\section*{Experiment E1042}

\textbf{βNMR investigation of the magnetism near the surface of unconventional superconductors}

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In contrast to the detailed experimental understanding of the hole-doped cuprate high temperature superconductors, less is known about the corresponding electron-doped materials. One key issue is the pairing symmetry in the superconducting state, with \textit{s}- and \textit{d}-wave order parameters being the most debated. The \textit{d}-wave pairing symmetry is supported by phase-sensitive and angle-resolved photoemission experiments, while measurements of thermodynamic quantities showed more evidence of \textit{s}-wave symmetry. One of the most studied electron-doped compounds is Pr$_{2-x}$Ce$_x$CuO$_4$ (PCCO), where recent measurements have reached inconsistent conclusions. Techniques such as $\mu$SR, NMR, and small-angle neutron diffraction (SANS) measurements are often used to study the internal field variation within the vortex state (above the lower critical field). In this experiment, we performed the first $\beta$NMR study of the vortex state in superconducting PCCO films.

Using $\beta$NMR, we studied an optimally doped ($T_C \sim 20$ K) sample of PCCO. A beam of $^8$Li$^+$ with kinetic energy $E = 3$ keV was implanted into a thin overlayer of Ag (400Å thick) on the PCCO film (3000Å thick). The measurements were carried out in the vortex state by applying a magnetic field $B_{\text{ap}} = 100$ G normal to the film (the crystalline c-axis). In this geometry, currents flowing in the \textit{ab} planes determine the magnetic field profile both inside the crystal, \textit{and} in the Ag layer. The field in the silver, however, will have little or no contribution from the intrinsic atomic magnetism in the PCCO (e.g. due to Pr$^{3+}$). Measurements of the temperature dependence of the $\beta$NMR resonance in the Ag showed a dramatic broadening in the vortex state (below $T_C$). The width of the line increases as temperature is decreased, while it is $T$-independent above the transition. Note that the data was collected in a newly developed and implemented mode of $\beta$NMR that employs pulsed RF field as well as pulsed beam. This mode allows a measurement of the lineshape free from many systematic effects found in continuous data acquisition modes.

In Fig. 1-a, we display the measured lineshape at four different temperatures. The spectrum, with a $T$-independent line width above the transition temperature $T_C$, broadens as we cool below $T_C$. The resulting lineshape is inconsistent with either the ideal triangular or square lattice arrangements, i.e. it is missing the characteristic high field tail and is too symmetric. This likely reflects a significant change of the vortex state in the thin film geometry. To quantify our measurements, we extracted the second moment, $\langle \Delta B^2 \rangle$, a measure of the line width. The second moment, plotted in Fig. 1-b, shows evidence of a flat temperature dependence at low temperatures, but better statistics are required to determine whether this $T$ dependence can be used to discriminate between \textit{s} and \textit{d} wave states. We can tentatively extract, from $\langle \Delta B^2 \rangle$ an estimate of the low temperature magnetic penetration depth in PCCO, $\lambda$. Normalizing to our results in the conventional superconductor NbSe$_2$ at similar fields, yields values of $\lambda$ in PCCO between 250-300 nm, consistent with other results (180-300 nm).

As the deceleration system is commissioned on the $\beta$NQR spectrometer, this experiment will focus there on measurements in PCCO and related materials, seeking signatures of interfacial magnetism.