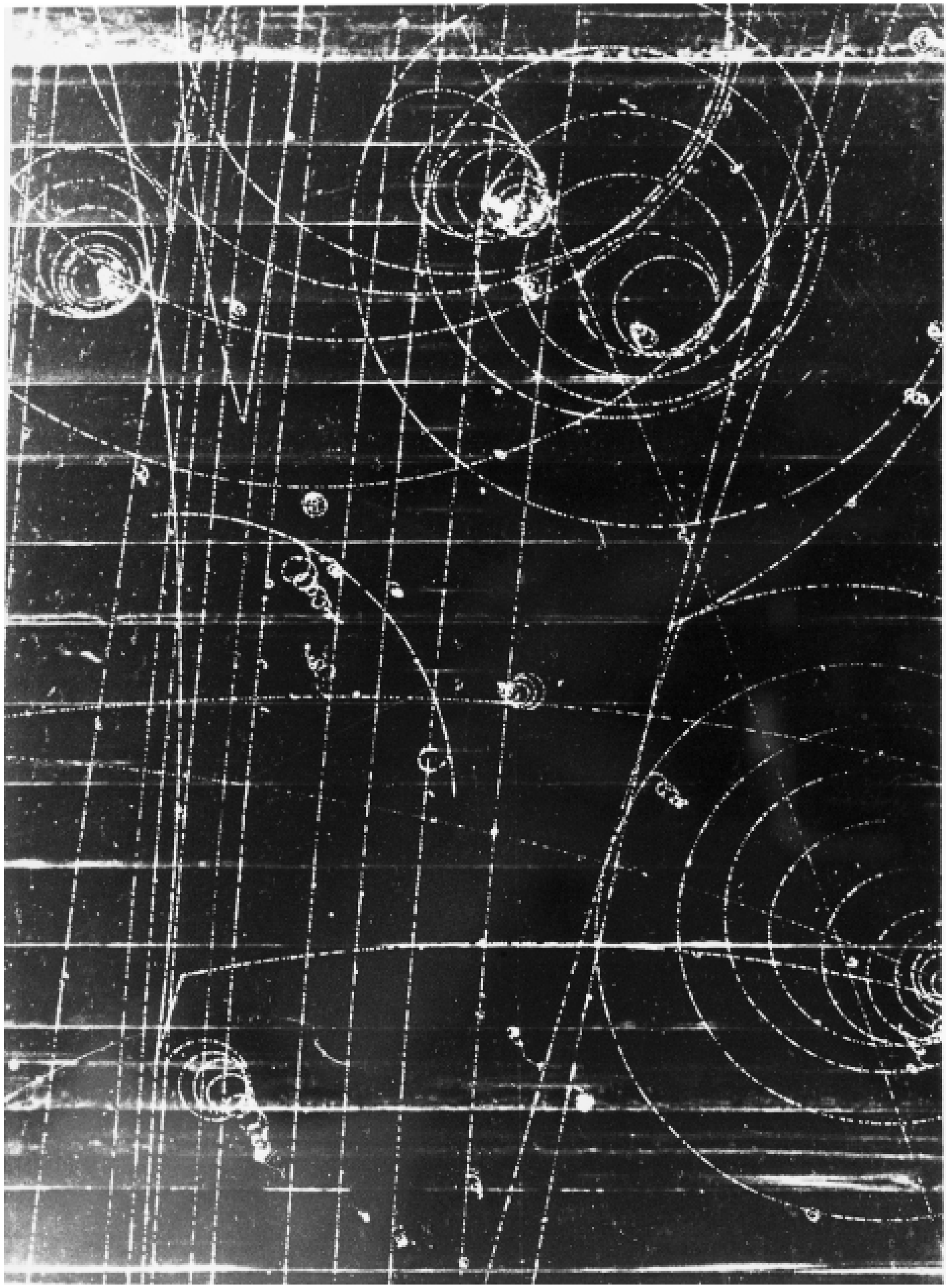
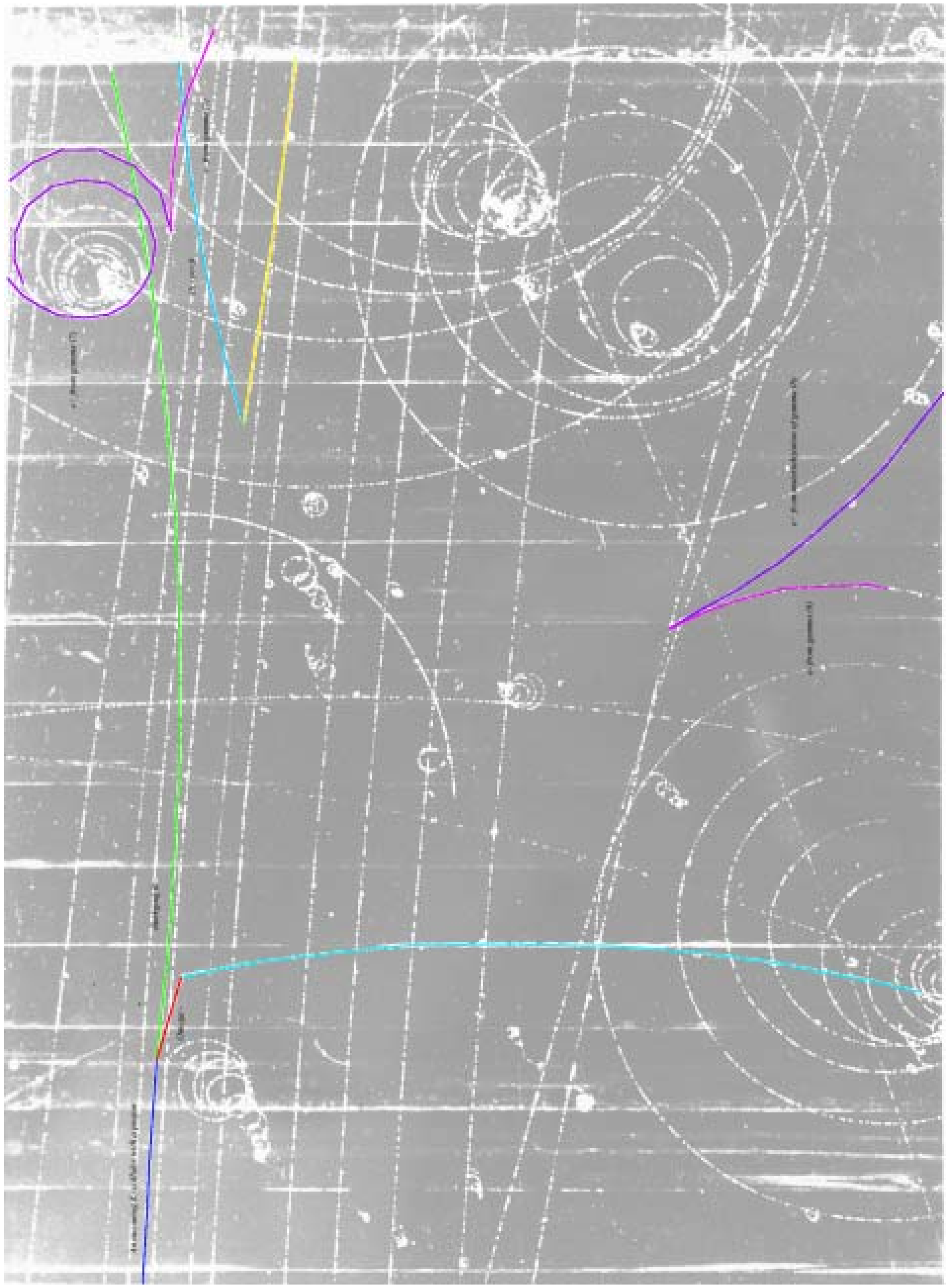
Hogyan lehet ezzel a fényképpel Nobel-díjat nyerni?



- Így



Strangeness

Late 1940's: discovery of a variety of heavier mesons (K – mesons) and baryons ("hyperons") – studied in detail in the 1950's at the new high-energy proton synchrotrons (the 3 GeV "cosmotron" at the Brookhaven National Lab and the 6 GeV Bevatron at Berkeley)

Mass values

Mesons (spin = 0): $m(K^{\pm}) = 493.68\ \mathrm{MeV}/c^2$; $m(K^{\circ}) = 497.67\ \mathrm{MeV}/c^2$

Hyperons (spin = ½): $m(\Lambda) = 1115.7\ \mathrm{MeV}/c^2$; $m(\Sigma^{\pm}) = 1189.4\ \mathrm{MeV}/c^2$

$m(\Xi^{\circ}) = 1314.8\ \mathrm{MeV}/c^2$; $m(\Xi^{-}) = 1321.3\ \mathrm{MeV}/c^2$

Properties

- **Abundant production in proton – nucleus , π – nucleus collisions**
- **Production cross-section typical of strong interactions ($\sigma > 10^{-27}\ \mathrm{cm}^2$)**
- **Production in pairs (example: $\pi^- + p \rightarrow K^{\circ} + \Lambda$; $K^- + p \rightarrow \Xi^- + K^+$)**
- **Decaying to lighter particles with mean life values $10^{-8} - 10^{-10}$ s (as expected for a weak decay)**

Examples of decay modes

$K^{\pm} \rightarrow \pi^{\pm}\pi^{\circ}$; $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$; $K^{\pm} \rightarrow \pi^{\pm}\pi^{\circ}\pi^{\circ}$; $K^{\circ} \rightarrow \pi^{+}\pi^{-}$; $K^{\circ} \rightarrow \pi^{\circ}\pi^{\circ}$; . . .

$\Lambda \rightarrow p\,\pi^{-}$; $\Lambda \rightarrow n\,\pi^{\circ}$; $\Sigma^{+} \rightarrow p\,\pi^{\circ}$; $\Sigma^{+} \rightarrow n\,\pi^{+}$; $\Sigma^{+} \rightarrow n\,\pi^{-}$; . . .

$\Xi^{-} \rightarrow \Lambda\,\pi^{-}$; $\Xi^{\circ} \rightarrow \Lambda\,\pi^{\circ}$

THE "STATIC" QUARK MODEL

Late 1950's – early 1960's: discovery of many strongly interacting particles at the high energy proton accelerators (Berkeley Bevatron, BNL AGS, CERN PS), all with very short mean life times ($10^{-20} - 10^{-23}$ s, typical of strong decays)

⇒ catalog of > 100 strongly interacting particles (collectively named "hadrons")

ARE HADRONS ELEMENTARY PARTICLES?

1964 (Gell-Mann, Zweig): Hadron classification into "families"; observation that all hadrons could be built from three spin ½ "building blocks" (named "quarks" by Gell-Mann):

	u	***d***	***s***
Electric charge (units |*e*|)	+2/3	–1/3	–1/3
Baryonic number	1/3	1/3	1/3
Strangeness	0	0	–1

and three antiquarks ($\bar{u}$, $\bar{d}$, $\bar{s}$) with opposite electric charge and opposite baryonic number and strangeness

Prediction and discovery of the Ω^- particle

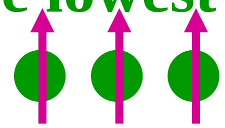
A success of the static quark model

The “decuplet” of spin $\frac{3}{2}$ baryons

Strangeness								Mass (MeV/c^2)
0	N^{*++} *uuu*		N^{*+} *uud*		$N^{*\circ}$ *udd*		N^{*-} *ddd*	1232
–1		Σ^{*+} *suu*		$\Sigma^{*\circ}$ *sud*		Σ^{*-} *sdd*		1384
–2			$\Xi^{*\circ}$ *ssu*		Ξ^{*-} *ssd*			1533
–3				Ω^- *sss*				1680(predicted)

Ω^-: the bound state of three *s* – quarks with the lowest mass

with total angular momentum = 3/ 2 ⇒



Pauli’s exclusion principle requires that the three quarks cannot be identical

The first Ω^- event (observed in the 2 m liquid hydrogen bubble chamber at BNL using a 5 GeV/c K^- beam from the 30 GeV AGS in 1964)

-1 O -3 1 1

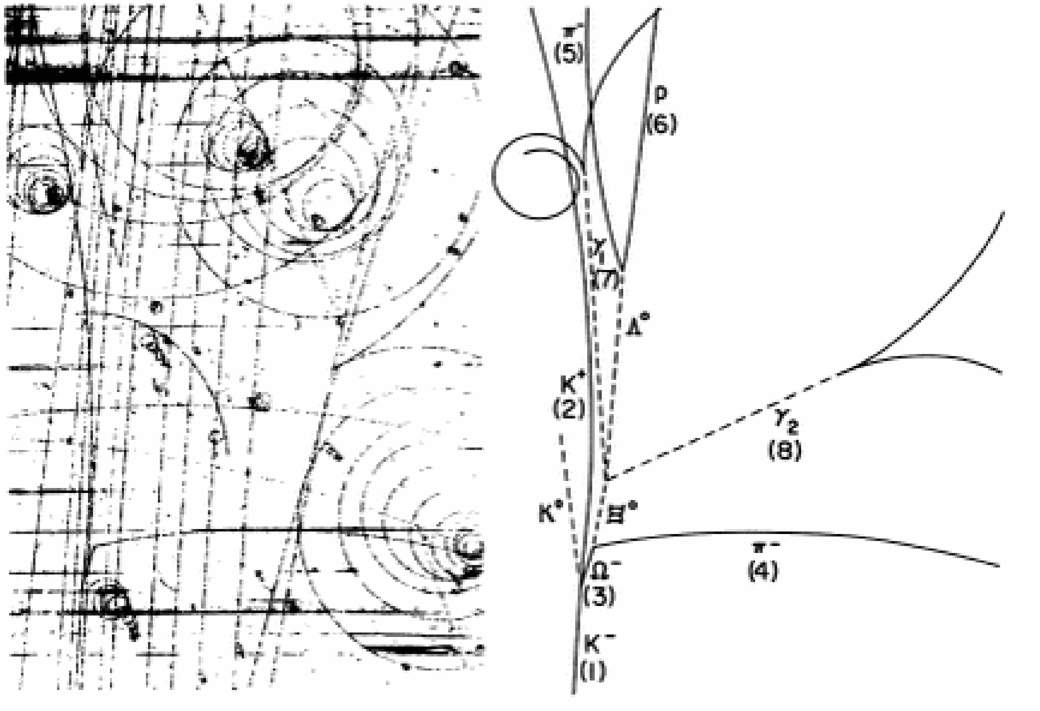
Chain of events in the picture:

$K^- + p \rightarrow \Omega^- + K^+ + K°$
(strangeness conserving)

$\Omega^- \rightarrow \Xi° + \pi^-$
($\Delta S = 1$ weak decay)

$\Xi° \rightarrow \pi° + \Lambda$
($\Delta S = 1$ weak decay)

$\Lambda \rightarrow \pi^- + p$
($\Delta S = 1$ weak decay)

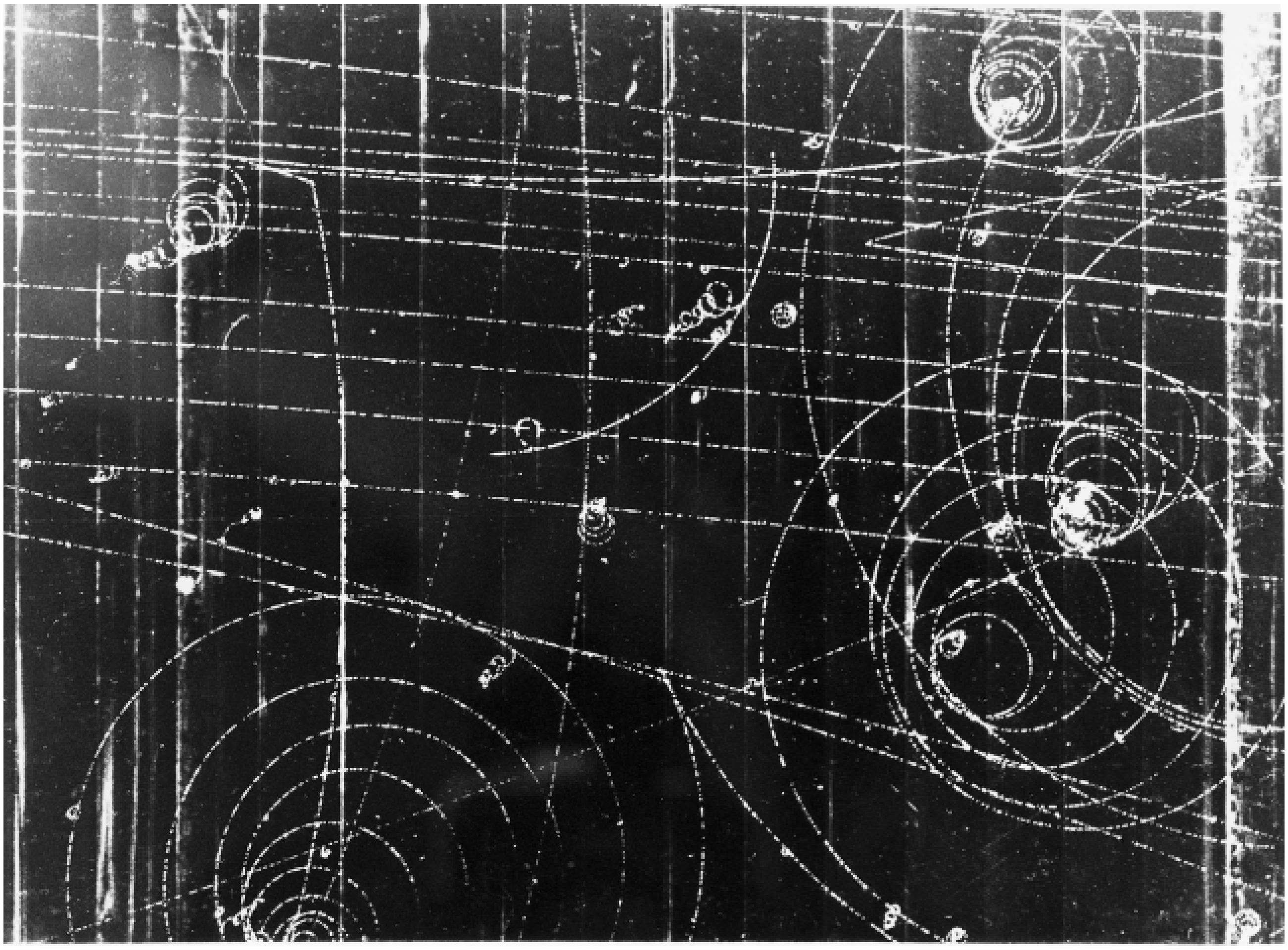


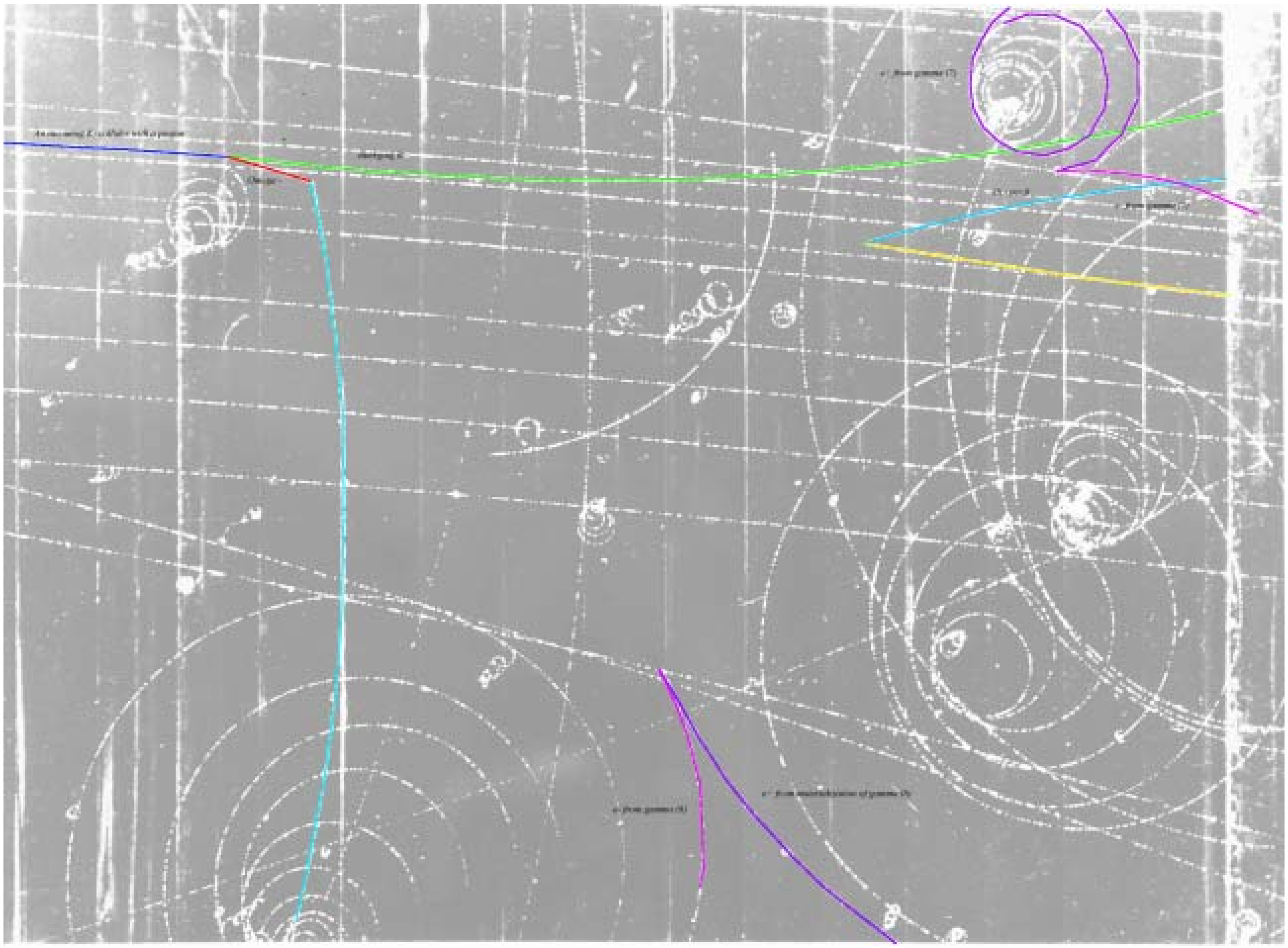
$\pi° \rightarrow \gamma + \gamma$ (electromagnetic decay)
with both γ – rays converting to an e^+e^- in liquid hydrogen
(very lucky event, because the mean free path for $\gamma \rightarrow e^+e^-$ in liquid hydrogen is ~10 m)

Experiment: 100 000 pictures K^- track length 10^6 feet (300 km)
Ω^- mass measured from this event = 1686 ± 12 MeV/c^2

Theory: Nobel-prize Gell-Mann 1969
Gell-Mann Okubo formula predicts: 1680 MeV/c^2

1232 152 1384 149 1533 147 1680 1672




An incoming K⁻ collides with a proton
e⁻ from gamma (2)
e⁺ from gamma (2)
e⁻ from gamma (1)
e⁺ from materialization of gamma (1)

OBSERVATION OF A HYPERON WITH STRANGENESS MINUS THREE*

V. E. Barnes, P. L. Connolly, D. J. Crennell, B. B. Culwick, W. C. Delaney,
W. B. Fowler, P. E. Hagerty,† E. L. Hart, N. Horwitz,† P. V. C. Hough, J. E. Jensen,
J. K. Kopp, K. W. Lai, J. Leitner,† J. L. Lloyd, G. W. London,‡ T. W. Morris, Y. Oren,
R. B. Palmer, A. G. Prodell, D. Radojičić, D. C. Rahm, C. R. Richardson, N. P. Samios,
J. R. Sanford, R. P. Shutt, J. R. Smith, D. L. Stonehill, R. C. Strand, A. M. Thorndike,
M. S. Webster, W. J. Willis, and S. S. Yamamoto
Brookhaven National Laboratory, Upton, New York

(Received 11 February 1964)

It has been pointed out[1] that among the multitude of resonances which have been discovered recently, the $N_{3/2}^*(1238)$, $Y_1^*(1385)$, and $\Xi_{1/2}^*(1532)$ can be arranged as a decuplet with one member still missing. Figure 1 illustrates the position of the nine known resonant states and the postulated tenth particle plotted as a function of mass and the third component of isotopic spin. As can be seen from Fig. 1, this particle (which we call Ω^-, following Gell-Mann[1]) is predicted to be a negatively charged isotopic singlet with strangeness minus three.[2] The spin and parity should be the same as those of the $N_{3/2}^*$, namely, $3/2^+$. The 10-dimensional representation of the group SU_3 can be identified with just such a decuplet. Consequently, the existence of the Ω^- has been cited as a crucial test of the theory of unitary symmetry of strong interactions.[3,4] The mass is predicted[5] by the Gell-Mann–Okubo mass formula to be about 1680 MeV/c^2. We wish to report the observation of an event which we believe to be an example of the production and decay of such a particle.

The BNL 80-in. hydrogen bubble chamber was exposed to a mass-separated beam of 5.0-BeV/c K^- mesons at the Brookhaven AGS. About 100 000 pictures were taken containing a total K^- track length of ~10^6 feet. These pictures have been partially analyzed to search for the more characteristic decay modes of the Ω^-.

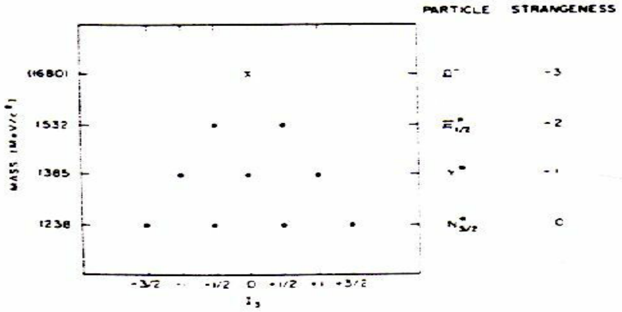
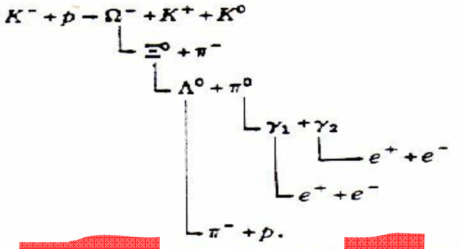


FIG. 1. Decuplet of $\frac{3}{2}^+$ particles plotted as a function of mass versus third component of isotopic spin.

The event in question is shown in Fig. 2, and the pertinent measured quantities are given in Table I. Our interpretation of this event is



(1)

From the momentum and gap length measurements, track 2 is identified as a K^+. (A bubble density of 1.9 times minimum was expected for this track while the measured value was 1.7 ± 0.2.) Tracks 5 and 6 are in good agreement with the decay of a Λ^0, but the Λ^0 cannot come from the primary interaction. The Λ^0 mass as calculated from the measured proton and π^- kinematic quantities is 1116 ± 2 MeV/c^2. Since the bubble density from gap length measurement of track 6 is 1.52 ± 0.17, compared to 1.0 expected for a π^+ and 1.4 for a proton, the interpretation of the V as a K^0 is unlikely. In any case, from kinematical considerations such a K^0 could not come from the production vertex. The Λ^0 appears six decay lengths from the wall of the bubble chamber, and there is no other visible origin in the chamber.

The event is unusual in that two gamma rays, apparently associated with it, convert to electron-positron pairs in the liquid hydrogen. From measurements of the electron momenta and angles, we determine that the effective mass of the two gamma rays is 135.1 ± 1.5 MeV/c^2, consistent with a π^0 decay. In a similar manner, we have used the calculated π^0 momentum and angles, and the values from the fitted Λ^0 to deter-

Heavy QUARK Drama

Main actors:

p	AGS	1970	fix target	30 GeV
p	AGS	1974	fix target	30 GeV
ee	ADONE	1974	collider	3 GeV
ee	SPEAR	1974	collider	7 GeV
p	PS	1974	fix target	30 GeV
pp	ISR	1975	collider	60 GeV
ee	SPEAR	1975..	collider	7 GeV
p	NAL	1977	fix target	400 GeV
ee	DORIS	1977	collider	9 GeV
pp	SPPS	?1985	collider	900 GeV
pp	FNAL	1995	collider	1800 GeV

- Fabrizio del Dongo in the battle field of Waterloo

Observation of Massive Muon Pairs in Hadron Collisions*

J. H. Christenson, G. S. Hicks, L. M. Lederman, P. J. Limon, and B. G. Pope
Columbia University, New York, New York 10027, and Brookhaven National Laboratory, Upton, New York 11973

and

E. Zavattini
CERN Laboratory, Geneva, Switzerland

(Received [illegible] September 1970)

Muon pairs in the mass range $1 < m_{\mu\mu} < 6.7$ GeV/c^2 have been observed in collisions of high-energy protons with uranium nuclei. At an incident energy of 29 GeV, the cross section varies smoothly as $d\sigma/dm_{\mu\mu} \approx 10^{-32} m_{\mu\mu}^{-5}$ cm^2 (GeV/c^2)$^{-1}$ and exhibits no resonant structure. The total cross section increases by a factor of 5 as the proton energy rises from 22 to 29.5 GeV.

Various techniques have been used to probe the electromagnetic structure of hadrons. By far the most extensive has been electron-proton scattering which explored the region of large spacelike momentum transfers up to $q^2 = 25$ (GeV/c)^2. We report here on an experiment designed to extend this probe to large timelike momentum transfers via the reaction

$$p + \mathrm{U} \to \mu^+ + \mu^- + \text{anything}.$$

The spectrum of effective masses of the muon pair emerging from high-energy proton-nucleus collisions is observed. Earlier research[1-4] in this domain has been limited to momentum transfers $\lesssim 1$ (GeV/c)^2. The high energy and intensity of the primary proton beam at the alternating-gradient synchrotron (AGS) enabled us to record muon pairs with effective masses squared ($m^2 = -q^2$) up to 40 (GeV/c^2)^2, where the cross section $d\sigma/dm \sim 10^{-39}$ cm^2/(GeV/c)^2. This timelike reaction is also sensitive to the possible existence of resonant structures, i.e., massive vector mesons, neutral weak bosons, etc. Data were taken at incident proton energies of 22, 25, 28.5, and 29.5 GeV/c.

Muon pairs produced by totally absorbing the slow extracted proton beam in a thick uranium target were detected by the apparatus shown in Fig. 1. The direction and range of each muon were measured to allow the determination of the mass and vector momentum of the dimuon. An iron and concrete wall following the target suppressed the overwhelming flux of nonmuonic background while eliminating muons with momenta less than 5 GeV/c. The very dense target absorbed most pions and kaons before they decayed. Nevertheless, the high intensity of pions and kaons resulted in a large flux of muons which penetrated the shielding wall. To suppress this background further, a thick, tapered, iron absorber required the transverse momentum of a detected muon to exceed 0.5 GeV/c. These background muons were thereby strongly reduced without seriously affecting the detection efficiency for muon pairs of effective mass greater than ~1 GeV/c^2.

The mass resolution of the lepton pairs was limited by multiple scattering in the shield. Hence, modest precision in measuring the direction and range of each muon was adequate. Minimum angular uncertainty was obtained by assuming the muon originated in the target and measuring its direction by means of a single counter in a 36-element plastic scintillation-counter hodoscope mounted on the face of the tapered absorber. A subsequent plane of liquid scintillators provided crude angular confirmation. Additional planes following 4-, 6-, and $8\frac{1}{2}$-ft-thick steel walls defined the muon range. Monte Carlo studies indicate a mass resolution that varies from ±15% at a mass of 2 GeV/c^2 to ±8% at 5 GeV/c^2. Additional counters placed at large angles to the proton direction served to extend the mass range to ~7 GeV/c^2. These were used only during the 29.5-GeV run.

Muon-pair candidates were signaled by a coin-

FIG. 1. Plan view of the apparatus.

The most STUPID experiment

DE: Hogyan vizsgáljuk a napfogyatkozást?

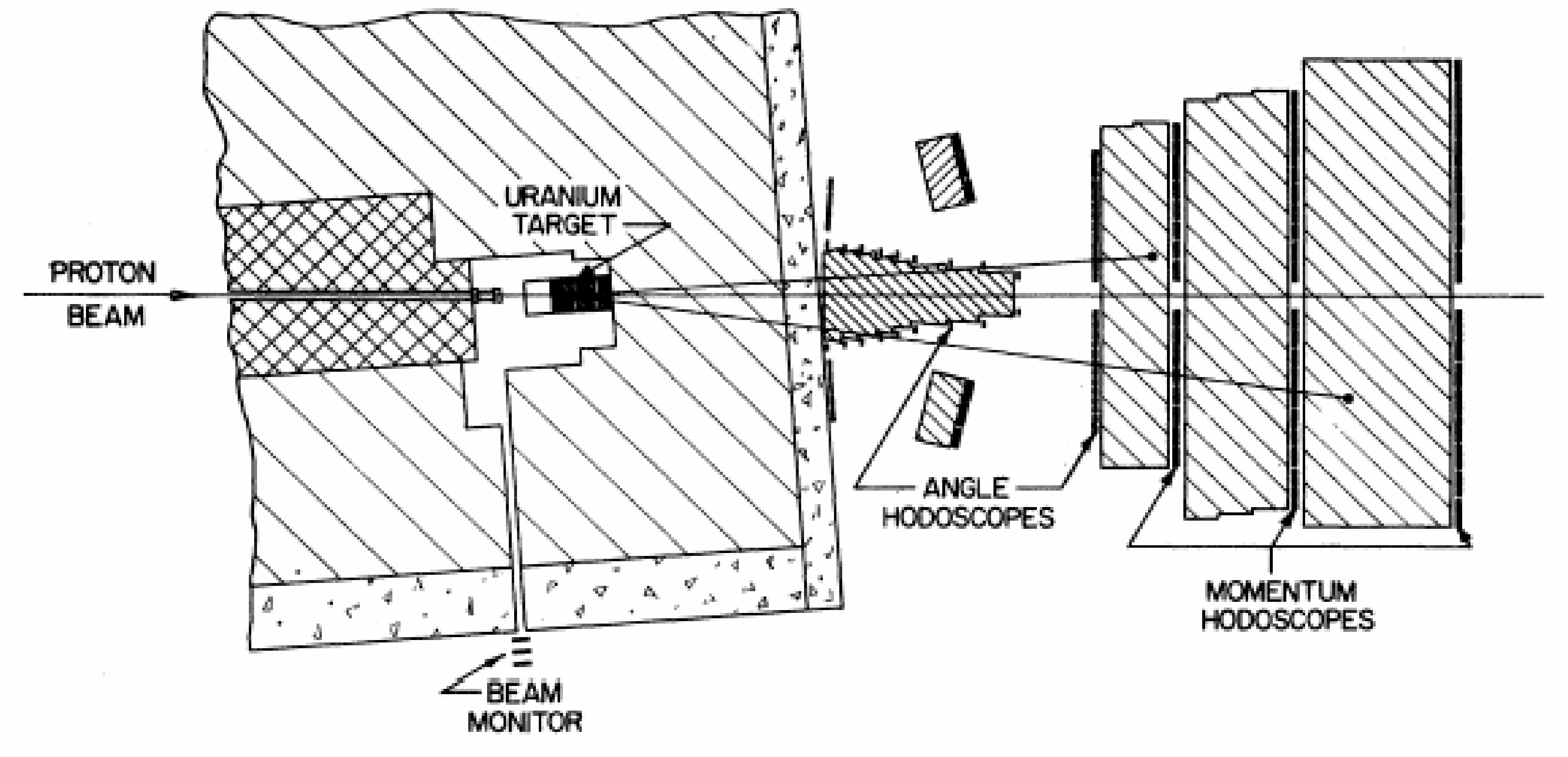


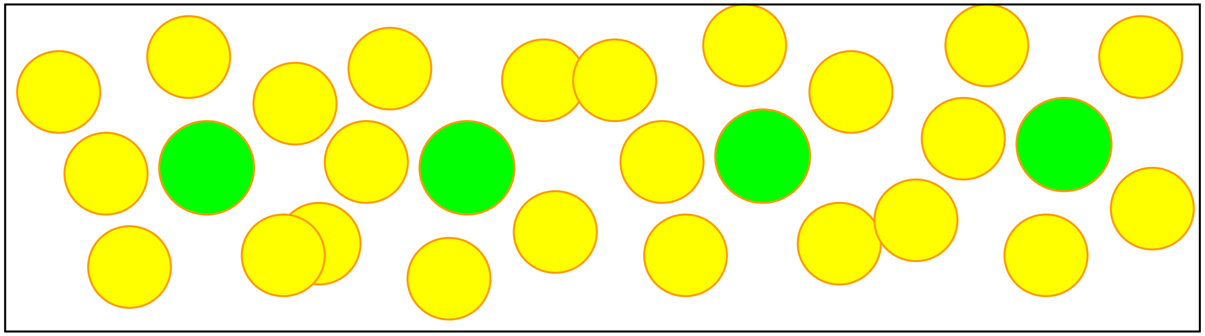
FIG. 1. Plan view of apparatus.

Mindent megölünk, csírájában elfojtunk, csak a MUON-ok jutnak el a detektorokig.

Muon csak ionizacóval veszít energiát. Energia mérés: futás kifulladásig (RANGE)

Coulomb-anyag

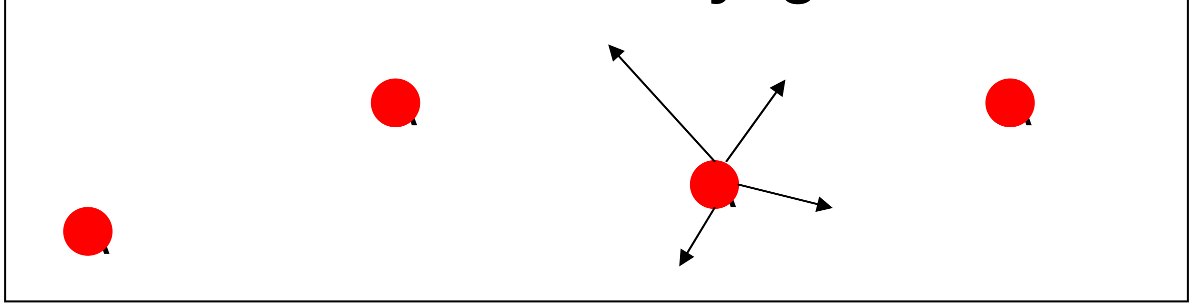
Lassít minden töltött részecskét



Hadron-anyag

Elnyel minden hadront

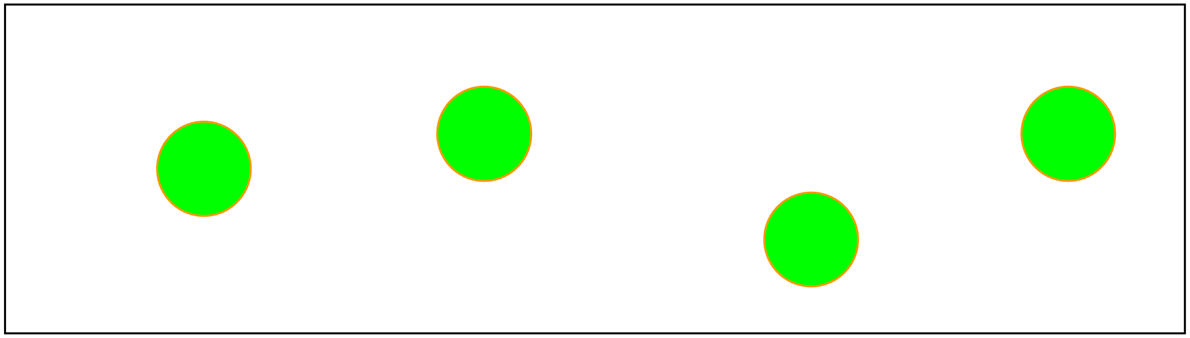
Hadron-kaloriméter



Nukleáris Coulomb-anyag

Gyorsan elnyel fotont és elektront

EM-kaloriméter



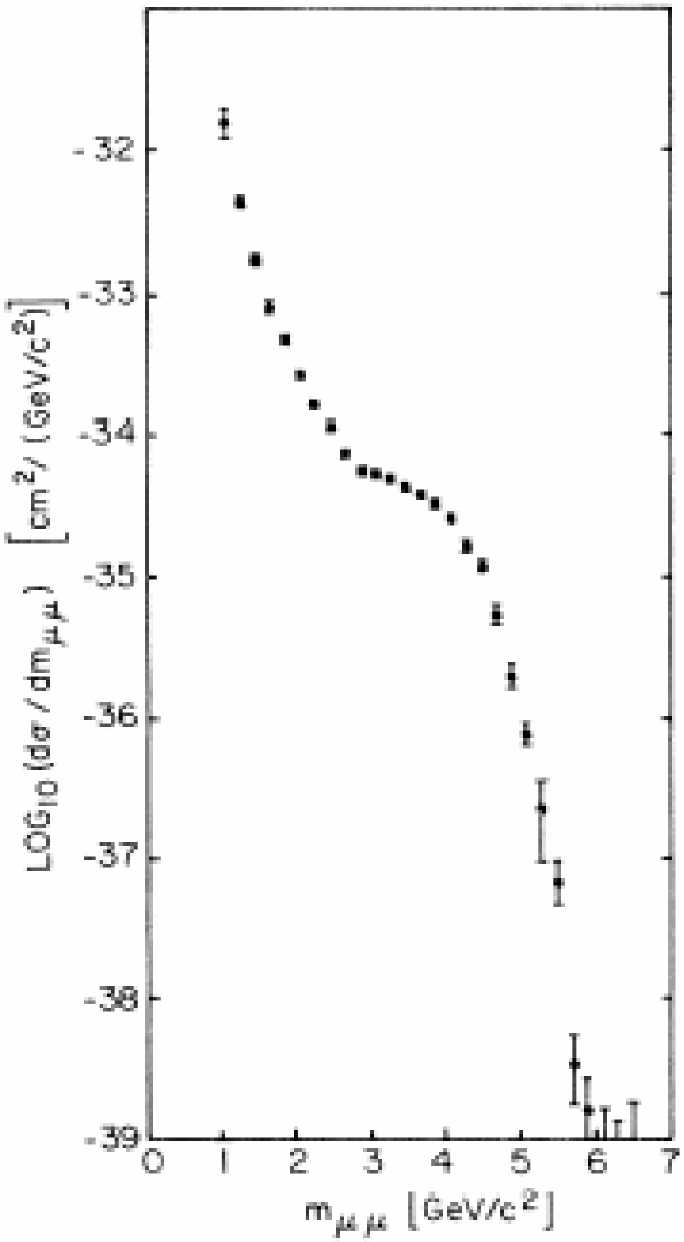


FIG. 10. *dσ/dm*. Weighted average of standard and "wide angle" events. Proton energy = 29.5 GeV.

V. DISCUSSION OF RESULTS

A. Nonobservation of Resonances

The invariant mass of the muon pair was the variable of primary interest for a simultaneous and, of course, highly related search made for "resonant" states. Any massive vector mesons would be expected to enhance the continuum near the resonance mass. As seen both in the observed mass spectrum (Fig. 4) and in the resultant cross sections $d\sigma/dq$ (Figs. 6–10) there is no forcing evidence of any resonant structure. However, to some extent, the smoothness of the cross section (for example, Fig. 10) is a reflection of the required smoothness of the input distribution to the Monte Carlo calculation. In order to properly investigate the production probability of a vector meson at a given mass, a narrow resonance was introduced into the Monte Carlo program, as an enhancement to a smooth continuum. The resonance was increased in amplitude until the resulting bump visibly distorted the output spectrum. This procedure properly introduced the single-particle mass resolution and efficiency into the analysis and enabled limits on vector-meson production to be calculated. The limits listed in Table VI represent the inseparable product of the production cross section of the vector particle and its branching ratio into two muons. It is noted that those limits apply to strong production of ρ-type particles as well as to production of neutral weak intermediate bosons.

Final publication: Phys. Rev. D8, 1 October 1973

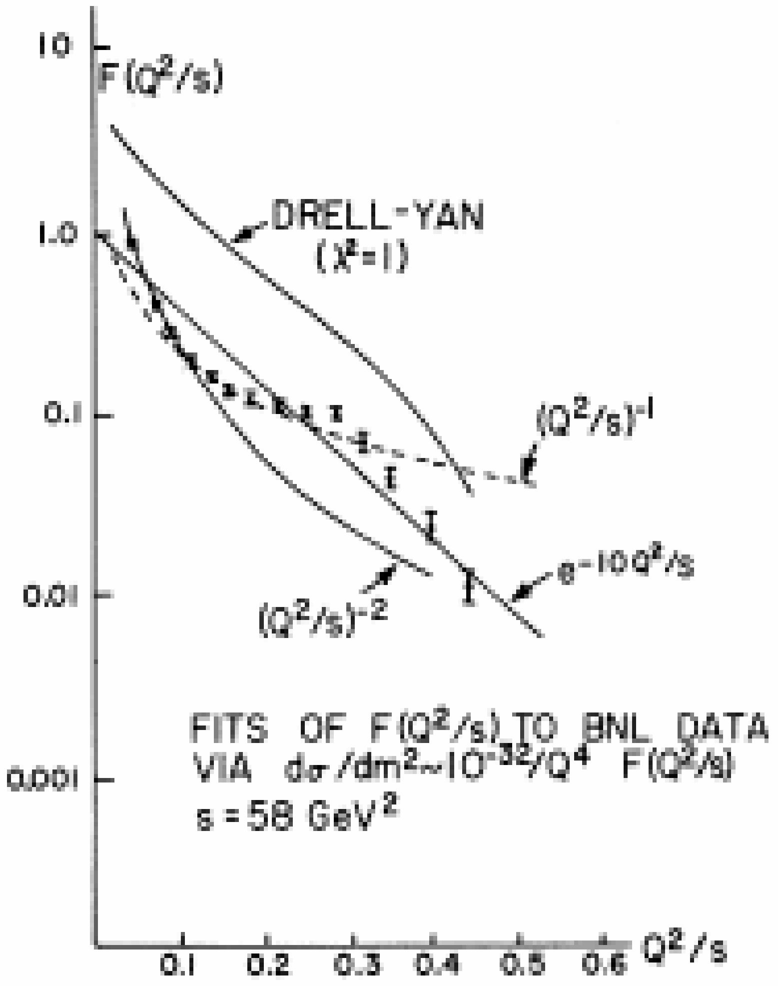
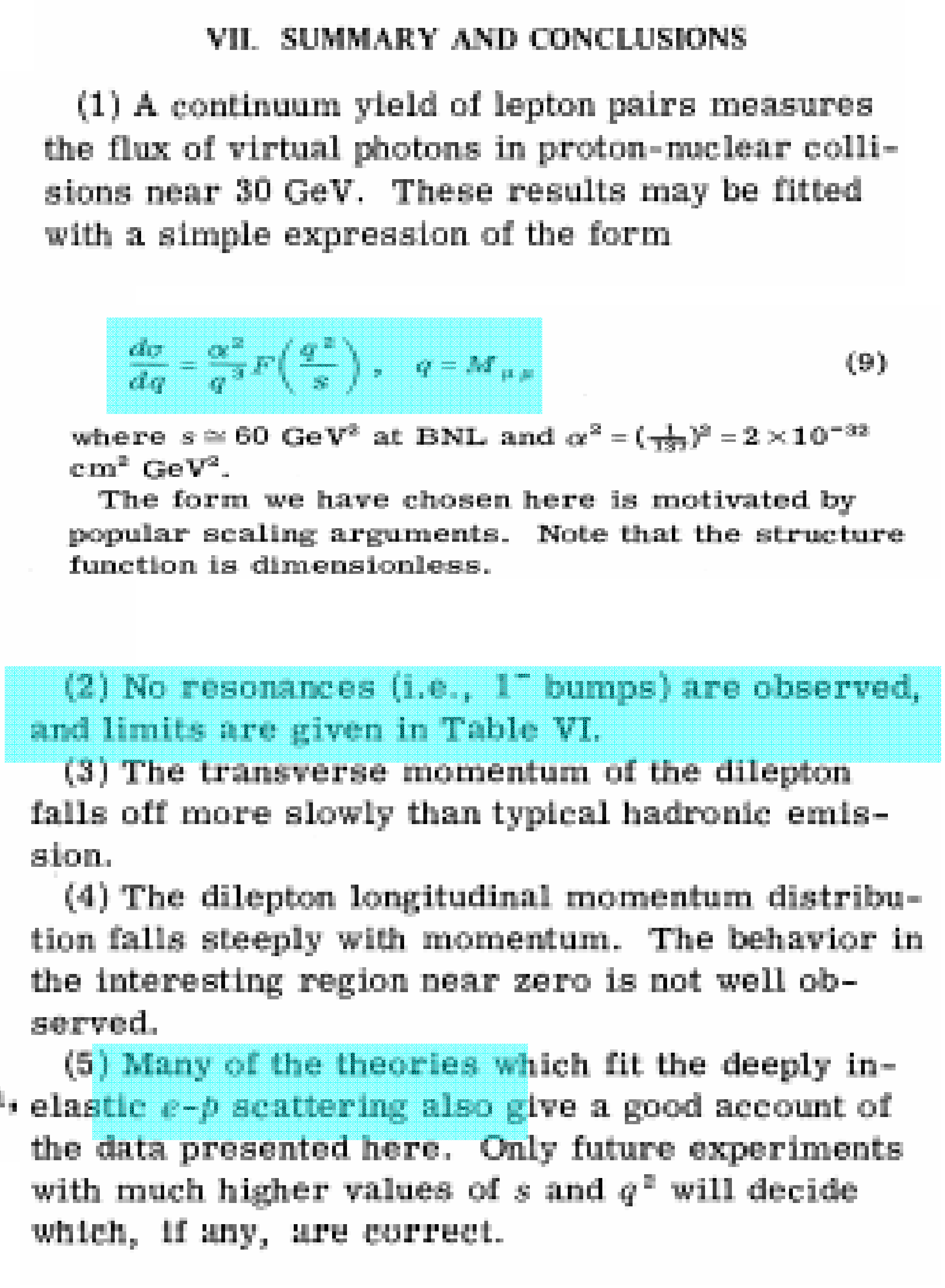


FIG. 17. $F(Q^2/s)$ shown for the experimental data, and various models.



VII. SUMMARY AND CONCLUSIONS

(1) A continuum yield of lepton pairs measures the flux of virtual photons in proton-nuclear collisions near 30 GeV. These results may be fitted with a simple expression of the form

$$\frac{d\sigma}{dq} = \frac{\alpha^2}{q^3} F\left(\frac{q^2}{s}\right), \quad q = M_{\mu\mu} \tag{9}$$

where $s \cong 60\ \text{GeV}^2$ at BNL and $\alpha^2 = (\frac{1}{137})^2 = 2 \times 10^{-32}\ \text{cm}^2\ \text{GeV}^2$.

The form we have chosen here is motivated by popular scaling arguments. Note that the structure function is dimensionless.

(2) No resonances (i.e., 1^- bumps) are observed, and limits are given in Table VI.

(3) The transverse momentum of the dilepton falls off more slowly than typical hadronic emission.

(4) The dilepton longitudinal momentum distribution falls steeply with momentum. The behavior in the interesting region near zero is not well observed.

(5) Many of the theories which fit the deeply inelastic e-p scattering also give a good account of the data presented here. Only future experiments with much higher values of s and q^2 will decide which, if any, are correct.

ALVAJÁRÁS a legfelsőbb fokon

Volume 33, Number 23 PHYSICAL REVIEW LETTERS 2 December 1974

Experimental Observation of a Heavy Particle J†

J. J. Aubert, U. Becker, P. J. Biggs, J. Burger, M. Chen, G. Everhart, P. Goldhagen,
J. Leong, T. McCorriston, T. G. Rhoades, M. Rohde, Samuel C. C. Ting, and Sau Lan Wu
*Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology,
Cambridge, Massachusetts 02139*

and

Y. Y. Lee
Brookhaven National Laboratory, Upton, New York 11973

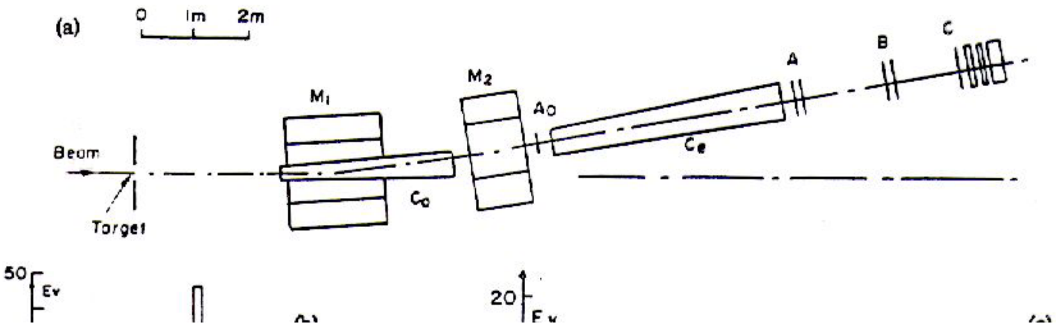
(Received 12 November 1974)

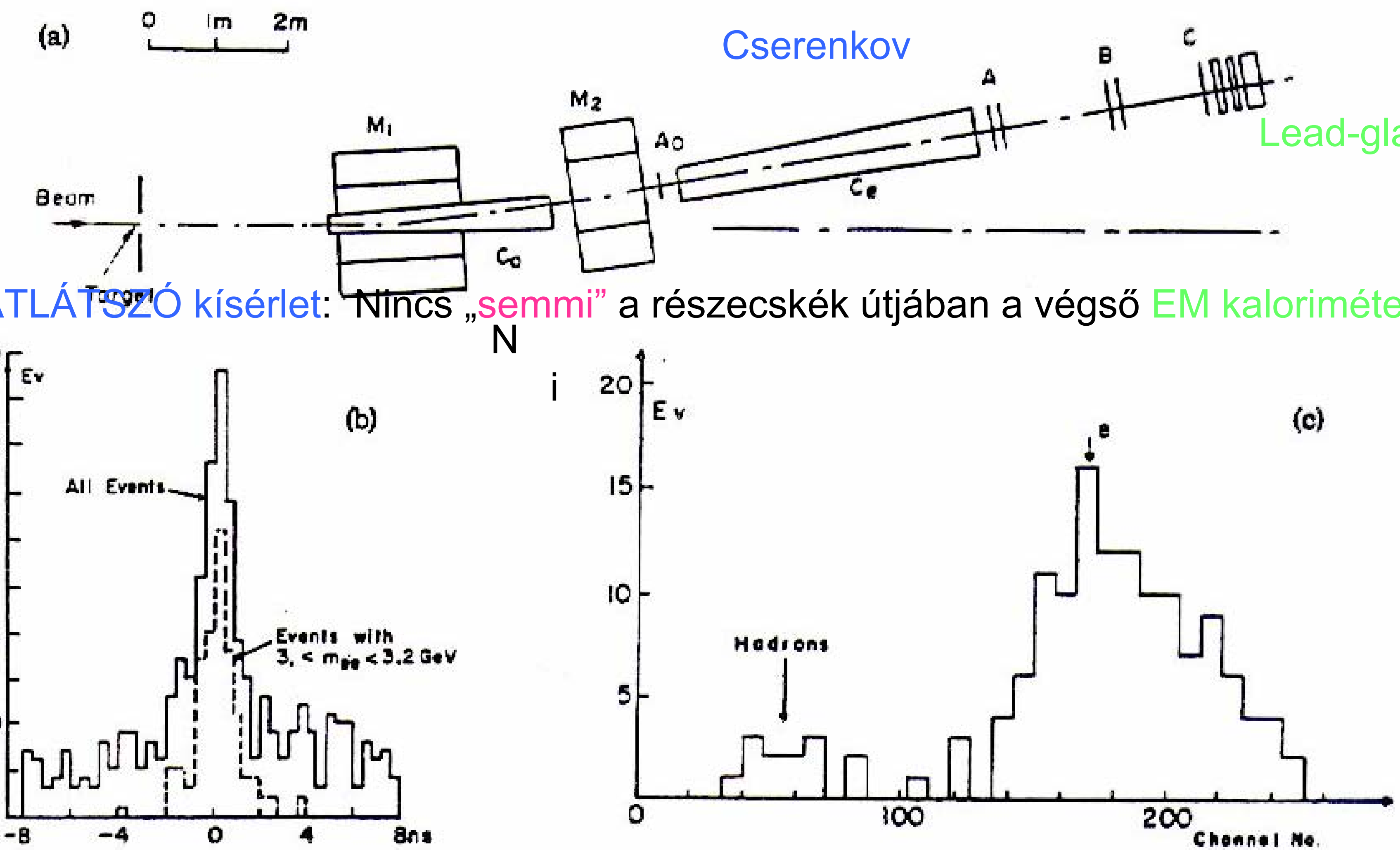
We report the observation of a heavy particle J, with mass $m = 3.1$ GeV and width approximately zero. The observation was made from the reaction $p + \mathrm{Be} \rightarrow e^+ + e^- + x$ by measuring the e^+e^- mass spectrum with a precise pair spectrometer at the Brookhaven National Laboratory's 30-GeV alternating-gradient synchrotron.

This experiment is part of a large program to study the behavior of timelike photons in $p + p \rightarrow e^+ + e^- + x$ reactions[1] and to search for new particles which decay into e^+e^- and $\mu^+\mu^-$ pairs.

We use a slow extracted beam from the Brookhaven National Laboratory's alternating-gradient synchrotron. The beam intensity varies from 10^{10} to 2×10^{12} p/pulse. The beam is guided onto an extended target, normally nine pieces of 70-mil Be, to enable us to reject the pair accidentals by requiring the two tracks to come from the same origin. The beam intensity is monitored with a secondary emission counter, calibrated daily with a thin Al foil. The beam spot size is 3×6 mm^2, and is monitored with closed-circuit television. Figure 1(a) shows the simplified side view of one arm of the spectrometer. The two arms are placed at 14.6° with respect to the incident beam; bending (by $M1$, $M2$) is done vertically to decouple the angle (θ) and the momentum (p) of the particle.

The Cherenkov counter C_0 is filled with one atmosphere and C_e with 0.8 atmosphere of H_2. The counters C_0 and C_e are decoupled by magnets $M1$ and $M2$. This enables us to reject knock-on electrons from C_0. Extensive and repeated calibra-





Cserenkov

Lead-glass

ÁTLÁTSZÓ kísérlet: Nincs „semmi” a részecskék útjában a végső EM kaloriméterig

N

i

G. 1. (a) Simplified side view of one of the spectrometer arms. (b) Time-of-flight spectrum of e^+e^- pairs a
ose events with $3.0 < m < 3.2$ GeV. (c) Pulse-height spectrum of e^- (same for e^+) of the e^+e^- pair.

Received 12 Nov. 1974

tion of all the counters is done with approximately 6-GeV electrons produced with a lead converter target. There are eleven planes ($2\times A_0$, $3\times A$, $3\times B$, $3\times C$) of proportional chambers rotated approximately 20° with respect to each other to reduce multitrack confusion. To further reduce the problem of operating the chambers at high rate, eight vertical and eight horizontal hodoscope counters are placed behind chambers A and B. Behind the largest chamber C (1 m × 1 m) there are two banks of 25 lead glass counters of 3 radiation lengths each, followed by one bank of lead-Lucite counters to further reject hadrons from electrons and to improve track identification. During the experiment all the counters are monitored with a PDP 11-45 computer and all high voltages are checked every 30 min.

The magnets were measured with a three-dimensional Hall probe. A total of 10^5 points were mapped at various current settings. The acceptance of the spectrometer is $\Delta\theta = \pm 1°$, $\Delta\varphi = \pm 2°$, $\Delta m = 2$ GeV. Thus the spectrometer enables us to map the e^+e^- mass region from 1 to 5 GeV in three overlapping settings.

Figure 1(b) shows the time-of-flight spectrum between the e^+ and e^- arms in the mass region $2.5 < m < 3.5$ GeV. A clear peak of 1.5-nsec width is observed. This enables us to reject the accidentals easily. Track reconstruction between the two arms was made and again we have a clear-cut distinction between real pairs and accidentals. Figure 1(c) shows the shower and lead-glass pulse height spectrum for the events in the mass region $3.0 < m < 3.2$ GeV. They are again in agreement with the calibration made by the e beam.

Typical data are shown in Fig. 2. There is a clear sharp enhancement at $m = 3.1$ GeV. Without folding in the 10^5 mapped magnetic points and

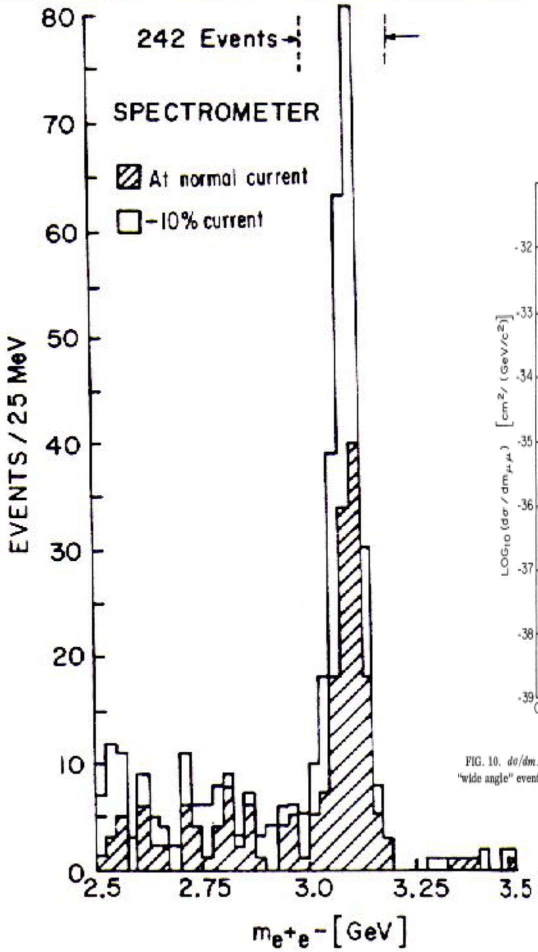


FIG. 2. Mass spectrum showing the existence of J. Results from two spectrometer settings are plotted showing that the peak is independent of spectrometer currents. The run at reduced current was taken two months later than the normal run.

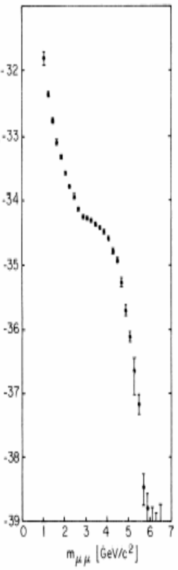
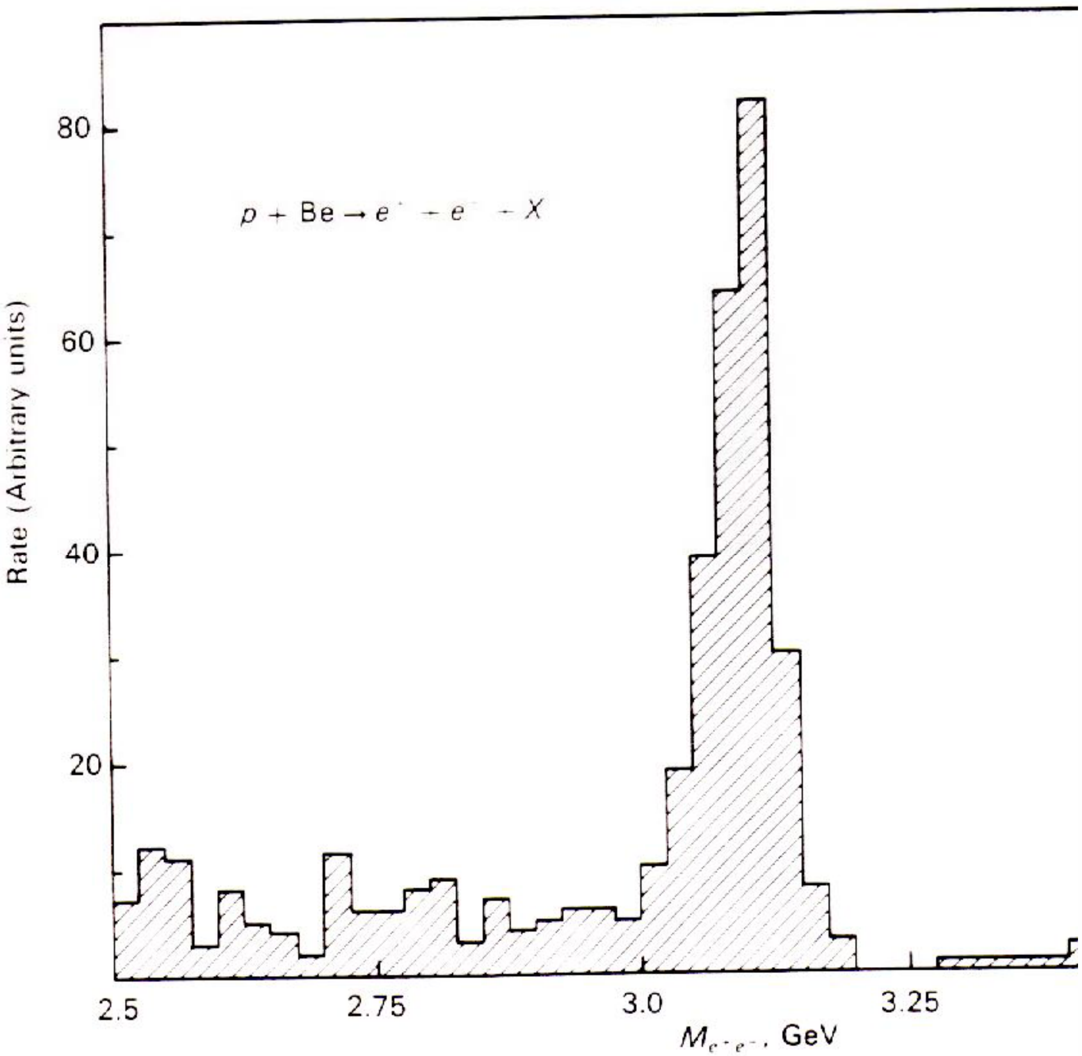


FIG. 10. $d\sigma/dm$. Weighted average of standard and "wide angle" events. Proton energy = 29.5 GeV.

(4) To ensure that the peak is not due to scatte ing from the sides of magnets, cuts were made



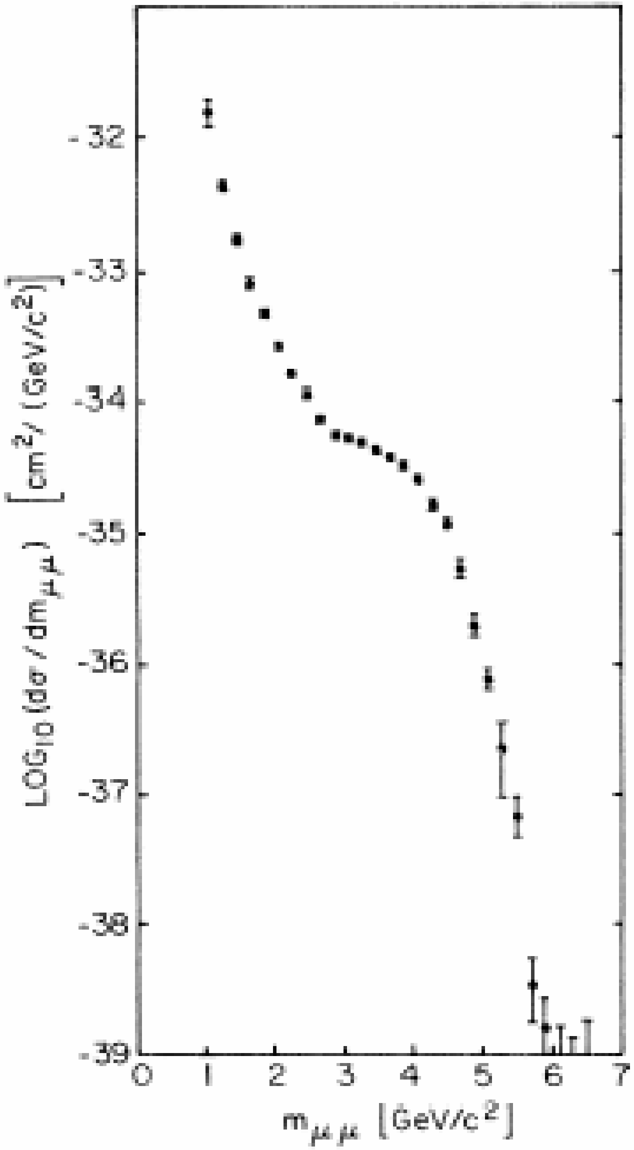


Fig. 5.11 Results of Aubert *et al.* (1974) indicating the narrow resonance ψ/J in t mass distribution of e^+e^- pairs produced in inclusive reactions of protons wit target. The experiment was carried out with the 28-GeV AGS at Brookhaven National Laboratory.

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

2 Dec 1974 PRL 35 (1974) 1406

Received 13 Nov 1974

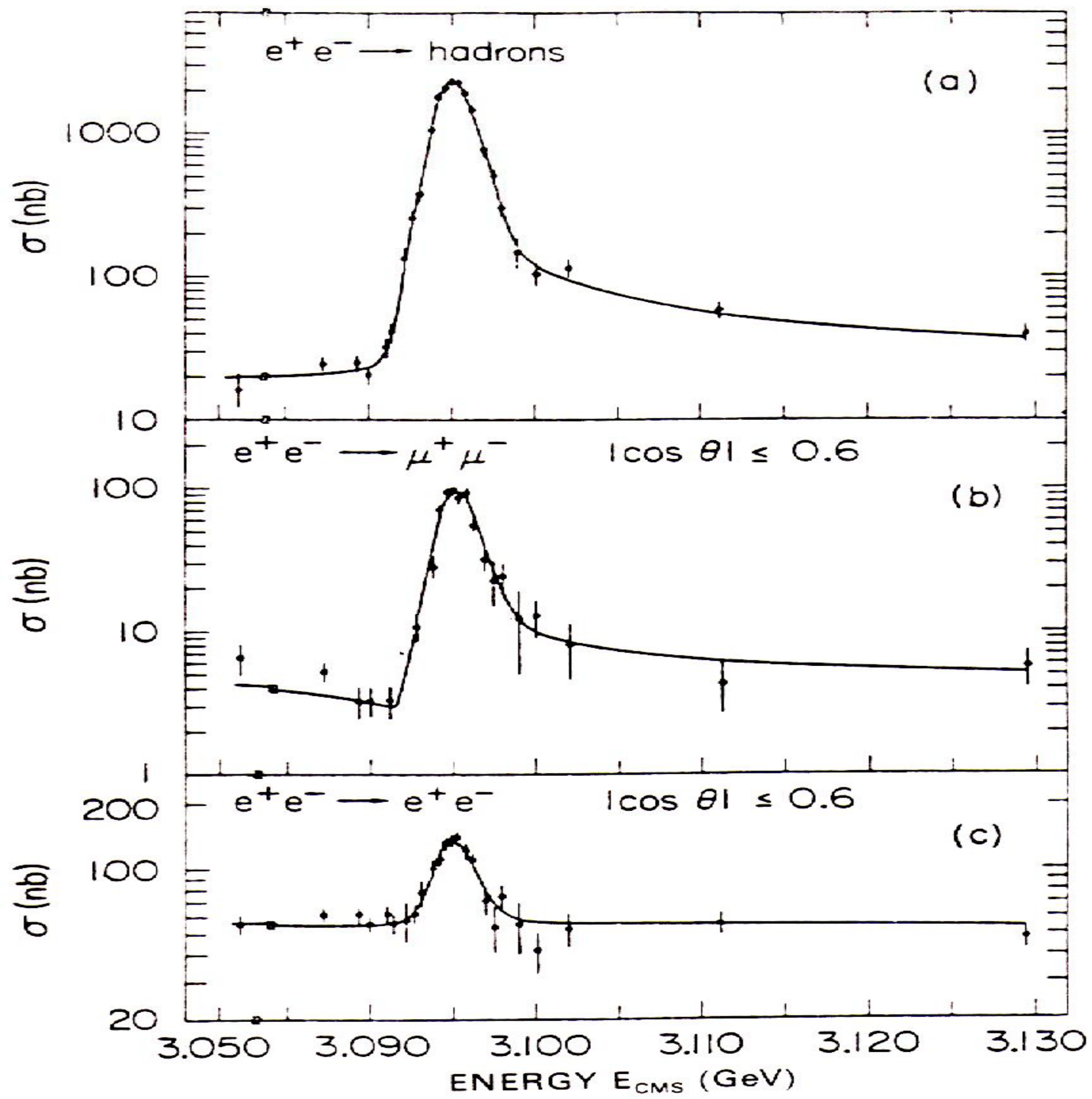


Fig. 5.10 Results of Augustin *et al.* (1974) showing the observation of the ψ/J resonance of mass 3.1 GeV, produced in e^+e^- annihilation at the SPEAR storage ring, SLAC.

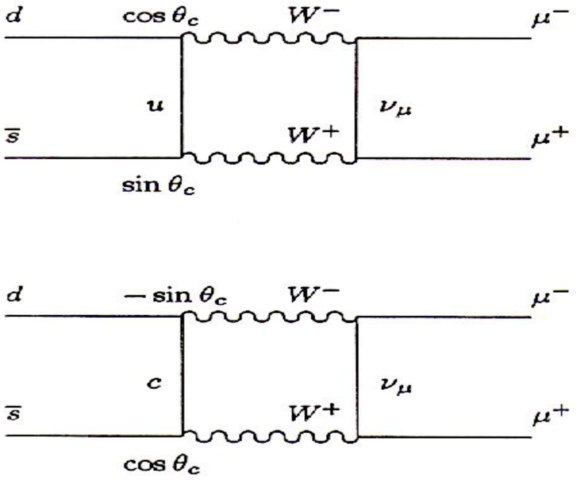


Figure 9.4: Two contributions to the decay $K^0_L \rightarrow \mu^+\mu^-$ showing the factors present at the quark vertices. If only the upper contribution were present, the decay rate would be far in excess of the observed rate. The second contribution cancels most of the first. The cancellation would be exact if the c quark and u quark had the same mass. This cancellation is an example of the Glashow–Iliopoulos–Maiani mechanism.

lacking was proof that its constituents were indeed the charmed quarks first proposed by Bjorken and Glashow. As Glashow, Iliopoulos, and Maiani showed in 1970, charmed quarks were the simplest way to explain the absence of neutral strangeness-changing weak currents.

Until 1973 only weak currents that change charge had been observed. For example, in μ decay, the μ turns into ν_μ, and its charge changes by one unit. The neutral weak current, which can cause reactions like $\nu p \rightarrow \nu p$, as discussed in Chapter 12, does not change strangeness. If strangeness could be changed by a neutral current, then the decays $K^0 \rightarrow \mu^+\mu^-$ and $K^+ \rightarrow \pi^+e^+e^-$ would be possible. However, very stringent limits existed on these decays and others requiring strangeness-changing neutral weak currents. So restrictive were these limits that even second order weak processes would violate them in the usual Cabibbo scheme of weak interactions. Glashow, Iliopoulos, and Maiani showed that if in addition to the charged weak current changing an s quark into a u quark, there were another changing an s quark into a c quark, there would be a cancellation of the second order terms.

Consider the decay $K^0_L \rightarrow \mu^+\mu^-$ for which the rate was known to be extremely small. The decay can proceed through the diagrams shown in Figure 9.4. Aside from other factors, the first diagram is proportional to $\sin\theta_C$ from the usW vertex and to $\cos\theta_C$ from the udW vertex. Here, W stands for the carrier of the weak interaction mentioned in Chapter 6 and discussed at length in Chapter 12.

$\psi(3700)$	3685 ± 1	1^-, 0	0.228	$\psi + 2\pi$	[illegible]
				$\chi + \gamma$	21%
				e^+e^-	0.9%
				$\mu^+\mu^-$	0.9%

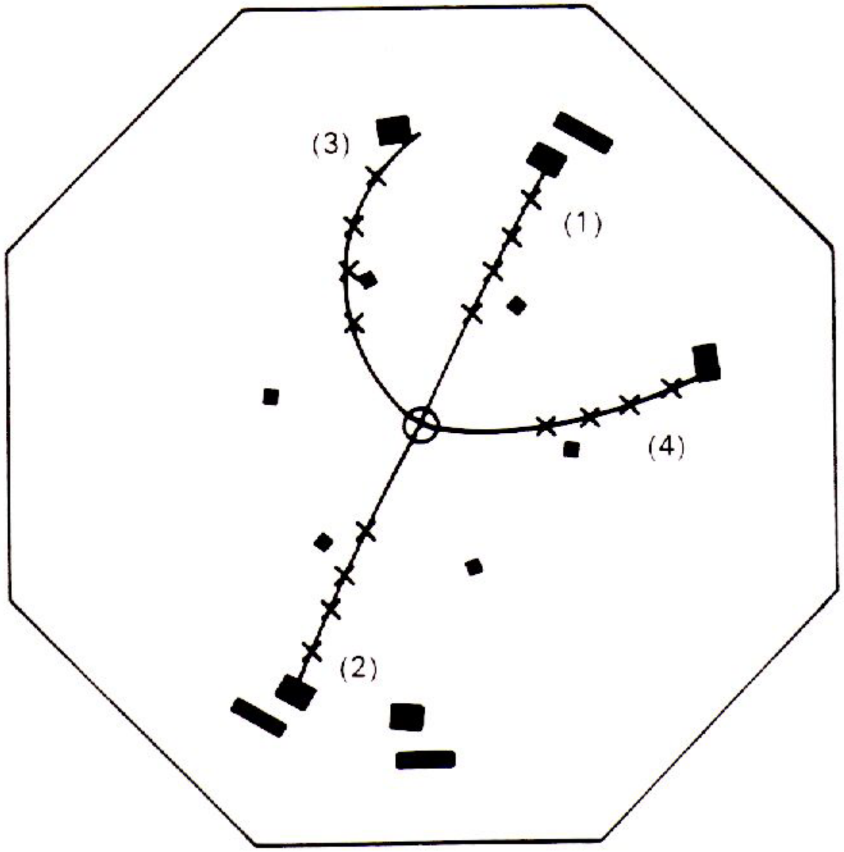
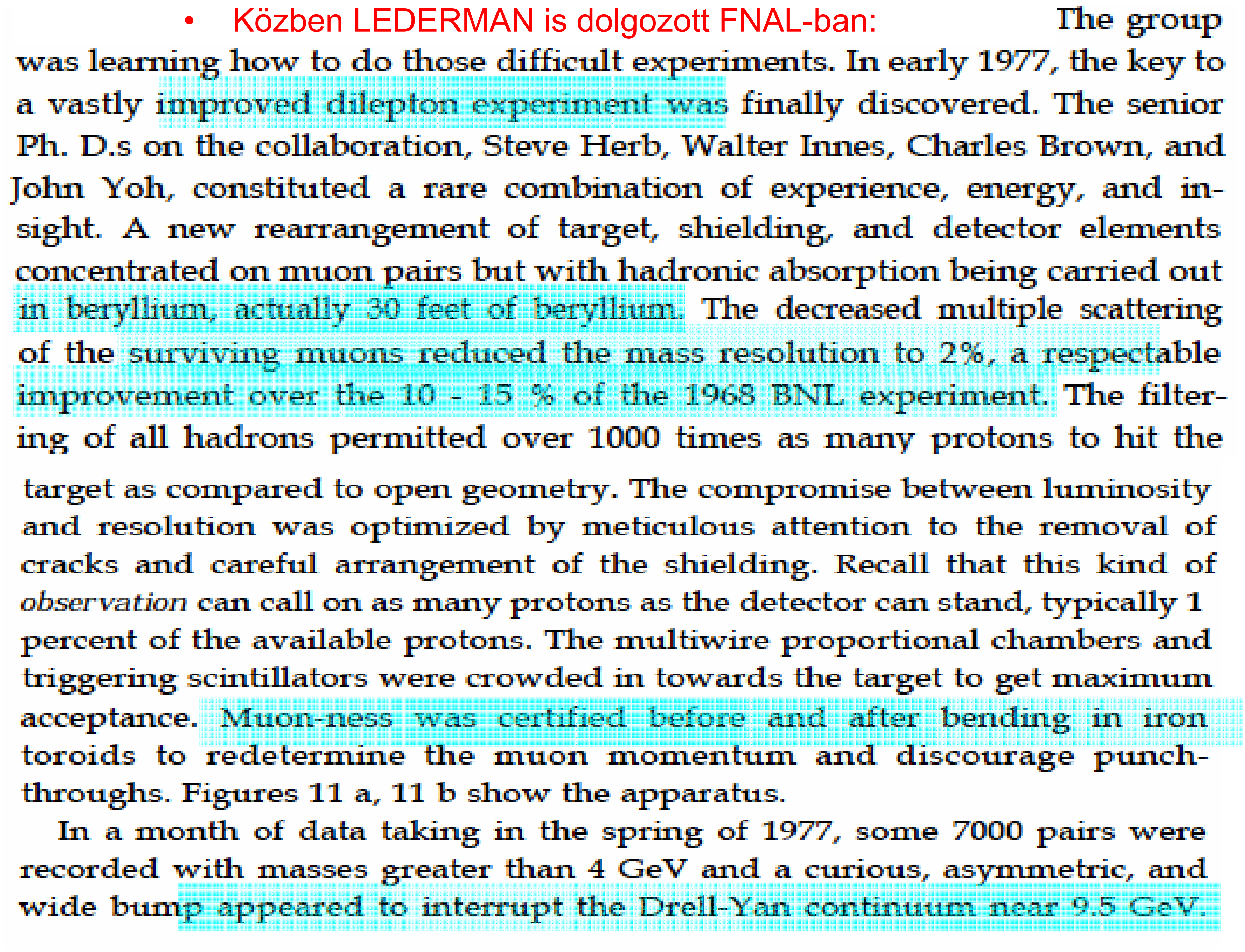


Fig. 5.13 Example of the decay $\psi'(3.7) \rightarrow \psi(3.1) + \pi^+ + \pi^-$ observed in a spark chamber detector. The $\psi(3.1)$ decays to $e^+ + e^-$. Tracks (3) and (4) are due to the relatively low-energy (150-MeV) pions, and (1) and (2) to the 1.5-GeV electrons. The magnetic field and the SPEAR beam pipe are normal to the plane of the figure. The trajectory shown for each particle is the best fit through the sparks, indicated by crosses. [From G. S. Abrams *et al.*, *Phys. Rev. Letters* **34**, 1181 (1975).]

- Közben LEDERMAN is dolgozott FNAL-ban:



The group was learning how to do those difficult experiments. In early 1977, the key to a vastly improved dilepton experiment was finally discovered. The senior Ph. D.s on the collaboration, Steve Herb, Walter Innes, Charles Brown, and John Yoh, constituted a rare combination of experience, energy, and insight. A new rearrangement of target, shielding, and detector elements concentrated on muon pairs but with hadronic absorption being carried out in beryllium, actually 30 feet of beryllium. The decreased multiple scattering of the surviving muons reduced the mass resolution to 2%, a respectable improvement over the 10 - 15 % of the 1968 BNL experiment. The filtering of all hadrons permitted over 1000 times as many protons to hit the target as compared to open geometry. The compromise between luminosity and resolution was optimized by meticulous attention to the removal of cracks and careful arrangement of the shielding. Recall that this kind of *observation* can call on as many protons as the detector can stand, typically 1 percent of the available protons. The multiwire proportional chambers and triggering scintillators were crowded in towards the target to get maximum acceptance. Muon-ness was certified before and after bending in iron toroids to redetermine the muon momentum and discourage punch-throughs. Figures 11 a, 11 b show the apparatus.

In a month of data taking in the spring of 1977, some 7000 pairs were recorded with masses greater than 4 GeV and a curious, asymmetric, and wide bump appeared to interrupt the Drell-Yan continuum near 9.5 GeV.

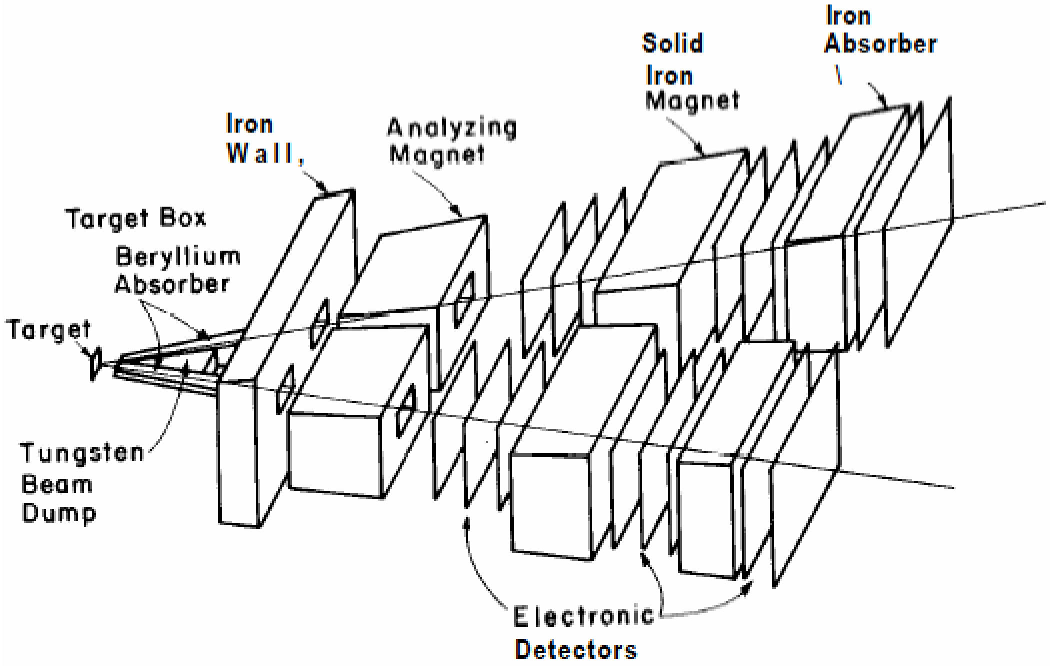


Figure *11b.* Schematic sketch of Fermilab dimuon experiment which led to the discovery of the Upsilon particle.

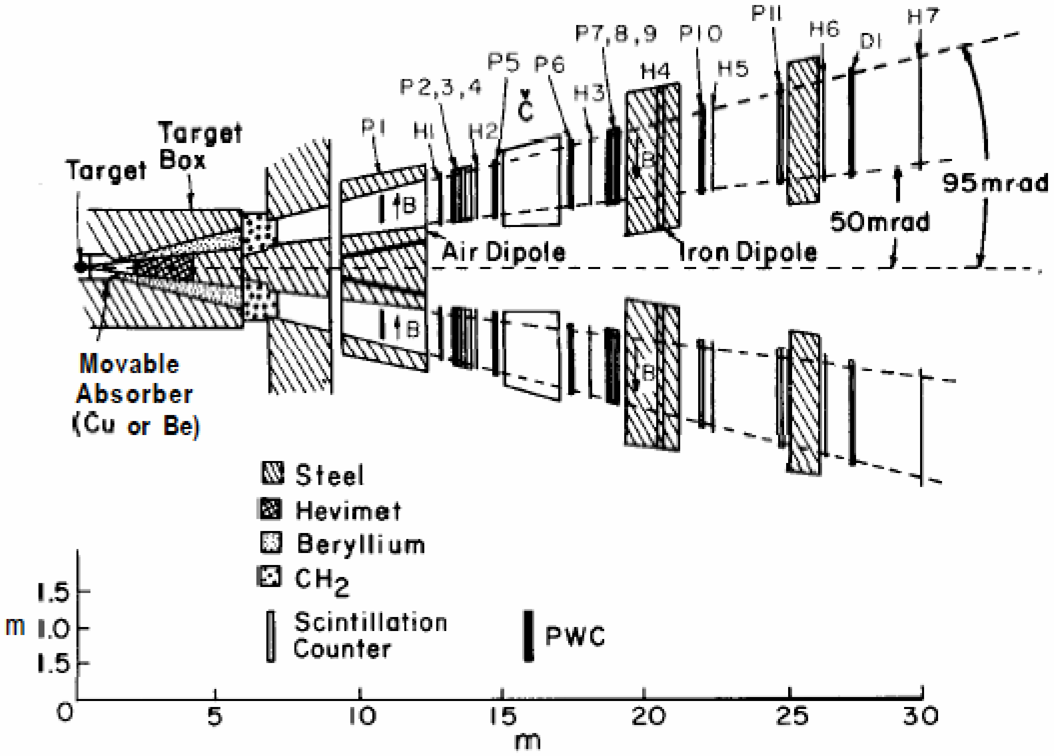


Figure *11a.* Plan view of the apparatus. Each spectrometer arm includes 11 PWC's P1-P11, 7 scintillating counter hodoscopes H1-H7, a drift chamber Dl, and a gas-filled threshold Cerenkov counter C.

the gauge is fixed up to boundary conditions, and the above results are encouraging. One may also argue that direct closed loop calculations will not produce a cosmological term either, simply because dimensional regularization (which respects the gauge invariances) leads to vanishing of tadpole diagrams.

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

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

and

J. A. Appel, B. C. Brown, C. N. Brown, W. R. Innes, K. Ueno, and T. Yamanouchi
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

and

A. S. Ito, H. Jöstlein, D. M. Kaplan, and R. D. Kephart
State University of New York at Stony Brook, Stony Brook, New York 11974

(Received 1 July 1977)

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

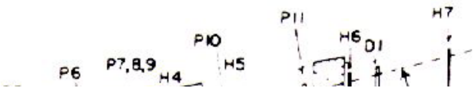
Dimuon production is studied in 400-GeV proton-nucleus collisions. A strong enhancement is observed at 9.5 GeV mass in a sample of 9000 dimuon events with a mass $m_{\mu^+\mu^-} > 5$ GeV.

We have observed a strong enhancement at 9.5 GeV in the mass spectrum of dimuons produced in 400-GeV proton-nucleus collisions. Our conclusions are based upon an analysis of 9000 dimuon events with a reconstructed mass $m_{\mu^+\mu^-}$ greater than 5 GeV corresponding to 1.6×10^{16} protons incident on Cu and Pt targets:

$$p + (\mathrm{Cu}, \mathrm{Pt}) \to \mu^+ + \mu^- + \text{anything}.$$

The produced muons are analyzed in a double-arm magnetic-spectrometer system with a mass resolution $\Delta m/m$ (rms) $\approx 2\%$.

The experimental configuration (Fig. 1) is a modification of an earlier dilepton experiment in the Fermilab Proton Center Laboratory.[1-3] Narrow targets (~0.7 mm) with lengths corresponding to 30% of an interaction length are employed.



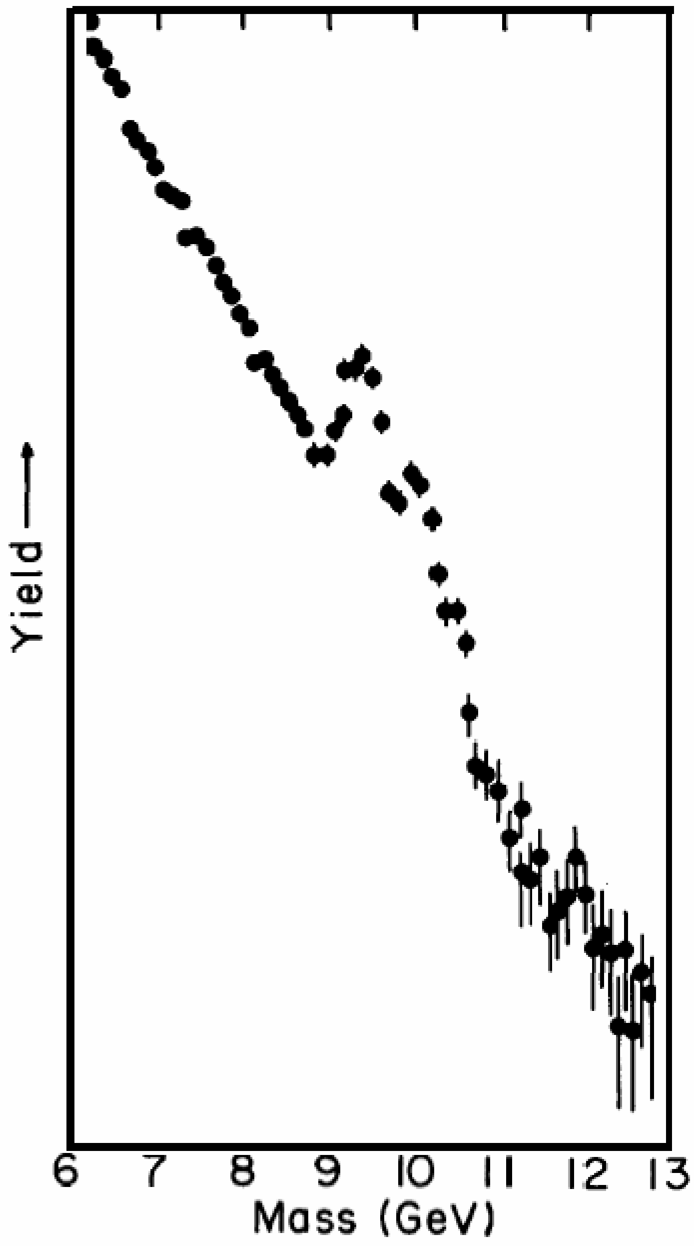


Figure 12a. Peaks on Drell-Yan continuum.

Data 1977

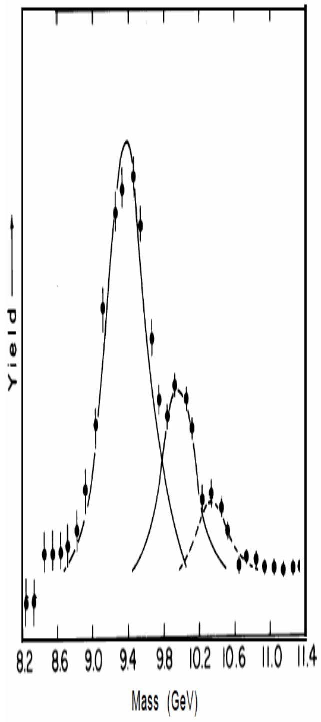
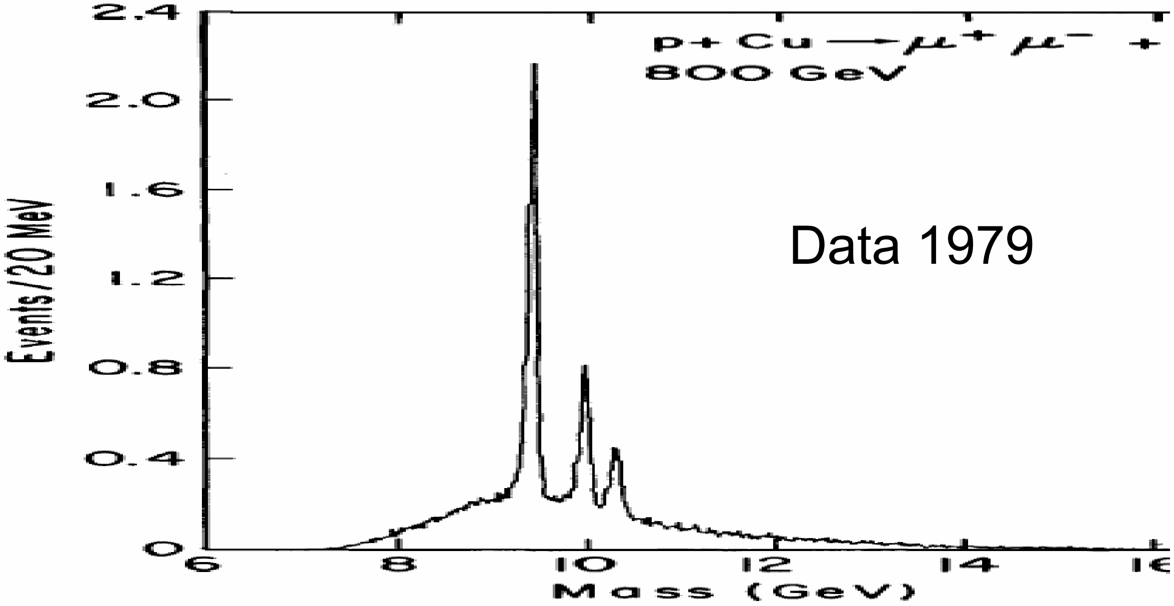


Figure 12b. Peaks with continuum subracted.



Data 1979

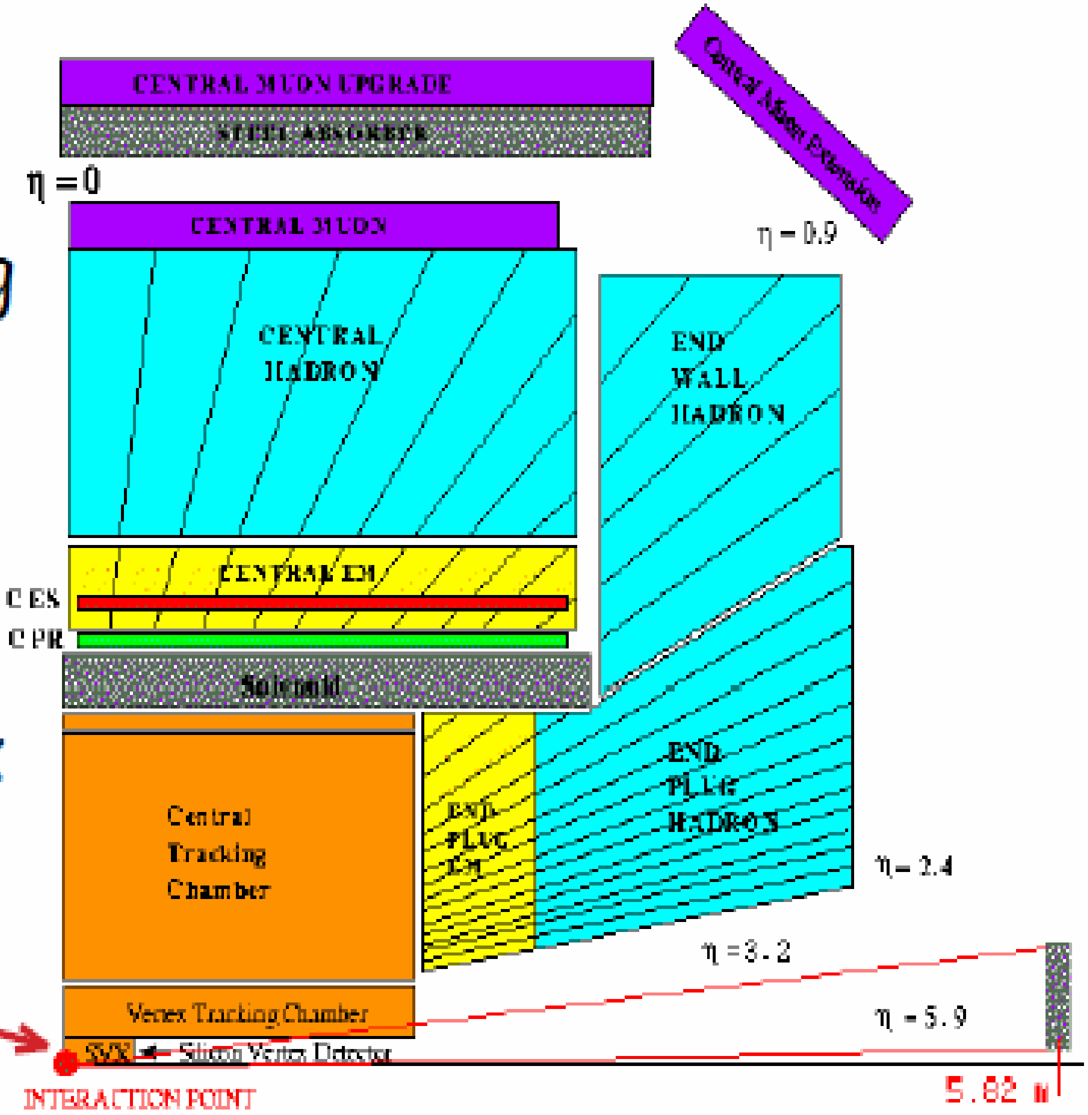
Figure 13. Fermilab E-605 data.

(einviertel) CDF Detektor

Schwerpunkt Tracking

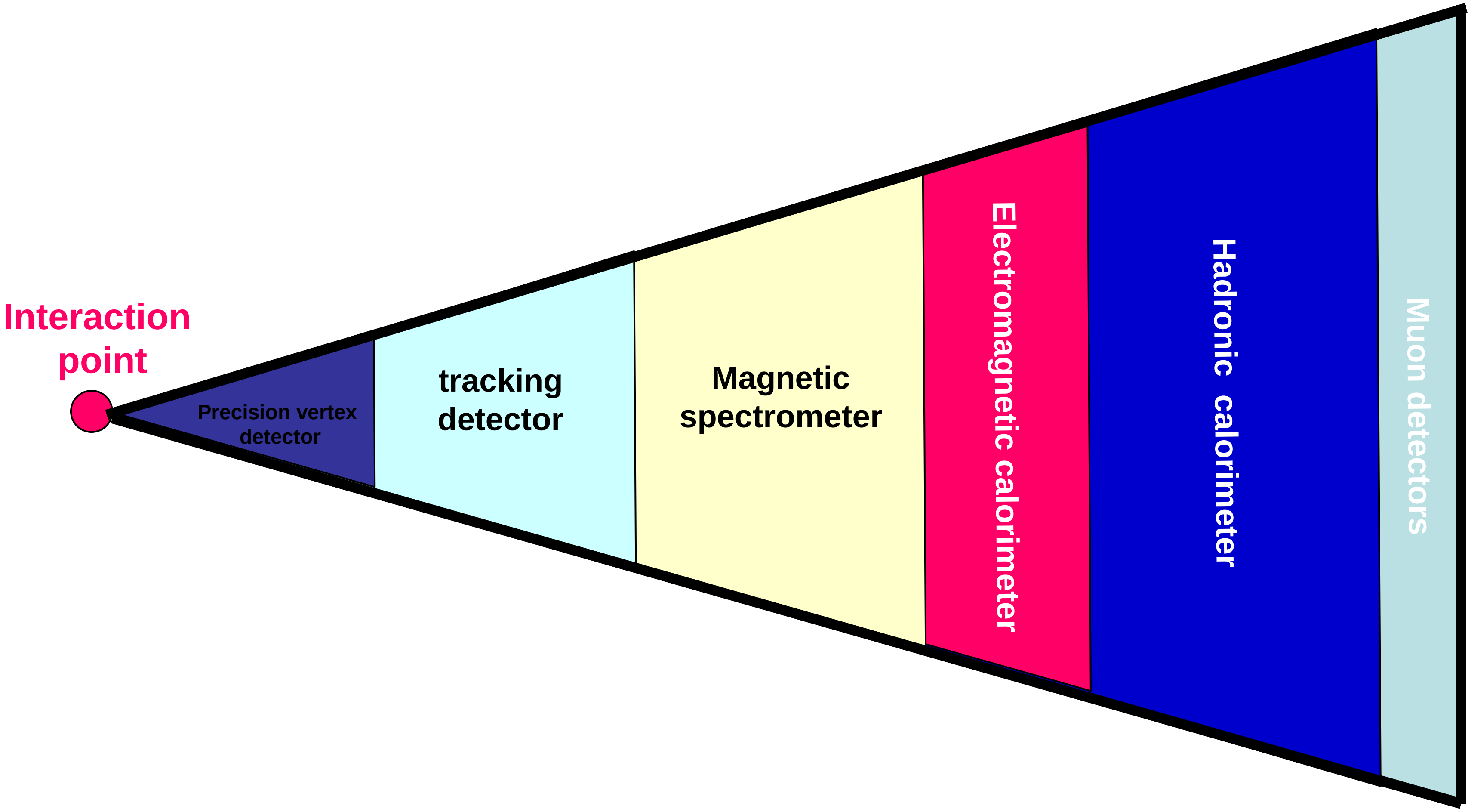
SVX - Silizium Vertex

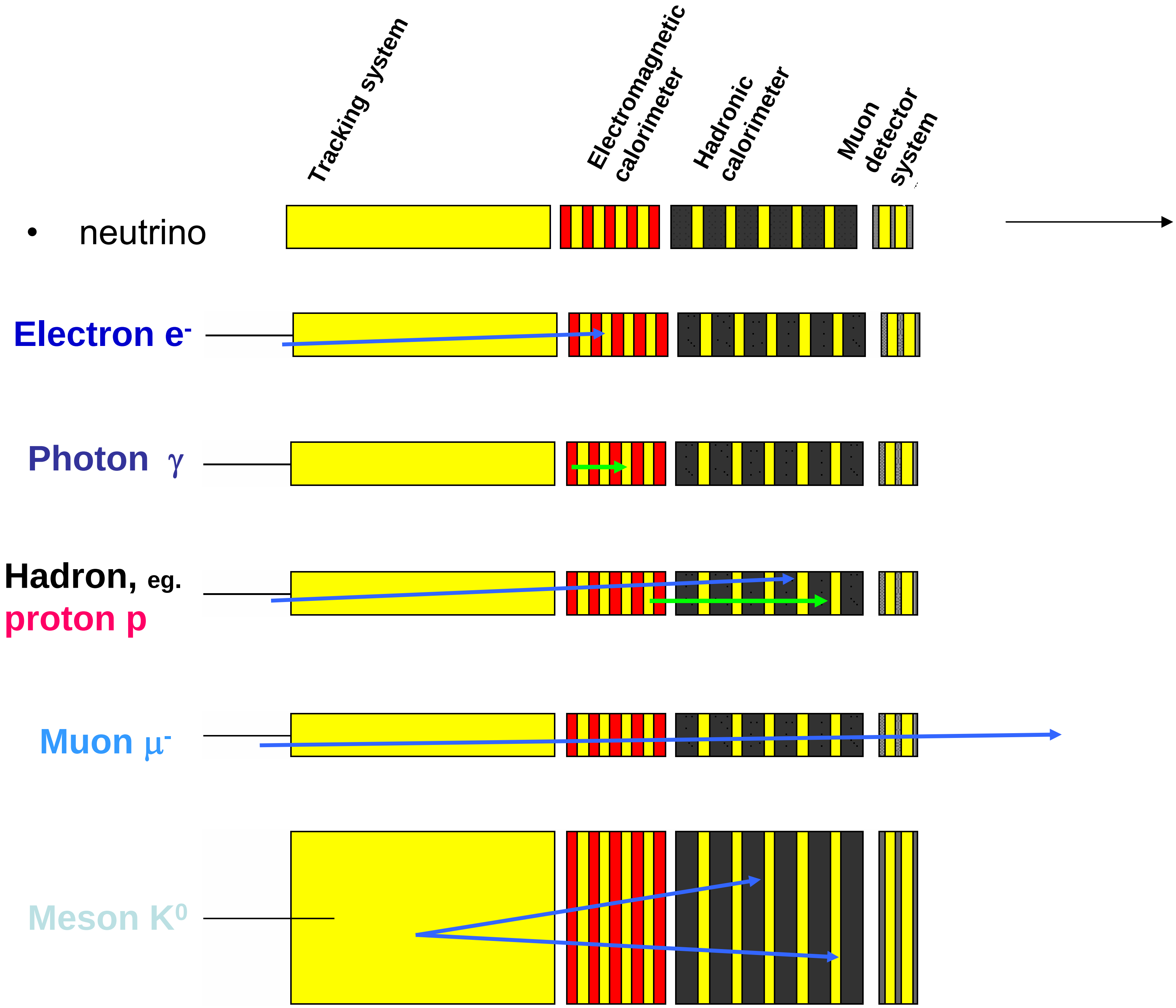
Detektor: b-tagging



Typical detector concept

- Combine different detector types/technologies into one large detector system





Tracking system

Electromagnetic calorimeter

Hadronic calorimeter

Muon detector system

- neutrino

Electron e^-

Photon γ

Hadron, eg.
proton p

Muon μ^-

Meson K^0

Geschichte des Top-Quarks

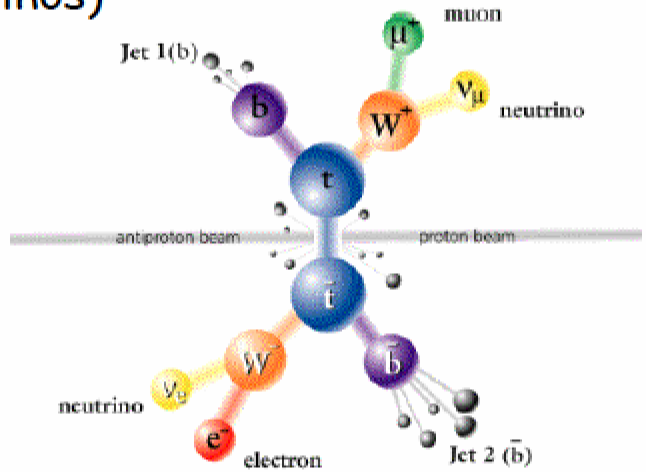
1974	Entdeckung Charm-Quark - J/Psi ($c\bar{c}$)
1977	Entdeckung Beauty/Bottom-Quark
...	Petra (e^+e^-): $m_t > 23$ GeV (?)
1990	UA1/UA2 am SppS (Cern): $m_t > 69$ GeV
1992	CDF (TeVatron): $m_t > 91$ GeV
1994	D0 (TeVatron): $m_t > 131$ GeV
1995	Entdeckung des Top-Quarks:
	CDF: (176 ± 8 ± 10) GeV
	D0: (199 ± 20 ± 22) GeV

Dilepton Ereignisse

beide W-Bosonen zerfallen leptonisch:

- zwei Leptonen mit hohen p_T
- fehlende Energie (Neutrinos)
- zwei b-Jets

wenig Background



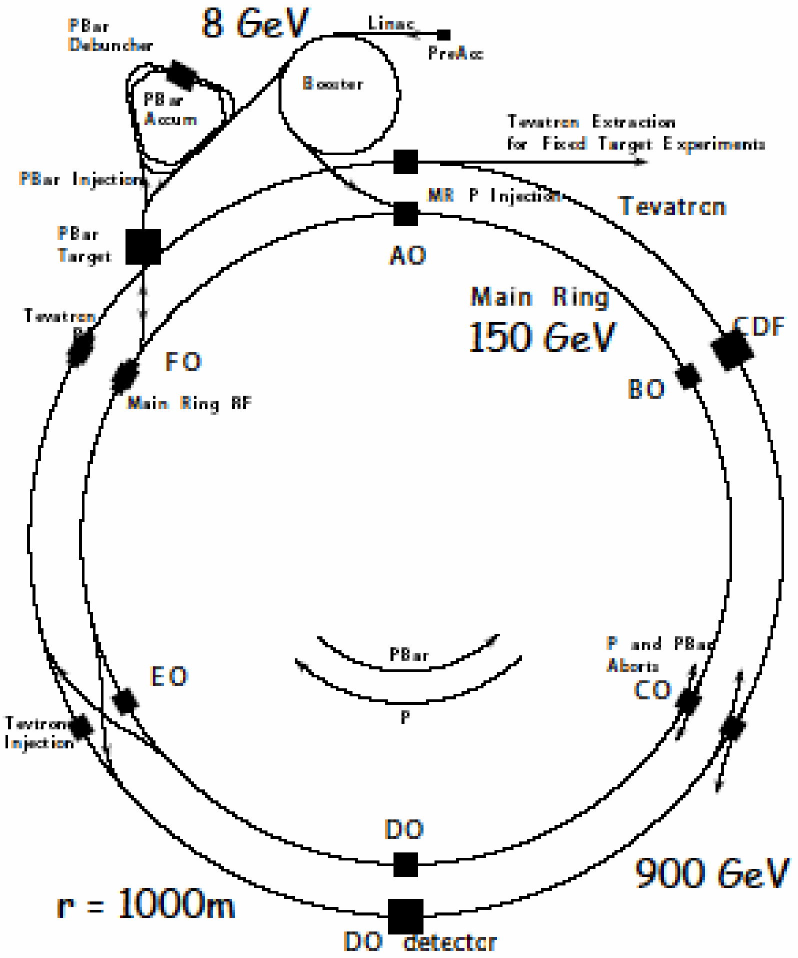
Nur Jets

beide W-Bosonen zerfallen in $q\bar{q}$:

- 6 Jets (zwei b-Jets)
- keine Leptonen mit hohen p_T
- keine fehlende Energie

viel QCD Background

Top-Quark Nachweis am TeVatron: CDF und D0



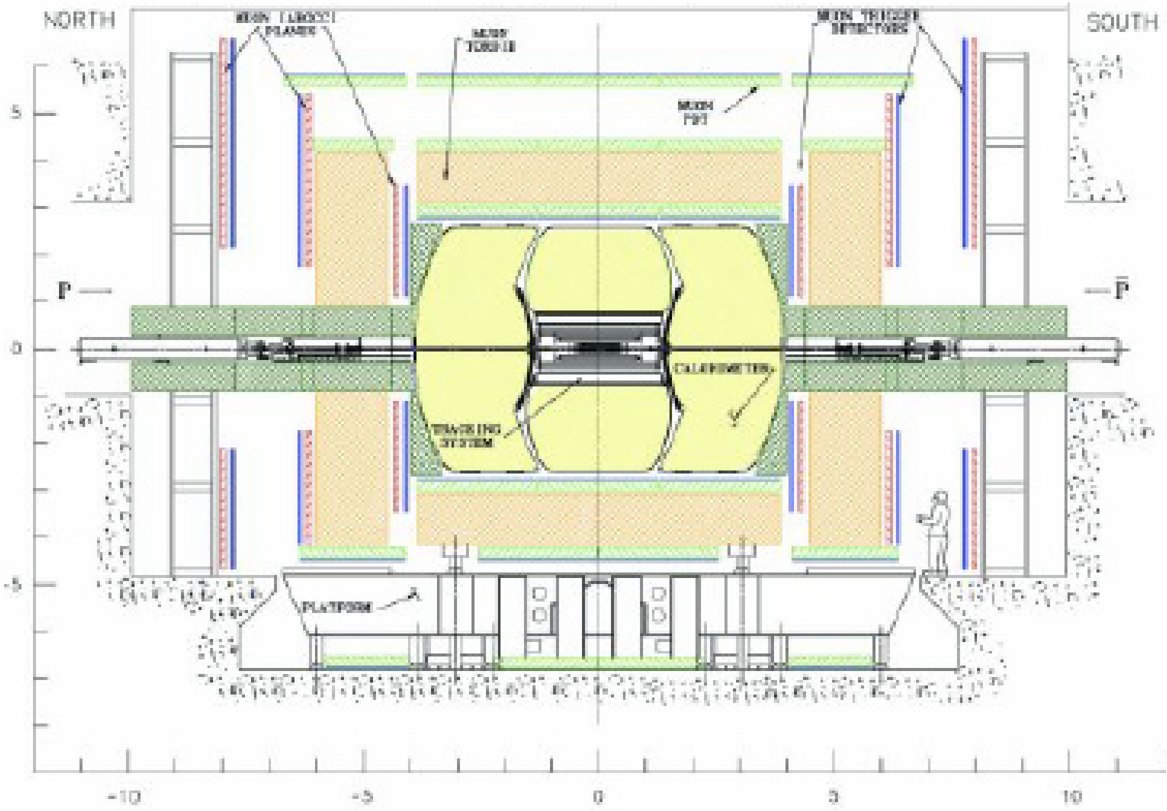
- je 6 Bunche
- 20h Füllung

- $\sqrt{s} = 1.8$ TeV
- CDF (1988)
- D0 (1992)

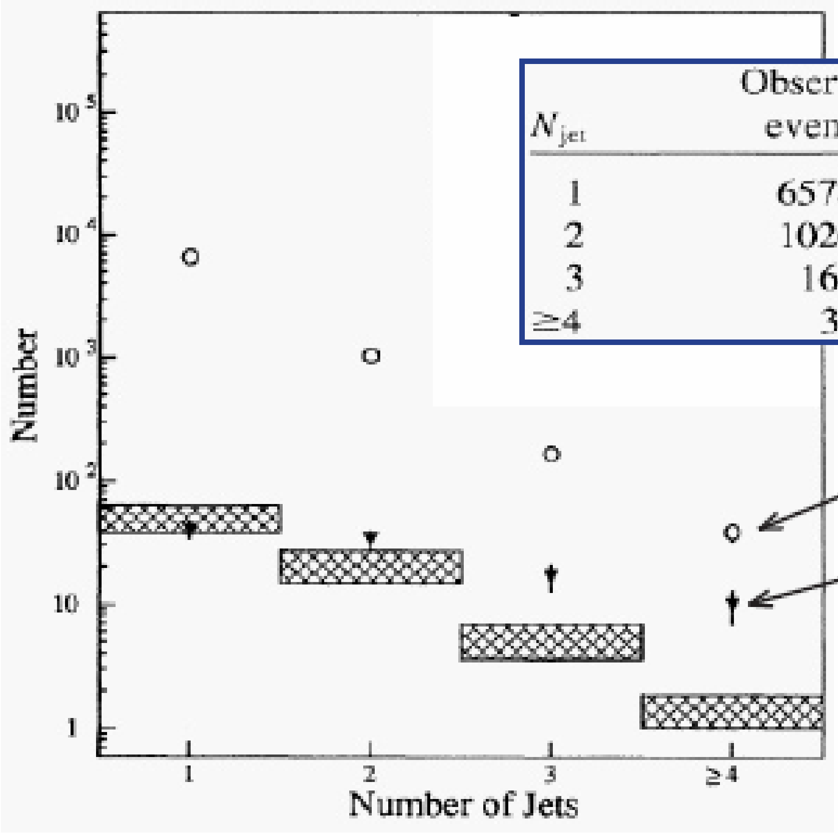
D0 Detektor

- Schwerpunkt Kalorimeter (Uran/Stahl und LAr)
- nicht-magnetische Spurkammer (bis Run II)

Muon Impulsmessung mit 1.9T Magnetfeld



SVX b-Tagging (CDF 1995)



N_{jet}	Observed events	Observed SVX tags	Background tags expected
1	6578	40	50 ± 12
2	1026	34	21.2 ± 6.5
3	164	17	5.2 ± 1.7
≥4	39	10	1.5 ± 0.4

observed events

observed SVX tags

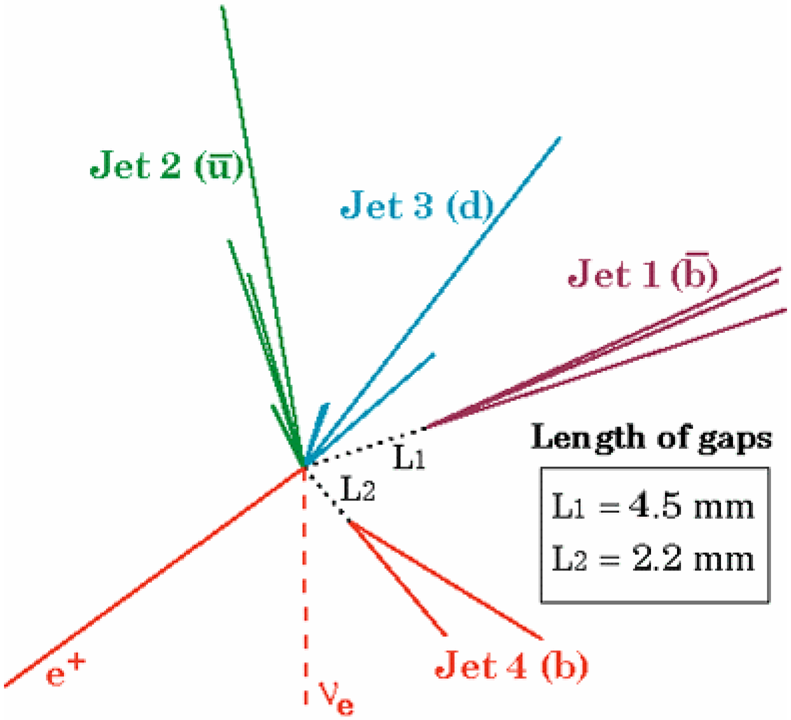
Background tags expected

-> 27 tags (6.7 ± 2.1 Background expected)

$p + \bar{p} \longrightarrow t + \bar{t}$

$t \longrightarrow b + W^+$ $\quad$ $W^+ \longrightarrow e^+ + \nu_e$

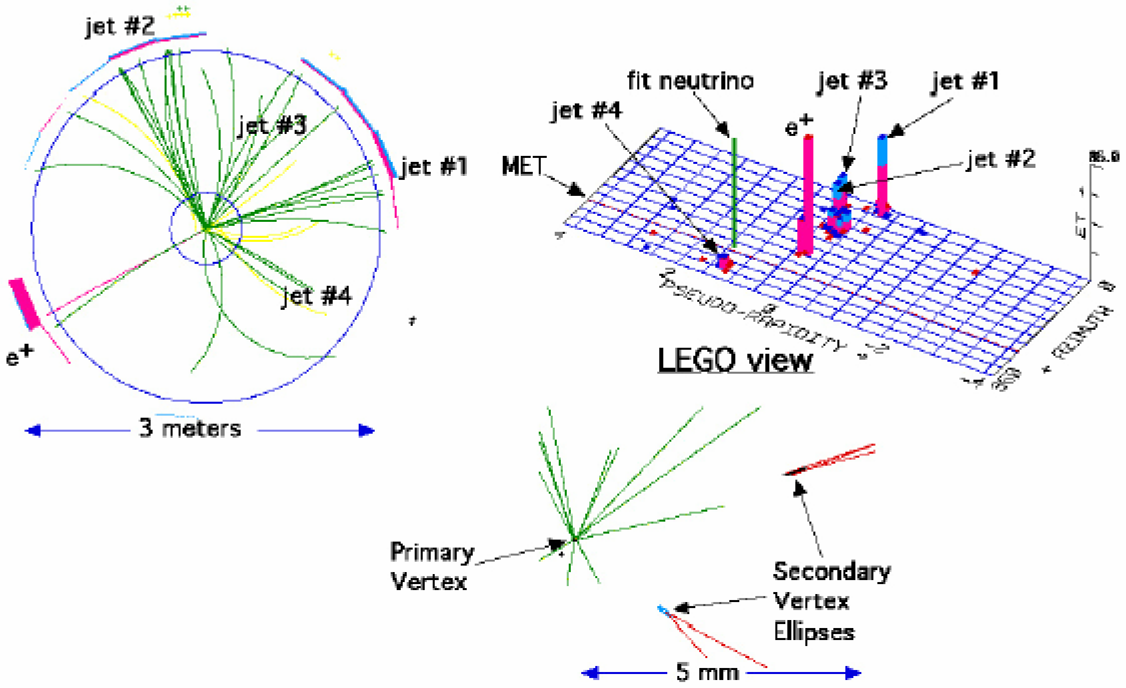
$\bar{t} \longrightarrow \bar{b} + W^-$ $\quad$ $W^- \longrightarrow \bar{u} + d$

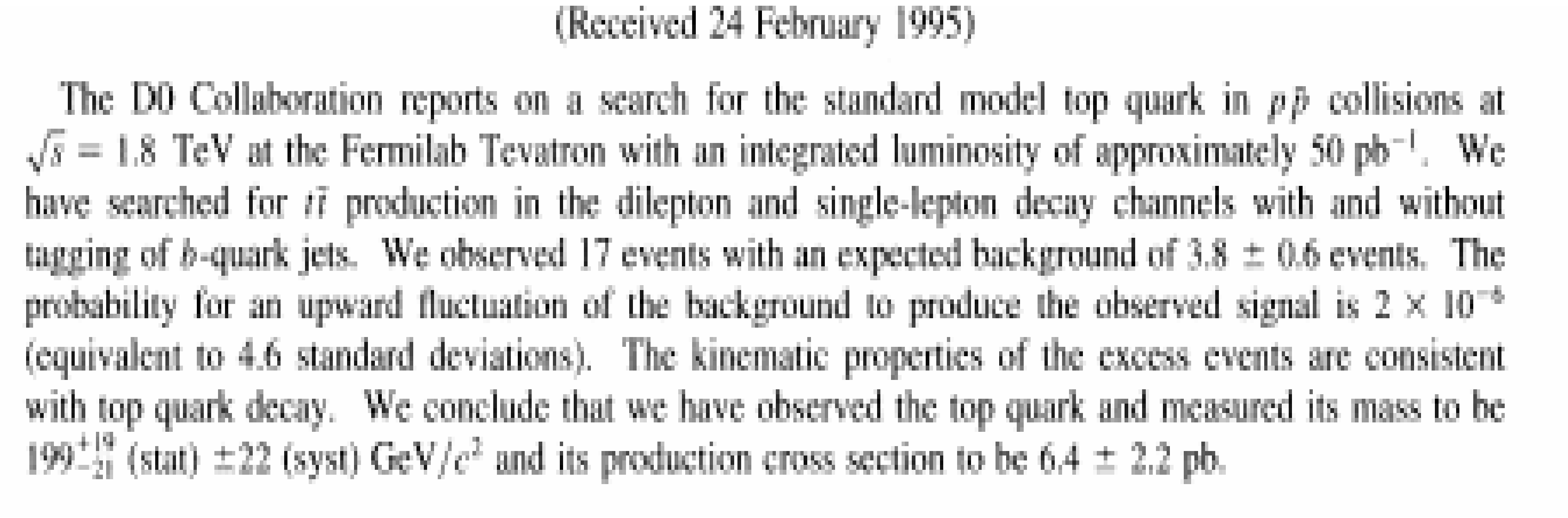


Length of gaps

$L_1 = 4.5$ mm
$L_2 = 2.2$ mm

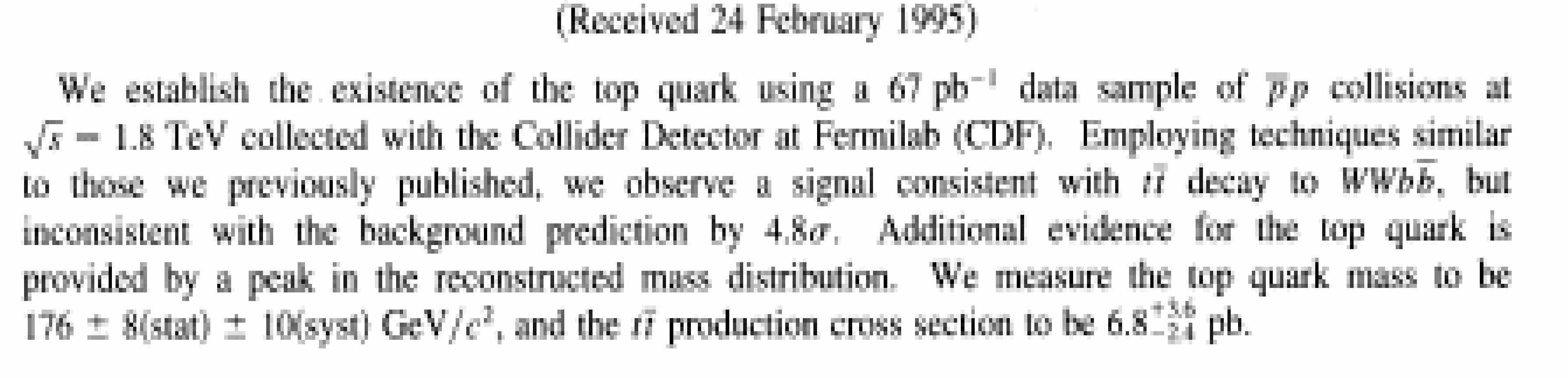
Top Ereignis im Event-Display





(Received 24 February 1995)

The D0 Collaboration reports on a search for the standard model top quark in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV at the Fermilab Tevatron with an integrated luminosity of approximately 50 pb^{-1}. We have searched for $t\bar{t}$ production in the dilepton and single-lepton decay channels with and without tagging of b-quark jets. We observed 17 events with an expected background of 3.8 ± 0.6 events. The probability for an upward fluctuation of the background to produce the observed signal is 2×10^{-6} (equivalent to 4.6 standard deviations). The kinematic properties of the excess events are consistent with top quark decay. We conclude that we have observed the top quark and measured its mass to be 199^{+19}_{-21} (stat) ±22 (syst) GeV/c^2 and its production cross section to be 6.4 ± 2.2 pb.



(Received 24 February 1995)

We establish the existence of the top quark using a 67 pb^{-1} data sample of $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV collected with the Collider Detector at Fermilab (CDF). Employing techniques similar to those we previously published, we observe a signal consistent with $t\bar{t}$ decay to $WWb\bar{b}$, but inconsistent with the background prediction by 4.8σ. Additional evidence for the top quark is provided by a peak in the reconstructed mass distribution. We measure the top quark mass to be 176 ± 8(stat) ± 10(syst) GeV/c^2, and the $t\bar{t}$ production cross section to be $6.8^{+3.6}_{-2.4}$ pb.

In 1994 t'Hooft and Veltman connecting m to electroweak boson masses and couplings predicted the value between 145 and 185 GeV. In 1999 they shared a Nobel-prize.

Ki ismeri egyetlen CDF vagy DO kísérleti fizikusnak a nevét?

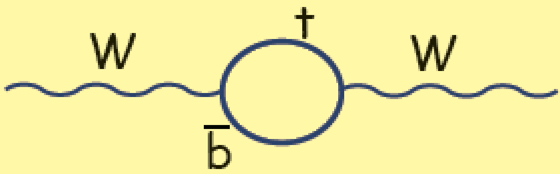
Indirekt Messung: Präzisions Messungen am LEP

- QED Korrekturen bei LEP ~ 23%

  unabhänigig von m_t und m_H
- elektro-schwache Korrekturen ~ 1%

  abhängig von m_t und m_H:

Vakuum Polarisation:



Korrektur

z.B.: $\rho = \frac{M_W^2}{M_Z^2(1-\sin^2\Theta_W)} = 1 + \Delta r$

$$\Delta r \sim G_F m_t^2 + G_F M_W^2 (\ln \frac{M_H^2}{M_W^2} \ldots + \ldots)$$

Vorhersage('89-'93):

$m_t = 177 \pm 11 \pm 18$ GeV

Heavy QUARK Drama

Main actors:

p	AGS	1970	fix target	30 GeV
p	AGS	1974	fix target	30 GeV
ee	ADONE	1974	collider	3 GeV
ee	SPEAR	1974	collider	7 GeV
p	PS	1974	fix target	30 GeV
pp	ISR	1975	collider	60 GeV
ee	SPEAR	1975..	collider	7 GeV
p	NAL	1977	fix target	400 GeV
ee	DORIS	1977	collider	9 GeV
pp	SPPS	?1985	collider	900 GeV
pp	FNAL	1995	collider	1800 GeV

- pp felfedező !

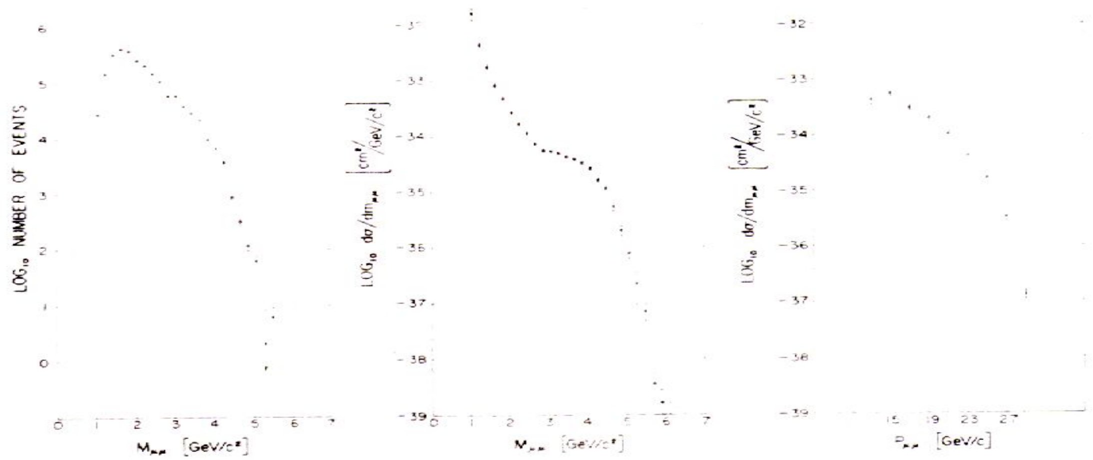


FIG. 2. (a) Observed events as a function of the effective mass of the muon pair. (b) Cross section as a function of the effective mass of the muon pair (these data include the wide-angle counters). (c) Cross section as a function of the laboratory momentum of the muon pair.

cidence between the left and right halves of the first hodoscope. About 10^6 muons (from pion and kaon decay) passed through this hodoscope per AGS cycle, resulting in ~2000 accidental coincidences per pulse. To facilitate removal of this large background, the following system was devised: Two precisely adjusted coincidence circuits (resolving times ~2.7 nsec) triggered the electronics, one sensitive to in-time or simultaneous pairs, the other to muons arriving 5 nsec apart in time. Between AGS pulses, coaxial relays interchanged the roles of these two circuits thereby canceling the error arising from slight differences in their resolving times. A third broad coincidence monitored the accidental rate for each relay position and permitted corrections due to fluctuations in beam intensity and duty cycle. The system was adjusted and tested by means of a set of radioactive sources distributed among the hodoscope counters to provide realistic rates. The numbers of in-time and delayed coincidences recorded in these tests were always the same within 0.03%.

For each muon pair detected, the status of all counters was ascertained and electronic logic performed quality checks on the event, rejecting those containing incomplete muon trajectories or extraneous counter firings. In the course of the experiment, some 300 million events were recorded, most being unwanted accidentals. The Brookhaven PDP-6 computer received these events on-line and reduced the large bulk of data to a compact form in real time.

Subtraction of the delayed events from those in-time revealed a definite residue of real muon pairs comprising some 4% of the in-time data sample. The effect varied with dimuon mass from ~2% at 1.5 GeV/c^2 to 40% at 5 GeV/c^2. As seen in Fig. 2(a), the events appear as a broad continuum in dimuon effective mass, extending over the entire mass aperture of the experiment

Since the signal-to noise ratio is very small, exhaustive tests were performed to ensure that the real mass spectrum was not distorted by the background subtraction. One check that probed the electronics and computer system in depth was made by inserting 5-nsec relative delays in both coincidence circuits and accumulating data in an otherwise normal fashion. The two mass spectra should be identical within statistics and should yield a null result on subtraction. The result was indeed consistent with zero, yielding a χ^2 of 18 for 20 degrees of freedom. The total numbers of events in the two categories were the same to 0.3%, contributing an uncertainty in the final absolute cross section of ≤10%. Further tests ruled out any mass bias induced by timing correlations. Lack of systematic variation of the real muon-pair cross section with proton intensity further indicates that all accidentals

CONSERVED QUANTUM NUMBERS

Why is the free proton stable?

Possible proton decay modes (allowed by all known conservation laws: energy – momentum, electric charge, angular momentum):

$$p \rightarrow \pi^\circ + e^+$$
$$p \rightarrow \pi^\circ + \mu^+$$
$$p \rightarrow \pi^+ + \nu$$

. . . . .

No proton decay ever observed – the proton is STABLE

Limit on the proton mean life: $\tau_p > 1.6 \times 10^{25}$ **years** Ma $> 10^{35}$

Invent a new quantum number : "Baryonic Number" B

B = 1 for proton, neutron

B = -1 for antiproton, antineutron

B = 0 for $e^\pm$, $\mu^\pm$, neutrinos, mesons, photons

Require conservation of baryonic number in all particle processes:

$$\sum_i B_i = \sum_f B_f$$

(***i*** **:** initial state particle ; ***f*** **:** final state particle)

Invention of a new, additive quantum number "Strangeness" (S)

(Gell-Mann, Nakano, Nishijima, 1953)

- **conserved in strong interaction processes:** $$\sum_i S_i = \sum_f S_f$$
- **not conserved in weak decays:** $$\left| S_i - \sum_f S_f \right| = 1$$

$S = +1$: K^+, $K°$; $S = -1$: Λ, $\Sigma^\pm$, $\Sigma°$; $S = -2$: $\Xi°$, Ξ^- ; $S = 0$: all other particles
(and opposite strangeness –S for the corresponding antiparticles)

Example of a K^- stopping in liquid hydrogen:

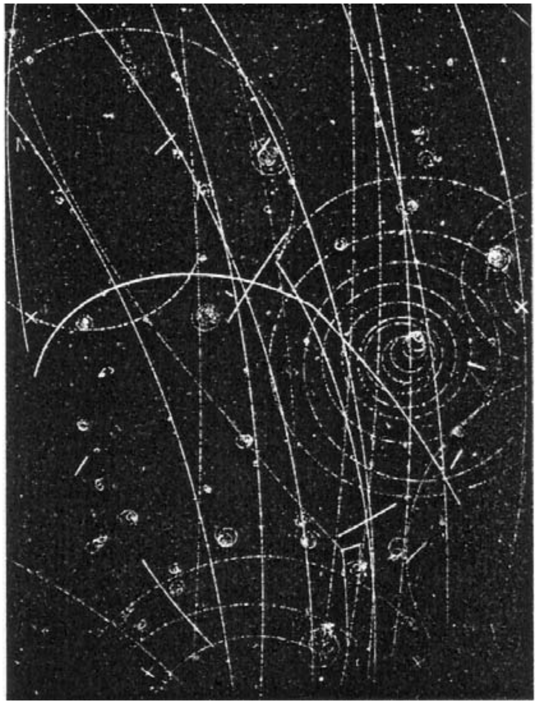
$$K^- + p \rightarrow \Lambda + \pi°$$

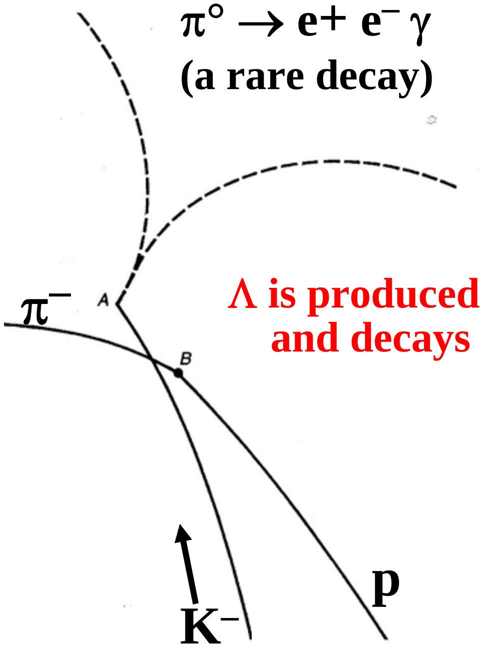
(strangeness conserving)

followed by the decay

$$\Lambda \rightarrow p + \pi^-$$

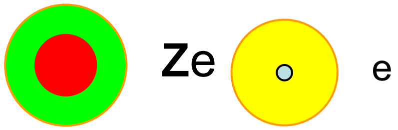
(strangeness violation)



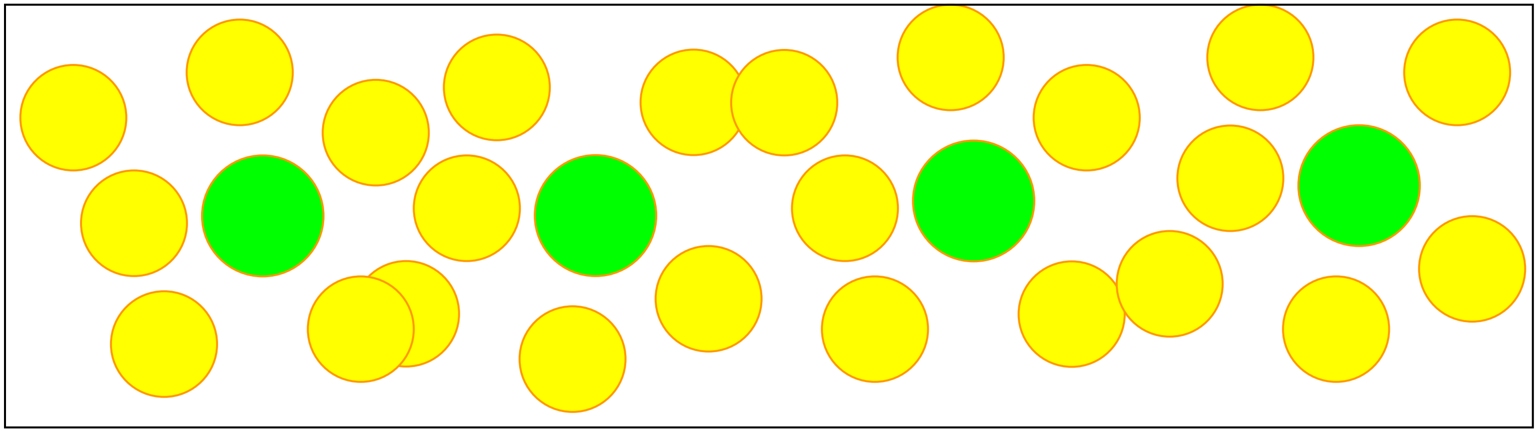


$\pi° \rightarrow e^+ e^- \gamma$
(a rare decay)

Λ is produced in A and decays in B

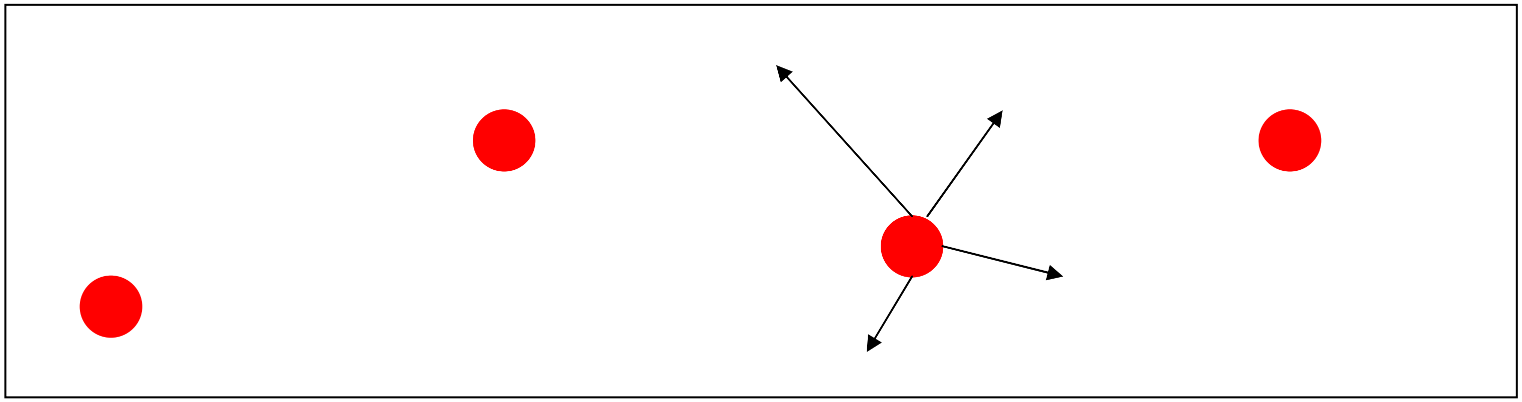


Coulomb-anyag

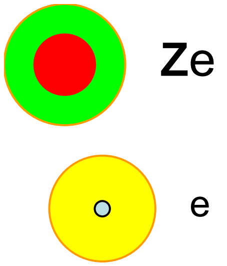


Minden **töltött** részecske érzi ezt: gerjeszt, ionizál vagy elektron-lyuk párt kelt (C,TRD)

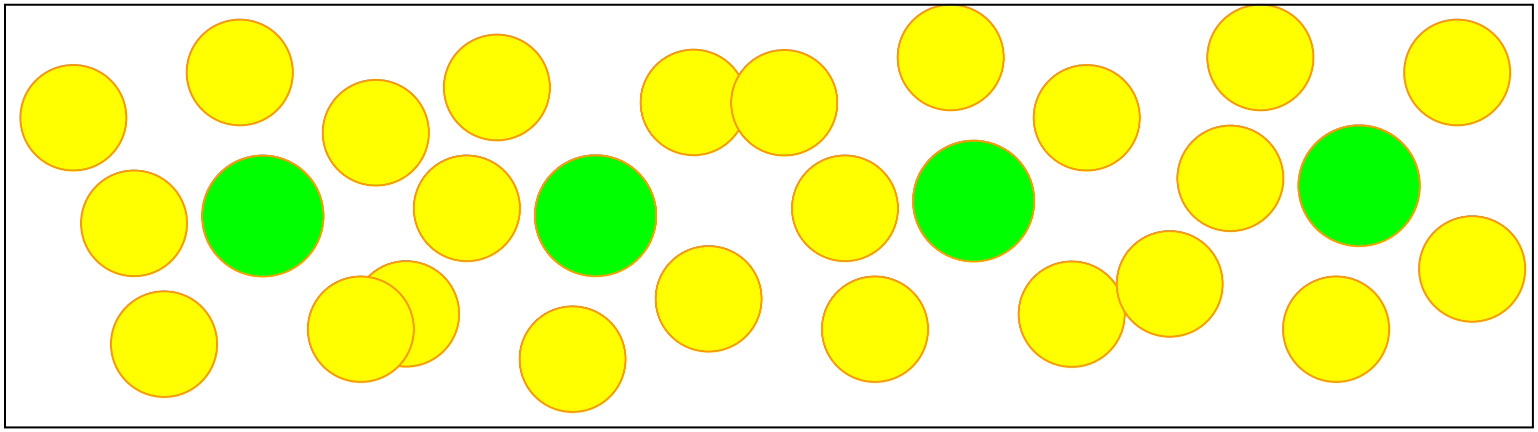
Hadron-anyag



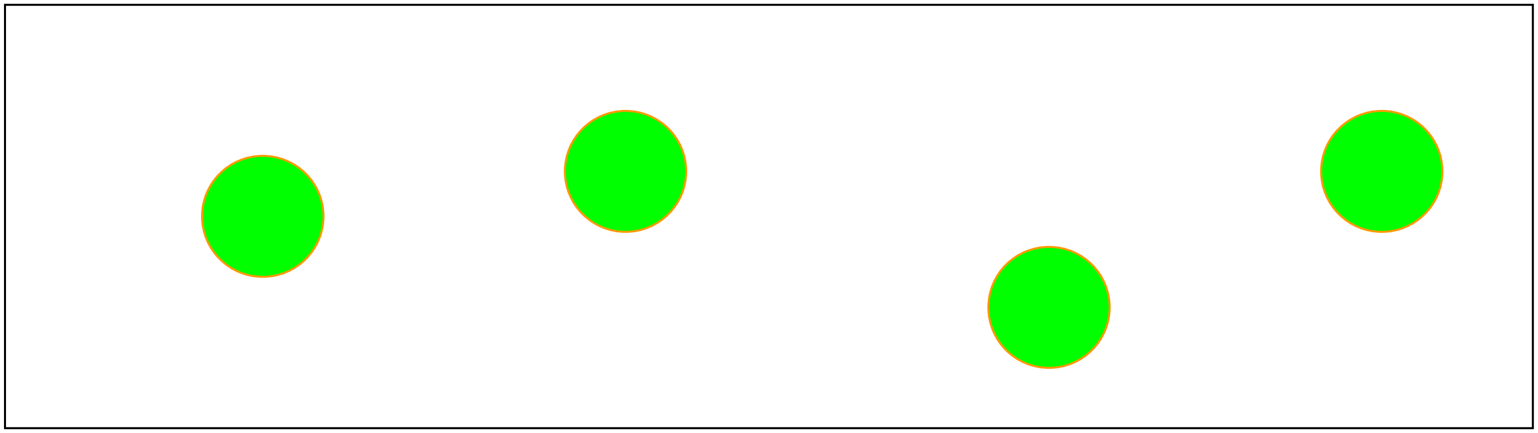
Minden hadron (neutron is) látja, ritkán van ütközés, de akkor nagyot durran.



Coulomb-anyag



Nukleáris Coulomb-anyag



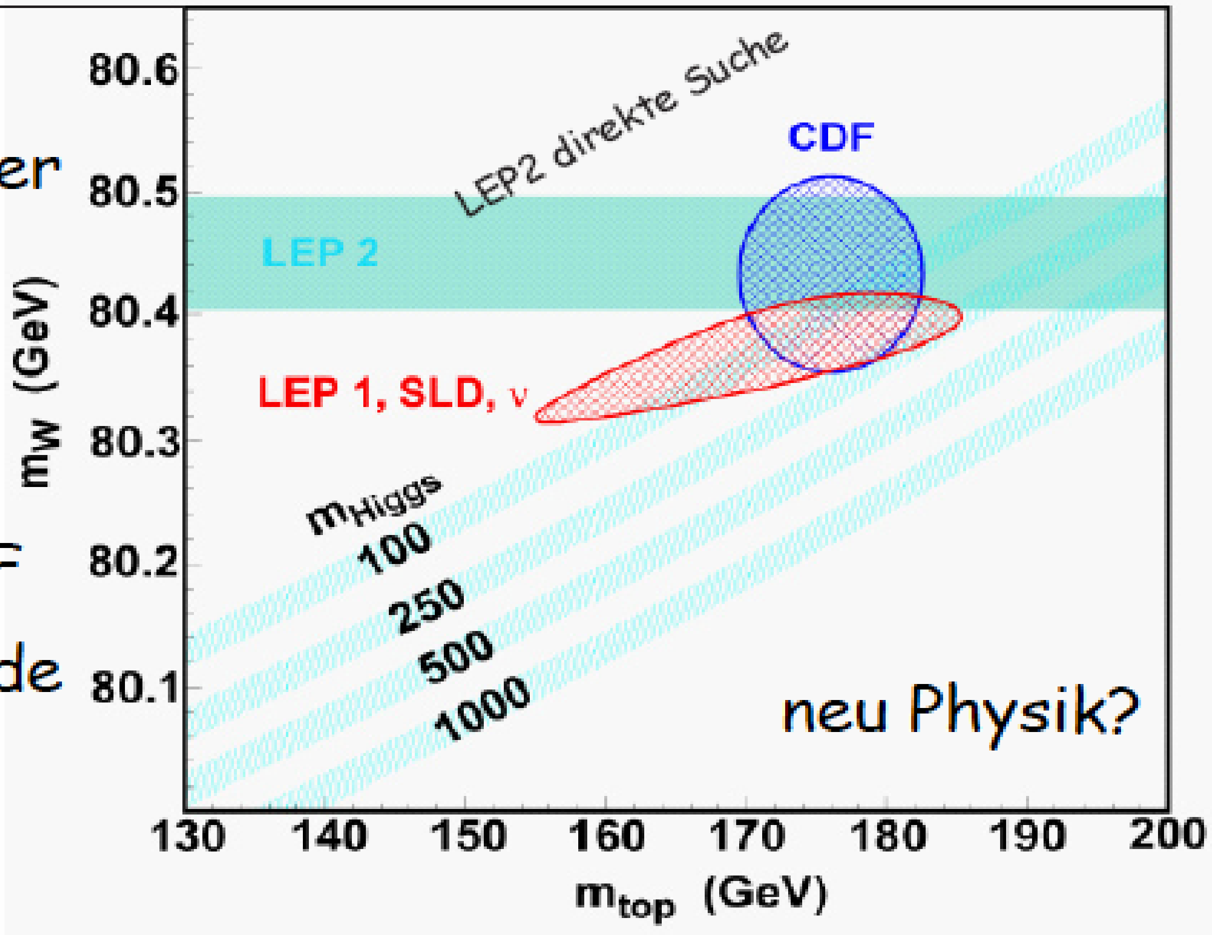
A rendkívüli kis tömegű FOTON és ELEKTRON különlegesen intenzíven kölcsönhat a magok erős (ha Z nagy!) Cb-terével: Párkeltés illetve Bremsstrahlung (fékezési sugárzás)

Higgs Lebensraum

m_t und m_W genauer Bestimmen.

-> TeVatron, CDF und D0 Upgrade

-> Run II

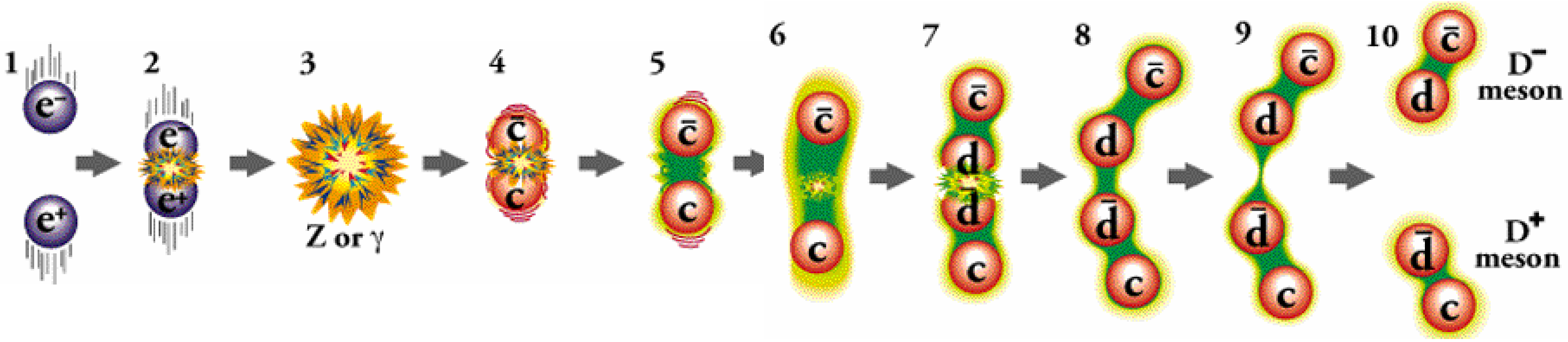


Jesko Merkel, Universität Dortmund

Best t-mass in Aug. 2006 is m_t = 172.5 +/- 2.3

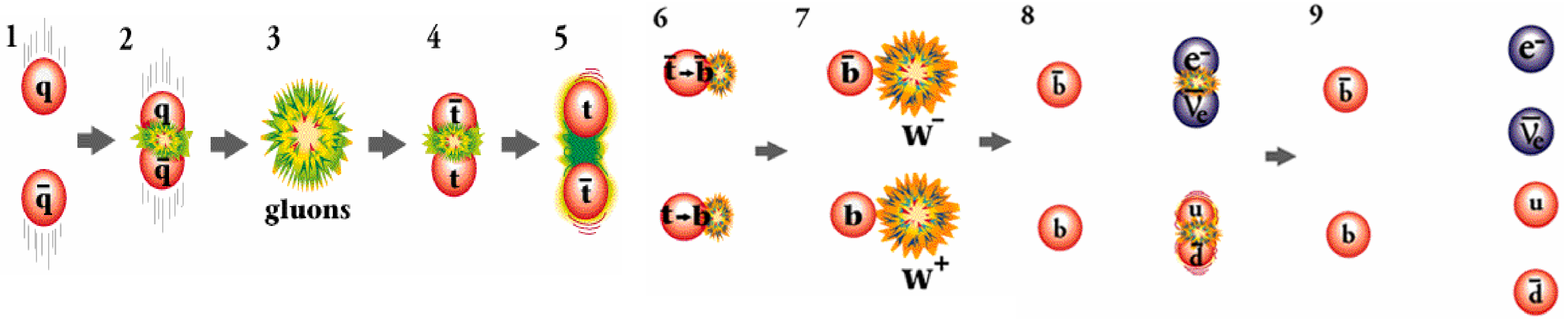
$e^+e^- \to D^+D^-$

A c-quark helyettesíthető b-quarkkal, akkor B mezonokat kapunk

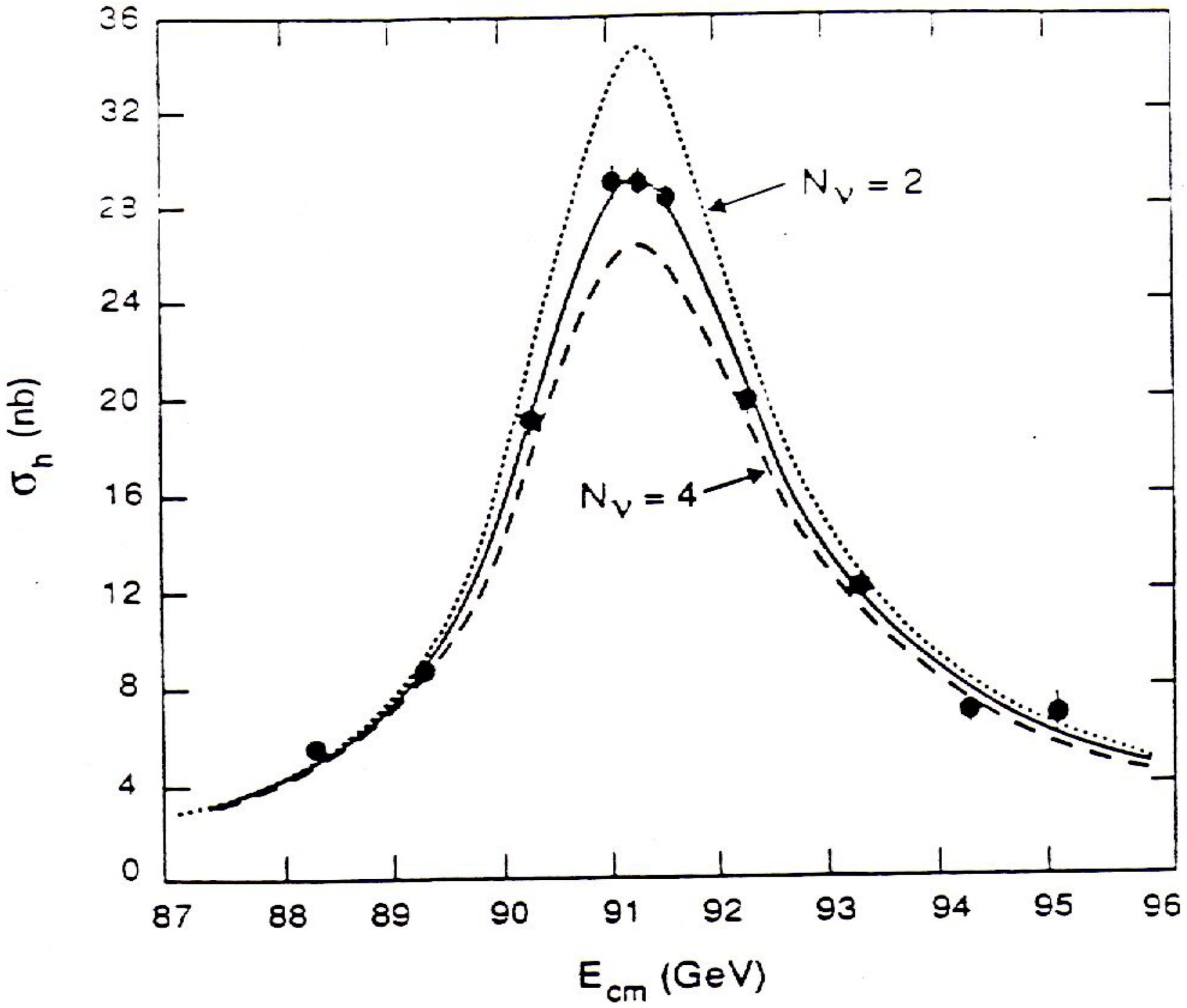


top

A t-quark előbb átalakul bW párrá mielőtt hadronizálna



A b-quarkok persze hadronizálnak „jet”-t keltve (u,d is), de az itt nincs jelölve.



$\Gamma = 2.6\,\mathrm{GeV}$ $\qquad$ $\tau = 2.6 \times 10^{-25}\,\mathrm{sec}$

$c\tau = 8 \times 10^{-17}\,\mathrm{m} \approx 0.1\,\mathrm{fm}$