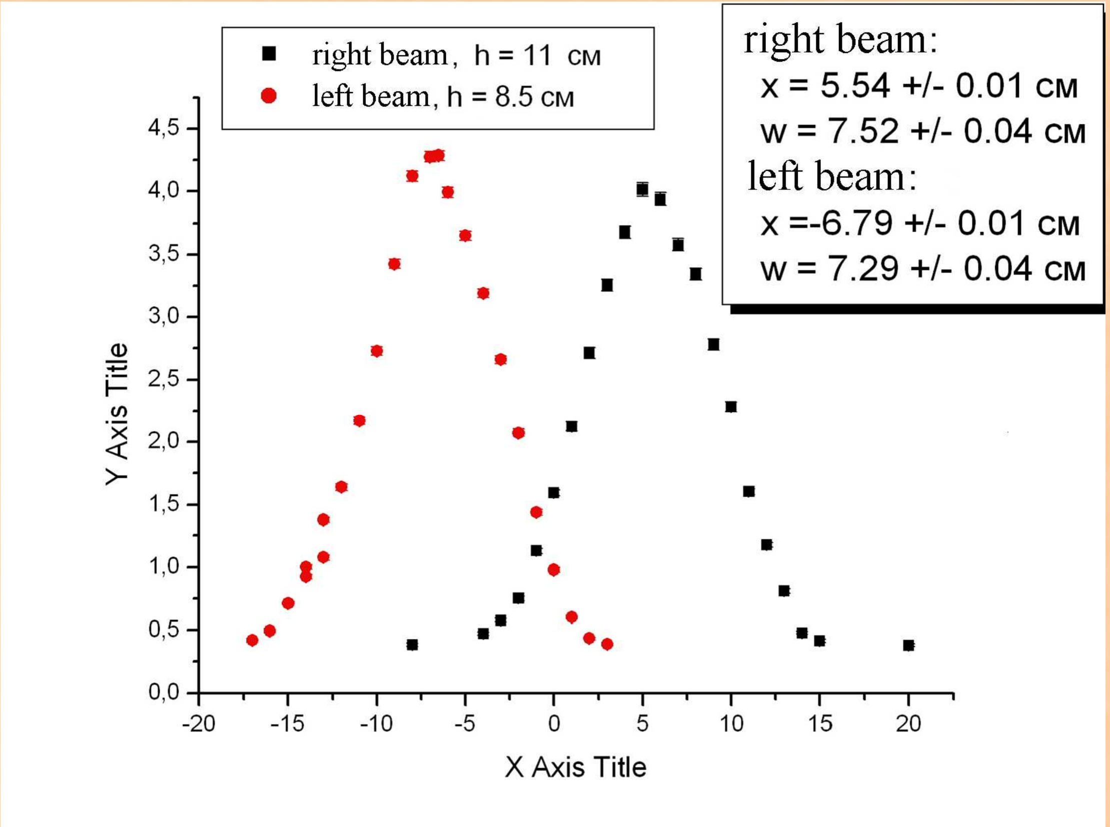


α-particle spectrum



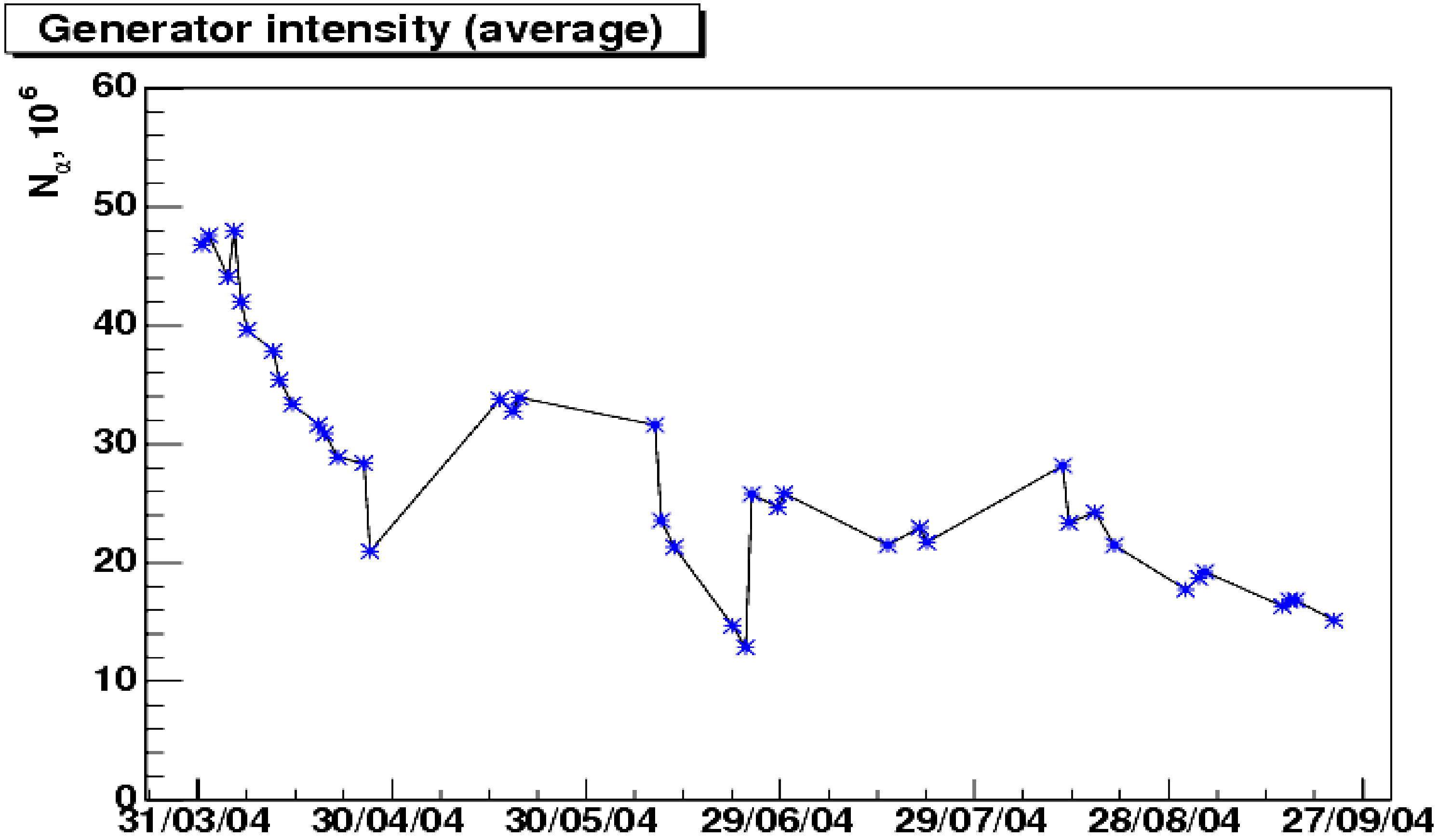
- Spectrum broadens as intensity grows
- It does not affect operation of the device

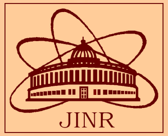
Tagged neutron beam



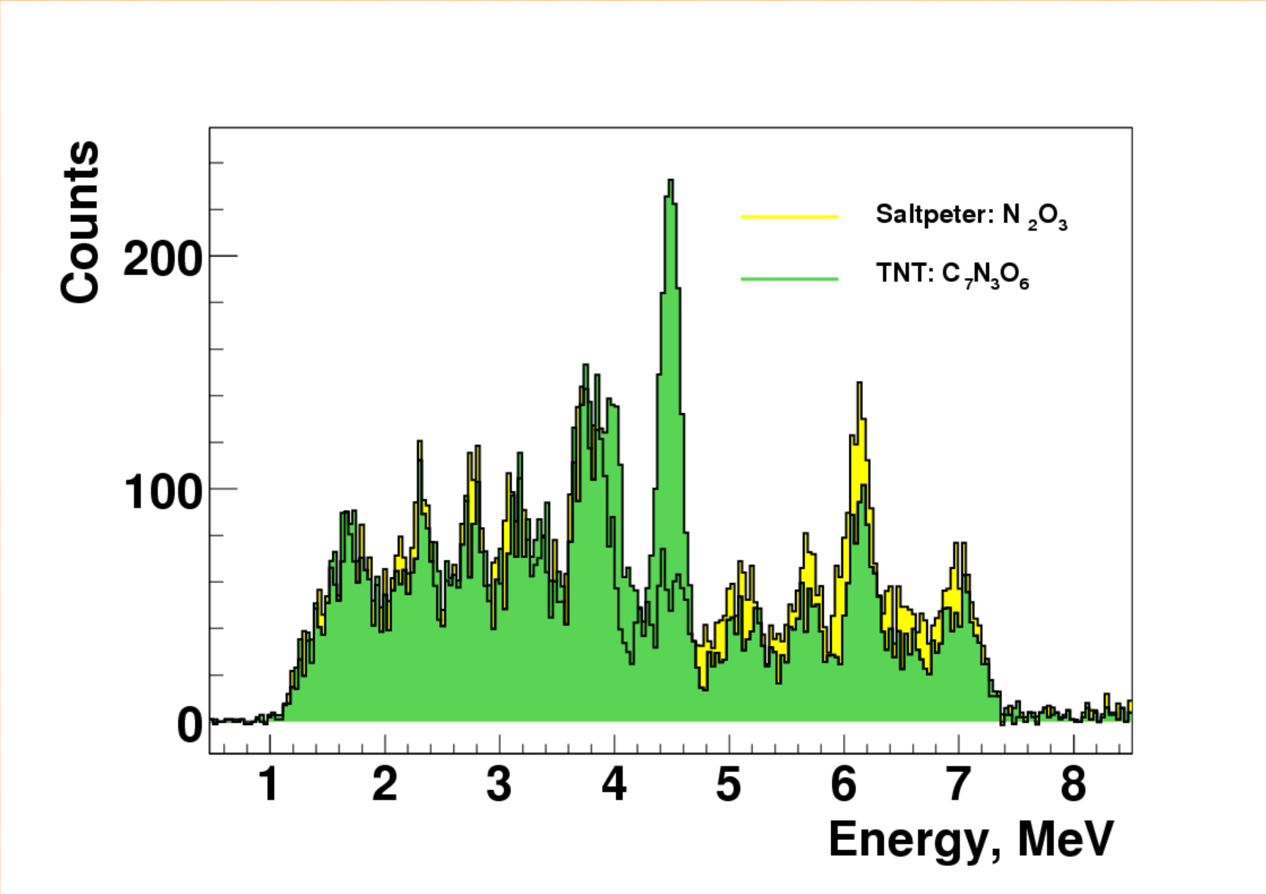
- Square 7x7 cm^2 distance of 70 cm

Neutron intensity of PNG





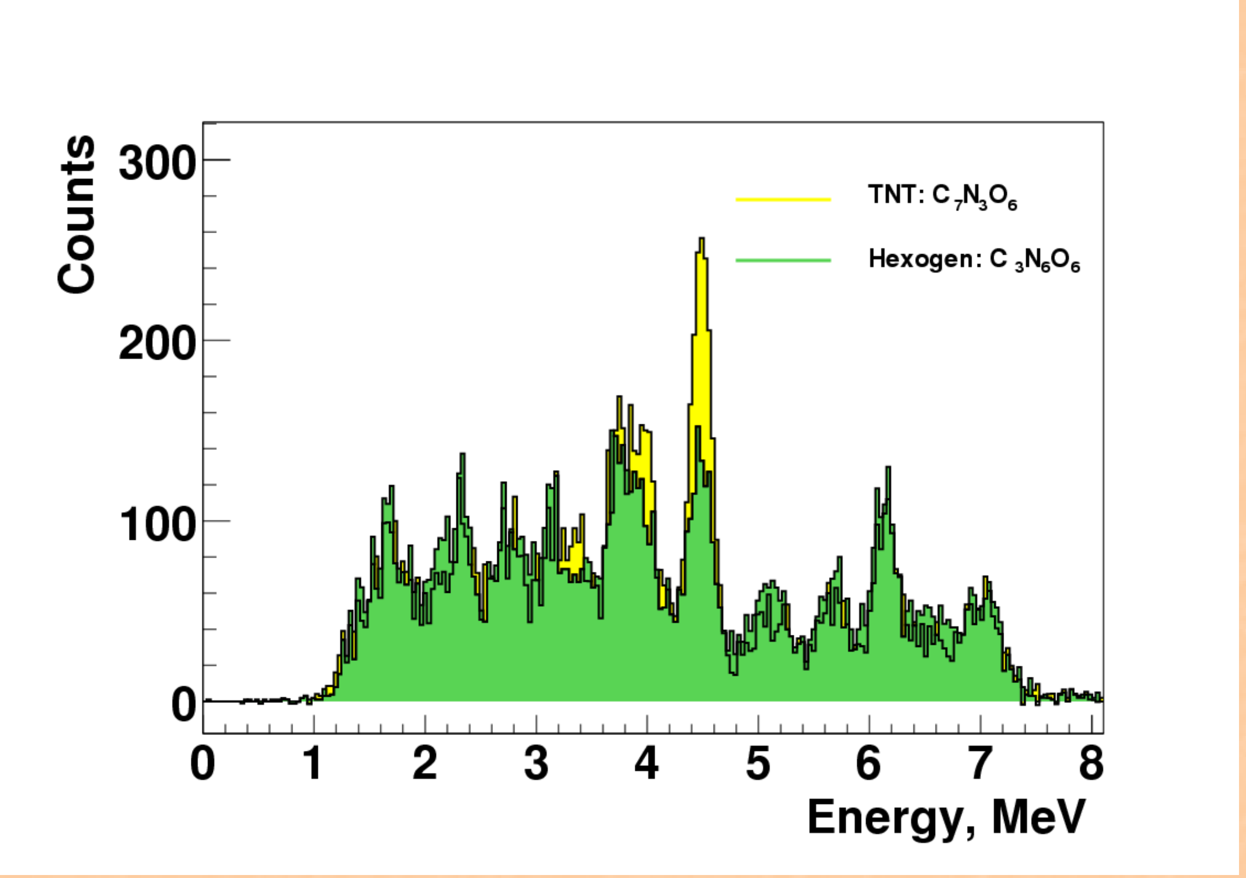
Main results (Si PNG)
Saltpeter and TNT



Saltpeter (N_2O_3)
m=800 g
t=1 h

TNT ($C_7N_3O_6$)
m=800 g
t=1 h

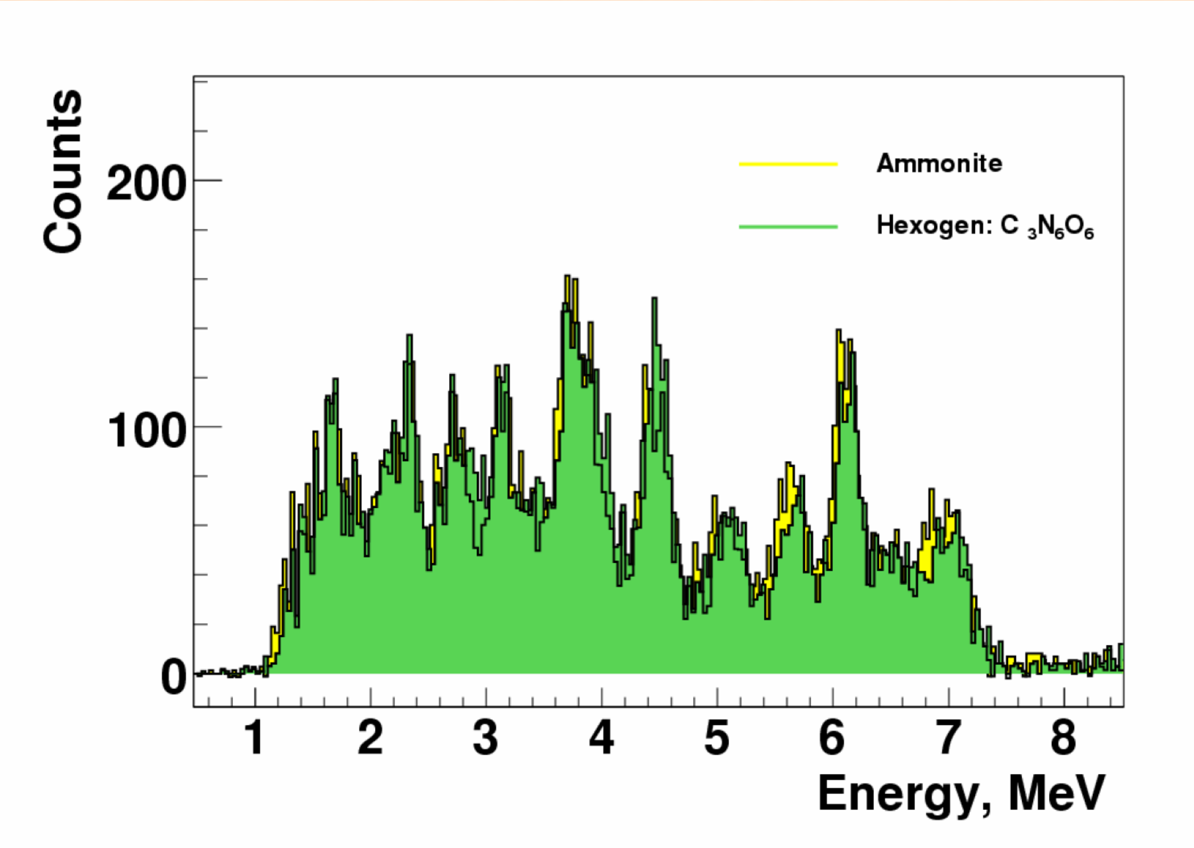
TNT and Hexogen (Si PNG)



TNT ($C_7N_3O_6$)
m=800 g
t=1 h

Hexogen ($C_3N_6O_6$)
m=800 g
t=1 h

Ammonite and Hexogen (Si PNG)



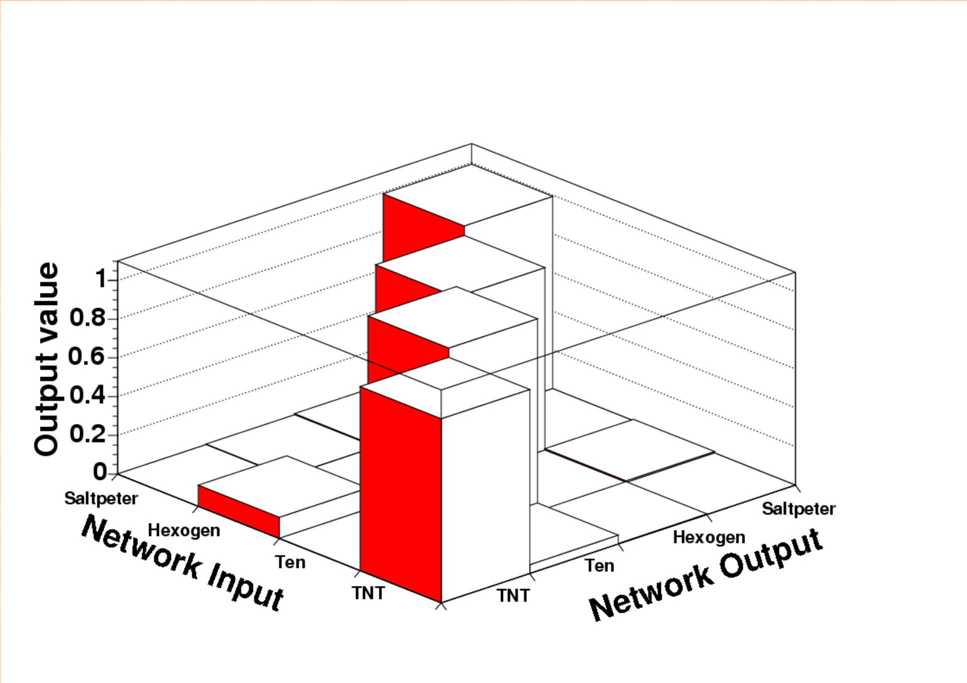
Ammonite (20% TNT + 80% of saltpeter) (~$C_3N_5O_7$)
m=800 g
t=1 h

Hexogen ($C_3N_6O_6$)
m=800 g
t=1 h

Identification of hidden substances
Teaching of the network

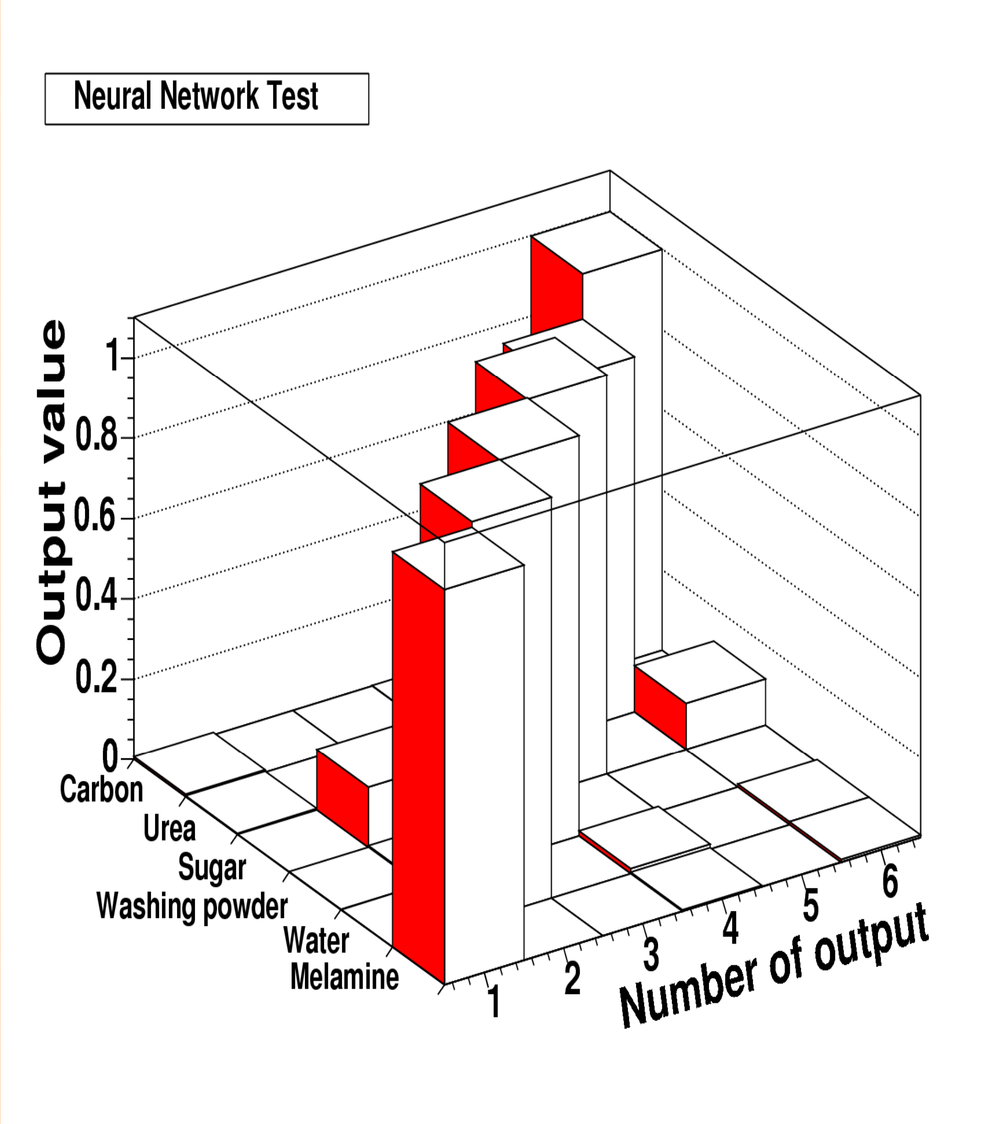
We have applied two methods of hidden substance identification by using:

- χ^2-analysis
- Neural network



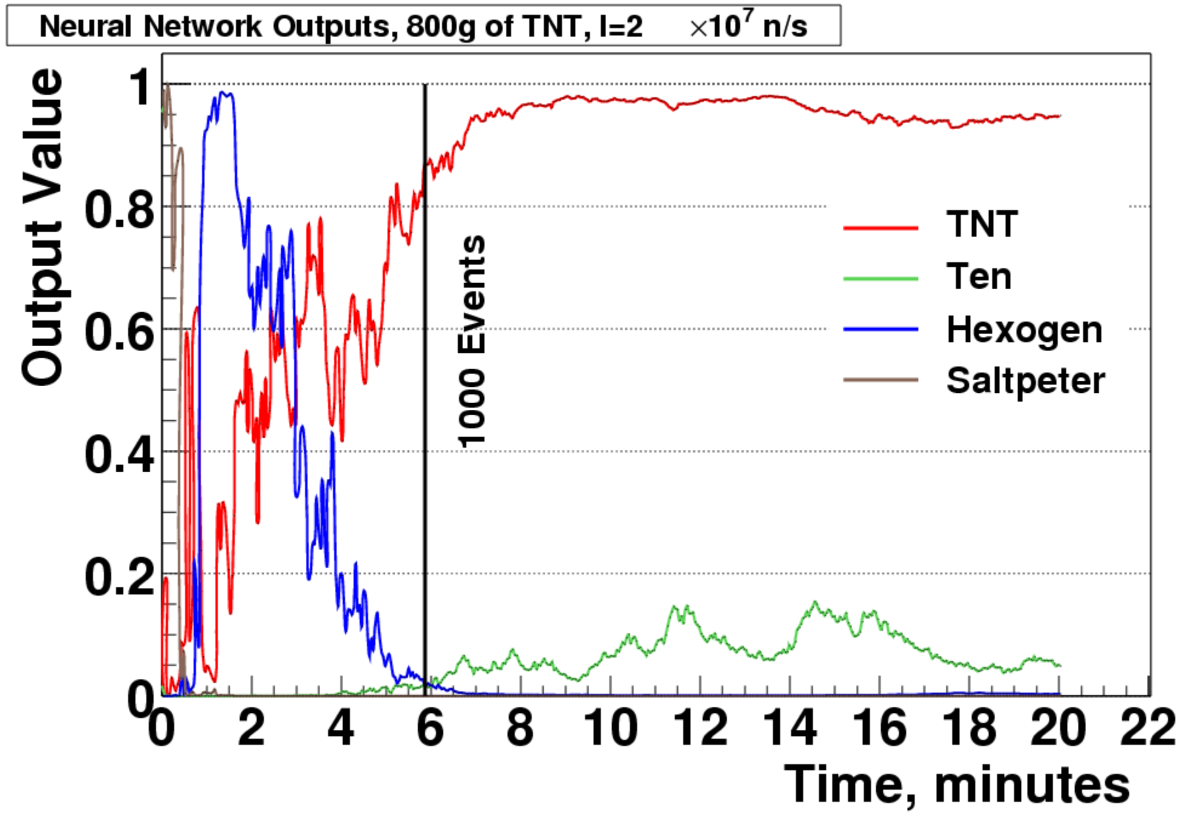
- 800g samples
- Teaching: hour-long exposures
- Testing: 20-minute exposure
- Identification time: value of output of “major” neuron is above 0.8, value of all other outputs is below 0.2

The test of the neural network performance

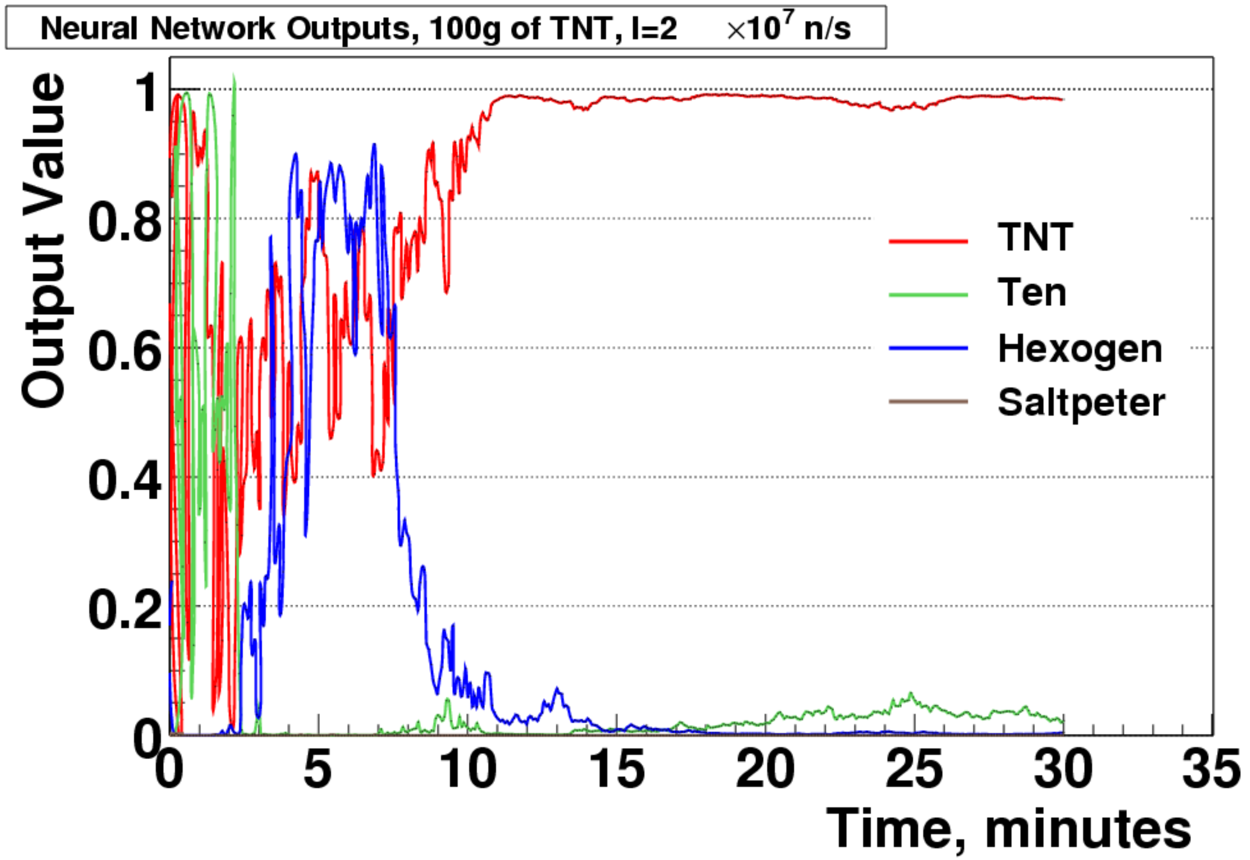


On the Y axis the number of interrogated substance is plotted. The result is the corresponding identification probability. It is plotted on the Z axis.

Identification of TNT spectra (800 g)



Identification of TNT spectra (100 g)



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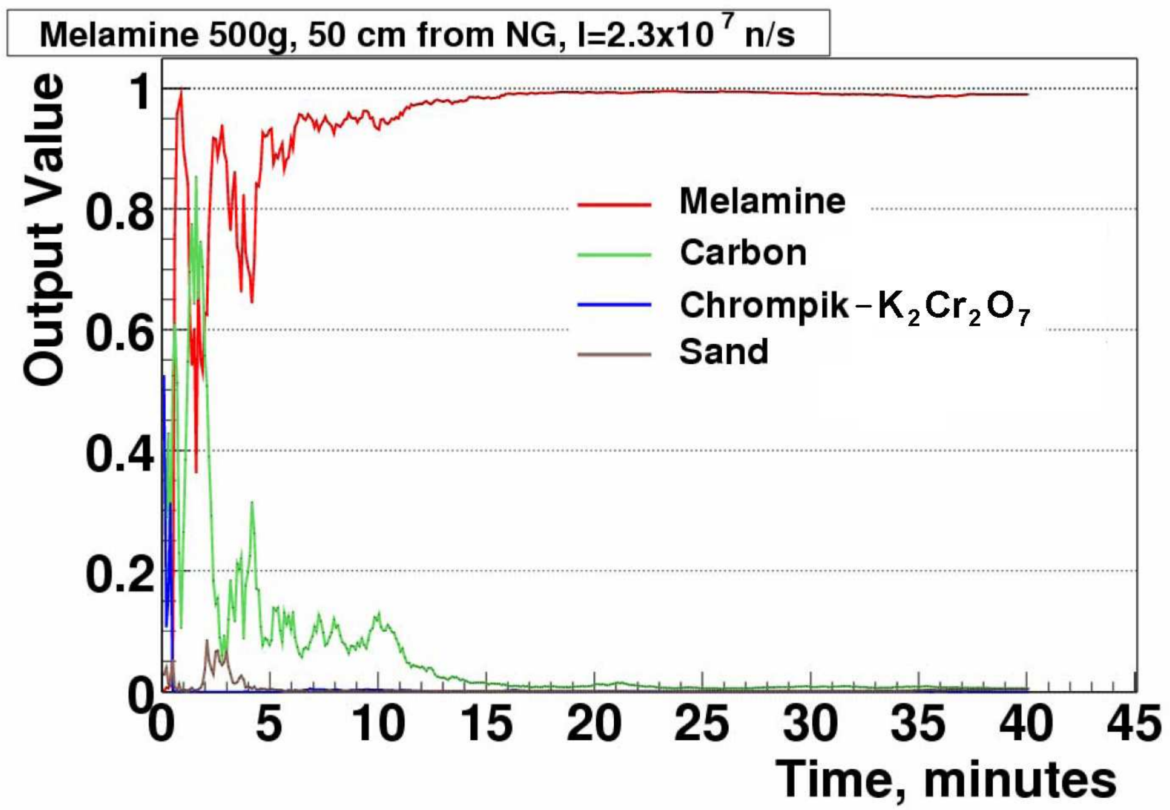
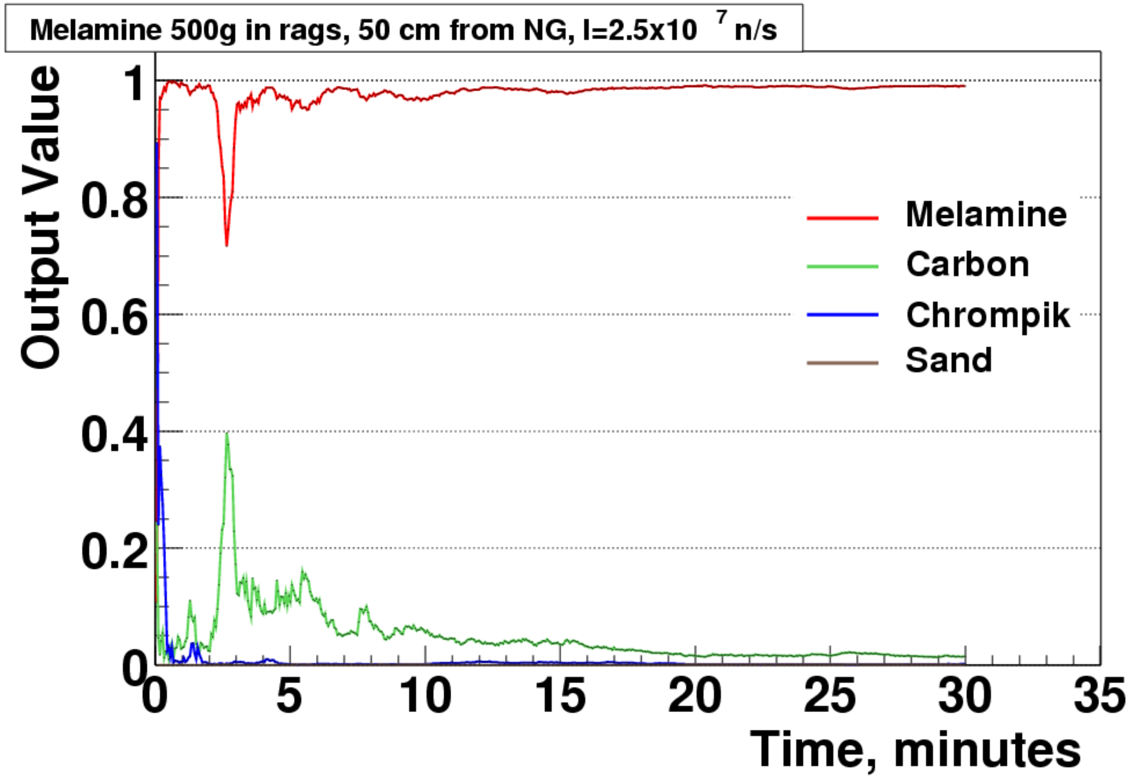
Identification of melamine spectra (500 g)

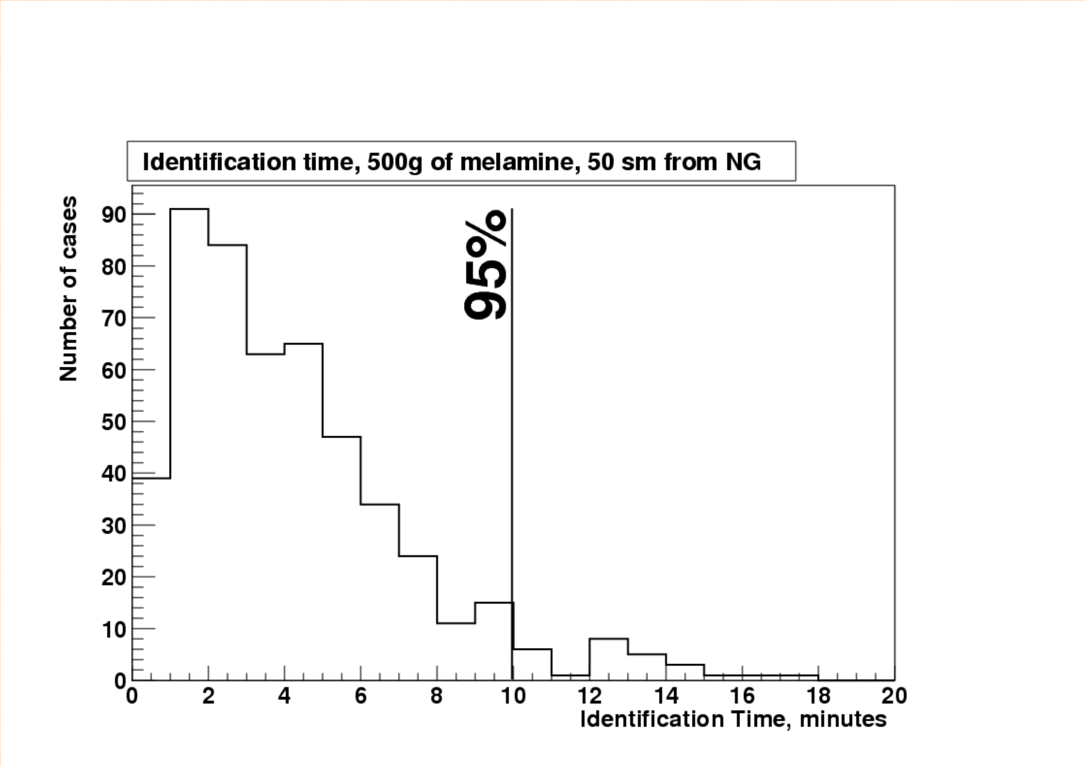


Identification of shielded melamine spectra (500 g)



Identification of spectra

Identification time estimation



- 500 trials
- Identification within 10 minutes with 95% probability

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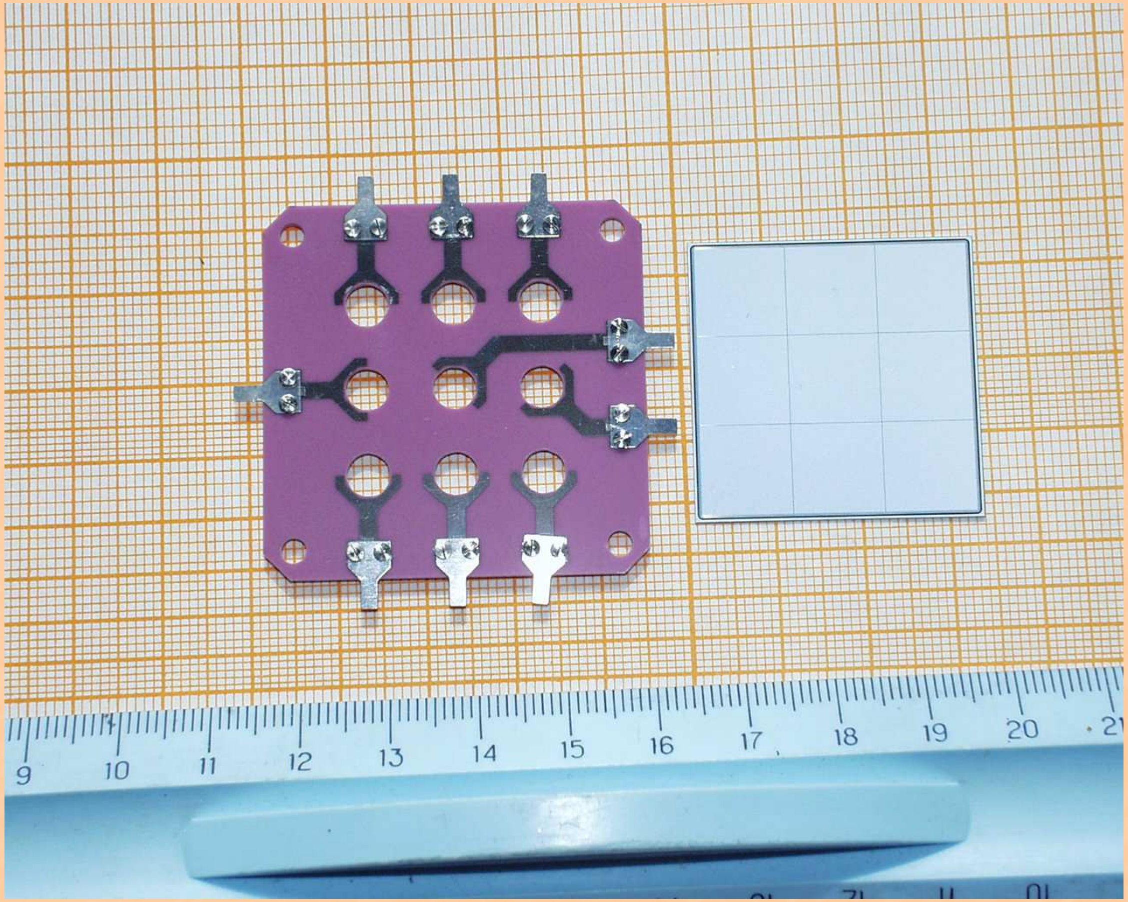
Our technical achievements: Si α-detector



- Si detector, 9 cells 10x10 mm^2

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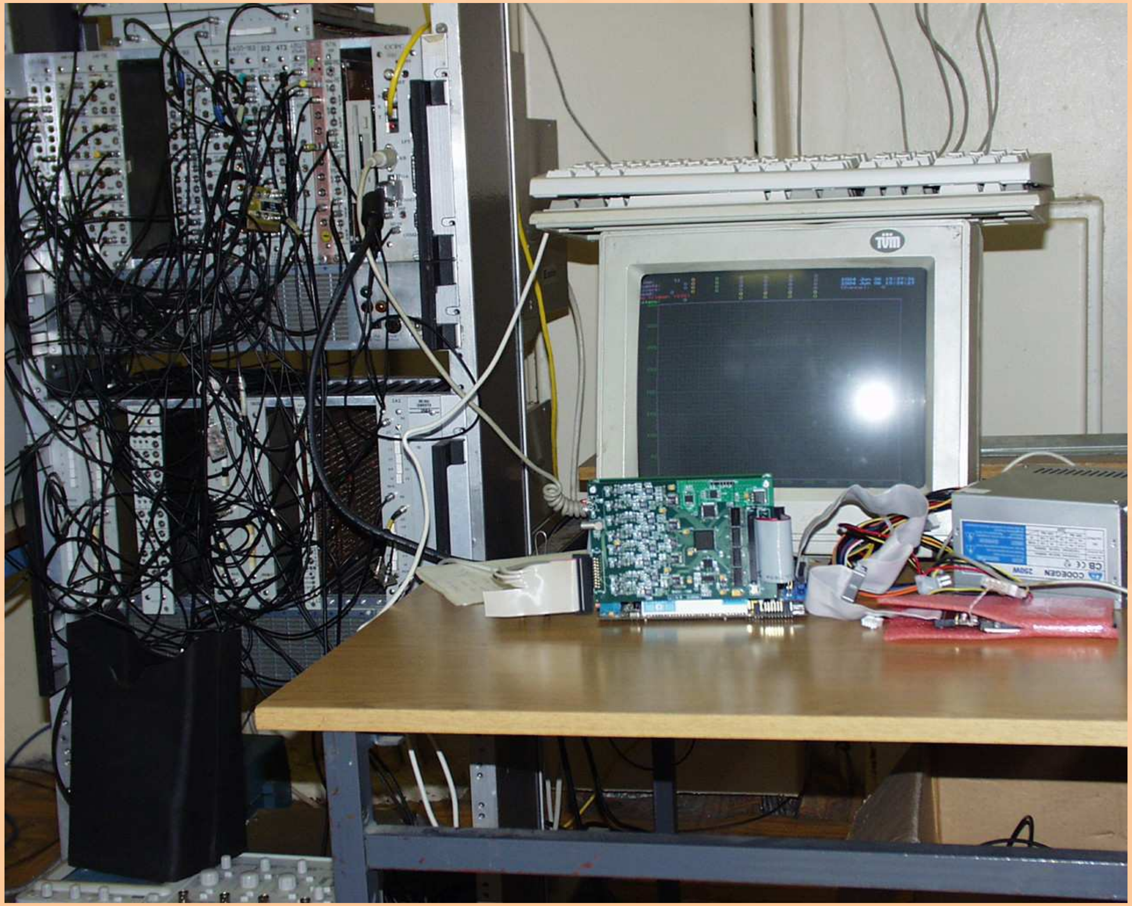
Our technical achievements: DAQ

A PCI card for data taking from 4 α- and 4 χ-detectors has been developed. The card is to the replace the old crate-based electronics (left).



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Conclusion

- R&D of the API method is completed
- The capabilities of the API method are studied
- An operating prototype of the detector for remote nondestructive identification of explosives hidden in containers or soil is made. The FCS tests have shown the suitability of this device for these goals.
- At present we are creating an experimental device to the specifications of RF FCS and FSB (Federal Service Security).

Our door is open for different collaborations.
We wait for interesting offers.

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Acknowledgements

We would like to thank VNIIA Director Prof. Yu.N. Barmakov, SPC “Aspect” Director Yu.K. Nedachin and Deputy Head of General Authority for Information Technologies of the RF FCS N.E. Kravchenko for their constant interesting and support of these investigations.

It is a pleasure for us to thank E.P. Bogolyubov, T.O. Khasaev, Yu.K. Presniakov and V.I. Ryzhkov for close and fruitful cooperation in the course of neutron generator development.

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END