Jim, Hard Scattering, and the Development of the Parton Model

We have become used to the idea that matter has a structure smaller than protons- it wasn't so in 1970…

1. Introduction: Partons & Hadrons, and Hadrons & Partons
2. Context: a new national lab, new energy reach, challenges
3. 1970: Jim and Pierre propose Fermilab Experiment E100
4. `Discoveries' (or almost)- parton-like particle production, direct muons, the 'Cronin-Effect' in nuclei
5. 1976: Jim heads up the Colliding Beam Experiments Dept. (the seeds of the Collider Detector at Fermilab (CDF))
6. 1984: If Wishes Were Horses: The pbar-p SSC option: Jim's vision of a more careful and more real approach to the SSC
7. Working with Jim…
8. Taking stock- high-Pt parton production, charm, RHIC/Alice

Probing a New Energy Region

Fermilab was coming on the air. Wilson's vision was it would be a national lab rather than 'in-house', and so an opportunity to propose new ideas with strong technical support ($, talent). It was exciting.

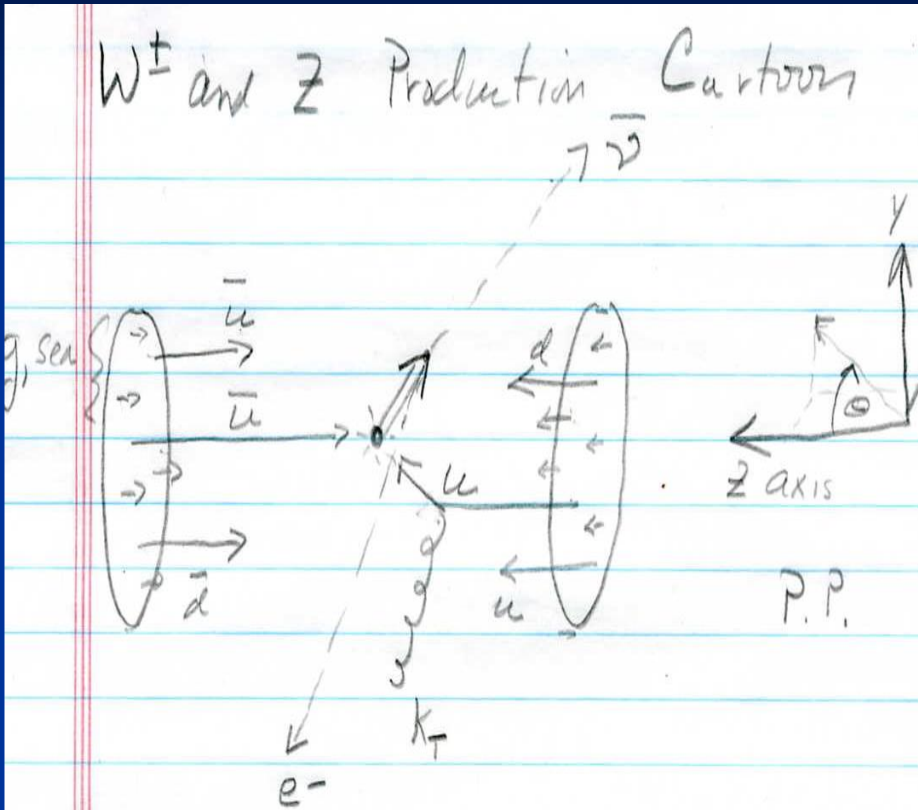
Going from 30 GeV to 200 GeV seemed like an enormous jump, opening up a huge energy region for the discovery of what was really going on at short distances. It was a simpler time, and the opportunity to explore was so clear…

But where to look? Jim and Pierre proposed looking at particle production in a region where conventional wisdom (sic) predicted there wouldn't be particles- large momentum perpendicular to the beam direction. The rule-of-thumb was the spectrum was exponential and very very steep (e^{-6P_T}), where P_T is 'transverse mom.'.

And in Jim's style, the apparatus was simple and could be built by a small group- 6 people. `Single-arm' magnetic spectrometer at 90^o

However, the scale was new- 90^o in the c.m. transforms into a long spectrometer at a small angle in the laboratory frame.

Hard Parton Scattering-Introduction



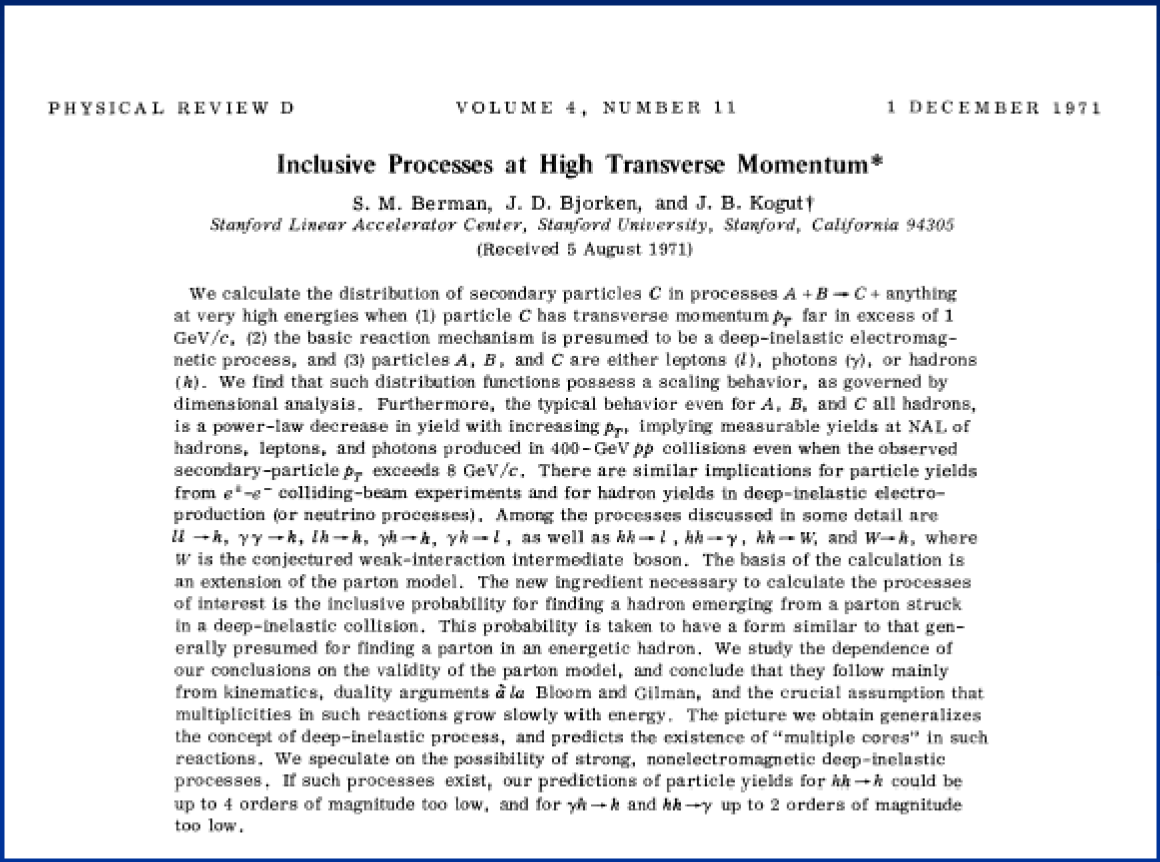
A parton is a quark or gluon- carry color, and so aren't `free

A hadron is a strongly interacting particle made of partons- e.g. the proton, neutron, pion, kaon, c- and b mesons, s,c,and b containing baryons

A "Cartoon" of a hard parton `scattering' producing a W boson in pbarp collisions

Hard Parton Scattering

Berman, Bjorken, and Kogut (BBK)- 1971



PHYSICAL REVIEW D VOLUME 4, NUMBER 11 1 DECEMBER 1971

Inclusive Processes at High Transverse Momentum*

S. M. Berman, J. D. Bjorken, and J. B. Kogut†

Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

(Received 5 August 1971)

We calculate the distribution of secondary particles C in processes $A+B\to C+$ anything at very high energies when (1) particle C has transverse momentum p_T far in excess of 1 GeV/c, (2) the basic reaction mechanism is presumed to be a deep-inelastic electromagnetic process, and (3) particles A, B, and C are either leptons (l), photons (γ), or hadrons (h). We find that such distribution functions possess a scaling behavior, as governed by dimensional analysis. Furthermore, the typical behavior even for A, B, and C all hadrons, is a power-law decrease in yield with increasing p_T, implying measurable yields at NAL of hadrons, leptons, and photons produced in 400-GeV pp collisions even when the observed secondary-particle p_T exceeds 8 GeV/c. There are similar implications for particle yields from e^+-e^- colliding-beam experiments and for hadron yields in deep-inelastic electroproduction (or neutrino processes). Among the processes discussed in some detail are $ll\to h$, $\gamma\gamma\to h$, $lh\to h$, $\gamma h\to h$, $\gamma h\to l$, as well as $hh\to l$, $hh\to\gamma$, $hh\to W$, and $W\to h$, where W is the conjectured weak-interaction intermediate boson. The basis of the calculation is an extension of the parton model. The new ingredient necessary to calculate the processes of interest is the inclusive probability for finding a hadron emerging from a parton struck in a deep-inelastic collision. This probability is taken to have a form similar to that generally presumed for finding a parton in an energetic hadron. We study the dependence of our conclusions on the validity of the parton model, and conclude that they follow mainly from kinematics, duality arguments *à la* Bloom and Gilman, and the crucial assumption that multiplicities in such reactions grow slowly with energy. The picture we obtain generalizes the concept of deep-inelastic process, and predicts the existence of "multiple cores" in such reactions. We speculate on the possibility of strong, nonelectromagnetic deep-inelastic processes. If such processes exist, our predictions of particle yields for $hh\to h$ could be up to 4 orders of magnitude too low, and for $\gamma h\to h$ and $hh\to\gamma$ up to 2 orders of magnitude too low.

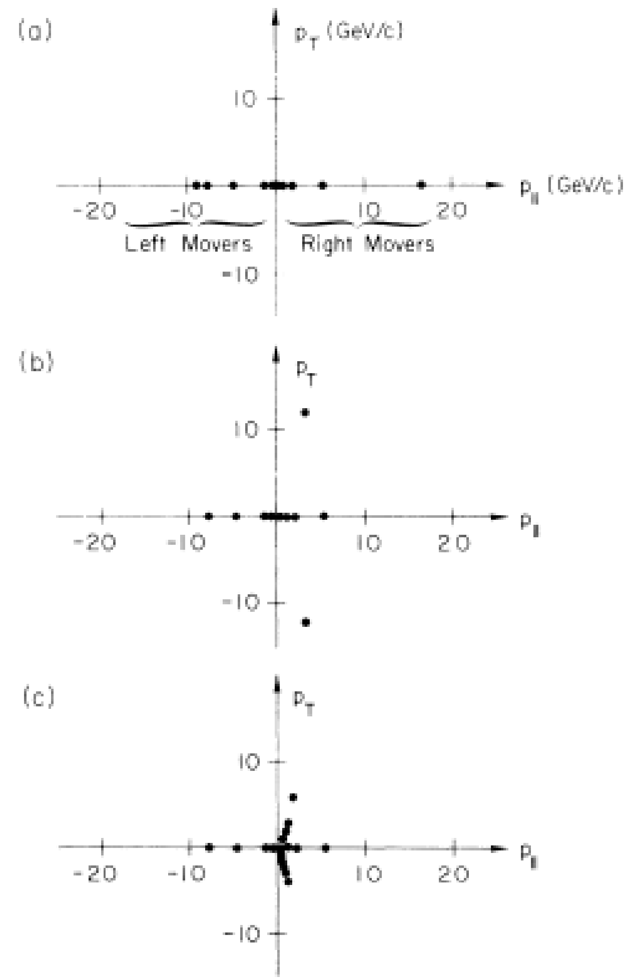


FIG. 4. A momentum-space visualization of hadron-hadron deep-inelastic scattering occurring in three steps.

Momentum space- $P_{longitudinal}$ along the beams; P_T Transverse

Dots are partons; scales are in GeV.

Hard Parton Scattering

BBK Predictions on hard parton scattering, annhilation to the W and Z, direct leptons,…

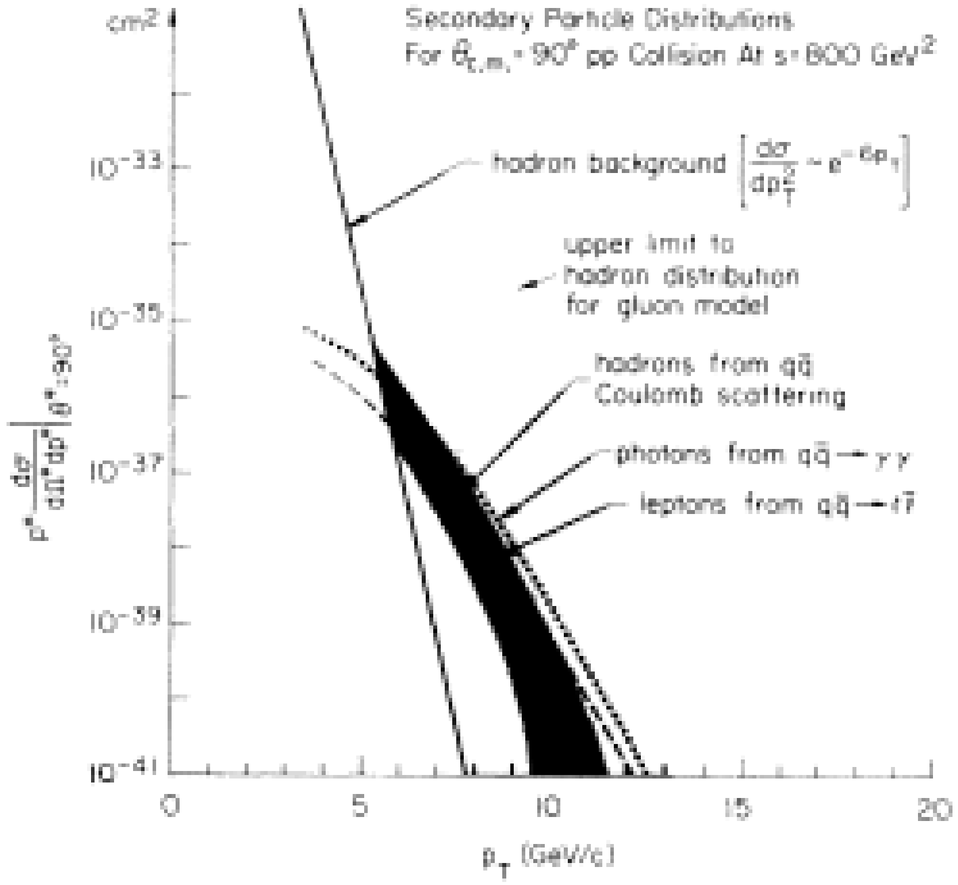


FIG. 1. Secondary-particle distributions as calculated in the parton model and compared to diffractive backgrounds for typical NAL conditions.

High-PT Particle Production: E100 at Fermilab: 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.

December 1, 1970

Correspondent: J. W. Cronin

Jim and Pierre: Fermilab Proposal, Expt100, 1970:

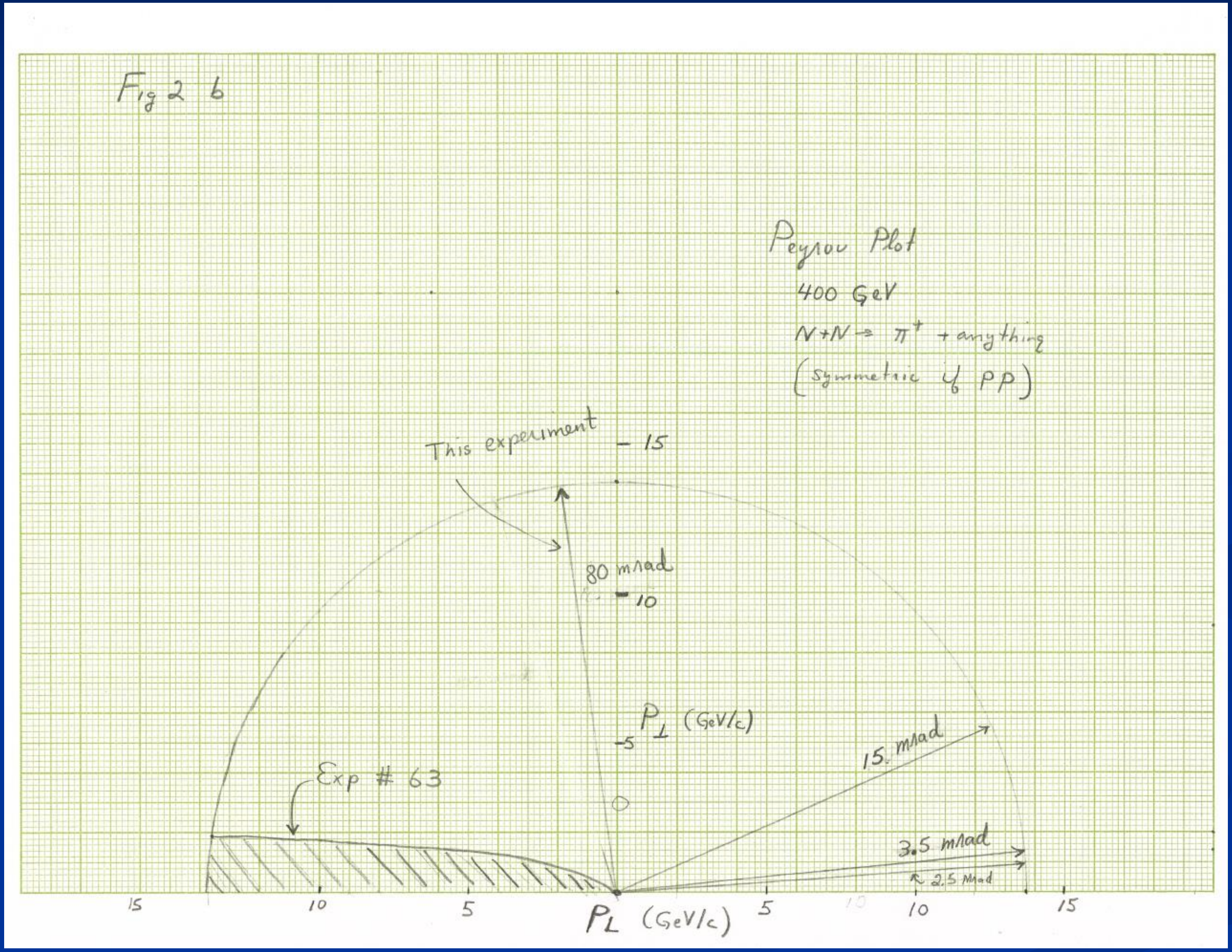
"…an Exploratory Investigation…"

1. **High Pt Hadron Production**
2. **The W boson**
3. **The Z boson (`heavy photon')**
4. **Charm, beauty (`Short-lived particles')**

E100 at Fermilab: 1970-77

Figure 1 of the E100 Proposal – the "Peyrou Plot" at NAL

(JWC hand-drawn original)

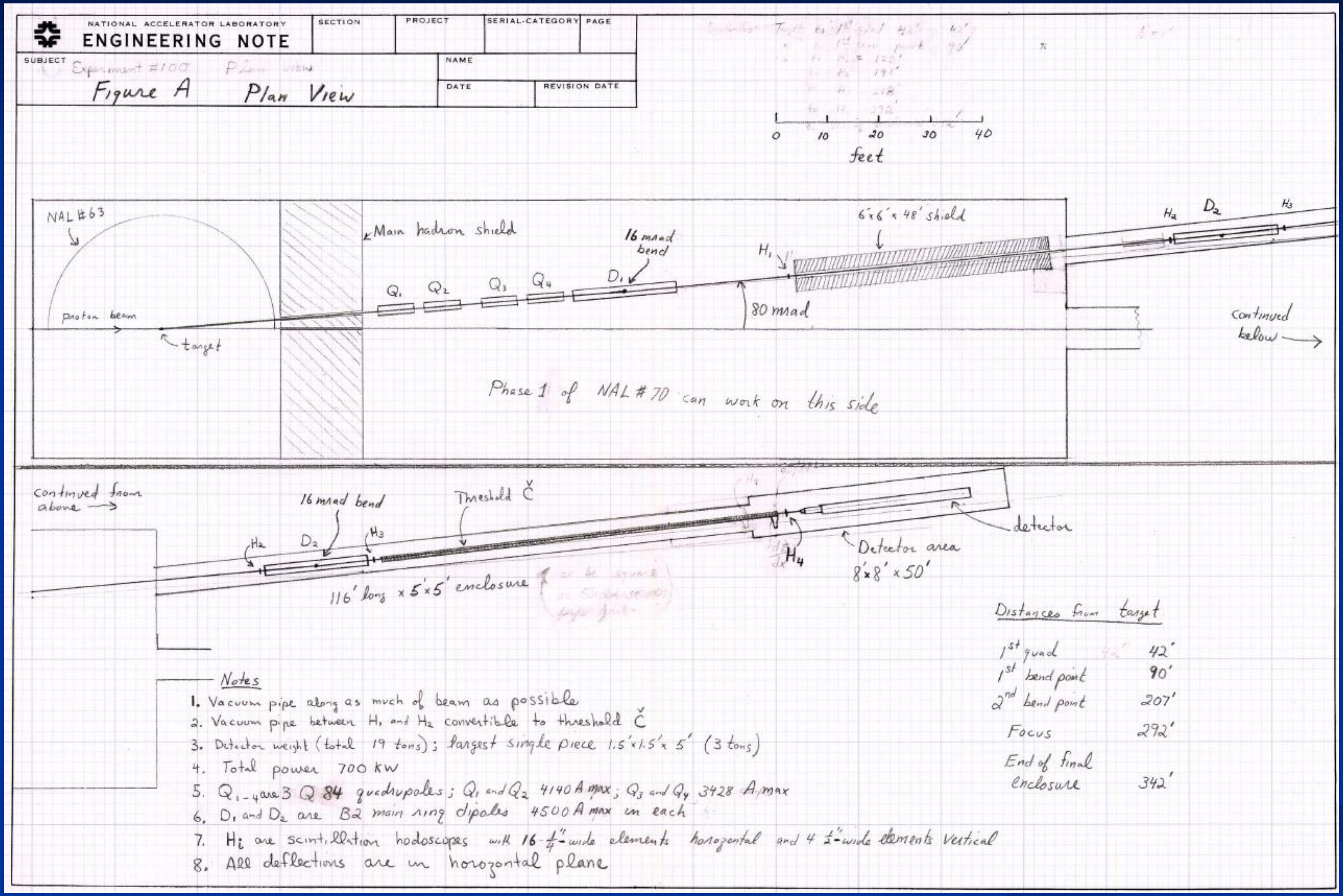


$P_{transverse}$

$P_{longitudinal}$ (along the initial beam direction)

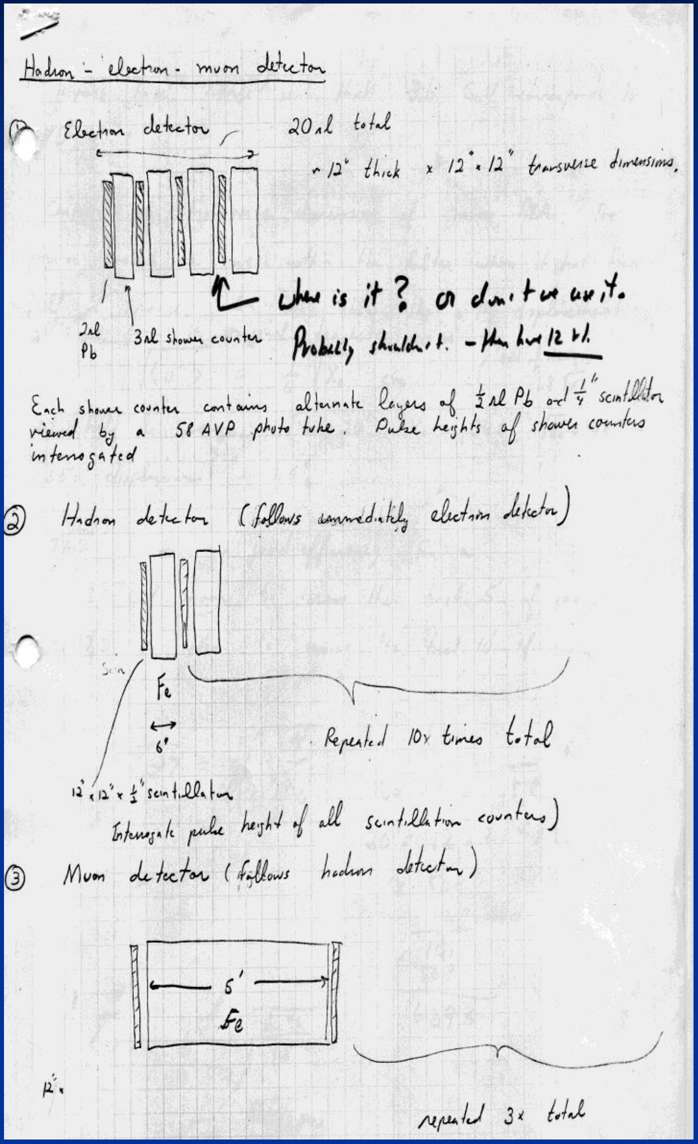
The transverse direction is perpendicular to the beam- looking at collisions that scatter at 90^{0}

E100 at Fermilab: 1970-77



Jim's hand-drawn layout of the E100 spectrometer- 100 yards long…

E100 at Fermilab: 1970-77



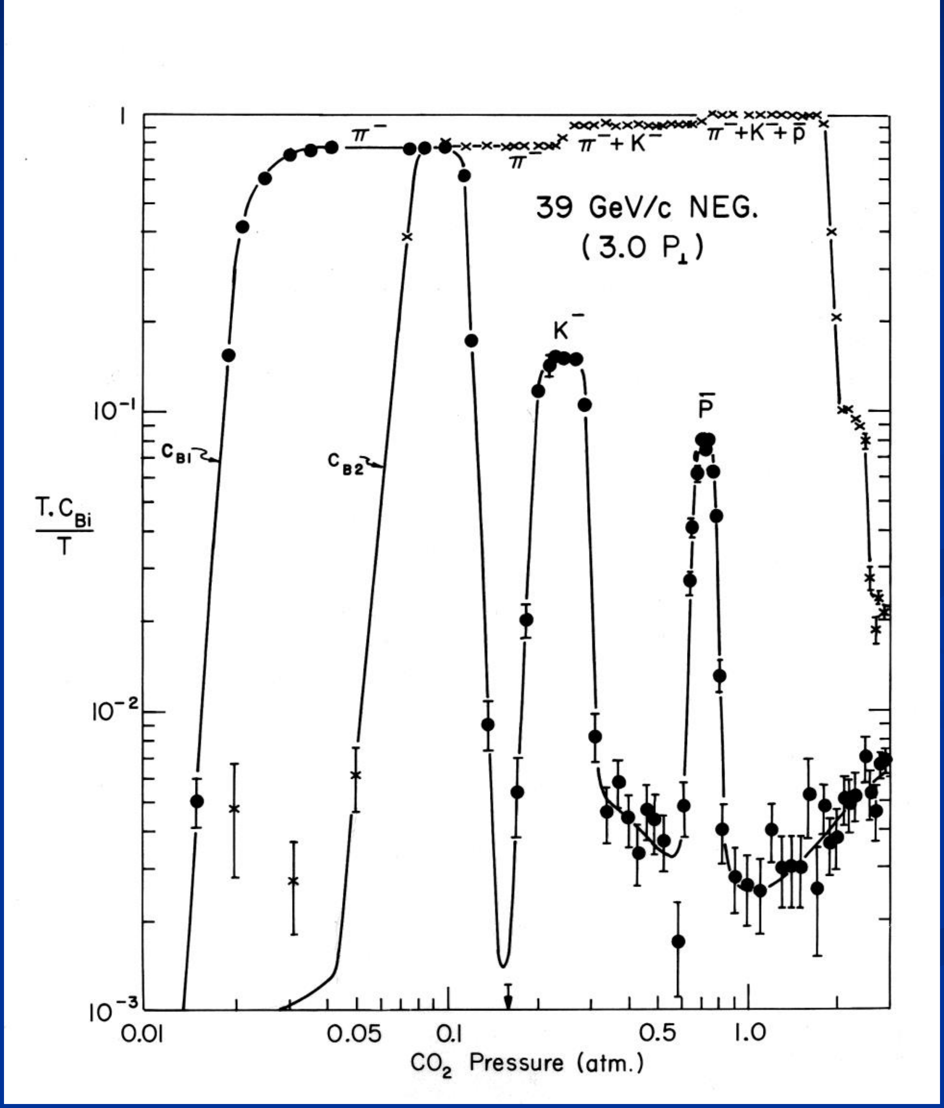
Particle Identification – not so different from the standard collider "kit" nowadays (exept for Pierre's beautiful Cherenkov counters, and the Lorentz frame):

1. Magnetic Spectrometer for momentum
2. Pb/Scint EM Calorimeter for Electron ID
3. Steel/Scint Stack for Muon/Hadron Separation
4. Innovative "Shutter" for Lifetime Extrapolation

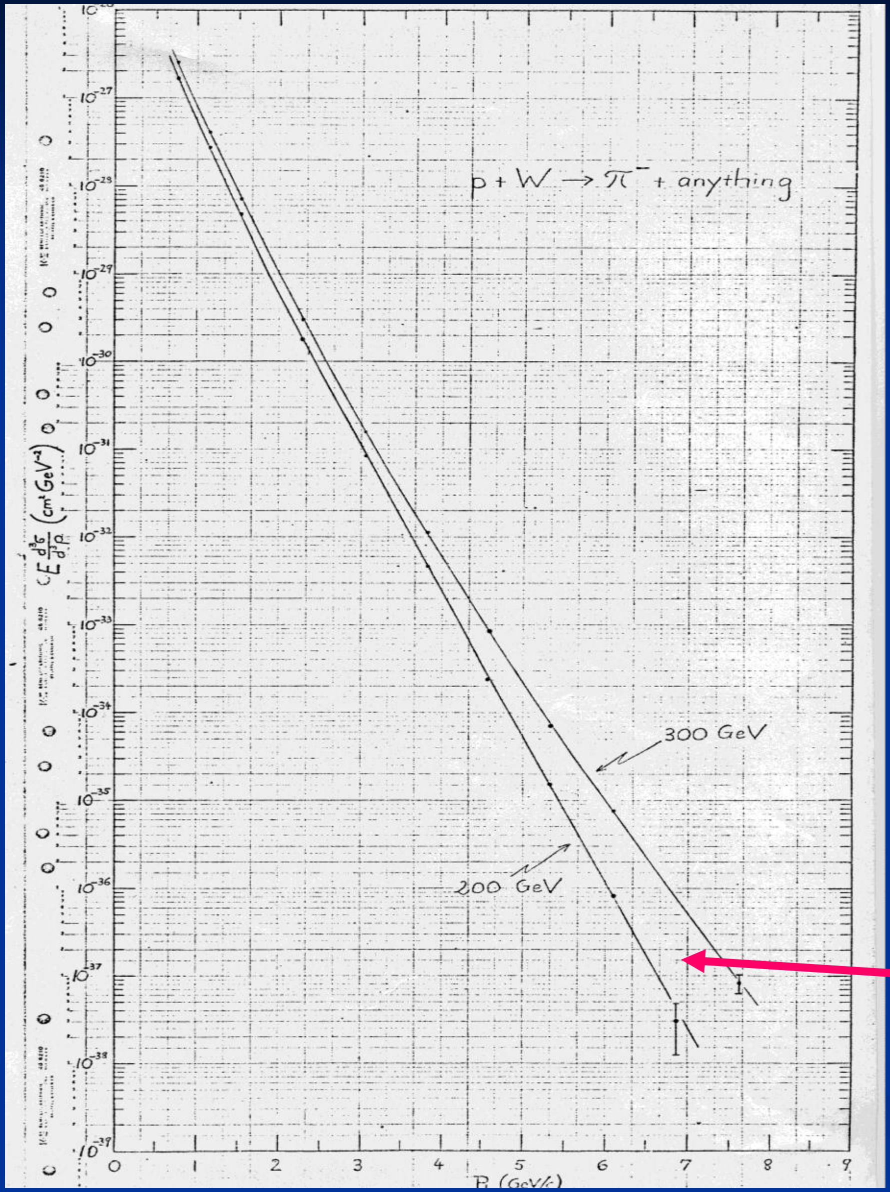
E100 at Fermilab: 1970-77

One real strength of E100 was particle identification via Pierre's Cherenkov ctrs- a capability largely lost in modern collider detectors:

A `Pressure Curve'- index of refraction of gas changes vs pressure, and particles at the same momenta but different velocities produce light at angle cos(theta) = 1/(beta n)



E100 at Fermilab: 1970-77



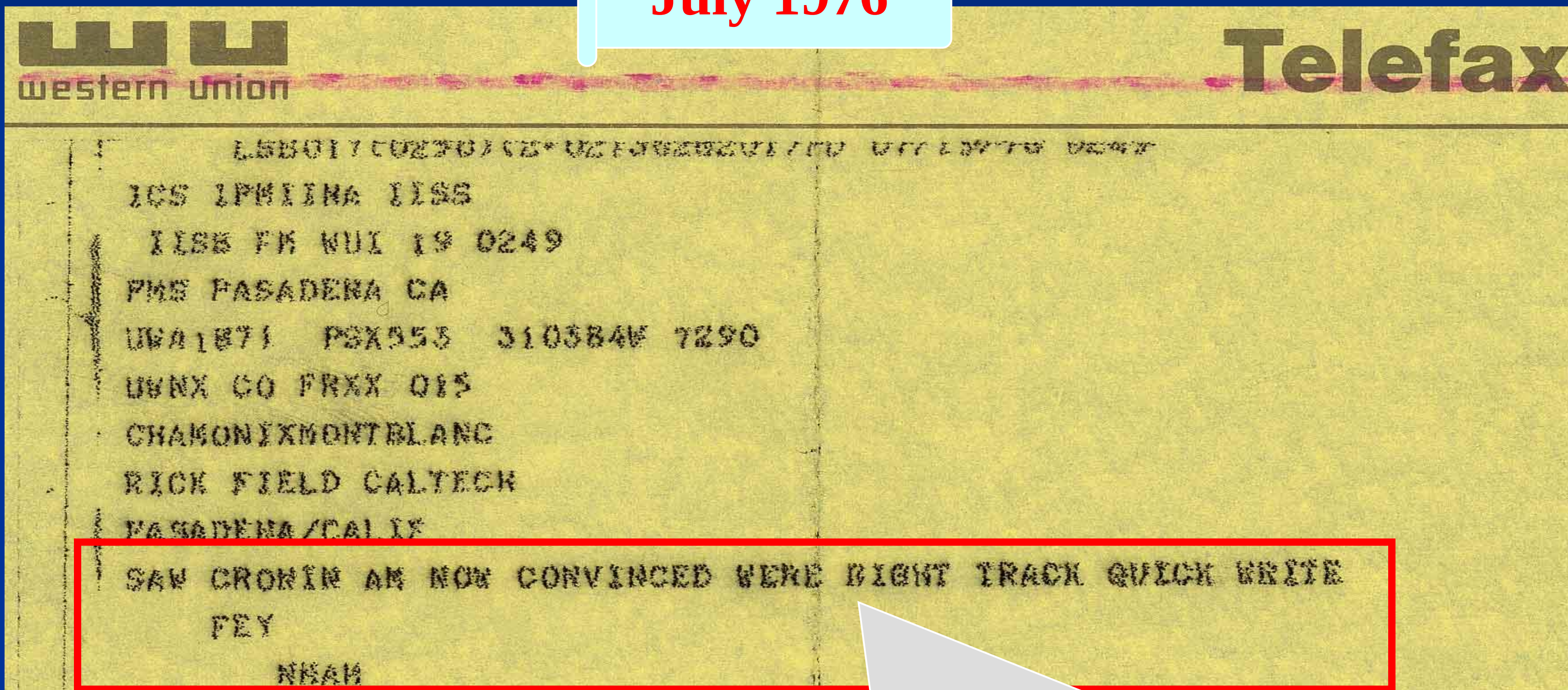
First Results- 1972- see power-law behavior and energy dependence at large Pt

BUT- ISR beat us to punch line (sadly, and barely)

Note energy-dependence at high Pt- evidence of hard scatters

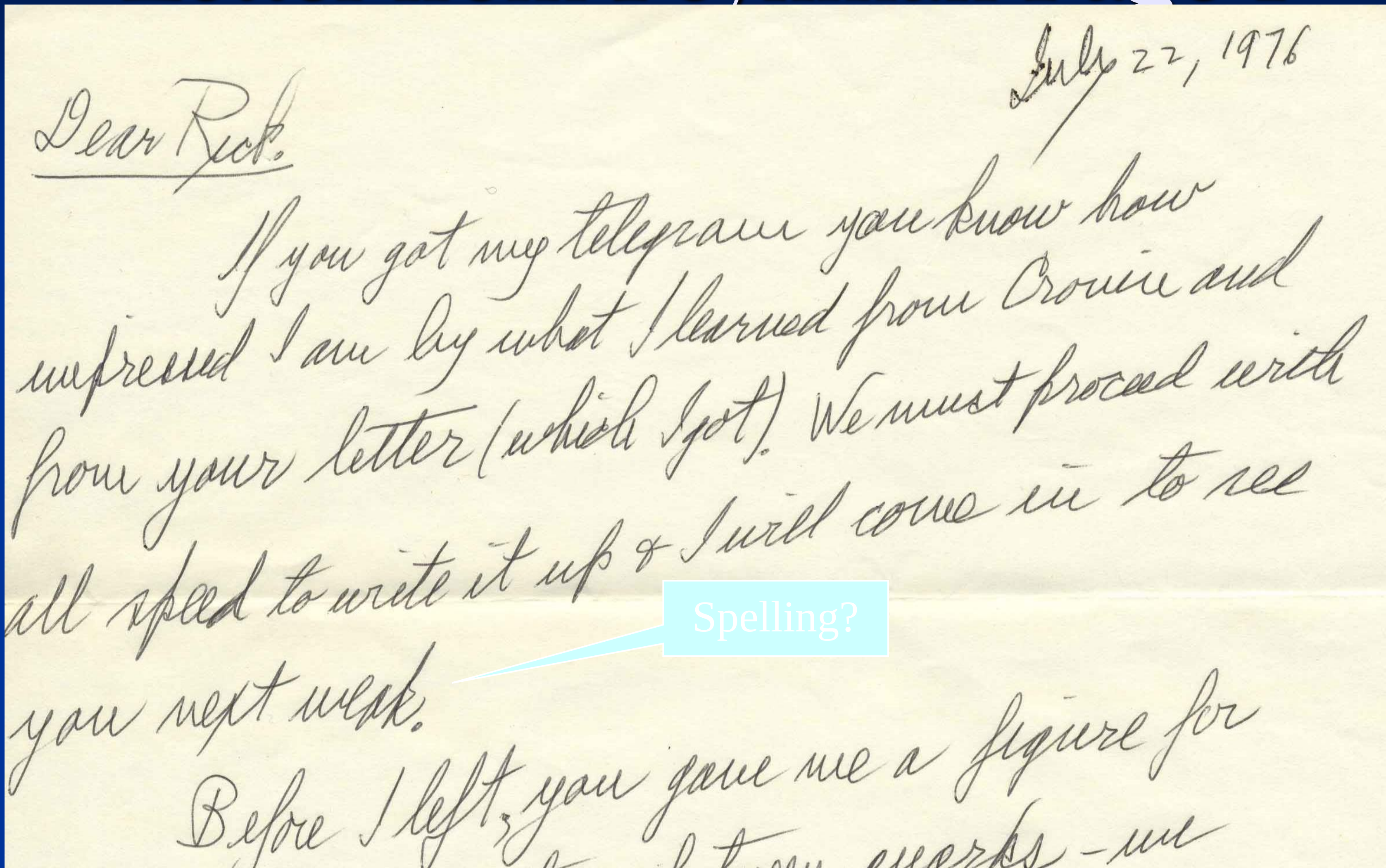
Telagram (sic) from Feynman

July 1976



SAW CRONIN AM NOW CONVINCED WERE RIGHT TRACK QUICK WRITE FEYNMAN

Letter from Feynman Page 1



July 22, 1976

Dear Rick.

If you got my telegram you know how impressed I am by what I learned from Cronin and from your letter (which I got). We must proceed with all speed to write it up & I will come in to see you next weak.

Before I left, you gave me a figure for ... between quarks – ...

Spelling?

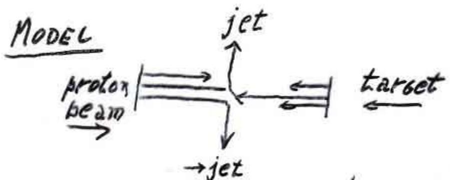
From Rick Field's Lectures at UC, July 2006

Feynman Talk at Coral Gables (December 1976)

1st transparency

Field & Feynman CALT-68-565
Fox (Brookhaven APS) CALT-68-573

MODEL



Quark-Quark Collision.
But $P_\perp^{-8}$ Not $P_\perp^{-4}$?

Need: (a) Quark distribution in hadron. (Pion?)
(b) The way quark makes hadron jet.
FROM EXPERIMENTS WITH LEPTONS,
(c) Quark-Quark scattering x-section.

$$\frac{d\hat{\sigma}}{d\hat{t}} = \frac{2300\ mb}{s(-t)^3}$$

Try to fit all correlation experiments
with no new parameters.

Last transparency

"Feynman-Field Jet Model"

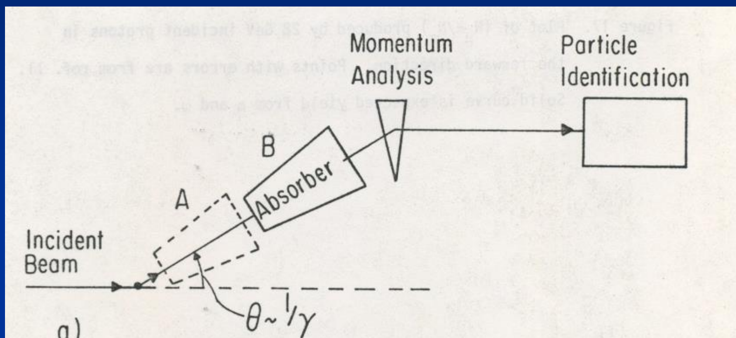
WORK IN PROGRESS

a) More detailed Calculations
b) Theory of q → hadron cascade

FUTURE.
Protons & baryons at high $P_\perp$.
Single γ's at high $P_\perp$.
Nuclear targets.
Are we really in trouble from Transverse p of quarks?
Unify theory to that of main collision at low $P_\perp$.

Direct Muon Production

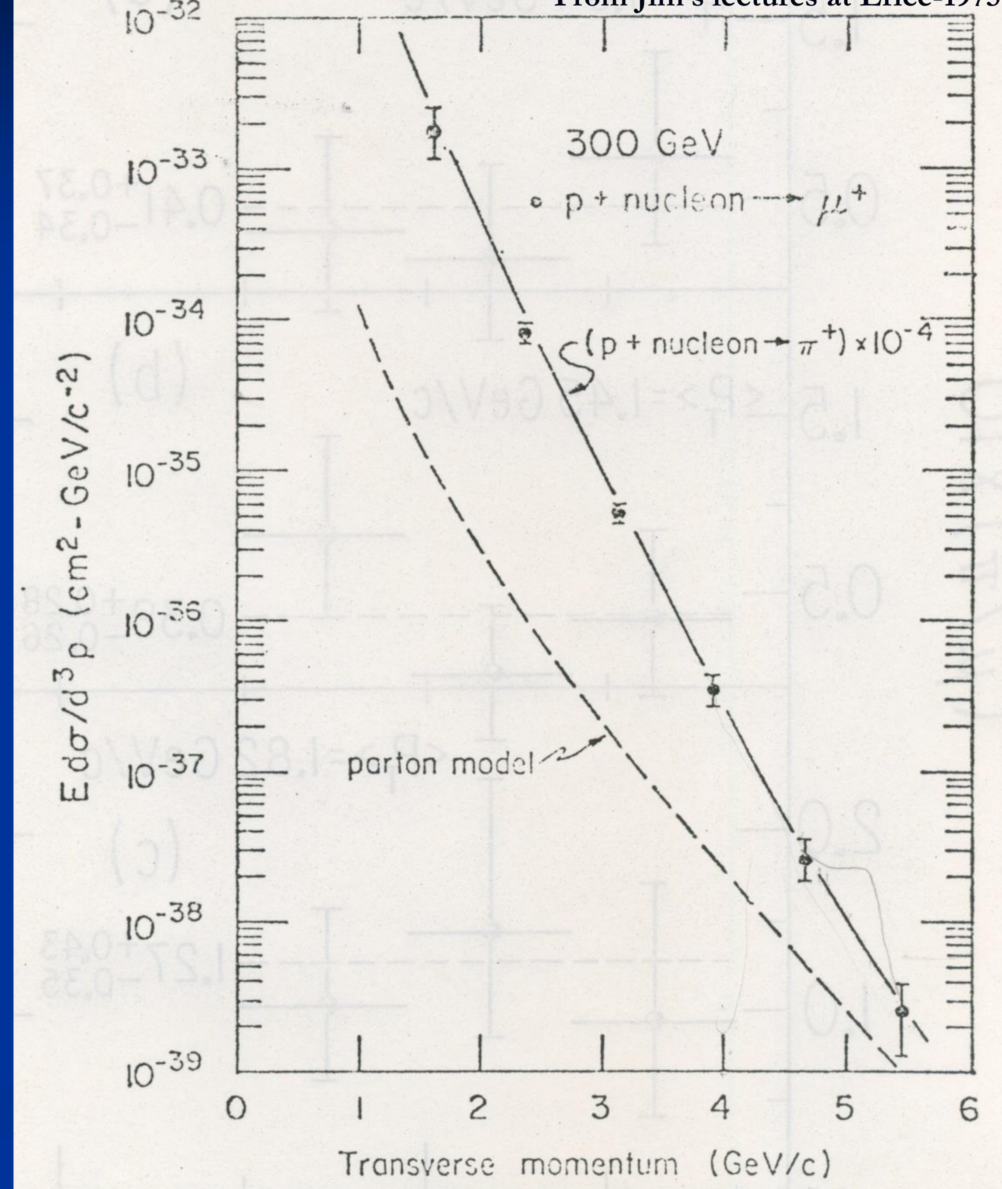
Pions and Kaons decay into muons- large background



Use a pair of movable 'shutters' to absorb pions, kaons, protons…

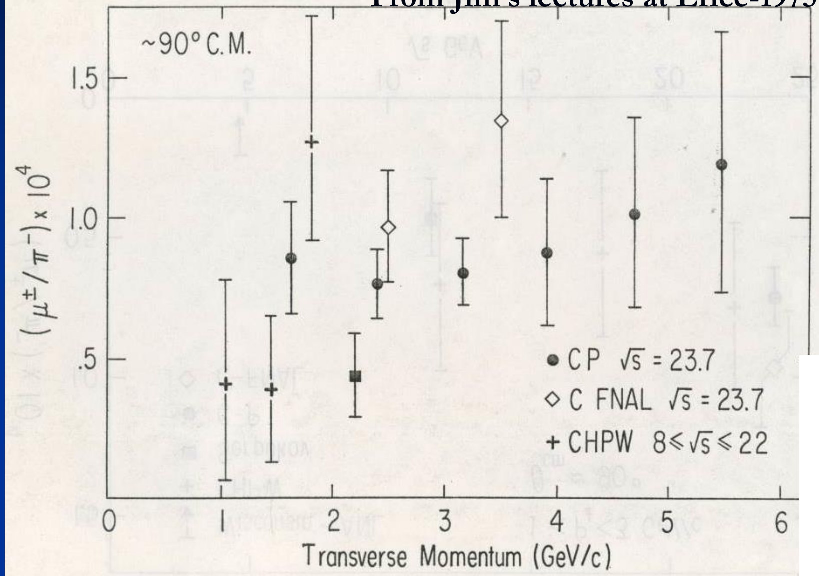
2 points allows extrapolating to zero lifetime- `aka direct'.

From Jim's lectures at Erice-1975



Direct Muon Production- July 74

From Jim's lectures at Erice-1975



Ratio of mu-to-pi. Note CP precision

Publication in PRL

(only 1 of 3 times I ever saw Jim angry- actually 1 of 2..
Stories over dinner or by request)

VOLUME 33, NUMBER 2 PHYSICAL REVIEW LETTERS 8 JULY 1974

Observation of Large-Transverse-Momentum Muons Directly Produced by 300-GeV Protons*

J. P. Boymond, R. Mermod,† P. A. Piroué, and R. L. Sumner
Department of Physics, Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08540
and
J. W. Cronin, H. J. Frisch, and M. J. Shochet
The Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637
(Received 8 May 1974)

We have observed muons produced directly in Cu and W targets by 300-GeV incident protons. We find a yield of muons which is approximately a constant fraction (0.8×10^{-4}) of the pion yield for both positive and negative charges and for transverse momenta between 1.5 and 5.4 GeV/c.

In this Letter we report on the observation of muons produced directly in nuclear targets by 300-GeV incident protons. Study of muon production at high transverse momentum was originally motivated by the search for the intermediate vector boson. Early experiments were carried out at the Argonne zero-gradient synchrotron[1] and the Brookhaven alternating-gradient synchrotron[2] with negative results. More recently, several experiments have shown evidence for the direct production either of single muons[3,4] or of muon pairs[5] in nucleon-nucleon collisions. Extensive theoretical work[6,7] suggests that collisions of pointlike constituents of the nucleon would result in the direct production of muons.

absorber, (2) W absorber inserted only, and (3) Fe absorber inserted only. Runs were made at 10-GeV/c intervals between 20 and 70 GeV/c corresponding to transverse momenta ($P_\perp$) from 1.5 to 5.4 GeV/c. At 20 and 30 GeV/c, data were also taken with both absorbers in the beam as a consistency check. To verify that the muons were associated with the target, we also took data with the target removed for the three principal conditions at 20, 30, and 40 GeV/c.

For each absorber condition we measured the ratio of muons detected at the end of our apparatus to pions of the same charge detected by the apparatus when the absorber was absent. Two counter telescopes which looked at the target at

The 'Cronin Effect'

We had nuclear targets- but wanted cross-sections on protons (nucleon)- extrapolated from 3 nuclei to A=1

Atomic-Number Dependence of Large-Transverse-Momentum Hadron Production by Protons*

L. Kluberg,† P. A. Piroué, and R. L. Sumner
Department of Physics, Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08540

and

D. Antreasyan, J. W. Cronin, H. J. Frisch, and M. J. Shochet
The Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637

(Received 20 December 1976)

We have measured at Fermilab the production of hadrons at ~90° in the c.m. system as a function of incident proton energy, atomic number A of the production target, and the transverse momentum $p_\perp$ of the produced hadron. The A dependence of the production cross section of the hadrons can be described by a function $A^{\alpha(p_\perp)}$, where the power α rises with $p_\perp$. At $p_\perp$ ~5 GeV/c, α is ~1.1 for $\pi^\pm$ and K^+, and ~1.3 for p, $\bar{p}$, and K^-. The energy dependence of the power is also measured.

In an earlier paper[1] we reported on the atomic-number (A) dependence of hadron production at large transverse momentum ($p_\perp$). Similar data have also been reported by other groups.[2,3] These results were surprising because the A dependence of the hadron yield, when fitted to a form $A^{\alpha(p_\perp)}$,

Volume 38, Number 13 PHYSICAL REVIEW LETTERS 28 March 1977

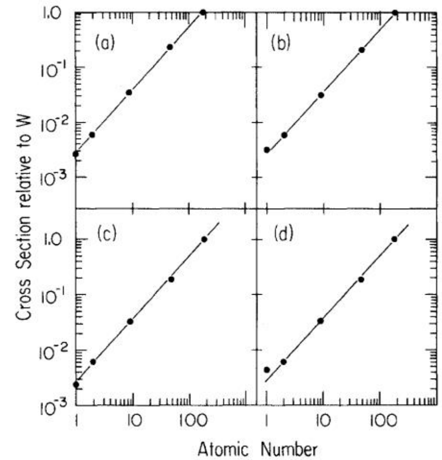


FIG. 1. The invariant cross section for π production relative to tungsten for various atomic numbers at 400 GeV; (a) π^- at $p_\perp = 3.85$ GeV/c, (b) π^+ at $p_\perp = 3.85$ GeV/c, (c) π^- at $p_\perp = 5.38$ GeV/c, (d) π^+ at $p_\perp = 5.38$ GeV/c. The errors are smaller than or equal to the size of the points.

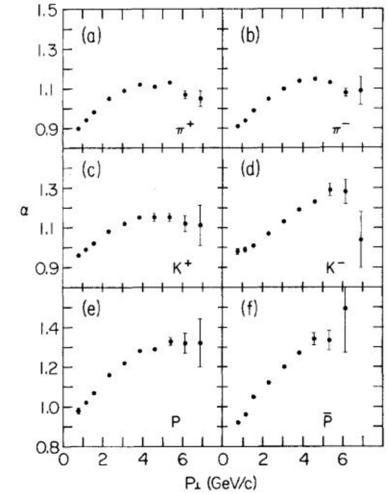


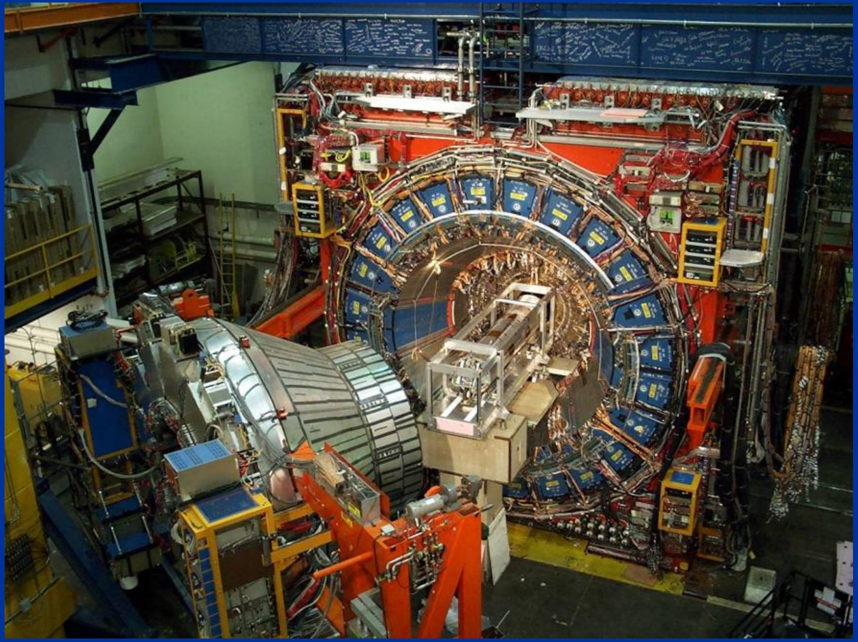
FIG. 2. The power α of the A dependence of the invariant cross section vs $p_\perp$ for the production of hadrons by 400-GeV protons; (a) π^+, (b) π^-, (c) K^+, (d) K^-, (e) p, and (f) $\bar{p}$. Unless indicated otherwise, the errors are smaller than or equal to the size of the points.

Found a surprising effect- the `Cronin Effect'- stronger dependence than $A^{1.0}$. Turns out to be scattering in the nucleus- now a major industry in the nuclear community.

"Colliding Beam Experiments Department"

Fermilab (not Jim's Dept.) still a mess a year later…

But, with Dennis Theriot and a really good crew derived from the group… (Dennis is a much unsung hero):



Fermilab

Colliding Detector Facility Meeting Minutes

September 15, 1978

Present: H. Frisch, M. Peshkin, A. Tollestrup, J. Rhoades, J. Walker, B. Diebold, L. Holloway, R. Loveless, I. Gaines, T. Collins, T. Rhoades, P. Limon, C. Ankenbrandt

Alvin announced that there will be a review of the entire colliding beam possibilities at Fermilab in the second week in November. In order to present this Group's work in a coherent fashion at that time, Alvin asked that each Group Leader have a written report on his section by October 1, 1978.

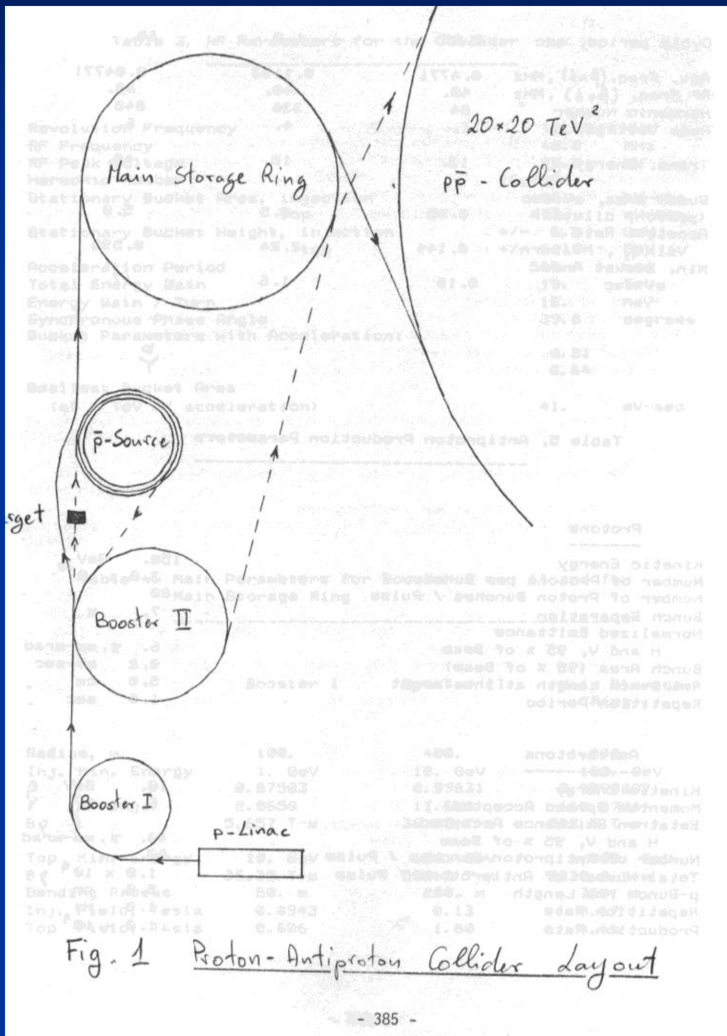
A very lively discussion followed on which of the several options (pp, $\bar{p}p$ in MR, $\bar{p}p$ in Doubler, etc.) was the best one to push here at Fermilab given CERN's $\bar{p}p$ program and their much larger financial commitment. Alvin appointed three groups to study various questions since the answers were not clear to those present at this meeting.

A.	I. Gaines, B. Diebold:	Monte Carlo pp interactions to determine if the unequal energies present any problems for the detector we have been considering.
B.	R. Loveless, T. Collins, S. Ecklund:	Squeezer magnets if no pre-bending.
C.	P. Limon, H. Frisch, C. Ankenbrandt:	$\bar{p}p$ luminosity estimates.

RL:clc

Jim's initiative led to the (now long-standing) involvement of Carla Pilcher, Mel Shochet, and myself in CDF and collider physics.

The Path Not Taken: LHC, ILC, and the pbarp SSC Option (mrcfly brief)



Jim had immense wisdom and vision, and the remarkable ability to apply his economical elegant style even to the largest projects. The idea was to go more adiabatically, and use resources at hand (Fermilab), and get to 40 TeV with pbarp and only one ring as a step along the way. It's a pity that we didn't start this way

(Aside- I was told in the Japanese Embassy in DC that Japan would have been willing to pay for the 2nd ring – - Jim's instincts were so on target.).

The pbarp SSC Option

2/9/84

WORKSHOP ON $\bar{p}p$ OPTIONS FOR THE SUPER COLLIDER

PROGRAM

Sunday, February 12

Registration at Hilton Inn	6:00 PM - 10:00 PM
Reception at Hilton Inn	8:00 PM - 10:00 PM
Meeting of Organizing Committee Working Group Leaders and Speakers at Hilton Inn	9:00 PM

Monday, February 13

Registration at Oriental Institute		9:00 AM - Noon
FIRST PLENARY SESSION, Oriental Institute (Breasted Hall) 1155 E. 58th Street		9:30 AM - Noon
Opening Remarks	Jim Cronin	
Speakers:		
"Views on a $\bar{p}p$ Super Collider"	Carlo Rubbia	
"Physics Signatures in Hadronic Collisions"	Frank Paige	
"Present Status of the SSC"	Maury Tigner	
LUNCH		12:00 - 1:30 PM
SECOND PLENARY SESSION, Oriental Institute		1:30 PM - 4:00 PM
Brief Talks by Working Group Leaders		
Speaker: "Vacuum Deformation by Heavy Particles"	Frank Wilczek	
Adjourn to Fermi Institute, 5640 S. Ellis Avenue		4:00 PM
Coffee in RI 480		4:00 PM - 4:30 PM
Organization of Working Groups		4:30 PM - 6:00 PM
OPEN HOUSE - after dinner - home of Jim Cronin 5825 Dorchester Ave.		8:00 PM - 10:00 PM

2

Tuesday, February 14

Working day (offices and seminar rooms open from 7:30 AM to midnight). Research Institutes

Wednesday, February 15

Working day	Research Institutes
RECEPTION for Workshop Participants hosted by Enrico Fermi Institute at the QUADRANGLE CLUB. 1155 E. 57th St.	5:30 PM
BANQUET at Greek Islands Restaurant (Board buses at 1155 E. 57th St.)	7:30 PM

Thursday, February 16

Working day	Research Institutes
Coffee in RI 480	4:00 PM - 4:30 PM
Physics Colloquium: Eckhart 133	4:30 PM

"The Fly's Eye: Cosmic Ray Detector"

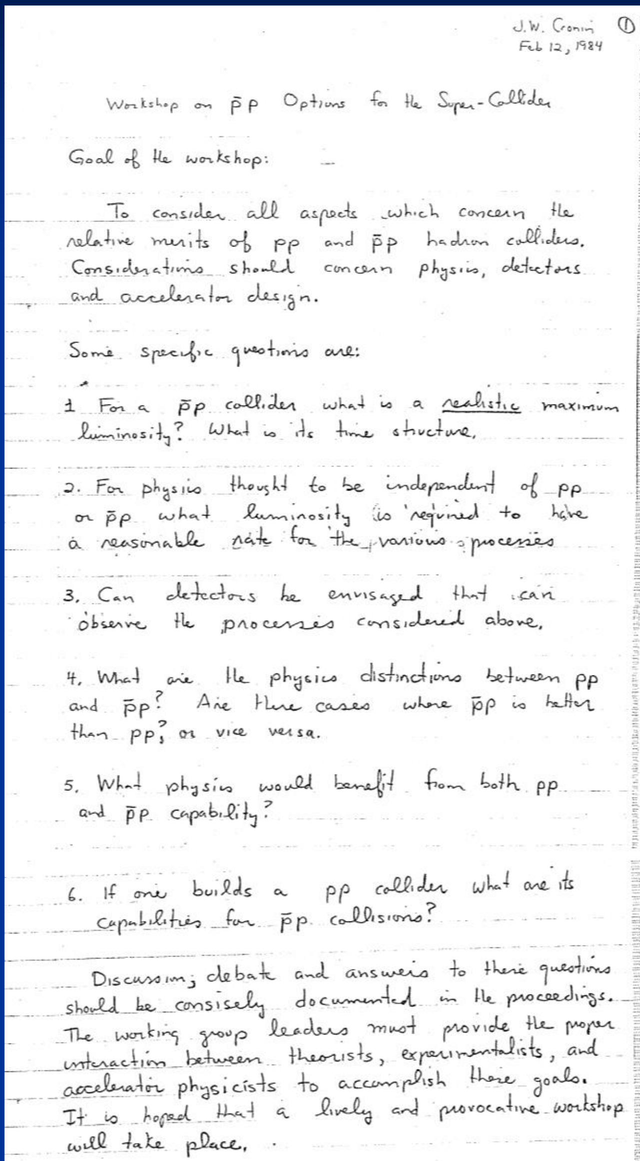
George L. Cassiday, Jr.
University of Utah

Friday, February 17

Summary Talks (Goodspeed Hall) (program to be arranged)	9:00 AM - 4:30 PM

1984 Workshop Initiated by Jim

The pbarp SSC Option



J.W. Cronin ①
Feb 12, 1984

Workshop on $\bar{p}p$ Options for the Super-Collider

Goal of the workshop:

To consider all aspects which concern the relative merits of pp and $\bar{p}p$ hadron colliders. Considerations should concern physics, detectors and accelerator design.

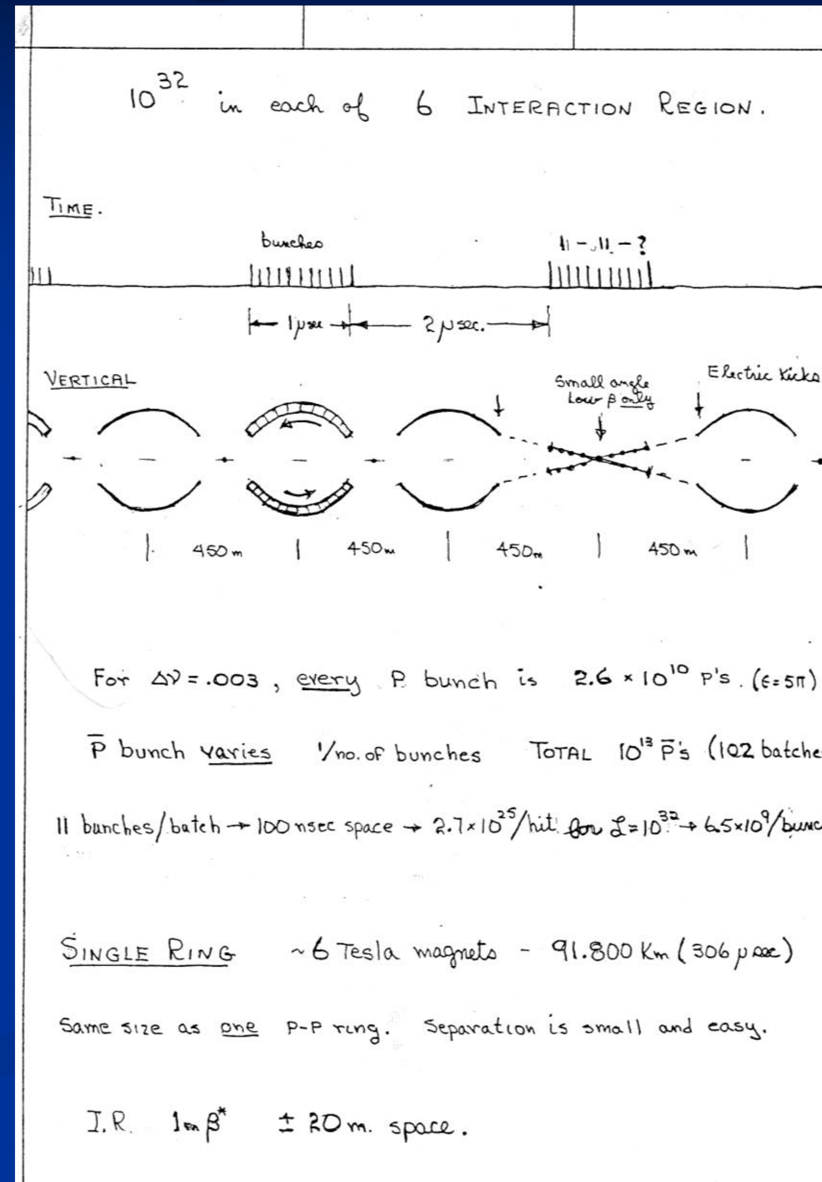
Some specific questions are:

1. For a $\bar{p}p$ collider what is a realistic maximum luminosity? What is its time structure.
2. For physics thought to be independent of pp or $\bar{p}p$ what luminosity is required to have a reasonable rate for the various processes
3. Can detectors be envisaged that can observe the processes considered above.
4. What are the physics distinctions between pp and $\bar{p}p$? Are there cases where $\bar{p}p$ is better than pp; or vice versa.
5. What physics would benefit from both pp and $\bar{p}p$ capability?
6. If one builds a pp collider what are its capabilities for $\bar{p}p$ collisions?

Discussion, debate and answers to these questions should be consisely documented in the proceedings. The working group leaders must provide the proper interaction between theorists, experimentalists, and accelerator physicists to accomplish these goals. It is hoped that a lively and provocative workshop will take place.

"Goals of the Workshop"

Hand-written detailed technical design- Jim's style as a leader (as opposed to Feynman's def. of a "position of responsibility")



The pbarp SSC Option

Jim several times was so right on major directions/facilities at critical junctures in the science:

– Fermilab Collider (went well after some initial “screwing around”

- SSC (not so much)..

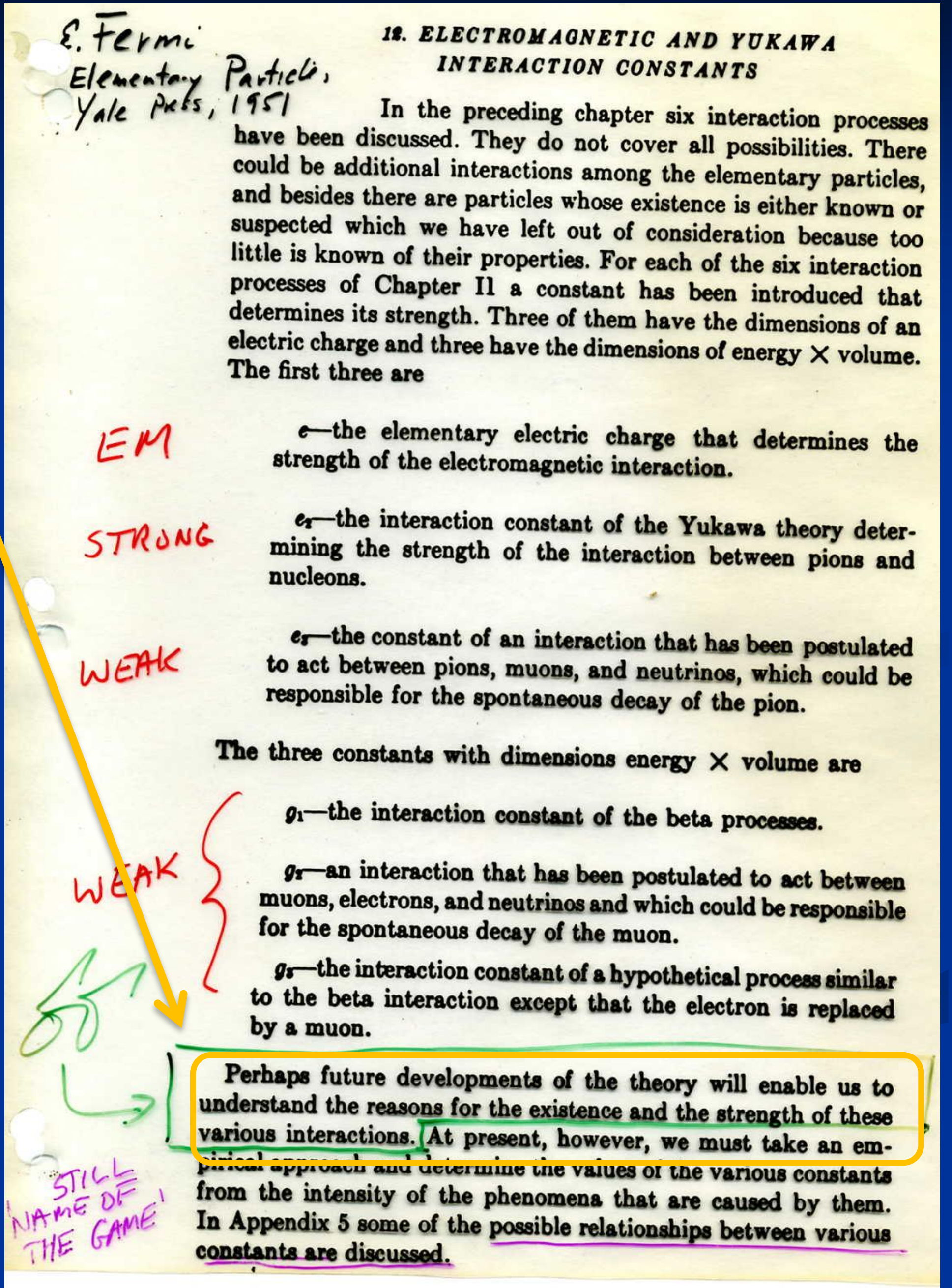
Picture from the Workshop Proceedings

Enrico Fermi on Fundamental Forces

Fermi in his 1951 Yale Lectures:

“ Perhaps future developments of the theory will enable us to understand the reasons for the existence and strength of these various interactions….”

As you know, Jim admired and studied Fermi. There is a wonderful, but not unexpected, strong intellectual connection between Jim’s pioneering work on hard-scattering at the shortest distances and the questions Fermi laid out for us 65 years ago:



E. Fermi
Elementary Particles,
Yale Press, 1951

12. *ELECTROMAGNETIC AND YUKAWA INTERACTION CONSTANTS*

In the preceding chapter six interaction processes have been discussed. They do not cover all possibilities. There could be additional interactions among the elementary particles, and besides there are particles whose existence is either known or suspected which we have left out of consideration because too little is known of their properties. For each of the six interaction processes of Chapter II a constant has been introduced that determines its strength. Three of them have the dimensions of an electric charge and three have the dimensions of energy × volume. The first three are

EM — e—the elementary electric charge that determines the strength of the electromagnetic interaction.

STRONG — e_2—the interaction constant of the Yukawa theory determining the strength of the interaction between pions and nucleons.

WEAK — e_3—the constant of an interaction that has been postulated to act between pions, muons, and neutrinos, which could be responsible for the spontaneous decay of the pion.

The three constants with dimensions energy × volume are

WEAK:

g_1—the interaction constant of the beta processes.

g_2—an interaction that has been postulated to act between muons, electrons, and neutrinos and which could be responsible for the spontaneous decay of the muon.

g_3—the interaction constant of a hypothetical process similar to the beta interaction except that the electron is replaced by a muon.

Perhaps future developments of the theory will enable us to understand the reasons for the existence and the strength of these various interactions. At present, however, we must take an empirical approach and determine the values of the various constants from the intensity of the phenomena that are caused by them. In Appendix 5 some of the possible relationships between various constants are discussed.

STILL NAME OF THE GAME!

I'd like to return to 1974- the Multi-Hole Spectrometer

What is was like to work with Jim

NAL PROPOSAL No. 325

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STUDY OF DI-MUON PRODUCTION AT HIGH TRANSVERSE MOMENTA

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Fermilab E325 Proposal
June 1974

We have given further consideration to the study of high mass dimuon events. In the original Proposal 325 (E-300 Addendum), we suggested using the east end of the pit being built for Adair (E-48). (We assume the reader has also read the E-300 Addendum). At the time of writing this note (August 1, 1974), the exact location of the pit is still uncertain. In addition, we have done more detailed calculations on muon background and find that a wide detector transverse to the muon direction is far from optimum. For the small angle muons there is insufficient thickness to suppress the μ background from π and K decay, while at larger angles, the desired muons do not have sufficient range. Thus, in this note we propose an alternative scheme which, on the one hand, is an escalation, but, on the other hand, is far superior and sensibly designed.

One should recall that E-100 was the first experiment at FNAL to successfully measure direct muons. Our results are now published (Phys. Rev. Letters 33, 114, 1974). We are most eager to continue this work in a modest but significant way. We realize that there are many muon experiments approved or proposed. We are still behaving as scientists, trying to follow up on a discovery with a reasonable next step, given the limitations of our location and apparatus.

It is well known that the invariant π and K production cross sections are functions only of $p_{\perp}$ in the central region (x = 0.) Thus, if one builds a detector parallel to the proton beam, the decay muons must penetrate a fixed amount of transverse shielding independent of angle

There's a subtext

Paper and pencil detector design

The detector is a set of 10 6' x 4' x 1' liquid scintillation counters, each placed in a 4' diameter 17' deep hole. The 10 holes are placed along a line 19' displaced from the incident beam direction. One has 15' of transverse earth shielding which corresponds to a 1.5 GeV/c cutoff in transverse momentum. The holes, which begin at 140' from the target, increase in distances from another in geometric progression with a factor 1.166 in distance from one to another.

Detector design details

Such a device cannot measure the μμ mass accurately. It can however measure the minimum mass which is given by $M_{\mu\mu} \gtrsim (p_{\perp}^{s} + 1.5)$ GeV/c^2 where $p_{\perp}^{s}$ is the transverse momentum setting of the spectrometer and 1.5 is the transverse momentum cutoff of the MHS. If the RMS transverse momentum of $M_{\mu\mu}$ is less than .5 GeV/c, then the dimuon mass resolution is $\Delta M_{\mu\mu}/M_{\mu\mu} \sim 0.1$.

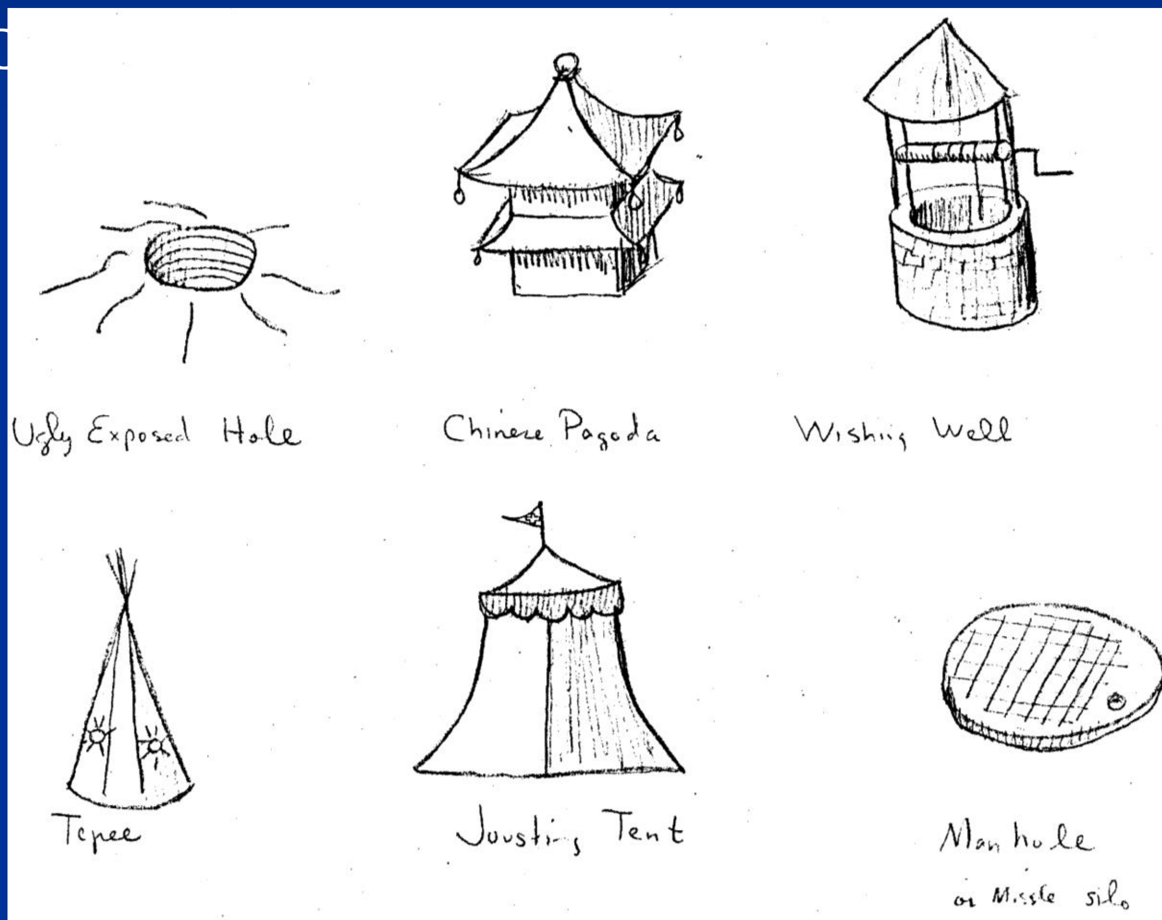
Performance

We have consulted a contractor (Case, Roselle, Ill.) for the price of holes. The contractor stated $1500/per hole for 10 4' diameter 17' deep holes lined with corregated steel. The additional cost to place a cover on each hole and a Sears-Roebuck sump inside may cost NAL $500/hole. Our detector cost is estimated to be $1000 each (4 665PM's, 24 cu. ft. liquid scintillator, and a rough aluminum tank.)

Practical details

Class

In order to make the MHS less unsightly, we have considered more decorative covers which may enhance the beauty of the site. Figure 3 shows several disguises which might be appropriate.



Taking Stock

Jim did all the right things at the right time- wonderful taste, sense of discovery, minimalist experimental style

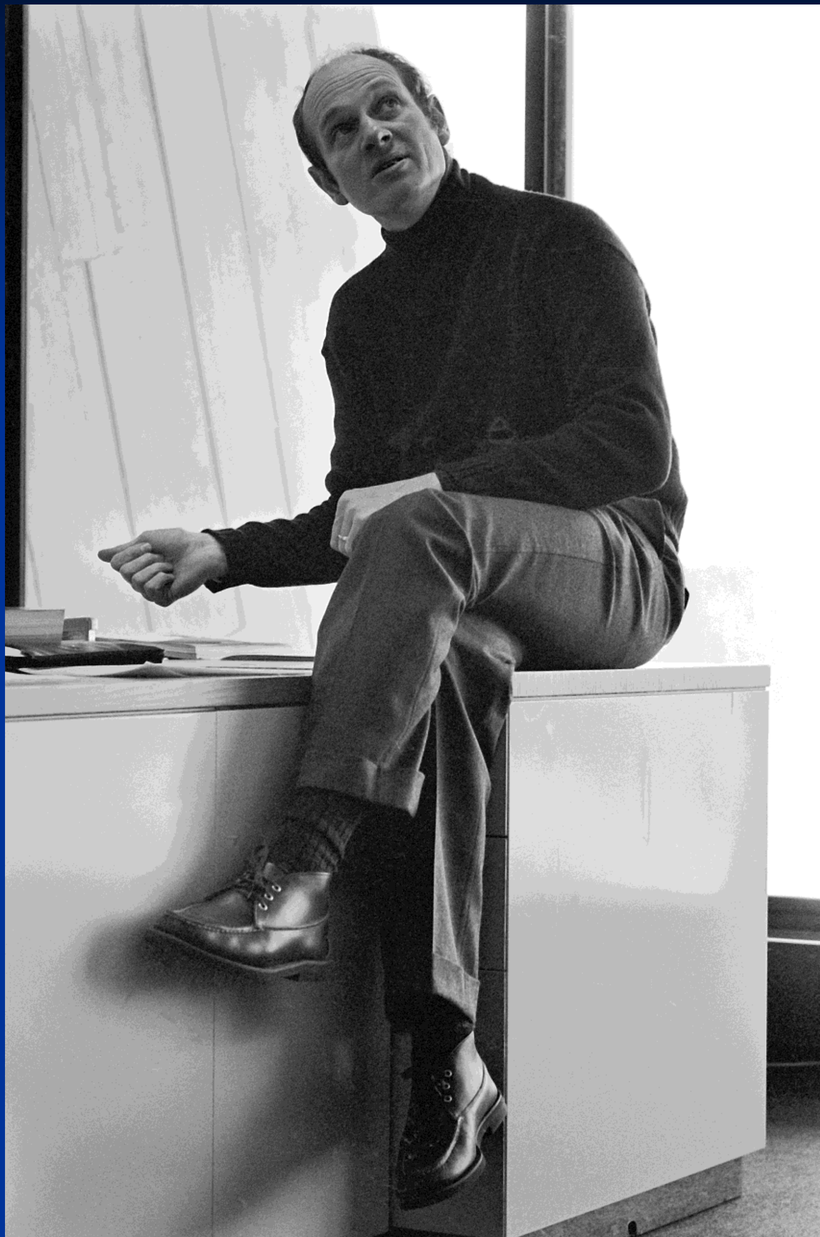
E100/325- the high-Pt 'investigations' at Fermilab were in the thick of the development of today's parton model- power-law behavior of cross-sections (point-like scattering), fragmentation of partons (PT^{-8} vs PT^{-4}) , direct muons (charm, June 1974 vs Nov), Cronin Effect.

Jim was instrumental in the start of the collider program at FNAL- at CDF alonge discovery of top, precision W and Z measurements, precision b-quark measurements, development of tools, hardware, ….

Jim was right on target on the SSC- if he had prevailed we would be running today at 40 TeV in pp with 2 rings.

Jim left a large legacy in protégé's- we owe him big-time.

Jim in 1977-



Hard-parton scattering and JWC

1977