PIONIUM PRODUCTION IN THE COOLER

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CE49 is an experimental search for the production of atomic states in the $\pi^+\pi^-$ system ("pionium"), utilizing the pd $\rightarrow$ ^{3}He X reaction very near the 2π production threshold. Pionium, whose production has been inferred from observation of correlated pion pairs in high-energy proton-nucleus reactions,[1] would provide a unique laboratory for the study of the $\pi - \pi$ strong interaction at essentially zero relative energy. In particular, if one could produce a clean *tagged* sample of pionium, then measurement of its decay branching ratio to 2γ would provide a model-independent determination[2] of the $\pi - \pi$ scattering-length combination $|a_{I=0} - a_{I=2}|$. These scattering lengths represent fundamental tests of any model of low-energy QCD incorporating chiral symmetry breaking, such as Chiral Perturbation Theory.

During the past year we have made significant progress in understanding the magnetic channel used in the Cooler T-section for ^{3}He detection, in probing relevant background rates, and in commissioning in-vacuum scintillators used to detect (and to veto for pionium production) low-energy $\pi^\pm$ deflected in the 6° magnet in the T-section. These advances will allow us to place a significant upper limit on the pionium production cross section.

We have tuned up the magnetic channel during each of our runs by detecting the full kinematic cone for ^{3}He's accompanying *single* π^0 production within 1 MeV of its production threshold. Here, the production cross section is large (~ 1 μb), the acceptance nearly 100%, and the background very small. In early CE49 runs, we found that the optimum settings of the channel magnets for the single π^0 production changed dramatically from run to run. This problem has recently been traced to intermittent shorts in the coils for both of the dipole magnets at the start of the detection channel. With these shorts repaired, we were able to adjust the channel magnets to optimize the ^{3}He acceptance in our most recent production run (June 1995). The resulting spatial distribution of ^{3}He's on the drift chamber at the entrance to the channel is shown in Fig. 1. We see very clearly the surface of the kinematic cone at an energy ≈ 0.8 MeV above threshold, marked by the yield enhancement associated with the peak in the c.m.-to-lab conversion Jacobian for pd $\rightarrow$ ^{3}He π^0. Under the conditions used in acquiring the data in Fig. 1, the channel acceptance appears to be limited slightly at only a few locations (especially near the top and bottom) on this cone, presumably by the gap size in the second of three quadrupole magnets in the channel. When the optimum magnet fields were scaled appropriately to detect ^{3}He's associated with $\pi^+\pi^-$ production, the acceptance of the channel was indeed observed to peak at the desired momentum.

The singles ^{3}He rate within the kinematic cone region shown in Fig. 1 falls to a level corresponding to a total background cross section $\lesssim 100$ pb *below the single* π^0 production

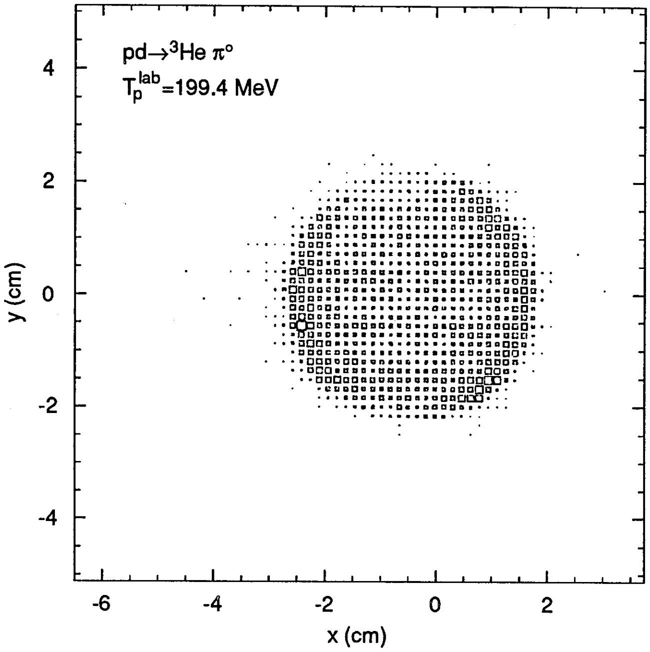

Figure 1. Distribution of ^{3}He's from pd → ^{3}He π^0 at a bombarding energy (199.4 MeV) 0.8 MeV above threshold on the drift chamber at the entrance to the magnetic channel. The circular spot indicates the extent of the ^{3}He kinematic cone in the laboratory, while the enhancement of event rate around the circumference of the circle corresponds to the peak in the Jacobian at the lab maximum angle ($\sim 1.0°$). Spots around the circumference where the enhancement is weak reflect acceptance limits of the channel.

threshold. In principle, conditions should be comparably clean just below the $2\pi^0$ threshold, since when the channel is properly tuned, there should be no acceptance for the open two-body channels (^{3}He π^0, ^{3}He γ), and negligible cross section times acceptance for the open electromagnetic reactions pd → ^{3}He e^+e^-, ^{3}He $\gamma\gamma$, ^{3}He $\mu^+\mu^-$. However, we have observed appreciable background at these energies ($<$ 415 MeV), consisting of ^{4}He as well as m^{3}He production, at rates dependent on the tuning of the Cooler beam. The ^{4}He must arise, and the background ^{3}He presumably as well, from reactions induced on material outside the D_2 gas jet target, either by primary beam halo or by particles first scattered by the D_2 jet. Under the best beam conditions we have achieved, the background ^{3}He rate corresponds to a total cross section ~1 nb, making it difficult, for example, to observe clear, statistically convincing evidence for the pd → ^{3}He $\pi^0\pi^0$ reaction by comparing ^{3}He singles spectra 1 MeV above and 1 MeV below threshold.

In order to reduce the background rates, without having yet to understand their origin in detail, we have concentrated in our most recent run on measuring the cross section for *free* $\pi^+\pi^-$ pair production 1 MeV above threshold (i.e., at 431.5 MeV). For this purpose we searched for *coincidences* between ^{3}He detected in the magnetic channel and charged pions detected in one or two of the five plastic scintillators installed to *veto* charged pions in an eventual pionium search. The layout of three of the veto scintillators within the 6° magnet vacuum box is shown in Fig. 2. Light is transported from these counters via

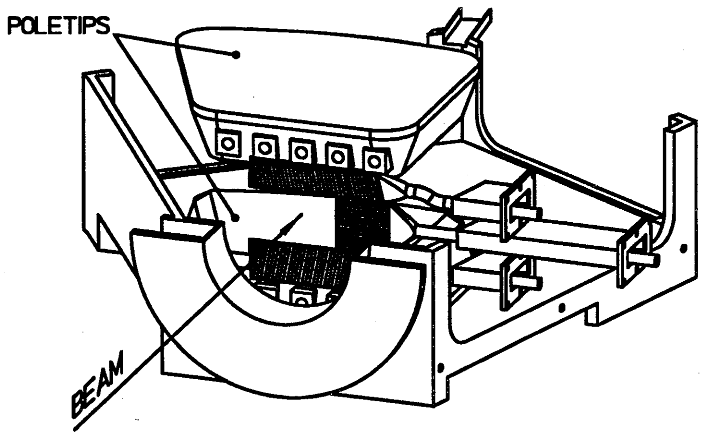

Figure 2. Layout of the plastic scintillators installed in the Cooler vacuum to detect low-energy charged pions near the 6° magnet poletips, before the pions enter the intense field region. In addition to the three (cross-hatched) scintillators pictured, two others are arranged further downstream, and to the left and right of those shown, in order to detect π^+ and π^- (or their daughter muons) that get bent (by $\gtrsim 90°$) through the magnet.

optical feedthroughs to photomultipliers outside the Cooler vacuum. The three scintillators pictured detect charged particles emitted from the target toward the upper or lower poletips of the 6° magnet, or low-rigidity negatively charged particles bent sharply toward beam right in the 6° magnet. In addition, a scintillator placed outside the vacuum on the beam-right side of the 6° vacuum box detects π^- (or their daughter μ^-) emerging through a thin (0.004" stainless steel) exit window, while one placed alongside a poletip spacer on beam left detects low-energy π^+. Within 1 MeV of the pd $\rightarrow$ ^{3}He $\pi^+\pi^-$ threshold, the pions are sufficiently confined in energy ($3 \leq T_\pi^{lab} \leq 12.5$ MeV) and angle ($\theta_\pi^{lab} \leq 16°$) that the simulated efficiency for detecting at least one of them in any of the five scintillators is 98%. The simulated efficiency for detecting *both* pions is $\approx 70\%$.

The coincidence requirement cleans up the ^{3}He spectrum substantially, as illustrated in Fig. 3. The left panel shows the ΔE–E particle identification spectrum acquired with Si and Ge detectors at the rear of the channel for all particles that fire scintillators at both the entrance and exit of the channel. The dominant groups correspond to ~100 MeV protons and ~50 MeV deuterons (from the pd $\rightarrow$ Ndπ continuum) that fall within the channel's acceptance, but ^{3}He and ^{4}He groups are also seen. The ^{3}He's here arise predominantly from background reactions not induced on D_2 and from pd $\rightarrow$ ^{3}He $\pi^0\pi^0$ (for which the energy was about 16 MeV above threshold). Only about 10% of the ^{3}He's correspond to $\pi^+\pi^-$ production. The right panel shows the same spectrum, now selecting only ^{3}He's and gating by a prompt coincidence with one or more of the charged-pion scintillators. One now sees a very clear bunching of events over a narrow energy interval, precisely that expected for the ^{3}He $\pi^+\pi^-$ channel 1 MeV above its threshold. When we lowered the bombarding energy below $\pi^+\pi^-$ threshold, only a flat background, at a level ~30 pb within the peak region, remained. However, the ^{3}He $\pi^+\pi^-$ coincidence signal itself in Fig. 3(b) corresponds to a total cross section times acceptance of only ~130 pb. The data are currently being

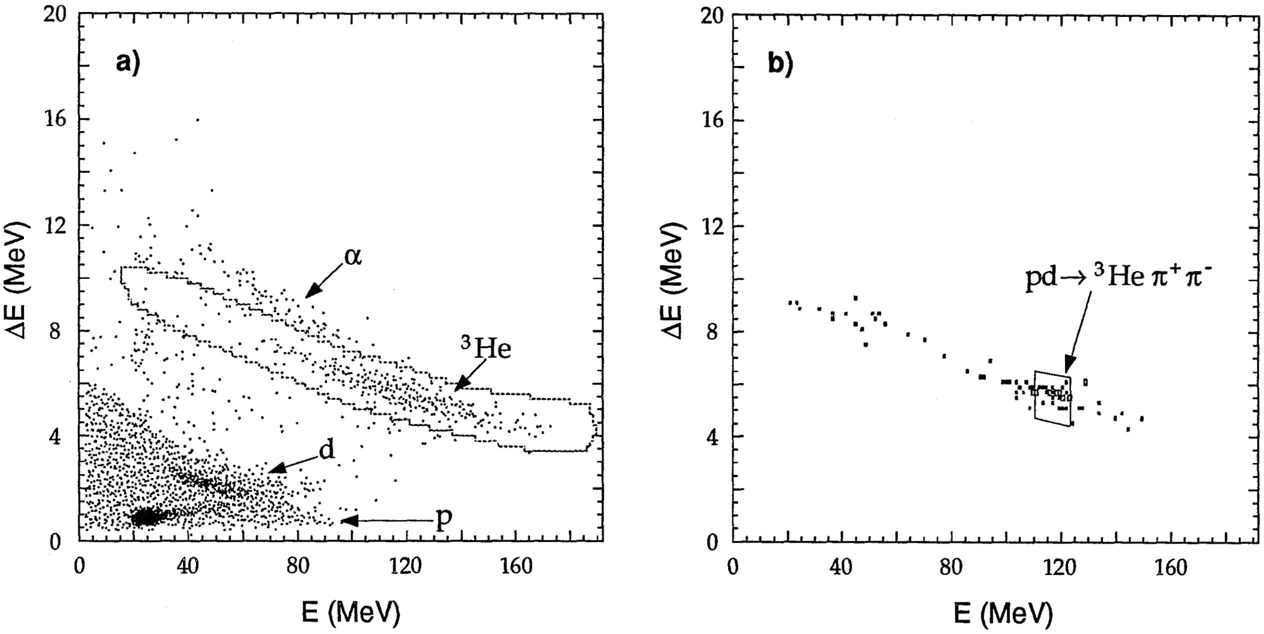

Figure 3. Particle identification spectra obtained at a bombarding energy of 431.5 MeV with Si (ΔE) and Ge (E) detectors at the exit of the magnetic channel. All particles that fire scintillators at the entrance and exit of the channel are included in (a), where the indicated two-dimensional window encloses ^{3}He's. Spectrum (b) includes only those particles within the ^{3}He gate that fire one or more of the charged-pion scintillators in prompt coincidence with the channel detectors. The window here indicates the energy range expected for pd → ^{3}He $\pi^+\pi^-$ events 1.0 MeV above threshold.

analyzed to extract information about the experimental acceptance (e.g., from the ratio of coincidence rates for two pion scintillators *vs.* one pion scintillator firing).

Pionium events and the detected pd → ^{3}He $\pi^+\pi^-$ coincidences are, to very good approximation, mutually exclusive, since pionium decays to neutral particles. However, it is reasonable to guess that the pionium production cross section is considerably smaller than that for free $\pi^+\pi^-$ pairs, since the relevant phase space for pionium is much smaller. We hope to extract from our recently acquired data a meaningful experimental upper limit on the pionium cross section, by comparing the ^{3}He singles rates, *vetoed* by the pion scintillators, in the relevant kinematic region above and below threshold. It appears probable that this limit will be sufficiently small to make an eventual coincidence measurement of the $\gamma\gamma$ decay of pionium of marginal feasibility with the pd → ^{3}He $(\pi^+\pi^-)_{atom}$ production reaction. Alternative production reactions are under consideration.

1. L.G. Afanasyev, *et al.,* Phys. Lett. B **255**, 146 (1991); and Phys. Lett. B **308**, 200 (1993).
2. A. Betker, *et al.,* IUCF Sci. and Tech. Rep., May 1993 - April 1994, p. 53.