# Constrained Positron Flight in PET Imaging via Strong Magnetic Fields

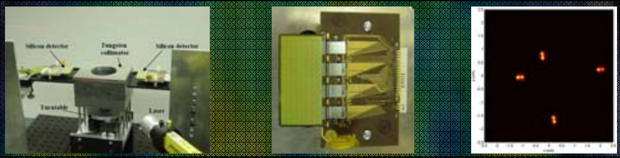
David Albani, Klaus Honscheid, Harris Kagan, Don Burdette, Eric Cochran
The Ohio State University Department of Physics

## What is PET Imaging?

Positron Emission Tomography is a noninvasive imaging method that allows for the mapping of metabolic processes in biological systems. It has become a valuable tool in studies such as understanding the effect of pharmaceuticals on a subject as well as in locating and tracing the evolution of cancer. This technology takes advantage of the nature of radioactive isotopes – in particular, it exploits the release of positrons from the radioisotope, which lead to annihilation events. Within biological hosts, a positron will collide with a number of electrons, scattering off of these electrons until its energy is low enough that it will annihilate with an electron. Annihilation events release a pair of photons travelling in opposite directions, each with an energy of 511 keV. Photodetectors outside of the host detect the two emitted photons in coincidence. Utilizing reconstruction algorithms produces an image of the annihilation positions.

## Modern PET Scanners

- Typical small animal PET scanners have resolution on the order of 1-2mm, while the average human PET scanner has resolution on the order of 5mm.
- Sub-millimeter resolution in PET scans is a highly desirable goal.
- In the laboratory of Drs. Honscheid and Kagan (OSU Department of Physics) and in collaboration with the University of Michigan a state-of-the-art system consisting of silicon pad detectors achieving 0.7 mm spatial resolution FWHM has been developed.




From left to right: The initial setup of the high resolution silicon-silicon pad detector system developed by our collaborators in Michigan; the Si-Si detector system achieves a resolution of 0.7mm FWHM. A close-up of a hybrid silicon detector consisting of 512 pads measuring 1.4 mm x 1.4 mm x 1 mm thick used in the detector system, developed in the laboratory of Drs. Honscheid and Kagan. A complete image reconstruction displaying the resolving power of the detector system. Images courtesy of Sang-June Park.

## Limitations on PET Systems

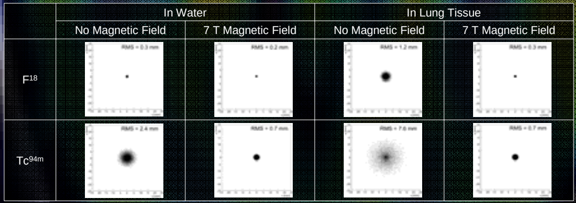
- Positron emission is a beta decay and consequently one can observe a spectrum of positron energies up to a maximum kinetic energy characteristic of the particular radioisotope.
- The flight distance of the positron is dependent upon the energy with which it is released from the radiotracer.
- Lower energy isotopes such as the commonly-used $F^{18}$ (635 keV maximum positron energy) exhibit fairly localized annihilation positions.
- Higher energy radioisotopes, such as $Tc^{94m}$ (2470 keV maximum positron energy), emit positrons that can travel a significant distance before annihilating.
- Positron travel over long distances preceding annihilation results in poor image resolution.
- Conclusion: **For our sub-millimeter resolution system the flight range of the positron is the ultimate limitation on spatial resolution.**

## The Influence of Strong Magnetic Fields on Positrons

- The positron is the antimatter partner of the electron - a positively charged particle with the same mass and magnitude of charge as an electron.
- Due to its charge, the positron is an ideal target for magnetic influence.
- Circular motion can be imposed upon positrons by magnetic forces acting in the direction transverse to the applied magnetic field.
- The positrons travel the same net distance in the presence of a magnetic field; however, due to the magnetic field the path that the positrons travel is curved and thus the displacement of the positron prior to annihilation is reduced.

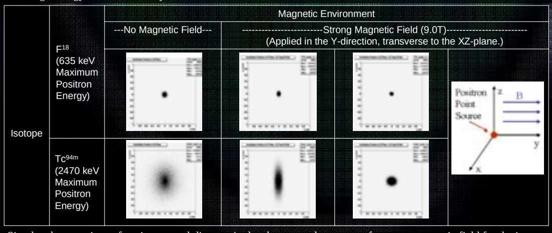
## Simulation of the PET Imaging Process

- Developing PET equipment and performing experiments with new technology is an expensive undertaking, therefore simulation is desirable to anticipate the challenges and limitations associated with the new technology.
- EGS4 (Electron Gamma Shower) is the primary programming utility in this simulation, generating user-specified particles under well-defined conditions.
- Elements such as acollinearity of travelling photons and the immersion of the isotope in a water environment to emulate human tissues enables the simulation to closely follow real life expectations.
- Most importantly, using simulation it is possible to assess the benefits of using an integrated PET-strong magnet system.




Simulation of high and low energy isotopes in varying media and in the presence of different magnetic field strengths. These images show the scattering of positron annihilation positions from varying isotopes and in different media.

- While this effect is not as distinct in lower energy positron emitters and electron-dense media, the influence of a strong magnetic field on positrons with high energy or in low-density media is evident.



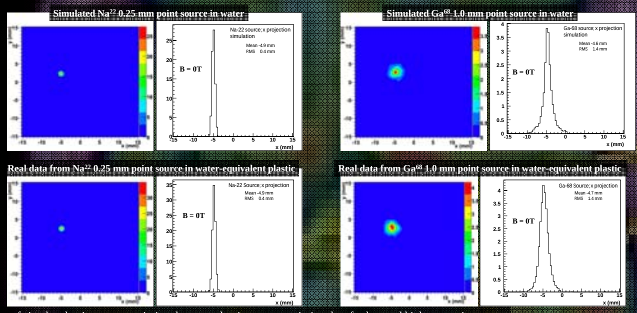

Simulated comparison of positron travel distance in the absence and presence of a strong magnetic field for the isotopes $F^{18}$ and $Tc^{94m}$.

- Implementing a strong magnetic field drastically improves the resolution of PET scans; however, due to the nature of magnetic fields the improvements are confined to one imaging plane

## Agreement between Simulation and Reality


- To ensure proper sampling in the presence of strong magnetic fields, the entire imaging apparatus has been reconstructed using non-magnetic components.
- Data was first taken using the new set-up in the absence of magnetic fields and compared to simulation data in order to verify the functionality of the new detector.
- The silicon chip detectors have been successfully tested for functionality in magnetic fields up to 8.0 Tesla.

Left: The improved set-up of the Si-Si detector system, utilizing components that will not be influenced by strong magnetic fields. Image courtesy of Don Burdette




Comparison of simulated point source emission data to real point source emission data for low and high energy isotopes.

| Source | Data Type | X FWHM (mm) | X FWTM (mm) | X rms (mm) | Y FWHM (mm) | Y FWTM (mm) | Y rms (mm) |
|---|---|---|---|---|---|---|---|
| $Na^{22}$ (0.25 mm disk source) | Simulated | 0.9 | 1.6 | 0.4 | 0.9 | 1.7 | 0.4 |
| | Real | 0.9 | 1.7 | 0.4 | 0.9 | 1.6 | 0.4 |
| $Ga^{68}$ (1.0 mm disk source) | Simulated | 1.6 | 4.7 | 1.4 | 1.6 | 4.3 | 1.4 |
| | Real | 2.3 | 4.7 | 1.4 | 2.3 | 4.7 | 1.3 |

Reconstructed image resolution for real and simulated sources.

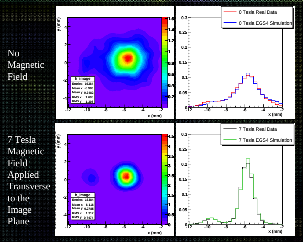
- In collaboration with the Ohio State University Medical School, the influence of strong magnetic fields on positron flight has been tested.
- Use of the silicon-silicon pad detector prototype inside the Medical School's large bore 7 Tesla MRI magnet confirms the influence of strong magnetic fields on improved image resolution.
- Comparison of distribution data shows strong agreement between simulated and experimental data.

Left: The Ohio State University Medical Center's 7 Tesla large-bore MRI magnet and table.

Near Right: Experimental data taken in the presence and absence of a 7 Tesla magnetic field. The data shows a comparison of two 1.0 mm $Ga^{68}$ disk sources separated by 3.6 mm, where the source on the right has ten times more activity than the left source.

Far Right: A comparison of experimental data to simulated data using the two source $Ga^{68}$ set-up.

Images courtesy Don Burdette.




## Conclusion

- The simulation accurately models the PET imaging process in the presence of a strong magnetic field.
- The PET-strong magnetic field system is capable of resolving images that would be blurred under typical PET imaging conditions.

## References

- S. Park, et al. A prototype of very high-resolution small animal PET scanner using silicon pad detectors, Nuclear Instruments and Methods in Physics Research A 570(2007) 543.
- Levin, C.S. and E.J. Hoffman, Calculation of positron range and its effects on the fundamental limit of positron emission tomography system spatial resolution, Physics in Medicine and Biology, 1999, 44: p.781-799.
- C. Knoess, et al. Comparative study of ECAT HRRT and microPET R4 for animal PET studies, IEEE Nuclear Science Symposium and Medical Imaging Conference. 2002, Norfolk VA November 6-11, 2002.
- Nelson, Walter R., H. Hirayama, and D.W.O. Rogers, The EGS4 Code System, December 1985, SLAC-265 UC-32 <http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-r-265.pdf>
- Raylman, Raymond R., B.E. Hammer, N.L. Christensen, Combined MRI-PET Scanner: A Monte Carlo Evaluation of the Improvements in PET Resolution Due to the Effects of a Static Homogenous Magnetic Field, IEEE Transactions on Nuclear Science, Vol. 43, No. 4, August 1996.
- Sanchez-Crespo, Alejandro, P. Andreo, S.A. Larsson, Positron flight in human tissues and its influence on PET image spatial resolution, Eur J Nucl Med Mol Imaging (2004) 31:44-51

## Acknowledgments

Support for this project provided by the Ohio State University Department of Physics and the group of Dr. Klaus Honscheid.

THE OHIO STATE UNIVERSITY
DEPARTMENT of Physics