The NArCos project
(Neutron ARray for Correlation Studies)

E.V. Pagano\textsuperscript{1} for NEWCHIM Collaboration

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Project’s motivations

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

Now, more than never, with the efforts of the international community to construct the new facility for the RIBs, we have more and more demanding for the simultaneous detection of charged particles and neutrons with high energy and angular resolution, in fact, in particular for the n-rich beams, neutrons assume a fundamental role, in the deep understanding of the property of the involved mechanism (both for dynamics and spectroscopy).

The neutron contribution reconstruction obtained by using reasonable assumptions and theoretical models validated for stable nuclei will be actually more and more questionable with RIBs.
IDEA

To realize a prototype of detector able to detect at the same time charged particles and neutrons with high energy and angular resolution

- **Candidate**: The plastic scintillator EJ276G (ex EJ299-33) (3x3x3cm³)
- **1 cluster**: 4 consecutively cubes → 3x3x12 cm³
- **Reading the 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** ($\Delta t \leq 1.5$ ns with $L_{ToF} \approx 1 \div 1.5$ m)
  
  ToF measured using the RF of the CS or with an ancillary MCP (low intensity exotic beams)

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![Diagram](image-url)
Just few numbers...

Time of Flight
L=100 cm; ΔT=1.5 ns

DSSSD 32x32
300 μm

NArCoS
≈ 12 cm

L_{DSSSD}=50 cm

θ≈7.5°

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

<EFF>≈12%
For a cluster

The mechanical structure will have the possibility of an angular movement.
EJ-276G
(ex EJ-299-33)

EJ-276 & EJ-276G EMISSION SPECTRUM

Spectral response

Spectral response (without window)

EJ-276
EJ-276G

AMPLITUDE

WAVELENGTH (nm)

PHOTO SENSITIVITY (AW)

WAVELENGTH (nm)

2.8 cm
2.8 cm

S3204/S3584-08
S3204/S3584-09

Typ. Ta=25 °C

Typ. Ta=25 °C

Catania
23 May 2018

E. V. Pagano
LNS-INFN
Some pictures: preparation

- Dimensions: 3x3x3 cm³
- Average efficiency (from MCNPX) ≈ 3%
- Read by the PMtube: EMI-9544QA
- High Voltage: 1500-1700 V
Some pictures: First tests using sources (controlled background condition)

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

PM -EMI 9954QA
Like in ARGOS detector

G. Lanzanó, et al NIM A 312, 3, (1992), 515-520
Some new results: the digitalized signal

The signal was stored and digitalized by using the GET electronic (General Electronic for TPC)
Sampling frequency 100 MHz (12 bit)

The output photomultiplier signal was filtered with the AGET front-end analog filter and shaper (Sallen-Key filter) with a peaking time of 70 ns.

Simul. by pascal.baron@cea.fr;
Some new results: some spectra

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

Detection threshold ≈ 1 MeV
Discrimination threshold ≈ 2.5 MeV

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

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

C. C. Lawrence et al., NIM A759 (2014) 16
Some new results: some spectra

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

Plastic energy intrinsic resolution for Alpha particles: $(E_\alpha)$ da 8.7 MeV $\approx 8.5\%$
Some new results: some spectra
Latest results: test in high background condition
Test performed during the Barier experiment $^{24}\text{Mg}+^{90,92}\text{Zr} @ 71.5\text{MeV} < E < 81 \text{ MeV} (@ \text{LNS})

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Latest results: High test in high background condition

Digitalized by GET electronic

**Total Component**

- **Fast**
- **Slow**

- Time (ns)
  - 0 100 200 300 400 500 600
- Pulse amplitude
  - 0 200 400 600 800 1000 1200 1400

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Latest results: High test in high background condition

E. V. Pagano et al. NIM A accepted
Latest results: High test in high background condition
Latest results: High test in high background condition

Digitalized by GET ek

- $^{24}\text{Mg}$
- $Z=2$
- $Z=1$

FOM($\gamma,p$) = 1.31
FOM($p,\alpha$) = 1.52

Total Comp. Slice: 3.7 - 4.2 MeVee

E. V. Pagano et al. NIM A accepted
Purposes of the project

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

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

Intensity interferometry (HBT effect)

Correlation functions

\[ \mathcal{S}(q) = C_K \left( \frac{q}{q_0} \right)^2 + C_P \left( \frac{q}{q_0} \right) \]

\[ 52\text{Ca} + 48\text{Ca} \quad E/A = 80\text{MeV} \]

Central collision

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


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

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Dr. Triestino Minniti
Director
Dr. Carlo Cazzaniga
Staff Scientist, STFC
CONCLUSIONS

In this talk the necessity to integrate neutrons detection and charged particles in the same detection cell has been discussed in view of reaction studies at Fermi energy with both stable and exotic beams.

An example of single detection cell, such as an EJ276 (ex-Ej-299-33) plastic scintillator, has been considered in some details. Experimental results, obtained by PM read out, have discussed.

In order to allow easier assembling of a large number of detection cells (~100) in cluster configuration, read-out by Si-PM or Si-PD have been envisaged for future steps of experimental investigation.

NArCoS is thought to be a flexible and portable device able to be coupled with complex charge particle detection systems (CHIMERA, FARCOS, INDRA, FAZIA, ….) for particle-particle correlations including neutrons.

Thank you for the attention
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