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Chris Quigg
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hep-ph/0111274 [abs, src, pdf, other] :

Title: Particle Physics-Future Directions
Authors: Chris Quigg
Comments: Invited paper at the 2001 Particle Accelerator Conference, Chicago; 5 pages; uses JAC2001.cls (included)

hep-ph/0111273 [abs, src, pdf, other] :

Title: Reply to Comment on Infrared Fixed Point Structure in the Minimal Supersymmetric Standard Model with Baryon and Lepton Number Violation
Authors: B. Ananthanarayan, P. N. Pandita
Comments: 4 pages in ReVTeX, to be published in Physical Review D

hep-ph/0111272 [abs, src, pdf, other] :

Title: Updating V_us from kaon semileptonic decays
Authors: G. Calderon, G. Lopez Castro
Comments: 19 pages, 2 figures

hep-ph/0111271 [abs, src, pdf, other] :

Title: The A Dependence of Open Charm and Bottom Production
Authors: R. Vogt (LBNL and UC Davis)
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hep-ph/0111270 [abs, src, pdf, other] :

Title: The Chiral Odd Nucleon Tensor Charge
Authors: Leonard Gamberg, Gary R. Goldstein
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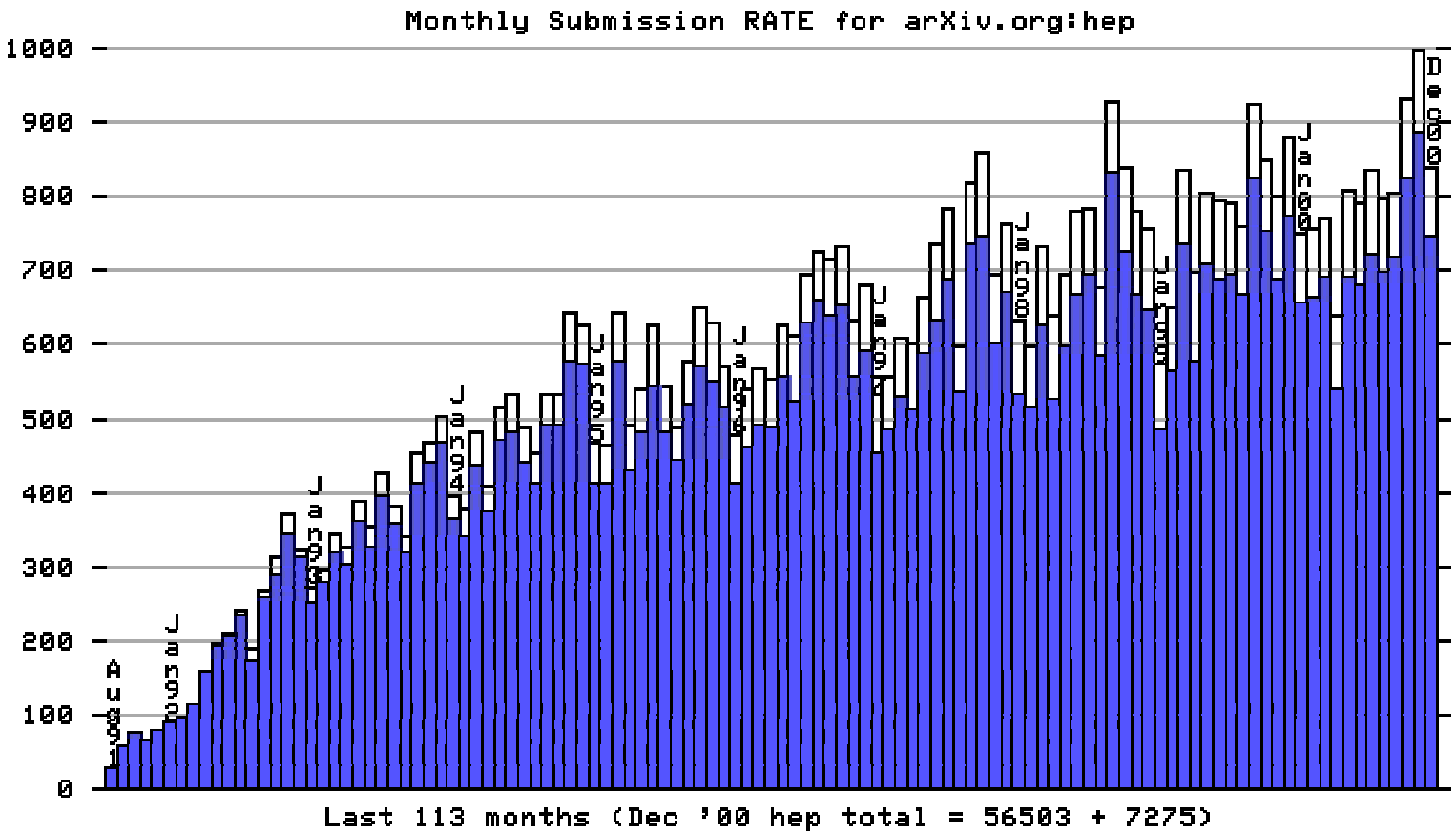
astro-ph/0111414 [abs, src, pdf, other] :

Title: Radial Modes of Neutron Stars with a Quark Core
Authors: P. K. Sahu, G. F. Burgio, M. Baldo (INFN Sezione di Catania, Italy)
Comments: 10 pages, TeX, submitted to Astrophysical Journal Letters

HEP Submission



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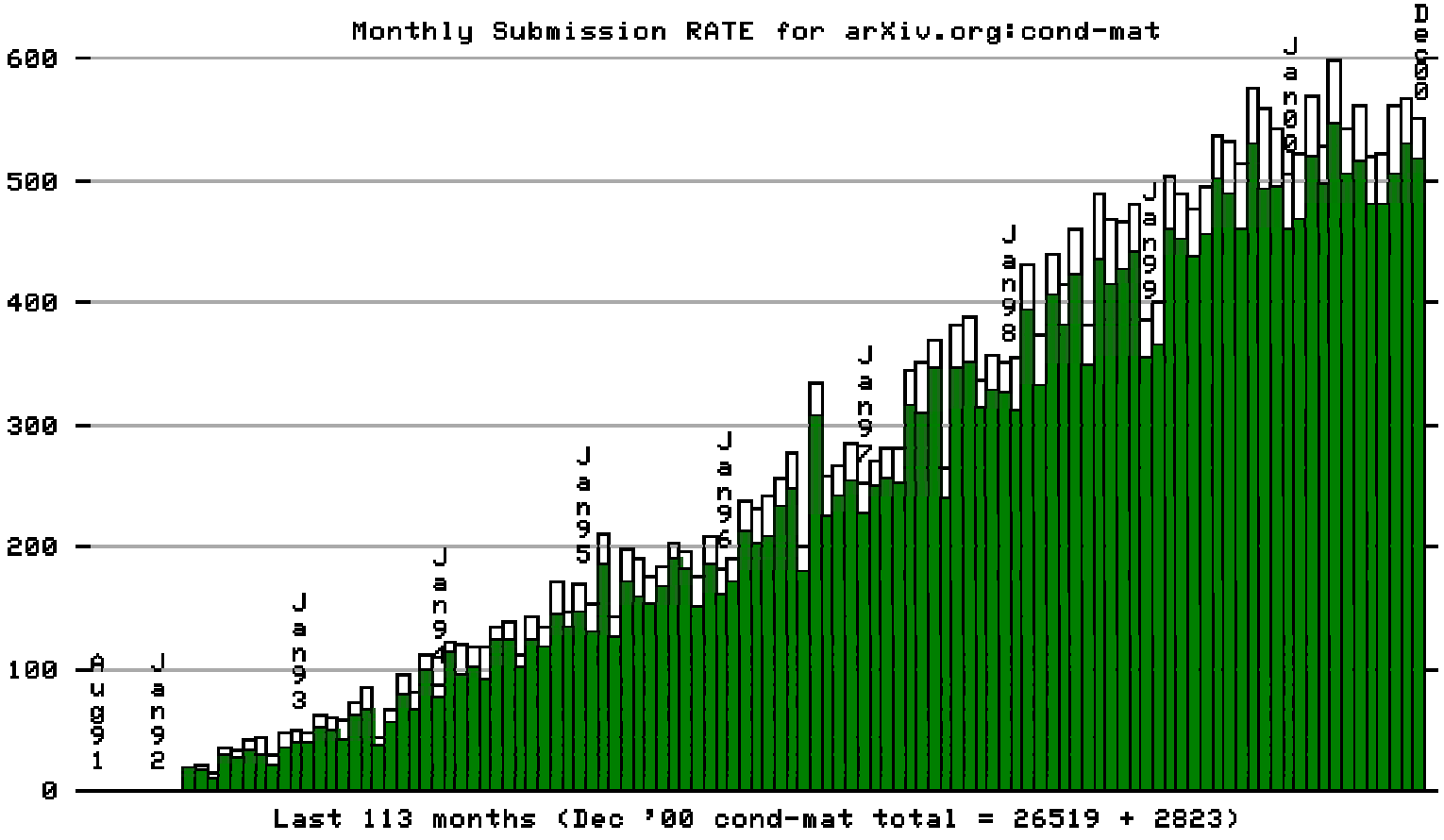

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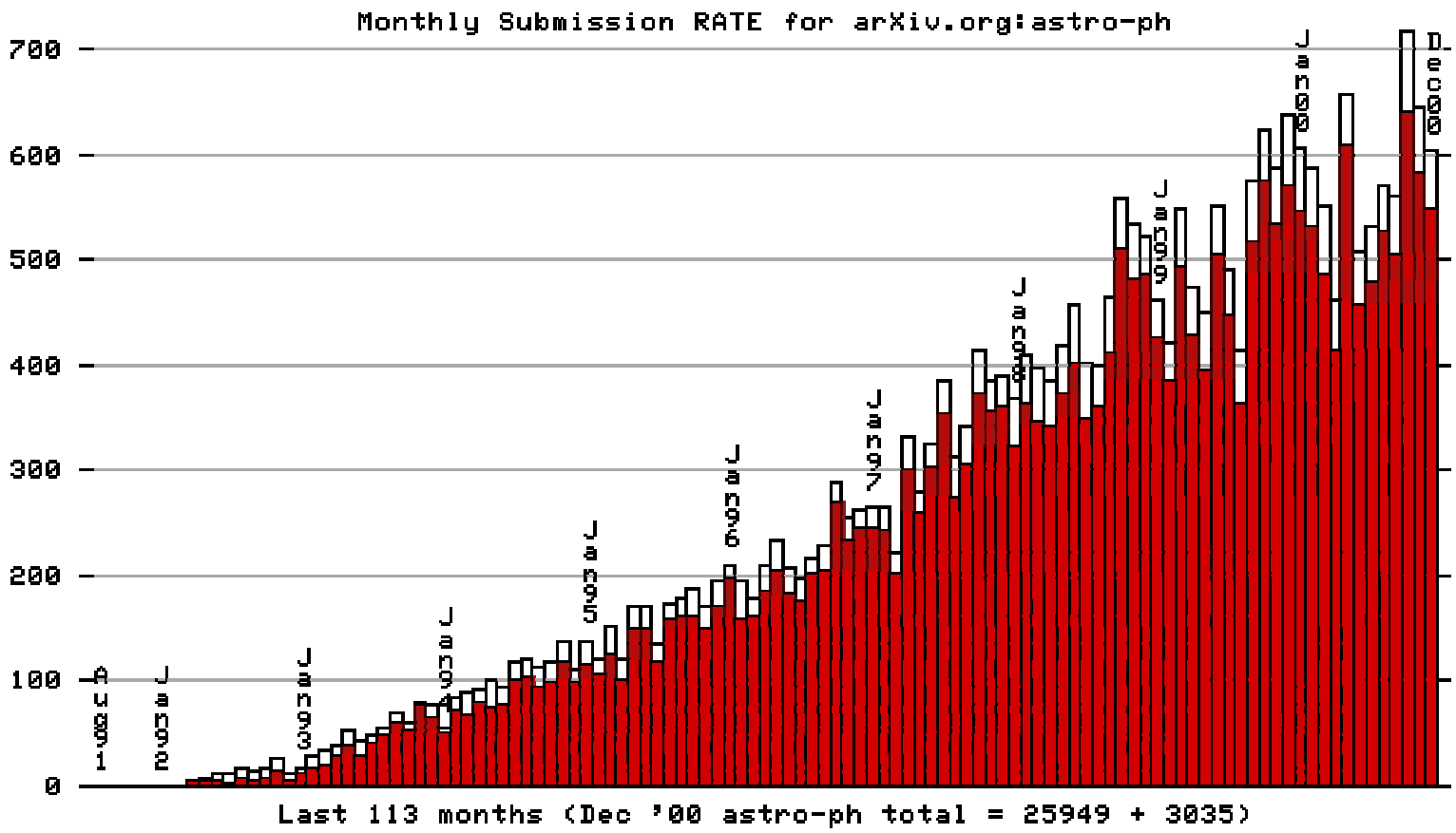

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Neutrino interactions at ultrahigh energies

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(Received 7 July 1998; published 30 September 1998)

We report new calculations of the cross sections for deeply inelastic neutrino-nucleon scattering at neutrino energies between 10^9 eV and 10^{21} eV. We compare with results in the literature and assess the reliability of our predictions. For completeness, we briefly review the cross sections for neutrino interactions with atomic electrons, emphasizing the role of the W-boson resonance in $\bar{\nu}_e e$ interactions for neutrino energies in the neighborhood of 6.3 PeV. Adopting model predictions for extraterrestrial neutrino fluxes from active galactic nuclei, gamma-ray bursters, and the collapse of topological defects, we estimate event rates in large-volume water Cerenkov detectors and large-area ground arrays. [S0556-2821(98)08621-4]

PACS number(s): 13.15.+g, 13.60.Hb, 95.55.Vj, 96.40.Tv

I. INTRODUCTION

Neutrino observatories hold great promise for probing the deepest reaches of stars and galaxies [1–4]. Unlike charged particles, neutrinos arrive on a direct line from their source, undeflected by magnetic fields. Unlike photons, neutrinos interact weakly, so they can penetrate thick columns of matter. For example, the interaction length of a 1-TeV neutrino is about 2.5 million kilometers of water, or 250 kton/cm^2, whereas high-energy photons are blocked by a few hundred g/cm^2.

Ultrahigh-energy neutrinos can be detected by observing long-range muons produced in charged-current neutrino-nucleon interactions. To reduce the background from muons produced in the atmosphere, it is advantageous to site a neutrino telescope at a depth of several kilometers (water equivalent) or to observe upward-going muons. The reactions $(\nu_l,\bar{\nu}_l)N\rightarrow(l^-,l^+)+$anything and $(\nu_l,\bar{\nu}_l)N\rightarrow(\nu_l,\bar{\nu}_l)+$anything are the major sources of both the desired signal and the attenuation of the neutrino ''beam'' as it passes through the Earth *en route* to the detector. Through the past dozen years, improving knowledge of the partonic structure of the nucleon has made possible a series of increasingly refined predictions for the interaction cross sections [5–13]. Over the same period, ideas about the flux of neutrinos from active galactic nuclei (AGNs) and other extraterrestrial sources have evolved considerably. The observation [14] of neutrinos correlated with supernova SN1987A and the detection of solar neutrinos by observing the direction of recoil electrons from neutrino interactions [15,16] showed the promise of neutrino observatories for astrophysical studies. The detection of neutrinos produced by cosmic-ray interactions in the Earth's atmosphere [17–20] has emerged as a tool for investigating neutrino oscillations [21–24]. Plans for neutrino observatories that will detect neutrinos that originate beyond Earth have matured to the point that it is now reasonable to contemplate instrumenting a volume of water or ice as large as 1 km^3 [25–32]. The ground array of the proposed Pierre Auger Cosmic Ray Observatory [33] would have an acceptance exceeding 1 km^3 sr of water for neutrino energies greater than 10^{17} eV [34]. The Orbiting Wide-angle Light collectors project (OWL) would place in Earth orbit a lens to study air showers initiated by $>10^{20}$-eV particles, including neutrinos [35].

In this paper we present new calculations of the cross sections for charged-current and neutral current interactions of neutrinos with nucleons, updating our results of Ref. [12] [Gandhi, Quigg, Reno, and Sarcevic 1996 (GQRS96)] to take account of new information about the parton distributions within the nucleon [36]. In place of the CTEQ3-DIS (deep inelastic scattering) parton distributions [37] that we adopted as our nominal set in GQRS96, we base our new calculations on the CTEQ4-DIS parton distributions [38]. The changes are modest, and only noticeable at the highest neutrino energies we consider: at $E_\nu=10^{21}$ eV, the new cross sections are about 25% smaller than those of GQRS96. We find that for neutrino energies up to 10^{16} eV, all the standard sets of parton distribution functions yield very similar cross sections. At higher energies, the predictions rely on incompletely tested assumptions about the behavior of parton distributions at very small values of the momentum fraction

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Technology of the Electronic Journal

- ▷ LaTeX (1979 technology), supplemented by PostScript and PDF, still the mainstay

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Phys. Rev. Lett. 33, 1406–1408 (1974)

[Issue 23 – 2 December 1974]

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Discovery of a Narrow Resonance in e^+e^- Annihilation

J. -E. Augustin*, A. M. Boyarski, M. Breidenbach, F. Bulos, J. T. Dakin, G. J. Feldman, G. E. Fischer, D. Fryberger, G. Hanson, B. Jean-Marie*, R. R. Larsen, V. Lüth, H. L. Lynch, D. Lyon, C. C. Morehouse, J. M. Paterson, M. L. Perl, B. Richter, P. Rapidis, R. F. Schwitters, W. M. Tanenbaum, and F. Vannucci§

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Received 13 November 1974

We have observed a very sharp peak in the cross section for e^+e^--->hadrons, e^+e^-, and possibly $\mu^+\mu^-$ at a center-of-mass energy of 3.105±0.003 GeV. The upper limit to the full width at half-maximum is 1.3 MeV.

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URL: http://link.aps.org/abstract/PRL/v33/p1406
DOI: 10.1103/PhysRevLett.33.1406

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See Also:

Comment: M. Suzuki, *Slope of psi Regge Trajectories and a Test of "Elementarity" of the psi Particles in 2 psi Production by Hadrons*, Phys. Rev. Lett. 34, 1412 (1975).

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proximately 10^{-34} cm^2.

The most striking feature of J is the possibility that it may be one of the theoretically suggested charmed particles[2] or a's[3] or Z_0's,[4] etc. In order to study the real nature of J,[5] measurements are now underway on the various decay modes, e.g., an $e\pi\nu$ mode would imply that J is weakly interacting in nature.

It is also important to note the absence of an e^+e^- continuum, which contradicts the predictions of parton models.[6]

We wish to thank Dr. R. R. Rau and the alternating-gradient synchrotron staff who have done an outstanding job in setting up and maintaining this experiment. We thank especially Dr. F. Eppling, B. M. Bailey, and the staff of the Laboratory for Nuclear Science for their help and encouragement. We thank also Ms. I. Schulz, Ms. H. Feind, N. Feind, D. Osborne, G. Krey, J. Donahue, and E. D. Weiner for help and assistance. We thank also M. Deutsch, V. F. Weisskopf, T. T. Wu, S. Drell, and S. Glashow for many interesting conversations.

†Accepted without review under policy announced in Editorial of 20 July 1964 [Phys. Rev. Lett. 13, 79 (1964)].

[1]The first work on $p+p\to\mu^++\mu^-+x$ was done by L. M. Lederman *et al.*, Phys. Rev. Lett. 25, 1523 (1970).

[2]S. L. Glashow, private communication.

[3]T. D. Lee, Phys. Rev. Lett. 26, 801 (1971).

[4]S. Weinberg, Phys. Rev. Lett. 19, 1264 (1967), and 27, 1688 (1971), and Phys. Rev. D 5, 1412, 1962 (1972).

[5]After completion of this paper, we learned of a similar result from SPEAR. B. Richter and W. Panofsky, private communication; J.-E. Augustin *et al.*, following Letter [Phys. Rev. Lett. 33, 1404 (1974)].

[6]S. D. Drell and T. M. Yan, Phys. Rev. Lett. 25, 316 (1970). An improved version of the theory is not in contradiction with the data.

Discovery of a Narrow Resonance in e^+e^- Annihilation*

J.-E. Augustin,† A. M. Boyarski, M. Breidenbach, F. Bulos, J. T. Dakin, G. J. Feldman, G. E. Fischer, D. Fryberger, G. Hanson, B. Jean-Marie,† R. R. Larsen, V. Lüth, H. L. Lynch, D. Lyon, C. C. Morehouse, J. M. Paterson, M. L. Perl, B. Richter, P. Rapidis, R. F. Schwitters, W. M. Tanenbaum, and F. Vannucci‡

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(Received 13 November 1974)

We have observed a very sharp peak in the cross section for $e^+e^-\to$ hadrons, e^+e^-, and possibly $\mu^+\mu^-$ at a center-of-mass energy of 3.105 ± 0.003 GeV. The upper limit to the full width at half-maximum is 1.3 MeV.

We have observed a very sharp peak in the cross section for $e^+e^-\to$ hadrons, e^+e^-, and possibly $\mu^+\mu^-$ in the Stanford Linear Accelerator Center (SLAC)–Lawrence Berkeley Laboratory magnetic detector[1] at the SLAC electron-positron storage ring SPEAR. The resonance has the parameters

$$E=3.105\pm0.003\text{ GeV},$$

$$\Gamma\leq1.3\text{ MeV}$$

(full width at half-maximum), where the uncertainty in the energy of the resonance reflects the uncertainty in the absolute energy calibration of the storage ring. [We suggest naming this structure $\psi(3105)$.] The cross section for hadron production at the peak of the resonance is ≥2300 nb, an enhancement of about 100 times the cross section outside the resonance. The large mass, large cross section, and narrow width of this structure are entirely unexpected.

Our attention was first drawn to the possibility of structure in the $e^+e^-\to$ hadron cross section during a scan of the cross section carried out in 200-MeV steps. A 30% (6 nb) enhancement was

observed at a c.m. energy of 3.2 GeV. Subsequently, we repeated the measurement at 3.2 GeV and also made measurements at 3.1 and 3.3 GeV. The 3.2-GeV results reproduced, the 3.3-GeV measurement showed no enhancement, but the 3.1-GeV measurements were internally inconsistent—six out of eight runs giving a low cross section and two runs giving a factor of 3 to 5 higher cross section. This pattern could have been caused by a very narrow resonance at an energy slightly larger than the nominal 3.1-GeV setting of the storage ring, the inconsistent 3.1-GeV cross sections then being caused by setting errors in the ring energy. The 3.2-GeV enhancement would arise from radiative corrections which give a high-energy tail to the structure.

We have now repeated the measurements using much finer energy steps and using a nuclear magnetic resonance magnetometer to monitor the ring energy. The magnetometer, coupled with measurements of the circulating beam position in the storage ring made at sixteen points around the orbit, allowed the relative energy to be determined to 1 part in 10^4. The determination of the absolute energy setting of the ring requires the knowledge of $\int B\,dl$ around the orbit and is accurate to $\pm 0.1\%$.

The data are shown in Fig. 1. All cross sections are normalized to Bhabha scattering at 20 mrad. The cross section for the production of hadrons is shown in Fig. 1(a). Hadronic events are required to have in the final state either ≥ 3 detected charged particles or 2 charged particles noncoplanar by $>20°$.[2] The observed cross section rises sharply from a level of about 25 nb to a value of 2300 ± 200 nb at the peak[3] and then exhibits the long high-energy tail characteristic of radiative corrections in e^+e^- reactions. The detection efficiency for hadronic events is 45% over the region shown. The error quoted above includes both the statistical error and a 7% contribution from uncertainty in the detection efficiency.

Our mass resolution is determined by the energy spread in the colliding beams which arises from quantum fluctuations in the synchrotron radiation emitted by the beams. The expected Gaussian c.m. energy distribution ($\sigma = 0.56$ MeV), folded with the radiative processes,[4] is shown as the dashed curve in Fig. 1(a). The width of the resonance must be smaller than this spread; thus an upper limit to the full width at half-maximum is 1.3 MeV.

Figure 1(b) shows the cross section for e^+e^- final states. Outside the peak this cross section

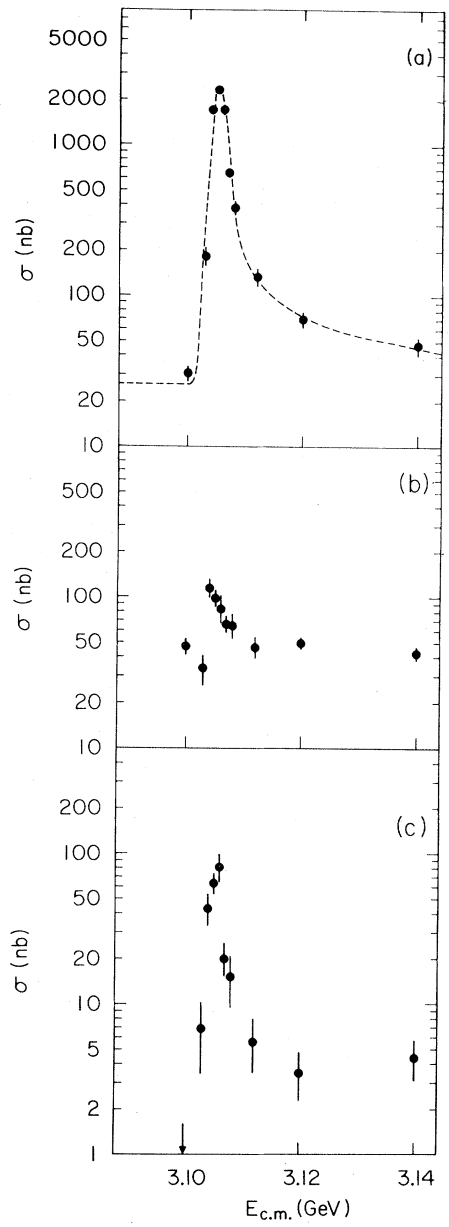

FIG. 1. Cross section versus energy for (a) multihadron final states, (b) e^+e^- final states, and (c) $\mu^+\mu^-$, $\pi^+\pi^-$, and K^+K^- final states. The curve in (a) is the expected shape of a δ-function resonance folded with the Gaussian energy spread of the beams and including radiative processes. The cross sections shown in (b) and (c) are integrated over the detector acceptance. The total hadron cross section, (a), has been corrected for detection efficiency.

is equal to the Bhabha cross section integrated over the acceptance of the apparatus.[1]

Figure 1(c) shows the cross section for the production of collinear pairs of particles, excluding electrons. At present, our muon identi-

fications system is not functioning and we therefore cannot separate muons from strongly interacting particles. However, outside the peak the data are consistent with our previously measured μ-pair cross section. Since a large $\pi\pi$ or KK branching ratio would be unexpected for a resonance this massive, the two-body enhancement observed is *probably* but not *conclusively* in the μ-pair channel.

The $e^+e^- \to$ hadron cross section is presumed to go through the one-photon intermediate state with angular momentum, parity, and charge conjugation quantum numbers $J^{PC} = 1^{--}$. It is difficult to understand how, without involving new quantum numbers or selection rules, a resonance in this state which decays to hadrons could be so narrow.

We wish to thank the SPEAR operations staff for providing the stable conditions of machine performance necessary for this experiment. Special monitoring and control techniques were developed on very short notice and performed excellently.

*Work supported by the U. S. Atomic Energy Commission.

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[1]The apparatus is described by J.-E. Augustin *et al.*, to be published.

[2]The detection-efficiency determination will be described in a future publication.

[3]While preparing this manuscript we were informed that the Massachusetts Institute of Technology group studying the reaction $pp \to e^+e^- + x$ at Brookhaven National Laboratory has observed an enhancement in the e^+e^- mass distribution at about 3100 MeV. J. J. Aubert *et al.*, preceding Letter [Phys. Rev. Lett. 33, 1402 (1974)].

[4]G. Bonneau and F. Martin, Nucl. Phys. B27, 381 (1971).

Preliminary Result of Frascati (ADONE) on the Nature of a New 3.1-GeV Particle Produced in e^+e^- Annihilation*

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G. Barbarino, G. Barbiellini, C. Bemporad, R. Biancastelli, F. Cevenini, M. Celvetti, F. Costantini, P. Lariccia, P. Parascandalo, E. Sassi, C. Spencer, L. Tortora, U. Troya, and S. Vitale
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(Received 18 November 1974)

We report on the results at ADONE to study the properties of the newly found 3.1-BeV particle.

Soon after the news that a particle of 3.1 GeV with a width consistent with zero had been observed at Brookhaven National Laboratory by the Massachusetts Institute of Technology group,[1] it was immediately decided to push ADONE beyond its nominal limit of energy (2×1.5 GeV) to look for this particle. On the following day the information had reached us that this particle had also been observed at SPEAR at the energy of exactly 3.10 GeV with a narrow width, <1.3 MeV.[2]

Three experiments[3] [the Gamma-Gamma Group, the Magnet Experimental Group for ADONE

EDITORIAL

Publication of a New Discovery

This issue of Physical Review Letters must certainly be one of the most unusual in our history, with not just one but three extremely stimulating reports of a new discovery. Undoubtedly, the activity which will be aroused will be enormous and we happily join the rest of the physics community in congratulating those involved.

At the same time we would like to point out that the events of the past weeks placed some considerable stress not only on our office staff but also on our editorial policy regarding prior publication. We are grateful to the authors who were willing to meet our desires to defer publication announcements until the journal issue appeared. When, however, upon consulting our advisors we became aware of the truly unusual extent to which the entire high energy physics community was involved, we concurred that the news justified early public release. We hope that this decision will not be used as a precedent in future controversies concerning our stated editorial policies but will instead be taken as an indication that we are willing to bend these policies so as to be of service to the physics community.

J. A. Krumhansl

George L. Trigg

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Rev. Mod. Phys. 4, 87–132 (1932)

[Issue 1 – January 1932]

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Quantum Theory of Radiation

Enrico Fermi

University of Rome, Italy

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Space-Time Approach to Quantum Electrodynamics

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(Received May 9, 1949)

In this paper two things are done. (1) It is shown that a considerable simplification can be attained in writing down matrix elements for complex processes in electrodynamics. Further, a physical point of view is available which permits them to be written down directly for any specific problem. Being simply a restatement of conventional electrodynamics, however, the matrix elements diverge for complex processes. (2) Electrodynamics is modified by altering the interaction of electrons at short distances. All matrix elements are now finite, with the exception of those relating to problems of vacuum polarization. The latter are evaluated in a manner suggested by Pauli and Bethe, which gives finite results for these matrices also. The only effects sensitive to the modification are changes in mass and charge of the electrons. Such changes could not be directly observed. Phenomena directly observable, are insensitive to the details of the modification used (except at extreme energies). For such phenomena, a limit can be taken as the range of the modification goes to zero. The results then agree with those of Schwinger. A complete, unambiguous, and presumably consistent, method is therefore available for the calculation of all processes involving electrons and photons.

The simplification in writing the expressions results from an emphasis on the over-all space-time view resulting from a study of the solution of the equations of electrodynamics. The relation of this to the more conventional Hamiltonian point of view is discussed. It would be very difficult to make the modification which is proposed if one insisted on having the equations in Hamiltonian form.

The methods apply as well to charges obeying the Klein-Gordon equation, and to the various meson theories of nuclear forces. Illustrative examples are given. Although a modification like that used in electrodynamics can make all matrices finite for all of the meson theories, for some of the theories it is no longer true that all directly observable phenomena are insensitive to the details of the modification used.

The actual evaluation of integrals appearing in the matrix elements may be facilitated, in the simpler cases, by methods described in the appendix.

THIS paper should be considered as a direct continuation of a preceding one[1] (I) in which the motion of electrons, neglecting interaction, was analyzed, by dealing directly with the *solution* of the Hamiltonian differential equations. Here the same technique is applied to include interactions and in that way to express in simple terms the solution of problems in quantum electrodynamics.

For most practical calculations in quantum electrodynamics the solution is ordinarily expressed in terms of a matrix element. The matrix is worked out as an expansion in powers of $e^2/\hbar c$, the successive terms corresponding to the inclusion of an increasing number of virtual quanta. It appears that a considerable simplification can be achieved in writing down these matrix elements for complex processes. Furthermore, each term in the expansion can be written down and understood directly from a physical point of view, similar to the space-time view in I. It is the purpose of this paper to describe how this may be done. We shall also discuss methods of handling the divergent integrals which appear in these matrix elements.

The simplification in the formulae results mainly from the fact that previous methods unnecessarily separated into individual terms processes that were closely related physically. For example, in the exchange of a quantum between two electrons there were two terms depending on which electron emitted and which absorbed the quantum. Yet, in the virtual states considered, timing relations are not significant. Olny the order of operators in the matrix must be maintained. We have seen (I), that in addition, processes in which virtual pairs are produced can be combined with others in which only positive energy electrons are involved. Further, the effects of longitudinal and transverse waves can be combined together. The separations previously made were on an unrelativistic basis (reflected in the circumstance that apparently momentum but not energy is conserved in intermediate states). When the terms are combined and simplified, the relativistic invariance of the result is self-evident.

We begin by discussing the solution in space and time of the Schrödinger equation for particles interacting instantaneously. The results are immediately generalizable to delayed interactions of relativistic electrons and we represent in that way the laws of quantum electrodynamics. We can then see how the matrix element for any process can be written down directly. In particular, the self-energy expression is written down.

So far, nothing has been done other than a restatement of conventional electrodynamics in other terms. Therefore, the self-energy diverges. A modification[2] in interaction between charges is next made, and it is shown that the self-energy is made convergent and corresponds to a correction to the electron mass. After the mass correction is made, other real processes are finite and insensitive to the "width" of the cut-off in the interaction.[3]

Unfortunately, the modification proposed is not completely satisfactory theoretically (it leads to some difficulties of conservation of energy). It does, however, seem consistent and satisfactory to define the matrix

[1] R. P. Feynman, Phys. Rev. **76**, 749 (1949), hereafter called I.

[2] For a discussion of this modification in classical physics see R. P. Feynman, Phys. Rev. **74** 939 (1948), hereafter referred to as A.

[3] A brief summary of the methods and results will be found in R. P. Feynman, Phys. Rev. **74**, 1430 (1948), hereafter referred to as B.

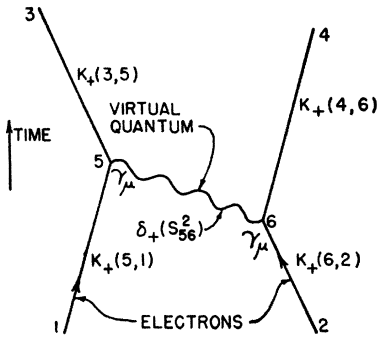

FIG. 1. The fundamental interaction Eq. (4). Exchange of one quantum between two electrons.

a general theoretical sense by this approximation. If it is not made it is not easy to study interacting particles relativistically, for there is nothing significant in choosing $t_1=t_3$ if $\mathbf{x}_1\neq\mathbf{x}_3$, as absolute simultaneity of events at a distance cannot be defined invariantly. It is essentially to avoid this approximation that the complicated structure of the older quantum electrodynamics has been built up. We wish to describe electrodynamics as a delayed interaction between particles. If we can make the approximation of assuming a meaning to $K(3,4;1,2)$ the results of this interaction can be expressed very simply.

To see how this may be done, imagine first that the interaction is simply that given by a Coulomb potential e^2/r where r is the distance between the particles. If this be turned on only for a very short time Δt_0 at time t_0, the first order correction to $K(3,4;1,2)$ can be worked out exactly as was Eq. (9) of I by an obvious generalization to two particles:

$$K^{(1)}(3,4;1,2)=-ie^2\int\int K_{0a}(3,5)K_{0b}(4,6)r_{56}^{-1}\times K_{0a}(5,1)K_{0b}(6,2)d^3\mathbf{x}_5d^3\mathbf{x}_6\Delta t_0,$$

where $t_5=t_6=t_0$. If now the potential were on at all times (so that strictly K is not defined unless $t_4=t_3$ and $t_1=t_2$), the first-order effect is obtained by integrating on t_0, which we can write as an integral over both t_5 and t_6 if we include a delta-function $\delta(t_5-t_6)$ to insure contribution only when $t_5=t_6$. Hence, the first-order effect of interaction is (calling $t_5-t_6=t_{56}$):

$$K^{(1)}(3,4;1,2)=-ie^2\int\int K_{0a}(3,5)K_{0b}(4,6)r_{56}^{-1}\times\delta(t_{56})K_{0a}(5,1)K_{0b}(6,2)d\tau_5d\tau_6,\quad(2)$$

where $d\tau=d^3\mathbf{x}dt$.

We know, however, in classical electrodynamics, that the Coulomb potential does not act instantaneously, but is delayed by a time r_{56}, taking the speed of light as unity. This suggests simply replacing $r_{56}^{-1}\delta(t_{56})$ in (2) by something like $r_{56}^{-1}\delta(t_{56}-r_{56})$ to represent the delay in the effect of b on a.

This turns out to be not quite right,[7] for when this interaction is represented by photons they must be of only positive energy, while the Fourier transform of $\delta(t_{56}-r_{56})$ contains frequencies of both signs. It should instead be replaced by $\delta_+(t_{56}-r_{56})$ where

$$\delta_+(x)=\int_0^\infty e^{-i\omega x}d\omega/\pi=\lim_{\epsilon\to 0}\frac{(\pi i)^{-1}}{x-i\epsilon}=\delta(x)+(\pi ix)^{-1}.\quad(3)$$

This is to be averaged with $r_{56}^{-1}\delta_+(-t_{56}-r_{56})$ which arises when $t_5<t_6$ and corresponds to a emitting the quantum which b receives. Since

$$(2r)^{-1}(\delta_+(t-r)+\delta_+(-t-r))=\delta_+(t^2-r^2),$$

this means $r_{56}^{-1}\delta(t_{56})$ is replaced by $\delta_+(s_{56}^2)$ where $s_{56}^2=t_{56}^2-r_{56}^2$ is the square of the relativistically invariant interval between points 5 and 6. Since in classical electrodynamics there is also an interaction through the vector potential, the complete interaction (see A, Eq. (1)) should be $(1-(\mathbf{v}_5\cdot\mathbf{v}_6)\delta_+(s_{56}^2)$, or in the relativistic case,

$$(1-\boldsymbol{\alpha}_a\cdot\boldsymbol{\alpha}_b)\delta_+(s_{56}^2)=\beta_a\beta_b\gamma_{a\mu}\gamma_{b\mu}\delta_+(s_{56}^2).$$

Hence we have for electrons obeying the Dirac equation,

$$K^{(1)}(3,4;1,2)=-ie^2\int\int K_{+a}(3,5)K_{+b}(4,6)\gamma_{a\mu}\gamma_{b\mu}\times\delta_+(s_{56}^2)K_{+a}(5,1)K_{+b}(6,2)d\tau_5d\tau_6,\quad(4)$$

where $\gamma_{a\mu}$ and $\gamma_{b\mu}$ are the Dirac matrices applying to the spinor corresponding to particles a and b, respectively (the factor $\beta_a\beta_b$ being absorbed in the definition, I Eq. (17), of K_+).

This is our fundamental equation for electrodynamics. It describes the effect of exchange of one quantum (therefore first order in e^2) between two electrons. It will serve as a prototype enabling us to write down the corresponding quantities involving the exchange of two or more quanta between two electrons or the interaction of an electron with itself. It is a consequence of conventional electrodynamics. Relativistic invariance is clear. Since one sums over μ it contains the effects of both longitudinal and transverse waves in a relativistically symmetrical way.

We shall now interpret Eq. (4) in a manner which will permit us to write down the higher order terms. It can be understood (see Fig. 1) as saying that the amplitude for "a" to go from 1 to 3 and "b" to go from 2 to 4 is altered to first order because they can exchange a quantum. Thus, "a" can go to 5 (amplitude $K_+(5,1)$)

[7] It, and a like term for the effect of a on b, leads to a theory which, in the classical limit, exhibits interaction through half-advanced and half-retarded potentials. Classically, this is equivalent to purely retarded effects within a closed box from which no light escapes (e.g., see A, or J. A. Wheeler and R. P. Feynman, Rev. Mod. Phys. 17, 157 (1945)). Analogous theorems exist in quantum mechanics but it would lead us too far astray to discuss them now.

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5/20 2:00	Dr. Leda Cosmides UCSB, Evolutionary Psychology Dr. John Tooby UCSB, Anthropology Dept.	Has Natural Selection Shaped How Humans Reason?[Aud]

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10/08, 4:00 p.m.	Dr. A. Yacoby Weizmann Institute	Tunneling Spectroscopy of Elementary Excitation in 1D
10/10, 2:00 p.m.	Dr. Mehran Kardar ITP & MIT	The `Friction' of Vacuum, and other Fluctuation-Induced Forces[Slides][Aud][Cam]
10/12, 10:30 a.m.	Dr. Ilya Nemenman ITP	Predictability, Complexity and Learning[Slides][Aud][Cam]
10/17, 2:00 p.m.	Dr. Victor Gurarie Oxford	Disorder Symmetry and Universality Classes[Slides][Aud][Cam]
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10/24, 2:00 p.m.	Dr. S. C. Zhang Stanford University	A Four Dimensional Generalization of the Quantum Hall Effect[Aud][Cam]
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11/06, 2:30 p.m.	Dr. Kay Wiese ITP	Disordered Systems and the Functional Renormalization Group[Slides][Aud][Cam]
11/14, 2:00 p.m.	Dr. J. E. Mooij ITP & Delft University of Technology	Macroscopic Quantum Effects in Josephson Junction Circuits[Aud][Cam]
11/19, 2:00 p.m.	Dr. Boris Shraiman Bell Labs	Statistical Mechanics in Modeling of Transcription Control Networks
11/28, 2:00 p.m.	Dr. Art Wolfe UCSD	Does the Fine Structure Constant Vary Over Cosmological Time Scales?

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2/14, 2:00 p.m.	Dr. David Kleinfeld UCSD	Phase Oscillators and Traveling Electrical Waves in Cortex[Slides][Aud]
2/28, 2:00 p.m.	Dr. Steven Girvin ITP & Indiana University	Physical Realizations of Quantum Bits: Trapped Ions and Cooper Pair Boxes[Slides][Aud]
3/14, 2:00 p.m.	Dr. Angela Olinto U. Chicago	The Highest Energy Cosmic Rays[Slides][Aud]
3/21, 2:00 p.m.	Dr. Henry W. Sobel University of California, Irvine	Neutrino Mass from Super-Kamiokande[Slides][Aud]
4/11, 2:00 p.m.	Dr. Michael Peskin SLAC	A Decade of Precision Electroweak Experiments[Slides][Aud]
4/13, 3:30 p.m.	Dr. Michael H. Freedman Microsoft	A Two-Dimensional Antiferromagnet Which "Knows" Chern-Simons Theory[Slides][Aud][Cam]
4/18, 2:00 p.m.	Dr. Thomas Junk CERN	Searches for the Higgs Boson at LEP[Slides][Aud]
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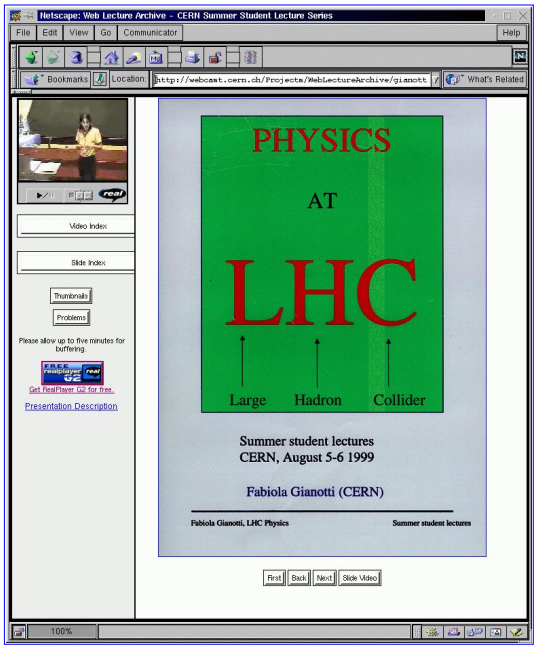

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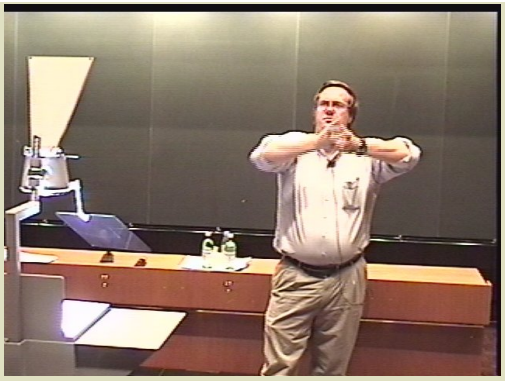

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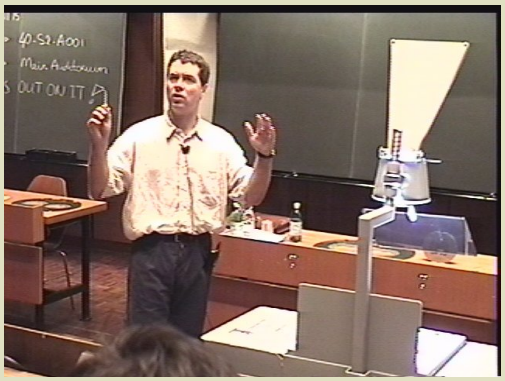

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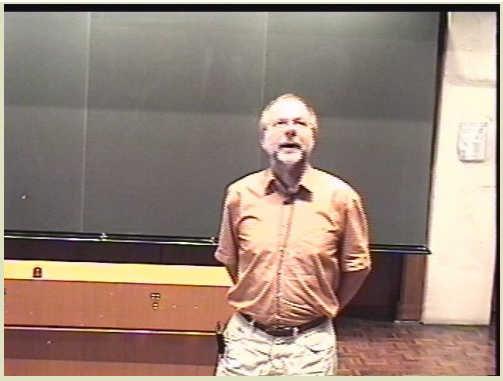
Part	Date	Video Plug-In	Video Detached	Archive Notes
1	27-jul-1999			



Physics at LEP - *P. Janot* (Course Description)

Part	Date	Video Plug-In	Video Detached	Archive Notes
1	29-jul-1999			
2	29-jul-1999			
3	30-jul-1999			
4	2-aug-1999			

Beyond the Standard Model - *G. Giudice* (Course Description)

Part	Date	Video Plug-In	Video Detached	Archive Notes
1	2-aug-1999			
2	3-aug-1999			
3	4-aug-1999			

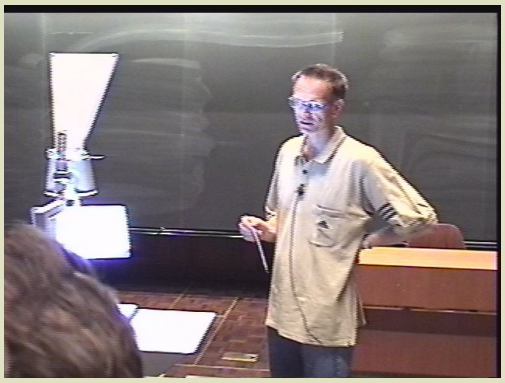
CP Violation - *J. Lee-Franzini* (Course Description)

Part	Date	Video Plug-In	Video Detached	Archive Notes
1	3-aug-1999			
2	4-aug-1999			
3	5-aug-1999			

Physics at LHC - *F. Gianotti* (Course Description)

Part	Date	Video Plug-In	Video Detached	Archive Notes
1	5-aug-1999			
2	5-aug-1999			
3	6-aug-1999			

Neutrino Physics - *J. Panman* (Course Description)



Part	Date	Video Plug-In	Video Detached	Archive Notes
1	9-aug-1999			
2	10-aug-1999			
3	11-aug-1999			

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WLAP Team for the Summer Students Lectures 1999:
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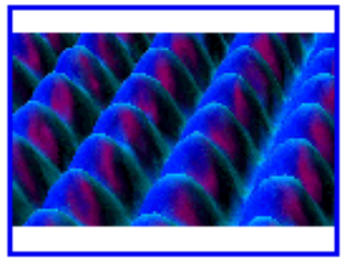

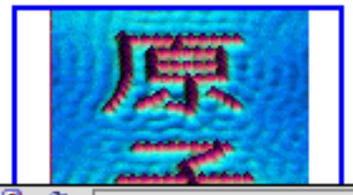

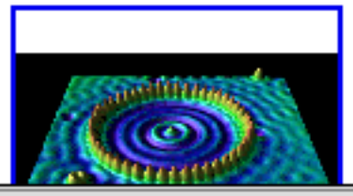

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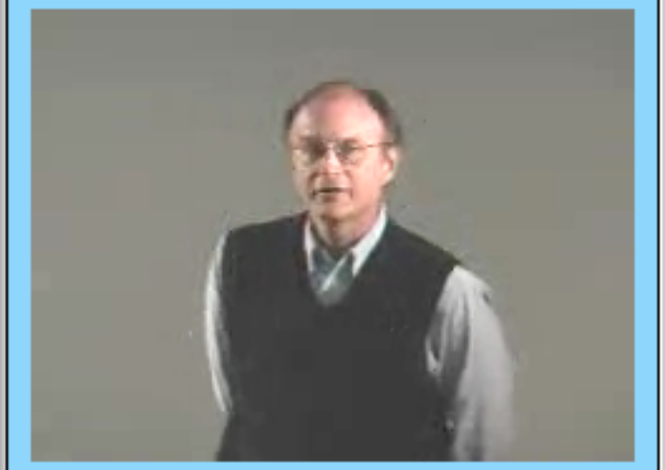

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WHERE TO FIND ME CURRICULUM VITAE FUTURE LECTURES

Snowmass 2001 Web Site

"Fermilab as a Creative Community," invited lecture (PDF file) at the Symposium on the Future of Creativity, School of the Art Institute of Chicago, 3 November 2001.

"Visions: the Coming Revolutions in Particle Physics," Closing Lecture (PDF file) of the Third International Symposium on Large Hadron Collider Physics and Detectors, Chia, Sardinia, Italy, 27 October 2001

"The Last Universal Physicist," a brief appreciation of Enrico Fermi, from *FermiNews*

"Why We Are Here," Snowmass 2001 Opening Talk (PDF) and Streaming Video

"Next Steps," Snowmass 2001 Closing Talk (PDF) and Streaming Video

"The Futures of Particle Physics," Plenary Talk (PDF) at the 2001 Particle Accelerator Conference and Streaming Video; "Particle Physics--Future Directions," paper for conference proceedings.

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Gauge Theories of the Strong, Weak, and Electromagnetic Interactions

"Particle Physics: The World of Matter, Space, and Time,"
streaming video of my Science for Everyone lecture at Fermilab, November 14, 2000.

WEBCAST OF MY 1999 AND 2000 CERN LECTURES FOR SUMMER STUDENTS

Web references for "The Secret Life of the Higgs Boson," (one PDF page)
for the Quarknet Teachers Weekend @ Fermilab, November 11, 2000.

"The Nature of Science," streaming video of my keynote lecture at the Fermilab Symposium on the Nature of Science

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