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HYPERON AND KAON PHYSICS PROGRAMS AT THE FERMILAB TEVATRON, 1983–2000

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After discussing the origins of the Tevatron Hyperon and Kaon programs, I present the major themes and results of the 10 experiments. I close with some summary comments.

1. INTRODUCTION

There were ten experiments that ran during the Tevatron era at Fermilab, between 1983 and 2000, with the purpose of determining the physics of hyperon and/or kaon production and decay. The experiments ran in either the proton center (PC) line, which was configured for either charged or neutral beams, the meson center (MC) beam, or the new muon beam (NM). Table 1 shows, for each year the Tevatron ran, how many months of operation there were and which experiments (by their number) were running in each of the beamlines.

Both programs can be traced back a decade earlier when Fermilab first delivered beam. We will see that the physics and technology of the programs are related. Of course from the very beginning, they were associated with each other: "associated production" was the concept that

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TABLE 1.

Tevatron hyperon and kaon programs

		"Hyperons"			
		PC		*"Kaons"*	
Year	*Beam (months)*	*"Charged"*	*"Neutral"*	*MC*	*NM*
1983/1984[a]	4.5	715			
1984	3.5		621		
1985	8		621	731T	
1987/1988	8		756	731	
1990	6.5	761		773	
1991	5.5		800	799-I	
1996/1997	14			871	KTeV
1999/2000	7			871	KTeV
	57 (28% live)				

[a]400 GeV.

could explain the large production cross-sections for the "strange" particles even though they decayed so slowly. These programs have ended up studying 5 members of the meson octet, 5 of the baryon octet, and one member of the baryon decuplet: the Ω^-.

At Fermilab, the original kaon program was begun by Telegdi and its thrust was strong interaction physics, particularly a precision determination of the validity of the Pomeranchuk Theorem. This and Regge Pole formalism told us that asymptotically the total cross-sections for particle/anti-particle should approach each other (even though both may rise logarithmically). As the K_L contains a nearly equal coherent mixture of particle and anti-particle, it allows direct comparison of particle, anti-particle processes without the drawback, for example with charged mesons, of differencing two numbers determined at different times with different systematics, etc. The program evolved over time to the study of CP violation, rare K decays, and even rare π^0 and hyperon decays.

The original thrust in the hyperon program, initially led by Devlin and Pondrom, was the production mechanisms: x, P_T, and A-dependences. The surprising discovery at Fermilab that the hyperons were *polarized* then enabled an extensive program studying magnetic moments, β decay and CP violation. The key factors in hyperon beam design and the advantages of higher energy primary beam are spelled out in the following, from a comprehensive review article by Lach and Pondrom from 1979 in the ARNPS:

For example, a 10-GeV/c Λ beam is attenuated by 1/e in only 69 cm. Since the fractional yield of hyperons at the target remains essentially constant at about 10% as the energy is increased, good hyperon beams clearly become easier to make at higher energy, provided that the length necessary to shield the experiment from the primary production target does not also scale with the energy. This is indeed the case, because adequate shielding for hadronic cascades requires a thickness of material that grows only logarithmically with the primary energy. Thus, as seen below, beam lines designed to operate at 400 GeV are only about a factor of two longer than those designed for 30 GeV, which gives a substantial advantage in signal-to-noise ratio to the higher energy beams.

2. THE EXPERIMENTS

Before discussing the individual experiments, I want to begin with a disclaimer. I cannot do justice in this short article, or even in the available time to research the work described here, to all of the the physics and the ingenious ways invented for meeting experimental challenges, in beam design, in background rejection, in triggering, in calibration, in data acquisition, etc. I confess that this contribution will be somewhat impressionistic. The real "action" in these experiments takes place during the data collection; I estimate that physicists took about 20,000 shifts over the course of the program and we need to remember the drama, the discoveries, the disappointments, the revelations, the seeming routineness (until later one looks at the data collected), in short the period and process where the scope of the eventual physics is determined, even though this has not been effectively captured before.

Table 1 shows the experiments we will discuss. The collaborations evolved over time and although the physics thrusts changed, it is still useful to trace the programs with this evolution in mind. There are three such chains, which we will discuss in turn:

- E715/E761 in the PC charged beam.
- E621/E756/E800/E871 beginning in the neutral PC beam and moving to the MC beam.
- E731/E773/E799-I/KTeV beginning in MC and moving to the NM beam.

3. PC, CHARGED HYPERON BEAM

3.1. E715

E715 was the first experiment, either hyperon or kaon, to run during the tevatron era. It actually ran with the machine at 400 GeV with the goal of a precision measurement of the Σ^- decay to $ne^-\nu$.

The proposal, from 2/19/82, with Peter Cooper as "Correspondent" stated that the goal was to "collect more than one hundred times the current world sample of polarized Σ beta decay events." This was to resolve an apparent discrepancy in the earlier measurements with the expectation from the Cabibbo-model. They ended up collecting about 90 K such events and made important advances in the performance of their TRD system. The systematic uncertainties were controlled by frequent reversal of the Σ polarization. Their result for the asymmetry was $\alpha_e = -0.53(5)(4)(12)$ (S. Y. Hsueh et al., 1985). The group also published a measurement of the Σ^- magnetic moment (G. Zapalac et al., 1986), and a long PRD article in 1989.

Their 1985 article said, "This result is in excellent agreement with the Cabibbo-model value $\alpha_e = -0.51(4)$ and thus confirms a key prediction of the theory."

3.2. E761

E761 was a follow-up experiment whose goal was to "measure the asymmetry parameter for the electroweak decay $\Sigma^+ \rightarrow p\gamma$ and verify its branching ratio." They pointed out "that modern high energy, high intensity polarized hyperon beams have shown themselves to be unique instruments ideally suited to the study of such rare decay processes." A. Vorobyov was the spokesman for this 4/3/85 proposal.

The context for the experiment was described in the 1992 publication of M. Foucher et al.:

> The main difficulty in such experiments is separation of the $\Sigma^+ \rightarrow p\gamma$ decay from the 400 times more abundant hadronic decay $\Sigma^+ \rightarrow p\pi^0$. Moreover, the asymmetry parameter in the hadronic decay is large and negative ($\alpha_{\pi^0} = -0.980 \pm 0.016$ [4]), which raised the concern that the observed asymmetry in the $\Sigma^+ \rightarrow p\gamma$ decay might be, in fact, due to some

> contamination of the background into the pγ sample. In addition, the number of pγ events detected in both experiments was very small (61 [2] and 46 [3], respectively).

They obtained the result $\alpha_\gamma = -0.720(86)(45)$ with 35K events, a tracking gamma detector, and recording 220M triggers/month.

This experiment observed for the first time precession of a magnetic moment in a bent crystal (D. Chen, 1992), measured the polarization of the Σ^+ and its anti-particle (A. Morelas, 1993), and performed a search for light SUSY baryons (I. Albuquerque, 1997). In addition they published four PRD articles on their work.

4. PC (AND MC), NEUTRAL K AND HYPERON BEAMS

4.1. E621

The E621 proposal, to search for CP violation in the $\pi^+\pi^-\pi^0$ decay of the neutral K (G. Thomson, spokesman) stated: "We should use the M2 beam and the "E8" spectrometer, modifying the beam to hit two targets, one to give the interference, and the other upstream to give pure K_L decay for normalization."

The experiment was performed in PC; they collected 272K events and their result was $\text{Im}(\eta_{+-0}) = -0.015(17)(25)$ (Y. Zou, 1996), "consistent with pure K_L decays."

The group also published on the CP conserving piece, a limit on a possible momentum-dependence to the K_S lifetime (N. Grossman, 1987), and a measurement of the Ξ^0 lifetime (S. Tiege, 1989). Thomson and Zou also published a review article on the status of CPT symmetry in the K system (Thomson and Zou, 1995).

4.2. E756

The goal of this experiment was a measurement of the magnetic moment of the Ω^- Hyperon: "A precision of 0.01 nuclear magnetons can be achieved in 1000 hours of running in Proton Center." The run yielded the measurement $\mu_\Omega = -1.94(17)(14)$ n.m. (Diehl, 1991), and it took the follow up run (see E800 below) to achieve the stated goal. But perhaps more significantly, the group " ... discovered that anti-Ξ^+'s produced by protons have a polarization approximately equal to the Ξ^-. The presence of a significant polarization for the anti-Ξ^+ makes possible the first measurement of the magnetic moment of an antihyperon (Ho, 1990)." The group also has published a limit on the CP asymmetry in the Ξ decays (Luk, 2000 and see E871 below). In addition, two PRD articles were published.

The group argued for an immediate extension, to improve the Ω^- magnetic moment measurement, arguing that "Our spectrometer is tuned and ready, our analysis is tuned and ready, and the E756 collaborators are tuned and ready." The Director Leon Lederman wrote an encouraging response, saying, "There are lots of possibilities but no certainties." In the end, the extension ran after the E761 run and the new run was called E800.

4.3. E800

This experiment, led by K. Johns and G. Rameika, was able to make a mid-course correction: "In this experiment polarized Ω^-'s were produced by using two different techniques: the spin transfer technique from a polarized neutral beam, which was used in the previous Ω^- magnetic moment measurement, and a new technique that used an unpolarized neutral beam." Their measurement of $\mu_\Omega = -2.024(56)(0!)$ n.m. (Wallace, 1995), stands as the best determination to date. The group also reported in a PRD article the production polarizations of the Ξ^- and Ω^-.

4.4. E871

E871 may be the most ambitious experiment ever attempted at Fermilab. It is directed at the question of direct CP violation in strange quark decays but in a system outside of that of the neutral kaons. We have well established indirect and now direct CP violating effects with the neutral kaons. If our understanding is correct, there should also be direct effects in the decays of the charged kaons and hyperons. These effects are expected to be larger than epsilon prime (not being suppressed by the delta I = 1/2 rule) but more difficult to measure because of the need to directly compare particle and anti-particle distributions. These are important to pursue in part because establishing any additional direct effect in the decays of B mesons will be difficult.

E871 was proposed in 1993 with the aim of limiting or establishing a CP asymmetry in the decay sequence $\Xi^- \to \Lambda\pi^-$, $\Lambda \to p\pi^-$ compared to the same sequence beginning with the anti-Ξ^- "well over two orders of magnitude better than at present." In the standard model, the asymmetry could be up the level of order 10^{-4}. The proposal further states that "[such] asymmetries ... were presumed to be difficult if not impossible to measure experimentally. In the past decade, however, considerable advances have been made in the development and operation of very high-rate experiments. It is no longer inconceivable for an experiment to acquire in a year's time the order of a billion events needed to measure such asymmetries."

The experiment was designed to collect the data in such a way as to reduce and be able to understand a variety of systematic effects. To date, the group has looked at a sample corresponding to about 6 million anticascades and "at the 10^{-3} level, things are OK."*

The issue will be whether the result is statistics limited when the roughly 100 times more data is fully analyzed. This is certainly the measurement that is the most demanding in terms of systematic understanding. Such challenges are certainly not to everyone's taste: I wonder if this might be the last such experiment in high-energy physics. I certainly hope not.

5. MC (AND NM) NEUTRAL KAON BEAMS

5.1. E731

The neutral kaon program began, in the Tevatron era, with E731. The proposal for E731, from February of 1983, indicates that the only physics that was considered was a measurement of ϵ'/ϵ, this to a claimed precision of 0.001. The considerable improvement over previous efforts came from attention to systematics and, "The construction of a new neutral beam coupled with the long spill available at the Tevatron provides a factor of nearly six improvement in the (hourly) kaon flux. Improvements to the

*Kam-Biu Luk, private communication. Luk and Dukes are cospokesmen for E871. While KTeV is distinguished in having the largest number of spokespersons, E871 had by far the highest fraction of authors on the proposal listed as spokespeople: 50%! And while KTeV had a full book of budget figures, E871 provided just one page on which they added 15 items each with one significant figure to arrive at a total budget having three significant figures.

detector yield another factor of six increase in acceptance without any sacrifice in resolution."

The beam was another important ingredient for E731. In the proposal it was stated that "the total neutron interaction rate will be only about 60 KHz *assuming no improvement in the anomalous neutron flux* [seen in earlier experiments]." In fact, the neutron flux was dramatically reduced when the beams group understood and corrected for the problems in design of the first generation neutral beams at the lab.

In the end, the experiment exceeded its goal, achieving $\mathrm{Re}(\epsilon'/\epsilon) = (7.4 \pm 5.9) \times 10^{-4}$ (Woods, 1988; Patterson, 1990; Gibbons, 1992). A sensitive CPT study was also published (Karlsson, 1990). Sensitivity to rare kaon decay physics came as a bonus; several searches and measurements were published and this set the stage for subsequent experiments dedicated to rare kaon decay physics.

5.2. E773

Another follow-up experiment was E773, led by G. Gollin in which it was proposed "to add an additional regenerator to the E731 spectrometer in the MC beamline to enable us to measure the phase difference between the CP violation parameters η_{00} and η_{+-} to an accuracy of 1^0." The experiment was a success, reaching the stated precision, where the result (Schwingenheuer, 1995) effectively determines that the kaon and anti-kaon have the same mass to a part in 10^{-18}!

5.3. E799

E799, led by Y. Wah and T. Yamanaka, was proposed to study the rare decay $K_L \rightarrow \pi^0 e^+ e^-$. In the end it did this as well as the related mode with muons where it reached "an improvement in sensitivity of over a factor of 200" (Harris, 1993). The K_L decays to 4 electrons, to $ee\gamma\gamma$, and to $\mu\mu\gamma\gamma$ were all measured with precision exceeding all previous attempts (Gu, 1994; Nakaya, 1994; and Spencer, 1995, respectively). A new technique, of tagging π^0 decays using the $3\pi^0$ decay of the K_L was used to provide a very clean determination of the rare $\pi^0 \rightarrow e^+e^-$ decay (McFarland, 1993).

Even with far less flux than that available at other labs, E799 established the superiority of high energy kaon beams for multibody decays.

5.4. KTeV

KTeV was a grounds-up new initiative designed to determine ϵ'/ϵ and study a large variety of rare neutral kaon decay modes. A new beam, new building, and new detector were built to make the measurements. KTeV built upon the ideas and successes of the earlier generation of experiments, duplicating their strong points and correcting their deficiencies. It entered the "modern era," with WBS nomenclature, management plans, elected and multiple rotating spokespersons,* and unwieldy alphabetized author lists. It was well supported by the laboratory, this after it was clear that costs were under control. Some key features of KTeV were: a pure CsI electromagnetic calorimeter, which achieved stunning resolution; an active regenerator, made of pure scintillator; the beam, which was cleaner and with fewer contaminants than before; a new large-aperture highly-uniform analysis magnet; an elaborate photon veto system; a set of transition radiation detectors achieving record-setting π/e separation at very high rates; and a DAQ system, which allowed collection and full on-line reconstruction/selection of tens of thousands of kaon decays per second.

KTeV ran in two modes: when studying the 2π decays, the regenerator was present in one of the two neutral beams to provide K_S decays; otherwise, the beam intensity was turned up and the TRD system was employed to have the best sensitivity to much rarer decays.

Several results have been published from partial samples of the data collected. Direct CP violation was clearly established with the measurement, from just 12% of the data, of:

$$\mathrm{Re}(\epsilon'/\epsilon) = (28.0 \pm 3.0 \pm 2.8) \times 10^{-4}$$

[Phys. Rev. Lett. **83**, 22 (1999)]

The statistical precision is based upon signal levels at the 1-2 million level and the challenge will be to improve the understanding of the systematic errors to take full advantage at the roughly ten million level. This result is somewhat higher than that obtained in E731 and agrees well with the earlier NA31 result; on the other hand, the more recent results from CERN are favoring lower values so we must wait until all data has been analyzed before we are sure of the precise value of this parameter.

*KTeV spokespersons include Wah, Barker, Tschirhart, Yamanaka, Hsiung, Blucher, . . . ; the author apologizes if anyone was left out.

And, while a new form of CP violation has been established, it depends upon the theorists as to how useful this quantity will be in constraining parameters of the CKM matrix or isolating a non-Standard Model effect.

Other results from the 2π samples include a precise measurement of the branching ratio and form factor for the $K_L \to \pi^0\gamma\gamma$ decay [Phys. Rev. Lett. **83**, 917 (1999)] and a limit on the existence of light gluinos [Phys. Rev. Lett. **83**, 2128 (1999)].

The rare decay part of KTeV (E799) has also published some early results. These include the first observation of the $K_L \to \pi^+\pi^-e^+e^-$ decay mode [Phys. Rev. Lett. **80**, 4123 (1998)] together with a measurement of CP violation and a demonstration of a very large T-odd effect in the angular distribution of the decay products [Phys. Rev. Lett. **84**, 408 (2000)]; the clean measurement of the rare $\pi^0 \to e^+e^-$ decay [Phys. Rev. Lett. **83**, 922 (1999)]; and major advances in limiting the $K_L \to \pi^0 l^+ l^-$ modes [Phys. Rev. Lett. **84**, 5279 (2000); Phys. Rev. **D61**, 072006 (1999), hep/ex/0009030 submitted to Phys. Rev. Lett. (2000)]. In addition, even though the detector was located many hyperon-lifetimes from the production target, significant measurements of hyperon decay modes were made, including the discovery of the β-decay of the Ξ^0 [Phys. Rev. Lett. **82**, 3751 (1999)].

6. STUDENTS, INSTITUTIONS, PUBLICATIONS

Table 2 shows the students that have graduated with advanced degrees from the Hyperon program; Table 3 gives the same information for the Kaon program; Table 4 shows the institutions that participated in the Kaon program; and Table 5 lists the institutions that participated in the Hyperon program.

The numbers of students and numbers of publications for the individual experiments are shown in Table 6. To date, there have been 62 students receiving advanced degrees; this figure extrapolates to about 80 when all the data is analyzed. Similarly there have been 73 publications with about 100 total expected.

Let me mention that I have neglected singling out postdocs in this talk. That would be another equally valid way of presenting the richness of the work. It is during the postdoctoral years that young scientists develop a passion for measurement and begin to forge the science interests that will stay with them for decades beyond. It's a wonderful time in one's career,

TABLE 2. Students: Hyperon Program, 1983–2000

P. Border	E621	Michigan
K. Thorne	E621	Minnesota
N. Grossman	E621	Minnesota
Y. Zou	E621	Rutgers
S. Hsueh	E715	Chicago
A. Razis	E715	Yale
L. H. Trost	E715	Iowa
G. Zapalac	E715	Chicago
T. Diehl	E756	Rutgers
J. Duryea	E756	Minnesota
P. M. Ho	E756	Michigan
A. Nguyen	E756	Michigan
I. Albuquerque	E761	Sau Paulo
R. Barbosa	E761	Sau Paulo (MS)
D. Chen	E761	SUNY
T. Dubbs	E761	Iowa
M. Foucher	E761	Yale
G. Langlund	E761	Iowa
J. Mahon	E761	Sau Paulo
A. Pineda	E761	Cinvestav
S. Timm	E761	CMU
D. M. Woods	E800	Minnesota
G. M. Guglielmo	E800	Minnesota
N. B. Wallace	E800	Minnesota
G. Gerbi	E871	Virginia
D. Ramajaran	E871	Virginia

arguably the best, and it is equally wonderful for the invigoration it brings to more senior scientists.

Another unfortunately neglected area is advances in data acquisition. Indeed almost none of the significant results from these programs could have come without the major progress in DAQ. Again one could have organized this entire review with this in mind.

I want to add some words about the papers that have come from these programs. In preparing this review, I had the opportunity to read many of them and they are wonderful to read. There are few results that are "below the line" in the jargon of the PDG (i.e. they are long-lasting results); a large number of them are either first measurements or definitive measurements; there are several phenomenological papers; and there is a rich structure in the referencing: predictions from a number of sectors, previous measurements with which to compare, etc. A quick search gives an estimate of about 1500 citations for the work in question, comparing favorably with that of any other area in our discipline.

TABLE 3. Students: Kaon Program, 1983–2000

M. Woods	E731	Chicago
V. Papadimitriou	E731	Chicago
J. R. Patterson	E731	Chicago
G. Makoff	E731	Chicago
G. L. Grazer	E731	Princeton
M. Karlsson	E731	Princeton
R. Daudin	E731	Saclay
P. Jarry	E731	Saclay
P. Cabeza-Orcel	E731	Saclay
L. Gibbons	E731	Chicago
R. Briere	E773	Chicago
P. Gu	E773	Rutgers
J. Matthews	E773	Rutgers
B. Schwingenheuer	E773	Chicago
K. McFarland	E799	Chicago
D. Harris	E799	Chicago
M. Weaver	E799	UCLA
D. Roberts	E799	UCLA
T. Nakaya	E799	Osaka
M. Spencer	E799	UCLA
F. Kato	E799	Osaka(MS)
M. Yagi	E799	Osaka(MS)
Y. Matsumiya	E799	Osaka(MS)
K. Hanagaki	E799	Osaka(MS)
T. Tsuji	E799	Osaka(MS)
M. Sadomoto	E799	Osaka(MS)
E. Zimmerman	KTeV	Chicago
A. Alavi-Harati	KTeV	Wisconsin
G. Graham	KTeV	Chicago
K. Senyo	KTeV	Osaka
P. Mikelsons	KTeV	Colorado
S. Bright	KTeV	Chicago
B. Quinn	KTeV	Chicago
M. Sogo	KTeV	Osaka(MS)
S. Hidaka	KTeV	Osaka(MS)
P. Shawhan	KTeV	Chicago

TABLE 4. Participating Institutions: Kaon Program, 1983–2000

Rutgers	RICE
Chicago	Virginia
Elmhurst	Wisconsin
Princeton	Fermilab
Illinois	Saclay
UCLA	Osaka
Colorado	Saõ Paulo
Arizona	Campinas
UCSD	

TABLE 5. Participating Institutions:
Hyperon Program, 1983–2000

Rutgers	LBNL
Minnesota	FNAL
Michigan	Leningrad
Chicago	Bristol
Elmhurst	CBPF
Iowa	Beijing
Iowa State	ITEM
Yale	PNPI
Virginia	Rio de Janeiro
South Alabama	Saõ Paulo
Washington	Taiwan
Arizona	Mexico
Berkeley	Lausanne
IIT	

TABLE 6. Hyperon and Kaon Tevatron Programs,
Students and Publications, 1983–2000

Experiment	*Students*	*Publications*
E621	4	6
E756	4	7
E800	3	2
E871	2	—
E715	4	4
E761	9	10
Hyperon total	26	29
E731	10	15
E773	4	3
E799-I	12	12
E799-II	9	10
E832	1	4
Kaon total	36	44

7. THE FUTURE

7.1. The Future for Hyperon Physics

Let me quote from the summary talk from the Hyperon '99 conference held at Fermilab. In what he calls "the last hyperon beta decay," the speaker says:

> I have been particularly impressed by the new results on the beta decay of the neutral cascade, $\Xi^0 \rightarrow \Sigma^+ + e^- + \nu_e$

> presented here by Steve Bright for the KTeV collaboration. The new results include both a determination of the branching fraction for this mode and a determination of the axial/vector coupling ratio.
>
> $$g_1/f_1 = 1.24^{+0.20}_{-0.17} \pm 0.20 \pm 0.17(stat) \pm 0.07(syst)$$
>
> $$B.R. = (2.54 \pm 0.11 \pm 0.16) \times 10^{-4}$$
>
> In the limit of exact SU(3) symmetry the predictions on the beta decay of Ξ^0 involve only the value of the θ angle.

From this last quote, you can guess who the summary speaker is: There is only one man on the planet who refers to the Cabibbo angle as "the θ angle."

He goes on to mention:

> The study of CP violation in Hyperon decays merits all of our attention, and it would complement the large efforts lavished on the measurement of ϵ'/ϵ and of CP violation in the B meson system.

Where might this work be done? There is revived interest in building a storage ring to copiously make Λ, anti Λ. A hyperon program with a 3-TeV ring at Fermilab is also a possibility. There is even some discussion of hyperon physics at the Main Injector, although most likely the price one pays in production at 120 GeV is too great. And a recent possibility is at CERN where the NA48 collaboration is considering a program in K_S physics.

7.2. The Future of Kaon Physics

Here I will just quote from Bill Marciano, who delivered the summary talk at the Kaon '99 meeting held in June at the University of Chicago.

> The Kaon system is still the best place to look for CPT violation.... The rare decays $K^+ \to \pi^+\nu\bar{\nu}$ and $K_L \to \pi^0\nu\bar{\nu}$ are exceptionally clean theoretically. Besides testing CKM mixing with great precision, they are capable of probing

"New Physics" up to about the 3000 TeV level.... The decay $K_L \to \pi^0 \nu\bar{\nu}$ is very special.... $K_L \to \pi^0 e^+ e^-$, $K_L \to \pi^0 \mu^+ \mu^-$, $K^+ \to \pi^+ \mu^+ \mu^-$... Kaon physics has had a glorious history. It continues to be exciting (e.g. ϵ'/ϵ, $K^+ \to \pi^+ \nu\bar{\nu}$, $K_L \to \pi^0 \nu\bar{\nu}$ etc.). Are there any future big surprises or great discoveries waiting still to be uncovered in the kaon system? We will find out only if we continue to expand our efforts and follow our instinct to explore.

8. FINAL COMMENTS

The experiments we are talking about were not "search" experiments. They were designed largely for one measurement and were uncompromised, to the extent required to make significant advances. Even so, they had several important byproducts. They were largely evolutionary, sometimes going to three generations. They were "looking deep," with exposures of order 3000 fb^{-1}, to put the luminosity in units collider physicists will recognize. It simply takes that many collisions to do the physics. Many had mid-course corrections/discoveries, examples being the measurement of the Ω^- magnetic moment, the work on channeling of charged hyperons, the invention of the 3 π^0 tag for rare π^0 decays and the clean observation of T-violation.

There are no doubt other surprises that could come from a new generation of such experiments. Yet one hears words like: "These days, who is going to risk starting something new?"

Perhaps we could learn something from the astrophysicists, both in terms of management and science. In that area, there are a large number of small efforts; there are annual competitions for small scale and medium scale projects which the community supports along with the very large ones. The field is accordingly vibrant, as a look at astro-ph on any given day will reveal. And an important part of the science done by astrophysicists is really "our science," i.e. it deals with the same fundamental issues that we as particle physicists probe. Just think of the dark matter and the dark energy. I believe the associated phenomena are real and very much worthy of study; yes, it is true they could go away but they seem just as important if not more so than whatever hints of new physics there may be at the edge of the phase space in HEP data sets.

We need to pay more attention to these issues. I know the organizers of this meeting do (even if they don't want to admit it): the date for this symposium, June 2, is the day the earth has the maximum velocity with respect to the galaxy!

We can be proud of FNAL strange quark physics. I'm speaking of the papers and the students and the postdocs we have produced.