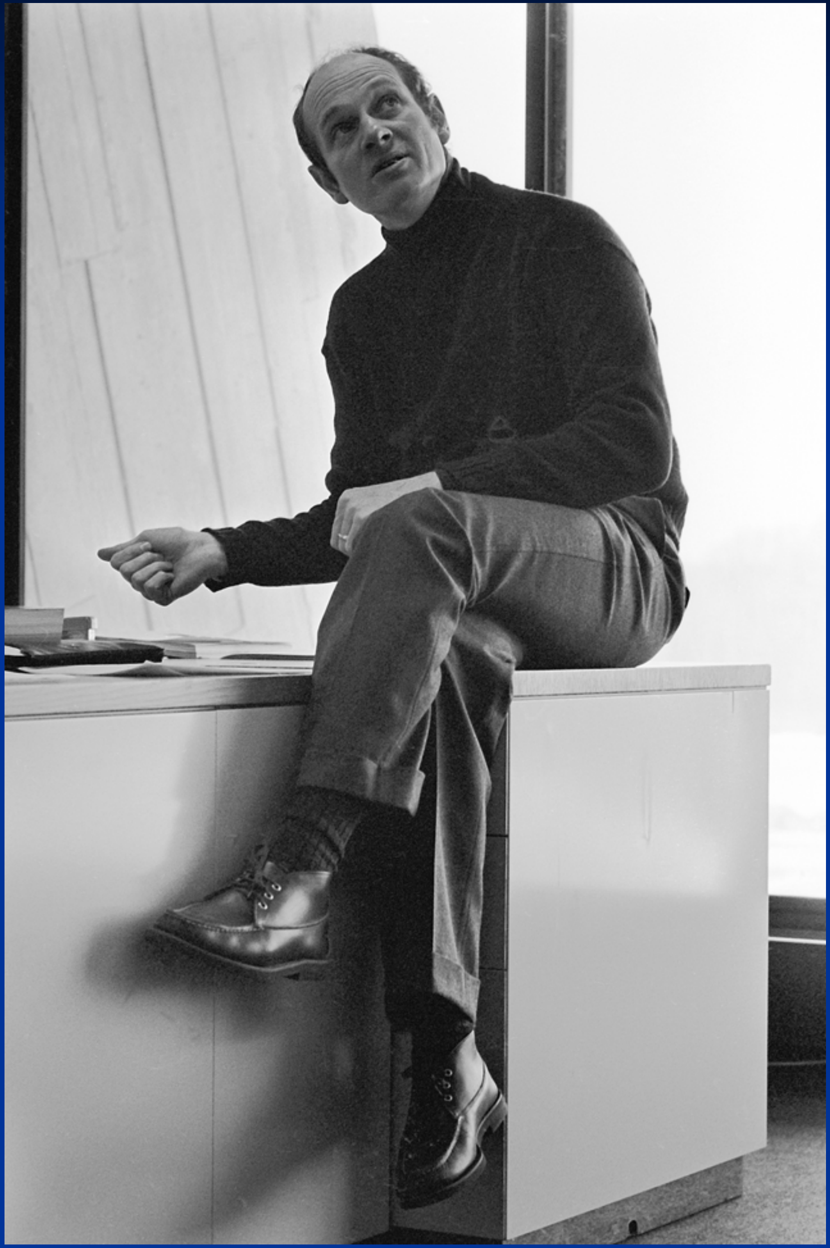
Hard Parton Scattering

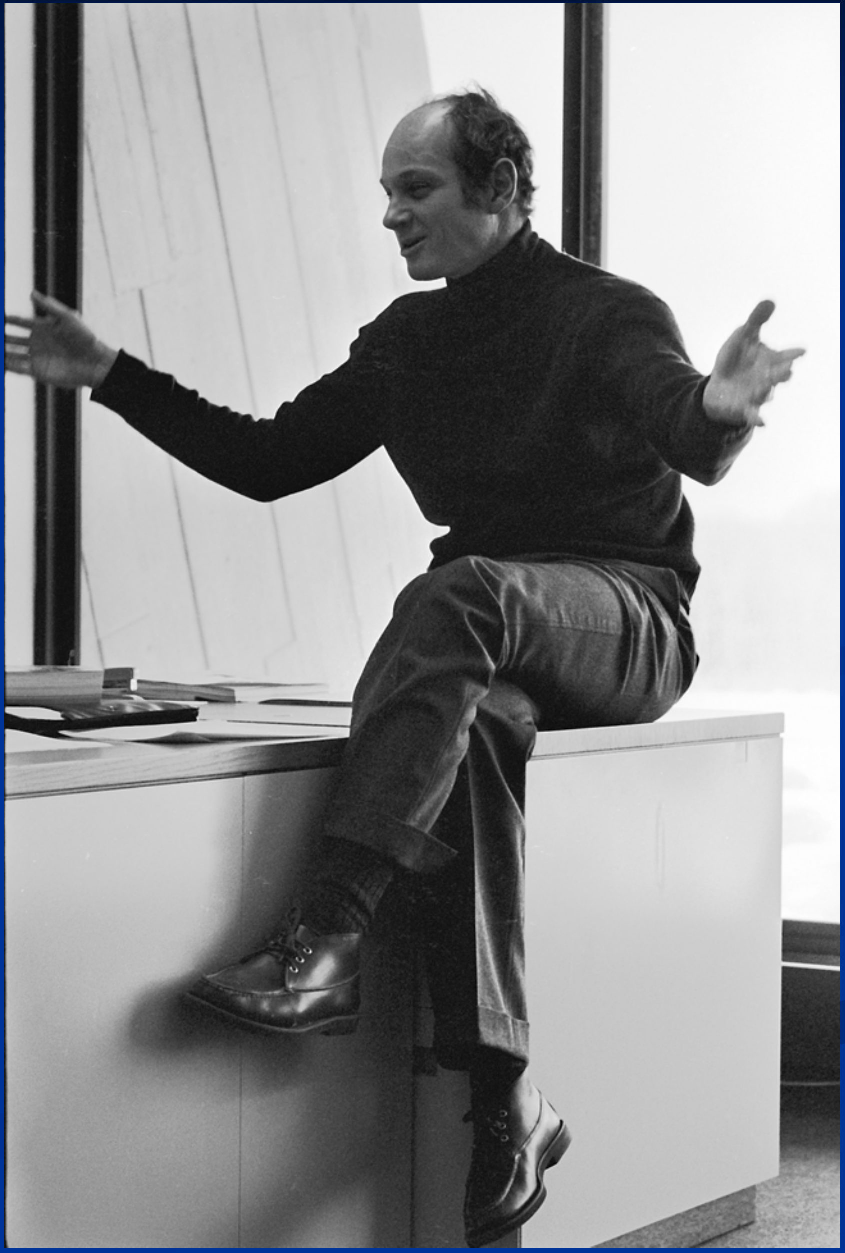
Henry Frisch

Enrico Fermi Institute, U of C

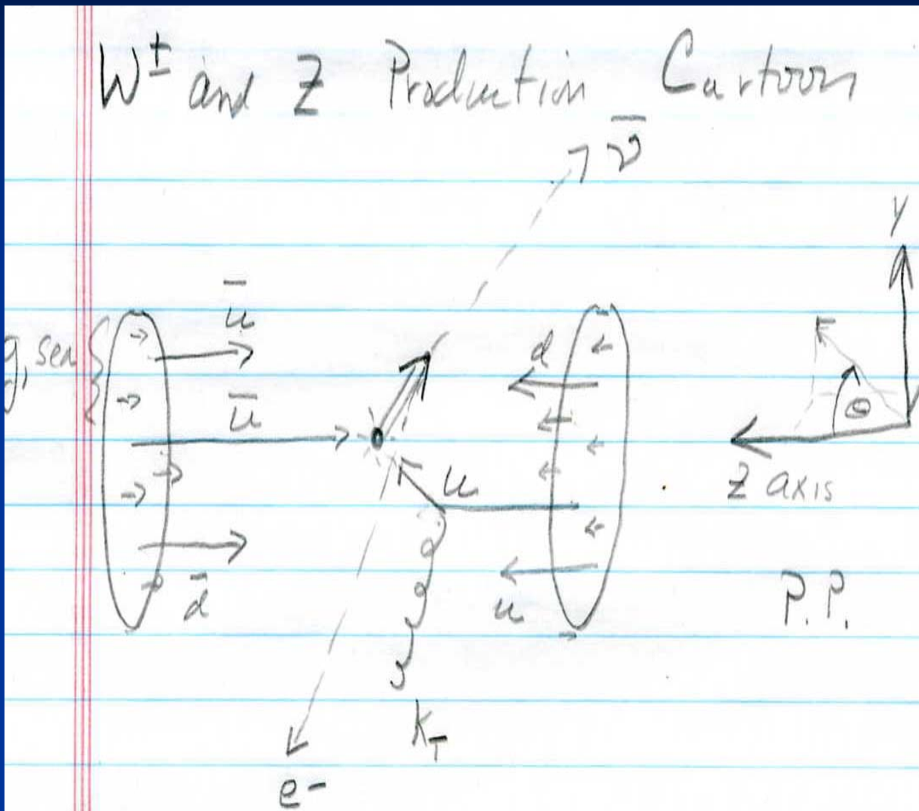
1. Introduction: Partons & Hadrons, and Hadrons & Partons
2. 1970: JWC and PP propose Fermilab Experiment E100
3. 1976: Jim heads up the Colliding Beam Experiments Dept. (the seeds of the Collider Detector at Fermilab (CDF))
4. 1984: If Wishes Were Horses: The pbar-p SSC option: Jim's vision of a more careful and more real approach to the SSC (relevant to our present long-term plans).
5. The present: we've entered a Golden Age of Hard Parton Scattering (no pun): Do We Finally Get to a more basic understanding of Parity Violation, Flavor and CKM Mixing, EWK Symmetry Breaking, Larger Symmetries,….?

Jim in 1977-





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

"Hard" means large momentum transfer- either a violent scatter or creation of a system of large mass

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.

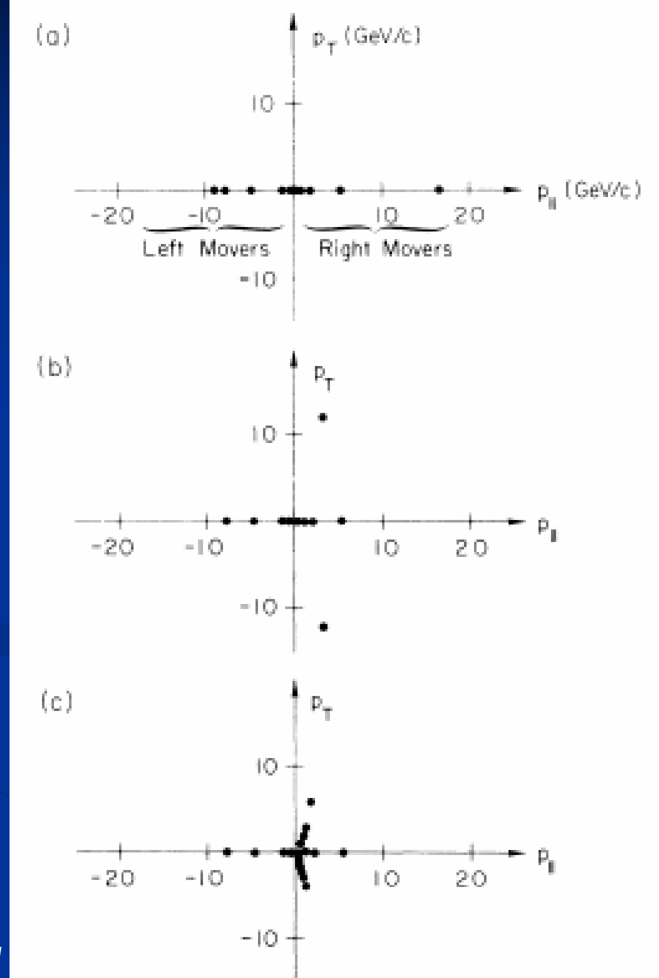


FIG. 4. A momentum-space visualization of hadron-hadron deep-inelastic scattering occurring in three steps.

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,…

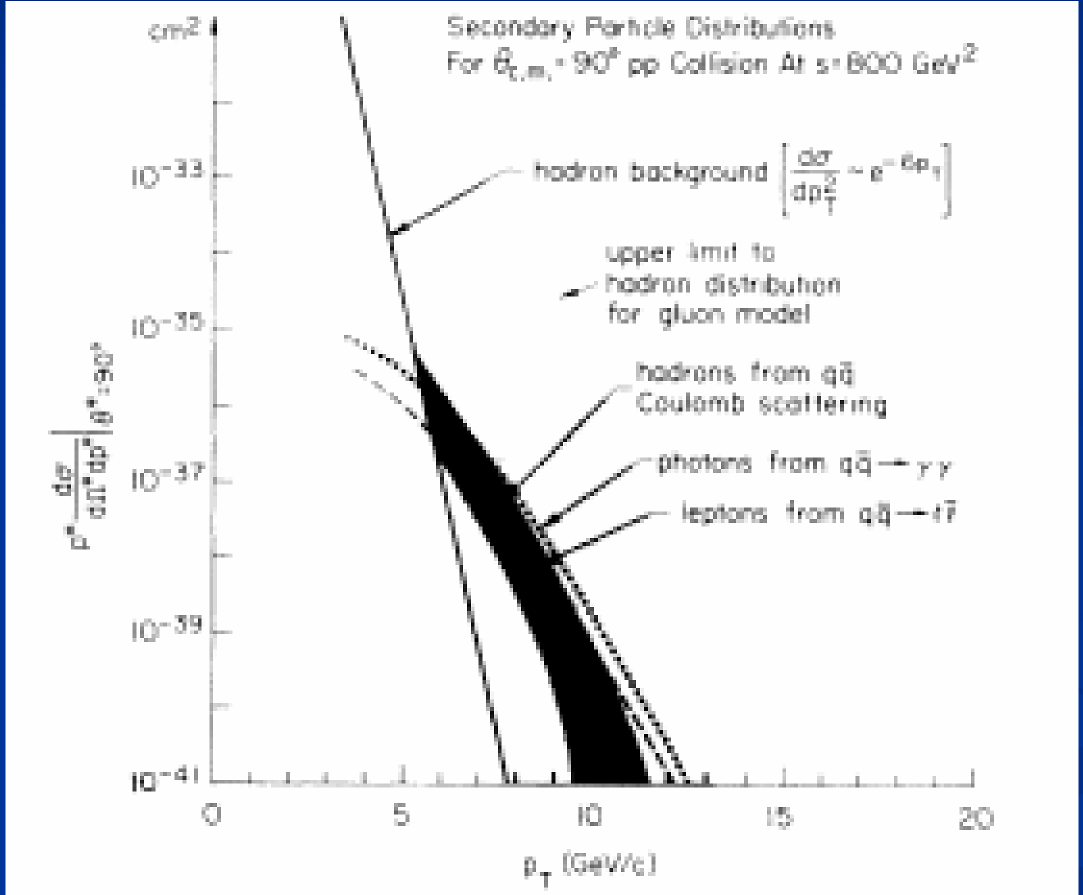


FIG. 1. Secondary-particle distributions as calculated in the parton model and compared to diffractive backgrounds for typical NAL conditions.

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 ($\sim 90^\circ$ 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:

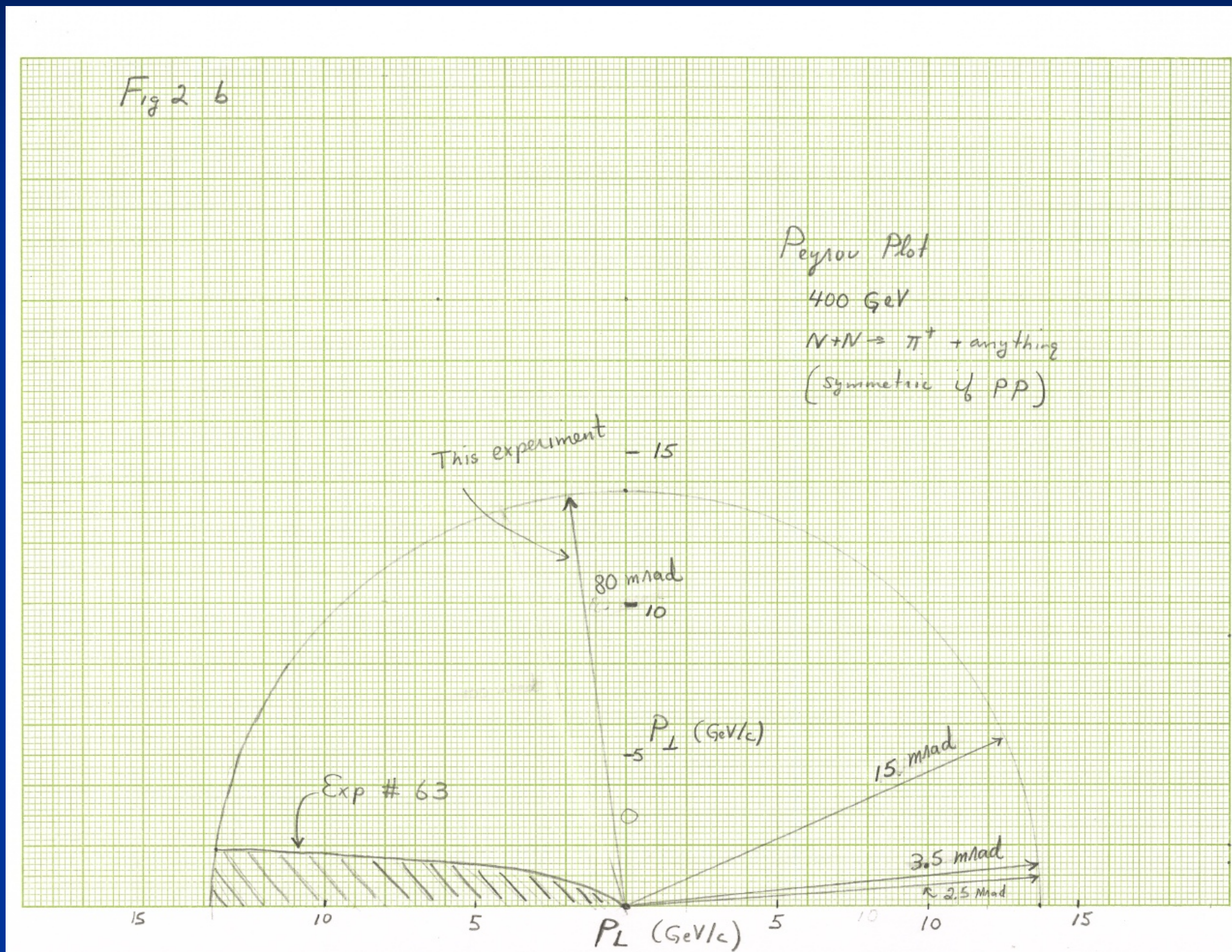
"…an Exploratory Investigation…"

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

$P_{transverse}$

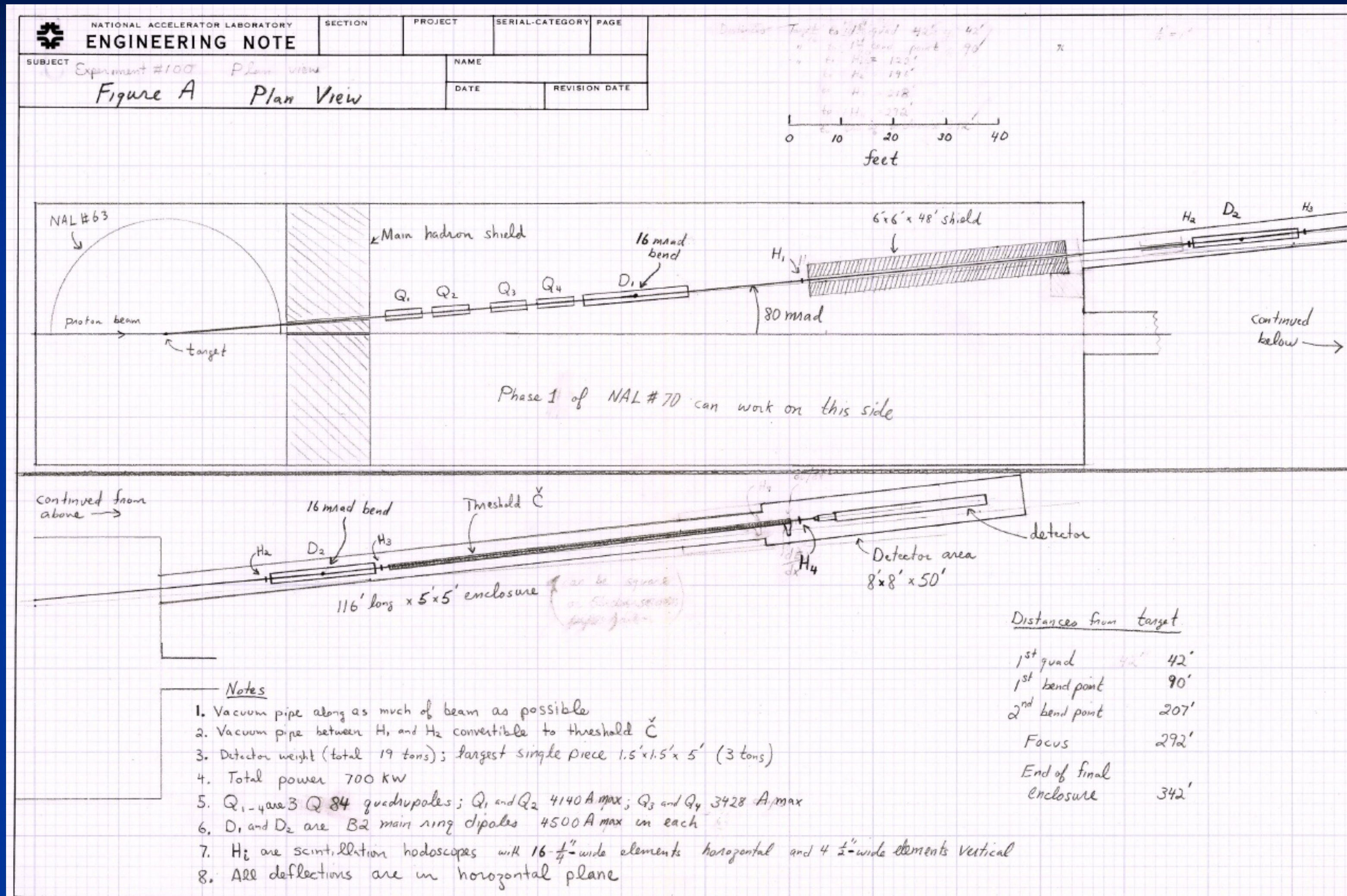


(JWC hand-drawn original)

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

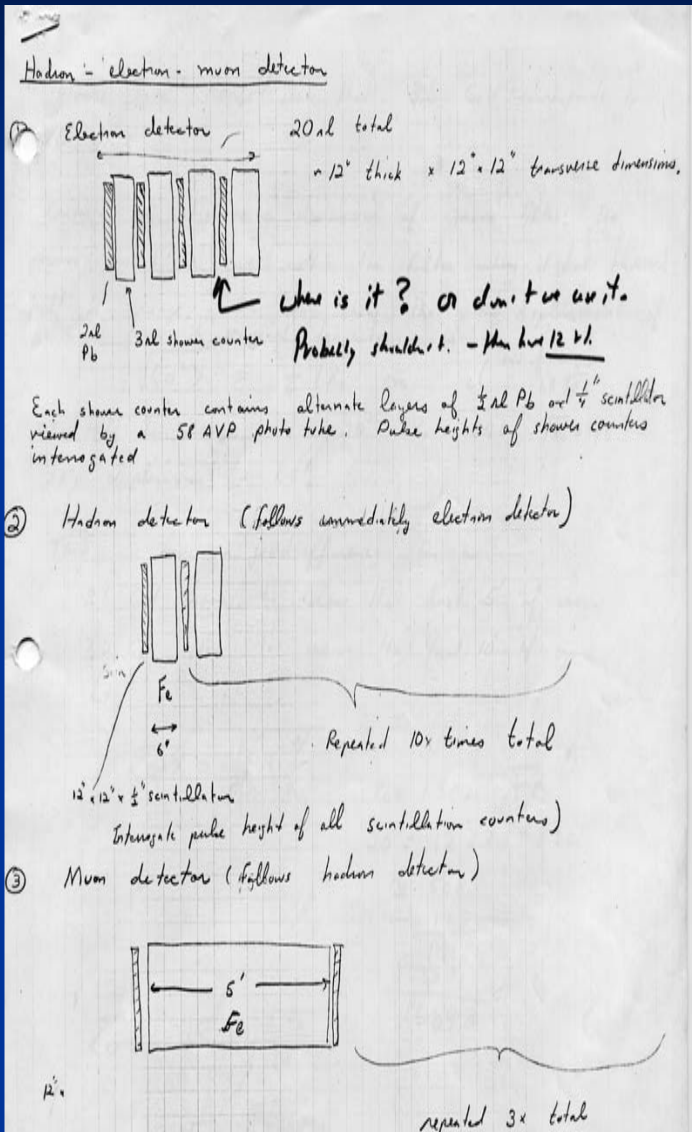
$P_{longitudinal}$ (along the initial beam direction)

E100 at Fermilab: 1970-77



Hand-drawn layout of the E100 spectrometer- about 100 yards long…

E100 at Fermilab: 1970-77

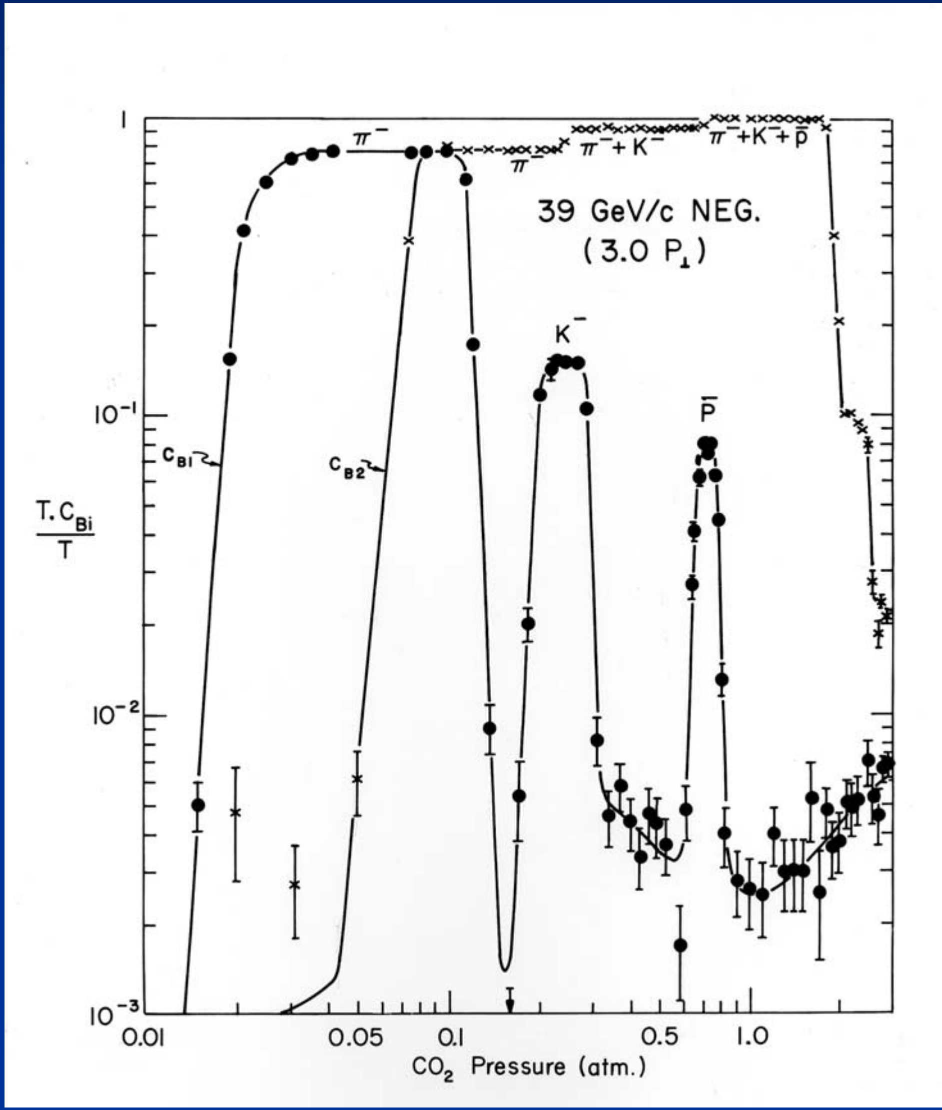


Particle Identification – not so differen from the standard collider “kit” nowadays (exept for Pierre’s beautiful Cherenkov counters, and the Lorentz frame):

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**

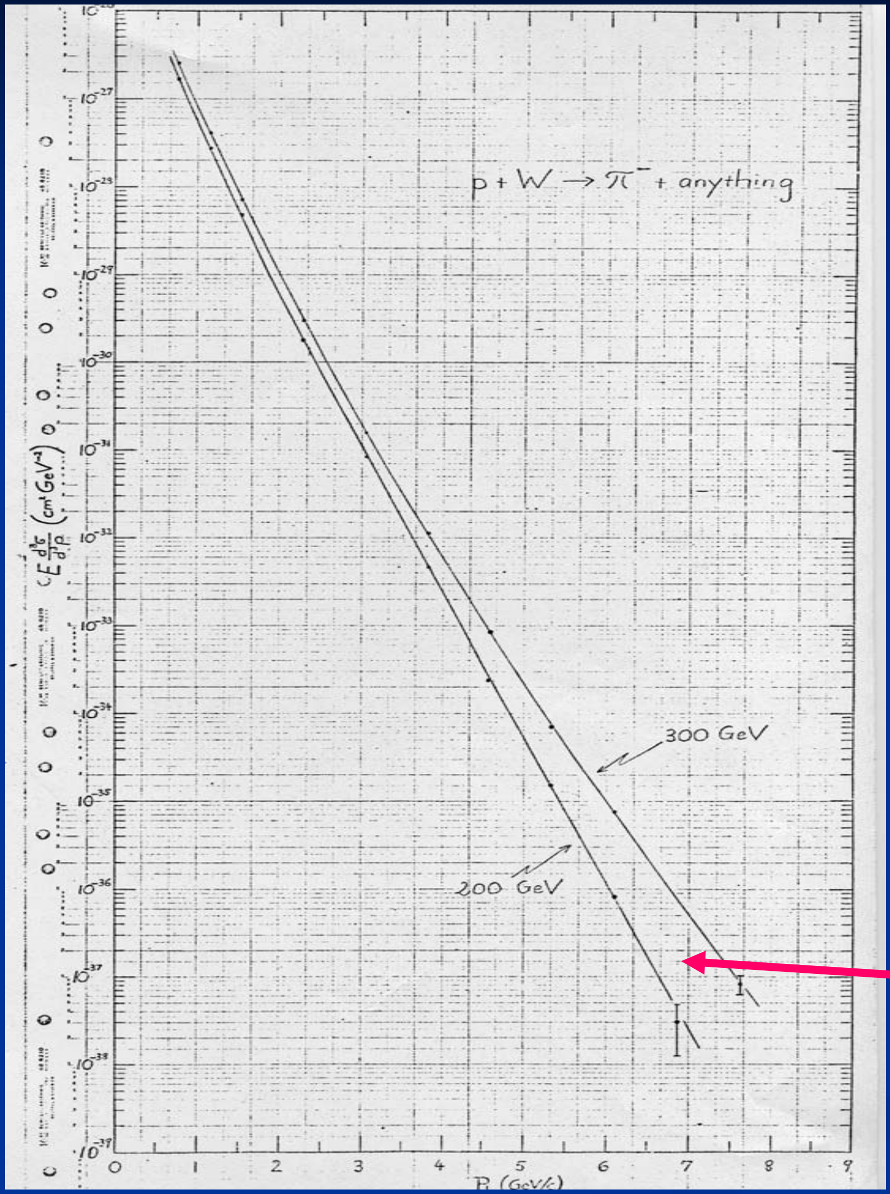
E100 at Fermilab: 1970-77

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



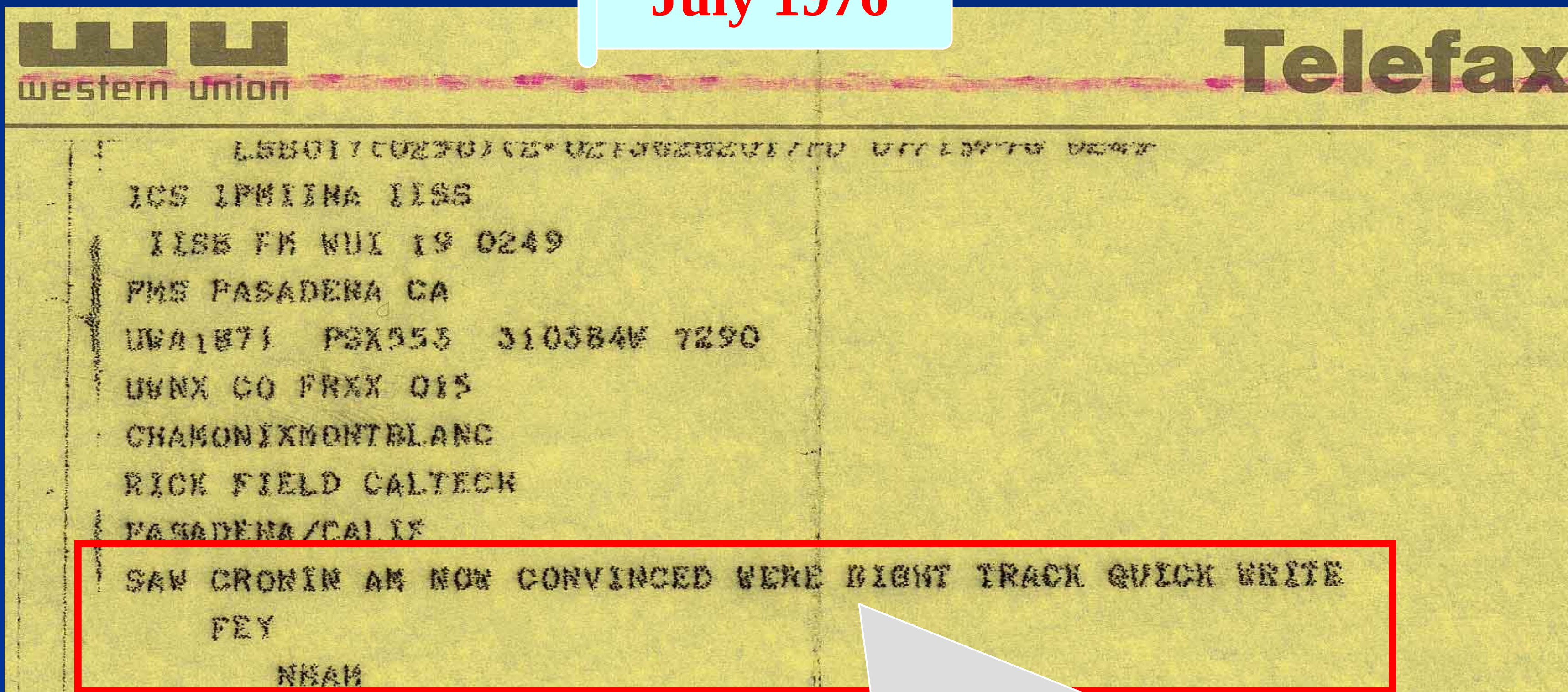
First Results- 1972- see power-law behavior and energy dependence at large Pt

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



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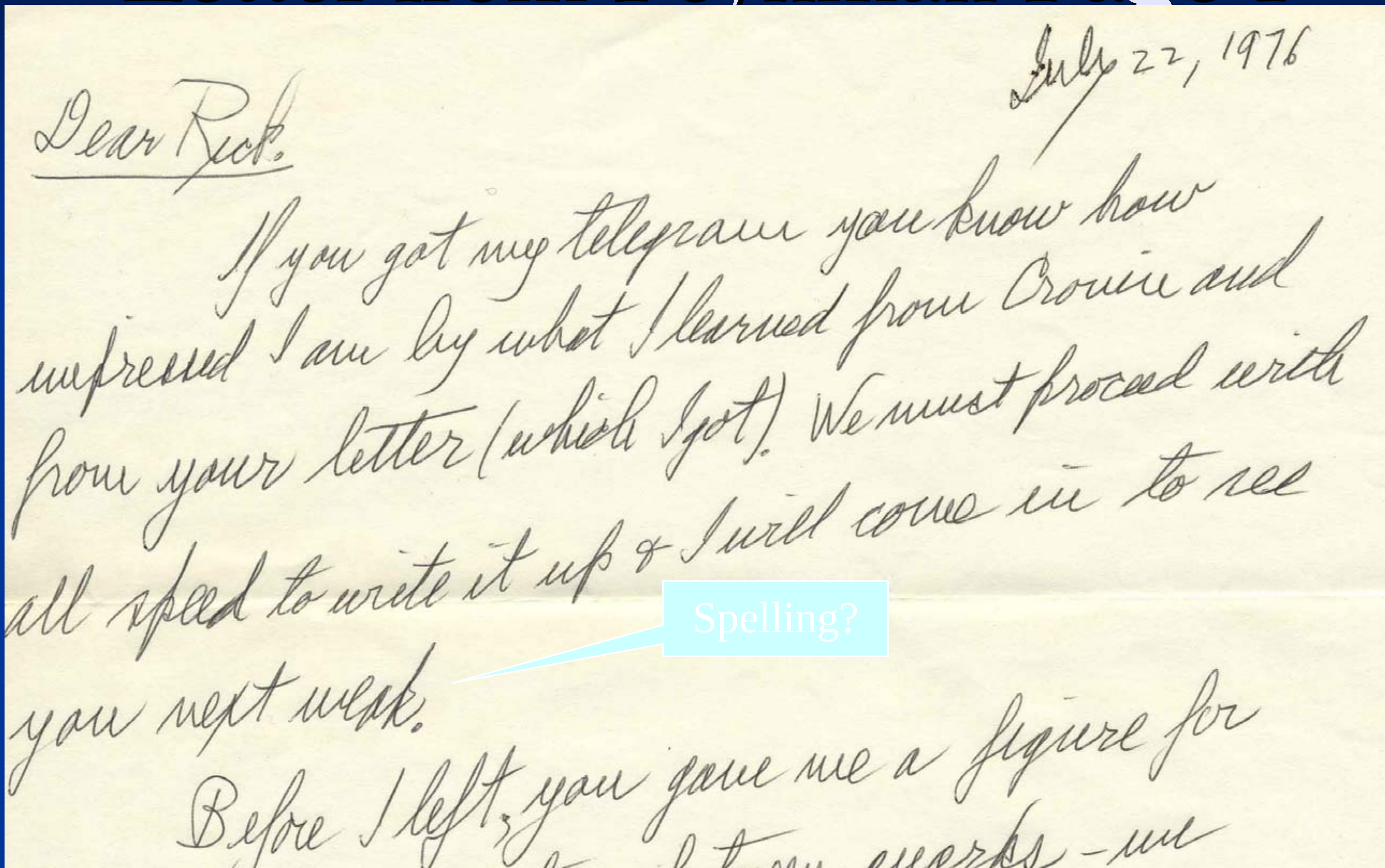
IISS FM WUI 19 0249
PMS PASADENA CA
UWA1871 PSX553 310384W 7290
UWNX CO FRXX 015
CHAMONIXMONTBLANC
RICK FIELD CALTECH
PASADENA/CALIF
SAW CRONIN AM NOW CONVINCED WERE RIGHT TRACK QUICK WRITE
FEY
NMAN

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 week.

Before I left, you gave me a figure for

between quarks – we

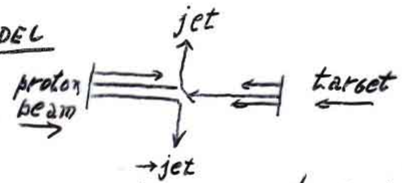
From Rick Field's Lectures at UC, July 2006

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.

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

Try to fit all correlation experiments with no new parameters.

Last transparency

"Feynman-Field Jet Model"

WORK IN PROGRESS

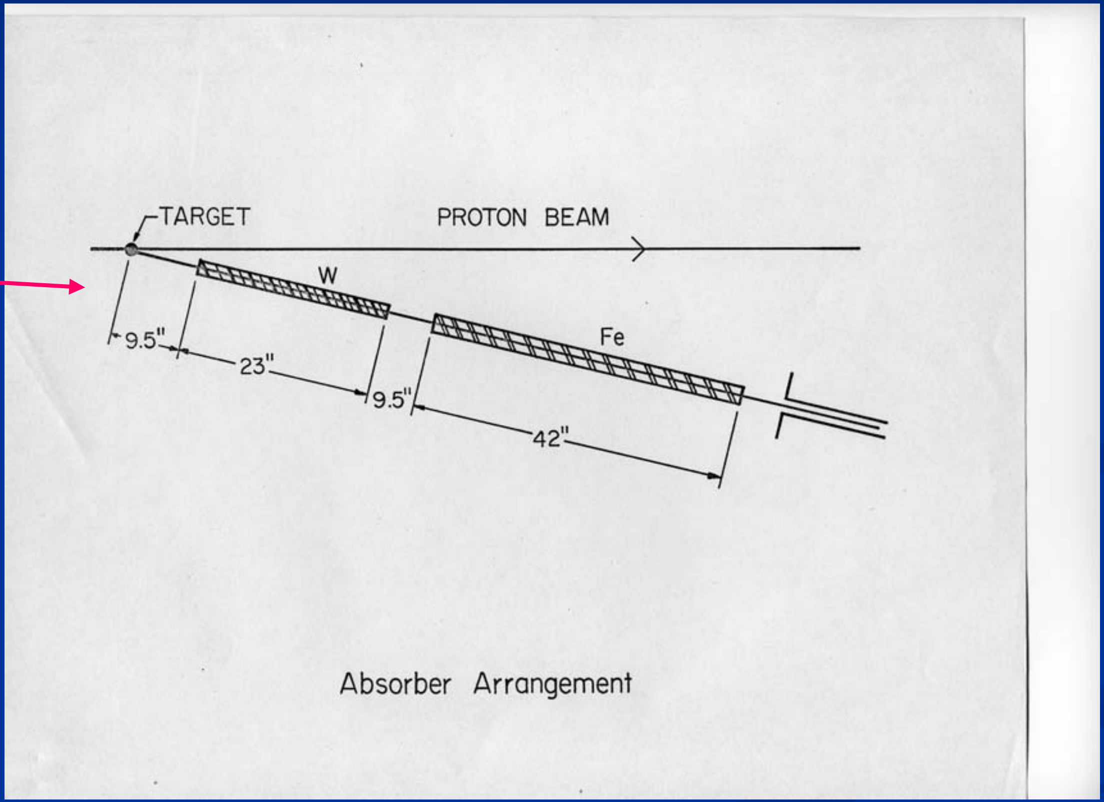
a) More detailed Calculations
b) Theory of q → hadron cascade

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

E100 at Fermilab: 1970-77

The discovery of `direct leptons'- a really sweet idea of Jim's- measure muons, and extrapolate to zero lifetime of any production mechanism (mostly pi and K decays- long-lived)

Moveable absorbers ("shutters") that could be put in the path of the particles in the spectrometer to absorb any pions, kaons, etc.



E100 at Fermilab: 1970-77

The discovery of `direct leptons'- a really sweet idea of Jim's- measure muons, and extrapolate to zero lifetime of any production mechanism (mostly pi and K decays- long-lived)

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.

E100 at Fermilab: 1970-77

The discovery of `direct leptons'- a really sweet idea of Jim's- measure muons, and extrapolate to zero lifetime of any production mechanism (mostly pi and K decays- long-lived)

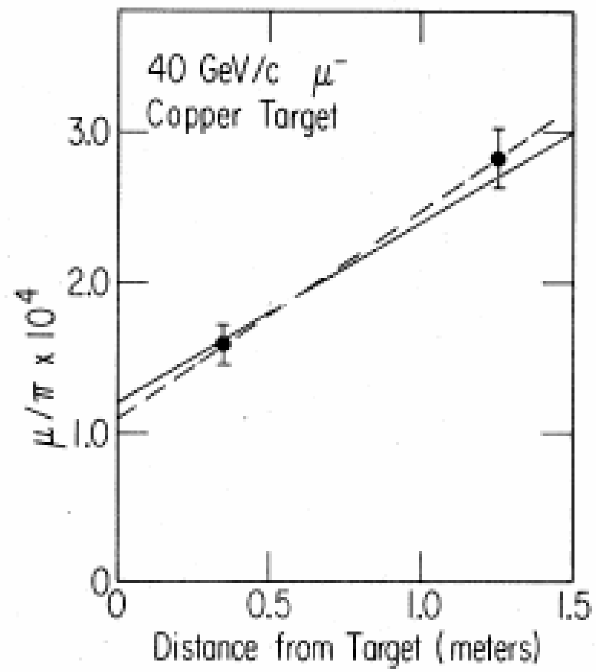


FIG. 1. Plot of data reduced in Table I. Dashed curve, linear extrapolation to the target; solid line, calculated slope.

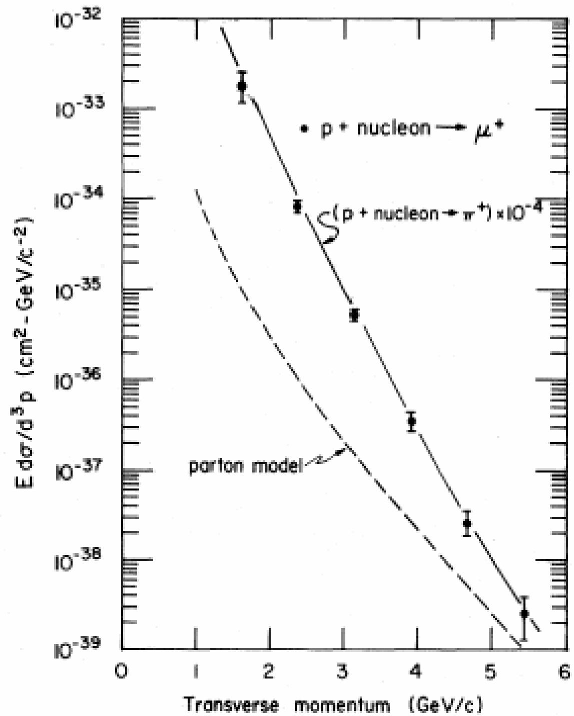


FIG. 3. Plot of the invariant cross section for direct muon production versus P. Also shown is the pion cross section multiplied by 10^{-4} and the cross section predicted by a parton model.

Important, but we needed more information- experimental and theoretical

E100 at Fermilab: 1970-77

The discovery of `the Cronin Effect’: proton-Linoleum Scattering

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.

E100 at Fermilab: 1970-77

The discovery of `the Cronin Effect': proton-Linoleum Scattering

VOLUME 38, NUMBER 13 PHYSICAL REVIEW LETTERS 28 MARCH 1977

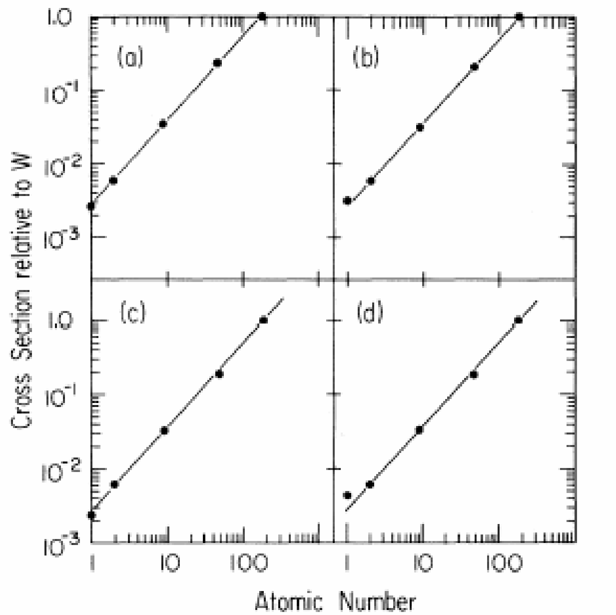


FIG. 1. The invariant cross section for π production relative to tungsten for various atomic numbers at 400 GeV; (a) π^- at $p_\perp = 3.85$ GeV/c, (b) π^+ at $p_\perp = 3.85$ GeV/c, (c) π^- at $p_\perp = 5.38$ GeV/c, (d) π^+ at $p_\perp = 5.38$ GeV/c. The errors are smaller than or equal to the size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

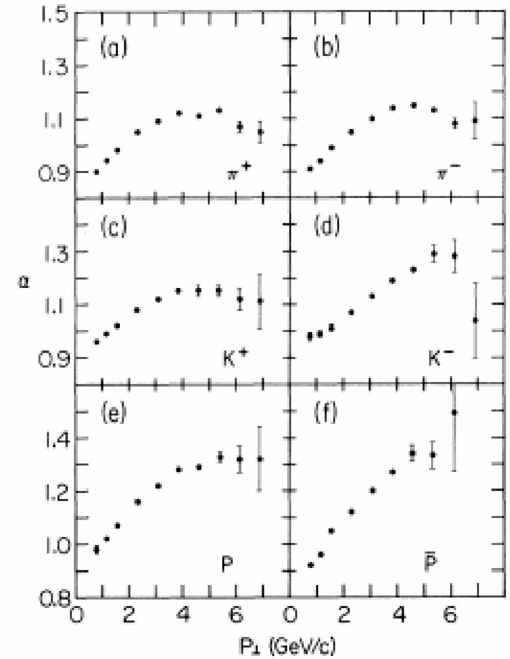


FIG. 2. The power α of the A dependence of the invariant cross section vs $p_\perp$ for the production of hadrons by 400-GeV protons; (a) π^+, (b) π^-, (c) K^+, (d) K^-, (e) p, and (f) $\bar{p}$. Unless indicated otherwise, the errors are smaller than or equal to the size of the points.

showed values of α in excess of unity at large $p_\perp$. This effect has been the subject of considerable discussion in the recent literature.[4-12]

sively placed in the beam. Hence the relative

A measurement of partons traversing nuclear material- Has fostered a whole field, though (perhaps) inadvertently

"Colliding Beam Experiments Department"

From "Fermilab Report, Dec. 1976"- Jim heads up the new Colliding Beam Experiments Department at Fermilab

Fermilab Report

DEPARTMENT OF COLLIDING BEAM EXPERIMENTS

A meeting was held at Fermilab on November 17 to discuss various possibilities for the organization of work on colliding beam experiments. In accordance with some of the ideas which were discussed at that meeting a Colliding Beam Experiments Department has now been set up. Professor James Cronin of the University of Chicago has agreed to head this new department.

The department is to be a center for a number of activities directed toward planning for the exploitation of pp and $\overline{p}p$ colliding beams in the present Main-Ring tunnel. Financial restrictions prevent adding very many

"Colliding Beam Experiments Department"

From "Fermilab Report, Dec. 1977"- Jim resigns as Head of the old Colliding Beam Experiments Department at Fermilab:

Dec. '77

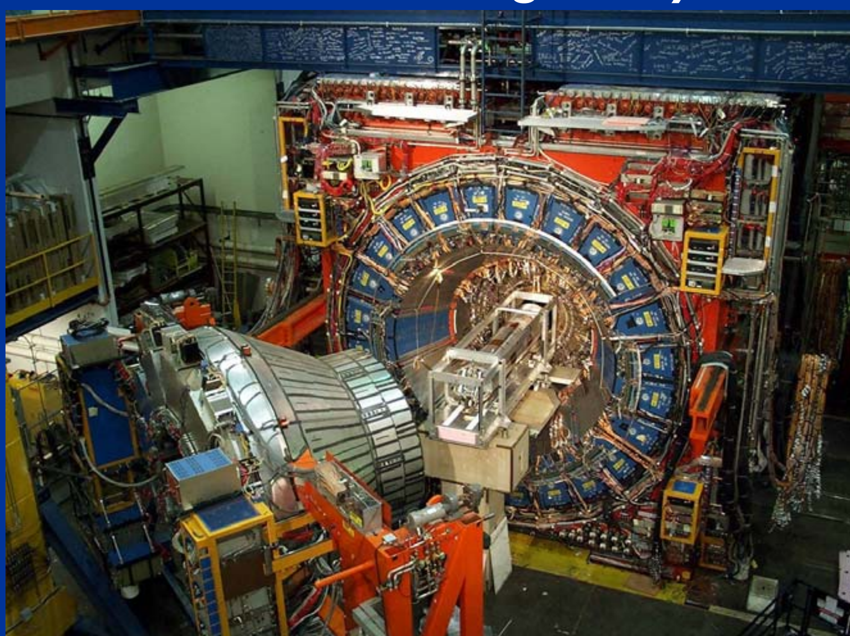
REORGANIZATION OF COLLIDING BEAMS RESEARCH

The Colliding Beam Experiments Department, originally headed by Jim Cronin, has now been disbanded. In its place there will be a Colliding Detector Facility (CDF) Department within the Research Division, a Colliding Beam (CB) Group in the Accelerator Division, and an Antiproton Cooling (AC) Group in the Accelerator Division.

"Colliding Beam Experiments Department"

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

But, with Dennis Theriot and a wonderful crew largely assembled by Jim… (Dennis is also 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)

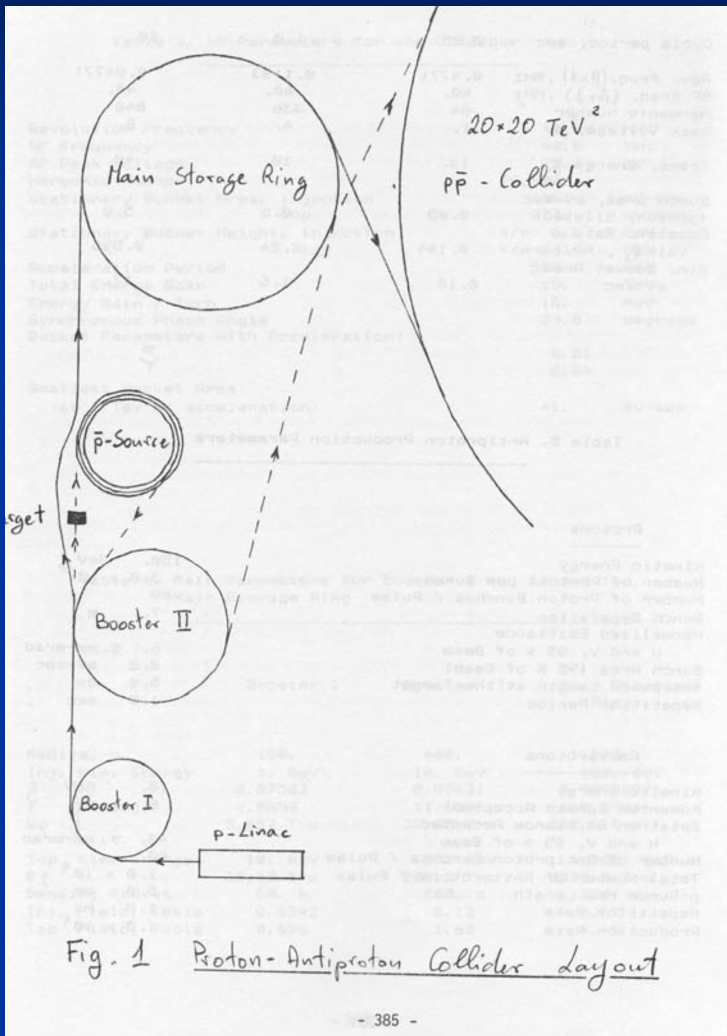


Fig. 1 Proton-Antiproton Collider Layout

Jim has 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. Recognizes that the key parameter is collision energy if one has decent luminosity

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:

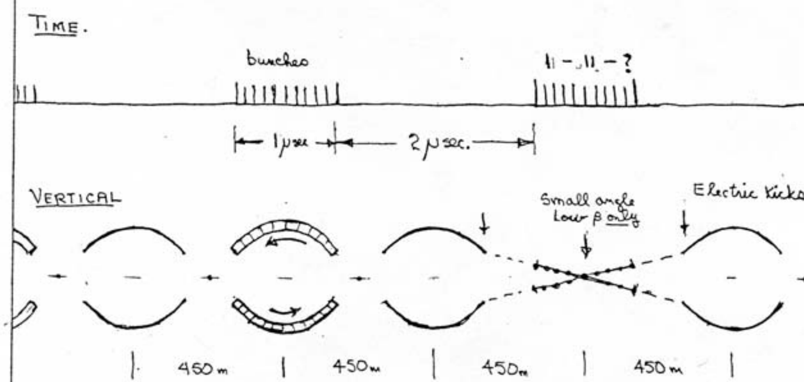
1. For a $\bar{p}p$ collider what is a realistic maximum luminosity? What is its time structure.
2. For physics thought to be independent of pp or $\bar{p}p$ what luminosity is required to have a reasonable rate for the various processes
3. Can detectors be envisaged that can observe the processes considered 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 concisely 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")

10^{32} in each of 6 INTERACTION REGION.



For $\Delta\nu = .003$, every P bunch is 2.6×10^{10} P's. ($\epsilon = 5\pi$)

$\bar{P}$ bunch varies 1/no. of bunches TOTAL 10^{13} $\bar{P}$'s (102 batches)

11 bunches/batch → 100 nsec space → 2.7×10^{25}/hit for $\mathcal{L} = 10^{32}$ → 6.5×10^{9}/bunch

SINGLE RING ~6 Tesla magnets - 91.800 Km (306 μsec)

Same size as one P-P ring. Separation is small and easy.

I.R. 1m β^* ± 20 m. space.

The pbarp SSC Option

Not just a sorrowful "what could have been"- **we should listen to (and learn from) Jim's wisdom** as many of the same issues are on the table now with the question of unique Tevatron capabilities (pbarp but at 1/7 the energy of the LHC) and when to shut it off (analogous to the AGS), and also the path to the ILC.

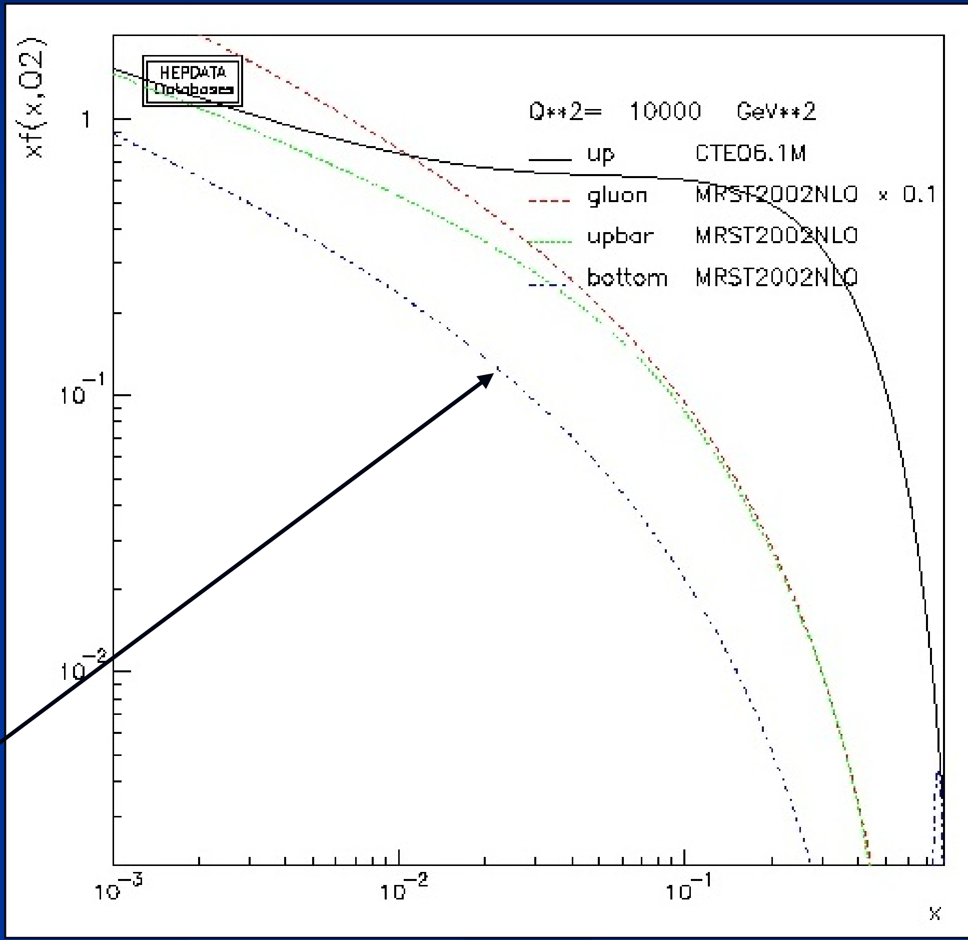
Picture from the Workshop Proceedings

This is the era of hard-parton scattering

To Where Have We Come, and From These Beginnings Why is it Now a Golden Era?

1. Unlike as in 1970 we have models for the types and properties of the partons, for their distributions inside hadrons, and for the force with which the scatter and annihilate- i.e. Feynman diagrams and parameterized parton fluxes inside the proton.

Parton "Density"

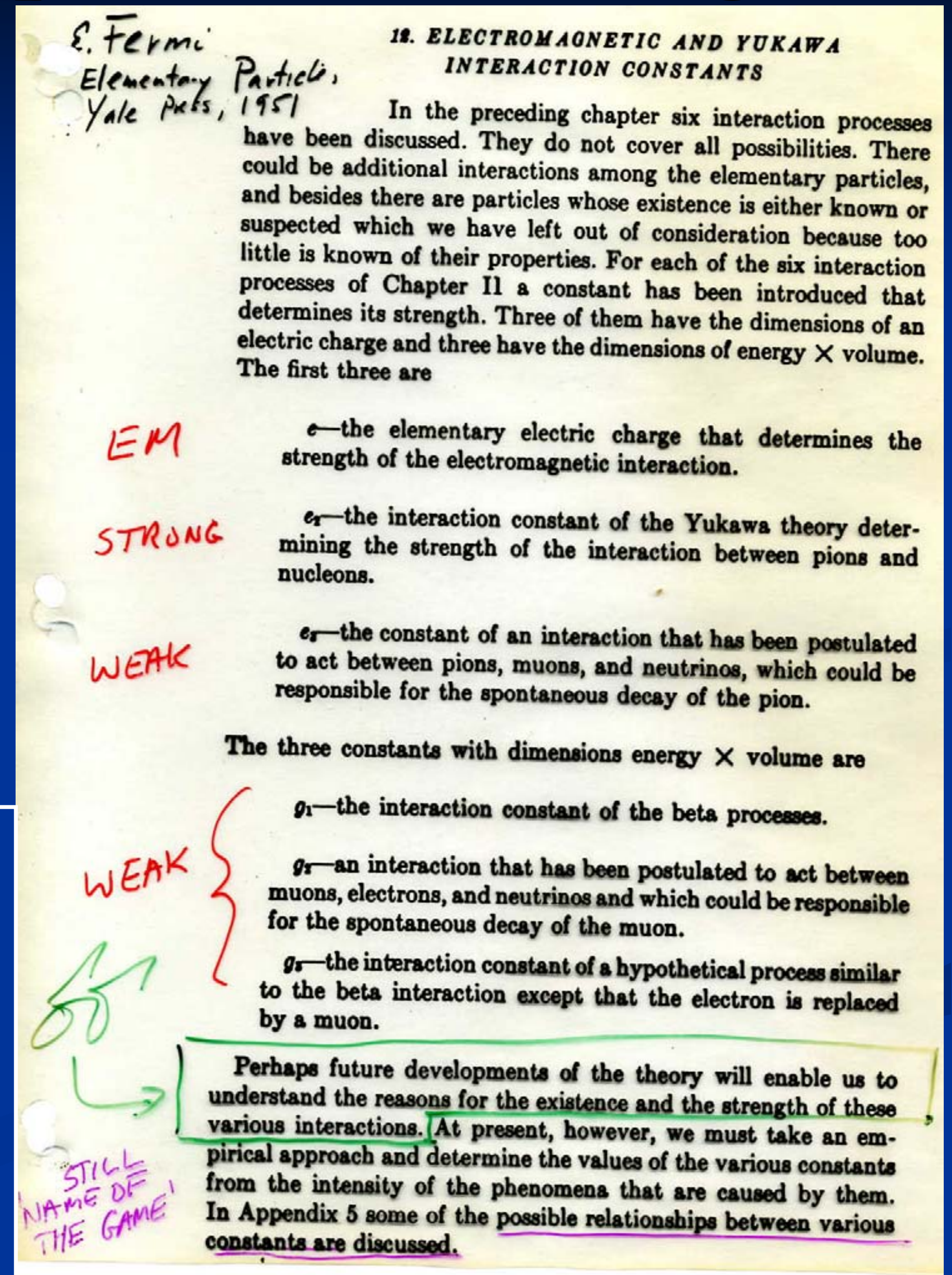


Probability of finding a bottom quark in the proton (!)

Fraction of proton momentum carried by the parton

The era of hard-parton scattering

2. **Have a predictive theory, experimentally tested widely and deeply, of the strong and electro-weak forces (the "Standard Model" ($SU(3) \times SU(2)_L \times U(1)$))**



E. Fermi
Elementary Particles,
Yale Press, 1951

18. 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 11 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.

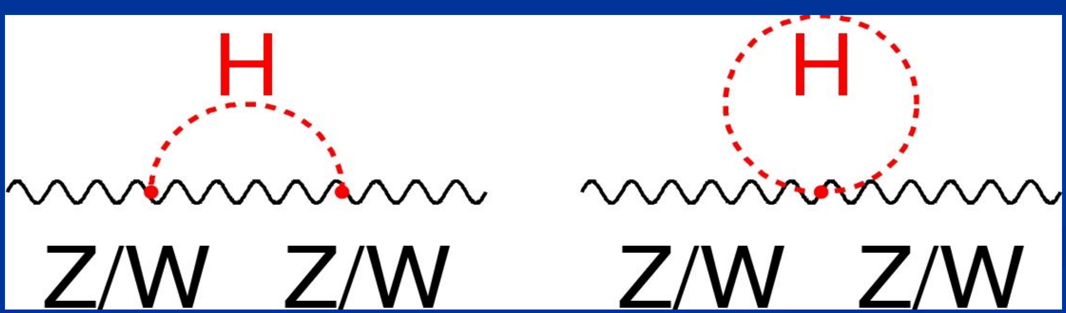
Perhaps future developments of the theory will enable us to understand the reasons for the existence and the strength of these various interactions. At present, however, we must take an empirical approach and determine the values of the various constants from the intensity of the phenomena that are caused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

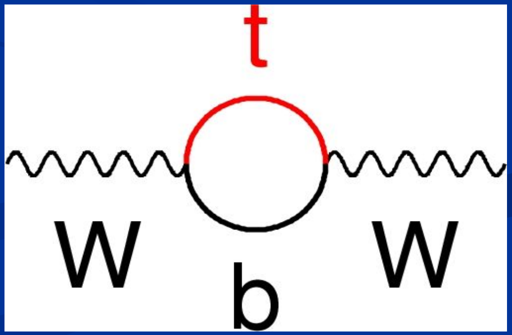
STILL NAME OF THE GAME!

Fermi in his 1951 Yale Lectures:
" Perhaps future developments of the theory will enable to understand the reasons for the existence and strength of these various interactions…."

The era of hard-parton scattering

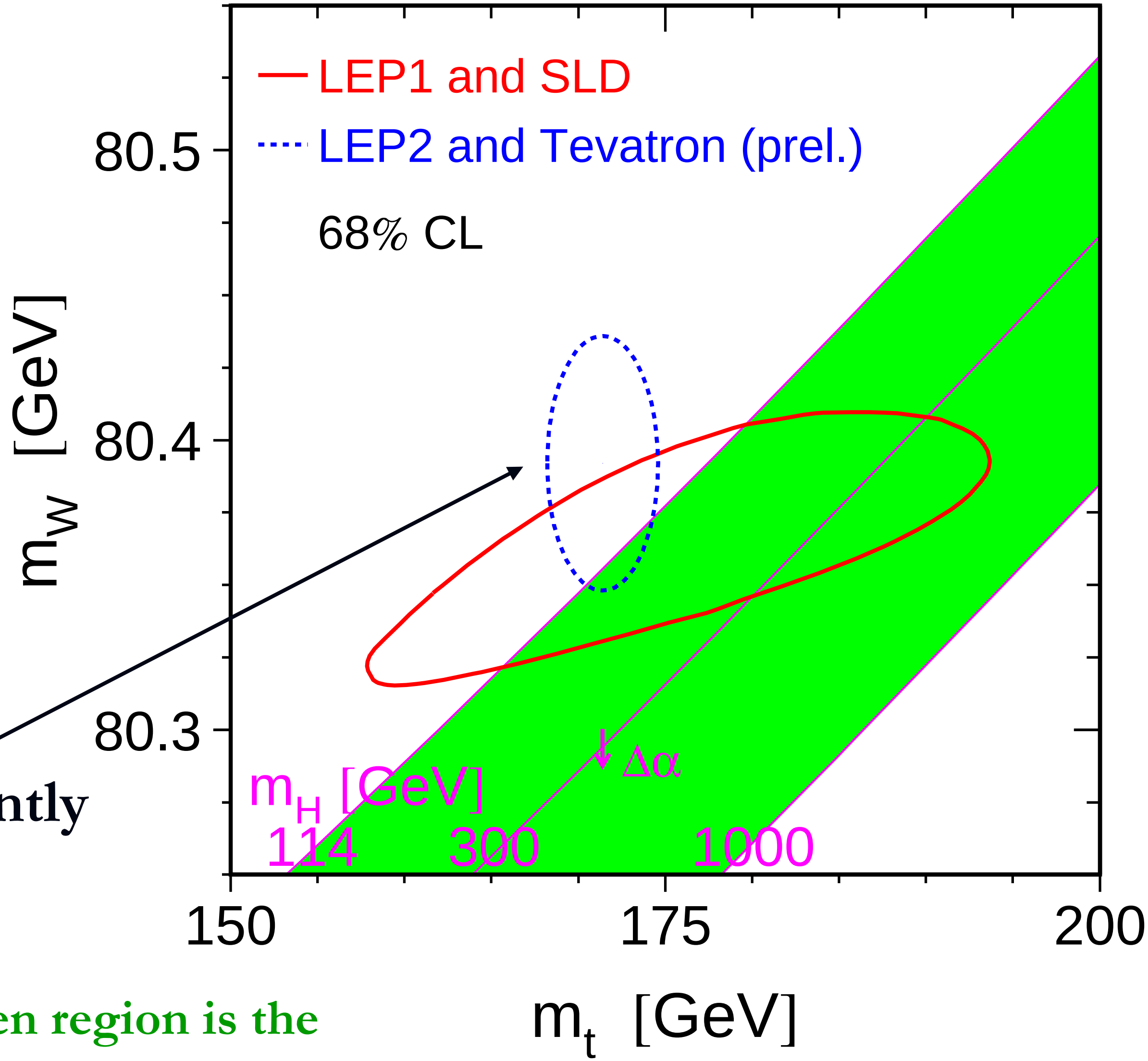
- But there is a fly in the ointment: the Standard Model has to fail at energies of a few TeV or so as higher-order Feynman diagrams diverge. This is the root of the optimism (of theorists!) that we are on the verge of finding something new.





The era of hard-parton scattering

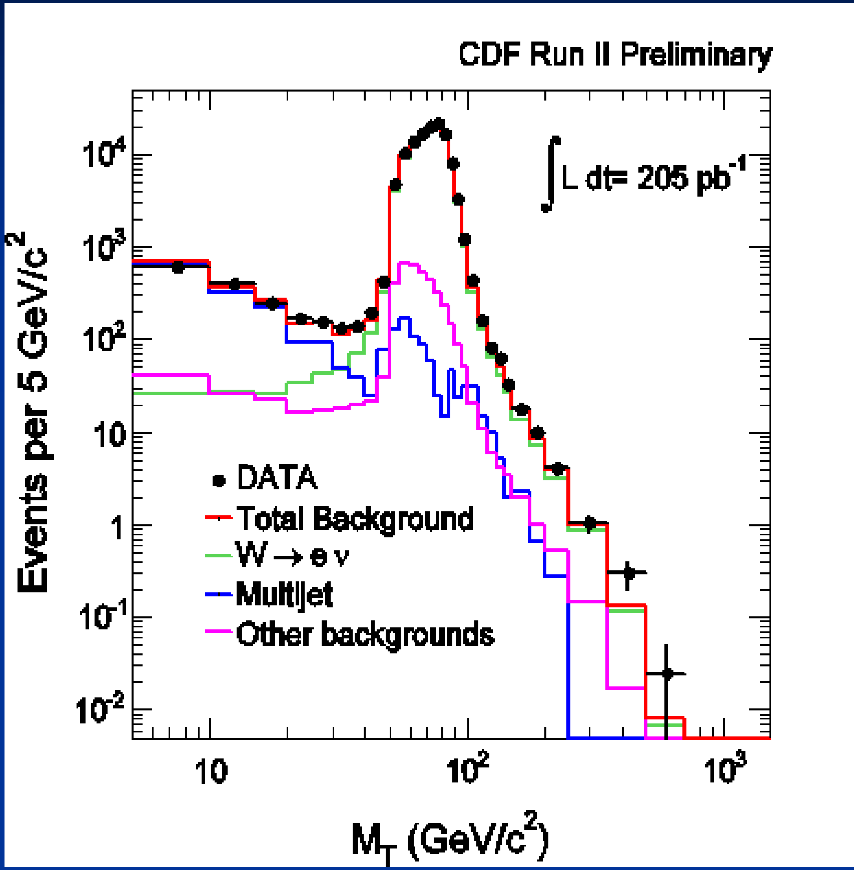
In the Standard Model the radiative corrections make the Higgs mass dependent on Mtop and MW, so that only 2 of the 3 are independent:

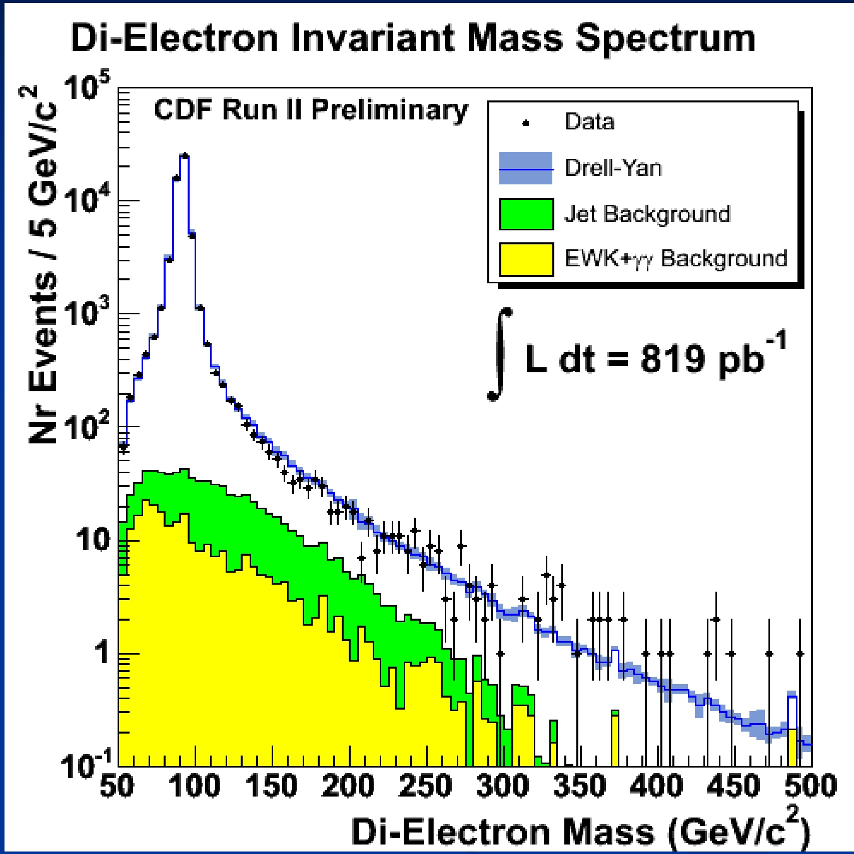


Blue ellipse is the presently allowed area (68% CL)

The upper edge of the green region is the boundary of the allowed Higgs region

The era of hard-parton scattering





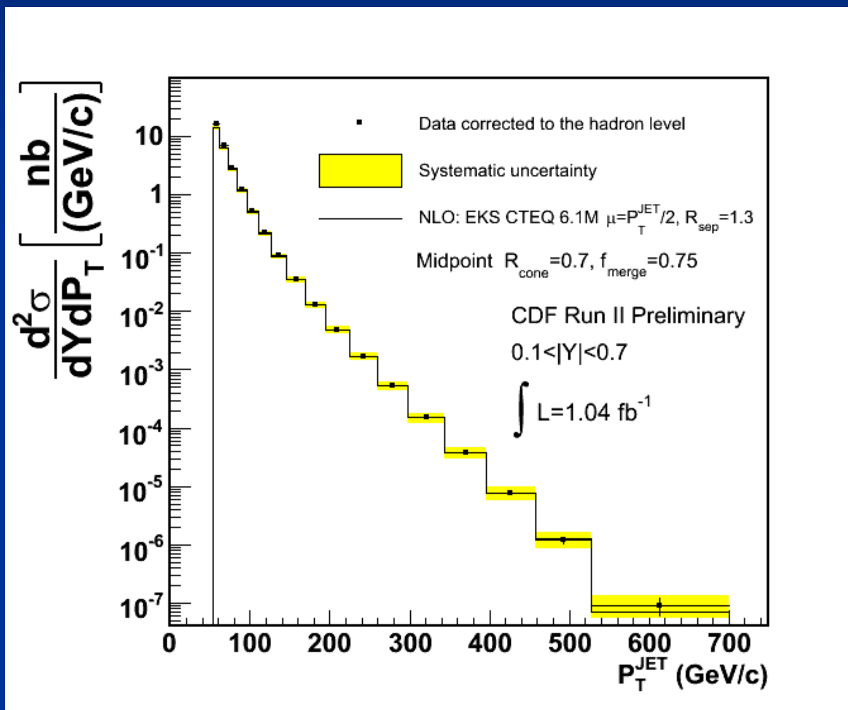
Mass spectrum of electron-neutrino system – the peak is the W boson (CDF data)

Mass spectrum of e^+e^- pairs- the peak is the Z boson (CDF data)

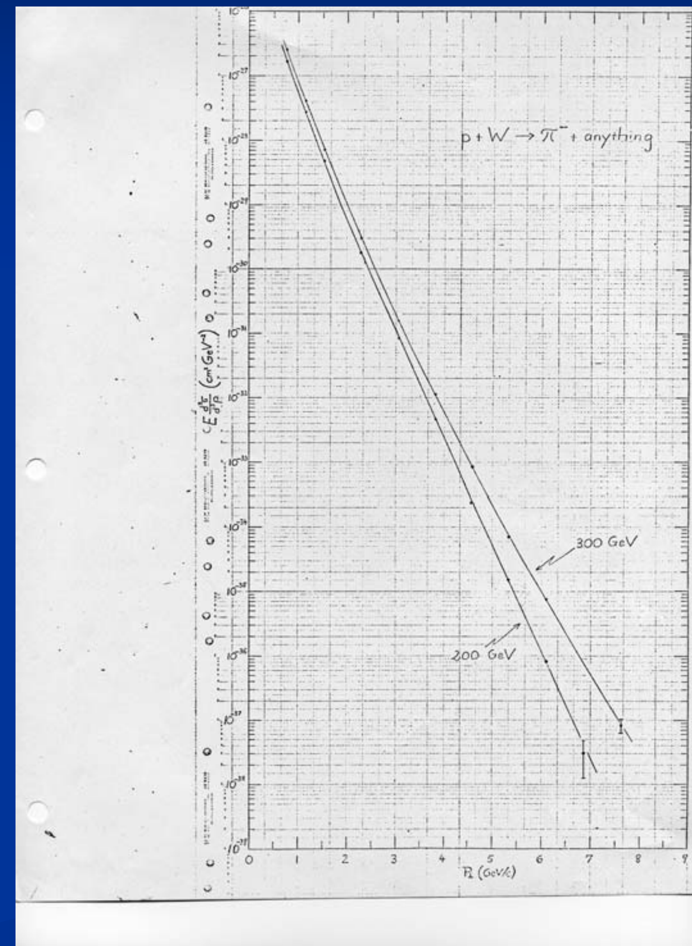
We've come a long way from the discovery of `direct leptons'

The era of hard-parton scattering

Now know that we are knocking out partons that then fragment to hadrons- in E100 were seeing the hadrons, but not the `jets'



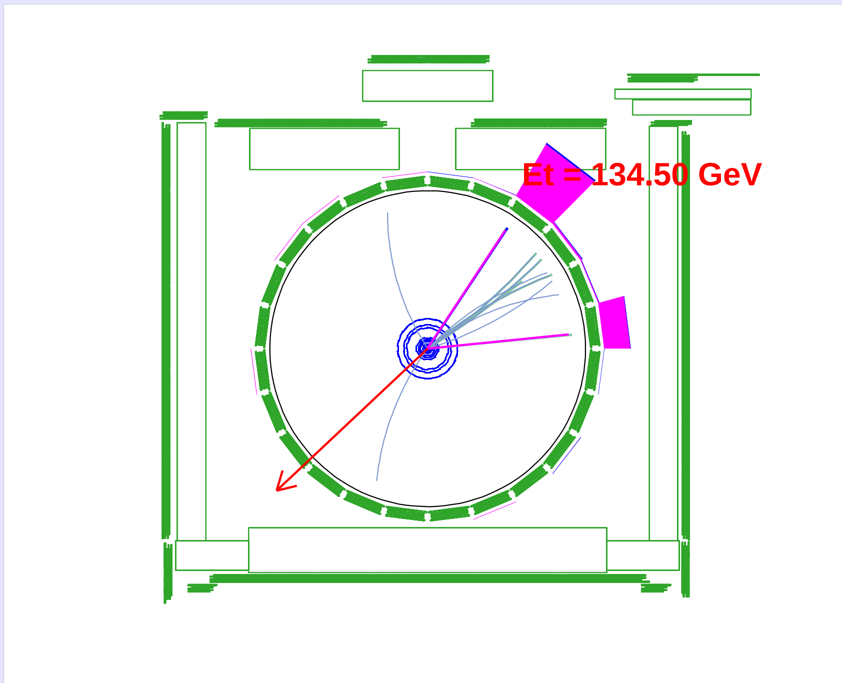
Pt spectrum of jets (CDF data)- note the scale (out to 700 GeV)

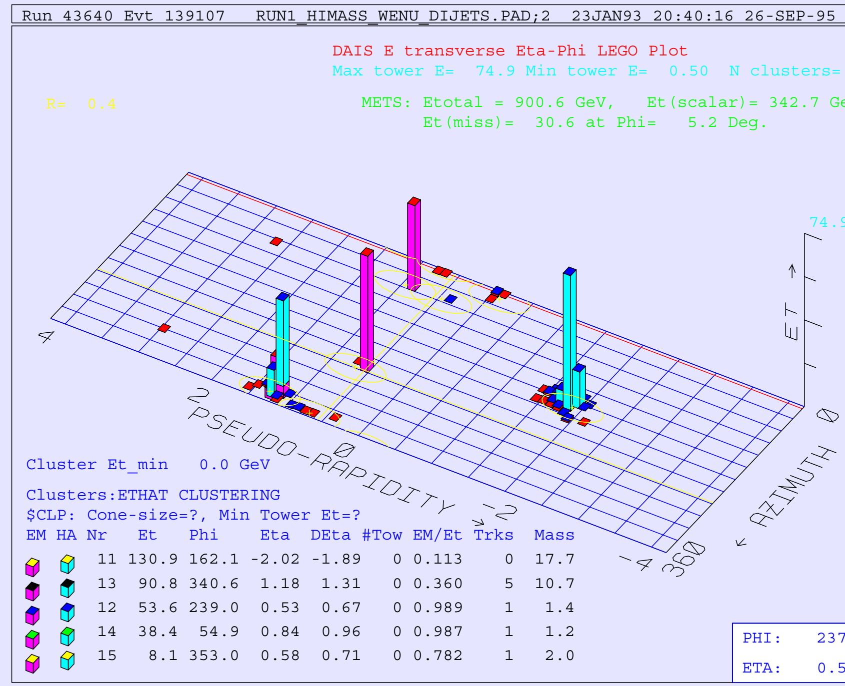


The E100 single-particle spectrum (again)- scale is out to 7 GeV

The era of hard-parton scattering

L



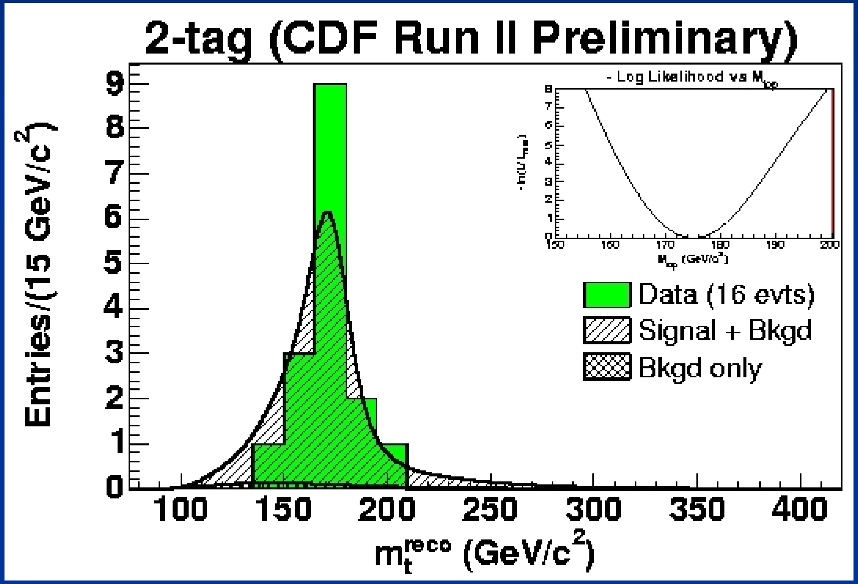


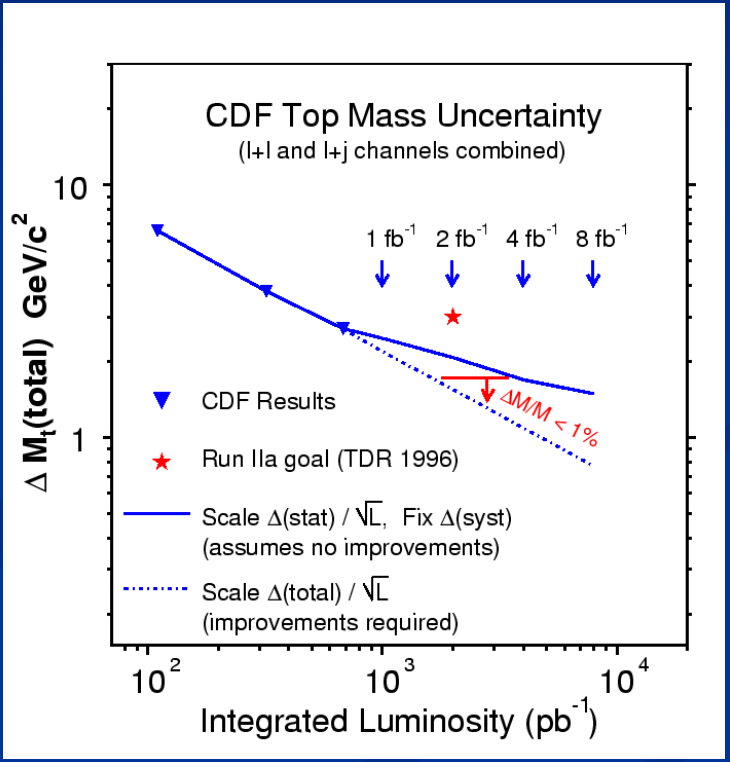
A Z-boson (mass=90 GeV) with 200 GeV of Pt balanced by `nothing' (CDF Data- beam's eye view- the 2 magenta tracks are the electrons from the Z)

A `Lego plot' of a Z-boson produced with 2 jets- total inv. mass 900 GeV (Run I CDF data)- Z is at rest- big jets forward and backward.

The era of hard-parton scattering

The mass scale of the top quark, W, Z is special- top the only quark with a "natural mass". This is the domain of Fermilab..



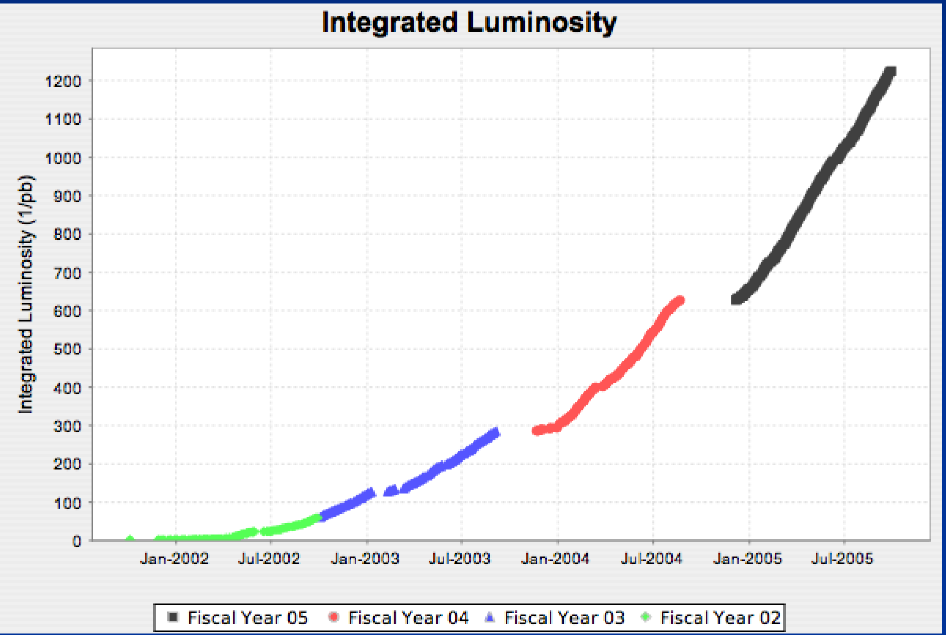


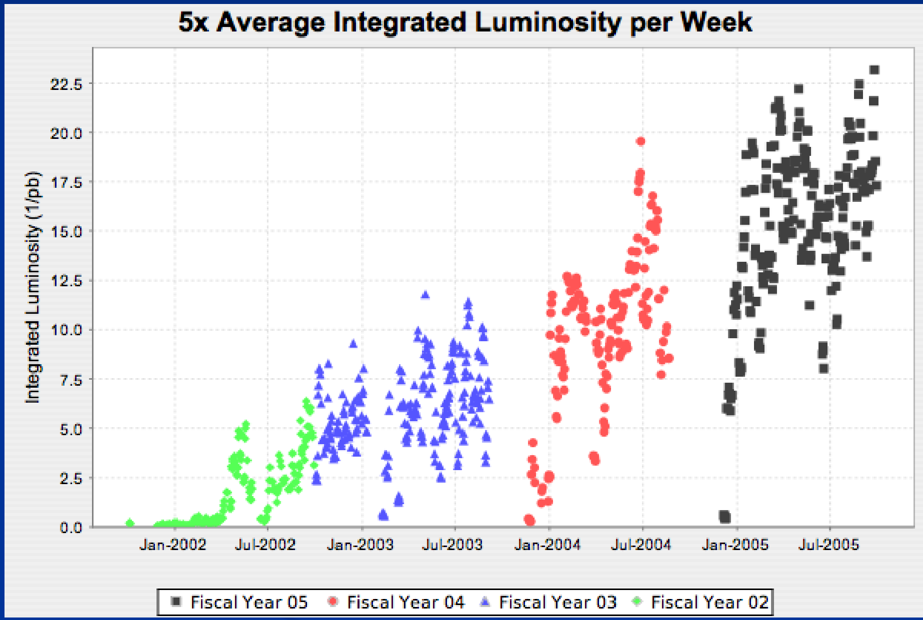
Reconstructed top quark mass (CDF data)

How well can we measure the top mass? Techniques, ideas, and experience are as or more important than luminosity (typical of all precision measurements)

The era of hard-parton scattering

The Fermilab Beams Division has done really remarkable things (electron cooling, Recycler/Accumulator gymnastics..)





Tevatron Integrated luminosity by year (note slope)

Tevatron Luminosity per Week, by year

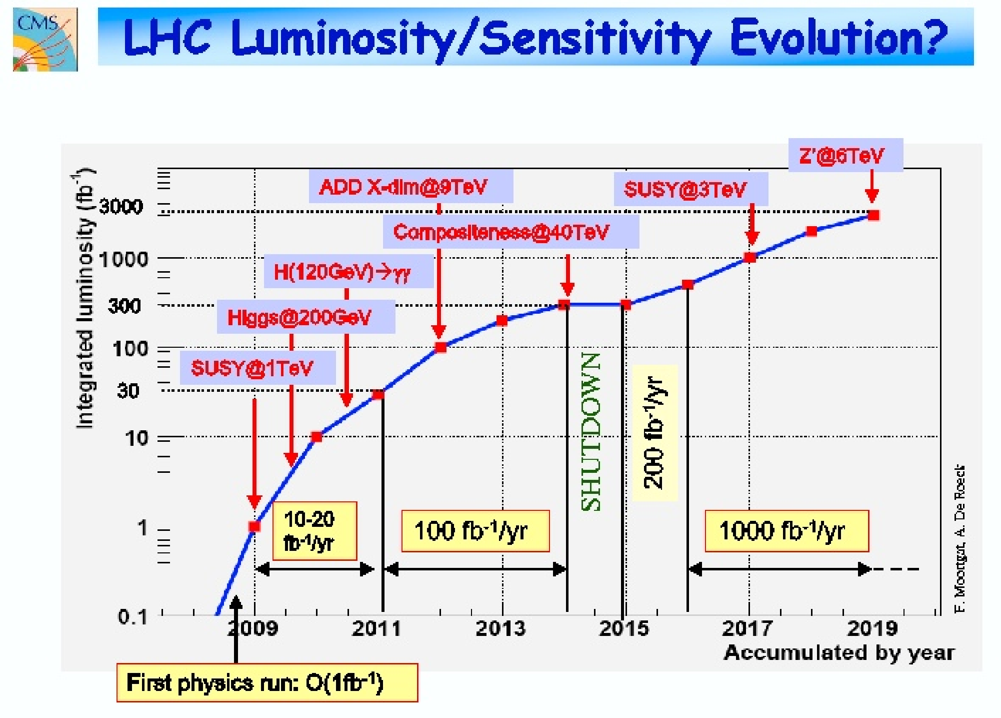
This is the era of hard-parton scattering

1. The Tevatron is running well- has unique capabilities we could exploit for years. Two big detectors and groups, CDF and D0, are up the learning curve (learning time constant=3 yrs?)

2. LHC startup approx a year away- ATLAS and CMS

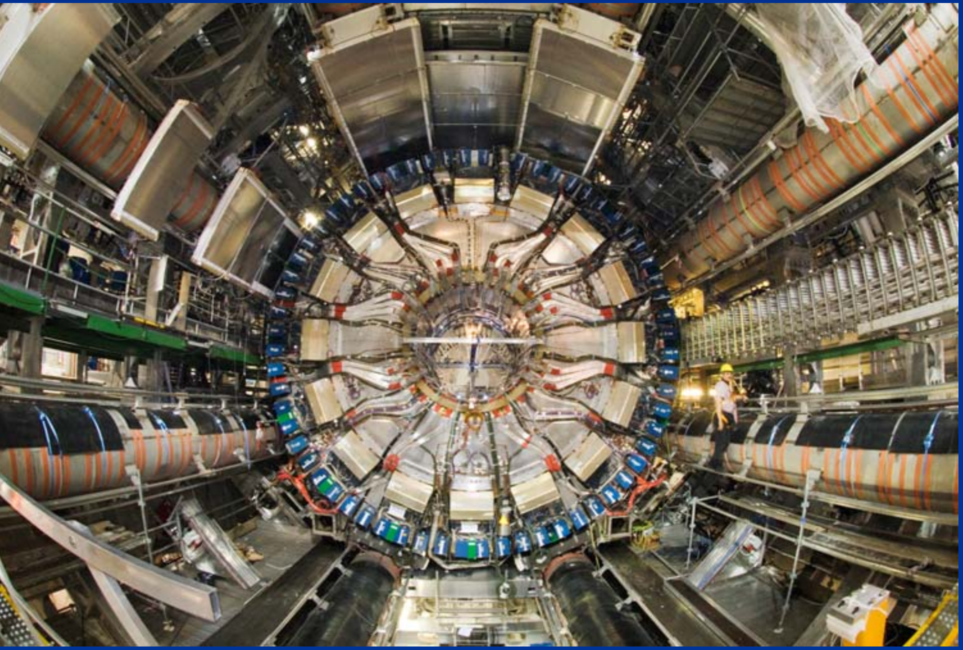
3. Have gone from Ecm of 20-60 (E100, ISR) to 1,960 (Tevatron), soon 14,000 (LHC).

4. Have a major upgrade planned for the LHC- long-term exploratory program in the next decade →



This is the era of hard-parton scattering

LHC Detector Installation: ATLAS,CMS, LHCb, ALICE



Inside the ATLAS Detector
(June 06; note person for scale)

The Alice detector
(`Linoleum-Linoleum collisions'- Cronin Effect squared).

Hard-parton scattering and JWC

Thirty-six years later, where are we?

We've come a long ways in studying hadron collisions from E100's first spectra, direct leptons, and A-dependence in 1970. Charm, bottom, top, the W, Z; factors of almost 1000 in CM energy, and detectors of unimagined size and sophistication. We are taking data at Fermilab in pbar-p collisions, about to commission the LHC, planning a major LHC upgrade, and agressively planning the next machine after that. Most of all, we believe that the Standard Model has to break at the TeV scale, and so we are about to learn what is beyond it, and hopefully under it as well.

THE END

Next slide

Hard-parton scattering and JWC

1977