Letter of intent for an experiment at PSI

A new search for the C-noninvariant decay $\pi^0 \to 3\gamma$

The PIBETA Collaboration:

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Abstract

We propose to carry out a search for the charge-conjugation-noninvariant decay $\pi^0 \to 3\gamma$ at the PSI πE1 beamline using the PIBETA spectrometer. The detection of this process would be an unambiguous sign of physics beyond the Standard Model. Nonobservation of the decay would improve the experimental limit on the direct verification of charge-conjugation invariance. The objective of the experiment is to search for this decay with a sensitivity roughly two orders of magnitude higher than the most recent experiment which resulted in an upper limit for the branching-ratio of 3.1×10^{-8}. By-products of this experiment will be improved measurements of $\pi^0 \to e^+e^-\gamma$ and $\pi^0 \to 4\gamma$ decays.

Neutral pions will be produced by stopping negative pions in a liquid hydrogen target. Photons and charged decay products will be detected with high efficiency by the PIBETA spectrometer to allow for a complete kinematic reconstruction of individual events.

*co-spokesmen

Beam Requirements

Experimental area: πE1

Beam particles: π^-

Beam momentum: 90–120 MeV/c

Beam momentum spread: $< 2.0\,\%$

Beam spot size: ~ 10 mm FWHM

Beam intensity: $(1-3) \times 10^5\, \pi^-/\mathrm{s}$

Beam purity: minimal μ^-'s and e^-'s contamination

Duration of experiment:

The experiment will be mounted in stages over a period of 2–3 years. We estimate that the total beam time required for successful experiment completion will amount to approximately 6 months. At present we are asking for 5 weeks of beam time in 2003 to test the liquid hydrogen target in beam, to optimize the beam parameters, and to confirm experimentally our expectations about the detector rates and backgrounds.

Safety questions

A cylindrical liquid hydrogen target ($\varnothing\,40\,\mathrm{mm}$, $L = 200\,\mathrm{mm}$, shown in Fig. 2) will be used in the experiment. The volume of liquid hydrogen will be $\sim 280\,\mathrm{cm}^3$, and the mass of hydrogen $\sim 20\,\mathrm{g}$. Equivalent volume of hydrogen at atmospheric pressure is $\sim 0.22\,\mathrm{m}^3$. Gaseous hydrogen will be kept in a stainless steel tank of $\sim 0.4\,\mathrm{m}^3$ under $\sim 1.6\,\mathrm{bar}$ of pressure. The tank volume will be connected to the target volume via a stainless steel tube. During target operation the hydrogen tank pressure will be $\sim 1\,\mathrm{bar}$.

1. Scientific motivation

1.1. Goal of the experiment

We propose to carry out a new experimental search for the charge-conjugation-noninvariant decay $\pi^0 \to 3\gamma$ in the PSI πE1 area, using a π^- beam and the PIBETA detector. Detection of this process would provide evidence of new physics beyond the Standard Model. We propose to improve the sensitivity to the $\pi^0 \to 3\gamma$ decay by a factor of $\sim$30–100 (i.e., down to $\sim 10^{-10}$ level). By-products of this experiment will be improved measurements of $\pi^0 \to e^+e^-\gamma$ and $\pi^0 \to 4\gamma$ decays.

1.2. Theoretical predictions

By definition, the charge conjugation transformation C changes the sign of all generalized charges, including additive quantum numbers such as the baryon B, lepton L and hypercharge Y numbers, leaving momenta and spins unaffected. This corresponds to the replacement of particles by antiparticles. Thus, the effect of C on, say, a baryon is:

$$C|B, Y, q\rangle = \eta_c| - B, -Y, -q\rangle \ ,$$

where $\eta_c = \pm 1$. Considering the operations Q and C, where $Q|q\rangle = q|q\rangle$ and $C|q\rangle = | - q\rangle$, we obtain

$$\{Q, C\} = 0 \qquad \text{and} \qquad [Q, C] = 2QC \ ,$$

i.e., that Q and C do not commute. Nature has, of course, realized the eigenstates of Q, B or L. Thus C-parity is a good quantum number only for states with $Q, B, L = 0$, in particular for neutral bosons such as γ, π^0, etc. In QED the photon is represented by the operators of the vector potential $\mathbf{A}$, which, in turn, behaves like an e–m current with respect to the C transformation:

$$\mathbf{J} = q\mathbf{v} \qquad \xrightarrow{C} \qquad (-q)\mathbf{v} = -\mathbf{J} \ ,$$

thus yielding the eigenvalue $\eta_c(\gamma) = -1$. The processes $\pi^0 \to 2\gamma$ and $\eta^0 \to 2\gamma$ fix the C-parity of these mesons at

$$\eta_c(\pi^0) = \eta_c(\eta^0) = 1 \ ,$$

which, coupled with C-invariance in e–m decays, rules out 3γ decay modes for both particles. Thus the experimental upper limits on the branching ratios of the C-forbidden $\pi^0 \to 3\gamma$ and $\eta^0 \to 3\gamma$ decays provide the best direct test of C symmetry conservation to date.

While the electromagnetic interaction is thus believed to fully preserve C symmetry, the weak interaction with its pronounced P violation and small ($\sim 10^{-3}$) CP violation clearly violates C invariance. This view of C symmetry invariance lies at the foundations of the Standard Model (SM) of elementary particles and interactions [1]. At present, CP violation, though experimentally well established, is not understood in all its aspects, and its experimental study continues vigorously. At the same time, relatively few experiments have tested C invariance. Interpretation of these experiments is handicapped by the absence of a theory that incorporates C violation, making it difficult to relate results of different searches, e.g., for $\eta \to 3\gamma$ and $\pi^0 \to 3\gamma$.

Several estimates of the $\pi^0 \to 3\gamma$ decay rate have been published over the past four decades, based on various models, cf. Refs. [2]–[6]. The predicted branching ratio is in general rather small, though in some cases as large as 10^{-9}. One fact, however, remains certain: any experimental evidence of C noninvariance in electromagnetic interactions would constitute a signal of new physics, not contained in the SM.

We, therefore, view the experimental search for C violation in the context of the broad worldwide effort in exploring the limits of validity of the SM by all means available. We believe that the fundamental implications of C (non)invariance clearly warrant the effort.

Any search for the $\pi^0 \to 3\gamma$ decay must contend with the background posed by the so far unobserved decay $\pi^0 \to 4\gamma$. Estimates of its rate are given, for example, in Refs. [7, 8].

1.3. Previous Measurements

The most precise search to date for the $\pi^0 \to 3\gamma$ decay was performed at the Los Alamos meson facility using the Crystal Box detector [9]. The upper limit for the branching ratio obtained in this work was 3.1×10^{-8} at 90 % C.L. The same work also reported the most sensitive upper limit to date on the allowed decay $\pi^0 \to 4\gamma$ ($BR < 2 \times 10^{-8}$ at 90 % C.L.).

The analogous process $\eta^0 \to 3\gamma$ was also searched for [10]. The authors found no indication of C-violation, however, at a much larger upper limit (5×10^{-4}).

2. Experimental Method

2.1. Basic approach

The basic idea of the experiment is to produce π^0's by charge exchange of π^- in hydrogen at rest, and subsequently to search for the $\pi^0 \to 3\gamma$ decay using the PIBETA detector, shown schematically in Fig. 1. This detector system is described in detail in the original PIBETA experiment proposal [11], on the project's home page [12], and in a forthcoming publication [13].

In order to obtain a sufficiently high yield of π^0's, the π^- beam particles must be stopped in liquid hydrogen. The only significant reactions of π^- with hydrogen are charge exchange: $\pi^- p \to \pi^0 n$, and radiative capture: $\pi^- p \to \gamma n$, occurring in the familiar Panofsky ratio of 1.55:1 [14]. The π^0 rate required for our $\pi^0 \to 3\gamma$ search is of the order of $\sim (1-3) \cdot 10^5$/s.

A π^0 produced in the $\pi^- p \to \pi^0 n$ reaction at rest recoils with a momentum of 27.9 MeV/c, so that the resulting photons from $\pi^0 \to 2\gamma$ decay are non-collinear by as

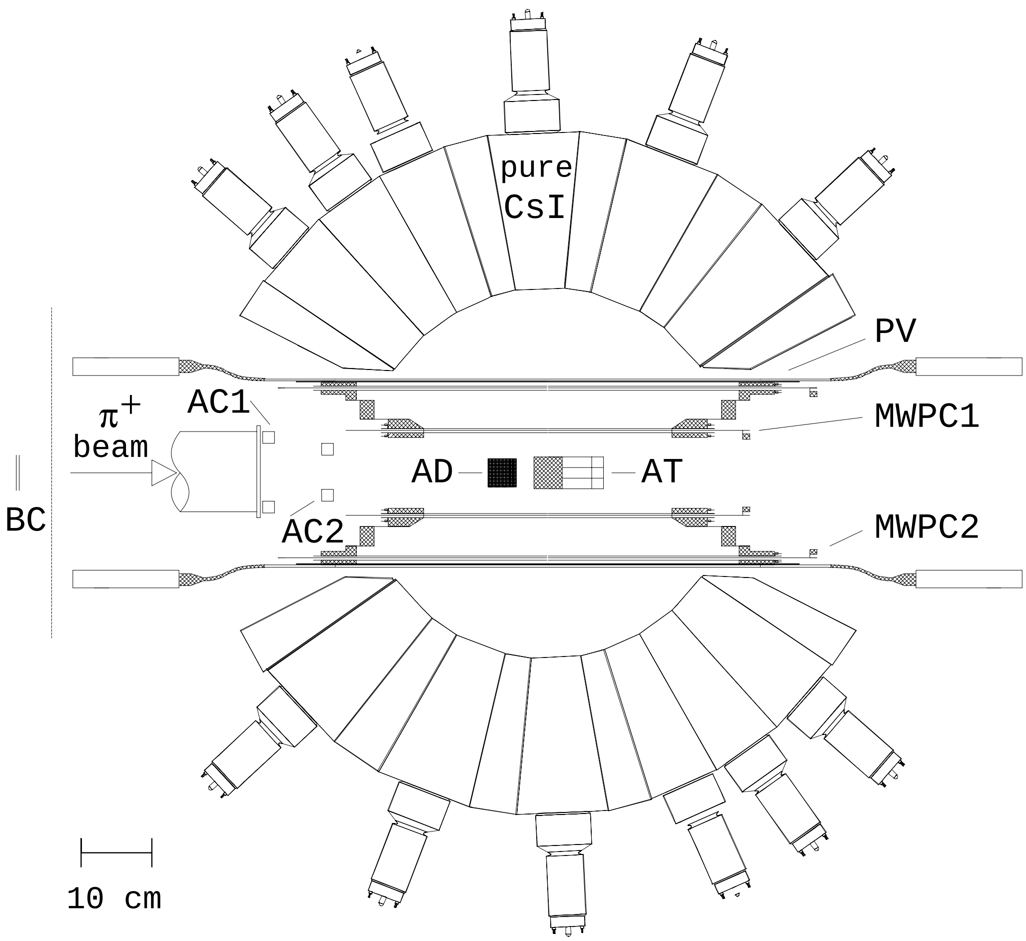

Figure 1: Schematic cross section of the PIBETA apparatus showing the main components: beam entry counters (BC, AC1, AC2), active degrader (AD), active target (AT), wire chambers (MWPCs) and support, plastic veto (PV) detectors and PMTs, pure CsI calorimeter and PMTs.

much as 23°, and have a continuous energy spectrum between 55 MeV and 83 MeV. This decay mode will present the main source of backgrounds for the experiment, but it will also provide data for time and energy calibrations of the detector, and will serve as a monitor of the total π^0 yield.

The 129.4 MeV photons from radiative capture on hydrogen will serve as another, higher energy calibration point for the detector. The Dalitz decay $\pi^0 \to \gamma e^+ e^-$, on the other hand, will provide a check of the time response at energies down to a few MeV.

The experiment will be carried out in the πE1 beam line at PSI, using a beam of 90–114 MeV/c negative pions stopped near the center of the PIBETA detector system, briefly described below.

2.2. The PIBETA spectrometer

The liquid hydrogen target will be placed centrally in the PIBETA detector, replacing thus the standard plastic scintillator active target. All remaining parts of the PIBETA detector will be operated in the same manner as in the previous measurements of the pion beta decay.

A schematic cross section of the PIBETA detector is shown in Fig. 1. The PIBETA apparatus is a large solid angle non-magnetic detector optimized for measurements of photons and electrons in the energy range of 5–150 MeV. The main sensitive components of the apparatus, shown and labelled in Fig. 1, are:

1. a passive lead collimator PC, a thin forward beam counter BC, two cylindrical active collimators AC1 and AC2, and an active degrader AD, all made of plastic scintillator, used for the beam definition;
2. a segmented active plastic scintillator target AT, used to stop the beam particles and sample lateral beam profiles;
3. two concentric low-mass cylindrical multi-wire proportional chambers, $MWPC_1$ and $MWPC_2$, for charged particle tracking, surrounding the active target;
4. a segmented thin plastic scintillator hodoscope PV surrounding the MWPCs used for particle identification and charged track timing;
5. a high-resolution segmented fast shower CsI calorimeter surrounding the target region and tracking detectors in a near-spherical geometry;
6. cosmic muon plastic scintillator veto counters CV around the entire apparatus (not shown in Fig. 1).

These detector components, together with the delay cables for analog signals from photomultiplier tubes, high voltage supplies, MWPC instrumentation and gas system, fast trigger and digitizing electronics, two front end computers used for data acquisition and slow control, as well as a fine temperature control system are mounted on a single platform and can be moved as one unit into the experimental area. After the detector platform is precisely positioned with respect to a beam line, providing the electrical power and Ethernet connections makes the detector operational immediately.

The thin forward beam counter BC is the first detector placed in the beam just after a narrow lead collimator, in front of the πE1 area beam magnets. In order to maximize the pion beam transmission along the length of the beam line, pions reach the central detector area with a relatively high momentum of 90–114 MeV/c where they are subsequently moderated by the active degrader AD made of Bicron BC-400 plastic scintillator. The active degrader easily identifies the events with two or more beam particles, piling up from a single or two adjacent primary beam pulses. A suitably modified “3-fold-low threshold” trigger, available in the PIBETA menu of triggers, will be used as the main trigger for the $\pi^0 \to 3\gamma$ search.

2.3. Liquid hydrogen target

A special liquid hydrogen target has been designed for the proposed experiment, and is currently being fabricated (Fig. 2). The hydrogen cell is a $100\,\mu$m thick mylar cylinder 200 mm long and 40 mm in diameter. An outer chamber made of 10 mm thick styrofoam of $100\,\mathrm{mg/cm^3}$ density surrounds the hydrogen cell. We plan to use a closed-cycle helium refrigerator (Displex Model CSW-208L) to cool the hydrogen. A liquification test is planned for January 2003.

The helium compressor will be located a few meters away from the spectrometer outside the shielding house and connected to the expansion module by means of flexible pressure hoses. Several devices of this type exist at PSI; a fully operational one has been identified and tested without hydrogen.

The amount of liquified hydrogen needed is about $300\,\mathrm{cm^3}$, corresponding to about $0.28\,\mathrm{m^3}$ of gas at normal temperature and atmospheric pressure. We plan to operate the target such that the hydrogen flask will be permanently connected to an expansion volume of about $0.4\,\mathrm{m^3}$ outside the spectrometer. Filling this volume with hydrogen gas of about 1.6 bar (abs.) prior to cooling allows us to liquify as much hydrogen as is required for filling the flask without reducing the final system pressure below 1 atmosphere (abs.). In this way hydrogen is always kept above atmospheric pressure, thereby preventing air from leaking in, and thus reducing the danger of explosion. In case of loss of cooling power no special device is needed to handle rising gas pressure as the gas simply expands back into the expansion volume.

Gas sensors will be mounted inside and outside the spectrometer to signal leaking hydrogen. We plan to install a forced ventilation system inside the spectrometer housing which should be triggered by a gas alarm to quickly extract leaking hydrogen gas. After gaining some experience in mounting the target we will decide (jointly with experienced technicians at PSI) whether to allow the insertion of the cold hydrogen filled target into the spectrometer, or, to plan for an empty insertion with cooling down after the target is already in place. This precaution is justified as the insertion is likely the most delicate operation with the target. (We are aware of the explosion at LAMPF several years ago which happened during the insertion of a liquid hydrogen target into an apparatus.)

2.4. Pion stopping efficiency

The design of the target flask was accompanied in parallel by Monte-Carlo simulations. Here are some of the main results.

Keeping the same pion beam momentum, momentum spread, and the same degrader setup as for the pion beta decay measurement, would result in a pion stopping efficiency of $\simeq 55\,\%$. The pion stop distribution would in this case peak close to the downstream end of the flask. The stopping distribution would be approximately Gaussian along the beam axis, with a σ of 1.3 cm.

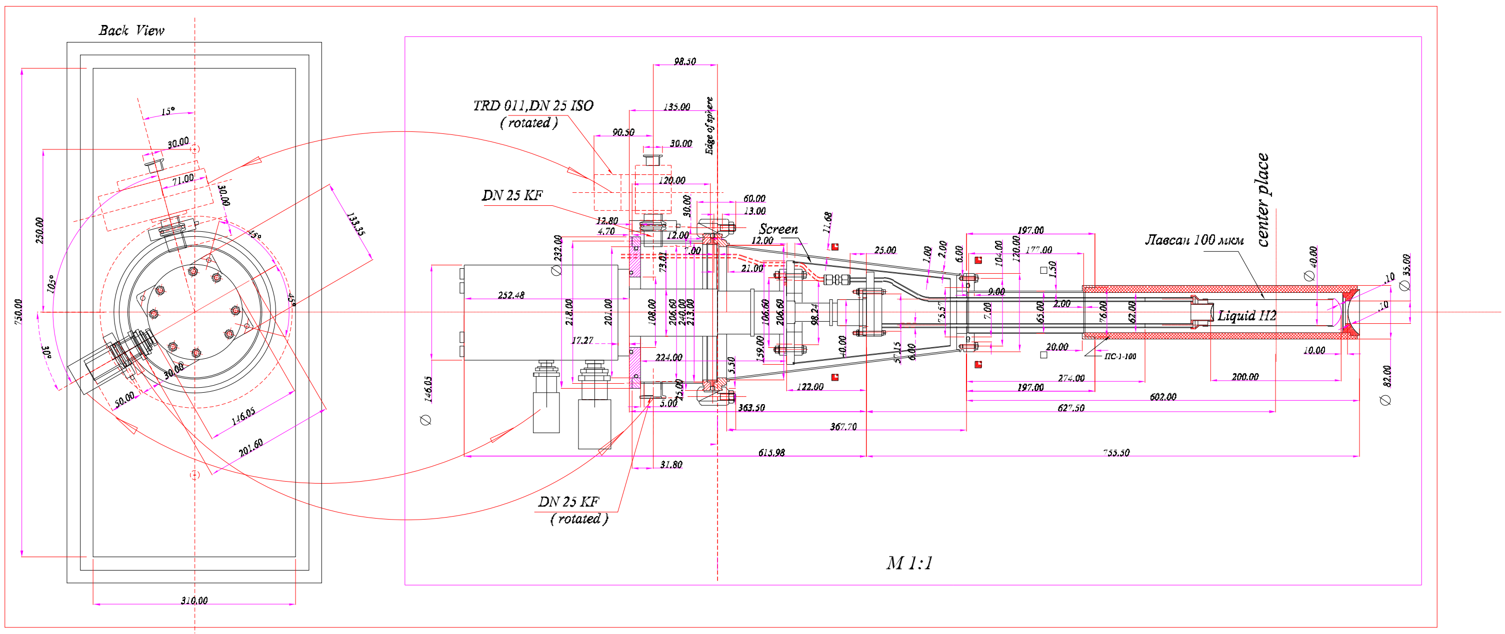

Figure 2: Schematic drawing of the proposed liquid hydrogen target.

A preferable experimental arrangement involves making the upstream target vacuum window of 1.4 cm thick beryllium instead of mylar. This would provide an additional thickness of inactive degrader and increase the stopping efficiency, broadening, however, the axial stopping distribution ($\sigma_z = 1.5$ cm).

Another way to increase the pion stopping efficiency is by reducing the beam momentum to ~ 99 MeV/c ($\sigma_p/p = 1\,\%$). In this case some 95 % of the pions are stopped in the target. The center of the resulting π^- stopping distribution (Gaussian, with $\sigma \simeq 1.1$ cm) is located at 3 cm from the upstream wall of the target. Fig. 3 depicts the beam momentum dependence of the π^- stopping rate, as well as of the center of the stopping distribution. Further simulations with improved geometrical details and measured beam parameters are under way.

It is clearly possible to achieve a sufficiently high pion stopping efficiency in the liquid hydrogen target by selecting an appropriate combination of the beam momentum and degrader thickness. Optimizing these parameters, while keeping backgrounds down, is one of the aims of the requested test beam time.

2.5. Expected Rates

The PIBETA spectrometer is equipped with a flexible trigger system which is described in detail in Ref. [13]. Its most important feature is the ability to trigger on an isolated cluster of CsI crystals hit by a shower originating from a photon/electron interaction in one of the crystals. The summed cluster energy can be discriminated with low and high thresholds in parallel. The trigger is programmable and it can fire on a single cluster, on two isolated and on three isolated clusters simultaneously, with flexible Hi/Lo threshold settings and prescaling (abbreviated to: 1L, 1H, 2L, 2H, 3L and 3H triggers, respectively). The 3L trigger is the most suitable one for the detection of the 3γ events, while a prescaled 2H trigger will be used to record predominantly single π^0-decays used for normalization.

We have simulated the detection efficiency of $\pi^0 \to 3\gamma$ events by the 3L trigger for various threshold settings. Results of our simulations are presented in Table 1. With a threshold set to 35 MeV for each cluster the efficiency is still about 5 %.

One source of the 3L triggers will be events with two π^-'s in a single accelerator bunch, each producing a π^0 in the hydrogen. For an incident beam rate of $3 \times 10^5 \pi^-$/s the probability for such an event is 0.0022 and therefore the 3L trigger must cope with a rate of $\sim 700\,\mathrm{s}^{-1}$. This rate will be reduced by setting an upper threshold discriminator on the analog signal from the active degrader which would give a pulse height twice as high as for a single pion. Experience from our previous measurements with the PIBETA detector indicates that an online reduction factor of 10–20 can be easily accomplished, thereby reducing the rate of recorded triggers to below 50 Hz.[†]

Single $\pi^0 \to 2\gamma$ decays have a 3L trigger acceptance of only 2×10^{-5} for a cluster threshold of 20 MeV, and will therefore contribute negligibly to the trigger rate.

[†]We have operated the detector up to 100 Hz successfully, though at the expense of a considerable increase in the dead time.

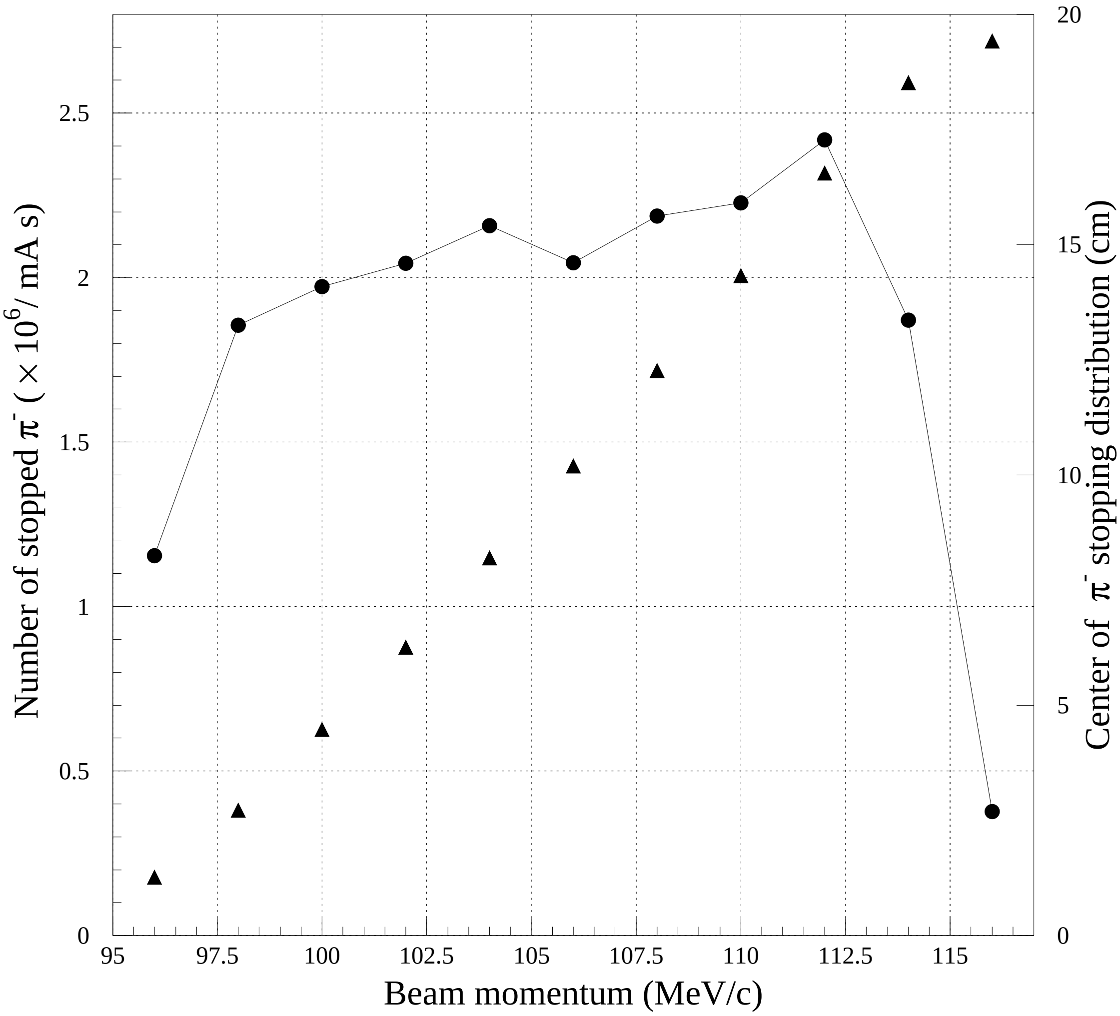

Figure 3: Monte Carlo calculated π^- stopping rate (per mA of primary proton beam) in the liquid hydrogen target (solid circles, left ordinate), and the corresponding center of the axial stopping distribution in cm (solid triangles, right ordinate). The data points for the π^- stopping rate are connected by lines to guide the eye. Optimum is achieved in the neighborhood of $p(\pi^-) \simeq 98 - 100\,\mathrm{MeV/c}$.

Table 1: Detection efficiency of the $\pi^0 \to 3\gamma$ decay with the 3-arm low threshold (3L) PIBETA trigger as a function of threshold energy and θ_{ij}, the angle between any two clumps. We have used the matrix element $|M|^2$ from the work of Berends [3]. Results don't change significantly for $|M|^2 = 1$. The angle between the two clumps with maximum energy was constrained to be $< 145°$. For comparison, the last column lists the Monte Carlo calculated detection efficiency of $\pi^0 \to 2\gamma$ decay detection with the PIBETA 3L trigger as a function of threshold energy.

Thresh. (MeV)	θ_{ij} $> 20°$	θ_{ij} $> 25°$	θ_{ij} $> 30°$	θ_{ij} $> 40°$	θ_{ij} $> 50°$	θ_{ij} $> 60°$	$\pi^0 \to 2\gamma$ Det. Eff.
5	0.1845	0.1842	0.1840	0.1832	0.1796	0.1694	
8	0.1713	0.1711	0.1710	0.1706	0.1681	0.1596	$1.0 \cdot 10^{-2}$
10	0.1646	0.1644	0.1644	0.1640	0.1622	0.1542	$5.6 \cdot 10^{-4}$
15	0.1558	0.1557	0.1556	0.1554	0.1537	0.1466	$7.0 \cdot 10^{-5}$
20	0.1437	0.1436	0.1435	0.1433	0.1419	0.1358	$2.0 \cdot 10^{-5}$
25	0.1207	0.1206	0.1206	0.1204	0.1194	0.1145	
30	0.0833	0.0833	0.0833	0.0832	0.0825	0.0795	
35	0.0406	0.0406	0.0406	0.0406	0.0403	0.0398	
40	0.0115	0.0115	0.0115	0.0115	0.0115	0.0111	
45	0.00147	0.00147	0.00147	0.00147	0.00147	0.00147	

Dalitz decays ($\pi^0 \to ee\gamma$), on the other hand, have an acceptance in the 3L trigger only about an order of magnitude lower than that for the 3γ events. Thus their rate in the 3L trigger has to be suppressed by inclusion of a charged particle veto condition in the trigger logic.

In addition to both mentioned triggers (2H and 3L, respectively) we plan to record other events like 1H triggers (mainly from the reaction $\pi^- p \to \gamma n$), cosmic ray events, and random triggers, all properly prescaled for calibration purposes, as we have done for the PIBETA experiment.

The standard PIBETA trigger logic is based on 20 "supercluster" (SC) signals (10 high-threshold and 10 low-threshold), optimized for the pion beta decay measurement. The $\pi^0 \to 3\gamma$ search may require a more granular trigger, one based directly on the 120 cluster signals (60 low-, and 60 high-threshold), which currently serve as inputs to the SC signals. This modification is technically feasible, but would require additional trigger logic modules.

2.6. Backgrounds

A full treatment of backgrounds for the proposed experiment will not be given here. In this letter of intent we intend merely to argue the feasibility of the proposed experimental search in principle, leaving the full accounting of the backgrounds for the final proposal.

Two main background processes were identified in the LAMPF experiment:

- Random coincidences between a $\pi^0 \to 2\gamma$ decay with another process producing one or two high energy photons, predominantly another π^0 decay.
- $\pi^0 \to 2\gamma$ decays that produced three clumps when a secondary photon from one of the initial γ showers interacted far enough from the primary clump to appear as a third clump ("split-photon" events).

In order to quantify the effect of random events we have simulated the detector response for the most serious case of two simultaneously decaying π^0's. We generated a sample of 10^8 events and subjected them to the following selection criteria:

- The 3L trigger with a threshold of 5 MeV on each cluster was fired.
- The total energy deposited in the calorimeter was below 200 MeV.
- The energy deposited in the veto counters of the calorimeter was < 5 MeV.
- No hit was registered in any of the wire chambers.
- Each of the three clumps contained between 10 and 100 MeV of shower energy.

Two further event selection criteria were applied to all 17720 events surviving the above cuts:

- All clump–clump angles must be smaller than $150°$. This condition removes events showing the typical decay pattern of the almost collinear $\pi^0 \to \gamma\gamma$ decays.
- The norm of the vector sum of the three clump momenta must be below 50 MeV/c, since $p(\pi^0)$ at its decay is 28 MeV/c.

Fig. 4 shows the invariant mass spectrum taken from all 3-clump events surviving all of the above selection criteria. Only two events remain in the region of the pion mass, leading to an offline suppression of pileup events of 2×10^{-8}. This suppression, when combined with the pileup probability given by the incident beam rate of $3 \times 10^5\ \pi^-/\mathrm{s}^{-1}$, a π^0 production branching ratio of 0.61 and the 50 MHz primary beam time structure, leads to a probability $< 10^{-10}$ for a fake $\pi^0 \to 3\gamma$ event due to two simultaneously decaying π^0's. This probability can be further reduced by analyzing the signal amplitude of the active degrader which should be twice as large for pile-up events as for single pions. Therefore pileup induced background of this type seems to be well controlled. Random coincidences of other π^0 decay channels are less serious due to their smaller branching ratios, and should therefore be negligible.

A more serious background will arise from the so-called "split-photon" events, caused by a single photon producing two isolated clumps in the calorimeter instead of one, making a single $\pi^0 \to 2\gamma$ decay simulate a 3γ decay. This type of background limited the LAMPF experiment's sensitivity and is difficult to simulate reliably at the required precision (in principle one would have to run a full detector Monte-Carlo program with about 10^{11} events). Several cuts can be applied to eliminate split-photon events from the data, such as a minimum clump energy cut, a minimum distance required between the two lowest energy photons and a restrictive cut on the timing of the clumps.

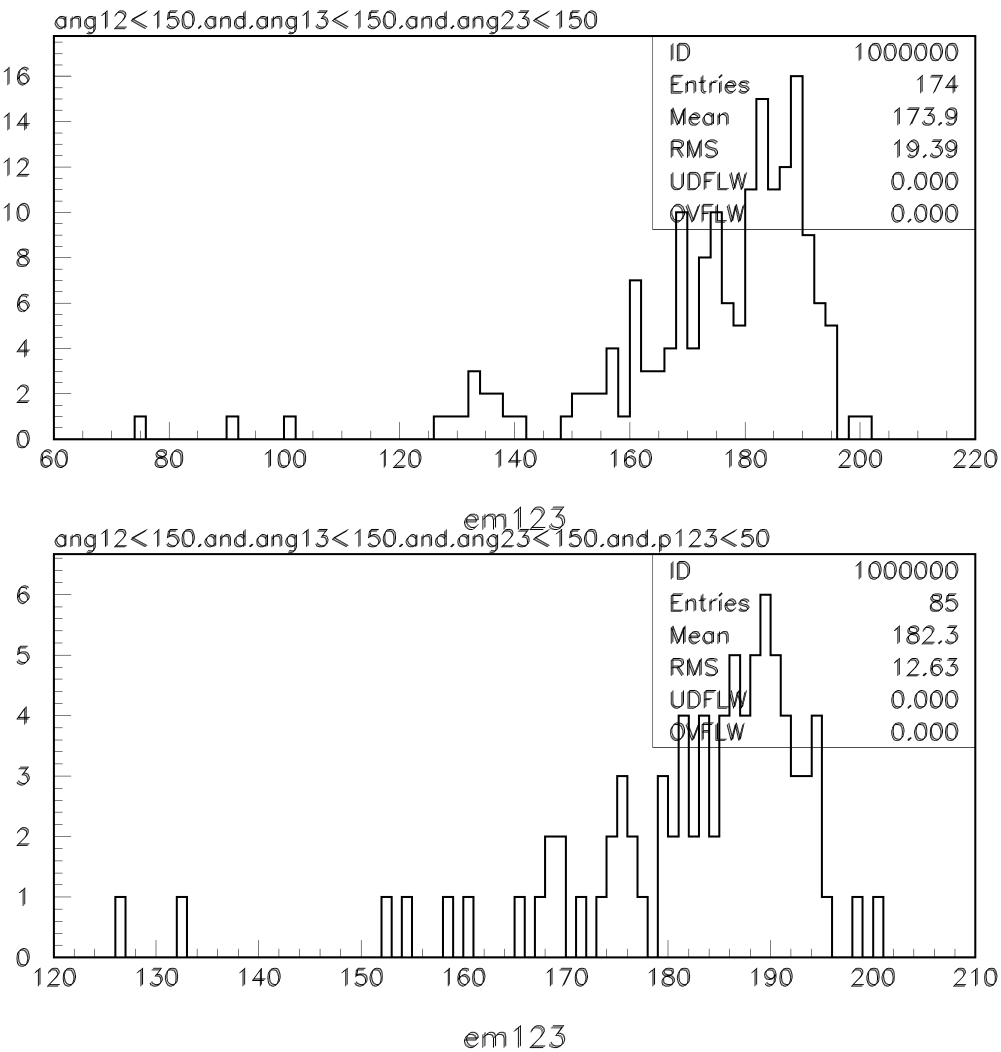

Figure 4: Invariant mass plots for 3-clump events in the $\pi^0 \to 2\gamma$ Monte Carlo simulation surviving $\pi^0 \to 3\gamma$ event selection cuts. See text for detailed explanation of cuts.

In coping with the split-photon background we plan to rely on the following. First, this background is proportional to the beam intensity I_π instead of I_π^2 like the random background. Therefore, our higher beam rate compared to the LAMPF experiment should not aggravate this background problem. Second, the shorter radiation and Molière lengths of CsI reduce the mean free path of secondary photons and lateral shower spreading. Finally, in principle the timing resolution of the CsI crystals is better than for NaI crystals, hence making the timing cut more effective.

Nevertheless, we regard the split-photon event background as the most serious one. Table 1 demonstrates the great latitude available in the θ_{ij} cut for suppression of "split-photon" events without much reduction of the 3γ acceptance. The best approach to gain a reliable quantitative measure of the effect is a test run with the full setup over a period of days to study this background under real condition.

In order to get an idea of the backgrounds we have analyzed the data recorded in a short calibration run at the end of the PIBETA 2001 running period. A $\sim 114\,\mathrm{MeV/c}$ π^- beam was stopped in the standard PIBETA active plastic scintillator target. Data were taken during about a half of a day. The π^- beam rate was $\sim 3 \cdot 10^4\,\mathrm{s}^{-1}$. However, the number of π^0's produced was far lower due to predominant pion capture on the carbon nuclei in the target, while the related hadronic backgrounds were high. The results are summarized in Fig. 5.

The π^- run results in Fig. 5 illustrate some of the points already made: (a) the CsI calorimeter energy resolution is well matched to the proposed task, (b) there is virtually no accidental background in the γ–γ coincidences at these stopping rates, and (c) the third, "split" clumps do occur. However, once a simple cut is imposed on the clump–clump angle, $\theta_{ij} > 30^\circ$, all of the third-clump events were removed. Based on the accumulated sample of clean $\pi^0 \to 2\gamma$ events, we would place an upper bound on the 3γ branching ratio of several times 10^{-6} on the basis of this short run.

We note that the new measurement proposed in this document will be optimized far better for the $\pi^0 \to 3\gamma$ search than the short calibration run discussed above was.

3. Costs and Manpower

The PIBETA spectrometer exists, it is fully instrumented and ready to be used again. The main modifications required for the $\pi^0 \to 3\gamma$ search are (a) the replacement of the standard active plastic scintillator target by the new hydrogen target, and (b) an upgrade of the trigger electronics.

The hydrogen flask and vacuum chamber are being built by the Dubna collaborators, while a refrigerator is readily available at PSI. The trigger electronics upgrade will be undertaken by UVa group. In this way the collaborating institutions will bear the cost of the required new construction.

The running costs of the experiment consist only of the normal operating expenses. For typical PIBETA running of about 8 months per year they amounted to $\sim 40\,\mathrm{kCHF}$ annually. Since the running time for the proposed $\pi^0 \to 3\gamma$ search is shorter, the operating expenses should be somewhat lower.

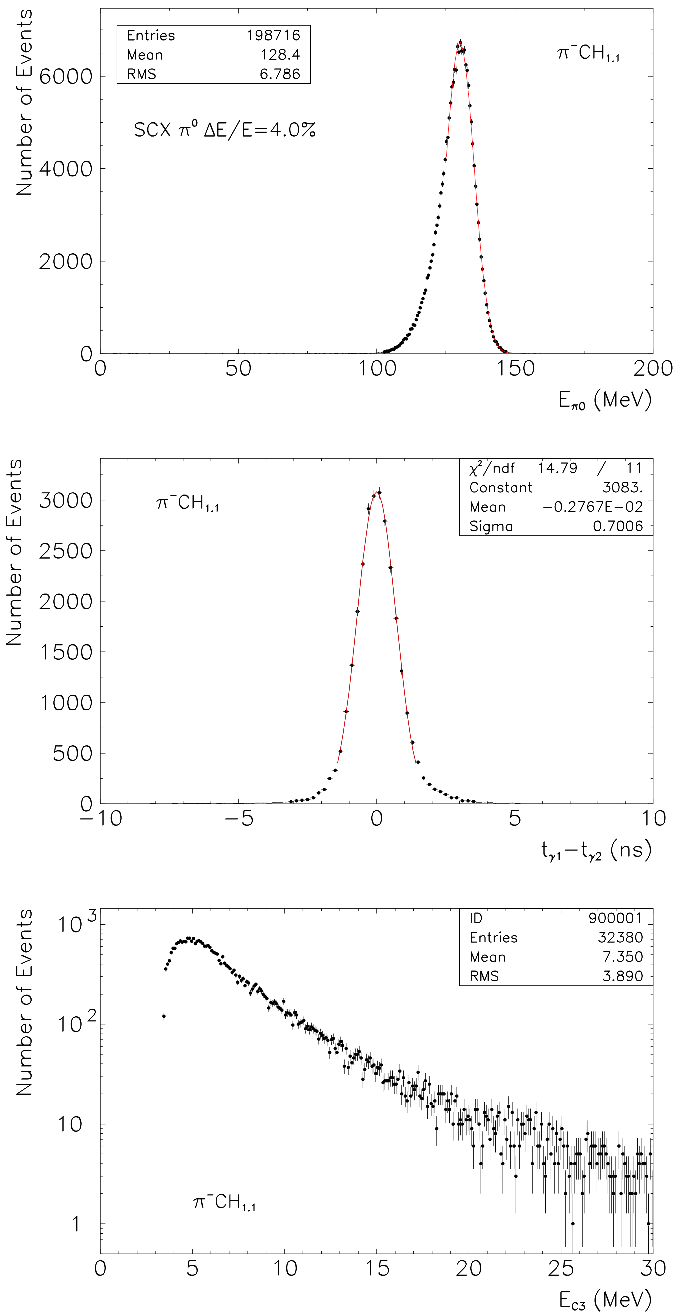

Figure 5: Partial results of a short test run with a π^- beam in the standard PIBETA setup (see text for details). Shown are: the total energy spectrum of the $\pi^-\mathrm{CH}_{1.1} \rightarrow \pi^0 n$ (top panel), the γ_1–γ_2 time difference spectrum (middle panel), and the spectrum of energy contained in the third clump, when detected (bottom panel).

Manpower requirements peak during the hydrogen target and spectrometer setup, when 6-8 experienced physicists/technicians are required. Less on-site manpower is needed to run the experiment as most of the spectrometer operation is automated and can be controlled remotely. For example, during 2001 this collaboration ran for over 8 months, mostly with just two physicists present at PSI, with continuous remote control from Virginia. Thus, the current collaboration provides adequate manpower for the task at hand.

4. Summary

The excellent performance of the PIBETA spectrometer makes it possible to pursue a significant improvement of experimental limits on rare and forbidden decays of pions and muons with little additional effort. The decay $\pi^0 \to 3\gamma$ with its 3-body final state appears to be particularly well suited to a study using the PIBETA detector system.

Our calculations indicate that a significant improvement in efficiency compared with the best experiment to date (at LAMPF) may be possible. This improvement, combined with the gain in accelerator duty cycle by a factor of ~ 20, leads us to expect to be able to improve the existing sensitivity in $\pi^0 \to 3\gamma$ by up to two orders of magnitude. According to simulations made with Monte-Carlo programs well calibrated in the analysis of the PIBETA experiment data, random coincidence background seems to be under control even with an almost 10 times higher beam rate envisaged. The split-photon background, the limiting factor in the Los Alamos experiment, is not expected to worsen at higher beam intensity. In addition, the favorable performance characterstics of the PIBETA spectrometer should help to keep it at an acceptable level. However, quantitative determination of this background should be addressed in a dedicated test run which we would like to make in 2003.

5. Beam time estimate

For the first step of this project we need 5 weeks of beam time in the πE1 beam area in the second half of 2003.

6. Technical requests of PSI

We kindly request the use of the DISPLEX closed-cycle refrigeration system, model CSW-208L.

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