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New analysis software for β-γ coincidence technique to be applied for activity measurements of short-lived radionuclides used in nuclear medicine

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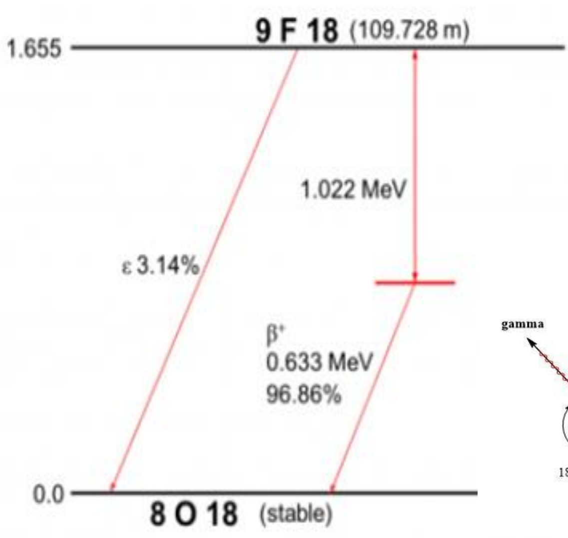
Outline

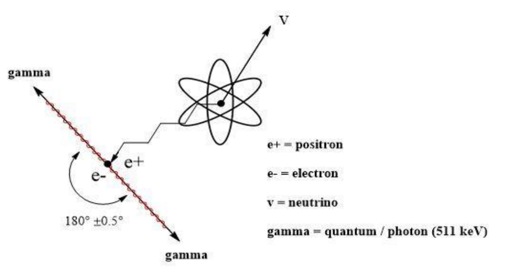
- The experimental set up of $4\pi\ \beta(LS) - \gamma$ coincidence system
- CAEN TDCR Data Analysis Software
- CAEN $4\pi\beta-\gamma$ Coincidence system Data Analysis Software
- Result and Conclusion

4π β(LS) –γ coincidence system

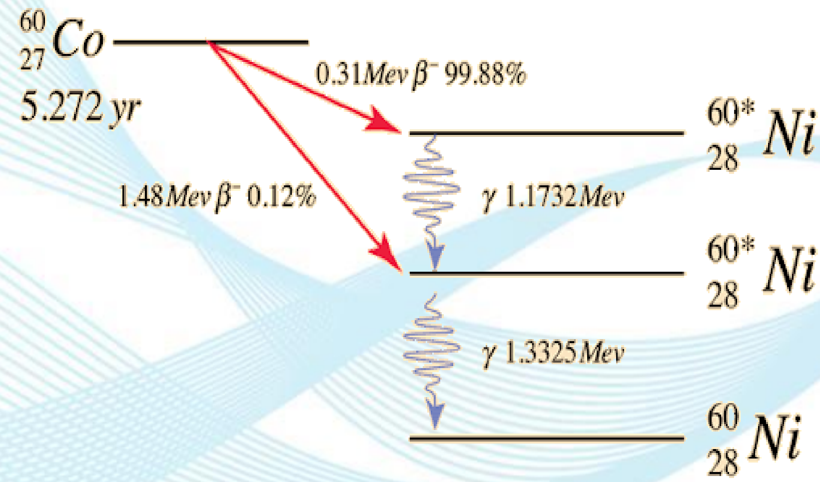
- The 4πβ–γ coincidence method is a method that can be used for determining the activity measurement to standardize the β–γ or ec-γ radionuclide emitters, especially in nuclear medicine.

F-18 Decay scheme



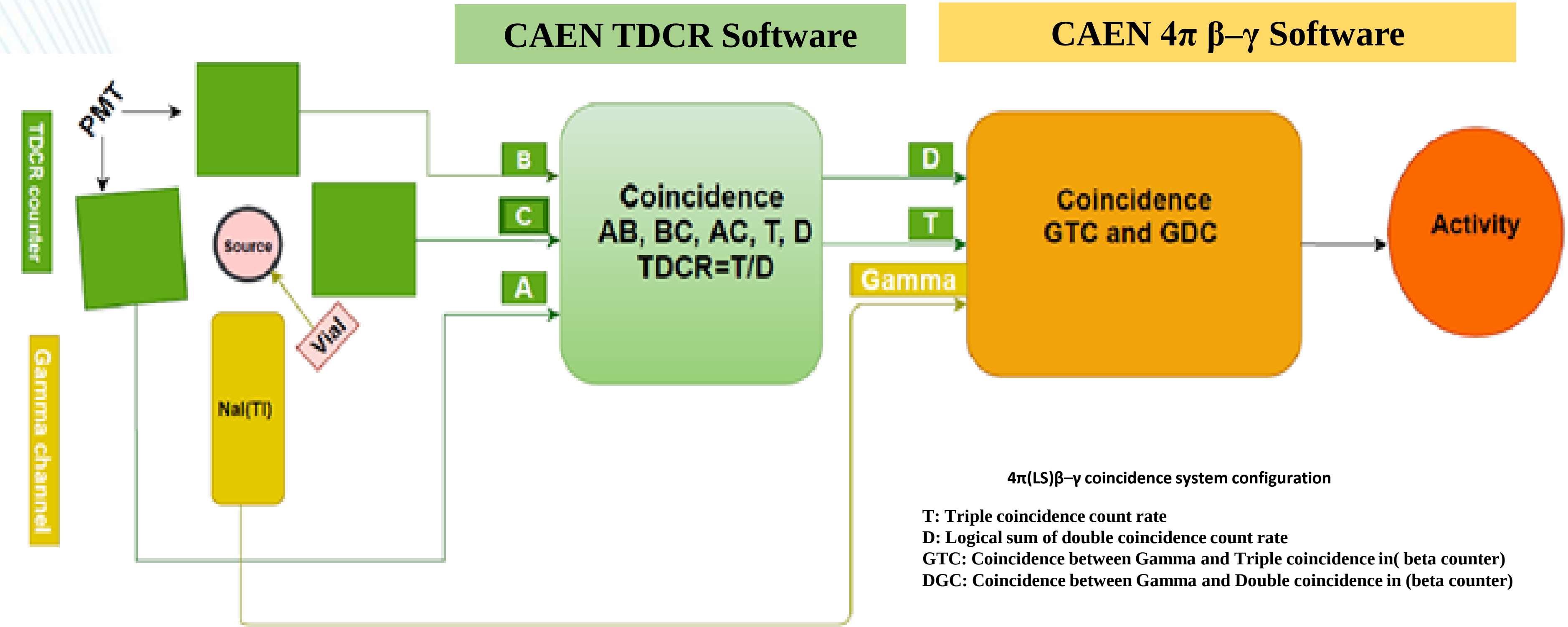


Co-60 Decay scheme



Geometry of ENEA 4π (LS) β–γ coincidence system

- National Institute of Ionizing Radiation Metrology (ENEA-INMRI) developed 4πβ−γ coincidence system by implementing a cylindrical-type NaI(Tl) Scionix Standard **(2” ×2”) crystal dimension includes a 14 pins photomultiplier with in (0.4 mm) thick of Aluminum housing** as gamma-rays counter at the bottom of the **portable TDCR counter at ENEA**.

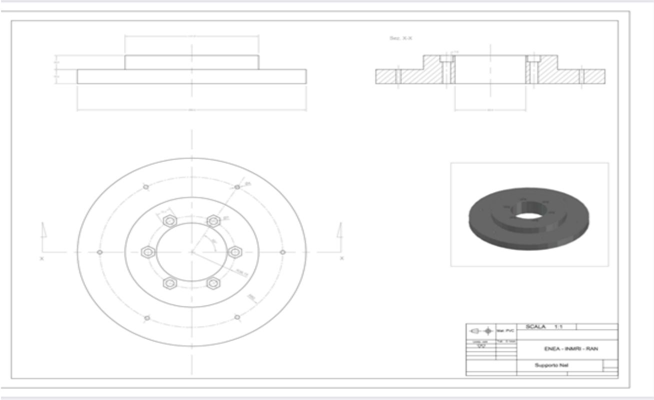


4π(LS)β–γ coincidence system configuration

T: Triple coincidence count rate
D: Logical sum of double coincidence count rate
GTC: Coincidence between Gamma and Triple coincidence in(beta counter)
DGC: Coincidence between Gamma and Double coincidence in (beta counter)

The experimental set up of $4\pi\ \beta(LS) - \gamma$ system

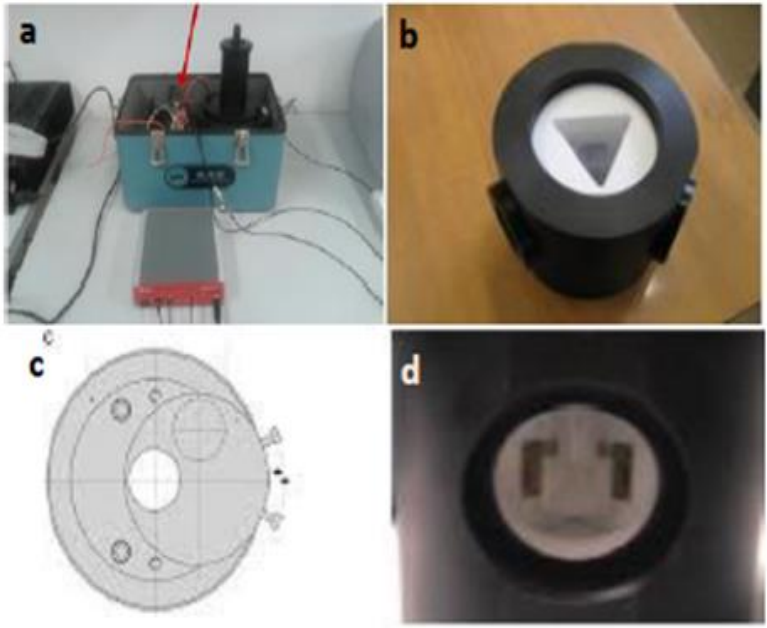
Adapter designe for the wood table of the TDCR+NaI detector



ENEA Portable TDCR Counter

- **TDCR** is acronym of **T**riple-to-**D**ouble **C**oincidence **R**atio
- TDCR is a method uses for absolute activity measurement for pure-beta and pure electron-capture radionuclides in Liquid Scintillation counter (LSC).
- **One optical chamber** white inner prismatic PTFE (H=73mm, L=60mm), surrounded by black PTFE cylindrical box (Ø = 150mm, H = 15mm).
- **Three Hamamatsu R7600U-200 PMTs** arranged symmetrically around the liquid scintillation vial.
- **DT5720 CAEN** digitizer is connected directly to the detectors.

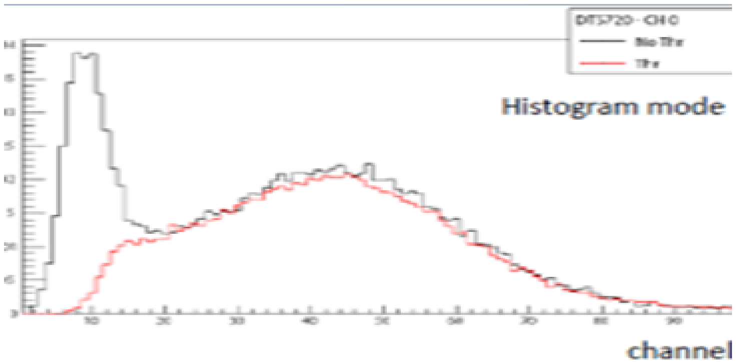
Desktop-type CAEN digitizers DT5720



The portable TDCR system at ENEA. (b, d) The external and the internal view (up and down) respectively of the optical chamber(c) Optical shutter design.

Experimental Measurements

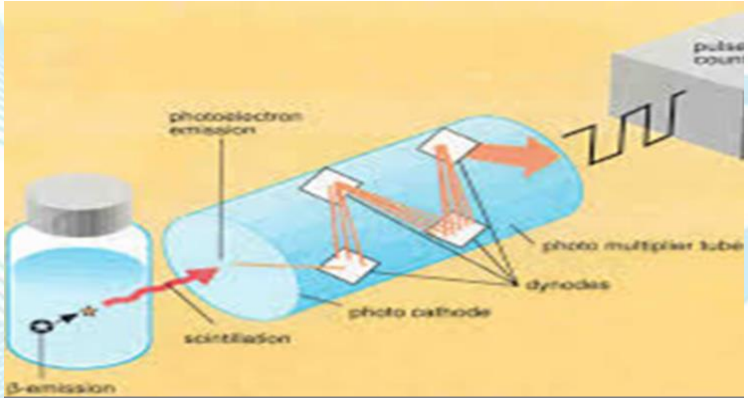
- The Activity can be measured by using the ENEA portable TDCR detector and gamma channle linked with CAEN DT5720 digitizer.
- The Single-Electron-Peak (SEP) signal is generated by each PMT .



Single Electron Peak (SEPs) for DT5720 –ch0

The Liquid Scintillation solution contain

- 10 ml Ultima Gold (UG) as liquid scintillator and
- approximately 10 mg of radioactive source
- (with different aliquots of CCl_4 as a quenching agent) in 20 ml borosilicate glass vials.
- The sources were prepared at the Radiochemistry laboratory at the ENEA- INMRI; the solutions were checked by a high energy resolution HPGe detector to perform a preliminary gamma-impurity check.
- At the first, for background measurements one blank source was prepared containing only 10 ml of UG.



Liquid scintillation Process

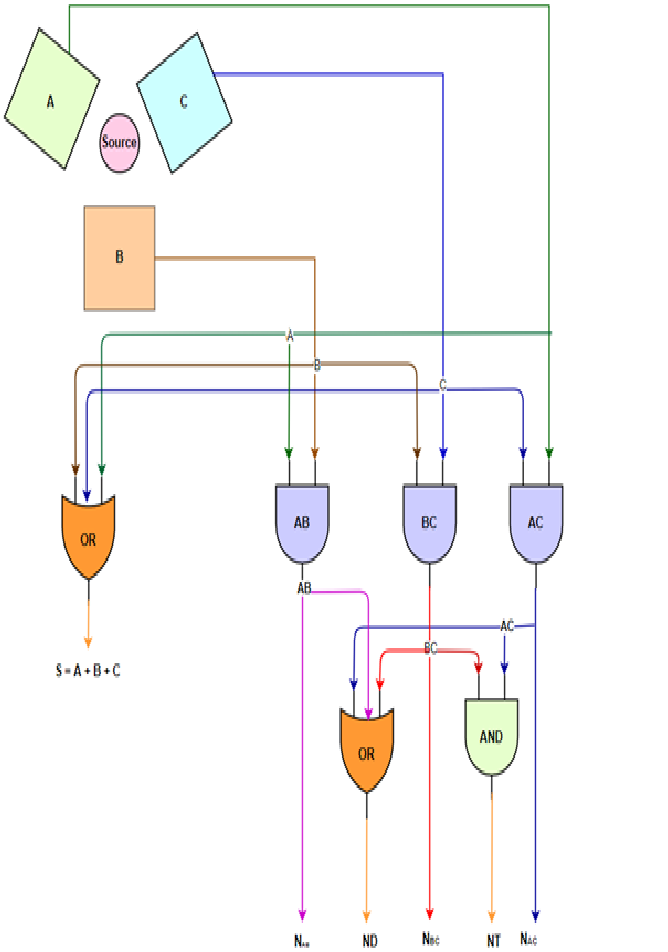
CAEN TDCR Software Analysis

- Data acquisition software perform a TDCR analysis on the events which are collected in a list-mode file; corresponding events from different input channels can then be compared to their Triger Time Tag (TTT)s when each of the acquisition channels of a digitizer are synchronized.

- **The CAEN digitizers are dead-timeless acquisition devices**.
- The software ignores all those events found in the lists whose Trigger Time Tag(TTTs) lie in a dead time window, the dead time is then extended according to the **MAC3 logic.**
- TDCR parameter $TDCR = \frac{T}{D}$, for high energy beta emitter radionuclides the

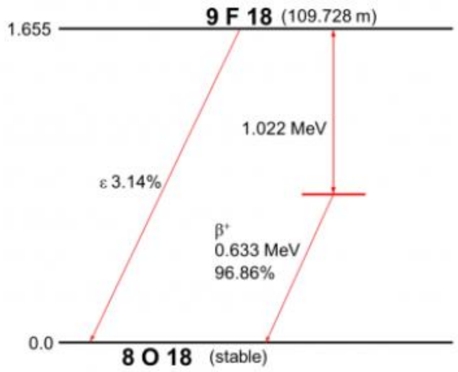
$$\mathrm{TDCR} = \frac{\varepsilon_T}{\varepsilon_D} = \frac{T}{D},$$

where $\boldsymbol{\varepsilon_T}$ and $\boldsymbol{\varepsilon_D}$ are triple coincidence efficiency and logical sum double coincidence efficiency, respectively.



F-18 TDCR parameter

Half-life = 1.8288 hours
Decay by β+ with 96.86% and with electron capture 3.14% probability.
The maximum e+ energy is 633.5 KeV
β+ annihilatation produce two gamma-rays of 511 KeV.



- Independently from CAEN, another TDCR analysis software was developed at ENEA-INMRI by implementing the MAC3 philosophy described in the CERN ROOT Framework.
- Then, the TDCR parameters are measured for standard solutions of ^{18}F by using CAEN and ENEA software.
- The coincidence window is fixed $t_c = 140ns$, the **Dead Time DT= 50μs**
- The TDCR parameter which is computed by CAEN and ENEA software for both sources are exacly the same with zero deviasion Δ%=0.

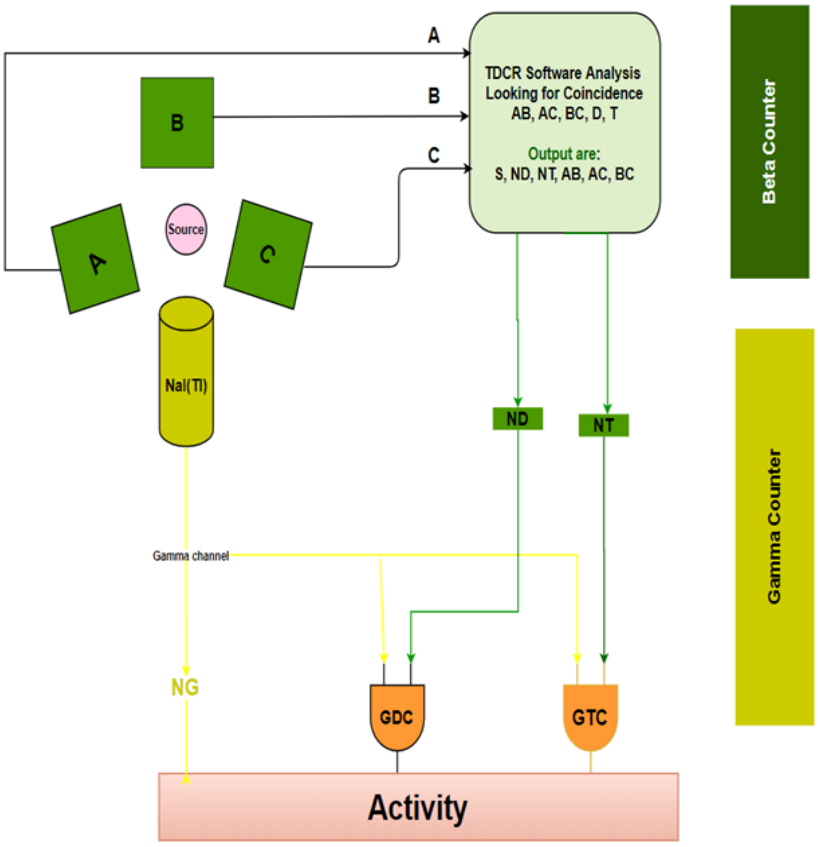
^{18}F								
Software	Time	TDCR	AB	AC	BC	D3	T	DeadTime(μs)
CAEN	600.001	0.9928	2680566	2679753	2680553	2693230	2673821	530564.92
ENEA	600.001	0.9928	2680437	2679628	2680421	2693096	2673695	530958.47
Δ(%)	0.000	0.000	0.005	0.005	0.005	0.005	0.005	0.074

4πβ−γ Coincidence Data Analysis Software

For that reason, CAEN TDCR data analysis software is modified and updated as the following.

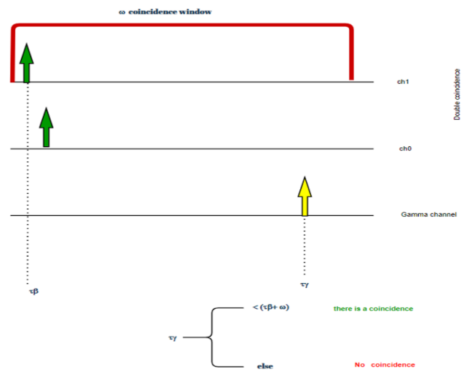
- The 4πβ−γ coincidence system DQC software written in C language
- At the first the two output files are created for both Triple (N_T) and Double (N_D) coincidences data and they are saved as a (ASCII file or binary file) inside the TDCR code.
- These two outputs files are used as input files for the 4πβ−γ coincidence system counter code.
- Once the run is over, the DAQ software scans the resulting event lists looking for coincidences between gamma channel and beta channel (Triple and Double coincidences) output files in the TDCR counter.
- As a result of this analysis, the new CAEN DAQ software will provide the counting from the three channels (data files). The single count rate for (N_γ, N_D, N_T) for gamma channel and triple coincidence and double coincidence respectively, the coincidence between gamma channel with double coincidence in beta counter (N_{GDC}) and the coincidence between gamma channel with triple coincidence in beta counter (N_{GTC}).
- The activity of the radionuclides can be measured, by using the following formula

$$A = \frac{N_{NG} \cdot N_D}{N_{GDC}} \cong \frac{N_{NG} \cdot N_T}{N_{GTC}}$$

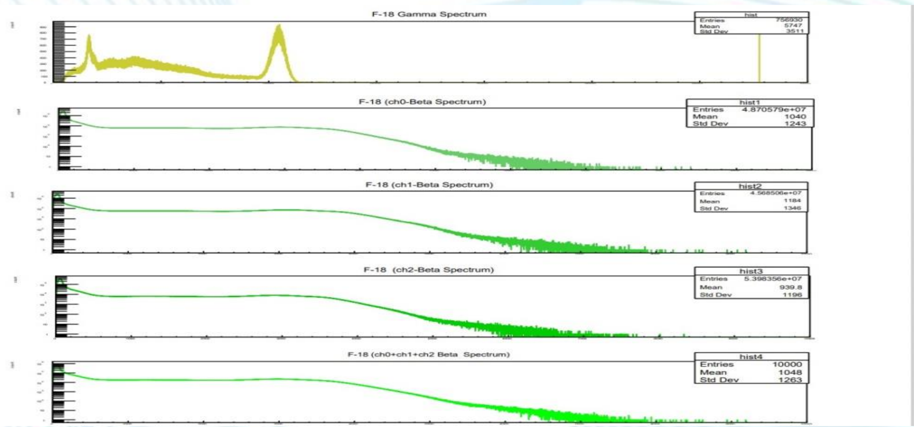


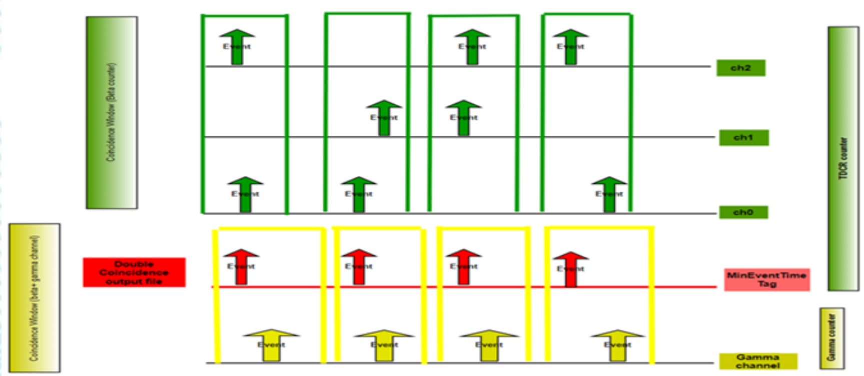
Time Coincidence management in 4πβ−γ coincidence system

- Two different types of scintillator detectors are used in the new 4πβ−γ coincidence system : the organic liquid scintillation detector as a beta counter and the inorganic scintillation detector as a gamma counter. Liquid scintillation detector has fast light response about 3-4 ns while NaI(Tl) has slow light response about 40 -50 ns.
- In other word, if τ_γ and τ_β are the minimum Trigger Time Tag of gamma and beta events respectively, and ω is the coincidence window, then if $\boldsymbol{\tau_\gamma < (\tau_\beta + \omega)}$ so there is a coincidence between gamma channel and beta channel.
- Then, the TTT for each selected event in coincidence in the TDCR counter and gamma channel will be saved.
- **The dead time = 10 μs and coincidence window = 1 μs.**
- **The gamma window set around the 511 KeV for gamma ray produce as positron annihilation**
- The new software ignores all those events found in the lists whose TTTs lie in a dead time window.



Coincidence time management for 4πβ−γ system





coincidence logic between gamma channel and double in TDCR counter (beta channel) with new coincidence window

F-18 Activity Measurement

- The activity of F-18 has been measured by coincidence counting with LSC using Logical Sum of double coincidence and in **TDCR** by

$$Activity = \frac{R_{c}\_D}{\varepsilon_D} = \frac{R_{c}\_T}{\varepsilon_T}$$

R_{c}_D , R_{c}_T are double and triple corrected count rates ,
ε_D *and* ε_T are double and triple efficiency computed in Monte Carlo Simulation using Geant4 code for **kB factor = 0.1 mm/MeV and Defocusing parameter = 1.0** .

- The activity A can be calculated in **4πβ–γ** coincidence method by

$$A = \frac{N_\beta \cdot N_\gamma}{N_{\beta\gamma}}$$

A is depend only on the counting rates N_β *and* N_γ in β- and γ- channels respectively and the coincidence count rate $N_{\beta\gamma}$ which records a disintegration events when it is detected in both β- and γ- channels

Radionuclide	Methods	Activity(Bq)
F-18	TDCR	41379.69 ± 0.01
F-18	4πβ–γ	41777.06 ± 0.04
	Δ_(4πβ-γ -TDCR) %	0.09%

Summary

- The $4\pi\beta-\gamma$ coincidence method has proved to be a powerfull method for primary standarization of short half-life radionuclides used in Nuclear medicine especially F-18.
- The activity of radionuclides can be measured by the $4\pi\beta-\gamma$ coincidence technique without any knowledge of the detection efficiency of either detectors
- The study of F-18 opens interesting perspectives on in situ measurements of very short-lived radionuclides such as C-11.
- Future project is analysing long-lived radionuclides such as Co-60 to validate the new instrument in collaboration with CIEMAT-Madrid starting from 1 October 2021 for 6 months.

Thanks for your attention