Stage B: Allo scoperta del nucleo atomico: l'esperimento di Rutherford

Giacomo Brunello
Anna Fiorentin
Leonardo Schiavo
Matteo Stefanelli

Stage C: Informatica e fisica sperimentale

Alessandro Benetton
Nicole Busdon
Matteo Catania
Nicola Vianello

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   - 2.2 The Experiment
   - 2.3 Cross Section and Kinematic Factor
   - 2.4 Graphs
3. **Experimental setup**
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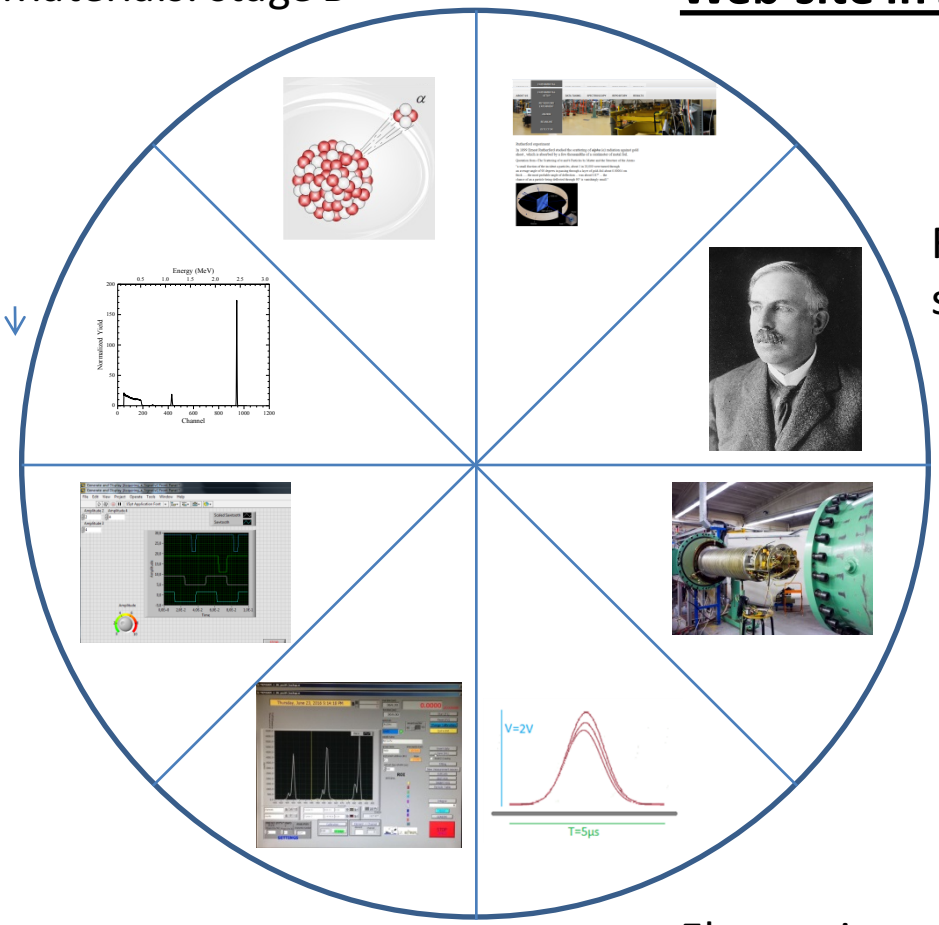
Interaction Radiation Materials: stage B

Web site in JOOMLA: stage C



Spectroscopy and Results: stage B

Rutherford Experiment: stage B

Experimental Setup: stage B

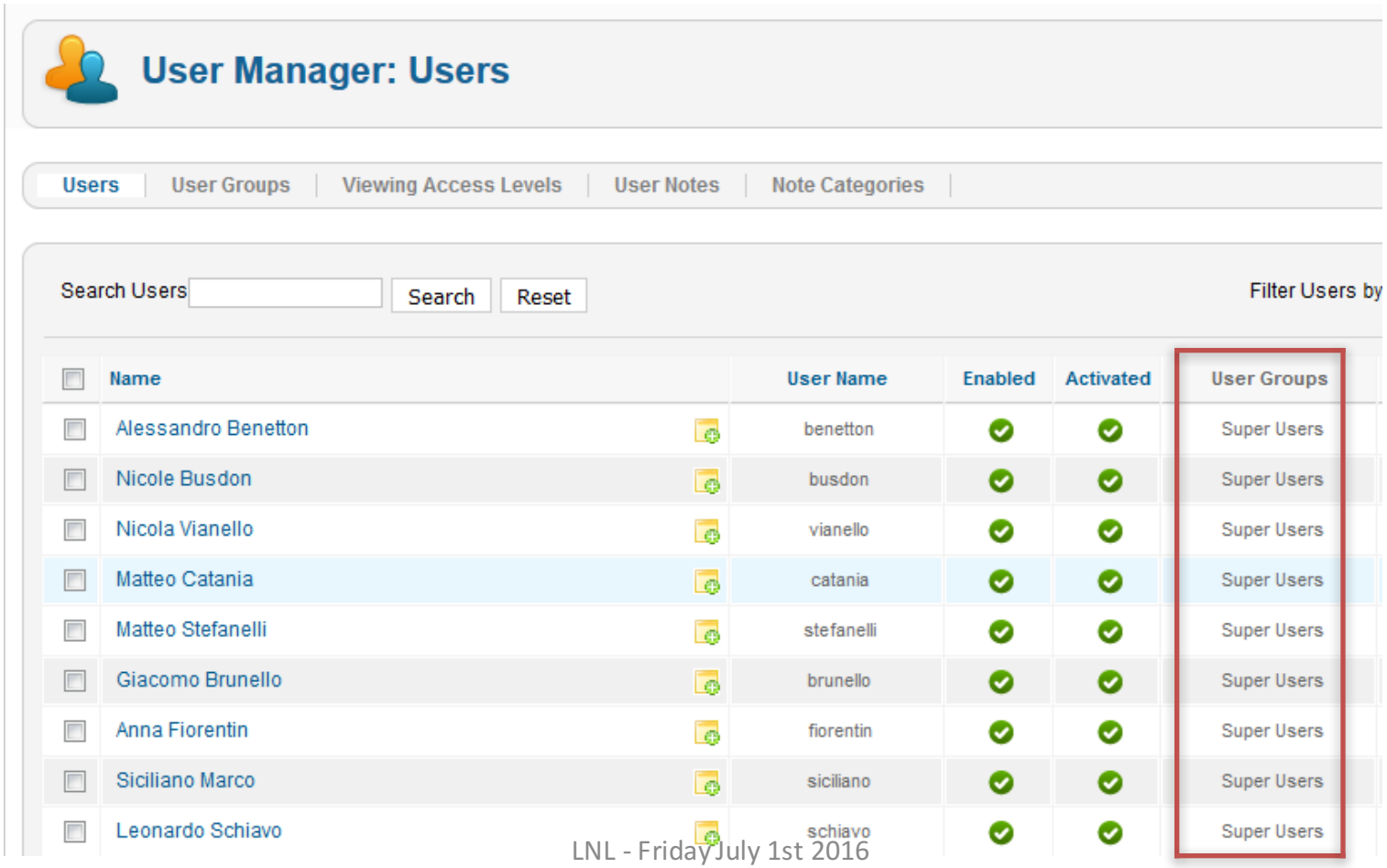
Software: stage C

Computing: stage C

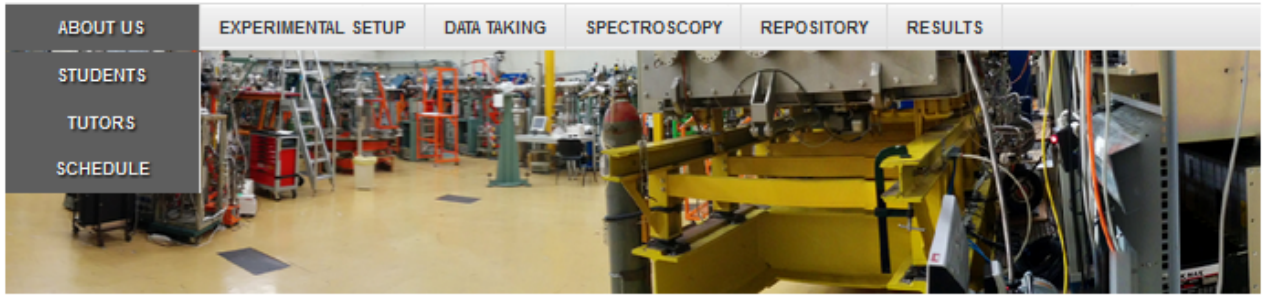
Electronics: stage C

WEB SITE ADMINISTRATORS

Web site link: http://jmtest.lnl.infn.it/~stage/administrator/index.php

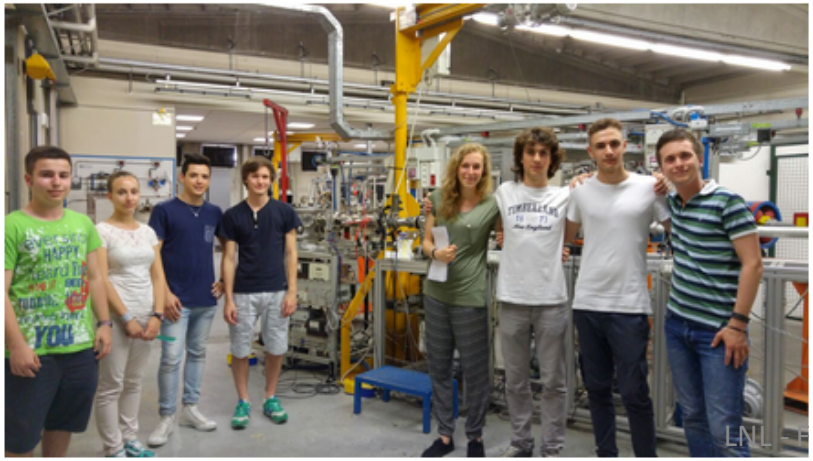


WEBSITE STRUCTURE



Istituto Nazionale di Fisica Nucleare (INFN)
Laboratori Nazionali di Legnaro (LNL)

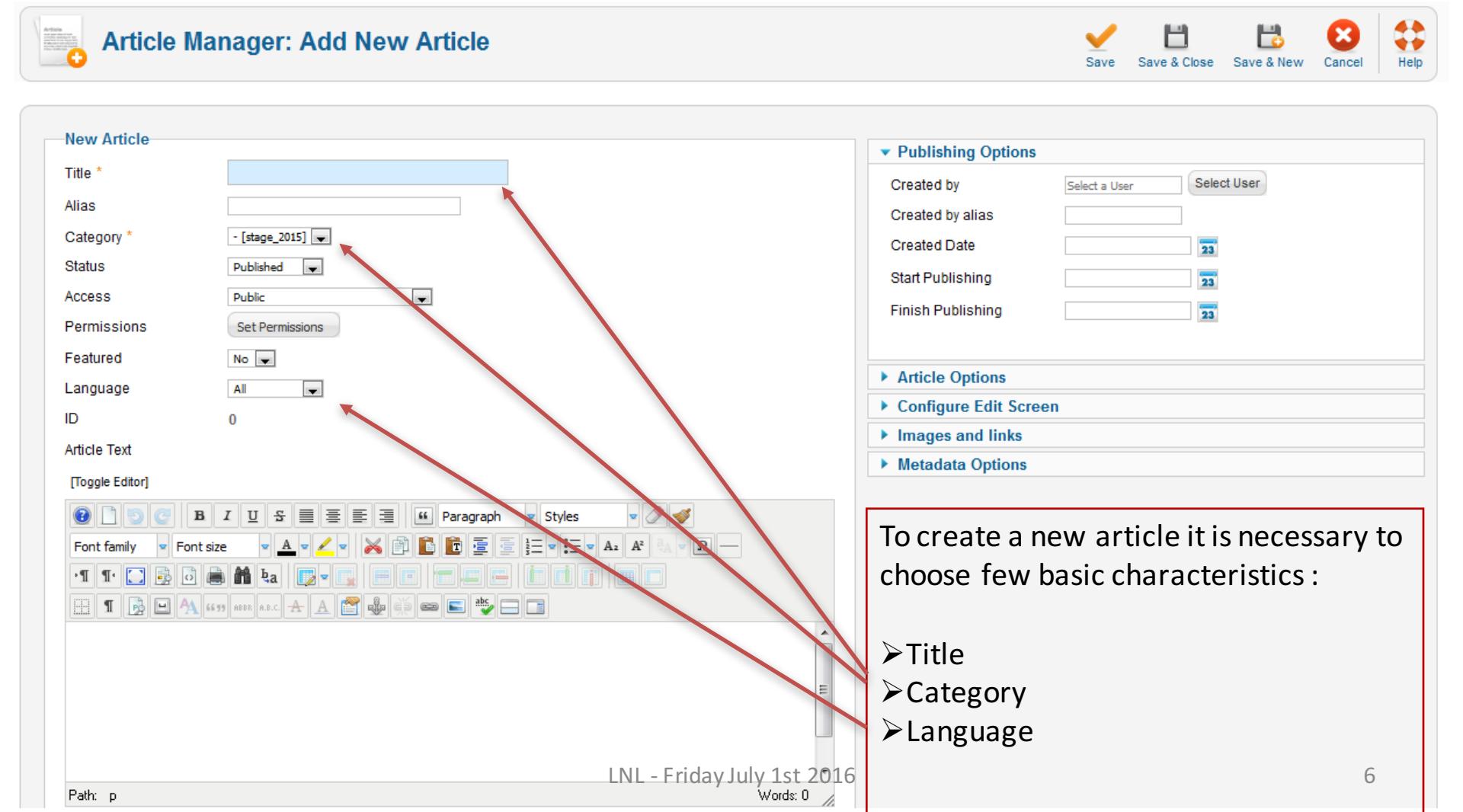
Stage 2016 (B e C):
"Alla scoperta del nucleo atomico: l'esperimento di Rutherford"
"Informatica e fisica sperimentale"



Every page presents:

- Drop-down menu
- Images
- Articles
- Possible tables and spectra

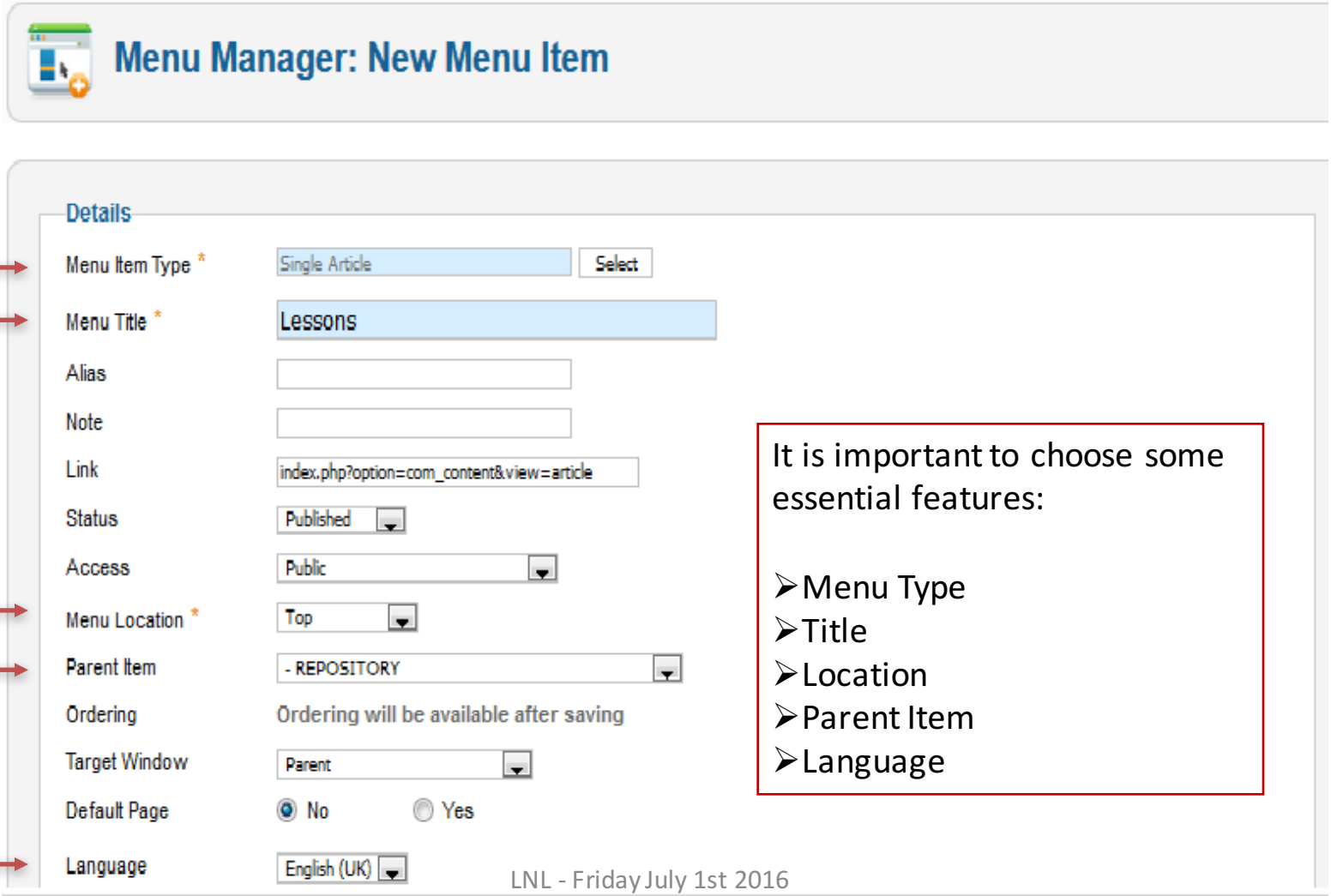
CREATION OF ARTICLES



To create a new article it is necessary to choose few basic characteristics :

- Title
- Category
- Language

CREATION OF MENU



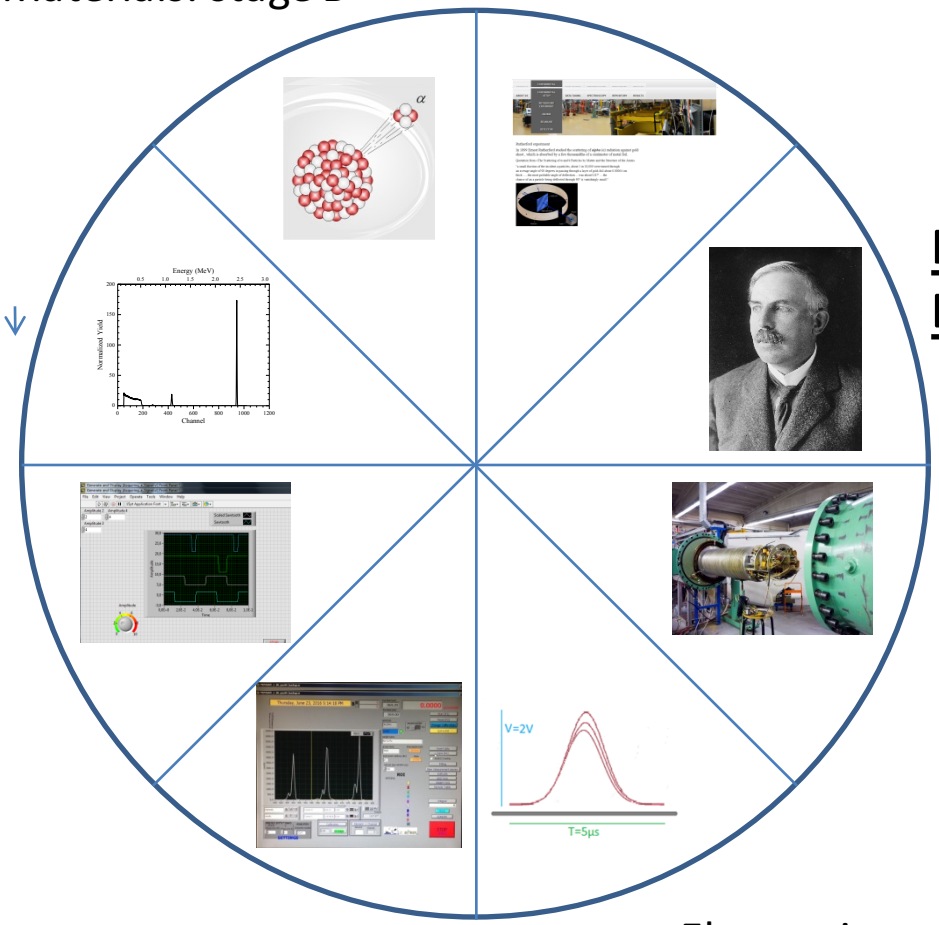
It is important to choose some essential features:

- Menu Type
- Title
- Location
- Parent Item
- Language

Interaction Radiation Materials: stage B

Web site in JOOMLA: stage C

Spectroscopy and Results: stage B



Rutherford Experiment: stage B

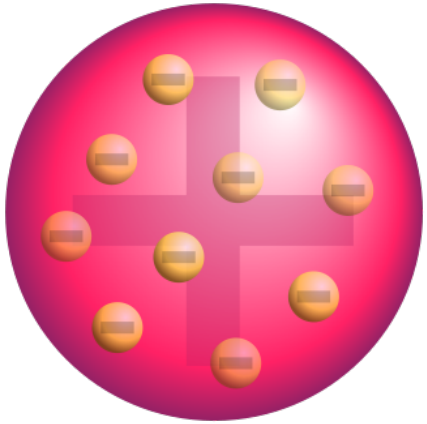
Software: stage C

Experimental Setup: stage B

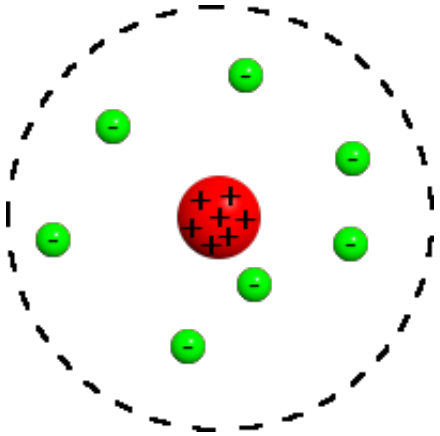
Computing: stage C

Electronics: stage C

ATOMIC MODELS



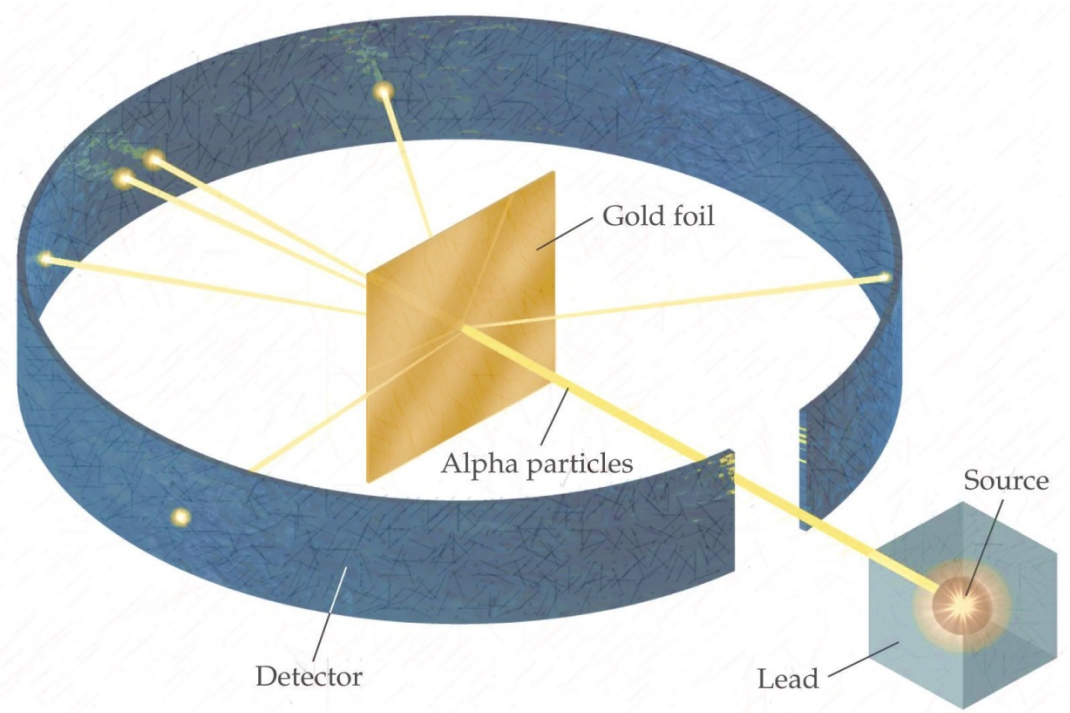
Plum Pudding Model
J. J. Thomson
1904 soon after the discovery of the electron

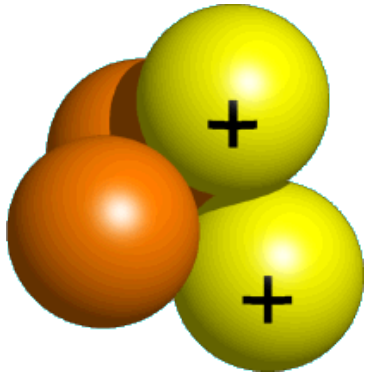


Rutherford Model
E. Rutherford
1911 after the experiment of
H. W. Geiger and E. Marsden

HOW DID THEY GET TO THIS RESULT?

RUTHERFORD EXPERIMENT
RBS (Rutherford BackScattering)





Alpha particle

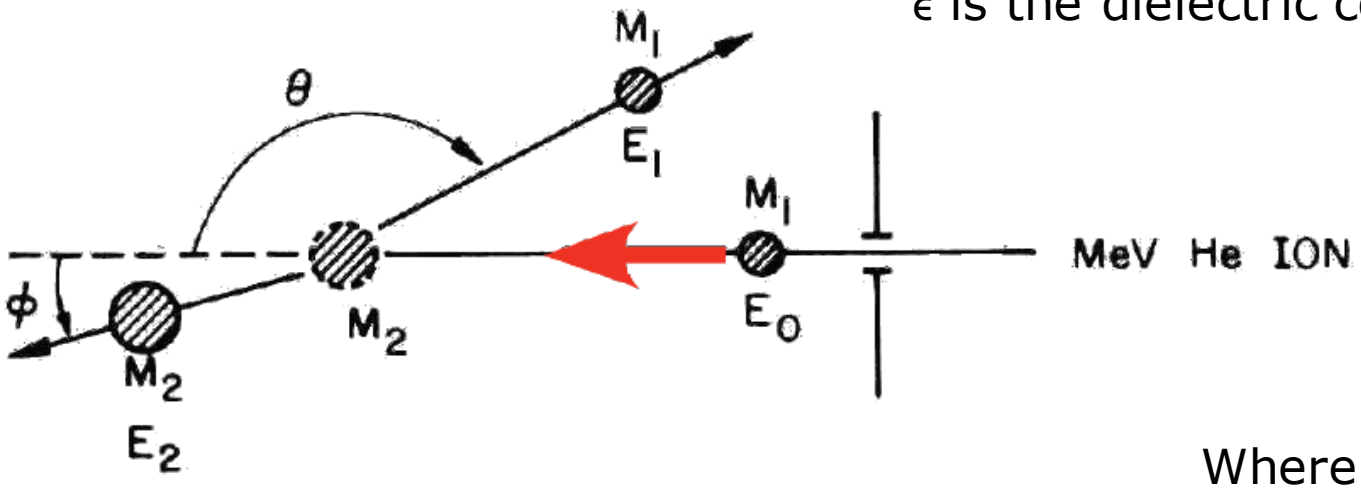
"a small fraction of the incident a particles, about 1 in 20,000 were turned through an average angle of 90 degrees in passing through a layer of gold-foil about 0.00004 cm thick [...] the most probable angle of deflection [...] was about 0.87° [...] the chance of an a particle being deflected through 90° is vanishingly small"

E. Rutherford, 1911

RUTHERFORD CROSS SECTION AND KINEMATIC FACTOR

$$\frac{d\sigma}{d\Omega} = \left(\frac{\alpha}{4E}\right)^2 \frac{1}{\left(\sin\frac{\theta}{2}\right)^4} \qquad \alpha = \frac{Z_1 Z_2 e^2}{4\pi\varepsilon_0}$$

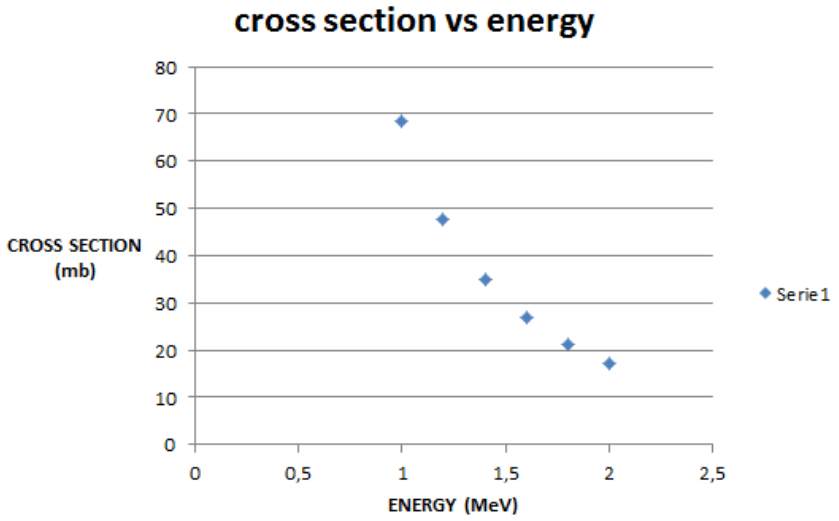
σ is the cross section
Ω is the solid angle of the detector
E is the energy of the particles
θ is the scattering angle
Z is the number of protons
e is the elementary electric charge
ϵ is the dielectric constant

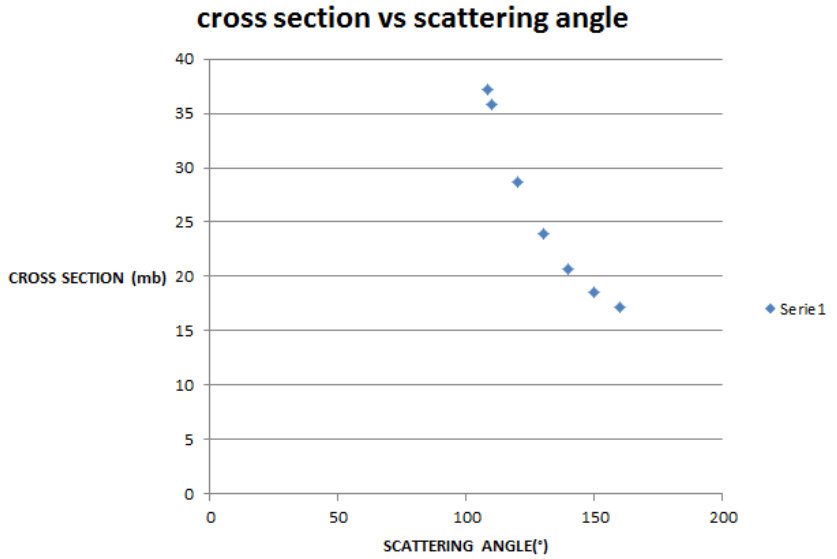


$$E_1 = kE_0$$

Where k is the kinematic factor

THEORETICAL CROSS SECTION (I)

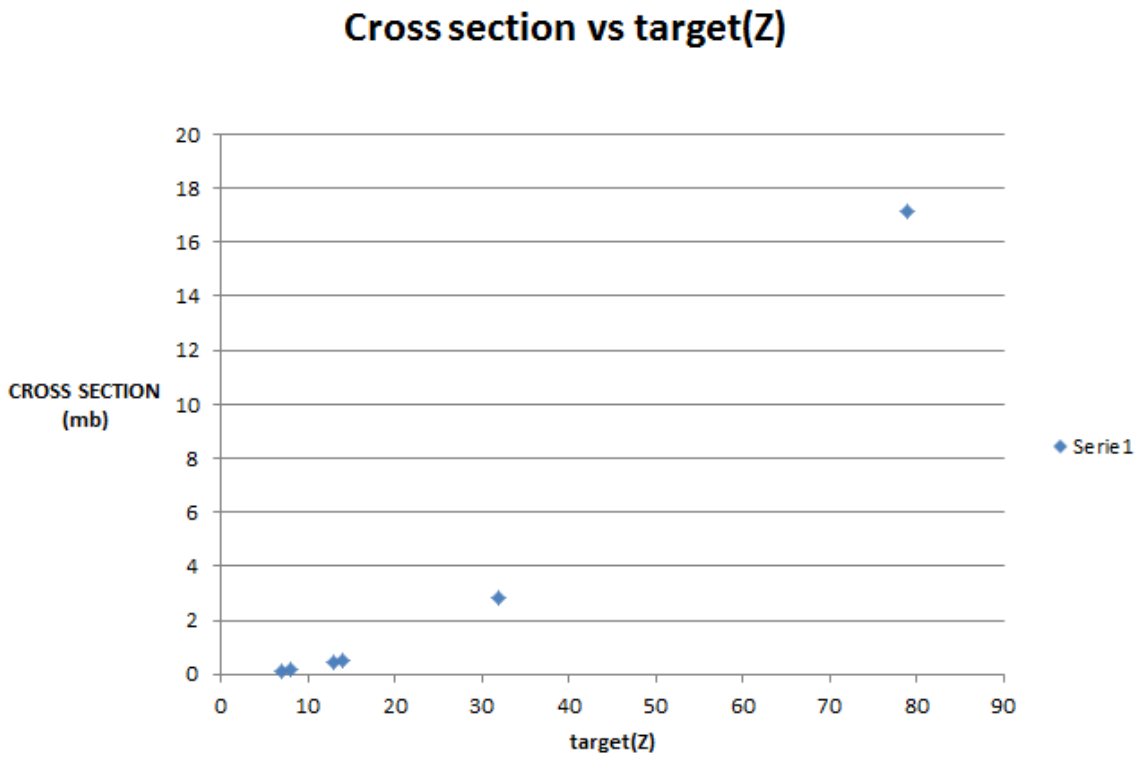




Energy [MeV]	Cross section [mb]
2,0	17,16
1,8	21,17
1,6	26,79
1,4	35,00
1,2	47,63
1,0	68,59

theta [°]	Cross section [mb]
20,0	17,16
30,0	18,53
40,0	20,69
50,0	23,91
60,0	28,68
70,0	35,82
71,5	37,18

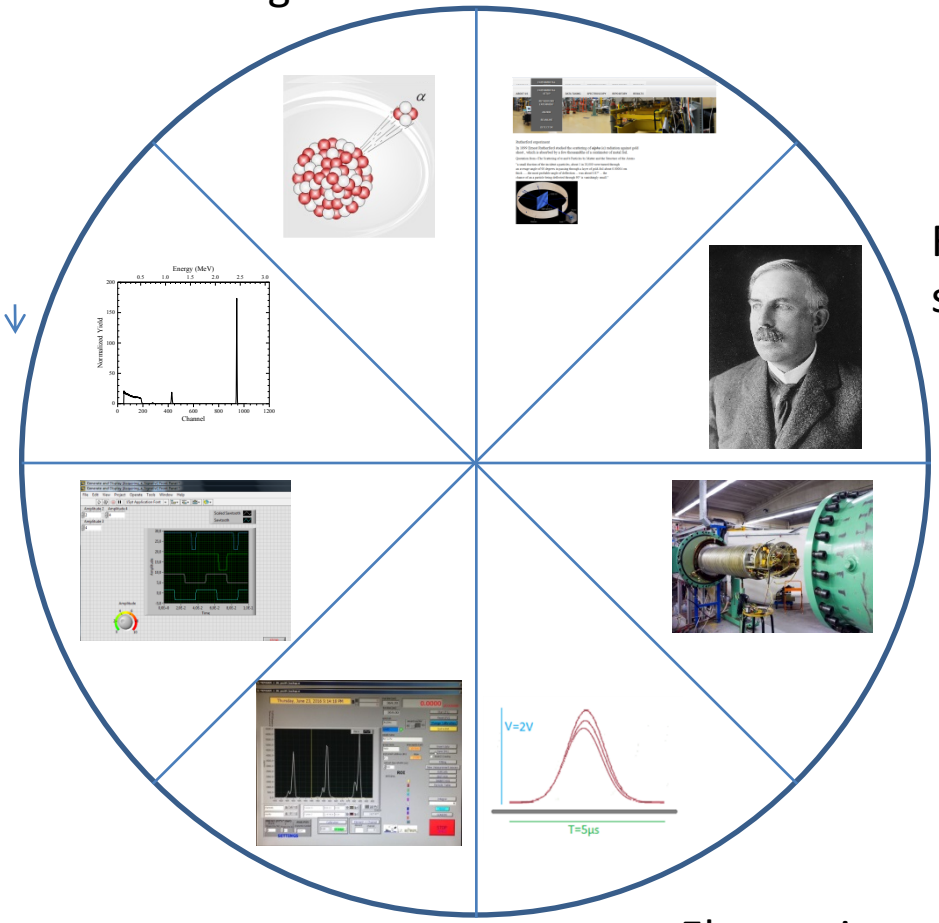
THEORETICAL CROSS SECTION (II)



Z Target	Cross section [mb]
7	0,13
8	0,18
13	0,46
14	0,54
32	2,82
79	17,16

Interaction Radiation Materials: stage B

Web site in JOOMLA: stage C



Spectroscopy and Results: stage B

Rutherford Experiment: stage B

Experimental Setup: stage B

Software: stage C

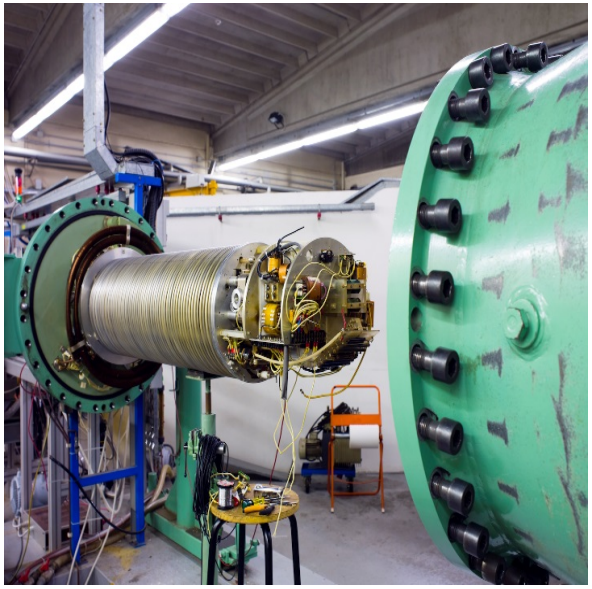
Computing: stage C

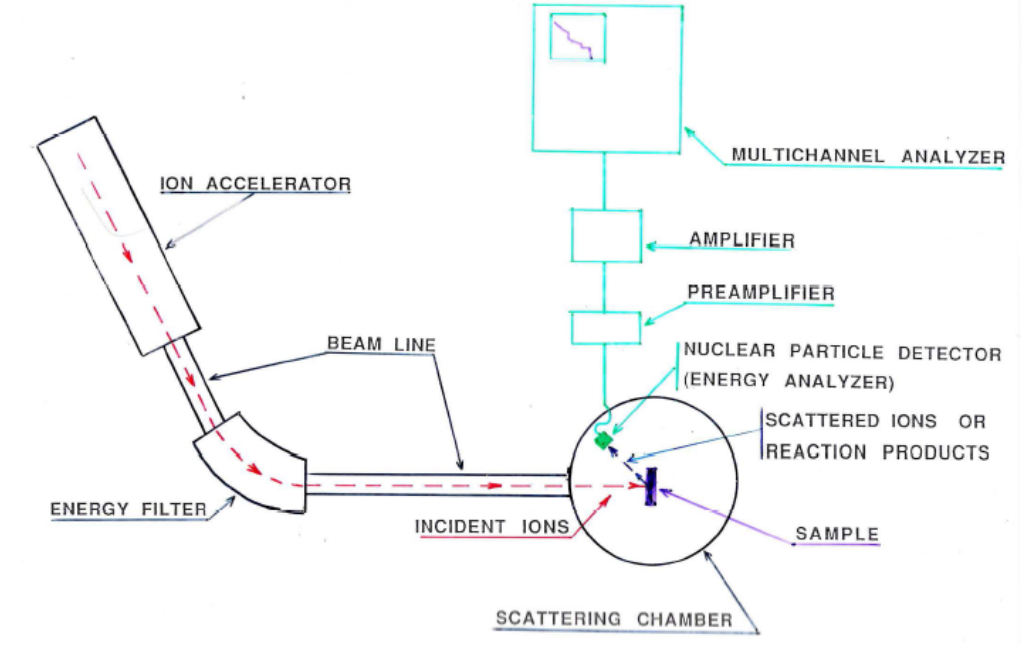
Electronics: stage C

AN 2000

- The **AN2000** is an electrostatic accelerator (with a voltage terminal of 2MV)

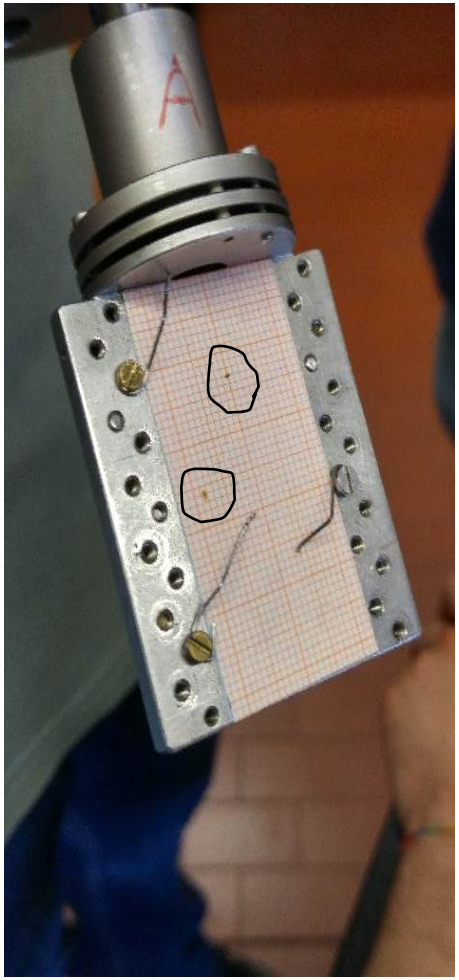
- It can accelerate <u>protons</u> or <u>helium ions</u> (alpha particles)



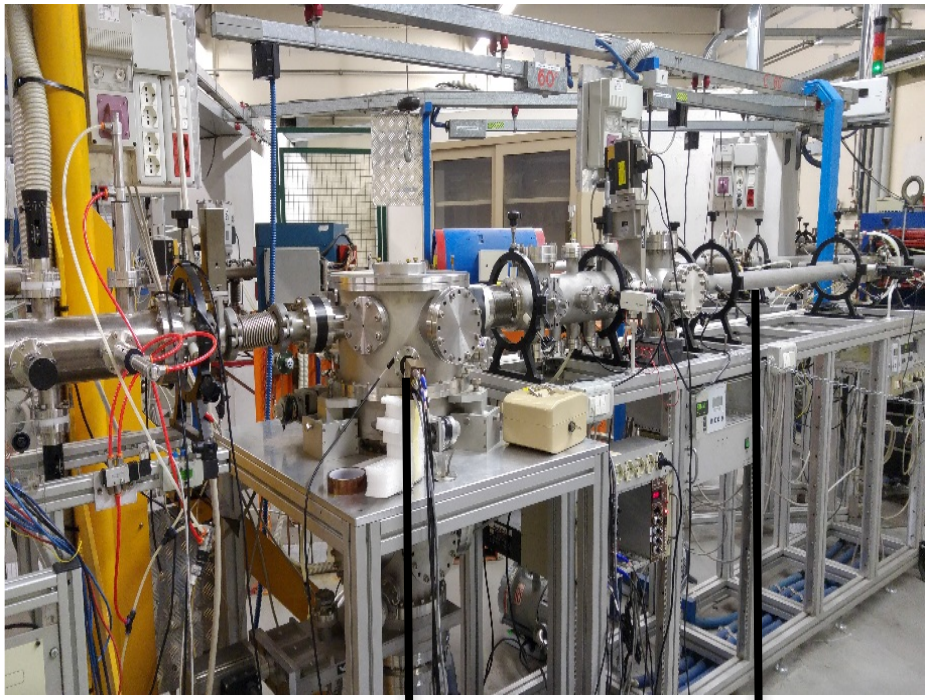


- Using the AN2000 accelerator, detailed measurements for the <u>elemental composition analysis of any material</u> can be performed, by bombarding samples and identifying the particles which are produced in <u>the beam interaction with the target.</u>

BEAM LINE



- **Beam Line**: a line with a few mm transverse size
- Beam line at 60°
- **Beam**: $^{4}He^{+}$ (alpha particles)
- **Pressure**: 10^{-6} mbar (vacuum, which is produced by 2 pumps under the reaction chamber)



Reaction Chamber

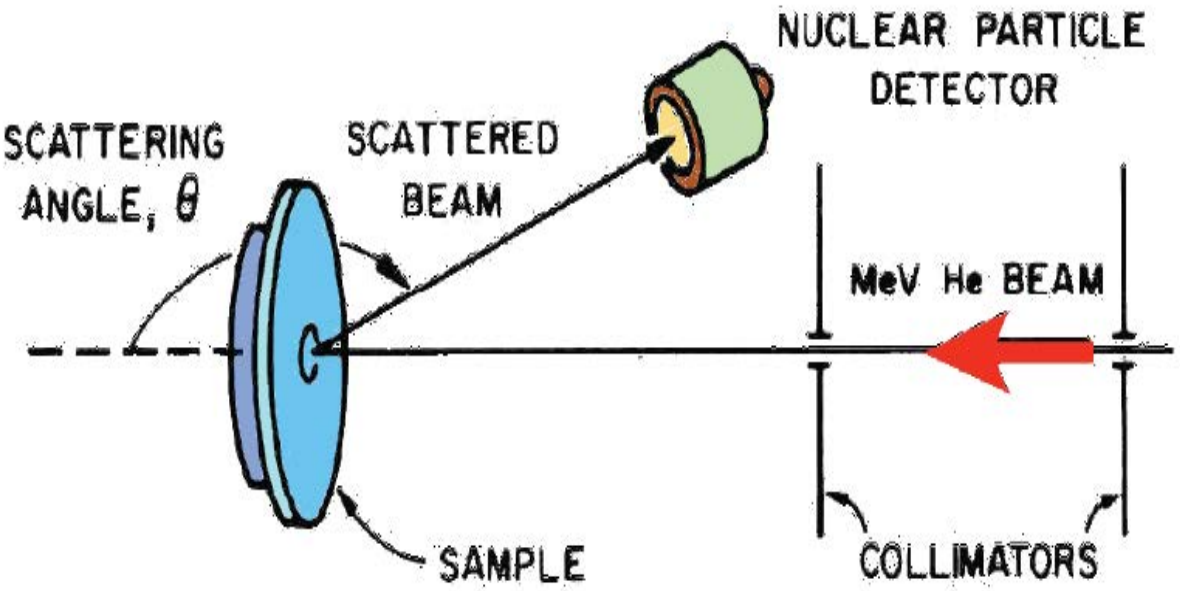
Beam Line

DETECTOR

- The detector used in the experiment is an instrument which measures the time of the passage of a particle and the energy of that particle

- Characteristics:

1. Sensitivity
2. Detector response
3. Energy resolution
4. Detector efficiency
5. Dead time

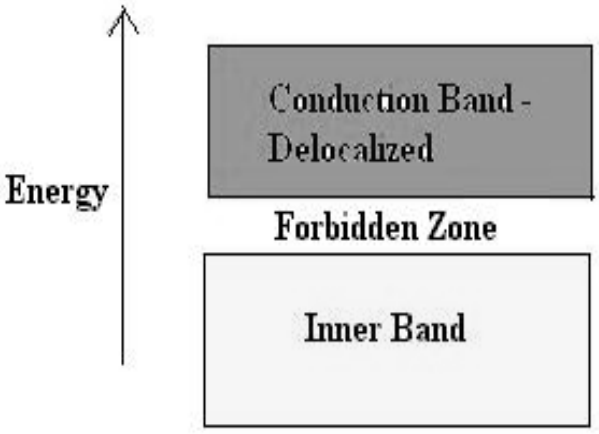


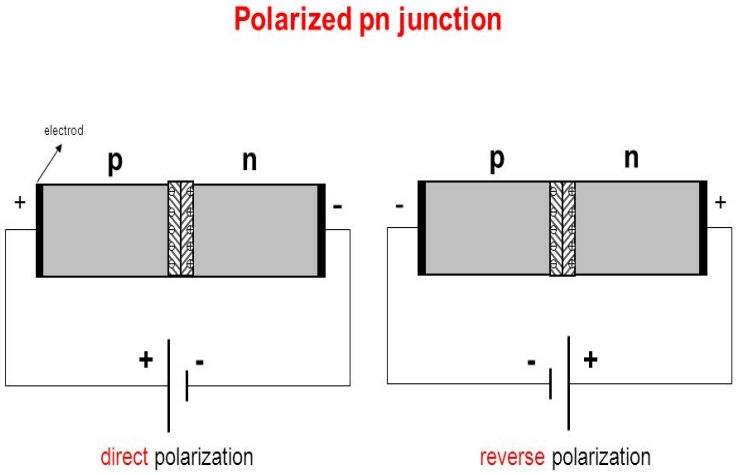
SEMICONDUCTORS

- At temperatures near 0 K, **semiconductors** are similar to insulators, while, when the temperatures are higher, they can conduct current (as the conductors)

- **Doping** (electron and electron holes):

1. n-doping (more e^- than e^- holes)
2. p-doping (more e^- holes than e^-)



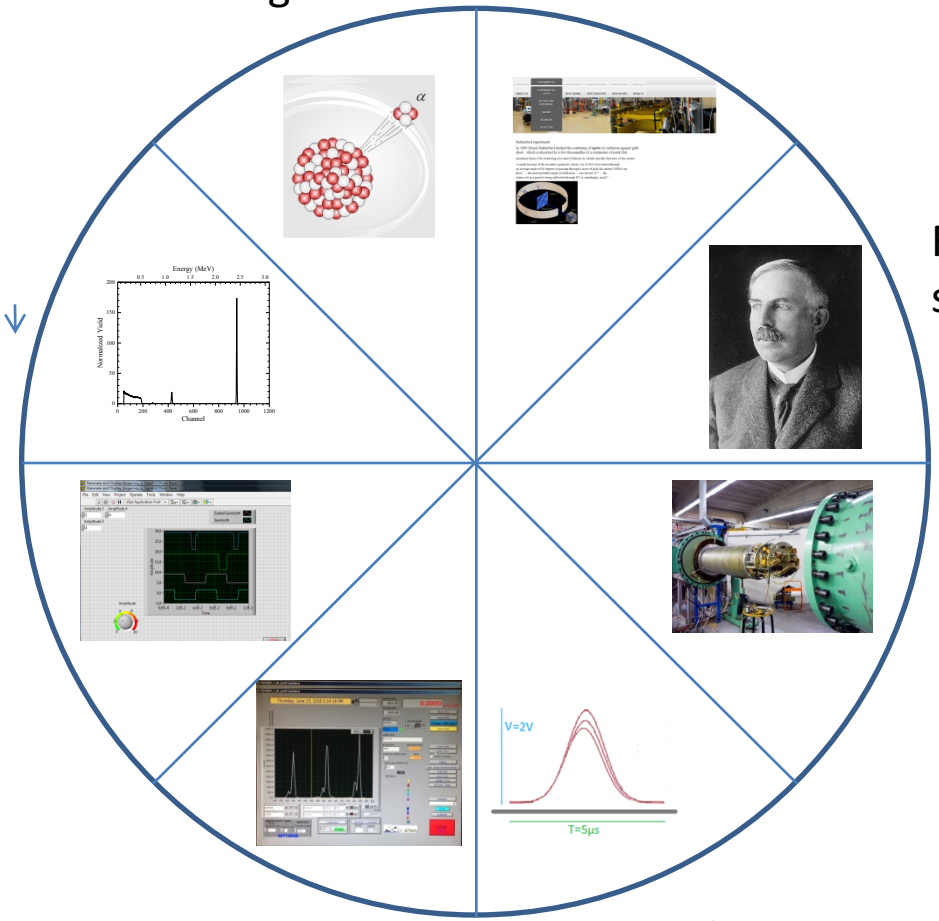


SILICON DETECTOR

- The **detector** was: solid, semiconductor and made of silicon.
- **Power supply**: 40 V
- **Active area**: 0,13 cm^2
- **Solid angle**: 2 msr
- **Resolution**: 13.5 keV
  (at the energy of pulser: 2.38 MeV)
- **Resolution** (*with α source*): 36 keV
  (at the energy of Am-241: 5.484 MeV)

Interaction Radiation Materials: stage B

Web site in JOOMLA: stage C



Spectroscopy and Results: stage B

Rutherford Experiment: stage B

Experimental Setup: stage B

Software: stage C

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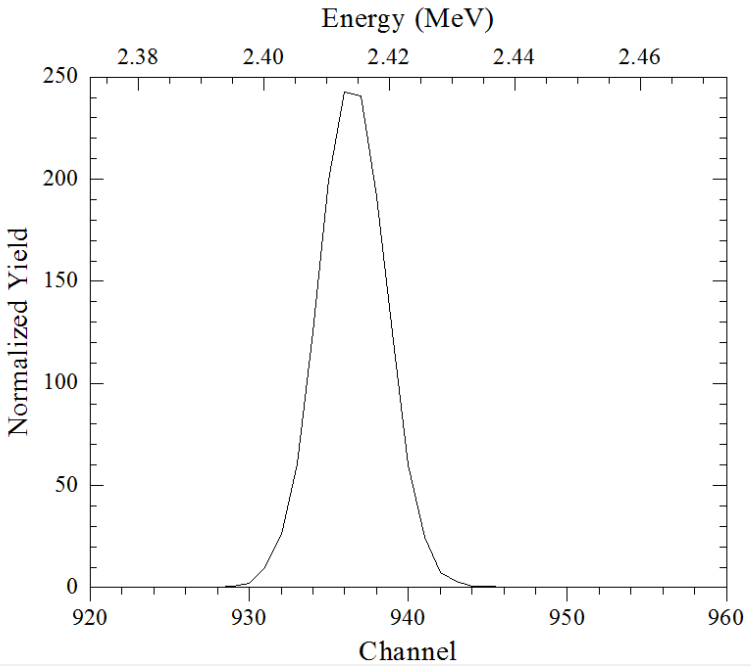
PULSE GENERATOR

It is a device which generates a pulse used to determine the channel corresponding to a defined amount of energy. This appliance doesn't belong to acquisition chain but it is an important device which allows to know if acquisition chain works accurately and it is useful to determine detector resolution.



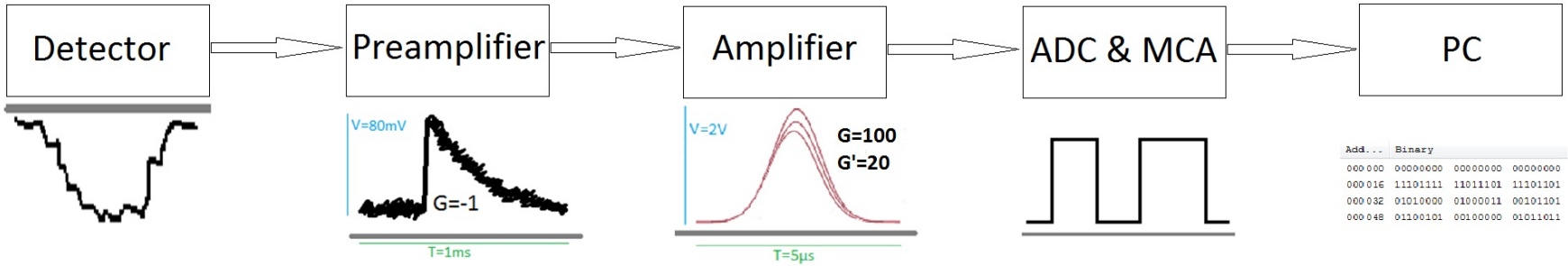
Pulse generator peak

ACQUISITION CHAIN

The main purpose of the acquisition chain is to achieve some information like:

- Rate (number of counts)
- Registered energy
- Detection time

Basic electronic chain is composed of:



ADC: Analog to Digital Converter
MCA: MultiChannel Analyzer

PREAMPLIFIER

It is a device situated near the detector: it overturns the signal generated by the detector and has the essential function to return as output a signal whose width is proportional to the energy released by the radiation in the detector.

Gain: -1

AMPLIFIER

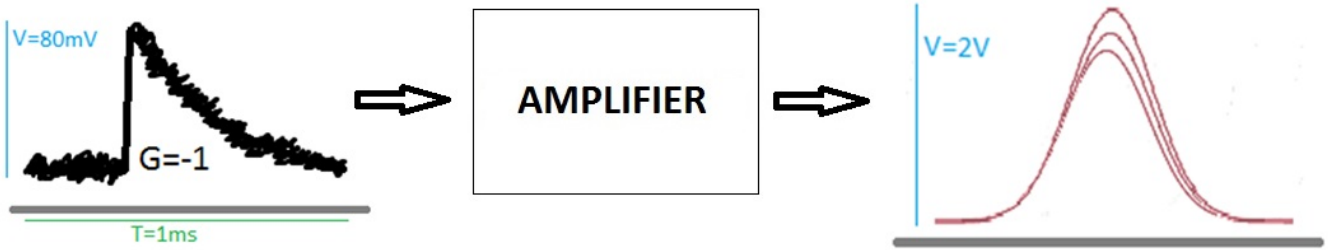
It is a device which filters the signal coming from the preamplifier reducing electronic noise. It shapes the signal to make it more suitable for Analog to Digital Converter (ADC):

- Amplitude proportional to the energy deposited from radiation
- Gaussian waveform
- Rising time greater than 500 ns

In most cases the rising time of signals coming out from the preamplifier and entering the amplifier reflects charge-collection time.

Used gain:

- 100 (in measurements with beam)
- 20 (in measurements with source)

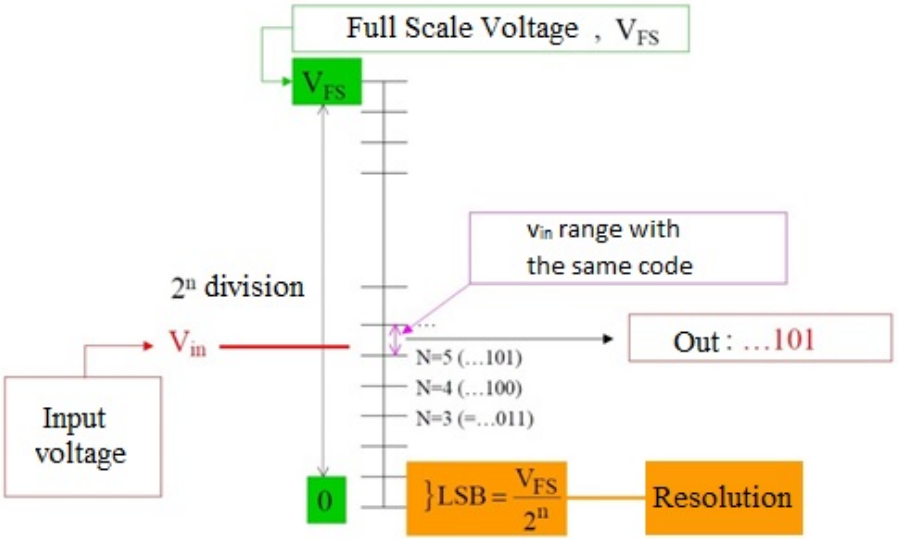


ANALOG TO DIGITAL CONVERTER (ADC) & MULTICHANNEL (MCA)

It is a device which converts analog signal to digital signal. It returns a series of bits (0/1), which will be read by Data Acquisition System (DAQ).

Used ADC:

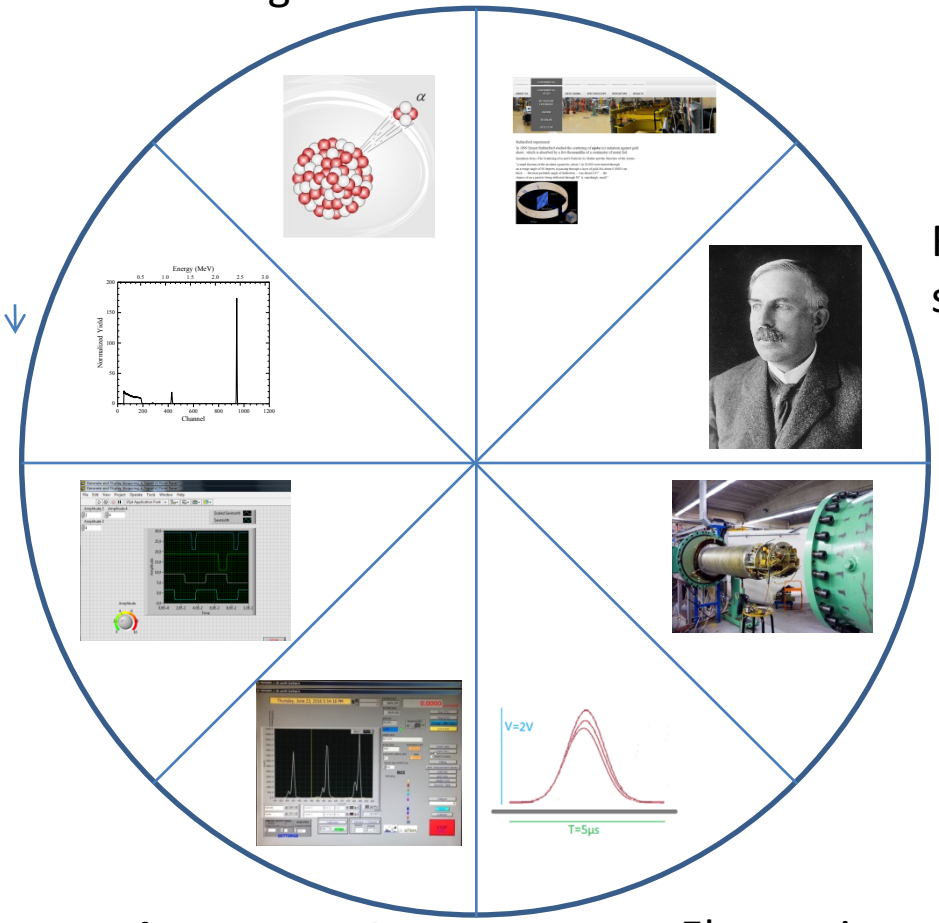
- Multichannel: 0÷1023 channel
- Samples frequency: 10MHz



Interaction Radiation Materials: stage B

Web site in JOOMLA: stage C

Spectroscopy and Results: stage B



Rutherford Experiment: stage B

Software: stage C

Experimental Setup: stage B

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Electronics: stage C

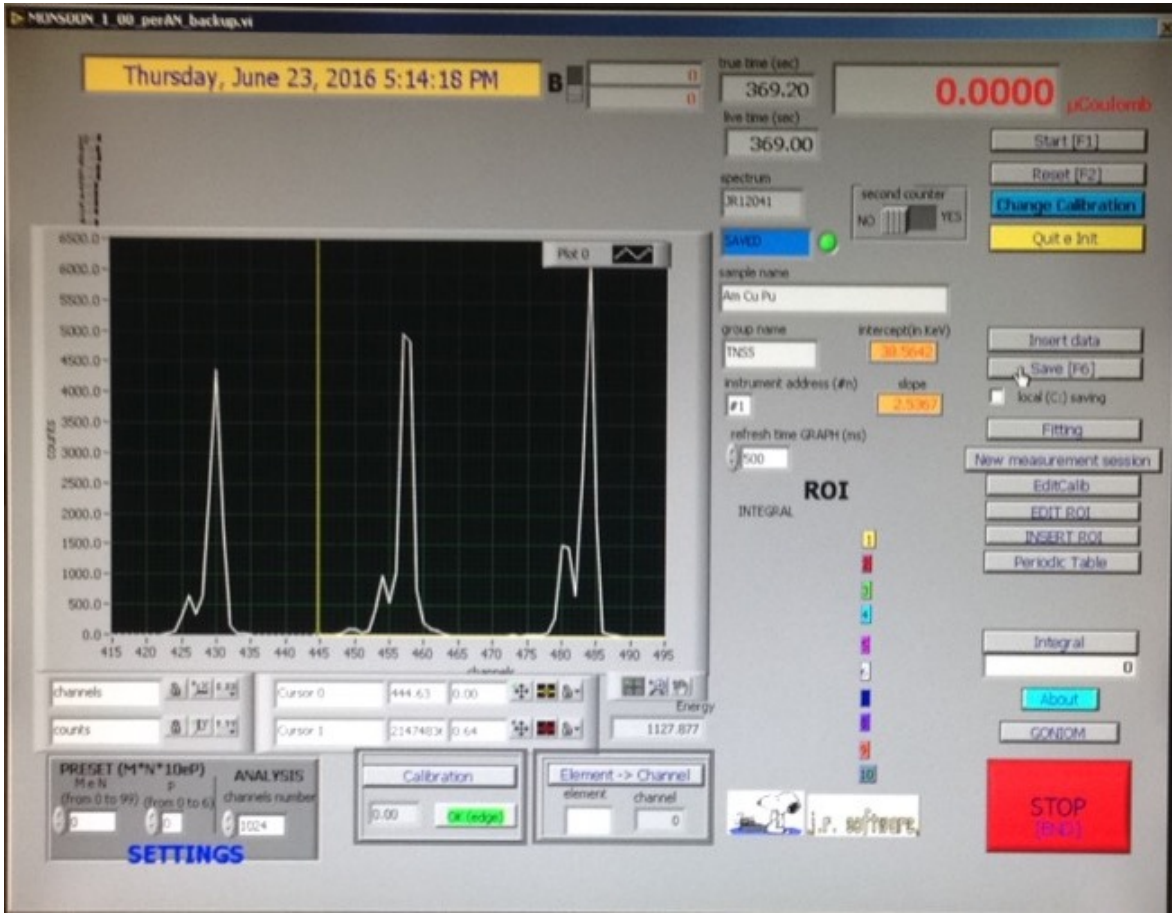
BINARY VIEW OF THE RESULTS

Acquired data were saved in a binary file with the extension .rbs (Rutherford BackScattering)

Add...	Binary													
000 000	00000000	00000000	00000000	00000101	00000000	00000000	00000000	00000000	00010000	00100001	00010010	00010000	00000000	00000001
000 016	11101111	11011101	11101101	11101011	00000000	00000000	00000000	00001011	00000000	00000000	00000000	00000010	00000000	00000000
000 032	01010000	01000011	00101101	01010010	01010101	01001101	01010000	00100000	01100100	01100001	01110100	01100001	00100000	01100110
000 048	01100101	00100000	01011011	01110110	00100000	00110001	00101110	00110000	01011101	00000000	00000000	00000000	11110011	01010110
000 064	00000000	00000000	00000000	00001100	00000000	00000000	00000001	00000001	00000000	00000000	00000000	00100000	01001010	01010010
000 080	00110000	00110010	00110101	00100000	00100000	01010010	01000010	01010011	00100000	00100000	00100000	00100000	01000001	01110101
000 096	01101001	00100000	01110100	01101000	01100101	01110100	01100001	00100000	00110111	00110001	00101110	00110101	11111101	11001110
000 112	00000000	00000000	00000000	00010000	00000000	00000000	00000001	00000010	00000000	00000000	00000000	00101111	01110100	01110010
000 128	00100000	01110100	01101001	01101101	01100101	00111010	00110101	00110100	00110010	00101110	00110110	00110000	00001001	01101100
000 144	01100101	00100000	01110100	01101001	01101101	01100101	00111010	00110101	00110100	00110000	00101110	00110000	00110000	00001001
000 160	01110101	01101110	01110100	01100101	01110010	00110010	00111010	00110000	00101110	00110000	00110000	00000000	01111101	10110100
000 176	00000000	00000000	00000000	00001001	00000000	00000000	00000001	00000011	00000000	00000000	00000000	00010001	00110110	00101111
000 192	00101111	00110010	00110000	00110001	00110110	00001001	00110001	00111010	00110010	00111001	00100000	01010000	01001101	01101100
000 208	11100100	11101111	11100001	01111111	00000000	00000000	00000000	00001001	00000000	00000000	00000001	00010001	00111111	11111111
000 224	00000000	00000000	00000000	00000010	01000000	10000000	00010101	01001101	00000000	00000000	00000000	00000001	01000001	00000000
000 240	01000001	01110000	00000000	00000000	11111101	00001111	01010000	01100110	00000000	00000000	00000000	00000111	00000000	00000000
000 256	01000000	00100010	01011000	10111111	01000010	00011010	01000001	10111001	00000000	00000000	00000000	00000000	01000001	10010000
000 272	00111100	00110011	01100100	01101111	00000000	00000000	00000000	00001000	00000000	00000000	00000001	00100000	00000000	00000000
000 288	00000000	00000000	00000000	00000000	01000010	10001111	00000000	00000000	00000000	00000000	00000000	00000000	00111111	10000000

GUI (Graphic User Interface) DAQ (Data AcQuisition)

This is the interface used to acquire data from the detector



Every time a Run is saved the software creates a new file and increments the run number.

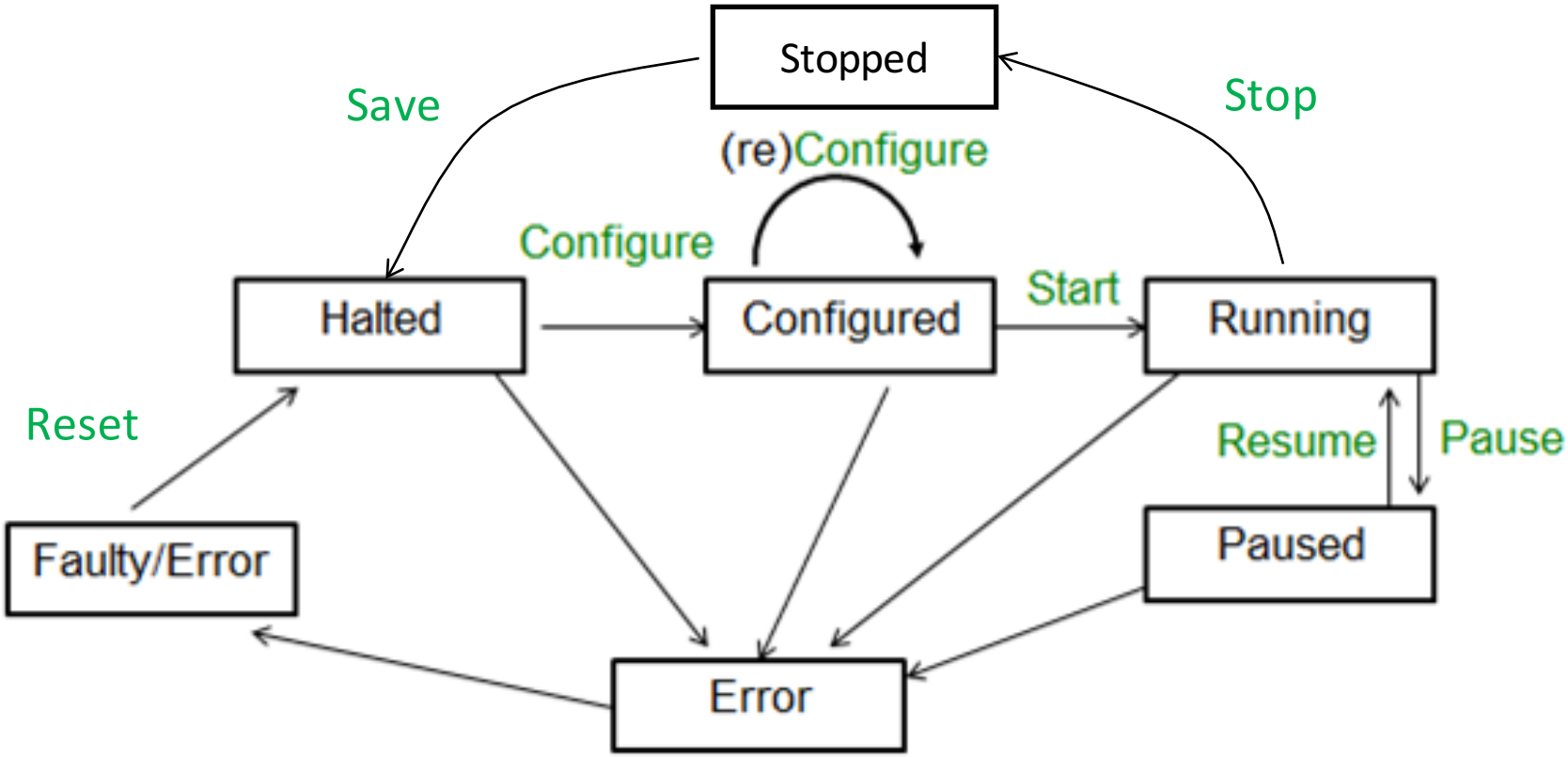
The number of files saved in our experiment is 18.

The average file size is 1,64 kB so the total size is 29,2 kB.

- JR12025.rbs
- JR12026.rbs
- JR12027.rbs
- JR12028.rbs
- JR12029.rbs
- JR12030.rbs
- JR12031.rbs
- JR12032.rbs
- JR12033.rbs
- JR12034.rbs
- JR12035.rbs
- JR12036.rbs
- JR12037.rbs
- JR12038.rbs
- JR12040.rbs
- JR12041.rbs
- JR12045.rbs
- JR12046.rbs

Different Status Of A Run

During every run the DAQ can have multiple status



The Logbook

The Logbook is the official document that reports the acquisition settings and everything happened during an experiment.

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ESPERIMENTO DI RUTHERFORD

Giovedì 23 giugno 2016

Acceleratore AN2000

Linea di fascio: +60°

Operatori: Gianluigi Maggioni, Leonardo La Torre
Persone: Matteo Stefanelli, Giacomo Brunello, Anna Fiorentin, Leonardo Schiavo, Nicola Vianello, Nicole Busdon, Matteo Catania, Alessandro Benetton

Materiale: acceleratore AN 2000, nuclei di elio 4He+, energia (< 2MeV), corrente (12 nA), bersaglio (film sottili),
rivelatore (a stato solido semiconduttore di silicio, area attiva: xx cm^2, angolo: 90°< xx < 180°, tensione: xx V, distanza: x m,
angolo solido: xx mrad), preamplificatore (guadagno: -1), amplificatore (572), ADC, MCA (range: 1024)

Output File Name: jr<numerodirun>.rbs

Numero run: 120
Nome file: jr120  .rbs
Conteggi:
Start time:
Target:
Energia: MeV
Angolo misurato:
Angolo di scattering:
Carica: nA
Corrente:
End time:

Numero run: 12019
Nome file: jr12019.rbs
Conteggi: 10040
Start time: 11:32
Target: Au/Si
Energia: 2 MeV
Angolo misurato: 20°
Angolo di scattering: 160°
Carica: 7.67 uC
Corrente: 12 nA
End time: 11:42

Numero run: 12020
Nome file: jr12020.rbs
Conteggi:
Start time: 11:5
Target: Au/Si
Energia: 2MeV
Angolo misurato: 20°
Angolo di scattering: 160°
Carica:
End time:
*ERRORE* *RUN NON VALIDA*
```

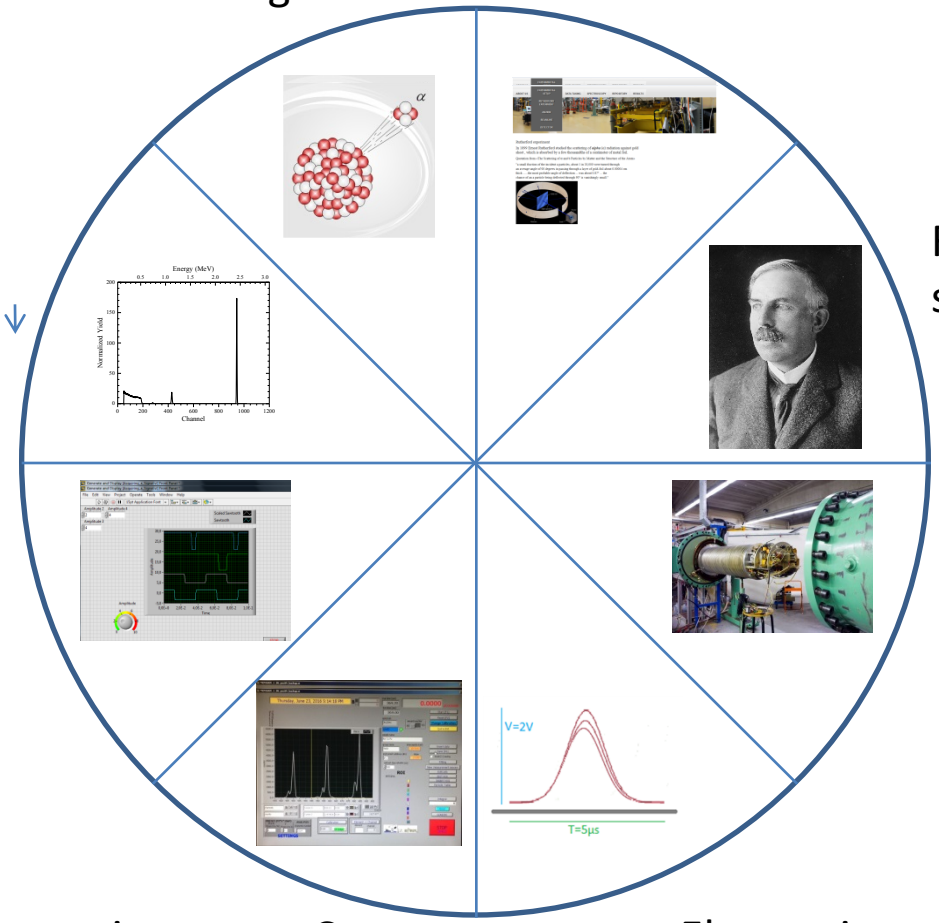
Acquisition Settings

Run Data

Interaction Radiation Materials: stage B

Web site in JOOMLA: stage C

Spectroscopy and Results: stage B



Rutherford Experiment: stage B

Experimental Setup: stage B

Software: stage C

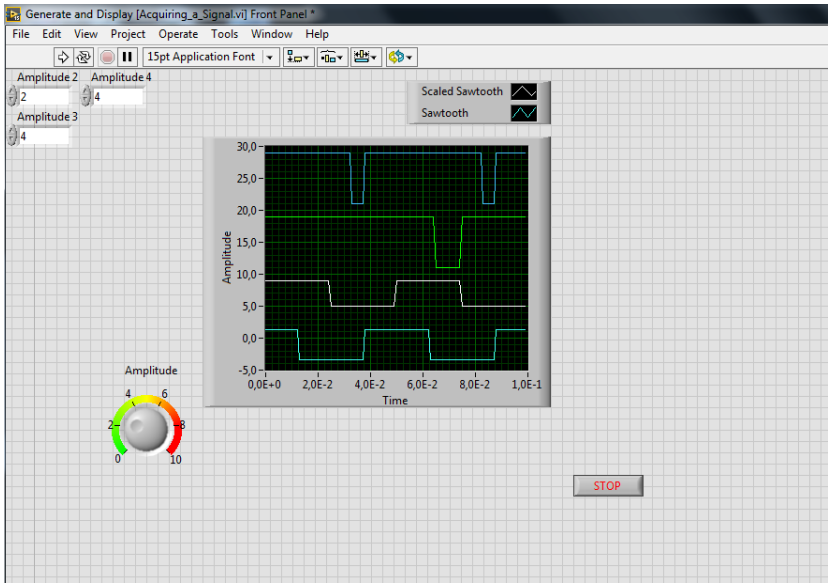
Computing: stage C

Electronics: stage C

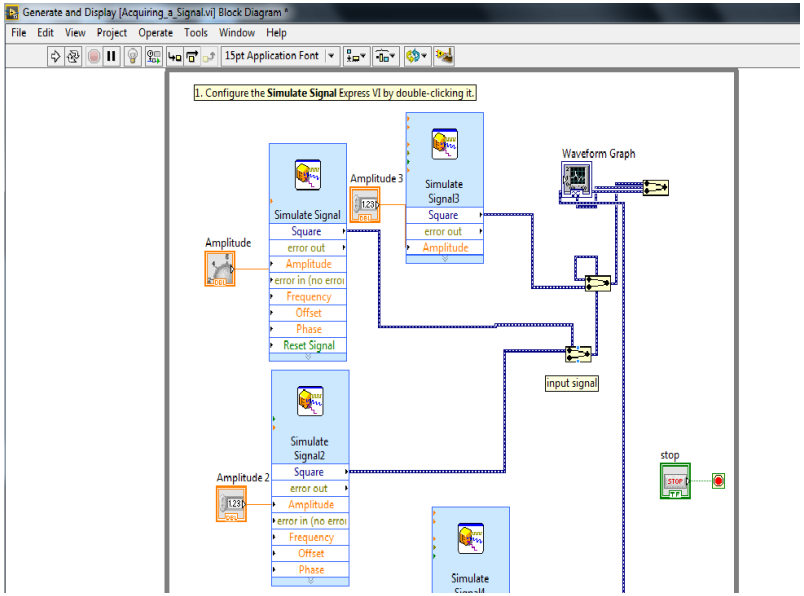
LABVIEW

LabVIEW programs are called virtual instruments, or VIs, because their appearance and operation imitate physical instruments, such as oscilloscopes and multimeters.
You can use LabVIEW to communicate with hardware such as data acquisition, vision, and motion control devices [1].

The front panel ⟶
- Controls
- Indicators



The block diagram ⟶
- VIs
- Structures

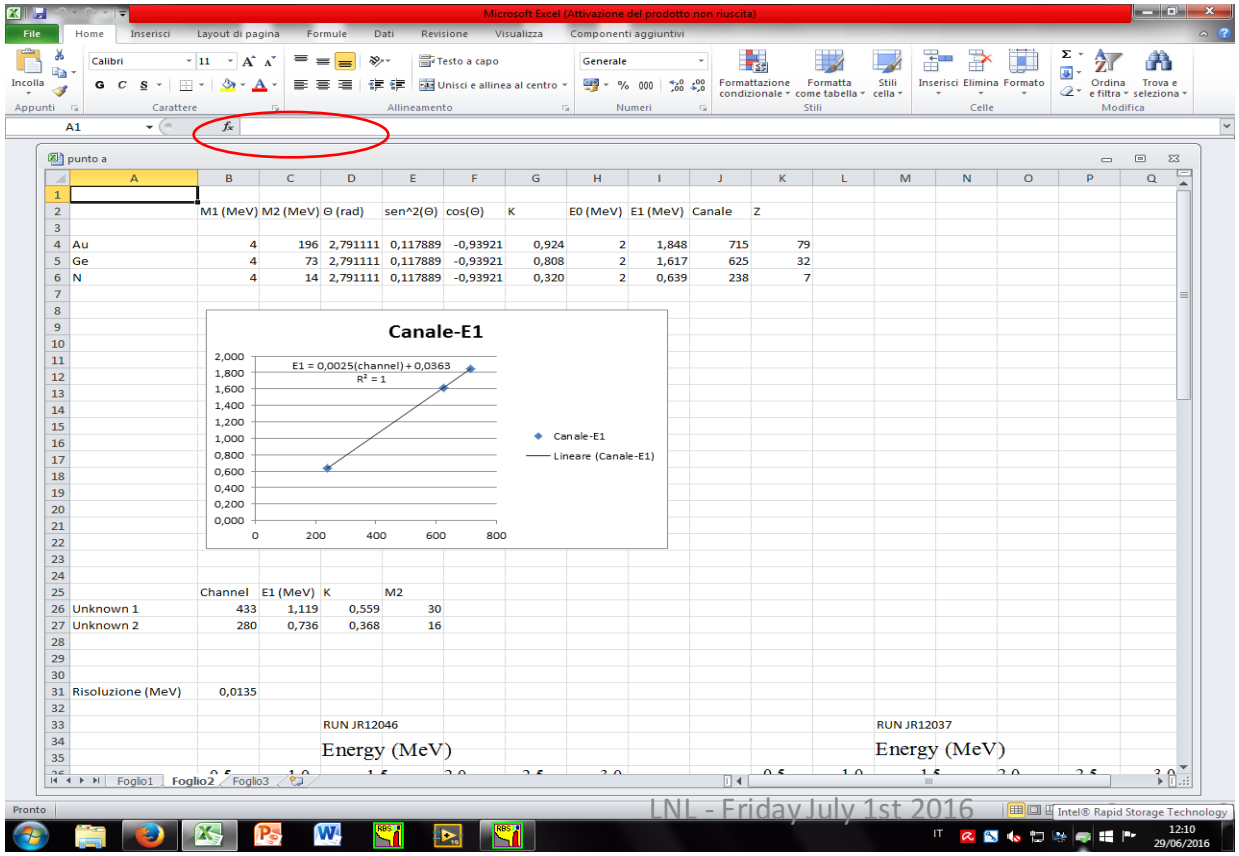


[1]: LabVIEW Manual

EXCEL

Excel is a software that allows the user to work on spreadsheets. It features calculation, graphing tools, pivot tables.

An example of spreadsheet in Excel



	A	B	C	D	E	F	G	H	I	J	K
2		M1 (MeV)	M2 (MeV)	Θ (rad)	sen^2(Θ)	cos(Θ)	K	E0 (MeV)	E1 (MeV)	Canale	Z
4	Au	4	196	2,791111	0,117889	-0,93921	0,924	2	1,848	715	79
5	Ge	4	73	2,791111	0,117889	-0,93921	0,808	2	1,617	625	32
6	N	4	14	2,791111	0,117889	-0,93921	0,320	2	0,639	238	7

	A	B	C	D	E
25		Channel	E1 (MeV)	K	M2
26	Unknown 1	433	1,119	0,559	30
27	Unknown 2	280	0,736	0,368	16
31	Risoluzione (MeV)	0,0135			

GNUPLOT

Gnuplot is an open source program that allows the realization of two- and three-dimensional plots of functions and data.

```
set term postscript eps solid enhanced color size 12 cm, 10 cm 18

set out "Yield_vs_Energy.eps"

data = "Yield_vs_E.dat"

unset key

f(x) = m*x +q
#g(x) = (x - q)/m #inverse formula for xerror bars

#fit f(x) data using 1:2:(sqrt($2)) via m,q
#
#set xlabel "Beam Energy [MeV]"
#set ylabel "Yeld [counts]"
#
#set xrange[0:2.1]
#set xtics 0.2
#
#plot data using 1:2:(sqrt($2)) with err lc 0, f(x) lc 1


fit f(x) data using ($1**(-2.)):2:(sqrt($2)) via m,q

set xlabel "1 / Energy^2 [MeV^{-2}]"
set ylabel "Normalized Yield [counts/{/Symbol m}C]"

set label "{/=20 Y = A/E^2 + B}" at 0.1 , 9000
set label "{/=20 A = (10426.5 +/- 371.7)}" at 0.1 , 8000
set label "{/=20 B = (-34.5082 +/- 174.5)}" at 0.1 , 7000

set xrange[0:1]
set xtics 0.2
set mxtics 2

plot data using ($1**(-2.)):2:(sqrt($2)) with err lc 0, f(x) lc 1
```

Reference to the file that contains all the data

Function that the software uses to create the graph

The *hash (#)* introduces comments

Labels are used to include some text in the output file

This line is needed to have the file in output

ROOT

ROOT is a scientific software framework. It provides all the functionalities needed to deal with big data processing, statistical analysis, visualisation and storage. It is mainly written in C++ [1].

```
/*
Title:      Rutherford's experiment at AN2000 accelerator in INFN Legnaro National Laboratory
Date:       Thursday, June 23th 2016
Authors:        Nicola Vianello, Nicole Busdon, Matteo Catania, Alessandro Benetton
Authors:        Giacomo Brunello, Anna Fiorentin, Leonardo Schiavo, Matteo Stefanelli
Descriptions:   Rutherford cross section versus energy
Use in ROOT:    .x stage2016_macroE.C

Output filename: stage2016_macroE.pdf
Input filename: no
*/


//include files
#include <iostream>

// Main function
void stage2016_macroE() {

   gStyle->SetOptStat(0);

   int n =6;
   float x[6]={1.0,1.2,1.4,1.6,1.8,2.0};
```

All the necessary information is written here in form of **comment** (it has nothing to do with the code)

The **main function** is the body of the program

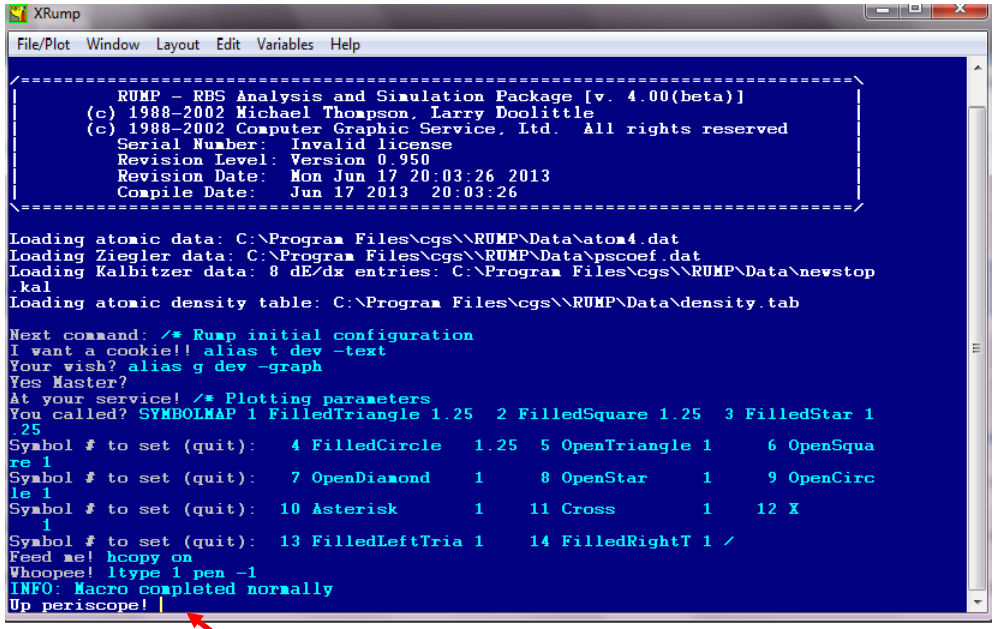
Declaration of an **array** containing 6 variables

[1]: https://root.cern.ch/

XRUMP

XRump is used to analyze the collected spectra (.rbs files)

XRump interface



Prompt command line

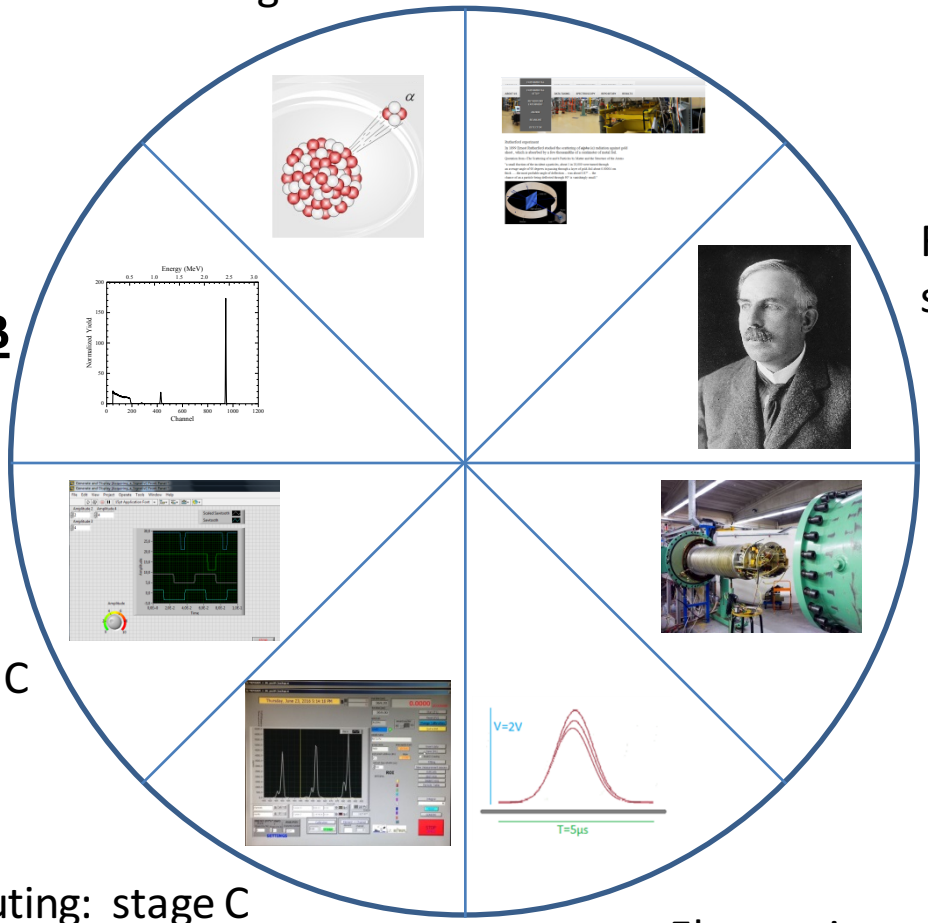
A simple manual

"ac": to get information about a file;
"cd .." to get to the upper folder;
"cd <*foldername*>" to open a folder;
"cur": to obtain information about a spectre point chosen by the user with the cursor;
"get <*filename.extension*>" to load a file;
"int": to calculate the integral of a part of a spectre;
"ls" to print a list of the files and folders in the current directory;
"pl": to obtain the spectre of the file;
"pwd" to print the current directory;
"raw pl": to get the spectre of the file without calibration;
"reg <*min*> <*max*> ": to set the definition of the graph;

Interaction Radiation Materials: stage B

Web site in JOOMLA: stage C

Spectroscopy and Results: stage B



Rutherford Experiment: stage B

Experimental Setup: stage B

Electronics: stage C

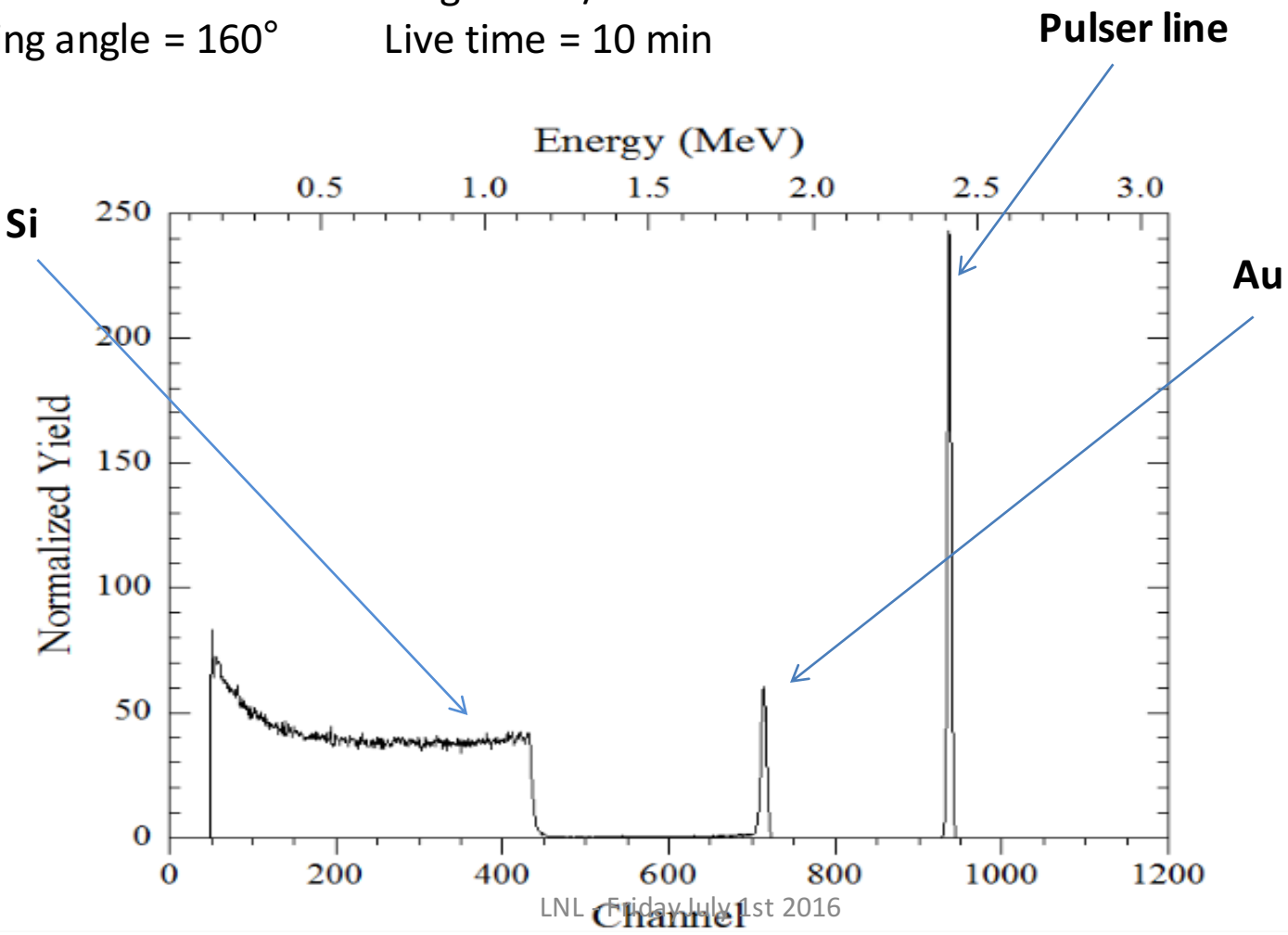
Computing: stage C

Software: stage C

SPECTROSCOPY

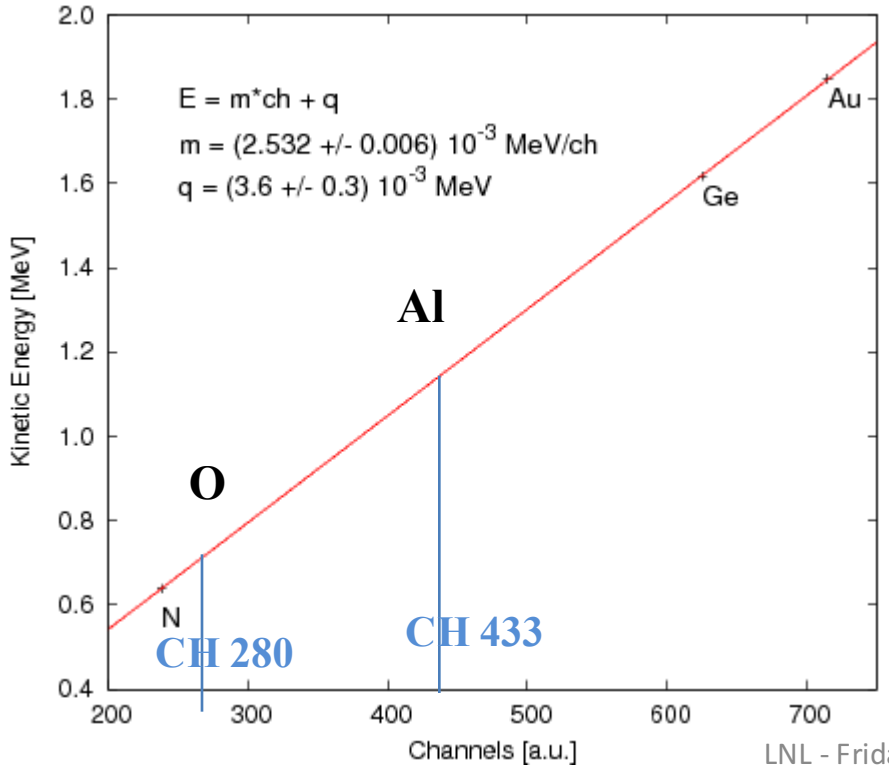
JR12025

Energy = 2 MeV
Scattering angle = 160°
Target = Au/Si
Live time = 10 min



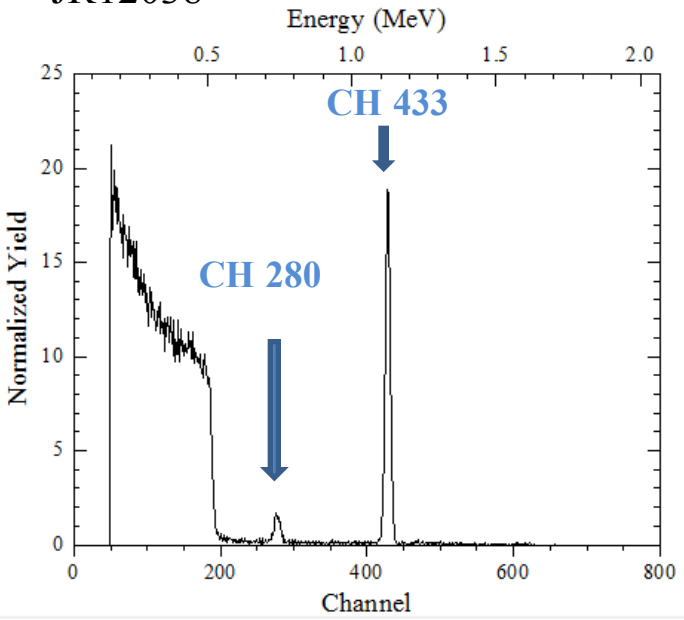
CALIBRATION WITH DIFFERENT MATERIALS

Element	Channel	E (MeV)	K
Au	715	1,848	0,924
Ge	625	1,617	0,808
N	238	0,639	0,320



Unknown target

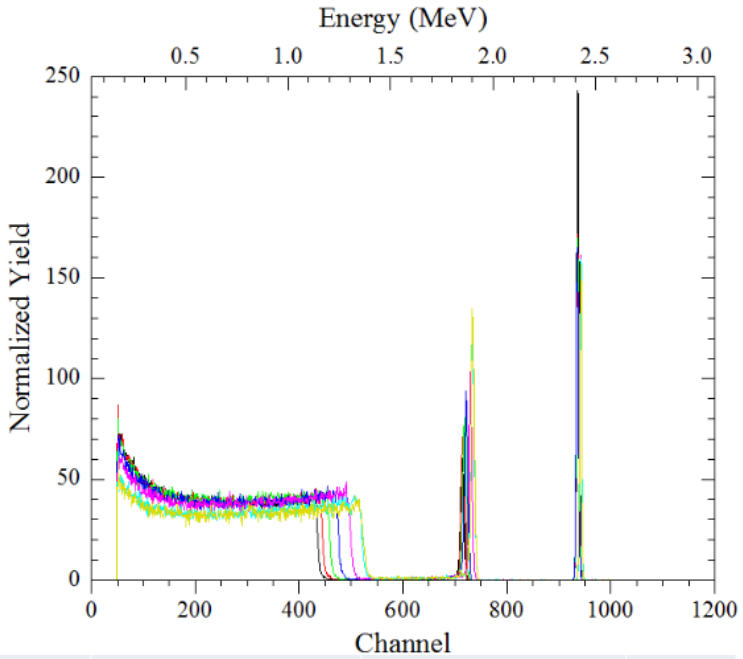
JR12038



Element	Channel	E (MeV)	K
Al	433	1,119	0,559
O	280	0,736	0,368

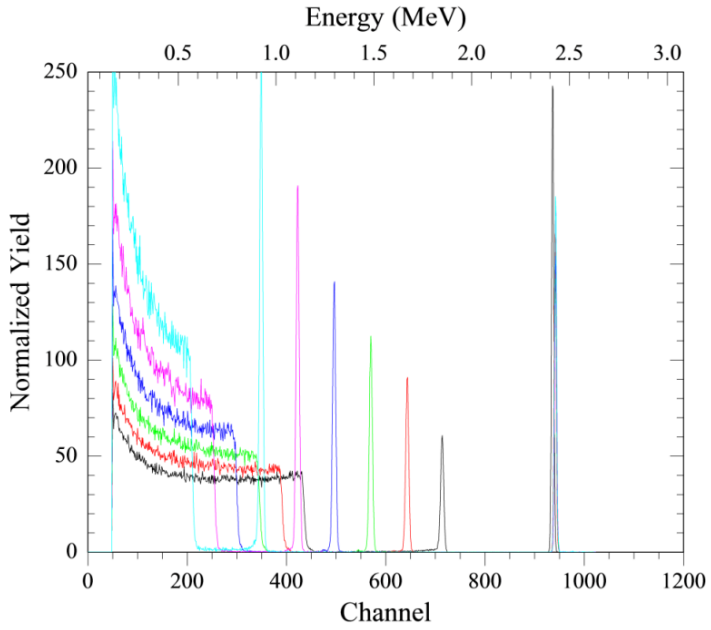
SPECTRA WITH DIFFERENT ...

SCATTERING ANGLES



Run	Normalized Yield	Scattering angle(°)	√Yn
12025	4331	160	65,81
12026	5099	150	71,41
12027	5552	140	74,51
12028	6476	130	80,47
12029	7716	120	87,85
12030	9785	110	98,92
12031	10113	108,5	100,56

ENERGIES

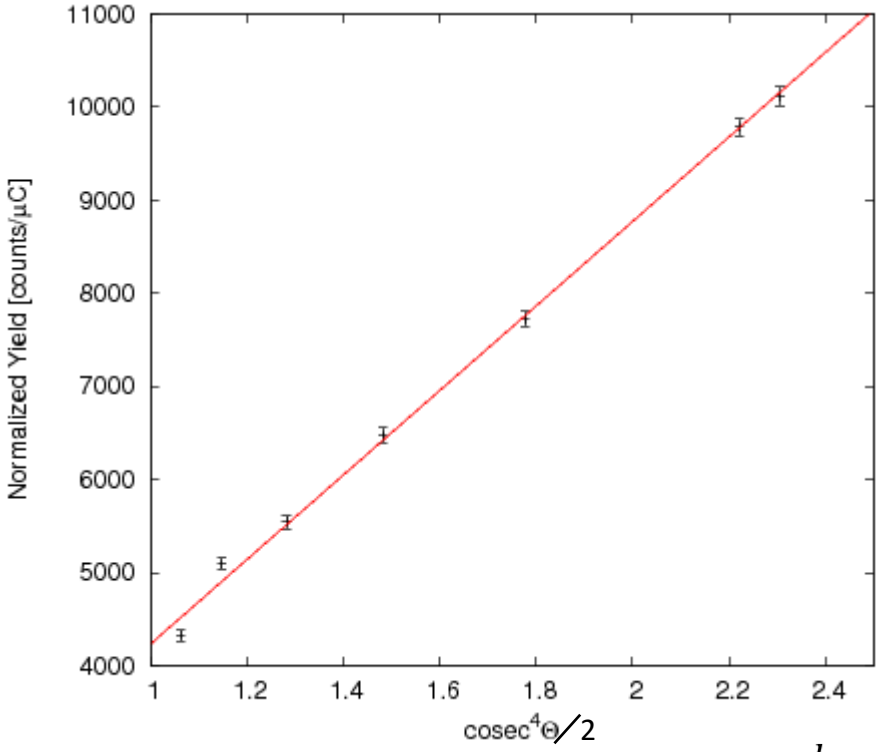


Run	Normalized Yield	E (MeV)	√Yn
12025	2378	2,0	48,77
12032	3341	1,8	57,80
12033	4181	1,6	64,66
12034	5331	1,4	73,01
12035	7293	1,2	85,40
12036	10187	1,0	100,93

RESULTS I

NORMALIZED YIELD VS SCATTERING ANGLE

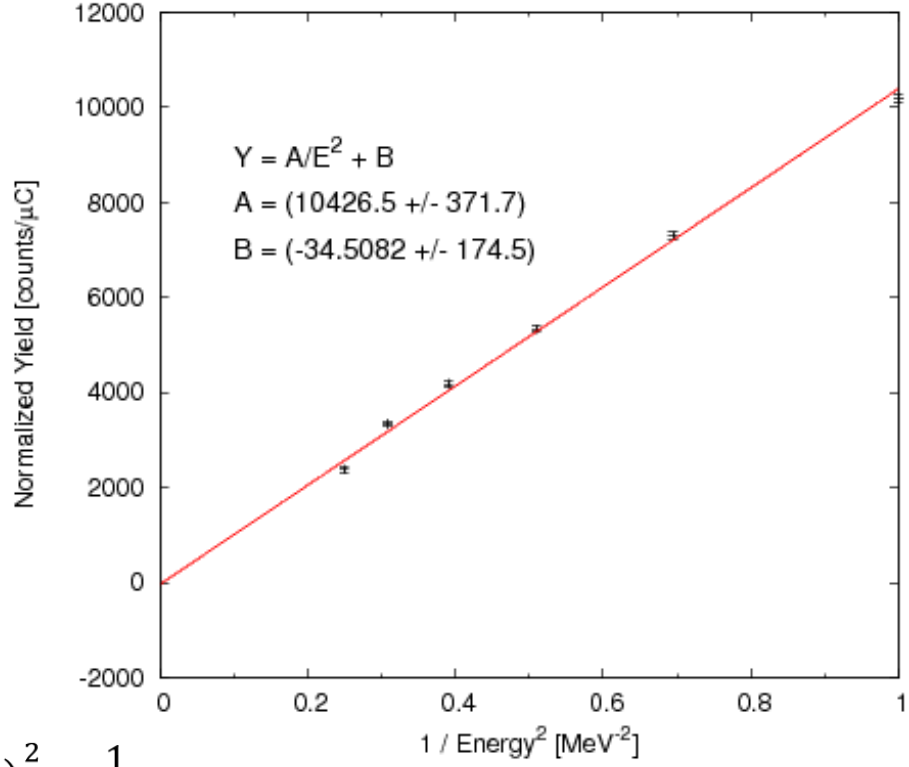
E = 2MeV Target = Au/Si



NORMALIZED YIELD VS ENERGY

Scattering angle = 160° Target = Au/Si

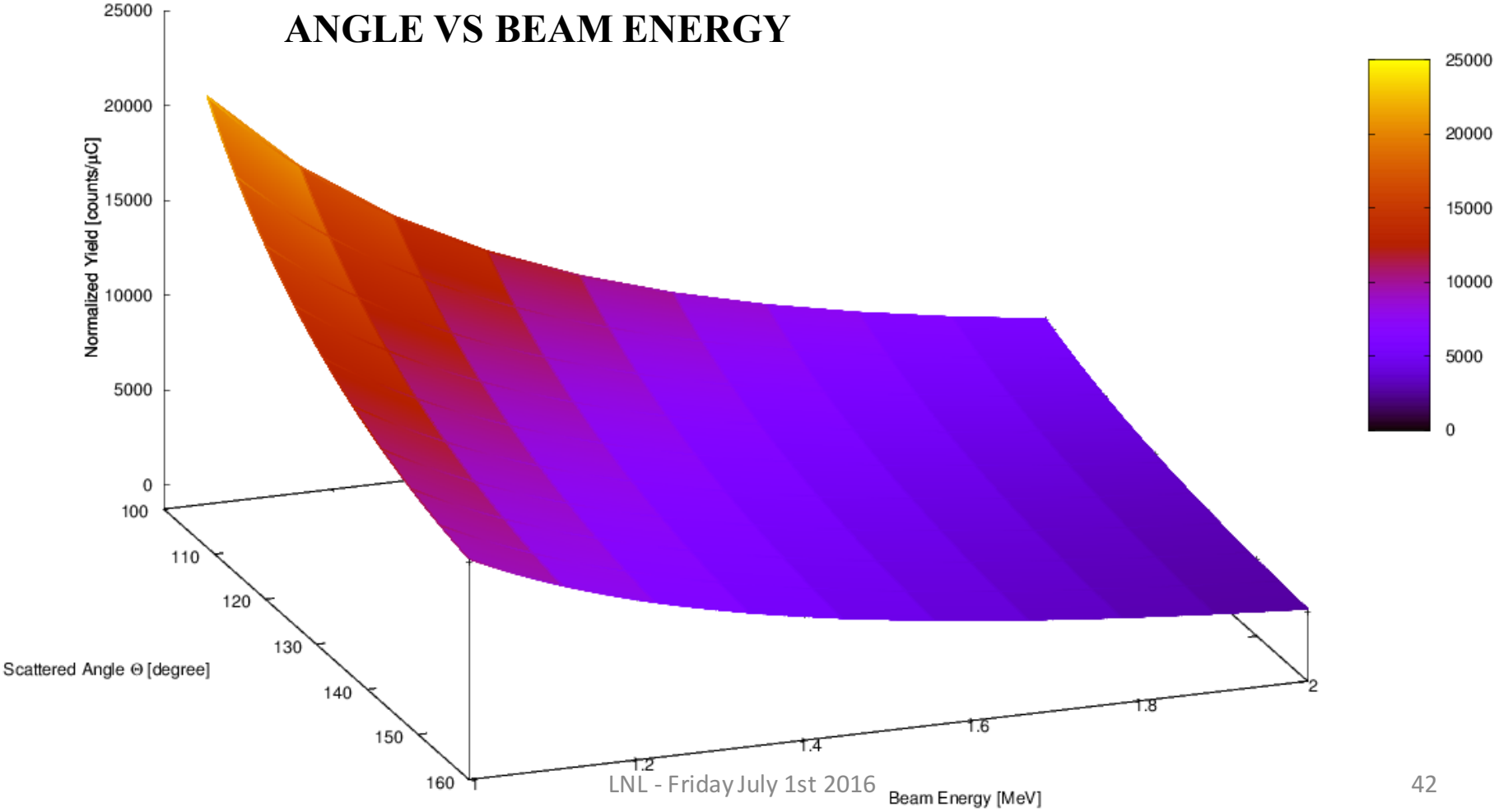
Energy changes from 2.0 MeV to 1.0 MeV



$$\frac{d\sigma}{d\Omega} = \left(\frac{\alpha}{4E}\right)^2 \frac{1}{\left(\sin\frac{\theta}{2}\right)^4}$$

RESULTS II

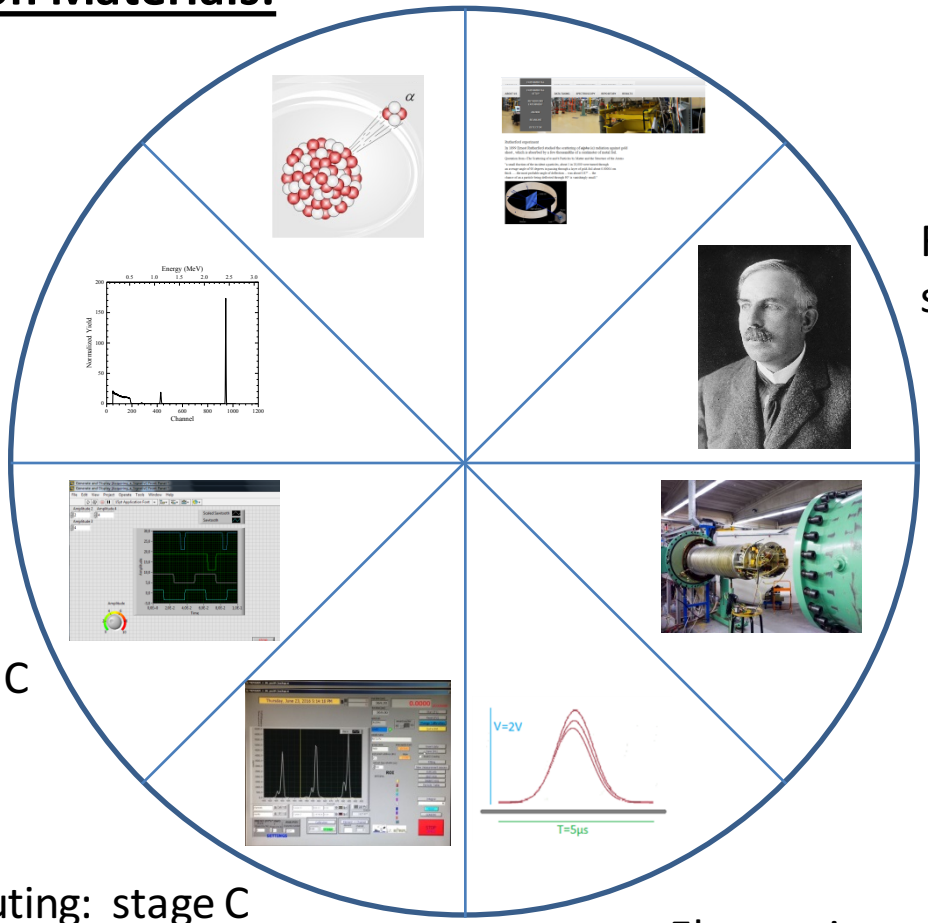
NORMALIZED YIELD VS SCATTERING ANGLE VS BEAM ENERGY



Interaction Radiation Materials: stage B

Web site in JOOMLA: stage C

Spectroscopy and Results: stage B



Rutherford Experiment: stage B

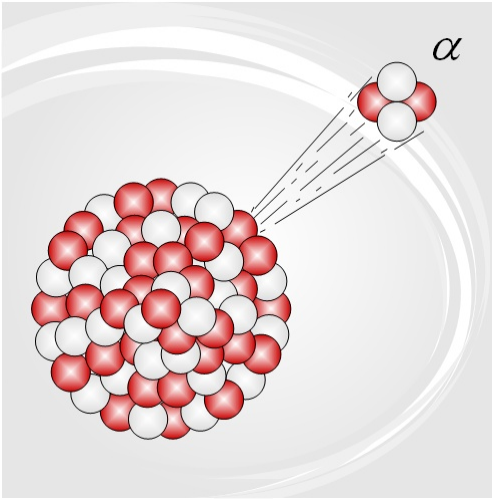
Experimental Setup: stage B

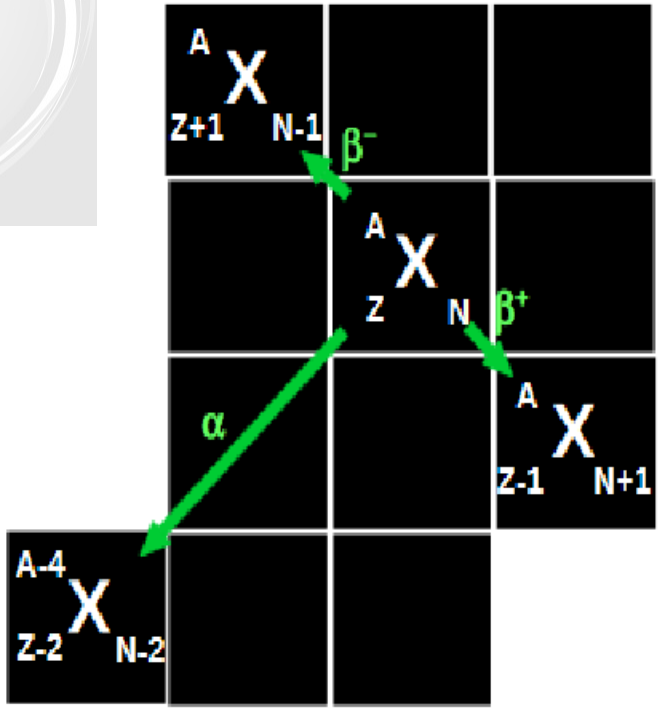
Electronics: stage C

Computing: stage C

Software: stage C

ALPHA SOURCE





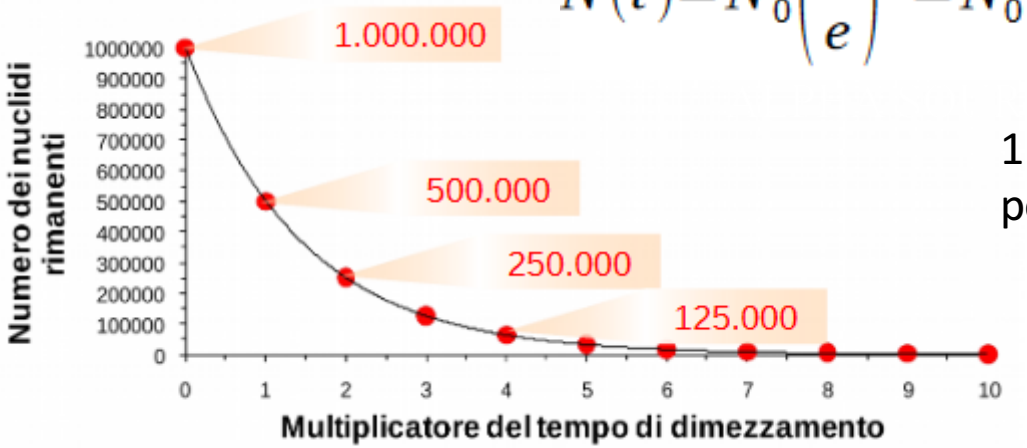
ALPHA DECAY

$$ {}^{A}_{Z}X \rightarrow {}^{4}_{2}He + {}^{A-4}_{Z-2}Y $$

ACTIVITY

Sources used:
- Triple source
- Unknown source

$$N(t) = N_0 \left(\frac{1}{e}\right)^{\frac{t}{\tau}} = N_0 \left(\frac{1}{2}\right)^{\frac{t}{T_{1/2}}} \qquad A(t) = \frac{\Delta N}{\Delta t} = \frac{N(t)}{\tau}$$



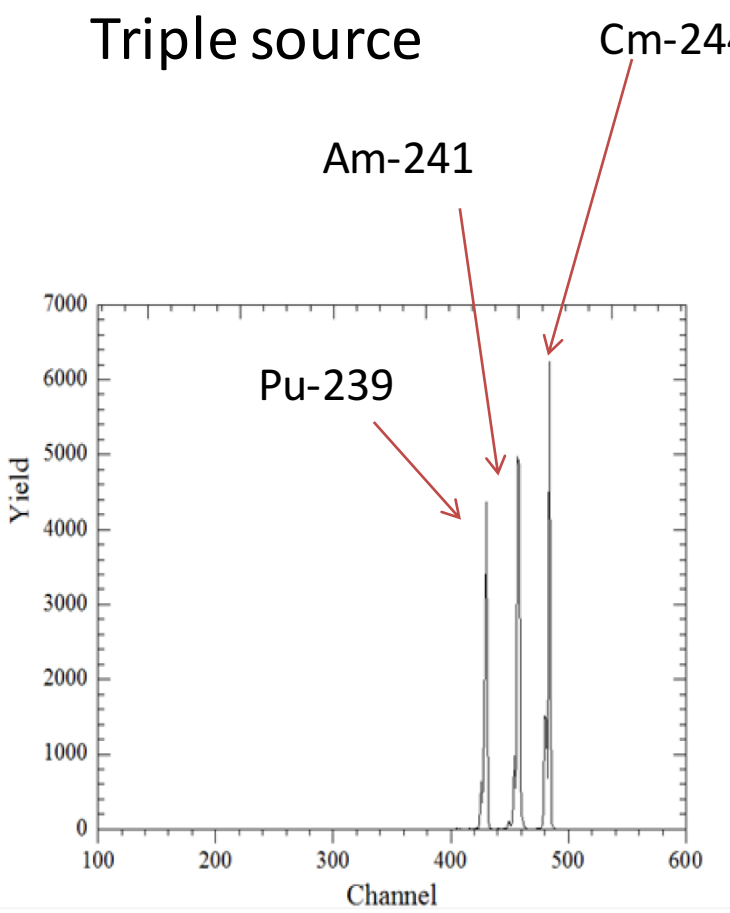
1 Becquerel (Bq) = one disintegration per second

Radionuclide	half-life	Important alpha articles energies MeV
Americium-241	433 years	5.442 (12.5%), 5.484 (85.2%)
Curium-244	17.8 years	5.763 (23.6%), 5.806 (76.4%)
Plutonium-239	24100 years	5.103 (11%), 5.142 (15%), 5.155 (73%)

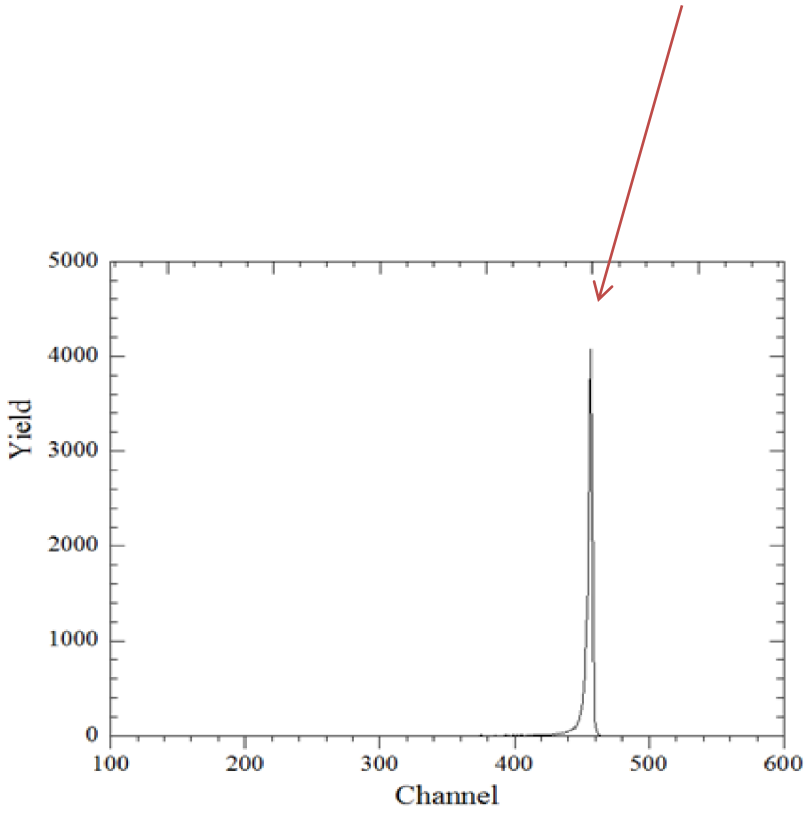
From: "http://www.nndc.bnl.gov/chart/"

CALIBRATION OF MCA WITH THE ALPHA SOURCE (I)

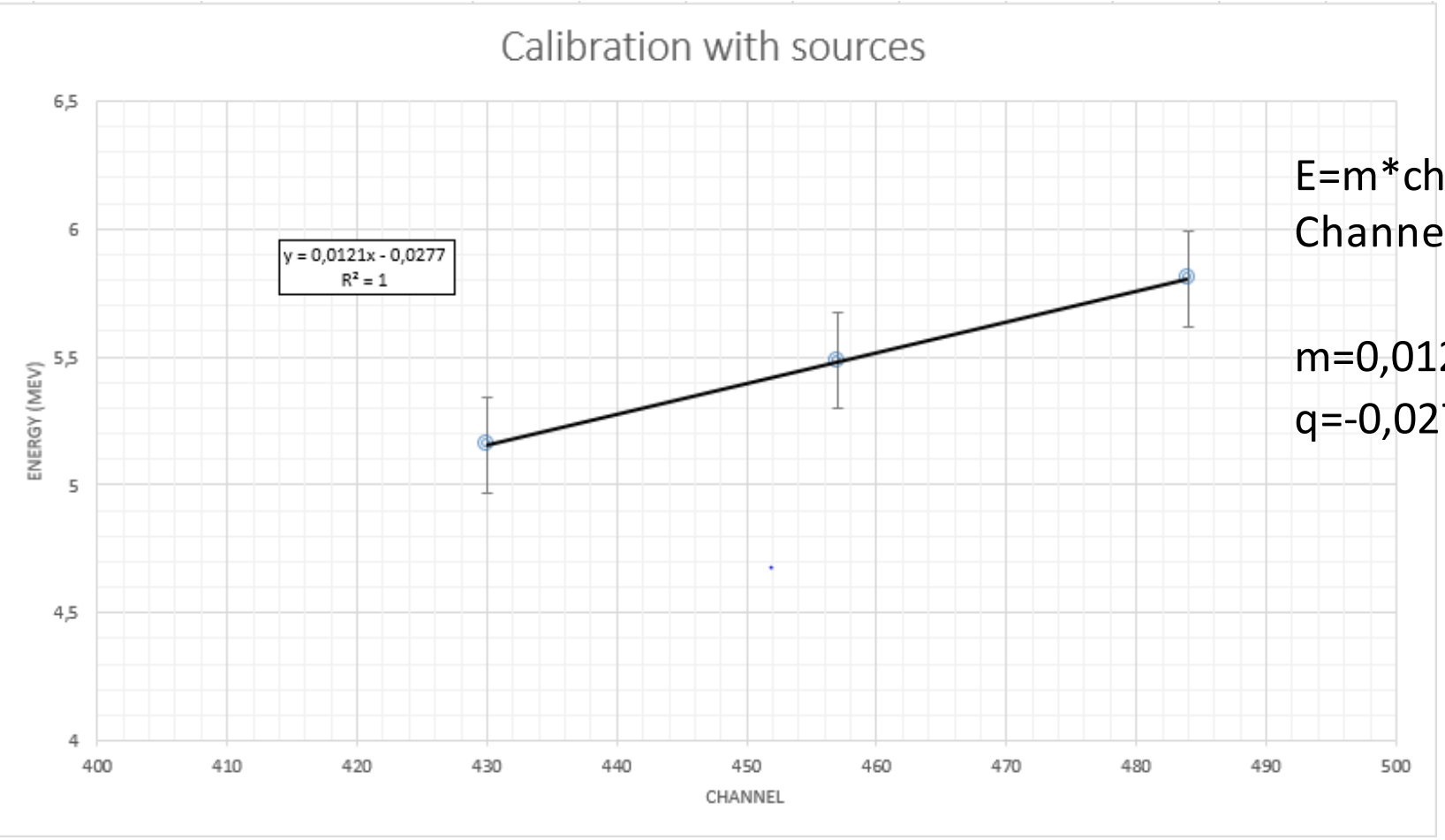
Triple source



Single source (86) unknown



CALIBRATION OF MCA WITH THE ALPHA SOURCE (II)



E=m*channel+q
Channel=430-485

m=0,0121 MeV/µm
q=-0,0277MeV

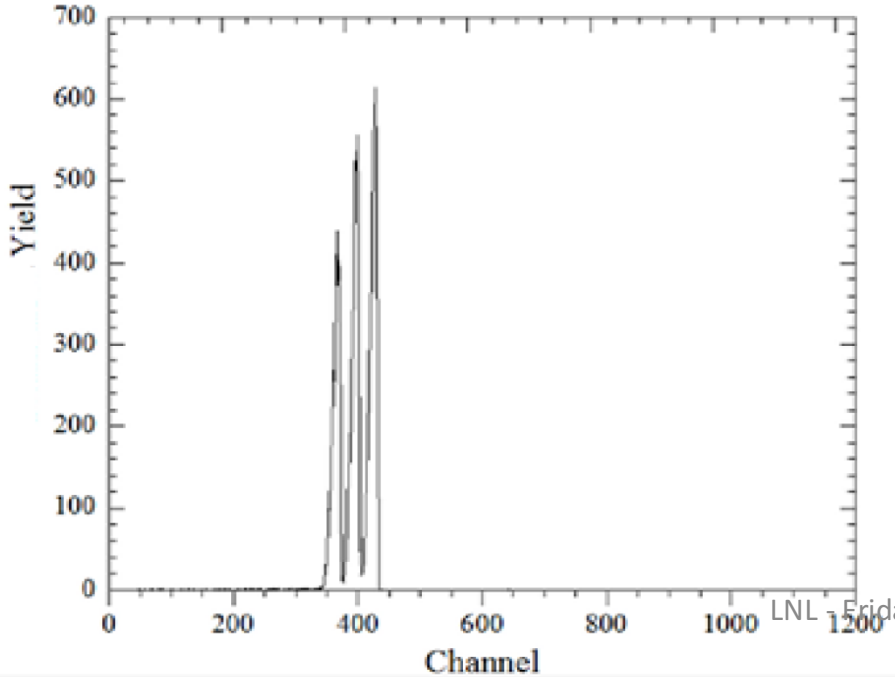
Unknown source: Americium

INTERACTION ALPHA-MYLAR

Triple source (Am-241, Cm-244, Pu-239) with MYLAR
Thickness: 6 µm

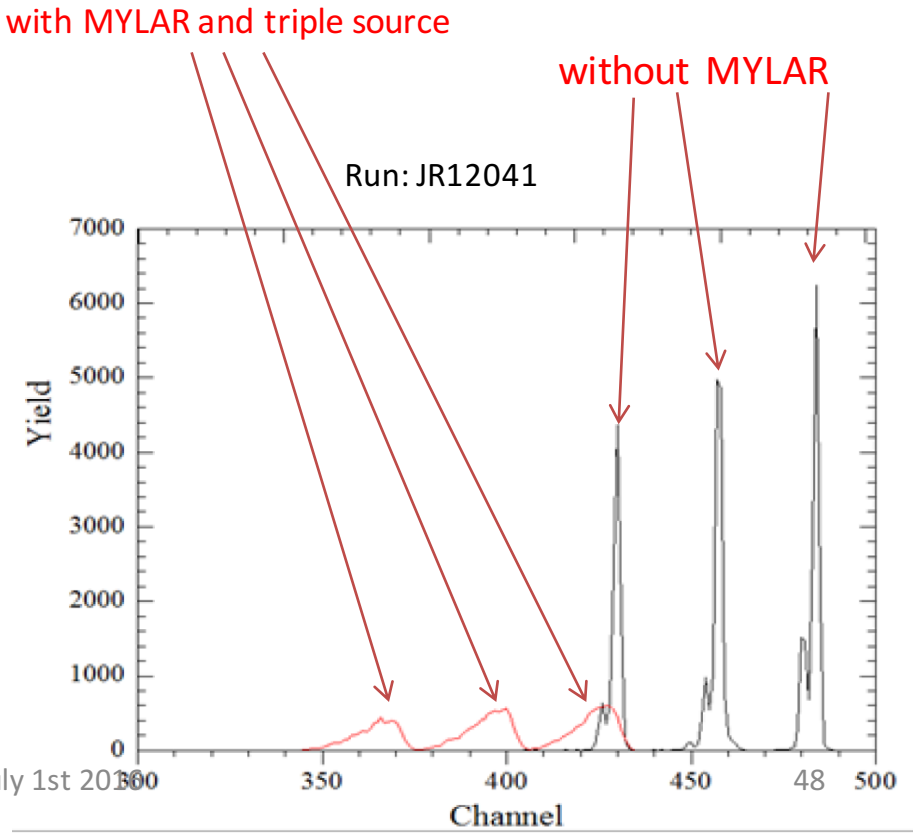
Run: JR12045

LINEAR ABSORPTION COEFFICIENT:
$-\Delta E/\Delta x = 115$ keV/µm



Spectra of triple source (Am-241, Cm-244, Pu-239)

Resolution for Americium = 36keV (gain=20)



CONCLUSIONS

- Development of a website in JOOMLA
- Determination of theoretical cross section through the Rutherford's experience
- Study of the beam line and of the electronic chain
- Comprehension of the experimental method and of the data acquisition with the employment of different analysis software
- Study of the interaction alpha-material to establish unknown material source

Thank you for your attention!