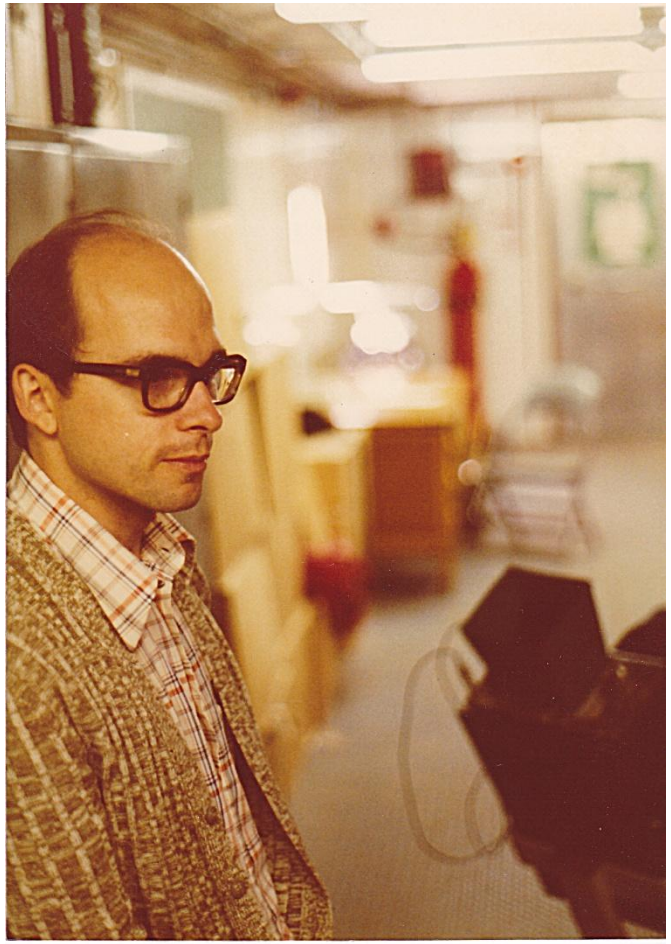
Muon Pair Production (cont'd): E-444



Fermilab Proposal P-443

NAL PROPOSAL NO. 443

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-8744

A PROPOSAL FOR CONTINUED STUDIES OF HADRON INDUCED μ-PAIRS
IN A LARGE ACCEPTANCE SPECTROMETER

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E. I. Rosenberg
Enrico Fermi Institute, University of Chicago

J. G. Branson, G. H. Sanders, A. J. S. Smith, J. J. Thaler
Princeton University

September 24, 1975

Abstract

We propose to continue our studies of hadron induced μ-pairs using hydrogen and deuterium targets and an incident positive and negative beam an order of magnitude more intense than has been normally available to us in E-331.

Fermilab Proposal P-444

NAL Proposal No. 444

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A SPECIAL REQUEST FOR HIGH-PRIORITY RUNNING TO MEASURE HIGH-MASS MUON PAIRS

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Enrico Fermi Institute
University of Chicago

and

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Princeton University

September 26, 1975

ABSTRACT

We request 400 hours (4 weeks) of high-intensity hadron running in the N1 line ($\sim 10^7$ particles/burst), with which we shall survey the dimuon spectrum in the mass range $\sim$1.5 — 15 GeV, with a sensitivity of $\sim$ 1 event/10^{-36} cm^2/nucleon. Protons, π^+, and π^- of $\sim$225 GeV/c momentum will be used to bombard a carbon target. This choice of interactions will produce significant tests of dimuon production mechanisms and the parton formalism as well. We also list many other exciting physics results we expect to obtain from this 400 hour run. It is crucial that this requested high-intensity run take place before our experiment is torn down to make way for E-398, deep inelastic muon scattering.

From the P-444 Introduction

It is essential that this high-intensity run take place toward the end of our parasite run which begins this November. Otherwise, for the want of a single month, the enormous advantages and efficiency of exploiting a completely tested and working experiment (including analysis programs) would be lost, since the muon laboratory is soon to be reconfigured for E-398, the deep inelastic muon-scattering experiment. Should our request be approved, the data will be completely analyzed by the summer. We reemphasize that no changes in the spectrometer are required - all we need is sufficient priority. In a separate proposal[4] we propose a longer term continuation of dimuon measurements, which does require substantial modification of the spectrometer, including the installation of a liquid H_2 target. We do not contemplate setting up this latter experiment till E-398 is completed.

- But this didn't happen. E-331 got more running time (to March, 1976).
- E-444 was approved, but there were changes made to the E-331 spectrometer.

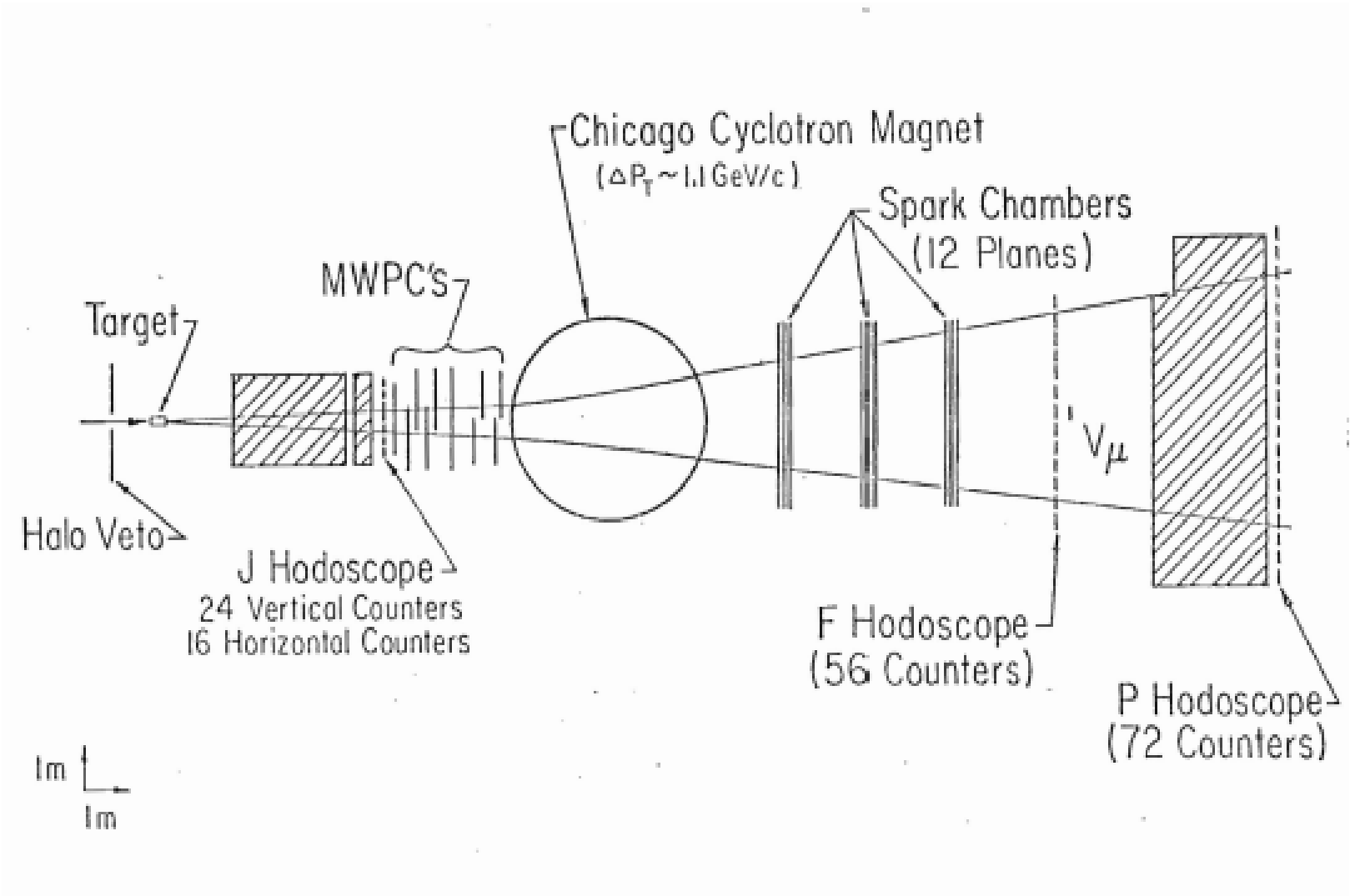
Beginning of E-444

- P-444 was approved.
  - P-443 was not.
- I signed on around March, 1976, right at the end of E-331 data taking.
- My first experimental activity – learning to drive a manual transmission car.

Beginning of E-444 (cont'd.)

- My second activity – pushing E-331 tapes through reconstruction program at the 7th floor computer center at FNAL.
  - And doing crossword puzzles with Kirk McDonald while we were waiting.

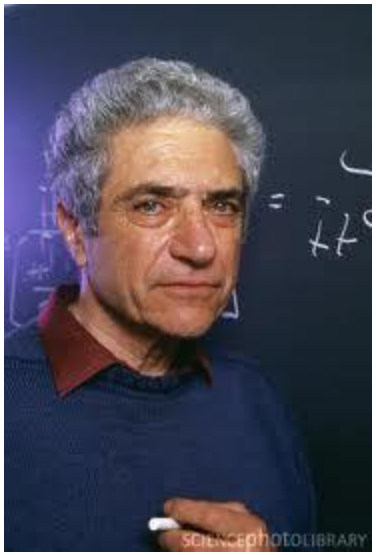
E-444 Apparatus



E-444 Detector

Improvements for E-444

- Increased acceptance for high mass, low x events.
  - Reconfigured MWPCs upstream of the magnet and added new chambers from CERN.
  - Back hodoscope (P) moved forward and enlarged.



The new chambers came from Jack Steinberger.

Apparatus from a muon scattering experiment, reconfigured for muon pair production.

Spark Chamber Improvements

Gas recirculation with a Berkeley gas cart.

Eli Rosenberg with Goofy

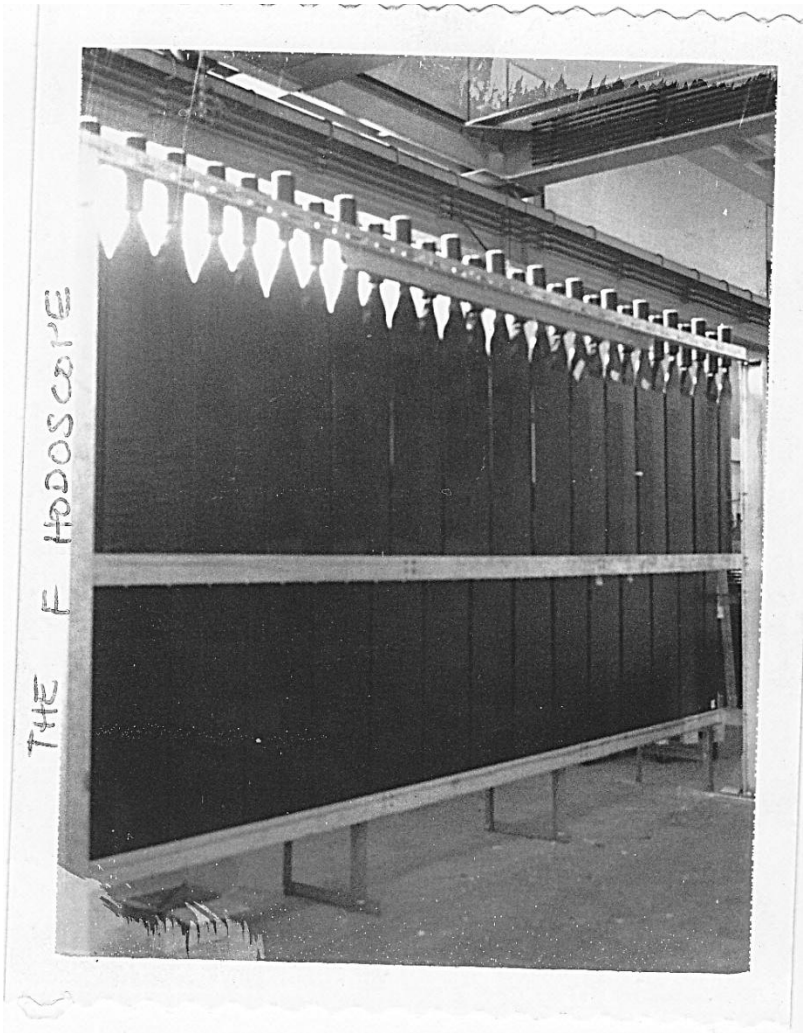
New pulsing system using thyratrons.

F Hodoscope

- New array of scintillation counters built at U of Chicago to improve triggering.

SHV Connector

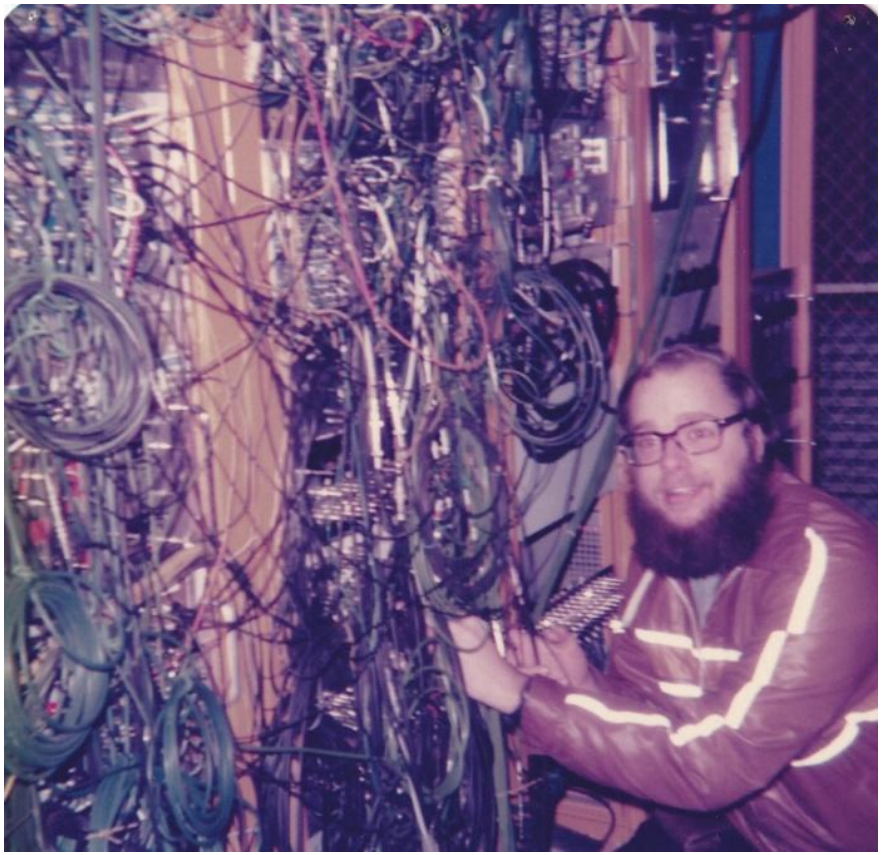
Nut Driver



Trigger, Data Acquisition Improvements

New branch driver for on-line computer speeded up data acquisition.

Kelby Anderson, on-line software expert.



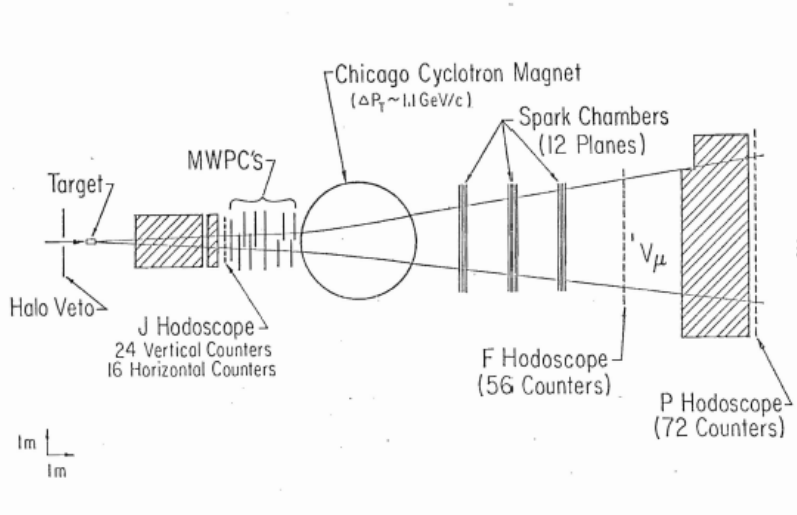
The Mass Box, for high mass triggers, developed by Gary Hogan (Princeton University).

Data taking started Fall, 1977

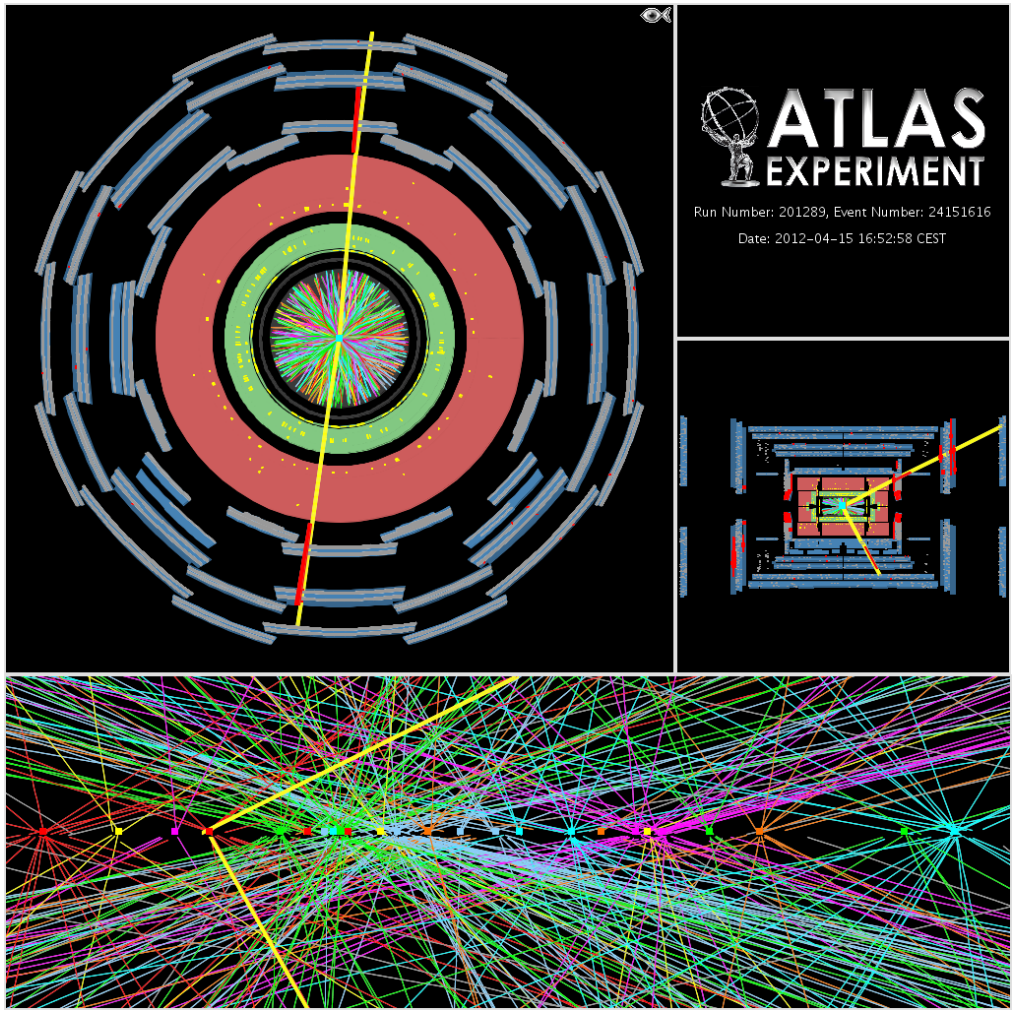
- Problem with neutrons in the J hodoscope.
- Add borax shielding to reduce neutron flux .

Kirk McDonald

“Typical Events” – Then and Now



I don’t have an event display from E-444 but the events basically looked like two tracks.



Z candidate with 25 reconstructed vertices.

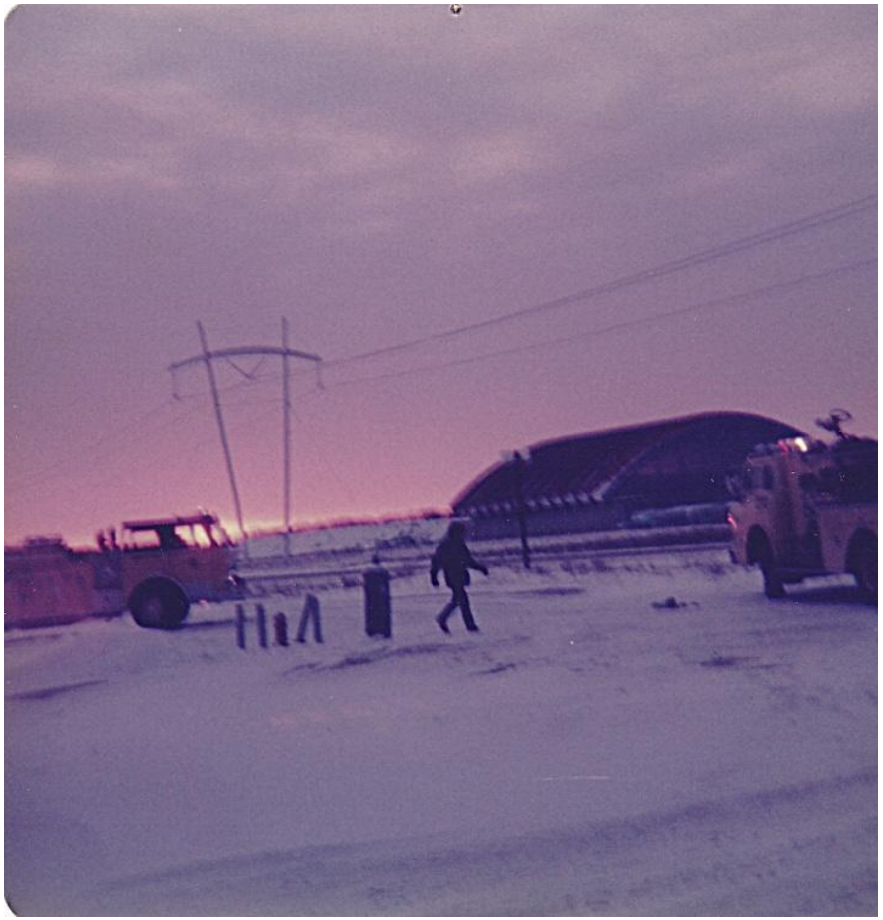
E-444 took data until January, 1978

More first-time experiences for me:

- Staying up all night.
- Having to chisel the car out of the block of ice encasing it.

Operations then and later

- E-444 total time collecting data = a few months.
- The CDF detector, from first observation of collisions to end of the Tevatron = 26 years.
- LHC experiments = ?



Meson Lab at FNAL as seen from Muon Lab parking lot.

Publications

VOLUME 42, NUMBER 15 PHYSICAL REVIEW LETTERS 9 APRIL 1979

Production of Muon Pairs by 225-GeV/c $\pi^{\pm}$, K^{+}, $p^{\pm}$ Beams on Nuclear Targets

K. J. Anderson, R. N. Coleman,[a] G. E. Hogan, K. P. Karhi, K. T. McDonald, C. B. Newman, J. E. Pilcher, E. I. Rosenberg, G. H. Sanders,[b] A. J. S. Smith, and J. J. Thaler
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(Received 22 January 1979)

Results are presented from a large-acceptance experiment in which muon-pair production was observed in the mass range 2 to 11 GeV/c^2. Data were taken with $\pi^{\pm}$, K^{+}, and p^{+} beams at 225 GeV/c on carbon, copper, and tungsten targets. Differential cross sections and the production dependence on pair mass, x_F, p_T, incident-particle type, and target nucleus are discussed.

Comparison of Muon-Pair Production to the Quark-Antiquark Annihilation Model

G. E. Hogan, K. J. Anderson, R. N. Coleman,[a] K. P. Karhi, K. T. McDonald, C. B. Newman, J. E. Pilcher, E. I. Rosenberg, G. H. Sanders,[b] A. J. S. Smith, and J. J. Thaler
Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637, and University of Illinois, Urbana, Illinois 61801, and Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08540
(Received 22 January 1979)

New data on muon-pair production at 225 GeV/c by π^{-}, π^{+}, and proton beams are analyzed with regard to the production mechanism. The observed spin alignment of the pair and the dependence of the cross section on beam-particle type are strong indications that the production is through electromagnetic quark-antiquark annihilation.

Determination of the Pion Structure Function from Muon-Pair Production

C. B. Newman, K. J. Anderson, R. N. Coleman,[a] G. E. Hogan, K. P. Karhi, K. T. McDonald, J. E. Pilcher, E. I. Rosenberg, G. H. Sanders,[b] A. J. S. Smith, and J. J. Thaler
Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637, and University of Illinois, Urbana, Illinois 61801, and Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08540
(Received 22 January 1979)

Data on muon-pair production by pions are used to determine the momentum distribution for valence quarks in the pion. The shape of a nucleon structure function is also obtained and is compared with a calculation based on existing data.

Muon Pair Production: J/ψ and ψ'

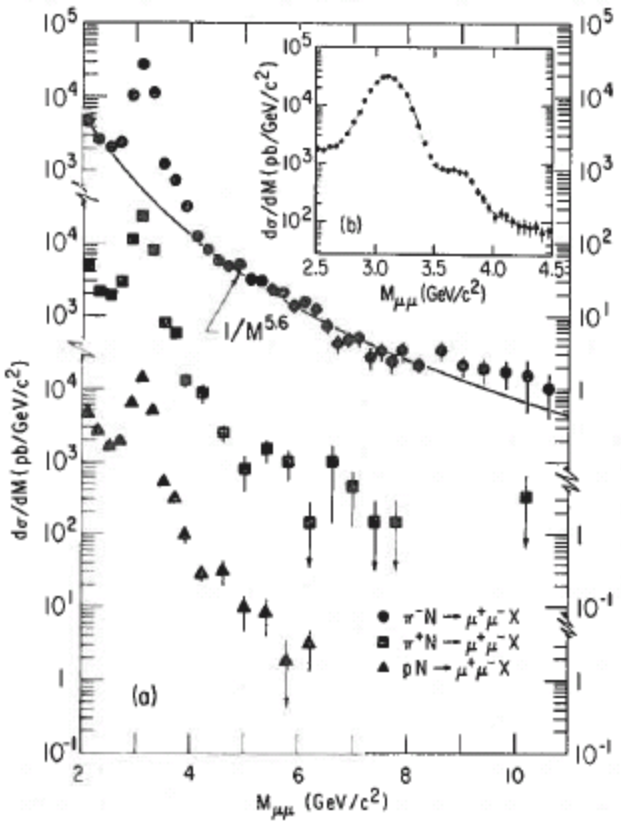


FIG. 1. (a) Differential cross section per nucleon vs mass for π^-, π^+, and proton beams. (b) Differential cross section per nucleon vs mass for $2.0 < M < 4.5$ GeV/c^2, $\pi^- N \to \mu^+\mu^- X$. The solid line is the sum of the Monte Carlo–calculated J/ψ and ψ' line shapes with an exponentially decreasing continuum.

Beam Particle Type	# J/ψ
π^-	66,000
π^+	5,100
p	5,200
$\bar{p}$	100

- E-331 collected about 2,100 J/ψ, with ~ 300 from π-.
- Unfortunately, we did not observe the ϒ produced with a pion beam.

Comparison with Quark-Antiquark Annihilation Model

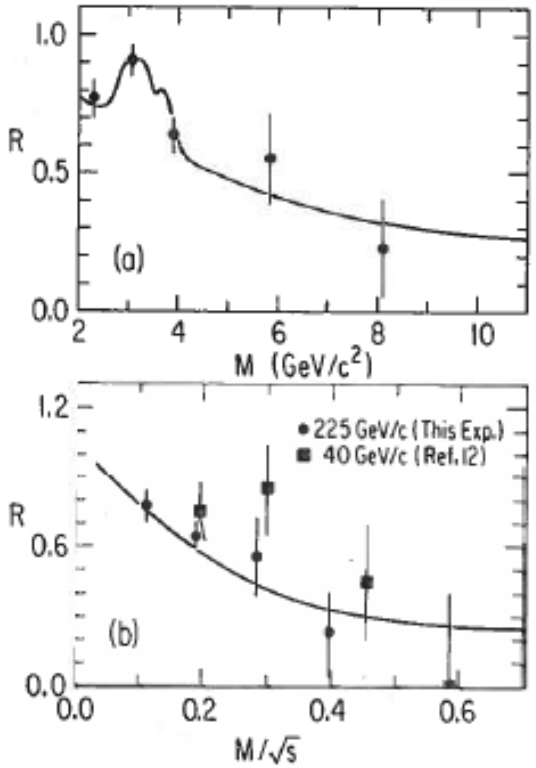


FIG. 2. (a) $R=\sigma(\pi^+C\to\mu^+\mu^-X)/\sigma(\pi^-C\to\mu^+\mu^-X)$ vs M_μ at 225 GeV/c. The solid curve is described in the text (b) R vs $M/\sqrt{s}$ for data at 225 and 40 GeV/c (Cu target) for continuum pairs. The curve is the same as shown in (a) but with resonance production excluded.

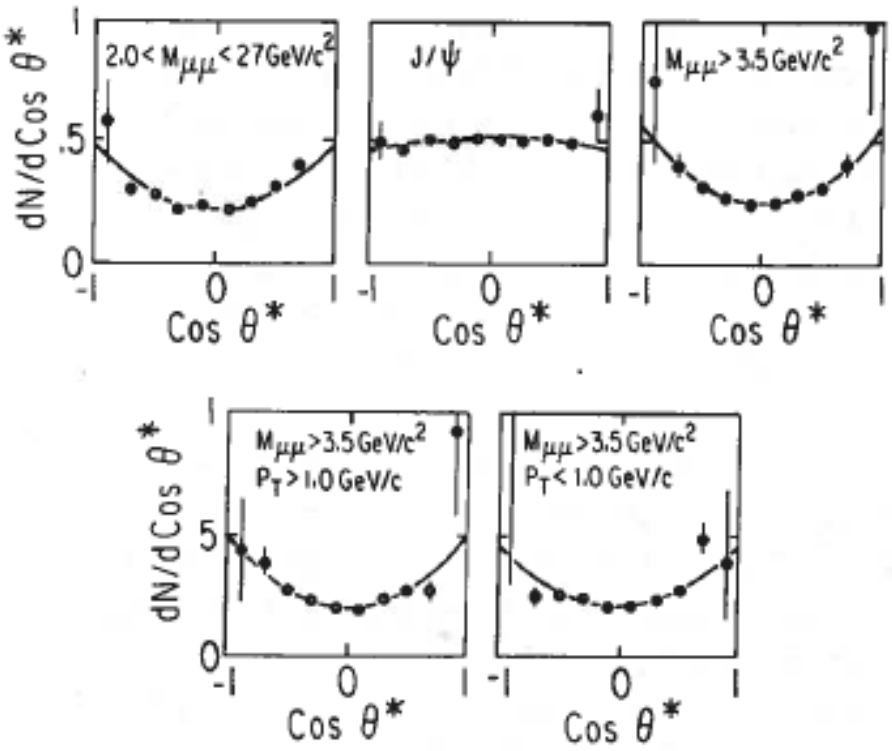


FIG. 3. Helicity angular distributions in three different mass intervals. The $M>3.5$ GeV/c^2 interval is also shown divided in two p_T intervals. The Collins-Soper angle (θ^*) is defined in the text.

Pion Structure Function

Jon Thaler

Drell-Yan cross section for $\pi^- N$ interactions and colored quarks becomes

$$\frac{d^2\sigma}{dM\,dx_F} = \frac{8\pi\alpha^2}{9M^3(x_1+x_2)}\, x_1 \bar{u}^{\pi}(x_1) \times \left[\tfrac{4}{9}x_2 u^N(x_2) + \tfrac{1}{9}x_2 \bar{d}^N(x_2)\right] \qquad (1)$$

or

$$M^4 \frac{d^2\sigma}{dx_1\,dx_2} = \frac{4\pi\alpha^2 s}{9} f^{\pi}(x_1) g^N(x_2), \qquad (2)$$

where $f^{\pi}(x_1) \equiv x_1 \bar{u}^{\pi}(x_1)$ and $g^N(x_2) \equiv \frac{4}{9}x_2 u^N(x_2) + \frac{1}{9}x^2 \times d^N(x_2)$.

Since $M^2/s = x_1 x_2$, the cross section as a function of x_1 and x_2 is predicted to factor into a function of x_1 times a function of x_2. Equation (2) is used to test the factorization hypothesis and to deduce the functions $f^{\pi}(x_1)$ and $g^N(x_2)$. To use

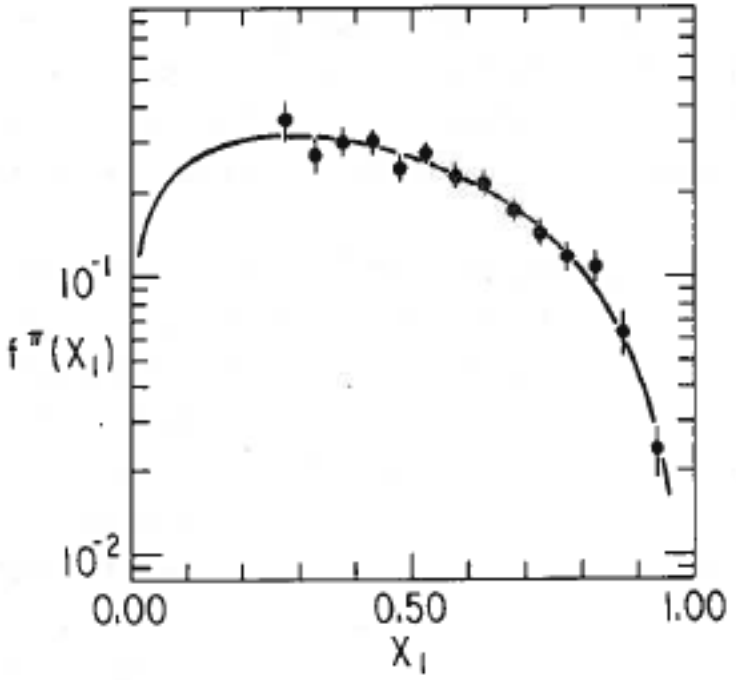
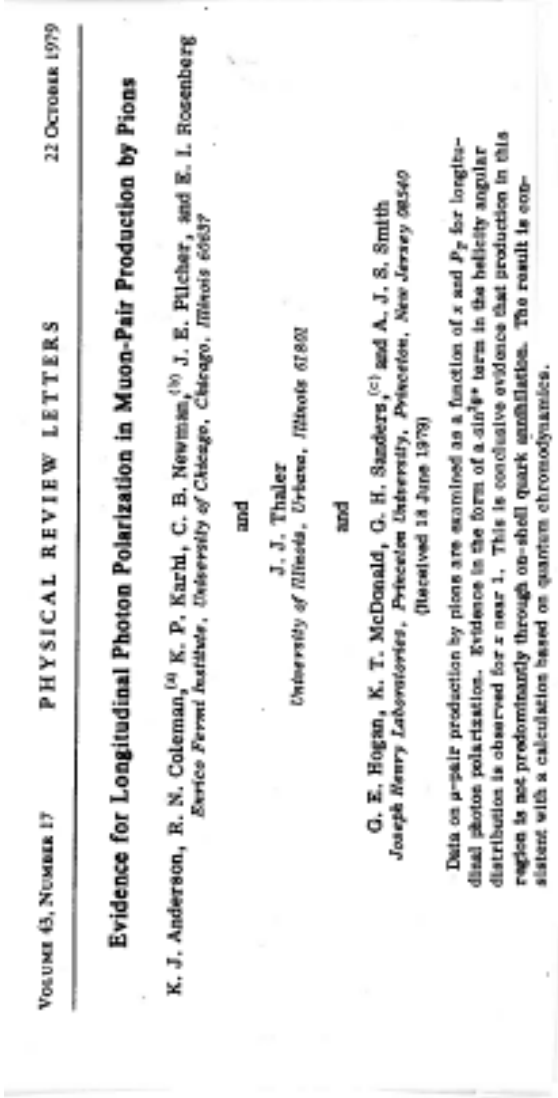


FIG. 3. The pion structure function $f^{\pi}(x_1) = x_1 \bar{u}^{\pi^-}(x_1)$.

Publications



VOLUME 43, NUMBER 17 PHYSICAL REVIEW LETTERS 22 OCTOBER 1979

Evidence for Longitudinal Photon Polarization in Muon-Pair Production by Pions

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(Received 18 June 1979)

Data on μ-pair production by pions are examined as a function of x and P_T for longitudinal photon polarization. Evidence in the form of a $\sin^2\theta^*$ term in the helicity angular distribution is observed for x near 1. This is conclusive evidence that production in this region is not predominantly through on-shell quark annihilation. The result is consistent with a calculation based on quantum chromodynamics.

VOLUME 44, NUMBER 20 PHYSICAL REVIEW LETTERS 19 MAY 1980

Limit on Bottom-Meson Pair Production in π^--Nucleus Interactions at 225 GeV/c

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(Received 28 February 1980)

In an experiment to measure multimuon final states in interactions of 225-GeV/c π^- with nuclear targets we have observed 65 300 $J/\psi \to \mu^+\mu^-$ decays, of which 487 are accompanied by a third muon. We have used this sample to search for production of bottom-meson pairs, followed by the decays $B \to J/\psi + X$, $\bar{B} \to \mu + X$. We find, supposing linear A dependence, that $\sigma(B\bar{B}) < 8$ nb/nucleon with 90% confidence. This limit is in contradiction with a recent report that $\sigma(B\bar{B}) \approx 200$ nb/nucleon.

PHYSICAL REVIEW D VOLUME 21, NUMBER 11 1 JUNE 1980

Search for additional muons in hadronic production of J/ψ particles

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(Received 28 January 1980)

A sample of $J/\psi \to \mu^+\mu^-$ decays produced by a 225-GeV/c π^- beam on nuclear targets has been analyzed for extra muons. Muons observed in coincidence with J/ψ production could indicate either the production of charmed particles or the production of pairs of J/ψ particles. We find 90% confidence limits of $\sigma_{J/\psi}/\sigma_J < 0.016$ for associated charm production and $\sigma_{J/\psi}/\sigma_J < 0.005$ for the production of J/ψ pairs.

Evidence for Longitudinal Photon Polarization in Muon Pair Production by Pions

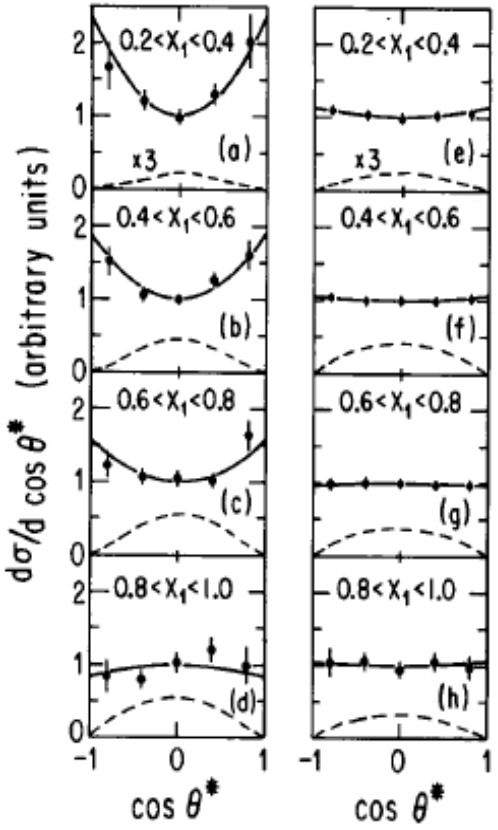

FIG. 1. $d\sigma/d\cos\theta^*$ in the t-channel helicity frame for various x_1 intervals. (a)–(d) Results for the mass continuum with $M > 4$ GeV; (e)–(h) results for the J/ψ resonance in the same x_1 intervals. Data are integrated over

- Recall Drell-Yan model predicted cross section ~ 1 + $\cos^2\theta^*$. These data are fit to 1 + $\alpha\cos^2\theta^*$ and deviations of α from 1 were observed, consistent with predictions from QCD.

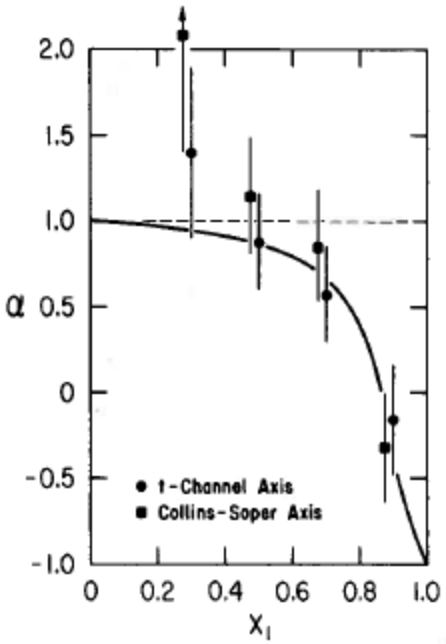

FIG. 2. The dependence of α on x_1 for data with $M > 4$ GeV. The dashed line is the expected result for the naive Drell-Yan model. The solid curve is the QCD prediction of Berger and Brodsky (Ref. 8).

Final Words

- E-444 was a great experiment.
- Enjoy your emeritus status, Jim!

Kelby Anderson

Jim Pilcher

Stew Smith

Rick Coleman and Jon Thaler