Research Proposal to the
Indiana University Cyclotron Facility
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A Search for the Charge Symmetry Breaking Reaction dd→$\alpha\pi^0$

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Abstract: We propose to search for the charge symmetry breaking reaction dd $\rightarrow \alpha\pi^0$ just above threshold using a magnetic channel and an array of Pb-glass detectors located in the T-region of the IUCF Cooler ring. Within the framework of a chiral effective interaction, the largest contribution to the isospin-breaking term comes directly from the difference between the up and down quark masses. Observation of the dd $\rightarrow \alpha\pi^0$ reaction at the expected level would represent a significant confirmation of this theoretical approach and lead to an independent measure of the quark mass difference.

Experimental Summary

Experiment:

- Reaction: dd $\rightarrow \alpha\pi^0$
- Energy: 231.4 MeV
- Measure total reaction cross section and T_{20} analyzing power

Apparatus:

- Location: Cooler T-region surrounding 6° magnet
- Upstream gas jet target box with thin sides
- Magnetic channel consisting of a septum and three quadrupole magnets
- Channel MWPC and scintillation detectors
- Array of Pb-glass detectors on beam left and right at the target box

Beam properties:

- Circulating current > 2 mA
- Tensor polarized deuterons (protons for setup)

Beam Time Request:

Type of run	number of runs	year of run	shifts (particle)	shifts (particle)
test beam	2	2000	9 (d)	18 (d)
luminosity/polarization	2	2000	15 (d)	30 (d)
channel commissioning	2	2001	15 (p)	30 (p)
channel commissioning	2	2001	15 (d)	30 (d)
Pb-glass commissioning	2	2001	15 (p)	30 (p)
background investigation	3	2002	15 (d)	45 (d)
production	4	2002	40 (d)	160 (d)
TOTAL:				60 (p) 283 (d)

Ready Date:

- magnetic channel: January, 2001
- target box and Pb-glass: September, 2001

I. Introduction

Studies of charge symmetry in the NN system began at IUCF in the 1980's with the measurement of the analyzing power for elastic n+p scattering [Vi92]. The experiment investigated the differences between the neutron and proton analyzing power as a signal (among other contributions) of the isospin mixing of the ρ and ω mesons. This led to a consideration of a search for the charge symmetry violating dd $\rightarrow \alpha\pi^0$ reaction as a possible experiment suitable for the Cooler environment and the inclusion of the idea in the laboratory's three-year proposal to the National Science Foundation [Ca96]. The concept of the experiment was built around a magnetic channel that would gather the forward-going cone of ^{4}He nuclei produced just above the π^0 production threshold at 225.4 MeV. The ^{4}He would be separated from the Cooler beam by a 6° magnet that is a permanent fixture of the T-region of the Cooler ring and a subsequent magnetic channel. The NSF proposal suggested reducing backgrounds by surrounding the target volume with Pb-glass detectors that would respond to the γ-rays from the π^0 decay, but it was not clear how best to arrange the detectors for high efficiency and still maintain good vacuum close to the gas jet target. In the summer of 1998, Mark Pickar and Andy Bacher undertook a GEANT simulation of various Pb-glass arrangements. This looked sufficiently promising that a Letter of Intent was generated to the PAC that fall [Ba98]. This was approved, and a copy of the PAC report on what was then called CE-78 is appended to this proposal (Appendix A).

In January, 1999, the laboratory presented its case to the National Science Foundation to extend the Cooler program for an additional year. The search for the dd $\rightarrow \alpha\pi^0$ reaction was one of the experiments this additional time would make possible. The NSF committee found these arguments compelling, and the NSF agreed. Shortly thereafter, permission was granted to purchase deuteron vanes for the RFQ so that polarized deuteron beams would be available for this experiment and for studies of three-body forces in the PINTEX region of the Cooler.

More evaluation studies were carried out the following summer. Two students in the Research Experience for Undergraduates (REU) program were involved with testing IUCF Pb-glass detectors and working on continued GEANT simulations of the detector response. Franz Sperisen came to IUCF for two weeks to work on a preliminary design for the gas jet target box. During this period concern grew that an experiment to search for the dd $\rightarrow \alpha\pi^0$ reaction on the Cooler was a major effort and that the development of the project should be accelerated if it was to be completed before the end of the Cooler life. To help focus the efforts of the group, it was decided to hold a technical review of CE-78 on February 4, 2000. In preparation, a Conceptual Design Report on CE-78 was generated. The review committee was chaired by Dave Hutcheon from TRIUMF. Other members were Roy Holt from the University of Illinois and Gary East, Will Jacobs, Bob Pollock and Barbara von Przewoski from Indiana University and IUCF. The report of the committee is appended to this proposal (Appendix B). The committee supported the findings of the PAC that these physics objectives should be pursued. In the short term, the committee suggested that the CE-78 group and the laboratory address the need for (1) adequate staff with Cooler experience, (2) technical coordination, and (3) the development of a management plan for conducting the experiment. They also asked that within 4 months (4) the septum magnet go out for bid, (5) a test run be made to measure rates applicable to the magnetic channel, (6) data from the test run be analyzed to assess the ability to suppress backgrounds, and (7) a design be made of the gas-jet target box. Other comments and concerns of the committee may be found in their report (Appendix B).

In mid-January, 2000, experimental running was suspended to allow the new deuteron vanes to be installed in the RFQ and tested. A debuncher was installed in the beam line from the linac to CIS and much of the CIS vacuum chamber was made bakeable in order to improve the deuteron beam intensity. Much of the month of March was devoted to commissioning the new vane system and developing acceleration schemes for deuterons in CIS. Toward the end of this period, deuteron beams were available at 90 and 240 MeV for several hours of testing in the Cooler ring.

In anticipation of test beam being available, a series of scintillators and an MWPC were placed along a 12.5° line on beam left at the exit of the 6° magnet in the T-region. A position-sensitive silicon detector was installed on the beam right side of the gas jet, and 15 Pb-glass detectors were arranged in an array near 90° on beam right. The goals of the test run were to (1) measure the rates for deuteron breakup and other major reaction channels into the direction where the magnet channel would be installed, (2) check for rates in Pb-glass detectors located near the gas jet target, (3) investigate backgrounds present in a stack of scintillators used for particle identification of Z=2 reaction products, and (4) examine the time-of-flight resolution for particles travelling along the magnetic channel axis. Approximately 5 hours of d+d data were taken at 240 MeV to address these questions.

The following sections of this proposal cover (II) the scientific motivation for this experiment, (III) a brief description of the experimental apparatus, (IV) a discussion based in part on the results of the test run covering rates and backgrounds in the experiment and pointing out needed calibrations, (V) a summary of development goals, beam requests, and needed financial and personnel resources, (VI) a discussion of the scientific personnel commitments to this experiment, and (VII) a conclusion that summarizes the response to the technical review committee report.

II. Scientific Motivation

Charge symmetry is an approximate symmetry of the strong interaction whose breaking arises out of the small difference between the masses of the up and down quarks (a few MeV) in comparison to their constituent masses when bound inside nucleons. This gives rise to a number of observable effects in nuclear systems [Mi95]. Precise measurements at the proton energies available at IUCF [Vi92] and TRIUMF [Ab89, Zh98] have shown a small difference in the analyzing power for n+p elastic scattering depending on whether the neutron or the proton is polarized. There are contributions to this difference from electromagnetic effects (scattering of the charged proton in the presence of the neutron's magnetic field) and the neutron-proton mass difference (as it changes the coupling at the pion exchange vertex). In addition, the IUCF measurement is sensitive to the isospin mixing of the ρ^0 and ω mesons, another manifestation of the quark mass difference. Because these mesons overlap in mass, their mixing has also been observed in the annihilation process $e^+e^- \to \pi^+\pi^-$ [Qu78] where the size of the mixing matrix element is well determined.

The quark mass difference also leads to charge symmetry breaking effects in pion production. Recent calculations [Ni99] illustrate the contribution of isospin mixing between the π^0 and either the η or η' mesons for π^0 production in the $np \to d\pi^0$ process. Near threshold where S-wave pion production dominates, this mixing generates P-wave amplitudes that distort the spherical symmetry of the final state. At TRIUMF, an experiment is underway [Op99] to measure the fore-aft asymmetry in the $np \to d\pi^0$ reaction. At 283.0 MeV, the energy of the TRIUMF experiment, this asymmetry is expected to be -0.37% [Ni99]. A consideration of this reaction based on chiral effective field theory [Mi00] suggests that an even larger contribution to the asymmetry arises directly from the quark mass difference.

Sensitivity to isospin mixing between the π^0 and η, η' mesons is also expected in the difference in the η-production cross section when π^+ and π^- beams hit a deuteron target [Ti99]. A preliminary difference of about 6% is observed in Brookhaven AGS experiment E890. Final analysis is still in progress.

In the case of the $dd \to \alpha\pi^0$ reaction, sensitivity to isospin mixing between the π^0 and η, η' mesons is suppressed since L-odd partial waves are forbidden in the final channel. On the other hand, the contribution from the quark mass difference term in the chiral Lagrangian remains. This offers a way to predict the size of the $dd \to \alpha\pi^0$ total cross section using the quark mass difference that is obtained from the proton-neutron mass difference after making Coulomb corrections. The observation of the $dd \to \alpha\pi^0$ cross section at the predicted level would represent an important confirmation of the chiral effective field theory. This would complement any result that comes from the fore-aft asymmetry in the $np \to d\pi^0$ reaction since the Coulomb correction and $\pi^0 - \eta, \eta'$ mixing also contribute in the $np \to d\pi^0$ case.

While a number of searches for the $dd \to \alpha\pi^0$ reaction have been made, only one reports a result (0.8 pb/sr) [Ba87]. This claim has been called into question because the experiment did not discriminate well against uncorrelated γ's arising from double radiative capture [Do99]. Thus to date we have no definitive observation of the $dd \to \alpha\pi^0$ reaction.

The design of CE-78 uses equipment and techniques already developed for the IUCF Cooler. Near threshold, the ^{4}He nuclei emerge in a narrow forward cone. Using the 6° bend in the T-region Cooler beam line, these ^{4}He nuclei can be separated from the beam and gathered for detection in a magnetic channel. Such a channel has been used previously in the search for pionium (a bound $\pi^+\pi^-$ atom) with a sensitivity near 1 pb [Be96]. Open space around the target upstream of the 6° magnet will be used for an array of Pb-glass counters that detect the two γ's emerging from π^0 decay. Near threshold, other π^0 production reactions are energetically forbidden. The target is a (windowless) gas jet, thus reducing background from reactions on heavier nuclei.

Geometrical constraints on the detection of the forward cone of ^{4}He nuclei suggest 231.4 MeV as the appropriate energy for a search at IUCF. It is likely that this energy is close to a maximum in the cross section that arises from the competition between expanding phase space and declining overlap between the deuteron and ^{4}He wavefunctions. (Such a maximum occurs for the $\pi^0 - \eta, \eta'$ mixing contribution to np $\rightarrow$ dπ^0 [Ni99].) An estimate [St00] based on a scaling argument developed by Greider [Gr61] (and investigated by Miller [Mi98]) predicts 20 pb for the total cross section at 231.4 MeV.

Compared to the previous searches at high energy [Ba87], a search just above threshold at 231.4 MeV would operate below the pion production threshold for a number of possible processes on light targets. A windowless gas jet target should help to reduce the need for heavier materials in the vicinity of the interaction region.

Another advantage lies in the availability of polarized deuterons at IUCF. Restrictions on the angular momentum coupling and parity conservation in the dd $\rightarrow \alpha\pi^0$ reaction show that the tensor analyzing power is maximum ($A_{zz} = 1$). The analyzing power for the production of uncorrelated γ's is expected to be small [Do99]. Thus a measurement which yields the maximum analyzing power for the dd $\rightarrow \alpha\pi^0$ candidate events would be an important confirmation for the experiment.

The estimate quoted earlier for the dd $\rightarrow \alpha\pi^0$ total reaction cross section (20 pb at 231.4 MeV) [St00] is based on the scaling of the nuclear overlap from the pd $\rightarrow$ ^{3}Heπ^0 reaction by a calculated factor of 0.31 and on the estimate of the size of the quark mass difference contribution from chiral field theory [Mi00]. The earlier search at higher energy [Ba87] stimulated the calculation of γ-ray production from double radiative capture [Do99]. We have contacted the authors and obtained information on the phase space distribution of such events for the energy of the Cooler experiment since this process represents a major physics background for the charge symmetry breaking reaction. They calculate a total cross section of 320 pb [Ga00], of which about 16 pb falls within the angle and momentum acceptance of the magnetic channel. Thus, it is important to simulate these two processes and check in the context of the expected experimental errors how well these processes might be distinguished. The best separation, as discussed later, comes from a calculation of the missing mass based on the measurement of the four-momentum of the outgoing ^{4}He nuclei in the magnetic channel.

Other background will originate from the large rate of particles seen by this experiment. In particular, protons from the breakup of deuterons from the beam will have the same rigidity as the ^{4}He of interest and will go down the channel. Mark Pickar [Pi00] has estimated these rates, and additional information is now available from the test run. It is thus essential that the detectors be designed to operate with this incident flux.

The event rate expected in the experiment can be estimated from the cross section and the typical beam properties for the Cooler. From recent performance for protons, it is reasonable to expect an average of 2 mA of circulating current for the polarized deuteron beam. Injection from CIS into the Cooler would occur at 90 or perhaps 100 MeV, followed by cooling and ramping the beam. Experience with the pd $\rightarrow$ pdπ^0 experiment [Ro93] in the T-region suggests that a deuterium target thickness of 2.5×10^{15} cm^{-2} is consistent with about a 30 s lifetime for the Cooler beam. If this is also the flattop time, then the duty factor for operation is roughly 60%. The average luminosity is 3×10^{31} cm^{-2}s^{-1}. If both π^0 decay γ-rays are required to identify an $\alpha\pi^0$ event, then 33% of these events will have γ-rays that fall within the detector acceptance. For an expected cross section of 20 pb, the event rate will be 10/day or about 500 events during the 160 shift production running time.

III. Experimental Apparatus

The design of the magnetic channel and detector arrangement for CE-78 is based on other similar arrangements that have been used in the IUCF Cooler T-region [Be96]. An overview of the T-region setup for CE-78 is shown in Fig. III.1. The main features of this arrangement are:

- The **gas jet target** sits in the middle of a target box over half a meter upstream of the entrance to the Cooler T-region 6° magnet. This location is also upstream of the optimum position for the operation of the tagger. The location represents a compromise between getting the forward cone of ^{4}He nuclei into the entrance to the magnetic channel and allowing space surrounding the target for arrays of Pb-glass detectors. While target densities can be made thicker, the optimum thickness is close to 2.5×10^{15} cm^{-2}. A series of pumping baffles upstream and downstream separate the target region from the better vacuum of the Cooler ring.
- Near the gas jet target will be a **luminosity monitor** in the form of two or more position sensitive silicon detectors. In coincidence with scintillators near the beam downstream, these detectors observe elastic d+d scattering as a monitor of the luminosity. The position sensitivity is oriented along the beam direction, and this readout produces a projection of the gas jet target density along the beam axis. The cross section for d+d scattering will need to be measured in a separate calibration run using the PINTEX detector system.
- The walls of the target box will be made thin in order not to severely attenuate γ-rays produced by the decay of the π^0. Surrounding the target box will be two arrays of **Pb-glass detectors**. The top and bottom of the target box will be left clear for the gas jet target, vacuum pumping, and other services. These detectors offer a way to observe the presence of high energy γ-rays without sensitivity to a large fraction of the charged and neutral particle flux that will emerge from the target region. The detectors on beam right will be arranged in a circular arc three detectors deep. They have been used previously in experiments at IUCF. The modules are 50 cm in length and have a 6.4-cm square cross section that tapers to 4.2 cm in one dimension at the end away from the PMT. On beam left are detectors on loan from Argonne National Laboratory. These modules are 36 cm in length with a 6.4-cm square cross section. GEANT simulations by Mark Pickar predict that the beam right/left arrays will see 45.5%/47.0% of the γ-rays emitted from π^0 decay. The probability of detecting at least a single γ-ray anywhere is 59.0% and of detecting both π^0 decay γ-rays is 33.0%.
- The **magnetic channel** consists of a septum magnet (new with this experiment) that bends the forward cone of ^{4}He nuclei away from the Cooler beam line and a set of three quadrupole magnets (already at IUCF) that refocus the cone onto a final set of detectors. The septum magnet is a high-current device with a field clamp that keeps stray magnetic flux from the vicinity of the beam. Tilted entrance and exit pole faces provide vertical focussing. The details of the design have been confirmed by Hermann Nann using 3D magnet calculations. The mechanical design of the septum is in progress.

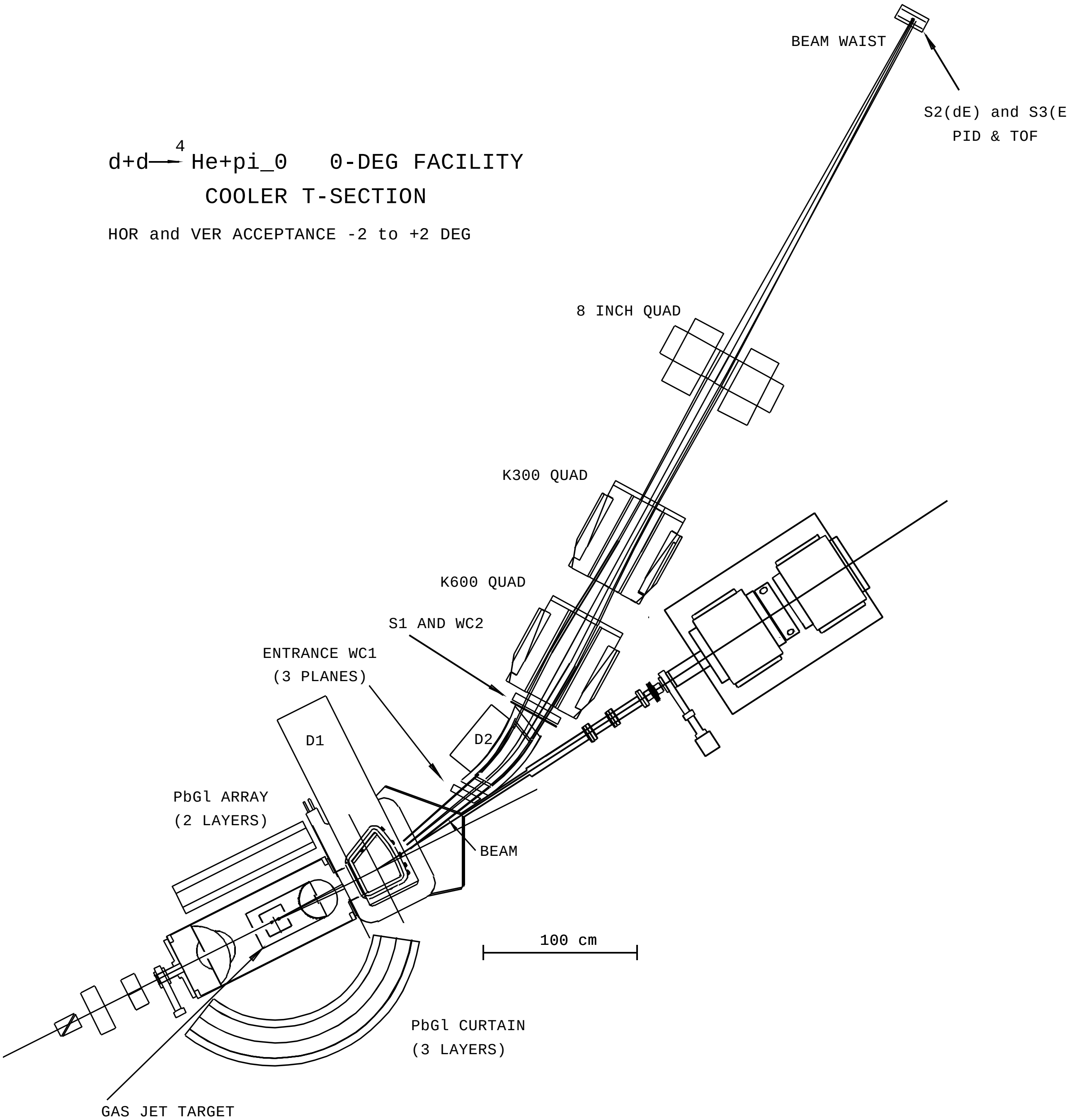

Figure III.1: Layout of the proposed CE-78 experiment showing the location of the gas jet target, the Pb-glass detector arrays, the 6° bending magnet, the magnetic channel, the first two MWPC detectors, and the channel scintillation detectors.

- Two sets of **MWPC detectors** located on either side of the septum magnet provide ray-tracing capability in both X and Y. Identifying a point of origin that is consistent with the location of the gas jet target is one method for reducing background. More importantly, the first chamber position is used to determine the transverse momentum of the ^{4}He nuclei as they enter the channel. The front chamber will be equipped with an additional diagonal set of wires to help resolve ambiguities from multiple hits. One additional MWPC will be located at the end of the channel to verify the momentum of the ^{4}He nuclei (based on the dispersion of the channel) and to aid in tuning the channel magnets.
- The **scintillation detectors** in the channel will serve the dual role of particle identification and measuring the z-component of the ^{4}He momentum through time-of-flight. Data from the test run indicates that the timing for Z=2 particles can be determined with high resolution (Gaussian $\sigma \leq 100$ ps). Pulse height information differentiates particle type. At the end of the scintillator stack, there will be a veto counter that eliminates most of the Z=1 flux.
- Not shown on this diagram of the T-region is a **beam polarization monitor**. The best analyzer is d+p elastic scattering whose T_{22} sensitivity is large throughout this energy region [Sa96,Gl96]. We plan to run a thin proton gas cell target in the Cooler A-region and to use the PINTEX wire chamber and scintillator system to observe backward-angle d+p elastic scattering. This will provide a polarization monitor that operates simultaneously with data acquisition. For 231 MeV, the analyzing powers will be extrapolated from higher energies (near 270 MeV [Sa96]) using Faddeev calculations.

IV. Technical Considerations

IV.a. Rates and detector performance

Information from the test run may be used to estimate the rates that will impinge on the magnetic channel (and check predictions made for the technical review by Mark Pickar). From runs with a hydrogen target, it was possible to extract an integrated luminosity based on measured d+p elastic cross sections [Gl96]. By scaling the target density from hydrogen to deuterium, this calibration was transferred to processes initiated with d+d. From this analysis, the average d+d elastic scattering cross section near $\theta_{\rm lab} = 6°$ is 230 mb/sr (at the edge of Pickar's range of 50–200 mb/sr), and protons from deuteron breakup have an average cross section of 620 mb/sr. Integrated over the design acceptance of the magnetic channel, the proton rate is 9×10^4 s^{-1} at the expected luminosity (down about a factor of 3 from Pickar's estimate). The front-end detectors in the magnetic channel must be designed to perform reliably at such rates.

Some rates anticipated for CE-78 are:

Expected rates

source	events/s
$\alpha\pi^0$	1.1×10^{-4}
$\alpha\gamma\gamma$	9×10^{-5}
elastic deuteron	3×10^4
breakup proton	9×10^4

IV.b. Identification of the π^0 candidates

The identification of charge symmetry breaking dd $\rightarrow \alpha\pi^0$ events requires separation from real $\alpha\gamma\gamma$ background and other events that, through accidental coincidence or other processes, only appear to have the correct signature in the detectors. Real $\alpha\gamma\gamma$ events are particularly hard to distinguish since energy and momentum conservation for those ^{4}He nuclei that proceed down the channel mandates a nearly back-to-back γ-ray geometry that resembles the π^0 decay.

To investigate the effects of experimental errors on the separation of the $\alpha\pi^0$ from the $\alpha\gamma\gamma$ channel, Ed Stephenson made Monte Carlo simulations of the reactions and their appearance in the channel detectors. Given the coarseness of the angle measurements available from the Pb-glass detectors, the geometrical information available from γ-ray angle data does not provide a way to distinguish these two final reaction channels. The only separation relies on the observation of the kinematic locus for the two-body $\alpha\pi^0$ final state from precise measurements of the ^{4}He momentum in the magnetic channel. The essential observations that determine the four-momentum components are the X and Y positions in the first MWPC detector, the z-component of the momentum extracted from time-of-flight observations in the channel, and the ^{4}He rest mass. From this information it is possible to calculate the missing mass and look for a peak associated with the π^0 mass. The $\alpha\gamma\gamma$ channel produces a wide distribution of missing masses from its endpoint near 138 MeV down nearly 20 MeV. However, just below the π^0 peak, the phase space distribution is cut away by the momentum acceptance of the channel for ^{4}He nuclei until it is gone just above 120 MeV.

The result of the simulations is shown in Fig. IV.1. The rates for the two reaction channels are based on the 20-pb cross section expected for the $\alpha\pi^0$ reaction and calculations from Colin Wilkin and Anders Gårdestig [Do99] for $\alpha\gamma\gamma$. Integrated over the acceptance of the channel in angle and momentum, the cross section for $\alpha\gamma\gamma$ is expected to be about 16 pb. The width of the π^0 peak in Fig. IV.1 reflects simulated experimental errors including (1) the target spot size, (2) the multiple scattering in the vacuum and wire chamber windows, (3) the discretization of the MWPC position readout, and (4) the time resolution of the scintillator measurements. The two panels represent the signal for positive and negative tensor polarization (p_{yy}) of the deuteron beam with a vertical quantization axis. The $\alpha\gamma\gamma$ events are expected to have almost no sensitivity to the deuteron tensor polarization [Do99] while the $\alpha\pi^0$ tensor analyzing power is maximal.

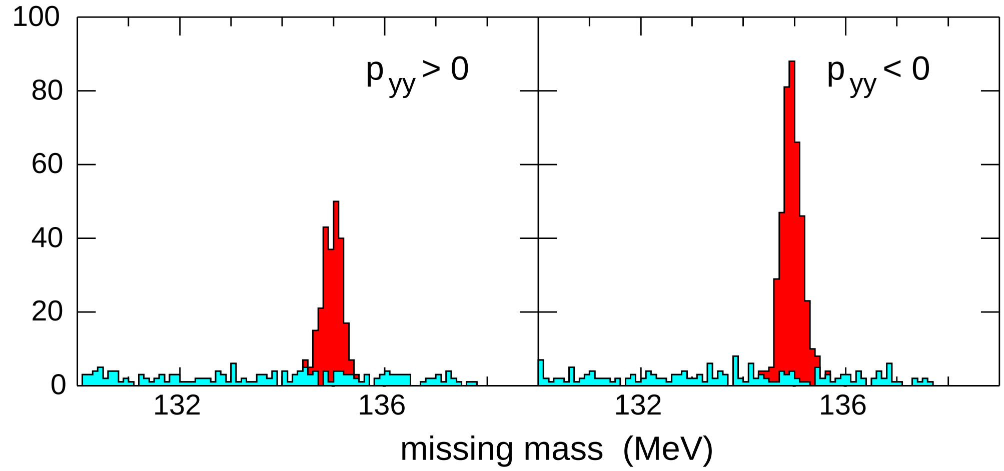

Figure IV.1. Monte Carlo missing mass (MeV) spectra showing the $\alpha\pi^0$ peak and the $\alpha\gamma\gamma$ background for the tensor plus and tensor minus polarization measurements.

The observation of the correct change in the $\alpha\pi^0$ event rate with polarization state is an important confirmation of the correct identification of charge symmetry breaking events.

Other events which resemble the correct particles can originate from accidental coincidences or particles in the channel that are either misidentified or which have changed through secondary reactions into ^{4}He nuclei. Backgrounds of these types can be characterized and subtracted using either time information between the channel and the Pb-glass detectors or the geometry of the coincident γ-rays. For the geometry test, a good event must be coplanar with the reconstructed π^0 momentum vector (assuming a two-body final state) and lie within the right range of opening angle (130° to 180°).

IV.c. Luminosity and polarization calibrations

Measurements are not available for the d+d elastic scattering cross section in the energy range of this experiment. Thus it will be necessary for luminosity monitoring to obtain the cross section information using a comparison experiment made with the PINTEX detectors. The best reference cross section is d+p elastic scattering, which has been measured at a number of energies [see Gl96 for references]. In order to transfer the calibration, the target cell for the Cooler A-region must contain an HD molecular gas to provide a known ratio of hydrogen to deuterium. Elastic scattering loci will be visible in the PINTEX detectors for both the d+p and d+d processes at the same time. It will be important to conduct this cross calibration with a polarized beam, as the tensor analyzing powers at forward angles are also not known. Measurements in the mid-angle region are available [Ga86] and would suggest that the tensor analyzing powers are small.

We will also need to develop the PINTEX setup as a monitor of the deuteron polarization. Measurements of the vector and tensor analyzing powers are available at 270 MeV [Sa96] and more complete angular distributions are expected to be published shortly. These analyzing powers change only slowly with decreasing energy [Gl96], so an extrapolation to 231.4 MeV does not represent a limitation on the precision of the experiment.

V. Experiment Plan

V.a. Overview and Beam Time Estimates

The experimental run plan divides into a number of objectives for the next three years:

- **Test Runs** [Year 2000]
  The first test run with deuteron beam was completed on April 3. A series of detectors and wire chambers were located after the 6° magnet to simulate channel detectors, and 15 Pb-glass detectors of both types were located to beam right. The test run produced information on particle identification, time-of-flight resolution, and rough cross sections for deuteron elastic scattering and breakup. This test run was characterized by low beam and large backgrounds from errors in the Cooler beam tune. A second and possible third test run is needed with deuterons to verify that the detector designs are capable of operating at the rates expected in the experiment.

  Shifts needed: 2×9 shifts (deuterons)

- **Luminosity and Polarization Development** [Year 2000]
  A run with the PINTEX apparatus is needed to measure the d+d elastic scattering cross sections needed for the luminosity measurement in the T-region. The analyzing powers of d+d need to be measured in order to allow corrections to be made for the spin dependence of the luminosity monitors. A second objective is to develop a routine scheme for making polarization measurements using d+p elastic scattering with the PINTEX detectors. Two runs are likely to be needed to complete this development.

  Shifts needed: 2×15 shifts (polarized deuterons)

- **Channel Commissioning** [Year 2001]
  Following a January, 2001 installation of the magnetic channel in the Cooler T-region, a number of runs with proton and deuteron beams will be needed to commission the channel detectors and provide a data base for investigating backgrounds. The proton running will utilize the $pd \to {}^3He\pi^0$ reaction, which has a cross section of several μb near threshold, to generate a cone of Z=2 particles in the channel with kinematic characteristics like those expected for the $dd \to \alpha\pi^0$ process. Toward the end, deuteron beams will be used to investigate rates and background processes as they appear in the channel. If available, some Pb-glass detectors will be used to get a first indication of the utility of the Pb-glass array.

  Shifts needed: 4×15 shifts (30 protons, 30 deuterons)

- **Pb-glass Commissioning** [Year 2001]
  After the installation of the new target box and the arrays of Pb-glass, commissioning will shift to bringing these new detectors on line. Here, the use of the two γ-rays from $pd \to {}^3He\pi^0$ will be crucial.

Shifts needed: 2×15 shifts (protons)

- **System Commissioning** [Year 2002]
  With the Pb-glass and software in place, the commissioning task shifts to running with the deuteron beam and checking for ways to reduce and eliminate backgrounds. In this case, reactions with lower cross sections than the pd $\rightarrow$ ^{3}Heπ^0 reaction will be useful. Candidates include the radiative capture reactions pd $\rightarrow$ ^{3}Heγ and dd $\rightarrow$ $\alpha\gamma$. For nuclei that travel down the magnetic channel, the γ-rays proceed forward in the beam direction, where a separate set of Pb-glass detectors will need to be placed. It may also be useful to consider reactions with a three-body final state, such as dd $\rightarrow$ ^{3}He n γ.

  Shifts needed: 3×15 shifts (deuterons)

- **Production Running** [Year 2002]
  Production running will be in longer blocks with enough time in between to allow for some data processing.

  Shifts needed: 4×40 shifts (polarized deuterons)

  TOTAL shifts needed: 343 shifts (60 protons, 283 deuterons)

V.b. Resource plan

At this time of transition, IUCF finds itself with limited resources for the design and construction of new equipment. The general plan is to place effort first into the construction of the magnet channel and its detectors. The longest lead time items are the septum magnet and the MWPC detectors, both of which require design from the beginning. (There is an already existing channel mount that can probably be modified for the needs of CE-78.) Both of these items are now part way through the design process. Some parts of the septum magnet will need to be constructed in outside machine shops since the IUCF shop equipment no longer is the most efficient way to prepare pieces with complicated shapes. The plan calls for the completion of channel construction by the beginning of 2001 with installation in the early part of that year. This would also allow the tagger to continue to run while the channel is commissioned (although not with the final gas jet target position).

The second phase of design and construction begins in the summer of 2000 with the target box (to be designed at IUCF) and the mounts for the Pb-glass (to be built at Argonne). Both of these would be ready in the summer or early fall of 2001. The installation of the target box requires a major rebuilding of this part of the Cooler ring, and will require an access period of about two months during which there is no other beam running.

The support staff requirements have been estimated by Chuck Foster based on a list of the construction tasks and the amount of effort required for each one. The totals for the next two years are given here and are a rough guide to the size of this effort.

Most of the design, drafting, and shop work takes place in 2000, with installation coming in 2001. IUCF has two people for design (Walt Fox and Jack Doskow) and one person who concentrates on wire chambers (Keith Solberg). There is one draftsman and

Effort (person-weeks)

category	2000	2001
engineering	15	2
drafting	25	6
machine shop	55	8
professional	5	16
technical	12	33

there are three machinists. Installation will be coordinated by Tom Rinckel with help from a few technicians (and scientists as needed). Thus this project represents a major commitment by members of the IUCF staff over the next year. These same people also will be involved with the support for the rest of the scientific program.

It is clearly beneficial if parts of this work can be moved to other institutions. At this time, Hal Spinka has agreed to help build the support for the Pb-glass detectors at Argonne. There are also budget items that have been identified for the CE-78 effort. They are distributed over 2000 and 2001 as shown in the table.

Budget Summary (k$)

item	2000	2001
target box	15	
cryopump		30
gases		3
channel stand	3	
septum magnet	14	
vacuum pipe	8	
MWPC	10	
scintillators	2	
Pb-glass stands	5	
cables	9	
timing system	15	
electronics	65	40
TOTAL	146	73

The largest single item is new electronics. We are currently looking for possible ways to borrow some essential items. The cryopump has been purchased and installed.

VI. Duties of the Collaboration

The scientific effort behind CE-78 appears in the author list for this proposal. It is important to review this list and discuss what level of commitment is available from each person.

From the Indiana University faculty, Andy Bacher and Hermann Nann both spend part of their time teaching. Hermann also helps Mike Snow with his experiments at NIST and LANSCE on ultra-cold neutrons. Andy is also responsible for the operation of the IUCF Research Experience for Undergraduates program in the summer. Chris Allgower began a post-doctoral appointment in the fall of 1999 and intends to split his time between CE-78 and the construction of the STAR endcap calorimeter. Dennis Friesel and Chuck Foster are both members of the IUCF staff. Dennis will help with the development of the deuteron beam and be available for run-by-run setup issues. Chuck Foster carries primary responsibility for the Radiation Effects Research Program at IUCF. Ed Stephenson has a research appointment and will be coordinating activities and schedules for the operation of the Cooler. A large fraction of his coordinating time will be devoted to CE-78. Georg Berg is on a leave of absence from IUCF, but remains in contact to help with questions about the design of the magnetic channel.

To augment the local effort, and agreement was reached with Protvino to have one scientist visit IUCF for three years (Dmitri Patalahka) and to devote his efforts exclusively to CE-78. He has additional help from two other scientists or technicians who rotate through their positions every 4 months.

There are also a number of active outside users. Mark Pickar is available during the summers when he comes to help with the REU program. Otherwise, he teaches full time. Paul Pancella, who is in a similar position, is planning a sabbatical year so that he can be at IUCF from July, 2000 through the summer of 2001. He will divide his efforts between the PINTEX collaboration and CE-78. Hal Spinka, who has just received funding to support his participation in STAR, will be available for visits and running, and plans to contribute the equivalent of one full-time post-doc to CE-78. Such a person has not yet been hired.

Roger Finlay and Jack Rapaport are on an "early-retirement" position at Ohio University and they teach only during the spring quarter of 2001. Although they are involved in other research projects, they should be able to contribute during the running of the experiment and during the data analysis phase. Ohio University is willing to contribute shop time toward the construction of parts for CE-78 and, as they have in the past, financial assistance to bring Franz Sperisen to IUCF to consult on get target design.

VII. Status of CE-78

The Technical Review Committee that met on February 4 had a number of concerns about the planning for CE-78. Foremost in their minds was the question of adequate scientific talent. Some short-term tasks have been picked up by Ed Stephenson, including simulations of the detector performance and a number of management tasks. This area will continue to be tight until more people arrive in the summer of 2000.

Another concern was the lack of a plan for implementing this experiment. Since the review, a plan has been created in which the major order of tasks gives first emphasis to the construction and commissioning of the magnetic channel. Rebuilding the target box and mounting the Pb-glass have been placed next in line. This allows an early start to commissioning while runs with the tagger and CE-78 can be interleaved. The running time associated with this plan has been sumarized earlier. Tom Rinckel has accepted the post of project manager. One of his duties is to expand the details of the plan and to make sure these are included with overall planning for IUCF.

At the time of the review, there were a number of issues concerning background rates and detector performance for which there were only crude estimates. Many of these questions have now been answered by the test run and subsequent analysis. These include cross section estimates for d+d elastic and deuteron breakup channels, time-of-flight resolution, and separation of the Z=2 particles using scintillator pulse height information.

The committee also wanted to see progress made toward the design and construction of some of the major pieces of equipment. The septum magnet design has been slowed by conflicts with other laboratory projects and will not be completed in all phases until the middle of the summer. The drawings for machining the magnet iron will be sent out for bids around May 1. At the time of the review, it was expected that the gas jet target box would be the first item to be completed. Because of the change in priorities with the formulation of the management plan, it is now possible to allow design effort to be more spread in time and shared with other institutions. So this is less an issue for staying on the critical path, and work has not started on the design of the target box. This will begin in earnest early this summer when Franz Sperisen returns to bring his previous design up to date. In preparation, we will need to consider the design of a magnetic field clamp for the 6° magnet and the detector arrangement for monitoring the luminosity.

Other concerns of the committee have also been addressed, including the availability of better simulations, a plan to use the PINTEX facility for polarization monitoring, and less interference in the short term with the tagger program. Responsibilities are being assigned as there are people able to assume them.

It is clear that a search for the dd $\to \alpha\pi^0$ reaction at the level of < 1 pb is a challenging task requiring a major commitment of IUCF personnel and financial resources, especially in view of the end of Cooler operations for nuclear physics in 2002. We feel that the project is possible if we meet the milestones for equipment installation and running outlined in this proposal. Given the concept of a search just above threshold, we feel that the equipment design has been optimized to make the best use of the potentially available experimental information. Since other magnetic channel experiments have approached this level of sensitivity, we feel that the goals of this search are within reach.

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Appendix A: PAC Report on Proposal 98-04

Search for Charge Symmetry Breaking via Observation of dd $\rightarrow \alpha\pi^0$
Close to Threshold [Letter of Intent]

A. Bacher (*Indiana University*)

Abstract: In this Letter of Intent we request beam time to evaluate detector configurations required to make a measurement of the cross section for the charge-symmetry-forbidden reaction dd $\rightarrow \alpha\pi^0$ close to the reaction threshold at a deuteron energy of 225.4 MeV. Time is also requested to make a determination of background processes present in the T-section of the Cooler Ring.

Recommendation: The observation of charge symmetry breaking in the dd $\rightarrow \alpha\pi^0$ reaction would be a major triumph for this group and for the laboratory. To make a meaningful statement about the Weinberg mechanism, however, the experiment must be designed with a sensitivity at the 1-pb level. As with previous CSB experiments, this experiment is likely to be difficult and will require a significant investment of money and manpower for the laboratory. The proposal time frame should be shorter than that in the Letter of Intent.

Recommended Allocation: 18 shifts

Priority: A–

Cyclotron Experiment Number: CE-78

Appendix B: Conceptual Design Review of CE-78

On February 4, 2000 a conceptual design for IUCF Cooler experiment CE-78 was reviewed by a committee consisting of Gary East (IUCF), Roy Holt (University of Illinois), Dave Hutcheon (TRIUMF, chair), Will Jacobs (IUCF), Bob Pollock (Indiana University) and Barbara von Przewoski (IUCF). The committe heard 10 presentations by collaboration members, followed by an open discussion session.

The reaction dd $\rightarrow \alpha\pi^0$ is forbidden by Charge Symmetry and its observation would be a direct and striking demonstration of Charge Symmetry Breaking (CSB). Models of CSB have yielded estimates for the total dd $\rightarrow \alpha\pi^0$ cross section at 231.4 MeV from 2 pb to several 100's of pb. An unavoidable background reaction is dd $\rightarrow \alpha\gamma\gamma$, which a recent publication estimates to be 3.6 pb/MeV/c^2 at 236 MeV. A characteristic of the dd $\rightarrow \alpha\pi^0$ reaction at threshold is that its analyzing power T_{20} is constrained to its maximum positive value, $1/\sqrt{2}$.

The conceptual design proposed creation of a 6m-long magnetic channel for detection of the α's and two walls containing more than 200 lead-glass scintillators to detect both γ's from decay of the π^0. A polarized beam would provide data on T_{20} in addition to the cross section. The timetable called for design, installation, commissioning, and up to 60 days of production running before the end of the nuclear physics program on the Cooler in October 2002.

This committee concurs with the PAC's view that dd $\rightarrow \alpha\pi^0$ is an important experiment, and supports the proposal to measure tensor analyzing power as a confirmation that the reaction was observed. The goal of the experiment should be a sensitivity for dd $\rightarrow \alpha\pi^0$ at the 1-pb level, in the presence of a possible dd $\rightarrow \alpha\gamma\gamma$ background of several pb/MeV/c^2.

Considering the magnitude of the task and the tight timeframe, the committee concludes that the collaboration is seriously understaffed and needs the addition of key people, especially a technical coordinator and collaborators with previous experience on the Cooler. This is a serious threat to the success of the experiment and a plan to address it must be put in place within the next 4 months, by the time of a June 2000 PAC meeting.

An immediate need is to develop, in cooperation with IUCF management, a detailed list of tasks and to identify people to carry them out, so that manpower conflicts with other projects are known. This, together with a budget and a timetable with key milestones, should be submitted to the laboratory management before March 1, 2000.

The committee strongly urges that the following be completed within the next 4 months as a minimum step towards meeting the very tight timelines for CE-78:

- septum magnet out to bid
- test of rates from an accelerated d beam on a d gas jet in a plastic scintillator stack and 12 lead-glass scintillators
- analysis of test runs and an estimate of the α PID efficiency of the plastic scintillators
- design of the target box

Extensive technical support by the Laboratory will be essential. Tests with a deuteron beam in the Cooler should be scheduled for Spring 2000, and a polarized deuteron beam of intensity $> 10^{10}$ after acceleration must be developed by the time CE-78 production runs begin. Space will be required for assembly and testing of detector arrays.

The committee has the following observations on technical aspects of the Conceptual Design:

- detection of both γ rays in coincidence with the α should be an effective, and possibly necessary, way to suppress backgrounds other than dd $\rightarrow \alpha\gamma\gamma$.
- the projected counting rate of 0.7 events/day is the minimum that is viable for this experiment. Higher rates should be sought by optimizing the luminosity, decreasing the dead-time of the data acquisition system, and designing the detectors to have high-rate capabilities.
- the collaboration is to be commended for the good progress in design of the magnetic channel and the testing/simulation of the lead-glass blocks.
- a single commissioning run is unlikely to be enough for a measurement of this degree of difficulty. Every effort should be made to advance the date of the first commissioning run for the full system into the first half of 2001. Tests of the apparatus at yields between the design sensitivity (pb) and the pd $\rightarrow$ ^{3}Heπ^0 cross section (μb) should be planned.
- provision of a polarimeter to measure deuteron tensor polarization at 231 MeV will be a major task. The CE-78 group should work closely with other groups having similar needs, to avoid duplication of effort.
- the experience of groups which have already built and used monitors of luminosity and gas jet location should be sought
- the lack of a simulation program is preventing informed decision-making on MWPC wire spacing, scintillator thickness, and other design parameters. Realistic simulation is essential for understanding and improving the missing-mass resolution of the experiment.
- CE-78 will have a serious impact on tagger experiments after the year 2000. Estimated switch-over times of 8–10 weeks will severely constrain the scheduling options in the Cooler. Where feasible, apparatus should be designed to simplify switch-over.
- responsibilities must be assigned and plans developed for:
    - installation and commissioning of the α channel and detectors
    - installation and calibration of the arrays of lead-glass counters
    - installation and commissioning of the target chamber, gas target, and luminosity monitor
    - data acquisition, including selection of monitor event streams
    - data analysis