FNAL $\bar{p}p$ PROJECT

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I. OVERVIEW

The Tevatron I project at Fermilab was approved and funded in FY 1981. This project calls for construction of a $\bar{p}p$ source capable of producing a luminosity of 10^{30} at center of mass energies of the order of 2 TeV or 3 ergs. In addition, provision was made for two experimental areas; one at B0 and the second at D0. A large detector is being constructed as a Laboratory facility at B0, and a workshop was held for the D0 area where a number of groups presented a wide range of proposals.

The time schedule for this facility is as follows:

1. Finish Saver installation during the period of June to December 1982. At present, well over half of the collared coils have been constructed. Cryostat production is at the rate of 12 per week, and the Magnetic Test Facility is measuring finished dipoles at a rate of 10 to 12 per week. These production rates are consistent with finishing the Saver from the schedule mentioned above.
2. Commission the Saver starting from CY 1983.
3. Construction of the assembly hall and collision hall from the fall of 1981 to the summer of 1983. The collision hall involves a penetration into the tunnel, and its construction will be synchronized with the final phase of Saver installation.
4. Construction of the Source starting in 1982 and finishing in 1984.

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5. Detector construction from the present through 1984.

6. Commissioning the Source starting in the summer of 1984.

The schedule for the construction of D0 is still under discussion. In addition, studies have recently shown that it should be possible to bypass the main ring around the collision hall. The cost and the impact of this option on the program is being studied.

In this report, I will discuss the status of the Source, the collision hall, and the detector. Finally, I would like to compare the potential for colliding beam physics at the Tevatron with that of ISABELLE.

II. SOURCE

A detailed design for the Source has been presented in "The Fermilab Antiproton Source Design Report of June 1981." Here a design that generates $\bar{p}$'s at the rate of 7.9×10^9 per hour is presented. The $\bar{p}$'s are then cooled by longitudinal stochastic cooling. Next, they are decelerated, and the cooling is repeated. After three such cycles, the $\bar{p}$'s are injected into an accumulator ring where they are cooled in all three dimensions by electron cooling. After an elapsed time of 12.7 hours, 10^{11} $\bar{p}$'s have been accumulated. They have a $\Delta p/p$ of .1 percent and an emittance of 1π mm-mrad in each plane. The antiprotons are then formed into three bunches and reaccelerated to 1 TeV for colliding beam physics.

Many technical hurdles for the Source design have been overcome, and the projected luminosity of 10^{30} is realistic.

This proposal was reviewed in detail in June 1981 by a committee appointed by the Director. The conclusion of this committee was that the design was technically correct and could form a basis for our program. However, they also pointed out that the potential at FNAL was much greater than was being

exploited in the design and consequently urged the Laboratory to be more bold. They suggested that FNAL has a potential factor of 10 greater $\bar{p}$ production rate when compared to CERN, and that this could be achieved by use of techniques that have already been demonstrated. Using the previous work as a basis, a scheme along the lines suggested has been developed, and the complete design will be available before 1982 for an enhanced Source.

CERN is paving the way in this new technology. Many of the techniques they have developed are adaptable for use at FNAL. However, it is also true that there are vast differences between the two machines and that the potential resides at Fermilab for higher $\bar{p}$ production rates and higher luminosities. In addition, our biggest physics advantage is our higher collision energy.

III. DETECTOR

The detector is being built as a facility at Fermilab and will be installed in a collision hall at B0. The group at present consists of six universities: University of Chicago, University of Illinois, Harvard University, Purdue University, Texas A&M University, and University of Wisconsin. In addition, there are three national laboratories: Fermi National Accelerator Laboratory, Argonne National Laboratory, and Lawrence Berkeley Laboratory. Finally, we have collaborators from Italy (Frascati and University of Pisa) and Japan (KEK and University of Tsukuba). In addition, valuable help has been received from the California Institute of Technology. An overall view of the detector is given in Figs. 1 and 2. This detector covers an angular region from 2° to 178° in the laboratory system. The central magnetic detector covers the region from 10° to 170° and will roll in and out of the collision hall as a unit. The detectors covering 2° to 10° and

170° to 178° consist of toroids with tracking and hadron/electron calorimetry and will be assembled in their respective areas by means of transfer carts that are designed to move large pieces of equipment between the assembly hall and the collision hall.

The central detector consists of tracking chambers around the beam pipe and a 1.5 Tesla axial field produced by superconducting solenoid. Next in radius are electron calorimetry, hadron calorimetry, and finally muon tracking chambers.

Extensive model tests have produced a design for the electron and hadron calorimeters for this detector, and construction of these components is now underway. Model tests of the solenoid have been successfully carried out in Japan, and final design is now underway. Design and construction of prototypes for the tracking chambers is also underway.

A brief description of the design principles used for this detector is now given. The rapidity interval covered by 2 TeV pp collisions is -7.6 to +7.6. High p_T jets (100 GeV) and massive particles have a more restricted region in rapidity. Our detector will cover the region from 2° to 178° or $-4 < y < 4$.

The calorimetry of the central detector is divided into towers such that the granularity is about .1 units in y and 15° in $\Delta\phi$. There is some interpolation in $\Delta\phi$ because each tower is read out by means of two independent phototubes. These tubes look at the two edges of the scintillator plates in constant ϕ planes, and hence the ϕ resolution will be better than the 15°. Early studies were carried out using as a model the decay of a heavy quark of mass 50 GeV. This quark was assumed to decay into three jets, and the granularity of the calorimeter was investigated in order to determine

how many cells were necessary to reconstruct the individual jets and obtain the mass of the parent quark. These studies indicated that 500 or more cells in the region of $\theta = 45^{\circ}$ to 135° would be sufficient to resolve the jet structure and measure mass. Fewer cells could reconstruct the mass of the parent quark but would lose the substructure. This then fixed the granularity in the central region. Fig. 3 shows the mass spectrum expected from a calorimeter with 640 elements in the central region.

The end plugs as well as the forward calorimeters will utilize gas calorimetry with cathode pads for readout. This choice was dictated by the very difficult mechanical and magnetic problems encountered in this region as well as the requirement for increased spatial resolution. The gas calorimetry provides for greater flexibility of readout than scintillator technology does.

In the forward and backward region, the hadron shower size becomes large enough so that the resolution in both Δy and $\Delta\phi$ is reduced. Hence, at angles less than 10°, the calorimeters are moved further from the interaction points so that a typical QCD jet can still be resolved. Fig. 4 shows the resolution of the calorimetry in ϕ and y with typical QCD jets superimposed.[2]

Extensive studies were made of requirements for a magnet and the direction of its field. The reason for a field are diverse but when taken together, become decisive. Some of these are:

1. Increased information about particle charge in new and unexpected phenomena.
2. Enhanced πe separation.
3. Muon momentum measurement.

4. Help in ascertaining and maintaining the calibration of the calorimeters.

5. Asymmetries expected in some decays requires knowledge of the μ or e sign.

6. Enhanced momentum measurement of low momentum particles.

A solenoid was chosen because of its ease of construction and integration into the machine. It does not sweep particles from the leading beam jets into the detector and in addition, there is a large amount of experience and expertise in the physics community with tracking for this geometry. It obviously fails to provide information below about 30°, and so this region will be covered by magnetized iron toroids which will measure the momentum of muons in this angular region.

This completes a rather cursory description of the detector. A more complete description will be available shortly from Fermilab in the form of the CDF Detector Design Report. The design of the calorimetry has been intensively pursued during the last year, and agreements are now being drafted for construction of the various components. The construction will take place largely over the three year period from 1982 to 1984 and will be closely coordinated with the construction of the $\bar{p}$ Source.

IV. COLLIDING AREAS

There will be two colliding areas available for $\bar{p}p$ experimentation; one at B0 and a second at D0. The detector just described will go in the area at B0 and will be a major Laboratory facility. The Director has issued a call for proposals for the D0 area, and the detailed developments of plans for this facility will be heavily dependent upon the proposals that are

received. The B0 assembly hall and collision hall are nearly complete and ready for Title I approval, and we wish to have the Title II ready by October.

Figs. 5 and 6 show a view of the collision hall and the assembly hall as well as the support area. The first two are nearly 40 ft. below ground level while the support area is at the surface.

The collision hall consists of a region of a length 100 ft. Its width varies as shown. The central region is slightly deeper and provides a nearly cubical space 50 ft. x 50 ft. and 40 ft. high for housing the central detector which can move in and out. The two smaller halls in the forward and backward region contain magnetized iron toroids and electron and hadron calorimetry. A bypass is provided around the outside of this region for servicing the main ring in the Tevatron. The floor is a concrete pad 4 ft. thick in order to support the weight of the detector elements. The assembly hall is located parallel to the collision hall and separated from it by a tunnel in which a retractable shielding door is placed, which when removed from the tunnel can be stored at either side in the assembly hall. The assembly area is covered by a 50 ton crane, and in addition, transfer carts will be provided to move heavy equipment from the assembly area into the forward and backward collision halls. The floor level not occupied by the transfer carts or the central detector is raised 4 ft. in order to facilitate work on the detector and its components and to facilitate support of the components in the forward and backward halls. The building at ground level will provide adequate room for assemblying the smaller components of the detector. Fig. 7 shows an outline of the B0 area and with the same scale, the CERN UA1 Pit and the BNL Major Facility 8.

In addition to the support, the assembly, and the collision areas, this building will contain a fixed electronics house for the detector. The cabling problems presented by this decision as well as the division of the electronics between the detector and the electronics house has not yet been resolved. A $\bar{p}$ source with a high production rate will obviously make it more practical to obtain access to components of the detector within the collision hall during running. Placing more of the electronics immediately at the detector simplifies the cabling but increases the need for highly reliable electronics.

A large detector such as has been described here is obviously a very versatile instrument for physics. However, there are many regions where it has obvious deficiencies. For this reason and for the reason that Fermilab desires an increased user participation in its $\bar{p}$ colliding beam program, a second collision area will be provided. The Director has called for proposals for experiments in this area. The area will not accommodate a major facility such as we have been describing but will be dedicated to more highly specialized experiments that supplement the major facility. The design of this area iwll be influenced by the proposals that are received and approved by the PAC.

V. BYPASS

An examination of all of the detector drawings shows the main ring beam pipe passing through the detector 25 in. above the Tevatron center line. This obviously poses difficulties for all of the detector elements that the main ring beam must pass through. A configuration of the main ring that would allow it to bypass the collision hall has been sought for a long time. It has recently become clear that such a configuration for the main ring

exists and that the main trick is to bend the main ring in the vertical direction to pass over the collision hall.[3] In order to keep the path length fixed in the main ring, the orbit must move to a slightly smaller radius. The details of various schemes are now being carefully examined and evaluared. Since such a bypass may be as long as 1,500 ft., it will involve considerable expense and additional engineering in the main ring runnel. It is unlikely that such a bypass could be installed before the Source is commissioned. However, the ultimate opportunity to remove the main ring from interference with the detector is an exciting prospect.

VI. PHYSICS

Inevitably, the physics capability of ISABELLE pp collisions at less than 800 GeV in the center of mass system will be contrasted with the $\bar{p}p$ colliders. In particular, this question will arise in trying to evaluate the proposed[4] Phase I ISABELLE (using FNAL magnets) with a luminosity of 2.7×10^{31}. The ultimate outcome of this discussion will have to consider problems of funding, politics, and physics. However, here I would like to restrict these remarks to physics and technology.

The $W^{\pm}$ and the Z^{o} will probably have been discovered at CERN by the time either ISABELLE or TeV I is operational. It is also true that the fundamental properties of the Z^{o} are better studied in an $e^{+}e^{-}$ machine such as LEP. In the past, physicists have been extremely successful in deducing the fundamental properties of a particle from a very small number of events. It is not productive to argue about the relative numbers of these particles that will be produced per hour at the various machines. A better comparison is given by a set of curves that compares colliders in terms of the luminosity

of quark-quark collisions.[5] Thus, the interaction rate for any given channel can be computed from these luminosity curves times the fundamental cross section. It forms an easy way to compare various machines. Clearly, qq interactions will be enhanced in pp collision, and $\bar{q}q$ interactions will be suppressed. The gg interactions are relatively insensitive to the type of particles. Curves from Ref. 5 are presented in Figs. 8 through 10, and they incorporate the scaling violations as calculated by QCD. (It is useful to make transparencies of these curves so that they may be compared for different machine energies and luminosities.)

It is seen that at the same luminosity, CERN $\bar{p}p$ and ISABELLE pp are essentially equivalent. However, a comparison of TeV I shows that for W = 100 GeV, a factor of 10 lower machine luminosities leaves TeV I equal to ISABELLE, and for W greater than 200 GeV, TeV I is superior even for a ratio of 100 in basic luminosity. These curves display the enormous leverage that energy has over luminosity in the search for high mass states.

The remaining figures show the results of calculations for high p_T jets, single π^0, single γ, and $W^{\pm}$ or Z production. For instance, at a p_T of 100 GeV/c, there is a factor of 100 difference in the jet cross section between $\sqrt{s} = 2000$ and $\sqrt{s} = 500$ for jets.

In summary, it is clear that any comparison between ISABELLE and the $\bar{p}p$ machines must take into account the following:

1. The intermediate vector boson will have been discovered. Comparing machines by comparing W production rates is not meaningful. CERN will have had too long a lead time.
2. $\bar{p}$ source technology is new and advancing rapidly. A luminosity equal 10^{31} is realistic to achieve.

3. The higher energy of TeV I gives it an advantage of approximately 100 or more for high p_T states.

From the above considerations, it appears that a machine with a Phase I luminosity of 2.7×10^{31} may be marginal in its appeal.

These considerations are offset by the fact that at ISABELLE there will be more than two interaction regions and that the machine is a dedicated facility. Furthermore, at the luminosities quoted for Phase I, the beam-beam tune shift is not large, and one is not making a big extrapolation into regions of unknown machine stability. Until the luminosity is raised, the problem of multiple interactions in a beam bunch does not seem serious.

The above is a summary of the colliding beam program at FNAL. CERN is aggressively pushing their own programs. ISABELLE will be born into a very competitive environment - one of new technologies that are advancing rapidly.

These considerations plus others such as funding, access of the university community to facilities, and the support and development of new accelerator technology will have to guide the future of ISABELLE.

REFERENCES

1. A Longer Note on Top Quarks, G. Fox and L. Romans, FNAL Pub. CDF-70. Also, private communication, Irwin Gaines.
2. CDF Design Report.
3. Private Communication, T. Collins. Also, D. Johnson and R. Huson.
4. Preliminary Report of the Task Force to Study the Possibility of Using Fermilab Magnets in ISABELLE, BNL, June 12, 1981.
5. Comparing Collider Capabilities, C. Quigg, FNAL Pub., July 8, 1981.

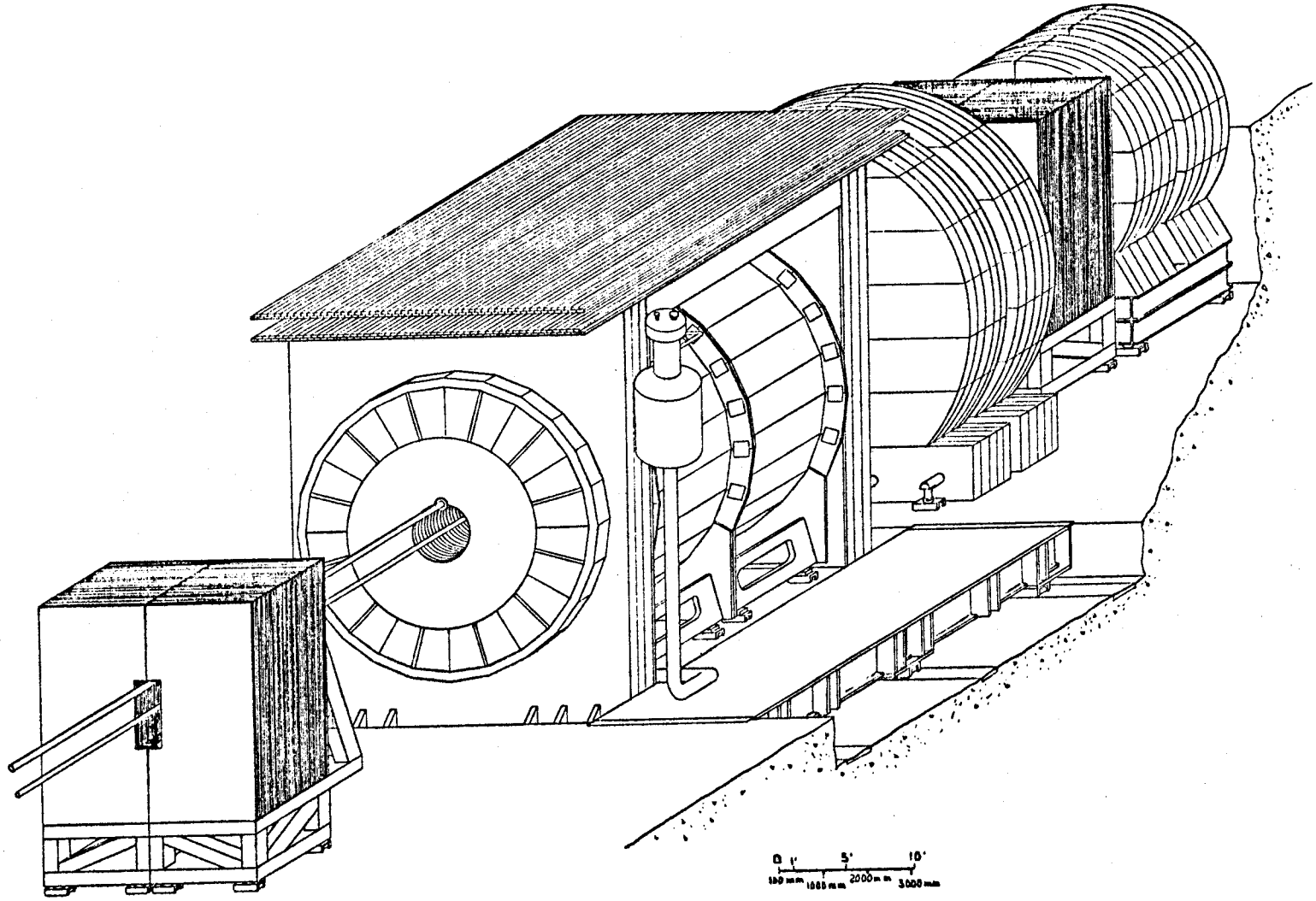


Fig. 1

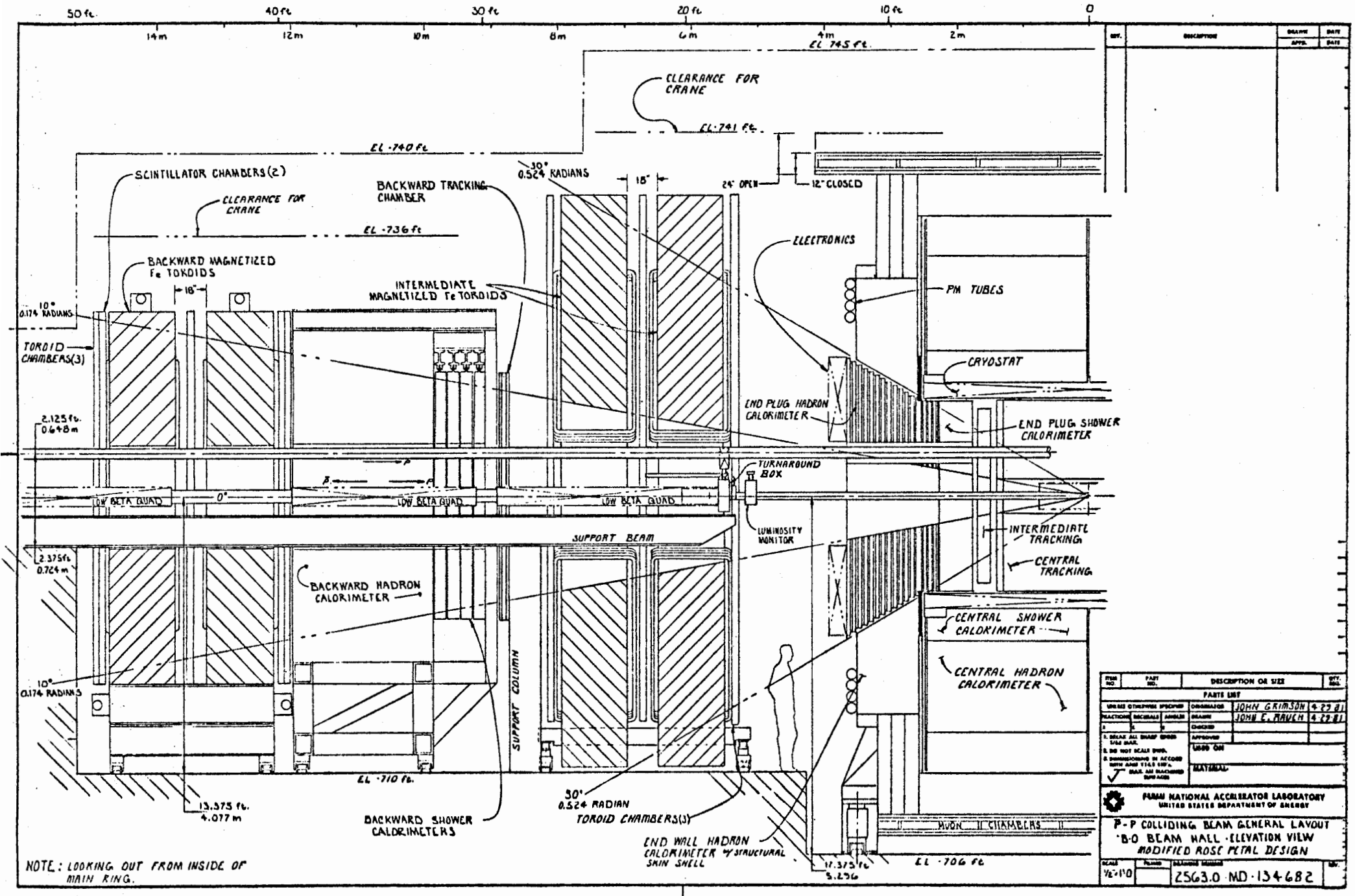
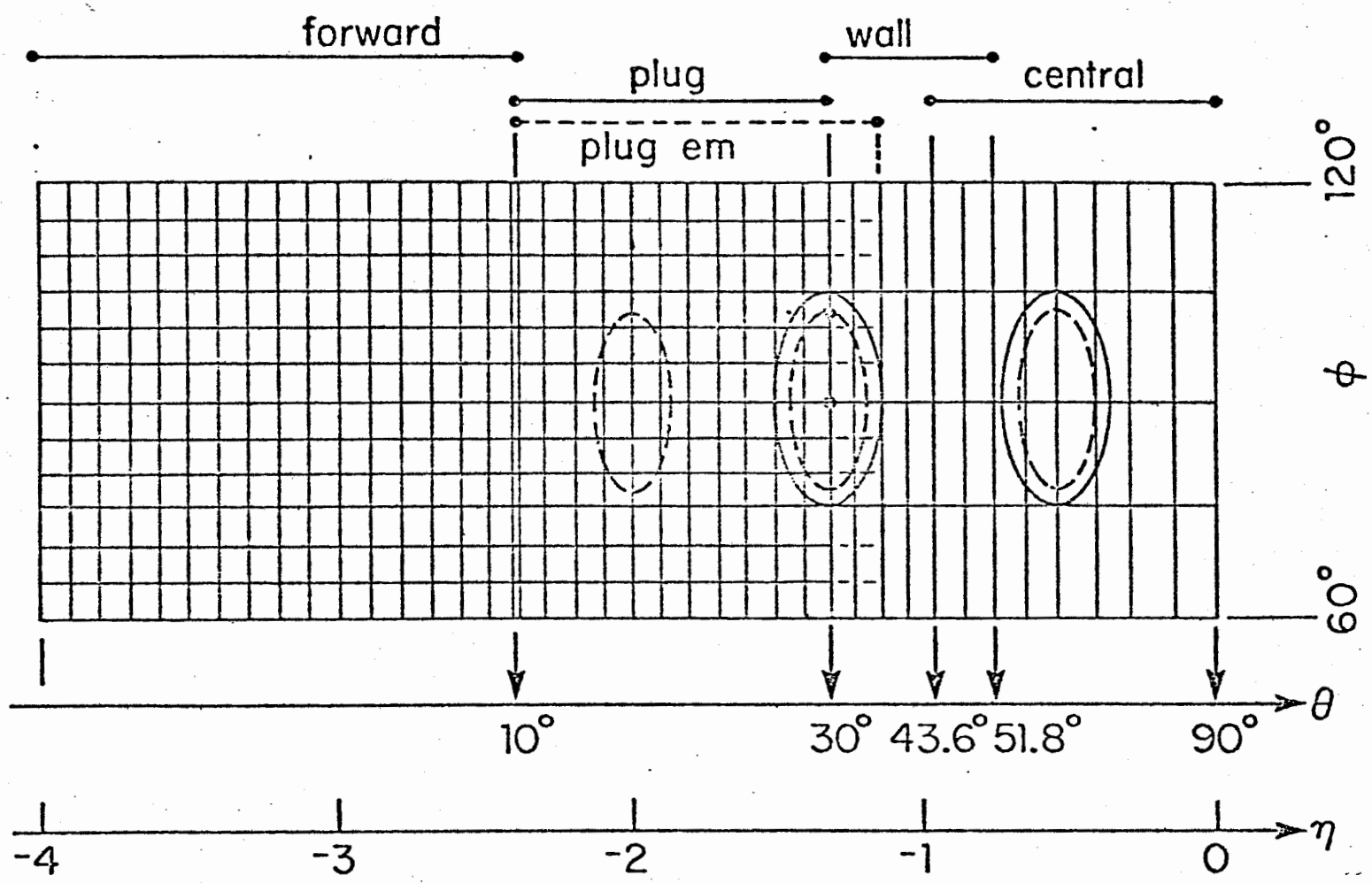

50 ft
40 ft
30 ft
20 ft
10 ft
0
14m
12m
10m
8m
6m
4m
2m
EL 745 ft
CLEARANCE FOR CRANE
EL 741 ft
EL 740 ft
SCINTILLATOR CHAMBERS(2)
CLEARANCE FOR CRANE
EL 736 ft
BACKWARD TRACKING CHAMBER
30° 0.524 RADIANS
18"
24" OPEN
12" CLOSED
ELECTRONICS
BACKWARD MAGNETIZED Fe TORIDS
18"
INTERMEDIATE MAGNETIZED Fe TORIDS
PM TUBES
10° 0.174 RADIANS
TORID CHAMBERS(3)
CRYOSTAT
END PLUG HADRON CALORIMETER
END PLUG SHOWER CALORIMETER
2.125 ft. 0.648 m
TURNAROUND BOX
LOW BETA QUAD
0°
LOW BETA QUAD
LOW BETA QUAD
LUMINOSITY MONITOR
SUPPORT BEAM
INTERMEDIATE TRACKING
CENTRAL TRACKING
2.375 ft 0.724 m
BACKWARD HADRON CALORIMETER
CENTRAL SHOWER CALORIMETER
CENTRAL HADRON CALORIMETER
10° 0.174 RADIANS
SUPPORT COLUMN
EL 710 ft.
13.375 ft. 4.077 m
BACKWARD SHOWER CALORIMETERS
30° 0.524 RADIAN
TOROID CHAMBERS(3)
END WALL HADRON CALORIMETER w/ STRUCTURAL SKIN SHELL
MUON CHAMBERS
17.375 ft 5.296
EL 706 ft
NOTE: LOOKING OUT FROM INSIDE OF MAIN RING.
DESCRIPTION OR SIZE
PARTS LIST
JOHN GRIMSON 4-29-81
JOHN E. MAUCH 4-29-81
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
P-P COLLIDING BEAM GENERAL LAYOUT
B-0 BEAM HALL ELEVATION VIEW
MODIFIED ROSE PETAL DESIGN
1/2"=1'0
2563.0 MD 134682

Fig. 2


forward
wall
plug
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plug em
120°
60°
φ
θ
10°
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43.6°
51.8°
90°
η
-4
-3
-2
-1
0

Fig. 3

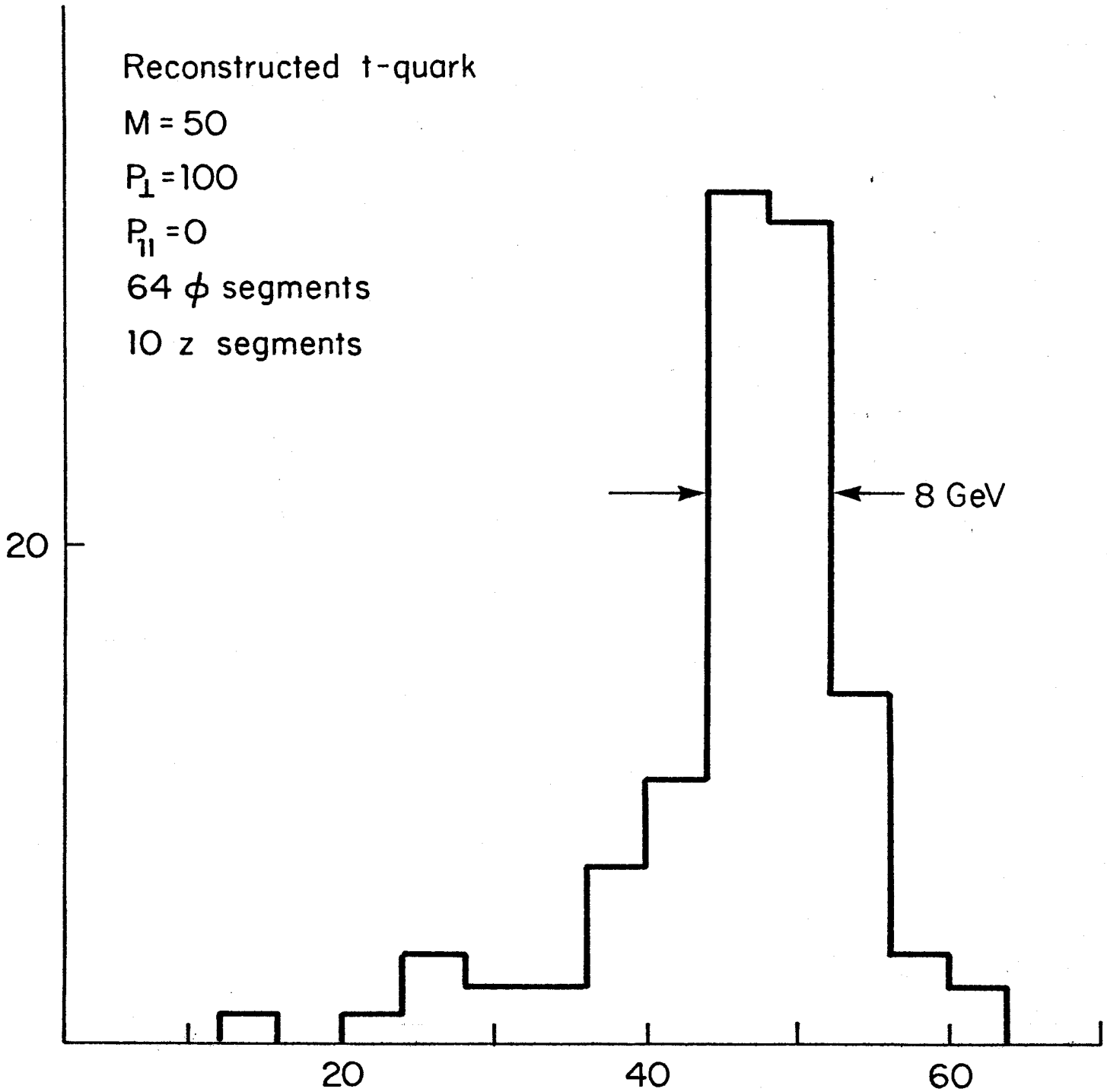

Reconstructed t-quark
M = 50
$P_\perp$ = 100
$P_{\parallel}$ = 0
64 ϕ segments
10 z segments
8 GeV
20
20
40
60

Fig. 4

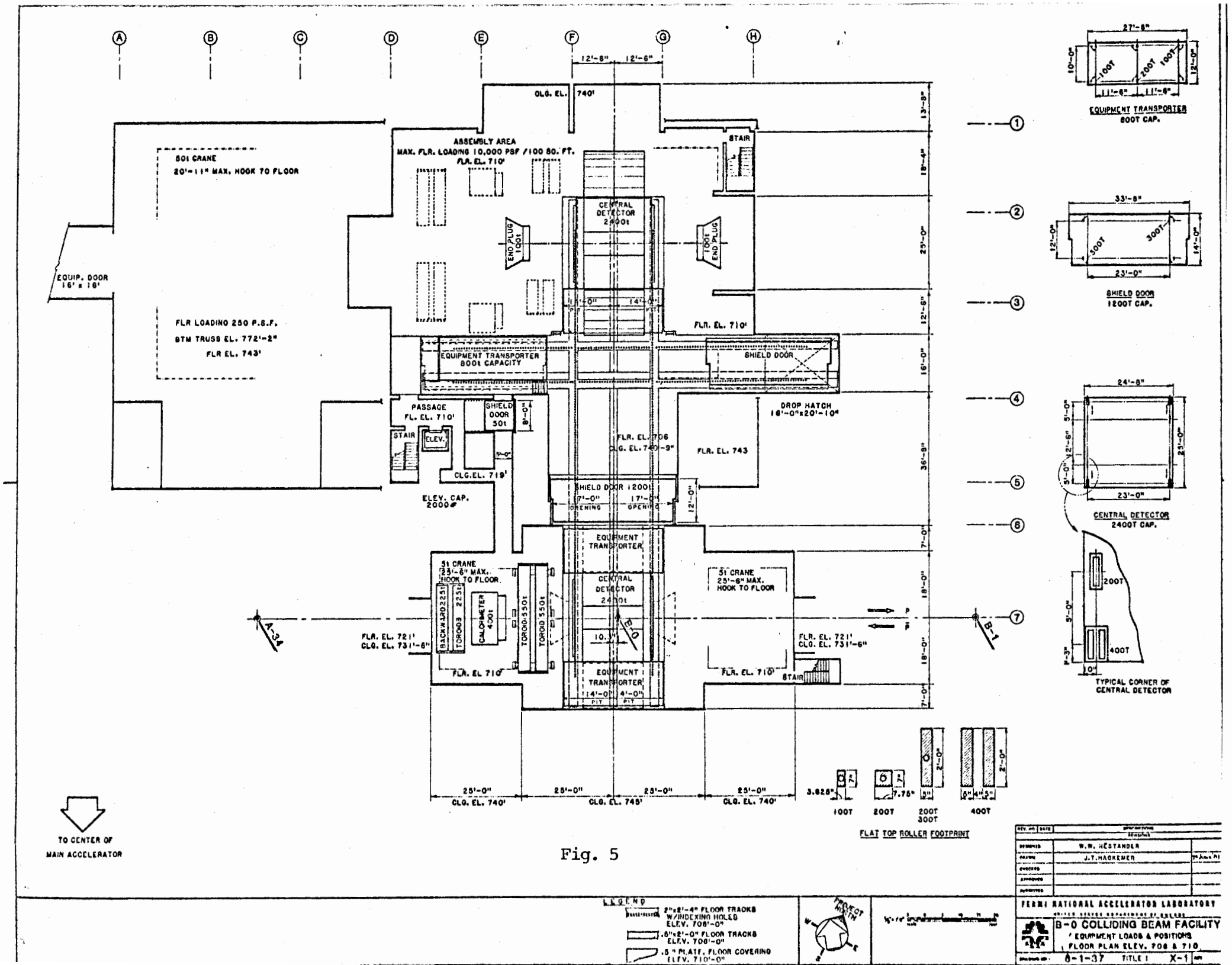

A
B
C
D
E
F
G
H
1
2
3
4
5
6
7
12'-8"
12'-6"
CLG. EL. 740'
ASSEMBLY AREA
MAX. FLR. LOADING 10,000 PSF /100 SQ. FT.
FLR. EL. 710'
STAIR
50t CRANE
20'-11" MAX. HOOK TO FLOOR
CENTRAL DETECTOR 2400t
END PLUG 100t
100t END PLUG
EQUIP. DOOR 16' x 16'
FLR LOADING 250 P.S.F.
BTM TRUSS EL. 772'-2"
FLR EL. 743'
FLR. EL. 710'
EQUIPMENT TRANSPORTER 800t CAPACITY
SHIELD DOOR
PASSAGE FL. EL. 710'
SHIELD DOOR 50t
STAIR
ELEV.
CLG.EL. 719'
ELEV. CAP. 2000#
DROP HATCH 18'-0"x20'-10"
FLR. EL. 706
CLG. EL. 740'-9"
FLR. EL. 743
SHIELD DOOR 1200t
OPENING
EQUIPMENT TRANSPORTER
CENTRAL DETECTOR 2400t
51 CRANE 25'-6" MAX. HOOK TO FLOOR
BACKWARD 225t
TOROID 225t
CALORIMETER 400t
TOROID 550t
TOROID 550t
A-34
B-1
FLR. EL. 721'
CLG. EL. 731'-6"
FLR. EL. 710'
STAIR
EQUIPMENT TRANSPORTER
25'-0"
CLG. EL. 740'
CLG. EL. 745'
CLG. EL. 740'
TO CENTER OF MAIN ACCELERATOR
EQUIPMENT TRANSPORTER 800T CAP.
SHIELD DOOR 1200T CAP.
CENTRAL DETECTOR 2400T CAP.
TYPICAL CORNER OF CENTRAL DETECTOR
100T
200T
200T 300T
400T
FLAT TOP ROLLER FOOTPRINT
LEGEND
2"x2'-4" FLOOR TRACKS W/INDEXING HOLES ELEV. 706'-0"
.6"x2'-0" FLOOR TRACKS ELEV. 706'-0"
.5" PLATE FLOOR COVERING ELEV. 710'-0"
PROJECT NORTH
W. W. HESTANDER
J. T. HACKEMER
FERMI NATIONAL ACCELERATOR LABORATORY
B-0 COLLIDING BEAM FACILITY
EQUIPMENT LOADS & POSITIONS
FLOOR PLAN ELEV. 706 & 710
6-1-37
TITLE I
X-1

Fig. 5

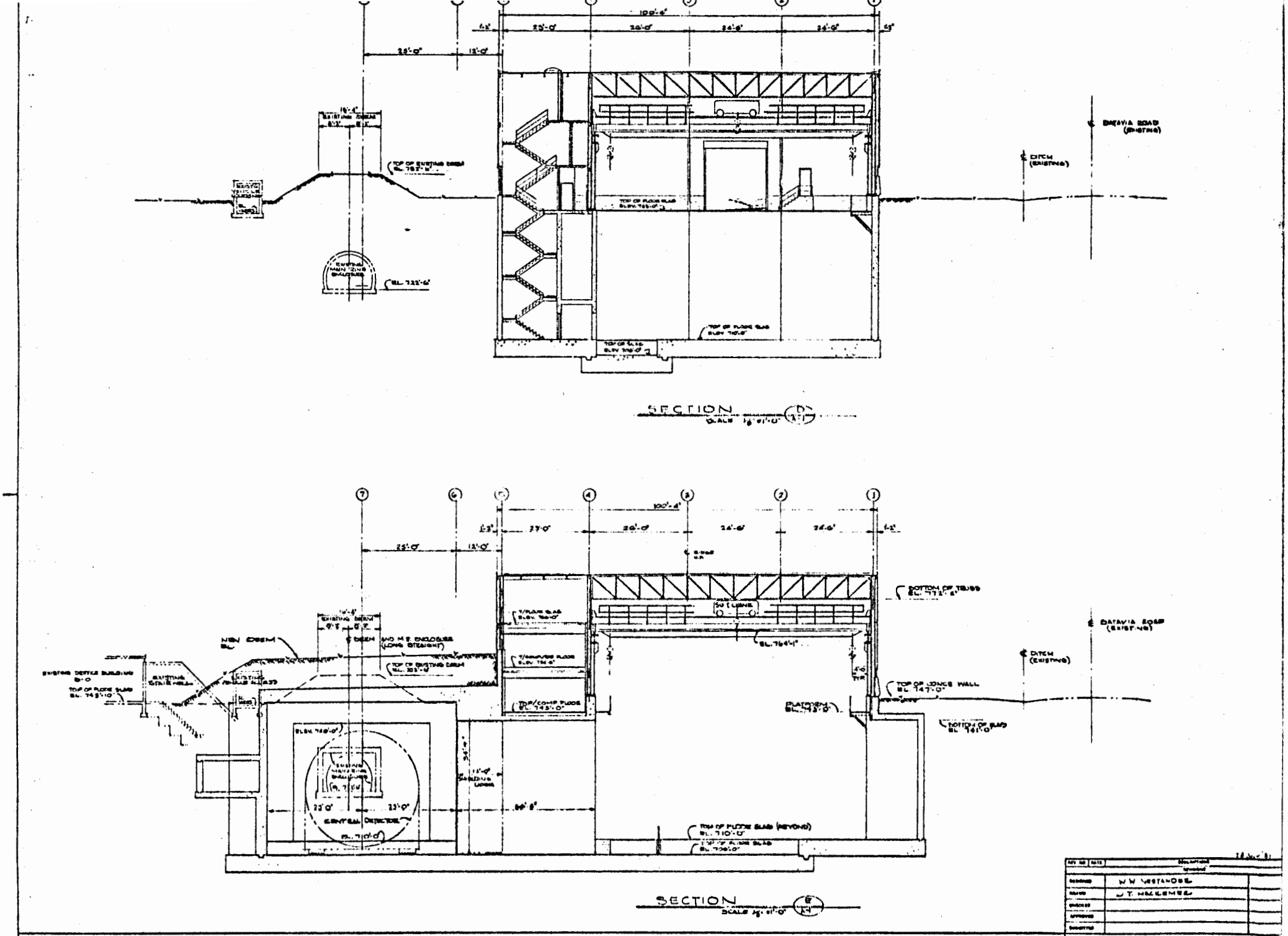
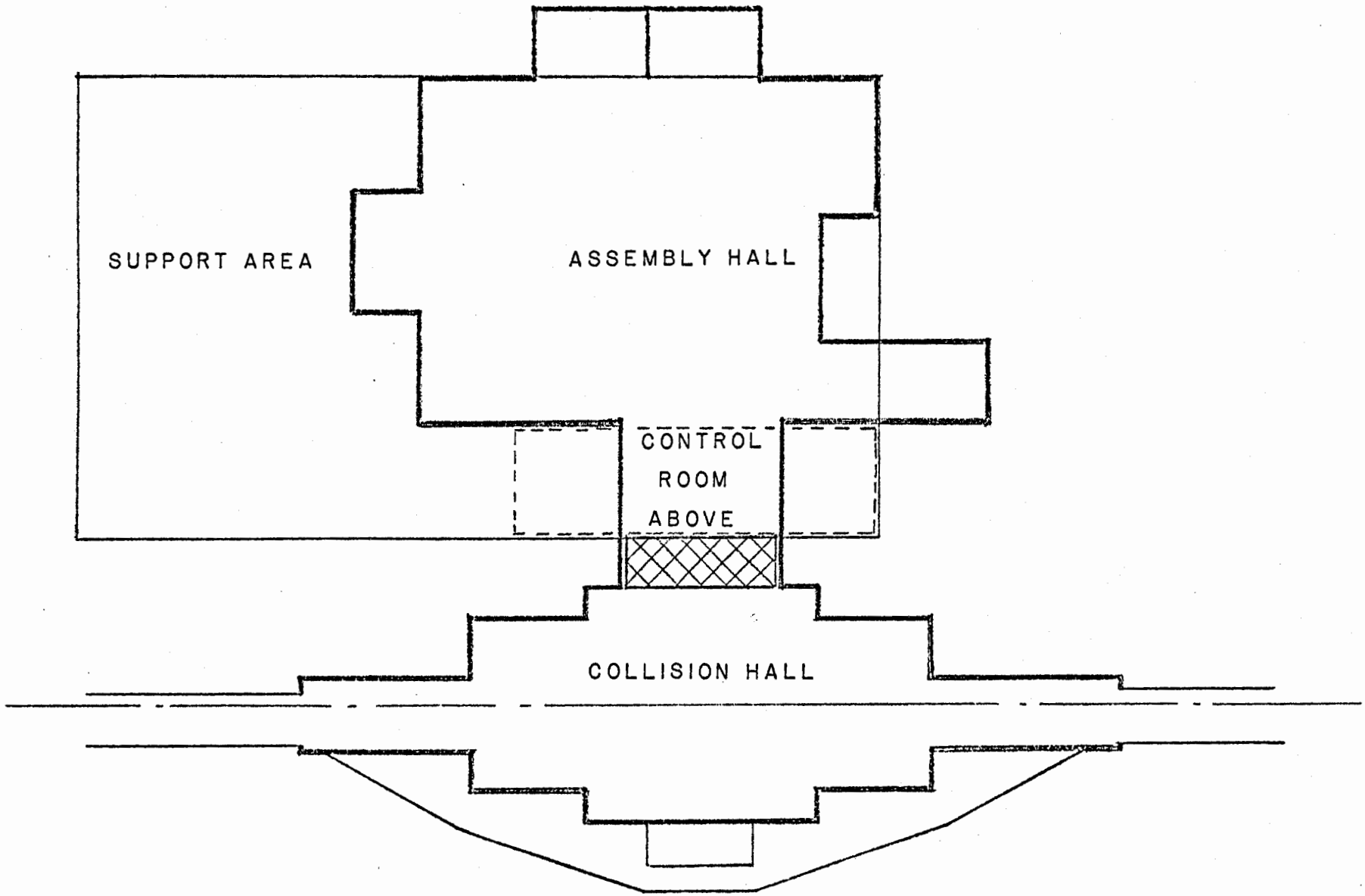
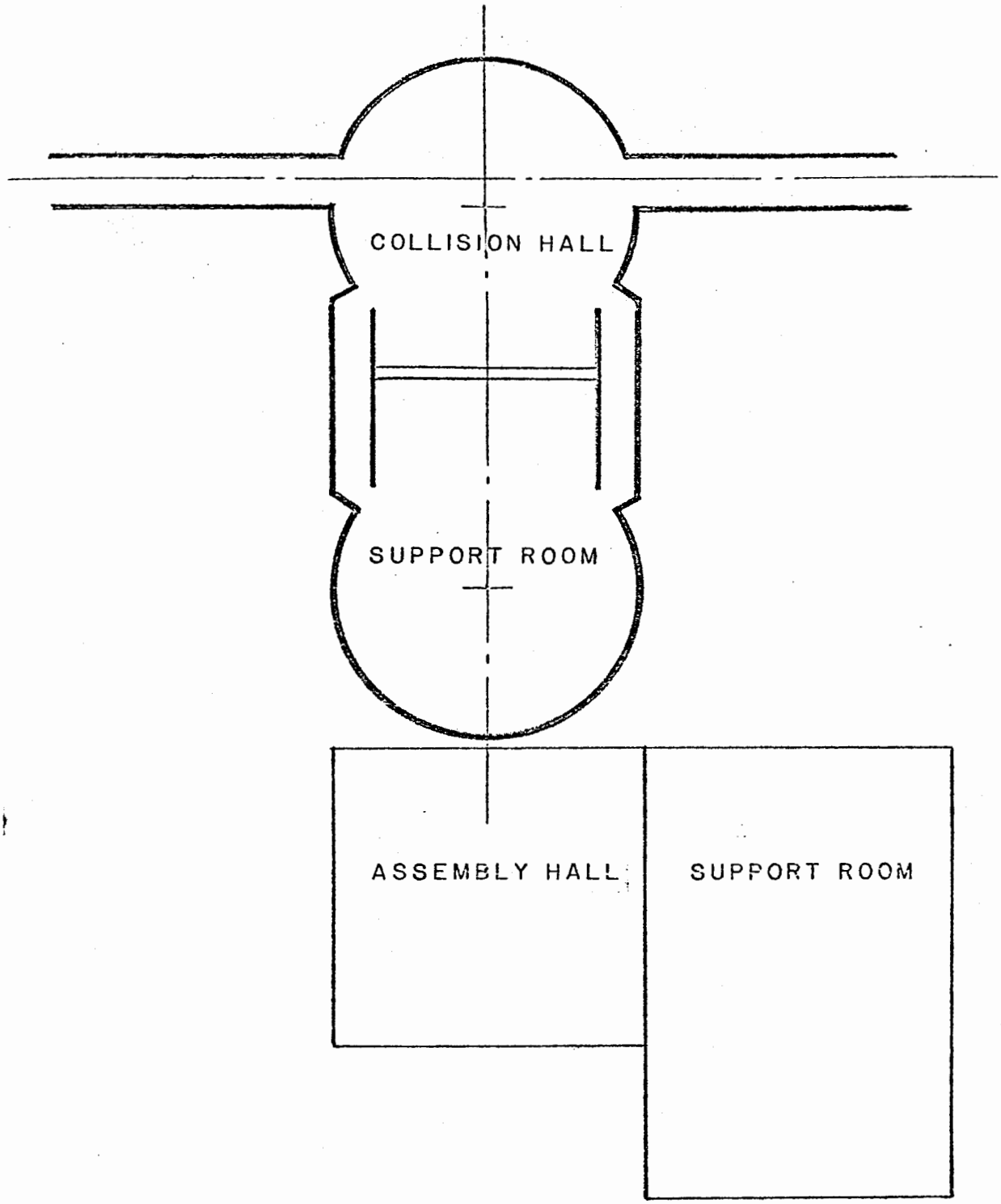

SECTION
SECTION
BATAVIA ROAD (EXISTING)
DITCH (EXISTING)
TOP OF CONCE WALL
CENTRAL DETECTOR
W W VESTANDER
J T MACKEMER
FERMI NATIONAL ACCELERATOR LABORATORY
B-0 COLLIDING BEAM FACILITY
CROSS SECTIONS
6-1-37
A-6

Fig. 6



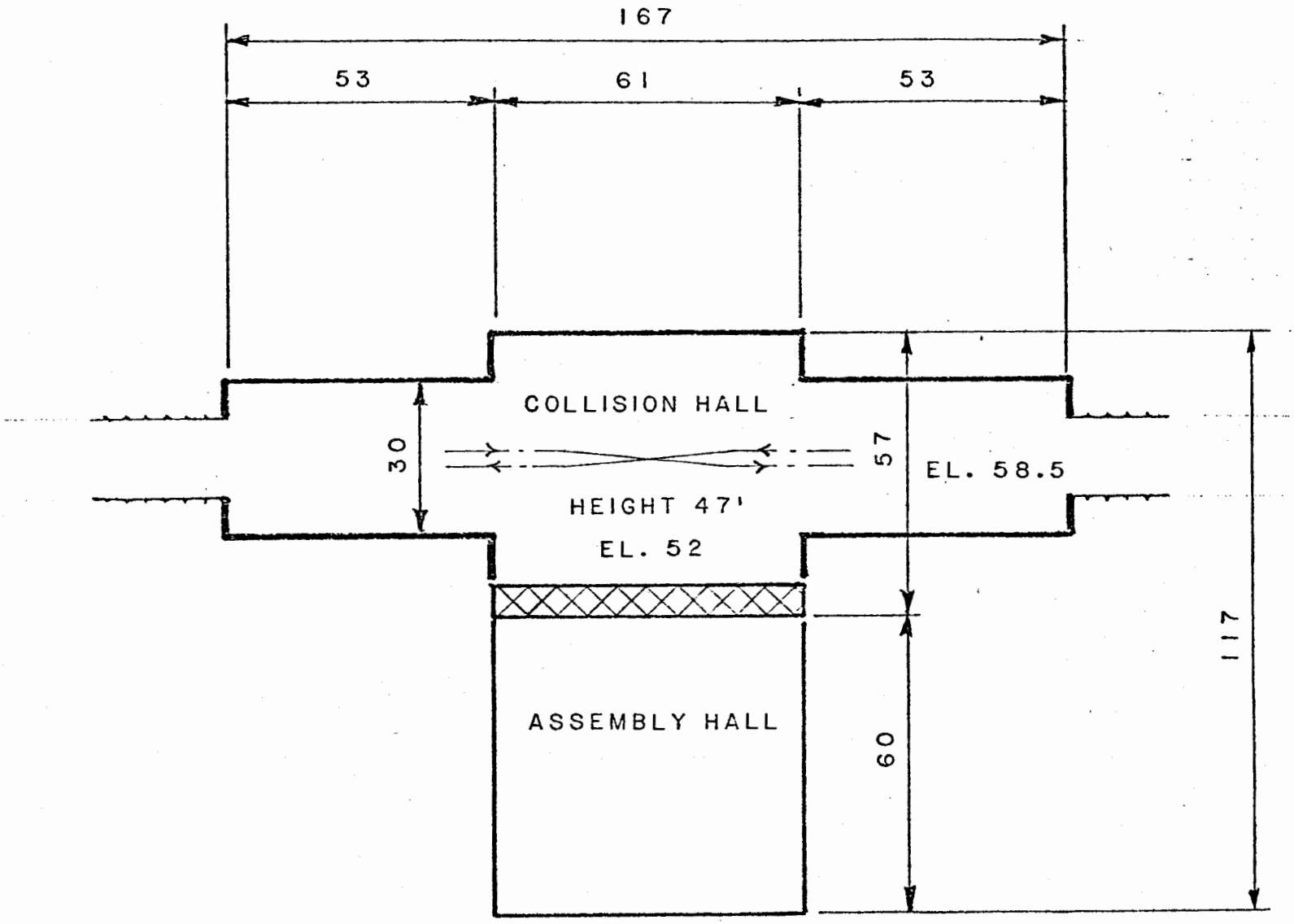
FERMILAB

Fig. 7a



CERN

Fig. 7b



B N L

MAJOR FACILITY 8

Fig. 7c

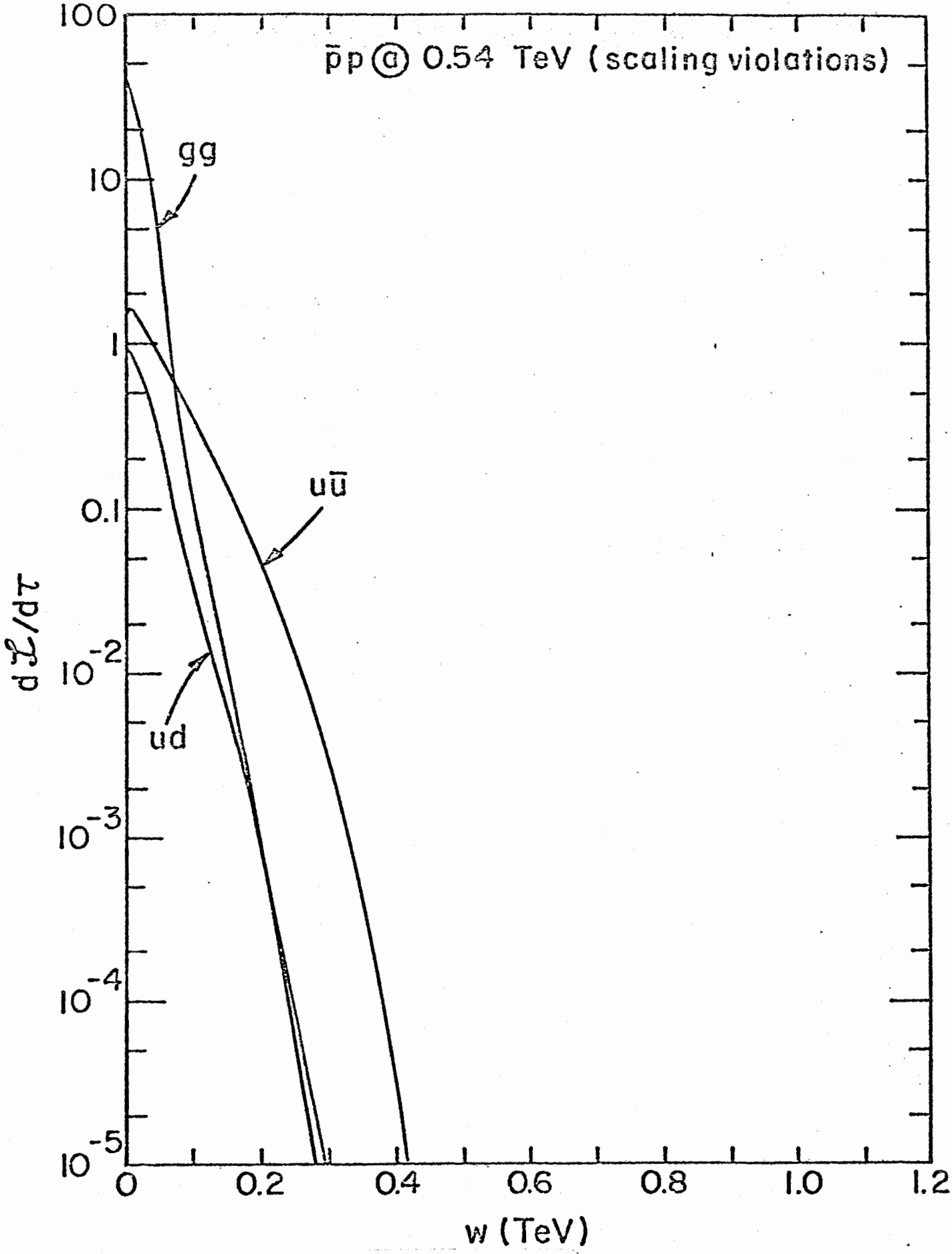

p̄p @ 0.54 TeV (scaling violations)
gg
uū
ud
100
10
1
0.1
10^-2
10^-3
10^-4
10^-5
dℒp/dτ
0
0.2
0.4
0.6
0.8
1.0
1.2
w (TeV)

Fig. 8

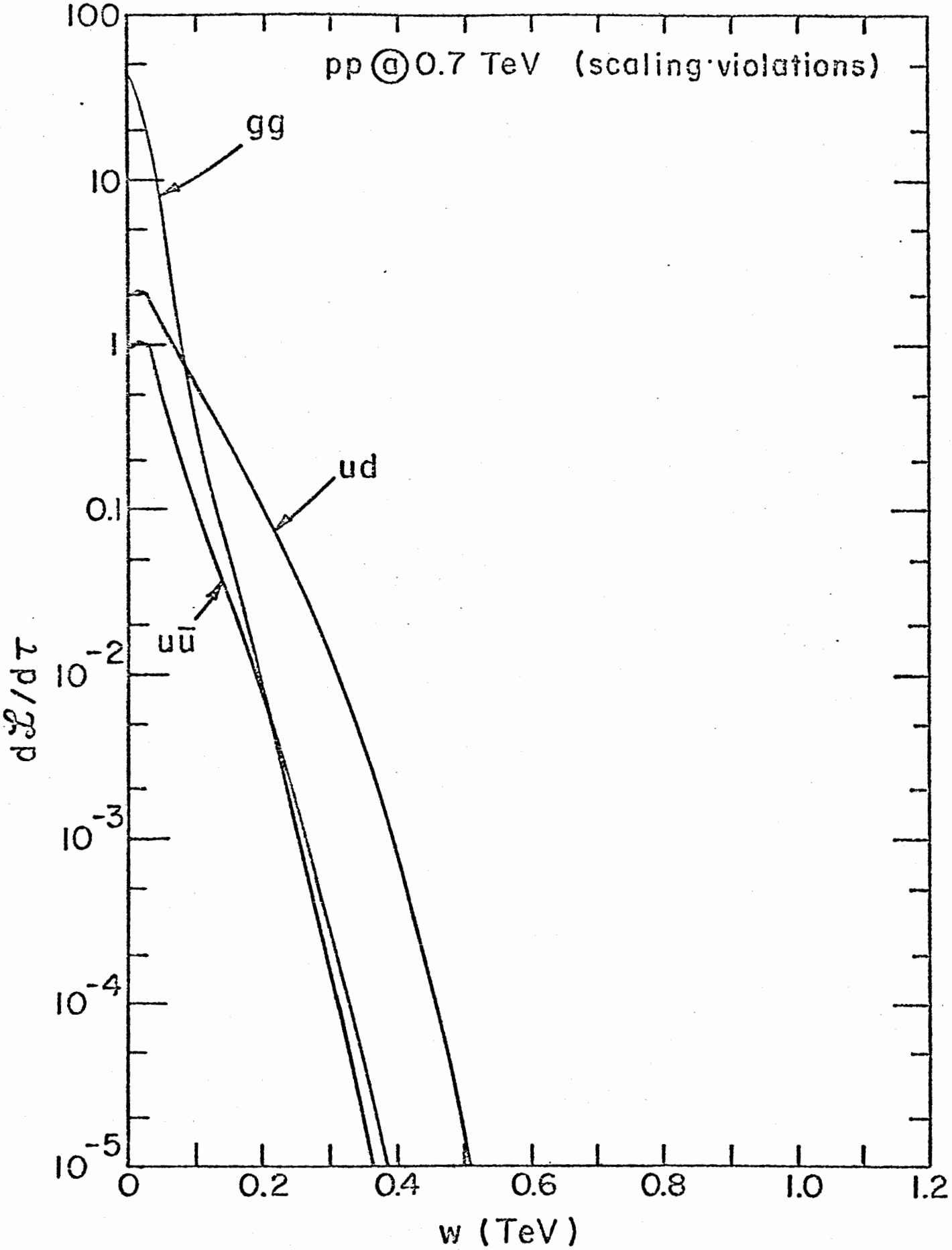
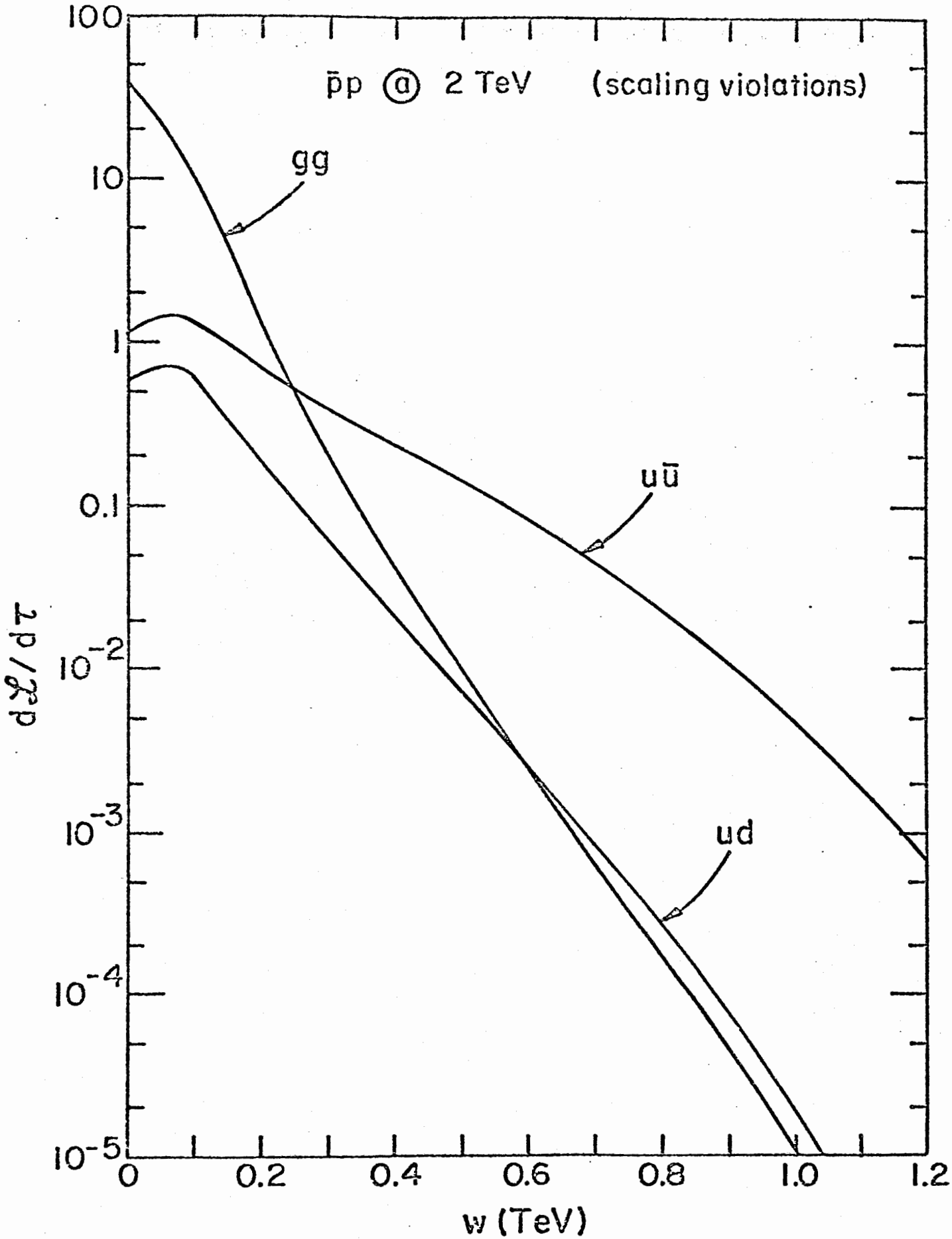

pp @ 0.7 TeV (scaling violations)
gg
ud
$u\bar{u}$
100
10
1
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}
$d\mathcal{L}/d\tau$
0
0.2
0.4
0.6
0.8
1.0
1.2
w (TeV)

Fig. 9


p̄p @ 2 TeV (scaling violations)
gg
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ud
100
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1
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}
$d\mathcal{L}/d\tau$
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0.2
0.4
0.6
0.8
1.0
1.2
w (TeV)

Fig. 10

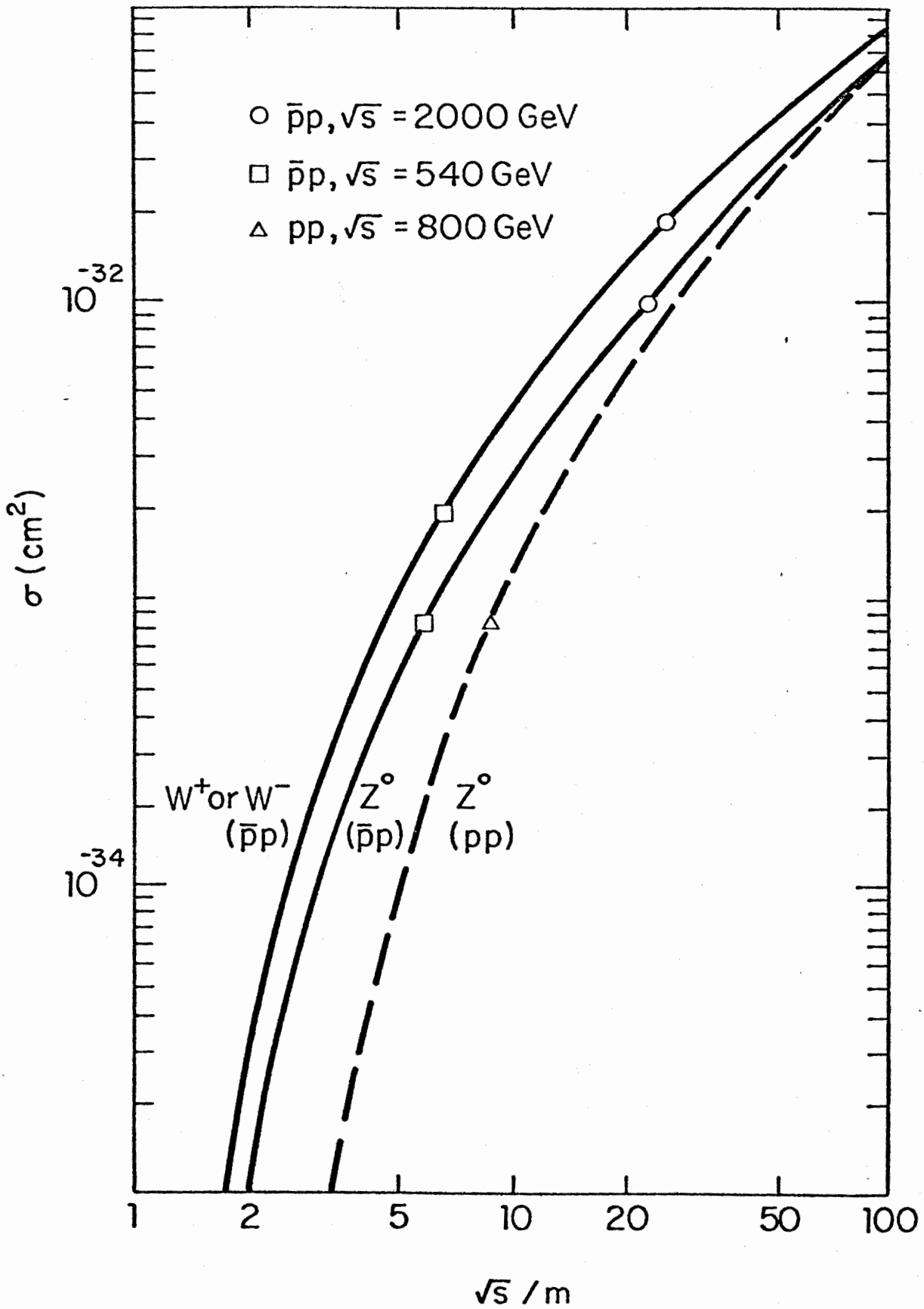
○ p̄p, √s = 2000 GeV
□ p̄p, √s = 540 GeV
△ pp, √s = 800 GeV
10^-32
10^-34
σ (cm²)
W⁺ or W⁻ (p̄p)
Z° (p̄p)
Z° (pp)
1
2
5
10
20
50
100
√s / m

Fig. 11

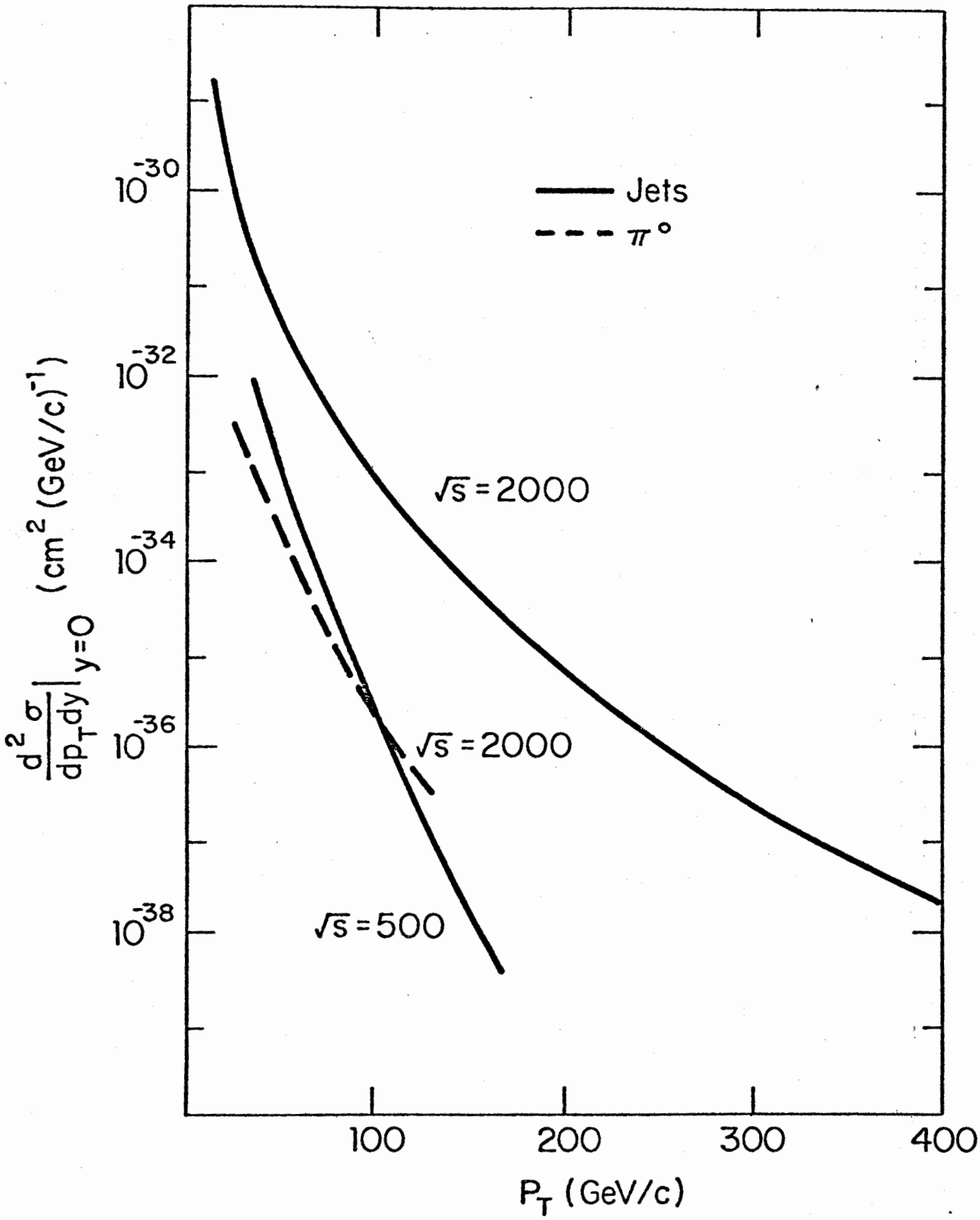
Jets
π°
√s = 2000
√s = 2000
√s = 500
10^-30
10^-32
10^-34
10^-36
10^-38
100
200
300
400
P_T (GeV/c)
d²σ/dp_T dy |_y=0 (cm² (GeV/c)⁻¹)

Fig. 12

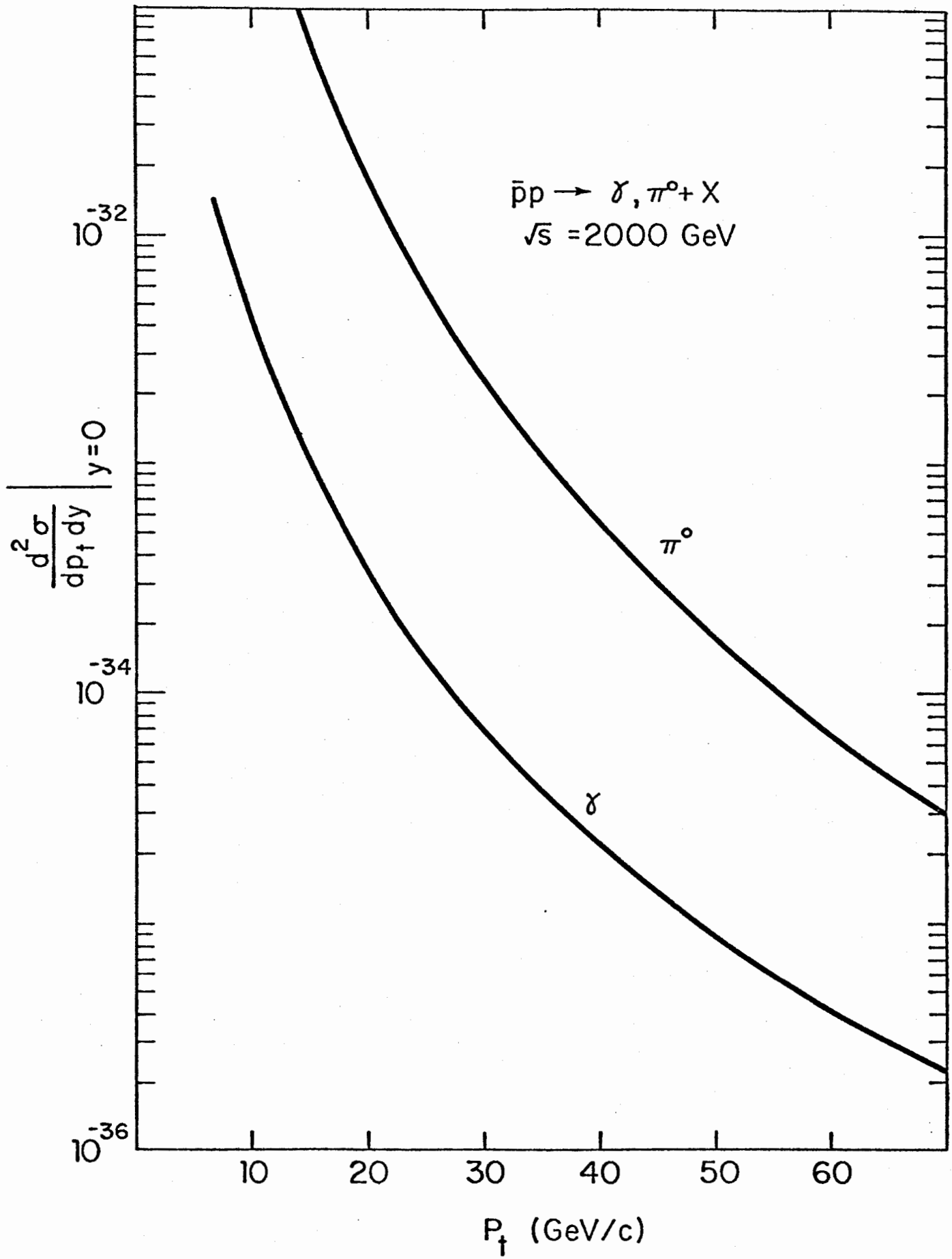
$\bar{p}p \rightarrow \gamma, \pi^0 + X$
$\sqrt{s}$ =2000 GeV
π^0
γ
10^{-32}
10^{-34}
10^{-36}
$\left.\frac{d^2\sigma}{dp_t\,dy}\right|_{y=0}$
10
20
30
40
50
60
P_t (GeV/c)

Fig. 13

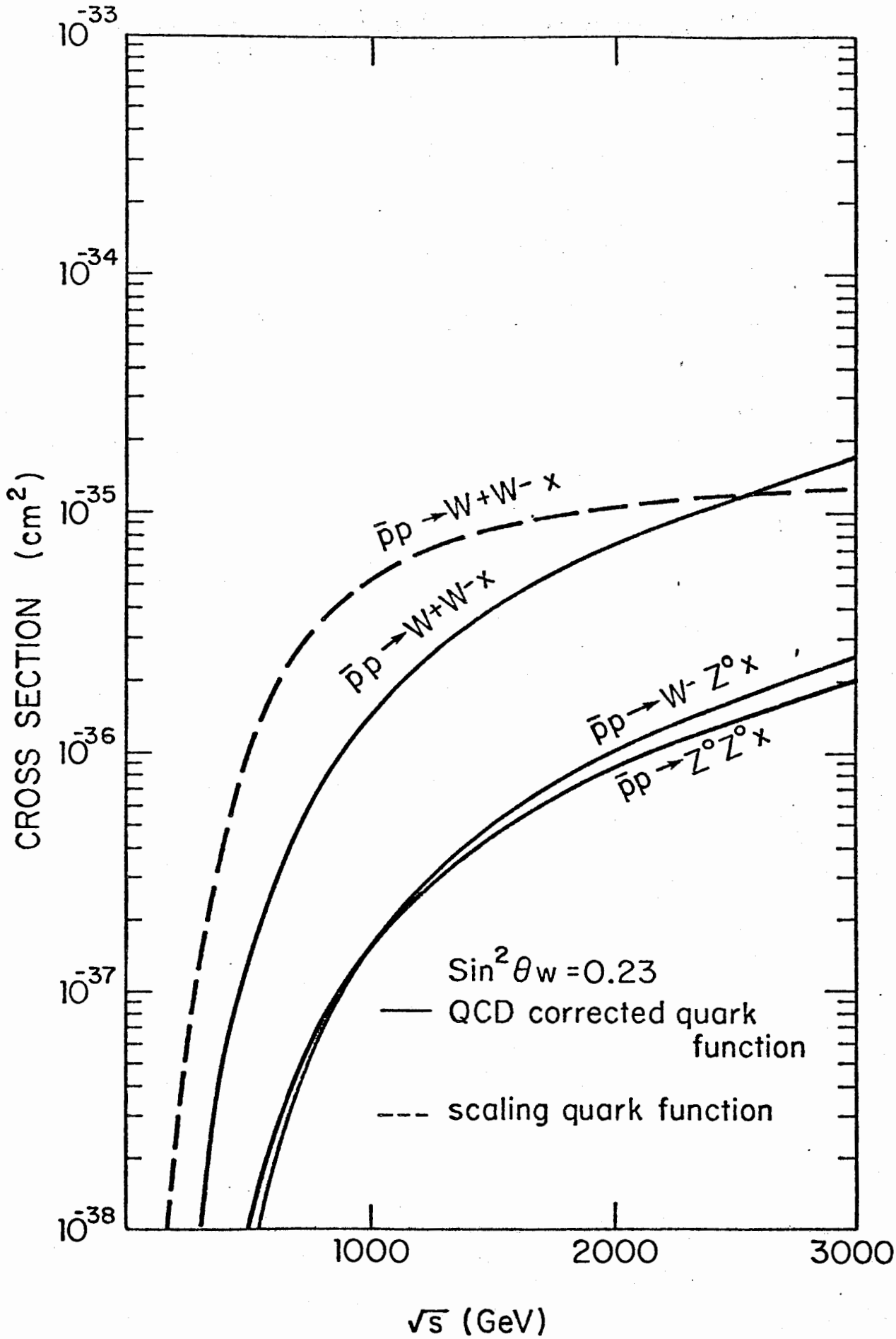
10^{-33}
10^{-34}
10^{-35}
10^{-36}
10^{-37}
10^{-38}
CROSS SECTION (cm^2)
$\bar{p}p \to W^+W^- x$
$\bar{p}p \to W^+W^- x$
$\bar{p}p \to W^- Z^0 x$
$\bar{p}p \to Z^0 Z^0 x$
$\sin^2\theta_W = 0.23$
QCD corrected quark function
scaling quark function
1000
2000
3000
$\sqrt{s}$ (GeV)

Fig. 14