Neutron induced reaction measurements

in accelerator facilities

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Outline

Introduction

motivation (Nuclear Data and Applications)

Principles and experimental details

Neutron x-section and Time Of Flight concept

facilities (GELINA, n_TOF)

measurement setups

Data reduction

analysis process

neutron flux – capture yield

applications (archaeology, research, safeguards etc.)

Summary

future perspectives/links

Motivation

Nuclear waste management:

a major pressing and potentially costly environmental problem

Sources:

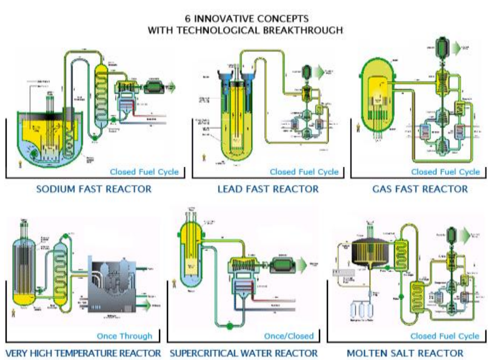
- Power generation reactors, military (e.g. dismantled weapons), other applications (medicine, industry, research)

Treatment:

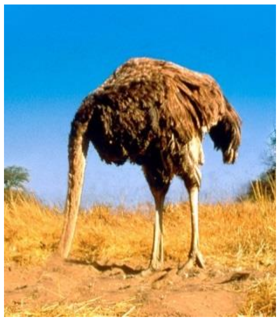
- Surface storage or geological disposal

Need to improve specific nuclear data

Produce x-sections/improve uncertainty



Waste disposal issues



- Where (?) - geological and public issues
- How (?) – technological aspects
- Long term safety (studies on effects projected for the next 10^5y!)

Motivation/Solution

Possible solution:
Transmutation

Burn or transform a long-lived isotope to a short-lived or a stable one via neutron induced fission or capture

Advanced reactor concepts:
Generation IV reactors and Accelerator Driven Systems (ADS)

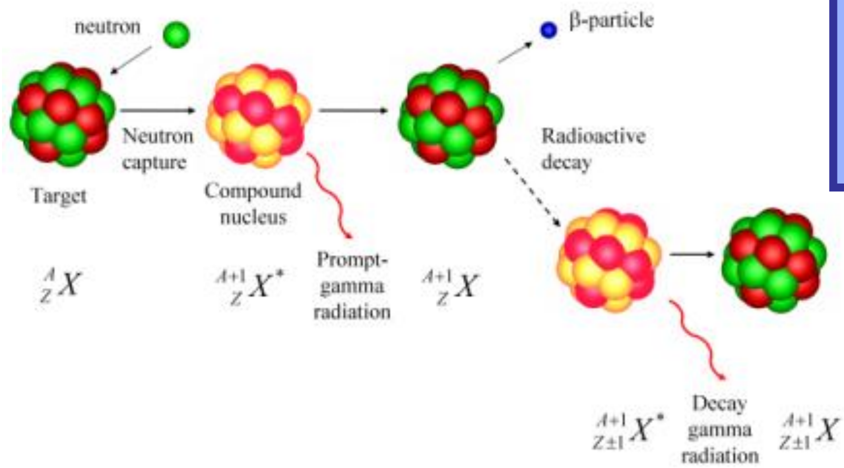
- Main challenge: to be able to recycle large fraction of the long-lived radioactive waste during operation
- R&D on several fields required

NEED
for new and more accurate neutron data

uncertainties

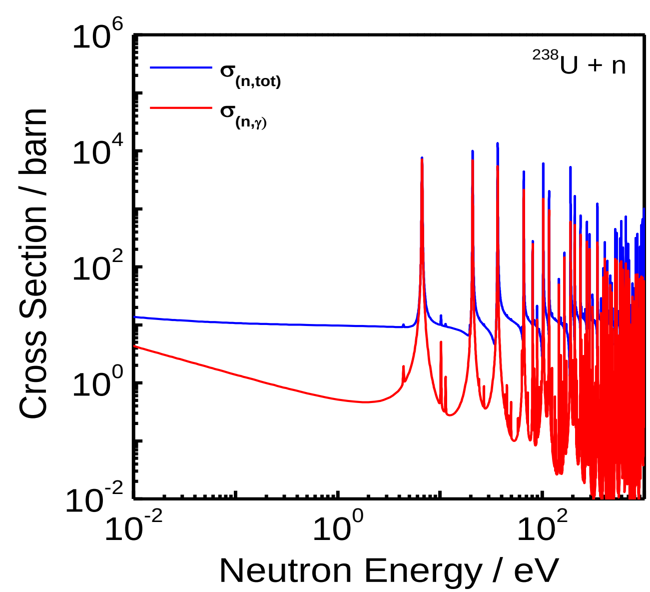
Nuclear reactions induced by neutrons

- elastic scattering, inelastic scattering, **capture (n,γ)**, fission (n,f), (n,xn), (n,a)…etc.

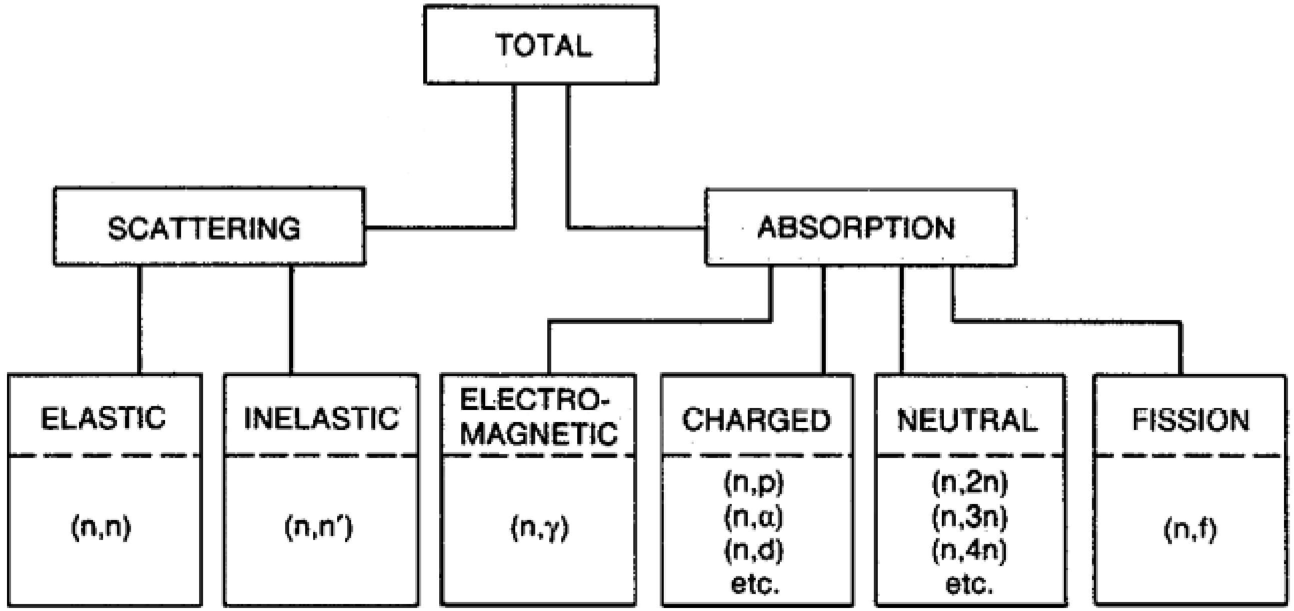


The probability that a specific interaction will take place between an incident neutron and a nucleus is expressed by a quantity called **cross section, σ**

The cross section depends strongly on the velocity of the neutron (E_n) and interacting nucleus



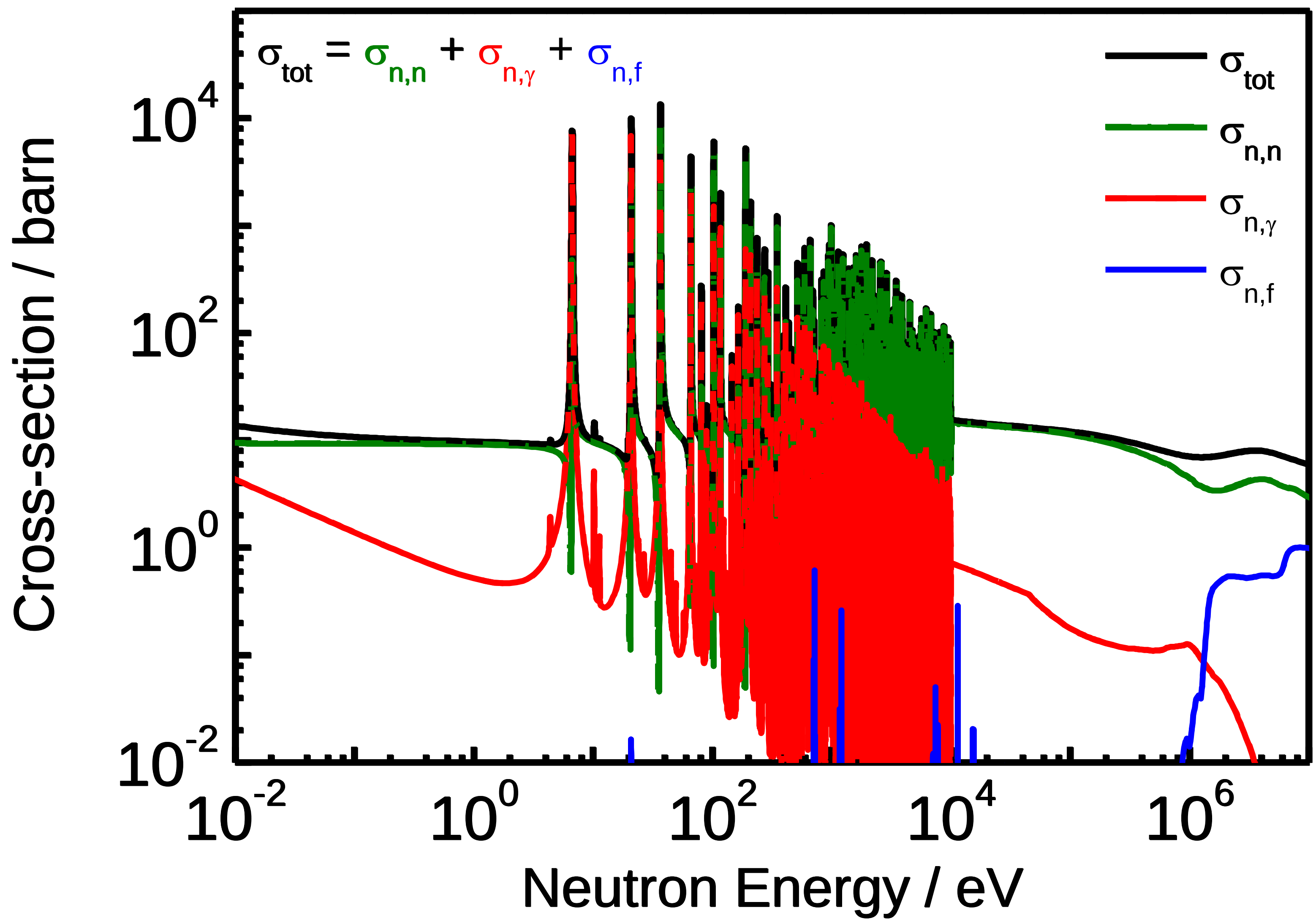
Neutron induced reactions



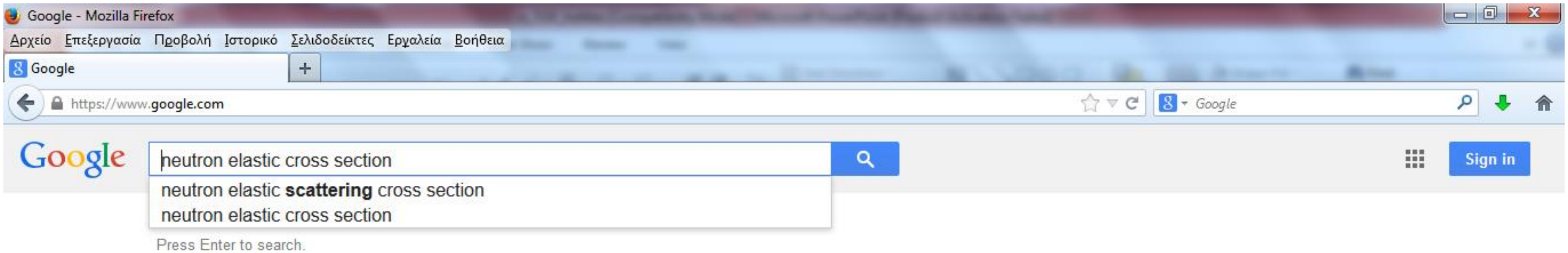
For every type of reaction we can determine the corresponding cross section: σ_{tot}, σ_{f}, σ_{γ}, σ_{el} ….

Neutron cross section

$^{238}U + n$



Quest for a specific number



?

search for a specific value and you end up

experimental results

evaluated files

EXFOR

- *www-nds.iaea.org/exfor/*
- *www.nndc.bnl.gov/exfor/*
- *www.jcprg.org/exfor/*
-
-

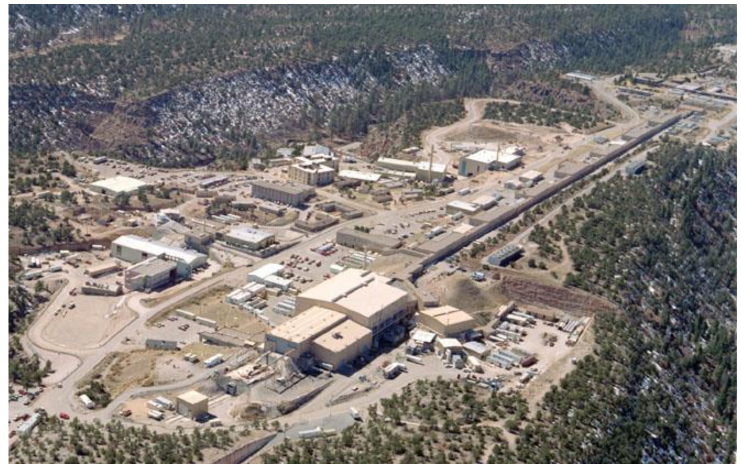
ENDF

- *BROND (Russia)*
- *CENDL (China)*
- *ENDF (USA)*
- **JEFF (international)**
- **JENDL (Japan)**

An evaluated nuclear data library is a data file (of specific format) of recommended nuclear data

Neutron induced reactions are under study since 1950s

- in numerous facilities
- for the vast majority of isotopes



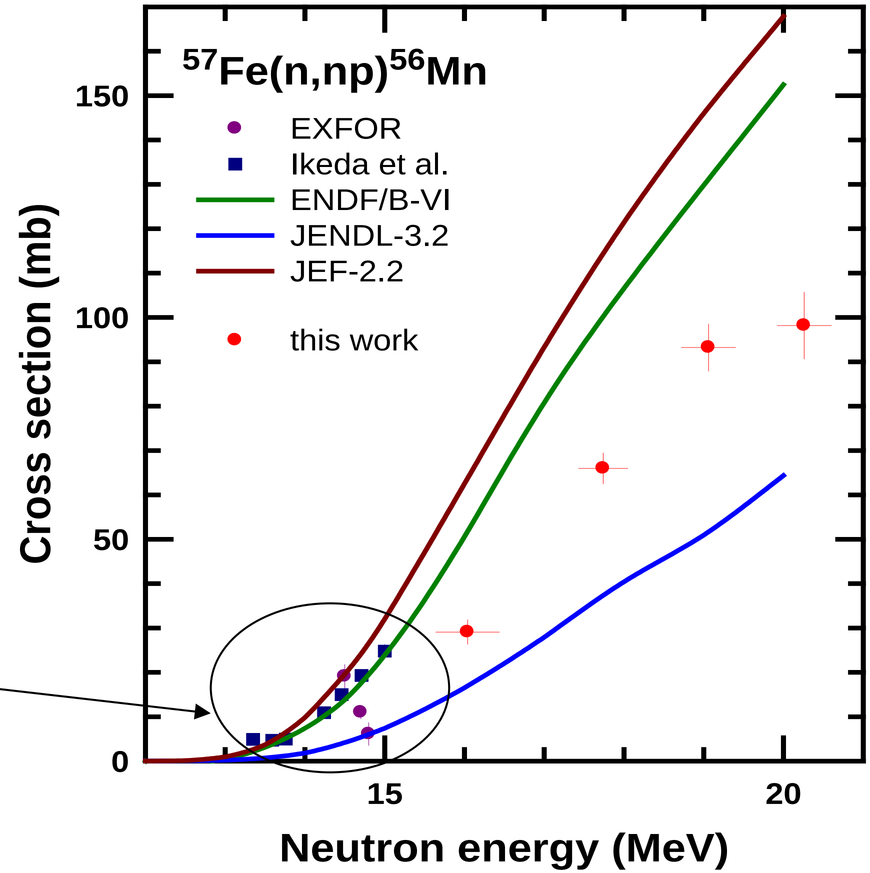
- **LOS ALAMOS**
- **OAK RIDGE**
- **JAPAN**
- **RUSSIA**
- **n_TOF (CERN)**
- **GELINA (IRMM)**
- **VdG accelerators (France, Germany, Belgium, Greece etc.)**
- **HIGH-FLUX REACTORS**

Why continue experiments ?

X-section in literature I

large uncertainties in data files due to lack of experimental data

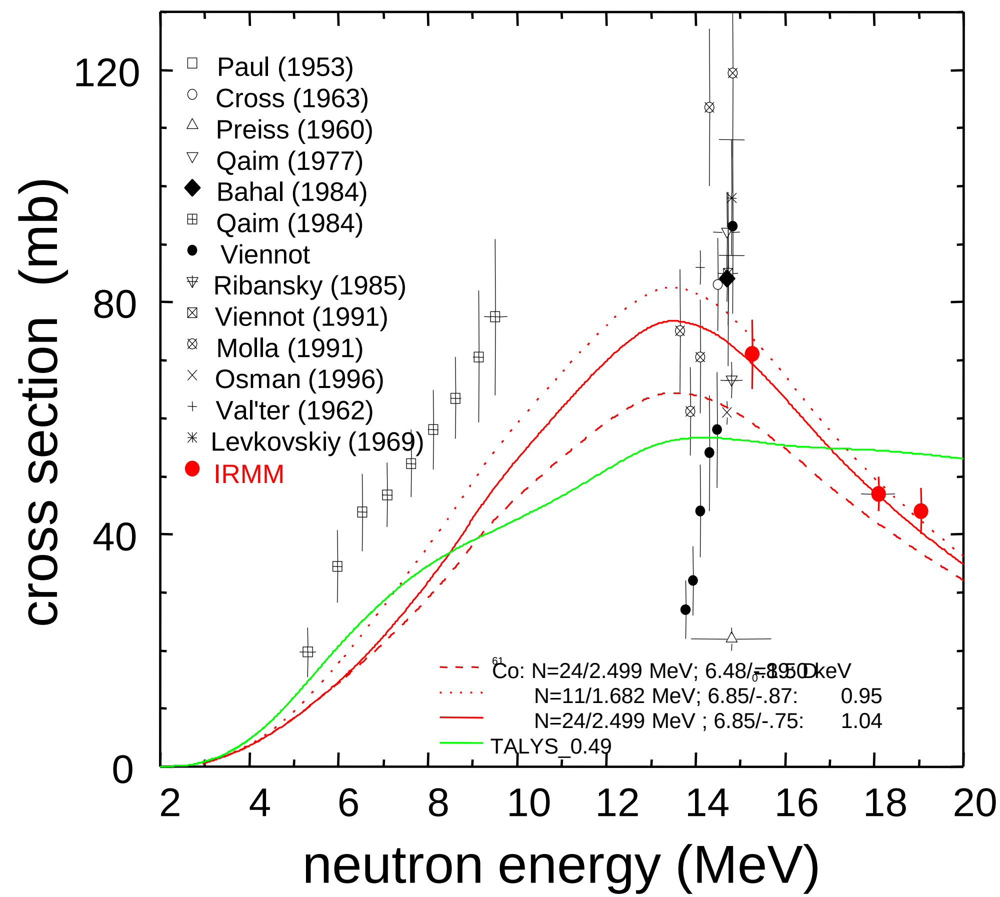
previous knowledge



X-section in literature II

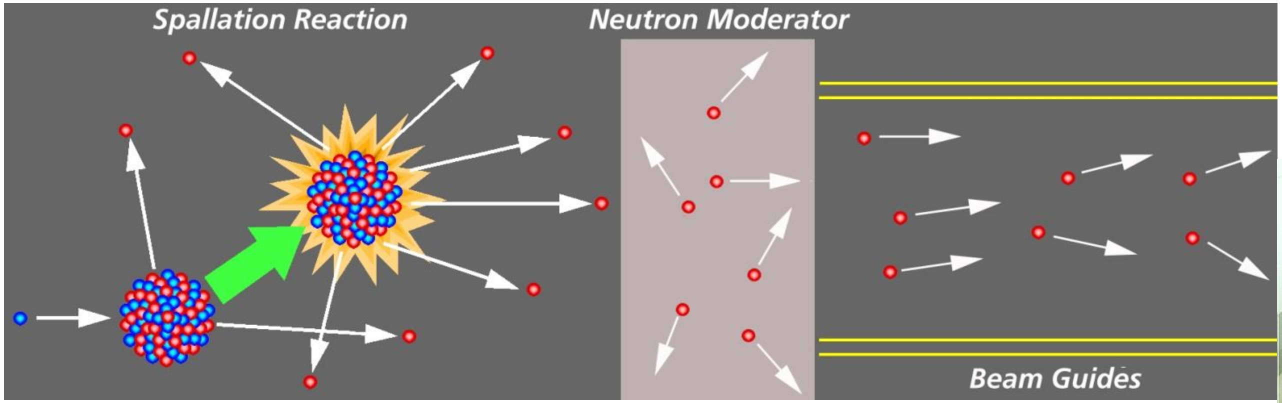
$^{61}Ni(n,p)^{61}Co$

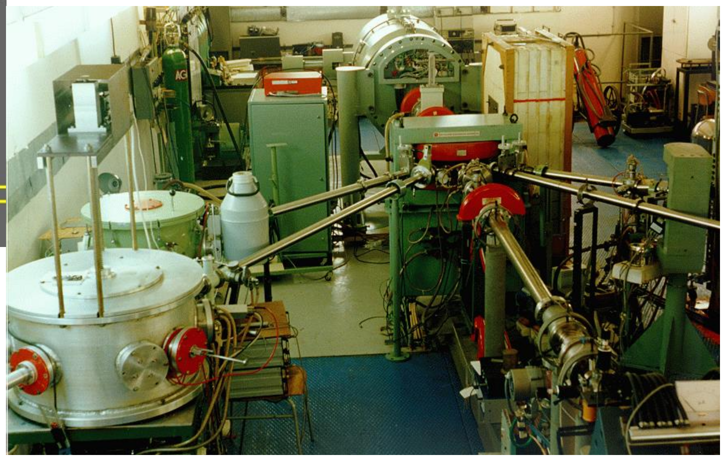
large uncertainties in data files due to inconsistency of experimental data



Neutron sources

Neutron beams are mainly produced:
- In reactors via fission
- In accelerators via the spallation process after bombarding heavy elements with energetic particles like a proton
- In accelerators via charged particle reactions and subsequent neutron production





Neutron beams

Separate according to neutron spectrum

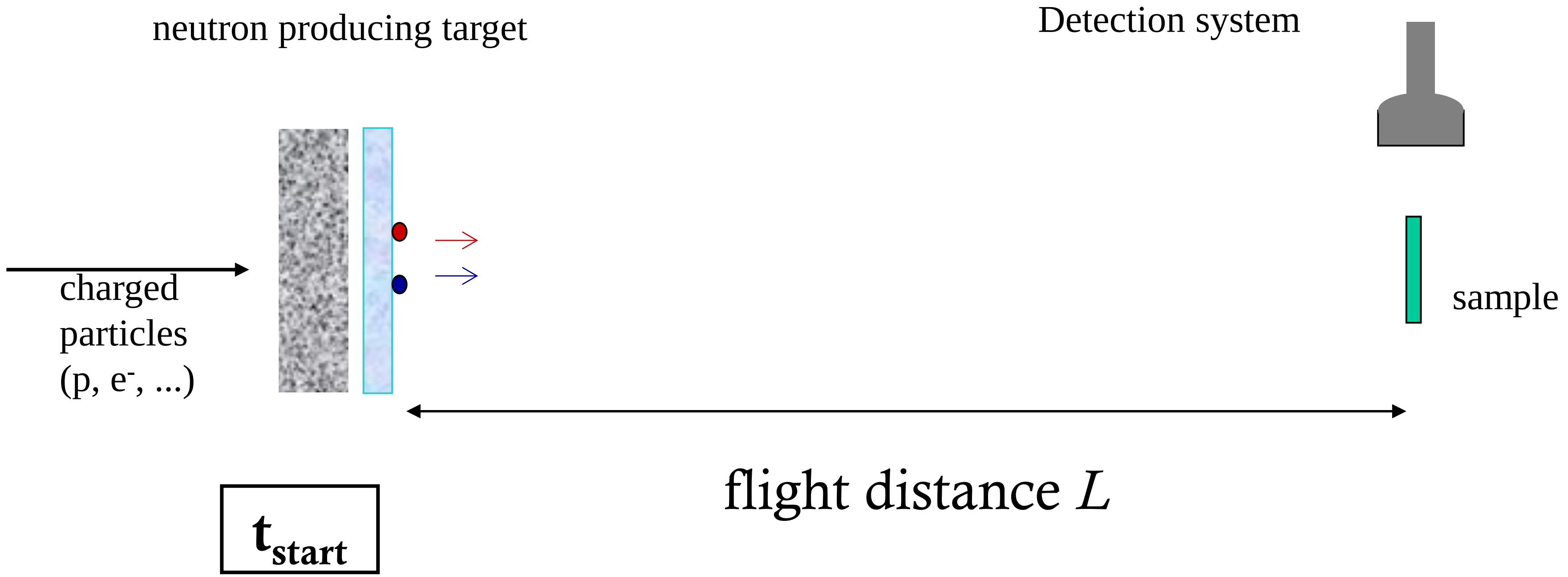
monochromatic

pulsed 'white' source

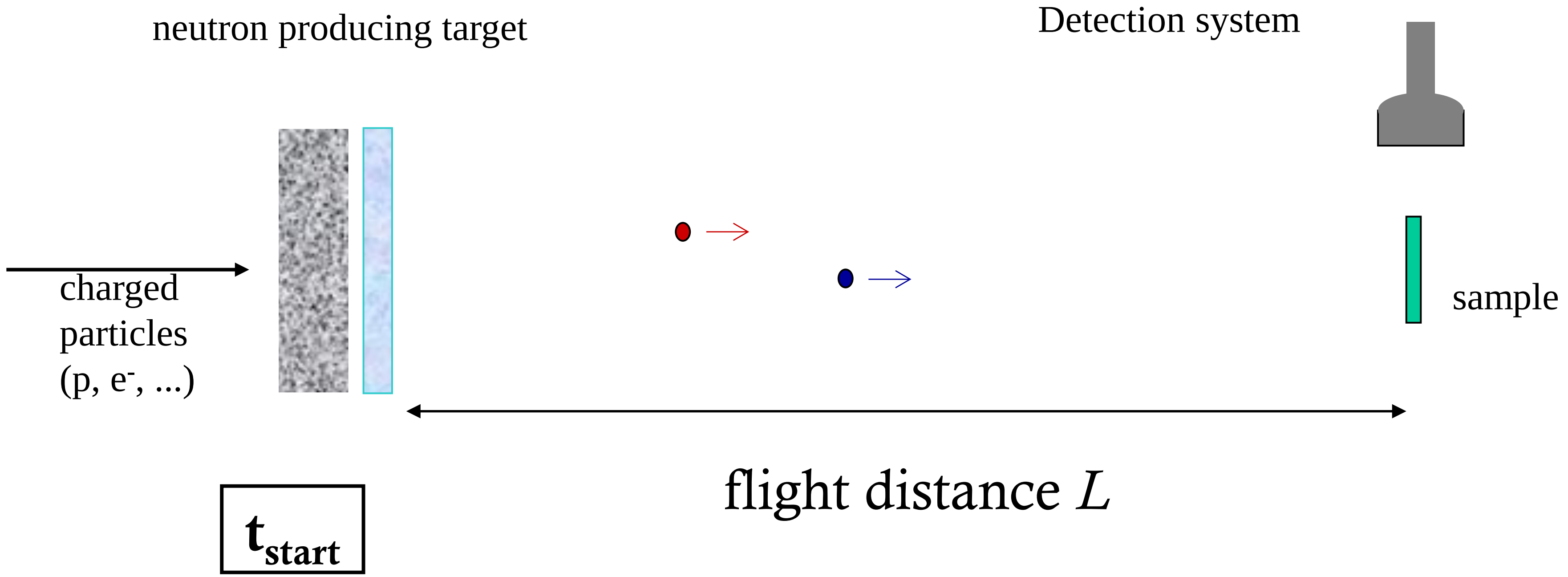
Athens-Greece

Geel-Belgium

the **Time Of Flight** principle

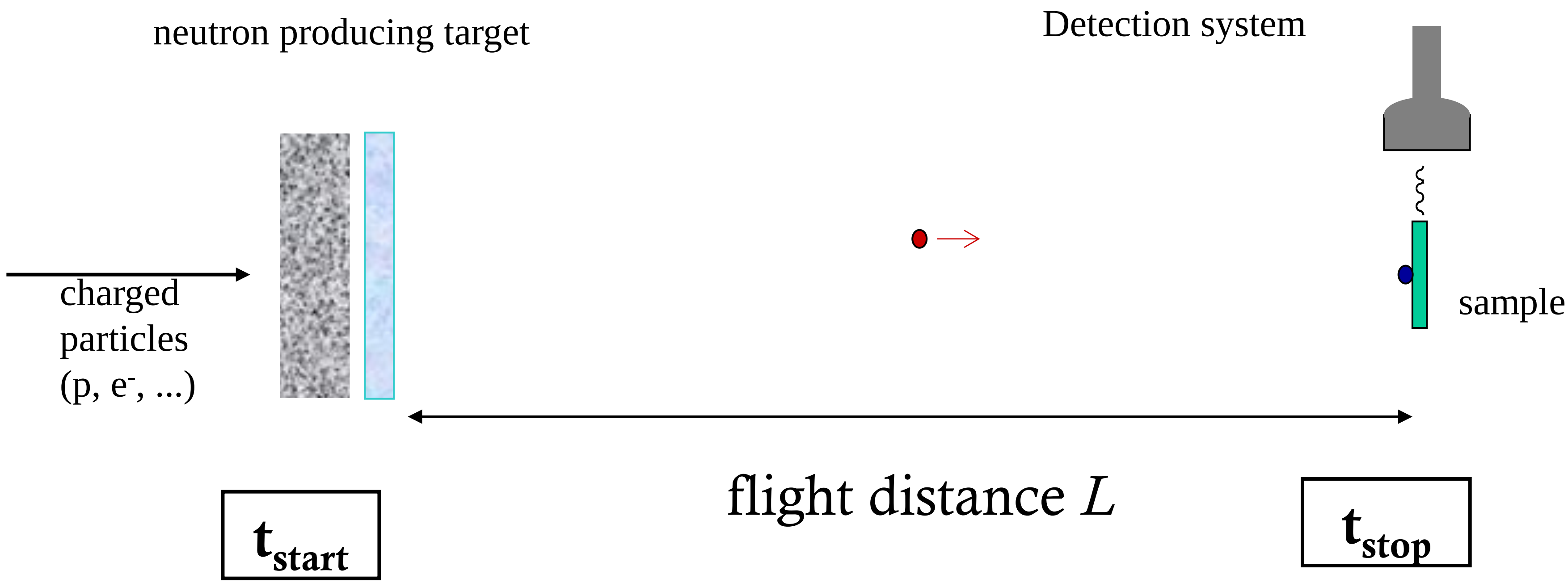


Time Of Flight



Time Of Flight

We have to measure two quantities: the distance and time required by the particle to reach the end of the given flight



$$\mathbf{ToF = t_{stop} - t_{start}}$$

$$E_n = ½\, m\, v^2 = ½\, m\, L^2 / (ToF)^2$$

Neutron racing

t_{start}

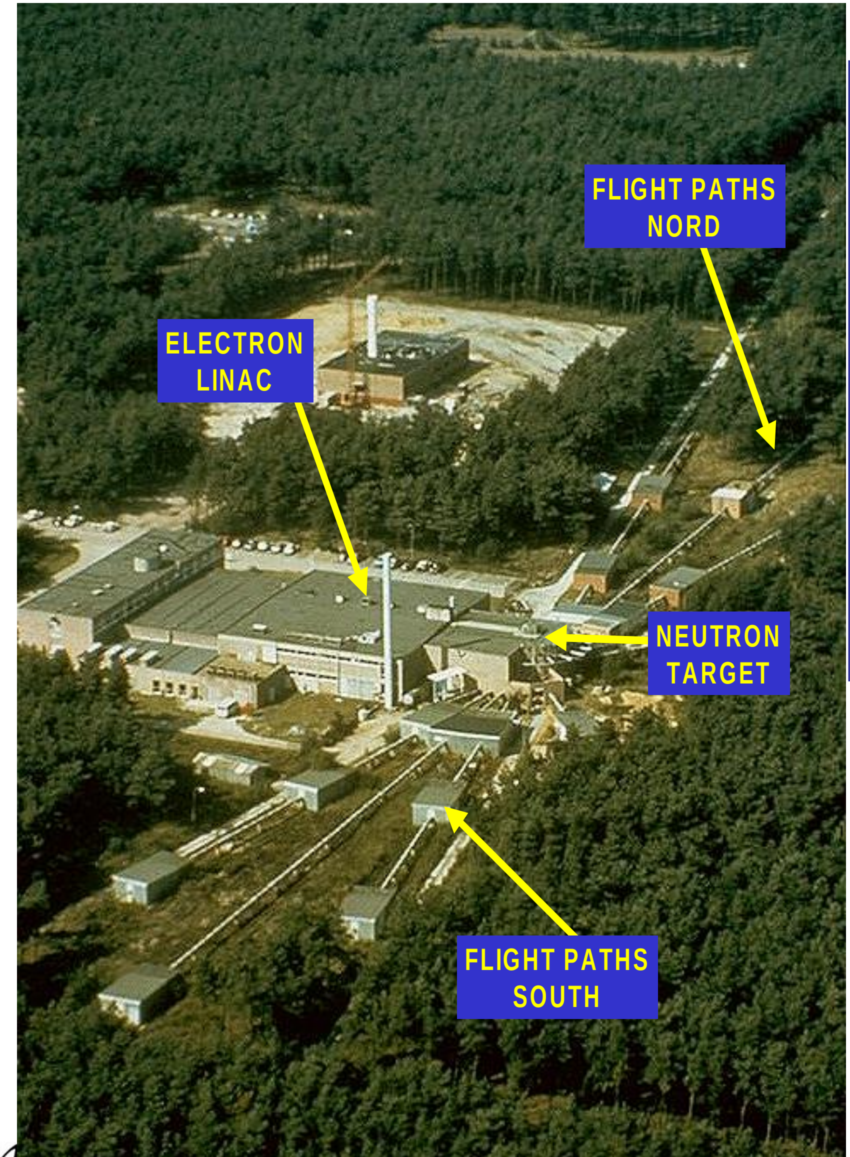
t

Neutron racing

Flight path lenth ?!

t_{stop}

GELINA facility (JRC-IRMM)



Time-Of-Flight facility
Pulsed white neutron source
(10 meV < E_n < 20 MeV)
Multi-user facility with 10 flight paths
(10 m - 400 m)
The measurement stations have equipment to perform:
- Total cross section measurements
- Partial cross section measurements

Pulse width : **1ns**
Frequency : **50 – 800 Hz**
Neutron intensity : **1.6 10^{12} – 2.5 10^{13} n/s**

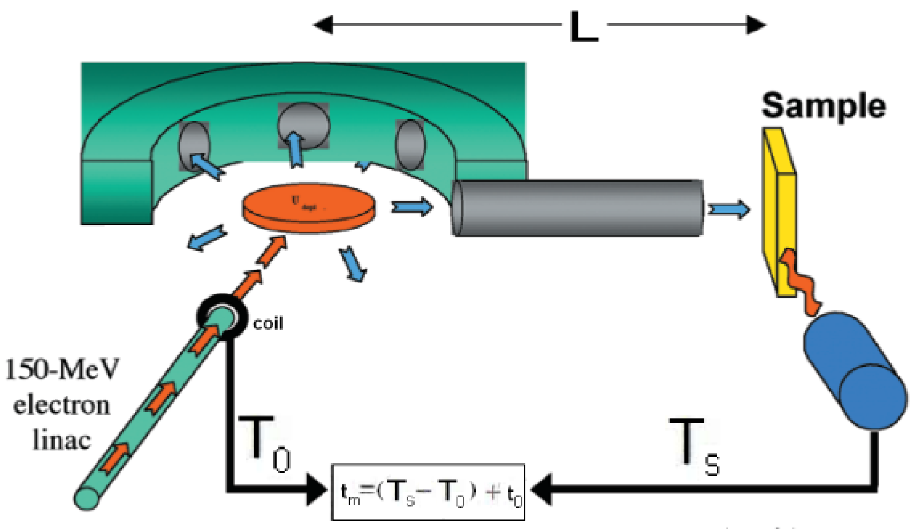
Neutron TOF at GELINA

We need to determine the velocity of the neutron

$E_n = ½(m_n v_n^2)$ where $v_n = L/t$ *

so we have to measure L and t

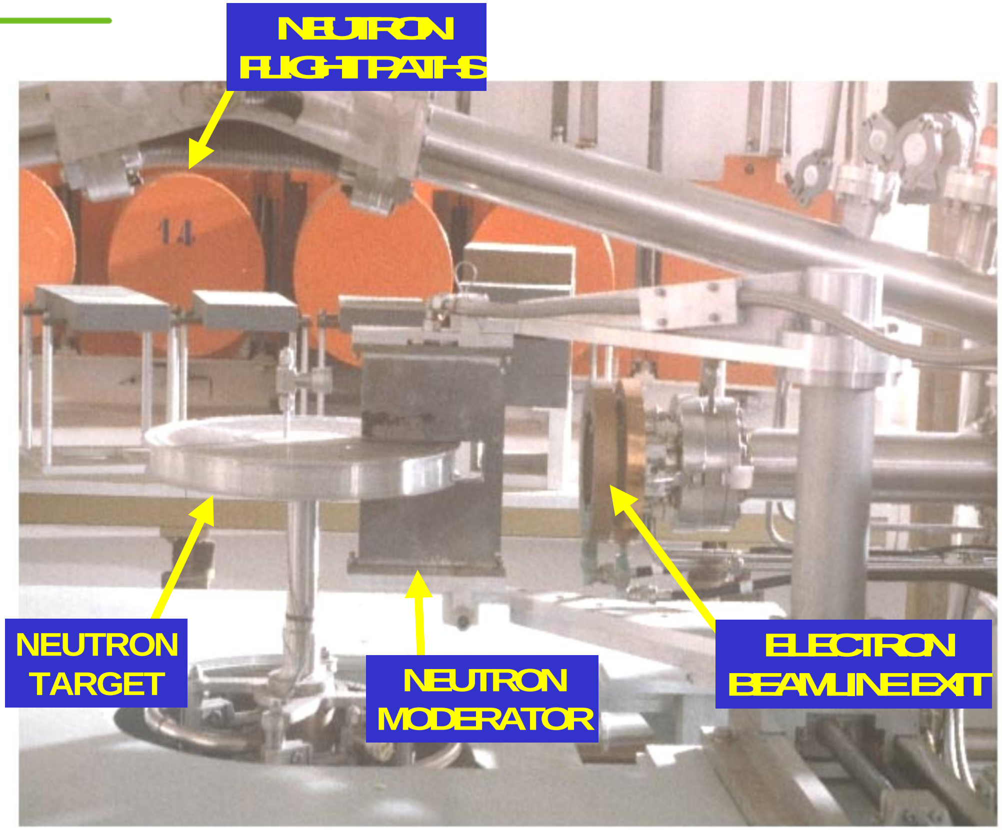
*** non-relativistic**



L: the distance neutrons 'fly'

t: the TOF equals to T_S-T_0

GELINA neutron source



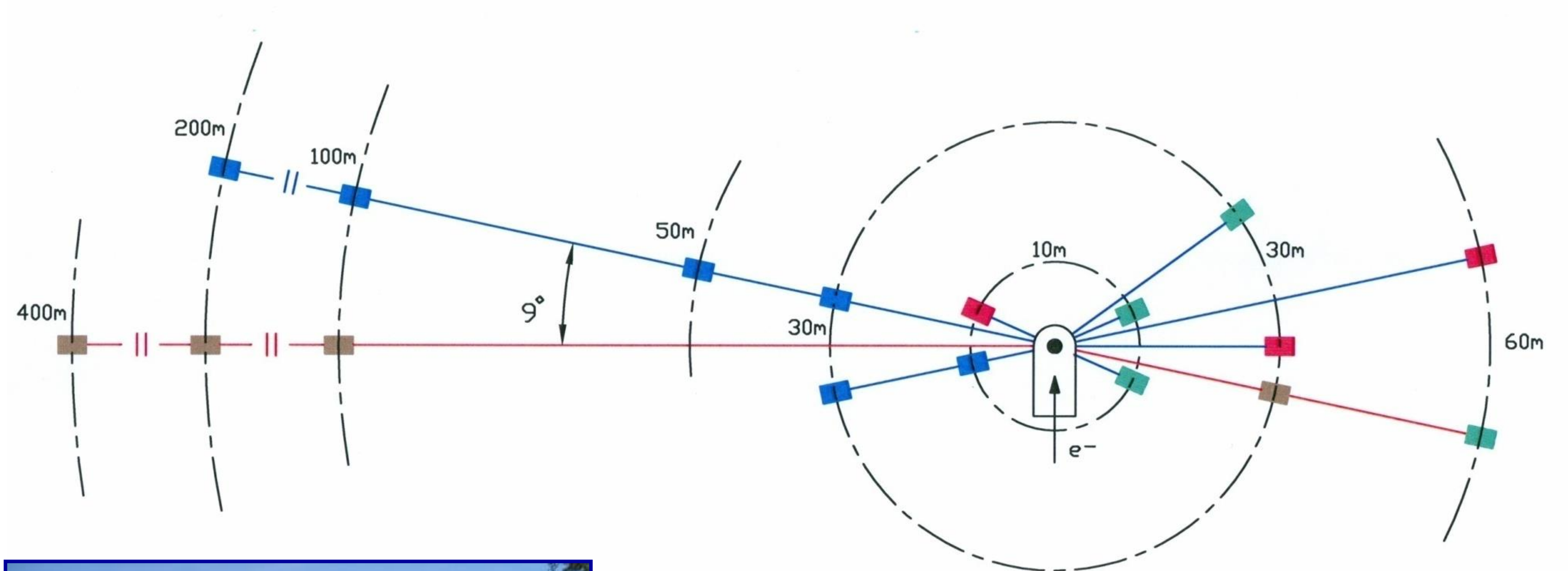
- e^- accelerated to $E_{e-,max} \approx 140$ MeV
- (e^-,γ) Bremsstrahlung in U-target (rotating & cooled with liquid Hg)
- (γ,n), (γ,f) in U-target
- Low energy neutrons by water moderator in Be-canning

GELINA control room

GELINA control room - 1965

GELINA control room - 2009

GELINA top view



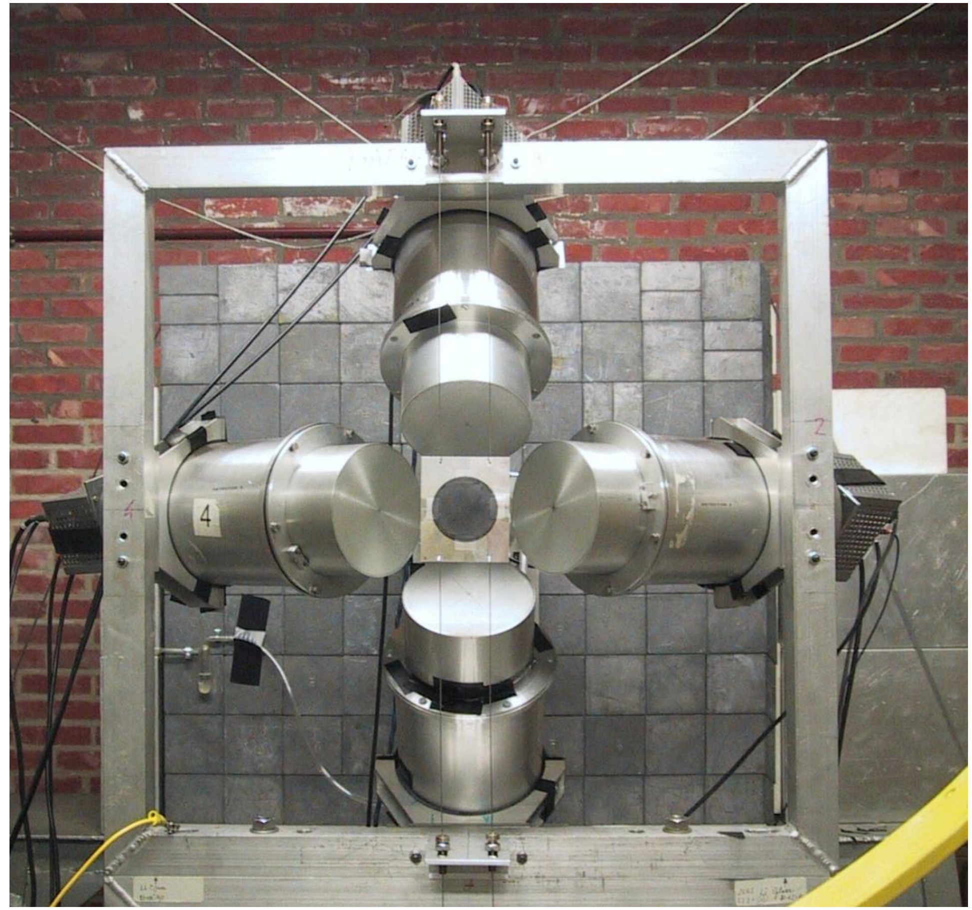
(orange)	**(n,γ)**	**NIM, A577 (2007) 626**
(blue)	**(n,tot)**	**NP A 773, 173 (2006)**
(green)	**(n,f) and (n,cp)**	**NSE 156, 211 (2007)**
(brown)	**(n,n'γ)**	**NP A 786, 1 (2007)**

Capture measurements at GELINA

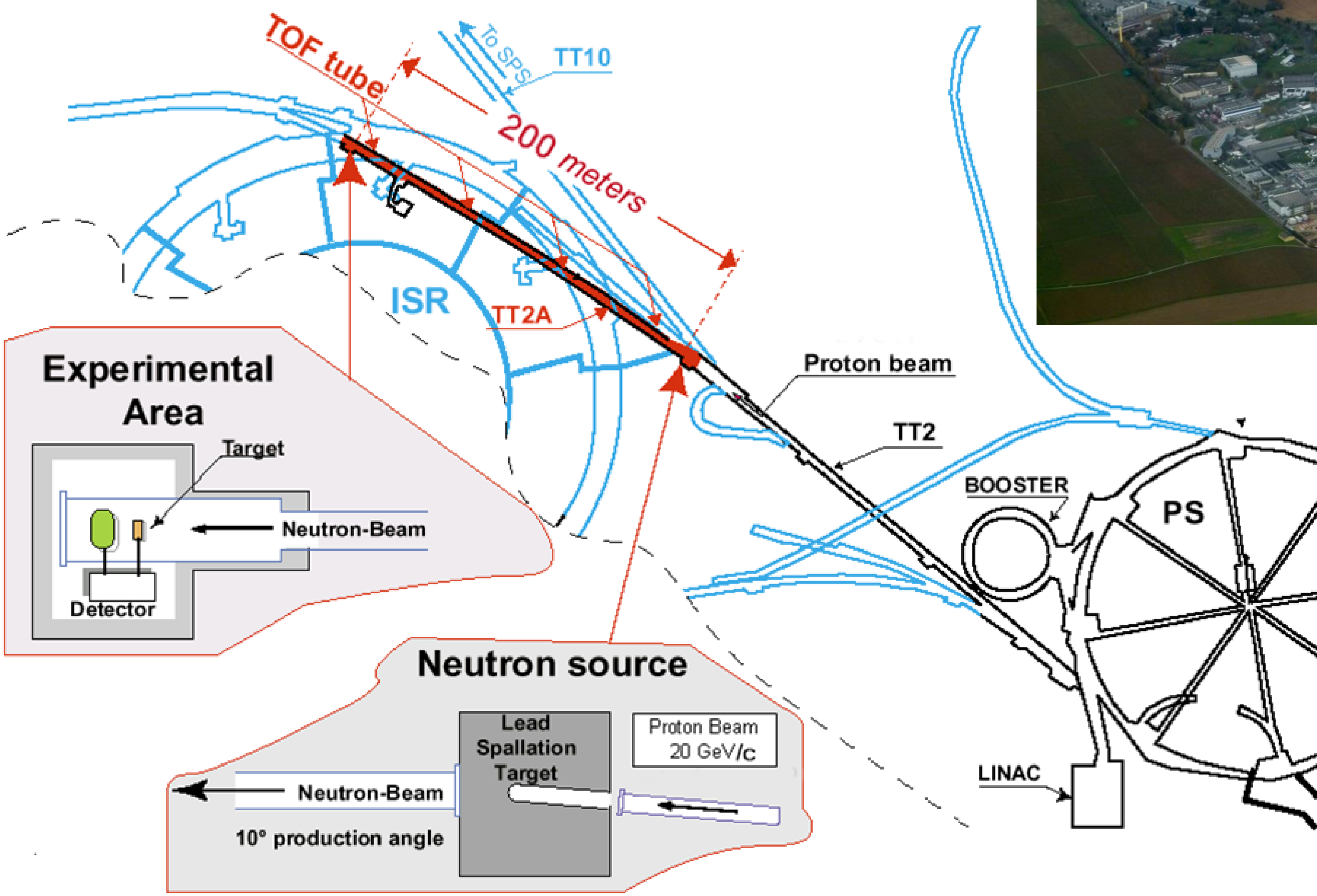
L = 12.9 m

Total energy detection

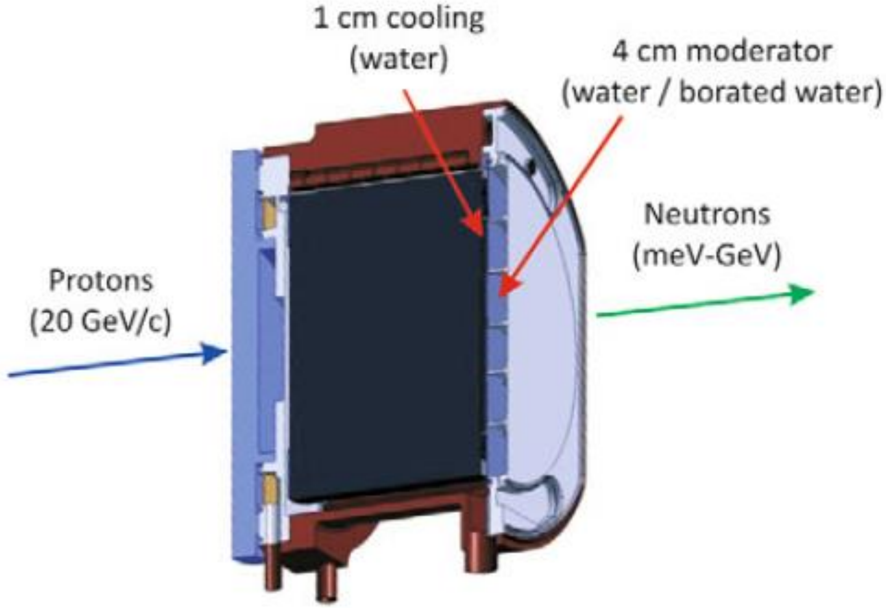
- **C_6D_6 liquid scintillators**
  - 125º
  - PHWT
- **Flux measurements (IC)**
  - $^{10}B(n,\alpha)$



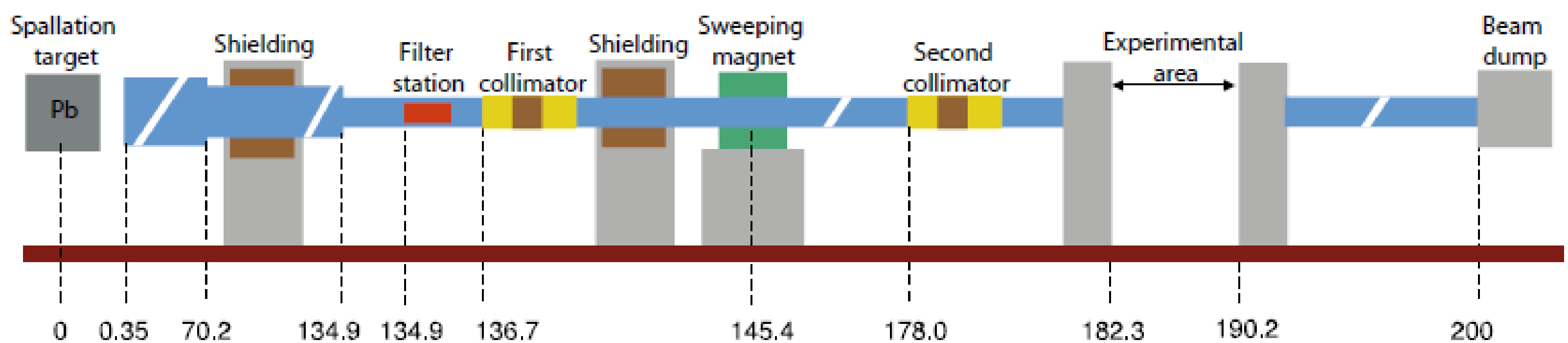
n_TOF facility (CERN)



n_TOF neutron source



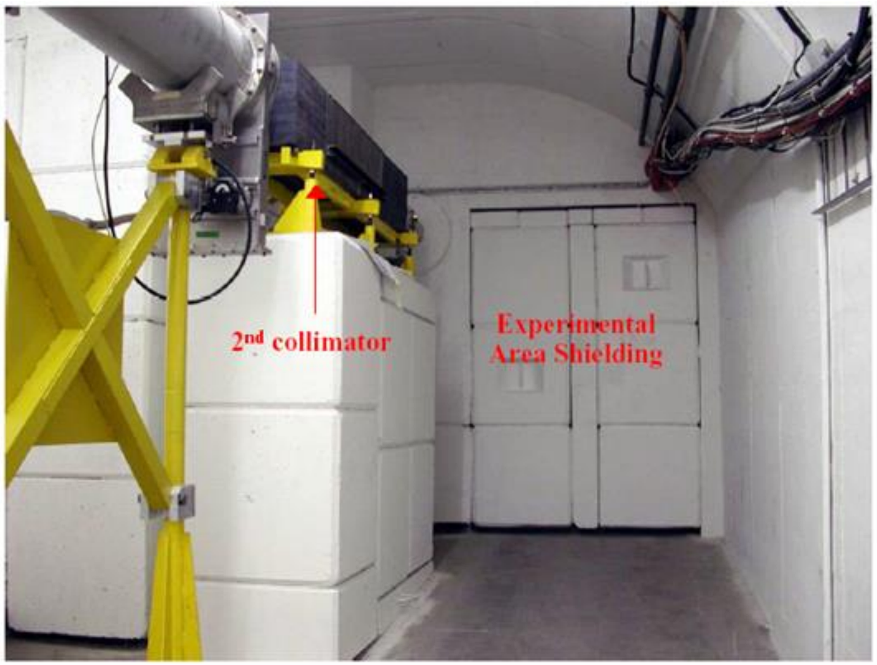
- accelerated protons of 20GeV/c hit the lead block target
- 7 x 10^{12} neutrons ppp
- partial cross section measurements setups
- 200m flight path length



n_TOF tunnel

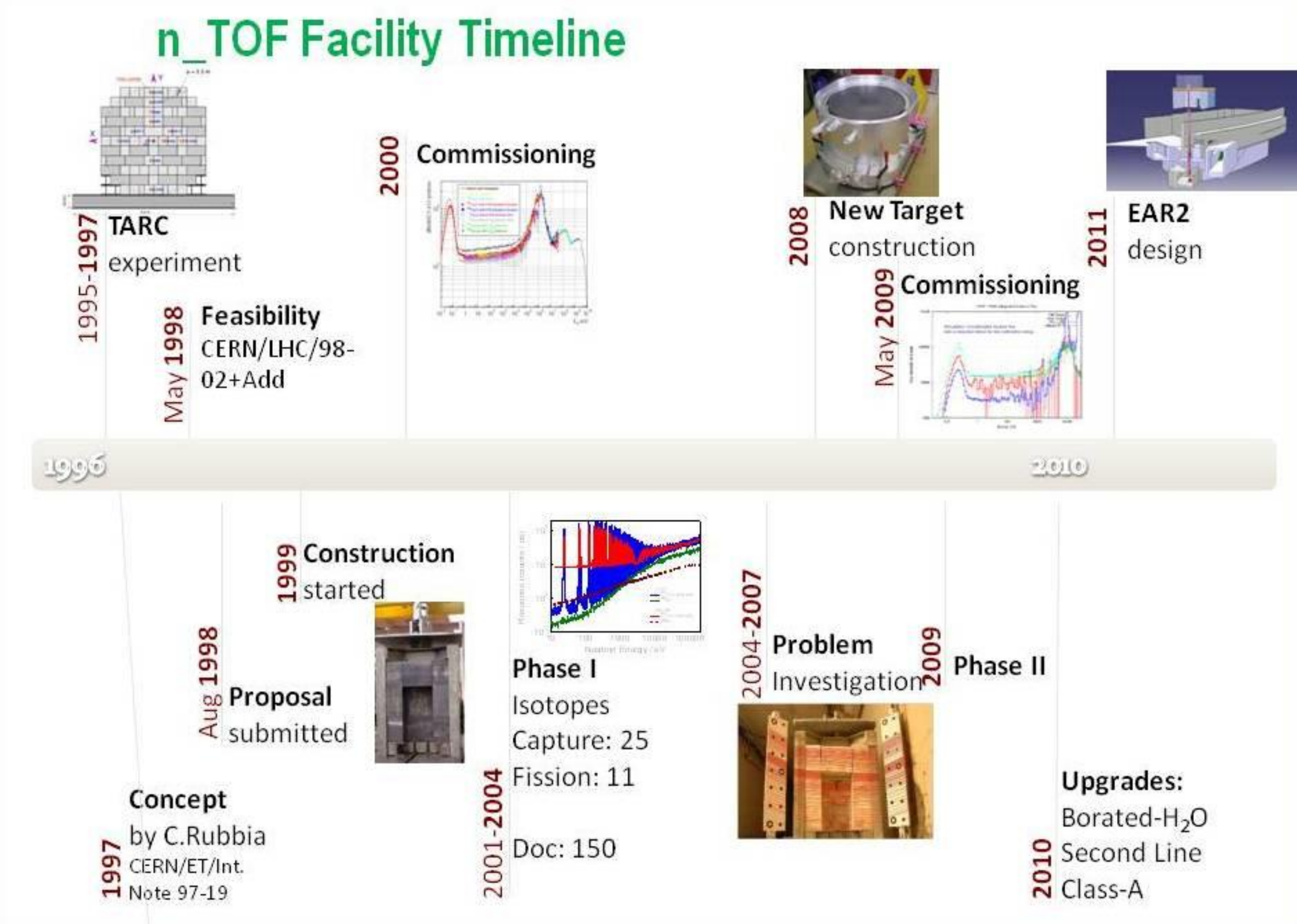

proton beam line


Lead target


2nd collimator
Experimental
Area Shielding

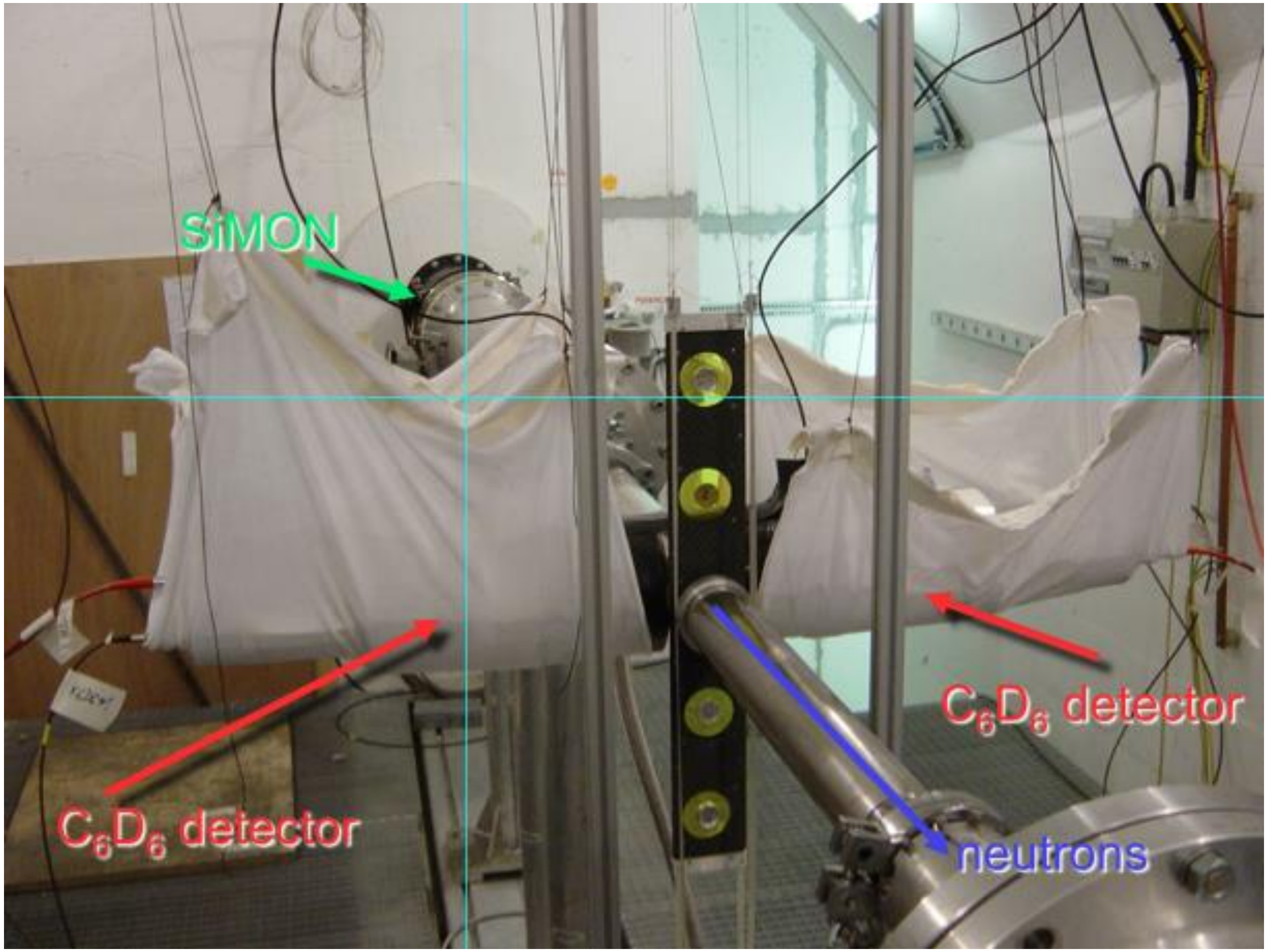

neutron escape line

n_TOF facility history



Capture (n,γ)

^{151}Sm
$^{204,206,207,208}Pb$
^{209}Bi
^{232}Th
$^{24,25,26}Mg$
$^{90,91,92,94,96}Zr$
^{93}Zr
^{139}La
$^{186,187,188}Os$
^{197}Au
$^{233,234}U$
^{237}Np, ^{240}Pu
^{243}Am



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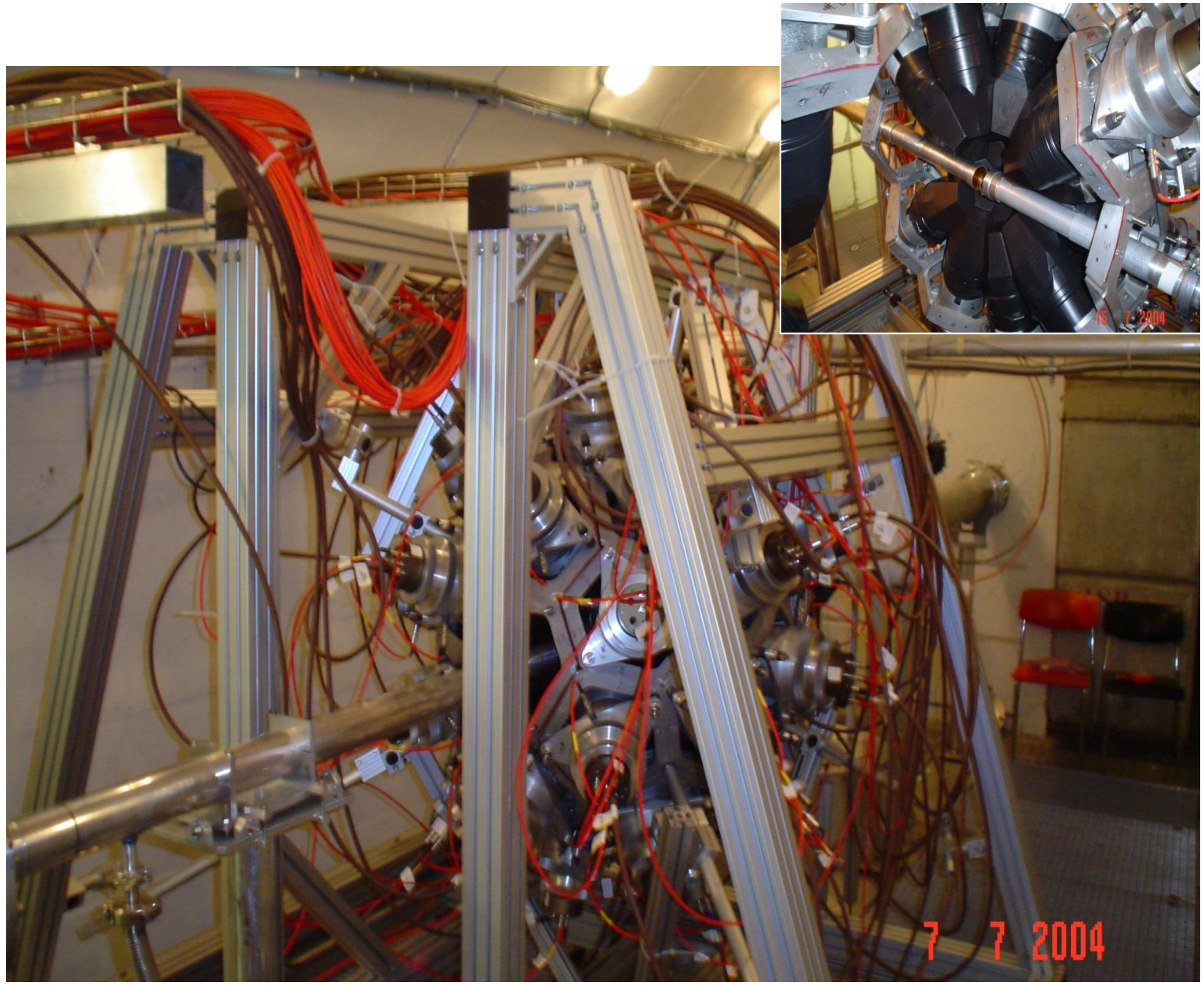
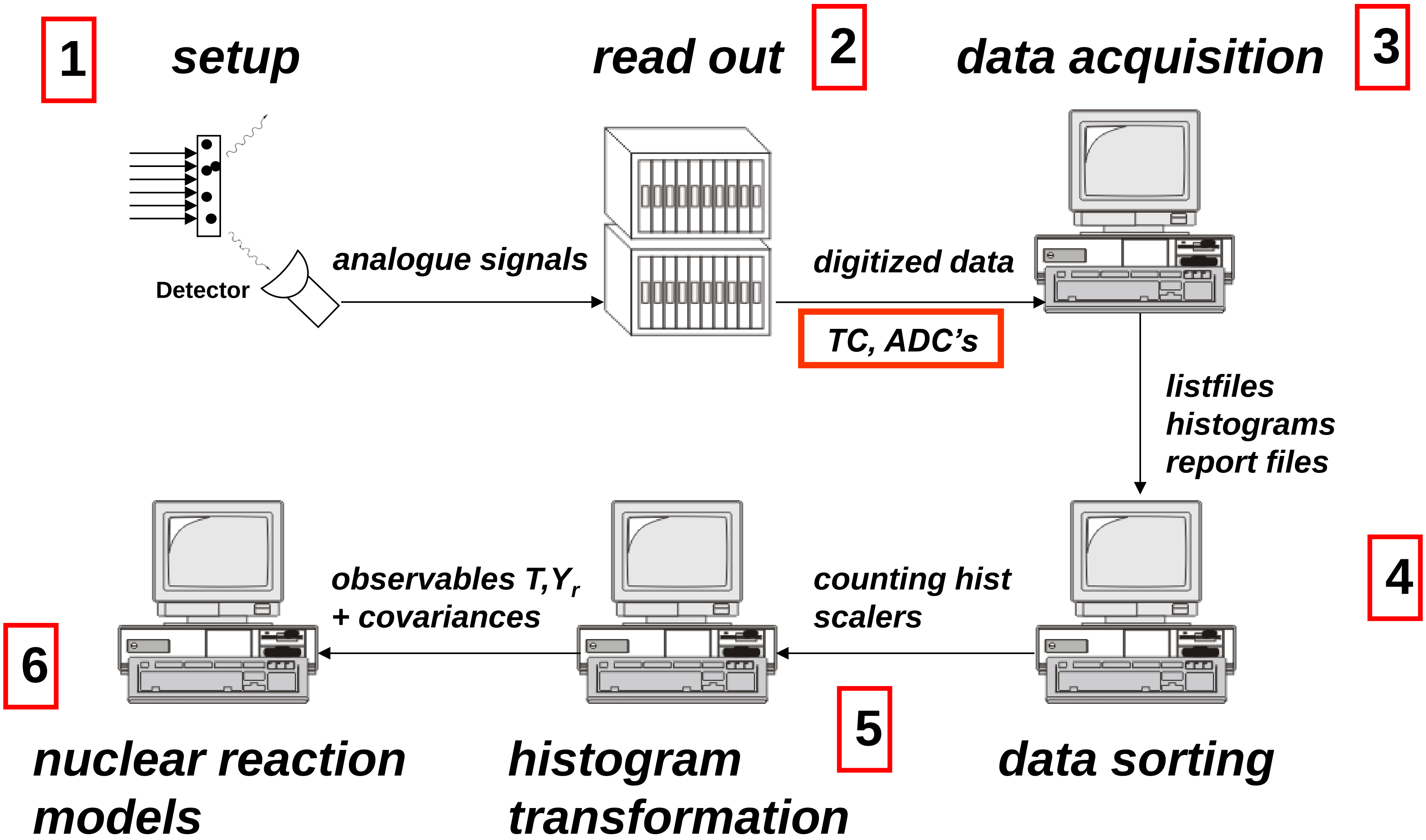


Data reduction workflow

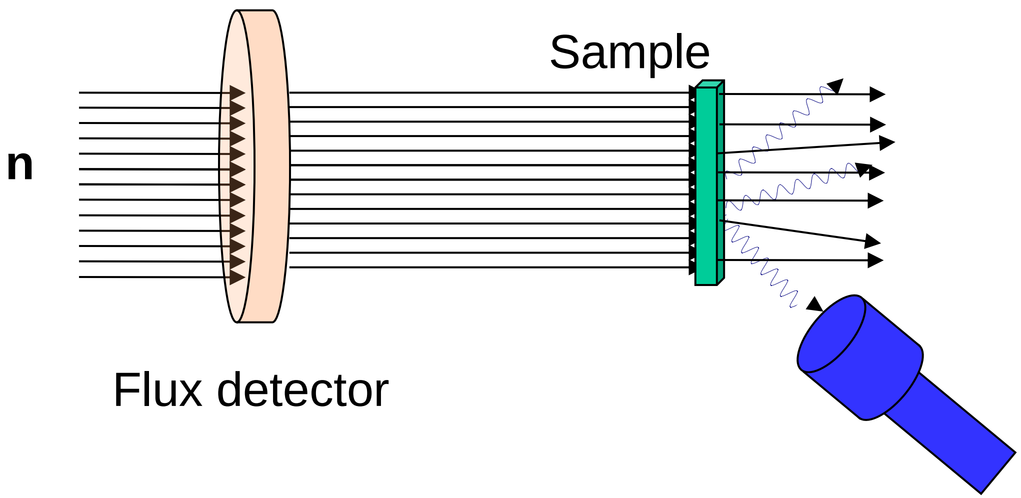


Basic principles

Determined quantity: capture yield, Y_c

Results via fitting code: REFIT

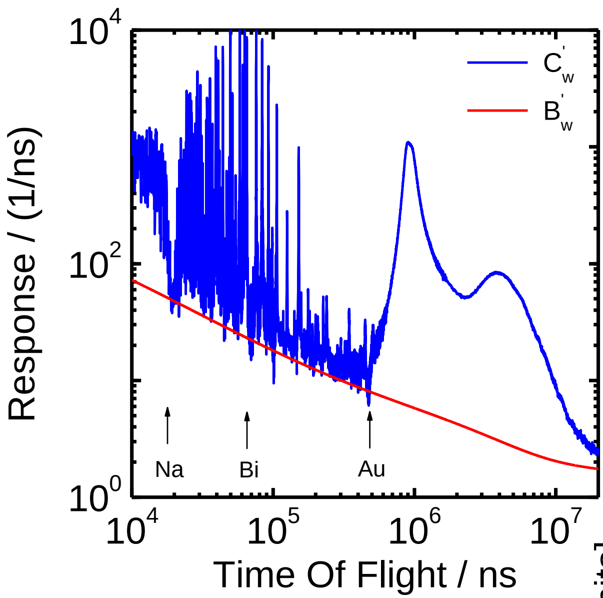
$$Y_{exp} = N \frac{C'_w - B'_w}{C'_\varphi - B'_\varphi} Y_\varphi$$



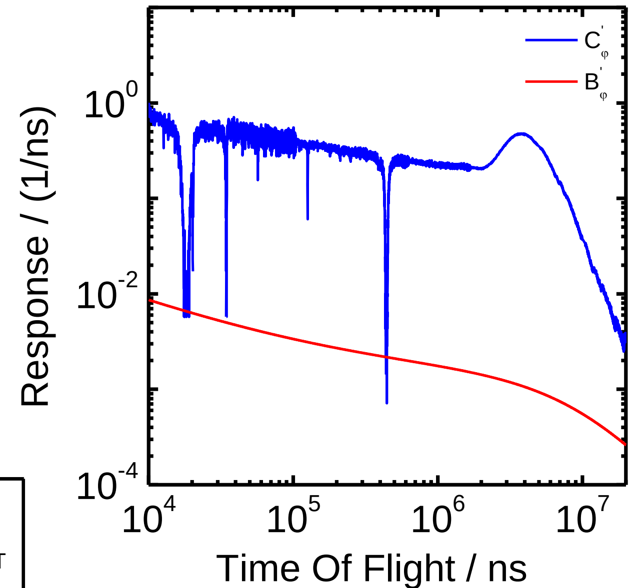
Need to determine accurately:
Net neutron FLUX count rate
Net CAPTURE count rate

Measured quantities

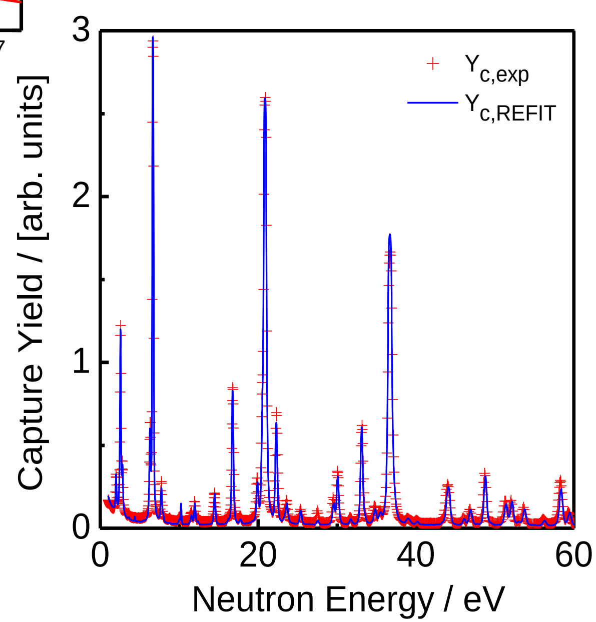
Capture



Flux



Yield



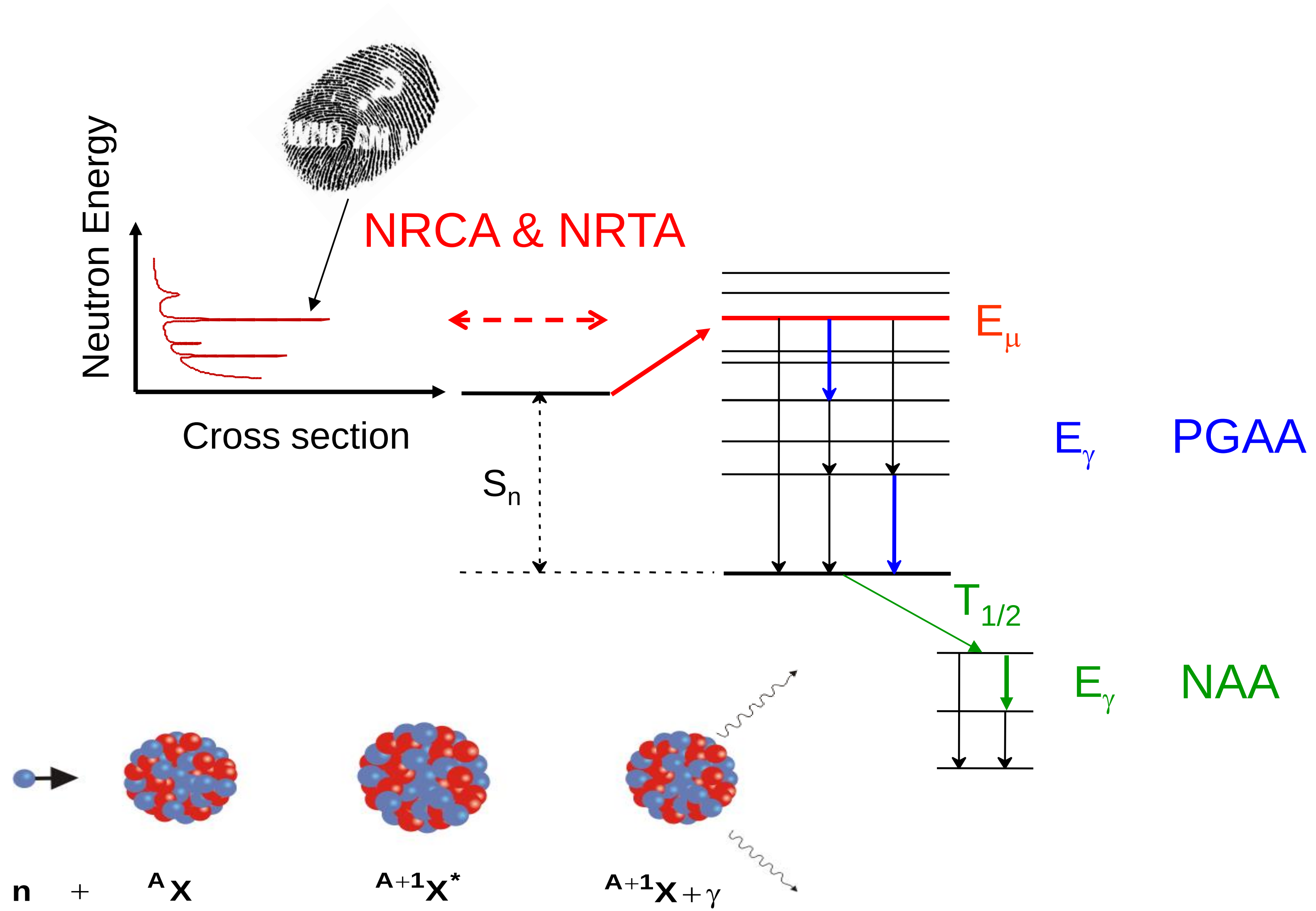
Applications

Many applications make use of neutrons within different fields

- ✓ **Neutrons in the service of Art (Archaeology)**
- ✓ **Security and safety (Detection of illegal substances and explosives)**
- ✓ **Research and Industry (Elemental analysis and isotopic composition)**
- ✓ **Industry and economy (localization of diamonds in rocks)**

irfu cea saclay

Resonances used as fingerprints



Institute for Reference Materials and Measurements

Detection of explosives (monoenergetic)

Neutron source

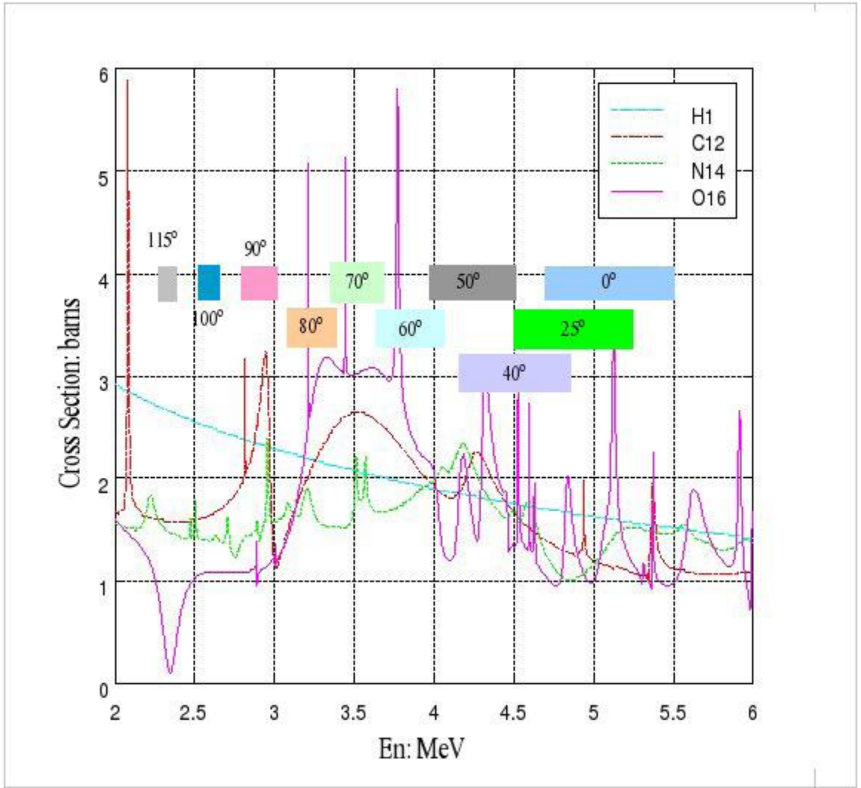
– d(d,n)^{3}He at E_d = 2.5 MeV

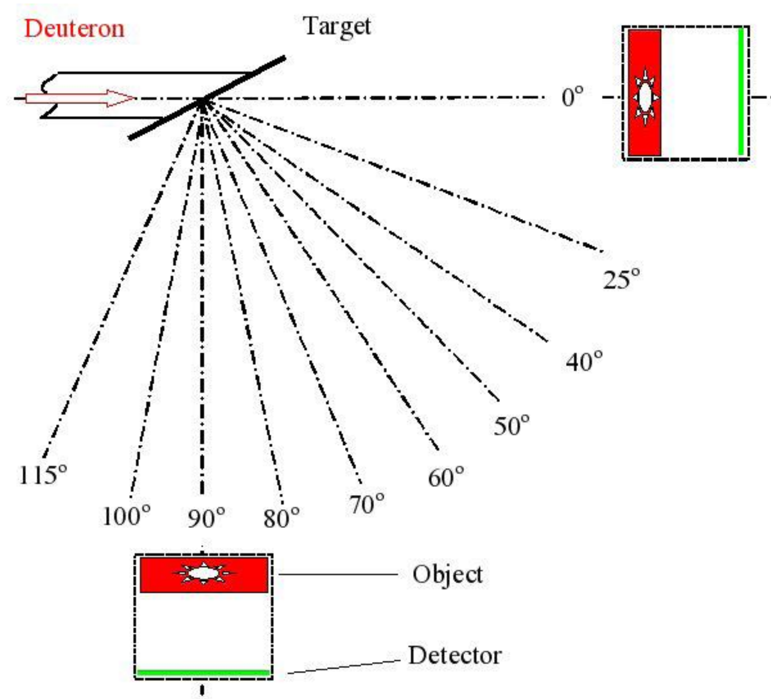
Neutron detector

– a plastic scintillator viewed by a CCD camera

Different angles

– solve a set of linear equations for n_H, n_C, n_N and n_O





G. Chen and R.C. Lanza, IEEE Transactions on Nuclear Science, 49 (2002) 1919 – 1924

Always have alternatives

Pros and Cons

- ✓ **These are full non-destructive methods especially compared to other methods**
- ✓ **No special preparation of the samples required**
- ✓ **Reliable results based on well established procedures**

- ✗ **Require special facilities or devices**
- ✗ **Place restrictions (public places)**
- ✗ **Specialized personnel and time consuming analysis**

Future and perspectives

Neutron experiments and related studies

- ✓ Always room for improvements in experimental performance and analysis techniques
- ✓ Neutron data needs arise from demands (energy, safety, industry…)
- ✓ Research slowed down recently – budget cuts (Fukushima effect)
- ✓ Many new applications using neutrons as probes

Need for new scientists

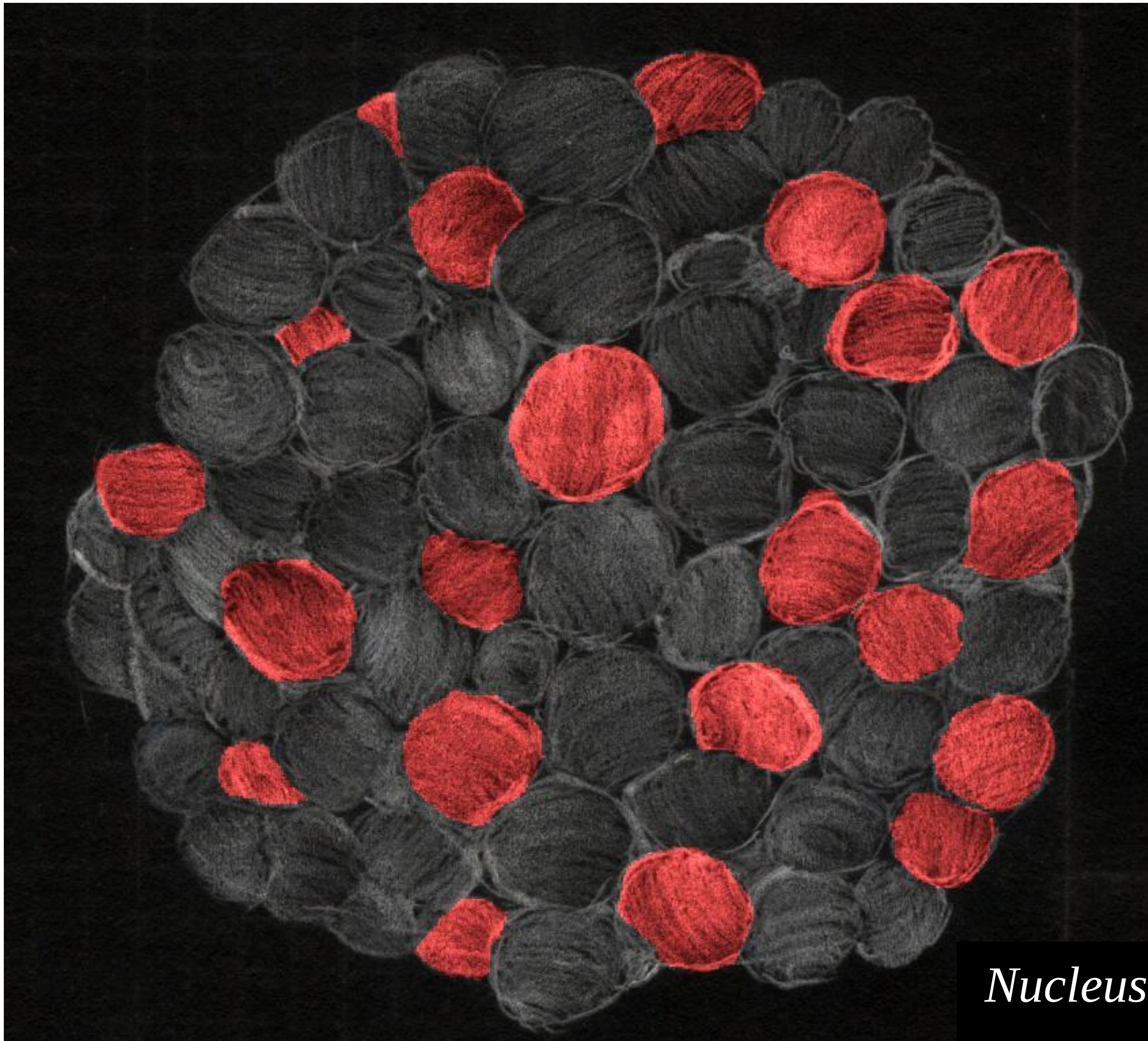
References

You can find additional information

- ✓ *irmm.jrc.ec.europa.eu/*
- ✓ *cern.ch/ntof*
- ✓ *lansce.lanl.gov/*
- ✓ *neutrons.ornl.gov/*
- ✓ *http://www.neutron.anl.gov/facilities.html*

Institute for Reference Materials and Measurements

Thank you



Nucleus of U-235: protons in red, neutrons in grey. (Art by Blake Stacey.)