Congreso
Revisión

Revista Mexicana de Física **34** *No. 3(1988) 492–510*

High energy physics at Fermilab and in the USA*

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(recibido el 19 de enero de 1988; aceptado el 25 de febrero de 1988)

Abstract. This article will cover the following topics: A very brief review of the current state of high energy physics. A discussion of USA accelerators and their program, with particular emphasis on Fermilab. A listing of some of the unanswered questions in the field. An introduction to the Superconducting Super Collider (SSC).

PACS: 12.10.-g

1. The current status of high energy physics

The object of high energy physics is to identify the ultimate constituents of matter, and to understand the forces which bind these constituents to form our world. There has been a tremendous increase in our knowledge by the experimental results from particle accelerators constructed over the past 30 years. The progress in assembling the data into a coherent theoretical structure has also been dramatic, with a major synthesis being the Standard Model. In addition, there is now an important connection between the two fields of cosmology and particle physics. The young universe was hot enough to reduce matter to its smallest components; as a consequence, the properties of basic particles and forces are fundamental to an understanding of the subsequent history of the universe. Some relations between cosmology and high energy physics are shown in Fermilab's "Big Bang" illustration (Fig. 1); the Fermilab Collider is currently exploring phenomena that took place $\sim 10^{-12}$ seconds after the Big Bang, while the proposed SSC will be able to study down to $\sim 10^{-15}$ seconds.

The Standard Model says that all matter is made up of leptons (which do not experience the strong force) and quarks, and that the interactions between particles are mediated by gauge particles. There are four interactions: strong, weak, electromagnetic and gravity. It is now known that there is a strong similarity in the mathematical descriptions of the first three, and some progress is being made on incorporating gravity. Already there is a successfull synthesis of the weak and electromagnetic forces (the "electroweak force"); inclusion of the strong force makes the Standard Model. Some of the properties of the four forces are given in table I.

Some common processes illustrating the carriers of the different forces are:

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*Based on a talk given at the XXX Congreso Nacional de Física in Mérida, Yucatán, October 30, 1987.

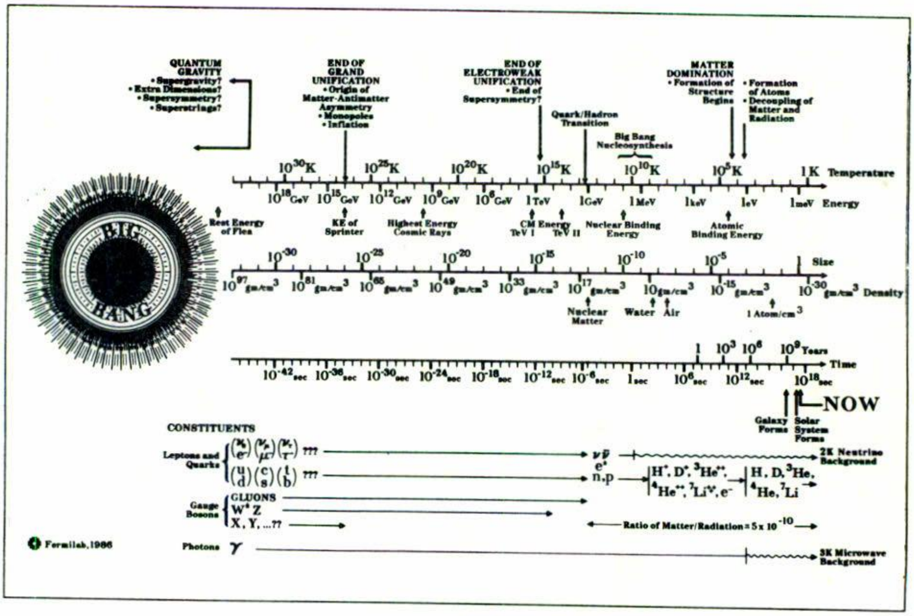


FIGURE 1. Some relations between cosmology and high energy physics.

Type	*Relative strenght*	*Range*	*Carrier*
Gravity	10^{-39}	infinite	graviton
Weak	3×10^{-2}	10^{-17} cm	W^+, W^-, Z^0
Electromagnetic	10^{-2}	infinite	photon
Strong	0.2	10^{-13} cm	gluon

TABLE I. Properties of the four types of interactions between particles that make up matter.

a) The electromagnetic interaction between an electron and a proton is mediated by a photon.

b) β-decay is mediated by a weak vector boson.

c) Quarks in a proton are held together by the strong interaction mediated by gluons.

The 6 quarks and 6 leptons known (or predicted) at the present time are shown in table II, grouped in related families, and with mass increasing from left to right.

All of the particles in the table have spin 1/2; they all have antiparticles and in addition the quarks have another property, they can come in any one of three "colors". The top row of quarks have charge 2/3, and the bottom row $-1/3$. Using

	Quarks	
u	c	t
d	s	b
	Leptons	
e	μ	τ
ν_e	ν_μ	ν_τ

TABLE II. Quarks and leptons at the present time.

the quarks as building blocks we can build up the known particles. For example, the proton is uud + gluons; the neutron is udd + gluons; the Λ hyperon is uds + gluons.

The experimental evidence for quarks is very strong. We give three examples:

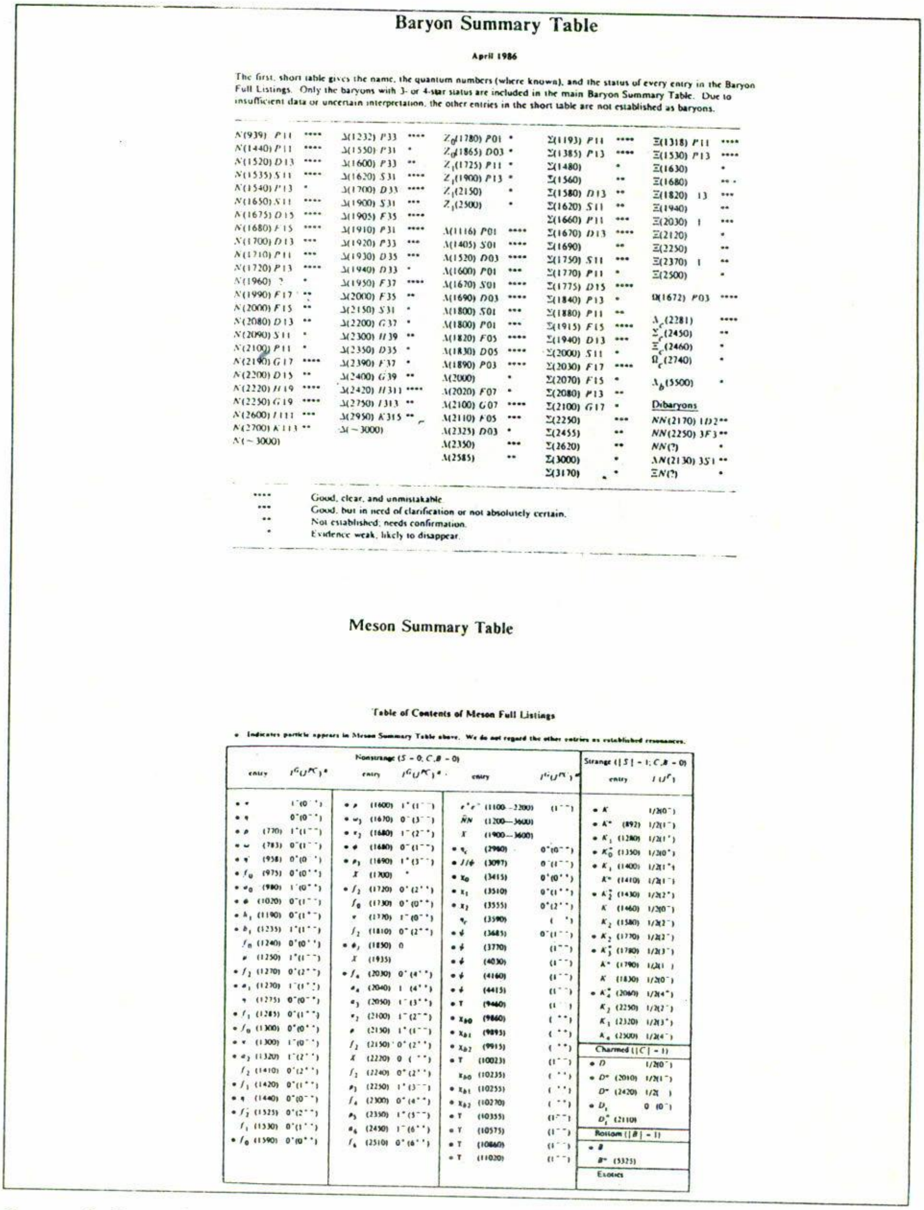
1. All of the known hadrons (Fig. 2) can be formed from combinations of the quarks, either three quarks for a baryon or quark-antiquark for a meson. In addition, the properties of allowed combinations of quarks have been used to predict the existence of new hadrons which were subsequently discovered.
2. Quarks cannot be observed as free particles, but they do manifest themselves in high energy collisions as "jets" of many particles clustered together coming from an interaction. The simple process of a high energy e^+e^- collision producing a virtual photon which in turn produces a quark-antiquark pair is observed experimentally as 2 "jets". An example of this is given in figure 3.
3. The ratio of e^+e^- collisions producing hadrons to that of the simple quantum electrodynamic process of producing muon pairs should have increasing steps as the e^+e^- energy increases past the threshold for production of new, increasingly heavy quarks. This is indeed observed.

The existence of gluons can be inferred from experiment as shown in figure 4 where the gluon emitted in a bremstrahlung-like process materializes as a third "jet" in the detector.

2. USA accelerators and their programs

The experimental activities in high energy physics center around large particle accelerators; we shall discuss only USA activities, but there are equally important frontier accelerators at CERN (Switzerland), and in China, West Germany, Japan and the USSR. In addition, information pertinent to this field can also be obtained from studies of cosmic rays, low energy physics phenomena, and from proton decay searches, etc. We will not discuss such work here.

Accelerators produce the beams of particles which are used to collide with targets or other particles; detectors then observe the particles emerging from the collisions. Figure 5, (the "Livingston Plot") shows how the maximum available



Baryon Summary Table

April 1986

The first, short table gives the name, the quantum numbers (where known), and the status of every entry in the Baryon Full Listings. Only the baryons with 3- or 4-star status are included in the main Baryon Summary Table. Due to insufficient data or uncertain interpretation, the other entries in the short table are not established as baryons.

$N(939)$ $P11$ ****
$N(1440)$ $P11$ ****
$N(1520)$ $D13$ ****
$N(1535)$ $S11$ ****
$N(1540)$ $P13$ *
$N(1650)$ $S11$ ****
$N(1675)$ $D15$ ****
$N(1680)$ $F15$ ****
$N(1700)$ $D13$ ***
$N(1710)$ $P11$ ***
$N(1720)$ $P13$ ****
$N(1960)$? *
$N(1990)$ $F17$ **
$N(2000)$ $F15$ **
$N(2080)$ $D13$ **
$N(2090)$ $S11$ *
$N(2100)$ $P11$ *
$N(2190)$ $G17$ ****
$N(2200)$ $D15$ **
$N(2220)$ $H19$ ****
$N(2250)$ $G19$ ****
$N(2600)$ $I111$ ***
$N(2700)$ $K113$ **
$N(\sim 3000)$

$\Delta(1232)$ $P33$ ****
$\Delta(1550)$ $P31$ *
$\Delta(1600)$ $P33$ **
$\Delta(1620)$ $S31$ ****
$\Delta(1700)$ $D33$ ****
$\Delta(1900)$ $S31$ ***
$\Delta(1905)$ $F35$ ****
$\Delta(1910)$ $P31$ ****
$\Delta(1920)$ $P33$ ***
$\Delta(1930)$ $D35$ ***
$\Delta(1940)$ $D33$ *
$\Delta(1950)$ $F37$ ****
$\Delta(2000)$ $F35$ **
$\Delta(2150)$ $S31$ *
$\Delta(2200)$ $G37$ *
$\Delta(2300)$ $H39$ **
$\Delta(2350)$ $D35$ *
$\Delta(2390)$ $F37$ *
$\Delta(2400)$ $G39$ **
$\Delta(2420)$ $H311$ ****
$\Delta(2750)$ $I313$ **
$\Delta(2950)$ $K315$ **
$\Delta(\sim 3000)$

$Z_0(1780)$ $P01$ *
$Z_0(1865)$ $D03$ *
$Z_1(1725)$ $P11$ *
$Z_1(1900)$ $P13$ *
$Z_1(2150)$ *
$Z_1(2500)$ *

$\Lambda(1116)$ $P01$ ****
$\Lambda(1405)$ $S01$ ****
$\Lambda(1520)$ $D03$ ****
$\Lambda(1600)$ $P01$ ***
$\Lambda(1670)$ $S01$ ****
$\Lambda(1690)$ $D03$ ****
$\Lambda(1800)$ $S01$ ***
$\Lambda(1800)$ $P01$ ***
$\Lambda(1820)$ $F05$ ****
$\Lambda(1830)$ $D05$ ****
$\Lambda(1890)$ $P03$ ****
$\Lambda(2000)$ *
$\Lambda(2020)$ $F07$ *
$\Lambda(2100)$ $G07$ ****
$\Lambda(2110)$ $F05$ ***
$\Lambda(2325)$ $D03$ *
$\Lambda(2350)$ ***
$\Lambda(2585)$ **

$\Sigma(1193)$ $P11$ ****
$\Sigma(1385)$ $P13$ ****
$\Sigma(1480)$ *
$\Sigma(1560)$ **
$\Sigma(1580)$ $D13$ **
$\Sigma(1620)$ $S11$ **
$\Sigma(1660)$ $P11$ ***
$\Sigma(1670)$ $D13$ ****
$\Sigma(1690)$ **
$\Sigma(1750)$ $S11$ ***
$\Sigma(1770)$ $P11$ *
$\Sigma(1775)$ $D15$ ****
$\Sigma(1840)$ $P13$ *
$\Sigma(1880)$ $P11$ **
$\Sigma(1915)$ $F15$ ****
$\Sigma(1940)$ $D13$ ***
$\Sigma(2000)$ $S11$ *
$\Sigma(2030)$ $F17$ ****
$\Sigma(2070)$ $F15$ *
$\Sigma(2080)$ $P13$ **
$\Sigma(2100)$ $G17$ *
$\Sigma(2250)$ ***
$\Sigma(2455)$ **
$\Sigma(2620)$ **
$\Sigma(3000)$ *
$\Sigma(3170)$ *

$\Xi(1318)$ $P11$ ****
$\Xi(1530)$ $P13$ ****
$\Xi(1630)$ *
$\Xi(1680)$ **
$\Xi(1820)$ 13 ***
$\Xi(1940)$ **
$\Xi(2030)$ I ***
$\Xi(2120)$ *
$\Xi(2250)$ **
$\Xi(2370)$ I **
$\Xi(2500)$ *

$\Omega(1672)$ $P03$ ****

$\Lambda_c(2281)$ ****
$\Sigma_c(2450)$ **
$\Xi_c(2460)$ *
$\Omega_c(2740)$ *

$\Lambda_b(5500)$ *

Dibaryons
$NN(2170)$ $1D2$ **
$NN(2250)$ $3F3$ **
$NN(?)$ *
$\Lambda N(2130)$ $3S1$ **
$\Xi N(?)$ *

**** Good, clear, and unmistakable.
*** Good, but in need of clarification or not absolutely certain.
** Not established; needs confirmation.
* Evidence weak, likely to disappear.

Meson Summary Table

Table of Contents of Meson Full Listings

• Indicates particle appears in Meson Summary Table above. We do not regard the other entries as established resonances.

Nonstrange ($S = 0$; $C, B = 0$)

entry	$I^G(J^{PC})$•
• π	$1^-(0^{-+})$
• η	$0^+(0^{-+})$
• ρ (770)	$1^+(1^{--})$
• ω (783)	$0^-(1^{--})$
• η' (958)	$0^+(0^{-+})$
• f_0 (975)	$0^+(0^{++})$
• a_0 (980)	$1^-(0^{++})$
• ϕ (1020)	$0^-(1^{--})$
• h_1 (1190)	$0^-(1^{+-})$
• b_1 (1235)	$1^+(1^{+-})$
f_0 (1240)	$0^+(0^{++})$
ρ (1250)	$1^+(1^{--})$
• f_2 (1270)	$0^+(2^{++})$
• a_1 (1270)	$1^-(1^{++})$
η (1275)	$0^+(0^{-+})$
• f_1 (1285)	$0^+(1^{++})$
• f_0 (1300)	$0^+(0^{++})$
• π (1300)	$1^-(0^{-+})$
• a_2 (1320)	$1^-(2^{++})$
f_2 (1410)	$0^+(2^{++})$
• f_1 (1420)	$0^+(1^{++})$
• η (1440)	$0^+(0^{-+})$
• f_2' (1525)	$0^+(2^{++})$
f_1 (1530)	$0^+(1^{++})$
• f_0 (1590)	$0^+(0^{++})$

entry	$I^G(J^{PC})$•
• ρ (1600)	$1^+(1^{--})$
• ω_3 (1670)	$0^-(3^{--})$
• π_2 (1680)	$1^-(2^{-+})$
• ϕ (1680)	$0^-(1^{--})$
• ρ_3 (1690)	$1^+(3^{--})$
X (1700)	*
• f_2 (1720)	$0^+(2^{++})$
f_0 (1730)	$0^+(0^{++})$
π (1770)	$1^-(0^{-+})$
f_2 (1810)	$0^+(2^{++})$
• ϕ_3 (1850)	0
X (1935)	
• f_4 (2030)	$0^+(4^{++})$
a_4 (2040)	$1\ (4^{++})$
a_3 (2050)	$1^-(3^{++})$
π_2 (2100)	$1^-(2^{-+})$
ρ (2150)	$1^+(1^{--})$
f_2 (2150)	$0^+(2^{++})$
X (2220)	$0\ (\ ^{++})$
f_2 (2240)	$0^+(2^{++})$
ρ_3 (2250)	$1^+(3^{--})$
f_4 (2300)	$0^+(4^{++})$
ρ_5 (2350)	$1^+(5^{--})$
a_6 (2450)	$1^-(6^{++})$
f_6 (2510)	$0^+(6^{++})$

entry	$I^G(J^{PC})$•
e^+e^- (1100–2200)	(1^{--})
$\bar{N}N$ (1200–3600)	
X (1900–3600)	
• η_c (2980)	$0^+(0^{-+})$
• J/ψ (3097)	$0^-(1^{--})$
• χ_0 (3415)	$0^+(0^{++})$
• χ_1 (3510)	$0^+(1^{++})$
• χ_2 (3555)	$0^+(2^{++})$
η_c (3590)	$(\ \ ^{+})$
• ψ (3685)	$0^-(1^{--})$
• ψ (3770)	(1^{--})
• ψ (4030)	(1^{--})
• ψ (4160)	(1^{--})
• ψ (4415)	(1^{--})
• Υ (9460)	(1^{--})
• χ_{b0} (9860)	$(\ ^{++})$
• χ_{b1} (9893)	$(\ ^{++})$
• χ_{b2} (9915)	$(\ ^{++})$
• Υ (10023)	(1^{--})
χ_{b0} (10235)	$(\ ^{++})$
• χ_{b1} (10255)	$(\ ^{++})$
• χ_{b2} (10270)	$(\ ^{++})$
• Υ (10355)	(1^{--})
• Υ (10575)	(1^{--})
• Υ (10860)	(1^{--})
• Υ (11020)	(1^{--})

Strange ($|S| = 1$; $C, B = 0$)

entry	$I(J^P)$
• K	$1/2(0^-)$
• K^* (892)	$1/2(1^-)$
• K_1 (1280)	$1/2(1^+)$
• K_0^* (1350)	$1/2(0^+)$
• K_1 (1400)	$1/2(1^+)$
K^* (1410)	$1/2(1^-)$
• K_2^* (1430)	$1/2(2^+)$
K (1460)	$1/2(0^-)$
K_2 (1580)	$1/2(2^-)$
• K_2 (1770)	$1/2(2^-)$
• K_3^* (1780)	$1/2(3^-)$
K^* (1790)	$1/2(1\ )$
K (1830)	$1/2(0^-)$
• K_4^* (2060)	$1/2(4^+)$
K_2 (2250)	$1/2(2^-)$
K_3 (2320)	$1/2(3^+)$
K_4 (2500)	$1/2(4^-)$
Charmed ($\lvert C\rvert = 1$)	
• D	$1/2(0^-)$
• D^* (2010)	$1/2(1^-)$
D^* (2420)	$1/2(\ \ )$
• D_s	$0\ (0^-)$
D_s^* (2110)	
Bottom ($\lvert B\rvert = 1$)	
• B	
B^* (5325)	
Exotics	

FIGURE 2. Known baryons and mesons as reported in the "Review of particle properties", *Phys. Lett.* **170B**.

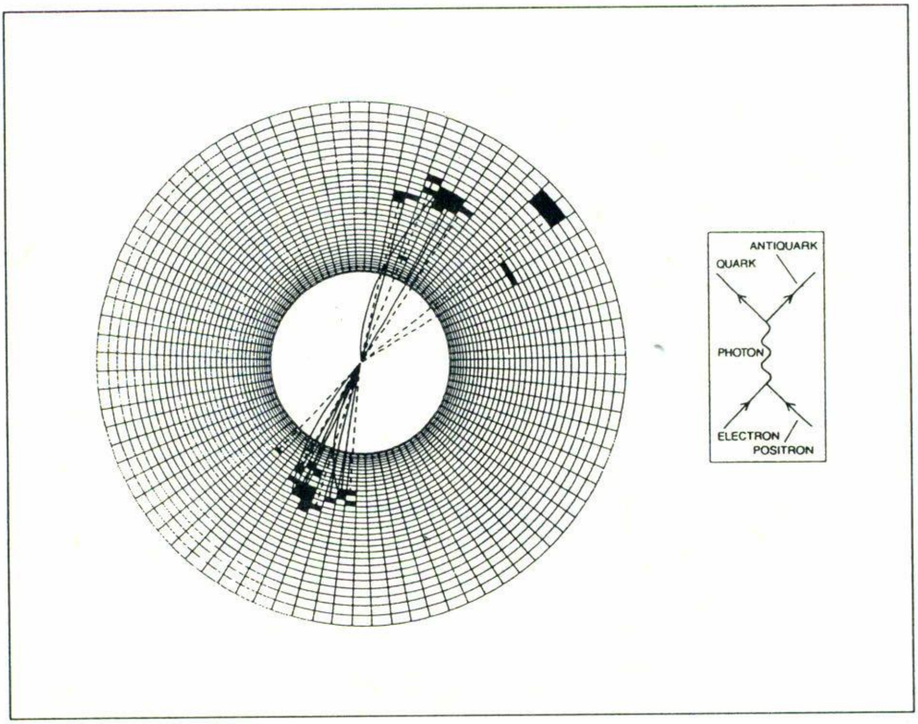


FIGURE 3. Evidence of quarks. Two narrow jets of particles emerge from the collision and mutual annihilation of an electron and an antielectron, or positron. The annihilation releases energy, which gives rise to matter. the detected particles have a variety of masses and spins; some are neutral (broken lines) and some electrically charged (solid lines). If the particles arose directly from the annihilation, they would be expected to follow widely divergent paths. The focused character of the jets suggests instead that each jet developed from a single precursor: a quark or an antiquark. They are the immediate products of the photon of electomagnetic energy released in the collision, which is diagrammed at the left using arrows to represent the relative motion of the particles. The even shown was recorded in the JADE detector of the PETRA accelerator at the Deutsches Elektronen-Synchrotron (DESY) in Hamburg. The paths of the particles were reconstructed by computer from ionization tracks and from the pattern of energy (color) deposited as the particles struck the inner layer of the 2.4-meter-long cylindrical detector.

energy of accelerators has increased by around ten orders of magnitude in about six decades due to the successive invention of new types of accelerators. Detectors have also grown over the same period; an example illustrating the size and complexity of a modern detector is shown in figure 6.

While the energy of accelerators has been increasing so has their cost, although fortunately at a much smaller rate. The consequence has been that the number of

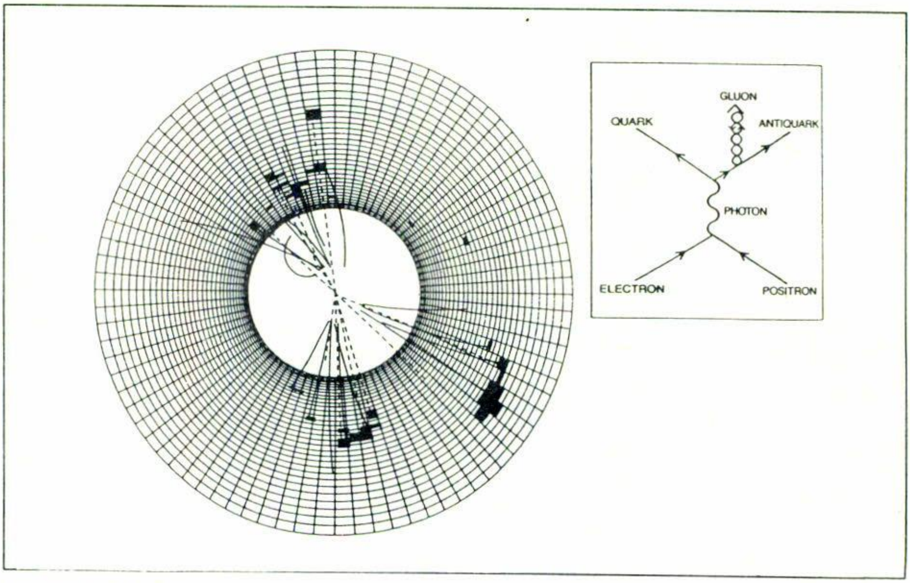


FIGURE 4. Three-jet event, recorded in the JADE detector, confirms the existence of the gluon, the mediating particle of the color force. An electron and a positron collided at high energy, creating a quark and an antiquark, as in the event shown somewhere else. In this case one of the quarks radiated a gluon (above). The quarks and the gluon diverged; each promptly gave rise to a shower of particles, which preserved the trajectory of the original entity (left). The event reveals the asymptotic freedom of quarks and gluons: their ability to move independently within a very small region in spite of the enormous strength of the color force across larger distances.

frontier accelerators has decreased over the years; this is illustrated in table III with a list of such accelerators in the USA around 1960 an at present.

Although the number of accelerators has decreased over the ~ 25 years, energies have increased substantially. The maximum fixed target energy has gone from 30 GeV to 800 GeV, while Fermilab now collides 900 GeV protons and antiprotons, which provides a center-of-mass energy equivalent to that of a fixed-target accelerator of 1.6×10^6 GeV.

Support for high energy physics in the USA come fromn two government agencies. The Department of Energy supports 120 experimental groups from 60 universities and laboratories, 60 theory groups, and the Brookhaven, Fermilab and SLAC laboratories. The National Science Foundation funds 90 experimental groups from 50 universities and laboratories, 50 theory groups and the Cornell accelerator.

Although funded by the USA government, accelerator facilities in the USA are open not just to USA physicists, but to physicists of all countries.

The major current experimental activity in high energy physics is tests of the Standard Model. This includes measuring the parameters which appear in the

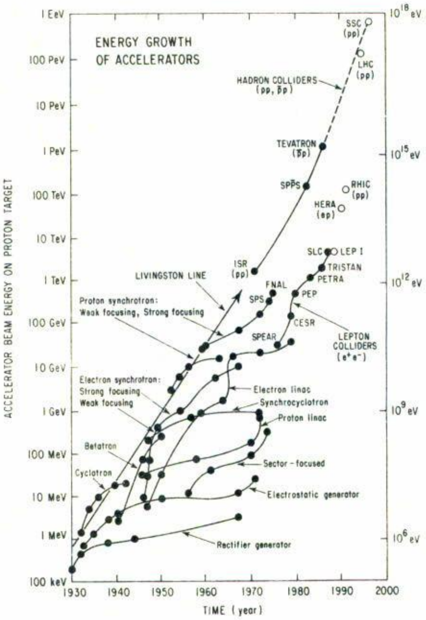


FIGURE 5. Livingston Plot.

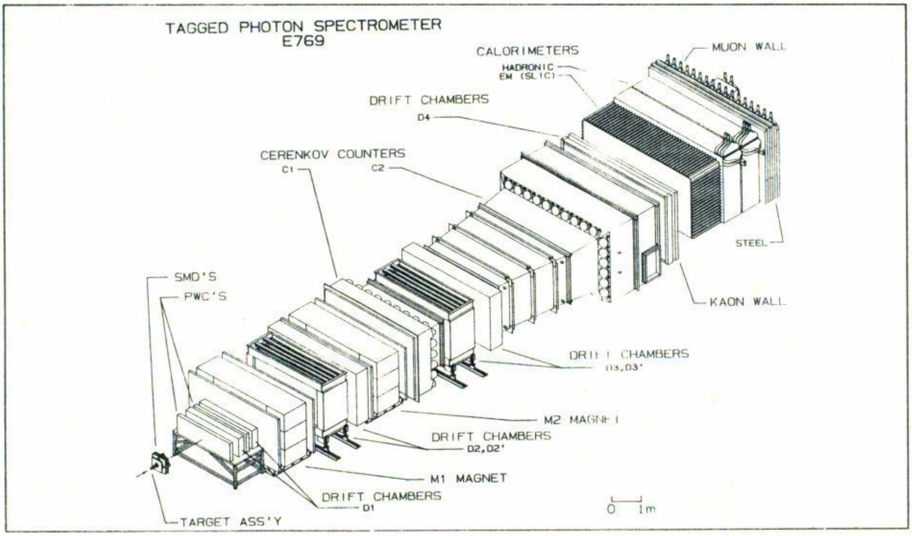


FIGURE 6. Tagged photon spectrometer E769.

Year	*Proton accelerators*	*Electron accelerators*
~ 1960	Argonne Berkeley (2) Brookhven (2) Carnegie Chicago Columbia Harvard Princeton Rochester	Caltech Cambridge Cornell Stanford
~ 1987	Brookhaven (F) Fermilab (F, C)	Cornell (C) SLAC (C)

For 1987, F indicates fixed-target operation, and C is colliding beams.

TABLE III. Comparison of frontier accelerators in the USA.

model; verification of predictions of the model, such as searches for particles or decay modes forbidden by the model, and searches for the predicted t quark and ν_τ lepton (which have not yet been experimentally observed).

We will give very brief descriptions of the experimental programs at Cornell, Brookhaven and SLAC, before concentrating on the program at Fermilab.

2.1. *Cornell*

High energy physics research is carried out at an electron-positron collider, CESR, which generally operates at a beam energy of around 5 GeV; this energy is optimum for the study of particles containing b-quarks. There are 2 detectors in operation.

2.2. *Brookhaven*

The Brookhaven AGS is a synchrotron producing 30 GeV protons; it is also used for an active heavy-ion program with ions of about 15 GeV per nucleon. The major current high energy research activity is the search for decays of K mesons forbidden by the Standard Model. There are also important programs in neutrino physics and in the use of polarized proton beams.

2.3. *SLAC*

Properties of charmed mesons are studied using the 3×3 GeV e^+e^- storage ring SPEAR; PEP, a $14.5 \times 14.5 e^+e^-$ collider has been actively used for research on the τ lepton, particles containing b quarks and general properties of high energy e^+e^- reactions. A major new facility is SLC, a 50×50 GeV e^+e^- collider which is being

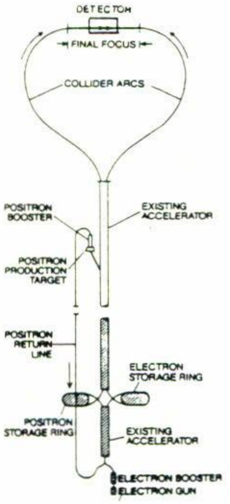


FIGURE 7. General layout of the SLAC Linear Collider (SLC): the injection system (electron gun and boosters), storage (damping) rings which serve to reduce the size and energy spread of the electron and positron bunches by radiation damping, the existing Linac which accelerates bunches of electrons and positrons to 50 GeV, and the transport and final focusing systems which bring micron-sized bunches of electrons and positrons into head-on collisions. The positron target and booster use electron bunches to produce positrons for injection into the front end of the Linac.

added to the existing 3.2 Km linear accelerator (Fig. 7). This should be in operation in early 1988; a major research activity will be the study of properties of the Z^0, and, if its mass is appropriate, the study of particles containing the t quark.

2.4. *Fermilab*

Aerial views of the overall site, and of the Central Laboratory/Booster/Antiproton Source area are shown in figures 8 and 9. A schematic of the accelerators is shown in figure 10. Protons are accelerated, in sequence, in a 750 KeV Cockcroft Walton accelerator, a 200 MeV Linac, and 8 GeV Booster Synchrotron, a 150 GeV Main Ring and the Tevatron currently operating at 900 GeV; the Main Ring was Fermilab's primary accelerator, operating up to 500 GeV, until the Tevatron with its superconducting magnets became operational. The Tevatron is located under the Main Ring in the same 1 Km radius tunnel, as seen in figure 11. The magnets of the Tevatron operate at over 4 Tesla; in addition to allowing energies twice those of the old Main Ring, the electric power usage has been reduced to 1/3 of the original amount due to this use of superconductivity.

The Tevatron can be operated for fixed target physics, or as a $\overline{p}p$ colliding beams storage ring. We will consider here the comparison between these two modes

FIGURE 8. Fermilab aerial view.

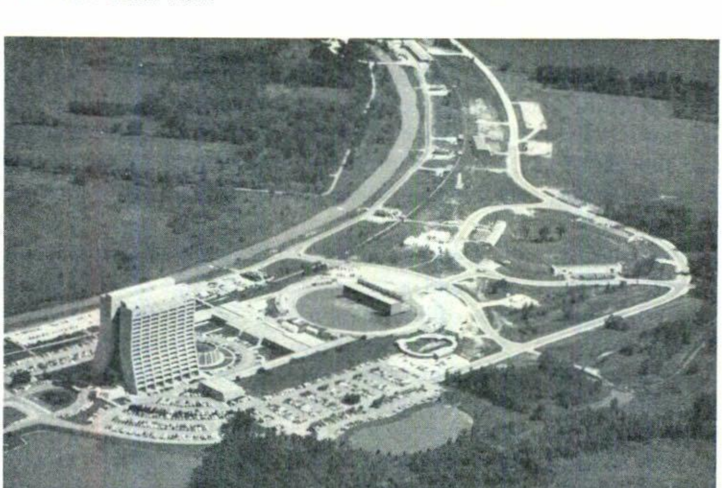


FIGURE 9. Fermilab central building and linac.

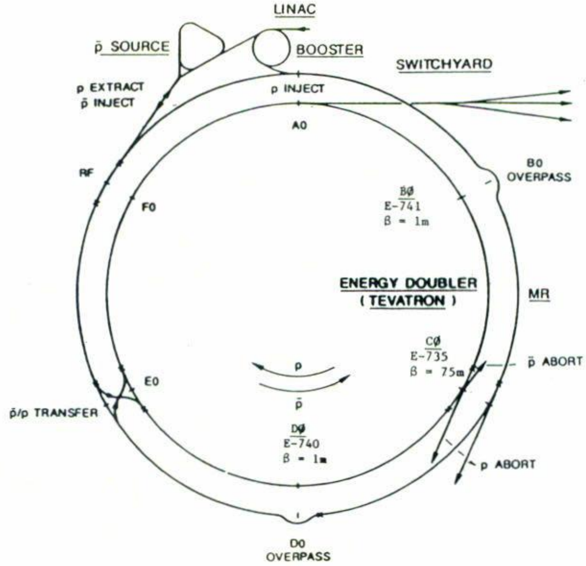


FIGURE 10. TeV I accelerator complex showing locations of experiments E-741 (CDF), E-735, and E-740 (D0) and beta values.

of operation, with a maximum accelerator energy of 900 GeV. For *pp* or $\overline{p}p$ collisions, the available center-of-mass energy is 1800 GeV for the collider, to be compared to only 42 GeV for fixed-target operation, where most of the available energy goes into longitudinal motion of the produced particles. However, the price to pay for this improvement in physics capability is in luminosity, the rate at which the physics occurs.

In the Tevatron collider, a goal is to have 3 bunches of protons and antiprotons, each with 10^{11} particles, and a beam-transverse size of ~ 1 mm; this gives a luminosity (the approximate collider equivalent of fixed target beam intensity) of $\sim 10^{30}\,\mathrm{cm}^{-2}\,\mathrm{sec}^{-1}$, and for some processess with an assumed cross-section of $10^{-36}\,\mathrm{cm}^2$, there will be 30 events per year. We can contrast this with a fixed-target experiment using 10^{12} protons every 60 seconds on a 1 metre liquid hydrogen target, which for the same cross-section gives 1 event every 10 seconds. Thus the collider mode can reach to much higher energies, and therefore study new phenomena not observable in the fixed-target mode, but the rate at which most interesting interactions occur is relatively low.

The fixed-target beam lines available at Fermilab are shown in figure 12; there are currently 15 beams (including test beams) operating simultaneously, with 16 experiments active. The collider program is shown in figure 13. The antiproton source needed for the collider mode uses antiprotons produced by 120 GeV protons from the Main Ring incident on a target; 10^{12} protons are targeted every 3 seconds.

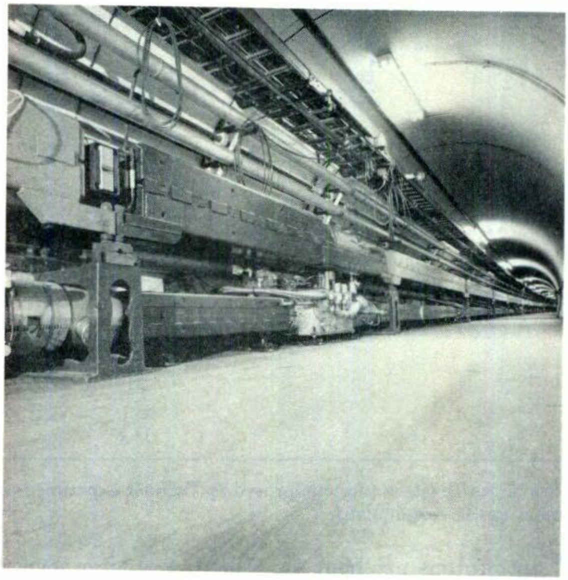


FIGURE 11. Magnets of the Tevatron are located under the Main Ring.

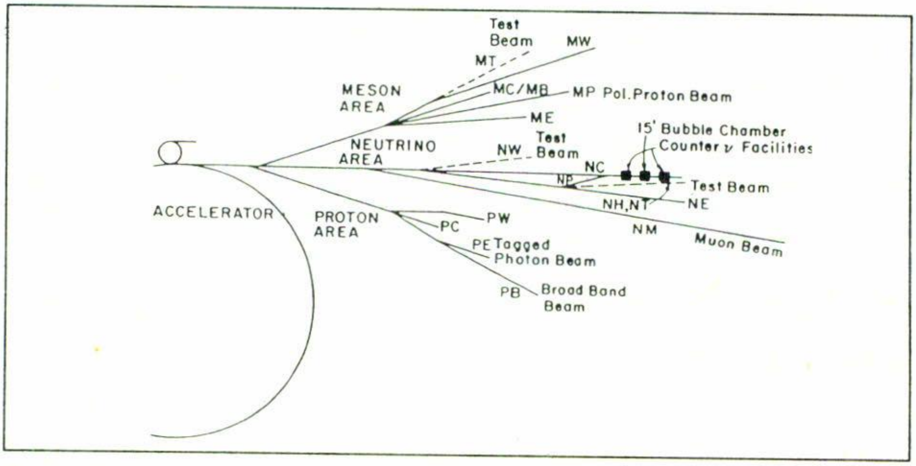


FIGURE 12. Layout of Fermilab fixed-target beams.

From the particles produced in the collision, a beam line selects those of -8 GeV and transfers them to a complex of 2 storage rings. All of the short-lived particles decay, leaving only the antiprotons which are stored and stochastically colled; cooling involves reducing the phase space of the antiproton beam using a feedback system.

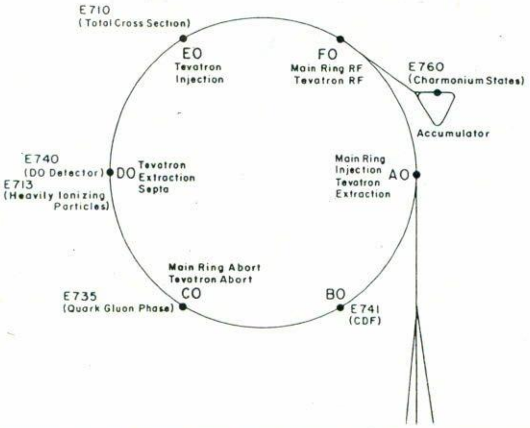


FIGURE 13. Locations in the Tevatron of the approved $\overline{p}p$ Collider experiments, and of the gas jet experiment in the Accumulator.

Typically $\sim 10^{10}$ antiprotons per hour are stored, and after several hours, a total of $\sim 10^{11}$ antiprotons is reached, with momentum spread and angular divergence small enough, due to cooling, that they can be injected back into the Main Ring and the Tevatron for collision with counter-rotating protons. Figure 14 shows CDF, the Collider Detector at Fermilab, which is at present the major detector in the Collider program. In addition to the USA, teams from Japan and Italy were involved in building and operating this major facility.

The currently approved Fermilab program is given in figure 15; it involves some 90 physicists and graduate students from USA institutions and some 40 from outside the USA. These latter come from 60 institutions in 17 countries, including groups from Mexico and Brazil. Many physicists and engineers from Latin America are active at Fermilab; a listing is shown in figure 16.

3. Where is high energy physics today?

There are many open questions in the field at present, among them being the following:

1. There need to be more detailed tests of predictions of the Standard Model. As an example, studies of properties of the Z^0 and the $W^{\pm}$ are as yet in an early stage.
2. Where do the masses of the quarks and leptons come from? Why do quarks and leptons group into families? We know that these questions are related to symmetry breaking, and to the existence of new particles such as the (as yet undiscovered) Higgs boson.

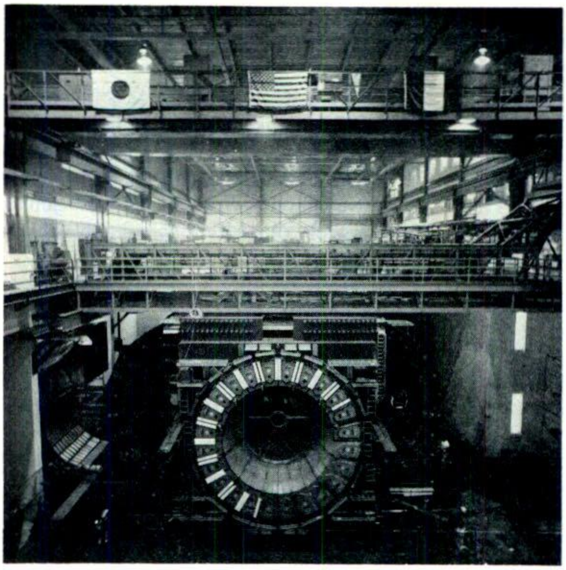


FIGURE 14. Collider Detector at Fermilab.

3. Why are there so many unknown parameters in the Standard Model? In addition to the coupling strengths of the four interactions, there are: 18 quarks, 6 leptons, 8 gluons, 3 intermediate bosons, the Higgs sector: 1 photon and 1 graviton. This number of "elementary" particles seems excessive and unaesthetic.
4. Are quarks and leptons elementary?
5. Can the gauge forces be unified?

Existing (or about to be) accelerators, such as the Tevatron, SLC, LEP, and SPS, can test the Standard Model to a mass scale of order 0.3 TeV. (In hadron-hadron collisions, the relevant interaction is of course that of the constituent quarks. Thus with the Tevatron operating at 0.9×0.9 TeV, phenomena can only be studied up to ~ 0.3 TeV). However, there are already strong arguments that new phenomena may be expected at a mass scale no higher than 1 TeV. At present, only a few tests can be done even now at that level, such as searches for proton decay, and studies of certain forbidden particle decay processes.

Because of the open questions listed above, and the hints that an appropriate energy scale for a new accelerator to reach is ~ 1 TeV, physicists in the USA are designing a 20×20 TeV proton-proton collider, called the Superconducting Super Collider (SSC). This should be capable of exploring mass scales up to $\sim$ 1-6 TeV (depending on the exact process to be studied). A schematic of the 84 Km circumference SSC is shown in figure 17, superimposed on a map of New York City to illustrate its size. Figure 18 shows a cross-section of the SSC tunnel (3 metres

Fixed-target		
ELECTROWEAK		
E–632	(Morrison/ Peters)	wide band neutrinos in the 15 FT bubble chamber (16/84)
E–665	(Montgomery)	muon scattering with hadron detection (13/79)
E–773	(Brock)	neutrino interactions with quad tripled beam (4/26)
E–745	(Kitagaki)	neutrino physics with quadtriplet beam (10/43)
E–770	(Smith)	neutrino physics with quad triplet beam (4/28)
E–782	(Kitagaki)	muon scattering with tohoku bubble chamber (7/33)
DECAYS AND CP		
T–721	(Rosen)	CP violation (8/44)
E–731	(Winstein)	measurement of ϵ'/ϵ (5/27)
E–756	(Luk)	Ω^- magnetic moment (4/16)
E–761	(Verobyov)	hyperon radiative decay (6/16)
E–773	(Gollin)	phase difference between η_{00} and η_{+-} (4/12)
E–774	(Crisler)	electron beam dump particle search (4/7)
HEAVY QUARKS		
E–653	(Reay)	hadronic production of charm and B (19/79)
E–687	(Butler)	photoproduction of charm and B (8/58)
E–690	(Knapp)	hadronic production of charm and B (5/21)
E–705	(Cox)	charmontum and direct photon production (8/47)
E–760	(Cester)	charmonium states (7/59)
E–769	(Appel)	pion and kaon production of charm (8/25)
E–771	(Cox)	beauty production by protons (9/68)
HARD COLLISIONS AND QCD		
E–672	(Zieminski)	high P_T jets and high mass dimuons (7/28)
E–683	(Corcoran)	photoproduction of jets (9/33)
E–704	(Yokosawa)	experiments with a polarized beam (16/50)
E–706	(Slattery)	direct photon production (9/75)
E–711	(Levinthal)	constituent scattering (3/23)
E–772	(Moss)	nuclear antiquarks structure functions (9/26)
COLLIDER		
E–710	(Orear/ Rubinstein)	total cross-section (6/18)
E–713	(Price)	highly ionizing particles (2/3)
E–735	(Gutay)	search for quark gluon phase (7/52)
E–740	(Grannis)	do detector (20/124)
E–741/ E–775	(Schwitters/ Tollestrup)	Collider detector at Fermilab (20/247)
OTHERS		
E–466	(Porile)	nuclear fragments (3/7)
E–754	(Sun)	channeling tests (4/8)
E–755	(Majka/ Slaughter)	streamer chamber tests (2/10)
E–776	(Baker)	nuclear calibration cross-section (3/7)
E–777	(Mc Caslin)	neutron flux measurements in the tevatron tunnel (3/9)
E–778	(Edwards)	study of SSC magnet aperture criterion (5/15)
E–790	(Sciulli)	zeus calorimeter module test (7/?)

FIGURE 15. Currently approved Fermilab experiments. E = experiment; T = test. Numbers in parenthesis denote total number of institutions and physicists, respectively.

Carlos Alcalde	Perú	Visiting theoretical physicist
Gilvan Alves	Brasil	Visiting physicist
Joao Anjoa	Brasil	Visiting physicist
Clicerio Avilez	México	Visiting physicist
Miguel Awschalom	Argentina	Resident physicist
Carla Barros	Brasil	Visiting ingineer
Edgar Black	Ecuador	Resident engineer
Juan Bonfill	Venezuela	Resident physicist
Oscar Calvo	Argentina	Visiting engineer
Milciades Contreras	Chile	Visiting physicist
Walter Correa	México	Visiting engineer
Carlos Escobar	Brazil	Visiting physicist
Graciela Gelmini	Argentina	Visiting theoretical physicist
Francisco Gerson	Brasil	Visiting theoretical physicist
Marcelo Gleiser	Brasil	Visiting theoretical physicist
Ricardo Gómez	Colombia	Visiting physicist
Héctor González	Puerto Rico	Resident engineer
Rodolfo González	Colombia	Resident technician
Jesse Guerra	México	Resident technician
Philippe Gouffon	Brazil	Visiting physicist
Gastón Gutiérrez	Argentina	Resident physicist
Enrique Henestroza	México	Visiting theoretical physicist
Bruce Hoeneisen	Chile	Visiting physicist
Carlos Hojva	Argentina	Resident physicist
Juan León	Spain	Visiting theoretical physicist
Angel López	Puerto Rico	Visiting physicist
Sirley Marques	Brasil	Visiting theoretical physicist
Manuel Martín	Spain	Resident engineer
Héctor Méndez	Chile	Visiting physicist
Antonio Morelos	México	Visiting physicist
Gerardo Moreno	México	Visiting physicist
Jorge Morfín	México	Resident physicist
Helio Motta	Brazil	Visiting physicist
Juan Pablo Negret	Colombia	Visiting physicist
René Padilla	Puerto Rico	Resident technician
Gustavo Pérèz	Honduras	Visiting theoretical physicist
Nelson Pinto	Brazil	Visiting theoretical physicist
José Poces	Spain	Resident engineer
Joao Pulido	Portugal	Visiting theoretical physicist
Alejandro Salvarani	Chile	Visiting physicist
Alberto Santoro	Perú	Visiting physicist
Miguel Sarmiento	Perú	Visiting physicst
Bruno Schuize	Brazil	Visiting physicst
Moacyr Souza	Brazil	Visiting physicst
Jaime Stein-Schabes	México	Visiting theoretical physicst
Leticia Stein	México	Visiting mathematician
Sergio Torres	Colombia	Visiting physicst
Jorge Uribe	Colombia	Visiting physicst
Eugenio Valdés	Cuba	Resident engineer
Roberto Vignoni	Argentina	Visiting engineer
Carlos Yosef	Colombia	Visiting physicst
Manuel Zanabria	Perú	Visiting physicst

FIGURE 16. Latin Americans and Iberians associated or in collaborations with Fermilab in July of 1987.

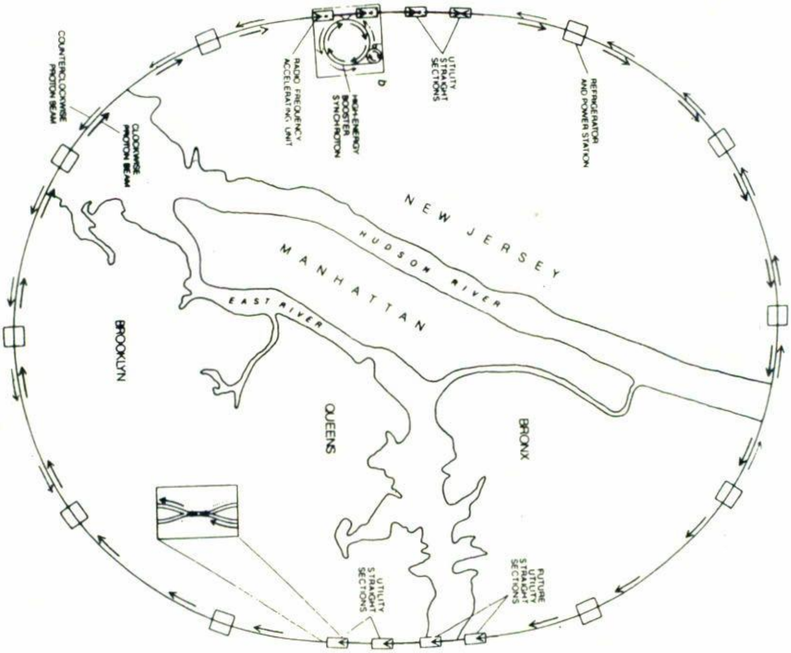


FIGURE 17. Schematic view of the SSC superimposed on a New York map.

maximum width), and a cross-section of a magnet; the magnets will operate up to 6.6 Tesla. The current status of SSC is as follows.

Approval by President	Yes
Approval by Congress	Not Yet
Site proposals received ($\sim$ 40 sites in $\sim$ 30 states)	September 1987
National Academy of Sciences Committee site evaluation	Completed December 1987
Choice of preferred site	July 1988
Final site choice (after environmental review)	January 1989
Completion	1996

We list here a few of the frontiers of particle physics that will be impacted by the SSC.

Origin of mass.
Symmetry breakin of the electoweak theory.

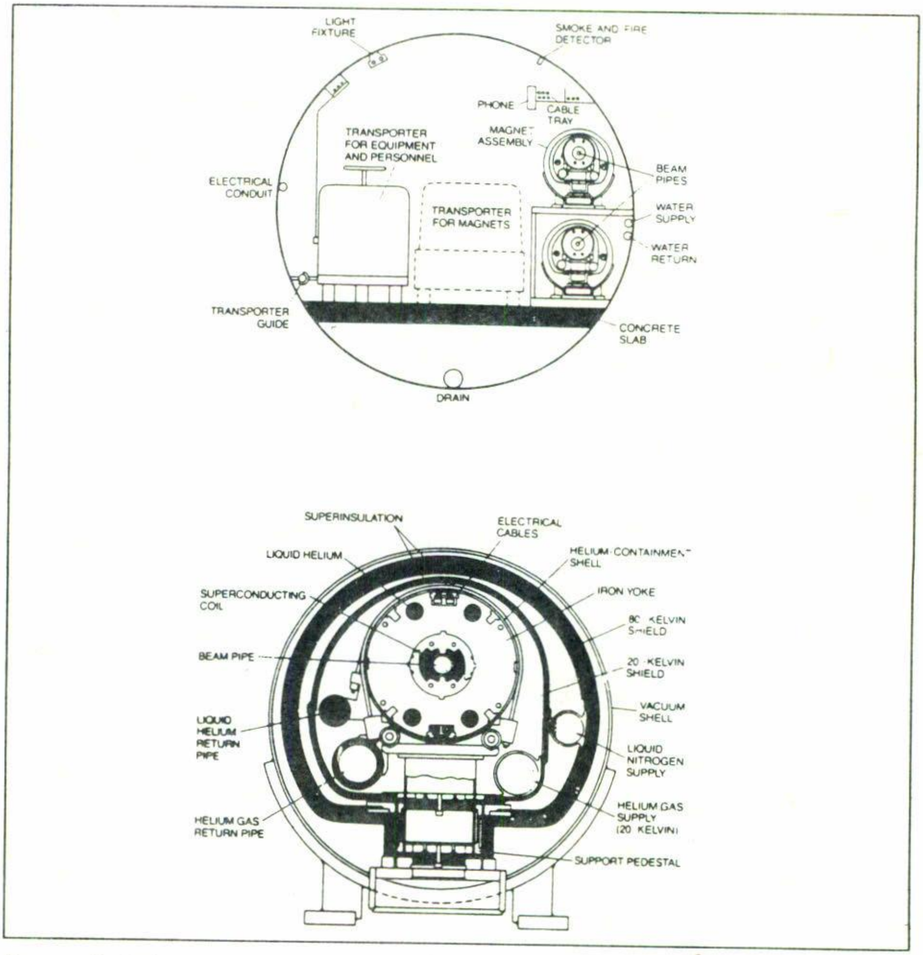


FIGURE 18. Main tunnel proposed for the SSC is shown in cross-section. The two beam pipes for the counterrotating beams of protons are at the right. The tunnel is about 10 feet across (above). Detail of magnet assembly to be mounted in the tunnel of the SSC is shown in schematic cross-section. One of the proton beams passes through an evacuated beam pipe in the central, upper part of the assembly. The pipeline is surrounded by coils of superconducting wire; current passing without resistance through the wire creates the enormous magnetic field needed for bending the proton beam. The rest of the system enclosing the beam pipe serves to keep the magnet at the low temperatures necessary to maintain the superconductivity of the coils. The first layer of piping surrounding the magnet carries liquid helium refrigerant held at 4.35 degrees Kelvin; this layer is surrounded by piping that carries liquid nitrogen at 80 degrees Kelvin. Layers of insulating material surround the piping (below).

Are there more than three generations?
Why do quark and lepton masses increase with generation?
Are quarks always bound?
Are quarks and leptons related – if so, how?
Why do weak interactions show a handedness?
Are quarks and leptons composite?

4. Summary

The current state of USA high energy physics is one of very high activity; it is exciting to be in the field with the successes of the Standard Model and with so much activity on the unification of the forces. The USA has two new, frontier accelerators in the Tevatron Collider and SLC in order to pursue this work, and there is the exciting future possibility of the SSC.

Resumen. Se hace un resumen del estado actual de la física de altas energías y se describen los programas de los aceleradores existentes en los Estados Unidos de América, en particular el de Fermilab. Asimismo, se da una lista de algunas preguntas sin respuesta en esta área de la física y se introducen algunas características de un nuevo proyecto que involucra la construcción de un acelerador superconductor (*Superconducting Super Collider*).