Felmilab

研究活動の紹介

平成十四年十月

山内泰二

1930		Neutrino hypothesis
	Discovery of neutron	
	Discovery of positron	Theory of β decay
		Meson theory
	Discovery of μ meson	
1940		
		Two meson theory
	Discovery of π meson and	Renormalization theory
	Discovery of strange particles	
1950		
		Strangeness
	Discovery of anti-proton	
	First detection of anti-ν interaction	Sakata model
		V-A of weak interactions
1960		
		SU(3) symmetry of hadron
	Discovery of mu-neutrino	
	Discovery of Omega minus	
	CP violation	Quark model
		Han-Nambu quark
		Electro-weak unification
		Scaling and Parton
	Deep inelastic scattering	
1970		GIM mechanism
		String theory
		QCD
	Evidence of neutral current	Supersymmetry
	Discovery of J/psi	Kobayashi-Maskawa
	Discovery of τ lepton	Lattice gauge theory
	Discovery of Upsilon	
	Evidence for gluon	
1980		
		Superstring theory
1983	Discovery of W and Z	
1990		
	Discovery of top quark	
	Discovery of Bc meson	
2000	First observation of tau neutrino interaction	

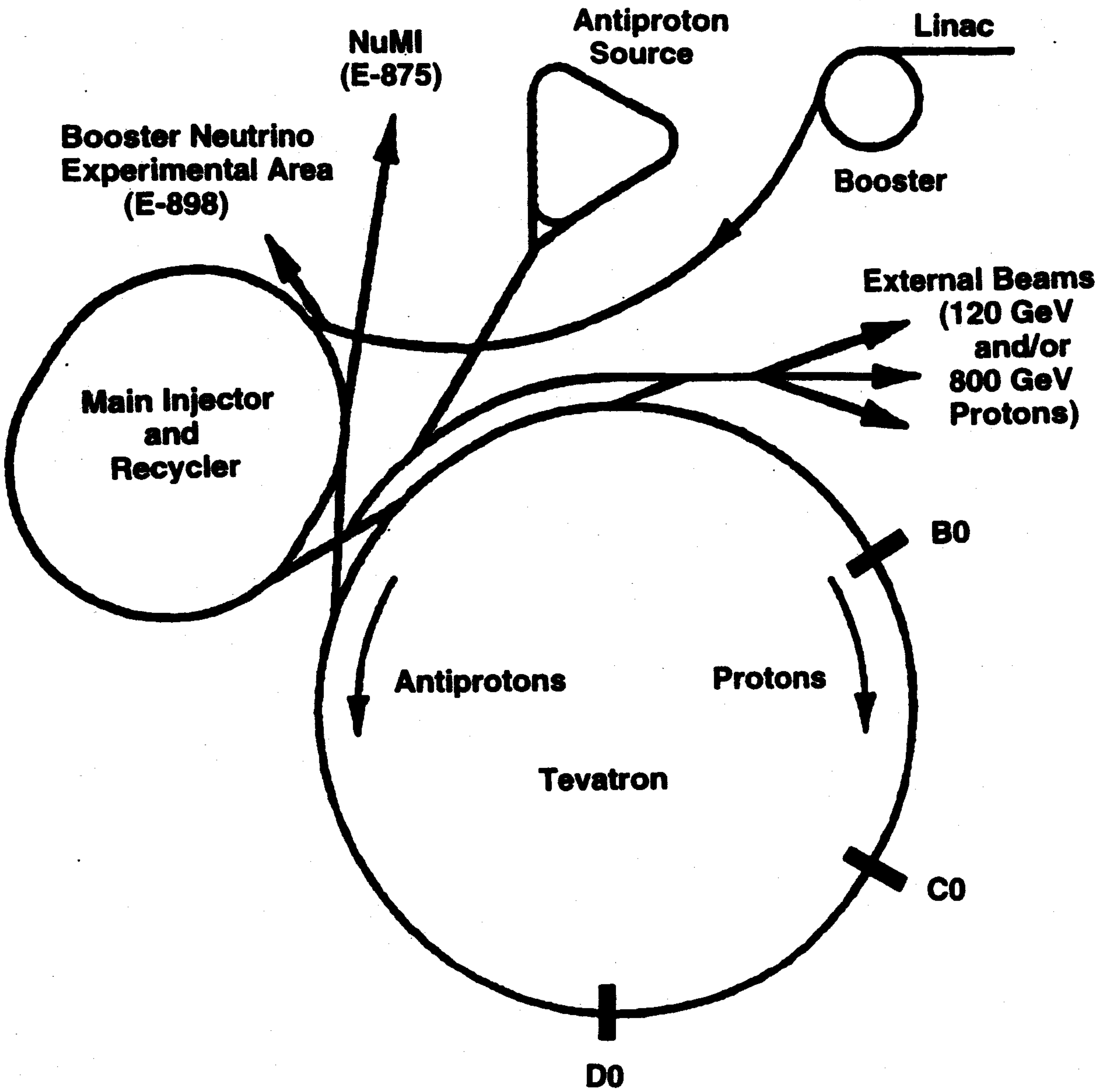
Fermilabの歴史

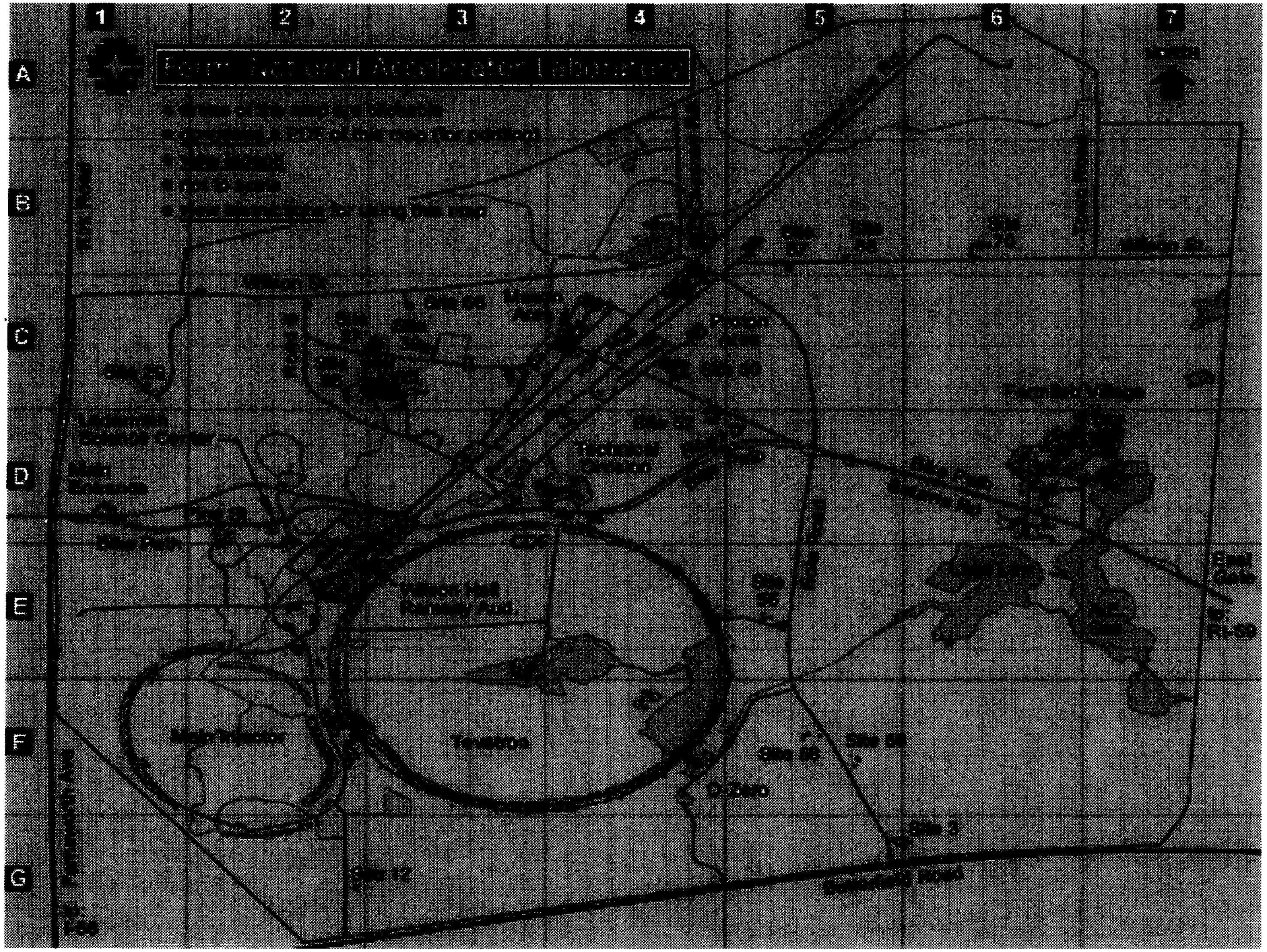
- 1966年12月～ 1968年4月:敷地、初代所長、等の決定。
  大統領に依る設立の正式承認、国会に依る予算承認
- 1968年12月:建設開始
- 1972年3月:200GeVビーム
- 1972年12月: 400GeVビーム
- 1977年6月: ウプシロンの発見
- 1984年2月:800GeVビーム
- 1985年2月:陽子・反陽子衝突の観測(CDF)
- 1986年10月:900GeVビーム
- 1994~5年: トップ・Quarkの発見(CDF/D0)
- 1998年3月: Bcメソンの発見(CDF)

Fermilabに在る加速器

- Cockcroft-Walton 型静電加速器 (750 KeV)
- 線型加速器 (400 MeV)
- Booster (8 GeV Synchrotron))
- Main Ring (400 GeV Synchrotron)
- Main Injector (150 GeV Synchrotron)
- Tevatron (980 GeV Synchrotron)

運動量
と反陽
する。
型実
に残っ


Booster Neutrino
Experimental Area
(E-898)
NuMI
(E-875)
Antiproton
Source
Linac
Booster
External Beams
(120 GeV
and/or
800 GeV
Protons)
Main Injector
and
Recycler
Antiprotons
Protons
Tevatron
B0
C0
D0



Fermi National Accelerator Laboratory
NORTH
Kirk Road
Wilson St.
Lederman Science Center
Main Entrance
Pine St.
Technical Division
Wilson Hall Ramsey Aud.
Main Injector
Tevatron
D-Zero
Site 3
Site 12
Butterfield Road
Farnsworth Ave
Fermilab Village
East Gate

初期の研究

~80 Proposals	1970年6月
~20 Approved	1970年末迄

- **Neutrino散乱**
- **Muon散乱**
- **Hadron散乱**
- **Quark/Monopole Search**

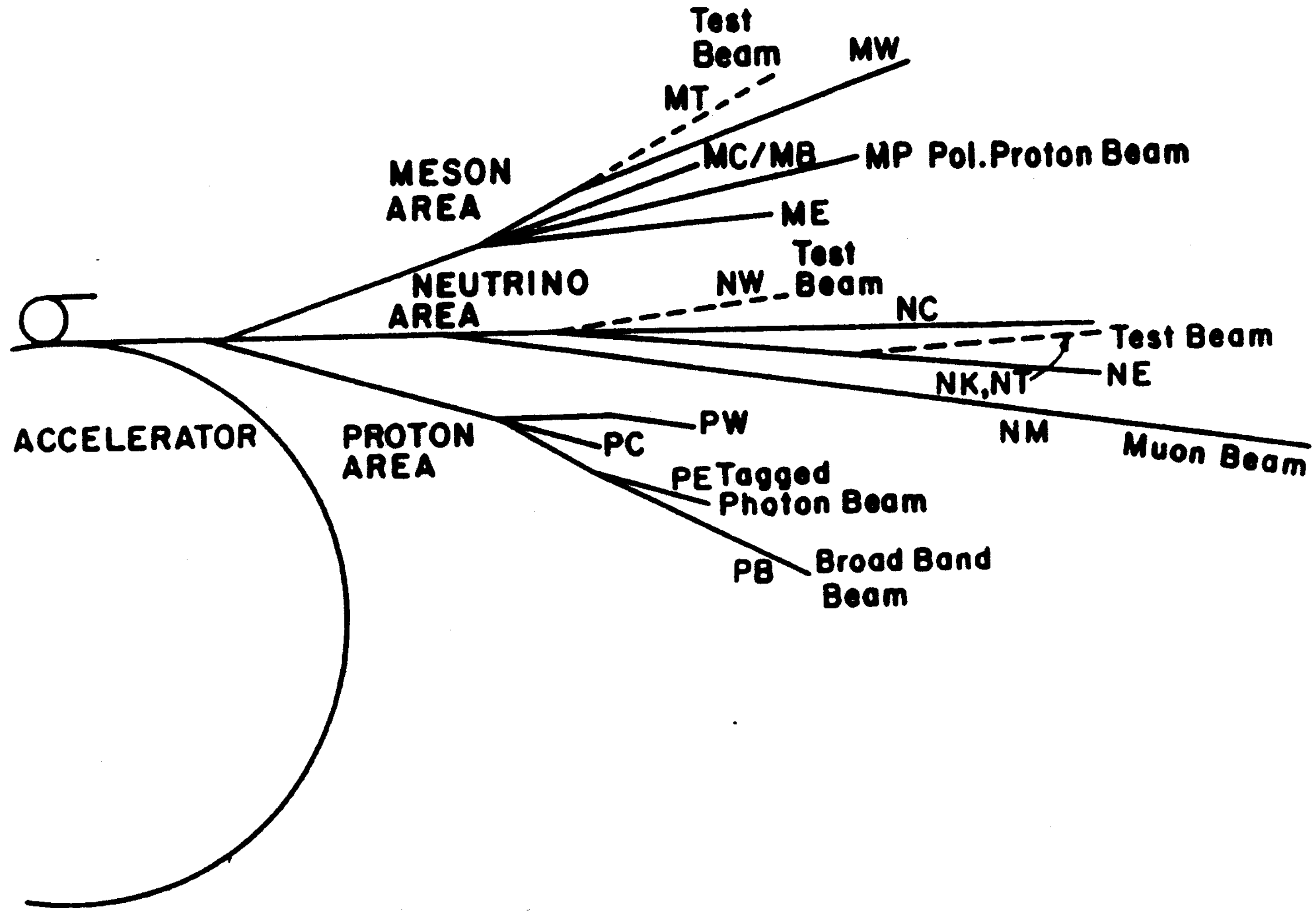


Figure 8. Layout of Fermilab Fixed Target beams. Properties of individual beams are given in Table 2.

Nakano/Nishijima/Gell-Mann の式

Strangeness と Iso Spin の関係

$$Q = I_3 + (B+S)/2$$

Example:

	I_3	B	S
Proton	1/2	1	0
Neutron	-1/2	1	0
Λ	0	1	-1
π^+	1	0	0
K^-	-1/2	0	-1

Table 6A-1
Stable and Metastable Particles[89]

Family	Particle	Mass: Mev	Mass: m_e	Mean lifetime, sec
Photon	γ	0	0	∞
Leptons	ν	0	0	∞
	e^+	0.510976 ± 0.000007	1	∞
	$\mu^\pm$	105.655 ± 0.010	206.77	$(2.212 \pm 0.002) \times 10^{-6}$
Mesons	π^0	135.00 ± 0.05	264.20	$(1.9 \pm 0.6) \times 10^{-16}$
	$\pi^\pm$	139.59 ± 0.05	273.18	$(2.55 \pm 0.03) \times 10^{-8}$
	$K^\pm$	493.9 ± 0.2	966.6	$(1.224 \pm 0.013) \times 10^{-8}$
	K^0	497.8 ± 0.6	974.2	K_1^0: $(1.00 \pm 0.04) \times 10^{-10}$ K_2^0: $\left(6.1 {+1.6 \atop -1.1}\right) \times 10^{-8}$
Baryons	p	938.213 ± 0.01	1836.12	∞
	n	936.507 ± 0.01	1838.65	$(1.013 \pm 0.029) \times 10^{3}$
	Λ^0	1115.36 ± 0.14	2182.80	$(2.51 \pm 0.09) \times 10^{-10}$
	Σ^+	1189.4 ± 0.2	2327.7	$\left(0.81 {+0.06 \atop -0.05}\right) \times 10^{-10}$
	Σ^0	1191.5 ± 0.5	2331.8	$< 0.1 \times 10^{-10}$
	Σ^-	1196.0 ± 0.3	2340.6	$\left(1.61 {+0.10 \atop -0.09}\right) \times 10^{-10}$
	Ξ^0	1311 ± 8	2566	$\sim 1.5 \times 10^{-10}$
	Ξ^-	1318.4 ± 1.2	2580.2	$\left(1.3 {+0.4 \atop -0.3}\right) \times 10^{-10}$

Sakata Model と Quark Model の比較

• Sakata Model	• Quark Model
• P, N, and Λ	• u, d, ans s
$\pi^+ = (P\bar{N})$	$P = (uud)$
$K^- = (\bar{P}\Lambda)$	$N = (udd)$
$\Sigma^+ = (P\bar{N}\Lambda)$	$\Sigma^+ = (uus)$
$\Xi^- = (\bar{P}\Lambda\Lambda)$	$\Xi^- = (dss)$
etc.	etc.

Quark の電荷　I

QuarkのBaryon Number = 1/3

u-quarkのI_3 = 1/2　　strangeness = 0
d-quarkのI_3 = -1/2　　strangeness = 0
s-quarkのI_3 = 0　　　strangeness = -1

u-quarkの電荷 = 1/2 + (1/3 + 0)/2 = 2/3
d-quarkの電荷 = -1/2 + (1/3 + 0)/2 = -1/3
s-quarkの電荷 = 0 + (1/3 −1)/2 = -1/3

Quark の電荷 II

Han-Nambu

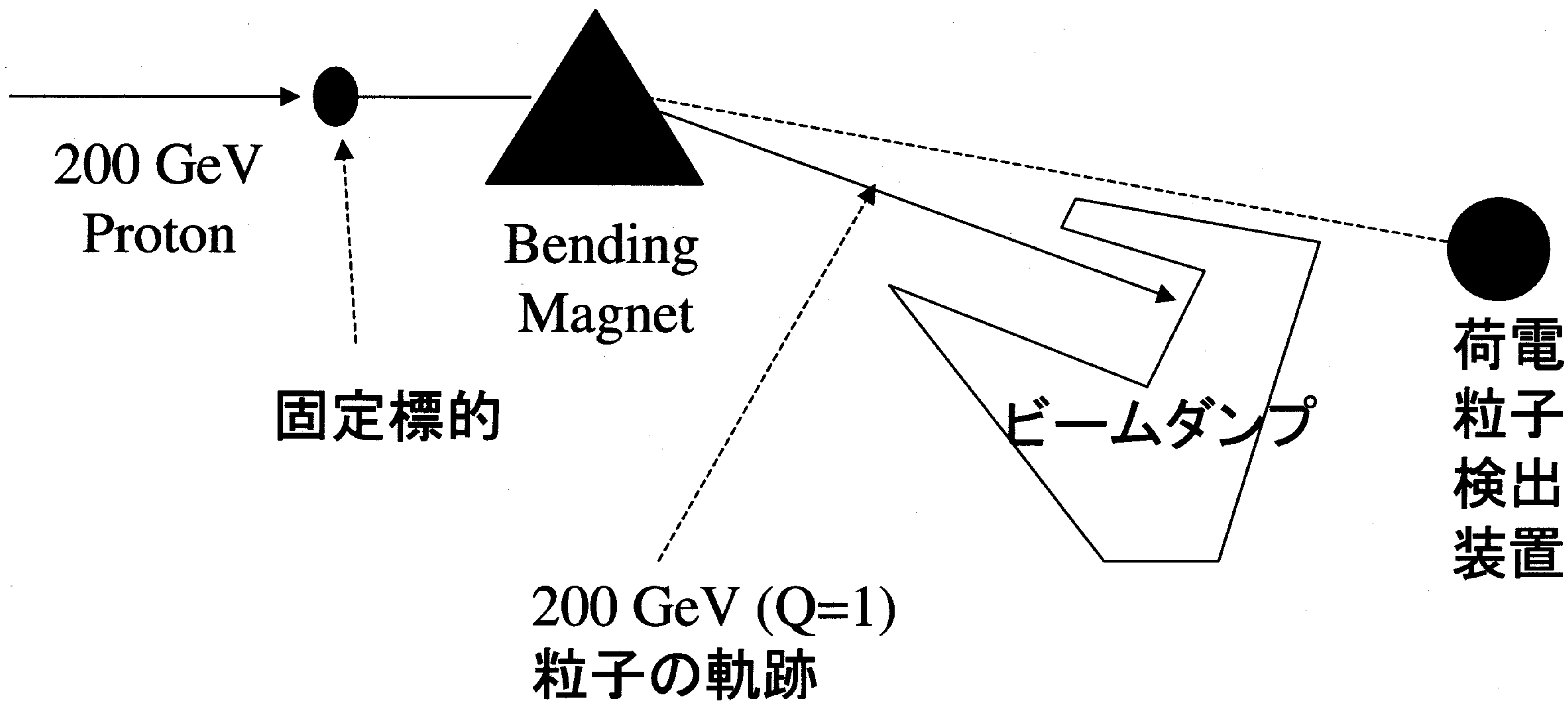
		u	d	s
青	Q=	1	0	0
緑	Q=	1	0	0
赤	Q=	0	-1	-1

Gell-mann/Zweig

		u	d	s
青	Q=	2/3	-1/3	-1/3
緑	Q=	2/3	-1/3	-1/3
赤	Q=	2/3	-1/3	-1/3

E75 Quark Search

Proton + Target ⟶ Free Quark (Q = 1/3 or 2/3) + X



Search for Fractionally Charged Quarks Produced by 200- and 300-GeV Proton-Nuclear Interactions

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and

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and

J. Sculli
New York University, New York, New York 10003
(Received 4 March 1974)

We describe an experimental search for particles with fractional charge (quarks) with mass below 11 GeV/c^2 produced by proton-nucleus collisions at 200 and 300 GeV. No evidence for such particles was found. Limits on the quark production cross section are given.

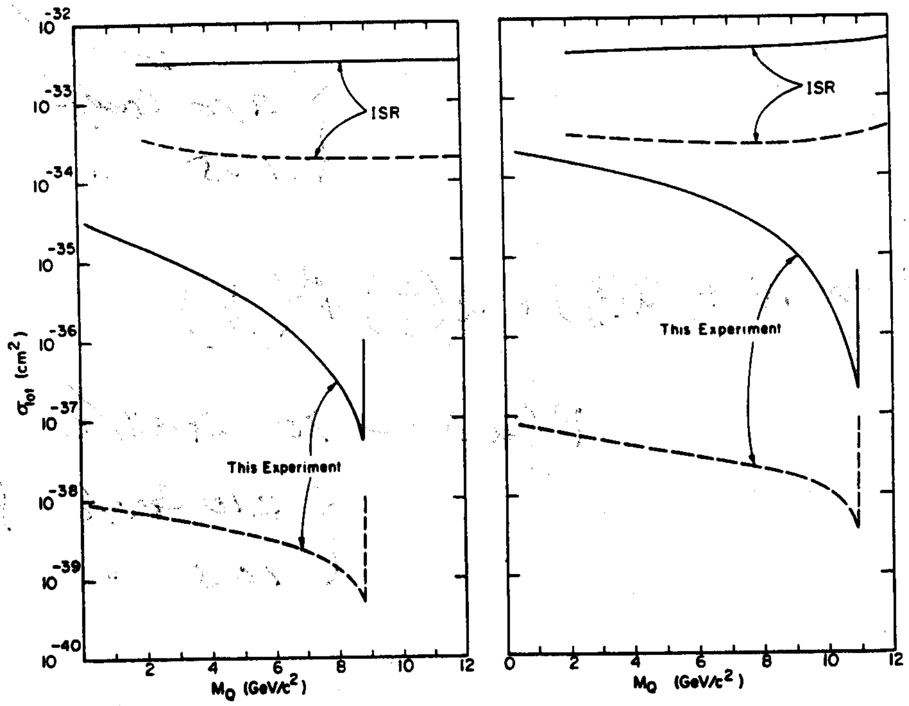

FIG. 2. Upper limits on total cross section for fractionally charged particle production. (a) Charge $-\frac{1}{3}$; (b) charge $-\frac{2}{3}$. Solid lines, limits obtained assuming four-body phase space (with an isotropic center-of-mass angular distribution). Dashed lines, limits with the four-body phase space constrained by a multiplicative factor of $\exp(-6P_t)$, where P_t is the transverse momentum in GeV/c. Shown are results from this experiment and from Bott-Bodenhausen *et al.* (Ref. 4) at the CERN intersecting storage rings.

(D) Finally, the large transverse momentum single particle inclusive distribution indicate a power law, again in agreement with the parton model.

We see that the overall picture is quite good even if there are many fine points to be clarified. It is important to notice that the number n_i and N appearing in the asymptotic exponents (which are in reasonable experimental agreement) are those evaluated on the basis of the original quark model which lead to a qqq structure for the lowest fermions and a $q\bar{q}$ structure for the lowest bosons.

Let us now discuss in more detail the problem of quarks and of their dynamics.

The two main sources of evidence in favour of presence of quarks are the following.

(1) The existance of point structures in hadrons as revealed by high energy experiments. The most direct and reliable information comes from high energy deep inelastic lepton scattering which can be interpreted in terms of light plane commutators of local currents.

(2) The structure of low lying levels of hadrons is strongly suggesting a qqq model for fermions and the $q\bar{q}$ model for bosons. The simplest and most successful interpretation of hadron structure requires quarks obeying parastatistics. The application of the exclusion principle to quarks is best described by attributing a new colour quantum number to quarks and by requiring that only colour singlets are observable.

It is important to know the relation between the quark wave function as revealed by (1) (current quarks) and by (2) (constitutent quarks). The canonical transformation connecting current quarks to constituent quarks has been the object of numerous investigations. It has led to remarkable progress in the study of the structure of hadrons and their strong and electromagnetic properties.

The beautiful success of the quark model in explaining many features of hadron physics gives a somewhat urgent touch to the question: why have quarks never been seen?

It is unfortunate that until now no completely satisfactory answer has been suggested. Some possibilities are the following.

(A) In the framework of gauge theories, strong deviation of infra-red behaviour from free theory may give rise to a barrier responsible for complete confirnment of quarks inside hadrons. Examples supporting this view have been given in the framework of two dimensional field theoretic models. It is still unclear whether realistic four-dimensional Lagrangian (which exhibit a much weaker infra-red behaviour)will also lead to a similar situation.

(B) It is possible to introduce confinement in a more direct way by starting from new field theories with confined fields. This can either be introduced as a new dynamical starting point or derived from a conventional Lagrangian by a variational approach. This will be discussed later in this talk.

(C) One can finally reverse the problem and interpret strong interactions as a pure consequence of the boundary conditions responsible for confinement.

We indeed see that the theoretical situation on this question is still in a very preliminary stage. It is unclear whether the present theories will lead at

The beautiful success of the quark model in explaining many features of hadron physics gives a somewhat urgent touch to the question: why have quarks never been seen?

It is unfortunate that until now no completely satisfactory answer has been suggested. Some possibilities are the following.

Observation of Muon Pairs in High-Energy Hadron Collisions*

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Columbia University, New York, New York 10027

and Brookhaven National Laboratory, Upton, New York 11973

E. Zavattini

CERN Laboratory, Geneva, Switzerland

(Received 30 March 1973)

Muon pairs with effective masses between 1 GeV/c^2 and 6.5 GeV/c^2 have been observed in the collisions of 30-GeV protons with a uranium target. The production cross section was seen to vary smoothly with mass exhibiting no resonant structure. Data were taken at incident proton energies of 22, 25, 28.5, and 29.5 GeV. Within the experimental aperture the total cross section increased with energy by a factor of 5. The experimental results are compared with the predictions of several theoretical models. Limits are presented for the contributions to the signal from both massive muon-pair resonances and antiproton-proton annihilation. Implications are presented for higher-energy accelerators, using current ideas involving scaling.

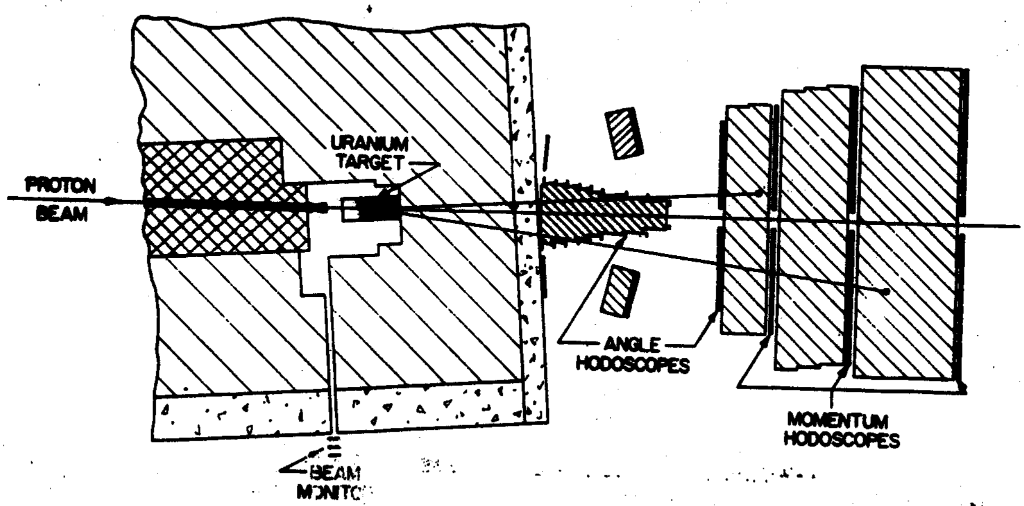


FIG. 1. Plan view of apparatus.

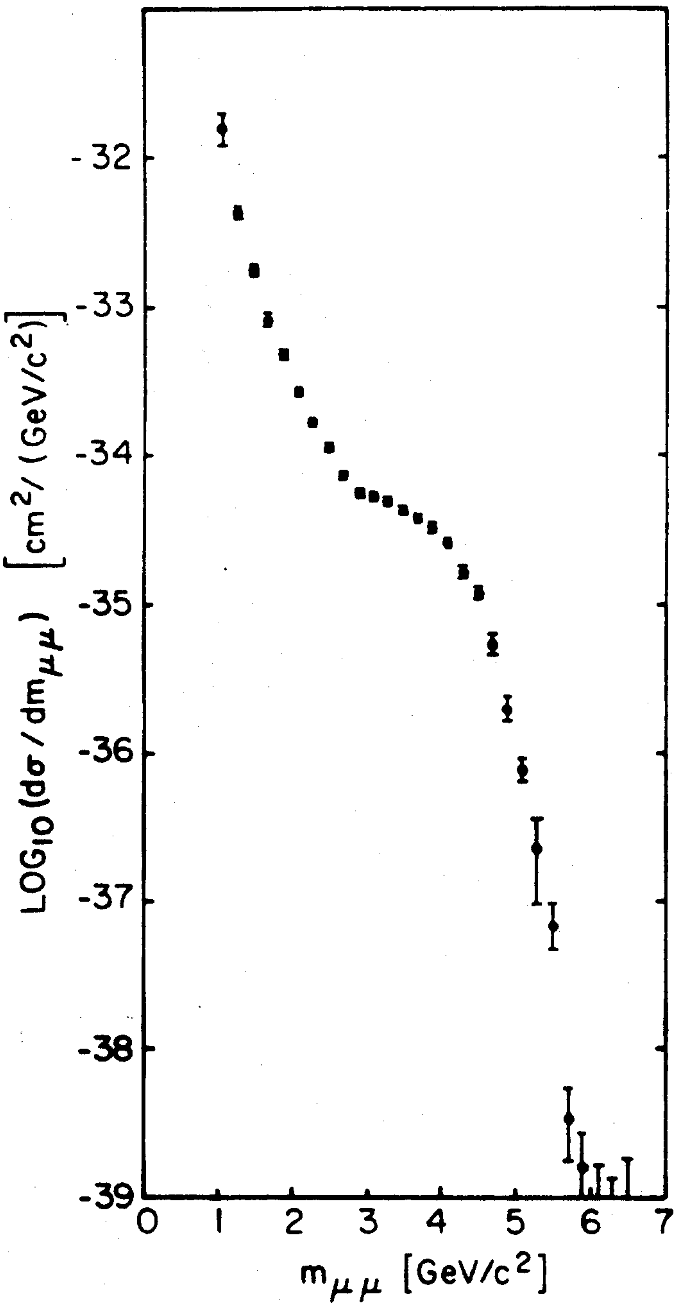
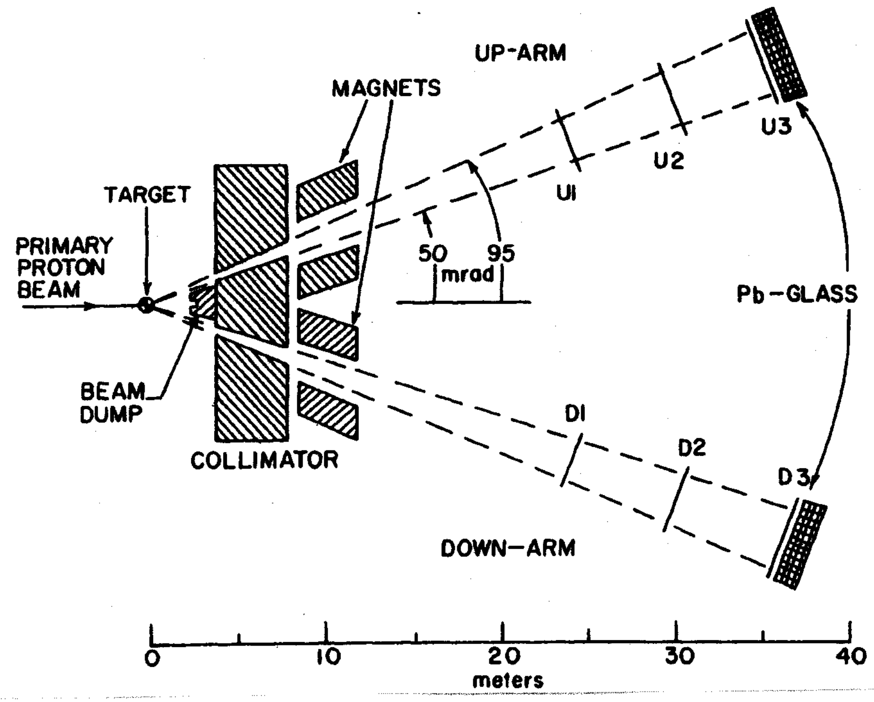


FIG. 10. $d\sigma/dm$. Weighted average of standard and "wide angle" events. Proton energy = 29.5 GeV.



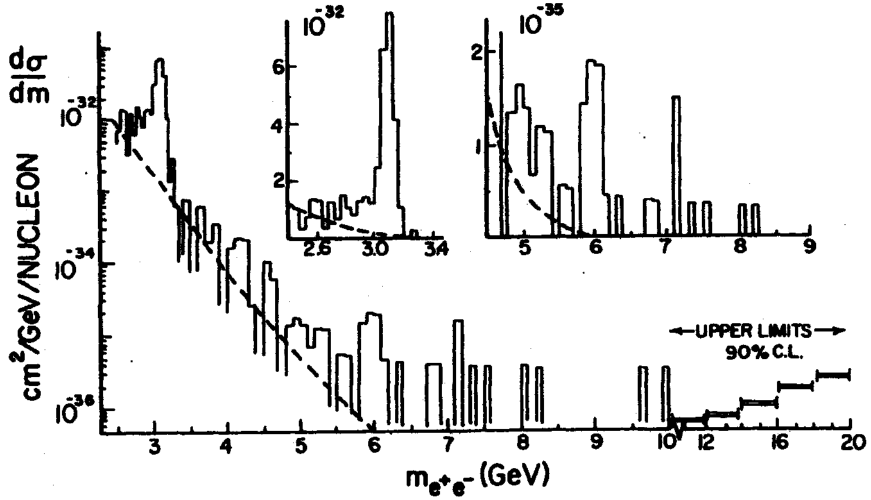


FIG. 2. Electron-positron mass spectrum: $d\sigma/dm$ per nucleon versus the effective mass. A linear A dependence is assumed. Note bin-width changes.

E288 Discovery of Upsilon

$$P + Be \rightarrow \text{Upsilon} + X$$

$$\text{Upsilon} \rightarrow \mu^+ + \mu^-$$

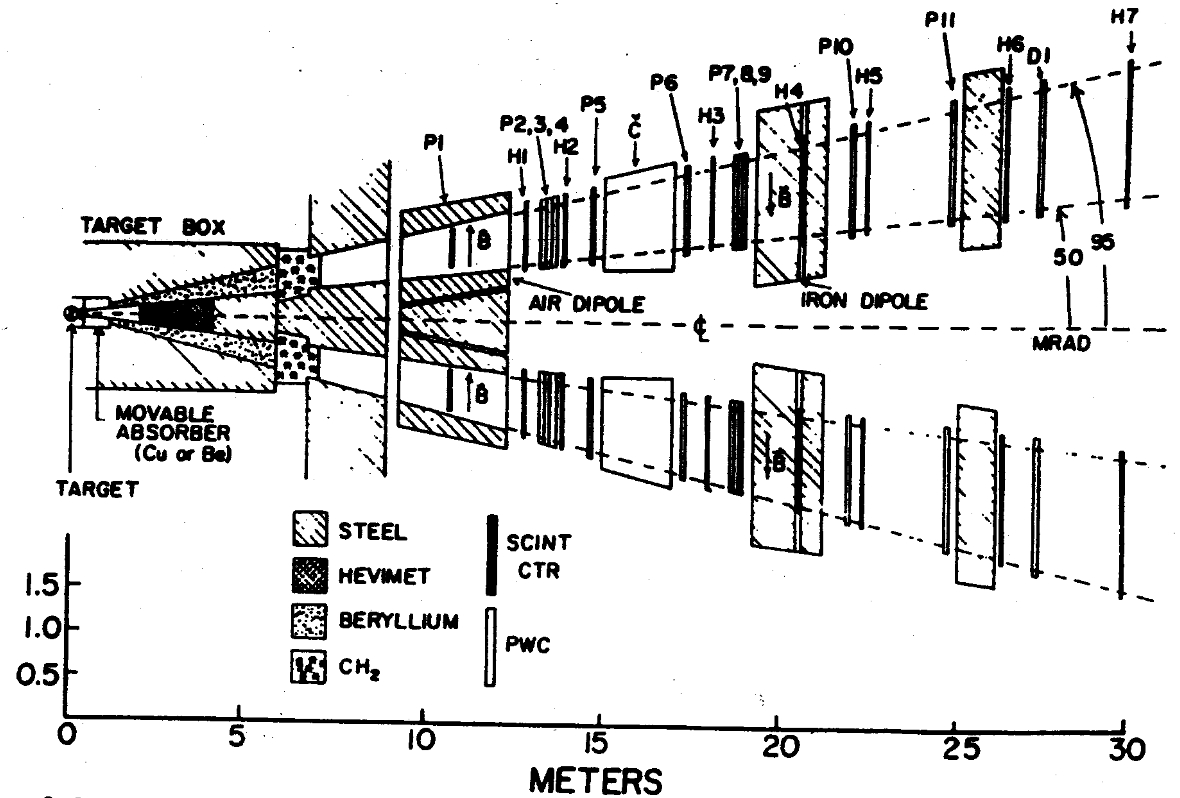


FIG. 1. Plan view of the apparatus. Each spectrometer arm includes eleven PWC's P1–P11, seven scintillation counter hodoscopes H1–H7, a drift chamber D1 and a gas-filled threshold Čerenkov counter Č. Each arm is up/down symmetric and hence accepts both positive and negative muons.

Observation of a Dimuon Resonance at 9.5 GeV in 400-GeV Proton-Nucleus Collisions

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and

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(Received 1 July 1977)

Accepted without review at the request of Edwin L. Goldwasser under policy announced 26 April 1976

Dimuon production is studied in 400-GeV proton-nucleus collisions. A strong enhancement is observed at 9.5 GeV mass in a sample of 9000 dimuon events with a mass $m_{\mu^+\mu^-} > 5$ GeV.

Observation of Structure in the Υ Region

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S. W. Herb, D. C. Hom, L. M. Lederman, J. C. Sens,[a] H. D. Snyder, and J. K. Yoh
Columbia University, New York, New York 10027

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R. J. Fisk, A. S. Ito, H. Jöstlein, D. M. Kaplan, and R. D. Kephart
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(Received 9 September 1977)

The properties of the dimuon enhancement seen in 400-GeV proton-nucleus collisions have been clarified by a threefold increase in data. We find two peaks whose widths are consistent with our resolution: $M_1 = 9.4$ GeV with $B\,d\sigma/dy|_{y=0} = 1.8 \times 10^{-37}$ cm^2/nucleon and $M_2 = 10.0$ GeV with $B\,d\sigma/dy|_{y=0} = 0.7 \times 10^{-37}$ cm^2/nucleon. Evidence for the possible existence of a third peak near 10.4 GeV is discussed as are the comparisons with the properties of a $q\bar{q}$ system, where q is a new heavy quark.

Evidence for the Υ″ and a Search for New Narrow Resonances

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Fermi National Accelerator Laboratory, Batavia, Illinois 60510

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The production of the Υ family in proton-nucleus collisions is clarified by a sixfold increase in statistics. Constraining Υ,Υ′ masses to those observed at DORIS we find the statistical significance of the Υ″ to be 11 standard deviations. The dependence of Υ production on p_t, y, and s is presented. Limits for other resonance production in the mass range 4–18 GeV are determined.

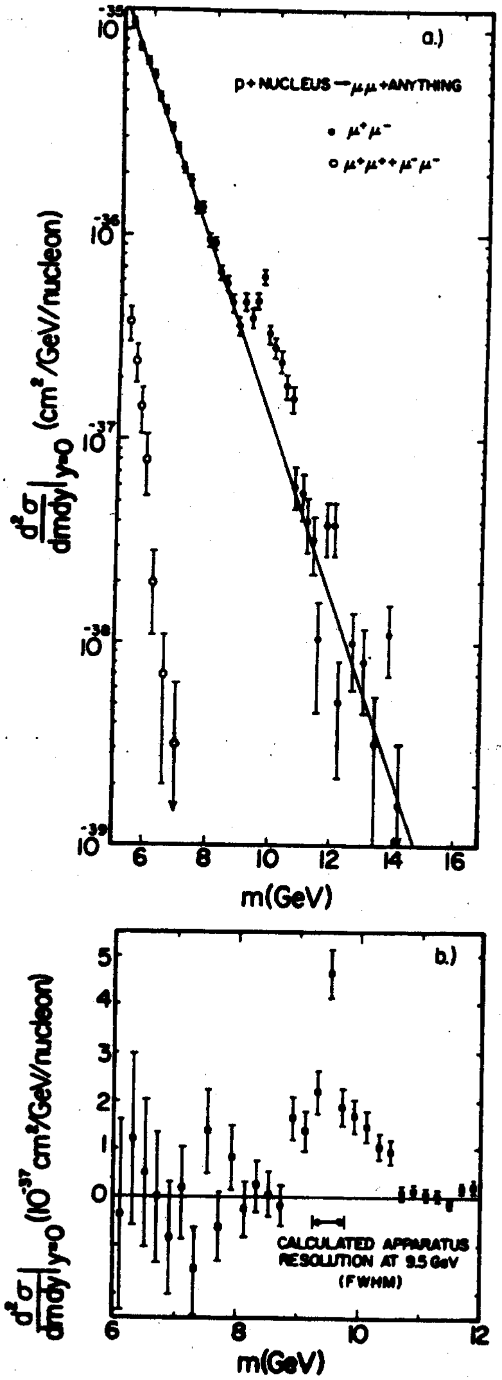


FIG. 3. (a) Measured dimuon production cross sections as a function of the invariant mass of the muon pair. The solid line is the continuum fit outlined in the text. The equal-sign–dimuon cross section is also shown. (b) The same cross sections as in (a) with the smooth exponential continuum fit subtracted in order to reveal the 9–10-GeV region in more detail.

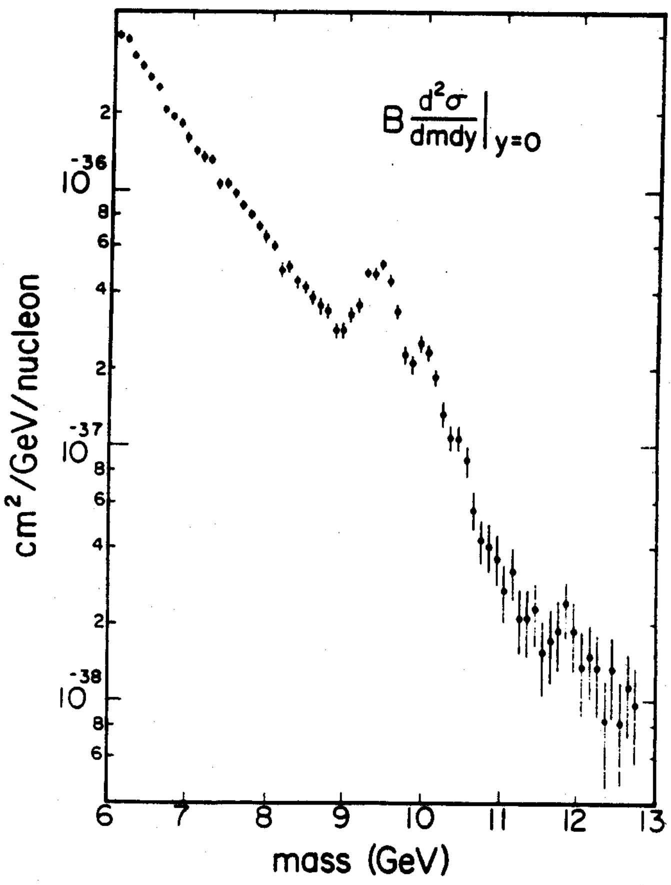


FIG. 1. Dimuon spectrum above 6 GeV.

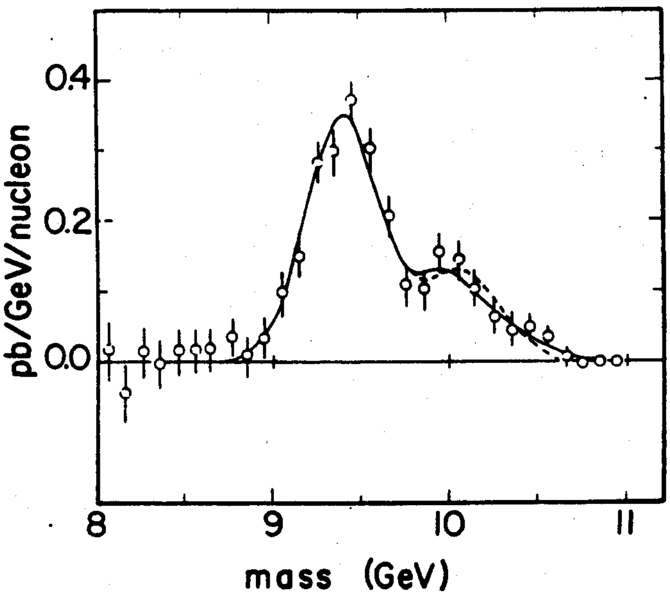


FIG. 2. Excess of the data over the continuum fit of Eq. (1). Errors shown are statistical only. The solid curve is the three-peak fit; the dashed curve is the two-peak fit.

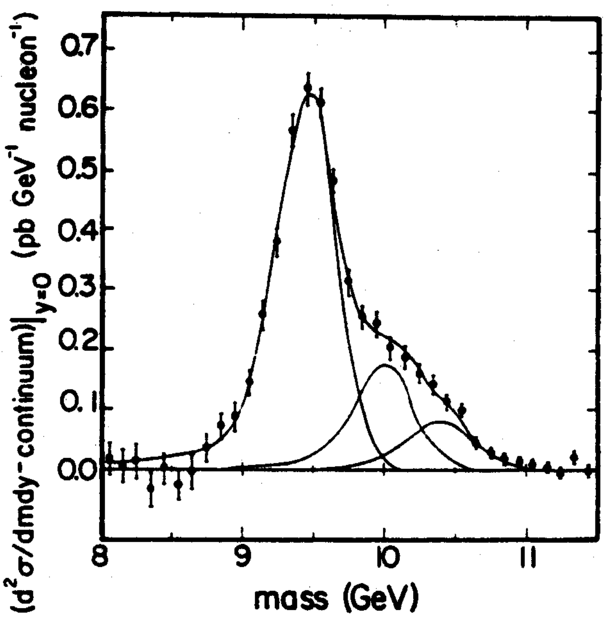


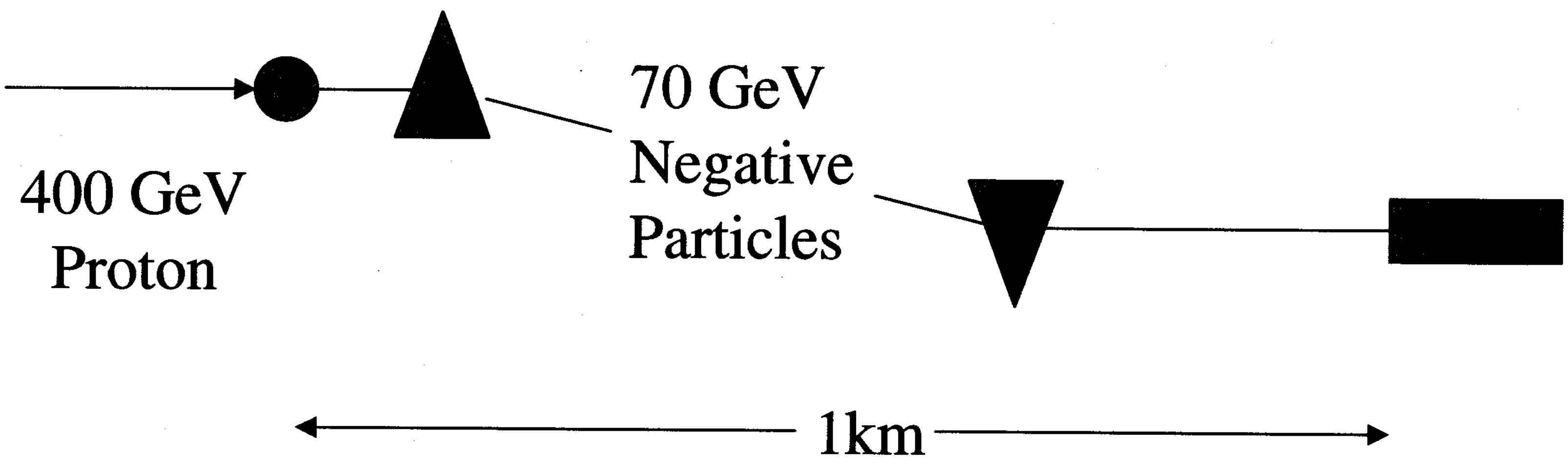
FIG. 1. Mass spectrum in the Υ region with continuum subtracted (from data set III). The curve is the fit described in the second column of Table I.

ウプシロンの質量

	PDG	1st.Paper	2nd.Paper	3rd.Paper
Y(1S)	9460	9440(30)	9440(13)	9460
Y(2S)	10023	10170(50)	10010(50)	10034(27) 10018(11)
Y(3S)	10355		10400(120)	10430(50) 10410(30)

E596 Stable b Search

$$\text{Proton} + \text{Be} \rightarrow (b\bar{u}) + (\bar{b}u) + X$$



$\Delta t = 9.5$ nsec for
mass 5.3 GeV and $P = 70$ GeV/c

RF structure of Main Ring is 18.9 nsec

A SEARCH FOR NEW MASSIVE PARTICLES

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Received 16 June 1978

We have searched for an almost stable, charged particle produced in 400 GeV proton–nucleus collisions. A total of 5×10^{10} light secondary particles were sampled in a secondary beam of 70 GeV/*c* momentum. If a 4.5 to 6.0 GeV mass particle is produced with a cross section comparable with the production cross section of the upsilon then this experiment places an upper limit on the lifetime of such a particle of about 5×10^{-8} s.

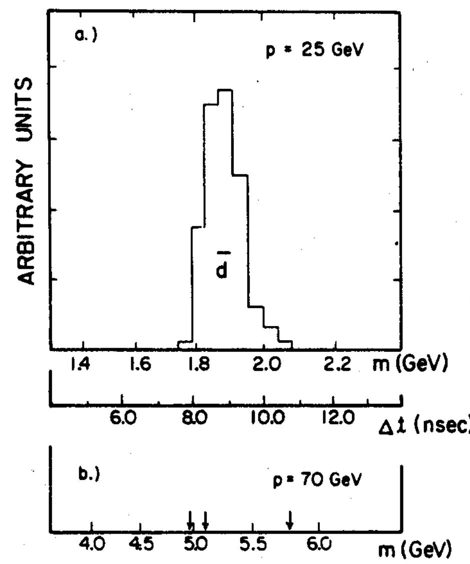


Fig. 2. (a) Yield of anti-deuterons in a calibration run with the beam line tuned to 25 GeV, plotted versus time delay with respect to the prompt pions and equivalently mass of the heavy particle. (b) Three events mentioned in text recorded with the beam line set for 70 GeV.

b Quark の寿命と V_{bc}

$$\Gamma_\mu = (G_F^2 / 192\pi^3)\, m_\mu^5$$

$$\Gamma_b \sim (G_F^2 / 192\pi^3)\, m_b^5\, |V_{bc}|^2 (2x3+3)$$

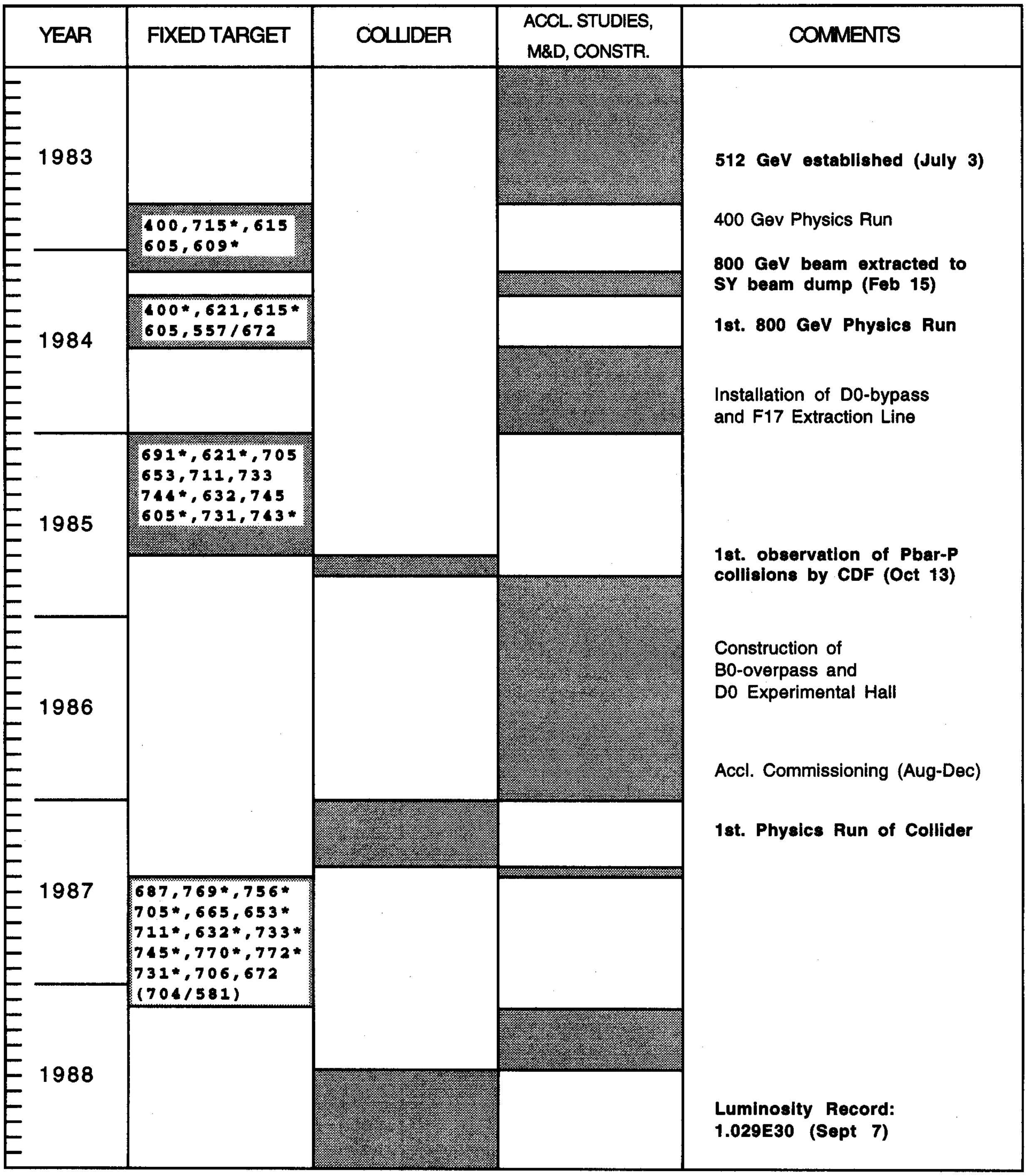
$$(\tau_\mu / \tau_b) = (\Gamma_b / \Gamma_\mu) \sim (m_b/m_\mu)^5 |V_{bc}|^2 x\, 9$$

$\tau_\mu = 2x10^{-6}sec$
$\tau_b < 5x10^{-8}sec$ を入れると $|V_{bc}| > 10^{-4}$

現在の値は~ 0.04

HISTORY OF TEVATRON OPERATION

1983 - 1988



HISTORY OF TEVATRON OPERATION

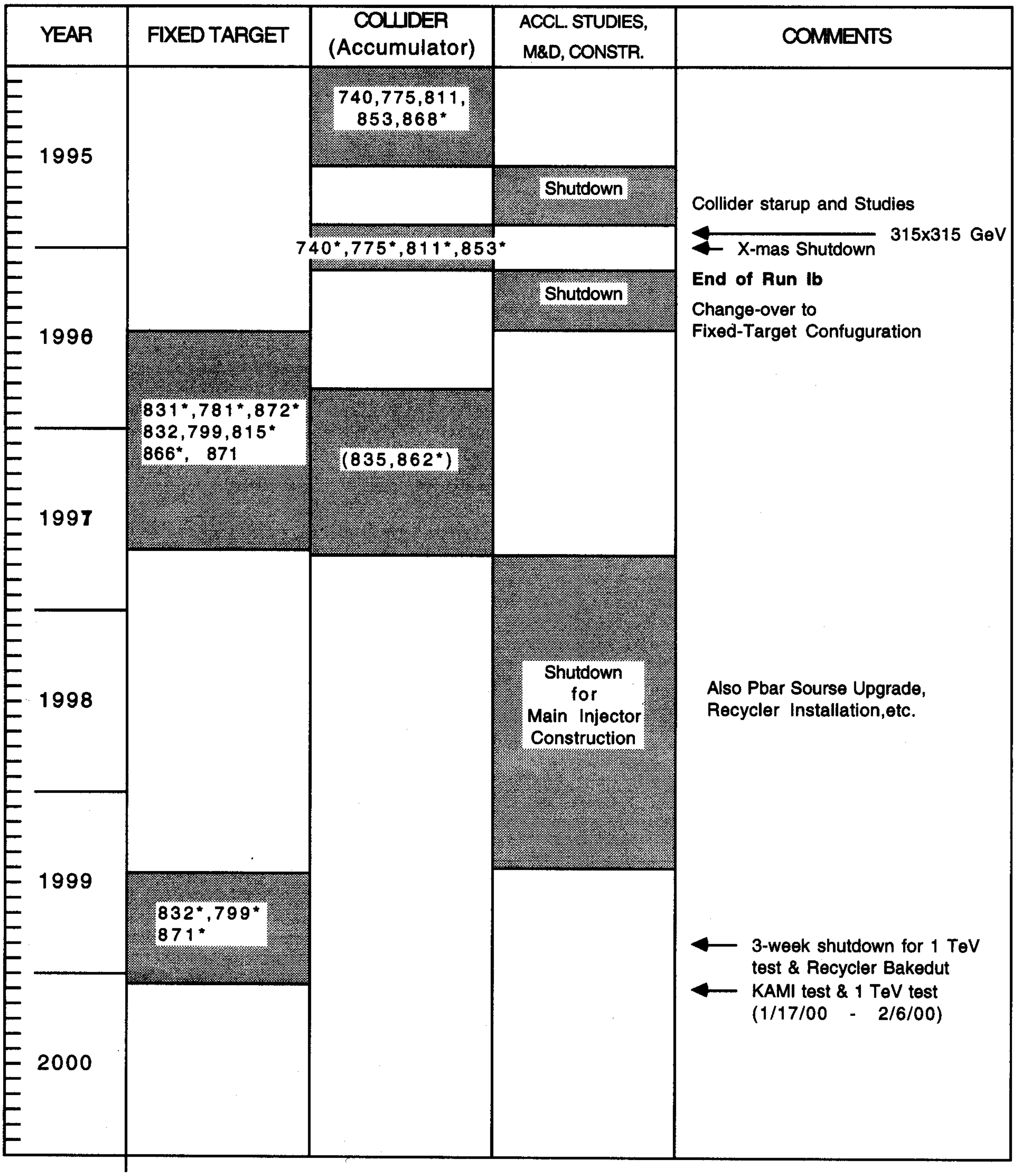
1989 - 1994

YEAR	FIXED TARGET	COLLIDER (Accumulator)	ACCL. STUDIES, M&D, CONSTR.	COMMENTS
1989		710*,713* 735*,741* 778		778 run only two weeks at the end
1989–1990			(shaded)	
1990	687,774*,683 791,761*,771 665,690,782* 789,704*,773 706,672	(760)		Mid February to End of August 6.5 months
1990–1991		778*	(shaded)	A short run for SSC related accelerator study
1991	683*,687*,791* 800*,771*,665* 690*,789*,773* 799,672*,706*	(760*)		Mid July to Mid January 6 months
1992			(shaded)	Accelerator Startup (Mid May through August)
1992–1993		740,775		September 92 to May 93 9 months
1993			(shaded)	Accelerator Startup
1994		740,775,853		12/15/93 to 8/26/94 8.5 months
1994		740,775,811 853,868		

* Completed

HISTORY OF TEVATRON OPERATION

1995 - 2000



* Completed

f

Run II Parameters

RUN	Ib (1993-95) (6x6)	Run IIa (36x36)	Run IIa (140x103)	Run IIb (140x103)	
Protons/bunch	2.3×10^{11}	2.7×10^{11}	2.7×10^{11}	2.7×10^{11}	
Antiprotons/bunch*	5.5×10^{10}	3.0×10^{10}	4.0×10^{10}	1.0×10^{11}	
Total Antiprotons	3.3×10^{11}	1.1×10^{12}	4.2×10^{12}	1.1×10^{13}	
Pbar Production Rate	6.0×10^{10}	1.0×10^{11}	2.1×10^{11}	5.2×10^{11}	hr^{-1}
Proton emittance	23π	20π	20π	20π	mm-mrad
Antiproton emittance	13π	15π	15π	15π	mm-mrad
β^*	35	35	35	35	cm
Energy	900	1000	1000	1000	GeV
Antiproton Bunches	6	36	103	103	
Bunch length (rms)	0.60	0.37	0.37	0.37	m
Crossing Angle	0	0	136	136	μrad
Typical Luminosity	0.16×10^{31}	0.86×10^{32}	2.1×10^{32}	5.2×10^{32}	$cm^{-2}sec^{-1}$
Integrated Luminosity†	3.2	17.3	42	105	pb^{-1}/week
Bunch Spacing	~3500	396	132	132	nsec
Interactions/crossing	2.5	2.3	1.9	4.8	

†The typical luminosity at the beginning of a store has traditionally translated to integrated luminosity with a 33% duty factor. Operation with antiproton recycling may be somewhat different.