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$\bar{p}p$ Searches for Quark-Gluon Plasma at TeV I*

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Introduction

The objective of the Tevatron I project at Fermilab[1] is to produce $\bar{p}p$ collisions at center-of-mass energies near 2 TeV with a peak luminosity (L) of $10^{30}cm^{-2}sec^{-1}$. First operation of the Tevatron in $\bar{p}p$ collider mode took place in October of last year (1985); Fig. 1 is a $\bar{p}p$ event at 0.8 TeV x 0.8 TeV as observed in the vertex chamber of the CDF detector at that time. During this first test run, a luminosity of ~ $10^{24}cm^{-2}sec^{-1}$ was achieved for just a few hours duration. In order to complete the collision halls, an essential step in the utilization of the collider, major civil construction was required and the Fermilab accelerator complex is now at midpoint in a year-long shutdown to accomplish this.

The present schedule calls for the next collider run to start in December of 1986, lasting for about 3 months. The goals for this run are a peak luminosity of $10^{29}cm^{-2}sec^{-1}$ (at β* of 1 m) and an integrated luminosity of 10-100 nb^{-1}. Four experiments will be installed from this run with the expectation of obtaining first physics results in this new energy regime.

Various estimates have been made[2] that the energy densities available in $\bar{p}p$ collisions are well above the 2 GeV/Fm³ required for QGP formation. Although our predictive power of the expected consequences in nucleon-nucleon collisions is admittedly even weaker than that in nucleus-nucleus collisions, it is clearly an area worthy of exploration. In the remainder of the talk I will discuss the experiments that have been approved to run at TeV I from the viewpoint of their capability to search for evidence of the QCD phase transition.

II. Approved Experiments

Of the five experiments presently approved for TeV I, three have some capability to look for the traditional signals of QGP formation; these three are listed in Table I along with the spokesmen, size of collaboration and approximate cost of the detector. As might be inferred from the detector costs, the first two (CDF and DØ) embody general purpose 4π detectors designed primarily to study the physics of W and Z bosons and other large P_T phenomena. These detectors can measure electromagnetic and hadronic energy flow in fine bins of rapidity and azimuth (tower geometry) to within about ~2^o of the beam direction. The third experiment, E-735, was proposed as a dedicated search for QGP effects, the detector is designed to study large total E_T, but the low P_T regime of individual particles.

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A sketch of the Fermilab accelerator complex is seen in Fig. 2, showing the locations around the ring of the three experiments. Large scale collision halls have been constructed at the BØ and DØ locations along with vertical displacements of the Main Ring (overpasses), which provide more transverse space for the large detectors. A considerably more modest 18" deep pit has been implemented to accommodate the E-735 detector at CØ. A low-beta insertion with a $\beta^* = 1$ m has been exercised at BØ and a similar one is planned for DØ; CØ will operate at its normal beta, which implies a luminosity lower by a factor or 75. With regard to running schedules, CDF and E-735 are expected to be ready for the December $\bar{p}p$ run of this year, while the DØ detector is scheduled for running in 1988.

III. Description of Experiments

Among the three experimental proposals, only E-735 has given fairly specific detail of the intended physics measurements[3] directed at a search for QGP. Mainly for this reason (it should also be mentioned that the author is a member of the E-735 collaboration) we describe it first and provide somewhat more detail than for the other two.

III.1 E-735

This experiment was motivated by the observation of the UA1 experiment at the CERN S$\bar{p}$PC of a rise in $\langle P_T \rangle$ vs dn_c/dy followed by a plateau; Van Hove[4] interpreted this behaviour as a possible indication of the QCD phase transition. The detector design was based on two other observations of the UA1 experiment, viz: (a) the total E_T correlates well with the charged track multiplicity[5], and (b) the cross section for sizable E_T at $\sqrt{s} = 540$ GeV is fairly large[6], about 300 times that of the inclusive jet cross section at $E_T = 50$ GeV. The basic idea of the experiment is to trigger on total number of charged tracks, n_c, with $|\eta|<3$ and measure the momentum of charged tracks (with particle identification for $P < 1.5$ GeV/c) emitted near $\eta=0$ into a solid angle of 0.5 steradians. The goal is to record events with up to 200 charged tracks (~ 125 of which are detected in the η range covered).

A plan view of the detector is displayed in Fig. 3. The barrel hodoscope which surrounds the 1.9 m long central tracking chamber contains 96 scintillation counters; two end-cap hodoscopes, just beyond the end-cap drift chambers, each contain three azimuthal rings of 24 counters each. In a typical $n_c = 130$ event, about 80 tracks will traverse the central chamber and 25 tracks cross each of the end cap chambers. The central chamber is a variant of a JADE-type jet chamber[7] with 25 sense wires in the radial dimension; the modified cell geometry is expected to give a two-track resolution of less than 2 mm. In order to minimize the mass of the central chamber, carbon fiber technology has been used in the fabrication of the frame, a particle at 90° traverses only 1.1% of a radiation length. The charged particle spectrometer at 90° has an azimuthal acceptance of 20° and covers the η range from +1 to -.35. Two planes of time-of-flight scintillation counters at 2m and 4m from the beam line provide the particle identification.

The expected counting rate as a function of total charged multiplicity (~ 2/3 of which is seen in the detector) is displayed in Fig. 4; the curve is a negative binomial distribution with $\bar{n}_c = 41$, $K = 3$. From this curve one predicts a rate of 4 per minute for $n_c \geq 200$ at full luminosity. Table II summarizes the physics measurements to be made in the experiment and estimates of the data samples.

III.2 E-741 (CDF) and E-740 (DØ)

Isometric views of the CDF[*] and DØ[*] detectors are shown in Fig. 5 and Fig. 6. Here we will only point out the main differences between the two detectors and refer the reader to recent articles for detailed information. Both detectors have vertex chambers close to the beam pipe followed by fairly large central tracking chambers; in DØ there is a transition radiation detector (for π/e separation) interposed between vertex and central chambers. A major difference between the two is the absence of magnetic field in the central tracking region for DØ, whereas the CDF detector has a 15 kG axial field provided by a superconducting solenoid 3 m in diameter and 5 m long. Both detectors have finely segmented calorimetry; the DØ system, which utilizes liquid-argon uranium has a more uniform response to electromagnetic and hadronic energy deposition. There is about one radiation length of material preceding the electromagnetic calorimeter in either detector. Finally, both systems have muon detection, the angular coverage of DØ is more complete; the minimum muon energy is 2 GeV for CDF and 5 GeV for DØ.

III.3 Comparison of Detectors

In Table III we summarize the basic capabilities of the three detectors with regard to tracking, momentum measurement, particle identification, etc. It is clearly presumptuous to include the E-735 detector with the two general purpose detectors, particularly in the area of energy flow and sophisticated triggering, on the other hand it does have certain advantages in the energy regime below 2 GeV.

IV. Comparison of Experiments for QGP Signals

In Table 4 we have attempted to rate the three detectors with regard to their capabilities for observing some of the possible signals anticipated for plasma formation; a "0" rating implies no capability, while a "3" reflects good capability. This analysis is somewhat superficial, intuitive, and obviously predicated on the detectors performing up to their design specifications.

Some comments to be made in conjunction with Table 3:

1. Charged particle (identified) P_T spectra correlated with dn_c/dn : E-735 was specifically designed to accomplish this and is superior to CDF in particle identification and momentum coverage
2. Muon pairs: in the mass range below 1 GeV, CDF has the best chance due to its good momentum measurement

3. e^+e^- pairs: again CDF has good momentum measurement, but for E_e>1 GeV DØ will have better e identification.
4. γ: here DØ should have the edge by virtue of the better resolution in the uranium-liquid argon calorimeter.
5. K, Y, $\bar{Y}$: CDF is best due to its larger tracking chamber and momentum measurement.
6. Base-Einstein π-π correlations: CDF has better solid angle but poorer identification than E-735.
7. Multiparticle correlations: E-735 has less mass in the tracking chamber, but CDF has better track recognition.

In an overall rating, Table 3 leans towards CDF having the best global capability for QGP signals.

V. Conclusion

There are three experiments approved to run at TeV I which have considerable capability to look for evidence of the QCD deconfinement phase transition in $\bar{p}p$ collisions at $\sqrt{s}$ = 1.6 TeV. Two of these experiments, E-735 and E-741, are scheduled to start up in December; with a modicum of luck in commissioning the Collider and the experiments, it is just possible that they will produce interesting new data for discussion at Quark Matter '87.

Acknowledgement

I am indebted to Joh Yoh for an enlightening discussion on the properties of the CDF detector; similarly, I am grateful to Paul Grannis for conveying information on the DØ detector.

References

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3. Fermilab Proposal P-735, "Search for a Deconfined Quark Gluon Phase of Strangely Interacting Matter in $\bar{p}p$ Interactions at $\sqrt{s}$ = 2 TeV", Sept. (1983).
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9. Design Report, The DØ Experiment at the Fermilab Antiproton - Proton Collider, November 1984 (Fermilab).

Table I

Approved Experiments

Experiment	Spokesmen	Number of Physicists	Approx. cost of Detector
E-741 (CDF)	Schwitters Tollestrup	200	65M$
E-740 (DØ)	Grannis	125	50M$
E-735 (CØ)	Gutay	27	2M$

Table II

E-735 Measurements

1. $\left[\frac{dN}{dP_T}\begin{pmatrix}\pi\\K\\P\end{pmatrix}^{\pm}, \quad P_T = 0.2 - 1.5 \text{ GeV/c}\right]$ vs. $\left[\begin{matrix}n'_c\\ \frac{dn'_c}{d\eta}\end{matrix}\right]$

   $n'_c = 10 - 130$ with $|\eta| < 3$; $\left.\frac{dn'_c}{d\eta}\right|_0 = 2 - 25$

   100K events at $n_c \geq 200$ (10^3 hrs.)

   $\left\{\langle P_T\rangle_i, \quad K/\pi, \quad P^{\pm}/\pi\right\}$ vs. P_T, $\frac{dn'_c}{d\eta}$

2. Bose-Einstein π-π interferometry, 30K events
3. Multiparticle correlations in $\eta,\emptyset$.
4. γ spectrum, $\eta \sim 0$, $E_\gamma = 50 - 2000$ Mev.

Table III – Comparison of Detectors

	E735	CDF	DØ
Tracking: $\|\vec{B}\|$	0 KG	15	0
η range	± 3	± 4	± 3
CTC, Radius x Length	.4 m x 1.9 m	1.3 x 3.2	.72 x 1.8
2 Track Resolution	2 mm	5	2
Material at 90°	1% l_R	4%	25%
No. Wire Layers (3D)	25 (25)	108 (24)	48 (20)
Momentum Measure ±:			
η Range	+ 1 → − .35	+ 1 → − 1	
Ø Range, ΔΩ	20°, .4 ST.	360°, 10	
ΔP/P	.03 P (GeV/c)	.002 P	
Particle Ident. ±:	P + TOF (.25 ns)	P + TOF (1 ns)	TRD (γ = 1400)
Calorimetry:			
Segmentation, Δη x Δϕ		~0.1 x 0.1	~ 0.1 x 0.1
Electromag. Resolution		14%/√E	14%/√E
Hadronic Resolution		70%/√E	40%/√E
Muon Detection:		E_μ > 2 GeV	> 5 GeV
θ Range		2°–17°, 50°–90°	2° – 90°
ΔP/P		20%, 2% P	20%
Trigger:	n_c, 90° Spect.	$\Sigma E_i^T > C_j$, etc.	~ same

Table IV
<u>QGP Signal Comparison</u>

	E-735	CDF	DØ
$\left.\frac{dN}{dP_T}\right)_i$ vs $\left[\begin{array}{c}\frac{dn}{d\eta}\\ E_T\end{array}\right]$	3 0	2 2	0 0
$\mu^+\mu^-$	0	2	1
e^+e^-	0	2	2
γ	?	1	2
K, Y, $\bar{Y}$	1	3	1
B.E. π-π	2	2	0
Multiparticle Correlations	3	3	2

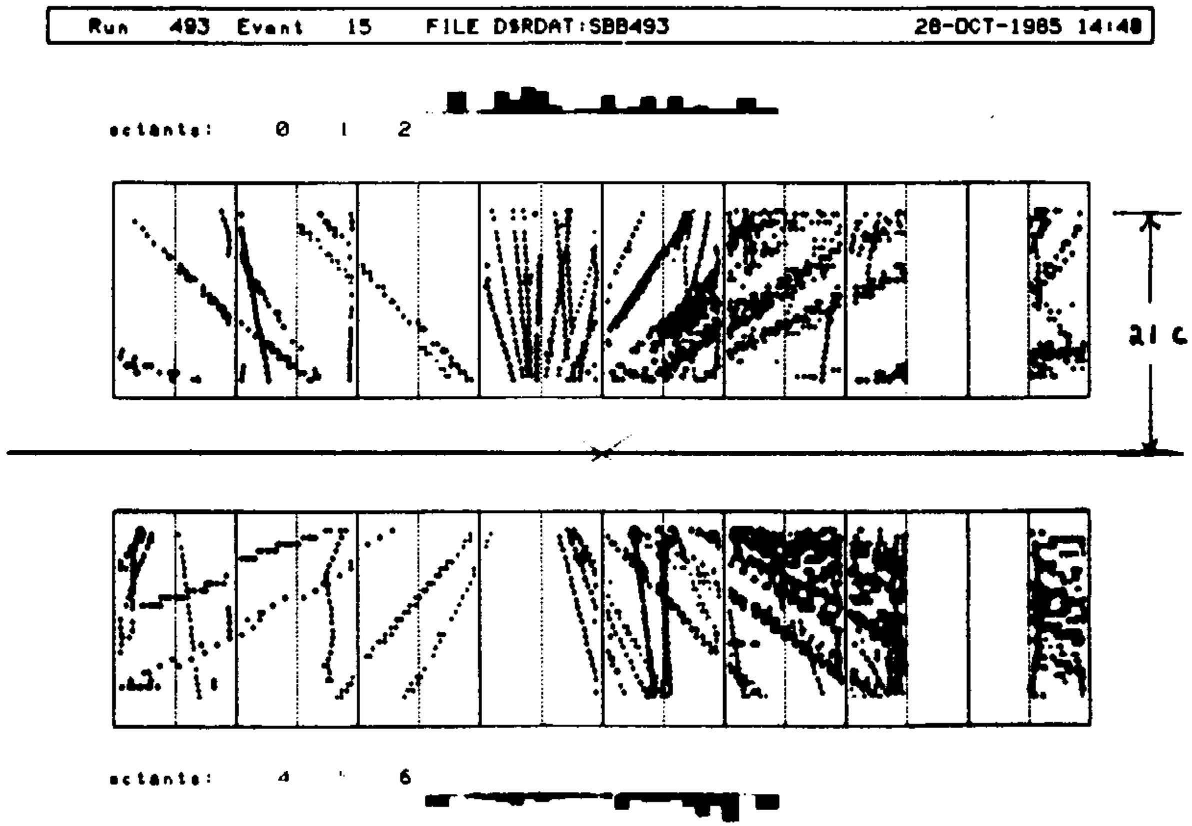


Fig. 1: A 1.6 TeV $\bar{p}p$ collision as recorded in the vertex TPC chambers of the CDF detector in October 1985 (horizontal scale $\div$ 3.6).

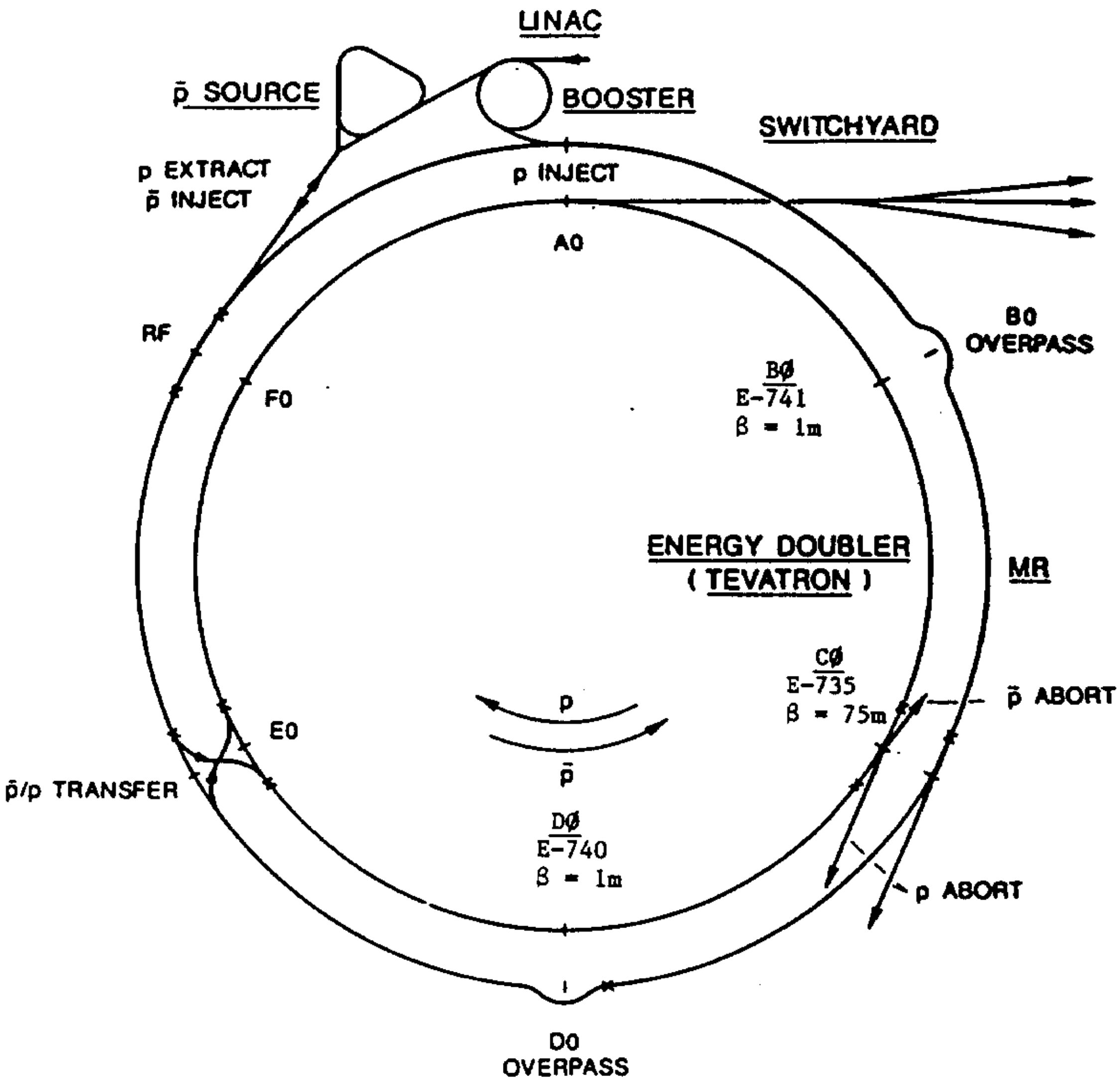
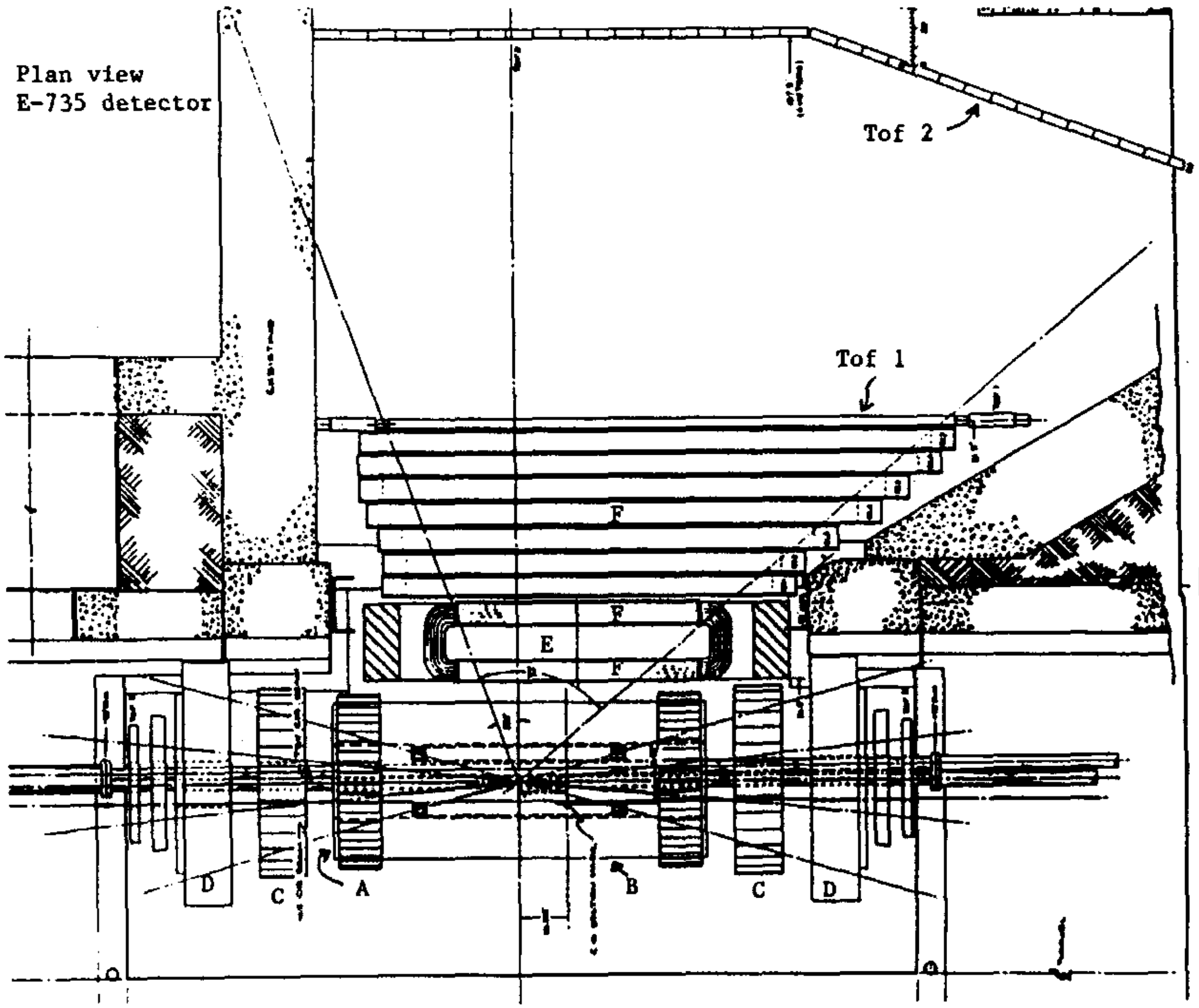


Fig. 2: TeV I accelerator complex showing locations of experiments E-741 (CDF), E-735, and E-740 (DØ) and beta values.

Fig. 3: Plan view
E-735 detector



A = central chamber
B = barrel hodoscope
C = end cap chambers
D = end cap hodoscopes
E = magnet
F = 90^o spectrometer chambers

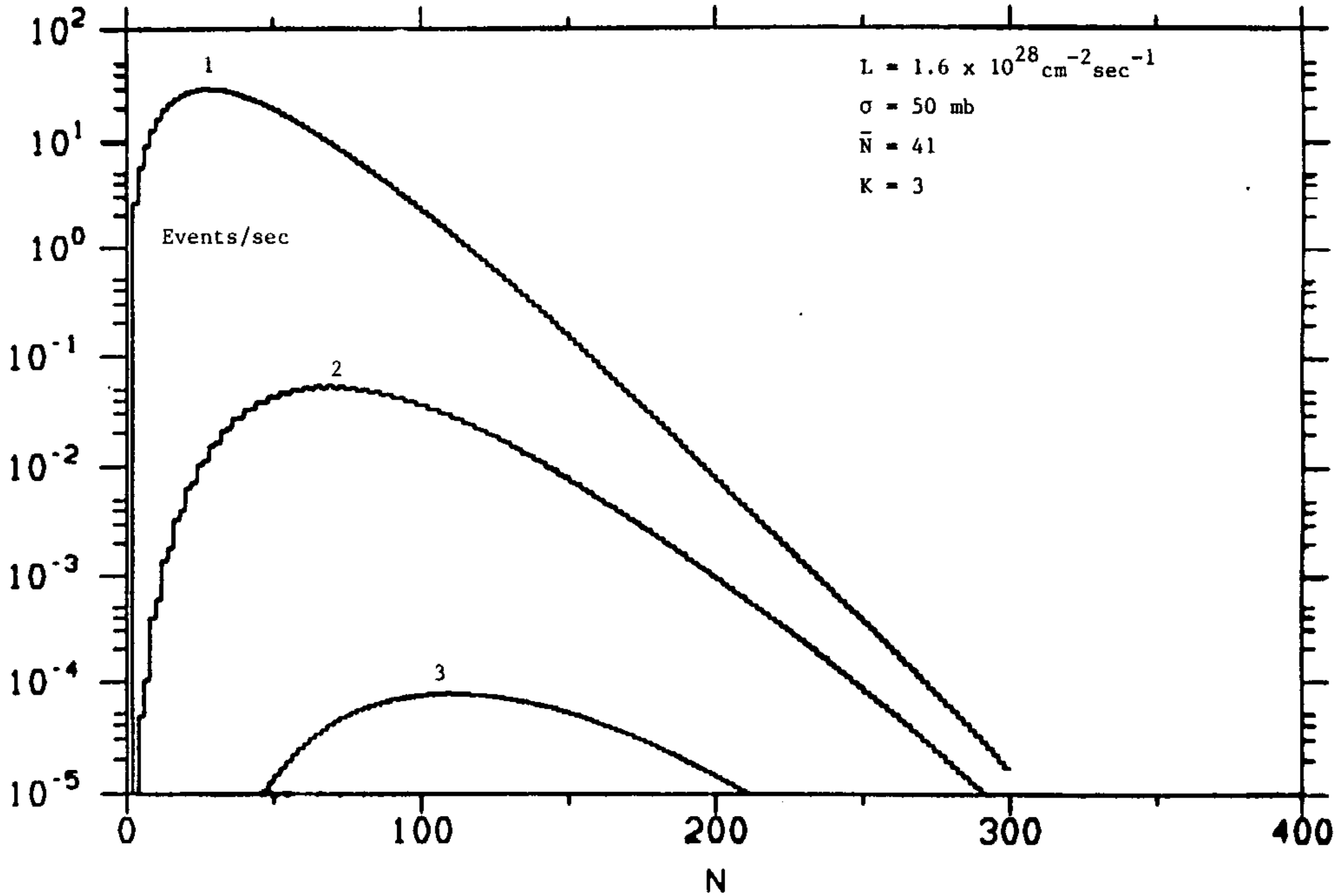


Fig. 4: Expected counting rate of E-735 for events with N charged particles from one, two, and three interactions per bunch crossing.

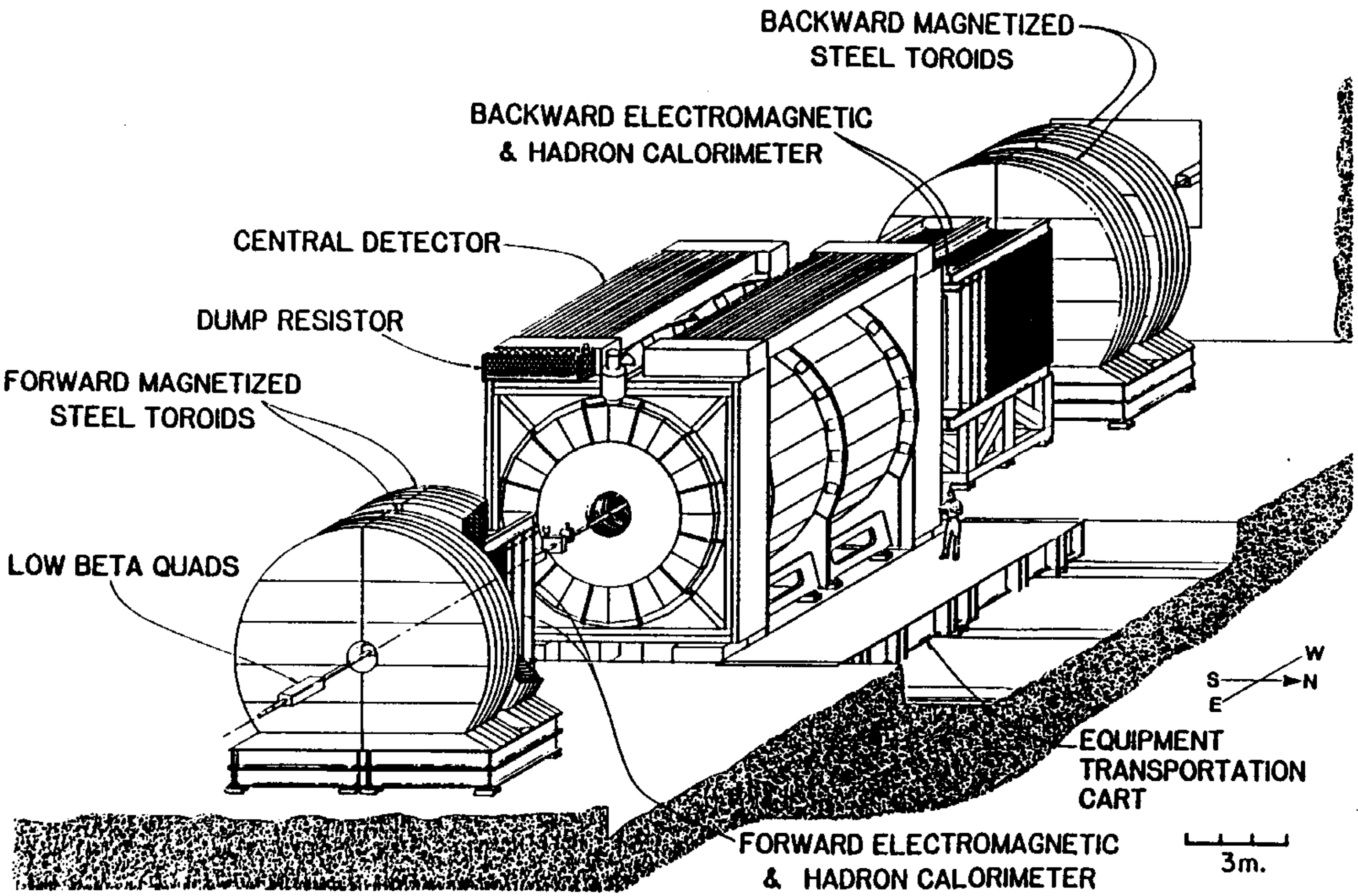


Fig. 5: E-741 (CDF) detector, 4500 tons.

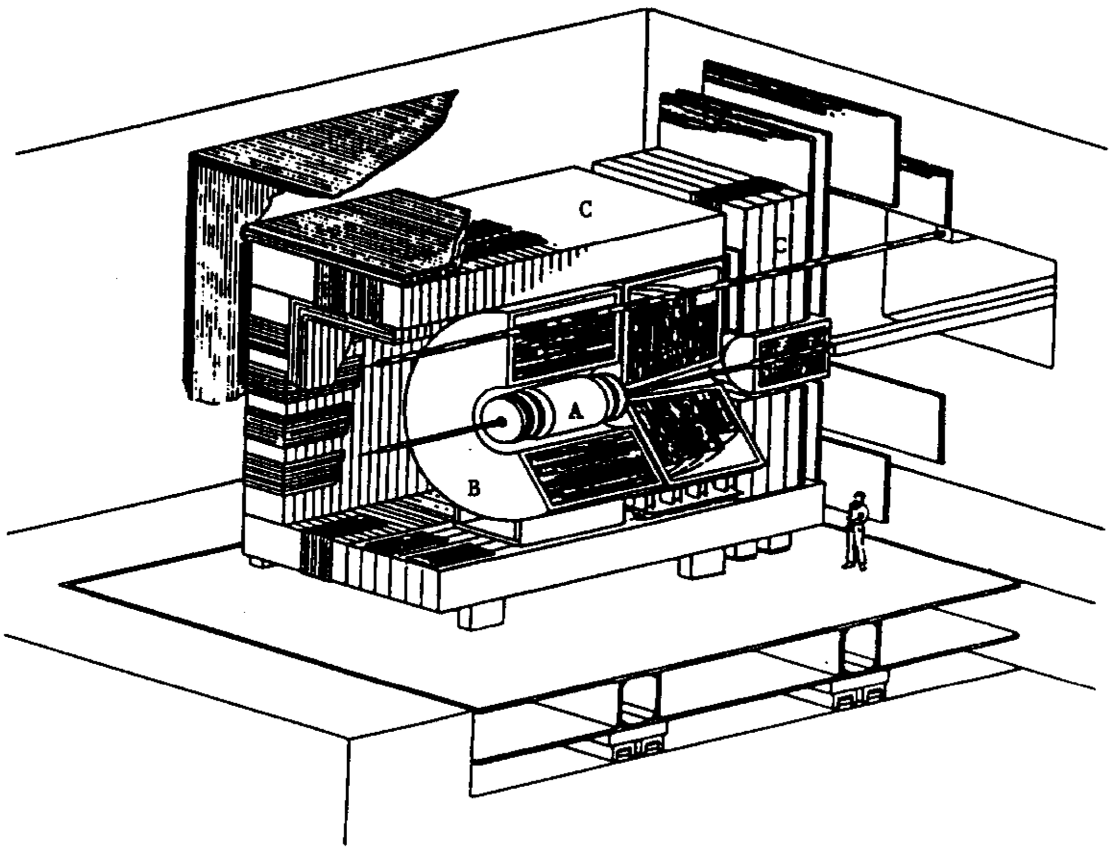


Fig. 6: E-740 (DØ) detector, 5500 tons.
A = central chamber
B = U - liq. argon calorimeter
C = muon toroids