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PROGRESS REPORT FOR AN OUTSTANDING JUNIOR INVESTIGATOR AWARD IN EXPERIMENTAL HIGH ENERGY PHYSICS

Task J
Progress Report
for Contract Period January 1, 1990 to December 31, 1990

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MASTER

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ABSTRACT

An experimental program based upon the study of hadron collisions at the highest available energy is being carried out with the support of an Outstanding Junior Investigator Award to Prof. Richard Partridge. The work described in this report includes the development of the Level 0 trigger for the D0 experiment at Fermilab, preparation for the D0 physics program, and studies of detector design for the Superconducting Super Collider (SSC).

Progress Report for a Research Program in Experimental High Energy Physics

We present herein a report of the progress made in a research program in experimental high energy physics supported by an Outstanding Junior Investigator Award to Prof. Richard Partridge. This report covers the period 1 January 1990 - 31 December 1990. This work has been supported by the U.S. Department of Energy under Contract No. DE-AC02-76ER03130 (Task J).

This report is divided into sections that provide an overview of the program (Sec. 1), describe progress in developing the Level 0 trigger for the D0 experiment (Sec. 2), preparations for the D0 physics program (Sec. 3), report results from SSC detector design studies (Sec. 4), discuss associated matters (Sec. 5), and list papers produced during the year (Sec. 6).

1. Overview of the Program

Task J of the Brown University effort in experimental particle physics supports development of the Level 0 trigger system being built for the D0 detector at the Fermilab Tevatron collider. The D0 experiment will bring a strong focus upon high energy, short distance $\bar{p}p$ collisions in a manner that compliments the capabilities of the CDF detector. Together, these detectors will exploit the opportunity for discovery opened up by the Tevatron collider in the 100-500 GeV mass range.

The Level 0 trigger is the first level in a multi-level trigger scheme being developed for D0. It consists of two arrays of scintillation counter placed near the collider beam pipe on opposite ends of the detector and features extremely precise time-of-flight measurement for particles striking the detectors. The goals for the Level 0 trigger include identifying interactions, determining the position of the interaction point within the luminous region, detecting multiple interactions in a single beam crossing, and measuring the luminosity of the collider.

In addition to the Level 0 project, Prof. Partridge has been active in preparations for the D0 physics program and various SSC related activities. This report describes the progress made during the past year in the above areas.

2. Progress in Developing the Level 0 Trigger for D0

Substantial progress has been made in design, testing, and construction of the Level 0 trigger system for the D0 detector. Areas of progress include final design and initiation of fabrication of the Level 0 counters, development of a laser calibration system, and design, prototype testing, and fabrication of Level 0 electronics components. The achievements in these areas during the past year are described below.

2.1. LEVEL 0 COUNTERS

Two Level 0 detectors will be built and installed on opposite ends of the central detector. Each Level 0 detector will consist of an array of plastic scintillation counters with photomultiplier readout for detecting charged particles in the beam jets. The counters will make precise measurements of charged particle arrival times for locating the position of the primary vertex, detecting multiple interactions, and measuring the relative collider luminosity.

Each Level 0 detector will be made of two layers, both having the design shown in Fig. 1. The two layers will be oriented orthogonal to each other, to give essentially complete coverage of the region around the beam pipe (see Fig. 2). Two types of counters are used: short counters surrounding the beam pipe and long counters completing the coverage. Both ends of the long counters will have photomultiplier readout, with the standard technique of averaging the times used to determine the arrival time of the charged particle. Long counters cannot be placed close to the beams because of the large probability for multiple hits which would degrade the time resolution. Instead, short counters with photomultiplier readout on one end only are used next to the beam pipe. The short counters are insensitive to multiple hits since the time variation across the counter is small.

The Level 0 counters are currently being built by the plastics shop at Fermilab using Bicron BC-408 scintillator and quenched PVT light guides. The Phillips XP2282 photomultiplier tube has been selected with delivery scheduled for this fall. A voltage divider printed circuit board has been designed for this tube and is ready for manufacture. The mechanical enclosure has been designed and prototypes are under fabrication. Our goal is to install these counters at D0 this fall and use them in the cosmic ray testing of D0 components. They will be particularly useful for generating triggers on horizontal cosmic rays for testing the forward drift chambers.

Changes were made during the past year in the photomultiplier tube and magnetic shielding choices for Level 0. The XP2282 supersedes our previous selection of the XP2262; the XP2282 is a new model that is identical to the XP2262 except for a reduction in the number of gain stages from 12 to 8. The ability to operate the tubes with reduced gain is expected to prolong the tube life in the high rate environment at the Tevatron collider. Figure 3 shows the measured time response of a short counter with an XP2282 photomultiplier; a time resolution of 144 ps is obtained. The choice of a low gain tube will be compensated for by using preamplifiers on the photomultiplier signal. The presence of a moderate magnetic field ($\approx$ 20 gauss) in the Level 0 region required increased magnetic shielding. This caused a change to a thicker shield with the photomultiplier tube recessed by the shield diameter. Figure 4 shows the measured attenuation of a 17 gauss transverse magnetic field as a function of the depth inside the shield.

2.2. CALIBRATION AND MONITORING

Since the Level 0 detector is part of the trigger, the results of its operation are permanent and not subject to further offline processing or recalibration. Continuous monitoring of the performance and calibration of the Level 0 detector is essential. Of particular importance is the elimination of small timing shifts that would affect the vertex location and, in extreme cases, reduce the trigger efficiency.

The calibration will be maintained using a single pulsed light source whose light will be distributed to each counter via quartz fiber optics. During the run, the system will be pulsed periodically and the data analyzed by the online computer system. The calibration data will be used to monitor the performance of the Level 0 detector and measure small shifts in the timing. This system will also provide an important diagnostic tool for locating and correcting problems in the Level 0 system.

The source of the light pulse will be a pulsed nitrogen laser, which will send a short light pulse to the two Level 0 detectors using quartz fiber optics (see Fig. 5). The light pulse will be fanned out on the Level 0 detector by illuminating a small piece of waveshifter, with the shifted light viewed by 36 quartz fibers that will transmit the light to the PMT's. A photodiode will monitor the timing and amplitude of the light output from the waveshifter using the same electronics being built for the photomultipliers. Progress this past year was made in design of a preamplifier for the photodiode signal and design of the fiber optic fanout.

2.3. LEVEL 0 ELECTRONICS

The Level 0 electronics must separate $\bar{p}p$ interactions from beam-gas events, provide vertex positions to the Level 1 trigger and Level 2 triggers, and identify multiple interactions. The goal of the Level 0 electronics is to provide a fast vertex position measurement within 150 ns of the beam crossing, with a precision measurement of the vertex position and other Level 0 information coming 1000 ns following the beam crossing (these times do not include the cable delay from the detector to the moving counting house, which is roughly the same for all detector elements).

The design of electronics for the Level 0 system is one of the most challenging aspects of the project. Obtaining 150 ps time resolution in trigger electronics makes stringent demands on the stability and reliability of the electronics. Particularly challenging is the need to combine the signals from various counters in a sensible way, while allowing for the possibility of stray tracks or albedo from the shower counter immediately behind the detector. The architecture for the Level 0 electronics and the progress made during the past year is described below.

The photomultiplier signals will be brought out of the detector to front-end electronics mounted on the platform underneath the detector. The photomultiplier signals have their delays adjusted so that individual photomultiplier signals arrive simultaneously at the platform, where they are fed into gain 10 preamplifiers and then into the Level 0 QTAC modules. The QTAC modules discriminate the photomultiplier signal, provide time-to-amplitude conversion (TAC), and integrate the charge output from the photomultiplier tube. The TAC and integrated charge signals are then brought to the movable counting house for digitization and processing. The printed circuit layout and testing of the QTAC design were completed this year and a student technician is currently assembling the modules.

In the movable counting house, L0FADC boards will digitize the TAC and charge signals using flash ADC's for speedy digitization, with memories used to make slewing and t_0 corrections and adders used to average the two time measurements from a long counter. The L0FADC boards will also count in-time hits as a measure of the collider luminosity. These boards will have a VME interface that allows them to use VBD boards for readout (see Task C progress report) and Vertical Interconnect modules for downloading constants. The L0FADC boards are currently being designed, with prototype tests of the combined QTAC-L0FADC system showing excellent linearity (see Fig. 6).

The corrected times from the L0FADC boards are then processed by L0TP-I and L0TP-II boards to obtain statistical measurements of the time distribution for an array of Level 0 counters. These measurements include average time, time variance, minimum time, maximum time, and number of counters hit. The L0TP-I combines the results from 8 counters, while the L0TP-II combines the results from several L0TP-I boards and finds the best estimate of the vertex position and a flag to indicate the presence of multiple interactions. The L0TP-I board was designed in the past year but still requires printed circuit board layout.

The effectiveness of these statistical measures in determining the vertex position and the occurrence of multiple interactions was studied using a Monte Carlo simulation program. Figure 7 shows the error in the vertex position as a function of the luminosity and number of bunches in the collider. The increased error at high luminosity is due to the effects of multiple interactions. The algorithms implemented in Level 0 are expected to be $\approx 90\%$ effective in identifying multiple interactions, but once there are additional interactions in a crossing there is no way to correctly assign a vertex position. By providing a flag indicating a multiple interaction occurred we are able to warn the higher level triggers that the Level 0 vertex position is unreliable.

A second measurement of the vertex position is made using the FASTZ module. The FASTZ position is used at an early point in the Level 1 calorimeter trigger to make vertex position corrections for its E_T and p_T energy sums. An analog sum of the signals from the short counters is made for each of the two Level 0 arrays and a constant fraction discriminator is used to generate timing pulses from the sum signals. The difference in time between the two timing pulses is related to the vertex position. The FASTZ module uses commercial GaAs integrated circuits to make a digital TDC that counts the number of 2.4 GHz clock pulses between the timing pulses. The fast vertex measurement is available $\approx$ 100 ns after beam crossing (excluding cable delays) and a vertex position resolution is expected to be $\sigma_v \approx 3-6$ cm. A prototype of the fast vertex electronics was built and tested during the past year, with successful operation at clock frequencies up to 2.3 GHz. It is anticipated that the improvements resulting from a printed circuit board layout, currently in progress, will allow the design clock speed of 2.4 GHz to be reached. Figure 8 shows the probability of recording two adjacent codes from the digital TDC as a function of the stop time for a clock frequency of 2.03 GHz. Since the internal clock is unsynchronized with the start time, the theoretical probability distributions are overlapping triangles that peak at a probability of 1 and have a base of twice the clock period. The measured distributions are in good agreement with this prediction except for a small odd-even effect, which is not expected to cause significant deterioration in the theoretical accuracy of the TDC, $\sigma_t = (\sqrt{6}f)^{-1}$.

Finally, an interaction signal is generated by requiring the vertex lie within ±100 cm of the detector midpoint. Upstream beam-gas interactions appear to have an interaction vertex at ±140 cm and thus fail to yield an interaction signal. The interaction signal, occupancy of each Level 0 counter, and out-of-time hits are recorded to provide luminosity monitoring. The above design provides precision vertex information ($\sigma_v < 3$ cm) for use in Level 1 and Level 2 trigger processing and the capability to detect multiple interactions with good efficiency. Events that are accepted by Level

1 have the digitized times, charges, and time processor results recorded and this data becomes part of the trigger block transferred to the Level 2 node.

In summary, significant progress has been made in the area of Level 0 electronics during the past year, including completion of the QTAC design, partial design and prototype testing of the L0FADC boards, design of the L0TP-I time processor, and design and prototype testing of the FASTZ board. The electronics design for Level 0 is being carried out by two talented engineers: Mr. Lang Wang and Prof. Guo-Sheng Gao. Prof. Gao is on leave of absence from his home institution of Nanjing University in China, where he is an associate professor of engineering. He is visiting Brown under an exchange program between the two universities with partial support provided by Task C. Mr. Lang Wang is an excellent young electronics engineer hired by Brown and is currently funded through DØ ED&I funds. Completion of the Level 0 electronics will be one of the major undertakings of Task J during the coming year.

3. Preparations for the DØ Physics Program

Given the significant headstart achieved by CDF, it is essential that DØ be ready to produce physics at startup. One way to be prepared for data is to perform "mock" physics analyses using full Monte Carlo simulations of interesting physics signatures. Task J supervised two talented undergraduate students, Chris Barter and David Ascher, in two such Monte Carlo studies that served to fulfill the departmental requirement for a senior thesis. These projects involved ISAJET simulation of the physics process, use of D0GEANT to simulate the detector response, and the DØ reconstruction package to analyze the results. Chris Barter performed a simulation of top quark production and detection while David Ascher simulated detection of the Z^0 boson in DØ. Figure 9 shows the $e\nu_e$ transverse mass distribution for W bosons from the decay of a 150 top quark; note that the transverse mass distribution does not exhibit the same sharp Jacobian peak seen in Drell-Yan W production due to the different production mode. The e^+e^- mass distribution from Z^0 decays is shown in Fig. 10, showing a clear peak at the Z mass. These studies have proven to be extremely useful in developing and testing procedures for physics analysis using DØ.

A second area of preparation for physics at D0 is the development of a Monte Carlo program for low-p_T physics process adapted from the MBR Monte Carlo developed by Rockefeller University for CDF. The Monte Carlo includes elastic scattering, single and double diffractive processes, and hard core inelastic scattering. One of the primary uses of the low p_T Monte Carlo is to calculate the acceptance of the Level 0 counters for these processes, which is needed for determining the collider luminosity based on the counting rates in the Level 0 counters.

4. SSC Detector Design and Physics Studies

The research program emphasizes the study of hadron-hadron collisions at the highest available energy to study new phenomena and test the assumptions of the standard model. The long term future of such a program lies with active participation in the SSC program. At this time, our participation takes the form of contributing to SSC workshops, use of Brown computing facilities to simulate SSC physics, and studies of data acquisition architectures for the SSC. Brown University has joined the Solenoidal Detector Collaboration (SDC) and has begun to take a leading role in the area of data acquisition, with Prof. Partridge responsible for this section of the Expression of Interest (EOI) and serving on the Electronics, Trigger and Data Acquisition technical steering committee.

The major focus of our SSC activity at this time is the study of data acquisition architectures for the SSC. This builds on the existing expertise at Brown in the area of data acquisition (see Task C progress report) and is potentially applicable to high luminosity upgrades of the D0 data acquisition system. A new data acquisition architecture has been developed at Brown that extends the D0 architecture to the high rates at the SSC (see Fig. 11). Brown has recently received funding from the SSC Subsystem R&D program to support functional modeling and simulation of the novel parts of this architecture. The subsystem R&D program is supported by Task E, with Prof. Partridge serving as Principle Investigator.

5. Associated Matters

During the past year, Prof. Partridge devoted essentially all his research time to the research program described in this report. Professor Partridge is the Brown University representative on the D0 executive board, serves as the Contact Person and Institutional Representative for the SDC collaboration, and is a member of the SDC technical steering committee for Electronics, Trigger, and Data Acquisition. During the past year he gave an invited talk on SSC data acquisition architectures at the Computing in High Energy Physics conference in Santa Fe and was co-leader of the following working groups: Level 2 working group at the D0 upgrade workshop, trigger working group at the Tucson Workshop on Major SSC Detectors, and top quark working group at the 1990 Snowmass Meeting. He recently received an SSC fellowship that allows him to devote approximately 50% of his time on SSC matters over the next two years. Professor Partridge also receives partial support from Task C of the Brown University high energy physics contract.

6. Publications and Reports Produced During the Reporting Period

A Data Acquisition Architecture for the SSC, R. Partridge, to be published in *Proceedings of Computing in High Energy Physics '90*, (Santa Fe, 1990).

Backgrounds from Overlapping Events at the Upgraded Tevatron, Andrew Milder, John Rutherfoord, and Richard Partridge, to be published in *Physics at Fermilab in the 1990s*.

Search for the Decay $D^0 \rightarrow \bar{K}^0 e^+ e^-$, J. Adler *et al.*, Phys. Rev. D **40**, 906 (1989).

Observation of $D_s^+ \rightarrow \bar{K}^0 K^+$ and $D_s^+ \rightarrow \bar{K}^{*0} K^+$ and an Upper Limit on $D_s^+ \rightarrow K^0 \pi^+$, J. Adler *et al.*, Phys. Rev. Lett. **63**, 1211 (1989).

Resonant Substructure in $K^- \pi^+ \pi^+ \pi^-$ Decays of D^0 Mesons, J. Adler *et al.*, Phys. Rev. Lett. **64**, 2615 (1990).

Study of the Doubly Radiative Decay $J/\psi \rightarrow \gamma\gamma\rho^0$, D. Coffman *et al.*, Phys. Rev. D **41**, 1410 (1990).

Upper Limit on the Absolute Branching Fraction for $D_s^+ \rightarrow \phi\pi^+$, J. Adler *et al.*, Phys. Rev. Lett. **64**, 169 (1990).

Simulation of Z Boson Production at D0, David Ascher (Senior Thesis).

Simulation of Top Quark Production at D0, Christopher M. Barter (Senior Thesis).

FIGURE CAPTIONS

1) One of two layers in a Level 0 detector. The shaded regions show the position of scintillator material; unshaded regions show light guides and photomultipliers.

2) Superposition of the two layers in a Level 0 detector.

3) Time response of a short counter with an XP2282 photomultiplier tube.

4) Magnetic field measurements inside the magnetic shield with a 17 gauss transverse magnetic field applied.

5) Schematic diagram of the laser calibration system.

6) Flash ADC response as a function of start time.

7) Error in vertex position from Level 0 versus luminosity for various number of bunches. For the first run of D0 the collider will operate with 6 bunches and an expected luminosity of $5 \times 10^{30} cm^{-2} s^{-1}$.

8) Probability of two adjacent TDC codes versus the stop time.

9) The $e\nu_e$ transverse mass distribution for W bosons from top quark decay.

10) The e^+e^- mass distribution from Z^0 decays.

11) A data acquisition architecture for the SSC.

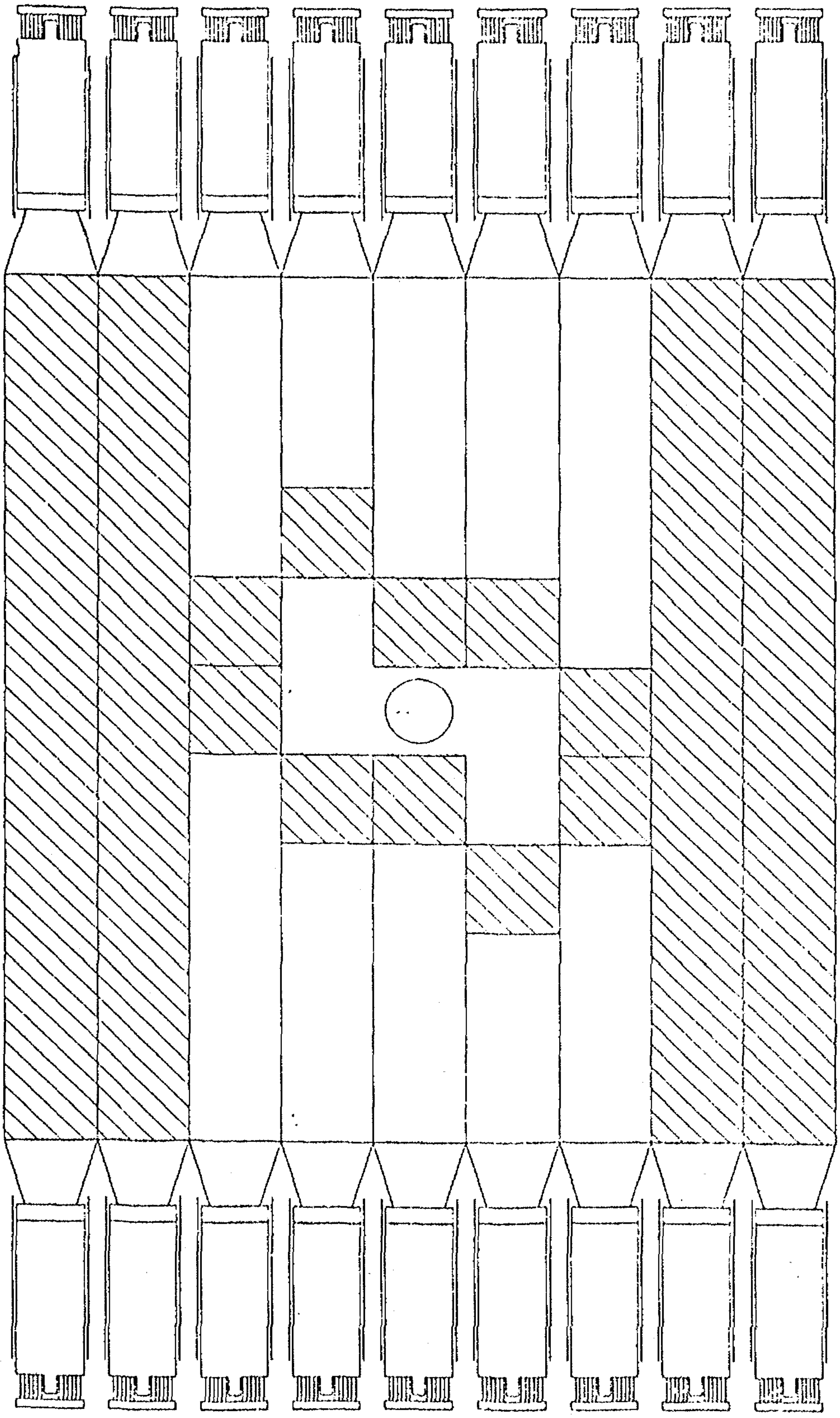

Figure 1

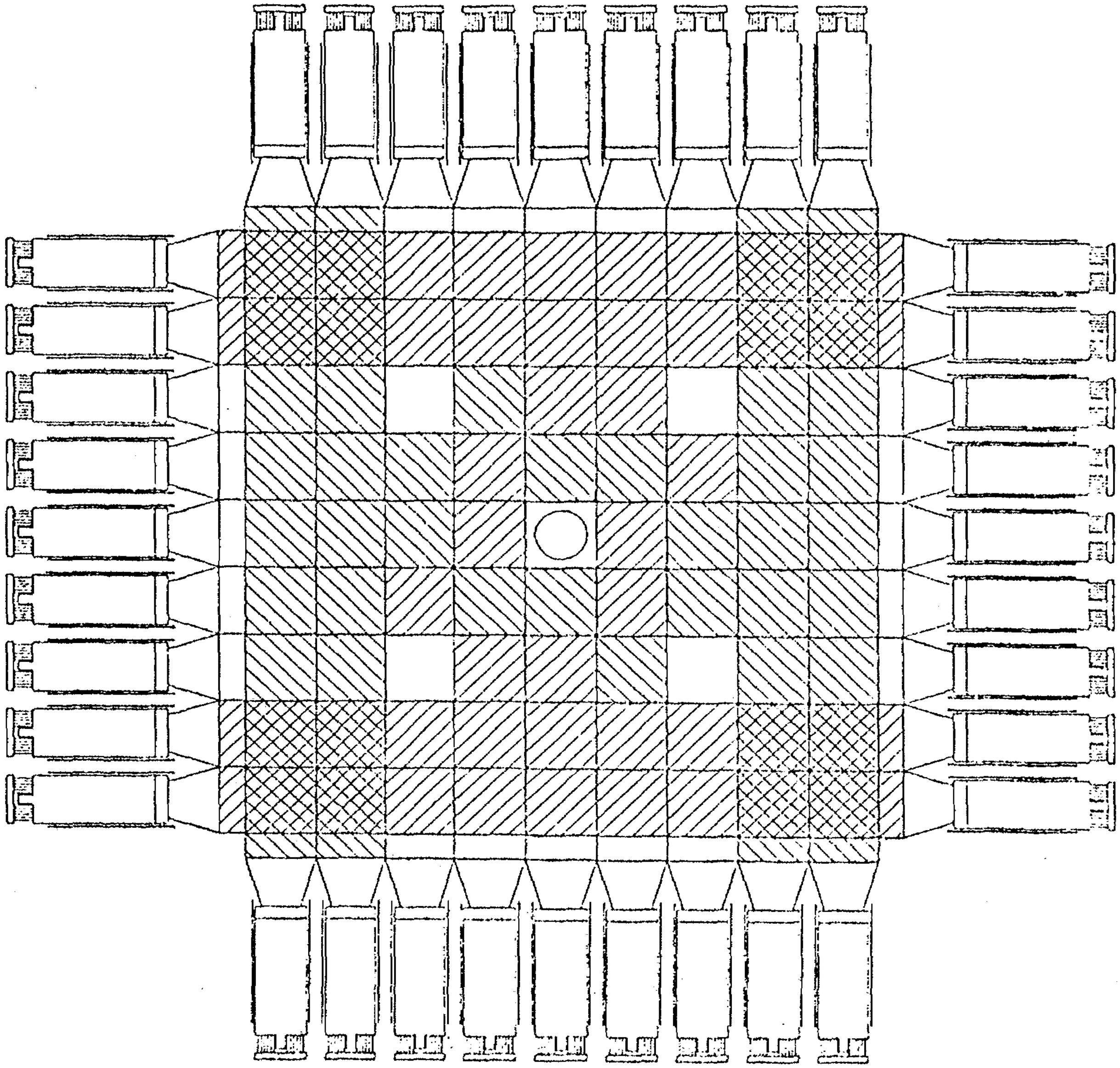

Figure 2

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COUNTER1 TIME DIFFERENCE

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     185                                                        I
     180                                                        I-
     175                                                        II
     170                                                        II-
     165                                                        I I
     160                                                        I I--
     155                                                        I   I-
     150                                                       -I    I
     145                                                       I     I
     140                                                     - I     I
     135                                                     I I     I
     130                                                     I-I     I
     125                                                     I       I-
     120                                                     I        I
     115                                                    -I        I-
     110                                                    I          I
     105                                                   -I          I-
     100                                                   I            I
      95                                                   I            I
      90                                                   I            I-
      85                                                   I             I
      80                                                  -I             I
      75                                                  I               I
      70                                                - I              I  -
      65                                                I-I              I  I
      60                                                I                I  I
      55                                                I                I -I
      50                                              - I                I-II
      45                                              I-I                   I
      40                                              I                     I-
      35                                              I                      I
      30                                              I                      I
      25                                              I                      I-
      20                                             -I                       I-
      15                                           --I                         I---
      10                                      -  --I                              I--
       5        -    - -   -   -   -- --------I--I                                  I-- ---- ------   ---  - - - - -

CHANNELS 100    0                                                                                                  1
         10     0        1         2         3         4         5         6         7         8         9         0
          1     1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890

CONTENTS 100                                               11111111111111
         10                                        11144667013248775552108556321111 1
          1.    1    1 1   1   1   12 1221235272288159746495197868099232590267592116042 2413 122111   111  3 1 1 1 1

LOW-EDGE        --------------------------------------------------
          1.    11111111111                                                                               1111111111
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          0     5207520752075207520752075207520752075207520752075202570257025702570257025702570257025702570257025702
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****** HBOOK   NO ENTRIES FOR HISTOGRAM ID=          51
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Figure 3

Fig2.1: MAGNETIC FIELD VS DISTANCE ALONG Z-AXIS

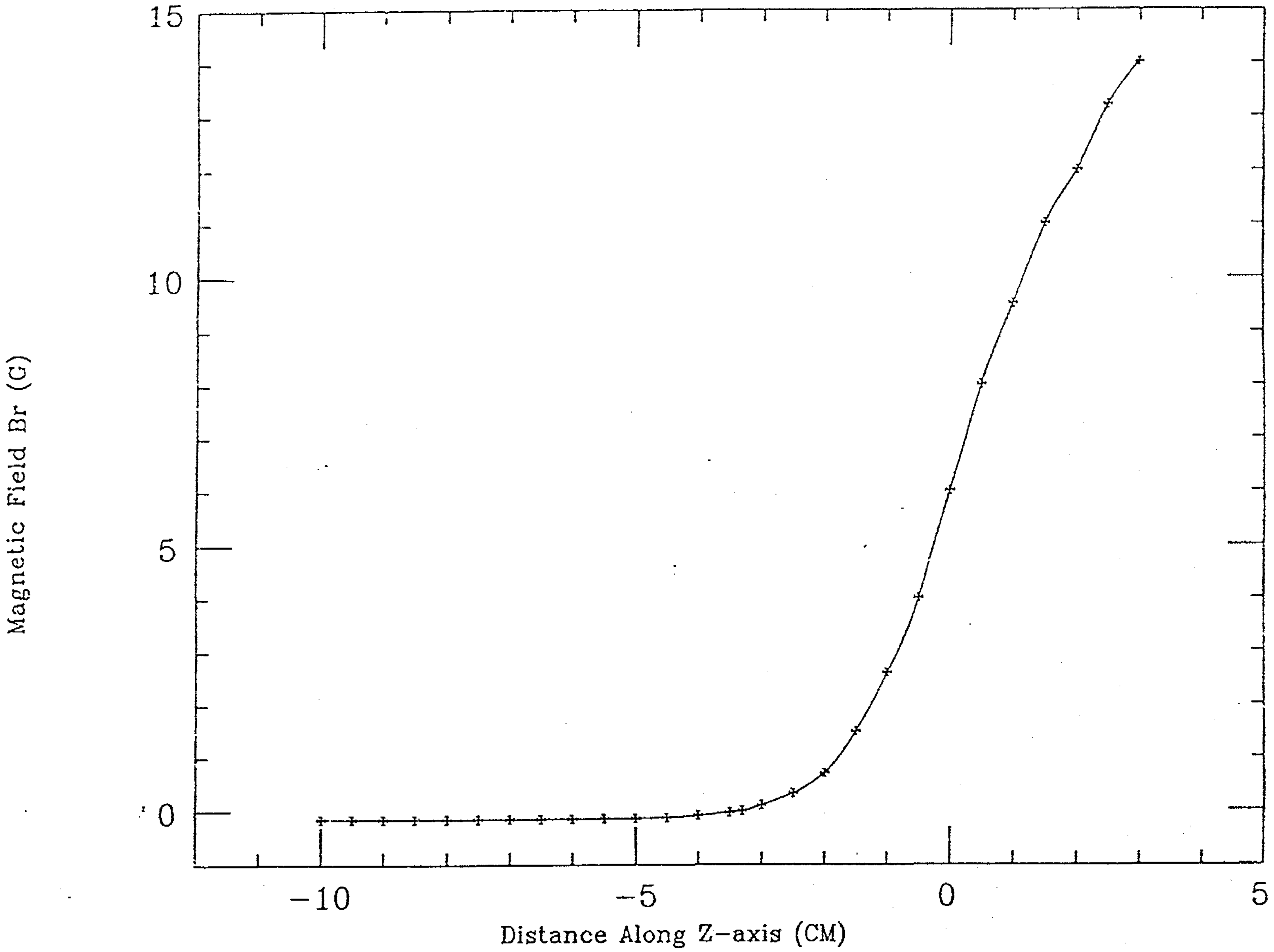
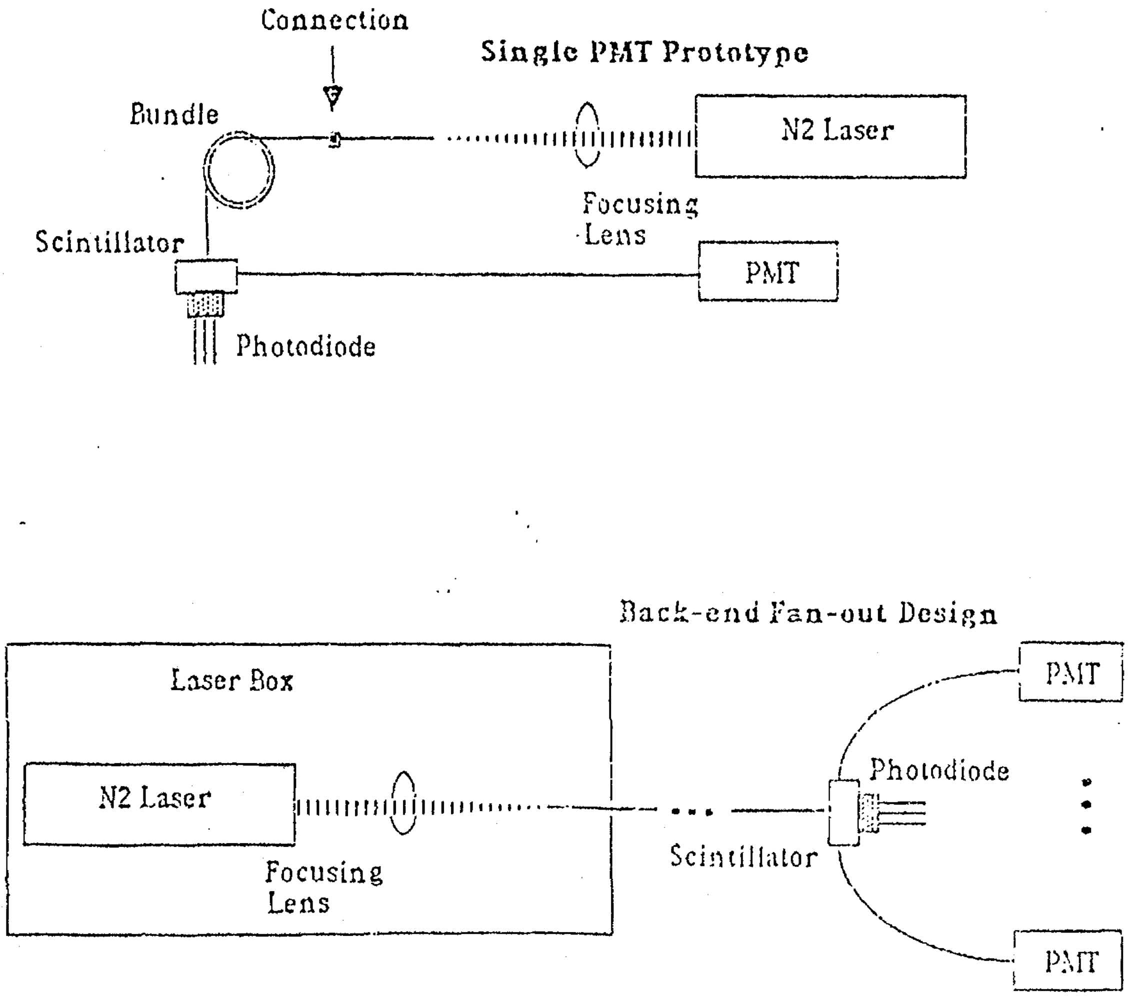


Figure 4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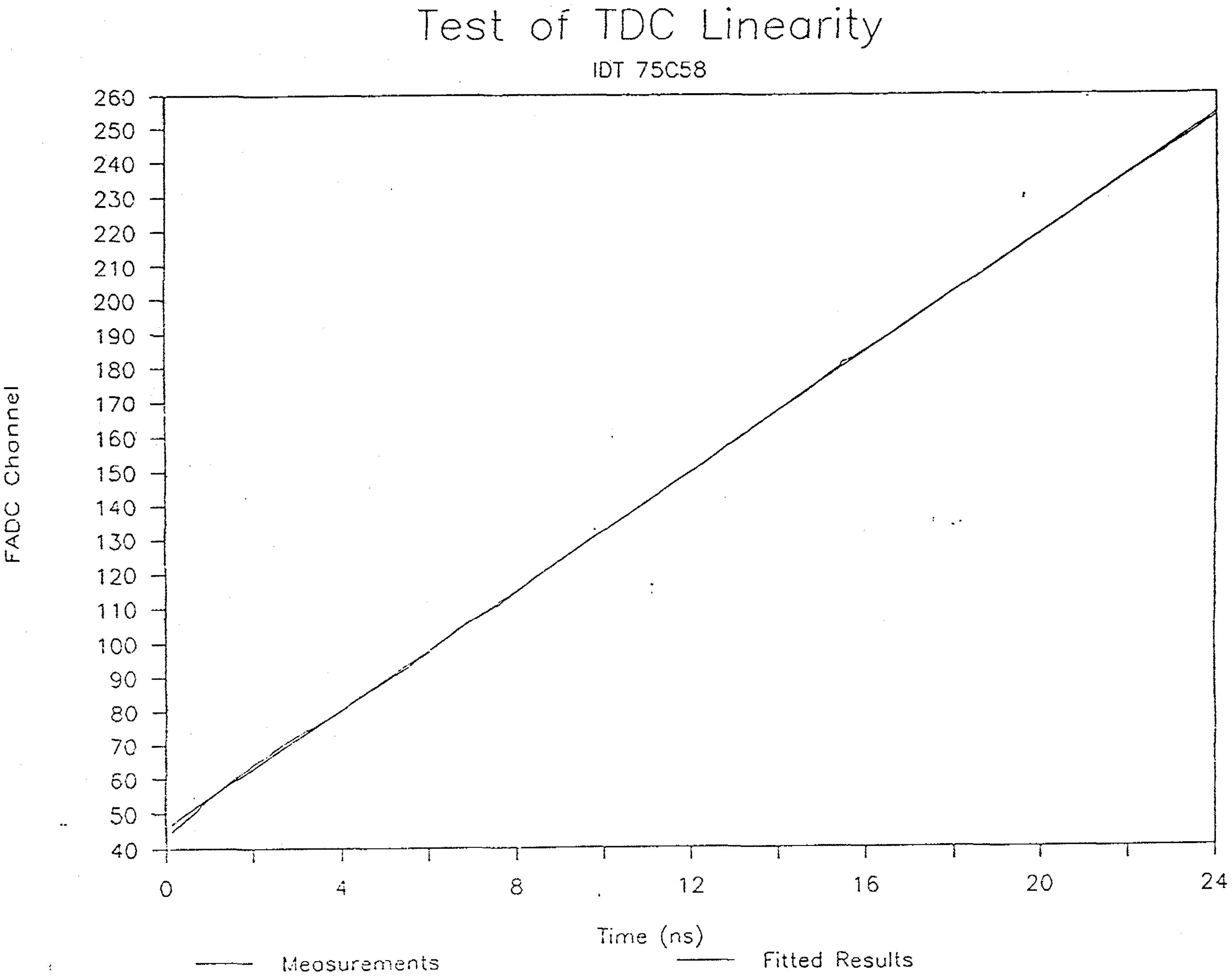
Focusing Lens
Scintillator
PMT
Photodiode
Back-end Fan-out Design
Laser Box
PMT
N2 Laser
Photodiode
Focusing Lens
Scintillator
PMT

Figure 5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IDT 75C58
FADC Channel
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210
200
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130
120
110
100
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60
50
40
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4
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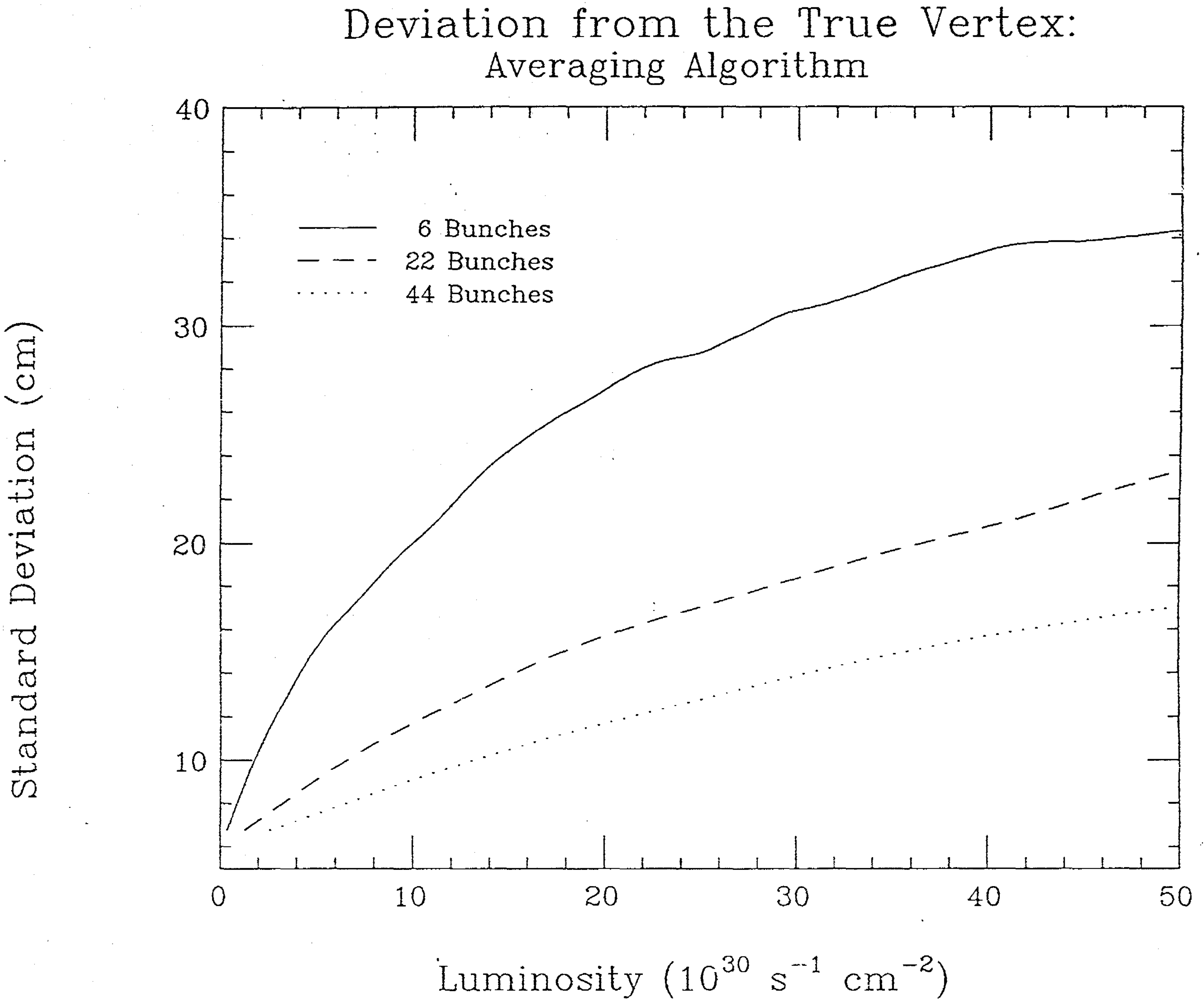
12
16
20
24
Time (ns)
Measurements
Fitted Results

Figure 6


Deviation from the True Vertex:
Averaging Algorithm
6 Bunches
22 Bunches
44 Bunches
Standard Deviation (cm)
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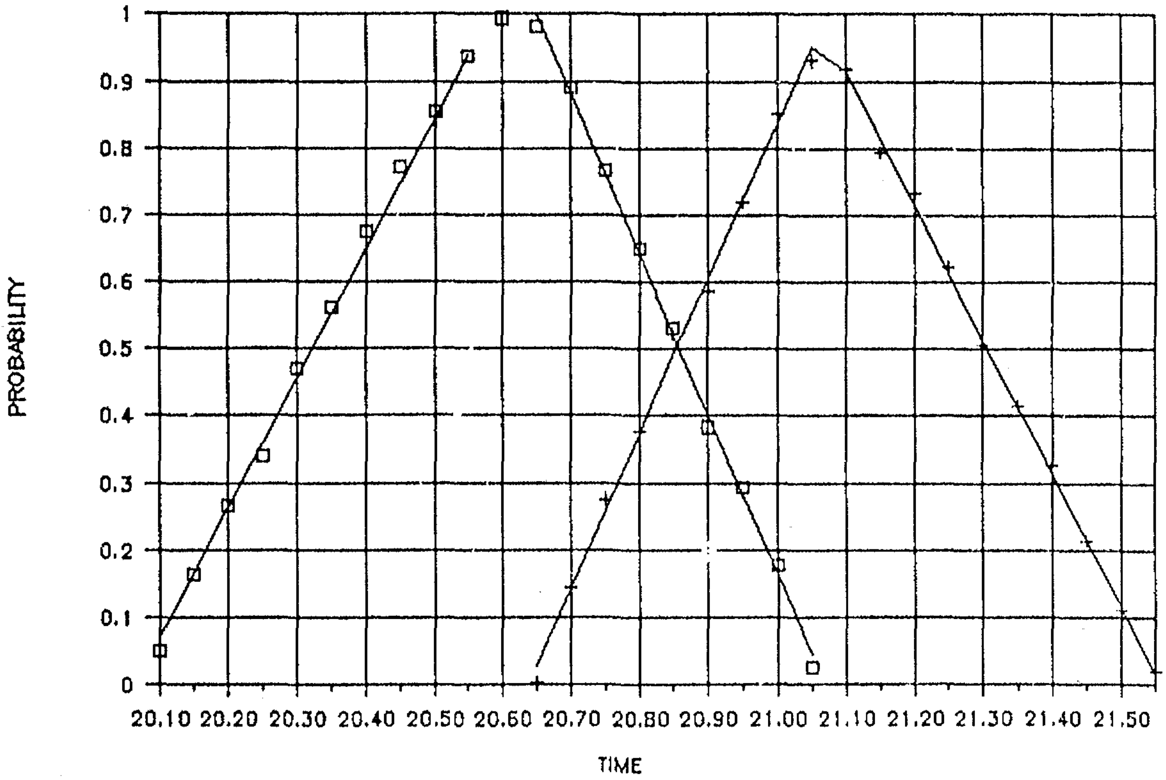
30
20
10
0
10
20
30
40
50
Luminosity (10^{30} s^{-1} cm^{-2})

Figure 7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20.20
20.30
20.40
20.50
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21.00
21.10
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21.30
21.40
21.50
TIME

Figure 8

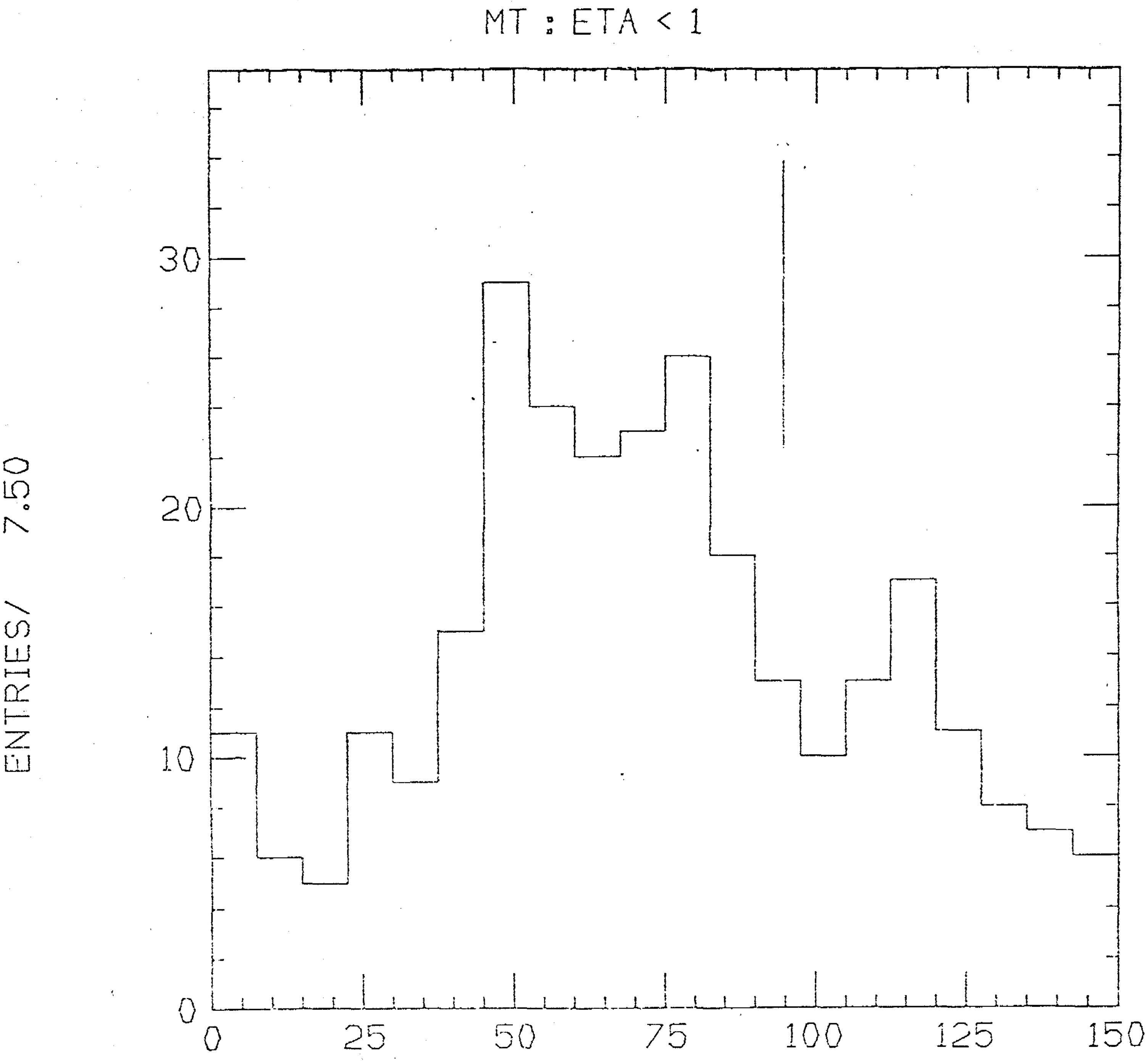


Figure 9

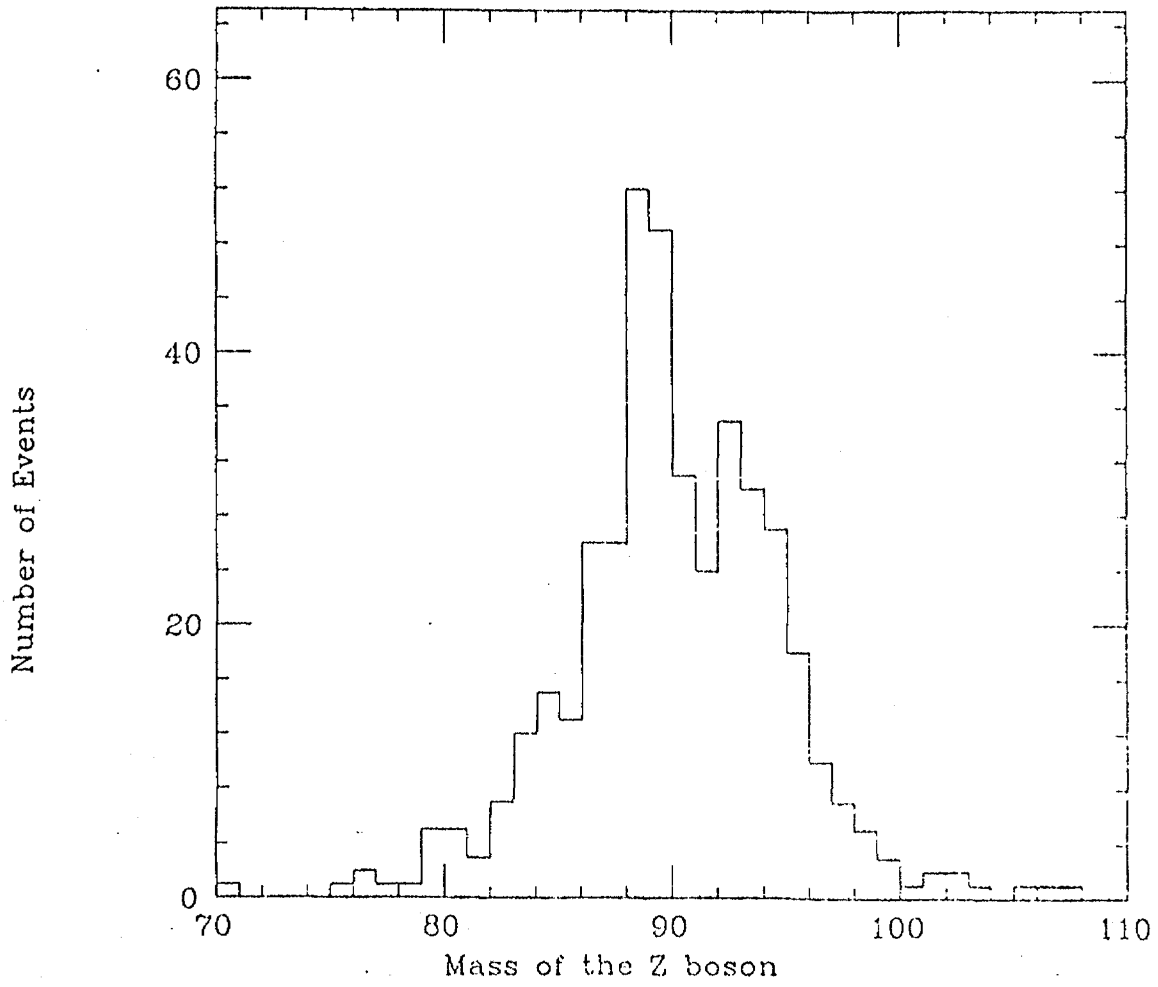
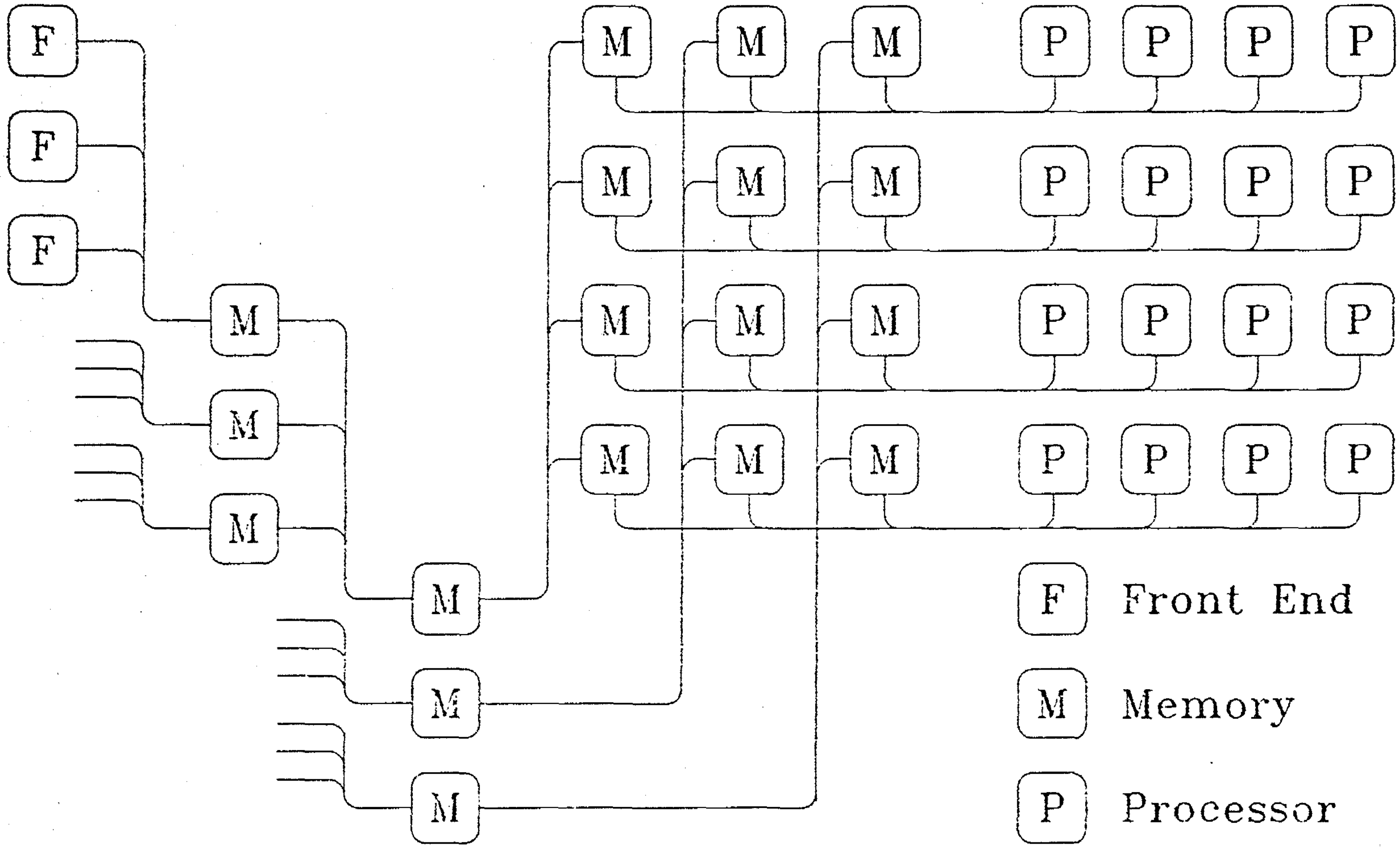


Figure 10


F
F
F
M
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M
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M
M
M M M P P P P
M M M P P P P
M M M P P P P
M M M P P P P
F Front End
M Memory
P Processor

Figure 11

- END -

DATE FILMED

07 / 24 / 90