Validation and investigation of the PeneloPET Application for Biograph

Author: Khaled Abushab
Directors: José Manuel Udías Moinelo y Joaquín Lopez Herraiz

Departamento de Física Atómica, Molecular y Nuclear
Universidad Complutense de Madrid

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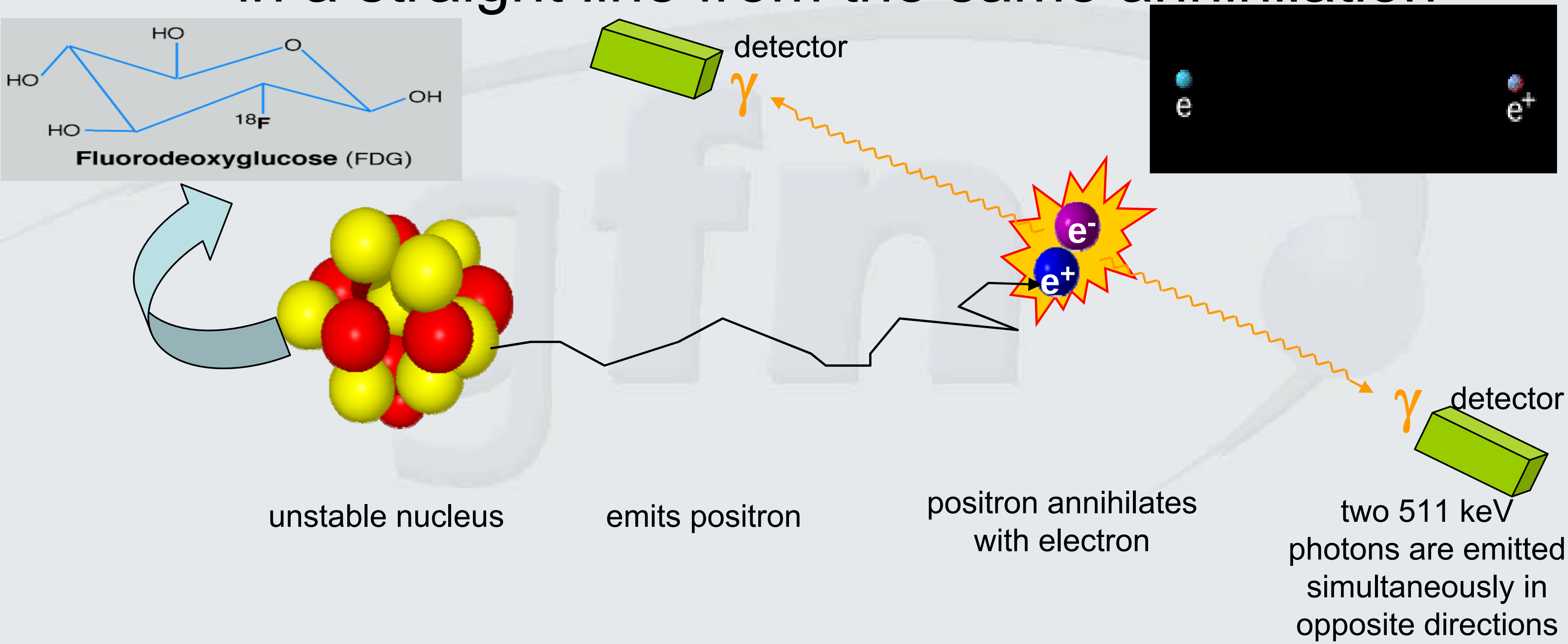
Research Project outline

- Introduction and objectives
- Validation of the PeneloPET code
- Factors affecting Sensitivity, Noise equivalent count rate (NEC), Scatter fraction and Time-of-flight (TOF)
- TOF characterization
- Conclusions

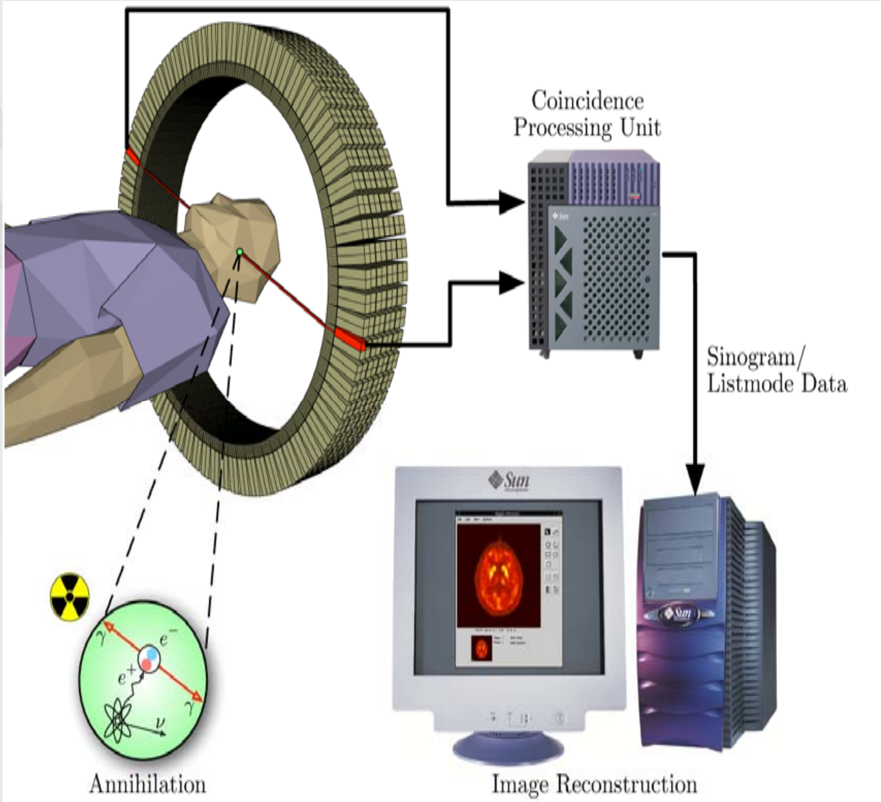
PET Physics

2 photons of 511 keV in coincidence, coming in a straight line from the same annihilation



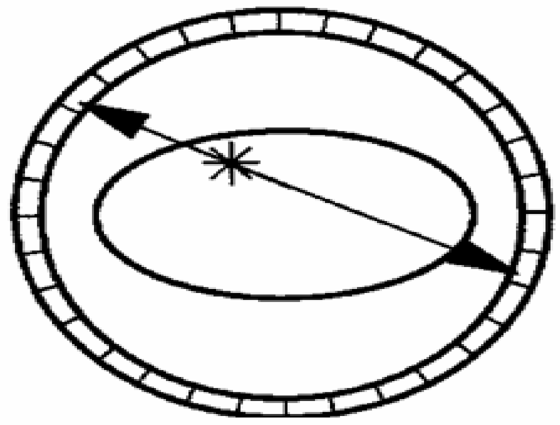
Clinical PET Imaging

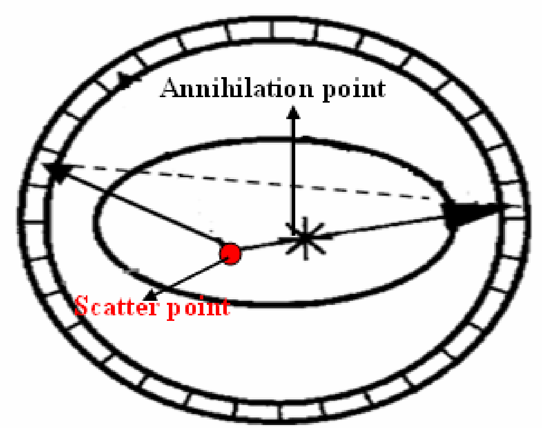
- Inject radiotracer
- Detect (scintillation detectors) two annihilation photons in coincidence.
- Defines line along which annihilation lies
- Use reconstruction algorithms to compute image of radiotracer distribution using all the different angular views.
- Analyze data



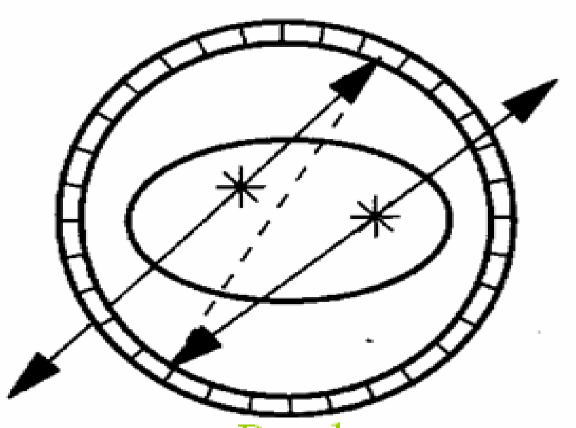
Types of Coincidences

- **True coincidence** This event occurs when both annihilation photons reached detectors without being scatter in the patient and both photons are successfully detected.
- **Scatter coincidence** is when one or both photons from a single event are scattered and both are detected.
- **Random coincidence** They arise when two unrelated photons are detected in opposing detectors.


True



Scatter


Random

Noise equivalent count rate (NEC)

The NEC rate is a global measure of scanner count rate performance which takes into account that a fraction of counts (scatter and random coincidences) do not contribute to the quality of the images

$$NEC = \frac{T^2}{(T+S+R)}$$

Scatter Fraction (SF)

The proportion of accepted coincidences which have undergone Compton scattering prior to detection is called a scatter fraction (SF)

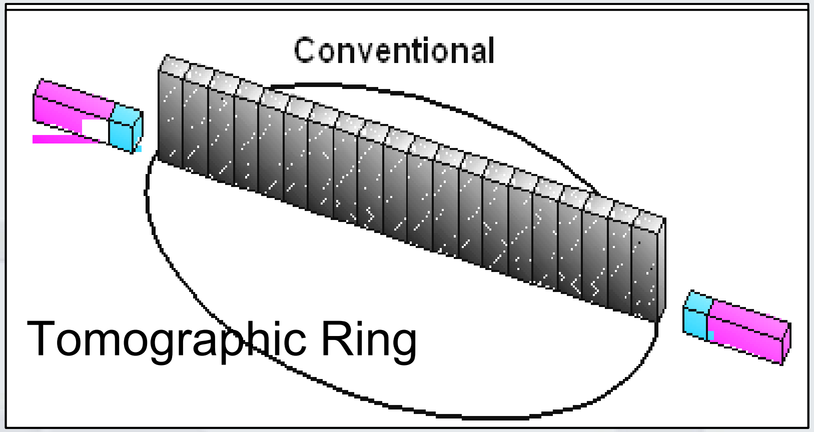
$$SF = \frac{S}{T+S+R} x100$$

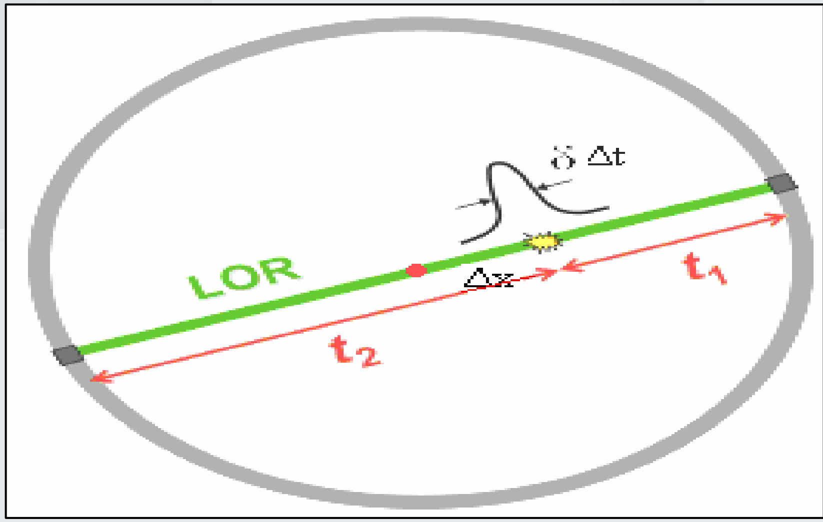
Time of Flight (TOF)

The annihilation position can be estimated by determining the difference in time arrival of the two photons

Time-of-flight difference (Δt) is immediately related to the distance of the annihilation point from the center of the line of response (LOR) by;

$$\delta\Delta t = 2 \times \delta\Delta x \,/\, c$$





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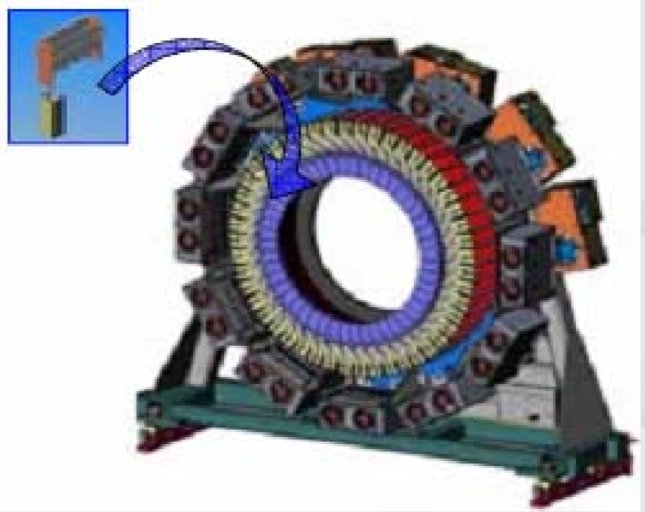
Objectives

- Validate of PeneloPET simulation for clinical Biograph (Sensitivity, Noise equivalent count rate (NEC) and scatter fraction (SF)) (Jakoby et al. 2009)
- Study the factors which affect the sensitivity, NEC, scatter fraction and Time-of-Flight (TOF)

Biograph PET/CT with TrueV



- Cylinder scanner geometry
- 4 rings of 48 blocks of 13 x 13 LSO 4 mm x 4 mm x 20 mm pixels
- 32,448 individual pixels
- 109 transaxial image planes
- 21.8 cm axial field-of-view

- Patient port: 70 cm
- Timing window : 4.5 ns
- NEC :161 Kcps
- Energy windows 425-650 keV

Total PET scan duration: 3 min.

Validation of the PeneloPET

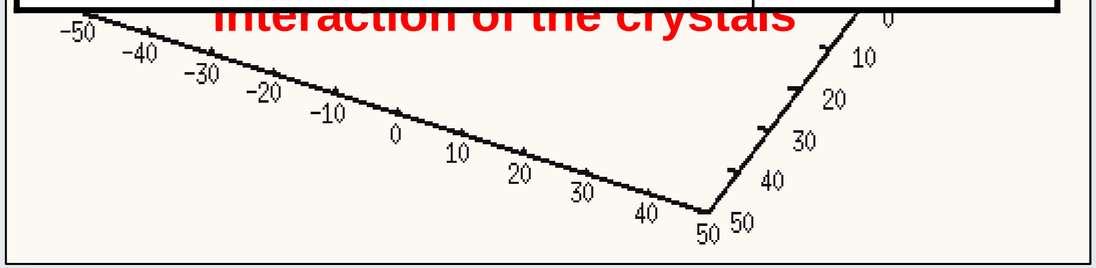
- peneloPET simulation

PeneloPET is a Monte Carlo code based on PENELOPE, which allows fast and easy simulation of common PET scanners (España et al. 2009).

The basic components of the peneloPET simulation are the definition of detector geometry, source and object.

Detector ring diameter (mm)	824
Axial FOV (mm)	218
Energy window (keV)	450-650
Coincidence time window (ns)	4.5 (2.25 ±)
Energy resolution (%)	14

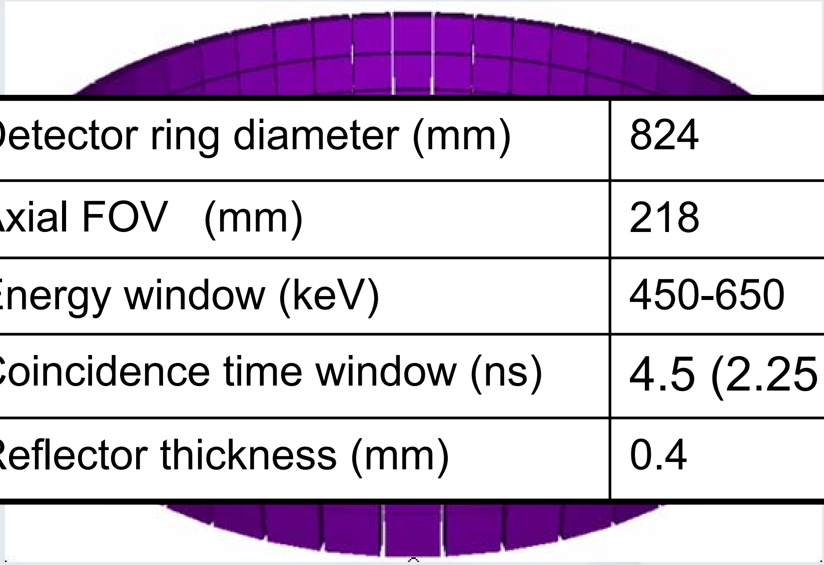
NEMA cylinder



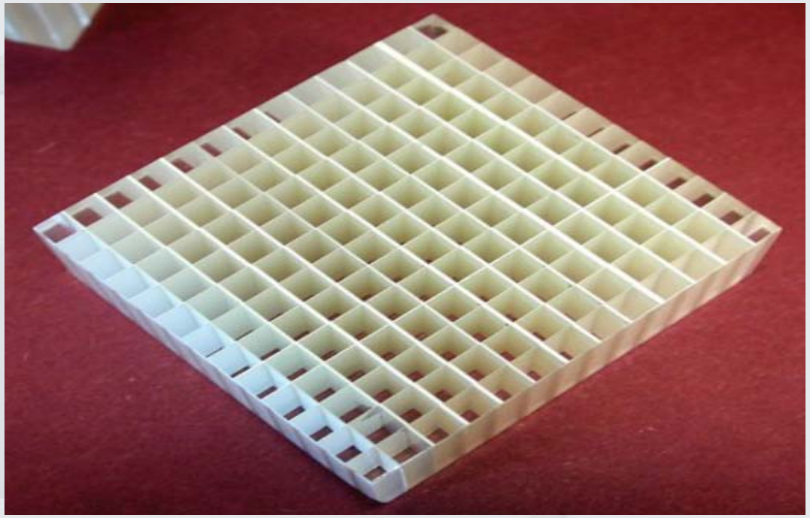
Crystal modules

Validation of the PeneloPET
Sensitivity

The sensitivity of the PET scanner represents the ability to detect 511 keV photons resulting from positron annihilation.



Detector ring diameter (mm)	824
Axial FOV (mm)	218
Energy window (keV)	450-650
Coincidence time window (ns)	4.5 (2.25 ±)
Reflector thickness (mm)	0.4



Detector elements/block (4×4×20mm^3) (Siemens)

Experimental sensitivity (maximum ring difference =38)	Simulated sensitivity (all events)	Simulated sensitivity (maximum ring difference =38)
8.1 Kcps	9.0 Kcps	8.1 Kcps

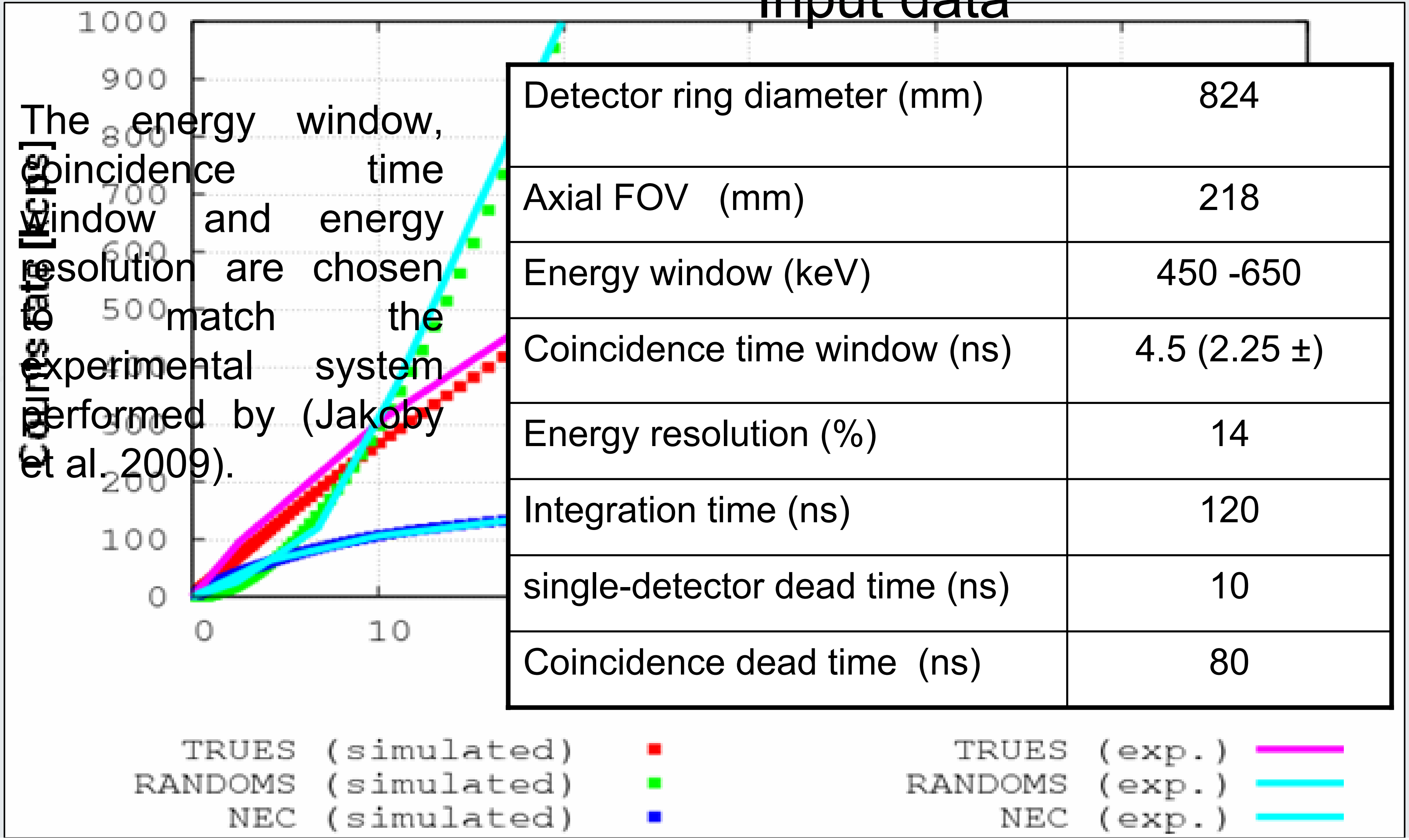
Validation of the PeneloPET

NEC and SF

Input data

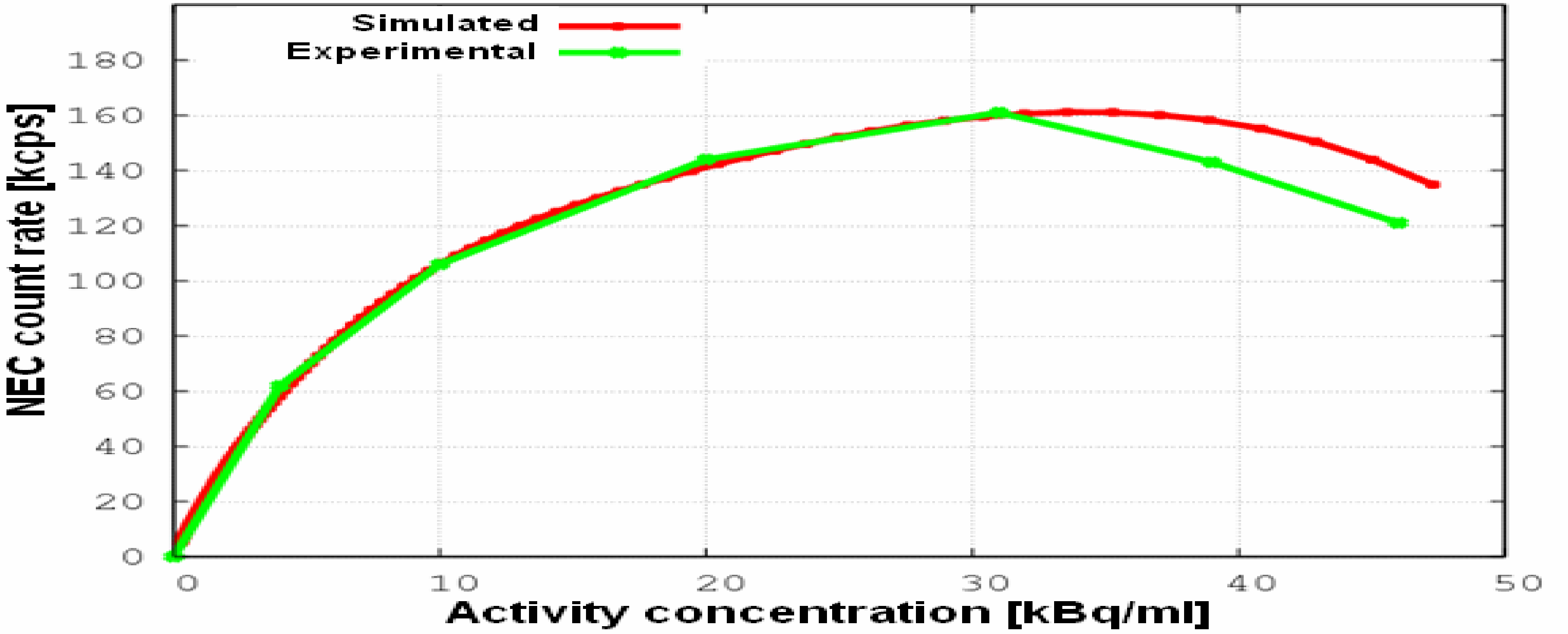
The energy window, coincidence time window and energy resolution are chosen to match the experimental system performed by (Jakoby et al. 2009).

Detector ring diameter (mm)	824
Axial FOV (mm)	218
Energy window (keV)	450 -650
Coincidence time window (ns)	4.5 (2.25 ±)
Energy resolution (%)	14
Integration time (ns)	120
single-detector dead time (ns)	10
Coincidence dead time (ns)	80



Validation of the PeneloPET

NEC and SF



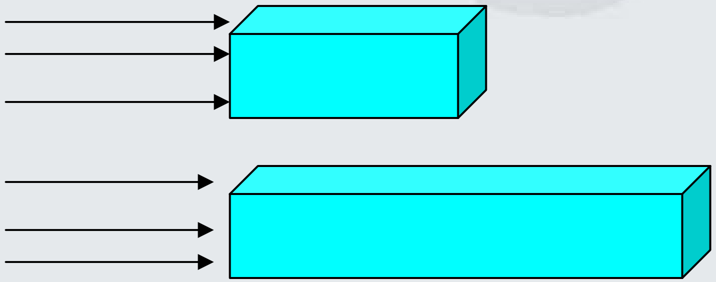
simulated and measurements values		
Results	**Simulation**	**Experimental**
Peak NEC (Kcps)	**161**	**161**
Scatter fraction (%)	**31.3**	**32.5**

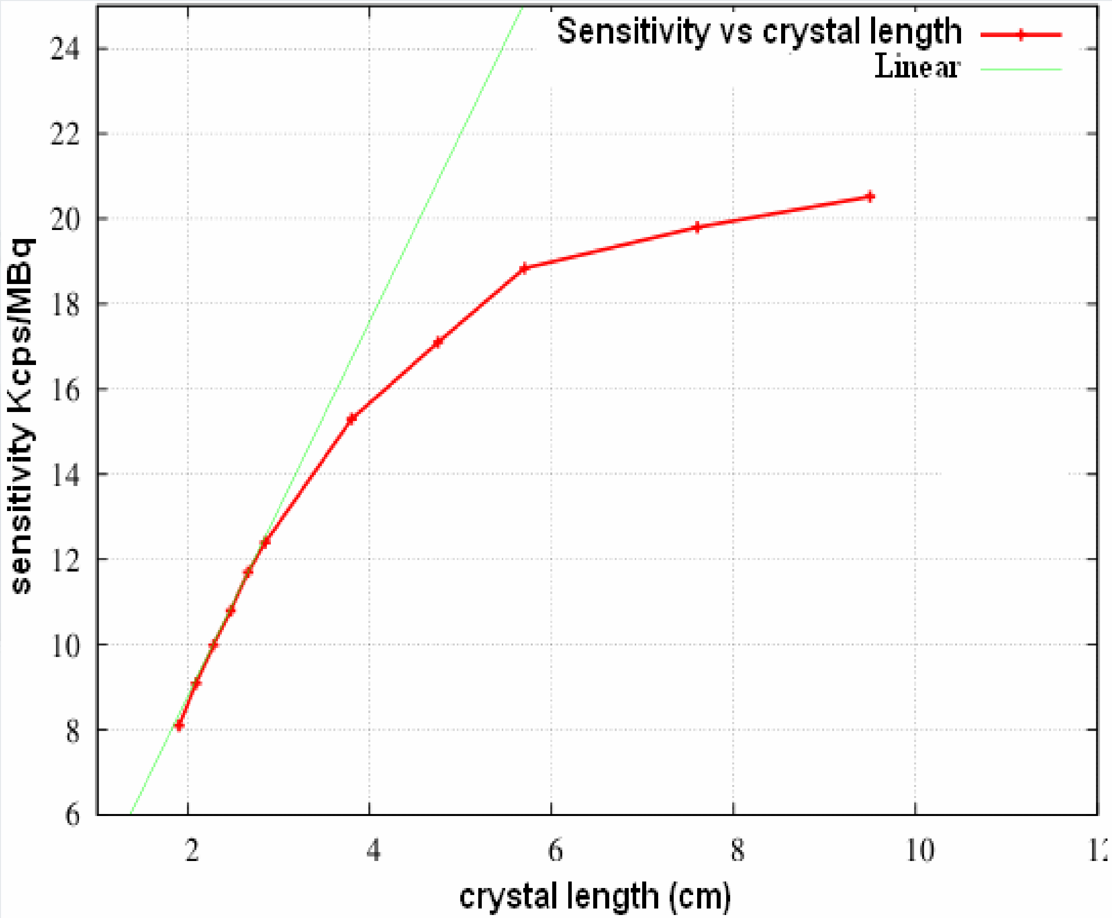
A good agreement between the simulated and experimental results of Jakoby et al (2009)

Crystal length

The sensitivity increases with the crystal length linearly up to 3 cm, and beyond that we see saturation, because as most of the photons are detected, no further increase of the sensitivity

The larger the detector crystal size the more sensitivity.



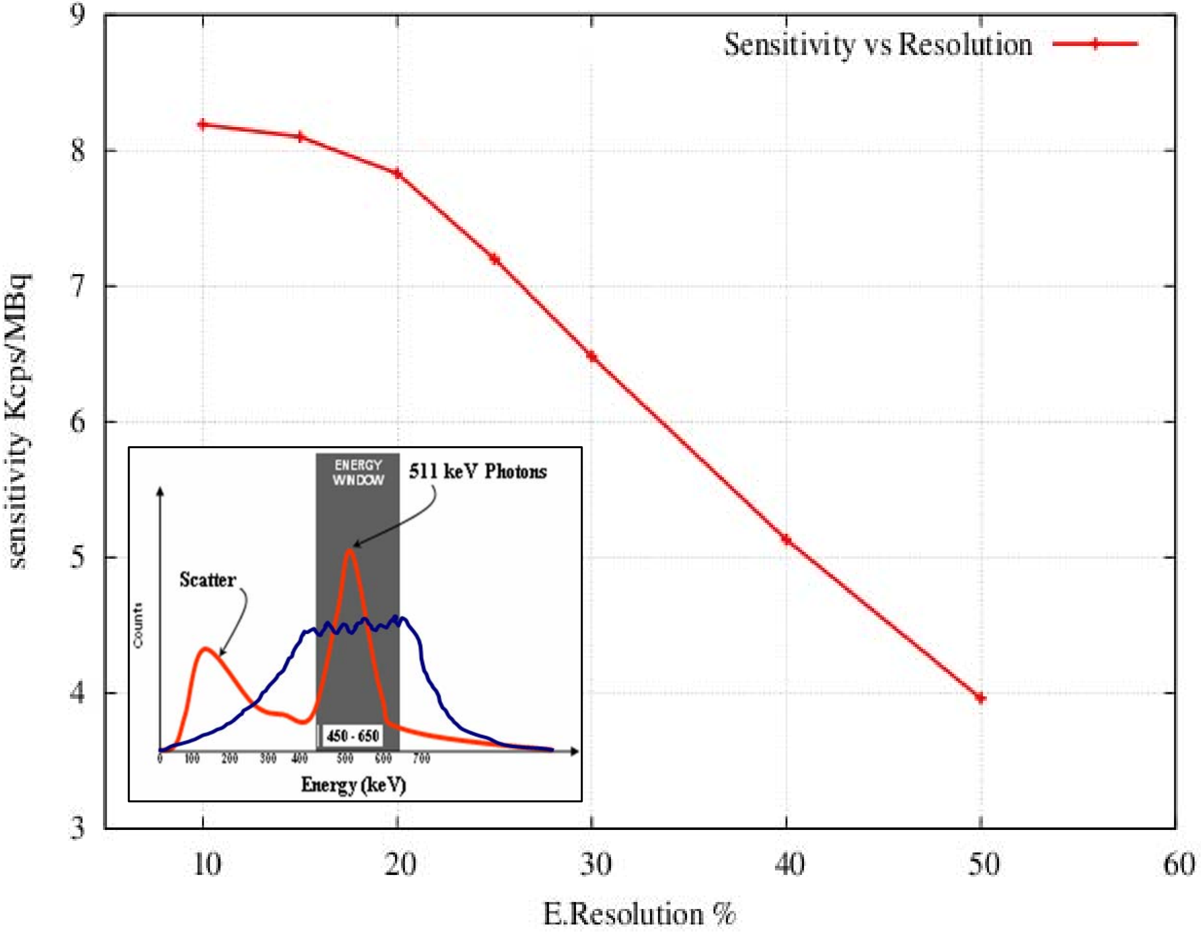


Crystal Energy resolution

Energy resolution measured the precision with which the system can determine the energy deposited by incident photons.

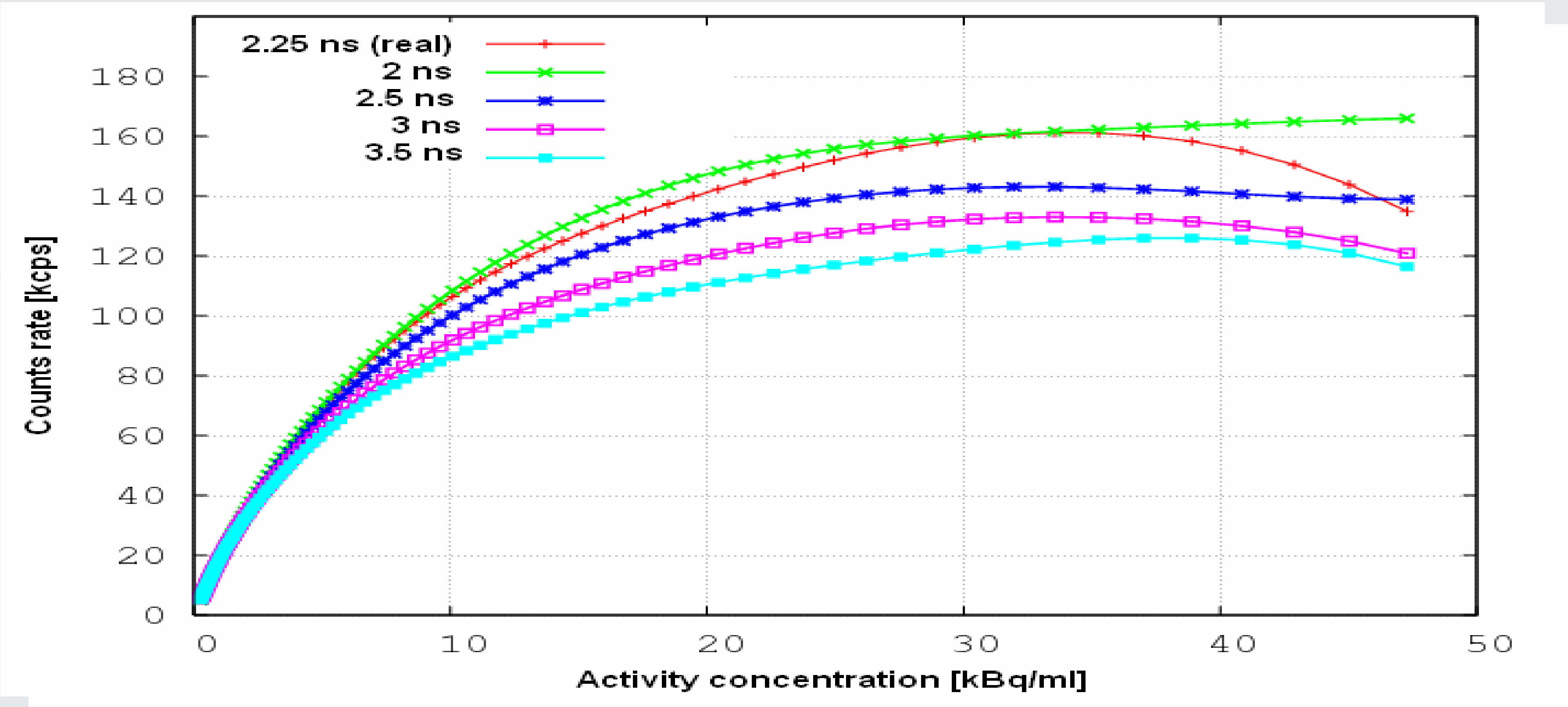
it is measured by histograming the energy of the events acquired and plotting the number of events versus the energy measured

$$ER(\%) = \frac{FWHM}{Centroid} \times 100$$



The prolongation of the *coincidence time window* results in an increased probability that two single photons that belong to two different annihilation events will be registered by opposing detectors.

As we increase the ***integration time*** count rate decrease. This is due to lose of many events during the long processing time of the detector.



Factors affecting Sensitivity, NEC and Scatter fraction

- Scatter fraction can be measured at low activity where the randoms are negligible

  (NEMA, N-2, 2007).

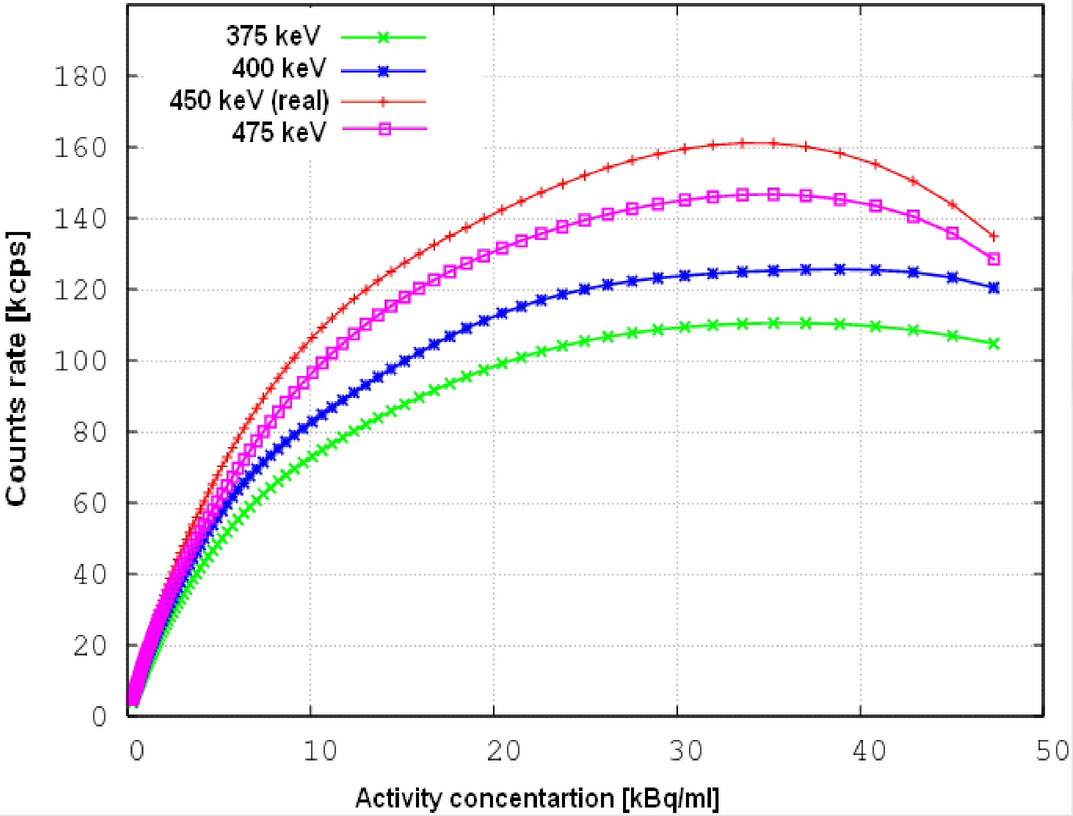
Energy window (keV)	450 -650
Coincidence time window (ns)	4.5 (2.25 ±)
Integration time (ns)	120
Activity (kBq) ^{18}F	1.04

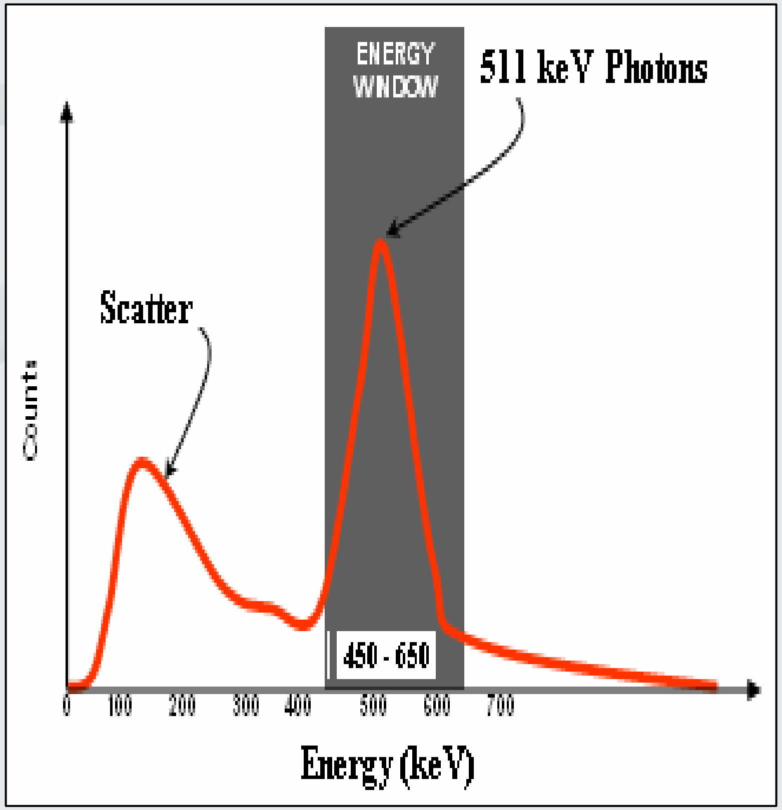
Lower energy window

More scatter events are rejected initially through the use of higher LLD and the result is that the fraction of true coincidence events involving scatter that are processed is lower.

Lower energy window (keV)	Scatter fraction %
Experimental	32.5
375	53.1
400	46.8
450 (simulated)	**31.3**
475	23.2

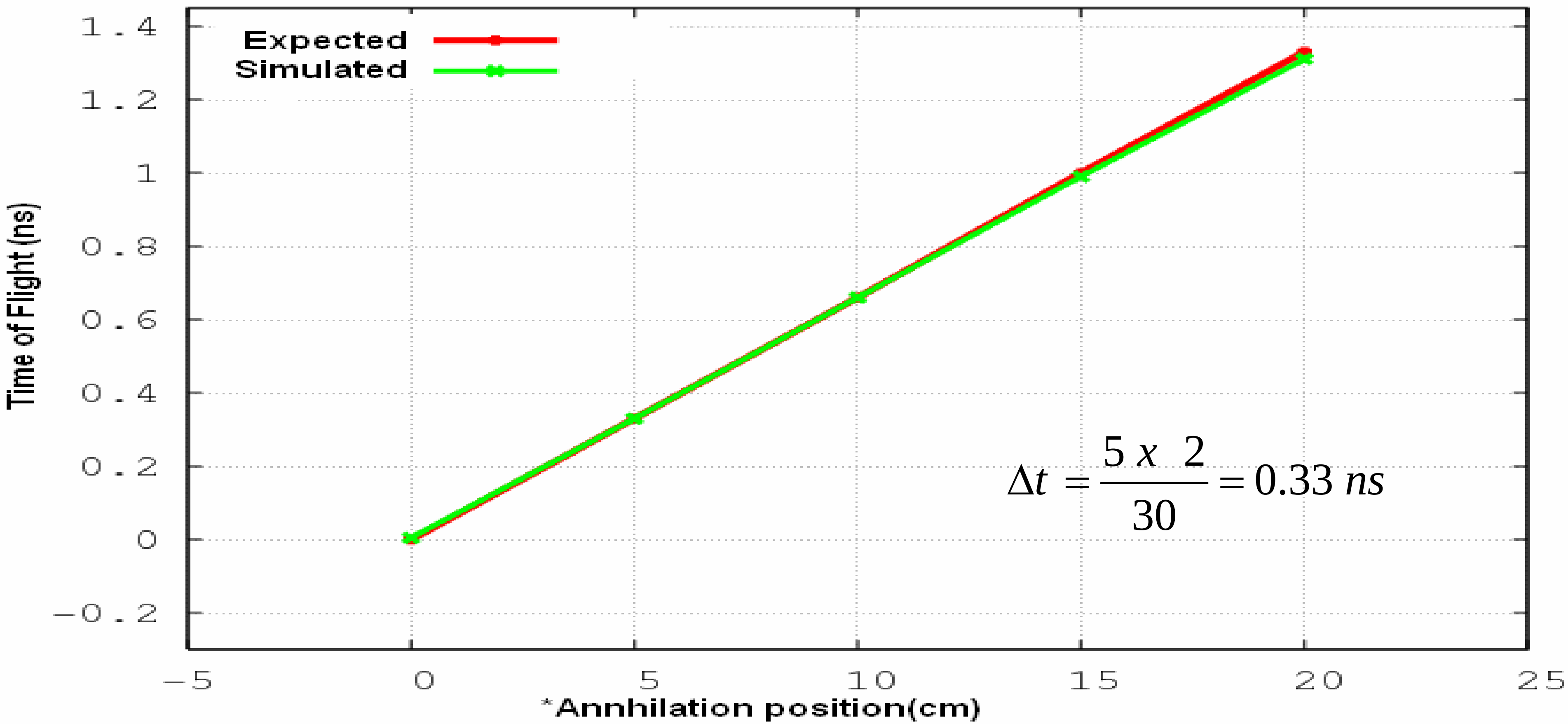
Low energy window will have an effect of the counts rate due to number of scatter events





Validation of the PeneloPET
TOF

Simulation with TOF resolution

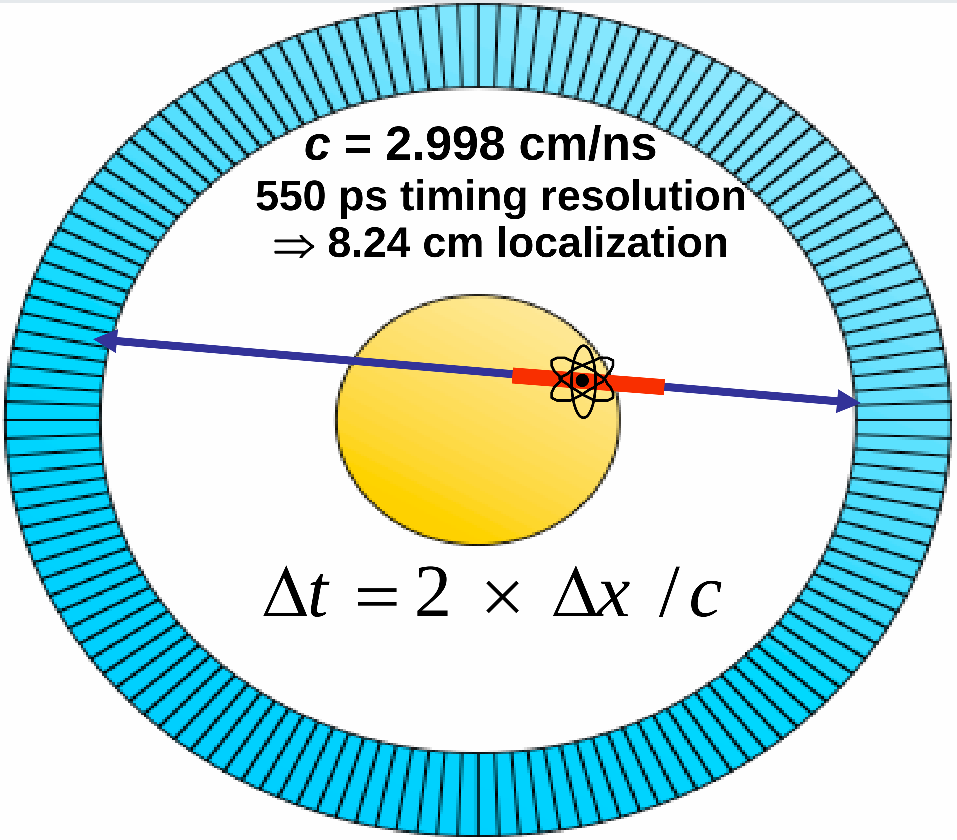


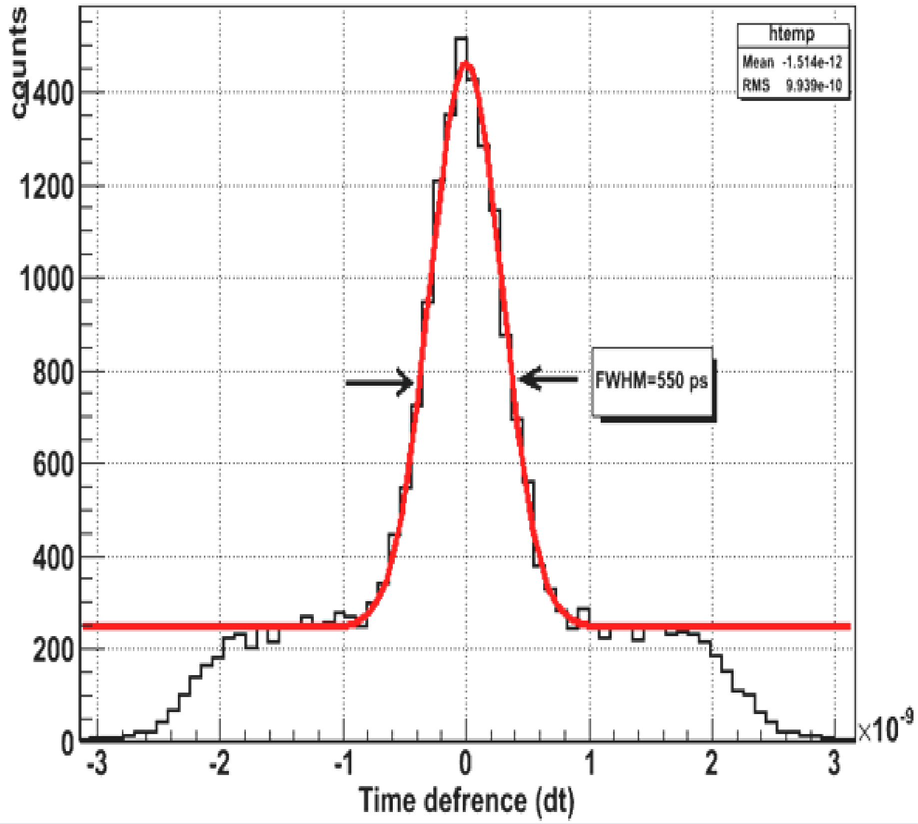
$$\Delta t = \frac{5\,x\;\;2}{30} = 0.33\;ns$$

* Distance from the center of line of response (LOR)

The simulation output is in good agreement with the calculated values.

Time Resolution (FWHM)



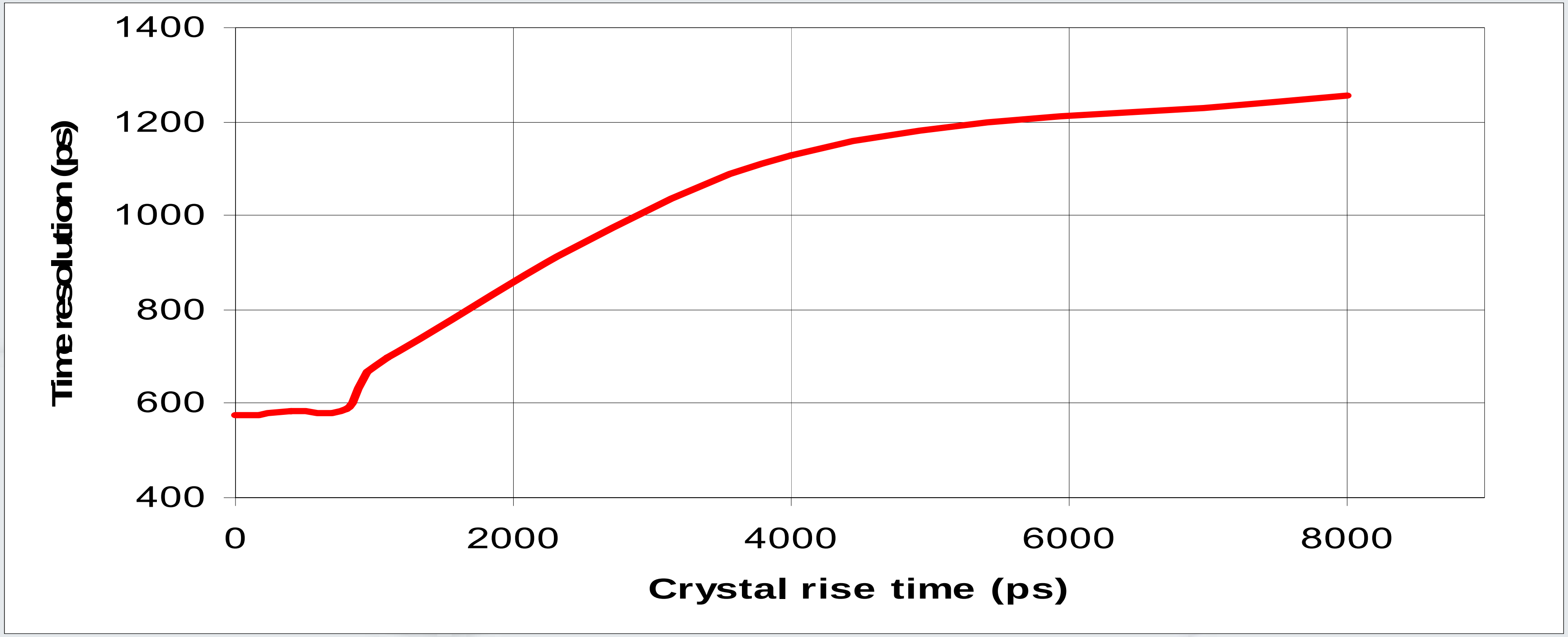


TOF resolution would allow determining the position of the source within a distance;

Δx = 2.998×10^{10} cm/s$\times 550 \times 10^{-12}$s /2

= 8.24 cm.

Crystal rise time



- At rise time below 800 ps there is no change with the time resolution, where at the rise time of greater than 800 ps, as the crystal rise time increases also time resolution increases

Conclusion

- In this work we validated peneloPET simulation for Biograph (B-TPTV) PET. The output data of the peneloPET simulations have a good agreement with both calculated and experimental results of the NEC, scatter fraction and TOF.
- The study of the various factors which influence the count rate, performed us information about these factors and their effects. In general PeneloPET emerges as a powerful tool for clinical PET simulations.

- The validation of PeneloPET simulations would allow to use these simulations to study the effect of changing the geometry of the scanner (adding extra rings), as well as to study the impact in the reconstruction of using different TOF windows. This will be the goal for a further study.

Thanks for your attention