science & technology
Department: Science and Technology
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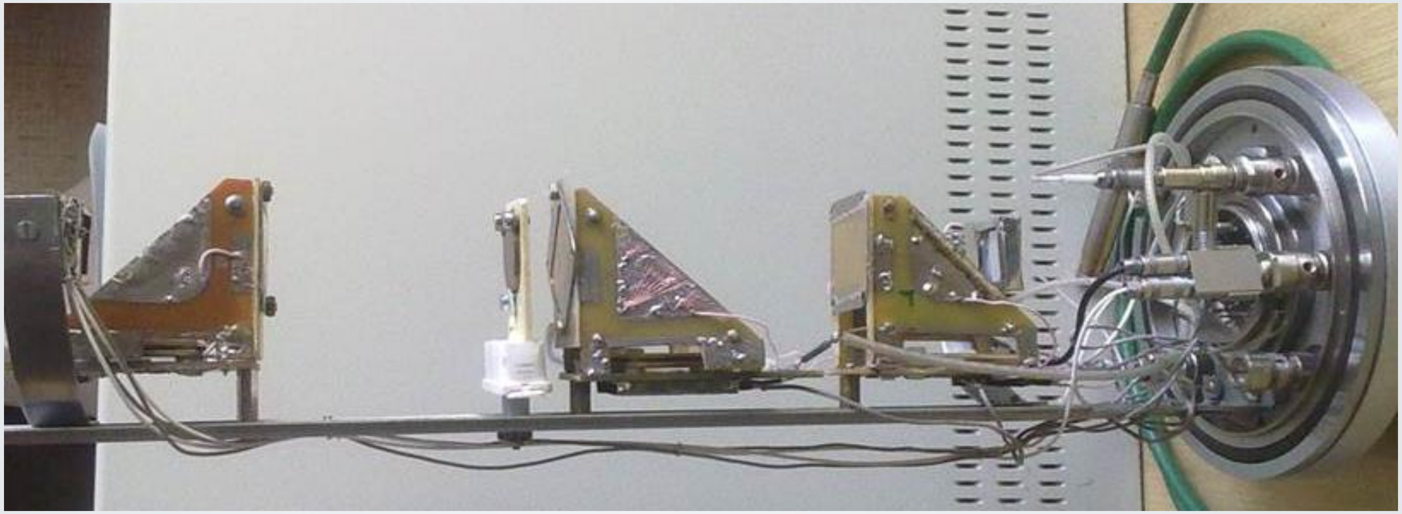
MEPhI

INTERGRAPHICS

Virtual Laboratory of Nuclear Fission

Virtual Laboratory of Nuclear Fission

The goal of the project is to include current scientific data into the educational process, to conduct virtual and online laboratory research based on using modern scientific equipment and data obtained from the existing physical facilities.



Project Team

Members, involved in the project:

1. Stellenbosch University, South Africa
2. iThemba LABS, South Africa
3. University of Western Cape, South Africa
4. University of South Africa, South Africa
5. University of Venda, South Africa
6. University of the Witwatersrand, South Africa
7. Joint Institute for Nuclear Research (JINR), Russia
8. National Nuclear Research University MEPhI, Russia
9. InterGraphics LLC, Russia

Project Team

Project Leaders:

Noel Mkaza, Shaun Wyngaardt, Mantile Leslie Lekala,
Vusi Malaza, Dmitry Kamanin, Stanislav Pakuliak,
Yuri Panebrattsev, Victoria Belaga, Kseniya Klygina, Yuri Pyatkov.

Leading methodists: Natalia Vorontsova, Marina Osmachko, Vusi Malaza.

Leading experimentalist: Alexander Strekalovsky.

Leading programmers:

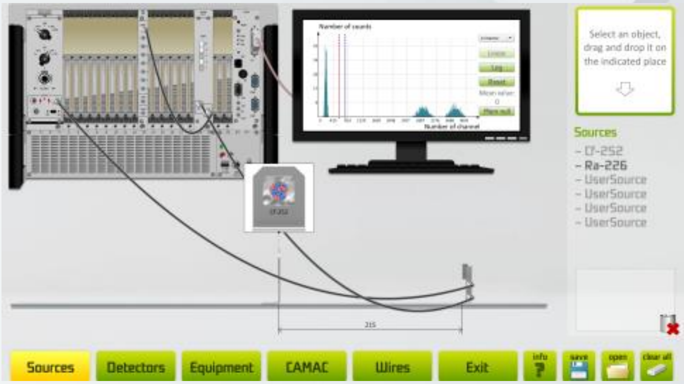
Pavel Semchukov, Pavel Kochnev, Eugeny Dolgy.

Leading computer designers:

Nikita Sidorov, Eugeniya Golubeva, Anna Komarova, Dariya Zhuravleva

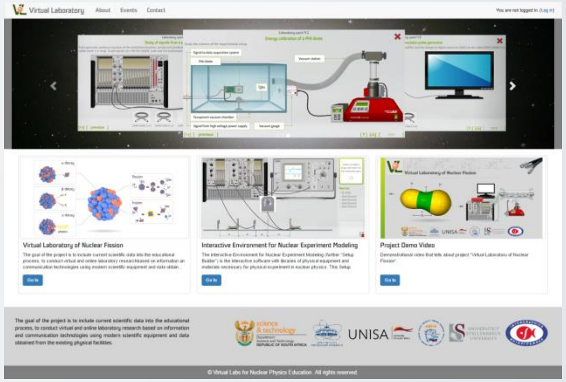
Virtual Laboratory of Nuclear Fission

Software complex "Virtual Laboratory of Nuclear Fission"



Interactive environment for nuclear experiment modeling (Setup Builder)

Hardware complex "Virtual Laboratory of Nuclear Fission" for student practices



Interactive web-version of the project

The project is comprised of three educational levels:

Elementary level. A typical target group at this level are high school students, science teachers, undergraduate students and participants of summer practices.

Basic level. The goal at this level is to study various types of radiation detectors, nuclear electronics & DAQ systems and some important methods of experimental data processing.

Advanced level. A typical target group at this level are students who plan to prepare their bachelor and master theses based on the measurements at the LISSA project. This level may be useful as a training before independent work as experimentalists in nuclear physics.

Input knowledge

Elementary level: high school physics

Basic level: university course on general physics; section “Nuclear Physics”

Advanced level: university courses “Quantum Physics” and “Nuclear Physics”

Project content

About: About Virtual Laboratory of Nuclear Fission

Part 1: Some Concepts of Nuclear Physics

Part 2: How to Measure Radioactivity

Part 3: Theoretical Models of the Atomic Nucleus

Part 4: How to Measure Nuclear Fission

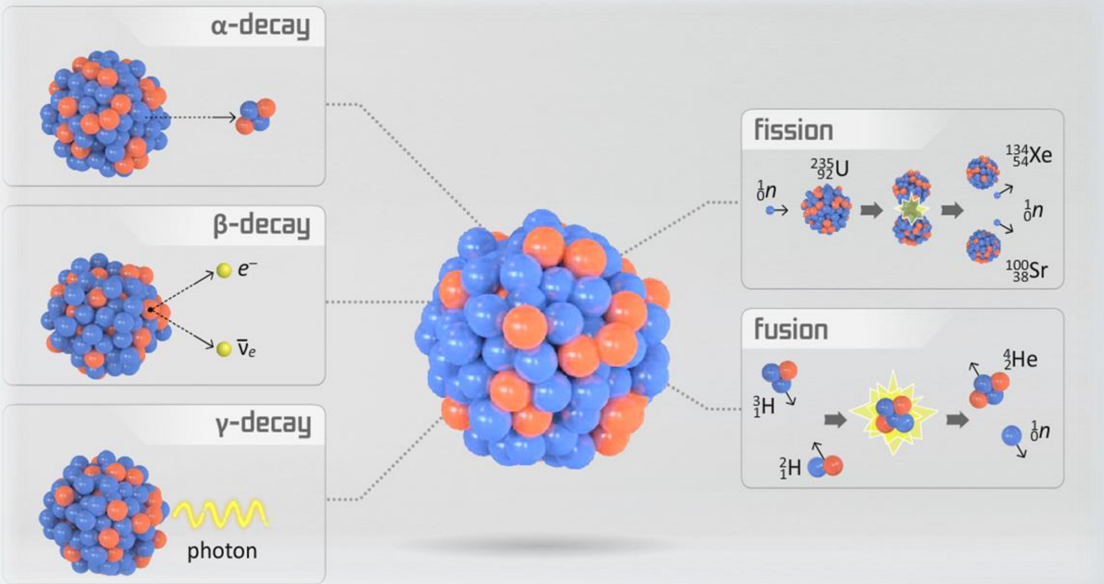
Part 5: Light Ions Spectrometer – Measurements

Part 6: Light Ions Spectrometer – Data Analysis

Part 7: Interactive Environment for Nuclear Experiment Modeling

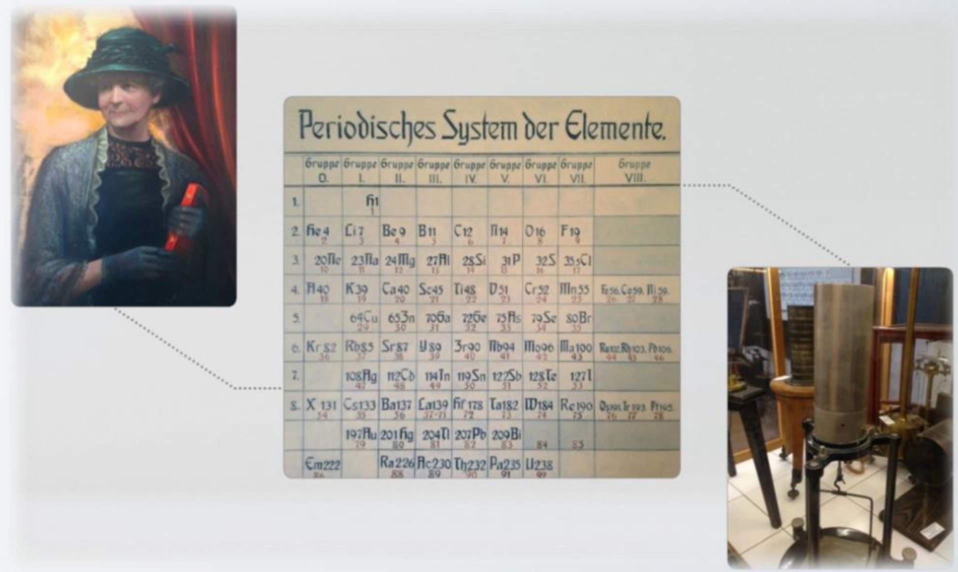
Part 1: Some Concepts of Nuclear Physics

1. World of the Atom
2. Atomic Nucleus
3. Mass and Energy
4. Fusion and Fission
5. Radioactivity:
   - Alpha Decay
   - Beta Decay
   - Gamma Decay
   - Spontaneous Fission
6. Radioactive Decay Law
7. Quiz
8. Exercises



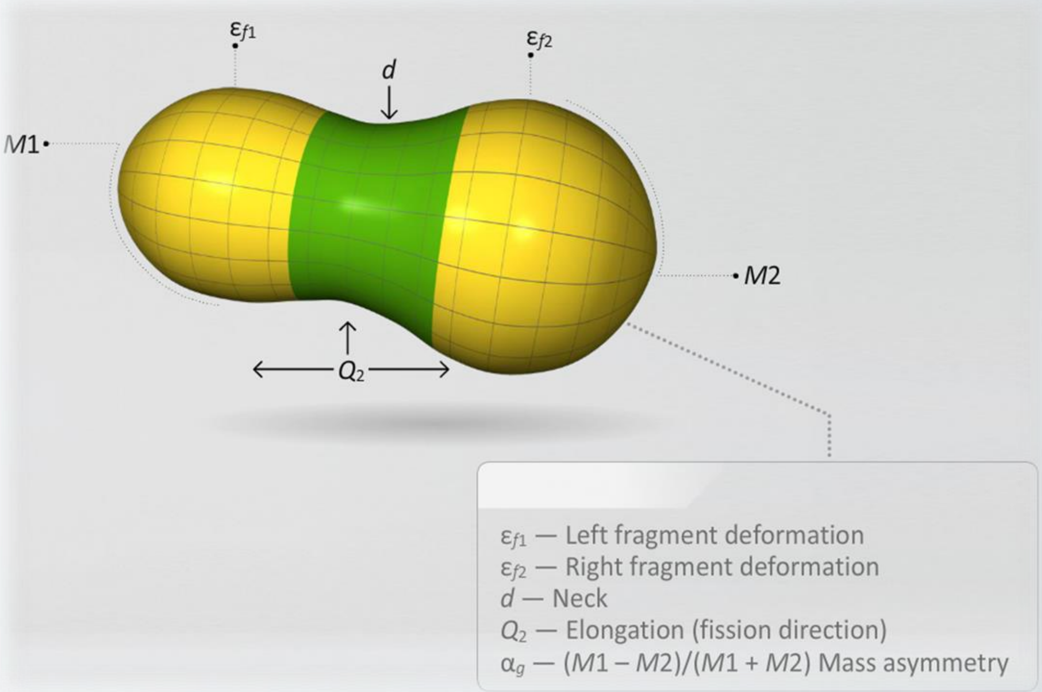
Part 2: How to Measure Radioactivity

1. Introduction
2. Radioactive Sources
3. Interaction of Radiation with Matter
4. Radiation Detectors:
   - Gas-Filled Detectors
   - Scintillation Detectors
   - PIN Diodes
   - Detectors Based on Microchannel Plates
5. Measurement of Radioactivity
6. Quiz
7. Practicum



Part 3: Theoretical Models of the Atomic Nucleus

1. Introduction
2. Nuclear Models
   – Liquid Drop Model
   – Fermi Gas Model
   – Shell Model
   – Collective Model
3. Quantum Mechanics in Nuclei
4. Fission and Quantum Tunneling
5. Basic Regularities of Spontaneous Fission
6. Collinear Cluster Tri-Partition (CCT)
7. Quiz
8. Exercises

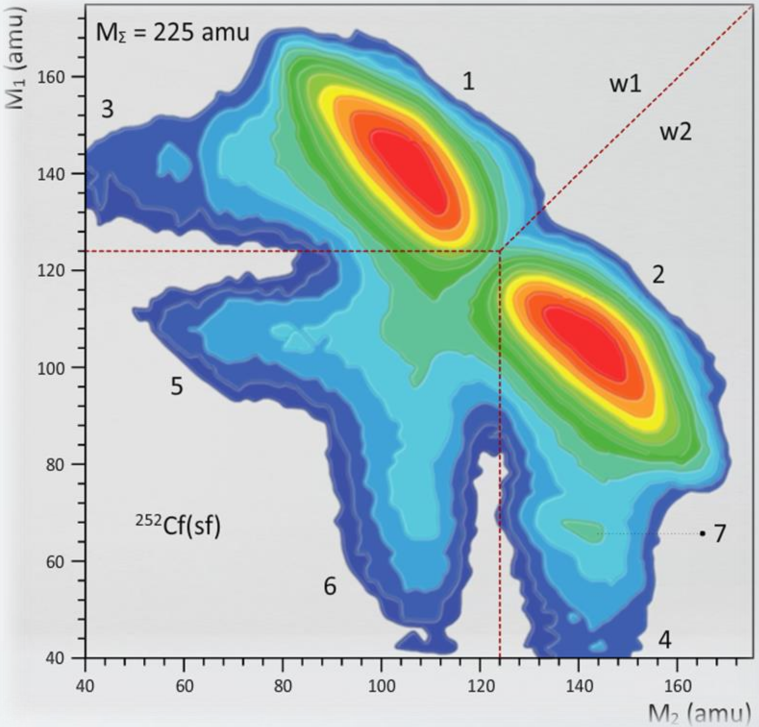


Part 4: Nuclear Fission Experiment

1. Introduction
2. Physics of Binary Fission
3. Methods of Detection of Fission Fragments
4. Energy Measurements of Fission Fragments from Californium-252
5. Time Measurements of Fission Fragments
6. Quiz
7. Practicum

Part 5: Light Ions Spectrometer – Measurements

1. Physical Motivation
2. LIS Setup
3. Electronics of the LIS Setup
4. Block Diagram and Data Acquisition System
5. CAMAC Practicum
6. PIN Diode Calibration
7. Time of Flight Calibration



Part 6: Light Ions Spectrometer – Data Analysis

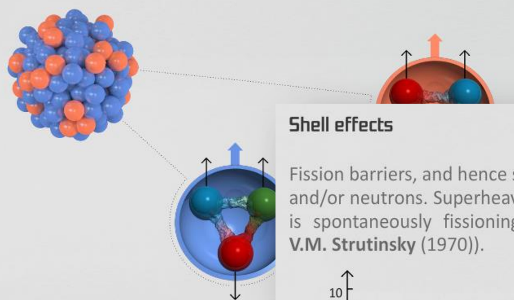
1. Introduction
2. Data Viewer
3. Preparation to Time Calibration
4. Time Calibration
5. Preparation to Energy Calibration
6. Energy Calibration
7. Mass Calculation

ROOT
Data Analysis Framework

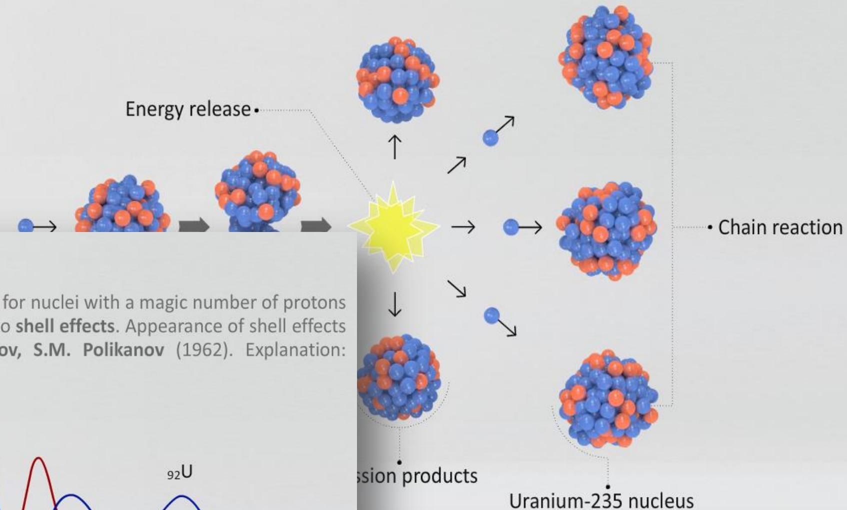
Theory

Nuclear Models

For explanation of properties of the atomic nucleus scientist represent nuclear models, because there are not a theory which could describe all the phenomena inside the nucleus. The exact potential of forces acting between nucleons inside the nucleus is not determined yet.

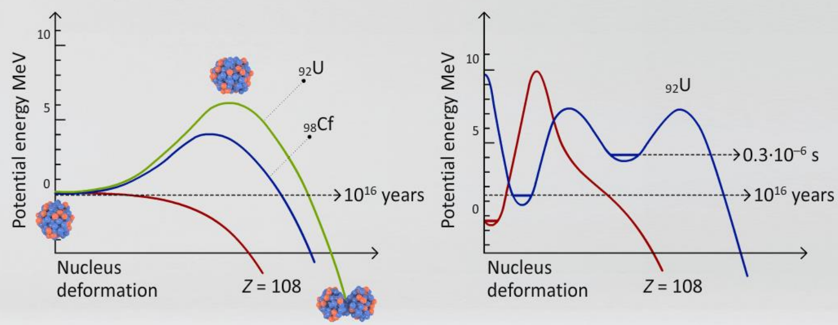


Each nucleon inside the nucleus can be describe
and momentum characteristics p_x, p_y, p_z ... There
variables. The task becomes indefinitely compl



Shell effects

Fission barriers, and hence stability against fission, are higher for nuclei with a magic number of protons and/or neutrons. Superheavy elements exist exclusively due to **shell effects**. Appearance of shell effects is spontaneously fissioning isomers (Discovery: **G.N. Flerov, S.M. Polikanov** (1962). Explanation: **V.M. Strutinsky** (1970)).

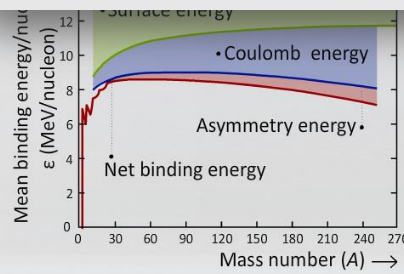


Liquid drop model *Microscopic theory*

$E_b = \alpha A - \beta A^{2/3} -$

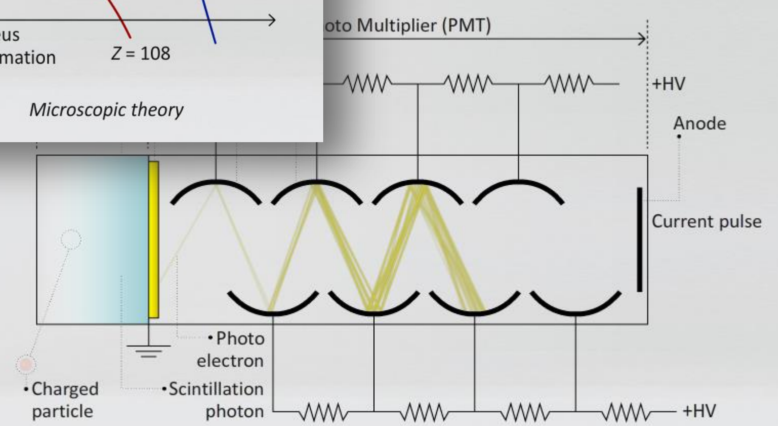
- Binding energy

The binding energy E_b of any nucleus of n
number A and atomic number Z is given by the Weizsäcker's formula. In nuclear physics formula is used to approximate the mass and various other properties of an atomic nucleus from its number of protons and neutrons. It is based partly on theory and partly on empirical measurements.



Behavior of different terms

an anode at the end of the tube forming an electronic pulse.
the instrument.

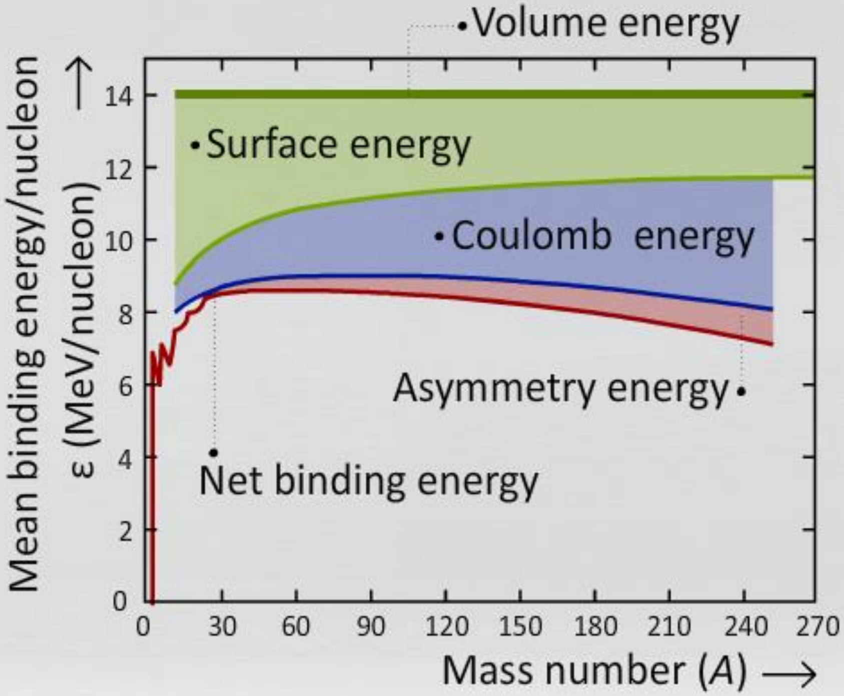


Theory: Interactive Formulas

$$E_b = \alpha A - \beta A^{2/3} - \gamma \frac{Z^2}{A^{1/3}} - \varepsilon \frac{(A/2-Z)^2}{A} + \delta$$

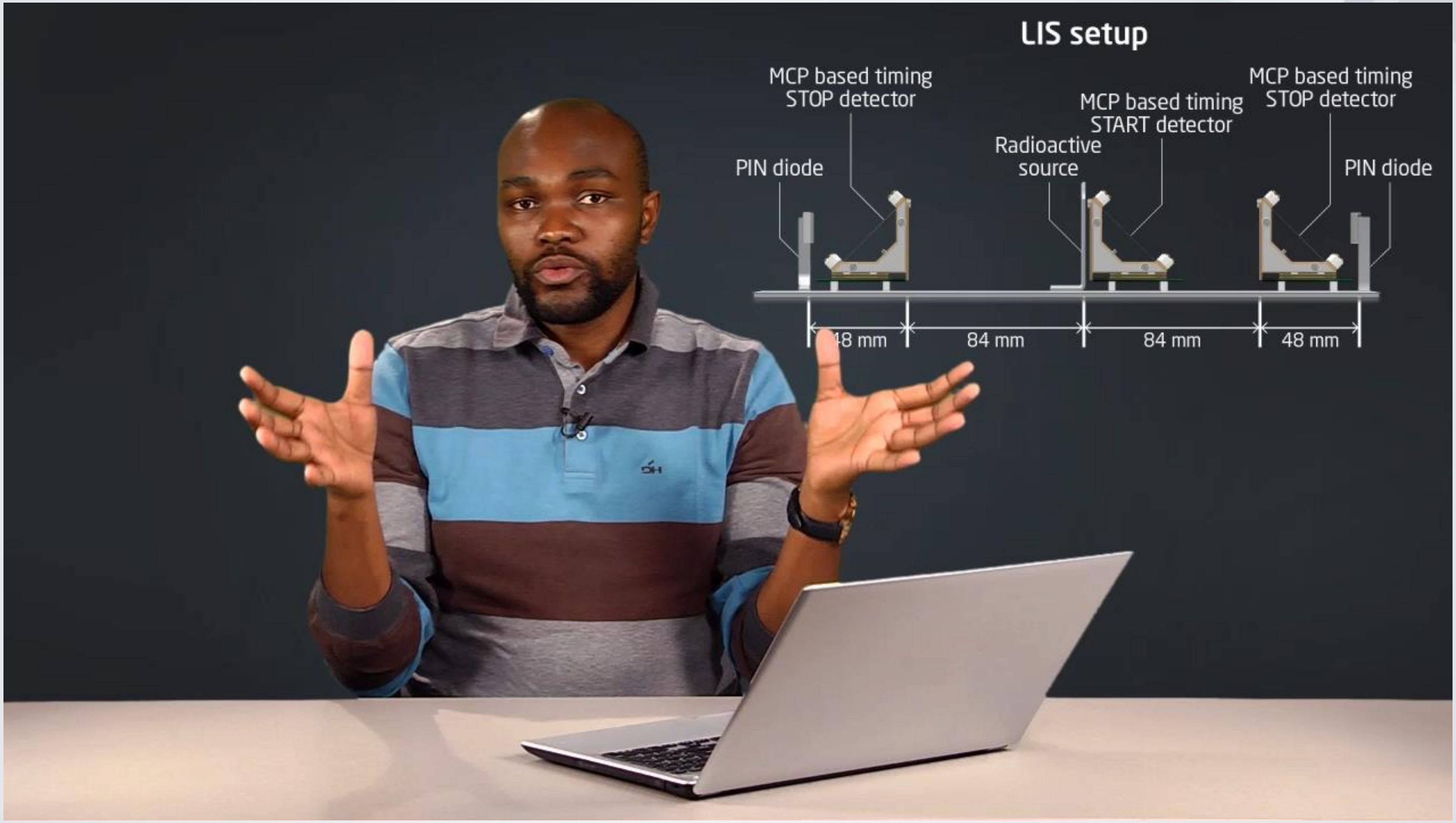
- Binding energy

The binding energy E_b of any nucleus of mass number A and atomic number Z is given by the Weizsäcker's formula. In nuclear physics formula is used to approximate the mass and various other properties of an atomic nucleus from its number of protons and neutrons. It is based partly on theory and partly on empirical measurements.



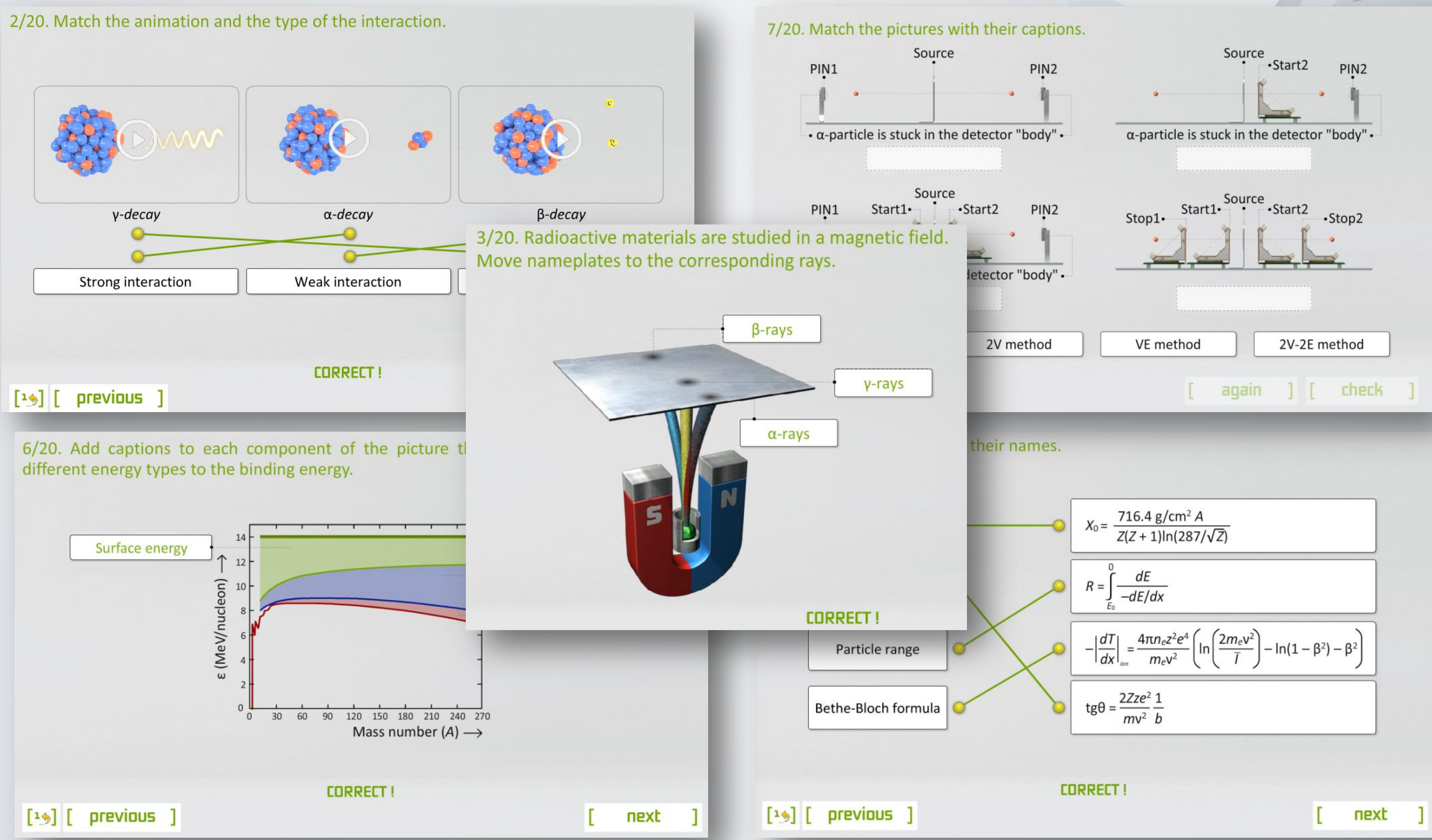
Behavior of different terms

Video Lectures

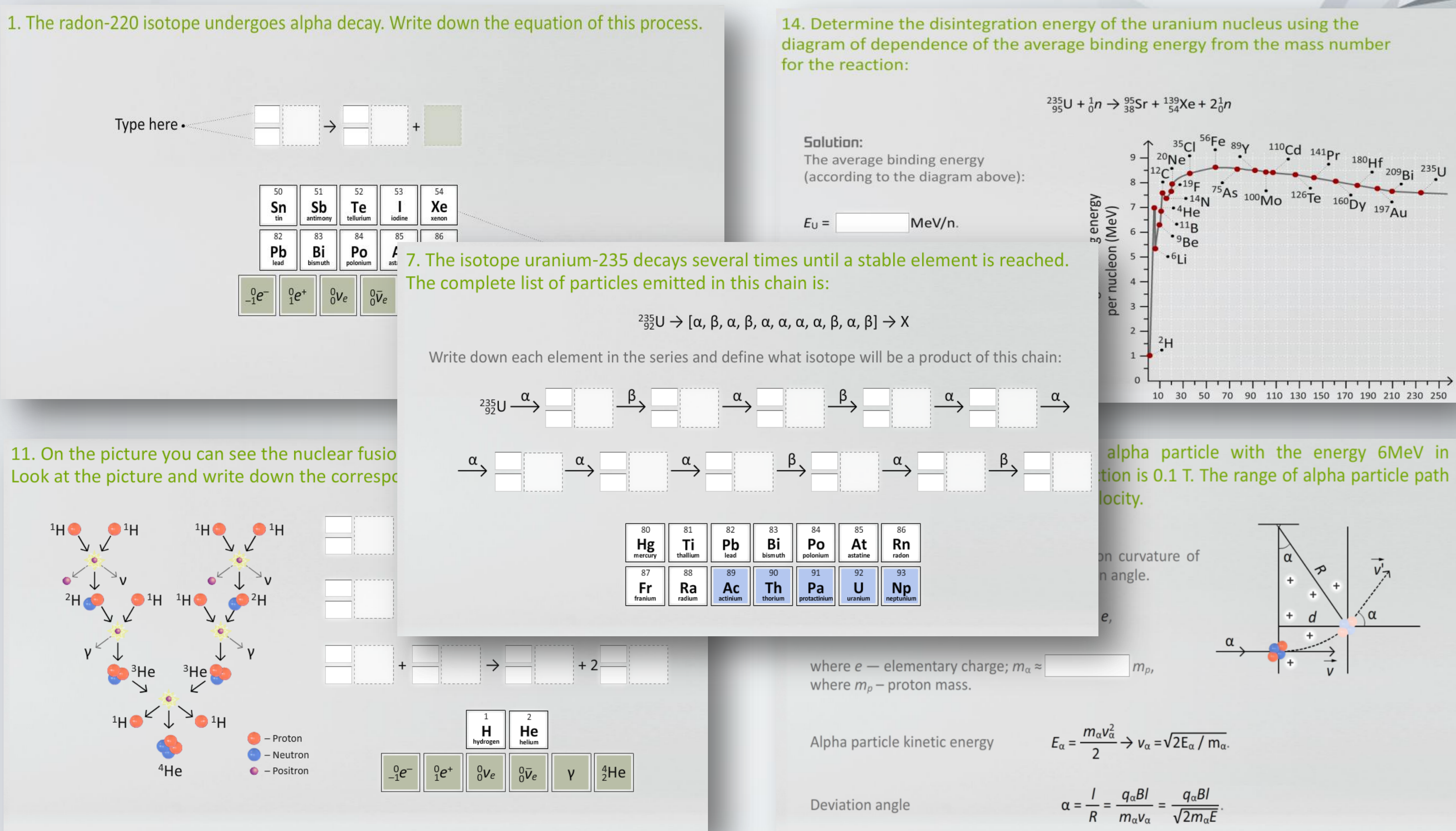


Vusi Daid Malaza*. Stellenbosch University, Faculty of Military Science, Military Academy, Saldanha, South Africa*

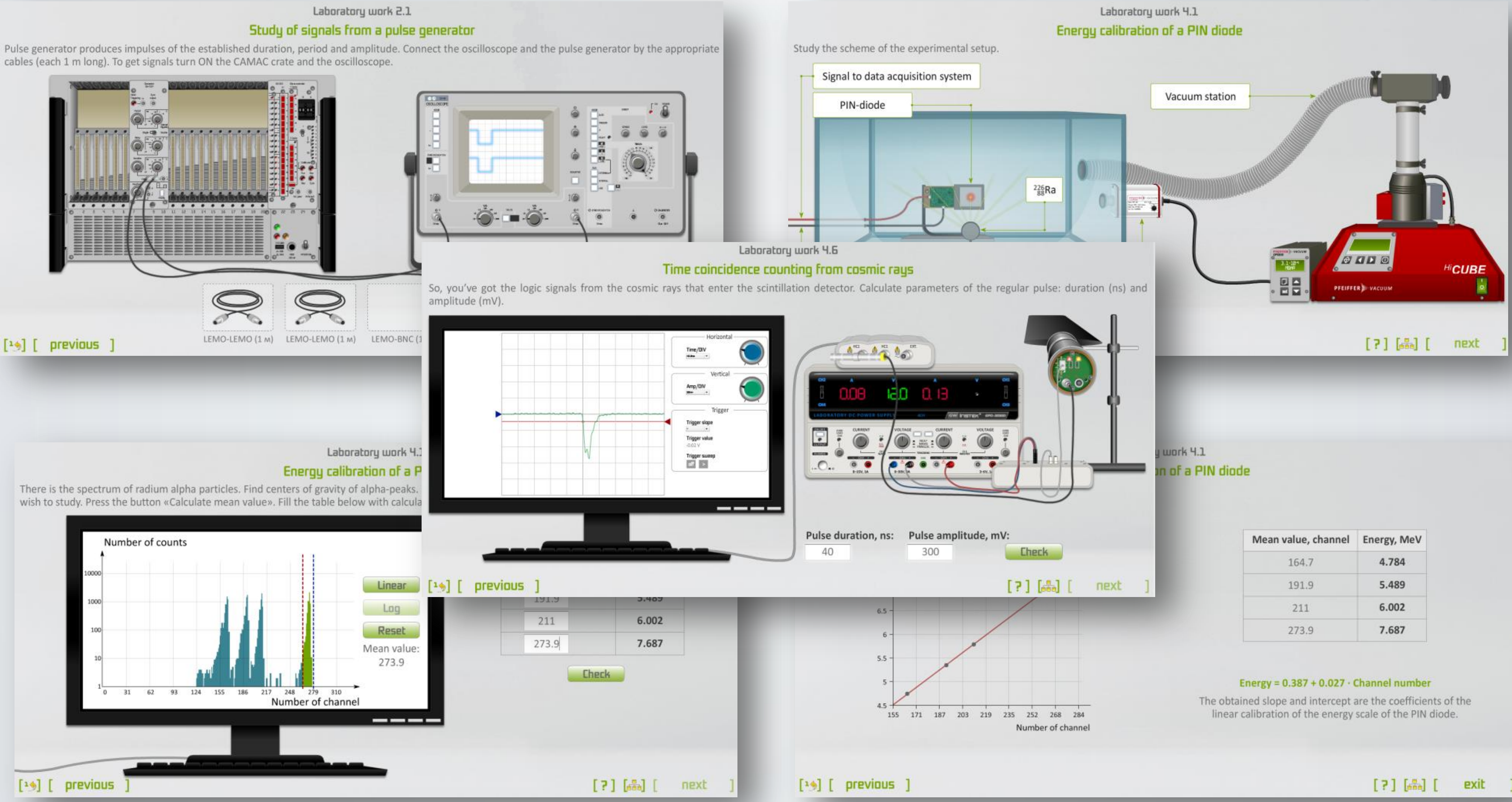
Quizzes


2/20. Match the animation and the type of the interaction.
γ-decay
α-decay
β-decay
Strong interaction
Weak interaction
CORRECT !
[previous]
7/20. Match the pictures with their captions.
Source
PIN1
PIN2
Start1
Start2
Stop1
Stop2
α-particle is stuck in the detector "body"
2V method
VE method
2V-2E method
[again]
[check]
3/20. Radioactive materials are studied in a magnetic field. Move nameplates to the corresponding rays.
β-rays
γ-rays
α-rays
S
N
CORRECT !
6/20. Add captions to each component of the picture
different energy types to the binding energy.
Surface energy
ε (MeV/nucleon)
Mass number (A)
CORRECT !
[previous]
[next]
their names.
Particle range
Bethe-Bloch formula
$X_0 = \frac{716.4\ g/cm^2\ A}{Z(Z+1)\ln(287/\sqrt{Z})}$
$R = \int_{E_0}^{0} \frac{dE}{-dE/dx}$
$-\left|\frac{dT}{dx}\right|_{ion} = \frac{4\pi n_e z^2 e^4}{m_e v^2}\left(\ln\left(\frac{2m_e v^2}{I}\right) - \ln(1-\beta^2) - \beta^2\right)$
$tg\theta = \frac{2Zze^2}{mv^2}\frac{1}{b}$
CORRECT !
[previous]
[next]

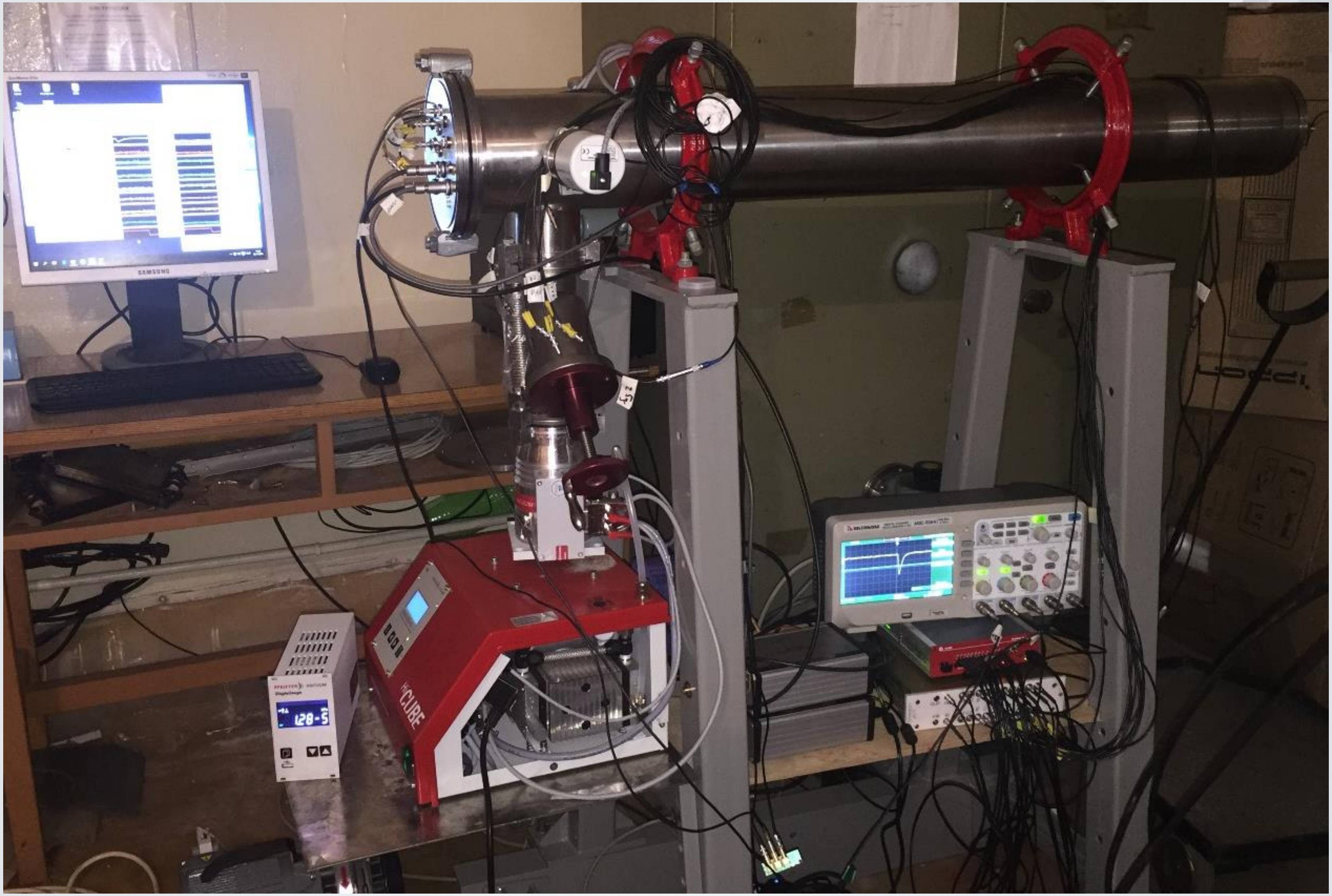
Exercises


1. The radon-220 isotope undergoes alpha decay. Write down the equation of this process.
Type here
14. Determine the disintegration energy of the uranium nucleus using the diagram of dependence of the average binding energy from the mass number for the reaction:
$^{235}_{92}U + ^{1}_{0}n \to ^{95}_{38}Sr + ^{139}_{54}Xe + 2^{1}_{0}n$
Solution:
The average binding energy (according to the diagram above):
$E_U =$ MeV/n.
7. The isotope uranium-235 decays several times until a stable element is reached. The complete list of particles emitted in this chain is:
$^{235}_{92}U \to [\alpha, \beta, \alpha, \beta, \alpha, \alpha, \alpha, \alpha, \beta, \alpha, \beta] \to X$
Write down each element in the series and define what isotope will be a product of this chain:
11. On the picture you can see the nuclear fusio
Look at the picture and write down the correspo
– Proton
– Neutron
– Positron
alpha particle with the energy 6MeV in
tion is 0.1 T. The range of alpha particle path
locity.
on curvature of
n angle.
where e — elementary charge; $m_\alpha \approx$ m_p,
where m_p – proton mass.
Alpha particle kinetic energy
$E_\alpha = \frac{m_\alpha v_\alpha^2}{2} \to v_\alpha = \sqrt{2E_\alpha / m_\alpha}$
Deviation angle
$\alpha = \frac{l}{R} = \frac{q_\alpha B l}{m_\alpha v_\alpha} = \frac{q_\alpha B l}{\sqrt{2 m_\alpha E}}$

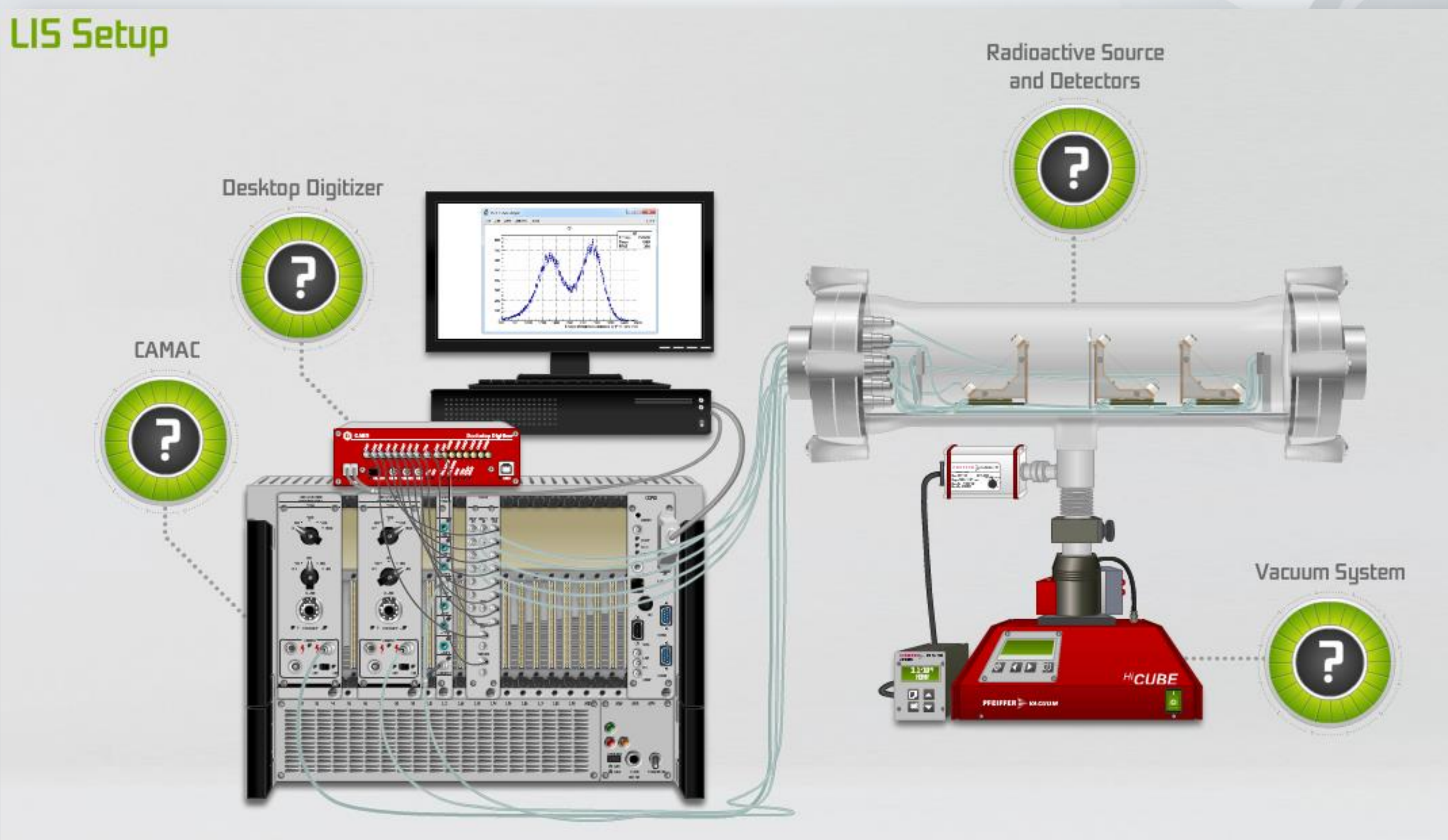
Virtual Practicum



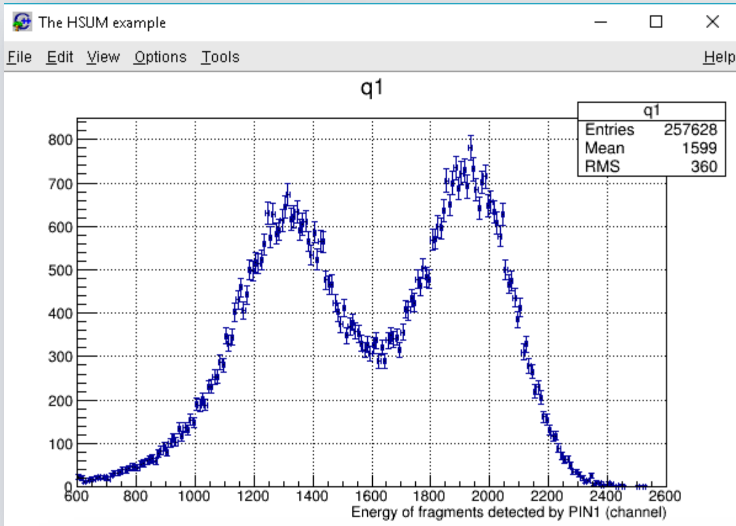
Light Ions Spectrometer

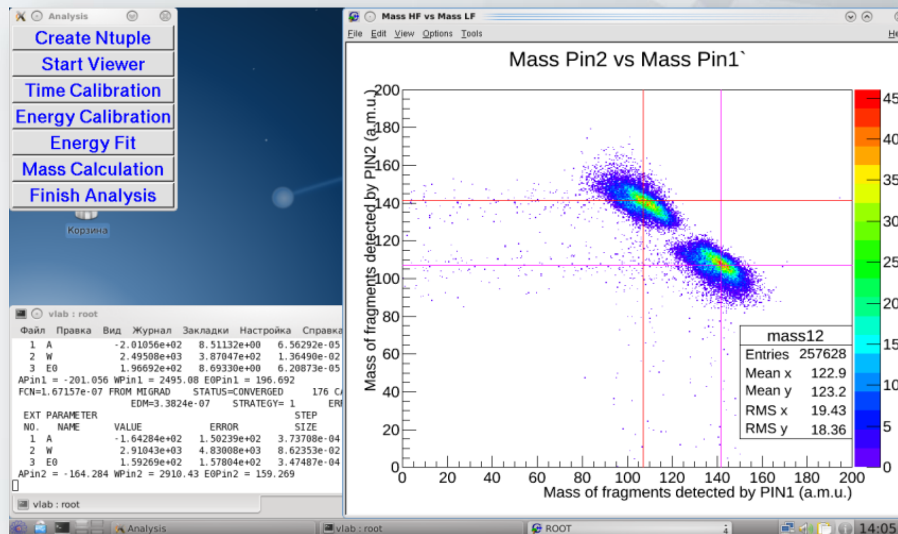


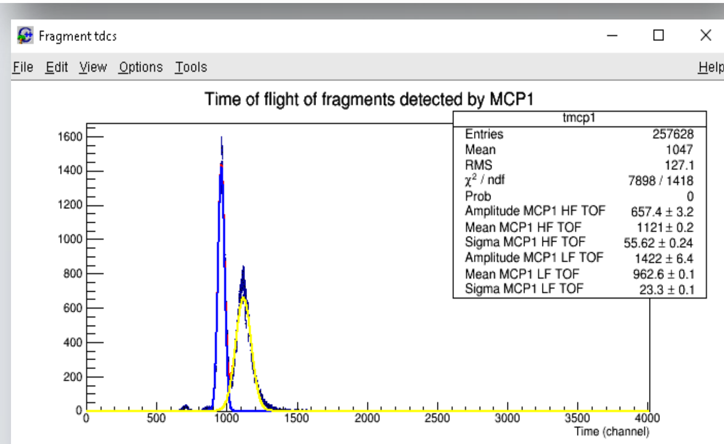
Light Ions Spectrometer

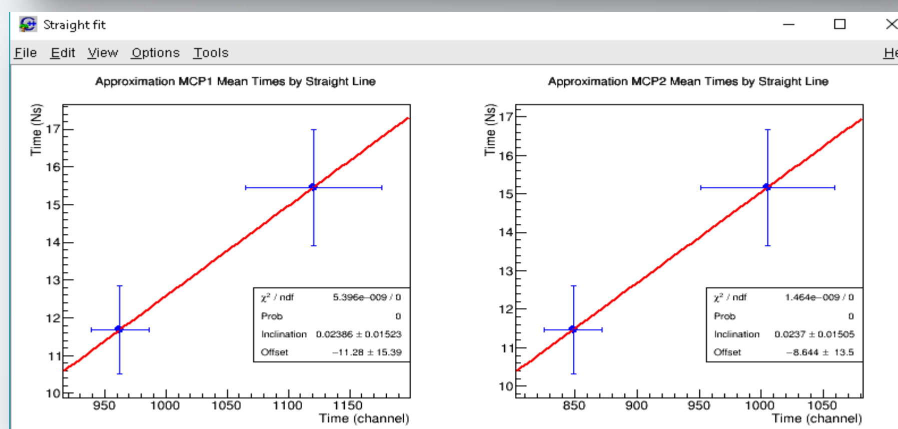


Data Analysis









Hardware-Software Complex “Interactive Environment for Nuclear Experiment Modeling”

Sources

- Cf-252
- Ra-226
- UserSource
- UserSource
- UserSource
- UserSource

Detectors

- MCP detector
- PIN diod
- UserDetector
- UserDetector
- UserDetector
- UserDetector

Equipment

- Oscilloscope
- Computer

CAMAC

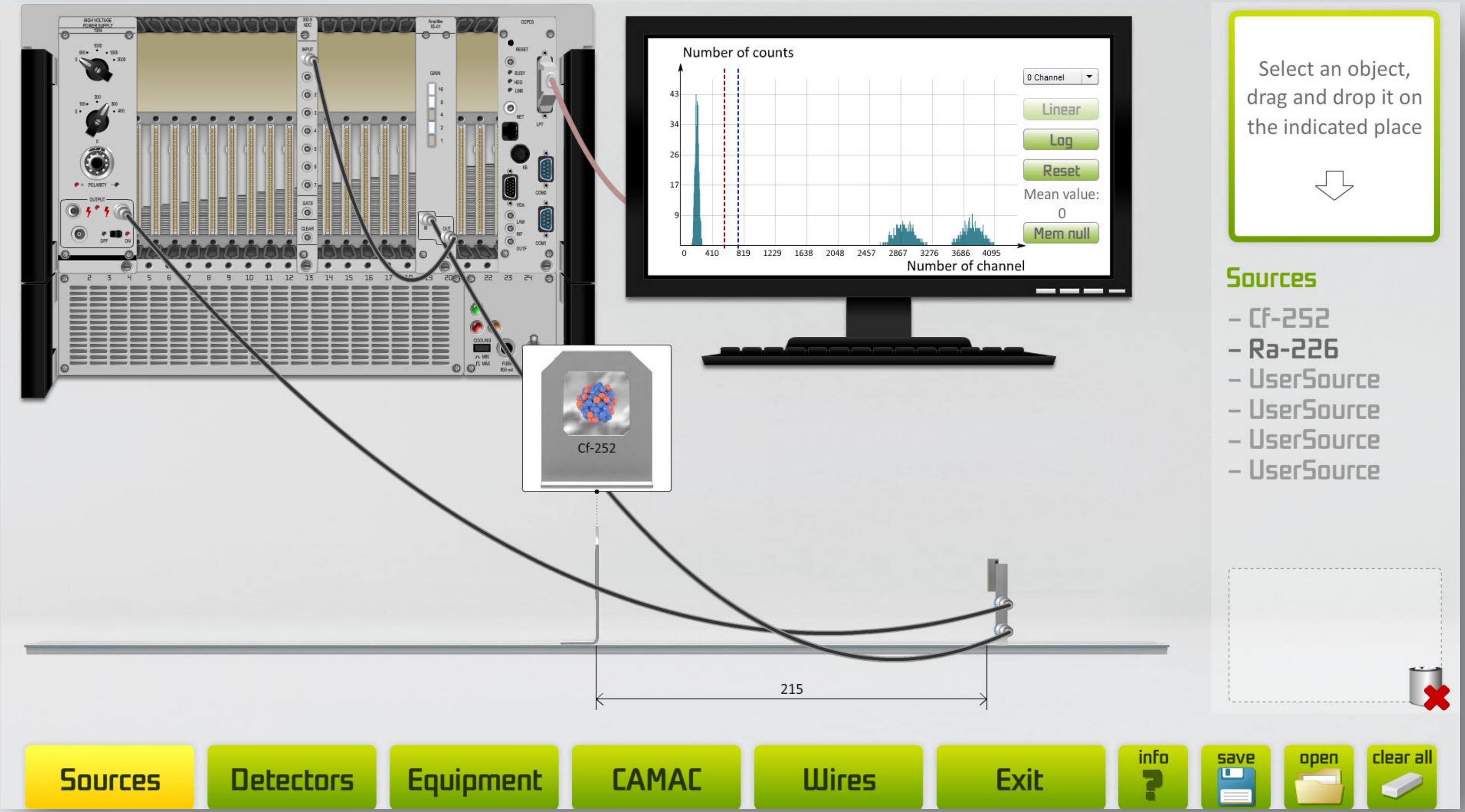
- ADC
- Amplifier
- Controller
- Delay
- Discriminator
- Generator
- High Voltage

Wires

- LEMO-LEMO 1 m
- LEMO-LEMO 10 m
- LEMO-BNC 1 m
- LEMO-BNC 10 m
- LEMO-BNC ? m
- BNC-BNC 1 m
- BNC-BNC 10 m
- LPT-LPT

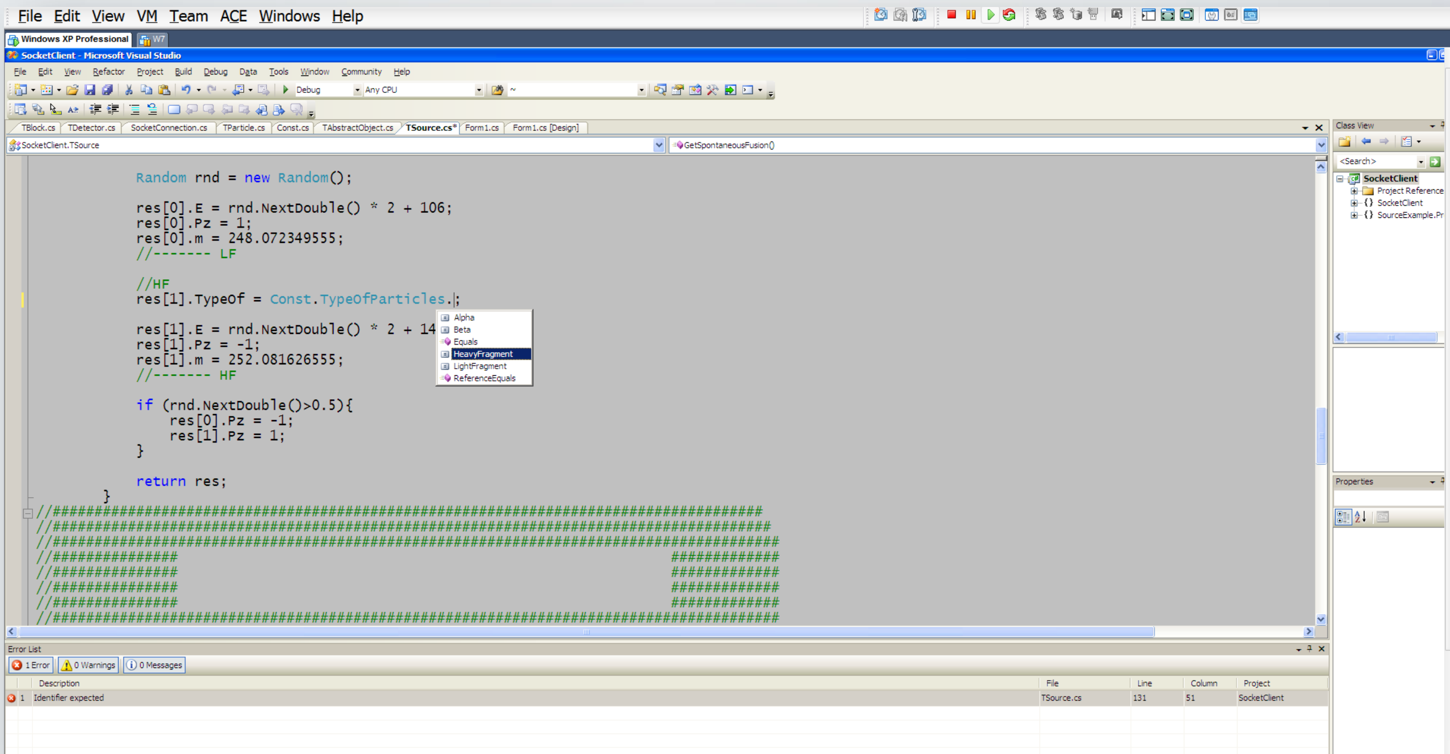
Libraries of the Setup Builder

Hardware-Software Complex "Interactive Environment for Nuclear Experiment Modeling"



You can arrange your own setup

Hardware-Software Complex “Interactive Environment for Nuclear Experiment Modeling”

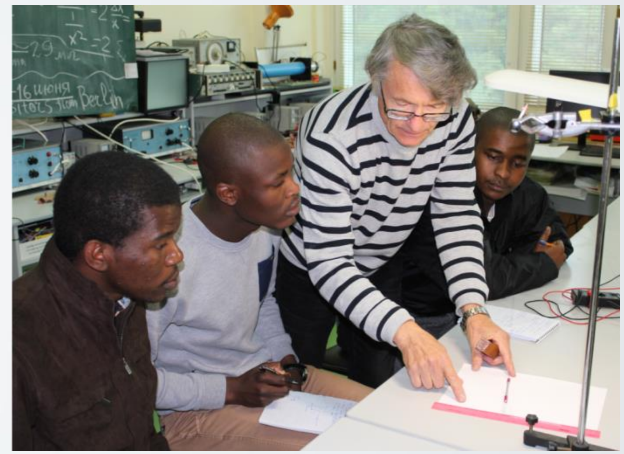


You can develop your own sources and equipment and integrate them into the Setup Bulider

Student Practices

- Live lectures

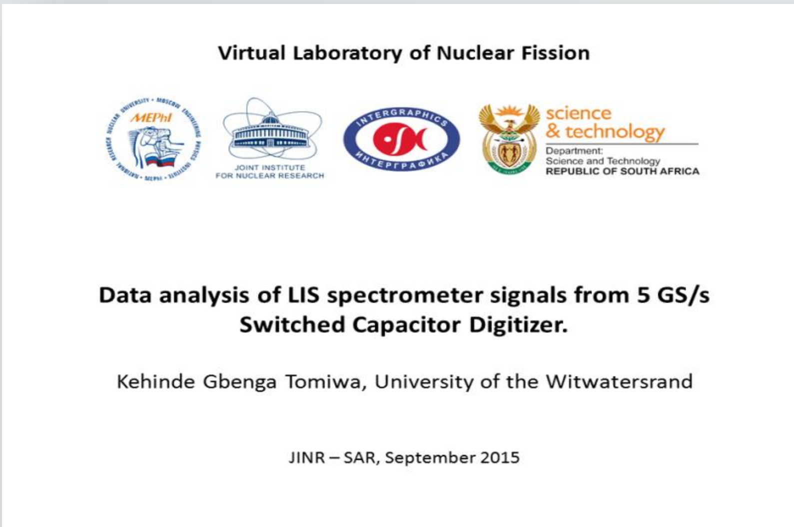
- Lab exercises

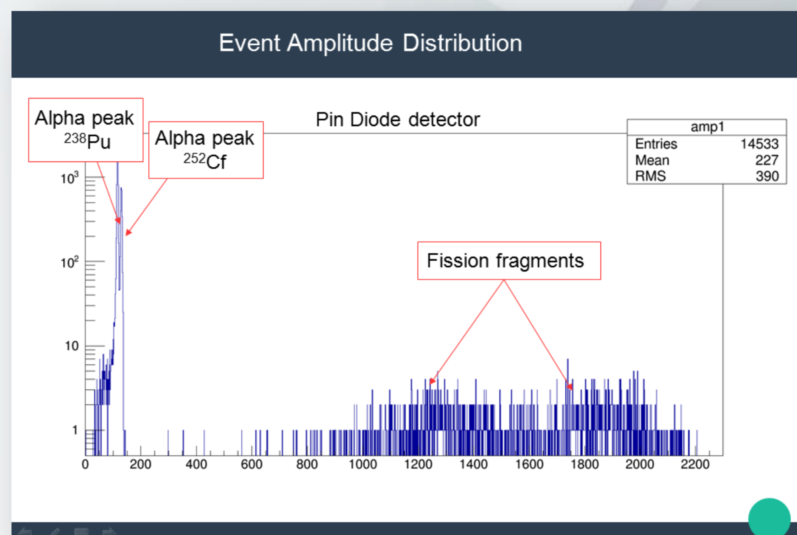


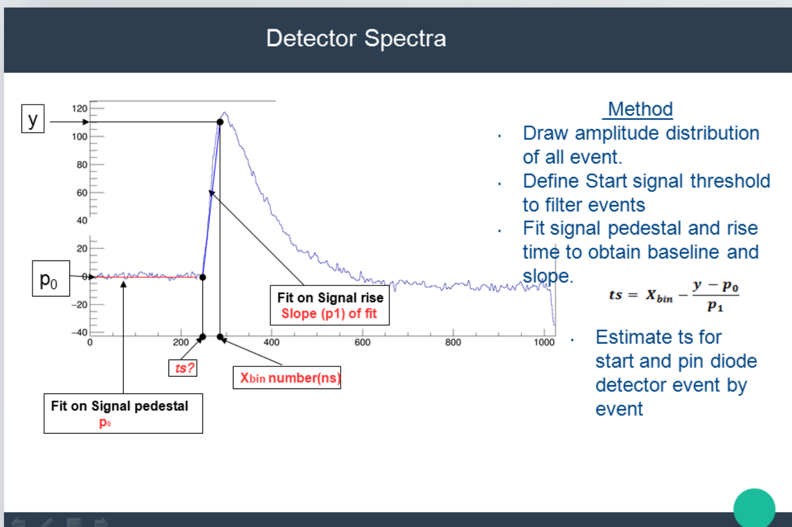
- Real equipment

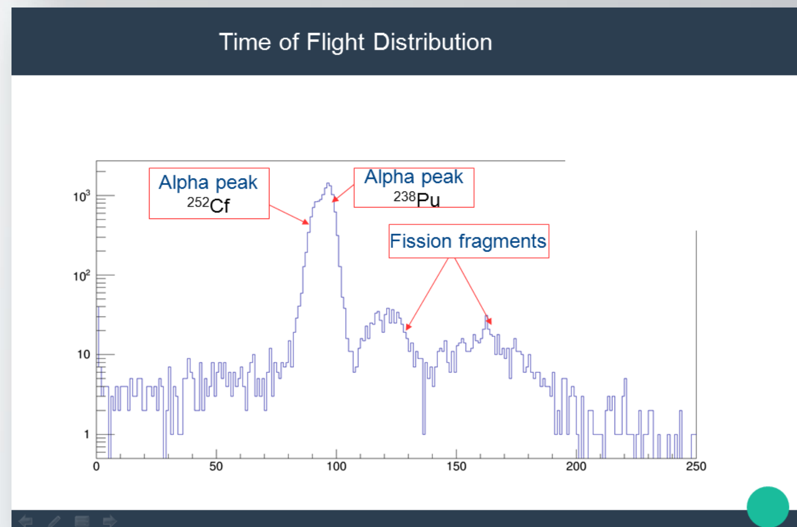
- Virtual labs

Student Practices

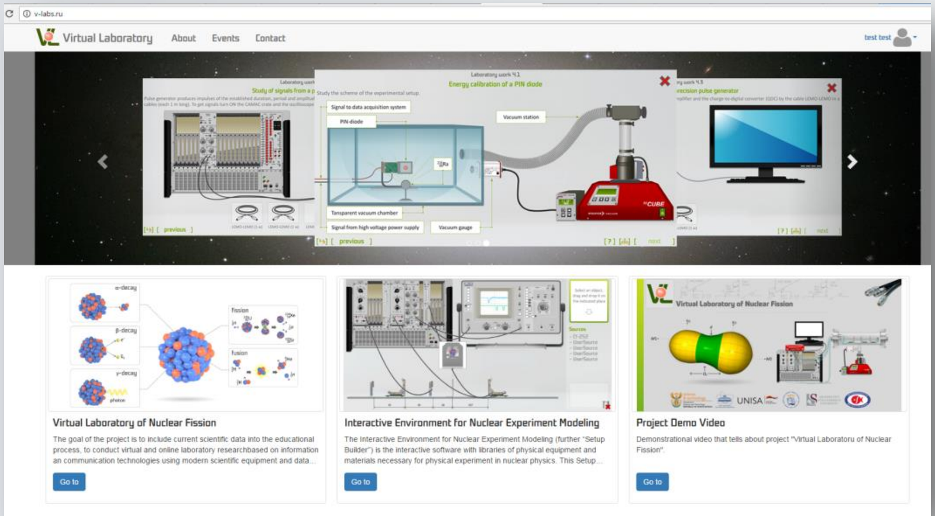


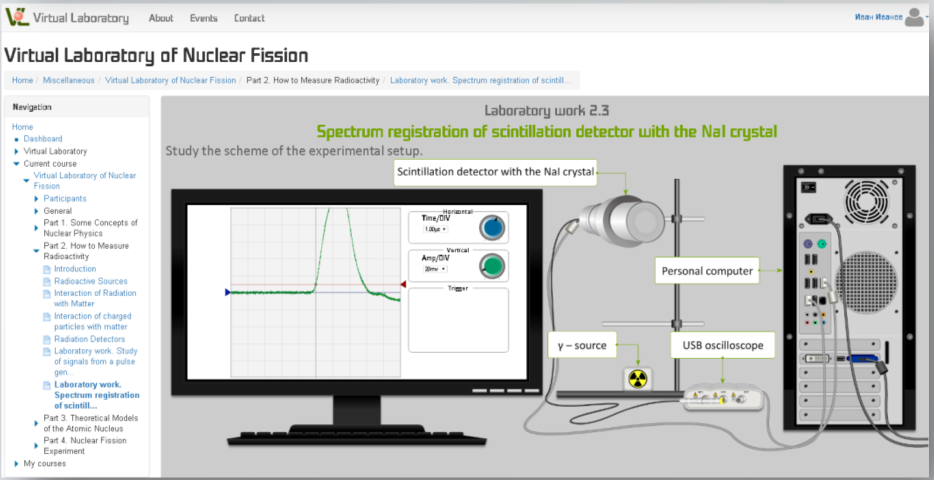






Web-version of the Project. Advantages





1. Access through the Internet.
2. You can control the educational process as a tutor.
3. You can see the progress of passing the course as a student.
4. You can communicate with peers and tutors.