JLAB USER GROUP

Jefferson Lab PAC15
Proposal Cover Sheet

This document must be received by close of business Thursday, Dec 17, 1998 at:

Jefferson Lab
User Liaison,
Mail Stop 12B
12000 Jefferson Ave.
Newport News, VA
23606

Experimental Hall: C

Days Requested for Approval: 7

Proposal Title:

Direct Measurement of the Lifetime of the Heavy Hypernuclei at CEBAF

Proposal Physics Goals

Indicate any experiments that have physics goals similar to those in your propos

Approved, Conditionally Approved, and/or Deferred Experiment(s) or proposals:

Update to the originally approved E95-002

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Jefferson Lab Use On

Receipt Date: 12/16/98 PR 99-003

By: [redacted]

BEAM REQUIREMENTS LIST

JLab Proposal No.: E95-002 Date: 12/17/1998

Hall: C Anticipated Run Date: 7 PAC Approved Days: 7

Spokesperson: L. Tang/A. Margaryan Hall Liaison: Rolf Ent
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List all combinations of anticipated targets and beam conditions required to execute the experiment. (This list will form the primary basis for the Radiation Safety Assesment Document (RSAD) calculations that must be performed for each experiment.)

Condition No.	Beam Energy (MeV)	Mean Beam Current (μA)	Polarization and Other Special Requirements (e.g., time structure)	Target Material (use multiple rows for complex targets — e.g., w/windows)	Material Thickness (mg/cm²)	Est. Beam-On Time for Cond. No. (hours)
1	1600 - 2000	10	CW	Target: Bi	2 mg/cm	98 hours
				Window: Al	0.4 mm	98 hours
			Target backing: ~~at~~ Be		0.001 mm	98 hours

The beam energies, E_{Beam}, available are: $E_{Beam} = N \times E_{Linac}$ where N = 1, 2, 3, 4, or 5. E_{Linac} = 800 MeV, i.e., available E_{Beam} are 800, 1600, 2400, 3200, and 4000 MeV. Other energies should be arranged with the Hall Leader before listing.

HAZARD IDENTIFICATION CHECKLIST

JLab Proposal No.: E95-002 (For CEBAF User Liaison Office use only) Date: 12/17/1998

Check all items for which there is an anticipated need.

Cryogenics ___ beamline magnets ___ analysis magnets ___ target type: ___ flow rate: ___ capacity: ___	**Electrical Equipment** ___ cryo/electrical devices ___ capacitor banks ___ high voltage ___ exposed equipment +370V/-100V inside the Low pressure chamber	**Radioactive/Hazardous Materials** List any radioactive or hazadorous/ toxic materials planned for use: ___
Pressure Vessels ___ inside diameter ___ operating pressure ___ window material ___ window thickness	**Flammable Gas or Liquids** type: Heptane flow rate: 0 capacity: < 5 cc **Drift Chambers** type: ___ flow rate: ___ capacity: ___	**Other Target Materials** ___ Beryllium (Be) ___ Lithium (Li) ___ Mercury (Hg) ___ Lead (Pb) ___ Tungsten (W) ___ Uranium (U) ✓ Other (list below) Bi
Vacuum Vessels 14" inside diameter 1·1 Torr operating pressure Al window material 0·4 mm window thickness	**Radioactive Sources** ___ permanent installation ___ temporary use type: ___ strength: ___	**Large Mech. Structure/System** ___ lifting devices ___ motion controllers ___ scaffolding or ___ elevated platforms
Lasers type: ___ wattage: ___ class: ___ Installation: ___ permanent ___ temporary Use: ___ calibration ___ alignment	**Hazardous Materials** ___ cyanide plating materials ___ scintillation oil (from) ___ PCBs ___ methane ___ TMAE ___ TEA ___ photographic developers ___ other (list below)	**General:** Experiment Class: ___ Base Equipment ✓ Temp. Mod. to Base Equip. ___ Permanent Mod. to Base Equipment ___ Major New Apparatus Other: ___

LAB RESOURCES LIST

JLab Proposal No.: E95-002 Date 12/17/98

(For JLab ULO use only.)

List below significant resources — both equipment and human — that you are requesting from Jefferson Lab in support of mounting and executing the proposed experiment. Do not include items that will be routinely supplied to all running experiments such as the base equipment for the hall and technical support for routine operation, installation, and maintenance.

Major Installations *(either your equip. or new equip. requested from JLab)*

Remove standard Hall C target chamber and install the LPMWPC chamber onto Hall C pivot.

New Support Structures:

Data Acquisition/Reduction

Computing Resources:

New Software:

Major Equipment

Magnets:

Power Supplies:

Targets:

Detectors:

Electronics:

Computer Hardware:

Other:

Other:

Update for E95-002:
Direct Measurement of the Lifetime of the Heavy Hypernuclei at CEBAF

to PAC15 at Jlab

Updated Collaboration

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Abstract

In this document, we are presenting a brief updated view to this previously approved experiment. We will give a brief revisit to the physics goals and a view of the applied technique and method of this experiment. We will also give an update to its plan of action on carrying out the experiment. It will followed by an update on these type of experiments carried out elsewhere after E95-002 was approved at Jlab. A comparison is then given to justify that E95-002 is still an unique experiment which has some significant advantages to all other technique at any other facility.

Background of Physics for E95-002

The lifetime of heavy Λ hypernuclei is a specially interesting subject from the viewpoint of the weak decay mechanism of the Λ in a nucleus. High precision measurements of hypernuclear lifetimes and their A dependence will provide valuable constraints in attempts to understand many fundamental issues in hypernuclear physics. Such open issues are the effective YN interaction mechanisms and range; $\Lambda N \rightarrow \Sigma N$ conversion; and the ΛNN three body interactions. At the quark level, Pauli blocking may lead to an observable deviation from the expected A dependence of the hypernuclear lifetime as calculated by conventional hadronic models, especially in the very high mass region.

It is commonly believed that only the lifetimes of very light Λ hypernuclei are dominantly determined by the mesonic decay, $\Lambda \rightarrow \pi + N$ (+40 MeV). As the mass of the hypernucleus increases, the rate of the nonmesonic decay, $\Lambda N \rightarrow N + N$ (+176 MeV) increases while that of mesonic decay decreases rapidly because of Pauli suppression of the low momentum final state nucleons. Thus, it is generally believed that the lifetime of Λ hypernuclei is a decreasing function of mass number A. However, the effective YN interaction range may change this description, i.e. additional nucleons may appear to have no effect upon the lifetime of hypernuclei as A reaches a certain level. The very limited data seems to have such suggestion (see later discussion). Theoretically, it is still unclear why should not the lifetime of hypernuclei differ significantly from that of a free Λ.

The $\Delta I = 1/2$ rule, until now, is still a key constrain to build up the model for hadronic weak decays. Such rule was empirically obtained from the pionic decay of kaons and then observed also in the mesonic decay of free Y. The origin of the rule is unclear nor suggested by the standard model. Many studies have hinted that $\Lambda N \rightarrow NN$ decay will be a powerful tool to study the weak decay involving purely the baryons and observe a violation of such rule. Many references can be found from Ref.1. A lifetime of heavy hypernuclei which is dominated by such decay will give important information for further theoretical investigation.

In very heavy hypernuclei, partial deconfinement may require that the u and d quarks in the Λ be antisymmetrized with the nonstrange quarks in the neighboring nucleons so that observable effects, such as isospin mixing in hypernuclei or modification of the mesonic decay rate in the nuclear medium, may occur. The partial widths of different decay modes and the A dependence are subjects of many theoretical investigations [2-18].

A high precision hypernuclear lifetime measurement for various masses, especially in the heavy region, is necessary and important. However, the available data before approval of E95-002 were scarce and extremely poor in quality (about 100% relative error in most of cases), and virtually no data was available for A>16 (see figures in the original proposal). Recently, two experiments used proton beam on both Bi and U targets without kaon tagging and positive pion beam on C, Si, and Fe targets using (π^+,K^+) reaction were carried out at Julich [19] and KEK [20], respectively. It will be discussed in more detail in a comparison to E95-002 later in this report.

Background of the experiment E95-002

Exp95-002 is designed to carry out a direct measurement of the lifetime of heavy Λ hypernuclei by fully utilizing the unique features of the CEBAF beam (2 ns beam bunch spacing and 1.67 ps bunch width) and a fission fragment detection technique. Since the hypernuclei will be produced by $(e,e'K^+)$ reactions, this experiment is designed to ensure Λ production once a kaon has been detected near production threshold by the SOS spectrometer. Since the nonmesonic decay of the Λ hypernuclei, in which a large amount of energy (176 MeV) is released, dominantly determines the lifetime, the probability of a time-delayed fission ($\sim 10^{-10}$ sec) due to Λ hypernuclear decay is sufficiently high to use fission as a gate for the hypernuclear decay. Thus, a coincidence detection of a kaon and fission fragments will select the production and decay of a Λ hypernucleus unambiguously [21].

The delayed fisson due to nonmesonic hypernuclear decay features by releasing a pair of heavy fission fragments in a binary mode. The fragments will be detected by a Low Pressure MWPC chamber system (LPMWPC) mounted around the target. Fig.1 shows the schematic layout of the system and experimental principle. The detected kaon will be used to select the event in coincidence with fission and, more importantly, to reconstruct the correct beam bucket during which the hypernucleus was produced. The SOS system has demonstrated excellent beam bucket reconstruction capability with a timing resolution of about 130 ps in RMS. Since the beam bunch width is only 1.67 ps, the reconstructed beam bucket provides an absolute zero time for the production of a Λ hypernucleus. The kaon momentum will be used to select the hypernuclear excitation energy range as discussed in the original proposal of E95-002. The LPMWPC has excellent position and timing resolution, sensitive only to the desired Z range of fragments, and has about 100% detection efficiency. Fig.2 shows a single LPMWPC plane (or unit) composition. Fig.3 shows the readout method for timing from anode plane and for position from the cathode planes in one unit. With high count rate capability and radiation resistance, the position

and timing information provided by a double unit system will allow reconstruction of actual decay time with respect to the production beam pulse. Overall timing resolution for the decay time will be about 210 ps in FWHM. In addition, the prompt fission time spectra from various channels are measured simultaneously, providing an accurate determination of the prompt fission background shape and an accurate absolute time-zero measurement to cancel almost all possible systematic errors. With a statistics of about or more than a total of 1000 events, the lifetime extraction accuracy can be about ±7 ps (<5%). Finally, the measurement of the complete coordinates (positions and timings) at the four separated units allow us to fully reconstruct the information such as the mean velocity (V_{rms}) and kinematics folding angle of the fission fragments. The measurement of V_{rms} of the fragments from the fission event provides us a determination of the final state hypernuclear mass by [22]

$$M = [0.498\, Z/V_{rms}]^{3/2}, \qquad \text{where} \quad Vrms = [V_1\, V_2]^{1/2}$$

with an accuracy of $\Delta A \approx 1$. The measured distributions of velocities and folding angles can allow us to investigate the branching ratio of Γ_n/Γ_p.

Status of the experiment E95-002 and its preparation

This experiment was approved by PAC10 for 7 days of beam with a rating of B for Bi target only. This experiment will serve as a feasibility test of such technique. Because this is a new technique in such study, the collaboration took a stepped approach in completing its preparation and experiment.

Step I - Prototype

A small scale LPMWPC was built and tested. From this work we identified its characters, design parameters for the real device, and fast amplifier technique. Also, we have carried out a series of Monte Carlo simulations to optimize the LPMWPC design.

Step II - Construction of real LPMWPC and source test

Based on the tests on the prototype, we have completed construction of the real experimental device, LPMWPC fission fragment detector system. Fig.4 shows pictures of the wire chamber array layout on the construction and test bench. This MWPC system was then mounted into a vacuum chamber with a low pressure gas control and monitor system.

It was then tested by mounting a Cf-252 fission source at the center top inside and vacuum chamber. We have studied the timing resolution as a function of pressure. A single plane resolution of $\sigma_t \approx 90$ ps was obtained at a pressure of about 1.3 Torr. Fig.5

shows the rescontruction timing resolution by two LPMWPC planes. Since all planes are made identical, the single plane timing resolution is reduced by a factor of 1.4. In the actual experiment, the rescontruction timing resolution will represent that for single arm on one fragment. The decay time is determined by two arm average, thus the overall resolution is about $\sigma_t \approx 90$ ps. The position resolution is about $\sigma \approx 256$ μm which is more than 10 times smaller than the readout wire group spacing (3 mm) using delay line technique (see Fig.6). These results satisfied our experimental condition. Detailed discussion of the test results can be found in the paper which was accepted for publication by NIM [23].

Step III - Test with beam background

Currently, the completed chamber is setup in Hall C near beam dump and beam line (see Fig.7) for a test with beam background. Characters of the detector will be tested with beam background in comparison to that from the previous source test. Preliminary test was carried out during Hall C GeN experiment. 40% worse timing resolution was obtained due to the strong fringe field from the GeN polarized target. Thus, the test will be continued during the experiments in the first half of 1999 with various of beam intensity and background level from the experiments.

Step IV - Parasitic run with HNSS (E89-009)

Currently, the HNSS experiment is tentatively scheduled to be installed in December of 1999. In this experiment, a beam of 1.6 or 1.8 GeV and 1.7 μA current will be bent by 8 degrees by a Splitter magnet after the target with only 0.02% radiation length. This beam will go to a heavily shielded small local dump in the hall through a dump line. This dumped beam is ideal to be used to carry out a parasitic run for the lifetime measurement with the LPMWPC detector system.

The setup of LPMWPC system including cables, electronics, and trigger is already established in the hall. It can be moved directly in front of the local dump to accept the dumped beam. The LPMWPC trigger formed by its own double arms coincidence will be sent to HNSS trigger supervisor and prescaled if needed. The HNSS trigger rate is less than 100 Hz which is much lower than the capability of Hall C DAQ system.

Operation of this detector is simple. No dedicated manpower is needed to maintain its normal operation. Only check on the gas pressure once per shift is needed. The trigger rate is expected to be low at a level of 20-50 Hz with this beam current. The event size is very small since there are only 24 channels (4 timing TDCs, 16 position TDCs, and 4 dE/dx ADCs). Because the collaborations of HNSS and E95-002 are almost the same, such parasitic run will be handled properly. The events from LPMWPC will be labeled by the HNSS trigger supervisor thus the lifetime measurement events will be analyzed separately by a dedicated Ph.D. student.

No kaons will be tagged in the parasitic run, thus it will have the same experimental condition as the experiments carried out in Julich with p beam and at CERN with antiproton beam. Similar method of recoil distance will be used also in identifying the delay and prompt fission events. However, our RF timing and velocity measurement will allow us to extract the delay time spectrum directly. An off-line cut on two arm coincidence can separate real and accidentals using the 2 ns pulse separation. The technique and characters of this system, experimental method, and physics analysis will be all fully tested by this parasitic run. The lifetime of long lived nuclear systems (presumably from hypernuclear formation only) will be measured and mass of the fission system will be reconstructed.

Step V - Carry out E95-002

We are planning to carry out E95-002 in a later time after the parasitic run data is fully analyzed and understood. In the real experiment, the only difference is that a kaon is required in coincidence with the fission trigger used in the parasitic run in order to clearly identify the production of hypernuclei and its decay. The spectra will be compared.

Recent experiments on the lifetime of Λ-hypernuclei and comparison to E95-002

Since E95-002 was approved, there are two hypernuclear lifetime measurement experiments carried out at Julich and KEK. We present here a brief view of these two experiments and give a comparison to E95-002 at Jlab.

(1) Julich experiment [19]

This experiment attempted to measure the lifetime of a heavy Λ-hypernuclear system produced in bombardment of Bi and U targets with proton beam. Fission process, same as that applied in our E95-002, was used. The beam time structure does not allow a direct measurement. Thus, a recoil shadow method was used. Fragments reached the shadow area can only come from long lived systems, assumed to be hypernuclei, which can fly out of the thin target before fission due to nonmesonic decay. The event geometric distribution in the shadow region was translated into lifetime by using a theoretical model which gives the momentum distribution of hypernuclei and assumed that every event was from a hypernuclear decay. Kaons were not identified due to the rate problem, thus a hypernuclear production was not positively identified. The only verification of Λ production was done by using two different beam energies. In the lower energy case, no significant delayed fission events were seen.

The lifetime result was reported to be: $\tau \sim 145 \pm 7$ (stat) ± 23 (sys) ps for Bi and 240 $\pm$ 60 ps for U. Good statistics was obtained in the Bi measurement but the systematic

error is still large. The lifetime extraction relied on theoretical predictions on the momentum distribution of final state hypernuclei thus is strongly model dependent. Since there was no confirmation on the mass of the final state hypernuclei, no confirmation can be unambiguously made on what kind of hypernuclei the lifetime was measured. The new results are different from that obtained at CERN using the same technique, 180 ±40 (stat) ± 60 (sys) ps for Bi and 130 ± 30 (stat) ± 30 (sys) ps for U [24]. More importantly, the new measurement did not improve the quality of data in the heavy mass region (see Fig.8).

In contrast, E95-002 can measure the decay time directly with a good timing resolution and reconstruction capability from the LPMWPC system and the CEBAF beam microstructure. Hypernuclear production will be positively identified. The final state fragments were fully measured in time, position, and orientation, thus we can study the final state hypernuclear mass distribution and select and gate with the desired regions. Such complete set of information allow us to study the final state hypernuclei in more detail. Precise study of the prompt fission can accurately calibrate the time zero.

(2) KEK experiment [20]

In this experiment, lifetime of the ${}^{12}{}_{\Lambda}C$, ${}^{28}{}_{\Lambda}Si$, and ${}^{56}{}_{\Lambda}Fe$ systems was measured directly in between the production time determined by (π^+,K^+) reaction and the decay time measured by a timing spectrometer on nonmesonic decay protons. Excellent timing were obtained by both the timing spectrometer and beam counters. The spectrometer also has excellent particle identification capability which gates cleanly on the decay protons. Also, the measurement was gated to the missing mass of the produced hypernuclei. Due to the limitation on the maximum acceptable π beam, the experiment has to use 6 to 10 g/cm^2 target thickness to gain yield rate. Thus, the measurement on ${}^{12}{}_{\Lambda}C$ and ${}^{28}{}_{\Lambda}Si$ were gated in the region around ground state with a width of about 10 MeV while the ${}^{56}{}_{\Lambda}Fe$ system was gated over the entire bound region (about 24 MeV). By using the $(\pi^+,2p)$ reaction with one proton detected by the kaon spectrometer, an excellent calibration for the prompt time response was done to obtain the time response for the system and time offset. The overall timing resolution is about $\sigma = 85$ ps. The reported results are:

$$\tau\,({}^{12}{}_{\Lambda}C_{g.s.}) = 231 \pm 15 \text{ ps},\ \tau\,({}^{28}{}_{\Lambda}Si_{g.s.}) = 206 \pm 12 \text{ ps},\ \text{and}\ \tau\,({}^{56}{}_{\Lambda}Fe) = 215 \pm 14 \text{ ps}.$$

The main contribution to the error is believed mainly from statistics. Total events obtained for these three systems are only 323, 527, and 309, respectively. The results are much better in quality comparing to the existing data.

In comparison to E95-002, this experiment had a similar timing resolution. Also, the branching ration is measured. The main problem is production rate. The experiment was carried out with very long running time. A similar experiment measuring the lifetime of ${}^{208}{}_{\Lambda}Bi$ with about 250 events in the time spectrum is estimated to require more than 800 hours of beam time. No such beam time is available at KEK for the next few years until JHF 50 GeV machine is approved and becomes available. With a similar timing resolution and minimized systematic errors, the E95-002 experiment is estimated to have

even better accuracy ($\approx \pm 7$ ps) and more than 1000 events in the time spectrum in the 7 days (about 100 hours) of the approved CEBAF beam time.

Conclusion

The KEK results seem to suggest that the lifetime of Λ-hypernuclei has saturated around ${}^{28}_{\Lambda}$Si which can not be explained with the currently available theoretical model calculations for non-mesonic decay. Fig.8 shows the up-to-date lifetime data as function of mass A from Ref. 20. The solid line represent a calculation based on the one-pion and correlated two-exchange model by Itonaga [25]. It reproduced the A dependence well up to ${}^{28}_{\Lambda}$Si but not suggest a saturation even at ${}^{56}_{\Lambda}$Fe level. Another calculation (dashed line) by Ramos [26] based on pion exchange and the two-nucleon induced non-mesonic decay model fails to explain the mass dependence of the lifetime. If true, such saturation may indicate that the short range component of baryon-baryon weak interaction may be more important than has been considered. However, the combination of the new Julich data and the previous CERN data in the heavy mass region does not allow to make a definite conclusion of the lifetime behavier in A dependence (see Fig.8). Therefore, good quality data in the very heavy mass region without ambiguity is still needed in helping to understand the non-mesonic decay process.

The experiment E95-002 can carry out such task with minimum effort and excellent accuracy. Our equipment has been built and is under systematic test. The major collaborators in the KEK experiment has joined the E95-002 collaboration. Physics result can be obtained and examined even at parasitic run level. The physics result will have import impact on our current limited understanding of the unique weak interaction. Therefore, we believe that this experiment should remain as approved and be carried out timely.

Reference

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Figure Captions

Figure 1 Schematic illustration of LPMWPC system and the E95-002 experimental technique.

Figure 2 Illustration of the MWPC composition for a single unit (one anode, two cathode, and two guard planes).

Figure 3 Signal readout method for cathode (positions) and anode (timing).

Figure 4 Assembly of the LPMWPC and tests of wiring and front end electronics.

Figure 5 Timing resolution obtained by tracking the fission fragments traveled through the LPMWPC planes from a Cf-252 source mounted on top of the system but inside the low pressure chamber.

Figure 6 Position resolution obtained by tracking reconstruction of the fission fragments gone through the LPMWPC planes from the fission source.

Figure 7 A photo shows the completed LPMWPC system mounted inside Hall C near beam dump line and dump for a hall setup test using source with and without beam background.

Figure 8 Up-to-date available data for the lifetime of Λ-hypernuclei.

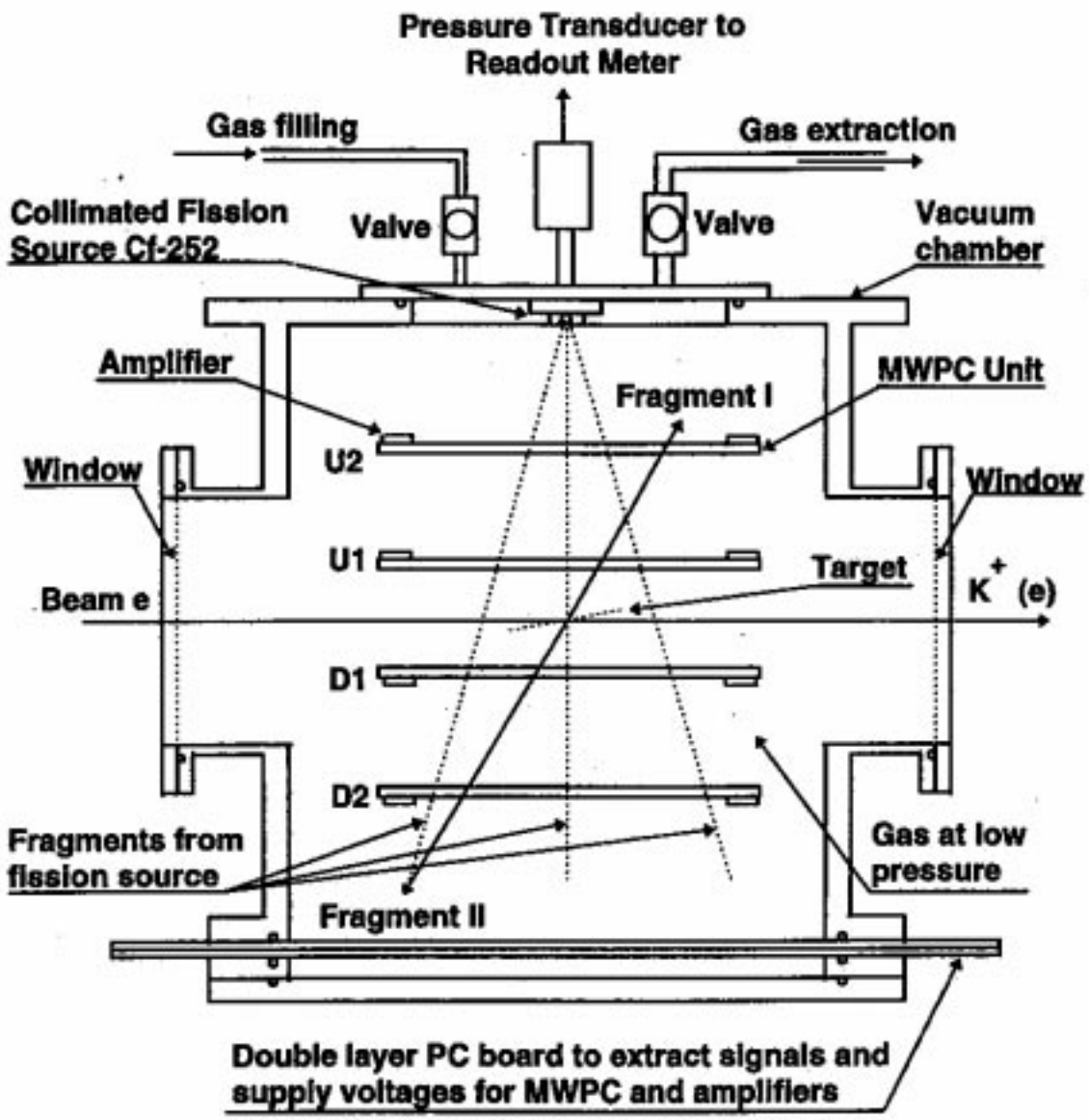

Pressure Transducer to
Readout Meter
Gas filling
Gas extraction
Collimated Fission
Source Cf-252
Valve
Valve
Vacuum
chamber
Amplifier
MWPC Unit
Fragment I
U2
Window
Window
U1
Target
Beam e
K+ (e)
D1
D2
Fragments from
fission source
Gas at low
pressure
Fragment II
Double layer PC board to extract signals and
supply voltages for MWPC and amplifiers

Figure 1

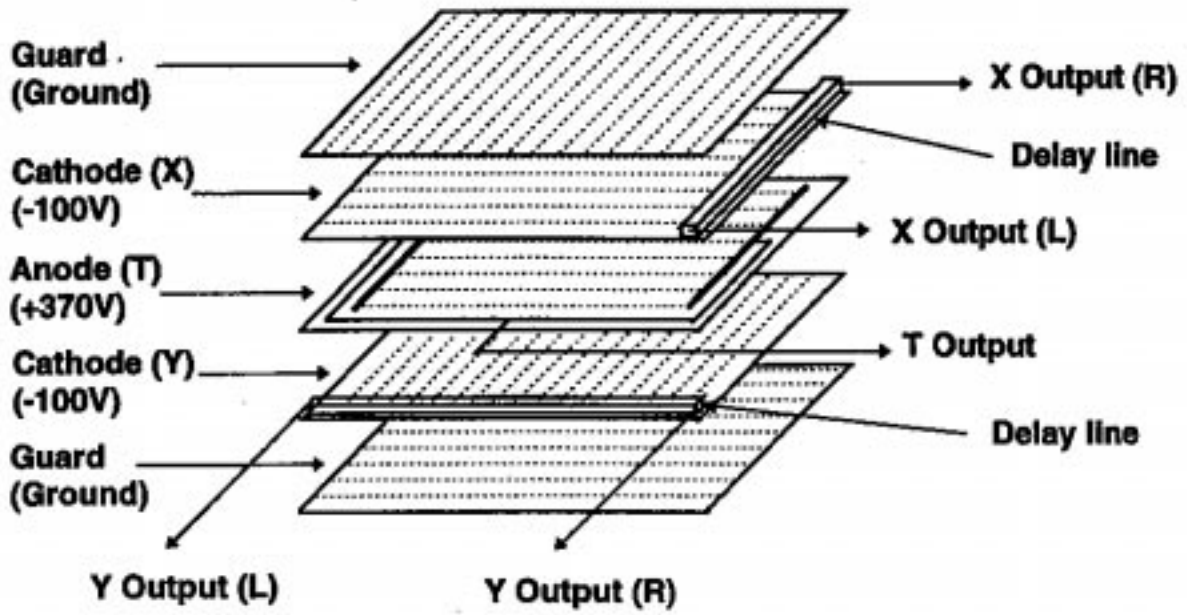

Guard
(Ground)
Cathode (X)
(-100V)
Anode (T)
(+370V)
Cathode (Y)
(-100V)
Guard
(Ground)
X Output (R)
Delay line
X Output (L)
T Output
Delay line
Y Output (L)
Y Output (R)

Figure 2

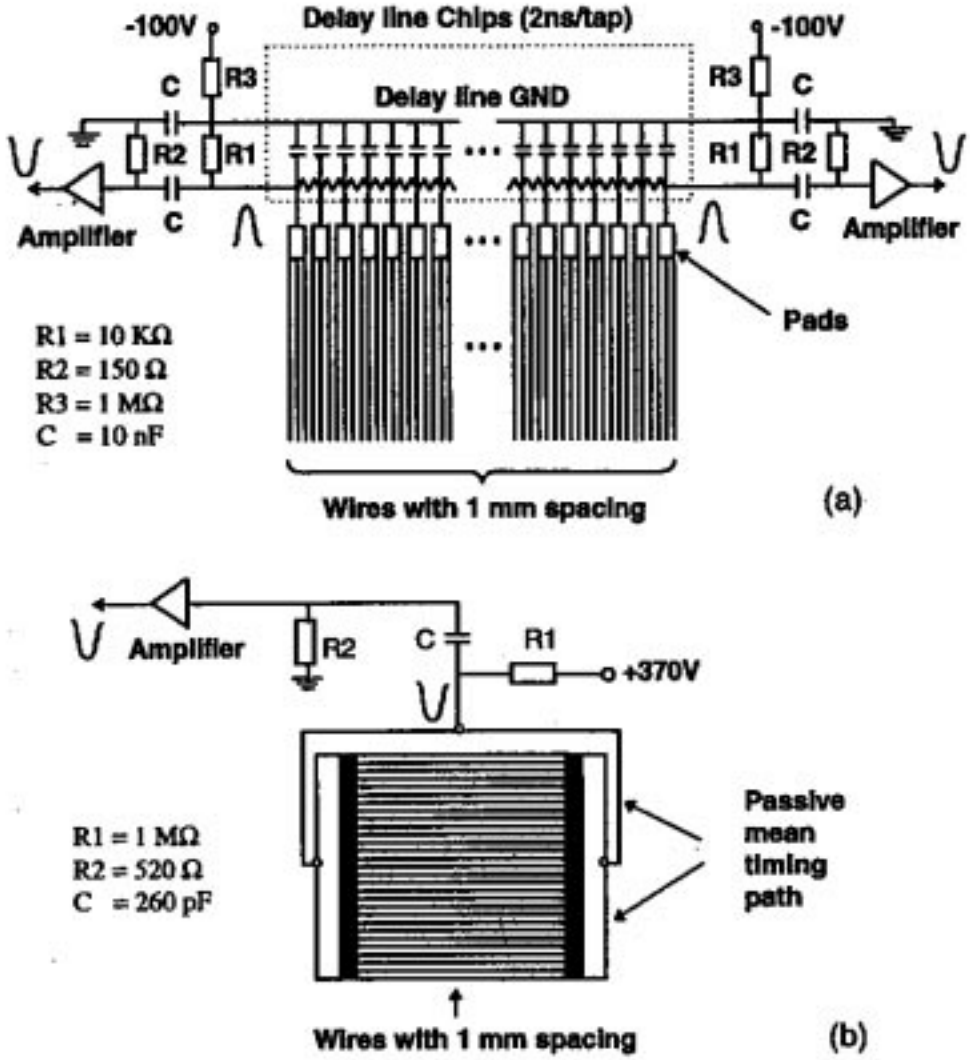
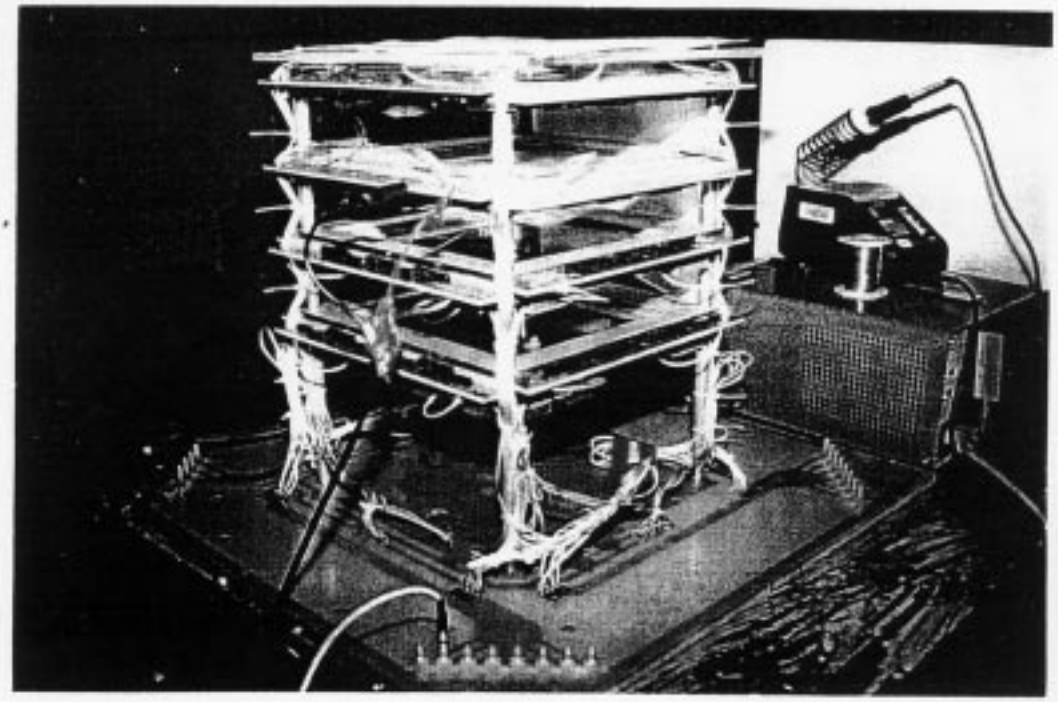

-100V
Delay line Chips (2ns/tap)
-100V
C
R3
Delay line GND
R3
C
R2
R1
R1
R2
Amplifier
C
C
Amplifier
Pads
R1 = 10 KΩ
R2 = 150 Ω
R3 = 1 MΩ
C = 10 nF
Wires with 1 mm spacing
(a)
Amplifier
R2
C
R1
+370V
R1 = 1 MΩ
R2 = 520 Ω
C = 260 pF
Passive
mean
timing
path
Wires with 1 mm spacing
(b)

Figure 3



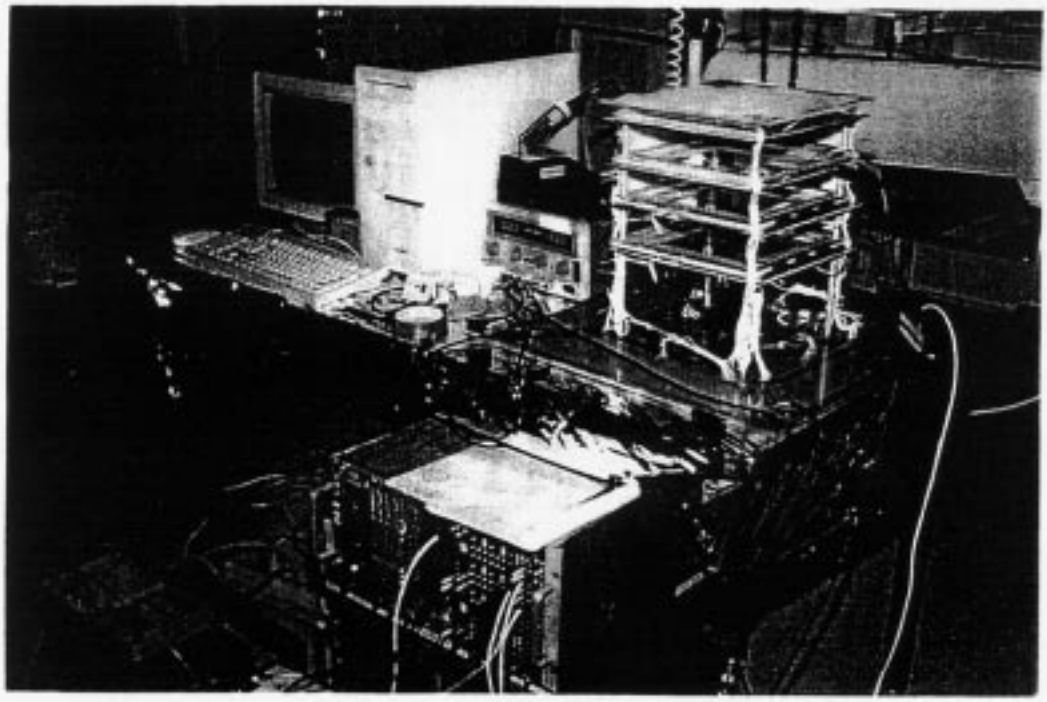


Figure 4

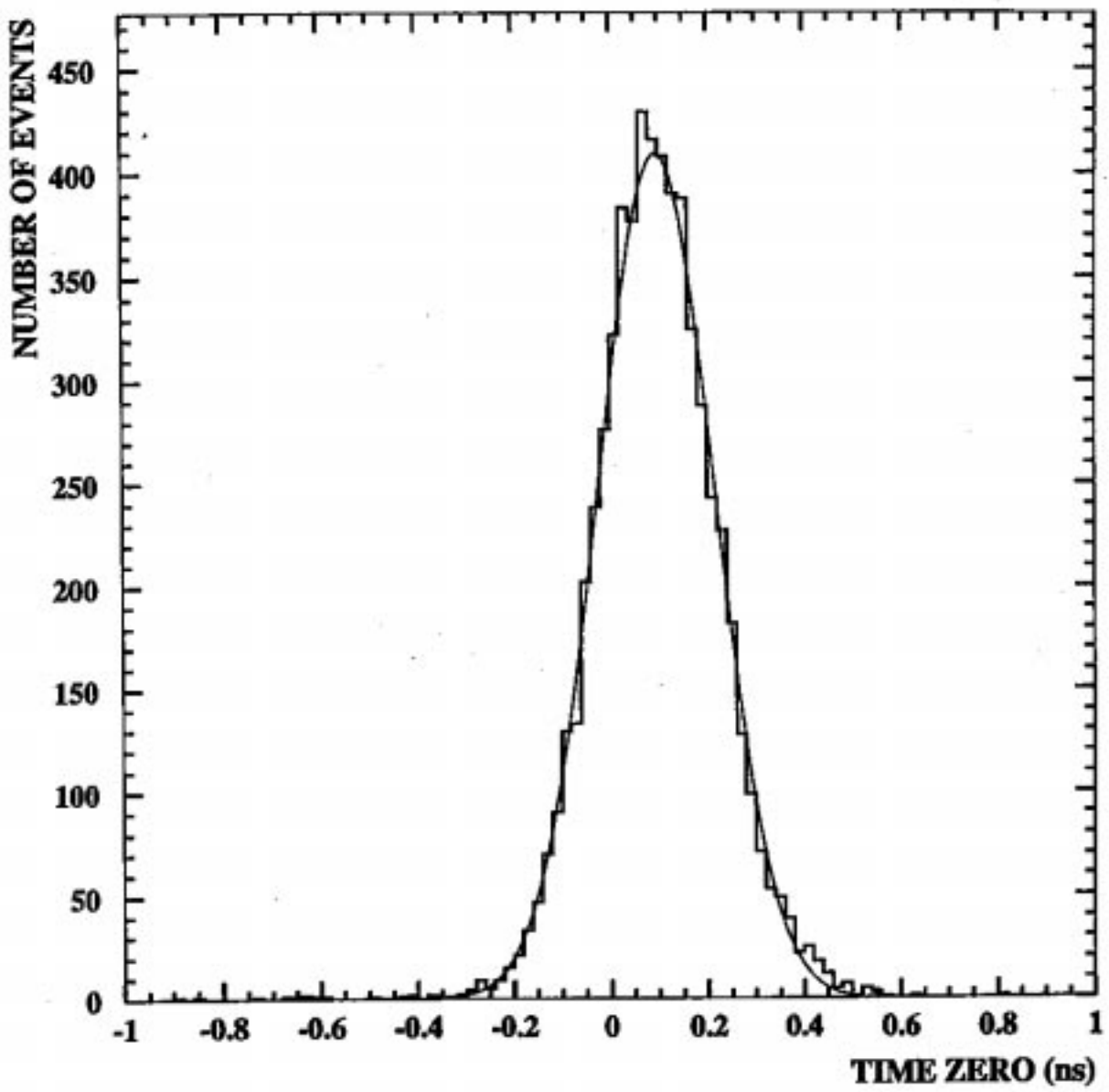

NUMBER OF EVENTS
450
400
350
300
250
200
150
100
50
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
TIME ZERO (ns)

Figure 5

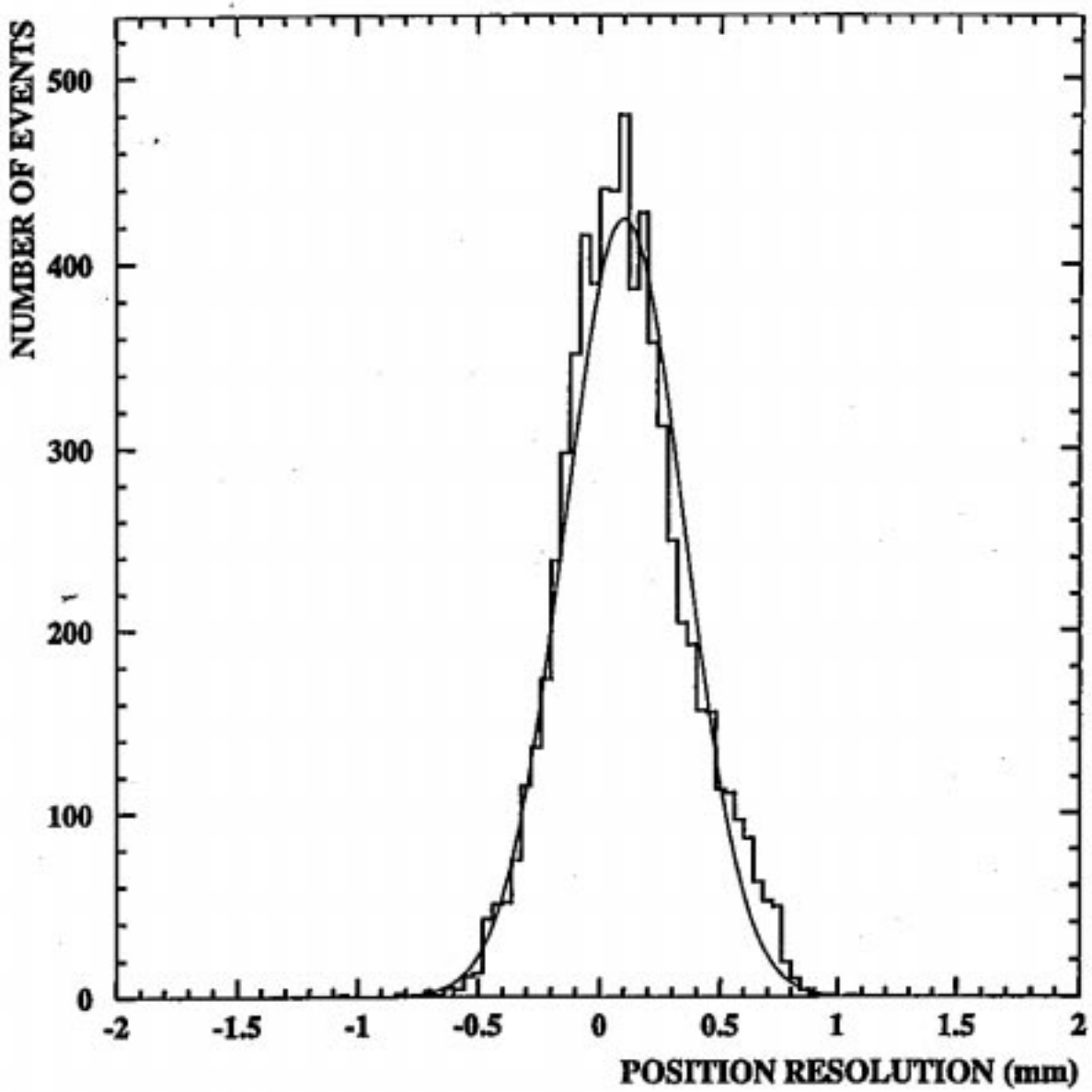

NUMBER OF EVENTS
500
400
300
200
100
0
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
POSITION RESOLUTION (mm)

Figure 6

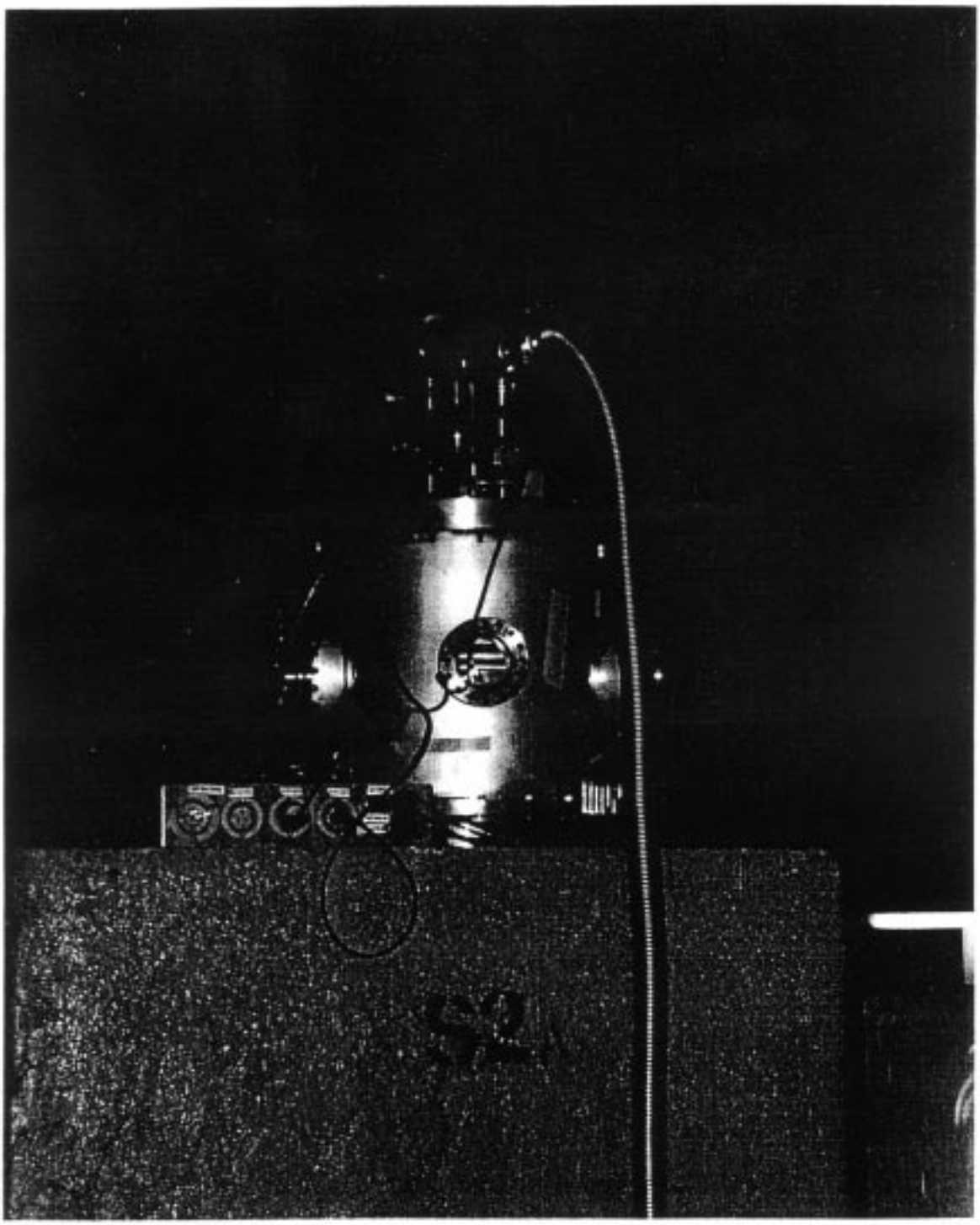
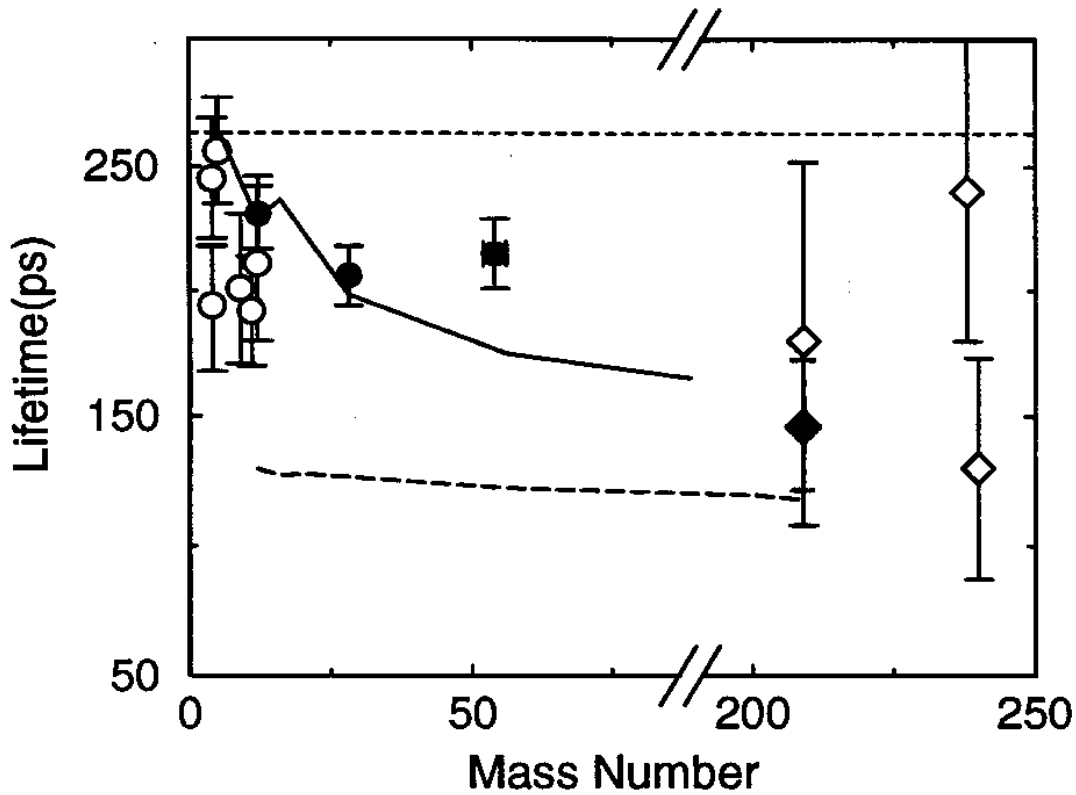


Figure 7



○ Previously existed data from KEK and BNL

◇ Previously existed data from CERN and Julich

● Recent KEK data

◆ Recent Julich data

Figure 8