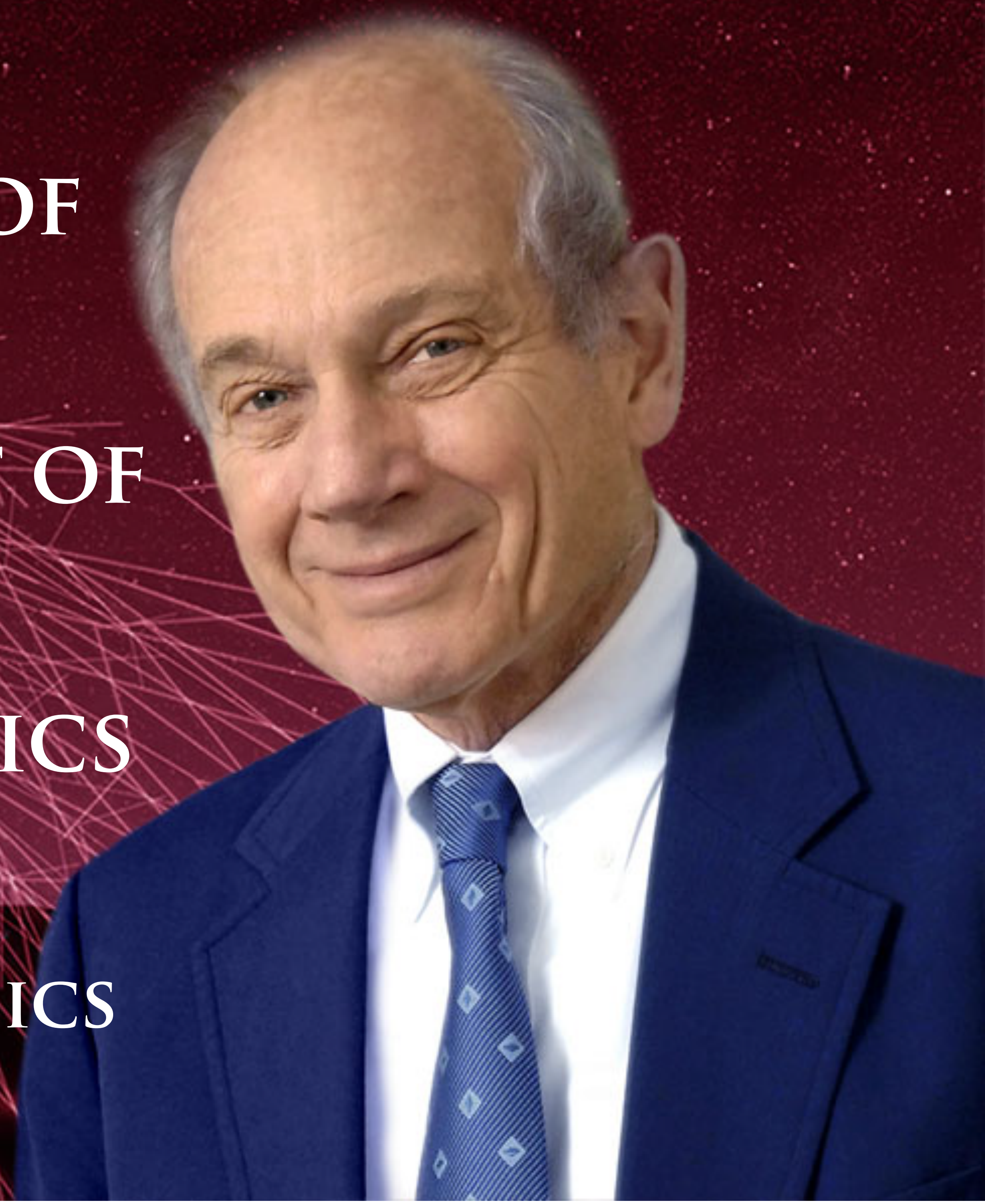
James W. Cronin (1931-2016)

NOBEL LAUREATE AND PIONEERING PHYSICIST



FROM THE DISCOVERY OF
CP-VIOLATION

OVER THE DEVELOPMENT OF
THE PARTON-MODEL

TO ASTROPARTICLE PHYSICS
AND AUGER:

RAISING THE PROFILE OF PHYSICS
WORLDWIDE

K.-H. Kampert BERGISCHE UNIVERSITÄT WUPPERTAL with contributions by Stewart Smith, Henry Frisch, A. Watson, P. Privitera, and P. Mantsch

A Life in High-Energy Physics: Success Beyond Expectations

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Keywords

hyperons, *K* mesons, elementary particles, autobiography, experimental physics, *CP* violation

Abstract

The author describes in some technical detail his career in experimental particle physics. It began in 1955, when he joined Brookhaven National Laboratory, and ended in 1985, when he moved to the field of cosmic-ray physics. The author discusses not only his successes but also his failures and his bad judgments. This period was the golden age of particle physics, when the experimental possibilities were abundant and one could carry out experiments with a small team of colleagues and students.

Partial Chronology

Sep 29,1931 Born in Chicago (Father was UC GS)

1936 – 1939 Marion, Alabama

1939 – 1951 Public school in Dallas, Texas

1948 – 1951 Undergraduate, Southern Methodist University

1st paper as undergraduate on studies with electric eels: Curtis L, Cronin JW. *Proc. Tex. Acad. Sci.* 1:41 (1952)

1951 – 1955 Graduate student, U. Chicago

Teachers included: Fermi, Teller, Goeppert- Mayer, Gell-Mann, Telegdi, and Chandrasekhar

1955 – 1958 Postdoctoral scientist, Brookhaven Lab

1958 – 1971 Faculty member, Princeton Univ.

1963 – 1964 CP Violation!!

1971 – 1996 Distinguished Professor, U. Chicago

1980 Nobel Prize in Physics

1996 – 2016 Distinguished Professor Emeritus

PhD Thesis: 1953-1955

Title:

Excitation functions and angular distributions of alpha particles leading to the ground and first excited states of Be^7 in the reaction B^{10} (p,α) Be^7

(Cronin JW., Phys. Rev. 101:298 (1956); 13 citations)

Annu. Rev. Nucl. Part. Sci. 64, 1 (2014)

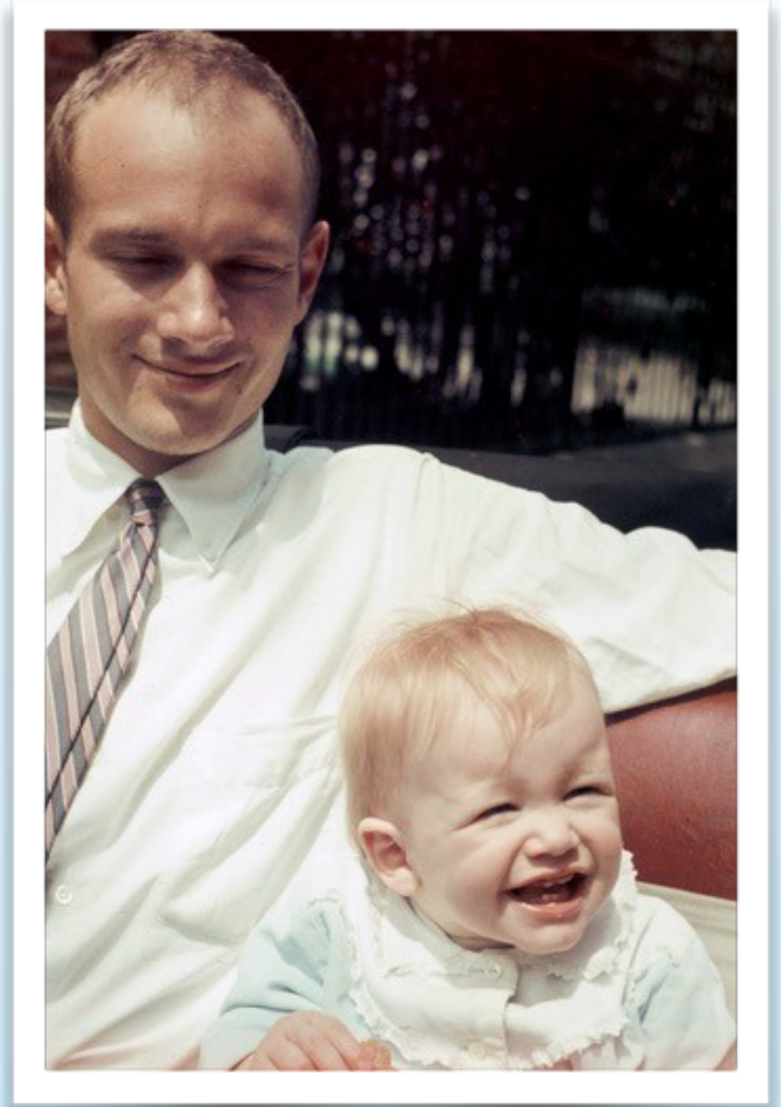
Measurements performed at 2 MeV Van de Graaff Accelerator

Jim's work at Brookhaven: 1955-1958

- Married and with a new baby, in 1955 Jim accepted an assistant scientist position at Brookhaven National Laboratory to work in a group led by Rod Cool and Oreste Piccioni.
- At the Cosmotron, a new 3 GeV proton accelerator, they measured absorption and diffractive cross sections of pions on nuclei. Jim used the optical model to find that a Fermi distribution with reasonable radius and skin width fit the data extremely well.
- In 1957 Jim had just built an innovative K^+ meson detector in anticipation of measuring more total cross sections. However, at this time parity violation was discovered by Wu.
- So Jim and Cool used it instead to search for parity-violating asymmetries in as many weak decays as possible, including Σ^+ and Σ^- hyperons.
- Had to use the Berkeley Bevatron because the Cosmotron was out of action.
- Their measurements were suggestive but not conclusive.
- The experience at Berkeley inspired Jim "to do it right".

„I had found in my character a strong desire to contribute significantly to any project in which I was involved.“ JWC in Annu. Rev. Nucl. Part. Sci. 64, 1 (2014)

Life at BNL



With their new baby Cathryn, Jim and Annette greatly enjoyed the Brookhaven experience, including the beaches.

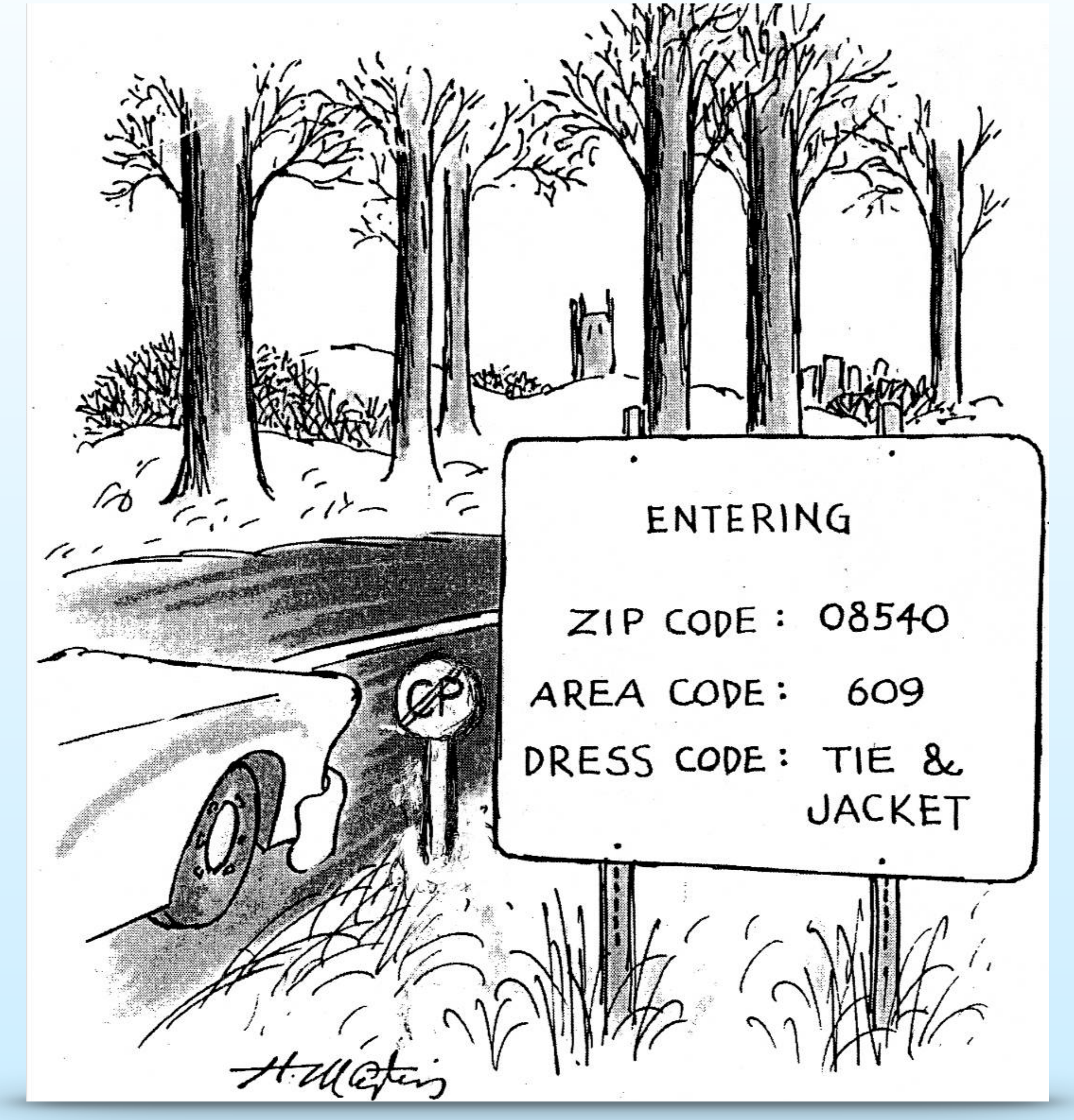
Brookhaven was arguably the center of the particle physics universe
A satirical restaurant guide rated the BNL cafeteria as "the worst," with the comment
"we just don't understand why people come from all over the world to eat here."

courtesy Stewart Smith, Chicago, Oct. 2016

1958: From BNL to Princeton

Val Fitch got to know Jim at the Cosmotron, as a “neighbor” and as a bridge companion.

Even though Jim’s list of publications was a bit thin, Val managed to bring Jim to Princeton as assistant professor at the age of 27!



courtesy S. Smith, Chicago, Oct. 2016

1959-1960: From Counters to Spark Chambers

A brief stint with a bubble chamber experiment showed Jim the power of visual tracking:
In 1959, Fukui & Miyamoto introduced the "discharge chamber". Jim quickly tested and improved this technology, called it the „spark chamber", and immediately designed experiments around it. Counters and fast logic selected interesting events at 1 MHz!

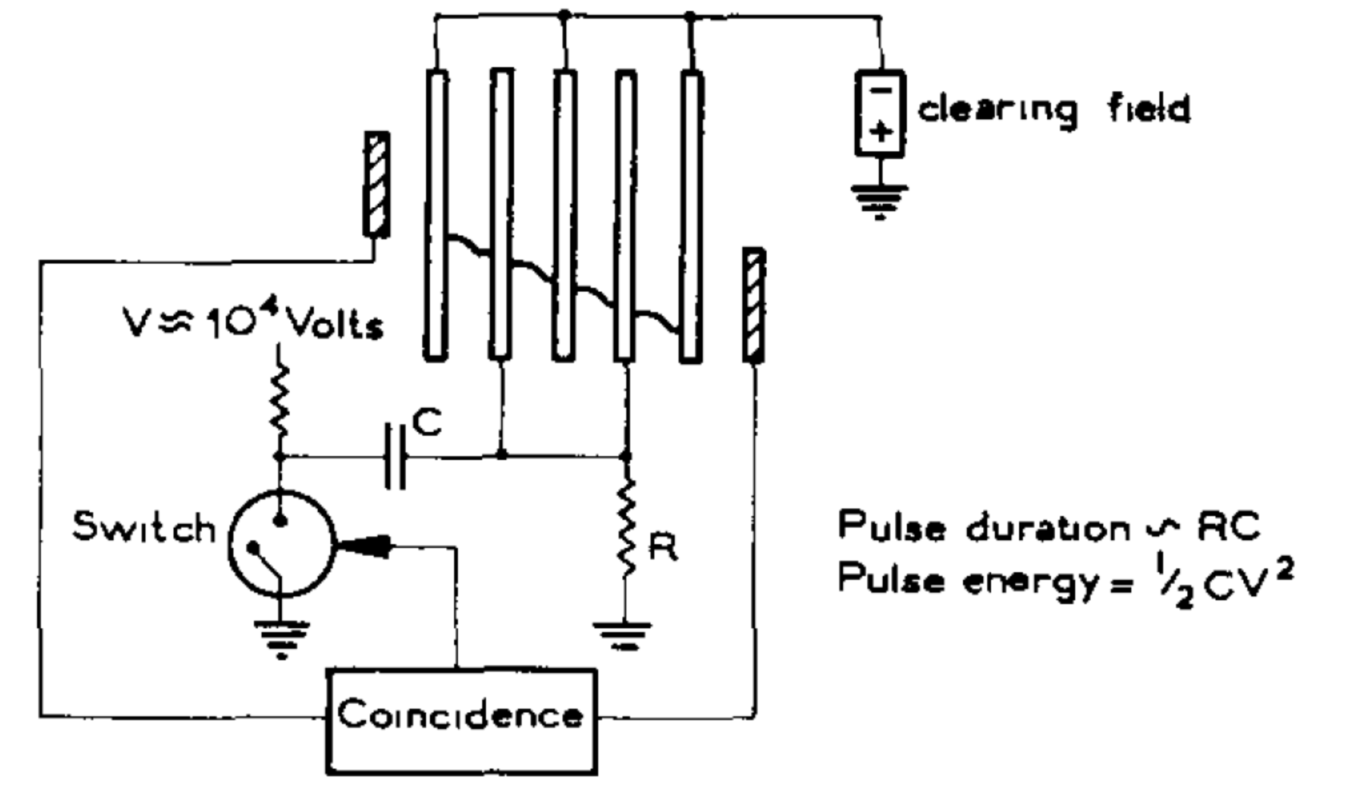
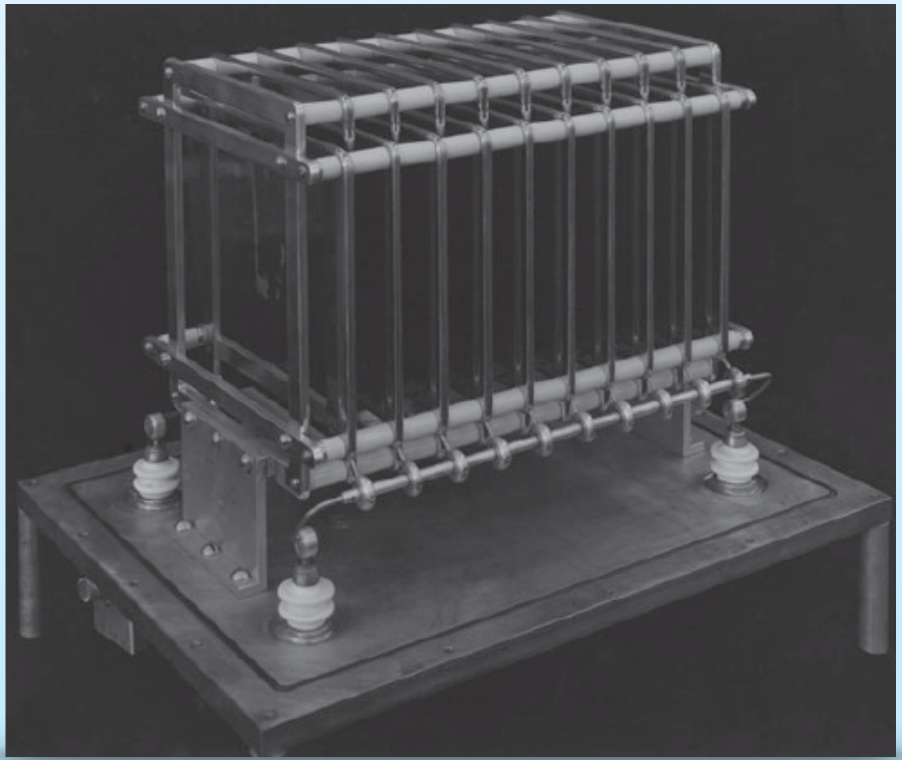
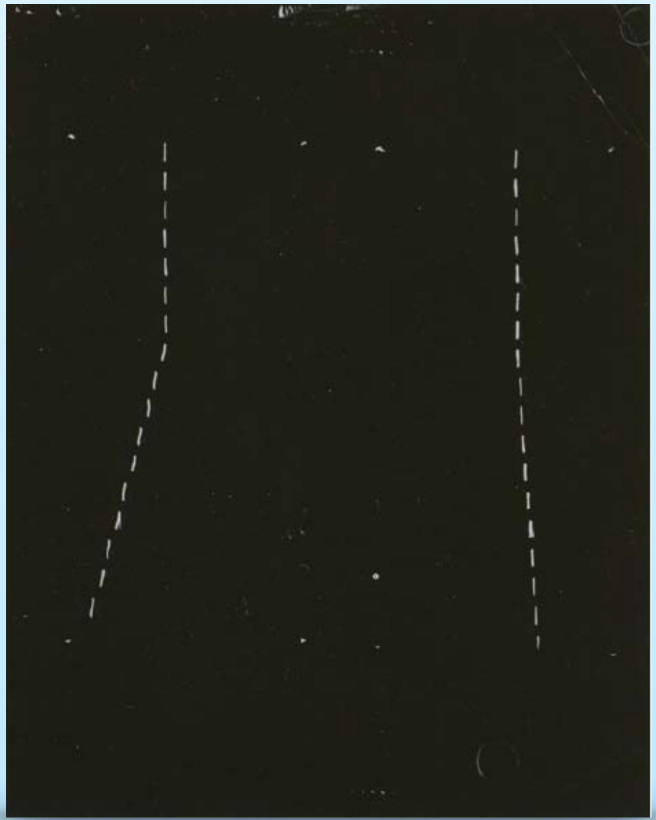


Fig 1 Schematic view of a 4-gap spark chamber



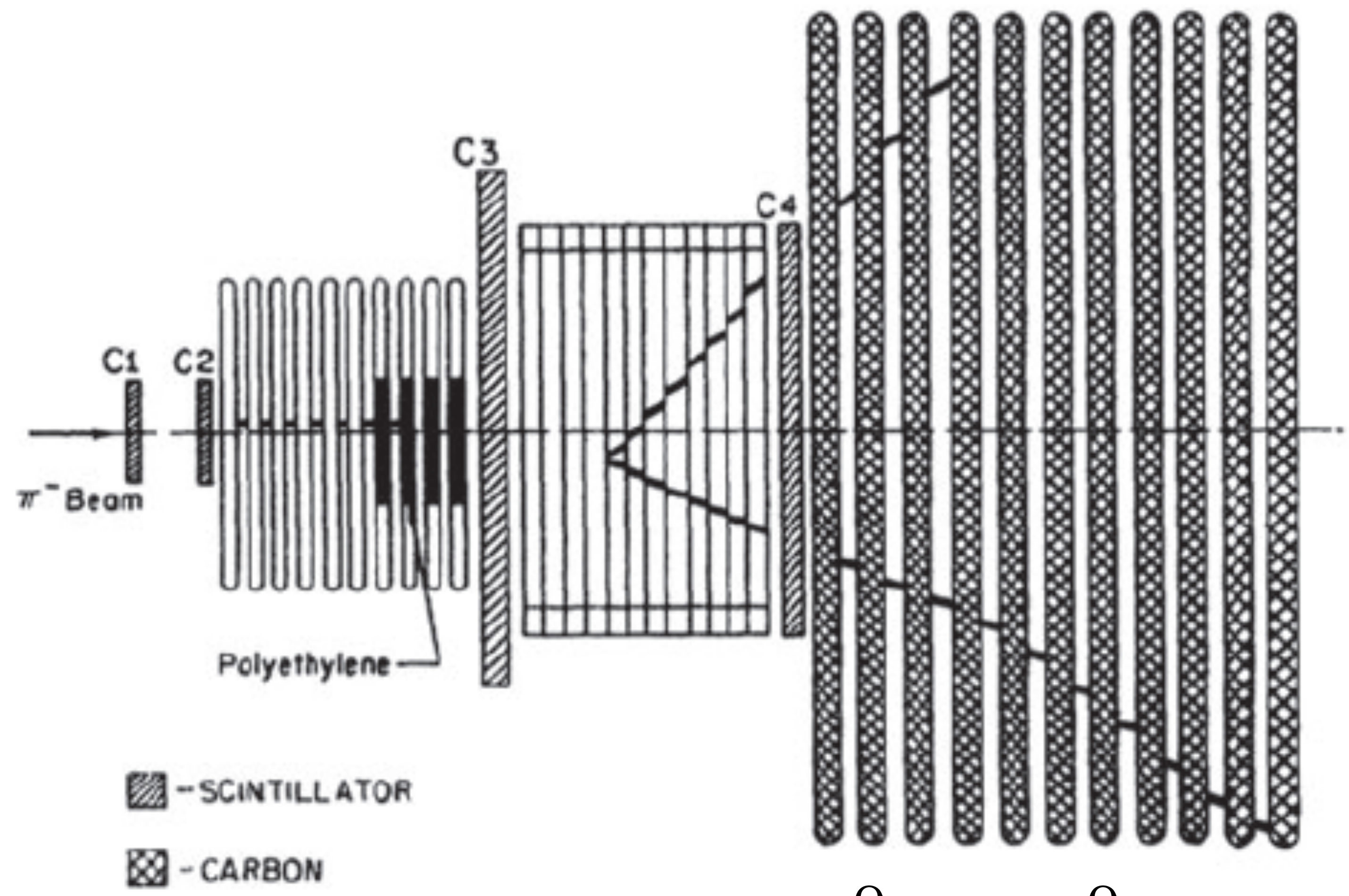
Jim's 18-gap spark chamber



Orthogonal view of a scattered proton

Jim was invited to give the plenary talk on spark chambers at the 1962 International Conference on Instrumentation held at CERN

A 3-Spark-Chamber Experiment



$$\pi^- + p \rightarrow \Lambda^0 + K^0$$

spark chambers and scintillators to study asymmetries and proton polarization in Λ^0 decay.

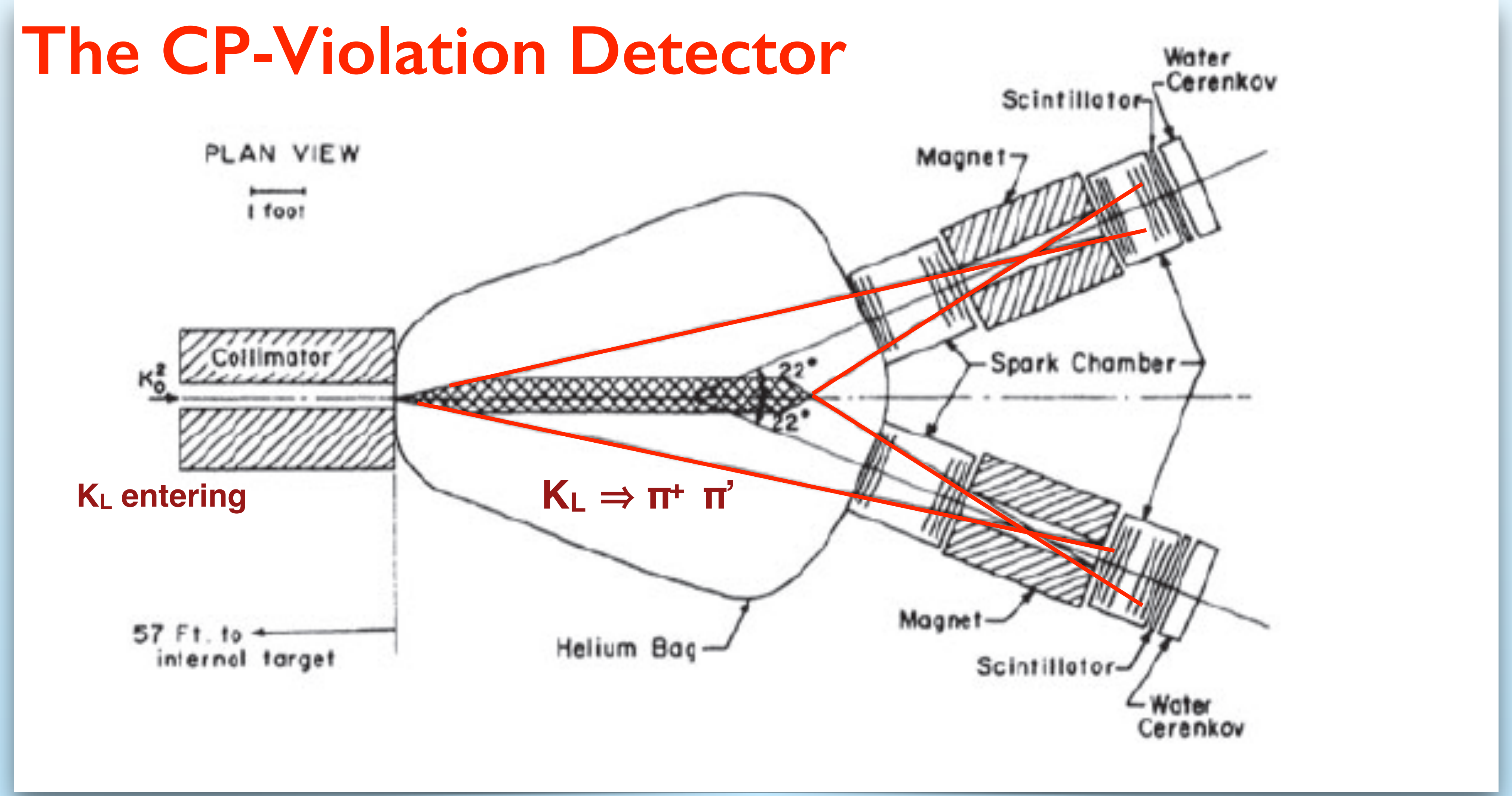
Longitudinal proton polarisation in Λ^0 decays: **parity violation polarisation**.
As a by-product, lifetimes of the Λ^0 hyperon and K^0 meson were measured

Jim builds a Pair-Spectrometer

... a fateful move!

For his next experiment, in 1961 Jim designed a high-resolution pair spectrometer for an experiment at the Cosmotron, to study the production cross section and line shape of the recently discovered ρ^0 meson, via its decay $\rho^0 \rightarrow \pi^+\pi^-$.

In spring 1963, Val Fitch proposed moving Jim's spectrometer to a neutral beam at the new AGS, to study interesting phenomena in decays of the long-lived neutral K-meson.



Primary goal was to verify anomalously large regeneration of K_S mesons in hydrogen, as observed by Adair

2 Page Proposal for CP-Experiment

PROPOSAL FOR K^o_2 DECAY AND INTERACTION EXPERIMENT

J. W. Cronin, V. L. Fitch, R. Turlay

(April 10, 1963)

I. INTRODUCTION

The present proposal was largely stimulated by the recent anomalous results of Adair et al., on the coherent regeneration of K^o_1 mesons. It is the purpose of this experiment to check these results with a precision far transcending that attained in the previous experiment. Other results to be obtained will be a new and much better limit for the partial rate of $K^o_2 \to \pi^+ + \pi^-$, a new limit for the presence (or absence) of neutral currents as observed through $K_2 \to \mu^+ + \mu^-$. In addition, if time permits, the coherent regeneration of K_1's in dense materials can be observed with good accuracy.

II. EXPERIMENTAL APPARATUS

Fortuitously the equipment of this experiment already exists in operating condition. We propose to use the present 30° neutral beam at the A.G.S. along with the di-pion detector and hydrogen target currently being used by Cronin, et al. at the Cosmotron. We further propose that this experiment be done during the forthcoming μ-p scattering experiment on a parasitic basis.

The di-pion apparatus appears ideal for the experiment. The energy resolution is better than 4 Mev in the m^* or the Q value measurement. The origin of the decay can be located to better than 0.1 inches. The 4 Mev resolution is to be compared with the 20 Mev in the Adair bubble chamber. Indeed it is through the greatly improved resolution (coupled with better statistics) that one can expect to get improved limits on the partial decay rates mentioned above.

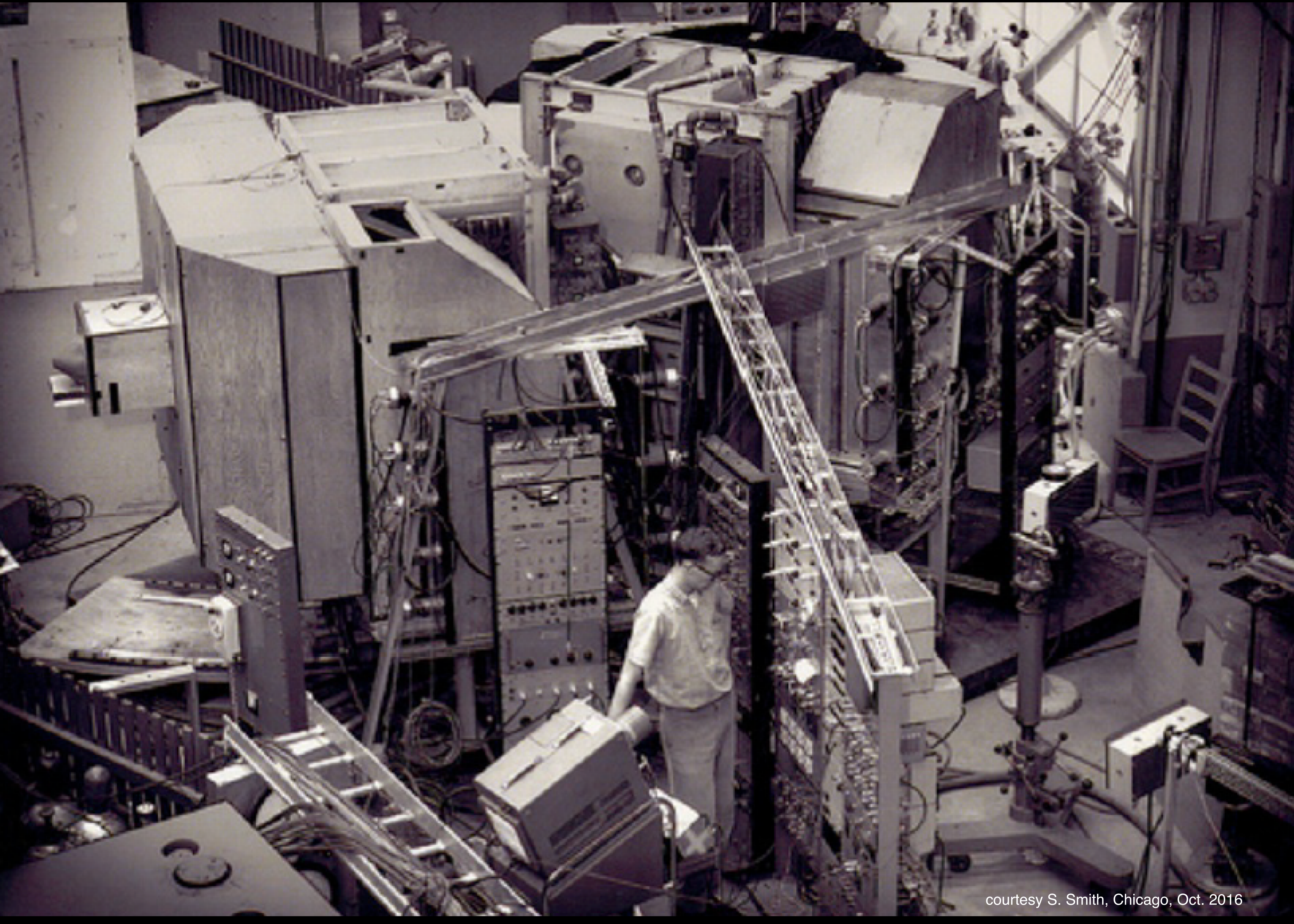
III. COUNTING RATES

We have made careful Monte Carlo calculations of the counting rates expected. For example, using the 30° beam with the detector 60-ft. from the A.G.S. target we could expect 0.6 decay events per 10^{11} circulating protons if the K_2 went entirely to two pions. This means that one can set a limit of about one in a thousand for the partial rate of $K_2 \to 2\pi$ in one hour of operation. The actual limit is set, of course, by the number of three-body K_2 decays that look like two-body decays. We have not as yet made detailed calculations of this. However, it is certain that the excellent resolution of the apparatus will greatly assist in arriving at a much better limit.

If the experiment of Adair, et al. is correct the rate of coherently regenerated K_1's in hydrogen will be approximately 80/hour. This is to be compared with a total of 20 events in the original experiment. The apparatus has enough angular acceptance to detect incoherently produced K_1's with uniform efficiency to beyond 15°. We emphasize the advantage of being able to remove the regenerating material (e.g., hydrogen) from the neutral beam.

IV. POWER REQUIREMENTS

The power requirements for the experiment are extraordinarily modest. We must power one 18-in. x 36-in. magnet for sweeping the beam of charged particles. The two magnets in the di-pion spectrometer are operated in series and use a total of 20 kw.

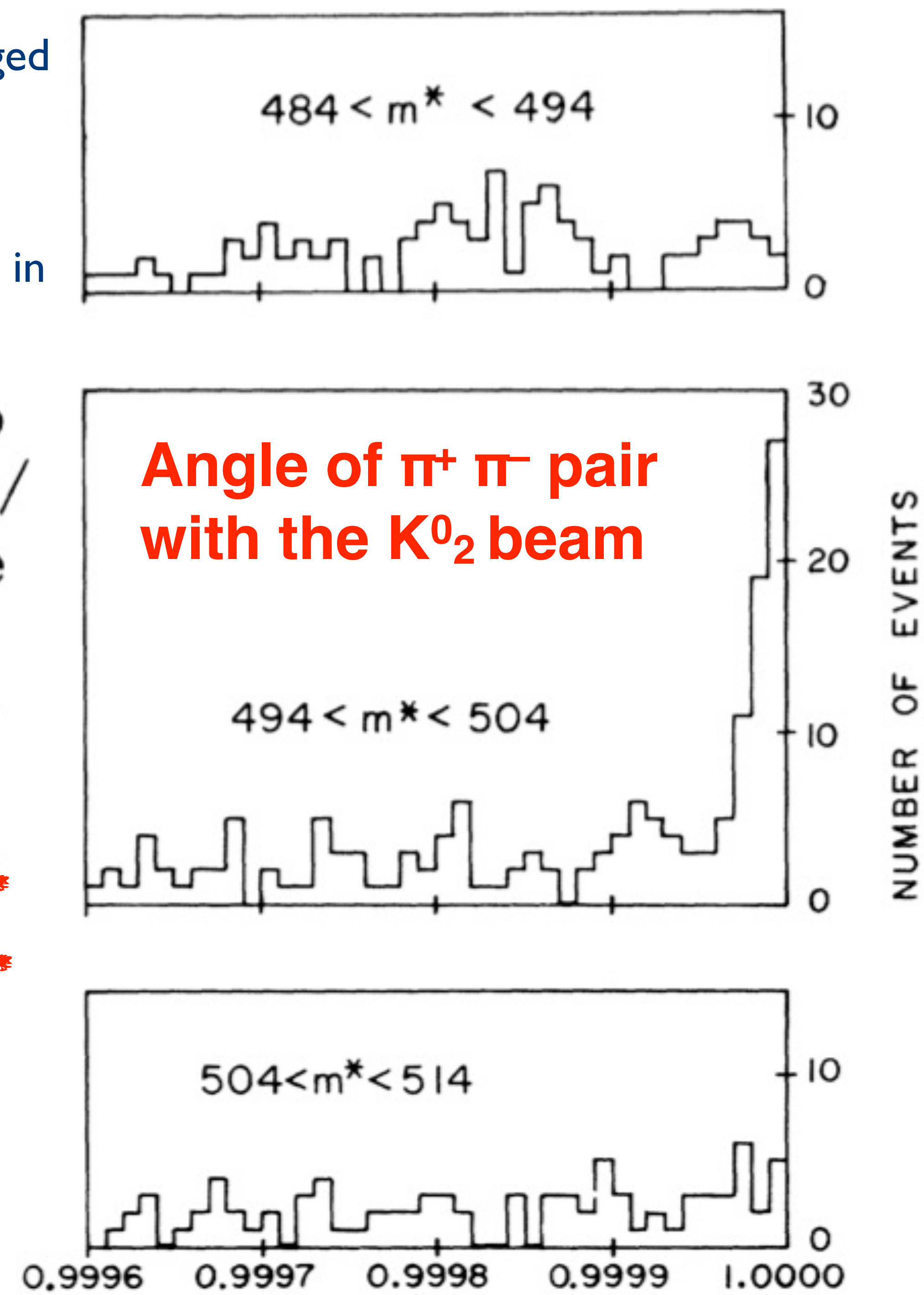

courtesy S. Smith, Chicago, Oct. 2016

EVIDENCE FOR THE 2π DECAY OF THE K_2^0 MESON*†

J. H. Christenson, J. W. Cronin,‡ V. L. Fitch,‡ and R. Turlay§
Princeton University, Princeton, New Jersey
(Received 10 July 1964)

m^* is the effective mass of the two charged particles, assuming each is a pion.

For a vacuum decay, the direction of the vector sum of the 2π momenta must lie in the direction of the beam.



cos Θ with respect to the K^0_2 beam

We would conclude therefore that K_2^0 decays to two pions with a branching ratio $R = (K_2 \to \pi^+ + \pi^-)/(K_2^0 \to \text{all charged modes}) = (2.0 \pm 0.4) \times 10^{-3}$ where the error is the standard deviation. As emphasized above, any alternate explanation of the effect requires highly nonphysical behavior of the three-body decays of the K_2^0. The presence of a two-pion decay mode implies that the K_2^0 meson is not a pure eigenstate of CP. Expressed as

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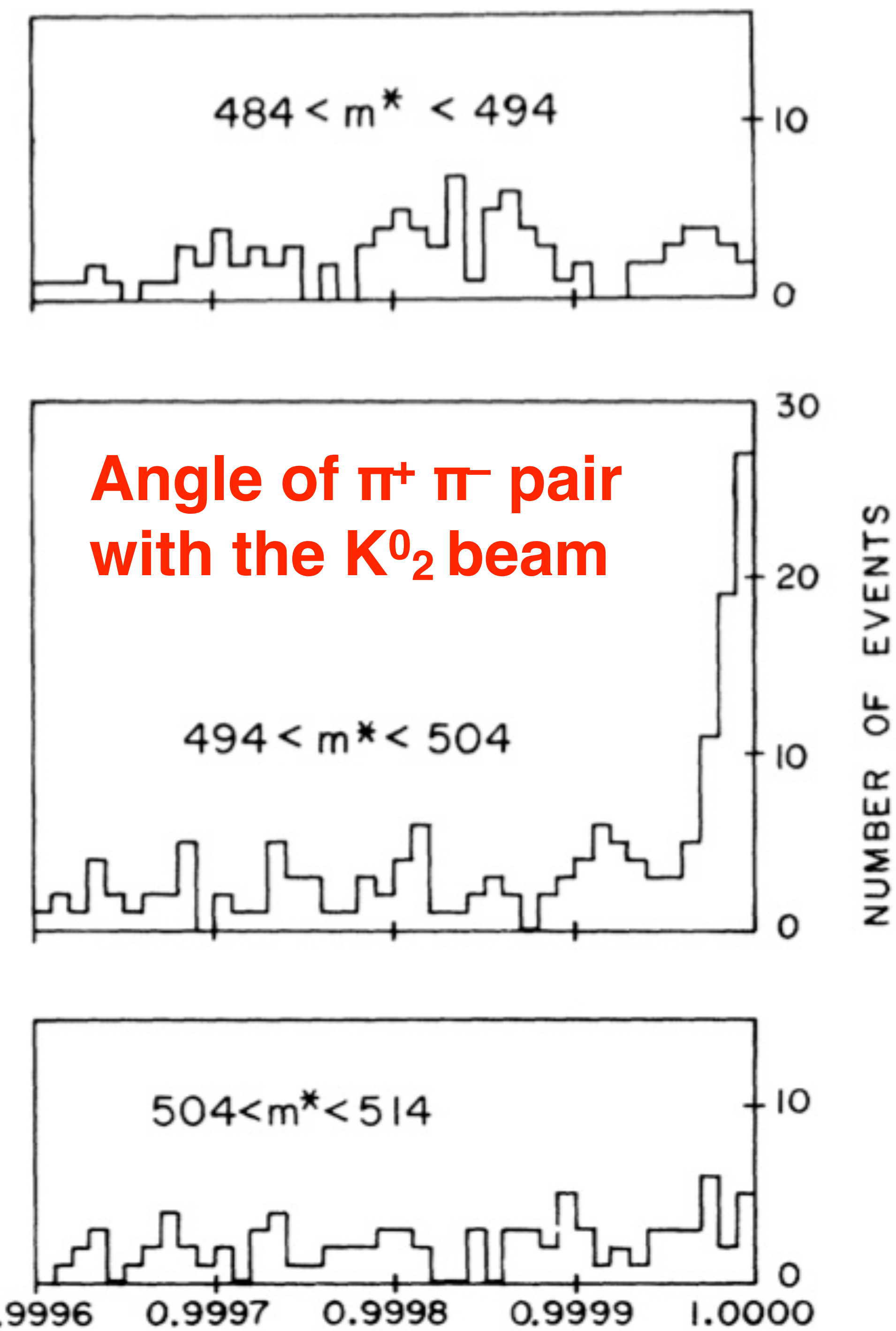

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Much more work was needed to fully establish the effect and measure

$$(K_L \rightarrow 2\pi^0)/(K_L \rightarrow 3\pi^0) = (19 \pm 3) \cdot 10^{-3}$$

„nothing to nothing“

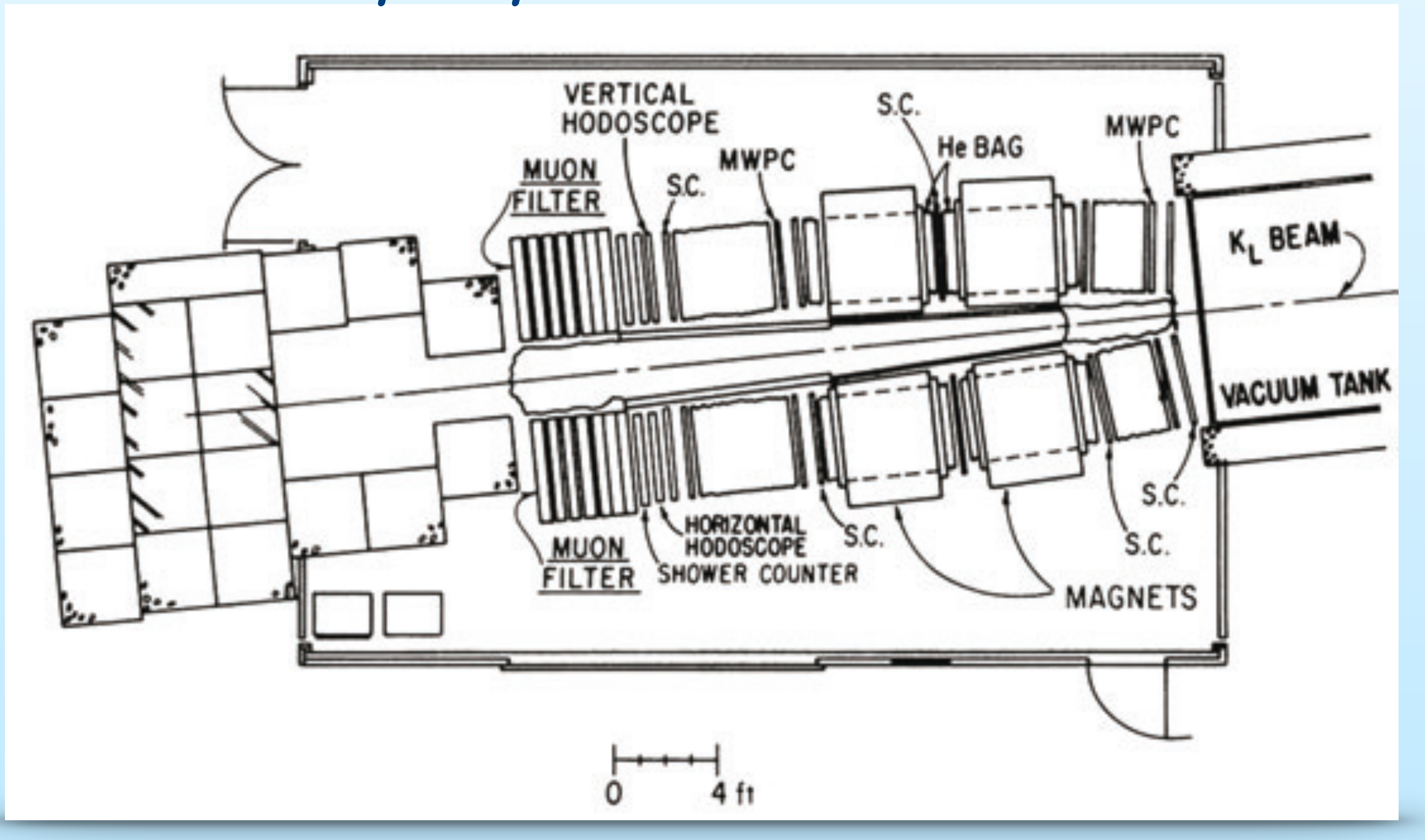
1971: Move to Chicago

1970-71: Sabbatical at new NAL (now FNAL) to look for new area of research

1971: Received an offer; accepted because of experimental opportunities

$$K_L \to \mu^+ \mu^-$$

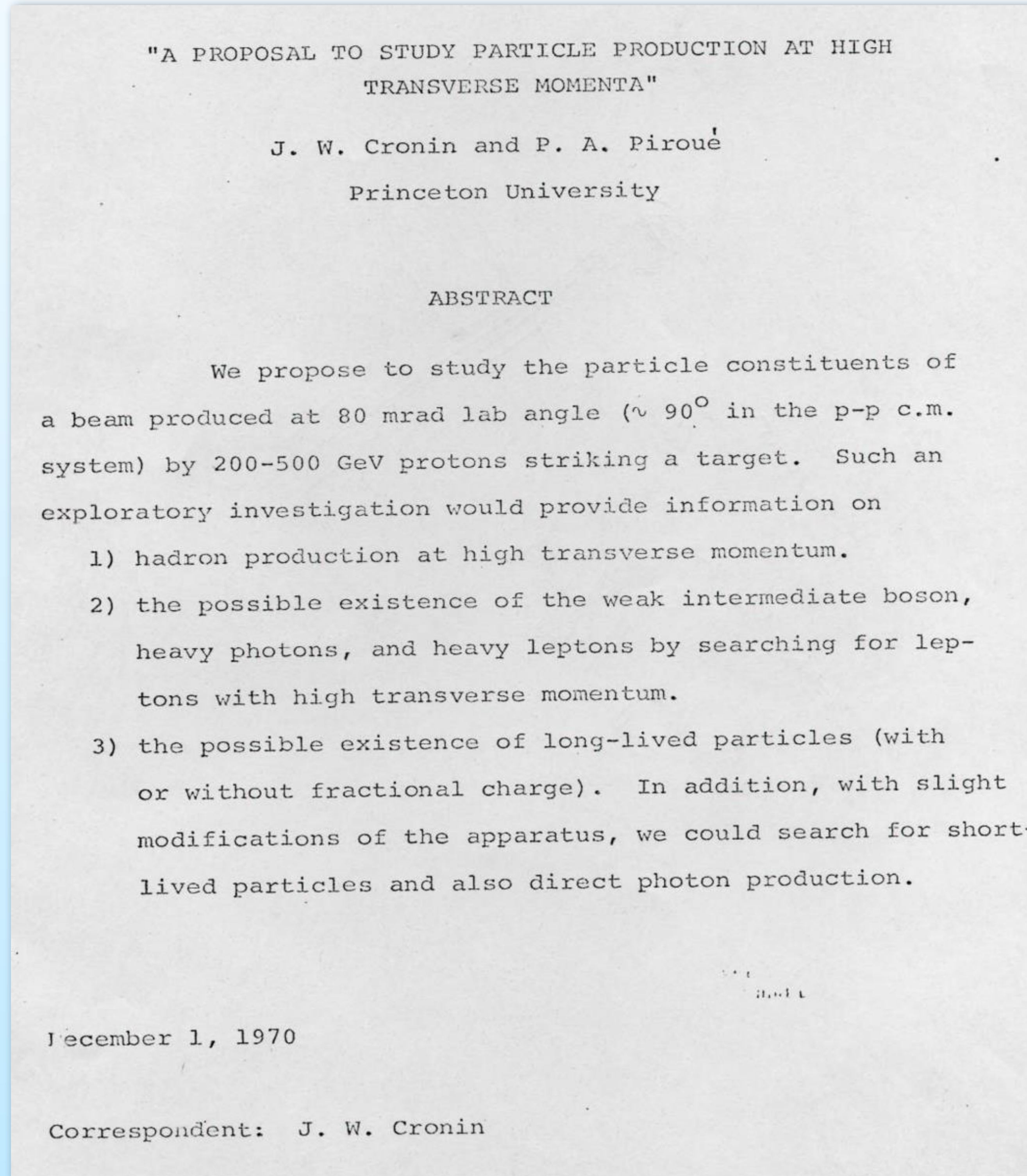
R=$(7.18 \pm 0.17) \times 10^{-9}$



The Parton Model

1970: R. Feynman gave a talk at NAL about the parton model arguing that all the physics happens at low p_T.

Jim with his French colleague Pierre Piroué planned to use their *μ*-spectrometer to look for large p_T muons.
⇒ E100 (1970-77)



"A PROPOSAL TO STUDY PARTICLE PRODUCTION AT HIGH TRANSVERSE MOMENTA"

J. W. Cronin and P. A. Piroué

Princeton University

ABSTRACT

We propose to study the particle constituents of a beam produced at 80 mrad lab angle (∿ 90° in the p-p c.m. system) by 200-500 GeV protons striking a target. Such an exploratory investigation would provide information on

1) hadron production at high transverse momentum.
2) the possible existence of the weak intermediate boson, heavy photons, and heavy leptons by searching for leptons with high transverse momentum.
3) the possible existence of long-lived particles (with or without fractional charge). In addition, with slight modifications of the apparatus, we could search for short-lived particles and also direct photon production.

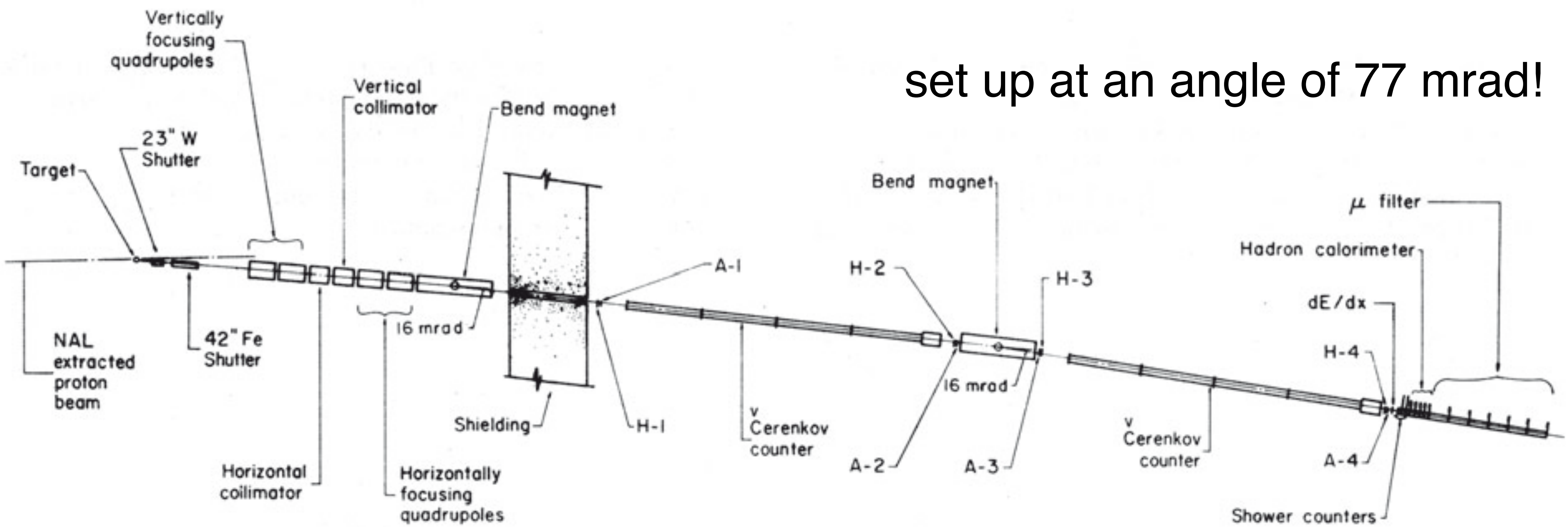
Iecember 1, 1970

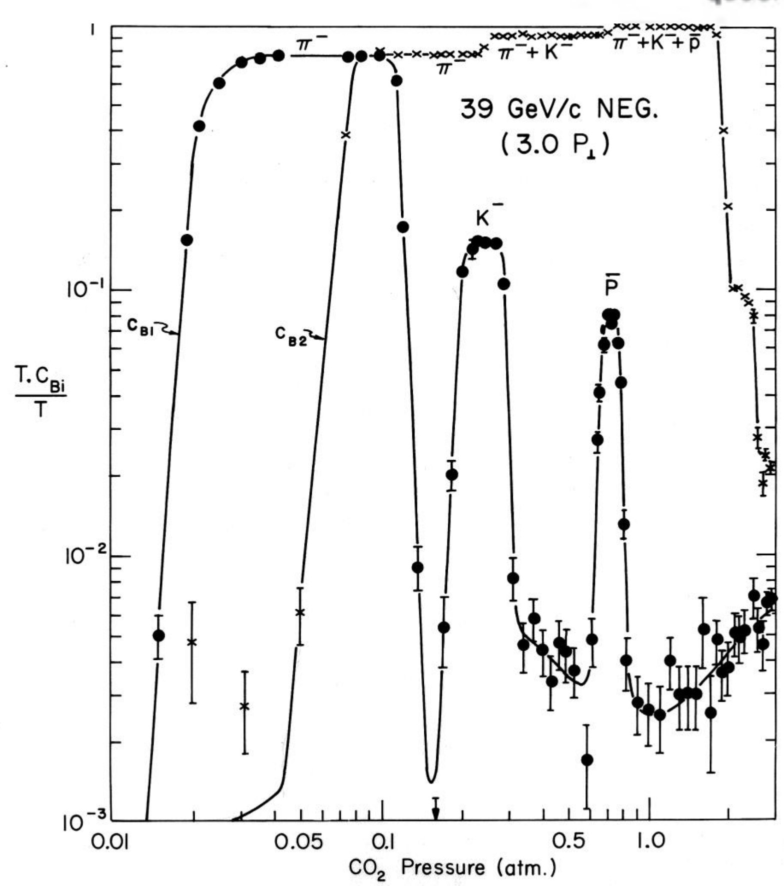
Correspondent: J. W. Cronin

courtesy S. Smith, Chicago, Oct. 2016

The High-p_T Spectrometer

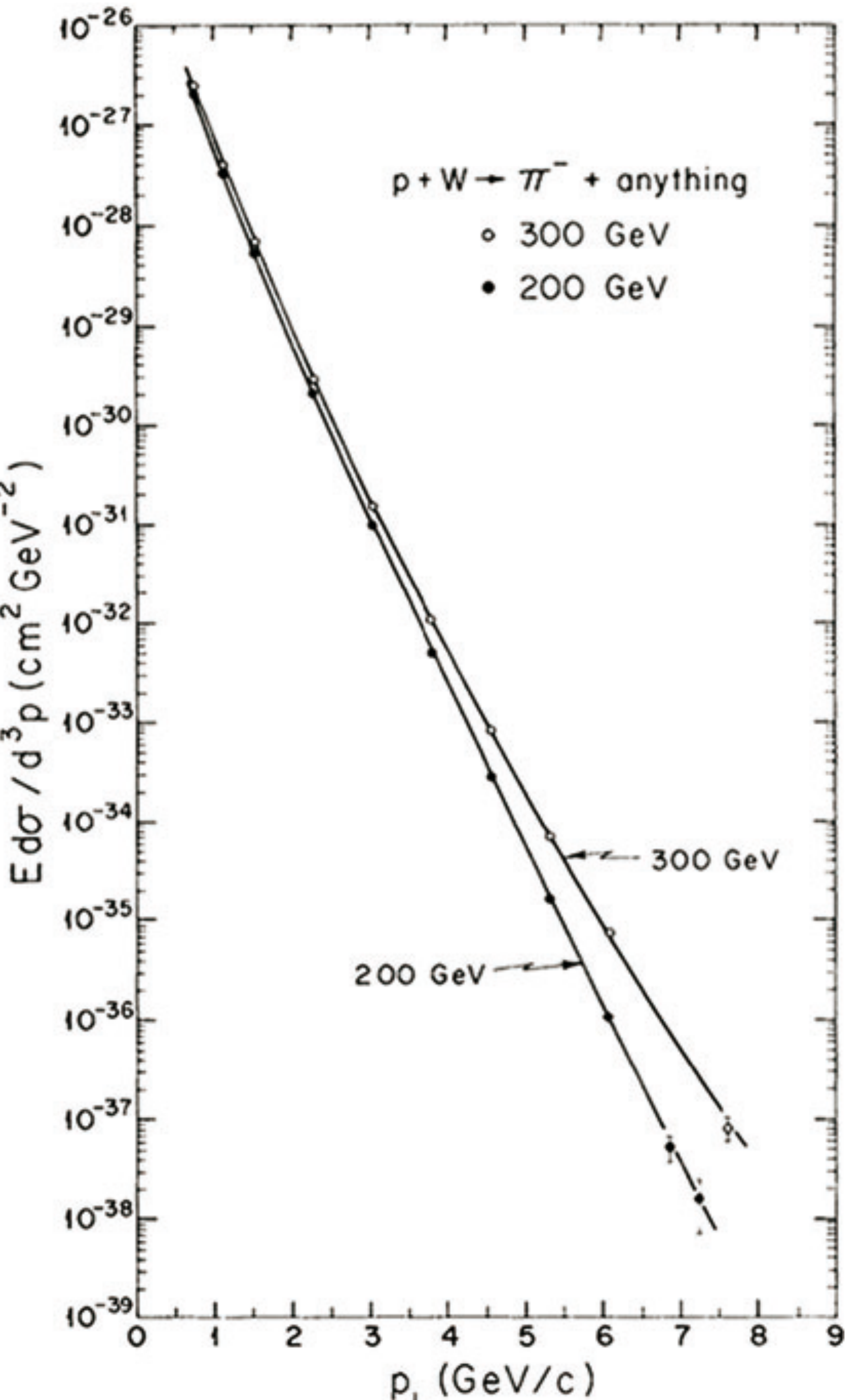
set up at an angle of 77 mrad!





Very clean particle identification by C-counters!

See Power-Law behaviour and E-dependence

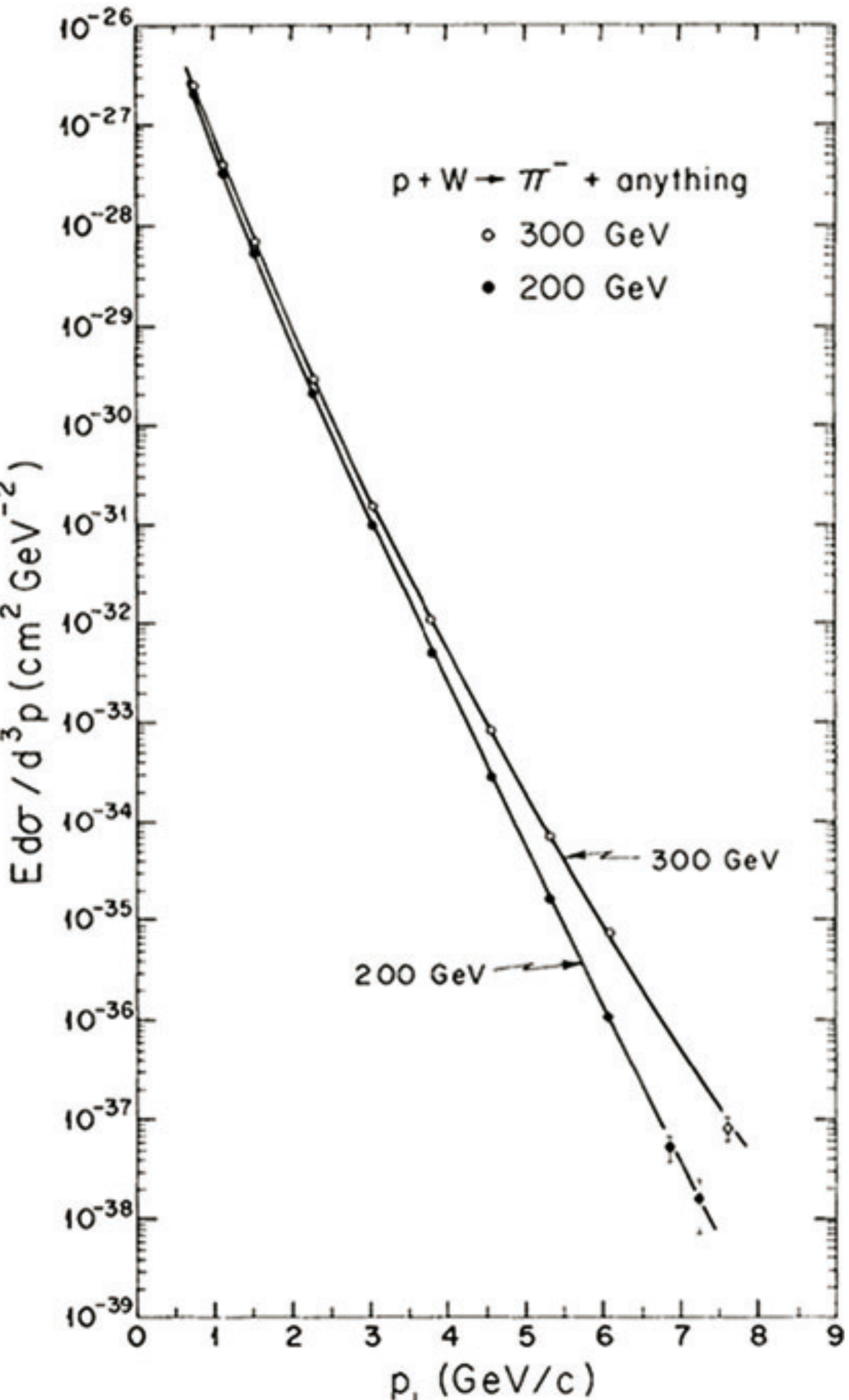


p_T reaches close to kinematical limit of 11.9 GeV/c!

at large p_T the cross is a strong function of E_{beam}

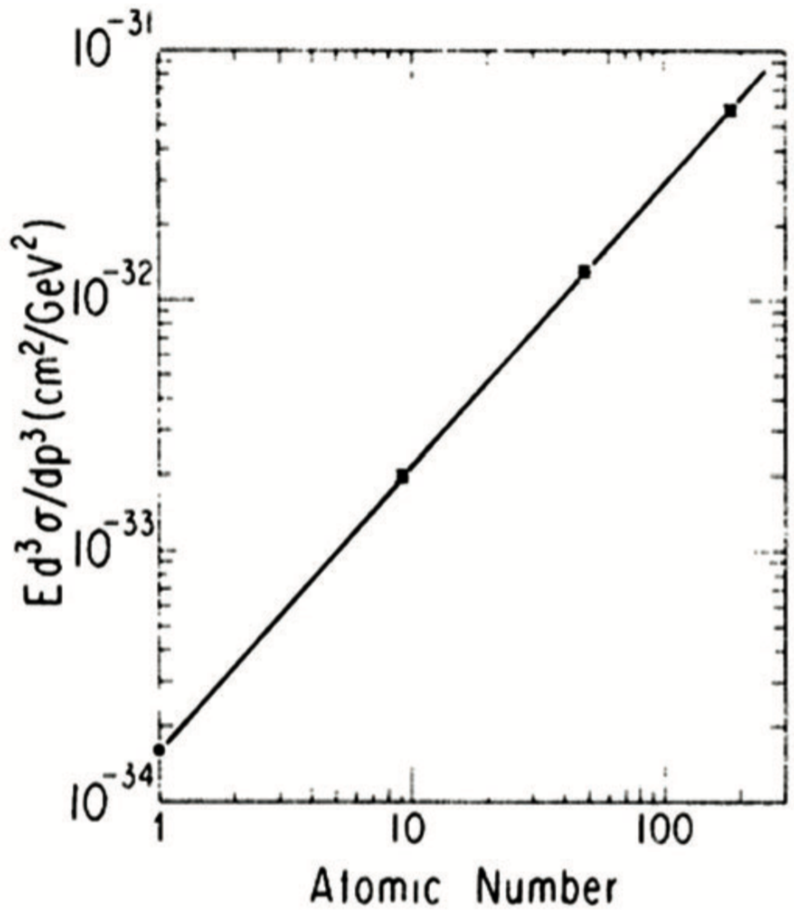
Phys. Rev. D11 (1975)

See Power-Law behaviour and E-dependence



p_T reaches close to kinematical limit of 11.9 GeV/c!

at large p_T the cross is a strong function of E_{beam}
and of **mass** number !



Phys. Rev. D11 (1975)

$$E\frac{d^3\sigma}{dp^3} \propto A^\alpha$$

expect α ≈ ⅔
find: α > 1 !

Known as **„Cronin-Effect"** by multiple parton scattering in nuclei

16 years after discovery of CP-violation: Stockholm 1980

Jadwin Hall of Fame

In 1980, Jim was still working with his younger colleague Bruce Winstein on |ε'/ε| , planning a new experiment…

Because of Jim's Noble prize, it was then difficult for Bruce to get recognition for his work, so Jim decided to let him go and look for something else.

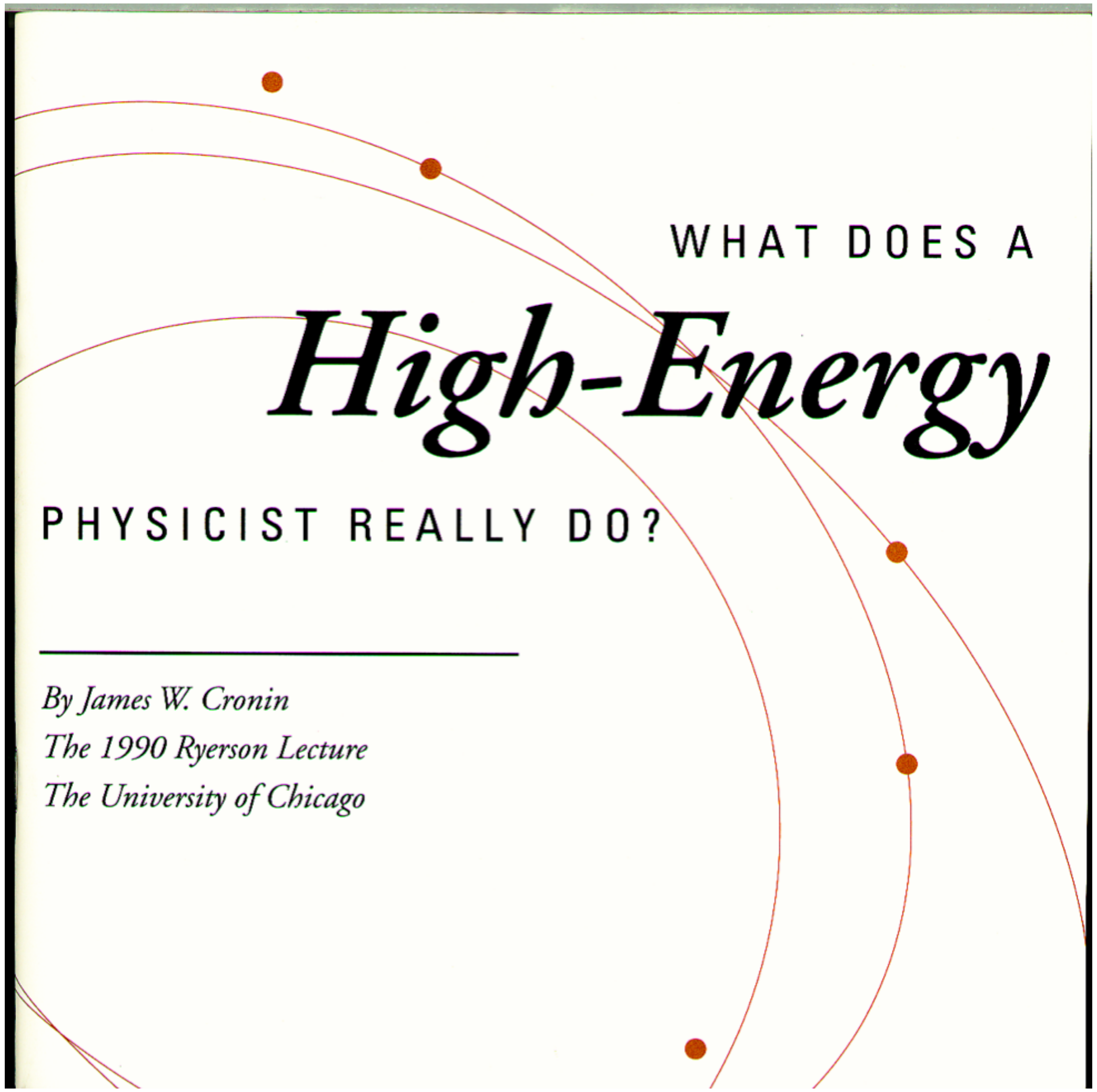
⇒ sabbatical at CERN 1982/83

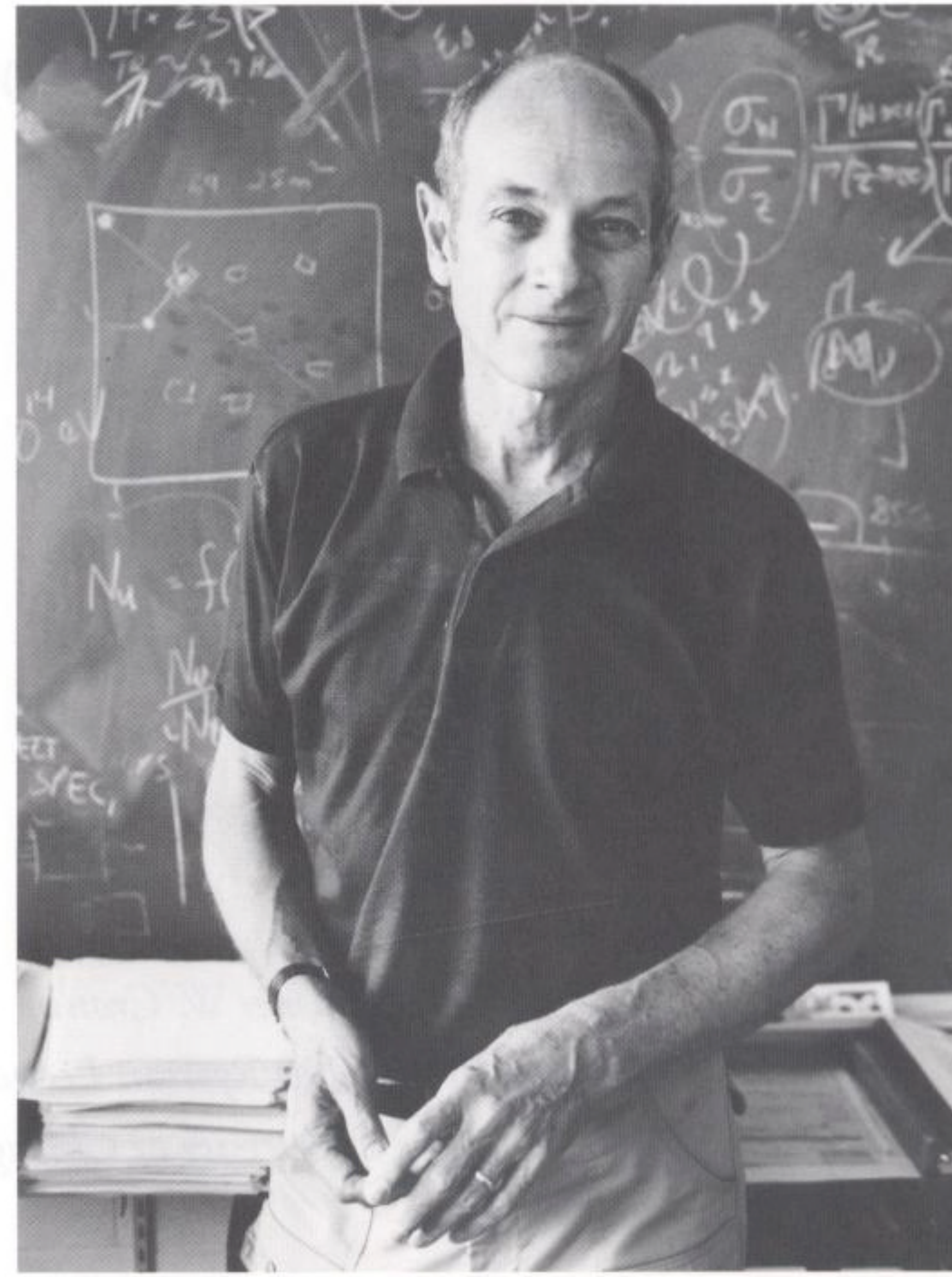
„I wanted to revisit for the last time the experience of a conceptually simple measurement that could be carried out with a small group.“

⇒ Measured π^0 lifetime with a 10 kCHF CERN budgeted experiment. This was his last experiment in particle physics.

„Important as these future experiments were, I realized that they would take place with or without me.
For any future experiment in which I would participate, I wanted to make a difference even if the experiment was not of the greatest importance. Thus, I began to look for other areas of research.“

Annu. Rev. Nucl. Part. Sci. 64, 1 (2014) courtesy Paolo Privitera, Chicago, Oct. 2016



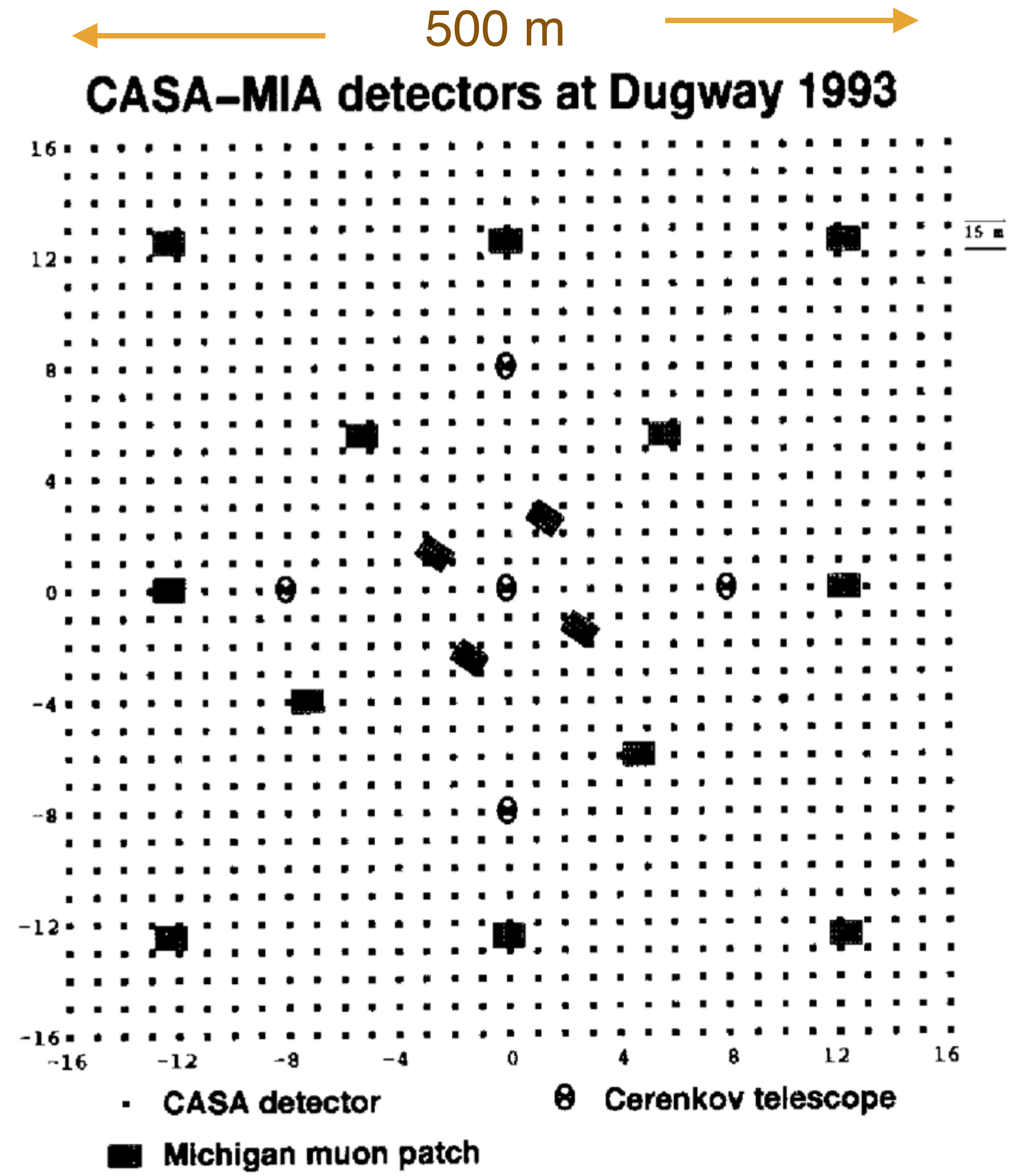


Jim speaking of the CASA array:

This is the way a high-energy physicist attacks this problem. It's large; it's brute force; just make it big and let's see if there's anything there. There are, in fact, some nice

The Chicago Air Shower Array (CASA)

courtesy Paolo Privitera, Chicago, Oct. 2016



1089 detectors with 15 m spacing covering an area of ~ 500 m x 500 m

> ten times bigger than previous detectors

The Legacy of CASA-MIA

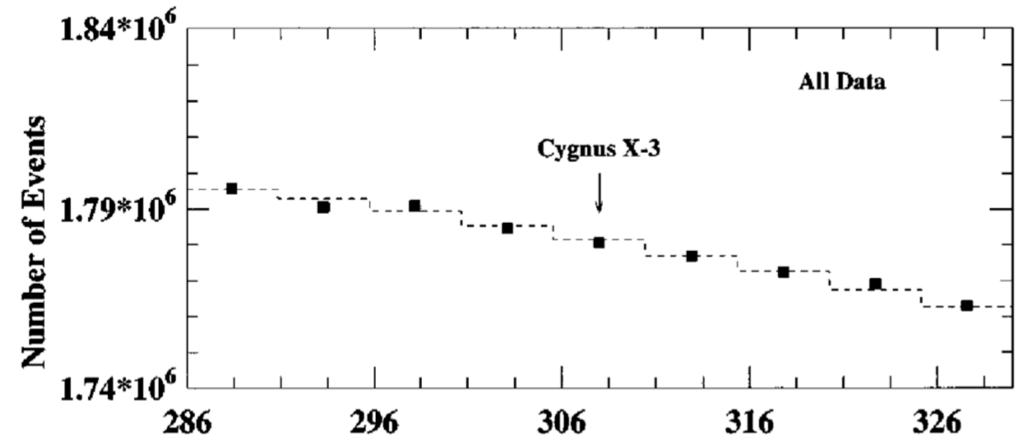
courtesy Paolo Privitera, Chicago, Oct. 2016

Gamma-ray astronomy by the air shower technique: Performance and perspectives (*)

J. W. CRONIN

Department of Physics and Enrico Fermi Institute, University of Chicago Chicago, IL 60637, USA

(*) Invited talk given at the XXIV International Cosmic-Ray Conference, Rome, August 28-September 8, 1995.



The large arrays, built to exploit the tantalizing results from Cygnus X-3, have completed their mission with the disappointing result that this and other similar sources of 100 TeV γ-rays do not exist. A number of groups are modifying their

the next few years we can expect great progress in this area. Thirdly, the new arrays have brought new researchers to cosmic rays, who, once introduced to the field, are extending their interests to γ-ray astronomy with the air Cherenkov technique, to neutrino astronomy, and to the study of the highest-energy cosmic rays.

This brought Jim Cronin to the Auger adventure, and ultimately to inspire so many of us all around the world.

Design Concept for a 5000 km² Air Shower Array

EFI 92-08

James W. Cronin

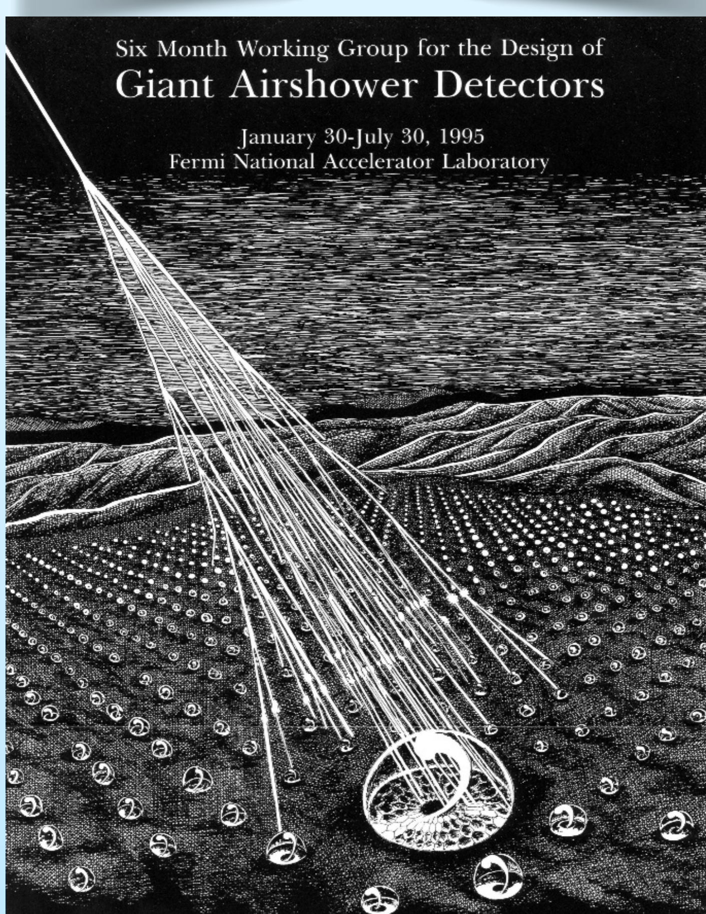
Department of Physics and Enrico Fermi Institute
University of Chicago
Chicago Ill. 60637 U.S.A.

Abstract

I describe a conceptual design for an air shower array with an area of 5000 km^2 to study cosmic rays with energies $\geq 10^{19}$eV. The individual detectors can operate without external connections. Power comes from solar collectors, communications are by microwaves, and relative and absolute timing are provided by the GPS satellite system. It is hoped that this will stimulate others to consider how a giant array should be built.

This work was begun during a visit to the University of Leeds from September to December 1991. I wish to thank Alan Watson for providing a tranquil setting with abundant intellectual stimulation. There were extensive discussions about the design of a giant array. Many people have contributed their ideas to this study. In fact some of the individuals will see that their ideas have been adopted in this paper after first being rejected by me. I apologise for being slow to recognize their wisdom. From Leeds I thank Alan Watson, Michael Hillas, Jeremy Lloyd-Evans, John McMillan, Peter Daly and Kevin de Souza for their ideas and contributions. At the University of Chicago where this paper was completed Ken Gibbs and Leslie Rosenberg have made valuable comments and suggestions. But in the end this document is my own rendition of all of the ideas I have absorbed. If it serves as a stimulus for further thinking and ultimately a real array then we all benefit!

6 months Workshop @ Fermilab 1995



Groundbreaking in March 1999

Inauguration November 2008

Auger Observatory and Jim's Legacy

- 70 Journal papers with more coming
- 270 PhDs earned with 100 in the pipeline
- The surprising and unexpected heavy composition of the highest energy cosmic rays and other key results are providing the direction for future research in particle astrophysics.

Conclusion

What an amazing man and what a fascinating road he led us along!

A.A. Watson, 10/2016