Latest results of NArCoS: a new correlator for neutrons and light charged particles

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Project’s motivations

The advent of the new facility for Radioactive Ion Beams (RIBs) in particular for the n-rich ones

“The RIBs are an important opportunity”

(C. Horovitz)
To realize a prototype of detector able to detect at the same time charged particles and neutrons with high energy and angular resolution for reaction studies and applications

- Candidate: The plastic scintillator EJ276-Green Type (ex EJ299-33) (3x3x3cm³)
- 1 cluster: 4 consecutively cubes -> 3x3x12 cm³
- Reading the light signal: Si-PD or Si-PM and digitalization
- Modular, reconfigurable (in mechanic and electronic)
- Discrimination of n/γ from PSD (but also light charged particles)
- Energy measurement from ToF (Δt≤1 ns with LToF≈1÷1.5m)
  TOF measured using the RF of the CS or with an ancillary MCP (low intensity exotic beams)
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*Si incrocia l’info ampiezza-PSD e info da fasci di calibrazione (n,CP)
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*Si incrocia l’info ampiezza-PSD e info da fasci di calibrazione (n,CP)
**Just few numbers**

- **Time of flight**
  - $L = 150$ cm; $\Delta T = 0.5$ ns

- **Solid angle**
  - $\approx 7$ msr (0.07%)

- **Angular resolution**
  - $\Delta \theta$ (DSSSD) $\approx 0.15^\circ$
  - $\Delta \theta$ (NArCos) $\approx 1.25^\circ$

- **Efficiency**
  - $\approx 25\%$

For one cluster:

- **Energy vs. Time of Flight**
  - $L = 150$ cm; $\Delta T = 0.5$ ns

*The mechanical structure will have the possibility of an angular movimentation*
**Just few numbers**

- Time of flight:
  - $L = 150 \text{ cm}$; $\Delta T = 0.5 \text{ ns}$

- NArCoS:
  - $\approx 12 \text{ cm}$

- DSSSD 32x32
  - $300 \mu$m

Solid angle:
- $\approx 7 \text{ msr (0.07\%)}$

Angular resolution:
- DSSSD $\approx 0.15^\circ$
- NArCos $\approx 1.25^\circ$

- $<\text{EFF}> \approx 25\%$
- For one cluster

- Energy vs. Time of Flight
  - For $\Delta T = 0.5 \text{ ns}$
  - *the mechanical structure will have the possibility of an angular movimentation*
Just few numbers

Time of flight

\[ L = 150 \text{ cm}; \ \Delta T = 0.5 \text{ ns} \]

DSSSD 32x32

300 μm

\[ L_{\text{DSSSD}} = 75 \text{ cm} \]

\[ L_{\text{NArCoS}} = 150 \text{ cm} \]

Solid angle \( \approx 7 \text{ msr (0.07%)} \)
Angular resolution DSSSD \( \approx 0.15^\circ \)
Angular resolution NArCoS \( \approx 1.25^\circ \)

\[ \theta = 5^\circ \]

\[ \approx 12 \text{ cm} \]

\[ \approx 25\% \]

For one cluster

\[ \Delta T / T \ (\Delta T = 0.5 \text{ ns}) \]

\[ \Delta E / E \ (\Delta T = 0.5 \text{ ns}) \]

*the mechanical structure will have the possibility of an angular movement*
Just few numbers

- **Time of flight**
  - \( L = 150 \text{ cm}; \Delta T = 0.5 \text{ ns} \)

- **Solid angle**
  - \( \approx 7 \text{ msr (0.07\%)} \)

- **Angular resolution**
  - DSSSD: 0.15°
  - NArCos: 1.25°

- **<EFF>\approx 25\%**
  - For one cluster

- **Energy resolution**
  - \( \Delta T / T \) (\( \Delta T = 0.5 \text{ ns} \)) (150 cm)
  - \( \Delta E / E \) (\( \Delta T = 0.5 \text{ ns} \)) (150 cm)

- The mechanical structure will have the possibility of an angular movimentation
Just few numbers

Time of flight

$T = 150 \text{ cm}; \Delta T = 0.5 \text{ ns}$

DSSSD $32 \times 32$

300 µm

NArCoS

$\approx 12 \text{ cm}$

Solid angle $\approx 7 \text{ msr (0.07%)}$

Angular resolution DSSSD $= 0.15^\circ$

Angular resolution NArCos $= 1.25^\circ$

$\langle \text{EFF} \rangle \approx 25\%$

For one cluster

$\Delta \theta = \Delta T / L$

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Just few numbers

Time of flight

$L = 150 \text{ cm}; \Delta T = 0.5 \text{ ns}$

$\theta = 5^\circ$

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$\text{Solid angle} \approx 7 \text{ msr (0.07\%)}$

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For one cluster
Time of flight

$T = 150 \, \text{cm}; \ \Delta T = 0.5 \, \text{ns}$

DSSSD 32x32

300 $\mu$m

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Angular resolution DSSSD $=0.15^\circ$
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$<\text{EFF}> \approx 25\%$

For one cluster

$\Delta T/T \ (\Delta T = 0.5 \, \text{ns}) \ (150 \, \text{cm})$

$\Delta E/E \ (\Delta T = 0.5 \, \text{ns}) \ (150 \, \text{cm}) \ (\Delta L = 1.5 \, \text{cm})$

$\Delta M/M \ (\Delta T = 0.5 \, \text{ns}) \ (150 \, \text{cm})$

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$\Delta E/E \ (\Delta T = 0.5 \, \text{ns}) \ (150 \, \text{cm}) \ (\Delta L = 1.5 \, \text{cm})$
What about the neutron detection efficiency?

GEANT 4 simulation in order to estimate the neutron detection efficiency

Mean value for one detection cell (3x3x3 cm$^3$) $\approx 9\%$

Mean value for one detection cluster (3x3x12 cm$^3$) $\approx 25\%$
L’EJ276
(ex EJ-299-33)

N. P. Hawkes et al., NIM A729 (2013) 522
S.A. Pozzi et al., NIM A723 (2013) 19
E. V. Pagano et al. NIM A 889 (2018) 83-88
E. V. Pagano et al. NIM A 905 (2018) 47-52
L’EJ276
(ex EJ-299-33)
### PROPERTIES

<table>
<thead>
<tr>
<th>Property</th>
<th>EJ-276</th>
<th>EJ-276G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Output (% Anthracene)</td>
<td>56</td>
<td>52</td>
</tr>
<tr>
<td>Scintillation Efficiency (photons/1 MeV e⁻)</td>
<td>8,600</td>
<td>8000</td>
</tr>
<tr>
<td>Wavelength of Maximum Emission (nm)</td>
<td>425</td>
<td>490</td>
</tr>
<tr>
<td>No. of H Atoms per cm³ (x10²²)</td>
<td>4.53</td>
<td>4.53</td>
</tr>
<tr>
<td>No. of C Atoms per cm³ (x10²²)</td>
<td>4.89</td>
<td>4.89</td>
</tr>
<tr>
<td>No. of Electrons per cm³ (x10²³)</td>
<td>3.52</td>
<td>3.52</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.096</td>
<td>1.096</td>
</tr>
<tr>
<td>Approx. Mean Decay Times of First 3 Components (ns)</td>
<td>13, 35, 270</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>13, 59, 460</td>
<td>—</td>
</tr>
</tbody>
</table>
L’EJ276
(ex EJ-299-33)
L’EJ276
(ex EJ-299-33)

Si PIN photodiode
S3204/S3584 series

Large area sensors for scintillation detection

S3204/S3584 series are large area Si PIN photodiodes having an epoxy resin window. These photodiodes are also available without window.
L’EJ276
(ex EJ-299-33)

S3204/S3584 series are large area Si PIN photodiodes having an epoxy resin window. These photodiodes are also available without window.
Test using radioactive sources @ LNS

Dimension: 3x3x3 cm³
\langle\text{neutron EFF}\rangle (GEANT4) \approx 9\%
Read by PM tube: EMI-9544QA
High Voltage: 1500-1700 V
Test using radioactive sources @ LNS

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Test using radioactive sources @ LNS

Dimention: 3x3x3 cm³

<neutron EFF> (GEANT4) ≈ 9%

Read by PM tube: EMI-9544QA

High Voltage: 1500-1700 V

Like in ARGOS detector

G. Lanzanó, et al., NIM A 312, 3, (1992), 515-520

PM -EMI 9954QA

Like in ARGOS detector

G. Lanzanó, et al., NIM A 312, 3, (1992), 515-520
Test using radioactive sources @ LNS

Sources:
1) $\gamma$ $^{60}$Co
2) $\alpha$ $^{241}$Am
3) $\alpha$ $^{232}$Th
4) n e $\gamma$ AmBe

Dimention: 3x3x3 cm³
$<\text{neutron EFF}>$ (GEANT4) $\approx$ 9%
Read by PM tube: EMI-9544QA
High Voltage: 1500-1700 V
Some results: the digitalized signal

Signal acquired and digitalized by using the GET system (General Electronic for TPC)
Sampling frequency: 100 MHz

Trace sample visualized:

“Fast” component:
10 channels $\rightarrow$ 100ns

“Slow” component:
40 channels $\rightarrow$ 400ns

Channels (1 = 10 ns)
Some results: A few of spectra

E. V. Pagano et al. NIM A 889 (2018) 83-88
Some results: A few of spectra

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Some results: A few of spectra

E. V. Pagano et al. NIM A 889 (2018) 83-88

Detection threshold ≈ 0.7 MeV
Discrimination threshold ≈ 1.5 MeV (FOM\textsubscript{PSD}=0.43)

\[ L_{\text{out}} = A \cdot E_{\text{dep}} - B \cdot (1 - e^{C \cdot E_{\text{dep}}}) \]

\[ A = 0.8 \text{ MeVee MeV}^{-1}; \]
\[ B = 3.9 \text{ MeVee}; \]
\[ C = 0.19 \text{ MeV}^{-1}; \]

C. C. Lawrence et al., NIM A759 (2014) 16
Some results: A few of spectra

E. V. Pagano et al. NIM A 889 (2018) 83-88

Thorium source

Plastic energy intrinsic resolution for Alpha particles:
\( (E_\alpha) \) of 8.7 MeV \( \approx \) 15%
Some results: A few of spectra
Second results: tests in high background condition

The test was done during the Barrier experiment @ LNS $^{24}\text{Mg} + ^{90,92}\text{Zr} @ 71.5\text{MeV} < E < 81\text{ MeV}$
Second results: tests in high background condition

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E. V. Pagano et al. NIM A 905 (2018) 47-52
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E. V. Pagano et al. NIM A 905 (2018) 47-52

- Fast
- Slow

- $^{24}\text{Mg}$
- $Z=2$
- $Z=1$
Purposes of the project

Energy of interest: $5 \leq E \leq 100$ AMeV (having particular attention to the Fermi regime)

Nuclear fundamental physics

- Intensity interferometry (HBT effect)
  - n-n, n-p, n-LCP, n-IMF, n-TLF, n-PLF
- Studies related to the nuclear symmetry energy (EOS) and its dependence to the nuclear density
- Neutron stars (nuclear astrophysics)
- Reaction mechanism
- Reaction times
- Clustering
- Validation of nuclear dynamics model (BUU,QMD)
- Measurements of the neutron signal in the n-rich RIBs (SPES, SPIRAL2, FRIB, FAIR)

Some applications

- Radioprotection
- Measurement of neutron flux (single measurement, cross section)
- Validation of MC based code (GEAN4, MCNPX)
- Homeland security
Correlation functions

\[ 1 + R(q) = \frac{C_{\text{Corr}}(q)}{C_{\text{Uncor}}(q)} \]

Intensity interferometry (HBT effect)

Purposes of the project: a few example for the fundamental nuclear physics

Space-time characterization of the emitting source
Intensity interferometry (HBT effect)

\[ 1 + R(q) = C \frac{Y_{\text{Corr}}(q)}{Y_{\text{Uncor}}(q)} \]

ion of the emitting source

**FIG. 3.** Angle-integrated correlation functions for two cuts on the total neutron pair momentum in the compound nucleus frame. The solid and dashed curves are results of theoretical calculations with the indicated emission time scales.
Correlation functions

1 + R(q)

Intensity interferometry (HBT effect)

N. Colonna et al., PRL 75, 23 (1995) 4190-4193

R. Ghetti et al., PRL 87, 10 (2001)

FIG. 2. Experimental ungated np correlation function \( C(q) \), from the \( E/A = 45 \) MeV \( ^{58}\text{Ni} + ^{27}\text{Al} \) reaction [solid dots in panels (a),(b)] compared to panel (a), open circles: \( C_s(q) \), constructed from pairs of type \( E_n > E_p \), and panel (b), open squares: \( C_p(q) \), constructed from pairs of type \( E_n < E_p \). The ratio \( C_s/C_p \) is shown in panel (c).

FIG. 3. Angle-integrated correlation functions for two cuts on the total neutron pair momentum in the compound nucleus frame. The solid and dashed curves are results of theoretical calculations with the indicated emission time scales.
Correlation functions

\[ 1 + R(q) = \frac{Y_{\text{Corr}}(q)}{Y_{\text{Uncorr}}(q)} \]

Intensity interferometry (HBT effect)

Space-time characterization of the emitting source
Correlation functions

\[ R(q) = C_Y C_0(q) + \frac{1}{Y} C_U Y_0(q) \]

Intensity interferometry (HBT effect)

Correlation function

\[ S(\rho) = C_K (\rho / \rho_0)^2 + C_p (\rho / \rho_0)^\gamma \]

\[ \frac{1+R(q)}{R(q)} \]

\( ^{52}\text{Ca}+^{48}\text{Ca} \quad E/A=80\text{MeV} \)

Central collision

Lie-Wen Chen et al., PRL (2003); PRC(2005)
In proton therapy, in particular in the pediatric one (but not only), the “damage” caused from the neutron to the healthy cells is one of the principal causes of the so-called “secondary radio-induced tumors” in particular if there are used degraders or collimators (passive technique)[1].

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Measurement of cross sections \( \frac{d^2\sigma}{d\theta dE} \) have a huge interest for the validations of Monte Carlo code like GEANT4 in particular for neutrons in the Fermi energy regime.
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**Validation of Monte Carlo codes**

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**Neutron Camera**

Possible device for homeland security and health safety to be installed in airports, ports, etc...
New test experiment proposed to next PAC @ LNS: **PLASTICTEST**

The idea of the test is to study the performances of the EJ276G coupled with Si-PD and of the EJ276 coupled with Si-PM about energy resolution, neutron detection efficiency, timing and PSD properties.

We also want to make a preliminary study about the background reduction and the crosstalk problem.

Using the reaction:

\[ ^7\text{Li} + H \rightarrow ^7\text{Be} + n \ @ 45 \text{ and } 35 \text{ MeV (total)} \]

Mean neutron of about 14 and 10 MeV at about 20° (lab frame)

* Hamamatsu PIN photodiode 28X28 mm² (S3584 series)

** i-Spector produce by CAEN
The results carried out so far are with EJ276 coupled by PM are encouraging. It seems possible to build a versatile and modular detector for neutrons and light charged particles with high angular and energy resolution, read by using silicon technology and signal digitalization. The studies of the background and of the cross-talk problems and theirs influence on the experimental results are going on using the GEANT4 software. The studies on the timing properties of the EJ-276 green version and its PSD capability, performed by using silicon technology (PD, or SIMP) are going on.
Conclusions

The results carried out so far are with EJ276 coupled by PM are encouraging. It seems possible to build a versatile and modular detector for neutrons and light charged particles with high angular and energy resolution, read by using silicon technology and signal digitalization. The studies of the background and of the cross-talk problems and their influence on the experimental results are going on using the GEANT4 software. The studies on the timing properties of the EJ-276 green version and its PSD capability, performed by using silicon technology (PD, or SIMP) are going on.

Thank you for the attention
Backup Slides
Just few numbers

Time of flight

\( L = 100 \text{ cm}; \Delta T = 1 \text{ ns} \)

\( \theta = 7.5^\circ \)

\( L_{\text{DSSSD}} = 50 \text{ cm} \)

\( L_{\text{NArCoS}} = 100 \text{ cm} \)

\( \Delta T / T \ (\Delta T = 1 \text{ ns}) \ (100 \text{ cm}) \)

- \( p \) (6 MeV Th)
- \( d \) (8 MeV Th)
- \( t \) (10 MeV Th)
- \( \alpha \) (25 MeV Th)

*the mechanical structure will have the possibility of an angular movimentation*
Just few numbers

Time of flight

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DSSSD 32x32

300 \mu m

\[ L_{\text{DSSSD}} = 50 \text{ cm} \]

\[ L_{\text{NArCos}} = 100 \text{ cm} \]

NArCos \approx 12 \text{ cm}

Solid angle \approx 14 \text{ msr (0.12\%)}
Angular resolution DSSSD = 0.2°
Angular resolution NArCos = 2°

\[ \theta \approx 7.5° \]

\[ L = 100 \text{ cm}; \Delta T = 1 \text{ ns} \]

\[ \Delta T / T (\Delta T = 1\text{ ns}) (100 \text{ cm}) \]

\[ \text{Energy (MeV)} \]

\[ \text{p (6 MeV Th)} \]
\[ \text{d (8 MeV Th)} \]
\[ \text{t (10 MeV Th)} \]
\[ \text{α (25 MeV Th)} \]

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Angular resolution NArCoS $= 2^\circ$

$\langle\text{EFF}\rangle \approx 25\%$

For one cluster

*$\text{the mechanical structure will have the possibility of an angular movimentation}$
Just few numbers

Time of flight

$L = 100\,\text{cm}; \Delta T = 1\,\text{ns}$

DSSSD $32 \times 32$

300 $\mu\text{m}$

$\theta \approx 7.5^\circ$

$L_{\text{DSSSD}} = 50\,\text{cm}$

$L_{\text{NArCoS}} = 100\,\text{cm}$

$\approx 12\,\text{cm}$

Solid angle $= 14\,\text{msr} (0.12\%)$

Angular resolution DSSSD $= 0.2^\circ$

Angular resolution NArCoS $= 2^\circ$

For one cluster $<\text{EFF}> \approx 25\%$

* the mechanical structure will have the possibility of an angular movimentation

\[\Delta T \approx 1\,\text{ns} (100\,\text{cm})\]

\[\Delta E \approx 1\,\text{ns} (100\,\text{cm})\]
Just few numbers

Time of flight

\( L = 100 \text{ cm}; \Delta T = 1 \text{ ns} \)

DSSSD 32x32

300 \( \mu \)m

\( \theta \approx 7.5^\circ \)

\( L_{\text{DSSSD}} = 50 \text{ cm} \)

\( L_{\text{NArCoS}} = 100 \text{ cm} \)

\( \approx 12 \text{ cm} \)

Solid angle = 14 msr (0.12%)
Angular resolution DSSSD = 0.2°
Angular resolution NArCoS = 2°

\(<\text{EFF}>\approx 25\%\)

For one cluster

\( \Delta M / M \ (\Delta T = 1\text{ ns}) \ (100 \text{ cm}) \)

\( \Delta E / E \ (\Delta T = 1\text{ ns}) \ (100 \text{ cm}) \)

*the mechanical structure will have the possibility of an angular movimentation*
Just few numbers

Time of flight
L = 100 cm; ∆T = 1 ns

DSSSD 32x32
300 μm

L_{DSSSD} = 50 cm
L_{NArCoS} = 100 cm

NArCoS
≈ 12 cm

Solid angle = 14 msr (0.12%)
Angular resolution DSSSD = 0.2°
Angular resolution NArCos = 2°

<EFF> ≈ 25%
For one cluster

*the mechanical structure will have the possibility of an angular movimentation
Just few numbers

Time of flight

$L=100\,\text{cm};\,\Delta T=1\,\text{ns}$

$T$

$\theta=7.5^\circ$

$L_{\text{DSSSD}}=50\,\text{cm}$

$L_{\text{NArCoS}}=100\,\text{cm}$

DSSSD 32x32

300 $\mu\text{m}$

$\approx 12\,\text{cm}$

$\text{NArCoS}$

Solid angle $= 14\,\text{msr} (0.12\%)$

Angular resolution DSSSD $= 0.2^\circ$

Angular resolution NArCos $= 2^\circ$

$\langle \text{EFF} \rangle = 25\%$

For one cluster

$\Delta T/T (\Delta T=1\,\text{ns}) (100\,\text{cm})$

$\Delta E/E (\Delta T=1\,\text{ns}) (100\,\text{cm})$

$\Delta M/M (\Delta T=1\,\text{ns}) (100\,\text{cm})$

*the mechanical structure will have the possibility of an angular movementation
External interest for the project
External interest for the project

Dr. Emanuele Vincenzo Pagano
Università degli Studi di Catania
and INFN Laboratori Nazionali del Sud
via Santa Sofia 62
95123 Catania
Italy

Date: 10-July-2017

Research Project: Neutron Array for Correlations Studies (NArCoS)

The aim of the “Neutron Array for Correlations Studies” (NArCoS) research project focuses on the development of a neutron detector prototype for neutron spectroscopy. We believe that it will benefit from the experience about neutrons detection that is available at the ISIS spallation neutron source (UK) and from the availability of neutron beam time required for testing purpose. Moreover, this project can represent a further extension in neutron detection for applications at ISIS and in general for neutron spallation sources.

For these reasons, we are pleased to express with this letter our interest and research involvement.

Yours sincerely,

Dr. Triestino Minniti
Dr. Carlo Cazzaniga
Staff Scientist, STFC
External interest for the project

DECLARATION

To whom it may concern, in charge of Full Professor of Experimental Physics since 2002 at the Department of Mathematical and Computer Science, Physical Sciences and Earth Sciences of the Messina University (Italy), of President of the Interuniversity Consortium for Applied Physics, of previous chairman of the Scientific Committee on Glass Forming Systems at the European Synchrotron Radiation Facility (ESRF, Grenoble), member of several Scientific Committees of synchrotron radiation and neutron scattering at ESRF and at Institute Laue Langevin (ILL, Grenoble), and member of the Italian team for the neutron scattering project VESPA for the European Spallation Source, I strongly support the project led by Dr. Emanuele Pagano and I declare that the portable neutron source hosted at the Department of Mathematical and Computer Science, Physical Sciences and Earth Sciences of the Messina University is available for all the experimental tests requested in the project Dr. E. Pagano will be dealing with.

Prof. Salvatore Magazu

Date: 10-July-2017

Research Project: Neutron Array for Correlations Studies (NArCoS)

The aim of the “Neutron Array for Correlations Studies” (NArCoS) research project focuses on the development of a neutron detector prototype for neutron spectroscopy. We believe that it will benefit from the experience about neutrons detection that is available at the ISIS spallation neutron source (UK) and from the availability of neutron beam time required for testing purpose. Moreover, this project can represent a further extension in neutron detection for applications at ISIS and in general for neutron spallation sources.

For these reasons, we are pleased to express with this letter our interest and research involvement.

Yours sincerely,

Dr. Triestino Minniti
Dr. Carlo Cazzaniga
Staff Scientist, STFC
Esempio di accoppiamento con correlatore per particelle cariche

Accoppiamento FARCOS + NArCoS

FARCOS
DSSSD 32x32
300 μm+1500 μm

NArCoS

CP
T

≈ 12 cm

6 cm

CsI(Tl)

CsI(Tl)
Energy resolution of the 8.7 alpha peak

For $E_\alpha=8.7$ MeV

$$\sigma_{\text{tot}}^2 = \sigma_{\text{int}}^2 + \sigma_{\text{ele}}^2 \quad \rightarrow \quad \sigma_{\text{int}}^2 = \sigma_{\text{tot}}^2 - \sigma_{\text{ele}}^2 \quad \rightarrow \quad \sigma_{\text{int}} = \sqrt{\sigma_{\text{tot}}^2 - \sigma_{\text{ele}}^2}$$

$$\sigma_{\text{ele}} = 450; \quad \sigma_{\text{tot}}^2 = 1000 \quad \rightarrow \quad \frac{\Delta E_{\text{tot}}}{E} \approx 11\%$$

$$\sigma_{\text{int}} = 23 \quad \rightarrow \quad \text{FWHM} = 55$$

$$\Delta E_{\text{bin}} = 13.6 \frac{\text{KeV}}{\text{ch}} \quad \rightarrow \quad \Delta E = 750 \text{KeV} \quad \rightarrow \quad \frac{\Delta E_{\text{int}}}{E} \approx 8.5\%$$
THE AGET ASIC in the ASAD board

- Pulser
- Internal pulser
- Discriminator
- Sampling frequency up to 100 MHz
- Readout/Trigger µTCA crate

- PAC
- Filter
- Ana. Mem. SCA
- 512-sample analog memory. Switched capacitors array

- Dual Gain
- PAC
- 256 + (16 FPN) input channels

- DISC
- HIT Reg.
- Mulx
- CoBo
- Mutant Trigger FPGA

64 analog channels

AGET: Asic for GET – 64 analog channels (+4 FPN) - 512 cells/channel

ASAD: AGET Support for Analog to Digital – 4 AGET

COBO: Collection Board – 4 ASAD - 1024 digital channels

MUTANT: MUltiplicity, Trigger ANd Time (3 trigger levels)

MicroTCA: Micro Telecommunications Computing Architecture

MCH: Carrier Hub with 10 Gb and 1 Gb ethernet link
È un problema poco rilevante in misure in singola mentre non si può sottovalutare per misure in coincidenza e soprattutto a piccoli impulsi relativi!

\[ E_{\text{diff}} = E_i - \frac{1}{2} \mu D_{\text{min}} / \Delta t \]^2 \]

\[ E_i \] è l'energia del neutroni più veloce
\[ D_{\text{min}} \] è la minima distanza tra due rivelatori colpiti
\[ \Delta t \] è la differenza temporale tra i due rivelatori colpiti
\[ E_{\text{diff}} \] rappresenta l'energia persa dal neutrone le primo detector

Se \( E_{\text{diff}} < 0 \) la coincidenza è reale
Se \( E_{\text{diff}} > 0 \) ulteriori analisi statistiche sono necessarie
$\Delta L = 1.5\text{ cm}$

$\Delta E/E$
Sorgente portatile di neutroni (Messina)

reactions:
d+d -> n da 2.5 MeV $10^6$ n/s
d+t -> n da 14 MeV $10^8$ n/s

<table>
<thead>
<tr>
<th>Attributes</th>
<th>MP 320</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-T Maximum Yield, n/s</td>
<td>$1.0E+08$</td>
</tr>
<tr>
<td>D-D Maximum Yield, n/s</td>
<td>$1.0E+06$</td>
</tr>
<tr>
<td>Maximum High Voltage, kV</td>
<td>-90</td>
</tr>
<tr>
<td>Typical Tube Life, Hrs</td>
<td>1,200</td>
</tr>
<tr>
<td>Operating Temperature, °C</td>
<td>50</td>
</tr>
<tr>
<td>Potential of Target</td>
<td>HV</td>
</tr>
<tr>
<td>Continuous Operation</td>
<td>Yes</td>
</tr>
<tr>
<td>Pulsing Range, kHz</td>
<td>0.50 to 20</td>
</tr>
<tr>
<td>Duty Cycle</td>
<td>5-95%</td>
</tr>
<tr>
<td>Minimum Pulse Width, usec</td>
<td>5</td>
</tr>
<tr>
<td>Control</td>
<td>Digital</td>
</tr>
<tr>
<td>Keylock for Neutrons On/Off</td>
<td>Yes</td>
</tr>
<tr>
<td>HV Insulating Material</td>
<td>SF-6 Gas, 99.99% pure or better</td>
</tr>
<tr>
<td>Other Safety Interlocks</td>
<td>Yes</td>
</tr>
<tr>
<td>Input Power, Watts</td>
<td>&lt; 75</td>
</tr>
<tr>
<td>Input Voltage</td>
<td>120/220 VAC</td>
</tr>
<tr>
<td>or 24 VDC</td>
<td></td>
</tr>
<tr>
<td>Accelerator Head Weight, Kg</td>
<td>10</td>
</tr>
<tr>
<td>System Weight, Kg</td>
<td>12</td>
</tr>
<tr>
<td>Accelerator Head length and</td>
<td></td>
</tr>
<tr>
<td>diameter, in.</td>
<td>22&quot; L x 4.75&quot; dia.</td>
</tr>
</tbody>
</table>
Just few numbers

\[ L = 150 \text{ cm}; \ \Delta T = 1 \text{ ns} \]

\[ \theta \approx 5^\circ \]

\[ \text{DSSSD 32x32} \]

\[ 300 \mu\text{m} \]

\[ \text{NArCoS} \]

\[ \approx 12 \text{ cm} \]

\[ \text{Solid angle} = 7 \text{ msr (0.07\%)} \]

\[ \text{Angular resolution DSSSD} = 0.15^\circ \]

\[ \text{Angular resolution NArCos} = 1.25^\circ \]

\[ \text{<EFF> \approx 25\%} \]

\[ \text{For one cluster} \]

\[ \Delta T/T (\Delta T = 1\text{ ns}) (150 \text{ cm}) \]

\[ \text{Energy (MeV)} \]

\[ \text{p (6 MeV Th)} \]

\[ \text{d (8 MeV Th)} \]

\[ \text{t (10 MeV Th)} \]

\[ \alpha (25 \text{ MeV Th}) \]

*the mechanical structure will have the possibility of an angular movement

*FATA2019 Fast Timing Application for Nuclear Physics and Medical Application – Acireale, Italy – 5 September 2019
Just few numbers

**Time of flight**

L = 150 cm; ΔT = 1 ns

- **DSSSD 32x32**
  - 300 μm

- **NArCoS**

  \[ \approx 12 \text{ cm} \]

- Solid angle: \( \approx 7 \text{ msr (0.07\%)} \)
- Angular resolution DSSSD: \( \approx 0.15^\circ \)
- Angular resolution NArCoS: \( \approx 1.25^\circ \)

\[ \langle \text{EFF} \rangle \approx 25\% \]

For one cluster

\[ \text{ΔT/T (ΔT=1ns) (150 cm)} \]

\[ \text{Energy (MeV)} \]

\[ \text{p (6 MeV Th)} \]
\[ \text{d (8 MeV Th)} \]
\[ \text{t (10 MeV Th)} \]
\[ \text{α (25 MeV Th)} \]

*the mechanical structure will have the possibility of an angular movement*
Just few numbers

Time of flight

$\Delta T = 1 \text{ ns}$

$T$

$\theta = 5^\circ$

$DSSSD$ $32 \times 32$

$300 \mu m$

$NArCoS$ $\approx 12 \text{ cm}$

Solid angle $\approx 7 \text{ msr (0.07\%)}$

Angular resolution $DSSSD = 0.15^\circ$

Angular resolution $NArCos = 1.25^\circ$

$<\text{EFF}> \approx 25\%$

For one cluster

*the mechanical structure will have the possibility of an angular movement
Just few numbers

Time of flight

\( L = 150 \text{ cm}; \ \Delta T = 1 \text{ ns} \)

\[
\begin{align*}
\text{DSSSD 32x32} & \quad 300 \text{ µm} \\
\text{NArCoS} & \approx 12 \text{ cm}
\end{align*}
\]

Solid angle \( \approx 7 \text{ msr (0.07\%)} \)

Angular resolution DSSSD \( = 0.15^\circ \)

Angular resolution NArCoS \( = 1.25^\circ \)

\(<\text{EFF}>\approx 25\% \)

For one cluster

\( \frac{\Delta T}{T} (\Delta T = 1\text{ ns}) \) (150 cm)

\( \frac{\Delta E}{E} (\Delta T = 1\text{ ns}) \) (150 cm)

*the mechanical structure will have the possibility of an angular movementation*
Just few numbers

Time of flight

L = 150 cm; ΔT = 1 ns

DSSSD 32x32

300 μm

NArCoS

≈ 12 cm

θ = 5°

Solid angle

≈ 7 msr (0.07%)

Angular resolution DSSSD = 0.15°

Angular resolution NArCoS = 1.25°

<EFF> ≈ 25%

For one cluster

*the mechanical structure will have the possibility of an angular movementation
Just few numbers

Time of flight

$L = 150\text{ cm}; \Delta T = 1\text{ ns}$

$T$

$\theta = 5^\circ$

$L_{\text{DSSSD}} = 75\text{ cm}$

$L_{\text{NArCoS}} = 150\text{ cm}$

$\Delta M/M (\Delta T = 1\text{ ns}) (150\text{ cm})$

$\Delta E/E (\Delta T = 1\text{ ns}) (150\text{ cm})$

$\approx 12\text{ cm}$

Solid angle $\approx 7\text{ msr (0.07\%)}$

Angular resolution DSSSD $= 0.15^\circ$

Angular resolution NArCos $= 1.25^\circ$

$<\text{EFF}> \approx 25\%$

For one cluster

$\Delta E/E (\Delta T = 1\text{ ns}) (150\text{ cm})$

*the mechanical structure will have the possibility of an angular movementation
Just few numbers

Time of flight

$L = 150 \text{ cm;} \ \Delta T = 1 \text{ ns}$

**DSSSD 32x32**

$300 \mu \text{m}$

$T$

$\theta = 5^\circ$

$L_{\text{DSSSD}} = 75 \text{ cm}$

$L_{\text{NArCoS}} = 150 \text{ cm}$

$NArCoS \approx 12 \text{ cm}$

Solid angle $\approx 7 \text{ msr (0.07\%)}$

Angular resolution DSSSD $= 0.15^\circ$

Angular resolution NArCos $= 1.25^\circ$

$\angle \text{EFF} \approx 25\%$

For one cluster

$\Delta T / T (\Delta T = 1 \text{ ns}) (150 \text{ cm})$

$\Delta E / E (\Delta T = 1 \text{ ns}) (150 \text{ cm})$

$\Delta M / M (\Delta T = 1 \text{ ns}) (150 \text{ cm})$

*the mechanical structure will have the possibility of an angular movimentation*
Just few numbers

Time of flight

\[ L = 100 \text{ cm}; \Delta T = 0.5 \text{ ns} \]

\[ T \]

\[ \theta \approx 7.5^\circ \]

\[ L_{\text{DSSSD}} = 50 \text{ cm} \]

\[ L_{\text{NArCoS}} = 100 \text{ cm} \]

DSSSD 32x32

300 μm

NArCoS

\[ \approx 12 \text{ cm} \]

Solid angle = 14 msr (0.12%)
Angular resolution DSSSD = 0.2°
Angular resolution NArCoS = 2°

\[ \Delta T / T \ (\Delta T = 0.5 \text{ ns}) \ (100 \text{ cm}) \]

\[ \begin{align*}
\text{p (6 MeV Th)} & \quad \text{d (8 MeV Th)} & \quad \text{t (10 MeV Th)} & \quad \text{α (25 MeV Th)} \\
0 & \quad 1 & \quad 2 & \quad 3 \\
5 & \quad 4 & \quad 3 & \quad 2 \\
6 & \quad 5 & \quad 4 & \quad 3 \\
0 & \quad 5 & \quad 10 & \quad 15 & \quad 20 & \quad 25 & \quad 30 & \quad 35 & \quad 40 & \quad 45 & \quad 50 & \quad 55 & \quad 60 \\
\end{align*} \]

*the mechanical structure will have the possibility of an angular movement.

\[ \text{For one cluster} \]

<EFF> \approx 25%
**Just few numbers**

- **Time of flight**
  - \( L = 100 \text{ cm}; \Delta T = 0.5 \text{ ns} \)

- **Solid angle**
  - \( \approx 14 \text{ msr} (0.12\%) \)
  - Angular resolution DSSSD = 0.2°
  - Angular resolution NArCos = 2°

- **Energy vs. \( \Delta T/T \)** (\( \Delta T = 0.5 \text{ ns} \) for 100 cm)
  - \( \Delta T/T \) for various energies:
    - p (6 MeV Th)
    - d (8 MeV Th)
    - t (10 MeV Th)
    - α (25 MeV Th)

- **Angular resolution**
  - DSSSD ≈ 0.2°
  - NArCos ≈ 2°

- **Approximate effectiveness**
  - ≈ 25% for one cluster

*The mechanical structure will have the possibility of an angular movement.*
Just few numbers

Time of flight

L = 100 cm; ΔT = 0.5 ns

DSSSD 32x32
300 μm

NArCoS
≈ 12 cm

Solid angle = 14 msr (0.12%)
Angular resolution DSSSD = 0.2°
Angular resolution NArCos = 2°

Solid angle ≈ 14 msr (0.12%)
Angular resolution DSSSD = 0.2°
Angular resolution NArCos = 2°

For one cluster
<EFF> ≈ 25%
Just few numbers

Time of flight

$L=100\,\text{cm};\,\Delta T=0.5\,\text{ns}$

DSSSD $32\times32$

$300\,\mu\text{m}$

$\approx 12\,\text{cm}$

$T$

$\theta=7.5^\circ$

$L_{\text{DSSSD}}=50\,\text{cm}$

$L_{\text{NArCoS}}=100\,\text{cm}$

Solid angle $= 14\,\text{msr (0.12\%)}$

Angular resolution DSSSD $= 0.2^\circ$

Angular resolution NArCos $= 2^\circ$

$\text{\textless EFF} \text{\textgreater} = 25\%$

For one cluster

*the mechanical structure will have the possibility of an angular movimentation*
Just few numbers

Time of flight

$L = 100 \, \text{cm}; \Delta T = 0.5 \, \text{ns}$

DSSSD 32x32

300 μm

$NArCoS \approx 12 \, \text{cm}$

$\theta \approx 7.5^\circ$

$L_{DSSSD} = 50 \, \text{cm}$

$L_{NArCoS} = 100 \, \text{cm}$

Solid angle = 14 msr (0.12%)
Angular resolution DSSSD = 0.2°
Angular resolution NArCos = 2°

$\langle \text{EFF} \rangle \approx 25\%$

For one cluster

$\Delta T / T (\Delta T = 0.5 \, \text{ns}) (100 \, \text{cm})$

$\Delta E / E (\Delta T = 0.5 \, \text{ns}) (100 \, \text{cm})$

*$\text{the mechanical structure will have the possibility of an angular movimentation}$
Just few numbers

\[ L = 100 \text{ cm}; \Delta T = 0.5 \text{ ns} \]

\[ \theta \approx 7.5^\circ \]

\[ L_{\text{DSSSD}} = 50 \text{ cm} \]

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\[ \text{Solid angle} \approx 14 \text{ msr (0.12\%)} \]

Angular resolution DSSSD = 0.2°

Angular resolution NArCos = 2°

\[ \text{<EFF>} \approx 25\% \]

*the mechanical structure will have the possibility of an angular movementation

\[ \text{Time of flight} \]

\[ \Delta T/T \ (\Delta T = 0.5 \text{ ns}) \ (100 \text{ cm}) \]

\[ \Delta E/E \ (\Delta T = 0.5 \text{ ns}) \ (100 \text{ cm}) \]

*Efficiency *the mechanical structure will have the possibility of an angular movementation
Just few numbers

Time of flight

$L = 100 \text{ cm}; \Delta T = 0.5 \text{ ns}$

DSSSD 32x32

300 μm

$\Lambda_{\text{DS}} = 50 \text{ cm}$

$\Lambda_{\text{NAR}} = 100 \text{ cm}$

Solid angle $= 14 \text{ msr (0.12\%)}$

Angular resolution DSSSD $= 0.2^\circ$

Angular resolution NArCos $= 2^\circ$

$\Theta \approx 7.5^\circ$

Solid angle $\approx 14 \text{ msr (0.12\%)}$

Angular resolution DSSSD $\approx 0.2^\circ$

Angular resolution NArCos $\approx 2^\circ$

For one cluster $<\text{EFF}> \approx 25\%$

$\Delta T / T$ ($\Delta T = 0.5 \text{ ns}$) (100 cm)

$p$ (6 Mev Th), $d$ (8 MeV Th), $t$ (10 MeV Th), $\alpha$ (25 MeV Th)

$\Delta E / E$ ($\Delta T = 0.5 \text{ ns}$) (100 cm) ($\Delta L = 1.5 \text{ cm}$)

$1^\circ$ Step, $2^\circ$ Step, $3^\circ$ Step, $4^\circ$ Step

*the mechanical structure will have the possibility of an angular movementation