



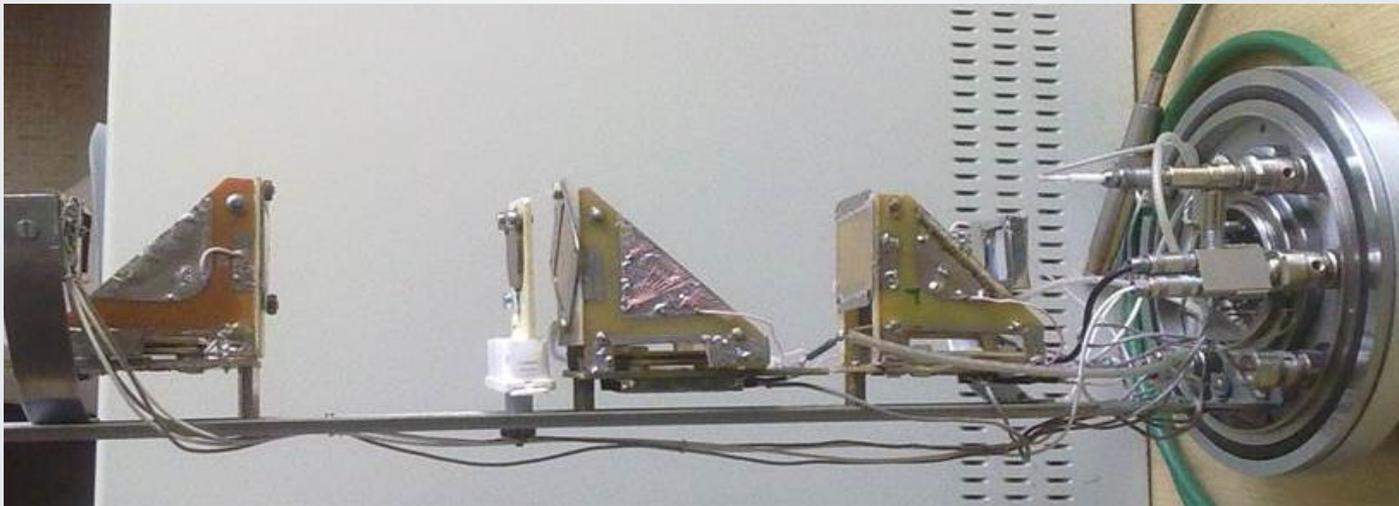
University of Fort Hare
Together in Excellence



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.

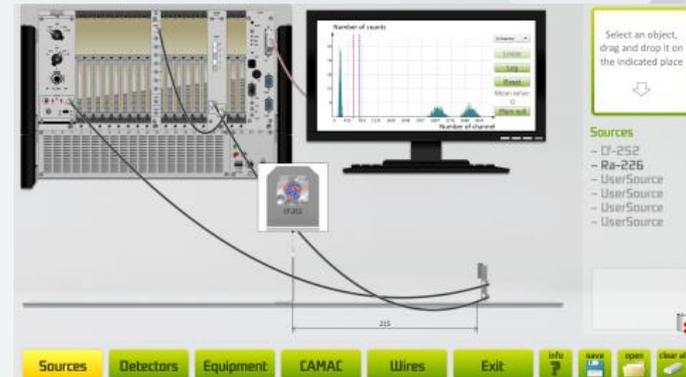
Leading computer designers:

Nikita Sidorov, Eugeniya Golubeva, Anna Komarova, Dariya Zhuravleva

Virtual Laboratory of Nuclear Fission



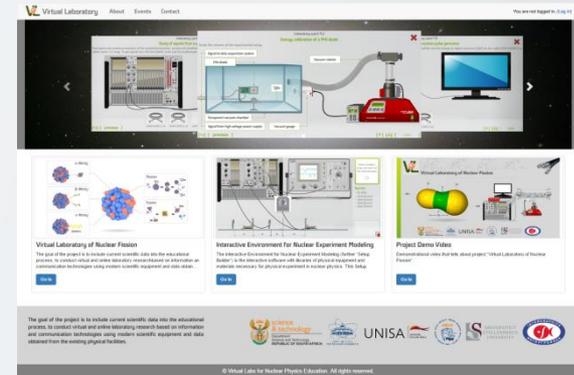
Software complex “Virtual Laboratory of Nuclear Fission”



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

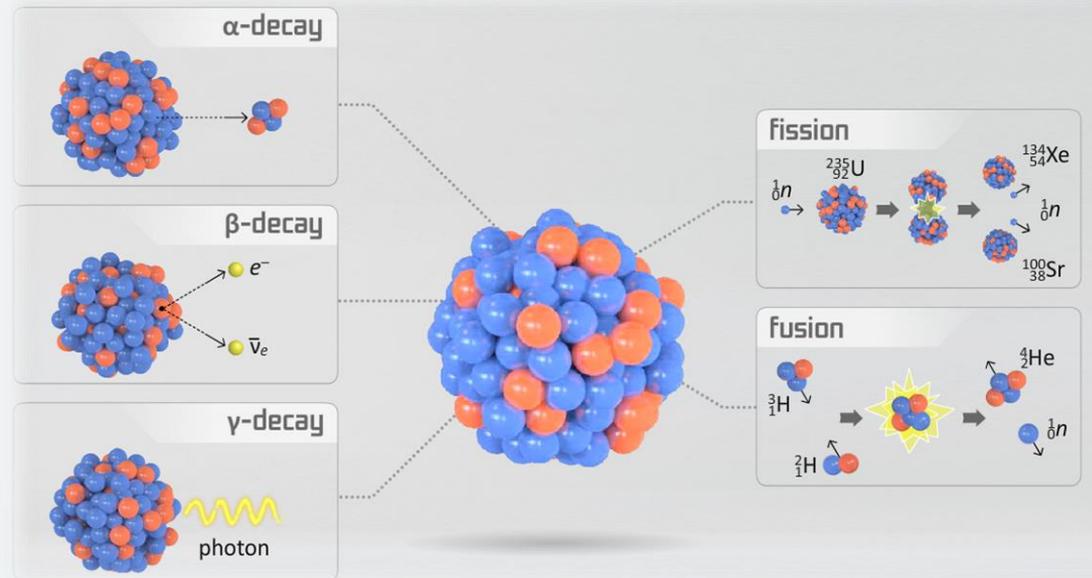
Part 5: Light Ions Spectrometer – Measurements

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



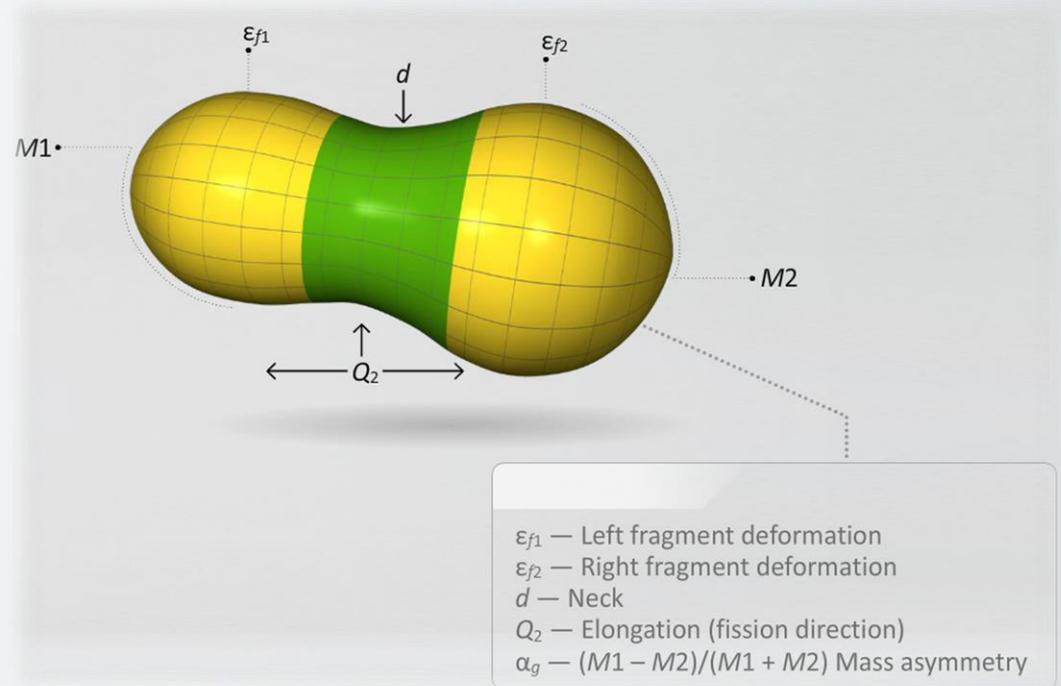
Periodisches System der Elemente.

Gruppe											
I.	II.	III.	IV.	V.	VI.	VII.	VIII.	VIII.			
1.	H 1										
2.	He 4	Li 7	Be 9	B 11	C 12	N 14	O 16	F 19			
3.	Ne 20	Na 23	Mg 24	Al 27	Si 28	P 31	S 32	Cl 35,5			
4.	Ar 40	K 39	Ca 40	Sc 45	Ti 48	V 51	Cr 52	Mn 55	Fe 56	Co 59	Ni 58
5.		Cu 64	Zn 65	Ga 70	Ge 72	As 75	Se 79	Br 80			
6.	Kr 84	Rb 85	Sr 88	Y 89	Zr 90	Nb 94	Mo 96	Tc 98	Ru 101	Rh 103	Pd 106
7.		Hg 201	Tl 204	Pb 207	Bi 209	Po 210	At 210				
8.	X 131	Cs 133	Ba 137	La 139	Hf 178	Ta 182	W 184	Re 187	Os 190	Ir 193	Pt 195
		Fr 223	Ra 226	Ac 227	Th 232	Pa 231	U 238	Pu 244	Am 243	Cm 247	Bk 247



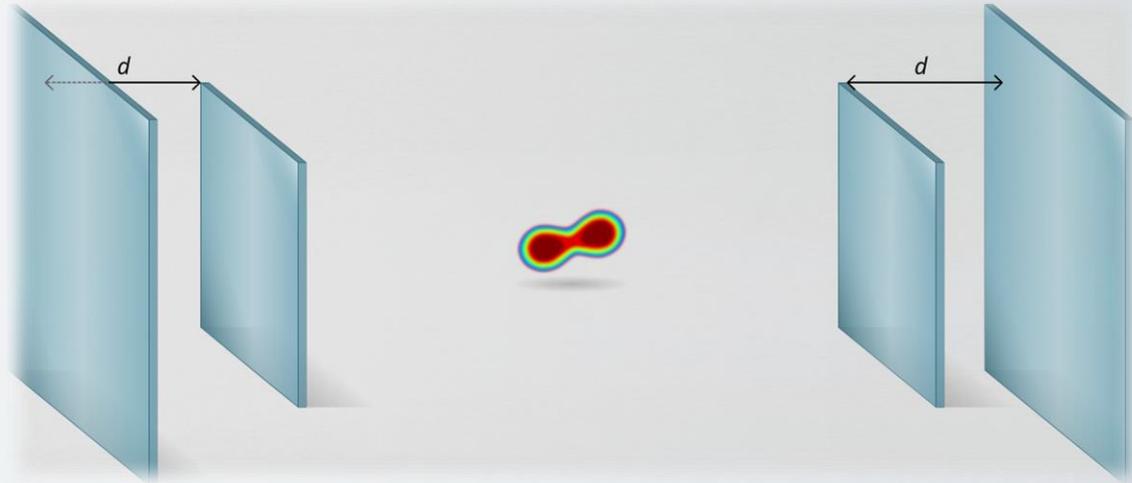
Part 3: Theoretical Models of the Atomic Nucleus

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



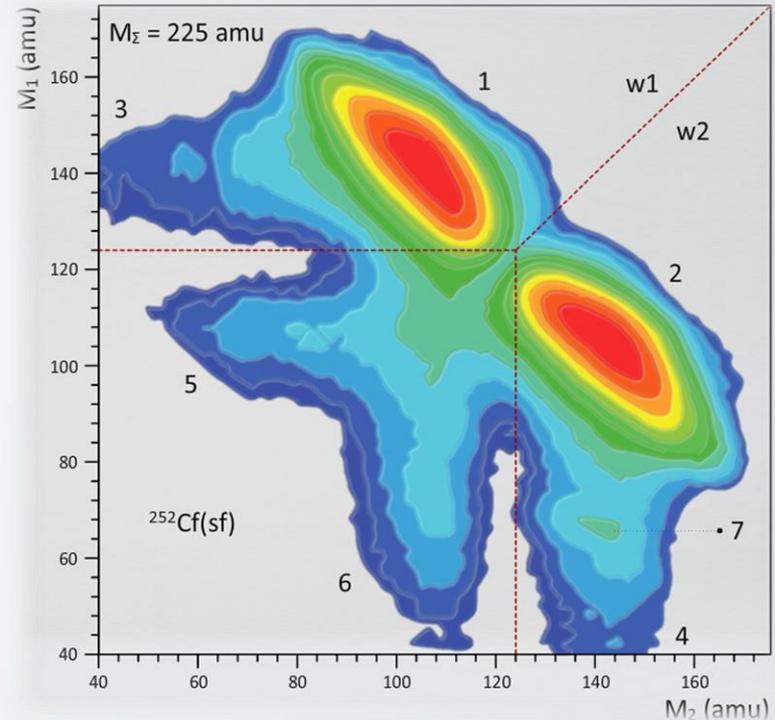
Part 4: Nuclear Fission Experiment

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

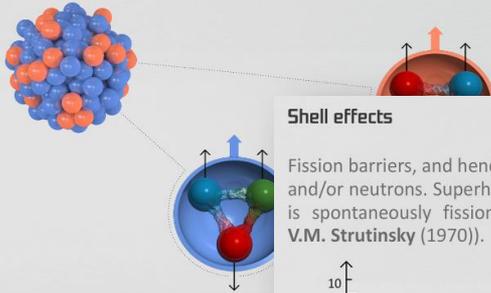


ROOT
Data Analysis Framework

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 described by its position and momentum characteristics $p_x, p_y, p_z \dots$. There are three variables. The task becomes indefinitely complicated.

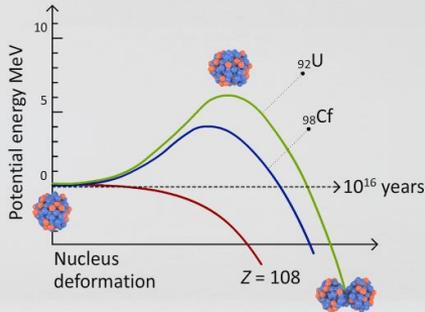
$$E_b = \alpha A - \beta A^{2/3}$$

Binding energy

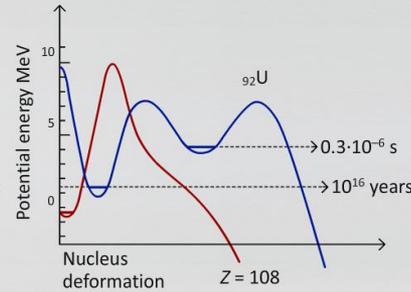
The binding energy E_b of any nucleus of mass number A and atomic number Z is given by the Weizsäcker's formula. In nuclear physics formula is used to approximate the mass and various other properties of an atomic nucleus from its number of protons and neutrons. It is based partly on theory and partly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

Shell effects

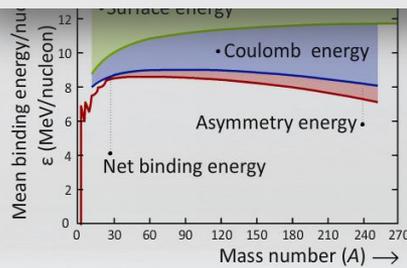
Fission barriers, and hence stability against fission, are higher for nuclei with a magic number of protons and/or neutrons. Superheavy elements exist exclusively due to **shell effects**. Appearance of shell effects is spontaneously fissioning isomers (Discovery: **G.N. Flerov, S.M. Polikanov** (1962).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



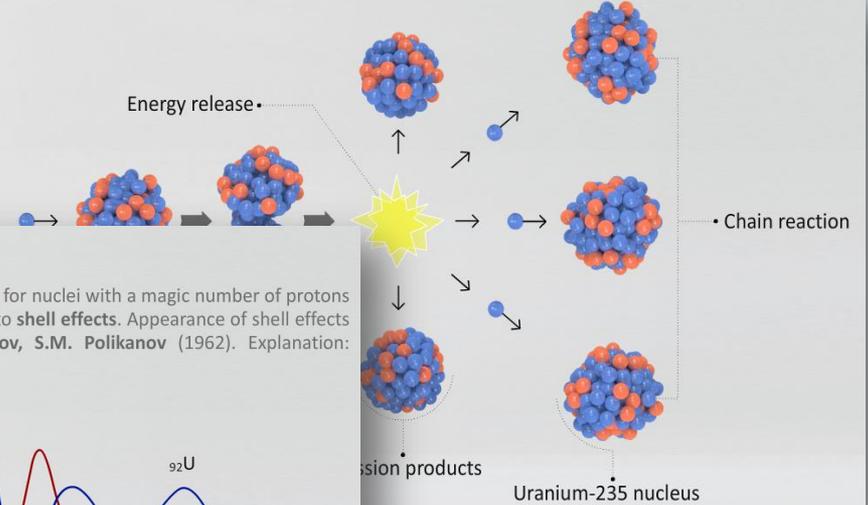
Liquid drop model



Microscopic theory



Behavior of different terms



Fission products
Uranium-235 nucleus

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

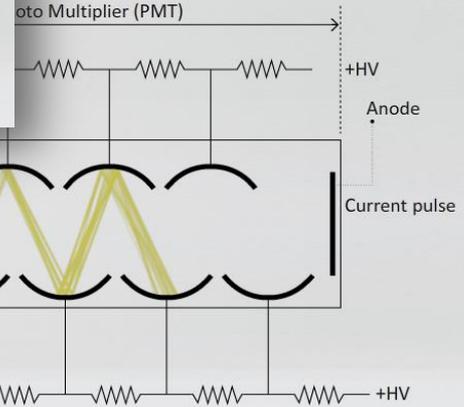


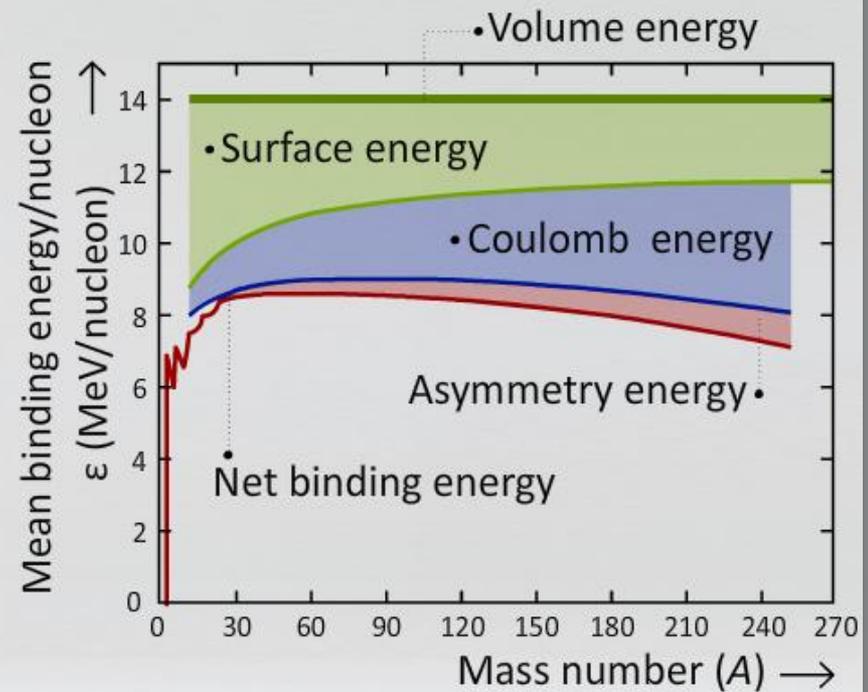
Photo Multiplier (PMT)
+HV
Anode
Current pulse
+HV
Charged particle
Photo electron
Scintillation photon

Theory: Interactive Formulas

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

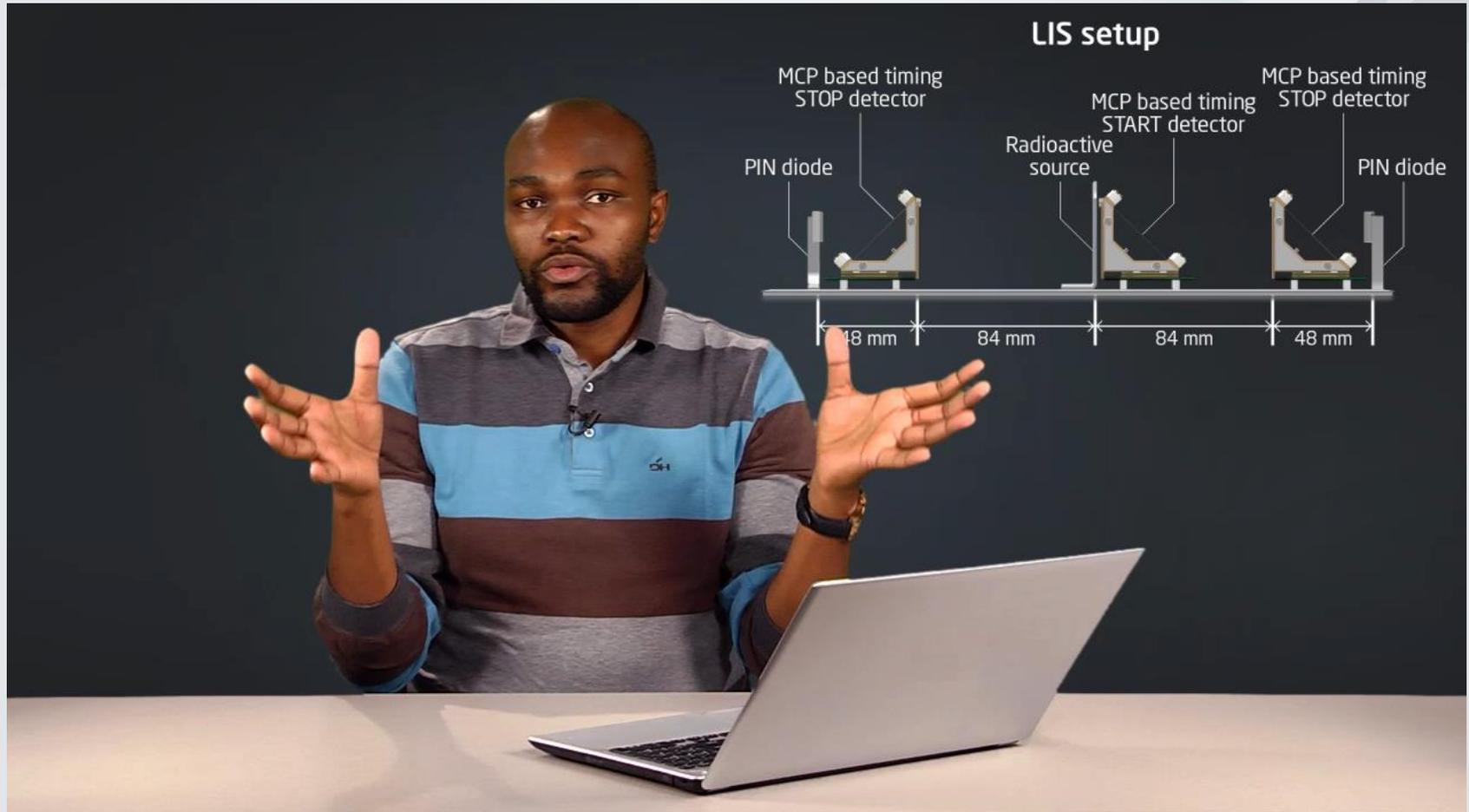
- **Binding energy**

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

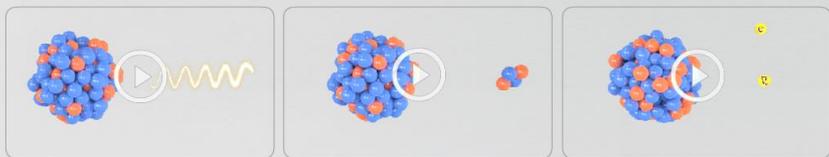
Video Lectures



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

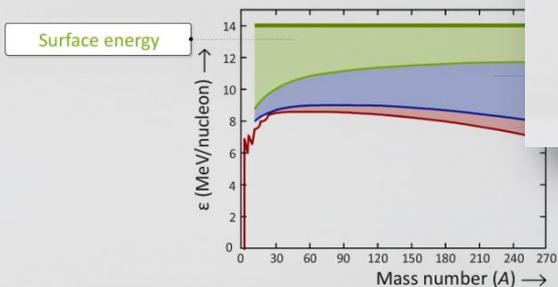
Strong interaction

Weak interaction

CORRECT!

[1 ↩] [previous]

6/20. Add captions to each component of the picture to the different energy types to the binding energy.

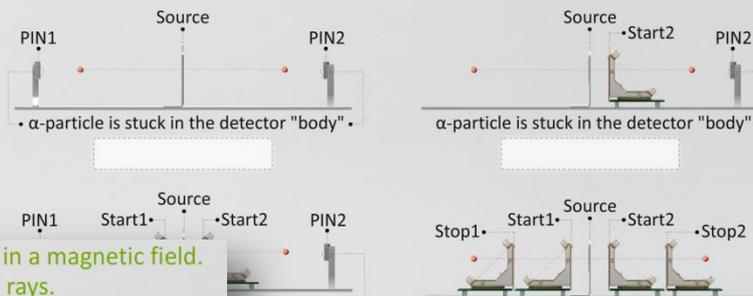


CORRECT!

[1 ↩] [previous]

[next]

7/20. Match the pictures with their captions.



α -particle is stuck in the detector "body".

α -particle is stuck in the detector "body".

detector "body".

2V method

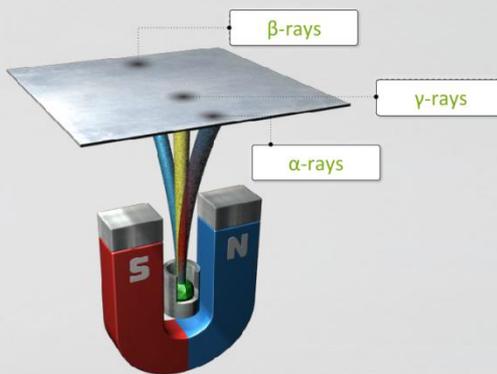
VE method

2V-2E method

[again] [check]

their names.

3/20. Radioactive materials are studied in a magnetic field. Move nameplates to the corresponding rays.



CORRECT!

Particle range

Bethe-Bloch formula

$$X_0 = \frac{716.4 \text{ g/cm}^2 A}{Z(Z+1)\ln(287/\sqrt{Z})}$$

$$R = \int_{E_0}^0 \frac{dE}{-dE/dx}$$

$$-\left| \frac{dT}{dx} \right|_{\text{ion}} = \frac{4\pi n_e z^2 e^4}{m_e v^2} \left(\ln \left(\frac{2m_e v^2}{T} \right) - \ln(1 - \beta^2) - \beta^2 \right)$$

$$\text{tg}\theta = \frac{2Zze^2}{mv^2} \frac{1}{b}$$

CORRECT!

[1 ↩] [previous]

[next]

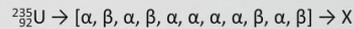
Exercises

1. The radon-220 isotope undergoes alpha decay. Write down the equation of this process.

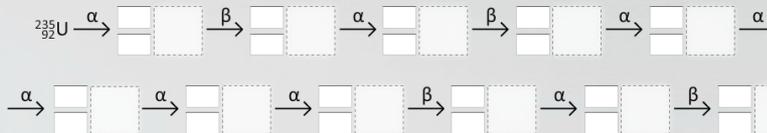
Type here • → +

50 Sn tin	51 Sb antimony	52 Te tellurium	53 I iodine	54 Xe xenon
82 Pb lead	83 Bi bismuth	84 Po polonium	85 At astatine	86 Rn radon
${}^0_{-1}e^-$	${}^0_1e^+$	${}^0_0\nu_e$	${}^0_0\bar{\nu}_e$	

7. The isotope uranium-235 decays several times until a stable element is reached. The complete list of particles emitted in this chain is:



Write down each element in the series and define what isotope will be a product of this chain:



80 Hg mercury	81 Tl thallium	82 Pb lead	83 Bi bismuth	84 Po polonium	85 At astatine	86 Rn radon
87 Fr francium	88 Ra radium	89 Ac actinium	90 Th thorium	91 Pa protactinium	92 U uranium	93 Np neptunium



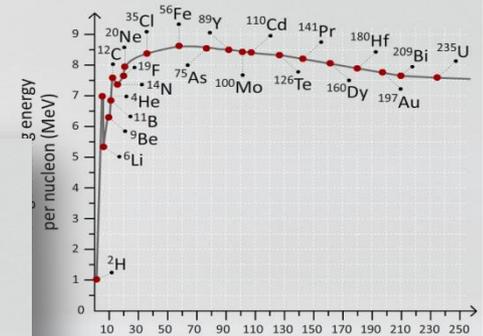
${}^1_1\text{H}$ hydrogen	${}^2_2\text{He}$ helium	γ	${}^4_2\text{He}$
${}^0_{-1}e^-$	${}^0_1e^+$	${}^0_0\nu_e$	${}^0_0\bar{\nu}_e$

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:

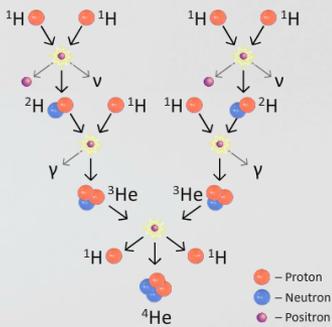


Solution:
The average binding energy (according to the diagram above):

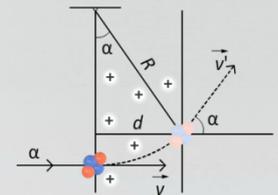
$$E_U = \boxed{} \text{ MeV/n.}$$



11. On the picture you can see the nuclear fusion. Look at the picture and write down the corresponding equation.



An alpha particle with the energy 6 MeV in a magnetic field of induction is 0.1 T. The range of alpha particle path is l . Determine the deviation angle α .



where e — elementary charge; $m_\alpha \approx 4 m_p$, where m_p — proton mass.

Alpha particle kinetic energy

$$E_\alpha = \frac{m_\alpha v_\alpha^2}{2} \rightarrow v_\alpha = \sqrt{2E_\alpha / m_\alpha}$$

Deviation angle

$$\alpha = \frac{l}{R} = \frac{q_\alpha B l}{m_\alpha v_\alpha} = \frac{q_\alpha B l}{\sqrt{2m_\alpha E}}$$

Virtual Practicum

Laboratory work 2.1

Study of signals from a pulse generator

Pulse generator produces impulses of the established duration, period and amplitude. Connect the oscilloscope and the pulse generator by the appropriate cables (each 1 m long). To get signals turn ON the CAMAC crate and the oscilloscope.

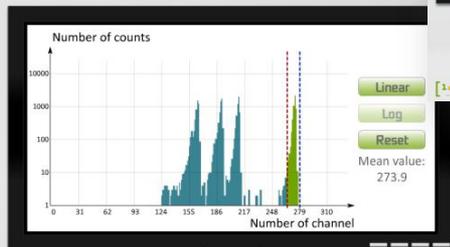


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Laboratory work 4.1

Energy calibration of a PIN diode

There is the spectrum of radium alpha particles. Find centers of gravity of alpha-peaks. Wish to study. Press the button «Calculate mean values». Fill the table below with calculated values.



Linear
Log
Reset
Mean value:
273.9

Channel	Mean value
211	6.002
273.9	7.687

Check

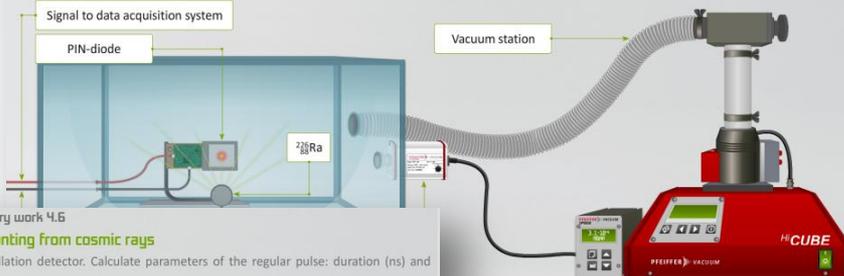
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Laboratory work 4.1

Energy calibration of a PIN diode

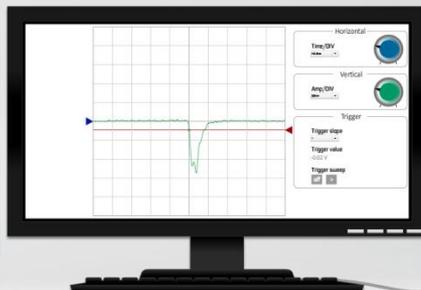
Study the scheme of the experimental setup.



Laboratory work 4.6

Time coincidence counting from cosmic rays

So, you've got the logic signals from the cosmic rays that enter the scintillation detector. Calculate parameters of the regular pulse: duration (ns) and amplitude (mV).



Pulse duration, ns: 40
Pulse amplitude, mV: 300
Check

[?] [<=>] [next]

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[?] [<=>] [exit]

Laboratory work 4.1

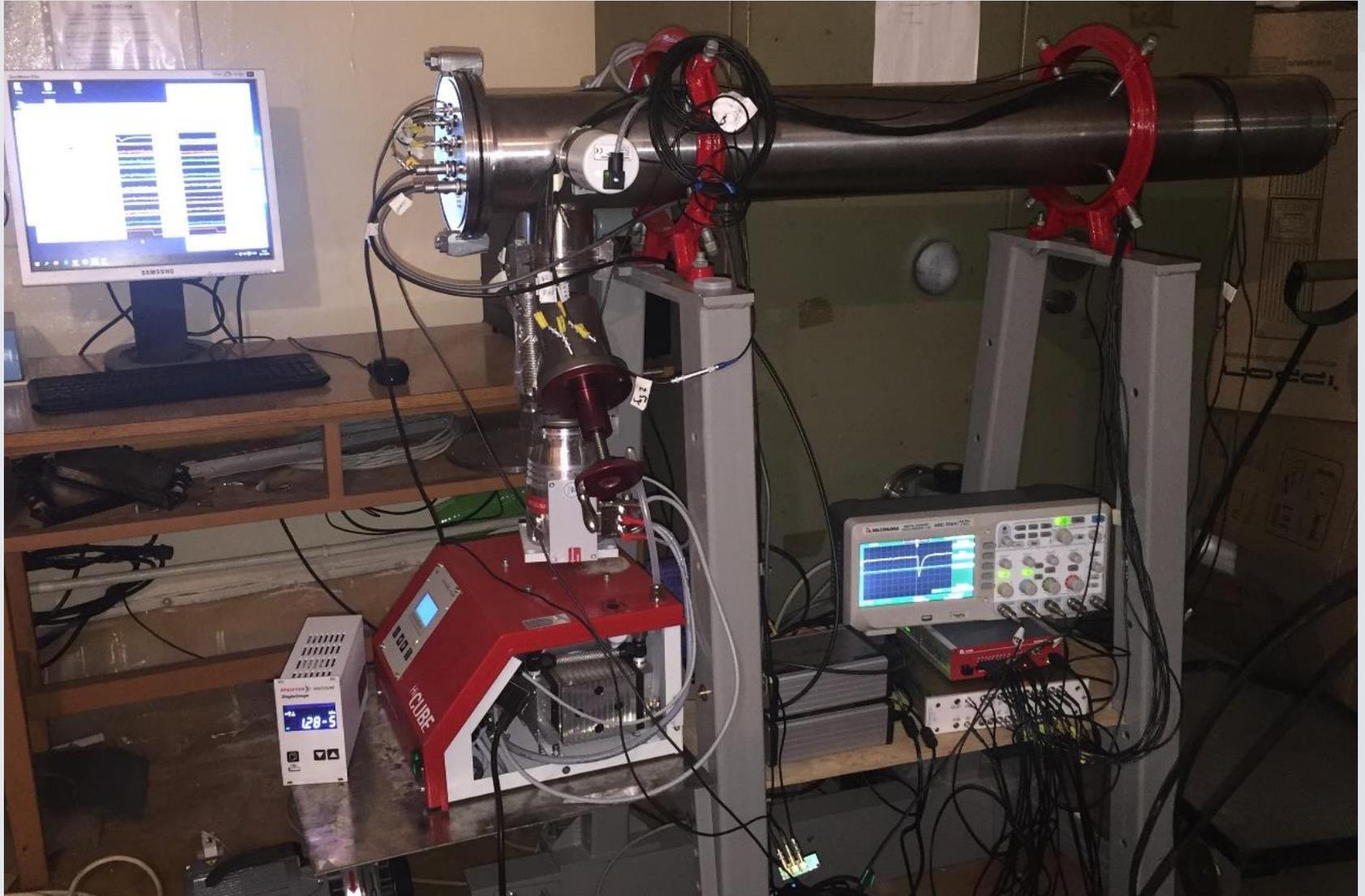
Energy calibration of a PIN diode

Mean value, channel	Energy, MeV
164.7	4.784
191.9	5.489
211	6.002
273.9	7.687

$$\text{Energy} = 0.387 + 0.027 \cdot \text{Channel number}$$

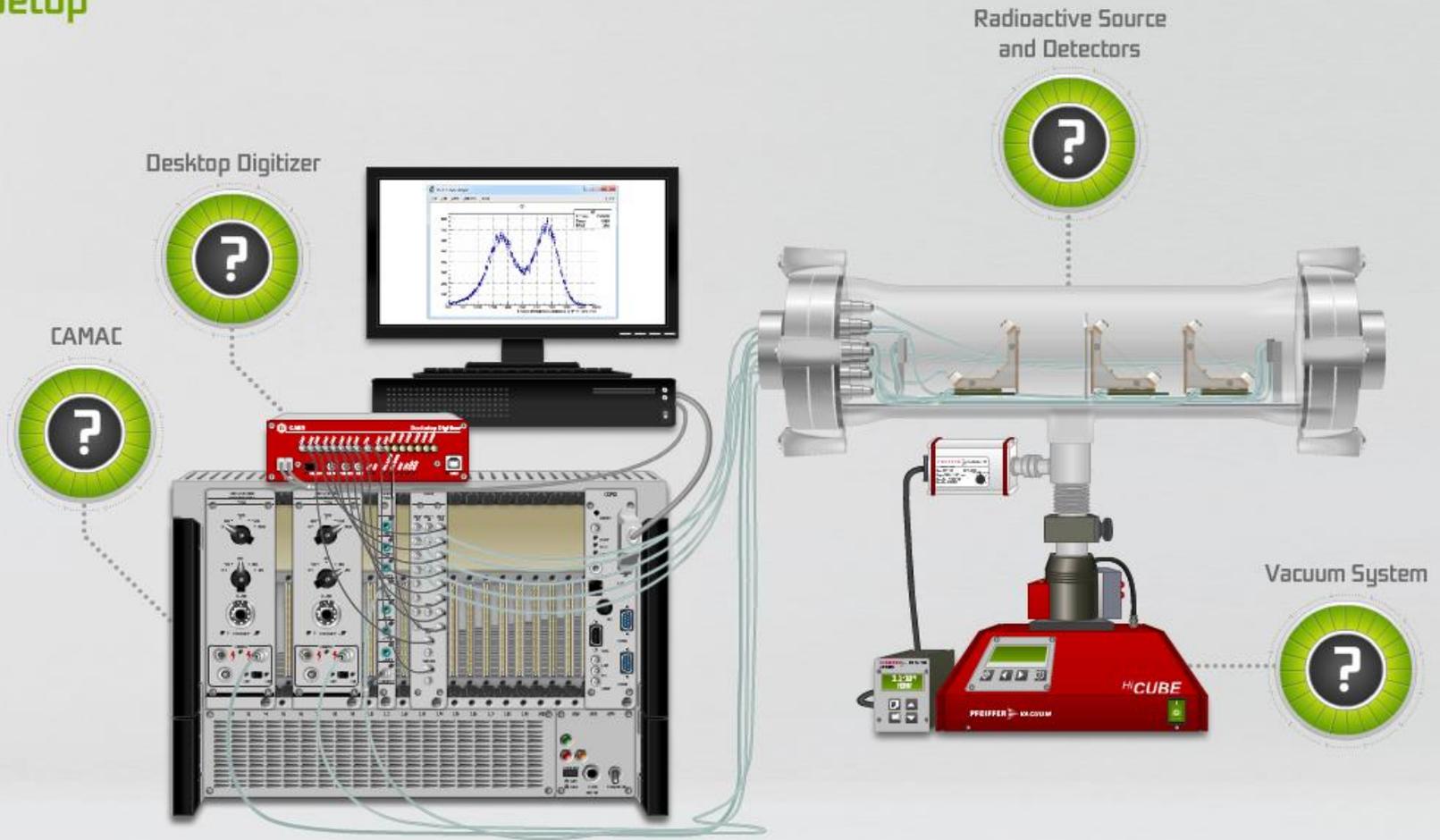
The obtained slope and intercept are the coefficients of the linear calibration of the energy scale of the PIN diode.

Light Ions Spectrometer

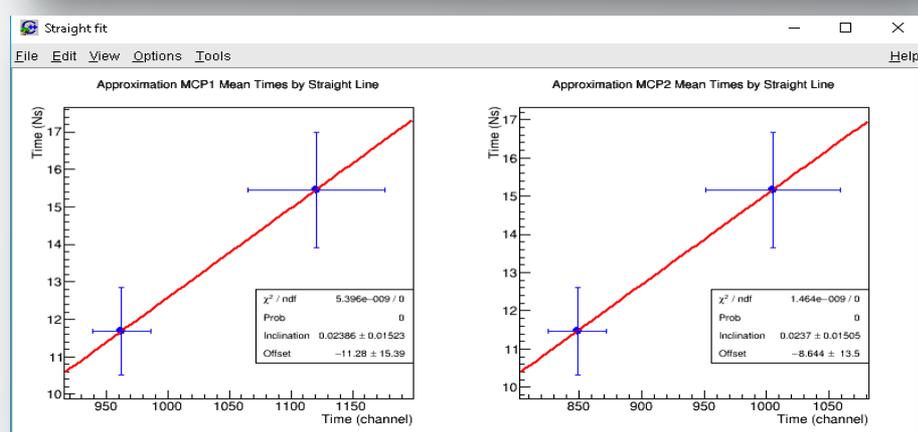
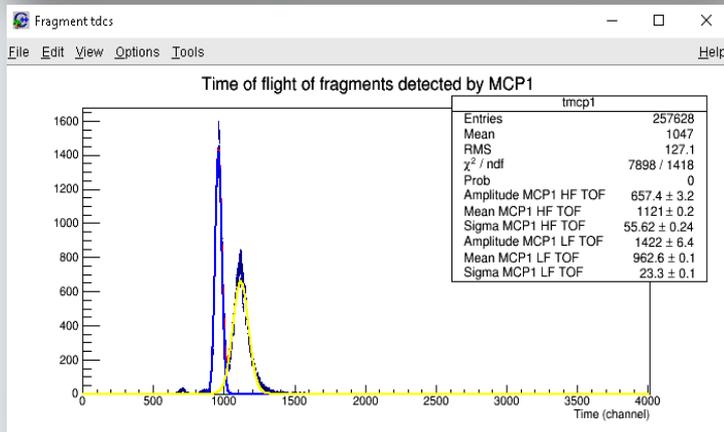
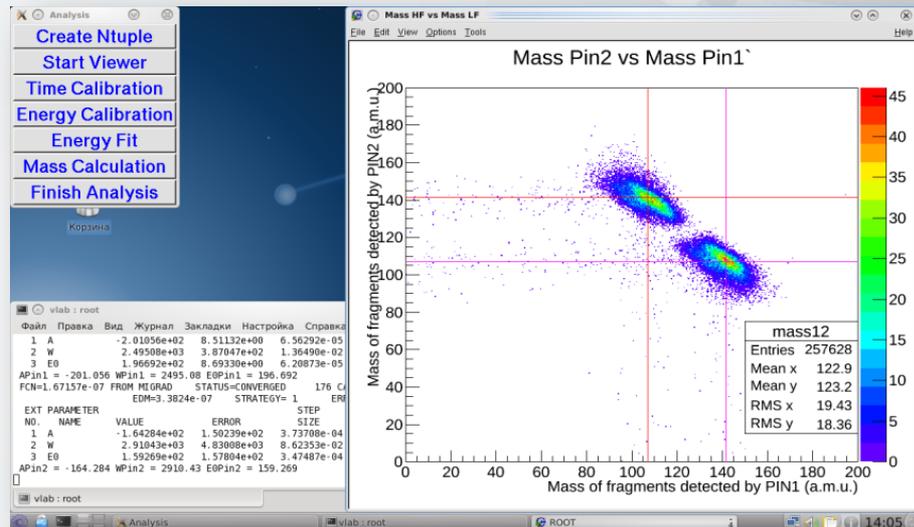
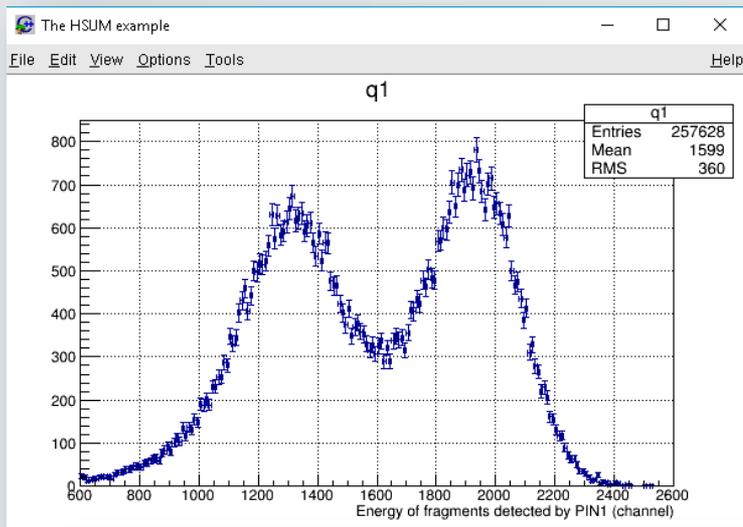


Light Ions Spectrometer

LIS Setup



Data Analysis



Hardware-Software Complex

“Interactive Environment for Nuclear Experiment Modeling”



$^{252}_{98}\text{Cf}$

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”

Number of counts

0 Channel

Linear

Log

Reset

Mean value:
0

Mem null

Number of channel

Sources

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

Cf-252

215

Sources Detectors Equipment CAMAC Wires Exit info save open clear all

You can arrange your own setup

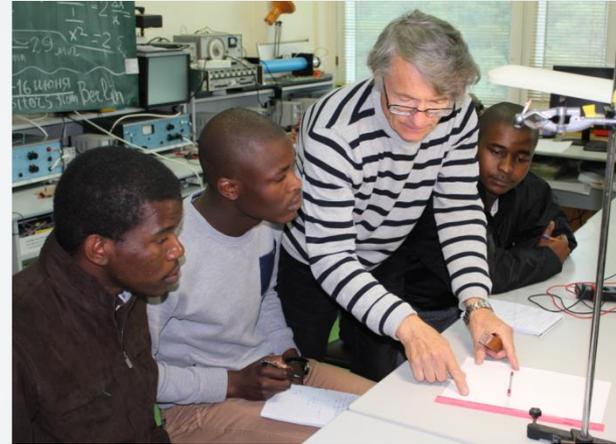
Student Practices



- Live lectures



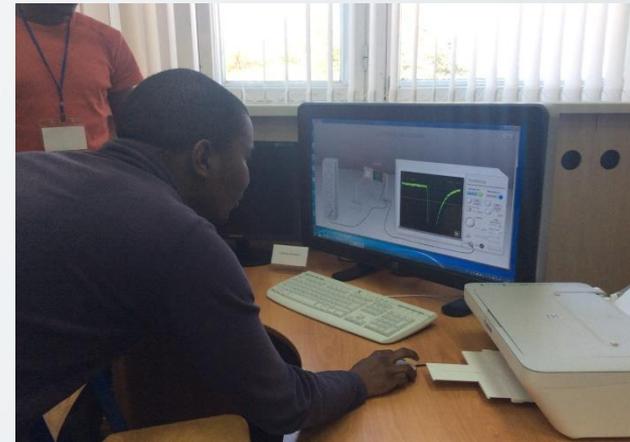
- Lab exercises



- Real equipment



- Virtual labs



Student Practices



Virtual Laboratory of Nuclear Fission

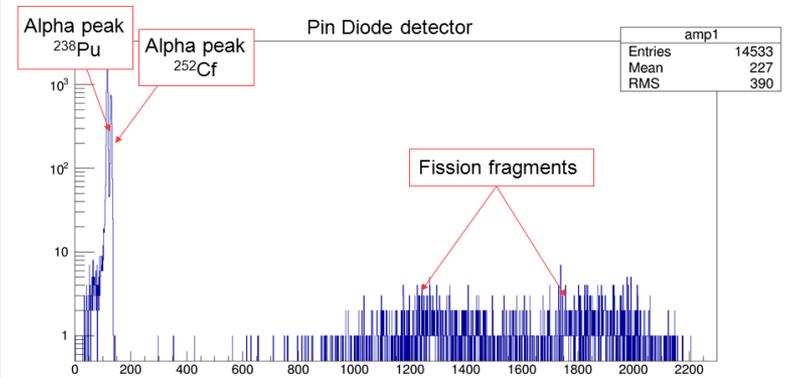


Data analysis of LIS spectrometer signals from 5 GS/s Switched Capacitor Digitizer.

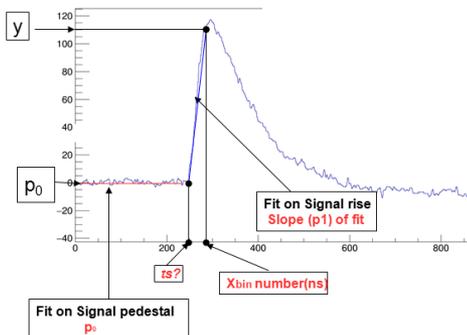
Kehinde Gbenga Tomiwa, University of the Witwatersrand

JINR – SAR, September 2015

Event Amplitude Distribution



Detector Spectra



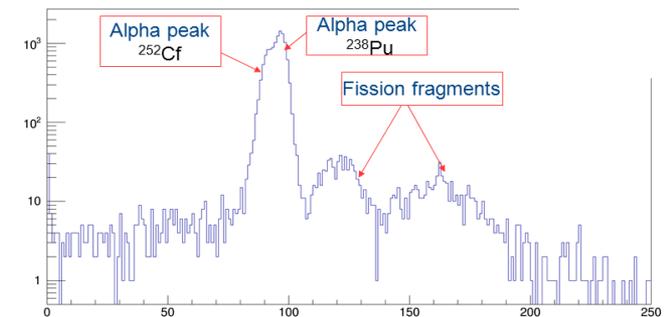
Method

- Draw amplitude distribution of all event.
- Define Start signal threshold to filter events
- Fit signal pedestal and rise time to obtain baseline and slope.

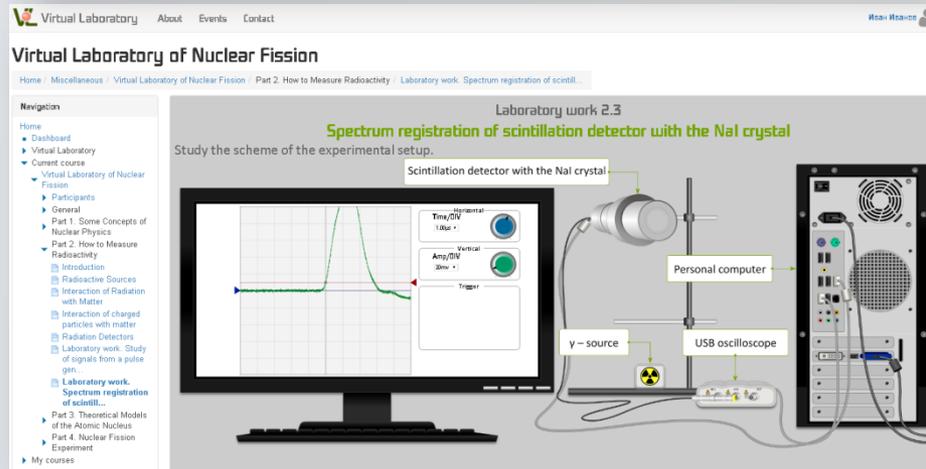
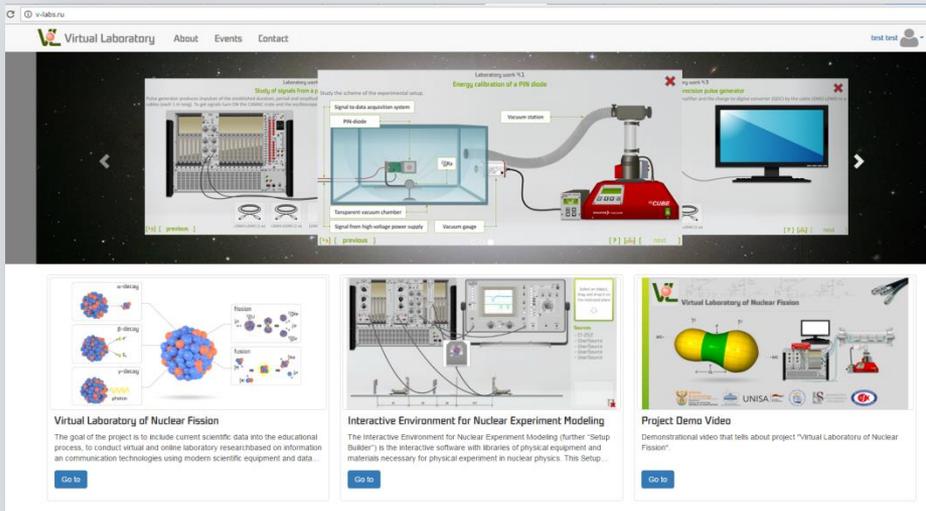
$$ts = X_{bin} - \frac{y - p_0}{p_1}$$

- Estimate ts for start and pin diode detector event by event

Time of Flight Distribution



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.