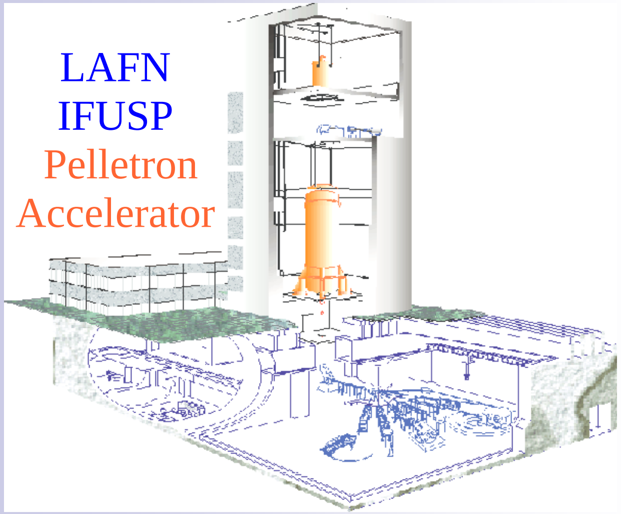
Pelletron-Linac Neutron Wall Detector



Marcelo Gimenez Del Santo

IFUSP - Brazil

FAPESP

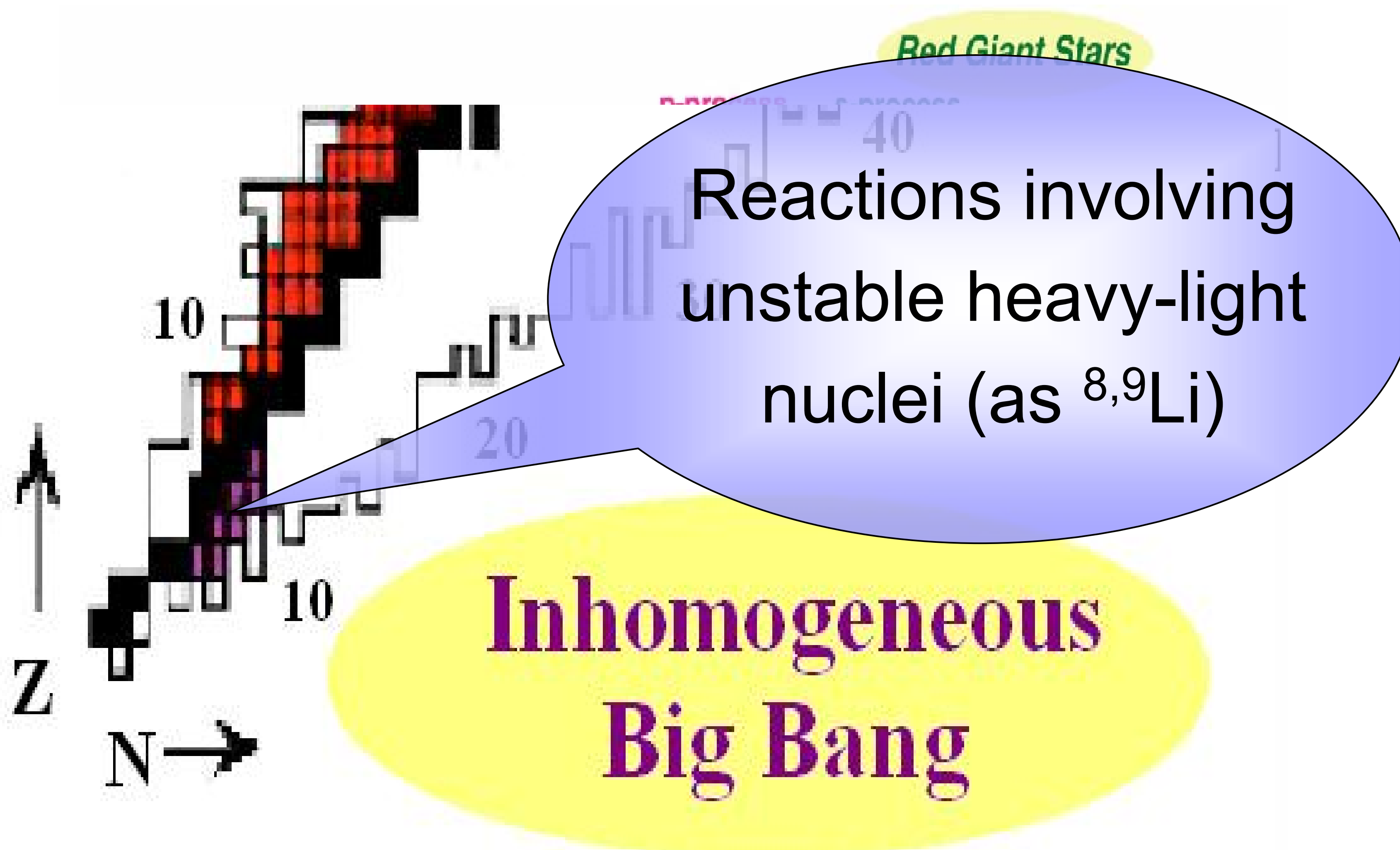
Talk outline

- Motivation
- The Neutron Wall Detector
- Neutron Detection
- Pulse Shape Discrimination (PSD)
- The $^{7}Li(p,n)^{7}Be$ Experiment
- Efficiency,Time Resolution, Position Resolution
- The Neutron Wall in Future Experiments

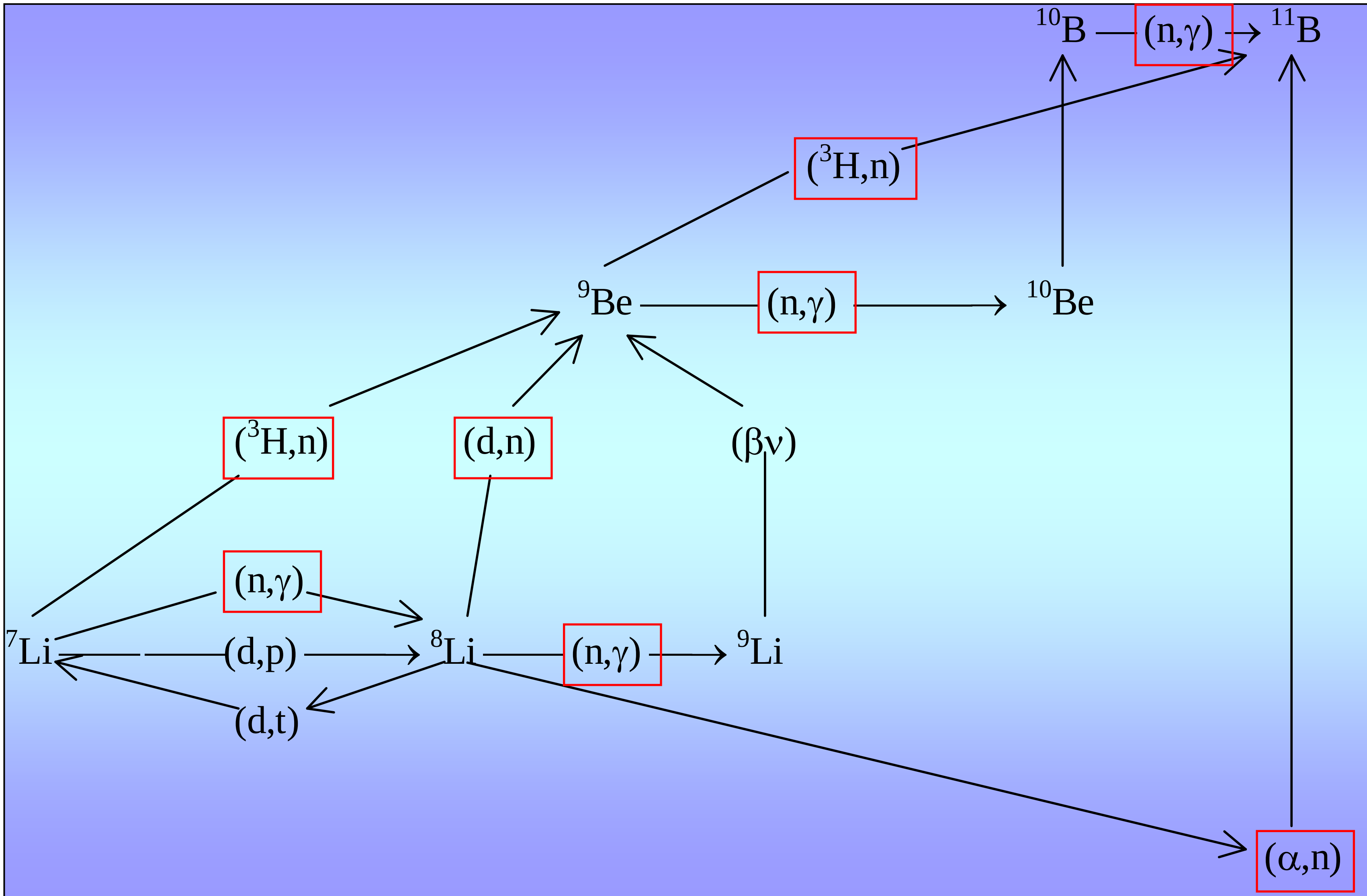
Motivation

- Many interesting aplications;
- Neutron correlations;
- Reactions of astrophysical interested, involving stable and unstable nuclei;

Nucleosynthesis scenarios



Interesting astrophysical reactions



αp - Process

Interesting Reactions:

6He(α,n) e 6He(p,n)

10Be(α,n) e 10Be(p,n)

12B(α,n) e 12B(p,n)

16N(α,n) e 16N(p,n)

20F(α,n) e 20F(p,n)

The Neutron Wall Array Detector

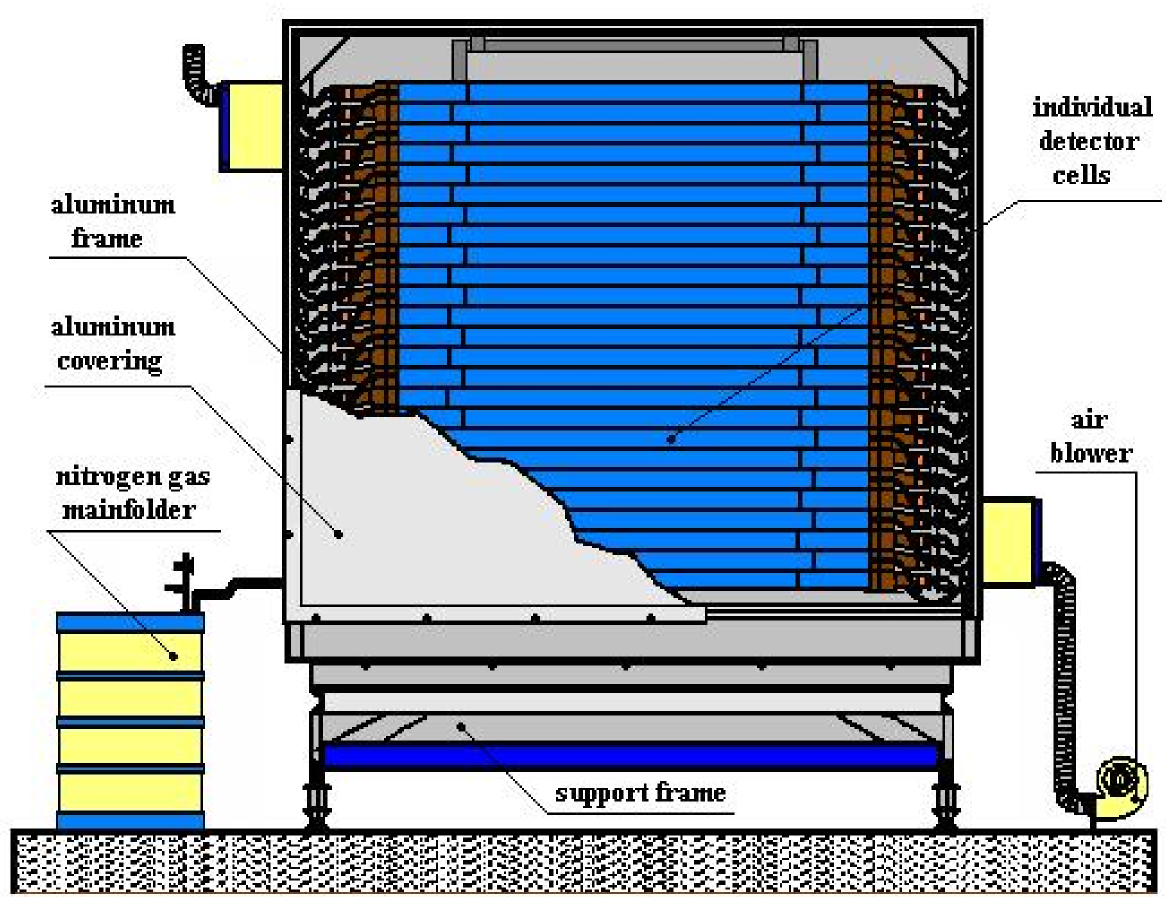
Design considerations

- Increase the angular acceptance of the array by increasing its area
- Greatly decrease the dead space between the individual detectors
- Reduce the inactive (non-scintillator) mass throught which the neutrons must pass to reduce out-scattering
- While increasing the area decrease the ratio of the number of electronic channels to the scintillator volume

Neutron Wall array characteristics

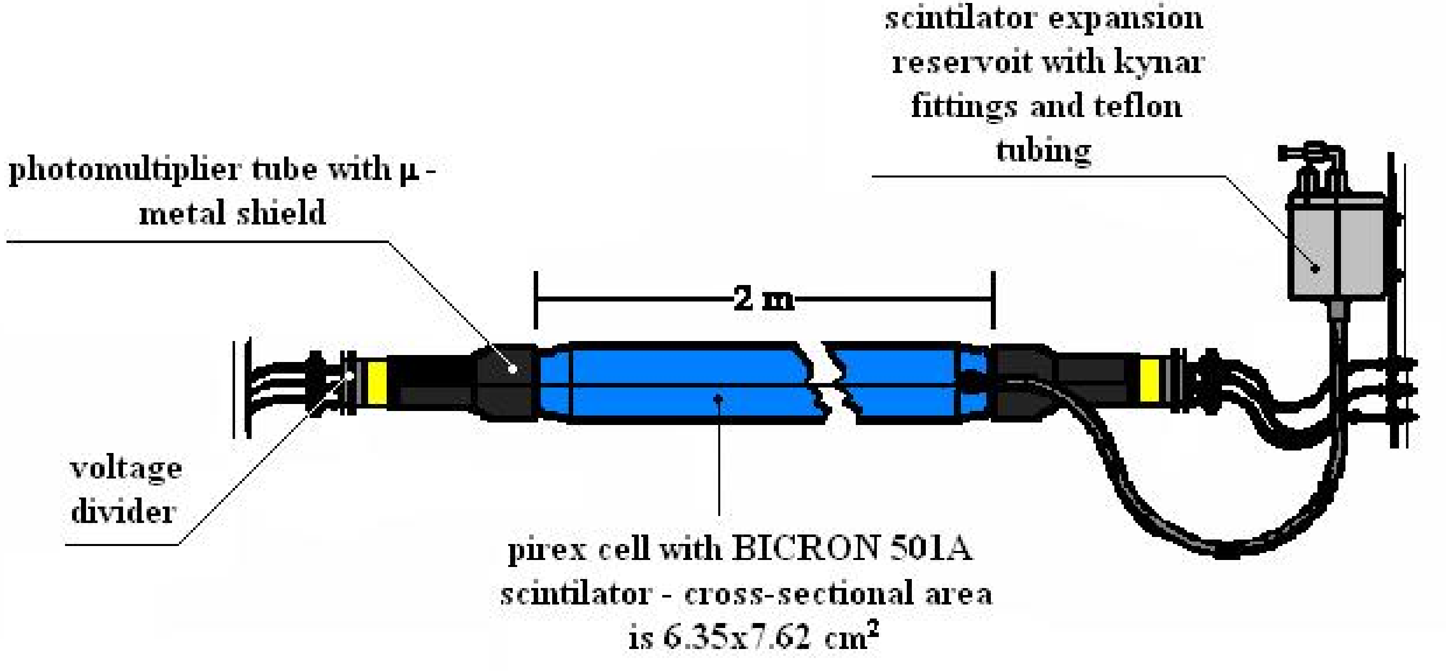
- Total area : 2x2 m^2
- Inactive area less than 12%
- Position-sensitive neutron detection
- Two independent walls
- Aluminium frames
- Each whit 24 detector cells
- Scintillator BICRON 501A
- The gas monitor detects high levels of xylene

Based on the Michigan State University Neutron Wall project



The cell

- Total length: 2m
- Pyrex cells filled with liquid organic scintilator BICRON 501A
- Two PMTs view the cell from both ends
- Surrounding each PMT there is a μ-metal shield
- The tubing and fittings are made of Teflon being chemically resistant to scintillator



The Neutron Wall Detector

Neutron Detection

in Pelletron-Linac Neutron Wall

Fast Neutrons (E_n > 1 MeV) detection

Elastic scattering (Q=0) of neutrons

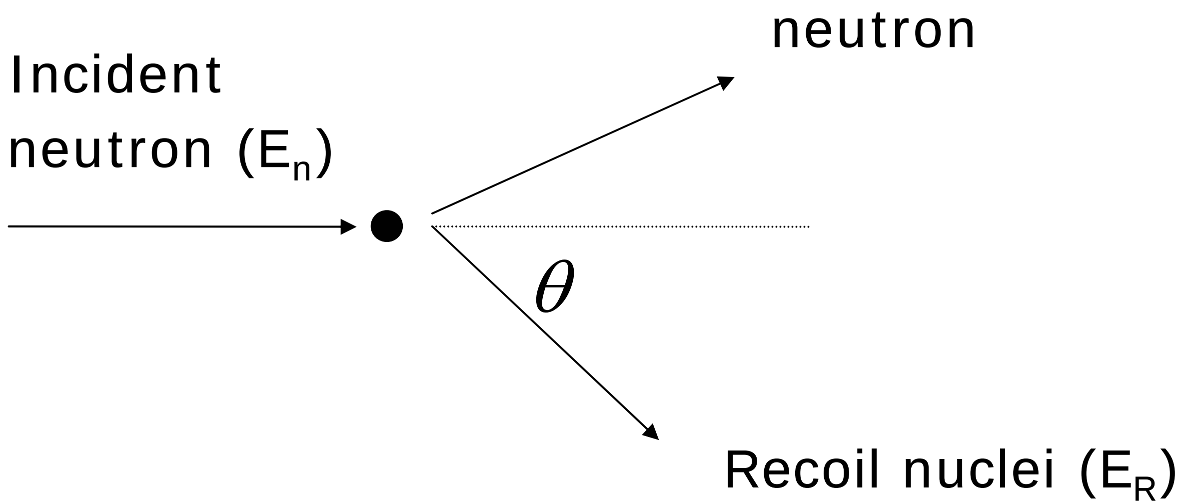
Organic scintillator

Photomultiplier

Elastic scattering

$$E_R = \frac{4A}{(1+A)^2}\left(\cos^2\theta\right)\cdot E_n$$

if A=1 $\rightarrow$ $E_R = E_R^{MAX}$



Organic Scintillator

Basic Principle:

Luminescence/Fluorescence

Absorption of energy and emission in the form of visible radiation

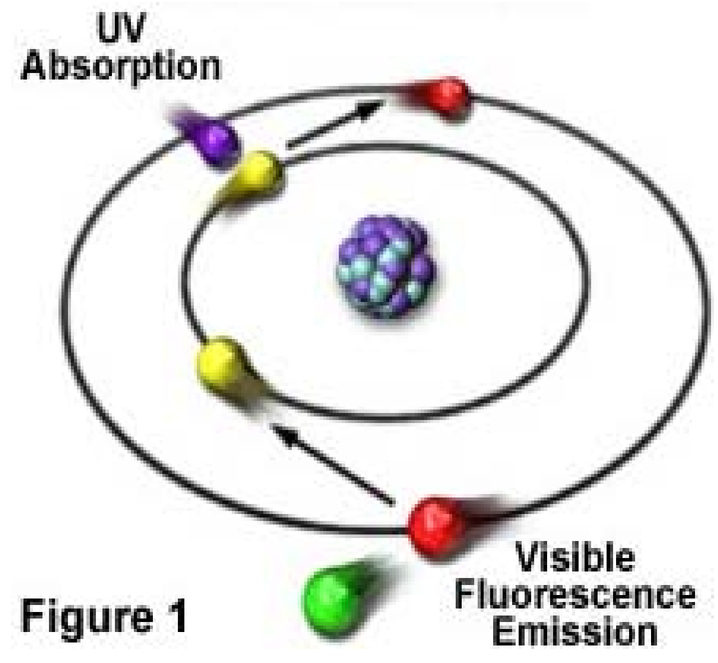


Figure 1

Scintillator Efficiency

$$\varepsilon = 1 - exp(-N \cdot \sigma \cdot d)$$

where:

N - nuclei density ;

σ - *neutron scattering cross section*;

d - distance covered by the neutron inside the detector.

Scintillator composition

nucleus	A	$\frac{E_{R\max}}{E_n} = \frac{4 \cdot A}{(1+A)^2}$
H	**1**	**1**
^{2}H	2	0,889
^{3}He	3	0,75
^{4}He	4	0,64
^{12}C	12	0,284
^{16}O	16	0,221

Ratio of energy tranfered from the neutron to diferent nucleus

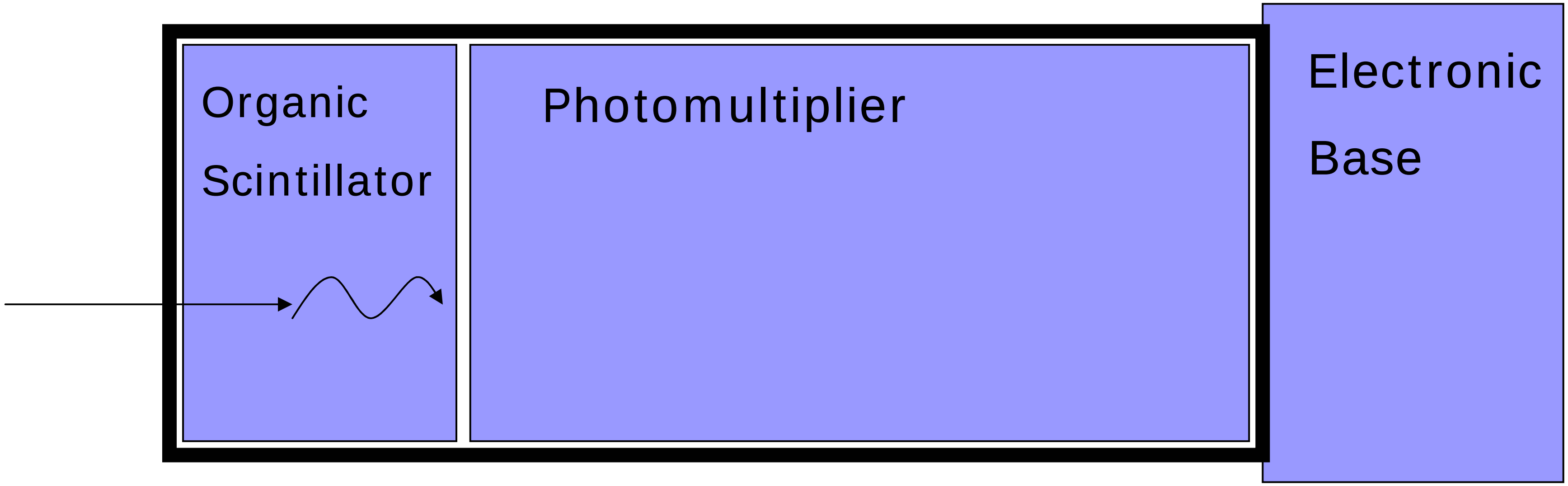
Process	σ_R (24MeV)
n + p → n + p	0,406 b
n + C → n + C	**0,900 b**
n + C → n + C´ + γ (4,44MeV)	0,104 b
n + C → He + Be – 5,71MeV	0,048 b
n + C → n + 3α – 7,26MeV	0,210 b

Cross sections for some process

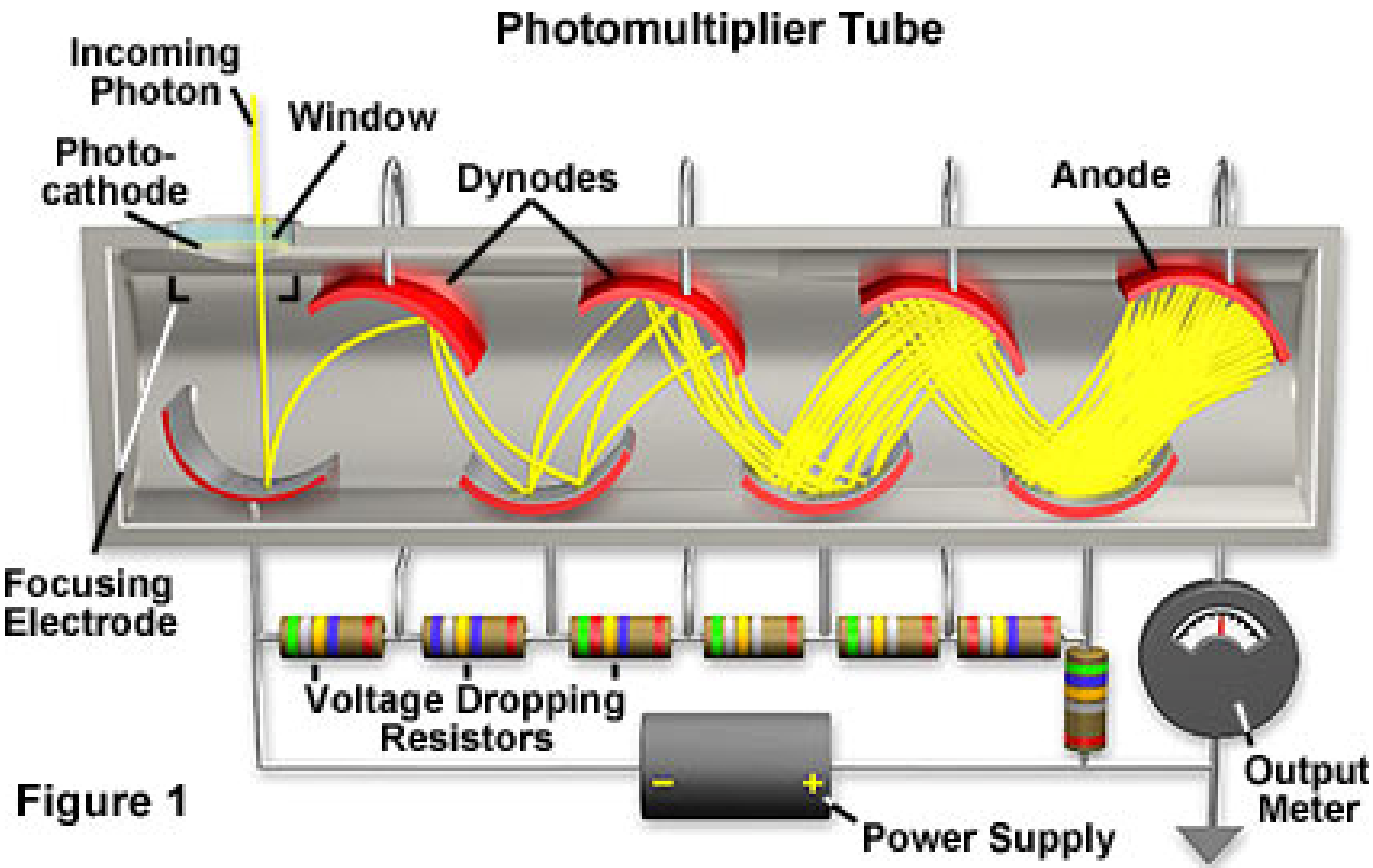
BICRON 501A – Liquid Scintillator - Ratio H:C Atoms = 1.2

Basic Elements

- Organic Scintillator
- Photomultiplier
- Electronic Base of the photomultiplier



Photomultiplier



Scintillator Caracteristics

- High efficiency in the conversion of the energy of excitement for fluorescent radiation;
- Transparency of the scintillator material for this radiation;
- Consistent spectral emission with the sensitivity of the photomultiplier;
- Short decay time (τ) ;

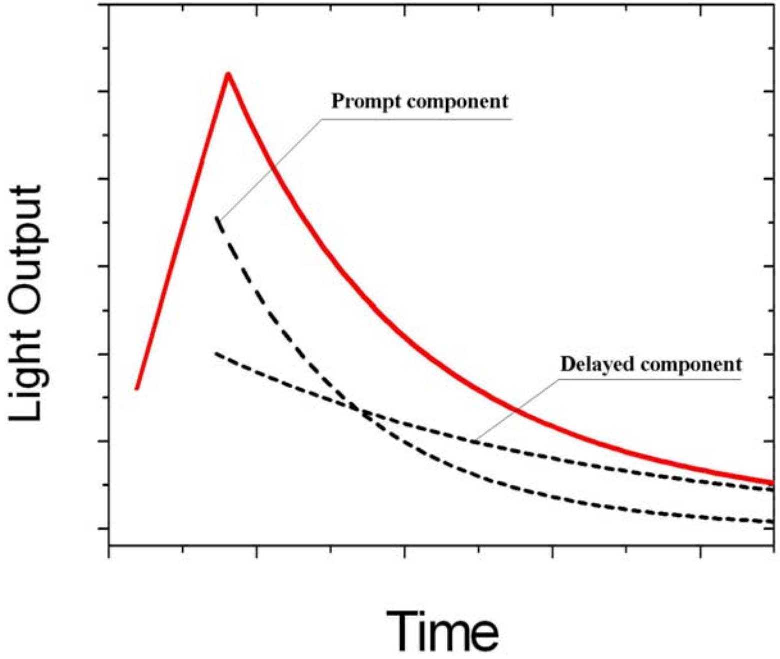
Pulse Shape Discrimination (PSD)

- The scintillator detector is sensitive to more than just neutrons
- Large background of γ-rays and cosmic-rays
- For some scintillator the shape of the pulse varies according to the specific ionization of the particle

Light emission

- The energy re-emission process is described in the equation below:

$$N = A\exp\left(\frac{-t}{\tau_f}\right) + B\exp\left(\frac{-t}{\tau_s}\right)$$

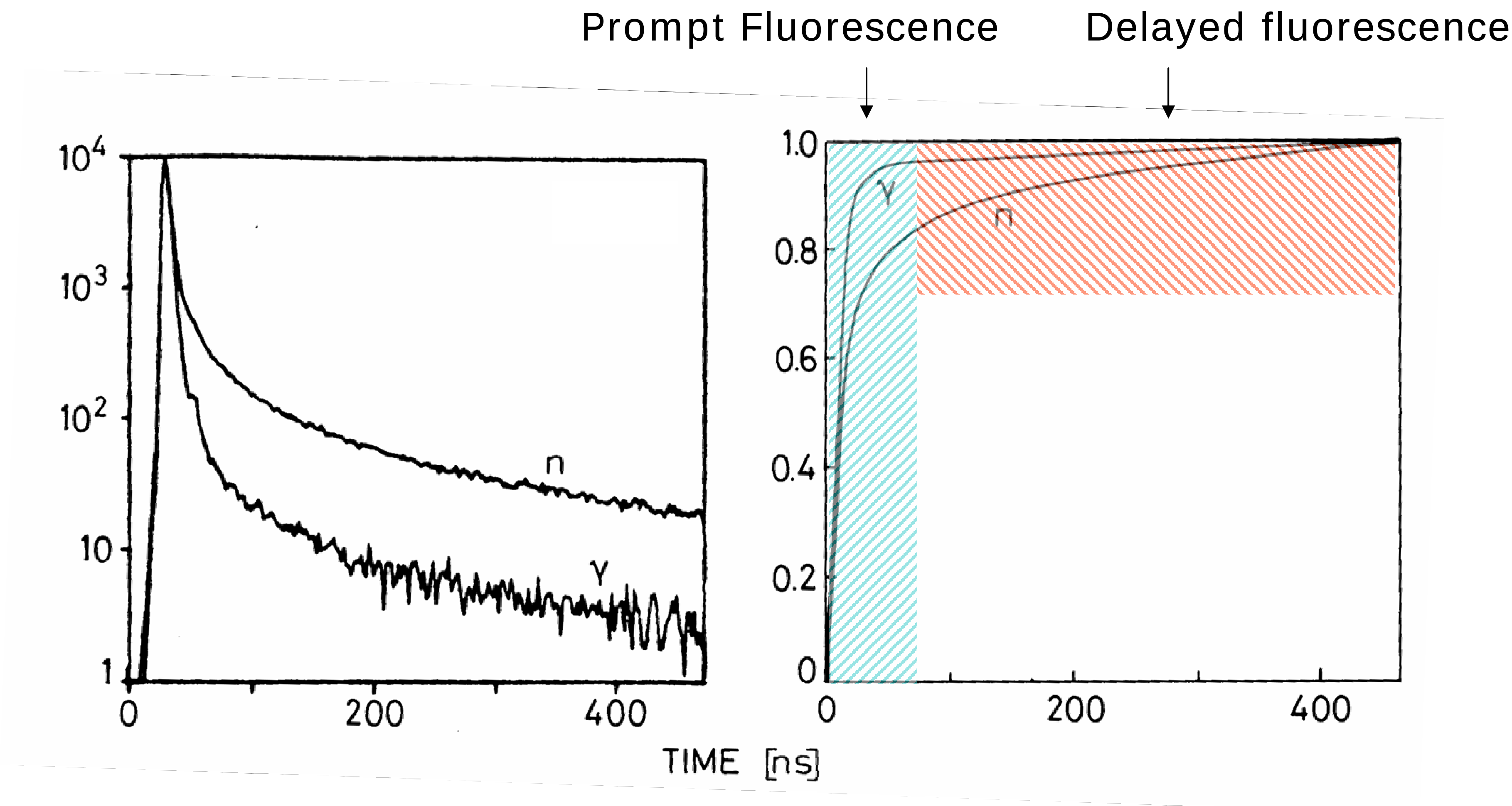


where:

N - number of photons emitted in the instant *t;*

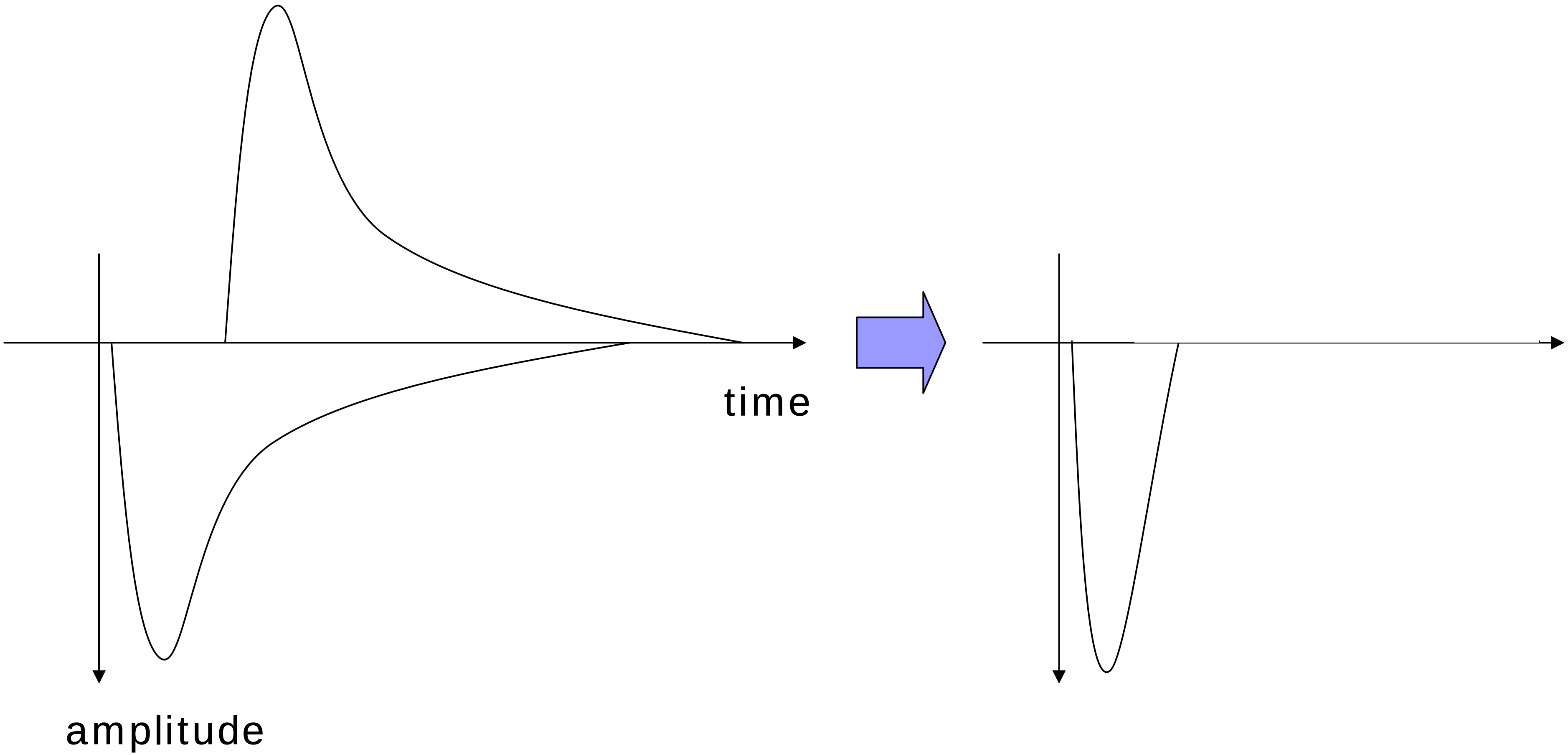
τ_f - decay constant of the prompt fluorescence component;

τ_s- decay constant of the delayed fluorescence component;



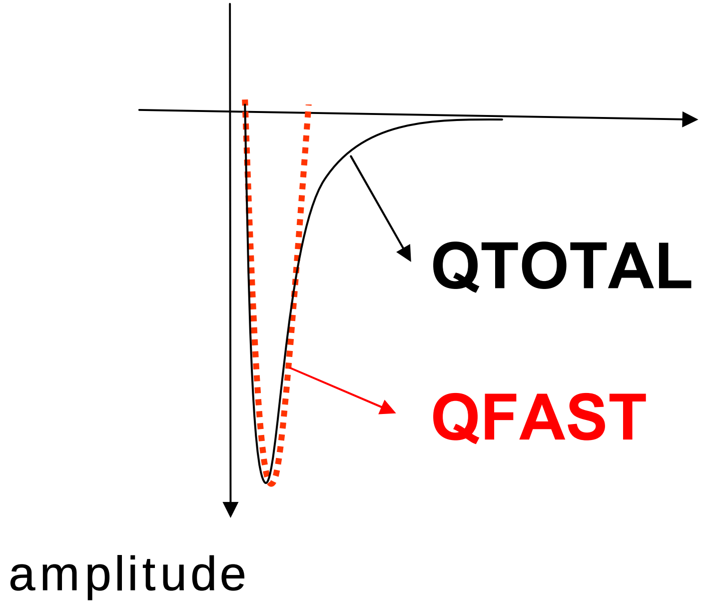
Pulse shape differences of BICRON 501A liquid scintillator light for neutrons ang gamma rays. The integral of the light pulses is also show. A discrimination between these radiations is possible

Neutron Wall
Pulse Shape Discrimination (PSD)

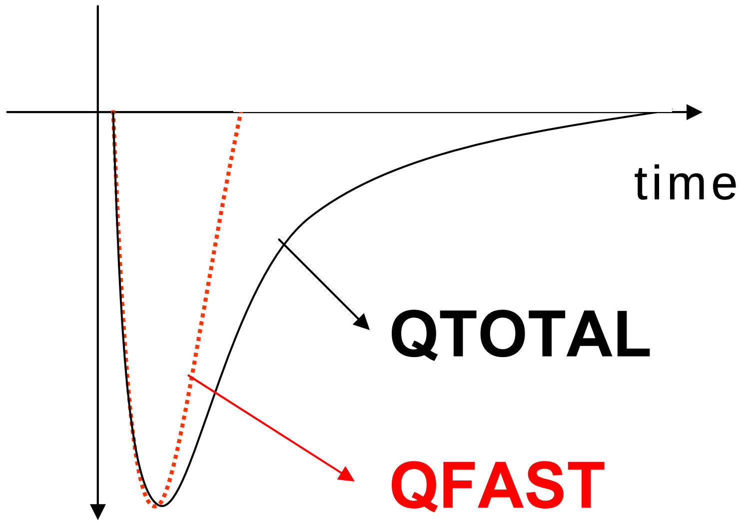


Neutron Wall
Pulse Shape Discrimination (PSD)

γ - ray



neutron



Neutron Wall Electronic

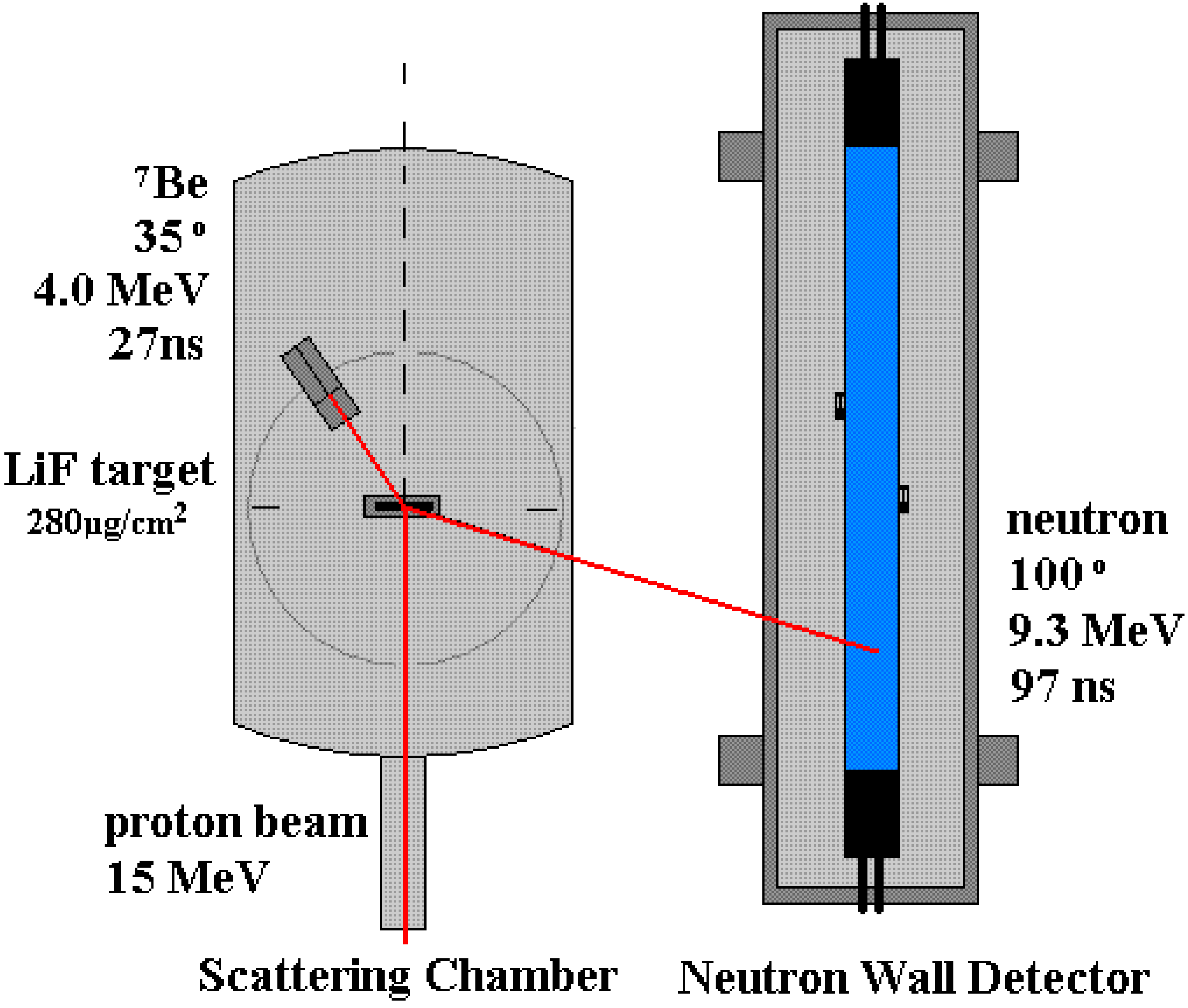
- What is measured ?

1. Total signal integral (QTOTAL);
2. Prompt component integral (QFAST);
3. Time signal of each event relative to another reference signal common to all the cells (TDC). This reference signal can be generated by a charged particle detector;

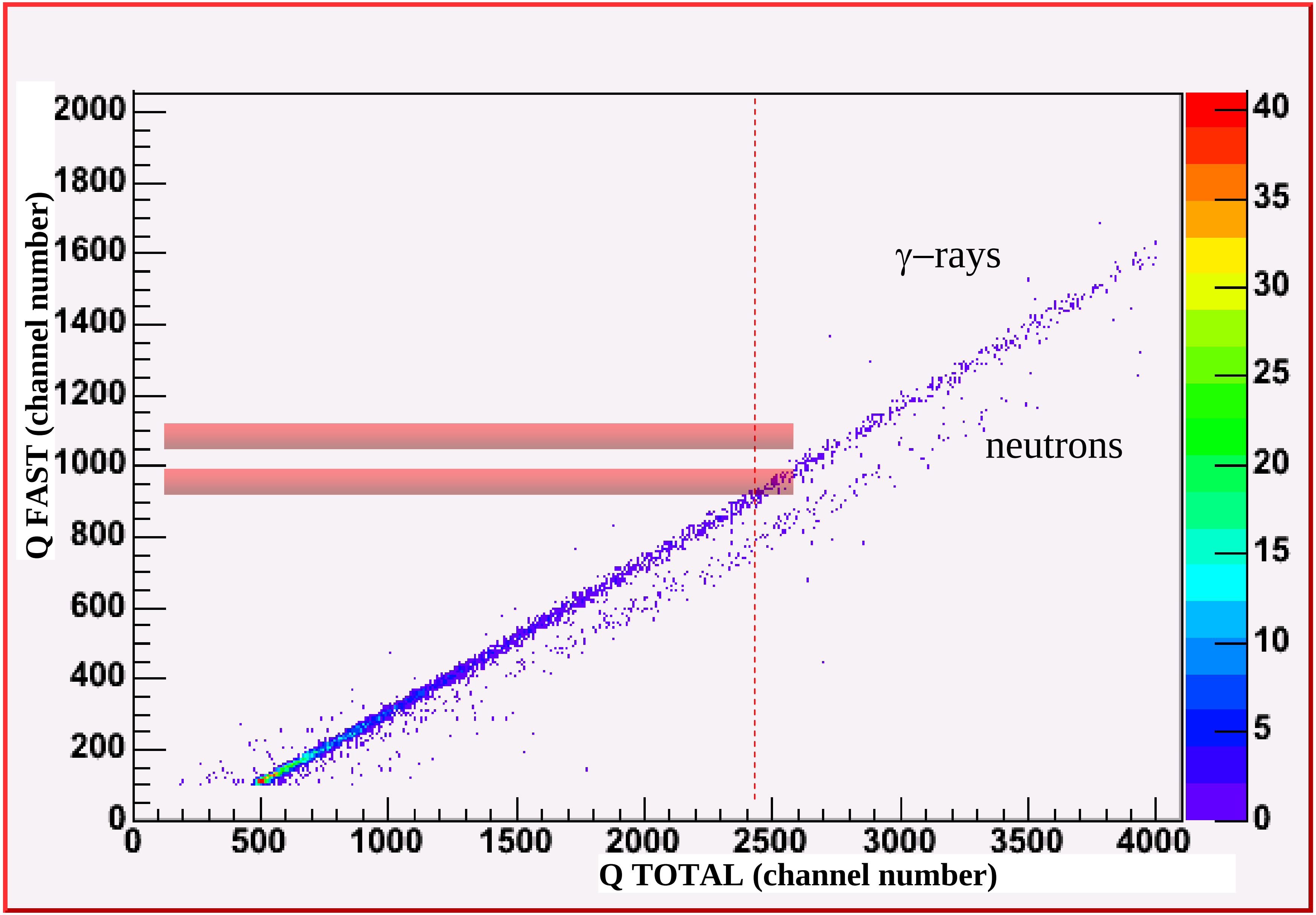
The $^7Li(p,n)^7Be$ reaction

- To test fully the functionality of the detector, it was used the $^7Li(p,n)^7Be$ reaction, a reaction that produces only one neutron whose angular and energy distribution are well know;

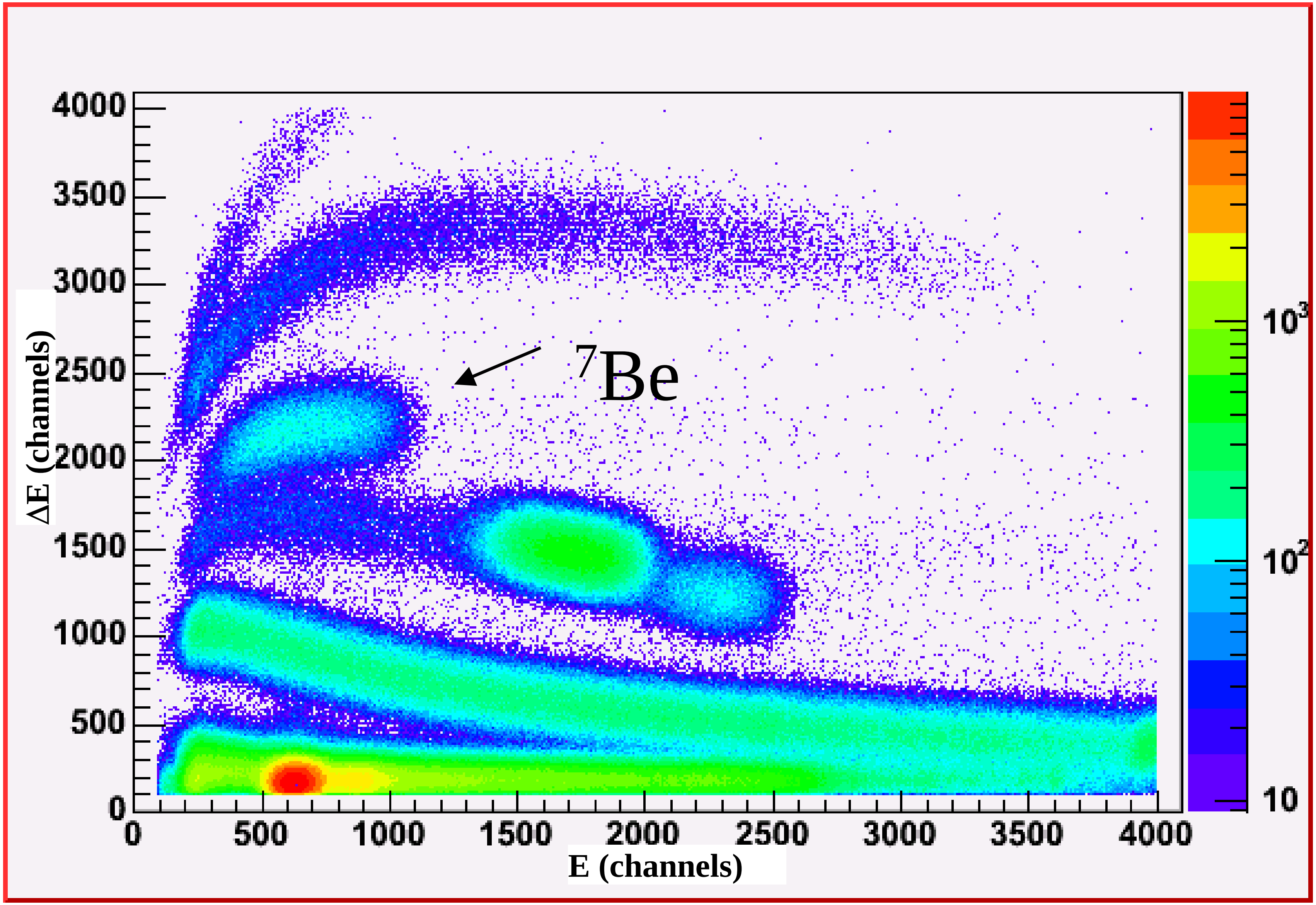
Experimental Setup



The $^7Li(p,n)^7Be$ reaction



The $^{7}Li(p,n)^{7}Be$ reaction

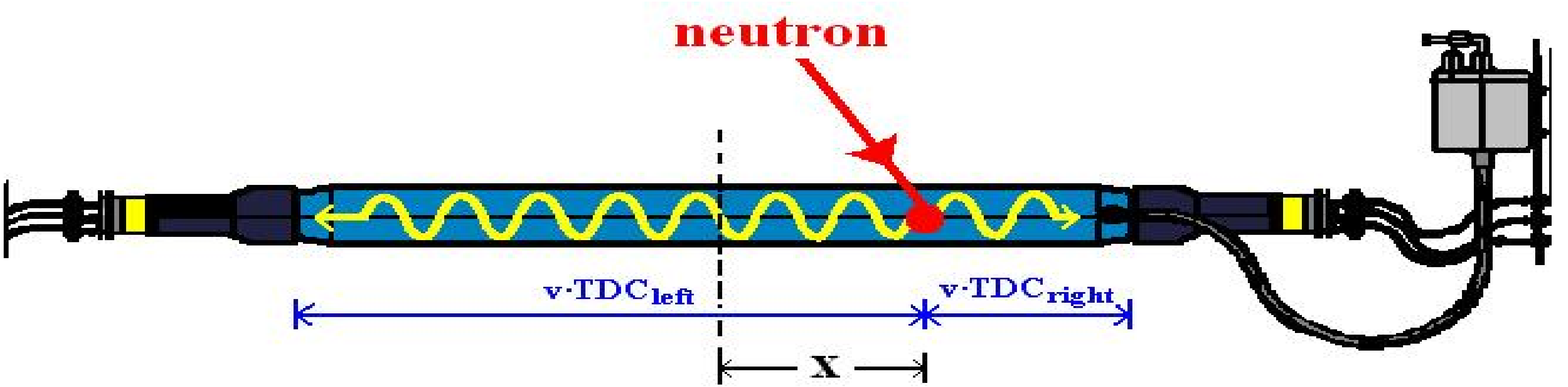


Efficiency

- The studied reaction gives one neutron for each ^7Be nucleus;
- The ^7Be efficiency detection is next to 100%;
- The Neutron Wall Detector efficiency can be calculate using the ratio between the neutron events and the ^7Be events;

$$\varepsilon = \frac{316}{28552} \cdot 100\% \simeq 1\%$$

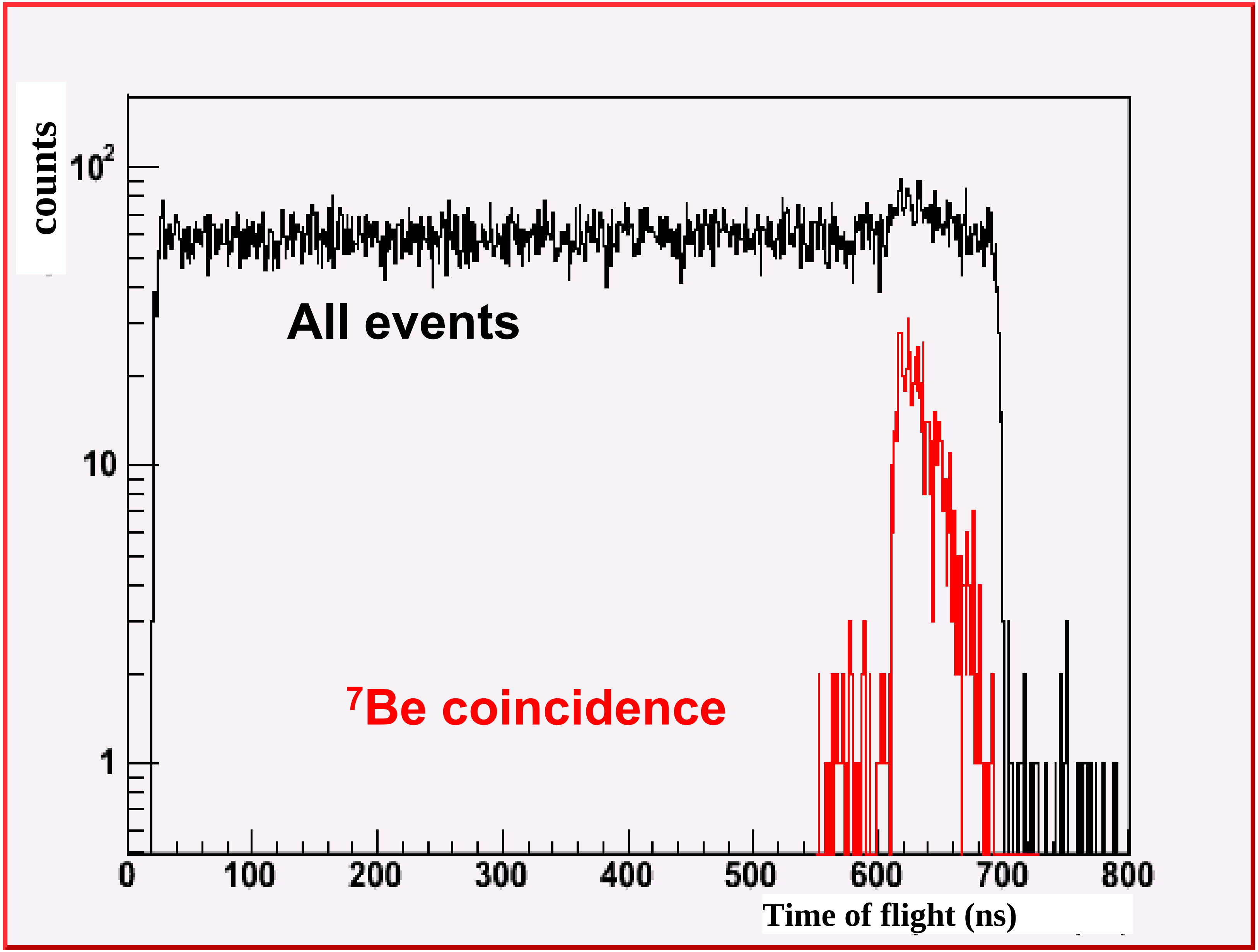
Position



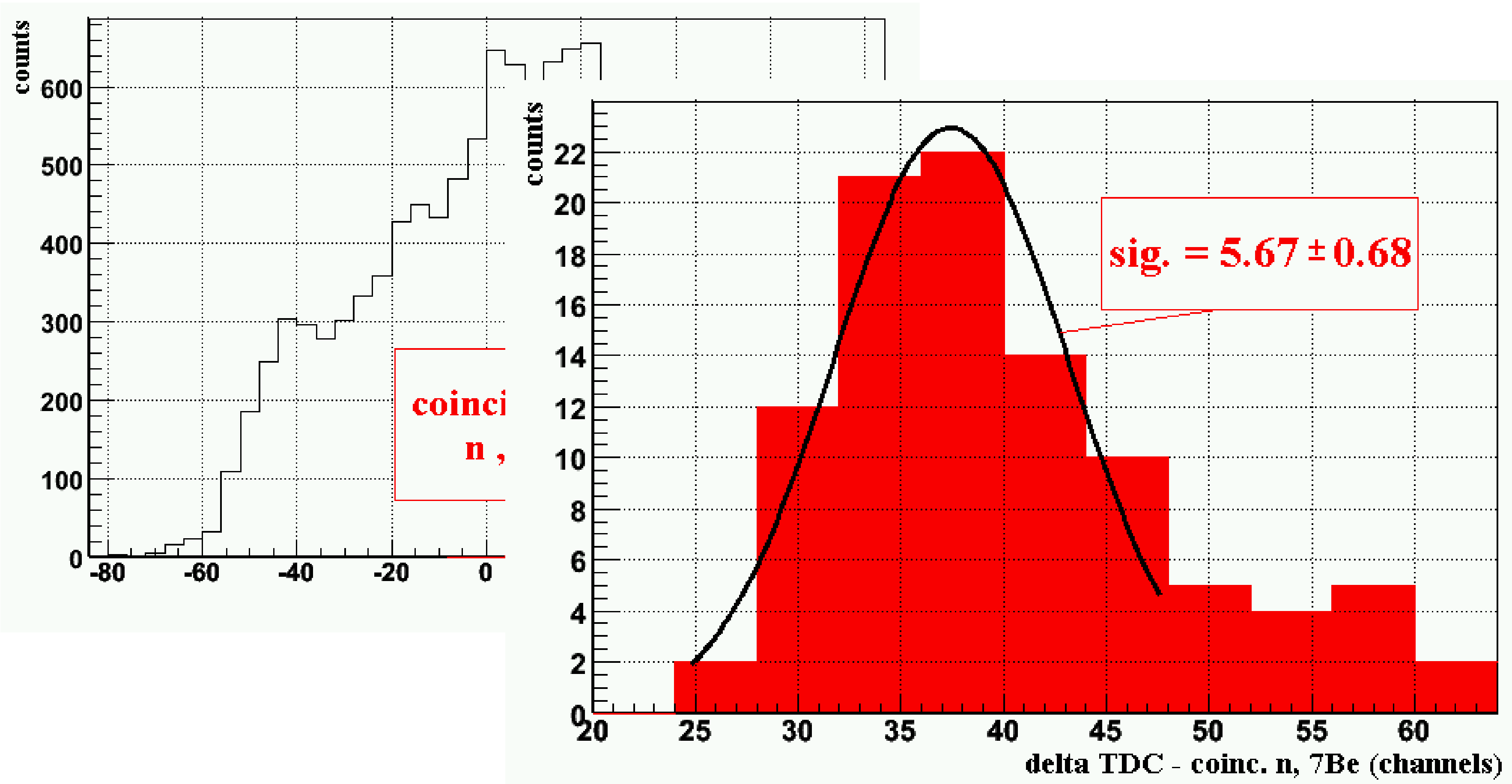
$$x = v \cdot (TDC_{left} - TDC_{right})$$

where:

v = 1.44(14).10^8 m/s is the effective velocity of the light inside the cell

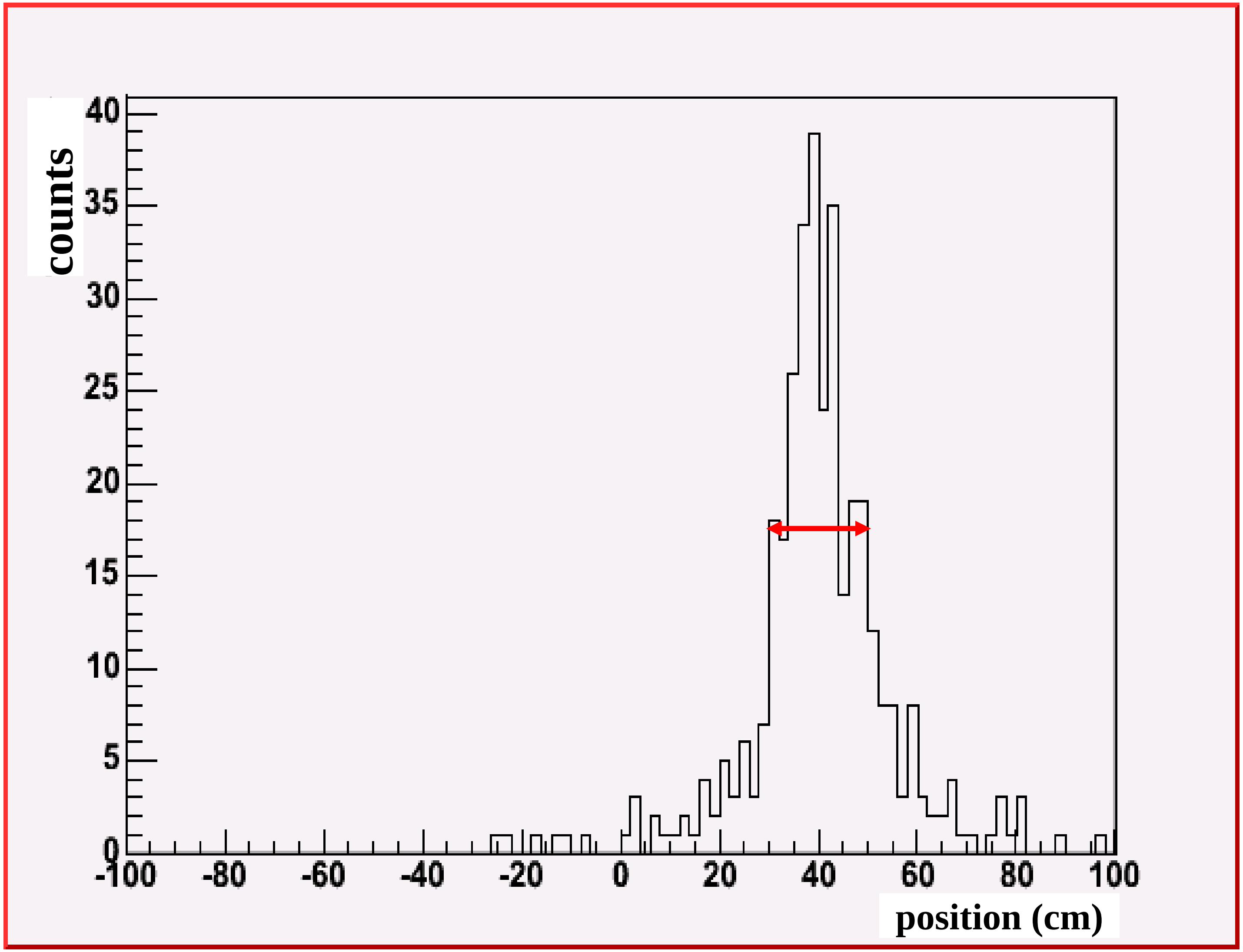

counts
10²
10
1
All events
⁷Be coincidence
0
100
200
300
400
500
600
700
800
Time of flight (ns)

Intrinsic Time Resolution



$$T.R. = \left(\frac{5.67 \cdot 0.2ns}{\sqrt{2}} \right) = 0.8ns$$

The $^{7}Li(p,n)^{7}Be$ reaction



$$P.R. = 0.8ns \cdot 1.44 \cdot 10^{8} \frac{m}{s} = 11cm$$

The Neutron Wall Array in **future experiments**