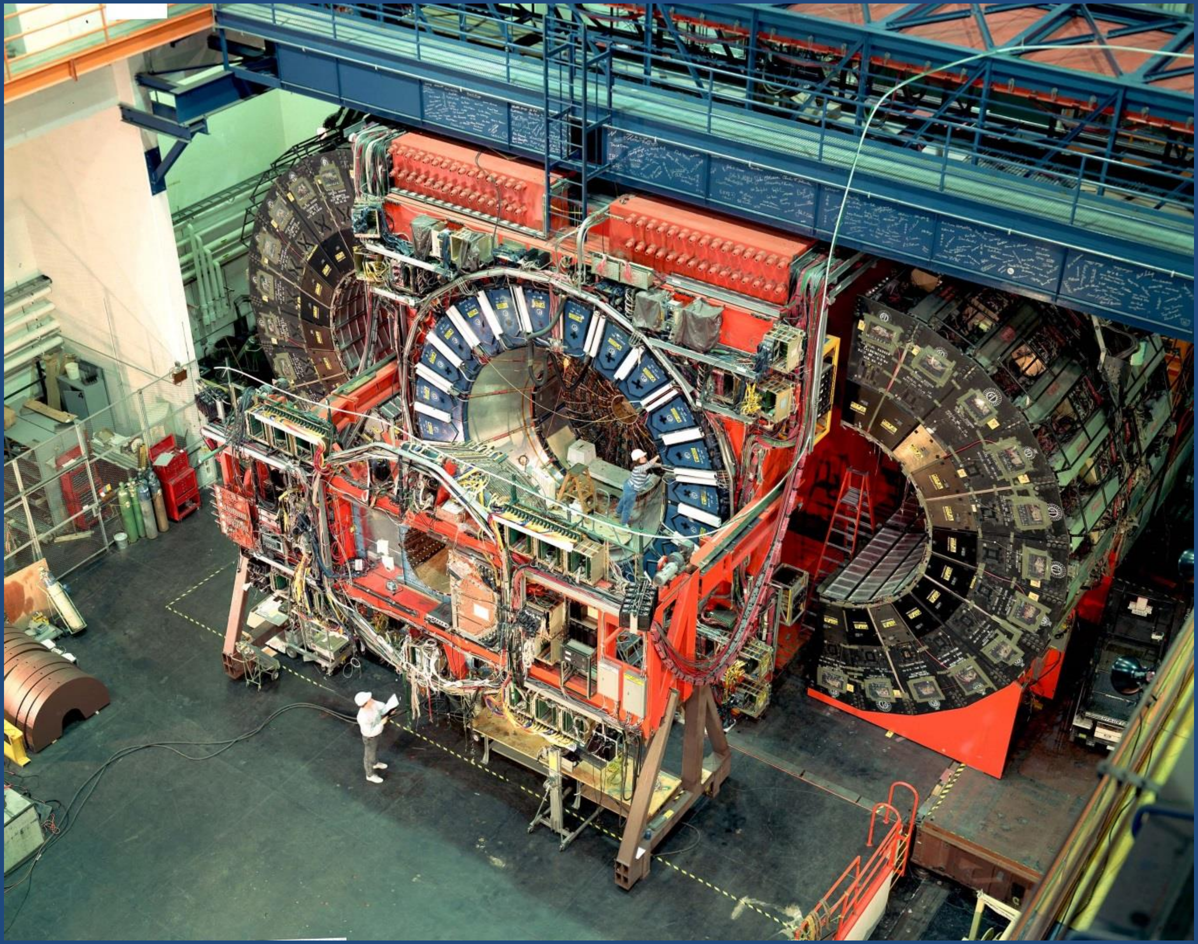
Pisa and the Collider Detector at Fermilab: a brief history of the establishment of precision physics with a calorimetric magnetic spectrometer at a hadron collider- very US-centric

Henry Frisch
Enrico Fermi Institute, University of Chicago



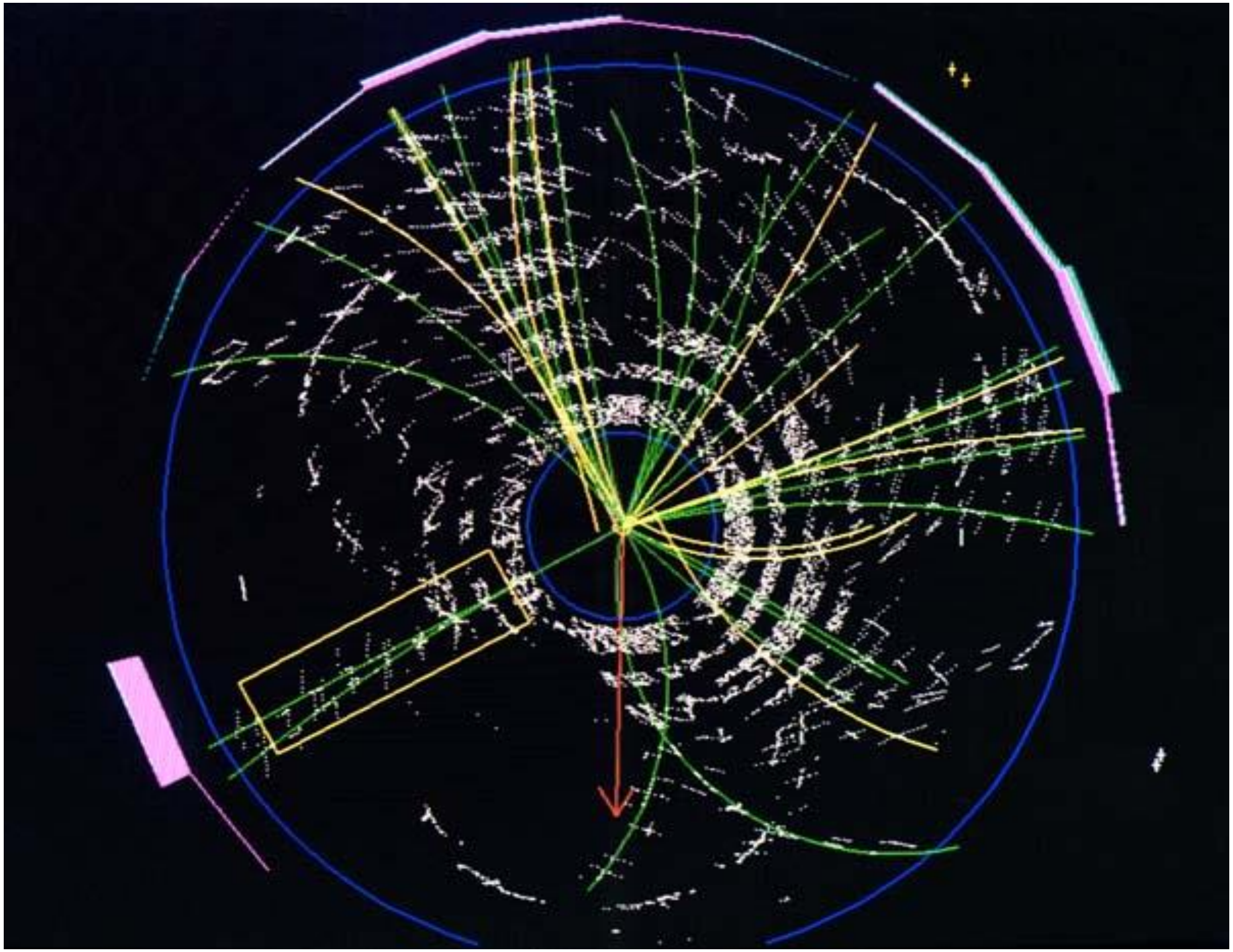
Three Themes in my talk:

1. The leadership role of Pisa in the CDF tracking and calorimeter design and construction

2. The development of precision mass measurements at a hadron collider using a magnetic spectrometer with precise tracking followed by good calorimetry (aka `E/p')

3. The essential role of Pisa hardware in the discovery of the top quark and the extensive B-physics results

Magnetic Spectrometer momentum and momentum-independent calorimeter energy:



A top quark event with b-tags

A. Mukherjee and A.B. Wicklund: development of E/p method for the Z-mass measurement

The path to precision physics at a hadron collider (heresy among some in Calif.)

- The start of high-PT physics (in US)
- The chaotic road to pbar-p in Tevatron
- Cronin starts the Collider Experiment Dept.- ZGS-MR (pp), MR, Tevatron
- Collider Detector: Giorgio Pisa MOUs
- Precision physics: calorimeter behind a precision tracking system: E/p
- Silicon Vertex Detector, Silicon Vertex Tracker- real-time tracking
- CDF (Pisa) footprint on hadron collider detector development
- W and Z precision masses; top, B_s mixing, …. and the end… (almost)

Hard Parton Scattering- 1971

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.

Hard Parton Scattering

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

AL REVIEW D VOLUME 4, NUMBER 11 1 DECEMBER 1971

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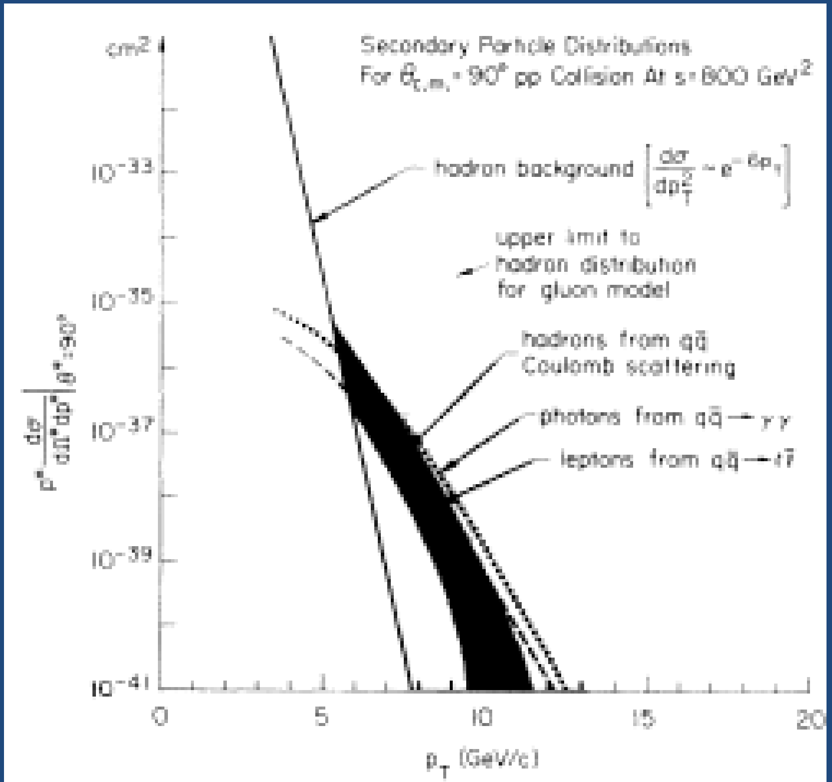
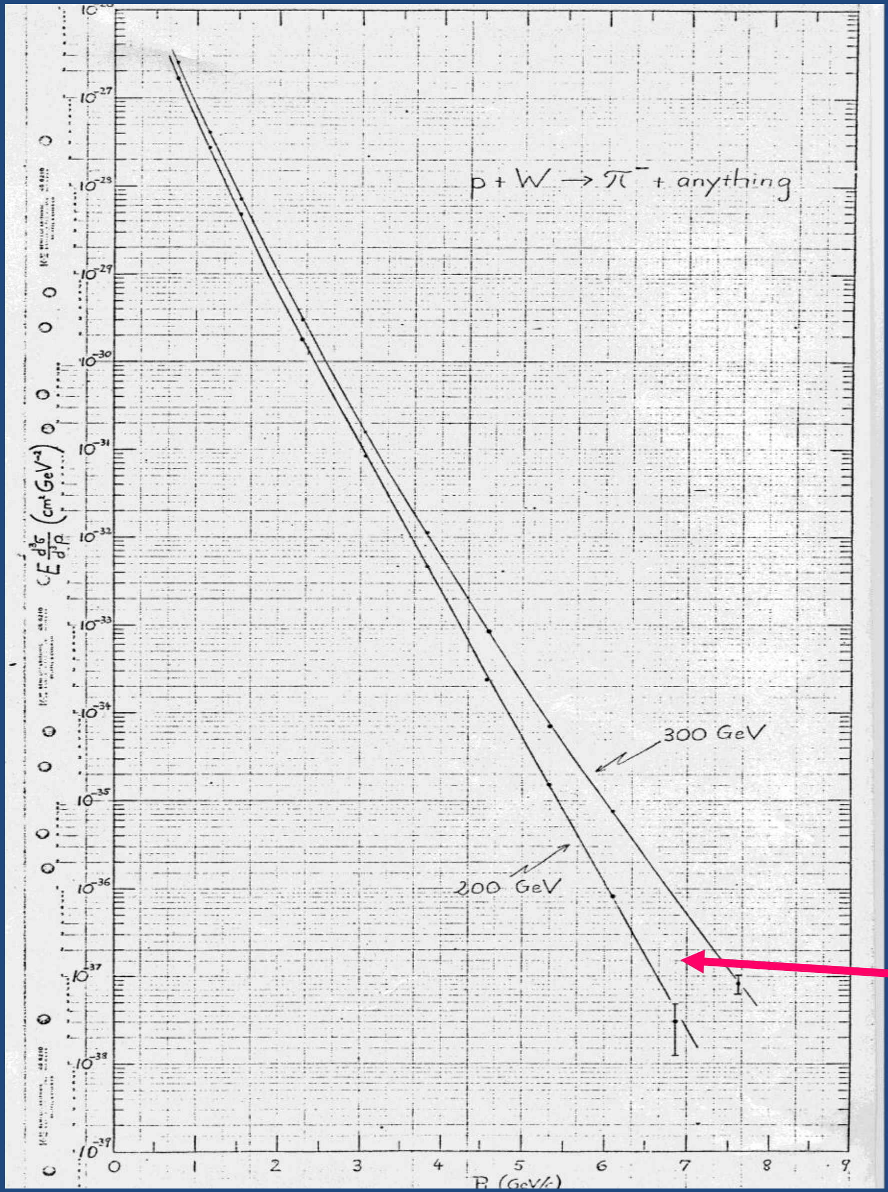


FIG. 1. Secondary-particle distributions as calculated in the parton model and compared to diffractive backgrounds for typical NAL conditions.

E100 at Fermilab: 1970-77

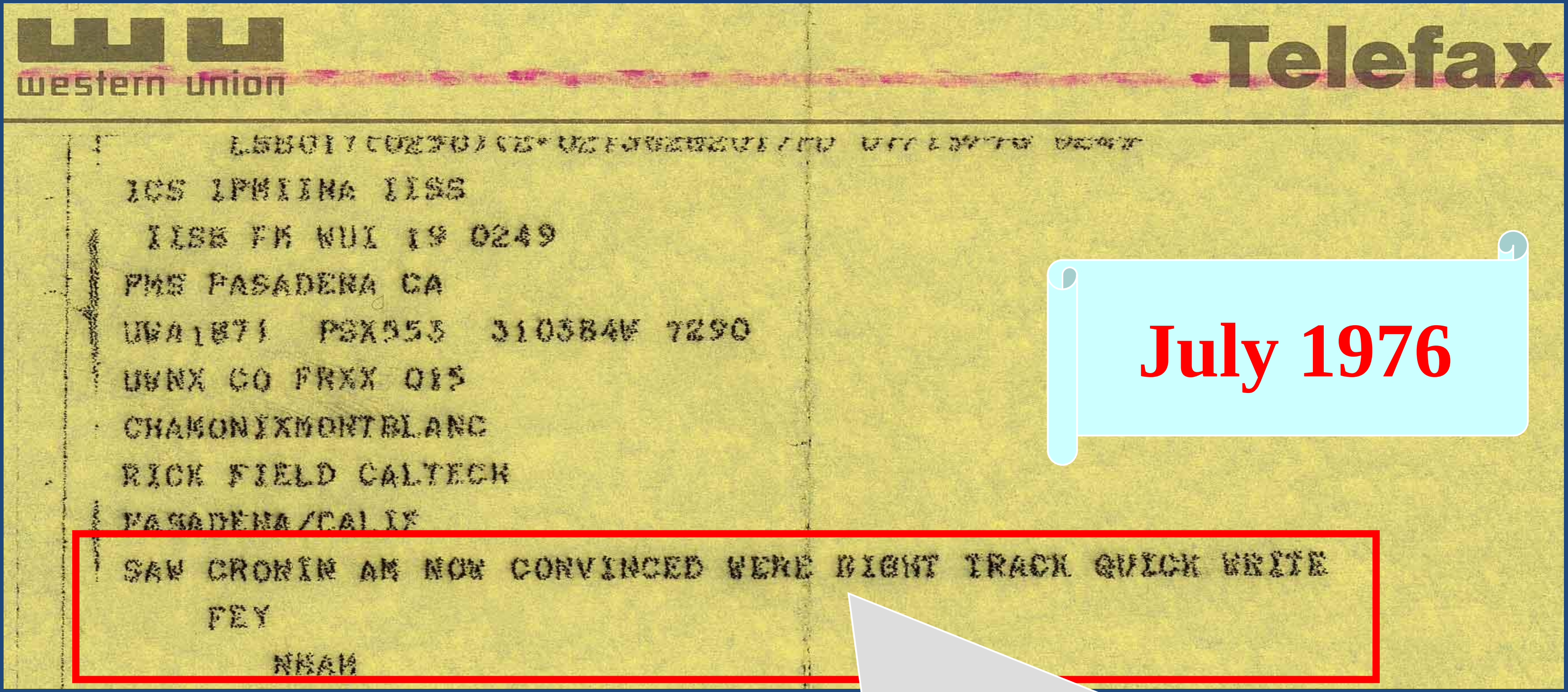


First Results- 1972- see power-law behavior and energy dependence at large Pt

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

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

Telagram (sic) from Feynman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CHAMONIXMONTBLANC

RICK FIELD CALTECH

PASADENA/CALIF

SAW CRONIN AM NOW CONVINCED WERE RIGHT TRACK QUICK WRITE

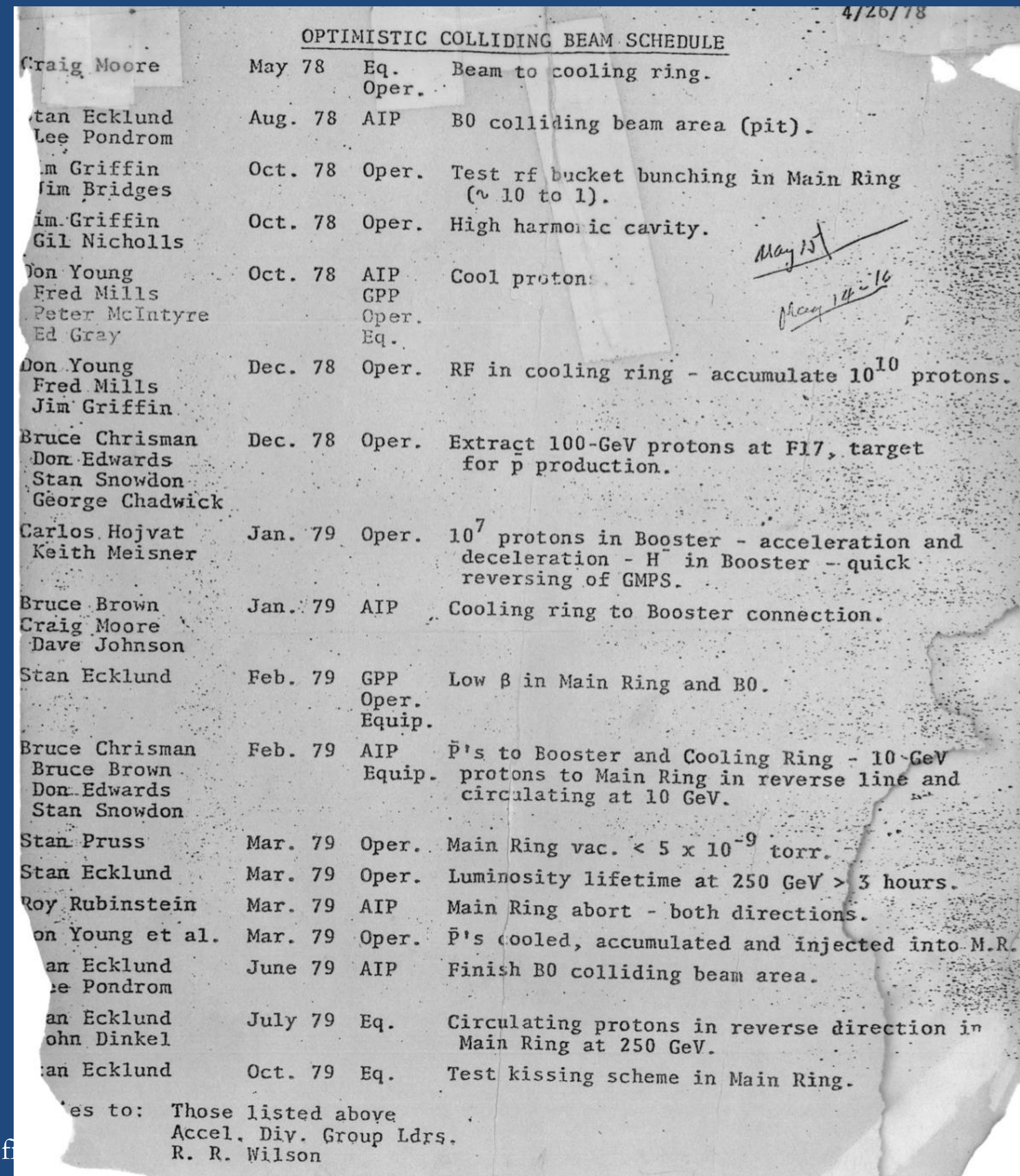
FEY

NMAN

July 1976

SAW CRONIN AM NOW CONVINCED WERE RIGHT TRACK QUICK WRITE FEYNMAN

What Collides at Fermilab?



4/26/78

OPTIMISTIC COLLIDING BEAM SCHEDULE

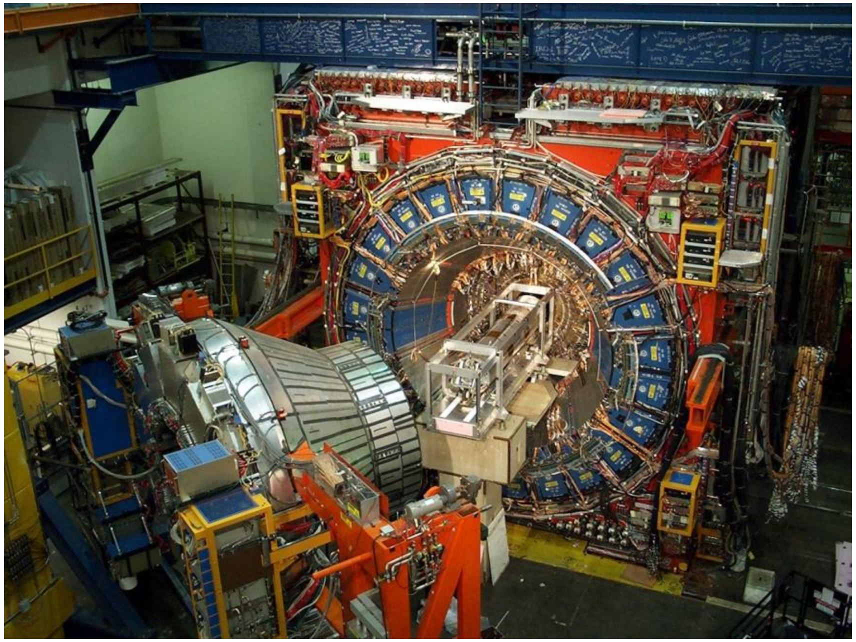
Craig Moore	May 78	Eq. Oper.	Beam to cooling ring.
tan Ecklund Lee Pondrom	Aug. 78	AIP	BO colliding beam area (pit).
m Griffin Jim Bridges	Oct. 78	Oper.	Test rf bucket bunching in Main Ring (~ 10 to 1).
im Griffin Gil Nicholls	Oct. 78	Oper.	High harmonic cavity.
Don Young Fred Mills Peter McIntyre Ed Gray	Oct. 78	AIP GPP Oper. Eq.	Cool protons.
Don Young Fred Mills Jim Griffin	Dec. 78	Oper.	RF in cooling ring - accumulate 10^{10} protons.
Bruce Chrisman Don Edwards Stan Snowdon George Chadwick	Dec. 78	Oper.	Extract 100-GeV protons at F17, target for $\bar{p}$ production.
Carlos Hojvat Keith Meisner	Jan. 79	Oper.	10^7 protons in Booster - acceleration and deceleration - H^- in Booster - quick reversing of GMPS.
Bruce Brown Craig Moore Dave Johnson	Jan. 79	AIP	Cooling ring to Booster connection.
Stan Ecklund	Feb. 79	GPP Oper. Equip.	Low β in Main Ring and BO.
Bruce Chrisman Bruce Brown Don Edwards Stan Snowdon	Feb. 79	AIP Equip.	$\bar{P}$'s to Booster and Cooling Ring - 10 GeV protons to Main Ring in reverse line and circulating at 10 GeV.
Stan Pruss	Mar. 79	Oper.	Main Ring vac. $< 5 \times 10^{-9}$ torr.
Stan Ecklund	Mar. 79	Oper.	Luminosity lifetime at 250 GeV > 3 hours.
Roy Rubinstein	Mar. 79	AIP	Main Ring abort - both directions.
on Young et al.	Mar. 79	Oper.	$\bar{P}$'s cooled, accumulated and injected into M.R.
an Ecklund e Pondrom	June 79	AIP	Finish BO colliding beam area.
an Ecklund ohn Dinkel	July 79	Eq.	Circulating protons in reverse direction in Main Ring at 250 GeV.
an Ecklund	Oct. 79	Eq.	Test kissing scheme in Main Ring.

es to: Those listed above
Accel. Div. Group Ldrs.
R. R. Wilson

"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, p̄p in MR, p̄p in Doubler, etc.) was the best one to push here at Fermilab given CERN's p̄p 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:	p̄p luminosity estimates.

RL:clc

Delegated to meet with Huson and settle MR (on ZGS?) luminosity

Early Accelerator Decision-making

Colin Taylor

Report of the Review Committee
for the Fermilab Antiproton Source Design Report

June 1981

T. Collins, D. Edwards, R. Johnson, I.Meshkov,
C. Taylor, M. Tigner, B. Wiik

Introduction

The Committee met June 8, 9, 10, 11 to consider the $\bar{p}$ source Design Report. We have concentrated on the $\bar{p}$ production and accumulation aspects of the design and have not reviewed the Colliding Scenario described in Part 6 of the Design Report.

The design described in the Design Report appears to the Committee to be adequate to meet the goals for $\bar{p}$ production and accumulation listed in that report. It is the conclusion of the Committee, however, that the stated goals are far too modest. We recommend therefore that the Laboratory re-examine the design goals for $\bar{p}$ production and accumulation and develop a feasibility design commensurate with the full potential of the Main Ring-Booster combination to produce antiprotons.

I. Comments on the General Scheme for $\bar{p}$ Accumulation

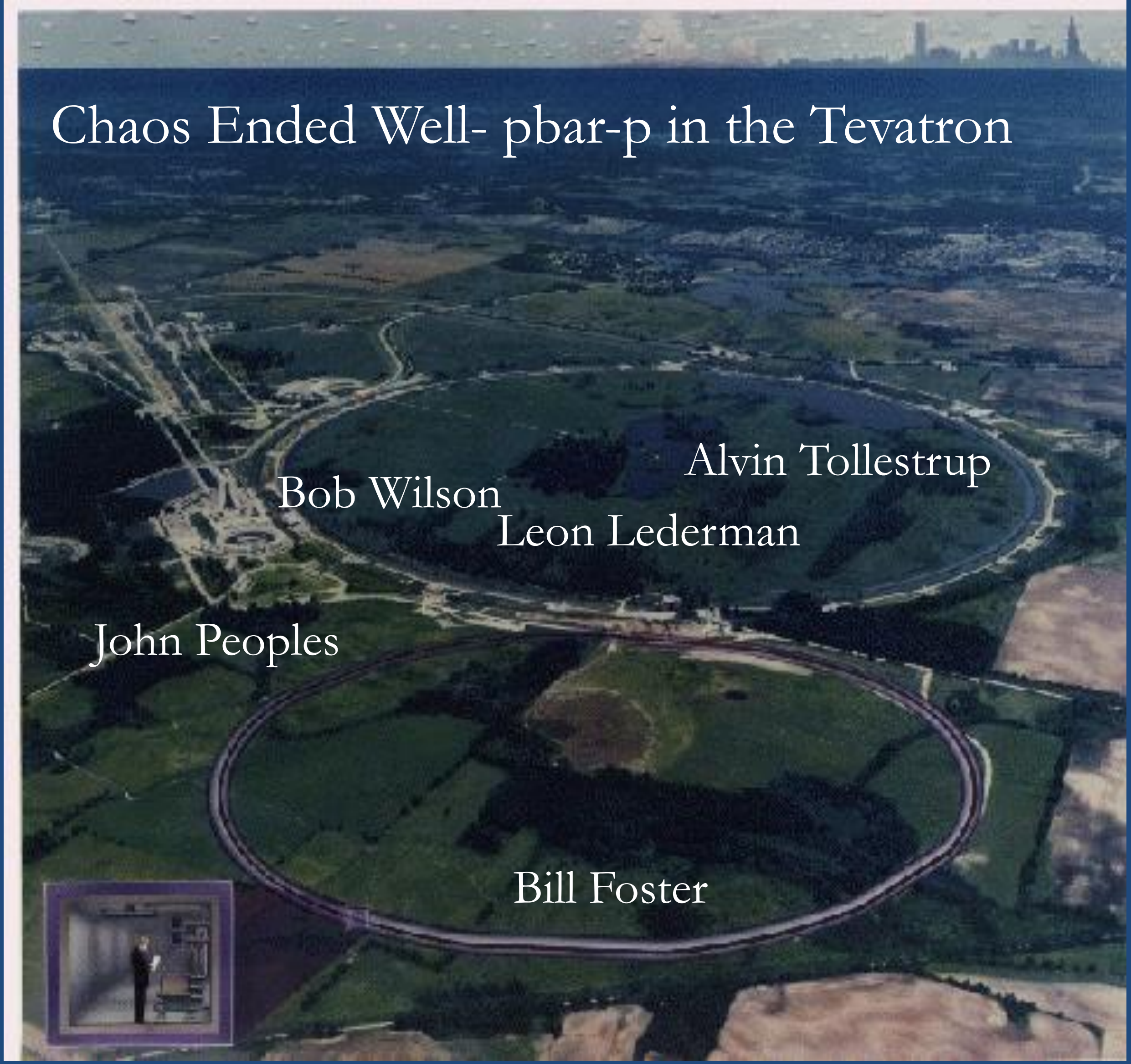
Fermilab

MINUTES OF THE COLLIDER DETECTOR FACILITY MEETING

November 20, 1981

1. Dave Ayres reported on visit to UA1/UA2 at CERN. Rubbia claims 500 people were working on UA1 at height of its construction (and that CDF is harder). Parts of the UA1 end plugs have suffered some radiation damage (estimated dose 10^6 rads). Dave described various UA1 and UA2 calibration systems.

CDF-58	The Criterion for Avoiding Hot Spots in Calorimeters - W. Selove
CDF-59	Luminosity and Very Small Angle Physics - G. Bellettini, C. Bradaschia, A. Menzione
CDF-60	Feasibility of Operating Silicon Detectors Inside the Collider Vacuum Pipe - C. Bradaschia, T. Collins, A. Menzione
CDF-61	Prototype Pad Chamber Hadron Calorimeter - M. Ono and R. Yamada
CDF-62	Endcap Hadron Calorimeters - G. Bellettini, R. Bertani, R. Del Fabbro, G. Gennaro, A. Scribano
CDF-63	Hybrid Shower Counters for CDF - L. Nodulman
CDF-64	Conceptual Design of a Forward Detector for the Antiproton-Proton Collider - P. McIntyre et. al.



1974, 75, 77 Woods Hole Panels; was not obvious how to compete with CERN. Present configuration shown above.

1979- Giorgio and Paolo Giormini talk to Alvin and Bob Diebold (per Giorgio)

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November 1983

(apologies for the print quality)

AGREEMENT CDF/4
between the
RESEARCH DIVISION of
FERMI NATIONAL ACCELERATOR LABORATORY
and the
ISTITUTO NATIONALE DI FISICA NUCLEARE
Italy

I. Composition and Purpose of the Collaboration

This agreement covers the activities that a team of the Istituto Nazionale di Fisica Nucleare (INFN) of Italy, comprising a group from Frascati and one from Pisa, will carry out in collaboration with groups from Argonne, Brandeis, Chicago, Fermilab, Harvard, Illinois, KEK, LBL, Pennsylvania, Purdue, Rutgers, Texas, Tsukuba, and Wisconsin.

The goal of this collaborative effort is the design, construction, and initial operation of the Collider Detector at Fermilab (CDF), a large detector which will be placed in the B0 interaction region to study collisions between p and $\bar{p}$ beams stored in the Fermilab Energy Doubler. The scope of the detector is given in the Design Report. The collaboration can be extended to other groups, as provided for in Paragraph VII.

II. Personnel

The following physicists are participants in the collaboration as members of the Italian team: S. Bartalucci**, G. Bellettini*, F. Bedeschi*, S. Bertolucci**, L. Bosisio*, F. Cervelli*, M. Cordelli**, R. Del Fabbro*, A. Di Virgilio*, E. Focardi*, P. Giannetti*, M. A. Giorgi*, P. Giromini**, A. Menzione*, M. Pallotta**, L. Ristori*, A. Sansoni**, A. Scribano*, G. Tonelli*, R. Tripiccione*.

It is expected that other INFN physicists might join this group in the future.

The leader of the Frascati group is P. Giromini.

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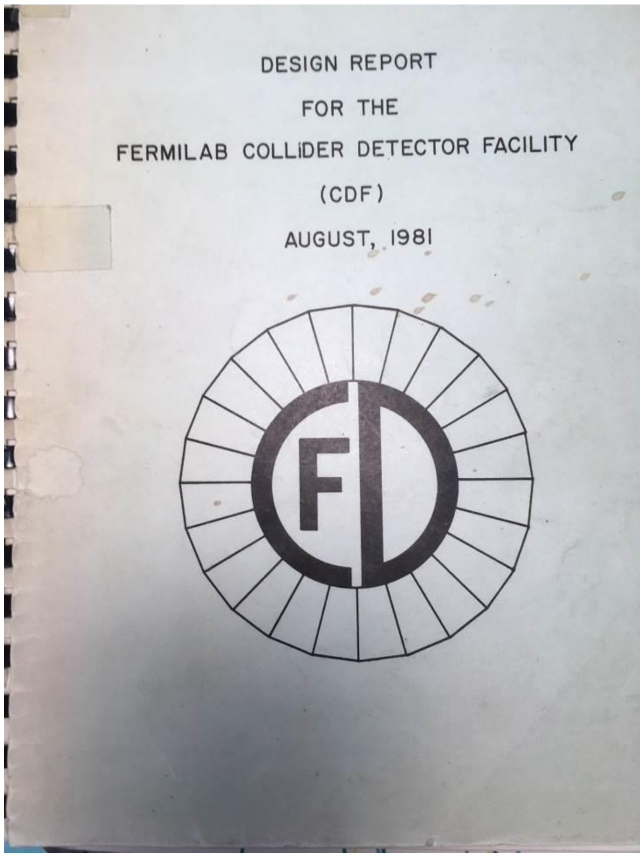
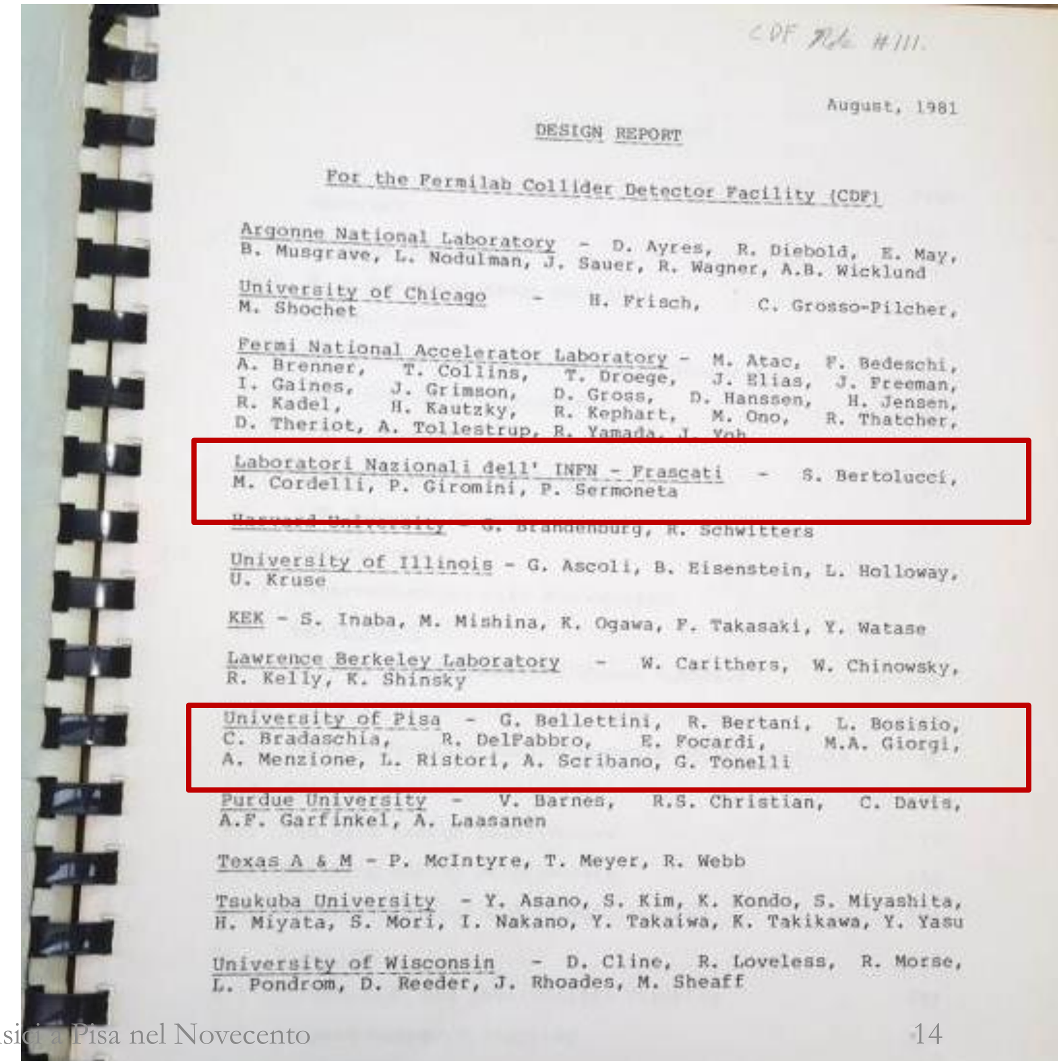
The spokesman for the INFN team is G. Bellettini.

*Sezione di Pisa dell'INFN

**Laboratori Nazionale di Frascati dell'INFN

CDF Technical Design Report





August, 1981

DESIGN REPORT

For the Fermilab Collider Detector Facility (CDF)

Argonne National Laboratory - D. Ayres, R. Diebold, E. May, B. Musgrave, L. Nodulman, J. Sauer, R. Wagner, A.B. Wicklund

University of Chicago - H. Frisch, C. Grosso-Pilcher, M. Shochet

Fermi National Accelerator Laboratory - M. Atac, F. Bedeschi, A. Brenner, T. Collins, T. Droege, J. Elias, J. Freeman, I. Gaines, J. Grimson, D. Gross, D. Hanssen, H. Jensen, R. Kadel, H. Kautzky, R. Kephart, M. Ono, R. Thatcher, D. Theriot, A. Tollestrup, R. Yamada, J. Yoh

Laboratori Nazionali dell' INFN - Frascati - S. Bertolucci, M. Cordelli, P. Giromini, P. Sermoneta

Harvard University - G. Brandenburg, R. Schwitters

University of Illinois - G. Ascoli, B. Eisenstein, L. Holloway, U. Kruse

KEK - S. Inaba, M. Mishina, K. Ogawa, F. Takasaki, Y. Watase

Lawrence Berkeley Laboratory - W. Carithers, W. Chinowsky, R. Kelly, K. Shinsky

University of Pisa - G. Bellettini, R. Bertani, L. Bosisio, C. Bradaschia, R. DelFabbro, E. Focardi, M.A. Giorgi, A. Menzione, L. Ristori, A. Scribano, G. Tonelli

Purdue University - V. Barnes, R.S. Christian, C. Davis, A.F. Garfinkel, A. Laasanen

Texas A & M - P. McIntyre, T. Meyer, R. Webb

Tsukuba University - Y. Asano, S. Kim, K. Kondo, S. Miyashita, H. Miyata, S. Mori, I. Nakano, Y. Takaiwa, K. Takikawa, Y. Yasu

University of Wisconsin - D. Cline, R. Loveless, R. Morse, L. Pondrom, D. Reeder, J. Rhoades, M. Sheaff

Hans Jensen and HJF eds.

Pisa/Frascati Took on the Hadron Calorimeters

November 1983

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The spokesman for the INFN team is G. Bellettini.

III. Responsibilities of the Italian Group

The responsibilities of the Italian team are as follows:

A. Fabrication of the scintillator/BBQ towers, the light pipes, and the associated photomultipliers, bases, and HV supplies for the central and endwall hadron calorimeters, and the shipping of this material to Fermilab. This will have to be done according to the time schedule indicated in Paragraph VI.

The iron structure of the calorimeters will be fabricated by Purdue and Fermilab.

The electromagnetic shower calorimeters of the central units will be fabricated by Argonne and KEK.

B. Assembly of the hadron calorimeters at Fermilab, jointly with Purdue and Fermilab.

C. Calibration of the calorimeters with cosmic rays, light flashers, and particle beams jointly with Pennsylvania, Purdue, and Fermilab. The Italian group will dedicate to the assembly and calibration work at Fermilab a minimum of:

Central Hadron Cal- Paolo Giromini (Frascati)
End Wall Hadron Cal- Giorgio Bellettini, Aldo Menzione, Angelo Scribano, … (Pisa)

The Development of Si Detectors at Pisa

S.R. AMENDOLIA, F. BEDESCHI, E. BERTOLUCCI, D. BETTONI, L. BOSISIO, U. BOTTIGLI, C. BRADASCHIA, M. DELL'ORSO, F. FIDECARO, L. FOÀ, E. FOCARDI, P. GIANNETTI, M.A. GIORGI, P.S. MARROCCHESI, A. MENZIONE, G. RASO, L. RISTORI, A. SCRIBANO, A. STEFANINI, R. TENCHINI, G. TONELLI and G. TRIGGIANI

Istituto di Fisica, Sezione INFN, Scuola Normale Superiore, Pisa, Italy

Resolution and linearity of the position measurement of Pisa multi-electrode silicon detectors are presented. The detectors are operated in slightly underdepleted mode and take advantage of their intrinsic resistivity for resistive charge partition between adjacent strips. 22 μm resolution is achieved with readout lines spaced 300 μm. Possible applications in colliding beam experiments for the detection of secondary vertices are discussed.

Nuclear Instruments and Methods 176 (1980) 457–460

A MULTI-ELECTRODE SILICON DETECTOR FOR HIGH ENERGY EXPERIMENTS

S.R. AMENDOLIA, G. BATIGNANI *, F. BEDESCHI, E. BERTOLUCCI, L. BOSISIO, C. BRADASCHIA †, M. BUDINICH, F. FIDECARO, L. FOÀ *†, E. FOCARDI, A. GIAZOTTO, M.A. GIORGI, M. GIVOLETTI, P.S. MARROCCHESI, A. MENZIONE, D. PASSUELLO, M. QUAGLIA, L. RISTORI, L. ROLANDI *, P. SALVADORI, A. SCRIBANO †, R. STANGA, A. STEFANINI and M.L. VINCELLI

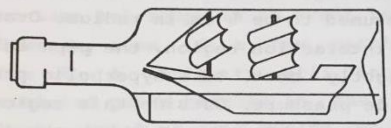
INFN, Sezione di Pisa, Italy and Istituto di Fisica dell'Università, Pisa, Italy

Received 19 May 1980

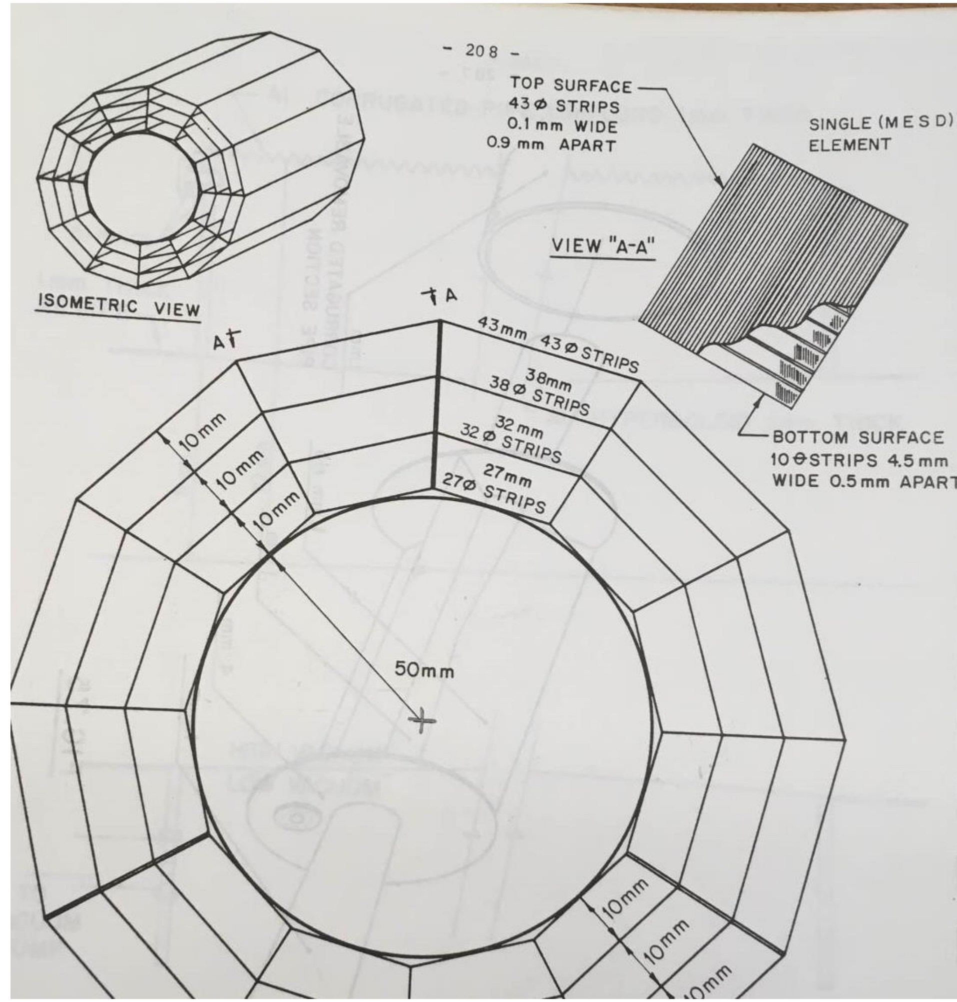
A detector has been developed in our laboratory for proposed use in high energy experiments. It works as a MWPC in which the ionizing medium consists of a thin layer of silicon crystal. The results of the test carried out at CERN show that the detector is ideally suited for the detection of minimum ionizing particles and can provide very high spatial resolution.

CDF Technical Design Report

7.2 VERTEX MINI-DETECTORS

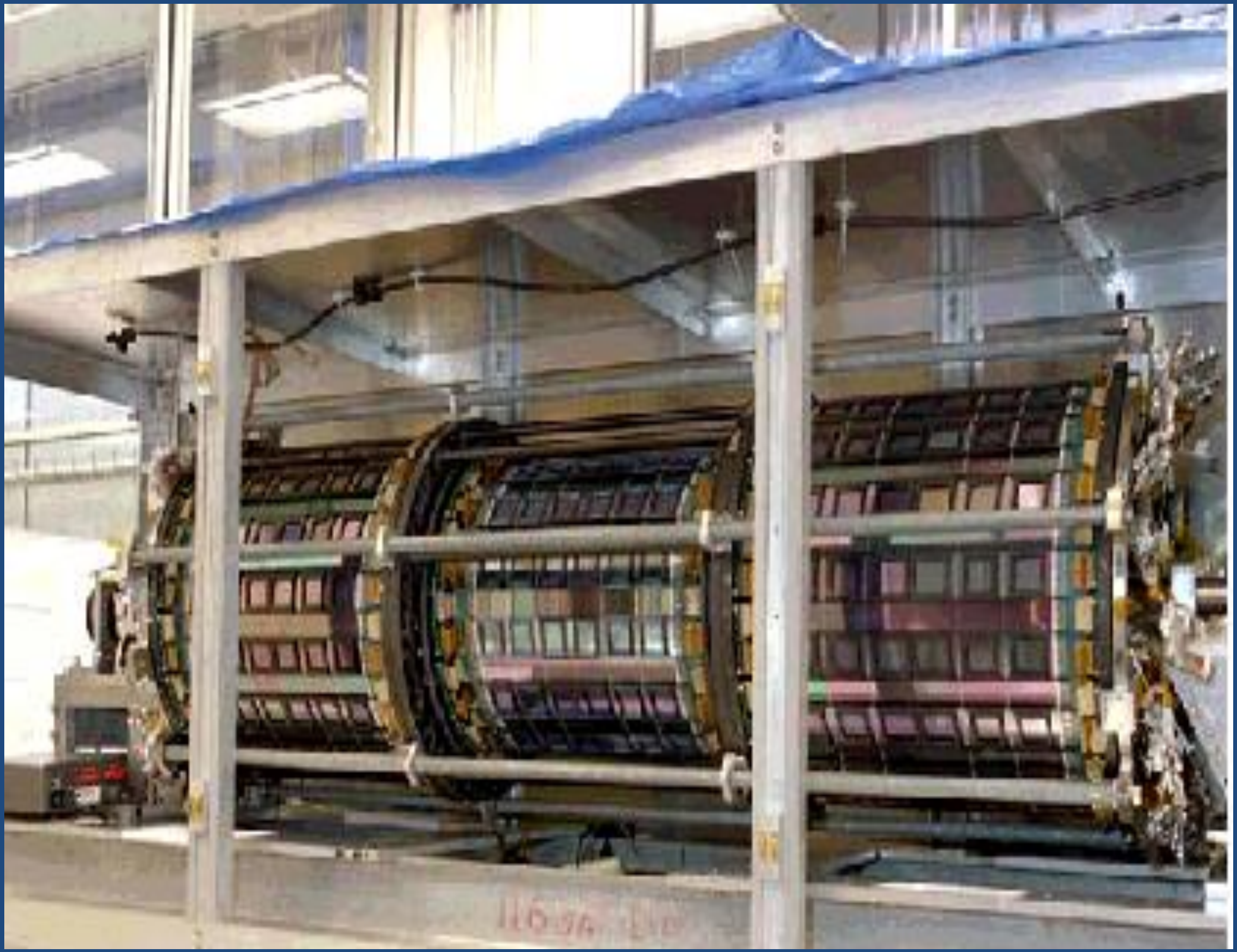


The desire to search for new particles with CDF points at the importance of augmenting the standard design with additional detectors for particle identification. With this problem in mind, the central calorimeter modules have been made removable such that, in the future, large acceptance spectrometers could be assembled on either side of the detector outside the magnet coil. Performing dE/dx measurements in the central tracking chamber in association with TOF measurements is another possibility. A very interesting possibility is also to insert miniaturized dE/dx and tracking detectors in the space (a cylindrical volume about 20 cm in diameter) that is available inside the central tracking chamber around the intersection point. We discuss here one possible system employing telescopes of multi-electrode silicon detectors (MESD). Although MESD have never been used under our expected conditions, enough is already known about this rapidly developing technique to sketch a realistic design for measuring ... of single particles with a resolution sufficient to



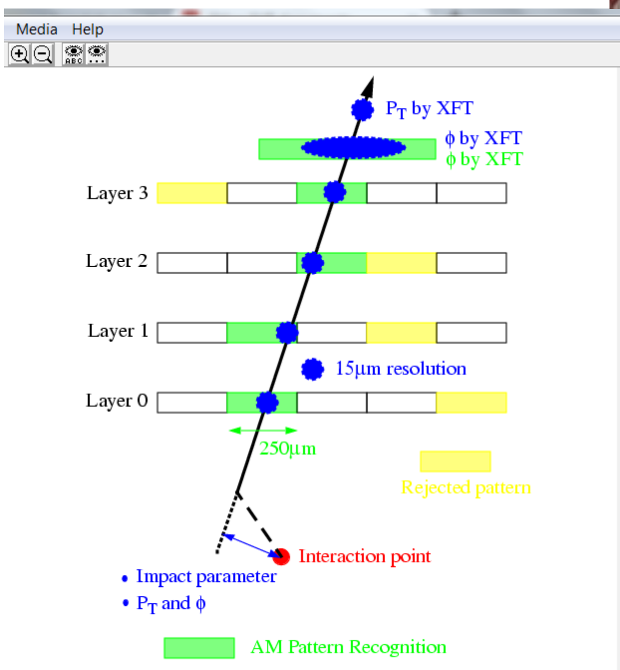

Aldo and Franco Cervelli
(?)

Run 2b: CDF SVX/ISL remains as is:



Silicon Vertex Tracker (SVT)

Luciano Ristori



2009 W.K.H. Panofsky Prize in Experimental Particle Physics Recipient

Luciano Ristori
INFN

Citation:

"*For their leading role in the establishment and use of precision silicon tracking detectors at hadron colliders, enabling broad advances in knowledge of the top quark, b-hadrons, and charm-hadrons.*"

Background:

Luciano Ristori was born in Prato (Italy) on December 13, 1948. In 1967 he was admitted at the Scuola Normale Superiore in Pisa where he graduated in 1971 with the title of ÒDottore in FisicaÓ. His thesis was on the measurement of the total p-p cross at the Intersecting Storage Rings (CERN-R801). In 1973, he joined the NA1 Collaboration at the CERN SPS for the first electronic measurement of the lifetime of charmed mesons using an active silicon target. In 1977, he obtained a permanent position at the Italian National Institute for Nuclear Physics (INFN). In 1991 he took a position of Associate Professor at the Scuola Normale Superiore in Pisa. In 1990 he conceived and proposed a trigger based on secondary verticles (SVT) to the CDF Collaboration. The SVT trigger, was commissioned in 2001 and has allowed CDF to perform measurements otherwise impossible, especially in the area of hadronic decays of B mesons and barions, including the precise measurement of the Bs oscillation frequency. Since 1998, he holds a position of Research Director at INFN in Pisa. He was Co-Spokesperson of the CDF Collaboration from 2003 to 2005. Since 2005 he is responsible for the whole Italian group in CDF.

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Aldo Menzione
INFN, Pisa

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"*For their leading role in the establishment and use of precision silicon tracking detectors at hadron colliders, enabling broad advances in knowledge of the top quark, b-hadrons, and charm-hadrons.*"

Background:

Aldo Menzione was born in Massa (Italy) on June 18, 1943. In 1961 he started his studies in University of Pisa where he graduated in 1967. Between 65 and 68 he worked on the CERN Karlsrhue Collab. The thesis work was Production of neutral mesons decaying in all neutral secondaries. 70 73 at CERN-ISR-R801. The reason for which this experiment is still known is the discovery of the rising p-p X-section. Other interesting results were in the area of correlations among secondaries and rapidity distributions as function of energy. 73 80 at CERN-SPS Experiments NA1 NA7. These experiments led to relevant results in charm physics and meson form factors. Many technical innovations were introduced in these experiments, most important, the active target, based on semiconductors. In the period 1990 -2000 he devoted part of his time to an astroparticle experiment CLUE finalized to establish a technique to detect the air shower by the UV Cherenkov light. 80 now CDF at Fermilab. He participates from the beginning to the design and the construction of the apparatus. Starting 1985 he had the responsibility of the design, construction and commissioning of the silicon vertex. The device was relevant in the top importance in a variety of measurements done by the collaboration. He has been responsible of the CDF-Pisa group until 2006.

Pisa/CDF Achievements/Contributions

(a personal list- apologies to those left out inadvertently)

1. **The silicon vertex detector- the top quark discovery and all the B physics, including Bs mixing, would have been impossible without Aldo's remarkable talents and the hard work of the Pisa group**
2. **The Level-2 silicon vertex trigger- also essential to the B-physics program- also impossible without Luciano's talents and leadership**
3. **The technical and construction contribution to the calorimeters- led by Paolo Giromini (Frascati) and Aldo Menzione and Angelo Scribano(Pisa)**
4. **The honing of CDF into a precision device through in-situ calibration by playing the magnetic spectrometer tracking against the calorimeters (and vice versa)**
5. **The many young talented young physicists who played such a large role in running the detector and in the analyses in the Physics Groups**
6. **An ineffable contribution to the wonderful quality of collaboration- the senior people provided leadership and a very high intellectual standard that was felt by everybody**

Backup Slides

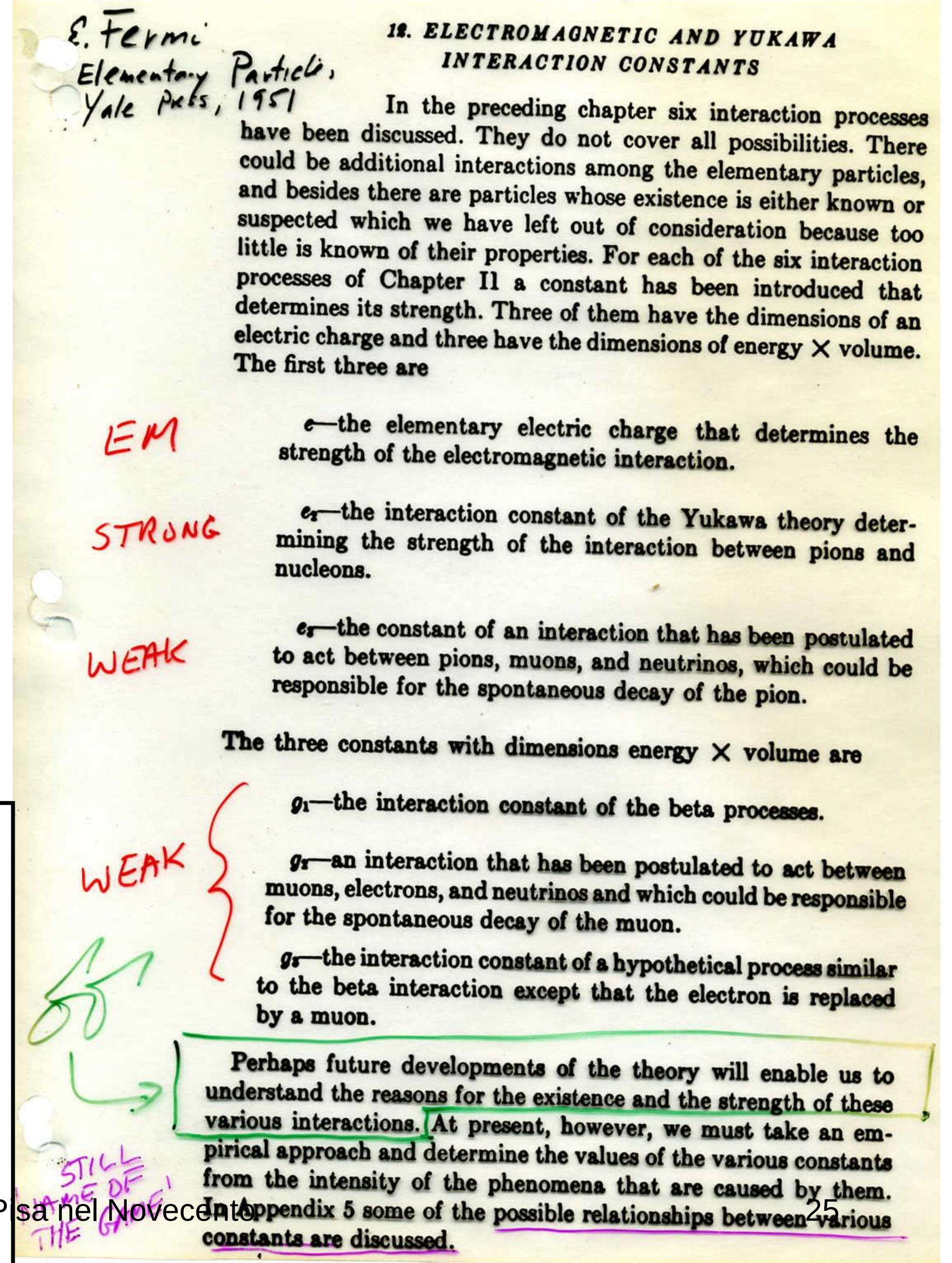
CDF Pisa Anecdotes

1. Aldo and 'Overlook' in writing the TDR
2. Aldo's petition on smoking in the Control Room
3. Paola Gianetti's "That's what it's supposed to do" to Myron Campbell after the FRED board worked 1st time
4. Dell'Orso's rule on time estimates
5. Send a 'control Italian' for radiation measurement

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)xSU(2)$_L$xU(1))**

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…."


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!