Aftermath of the H2020-ARIEL "HISPANOS Hands-on school on the production, detection and use of neutron beams"

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ARIEL 2nd Progress and Scientific Meeting

National Physics Laboratory (NPL)

15/3/2023

Selection of participants

- **Applications**:

  Number: 59 from 24 countries

  Academic level:
  - PhD students: 60%
  - McS students: 37%
  - Postdocs: 3%

  Gender:
  - Male: 54%
  - Female: 46%

- **International Advisory Committee:**

  Arnd Junghans (HZDR)
  Arjan Plompen (JRC)
  Gabriel Pavel (ENEN)
  Enrique González (CIEMAT)
  Roberto Capote (IAEA)

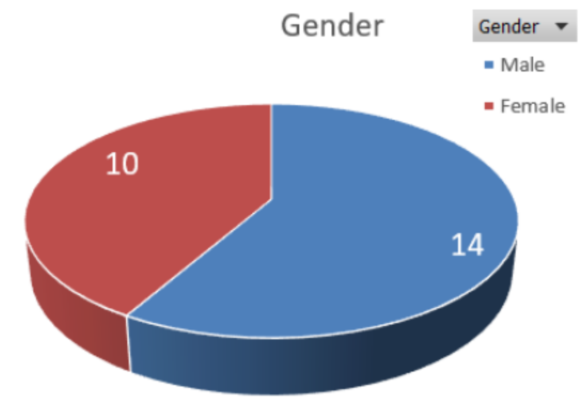
- **Selection process:**

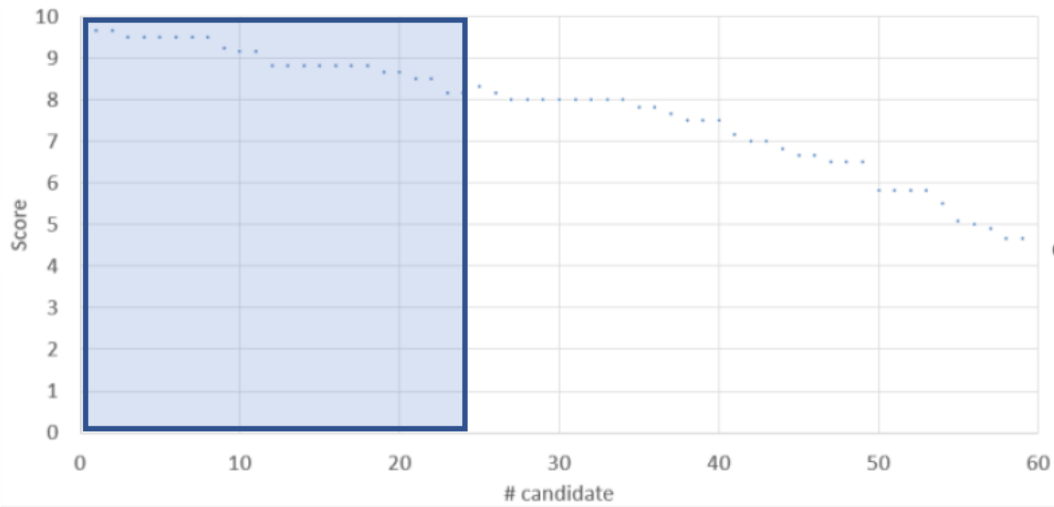
Academic level	=> MSc students: 1 pt	PhD & Postdocs: 3 pt
Origin	=> EU: 2 pt	non-EU: 0 pt
Affinity	=> up to 5 pt	

Selected participants

Selected candidates

Country	# selected candidates
Germany	5
France	4
Italy	3
Greece	3
Spain	3
Czechia	2
Belgium	2
Switzerland	1
Finland	1
TOTAL	**24**





The school

The school, organized by the Universidad de Sevilla in the framework of the H2020 ARIEL project (www.ariel-h2020.eu), aims at covering the experimental aspects related to the production, detection and use of neutron beams. To this purpose, the core of the school is a series of experiments that will be carried out during one week (September, 26th to 30th) at the HISPANOS facility (www.cna.us.es/HISPANOS) at the Centro Nacional de Aceleradores (CNA) in Seville, Spain. The experiments will be complemented with lectures and seminars that will be given online during two days (September, 21st and 22nd) in the week prior to the on-site experiments.

Introductory talks (online, 1 week before)

Lectures:

- Interaction of neutrons with matter (J.L. Taín)
- Principles and examples of neutron production (C. Guerrero)
- Principles and examples of neutron detection (D. Cano-Ott)

Seminars:

- The role of neutrons and neutron beam experiments on:
  - Nuclear technology (F. Álvarez & C. Guerrero)
  - Astrophysics (C. Domingo Pardo)
  - Medicine (I. Porras)

Experiments

- **Fast neutrons:**

  Time-of-flight with a fast pulsed neutron beam and detectors providing pulse shape discrimination.

- **Epithermal neutrons:**

  Neutron capture MACS measurements by activation using an epithermal neutron beam.

- **Thermal (and fast) neutrons:**

  Thermal neutron radiography with thermal neutrons via full moderation of an initially fast neutron beam.

- **Fission neutrons:**

  Study of the neutron distribution from ^{252}Cf fission with the *miniBELEN* detector

Plan for the rest of the week

- 4 different experiements, in 4 groups of 6 participants

Group 1		Group 2		Group 3		Group 4	
Andreea	Oprea	Antonia	Verdera Garau	Irene	Álvarez Castro	María Elena	López Melero
Sonia	Panizo	Daniela	Chiriac	Enya	MOBIO	Jelena	Bardak
Elisso	Stamati	Elisa Maria	Gandolfo	Lama	Al Ayoubi	Stephanie	Cancelli
Tim	Jäger	Jose Antonio	Pavon Rodriguez	Bernat	Ballester Vázquez	Stefan	Scheuren
Jiří	Čulen	Jonas	Kohl	Sotirios	Chasapoglou	Georgios	Gkatis
Baptiste	Fraisse	Nikolaos	Kyritsis	Aurélien	Chevalier	Daniil	Koliadko

	Monday	Tuesday				Wednesday				Thursday				Friday			
		Group 1	Group 2	Group 3	Group 4	Group 1	Group 2	Group 3	Group 4	Group 1	Group 2	Group 3	Group 4	Group 1	Group 2	Group 3	Group 4
8:30 - 12:30	Welcome & visit CNA (starts @9:30)	n-imaging	miniBELEN	MACS		MACS		n-imaging	miniBELEN		n-imaging	miniBELEN	fast neutrons	miniBELEN	fast neutrons		n-imaging
12:30 - 14:00					MACS		MACS			fast neutrons						fast neutrons	
14:00 - 15:00																	
15:00 - 18:30	n-imaging (I)																

- **n-imaging**: seminar room + Tandem (two sessions) (**M.A. "Llanlle" Millán**)
- **miniBELEN**: Sala de Juntas (1st floor) (**Ariel Tarifeño**)
- **Fast neutrons**: Tandem (**Begoña Fernández**)
- **Epithermal neutrons and MACS**: Tandem (**Carlos Guerrero & Pablo Pérez**)

Shared folder: https://nexus6.us.es/owncloud/index.php/s/OTOJdkvWuTgJH80

Fast neutrons: ToF and PSD

[H2020-ARIEL] "HISPANOS Hands-On school on the production, detection and use of neutron beams"

Fast neutron production and detection with a deuteron beam

Teachers: Begoña Fernández and Carlos Guerrero

Background: Fast neutrons have energies from hundreds of keV up to 20 MeV. Neutrons released by highly excited nuclei in the so-called evaporation process have this energy, which is also the case of neutrons emitted in nuclear reactions in general and, in particular, in both fission (few MeV) and fusion (2.5 or 14 MeV) reactions. These energetic neutrons are therefore present not only in fission and fusion reactors, but also in the vicinity of any high energy accelerator facility (for instance radio- and particle-therapy accelerators) and in in the high altitudes of the atmosphere, generated by cosmic-rays.

The energy of these neutrons is above many of the thresholds that prevent reactions other than the scattering and capture, wish is generally the case for slow and epithermal neutrons. Therefore fast neutrons often induce fission, inelastic scattering, neutron multiplication (n,xn) reactions, etc. They have also sufficient energy to produce energetic nuclear recoils, which can both affect materials and serve as signature of a neutron interaction in detectors.

Contents:

- Production of fast neutrons from nuclear reactions using an accelerator
- Detection of fast neutrons with and without Pulse Shape Discrimination capabilities
- Principles of the time-of-flight technique
- Principles of the shadow-cone technique
- Characterization of a fast neutron spectrum

Experimental set-up:

- CNA 3 MV Tandem accelerator equipped with a chopper and buncher
- Several neutron production targets
- Fast PKUP connected to oscilloscope for tunning of the buncher
- Current integrator
- Neutron detectors: 3xEJ301 (2"x2")
- CAEN digitizer V1751

Step-by-step:

@ Tandem Experimental Hall:
- Introduction to fast neutron organic scintillator detectors
- Introduction to the DAQ
- Energy calibration of the scintillators with Cs-137 and Co-60 g-ray sources
- Calibration of the PSD "cut" using the Cf-252 neutron source
- Revision of the beam line elements and diagnostics
- Placement of the 3 detectors: EJ301#1 (150cm, 0º), EJ301#2 (150cm, 45º), EJ301#3 (50cm, -45º)

@ Tandem Control Room:
- Introduction to the pulsing system operation and diagnostics
- Tunning of the pulsing system at 1.5 MeV (1st chopper, then buncher)

t pick to (pick pick up)	FWHM g-flas

- Data taking for d-D at 1.5 MeV

	Flight path	Angle	$t_{g\text{-flash}}$	$t_{neutrones}$	TOF (ns)	E (MeV)	Comp. Neusdesc	FWHM (neutrons)
Det 1								
Det 2								
Det 3								

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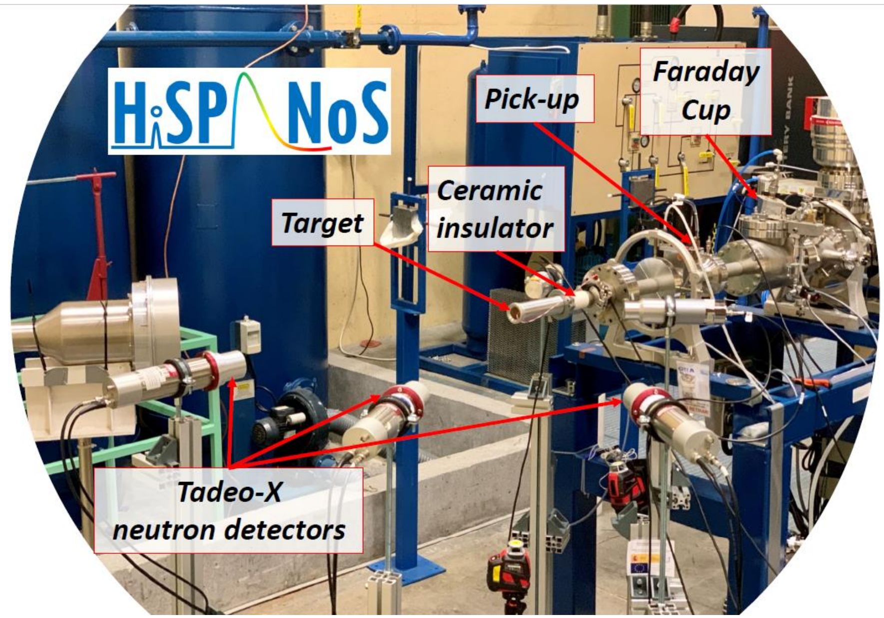
- Data taking for d-Be at 1.5 MeV

	Flight path	Angle	$t_{g\text{-flash}}$	$t_{neutrones}$	TOF (ns)	E (MeV)	E levels
Det 1							

If time allows:
- Tunning of the pulsing system at 5.0 MeV (1st chopper, then buncher)
- Data taking for d-Be at 5 MeV

@ Group analysis table
- Study the PSD spectra and select condition for neutrons and gammas
- Study ToF spectrum with without PSD conditions
- Extract neutron energy distribution
  - Illustrate and discuss the effect of distance and angle
  - Determine energy resolution for monoenergetic neutrons and compare to expectation
  - Compare distribution and structures with the theoretical distribution
  - Study the structures observed in the d-Be spectrum and compare with expectation



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Epithermal neutrons: MACS measurements

[H2020-ARIEL] "HISPANOS Hands-On school on the production, detection and use of neutron beams"

CNA HiSPANoS

Epithermal neutron production and activation for MACS measurements

Teachers: Carlos Guerrero y Pablo Pérez Maroto

Background: Epithermal neutrons cover the energy range between slow (meV-eV) and fast (MeV) neutrons, with and energy in the keV range. Neutrons with this energy are produced when fast neutrons are moderated, hence their role in neutronics calculations of nuclear reactors, or directly via specific reactions under quite specific conditions. For instance, in the core of stars epithermal neutrons with energy distributions in the 1 to 300 keV range are produced via $^{13}C(\alpha,n)$ or $^{22}Ne(\alpha,n)$ reactions, being these neutrons responsible of the nucleosynthesis of elements via neutron capture reactions in the so-called s-process.

In the laboratory, epithermal neutrons can be produced for instance by the $^{7}Li(p,n)^{7}Be$ reaction, which features a threshold at 1888 keV. Following the ideas of W. Ratynski and F. Käppeler (1988), setting the proton beam energy to 1912 keV one can produce a neutron energy mimicking a 25 keV Maxwellian distribution very similar to that produced in the star, and can then study the neutron capture reactions involved in the s-process by, for instance, the using activation technique.

Contents:

- Production of epithermal neutrons via the $^{7}Li(p,n)$ reaction
- Principles of the time-of-flight technique and characterization of an epithermal distribution
- Principles of the neutron activation technique
- Determination of a Maxwellian Averaged Cross Section (MACS) at 25 keV

Experimental set-up:

- CNA 3 MV Tandem accelerator equipped with a chopper and buncher
- LiF targets for neutron production
- Fast PKUP connected to oscilloscope for tunning of the buncher
- Current integrator
- Li-glass neutron detectors
- LaBr3 gamma-ray detectors
- Neutron dosimeter
- CAEN digitizer V1751

Step-by-step:

@ Tandem Experimental Hall:

- Introduction to epithermal neutron production
- Introduction to epithermal neutron detection with Li-glass detectors
- Introduction to the DAQ
- Set-up "used" LiF target
- Set-up current measurement
- Set-up neutron dosimeter (50 cm, forward direction)

@ Tandem Control Room:

- Look for the 1880 keV threshold and estimate the 1912 keV energy point
- Finding of the reaction threshold with continuous beam and the neutron dosimeter
- Introduction to the pulsing system operation and diagnostics
- Tunning of the pulsing system at 1912 keV (1st chopper, then buncher)
- Data taking for time-of-flight experiment
- Comparison of the measured and expected end point (R&K, 1988)
- Measure the activity of a fresh LiF target and install it
- Measure the activity of a Au target and install it
- Activation during 1 h at 1 uA with continuous beam

@ Group analysis table

- Determination of the 7Be activity from its 478 keV line
- Extract neutrons produced from Be and compare to the expected value
- Determination of the 198Au activity from its 412 keV line
- Calculate the s1, s2 s3 appearing in (R&K, 1988)
- Extract the 197Au MACS
- Compare to (R&K, 1988) and KADONIS

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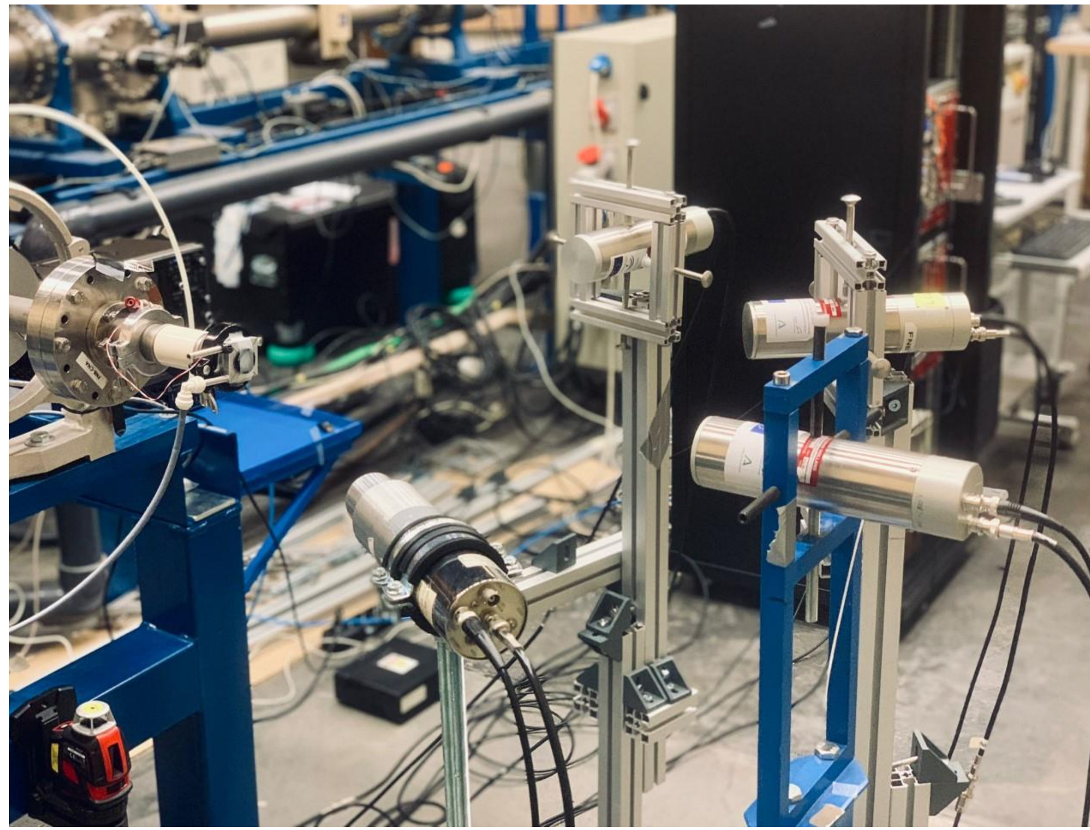

Thermal neutrons: n-imaging (& x-ray)

Fast/Thermal neutron imaging

Teachers: María de los Ángeles Millán-Callado

Background: Radiography is a non-destructive imaging technique that uses the attenuation of penetrating radiation passing through a sample to study its internal structure. Although the term usually refers to x-rays, different kinds of radiation can be used as a probe. Each type of radiation features different mechanisms of interaction with matter, revealing different structures and properties of an object. Therefore, the combined information from different types of radiographies of a given object provides a more complete knowledge about said sample.

In the case of photons, if the atomic number of the material increases, the number of electrons in the electronic shell increases as well and consequently, the probability of interaction. Then photons are barely attenuated by light materials such hydrogen compounds, and strongly shielding by heavy materials as metals. The case of neutrons is different. The probability of neutron interactions depends fundamentally of the nuclear structure so, the attenuation of neutrons is not related with the atomic number. The result is that neutron can be strongly attenuated by light materials such hydrogen or boron and barely by metals as lead. Also, we can obtain high contrast in elements which attenuation coefficient for photons is similar. For this reason, neutron radiography is an excellent complement to conventional X-ray and has a great interest in industry, avionics, cultural heritage or homeland security, among others.

Contents:

- Principles of radiation attenuation.
- Principles of imaging techniques: Resolution, exposure time, background subtraction and noise.
- Neutron inspection with thermal neutron.
- Neutron inspection with fast neutrons.
- Neutron radiography comparison with conventional x-rays.
- Image analysis and post-processing.

Experimental set-up:

- CNA 3 MV Tandem accelerator & 60 kV Mo X-ray tube.
- 0.5 mm thick Be target.
- Pb shielding and PE moderator.
- Air-cooling system.
- Current integrator.
- NeutronOptics FS60 250 x 220 mm Imaging Camera
- Imaging converters:
  - OG16 CAWO 250x200 mm x-ray scintillator with C-fibre window
  - 400 micron 250x200 mm ^{6}LiF / ZnS:Cu thermal neutron scintillator
  - PP/ZnS:Cu 125x100mm PSI/RC-Tritec hot neutron scintillator
- Artemis Capture software & ImageJ.

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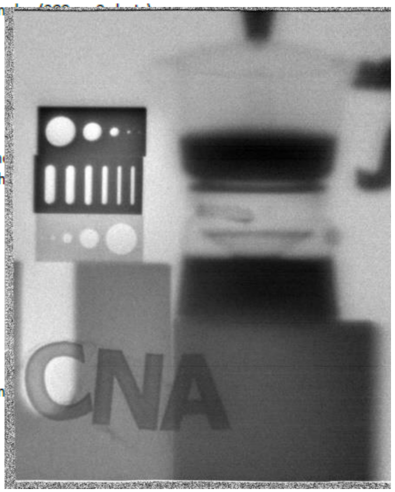
Step-by-step:

Neutron Imaging (I) @Seminar Room / Tandem Experimental Hall

- Brief introduction to imaging at CNA.
- Visit to the line. Description of the setup.
- Thermal Neutron Imaging
  - Bias acquisition (1 ms x 30 shots)
  - Collection of industrial/cultural heritage mock sam
  - Beam-on Background (300 s x 2 shots)
  - Unknown sample (300 s x 2 shots)
- Change of scintillator / Coffee break
- Fast Neutron Imaging
  - Mock industrial sample: Waste barrel (900 s x 2 sh
  - Mock cultural heritage sample: Vessel (900 s x 2 sh

Neutron Imaging (II) @Seminar Room

- Description of the X-Ray setup.
- X-Ray imaging
  - Bias (1 ms x 30 shots)
  - Determination of the exposure time.
  - Beam On background
  - Sample for LSF resolution
  - Collection of industrial/cultural heritage mock sam
  - Thermal unknown sample
  - Mock cultural heritage sample
- Coffee break



Fission neutrons: moderation + absorption

[H2020-ARIEL] "HISPANOS Hands-On school on the production, detection and use of neutron beams"

Study of the fission neutron with moderated 3He detectors

Teachers: Ariel Tarifeño Saldivia

Background: Spontaneous fission is a form of radioactive decay occurring in heavy nuclei. The fragments formed after the fission are typically very rich in neutrons. The neutron excess in the fragments is compensated through the emission of few neutrons immediately after the fission process, within a decay time of the order of 10^{-13} s or less (prompt neutrons). The isotope 252Cf is an unstable nucleus, decaying by alpha emission (96.9%) and spontaneous fission (3.1%). ^{252}Cf is a widely used fast neutron source, producing neutrons with a continuous Maxwellian distribution, with average neutron energy of 2.13 MeV, at a rate of 3.7573 neutrons per fission event.

Neutron coincidence counting or neutron multiplicity counting is a non-destructive technique used in safeguards and nuclear waste management to quantify the activity or mass of spontaneous fission or fissile nuclear materials in a container. The goal of this experience is to get a basic knowledge on neutron detection and neutron coincidence counting using proportional counters. A set of moderated 3He-filled proportional counters and digital electronics will be used for the study of fission neutrons, from a 252Cf source, by means of neutron coincidence counting.

Contents:

- Fast neutrons from 252Cf and neutron moderation
- Neutron detection with proportional counters
- Response of 3He counters to fast, epithermal and thermal neutrons. Response to gamma radiation.
- Principles of neutron coincidence counting
- Monte Carlo simulations of neutron detectors
- Characterization of fission neutrons in 252Cf

Experimental set-up:

- Neutron source (252Cf) and gamma sources
- 3He-filled neutron counters (8 and 10 atm) including electronics
- Modular high density polyethylene moderator
- Struck SIS3316 digitizer with acquisition software GASIFIC7
- An oscilloscope

Step-by-step:

→ Response of neutron detectors
- Setup of neutron counters & electronics
- Test with neutron and gamma sources
- Construction of pulse amplitude spectrum
- Configuration of data acquisition system

→ Experiments on neutron moderation
- Setup of neutron detectors and moderator
- Data taking at different positions in the moderator
- Measurement of the epithermal flux contribution

→ Neutron coincidence counting
- Processing and data analysis
- Determination of rates fort singles and doubles
- Determination of the source activity

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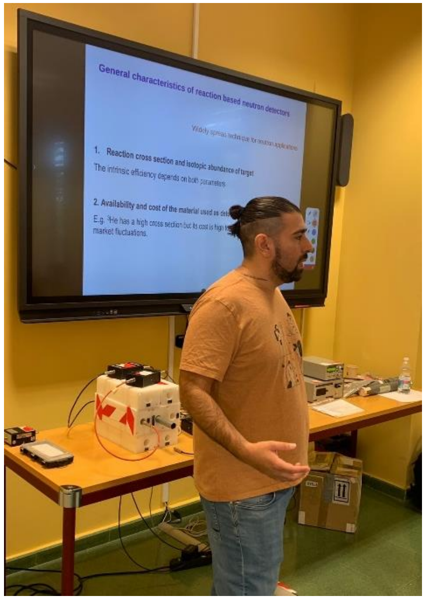
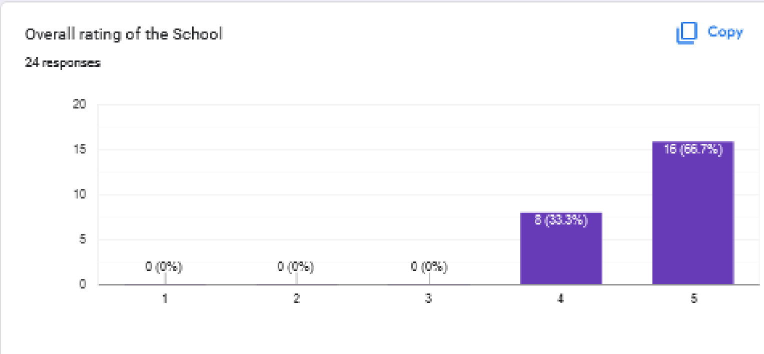
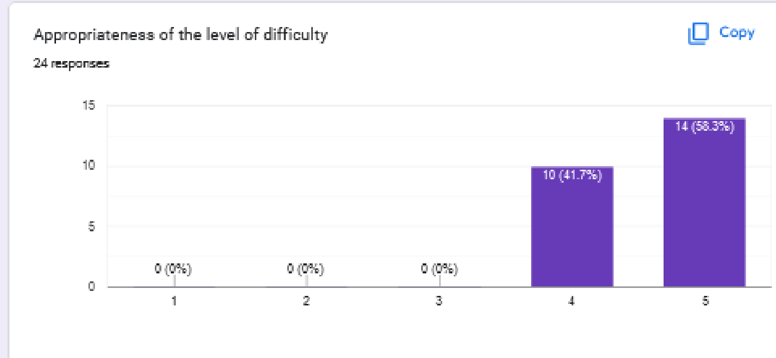
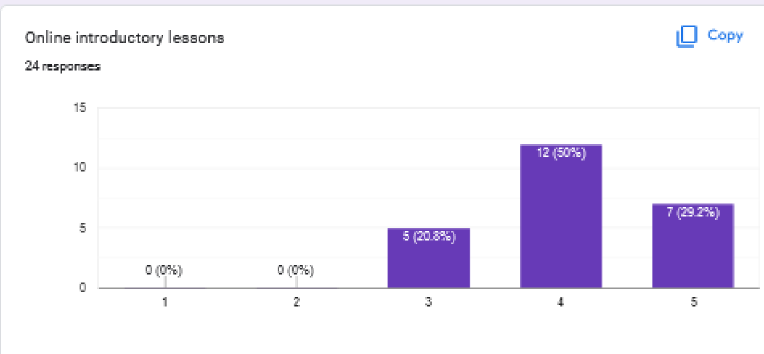
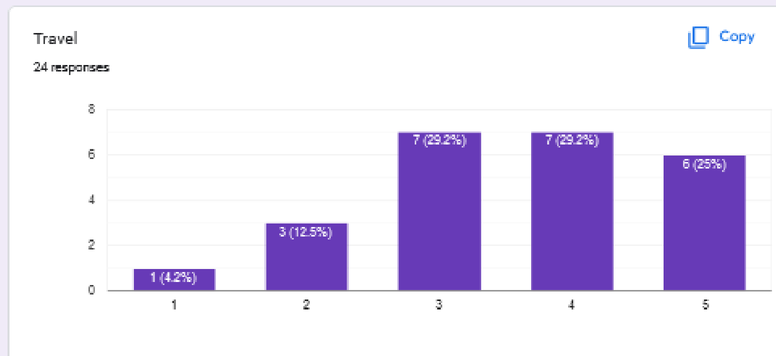


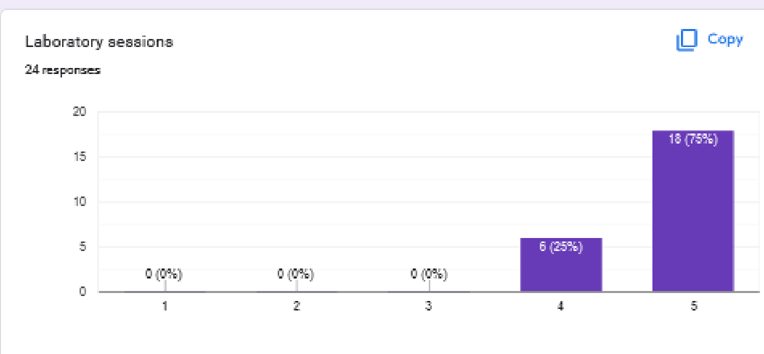
Feedback survey (I)

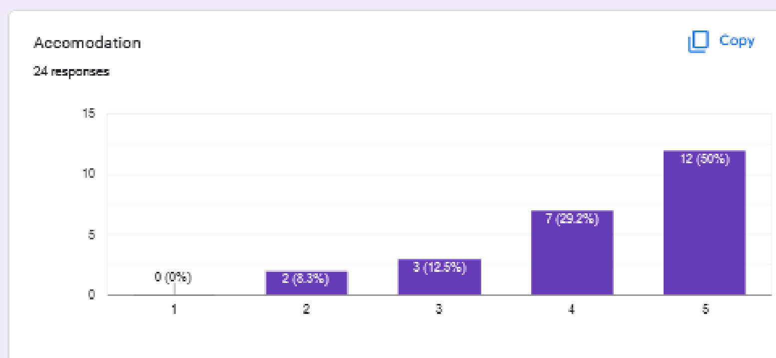




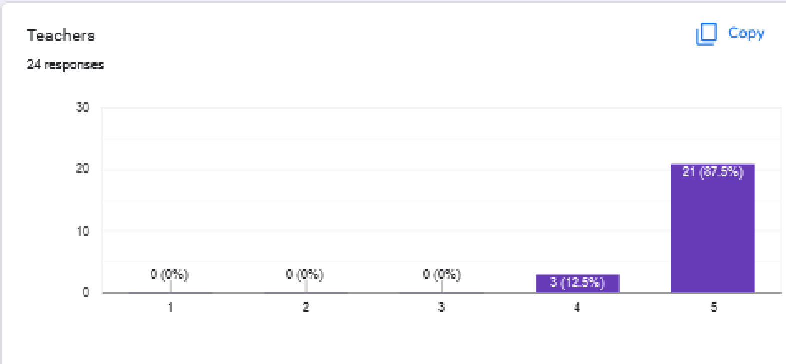


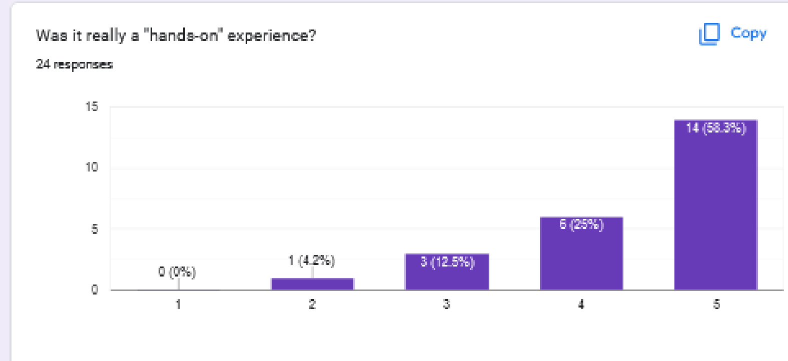


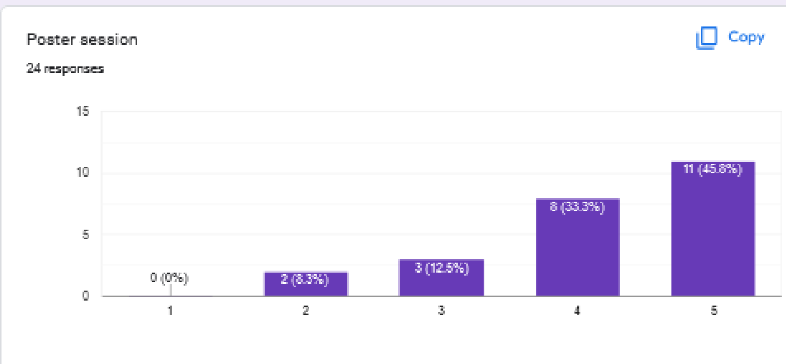


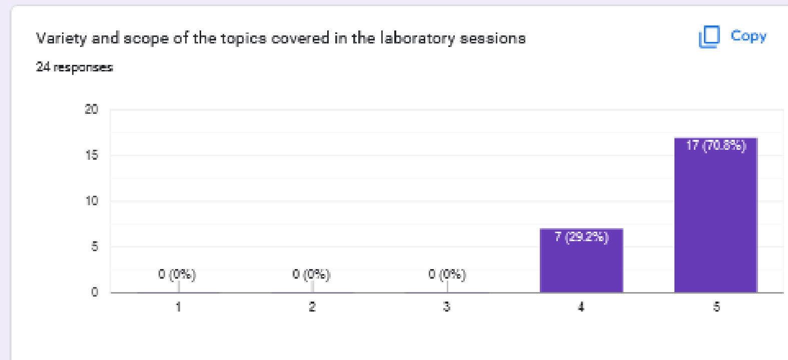


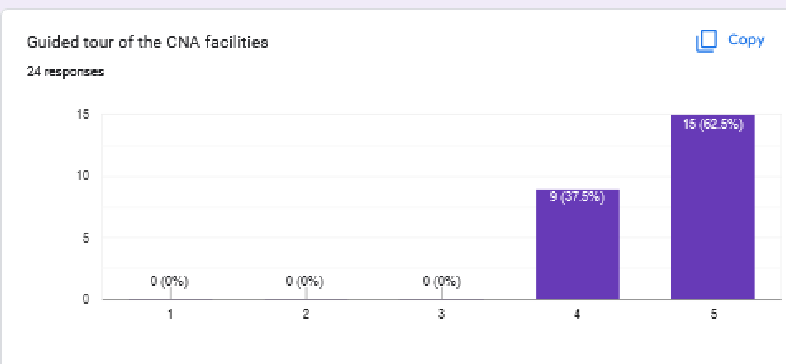
Feedback survey (II)



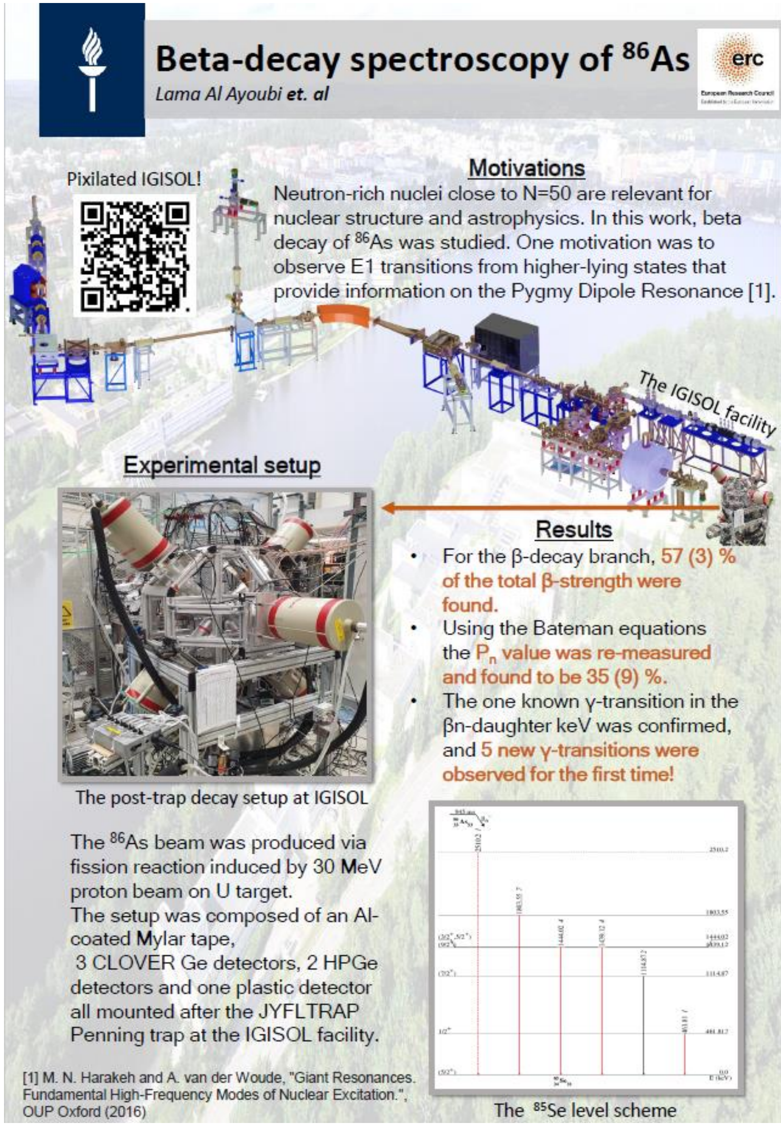








Best poster award & some more pictures



Beta-decay spectroscopy of ^{86}As

Lama Al Ayoubi ***et. al***

Pixilated IGISOL!

Motivations

Neutron-rich nuclei close to N=50 are relevant for nuclear structure and astrophysics. In this work, beta decay of ^{86}As was studied. One motivation was to observe E1 transitions from higher-lying states that provide information on the Pygmy Dipole Resonance [1].

The IGISOL facility

Experimental setup

The post-trap decay setup at IGISOL

The ^{86}As beam was produced via fission reaction induced by 30 MeV proton beam on U target.
The setup was composed of an Al-coated Mylar tape,
3 CLOVER Ge detectors, 2 HPGe detectors and one plastic detector all mounted after the JYFLTRAP Penning trap at the IGISOL facility.

Results

- For the β-decay branch, 57 (3) % of the total β-strength were found.
- Using the Bateman equations the P_n value was re-measured and found to be 35 (9) %.
- The one known γ-transition in the βn-daughter keV was confirmed, and 5 new γ-transitions were observed for the first time!

The ^{85}Se level scheme

[1] M. N. Harakeh and A. van der Woude, "Giant Resonances. Fundamental High-Frequency Modes of Nuclear Excitation.", OUP Oxford (2016)